



Annex 13

***STOCK ASSESSMENT AND FUTURE PROJECTIONS OF BLUE
SHARK IN THE NORTH PACIFIC OCEAN***

REPORT OF THE SHARK WORKING GROUP

*International Scientific Committee for Tuna and Tuna-like Species in the North
Pacific Ocean*



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Table of Contents

| | |
|--|-----------|
| EXECUTIVE SUMMARY | 5 |
| 1 INTRODUCTION..... | 24 |
| 2 BACKGROUND..... | 24 |
| 2.1 Biology..... | 24 |
| 2.1.1 Stock structure | 25 |
| 2.1.2 Reproduction..... | 25 |
| 2.1.3 Growth | 25 |
| 2.2 Fisheries | 26 |
| 2.3 Previous assessments..... | 26 |
| 3 DATA..... | 27 |
| 3.1 Spatial stratification..... | 27 |
| 3.2 Temporal stratification | 27 |
| 3.3 Definition of fisheries..... | 27 |
| 3.4 Catch data..... | 28 |
| 3.4.1 Japan | 28 |
| 3.4.2 Chinese Taipei | 29 |
| 3.4.3 Mexico | 29 |
| 3.4.4 USA..... | 30 |
| 3.4.5 Canada..... | 30 |
| 3.4.6 Korea..... | 30 |
| 3.4.7 China..... | 30 |
| 3.4.8 SPC | 31 |
| 3.4.9 IATTC..... | 31 |
| 3.5 Abundance indices | 31 |
| 3.5.1 Reference case abundance indices..... | 31 |
| 3.5.2 Alternative runs indices | 32 |
| 3.5.2.1 Hawaii deep-set longline | 32 |
| 3.5.2.2 Taiwanese large-scale longline..... | 33 |
| 3.5.2.3 SPC longline..... | 33 |
| 3.5.3 Other candidate indices..... | 33 |
| 3.6 Length-frequency data..... | 33 |
| 4 BSP MODEL DESCRIPTION..... | 34 |
| 4.1 BSP2 Software | 34 |
| 4.2 Biological and demographic assumptions..... | 35 |
| 4.2.1 Intrinsic rate of increase..... | 36 |
| 4.2.2 Shape parameter..... | 36 |

| | | |
|---------|---|----|
| 4.2.3 | Weighting of model components | 36 |
| 4.3 | Reference case specifications and input parameter choices | 37 |
| 4.4 | Model without indices | 38 |
| 4.5 | Specifications and parameter settings for sensitivity runs | 38 |
| 4.6 | Accounting for uncertainty..... | 38 |
| 4.7 | Evaluation of model convergence | 38 |
| 4.8 | Retrospective analysis | 39 |
| 4.9 | Evaluation with Bayes factor | 39 |
| 4.10 | Future projections..... | 39 |
| 5 | INTEGRATED MODEL DESCRIPTION..... | 39 |
| 5.1 | Stock Synthesis Software | 39 |
| 5.2 | Biological Assumptions | 40 |
| 5.2.1 | Growth | 40 |
| 5.2.2 | Plus group | 40 |
| 5.2.3 | Weight at length..... | 41 |
| 5.2.4 | Natural mortality | 41 |
| 5.2.5 | Maturity and fecundity..... | 41 |
| 5.3 | Model structure | 41 |
| 5.3.1 | Input fishery data | 41 |
| 5.3.2 | Length composition data..... | 41 |
| 5.3.3 | Population and fishery dynamics | 42 |
| 5.3.4 | Initial population state..... | 42 |
| 5.3.5 | Recruitment and the Low Fecundity Spawner Recruitment relationship (LFSR) .. | 42 |
| 5.3.6 | Selectivity curves | 44 |
| 5.3.7 | Parameter estimation and uncertainty | 44 |
| 5.3.8 | Assessment Strategy | 44 |
| 5.3.9 | Retrospective analysis..... | 44 |
| 5.3.10 | Future projections | 45 |
| 6 | BSP MODEL RESULTS | 45 |
| 6.1 | Eight reference cases..... | 45 |
| 6.1.1 | Model convergences of the eight reference cases..... | 45 |
| 6.1.2 | Model fits of the eight reference cases | 45 |
| 6.1.3 | Results for the eight reference cases | 46 |
| 6.1.3.1 | Stock assessment statistics and marginal posterior distributions for key parameters | 46 |
| 6.1.3.2 | Prior-only run analysis..... | 47 |
| 6.1.3.3 | Retrospective analyses..... | 47 |
| 6.1.3.4 | Historical stock dynamics..... | 48 |

| | | |
|--------------|---|-----|
| 6.1.3.5 | Kobe plots..... | 48 |
| 6.2 | Sensitivity analyses | 49 |
| 6.2.1 | Model convergence of the sensitivity runs | 49 |
| 6.2.2 | Model fits of the sensitivity runs | 49 |
| 6.2.3 | Results of sensitivity runs | 49 |
| 6.2.3.1 | Surplus production function, B_{MSY}/K (Shape parameter n)..... | 50 |
| 6.2.3.2 | r prior mean | 50 |
| 6.2.3.3 | Other sensitivity runs..... | 50 |
| 6.2.3.4 | Historical stock dynamics for sensitivity runs..... | 51 |
| 6.2.4 | Bayes factor evaluation..... | 51 |
| 6.3 | Future projections..... | 52 |
| 7 | INTEGRATED ASSESSMENT MODEL RESULTS..... | 52 |
| 7.1 | Reference case model..... | 52 |
| 7.1.1 | Estimated parameters and model performance | 52 |
| 7.1.2 | Estimated stock status and other quantities | 52 |
| 7.2 | One change sensitivity analyses..... | 53 |
| 7.3 | Retrospective analysis..... | 53 |
| 7.4 | Future projections..... | 53 |
| 7.5 | General patterns in the SS Appendix materials..... | 54 |
| 8 | STOCK STATUS AND CONSERVATION CONCLUSIONS | 54 |
| 8.1 | Status of the stock | 54 |
| 8.2 | Conservation information..... | 55 |
| 8.3 | Limitations and research needs | 56 |
| 8.3.1 | Catch | 56 |
| 8.3.2 | Abundance indices | 56 |
| 8.3.3 | Length and sex composition | 56 |
| 8.3.4 | Biological parameters | 56 |
| 8.3.5 | Stock-recruitment relationship..... | 56 |
| 9 | ACKNOWLEDGEMENTS | 56 |
| 10 | LITERATURE CITED | 57 |
| | TABLES | 64 |
| | FIGURES..... | 87 |
| | Appendix A. Additional diagnostics output for BSP model runs..... | 139 |
| | Appendix B. Summary of key outputs for the SS model runs using the JPN Early and JPN Late CPUE series combination (reference run). | 147 |
| | Appendix C. Summary of key outputs for the SS model runs using the JPN Early and HW Deep Late CPUE series combination (CPUE2). | 154 |
| | Appendix D. Summary of key outputs for the SS model runs using the SPC CPUE series (CPUE 4)..... | 161 |

| | |
|--|-----|
| Appendix E. Summary of key outputs for the SS model runs using the HW CPUE series (CPUE 5)..... | 168 |
| Appendix F. Summary of key outputs for the SS model runs using the TW CPUE series (CPUE 6)..... | 175 |
| Appendix G: Input files | 182 |
| G.1 BSP Input File | 182 |
| G.2 SS Input File..... | 184 |

EXECUTIVE SUMMARY

The ISC Shark Working Group (SHARKWG) used two stock assessment approaches to examine the status of blue shark (*Prionace glauca*) in the North Pacific Ocean: a Bayesian Surplus Production (BSP) model; and an age-based statistical catch-at-length model. These efforts provide an updated assessment of North Pacific blue shark based on the 2013 SHARKWG assessment.

1. Stock Identification and Distribution

Blue shark (BSH) are widely distributed throughout temperate and tropical waters of the Pacific Ocean. The ISC SHARKWG recognizes two stocks in the North and South Pacific, respectively, based on biological and fishery evidence. Relatively few BSH are encountered in the tropical equatorial waters separating the two stocks. Tagging data demonstrate long distance movements and a high degree of mixing of BSH across the North Pacific, although there is evidence of spatial and temporal structure by size and sex.

2. Catch History

Catch records for BSH in the North Pacific are limited and, where lacking, have been estimated using statistical models and information from a combination of historical landings data, fishery logbooks, observer records and research surveys. In these analyses, estimated BSH catch data refer to total dead removals, which includes retained catch and dead discards. Estimated catch data in the North Pacific date back to 1971, although longline and driftnet fisheries targeting tunas and billfish earlier in the 20th century likely caught BSH. The nations catching BSH in the North Pacific include Japan, Chinese Taipei, Mexico, and USA which account for more than 95% of the estimated catch (Figure 1E). Estimated catches of BSH were highest from 1976 to 1989 with a peak estimated catch of approximately 113,000 mt in 1981. Over the past decade BSH estimated catches in the North Pacific have remained relatively steady at an average of 46,000 mt annually. While a variety of fishing gears catch BSH, most are caught in longline fisheries and fewer are taken in gillnet fisheries (Figure 2E). The total catch in 2011 decreased from 2010 by close to 25% due to a decrease in Japanese effort associated with damage from the March 2011 Great East Japan Earthquake.

3. Data and Assessment

Annual catch estimates were derived for a variety of fisheries by nation. Catch, effort and size composition data were grouped into 18 fisheries for the period 1971 to 2012. Historical catch time series for Japan were improved for the current assessment by the use of more accurate processed-to-whole-weight conversion factors. Data for the Taiwanese large longline fishery were also updated by removal of erroneous catch. Blue shark catch in 2012, although estimated for many fleets, represents a large amount (about 60%) of substituted catch carried over from 2011, and is thus considered more uncertain than that prior to 2012. Models were run using data for both the 1971-2011 and 1971-2012 time periods.

The SHARKWG developed both new and revised standardized CPUE time series and used criteria to select representative indices for the assessment. Data for the recent (post-1994) Japanese shallow longline fleet that operates out of Hokkaido and Tohoku ports was separated into two periods for standardization before and after 2011 because the fleet behavior greatly changed as a result of the March 2011 Great East Japan Earthquake. The two year standardized CPUE index for the Japan longline fishery post-2011 was not used in the current assessment. Due to low observer coverage rates in the Hawaii deep-set longline fishery prior to 2000, the Hawaii index was shortened relative to that used in the prior assessment to incorporate only the higher quality data. Similarly, observer coverage decreased in the SPC longline fishery after 2009, thus the SPC index was standardized using data through 2009.

Due to uncertainty in the input data and life history parameters, multiple models were run with alternative data/parameters. In addition, two types of population dynamics models were used, a state-space Bayesian Surplus Production Model (BSP¹) and an age-based statistical catch-at-length model, Stock Synthesis (SS²). These models were designed to capture the maximum range of uncertainty in the input information. In total, 84 BSP models and 1080 SS models representing different combinations of input datasets and structural model hypotheses were used to assess the influence of these uncertainties on biomass trends and fishing mortality levels for North Pacific BSH. Though fewer BSP models were run, a far greater number of parameters were specified in the SS models to estimate sex-specific dynamics and take advantage of a novel stock recruitment function; the BSP runs used both the Bayesian approach and an appropriate range of input parameters to assess uncertainties given the model.

Reference case model runs were selected for the purpose of assessing the current stock status. Input parameter values for the reference case runs were chosen based on the best available information regarding the life history of Pacific blue sharks and knowledge of the historical catch time series and fishery data. For example, for the reference case, initial catch was set at 40,000 mt because Japan longline fishing effort increased and spread rapidly in the 1950s with effort stabilizing by the late 1950s into the 1960s. Standardized catch-per-unit-effort (CPUE) from the Japanese shallow longline fleet that operates out of Hokkaido and Tohoku ports for the periods 1976-1993 and 1994-2010 were used as measures of relative population abundance in the reference case assessments (Figure 3E).

For the BSP models, a single catch time series was used with a variety of CPUE time series and priors assigned to several parameters, including the intrinsic rate of population increase (r) and the ratio of initial biomass to carrying capacity (B_{init}/K) to fit a Fletcher-Schaefer production model in a Bayesian statistical framework to address uncertainty regarding these parameters. For the SS models, a two-sex, size-based model was used that explicitly modeled the different sizes of BSH taken in 18 fisheries and utilized a survival based spawner-recruit function, referred to as the Low Fecundity Spawner Recruitment relationship (LFSR). Historical information regarding exploitation levels prior to the start time of the model were examined to derive plausible input values, and sex-specific estimates of natural mortality-at-age were based on two independent growth studies from the North Pacific. The SS code searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian matrices. In both modeling approaches, estimated model parameters and derived outputs were used to characterize stock status and explore the range of uncertainty under different scenarios.

Stock projections of biomass and catch of BSH in the North Pacific from 2012 to 2031 were conducted assuming alternative harvest scenarios and starting biomass levels. *Status quo* catch and F were based on the average over the recent 5 years (2006-2010). Estimated catch from 2011 was not used for projections due to the impact of the March 2011 Great East Japan Earthquake on Japanese fishing effort. A simulation model was used for annual projections, and included uncertainty in the population size at the starting year of stock projection, fishing mortality and productivity parameters.

4. Status of the Stock

Model inputs for this assessment have been improved since the previous assessment and provide the best available scientific information. The main differences between the present assessment

¹ McAllister MK, Babcock EA (2006) Bayesian Surplus Production model with the Sampling Importance Resampling algorithm (BSP): a user's guide.

² Stock Synthesis (version 3.24F; <http://nft.nefsc.noaa.gov/Download.html>)

and the 2013 assessment are: 1) the inclusion of revised CPUE series; 2) some time series data updated through 2012; 3) further examination of the effect of the Bayesian priors on the BSP model outcomes; and 4) use of the SS model to provide an alternative approach that could be compared to the production modeling. However, there are uncertainties in the time series for estimated catch, the quality (observer vs. logbook) and timespans of abundance indices, the size composition data and many life history parameters such as growth and maturity schedules. Improvements in the monitoring of BSH catches, including recording the size and sex of sharks retained and discarded for all fisheries, as well as continued research into the biology and ecology of BSH in the North Pacific are recommended.

Results of the reference case model showed similar trends for the two modeling approaches. Both showed that the stock biomass was near a time-series high in 1971, fell to its lowest level between the late 1980s and early 1990s, and subsequently increased gradually and has leveled off at a biomass similar to that at the beginning of the time-series (Figures 4E and 5E). Stock status is reported in relation to maximum sustainable yield (MSY). Benchmark results are shown based on biomass (BSP runs) or female spawning stock biomass (SS runs). Stock biomass and spawning biomass in 2011 (B_{2011} and SSB_{2011}) were 65% and 62% higher than at MSY , respectively, and the annual fishing mortality in 2011 (F_{2011}) was estimated to be well below F_{MSY} (Tables 1E and 2E; Figures 6E and 7E).

Based on the trajectory of the BSP reference case model, median stock biomass of blue shark in 2011 (B_{2011}) was estimated to be 622,000 mt (Table 1E; Figure 4E). Median annual fishing mortality in 2011 (F_{2011}) was approximately 32% of F_{MSY} . Based on the trajectory of the SS reference case model, female spawning stock biomass of blue shark in 2011 (SSB_{2011}) was estimated to be 449,930 mt (Table 2E; Figure 5E). The estimate of F_{2011} was approximately 34% of F_{MSY} .

While the results varied depending upon the input assumptions, a few parameters were most influential on the results. These included the CPUE series selected as well as the shape parameters for the BSP models and the equilibrium initial catch and form of the LFSR relationship for the SS models. For the BSP modeling, the shape parameters had the greatest effects on biomass trends (Figures 8E and 9E), estimated fishing mortality rates, and current status relative to MSY .

For the SS modeling, the form of the LFSR relationship overwhelmed other sources of uncertainty (Figures 10E and 11E). Results were more pessimistic when S_{Frac} (one of the parameters controlling the shape of the spawner-recruit curve) was fixed at 0.1, whereas the majority of runs with S_{Frac} fixed at 0.3 and 0.5 resulted in terminal stock status where $F < F_{MSY}$ and $B > B_{MSY}$. The SHARKWG felt that the intermediate value of the parameter S_{Frac} , 0.3, was most probable. The low value produced lower levels of compensation which the SHARKWG felt were less plausible. Further, the higher value for S_{Frac} gave rapidly decreasing trends in recruitment with increasing spawner biomass, which was considered unlikely. Stock trends were also sensitive to changes in $Beta$ (another parameter controlling the shape of the spawner-recruit curve) although the differences were less extreme. Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modeled period.

Across both models, the parameter values considered most plausible produced terminal conditions that were predominantly in the green quadrant (not overfished and overfishing not occurring) of the Kobe plot. At the lower range of the productivity assumptions, which were considered less plausible, both models indicated some probability of the stock being overfished or undergoing overfishing.

5. Conservation Information

These results should be considered with respect to the management objectives of the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC), the organizations responsible for management of pelagic sharks caught in international fisheries for tuna and tuna-like species in the Pacific Ocean. Target and limit reference points have not yet been established for pelagic sharks in the Pacific. Relative to MSY , the reference case and the majority of models run with input parameter values considered more probable suggest that the North Pacific blue shark stock is not overfished and overfishing is not occurring.

Future projections of the reference case models show that median BSH biomass in the North Pacific will remain above B_{MSY} under the catch harvest policies examined (*status quo*, +20%, -20%). Similarly, future projections under different fishing mortality (F) harvest policies (*status quo*, +20%, -20%) show that median BSH biomass in the North Pacific will likely remain above B_{MSY} (Tables 3E and 4E; Figures 12E and 13E).

Due to data uncertainties, improvements in the monitoring of blue shark catches and discards, through carefully designed observer programs and species-specific logbooks, as well as continued research into the fisheries, biology and ecology of blue shark in the North Pacific are recommended.

Table 1E. Reference case BSP model results for North Pacific blue shark (*Prionace glauca*) – mean, standard deviation (SD), coefficient of variation (CV), median and 90% confidence intervals of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.41 | 0.14 | 0.33 | 0.20 | 0.41 | 0.65 |
| K ('000 MT) | 955 | 597 | 0.63 | 491 | 806 | 1884 |
| MSY ('000 MT) | 79 | 19 | 0.24 | 65 | 76 | 98 |
| B_{msy} ('000 MT) | 449 | 281 | 0.63 | 231 | 379 | 886 |
| B_{1971} ('000 MT) | 735 | 773 | 1.05 | 253 | 556 | 1657 |
| B_{2011} ('000 MT) | 744 | 542 | 0.73 | 373 | 622 | 1459 |
| B_{2011}/B_{msy} | 1.65 | 0.25 | 0.15 | 1.24 | 1.65 | 2.08 |
| B_{2011}/B_{1971} | 1.21 | 0.43 | 0.35 | 0.68 | 1.15 | 2.05 |
| B_{2011}/K | 0.78 | 0.12 | 0.15 | 0.62 | 0.82 | 1.04 |
| F_{msy} (ratio) | 0.20 | 0.07 | 0.33 | 0.10 | 0.20 | 0.33 |
| F_{2011} (ratio) | 0.07 | 0.02 | 0.37 | 0.03 | 0.07 | 0.11 |
| F_{2011}/F_{msy} | 0.33 | 0.07 | 0.23 | 0.22 | 0.32 | 0.45 |

Table 2E. Reference case SS model results for North Pacific blue shark (*Prionace glauca*). Mean, standard deviation, coefficient of variation, and 90% confidence intervals of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | 95th Percentile |
|-------------------------|---------|---------|-------|----------------|-----------------|
| MSY (MT) | 72,123 | 13,863 | 0.192 | 49,317 | 94,928 |
| SSB_{MSY} (MT) | 277,565 | 55,456 | 0.200 | 186,290 | 368,840 |
| SSB_{1971} (MT) | 430,336 | 121,860 | 0.283 | 229,876 | 630,796 |
| SSB_{2011} (MT) | 449,930 | 170,845 | 0.380 | 168,890 | 730,970 |
| SSB_{2011}/SSB_{MSY} | 1.621 | | | | |
| SSB_{2011}/SSB_{1971} | 1.046 | | | | |
| F_{MSY} (ratio) | 0.225 | 0.014 | 0.064 | 0.201 | 0.248 |
| F_{2011} (ratio) | 0.078 | 0.023 | 0.302 | 0.039 | 0.116 |
| F_{2011}/F_{MSY} | 0.345 | | | | |

Table 3E. Decision Table showing the expected catch (x1000 mt) and biological reference points with runs projecting 5, 10, and 20 years into the future, under different harvest policies with either constant catch or fishing mortality (*status quo*: $C_{2006-2010}$; $C_{2006-2010} +20\%$; $C_{2006-2010} -20\%$; $F_{2006-2010}$; $F_{2006-2010} +20\%$; $F_{2006-2010} -20\%$; and F_{MSY}), based on future projections for the BSP reference case model.

| Run ID | HCR | Total C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | Total C_{2016} | B_{2016} $/B_{msy}$ | $P(B_{2016}$ $>B_{msy})$ | F_{2016} $/F_{msy}$ | Total C_{2021} | B_{2021} $/B_{msy}$ | $P(B_{2021}$ $>B_{msy})$ | F_{2021} $/F_{msy}$ | Total C_{2031} | B_{2031} $/B_{msy}$ | $P(B_{2031}$ $>B_{msy})$ | F_{2031} $/F_{msy}$ |
|----------|-----------------|---------------------|--------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| JEJL_Ref | Status quo | 40.51 | 1.65 | 0.32 | 46.69 | 1.64 | 0.99 | 0.37 | 46.69 | 1.64 | 0.98 | 0.37 | 46.69 | 1.65 | 0.98 | 0.37 |
| | +20% | 40.51 | 1.65 | 0.32 | 56.03 | 1.56 | 0.98 | 0.47 | 56.03 | 1.54 | 0.96 | 0.48 | 56.03 | 1.51 | 0.95 | 0.48 |
| | -20% | 40.51 | 1.65 | 0.32 | 37.35 | 1.72 | 1.00 | 0.28 | 37.35 | 1.74 | 0.99 | 0.28 | 37.35 | 1.77 | 1.00 | 0.28 |
| | $F_{2006-2010}$ | 40.51 | 1.65 | 0.32 | 50.43 | 1.64 | 0.98 | 0.37 | 49.29 | 1.60 | 0.98 | 0.37 | 49.57 | 1.59 | 0.97 | 0.37 |
| | +20% | 40.51 | 1.65 | 0.32 | 57.88 | 1.56 | 0.97 | 0.37 | 56.01 | 1.51 | 0.93 | 0.37 | 55.07 | 1.50 | 0.94 | 0.37 |
| | -20% | 40.51 | 1.65 | 0.32 | 42.27 | 1.71 | 0.98 | 0.37 | 41.72 | 1.69 | 0.99 | 0.37 | 42.01 | 1.67 | 0.98 | 0.37 |
| | F_{msy} | 40.51 | 1.65 | 0.32 | 88.47 | 1.13 | 0.76 | 1.03 | 79.25 | 1.03 | 0.59 | 1.01 | 76.08 | 0.98 | 0.45 | 1.00 |

Table 4E. Decision Table showing the expected catch (mt) and biological reference points for runs projecting 5, 10, and 20 years into the future, under different harvest policies with either constant catch or fishing mortality (*status quo*: $C_{2006-2010}$; $C_{2006-2010} +20\%$; $C_{2006-2010} -20\%$; $F_{2006-2010}$; $F_{2006-2010} +20\%$; $F_{2006-2010} -20\%$; and F_{MSY}), based on future projections for the SS reference case model.

| Run ID | HCR | C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | C_{2016} | B_{2016} $/B_{msy}$ | F_{2016} $/F_{msy}$ | C_{2021} | B_{2021} $/B_{msy}$ | F_{2021} $/F_{msy}$ | C_{2031} | B_{2031} $/B_{msy}$ | F_{2031} $/F_{msy}$ |
|--------------------|-----------------|------------|--------------------------|--------------------------|------------|--------------------------|--------------------------|------------|--------------------------|--------------------------|------------|--------------------------|--------------------------|
| BSH_ref_projection | Status quo | 39083 | 1.62 | 0.35 | 46389 | 1.74 | 0.47 | 46389 | 1.80 | 0.47 | 46389 | 1.83 | 0.48 |
| | +20% | 39083 | 1.62 | 0.35 | 55667 | 1.72 | 0.57 | 55667 | 1.75 | 0.58 | 55667 | 1.76 | 0.59 |
| | -20% | 39083 | 1.62 | 0.35 | 37111 | 1.76 | 0.36 | 37111 | 1.85 | 0.37 | 37111 | 1.90 | 0.38 |
| | $F_{2006-2010}$ | 39083 | 1.62 | 0.35 | 49807 | 1.73 | 0.50 | 49305 | 1.78 | 0.50 | 48789 | 1.81 | 0.50 |
| | +20% | 39083 | 1.62 | 0.35 | 58437 | 1.71 | 0.59 | 57445 | 1.73 | 0.59 | 57118 | 1.75 | 0.59 |
| | -20% | 39083 | 1.62 | 0.35 | 40759 | 1.75 | 0.40 | 40620 | 1.83 | 0.40 | 39905 | 1.88 | 0.40 |
| | F_{msy} | 39083 | 1.62 | 0.35 | 89826 | 1.64 | 1.00 | 85580 | 1.55 | 1.00 | 84781 | 1.48 | 1.00 |

Figure 1E. Total estimated catch of North Pacific blue shark (*Prionace glauca*) from 1971-2012 by nation or region.

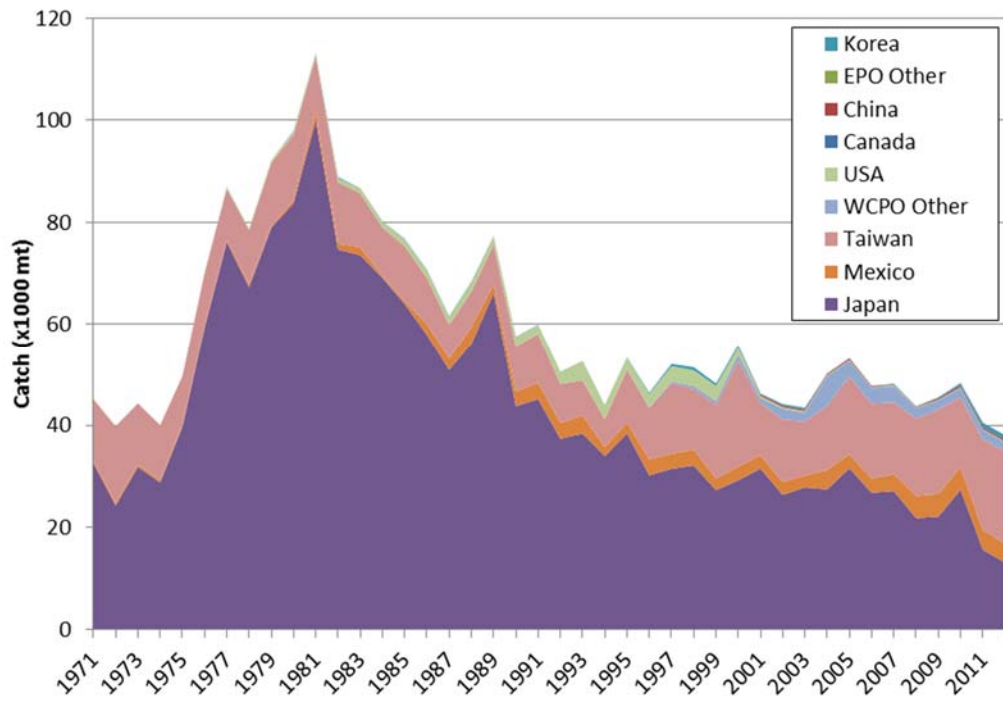


Figure 2E. Total estimated catch of North Pacific blue shark (*Prionace glauca*) by gear types from 1971-2012. Mixed gear reflects some combined longline, gillnet, pole and line, trap, purse seine.

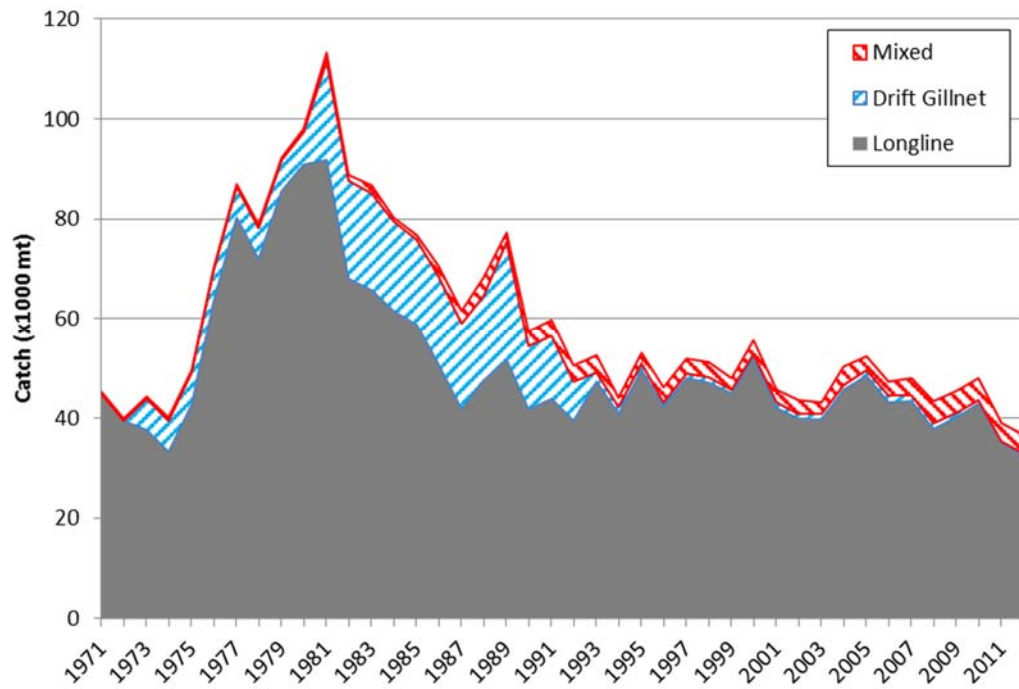


Figure 3E. Standardized CPUEs used as abundance indices in the blue shark (*Prionace glauca*) stock assessment. The reference case models were fitted to the Japanese longline early (1976-1993), and late indices (1994-2010). Alternate runs were fitted using combinations of the other indices with or without the Japanese longline early index.

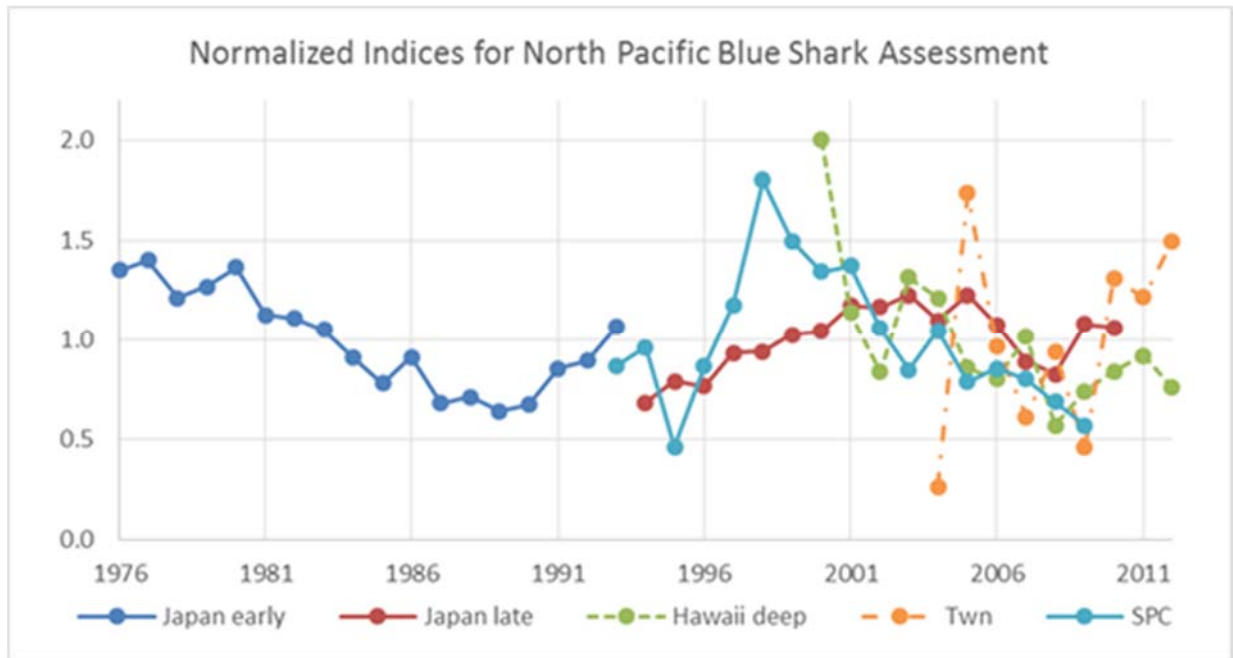


Figure 4E. Median and 90% confidence intervals for the estimated historical stock dynamics of North Pacific blue shark (*Prionace glauca*) from the BSP reference case run.

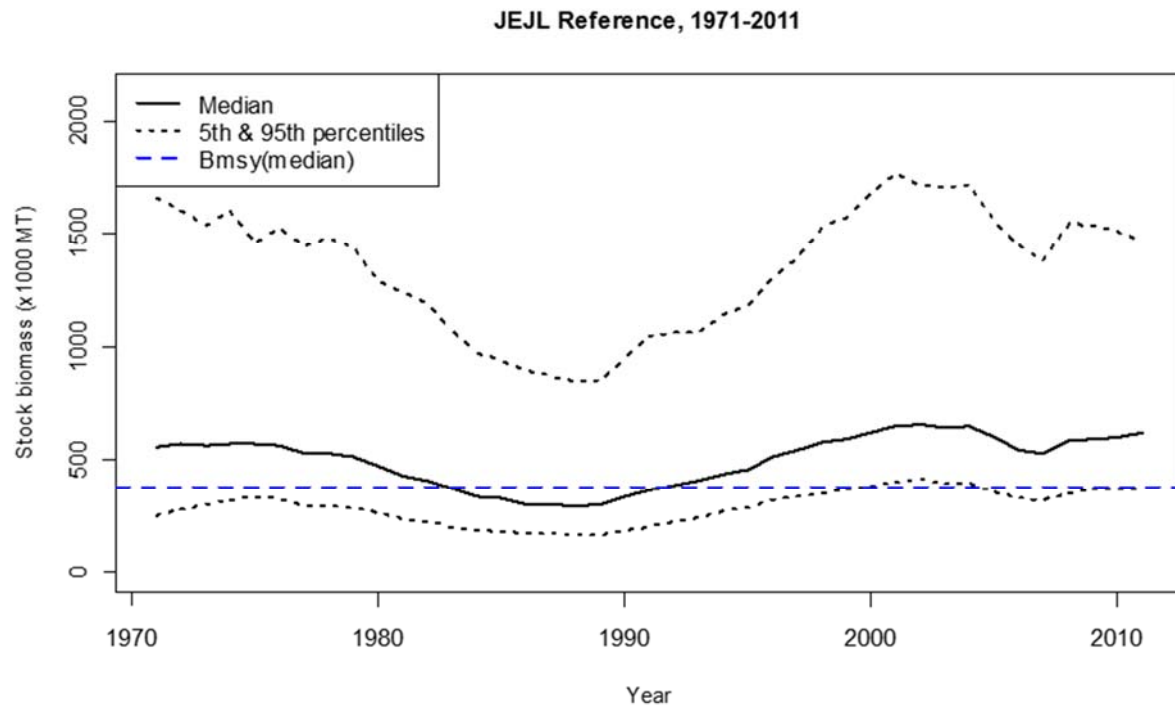


Figure 5E. Estimated female spawning biomass and 90% confidence intervals of North Pacific blue shark (*Prionace glauca*) from the SS reference case run.

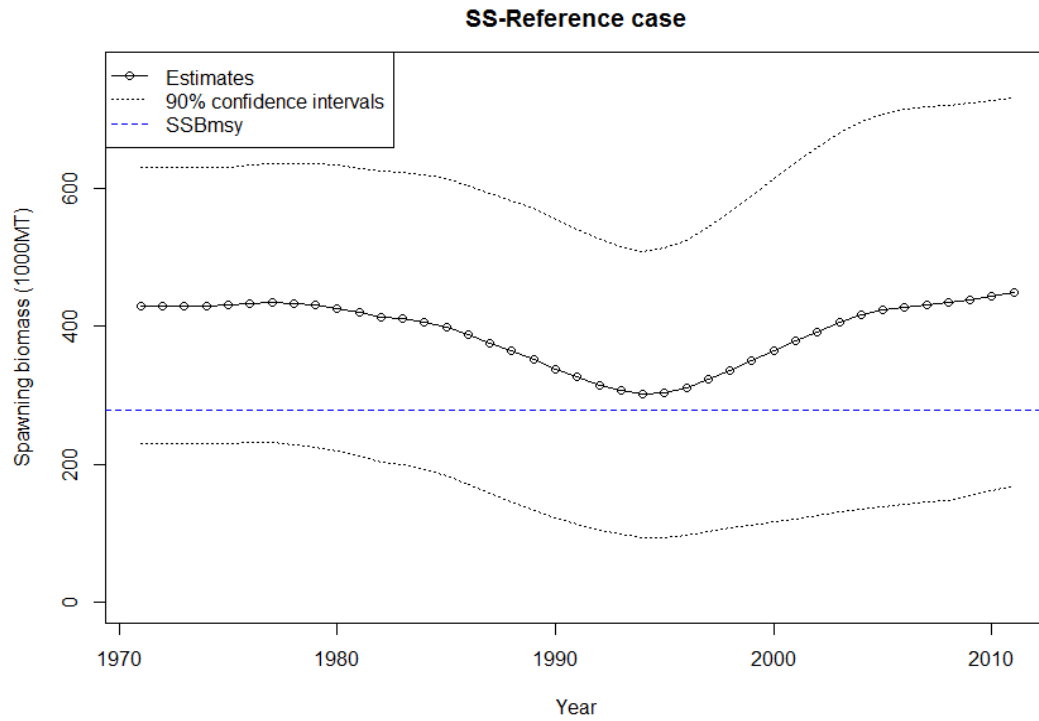


Figure 6E. Kobe plot showing median biomass and fishing mortality trajectories for the reference case BSP model for North Pacific blue shark (*Prionace glauca*). Solid blue circle indicates the median estimate in 1971 (initial year of model). Solid gray circle and its horizontal and vertical bars indicate the median and 90% confidence limits in 2011, respectively. Open black circles and black arrows indicate the historical trajectory of stock status between 1971 and 2011.

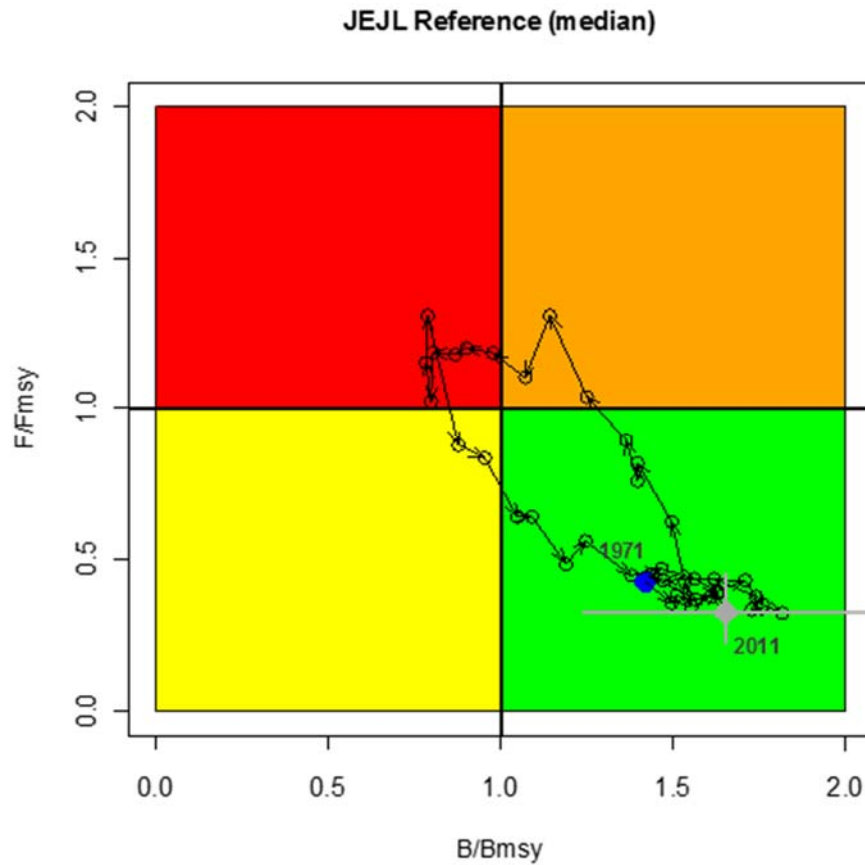


Figure 7E. Kobe plot showing estimated spawning biomass and fishing mortality trajectories for the reference case SS model for North Pacific blue shark (*Prionace glauca*). The circles indicate the historical trajectory from 1971-2011 colored from red (first year) to blue (terminal year).

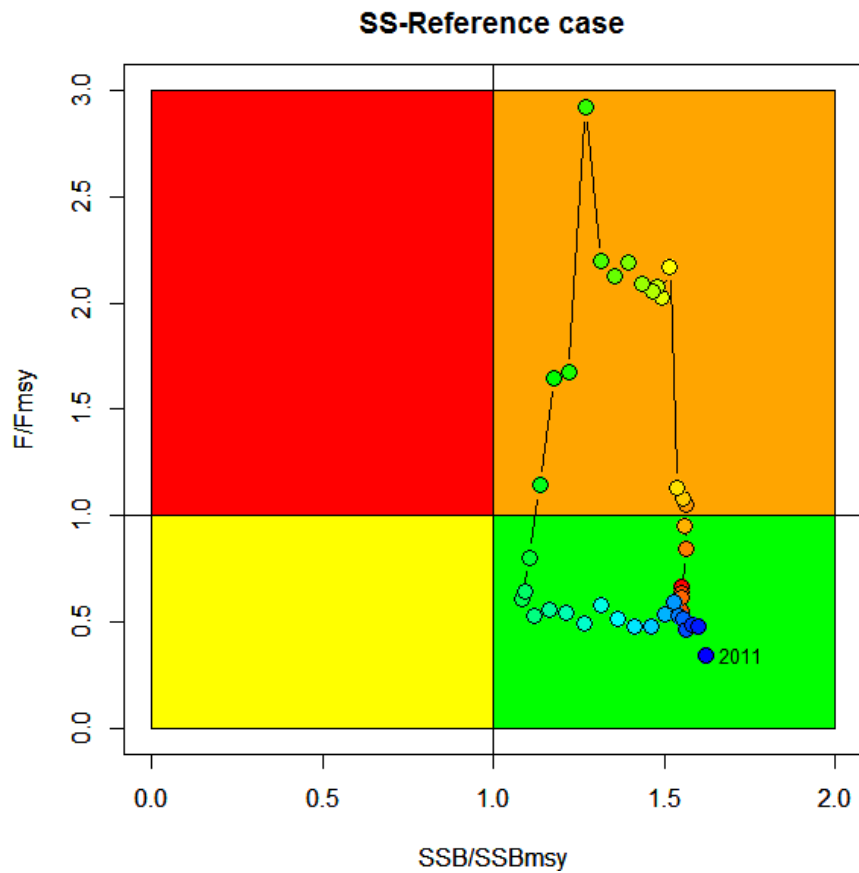


Figure 8E. Kobe plot showing the 2011 median estimates of F/F_{MSY} and B/B_{MSY} for all the BSP model runs for North Pacific blue shark (*Prionace glauca*). The horizontal and vertical bars indicate the 90% confidence limits of the 2011 estimates. Each circle with a different color indicates results of runs using the same CPUE index(ices) (e.g., JEJL represents a combination of Japanese longline early and late period indices.) See Table 2 in the assessment report for CPUE index identifiers.

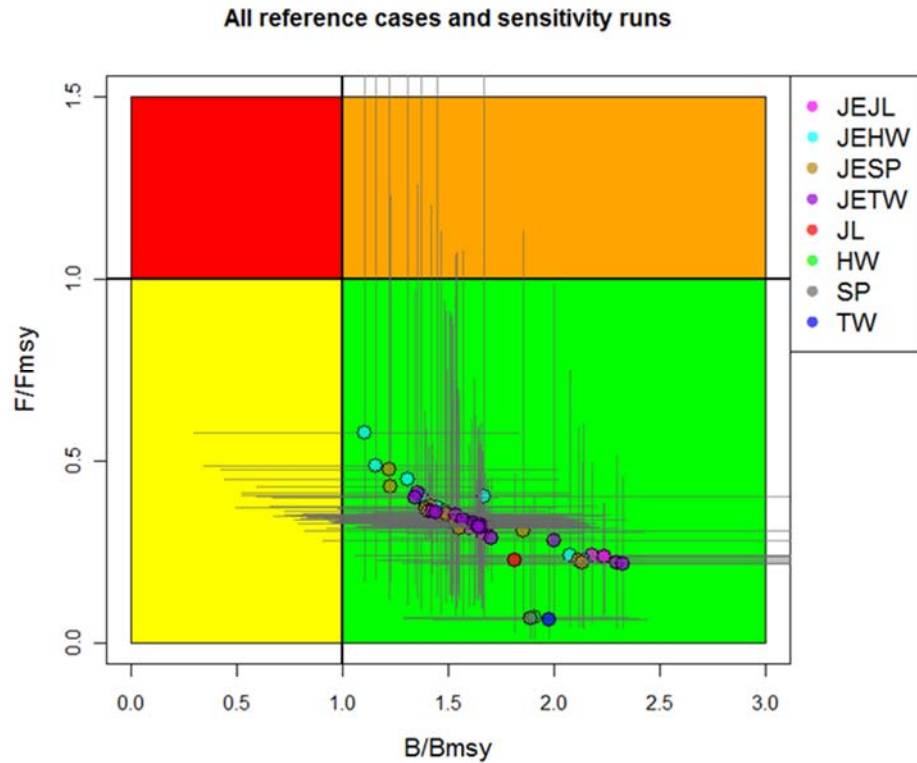


Figure 9E. Comparison of trajectories of median stock biomass of North Pacific blue shark (*Prionace glauca*) between the reference case and sensitivity runs using the reference case indices. See the assessment report text for run identifiers and detailed descriptions of the sensitivity runs.

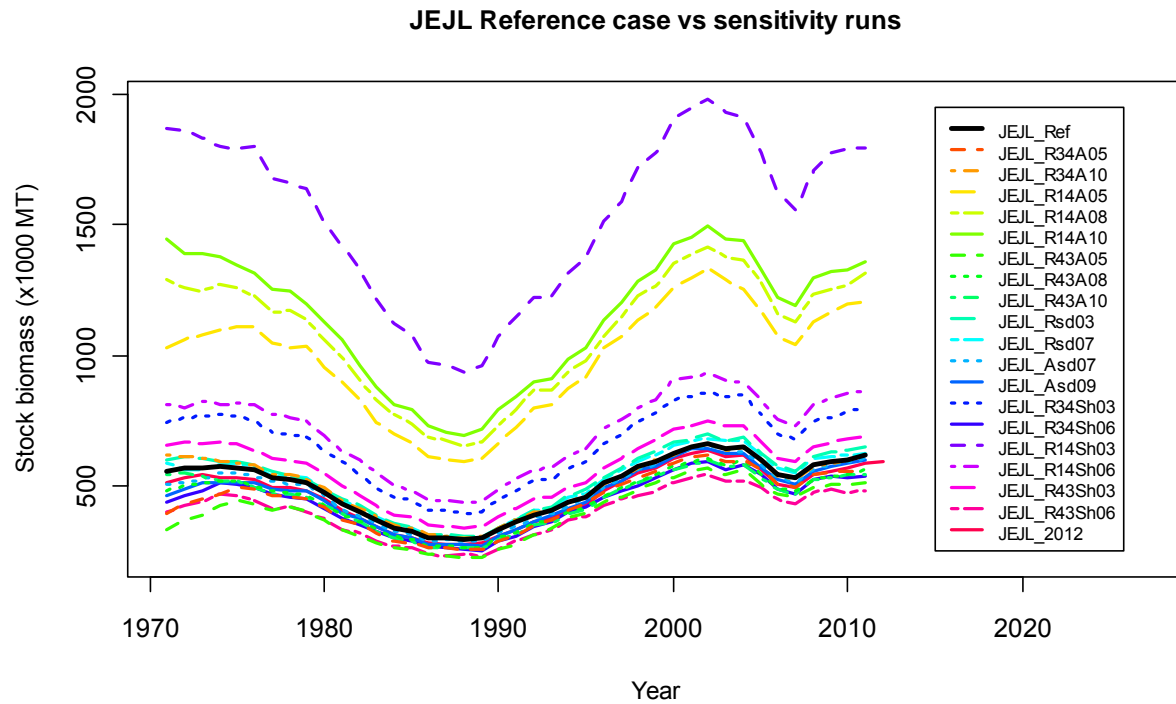


Figure 10E. Kobe bar plots showing the range of terminal year values for alternative SS runs that explored the main axes of uncertainties. The total number of runs was 1080. Note that each run is not considered equally likely, thus percentages should not be interpreted as probabilities.

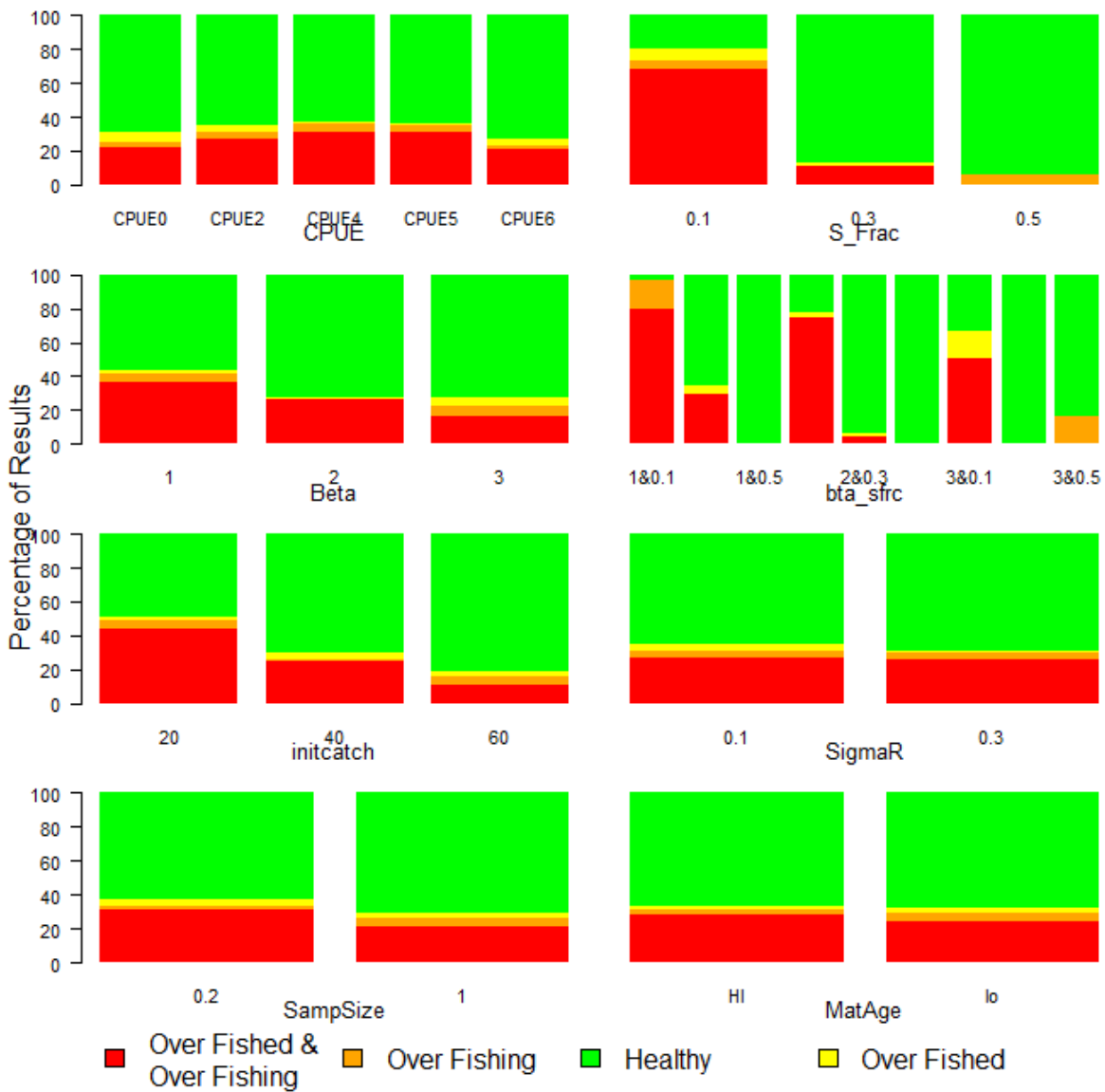


Figure 11E. Trajectories of SSB/SSB_{MSY} showing the range of estimates for SS models with single parameter changes across the major axes of uncertainty. These models were conducted with the reference case CPUE indices.

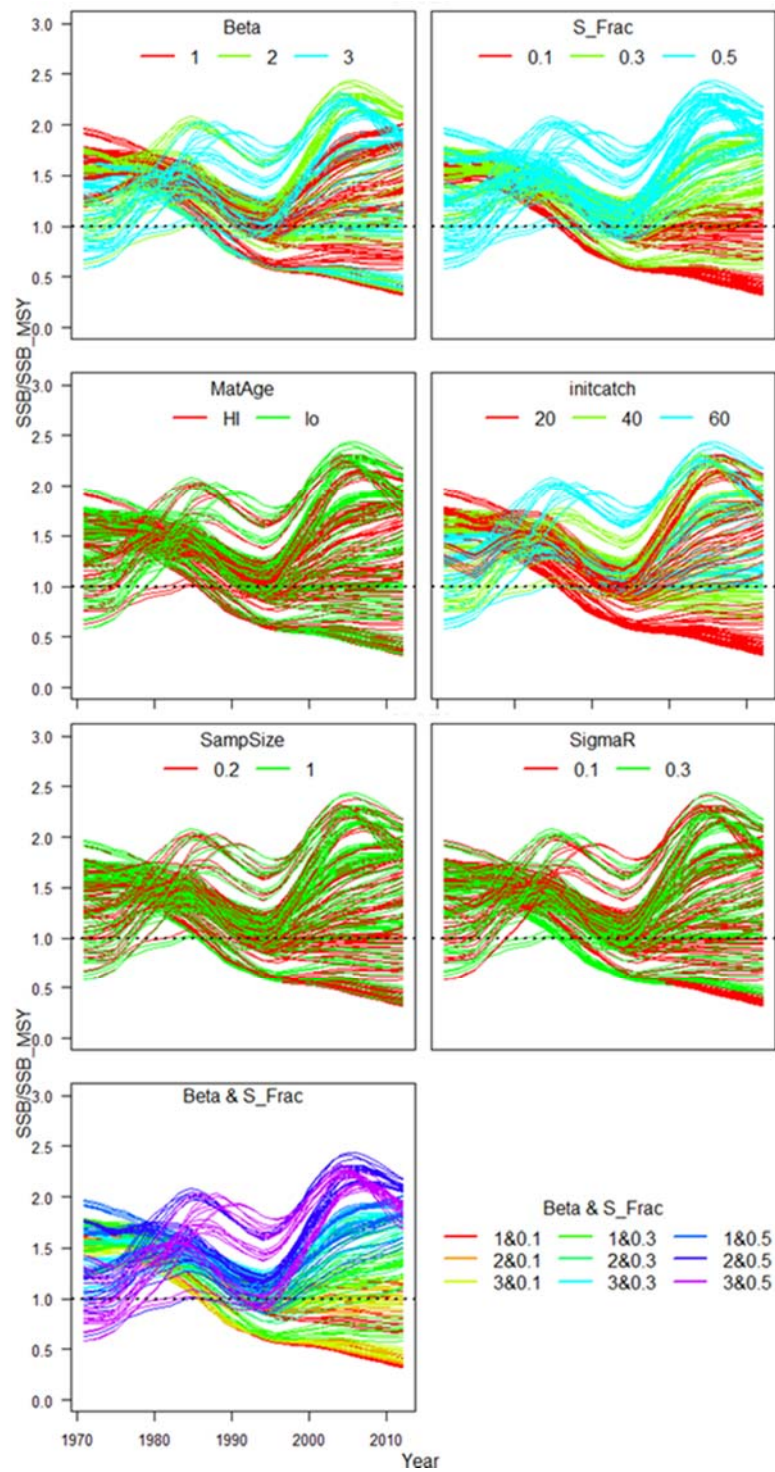


Figure 12E. Comparison of future projected blue shark (*Prionace glauca*) stock biomass (medians) under different constant catch (*status quo*, +20%, -20%) and constant F harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the BSP reference case model. *Status quo* catch and fishing mortality was based on the average from 2006-2010.

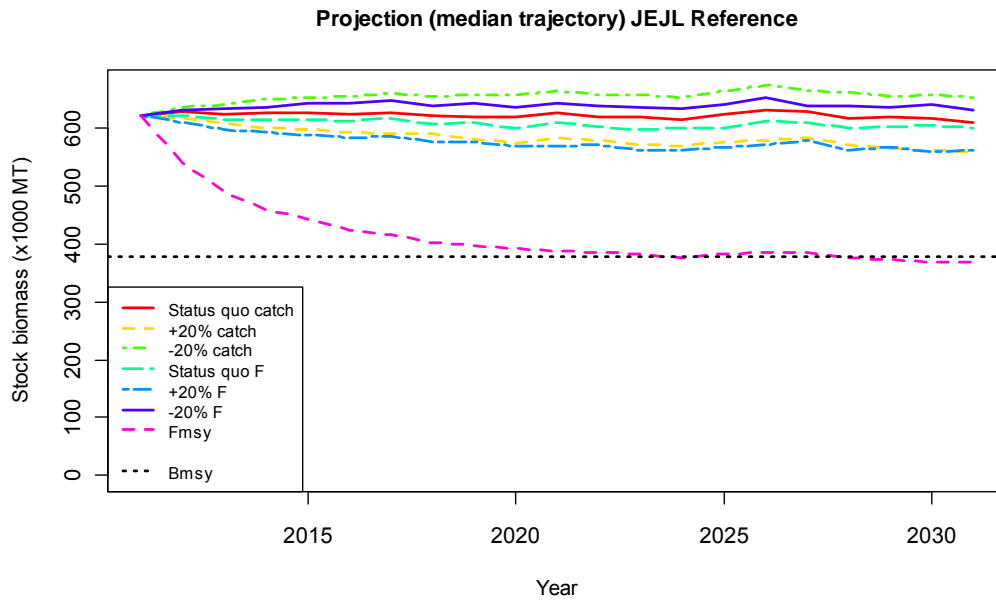
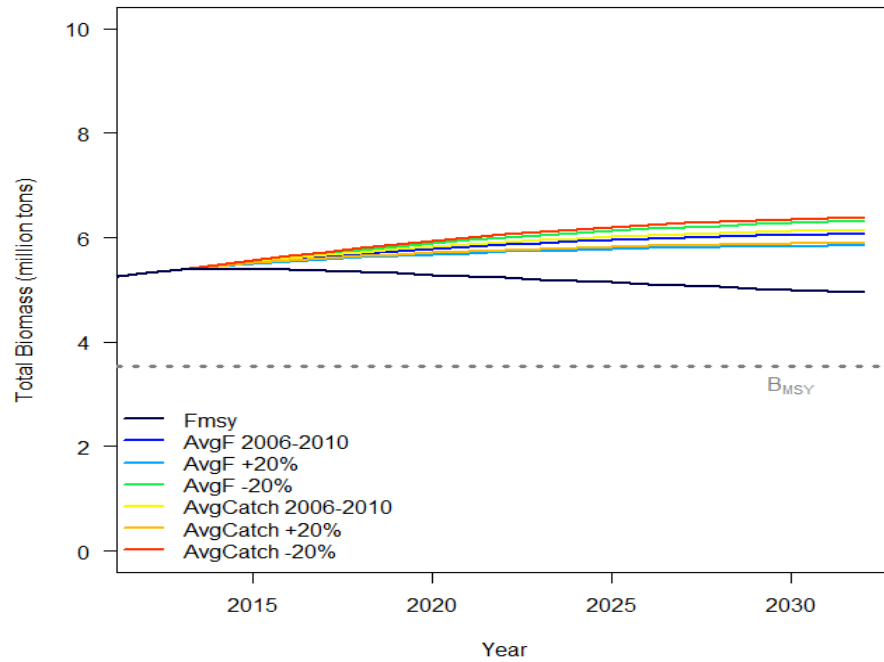


Figure 13E. Comparison of future projected blue shark (*Prionace glauca*) stock biomass under different constant catch (*status quo*, +20%, -20%) and constant F harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* catch and fishing mortality was based on the average from 2006-2010.



1 INTRODUCTION

Blue shark (*Prionace glauca*) is a common highly-migratory pelagic shark species distributed over temperate and tropical waters worldwide (Nakano and Seki 2003). Their flesh, fins and other body parts are utilized in many countries, and are thus an important fisheries resource. Along with other sharks, blue sharks are considered important in marine ecosystems as they feed at various trophic levels. Like other exploited marine resources, sound scientific knowledge of blue sharks is needed to maintain sustainable fisheries and their role in marine biodiversity.

Concern about the status of shark stocks (Barker and Schluessel 2005) has driven Regional Fishery Management Organizations (RFMOs) to heighten efforts to collect data on sharks from sources of fishery mortality for stock assessments. Unlike commercial targeting of higher value pelagic species such as tunas and billfish, which tend to have high reproductive potential, a greater portion of shark fishing mortality is the result of bycatch, and the reproductive potential of elasmobranchs in general is much lower than teleosts and higher fecundity species (Au et al. 2008). As largely non-targeted species, records of shark catches are often of lower quality and quantity than targeted species. However, the emergence of markets for shark fins has driven demand (Clarke 2004), providing a substantial source of cryptic shark mortality. Without reliable recorded data of retained catch and dead discards, it is difficult to estimate the number of mortalities and the population characteristics of those mortalities (size, sex, etc.) from only harvested parts. RFMOs have directed increased efforts to monitor and estimate shark catches and coordinate research into shark biology in an effort to quantify populations with respect to biological reference points (IATTC 2005, Clarke and Harley 2010)

This document presents outcomes of the latest stock assessment of blue sharks in the North Pacific conducted by the International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean (ISC) Shark Working Group (SHARKWG). The assessment is an update to the SHARKWG's 2013 north Pacific blue shark assessment (ISC SHARKWG 2013b). The Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee's Ninth Regular Session (SC9) reviewed the 2013 stock assessment, which was conducted using a Bayesian Surplus Production (BSP) model for north Pacific blue shark. In addition, SC9 reviewed a north Pacific blue shark assessment conducted using Stock Synthesis (SS), an age-based statistical catch-at-length model (Rice et al. 2013). In both cases, SC9 was concerned that the assessments used few alternative catch-per-unit-effort (CPUE) indices and that the SHARKWG should consider a broader range of uncertainties in the data and input parameters. SC9 did not reach consensus on whether either assessment reflected trends in abundance and fishing mortality and recommended that the ISC SHARKWG complete a revised assessment in 2014 (WCPFC 2013).

In this revised assessment, two modeling approaches (BSP and SS) and five different CPUE indices were used to account for a broader range of uncertainties about the blue shark stock dynamics. Standardizations of CPUE data were improved and catch estimates for Japanese and Taiwanese fleets were revised. The SS modeling platform allowed use of a novel low fecundity spawner recruit (LFSR) function appropriate for elasmobranchs, and enabled size and sex-specific modeling of the fishery data. In this report, background information (biology and fisheries) of north Pacific blue shark is summarized along with the assessment results.

2 BACKGROUND

2.1 Biology

Blue sharks are a temperate to tropical species found worldwide (Nakano and Stevens 2009). Their relative abundance is highest in temperate pelagic zones and decreases in neritic and warmer tropical waters, as well as cooler waters at latitudes higher than approximately 50 degrees. Telemetry studies in the eastern North Pacific indicate they spend most of their time in

the mixed layer, with forays as deep as 400 m while occupying temperatures from 14-27 °C predominantly (Weng et al. 2005). Satellite tagging in the southwest Pacific shows a similar preference for surface waters but with occasional dives in excess of 980 m, while occupying comparable water temperatures to those in the eastern North Pacific (Stevens et al. 2010). Within the North Pacific, males and females smaller than 50 cm pre caudal length (PCL) co-occur on the parturition grounds between approximately 35 and 40 °N. The habitat for subadults diverges between subadult females (35 and 50 °N) and males (30 and 40 °N) at around 100-150 cm PCL. The subadult sharks occur in the lower latitudes and adult habitat is believed to be more southerly with mating thought to occur in pelagic waters between 20-30 °N (Nakano 1994).

Further details on specific biological parameters used in the BSP and SS modeling can be found in sections 4 and 5, respectively.

2.1.1 Stock structure

Blue sharks have a pan-Pacific distribution, and genetic evidence of distinct population structure within the Pacific is not supported by mitochondrial and microsatellite markers (Taguchi et al. *In Press*). Conventional tagging in the eastern, central and western North Pacific regions has resulted in recoveries within each North Pacific region, providing evidence of wide movement throughout the North Pacific (Sippel et al. 2011). No tagging data have yet demonstrated movement across the equator (Weng et al. 2005, Stevens et al. 2010, Sippel et al. 2011). Consensus within the ISC Shark Working Group supports a single stock in 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).

2.1.2 Reproduction

As indicated above, mating is thought to occur in middle latitudes (20-30 °N). Mating scars, fertilized eggs and presence of embryos suggest mating occurs March – August, which is supported by the monthly change of GSI and maximum ova diameter found by Nakano (1994). Litter size ranging from 2-52 (mean 25.2) has been observed in the northwestern area off Taiwan (Joung et al. 2011) and was similar to that ranging from 1-62 (mean 25.6) reported in the North Pacific (Nakano 1994). Litter size has been recorded as high as 135 pups in the Indian Ocean (Gubanov 1975), suggesting that blue shark reproductive potential could be greater than observed to date in the western North Pacific. Joung et al. (2011) also estimated a two year cycle of female reproduction although other studies suggest an annual cycle (Suda 1953). Gestation is estimated to be 9-12 months (Cailliet and Bedford 1983) and 11-12 months (Nakano 1994). Blue sharks are considered relatively productive when compared to other pelagic sharks based on their maturation time and fecundity (Smith et al. 1998, Compagno 1984, Cortés 2002).

2.1.3 Growth

Pups are born at an estimated 40-50 cm fork length (FL) (Joung et al. 2011), and adults reach a maximum length of 380 cm total length (TL) (Hart 1988). Fifty percent of females are considered mature within the size range of 175-190 cm FL and males at 170-185 cm FL (Nakano et al. 1985, Joung et al. 2011), and age at 50% maturity for females and males are thought to be 5-7 years old and 4-6 years old, respectively (Cailliet and Bedford 1983, Nakano 1994). Improving growth models for blue shark is an ongoing focus of research. A number of growth models have been estimated across a range of geographic locales, with varying sample sizes and methodological approaches to ageing (Cailliet and Bedford 1983, Tanaka 1984, Nakano 1994, Skomal and Natanson 2003, Blanco-Parra et al. 2008, Hsu et al. 2011). For the last north Pacific blue shark assessment, Kleiber et al. (2009) estimated a growth model within the MULTIFAN-CL model.

2.2 Fisheries

Like other pelagic sharks, blue sharks are caught in many of the same fisheries as tunas and billfish, including longline, gillnet, troll, purse seine, and hook and line. However, they are targeted much less commonly than tunas and billfish and thus comprise an important component of bycatch from many commercial pelagic fishing operations (Worm et al. 2013). Many are discarded at sea, and the survivorship of those released depends on the condition of the released animals and environmental conditions. Many factors affect condition at release including capture methods, capture duration before fishing gear is retrieved, animal size, and handling at the boat, though across a wide range of studies, post-release mortality of blue sharks released alive is reported to be low (Musyl et al. 2011). Some information is available about these factors, but overall there are not enough data to understand the many variables affecting blue shark bycatch fishing mortality. Markets for blue shark products have developed in several western Pacific nations and Mexico (e.g. Sosa-Nishizaki et al. 2002). However, some markets value the fins primarily, and cryptic mortality of animals finned and discarded at-sea is a substantial source of uncertainty in blue shark fishing mortality (Clarke 2004).

Currently, the primary source of known blue shark fishing mortality is longline fishing. In the subtropics, deep-set longlines targeting tunas and shallow-set longlines targeting swordfish and marlin commonly encounter blue sharks. In more temperate waters, shallow-set longlines targeting swordfish, bluefin and albacore also frequently catch blue sharks. Historically, the primary fleets with effort in these fisheries have been from Japan and Chinese Taipei (Kleiber et al. 2009), and to a lesser extent Korea. More recently, Chinese operations have been identified as another important source of longline fishing effort. Japanese offshore surface longliners now seasonally target blue shark (Hiraoka et al. 2012d). Since the late 1980s, Mexico has been developing its pelagic commercial fishing operations, primarily targeting tunas and billfish, but markets developed for shark products have also increased shark targeting (Sosa-Nishizaki et al. 2002). They were also commonly caught in high seas drift gillnet fisheries, operated primarily by Japan, Korea and Chinese Taipei, until the early 1990s before the ban on high seas drift gillnets longer than 2.5 km was enacted in 1992. Drift gillnet fleets now operating within the EEZs of several nations including Japan, Chinese Taipei, Mexico, and the USA currently capture some blue sharks.

2.3 Previous assessments

Two north Pacific blue shark stock assessments were conducted in 2013. The ISC SHARKWG conducted a Bayesian Surplus Production (BSP) model for the period 1971-2011 using fishery data from throughout the North Pacific (ISC 2013). In parallel, the Secretariat of the Pacific Community (SPC) took the lead on an age-structured, integrated model conducted using Stock Synthesis (SS) using the same fishery catch data for the period 1976-2011 along with size and sex composition data obtained through the ISC SHARKWG (Rice et al. 2013). In both assessments, standardized catch-per-unit-effort (CPUE) indices developed using Japanese longline fishery logbook data for an early period (1976-1993) and late period (1994-2010) were used in the base cases. In alternative runs, the late Japan index was replaced with an index developed using Hawaii tuna longline fishery observer records for the period 1995-2011. The SS assessment also used an index from Japanese training vessel data for the late period but most models using that index failed to converge.

Results from the base case models showed similar biomass trajectories for the two assessments conducted in 2013. Biomass was highest at the beginning and end of the time series, but decreased in the 1980s reaching a low point in the late 1980s to early 1990s. The BSP base case model resulted in a terminal year biomass estimate of approximately 456,000 mt which was 59% above B_{MSY} . Fishing mortality in 2011 was estimated to be approximately 35% of F_{MSY} . The SS model estimated levels of biomass and fishing mortality lower relative to MSY than the BSP

model, but showed similar trends overall. Terminal year biomass was estimated to be 90% of B_{MSY} and the fishing mortality 77.6% of F_{MSY} . Models using the Hawaii index for the late period produced estimated an unhealthy stock condition, but the ISC SHARKWG considered those results less plausible; the Hawaii index was not considered to be representative of the stock due to the relatively small amount of catch and spatial coverage and the potential impact of regulatory changes in the fishery.

Prior to 2013, the last stock assessment of north Pacific blue shark was conducted using a fishery time-series ranging from 1971-2002 for Western Pacific (WPO) and Central Pacific (CPO) fisheries, but did not include the Eastern Pacific (EPO) fisheries (Kleiber et al. 2009). In that assessment, two assessment approaches were also used: a Bayesian Surplus Production model (a state-space model implementation was not used in the 2009 assessment as in 2013) and the integrated spatially disaggregated age-structured model, MULTIFAN-CL (Fournier et al. 1998). The assessment included data from the commercial longline and drift gillnet fisheries of Japan, Chinese Taipei, Republic of Korea, and the USA, with additional data provided by the SPC. A standardized catch-per-unit-effort (CPUE) index developed using Japanese longline fishery logbooks was used as an abundance index. Japanese catch and CPUE time-series were developed after using a filter to exclude logbook records that were considered unreliable (Nakano and Clarke 2006). The assessment was carried out on numbers of sharks, as opposed to biomass. A limited amount of size data, collected from Japanese and Hawaiian longline fisheries and some gillnet operations was also included in the MULTIFAN-CL model. Results of the 2009 BSP modeling indicated that blue sharks in the North Pacific were being harvested below MSY (3.58 million sharks y^{-1}), and population levels at the end of the model time period (2002) were close to levels at the beginning of the time period (1971). The intrinsic rate of increase (r) was assumed to be 0.30, with a median estimate of carrying capacity (K) of 49.15 million sharks indicating that MSY was 7.4% of K . The BSP model fit to the data was considered acceptable, with the caveat that the number of sensitivity runs using alternative assumptions in catch levels and model parameters was limited. Results of the integrated analysis were generally consistent with the BSP model, indicating a decline in the 1980s followed by a population increase in the 1990s with a leveling from 2000-2002.

3 DATA

The data used in this assessment were nearly the same as those used in the 2013 assessments with few updates as indicated below.

3.1 Spatial stratification

The assessment was conducted assuming 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).

3.2 Temporal stratification

An annual (Jan 1-Dec 31) time-series of fishery data for 1971-2011 was used for most BSP models with a sensitivity run using data through 2012, whereas all the SS models used the data through 2012. Blue shark catch in 2012, although estimated for several fleets, represents a large amount (about 60%) of substituted catch carried over from 2011, and is thus considered more uncertain than that prior to 2012.

3.3 Definition of fisheries

The SHARKWG estimated catches of many fisheries from different nations and member sources in an effort to understand the nature of fishing mortality on blue sharks in the North Pacific (Figure 2). All catch estimates were aggregated into a single time-series for the BSP model, and 18 distinct fisheries were defined in SS runs. The primary sources of catch were from longline

and drift gillnet fisheries, with smaller catches also from purse seine, trap, troll, and recreational fisheries (Figure 3). Most of the data were the same as those compiled by the SHARKWG for the 2013 assessment; the highest catches came from Japan and Chinese Taipei, with newly available Mexican fishery data providing a relatively smaller, but important source of catch. Japanese and Taiwanese fishery data were improved based on newly available information as described below.

3.4 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 SHARKWG held in the USA and Japan (ISC 2012a, ISC 2012b, ISC 2013a, ISC 2013b, ISC 2014a). Catches were extracted from databases of landings, vessel logbooks, and observer records. When reliable catch data were unavailable, catches were estimated using independently derived information such as observer or research vessel standardized CPUEs, which are believed to provide reliable data on retained catch, live and dead discards. This information was often combined to transform effort data into catch estimates. The SHARKWG agreed to conduct the assessment on units of biomass (as opposed to numbers of animals), so catches were compiled in metric tons (mt) if available, or in numbers of sharks which were converted to biomass. For each fishery, if a fishery specific conversion factor was available (e.g. Japanese fleets, see below), the catch in weight was estimated using the fishery specific size conversion equations. Otherwise, catch in weight was estimated with the agreed upon length-weight conversion: $Wt = 4.2 \times 10^{-6} * PCL^{3.1635}$, where weight is in kg and PCL is precaudal length in cm.

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. During the 1970s, more than 70% of the estimated catch came from Japan, but that proportion has been continuously declining and now comprises approximately 40% of the estimated catch. Recently, catch from Taiwan has been comparable to that of Japan (approximately 40%), and recent catch from Mexico comprises approximately 9% of the total (Figure 2). By gear, longline has comprised 85.2%, drift gillnet 11.1% and mixed gears 3.8% of the catch (Figure 3).

A single series of catch estimates, broken down by fleet for the SS models, was used in the current assessment (Figures 2, 3 and 4). This catch time series includes the SHARKWG's best estimates for discard mortality. Discard mortality is expected to differ by gear type and where available, information was considered with respect to each fishery and gear, including proportions of live and dead discards from observer records and telemetry studies.

3.4.1 Japan

The catches of the offshore (*Kinkai*) and distant-water (*Enyo*) longline fisheries accounted for approximately $\frac{3}{4}$ of total Japanese catches and were estimated as the product of standardized CPUE and effort during 1976-2012 from filtered logbook data (Kai et al. 2014). For this estimation, these longline fisheries were categorized by vessel size (offshore or distant-water), operational style (shallow- or deep-sets) and the prefecture of vessel register because the reporting ratios of blue shark were different by these categories. The total numbers of dead removals including discards of Japanese offshore and distant-water fisheries were estimated using the ratio of CPUE between the commercial longliners and the Japanese training vessels. The estimated annual removals were revised using updated conversion factors between processed and whole weights (Kai et al., 2014). The same methods described above were applied for the estimation of the total removals in 2011 and 2012. The CPUE of blue shark was standardized up to 2012 for this purpose but this updated standardized CPUE was not used for

this stock assessment because catch and effort data of Japanese longliners in 2011 and 2012 were heavily affected by the Great East Japan Earthquake. Total removals from 1971-1975 were estimated using the mean ratio of retained catch to estimated total removals during 1976-1980. The mean ratio was calculated for each category of the longline fishery.

Historical catch of blue shark caught by the Japanese coastal fisheries was estimated from Japanese year books since 1951 (Kimoto et al. 2012). These data were reported in species aggregated form as “sharks”, and the ratio of the catch of blue sharks to total sharks by fishing gear was calculated using available species-specific landing data. The estimated catches for the coastal longline varied between 200 and 1800 mt, while catches of other longline were between 70 and 750 mt. The estimated catches for the other fisheries were substantially smaller than longline catches, and were below 60 mt.

The catches of blue sharks in high seas squid drift net and high seas large mesh drift net prior to 1993 were obtained from Kleiber et al. (2009). The coastal large mesh drift net fishery within Japan’s EEZ started in 1993 (Yokawa et al. 2012). Species-aggregated shark catch were available in Japanese logbooks. Species-specific shark catch data during 2005-2011 was obtained from the wholesale auction records of the Kesennuma fishing port in the Miyagi prefecture, where more than 80% of the coastal driftnet fishery was unloaded. The ratio of blue shark catch to the species-aggregated shark catch was estimated using these auction records to estimate the annual blue shark catch. The ratio of blue shark catch in the period between 1993 and 2004 was assumed to be same as the average during 2005 and 2008 (48%).

3.4.2 Chinese Taipei

Chinese Taipei has small-scale (small boat, near-shore) and large-scale (large boat, distant water) longline fleets. There was a minor change in the Chinese-Taipei catch time series since the 2013 assessment. Due to a change in the logbook format, some catch from the South Pacific were miscounted as from the North Pacific. These erroneous data have been corrected as documented in Tsai and Liu (2014). Catch estimates from Taiwanese large-scale longline fisheries were the product of logbook effort and nominal CPUE to account for the under-reported blue shark catch in the logbook (Tsai and Liu 2014). Smaller vessel longline catches were estimated using observer based species compositions and dockside landing tickets (Chin and Liu 2013).

3.4.3 Mexico

The Instituto Nacional de Pesca (INAPESCA; the Mexican national fisheries and aquaculture institute) provided aggregated shark landings data classified as Tiburon (‘large’ sharks) and Cazon (‘small’ sharks) for each Pacific state from 1976-2011. These data were used to estimate blue shark catch (Sosa-Nishizaki 2013) for this assessment. Blue shark is grouped within the Tiburon category and is landed primarily in the Pacific states of Baja California, Baja California Sur, Sinaloa, Nayarit, and Colima. Two fisheries account for most blue shark catch: 1) near-shore artisanal vessels using longlines and/or drift gillnets, which target sharks and swordfish; and 2) offshore medium vessels, which also target sharks and swordfish with similar gears (Sosa-Nishizaki 2013). Regulations have changed through time, leading to different gears and fisheries existing through time. Species composition of blue sharks relative to total shark catches from artisanal fisheries was approximated with the best available information. Catch for 1971-1975 from these fisheries was assumed to be the average catch for these fisheries from 1976-1978, and the 2011 catch was carried forward to 2012. From discussion with Mexican scientists, two additional sources of likely blue shark fishing mortality were also identified. Discards from the medium-sized longline vessel fleet targeting swordfish from 1986-1993 were estimated as a multiple of swordfish landings (Holts and Sosa-Nishizaki 1994) assuming a blue shark to swordfish bycatch ratio of 63:24 (Dreyfus et al. 2008). For a joint venture longline fishery with Japan and Taiwan operating during 1980-1989, effort (Sosa-Nishizaki 1998) was multiplied by

blue shark CPUE for a fleet with comparable longline operations (Mendizábal et al. 2000, O. Sosa-Nishizaki pers. comm.).

3.4.4 USA

The primary source of US catch was the Hawaii-based longline fleet, which includes deep- and shallow-sets targeting tunas and swordfish, respectively (Walsh and Teo 2012). Estimates of blue shark catch were made from observed sets and logbooks, using catches predicted by a GLM when logbook records were considered unreliable (i.e. unreported catch). Catch for the California pelagic longline fishery, which historically has been small relative to the Hawaii-based fishery and currently is comprised of a single vessel, was estimated by multiplying the CPUE of observed sets by effort recorded in logbooks and average blue shark weight from observer records (Walsh and Teo 2012). A small amount of catch from a short-lived experimental longline fishery that operated in Southern California waters was included (O'Brien and Sunada 1994, Teo 2013). US longline blue shark catch estimates for 2011 were carried forward to 2012. Catches from the US west coast drift gillnet fishery that targets swordfish were estimated from 1981-2011 by Teo et al. (2012) and updated in January 2014 using the same methods to estimate 2012 catch. Catches from recreational fisheries for 1971-2011 were estimated based on 'RecFIN' data collected by telephone surveys and dockside interviews, as well as logbooks from the California Commercial Passenger Fishing Vessel (CPFV) database (Sippel and Kohin 2013) and updated in January 2014 using the same methods to estimate 2012 catch.

3.4.5 Canada

Canadian catch was negligible and estimated from three fisheries including groundfish longline, groundfish trawl, and salmon fisheries using trolls, gillnets and seines (King 2011). The 2011 catch estimates were carried forward to 2012.

3.4.6 Korea

Korean blue shark catch was assumed to be equal to North Pacific species-aggregated shark catch reported to the ISC. The Korean annual reports to the two past WCPFC SC meetings indicated that the catch of major shark species includes only blue and porbeagle sharks based on logbooks, and 65% of the catches of major shark species was comprised of blue shark based on observer records for one year. The Korean annual report in 2010 also indicated that the average CPUE of blue shark caught by Korean longliners was 0.07 (number/100 hooks) based on the observer data. Based on this information, it was assumed that all Korean reported catch of species-aggregated sharks in the North Pacific are blue sharks, because porbeagle sharks are not distributed in the North Pacific. Using the annual aggregated shark catch and effort data submitted to the ISC, and an average blue shark size of 30 kg, the average size caught in a comparable Japanese longline fishery, estimated CPUE by year in number of blue sharks per 1000 hooks caught by Korean longliners ranged from 0.0 to 0.89 which is comparable to the average CPUE obtained by the Korean observer data. The 2011 catch estimate was carried forward to 2012.

3.4.7 China

Species-specific longline catch and effort were available for 2009-2011 and effort data were available back to 2001. The 2009-2011 CPUE was applied to the 2001-2008 effort data to back calculate catch for those years. It was assumed that effort of Chinese longliners in the North Pacific was minimal prior to 2001. The 2011 catch estimate was carried forward to 2012.

3.4.8 SPC

SPC provided estimates of blue shark longline catches for non-ISC member countries in the WCPFC area north of the equator using their data holdings. Catch was estimated based on a standardized CPUE value for each 5 x 5 degree cell multiplied by the effort reported in that cell summed on an annual basis. The non-ISC countries represented in the dataset include 12 countries, many of them that likely fish only south of the equator, thus it is believed that the north Pacific blue shark catch of non-ISC member countries represented in the WCPFC database is attributed to Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea and Vanuatu. The 2011 catch estimate was carried forward to 2012.

3.4.9 IATTC

IATTC provided estimates of blue shark bycatch in tuna purse seines in the north EPO (IATTC 2013). The number of blue sharks caught in number from 1971-2010 was estimated from observer bycatch data, and observer and logbook effort data. Some assumptions regarding the relative bycatch rates of blue sharks were applied based on their temperate distribution and catch composition information. Estimates were calculated separately by set type, year and area. Small purse seine vessels, for which there are no observer data, were assumed to have the same blue shark bycatch rates by set type, year and area, as those of large vessels. Prior to 1993, when shark bycatch data were not available, blue shark bycatch rates assumed to be equal to the average of 1993-1995 rates were applied to the available effort information by set type, area and year. Numbers of sharks were converted to tons by applying an average annual weight estimate derived from blue sharks measured through the IATTC observer program. The catch estimate for 2010 was carried forward for 2011 and 2012.

Coastal fisheries and highseas longline fisheries catch of blue sharks for non-ISC member nations operating in the IATTC area are not accounted for in this assessment. However, the catch is considered to be relatively low compared to the total estimated catch. The SHARKWG is continuing to work with IATTC and nations fishing in the Eastern Pacific Ocean to get estimates of this unaccounted catch.

3.5 Abundance indices

Eight candidate standardized CPUE indices were considered for use in the stock assessment. These had been developed from catch and effort data of Japanese, Taiwanese, US and SPC longline fisheries. Increased bias and uncertainty in the assessment results would likely occur if multiple indices with confounding trends are used in the same assessment. As a result, a suite of criteria was used by the SHARKWG to select indices for the base case and alternative runs from the candidate indices (Table 1). Key criteria included 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.

Based on these criteria, the Japanese “early” (1976-1993) and Japanese “late” (1994-2010) longline indices (Kai et al. 2014) were selected for the reference case model (Figure 5, Table 1). Three indices that only covered the more recent period were selected to use in alternative runs in combination with or without the Japan early index. These included a Hawaii deep-set longline index (2000-2012) (Walsh and DiNardo 2014), a Taiwanese large-scale longline index (2004-2012) (Tsai and Liu 2014), and an SPC longline index (1993-2009) (Rice and Harley 2014). Figure 6 shows the spatial extent of the fishery data used in each index.

3.5.1 Reference case abundance indices

The Japanese early abundance index was developed from catch-and-effort data from the Japanese *Kinkai* (offshore) shallow-set longline fishery based in Hokkaido and Tohoku

prefectures from 1976-1993 (Hiraoka et al. 2013). The Japanese late abundance index was developed from catch-and-effort data from the Japanese *Kinkai* (offshore) and *Enyo* (distant water) shallow-set longline fisheries based in Hokkaido and Tohoku prefectures from 1994-2010 (Kai et al. 2014). The fishery data were also standardized separately to provide an index for 2011 and 2012, since there was a dramatic change in the fishery operation in 2011 due to the Great East Japan Earthquake, but the SHARKWG decided not to use the data since the time series was so short. Detailed descriptions of these fisheries and the development of these indices can be found in several SHARKWG papers (Hiraoka et al. 2011; Hiraoka et al. 2012a, 2012b, 2012c, 2012d; Hiraoka et al. 2013; Kai et al. 2014). The primary reasons for using these indices in the reference case model is that these fisheries have relatively large spatial and temporal coverage over the core blue shark distribution area, reflected large proportions of the overall catch and diagnostics from standardizations were acceptable, as compared to the other candidate indices (Table 1).

Logbook records were used to develop these indices but these logbooks only recorded species-aggregated catch of sharks before 1994. The proportions of blue sharks in the species-aggregated shark catch from 1975-1993 were therefore estimated using a binomial GLM based on species-specific data from 1994-2010. Since it was thought that some vessels do not record blue shark catch, the data for both periods were filtered with the composite reporting rate (RRZ) filter developed by Clarke et al. (2011), which retained data with an individual vessel base reporting rate of >94.6%.

Negative binomial GLMs were used to standardize the abundance indices with explanatory variables including year, area, season, vessel type, and target (Hiraoka et al. 2013; Kai et al. 2014). Model diagnostics and residuals did not indicate any substantial bias in the estimated abundance trends. A targeting variable was included in the standardization because Hiraoka et al. (2012b) and Clarke et al. (2011) observed annual changes in the target species of these fisheries, from swordfish and tunas to blue shark from the mid 1990s. The swordfish catch ratio by set were divided into 10 categories at each 10th percentile annually, and used as the target factor. Though the target variable only had minor effect on the CPUE standardization, spatiotemporal analysis of the data revealed this was due to the fact that most of the targeting shifts were explained by area and season variables (Hiraoka et al. 2013, Kai et al. 2014).

The Japanese early index indicated a decline in the blue shark relative abundance from 1976-1989 but the trend began to increase during 1990-1993 (Figure 5). The Japanese late index indicated that the increase in blue shark relative abundance generally continued during 1994-2010 (Figure 5).

3.5.2 Alternative runs indices

3.5.2.1 Hawaii deep-set longline

The Hawaii deep-set (2000-2012) longline index was developed from the catch-and-effort data gathered by onboard observers on longline vessels based in Hawaii (Walsh and DiNardo 2014). The deep-set fishery was separated from the shallow-set fishery based on the recorded number of hooks per float (≥ 15 hooks per float: deep-set; < 15 hooks per float: shallow-set). A delta-lognormal GLM was used to standardize the abundance index with a number of operational and environmental explanatory variables (Walsh and DiNardo 2014). Model diagnostics for this index were good, with relatively normal residuals. In contrast to the Japanese late index during the same period, the Hawaii deep-set index indicated a decline in the blue shark abundance during 2000-2012 (Figure 5).

The spatial and temporal coverage of the Hawaii deep-set longline fishery was relatively low, but given the overlap of this fishery with some of the Japanese longline fishery operations, the SHARKWG explored the trends in catch rates for a subset of the Japanese fishery while

operating over the same times and areas. Using set by set data, the Japanese fishery catch rates showed a trend similar to that of the Hawaii fishery that may indicate a regional local change in blue shark abundance. Throughout the range of the north Pacific blue shark, the broader coverage of the entire Japanese longline fleet is believed to be more representative of the stock. Thus, this index was not recommended for use in the reference case but was used in alternative runs to capture an alternative scenario given the uncertainty about the dynamics of the stock.

3.5.2.2 Taiwanese large-scale longline

An index for the Taiwanese large longline fishing fleet operating in the North Pacific Ocean from 2004-2012 was developed from observers' records of the blue shark catch and fishing effort (Tsai and Liu 2014). Due to the large percentage of zero shark catch, the catch per unit effort (CPUE) of blue shark, as the number of fish caught per 1,000 hooks, was standardized using a delta lognormal model. The analysis of standardized CPUE showed an increasing trend for blue sharks (Figure 5). Although the number of observed sets was small and the index time-series was short, its spatial extent was large and the diagnostics of the standardization were considered acceptable for use as an alternative abundance index in the assessment. The index will likely improve as a longer time series of observer data become available.

3.5.2.3 SPC longline

A standardized index of blue shark taken in longline fisheries in the North Pacific, based on observer data held by the SPC, was developed using the negative binomial approach (Rice and Harley 2014). Important factors explaining the variation in observed CPUE included SST, 5° latitudinal band and month. The index covered the years 1993 - 2009. A large percentage of the SPC observer record holdings are for the Hawaii longline fisheries and those were excluded from this analysis since a Hawaii longline index had been independently produced by US scientists. After exclusion of the Hawaii fishery data, the number of observed sets was fewer than 3000 and sets were concentrated in the subtropical areas of the western Pacific, close to the equator where the blue shark abundance is believed to be lower. Model diagnostics showed some residuals that may indicate a problem with model fitting, but generally the diagnostics were acceptable. The index was not used in the reference case because of the low observer coverage and area of operation but was used in alternative runs to capture an alternative scenario given the uncertainty about the dynamics of the stock.

3.5.3 Other candidate indices

Three other indices were evaluated but not used in this assessment: 1) Hawaii shallow-set longline (Walsh and Teo 2012; Walsh and DiNardo 2014); 2) Taiwan small-scale longline (Chin and Liu 2013); and 3) Japanese longline training vessel (Clarke et al. 2011). These candidate indices were not used for a variety of reasons. The Hawaii shallow-set longline index had a relatively small spatio-temporal coverage and numerous regulations unrelated to blue shark have also probably influenced fishery operations and affected catchability (Table 1). The Taiwan small scale longline fleet has a large spatial coverage but short temporal coverage (Table 1). In addition, more work needs to be done to understand the representativeness of the data as it is not based on observer data. The Japanese training vessel index had relatively small spatial coverage (approximately the same as the Hawaii indices), poor data quality after 2006 (Yokawa et al. 2014) and exhibited strong non-normal residual patterns in the standardization model. In addition, Clarke et al. (2011) indicated that fishing operations appeared to avoid high CPUE areas for blue shark (Table 1).

3.6 Length-frequency data

The SHARKWG reviewed size-, and where available, sex-frequency data provided for 10 fisheries for use in the SS models (Figure 7). Time-series of length data were provided for the

following fleets: Mexico (1992-1996, 2000-2012); China (1993-2008), Japan *Kinkai* (offshore) shallow-set longline (2008-2011), Japan *Kinkai* and training vessel deep-set longline (1992-2011), Japan large-mesh drift gillnet (1991, 2011), Asian (Japan, Korea and Taiwan) small-mesh drift gillnet (1990-1991), USA EEZ pelagic drift gillnet (1990-2012), USA longline (1995-2012), Taiwan large vessel longline (2004-2012), Taiwan small vessel longline (2009). Many of the time series suffered from low sample sizes and inconsistencies in sampling across years. Length observations measured in total length (TL) or fork length (FL), were converted to precaudal length (PCL) using the following agreed upon relationships: $PCL=0.748*TL+1.063$ and $PCL=0.894*FL+2.547$, where length is in cm.

4 BSP MODEL DESCRIPTION

4.1 BSP2 Software

For the production modeling, the SHARKWG decided to use a non-equilibrium, age-aggregated Bayesian surplus production (BSP) model (Stanley et al. 2012) and chose the BSP2 implementation developed for ICCAT (McAllister and Babcock 2006³). It is a state-space version of BSP model that incorporates stochastic process error in the stock dynamics and thereby allows a more thorough accounting of uncertainty in estimates of stock biomass, future projections, and deviations as compared to a deterministic BSP model. BSP2 uses a Bayesian approach in which the posterior distribution of key parameters given the data is obtained from the likelihood of the data and the prior distribution of the data using Bayes theorem (McAllister and Babcock 2006). Using the priors enables the model to incorporate existing information and expert judgments. The BSP2 approximates the posterior distribution applying the Sampling Importance Resampling (SIR) algorithm. BSP2 fits either a Schaefer or Fletcher/Schaefer production model to time-series of catch and indices of abundance (CPUE), with CVs if available. The parameters that can be fit include carrying capacity (K), intrinsic rate of increase (r), biomass in the first modeled year defined as a proportion of K ($\alpha.b_0$), the shape parameter for the surplus production function for the Fletcher/Schaefer fit (n), the average annual catch for years prior to recorded catch data (cat_0), and catchability for each CPUE series (q). Priors can be used for all parameters. The biomass trajectory can be projected under any catch or harvest policy with the fitted model, as well as associated confidence bounds.

The Schaefer surplus production model is expressed as (Prager 1994):

$$(1) \quad \frac{dB_t}{dt} = rB_t - \frac{r}{K} B_t^2 - F_t B_t$$

where r is intrinsic rate of increase, K is carrying capacity, B_t is biomass at time t , and F_t is fishing mortality rate at time t . In the Schaefer model, the biomass that produces maximum sustainable yield (B_{MSY}) is one half of K .

A generalized version of the model which allows B_{MSY}/K to vary includes a shape parameter, n , as well as the additional parameter m (maximum sustainable yield) (Fletcher 1978):

$$(2) \quad \frac{dB_t}{dt} = gm \frac{B_t}{K} - gm \left(\frac{B_t}{K} \right)^n - F_t B_t$$

³ The current software manual of the BSP model (McAllister and Babcock 2006) does not fully explain input parameters, model options and outputs for a state-space version of the BSP model, although it is still useful to learn how to run the software. The ISC Shark Working Group held a three-day workshop in Yokohama, Japan in November 2012 during which Dr. Murdoch McAllister demonstrated how to run the state-space BSP model software.

where;

$$(3) \quad g = \frac{n^{n/n-1}}{n-1}$$

and the inflection point is;

$$(4) \quad \phi = \frac{B_{MSY}}{K} = \left(\frac{1}{n}\right)^{1/n-1}$$

At $n=2$, the inflection point occurs at $0.5K$ and this model is identical with the Schaefer model (Prager 2002). This model predicts near-infinite rates of surplus production per capita as abundance decreases to low levels when $n \leq 1$ (i.e. $B_{MSY}/K \leq 1/e$) (Quinn and Deriso 1999, Prager 2002). The BSP2 software has been adapted to provide a more realistic production model by fitting a synthesis of the Fletcher and Schaefer models that can take on reasonable values of r at all inflection points (called the Fletcher-Schaefer model) (McAllister and Babcock 2006). For $n > 2$ the original Fletcher model as in equation 2 applies. For $n < 2$ and $B_i/B_{MSY} > 1$ the Fletcher model also applies. For $n < 2$ and $B_i/B_{MSY} \leq 1$ the functional Schaefer model as in equation 1 applies, where $h=2\phi K$, and ϕ is from equation 4.

A state-space version of the BSP model that incorporates lognormal deviates from total annual stock biomass predictions as described in Stanley et al. 2012 was used:

$$(5) \quad B_t = \left(B_{t-1} + rB_{t-1} - \frac{r}{K} B_{t-1}^2 - F_{t-1}B_{t-1} \right) \exp\left(s_t - \frac{\sigma_s^2}{2}\right)$$

where the prior probability distribution for the process error term is given by $s_t \sim \text{Normal}(0, \sigma_s^2)$.

4.2 Biological and demographic assumptions

This stock assessment assumes that the north Pacific blue shark is a single well-mixed stock, which is supported by current biological information (Section 2). For the production modeling, it is also assumed that age and sex structure, changes in gear selectivities, and stock-recruitment variability do not substantially affect the estimated stock dynamics.

The most important biological parameters in the BSP model were: K , B_{init}/K (biomass in the first year of the stock assessment as a proportion of K), r , and n . The model was initialized with priors and associated standard deviations (SDs) on each parameter, and the posterior distributions were evaluated after model convergence was obtained. The priors for K and B_{init}/K were based on preliminary BSP model runs, such that the priors were relatively uninformative but the SDs encompassed biologically plausible values (see sections below).

Demographic analyses were used to provide priors for: 1) the intrinsic rate of increase, r ; and 2) the shape parameter, n . However, there was a lack of demographic information on north Pacific blue shark that adequately incorporated the uncertainty in the stock's biological characteristics. Therefore, as in the Kleiber et al. (2009) assessment, it was assumed that the north Pacific blue shark had similar biological characteristics to the Atlantic blue shark. A reasonable range for these parameters for the reference and sensitivity cases was derived from Cortés (2002), which used Monte Carlo simulation to account for the uncertainty in biological characteristics.

4.2.1 Intrinsic rate of increase

The intrinsic rate of increase, r , was derived from the population growth rate (λ) estimate from Cortés (2002) (1.401; 95% CI: 1.284-1.534), using $r = \ln(\lambda)$, which resulted in a mean estimate of 0.34 y^{-1} (95%CI: 0.25-0.43) for r . This value was used in the reference runs with lower with higher values in sensitivity runs (0.14 and 0.43). However, a less informative SD of 0.5 was assigned to r in the reference runs because preliminary BSP model runs indicated that the data was informative on this parameter, which allowed the r prior to have a lognormal distribution with a 95% CI of 0.19 to 0.61 y^{-1} .

4.2.2 Shape parameter

The shape parameter, n , was derived from the population growth rate (λ) and generation time (T) estimates from Cortés (2002), the population growth relationship from Fowler (1988), and the relationship between B_{MSY}/K and n (eq. 4).

Fowler (1988) observed a population growth relationship between the B_{MSY}/K and demographics of a population:

$$(6) \quad \frac{B_{msy}}{K} = 0.633 - 0.187(\ln(rT))$$

Given that Cortés (2002) found Atlantic blue shark to have a r and T of 0.34 y^{-1} and 7 y, respectively, the mean B_{MSY}/K was found to be 0.47 (95% CI: 0.39-0.56). Using eq. 4, the corresponding n for this B_{MSY}/K value was approximately 1.71.

The priors for n should covary with the r priors, given the above relationships. However, in order to use a conjoint r and n prior, a highly informative prior is often necessary because the input data in a BSP model tend not to be informative on n (McAllister et al. 2000). Preliminary model runs indicated that the input BSP data for this assessment was not informative on n . Given this and that the r and n priors should not be overly informative, a conjoint r and n prior was not used (McAllister et al. 2000). Instead, the n parameter was fixed for the reference cases at the mean of the estimated n (1.71), corresponding to $B_{MSY}/K=0.47$, and sensitivity analyses were performed for a plausible range of values for both r and B_{MSY}/K . Since there is unaccounted uncertainty in the Fowler (1988) relationship (eq. 6), the sensitivity analyses encompass a wider range of values for B_{MSY}/K (0.3 – 0.6).

4.2.3 Weighting of model components

Within the model, inverse variance weighting of each yearly CPUE value was used to estimate variance, $\sigma_{j,k}^2$, according to the following equations;

$$\text{Ln}L = - \sum_j \sum_y \left[\frac{(\ln(I_{j,y}) - \ln(\hat{q}_j \hat{B}_y))^2}{2\sigma_{j,k}^2} + \ln(\sigma_{j,y}) \right]$$

where,

$$\hat{q}_j = \left(\frac{\sum_y (\ln(I_{j,k}) - \ln(\hat{B}_y)) / (\sigma_{j,k}^2)}{\sum_y 1 / (\sigma_{j,k}^2)} \right)$$

Here, $I_{j,y}$ is observed index of abundance for series j in year y . \hat{q}_j is the model predicted constant of proportionality for time series j . \hat{B}_y is the model predicted biomass in year y . $\sigma_{j,y}$ is the standard deviation of abundance index for series j in year y .

This approach was recommended when weighting uniform variance estimates across different index years (M. McAllister pers. comm.).

Because the BSP2 software treats the total coefficient of variation (CV) for the CPUE indices as the square root of ((observation error CV)² + (process error CV)²), and the observation error CV for indices is quite small, the total CV is dominated by the process error CV of the indices. CVs for indices were repeatedly adjusted (iterative reweighting) with an initial value of 0.20 until the ratio of the input CV to output CV ranged between 1.1-1.5. This assumes that the CV for each index is constant across years, while the SD of the process error for the biomass dynamics equation was fixed at 0.07. This value for the SD for the process error was chosen because it provided better model fits to the data and posterior mode estimation in some preliminary BSP2 model runs conducted to examine the relationship between SD for the process error, CVs for CPUE indices and model fits.

4.3 Reference case specifications and input parameter choices

When conducting the model runs, eight models which varied from each other only by the choice of abundance indices were called “reference cases”. These runs all used the same initial values, those considered most plausible, for the biological and demographic parameters. For the purposes of determining stock status and conservation advice, the single reference case using the Japan early and Japan late indices was chosen as the most representative, given the greater confidence of the SHARKWG in those indices and the model output when compared to the other reference cases.

Data and initial conditions for eight reference cases are summarized in Table 2. Details of biological and demographic assumptions made on the BSP modeling were described in the sections above. The initial settings for biological and demographic parameters in Table 2 were based on these assumptions.

The ISC SHARKWG agreed to use five abundance indices (JE, JL, HW, SP and TW CPUE indices) for investigating a full range of uncertainty about stock dynamics of north Pacific blue shark (ISC SHARKWG 2014). In this assessment, we set up the eight reference cases that the model was fitted to either each of four indices (JL, HW, SP and TW) alone or the combination of one of the four with the JE index (Table 2).

As in the assessment in 2013 (ISC SHARKWG 2013b), the initial and terminal years of the BSP runs were set to 1971 and 2011, respectively, because it was not possible to update all catch through 2012 by the end of the data preparatory meeting. The effect of using the incomplete catch data through 2012 (most of the catch data, with the exception of the Japanese, were carried over from 2011 to 2012) was examined in sensitivity runs (see the sensitivity run section below).

The lognormal prior for B_{init}/K and its SD were explored in preliminary runs and found to be uninformative such that plausible values of K were well within the bounds. Preliminary BSP model runs also indicated that the B_{init}/K parameter was approximately 0.8. The mean of the B_{init}/K lognormal prior was set to 0.8, with an SD of 0.5 in the reference runs so that the 95% CI of the prior ranged from approximately 0.3 to 2.1.

4.4 Model without indices

Relative influence of priors and data on the marginal posterior distributions for key assessment parameters and stock dynamics of north Pacific blue shark was examined using the reference run input configuration and 4 catch time series (the estimated catch, halving, doubling, and reversing the catch time series) without fitting to the CPUE indices (called prior-only runs). In addition, after exploring the model without indices while varying r and K across a wide range of values, a prior only run was conducted using the input parameters specified in Table 3 to check that the model structure was not biased.

4.5 Specifications and parameter settings for sensitivity runs

Nineteen sensitivity runs based on alternative data, biological and demographic parameters were conducted. These are summarized in Table 3. These include changes in the productivity parameters as well as including 2012 in the catch time series. Alternative choices of ‘low’ and ‘high’ r prior means were based on ranges considered biologically plausible from demographic analyses (Cortés 2002, Babcock and Cortés 2009, also see Kleiber et al. (2009) for choices for SD). Effects of lower and higher stock productivity values of the shape parameter on the results were examined. As in the reference cases, different assumptions of B_{init}/K (α_{b0}) prior mean and SD were made based upon expert opinion, after considering the work of Ohshimo et al. (2014), Matsunaga et al. (2005), Ward and Myers (2005), and reported longline effort in the North Pacific Ocean since 1950.

After close examination of the reference runs results, it was concluded that the JL_Ref, HW_Ref, SP_Ref and TW_Ref runs did not provide meaningful results about the stock dynamics and status of north Pacific blue shark (see Results below). Thus, further evaluations (i.e. the 19 sensitivity runs, model convergence evaluations and Bayes factor analysis) were conducted for the other four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) only.

4.6 Accounting for uncertainty

The approach used for the BSP modeling to account for uncertainties about stock dynamics and status differs from a grid approach used for the SS modeling. By setting the four reference cases using each of JL, HW, SP and TW indices and the other four cases fitting the model to each combination of these four indices with JE index together with the related sensitivity runs (Tables 2 and 3), a total of 84 runs (8 reference cases + 4 reference cases x 19 sensitivities) were conducted to investigate a full range of uncertainties associated with alternative CPUE indices and model input parameters. Further, the five prior-only runs (see above) were conducted to examine the relationship between the data, priors and the model, and effects of priors on results (Table 3).

4.7 Evaluation of model convergence

Model convergence was evaluated with the BSP2 model software diagnostics (McAllister and Babcock 2006). In general, the joint posterior distribution is sufficiently well estimated when the maximum weight of any draw is less than approximately 0.5~1% (McAllister and Babcock 2006, M. McAllister pers. comm.), which is a measure of the relative influence of the highest weighted draw. Adequate precision is likely to be achieved after saving at least 20,000 samples, as samples are discarded if parameters exceed their specified bounds. The CV of weights should be relatively low, especially the CV of importance sample weights should be less than the CV of likelihood priors multiplied by priors for the same draw (McAllister et al. 2002).

4.8 Retrospective analysis

Potential biases in parameter and biomass estimates were investigated using retrospective analysis. Using the four more meaningful reference case configurations (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref), the model was terminated during each of the five years prior (2006-2010) to the reference case terminal year (2011).

4.9 Evaluation with Bayes factor

Bayes factors (Kass and Raftery 1995) for the reference cases and for each of the corresponding sensitivity runs were calculated to compare the credibility of a model given the data. Bayes factors provide a basis for examining both the relative goodness of model fit to the data and the parsimony for each of the alternative models. Factor values are calculated as the ratio of the marginal probability of the data for one model to that of another model. The average value for the importance weights from a given model result was used as an approximation of the probability of the data given the model (Kass and Raftery 1995, Stanley et al. 2012). This is a numerically stable approximation for the data probability, given the model and approximations obtained through importance sampling. In comparison, Bayes factors for sensitivity runs were compared to each corresponding reference case. In general, Bayes factors need to differ substantially from 1.0 for inferences to be made from the analysis. However, even considerably small or large differences in the factors can be caused by random chance in the data and/or misspecification of probability models. Thus, values for Bayes factors within the range of 0.01 and 100 that differ greatly from 1.0 could be interpreted as unlikely but not discredited and must be carefully interpreted (Stanley et al. 2012). If the Bayes factor ratio is less than 0.01 or greater than 100, then one model could be considered highly unlikely compared to the other.

4.10 Future projections

It was concluded that insights about the stock dynamics and status for north Pacific blue shark could not be confidently drawn from results of the JL_Ref, HW_Ref, SP_Ref and TW_Ref cases (see Results below), thus future projections were conducted for the other four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) only.

Future projections using seven harvest control policies (three levels of constant catch, three levels of constant F and F_{MSY} policies) were conducted for the four reference cases. The three levels of constant catch applied were 46,690, 56,030, and 37,350 mt for each of the four reference cases. The three levels of constant F assumed were: 0.0821, 0.0985 and 0.0657 for JEJL_Ref; 0.0675, 0.0810 and 0.0540 for JEHW_Ref; 0.0685, 0.0822 and 0.0548 for JESP_Ref; and 0.0798, 0.0958 and 0.0639 for JETW_Ref. These F values were calculated using estimates from the results of each reference case. For both constant catch and F harvest policies, the three levels examined correspond to the average of 2006-2010 catch or F (*status quo*), a 20% increase and 20% decrease from the average. Catch and F in 2011 were excluded from the averaging because the Japanese longline fleet was greatly affected by the Great East Japan Earthquake of March 2011 (major longline ports in the Tohoku area were destroyed), thus effort and catch subsequently decreased in 2011. For the F_{MSY} harvest policy, estimated values of F_{MSY} for each simulation in each reference case were used. Time horizons of the projections were set at 5, 10, and 20 years from the terminal year (2011).

5 INTEGRATED MODEL DESCRIPTION

5.1 Stock Synthesis Software

For the integrated modeling, the SHARKWG agreed to use a length-based, age-structured, forward-simulation population model conducted using Stock Synthesis (SS), version 3.24F (Methot 2005, Methot 2009, Methot and Wetzel 2013) in addition to the BSP to examine the

north Pacific blue shark stock status. The underlying integrated analysis approach of SS is similar to other commonly-used statistical age-structured models such as MULTIFAN-CL (Fournier et al. 1998) and CASAL (Bull et al. 2005). SS is designed to accommodate both age- and size-structure in the population. Some SS features include incorporating ageing error, growth estimation, a spawner-recruitment relationship, sex-specific biological parameters and sex-specific fishery data. However, SS is currently the only model offering a stock-recruitment relationship specifically designed for low-fecundity species such as sharks (Taylor et al. 2013). In fitting the model, the SS code searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian matrices.

5.2 Biological Assumptions

Critical information on the biology of blue shark necessary for the SS assessment relates to sex-specific growth, natural mortality, maturity and fecundity.

5.2.1 Growth

Sex-specific estimates of growth from Nakano (1994) were assumed in the assessment. The length-at-age relationships were based on reading vertebrae samples from 123 female and 148 male sharks, ranging from about 30 to 290 cm PCL (Nakano 1994)(Figure 8). The standard assumption 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 equation used in SS,

$$L_2 = L_{\infty} + (L_1 - L_{\infty})e^{-K(A_2 - A_1)}$$

where L_1 and L_2 are the sizes associated with ages near the first (A_1) and second (A_2) ages, L is the theoretical maximum length, and K is the growth coefficient. K and L_{∞} can be solved based on the length-at-age and L_{∞} was thus re-parameterized as:

$$L_{\infty} = L_1 + \frac{L_2 - L_1}{1 - e^{-K(A_2 - A_1)}}$$

The growth parameters K , L_1 and L_2 were fixed in the SS model, with K at 0.144 (0.129) y⁻¹ for female (male) and L_1 and L_2 at 42 (43) cm and 234 (274) cm for age 0.5 and age 22, respectively (Nakano 1994). A CV of 0.25 was used to model variation in length-at-age. The value of CV was fixed to the common value used in the other tuna and tuna-like species stock assessments. No attempt was made to estimate growth due to the uninformative nature of the size data to 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 assessments 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.

All lengths reported in the assessment are given in precaudal length unless otherwise specified.

5.2.2 Plus group

For any age-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 the age at the theoretical maximum length of an average fish.

5.2.3 Weight at length

Sex-specific weight-at-length relationships were used to convert body length (PCL) in cm to body weight (W) in kg (Nakano 1994). The sex-specific weight-length relationships are:

$$W = 5.388 \times 10^{-6} PCL^{3.102}, \text{ for female and}$$

$$W = 3.293 \times 10^{-6} PCL^{3.225}, \text{ for male.}$$

These weight-at-length relationships were applied as a fixed parameters in the model (Figure 9).

5.2.4 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 4). We note that in general these estimates are similar, however they represent spatially separate studies (Nakano 1994, Hsu et al. 2011) and have differences in the particularly influential early life stages. For the reference case we used the estimates based on Nakano's (1994) data, which was based on a broader area of sample collection, with a sensitivity using the estimates based on Hsu et al. (2011).

5.2.5 Maturity and fecundity

For a shark stock assessment, it is critically important to estimate 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 runs⁴. In Section 5.3.5 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 assumed a logistic maturity schedule based on length with the age-at-50% maturity for females equal to 145 cm (Nakano and Seki 2003)(Figure 10). There is no information which indicates that sex ratio differs from parity throughout the lifecycle of blue shark.

5.3 Model structure

5.3.1 Input fishery data

The input fisheries and survey data consist of catch, catch/effort (CPUE) and sex-specific length-composition data (Figure 7). An annual (Jan 1-Dec 31) time-series of fishery data for 1971-2012 was used in this assessment. However, the catches in 2012 for the majority of fisheries were not available and assumed to be the same as 2011. Although the SS reference case used data through 2012, the stock status and conservation advice was developed from 2011 model output. It is important to note that the estimated dynamics of biomass and spawning stock biomass (SSB) were not influenced by the inclusion of the 2012 assumed data for the reference case model specification (see results of the retrospective analysis).

5.3.2 Length composition data

Two types of data weighting were used in the model. One is relative weighting among length compositions (effective sample size), and the other is weighting of the different data types

⁴ While it was examined in earlier model iterations, the size-specific fecundity relationship described by Nakano (1994) was not statistically significant.

(recruitment penalty, CPUE and size data etc.) relative to each other, controlling the magnitude of the lambda. For the effective sample size calculation, the following equation was applied to the observed number of fish by sex, year and fishery:

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

Where $ESS_{j,y}$ is the effective sample size for fleet j in year y and $s_{j,y}$ is the observed number of fish for fleet j in year y . A lambda of 0.2 was applied for the reference case and lambda of 1 in the sensitivity analyses. 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 (Rice et al. 2013).

5.3.3 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 indicated below.

5.3.4 Initial population state

It is assumed that the blue shark population was not 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. SS has several approaches to start from a fished state and two of these were considered for 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 F is fixed, then catch can differ depending on estimated abundance and you can end up with an unintended discontinuity. Three values for equilibrium catch were examined: 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, a selectivity needed to be chosen to assign the catch to each length bin. The selectivity estimated for one of the Japanese fleets (F4 JPN_KK_SH) was used for the equilibrium catches 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 was estimated.

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

In the SS 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 is referred 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

$$z_0 = -\log\left(\frac{R_0}{B_0}\right),$$

and

$$z_{min} = z_0 (1 - s_{frac}).$$

R_0 is the recruitment at equilibrium, resulting from the exponential of the estimated $\log(R_0)$ parameter, B_0 is the equilibrium spawning output, and z_{min} 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 the density-dependent relationship between spawning depletion and pre-recruit survival.

Attempts were not made 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, values of 0.1, 0.3 and 0.5, for s_{frac} and 1, 2, and 3 for $Beta$ were selected. Examples of the behavior of some of the resulting curves are provided in Figure 11, with the impact of alternative parameterizations on the pre-recruit survival in Figure 12. From these we selected $s_{frac}=0.3$ and $Beta=2$ for the reference case because this resulted in moderate levels of compensation and depensation and the MSY was close to 0.5 as assumed in the BSP model. Note that in many cases recruitment for a depleted stock is higher than virgin due to the compensation implied by the parameterization of the LFSR relationship.

Annual recruitment deviations were estimated from the information available in the data. The central tendency that penalizes the log (recruitment) deviations for deviating from zero was assumed to sum to zero over the estimated period. Recruitment variability ($Sigma-R$): the standard deviation of log recruitment) was fixed at 0.3 and 0.1 was used as a sensitivity analysis because such a small value ($Sigma-R = 0.1$) implies little recruitment variability or little information on recruitment in the data. Further, assuming a smaller recruitment penalty ($Sigma-R = 0.3$) is biologically more realistic and a larger $Sigma-R$ allows more freedom to better fit the CPUE data. A log-bias adjustment factor was used to assure that the estimated mean log-normally distributed recruitments were mean-unbiased. SS allows for a user-defined fraction of the log bias adjustment implied by the specified $Sigma-R$ to be consistent with the estimated variability of the recruitment deviates.

The log of R_0 and annual recruitment deviates were estimated by the model. The offset for the initial recruitment relative to R_0 was estimated in the model. The deviations from the stock-recruitment relationships (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 (1985-1989) and one being the main recruitment deviates that covered the model period (1990-2011).

5.3.6 Selectivity curves

Selectivity patterns are used to model not only gear function but availability of the stock to the fishery (spatial patterns and movement) by stratifying fisheries spatially and temporally. Sex- and fishery-specific, and time-invariant selectivity patterns were assumed. A double 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 5.

5.3.7 Parameter estimation and uncertainty

Model parameters were estimated by minimizing the negative 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 catch data are assumed to be unbiased and relatively precise, so that the standard error of 0.05 was assigned for all fleets. 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. This analysis (i.e. likelihood profile tests) was conducted as a quality control procedure to ensure that the model was not converging on a local minimum. The SS control file, BSH.ctl, documenting the phased procedure, initial starting values and model assumptions is included in Appendix B.2.

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.

5.3.8 Assessment Strategy

Although a single reference case was selected for purposes of determining stock status and conservation information, a grid of 1080 runs in total as described below was used to evaluate model uncertainty. A summary of the model options considered is provided in Table 6. This reflects the broader range of options available under the more complex SS assessment framework (in terms of both model assumptions and data inputs). The one-change model runs from the reference case are presented as sensitivity analyses. 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 describing the range of uncertainty, the reference case model characterizing stock dynamics and stock status was specified with these key settings: 1) length composition down weighted to account for observation error (not catch weighted composition), 2) LFSR with moderate compensation ($Beta=2$ and $S_{Frac}=0.3$), 3) equilibrium catch = 40,000 mt, 4) mortality based on growth by Nakano (1994), 5) Sigma-R = 0.3, and 6) Japanese early and Japanese late CPUE used to provide stock trends.

5.3.9 Retrospective analysis

Retrospective analysis was conducted based on the reference case with the same model configuration and parameter specifications to examine the consistency of the stock assessment

results when sequentially eliminated the final year of data. The data were removed for each of the five years up to five years from 2012 to 2008 using the retrospective function of SS. The estimates of spawning biomass were compared to elucidate the potential biases and uncertainty in the terminal year estimates.

5.3.10 Future projections

As for the BSP model runs, future projections were conducted on the reference case output assuming seven harvest policies. Projections were run using the code included as part of the SS model code. For both constant catch and F harvest policies, the three levels examined corresponded to the average of 2006-2010 catch or F (*status quo*), and a 20% increase and 20% decrease from the average catch or F . The input values for the SS projections are shown in Table 7. The fishing mortality and the catch amounts in 2011 were excluded from the averaging to remove the impacts of the Great East Japan Earthquake of March 2011 on the landings at major shark fishing ports in eastern and northern Japan (Kai et al. 2014). For the F_{MSY} harvest policy, the estimated value of F_{MSY} for the reference case was used. Time horizons of the projections were set at 5, 10, and 20 years from the terminal year (2011).

6 BSP MODEL RESULTS

6.1 Eight reference cases

For the BSP analyses, eight so named “reference cases” were selected based on the indices used along with the catch data and the initial values considered most plausible for the biological and demographic parameters (see section 4.3). Of these, the model configuration using the Japan early and Japan late indices (JEJL_Ref) was selected as the reference case for the purposes of determining stock status and conservation information.

6.1.1 Model convergences of the eight reference cases

Available diagnostic statistics for model convergence of the eight reference cases from the BSP2 model software were checked to verify low posterior correlations (r and K), an adequate number of saved draws in importance sampling (>20,000 samples), a low maximum weight of any draw (< 1%), and that the CV of the weights of the importance draws was less than the CV of the likelihood times priors for the same draws (Tables A1 to A4). Although the CVs of the weights were large, other statistics indicated that the joint posterior distribution was sufficiently estimated and it did not result in non-identifiability of parameters (M. McAllister, pers. comm.).

6.1.2 Model fits of the eight reference cases

Model fits to the standardized CPUE indices for the eight reference cases and the relevant residual plots were checked to verify whether reasonable results of posterior mode estimates were obtained (Figures A1 (a) to (h)). Model fits to the CPUE indices for JEJL_Ref and JL_Ref were quite good and there was no systematic pattern observed in the residual plots (Figures A1 (a) and (e)).

For the other reference cases, model fits to the late period CPUE indices in the HW_Ref, SP_Ref, TW_Ref runs and the fit to the late period indices when run in combination with the JE index (JEHW_Ref, JESP_Ref, JETW_Ref) were not good, while fits of the JE were reasonable when run with any of the late period indices (Figures A1 (b), (c), (d), (f), (g) and (h)). There were also some systematic trends (positive to negative or vice versa) in the residuals depending upon the run, indicating some autocorrelation in the deviates. In the estimation process, we tried to obtain better model fits to the CPUE data (HW, SP and TW with and without the JE index) for these six cases by adjusting input values for the SD of the process error for stock dynamics and total CVs for CPUE indices by the iterative reweighting procedure. However, marginally better fits to the

CPUE data for these cases could be achieved only when unreasonable input settings were used, i.e., when unacceptably large or small total CVs were assigned to CPUE index(ices) by iterative reweighting. This resulted in ratios of the inputted total CV to the empirical model fit CV for some indices that were too low or high, causing uncertainty in the model parameter estimations, and did not allow for reasonably efficient important sampling (i.e., model convergence got worse or was never achieved). This is probably due to inconsistency between the catch and CPUE (of HW, SP and TW) trends. It was concluded that the poor performance was not due to model misspecification and the results presented here are the best that could be obtained with these CPUE data and the current catch data.

6.1.3 Results for the eight reference cases

6.1.3.1 Stock assessment statistics and marginal posterior distributions for key parameters

Comparison of stock assessment statistics (medians) for the eight reference cases is summarized in Table 8 and detailed statistics for each case are shown in Tables 9 to 16. Comparison of marginal posterior distributions for key assessment statistics are plotted in Figures 13 and 14. Priors (for r and K) and marginal posterior distributions resulted from prior-only runs were also plotted in Figures 13 and 14.

Overall, the results of the eight reference cases can be categorized into four groups based on similarities of the assessment statistics: (1) JEJL_Ref; (2) JEHW_Ref, JESP_Ref and JETW_Ref; (3) JL_Ref; and (4) HW_Ref, SP_Ref and TW_Ref (Tables 9 to 16 and Figure 13 and 14). Details of differences in the parameter estimates are explained below.

The posterior median estimate for r in JEJL_Ref case was the largest (0.41) of the eight reference cases (Table 8 and Figure 13 (a)). The medians for r in HW_Ref, SP_Ref and TW_Ref (0.34 to 0.35) were smaller than that in JEJL_Ref but larger than those in JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref (0.28 to 0.30). The posterior medians for r were slightly smaller than the posterior means in all reference cases except for JEJL_Ref, indicating some skewness to the right in the posterior distributions (Tables 9 to 16 and Figure 13 (a) and 14 (a)). The r posterior distributions in all reference cases except for JEJL_Ref were quite similar in shape to the prior distribution and the posterior distribution resulting from the prior-only run, implying that the data used in JEJL_Ref case were informative and updated the distribution of r (Figures 13 (a) and 14 (a)).

The posterior median estimates of carrying capacity (K), stock biomass at maximum sustainable yield, MSY (B_{MSY}), stock biomass in the initial year of assessment (B_{1971}) and the stock biomass in 2011 (B_{2011}) for the JEJL_Ref case were smaller than those in other seven reference cases (Table 8). The posterior medians for these parameters were smaller than the posterior means in all eight reference cases (Tables 9 to 16). This indicates skewness to the right in the posterior distributions (Figures 13 and 14). The larger estimates of posterior mean, median and 90% confidence intervals for these parameters in JL_Ref, HW_Ref, SP_Ref and TW_Ref cases than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases resulted from this skewness and vagueness in the posterior distributions with considerably long, fat tails (Figure 14).

The posterior median estimates of maximum sustainable yield (MSY) for the JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref runs were of the same order of magnitude (75,000 to 98,000 mt; Table 8). Compared to this, the median estimates of MSY for the HW_Ref, SP_Ref and TW_Ref were 3 to 4 times higher (303,000 – 325,000 mt). The posterior mean estimates of MSY were similar to the posterior medians for the JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases, whereas for the JL_Ref, HW_Ref, SP_Ref and TW_Ref cases, the skewed and vague posterior distributions for MSY resulted in far greater posterior means than medians (Tables 9 to 16 and Figures 13 (b) and 14 (b)).

The posterior median estimates for the ratio of B_{2011}/B_{MSY} ranged approximately from 1.5 to 2.0 across the eight reference cases (Table 8). The posterior mean values for this ratio were very similar to the posterior medians in all reference cases (Tables 9 to 16).

The posterior median estimates of the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{MSY}) ranged from 0.06 to 0.35 in the eight reference cases (Table 8). The small values of F_{2011}/F_{MSY} in HW_Ref, SP_Ref and TW_Ref resulted from large estimates of B_{2011} compared to the catch in 2011. The estimates for F_{2011}/F_{MSY} are considered low compared to ‘normal’ years because of the effect of the Great East Japan Earthquake on the base ports for the Japanese longline fleet.

For the JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref runs, although the marginal posterior distributions indicate moderate to high precision in the estimates for most key parameters, distributions for some parameters were skewed and had long tails (Figure 13). In contrast, the posterior distributions with skewed and very long, fat tails for the JL_Ref, HW_Ref, SP_Ref and TW_Ref runs show low precision in the estimates for the parameters, although the JL_Ref posterior distributions were somewhat exceptional (Figure 14). Further, the posterior distributions in HW_Ref, SP_Ref and TW_Ref were quite similar to those resulting from the prior-only run, meaning that the CPUE data used in these reference cases added little information.

6.1.3.2 Prior-only run analysis

Results from fitting to the data using only priors indicate that the CPUE indices are quite informative to the results, and the model is not overly influenced by priors in JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref cases (Figure 13 and 14). Ranges of posterior distributions estimated from the prior-only run are still quite wide with long fat tails. This implies that the priors provide only vague information about most key parameters, and the results were driven primarily by the data (i.e., the priors are not too informative to the results). Similarities in shape of the posterior distributions between the prior-only, HW_Ref, SP_Ref and TW_Ref runs suggest that HW, SP and TW CPUE indices are informative only when these indices are incorporated in the model in combination with JE CPUE index (Figures 13 and 14).

The marginal posterior distributions for the key parameters from prior-only runs using catch data which have very different trajectories and magnitude (reversed, doubling and halving of catch) were plotted in Figures 15 (a) and 15 (b). These plots for the posteriors show skewed and quite wide distributions with long fat tails, indicating that catch data also give vague information about the parameters and are not influential on the results.

To verify the ability of the BSP model to produce overfished/overfishing conditions (to confirm that given priors and model structure, the results are not inherently biased), a prior-only run with fixed K was conducted. However, using the observed catch trajectory, the prior-only run with fixed K resulted in a population crash and an acceptable result could not be obtained. A model with a flat catch series (the average observed catch of 60,000 mt) and a tighter prior on K (Ponly_pessim run, see Table 3) resulted in a data-free posterior with 50% probability of $B_{2011} < B_{MSY}$ (Figure 15 (c)). It was therefore concluded that the catch trend itself has information about stock status and this is one of the reasons why most results from prior only runs with the estimated catch data and prior distributions show the stock in a healthy condition. The SHARKWG examined whether the shape of the K prior distribution may provide biased results. However, the BSP model tries to fit the stock dynamics to the CPUE data more so than to the prior distributions, thus it is possible to get posterior distributions which are different from their associated prior distributions. From these results, the SHARKWG concluded that although this issue remains an area for further research, the results based on the existing data should accurately reflect the stock dynamics of north Pacific blue shark.

6.1.3.3 Retrospective analyses

The retrospective patterns for the JETW_Ref run showed the smallest changes in absolute abundance when sequentially eliminating the final year, while the patterns for the JESP_Ref run showed the largest (Figure 16). The JEHW_Ref and JESP_Ref runs had the most systematic retrospective patterns. The SHARKWG was unable to determine if the retrospective analysis could be used to judge the reliability of the different indices as measures of stock relative abundance. However, none of the retrospective patterns were judged to be extreme enough to exclude the model results from consideration.

6.1.3.4 Historical stock dynamics

The median estimate and 90% confidence limits for the historical stock dynamics in the eight reference cases and four alternate catch prior-only runs are shown in Figures 17 and 18, respectively. Although there are some differences in trend and magnitude, fluctuation patterns of the historical stock dynamics of north Pacific blue shark in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases were similar (Figures 17 (a) to (d)). Among the four cases, 90% confidence limits in JEJL_Ref case were noticeably narrower than those in the other three cases. The median stock biomass declined to a level below B_{MSY} from the mid 1970s to the mid 1980s. The stock subsequently increased after the late 1980s and by the early 1990s had recovered to a level above B_{MSY} , and to a stock level similar to that of the mid 1970s. The blue shark biomass has been more or less stable since, indicating that total catches in recent years have been near replacement yield. The stock biomass dynamics in JL_Ref also showed somewhat a comparable trend to those in these four reference cases (Figure 17 (e)). However, the 90% confidence limits for the stock biomass in JL_Ref case were much broader than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref whereas the magnitude of the median stock biomass in JL_Ref was only slightly higher than those in the four reference cases.

The median trajectories for the stock biomass in the HW_Ref, SP_Ref and TW_Ref cases and prior-only runs did not show reductions of the stock biomass below B_{MSY} during the mid and late 1980s which were observed in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases (Figures 17 and 18). The median trajectories in these three reference cases and prior-only runs had rather monotonic trends with slight increases. In the same as JL_Ref case, the 90% confidence limits for the stock biomass in HW_Ref, SP_Ref and TW_Ref cases and prior-only runs were noticeably wider than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref (Figures 17 and 18).

Considering these monotonic trends and very wide confidence intervals together with the vague marginal posteriors for key assessment parameters (discussed above) for the JL_Ref, HW_Ref, SP_Ref and TW_Ref cases, the CPUE index data of JL, HW, SP and TW did not provide any valuable information about stock dynamics and status of north Pacific blue shark when used alone in the model (i.e., without the JE CPUE index). Therefore, insight about stock dynamics and status of the blue shark could not be drawn from the results of the JL_Ref, HW_Ref, SP_Ref and TW_Ref runs.

6.1.3.5 Kobe plots

Degrees of stock depletion and overfishing for the eight reference cases were illustrated using Kobe plots (Figure 19). Overall, the resultant Kobe plots of the eight reference runs could be roughly divided into two groups based on resemblance of the trajectory patterns of the median estimates: JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref; JL_Ref, HW_Ref, SP_Ref and TW_Ref.

For the first group (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref), the stock biomass of north Pacific blue shark was well above the biomass at the maximum sustainable yield (B_{MSY}), and the fishing rate well below that at F_{MSY} in 1971 (Figures 19 (a) to (d)). The historical trajectories of stock status revealed that north Pacific blue shark had experienced some levels of

depletion and overfishing in previous years showing that the trajectories moved through the orange (overfishing), red (overfished and overfishing) and yellow (overfished) zones in sequence in the Kobe plots. In recent years, the stock condition returned to the green zone and stock biomass has remained above B_{MSY} with fishing mortality below F_{MSY} . Only the 90% confidence limits for B/B_{MSY} in 2011 in JEHW_Ref and JESP_Ref extended to the yellow zone (Figures 19 (b) and (c)).

The historical trajectories of stock status for the second group (JL_Ref, HW_Ref, SP_Ref and TW_Ref) were within the green zone throughout the assessment period, 1971 to 2011 (Figures 19 (e) to (h)). Although there were some small changes to the stock status observed in the JL_Ref output, the stock status almost did not change during the assessment period in these four reference cases. This is not surprising given the monotonic trends for the historical stock dynamics discussed above for these four cases.

6.2 Sensitivity analyses

Again, because results regarding stock dynamics from the JL_Ref, HW_Ref, SP_Ref and TW_Ref cases were equivocal, sensitivity analyses were further conducted for the JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases only.

6.2.1 Model convergence of the sensitivity runs

As for the eight reference case, available diagnostic statistics for model convergence were checked to verify low posterior correlations (r and K) for all sensitivity run results, an adequate number of saved draws in importance sampling (>20,000 samples), a low maximum weight of each draw (< 1%), and that the CV of the weights of the importance draws was less than the CV of the likelihood times the priors for the same draw (Tables A1 to A4).

6.2.2 Model fits of the sensitivity runs

Model fits to the standardized CPUE indices and the relevant residual plots for all sensitivity runs (corresponding to each of the four reference cases, JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref), and posterior mode estimation were examined in the same way as for the reference cases explained in section 6.1.2. Although there were some slight differences in residual patterns between each reference case and related sensitivity run results, the overall patterns for sensitivity runs were similar (Figures not shown) to that for each reference case (Figures A1 (a) to (d)).

6.2.3 Results of sensitivity runs

Although there were some differences in parameter estimates found between each of the four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) and some corresponding sensitivity runs, overall the sensitivity analyses did not reveal any substantially different stock status compared to the reference cases (Tables 17 to 20, and Figures 20 and 21). With respect to median estimates, all of the sensitivity runs indicated that the stock biomass of north Pacific blue shark in 2011 is above B_{MSY} (estimates of B_{2011}/B_{MSY}) and 2011 fishing mortality rate is below F_{MSY} (estimates of F_{2011}/F_{MSY}). However, estimates of B_{2011}/B_{MSY} and F_{2011}/F_{MSY} were highly uncertain, as shown by the broad 90% confidence intervals, in some sensitivity runs for JEHW_Ref, JESP_Ref and JETW_Ref cases (Figures 21 (b) to (d)). Furthermore, as mentioned before, the exploitation rate in 2011 was probably underestimated because the Japanese longline effort was affected by the 2011 Great East Japan Earthquake.

The differences in sensitivities to alternative input choices varied depending upon the combination of CPUE indices used and the related sensitivity runs examined. While the results of all runs estimated a relatively healthy condition in the terminal year (Figure 22) a few parameters were most influential on the results. These included the CPUE series selected as well

as the shape parameters. The shape parameters had the greatest effects on biomass trends, estimated fishing mortality rates, and current status relative to *MSY*.

Details of differences in each parameter estimate between the reference cases and sensitivity runs are explained and discussed below.

6.2.3.1 Surplus production function, B_{MSY}/K (Shape parameter n)

Results were relatively sensitive to the choice of B_{MSY}/K (runs **_R34Sh03⁵ and **_R34Sh06 in Tables 17 to 20, and Figure 20; also see r versus B_{MSY}/K grid results in Tables 17 to 20). Posterior median values for B_{2011}/B_{MSY} increased when B_{MSY}/K was decreased from 0.6 to 0.3. This difference in B_{2011}/B_{MSY} represented the largest range observed among all sensitivity runs in which only one input assumption was changed. Median estimates of the ratio of the 2011 fishing mortality to that at *MSY* (F_{2011}/F_{MSY}) were slightly sensitive to changes in B_{MSY}/K . The estimates of current stock biomass (B_{2011}) and biomass at *MSY* (B_{MSY}) were scaled up and down when B_{MSY}/K was set to 0.3 and 0.6, respectively.

6.2.3.2 r prior mean

Results were modestly sensitive to the run where the r prior mean was set at a biologically plausible minimum value of 0.14 (runs **_R14A08⁶ in Tables 17 to 20, and Figure 20; also see r versus B_{init}/K grids results in Tables 17 to 20). Posterior medians for B_{2011}/B_{MSY} in the four reference case were greater than those in the corresponding sensitivity runs. Median values for F_{2011}/F_{MSY} in the reference cases were almost the same as those in the sensitivity runs except for JEHW_Ref. In addition, the estimates of current stock biomass (B_{2011}) and biomass at *MSY* (B_{MSY}) were scaled up and down when r prior mean was set to biological minimum and maximum values, respectively.

The posterior medians for r in the sensitivity runs were estimated lower than in the corresponding reference cases when the r prior mean was set at biologically plausible minimum value of 0.14 (see estimates indicated by run identifiers which contain “R14” in Tables 17 to 20). However, in the JEJL_Ref case this does not indicate that the data contain information that supports the lower r value because the sensitivity run with a more diffuse r prior resulted in a similar posterior median for r to the JEJL_Ref run, suggesting that the data supported larger r values (JEJL_Rsd07 in Table 17). As discussed below, a Bayes factor comparison also indicates that the model run using the biological minimum r prior resulted in worse fits to the data than the JEJL_Ref run (Table 21, see below).

Unlike JEJL case, although estimated medians were not so low as the biological minimum value, the data used in JEHW, JESP and JETW cases somewhat support lower r values than those in the reference cases. This is apparent from the median estimates for r in the sensitivity runs with a more diffuse r prior (JEHW_Rsd07, JESP_Rsd07 and JETW_Rsd07 in Tables 18 to 20, respectively). Further, Bayes factors also imply that the data favor (although not strongly) lower values of r in JEHW, JESP and JETW cases (Table 21, see below). However, it is also worthwhile to note that the estimates for stock status parameters had considerably wide confidence intervals, indicating high uncertainty about stock status.

6.2.3.3 Other sensitivity runs

⁵ A symbol “**” represents identifiers for combinations of the CPUE indices described in Table 2 such as “JEJL_R34Sh03” or “JEHW_R14Sh06.”

⁶ A symbol “**” represents identifiers for combinations of the CPUE indices described in Table 2 such as “JEJL_R14A08” or “JEHW_R43A08.”

Estimated medians for all other sensitivity runs were quite similar to the corresponding reference cases with respect to stock status parameters (Tables 17 to 20, and Figures 20 and 21). Thus, it can be concluded that the results were insensitive to these alternative assumptions in terms of medians. However, 90% confidence limits for some sensitivity runs were considerably broader than in the references, especially for JEHW, JESP and JETW cases.

6.2.3.4 Historical stock dynamics for sensitivity runs

Although the historical stock dynamics for north Pacific blue shark differed depending upon the reference cases and the corresponding sensitivity runs examined, comparison of median trajectories of the stock dynamics between the reference runs and all the sensitivity runs exhibited that overall patterns of the dynamics for the sensitivity runs were fairly similar to that for the corresponding reference run and the only noticeable differences were in levels of stock biomass (Figure 21). The highest biomass level was estimated when r prior mean was set to a biologically plausible minimum value of 0.14 and B_{MSY}/K was equal to 0.3 (**_R14Sh03) while the lowest level resulted from the sensitivity run with r set to biologically maximum of 0.43 and B_{MSY}/K being equal to 0.6 (**_R43Sh06). Generally the consistency of sensitivity analyses supports the stock status and relative historical stock dynamics represented by each reference case.

6.2.4 Bayes factor evaluation

Table 21 summarizes the comparisons of Bayes factors for the sensitivity runs relative to the corresponding reference cases (**_Ref). Bayes factor is an indicator to explain the degree of fitting between the data and model. Bayes factors are usually interpreted such that if the difference is between roughly 0.33 and 3 times the reference case, then the difference is not considered significant. In these analyses, none of the Bayes factors indicated that any of the alternative sensitivity runs could be viewed as much less or more likely than the corresponding reference case. (Note that Bayes factor comparisons are only meaningful within the same column, i.e. comparisons to each reference case.) However, some differences in Bayes factor were detected for some sensitivity runs as follows.

The sensitivity run assuming a lower B_{MSY}/K of 0.3 in JEJL case (JEJL_R34Sh03) had a Bayes factor of 0.92, indicating that the reference case showed a better fit to the data than with the lower alternative B_{MSY}/K value, whereas in other three cases the lower B_{MSY}/K alternative runs resulted in Bayes factors which were greater than those in the corresponding reference cases (1.80 for JEHW_R34Sh03, 1.75 for JESP_R34Sh03 and 1.69 for JETW_R34Sh03), indicating that the reference cases gave slightly worse fits than the lower alternatives for B_{MSY}/K . This was consistent with the sensitivity run with a biologically plausible minimum for r prior mean (0.14) for the JEJL case; JEJL_R14A08 resulted in a Bayes factor of 0.38, showing that the reference case gave a better fit to the data than with the lower alternative, while in other three cases the same lower alternative runs for r prior mean ended up with larger Bayes factors than those in the references (1.72 for JEHW_R14A08, 1.17 for JESP_R14A08 and 1.09 for JETW_R14A08), suggesting a slightly worse fit of the reference cases than the lower alternative r prior.

This tendency toward better fits associated with higher productivity alternatives in the JEJL case and better fits for lower productivity alternatives in JEHW, JESP and JETW cases is also consistent with differences in Bayes factors for alternative assumptions of B_{init}/K , i.e., a relatively highly productive stock does not need larger initial biomass compared to the catch taken, whereas a lower productivity stock needs a higher B_{init}/K ratio to support the catch. The assumption of B_{init}/K prior mean set at 0.5 produced a Bayes factor of 1.10 in the JEJL case (JEJL_R34A05), indicating that this alternative provided a slightly better fit to the data than the reference case. In contrast, the sensitivity runs using B_{init}/K prior mean of 1.0 had higher Bayes factors than the reference cases for JEHW, JESP and JETW (1.16, 1.18 and 1.11, respectively), showing slightly better fits to the data than for the reference runs.

The differences in Bayes factor explained above did not affect the relative trends of stock dynamics and stock status with respect to median estimates (Figures 20 and 21).

6.3 Future projections

Future projections were conducted for the JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref runs. Figures 23 and 24 illustrate the median future projected stock dynamics and catch trends for north Pacific blue shark under seven different harvest policies using the four reference case models: *status quo* catch, +20% and -20% *status quo* catch, *status quo* F , +20% and -20% *status quo* F and F at MSY (F_{MSY}). *Status quo* catch and F rules were based on the average catch and F over the recent 5 years of 2006 to 2010. Information regarding the projections to guide management decisions is summarized in Tables 22 to 25.

With respect to median estimates, future projected dynamics of stock biomass and catch for blue shark had very similar patterns in all JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases while there were some differences observed in the magnitudes of stock biomass and catch (Figures 23 and 24). For all reference cases, under the *status quo* policy, the median stock biomass of blue shark will remain stable. This was expected because the current catch level was estimated at near replacement yield. Even under +20% constant catch and constant F harvest policies, the blue shark stock will stay above the biomass at maximum sustainable yield, B_{MSY} , throughout the projection time horizon with a probability higher than 85% (Tables 22 to 25). Similarly, future median fishing mortality will remain well below F_{MSY} . A *status quo* constant F policy will produce approximately 50,000 mt to 60,000 mt catch over the projection years depending upon the reference case.

7 INTEGRATED ASSESSMENT MODEL RESULTS

7.1 Reference case model

The basis for choosing the reference case model was provided in Section 5.3.8. It is important to reiterate that by using the grid approach all model runs were available for the SHARKWG to develop conservation information. The reference case model chosen was the one with the JPN early and JPN late CPUE series along with $S_{Frac} = 0.3$ and $Beta = 2$, natural mortality based on Nakano (1994) (the higher of the two), sample size weighting of 0.2, Sigma-R of 0.3 and initial catch fixed at 40,000 mt. (Table 6).

7.1.1 Estimated parameters and model performance

Key likelihood components and penalties from the reference case model and all one-change sensitivity analyses are shown in Table 26. Strong differences in the sex-specific selectivity curves for many of the fisheries were found which reinforces the observations of biologists for areas of sex-segregation during the life history of blue sharks (Figure 25). 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 26). 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 selectivity curves were estimated, the overall fit to the length data was generally good (Figures 27 and 28), but for those fisheries where selectivity was mirrored (e.g. fishery 18) the fits were poor.

7.1.2 Estimated stock status and other quantities

Recruitment was higher than the virgin level due to the compensation implied by the parameterization of the LFSR and varied around 30,000,000 recruits through the time period (Figure 29). The estimates of recruitment were constrained by the estimated LFSR relationship (**Error! Reference source not found.**30, but see Figure 11 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, likely due to the small mesh gillnet fishery (Figure 31).

SS provides estimates of the *MSY*-related quantities. These and other quantities of interest for the reference run and all one change sensitivity runs are provided in Table 27. We note that the RFMOs have 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 72,123 mt and this is predicted to occur at about 47% of the unfished biomass (Figure 32), which is similar to the *MSY* level of 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 35% of F_{MSY} , and recent current spawning stock biomass is estimated to be 74% of the unfished level and 162% of B_{MSY} (Figure 33). By the standard terminology, this would indicate that the stock is not in an overfished state, and that overfishing is not occurring (Figure 34).

7.2 One change sensitivity analyses

A summary of the general outcomes from the other sensitivity analyses are as follows. 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 lower Sigma-R runs resulted in slightly higher 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 where lower initial catches resulted in lower estimates of B_{zero} and $B_{CURRENT}/B_{MSY}$, while higher initial catches resulted in higher estimates of the same quantities. These same trends are evident in the overall results (Figure 35).

7.3 Retrospective analysis

The retrospective analysis showed no clear systematic pattern in the estimates of spawning biomass from 2008 to 2012 (Figure 36) but the scenario which used data only through 2007 showed a slight negative bias and underestimation of the spawning biomass relative to the other runs.

7.4 Future projections

Future projections showed that maintaining current catch and fishing mortality levels results in much higher levels of total biomass than B_{MSY} throughout the future projection periods, even with substantial uncertainties in estimated catch and fishing mortality (Figure 37). Except for the F_{MSY} scenario which showed a decreasing trend, the total biomass for all other scenarios gradually increases and reaches approximately 6 million tons. The catch expected under the F_{MSY} scenario is relatively stable around 85,000 tons in 2016, 2021, and 2031 (Table 28).

7.5 General patterns in the SS Appendix materials

The Appendix materials (Appendices B-F) present CPUE specific results. Each appendix presents CPUE specific results for the CPUE series (or series combination listed in the title). The first three multi-panel figures (Figures 1, 2 and 3 in each Appendix) 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 parameterizations used for the other parameters not shown in the figures; these were the same as in the reference case run. Figures 1, 2 and 3 show the diagonal elements of the LSFR parameterizations, and thus illustrate the extreme and middle parameterizations.

In Figures 1, 2, and 3, the panels are: total biomass trajectory (top left); stock recruitment curve (second from top left); equilibrium catch curve with the equilibrium point printed on the figure and the catch in 2011/ MSY shown above 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.

Figure 4 in each Appendix shows the SSB/SSB_{MSY} trajectories color coded for each of the axes of uncertainty considered in this assessment. Figure 5 shows the CPUE specific results via bar plots in a Kobe matrix results framework. Figure 6 shows the management quantities (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 results can be summarized as follows:

- (I) The cross cutting themes are that there was a strong trend with S_{Frac} , with the large majority of runs undertaken with $S_{Frac} = 0.1$ giving results where $F > F_{MSY}$ and $B < B_{MSY}$ and the majority of runs with $S_{Frac} = 0.3$ and 0.5 resulting in terminal stock status where $F < F_{MSY}$ and $B > B_{MSY}$;
- (II) There was also a strong trend in stock status with $Beta$, but it was less extreme than for S_{Frac} ;
- (III) Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modeled period;
- (IV) 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 in Rice et al. (2013);
- (V) The alternative values considered for the standard deviation of the recruitment deviates had little impact on the estimates of stock status.

8 STOCK STATUS AND CONSERVATION CONCLUSIONS

8.1 Status of the stock

Model inputs for this assessment have been improved since the previous assessment and provide the best available scientific information. The main differences between the present assessment and the 2013 assessment are: 1) the inclusion of revised CPUE series; 2) some time series data updated through 2012; 3) further examination of the effect of the Bayesian priors on the BSP model outcomes; and 4) use of the SS model to provide an alternative approach that could be compared to the production model. However, there are uncertainties in the time series for estimated catch, the quality (observer vs. logbook) and timespans of abundance indices, the size composition data and many life history parameters such as growth and maturity schedules. Improvements in the monitoring of BSH catches, including recording the size and sex of sharks retained and discarded for all fisheries, as well as continued research into the biology and ecology of BSH in the North Pacific are recommended.

Results of the reference case models showed similar trends for the two modeling approaches. Both showed that stock biomass was near a time-series high in 1971, fell to its lowest level between the late 1980s and early 1990s, subsequently increased gradually and has leveled off at a biomass similar to that at the beginning of the time-series (Figures 4E and 5E). Stock status is reported in relation to maximum sustainable yield (MSY). Benchmark results are shown based on biomass (BSP runs) or female spawning stock biomass (SS runs). Stock biomass and spawning biomass in 2011 (B_{2011} and SSB_{2011}) were 65% and 62% higher than at MSY , respectively, and the annual fishing mortality in 2011 (F_{2011}) was estimated to be well below F_{MSY} (Tables 1E and 2E; Figures 6E and 7E).

Based on the trajectory of the BSP reference case model, median stock biomass of blue shark in 2011 (B_{2011}) was estimated to be 622,000 mt (Table 1E; Figure 4E). Median annual fishing mortality in 2011 (F_{2011}) was approximately 32% of F_{MSY} . Based on the trajectory of the SS reference case model, female spawning stock biomass of blue shark in 2011 (SSB_{2011}) was estimated to be 449,930 mt (Table 2E; Figure 5E). The estimate of F_{2011} was approximately 34% of F_{MSY} .

While the results varied depending upon the input assumptions, a few parameters were most influential on the results. These included the CPUE series selected as well as the shape parameters for the BSP models and the equilibrium initial catch and form of the LFSR relationship for the SS models. For the BSP modeling, the shape parameters had the greatest effects on biomass trends (Figures 8E and 9E), estimated fishing mortality rates, and current status relative to MSY .

For the SS modeling, the form of the LFSR relationship overwhelmed other sources of uncertainty (Figures 10E and 11E). Results were more pessimistic when S_{frac} (one of the parameters controlling the shape of the spawner-recruit curve) was fixed at 0.1, whereas the majority of runs with S_{frac} fixed at 0.3 and 0.5 resulted in terminal stock status where $F < F_{MSY}$ and $B > B_{MSY}$. The SHARKWG felt that the intermediate value of the parameter S_{frac} , 0.3, was most probable. The low value produced lower levels of compensation which the SHARKWG felt were less plausible. Further, the higher value for S_{frac} gave rapidly decreasing trends in recruitment with increasing spawner biomass, which was considered unlikely. Stock trends were also sensitive to changes in $Beta$ (another parameter controlling the shape of the spawner-recruit curve) although the differences were less extreme. Stock status improved considerably with higher initial equilibrium catches, as this increased mean recruitment levels relative to the observed catch history over the modeled period.

Across both models, the parameter values considered most plausible produced terminal conditions that were predominantly in the green quadrant (not overfished and overfishing not occurring) of the Kobe plot. At the lower range of the productivity assumptions, which were considered less plausible, both models indicated some probability of the stock being overfished or undergoing overfishing.

8.2 Conservation information

These results should be considered with respect to the management objectives of the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC), the organizations responsible for management of pelagic sharks caught in international fisheries for tuna and tuna-like species in the Pacific Ocean. Target and limit reference points have not yet been established for pelagic sharks in the Pacific. Relative to MSY , the reference case and the majority of models run with input parameter values considered more probable suggest that the North Pacific blue shark stock is not overfished and overfishing is not occurring.

Future projections of the reference case models show that median BSH biomass in the North Pacific will remain above B_{MSY} under the catch harvest policies examined (*status quo*, +20%, -20%). Similarly, future projections under different fishing mortality (F) harvest policies (*status quo*, +20%, -20%) show that median BSH biomass in the North Pacific will likely remain above B_{MSY} (Tables 3E and 4E; Figures 12E and 13E).

Due to data uncertainties, improvements in the monitoring of blue shark catches and discards, through carefully designed observer programs and species-specific logbooks, as well as continued research into the fisheries, biology and ecology of blue shark in the North Pacific are recommended.

8.3 Limitations and research needs

8.3.1 Catch

There is substantial uncertainty in the amount of historical catches of blue shark. The SHARKWG spent substantial time and effort estimating historical catch, but more work remains to be done. In particular, two improvements were deemed important by the SHARKWG: 1) identify all fisheries that catch blue shark in the North Pacific (i.e., are there any fisheries that catch blue shark that may not have been identified by the SHARKWG); and 2) methods to estimate blue shark catches should be improved.

8.3.2 Abundance indices

Assessment results are highly dependent on the relative abundance indices used. All abundance indices used in this assessment were derived from fisheries-dependent information. Therefore, the SHARKWG recognizes the importance of continuing to work on improving the data sources and standardization methods used to develop these abundance indices.

8.3.3 Length and sex composition

Preliminary information reviewed by the SHARKWG indicated that blue shark exhibit substantial size and sex structure patterns through space and time. Therefore, collection of composition data, including sex, is needed from all fleets.

8.3.4 Biological parameters

Improvements in the biological parameters (e.g., growth, natural mortality, reproduction cycle, intrinsic rate of increase) of north Pacific blue shark are needed. For example, in lieu of a single North Pacific or resolved region-specific growth curves, the BSP model employed productivity parameters similar to those estimated for blue shark in the Atlantic (Cortés 2002). In addition, research should be conducted on how these parameters vary in space and time.

8.3.5 Stock-recruitment relationship

The SS analysis uses the LFSR relationship, which is not yet fully understood, but was the most influential process in the model. In particular, it is not yet clear how density dependence affects the relationship between spawning biomass and recruitment in sharks. Therefore further research should be conducted on this.

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TABLES

Table 1. Characteristics of candidate abundance indices proposed to represent relative abundance of north Pacific blue shark (*Prionace glauca*) and criteria used to evaluate the indices.

| | Hawaii Deep-set Tuna Longline | Hawaii Shallow-set Swordfish Longline | Taiwan Large-scale Tuna Longline | Taiwan Small-scale Longline | Japan Early Offshore Shallow Longline (Hokkaido & Tohoku) | Japan Late Offshore & Distant Water (Hokkaido & Tohoku) | Japan Research and Training Vessel (Region 2) | SPC Observed Longline |
|------------------------------------|---|--|--|--|---|---|---|--|
| Quality of Observations | Good because using observer data and has 10-20% coverage and discards recorded. | Good because using observer data with 100% coverage and discards recorded. | Good because based on observer data but the number of sets observed is low. | Catch data are representative but effort data were estimated. Based only on landed catch and not discards. | Relatively reliable because 94.6% filtered data applied, logbook data were more reliable after filtering. Data are based on self- reported information and blue shark catch was derived from aggregated shark catch. | Relatively reliable because 94.6% filtered data applied. Logbook reporting rates were validated using available research data. | Species ID good until 2000, quality declining since; after 2005-2006 discarding underreported and data quality considered bad. | Good because it was observer measured, but coverage low. |
| Spatial distribution | Relatively small (Areas 4 & 5) | Relatively Small (Areas 2 & 5) | Large geographic area (Areas 1-5) | Large geographic area (Areas 1-5) | Medium (Area 1 & 3) | Large (Area 1, 2, 3 and 4) | Relatively Small (Areas 2 & some of 4) | Southwest North Pacific (140E-180, 0-15N) |
| Maximum size | 207 PCL (F); 225 PCL (M) | 207 PCL (F); 225 PCL (M) | 302 PCL (M and F) | 240 PCL | no information | 170 PCL | 180 PCL | 181 PCL |
| Minimum size | 132 PCL (M and F) | 76 PCL (M and F) | 40 PCL (F); 52 PCL (M) | 68 PCL | no information | 90 PCL | 120 PCL, median 160 PCL | 114 PCL |
| Statistical soundness | Yes. Diagnostics provided. | Yes. Diagnostics provided. | Yes. Reasonable based on diagnostics provided. Not many concerns were raised. | Yes. Diagnostics provided. | Yes. Diagnostics provided. | Yes. Diagnostics provided. | No. Strong patterns in residuals and departure from normality in qq plot; not enough information provided (e.g. deviance Table, CV's). | Yes. Diagnostics provided and considered fine, but some concerns raised. |
| Temporal coverage | 2000-2012 | 2000 & 2005-2012 | 2004-2012 | 2001-2010 (except 2004) | 1976-1993 | 1994-2010 | 1993-2008 | 1993-2009 |

Table 1. Continued

| | Hawaii Deep-set Tuna Longline | Hawaii Shallow-set Swordfish Longline | Taiwan Large-scale Tuna Longline | Taiwan Small-scale Longline | Japan Early Offshore Shallow Longline (Hokkaido & Tohoku) | Japan Late Offshore & Distant Water (Hokkaido & Tohoku) | Japan Research and Training Vessel (Region 2) | SPC Observed Longline |
|---|---|---|---|---|---|---|--|---|
| Q Changes (due to management, fishing practices, etc.) | Not likely because no major regulatory changes after the ban on finning in 2000. | Likely due to the regulatory requirements to avoid reaching turtle take caps. | Ban finning from 2005 (probably limited effect on Q) | Ban finning from 2005 (probably limited effect on Q) | No regulation or gear changes. | No regulation, gear and targeting change. | Opportunistic fishing effort, so changes in catchability are hard to determine. | Not likely. |
| Fishery relative catch contribution | <1500 to 2000 mt annually (for deep and shallow sectors combined) | | <500 mt/yr before 1999, ~800 mt annually since | >10000 mt/yr from 2004 | 19000-55000 mt/yr | 13000-24000 mt/yr | ~50 mt annually | low |
| Comments | | | | No discard data; more confidence in late than early time series due to higher coverage. | Blue shark was a part of target species which may have changed over time but the standardization and filtering addressed these concerns. | Blue shark is a primary target species. Some concerns about the high number of parameters estimated to address targeting. | Region 4 CPUE index not estimated reliably; Gulland index seems to indicate the vessels were avoiding the high CPUE areas for blue sharks. | In area of relatively lower blue shark density. |
| Supporting Working Papers or publications | ISC/11/SHARKWG- 1/05, ISC/11/SHARKWG- 2/02, ISC/12/SHARKWG- 1/02, ISC/14/SHARKWG- 1/05, ISC/14/SHARKWG- 2/05 | ISC/11/SHARKWG- 1/05, ISC/11/SHARKWG- 2/02, ISC/12/SHARKWG- 1/02, ISC/14/SHARKWG- 1/05, ISC/14/SHARKWG- 2/05 | ISC/11/SHARKWG- 4/06, ISC/13/SHARKWG- 1/07, ISC/14/SHARKWG- 1/07 | ISC/12/SHARKWG- 1/15, ISC/13/SHARKWG- 1/08 | ISC/11/SHARKWG- 2/10, ISC/12/SHARKWG- 1/07, ISC/12/SHARKWG- 1/08, ISC/12/SHARKWG- 1/09, ISC/12/SHARKWG- 2/02, ISC/13/SHARKWG- 1/03 | ISC/11/SHARKWG- 2/11, ISC/12/SHARKWG- 1/06, ISC/12/SHARKWG- 1/08, ISC/12/SHARKWG- 1/09, ISC/12/SHARKWG- 2/02, ISC/13/SHARKWG- 1/03, ISC/14/SHARKWG- 1/02 | SC7 Clarke et al. paper; ISC/14/SHARKWG- 1/03 | ISC/14/SHARKWG- 1/INFO02, ISC/14/SHARKWG- 2/04 |

Table 2. Specifications, key input parameter choices and case identifiers for the eight BSP reference trials that varied by CPUE indices used.

| Specifications/Parameters | Value | Description/comments |
|---------------------------------|---|---|
| K | Uniform distribution on $\log(K)$ | Range: [100, 20000] x 1000 MT The minimum value was determined based upon a value approximately similar to the historical largest catch. |
| r prior | mean=0.34, SD=0.5 Lognormal distribution | Based on Cortés (2002) and Kleiber et al. (2009) |
| B_{init}/K (α prior) | mean=0.8, SD=0.5 Lognormal distribution | The prior was developed, by expert opinion, after considering the work of Oshimo et al. (ISC/14/SHARKWG-1/04), Matsunaga et al. (2005), Ward and Myers (2005), and reported longline effort in the North Pacific Ocean since 1950. $init$ (initial year of assessment) = 1971 |
| Surplus production function | $B_{msy}/K=0.47$ | Fletcher-Schaefer model, corresponded to shape parameter of $\eta=1.71$ |
| Process error of stock dynamics | SD=0.07 | The value of process error of stock dynamics was determined considering balance between this value and CV(s) for CPUE index(ices) to obtain reasonable model fits to data. |
| Catch | | Total dead removals estimated by SHARKWG members. |
| Standardized CPUE index | | Each CPUE index is referred in this assessment by abbreviated identifiers below. |
| | Japanese offshore shallow longline (Hokkaido and Tohoku fleets) for 1976-1993 (Early period) | JE |
| | Japanese offshore and distant water longline (Hokkaido and Tohoku fleets) for 1994-2010 (Late period) | JL |
| | Hawaii Deep-set longline (2000-2012) | HW |
| | SPC longline (1993-2009) | SP |
| | Taiwan large longline (2004-2012) | TW |
| Reference case identifier | | In this assessment, eight reference cases were examined using the following index(ices). Each reference case is referred by case identifiers in the left column. |
| | JEJL_Ref | A combination of JE and JL indices |
| | JEHW_Ref | A combination of JE and HW indices |
| | JESP_Ref | A combination of JE and SP indices |
| | JETW_Ref | A combination of JE and TW indices |
| | JL_Ref | JL index only |
| | HW_Ref | HW index only |
| | SP_Ref | SP index only |
| | TW_Ref | TW index only |
| CV's for CPUE index | 0.100 for JE and 0.074 for JL | JEJL_Ref |
| | 0.097 for JE and 0.315 for HW | JEHW_Ref |
| | 0.095 for JE and 0.385 for SP | JESP_Ref |
| | 0.150 for JE and 0.640 for TW | JETW_Ref |
| | 0.084 for JL | JL_Ref |
| | 0.3288 for HW | HW_Ref |
| | 0.340 for SP | SP_Ref |
| | 0.680 for TW | TW_Ref |
| | | Considering that total CV for CPUE index is treated as the square root of $((\text{observation error CV})^2 + (\text{process error CV})^2)$ in the BSP2 software and the observation error CV for index is quite small, the total CV is dominated by the process error CV for index. To set the total CV for CPUE index properly, inputted CV for index was repeatedly adjusted (iterative reweighting) with an initial value of 0.20 until the ratio of inputted CV to outputted CV got roughly equal to 1.1-1.5 assuming that the CV for index is constant across years, while SD of the process error for the biomass dynamics equation is fixed at 0.07 (M. McAllister, pers. comm.). |

Table 3. Specifications and key parameter settings for the BSP sensitivity runs and prior-only runs.

| Category description | Run ID *1 | Run description/comments |
|---|---------------|--|
| B_{msv}/K (shape parameter n) | **_R34SH03 | $B_{msv}/K = 0.3$ ($n = 0.68$) |
| | **_R34SH06 | $B_{msv}/K = 0.6$ ($n = 3.39$) |
| r prior mean | **_R14A08 | mean = 0.14 (from Babcock and Cortés 2009) |
| | **_R43A08 | mean = 0.43 (from Cortés 2002) |
| r prior SD | **_Rsd03 | SD = 0.3 |
| | **_Rsd07 | SD = 0.7 |
| B_{init}/K ($\alpha.b0$) prior mean | **_R34A05 | mean = 0.5 |
| | **_R34A10 | mean = 1.0 |
| B_{init}/K ($\alpha.b0$) prior SD | **_Asd07 | SD = 0.7 |
| | **_Asd09 | SD = 0.9 |
| r versus B_{init}/K grids | **_R14A05 | r prior mean = 0.14, B_{init}/K prior mean = 0.5 |
| | **_R43A05 | r prior mean = 0.43, B_{init}/K prior mean = 0.5 |
| | **_R14A10 | r prior mean = 0.14, B_{init}/K prior mean = 1.0 |
| | **_R43A10 | r prior mean = 0.43, B_{init}/K prior mean = 1.0 |
| | | These sensitivity runs allow grid comparison to examine interactions of r [0.14, 0.34(reference), 0.43] and B_{init}/K [0.5, 0.8(Reference), 1.0] along with **_R34A05, **_R34A10, **_Ref, **_R14A08 and **_R43A08 sensitivity runs above. |
| r versus B_{msv}/K (shape parameter n) | **_R14Sh03 | r prior mean = 0.14, $B_{msv}/K = 0.3$ ($n = 0.68$) |
| | **_R43Sh03 | r prior mean = 0.43, $B_{msv}/K = 0.3$ ($n = 0.68$) |
| | **_R14Sh06 | r prior mean = 0.14, $B_{msv}/K = 0.6$ ($n = 3.34$) |
| | **_R43Sh06 | r prior mean = 0.43, $B_{msv}/K = 0.6$ ($n = 3.39$) |
| | | These sensitivity runs allow grid comparison to examine interactions of r [0.14, 0.34(reference), 0.43] and B_{msv}/K [0.3, 0.47(reference), 0.6] (n [0.68, 1.71, 3.39]) along with **_R34Sh03, **_R34Sh06, **_Ref, **_R14A08 ($B_{msv}/K=0.47$) and **_R43A08 ($B_{msv}/K=0.47$) sensitivity runs above. |
| Runs using catch and CPUE data through 2012 | **_2012 | Blue shark catch in 2012 represents a large amount (about 60%) of substituted catch carried over from 2011, and is thus considered more uncertain than that prior to 2012. |
| Prior-only runs | Ponly_obscat | with observed catch |
| | Ponly_hlfcats | with halving catch |
| | Ponly_dbcats | with doubling catch |
| | Ponly_rvscats | with reversed catch |
| | Ponly_pessim | with constant catch (60,000 MT) |
| | | K prior: uniform (not log) bounded between 100,000 and 200,000 MT. |
| | | r prior: lognormal (mean=0.34, SD=0.5) bounded between 0.001 and 2. |
| | | B_{init}/K ($\alpha.b0$) prior: lognormal (mean=0.5, SD=0.5) bounded between 0 and 1. |

Footnote *1: "***" represents identifiers for CPUE index or combinations of the indices described in Table 2 e.g., for a combination of JE and JL, the run identifier is like JEJL_R14A08.

Table 4. Estimates of age-specific natural mortality used in the SS modeling. The reference case used those based on the approach of Peterson and Wroblewski (1984) method and the Nakano (1994) data (Rice and Semba 2014).

| Age | Nakano (1994) | | Hsu et al. (2011) | |
|-----|---------------|--------|-------------------|--------|
| | Male | Female | Male | Female |
| 0 | 0.551 | 0.535 | 0.359 | 0.366 |
| 1 | 0.301 | 0.309 | 0.245 | 0.245 |
| 2 | 0.223 | 0.233 | 0.195 | 0.195 |
| 3 | 0.183 | 0.194 | 0.166 | 0.168 |
| 4 | 0.16 | 0.171 | 0.147 | 0.151 |
| 5 | 0.144 | 0.155 | 0.134 | 0.139 |
| 6 | 0.133 | 0.144 | 0.125 | 0.13 |
| 7 | 0.125 | 0.135 | 0.118 | 0.124 |
| 8 | 0.118 | 0.129 | 0.112 | 0.119 |
| 9 | 0.113 | 0.124 | 0.108 | 0.115 |
| 10 | 0.109 | 0.12 | 0.104 | 0.112 |
| 11 | 0.106 | 0.117 | 0.101 | 0.11 |
| 12 | 0.103 | 0.114 | 0.099 | 0.108 |
| 13 | 0.101 | 0.112 | 0.097 | 0.106 |
| 14 | 0.099 | 0.11 | 0.095 | 0.105 |
| 15 | 0.097 | 0.109 | 0.094 | 0.104 |
| 16 | 0.096 | 0.107 | 0.092 | 0.103 |
| 17 | 0.095 | 0.106 | 0.091 | 0.102 |
| 18 | 0.094 | 0.105 | 0.09 | 0.102 |
| 19 | 0.093 | 0.105 | 0.09 | 0.101 |
| 20 | 0.092 | 0.104 | 0.089 | 0.101 |
| 21 | 0.092 | 0.103 | 0.088 | 0.1 |
| 22 | 0.091 | 0.103 | 0.088 | 0.1 |
| 23 | 0.091 | 0.103 | 0.087 | 0.1 |
| 24 | 0.09 | 0.102 | 0.087 | 0.099 |
| 25 | 0.09 | 0.102 | 0.087 | 0.099 |
| 26 | 0.09 | 0.102 | 0.086 | 0.099 |
| 27 | 0.089 | 0.101 | 0.086 | 0.099 |
| 28 | 0.089 | 0.101 | 0.086 | 0.099 |
| 29 | 0.089 | 0.101 | 0.086 | 0.099 |
| 30 | 0.089 | 0.101 | 0.085 | 0.099 |

Table 5. Summary of the 18 fisheries defined for the SS assessment. The Japanese early and late CPUE series were based on fleets F4 and F5, respectively; the Hawaiian deepset CPUE series was based on F16; the Taiwan longline CPUE series was based on F17; and the SPC longline CPUE series based on F13.

| 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_GILL | 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 6. The five axes of uncertainty considered in the full structural uncertainty grid of the SS runs.

| 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 | <i>Beta</i> <i>S_{Frac}</i> |
| | | (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 7. Values of fishing mortality (F) and catch projected under the 7 different harvest scenarios for the SS projections.

| | Fishing mortality | Catch (mt) |
|---|-------------------|------------|
| <i>Status quo</i> (Average of 2006-2010) | 0.495 | 46,389 |
| <i>MSY</i> | 0.707 | |
| + 20% | 0.594 | 55,667 |
| - 20%- | 0.396 | 37,111 |

Table 8. Comparison of model results of the eight BSP reference cases: medians (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Median | | | | | | | |
|----------------------|----------|----------|----------|----------|--------|--------|--------|--------|
| | JEJL_Ref | JEHW_Ref | JESP_Ref | JETW_Ref | JL_Ref | HW_Ref | SP_Ref | TW_Ref |
| r | 0.41 | 0.29 | 0.29 | 0.30 | 0.28 | 0.34 | 0.34 | 0.35 |
| K ('000 MT) | 806 | 1129 | 1141 | 1088 | 1633 | 4021 | 4368 | 4148 |
| MSY ('000 MT) | 76 | 76 | 77 | 75 | 98 | 303 | 325 | 321 |
| B_{msy} ('000 MT) | 379 | 531 | 536 | 512 | 767 | 1890 | 2053 | 1950 |
| B_{1971} ('000 MT) | 556 | 982 | 994 | 877 | 1104 | 2975 | 3259 | 3090 |
| B_{2011} ('000 MT) | 622 | 720 | 754 | 783 | 1332 | 3563 | 3961 | 3932 |
| B_{2011}/B_{msy} | 1.65 | 1.51 | 1.52 | 1.63 | 1.82 | 1.91 | 1.89 | 1.98 |
| B_{2011}/B_{1971} | 1.15 | 0.77 | 0.78 | 0.91 | 1.22 | 1.17 | 1.17 | 1.22 |
| B_{2011}/K | 0.82 | 0.75 | 0.76 | 0.81 | 0.91 | 0.96 | 0.95 | 0.99 |
| F_{msy} (ratio) | 0.20 | 0.14 | 0.14 | 0.15 | 0.14 | 0.17 | 0.17 | 0.18 |
| F_{2011} (ratio) | 0.07 | 0.06 | 0.05 | 0.05 | 0.03 | 0.01 | 0.01 | 0.01 |
| F_{2011}/F_{msy} | 0.32 | 0.35 | 0.34 | 0.33 | 0.22 | 0.07 | 0.07 | 0.06 |

Table 9. **JEJL_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.41 | 0.14 | 0.33 | 0.20 | 0.41 | 0.65 |
| K ('000 MT) | 955 | 597 | 0.63 | 491 | 806 | 1884 |
| MSY ('000 MT) | 79 | 19 | 0.24 | 65 | 76 | 98 |
| B_{msy} ('000 MT) | 449 | 281 | 0.63 | 231 | 379 | 886 |
| B_{1971} ('000 MT) | 735 | 773 | 1.05 | 253 | 556 | 1657 |
| B_{2011} ('000 MT) | 744 | 542 | 0.73 | 373 | 622 | 1459 |
| B_{2011}/B_{msy} | 1.65 | 0.25 | 0.15 | 1.24 | 1.65 | 2.08 |
| B_{2011}/B_{1971} | 1.21 | 0.43 | 0.35 | 0.68 | 1.15 | 2.05 |
| B_{2011}/K | 0.78 | 0.12 | 0.15 | 0.62 | 0.82 | 1.04 |
| F_{msy} (ratio) | 0.20 | 0.07 | 0.33 | 0.10 | 0.20 | 0.33 |
| F_{2011} (ratio) | 0.07 | 0.02 | 0.37 | 0.03 | 0.07 | 0.11 |
| F_{2011}/F_{msy} | 0.33 | 0.07 | 0.23 | 0.22 | 0.32 | 0.45 |

Table 10. **JEHW_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.31 | 0.14 | 0.46 | 0.12 | 0.29 | 0.58 |
| K ('000 MT) | 1586 | 1700 | 1.07 | 558 | 1129 | 4121 |
| MSY ('000 MT) | 90 | 71 | 0.79 | 53 | 76 | 165 |
| B_{msy} ('000 MT) | 746 | 799 | 1.07 | 262 | 531 | 1937 |
| B_{1971} ('000 MT) | 1796 | 2521 | 1.40 | 338 | 982 | 5486 |
| B_{2011} ('000 MT) | 1151 | 1517 | 1.32 | 374 | 720 | 3401 |
| B_{2011}/B_{msy} | 1.48 | 0.36 | 0.24 | 0.80 | 1.51 | 2.04 |
| B_{2011}/B_{1971} | 0.83 | 0.36 | 0.43 | 0.37 | 0.77 | 1.52 |
| B_{2011}/K | 0.70 | 0.17 | 0.24 | 0.40 | 0.75 | 1.02 |
| F_{msy} (ratio) | 0.15 | 0.07 | 0.46 | 0.06 | 0.14 | 0.29 |
| F_{2011} (ratio) | 0.06 | 0.03 | 0.51 | 0.01 | 0.06 | 0.11 |
| F_{2011}/F_{msy} | 0.41 | 0.29 | 0.70 | 0.13 | 0.35 | 0.91 |

Table 11. **JESP_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.31 | 0.13 | 0.43 | 0.13 | 0.29 | 0.57 |
| K ('000 MT) | 1610 | 1738 | 1.08 | 572 | 1141 | 4121 |
| MSY ('000 MT) | 92 | 63 | 0.68 | 57 | 77 | 176 |
| B_{msy} ('000 MT) | 757 | 817 | 1.08 | 269 | 536 | 1937 |
| B_{1971} ('000 MT) | 1783 | 2433 | 1.37 | 354 | 994 | 5169 |
| B_{2011} ('000 MT) | 1205 | 1597 | 1.33 | 381 | 754 | 3409 |
| B_{2011}/B_{msy} | 1.52 | 0.36 | 0.24 | 0.92 | 1.52 | 2.13 |
| B_{2011}/B_{1971} | 0.85 | 0.35 | 0.42 | 0.41 | 0.78 | 1.53 |
| B_{2011}/K | 0.71 | 0.17 | 0.24 | 0.46 | 0.76 | 1.06 |
| F_{msy} (ratio) | 0.16 | 0.07 | 0.43 | 0.07 | 0.14 | 0.29 |
| F_{2011} (ratio) | 0.06 | 0.03 | 0.51 | 0.01 | 0.05 | 0.11 |
| F_{2011}/F_{msy} | 0.38 | 0.21 | 0.55 | 0.12 | 0.34 | 0.73 |

Table 12. **JETW_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.32 | 0.13 | 0.42 | 0.14 | 0.30 | 0.56 |
| K ('000 MT) | 1538 | 1720 | 1.12 | 565 | 1088 | 3911 |
| MSY ('000 MT) | 93 | 78 | 0.85 | 58 | 75 | 170 |
| B_{msy} ('000 MT) | 723 | 808 | 1.12 | 266 | 512 | 1838 |
| B_{1971} ('000 MT) | 1595 | 2322 | 1.46 | 338 | 877 | 4750 |
| B_{2011} ('000 MT) | 1235 | 1707 | 1.38 | 405 | 783 | 3557 |
| B_{2011}/B_{msy} | 1.62 | 0.33 | 0.21 | 1.06 | 1.63 | 2.15 |
| B_{2011}/B_{1971} | 0.99 | 0.44 | 0.44 | 0.47 | 0.91 | 1.79 |
| B_{2011}/K | 0.76 | 0.16 | 0.21 | 0.53 | 0.81 | 1.07 |
| F_{msy} (ratio) | 0.16 | 0.07 | 0.42 | 0.07 | 0.15 | 0.28 |
| F_{2011} (ratio) | 0.05 | 0.03 | 0.50 | 0.01 | 0.05 | 0.10 |
| F_{2011}/F_{msy} | 0.35 | 0.18 | 0.50 | 0.12 | 0.33 | 0.62 |

Table 13. **JL_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.31 | 0.13 | 0.43 | 0.14 | 0.28 | 0.55 |
| K ('000 MT) | 3281 | 3962 | 1.21 | 593 | 1633 | 12645 |
| MSY ('000 MT) | 188 | 226 | 1.20 | 64 | 98 | 627 |
| B_{msy} ('000 MT) | 1542 | 1862 | 1.21 | 279 | 767 | 5943 |
| B_{1971} ('000 MT) | 2256 | 2814 | 1.25 | 355 | 1104 | 8678 |
| B_{2011} ('000 MT) | 3104 | 4188 | 1.35 | 444 | 1332 | 12746 |
| B_{2011}/B_{msy} | 1.83 | 0.35 | 0.19 | 1.28 | 1.82 | 2.41 |
| B_{2011}/B_{1971} | 1.41 | 0.75 | 0.53 | 0.60 | 1.22 | 2.83 |
| B_{2011}/K | 0.86 | 0.17 | 0.19 | 0.64 | 0.91 | 1.21 |
| F_{msy} (ratio) | 0.15 | 0.07 | 0.43 | 0.07 | 0.14 | 0.28 |
| F_{2011} (ratio) | 0.04 | 0.03 | 0.79 | 0.00 | 0.03 | 0.09 |
| F_{2011}/F_{msy} | 0.23 | 0.14 | 0.63 | 0.03 | 0.22 | 0.46 |

Table 14. **HW_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.38 | 0.18 | 0.47 | 0.15 | 0.34 | 0.73 |
| K ('000 MT) | 5855 | 4998 | 0.85 | 884 | 4021 | 16731 |
| MSY ('000 MT) | 495 | 519 | 1.05 | 73 | 303 | 1543 |
| B_{msy} ('000 MT) | 2752 | 2349 | 0.85 | 415 | 1890 | 7864 |
| B_{1971} ('000 MT) | 4370 | 4080 | 0.93 | 582 | 2975 | 12927 |
| B_{2011} ('000 MT) | 5415 | 4906 | 0.91 | 584 | 3563 | 15799 |
| B_{2011}/B_{msy} | 1.87 | 0.35 | 0.19 | 1.29 | 1.91 | 2.35 |
| B_{2011}/B_{1971} | 1.29 | 0.60 | 0.47 | 0.57 | 1.17 | 2.44 |
| B_{2011}/K | 0.88 | 0.17 | 0.19 | 0.65 | 0.96 | 1.18 |
| F_{msy} (ratio) | 0.19 | 0.09 | 0.47 | 0.08 | 0.17 | 0.36 |
| F_{2011} (ratio) | 0.02 | 0.03 | 1.54 | 0.00 | 0.01 | 0.07 |
| F_{2011}/F_{msy} | 0.14 | 0.31 | 2.17 | 0.01 | 0.07 | 0.40 |

Table 15. **SP_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.37 | 0.17 | 0.46 | 0.15 | 0.34 | 0.69 |
| K ('000 MT) | 6168 | 5099 | 0.83 | 934 | 4368 | 16844 |
| MSY ('000 MT) | 509 | 517 | 1.02 | 77 | 325 | 1552 |
| B_{msy} ('000 MT) | 2899 | 2396 | 0.83 | 439 | 2053 | 7917 |
| B_{1971} ('000 MT) | 4593 | 4192 | 0.91 | 584 | 3259 | 13675 |
| B_{2011} ('000 MT) | 5658 | 4969 | 0.88 | 624 | 3961 | 16155 |
| B_{2011}/B_{msy} | 1.87 | 0.36 | 0.19 | 1.29 | 1.89 | 2.41 |
| B_{2011}/B_{1971} | 1.30 | 0.62 | 0.48 | 0.59 | 1.17 | 2.44 |
| B_{2011}/K | 0.88 | 0.17 | 0.19 | 0.64 | 0.95 | 1.20 |
| F_{msy} (ratio) | 0.18 | 0.08 | 0.46 | 0.08 | 0.17 | 0.35 |
| F_{2011} (ratio) | 0.02 | 0.03 | 1.68 | 0.00 | 0.01 | 0.06 |
| F_{2011}/F_{msy} | 0.13 | 0.38 | 2.84 | 0.01 | 0.07 | 0.37 |

Table 16. **TW_Ref** case model results: mean, standard deviation, coefficient of variation, and the median with 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.

| Variable | Mean | SD | CV | 5th Percentile | Median | 95th Percentile |
|----------------------|------|------|------|----------------|--------|-----------------|
| r | 0.39 | 0.18 | 0.47 | 0.15 | 0.35 | 0.74 |
| K ('000 MT) | 5964 | 5055 | 0.85 | 810 | 4148 | 16570 |
| MSY ('000 MT) | 515 | 527 | 1.02 | 73 | 321 | 1611 |
| B_{msy} ('000 MT) | 2803 | 2376 | 0.85 | 381 | 1950 | 7788 |
| B_{1971} ('000 MT) | 4402 | 4119 | 0.94 | 528 | 3090 | 13267 |
| B_{2011} ('000 MT) | 5761 | 5149 | 0.89 | 606 | 3932 | 16380 |
| B_{2011}/B_{msy} | 1.97 | 0.32 | 0.16 | 1.43 | 1.98 | 2.45 |
| B_{2011}/B_{1971} | 1.37 | 0.64 | 0.47 | 0.65 | 1.22 | 2.59 |
| B_{2011}/K | 0.92 | 0.15 | 0.16 | 0.71 | 0.99 | 1.22 |
| F_{msy} (ratio) | 0.19 | 0.09 | 0.47 | 0.08 | 0.18 | 0.37 |
| F_{2011} (ratio) | 0.02 | 0.02 | 1.16 | 0.00 | 0.01 | 0.07 |
| F_{2011}/F_{msy} | 0.12 | 0.16 | 1.39 | 0.01 | 0.06 | 0.37 |

Table 17. Comparison of medians and 90% credibility intervals drawn from the posterior distributions of r , B_{MSY} , B_{2011} , B_{2011}/B_{MSY} and F_{2011}/F_{MSY} for **JEJL** reference and sensitivity cases. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs.

| Run ID | r | | | B_{msy} ('000 MT) | | | B_{2011} ('000 MT) | | | B_{2011}/B_{msy} | | | F_{2011}/F_{msy} | | |
|--------------|--|--------|------|---------------------|--------|------|----------------------|--------|-------|--------------------|--------|------|--------------------|--------|------|
| | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% |
| JEJL_Ref | 0.20 | 0.41 | 0.65 | 231 | 379 | 886 | 373 | 622 | 1459 | 1.24 | 1.65 | 2.08 | 0.22 | 0.32 | 0.45 |
| | B_{msy}/K (shape parameter n) | | | | | | | | | | | | | | |
| JEJL_R34Sh03 | 0.14 | 0.43 | 0.75 | 199 | 373 | 2618 | 423 | 798 | 8479 | 1.54 | 2.23 | 3.72 | 0.07 | 0.23 | 0.38 |
| JEJL_R34Sh06 | 0.18 | 0.30 | 0.45 | 251 | 388 | 630 | 350 | 539 | 1004 | 1.17 | 1.43 | 1.69 | 0.28 | 0.36 | 0.46 |
| | r prior mean | | | | | | | | | | | | | | |
| JEJL_R14A08 | 0.07 | 0.19 | 0.46 | 333 | 820 | 3917 | 512 | 1313 | 8929 | 1.09 | 1.60 | 2.30 | 0.10 | 0.31 | 0.54 |
| JEJL_R43A08 | 0.24 | 0.45 | 0.70 | 218 | 344 | 683 | 356 | 563 | 1149 | 1.27 | 1.67 | 2.05 | 0.24 | 0.32 | 0.44 |
| | r prior SD | | | | | | | | | | | | | | |
| JEJL_Rsd03 | 0.24 | 0.39 | 0.58 | 260 | 398 | 728 | 411 | 649 | 1377 | 1.27 | 1.65 | 2.11 | 0.21 | 0.32 | 0.46 |
| JEJL_Rsd07 | 0.09 | 0.39 | 0.70 | 222 | 398 | 2243 | 354 | 626 | 3517 | 1.20 | 1.67 | 2.21 | 0.21 | 0.32 | 0.47 |
| | B_{1971}/K (α.$b0$) prior mean | | | | | | | | | | | | | | |
| JEJL_R34A05 | 0.22 | 0.44 | 0.71 | 222 | 353 | 730 | 340 | 565 | 1110 | 1.23 | 1.63 | 2.10 | 0.24 | 0.32 | 0.45 |
| JEJL_R34A10 | 0.19 | 0.41 | 0.64 | 236 | 376 | 965 | 374 | 621 | 1762 | 1.31 | 1.69 | 2.15 | 0.20 | 0.31 | 0.45 |
| | B_{1971}/K (α.$b0$) prior SD | | | | | | | | | | | | | | |
| JEJL_Asd07 | 0.21 | 0.41 | 0.70 | 224 | 370 | 854 | 358 | 608 | 1471 | 1.29 | 1.65 | 2.15 | 0.22 | 0.32 | 0.44 |
| JEJL_Asd09 | 0.19 | 0.41 | 0.73 | 215 | 371 | 843 | 338 | 604 | 1575 | 1.27 | 1.65 | 2.15 | 0.22 | 0.33 | 0.44 |
| | r versus B_{init}/K (α.$b0$) grids | | | | | | | | | | | | | | |
| JEJL_R14A05 | 0.07 | 0.20 | 0.45 | 331 | 818 | 3484 | 503 | 1209 | 5404 | 0.94 | 1.52 | 2.11 | 0.13 | 0.33 | 0.62 |
| JEJL_R43A05 | 0.26 | 0.49 | 0.76 | 202 | 321 | 592 | 316 | 511 | 987 | 1.25 | 1.65 | 2.11 | 0.24 | 0.32 | 0.45 |
| JEJL_R14A10 | 0.07 | 0.19 | 0.45 | 332 | 826 | 3995 | 541 | 1361 | 8854 | 1.17 | 1.67 | 2.43 | 0.09 | 0.30 | 0.53 |
| JEJL_R43A10 | 0.23 | 0.45 | 0.71 | 215 | 336 | 705 | 360 | 548 | 1274 | 1.28 | 1.69 | 2.08 | 0.22 | 0.32 | 0.45 |
| | r versus B_{msy}/K (shape parameter n) grids | | | | | | | | | | | | | | |
| JEJL_R14Sh03 | 0.07 | 0.19 | 0.46 | 334 | 883 | 3400 | 615 | 1792 | 10756 | 1.25 | 2.18 | 3.78 | 0.06 | 0.24 | 0.49 |
| JEJL_R43Sh03 | 0.19 | 0.49 | 0.80 | 189 | 323 | 1248 | 394 | 685 | 3318 | 1.54 | 2.24 | 3.35 | 0.08 | 0.24 | 0.38 |
| JEJL_R14Sh06 | 0.06 | 0.18 | 0.33 | 316 | 619 | 2858 | 466 | 862 | 3976 | 1.08 | 1.43 | 1.78 | 0.19 | 0.35 | 0.51 |
| JEJL_R43Sh06 | 0.19 | 0.32 | 0.47 | 244 | 350 | 579 | 347 | 483 | 871 | 1.15 | 1.41 | 1.67 | 0.29 | 0.36 | 0.47 |
| | Run using data up to 2012 | | | | | | | | | | | | | | |
| JEJL_2012 | 0.22 | 0.42 | 0.67 | 223 | 360 | 870 | 348 | 596 | 1327 | 1.31 | 1.66 | 2.13 | 0.19 | 0.30 | 0.41 |

Table 18. Comparison of medians and 90% credibility intervals drawn from the posterior distributions of r , B_{MSY} , B_{2011} , B_{2011}/B_{MSY} and F_{2011}/F_{MSY} for **JEHW** reference and sensitivity cases. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs.

| Run ID | r | | | B_{msy} ('000 MT) | | | B_{2011} ('000 MT) | | | B_{2011}/B_{msy} | | | F_{2011}/F_{msy} | | |
|--------------|--|--------|------|---------------------|--------|------|----------------------|--------|------|--------------------|--------|------|--------------------|--------|------|
| | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% |
| JEHW_Ref | 0.12 | 0.29 | 0.58 | 262 | 531 | 1937 | 374 | 720 | 3401 | 0.80 | 1.51 | 2.04 | 0.13 | 0.35 | 0.91 |
| | B_{msy}/K (shape parameter n) | | | | | | | | | | | | | | |
| JEHW_R34Sh03 | 0.14 | 0.31 | 0.62 | 262 | 540 | 2326 | 431 | 1019 | 6567 | 1.06 | 2.08 | 3.16 | 0.04 | 0.24 | 0.75 |
| JEHW_R34Sh06 | 0.13 | 0.29 | 0.52 | 215 | 388 | 839 | 298 | 522 | 1109 | 0.98 | 1.39 | 1.66 | 0.28 | 0.37 | 0.64 |
| | r prior mean | | | | | | | | | | | | | | |
| JEHW_R14A08 | 0.06 | 0.13 | 0.30 | 468 | 1052 | 4141 | 386 | 1192 | 6825 | 0.44 | 1.31 | 2.03 | 0.11 | 0.45 | 2.10 |
| JEHW_R43A08 | 0.15 | 0.34 | 0.64 | 241 | 440 | 1273 | 353 | 641 | 2086 | 0.98 | 1.54 | 2.01 | 0.17 | 0.34 | 0.69 |
| | r prior SD | | | | | | | | | | | | | | |
| JEHW_Rsd03 | 0.20 | 0.32 | 0.52 | 288 | 470 | 1114 | 383 | 685 | 1942 | 0.97 | 1.53 | 2.01 | 0.16 | 0.34 | 0.67 |
| JEHW_Rsd07 | 0.07 | 0.23 | 0.59 | 261 | 650 | 2666 | 357 | 757 | 4390 | 0.49 | 1.45 | 2.01 | 0.13 | 0.37 | 1.77 |
| | B_{1971}/K ($\alpha, b0$) prior mean | | | | | | | | | | | | | | |
| JEHW_R34A05 | 0.12 | 0.32 | 0.63 | 244 | 469 | 1260 | 355 | 646 | 1753 | 0.73 | 1.48 | 1.96 | 0.22 | 0.36 | 0.94 |
| JEHW_R34A10 | 0.12 | 0.27 | 0.54 | 276 | 564 | 2365 | 382 | 774 | 4344 | 0.85 | 1.52 | 2.07 | 0.11 | 0.34 | 0.90 |
| | B_{1971}/K ($\alpha, b0$) prior SD | | | | | | | | | | | | | | |
| JEHW_Asd07 | 0.13 | 0.28 | 0.57 | 267 | 541 | 1868 | 380 | 748 | 3337 | 0.83 | 1.52 | 2.04 | 0.13 | 0.35 | 0.90 |
| JEHW_Asd09 | 0.11 | 0.28 | 0.59 | 262 | 551 | 2050 | 378 | 764 | 3866 | 0.80 | 1.54 | 2.03 | 0.13 | 0.34 | 0.95 |
| | r versus B_{init}/K ($\alpha, b0$) grids | | | | | | | | | | | | | | |
| JEHW_R14A05 | 0.06 | 0.13 | 0.31 | 458 | 982 | 3275 | 340 | 983 | 4339 | 0.30 | 1.10 | 1.84 | 0.17 | 0.58 | 2.46 |
| JEHW_R43A05 | 0.13 | 0.38 | 0.68 | 224 | 396 | 1036 | 348 | 567 | 1267 | 0.67 | 1.54 | 1.97 | 0.23 | 0.35 | 1.08 |
| JEHW_R14A10 | 0.06 | 0.13 | 0.29 | 505 | 1111 | 4296 | 438 | 1374 | 7530 | 0.52 | 1.38 | 2.07 | 0.09 | 0.41 | 1.83 |
| JEHW_R43A10 | 0.15 | 0.32 | 0.62 | 243 | 469 | 1776 | 364 | 670 | 2978 | 1.00 | 1.55 | 2.03 | 0.13 | 0.34 | 0.70 |
| | r versus B_{msy}/K (shape parameter n) grids | | | | | | | | | | | | | | |
| JEHW_R14Sh03 | 0.06 | 0.14 | 0.33 | 431 | 885 | 3067 | 416 | 1339 | 7614 | 0.59 | 1.67 | 3.11 | 0.07 | 0.40 | 1.79 |
| JEHW_R43Sh03 | 0.17 | 0.37 | 0.70 | 234 | 468 | 2143 | 421 | 929 | 6218 | 1.21 | 2.14 | 3.16 | 0.04 | 0.22 | 0.60 |
| JEHW_R14Sh06 | 0.05 | 0.11 | 0.28 | 383 | 901 | 3248 | 342 | 869 | 4386 | 0.35 | 1.16 | 1.64 | 0.17 | 0.48 | 2.16 |
| JEHW_R43Sh06 | 0.16 | 0.33 | 0.57 | 203 | 335 | 709 | 281 | 458 | 931 | 1.09 | 1.41 | 1.66 | 0.28 | 0.36 | 0.54 |
| | Run using data up to 2012 | | | | | | | | | | | | | | |
| JEHW_2012 | 0.13 | 0.29 | 0.58 | 265 | 523 | 1715 | 376 | 720 | 2943 | 0.79 | 1.52 | 2.03 | 0.13 | 0.33 | 0.88 |

Table 19. Comparison of medians and 90% credibility intervals drawn from the posterior distributions of r , B_{MSY} , B_{2011} , B_{2011}/B_{MSY} and F_{2011}/F_{MSY} for **JESP** reference and sensitivity cases. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs.

| Run ID | r | | | B_{msy} ('000 MT) | | | B_{2011} ('000 MT) | | | B_{2011}/B_{msy} | | | F_{2011}/F_{msy} | | |
|--------------|--|--------|------|---------------------|--------|------|----------------------|--------|------|--------------------|--------|------|--------------------|--------|------|
| | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% |
| JESP_Ref | 0.13 | 0.29 | 0.57 | 269 | 536 | 1937 | 381 | 754 | 3409 | 0.92 | 1.52 | 2.13 | 0.12 | 0.34 | 0.73 |
| | B_{msy}/K (shape parameter n) | | | | | | | | | | | | | | |
| JESP_R34Sh03 | 0.15 | 0.33 | 0.63 | 257 | 525 | 2424 | 442 | 1038 | 6930 | 1.17 | 2.12 | 3.32 | 0.04 | 0.22 | 0.59 |
| JESP_R34Sh06 | 0.13 | 0.29 | 0.51 | 222 | 389 | 841 | 307 | 527 | 1096 | 0.98 | 1.39 | 1.70 | 0.28 | 0.37 | 0.59 |
| | r prior mean | | | | | | | | | | | | | | |
| JESP_R14A08 | 0.06 | 0.14 | 0.30 | 473 | 1099 | 4498 | 507 | 1407 | 8019 | 0.66 | 1.42 | 2.21 | 0.09 | 0.37 | 1.21 |
| JESP_R43A08 | 0.17 | 0.34 | 0.62 | 243 | 446 | 1351 | 360 | 657 | 2387 | 1.02 | 1.54 | 2.09 | 0.16 | 0.34 | 0.61 |
| | r prior SD | | | | | | | | | | | | | | |
| JESP_Rsd03 | 0.20 | 0.32 | 0.50 | 298 | 478 | 1166 | 402 | 709 | 2049 | 1.01 | 1.54 | 2.11 | 0.16 | 0.34 | 0.60 |
| JESP_Rsd07 | 0.08 | 0.25 | 0.57 | 268 | 620 | 3075 | 385 | 839 | 5145 | 0.81 | 1.49 | 2.13 | 0.11 | 0.35 | 0.92 |
| | B_{1971}/K (α, b_0) prior mean | | | | | | | | | | | | | | |
| JESP_R34A05 | 0.14 | 0.32 | 0.61 | 251 | 469 | 1252 | 361 | 670 | 1952 | 0.88 | 1.50 | 2.06 | 0.19 | 0.35 | 0.75 |
| JESP_R34A10 | 0.13 | 0.28 | 0.55 | 279 | 561 | 2396 | 397 | 800 | 4459 | 0.97 | 1.54 | 2.15 | 0.10 | 0.33 | 0.69 |
| | B_{1971}/K (α, b_0) prior SD | | | | | | | | | | | | | | |
| JESP_Asd07 | 0.14 | 0.29 | 0.57 | 268 | 540 | 2470 | 383 | 775 | 4712 | 0.95 | 1.54 | 2.15 | 0.10 | 0.33 | 0.70 |
| JESP_Asd09 | 0.13 | 0.28 | 0.56 | 273 | 541 | 1985 | 396 | 780 | 3444 | 0.96 | 1.54 | 2.12 | 0.12 | 0.33 | 0.69 |
| | r versus B_{init}/K (α, b_0) grids | | | | | | | | | | | | | | |
| JESP_R14A05 | 0.06 | 0.14 | 0.34 | 440 | 1029 | 3929 | 437 | 1100 | 5814 | 0.43 | 1.22 | 2.01 | 0.12 | 0.48 | 1.61 |
| JESP_R43A05 | 0.17 | 0.38 | 0.67 | 227 | 393 | 967 | 343 | 587 | 1437 | 0.98 | 1.53 | 2.05 | 0.22 | 0.34 | 0.64 |
| JESP_R14A10 | 0.06 | 0.14 | 0.30 | 492 | 1125 | 4624 | 543 | 1565 | 8335 | 0.76 | 1.47 | 2.24 | 0.08 | 0.35 | 1.13 |
| JESP_R43A10 | 0.16 | 0.33 | 0.61 | 250 | 465 | 1743 | 365 | 693 | 2989 | 1.02 | 1.55 | 2.13 | 0.13 | 0.33 | 0.62 |
| | r versus B_{msy}/K (shape parameter n) grids | | | | | | | | | | | | | | |
| JESP_R14Sh03 | 0.06 | 0.15 | 0.35 | 438 | 955 | 3474 | 558 | 1691 | 8854 | 0.82 | 1.86 | 3.34 | 0.06 | 0.31 | 1.13 |
| JESP_R43Sh03 | 0.19 | 0.40 | 0.70 | 232 | 454 | 2087 | 421 | 910 | 5733 | 1.28 | 2.14 | 3.27 | 0.04 | 0.22 | 0.50 |
| JESP_R14Sh06 | 0.05 | 0.12 | 0.29 | 382 | 851 | 3488 | 417 | 946 | 4754 | 0.59 | 1.23 | 1.71 | 0.17 | 0.43 | 1.23 |
| JESP_R43Sh06 | 0.16 | 0.32 | 0.55 | 208 | 345 | 688 | 288 | 473 | 922 | 1.06 | 1.41 | 1.70 | 0.28 | 0.36 | 0.54 |
| | Run using data up to 2012 | | | | | | | | | | | | | | |
| JEJSP2012 | 0.13 | 0.29 | 0.56 | 271 | 530 | 1879 | 389 | 773 | 3432 | 0.92 | 1.55 | 2.15 | 0.12 | 0.31 | 0.68 |

Table 20. Comparison of medians and 90% credibility intervals drawn from the posterior distributions of r , B_{MSY} , B_{2011} , B_{2011}/B_{MSY} and F_{2011}/F_{MSY} for **JETW** reference and sensitivity cases. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs.

| Run ID | r | | | B_{msy} ('000 MT) | | | B_{2011} ('000 MT) | | | B_{2011}/B_{msy} | | | F_{2011}/F_{msy} | | |
|--------------|---|--------|------|---------------------|--------|------|----------------------|--------|------|--------------------|--------|------|--------------------|--------|------|
| | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% | 5% | Median | 95% |
| JETW_Ref | 0.14 | 0.30 | 0.56 | 266 | 512 | 1838 | 405 | 783 | 3557 | 1.06 | 1.63 | 2.15 | 0.12 | 0.33 | 0.62 |
| | B_{msy}/K (shape parameter n) | | | | | | | | | | | | | | |
| JETW_R34Sh03 | 0.16 | 0.34 | 0.63 | 247 | 489 | 2226 | 474 | 1041 | 6786 | 1.34 | 2.30 | 3.42 | 0.04 | 0.22 | 0.51 |
| JETW_R34Sh06 | 0.13 | 0.27 | 0.50 | 228 | 407 | 908 | 323 | 567 | 1267 | 1.07 | 1.43 | 1.70 | 0.27 | 0.36 | 0.55 |
| | r prior mean | | | | | | | | | | | | | | |
| JETW_R14A08 | 0.07 | 0.15 | 0.31 | 472 | 1076 | 4532 | 558 | 1479 | 8747 | 0.73 | 1.53 | 2.26 | 0.08 | 0.35 | 1.07 |
| JETW_R43A08 | 0.17 | 0.34 | 0.63 | 245 | 438 | 1294 | 388 | 694 | 2451 | 1.15 | 1.65 | 2.13 | 0.15 | 0.32 | 0.55 |
| | r prior SD | | | | | | | | | | | | | | |
| JETW_Rsd03 | 0.20 | 0.32 | 0.50 | 295 | 467 | 1221 | 434 | 746 | 2351 | 1.16 | 1.65 | 2.17 | 0.13 | 0.32 | 0.55 |
| JETW_Rsd07 | 0.09 | 0.27 | 0.57 | 266 | 581 | 2805 | 409 | 861 | 4990 | 0.96 | 1.63 | 2.20 | 0.10 | 0.33 | 0.73 |
| | B_{1971}/K (α, b_0) prior mean | | | | | | | | | | | | | | |
| JETW_R34A05 | 0.15 | 0.32 | 0.60 | 255 | 479 | 1254 | 400 | 730 | 2003 | 0.99 | 1.61 | 2.08 | 0.20 | 0.33 | 0.62 |
| JETW_R34A10 | 0.14 | 0.29 | 0.55 | 273 | 524 | 2223 | 417 | 814 | 4419 | 1.09 | 1.66 | 2.19 | 0.10 | 0.32 | 0.60 |
| | B_{1971}/K (α, b_0) prior SD | | | | | | | | | | | | | | |
| JETW_Asd07 | 0.14 | 0.29 | 0.57 | 267 | 517 | 1956 | 418 | 796 | 3681 | 1.08 | 1.64 | 2.17 | 0.12 | 0.32 | 0.59 |
| JETW_Asd09 | 0.14 | 0.29 | 0.56 | 273 | 535 | 1942 | 414 | 828 | 3538 | 1.06 | 1.65 | 2.21 | 0.12 | 0.32 | 0.60 |
| | r versus B_{init}/K (α, b_0) grids | | | | | | | | | | | | | | |
| JETW_R14A05 | 0.06 | 0.15 | 0.32 | 443 | 1016 | 3652 | 512 | 1216 | 5666 | 0.52 | 1.35 | 2.07 | 0.13 | 0.41 | 1.26 |
| JETW_R43A05 | 0.18 | 0.37 | 0.67 | 228 | 404 | 946 | 373 | 641 | 1511 | 1.14 | 1.64 | 2.08 | 0.22 | 0.32 | 0.53 |
| JETW_R14A10 | 0.07 | 0.14 | 0.30 | 482 | 1104 | 4423 | 554 | 1634 | 8921 | 0.78 | 1.57 | 2.35 | 0.08 | 0.34 | 1.08 |
| JETW_R43A10 | 0.17 | 0.33 | 0.61 | 248 | 453 | 1604 | 394 | 719 | 3053 | 1.18 | 1.66 | 2.17 | 0.12 | 0.32 | 0.53 |
| | r versus B_{msy}/K (shape parameter n) grids | | | | | | | | | | | | | | |
| JETW_R14Sh03 | 0.07 | 0.16 | 0.35 | 420 | 952 | 3556 | 585 | 1756 | 9816 | 0.91 | 2.00 | 3.53 | 0.05 | 0.28 | 0.99 |
| JETW_R43Sh03 | 0.20 | 0.40 | 0.72 | 223 | 421 | 1837 | 442 | 913 | 5658 | 1.43 | 2.33 | 3.39 | 0.04 | 0.21 | 0.46 |
| JETW_R14Sh06 | 0.05 | 0.13 | 0.27 | 395 | 823 | 3316 | 468 | 1017 | 4663 | 0.67 | 1.34 | 1.74 | 0.16 | 0.40 | 0.97 |
| JETW_R43Sh06 | 0.15 | 0.31 | 0.58 | 199 | 356 | 730 | 281 | 504 | 1048 | 1.15 | 1.44 | 1.69 | 0.28 | 0.36 | 0.50 |
| | Run using data up to 2012 | | | | | | | | | | | | | | |
| JETW_2012 | 0.16 | 0.34 | 0.59 | 249 | 454 | 1243 | 414 | 763 | 2170 | 1.24 | 1.71 | 2.19 | 0.17 | 0.29 | 0.46 |

Table 21. Comparison of Bayes factors for the sensitivity runs relative to each of the four reference cases (JEJL, JEHW, JESP, JETW). Bayes factors reflect the ratio of the probability of the blue shark stock assessment data based on a sensitivity run to the probability of the data obtained from the reference case. Bayes factor comparisons are only meaningful within the same column, i.e. comparisons to each reference case.

| Category description | Run ID ^{*1} | Run description | Bayes factor by run case | | | |
|--|----------------------|-----------------------------------|--------------------------|------|------|------|
| | | | JEJL | JEHW | JESP | JETW |
| B_{msy}/K (shape parameter n) | **_Ref | $B_{msy}/K = 0.47$ ($n = 1.71$) | 1.00 | 1.00 | 1.00 | 1.00 |
| | **_R34Sh03 | $B_{msy}/K = 0.30$ ($n = 0.68$) | 0.92 | 1.80 | 1.75 | 1.69 |
| | **_R34Sh06 | $B_{msy}/K = 0.60$ ($n = 3.39$) | 0.63 | 0.42 | 0.44 | 0.40 |
| r prior mean | **_Ref | mean = 0.34 | 1.00 | 1.00 | 1.00 | 1.00 |
| | **_R14A08 | mean = 0.14 | 0.38 | 1.72 | 1.17 | 1.09 |
| | **_R43A08 | mean = 0.43 | 1.08 | 0.88 | 0.88 | 0.88 |
| r prior SD | **_Ref | SD = 0.5 | 1.00 | 1.00 | 1.00 | 1.00 |
| | **_Rsd03 | SD = 0.3 | 1.07 | 0.92 | 1.00 | 1.06 |
| | **_Rsd07 | SD = 0.7 | 1.17 | 1.37 | 1.02 | 0.96 |
| B_{ini}/K ($\alpha.b0$) prior mean | **_Ref | mean = 0.8 | 1.00 | 1.00 | 1.00 | 1.00 |
| | **_R34A05 | mean = 0.5 | 1.10 | 0.66 | 0.59 | 0.72 |
| | **_R34A10 | mean = 1.0 | 0.93 | 1.16 | 1.18 | 1.11 |
| B_{ini}/K ($\alpha.b0$) prior SD | **_Ref | SD = 0.5 | 1.00 | 1.00 | 1.00 | 1.00 |
| | **_Asd07 | SD = 0.7 | 0.97 | 1.02 | 0.93 | 1.00 |
| | **_Asd09 | SD = 0.9 | 1.05 | 1.10 | 0.86 | 1.00 |

Footnote *1: "***" represents identifiers for a CPUE index or combinations of indices as described in Table 2, e.g. for the combination of JE and JL with a change in r prior mean to 0.14, the Run ID is JEJL_R14A08.

Table 22. Decision Table based on results of future projections for **JEJL_Ref** case.

| Run ID | HCR | Total C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | Total C_{2016} | B_{2016} $/B_{msy}$ | $P(B_{2016}$ $>B_{msy})$ | F_{2016} $/F_{msy}$ | Total C_{2021} | B_{2021} $/B_{msy}$ | $P(B_{2021}$ $>B_{msy})$ | F_{2021} $/F_{msy}$ | Total C_{2031} | B_{2031} $/B_{msy}$ | $P(B_{2031}$ $>B_{msy})$ | F_{2031} $/F_{msy}$ |
|----------|-----------------|---------------------|--------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| JEJL_Ref | Status quo | 40.51 | 1.65 | 0.32 | 46.69 | 1.64 | 0.99 | 0.37 | 46.69 | 1.64 | 0.98 | 0.37 | 46.69 | 1.65 | 0.98 | 0.37 |
| | +20% | 40.51 | 1.65 | 0.32 | 56.03 | 1.56 | 0.98 | 0.47 | 56.03 | 1.54 | 0.96 | 0.48 | 56.03 | 1.51 | 0.95 | 0.48 |
| | -20% | 40.51 | 1.65 | 0.32 | 37.35 | 1.72 | 1.00 | 0.28 | 37.35 | 1.74 | 0.99 | 0.28 | 37.35 | 1.77 | 1.00 | 0.28 |
| | $F_{2006-2010}$ | 40.51 | 1.65 | 0.32 | 50.43 | 1.64 | 0.98 | 0.37 | 49.29 | 1.60 | 0.98 | 0.37 | 49.57 | 1.59 | 0.97 | 0.37 |
| | +20% | 40.51 | 1.65 | 0.32 | 57.88 | 1.56 | 0.97 | 0.37 | 56.01 | 1.51 | 0.93 | 0.37 | 55.07 | 1.50 | 0.94 | 0.37 |
| | -20% | 40.51 | 1.65 | 0.32 | 42.27 | 1.71 | 0.98 | 0.37 | 41.72 | 1.69 | 0.99 | 0.37 | 42.01 | 1.67 | 0.98 | 0.37 |
| | F_{msy} | 40.51 | 1.65 | 0.32 | 88.47 | 1.13 | 0.76 | 1.03 | 79.25 | 1.03 | 0.59 | 1.01 | 76.08 | 0.98 | 0.45 | 1.00 |

Table 23. Decision Table based on results of future projections for **JEHW_Ref** case.

| Run ID | HCR | Total C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | Total C_{2016} | B_{2016} $/B_{msy}$ | $P(B_{2016}$ $>B_{msy})$ | F_{2016} $/F_{msy}$ | Total C_{2021} | B_{2021} $/B_{msy}$ | $P(B_{2021}$ $>B_{msy})$ | F_{2021} $/F_{msy}$ | Total C_{2031} | B_{2031} $/B_{msy}$ | $P(B_{2031}$ $>B_{msy})$ | F_{2031} $/F_{msy}$ |
|----------|-----------------|---------------------|--------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| JEHW_Ref | Status quo | 40.51 | 1.51 | 0.35 | 46.69 | 1.57 | 0.91 | 0.39 | 46.69 | 1.60 | 0.90 | 0.38 | 46.69 | 1.61 | 0.90 | 0.37 |
| | +20% | 40.51 | 1.51 | 0.35 | 56.03 | 1.50 | 0.88 | 0.49 | 56.03 | 1.49 | 0.86 | 0.48 | 56.03 | 1.48 | 0.83 | 0.47 |
| | -20% | 40.51 | 1.51 | 0.35 | 37.35 | 1.64 | 0.92 | 0.30 | 37.35 | 1.69 | 0.93 | 0.28 | 37.35 | 1.72 | 0.94 | 0.28 |
| | $F_{2006-2010}$ | 40.51 | 1.51 | 0.35 | 50.26 | 1.54 | 0.90 | 0.39 | 50.14 | 1.53 | 0.89 | 0.38 | 50.36 | 1.52 | 0.88 | 0.37 |
| | +20% | 40.51 | 1.51 | 0.35 | 57.92 | 1.47 | 0.89 | 0.39 | 56.82 | 1.44 | 0.85 | 0.38 | 56.29 | 1.42 | 0.82 | 0.37 |
| | -20% | 40.51 | 1.51 | 0.35 | 41.81 | 1.61 | 0.92 | 0.39 | 42.51 | 1.62 | 0.92 | 0.38 | 43.74 | 1.62 | 0.92 | 0.37 |
| | F_{msy} | 40.51 | 1.51 | 0.35 | 88.58 | 1.13 | 0.72 | 1.03 | 80.27 | 1.03 | 0.56 | 1.01 | 75.80 | 0.98 | 0.47 | 1.00 |

Table 24. Decision Table based on results of future projections for **JESP_Ref** case.

| Run ID | HCR | Total C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | Total C_{2016} | B_{2016} $/B_{msy}$ | $P(B_{2016}$ $>B_{msy})$ | F_{2016} $/F_{msy}$ | Total C_{2021} | B_{2021} $/B_{msy}$ | $P(B_{2021}$ $>B_{msy})$ | F_{2021} $/F_{msy}$ | Total C_{2031} | B_{2031} $/B_{msy}$ | $P(B_{2031}$ $>B_{msy})$ | F_{2031} $/F_{msy}$ |
|----------|-----------------|---------------------|--------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| JESP_Ref | Status quo | 40.51 | 1.52 | 0.34 | 46.69 | 1.59 | 0.92 | 0.38 | 46.69 | 1.61 | 0.93 | 0.37 | 46.69 | 1.64 | 0.93 | 0.36 |
| | +20% | 40.51 | 1.52 | 0.34 | 56.03 | 1.52 | 0.90 | 0.47 | 56.03 | 1.51 | 0.88 | 0.47 | 56.03 | 1.51 | 0.87 | 0.46 |
| | -20% | 40.51 | 1.52 | 0.34 | 37.35 | 1.66 | 0.94 | 0.29 | 37.35 | 1.71 | 0.96 | 0.28 | 37.35 | 1.74 | 0.96 | 0.27 |
| | $F_{2006-2010}$ | 40.51 | 1.52 | 0.34 | 52.71 | 1.55 | 0.92 | 0.38 | 52.90 | 1.53 | 0.92 | 0.37 | 53.05 | 1.53 | 0.90 | 0.36 |
| | +20% | 40.51 | 1.52 | 0.34 | 60.76 | 1.48 | 0.90 | 0.38 | 59.62 | 1.44 | 0.88 | 0.37 | 59.02 | 1.43 | 0.84 | 0.36 |
| | -20% | 40.51 | 1.52 | 0.34 | 43.86 | 1.62 | 0.94 | 0.38 | 44.88 | 1.62 | 0.94 | 0.37 | 45.72 | 1.63 | 0.94 | 0.36 |
| | F_{msy} | 40.51 | 1.52 | 0.34 | 90.88 | 1.14 | 0.74 | 1.03 | 81.98 | 1.04 | 0.58 | 1.01 | 77.92 | 0.99 | 0.48 | 1.00 |

Table 25. Decision Table based on results of future projections for **JETW_Ref** case.

| Run ID | HCR | Total C_{2011} | B_{2011} $/B_{msy}$ | F_{2011} $/F_{msy}$ | Total C_{2016} | B_{2016} $/B_{msy}$ | $P(B_{2016}$ $>B_{msy})$ | F_{2016} $/F_{msy}$ | Total C_{2021} | B_{2021} $/B_{msy}$ | $P(B_{2021}$ $>B_{msy})$ | F_{2021} $/F_{msy}$ | Total C_{2031} | B_{2031} $/B_{msy}$ | $P(B_{2031}$ $>B_{msy})$ | F_{2031} $/F_{msy}$ |
|----------|-----------------|---------------------|--------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|---------------------|--------------------------|-----------------------------|--------------------------|
| JETW_Ref | Status quo | 40.51 | 1.63 | 0.33 | 46.69 | 1.64 | 0.95 | 0.37 | 46.69 | 1.64 | 0.95 | 0.37 | 46.69 | 1.64 | 0.95 | 0.37 |
| | +20% | 40.51 | 1.63 | 0.33 | 56.03 | 1.56 | 0.93 | 0.47 | 56.03 | 1.54 | 0.92 | 0.48 | 56.03 | 1.51 | 0.89 | 0.48 |
| | -20% | 40.51 | 1.63 | 0.33 | 37.35 | 1.70 | 0.97 | 0.29 | 37.35 | 1.74 | 0.97 | 0.28 | 37.35 | 1.74 | 0.98 | 0.28 |
| | $F_{2006-2010}$ | 40.51 | 1.63 | 0.33 | 59.52 | 1.53 | 0.94 | 0.37 | 58.08 | 1.49 | 0.92 | 0.37 | 56.82 | 1.46 | 0.88 | 0.37 |
| | +20% | 40.51 | 1.63 | 0.33 | 68.12 | 1.45 | 0.91 | 0.37 | 64.71 | 1.38 | 0.86 | 0.37 | 62.27 | 1.35 | 0.81 | 0.37 |
| | -20% | 40.51 | 1.63 | 0.33 | 49.98 | 1.61 | 0.96 | 0.37 | 50.02 | 1.60 | 0.95 | 0.37 | 49.48 | 1.58 | 0.94 | 0.37 |
| | F_{msy} | 40.51 | 1.63 | 0.33 | 90.95 | 1.17 | 0.78 | 1.04 | 81.48 | 1.06 | 0.61 | 1.01 | 76.34 | 0.99 | 0.49 | 1.00 |

Table 26. 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 | CPUE2 | CPUE4 | CPUE5 | CPUE6 | Beta=1& SFrac=0.1 | Beta=2& SFrac=0.1 | Beta=3& SFrac=0.1 | Beta=1& SFrac=0.3 |
|-------------|-----------|----------|----------|----------|----------|----------------------|----------------------|----------------------|----------------------|
| Catch | 6.95E-07 | 9.38E-08 | 8.52E-09 | 9.13E-09 | 4.31E-06 | 1.22E-06 | 5.36E-07 | 2.80E-07 | 4.17E-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 | 0.8 | 1.8 | 0.0 | 0.0 | 0.0 | 2.6 | 1.9 | 1.7 | 1.3 |
| Fleet_24 | 0.8 | 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 | 49.8 | 49.8 | 49.8 | 49.8 | 50.2 | 51.0 | 50.7 | 50.6 | 50.2 |
| Recruitment | -0.905 | -2.287 | -2.171 | -2.369 | -2.627 | -2.359 | -2.488 | -2.524 | -2.538 |
| Parm_priors | 0.007 | 0.009 | 0.012 | 0.012 | 0.006 | 0.013 | 0.013 | 0.012 | 0.011 |
| TOTAL | 8.406 | 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 | Mat Age=Low | Sample Size=1 | SigmaR =0.1 | Initial Catch=20K | Initial Catch=60K |
|-------------|----------------------|----------------------|----------------------|----------------------|----------------|------------------|----------------|----------------------|----------------------|
| Catch | 2.98E-07 | 9.02E-07 | 2.95E-06 | 3.74E-06 | 5.59E-07 | 2.20E-07 | 4.60E-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 | 1.3 | 1.9 | 1.4 |
| Fleet_24 | 0.9 | 1.1 | 0.8 | 3.1 | 1.0 | 1.0 | 1.2 | 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 | 49.9 | 50.7 | 49.9 |
| Recruitment | -2.541 | -2.541 | -2.623 | -1.283 | -2.546 | -2.393 | -2.527 | -1.992 | -2.522 |
| Parm_priors | 0.006 | 0.007 | 0.003 | 0.002 | 0.004 | 0.008 | 0.008 | 0.005 | 0.008 |
| TOTAL | 7.403 | 7.308 | 6.204 | 10.563 | 7.734 | 82.480 | 7.776 | 11.270 | 7.940 |

Table 27. Estimates of key management quantities for the reference case model and all one-change sensitivity analyses. Latest is the value in 2011, and current is the mean for the period 2006-2010. 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 | CPUE2 | CPUE4 | CPUE5 | CPUE6 | Beta=1 & SFrac=0.1 | Beta=2 & SFrac=0.1 | Beta=3 & SFrac=0.1 | Beta=1 & SFrac=0.3 |
|------------------|-------|-----------|-----------|------------|------------|-----------|-----------------------|-----------------------|-----------------------|-----------------------|
| C_latest | T | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 |
| C2011_msy | | 0.54 | 0.49 | 0.38 | 0.38 | 0.58 | 1.56 | 0.90 | 0.75 | 0.56 |
| Y_MSY | T | 72,123 | 79,988 | 102,516 | 102,089 | 67,534 | 24,980 | 43,584 | 52,455 | 69,967 |
| equil_pt | | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.49 | 0.51 | 0.52 | 0.46 |
| Recr_Virgin | T | 27,083 | 30,317 | 39,042 | 38,945 | 25,202 | 40,432 | 39,618 | 39,235 | 33,937 |
| B_zero | T | 7,581,720 | 8,487,030 | 10,929,400 | 10,902,300 | 7,055,200 | 11,318,500 | 11,090,900 | 10,983,500 | 9,500,410 |
| B_msy | T | 3,544,543 | 3,967,246 | 5,107,712 | 5,095,089 | 3,298,727 | 5,516,902 | 5,618,642 | 5,747,465 | 4,346,146 |
| B_cur | T | 5,626,520 | 6,512,480 | 8,848,908 | 8,892,304 | 5,145,788 | 7,056,418 | 7,525,998 | 7,806,270 | 6,887,692 |
| SB_zero | T | 593,707 | 664,600 | 855,860 | 853,739 | 552,477 | 886,330 | 868,501 | 860,095 | 743,956 |
| SB_msy | T | 277,565 | 310,666 | 399,975 | 398,987 | 258,316 | 432,018 | 439,982 | 450,072 | 340,337 |
| SB_cur | T | 435,351 | 553,269 | 771,274 | 783,318 | 369,998 | 327,055 | 382,677 | 426,512 | 417,102 |
| B_cur_F0 | T | 7,587,607 | 8,739,345 | 10,982,210 | 11,202,490 | 7,115,419 | 12,564,770 | 11,839,430 | 11,506,730 | 9,697,885 |
| SB_cur_F0 | T | 594,168 | 684,358 | 859,996 | 877,246 | 557,193 | 983,923 | 927,117 | 901,068 | 759,420 |
| B_cur/B_zero | | 0.74 | 0.77 | 0.81 | 0.82 | 0.73 | 0.62 | 0.68 | 0.71 | 0.72 |
| B_cur/B_msy | | 1.59 | 1.64 | 1.73 | 1.75 | 1.56 | 1.28 | 1.34 | 1.36 | 1.58 |
| B_cur/B_cur_F0 | | 0.74 | 0.75 | 0.81 | 0.79 | 0.72 | 0.56 | 0.64 | 0.68 | 0.71 |
| Bratio_1971 | | 0.72 | 0.76 | 0.81 | 0.81 | 0.70 | 0.81 | 0.81 | 0.81 | 0.78 |
| Bratio_2011 | | 0.76 | 0.82 | 0.87 | 0.89 | 0.72 | 0.36 | 0.43 | 0.49 | 0.57 |
| Bratio_cur | | 0.73 | 0.83 | 0.90 | 0.92 | 0.67 | 0.37 | 0.44 | 0.50 | 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 | | 0.73 | 0.83 | 0.90 | 0.92 | 0.67 | 0.37 | 0.44 | 0.50 | 0.56 |
| SB_cur/SB_msy | | 1.57 | 1.78 | 1.93 | 1.96 | 1.43 | 0.76 | 0.87 | 0.95 | 1.23 |
| SB_cur/SB_cur_F0 | | 0.73 | 0.81 | 0.90 | 0.89 | 0.66 | 0.33 | 0.41 | 0.47 | 0.55 |
| 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 | | 1.01 | 1.10 | 1.11 | 1.13 | 0.95 | 0.46 | 0.54 | 0.61 | 0.72 |
| Fcur | | 0.02 | 0.10 | 0.08 | 0.08 | 0.12 | 0.18 | 0.15 | 0.13 | 0.12 |
| F_msy | | 0.22 | 0.23 | 0.23 | 0.23 | 0.22 | 0.07 | 0.12 | 0.14 | 0.22 |
| F_2011_msy | | 0.08 | 0.32 | 0.25 | 0.25 | 0.37 | 1.94 | 0.89 | 0.65 | 0.38 |
| F_cur_msy | | 0.11 | 0.44 | 0.35 | 0.34 | 0.52 | 2.54 | 1.20 | 0.90 | 0.54 |

Table 27. Continued

| | Units | Beta=3 & SFrac=0.3 | Beta=1 & SFrac=0.5 | Beta=2 & SFrac=0.5 | Beta=3 & SFrac=0.5 | M at Age=Low | Sample Size=1 | Sigma R =0.3 | Initial Catch =20K | Initial Catch =60K |
|------------------|-------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------|------------------|--------------|-----------------------|-----------------------|
| C_latest | T | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 | 39,083 |
| C2011_msy | | 0.53 | 0.39 | 0.45 | 0.46 | 0.48 | 0.53 | 0.58 | 0.70 | 0.52 |
| Y_MSY | T | 73,305 | 100,013 | 86,719 | 85,006 | 81,845 | 74,303 | 67,352 | 56,029 | 74,956 |
| equil_pt | | 0.49 | 0.42 | 0.43 | 0.46 | 0.46 | 0.47 | 0.47 | 0.47 | 0.47 |
| Recr_Virgin | T | 24,530 | 25,431 | 17,045 | 14,765 | 20,010 | 27,888 | 25,381 | 20,578 | 28,164 |
| B_zero | T | 6,867,030 | 7,119,330 | 4,771,620 | 4,133,410 | 7,860,580 | 7,807,090 | 7,105,120 | 5,760,700 | 7,884,140 |
| B_msy | T | 3,382,371 | 3,005,244 | 2,050,677 | 1,919,312 | 3,620,931 | 3,650,697 | 3,321,101 | 2,695,911 | 3,685,793 |
| B_cur | T | 5,143,596 | 5,168,570 | 3,147,802 | 2,503,328 | 5,971,948 | 5,893,566 | 5,023,600 | 3,349,500 | 5,922,112 |
| SB_zero | T | 537,742 | 557,499 | 373,655 | 323,678 | 650,769 | 611,356 | 556,386 | 451,108 | 617,389 |
| SB_msy | T | 264,866 | 235,334 | 160,584 | 150,297 | 299,773 | 285,878 | 260,068 | 211,111 | 288,626 |
| SB_cur | T | 473,194 | 405,337 | 345,815 | 313,851 | 529,684 | 484,592 | 393,238 | 215,062 | 451,662 |
| B_cur_F0 | T | 6,854,743 | 7,118,697 | 4,758,520 | 4,266,406 | 7,864,639 | 7,965,468 | 7,163,564 | 5,687,103 | 7,887,739 |
| SB_cur_F0 | T | 536,780 | 557,449 | 372,629 | 334,093 | 651,105 | 623,758 | 560,963 | 445,345 | 617,671 |
| B_cur/B_zero | | 0.75 | 0.73 | 0.66 | 0.61 | 0.76 | 0.75 | 0.71 | 0.58 | 0.75 |
| B_cur/B_msy | | 1.52 | 1.72 | 1.54 | 1.30 | 1.65 | 1.61 | 1.51 | 1.24 | 1.61 |
| B_cur/B_cur_F0 | | 0.75 | 0.73 | 0.66 | 0.59 | 0.76 | 0.74 | 0.70 | 0.59 | 0.75 |
| Bratio_1971 | | 0.70 | 0.70 | 0.55 | 0.47 | 0.72 | 0.73 | 0.71 | 0.80 | 0.59 |
| Bratio_2012 | | 0.89 | 0.75 | 0.90 | 0.91 | 0.83 | 0.81 | 0.72 | 0.50 | 0.76 |
| Bratio_cur | | 0.88 | 0.73 | 0.93 | 0.97 | 0.81 | 0.79 | 0.71 | 0.48 | 0.73 |
| 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 | | 0.88 | 0.73 | 0.93 | 0.97 | 0.81 | 0.79 | 0.71 | 0.48 | 0.73 |
| SB_cur/SB_msy | | 1.79 | 1.72 | 2.15 | 2.09 | 1.77 | 1.70 | 1.51 | 1.02 | 1.56 |
| SB_cur/SB_cur_F0 | | 0.88 | 0.73 | 0.93 | 0.94 | 0.81 | 0.78 | 0.70 | 0.48 | 0.73 |
| 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 | | 1.27 | 1.03 | 1.70 | 2.04 | 1.13 | 1.08 | 1.00 | 0.60 | 1.23 |
| Fcur | | 0.11 | 0.12 | 0.16 | 0.19 | 0.10 | 0.10 | 0.13 | 0.20 | 0.11 |
| F_msy | | 0.22 | 0.39 | 0.31 | 0.27 | 0.24 | 0.22 | 0.22 | 0.22 | 0.22 |
| F_2011_msy | | 0.36 | 0.21 | 0.38 | 0.55 | 0.30 | 0.33 | 0.41 | 0.62 | 0.33 |
| F_cur_msy | | 0.50 | 0.30 | 0.50 | 0.69 | 0.42 | 0.46 | 0.57 | 0.90 | 0.47 |

Table 28. Decision Table based on results of future projections for SS reference case.

| Run ID | HCR | C_{2011} | B_{2011}/B_{MSY} | F_{2011}/F_{MSY} | C_{2016} | B_{2016}/B_{MSY} | F_{2016}/F_{MSY} | C_{2021} | B_{2021}/B_{MSY} | F_{2021}/F_{MSY} | C_{2031} | B_{2031}/B_{MSY} | F_{2031}/F_{MSY} |
|--------------------|-------------------|------------|--------------------|--------------------|------------|--------------------|--------------------|------------|--------------------|--------------------|------------|--------------------|--------------------|
| BSH_ref_projection | <i>Status quo</i> | 39083 | 1.62 | 0.35 | 46389 | 1.74 | 0.47 | 46389 | 1.80 | 0.47 | 46389 | 1.83 | 0.48 |
| | +20% | 39083 | 1.62 | 0.35 | 55667 | 1.72 | 0.57 | 55667 | 1.75 | 0.58 | 55667 | 1.76 | 0.59 |
| | -20% | 39083 | 1.62 | 0.35 | 37111 | 1.76 | 0.36 | 37111 | 1.85 | 0.37 | 37111 | 1.90 | 0.38 |
| | $F_{2006-2010}$ | 39083 | 1.62 | 0.35 | 49807 | 1.73 | 0.50 | 49305 | 1.78 | 0.50 | 48789 | 1.81 | 0.50 |
| | +20% | 39083 | 1.62 | 0.35 | 58437 | 1.71 | 0.59 | 57445 | 1.73 | 0.59 | 57118 | 1.75 | 0.59 |
| | -20% | 39083 | 1.62 | 0.35 | 40759 | 1.75 | 0.40 | 40620 | 1.83 | 0.40 | 39905 | 1.88 | 0.40 |
| | F_{MSY} | 39083 | 1.62 | 0.35 | 89826 | 1.64 | 1.00 | 85580 | 1.55 | 1.00 | 84781 | 1.48 | 1.00 |

FIGURES

Figure 1. Blue shark (*Prionace glauca*) stock boundaries and approximate spatial extent of the primary fisheries contributing catch for this assessment.

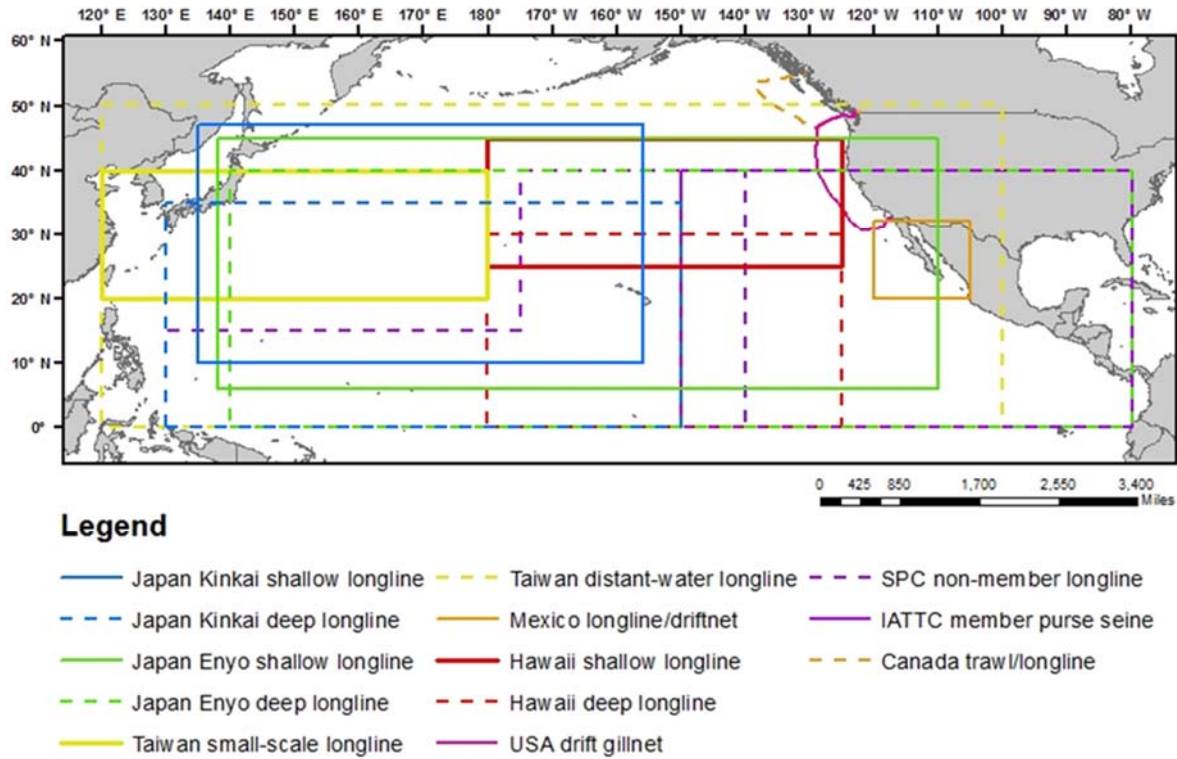


Figure 2. Total estimated catch of North Pacific blue shark (*Prionace glauca*) from 1971-2012 by nation or region.

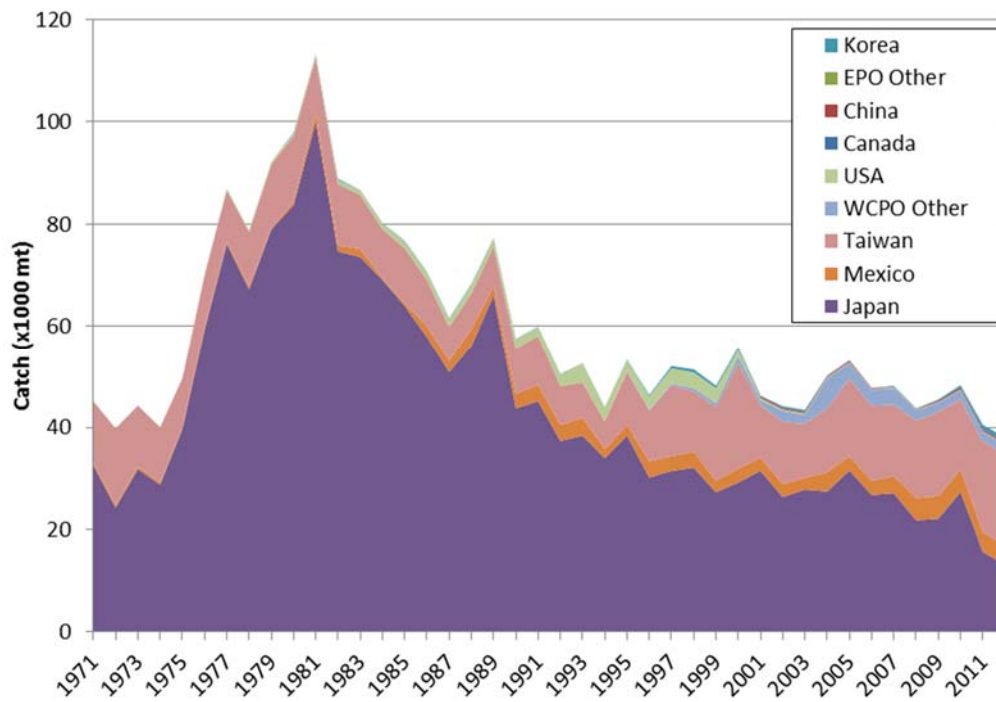


Figure 3. Total estimated catch of North Pacific blue shark (*Prionace glauca*) by gear types from 1971-2012. Mixed gear reflects some combined longline, gillnet, pole and line, trap, purse seine.

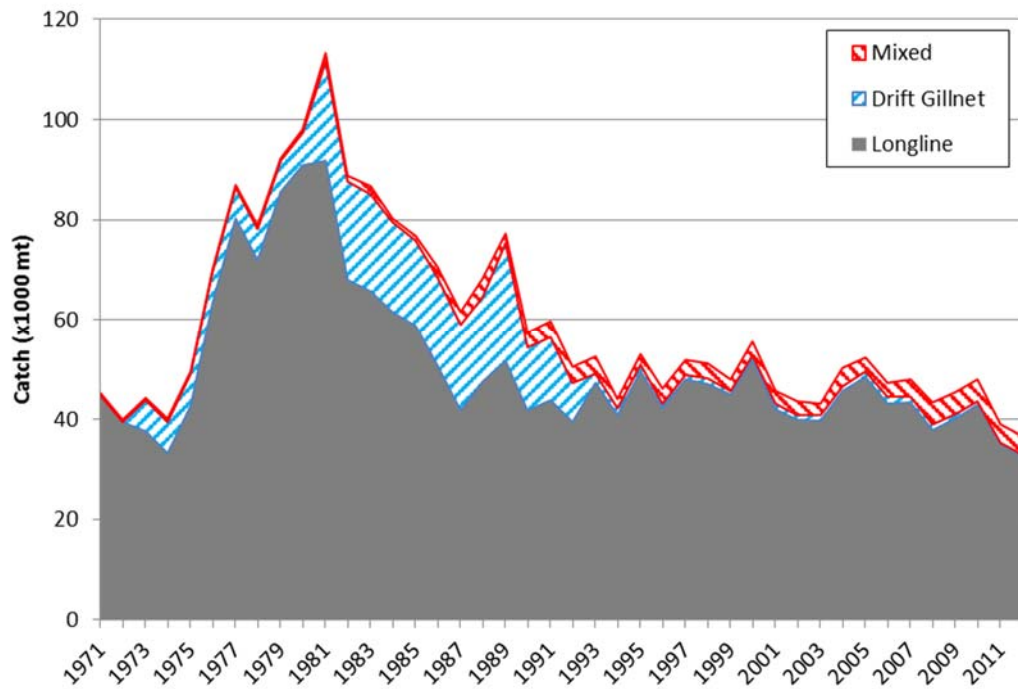


Figure 4: Assumed catch time series by fishery for the SS reference case model. For the BSP runs, catch of all fleets was summed into a single catch time series. Note: Catch in 1970 is an assumed level of catch used to derive the equilibrium fished condition and the selectivity of fishery 4 was assumed for these catches; this does not represent the actual assumed catches of this fleet.

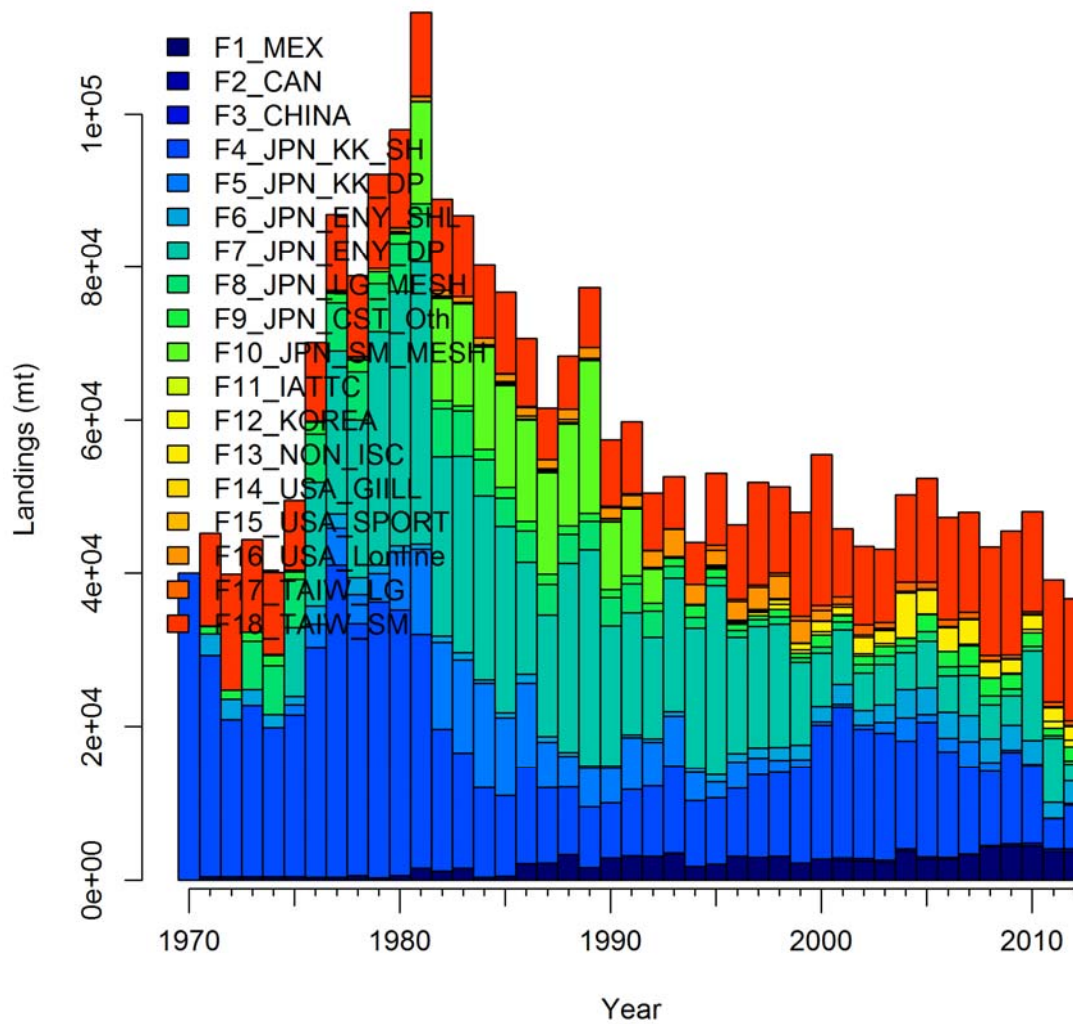


Figure 5. Standardized CPUE indices used in the North Pacific Ocean blue shark (*Prionace glauca*) stock assessment.

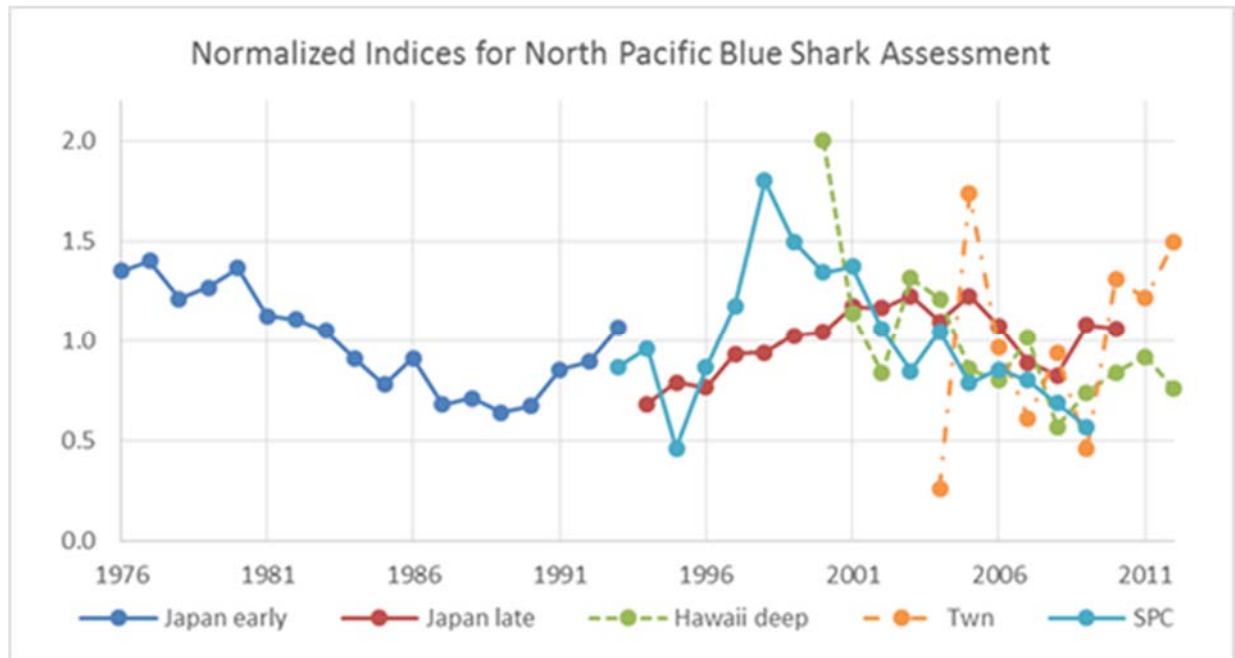


Figure 6. Spatial extent of fisheries used to derive abundance indices for the North Pacific blue shark (*Prionace glauca*) assessment.

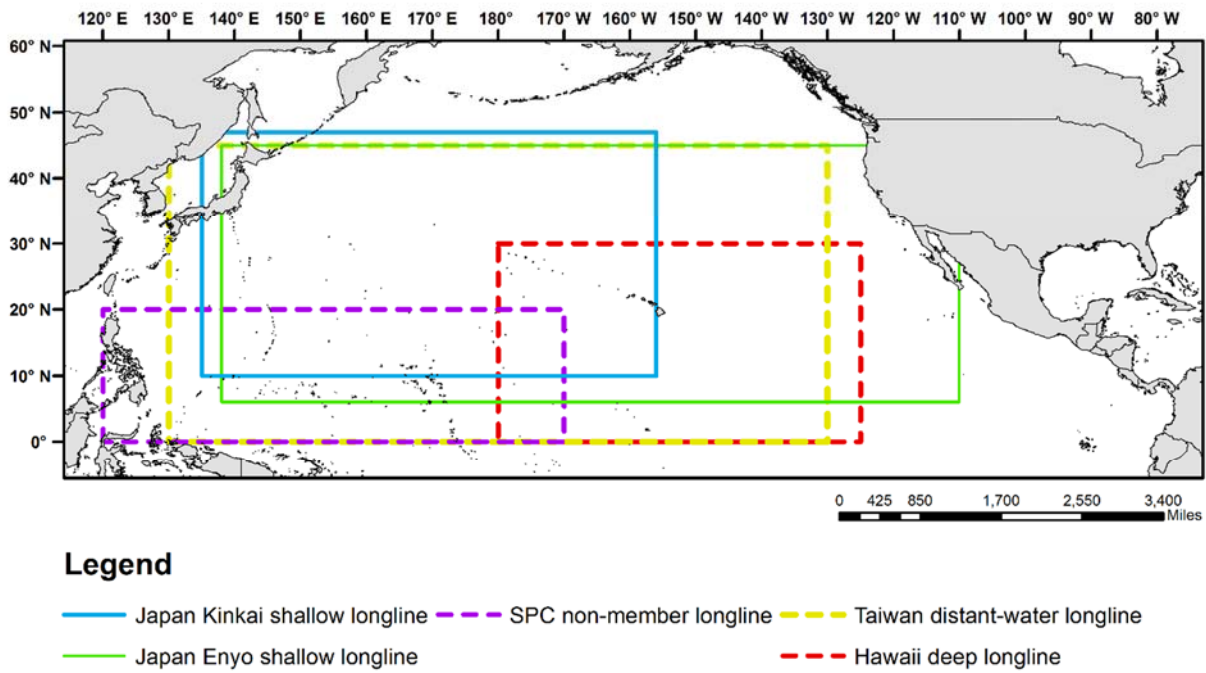


Figure 7. Coverage of catch, effort, and length composition data by year and fleet for the SS reference case. For the 2012 data, black triangles indicate data that were carried over from 2011 values; black circles are new estimates of 2012 data.

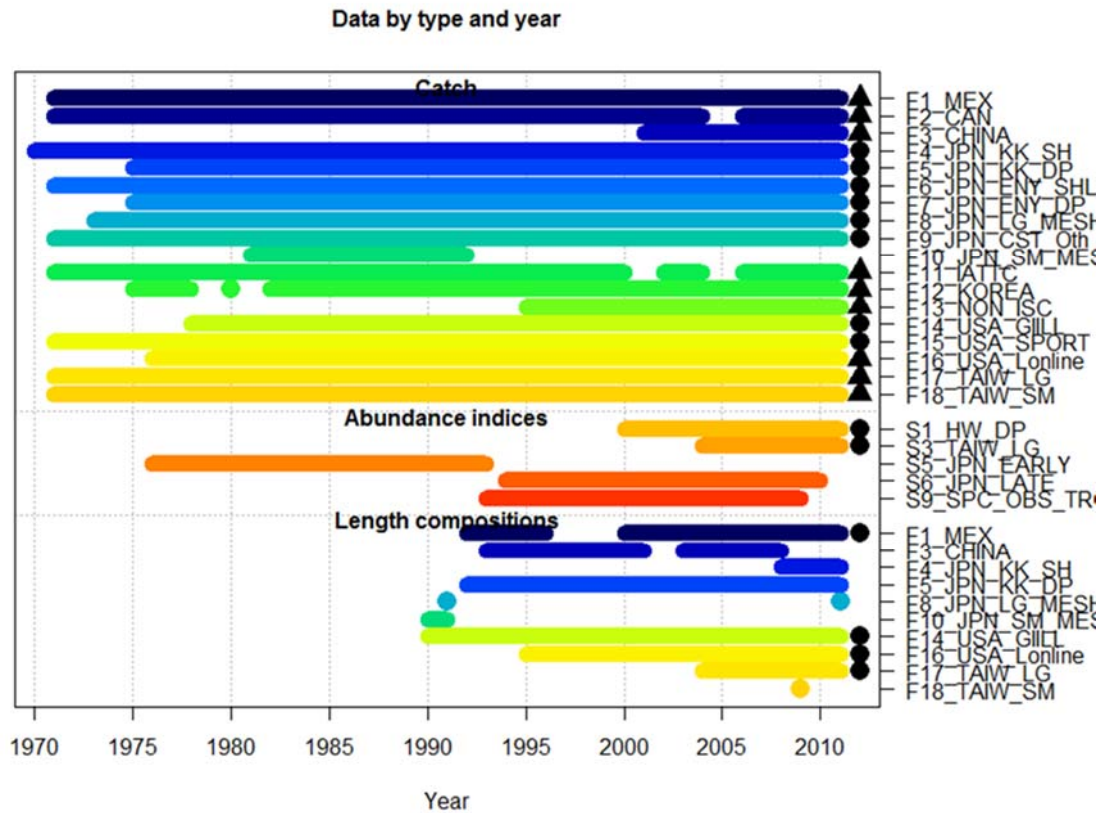


Figure 8. Sex-specific growth curves assumed in the SS analysis (from Nakano 1994).

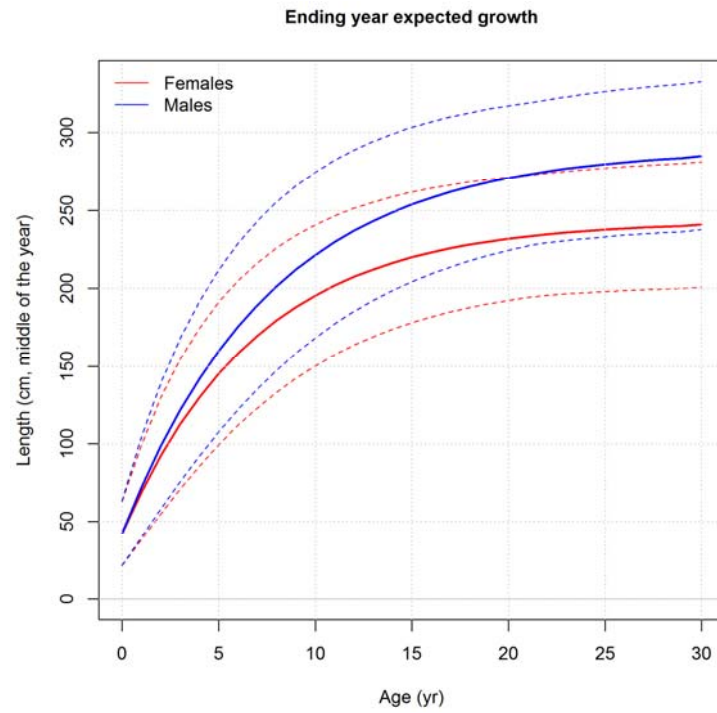


Figure 9. The sex-specific weight-at-length (from Nakano 1994) for female (red solid line) and male (blue solid line) blue sharks used in the SS analysis.

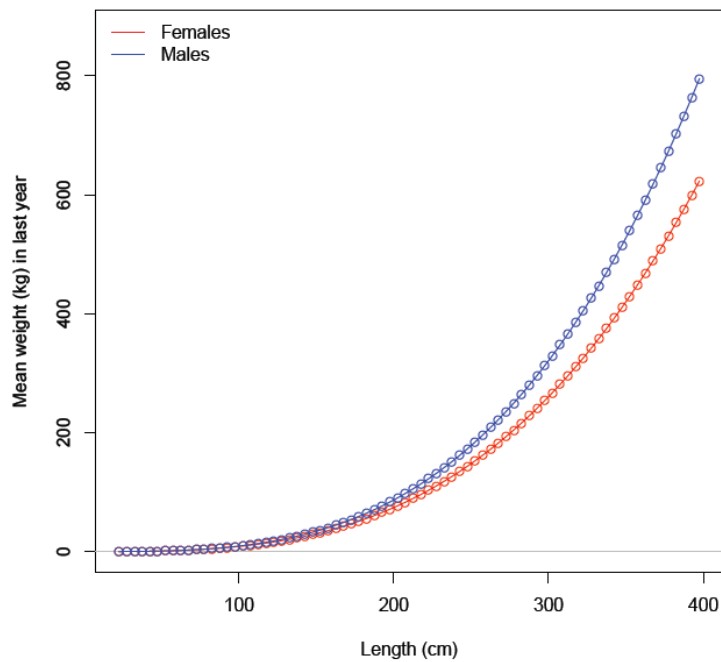


Figure 10. Assumed a logistic maturity schedule based on length with the age-at-50% maturity for females used in the stock assessment.

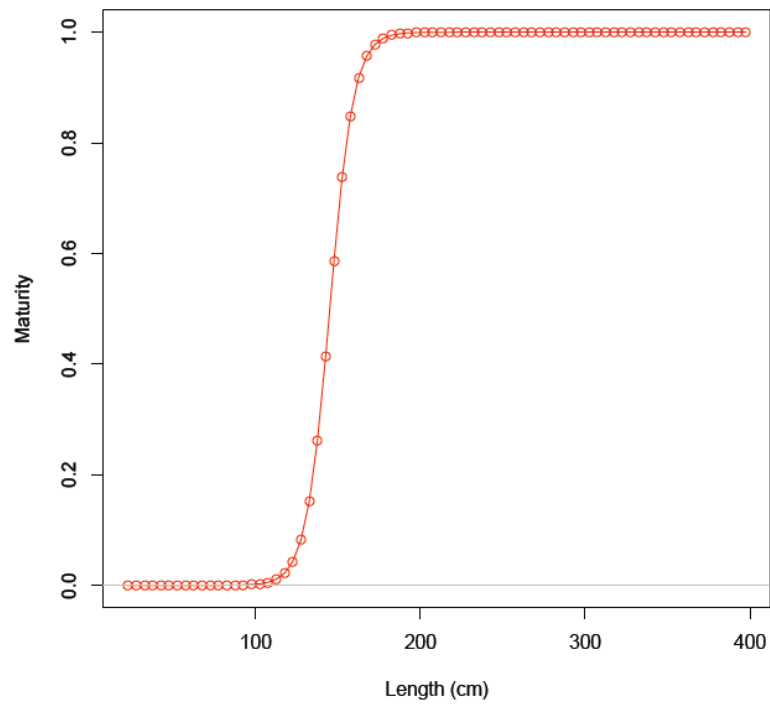


Figure 11. Spawner recruitment curves for the nine Low Fecundity Spawner Recruitment (LFSR) curves considered in the analysis. The reference case model used $S_{Frac} = 0.3$ and $Beta = 2$.

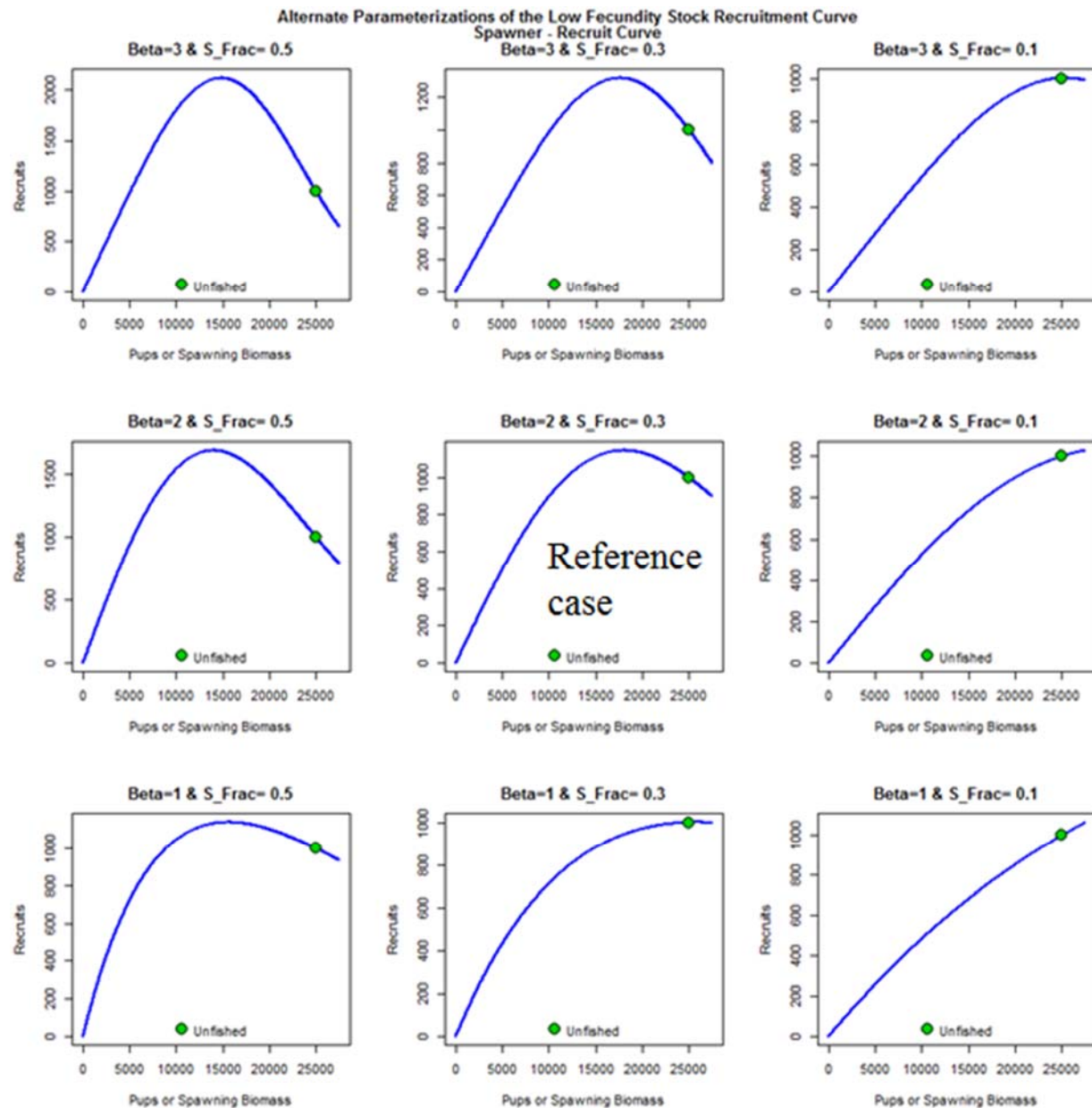


Figure 12. Pre-recruitment survival for the nine Low Fecundity Spawner Recruitment (LFSR) pre-recruit survival curves considered in the analysis. The reference case model used $S_{Frac} = 0.3$ and $Beta = 2$.

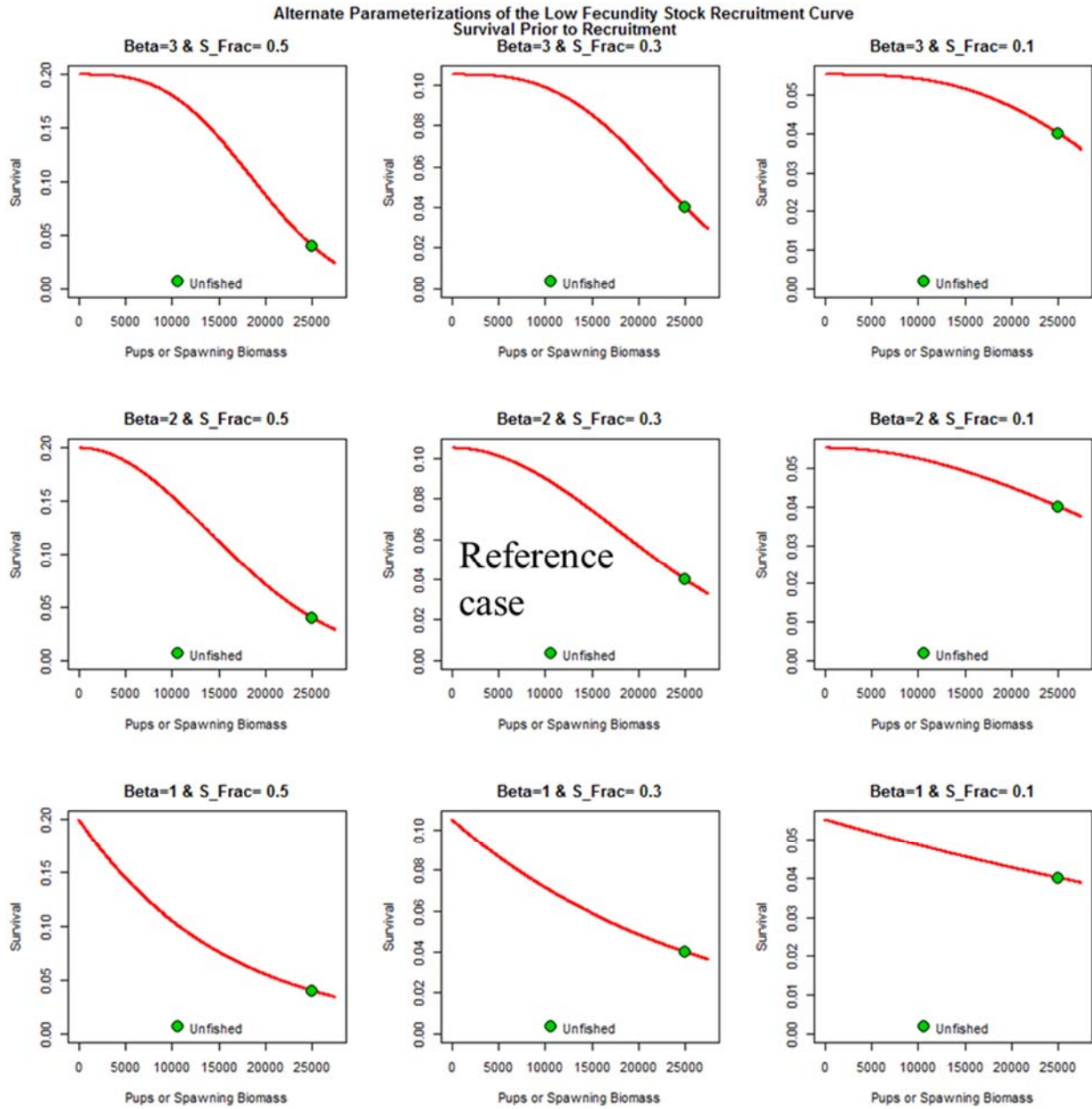


Figure 13. Comparison of marginal posterior distributions for the four reference cases (**JEJL_Ref**, **JEHW_Ref**, **JESP_Ref**, **JETW_Ref**). (a) Four panels showing carrying capacity (K), stock biomass at maximum sustainable yield (B_{MSY}), the maximum intrinsic rate of natural increase (r), and stock biomass in 2011. Note that the horizontal axis of the top left panel for K is log-scaled.

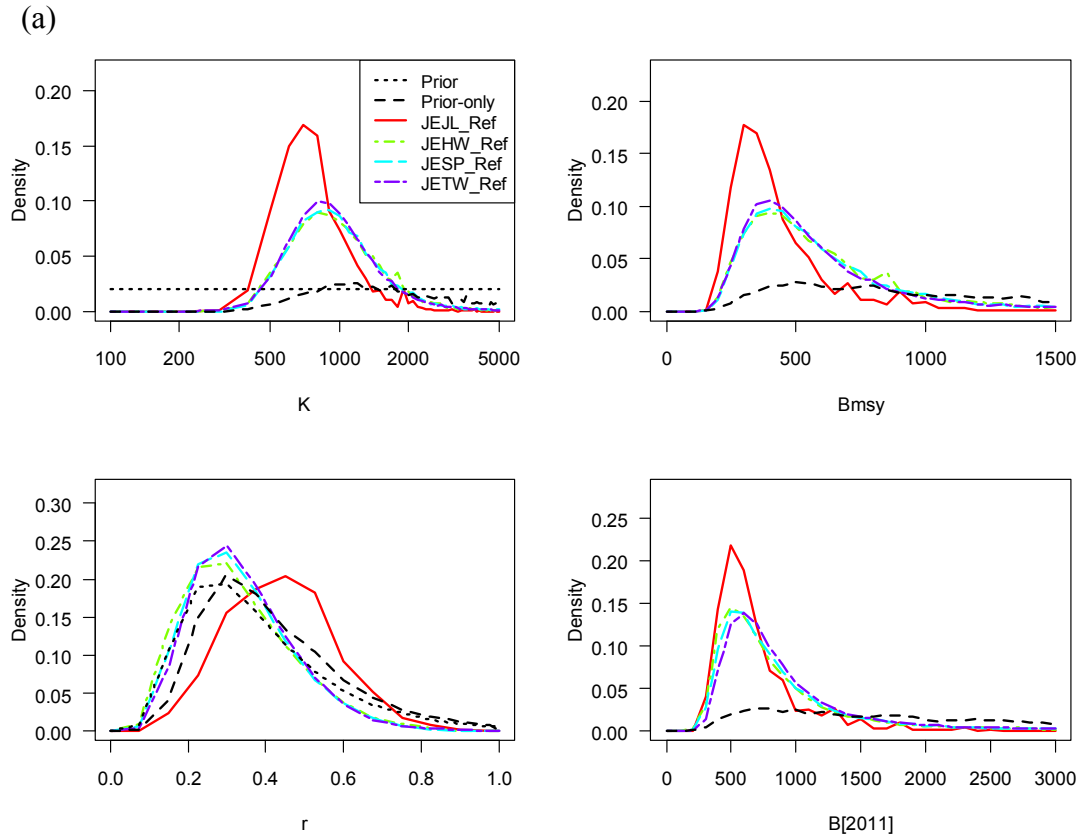


Figure 13 (continued). (b) Four panels showing MSY , stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{MSY}).

(b)

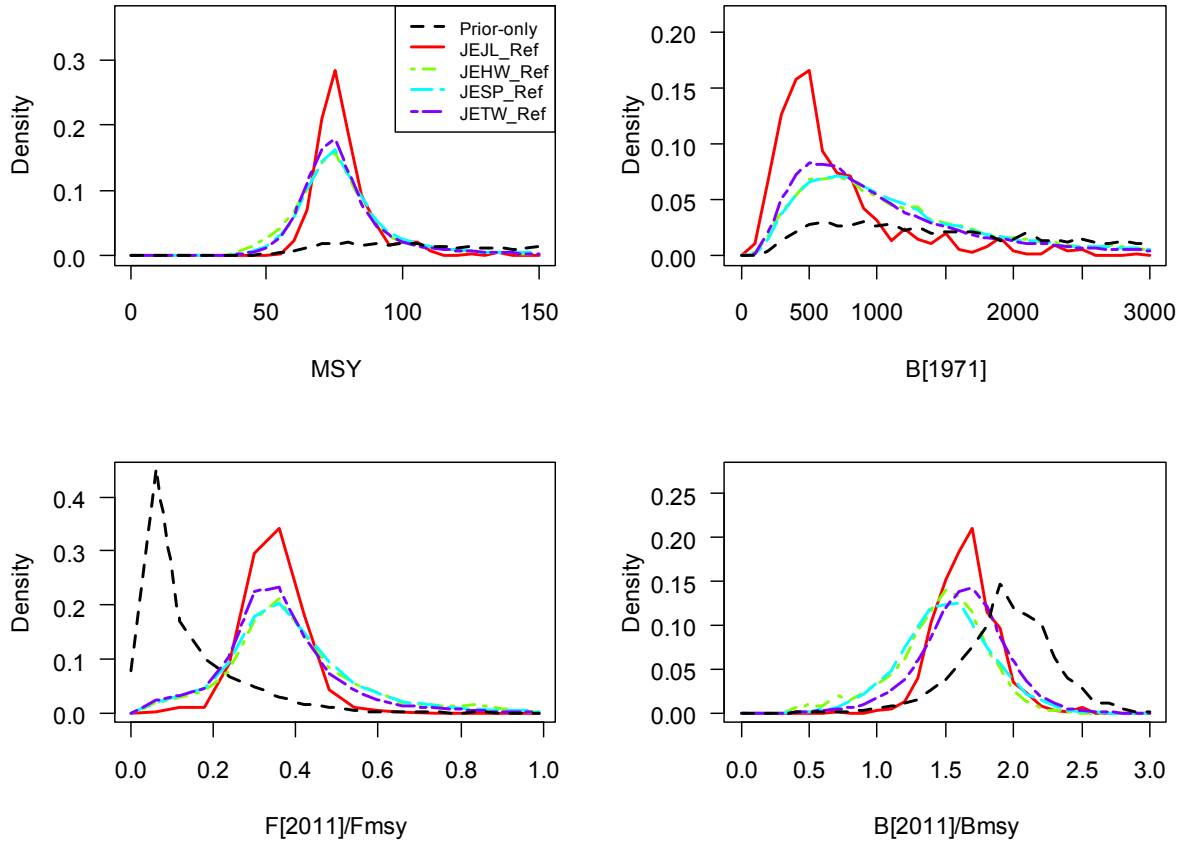


Figure 14. Comparison of marginal posterior distributions for the four reference cases (**JL_Ref**, **HW_Ref**, **SP_Ref**, **TW_Ref**). (a) Four panels showing the carrying capacity (K), stock biomass at maximum sustainable yield (B_{MSY}), the maximum intrinsic rate of natural increase (r) and stock biomass in 2011. Note that the horizontal axis of the top left panel for K is log-scaled.

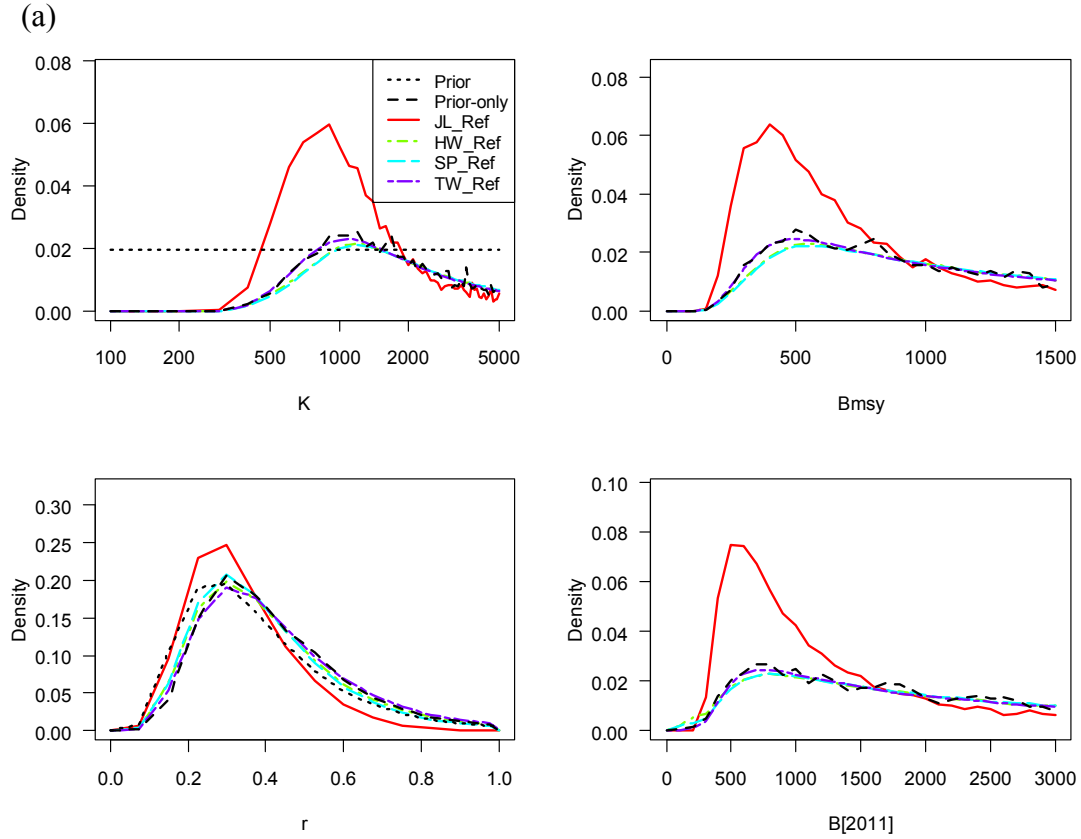


Figure 14 (continued). (b) Four panels showing MSY , stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{MSY}).

(b)

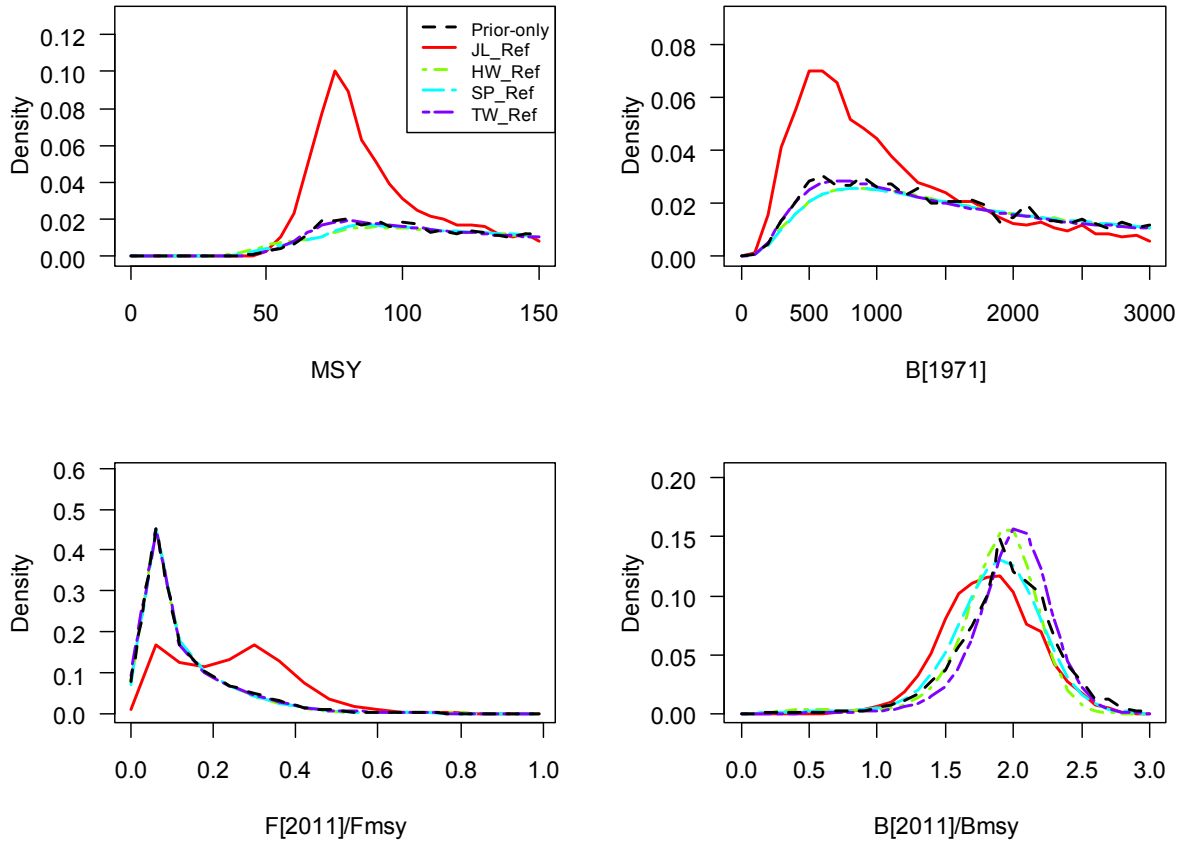


Figure 15. Comparison of marginal posterior distributions for four prior-only runs using different catch trajectories (**Ponly_obscat**, **Ponly_hlfc**, **Ponly_db**, **Ponly_rv**). (a) Four panels showing carrying capacity (K), stock biomass at maximum sustainable yield (B_{MSY}), the maximum intrinsic rate of natural increase (r), and stock biomass in 2011. Note that the horizontal axis of the top left panel for K is log-scaled.

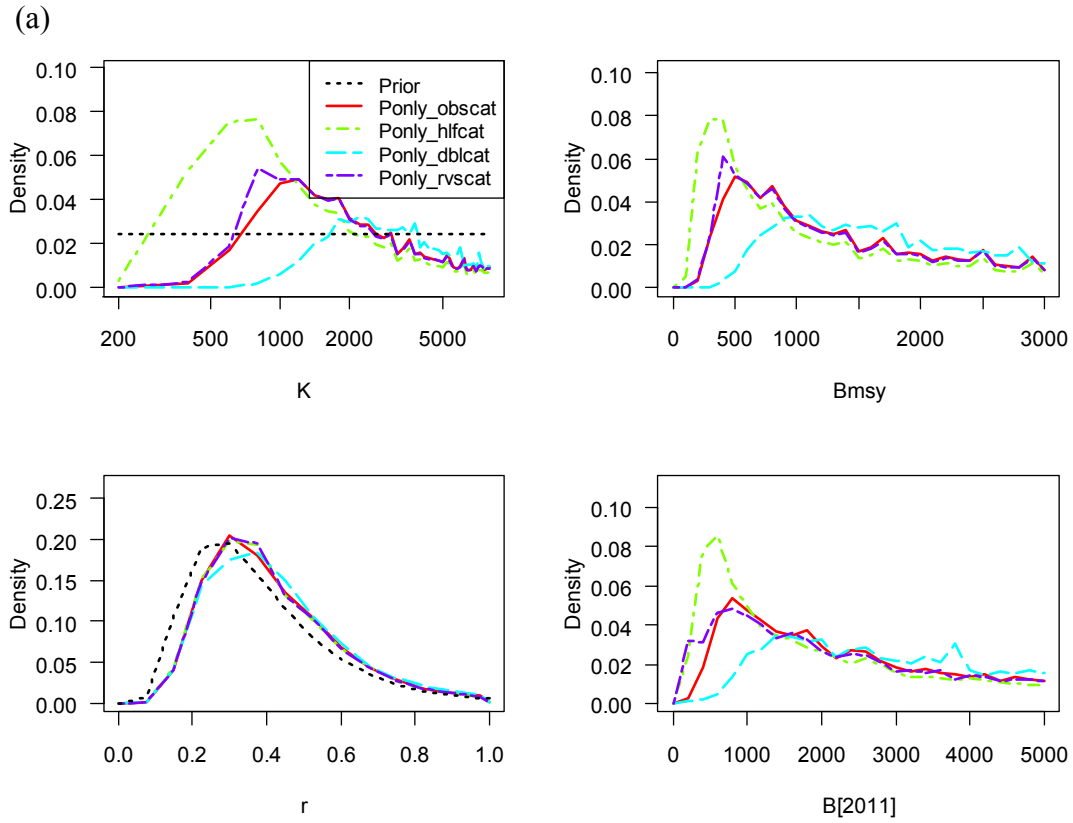


Figure 15 (continued). (b) Four panels showing MSY , stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{MSY}).

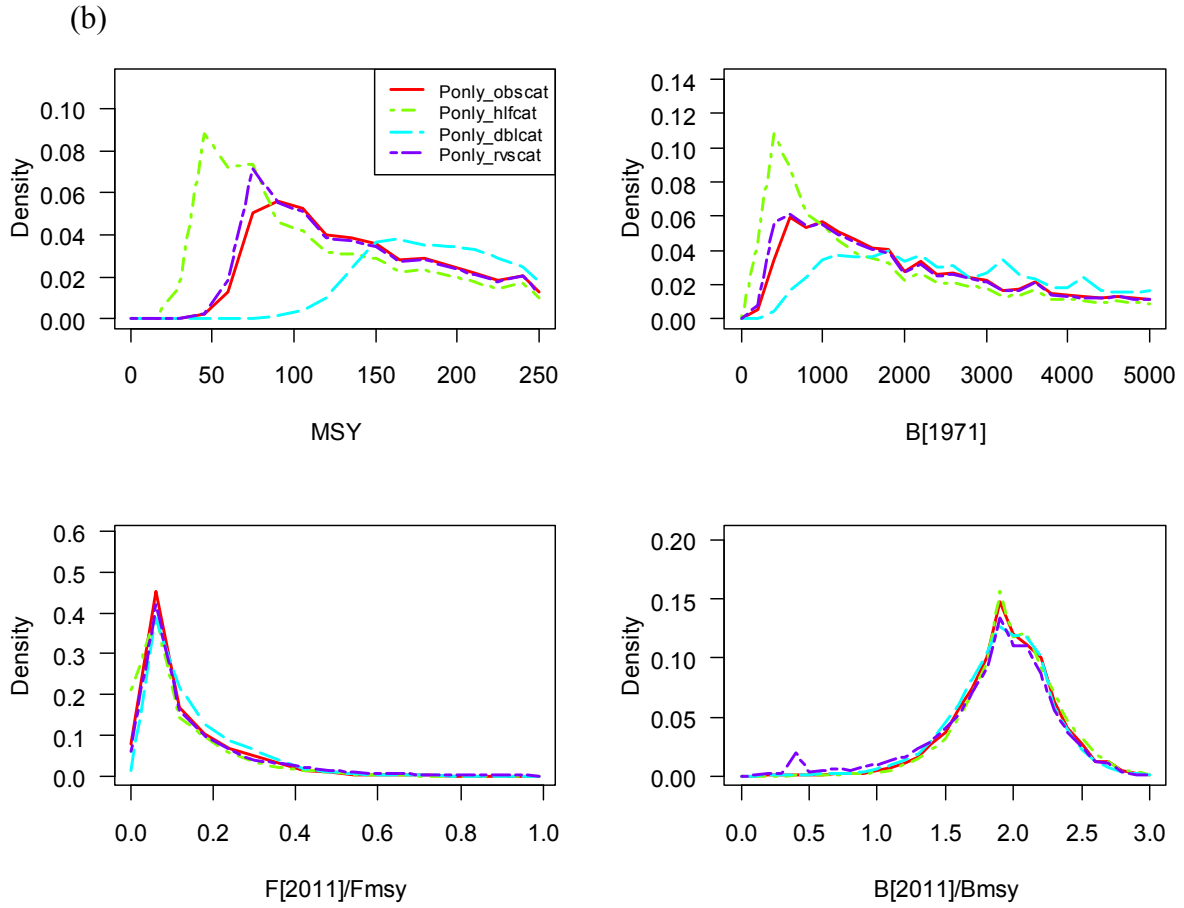


Figure 15 (continued). (c) Marginal posterior distribution of B_{2011}/K (median=0.43) for the prior only run, **Ponly_pessim**. In the Ponly_pessim case, B_{MSY} is approximately equal to $0.5K$ and thus the median B_{2011}/B_{MSY} is about 1.0. These results show approximately 50% probability that the estimated stock biomass is below B_{MSY} .

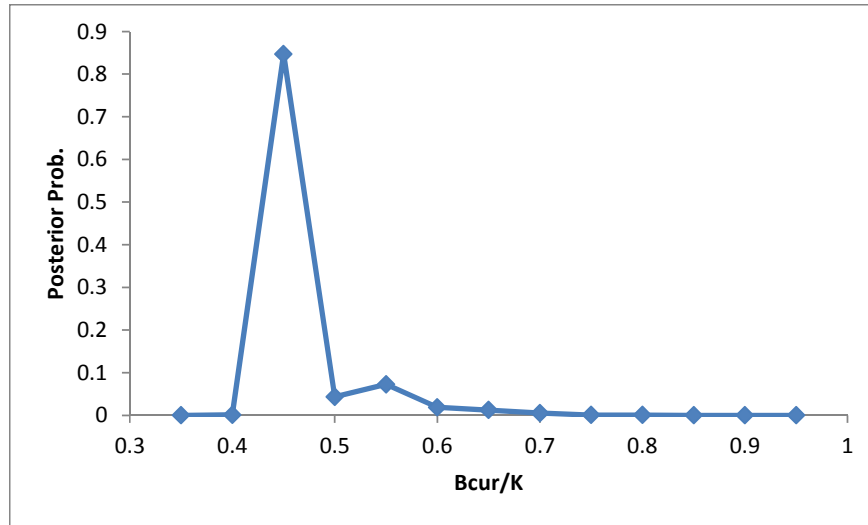
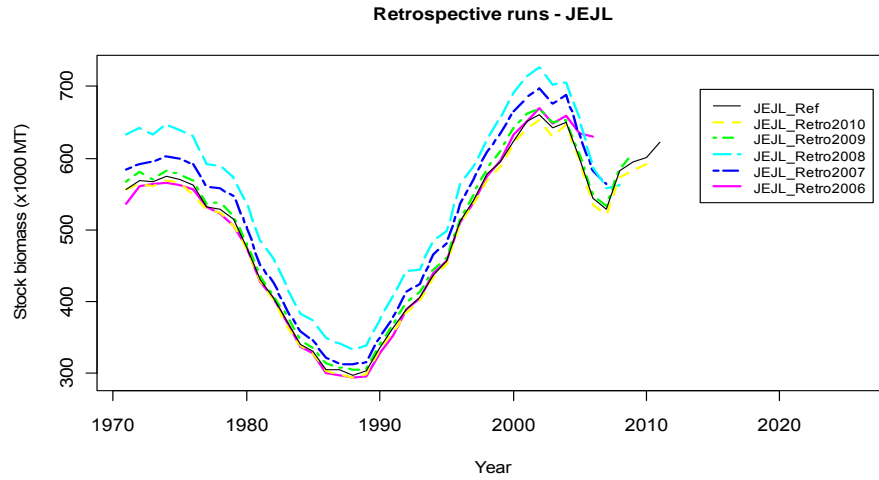


Figure 16. Retrospective analysis showing the historical stock dynamics resulting from termination of the model in each of the five years prior to the terminal year for the four reference runs. (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

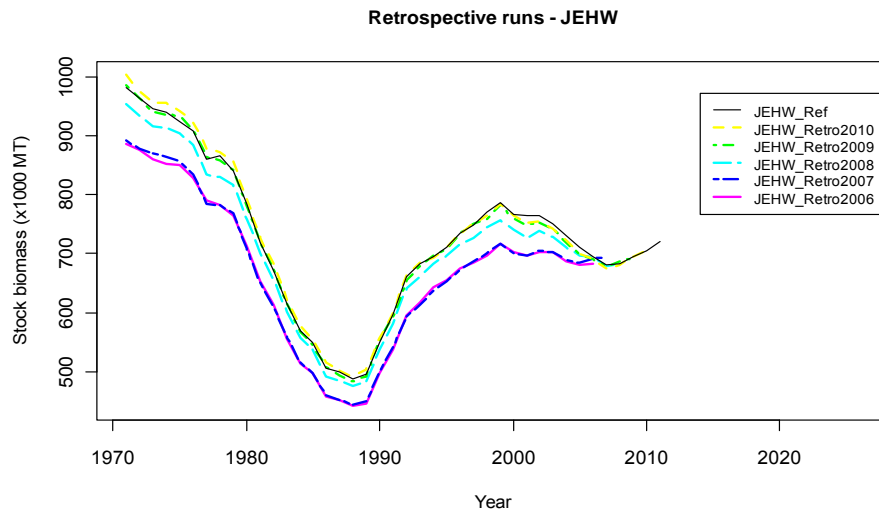
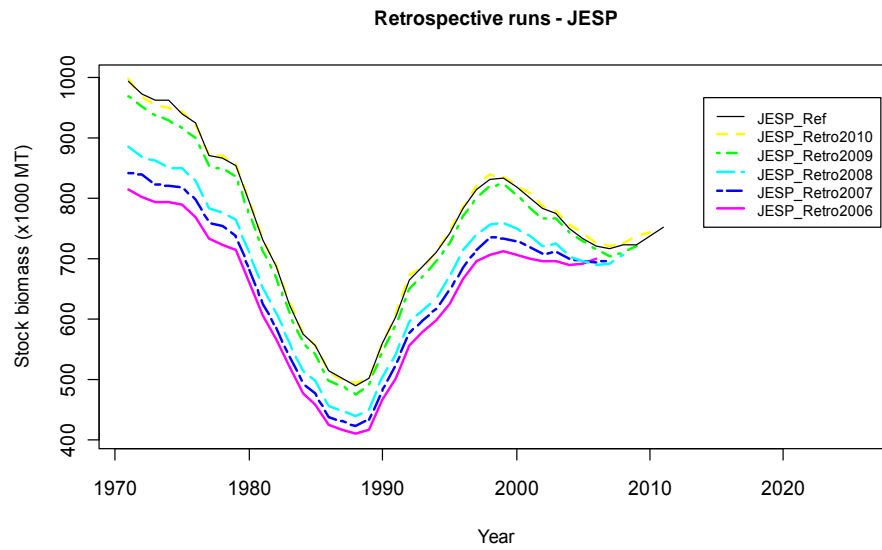


Figure 16 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

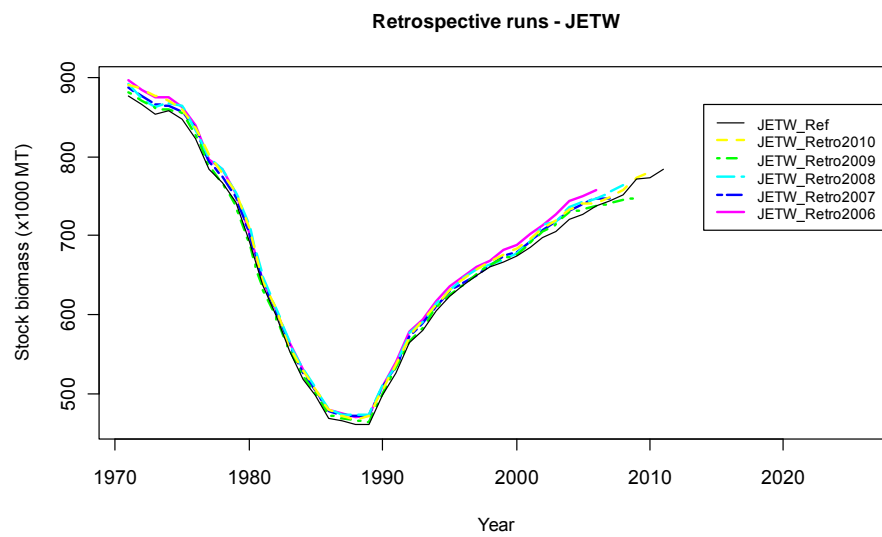
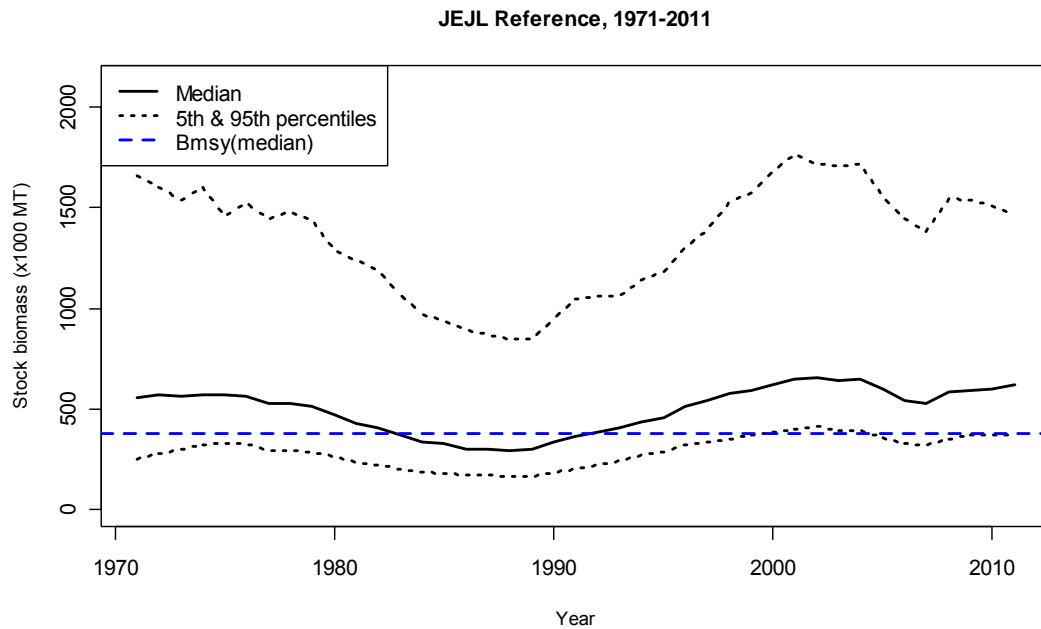


Figure 17. Median estimates and 90% confidence limits for the historical stock biomass of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{MSY}). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

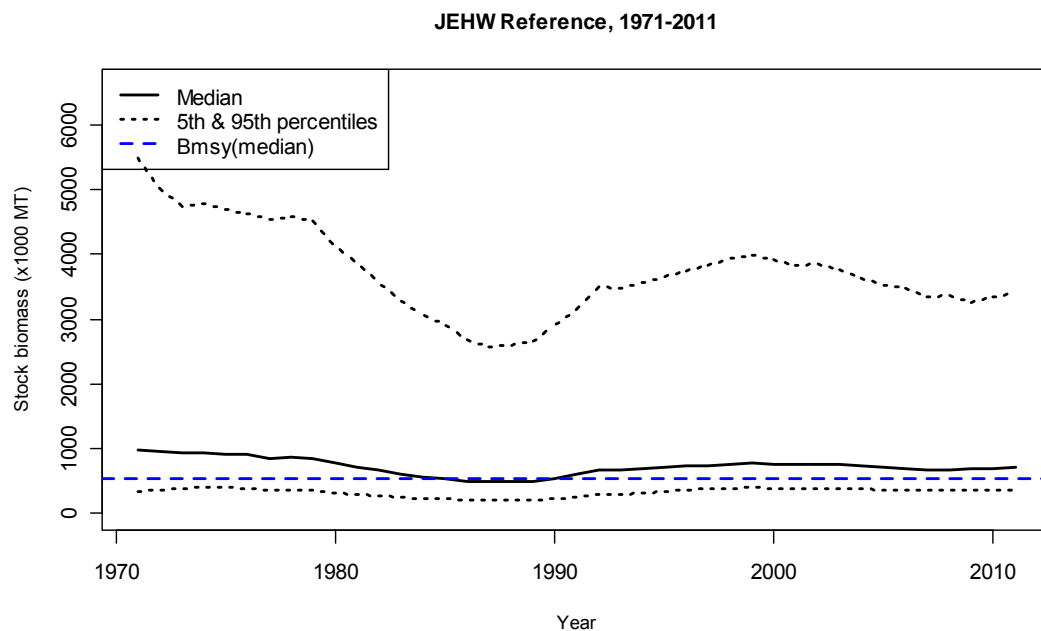
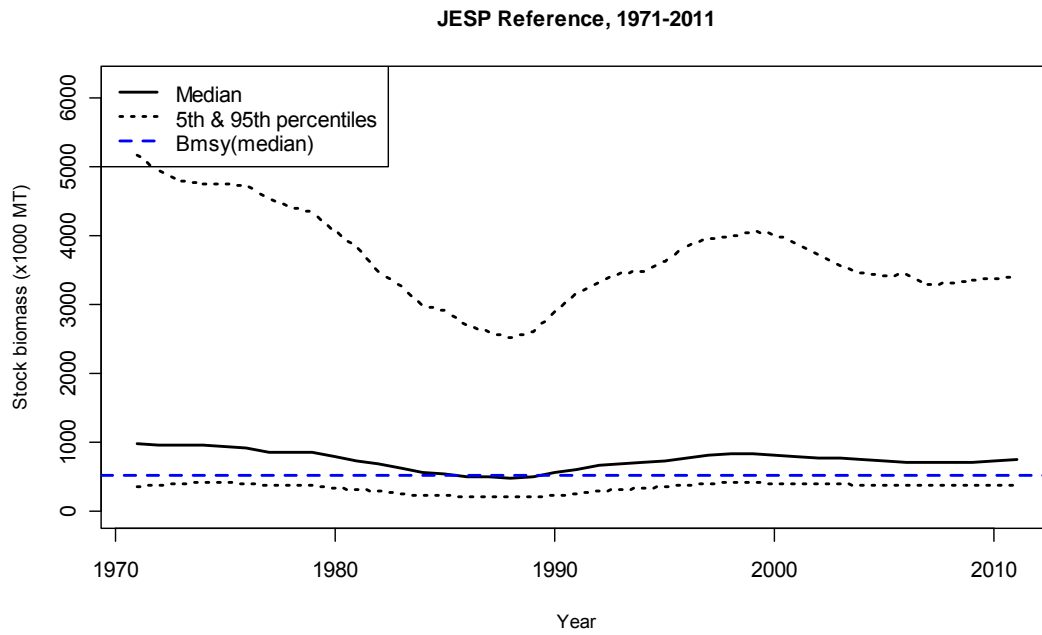


Figure 17 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

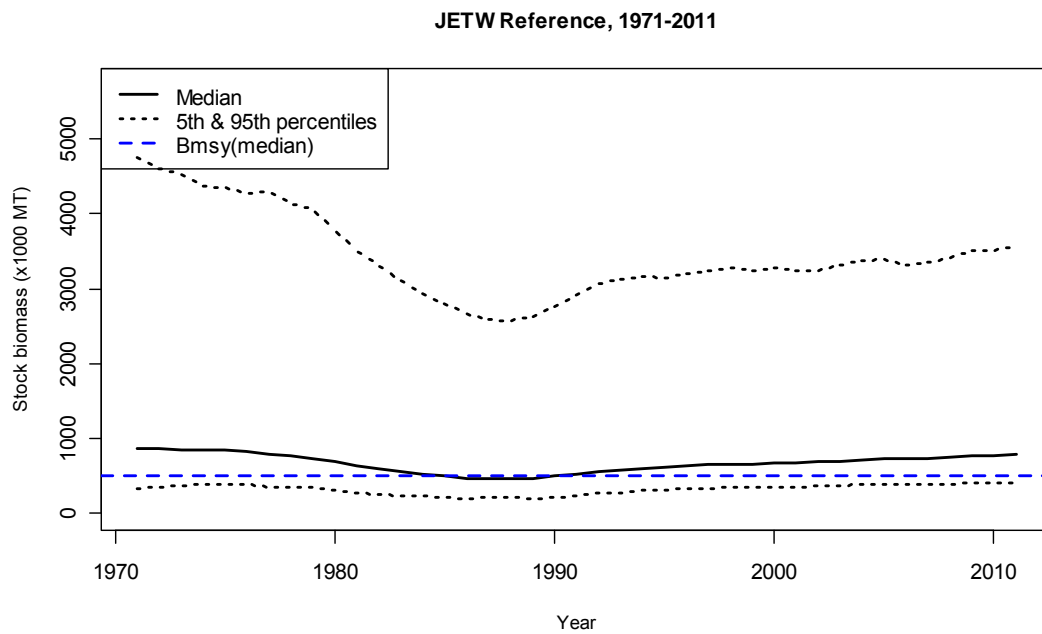
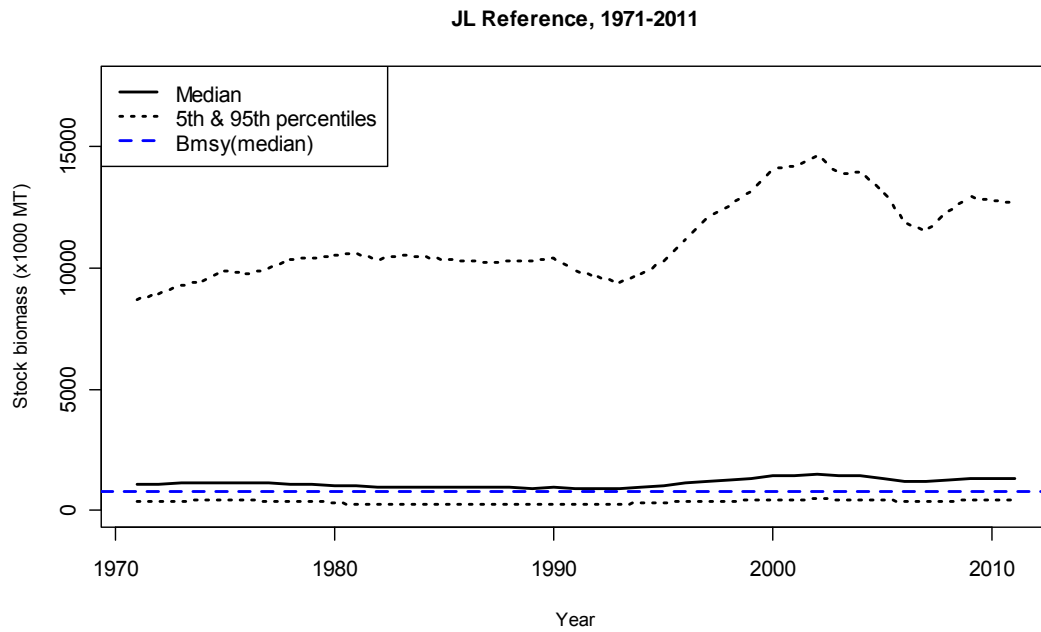


Figure 17 (continued). (e) **JL_Ref** case. (f) **HW_Ref** case.

(e)



(f)

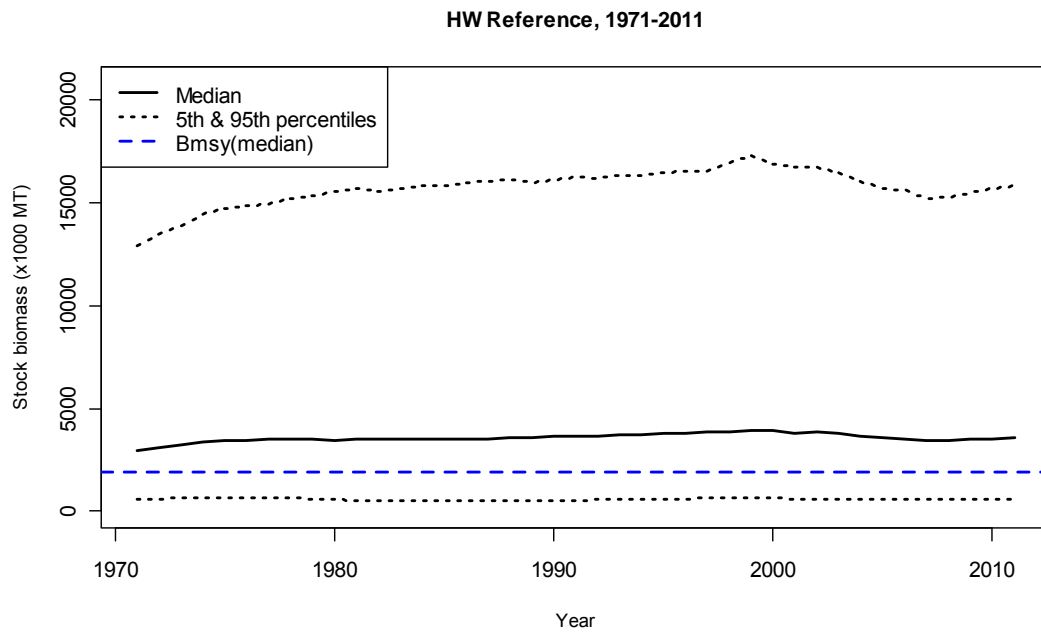
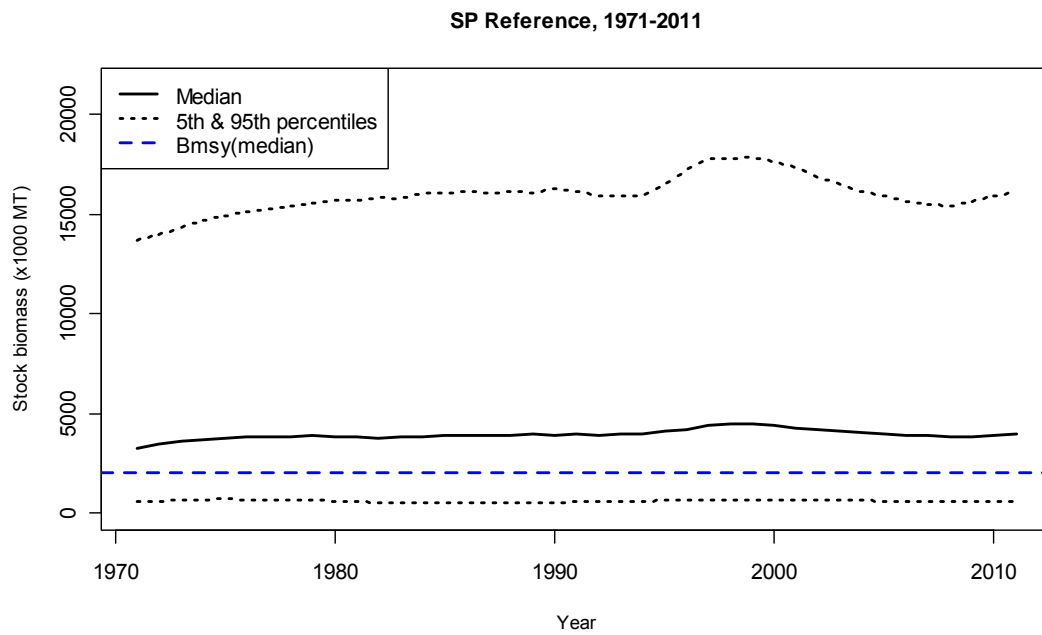


Figure 17 (continued). (g) **SP_Ref** case. (h) **TW_Ref** case.

(g)



(h)

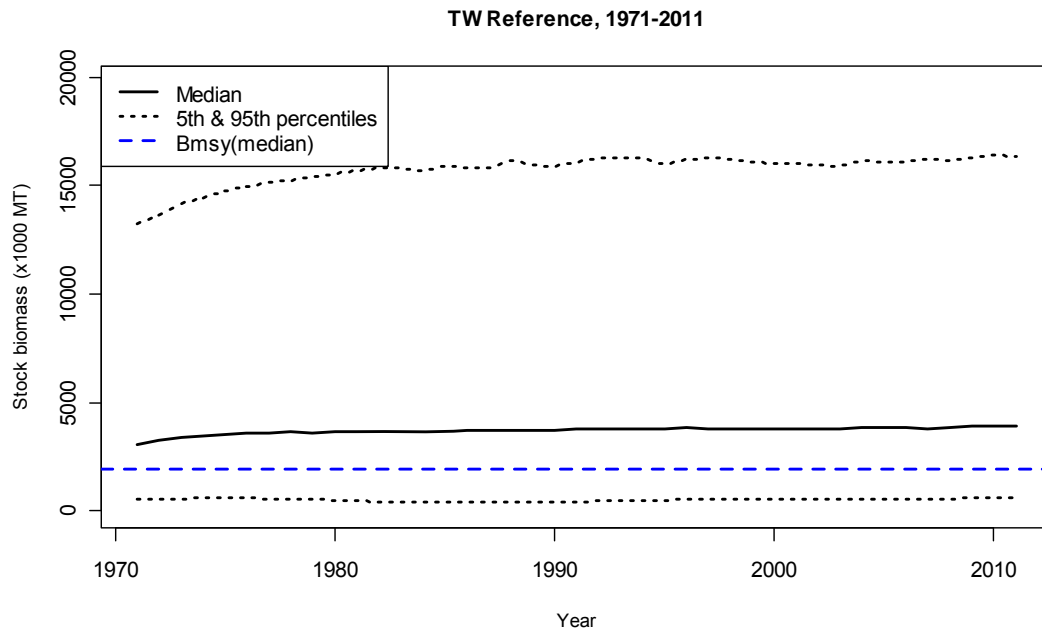
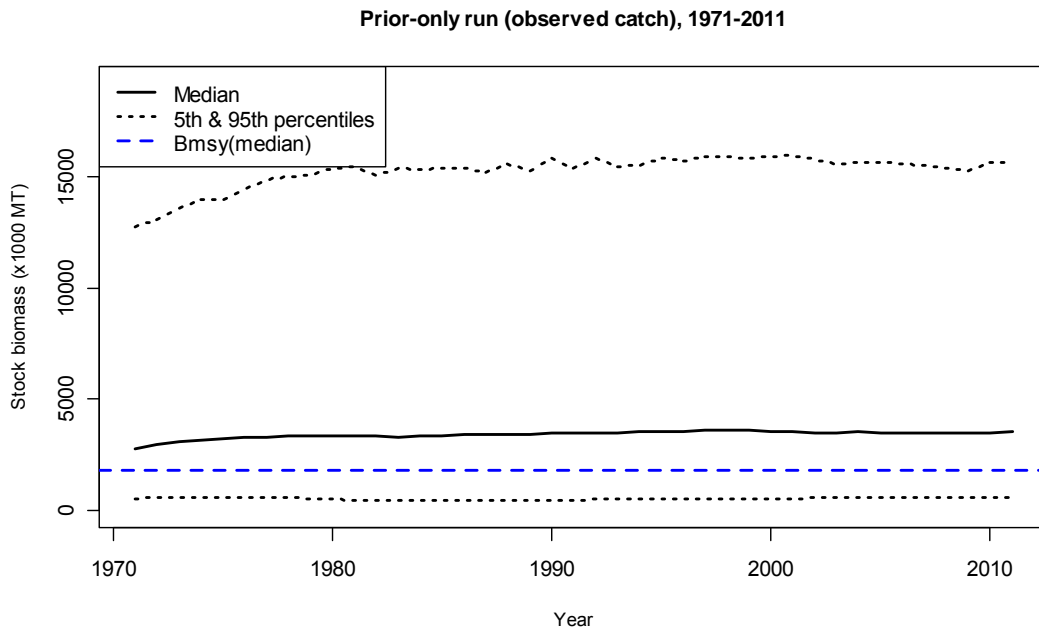


Figure 18. Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{MSY}). (a) **Ponly_obscat** case. (b) **Ponly_hlfc** case.

(a)



(b)

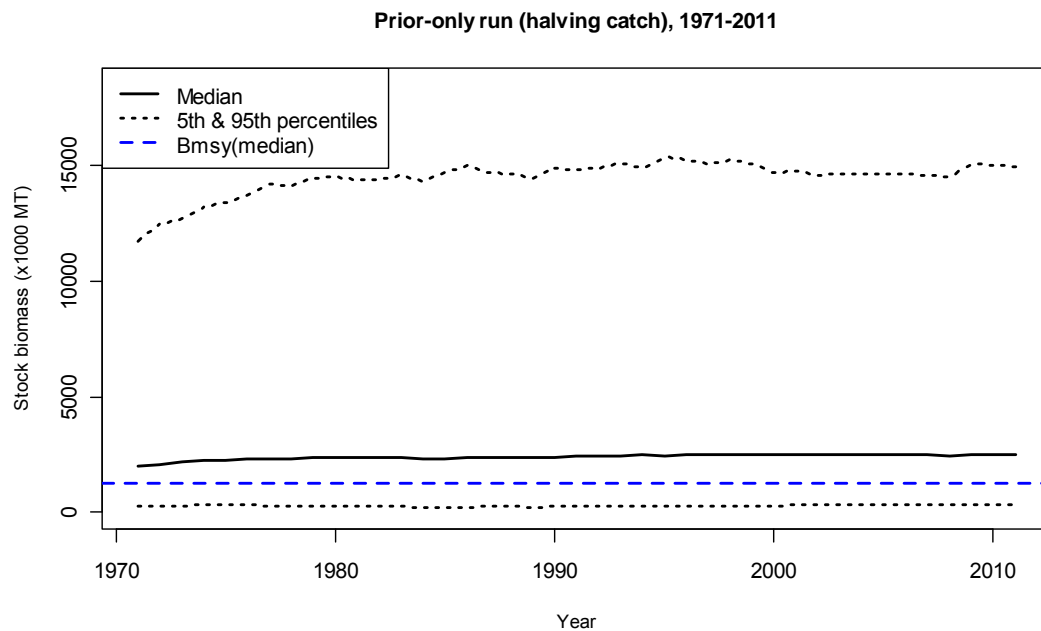
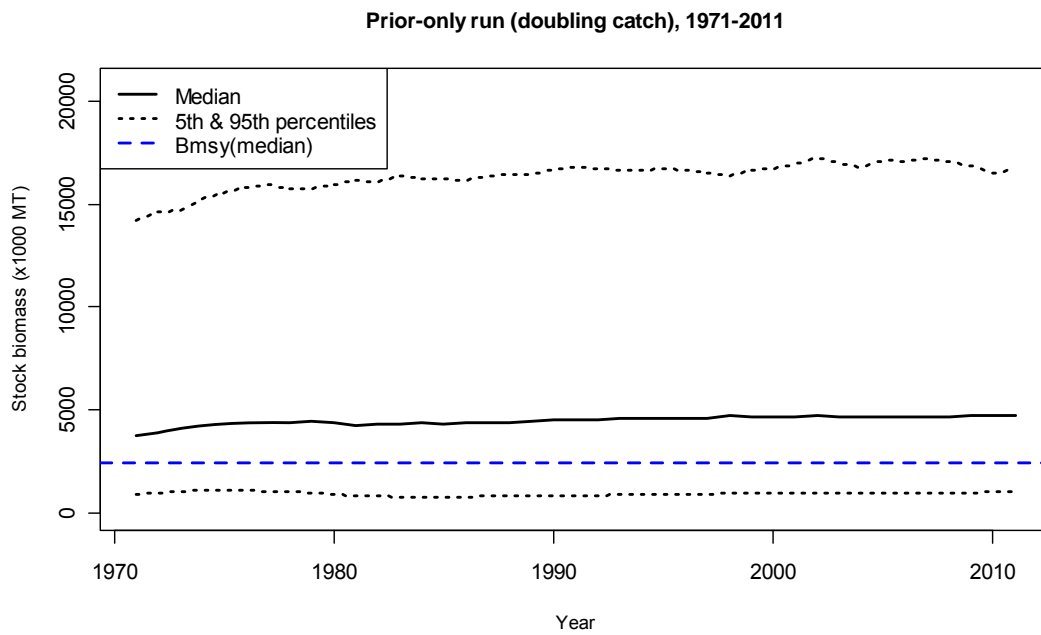


Figure 18 (continued). (c) **Ponly_dbldcat** case. (f) **Ponly_rvscat** case.

(c)



(d)

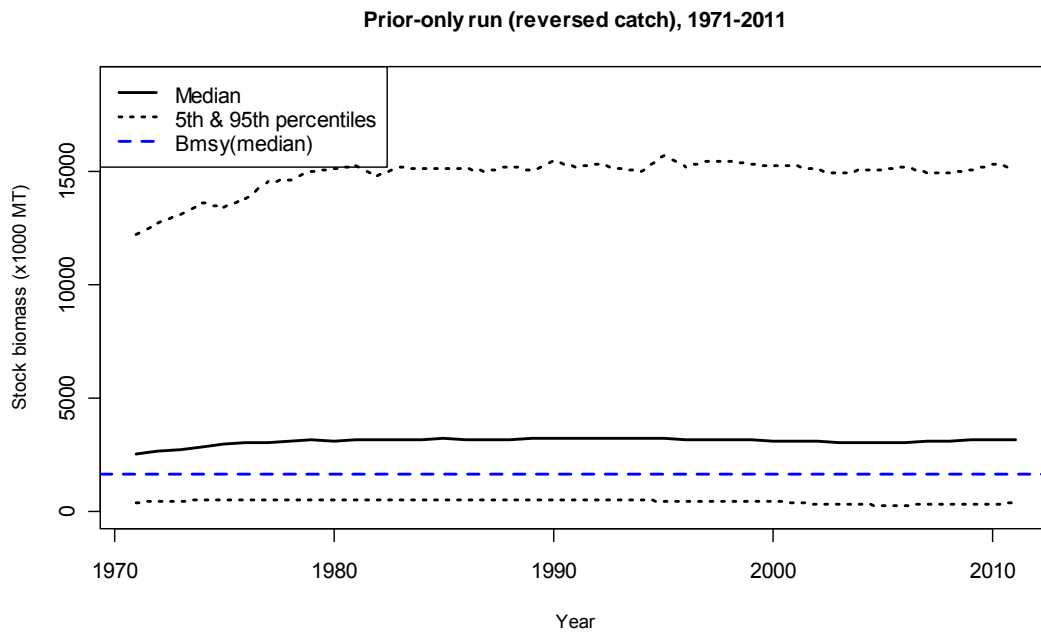
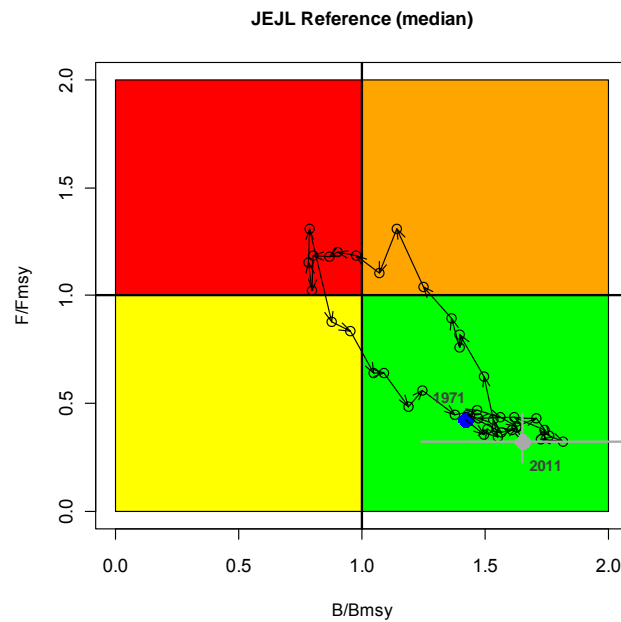


Figure 19. Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis) based on the median annual values of B/B_{MSY} and F/F_{MSY} . Colors represent the magnitude of risk of stock collapse and stock condition from green (safe, healthy) to red (high risk, poor condition). The solid blue circle indicates the median estimate in 1971 (the start year of the stock assessment). The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011. The open black circles and connected solid black arrows are the medians for 1971 to 2011 and the historical direction of changes in stock status. (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

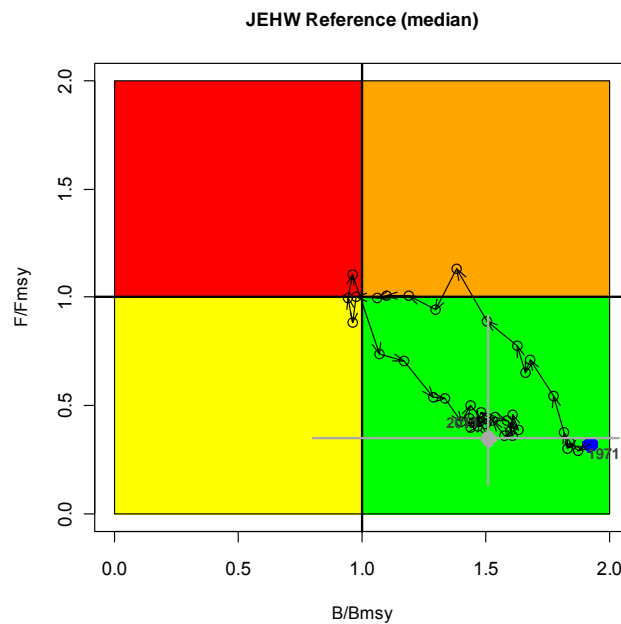
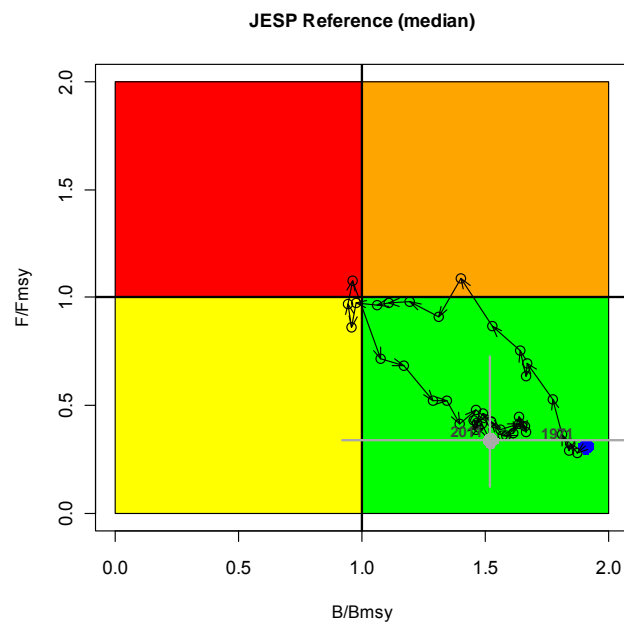


Figure 19 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

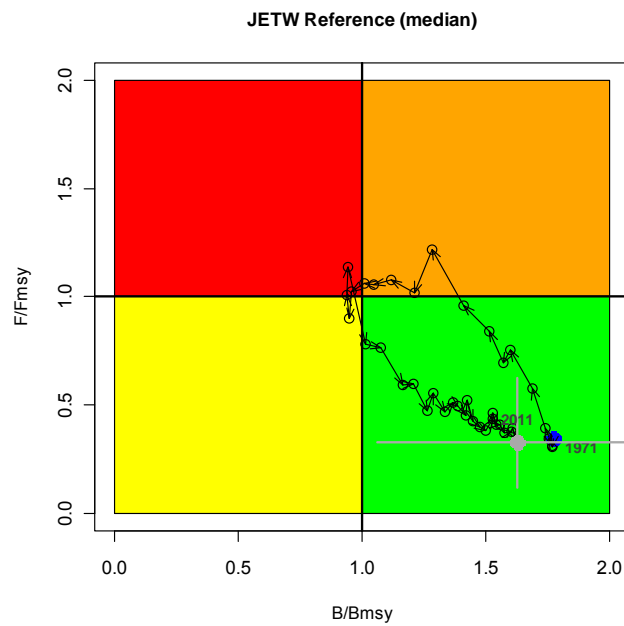
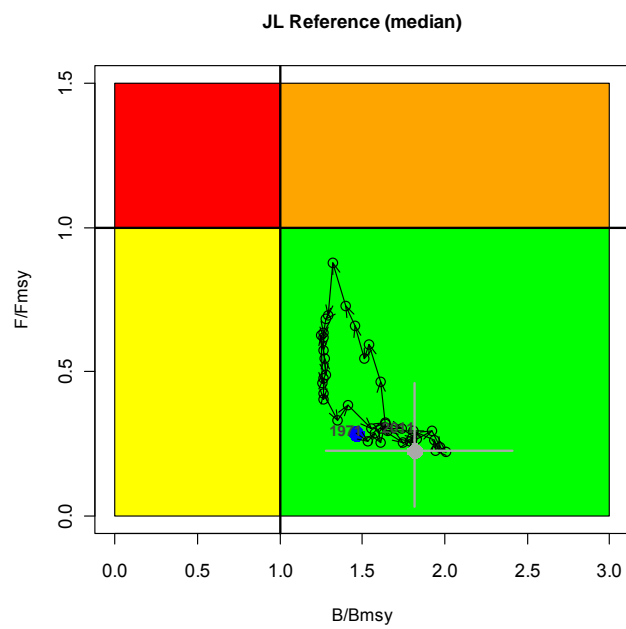


Figure 19 (continued). (e) **JL_Ref** case. (f) **HW_Ref** case.

(e)



(f)

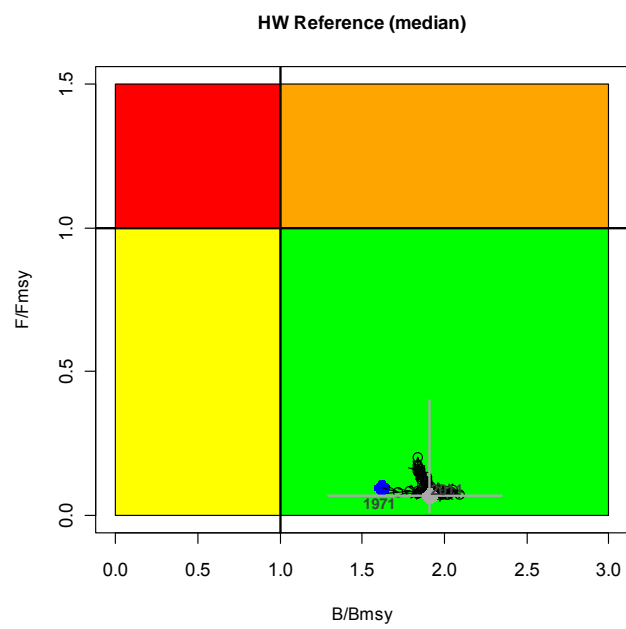
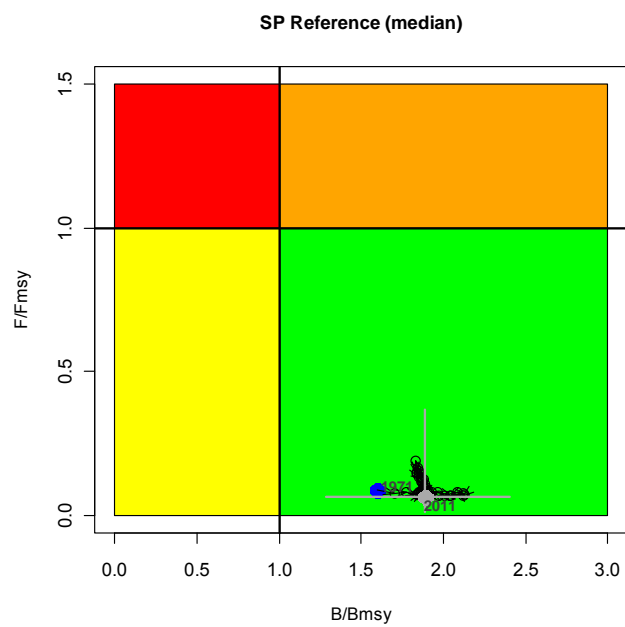


Figure 19 (continued). (g) **SP_Ref** case. (h) **TW_Ref** case.

(g)



(h)

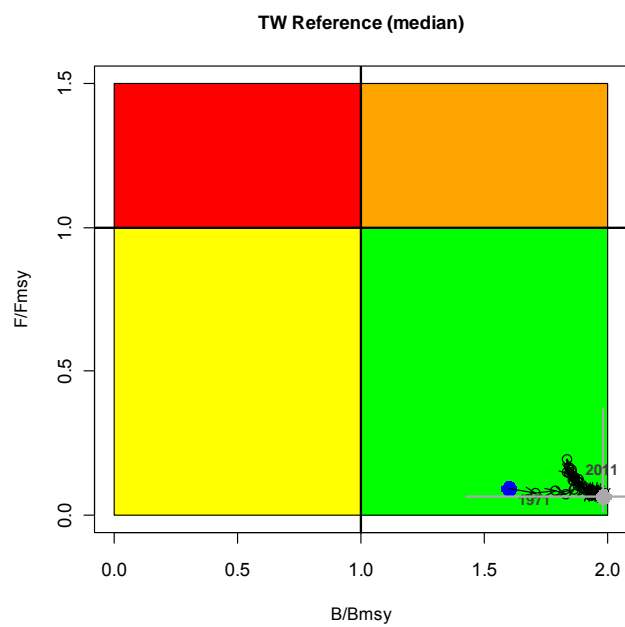
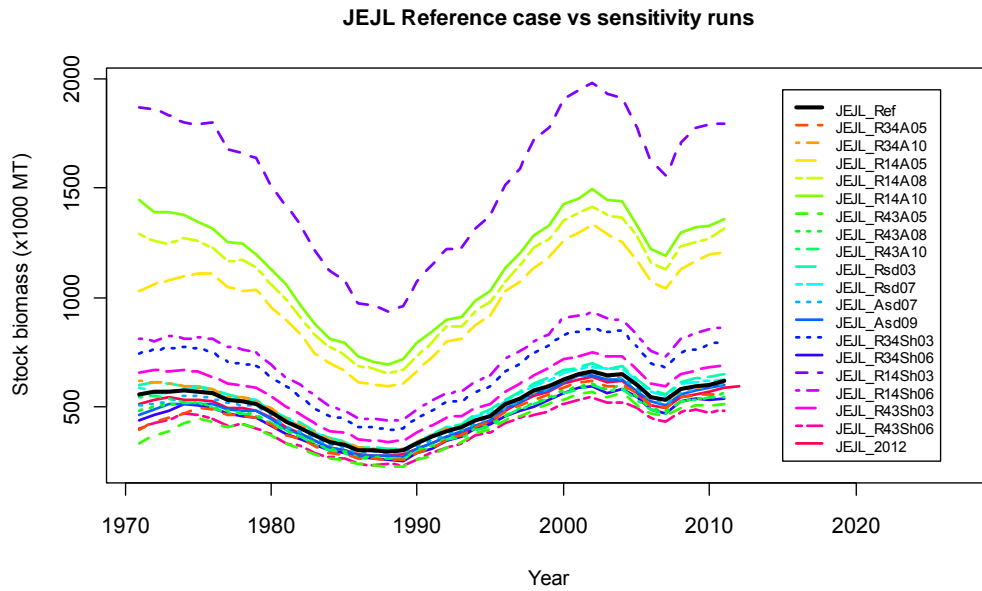


Figure 20. Comparison of median trajectories of historical blue shark stock biomass among the BSP reference cases (**JEJL_Ref**, **JEHW_Ref**, **JESP_Ref**, **JETW_Ref**) and sensitivity runs. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs. (a) **JEJL_Ref** case and sensitivity runs. (b) **JEHW_Ref** case and sensitivity runs.

(a)



(b)

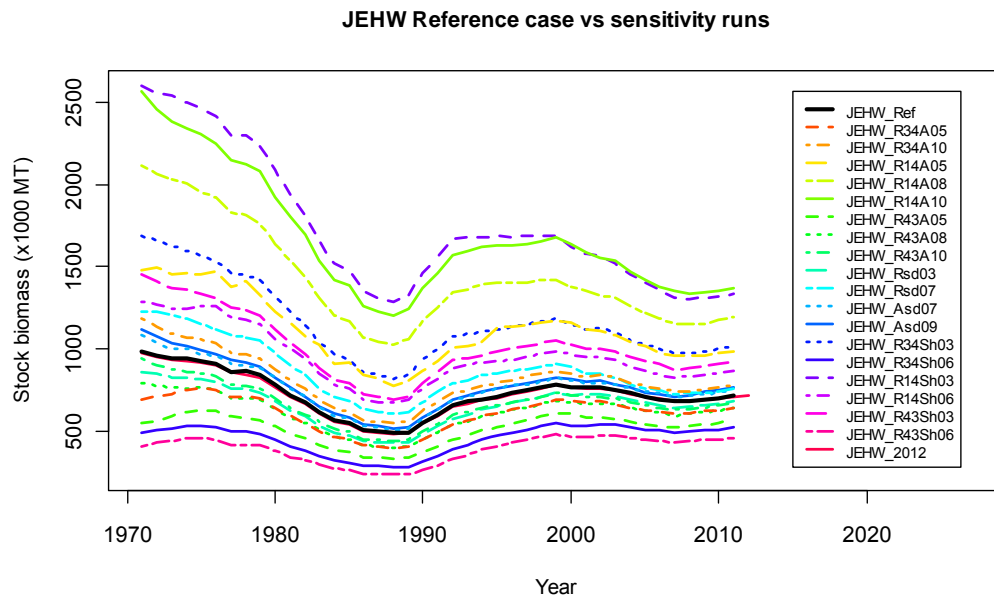
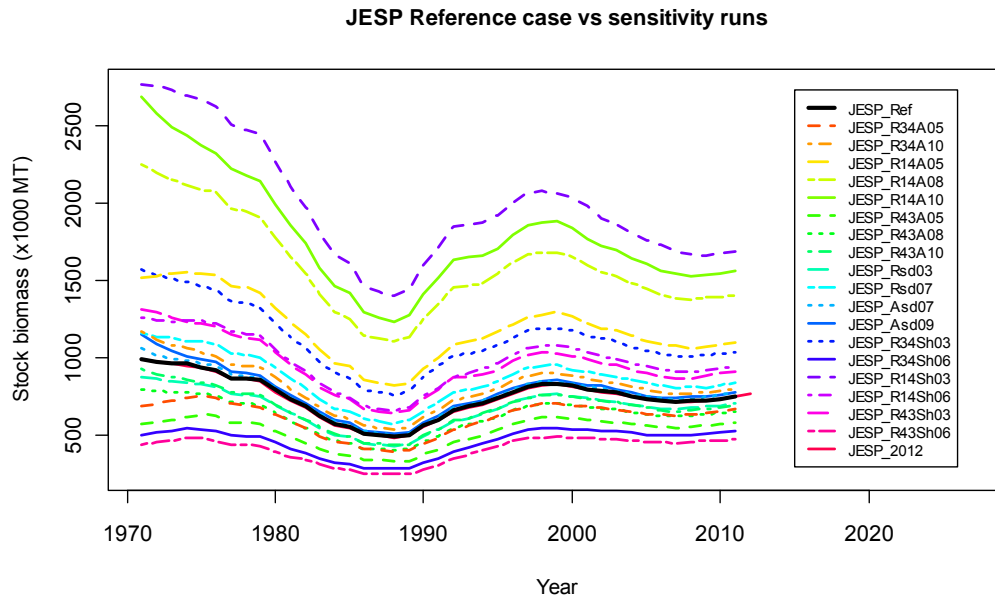


Figure 20 (continued). (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(c)



(d)

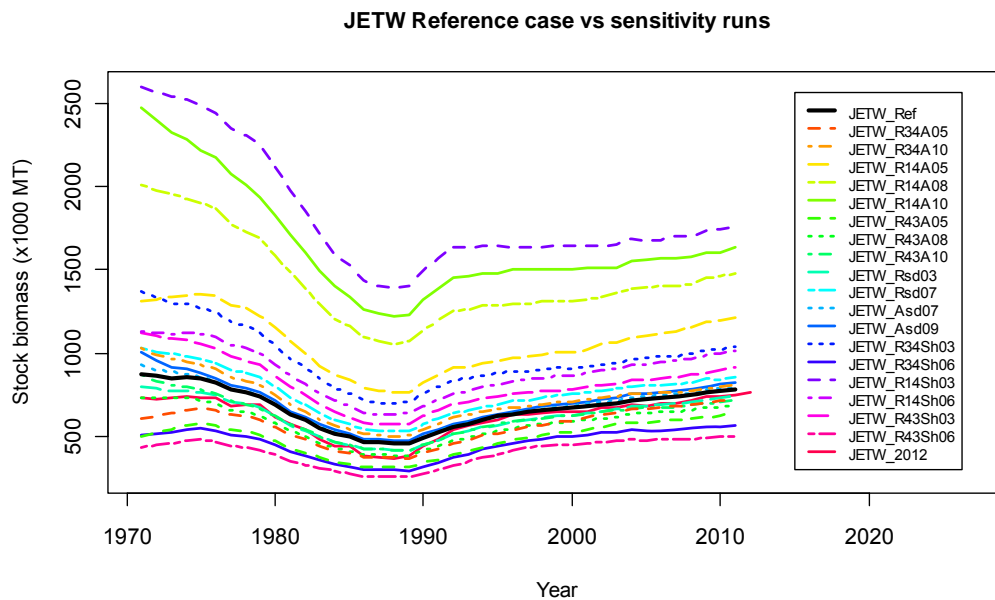
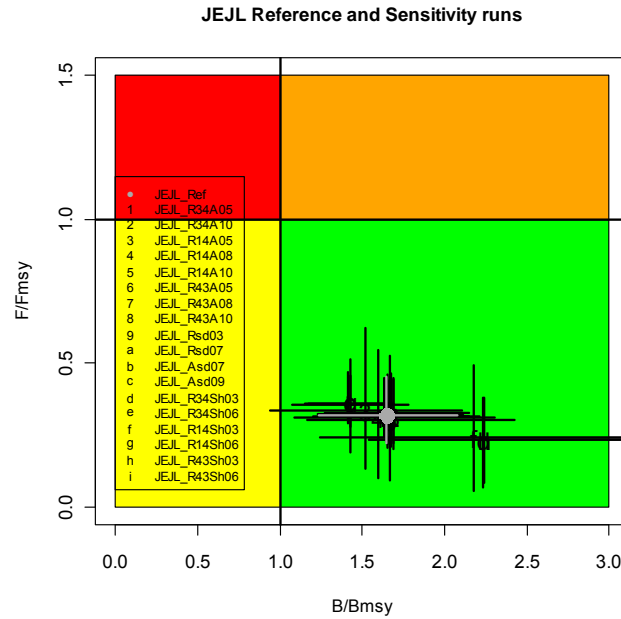


Figure 21. Kobe plot for the four BSP reference cases and sensitivity runs for the north Pacific blue shark stock assessment. The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011 for each respective reference case. Other different symbols (numbers and letters) and their horizontal and vertical solid black lines indicate the median and 90% confidence limits in 2011 for various sensitivity runs. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs. (a) **JEJL_Ref** case and sensitivity runs. (b) **JEHW_Ref** case and sensitivity runs.

(a)



(b)

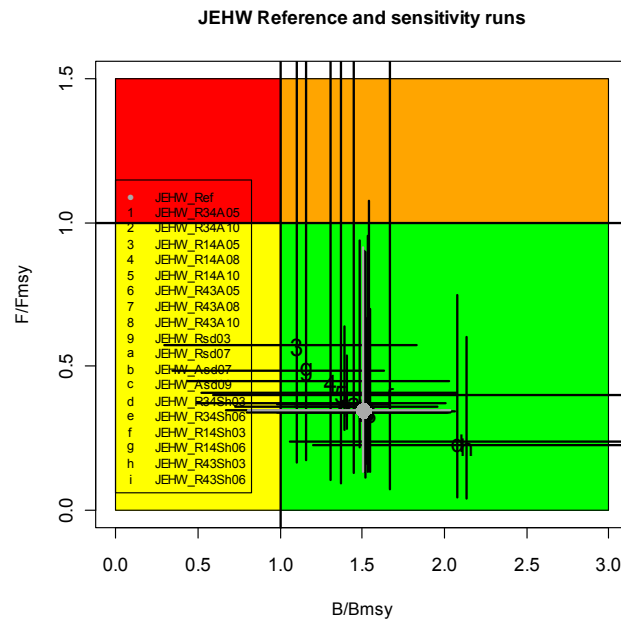
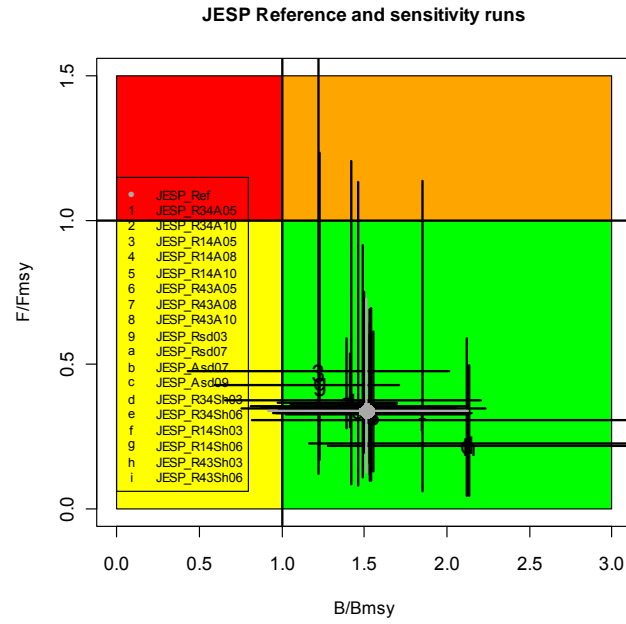


Figure 21 (continued). (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(c)



(d)

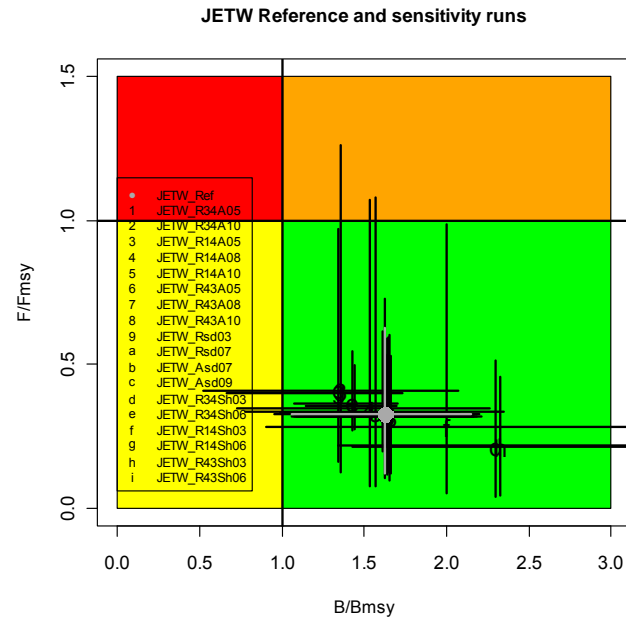


Figure 22. Kobe plot showing the 2011 median estimates of F/F_{MSY} and B/B_{MSY} for all the BSP model runs for North Pacific blue shark (*Prionace glauca*). The horizontal and vertical bars indicate the 90% confidence limits of the 2011 estimates.

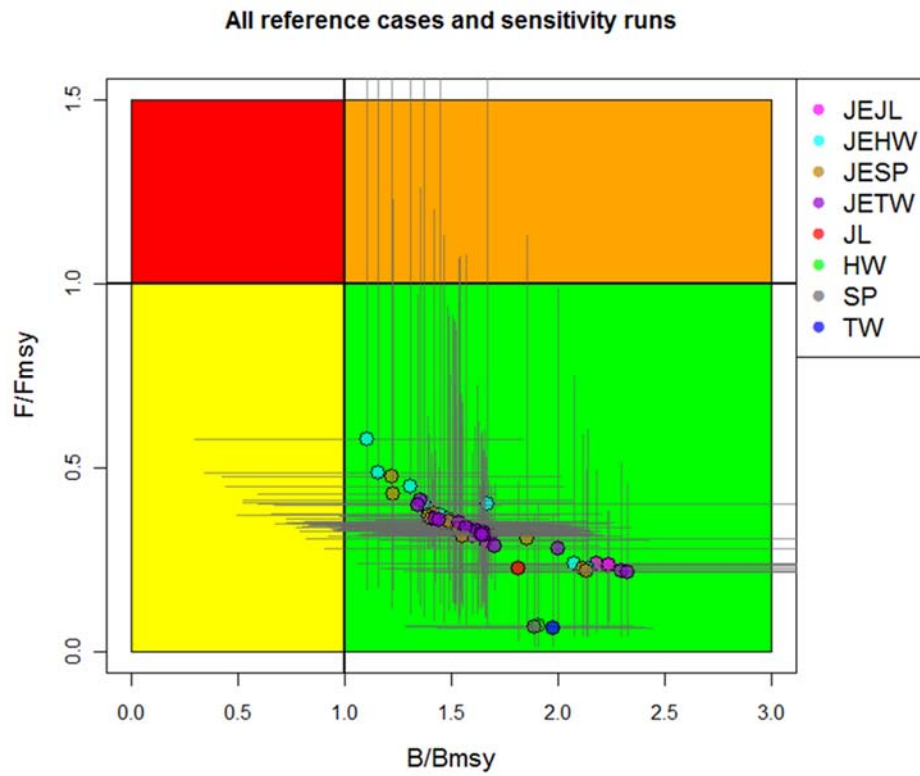
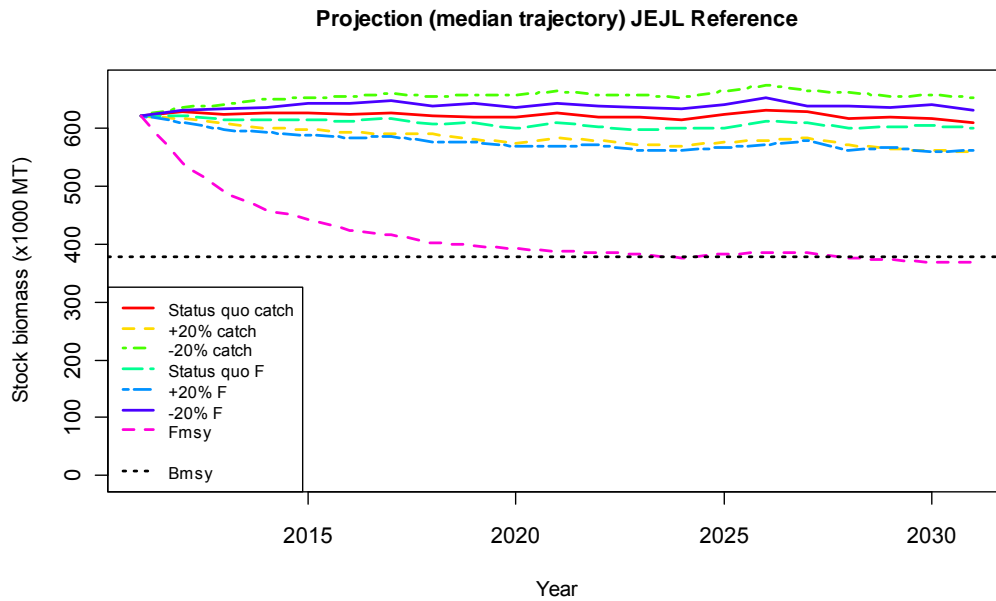


Figure 23. Comparison of future projected stock biomass (medians) of blue shark under different constant catch harvest policies (*status quo*, +20%, -20%) and different constant F harvest policies (*status quo*, +20%, -20%, F_{MSY}) in the four BSP reference cases. *Status quo* catch was based on the average catch over recent five years of 2006-2010 and *status quo* F was based on the average F over the recent five years. The biomass level at the maximum sustainable yield, MSY (B_{MSY}) was also plotted (black dotted line). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

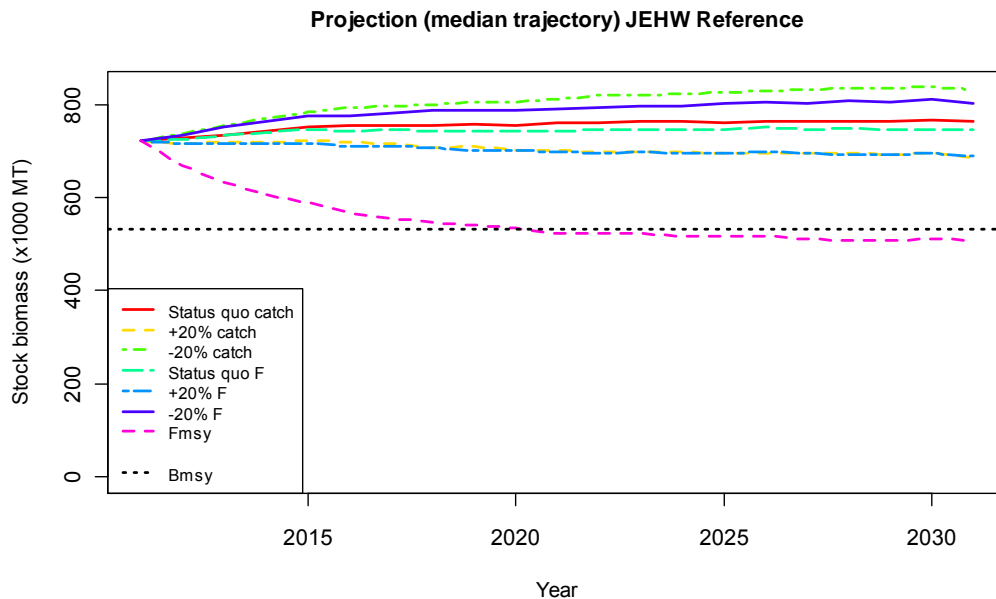
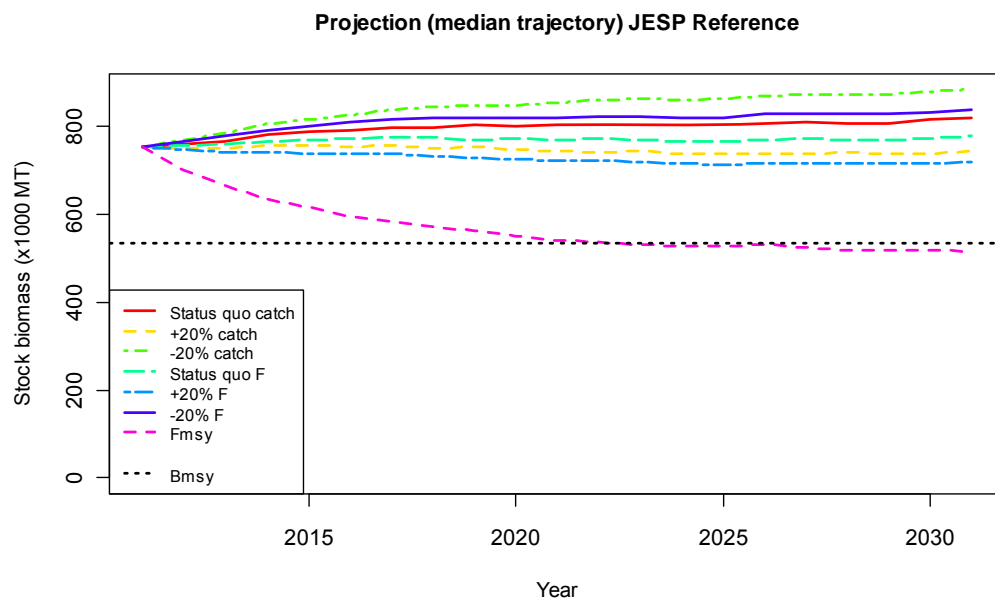


Figure 23 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

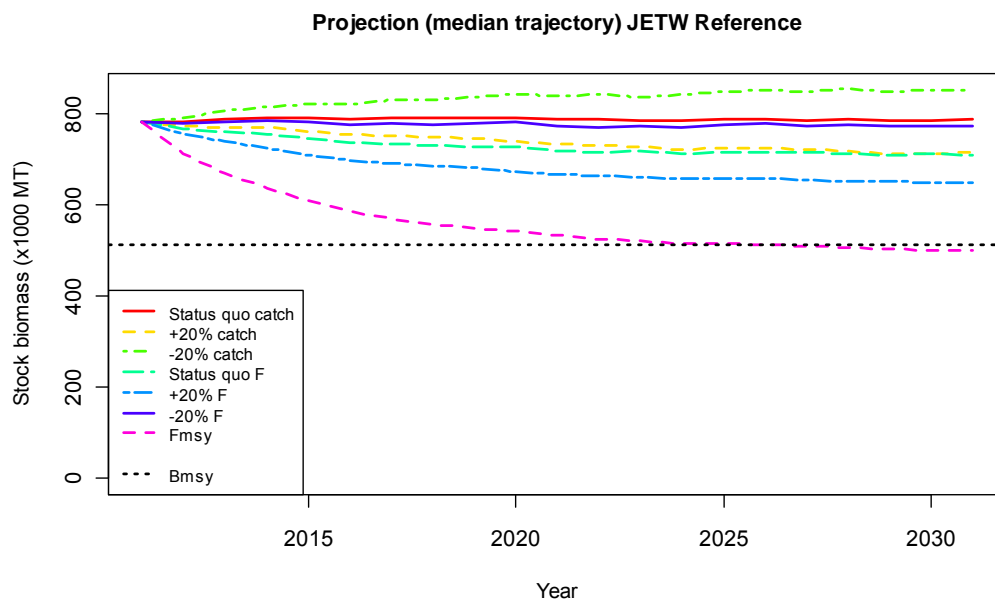
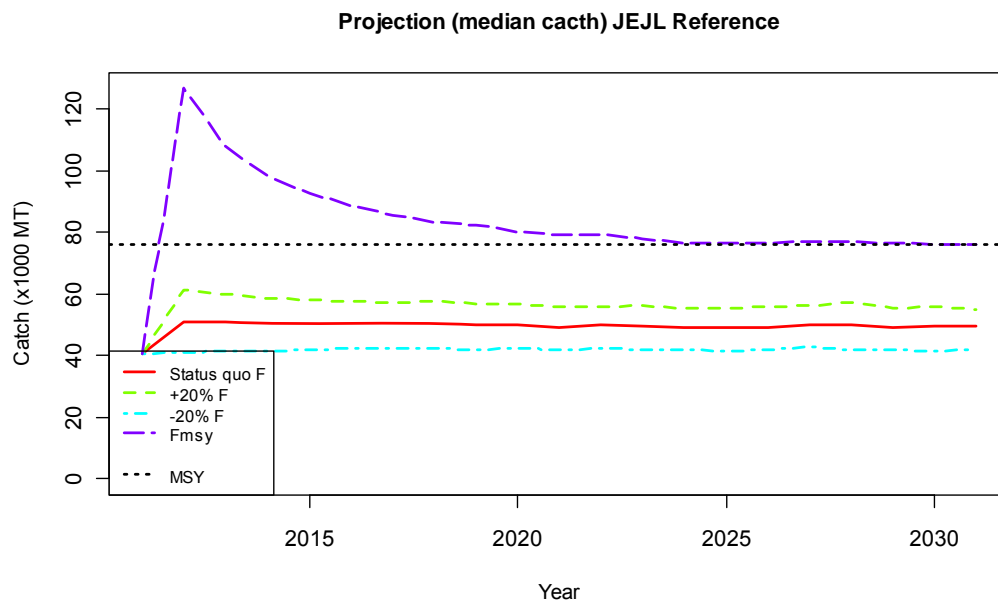


Figure 24. Comparison of future projected catches (medians) of blue shark under different constant F harvest policies (*status quo*, +20%, -20%, F_{MSY}) for the four BSP reference cases. *Status quo* F was based on the average F over the recent five years of 2006-2010. The maximum sustainable yield (MSY) was also plotted (black dotted line). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

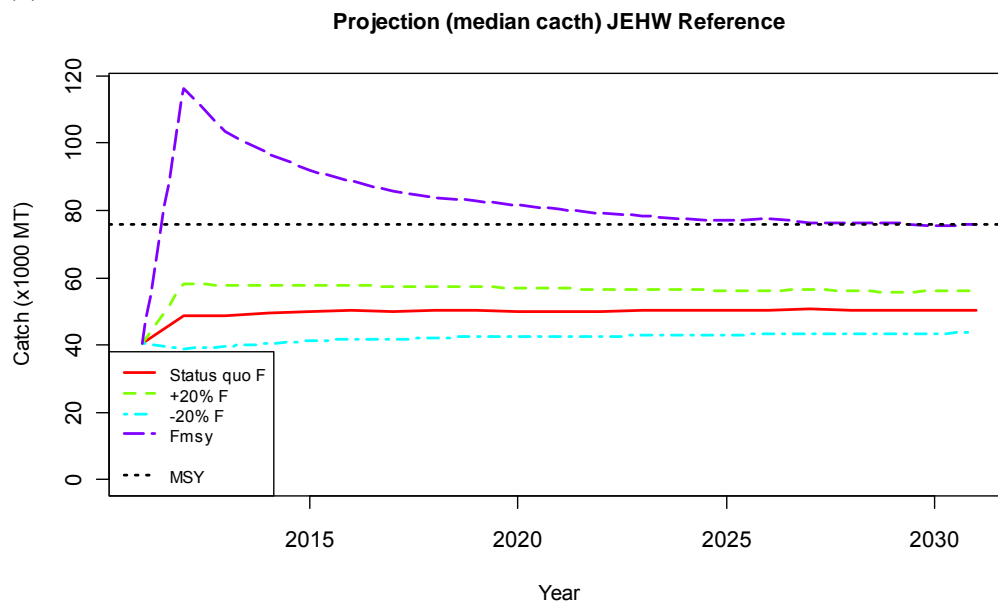
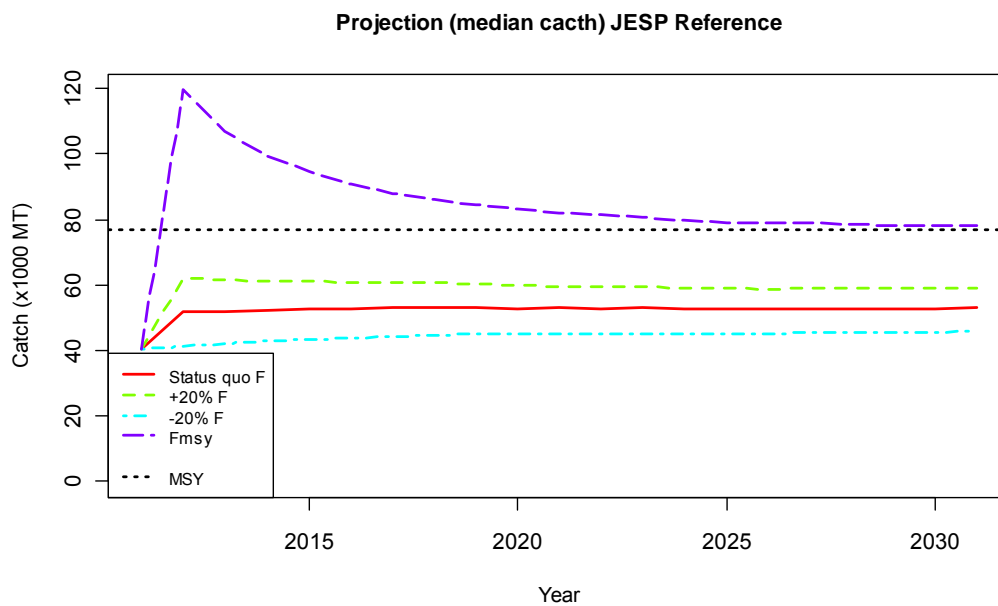


Figure 24 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

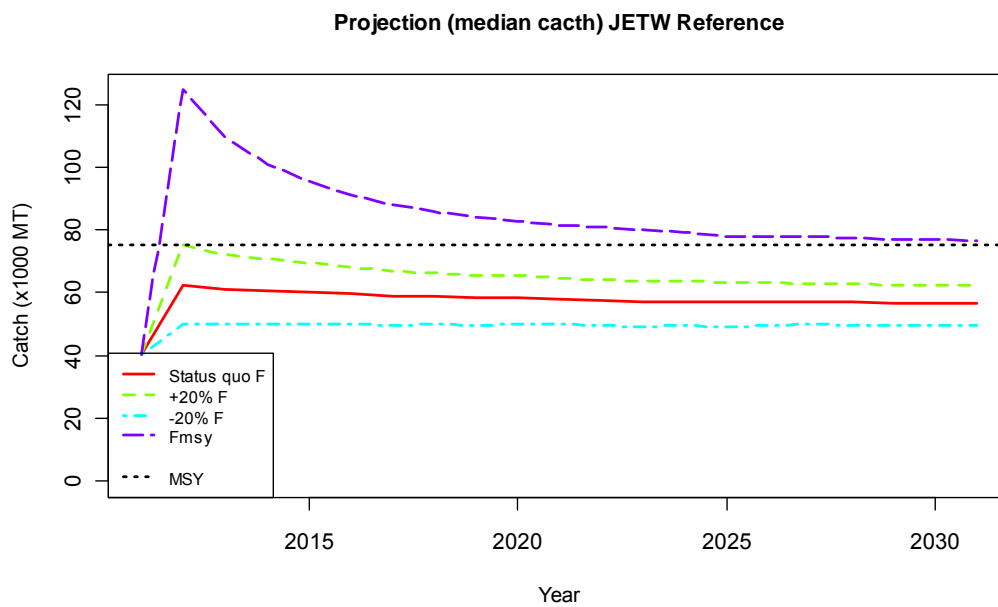


Figure 25. Selectivity curves estimated for female (top) and male (bottom) from the SS reference case model.

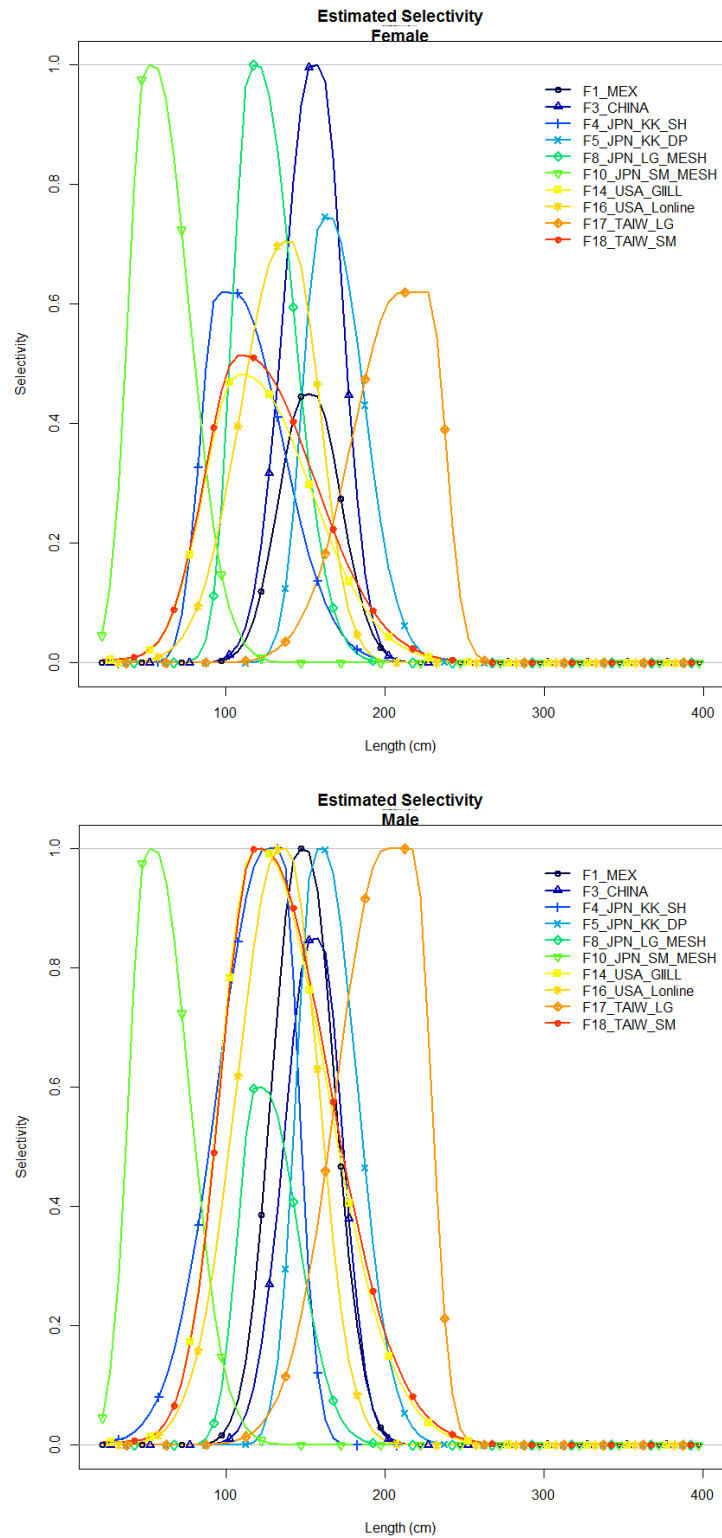


Figure 26. Fit to the Japanese early (top) and late (bottom) CPUE time series for the SS reference case model.

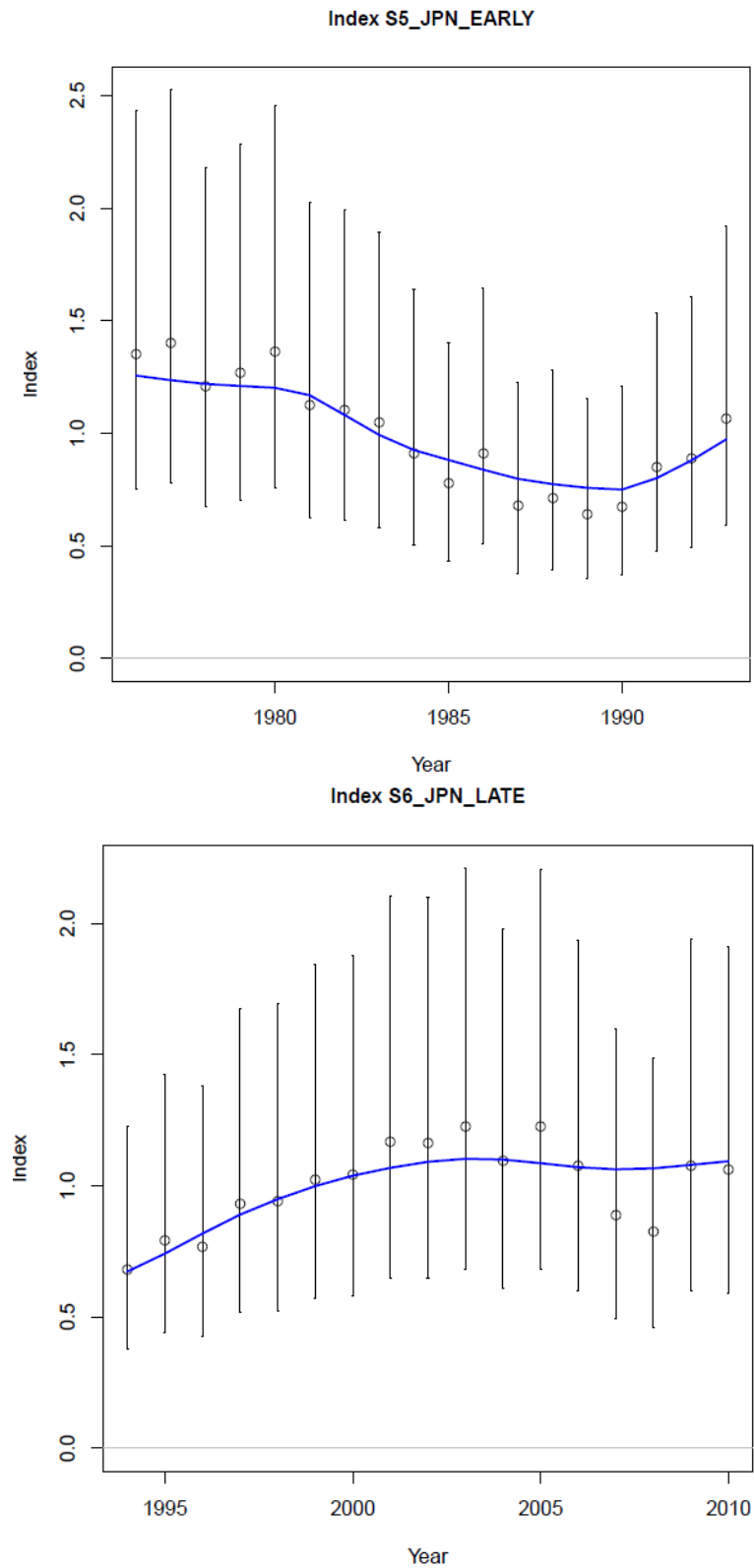


Figure 27. Fit to the female length frequency data for the SS reference case model.

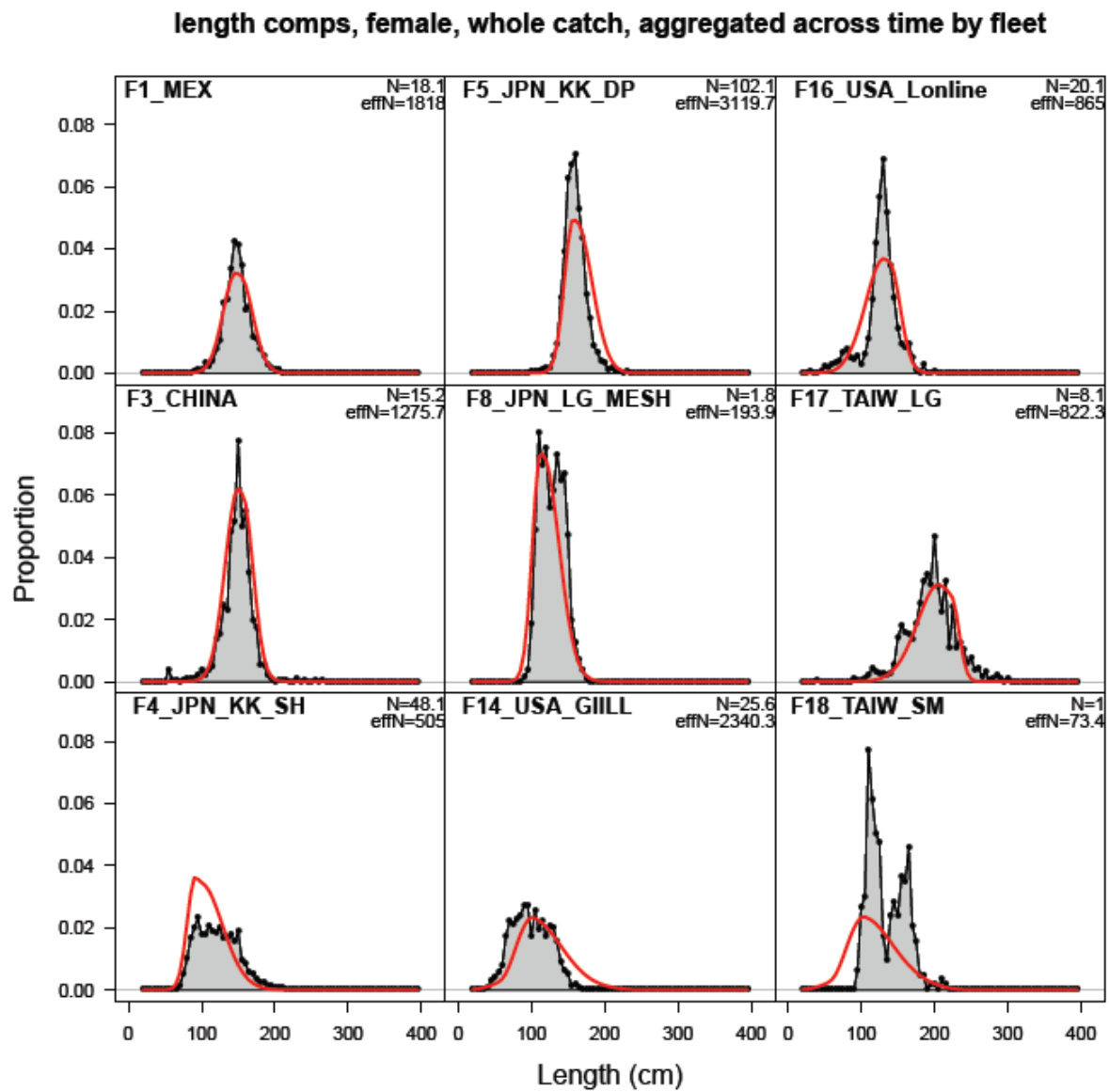


Figure 28. Fit to the male length frequency data for the SS reference case model.

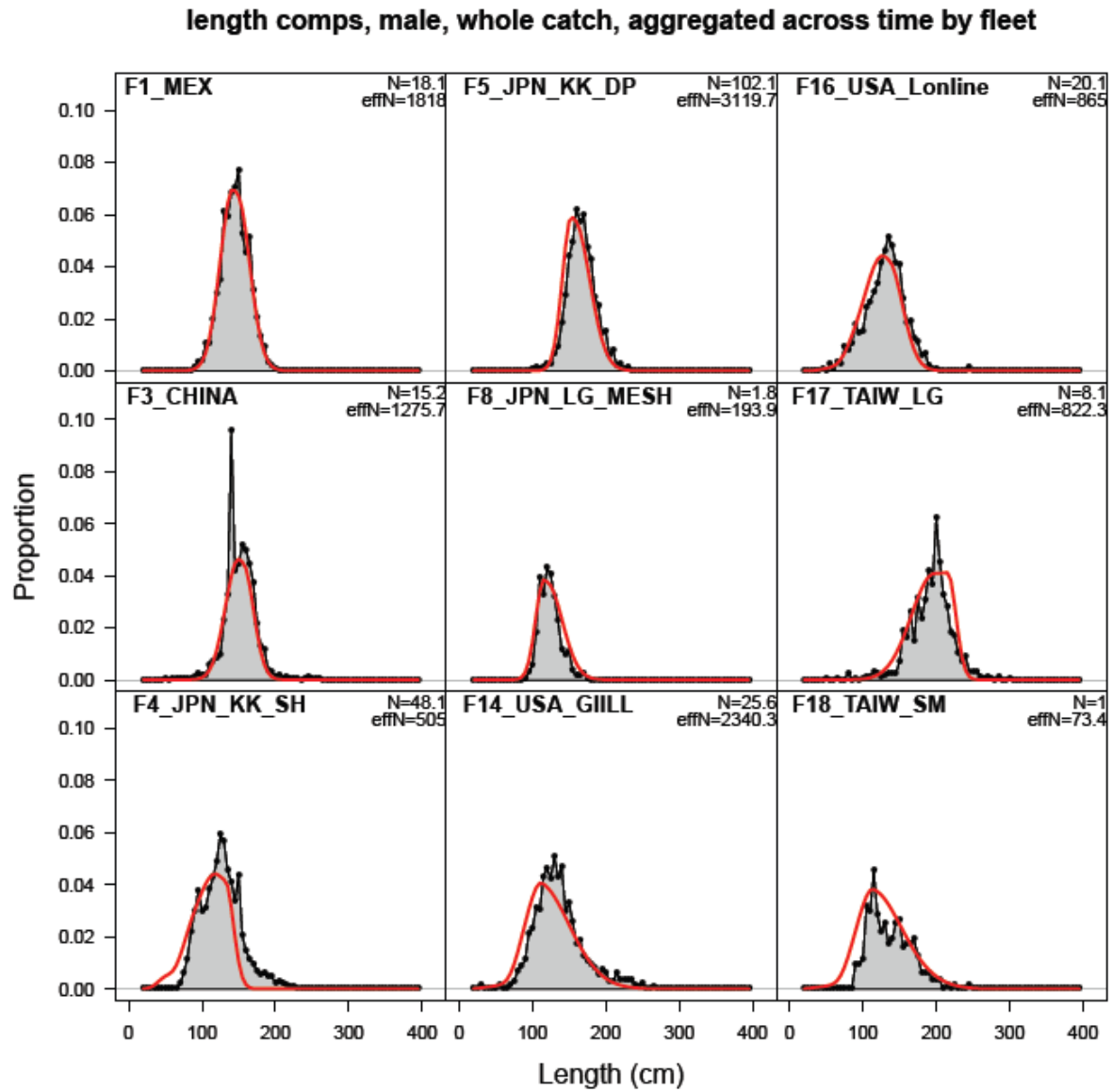


Figure 29. Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the SS reference case model, note that recruitment is higher than virgin due to the compensation implied by the parameterization of the LFSR.

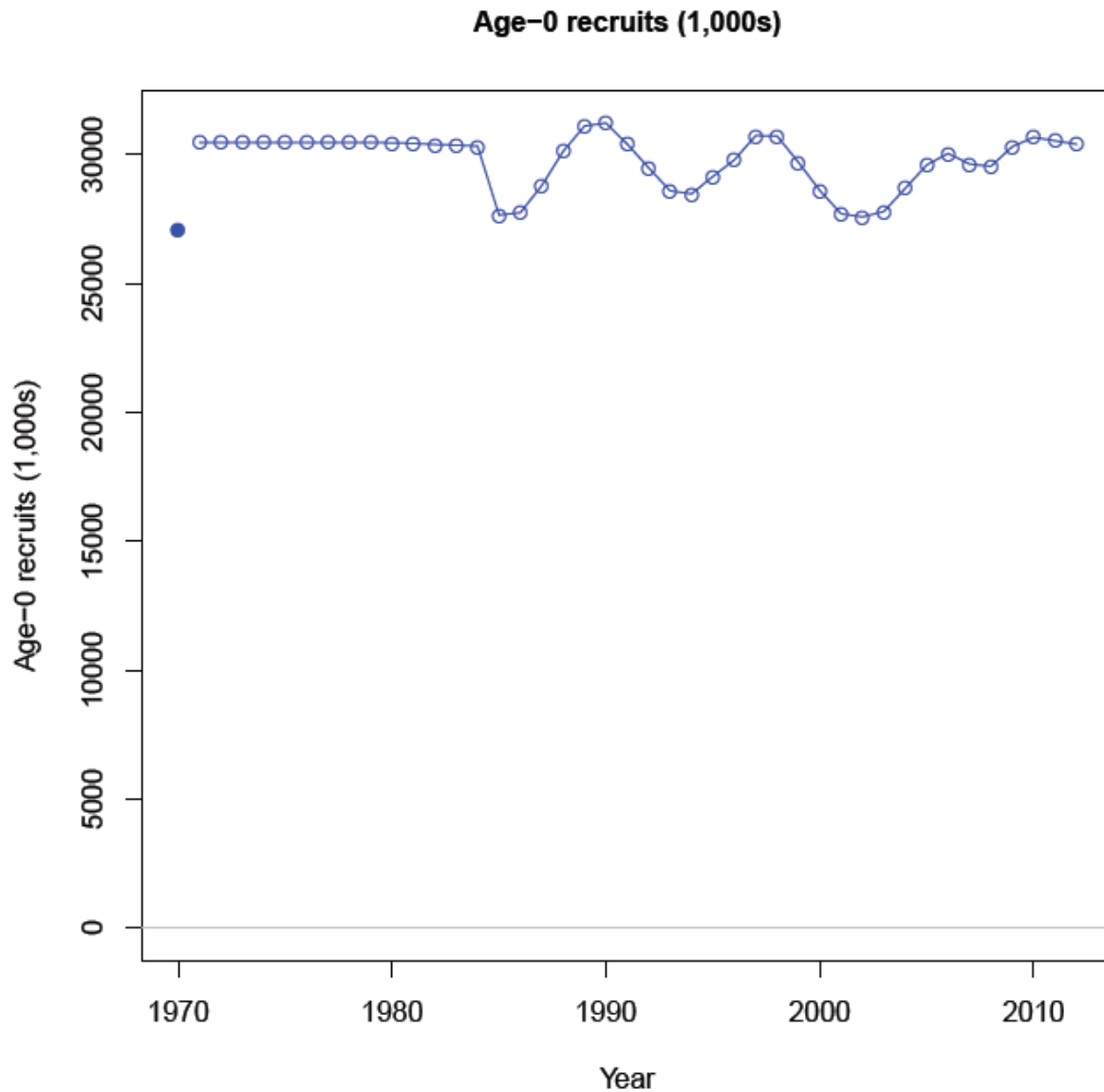


Figure 30. Spawner recruitment time series for the SS reference case model.

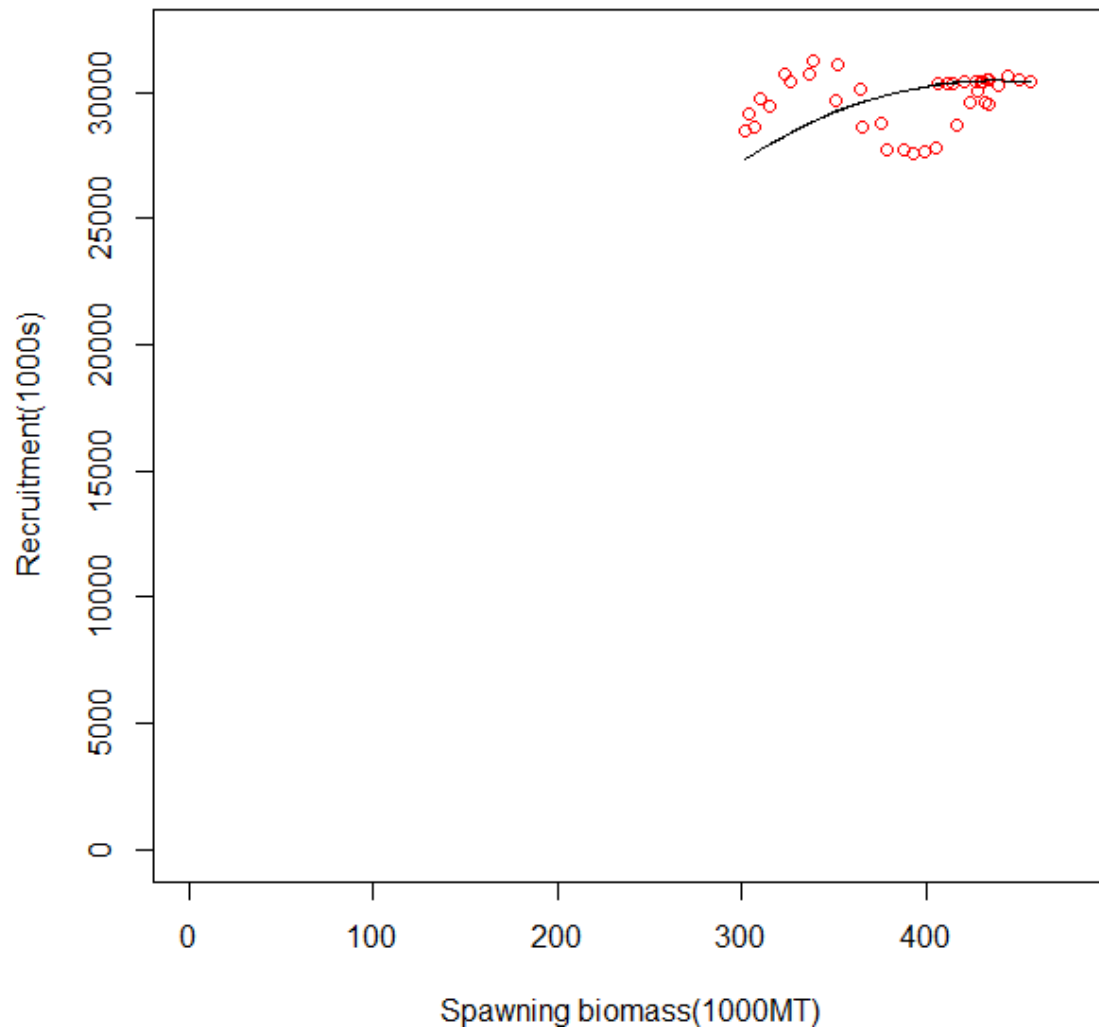


Figure 31. Estimated fishing mortality for each fishing gear for the SS reference case model.

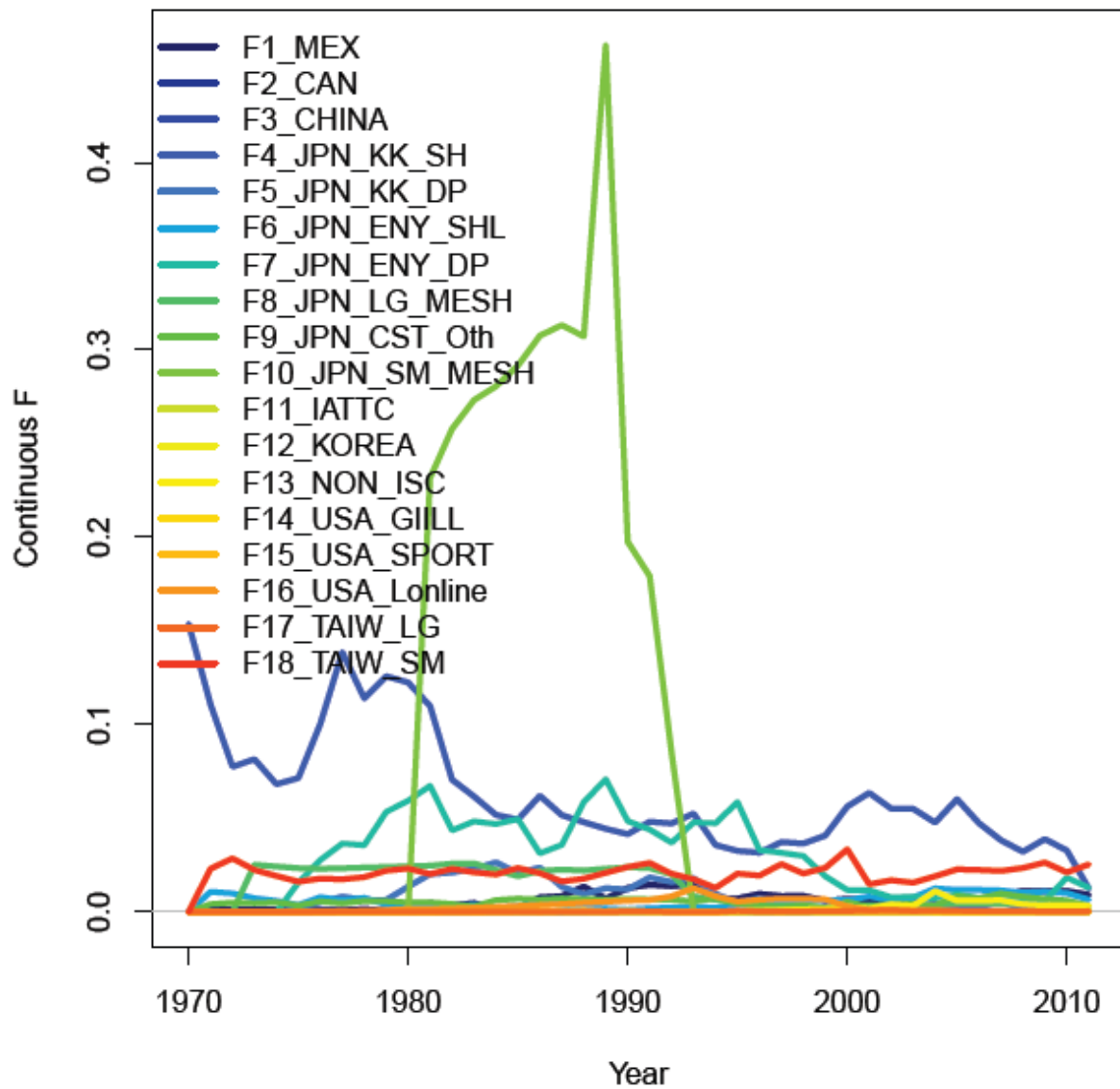


Figure 32. Equilibrium yield curve for the SS reference case model.

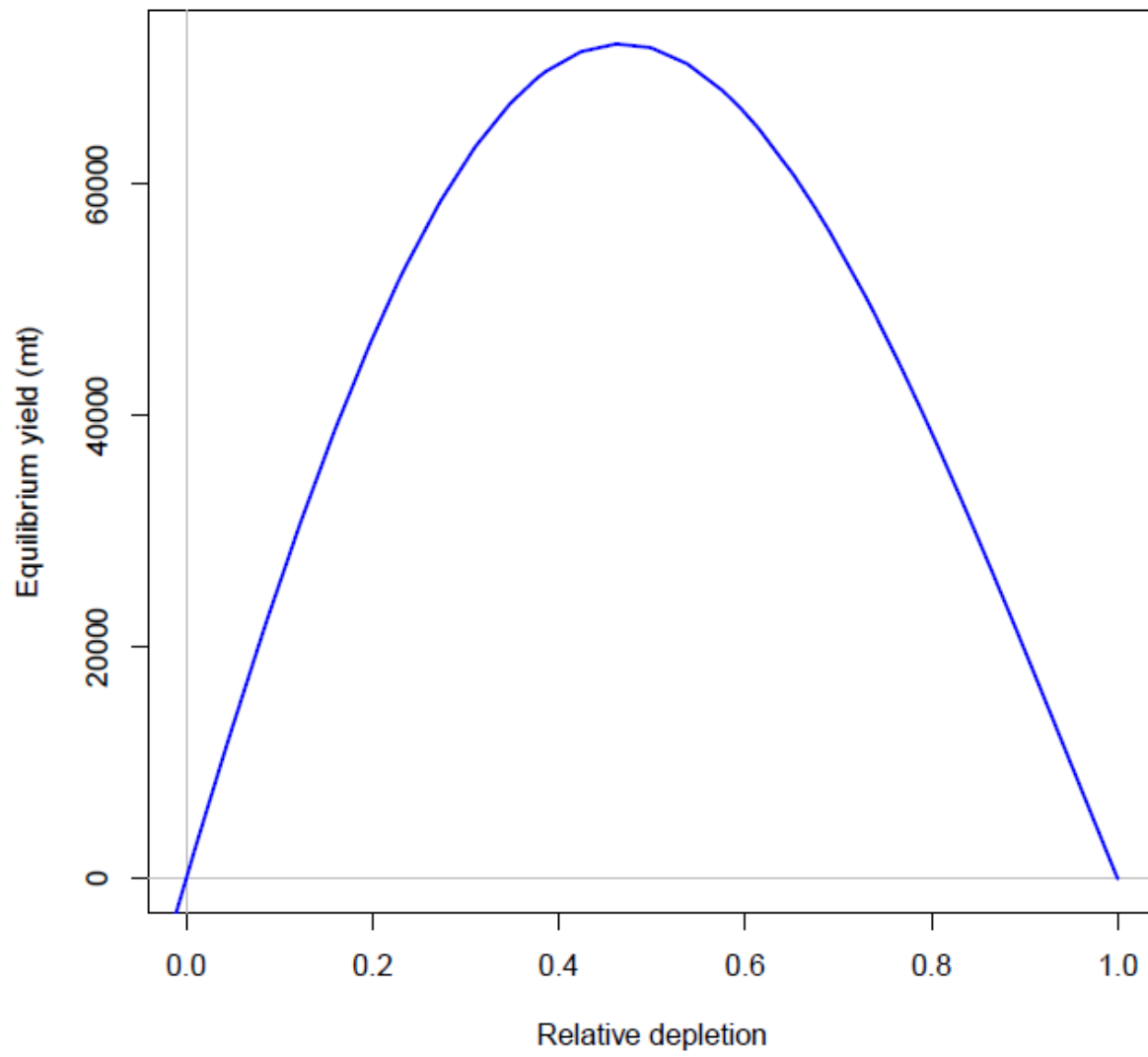


Figure 33. Estimated female spawning biomass and 90% confidence intervals for the SS reference case run.

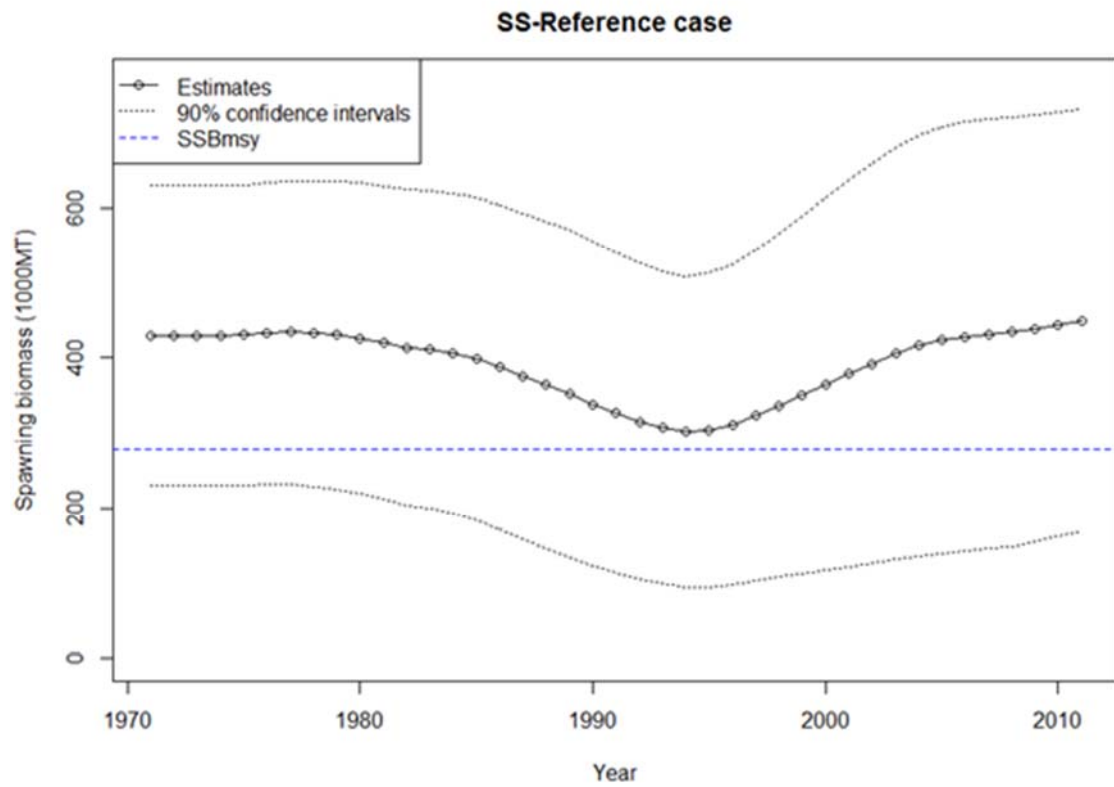


Figure 34. Kobe plot showing estimated spawning biomass and fishing mortality trajectories for the reference case SS model. The circles indicate the historical trajectory from 1971-2011 colored from red (first year) to blue (terminal year).

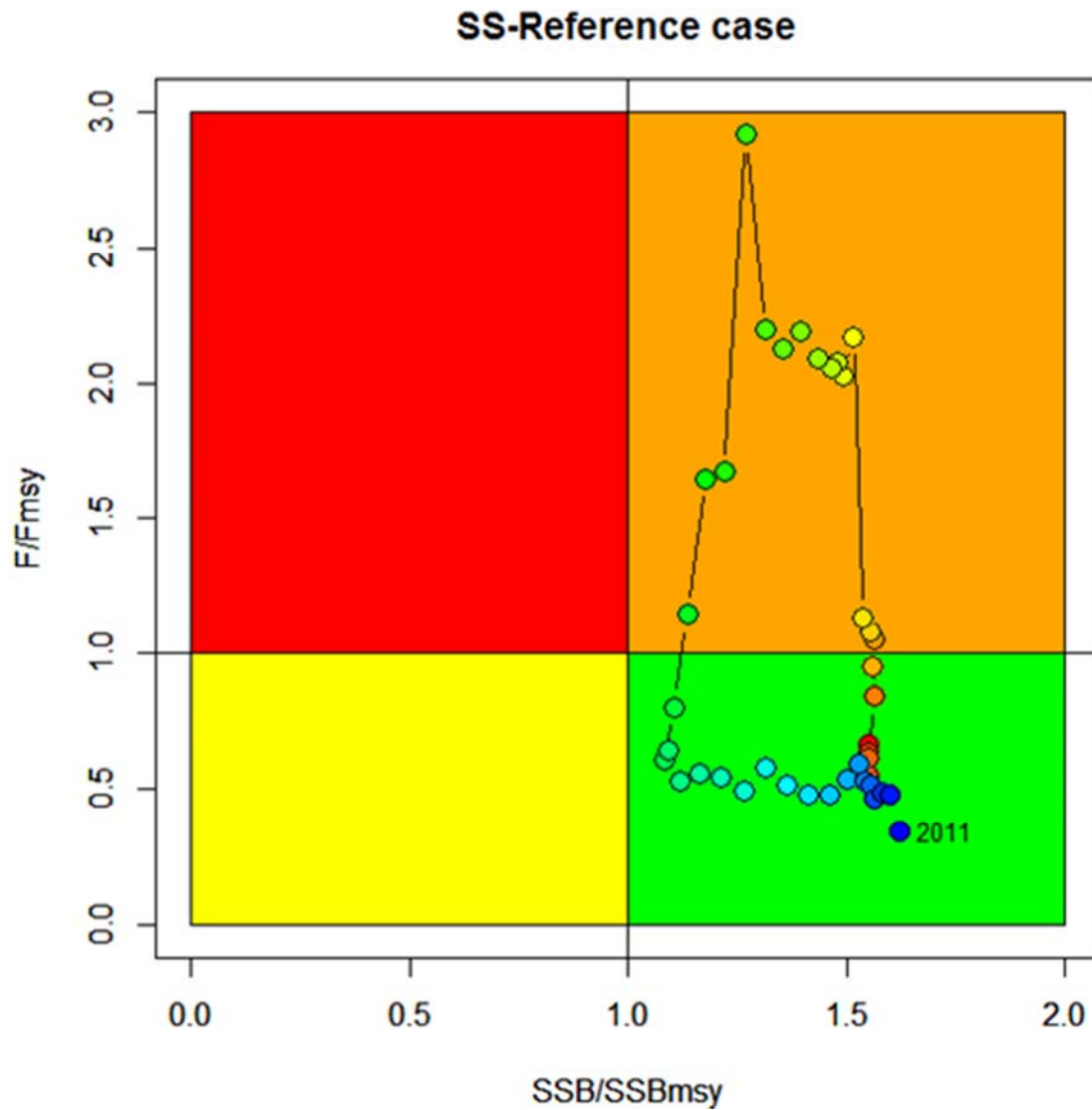


Figure 35. Kobe bar plots showing the range of terminal year values for alternative SS runs that explored the main axes of uncertainties. The total number of runs was 1080. Note that each run is not considered equally likely, thus percentages should not be interpreted as probabilities.

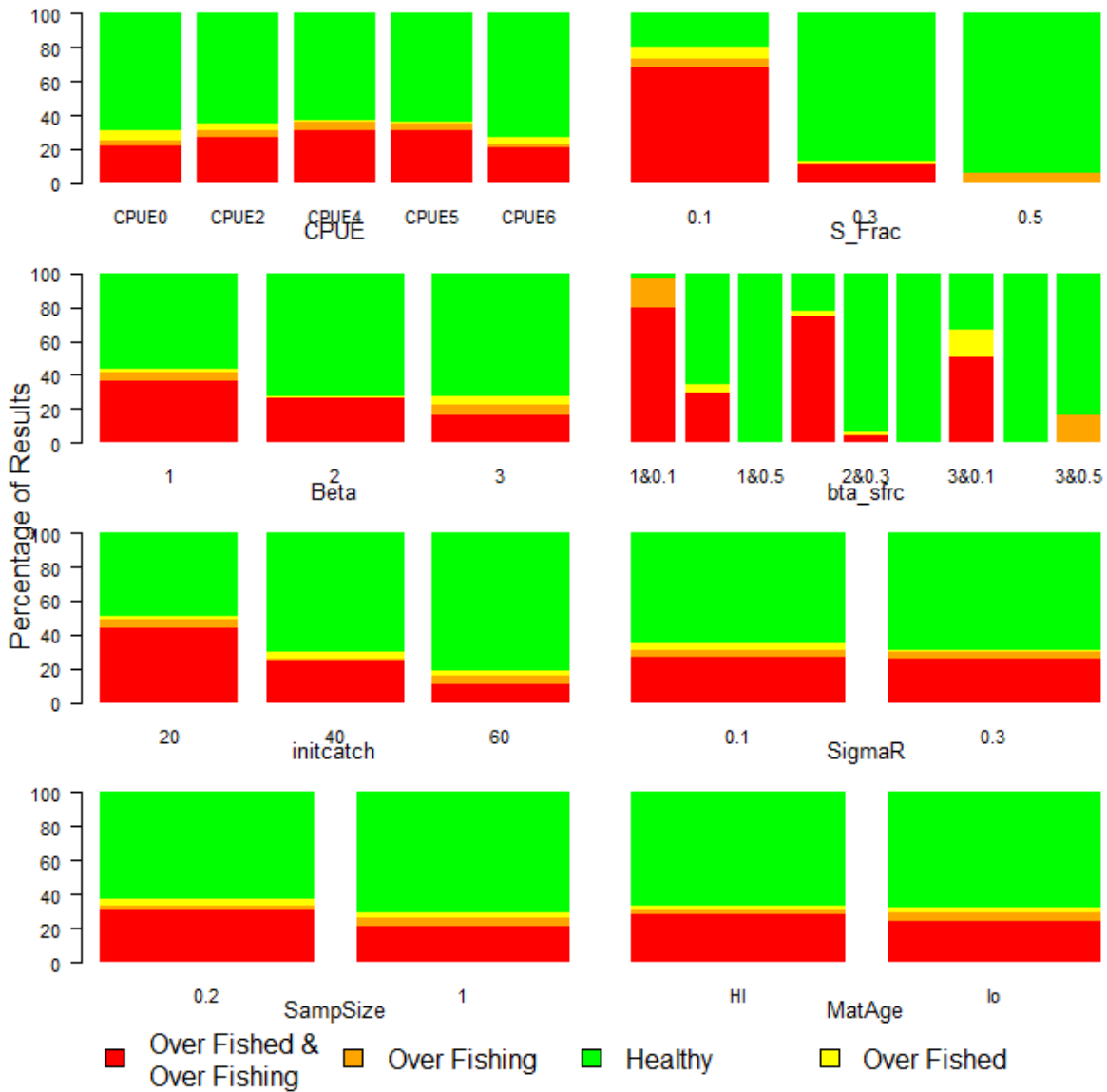


Figure 36. Five years retrospective analysis for the SS reference case.

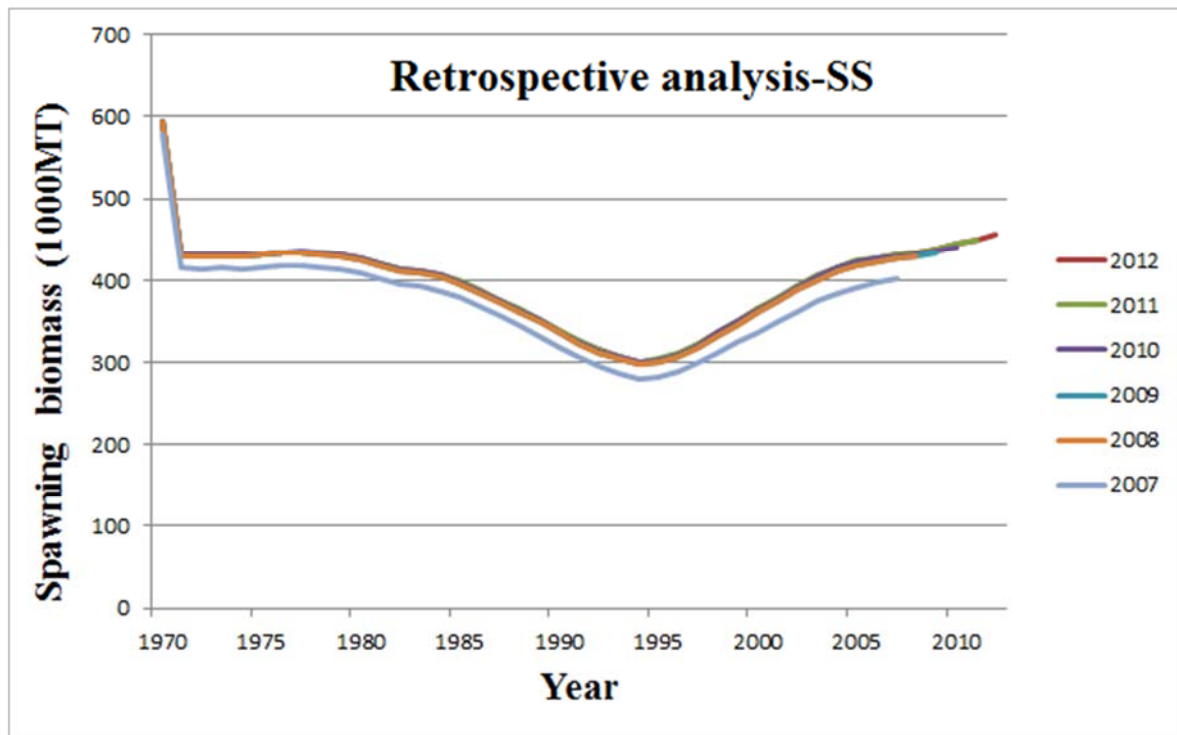
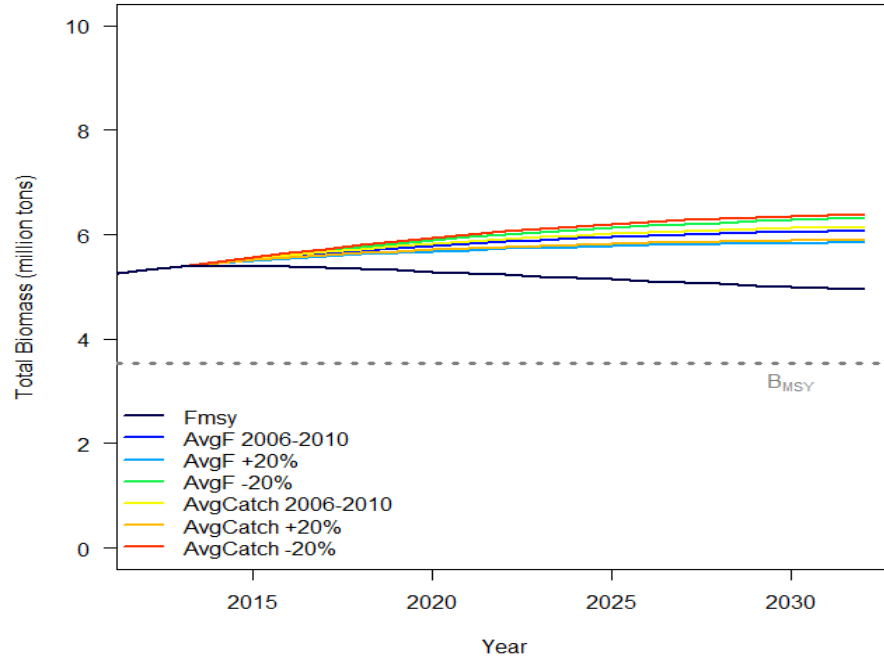


Figure 37. Comparison of future projected blue shark stock biomass under different constant catch (*status quo*, +20%, -20%) and constant F harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* catch and fishing mortality was based on the average from 2006-2010.



Appendix A. Additional diagnostics output for BSP model runs.

Table A1. Diagnostic statistics for model convergence of **JEJL** runs and **JL_Ref** run.

| Diagnostic statistics | JEJL_Ref | JEJL_R14A08 | JEJL_R43A08 | JEJL_Rsd03 | JEJL_Rsd07 | JEJL_R34A05 | JEJL_R34A10 | JEJL_Asd07 | JEJL_Asd09 | JEJL_R34Sh03 | JEJL_R34Sh06 |
|-----------------------|----------|-------------|-------------|------------|------------|-------------|-------------|------------|------------|--------------|--------------|
| Draws retained | 7032621 | 7516799 | 6707535 | 7601105 | 9657343 | 6490340 | 9655548 | 8479356 | 7332426 | 9701548 | 9993432 |
| CV(weight) | 69.72 | 80.32 | 73.87 | 75.57 | 100.37 | 96.83 | 77.99 | 87.97 | 95.06 | 82.60 | 132.03 |
| CV(likelihood*prior) | 426.21 | 487.52 | 443.13 | 987.73 | 653.07 | 724.18 | 430.79 | 497.48 | 596.16 | 328.40 | 532.85 |
| %maximum weight | 0.64 | 0.74 | 0.74 | 0.46 | 0.84 | 0.72 | 0.73 | 0.50 | 0.87 | 0.85 | 0.81 |

| Diagnostic statistics | JEJL_R14A05 | JEJL_R14A10 | JEJL_R43A05 | JEJL_R43A10 | JEJL_R14Sh03 | JEJL_R14Sh06 | JEJL_R43Sh03 | JEJL_R43Sh06 | JEJL_2012 | JL_Ref |
|-----------------------|-------------|-------------|-------------|-------------|--------------|--------------|--------------|--------------|-----------|---------|
| Draws retained | 7395652 | 7530755 | 6135917 | 6943032 | 10487092 | 8883278 | 9186611 | 14742993 | 13883990 | 2461028 |
| CV(weight) | 95.64 | 73.64 | 107.67 | 75.99 | 59.67 | 109.86 | 69.40 | 141.16 | 115.08 | 16.15 |
| CV(likelihood*prior) | 445.37 | 577.49 | 580.04 | 434.60 | 791.42 | 611.97 | 341.08 | 636.43 | 629.88 | 504.94 |
| %maximum weight | 0.62 | 0.88 | 0.91 | 0.79 | 0.29 | 0.90 | 0.57 | 0.73 | 0.69 | 0.26 |

Table A2. Diagnostic statistics for model convergence of **JEHW** runs and **HW_Ref** run.

| Diagnostic statistics | JEHW_Ref | JEHW_R14A08 | JEHW_R43A08 | JEHW_Rsd03 | JEHW_Rsd07 | JEHW_R34A05 | JEHW_R34A10 | JEHW_Asd07 | JEHW_Asd09 | JEHW_R34Sh03 | JEHW_R34Sh06 |
|-----------------------|----------|-------------|-------------|------------|------------|-------------|-------------|------------|------------|--------------|--------------|
| Draws retained | 7505521 | 7183609 | 7018950 | 8025877 | 7496731 | 6509690 | 7861762 | 6531042 | 5310240 | 8408927 | 7287085 |
| CV(weight) | 22.04 | 21.49 | 19.72 | 14.54 | 31.42 | 34.35 | 15.99 | 30.85 | 41.58 | 9.93 | 30.25 |
| CV(likelihood*prior) | 213.04 | 172.21 | 225.45 | 248.18 | 208.34 | 317.27 | 197.25 | 871.87 | 222.52 | 152.21 | 608.16 |
| %maximum weight | 0.16 | 0.14 | 0.15 | 0.06 | 0.23 | 0.46 | 0.08 | 0.38 | 0.70 | 0.03 | 0.14 |

| Diagnostic statistics | JEHW_R14A05 | JEHW_R14A10 | JEHW_R43A05 | JEHW_R43A10 | JEHW_R14Sh03 | JEHW_R14Sh06 | JEHW_R43Sh03 | JEHW_R43Sh06 | JEHW_2012 | HW_Ref |
|-----------------------|-------------|-------------|-------------|-------------|--------------|--------------|--------------|--------------|-----------|---------|
| Draws retained | 7232478 | 7117727 | 6018740 | 7385486 | 7472701 | 6664014 | 7848429 | 7001497 | 14970202 | 2682409 |
| CV(weight) | 48.15 | 17.16 | 44.22 | 17.45 | 10.48 | 34.18 | 10.71 | 36.36 | 21.09 | 2.47 |
| CV(likelihood*prior) | 275.29 | 170.19 | 332.67 | 190.97 | 160.44 | 253.80 | 151.23 | 689.30 | 270.84 | 40.21 |
| %maximum weight | 0.58 | 0.18 | 0.59 | 0.12 | 0.04 | 0.37 | 0.04 | 0.21 | 0.08 | 0.01 |

Table A3. Diagnostic statistics for model convergence of **JESP** runs and **SP_Ref** runs.

| Diagnostic statistics | JESP_Ref | JESP_R14A08 | JESP_R43A08 | JESP_Rsd03 | JESP_Rsd07 | JESP_R34A05 | JESP_R34A10 | JESP_Asd07 | JESP_Asd09 | JESP_R34Sh03 | JESP_R34Sh06 |
|-----------------------|----------|-------------|-------------|------------|------------|-------------|-------------|------------|------------|--------------|--------------|
| Draws retained | 4382007 | 4763509 | 4105030 | 4538257 | 10544890 | 3937815 | 4506974 | 4200221 | 10023559 | 4654898 | 4102016 |
| CV(weight) | 13.88 | 10.49 | 15.21 | 13.93 | 26.95 | 18.80 | 12.42 | 18.47 | 29.32 | 10.79 | 28.02 |
| CV(likelihood*prior) | 213.63 | 263.01 | 171.08 | 241.38 | 175.81 | 155.74 | 194.07 | 198.59 | 254.86 | 152.98 | 280.72 |
| %maximum weight | 0.09 | 0.06 | 0.10 | 0.05 | 0.19 | 0.13 | 0.07 | 0.11 | 0.23 | 0.06 | 0.14 |

| Diagnostic statistics | JESP_R14A05 | JESP_R14A10 | JESP_R43A05 | JESP_R43A10 | JESP_R14Sh03 | JESP_R14Sh06 | JESP_R43Sh03 | JESP_R43Sh06 | JESP_2012 | SP_Ref |
|-----------------------|-------------|-------------|-------------|-------------|--------------|--------------|--------------|--------------|-----------|---------|
| Draws retained | 11518278 | 4799626 | 9076741 | 4260408 | 4771248 | 4501509 | 4420447 | 14283021 | 4380359 | 5023545 |
| CV(weight) | 17.47 | 9.65 | 19.75 | 13.79 | 8.79 | 16.46 | 10.95 | 31.91 | 13.90 | 1.47 |
| CV(likelihood*prior) | 223.71 | 245.09 | 235.90 | 194.50 | 146.26 | 688.53 | 152.78 | 397.90 | 260.74 | 42.37 |
| %maximum weight | 0.16 | 0.04 | 0.05 | 0.11 | 0.02 | 0.13 | 0.05 | 0.07 | 0.09 | 0.002 |

Table A4. Diagnostic statistics for model convergence of **JETW** runs and **TW_Ref** run.

| Diagnostic statistics | JETW_Ref | JETW_R14A08 | JETW_R43A08 | JETW_Rsd03 | JETW_Rsd07 | JETW_R34A05 | JETW_R34A10 | JETW_Asd07 | JETW_Asd09 | JETW_R34Sh03 | JETW_R34Sh06 |
|-----------------------|----------|-------------|-------------|------------|------------|-------------|-------------|------------|------------|--------------|--------------|
| Draws retained | 4330153 | 4696591 | 4109513 | 4423078 | 4240815 | 4079840 | 4421797 | 4133031 | 3966219 | 4433422 | 4119671 |
| CV(weight) | 7.33 | 4.78 | 8.02 | 8.00 | 9.49 | 9.21 | 6.64 | 12.81 | 25.05 | 5.44 | 12.76 |
| CV(likelihood*prior) | 466.20 | 125.63 | 142.01 | 616.35 | 263.61 | 162.34 | 193.30 | 144.87 | 142.75 | 165.39 | 742.46 |
| %maximum weight | 0.04 | 0.01 | 0.04 | 0.03 | 0.10 | 0.03 | 0.02 | 0.06 | 0.35 | 0.02 | 0.03 |

| Diagnostic statistics | JETW_R14A05 | JETW_R14A10 | JETW_R43A05 | JETW_R43A10 | JETW_R14Sh03 | JETW_R14Sh06 | JETW_R43Sh03 | JETW_R43Sh06 | JETW_2012 | TW_Ref |
|-----------------------|-------------|-------------|-------------|-------------|--------------|--------------|--------------|--------------|-----------|---------|
| Draws retained | 4571729 | 4741956 | 3779672 | 5067917 | 4708204 | 4471709 | 4223236 | 3936527 | 6365115 | 4370889 |
| CV(weight) | 5.80 | 4.40 | 10.19 | 7.28 | 3.97 | 6.88 | 5.63 | 15.48 | 64.66 | 1.19 |
| CV(likelihood*prior) | 121.62 | 118.00 | 167.12 | 117.25 | 83.20 | 177.58 | 115.95 | 363.43 | 455.15 | 40.04 |
| %maximum weight | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 | 0.01 | 0.02 | 0.04 | 0.72 | 0.001 |

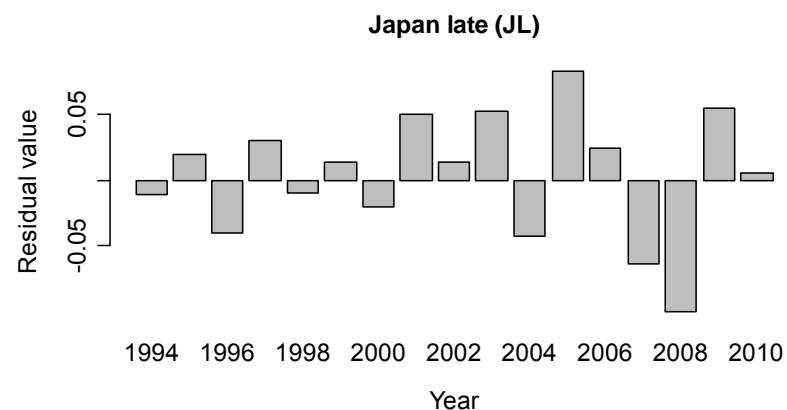
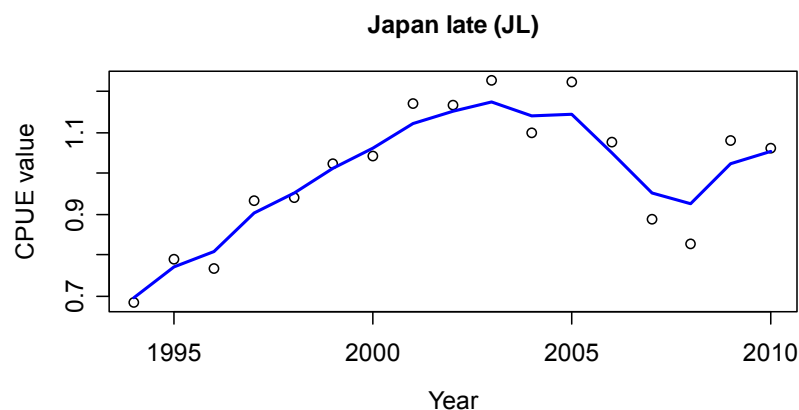
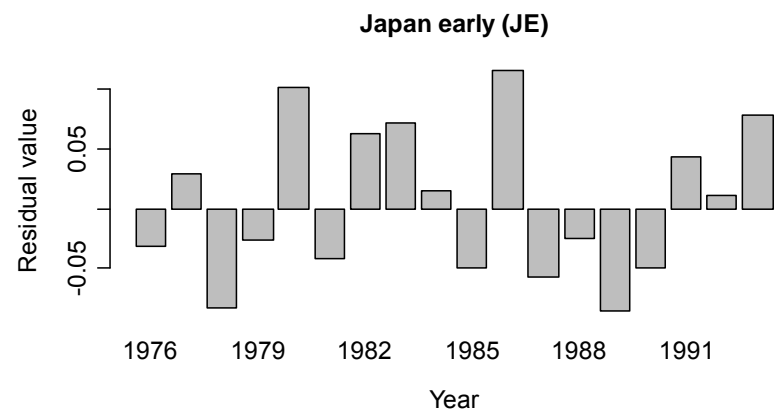
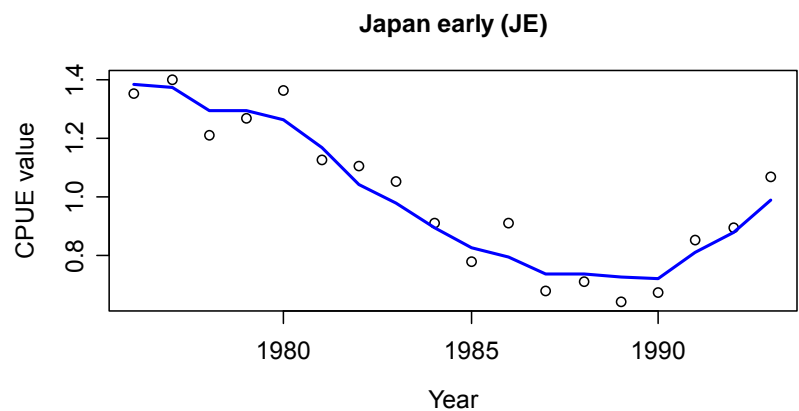


Figure A1. Model fits to the standardized CPUE indices used in the BSP blue shark reference runs (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. (a) Fits for indices used in **JEJL_Ref** case. Top and bottom panels correspond to Japanese longline indices for early (1976-1993) and late (1994-2010) periods, respectively.

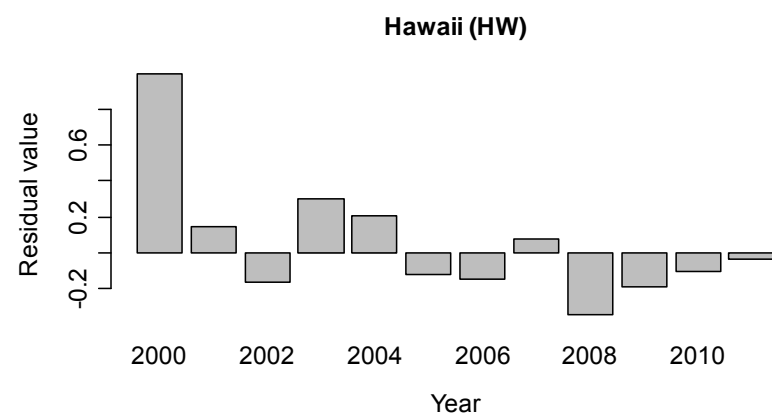
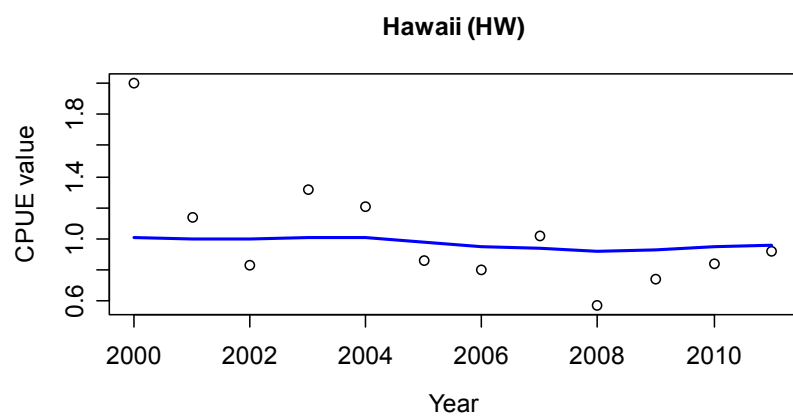
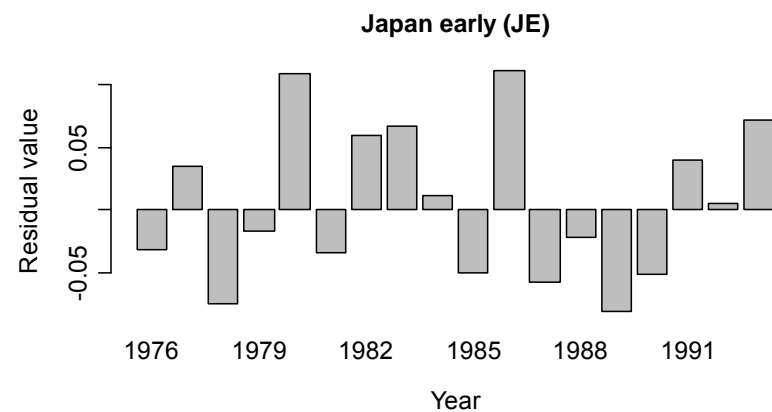
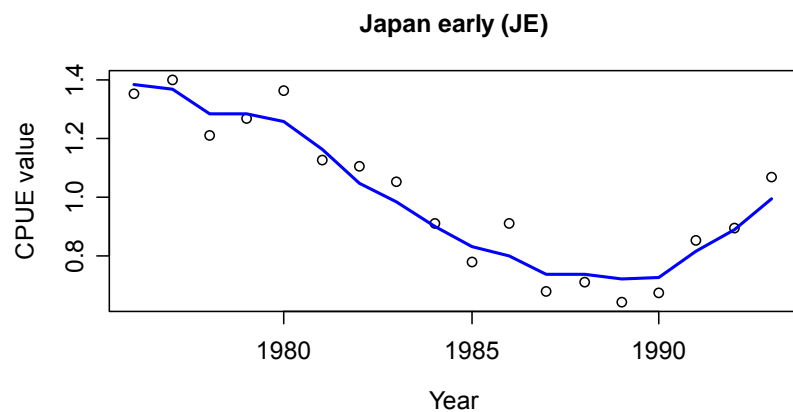


Figure A1. (b) Fits for indices used in the **JEHW_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and Hawaii longline index for 2000-2011, respectively.

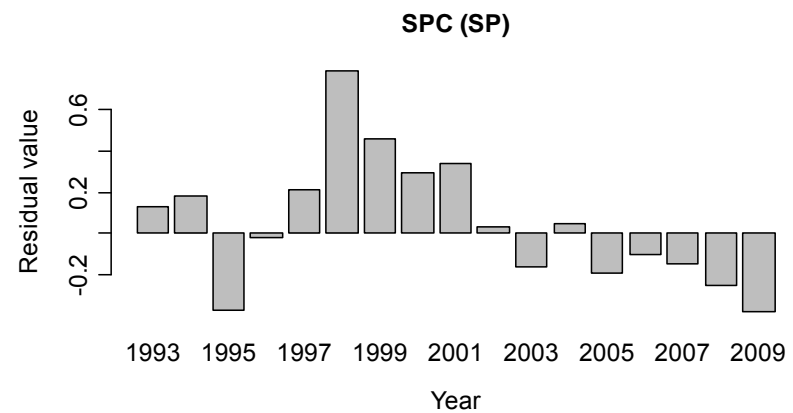
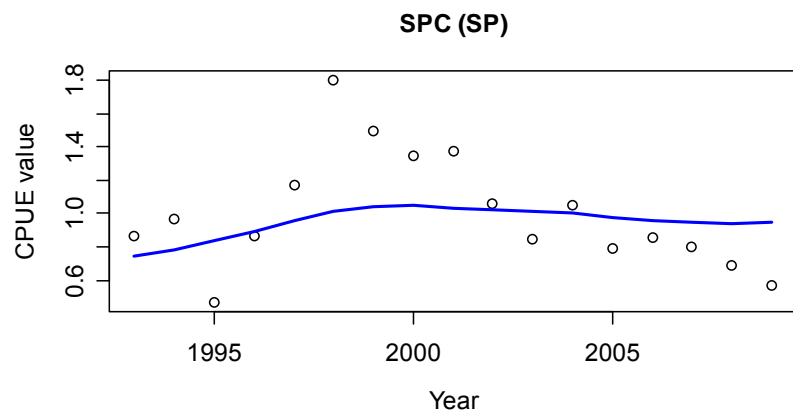
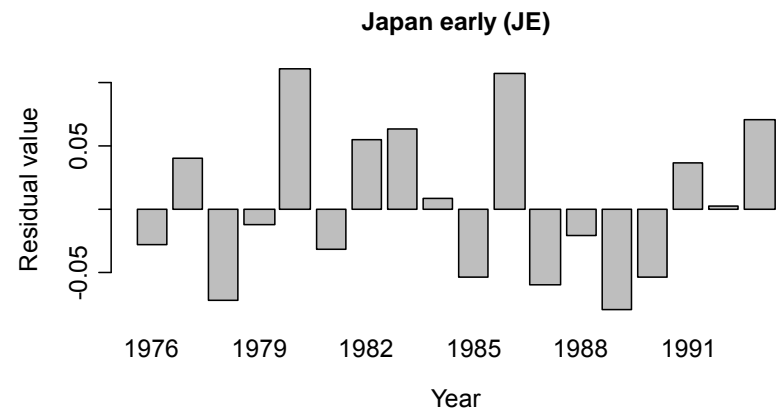
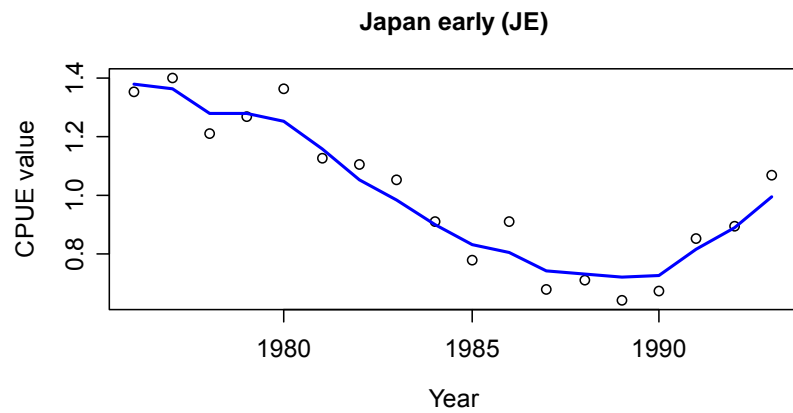


Figure A1. (c) Fits for indices used in the **JESP_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and SPC longline index for 1993-2009, respectively.

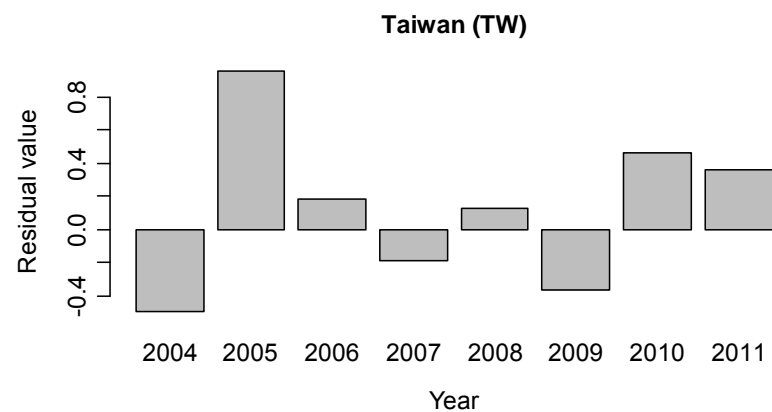
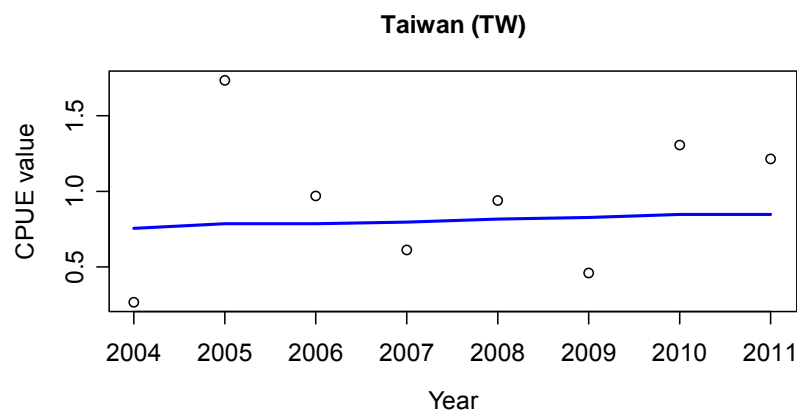
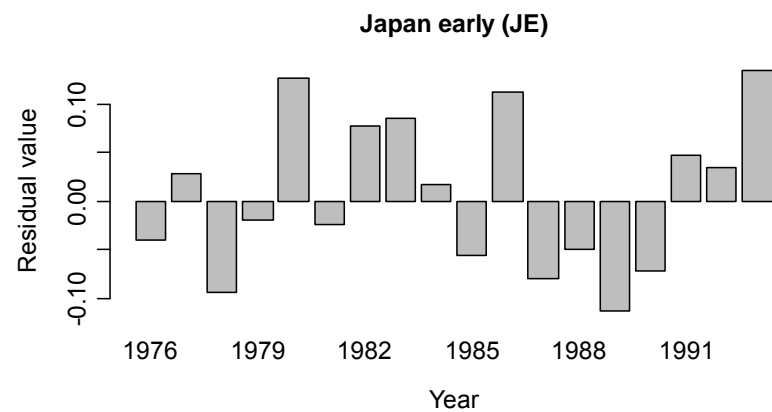
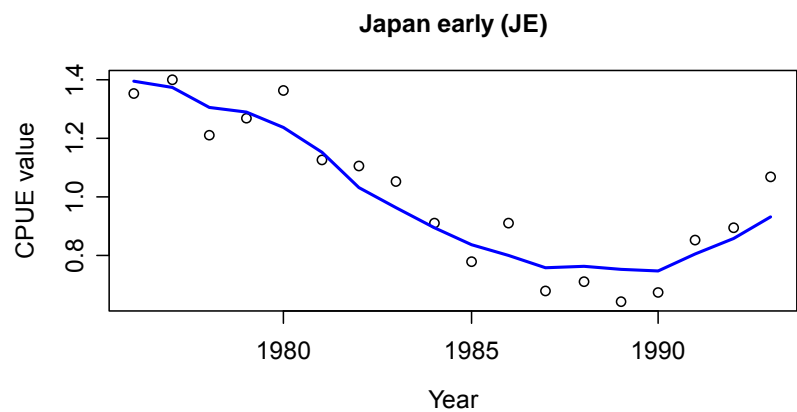


Figure A1. (d) Fits for indices used in the **JETW_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and Taiwan longline index for 2004-2011, respectively.

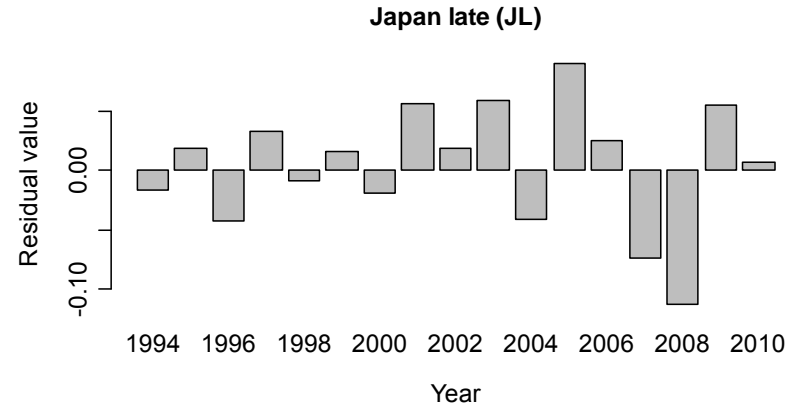
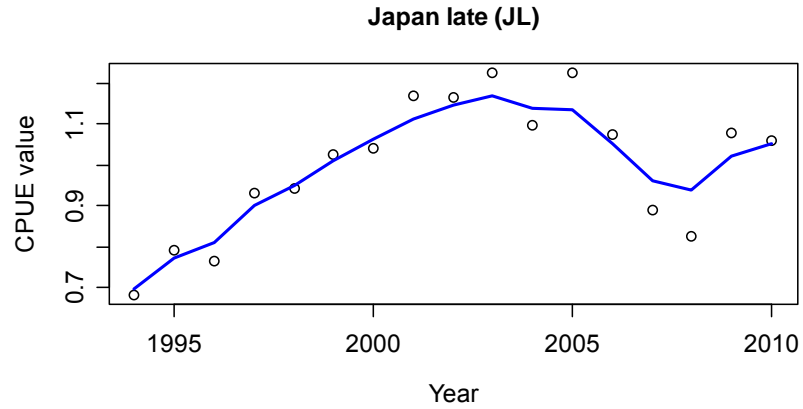


Figure A1. (e) Fits to the index used in the **JL_Ref** case. Panels correspond to the Japanese longline index for the late period (1994-2010).

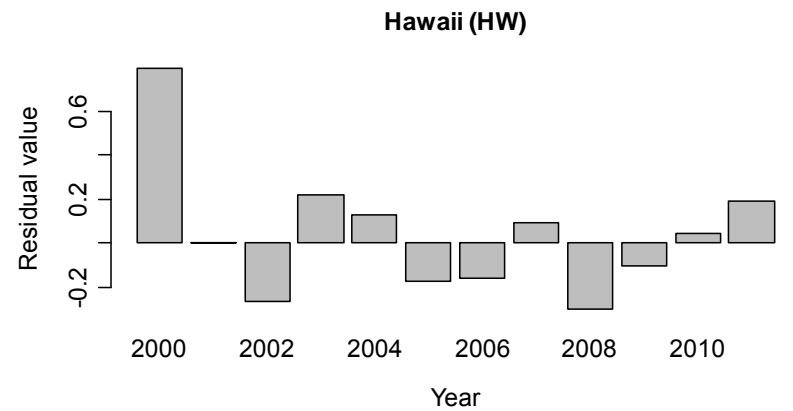
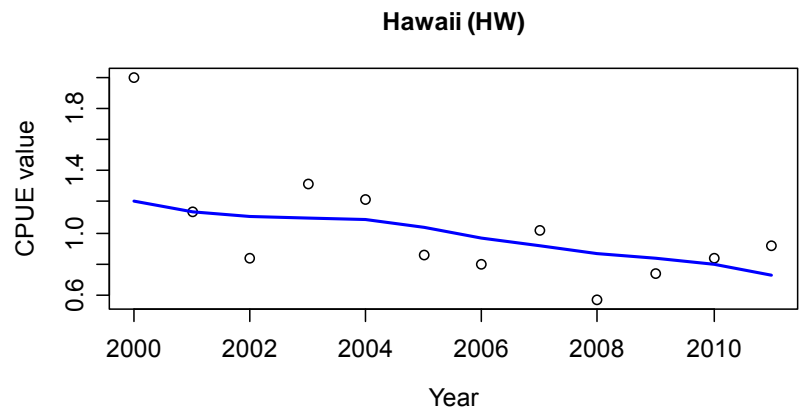


Figure A1. (f) Fits for the index used in the **HW_Ref** case. Panels correspond to the Hawaii longline index for 2000-2011.

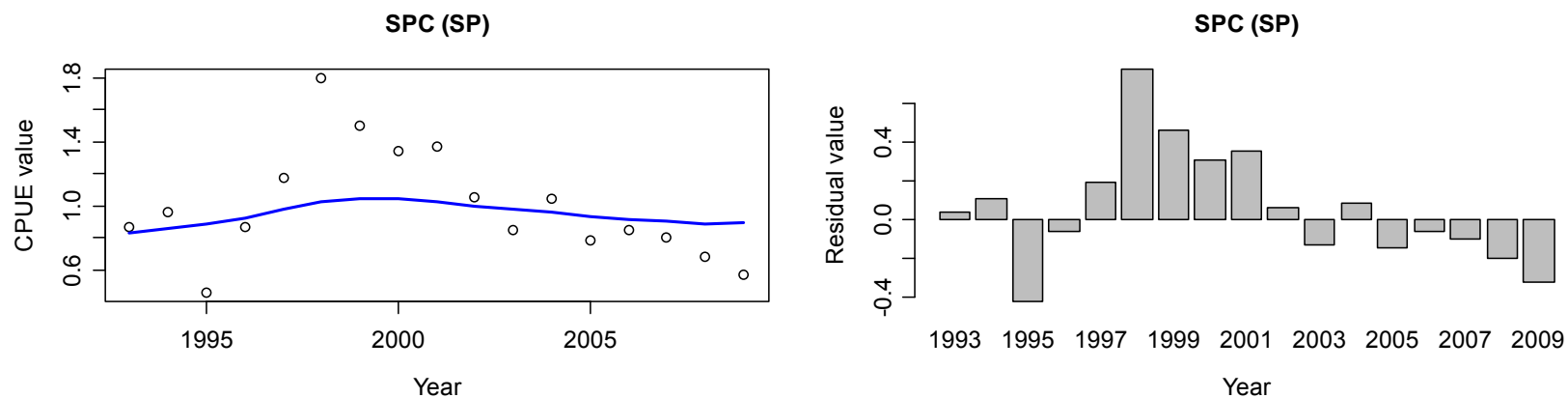


Figure A1. (g) Fits to the index used in the **SP_Ref** case. Panels correspond to the SPC longline index for 1993-2009.

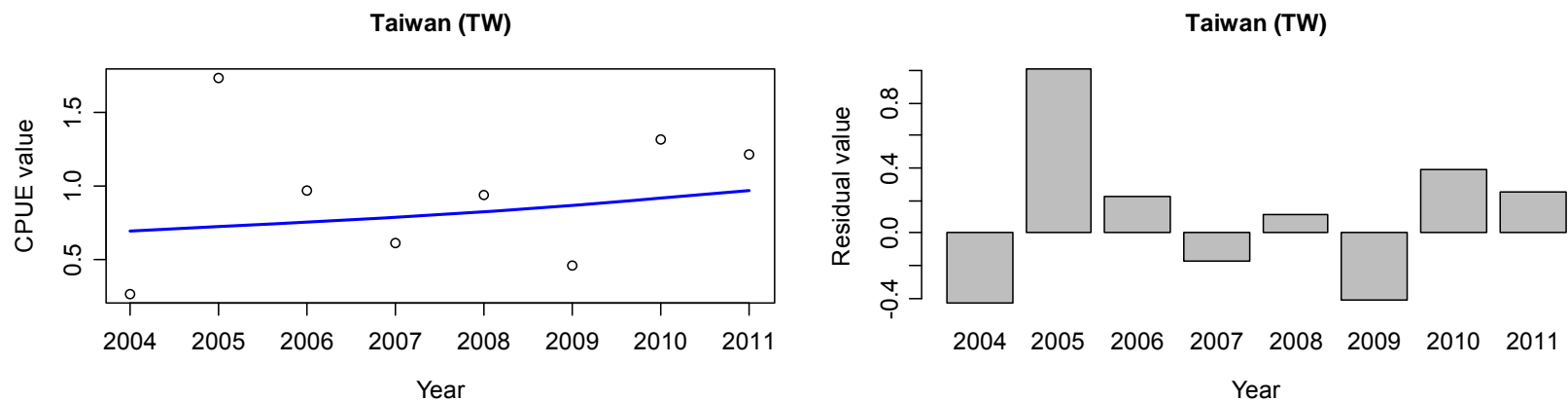


Figure A1. (h) Fits to the index used in the **TW_Ref** case. Panels correspond to the Taiwan longline index for 2004-2011.

Appendix B. Summary of key outputs for the SS model runs using the JPN Early and JPN Late CPUE series combination (reference run).

Figure B1.

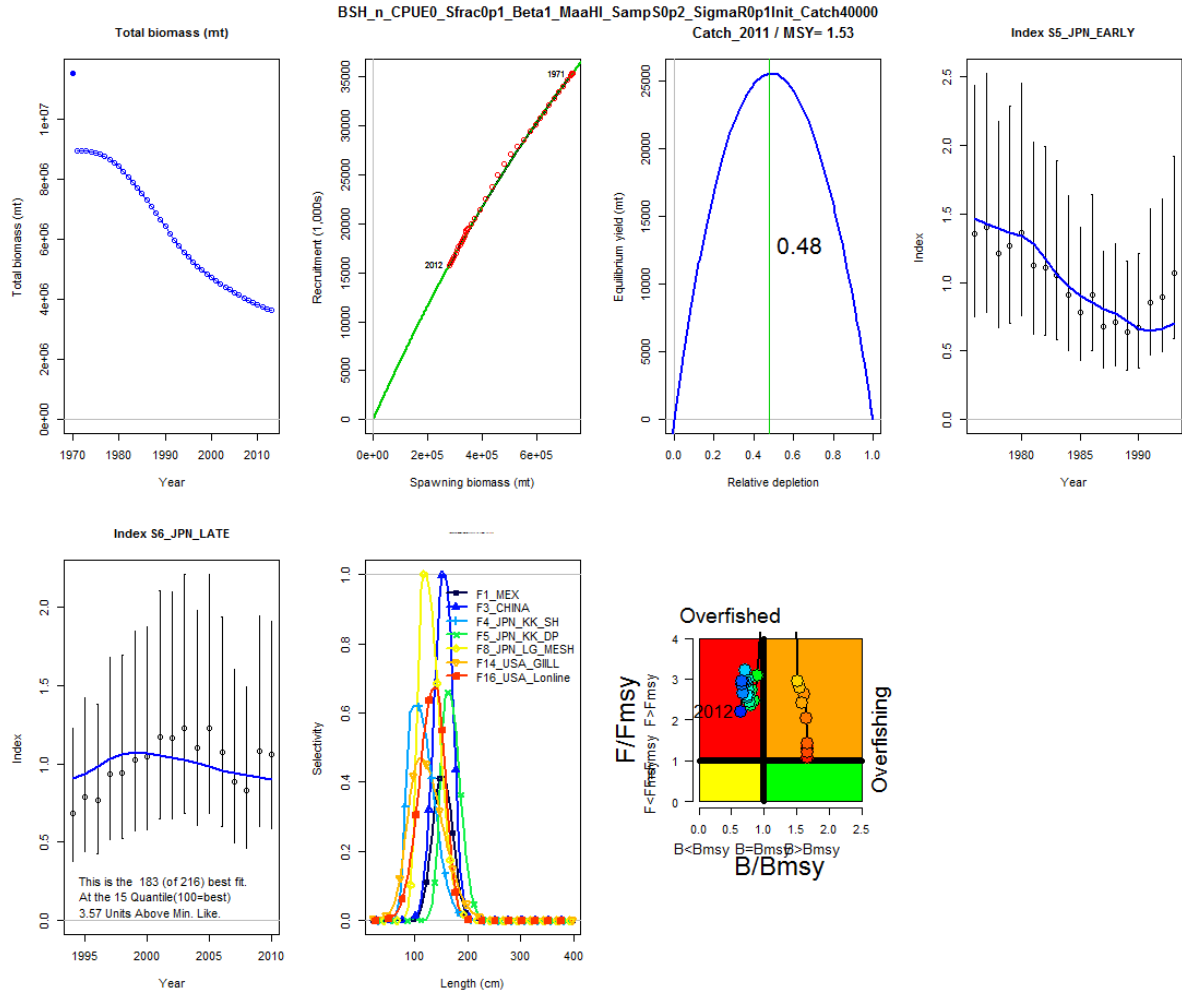


Figure B2.

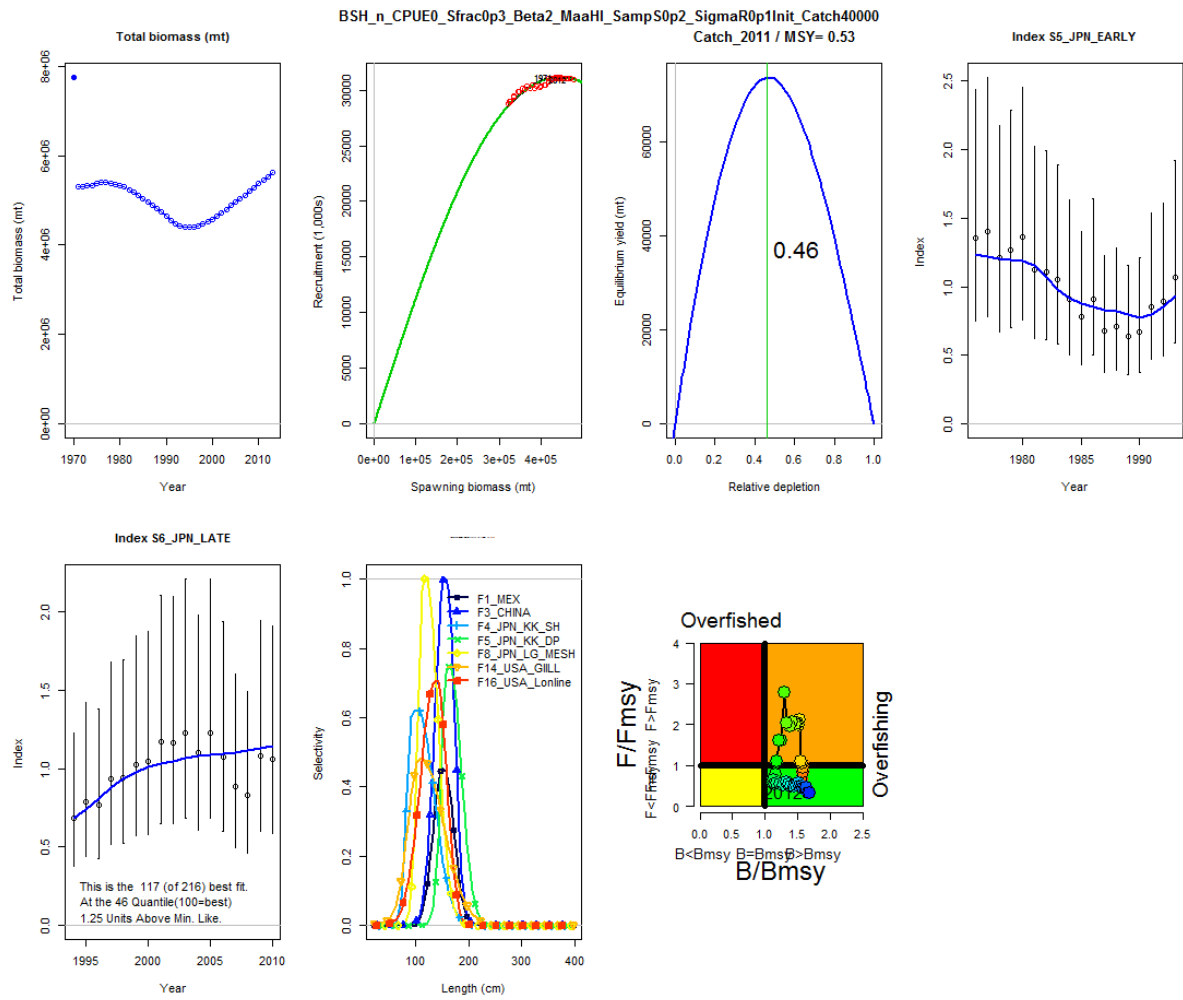


Figure B3.

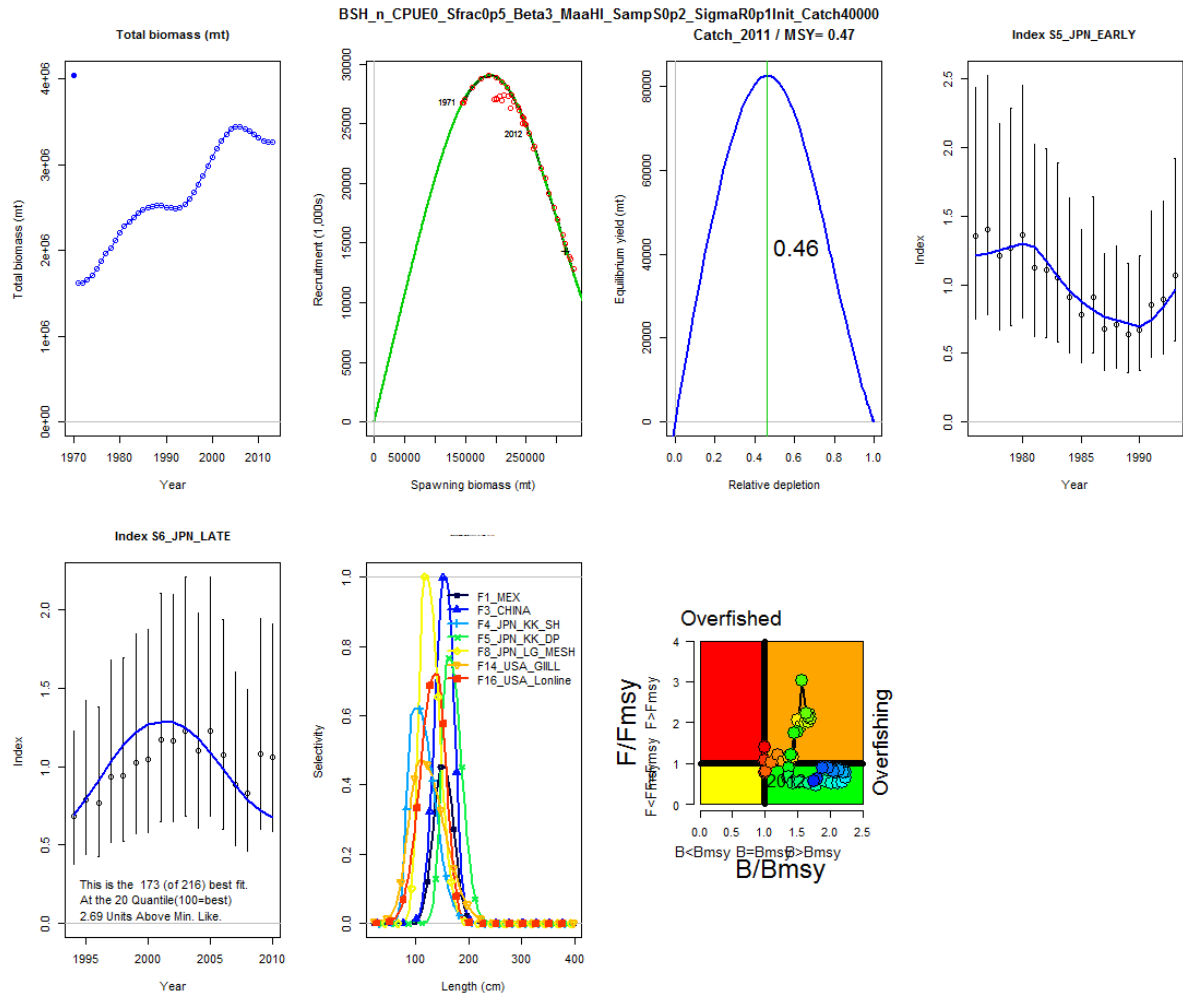
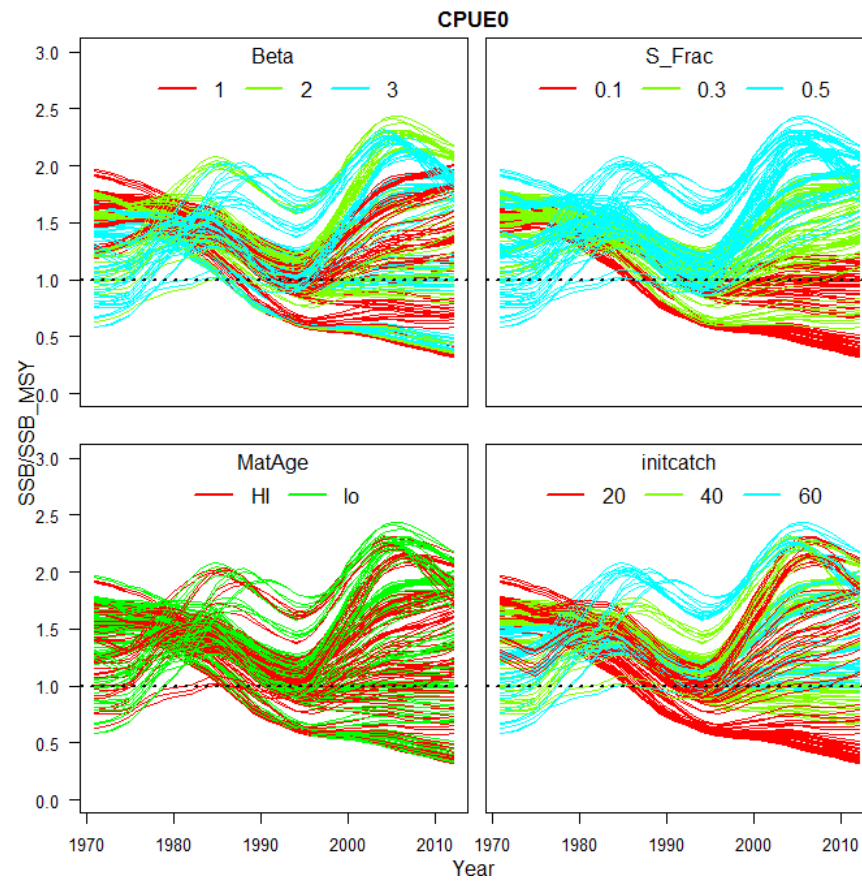


Figure B4.



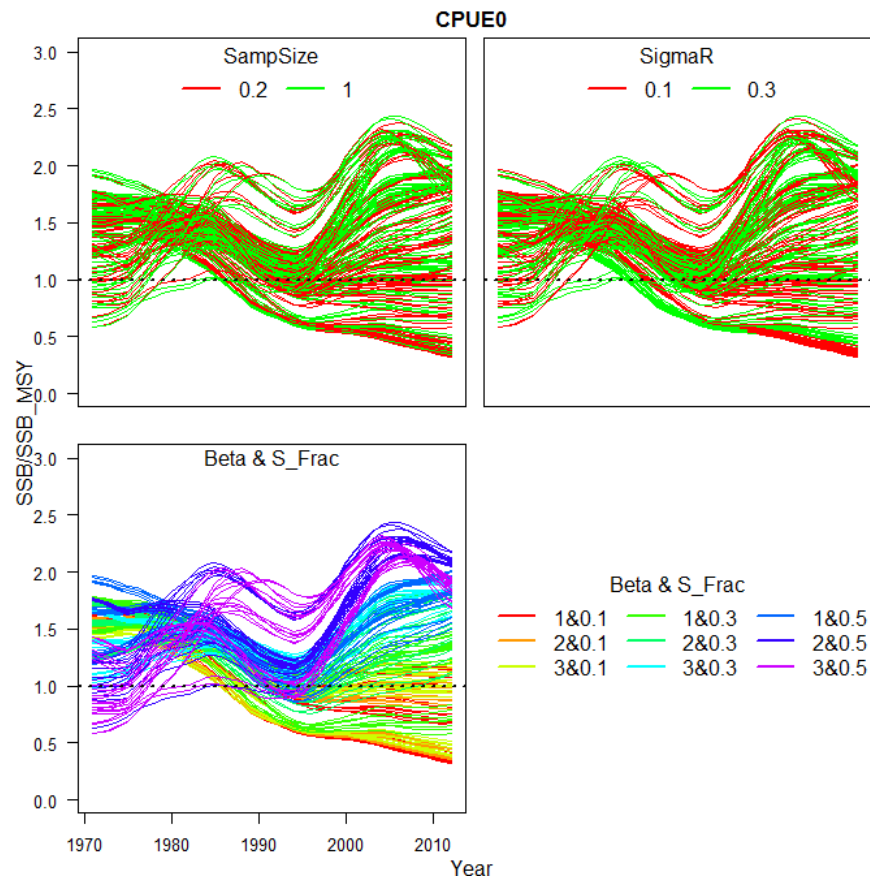


Figure B5.

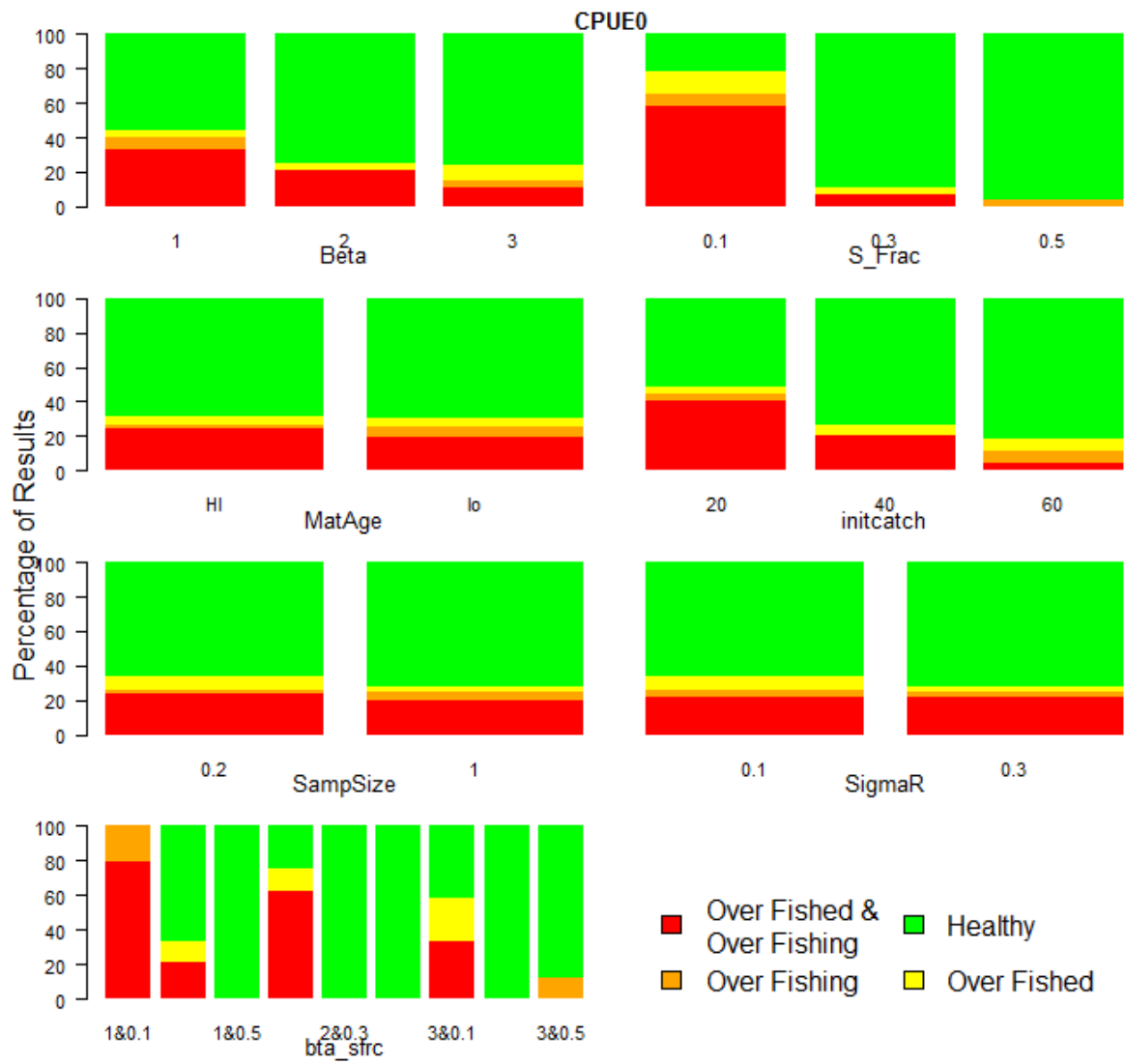
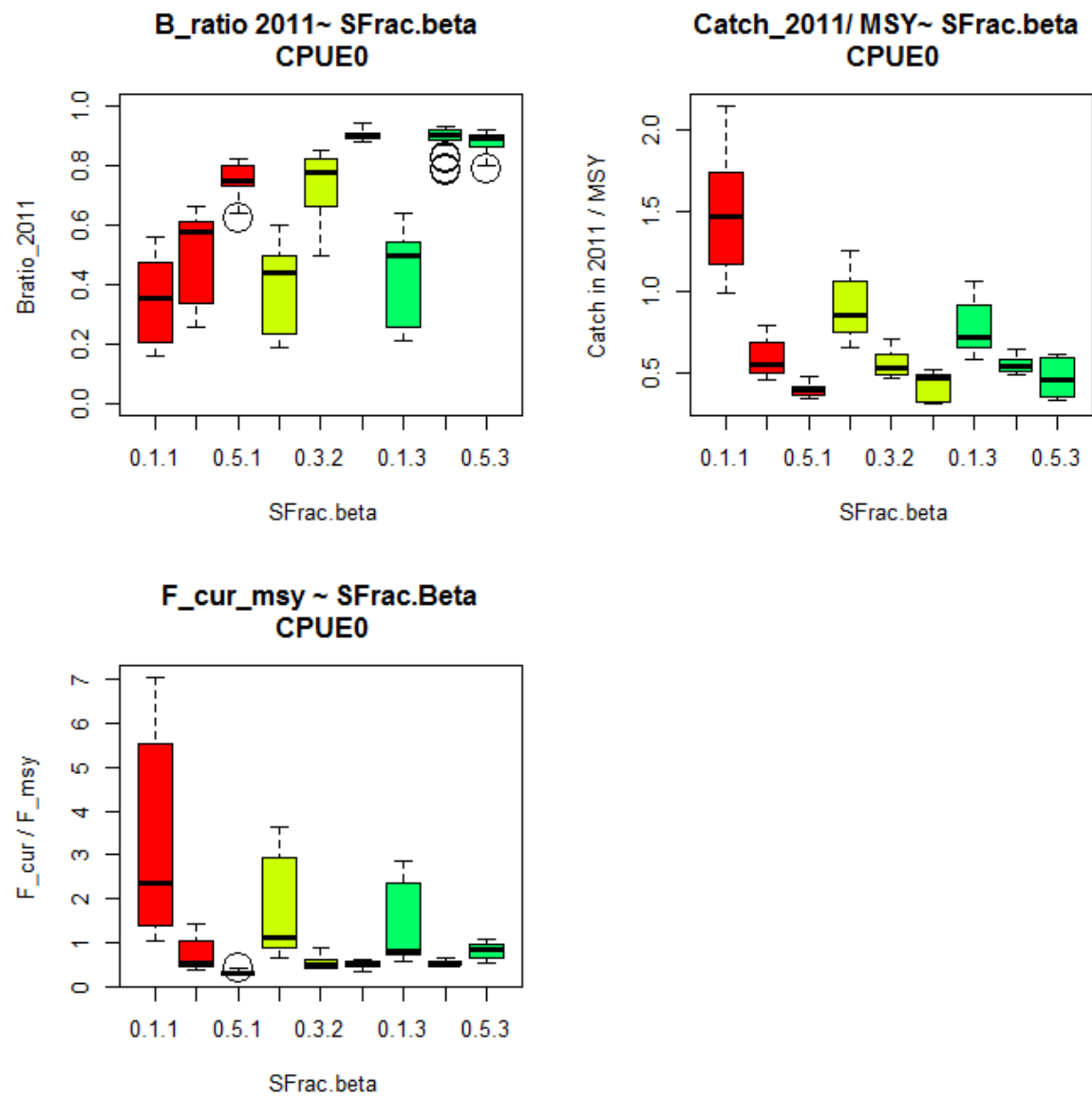


Figure B6.



Appendix C. Summary of key outputs for the SS model runs using the JPN Early and HW Deep Late CPUE series combination (CPUE2).

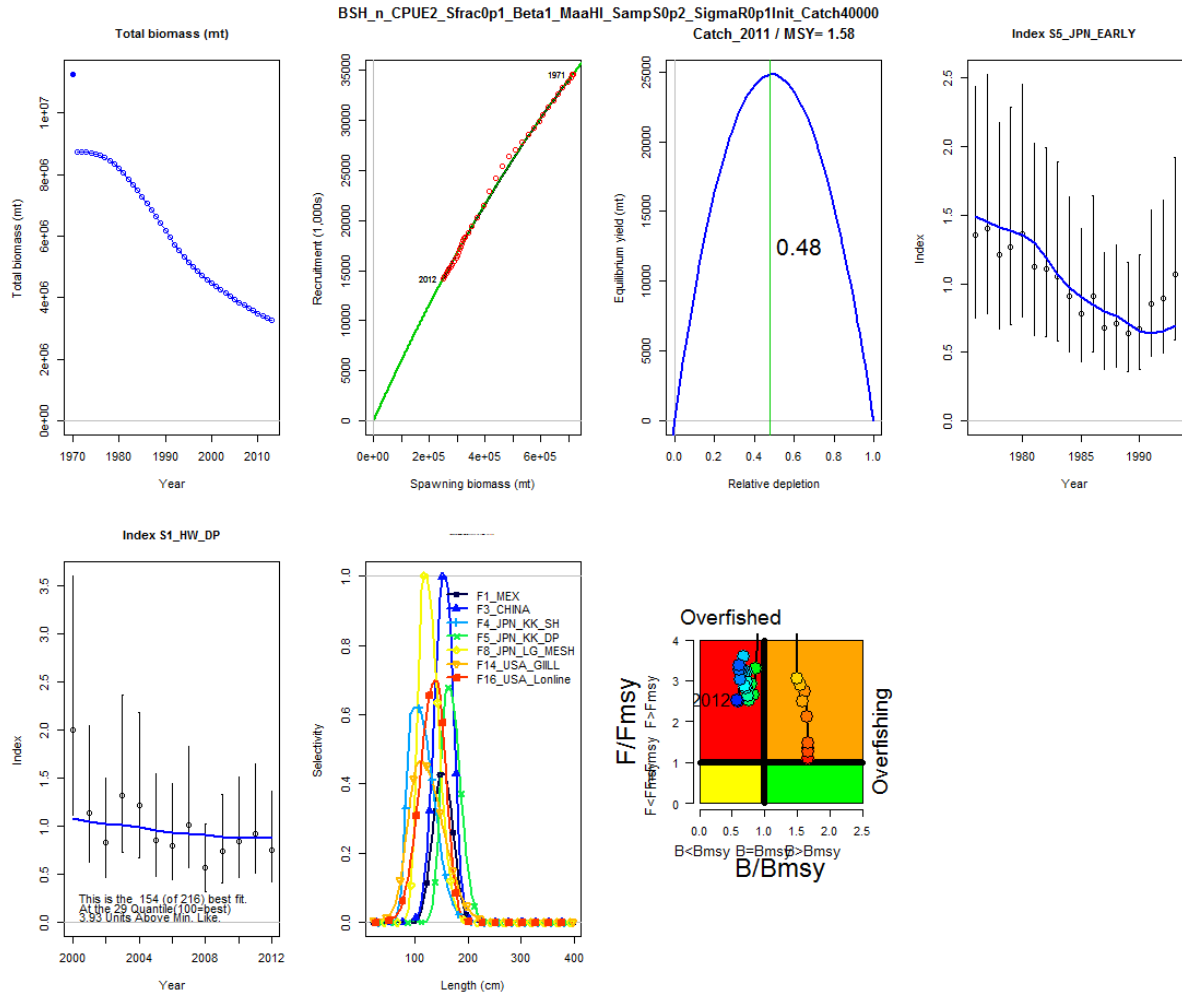


Figure C1.

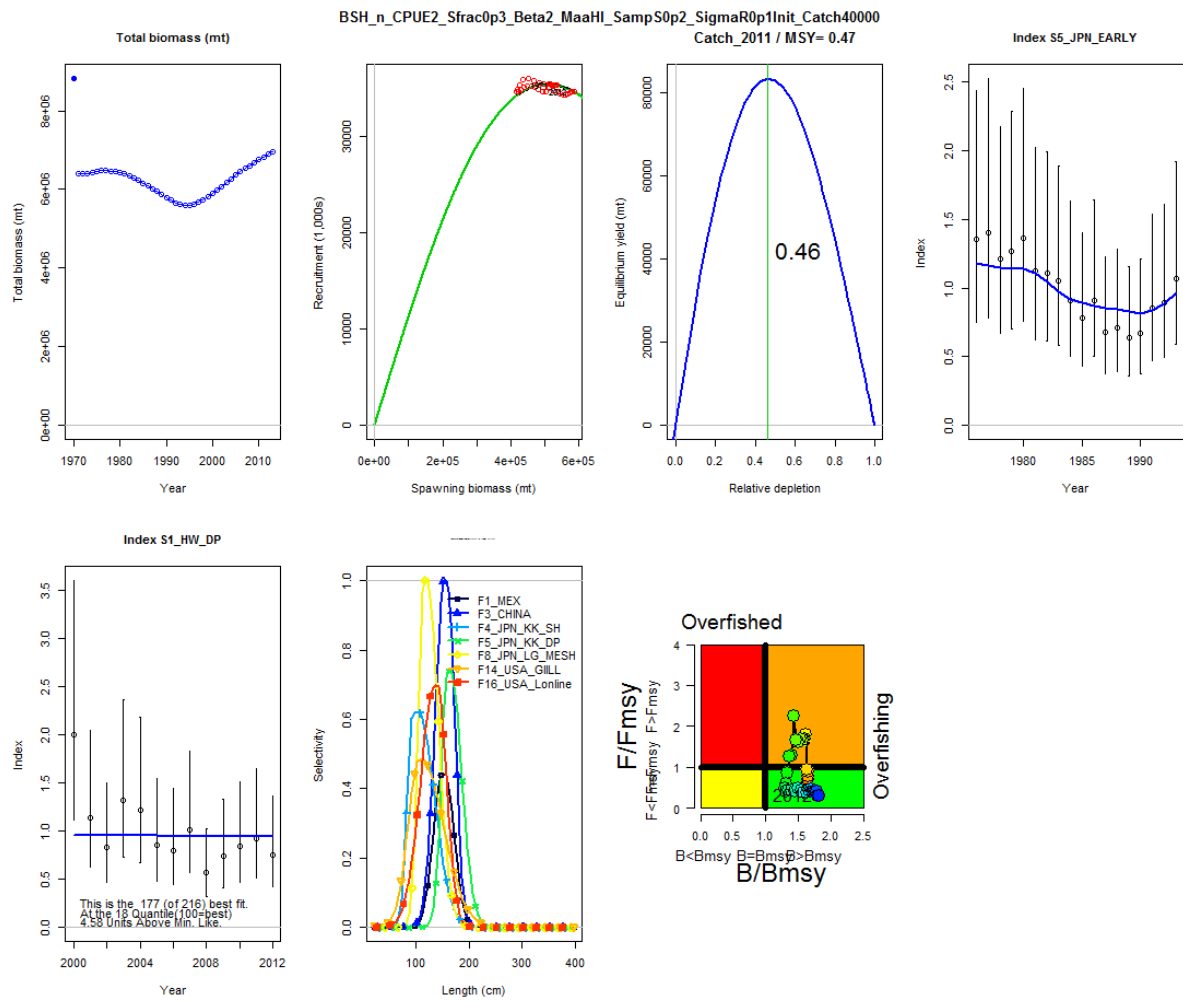


Figure C2.

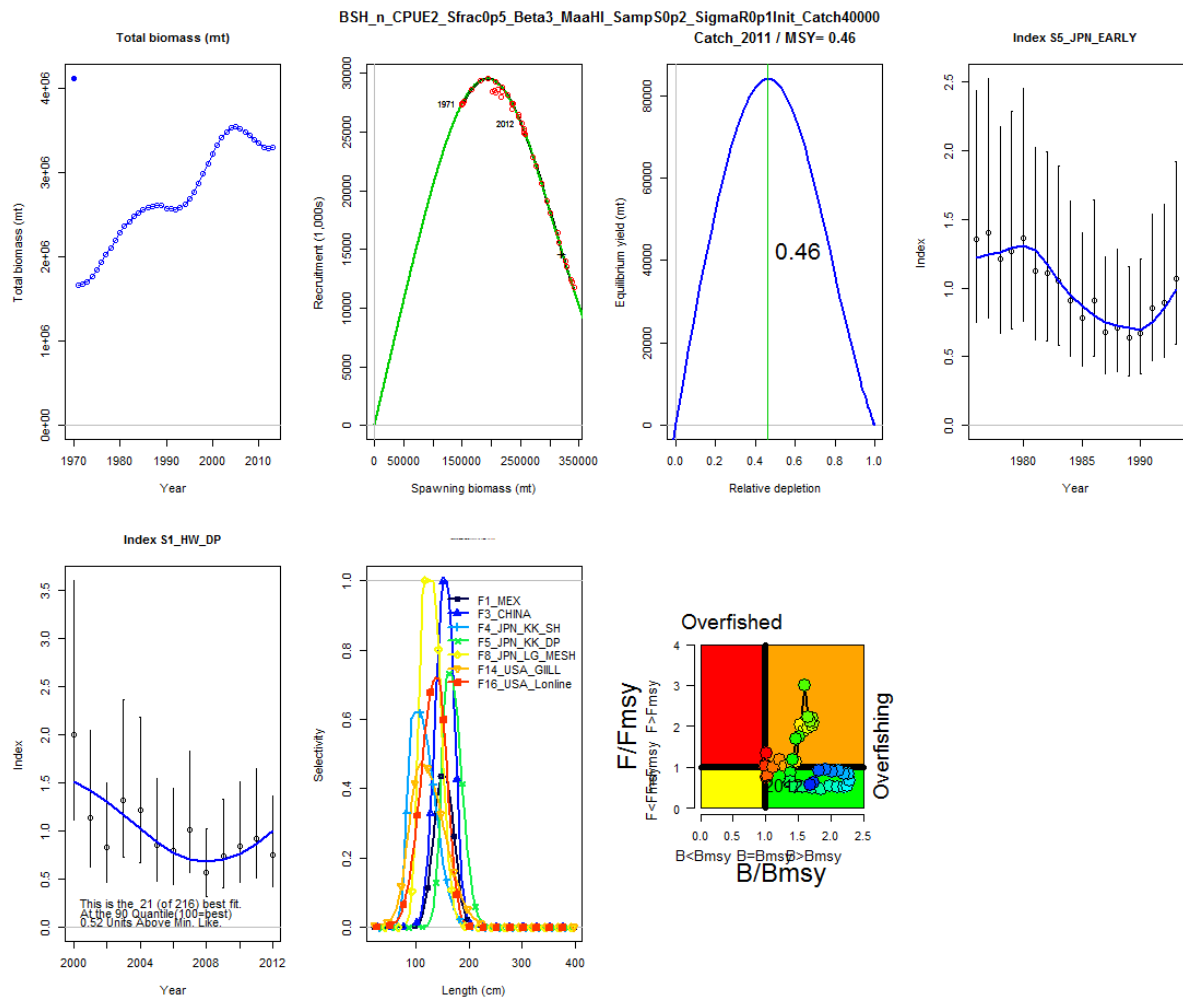
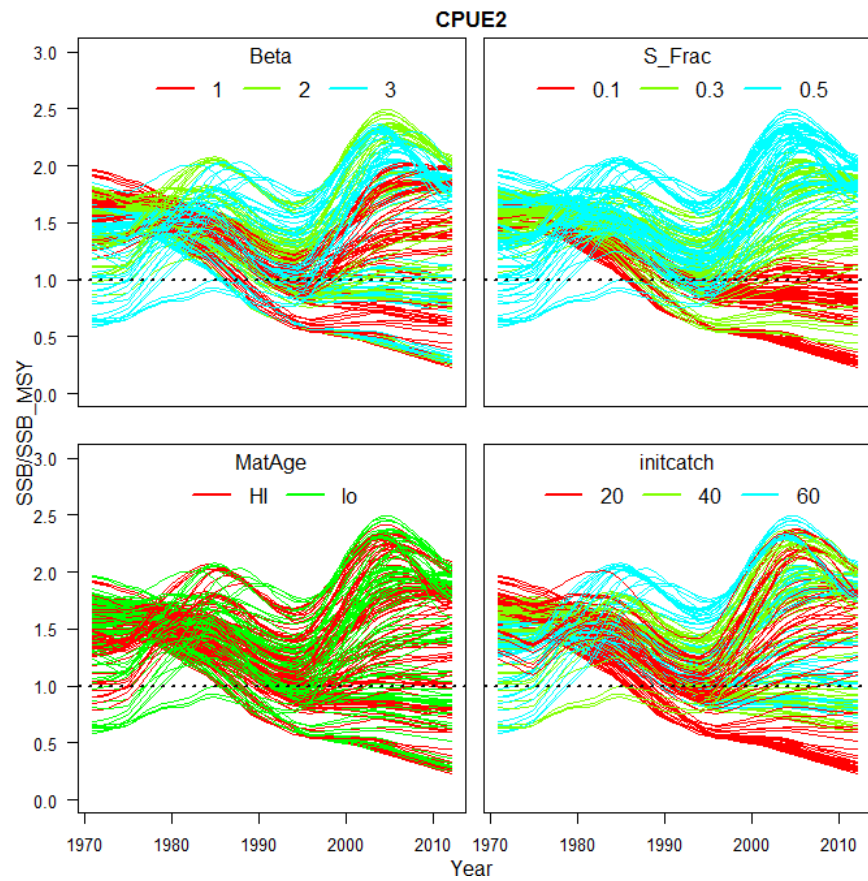


Figure C3.



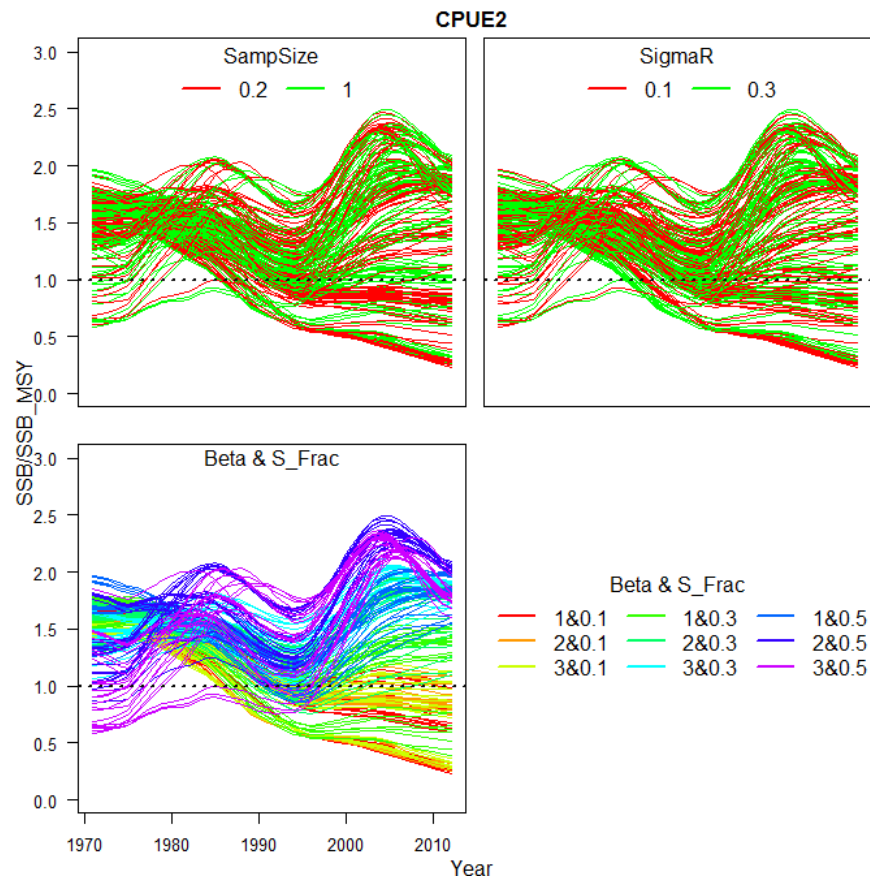


Figure C4.

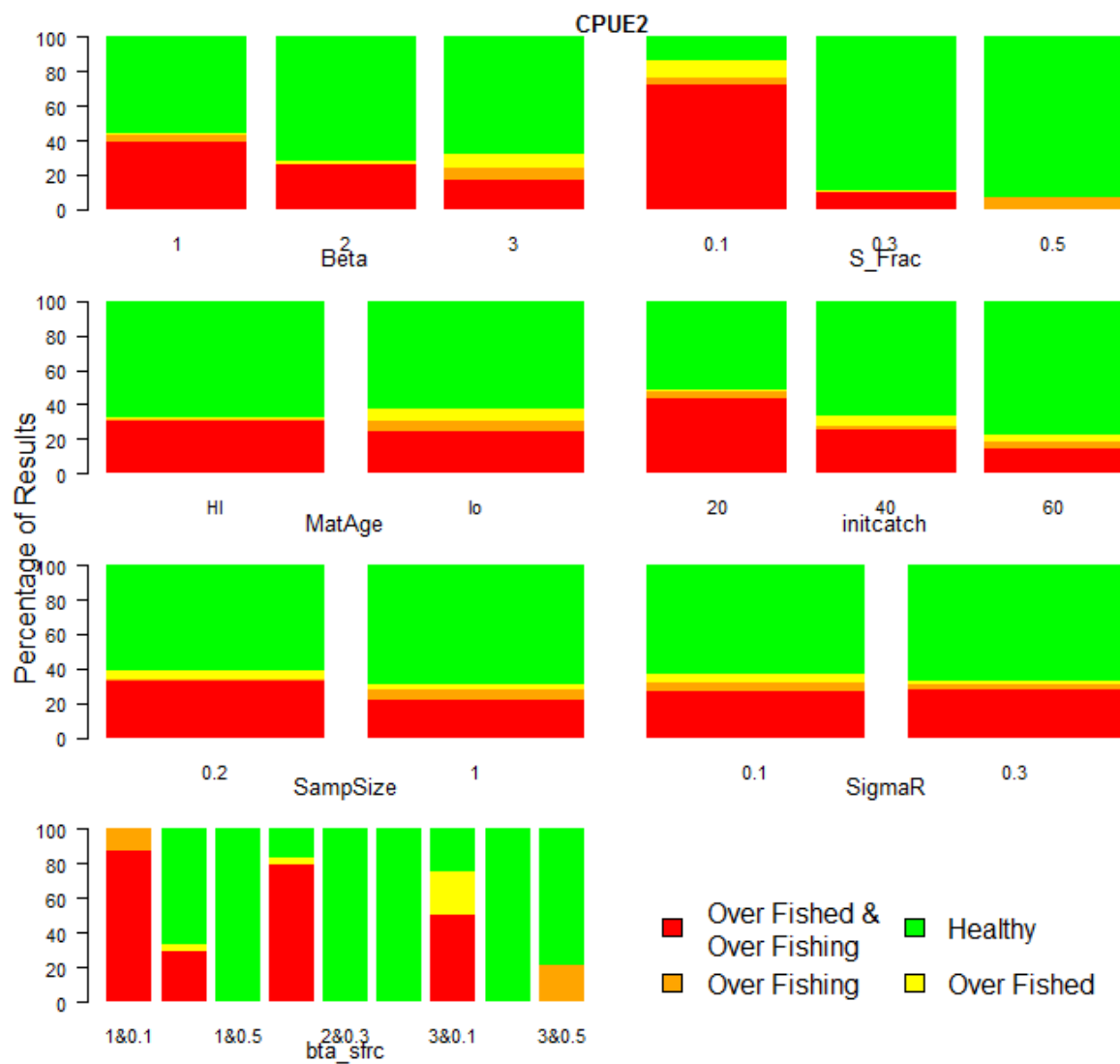


Figure C5.

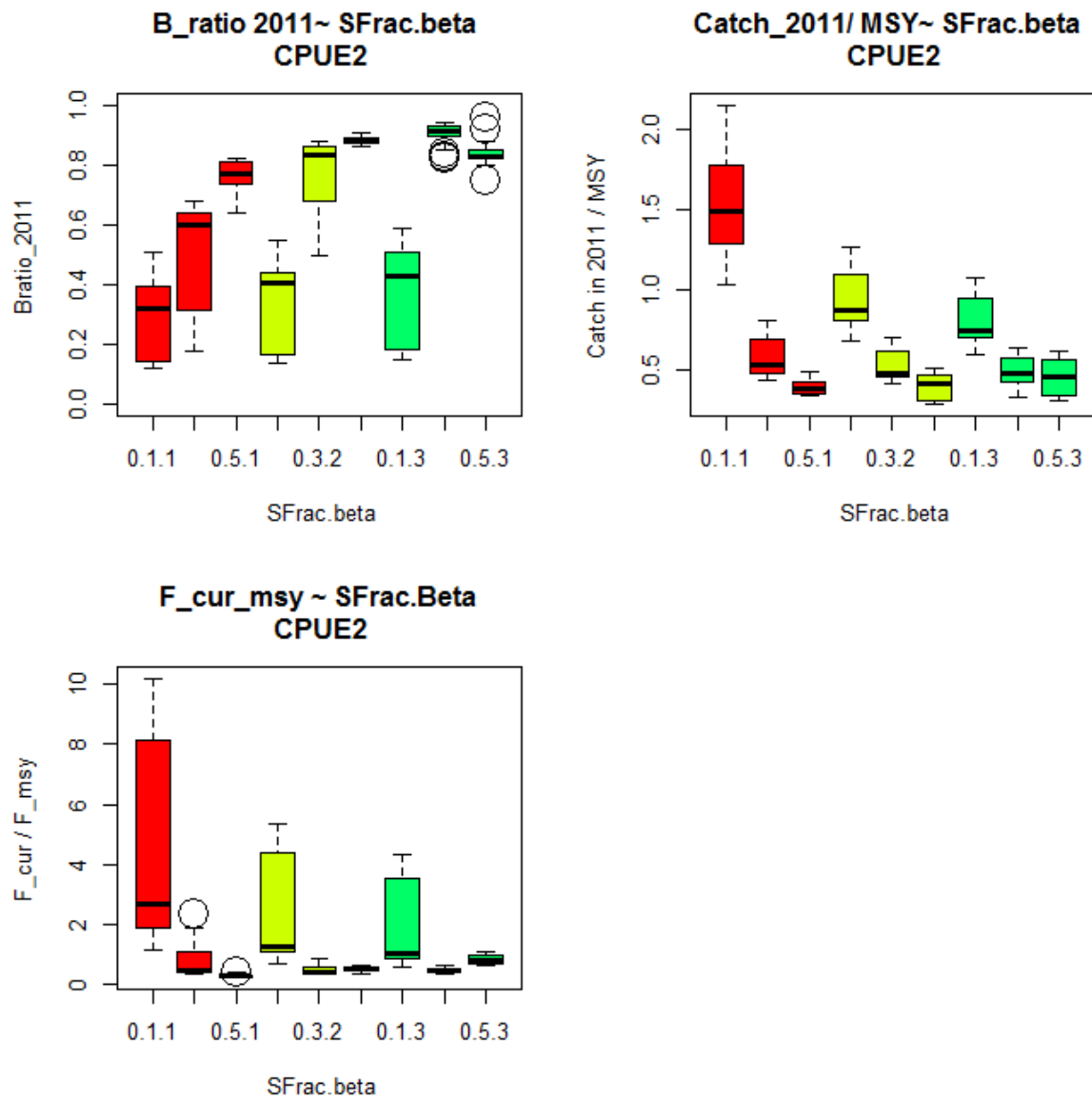


Figure C6.

Appendix D. Summary of key outputs for the SS model runs using the SPC CPUE series (CPUE 4).

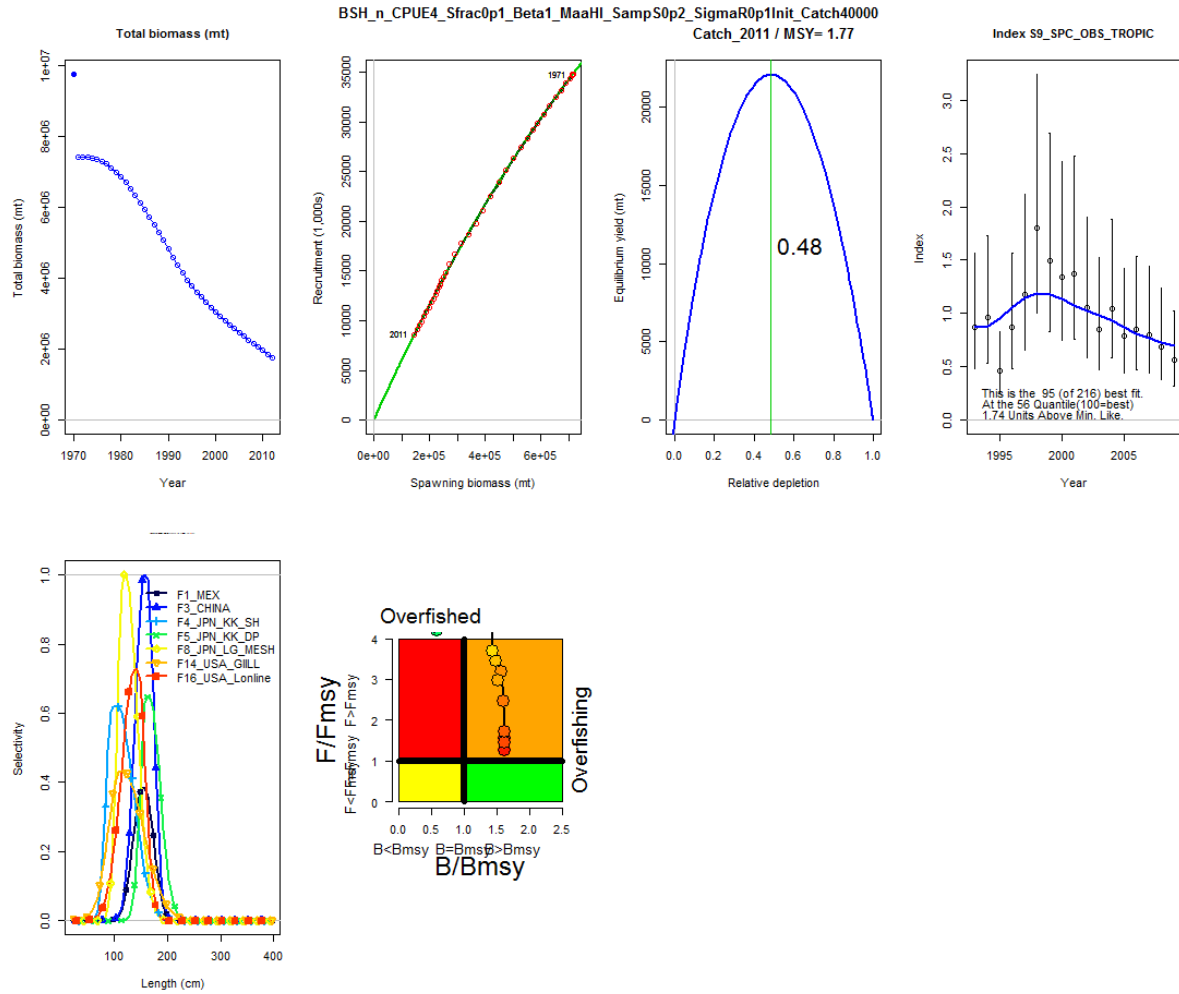


Figure D1.

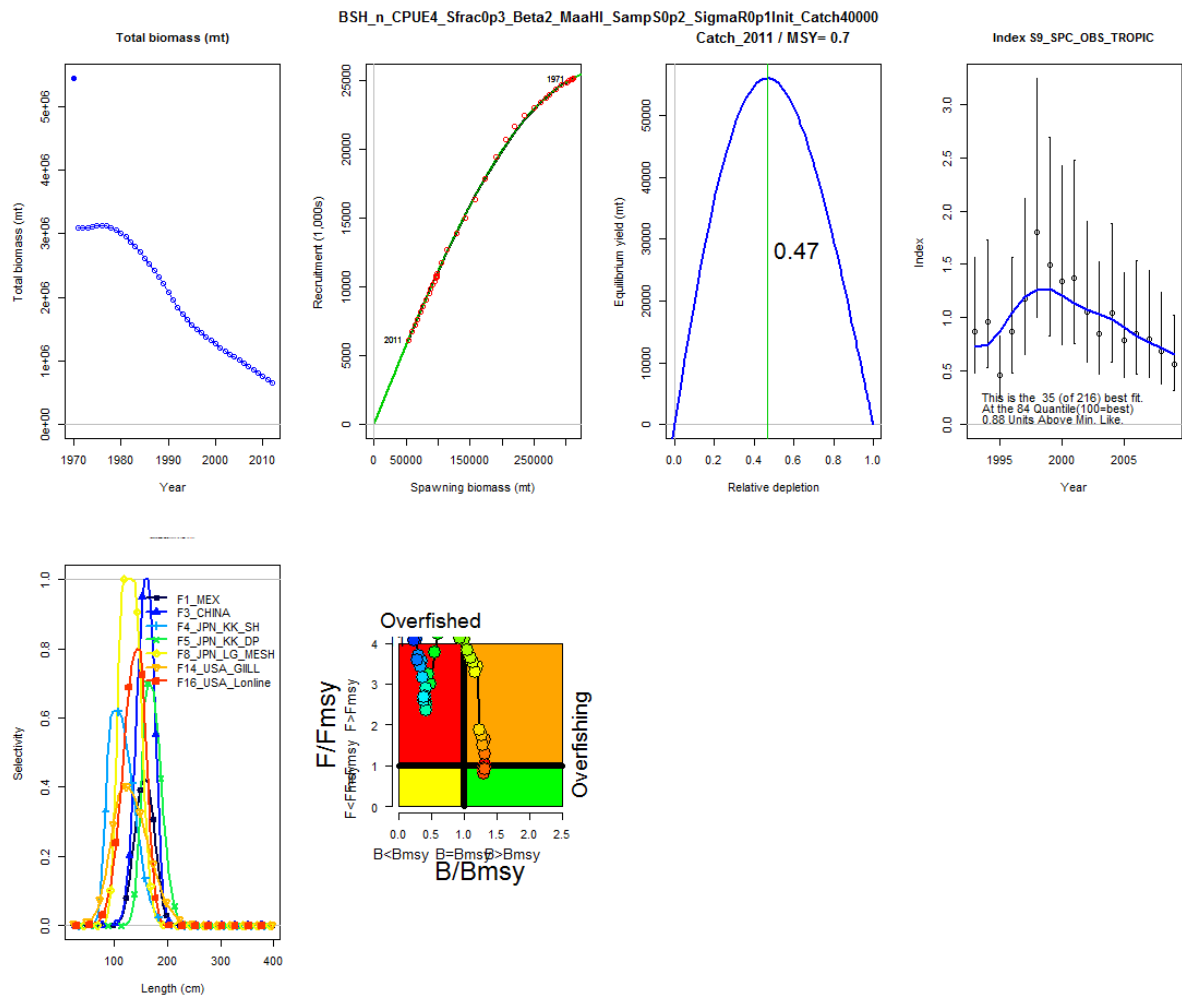


Figure D2.

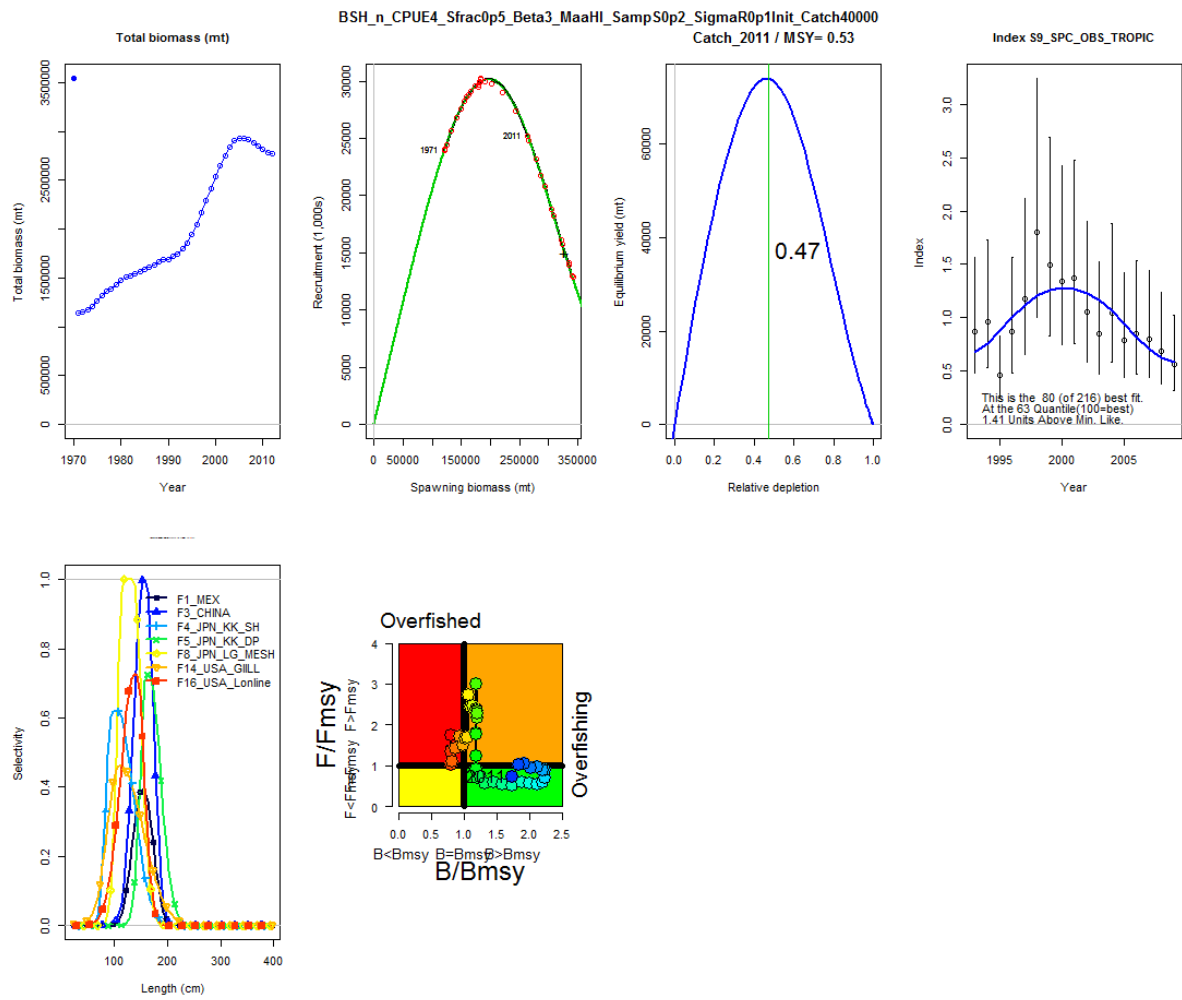
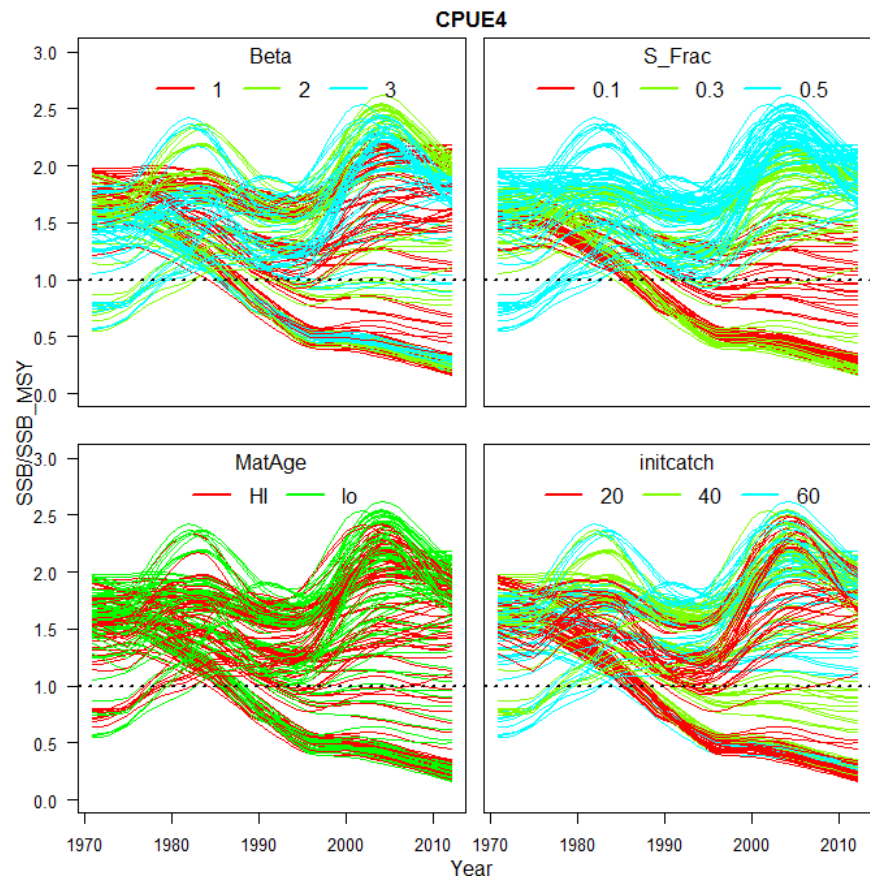


Figure D3.



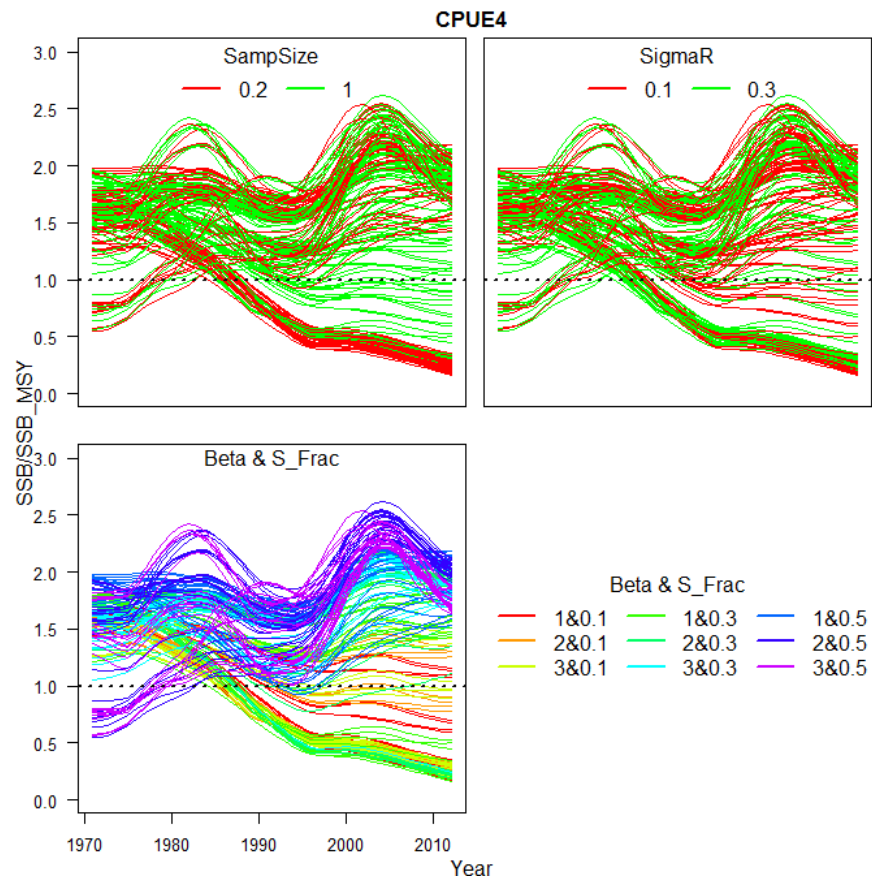


Figure D4.

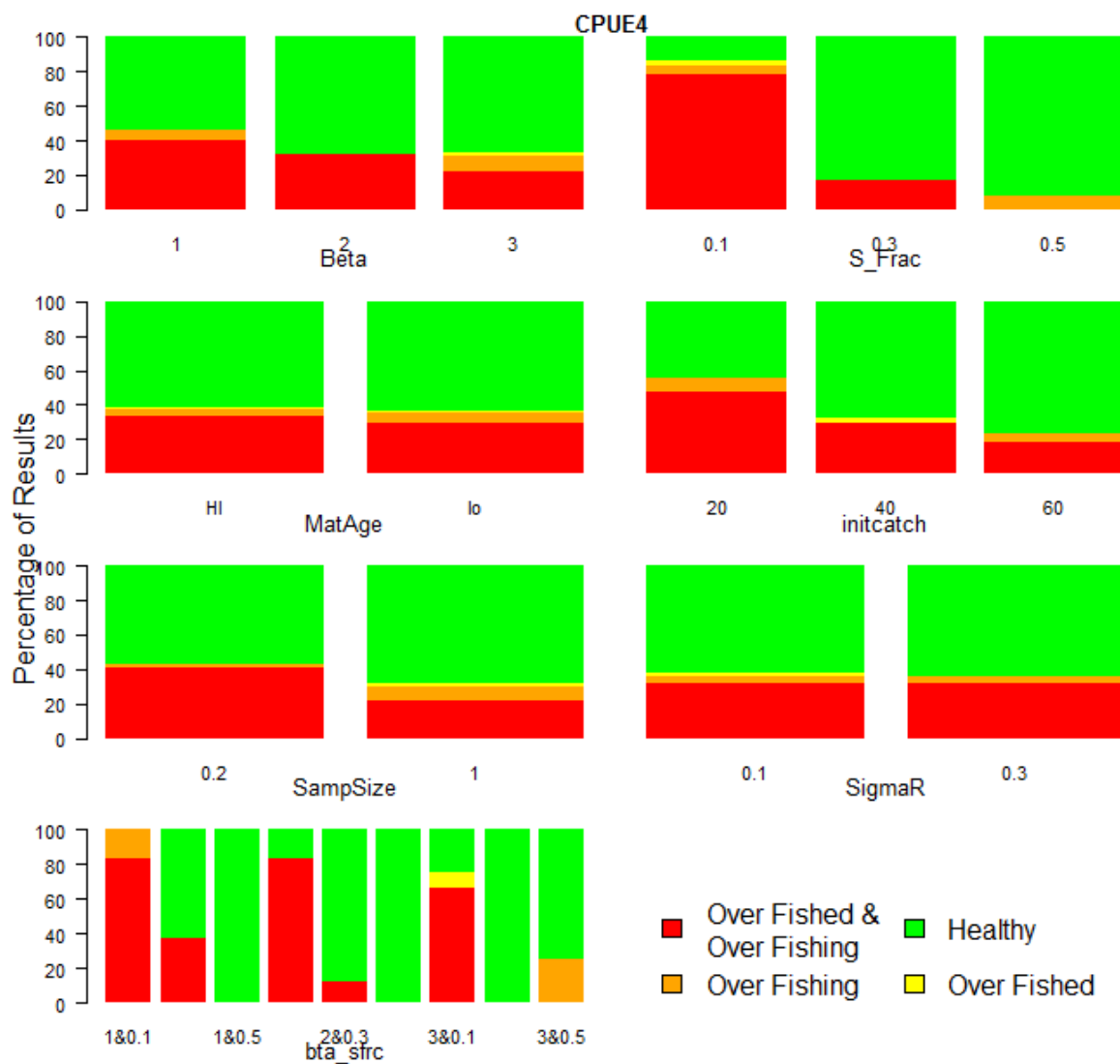


Figure D5.

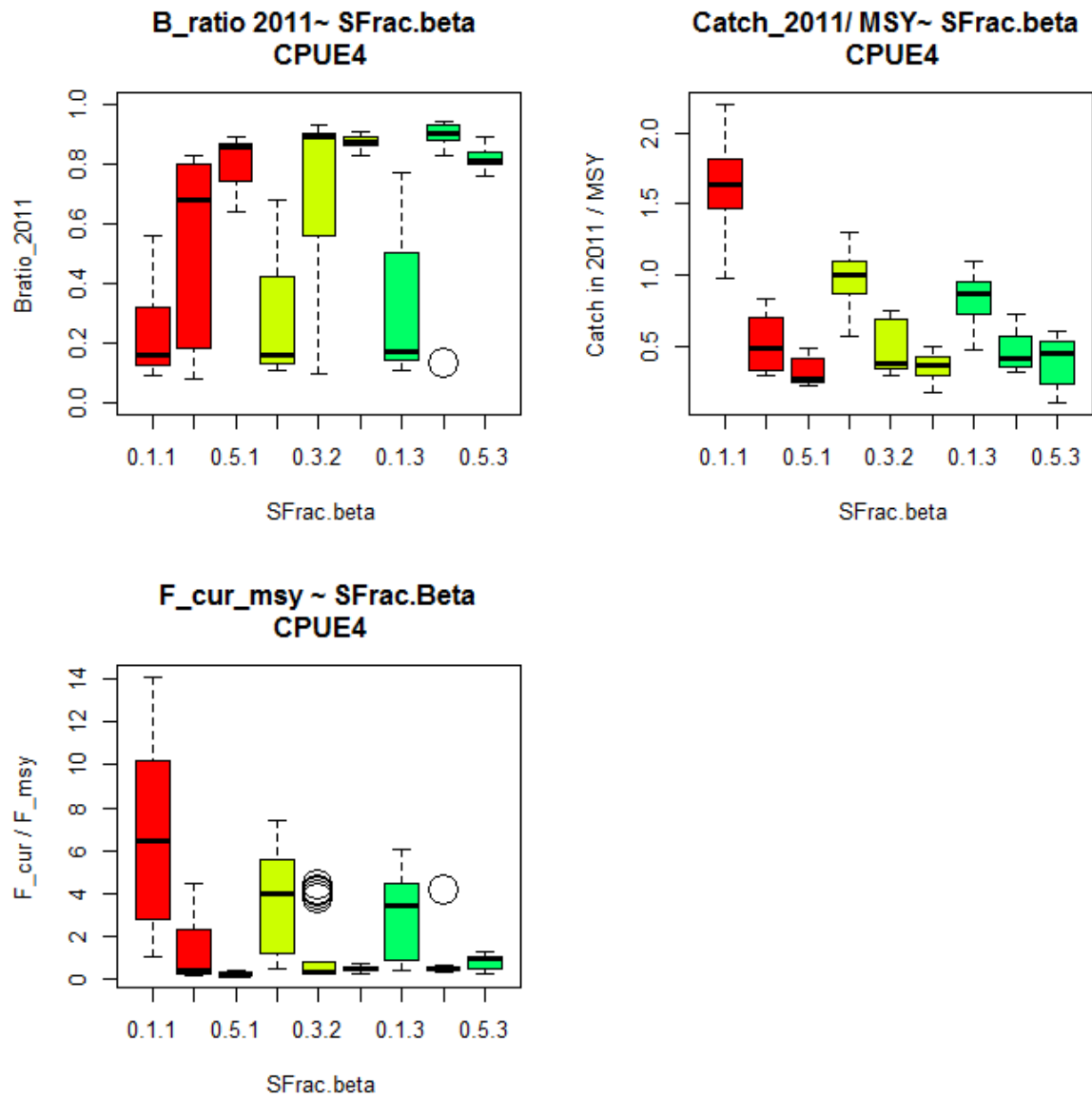


Figure D6.

Appendix E. Summary of key outputs for the SS model runs using the HW CPUE series (CPUE 5).

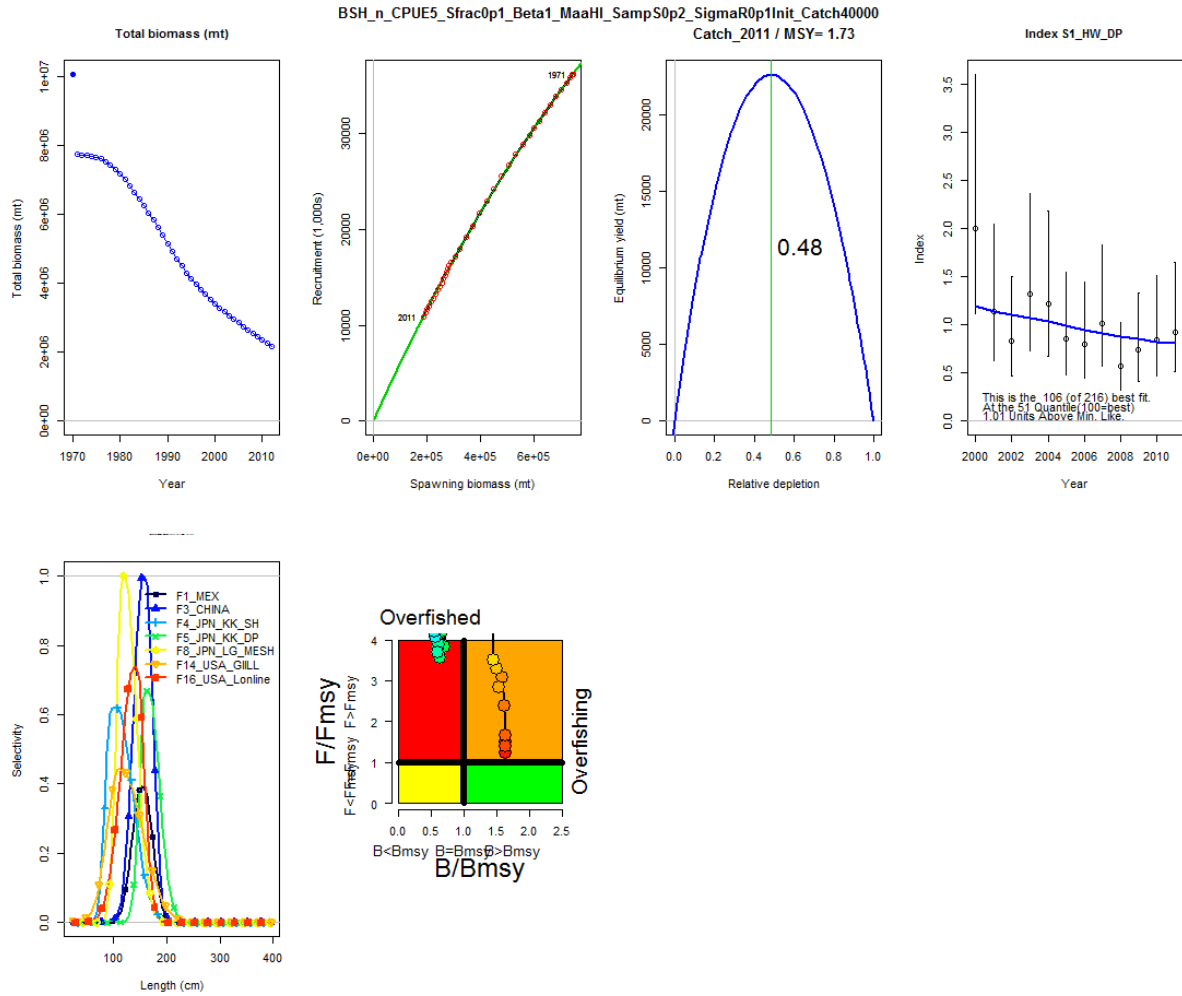


Figure E1.

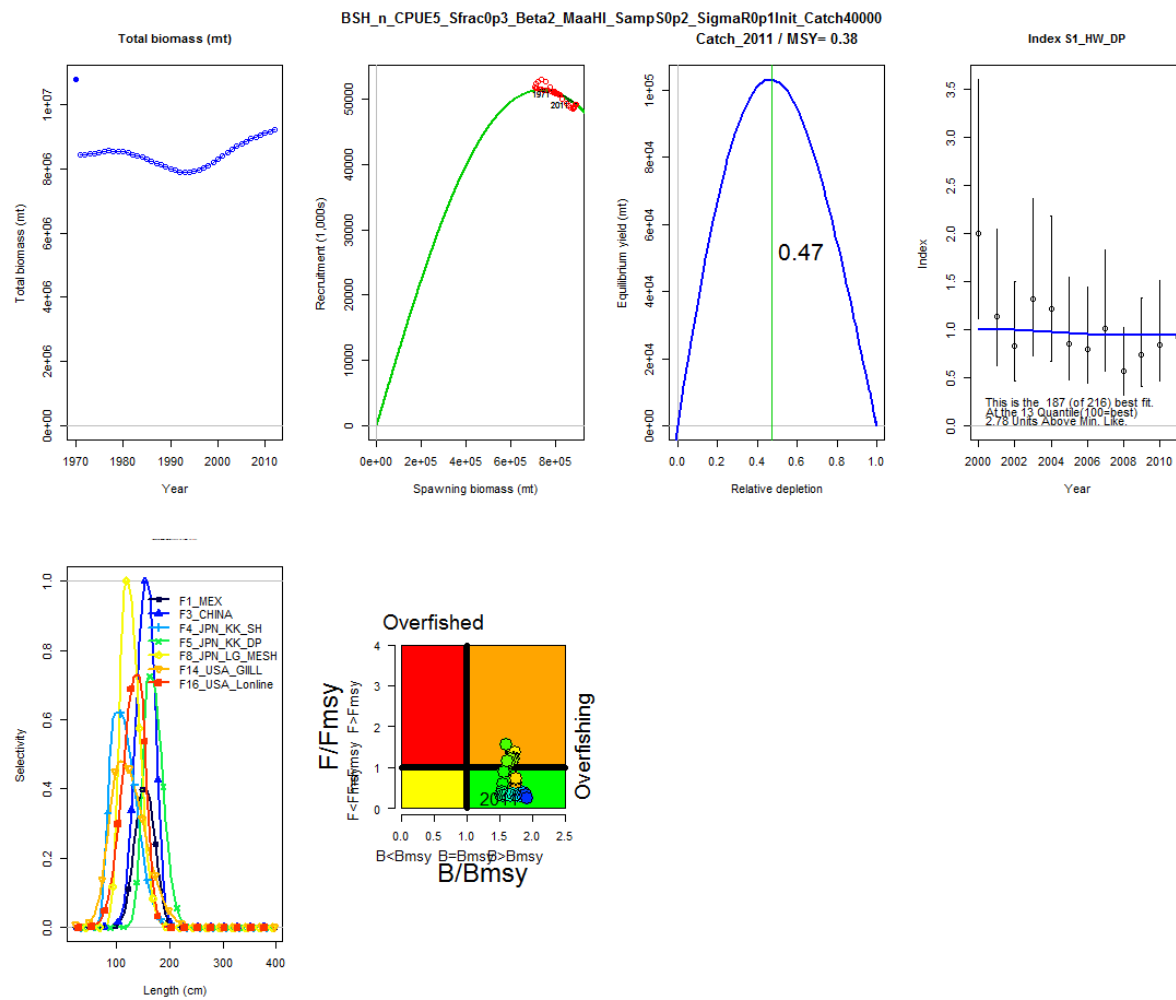


Figure E2.

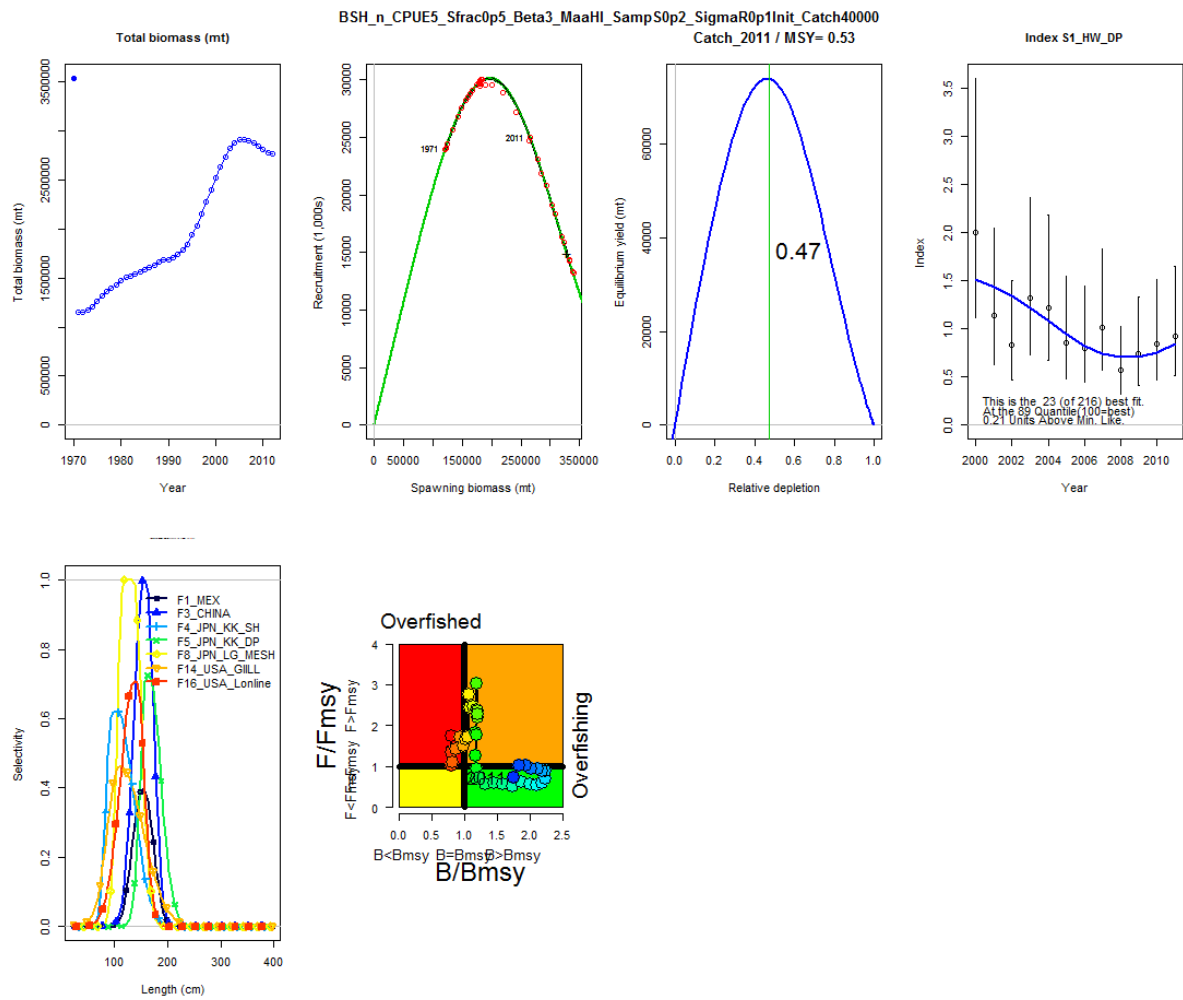
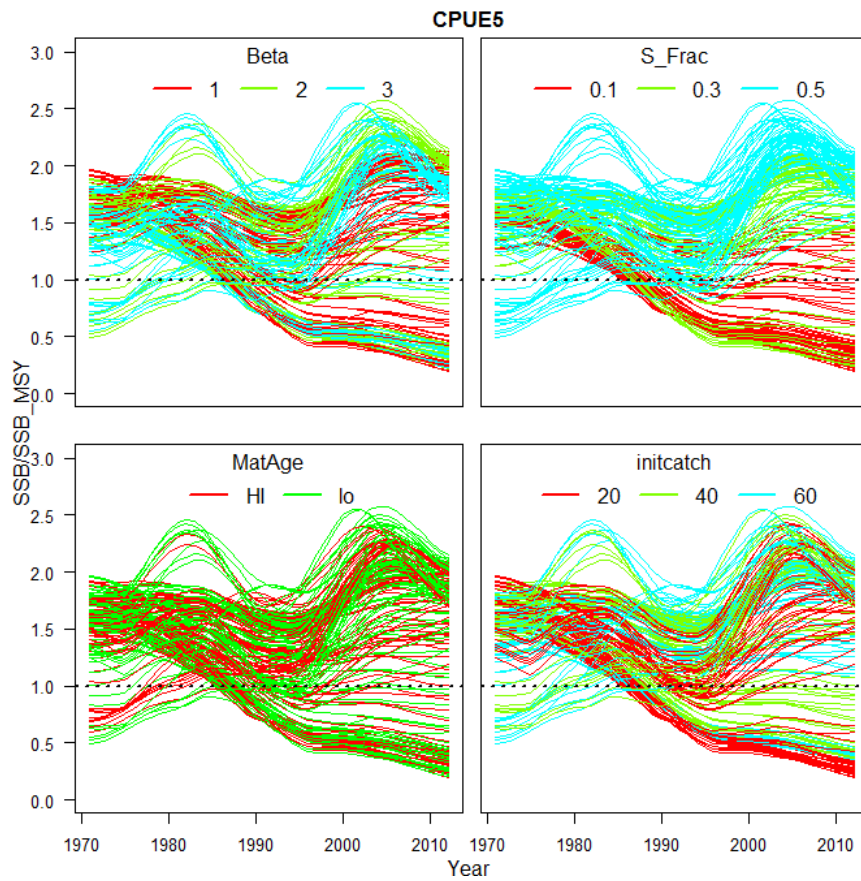


Figure E3.



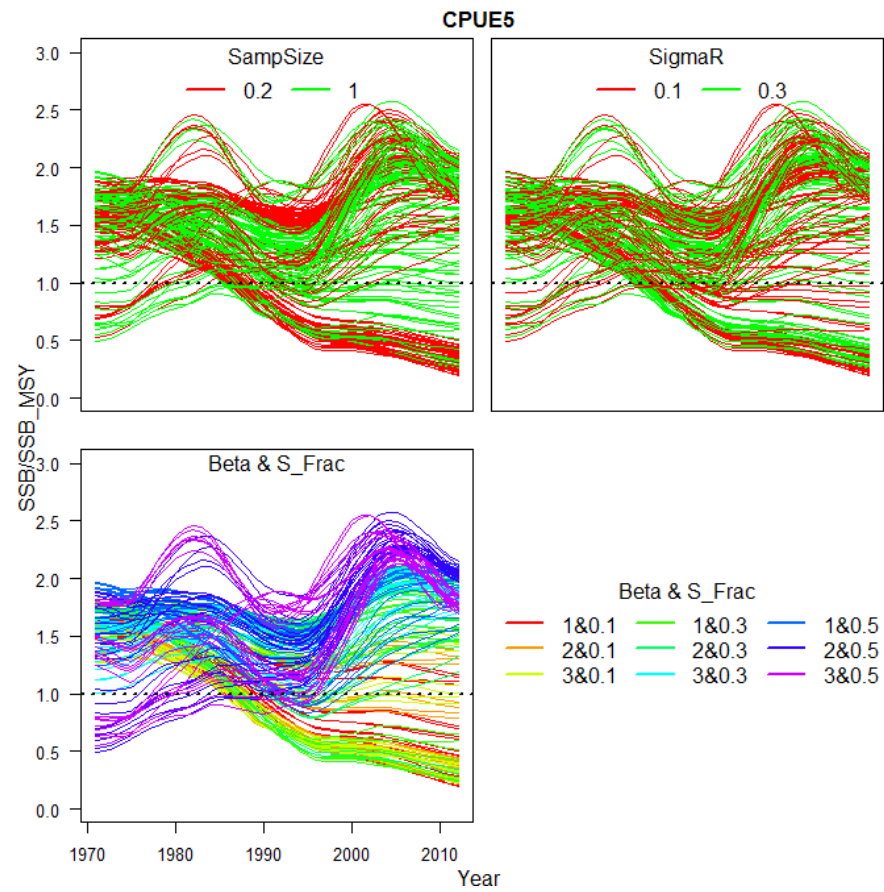


Figure E4.

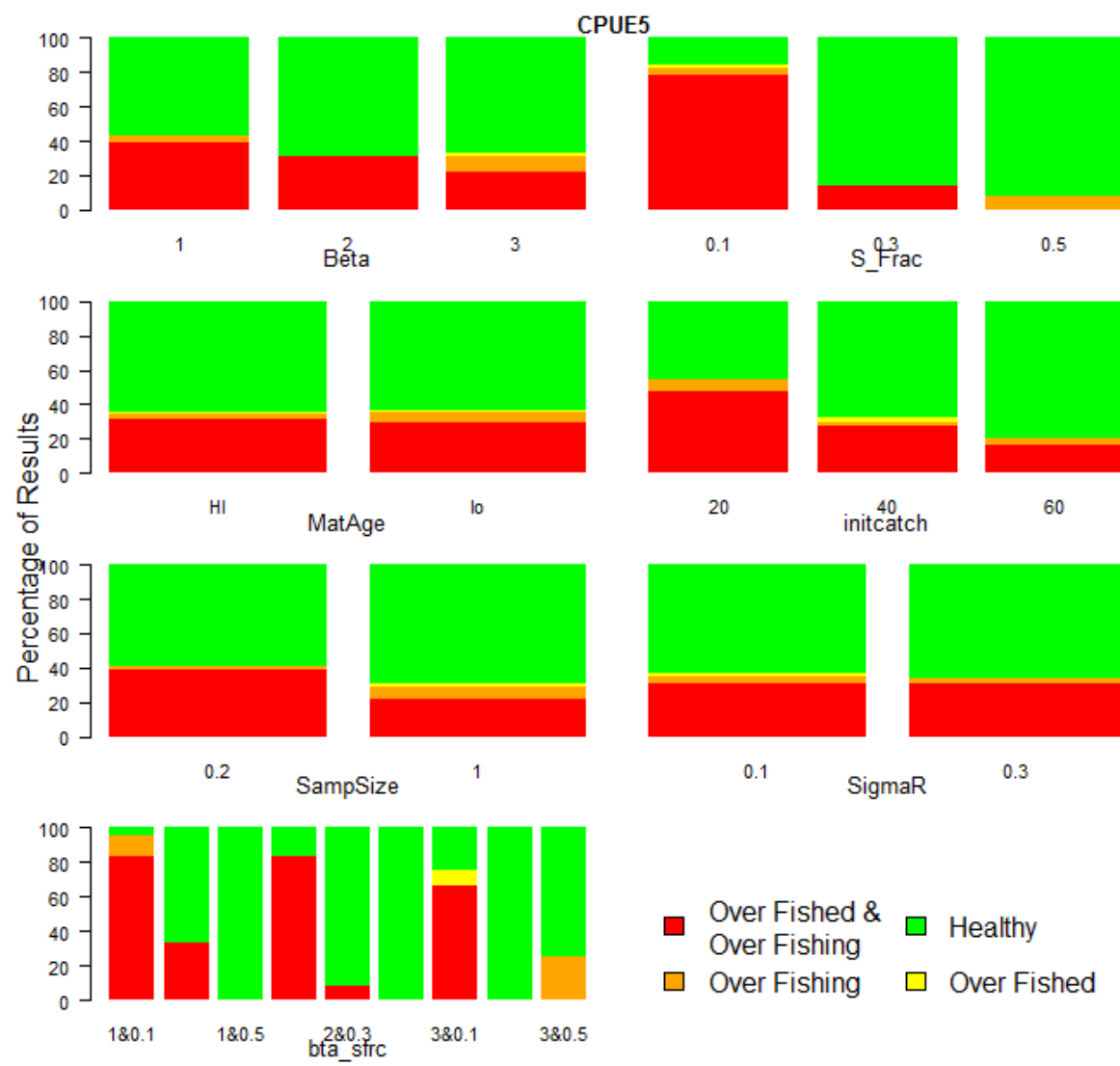


Figure E5.

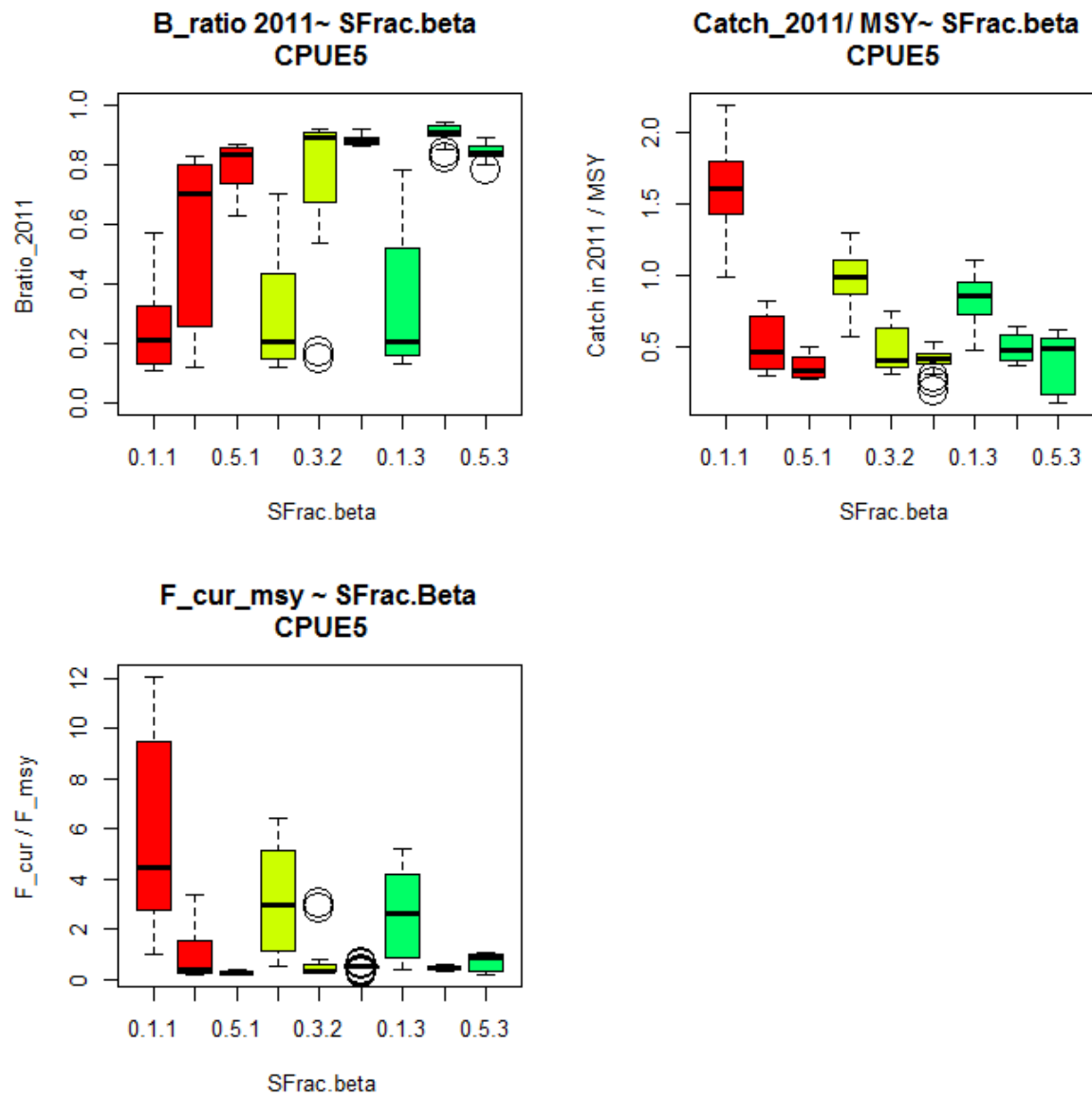


Figure E6.

Appendix F. Summary of key outputs for the SS model runs using the TW CPUE series (CPUE 6).

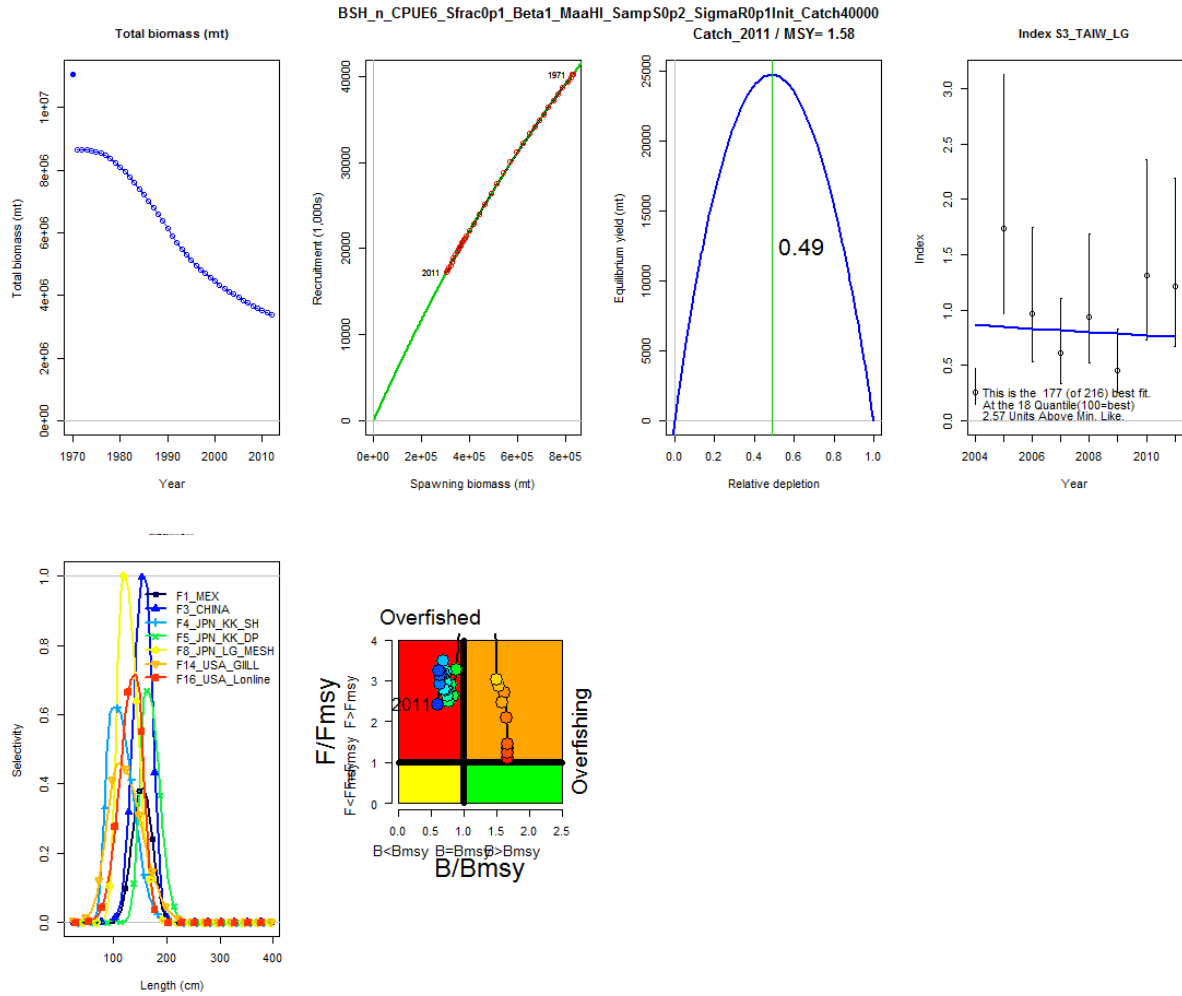


Figure F1.

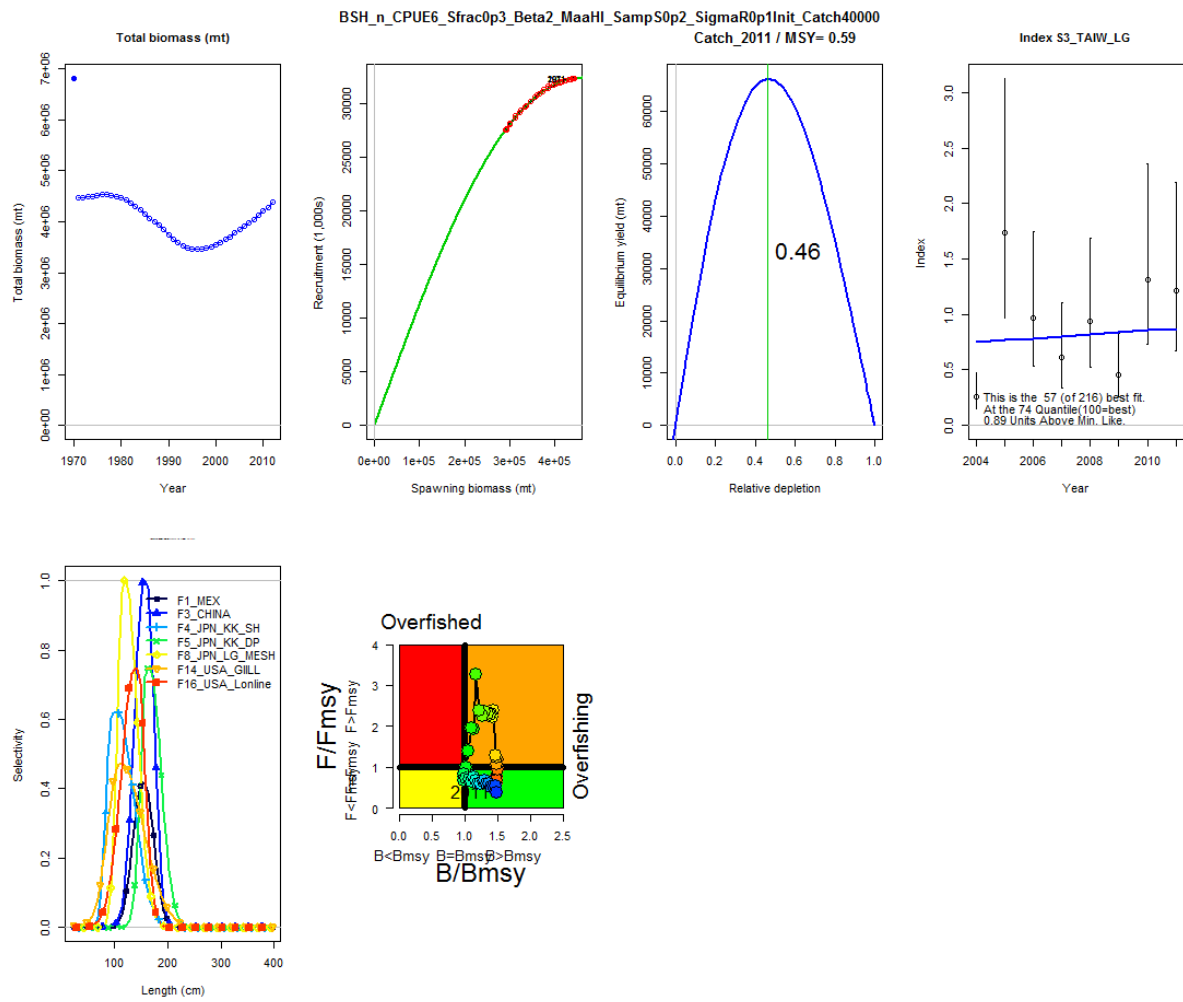


Figure F2.

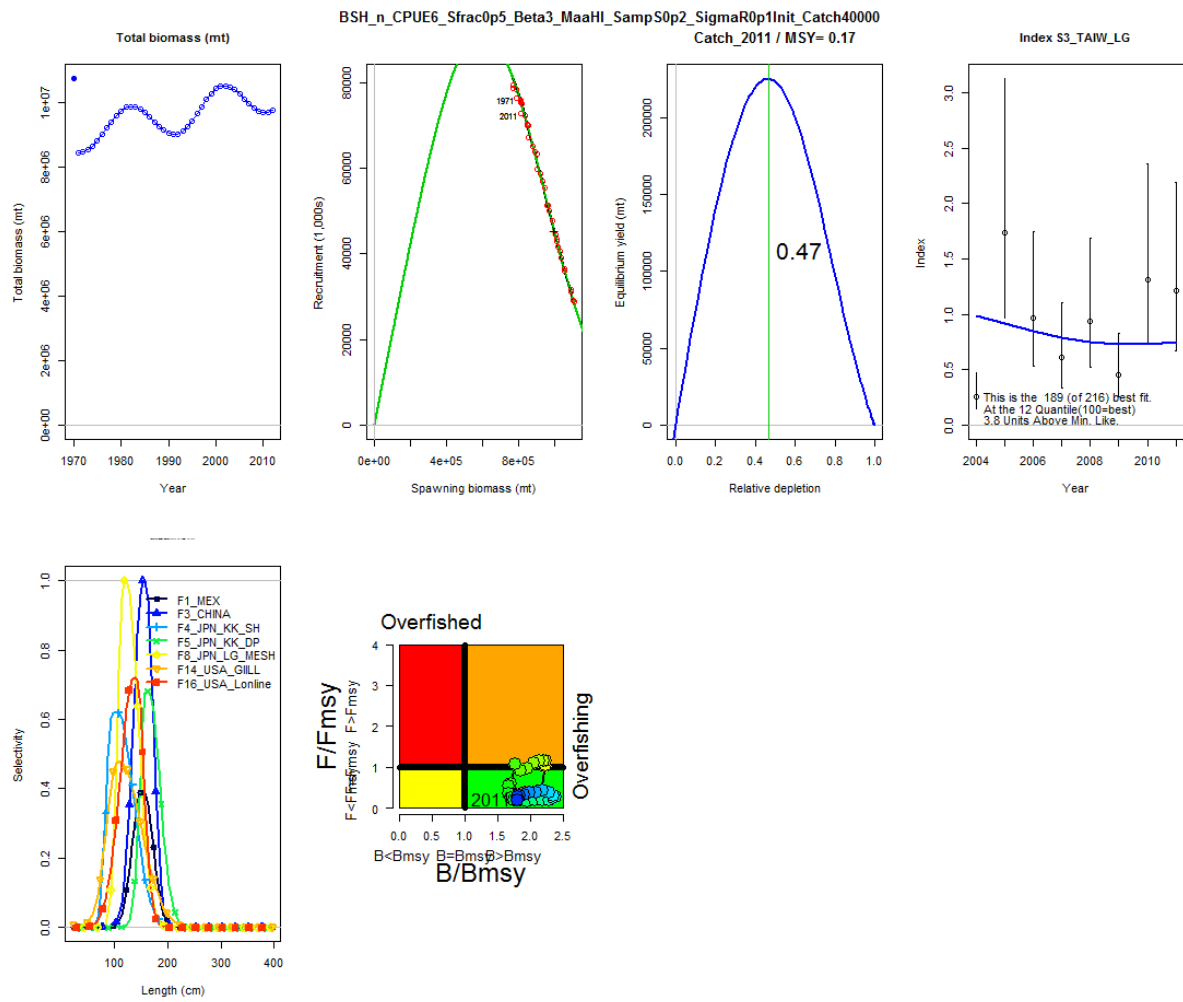
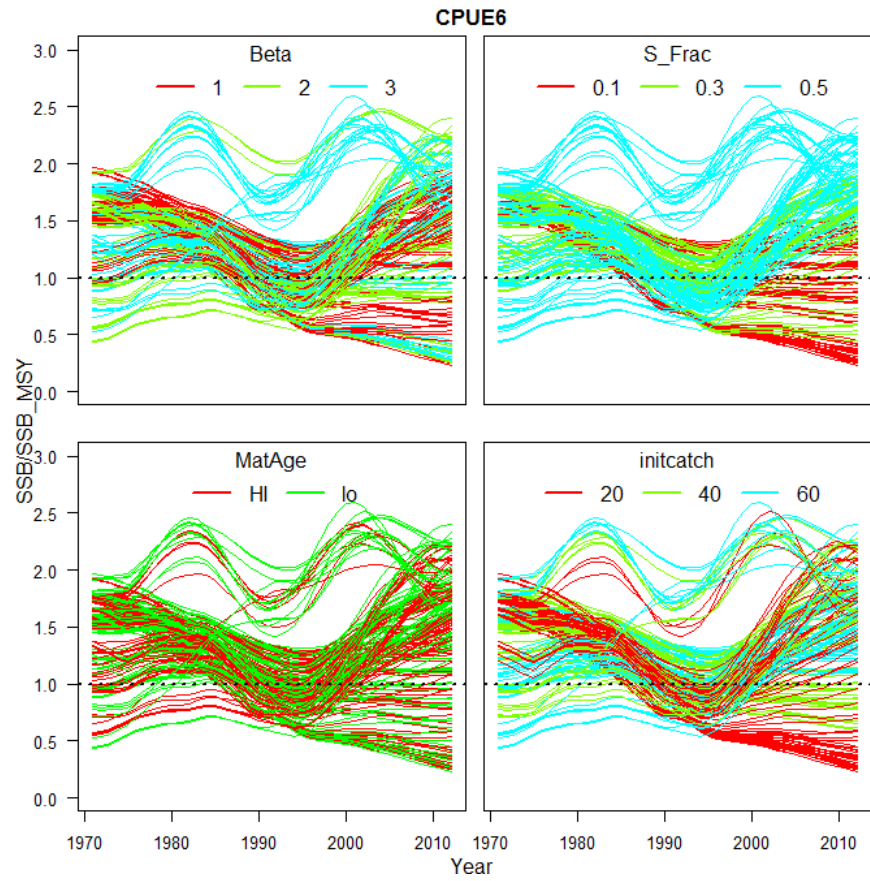


Figure F3.



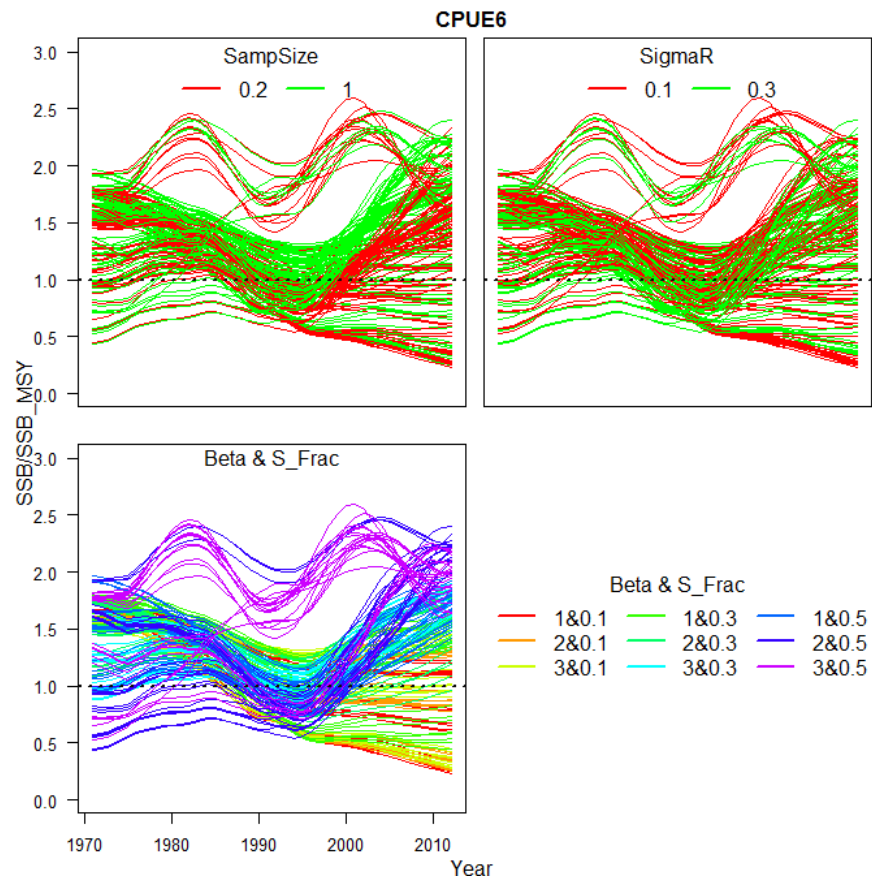


Figure F4.

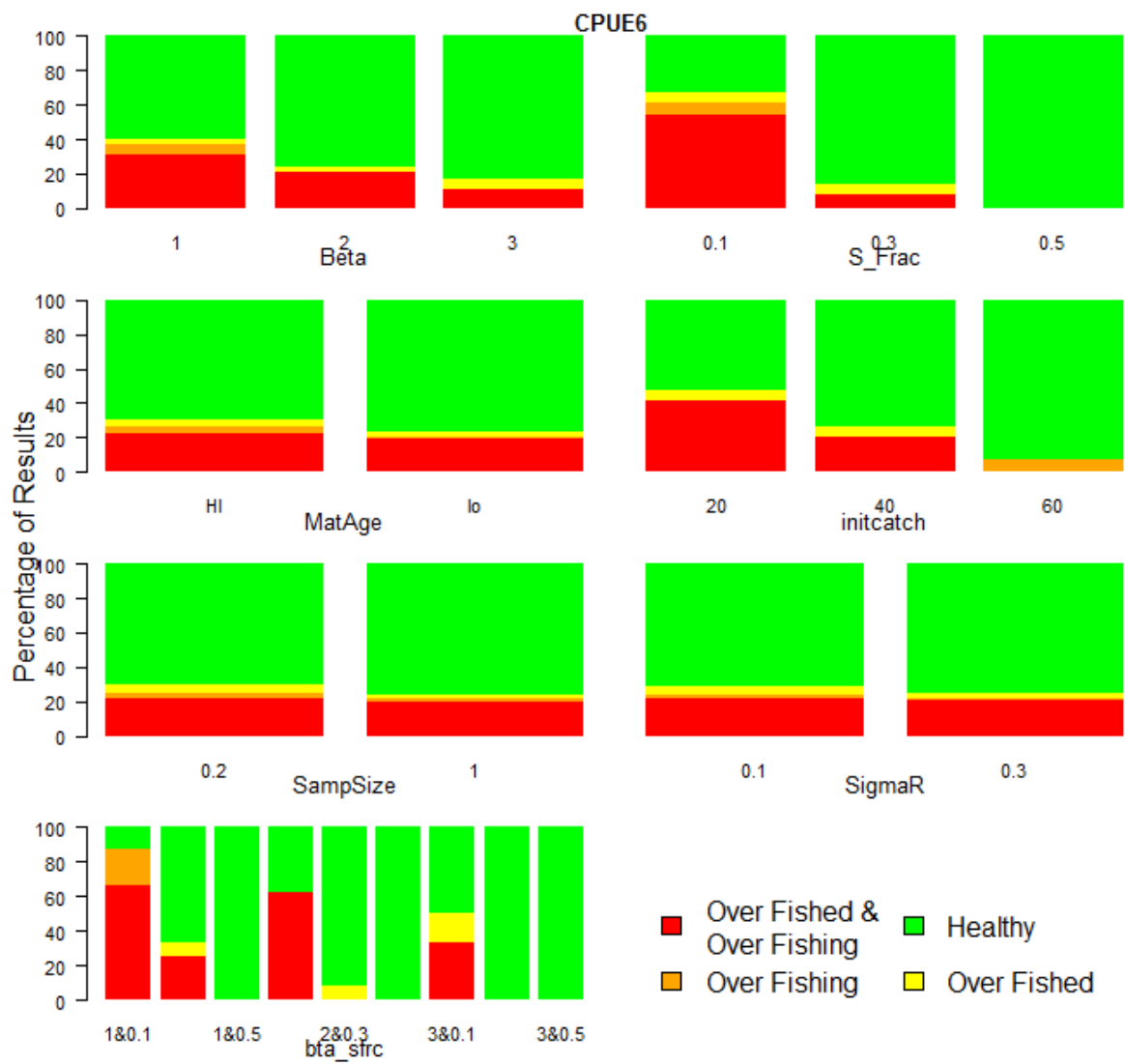


Figure F5.

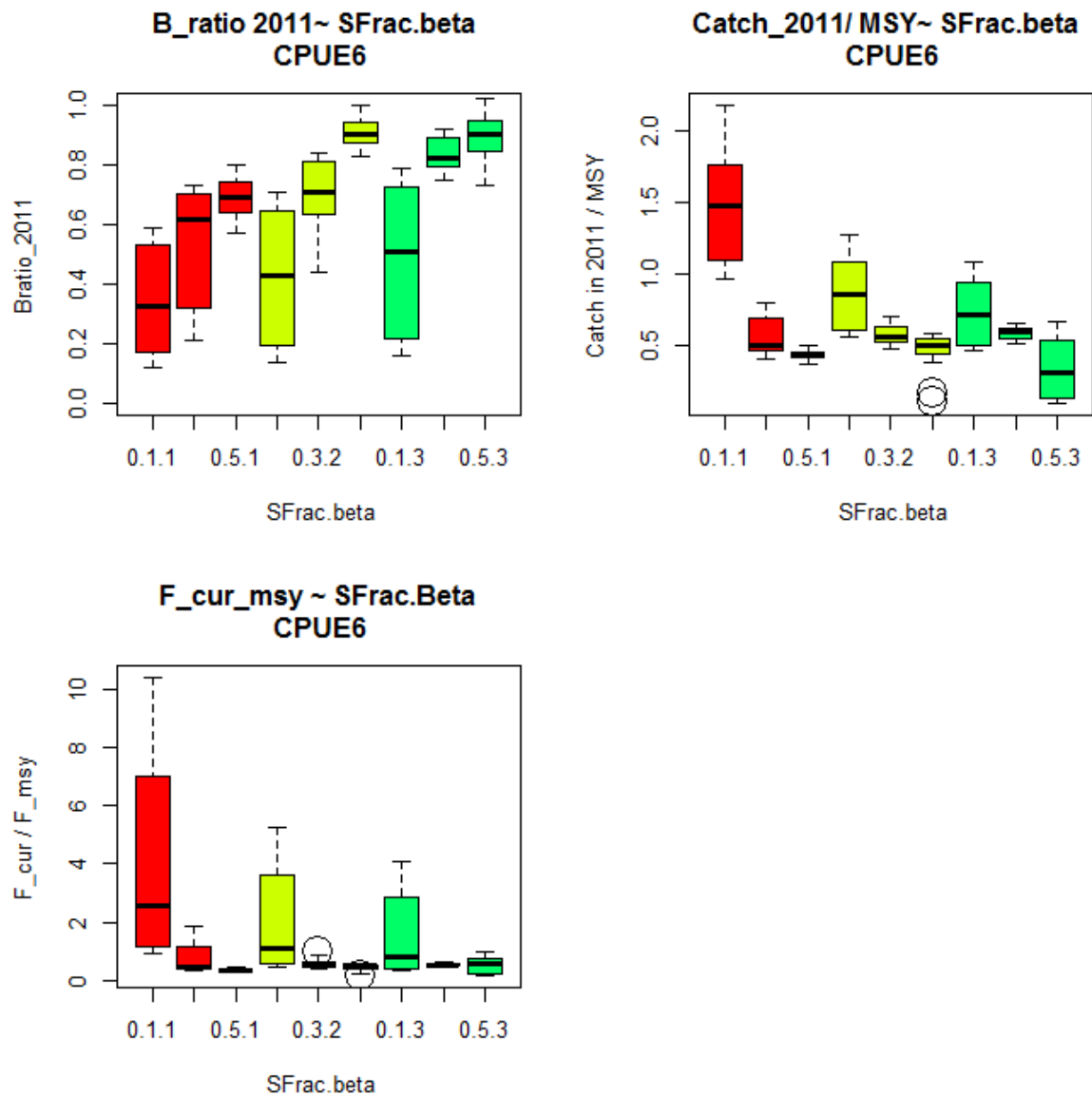


Figure F6.

Appendix G: Input files

G.1 BSP Input File

```
"NPBS, JEJL Ref Apr 23, 2014"
"NPBS, JEJL Ref, pe sigma 0.xx, Catchx000t, index CVo + CVp"
"files"
JEJL_Ref,run_i denti fier
1,hi stogram_file_name_extensi on
C:\DF0\BI ueShark2014_BSPA\output\param_JEJL_Ref_In.out,fil parin$
C:\DF0\BI ueShark2014_BSPA\output\param_JEJL_Ref_Out.out,fil parout$
C:\DF0\BI ueShark2014_BSPA\data\BSH2014_CPUE_JapanEarly_JapanLate.csv,cpue1f$
C:\DF0\BI ueShark2014_BSPA\data\BSH2014_catch.csv,catf$
C:\DF0\BI ueShark2014_BSPA\data\rec_ef_v1.csv,tbcef$
C:\DF0\BI ueShark2014_BSPA\data\rec_c_v2.csv,tbcbcf$
C:\DF0\BI ueShark2014_BSPA\data\seal_s_v11.csv,seal sf$
C:\DF0\BI ueShark2014_BSPA\data\seal_di et_v11.csv,seal _di etf$
"General inputs"
1,bayesi an
1,fletcher
0,F_i terate
0,impfunc
0,isetcov
1,expand_i mp
25,degf
8,iwted
2,ni nd
1976,i fyrdata%
2010,i endyrdata%
1971,i fyr
1971,i fyrobscat
2011,i cur
"Parameter inputs"
0,estn
0,l transn
0,ami nn
0,amaxn
1,estr
1,l transr
0.001,ami nr
1.0,amaxr
0,estcat0
1,l transcat0
10,ami ncat0
5000,amaxcat0
1,estk
1,l transk
50,ami nK
20000,amaxk
1.0,estab0
1,l transab0
0.001,ami nab0
3.0,amaxab0
0,l transig
0,ami nsi g
0,amaxsi g
1,estq
1,l transq
0.000000001,ami nq
2,amaxq
"Set up projecti ons"
5000,i si ms
```

```

7, npol
0, 46.69
0, 56.03
0, 37.35
1, 0.0798
1, 0.0958
1, 0.0639
3, 1.0
1, i DoCl y
0.05, l ci
0.95, uci
0, bi nvar
0, lowbi n
0, bi nwi dth
1, i bi ns
5, tyr1
10, tyr2
20, i hz
1971, refyear
"Set up pri ors"
0.8, al phamean
0.5, al phasd
0, catmean
0, catsd
0, si gmapri or
0, si gmamed
0, si gmasd
1, rpri or
0.34, armean
1.71250393, anmean
0, avarn
0.50, avarr

```


G.2 SS Input File

```
#V3.24f
#_data_and_control_files: BSH_n.dat // BSH_n.cti
#_SS-V3.24f-safe-
Win64;_08/03/2012;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_11
1 #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond 1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
#_Cond 0 # N recruitment designs goes here if N_GP*nseas*area>1
#_Cond 0 # placeholder for recruitment interaction request
#_Cond 1 1 1 # example recruitment design element for GP=1, seas=1, area=1
#
#_Cond 0 # N_movement_definitions goes here if N_areas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer)
also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1
dest=2, age1=4, age2=10
#
0 #_Nblock_Patterns
#_Cond 0 #_blocks_per_pattern
# begin and end years of blocks
#
0.5 #_fracfemale
3 #_natM_type:_0=1Parm;
1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withinseasinterpolate
0.535 0.309 0.233 0.194 0.171 0.155 0.144 0.135 0.129 0.124 0.120 0.117 0.114
0.112 0.110 0.109 0.107 0.106 0.105 0.105 0.104 0.103 0.103 0.103 0.102 0.102
0.102 0.101 0.101 0.101 0.101
0.564 0.300 0.220 0.180 0.156 0.140 0.128 0.120 0.114 0.109 0.105 0.101 0.099
0.096 0.095 0.093 0.092 0.090 0.089 0.089 0.088 0.087 0.087 0.086 0.086 0.085
0.085 0.085 0.085 0.084 0.084
#0.366 0.245 0.195 0.168 0.151 0.139 0.130 0.124 0.119 0.115 0.112 0.110
0.108 0.106 0.105 0.104 0.103 0.102 0.102 0.101 0.101 0.100 0.100 0.100 0.099
0.099 0.099 0.099 0.099 0.099 0.099
#0.359 0.245 0.195 0.166 0.147 0.134 0.125 0.118 0.112 0.108 0.104 0.101
0.099 0.097 0.095 0.094 0.092 0.091 0.090 0.090 0.089 0.088 0.088 0.087 0.087
0.087 0.086 0.086 0.086 0.086 0.085

2 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2;
3=age_specific_K; 4=not implemented
0.5 #_Growth_Age_for_L1
22 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern: 0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4
logSD=F(A)
1 #_maturity_option: 1=length logistic; 2=age logistic; 3=read age-maturity
matrix by growth_pattern; 4=read age-fecundity; 5=read fec and wt from
wtatage.ss
#_placeholder for empirical age-maturity by growth pattern
5 #_First_Mature_Age
2 #_fecundity_option: (1)eggs=Wt*(a+b*Wt); (2)eggs=a*L^b; (3)eggs=a*Wt^b;
(4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism_option: 0=none; 1=age-specific fxn
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-
GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in
base parm bounds; 3=standard w/ no bound check)
#
#_growth_parms
#_LO HI INIT PRI OR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr
dev_stddev Block Block_Fxn
```

```

10 120 42 45 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
40 410 234 400 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
0.1 0.25 0.144 0.15 0 0.8 -4 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
-10 10 1 1 0 0.8 -4 0 0 0 0 0.5 0 0 # Richards_Fem_GP_1
0.01 1 0.25 0.0834877 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1
-3 3 -1.07881 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Fem_GP_1
-3 3 0.00875604 0 0 0.8 -3 0 0 0 0 0.5 0 0 # L_at_Amin_Mal_GP_1
-3 3 0.1579413 0 0 0.8 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Mal_GP_1
-3 3 -0.110001 0 0 0.8 -3 0 0 0 0 0.5 0 0 # VonBert_K_Mal_GP_1
-3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Richards_Mal_GP_1
-3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Mal_GP_1
-3 3 -1.07881 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Mal_GP_1
-3 3 5.388e-006 5.388e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Fem
-3 3.5 3.102 3.102 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Fem
-3 300 145 55 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat50%_Fem
-3 3 -0.138 -0.138 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat_slope_Fem
-3 36 25 28 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_scalar_Fem
-3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_exp_len_Fem
-3 3 3.293e-006 3.293e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Mal
-3 3.5 3.225 3.225 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Mal
-4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_GP_1
-4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Area_1
-4 4 4 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Seas_1
1 1 1 1 -1 99 -3 0 0 0 0 0.5 0 0 # CohortGrowDev
#
#_Cond 0 #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #placeholder when no MG-environment parameters
#
#_Cond 0 #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
0 0 0 0 0 0 0 0 0 0
#_femwtlen1, femwtlen2, mat1, mat2, fec1, fec2, Malewtlen1, malewtlen2, L1, K
#_Cond -2 2 0 0 -1 99 -2 #placeholder when no seasonal MG parameters
#
#_Cond -4 #MGparm_Dev_Phase
#
#_Spawner-Recruitment
7 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop;
7=survival_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
3 20 11.1358 9 0 10 1 # SR_LN(R0)
0.01 1 0.3 0.5 0 0.2 -4 # SR_surv_Sfrac
0.01 10 2 1 0 0.2 -4 # SR_surv_Beta
0 2 0.3 0.6 0 0.8 -3 # SR_sigmaR
-5 5 0 0 0 1 -3 # SR_envlink
-5 5 0.00172569 0 0 1 1 # SR_R1_offset
0 0 0 0 -1 99 -1 # SR_autocorr
0 #_SR_envlink
0 #_SR_env_target_0=none; 1=devs; 2=R0; 3=steepness
2 #do_recdev: 0=none; 1=devvector; 2=simple deviations
1990 # first year of main recr_devs; early devs can precede this era
2010 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options
-5 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
1 #_recdev_early_phase
0 #_forecast_recruitment phase (incl. late recr) (0 value resets to
maxphase+1)
1 #_lambda for Fcast_recr_like occurring before endyr+1
1985 #_last_early_yr_nobias_adj_in_MPD
1990 #_first_yr_fullbias_adj_in_MPD

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2010 #_last_yr_fullbias_adj_in_MPD
2011 #_first_recent_yr_nobias_adj_in_MPD
0.05 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all
estimated recdevs)
0 #_period of cycles in recruitment (N parms read below)
-15 #min_rec_dev
15 #max_rec_dev
0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
#_Yr Input_value
#
# all recruitment deviations
#DisplayOnly -0.0410214 # Early_RecrDev_1985
#DisplayOnly -0.0442194 # Early_RecrDev_1986
#DisplayOnly -0.0427173 # Early_RecrDev_1987
#DisplayOnly -0.0380044 # Early_RecrDev_1988
#DisplayOnly -0.0302819 # Early_RecrDev_1989
#DisplayOnly -0.0216398 # Main_RecrDev_1990
#DisplayOnly -0.0120805 # Main_RecrDev_1991
#DisplayOnly -0.00312756 # Main_RecrDev_1992
#DisplayOnly 0.00307266 # Main_RecrDev_1993
#DisplayOnly 0.00920568 # Main_RecrDev_1994
#DisplayOnly 0.0151199 # Main_RecrDev_1995
#DisplayOnly 0.018696 # Main_RecrDev_1996
#DisplayOnly 0.021118 # Main_RecrDev_1997
#DisplayOnly 0.019333 # Main_RecrDev_1998
#DisplayOnly 0.0133617 # Main_RecrDev_1999
#DisplayOnly 0.00669596 # Main_RecrDev_2000
#DisplayOnly 0.000916127 # Main_RecrDev_2001
#DisplayOnly -0.00125242 # Main_RecrDev_2002
#DisplayOnly -0.00176714 # Main_RecrDev_2003
#DisplayOnly 0.000677714 # Main_RecrDev_2004
#DisplayOnly 0.00249898 # Main_RecrDev_2005
#DisplayOnly 0.00203598 # Main_RecrDev_2006
#DisplayOnly -0.0015993 # Main_RecrDev_2007
#DisplayOnly -0.00320316 # Main_RecrDev_2008
#DisplayOnly -0.000504672 # Main_RecrDev_2009
#DisplayOnly 0.000928374 # Main_RecrDev_2010
#DisplayOnly 0.000321983 # Late_RecrDev_2011
#DisplayOnly 0 # ForeRecr_2012
#DisplayOnly 0 # Impl_err_2012
#
#Fishing Mortality info
0.2 # F_ballpark for tuning early phases
2010 # F_ballpark year (neg value to disable)
3 # F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
5 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
# if Fmethod=2; read overall start F value; overall phase; N detailed inputs
to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
4 # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms
#_LO HI INIT PRIOR PR_type SD PHASE
0.1 5 0 0.01 0 99 -1 # InitF_1F1_MEX
0.1 5 0 0.01 0 99 -1 # InitF_2F2_CAN
0.1 5 0 0.01 0 99 -1 # InitF_3F3_CHINA
0.1 5 0.315485 0.01 0 99 1 # InitF_4F4_JPN_KK_SH
0.1 5 0 0.01 0 99 -1 # InitF_5F5_JPN_KK_DP
0.1 5 0 0.01 0 99 -1 # InitF_6F6_JPN_ENY_SHL

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0.1 5 0 0.01 0 99 -1 # InitF_7F7_JPN_ENY_DP
0.1 5 0 0.01 0 99 -1 # InitF_8F8_JPN_LG_MESH
0.1 5 0 0.01 0 99 -1 # InitF_9F9_JPN_CST_Oth
0.1 5 0 0.01 0 99 -1 # InitF_10F10_JPN_SM_MESH
0.1 5 0 0.01 0 99 -1 # InitF_11F11_IATTC
0.1 5 0 0.01 0 99 -1 # InitF_12F12_KOREA
0.1 5 0 0.01 0 99 -1 # InitF_13F13_NON_ISC
0.1 5 0 0.01 0 99 -1 # InitF_14F14_USA_GIILL
0.1 5 0 0.01 0 99 -1 # InitF_15F15_USA_SPORT
0.1 5 0 0.01 0 99 -1 # InitF_16F16_USA_Lonl i ne
0.1 5 0 0.01 0 99 -1 # InitF_17F17_TAIW_LG
0.1 5 0 0.01 0 99 -1 # InitF_18F18_TAIW_SM
#
#_Q_setup
# Q_type options: <0=mi rror, 0=fl oat_nobi asadj , 1=fl oat_bi asadj ,
2=parm_nobi asadj , 3=parm_w_random_dev, 4=parm_w_randwal k,
5=mean_unbi ased_fl oat_assi gn_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_l i nked
#_Den-dep env-var extra_se Q_type
0 0 0 0 # 1 F1_MEX
0 0 0 0 # 2 F2_CAN
0 0 0 0 # 3 F3_CHI NA
0 0 0 0 # 4 F4_JPN_KK_SH
0 0 0 0 # 5 F5_JPN_KK_DP
0 0 0 0 # 6 F6_JPN_ENY_SHL
0 0 0 0 # 7 F7_JPN_ENY_DP
0 0 0 0 # 8 F8_JPN_LG_MESH
0 0 0 0 # 9 F9_JPN_CST_Oth
0 0 0 0 # 10 F10_JPN_SM_MESH
0 0 0 0 # 11 F11_IATTC
0 0 0 0 # 12 F12_KOREA
0 0 0 0 # 13 F13_NON_ISC
0 0 0 0 # 14 F14_USA_GIILL
0 0 0 0 # 15 F15_USA_SPORT
0 0 0 0 # 16 F16_USA_Lonl i ne
0 0 0 0 # 17 F17_TAIW_LG
0 0 0 0 # 18 F18_TAIW_SM
0 0 0 0 # 19 S1_HW_DP
0 0 0 0 # 20 S2_HW_SH
0 0 0 0 # 21 S3_TAIW_LG
0 0 0 0 # 22 S4_TAIW_SM
0 0 0 0 # 23 S5_JPN_EARLY
0 0 0 0 # 24 S6_JPN_LATE
0 0 0 0 # 25 S7_JPN_RTV
0 0 0 0 # 26 S8_SPC_OBS
0 0 0 0 # 27 S9_SPC_COMB
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet
with random q; 1=read a parm for each year of index
#_Q_parms(i f_any)
#
#_si ze_sel ex_types
#di scard_opti ons:_0=none; _1=defi ne_retenti on; _2=retenti on&mortal i ty; _3=al l_di
scarded_dead
#_Pattern Di scard Mal e Speci al
24 0 4 0 # 1 F1_MEX
5 0 0 1 # 2 F2_CAN
24 0 3 0 # 3 F3_CHI NA
24 0 4 0 # 4 F4_JPN_KK_SH
24 0 4 0 # 5 F5_JPN_KK_DP
5 0 0 4 # 6 F6_JPN_ENY_SHL
5 0 0 5 # 7 F7_JPN_ENY_DP
24 0 3 0 # 8 F8_JPN_LG_MESH
5 0 0 8 # 9 F9_JPN_CST_Oth

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#5 0 0 4 # 10 F10_JPN_SM_MESH
24 0 0 0
5 0 0 1 # 11 F11_IATTC
5 0 0 3 # 12 F12_KOREA
5 0 0 3 # 13 F13_NON_ISC
24 0 4 0 # 14 F14_USA_GIILL
5 0 0 14 # 15 F15_USA_SPORT
24 0 4 0 # 16 F16_USA_Lonl i ne
24 0 4 0 # 17 F17_TAIW_LG
24 0 4 0 # 18 F18_TAIW_SM
5 0 0 16 # 19 S1_HW_DP
5 0 0 16 # 20 S2_HW_SH
5 0 0 17 # 21 S3_TAIW_LG
5 0 0 18 # 22 S4_TAIW_SM
5 0 0 4 # 23 S5_JPN_EARLY
5 0 0 5 # 24 S6_JPN_LATE
5 0 0 16 # 25 S7_JPN_RTV
5 0 0 13 # 26 S8_SPC_OBS
5 0 0 13 # 27 S9_SPC_COMB
#
#_age_sel ex_types
#_Pattern ____ Male Special
11 0 0 0 # 1 F1_MEX
11 0 0 0 # 2 F2_CAN
11 0 0 0 # 3 F3_CHI NA
11 0 0 0 # 4 F4_JPN_KK_SH
11 0 0 0 # 5 F5_JPN_KK_DP
11 0 0 0 # 6 F6_JPN_ENY_SHL
11 0 0 0 # 7 F7_JPN_ENY_DP
11 0 0 0 # 8 F8_JPN_LG_MESH
11 0 0 0 # 9 F9_JPN_CST_0th
11 0 0 0 # 10 F10_JPN_SM_MESH
11 0 0 0 # 11 F11_IATTC
11 0 0 0 # 12 F12_KOREA
11 0 0 0 # 13 F13_NON_ISC
11 0 0 0 # 14 F14_USA_GIILL
11 0 0 0 # 15 F15_USA_SPORT
11 0 0 0 # 16 F16_USA_Lonl i ne
11 0 0 0 # 17 F17_TAIW_LG
11 0 0 0 # 18 F18_TAIW_SM
11 0 0 0 # 19 S1_HW_DP
11 0 0 0 # 20 S2_HW_SH
11 0 0 0 # 21 S3_TAIW_LG
11 0 0 0 # 22 S4_TAIW_SM
11 0 0 0 # 23 S5_JPN_EARLY
11 0 0 0 # 24 S6_JPN_LATE
11 0 0 0 # 25 S7_JPN_RTV
11 0 0 0 # 26 S8_SPC_OBS
11 0 0 0 # 27 S9_SPC_COMB
#_L0 HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr
dev_stddev Block Block_Fxn
35 300 146.999 50 -1 0 2 0 0 0 0 0.5 0 0 # Si zeSel _1P_1_F1_MEX
-15 15 -9.46006 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _1P_2_F1_MEX
-15 15 6.38928 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _1P_3_F1_MEX
-15 15 6.40143 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _1P_4_F1_MEX
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _1P_5_F1_MEX
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # Si zeSel _1P_6_F1_MEX
-20 200 4.2 125 -1 50 -4 0 0 0 0 0 0 # SzSel _1Fem_Peak_F1_MEX
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 # SzSel _1Fem_Ascend_F1_MEX
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 # SzSel _1Fem_Descend_F1_MEX
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 # SzSel _1Fem_Fi nal _F1_MEX
-15 15 0.419063 4 -1 50 5 0 0 0 0 0 0 # SzSel _1Fem_Scal e_F1_MEX
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _2P_1_F2_CAN
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _2P_2_F2_CAN

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35 300 154.34 50 -1 0 2 0 0 0 0 0.5 0 0 # Si zeSel _3P_1_F3_CHI NA
-15 15 -9.75214 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _3P_2_F3_CHI NA
-15 15 6.41669 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _3P_3_F3_CHI NA
-15 15 6.04151 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _3P_4_F3_CHI NA
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _3P_5_F3_CHI NA
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # Si zeSel _3P_6_F3_CHI NA
-20 200 0 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel _3Mal e_Peak_F3_CHI NA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _3Mal e_Ascend_F3_CHI NA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _3Mal e_Descend_F3_CHI NA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _3Mal e_Fi nal_F3_CHI NA
-15 15 0.85 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel _3Mal e_Scal e_F3_CHI NA
35 300 125 50 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _4P_1_F4_JPN_KK_SH
-15 15 -4 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _4P_2_F4_JPN_KK_SH
-15 15 7.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _4P_3_F4_JPN_KK_SH
-15 15 5.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _4P_4_F4_JPN_KK_SH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _4P_5_F4_JPN_KK_SH
-999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # Si zeSel _4P_6_F4_JPN_KK_SH
-20 200 -30 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel _4Fem_Peak_F4_JPN_KK_SH
-15 15 -2 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _4Fem_Ascend_F4_JPN_KK_SH
-15 15 2 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _4Fem_Descend_F4_JPN_KK_SH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _4Fem_Fi nal_F4_JPN_KK_SH
-15 15 0.62 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel _4Fem_Scal e_F4_JPN_KK_SH
35 300 156.736 50 -1 0 2 0 0 0 0 0.5 0 0 # Si zeSel _5P_1_F5_JPN_KK_DP
-15 15 -11.2268 0 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _5P_2_F5_JPN_KK_DP
-15 15 5.68928 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _5P_3_F5_JPN_KK_DP
-15 15 6.78635 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _5P_4_F5_JPN_KK_DP
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _5P_5_F5_JPN_KK_DP
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # Si zeSel _5P_6_F5_JPN_KK_DP
-20 200 4 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel _5Fem_Peak_F5_JPN_KK_DP
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _5Fem_Ascend_F5_JPN_KK_DP
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _5Fem_Descend_F5_JPN_KK_DP
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _5Fem_Fi nal_F5_JPN_KK_DP
-15 15 0.740766 4 -1 50 5 0 0 0 0 0 0 0 # SzSel _5Fem_Scal e_F5_JPN_KK_DP
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _6P_1_F6_JPN_ENY_SHL
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _6P_2_F6_JPN_ENY_SHL
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _7P_1_F7_JPN_ENY_DP
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _7P_2_F7_JPN_ENY_DP
35 300 115.534 120 -1 0 2 0 0 0 0 0.5 0 0 # Si zeSel _8P_1_F8_JPN_LG_MESH
-15 15 -7.22456 0 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _8P_2_F8_JPN_LG_MESH
-15 15 5.48907 5 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _8P_3_F8_JPN_LG_MESH
-15 15 6.82727 5 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _8P_4_F8_JPN_LG_MESH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _8P_5_F8_JPN_LG_MESH
-999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # Si zeSel _8P_6_F8_JPN_LG_MESH
-20 200 3 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel _8Mal e_Peak_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _8Mal e_Ascend_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _8Mal e_Descend_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _8Mal e_Fi nal_F8_JPN_LG_MESH
-15 15 0.6 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel _8Mal e_Scal e_F8_JPN_LG_MESH
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _9P_1_F9_JPN_CST_0th
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _9P_2_F9_JPN_CST_0th

35 300 50 120 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _10P_1_F10_JPN_SM_MESH
-15 15 -9 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _10P_2_F10_JPN_SM_MESH
-15 15 5.5 5 -1 0 -4 0 0 0 0 0.5 0 0 # Si zeSel _10P_3_F10_JPN_SM_MESH
-15 15 6.85 5 -1 0 -4 0 0 0 0 0.5 0 0 # Si zeSel _10P_4_F10_JPN_SM_MESH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _10P_5_F10_JPN_SM_MESH
-999 -999 -999 0 -1 4 -3 0 0 0 0 0.5 0 0 # Si zeSel _10P_6_F10_JPN_SM_MESH

1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _11P_1_F11_IATTC
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _11P_2_F11_IATTC
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _12P_1_F12_KOREA
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _12P_2_F12_KOREA
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _13P_1_F13_NON_I SC

1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _13P_2_F13_NON_I SC
28 300 118.194 50 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _14P_1_F14_USA_GI I LL
-15 15 -9.7791 0 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _14P_2_F14_USA_GI I LL
-15 15 6.82267 0 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _14P_3_F14_USA_GI I LL
-15 15 8.17439 0 -1 0 3 0 0 0 0 0.5 0 0 # Si zeSel _14P_4_F14_USA_GI I LL
-10 10 -5.22115 0 -1 0 4 0 0 0 0 0.5 0 0 # Si zeSel _14P_5_F14_USA_GI I LL
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _14P_6_F14_USA_GI I LL
-20 200 -10 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel _14Fem_Peak_F14_USA_GI I LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _14Fem_Ascend_F14_USA_GI I LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _14Fem_Descend_F14_USA_GI I LL
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _14Fem_Fi nal_F14_USA_GI I LL
-15 15 0.51336 4 -1 50 4 0 0 0 0 0 0 0 # SzSel _14Fem_Scal e_F14_USA_GI I LL
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _15P_1_F15_USA_SPORT
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _15P_2_F15_USA_SPORT
35 300 133.521 50 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_1_F16_USA_Lonl i ne
-15 15 -10.2074 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_2_F16_USA_Lonl i ne
-15 15 7.25299 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_3_F16_USA_Lonl i ne
-15 15 6.66187 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_4_F16_USA_Lonl i ne
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_5_F16_USA_Lonl i ne
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _16P_6_F16_USA_Lonl i ne
-20 200 4.01541 0 -1 50 4 0 0 0 0 0 0 0 # SzSel _16Fem_Peak_F16_USA_Lonl i ne
-15 15 -0.117635 4 -1 50 4 0 0 0 0 0 0 0 #
SzSel _16Fem_Ascend_F16_USA_Lonl i ne
-15 15 -0.600908 4 -1 50 4 0 0 0 0 0 0 0 #
SzSel _16Fem_Descend_F16_USA_Lonl i ne
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _16Fem_Fi nal_F16_USA_Lonl i ne
-15 15 0.761592 4 -1 50 5 0 0 0 0 0 0 0 # SzSel _16Fem_Scal e_F16_USA_Lonl i ne
35 300 200 50 -1 0 -2 0 0 0 0 0.5 0 0 # Si zeSel _17P_1_F17_TAI W_LG
-15 15 -2.6 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _17P_2_F17_TAI W_LG
-15 15 7.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _17P_3_F17_TAI W_LG
-15 15 5.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _17P_4_F17_TAI W_LG
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _17P_5_F17_TAI W_LG
-999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # Si zeSel _17P_6_F17_TAI W_LG
-20 200 9.5 9 -1 50 -4 0 0 0 0 0 0 0 # SzSel _17Fem_Peak_F17_TAI W_LG
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _17Fem_Ascend_F17_TAI W_LG
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _17Fem_Descend_F17_TAI W_LG
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _17Fem_Fi nal_F17_TAI W_LG
-15 15 0.62 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel _17Fem_Scal e_F17_TAI W_LG

28 300 118.194 50 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _18P_1_F18_TAI W_SM
-15 15 -9.7791 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _18P_2_F18_TAI W_SM
-15 15 6.82267 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _18P_3_F18_TAI W_SM
-15 15 8.17439 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _18P_4_F18_TAI W_SM
-10 10 -5.22115 0 -1 0 -5 0 0 0 0 0.5 0 0 # Si zeSel _18P_5_F18_TAI W_SM
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # Si zeSel _18P_6_F18_TAI W_SM
-20 200 -10 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel _18Fem_Peak_F18_TAI W_SM
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _18Fem_Ascend_F18_TAI W_SM
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _18Fem_Descend_F18_TAI W_SM
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel _18Fem_Fi nal_F18_TAI W_SM
-15 15 0.51336 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel _18Fem_Scal e_F18_TAI W_SM

1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _19P_1_S1_HW_DP
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _19P_2_S1_HW_DP
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _20P_1_S2_HW_SH
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _20P_2_S2_HW_SH
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _21P_1_S3_TAI W_LG
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _21P_2_S3_TAI W_LG
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _22P_1_S4_TAI W_SM
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _22P_2_S4_TAI W_SM
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _23P_1_S5_JPN_EARLY
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _23P_2_S5_JPN_EARLY
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _24P_1_S6_JPN_LATE
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _24P_2_S6_JPN_LATE
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _25P_1_S7_JPN_RTV

```

1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _25P_2_S7_JPN_RTV
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _26P_1_S8_SPC_OBS
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _26P_2_S8_SPC_OBS
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # Si zeSel _27P_1_S9_SPC_COMB
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # Si zeSel _27P_2_S9_SPC_COMB
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _1P_1_F1_MEX
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _1P_2_F1_MEX
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _2P_1_F2_CAN
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _2P_2_F2_CAN
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _3P_1_F3_CHI NA
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _3P_2_F3_CHI NA
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _4P_1_F4_JPN_KK_SH
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _4P_2_F4_JPN_KK_SH
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _5P_1_F5_JPN_KK_DP
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _5P_2_F5_JPN_KK_DP
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _6P_1_F6_JPN_ENY_SHL
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _6P_2_F6_JPN_ENY_SHL
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _7P_1_F7_JPN_ENY_DP
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _7P_2_F7_JPN_ENY_DP
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _8P_1_F8_JPN_LG_MESH
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _8P_2_F8_JPN_LG_MESH
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _9P_1_F9_JPN_CST_0th
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _9P_2_F9_JPN_CST_0th
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _10P_1_F10_JPN_SM_MESH
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _10P_2_F10_JPN_SM_MESH
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _11P_1_F11_IATTC
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _11P_2_F11_IATTC
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _12P_1_F12_KOREA
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _12P_2_F12_KOREA
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _13P_1_F13_NON_I SC
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _13P_2_F13_NON_I SC
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _14P_1_F14_USA_GI ILL
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _14P_2_F14_USA_GI ILL
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _15P_1_F15_USA_SPORT
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _15P_2_F15_USA_SPORT
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _16P_1_F16_USA_Lonl i ne
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _16P_2_F16_USA_Lonl i ne
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _17P_1_F17_TAI W_LG
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _17P_2_F17_TAI W_LG
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _18P_1_F18_TAI W_SM
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _18P_2_F18_TAI W_SM
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _19P_1_S1_HW_DP
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _19P_2_S1_HW_DP
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _20P_1_S2_HW_SH
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _20P_2_S2_HW_SH
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _21P_1_S3_TAI W_LG
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _21P_2_S3_TAI W_LG
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _22P_1_S4_TAI W_SM
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _22P_2_S4_TAI W_SM
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _23P_1_S5_JPN_EARLY
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _23P_2_S5_JPN_EARLY
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _24P_1_S6_JPN_LATE
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _24P_2_S6_JPN_LATE
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _25P_1_S7_JPN_RTV
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _25P_2_S7_JPN_RTV
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _26P_1_S8_SPC_OBS
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _26P_2_S8_SPC_OBS
1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _27P_1_S9_SPC_COMB
1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel _27P_2_S9_SPC_COMB
#_Cond 0 #_custom_sel -env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
#_Cond 0 #_custom_sel -blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
#_Cond No sel ex parm trends

```



```

#_Cond -4 # placeholder for sel parm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep
in base parm bounds; 3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0 # TG_custom: 0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0 #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
27
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_survey_CV
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
#_add_to_discard_stddev
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 #_mult_by_lencomp_N
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_agecomp_N
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_size-at-
age_N
#
1 #_maxlambdaphase
1 #_sd_offset
#
55 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes: 1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq;
7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen;
14=Morphcomp; 15=Tag-comp; 16=Tag-negbin
#like_comp fleet/survey phase value sizefreq_method
1 1 1 0 1
1 2 1 0 1
1 3 1 0 1
1 4 1 0 1
1 5 1 0 1
1 6 1 0 1
1 7 1 0 1
1 8 1 0 1
1 9 1 0 1
1 10 1 0 1
1 11 1 0 1
1 12 1 0 1
1 13 1 0 1
1 14 1 0 1
1 15 1 0 1
1 16 1 0 1
1 17 1 0 1
1 18 1 0 1
1 19 1 0 1
1 20 1 0 1
1 21 1 0 1
1 22 1 0 1
1 23 1 1 1
1 24 1 1 1
1 25 1 0 1
1 26 1 0 1
1 27 1 0 1
4 1 1 1 0
4 2 1 0 0
4 3 1 1 0
4 4 1 0 0
4 5 1 1 0
4 6 1 0 0
4 7 1 0 0

```

```

4 8 1 1 0
4 9 1 0 0
4 10 1 0 0
4 11 1 0 0
4 12 1 0 0
4 13 1 0 0
4 14 1 1 0
4 15 1 0 0
4 16 1 1 0
4 17 1 0 0
4 18 1 0 0
4 19 1 0 0
4 20 1 0 0
4 21 1 0 0
4 22 1 0 0
4 23 1 0 0
4 24 1 0 0
4 25 1 0 0
4 26 1 0 0
4 27 1 0 0
9 1 1 1 0
#
# lambdas (for info only; columns are phases)
# 0 #_CPUE/survey: _1
# 0 #_CPUE/survey: _2
# 0 #_CPUE/survey: _3
# 0 #_CPUE/survey: _4
# 0 #_CPUE/survey: _5
# 0 #_CPUE/survey: _6
# 0 #_CPUE/survey: _7
# 0 #_CPUE/survey: _8
# 0 #_CPUE/survey: _9
# 0 #_CPUE/survey: _10
# 0 #_CPUE/survey: _11
# 0 #_CPUE/survey: _12
# 0 #_CPUE/survey: _13
# 0 #_CPUE/survey: _14
# 0 #_CPUE/survey: _15
# 0 #_CPUE/survey: _16
# 0 #_CPUE/survey: _17
# 0 #_CPUE/survey: _18
# 0 #_CPUE/survey: _19
# 0 #_CPUE/survey: _20
# 0 #_CPUE/survey: _21
# 0 #_CPUE/survey: _22
# 1 #_CPUE/survey: _23
# 1 #_CPUE/survey: _24
# 0 #_CPUE/survey: _25
# 0 #_CPUE/survey: _26
# 0 #_CPUE/survey: _27
# 1 #_I encomp: _1
# 0 #_I encomp: _2
# 1 #_I encomp: _3
# 0 #_I encomp: _4
# 1 #_I encomp: _5
# 0 #_I encomp: _6
# 0 #_I encomp: _7
# 1 #_I encomp: _8
# 0 #_I encomp: _9
# 0 #_I encomp: _10
# 0 #_I encomp: _11
# 0 #_I encomp: _12
# 0 #_I encomp: _13
# 1 #_I encomp: _14

```

```

# 0 #_l encomp: _15
# 1 #_l encomp: _16
# 0 #_l encomp: _17
# 0 #_l encomp: _18
# 0 #_l encomp: _19
# 0 #_l encomp: _20
# 0 #_l encomp: _21
# 0 #_l encomp: _22
# 0 #_l encomp: _23
# 0 #_l encomp: _24
# 0 #_l encomp: _25
# 0 #_l encomp: _26
# 0 #_l encomp: _27
# 1 #_i ni t_equ_catch
# 1 #_recrui tments
# 1 #_parameter-pri ors
# 1 #_parameter-dev-vectors
# 1 #_crashPenLambda
0 # (0/1) read specs for more stddev reporting
# 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex
bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N
Natages
# placeholder for vector of selex bins to be reported
# placeholder for vector of growth ages to be reported
# placeholder for vector of NatAges ages to be reported
999

```