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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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 (BSP[1]) and an age-based statistical catch-at-length model, Stock Synthesis (SS[2]). 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*: $C_{2006\text{-}2010}$; $C_{2006\text{-}2010}$ +20%; $C_{2006\text{-}2010}$ -20%; $F_{2006\text{-}2010}$; $F_{2006\text{-}2010}$ +20%; $F_{2006\text{-}2010}$ -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
	$F_{2006\text{-}2010}$	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*: $C_{2006\text{-}2010}$; $C_{2006\text{-}2010}$ +20%; $C_{2006\text{-}2010}$ -20%; $F_{2006\text{-}2010}$; $F_{2006\text{-}2010}$ +20%; $F_{2006\text{-}2010}$ -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
	$F_{2006\text{-}2010}$	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.

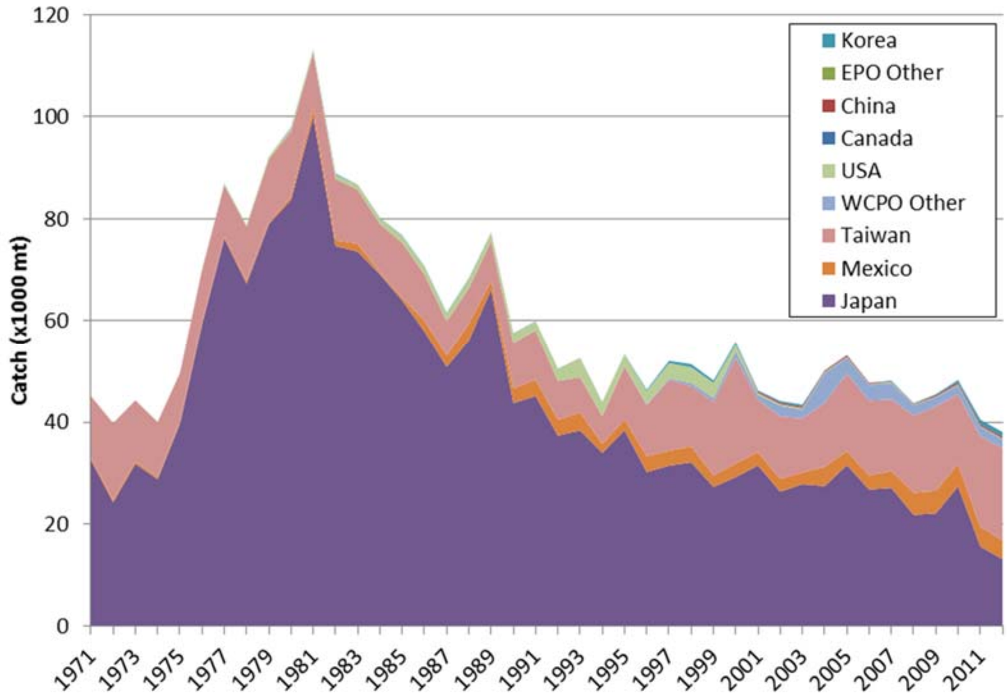


Figure 2E. Total estimated catch of North Pacific blue shark (*Prionace glauca*) by gear types from 1971-2012. Mixed gear reflects some combined longline, gillnet, pole and line, trap, purse seine.

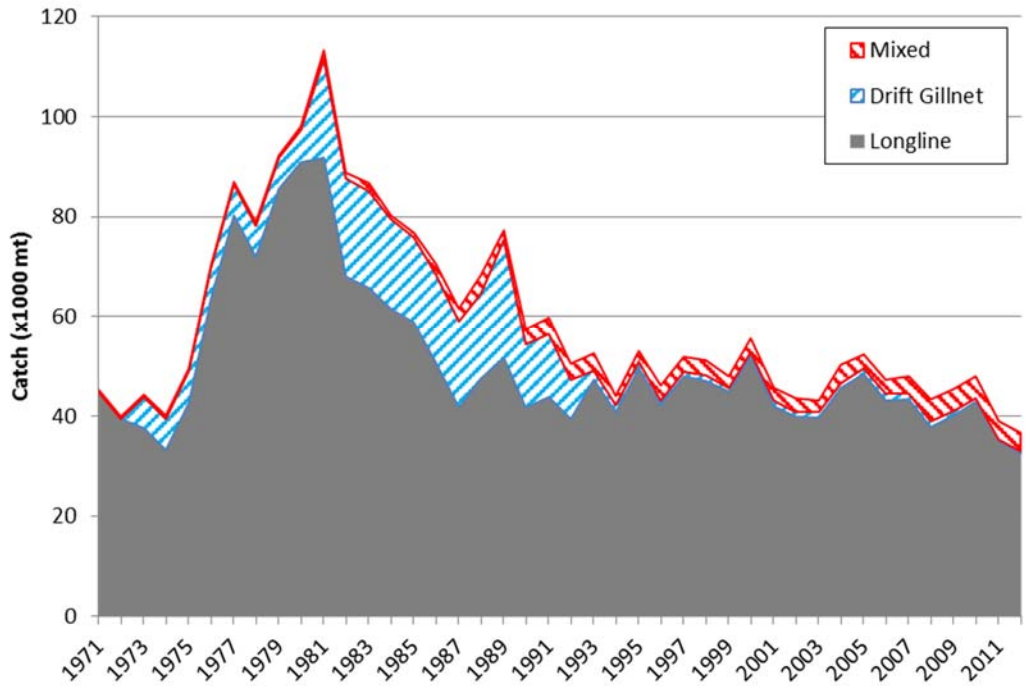


Figure 3E. Standardized CPUEs used as abundance indices in the blue shark (*Prionace glauca*) stock assessment. The reference case models were fitted to the Japanese longline early (1976-1993), and late indices (1994-2010). Alternate runs were fitted using combinations of the other indices with or without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

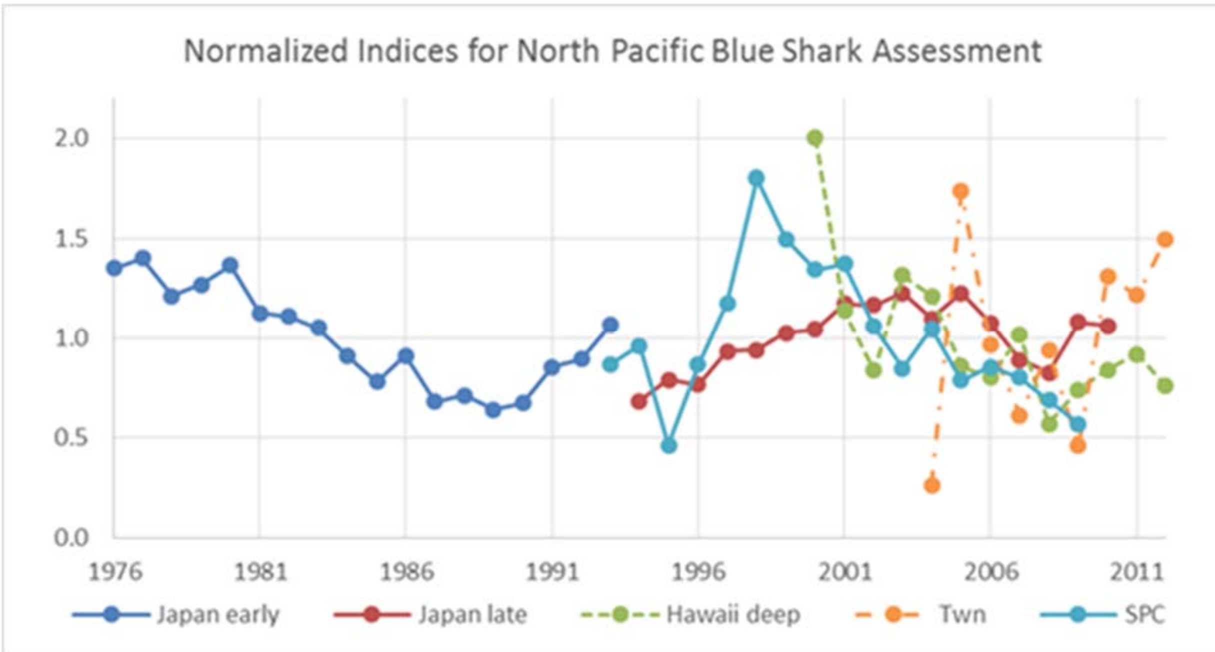


Figure 4E. Median and 90% confidence intervals for the estimated historical stock dynamics of North Pacific blue shark (*Prionace glauca*) from the BSP reference case run.

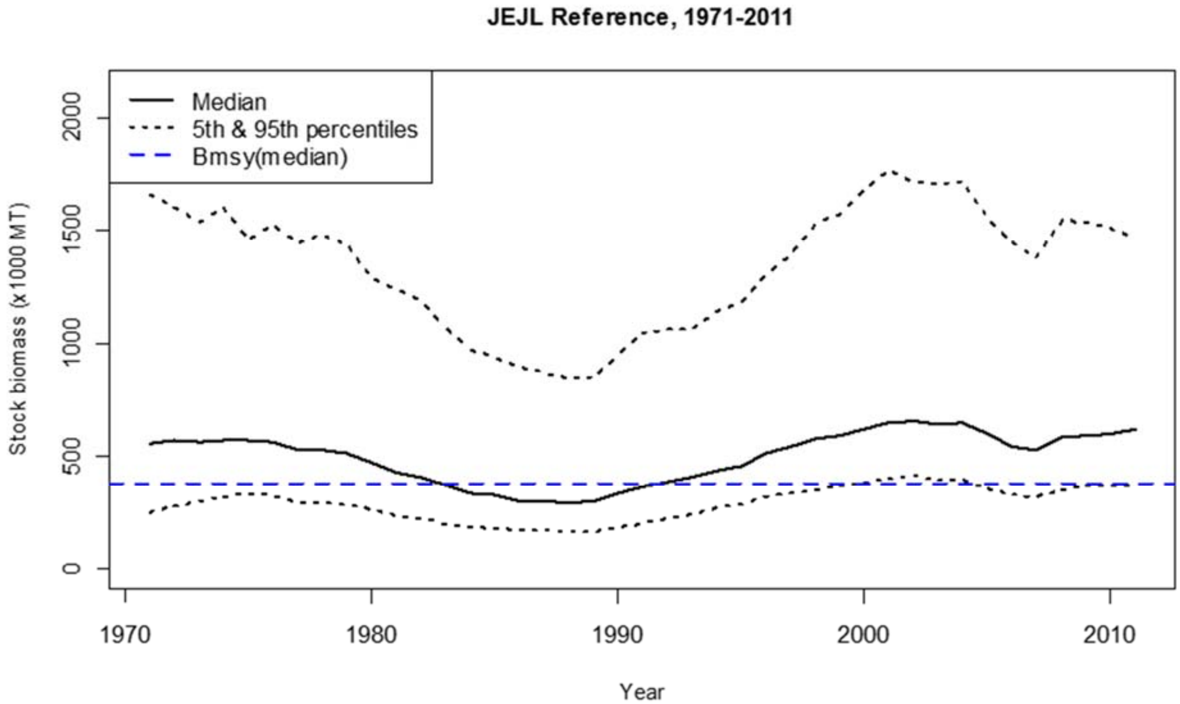


Figure 5E. Estimated female spawning biomass and 90% confidence intervals of North Pacific blue shark (*Prionace glauca*) from the SS reference case run.

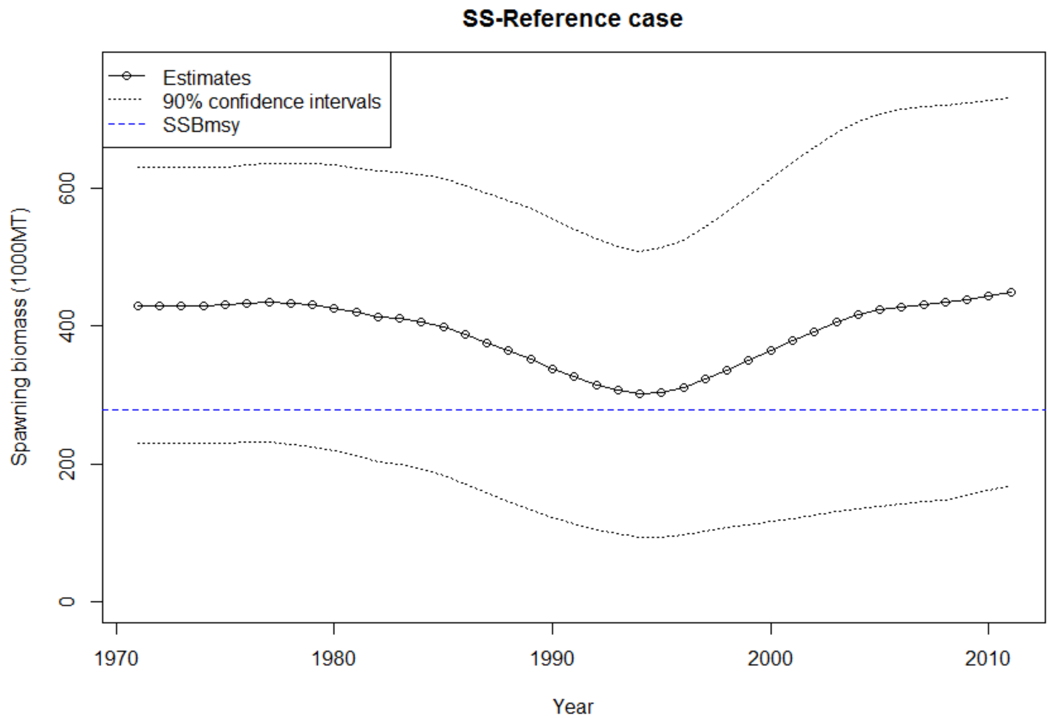


Figure 6E. Kobe plot showing median biomass and fishing mortality trajectories for the reference case BSP model for North Pacific blue shark (*Prionace glauca*). Solid blue circle indicates the median estimate in 1971 (initial year of model). Solid gray circle and its horizontal and vertical bars indicate 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.

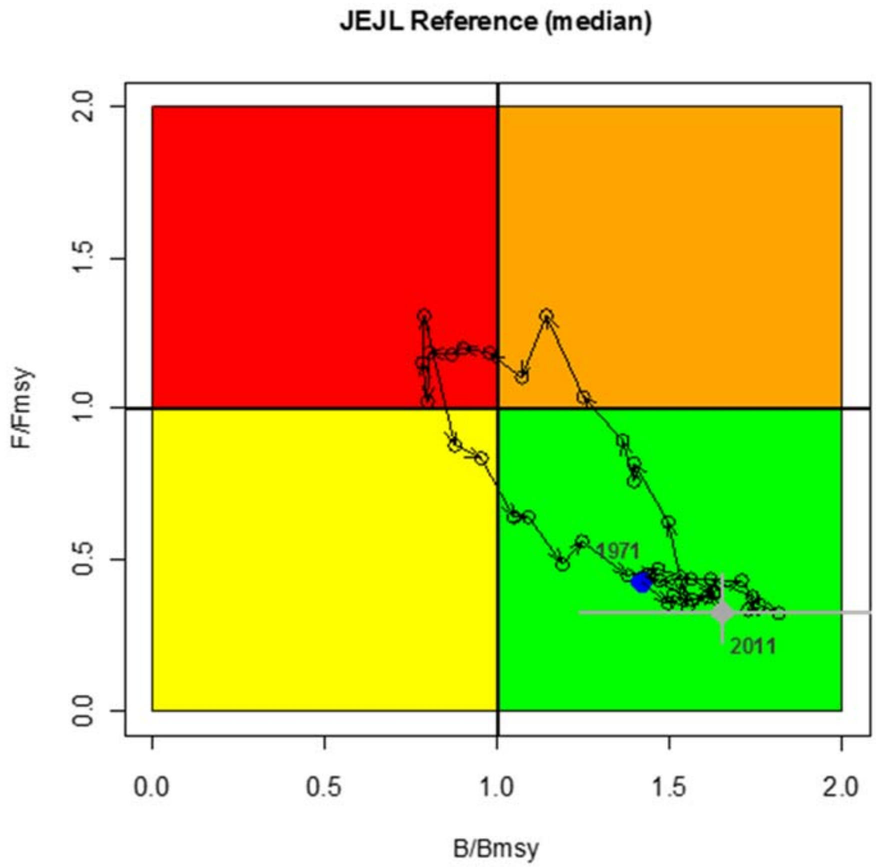


Figure 7E. Kobe plot showing estimated spawning biomass and fishing mortality trajectories for the reference case SS model for North Pacific blue shark (*Prionace glauca*). The circles indicate the historical trajectory from 1971-2011 colored from red (first year) to blue (terminal year).

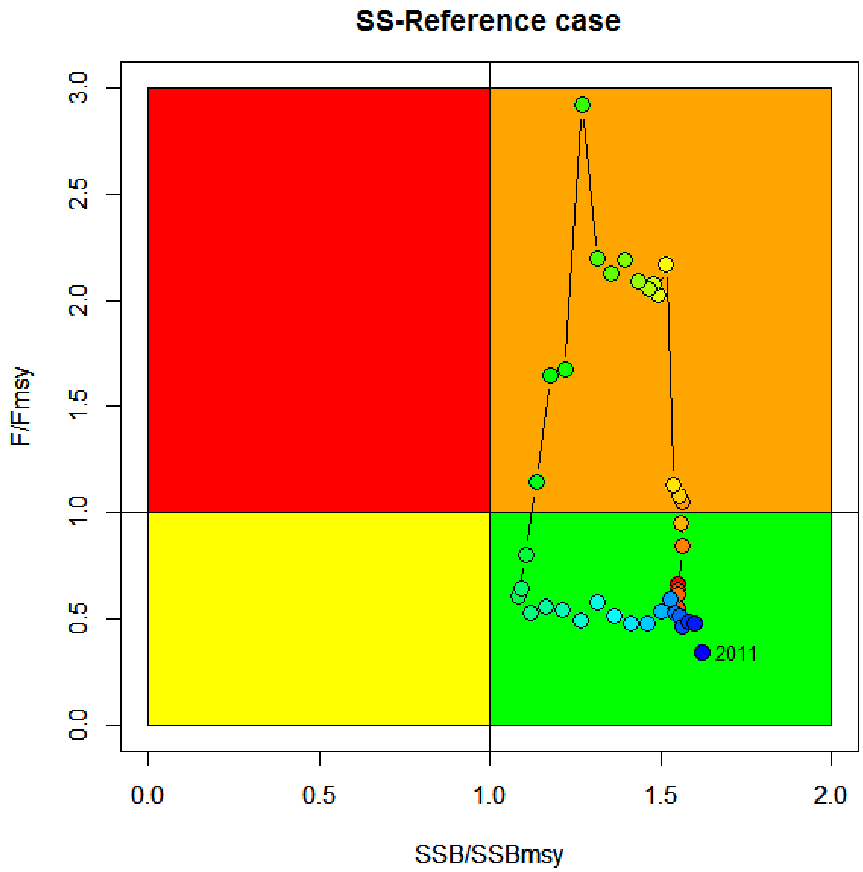


Figure 8E. Kobe plot showing the 2011 median estimates of F/F_{MSY} and B/B_{MSY} for all the BSP model runs for North Pacific blue shark (*Prionace glauca*). The horizontal and vertical bars indicate the 90% confidence limits of the 2011 estimates. Each circle with a different color indicates results 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.

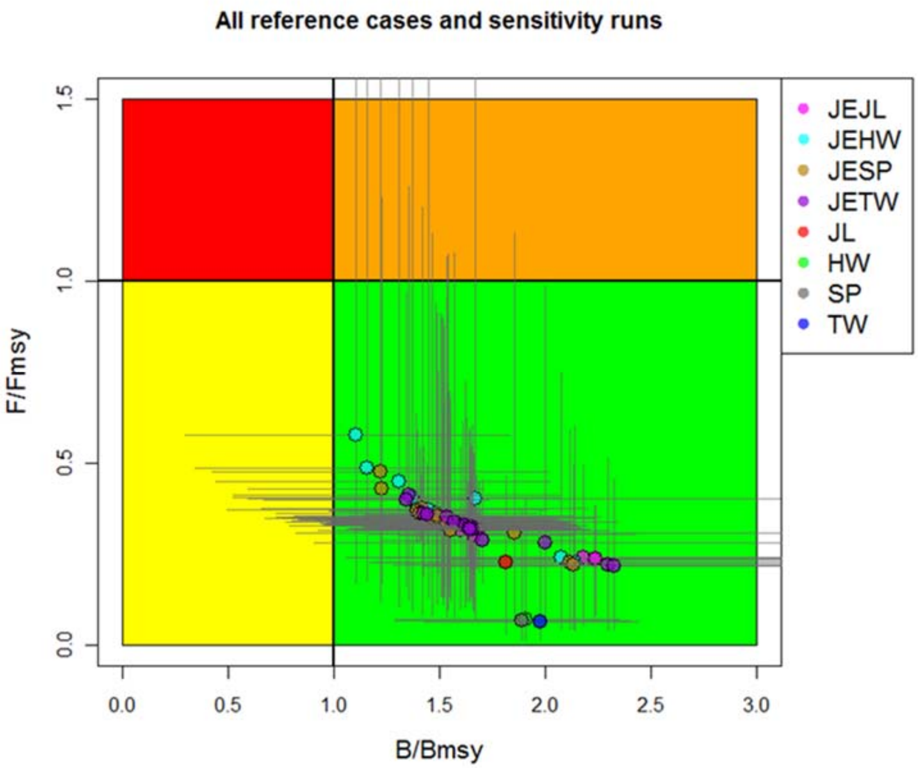


Figure 9E. Comparison of trajectories of median stock biomass of North Pacific blue shark (*Prionace glauca*) between the reference case and sensitivity runs using the reference case indices. See the assessment report text for run identifiers and detailed descriptions of the sensitivity runs.

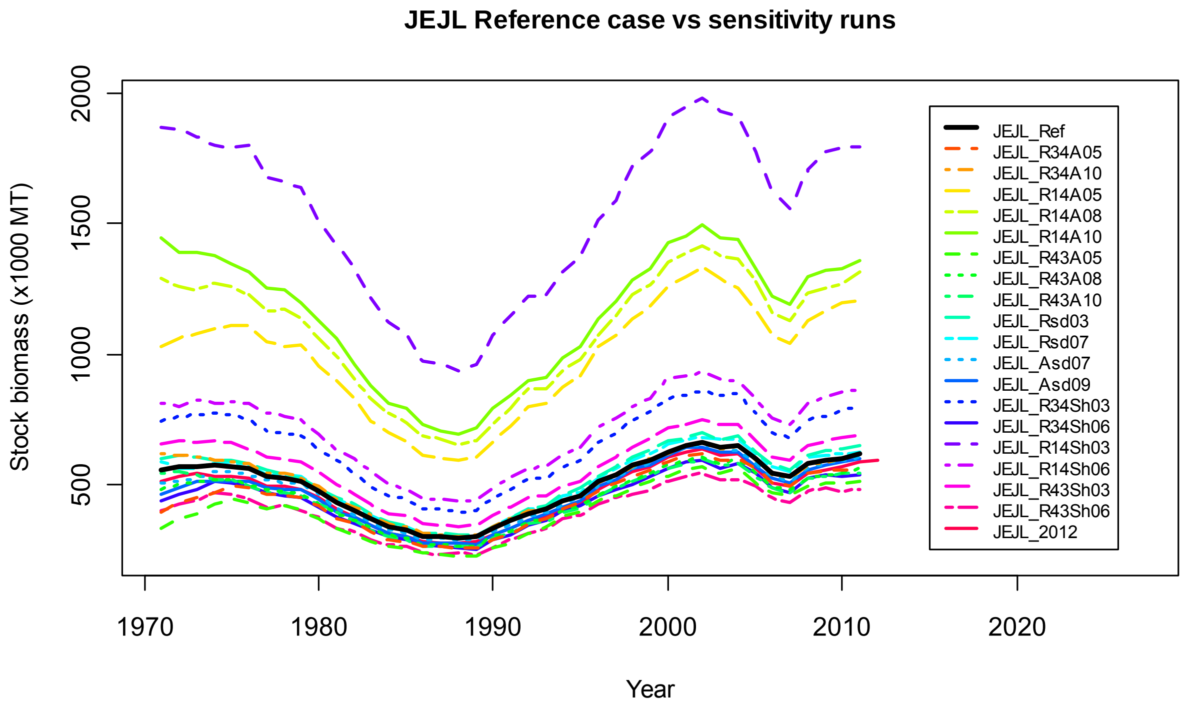


Figure 10E. Kobe bar plots showing the range of terminal year values for alternative SS runs that explored the main axes of uncertainties. The total number of runs was 1080. Note that each run is not considered equally likely, thus percentages should not be interpreted as probabilities.

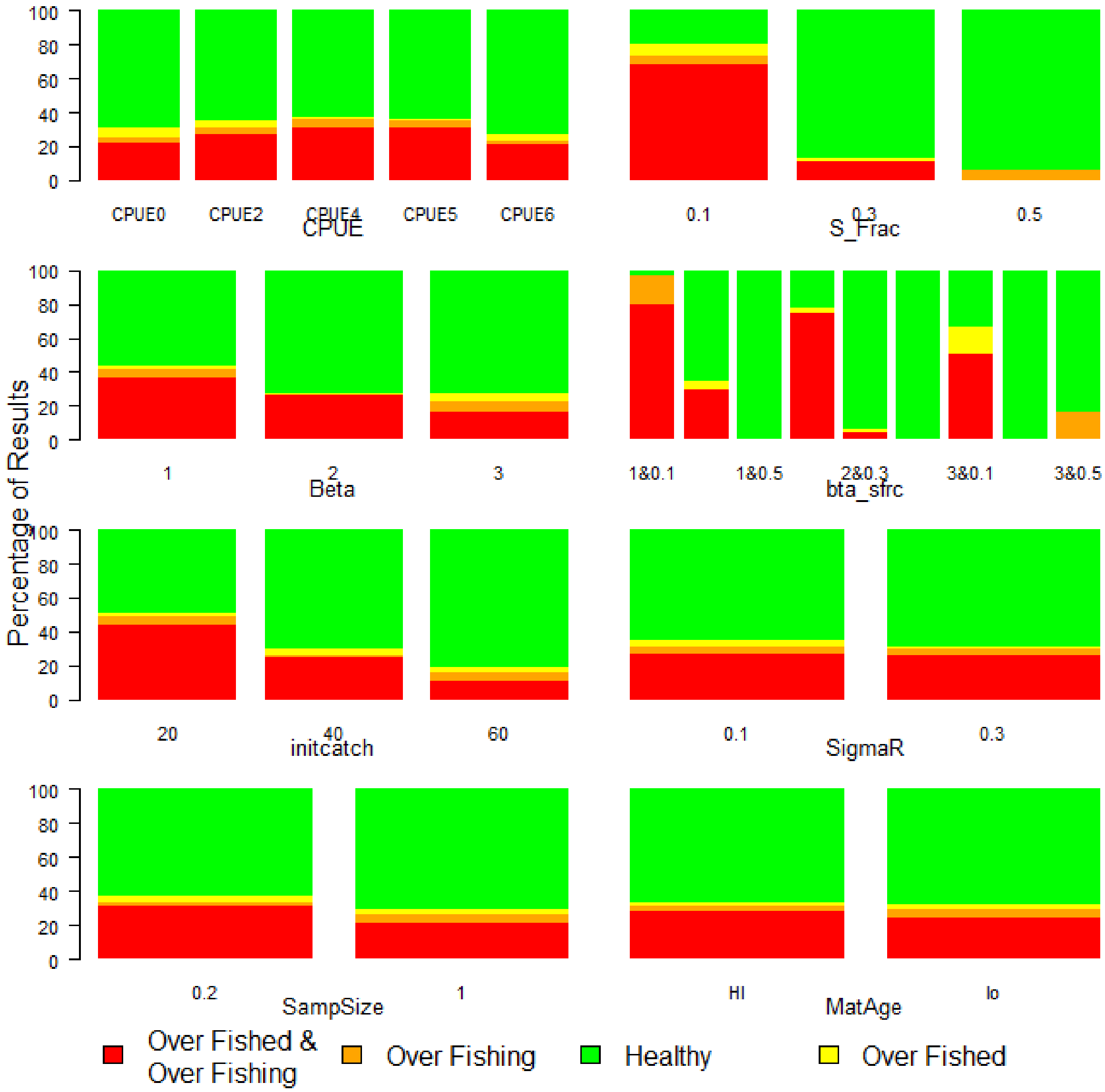


Figure 11E. Trajectories of SSB/SSB$_{MSY}$ showing the range of estimates for SS models with single parameter changes across the major axes of uncertainty. These models were conducted with the reference case CPUE indices.

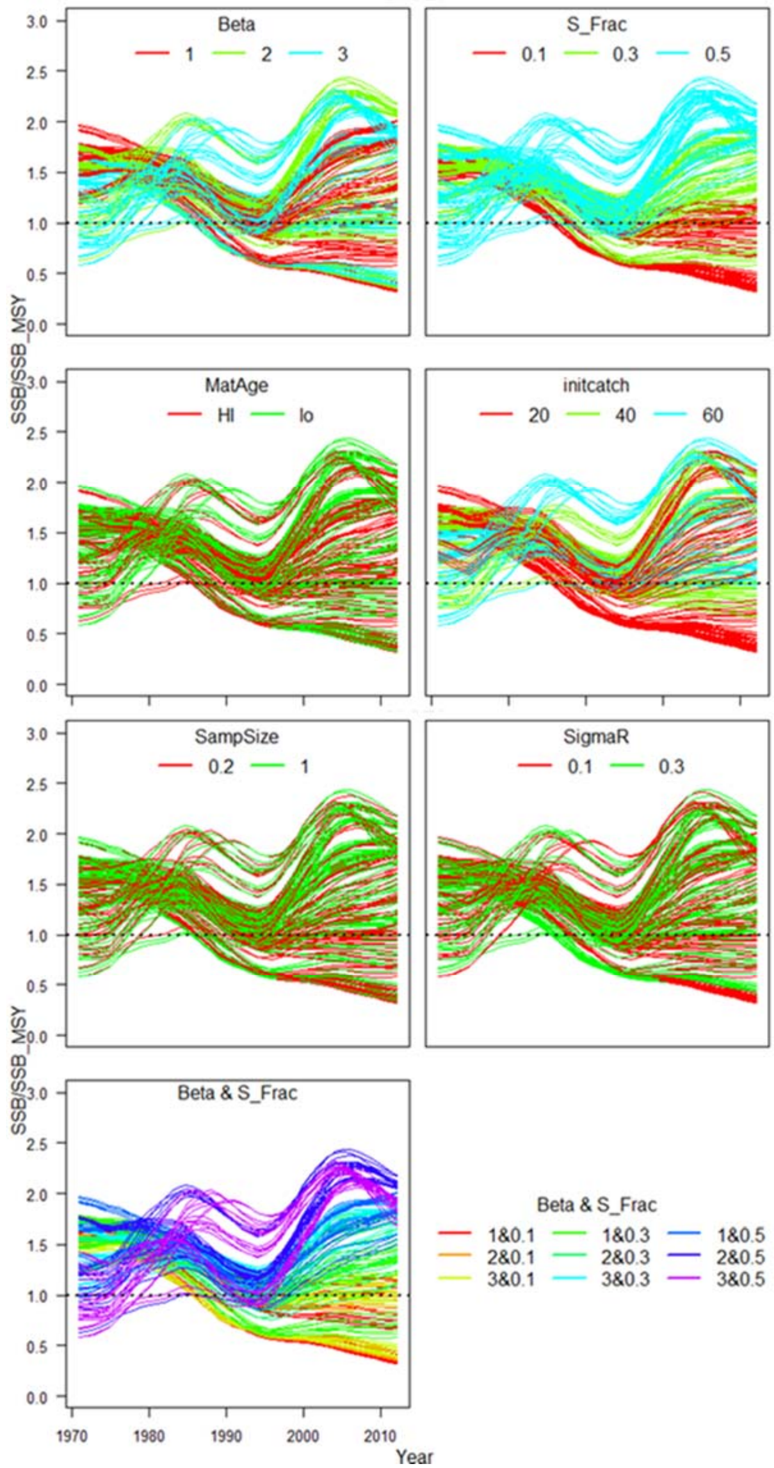


Figure 12E. Comparison of future projected blue shark (*Prionace glauca*) stock biomass (medians) under different constant catch (*status quo*, +20%, -20%) and constant *F* harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the BSP reference case model. *Status quo* catch and fishing mortality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

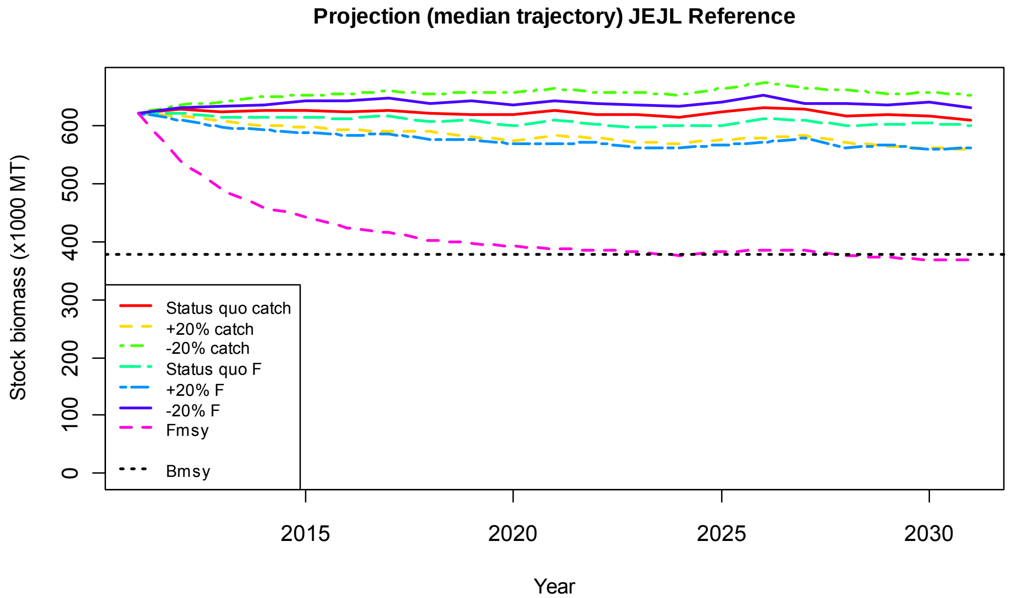
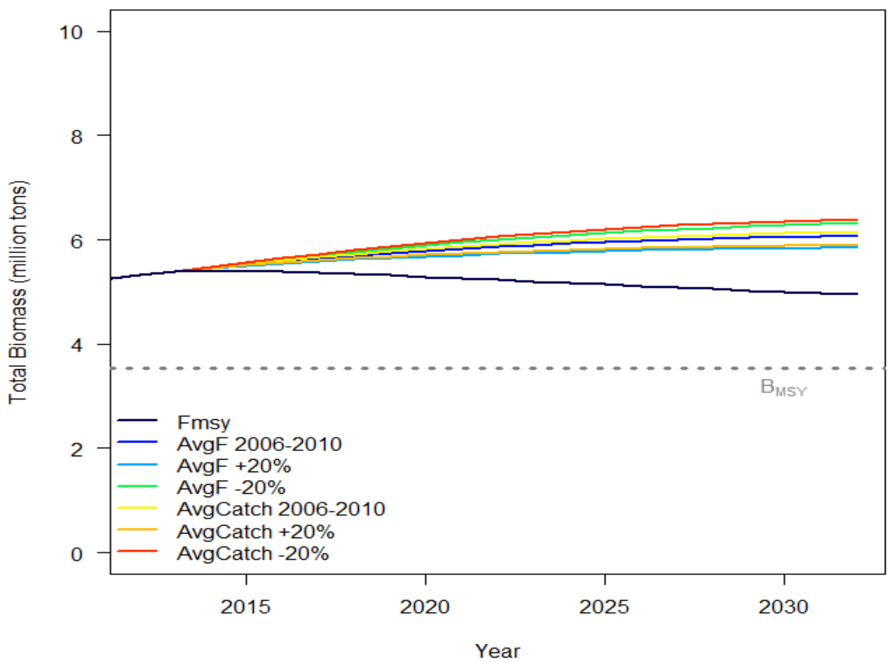


Figure 13E. Comparison of future projected blue shark (*Prionace glauca*) stock biomass under different constant catch (*status quo*, +20%, -20%) and constant *F* harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* catch and fishing mortality was based 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: $Wt = 4.2x10^{-6} * PCL^{3.1635}$, 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 ¾ 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 Hokkiado 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 Hokkiado 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 2006[3]). 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 Schafer surplus production model is expressed as (Prager 1994):

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

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

[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) $$g = \frac{n^{n/n-1}}{n-1}$$

and the inflection point is;

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

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 $B_t/B_{MSY} > 1$ the Fletcher model also applies. For $n < 2$ and $B_t/B_{MSY} \leq 1$ the functional Schaefer model as in equation 1 applies, where h=2$\emptyset K$, and $\emptyset$ 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) $$B_t = \left(B_{t-1} + rB_{t-1} - \frac{r}{K}B_{t-1}^2 - F_{t-1}B_{t-1}\right)exp\left(\varepsilon_t - \frac{\sigma_p^2}{2}\right)$$

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim Normal(0, \sigma_p^2)$.

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:

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

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, $\sigma^2_{j,k}$, according to the following equations;

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

where,

$$\hat{q}_j = \left(\frac{\Sigma_y \left(\ln(I_{j,k}) - \ln(B_y)\right)/(\sigma^2_{j,k})}{\Sigma_y 1/(\sigma^2_{j,k})} \right).$$

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_{ini}/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 (*alpha.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 $L\infty$ can be solved based on the length-at-age and $L\infty$ 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:

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

$W = 3.293\text{r}10^{-6} PCL^{3.225}$, 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 runs[4]. 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 biomasss (*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 temporarily. 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 **_R34Sh03[5] 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 **_R14A08[6] 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

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[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 no 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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10 LITERATURE CITED

Au DW, Smith SE, Show C (2008) Shark productivity and reproductive protection, and a comparison with teleosts. *In* Sharks of the Open Ocean: Biology, Fisheries and Conservation (eds. Camhi MD, Pikitch EK, Babcock EA). Blackwell Publishing, Oxford, UK 298-308 p.

Babcock EA, Cortés E (2009) Updated Bayesian surplus production model applied to blue and mako shark catch, CPUE, and effort data. Coll. Vol. Sci. Pap. ICCAT 64(5):1568–1577

Barker MJ, Schluessel V (2005) Managing global shark fisheries: suggestions for prioritizing management strategies. Aquatic Conservation: Marine and Freshwater Ecosystems 15:325–347

Blanco-Parra MP, Galván-Magaña F, Márquez-Farías F (2008) Age and growth of the blue shark, *Prionace glauca* Linnaeus, 1758, in the Northwest coast off Mexico. Revista de Biología Marina y Oceanografía 43:513–520

Cailliet GM, Bedford D (1983) The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. CalCOFI Rep 24:57–69

Compagno LJV (1984) Sharks of the world: an annotated and illustrated catalogue of shark species known to date. Food and Agriculture Organization Species Catalogue, Vol. 4, Part 2. Carcharhiniformes. FAO Fisheries Synopsis 125, 251–655

Chen S, Watanabe S (1989) Age dependence of natural mortality coefficient in fish population dynamics, Nippon Suisan Gakkaishi, 55(2):205-208

Chin C-P, Liu K-M (2013) Catch and abundance index of the blue shark by Taiwanese small-scale longline fishery in the North Pacific Ocean. ISC/13/SHARKWG-1/8. Working document submitted to the ISC Shark Working Group Workshop, 7-14 January 2013, La Jolla, California U.S.A.

Clarke S (2004) Understanding pressures on fishery resources through trade statistics: a pilot study of four products in the Chinese dried seafood market. Fish and Fisheries 5:53–74

Clarke S, Harley S (2010) A proposal for a research plan to determine the status of the key shark species. WCPFC-SC6-2010/EB-WP-01. Working paper submitted to the WCPFC Science Committee Meeting, 10-19 August 2010, Nukualofa, Tonga

Clarke S, Harley SJ, Hoyle SD, Rice J (2013) Population trends in Pacific oceanic sharks and the utility of shark finning regulations. Conservation Biology 27(1): 197-209

Clarke S, Yokawa K, Matsunaga H, Nakano H (2011) Analysis of North Pacific shark data from Japanese commercial longline and research/training vessel records. WCPFC-SC7-2011/EB-WP-02. Working paper submitted to the WCPFC Science Committee Meeting, 9-17 August 2011, Pohnpei, Federated States of Micronesia

Cortés E (2002) Incorporating uncertainty into demographic modeling: application to shark populations and their conservation. Conservation Biology 16:1048–1062

Dreyfus M, Fleischer L, Ramirez PU, Robles H (2008) Mexican Progress Report to the 8th ISC. ISC/08/Plenary/09. Eighth Meeting of the International Scientific Committee on Tuna and Tuna-like Species in the North Pacific Ocean (ISC), 15-27 July 2008, Takamatsu, Japan

Fletcher RI (1978) Time-dependent solutions and efficient parameters for stock-production models. Fishery Bulletin 76(2):377-388

Fournier DA, Skaug HJ, Ancheta J, Ianelli J, Magnusson A, Maunder MN, Nielsen A, Sibert J (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27:233-249

Fournier DA, Hampton J, Sibert JR (1998) MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Canadian Journal of Fisheries and Aquatic Sciences 55:2105–2116

Fowler CW (1988) Population dynamics as related to rate of increase per generation. Evolutionary Ecology 2:197–204

Francis RI (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68(6): 1124-1138

Francis RICC (2014) Replacing the multinomial in stock assessment models: A first step. Fisheries Research 151:70-84

Gubanov Y (1975) The reproduction of some species of pelagic sharks from the equatorial zone of the Indian Ocean. Journal of Ichthyology 18:781–792

Hart JL (1973) Fishes of the Pacific coast of Canada. Bulletin 180. Ottawa: Fisheries Research Board of Canada

Hiraoka Y, Kanaiwa M, Yokawa K (2012a) Estimation of total blue shark catches including releases and discards Japanese longline fisheries during 1975 and 2010 in the North Pacific. ISC/12/SHARKWG-1/08. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

Hiraoka Y, Kanaiwa M, Yokawa K (2012b) Extraction of blue shark catches from species-combined catches of sharks in the log-book data of Japanese offshore and distant-water longliners operated in the North Pacific in the period between 1975 and 1993. ISC/12/SHARKWG-1/07. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

Hiraoka Y, Kanaiwa M, Yokawa K (2012c) Estimation of abundance indices for blue shark in the North Pacific. ISC/12/SHARKWG-1/09. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

Hiraoka Y, Kanaiwa M, Kimoto A, Ichinokawa M, Yokawa K (2012d) Estimation of historical catch amount and abundance indices for blue shark caught by the Japanese offshore and distant water longline. ISC/12/SHARKWG-2/02

Hiraoka Y, Kanaiwa M, Yokawa K (2013) Summary of estimation process of abundance indices for blue shark in the North Pacific. ISC/13/SHARKWG-2/02. Working document submitted to the ISC Shark Working Group Workshop, 13 July 2012, Sapporo, Japan

Hiraoka Y, Taguchi M, Kanaiwa M, Yokawa K (2011) The operation pattern of Japanese tuna longline fishery with the information for prefecture of vessels register and reporting rate in the North Pacific Ocean, 1994-2010. ISC/11/SHARKWG-2/09. Working document submitted to the ISC Shark Working Group Workshop, 28 November – 3 December 2011, La Jolla, California U.S.A.

Holts D, Sosa-Nishizaki O (1994) Swordfish, *Xiphias gladius*, fisheries of the eastern North Pacific Ocean. In: Biology and fisheries of swordfish, *Xiphias gladius*. Papers from the International Symposium on Pacific Swordfish, Ensenada Mexico 11–14 p

Hsu HH, Joung SJ, Lyu GT, Liu KM, Huang CC (2011) Age and growth of the blue shark, *Prionace glauca*, in the northwest Pacific. ISC/11/SHARKWG-2/INFO02

IATTC (2005) Resolution on the conservation of sharks caught in association with fisheries in the Eastern Pacific Ocean. C-05-03 http://iattc.org/ResolutionsActiveENG.htm

IATTC (2013) Preliminary estimates of total purse-seine bycatch of blue sharks (in numbers of animals), 1971-2010, for the northern Eastern Pacific Ocean. ISC/13/SHARKWG-1/INFO-01. Working document submitted to the ISC Shark Working Group Workshop, 7-14 January 2013, La Jolla, California U.S.A.

ISC (2012a) Report of the Shark Working Group Workshop (November 2011). ISC/12/ANNEX04. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 20-25 July 2011, San Francisco, California, U.S.A.

ISC (2012b) Report of the Shark Working Group Workshop (May 2012). ISC/12/ANNEX07. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 18-23 July 2013, Sapporo, Japan

ISC (2013a) Report of the Shark Working Group Workshop (January 2013). ISC/13/ANNEX06. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 17-22 July 2013, Busan, Korea.

ISC (2013b) Report of the Shark Working Group Workshop (April 2013). ISC/13/PLENARY/ANNEX08. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 17-22 July 2013, Busan, Korea.

ISC (2013c). Stock assessment and future projections of blue shark in the North Pacific Ocean. ISC/13/ANNEX11. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 17-22 July 2013, Busan, Korea.

ISC (2014a) Report of the Shark Working Group Workshop (January 2014). ISC/14/ANNEX06. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 16-21 July 2014, Taipei, Taiwan

ISC (2014b) Report of the Shark Working Group Workshop (June 2014). ISC/14/ANNEX12. In Report of the Plenary Session of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, 16-21 July 2014, Taipei, Taiwan

Joung SJ, Hsu HH, Liu KM, Wu T (2011) Reproductive biology of the blue shark, *Prionace glauca*, in the northwestern Pacific. ISC/11/SHARKWG-2/12. Working document submitted to the ISC Shark Working Group Workshop, 28 November – 3 December 2011, La Jolla, California U.S.A.

Kai M, Shiozki K, Ohshimo S (2014) Update of Japanese abundance indices and catch for blue shark *Prionace glauca* in the North Pacific. ISC/14/SHARKWG-1/02. Working document submitted to the ISC Shark Working Group Workshop, 13 January – 18 January 2014, La Jolla, California U.S.A.

Kass RE, Raftery AE (1995) Bayes factors. Journal of the American Statistical Association 90:773–795

Kimoto A, Yano T, Yokawa K (2012) Historical catch amount of blue shark caught by the Japanese coastal fisheries. International Scientific Committee for Tuna and Tuna-like Species in the North Pacific ISC/12/SHARKWG-1/11. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

King J (2011) Blue shark (*Prionace glauca*) bycatch statistics in Canadian fisheries. ISC/11/SHARKWG-2/01.Working document submitted to the ISC Shark Working Group Workshop, 28 November – 3 December 2011, La Jolla, California U.S.A.

Kleiber P, Clarke S, Bigelow K, Nakano H, McAllister M, Takeuchi Y (2009) North Pacific Blue Shark Stock Assessment. NOAA Technical Memorandum NMFS-PIFSC-17:1–83

Matsunaga H, Shono H, Kiyota M, Suzuki, Z (2005) Long-term changes in CPUE of sharks and size of blue sharks caught by tuna longlines in the western North Pacific Ocean [EB WP-11]. First Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC1, New Caledonia, 8-19 August 2005, 11 p

McAllister M, Babcock E, Pikitch E, Bonfil R (2002) Importance sampling issues with the 1998 large coastal shark assessment. In: 2002 Shark Evaluation Workshop, National Marine Fisheries Service, Panama City, Florida

McAllister M, Babcock EA, Pikitch EK, Prager MH (2000) Application of a non-equilibrium generalized production model to South and North Atlantic swordfish: combining Bayesian and demographic methods for parameter estimation. Coll. Vol. Sci. Pap. ICCAT 51(5):1523-1550

McAllister MK, Babcock EA (2006) Bayesian Surplus Production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. Available from http://www.sefsc.noaa.gov/sedar/download/BSP%20User%20guide.pdf?id=DOCUMENT

Mendizábal OD, Vélez-Marín R, Soriano-Velásquez SR, Castillo-Géniz JL (2000) Tiburones oceánicos del Pacífico. In Sustentabilidad y Pesca Responsable en México: Evaluación y Manejo. Instituto Nacional de la Pesca: 179-210

Methot RD (2005) Technical Description of the Stock Synthesis II Assessment Program. NOAA Fisheries. http://www.sefsc.noaa.gov/sedar/download/S16_AW_04.pdf?id=DOCUMENT

Methot RD (2009) User Manual for Stock Synthesis. Model Version 3.24f. NOAA Fisheries

Methot RD, Wetzel CR (2013) Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish Res. 142: 86-99

Musyl MK, Brill RW, Curran DS, Fragoso NM, McNaughton LM, Nielsen A, Kikkawa BS, Moyes CD (2011) Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. Fishery Bulletin 109:341–368

Nakano H (1994) Age, reproduction and migration of blue shark (*Prionace glauca*) in the North Pacific Ocean. Bulletin - National Research Institute of Far Seas Fisheries (31):141-256

Nakano H, Clarke S (2006) Filtering method for obtaining stock indices by shark species from species-combined logbook data in tuna longline fisheries. Fisheries Science 72:322–332

Nakano H, Seki MP (2003) Synopsis of biological data on the blue shark (*Prionace glauca* Linnaeus). Bulletin of the Fisheries Research Agency of Japan 6: 8–55

Nakano H, Shimazaki K, Makihara M (1985) Distribution and biological characteristics of the blue shark [*Prionace glauca*] in the central North Pacific. Bulletin of the Faculty of Fisheries Hokkaido University 36 p

Nakano H, Stevens JD (2009) The biology and ecology of the blue shark, *Prionace glauca*. In Sharks of the Open Ocean: Biology, Fisheries and Conservation (eds. Camhi MD, Pikitch EK, Babcock EA). Blackwell Publishing, Oxford, UK 140–151 p.

O'Brien JW, Sunada JS (1994) A review of the Southern California experimental drift longline fishery for sharks, 1988-1991. CalCOFI Reports 35:222-229

Ohshimo S, Shiozaki K, Kai M., and Yokawa K. 2014. Comparison of CPUE level of blue shark in Japanese longline research activities before and after the World War II. ISC/14/SHARKWG-1/04. Working document submitted to the International Scientific Committee for Tuna and Tuna-like species in the North Pacific Ocean (ISC) Shark Working Group Workshop, 13-18 January 2014, La Jolla, California, U.S.A.

Peterson I, Wroblewski JS (1984) Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Science 41:1117-1120.

Prager M (1994) A suite of extensions to a nonequilibrium surplus-production model. Fishery Bulletin 92:374–389

Prager MH (2002) Comparison of logistic and generalized surplus-production models applied to swordfish, *Xiphias gladius*, in the North Atlantic Ocean. Fisheries Research 58:41–57

Quinn T, Deriso R (1999) Quantitative fish dynamics, Biological Resource Management Series, Oxford University Press, New York

R Development Core Team (2011) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Rice J, Harley S, Maunder M, Aires da-Silva A (2014) Stock assessment of blue shark in the North Pacific Ocean using Stock Synthesis WCPFC-SC9-2013/SA-WP-02. Working paper submitted to the WCPFC Science Committee Meeting, 6-14 August 2013, Pohnpei, Federated States of Micronesia

Rice J, Harley S (2014) Standardization of blue shark catch per unit effort in the North Pacific Ocean based on SPC held longline observer data for use as an index of abundance. ISC/14/SHARKWG-2/04. Working document submitted to the ISC Shark Working Group Workshop, 2-9 June 2014, Keelung, Chinese Taipei

Rice J, Semba Y (2014) Age and sex specific natural mortality of the blue shark (*Prionace glauca*) in the North Pacific Ocean. ISC/14/SHARKWG-2/04. Working document submitted to the ISC Shark Working Group Workshop, 2-9 June 2014, Keelung, Chinese Taipei

Sippel T, Kohin S (2013) Catches of blue sharks from US West Coast recreational fisheries during 1971-2011. ISC/13/SHARKWG-2/01. Working document submitted to the ISC Shark Working Group Workshop, 16-24 April 2013, Shizuoka, Japan

Sippel T, Wraith J, Kohin S, Taylor V, Holdsworth J, Taguchi M, Matsunaga H, Yokawa K (2011) A summary of blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) tagging data available from the North and Southwest Pacific Ocean. ISC/11/SHARKWG-2/04. Working document submitted to the ISC Shark Working Group Workshop, 28 November – 3 December 2011, La Jolla, California U.S.A.

Skomal GB, Natanson LJ (2003) Age and growth of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. Fishery Bulletin-National Oceanic and Atmospheric Administration 101:627–639

Smith SE, Au DW, Show C (1988) Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshwater Res. 49:663–78

Sosa-Nishizaki O (1998) Historical review of the billfish management in the Mexican Pacific. Ciencias Marinas 24:95–111

Sosa-Nishizaki O (2013) Unofficial blue shark catch estimations for the Mexican Pacific (1976-2011). ISC/13/SHARKWG-2/INFO-1. Working document submitted to the ISC Shark Working Group Workshop, 16-24 April 2013, Shizuoka, Japan

Sosa-Nishizaki O, Fulong-Estrada E, Reyes-Gonzales JA, Perez-Jimenez JC (2002) Blue shark (*Prionace glauca*) fishery in Baja California, Mexico: an example of artisanal and middle scale fisheries interaction. Science Council Research Document NAFO 02/140

Suda A (1953) Ecological study of blue shark (*Prionace glauca* LINNÉ). Bull. Nankai Fish. Res. Lab., 1(26):1-11

Stanley R, McAllister M, Starr P (2012) Updated stock assessment for Bocaccio (*Sebastes paucispinis*) in British Columbia waters for 2012. DFO Can Sci Advis Sec Res Doc:73

Stevens JD, Bradford RW, West GJ (2010) Satellite tagging of blue sharks (*Prionace glauca*) and other pelagic sharks off eastern Australia: depth behaviour, temperature experience and movements. Marine Biology 157:575–591

Taguchi M, King J, Wetklo M, Withler RE, Yokawa K (*In Press*) Population genetic structure and demographic history of blue sharks (*Prionace glauca*) in the Pacific Ocean inferred from mitochondrial DNA. Marine and Freshwater Research

Takahashi N, Sippel T, Teo S, Kohin S, King J, Hiraoka Y (2013) Stock assessment of blue shark in the North Pacific Ocean. ISC Shark Working Group

Takeuchi Y, Semba Y, Nakano H (2005) Demographic analysis on Atlantic blue and shortfin mako sharks. SCRS/2004/122. Col. Vol. Sci. Pap. ICCAT, 58(3):1157-1165

Tanaka S (1984) Present status of fisheries biology of sharks and rays. In: Jpn Soc Sci Fish Symp: 46–59

Taylor IG, Gertseva V, Methot RD, Maunder MN (2013) A stock-recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fisheries Research 142: 15– 21

Teo S (2013) Preliminary catch estimates of north Pacific blue shark from California experimental shark longline fisheries. ISC/13/SHARKWG-1/02. Working document submitted to the ISC Shark Working Group Workshop, 7-14 January 2013, La Jolla, California U.S.A.

Teo S, Sippel T, Wells D, Kohin S (2012) Preliminary time series for the north Pacific blue and shortfin mako sharks from the US West Coast drift gillnet fishery. ISC/12/SHARKWG-1/03. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

Tsai W, Liu K (2013) Update historical catches and standardized CPUE series of blue shark by Taiwanese tuna longline fisheries in the North Pacific Ocean. ISC/13/SHARKWG-2/05. 05 Working document submitted to the ISC Shark Working Group Workshop, 16-24 April 2013, Shizuoka, Japan

Walsh W, DiNardo GT (2014) Blue shark catch rates in the Hawaii-based pelagic longline fishery in 2000−2012: A re-evaluation of observer catch data and standardizations for both fishery sectors. ISC/14/SHARKWG-1/06. Working document submitted to the ISC Shark Working Group Workshop, 13 January – 18 January 2014, La Jolla, California U.S.A.

Walsh W, Teo S (2012) Catch statistics, length data and standardized CPUE for blue shark *Prionace glauca* taken by longline fisheries based in Hawaii and California. ISC/12/SHARKWG-1/02. Working document submitted to the ISC Shark Working Group Workshop, 28 May – 4 June 2012, Shizuoka, Japan

Ward P, Myers RA (2005). Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. Ecology, 86(4), 835-847

Weng KC, Castilho PC, Morrissette JM, Landeira-Fernandez AM, Holts DB, Schallert RJ, Goldman KJ, Block BA (2005) Satellite tagging and cardiac physiology reveal niche expansion in salmon sharks. Science 310:104-106

Western and Central Pacific Fisheries Commission (WCPFC). (2013) Summary Report for WCPFC Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean, Scientific Committee, Ninth Regular Session. Pohnpei, Federated States of Micronesia 6–14 August 2013

Worm B, Davis B, Kettemer L, Ward-Paige CA, Chapman D, Heithaus MR, Kessel ST, Gruber SH (2013) Global catches, exploitation rates, and rebuilding options for sharks. Marine Policy 40:194–204

Yokawa K, Kai M, Shiozaki K, Ohshimo S (2014) Blue shark catch and effort data collected by Japanese research and training vessels. ISC/14/SHARKWG-1/03. Working document submitted to the ISC Shark Working Group Workshop, 13 January – 18 January 2014, La Jolla, California U.S.A.

Yokawa K, Shiozaki K, Kimoto A (2012) Trials for the estimates of blue shark catches caught by Japanese longliners and drift netters in the North Pacific ISC/12/SHARKWG-2/01. Working document submitted to the ISC Shark Working Group Workshop, 13 July 2012, Sapporo, Japan

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
Qualilty 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 (*alpha.b0*) 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 n=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 ((observation error CV)^2+(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_{msy}/K (shape parameter n)	**_R34SH03 **_R34SH06	B_{msy}/K = 0.3 (n = 0.68) B_{msy}/K = 0.6 (n = 3.39)
r prior mean *r* prior SD	**_R14A08 **_R43A08 **_Rsd03 **_Rsd07	mean = 0.14 (from Babcock and Cortés 2009) mean = 0.43 (from Cortés 2002) SD = 0.3 SD = 0.7
B_{init}/K (*alpha.b0*) prior mean B_{init}/K (*alpha.b0*) prior SD	**_R34A05 **_R34A10 **_Asd07 **_Asd09	mean = 0.5 mean = 1.0 SD = 0.7 SD = 0.9
r versus B_{init}/K grids	**_R14A05 **_R43A05 **_R14A10 **_R43A10	*r* prior mean = 0.14, B_{init}/K prior mean = 0.5 *r* prior mean = 0.43, B_{init}/K prior mean = 0.5 *r* prior mean = 0.14, B_{init}/K prior mean = 1.0 *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_{msy}/K (shape parameter *n*)	**_R14Sh03 **_R43Sh03 **_R14Sh06 **_R43Sh06	*r* prior mean = 0.14, B_{msy}/K = 0.3 (*n* = 0.68) *r* prior mean = 0.43, B_{msy}/K = 0.3 (*n* = 0.68) *r* prior mean = 0.14, B_{msy}/K = 0.6 (*n* = 3.34) *r* prior mean = 0.43, B_{msy}/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_{msy}/K [0.3, 0.47(reference), 0.6] (*n* [0.68, 1.71, 3.39]) along with **_R34Sh03, **_R34Sh06, **_Ref, **_R14A08 (Bmsy/K=0.47) and **_R43A08 (Bmsy/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 Ponly_hlfcat Ponly_dblcat Ponly_rvscat Ponly_pessim	with observed catch with halving catch with doubling catch with reversed catch 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. *Binit / 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).

	Nakano (1994)		Hsu et al. (2011)	
Age	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	*Beta* (all combinations)	S_{Frac}
		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)
Status quo		
(Average of 2006-2010)	0.495	46,389
MSY	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 (*alpha.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 (*alpha.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 (*alpha.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 (*alpha.b0*) 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 (*alpha.b0*) 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 (*alpha.b0*) 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 (alpha.b0) 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 (alpha.b0) 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 (alpha.b0) 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_{init}/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_{init}/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
	$F_{2006\text{-}2010}$	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
	$F_{2006\text{-}2010}$	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	M at 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	***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
	$F_{2006\text{-}2010}$	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.

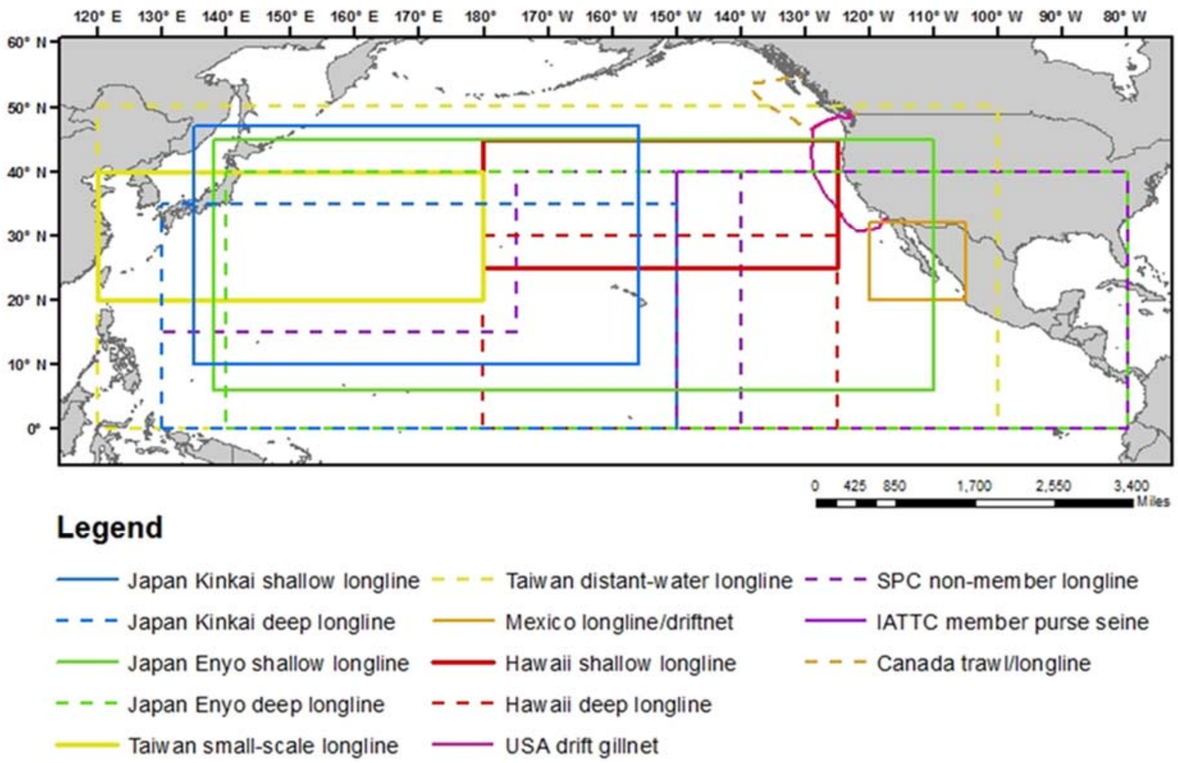


Figure 2. Total estimated catch of North Pacific blue shark (*Prionace glauca*) from 1971-2012 by nation or region.

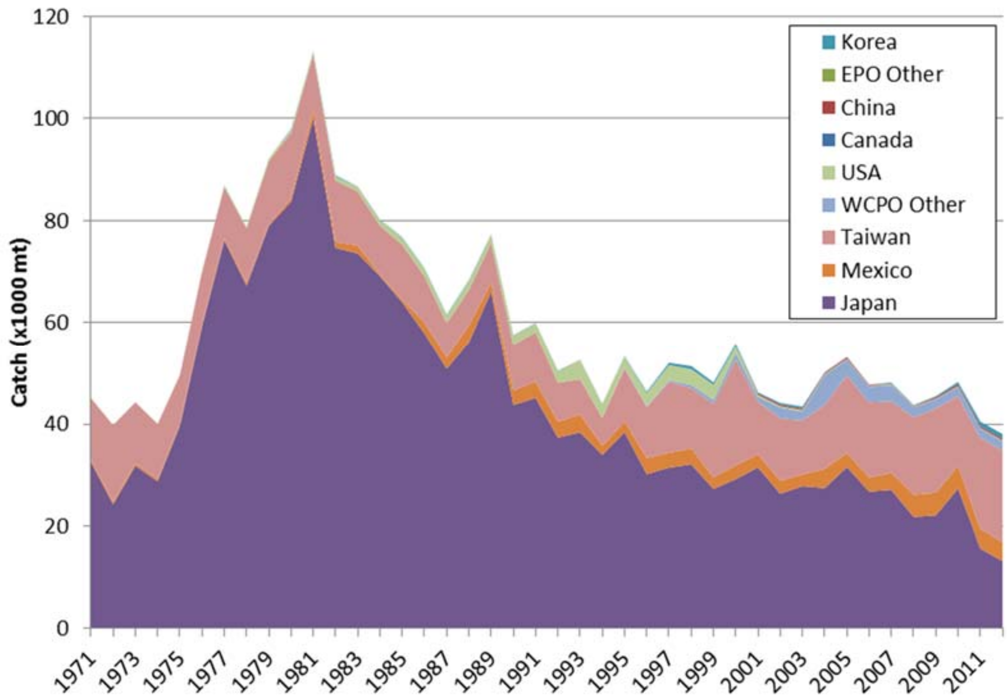


Figure 3. Total estimated catch of North Pacific blue shark (*Prionace glauca*) by gear types from 1971-2012. Mixed gear reflects some combined longline, gillnet, pole and line, trap, purse seine.

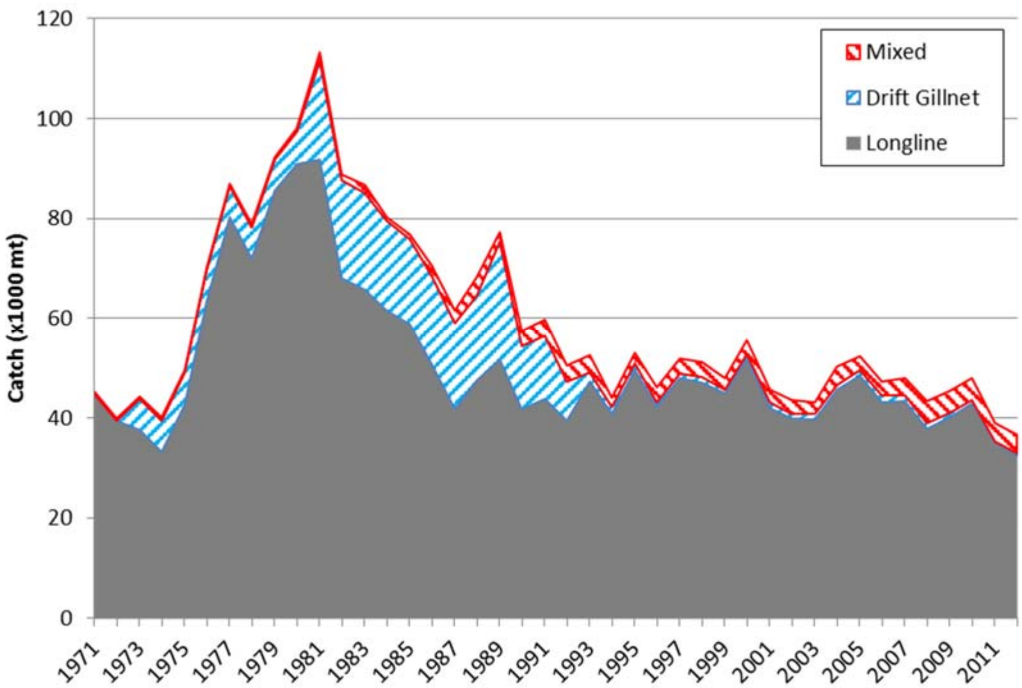


Figure 4: Assumed catch time series by fishery for the SS reference case model. For the BSP runs, catch of all fleets was summed into a single catch time series. Note: Catch in 1970 is an assumed level of catch used to derive the equilibrium fished condition and the selectivity of fishery 4 was assumed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

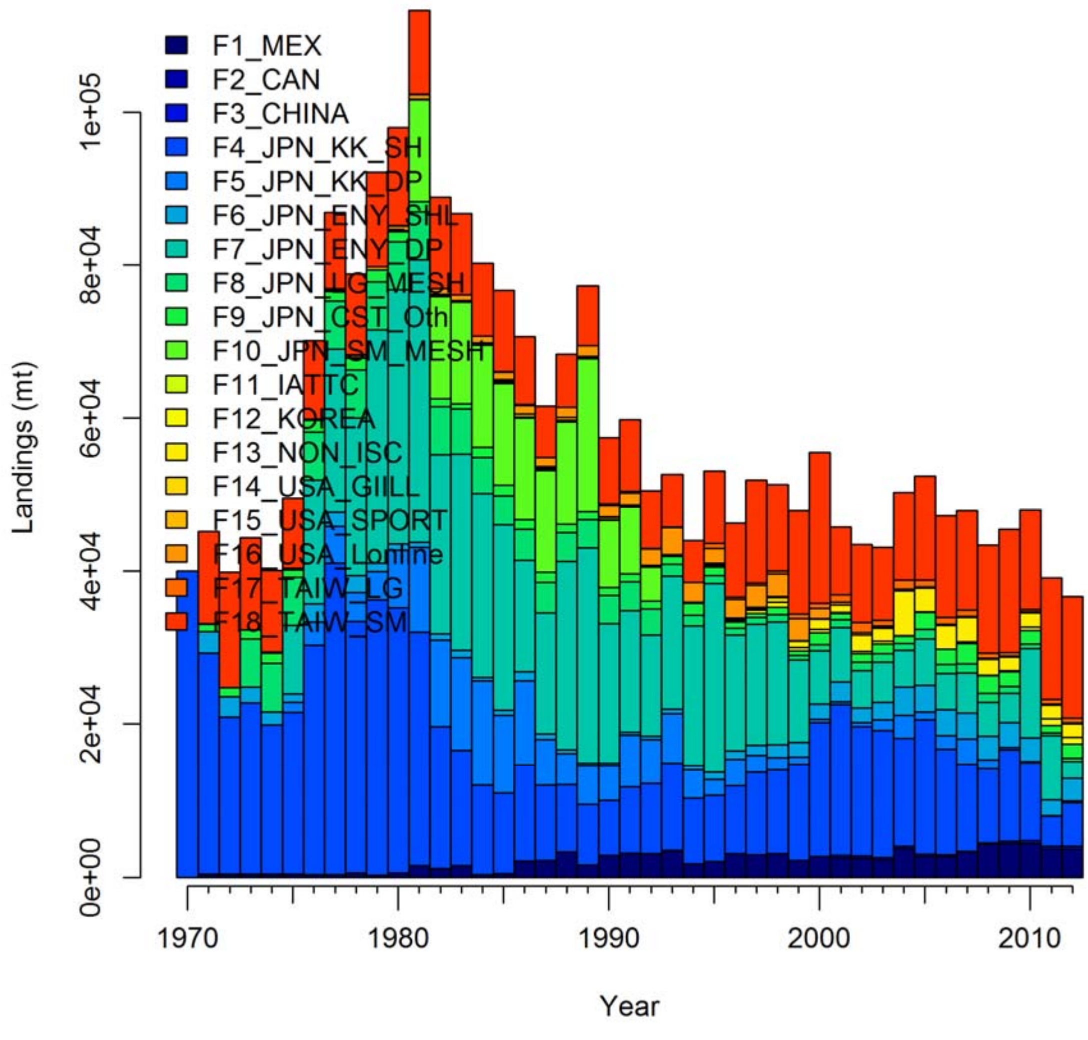


Figure 5. Standardized CPUE indices used in the North Pacific Ocean blue shark (*Prionace glauca*) stock assessment.

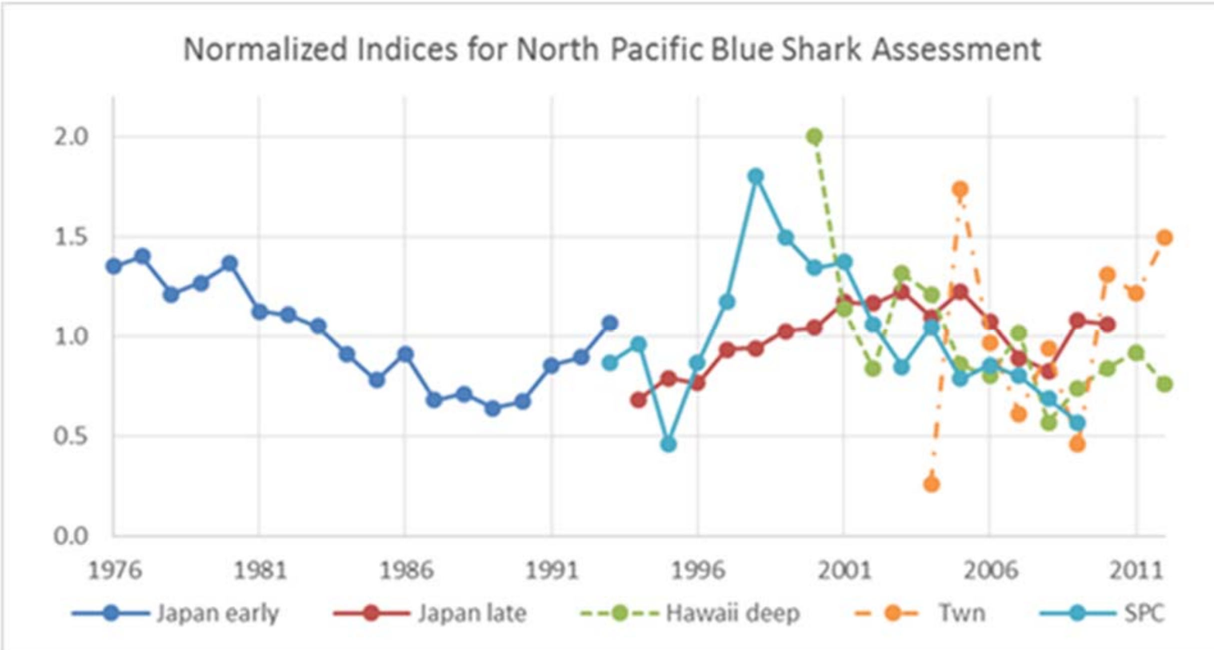


Figure 6. Spatial extent of fisheries used to derive abundance indices for the North Pacific blue shark (*Prionace glauca*) assessment.

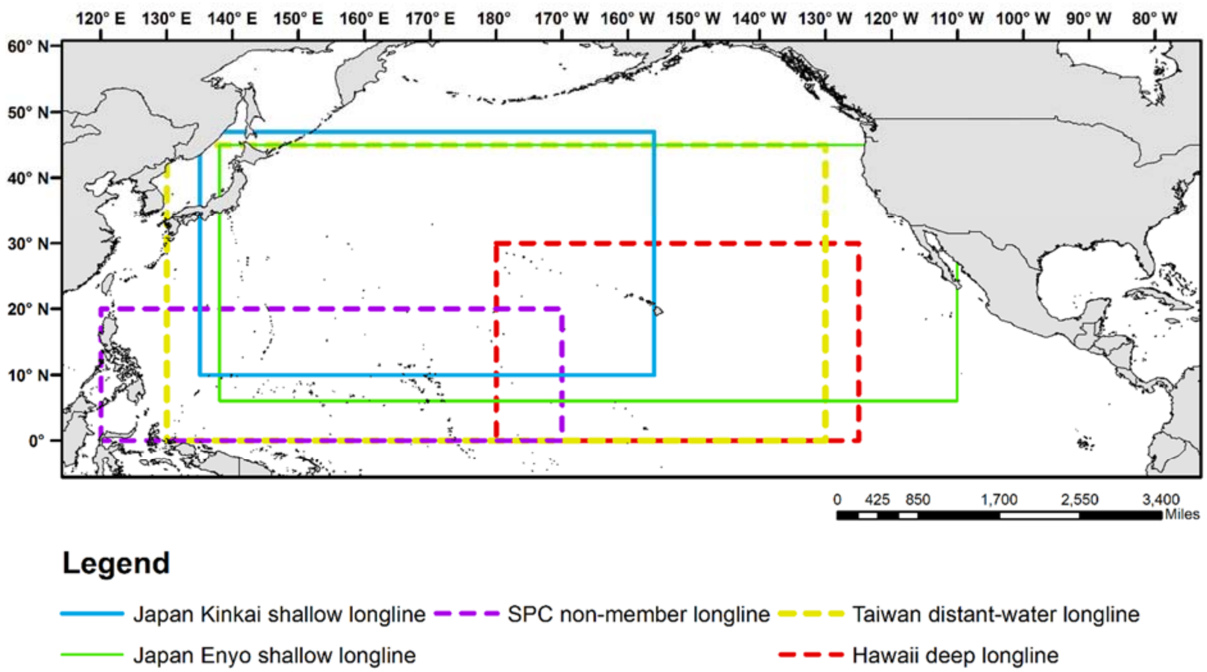


Figure 7. Coverage of catch, effort, and length composition data by year and fleet for the SS reference case. For the 2012 data, black triangles indicate data that were carried over from 2011 values; black circles are new estimates of 2012 data.

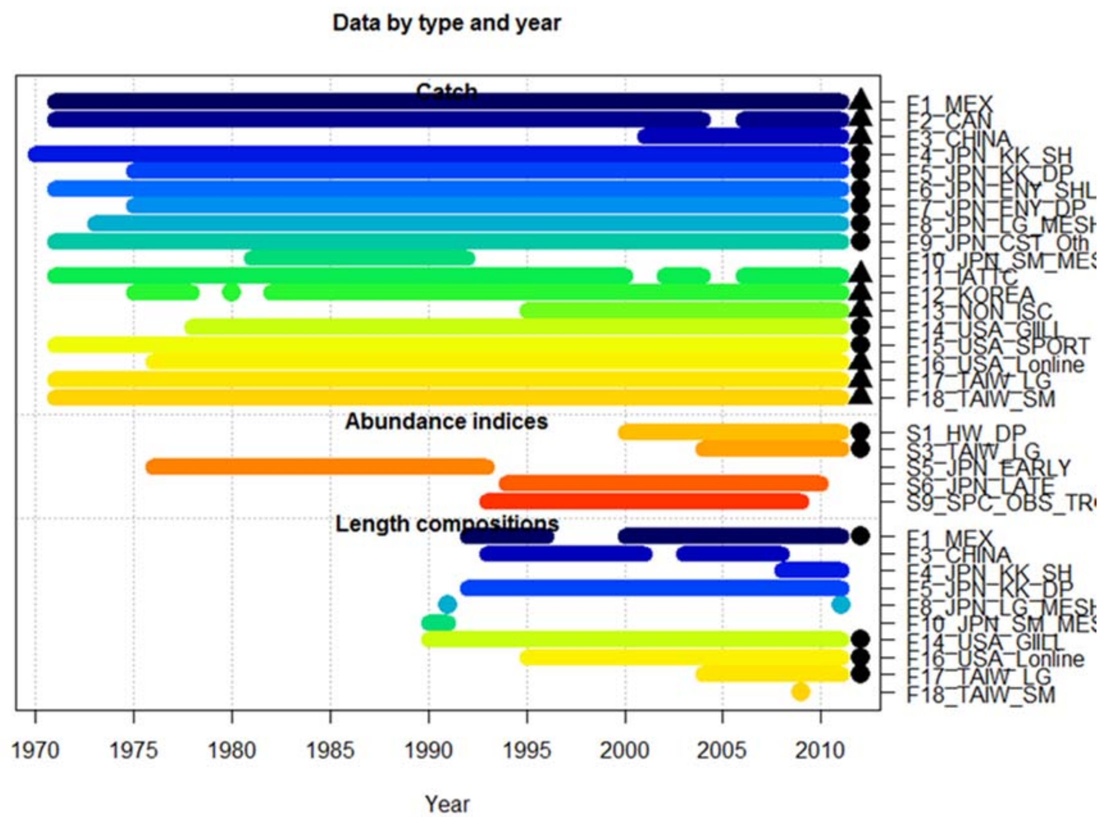


Figure 8. Sex-specific growth curves assumed in the SS analysis (from Nakano 1994).

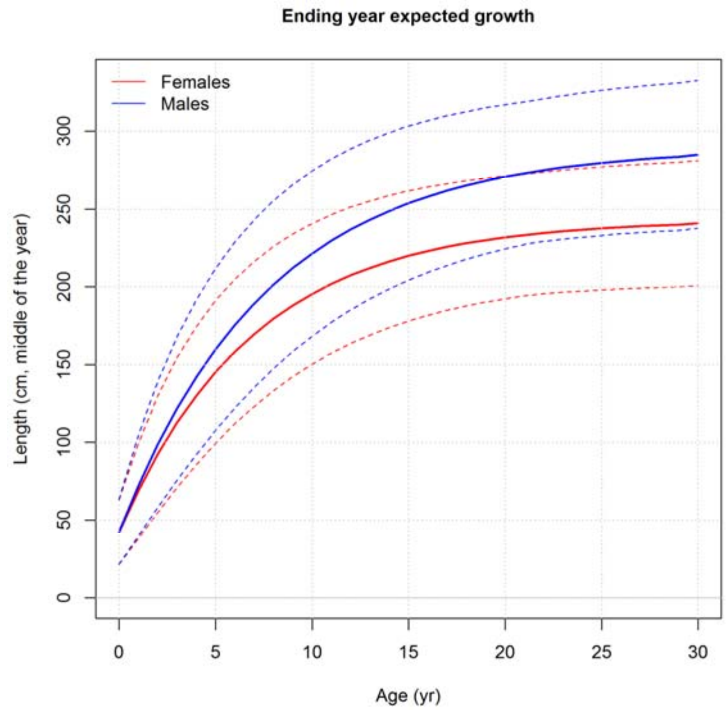


Figure 9. The sex-specific weight-at-length (from Nakano 1994) for female (red solid line) and male (blue solid line) blue sharks used in the SS analysis.

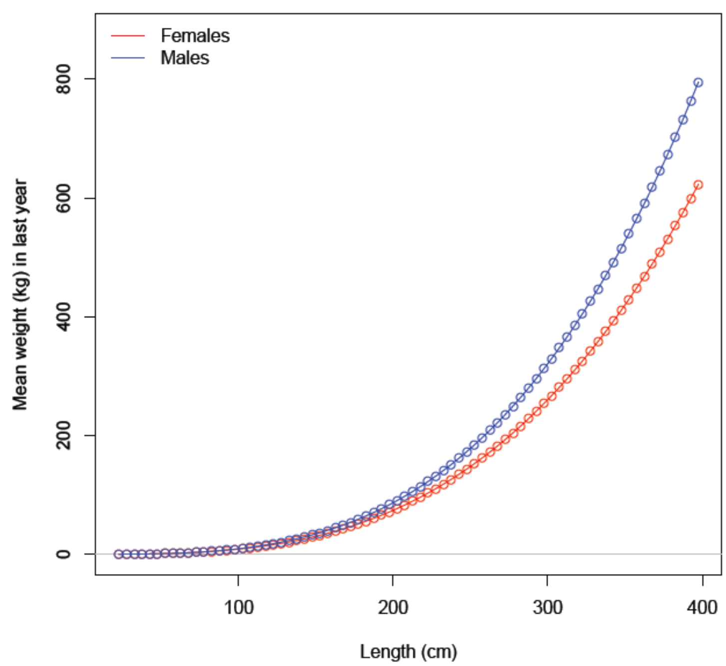


Figure 10. Assumed a logistic maturity schedule based on length with the age-at-50% maturity for females used in the stock assessment.

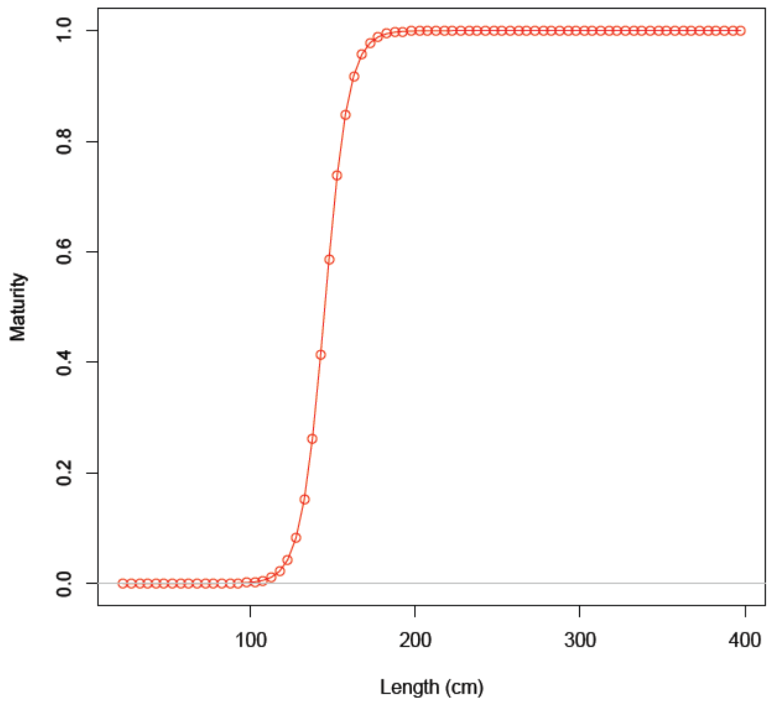


Figure 11. Spawner recruitment curves for the nine Low Fecundity Spawner Recruitment (LFSR) curves considered in the analysis. The reference case model used S_{Frac} = 0.3 and *Beta* = 2.

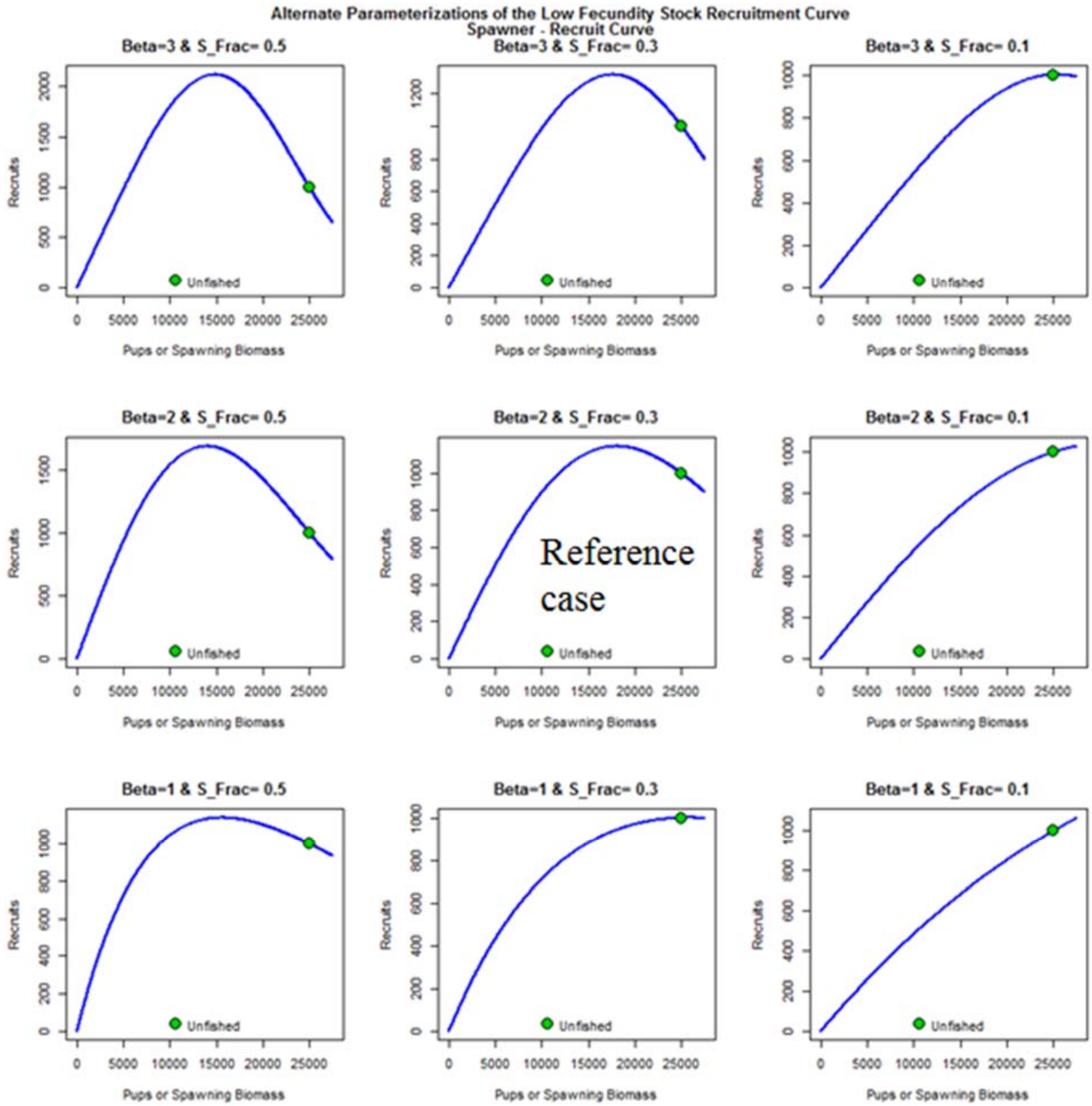


Figure 12. Pre-recruitment survival for the nine Low Fecundity Spawner Recruitment (LFSR) pre-recruit survival curves considered in the analysis. The reference case model used S_{Frac} = 0.3 and *Beta* = 2.

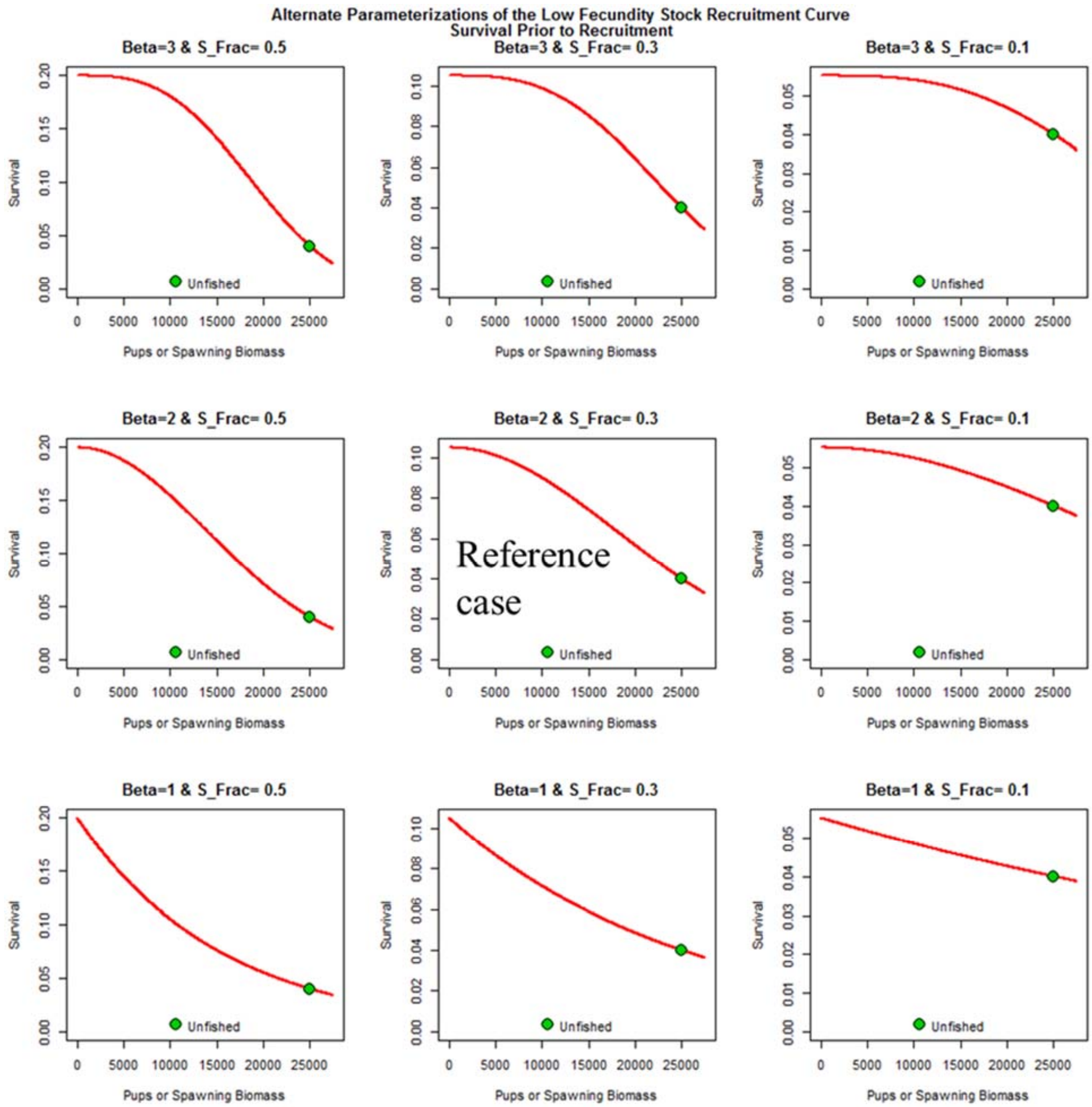


Figure 13. Comparison of marginal posterior distributions for the four reference cases (**JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref**). (a) Four panels showing carrying capacity (K), stock biomass at maximum sustainable yield (B_{MSY}), the maximum intrinsic rate of natural increase (r), and stock biomass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

(a)

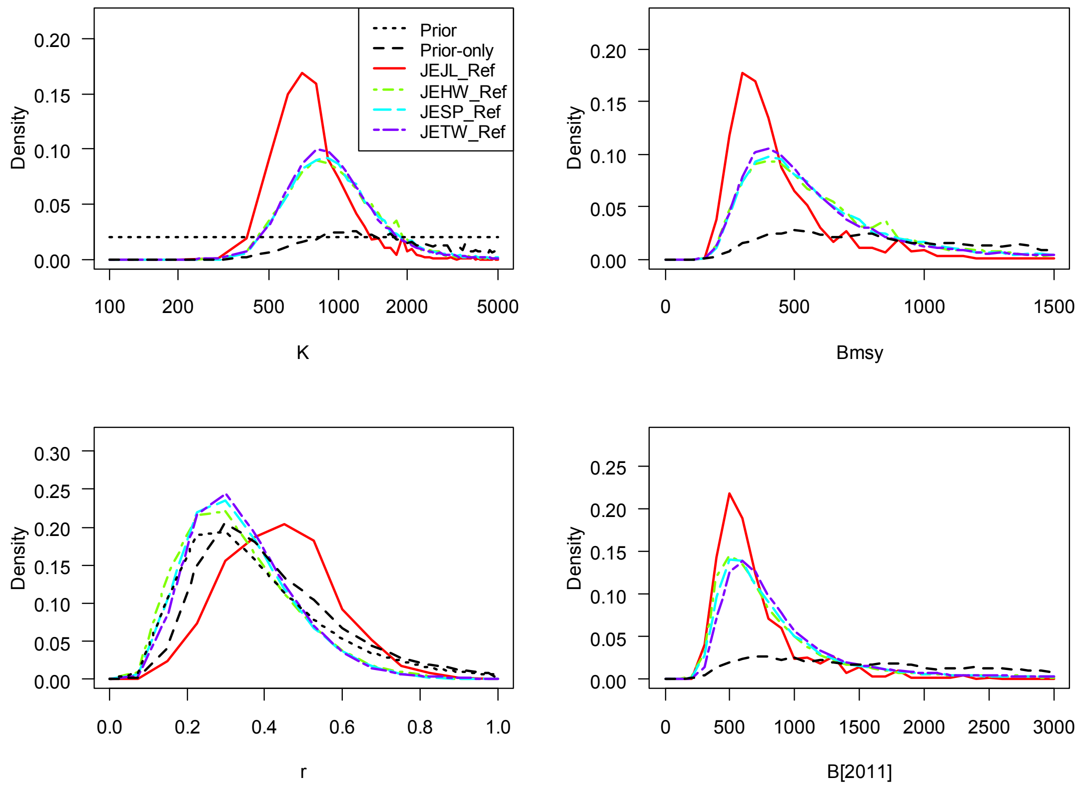


Figure 13 (continued). (b) Four panels showing *MSY*, stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at *MSY* (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at *MSY* (B_{2011}/B_{MSY}).

(b)

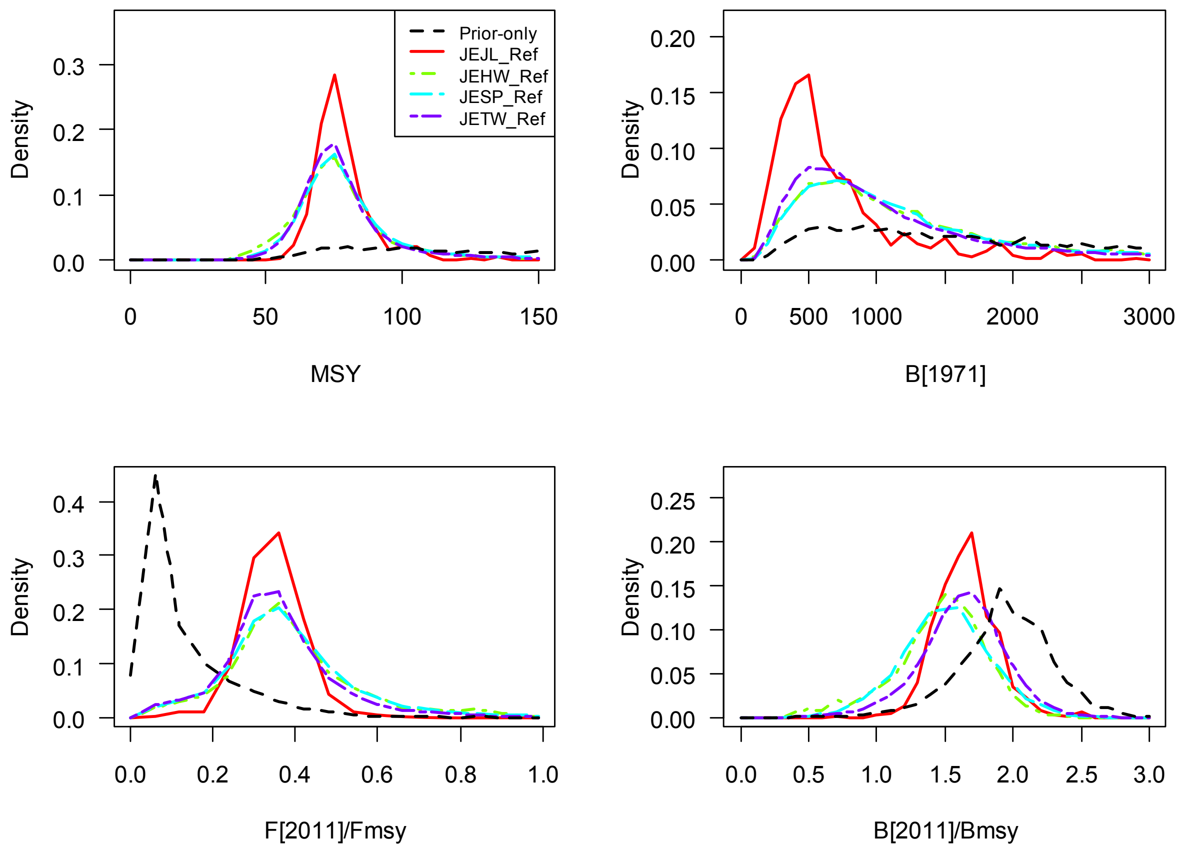


Figure 14. Comparison of marginal posterior distributions for the four reference cases (**JL_Ref, HW_Ref, SP_Ref, TW_Ref**). (a) Four panels showing the carrying capacity (*K*), stock biomass at maximum sustainable yield (B_{MSY})), the maximum intrinsic rate of natural increase (*r*) and stock biomass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

(a)

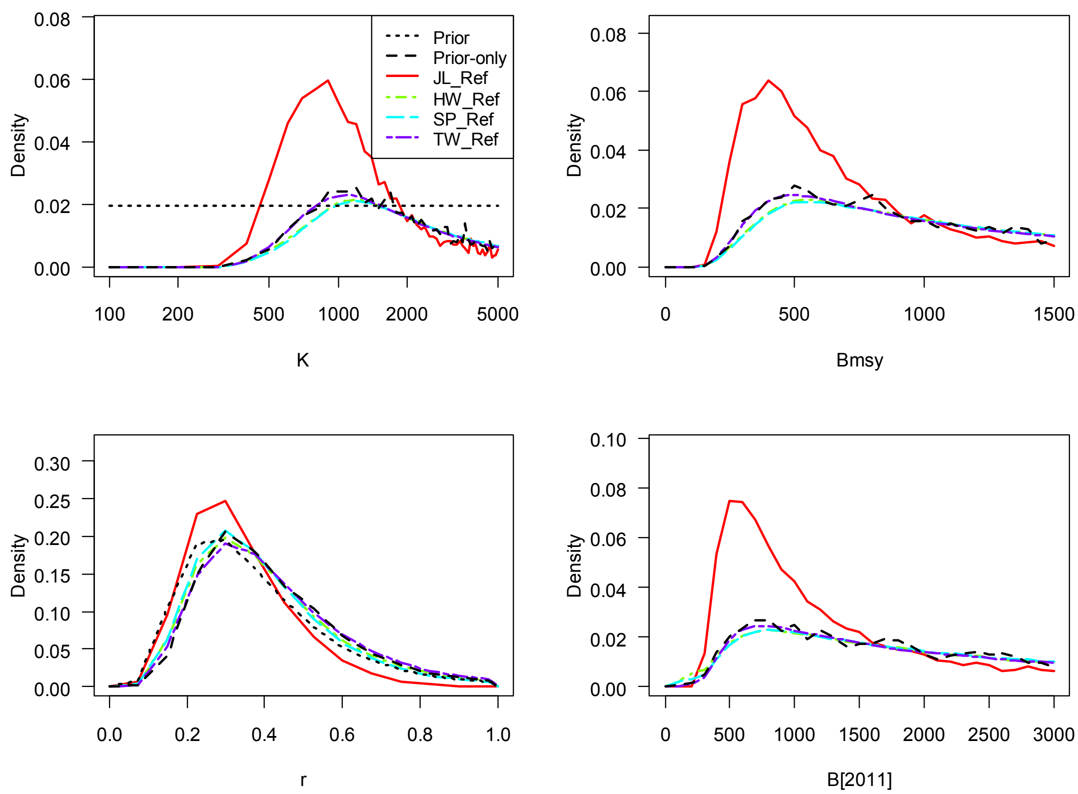


Figure 14 (continued). (b) Four panels showing *MSY*, stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at *MSY* (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at *MSY* (B_{2011}/B_{MSY}).

(b)

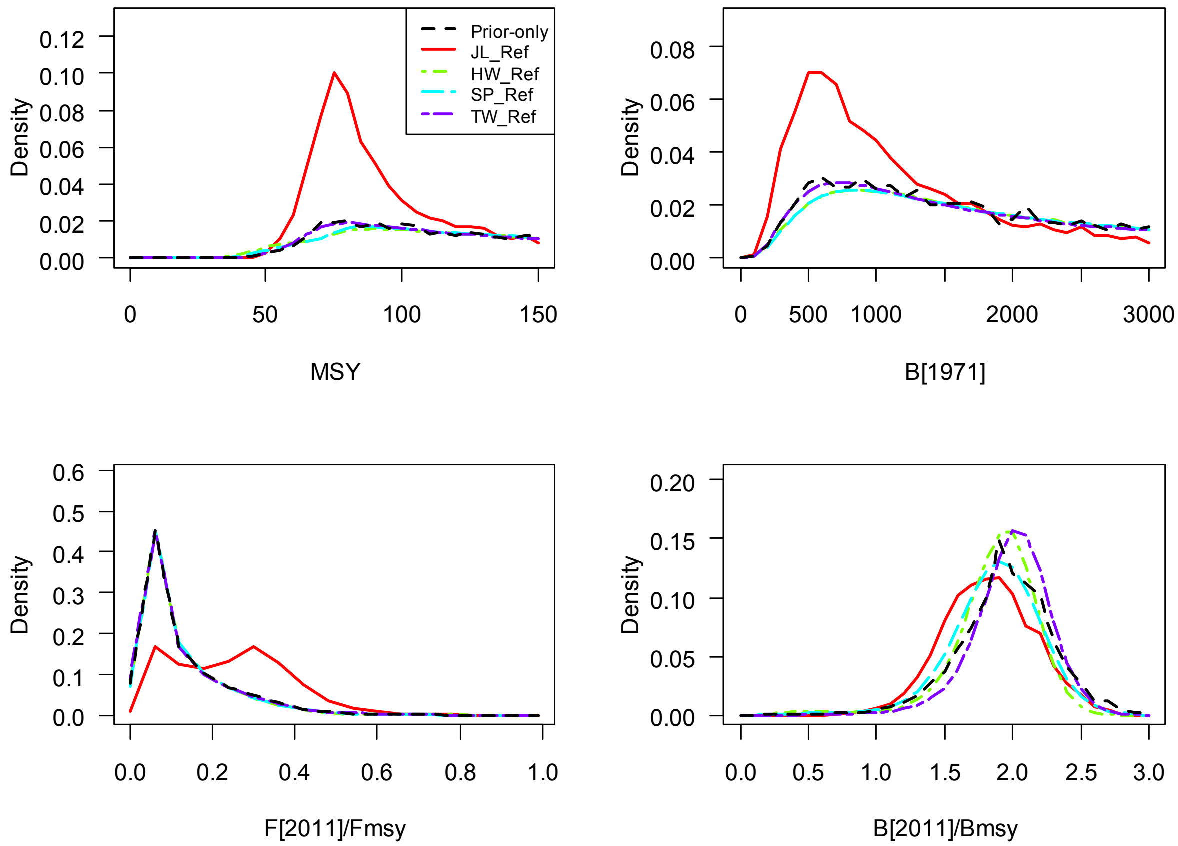


Figure 15. Comparison of marginal posterior distributions for four prior-only runs using different catch trajectories (**Ponly_obscat, Ponly_hlfcat, Ponly_dblcat, Ponly_rvscat**). (a) Four panels showing carrying capacity (K), stock biomass at maximum sustainable yield (B_{MSY}), the maximum intrinsic 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.

(a)

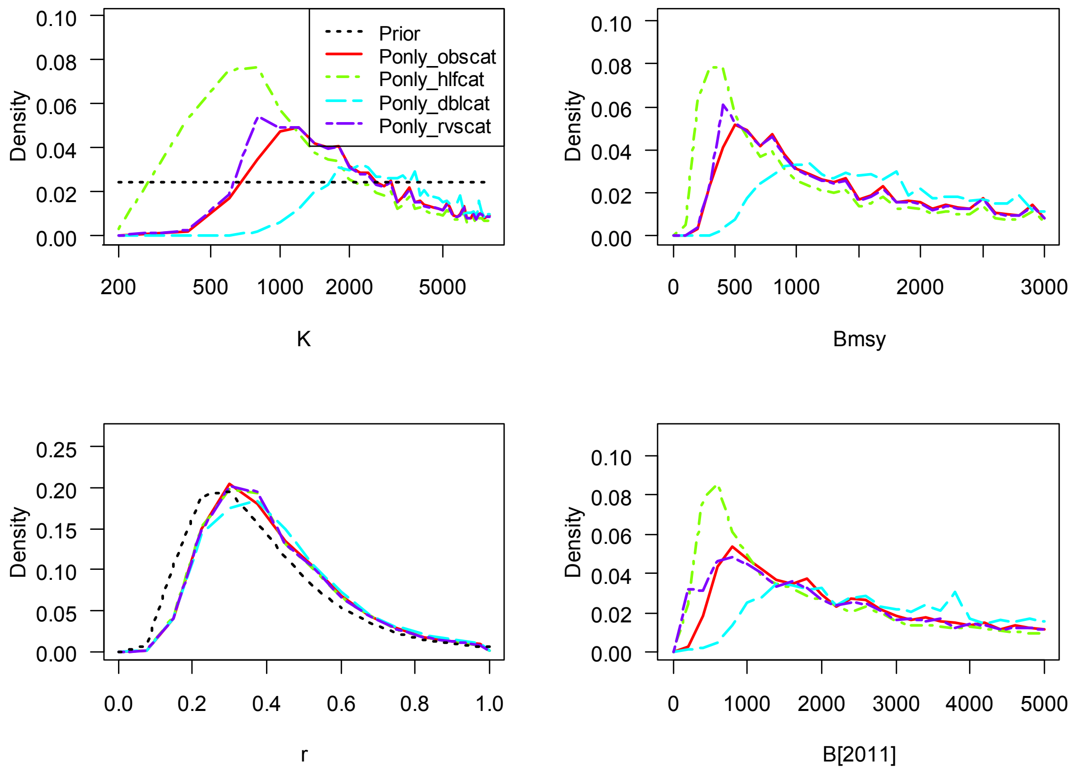


Figure 15 (continued). (b) Four panels showing *MSY*, stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at *MSY* (F_{2011}/F_{MSY}) and the ratio of stock biomass in 2011 to that at *MSY* (B_{2011}/B_{MSY}).

(b)

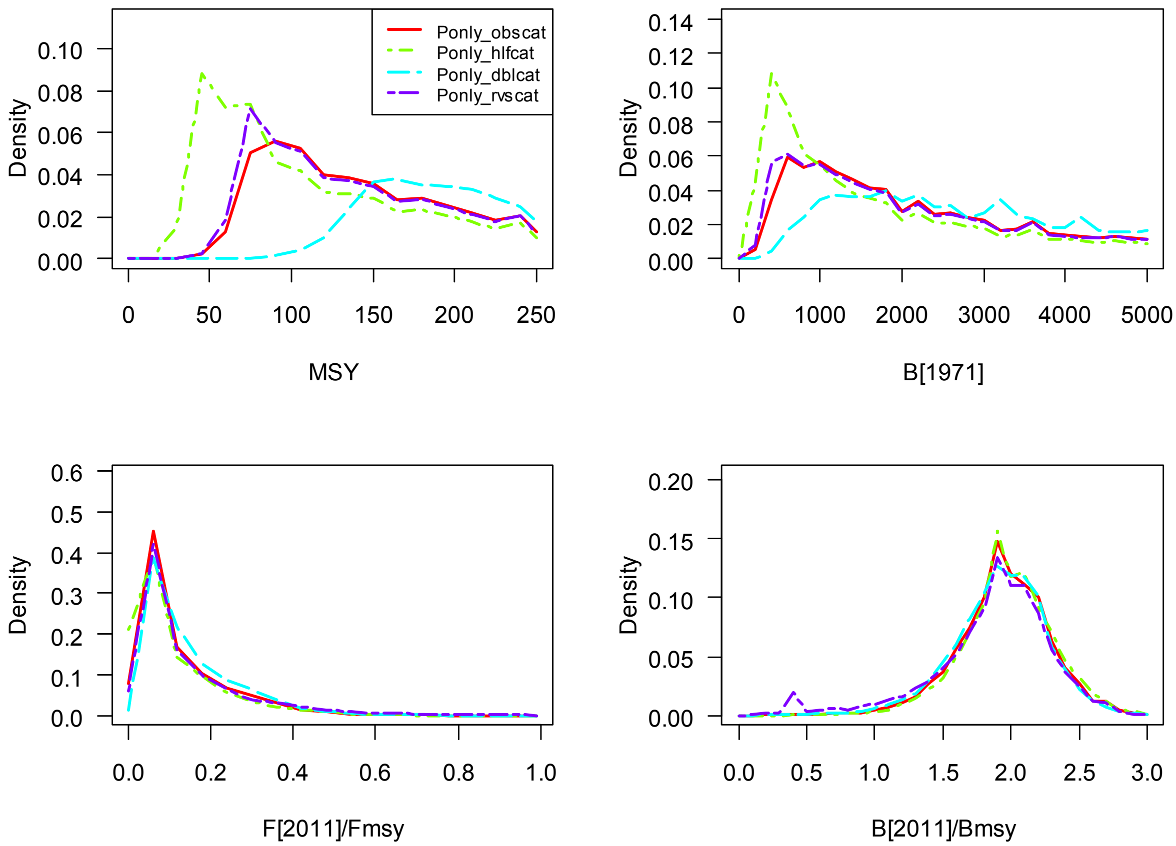


Figure 15 (continued). (c) Marginal posterior distribution of B_{2011}/K (median=0.43) for the prior only run, **Ponly_pessim**. In the Ponly_pessim case, B_{MSY} is approximately equal to 0.5K and thus the median B_{2011}/B_{MSY} is about 1.0. These results show approximately 50% probability that the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

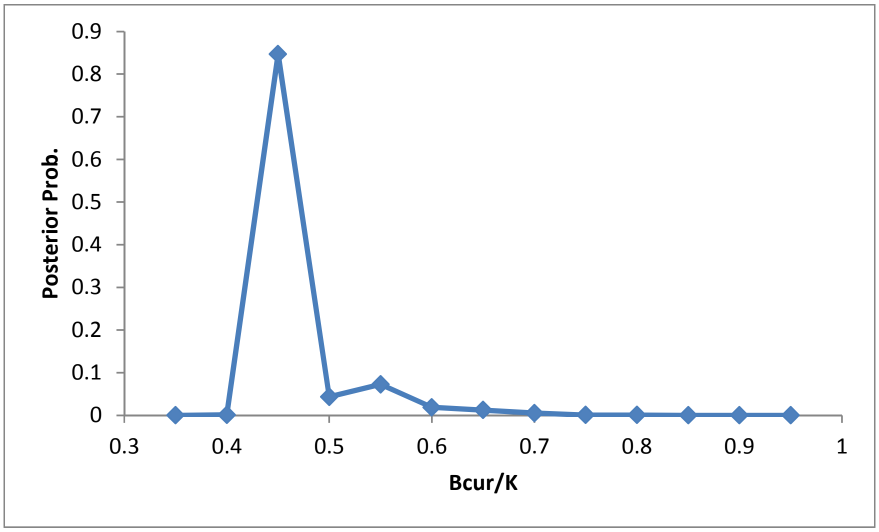
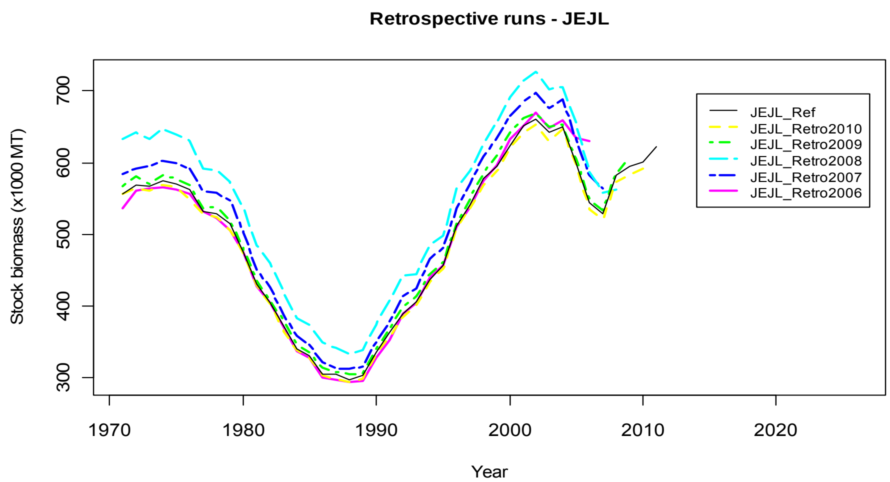


Figure 16. Retrospective analysis showing the historical stock dynamics resulting from termination of the model in each of the five years prior to the terminal year for the four reference runs. (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(a)



(b)

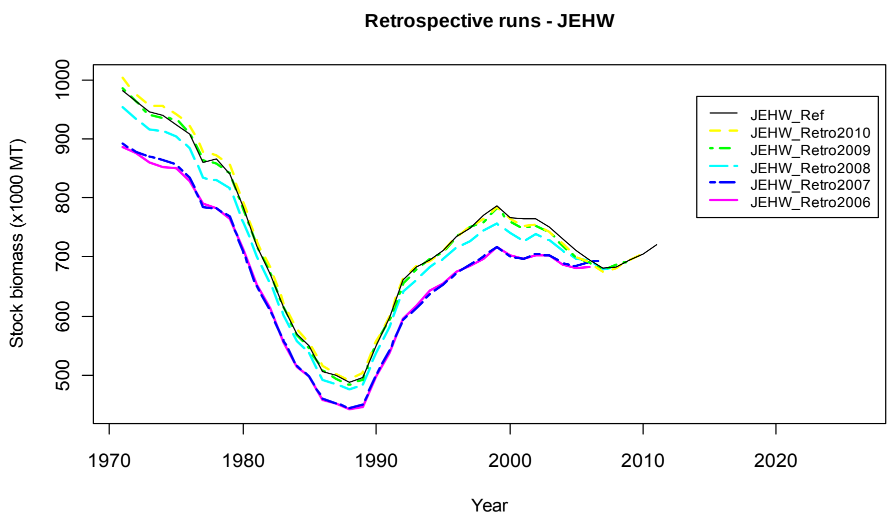
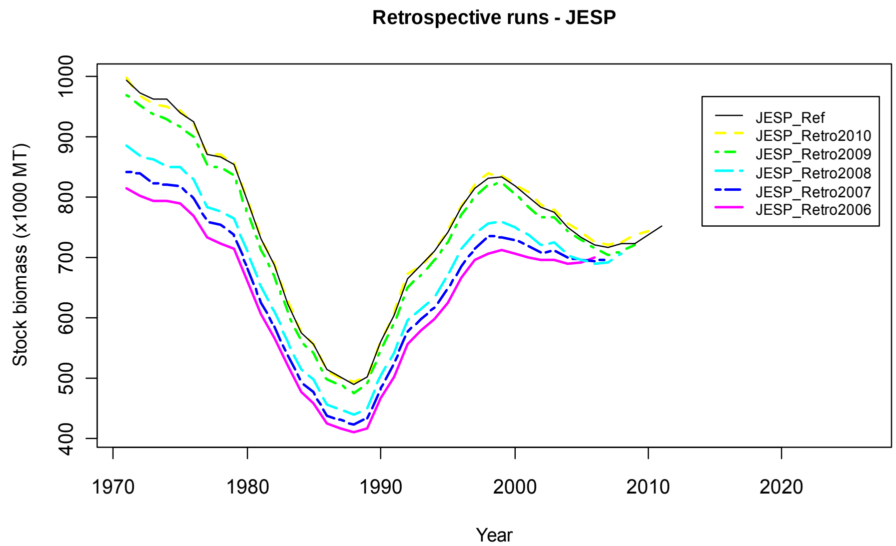


Figure 16 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

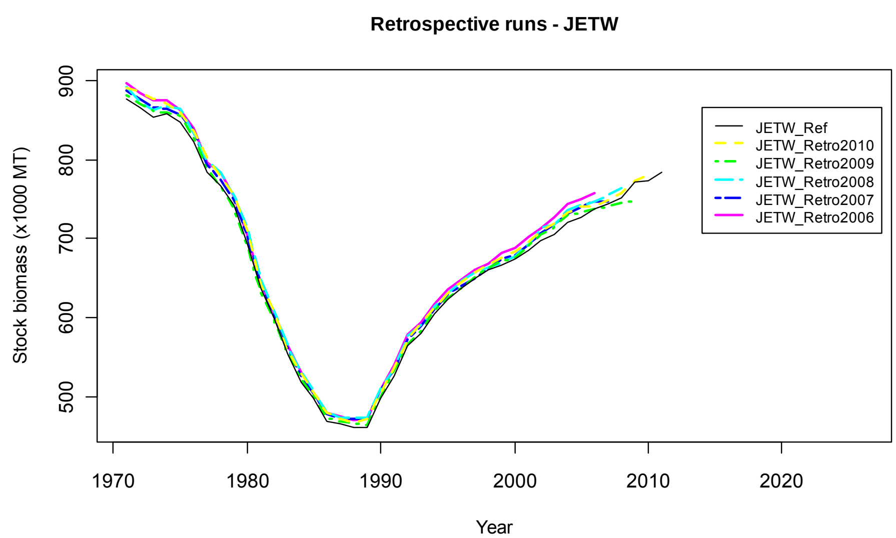
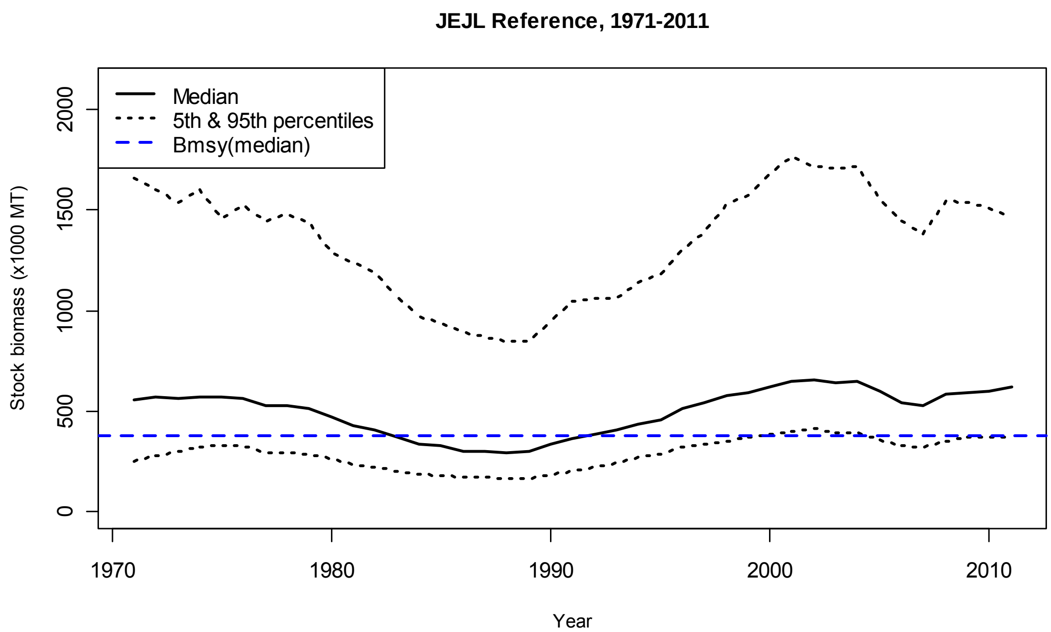


Figure 17. Median estimates and 90% confidence limits for the historical stock biomass of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable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

(a)



(b)

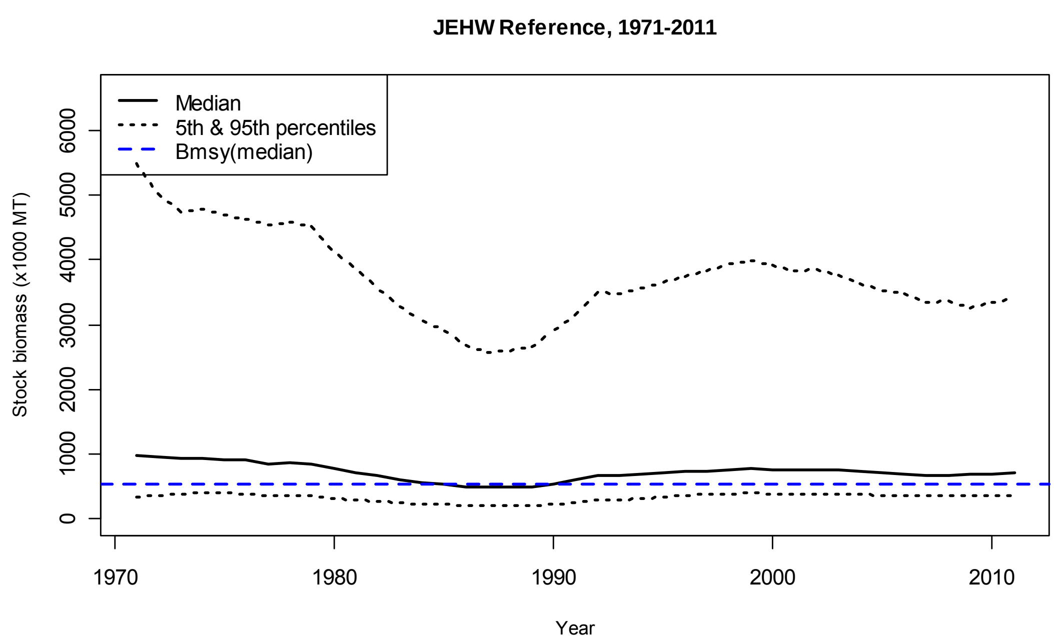
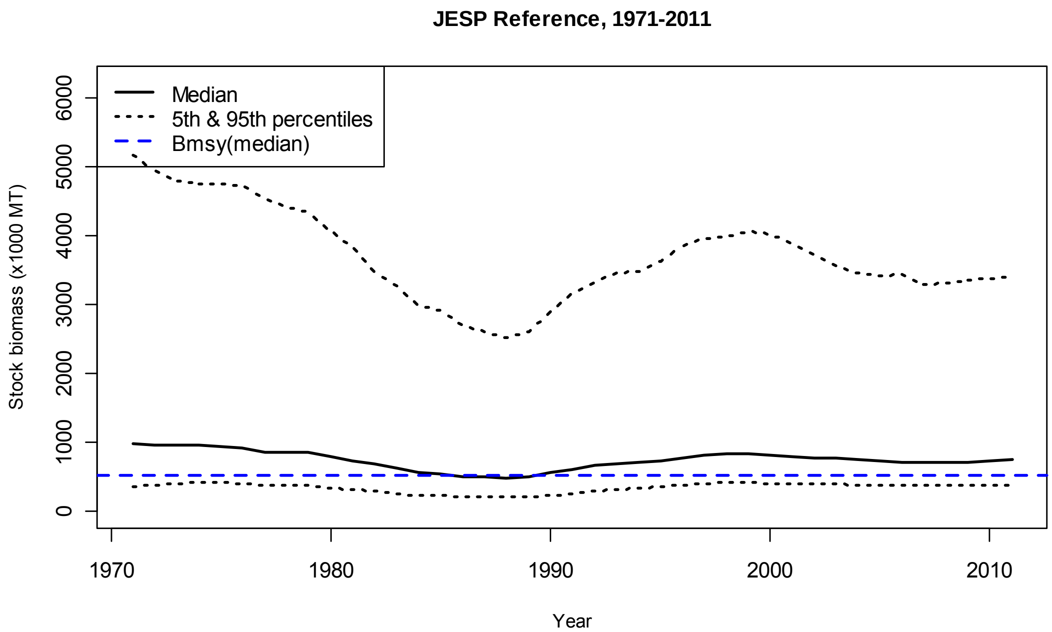


Figure 17 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

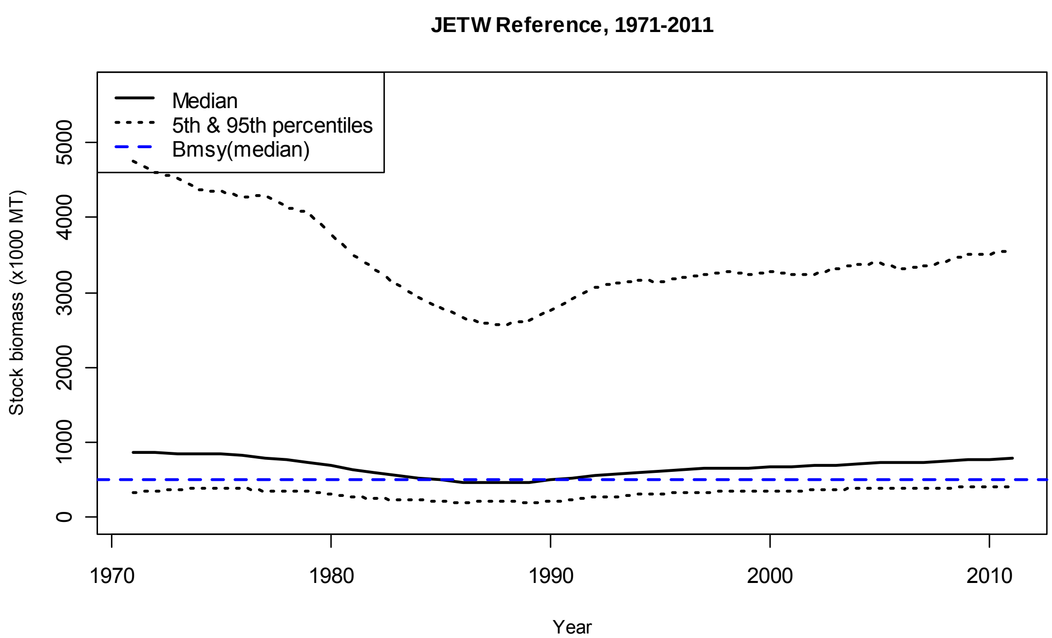
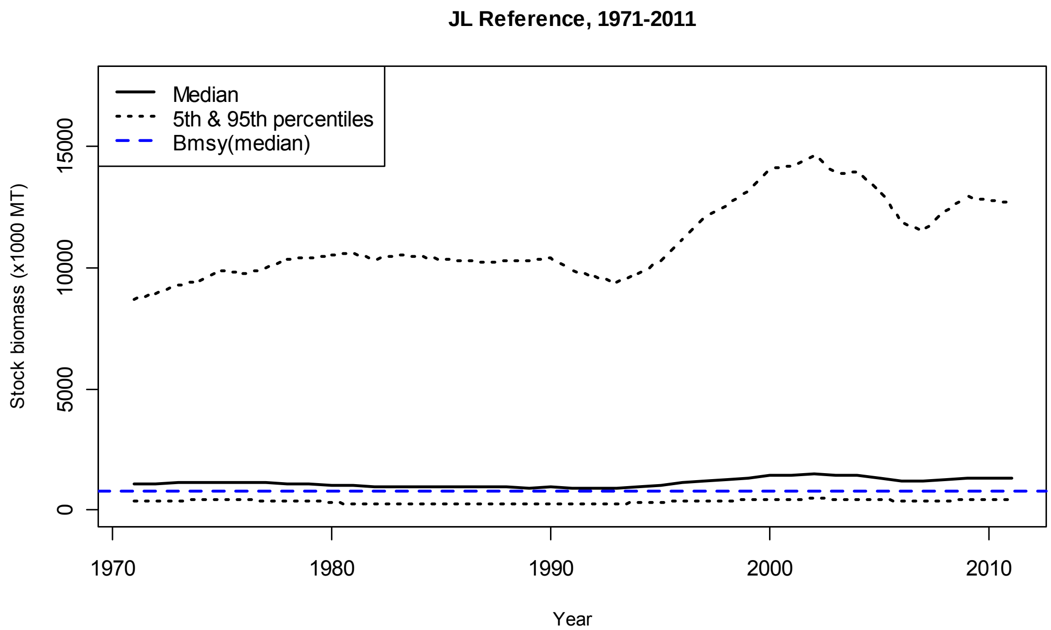


Figure 17 (continued). (e) **JL_Ref** case. (f) **HW_Ref** case.

(e)



(f)

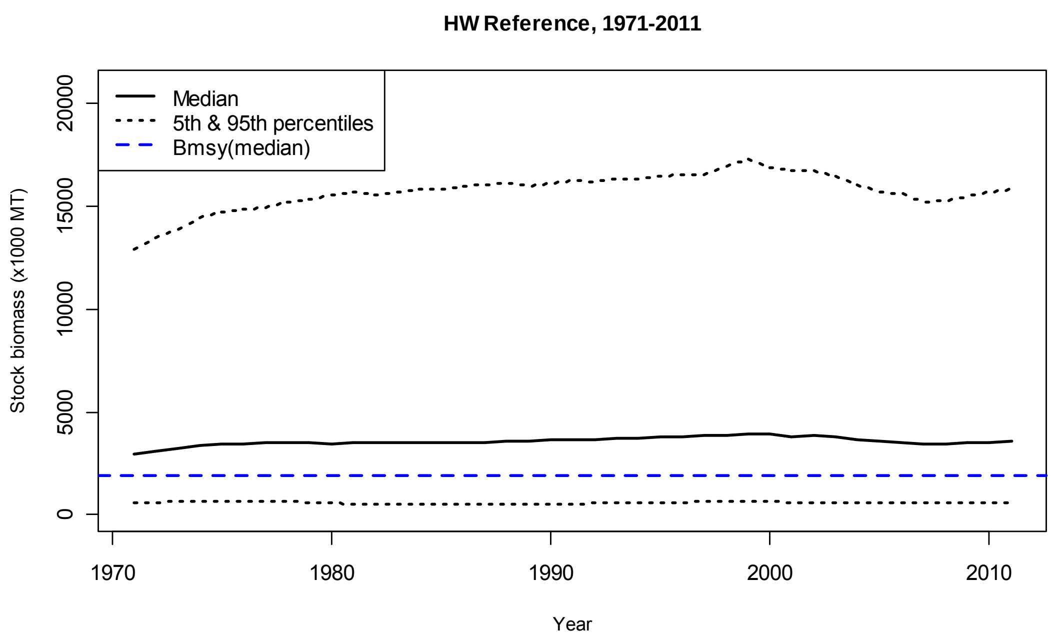
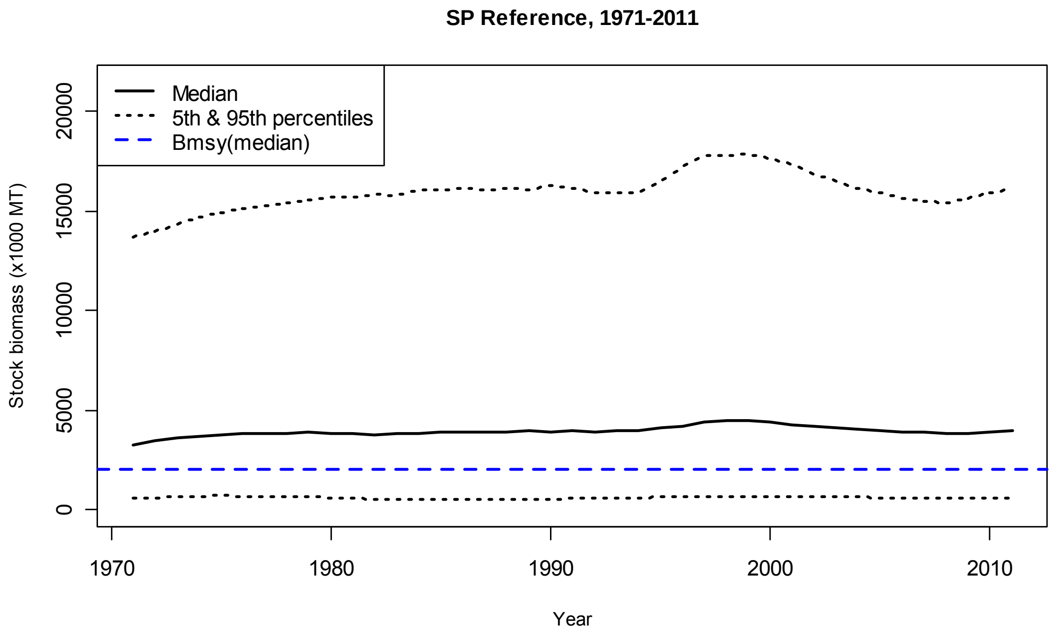


Figure 17 (continued). (g) **SP_Ref** case. (h) **TW_Ref** case.

(g)



(h)

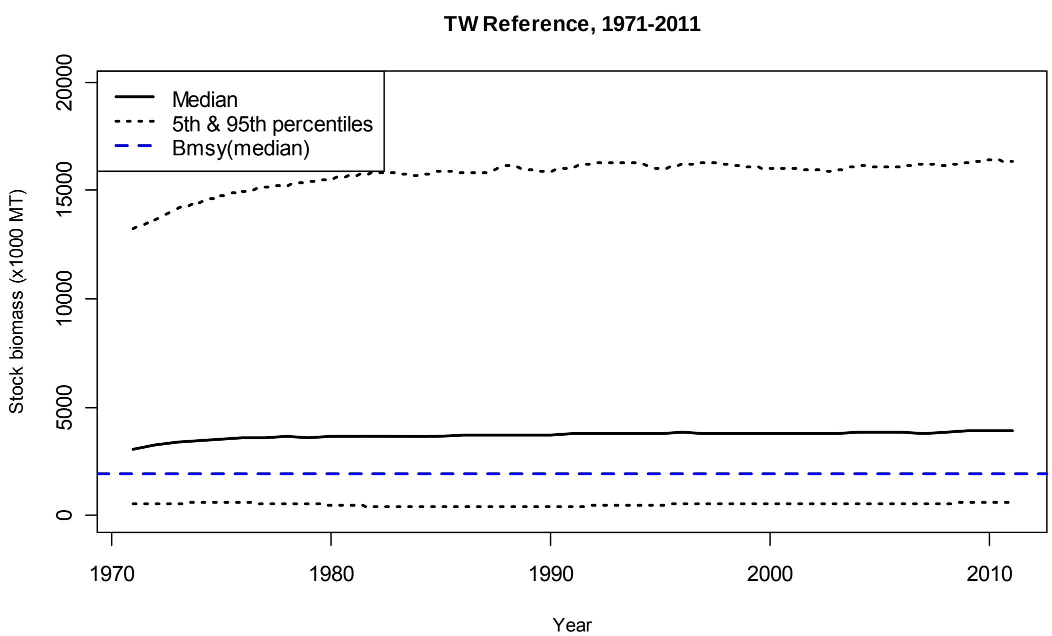
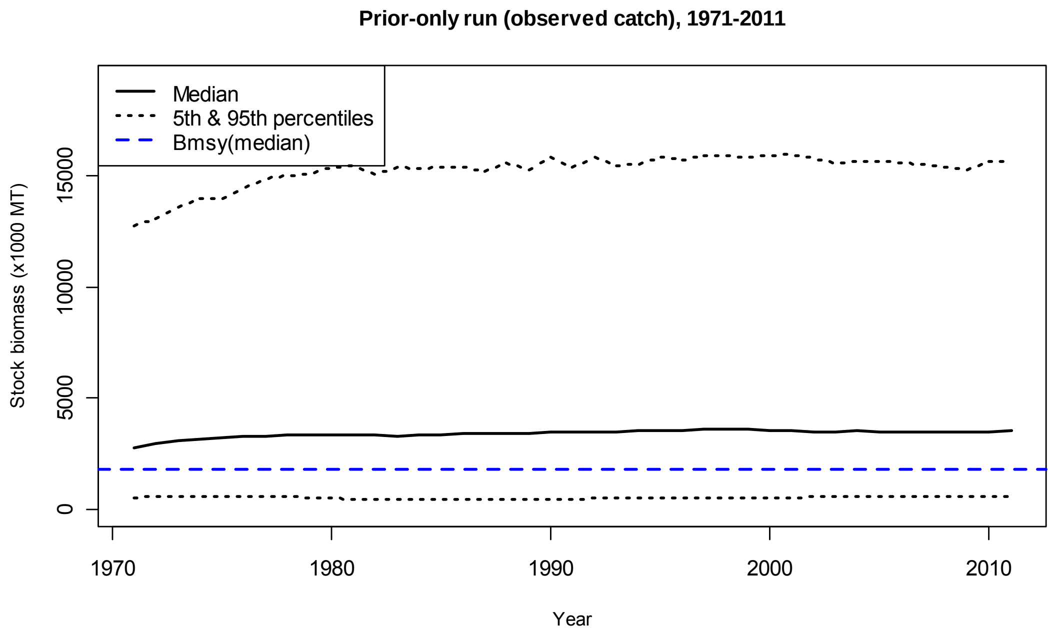


Figure 18. Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable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

(a)



(b)

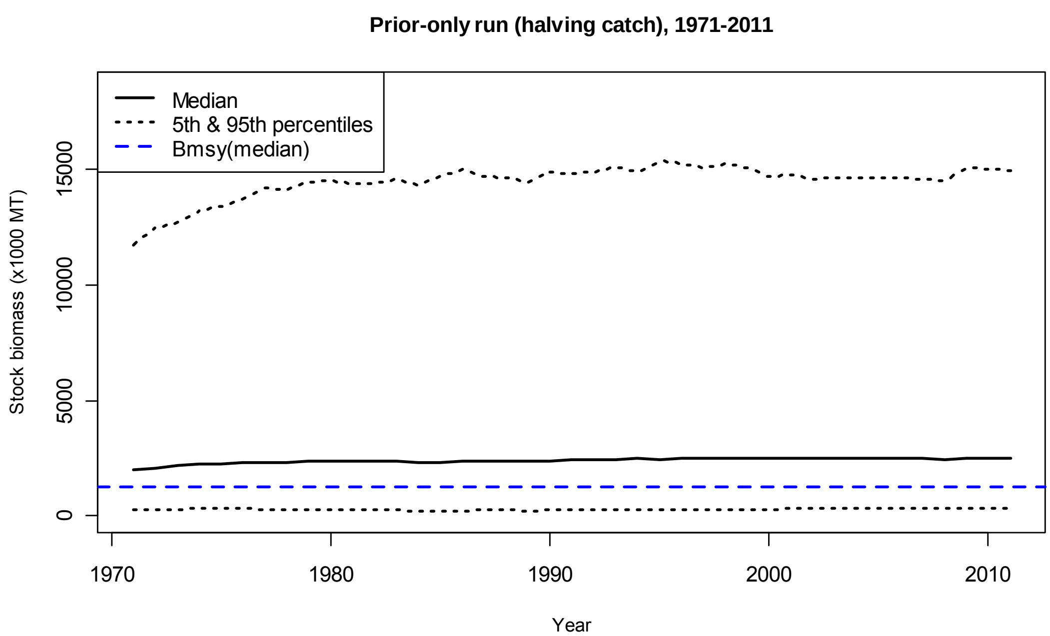
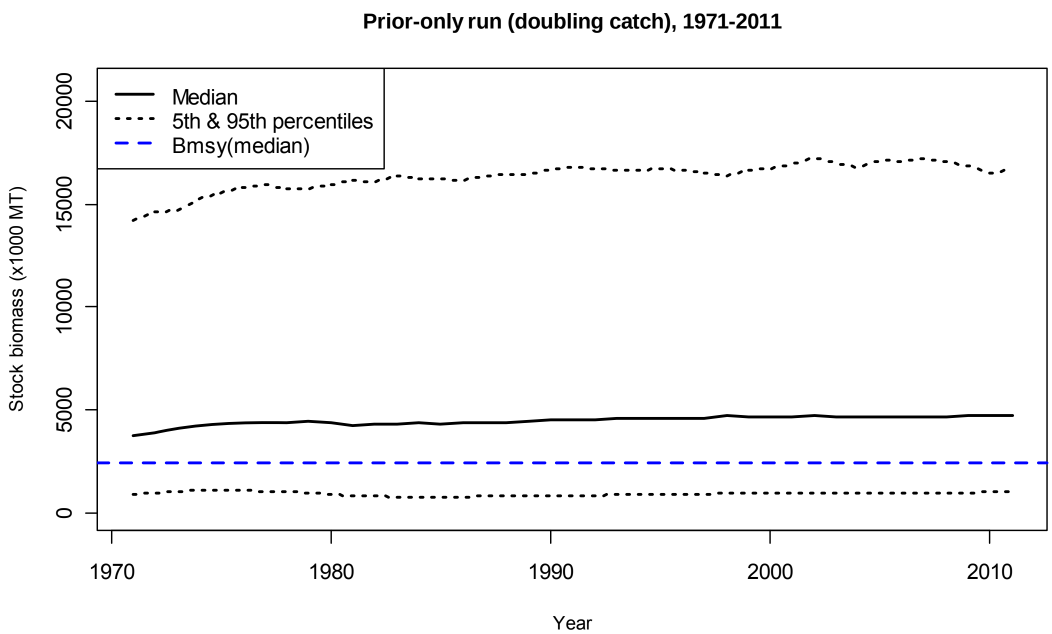


Figure 18 (continued). (c) **Ponly_dblcat** case. (f) **Ponly_rvscat** case.

(c)



(d)

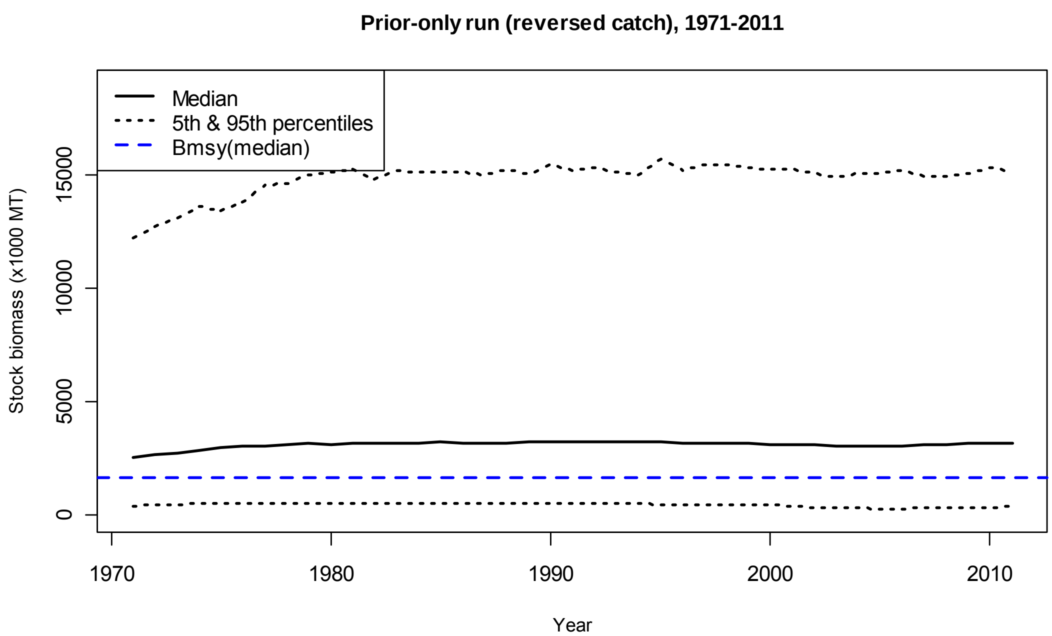
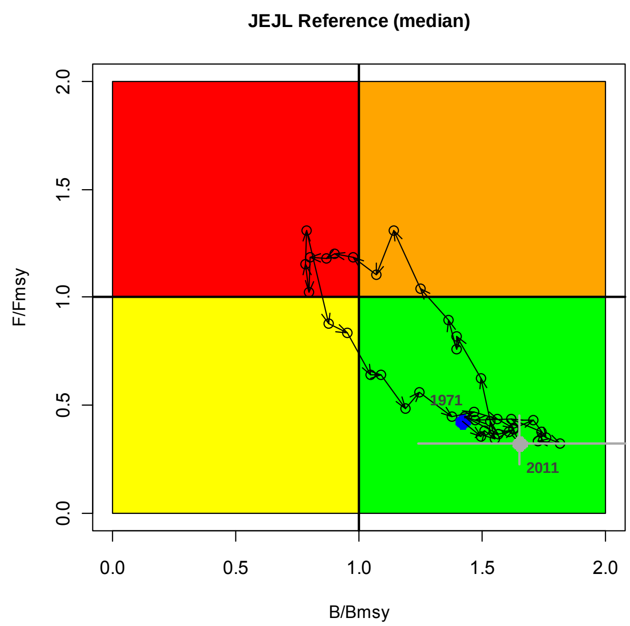


Figure 19. Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis) based on the median annual values of B/B_{MSY} and F/F_{MSY}. Colors represent the magnitude of risk of stock collapse 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)

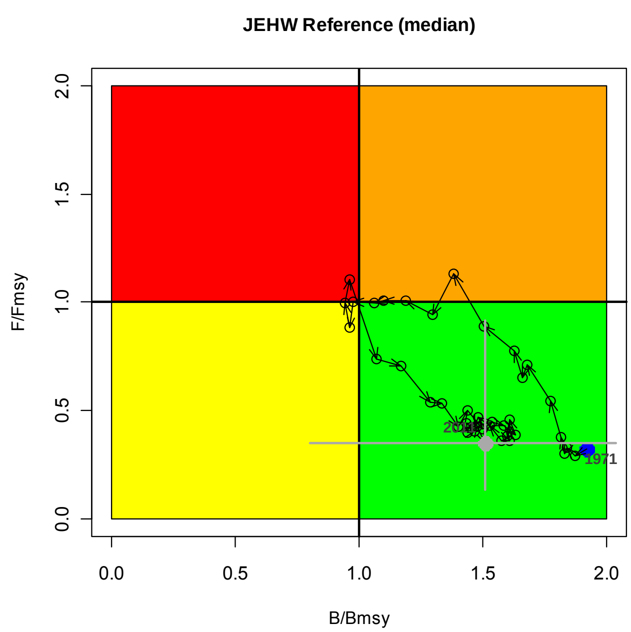
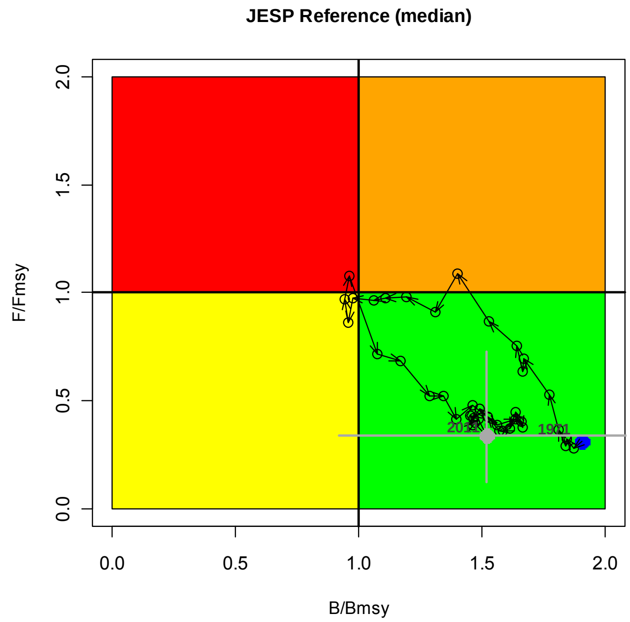


Figure 19 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

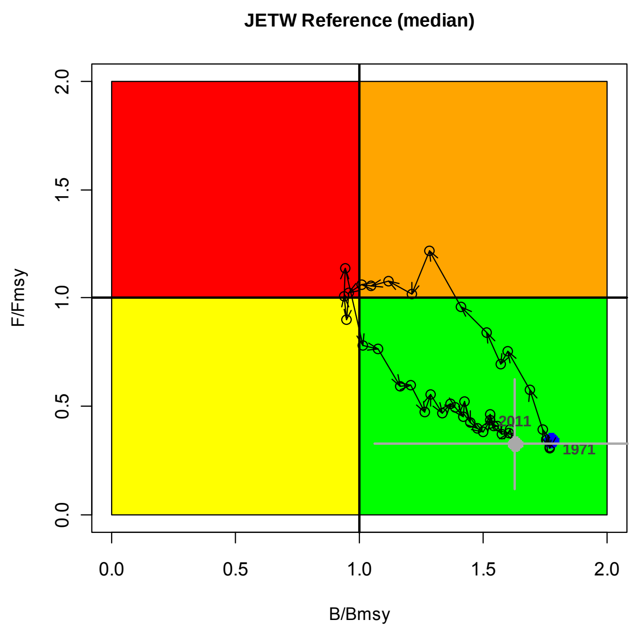
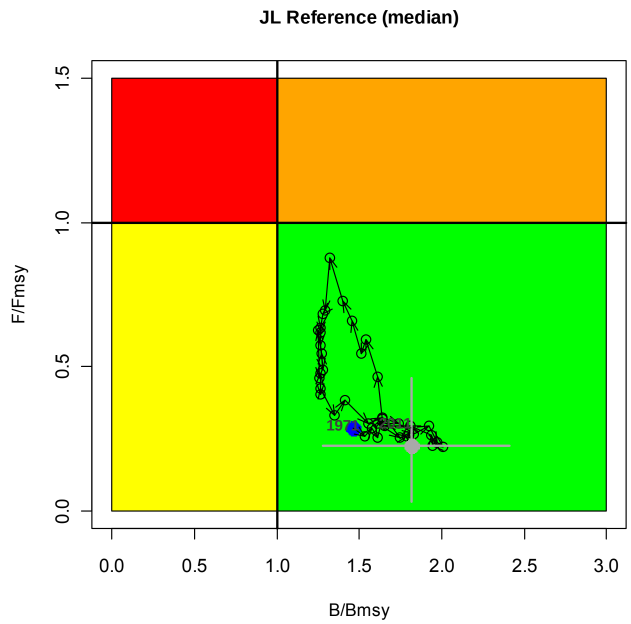


Figure 19 (continued). (e) **JL_Ref** case. (f) **HW_Ref** case.

(e)



(f)

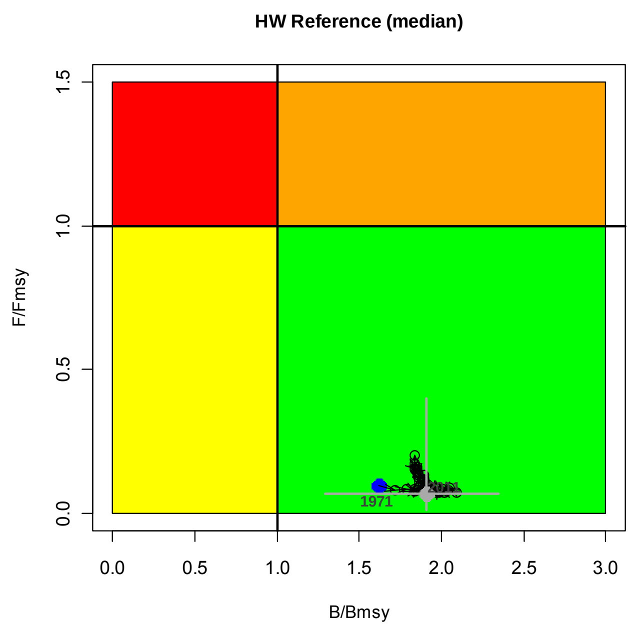
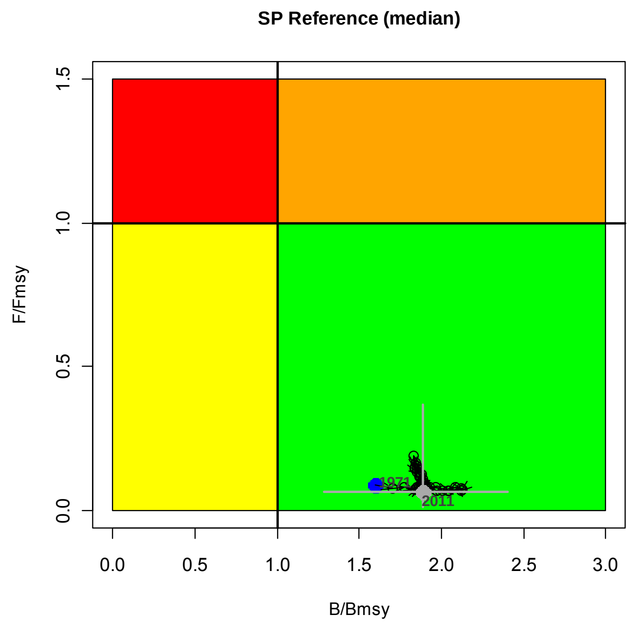


Figure 19 (continued). (g) **SP_Ref** case. (h) **TW_Ref** case.

(g)



(h)

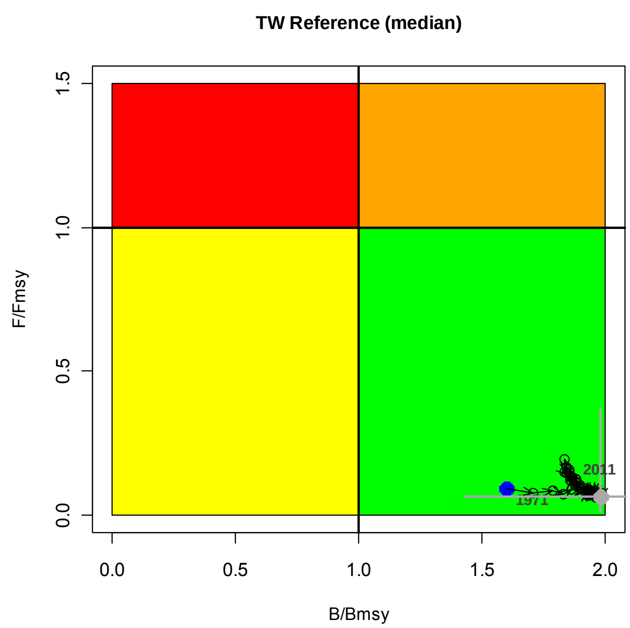
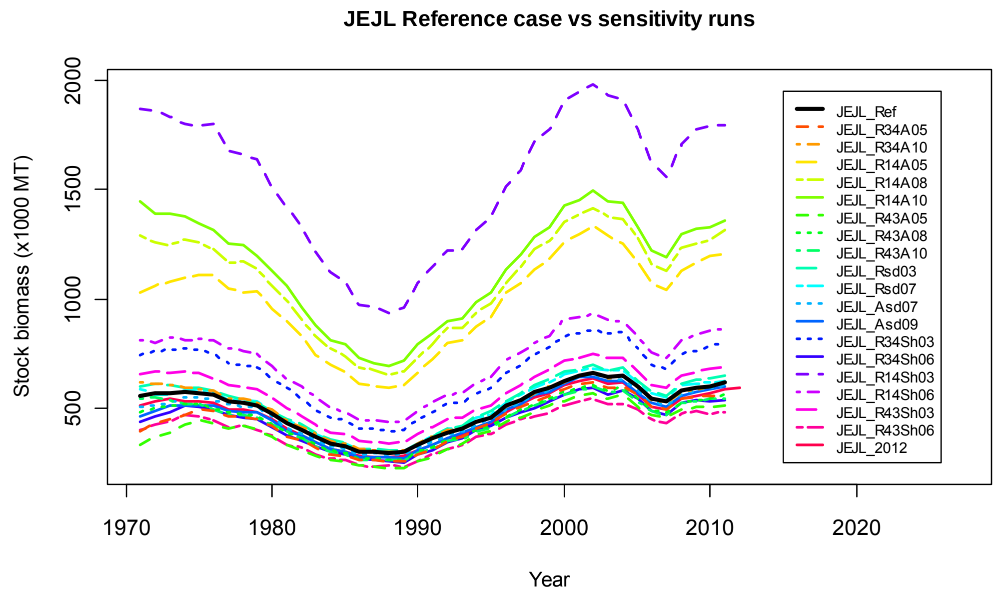


Figure 20. Comparison of median trajectories of historical blue shark stock biomass among the BSP reference cases (**JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref**) and sensitivity runs. See Table 3 for run identifiers and detailed descriptions of the sensitivity runs. (a) **JEJL_Ref** case and sensitivity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

(a)



(b)

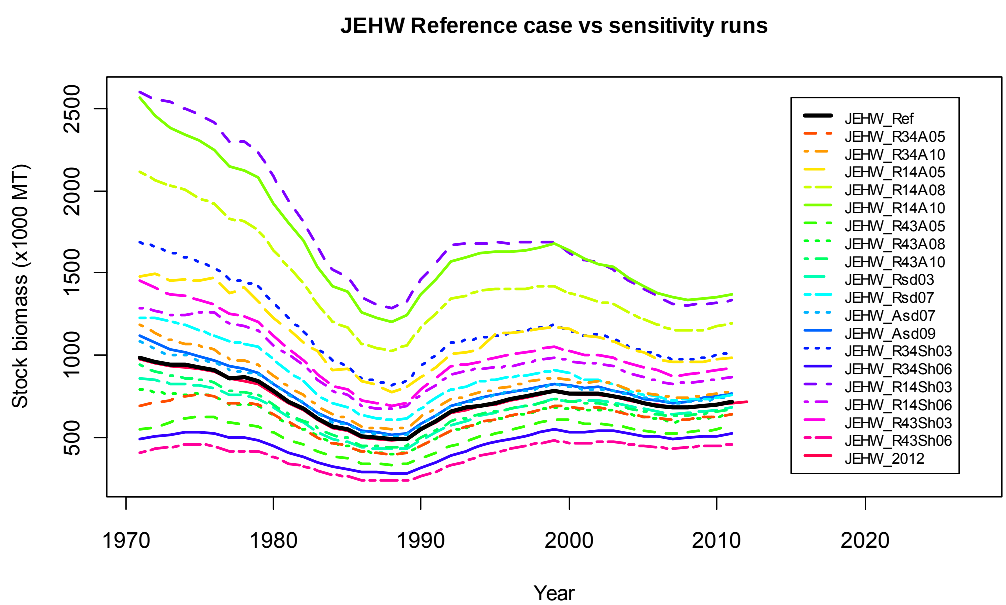
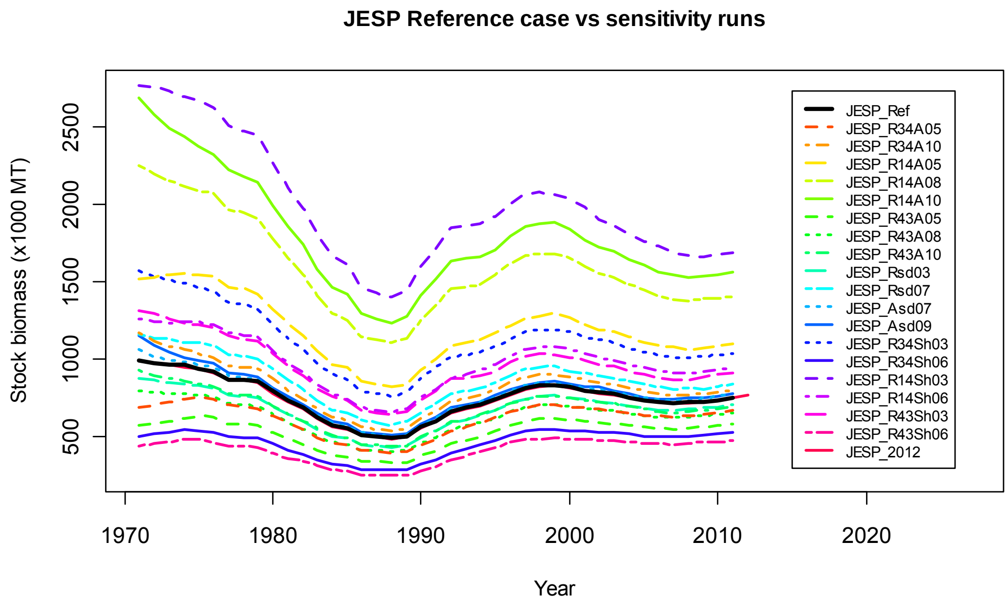


Figure 20 (continued). (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(c)



(d)

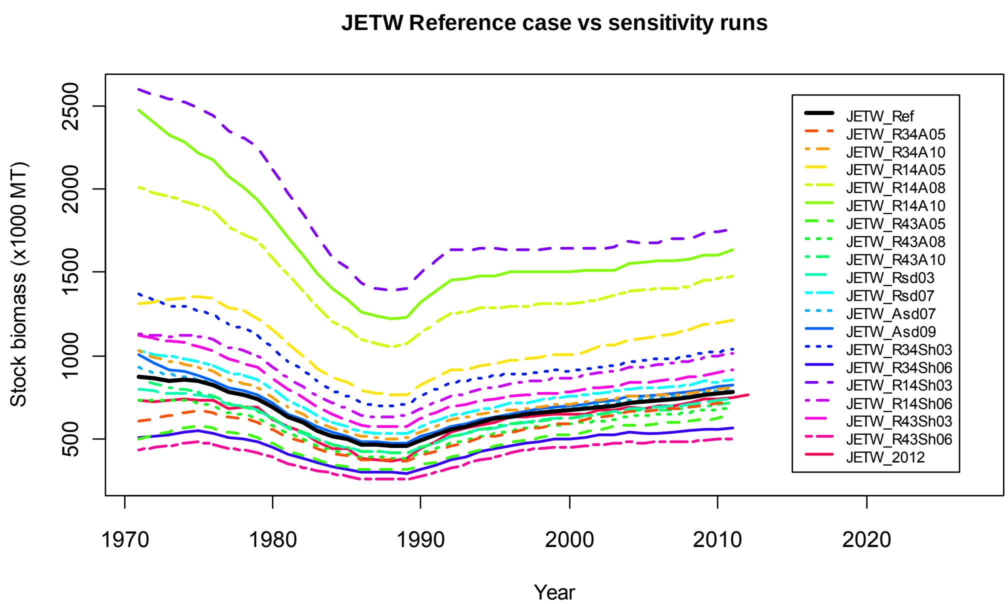
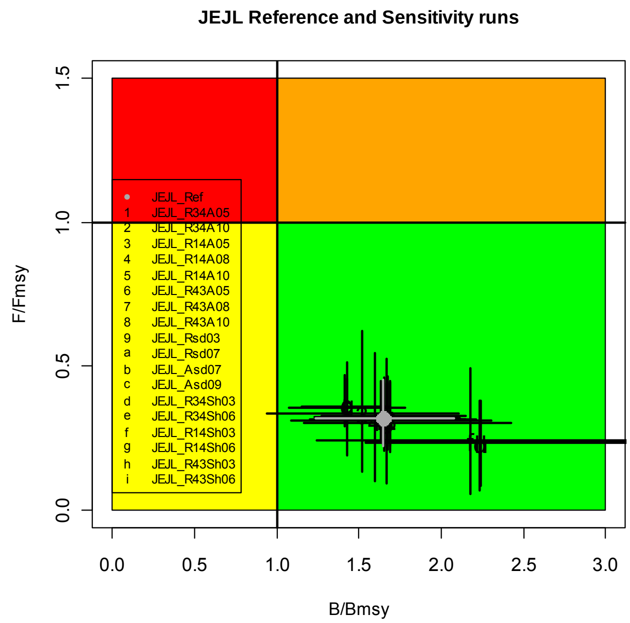


Figure 21. Kobe plot for the four BSP reference cases and sensitivity runs for the north Pacific blue shark stock assessment. The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011 for each respective reference case. Other different 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)

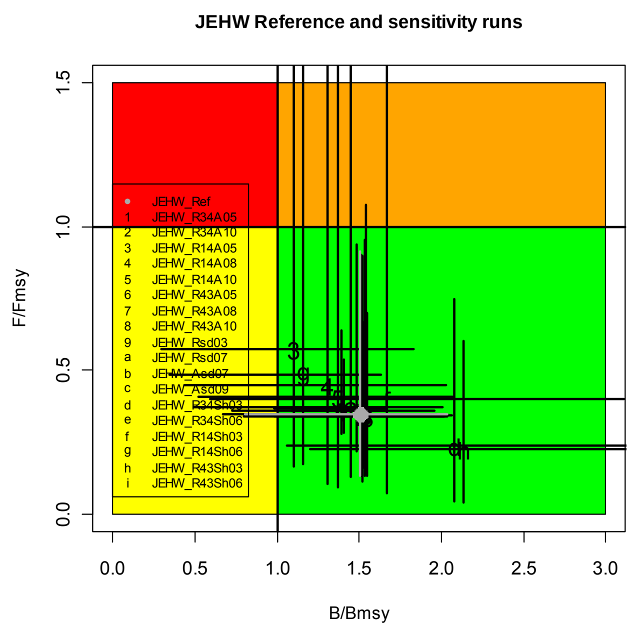
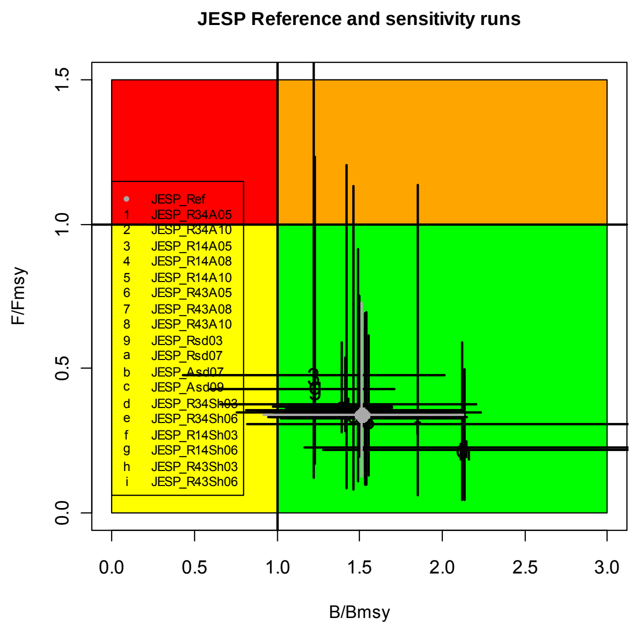


Figure 21 (continued). (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(c)



(d)

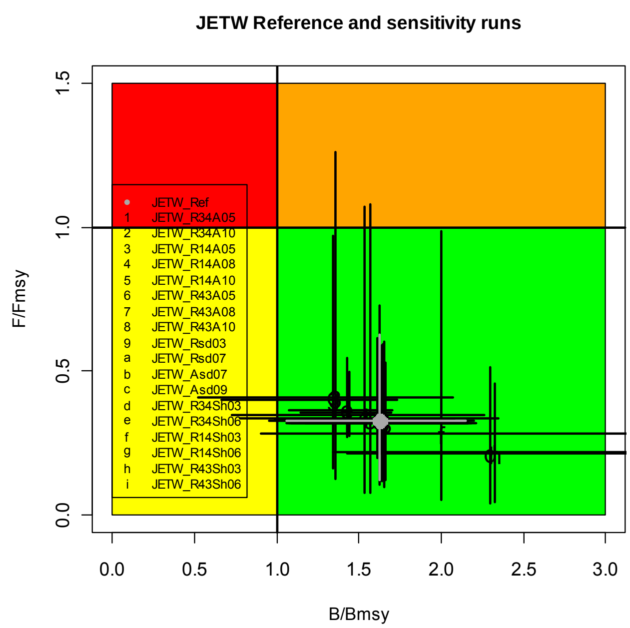


Figure 22. Kobe plot showing the 2011 median estimates of F/F_{MSY} and B/B_{MSY} for all the BSP model runs for North Pacific blue shark (*Prionace glauca*). The horizontal and vertical bars indicate the 90% confidence limits of the 2011 estimates.

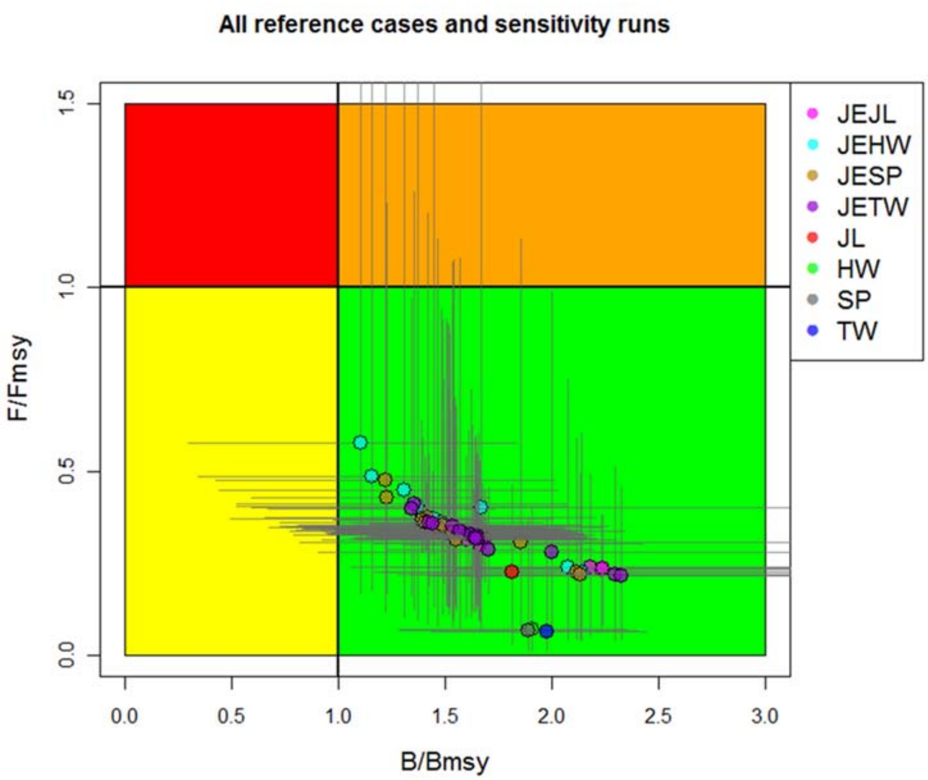
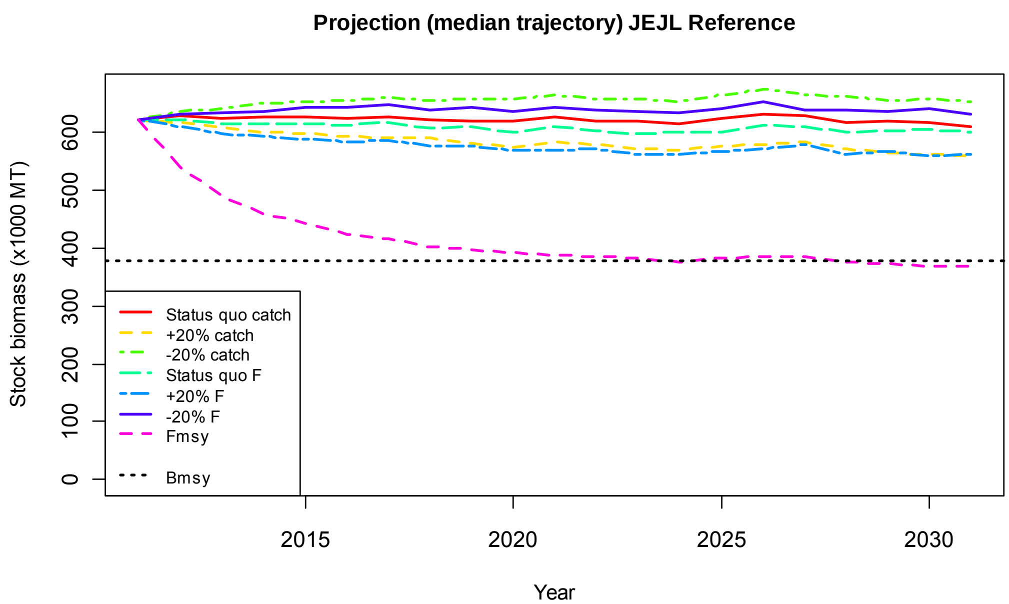


Figure 23. Comparison of future projected stock biomass (medians) of blue shark under different constant catch harvest policies (*status quo*, +20%, -20%) and different constant F harvest policies (*status quo*, +20%, -20%, F_{MSY}) in the four BSP reference cases. *Status quo* catch was based on the 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)

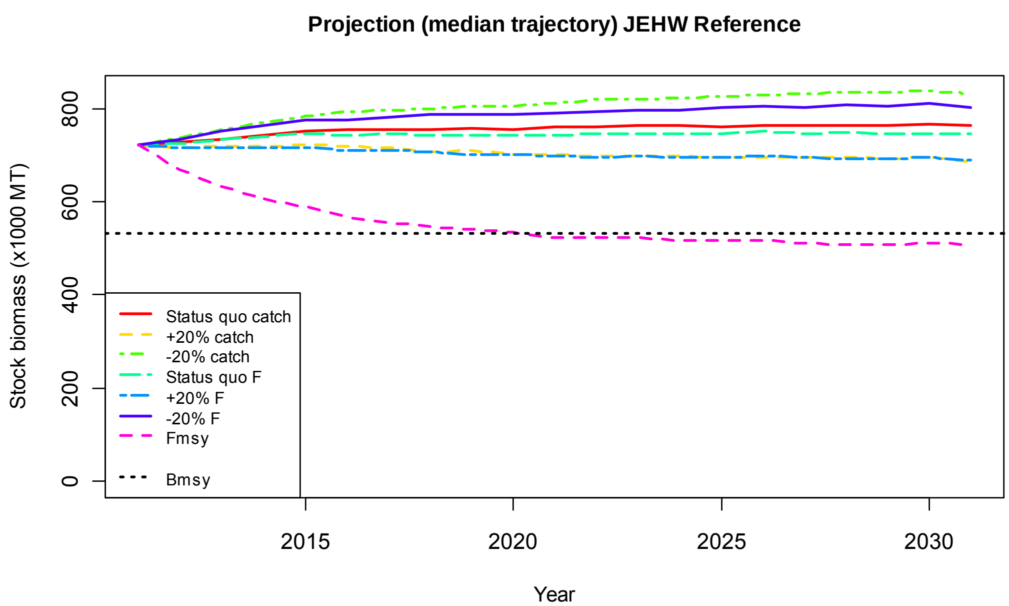
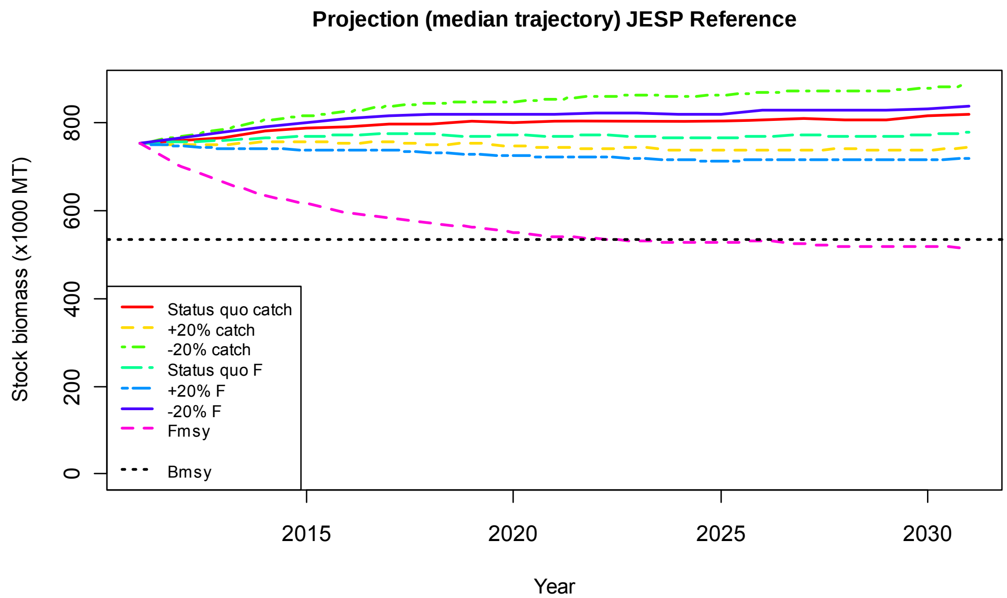


Figure 23 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

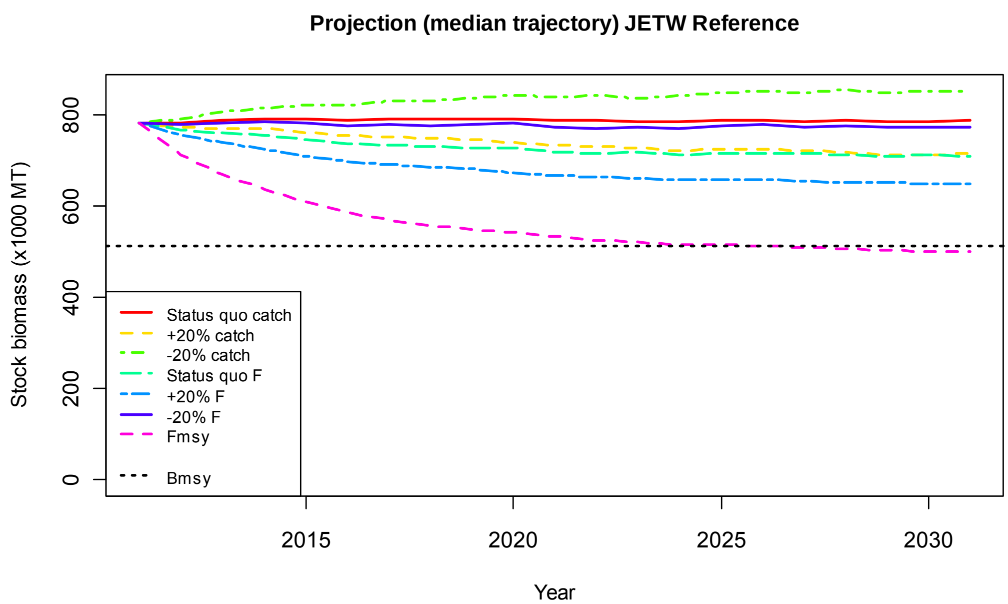
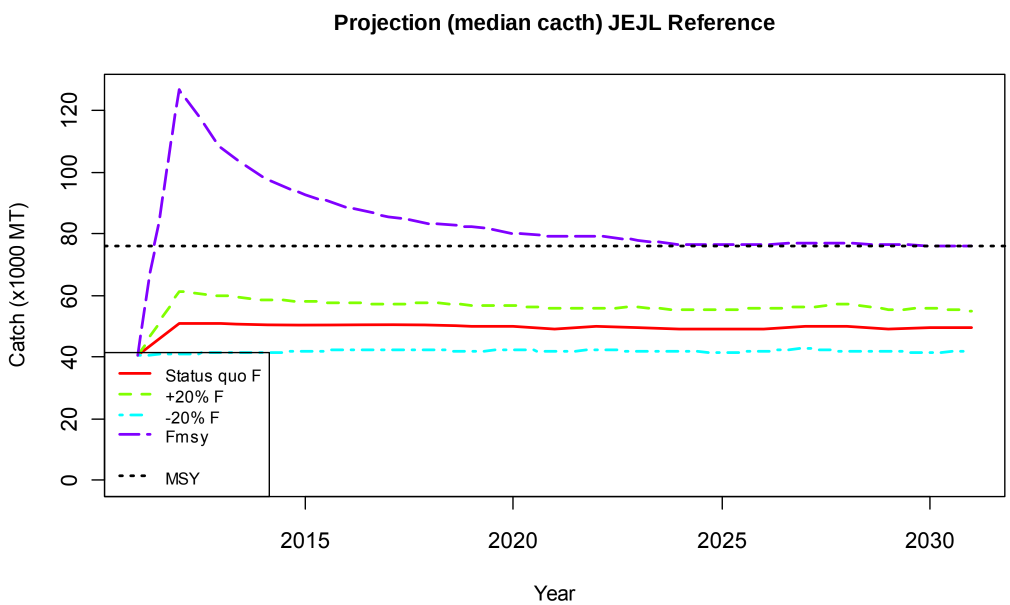


Figure 24. Comparison of future projected catches (medians) of blue shark under different constant *F* harvest policies (*status quo*, +20%, -20%, F_{MSY}) for the four BSP reference cases. *Status quo F* was based on the average *F* over the recent five years of 2006-2010. The maximum sustainable yield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

(a)



(b)

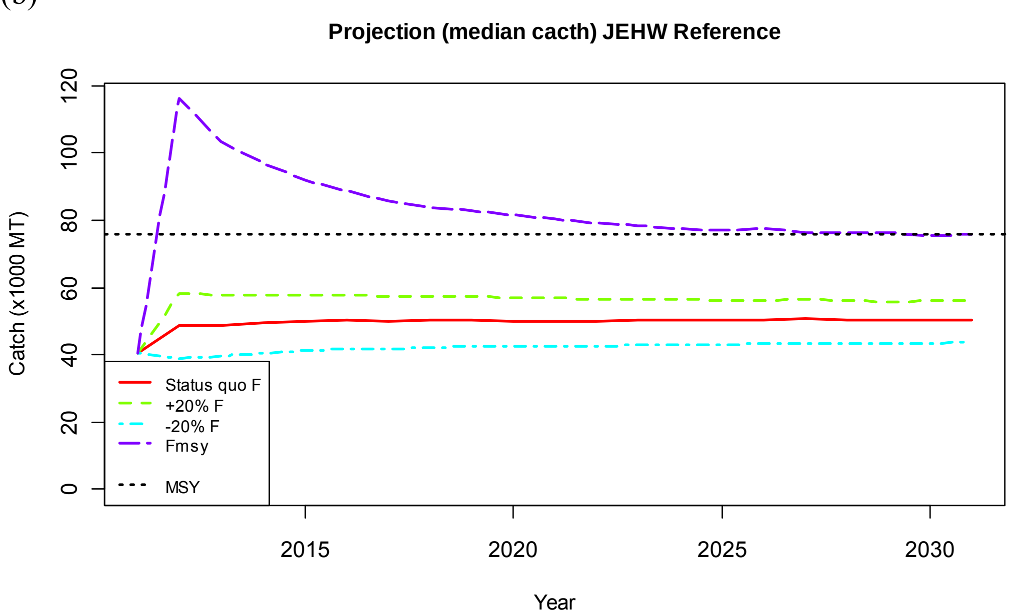
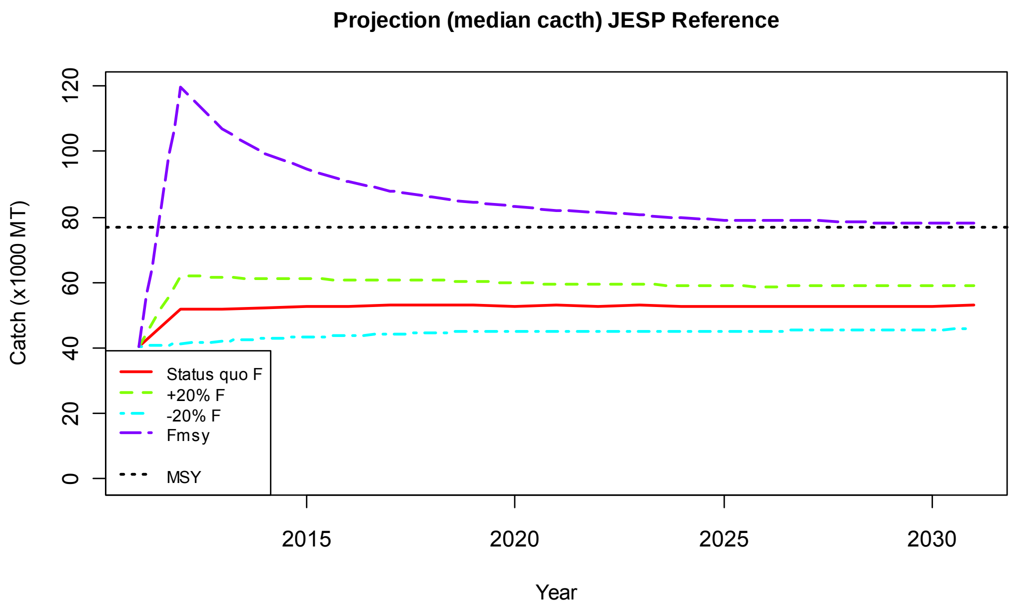


Figure 24 (continued). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(c)



(d)

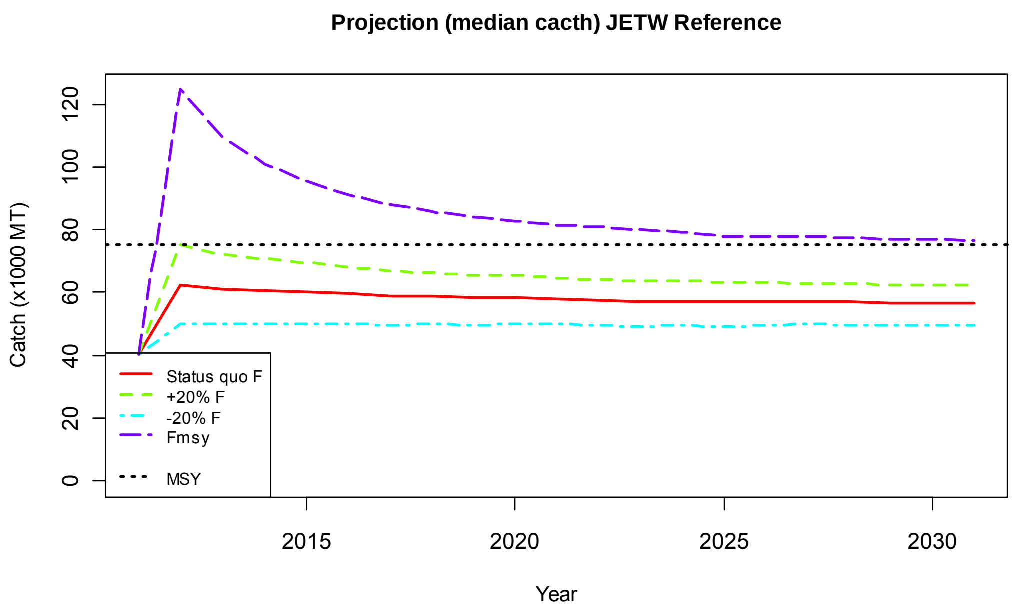


Figure 25. Selectivity curves estimated for female (top) and male (bottom) from the SS reference case model.

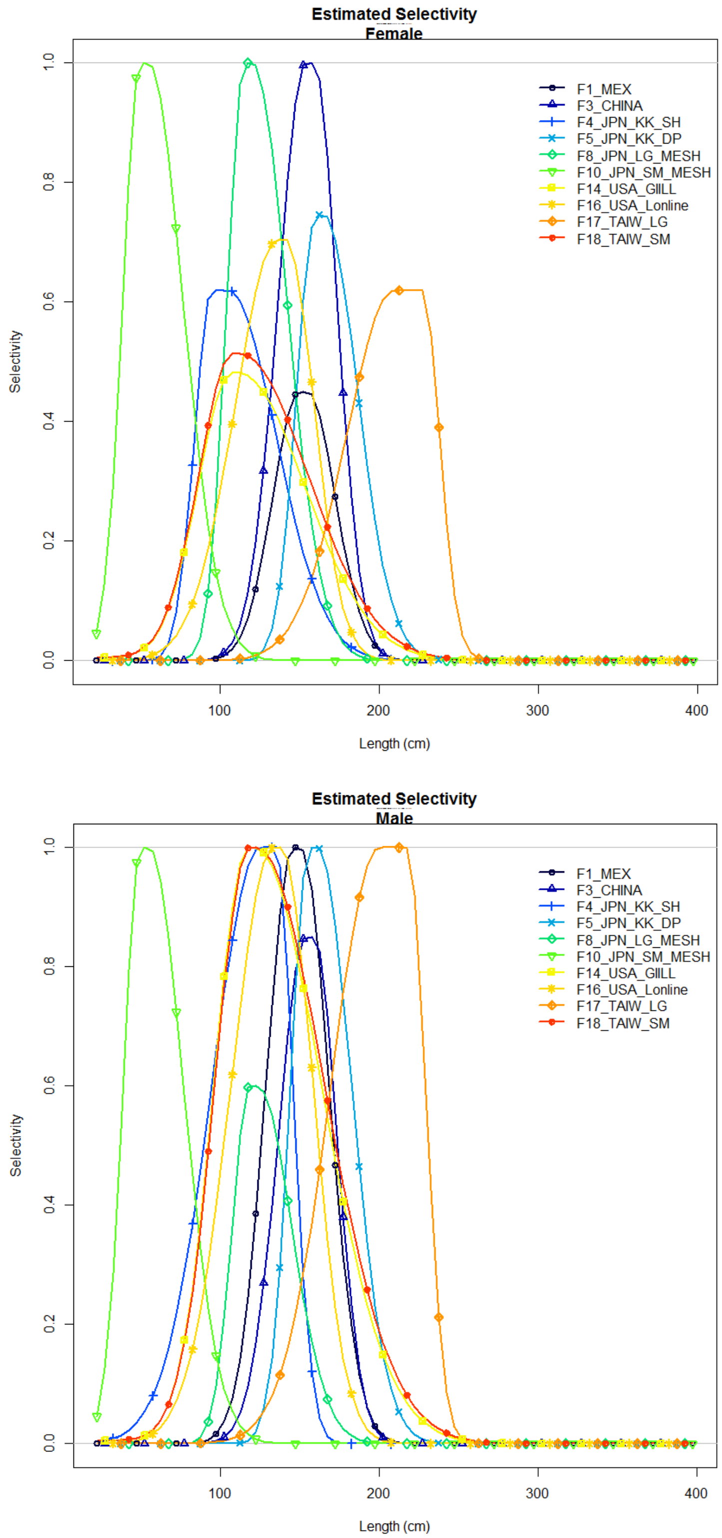


Figure 26. Fit to the Japanese early (top) and late (bottom) CPUE time series for the SS reference case model.

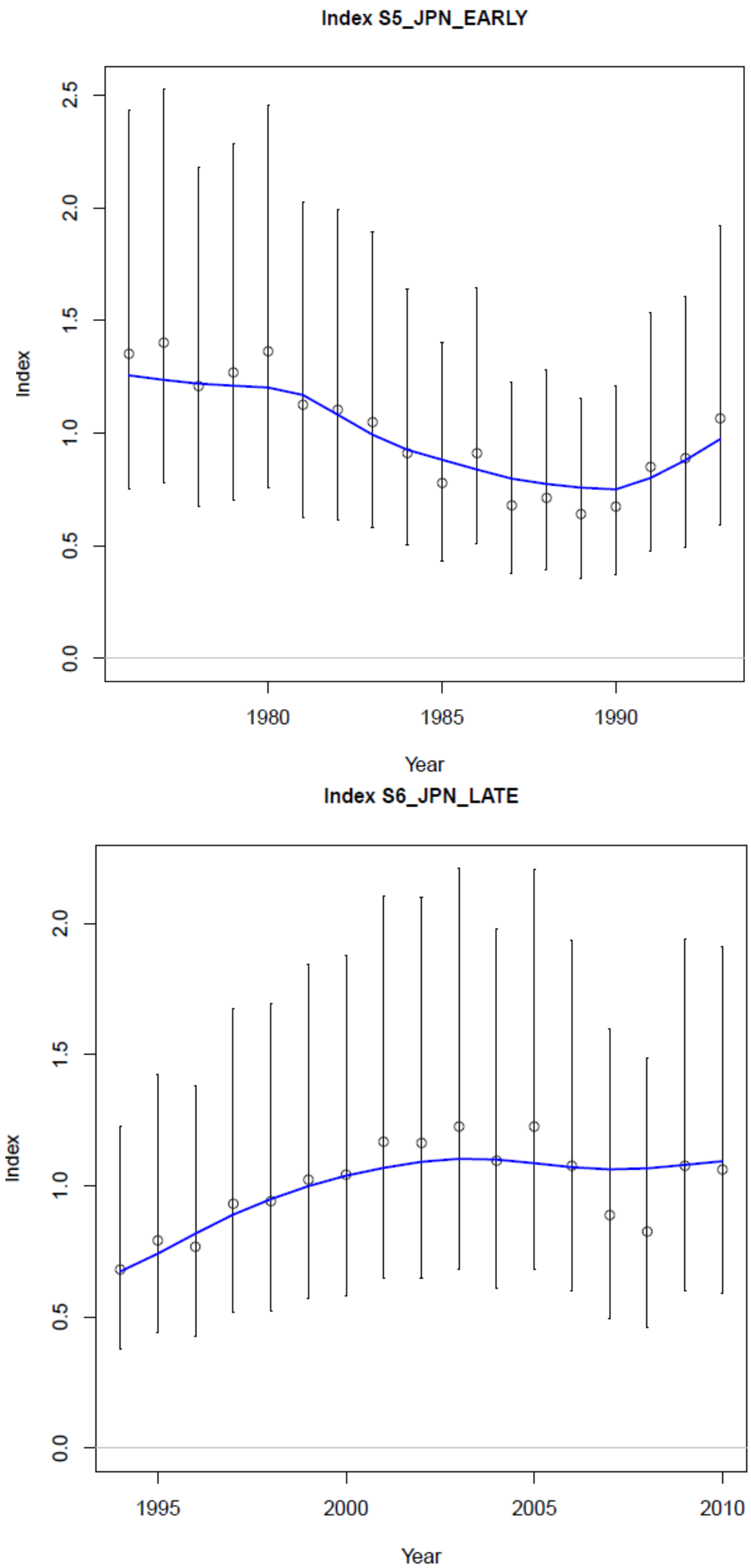


Figure 27. Fit to the female length frequency data for the SS reference case model.

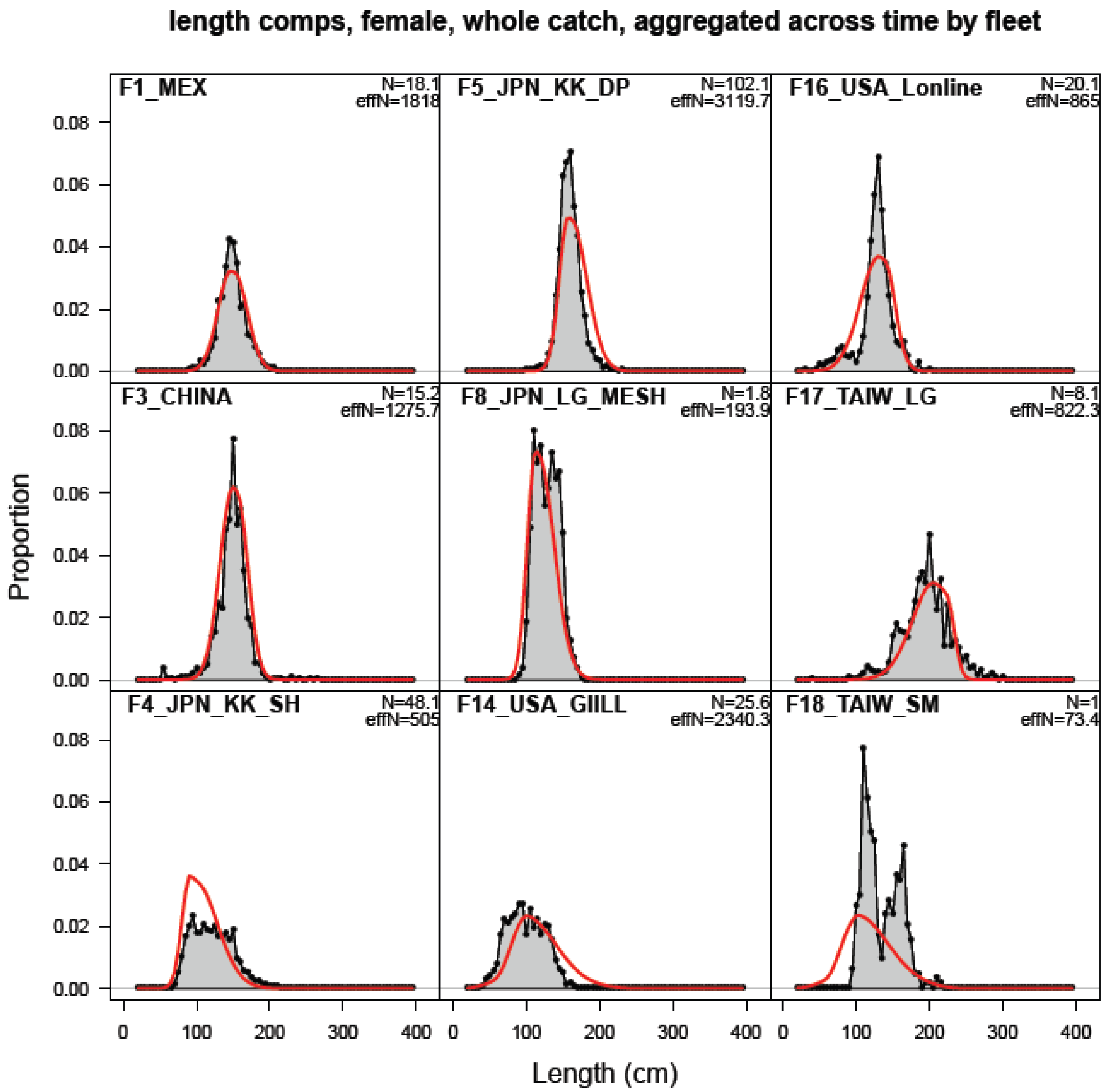


Figure 28. Fit to the male length frequency data for the SS reference case model.

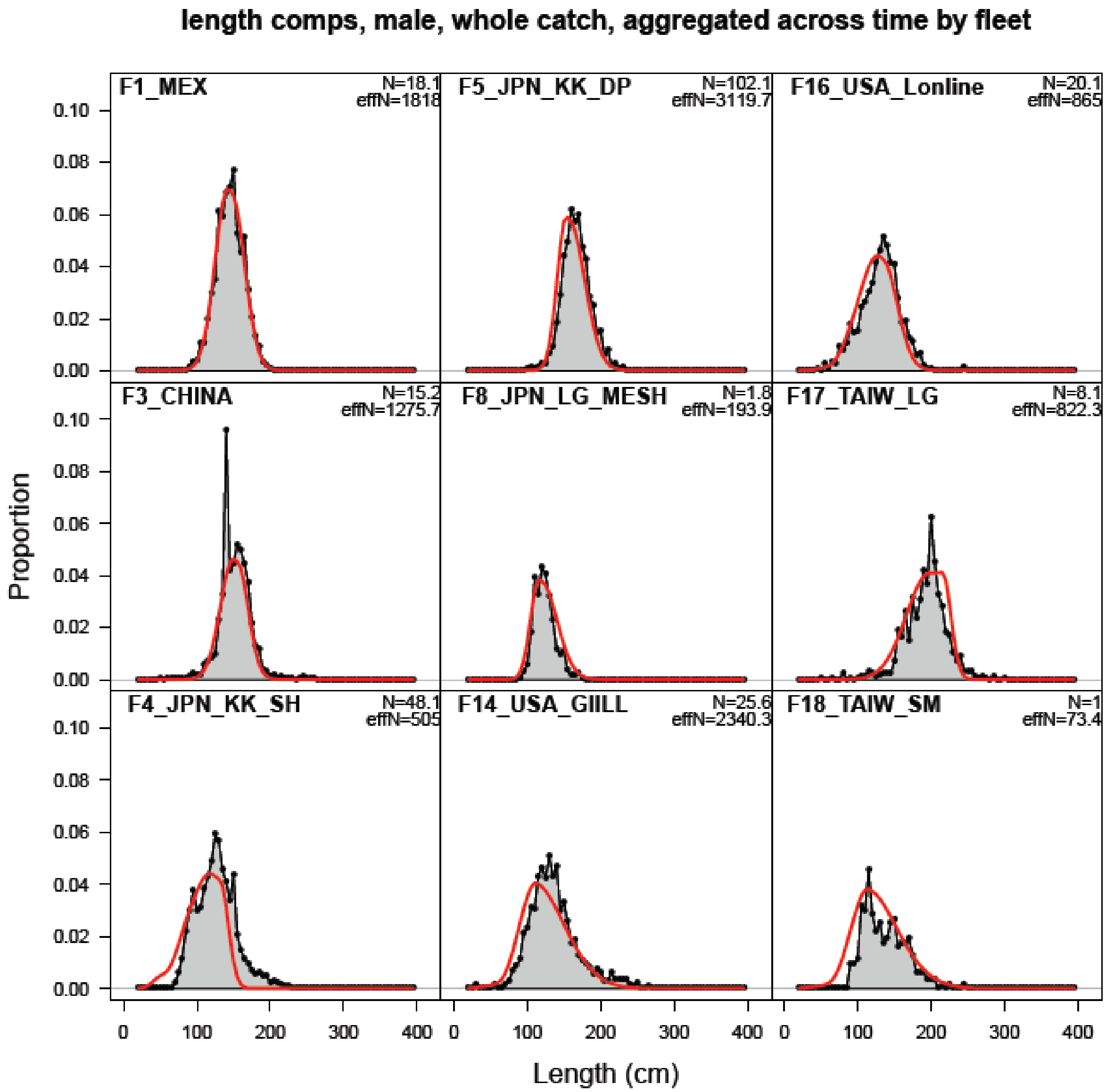


Figure 29. Estimated recruitment including the estimate of virgin recruitment (filled circle at the start of the time series) for the SS reference case model, note that recruitment is higher than virgin due to the compensation implied by the parameterization of the LFSR.

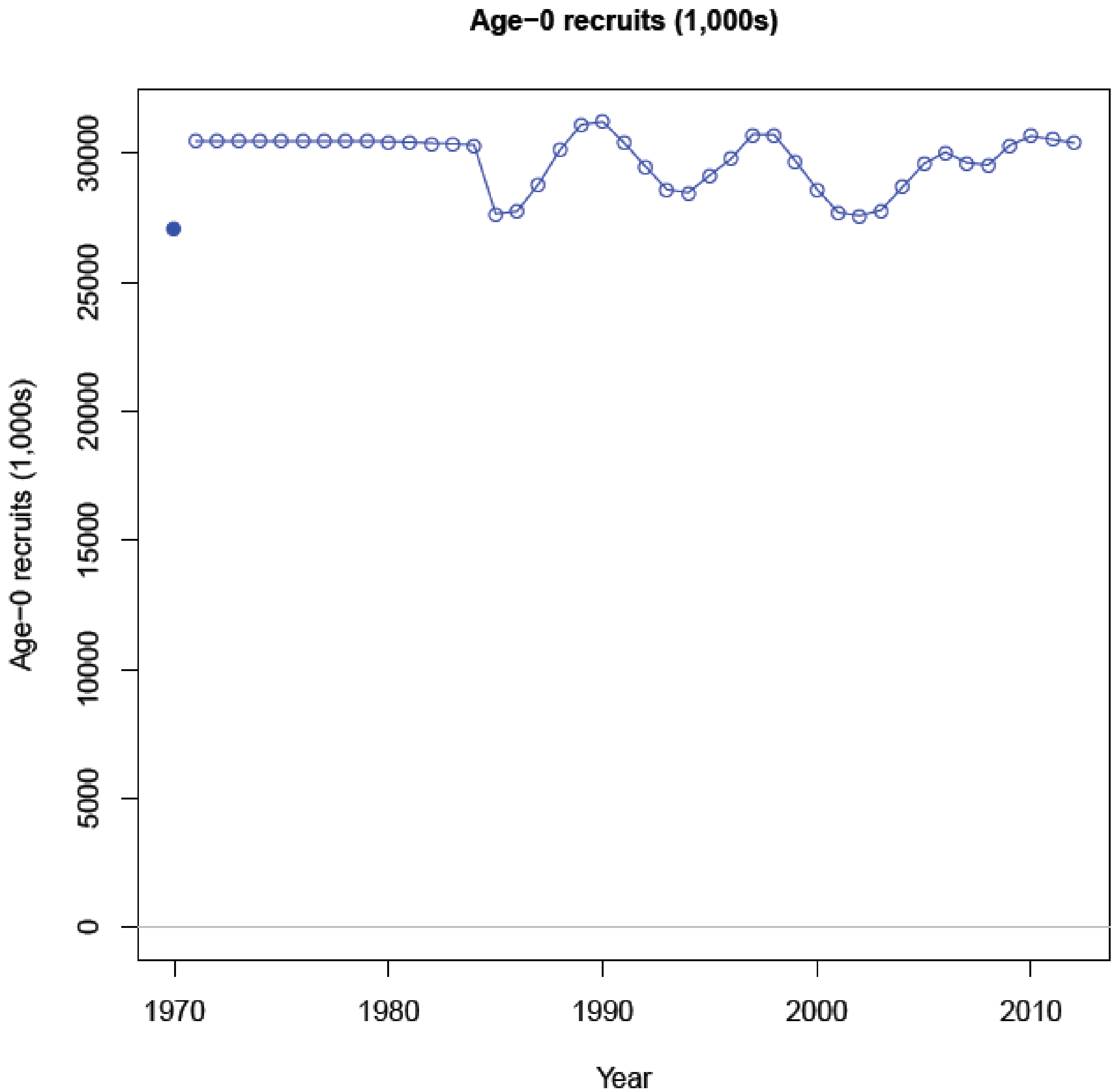


Figure 30. Spawner recruitment time series for the SS reference case model.

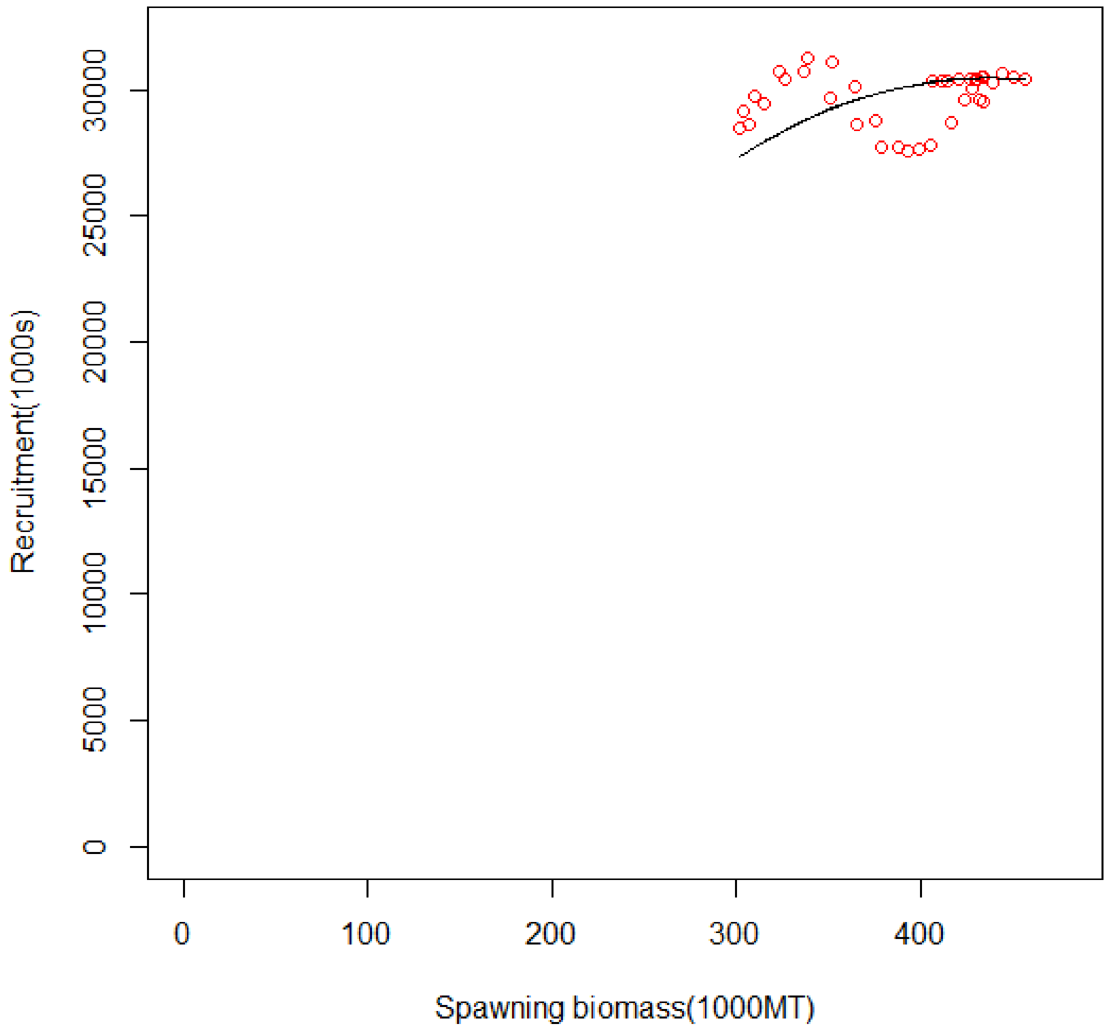


Figure 31. Estimated fishing mortality for each fishing gear for the SS reference case model.

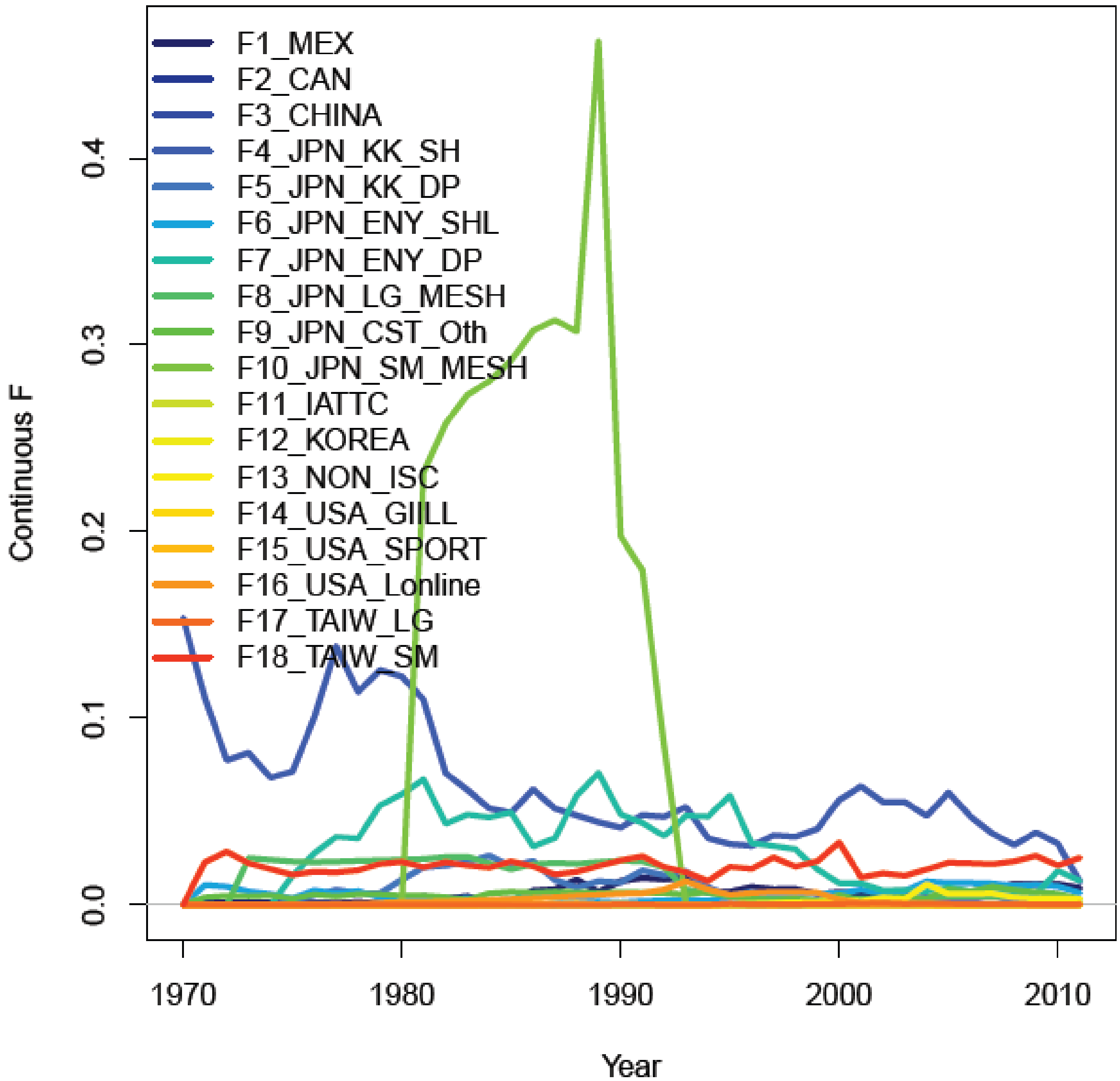


Figure 32. Equilibrium yield curve for the SS reference case model.

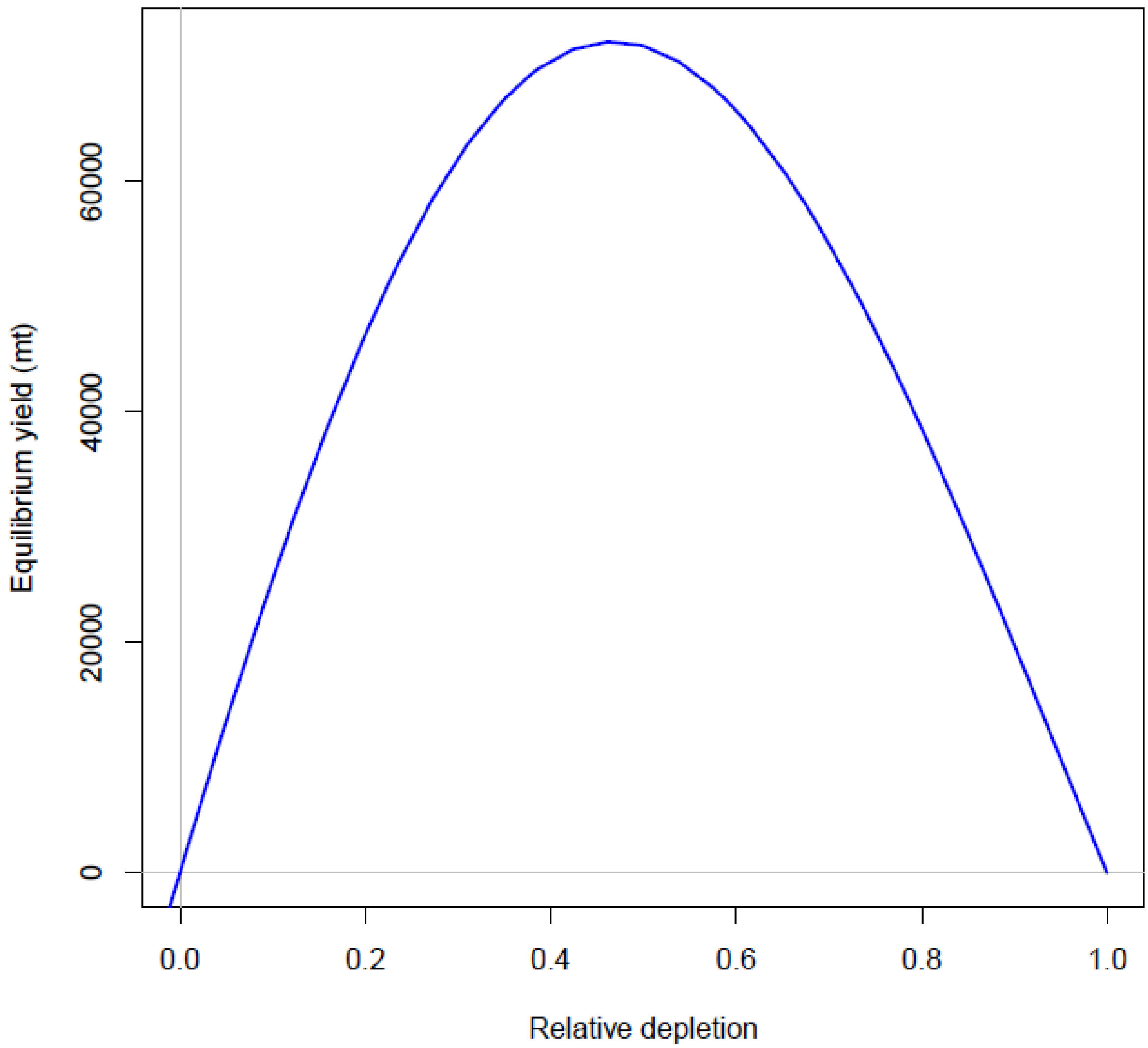


Figure 33. Estimated female spawning biomass and 90% confidence intervals for the SS reference case run.

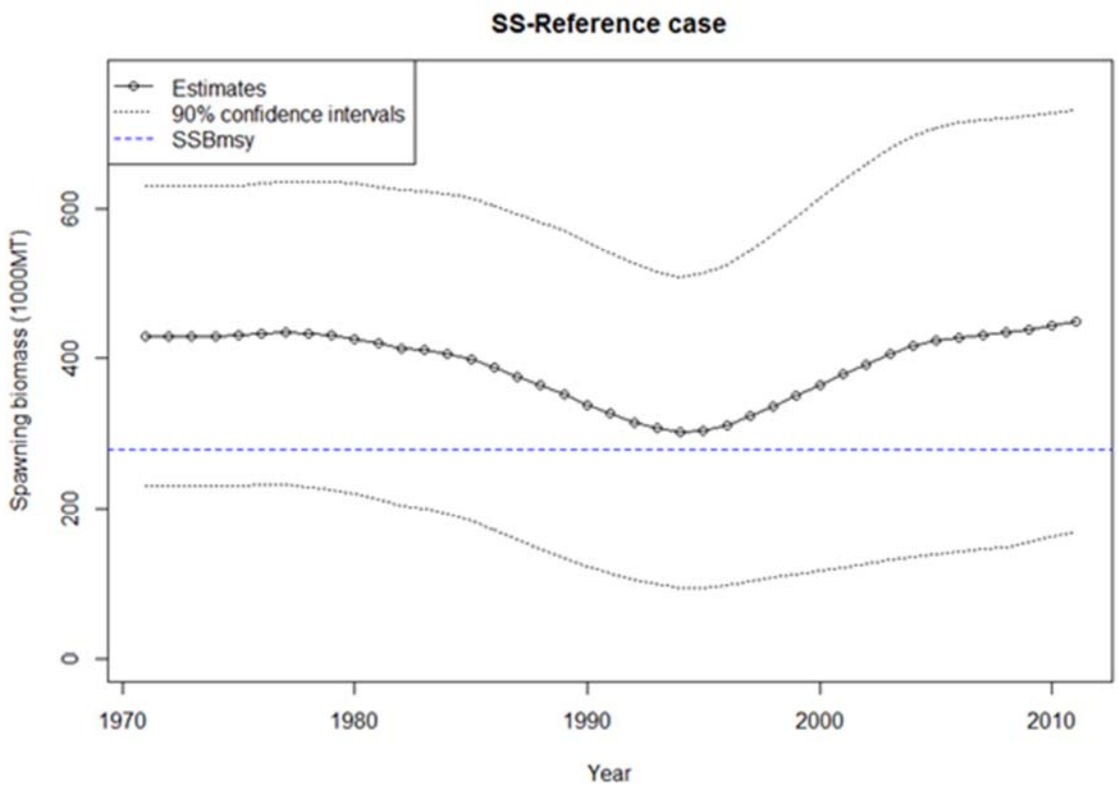


Figure 34. Kobe plot showing estimated spawning biomass and fishing mortality trajectories for the reference case SS model. The circles indicate the historical trajectory from 1971-2011 colored from red (first year) to blue (terminal year).

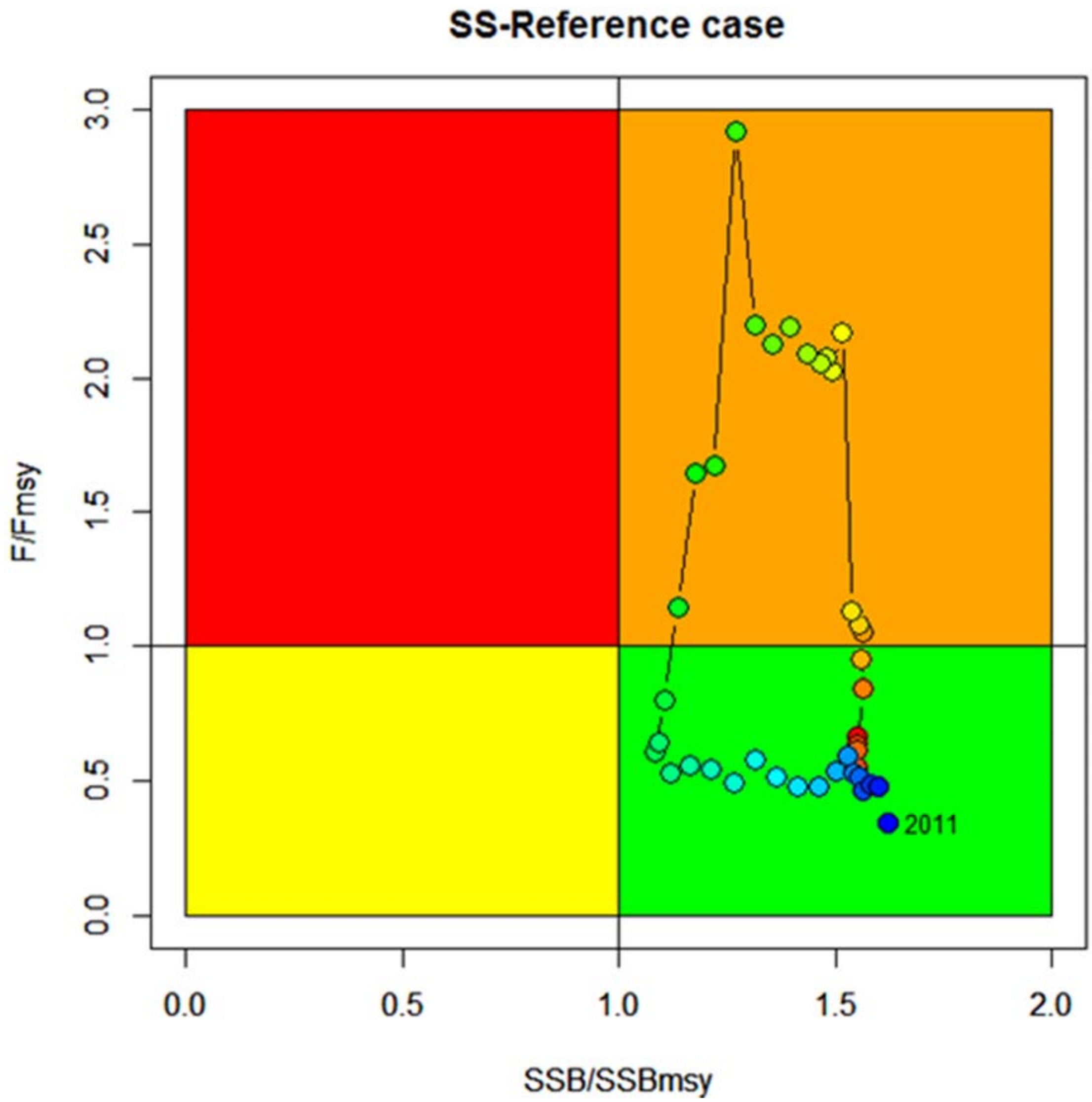


Figure 35. Kobe bar plots showing the range of terminal year values for alternative SS runs that explored the main axes of uncertainties. The total number of runs was 1080. Note that each run is not considered equally likely, thus percentages should not be interpreted as probabilities.

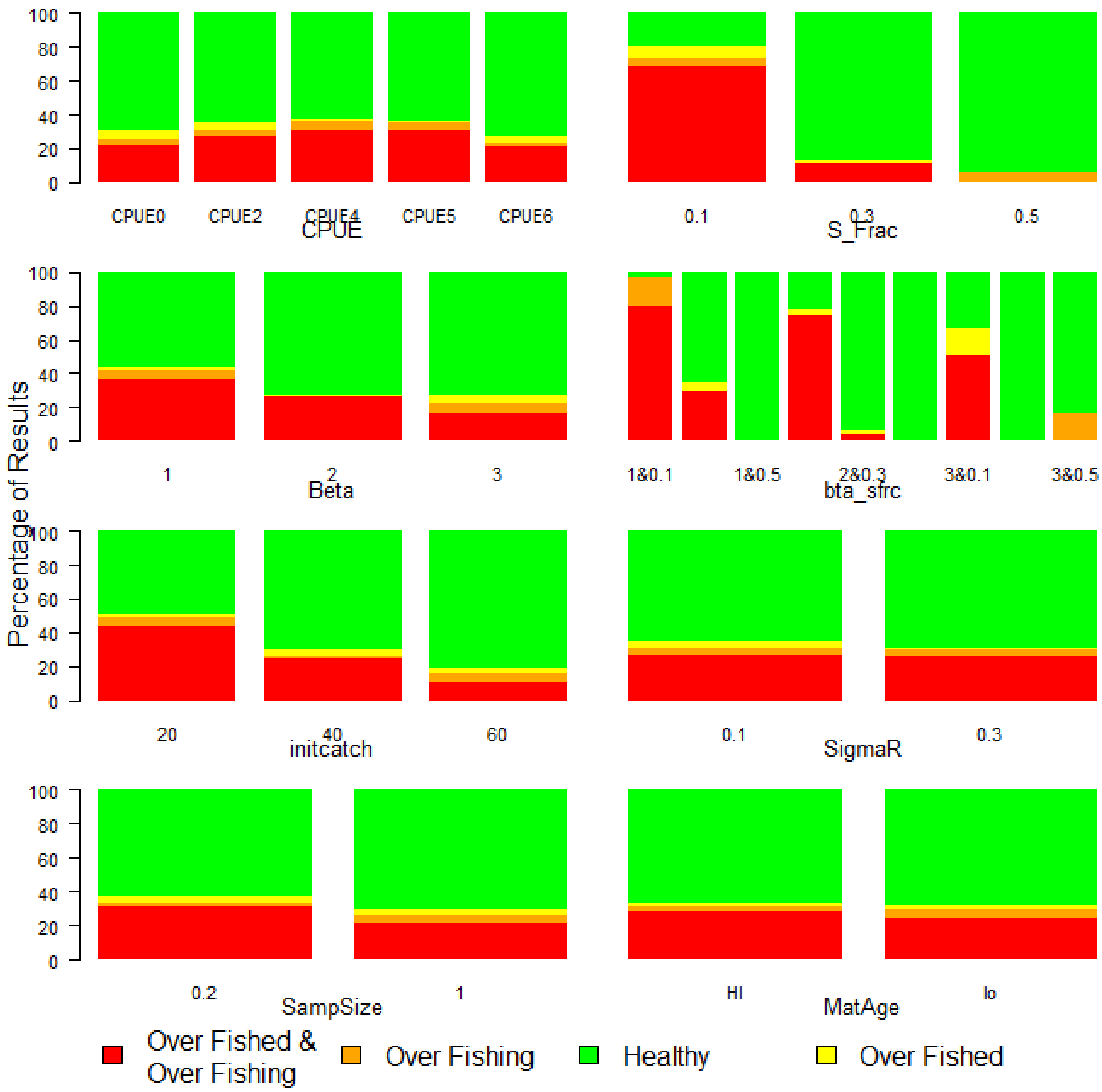


Figure 36. Five years retrospective analysis for the SS reference case.

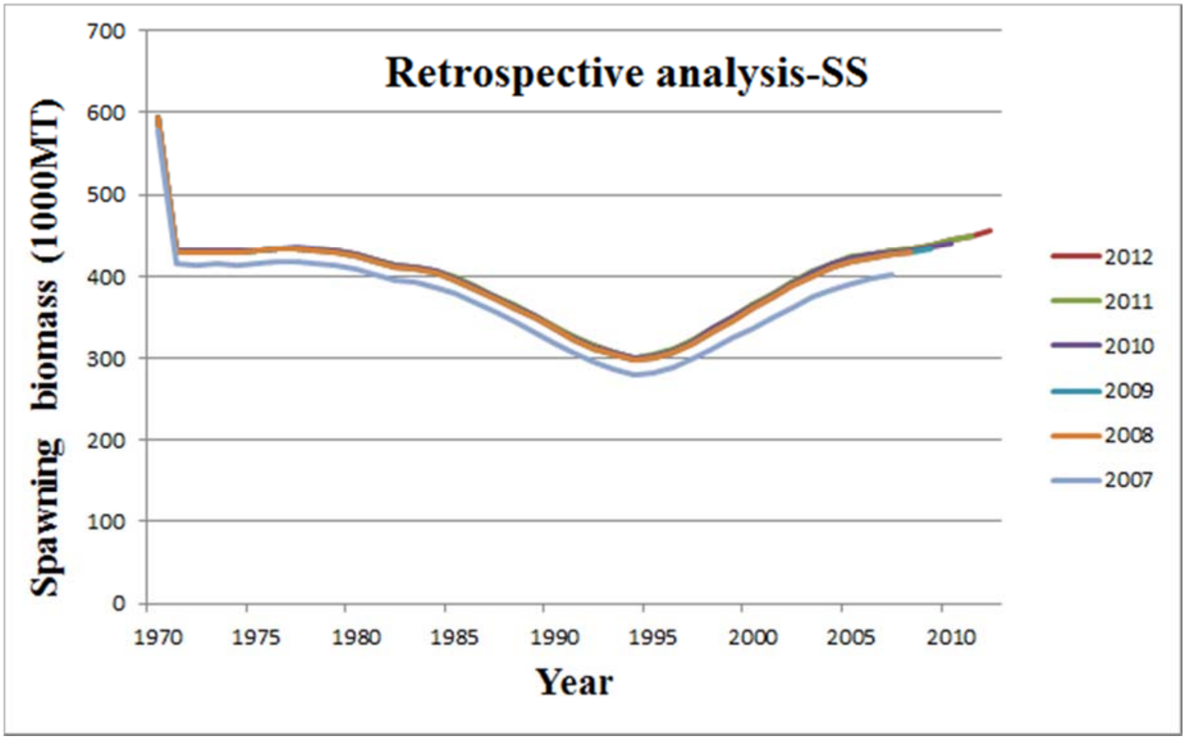
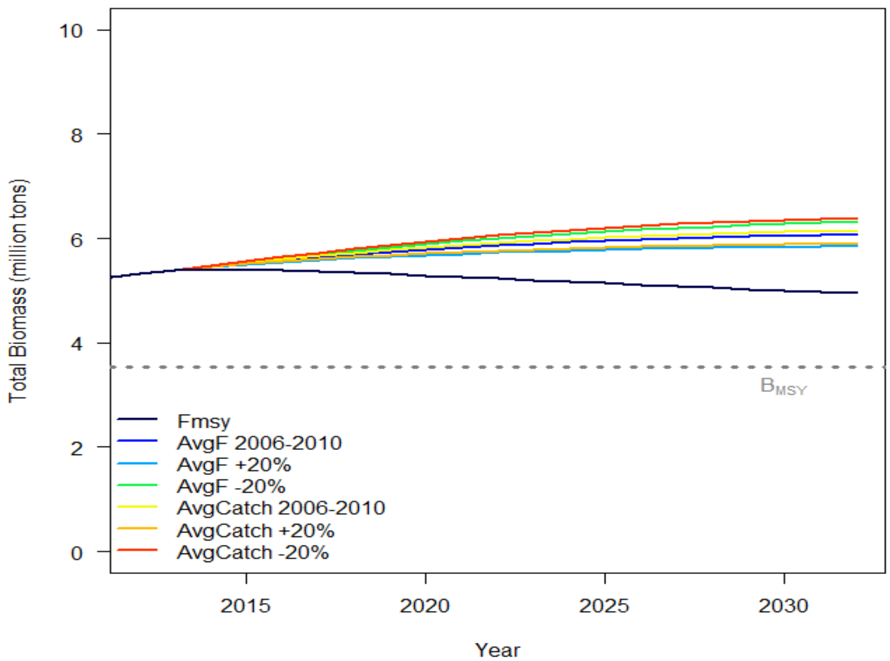


Figure 37. Comparison of future projected blue shark stock biomass under different constant catch (*status quo*, +20%, -20%) and constant F harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* catch and fishing mortality was based on the average from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

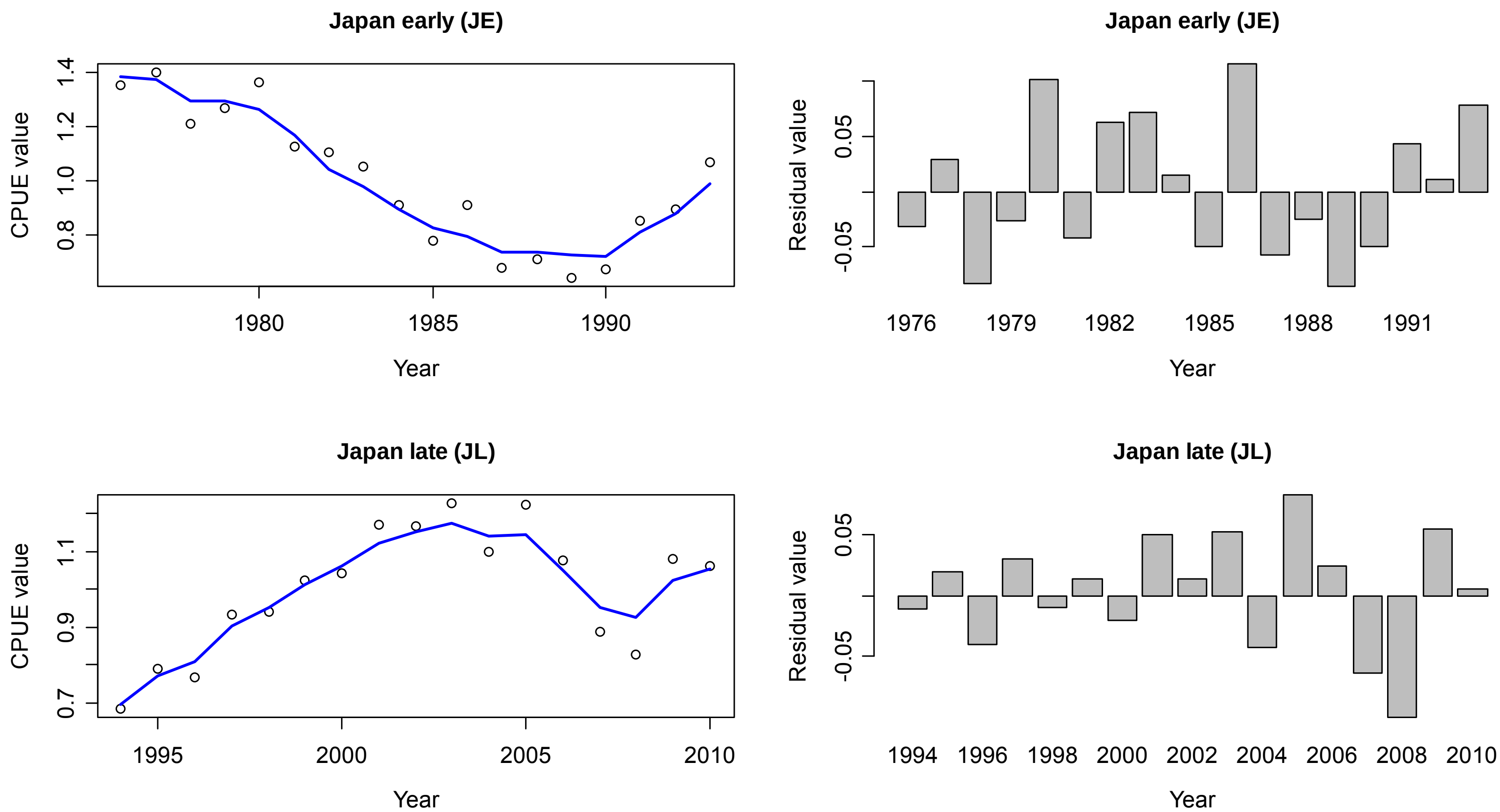


Figure A1. Model fits to the standardized CPUE indices used in the BSP blue shark reference runs (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. (a) Fits for indices used in **JEJL_Ref** case. Top and bottom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

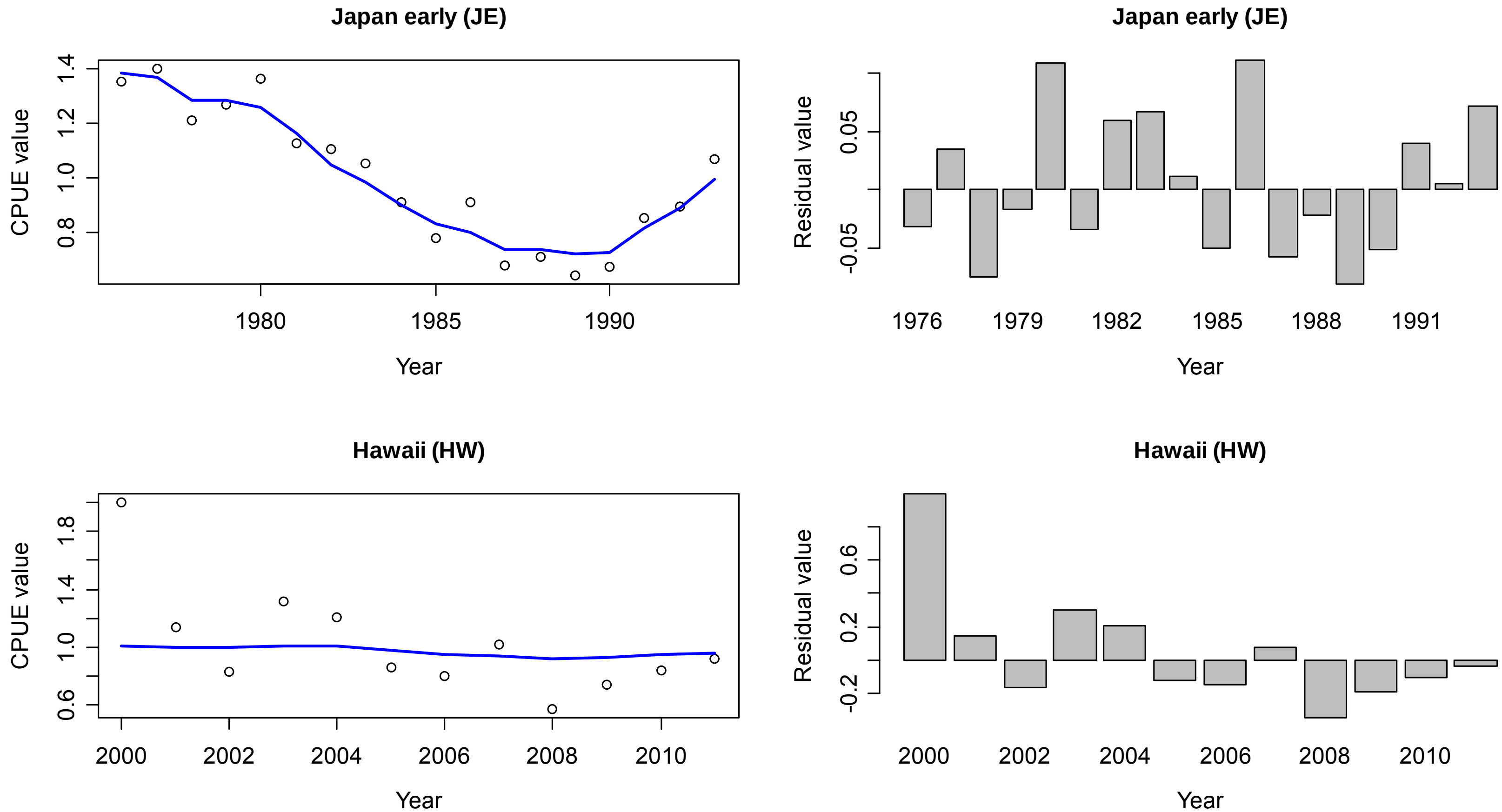


Figure A1. (b) Fits for indices used in the **JEHW_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and Hawaii longline index for 2000-2011, respectively.

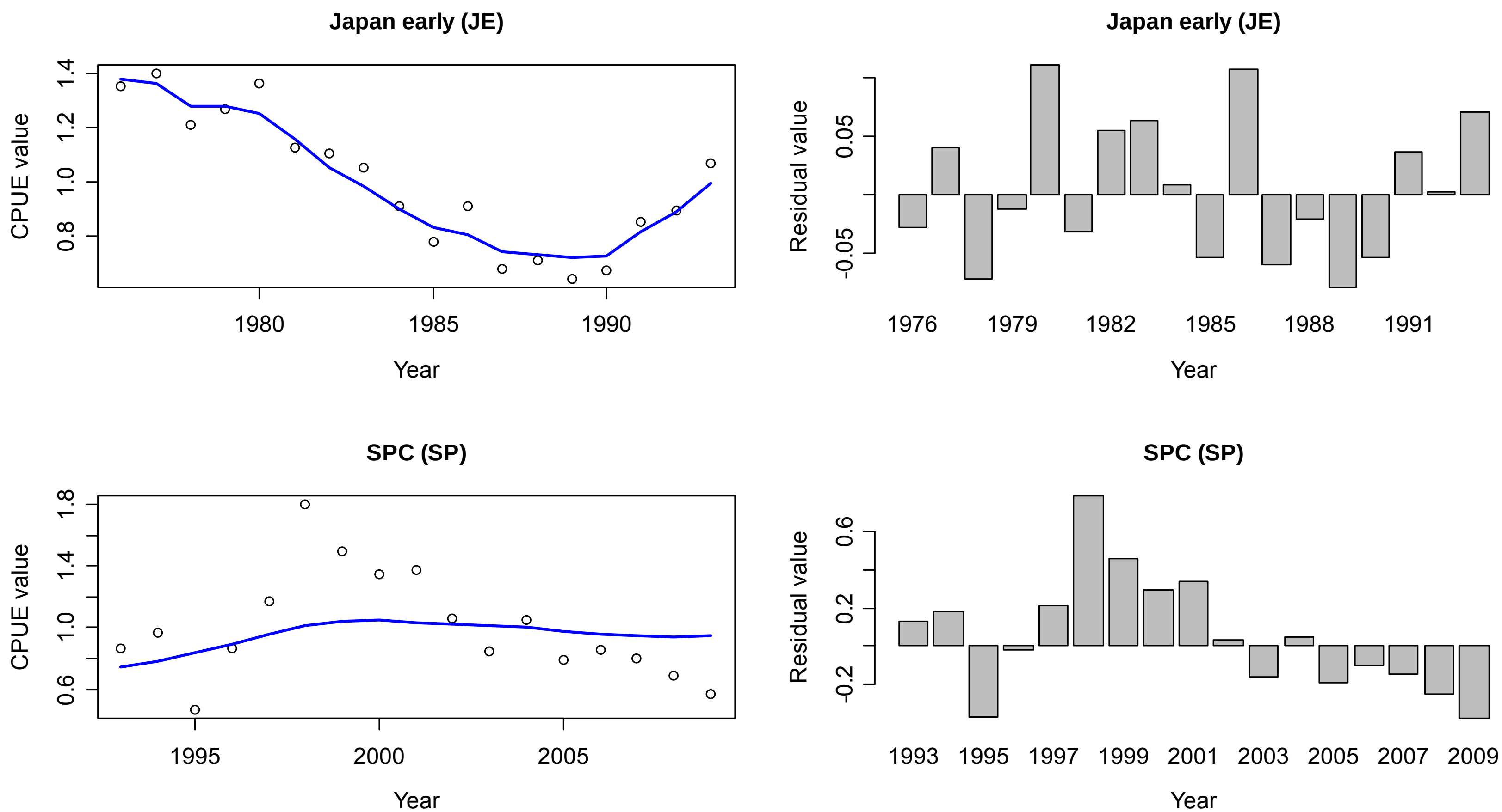


Figure A1. (c) Fits for indices used in the **JESP_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and SPC longline index for 1993-2009, respectively.

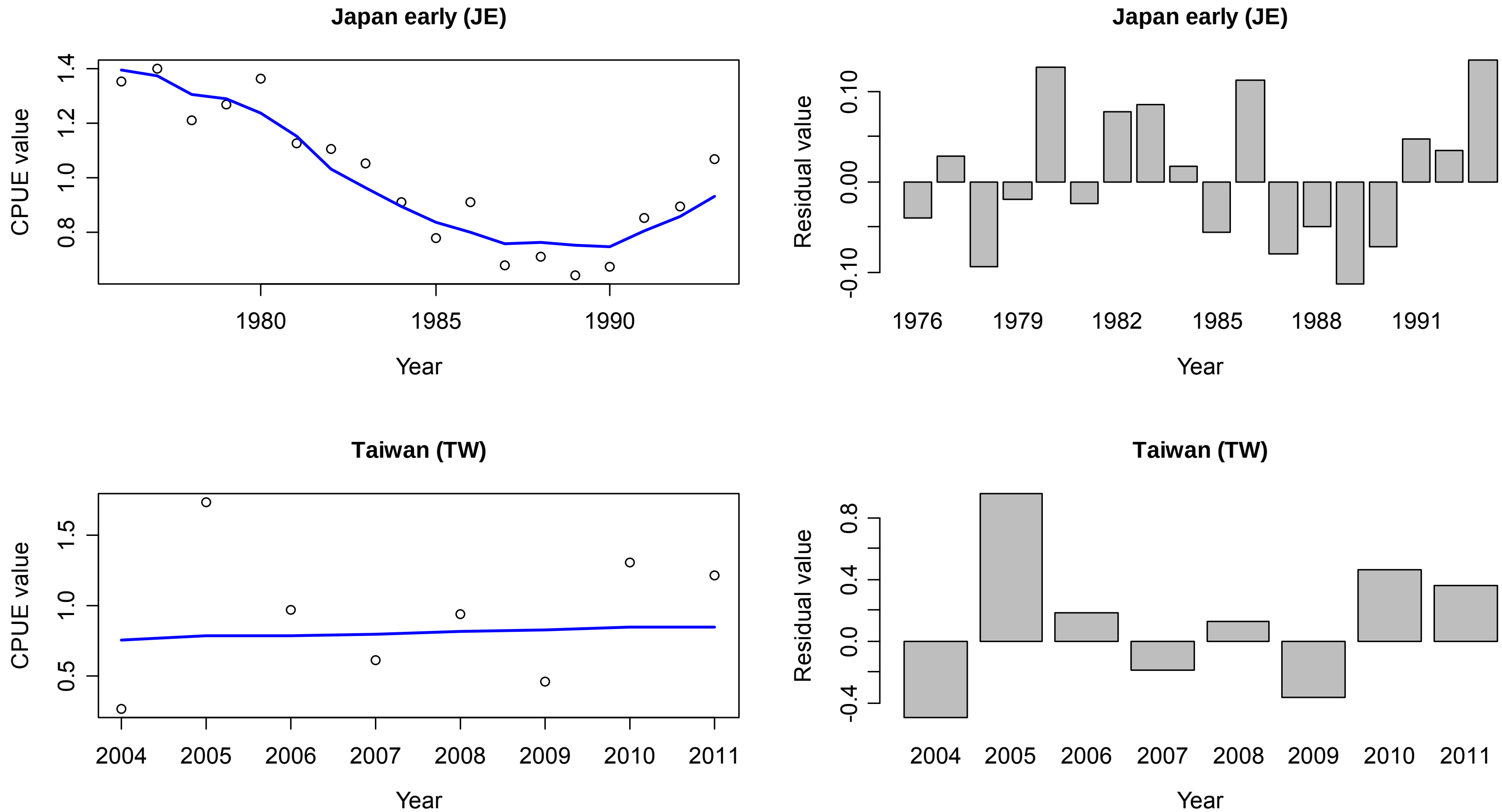


Figure A1. (d) Fits for indices used in the **JETW_Ref** case. Top and bottom panels correspond to Japanese longline index for 1976-1993 and Taiwan longline index for 2004-2011, respectively.

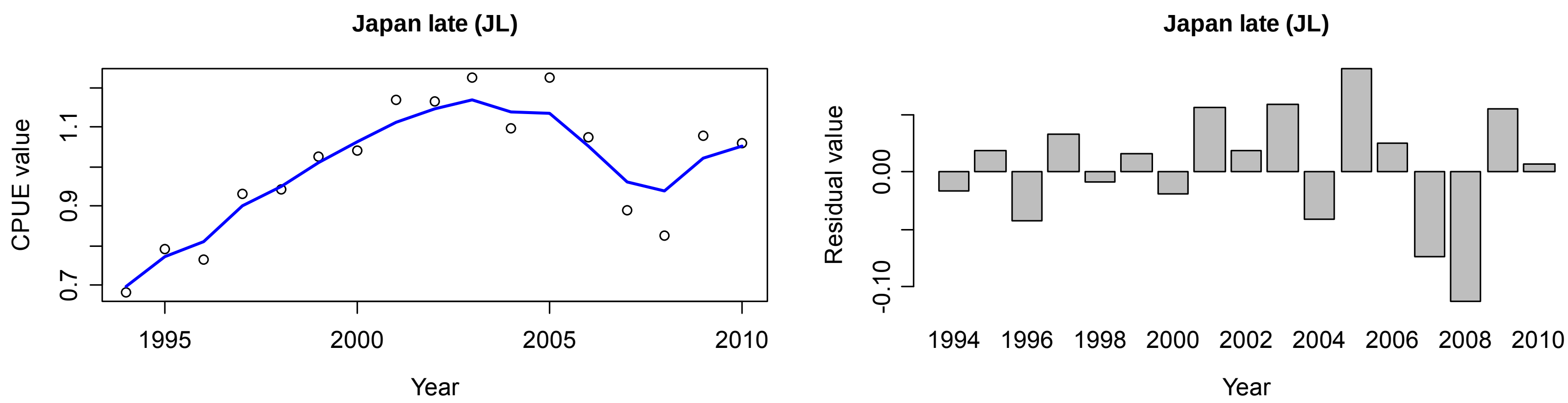


Figure A1. (e) Fits to the index used in the **JL_Ref** case. Panels correspond to the Japanese longline index for the late period (1994-2010).

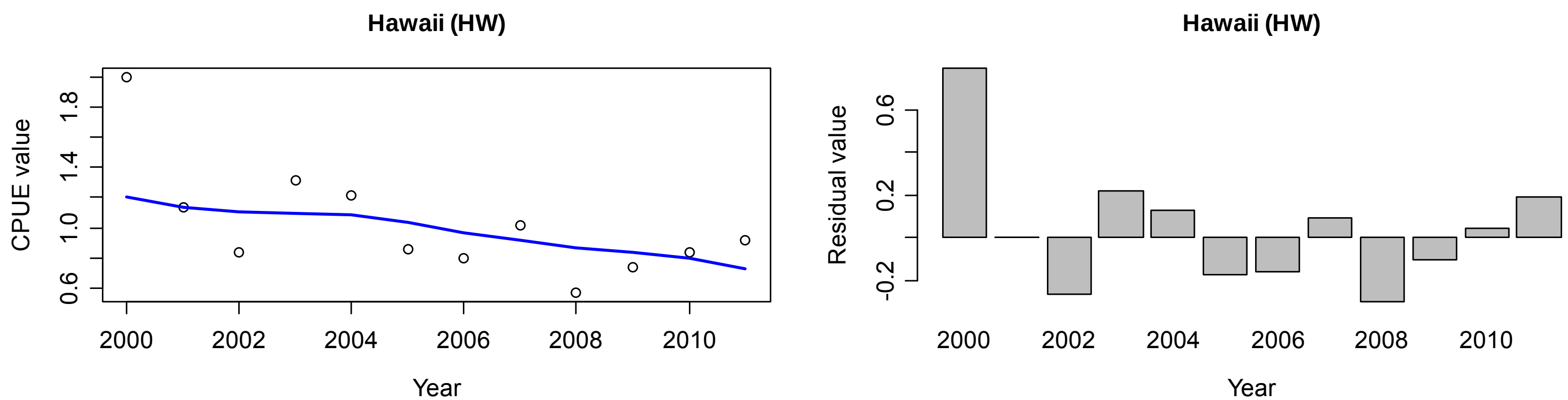


Figure A1. (f) Fits for the index used in the **HW_Ref** case. Panels correspond to the Hawaii longline index for 2000-2011.

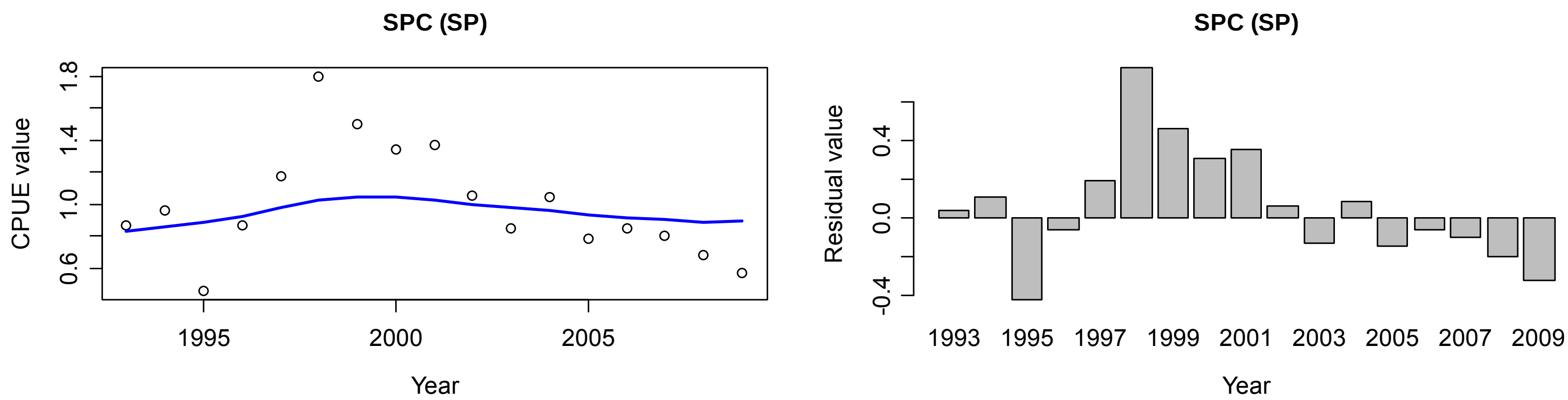


Figure A1. (g) Fits to the index used in the **SP_Ref** case. Panels correspond to the SPC longline index for 1993-2009.

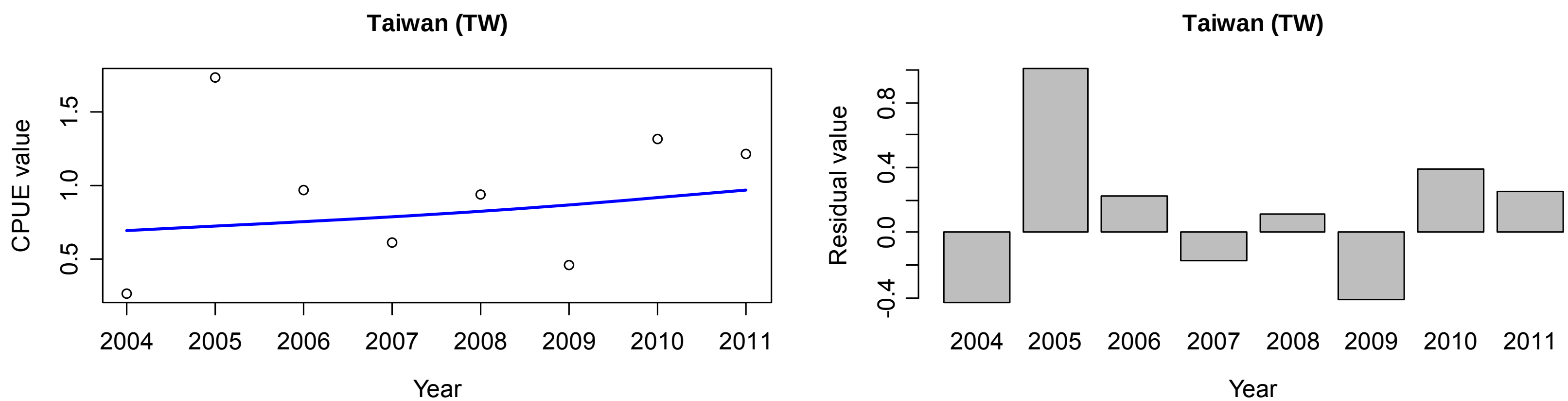


Figure A1. (h) Fits to the index used in the **TW_Ref** case. Panels correspond to the Taiwan longline index for 2004-2011.

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.

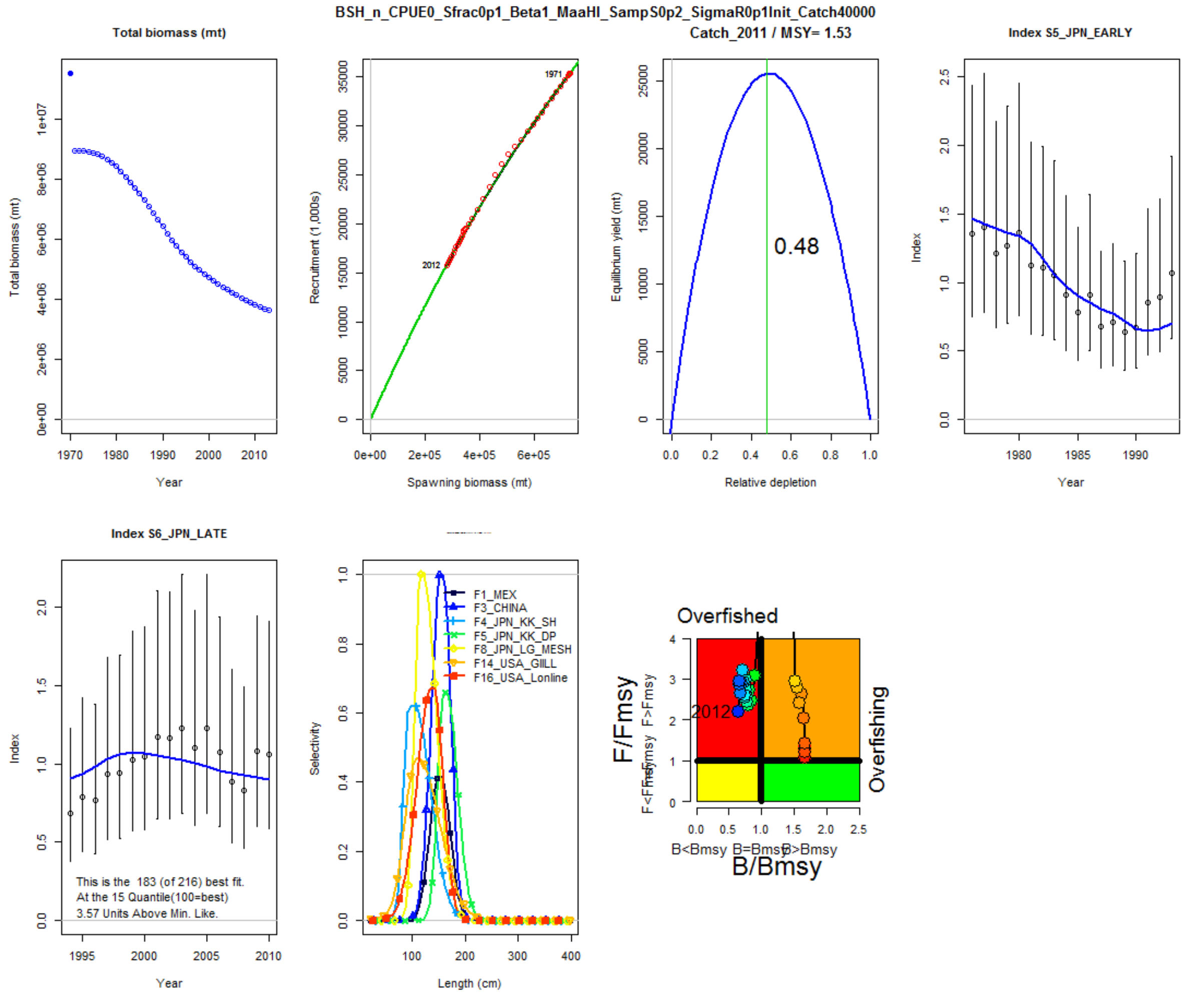
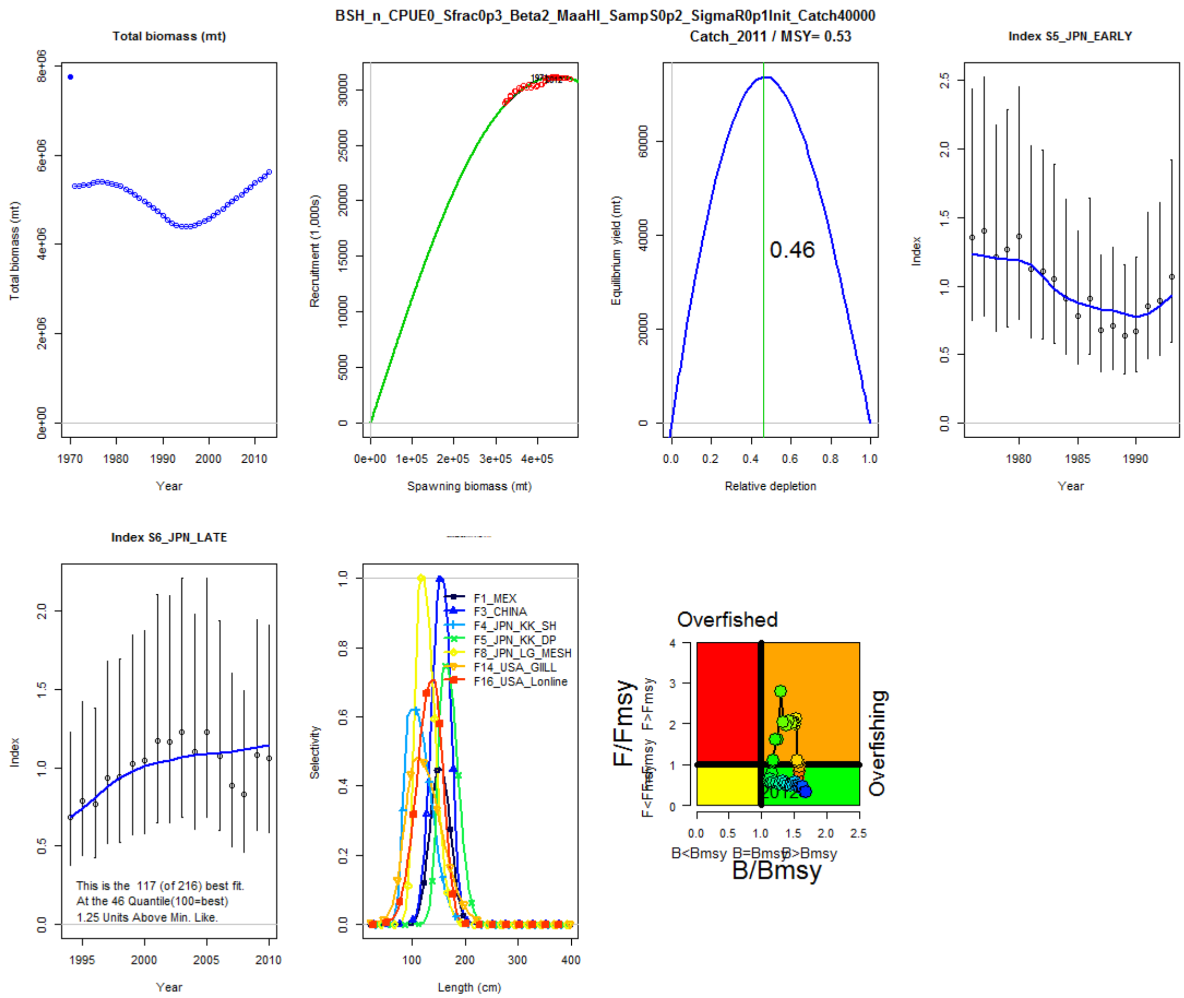


Figure B2.



BSH_n_CPUE0_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Catch_2011 / MSY= 0.53
Equilibrium yield (mt)
Relative depletion
0.46
Index S5_JPN_EARLY
Index
Year
Index S6_JPN_LATE
Index
Year
This is the 117 (of 216) best fit.
At the 46 Quantile(100=best)
1.25 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
2012

Figure B3.

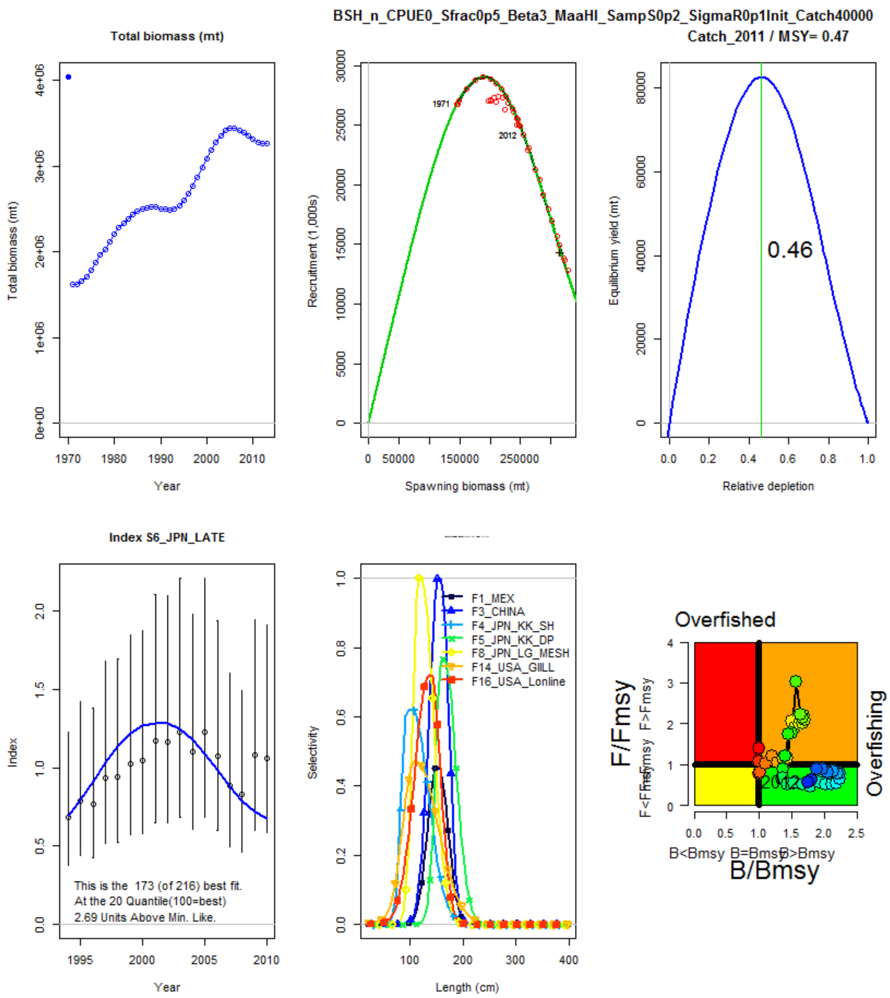
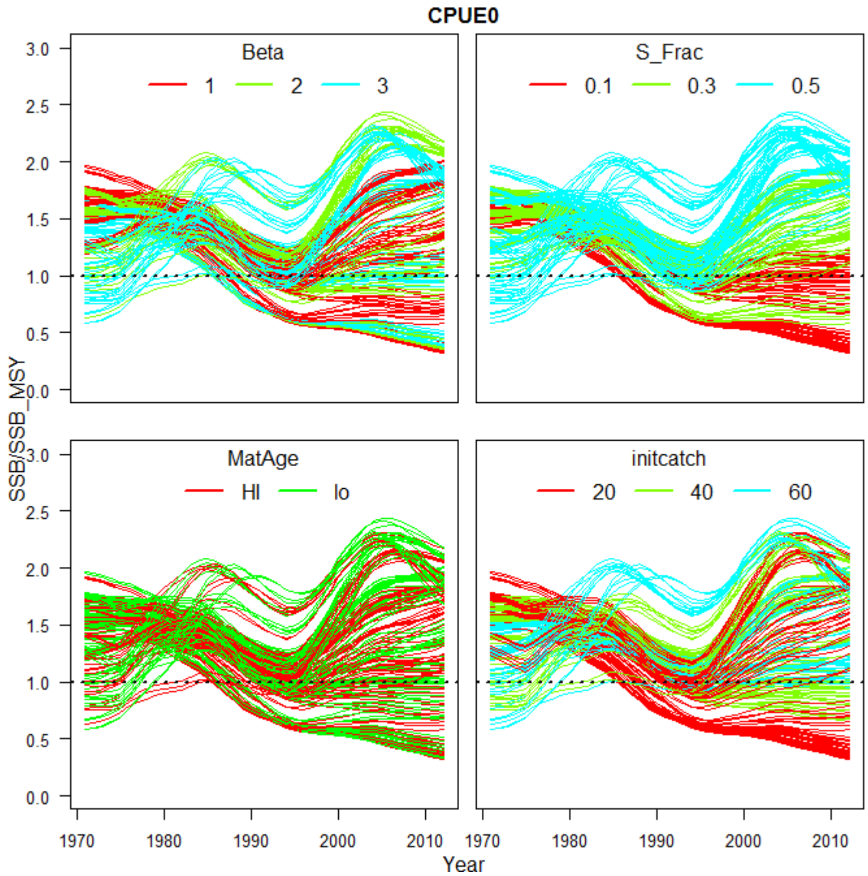

BSH_n_CPUE0_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.47
Index S5_JPN_EARLY
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.46
Index
Index S6_JPN_LATE
This is the 173 (of 216) best fit.
At the 20 Quantile(100=best)
2.69 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy B=Bmsy B>Bmsy
2012

Figure B4.



CPUE0
Beta
1
2
3
S_Frac
0.1
0.3
0.5
MatAge
HI
lo
initcatch
20
40
60
SSB/SSB_MSY
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010
Year

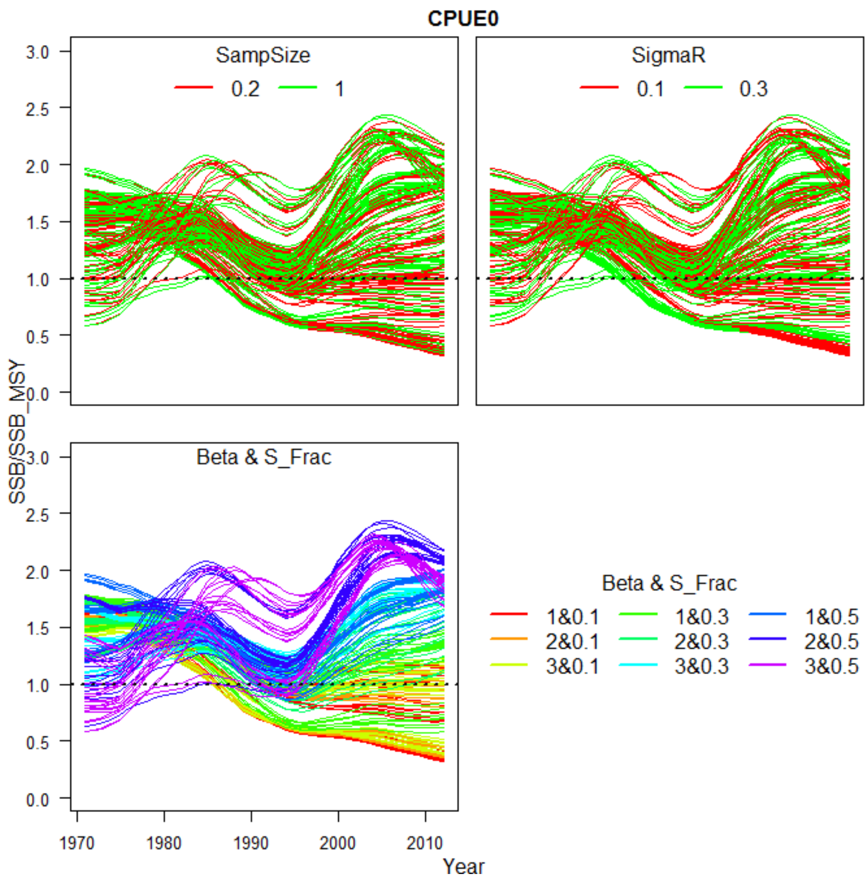

CPUE0
SampSize
0.2
1
SigmaR
0.1
0.3
Beta & S_Frac
1&0.1
2&0.1
3&0.1
1&0.3
2&0.3
3&0.3
1&0.5
2&0.5
3&0.5
SSB/SSB_MSY
Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010

Figure B5.

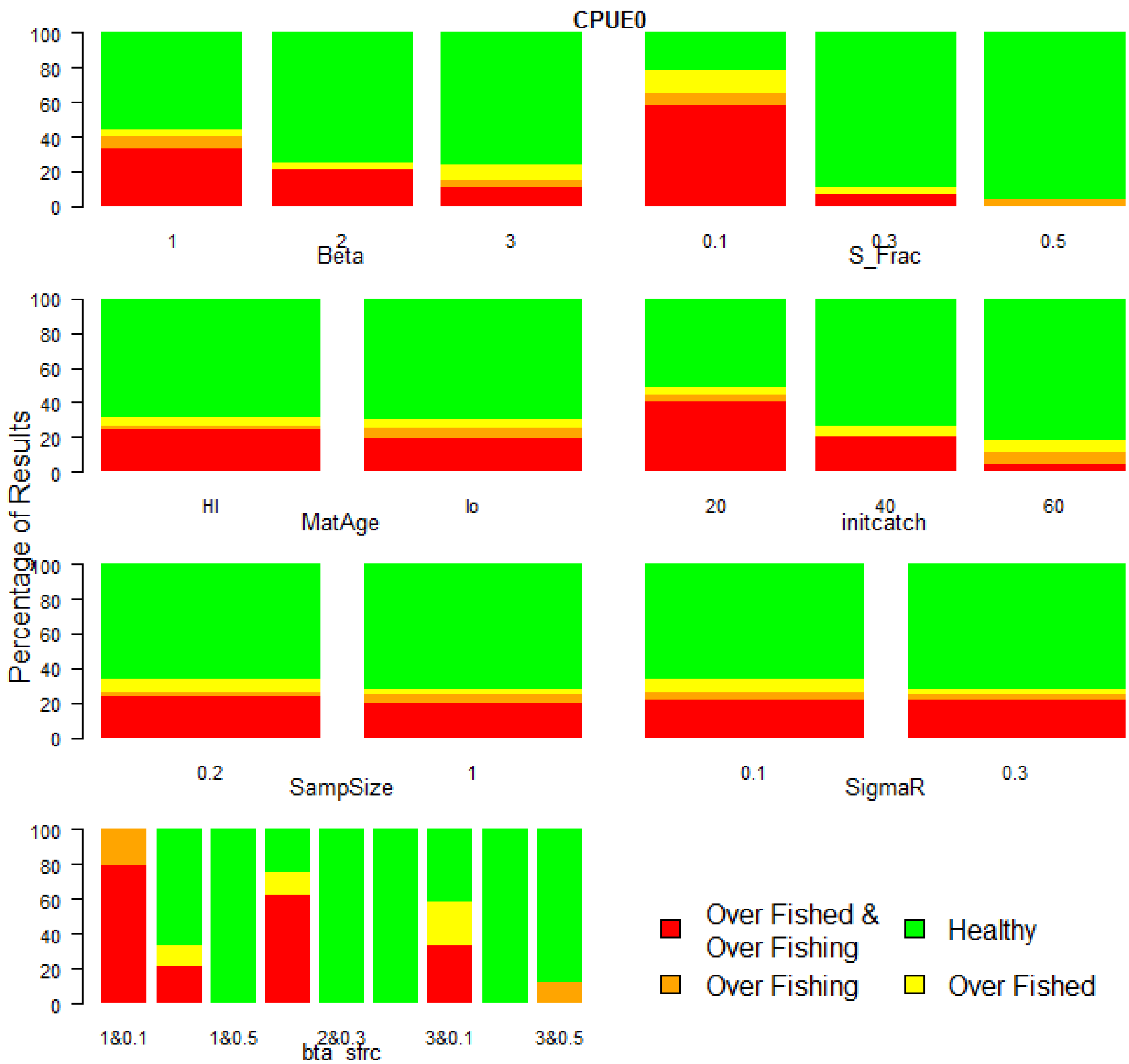
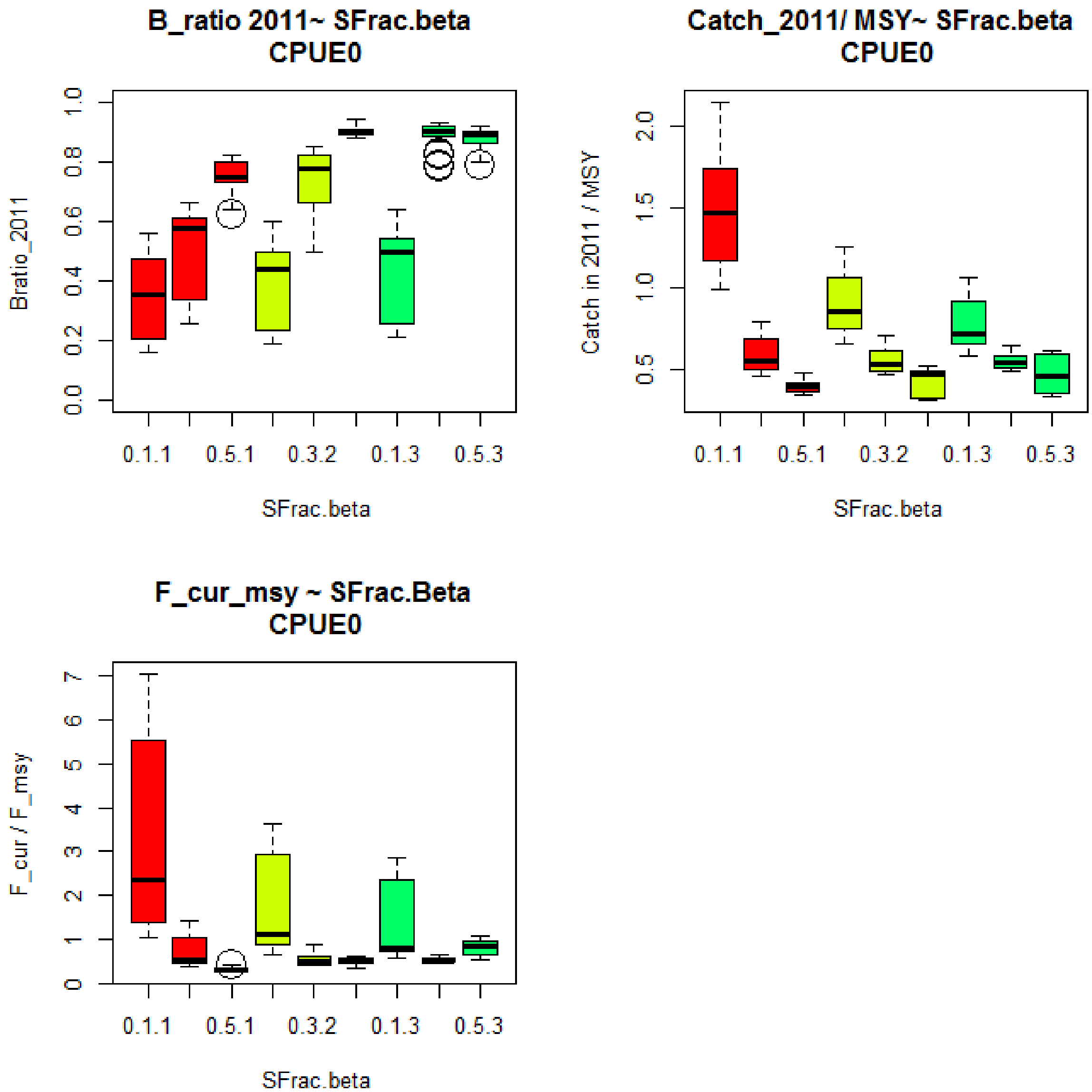

CPUE0
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure B6.


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

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

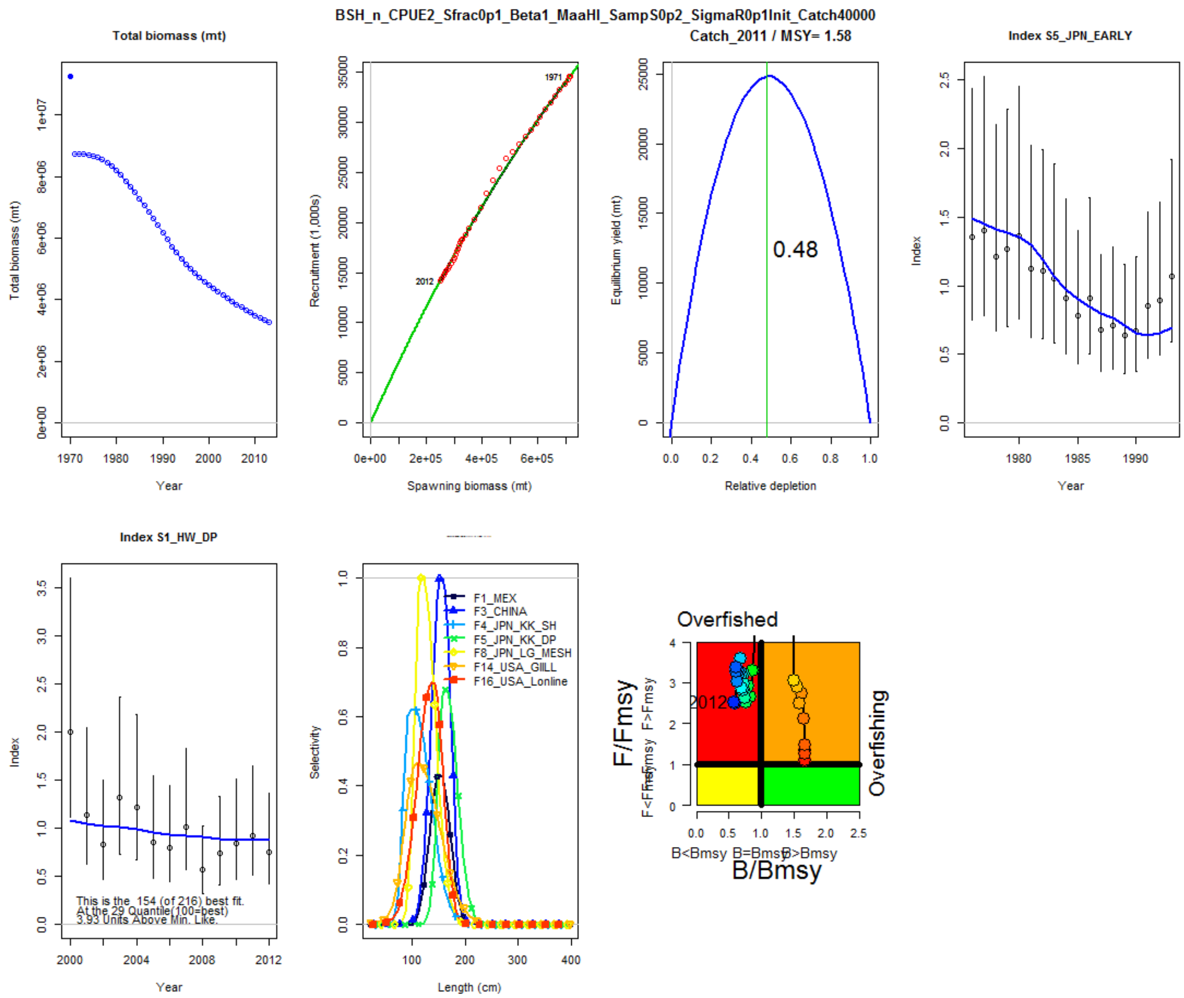


Figure C1.

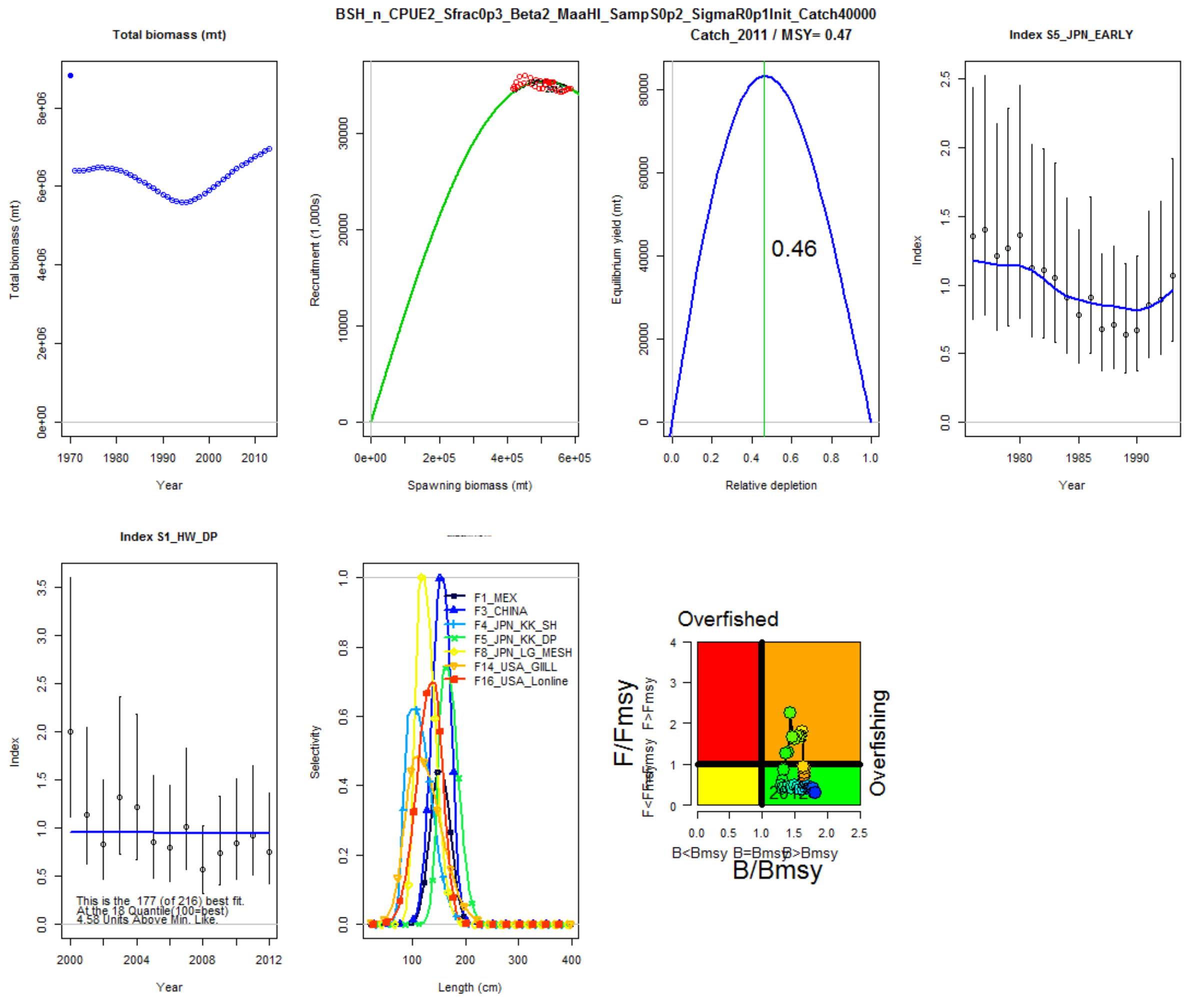

BSH_n_CPUE2_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Catch_2011 / MSY= 0.47
Equilibrium yield (mt)
Relative depletion
0.46
Index S5_JPN_EARLY
Index
Year
Index S1_HW_DP
Index
Year
This is the 177 (of 216) best fit.
At the 18 Quantile(100=best)
4.58 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
F>Fmsy
F<Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
2012

Figure C2.

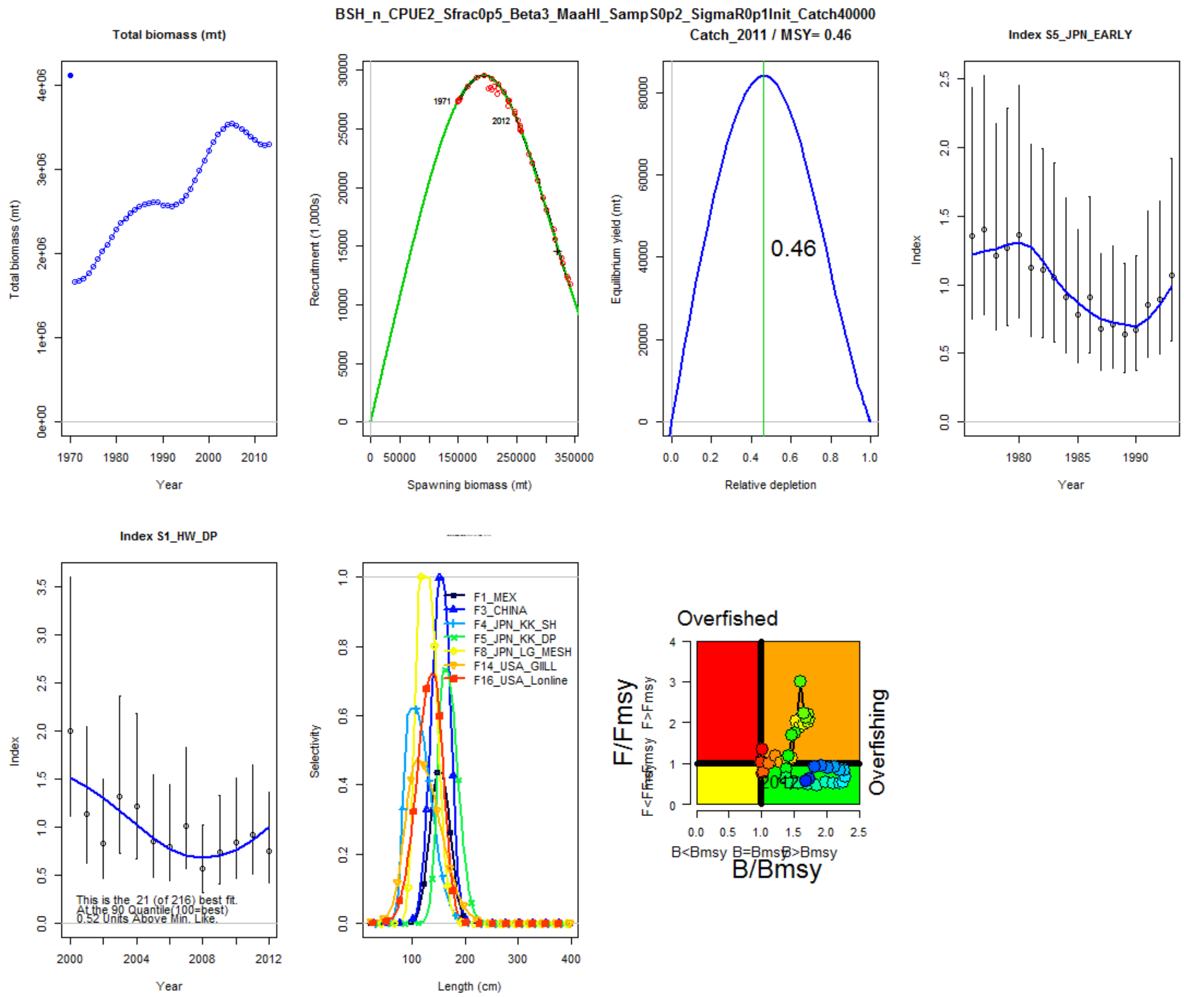
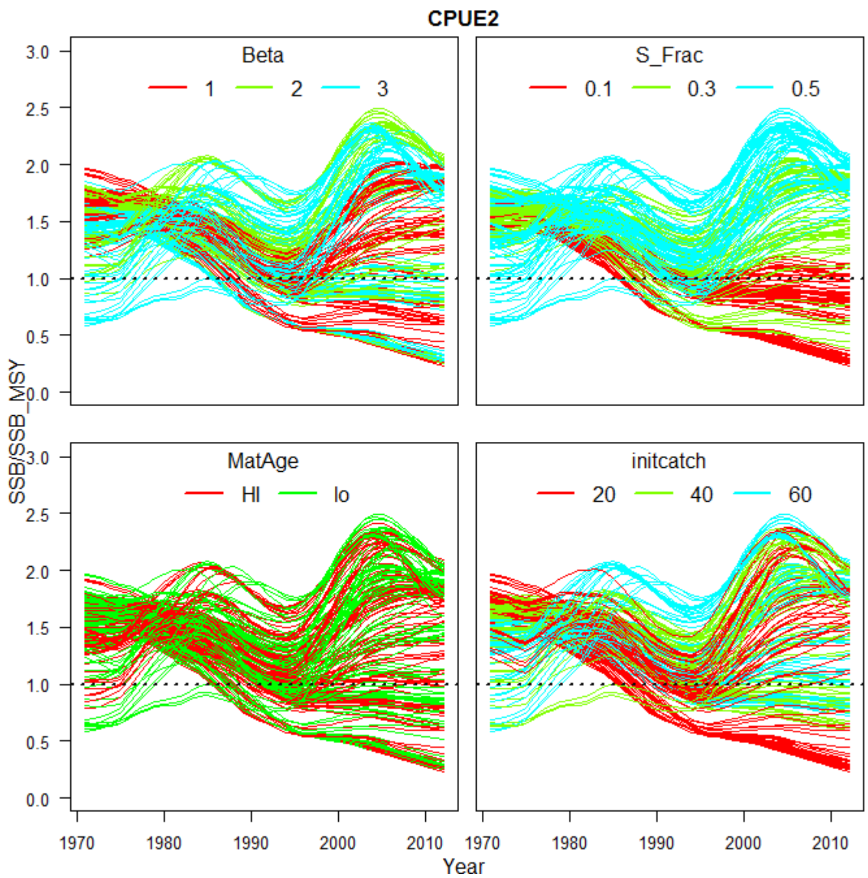
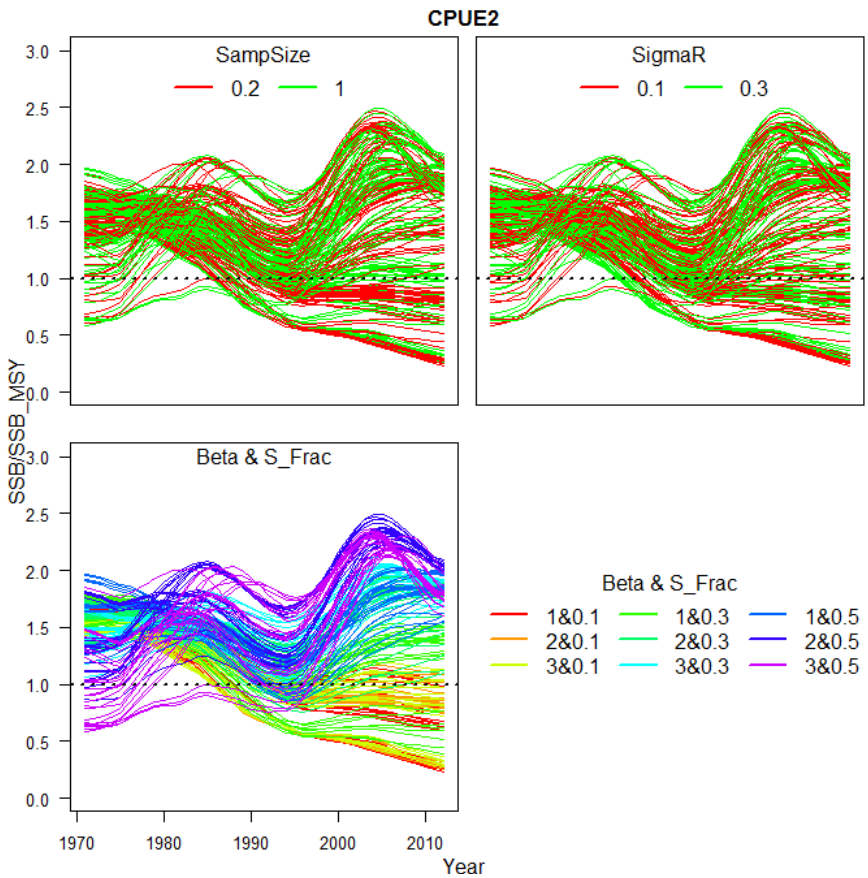

BSH_n_CPUE2_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
1971
2012
Catch_2011 / MSY= 0.46
Equilibrium yield (mt)
Relative depletion
0.46
Index S5_JPN_EARLY
Index
Year
Index S1_HW_DP
Index
Year
This is the 21 (of 216) best fit.
At the 90 Quantile(100=best)
0.52 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
F/Fmsy
F>Fmsy
Overfishing
B<Bmsy
B>Bmsy
B/Bmsy
2012

Figure C3.


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



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

Figure C4.

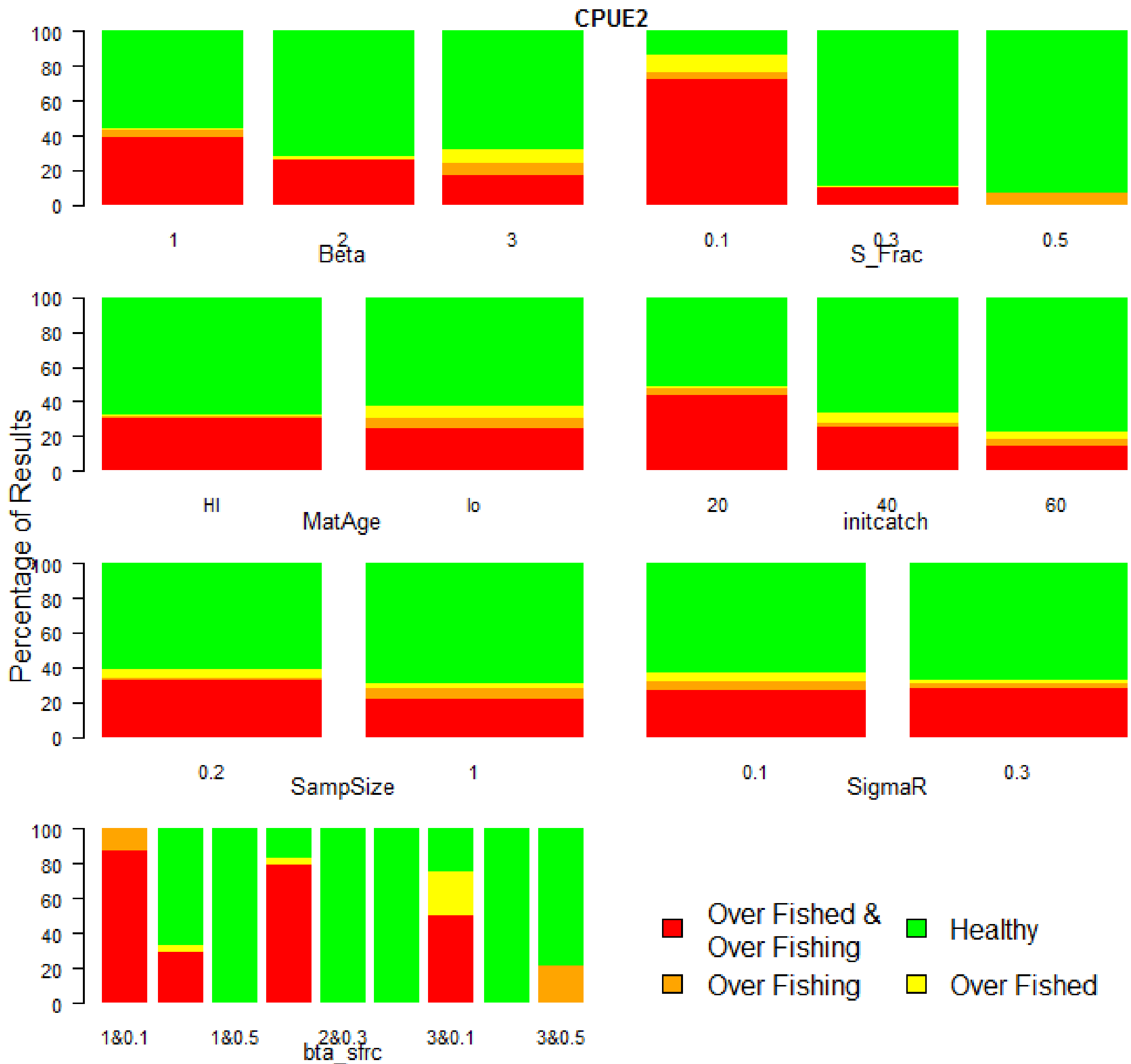

CPUE2
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished &
Over Fishing
Healthy
Over Fishing
Over Fished

Figure C5.

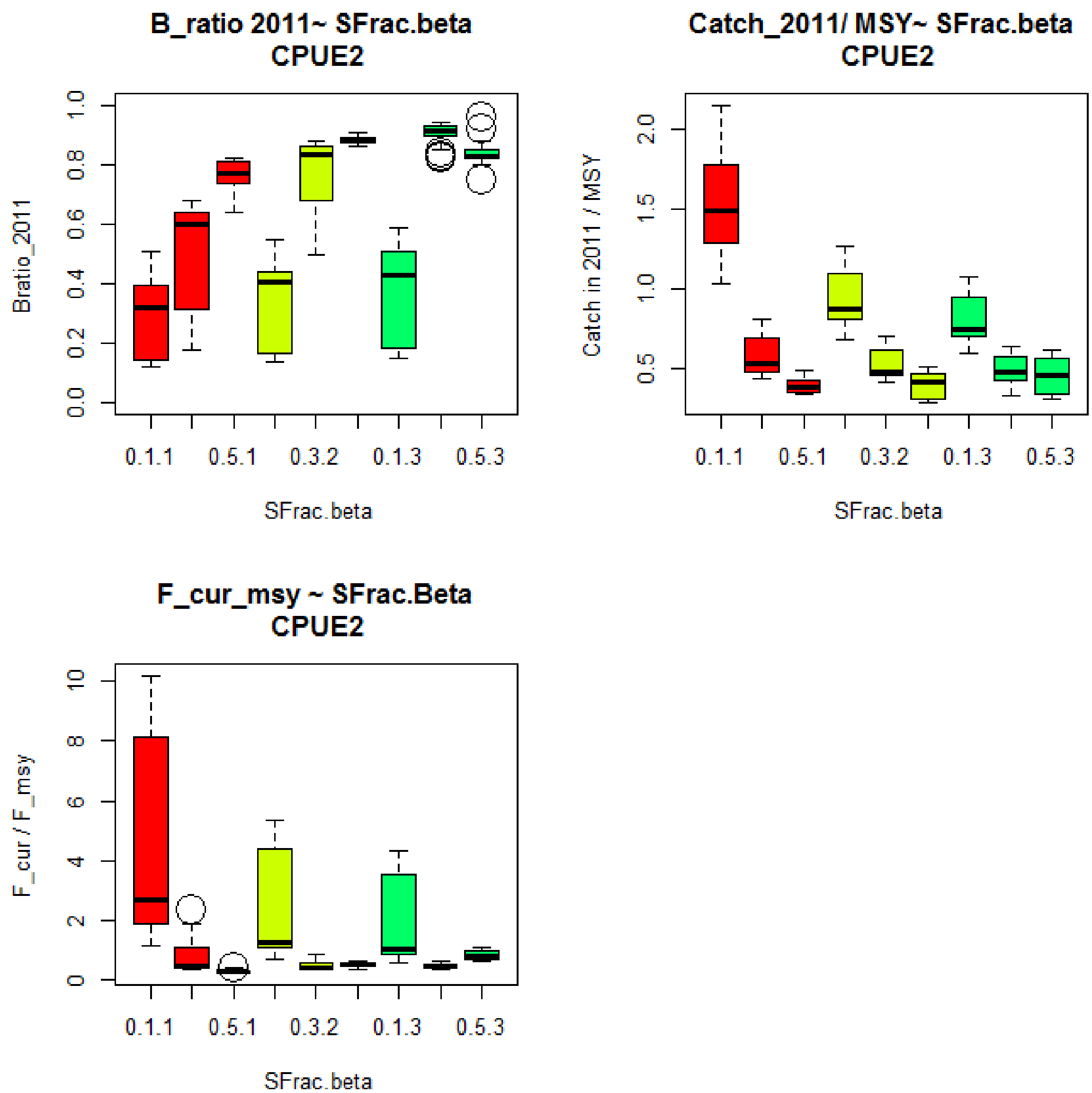

B_ratio 2011~ SFrac.beta
CPUE2
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE2
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE2
F_cur / F_msy
0
2
4
6
8
10
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3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

Figure C6.

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

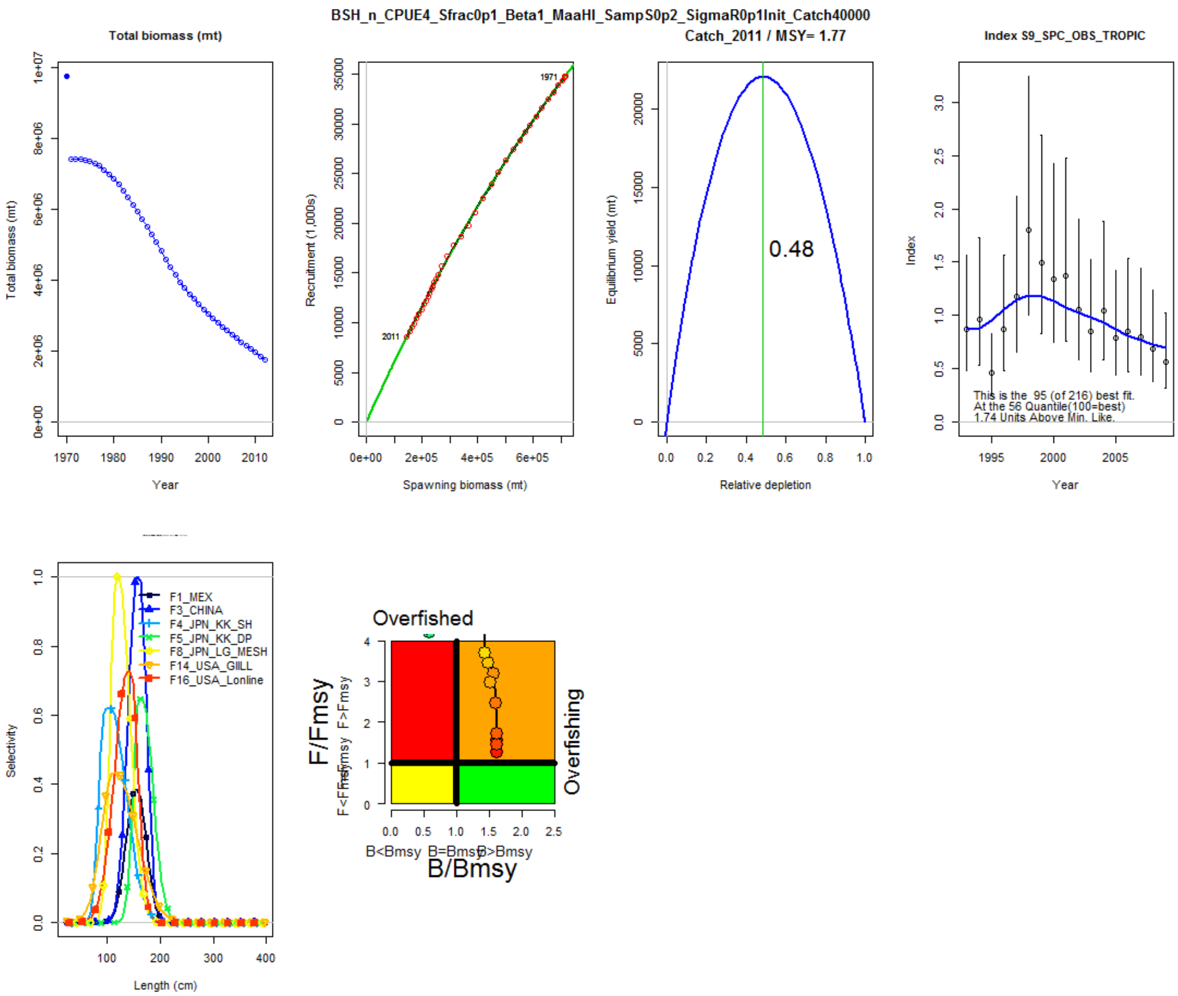


Figure D1.

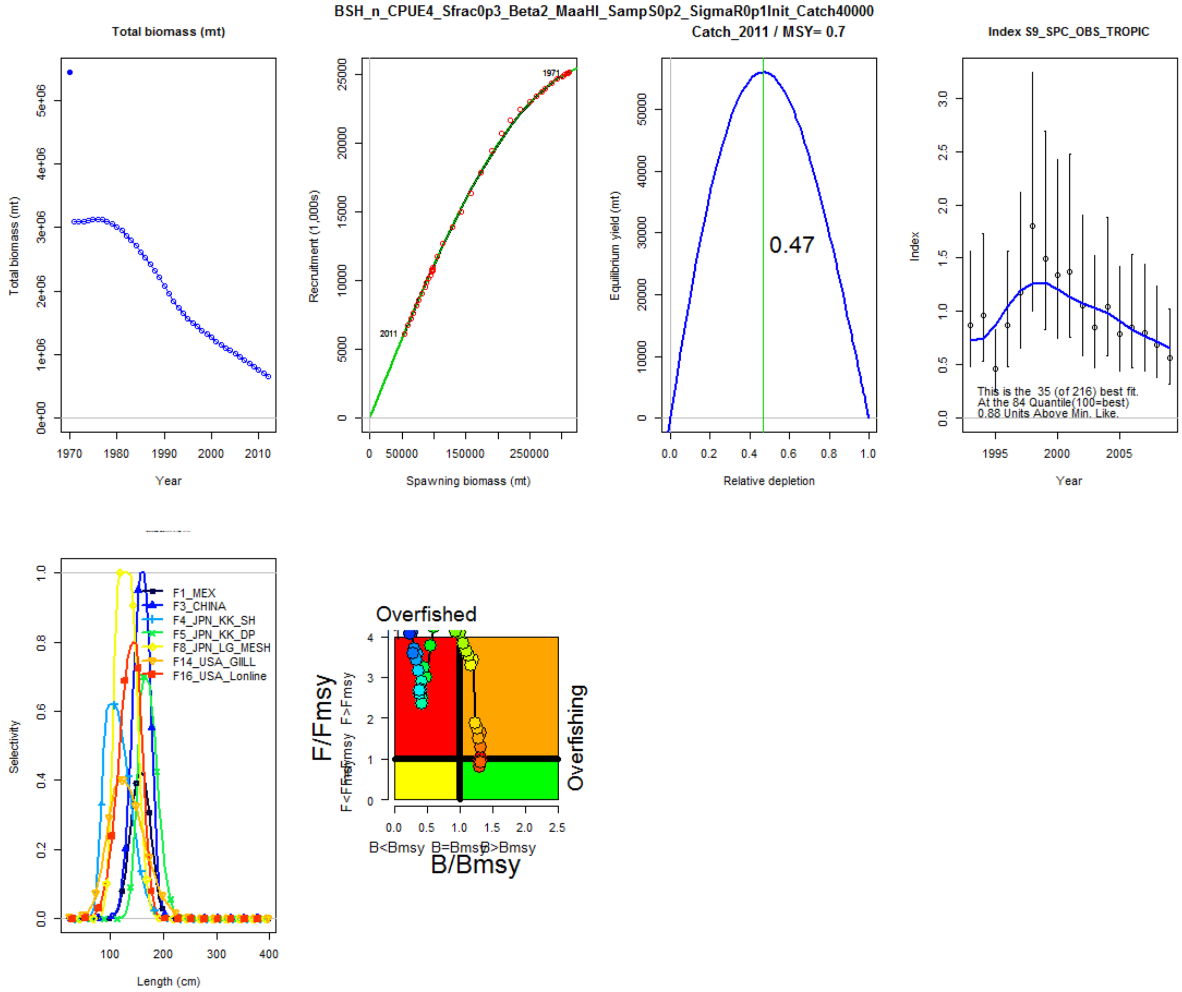
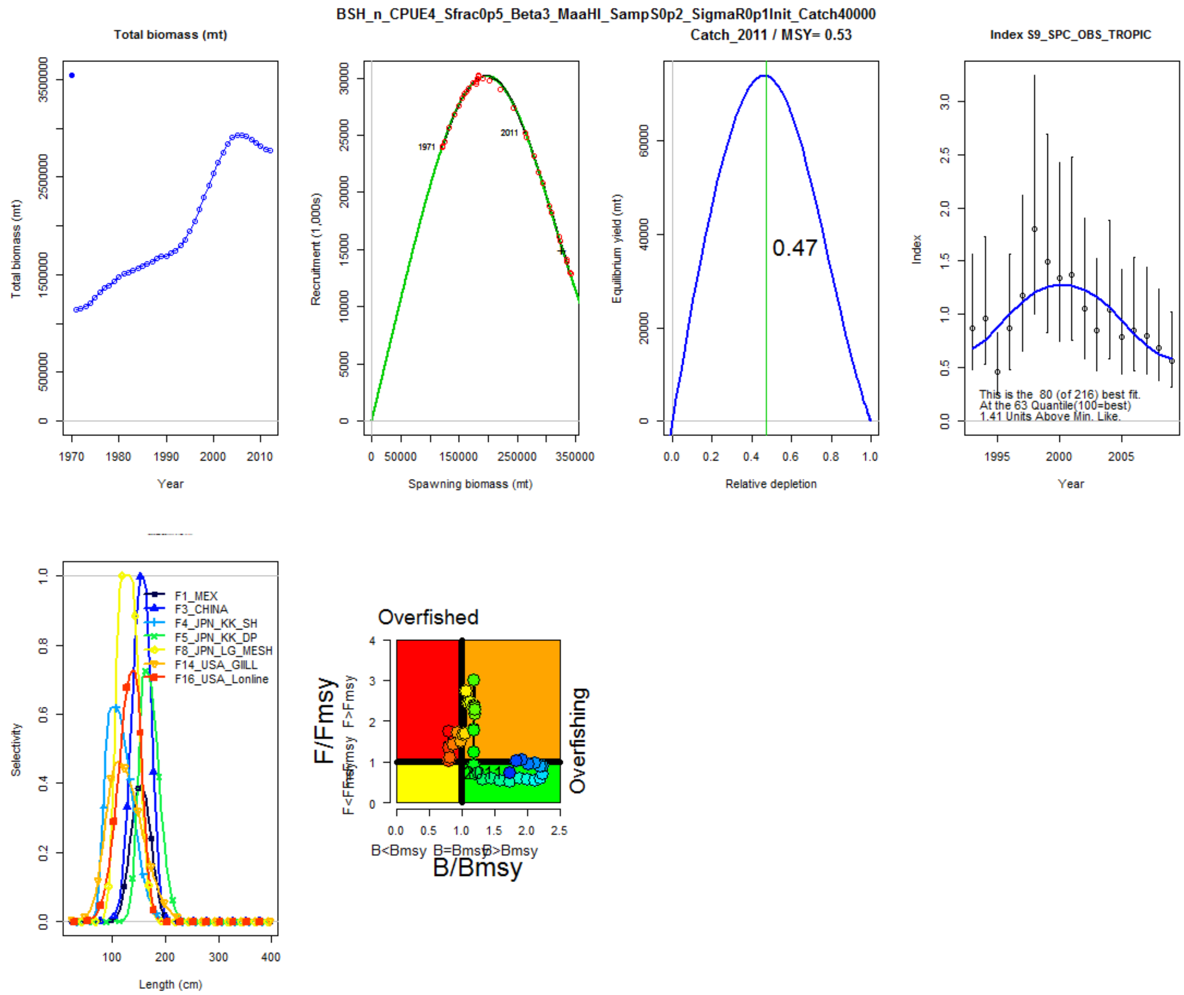
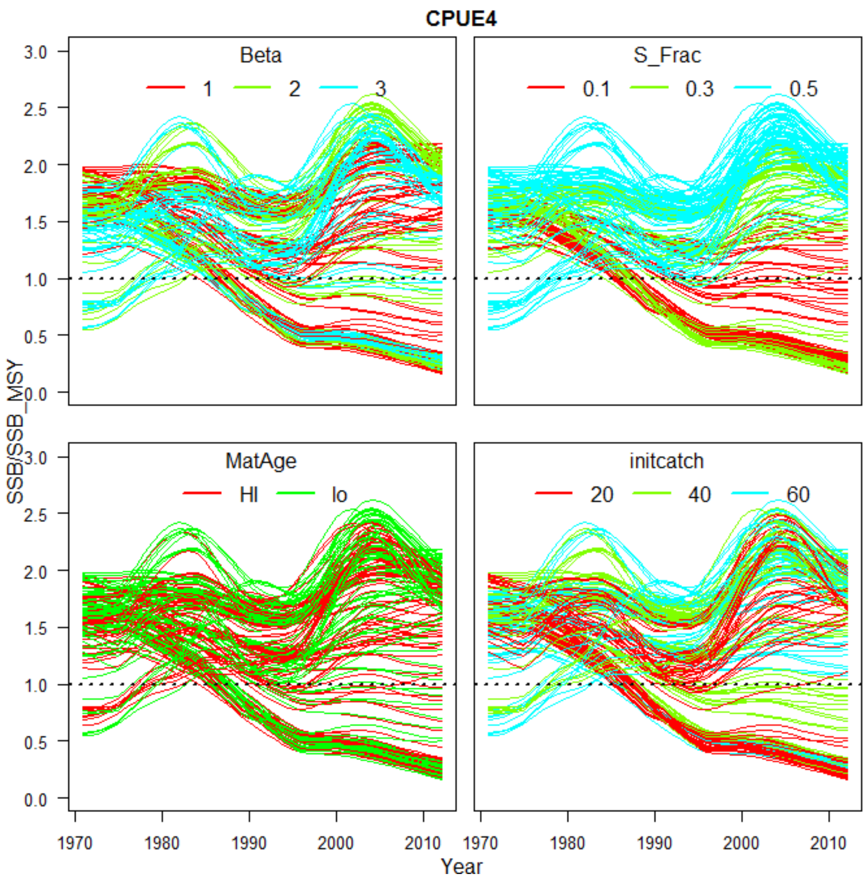

BSH_n_CPUE4_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Catch_2011 / MSY= 0.7
Total biomass (mt)
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
1971
2011
Equilibrium yield (mt)
Relative depletion
0.47
Index S9_SPC_OBS_TROPIC
Index
Year
This is the 35 (of 216) best fit.
At the 84 Quantile(100=best)
0.88 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy B=Bmsy B>Bmsy

Figure D2.

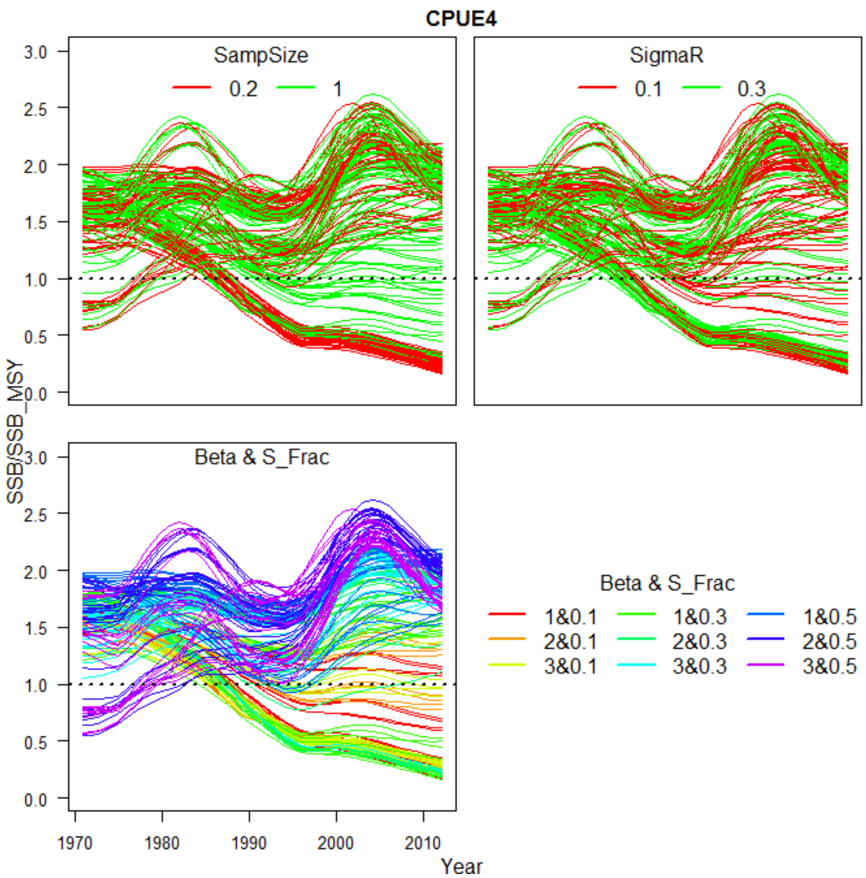


BSH_n_CPUE4_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.53
Index S9_SPC_OBS_TROPIC
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
1971
2011
Equilibrium yield (mt)
Relative depletion
0.47
Index
This is the 80 (of 216) best fit.
At the 63 Quantile(100=best)
1.41 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
F>Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
2011

Figure D3.



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



CPUE4
SampSize
0.2
1
SigmaR
0.1
0.3
Beta & S_Frac
SSB/SSB_MSY
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Year
Beta & S_Frac
1&0.1
2&0.1
3&0.1
1&0.3
2&0.3
3&0.3
1&0.5
2&0.5
3&0.5

Figure D4.

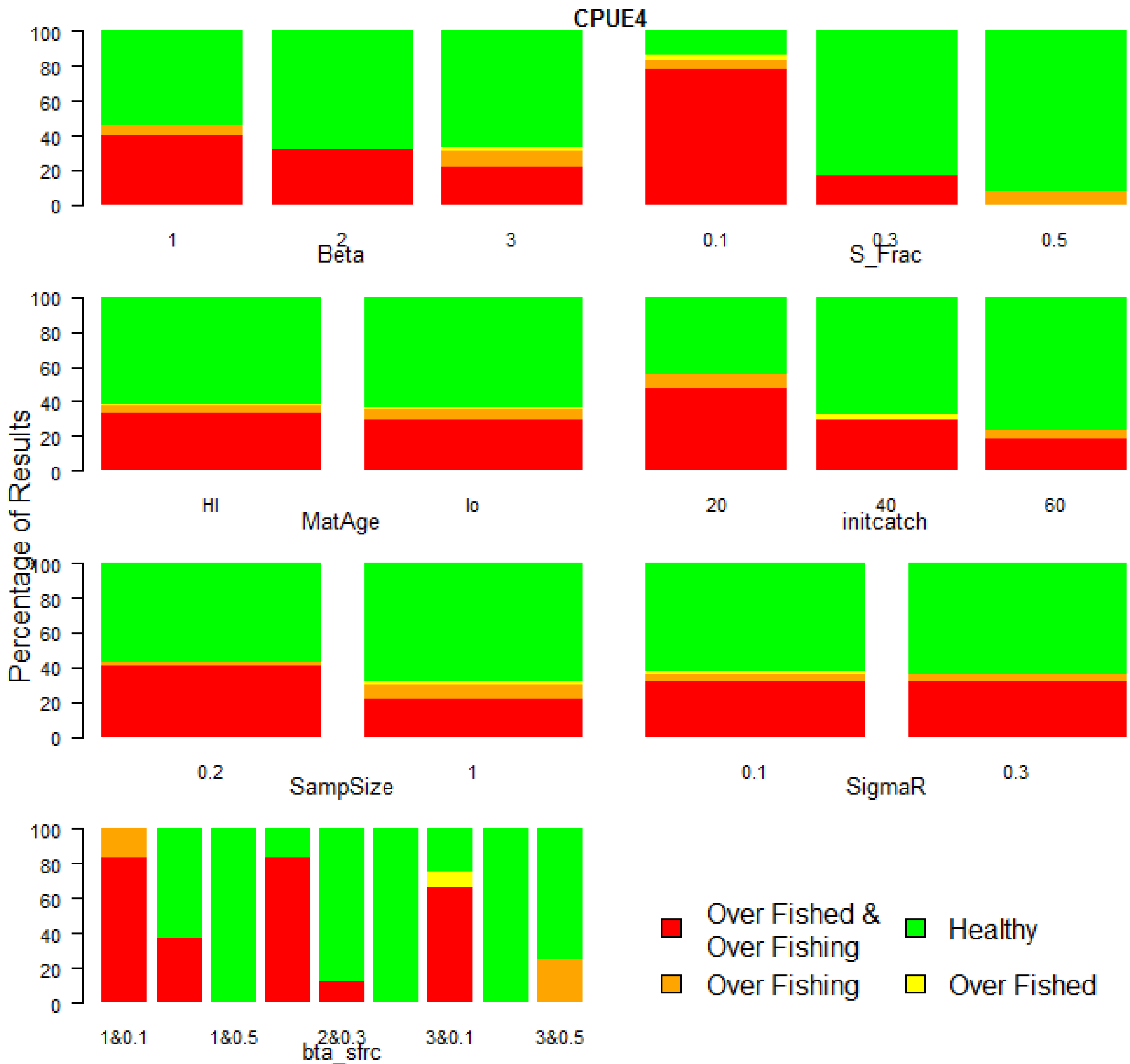

CPUE4
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Percentage of Results
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure D5.

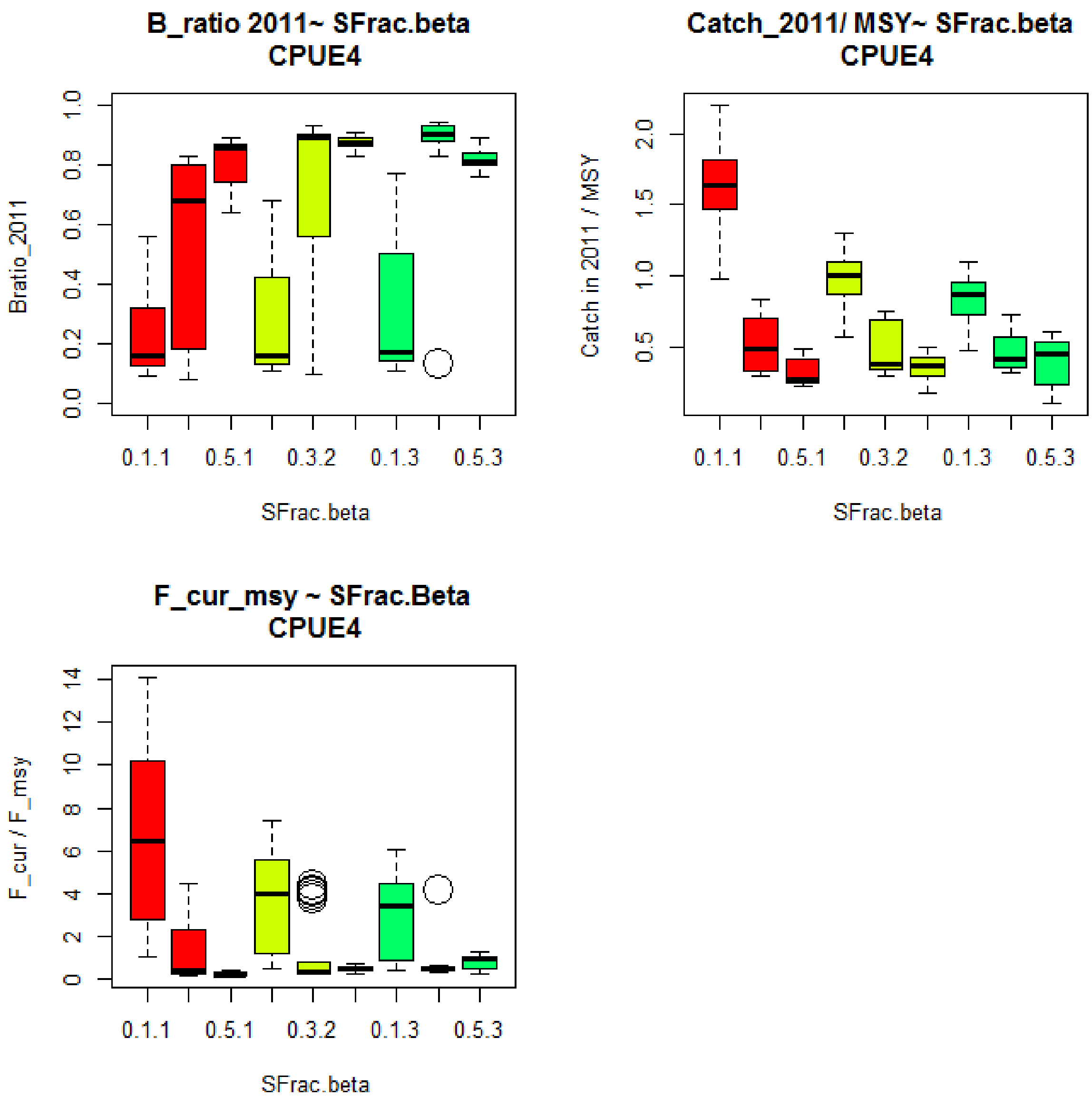

B_ratio 2011~ SFrac.beta
CPUE4
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE4
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE4
F_cur / F_msy
0
2
4
6
8
10
12
14
0.1.1
0.5.1
0.3.2
0.1.3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

Figure D6.

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

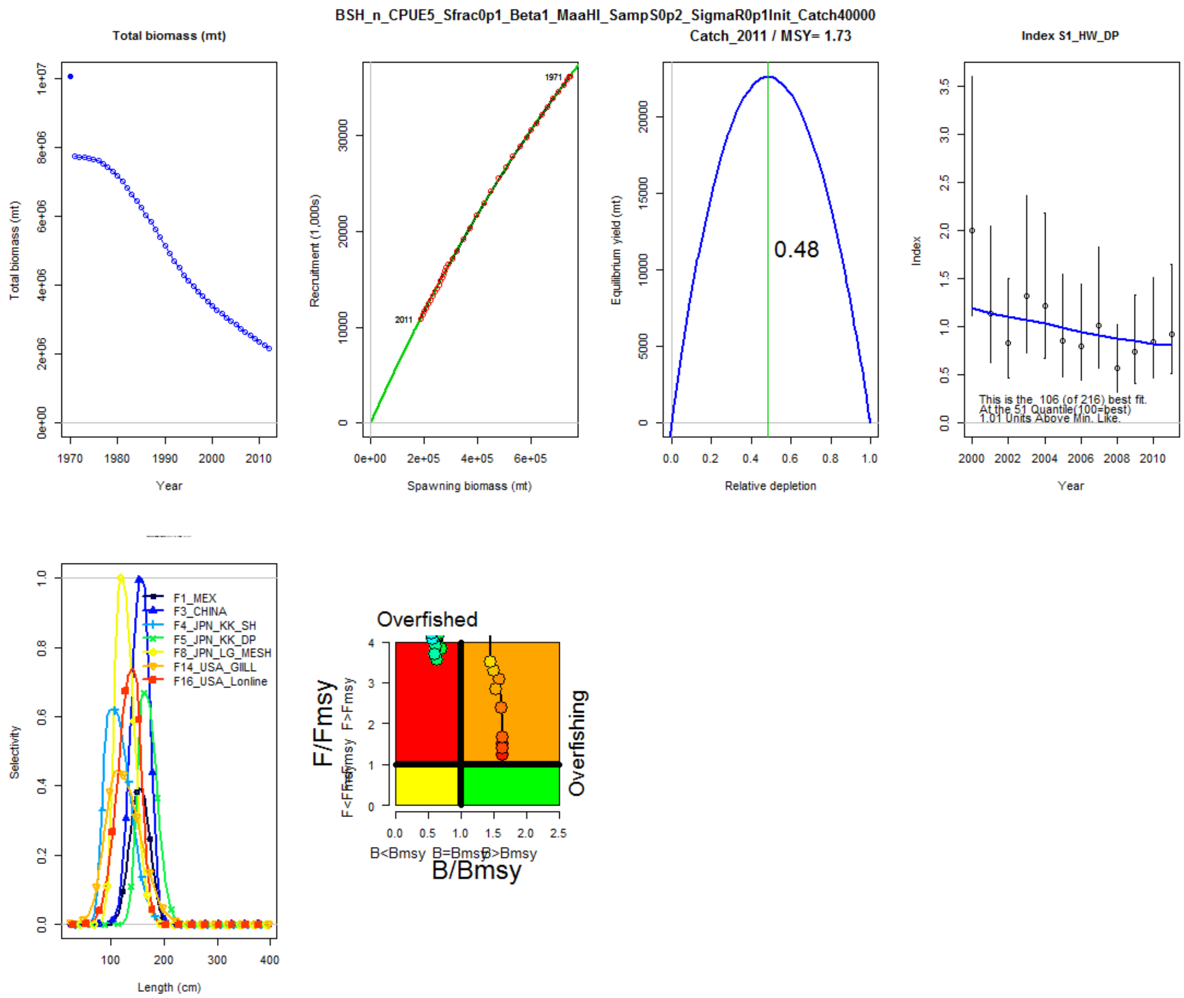
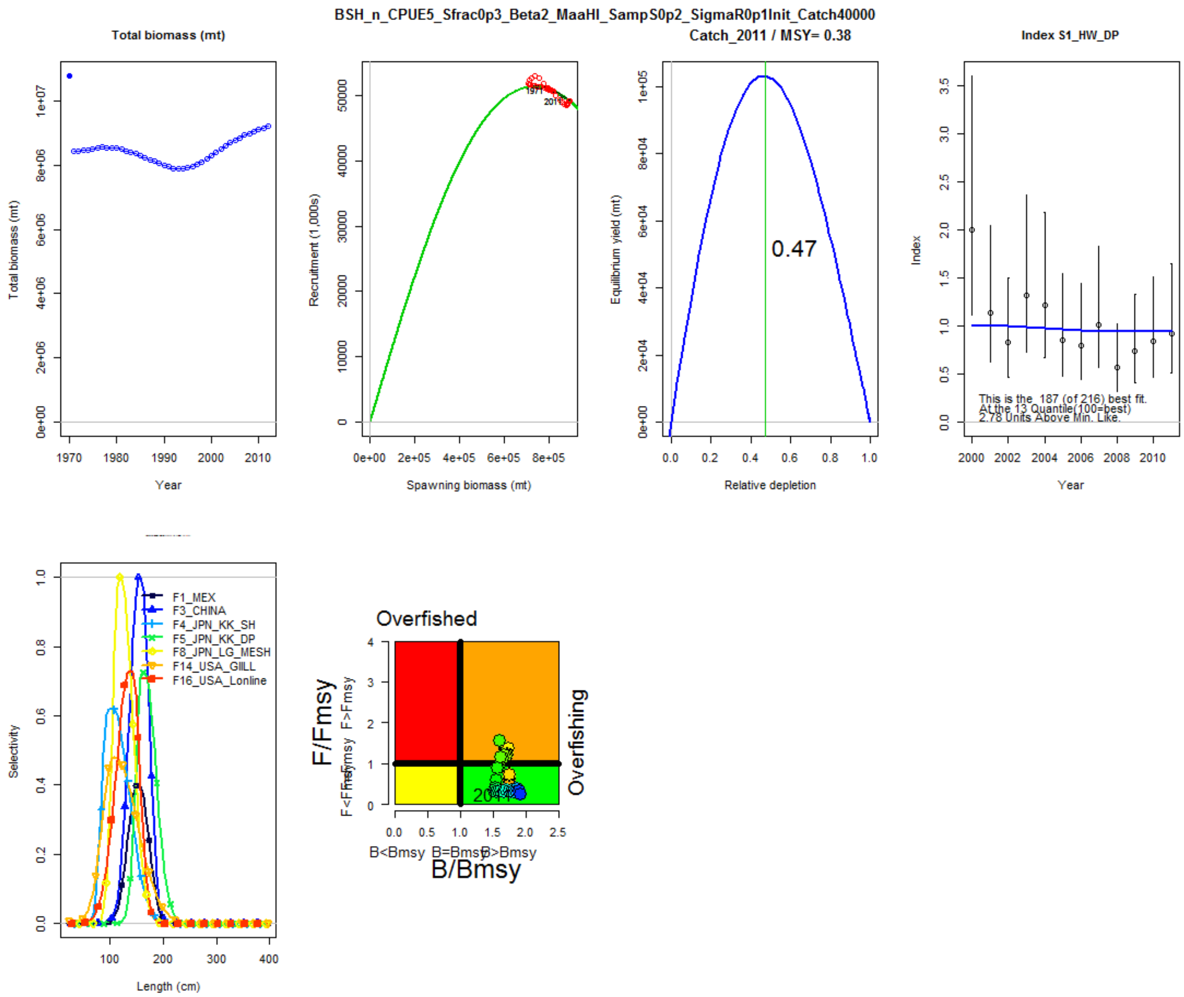


Figure E1.



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

Figure E2.

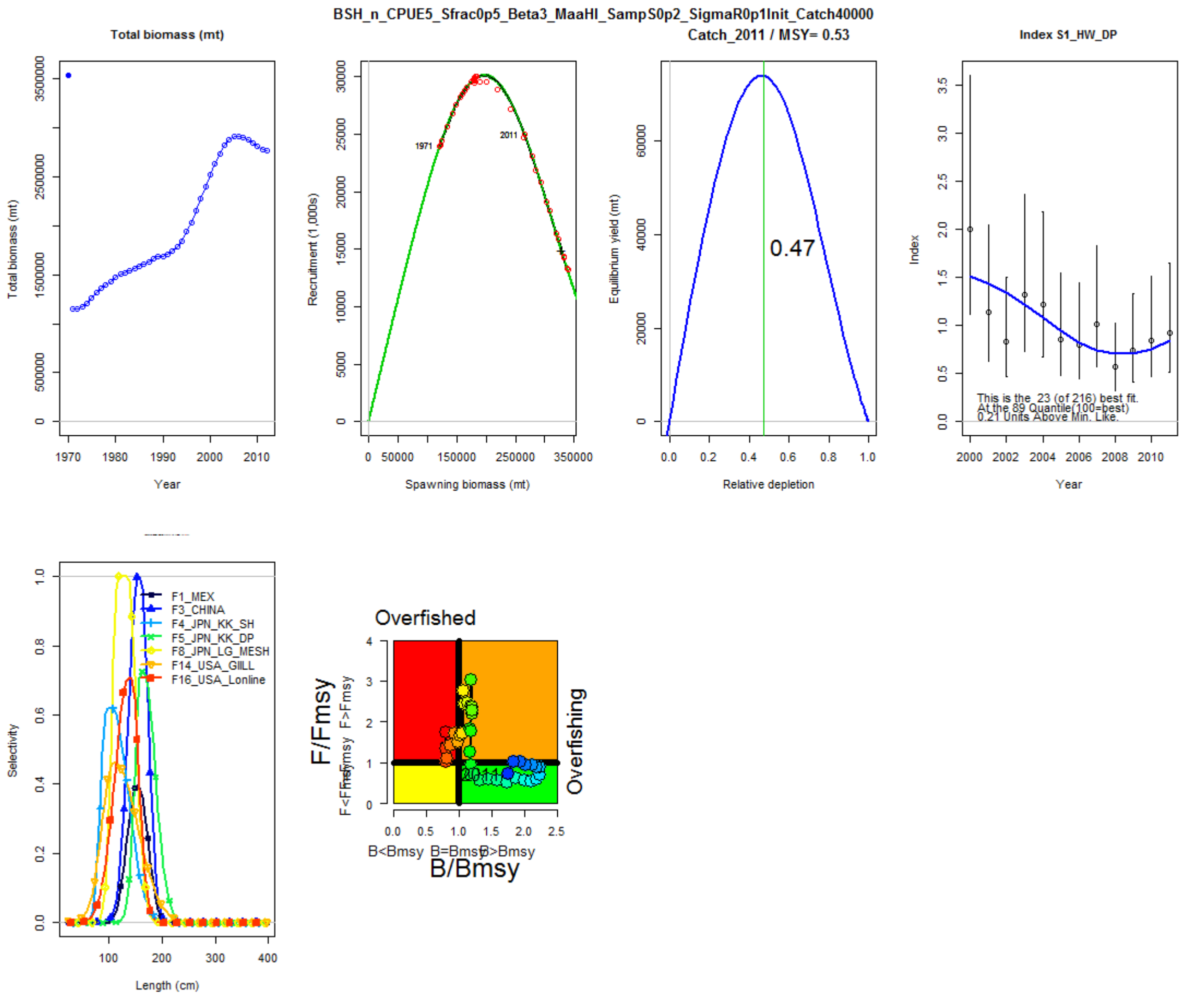
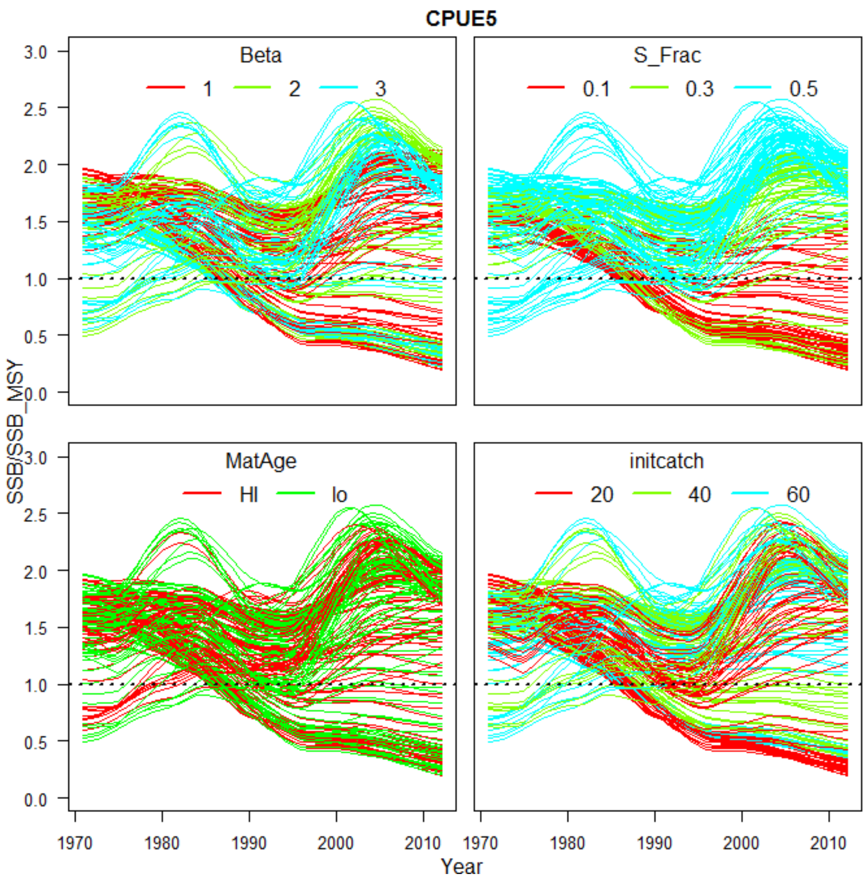

BSH_n_CPUE5_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Total biomass (mt)
Catch_2011 / MSY= 0.53
Index S1_HW_DP
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
1971
2011
Equilibrium yield (mt)
Relative depletion
0.47
Index
Year
This is the 23 (of 216) best fit.
At the 89 Quantile(100=best)
0.21 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
F>Fmsy
F<Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy
2011

Figure E3.


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

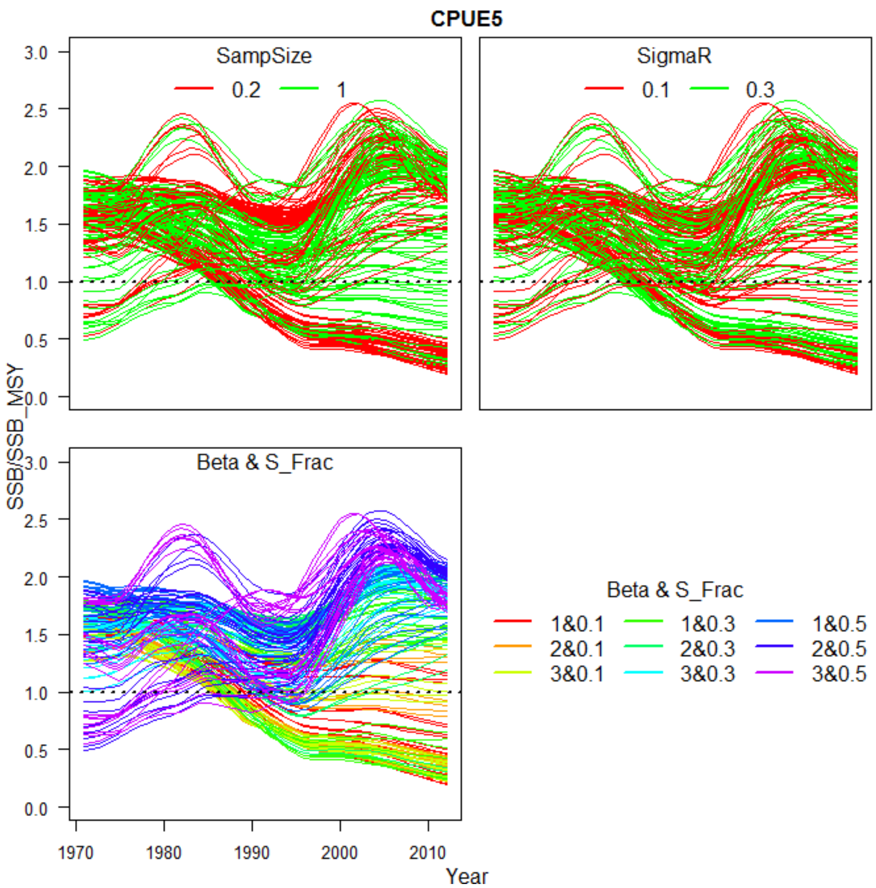

CPUE5
SampSize
0.2
1
SigmaR
0.1
0.3
Beta & S_Frac
1&0.1
2&0.1
3&0.1
1&0.3
2&0.3
3&0.3
1&0.5
2&0.5
3&0.5
SSB/SSB_MSY
Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010

Figure E4.

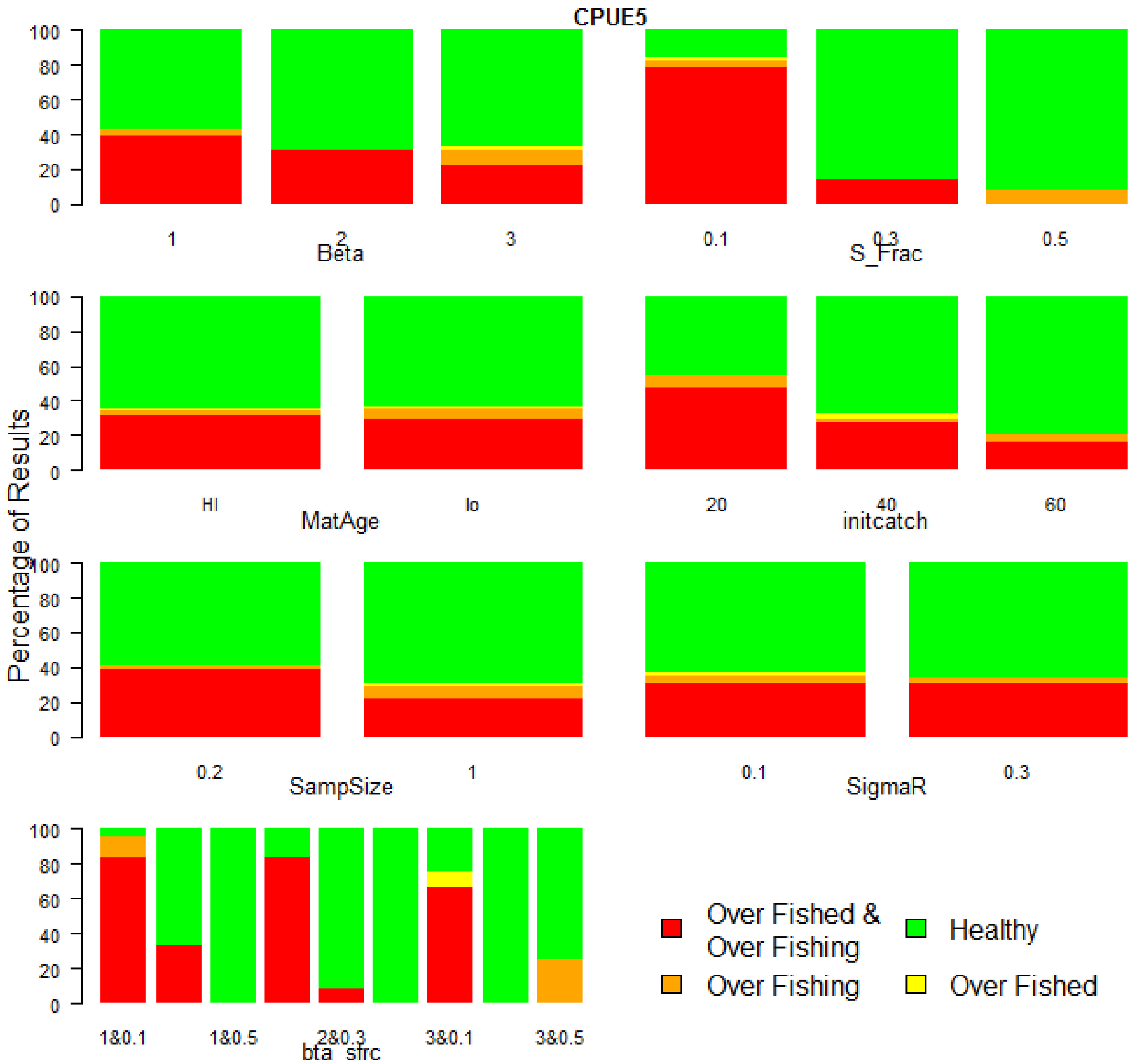

CPUE5
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished &
Over Fishing
Healthy
Over Fishing
Over Fished

Figure E5.

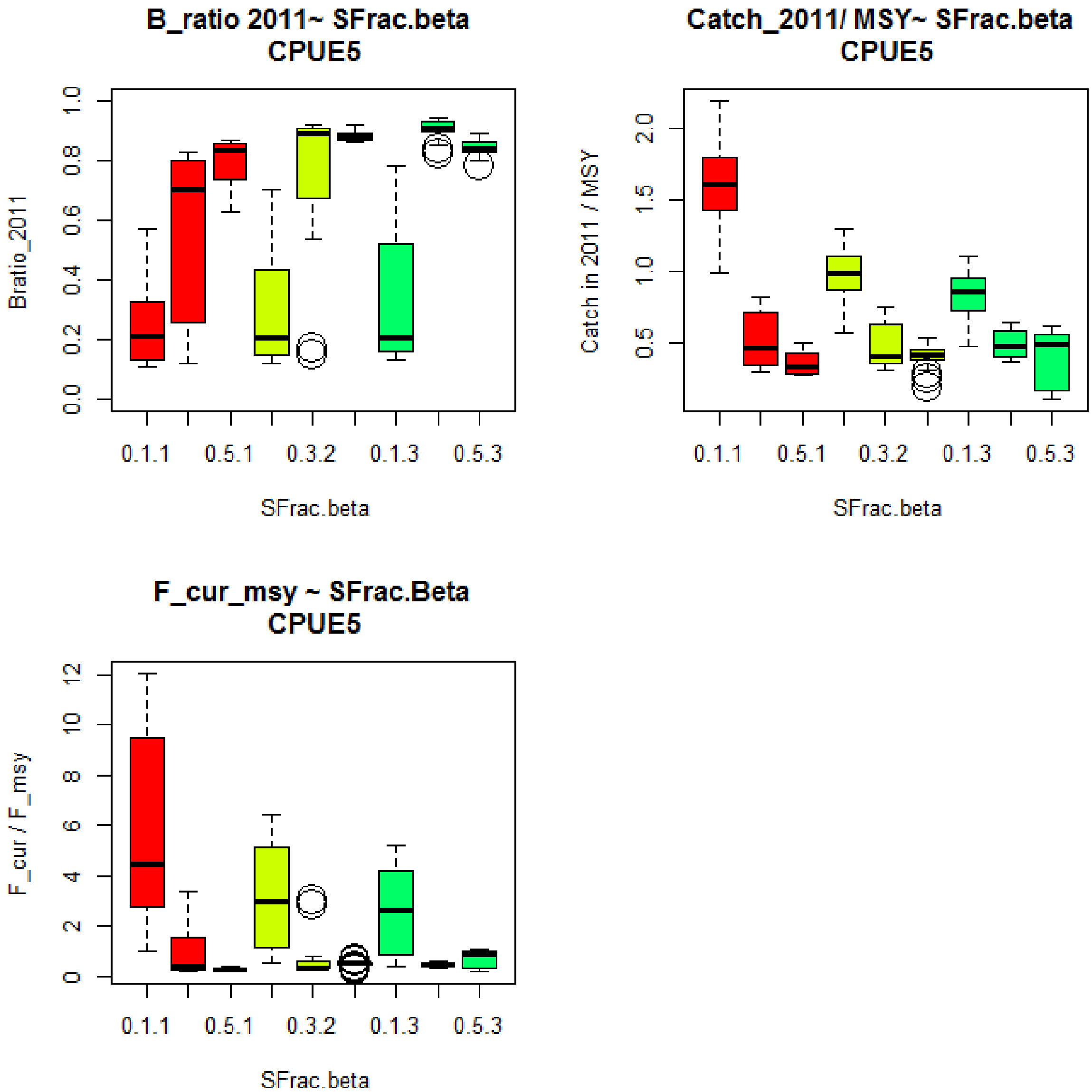

B_ratio 2011~ SFrac.beta
CPUE5
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE5
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE5
F_cur / F_msy
0
2
4
6
8
10
12
0.1.1
0.5.1
0.3.2
0.1.3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

Figure E6.

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

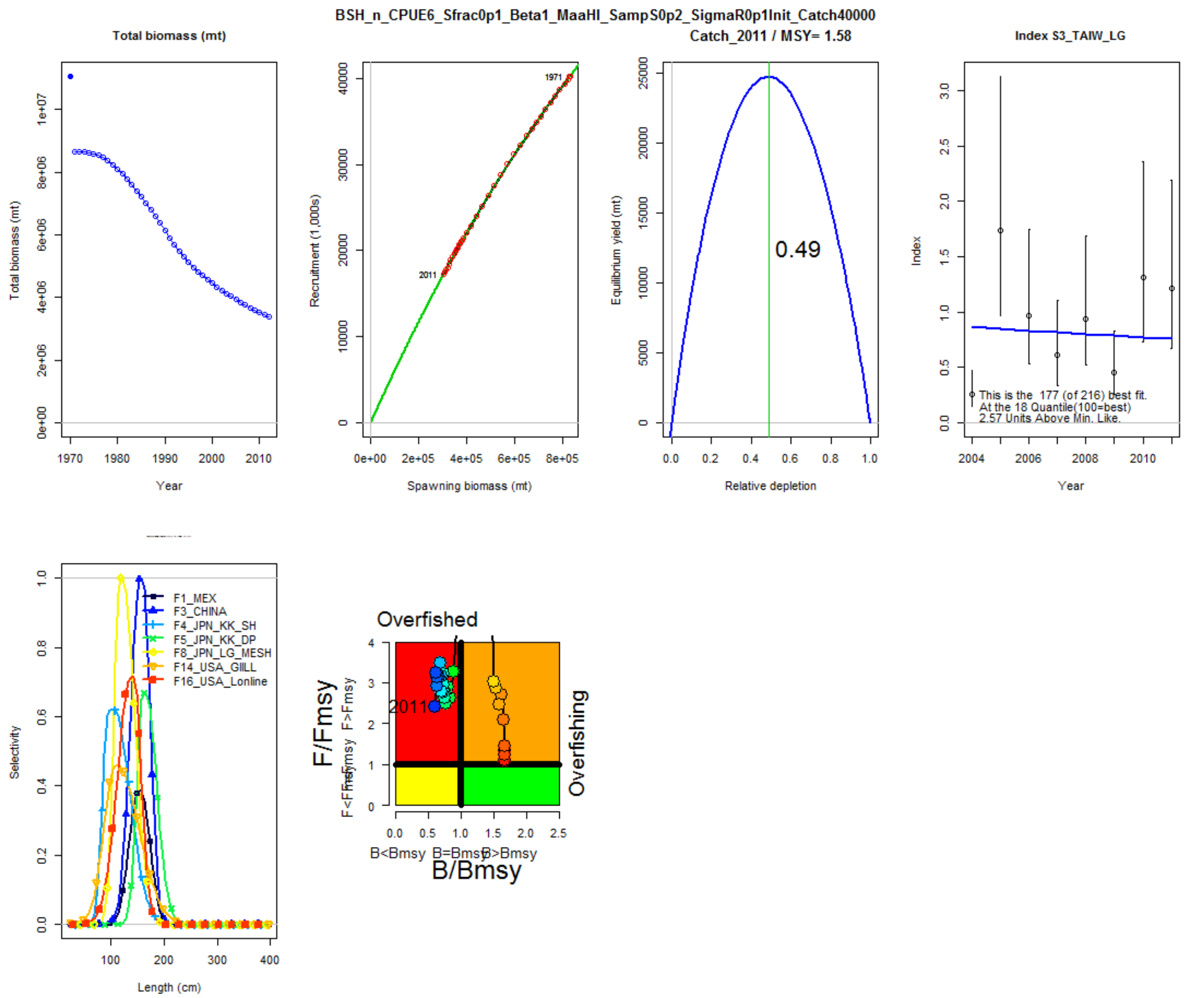


Figure F1.

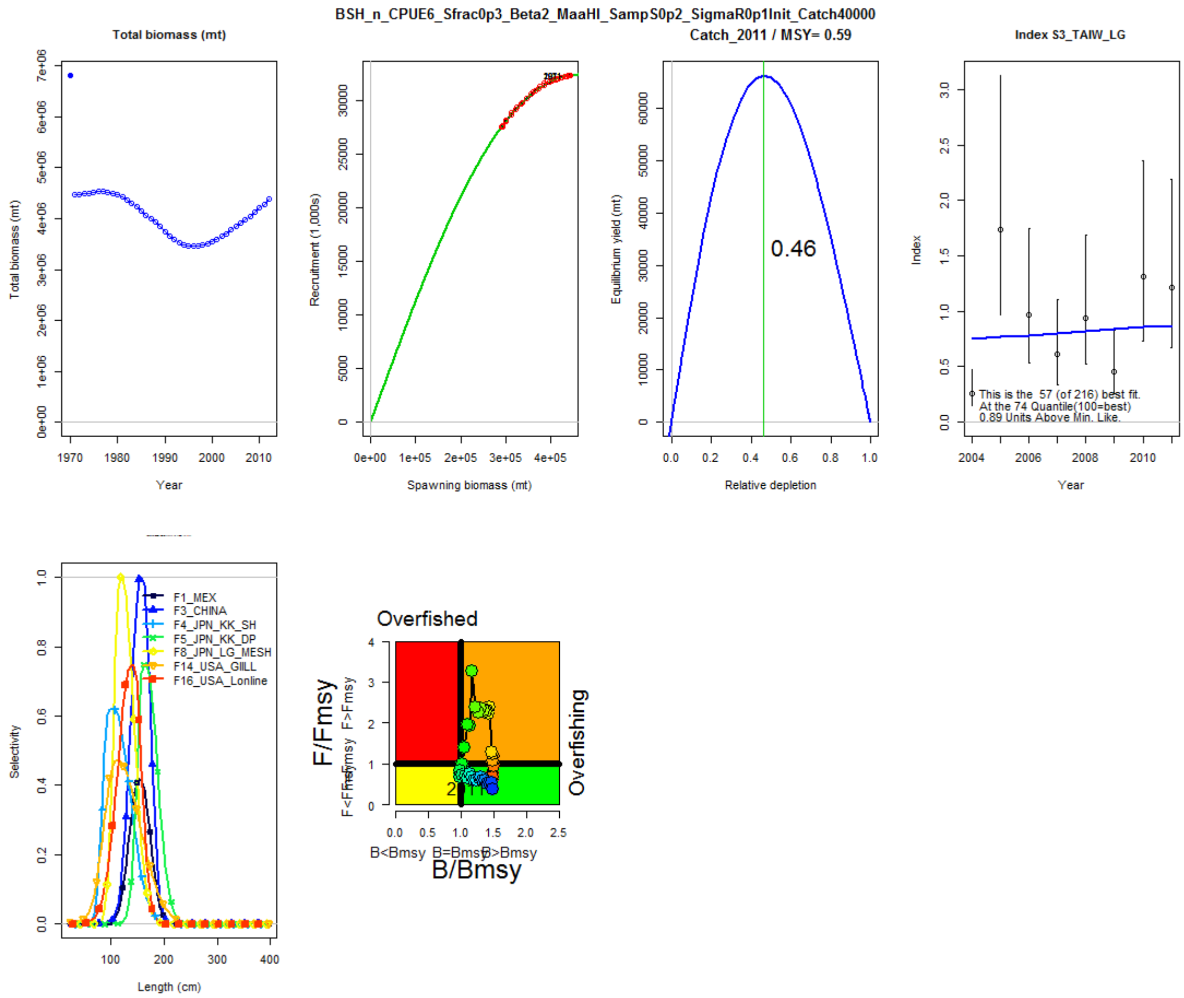

BSH_n_CPUE6_Sfrac0p3_Beta2_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Catch_2011 / MSY= 0.59
Total biomass (mt)
Index S3_TAIW_LG
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.46
Index
Year
This is the 57 (of 216) best fit.
At the 74 Quantile(100=best)
0.89 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy
B=Bmsy
B>Bmsy

Figure F2.

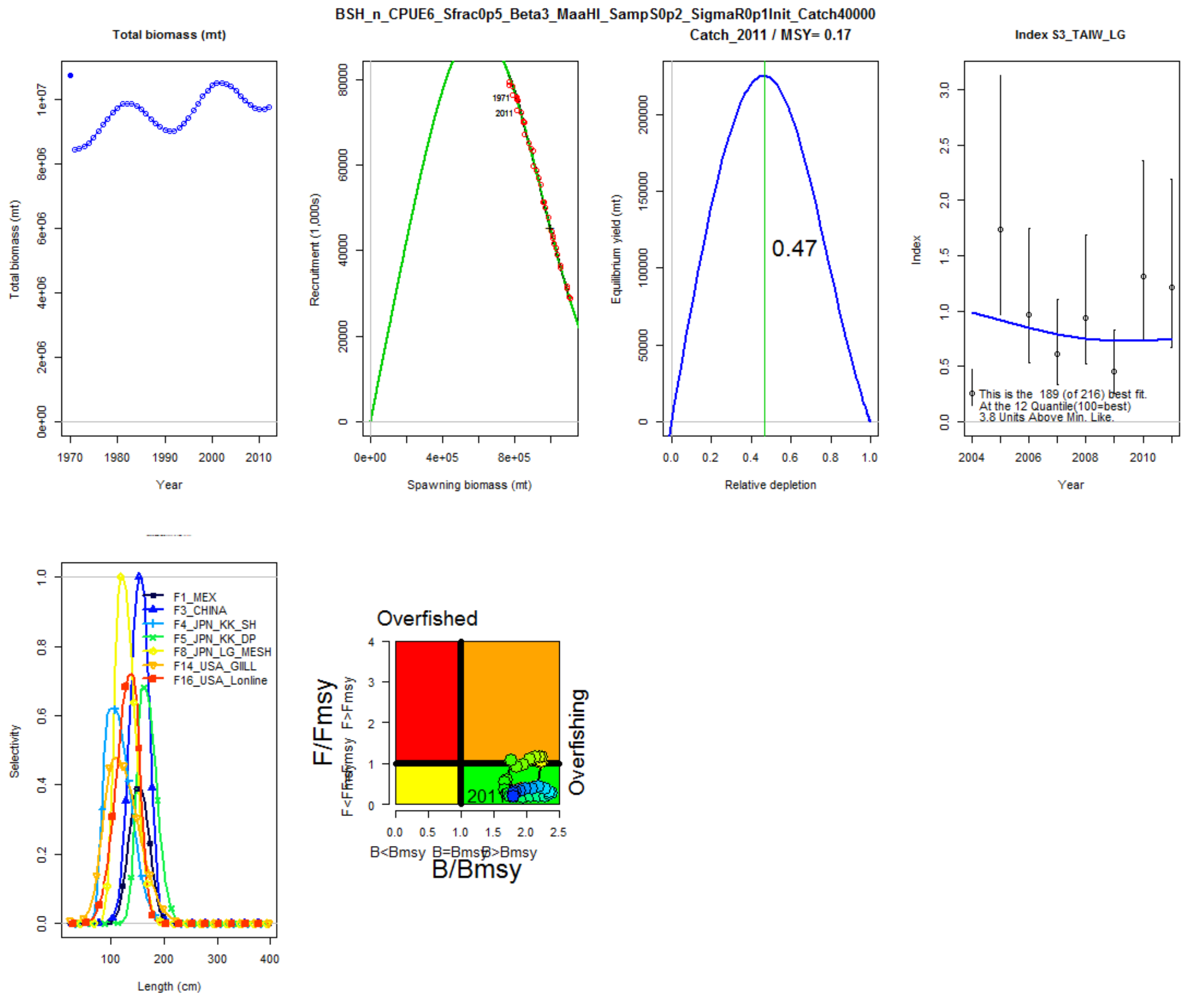
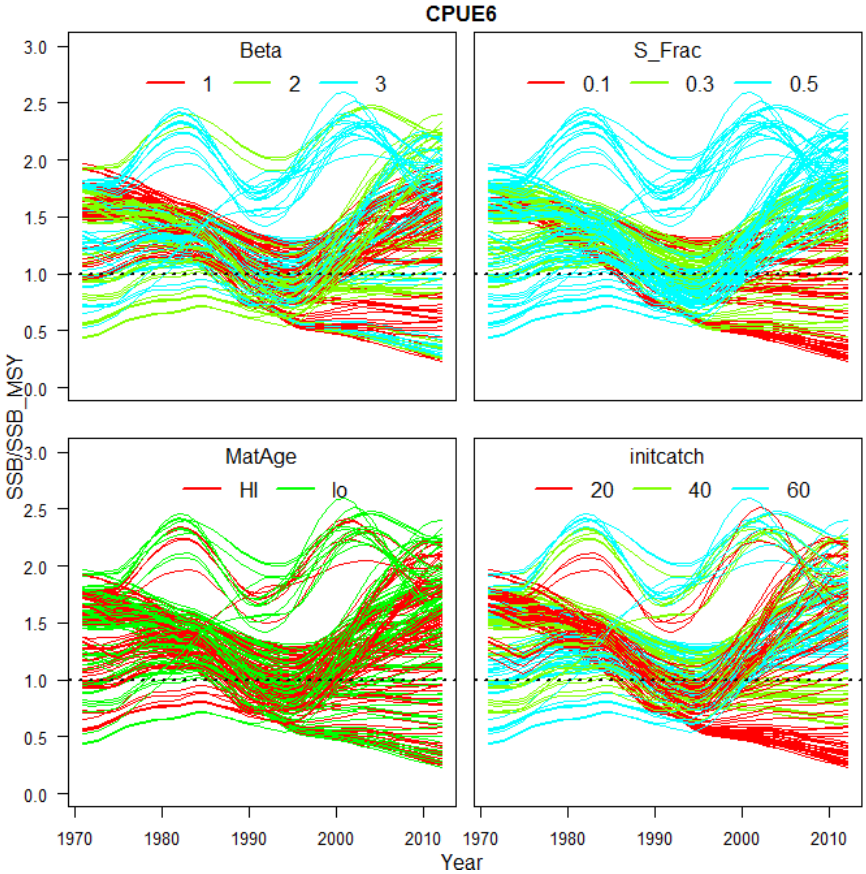
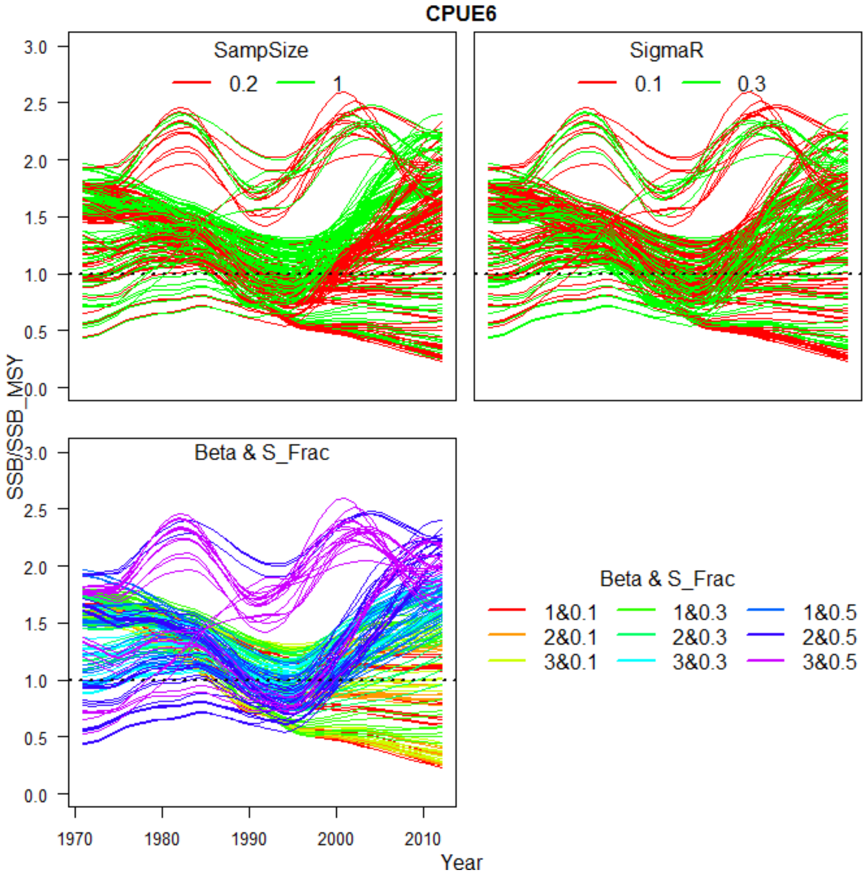

BSH_n_CPUE6_Sfrac0p5_Beta3_MaaHI_SampS0p2_SigmaR0p1Init_Catch40000
Catch_2011 / MSY= 0.17
Total biomass (mt)
Year
Recruitment (1,000s)
Spawning biomass (mt)
Equilibrium yield (mt)
Relative depletion
0.47
Index S3_TAIW_LG
Index
This is the 189 (of 216) best fit.
At the 12 Quantile(100=best)
3.8 Units Above Min. Like.
Selectivity
Length (cm)
F1_MEX
F3_CHINA
F4_JPN_KK_SH
F5_JPN_KK_DP
F8_JPN_LG_MESH
F14_USA_GILL
F16_USA_Lonline
Overfished
Overfishing
F/Fmsy
B/Bmsy
B<Bmsy B=Bmsy B>Bmsy

Figure F3.



CPUE6
Beta
1
2
3
S_Frac
0.1
0.3
0.5
MatAge
HI
lo
initcatch
20
40
60
SSB/SSB_MSY
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010
Year



CPUE6
SampSize
0.2
1
SigmaR
0.1
0.3
Beta & S_Frac
SSB/SSB_MSY
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Year
Beta & S_Frac
1&0.1
2&0.1
3&0.1
1&0.3
2&0.3
3&0.3
1&0.5
2&0.5
3&0.5

Figure F4.

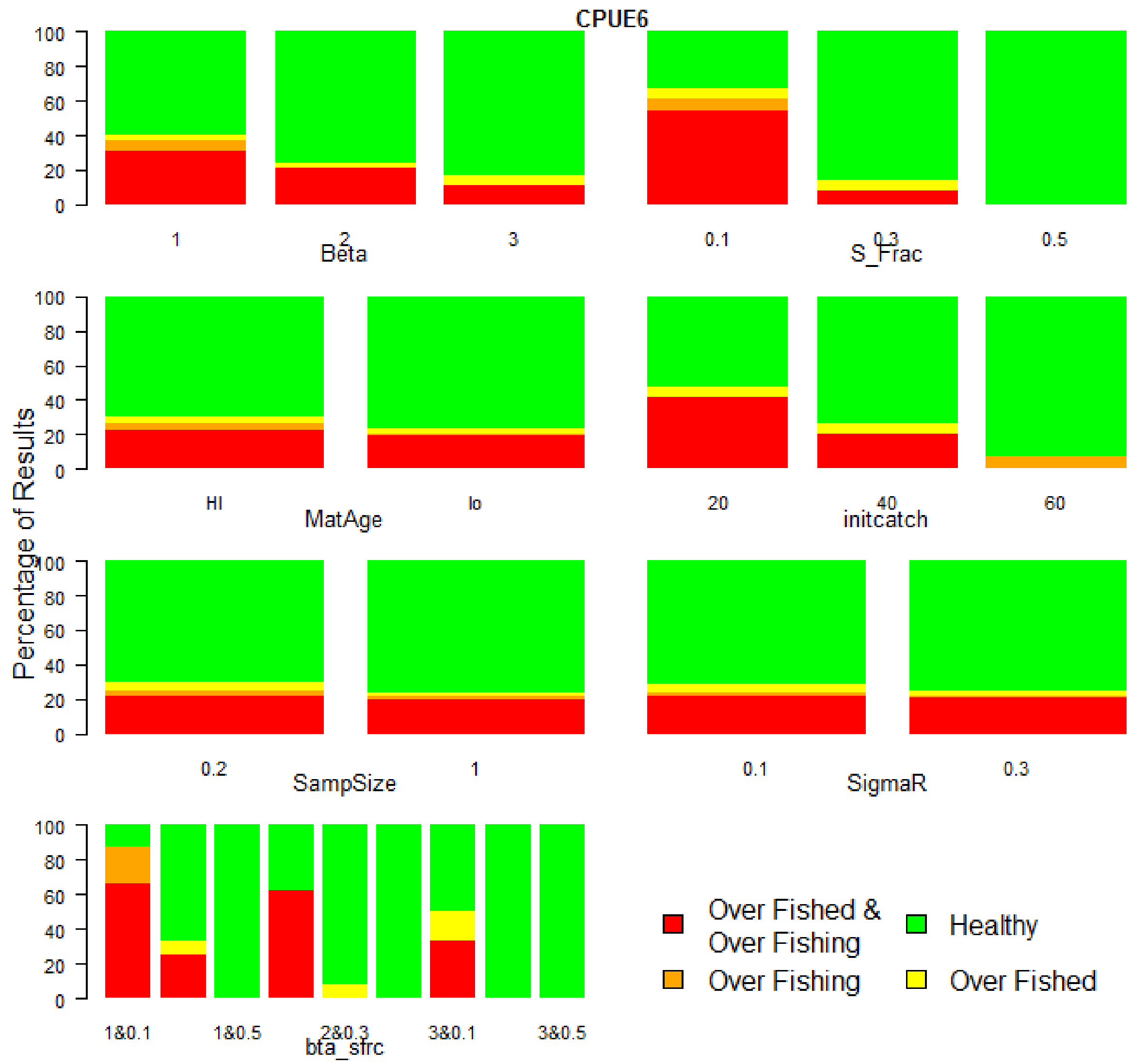

CPUE6
Percentage of Results
100
80
60
40
20
0
1
2
3
Beta
0.1
0.3
0.5
S_Frac
HI
lo
MatAge
20
40
60
initcatch
0.2
1
SampSize
0.1
0.3
SigmaR
1&0.1
1&0.5
2&0.3
3&0.1
3&0.5
bta_sfrc
Over Fished & Over Fishing
Healthy
Over Fishing
Over Fished

Figure F5.

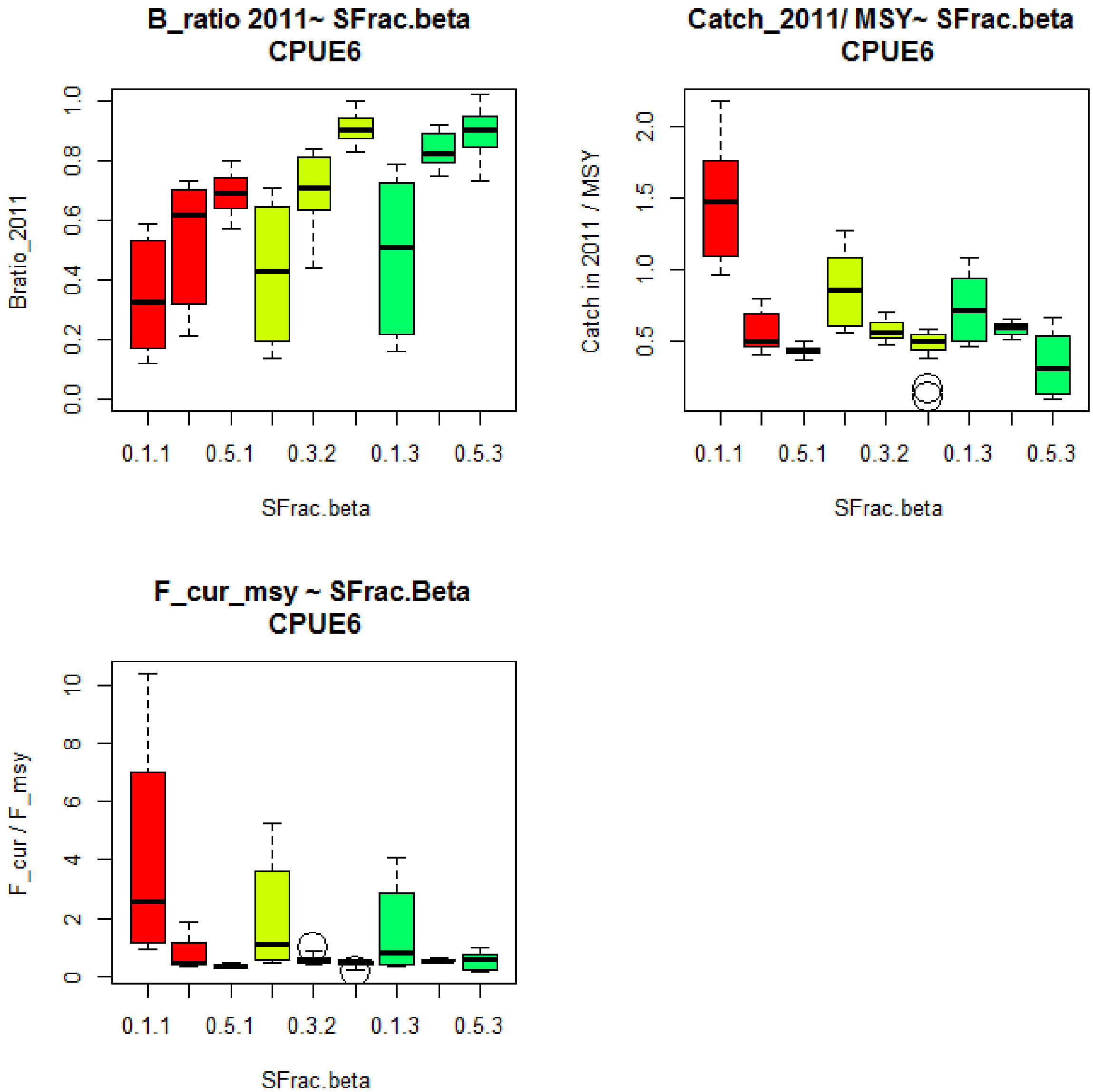

B_ratio 2011~ SFrac.beta
CPUE6
Bratio_2011
0.0
0.2
0.4
0.6
0.8
1.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
Catch_2011/ MSY~ SFrac.beta
CPUE6
Catch in 2011 / MSY
0.5
1.0
1.5
2.0
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3
SFrac.beta
F_cur_msy ~ SFrac.Beta
CPUE6
F_cur / F_msy
0
2
4
6
8
10
0.1.1
0.5.1
0.3.2
0.1.3
0.5.3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

Figure 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_identifier
1,histogram_file_name_extension
C:\DFO\BlueShark2014_BSPA\output\param_JEJL_Ref_In.out,filparin$
C:\DFO\BlueShark2014_BSPA\output\param_JEJL_Ref_Out.out,filparout$
C:\DFO\BlueShark2014_BSPA\data\BSH2014_CPUE_JapanEarly_JapanLate.csv,cpue1f$
C:\DFO\BlueShark2014_BSPA\data\BSH2014_catch.csv,catf$
C:\DFO\BlueShark2014_BSPA\data\rec_ef_v1.csv,tbcef$
C:\DFO\BlueShark2014_BSPA\data\rec_c_v2.csv,tbcbcf$
C:\DFO\BlueShark2014_BSPA\data\seals_v11.csv,sealsf$
C:\DFO\BlueShark2014_BSPA\data\seal_diet_v11.csv,seal_dietf$
"General inputs"
1,bayesian
1,fletcher
0,F_iterate
0, impfunc
0,isetcov
1,expand_imp
25,degf
8,iwted
2,nind
1976,ifyrdata%
2010,iendyrdata%
1971,ifyr
1971,ifyrobscat
2011,icur
"Parameter inputs"
0,estn
0,ltransn
0,aminn
0,amaxn
1,estr
1,ltransr
0.001,aminr
1.0,amaxr
0,estcat0
1,ltranscat0
10,amincat0
5000,amaxcat0
1,estk
1,ltransk
50,aminK
20000,amaxk
1.0,estab0
1,ltransab0
0.001,aminab0
3.0,amaxab0
0,ltransig
0,aminsig
0,amaxsig
1,estq
1,ltransq
0.000000001,aminq
2,amaxq
"Set up projections"
5000, isims
```

```
7,npol
0, 46.69
0, 56.03
0, 37.35
1, 0.0798
1, 0.0958
1, 0.0639
3, 1.0
1,iDoCIy
0.05,lci
0.95,uci
0, binvar
0 ,lowbin
0, binwidth
1, ibins
5, tyr1
10, tyr2
20, ihz
1971,refyear
"Set up priors"
0.8,alphamean
0.5,alphasd
0,catmean
0,catsd
0,sigmaprior
0,sigmamed
0,sigmasd
1,rprior
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.ctl
#_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_withseasinterpolate
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_speciific_K; 4=not implemented
0.5 #_Growth_Age_for_L1
22 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4
logSD=F(A)
1 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity
matrix by growth_pattern; 4=read age-fecundity; 5=read fec and wt from
wtatage.ss
#_placeholder for empirical age-maturity by growth pattern
5 #_First_Mature_Age
2 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b;
(4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-
GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in
base parm bounds; 3=standard w/ no bound check)
#
#_growth_parms
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr
dev_stddev Block Block_Fxn
```

```
 10 120 42 45 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
 40 410 234 400 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
 0.1 0.25 0.144 0.15 0 0.8 -4 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
 -10 10 1 1 0 0.8 -4 0 0 0 0 0.5 0 0 # Richards_Fem_GP_1
 0.01 1 0.25 0.0834877 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1
 -3 3 -1.07881 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Fem_GP_1
 -3 3 0.00875604 0 0 0.8 -3 0 0 0 0 0.5 0 0 # L_at_Amin_Mal_GP_1
 -3 3 0.1579413 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-environ parameters
#
#_Cond 0  #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0
#_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
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_env_link
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 preceed 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
```

```
 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
```

```
 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_Lonline
 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=mirror, 0=float_nobiasadj, 1=float_biasadj,
2=parm_nobiasadj, 3=parm_w_random_dev, 4=parm_w_randwalk,
5=mean_unbiased_float_assign_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_linked
#_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F1_MEX
 0 0 0 0 # 2 F2_CAN
 0 0 0 0 # 3 F3_CHINA
 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_Lonline
 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(if_any)
#
#_size_selex_types
#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_di
scarded_dead
#_Pattern Discard Male Special
 24 0 4 0 # 1 F1_MEX
 5 0 0 1 # 2 F2_CAN
 24 0 3 0 # 3 F3_CHINA
 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
```

```
 #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_Lonline
 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_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F1_MEX
 11 0 0 0 # 2 F2_CAN
 11 0 0 0 # 3 F3_CHINA
 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_Oth
 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_Lonline
 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
#_LO 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 # SizeSel_1P_1_F1_MEX
 -15 15 -9.46006 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_2_F1_MEX
 -15 15 6.38928 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_3_F1_MEX
 -15 15 6.40143 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_4_F1_MEX
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_5_F1_MEX
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_6_F1_MEX
 -20 200 4.2 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_1Fem_Peak_F1_MEX
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_1Fem_Ascend_F1_MEX
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_1Fem_Descend_F1_MEX
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_1Fem_Final_F1_MEX
 -15 15 0.419063 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_1Fem_Scale_F1_MEX
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_1_F2_CAN
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_2_F2_CAN
```

```
35 300 154.34 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_3P_1_F3_CHINA
-15 15 -9.75214 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_2_F3_CHINA
-15 15 6.41669 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_3_F3_CHINA
-15 15 6.04151 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_4_F3_CHINA
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_5_F3_CHINA
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_6_F3_CHINA
-20 200 0 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Male_Peak_F3_CHINA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Male_Ascend_F3_CHINA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Male_Descend_F3_CHINA
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_3Male_Final_F3_CHINA
-15 15 0.85 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_3Male_Scale_F3_CHINA
35 300 125 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F4_JPN_KK_SH
-15 15 -4 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_2_F4_JPN_KK_SH
-15 15 7.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_3_F4_JPN_KK_SH
-15 15 5.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_4_F4_JPN_KK_SH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_5_F4_JPN_KK_SH
-999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_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_Final_F4_JPN_KK_SH
-15 15 0.62 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_4Fem_Scale_F4_JPN_KK_SH
35 300 156.736 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_5P_1_F5_JPN_KK_DP
-15 15 -11.2268 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_F5_JPN_KK_DP
-15 15 5.68928 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_5P_3_F5_JPN_KK_DP
-15 15 6.78635 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_5P_4_F5_JPN_KK_DP
-999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_5_F5_JPN_KK_DP
-999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_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_Final_F5_JPN_KK_DP
-15 15 0.740766 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_5Fem_Scale_F5_JPN_KK_DP
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_1_F6_JPN_ENY_SHL
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_F6_JPN_ENY_SHL
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_1_F7_JPN_ENY_DP
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_7P_2_F7_JPN_ENY_DP
35 300 115.534 120 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_8P_1_F8_JPN_LG_MESH
-15 15 -7.22456 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_8P_2_F8_JPN_LG_MESH
-15 15 5.48907 5 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_8P_3_F8_JPN_LG_MESH
-15 15 6.82727 5 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_8P_4_F8_JPN_LG_MESH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_5_F8_JPN_LG_MESH
-999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_6_F8_JPN_LG_MESH
-20 200 3 125 -1 50 -4 0 0 0 0 0 0 0 # SzSel_8Male_Peak_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_8Male_Ascend_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_8Male_Descend_F8_JPN_LG_MESH
-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_8Male_Final_F8_JPN_LG_MESH
-15 15 0.6 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_8Male_Scale_F8_JPN_LG_MESH
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_9P_1_F9_JPN_CST_Oth
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_9P_2_F9_JPN_CST_Oth

35 300 50 120 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_10P_1_F10_JPN_SM_MESH
-15 15 -9 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_2_F10_JPN_SM_MESH
-15 15 5.5 5 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_10P_3_F10_JPN_SM_MESH
-15 15 6.85  5 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_10P_4_F10_JPN_SM_MESH
-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_5_F10_JPN_SM_MESH
-999 -999 -999 0 -1 4 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_6_F10_JPN_SM_MESH


1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_11P_1_F11_IATTC
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_11P_2_F11_IATTC
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_12P_1_F12_KOREA
1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_12P_2_F12_KOREA
1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_13P_1_F13_NON_ISC
```

```
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_13P_2_F13_NON_ISC
 28 300 118.194 50 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_14P_1_F14_USA_GIILL
 -15 15 -9.7791 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_14P_2_F14_USA_GIILL
 -15 15 6.82267 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_14P_3_F14_USA_GIILL
 -15 15 8.17439 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_14P_4_F14_USA_GIILL
 -10 10 -5.22115 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_14P_5_F14_USA_GIILL
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_14P_6_F14_USA_GIILL
 -20 200 -10 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel_14Fem_Peak_F14_USA_GIILL
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_14Fem_Ascend_F14_USA_GIILL
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_14Fem_Descend_F14_USA_GIILL
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_14Fem_Final_F14_USA_GIILL
 -15 15 0.51336 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_14Fem_Scale_F14_USA_GIILL
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_15P_1_F15_USA_SPORT
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_15P_2_F15_USA_SPORT
 35 300 133.521 50 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_1_F16_USA_Lonline
 -15 15 -10.2074 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_2_F16_USA_Lonline
 -15 15 7.25299 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_3_F16_USA_Lonline
 -15 15 6.66187 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_4_F16_USA_Lonline
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_5_F16_USA_Lonline
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_6_F16_USA_Lonline
 -20 200 4.01541 0 -1 50 4 0 0 0 0 0 0 0 # SzSel_16Fem_Peak_F16_USA_Lonline
 -15 15 -0.117635 4 -1 50 4 0 0 0 0 0 0 0 #
SzSel_16Fem_Ascend_F16_USA_Lonline
 -15 15 -0.600908 4 -1 50 4 0 0 0 0 0 0 0 #
SzSel_16Fem_Descend_F16_USA_Lonline
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_16Fem_Final_F16_USA_Lonline
 -15 15 0.761592 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_16Fem_Scale_F16_USA_Lonline
 35 300 200 50 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_17P_1_F17_TAIW_LG
 -15 15 -2.6 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_2_F17_TAIW_LG
 -15 15 7.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_3_F17_TAIW_LG
 -15 15 5.5 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_4_F17_TAIW_LG
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_5_F17_TAIW_LG
 -999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_6_F17_TAIW_LG
 -20 200 9.5 9 -1 50 -4 0 0 0 0 0 0 0 # SzSel_17Fem_Peak_F17_TAIW_LG
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_17Fem_Ascend_F17_TAIW_LG
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_17Fem_Descend_F17_TAIW_LG
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_17Fem_Final_F17_TAIW_LG
 -15 15 0.62 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_17Fem_Scale_F17_TAIW_LG

 28 300 118.194 50 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_1_F18_TAIW_SM
 -15 15 -9.7791 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_2_F18_TAIW_SM
 -15 15 6.82267 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_3_F18_TAIW_SM
 -15 15 8.17439 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_4_F18_TAIW_SM
 -10 10 -5.22115 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_18P_5_F18_TAIW_SM
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_6_F18_TAIW_SM
 -20 200 -10 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Peak_F18_TAIW_SM
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Ascend_F18_TAIW_SM
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Descend_F18_TAIW_SM
 -15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Final_F18_TAIW_SM
 -15 15 0.51336 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_18Fem_Scale_F18_TAIW_SM

 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_19P_1_S1_HW_DP
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_19P_2_S1_HW_DP
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_20P_1_S2_HW_SH
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_20P_2_S2_HW_SH
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_21P_1_S3_TAIW_LG
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_21P_2_S3_TAIW_LG
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_22P_1_S4_TAIW_SM
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_22P_2_S4_TAIW_SM
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_23P_1_S5_JPN_EARLY
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_23P_2_S5_JPN_EARLY
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_24P_1_S6_JPN_LATE
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_24P_2_S6_JPN_LATE
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_25P_1_S7_JPN_RTV
```

```
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_25P_2_S7_JPN_RTV
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_26P_1_S8_SPC_OBS
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_26P_2_S8_SPC_OBS
 1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_27P_1_S9_SPC_COMB
 1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_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_CHINA
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_2_F3_CHINA
 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_Oth
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_2_F9_JPN_CST_Oth
 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_ISC
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_13P_2_F13_NON_ISC
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_14P_1_F14_USA_GIILL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_14P_2_F14_USA_GIILL
 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_Lonline
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_16P_2_F16_USA_Lonline
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_17P_1_F17_TAIW_LG
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_17P_2_F17_TAIW_LG
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_18P_1_F18_TAIW_SM
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_18P_2_F18_TAIW_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_TAIW_LG
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_21P_2_S3_TAIW_LG
 1 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_22P_1_S4_TAIW_SM
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_22P_2_S4_TAIW_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 selex parm trends
```

```
#_Cond -4 # placeholder for selparm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep
in base parm bounds; 3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12 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 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 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 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  #_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 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 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 #_lencomp:_1
#  0 #_lencomp:_2
#  1 #_lencomp:_3
#  0 #_lencomp:_4
#  1 #_lencomp:_5
#  0 #_lencomp:_6
#  0 #_lencomp:_7
#  1 #_lencomp:_8
#  0 #_lencomp:_9
#  0 #_lencomp:_10
#  0 #_lencomp:_11
#  0 #_lencomp:_12
#  0 #_lencomp:_13
#  1 #_lencomp:_14
```

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