FINAL

ISC/18/ANNEX/12

ANNEX 12

18th Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Yeosu, Republic of Korea
July 11-16, 2018

Report of the BillFish Working Group Workshop

April 2018

July 2018

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REPORT OF THE BILLFISH WORKING GROUP WORKSHOP

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

17-24 April 2018
Shimizu, Japan

1.0 INTRODUCTION

An intercessional workshop of the Billfish Working Group (WG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) was convened in Shimizu, Japan during 17-24 April 2018. The goal of this workshop was to conduct modeling analyses for a benchmark stock assessment of the Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) stock. These analyses included developing and fitting the base case Stock Synthesis model, running sensitivity analyses and conducting stock projections.

Hitoshi Honda from the National Research Institute of Far Seas Fisheries welcomed participants from Chinese Taipei, Japan, and the United States of America (USA) (Attachment 1). Jon Brodziak, the Chair of the WG noted that no representatives were present from Canada, China, Korea, Mexico, Inter-American Tropical Tuna Commission (IATTC), or the Secretariat of the Pacific Community (SPC).

2.0 ADOPTION OF AGENDA AND ASSIGNMENT OF RAPPORTEURS

Rapporteuring duties for the working group (WG) were assigned to Jon Brodziak, Yi-Jay Chang, Hitoshi Honda, Jhen Hsu, Hirotaka Ijima, Minoru Kanaiwa, Michelle Sculley and Annie Yau. The meeting agenda was adopted on April 17, 2018 (Attachment 2).

3.0 COMPUTING FACILITIES

Computing facilities included the ISC Billfish Working Group Google drive “ISC BILLWG” for distribution of working papers and meeting documents and for sharing of assessment modeling information as well as a Wi-Fi wireless network access point for connection to the Internet.

4.0 NUMBERING OF WORKING PAPERS AND DISTRIBUTION POTENTIAL

Draft working papers were distributed and numbered (Attachment 3). It was agreed that all finalized working papers would be posted on the ISC website and made available to the public. The Chair noted that the draft working papers needed to be finalized by 15 May 2018.

5.0. STATUS OF WORK ASSIGNMENTS

The work assignments to be addressed at the April 2018 workshop as defined in the January 2018 WG workshop report (ISC 2018) were as follows:

The WG will use the fishery statistics information agreed upon in agenda item 8 and the life history information agreed upon in agenda item 9 of the 2018 swordfish data preparation meeting report (ISC 2018) to construct the base case Western and Central North Pacific Ocean (WCNPO) swordfish stock assessment (Figure 5.0) using the Stock Synthesis model (Methot and Wetzel 2013), version 3.30.

If time permits, the WG would also attempt to complete three additional work assignments:

- Update the 2014 Bayesian surplus production assessment model for the WCNPO swordfish using the new data for 2018.
- Conduct stock projections for the WCNPO swordfish stock.
- Complete a swordfish stock assessment model for the entire North Pacific using the WCNPO swordfish SS3.30 model augmented with data from the EPO region north of the equator.

All work assignments were completed, with the exception of completing a swordfish stock assessment model for the entire North Pacific using the WCNPO swordfish SS3.30 model augmented with data from the EPO region north of the equator.

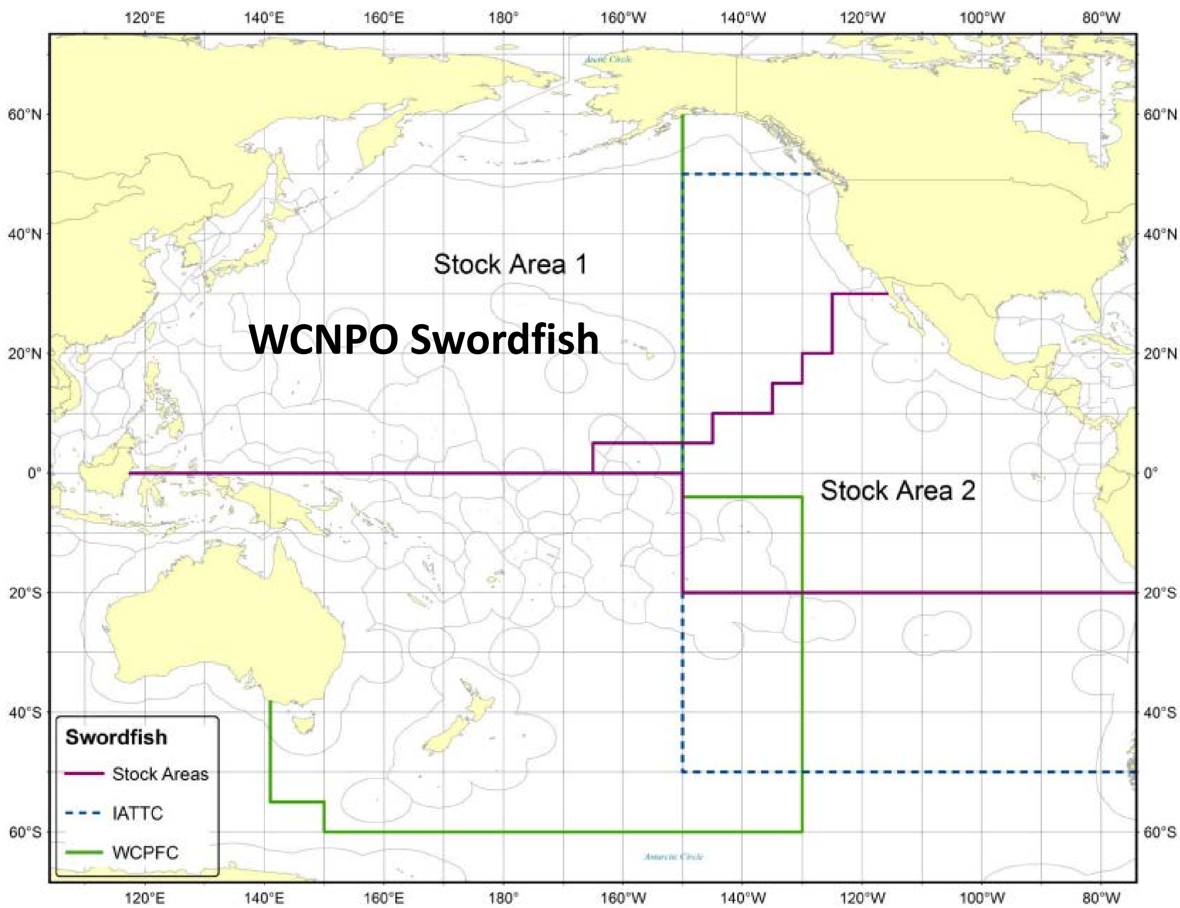
6.0 NORTH PACIFIC SWORDFISH STOCK ASSESSMENT MODELING

Two working papers on the topic of developing a WCNPO swordfish stock assessment model were presented to the WG by Michelle Sculley. The WG reviewed both working papers and discussed the presentations.

6.1 Input data available for the North Pacific swordfish stock assessment in Stock Synthesis.
Presented by Michelle Sculley (ISC/18/BILLWG-2/01)

The data provided to the ISC Billfish Working Group for the 2018 swordfish stock assessment in Stock Synthesis were summarized. An analysis of the WCNPO swordfish standardized catch-per-unit effort (CPUE) was performed to investigate potential conflict and correlations using the FLCore package (https://github.com/flr/FLCore). When there were multiple time periods of standardized CPUE indices for a fleet, they were combined into a single time series for the purpose of this analysis. The results show moderate positive correlations between most indices. The highest positive correlation was between the US longline shallow set index and Taiwanese longline (ρ=0.76). There were five negative correlations, the largest of which was between the Taiwan longline and Japan longline area 1 indices (ρ=-0.33). Overall, there were no substantial conflicts in the CPUE time series and all indices should be considered for inclusion in the Stock Synthesis base-case model.

Figure 5.0. Western and Central North Pacific Ocean swordfish stock boundaries in the North Pacific Ocean (Stock Area 1).



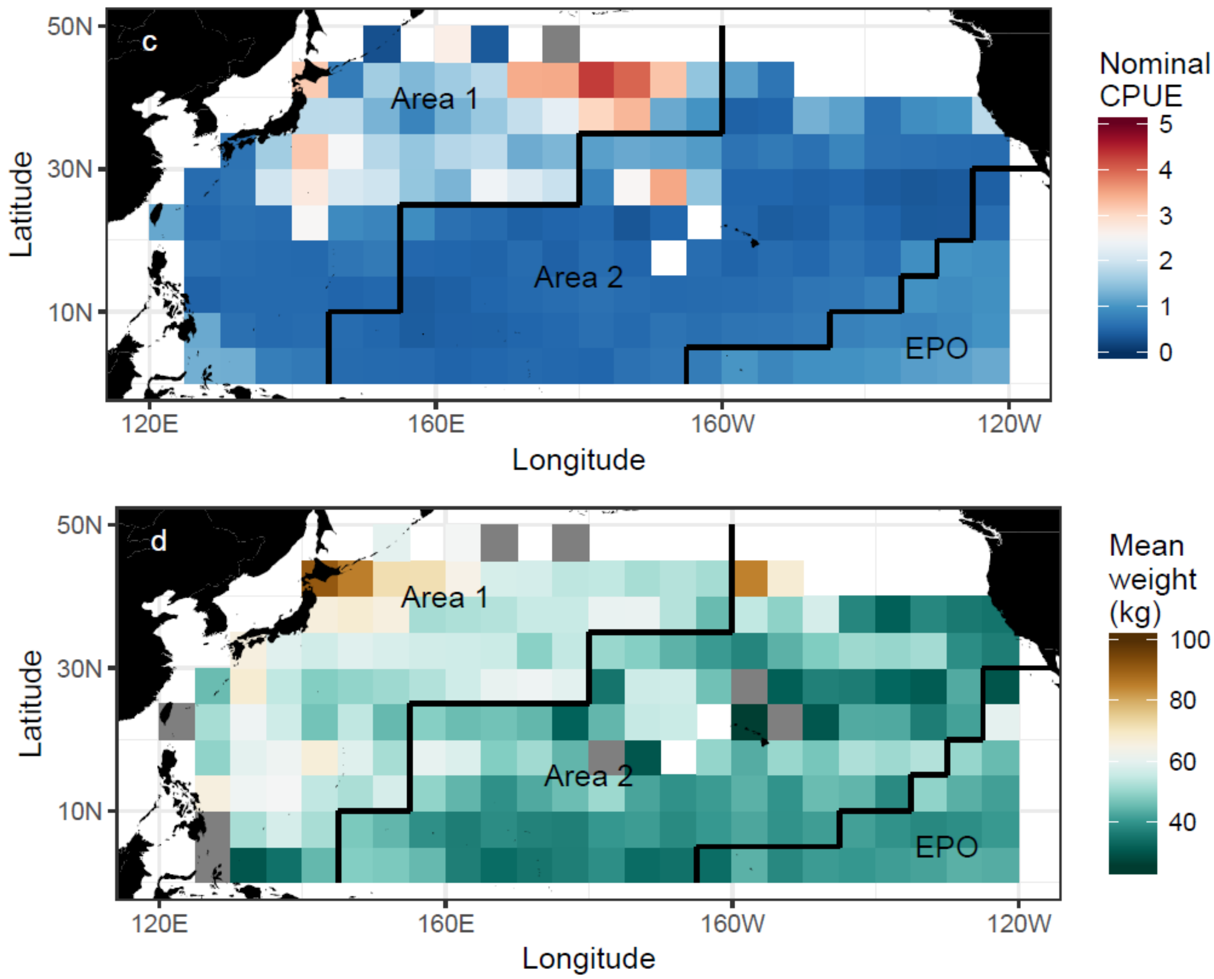
Discussion

The WG noted that the best available life history information for the development of the base case North Pacific swordfish stock assessment were finalized at the data preparation meeting held in Honolulu in January 2018 (Table 6.1.1). The standardized catch-per-unit effort data for the North Pacific swordfish stock assessment were also finalized at the data preparation meeting (Table 6.1.2). The WG also noted that the standardized Japanese longline CPUE were calculated in two subareas of the WCNPO (Figure 6.1, Areas 1 and 2) based on observed differences in CPUE and mean body weight (Ijima and Kanaiwa 2018).

The WG noted that loess fits were used to calculate RMSE values for each input CPUE time series. Details on the loess fits were provided in WP-01.

The fit to the combined Hawaii shallow-set CPUE showed patterning in the residuals, but it was shown that when a loess fit was applied to each time series individually (before and after the closure from 2001-2004), there was no longer a residual pattern in the early part of the time series but there remained some patterning in the later time series.

Figure 6.1. Differences in nominal longline CPUE and mean weights of swordfish in areas 1 and 2 for reporting Japanese fishery statistics of WCNPO swordfish based on Ijima and Kanaiwa (2018).



The WG noted that there was useful information in the cross correlation and autocorrelation plots for the CPUE time series. In the cross correlation plot, an interesting pattern was observed between the US longline shallow and Japan offshore distant water longline CPUE series, showing high positive autocorrelations at 5-10 year offsets. Since these two CPUE series come from different areas and the US longline shallow fishery catches smaller swordfish, it was possible this cross correlation pattern indicated movement of fish from the fishing grounds of the US longline fleet to the fishing grounds of the Japan offshore distant water longline fleet. The WG made a request to compare all indices, especially those after 1990, to determine whether any conflicts existed between the indices. It was noted that such an analysis was already complete and additional plots showing the results were made available to the group on the shared BILLWG Google drive.

Table 6.1.1. Key life history, recruitment, and selectivity parameters used in the swordfish stock assessment model. The column labeled "Estimated ?" identifies if the parameters are expected to be estimated within the assessment model (Estimated), fixed at a specific value, i.e., not estimated (Fixed) from Table 9.0 in the BILLWG Data Preparatory report (ISC 2018).

Parameter (units)	**Value**	**Estimated?**
Natural mortality (M, age-specific^{-yr})	Female: M_0 = 0.42, M_1 = 0.37, M_2 = 0.32, M_3 = 0.27, M_{4+} = 0.22 Male: M_0 = 0.40, M_{1-2} = 0.38, M_{3-5} = 0.37, M_{6+} = 0.36	Fixed
Length_at_min_age (EFL cm)	Female: L(A_{min}) = 97.7	Fixed
	Male: L(A_{min}) = 99.0	
Length_at_max_age (EFL cm)	Female: L(A_{max}) = 226.3	Fixed
	Male: L(A_{max}) = 206.4	
Von Bertalanffy_K	Female: k = 0.246	Fixed
	Male: k = 0.271	
$W=aL^b$ (kg)	Both genders: a = 1.299 ×10-5	Fixed
	b = 3.0738	
Size at 50-percent maturity (EFL cm) and maturity ogive slope parameter	Female: L_{50} = 143.6, β = -0.103	Fixed
	Male: L_{50} = 102.0, β = -0.141	
Stock-recruitment steepness (h)	h= 0.9	Fixed
Unfished log-scale recruitment (Ln(R_0))	-	Estimated
Standard deviation of recruitment (σR)	σR = 0.6	Fixed
Initial age structure	-	Estimated
Recruitment deviations	-	Estimated
Selectivity	-	Estimated
Catchability		Estimated

Table 6.1.2. List of fleets with swordfish catch data (F1-F18) and CPUE indices (S1-S10) provided for the 2018 assessment of the Western Central North Pacific Ocean swordfish stock along with the source for more information about the standardization of the CPUE series.

Catch Index	Abundance Index	Fleet Name	Time Period	Source
F1	S1	JPN_WCNPO_OSDWLL_early_Area1	1975-1993	Kanaiwa 2018
F2	S2	JPN_WCNPO_OSDWLL_late_Area1	1994-2016	Kanaiwa 2018
F3	S3	JPN_WCNPO_OSDWLL_early_Area2	1975-1993	Kanaiwa 2018
F4	S4	JPN_WCNPO_OSDWLL_late_Area2	1994-2016	Kanaiwa 2018
F5	-	JPN_WCNPO_OSDF	1960-1992	
F6	-	JPN_WCNPO_CODF	1993-2014	
F7	-	JPN_WCNPO_Other_Early	1952-1993	
F8	-	JPN_WCNPO_Other_Late	1994-2016	
F9	S5	TWN_WCNPO_DWLL _early	1975-1999	Chang et al. 2018
F10	S6	TWN_WCNPO_DWLL _late	2000-2016	Chang et al. 2018
F11	-	TWN_WCNPO_Other	1959-2016	
F12	S7	US_WCNPO_LL_deep	1995-2016	Sculley et al. 2018
F13	S8	US_WCNPO_LL_shallow_early	1995-2000	Sculley et al. 2018
F14	S9	US_WCNPO_LL_shallow_late	2005-2016	Sculley et al. 2018
F15	S10	US_WCNPO_GN	1985-2006	Courtney et al. 2009
F16	-	US_WCNPO_Other	1970-2016	
F17	-	WCPFC_LL	1970-2016	
F18	-	IATTC_LL_Overlap	1975-2016	

6.2 A Preliminary Base-case Model in Stock Synthesis 3.30 for the 2018 North Pacific Swordfish (*Xiphias gladius*) Stock Assessment. Presented by Michelle Sculley (ISC/18/BILLWG-2/02)

A preliminary base-case model in Stock Synthesis 3.30 for Western and Central North Pacific Ocean swordfish (*Xiphias gladius)* was described. The preliminary base-case model covers the time period 1952-2016 for the Western Central North Pacific Ocean region as determined by the Billfish Working Group at the January 2018 working group meeting. It included all the data available for the WCNPO region as of the January Billfish WG data preparatory meeting with the exception of two WCNPO indices which were not included in the likelihood estimation, and included data from three International Scientific Committee for the Conservation of Tuna and Tuna-like Species (ISC) countries and from other countries in aggregate from the Western Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC). Two alternative models were also described. Alternative model one was the base case model with the inclusion of the remaining two WCNPO indices in the likelihood estimation, to evaluate how they may have impacted model results if included. Alternative model two was the base-case model plus two environmental indices for recruitment. These indices were the Southern Oscillation Index from 1952-2016 which has been shown to correlate with swordfish recruitment deviations, and an index of estimated phytoplankton biomass from 2002-2016 which has been shown to correlate with bigeye tuna recruitment. The preliminary base-case model converged, but additional work is required to improve the fit to the length composition data. Preliminary results suggest that the WCNPO swordfish stock is being fished below F_{MSY} and spawning stock biomass is above SSB_{MSY}.

Discussion

The discussion of WP-02 was included in section 6.4 on the identification of the base case assessment model.

6.3 Update of the Western and Central North Pacific Swordfish Bayesian Production Model in 2018
Presented by Jon Brodziak (Presentation only)

In 2014, the WCNPO swordfish stock assessment was conducted using a Bayesian surplus production model. The base case assessment model was fitted to the time series of reported catch and three relative abundance indices. The catch time series consisted of all reported catches of swordfish in the WCNPO region during 1951-2012. The relative abundance indices consisted of time series of standardized CPUE for three longline fleets. These were: the Japanese distant water and offshore longline fleet (1952-2012), the Taiwanese distant water longline fleet (2000-2012), and the USA Hawaii shallow-set longline fleet (1995-2000 and 2005-2012).

The 2018 update of the WCNPO swordfish Bayesian surplus production (BSP) model was conducted as a strict update of the 2014 assessment to the extent practicable. The updated catch biomass time series during 1975-2016 was gathered from Ijima (2018) and Michelle Sculley, pers. comm. It is notable that the three swordfish CPUE standardization analyses changed from 2014 to 2018. For the USA shallow-set longline fishery, the CPUE standardization changed to consist of two separate periods (i.e., 1995-2000 and 2005-2016, Sculley et al. 2018). The Japanese longline CPUE standardization changed to start in 1975 versus in 1952 as in the 2014 assessment (Kanaiwa et al. 2017). Last, the Taiwanese longline CPUE standardization analyses were updated using a delta-lognormal model (Chang et al. 2018). The catch time series were also updated and some moderate differences were found in the catch estimates in the early portion of the time series. Despite these differences in the input data for the BSP, the exact same production model structure and input specifications, including prior distributions and initial conditions, were used for the 2018 BSP model update.

We used Markov chain Monte Carlo sampling to sample the posterior distribution for the 2018 BSP model. Three chains were used for the MCMC sampling. Each chain was sampled for 10^6 iterations. The first 250,000 samples were discarded to burn in or remove the dependence of the chain on initial conditions. The remaining 750,000 samples were thinned at a rate of 1/75 to remove autocorrelation leaving 10,000 samples per chain for inference. The BSP model was tested for convergence to the posterior distribution with the R package coda using the Geweke, Gelman and Rubin, Raftery and Lewis, and Heidelberger and Welch diagnostics (R Development Core Team 2017, Plummer et al. 2006). All nodes in the model were monitored for convergence. The WG noted that the results of the convergence tests were consistent and indicated that the MCMC chains had converged to the posterior distribution of the BSP model estimates.

The WG reviewed the results of the 2018 BSP model in comparison to the 2014 BSP model results. The WG noted that the initial exploitable biomass estimates for the 2018 update were larger than those for the 2014 assessment. It was suggested that this was due to both the change in the start of the Japanese longline CPUE index in 1975 and the change in the estimates of early period catch biomass (Figure 6.3.1). Despite the differences in the estimated biomasses, the WG noted that the estimated harvest rates were similar between the 2018 update and the 2014 assessment (Figure 6.3.2). The WG also noted some differences in the time series of relative biomass (B/B_{MSY}) and harvest rate (H/H_{MSY}) estimates for maximum sustained yield (MSY) based reference points with the 2018 update indicating lower relative biomasses since the 1980s (Figure 6.3.3) and indicating higher relative harvest rates since the1990s (Figure 6.3.4).

Overall, the WG noted that the relative stock status of swordfish during the last 3 years of both the 2018 update and the 2014 assessment were consistent and did not indicate overfishing was occurring or that there was an overfished condition relative to MSY-based reference points.

Figure 6.3.1. Comparison of mean estimates of exploitable biomasses (B) of WCNPO swordfish from the 2018 update and the 2014 assessment.

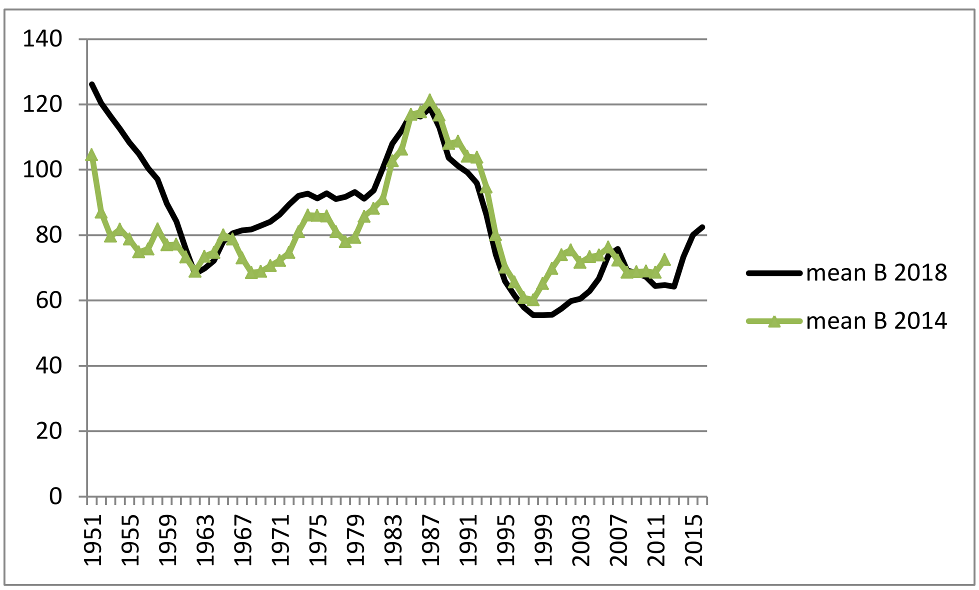


Figure 6.3.2. Comparison of mean estimates of harvest rates (H) of WCNPO swordfish from the 2018 update and the 2014 assessment.

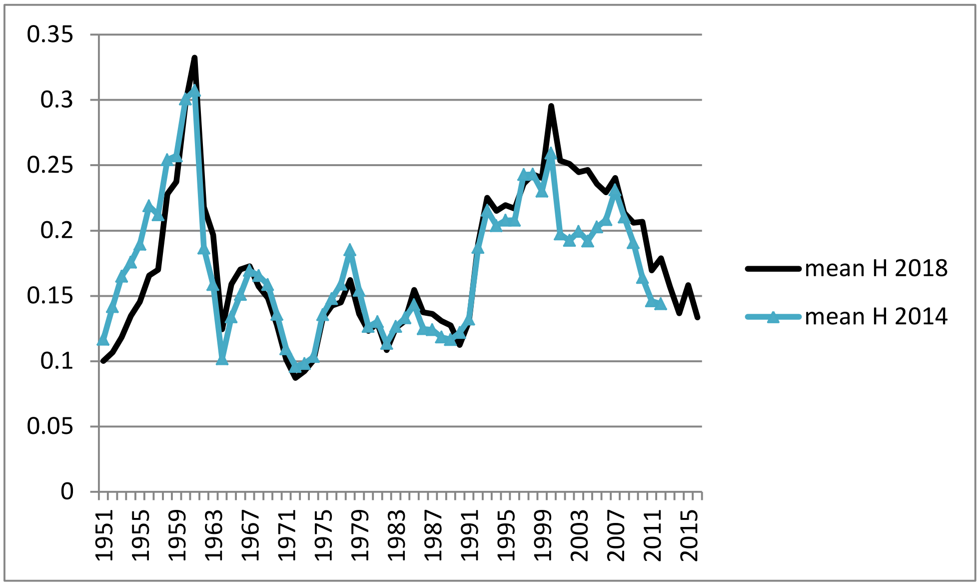


Figure 6.3.3. Comparison of mean estimates of relative biomasses (B/B_{MSY}) of WCNPO swordfish from the 2018 update and the 2014 assessment.

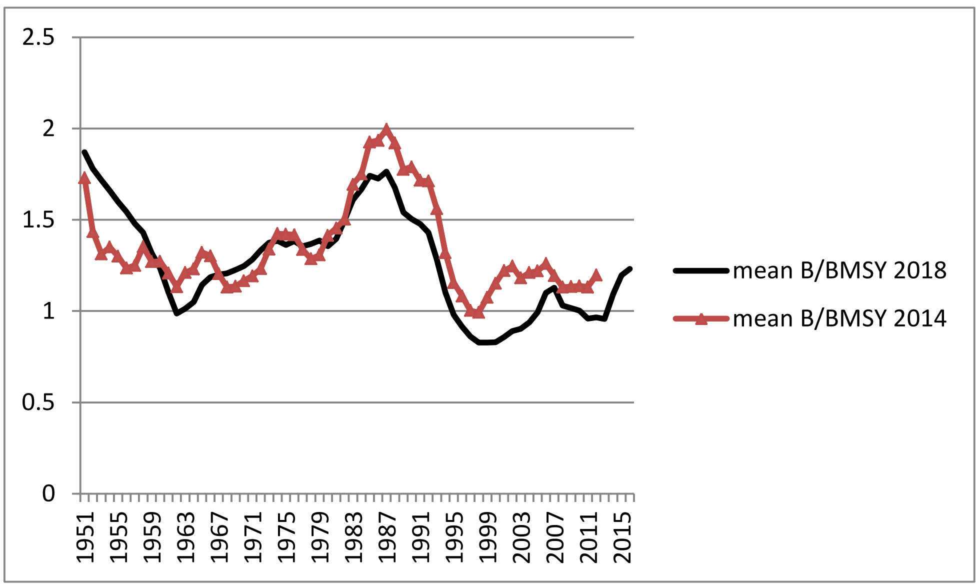
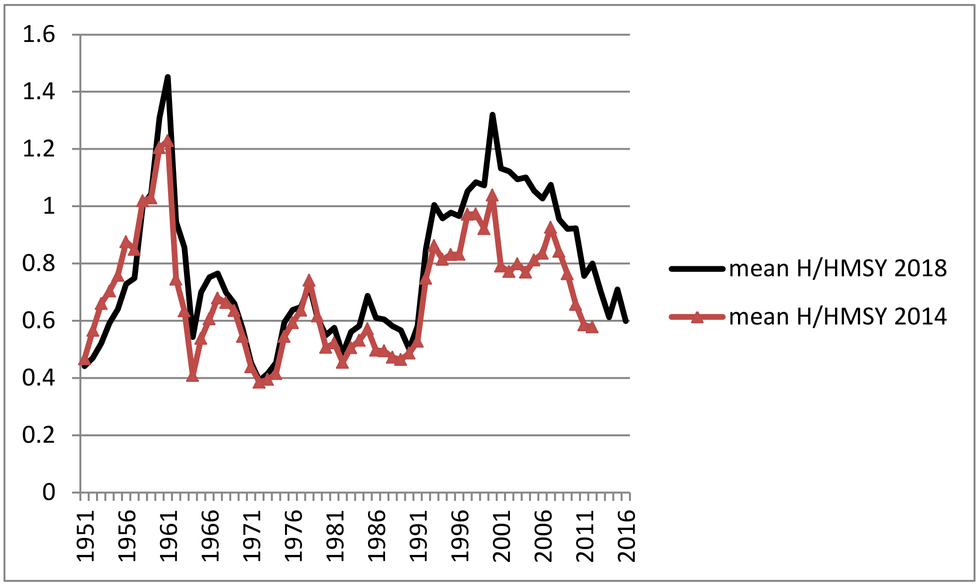


Figure 6.3.4. Comparison of mean estimates of relative harvest rates (H/H_{MSY}) of WCNPO swordfish from the 2018 update and the 2014 assessment.



In addition to the 2018 update, the WG also investigated a BSP sensitivity model to investigate the effect of including separate catchability parameter for two the Hawaii longline CPUE indices. Overall, the results of this BSP sensitivity model were generally similar to the strict update.

6.4 Model Runs to Identify a Base Case Stock Assessment Model

The WG selected the Stock Synthesis version 3.30 (SS3.30) model configuration from WP-02 as the initial candidate for the base case assessment model. This model was the seventh version of an SS3.30 model constructed since the data preparation meeting in January 2018 by a modeling sub-group consisting of Michelle Sculley, Hirotaka Ijima, and Yi-Jay Chang and was named V1.7. Model V1.7 was the result of a series of alternative configurations of selectivities, CPUE indices, and model parameterizations. The WG noted that the deep-set Hawaii longline fleet (F12) caught a high fraction of age-0 swordfish (less than 100 cm EFL). This suggested that the catch for this fleet contained some information for estimating recruitment, the abundance of age-0 fish. As a result, the WG agreed to include the fleet F12 CPUE index as a direct survey of recruitment strength, noting that this was a new modeling option in SS3.30. Overall, the WG reviewed the fit of the initial model to the available data and began a search for a best-fitting minimum adequate model for the WCNPO swordfish stock assessment.

The WG noted that although model V1.7 achieved convergence in the objective function value, this initial model had a relatively large maximum gradient value which suggested that this model did not produce a strict maximum likelihood fit (Table 6.4.1). Here the WG made a distinction between the notion of convergence in objective function value $\left(f\left(\theta, D\right)\right)$ for parameters θ and data D, which was set with a convergence criterion of $\varepsilon=10^{-4}$, and the notion of convergence in gradient $\left(\frac{\partial f}{\partial \theta_p}(\theta, D)\right)$, which was set with a maximum gradient convergence criterion of $1/20$ or less across all estimated model parameters.

As a result of the large maximum gradient value, the WG did not accept model V1.7 and began a step-wise model development approach to identify a base case model that provided the best fit to the available data. This search produced the list of models described below. The list shows the major structural changes investigated in each step of the search for a base case minimum adequate model (Table 6.4.1). This list does not cover all the models that were investigated but ultimately not used, e.g. age-structured production models.

Revision of Model V1.7 to Model V1.8

- Initial selectivity parameter values were changed to better fit the Hawaii deep-set longline length composition data.
- The starting year was changed to 1975 to avoid the use of uncertain Japanese early catch data, noting that the use of these data strongly influenced the initial population size and trend (Table 6.4.1). The WG was especially concerned about the accuracy of interview information to provide Japanese catch statistics for 1952-1960 because there was limited information on the total number of vessels and the data quality for reported catch during this time period.

Diagnostics for Model V1.8

- Model V1.8 converged in likelihood but not in gradient.

Revision to Model V1.9

- The length composition data from the Hawaii deep-set longline fleet (F12) were removed and the selectivity for fleet F12 was mirrored to the selectivity for fleet F13 (Table 6.4.1). This change was made because likelihood profiling showed these that length composition data were highly influential although the fleet F12 accounted for very little swordfish catch, i.e., the nearest fraction of total catch represented by F12 was 0%.

Diagnostics for Model V1.9

- This model converged in likelihood but not in gradient.
- The R_0 profile for fleet specific length composition data showed that there were fleets which had conflicting information (Figure 6.4.1, 6.4.2, and 6.4.3). Two groups of fleets were identified which had opposing trends: these were groups1 and 2 (Table 6.4.1). Two additional model runs of V1.9 were evaluated using each group of length composition data separately.
- Group 1 included the length composition data from the early time period before 1994 for fleets F1, F6, and F13. The model fit using the group 1 length composition data suggested an unrealistically large initial swordfish population size and the model did not converge. Thus, the WG noted that the result of using the group 1 set of length compositions produced infeasible population biomass estimates.
- Group 2 included the length composition data from the late time period after 1994 for fleets F2, F10, F14, and F18. The model fit using only the group 2 data converged in the objective function value but still had a maximum gradient component that was greater than 0.05.

Figure 6.4.1. Likelihood profiles of unfished recruitment for the total, length compositions, survey/CPUE indices, and recruitment deviation likelihood components of Model V1.9.

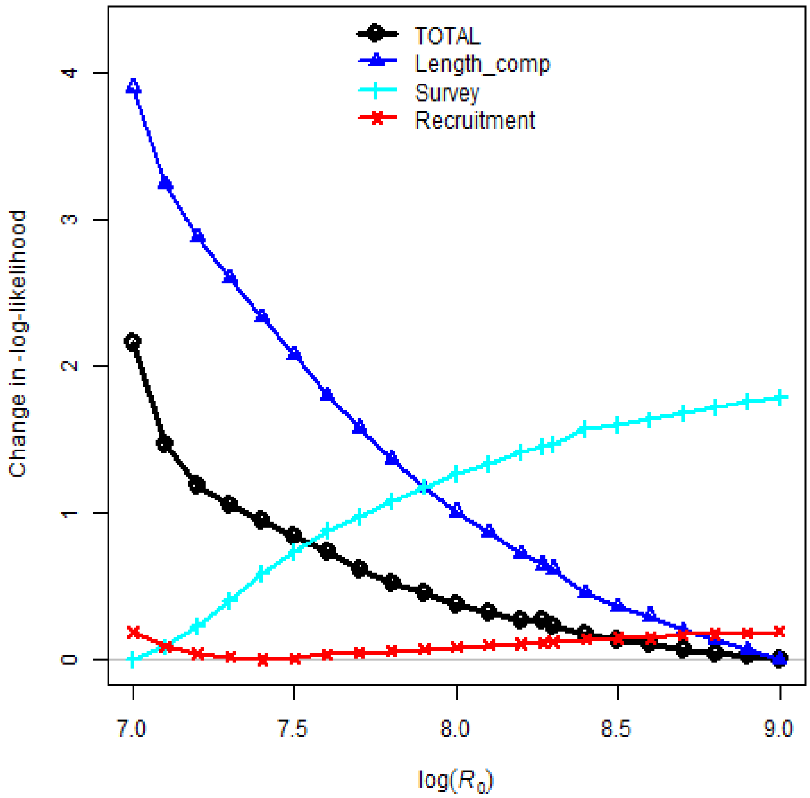


Figure 6.4.2. Likelihood profiles of unfished recruitment for the survey/CPUE index likelihood components of Model V1.9 by fleet.

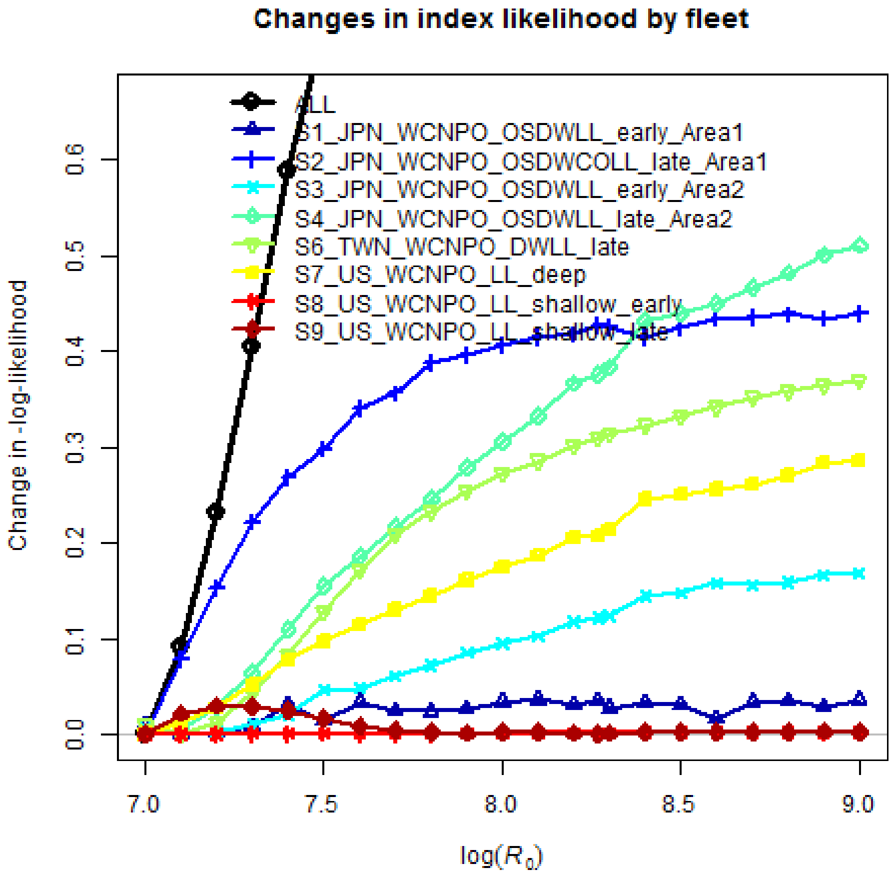
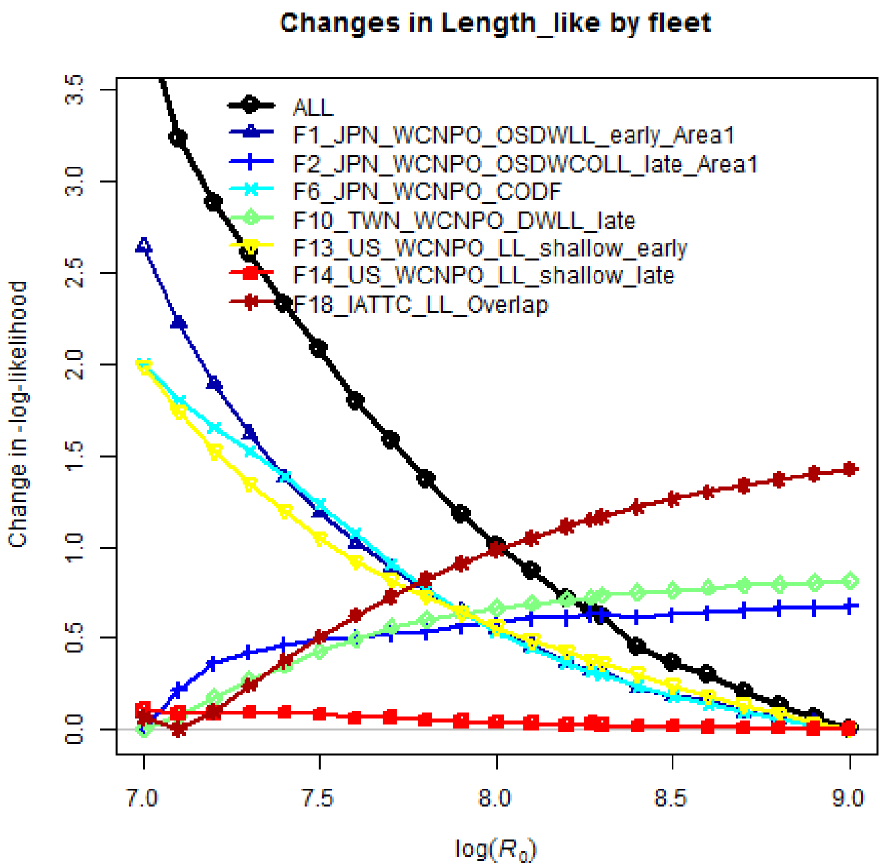


Figure 6.4.3. Likelihood profiles of unfished recruitment for the length composition likelihood components of Model V1.9 by fleet.



Revision to Model V1.10

- Model V1.10 included the group 2 length composition data (fleets F2, F10, F14, and F18) and did not include the group 1 length composition data. The WG noted that the unfished population size and R_0 values for model V1.10 were realistic in terms of the scale of the estimated biomass.
- Some selectivity patterns were changed to a 4-parameter double normal (Table 6.4.1) or logistic (fleet F6). This was done to reduce the number of estimated parameters and improve the convergence properties of the model.

Diagnostics for Model V1.10

- Model V1.10 converged in likelihood but not in gradient.
- This model showed some non-random residual patterns in the Japanese longline length compositions. These patterns were suggested to be year class effects with several cohorts dominating the length composition data from the large 1983, 1992, and 1998 year classes.

Revision to Model V1.11

- Selectivity time blocks were added in an attempt to resolve the residual patterns in the Japanese longline length compositions (Table 6.4.1). The WG considered it to be

important to fit the Japanese longline length composition in recent years as well as possible noting that the Japanese offshore distant water longliners accounted for about 44% of the total swordfish catch biomass during 1976-2016.
- The variance adjustment parameters were modified for the group 1 fleets (F1, F6, F13) to downweight their influence on model fit, especially for the unfished recruitment scale parameter R_0.

Diagnostics for Model V1.11
- This model converged in likelihood but not in gradient.
- This model improved the fits to the Japanese longline length composition data.

Revision to Model V1.12
- This model was the same as V1.10 but set the emphasis factor for the fleet F12 length compositions to be 0.001 to deemphasize this information in the objective function (Table 6.4.1).

Diagnostics for Model V1.12
- This model converged in likelihood but not in gradient.

Revision to Model V1.13
- This model was derived from V1.9 with the use of Group 2 length compositions and included different mirroring patterns (selectivities) for the Group 1 length compositions (Table 6.4.1).
- This model increased the coefficient of variation (CV) for the length at maximum age from a CV=0.10 to a CV=0.15, which was expected to provide a better fit to the length composition data for larger swordfish.
- This model also included a change in fishery selectivities for fleets F2, F10 and F14.

Diagnostics for Model V1.13
- This model converged in likelihood but not in gradient.

Revision to Model V1.14
- Changed the initial equilibrium catch estimate from 20,000 to 30,000 fish (equal to the average annual catch numbers between 1965 and 1974 for the Japanese longline fleet in area 1) to better match the initial population trend and catch time series.
- Changed the phase for estimating the initial fishing mortality.
- Anomalous length composition data for the Japanese longline fleet in area 1 during 1994-1998 were removed from the model because these converted weight frequency data were inconsistent with predicted length compositions.

Diagnostics for Model V1.14
- This model converged in likelihood but not quite in gradient.
- This was the penultimate candidate for the base case model.

Table 6.4.1. Model names, descriptions, and maximum gradient values (MaxGrad).

NAME	DESCRIPTION	MaxGrad
V1.7	Proposed base case described in WP2. Starts in 1952. CPUE indices for fleets S5 (Table 6.1.2) and S10 were not fitted in the likelihood estimation. Length compositions were downweighted with variance adjustment factor of 0.5.	1.73
V1.8	Changed assessment model time horizon to 1975-2016 from 1952-2016 based on poor fits to initial conditions in V1.7. Changed some initial conditions to adjust fitting to the recruitment survey index (USA deep-set longline fleet F12). As in V1.7 but with some length compositions downweighted with an emphasis of λ=0.01.	8.57
V1.9	Same as V1.8, but remove the length composition for USA deep-set longline fleet F12 from the likelihood estimation to avoid confounding with recruitment survey index and mirror the fishery selectivity of F12 to fleet F13. Model likelihood profiling on R0 indicates there are two groups of conflicting length composition data: the early period (~1975-1993) length composition data for Group 1 (fleets F1, F6, and F13) and the late period (~1994-2016) length composition data for Group 2 (fleets F2, F10, F14, and F18).	2.38
V1.10	Same as V1.9, but apply downweighting with emphasis of λ=0.001 to the Group 1 fleets F1, F6, F13 length compositions. Simplify selectivity models to have fewer parameters. Change the form of selectivity for fleets F6 and F10 to be logistic. Change the form of selectivity for fleets F1, F2, F13,and F14 to be a simple double-normal form (i.e., fix parameters P5 and P6).	2.34
V1.11	Same as V1.10, but include time blocks to the Japanese longline length composition data to account for non-random patterning due to apparent year class effects. There were 4 time blocks: fleet F1 from 1985-1993, fleet F2 from 1994-1998, fleet F2 from 1999-2002, and fleet F2 from 2003-2006. Apply a variance adjustment of 0.5 to fleets F1, F6, and F13 and a variance adjustment of 1 to fleets F2, F6, F10, and F14. Emphasis factors for all fleets were λ=1, except for fleet F12 where λ=0.	3.60
V1.12	Same as V1.10, but set emphasis for fleet F12 to be λ=0.	11.30
V1.13	Emphasize length composition data from Group 2 based on V1.9. Fleets F1, F6, and F13 are removed and mirrored to fleets F2, F18, and F14, respectively. Fleet 12 is removed and mirrored to fleet F14. Change selectivity forms for fleets F2 and F14 to be simple double-normal forms as in V1.10. Set the selectivity of fleet F10 to be asymptotic lognormal. Increase the CV to be 0.15 from 0.10 for old fish at age Amax.	2.05
V1.14	Changed the phase for estimating the initial F to be phase 2 from phase 1. Eliminated data from 1994-1998 in the fleet F2 length composition as these were based on converted weights.	0.35

6.5 Base Case Stock Assessment Model

The WG revised model V1.14 by increasing the variance adjustment factor (V_A) for the length composition data from V_A=0.5 to V_A=1 and including length composition data from 1994-1998 for fleet F2. The resulting model named V3.0 converged in likelihood and had a maximum gradient value that was less 0.01. The WG reviewed the model diagnostics for the base case model. The WG noted that the fits to the relative abundance indices by fleet were generally within the probable range of the observations (Figures 6.5.1 to 6.5.10). Although there was some patterning in the residuals for some of the fitted CPUE data, the WG agreed that the fits were adequate. The WG also reviewed the fits to the length composition data (Figures 6.5.11 to 6.5.25) and agreed that the fits were noisy but adequate for a two-sex population model fitted without sex-specific length composition data. The WG reviewed likelihood profiles on the logarithm of the unfished recruitment parameter (Figures 6.5.26 to 6.5.28) and noted that there was a consistent pattern of likelihood support around the value of $\log(R_0) \approx 6.8$, the point estimate of unfished recruitment. The WG reviewed an age-structured production model diagnostic (Figure 6.5.29) and noted that there was some inconsistency in terminal scaling of the base case model and the age-structured production model. This result was not unexpected because the length composition data were generally found to lack consistency through time. The WG also reviewed a 5-year retrospective analysis to check on whether there was a pattern of over- or underestimation of spawning potential or fishing intensity in recent years (Figure 6.5.30). The retrospective analysis suggested that there was a tendency for the base case model to underestimate spawning biomass in recent years but there was no clear pattern for spawning potential ratio. The WG also reviewed a randomized initial parameter analysis for the base case model (Figure 6.5.31). This analysis indicated that there was no apparent alternative maximum likelihood solution in the neighborhood of the maximum likelihood estimate. Overall, given the adequacy of the model diagnostics, the WG agreed upon the base case model with the attributes listed below.

In particular, the final base-case model included the following changes from the model described in ISC/18/BILLWG-2/02 (Sculley et al. 2018):

- The model start year was changed from 1952 to 1975. This change was made after discussion about the very large catches reported by Japan in the 1950s. Japan clarified that the reporting of catch during this period had high uncertainty due to the method of reporting catches from the fishermen. It was agreed that these very high catches were driving the initial population size and the population dynamics during this early period because there were no CPUE indices or length composition data to inform the model. Removing this data improved the convergence of the model.
- Four length composition time series were removed: Japan longline area 1 early (F1); Japan Coastal Driftnet (F6); US longline deep set (F12); and US longline shallow set early (F13). Fleet 12 was removed because it was a significant component in the log-likelihood however it had a very different selectivity pattern catching primarily age 0-1 fish and represented less than 0.5% of the total swordfish catch. Fleets F1, F6, and F13 were removed from the base-case model because they were shown to be in conflict with the trend in the CPUE index from the profiling on ln(R0) (Figure 6.4.3).

- The phase for estimating the initial fishing mortality rate was changed from 1 to 2. This allowed the model to fit the recruitment size in the first phase and the initial fishing mortality in the second phase.
- The selectivity patterns were changed for F2, F10, and F14. For fleet F10 (Taiwanese longline), the selectivity was changed from double normal to asymptotic lognormal. Selectivities for fleets F2 and F14 were changed from a 6-parameter double normal pattern to a 4-parameter double normal pattern. In the 4-parameter double normal pattern parameters 5 and 6, which are the initial and final selectivity parameters, were decayed to small and large fish, respectively. This reduced the number of parameters to be estimated in the model and improved fitting and convergence.
- The selectivity patterns for F1 was mirrored to F2, F6 was mirrored to F18, and F12 and F13 were mirrored to F14.
- The CV of the length at maximum age, an important growth parameter for older fish, was changed from 0.1 to 0.15. The WG noted that the synthesis model can be sensitive to the magnitude of this parameter. A larger CV for growth of old fish allowed the model more flexibility to fit the large fish caught. This allowed to the model to fit the fish caught which were larger than L_{Amax} which otherwise may have caused problems with fitting the length composition data and convergence of the model.
- Adjusted variance for the length composition data was changed from 0.5 to 1, which changed the average effective sample size from 12.5 to 25. Additional reweighting was not attempted as this would result in up-weighting the length composition data, which would not improve the model fit and cause problems with convergence.
- The base case model was found to be robust in the estimation of R_0 and the selectivity parameters, but estimates of recruitment deviations changed depending on the initial values provided. The initial recruitment deviation values also caused the maximum gradient component to change. The model was rerun until the maximum gradient component was approximately zero and the parameter file from that model run was used for all additional model runs and diagnostics.

The WG noted that the step-wise search for a minimum adequate model ended up with a base case model that had consistent convergence in derived quantities of interest, such as the time series of spawning biomass estimates. The base case model had a small maximum gradient value relative to the total negative loglikelihood and the WG noted that the likelihood maximum appeared to be sharp and peaked as opposed to being a smooth curve. It was suggested that some of the likelihood function shape near the maximum value may have resulted from parameter penalties that constrained the objective function through variance or recruitment deviation bias adjustments.

Table 6.5.1. List of fleets with catch used in the base case assessment model along with CPUE indices provided for the 2018 Western Central North Pacific Ocean Swordfish Stock Assessment, their source and whether the indices were used in the base case assessment model. Catch estimates for fleets F5 – F8 and F11 were provided to the WG after the January 2018 data preparation meeting.

Lengt hCom p – Used?	Relative Abundance Index – Used?	Fleet Name	Time Series	Source
F1 – N	S1 – Y	JPN_WCNPO_OSDWLL_early_Area1	1975-1993	Kanaiwa and Ijima 2018
F2-Y	S2 – Y	JPN_WCNPO_OSDWLL_late_Area1	1994-2016	Kanaiwa and Ijima 2018
F3	S3 – Y	JPN_WCNPO_OSDWLL_early_Area2	1975-1993	Kanaiwa and Ijima 2018
F4	S4 – Y	JPN_WCNPO_OSDWLL_late_Area2	1994-2016	Kanaiwa and Ijima 2018
F5	-	JPN_WCNPO_OSDF	1960-1992	Hirotaka Ijima, pers. comm.
F6 – N	-	JPN_WCNPO_CODF	1993-2014	Hirotaka Ijima, pers. comm.
F7	-	JPN_WCNPO_Other_Early	1952-1993	Hirotaka Ijima, pers. comm.
F8	-	JPN_WCNPO_Other_Late	1994-2016	Hirotaka Ijima, pers. comm.
F9	S5 – N	TWN_WCNPO_DWLL _early	1975-1999	Chang et al. 2018
F10-Y	S6 – Y	TWN_WCNPO_DWLL _late	2000-2016	Chang et al. 2018
F11	-	TWN_WCNPO_Other	1959-2016	Yi-Jay Chang, pers. comm
F12 – N	S7 – Y	US_WCNPO_LL_deep	1995-2016	Sculley et al. 2018
F13 – N	S8 – Y	US_WCNPO_LL_shallow_early	1995-2000	Sculley et al. 2018
F14-Y	S9 – Y	US_WCNPO_LL_shallow_late	2005-2016	Sculley et al. 2018
F15	S10 – N	US_WCNPO_GN	1985-2006	Courtney et al. 2009
F16	-	US_WCNPO_Other	1970-2016	Ito et al. 2018
F17	-	WCPFC_LL	1970-2016	Darryl Tagami, pers. comm.
F18-Y	-	IATTC_LL_Overlap	1975-2016	Shane Griffiths, pers. comm.

Table 6.5.2. Fishery selectivity models by fleet used in the base case assessment model.

Fleet	Selectivity Function
F1	Mirror F2
F2	Double-normal
F3	Mirror F14
F4	Mirror F14
F5	Mirror F10
F6	Mirror F18
F7	Mirror F2
F8	Mirror F2
F9	Mirror F10
F10	Asymptotic lognormal
F11	Mirror F2
F12	Mirror F14
F13	Mirror F14
F14	Double-normal
F15	Mirror F10
F16	Mirror F10
F17	Mirror F10
F18	Asymptotic lognormal

Diagnostics for the Base Case Model

Relative Abundance Index Fits

Figure 6.5.1. Fit to the CPUE abundance index for fleet S1 with predicted (solid line) and observed (open circle) values.

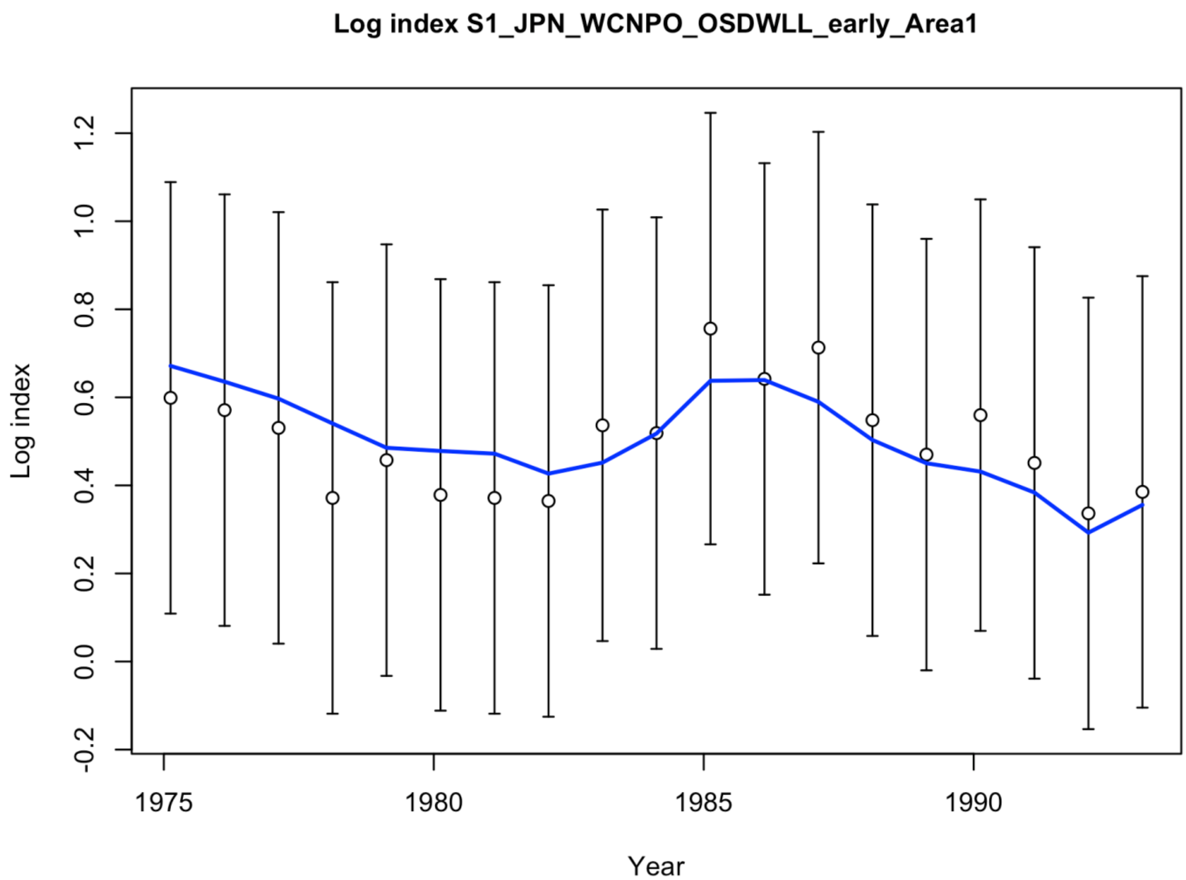


Figure 6.5.2. Fit to the CPUE abundance index for fleet S2 with predicted (solid line) and observed (open circle) values.

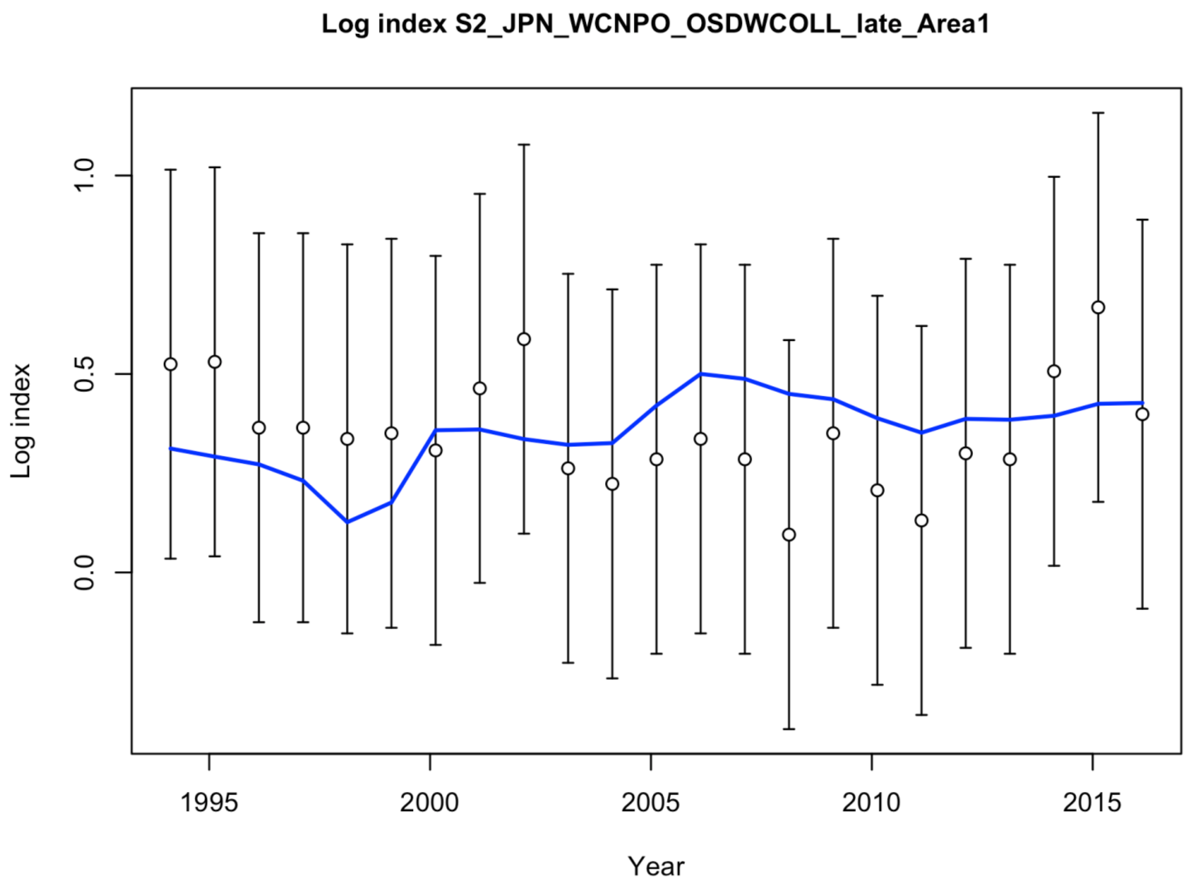


Figure 6.5.3. Fit to the CPUE abundance index for fleet S3 with predicted (solid line) and observed (open circle) values.

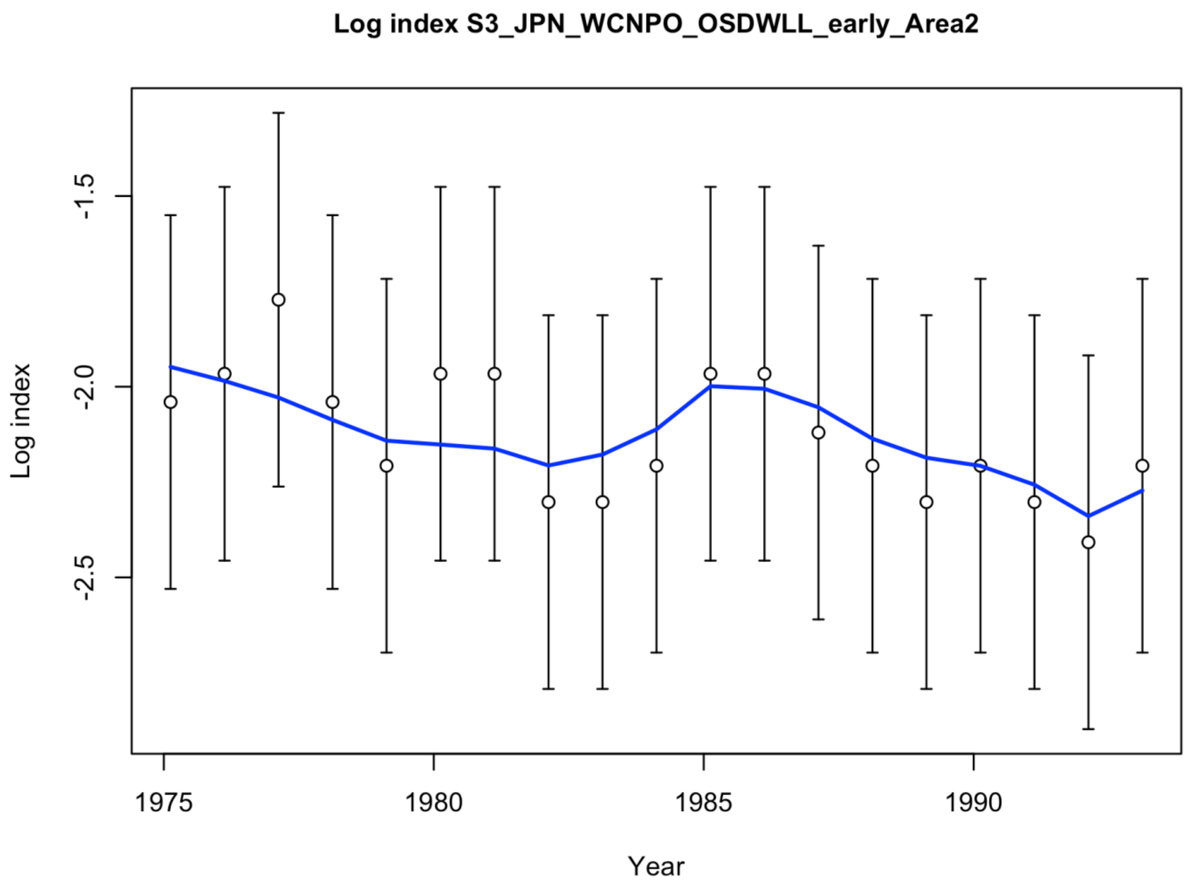


Figure 6.5.4. Fit to the CPUE abundance index for fleet S4 with predicted (solid line) and observed (open circle) values.

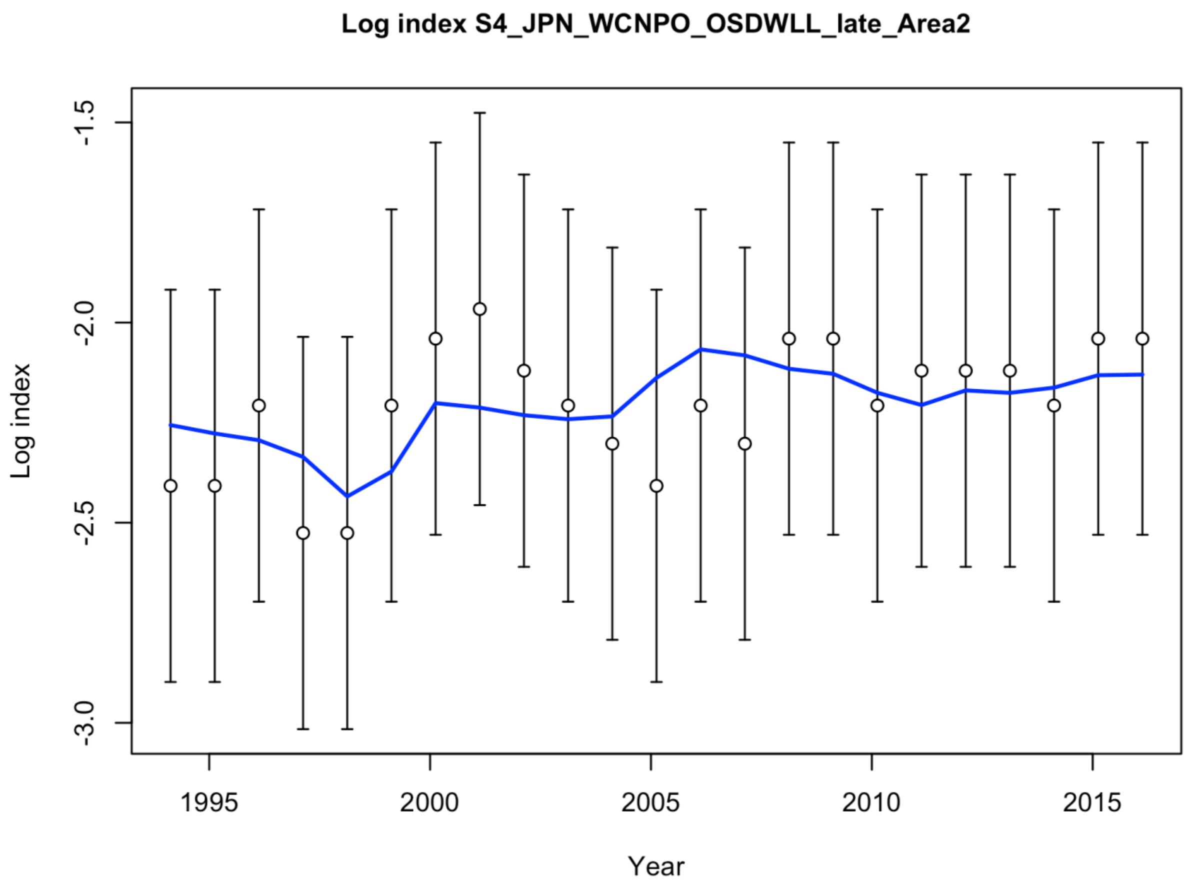


Figure 6.5.5. Nominal fit to the CPUE abundance index for fleet S5 with predicted (solid line) and observed (open circle) values, noting that CPUE for fleet S5 was not fitted in the objective function.

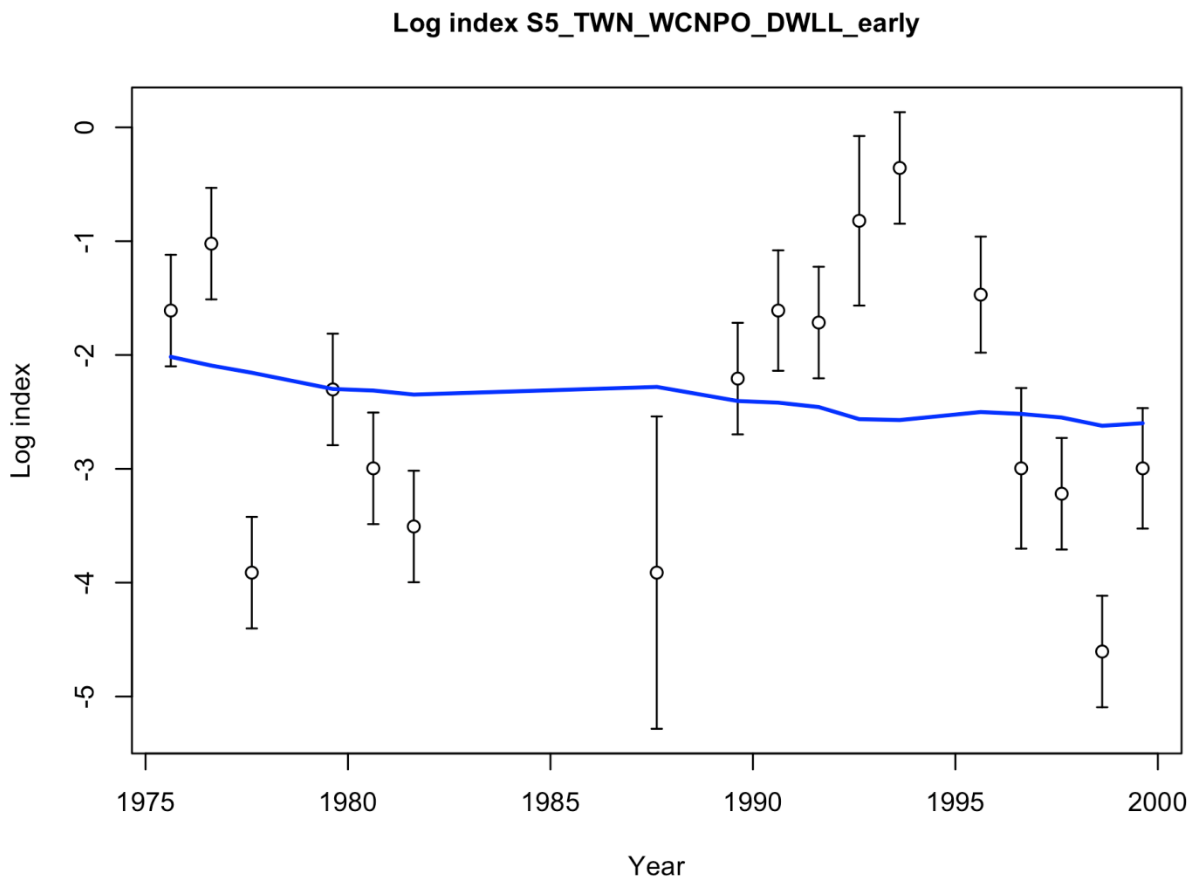


Figure 6.5.6. Fit to the CPUE abundance index for fleet S6 with predicted (solid line) and observed (open circle) values.

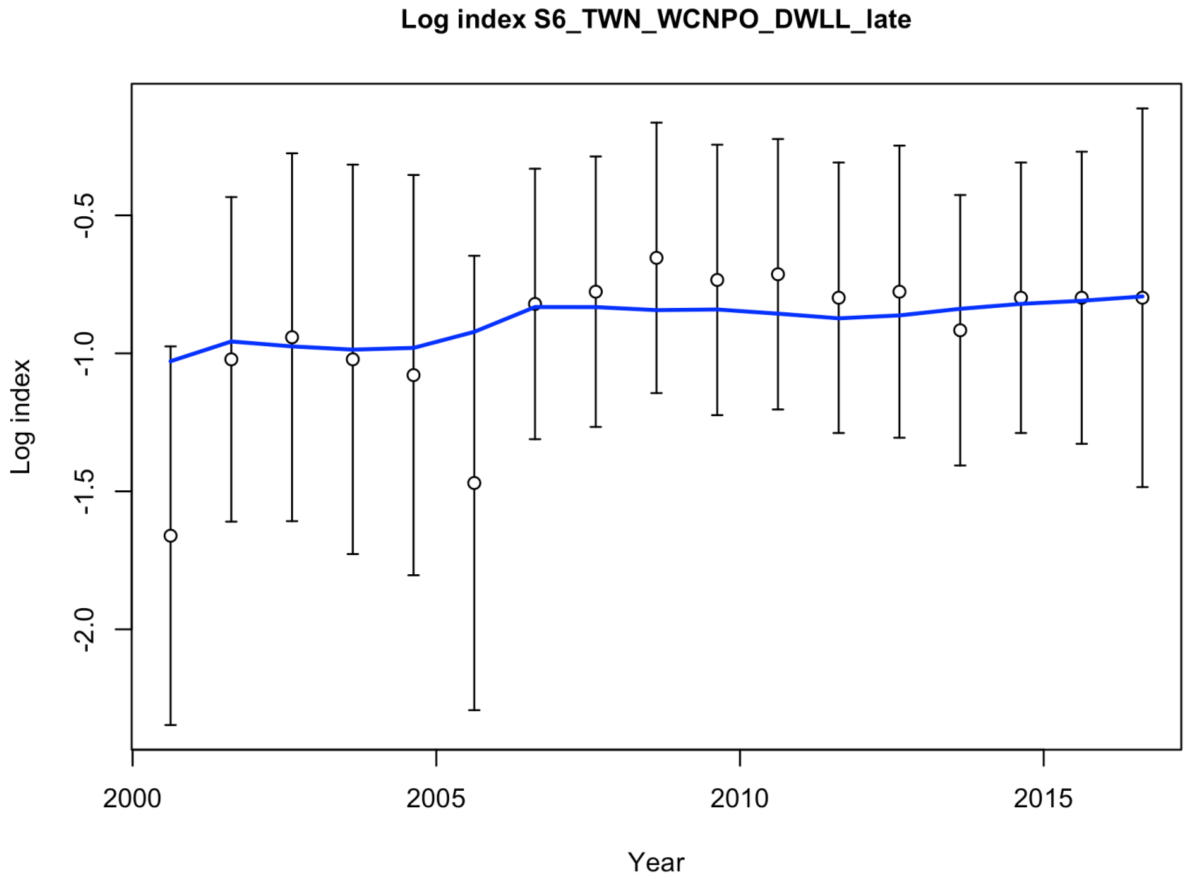


Figure 6.5.7. Fit to the CPUE recruitment index for fleet S7 with predicted (solid line) and observed (open circle) values.

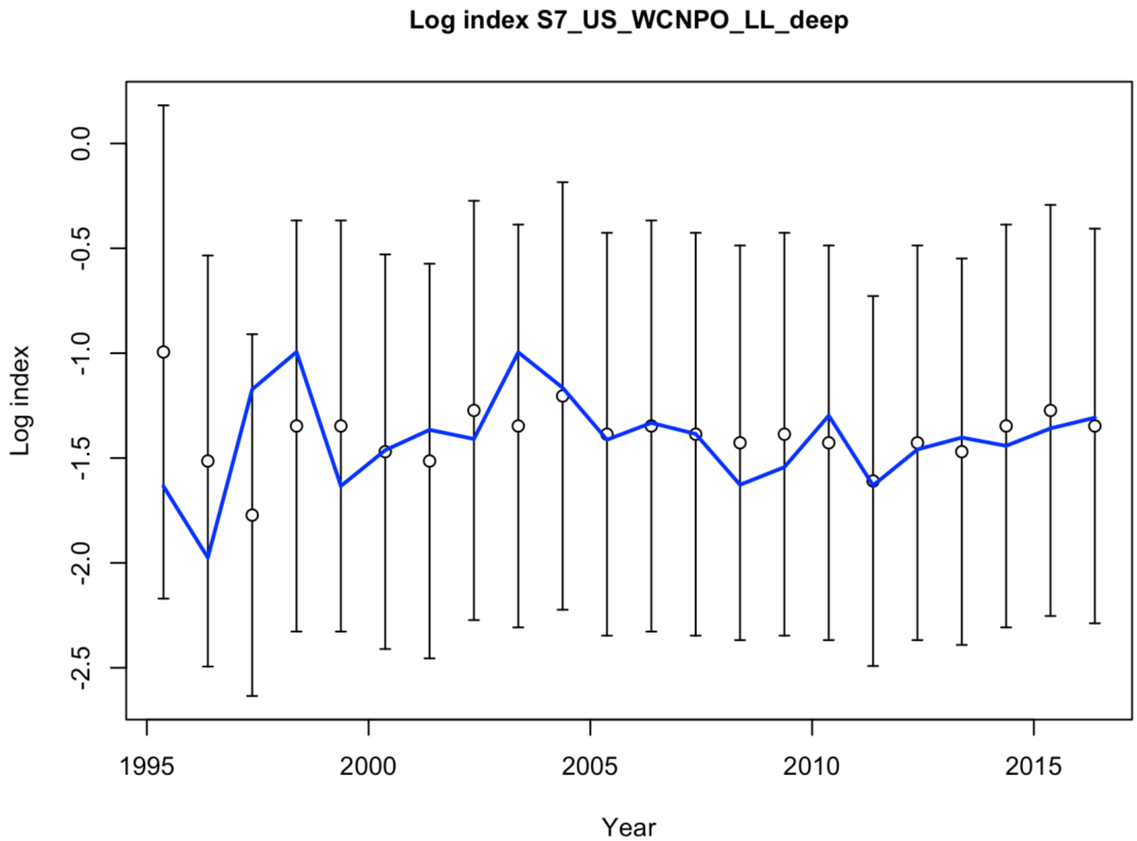


Figure 6.5.8. Fit to the CPUE abundance index for fleet S8 with predicted (solid line) and observed (open circle) values.

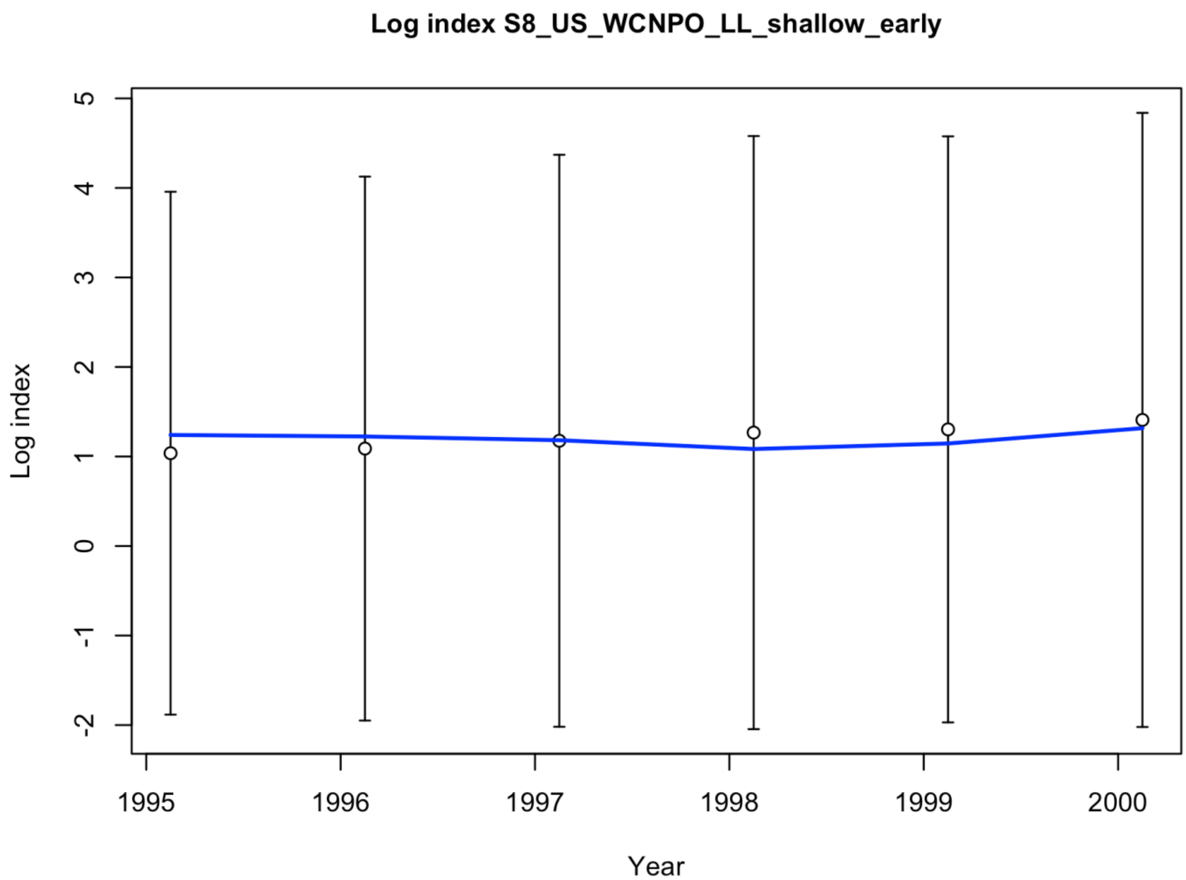
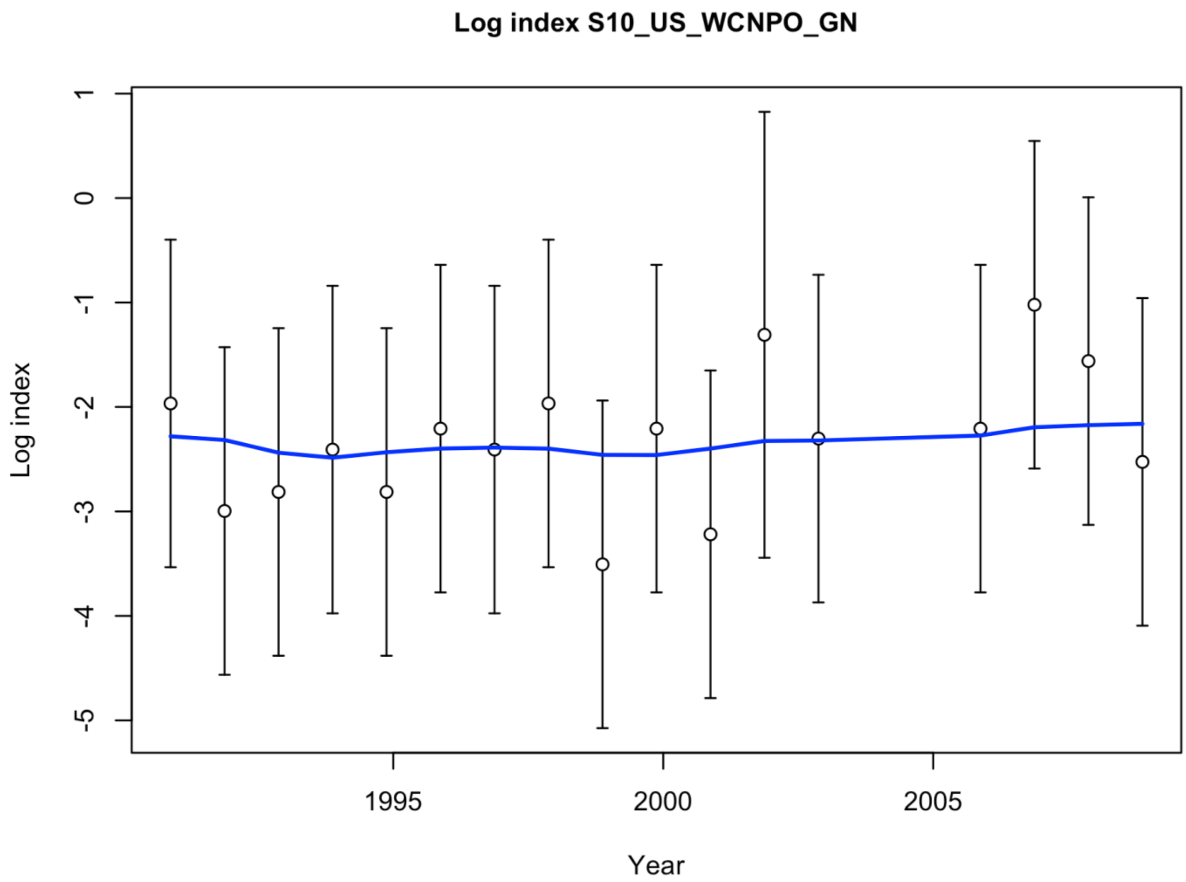


Figure 6.5.9. Fit to the CPUE abundance index for fleet S9 with predicted (solid line) and observed (open circle) values.

Figure 6.5.10. Nominal fit to the CPUE abundance index for fleet S10 with predicted (solid line) and observed (open circle) values, noting that CPUE for fleet S10 was not fitted in the objective function.



Length Composition Fits: Fleet 2

Figure 6.5.11. Fit to the length compositions from1994-1997 for fleet F2 with predicted (solid line) and observed (shaded area) values.

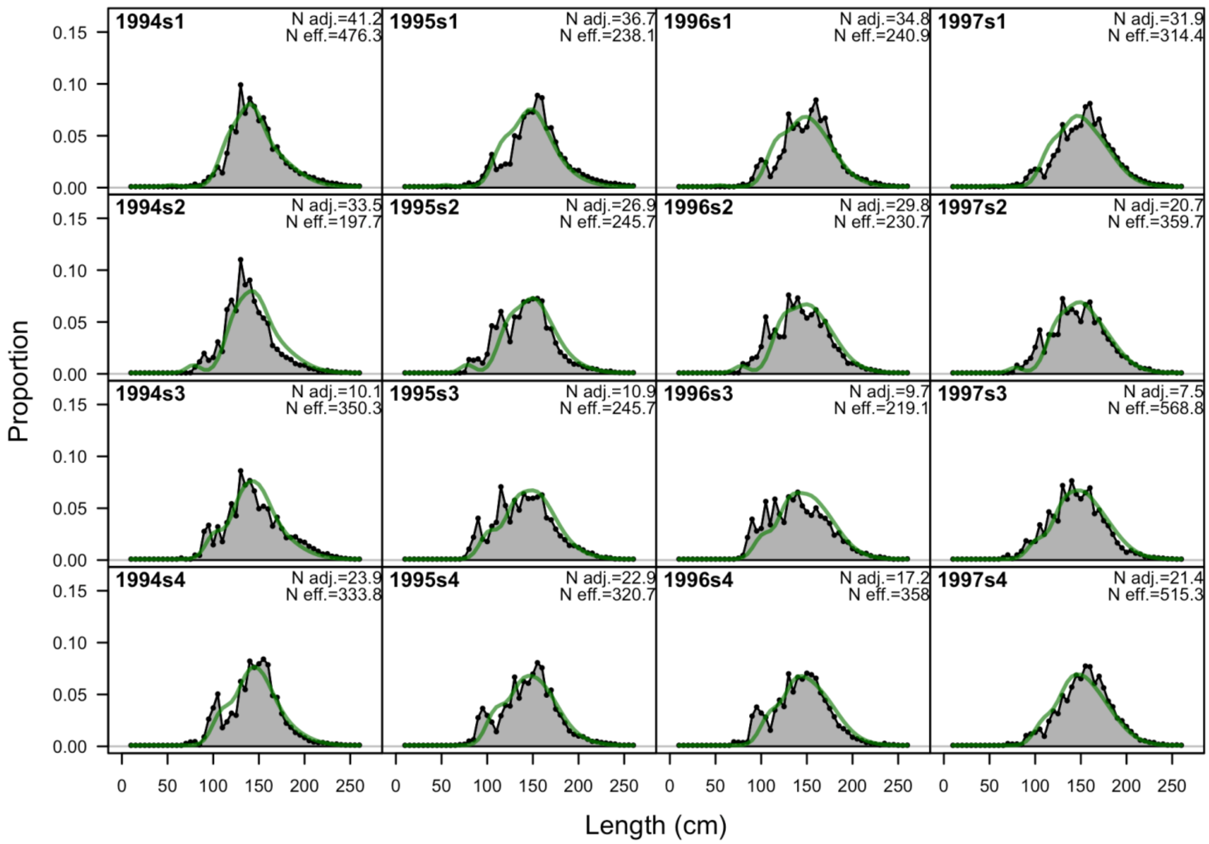


Figure 6.5.12. Fit to the length compositions from1998-2001 for fleet F2 with predicted (solid line) and observed (shaded area) values.

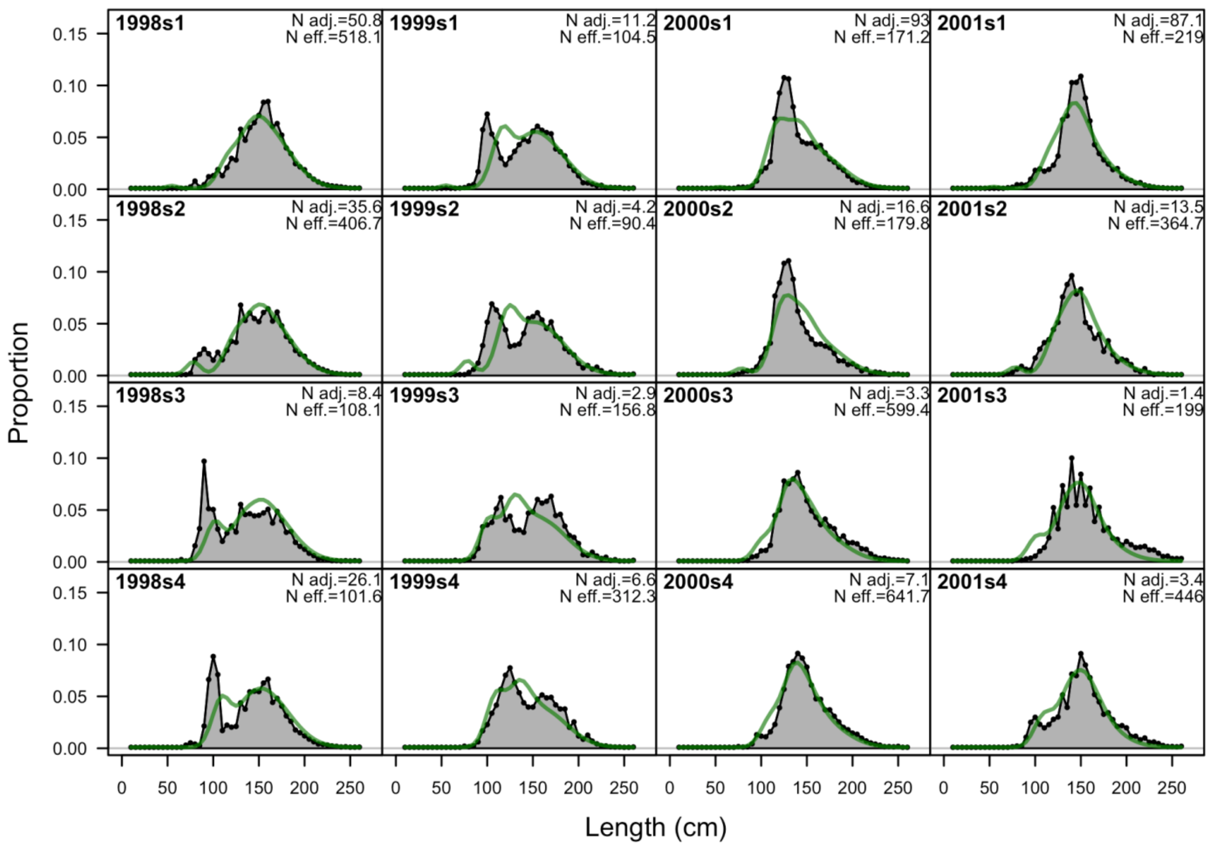


Figure 6.5.13. Fit to the length compositions from 2002-2005 for fleet F2 with predicted (solid line) and observed (shaded area) values.

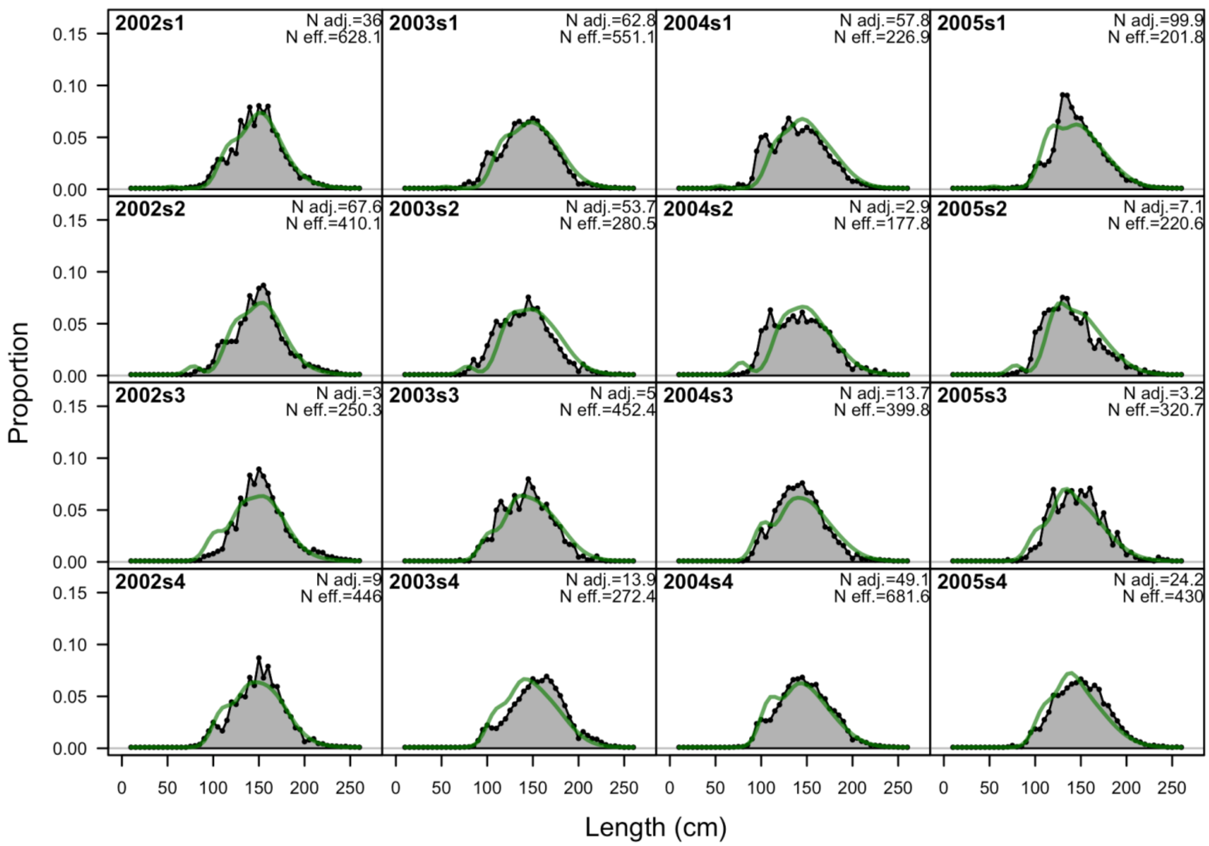


Figure 6.5.14. Fit to the length compositions from 2006-2009 for fleet F2 with predicted (solid line) and observed (shaded area) values.

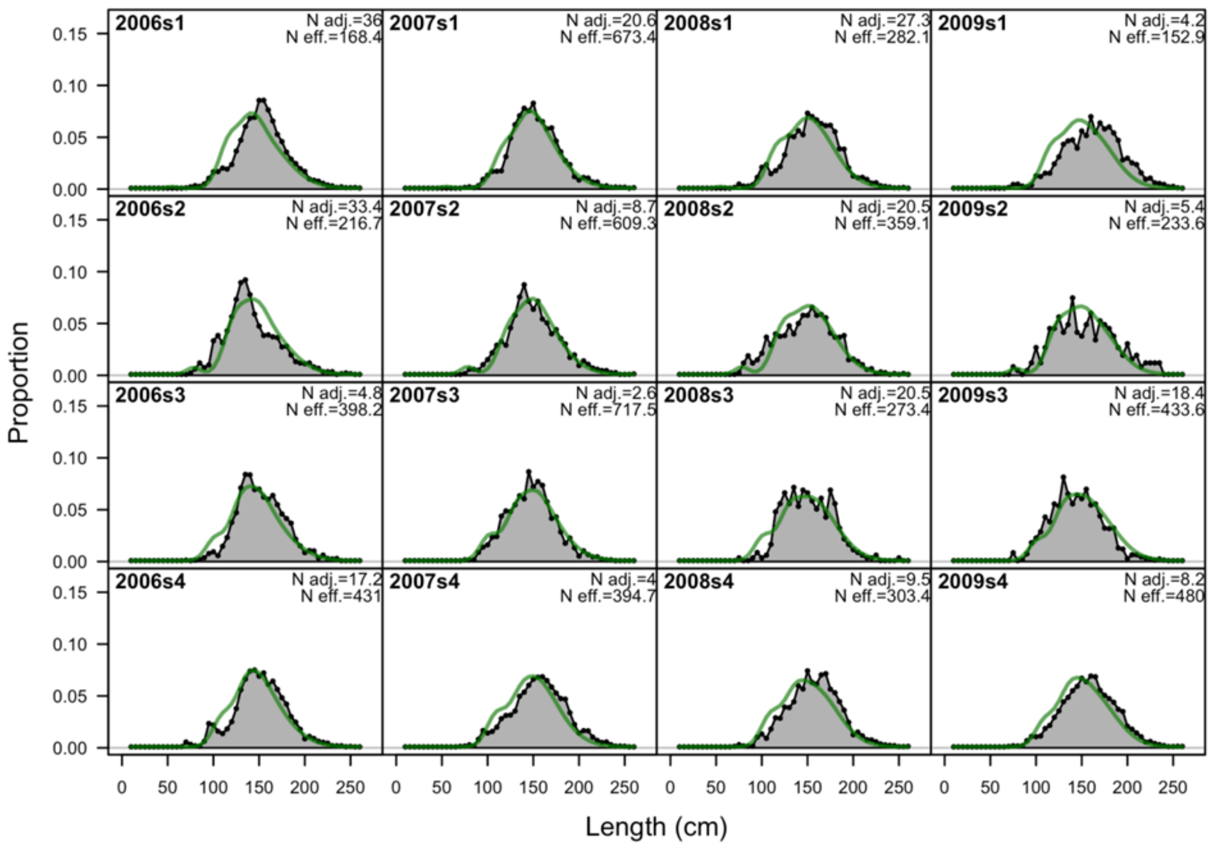


Figure 6.5.15. Fit to the length compositions from 2010-2013 for fleet F2 with predicted (solid line) and observed (shaded area) values.

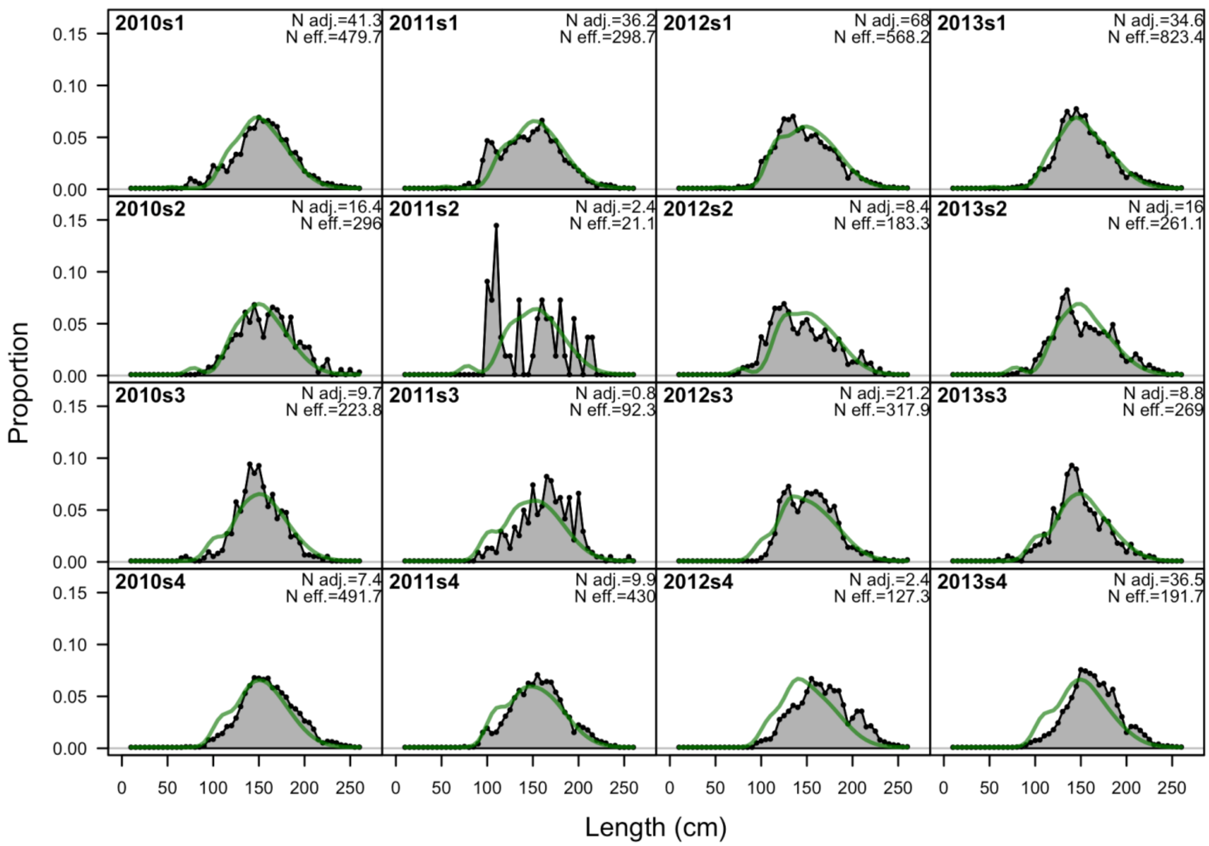
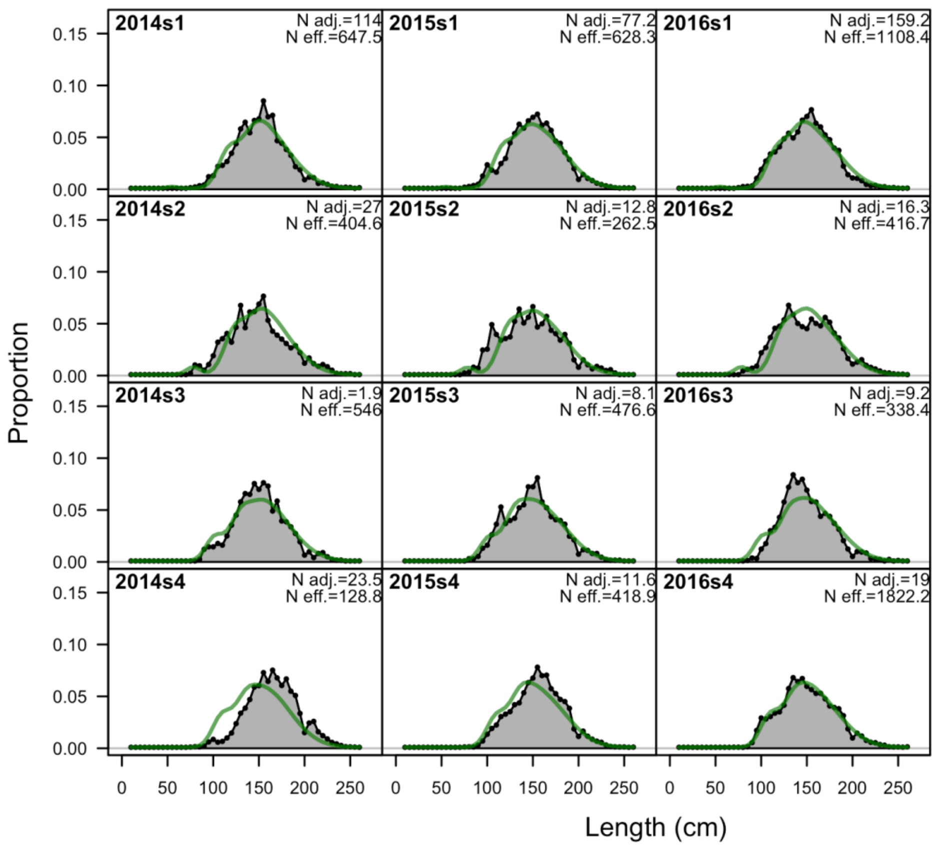


Figure 6.5.16. Fit to the length compositions from 2014-2016 for fleet F2 with predicted (solid line) and observed (shaded area) values.



Length Composition Fits: Fleet 10

Figure 6.5.17. Fit to the length compositions from 2004-2007 for fleet F10 with predicted (solid line) and observed (shaded area) values.

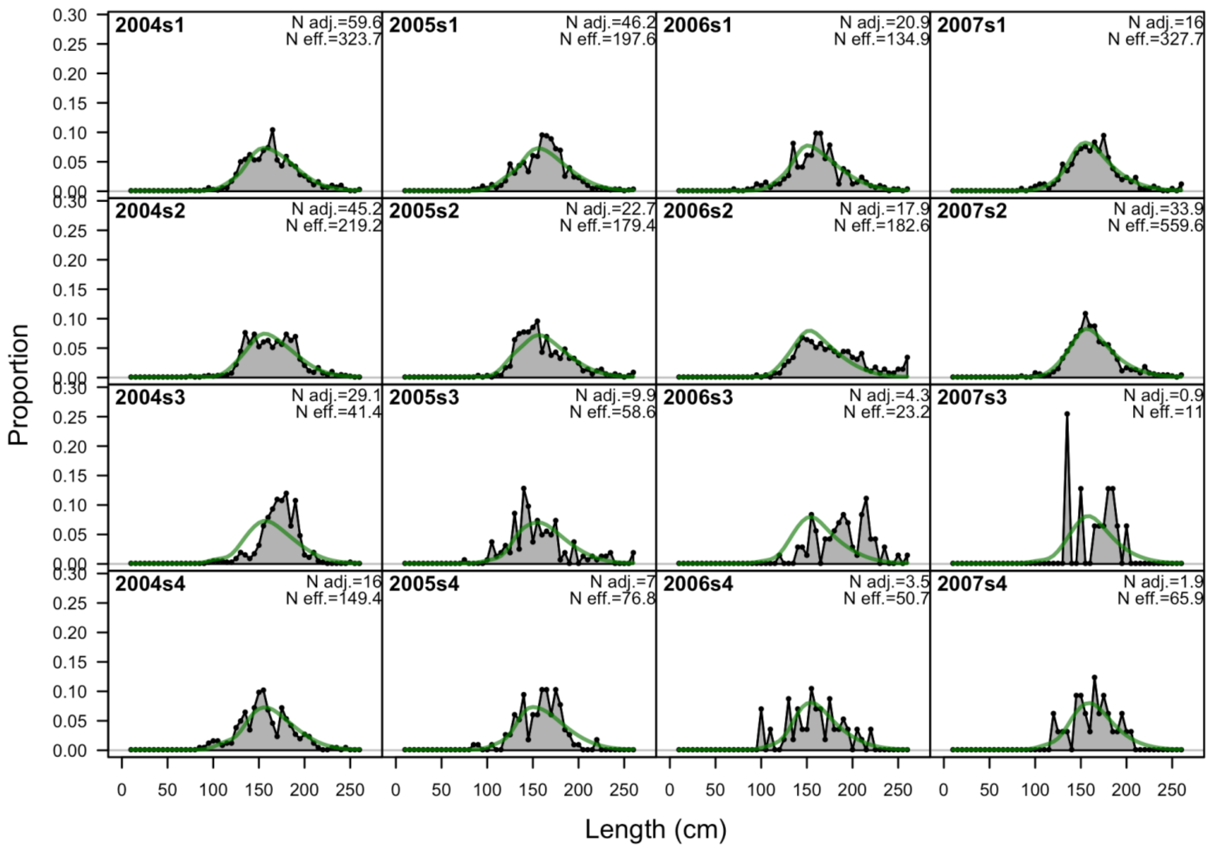


Figure 6.5.18. Fit to the length compositions from 2008-2011 for fleet F10 with predicted (solid line) and observed (shaded area) values.

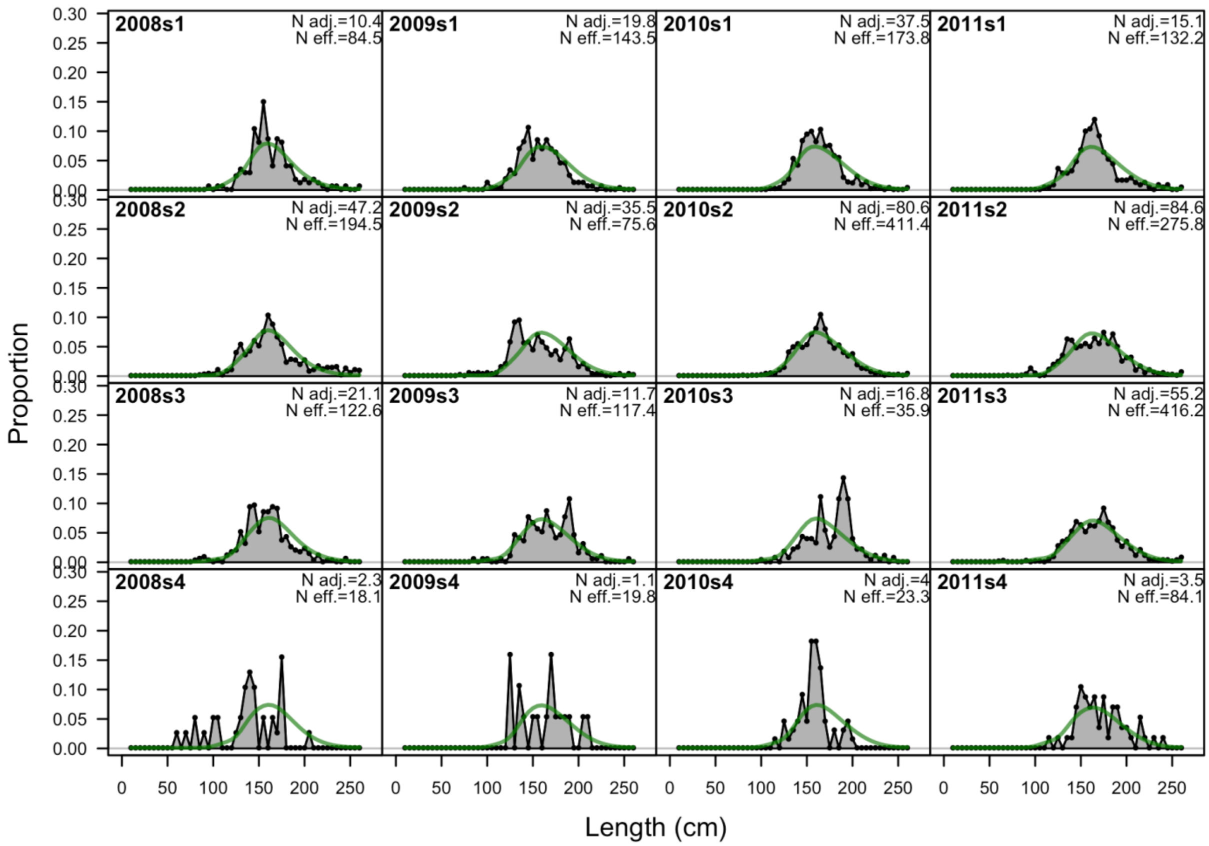


Figure 6.5.19. Fit to the length compositions from 2012-2016 for fleet F10 with predicted (solid line) and observed (shaded area) values.

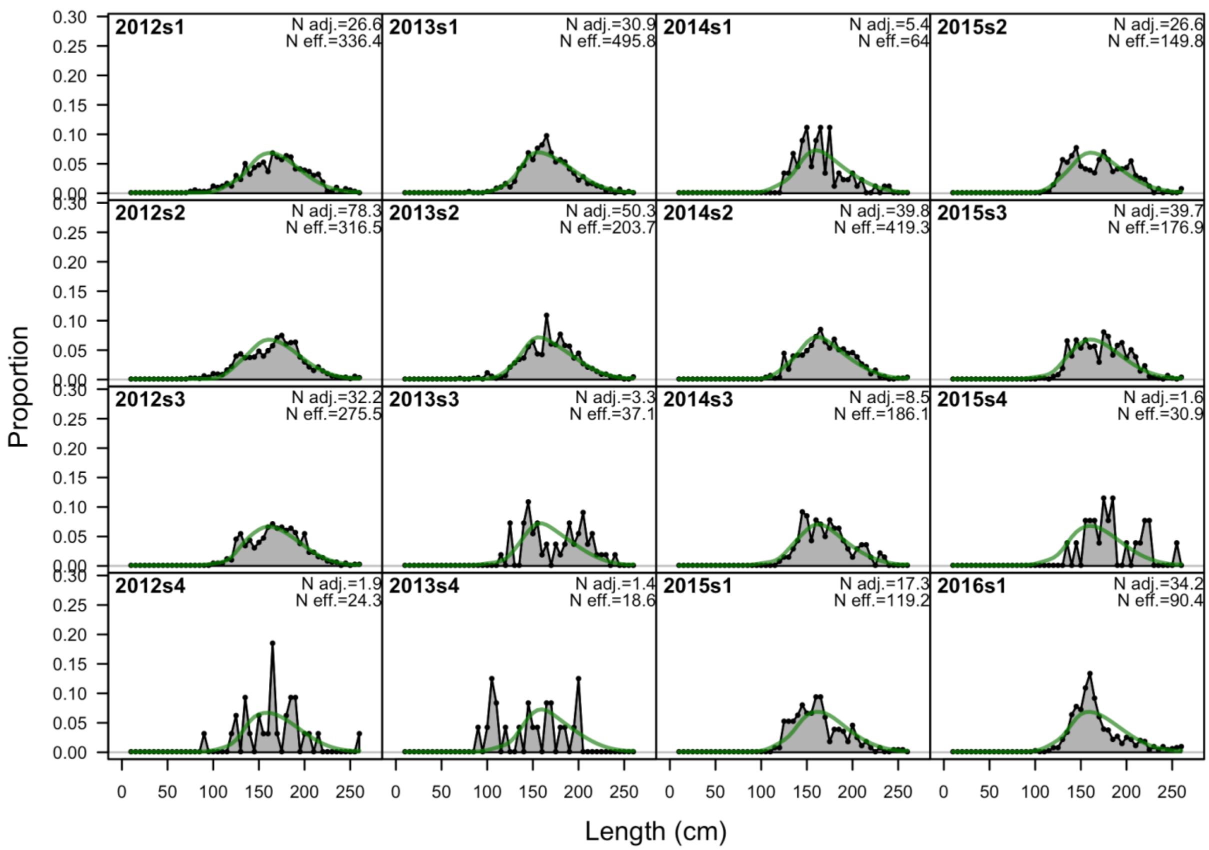
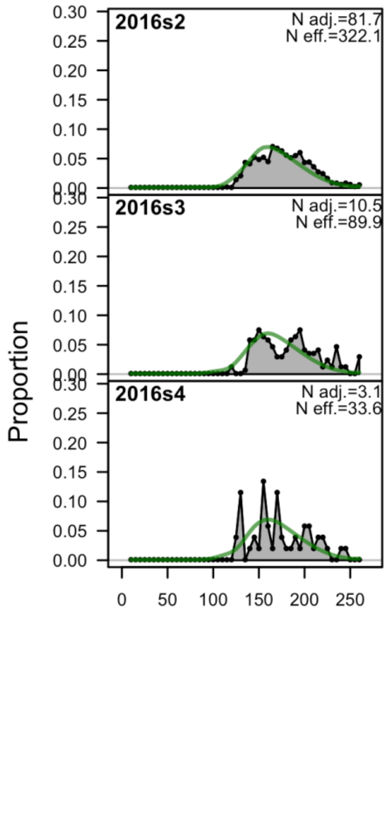


Figure 6.5.20. Fit to the length compositions from 2016 for fleet F10 with predicted (solid line) and observed (shaded area) values.



Length Composition Fits: Fleet 14

Figure 6.5.21. Fit to the length compositions from 2005-2009 for fleet F14 with predicted (solid line) and observed (shaded area) values.

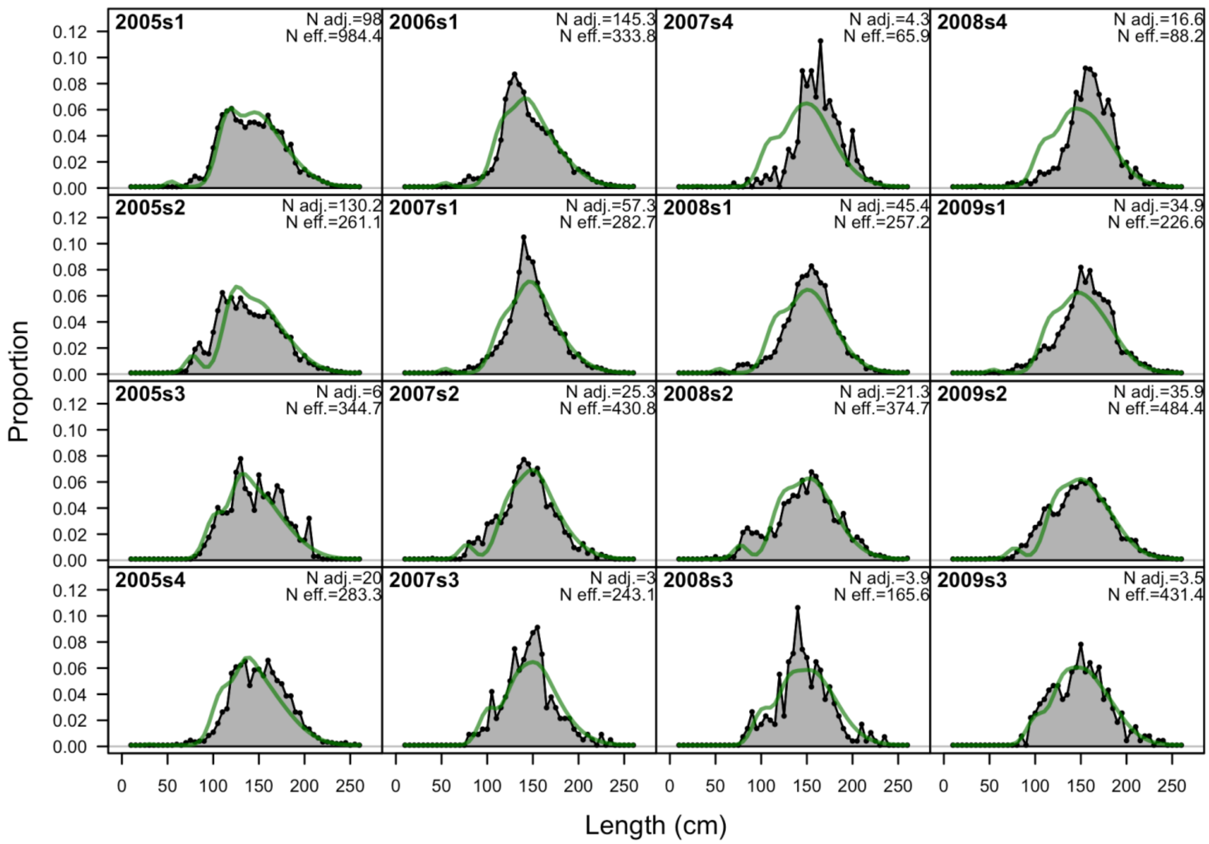


Figure 6.5.22. Fit to the length compositions from 2005-2009 for fleet F14 with predicted (solid line) and observed (shaded area) values.

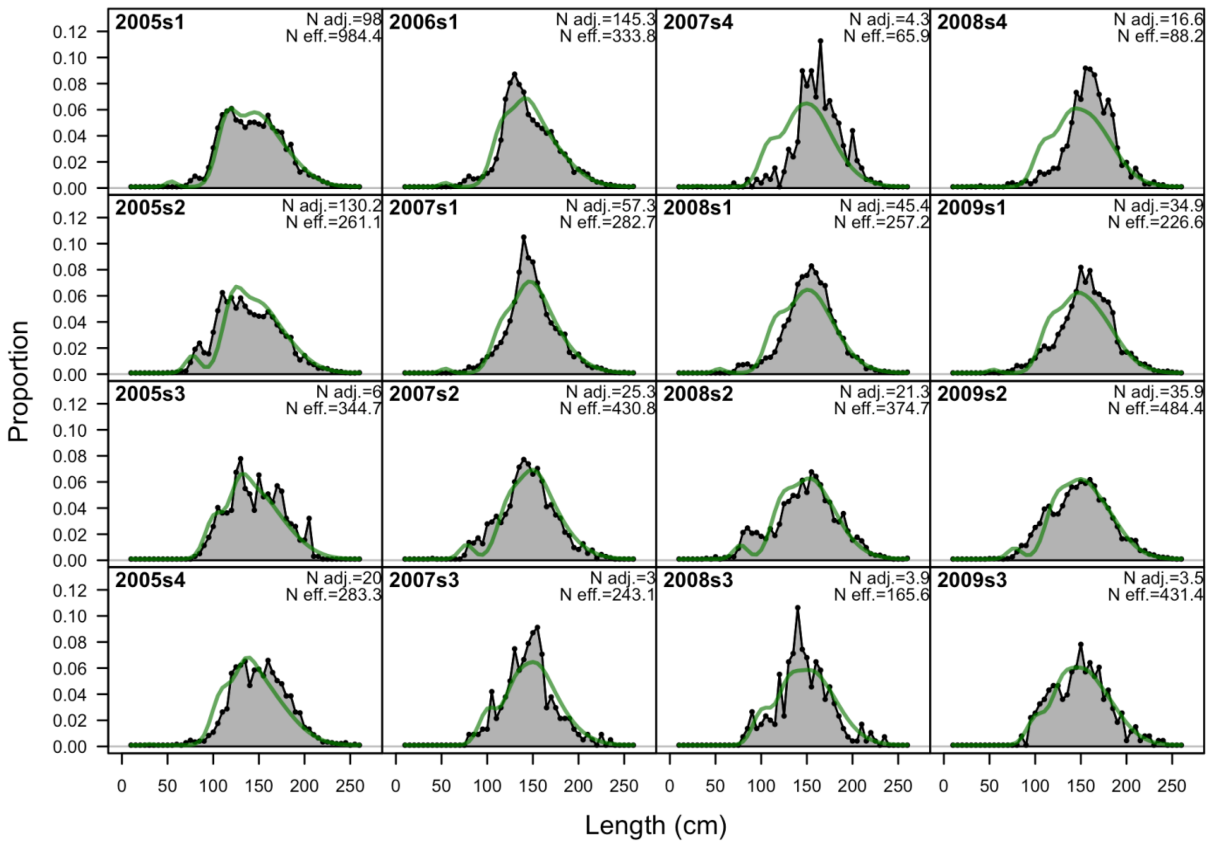


Figure 6.5.23. Fit to the length compositions from 2010-2014 for fleet F14 with predicted (solid line) and observed (shaded area) values.

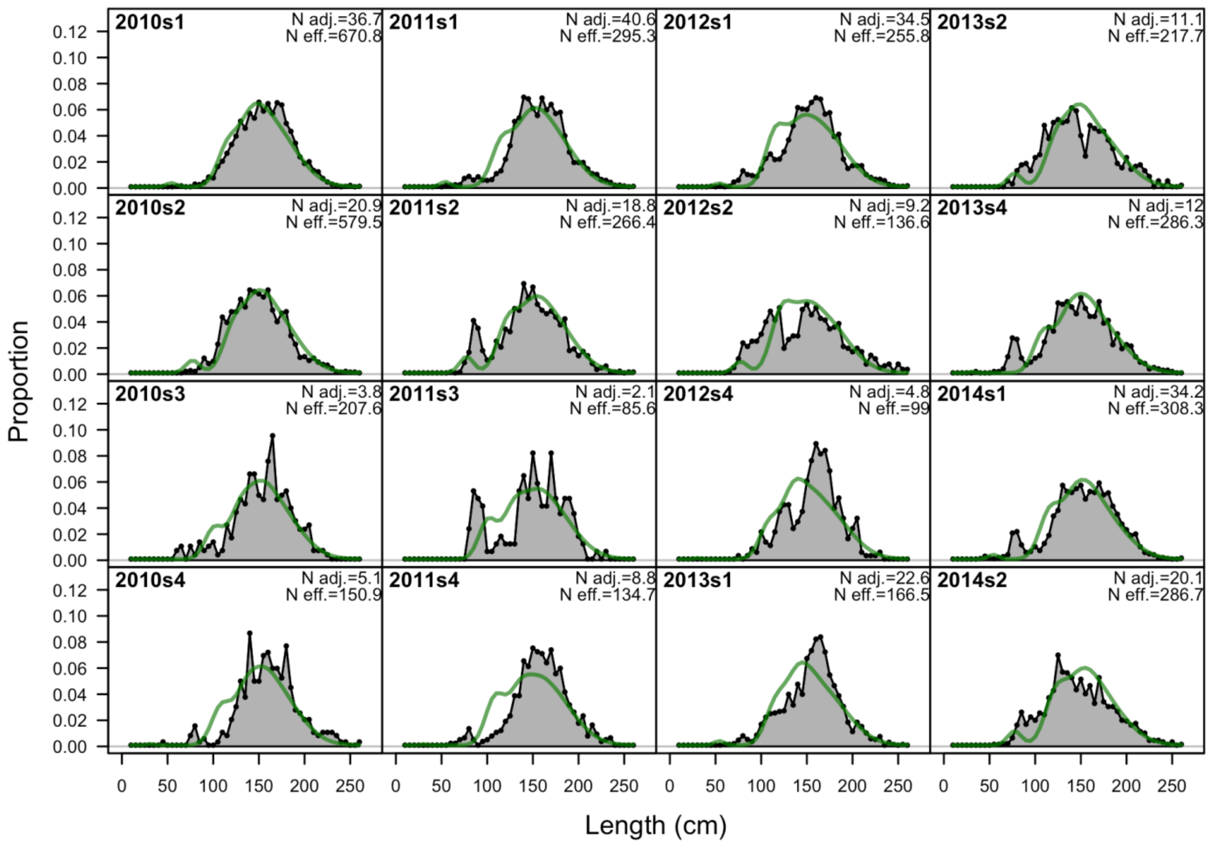
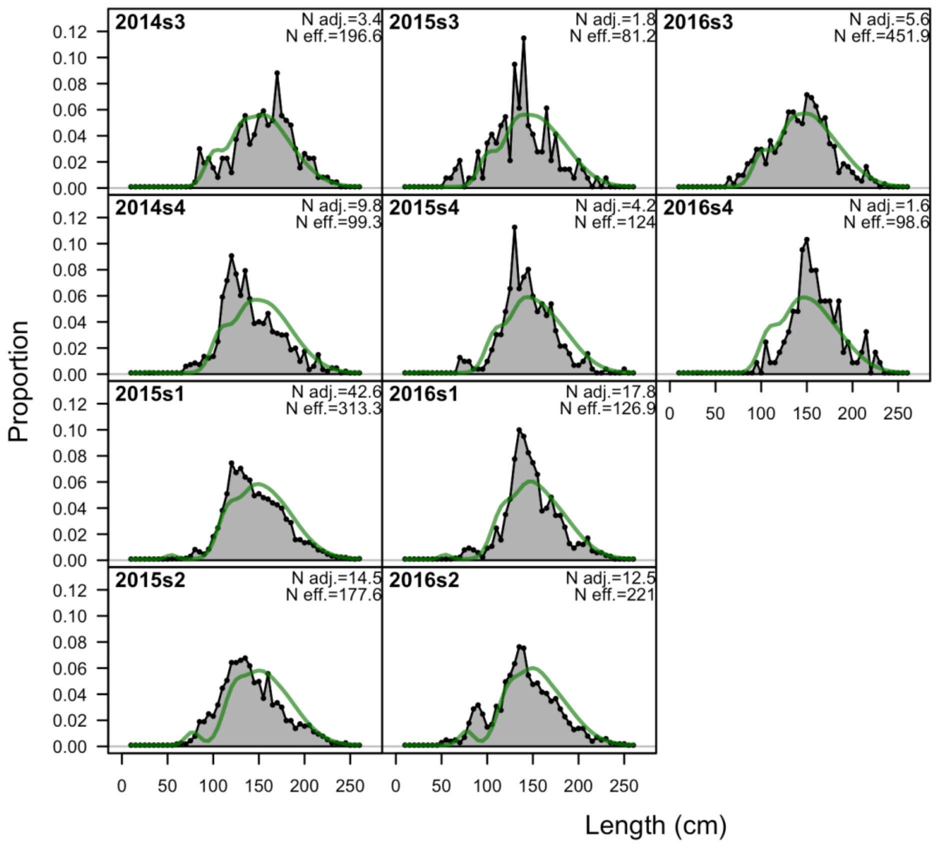


Figure 6.5.24. Fit to the length compositions from 2014-2016 for fleet F14 with predicted (solid line) and observed (shaded area) values.



Length Composition Fits: Fleet 18

Figure 6.5.25. Fit to the length compositions from 2009-2015 for fleet F18 with predicted (solid line) and observed (shaded area) values.

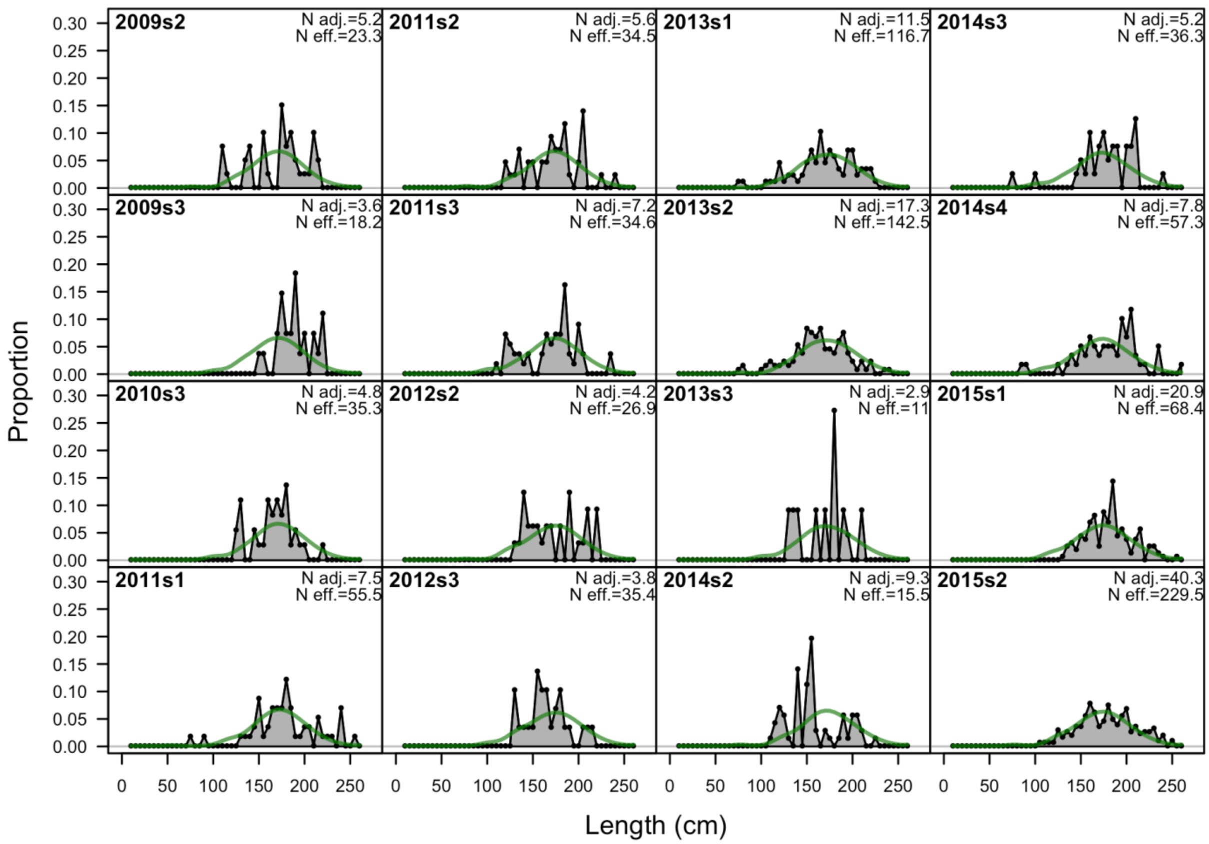
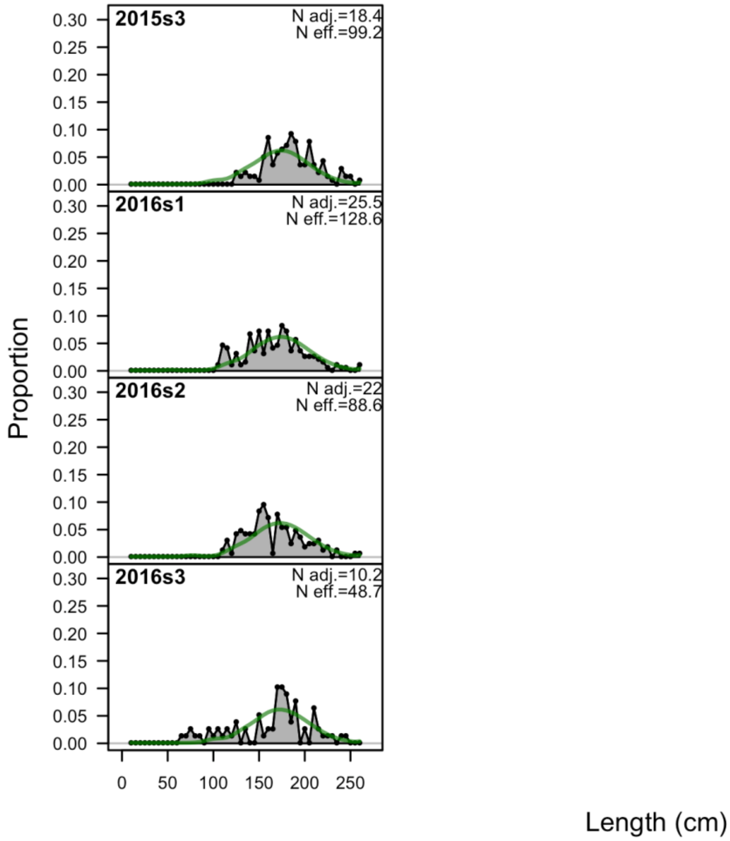


Figure 6.5.26. Fit to the length compositions from 2015-2016 for fleet F18 with predicted (solid line) and observed (shaded area) values.



Likelihood Profiles on R_0

Figure 6.5.27. Likelihood profile on the natural logarithm of unfished recruitment showing the total, length composition, survey and recruitment components of the negative log-likelihood for base case model.

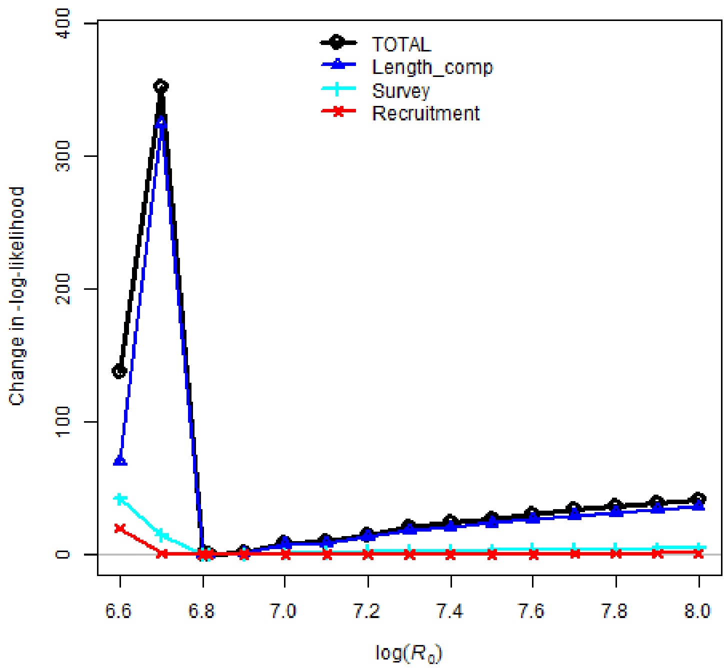


Figure 6.5.28. Likelihood profile on the natural logarithm of unfished recruitment showing the CPUE index components by fleet of the negative log-likelihood for base case model.

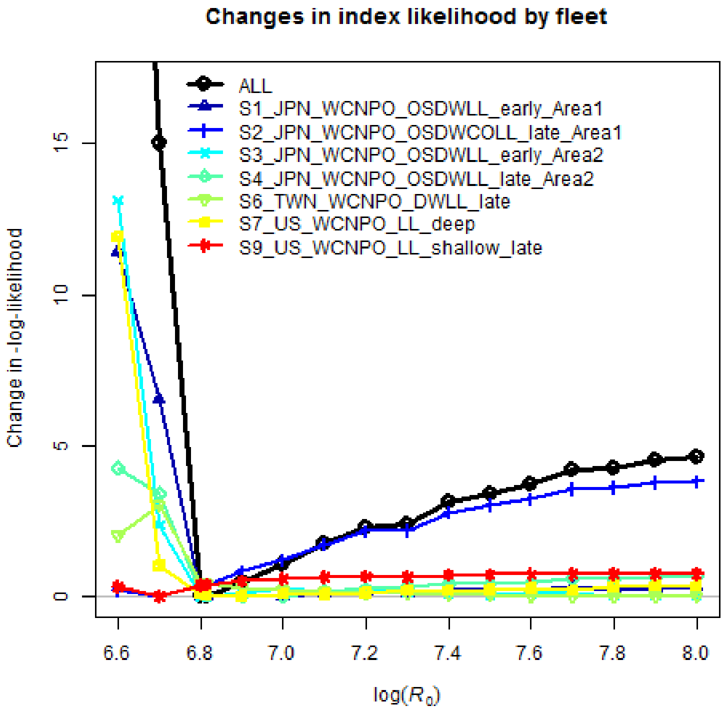
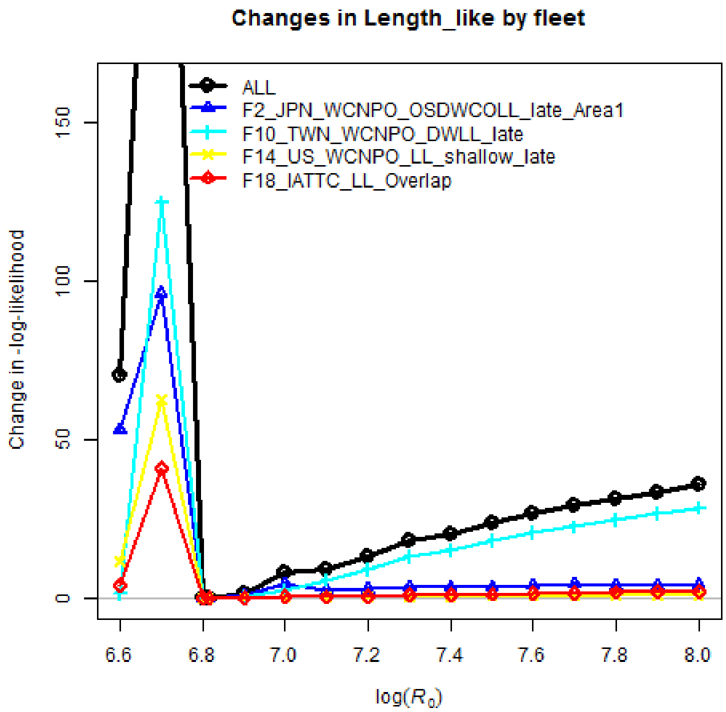
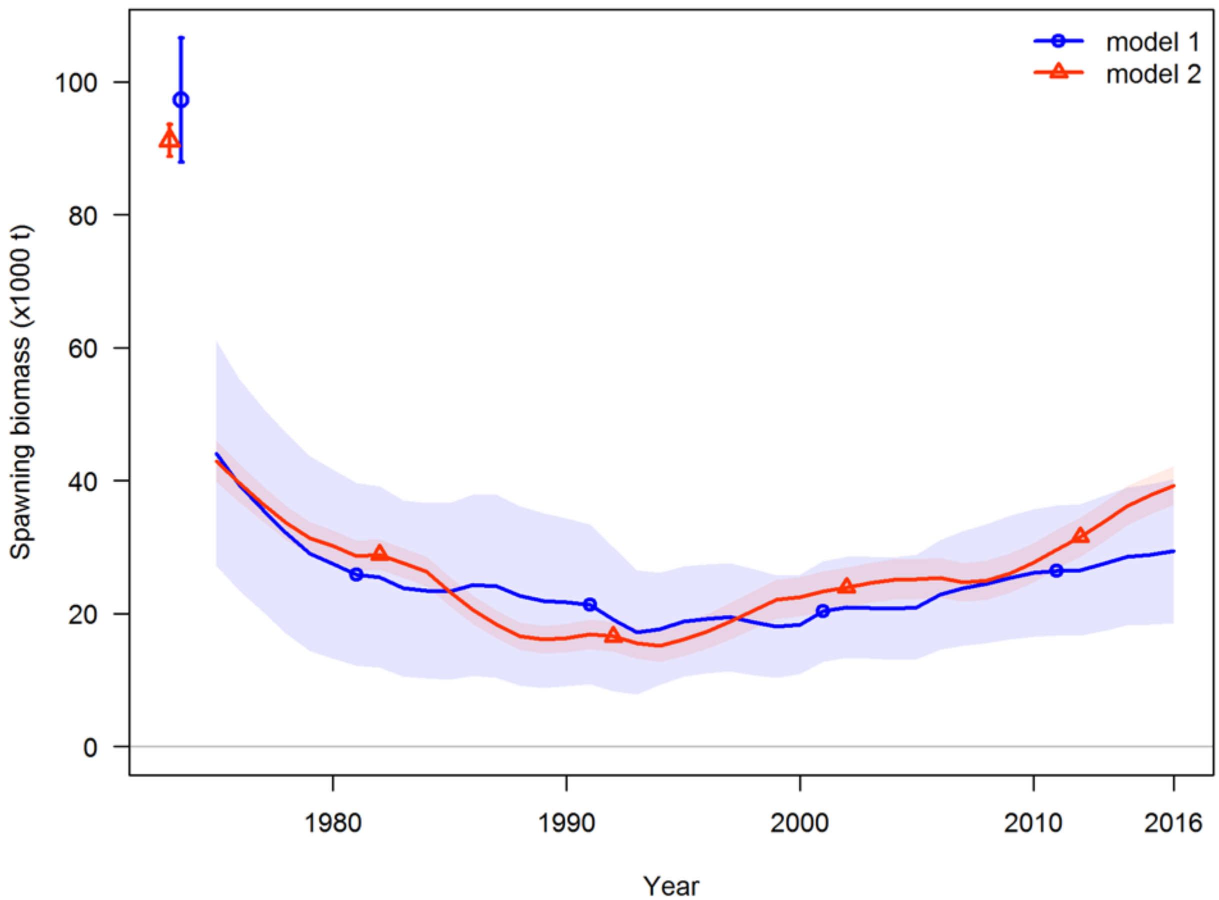


Figure 6.5.29. Likelihood profile on the natural logarithm of unfished recruitment showing the length composition components by fleet of the negative log-likelihood for base case model.



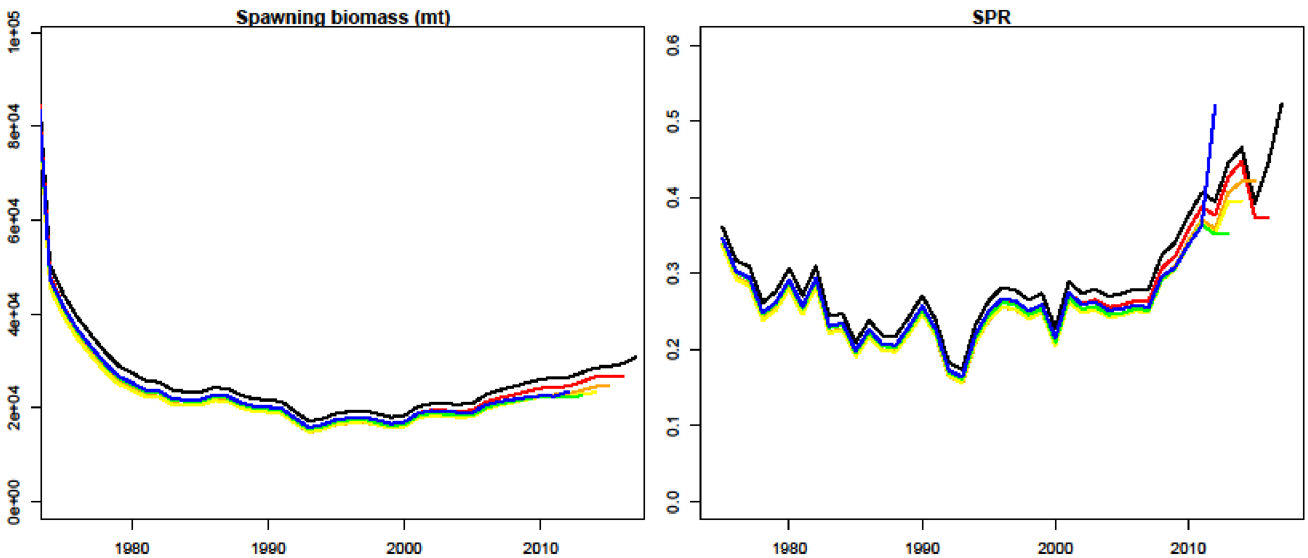
Age-Structured Production Model Diagnostic

Figure 6.5.30. The base case assessment (model 1, open blue circle) and the age-structured production model diagnostic (model 2, open red triangle) fitted without length composition data and with no recruitment deviations.



Retrospective Analysis

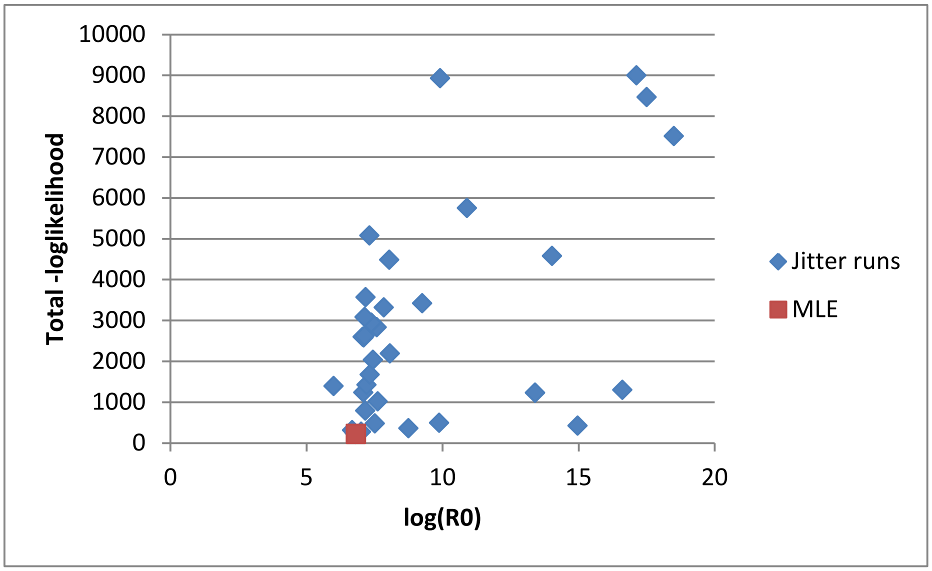
Figure 6.5.31. Retrospective analysis of spawning biomass and spawning potential ratio (SPR) consisting of 5 reruns of the base case model each fitted with one more year of data removed from the base case model (black line, 1975-2016).



Randomized Initial Parameter Value Diagnostic (Jitter Analysis)

Figure 6.5.32. Results of a randomized initial parameter value diagnostic for the base case model where 100 randomized initial conditions were used with a CV of 20% assigned to each

parameter. Results are shown for the base case model (MLE, solid red square) and for the base case model with randomized initial parameter values (Jitter runs, solid blue diamond) that had a fitted total negative log-likelihood value of less than 9,000.



6.6 Model Results

Results for the base case model provided estimates of biological reference points for WCNPO swordfish and included trends in estimates of total stock biomass, spawning stock biomass, recruitment, and fishing mortality, along with a Kobe plot indicating stock status over time.

Biological Reference Points

Biological reference points were computed for the SS3.30 base case model. Since most life history parameters for Western and Central North Pacific swordfish, including steepness, were reasonably well defined, the WG recommended that MSY-based biological reference points be used to assess stock status (Table 6.6.1). The point estimate of maximum sustainable yield was MSY = 14,942 metric tons. The point estimate of the female spawning stock biomass to produce MSY was SSB_{MSY} = 15,703 metric tons. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY on ages 1 to 10 fish was F_{MSY} = 0.17 (units are quarter^{-1}) and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

The WG agreed that the presentation of MSY-based biological reference points, SSB_{MSY} and F_{MSY}, was appropriate for the 2018 assessment of WCNPO swordfish. Assessment results showed that based on stock status relative to these MSY-based reference points, the stock is not overfished and is not experiencing overfishing.

Table 6.6.1. Estimated biological reference points derived from the base case model for WCNPO swordfish where F is the instantaneous annual fishing mortality rate, SPR is the annual spawning potential ratio, SSB is female spawning stock biomass, MSY indicates maximum sustainable yield, $F_{20\%}$ indicates the F that produces an SPR of 20%, $SSB_{20\%}$ is the corresponding equilibrium SSB at $F_{20\%}$,.

Reference Point	Estimate
F_{MSY}	0.68 yr^{-1}
$F_{0.2*SSB(F=0)}$	0.64 yr^{-1}
$F_{2013-2015}$	0.32 yr^{-1}
SSB_{MSY}	15,702 mt
SSB_{2016}	29,403 mt
$SSB_{F=0}$	97,286 mt
MSY	14,941 mt
$C_{2012-2016}$	10,160 mt
SPR_{MSY}	18%
SPR_{2016}	45%

Stock Status and Trends

Estimates of total stock biomass (age-1 and older) averaged roughly 86,207 metric tons during 1975-1979, exhibited a long-term decline to a low of 51,856 mt in 1998, before increasing to 71,979 metric tons in 2016. Spawning stock biomass declined from 44,100 mt in 1975 to about 17,191 mt in 1993, then increased to remain above 20,000 mt since 2001 and spawning biomass in 2016 totaled 29,404 mt. Fishing mortality (average F for ages 1 to 10) averaged roughly F = 0.12 during 1975-1984, then increased to an average of F=0.16 during 1985-1994 before declining to average of F=0.12 and F=0.10 during 1995-2004 and 2005-2014, respectively. The current fishing mortality is roughly $F_{2013\text{-}2015}$=0.08, or 44% of F_{MSY}. The predicted value of the current spawning potential ratio (SPR, the predicted spawning output at current F as a fraction of unfished spawning output) was $SPR_{2013\text{-}2015}$=57%. The annual recruitment (numbers of age-0 fish) during 1975-2016 averaged approximately 761,000 fish per year. While the overall pattern of swordfish recruitment was variable, we also found a significant positive correlation ρ=0.35 between recruitment success and El Nino strength as measured by the Oceanic Nino Index (P=0.025).

Discussion

The WG agreed that the use of MSY-based biological reference points, SSB_{MSY} and F_{MSY}, was appropriate for the 2018 assessment of Western and Central North Pacific swordfish. Assessment results showed that based on stock status relative to these MSY-based reference points, the stock is not overfished and is not experiencing overfishing.

Special Comments

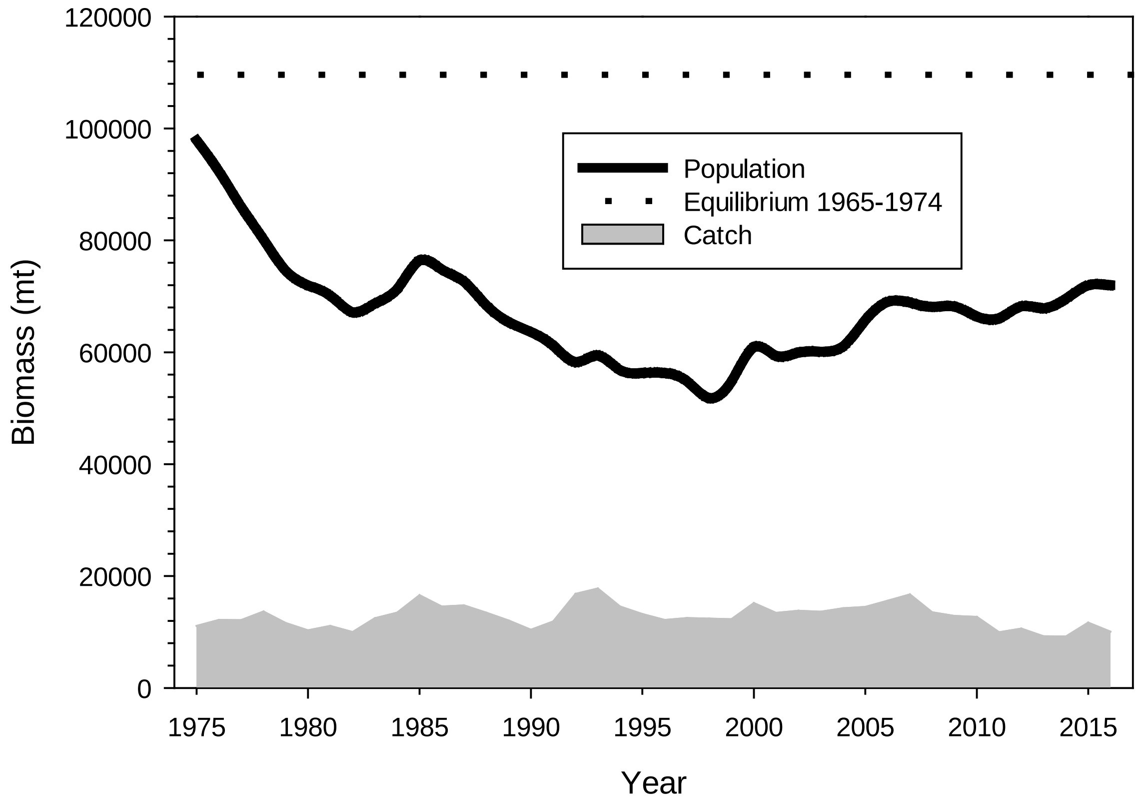
The WG noted that the lack of sex-specific size data and the simplified treatment of the spatial structure of swordfish population dynamics remained as two important sources of uncertainty for improving future assessments.

Table 6.6.2. Stock status and trends relative to MSY-based reference points.

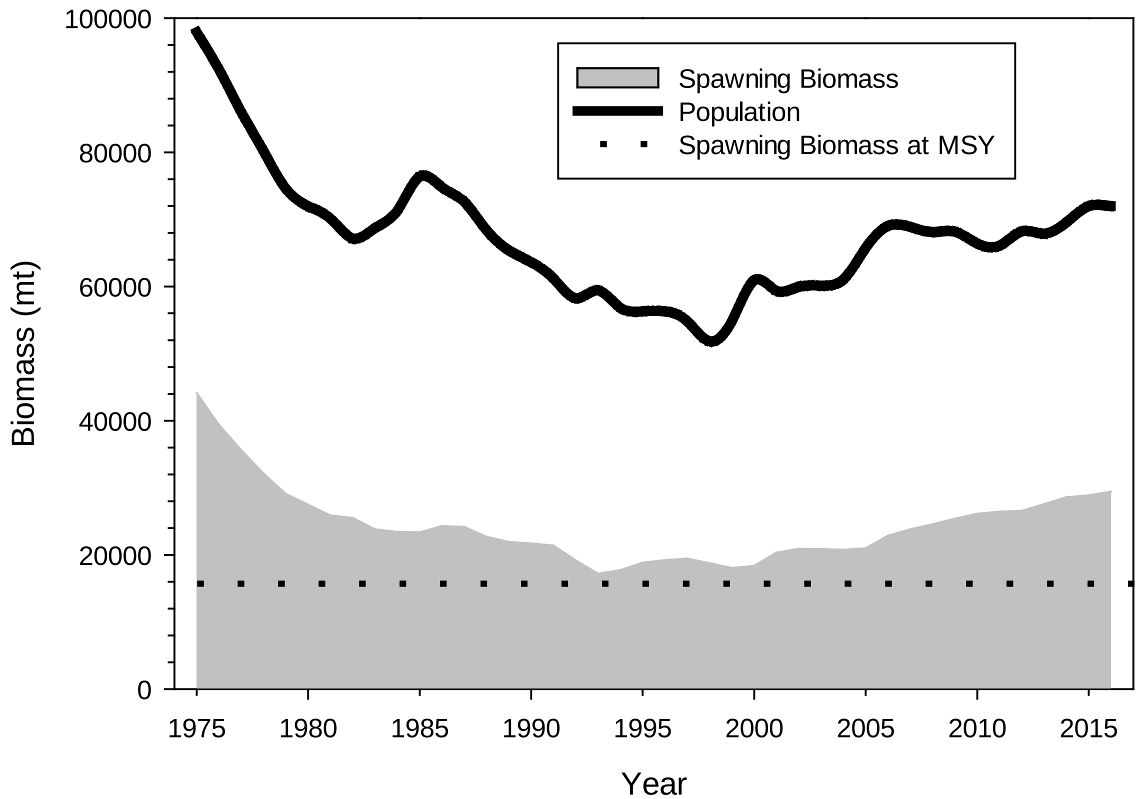
Year	Spawning Biomass (mt)	Spawning Biomass StDev	Relative Spawning Biomass	Relative Spawning Biomass StDev	Fishing Mortality	Fishing Mortality StDev	Relative Fishing Mortality	Relative Fishing Mortality StDev
1975	44100	8638	2.81	0.55	0.10	0.02	0.62	0.12
1976	39375	8115	2.51	0.52	0.12	0.02	0.70	0.14
1977	35617	7816	2.27	0.50	0.12	0.02	0.74	0.15
1978	32091	7697	2.04	0.49	0.14	0.03	0.82	0.17
1979	29057	7489	1.85	0.48	0.13	0.03	0.77	0.15
1980	27485	7253	1.75	0.46	0.12	0.02	0.69	0.14
1981	25871	7008	1.65	0.45	0.13	0.03	0.78	0.16
1982	25512	6953	1.62	0.44	0.11	0.03	0.65	0.15
1983	23811	6753	1.52	0.43	0.13	0.03	0.74	0.18
1984	23426	6730	1.49	0.43	0.12	0.03	0.70	0.15
1985	23356	6763	1.49	0.43	0.16	0.03	0.93	0.19
1986	24286	6946	1.55	0.44	0.15	0.03	0.89	0.18
1987	24154	7029	1.54	0.45	0.17	0.03	0.98	0.20
1988	22691	6876	1.44	0.44	0.16	0.03	0.92	0.19
1989	21921	6708	1.40	0.43	0.14	0.03	0.82	0.16
1990	21709	6454	1.38	0.41	0.13	0.02	0.79	0.14
1991	21373	6116	1.36	0.39	0.16	0.03	0.93	0.16
1992	19156	5522	1.22	0.35	0.15	0.02	0.88	0.12
1993	17191	4768	1.09	0.30	0.18	0.02	1.05	0.15
1994	17716	4320	1.13	0.28	0.15	0.02	0.87	0.12
1995	18832	4219	1.20	0.27	0.13	0.02	0.78	0.10
1996	19224	4191	1.22	0.27	0.13	0.02	0.77	0.10
1997	19451	4163	1.24	0.27	0.14	0.02	0.85	0.11
1998	18745	4081	1.19	0.26	0.11	0.02	0.68	0.09
1999	18039	3936	1.15	0.25	0.10	0.01	0.58	0.07
2000	18365	3815	1.17	0.24	0.15	0.02	0.86	0.11
2001	20322	3857	1.29	0.25	0.12	0.01	0.71	0.09
2002	20911	3889	1.33	0.25	0.12	0.01	0.72	0.09
2003	20866	3908	1.33	0.25	0.12	0.01	0.70	0.09
2004	20767	3939	1.32	0.25	0.11	0.01	0.63	0.08
2005	20990	4025	1.34	0.26	0.11	0.01	0.65	0.08
2006	22848	4215	1.46	0.27	0.13	0.02	0.75	0.09
2007	23811	4404	1.52	0.28	0.13	0.02	0.74	0.09
2008	24557	4573	1.56	0.29	0.11	0.01	0.63	0.08
2009	25392	4743	1.62	0.30	0.11	0.01	0.64	0.09
2010	26136	4891	1.66	0.31	0.10	0.01	0.57	0.08
2011	26448	4987	1.68	0.32	0.08	0.01	0.46	0.06
2012	26569	5056	1.69	0.32	0.09	0.01	0.51	0.07
2013	27546	5179	1.75	0.33	0.07	0.01	0.44	0.06
2014	28580	5295	1.82	0.34	0.07	0.01	0.40	0.06
2015	28865	5393	1.84	0.34	0.09	0.01	0.51	0.07
2016	29404	5533	1.87	0.35	0.07	0.01	0.44	0.07

Figure 6.6.1. Time series of estimates of **(a)** population and catch biomass (age 1 and older), **(b)** population and spawning biomass, **(c)** spawning biomass and its precision, **(d)** recruitment (age-0 fish), **(e)** spawning potential ratio, and **(f)** instantaneous fishing mortality (quarter^{-1}) for WCNPO swordfish along with **(g)** the positive association between recruitment success and the Oceanic Nino Index. The solid line with circles represents the maximum likelihood estimates for each quantity and the shadowed area represents the uncertainty of the estimates (80% confidence intervals). The solid horizontal lines indicated the MSY-based reference points.

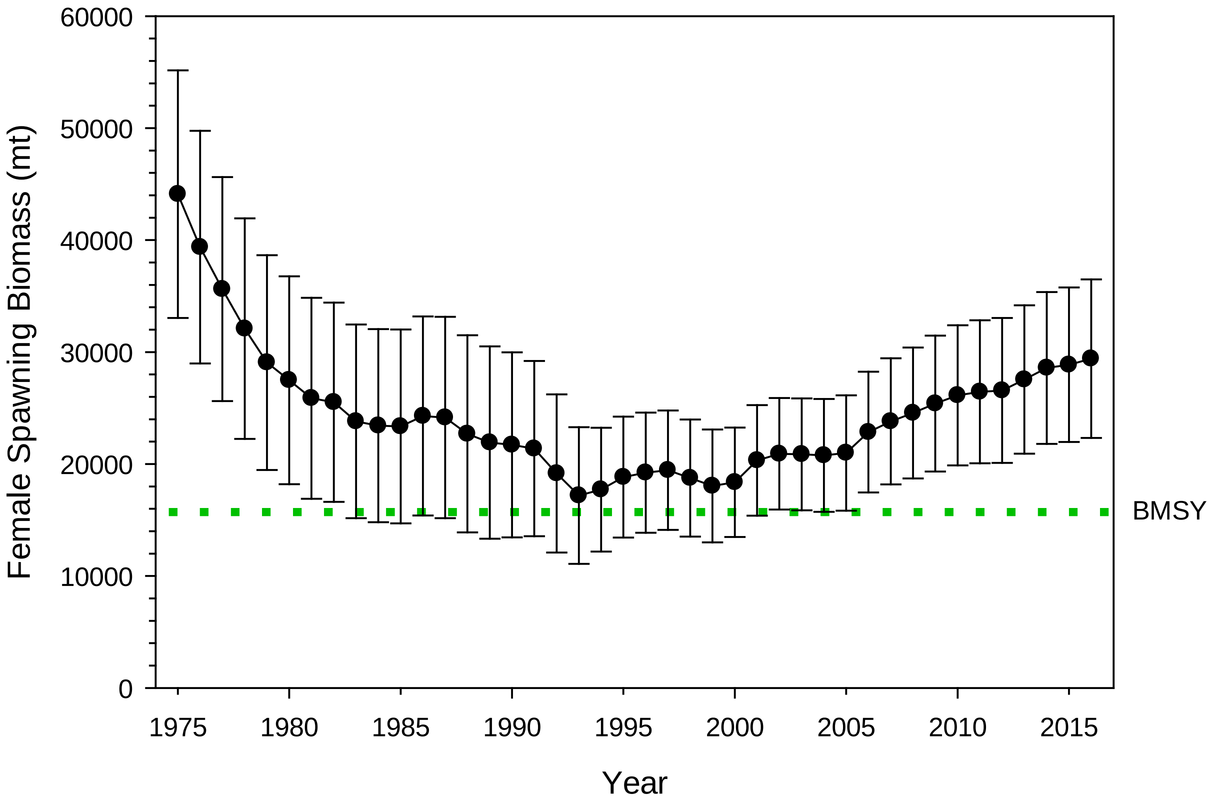
(a)



(b)

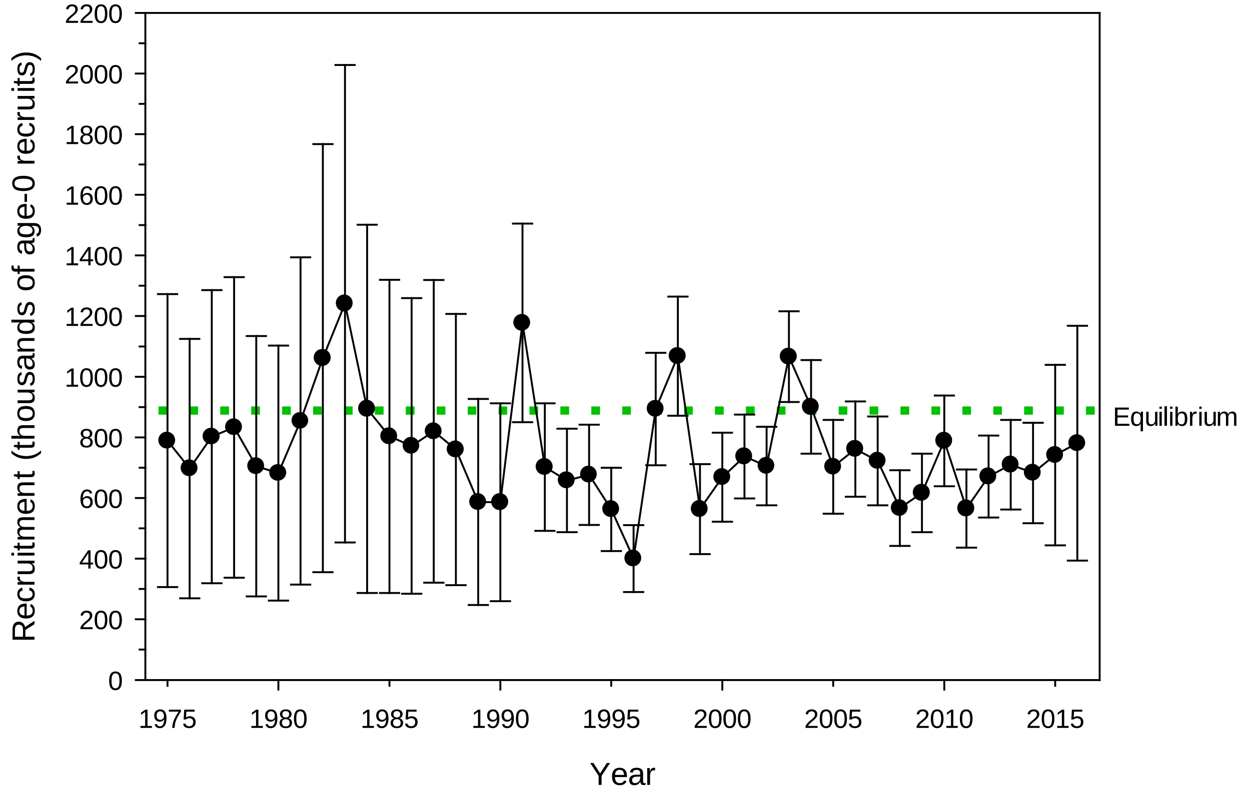

100000
80000
60000
40000
20000
0
Biomass (mt)
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
Spawning Biomass
Population
Spawning Biomass at MSY

(c)

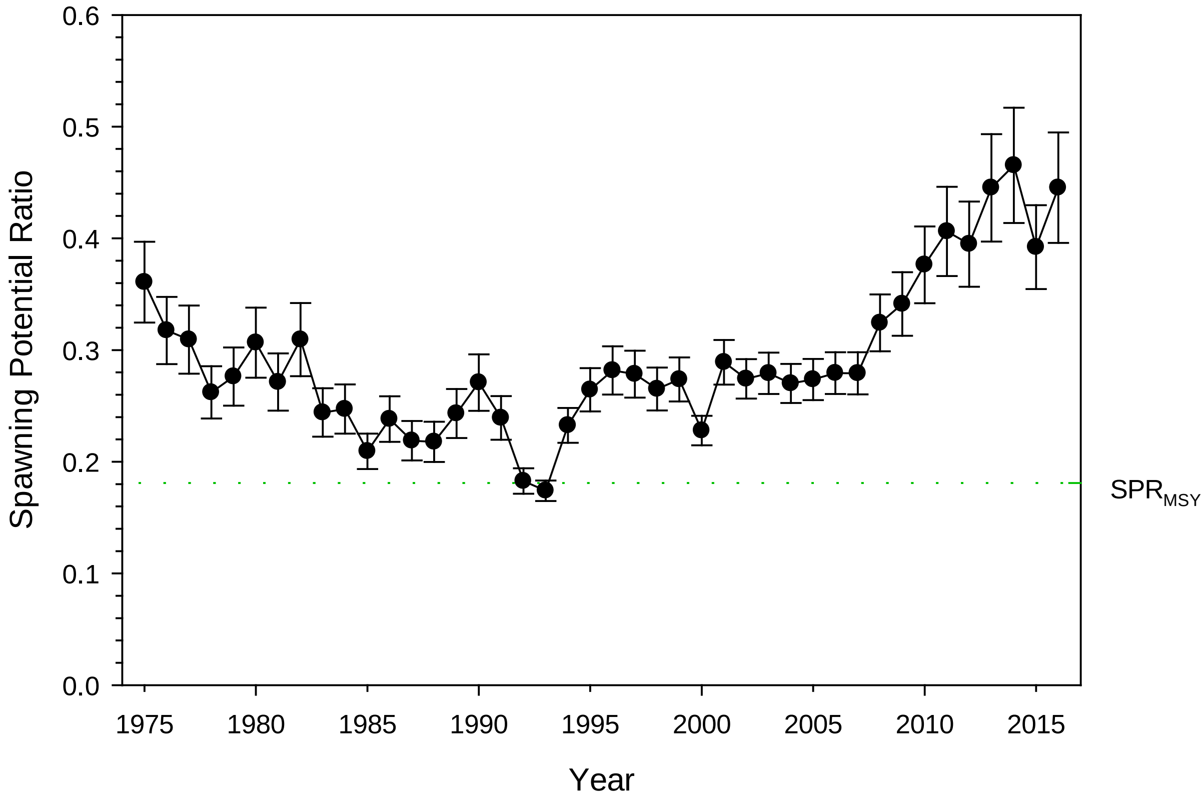


60000
50000
40000
30000
20000
10000
0
Female Spawning Biomass (mt)
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
BMSY

(d)

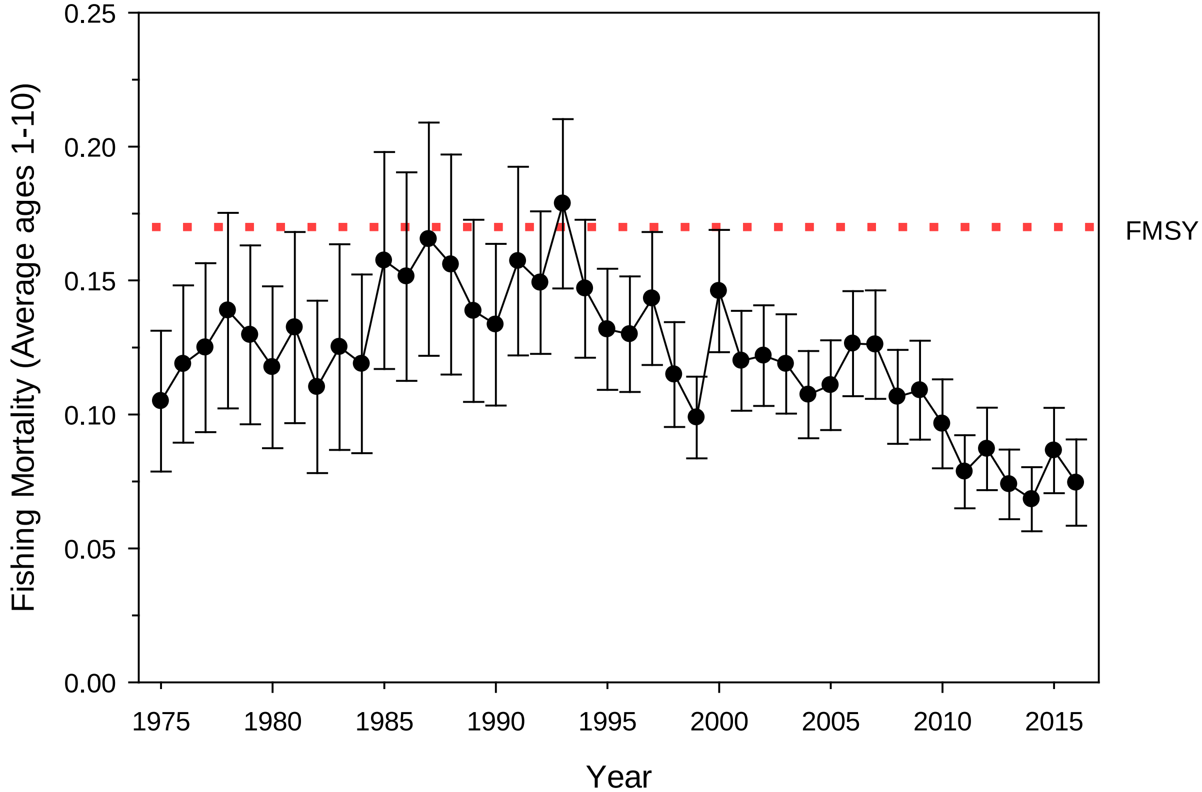

Recruitment (thousands of age-0 recruits)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
Equilibrium

(e)

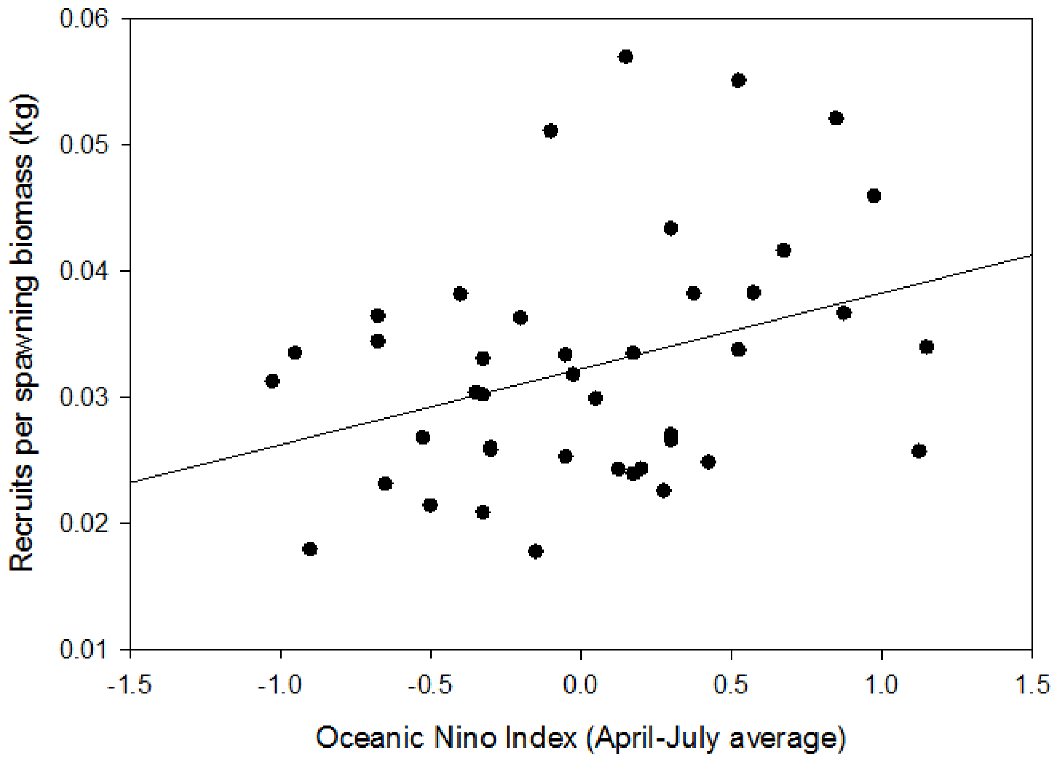


0.6
0.5
0.4
0.3
0.2
0.1
0.0
Spawning Potential Ratio
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
SPR$_{MSY}$

(f)

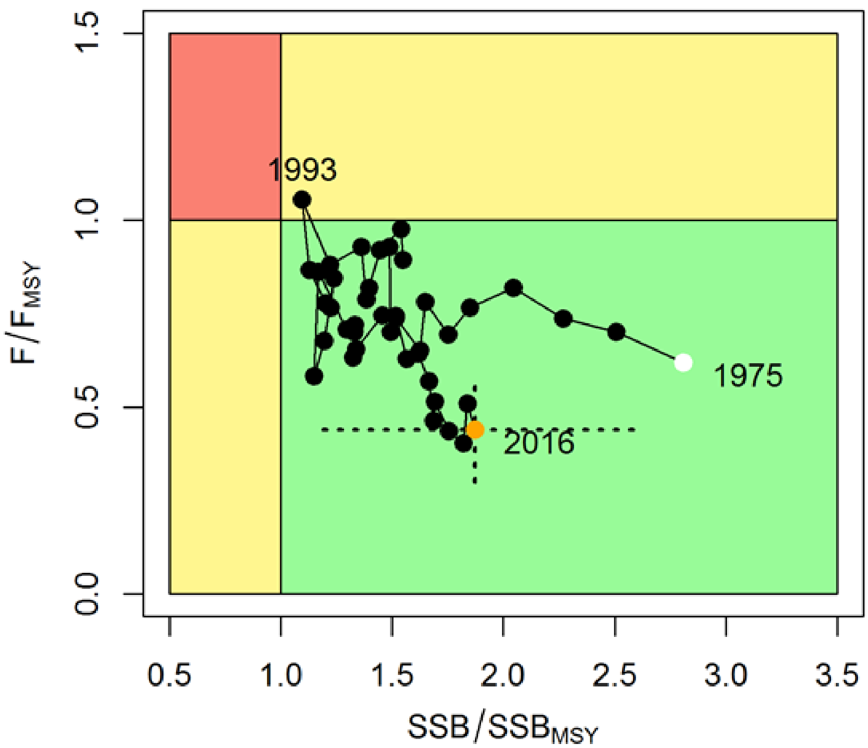

0.25
0.20
0.15
0.10
0.05
0.00
Fishing Mortality (Average ages 1-10)
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year
FMSY

(g)



Overall, the WG concluded that, relative to MSY-based reference points, the Western and Central North Pacific Ocean swordfish stock is currently not overfished and is not subject to overfishing (Figure 6.6.2).

Figure 6.6.2. Kobe plot indicating stock status of WCNPO swordfish as estimated relative to MSY-based reference levels in the 2018 stock assessment.



<u>Conservation Advice</u>

The WCNPO swordfish stock has produced annual yields of around 10,200 mt per year since 2012, or about 2/3 of the MSY catch amount. This suggests the stock may be able to support somewhat higher yields. Swordfish stock status is positive with no evidence of excess fishing mortality above F_{MSY} ($F_{Current}$ is 45% of F_{MSY}) or substantial depletion of spawning potential ($SSB_{Current}$ is 87% above SSB_{MSY}). It was also noted that retrospective analyses show that the assessment model appears to underestimate spawning potential in recent years.

6.7 Sensitivity Analyses

The working group agreed to run sensitivity analyses on four different model configurations.

(1) Sensitivity analysis on natural mortality: The WG agreed to conduct two sensitivity analyses for natural mortality at age. These were a low natural mortality scenario where M at age was 10% lower than the base case for each age group and a high natural mortality scenario where M at age was 10% higher than the base case for each age.

(2) Sensitivity analysis on steepness: The WG agreed to run two additional sensitivity runs on steepness, steepness was fixed at ± 10% of the value in the base-case model, or h=0.81 and h=0.99. In addition the WG agreed to use a steepness of h=0.7 which reflected a lower bound on stock resilience that was consistent with the reproductive longevity of swordfish of approximately $1/M_{4+} \approx 4.5$ years (i.e., Myers et al 2002, Figure 5).

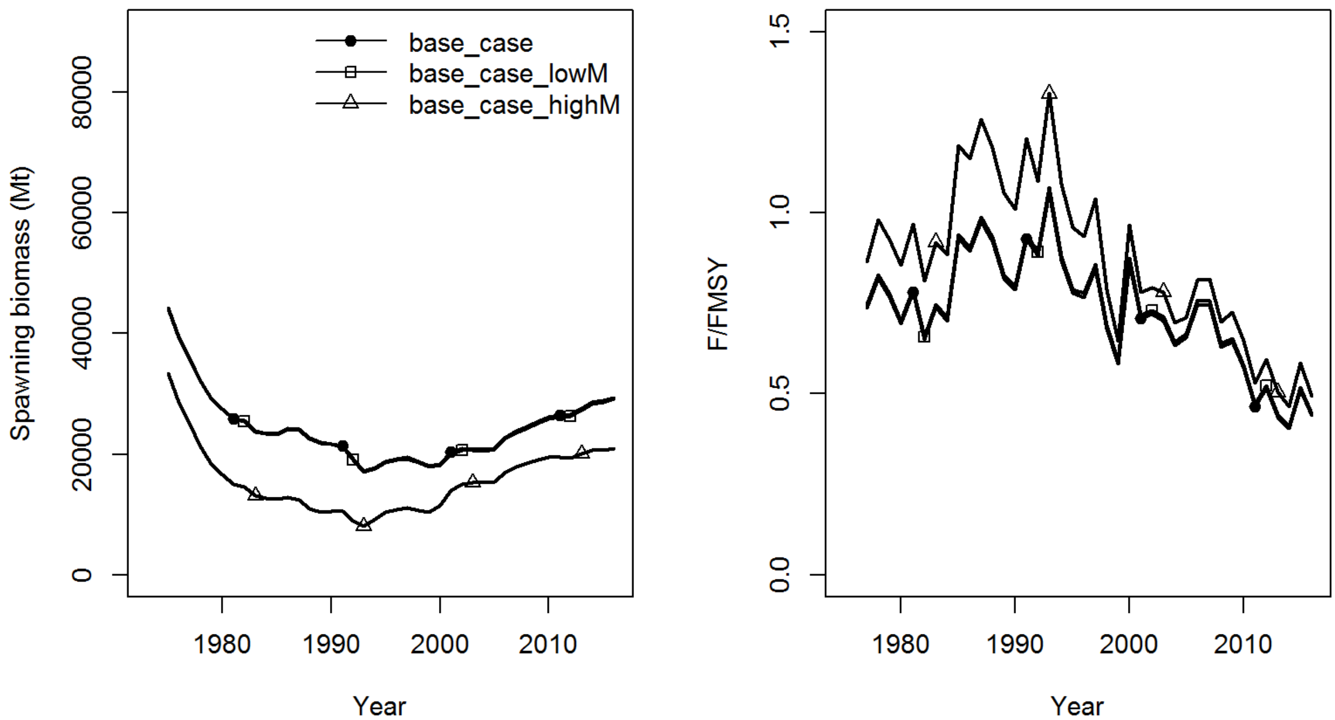
(3) Sensitivity analysis on growth: The group agreed to use an alternative growth curve described in Sun et al. (2002). This growth curve estimates a smaller maximum size for females and males. The new input parameters for SS3.30 were L_1 = 78.42 EFL (males) and 79.7 EFL (females); k = 0.198 (males) and 0.13 (females); L_{15} = 179.7 (males) and 216 (females). A 10% increase in L_1 and L_{15} was used for a second sensitivity run, setting k equal to the base-case value to explore the results if growth was underestimated. The 10% larger parameters for L_1 = 108.9 (males) 107.7 (females) and for L_{15} = 226 (males) and 248.7 (females).

(4) Sensitivity analysis on maturity: The group agreed to run sensitivity analyses using the maturity ogive in Wang et al. (2003) and also using the length at 50% maturity (L50) set to ± 10% than the value in the base-case model

Table 6.7.1. Sensitivity runs conducted for the 2018 stock assessment of WCNPO swordfish.

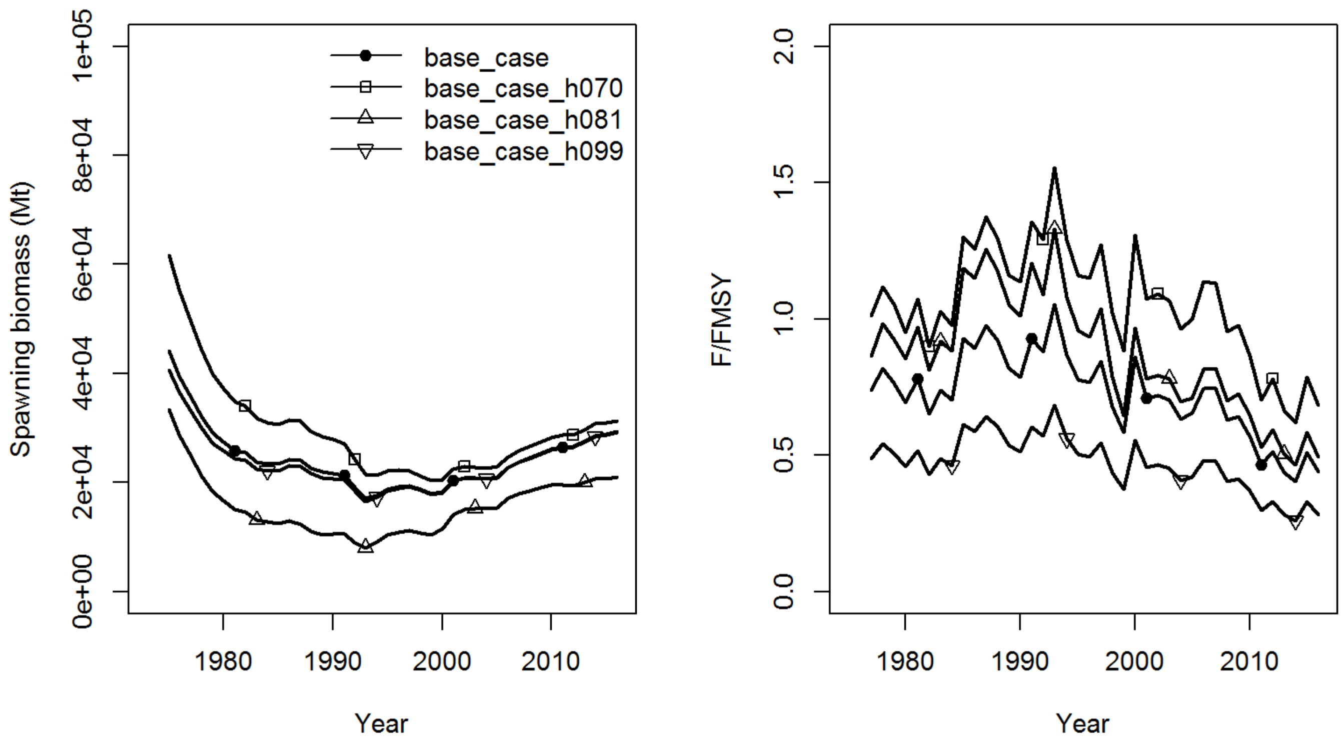
RUN	NAME	DESCRIPTION
	Alternative Life History Parameters: Natural Mortality Rates	
1	base_case_lowM	Alternative natural mortality rates are 10% lower than in the base case
2	base_case_highM	Alternative natural mortality rates are 10% higher than in the base case
	Alternative Life History Parameters: Stock-Recruitment Steepness	
3	base_case_h070	Alternative lower steepness with h=0.70
4	base_case_h081	Alternative lower steepness with h=0.81
5	base_case_h099	Alternative higher steepness with h=0.99
	Alternative Life History Parameters: Growth Curves	
6	base_case_large_Amax	Alternative growth curve with a 10% larger maximum size for each sex.
7	base_case_Sun_Growth	Alternative growth curves using growth parameters from Sun et al. (2002)
	Alternative Life History Parameters: Maturity Ogives	
9	base_case_high_L50	Alternative maturity ogives with L_{50} set 10% higher than base case
10	base_case_low_L50	Alternative maturity ogives with L_{50} set 10% lower than base case
11	base_case_Wang2003	Alternative maturity ogives with converted L_{50} from Wang et al. (2003)

Figure 6.7.1. Sensitivity analyses for natural mortality (M).



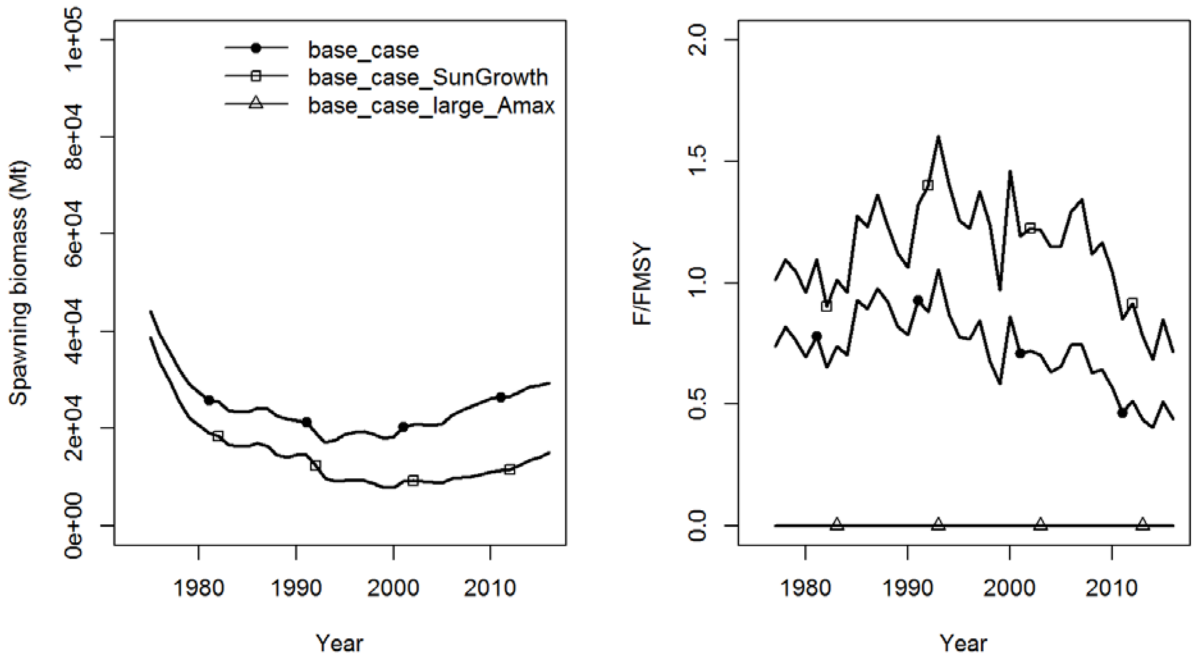
The WG noted that the results were not sensitive to the lower natural mortality rate scenario while the higher M scenario produced lower spawning biomass and a higher F/F_{MSY} ratio (Figure 6.7.1). Overall, the WG noted that the base case results were moderately sensitive to lower values of M.

Figure 6.7.2. Sensitivity analyses for stock-recruitment steepness (h).



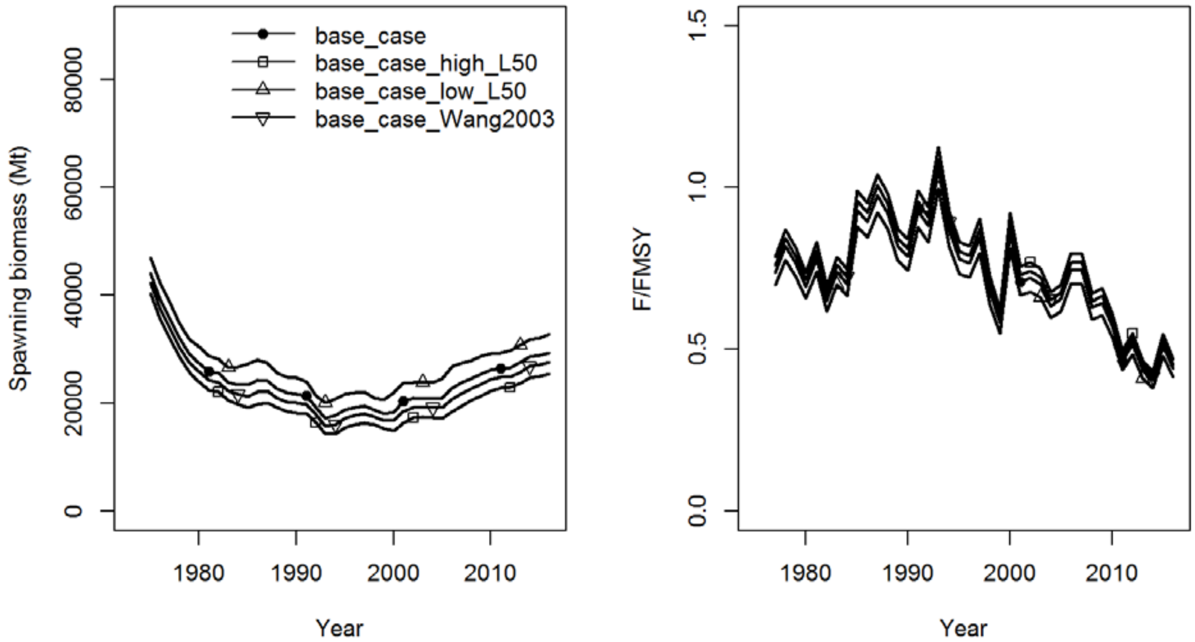
The WG noted that the trends in spawning biomass were similar for the alternative steepness scenarios but had different scales (Figure 6.7.2). For the F/F_{MSY} ratios, there was a greater spread in values with lower steepness values producing higher ratios but having similar trends. Overall, the WG noted that the base case results were sensitive to the stock-recruitment steepness with higher steepness values producing lower F/F_{MSY} ratios.

Figure 6.7.3. Sensitivity analyses for growth.



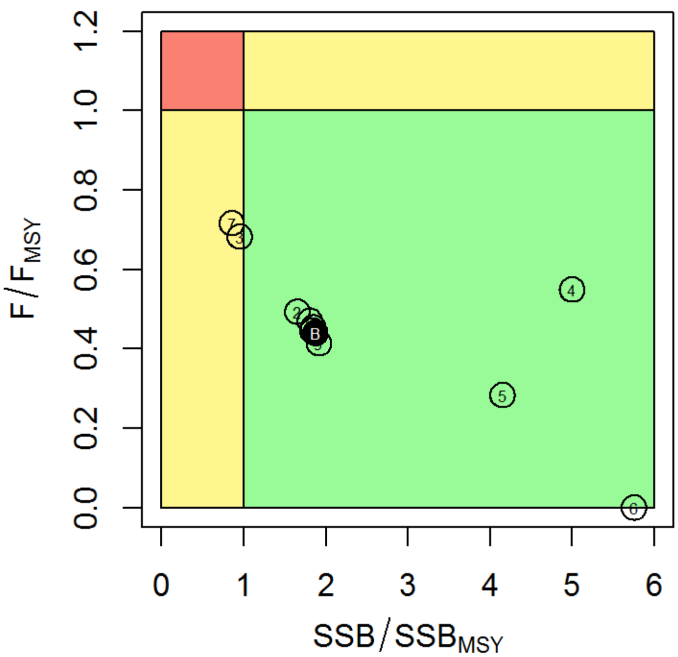
The WG noted that the Sun growth scenario produced a lower scaling of spawning biomass and higher F/F_{MSY} ratios than the base case (Figure 6.7.3). For the large maximum length scenario, the model results were not reasonable and produced very high spawning biomasses beyond the y-axis scale of Figure 6.7.3 and very low
F/F_{MSY} ratios. Overall, the base case model results were very sensitive to the growth parameters used for swordfish.

Figure 6.7.4. Sensitivity analyses for maturation.



The WG noted that the trends in spawning biomasses and F/FMSY ratios were very similar for the alternative maturation scenarios (Figure 6.7.4). Overall, the WG concluded that the base case results were not sensitive to the maturity ogives used for swordfish.

Figure 6.7.5. Kobe plot of sensitivity analysis results shows the terminal year stock status for the base case model and the sensitivity runs as indicated by numbers.



The WG reviewed the Kobe plot of the terminal year results of the sensitivity analyses (Figure 6.7.5). The WG noted that the results were robust for relative fishing mortality. All of the sensitivity analyses indicated that the WCNPO swordfish stock had an F/F_{MSY} ratio in 2016 that was less than 0.8 indicating that the stock was not experiencing excess fishing mortality relative to an MSY-based reference point. The WG also noted that the spawning potential of WCNPO swordfish in 2016 was above SSB_{MSY} for all sensitivity scenarios except scenarios 3 and 7, which were the low steepness and the Sun growth curve scenarios. For all the other sensitivity analyses, the stock was estimated to be in the green section of the Kobe plot, indicating that the WCNPO swordfish stock was not overfished and not experiencing overfishing relative to MSY-based reference points. Overall, the results of the sensitivity analyses confirmed the robustness of the base case model, and the WG concluded that other sensitivity runs were not needed.

6.8 Stock Projections

Scenarios for future 10-year projections under different fishing mortality-based harvest policies for the WCNPO swordfish stock were discussed. The WG agreed to use the two-gender projection software developed by Dr. Hirotaka Ijima for the projection analyses. This software accounts for uncertainty in the initial swordfish population size at age in 2017 based on Markov chain Monte Carlo samples of the population size estimator. The software also accounts for uncertainty in future recruitment based on stochastic sampling of the estimated stock-recruitment model from the SS3.30 base case model. The WG also agreed to apply the following five projection scenarios to the WCNPO swordfish stock during 2017-2018. These were: (1) F status quo, (2) F_{MSY}, (3) F at 0.2SSB(F=0), (4) High F=$F_{20\%}$, and (5) Low F=$F_{50\%}$ for WCNPO swordfish stock using the base case model. These scenarios are similar to those used in the 2016 Pacific blue marlin assessment and can be expressed in terms of the realized spawning potential ratio or the fishing mortality to produce a fixed SPR, denoted as $F_{X\%}$. Each of the scenarios uses the average fishery selectivities for 2013-2015.

(1) F=F status quo
    Use the 3-year average F for 2013-2015. This is equivalent to $F_{43\%}$.
(2) F=F_{MSY}
    Use the estimate of F_{MSY}. This is equivalent to $F_{18\%}$.
(3) F=F at 0.2SSB(F=0).
    Use the potential limit reference point based on 20% of unfished spawning biomass similar to the LRPs used for skipjack, bigeye and yellowfin tunas in the WCPFC. This is equivalent to $F_{22\%}$.
(4) High F= $F_{20\%}$
    This scenario applies the highest 3-year average F from the 1975-2016 time series of F estimates. This is equivalent to $F_{20\%}$
(5) Low F=$F_{50\%}$
(6) This scenario applies a low value of F=$F_{50\%}$ to the stock.

These five projection scenarios were completed after the April 2018 BILLWG meeting due to time constraints.

Results showed the projected median spawning stock biomass and the projected median catch under each of the five harvest scenarios. The central tendency of the future spawning potential of WCNPO swordfish was projected to be above the level needed to produce MSY under each harvest scenario (Table 6.8.1). For fishery yield, the central tendency of the future catch biomass of WCNPO swordfish was projected to above the pretty good yield level under the F_{MSY}, F at 20% of unfished spawning biomass, and the high F scenarios (Table 6.8.2).

Table 6.8.1. Projected median spawning stock biomass (SSB in metric tons) of Western and Central North Pacific Ocean swordfish under five alternative harvest scenarios. Green blocks indicate the projected SSB is greater than MSY level (SSB_{MSY} =15,704 metric tons).

Harvest scenario	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Average
1. $F_{Status\ quo}$ ($F_{43\%}$)	32118	33207	34599	35476	36270	37082	37951	38967	40083	41087	36684
2. F_{MSY} ($F_{18\%}$)	28267	23963	21443	19458	18303	17618	17293	17197	17253	17263	19806
3. $F_{20\%SSB(F=0)}$ ($F_{22\%}$)	28425	24384	21800	19735	18530	17874	17496	17586	17818	17779	20143
4. F_{High} ($F_{20\%}$)	29007	25431	23527	21763	20736	20131	19893	19883	19981	20066	22042
5. F_{Low} ($F_{50\%}$)	32559	34334	36290	37666	38836	39984	41148	42490	44049	45625	39298

Table 6.8.2. Projected median catch biomass (metric tons) of Western and Central North Pacific Ocean swordfish under five alternative harvest scenarios. Green blocks indicate the projected catch is greater than the pretty good yield level or 80% of MSY (0.8*MSY=11,954 metric tons).

Harvest scenario	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Average
1. $F_{Status\ quo}$ ($F_{43\%}$)	8851	9135	9407	9599	9794	10022	10275	10595	11053	11142	9987
2. F_{MSY} ($F_{18\%}$)	20885	18323	16509	15294	14666	14353	14308	14520	14650	14348	15786
3. $F_{20\%SSB(F=0)}$ ($F_{22\%}$)	20691	18122	16454	15261	14653	14361	14319	14554	14665	14384	15747
4. F_{High} ($F_{20\%}$)	18680	16933	15657	14726	14242	14033	14050	14292	14496	14253	15136
5. F_{Low} ($F_{50\%}$)	7556	7973	8343	8605	8847	9101	9366	9692	10087	10223	8979

7.0 OTHER BUSINESS

7.1 Election of Chair

There were no new nominees for Chair. Jon Brodziak indicated he was willing to serve as Chair for 1 more year. The WG re-elected Jon Brodziak as ISC Billfish WG Chair for 2018-2019.

7.2 Future Meetings

The ISC Billfish WG will meet on 8 July 2018 in Yeosu, Republic of Korea, prior to the ISC 2018 Plenary meeting. Tentative dates for the next 2018-2019 winter meeting are December 2018, in Honolulu, Hawaii, USA. Japan may offer to host the next spring 2019 assessment modeling meeting in Mie, Japan, the dates to be determined.

7.2 Work Assignments

The WG discussed and agreed upon the following work assignments.

<u>Working papers:</u> Working papers are to be finalized and sent to the ISC Billfish WG Chair (Jon Brodziak@NOAA.GOV) by 15 May 2018. Authors of working papers have agreed to allow final working papers to be posted for public access on the ISC website.

<u>April 2018 assessment modeling meeting report:</u> The first draft report of the assessment modeling meeting conducted in April 2018 will be distributed to WG members by 10 May 2018. The WG will review the draft report and provide comments and suggested revisions to the Chair by 14 May 2018. The WG Chair will revise the report and provide a final version of the report to the WG by 15 May 2018 and distribute the final report to the ISC Chair.

<u>Stock assessment report:</u> The stock assessment report describing the 2018 stock assessment of WCNPO swordfish, including sensitivities and projections, should be completed and sent to the ISC Chair by 31 May 2018.

7.3 Other Items

7.3.1 Future Work

The WG discussed future work. An assessment of the Western and Central North Pacific striped marlin stock was planned for 2018-2019.

8.0 ADJOURNMENT AND CLEARING OF REPORT

The WG cleared the draft report and adjourned the meeting at 16:45 on 24 April 2018. Jon Brodziak expressed his sincere thanks and appreciation to all participants for their contributions and cooperation in completing a successful meeting.

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Attachment 1. List of Participants

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INTERNATIONAL SCIENTIFIC COMMITTEE FOR TUNA AND TUNA-LIKE SPECIES IN THE NORTH PACIFIC

BILLFISH WORKING GROUP (BILLWG)

INTERSESSIONAL WORKSHOP ANNOUNCEMENT and AGENDA

Meeting Site: National Research Institute of Far Seas Fisheries
5-7-1 Orido, Shimizu
Shizuoka, Japan 424-8633
(+81)-54-336-5835, (+81)-54-335-9642 (fax)

Meeting Dates: 17-24 April 2018

Goals: The BILLWG is holding an intersessional meeting to complete the stock assessment modeling work for the North Pacific swordfish stock assessment. This includes developing and fitting the base case assessment model, running model sensitivity analyses, and conducting stock projections. The primary goal is to finalize the swordfish stock assessment model analyses in preparation for the ISC 18 Plenary meeting to be held in July 2018.

Meeting Attendance: Please send an email to Jon Brodziak (Email: Jon.Brodziak@noaa.gov) if you plan on attending this meeting

Working Papers: Submit working papers to Jon Brodziak by **Thursday April 12, 2018** Authors who miss the April 12 deadline must bring 10 hard copies of their working paper to the meeting.

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AGENDA

April 17 (Tuesday), 930-1000 – Registration

April 17 (Tuesday), 1000-1630

1. Opening of Billfish Working Group (BILLWG) Workshop
    a. Welcoming Remarks
    b. Introductions
    c. Standard Meeting Protocols

2. Adoption of Agenda and Assignment of Rapporteurs

3. Computing Facilities
    a. Access
    b. Security Issues

4. Numbering Working Papers and Distribution Potential

5. Status of Work Assignments

6. North Pacific Swordfish Stock Assessment Modeling
    a. Use of Life History Information
    b. Fishery Definitions and Selectivity Modeling
    c. Catch Time Series
    d. CPUE Time Series
    e. Size Compositions

April 18 (Wednesday) to April 21 (Saturday), 930-1700

6. North Pacific Swordfish Stock Assessment Modeling
    a. Use of Life History Information
    b. Fishery Definitions and Selectivity Modeling
    c. Catch Time Series
    d. CPUE Time Series
    e. Size Compositions
    f. Model Runs
    g. Model Diagnostics
    h. Model Results
    i. Biological Reference Points
    j. Sensitivity Analyses
    k. Stock Projections

7. Adoption of Assessment Model for North Pacific Swordfish
    a. Use of Life History Information
    b. Fishery Definitions and Selectivity Modeling
    c. Catch Time Series
    d. CPUE Time Series
    e. Size Compositions
    f. Model Runs

g. Model Diagnostics
h. Model Results
i. Biological Reference Points
j. Sensitivity Analyses
k. Stock Projections

April 22 (Sunday), No meeting unless additional work session needed

April 23 (Monday), 930-1700

6. and 7. Complete All Unfinished Work

8. Other Business
a. Future Meetings
b. Work Assignments for ISC18 Plenary
c. Other Items

9. Rapporteurs Complete Report Sections

10. Complete Workshop Report and Circulate; WG Reviews Report

April 24 (Tuesday), 930-1700

11. Clearing of report

12. Adjournment

Attachment 3. Working Papers

ISC/18/BILLWG-2/01	Input data available for the North Pacific swordfish stock assessment in Stock Synthesis. Michelle Sculley and Annie Yau. Michelle.Sculley@noaa.gov
ISC/18/BILLWG-2/02	A preliminary base-case model in Stock Synthesis 3.30 for the 2018 North Pacific. Michelle Sculley, Hirotaka Ijima, and Yi-Jay Chang. Michelle.Sculley@noaa.gov