Stock Assessment Update for Striped Marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2013

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Abstract

We present a preliminary update of the stock assessment of the Western and Central North Pacific Ocean (WCNPO) striped marlin (*Kajikia audax*) stock conducted in 2011 by the ISC Billfish Working Group (BILLWG). The assessment update consisted of running a Stock Synthesis model with newly available catch, abundance index, and size composition data for 1975-2013. We used the same model structure and parameters as were used in the base-case run from the 2011 stock assessment. The preliminary results indicated that biomass (age 1 and older) of the WCNPO striped marlin stock showed a long-term decline from 29,940 to 6,141 mt from 1975 to 2010 that was followed by an increase to around 8,800 mt for the last three years (2011-2013). Estimates of fishing mortality were stable, and fluctuated around 0.7 year^{-1} over the last six years. Compared to MSY-based reference points, the current spawning biomass (2013) was 48% below SSB_{MSY} and the current fishing mortality (average F for 2010-2013) was 19% above F_{MSY}. Consequently, the stock remained in an overfished state and overfishing was still occurring. The aim of this working paper is to provide the basic update

assessment model and its result to the BILLWG. Further in-depth exploration of various data sets and different alternative model scenarios will be discussed at the 2015 BILLWG assessment meeting.

Introduction

The ISC Billfish Working Group (BILLWG) completed a stock assessment for striped marlin (*Kajikia audax)* in the Western and Central North Pacific Ocean (WCNPO) in 2011 (ISC, 2012). The 2011 assessment used data through 2010, and the results indicated a long-term decline in population biomass. The population biomass (age-1 and older) during the first five years of the 2011 assessment (1975-1979) was roughly 18,200 mt, or 42% of unfished biomass, and declined to 6,625 mt in 2010, or 15% of unfished biomass. Spawning stock biomass (SSB) was approximately 938 mt in 2010, or 35% of SSB at maximum sustainable yield (SSB_{MSY}). Fishing mortality (F) on the stock (average F on ages 3 and older) was high, averaging roughly F = 0.76 during 2007-2009, or 24% above fishing mortality rate at maximum sustainable yield (F_{MSY}). The assessment suggested that overfishing was occurring relative to MSY and the WCNPO striped marlin stock was in an overfished state. In response to these findings, the BILLWG proposed to conduct an updated stock assessment with four additional years of fishery data (2010 to 2013) to monitor stock status carefully, and the work plan was approved at the 2014 ISC plenary meeting (ISC, 2014).

This working paper describes the updated assessment of striped marlin in the WCNPO, which was developed after BILLWG member countries provided the newly available catch, catch-per-unit-effort (CPUE), and size composition data (ISC, 2014). We used the same stock assessment model (Stock Synthesis, SS) but a newer version (version 3.24f compared to 3.20b) for the modeling platform. We also used the same model structure and parameters as were used in the base-case run from the 2011 stock assessment.

Materials and methods

Spatial and Temporal stratification

The geographic area encompassed in the assessment for the Western and Central North Pacific (WCNPO) striped marlin were the waters of the Pacific Ocean west of 140°W and north of the equator (Fig. 1). Three types of data were used: fishery-specific catches, relative abundance indices, and length measurements. These data were compiled for 1975-2013. Available data, sources of data and temporal coverage of the datasets used in the updated stock assessment are summarized in Fig. 2. Details are presented below.

Definition of fisheries

As in the 2011 assessment, 18 fisheries were defined on the basis of country, gear type, location, and season, and were considered relatively heterogeneous fishing units. These fisheries consisted of nine country-specific longline fisheries (JPN_DWLL_A1, JPN_DWLL_A2, JPN_DWLL_A3, JPN_CLL, JPN_OLL, TWN_LL, TWN_OSLL, HW_LL, KOR_LL), two driftnet fisheries (JPN_DRIFT and JPN_SQUID), one bait fishery (JPN_BAIT), one trap fishery (JPN_TRAP), one net fishery (JPN_NET), two harpoon fisheries (JPN_OTHER_Q12 and JPN_OTHER_Q34), one coastal fishery (TWN_CF) and one miscellaneous longline fishery (WCPO_OTHER). Detailed descriptions of the defined fisheries are presented in Table 1.

Catch

Catch was input into the model seasonally (i.e., by calendar years and quarters) from 1975 to 2013 for the 18 individual fisheries. Catch was recorded and reported in numbers (thousands of fish) for the Japan offshore and distant-water longline fisheries (JPN_DWLL_A1, JPN_DWLL_A2, and JPN_DWLL_A3) and in weight (metric tons) for all other fisheries. Because 2010 catch data were incomplete for the last assessment, updated catch data from 2010-2013 for all 18 fisheries were used for the assessment update, with the exception of TWN_OSLL, for which an updated time series from 2003-2013 was used.

Several countries (i.e., Japan, Taiwan, Korea, and the USA) provided updated national catch data (Yokawa et al., 2015; Su et al., 2015; Ito, 2015; Sang-Chul Yoon, personal communication, Jan 6, 2015). Striped marlin catches for all other fishing countries in the WCNPO area (WCPO_OTHER) were collected from WCPFC category I & II data (Tagami and Wang, 2015; Yau and Chang, 2015) and China category II data (Xiaojie Dai, personal communication, Jan 4, 2015). The annual catch was compiled based on the maximum catch value among these datasets. The updated catch of WCPO_OTHER included catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Guam, Kiribati, Marshall Islands, Philippines, New Caledonia, Papua New Guinea, and Vanuatu. Overall, use of the updated catch data led to an increase of about 7% in the 2003-2010 reported striped marlin catch biomass compared to the 2011 assessment.

Time-series of striped marlin catches by fishery from 1975-2013 are shown in Fig. 3. The historical maximum and minimum annual striped marlin catches were 10,557 metric tons in 1975 and 2,610 metric tons in 2009, respectively. The JPN_DWLL_A2, JPN_DWLL_A3, JPN_CLL, and JPN_DRIFT fisheries took most of the striped marlin catch throughout the assessment period. However, striped marlin catches by the JPN_DWLL_A2 and JPN_DWLL_A3 fisheries have gradually decreased since 1995. For the updated time period (2010-2013), the average catch of striped marlin in the WCNPO was about 3,300 metric tons. The JPN_CLL caught most of the striped marlin catch (30%). Striped marlin catches by the WCPO_OTHER and TWN_OSLL fisheries however, increased during 2010-2013 and comprised about 14% and 8% of the total catch, respectively. There has been a decrease of striped marlin catch by the JPN_DRIFT fishery since 2010.

Abundance indices

Relative abundance indices of CPUE were available for this assessment and are shown in Fig. 4 and Table 2. All indices were updated except for S12_JPN_DRIFT1 (1977-1993) and S14_TWN_LL1 (1975-1993). A monthly dataset aggregated by 5x5 degree grids from 1975-2013 was used in the CPUE standardization for Japanese distant water and offshore longline fisheries (Kanaiwa et al., 2015), which were also split into three areas and three time blocks (1975-1986, 1987-1999 and 2000-2013). The generalized linear model (GLM) for the standardization of abundance indices was the same as was used for the CPUE standardization for the last 2011 assessment. Logbook data from the Japanese coastal longline fishery (S11_JPN_CLL) during 1975-2013 was used in the CPUE standardization. Standardized CPUE was developed by GLM with negative binomial error (Oshimo et al., 2015). For S13_ JPN_DRIFT2, logbook data of core fishing seasons and fishing areas were standardized by GLMs with main effects and two way interactions of year*month and latitude*longitude (Yokawa and Shiozaki, 2015).

Data aggregated by 5x5 degree grids, quarters, latitude, longitude, and gear configurations were used for CPUE standardization for S15_TWN_LL2 (Sun et al., 2015). Information on hooks per basket (HPB) has been available since 1995, and was thus incorporated in the updated CPUE standardization model for 1995-2013.

Operational data of S16_ HW_LL in 1995-2013 collected by fishery observers were used for CPUE standardization (Walsh and Chang, 2015). Additional work on striped marlin CPUE standardizations for Hawaii demonstrated that the results were similar among alternative assumptions about the error distribution and covariates (Langseth, 2015). For this reason, the same approach used in the last assessment (the Poisson GLM) was used to develop the relative abundance index for S16_HW_LL.

Visual inspection of all indices grouped by fishery type showed an upward trend since 2010, although this varied among fleets in the timing and magnitude of the increase (Fig. 4). Updated CPUE indices in relative scale were compared to the indices used in the 2011 assessment (Appendix Fig. 1). In general, the updated CPUE indices show a consistent trend with the previous CPUE indices, although there was an extreme CPUE value during 2011 in S4_JPN_DWLL3_A1. Consequently, the updated CPUE of S4_JPN_DWLL3_A1 showed a higher variability during 2010-2013. The updated S10_JPN_DWLL3_A3 and S11_JPN_CLL were also more variable, and both showed a declining trend compared to the previous indices used in the 2011 assessment.

Correlations among CPUE indices were compared in the 2011 assessment (Appendix Table 1). Similarly, correlations among the updated CPUE indices were also examined within three time stratifications (1975–1986, 1987–1999, and 2000–2013). Pearson correlation coefficients (ρ) were interpreted as measuring the association among pairs of CPUE series. For the first time period, all Japanese DW longline indices (S2_JPN_DWLL1_A1, S6_JPN_DWLL1_A2, and S8_JPN_DWLL1_A3) showed a consistent trend (ρ ranged from 0.44 to 0.68). However, negative correlations were found between the Japanese DW longline indices and the early Japan drift (S12_JPN_DRIFT1) index (ρ ranged from -0.23 to -0.40). There were also some differences in the early trends between Japanese DW longline indices and early Taiwanese longline index (S14_TWN_LL1). There was a negative correlation between S8_JPN_DWLL1_A3 and S14_TWN_LL1 (ρ = -0.17).

During the second time period, there is variability of CPUE over time among the Japanese distant water longline indices (S3_JPN_DWLL2_A1 and S7_JPN_DWLL2_A2, and S9_JPN_DWLL2_A3) except a general increasing trend during 1990-1994. There was a negative correlation between S7_JPN_DWLL2_A2 and S9_JPN_DWLL2_A3 (ρ = -0.33). The S11_JPN_CLL, late Taiwanese longline (S15_TWN_LL2), and Hawaii longline (S16_HW_LL) indices generally declined since 1995, and these indices were positively correlated (ρ ranged from 0.21 to 0.52). The Japanese DW longline indices (S3_JPN_DWLL2_A1 and S7_JPN_DWLL2_A2) and the other longline indices (S11_JPN_CLL, S15_TWN_LL2, and S16_HW_LL) were negatively correlated (ρ ranged from -0.14 to -0.77). The early Japanese driftnet (S12_JPN_DRIFT1) and early Taiwanese longline (S14_TWN_LL1) indices showed an increasing trend during this period. Therefore, S12_JPN_DRIFT1 and S7_JPN_DWLL2_A2 (ρ = 0.76) and S14_TWN_LL1 and S7_JPN_DWLL2_A2 (ρ = 0.70) were positively correlated, but S9_JPN_DWLL2_A3 were negatively correlated with S12_JPN_DRIFT1 (ρ = -0.43) and S14_TWN_LL1 (ρ = -0.21).

During the third time period, the Japanese distant water longline indices (S4_JPN_DWLL3_A1, S5_JPN_DWLL3_A2, and S10_JPN_DWLL3_A3) generally showed a consistent decline in CPUE from 2000–2009, followed by an increase during 2010–2013. Positive correlation was found between S5_JPN_DWLL3_A2 and S10_JPN_DWLL3_A3 (ρ = 0.55). The Japanese coastal longline (S11_JPN_CLL), late Taiwanese longline (S15_TWN_LL2) and the Hawaiian longline (S16_HW_LL) indices were similar to the Japanese distant water longline indices. However, S5_JPN_DWLL3_A2 and S15_TWN_LL2 exhibited dissimilar, negatively correlated trends (ρ = -0.20). The late Japanese driftnet (S13_JPN_DRIFT2) index increased gradually over time. Negative correlations were found between S13_JPN_DRIFT2 and the CPUE indices of S10_JPN_DWLL3_A3, S11_JPN_CLL and S16_HW_LL (*ρ* ranged from -0.28 to -0.42).

Size composition data

Quarterly length composition data from 1975–2013 were used in the update assessment, and are summarized in Table 3. There were some inconsistencies in size composition between the updated and previously used datasets; differences in the size composition plots were described in detail in another working paper (Chang et al. 2015). We used updated size composition data from the last input year of the 2011 assessment for each fleet except L8_TWN_LL and L11_KOR_LL. A newer time-series of size composition data of L8_TWN_LL from 2006-2013 was used because it provided a more consistent pattern of size composition over time. The L11_KOR_LL data set was not used in the update assessment because the newly available size composition data of L11_KOR_LL (2009-2013) was variable compared to the size data of L11_KOR_LL (2005) used in the 2011 assessment. In total, length data were available for 11 of the 18 fisheries. Length measurements were compiled into 5-cm size bins, ranging from 120 to 230 cm eye-to-fork length (EFL). Each length frequency observation consisted of the actual number of striped marlin measured.

Figure 5 and Figure 6 show the updated quarterly size compositions and updated aggregated size compositions, respectively. Most of the fisheries exhibited consistent, clear seasonal cycles in size composition. There was also considerable variation in both the size distributions and modal positions among fisheries. Size distributions for L2_JPN_DWLL_A2, L3_JPN_DWLL_A3, L4_JPN_CLL, L9_HW_LL, and L10_WCPO_OTHER were generally skewed to sizes less than 160 cm EFL and typically exhibited a single mode near 140 cm EFL. L6_JPN_OTHER_Q12 and

L8_TWN_LL exhibited modes at sizes larger than 160 cm EFL, meaning that these fisheries caught larger striped marlin. The L1_JPN_DWLL_A1, L10_WCPO_OTHER, and L11_KOR_LL size distributions varied considerably among years and seasons.

Model Description

This stock assessment update for striped marlin was conducted using the same stock assessment model (Stock Synthesis, SS) as used previously, but with a newer version (Version 3.24f). The model structure and parameters were the same as used in the base-case run from the 2011 stock assessment. Biological and demographic assumptions and fishery dynamics are summarized in Table 4 and Table 5, respectively.

Data observation models

The assessment model fits three data components: 1) total catch; 2) relative abundance indices; and 3) size composition data. The observed total catches were assumed to be unbiased and relatively precise, and were fitted assuming a lognormal error distribution with standard error (SE) of 0.05. The relative abundance indices were assumed to have log-normally distributed errors with SE in log-space, which is approximately equivalent to the coefficient of variation (CV) (SE/estimate) in natural space. The CVs of each candidate index were first estimated by the statistical model used to standardize the index in the various BILLWG working papers (Table 2). However, the reported CVs for the abundance indices only capture observation error within the standardization model and do not reflect process error inherent between the unobserved vulnerable population and the observed abundance indices.

During preliminary analysis, observations in the abundance indices with CV < 0.2 were scaled to CV = 0.2 through the addition of a constant for each CPUE series. Observations with CV > 0.2 were input as given. The process error added to the CPUE indices was estimated following the recommendations of Francis (2011). The method involves fitting a series of data smoothers having different degrees of smoothing to the CPUE index, and calculating the total (i.e., observation + process) error of the residuals of the fit of the smoother to the data. In this study, an appropriate CV was chosen from the resulting plots qualitatively, and was the largest CV that still gave a smooth and good fit to the data (i.e., smooth.par = 0.7; Appendix Fig. 2). Input CPUE values and the reported CVs for all indices are shown in Tables 6 and 7, respectively.

The size composition data were assumed to have multinomial error distributions with the error variances determined by the effective sample sizes. Size measurements of fish are usually not random samples of fish from the entire population. Rather, they tend to be highly correlated within a set or trip (Pennington et al., 2002). The effective sample size is usually substantially lower than the actual number of fish measured because the variance within each set or trip is substantially lower than the variance within a population.

An approximation of the input effective sample size was taken from an analysis of trips sampled in the Hawaii-based longline fishery (Courtney, unpublished); the estimate was around 10 fish per trip. Thus, input effective sample size was assumed to be the number of fish measured/10 for all longline fisheries (L1_JPN_DWLL_A1, L2_JPN_DWLL_A2, L3_JPN_DWLL_A3, L4_JPN_CLL, L8_TWN_LL, L9_HW_LL, and L10_WCPO_OTHER) and L5_JPN_DRIFT. The input effective sample size was assumed to be the actual number of fish measured for L6_JPN_OTHER_Q12 and L7_JPN_OTHER_Q34. Based on the 2011 stock assessment, the minimum and maximum quarterly input effective sample sizes were set to 1 and 50, respectively. Size composition records with < 1 effective sample size were considered unrepresentative and removed while effective sample sizes > 50 were set to 50.

Data weighting

Relative abundance indices were prioritized in this assessment based on the principle that relative abundance indices should be fitted well because abundance indices are a direct measure of population trends and scale, and that other data components such as size composition data should not induce poor fits to the abundance indices (Francis, 2011). In this update assessment, we used an alternative weighting scheme for the size composition data (Francis, 2011: Method TA1.8), where the weight (w) was

$$w = 1/\mathrm{Var}\left[\left(\bar{O}_y - \bar{E}_y\right)/\left(v_y/n_y\right)^{0.5}\right],$$

where $\bar{O}_y$ and $\bar{E}_y$ are the observed and expected mean lengths for year y, v_y is the variance of expected length distribution for year y, and n_y is the effective sample size for year y. This method compares the mean observed length from some year to the expected length from the model, relative to the confidence interval for the mean. For any given data set, the weighting may change depending on how close the mean and expected values are for the data set. The aim of the weighting, which is parameterized by the multinomial sample size, is to make the standard deviation of the normalized residuals for the mean and expected values close to one. This weighting method accounts for the possibility of substantial correlations within a dataset, and generally produces relatively smaller sample size, thus down-weighting the composition data (Francis, 2011).

The initial input mean sample sizes and re-weighted estimated sample sizes are shown in Table 8. The effective sample sizes of most of the size compositions were scaled down by factors between 0.12 and 0.97, with the greatest effect being on L3_JPN_DWLL_A3, L6_JPN_OTHER_Q12, and L7_JPN_OTHER_Q34. The other fisheries (L2_JPN_DWLL_A2, L8_TWN_LL, L9_HW_LL, and L10_WCPO_OTHER) were scaled up.

Goodness-of-fit to abundance data

For each abundance index, the standard deviation of the normalized (or standardized) residuals (SDNR) was used to examine the goodness-of-fit (Francis, 2011). For an abundance data set to be well fitted, the SDNR should be less than $\left[\chi^2_{0.95,\,m-1}/(m-1)\right]^{0.5}$ where $\chi^2_{0.95,\,m-1}$ is the 95th percentile of a χ^2 distribution with m–1 degrees of freedom. Various residuals plots, including the observed and expected abundances, were also examined to assess goodness-of-fit.

Results

Base-case model

Our exploration of the updated data supported the use of a similar base-case to the one for the 2011 assessment. Although there was a higher variability in some relative CPUE indices used in the update assessment compared to the 2011 assessment (i.e., S4_JPN_DWLL3_A1, S10_JPN_DWLL3_A3, S11_JPN_CLL, and S13_JPN_DRIFT2), the correlative analyses supported the choice to utilize the same abundance indices in this update assessment (i.e., exclude S12_JPN_DRIFT1, S13_JPN_DRIFT2, and S14_TWN_LL1 from the total likelihood). Due to the inconsistency of size composition data between previous and newly available data sets, a new series of L8_TWN_LL was used and the L11_KOR_LL was dropped.

Furthermore, the weighting of the indices and the weighting of size compositions were done in a slightly different way.

A preliminary run revealed steep changes in the negative log-likelihood profile in a range of log(R0) values from 6.4 to 6.8 (Appendix Fig. 3a). The changes in the negative log-likelihood were further examined for each fishery. The results suggested that S7_JPN_DWLL2_A2 degraded the overall likelihood gradient for the CPUE data component (Appendix Fig. 3b), and the overall likelihood gradient for the size composition data component was degraded by the L5_JPN_DRIFT (Appendix Fig. 3c). Therefore, we sequentially down-weighted these two likelihood components by adding and subtracting a small constant value (0.05) to the input CPUE CV and a multiplier to the input mean effective sample size until the model gradient reached the defined threshold of < 0.0001. We adopted the above model configuration as the updated base-case assessment model to determine stock status and provide management advice for the WCNPO striped marlin stock.

Model convergence

All estimated parameters in the base-case model were within the set bounds, and the final gradient of the model was 1.99739e-005, which indicated that the model had likely converged onto a local or global minimum. Results from 50 model runs with different initial starting values suggested a global minimum was obtained (i.e., there was no evidence of a lack of convergence to a global minimum) (Fig. 7). In addition, the log(R0) values were similar from runs with total negative log-likelihoods similar to the base-case model.

Model diagnostics

Figure 8 presents the results of the likelihood profiling on log(R0) for each data component. Detailed information on changes in negative log-likelihoods among the various fisheries' data is shown in Tables 9 and 10. Changes in the likelihood of each data component indicate how informative that data component was to the overall estimated population scale. Ideally, relative abundance indices should be the primary sources of information on the population scale in a model (Francis, 2011). In general, the changes in negative log-likelihoods of abundance indices were small over the range of R0, except S7_JPN_DWLL2_A2 and S11_JPN_CLL. The most likely log(R0) values occurred at higher values of the profile range of log(R0) (6.3 – 7, see Table 9).

Important sources of information on scale for the size composition data in the model were the fisheries with logistic selectivity (Lee et al., 2014). In this assessment, the fisheries with estimated asymptotic selectivity were F5_JPN_DRIFT, F11_JPN_OTHER_Q12, and F13_TWN_LL. The F5_JPN_DRIFT contributed most of the striped marlin catch throughout the assessment period. The log(R0) likelihood profiles for F5_JPN_DRIFT (i.e., L5_JPN_DRIFT) were comparable to the maximum likelihood estimate (MLE) of 6.32, which indicated that size composition data from these fisheries were informative regarding population scale, and that log(R0) was likely at 6.3. In general, the changes in log-likelihoods of size composition data were small over a range of log(R0) values except for the L1_JPN_DWLL_A1 and L5_JPN_DRIFT (Table 10). The most likely log(R0) values occurred at values around or small than MLE of log(R0) (6.32). The log-likelihoods changed gradually over the range 6.1 to 6.5.

The likelihood profile analysis suggested that the abundance indices were possibly uninformative with respect to population scale in the base-case assessment model. The maximum likelihood estimate appears to be a tradeoff between the composition data (smaller relative likelihoods for smaller log(R0) values)and the abundance indices (smaller relative likelihoods for larger log(R0) values) based on log(R0) likelihood profiles. F5_JPN_DRIFT with a logistic selectivity contributed most of the gradient in the total likelihood at higher values of the profiled range of log(R0) (Fig. 8).

Residual analysis of abundance Indices

Goodness-of-fit diagnostics are presented in Table 11, and plots of predicted and observed CPUE by fishery for the base-case model are shown in Figure 9. As in the last stock assessment, the root-mean-square-error (RSME) was used as a goodness-of-fit diagnostic, with relatively low RMSE values (i.e., RMSE < 0.4) being indicative of a good fit. As in the 2011 assessment, the model fit the abundance indices of S2_JPN_DWLL1, S8_JPN_DWLL1_A3 and S9_JPN_DWLL2_A3, and S15_TWN_LL2 well, with RMSE < 0.4. The model did not fit the S3_JPN_DWLL2_A1 (0.44), S6_JPN_DWLL1_A2 (0.46), and S16_HW_LL well (0.47), and fit S5_JPN_DWLL3_A2 (0.63), S7_JPN_DWLL2_A2 (0.6), S10_JPN_DWLL3_A3 (0.73) poorly. There was a trend of negative residuals in the early time period (1987-1993) and of positive residuals in the late time period (1994-1999) for S7_JPN_DWLL2_A2 (Fig. 9).

In contrast to the 2011 assessment, the model did not fit the S4_JPN_DWLL3_A1 (0.64) and S11_JPN_CLL (0.47) well. This was caused by high variability in CPUE values later (2007−2013) in the S4_JPN_DWLL3_A1 time-series. The entire S11_JPN_CLL CPUE time-series was also more variable than the S11_JPN_CLL series used in the 2011 stock assessment. There were trends in the residuals for S11_JPN_CLL, but were opposite those for S7_JPN_DWLL2_A2, and consisted of positive and negative residuals patterns early (1994−2012) and late in the time-series (2003-2013), respectively (Fig. 9).

The SDNR of the CPUE fit was used as another goodness-of-fit diagnostic (Table 11). The SDNR is less sensitive than the RSME to variability in CPUE values. The SDNR diagnostics also indicated that the model did not fit S5_JPN_DWLL3_A2 (1.65 > 1.31), S7_JPN_DWLL2_A2 (1.98 > 1.32), and S11_JPN_CLL (1.66 > 1.26) well.

Residuals analysis of size composition

Reweighting of the size composition data followed the method of Francis (2011). Figure 10 shows the 95% credible intervals for mean size for the 10 size composition data sets. The reweighted model fit passed through almost all of the credible intervals (Fig. 10), although there was a poor fit between the observed and predicted mean sizes for the L1_JPN_DWLL_A1 during 1994-2006, L2_JPN_DWLL_A2 during 1975-1978, and L10_WCPO_OTHER in 2010. Similar patterns indicating poor fits for these fisheries were also observed in the Pearson residuals plots (Fig. 11).

The poor fit for L1_JPN_DWLL_A1 may have resulted from its inflexible selectivity pattern compared to other Japanese distant water longline fisheries. It should be noted the model generally fit L3_JPN_DWLL_A3 well. Most of the JPN DW longline catch of striped marlin during 1975−1999 was caught in area 3, so fitting these data was of primary concern. In contrast to the 2011 stock assessment, data from L5_JPN_DRIFT and L6_JPN_OTHER_Q12 did not exhibit poor fit in this updated assessment

The model fit the length modes in data aggregated by fishery fairly well using the re-weighted effective sample sizes (Fig. 12 and Table 12). Estimated effective sample size was used for the goodness-of-fit diagnostics for the size composition data in the 2011 assessment. The precision of the estimate was directly related to effective sample size. In this updated stock assessment, the re-weighted effective sample sizes as derived from Francis (2011)'s TA1.8 method were much smaller than the input effective sample sizes used in the 2011 assessment. In general, the precision of the model predictions was greater than that of the observations except for L2_JPN_DWLL_A2 and L9_HW_LL. It was notable, however, that the poor fit for the size composition data for these two fisheries was not characteristic of the fitted mean size plots and Pearson residuals plots.

Estimation of selectivity

The same selectivity configurations were used in this updated stock assessment as in 2011. The results of the estimated selectivity patterns were consistent with the assumed selectivity patterns. There was a slight change for JPN_DWLL_A1, as well as JPN_DWLL_A2 and JPN_DWLL_A3 during the first time block, with higher vulnerabilities for the smaller fish and lower vulnerabilities for the larger fish (i.e., the selectivity curves shifted left) (Fig. 13). There was also a slight change in the estimated selectivity during the third time block for JPN_DWLL_A3, again exhibiting a higher vulnerability for smaller fish after including the updated size composition data from 2010−2013. A moderate change in selectivity was also observed for JPN_DRIFT. There was a lower vulnerability for fish less than 160 cm EFL after including the updated size composition data. The TWN_LL was unique, in that there was a considerable change in selectivity compared to 2011. A different 2006−2013 time-series of size composition data was used, which resulted in a rightward shift of the logistic curve.

Stock assessment results

Estimates of population biomass (age 1 and older; quarter 1) showed a long-term decline from 1975 to 2000, increased to 11,940 mt in 2004, decreased again to the lowest level of 6,141 mt in 2010, and slightly increased to around 8,800 mt during the final three years (2011−2013) (Fig. 14a). Compared to the 2011 stock assessment, the population biomass estimates were higher in 1975-1985, lower in 1986-1993, then higher from 1995 thereafter except during 2010.

Spawning biomass also exhibited a declining trend during 1975−2001, an increase and a decrease before and after 2004, respectively, and a slight increase during 2011−2013 (Fig. 14b). The time-series of spawning biomass at the beginning of the spawning cycle (season 2) averaged 5,150 mt, or 28% of unfished spawning biomass, during 1975−1979, 3,693 mt (20% of unfished spawning biomass) during 1980−1989, 2,117 mt (11% of unfished spawning biomass) during 1990−1999, 1,577 mt (9% of unfished spawning biomass) during 2000−2009, and 1,343 mt (7% of unfished spawning biomass) in 2010−2013. Compared to the 2011 stock assessment, the spawning biomass estimates were higher in 1975−1986, lower in 1987-1994 and higher in 2008−2013.

Recruitment (age-0 fish) estimates declined from 2000−2009, but the trend has apparently changed in the most recent years. Recruitment increased during 2010−2013 (Fig. 14c). Average annual estimated recruitment was roughly 584,000 recruits during 1975−1979, 548,000 recruits during 1980-1989, 430,000 recruits during 1990−1999, 297,000 recruits during 2000−2009, and 353,000 recruits during 2010−2013. Compared to the 2011 stock assessment, the recruitment estimates were higher in 1975-1983, lower in 1984-1990, and higher in 2000-2013.

Estimates of fishing mortality (average on ages 3 and older) peaked at 1.26 year^{-1} in 1978, but then decreased to 0.43 year^{-1} in 1983 (Fig. 14d). Estimates of fishing mortality increased for roughly two decades after 1980, with high mortality estimates in 1988 (1.03 year^{-1}) and 1998 (1.24 year^{-1}). Fishing mortality estimates then decreased to 0.58 year^{-1} in 2007, and have since fluctuated around 0.7 year^{-1}.

Compared to the 2011 stock assessment, fishing mortality estimates were lower in 1975-1985, higher in 1988−1991 and 2003-2006, and lower in 2008−2010.

Compared to MSY-based reference points, the current spawning biomass (2013) is 48% below SSB_{MSY} and the current fishing mortality (average F for 2010-2013) is 19% above F_{MSY}. Similar to the 2011 stock assessment, overfishing is currently still occurring relative to F_{MSY} and the stock is in an overfished state relative to SSB_{MSY}.

Discussion

Inconsistency of catch and size composition data

We found there were some inconsistencies with the historical catch and size composition data between the 2011 assessment and the newly available data set (result were not shown in this working paper). We simply updated catch data from 2010-2013 for all 18 fisheries, with the exception of TWN_OSLL, for which an updated time series from 2003-2013 was used. For the size composition data, we used updated size composition data from the last input year of the 2011 assessment, with the exception of L8_TWN_LL, for which a new series of data set was used. The L11_KOR_LL was dropped due to the unexplained inconsistency of size composition between previous and newly available data sets. Further in-depth exploration of various data sets can be discussed at the 2015 BILLWG assessment meeting.

Alternative CPUE indices

Although there was a higher variability in some relative CPUE indices used in the update assessment compared to the 2011 assessment (i.e., S4_JPN_DWLL3_A1, S10_JPN_DWLL3_A3, S11_JPN_CLL, and S13_JPN_DRIFT2), the preliminary update assessment model provided a similar goodness-of-fit of CPUE indices compared the 2011 assessment. We found several CPUE indices were negatively correlated based on the correlation analyses, which suggested that these CPUE indices provided conflicting information about the trend of population abundance over time. If two abundance data sets are clearly contradictory (i.e., they show very different trends over the same years) then at least one of them is likely to be unrepresentative. Further in-depth exploration of different alternative model scenarios with subsets of CPUE indices can also be discussed at the 2015 BILLWG assessment meeting.

Sensitivity analyses

The current working paper only provided the basic updated base-case model and its result to the BILLWG and not results from sensitivity analyses. Sensitivity analyses to examine the effects of changing the assumed values of the input parameters or alternative model configurations for WCNPO striped will be conducted at the 2015 BILLWG assessment meeting.

Data weighting

The 2011 assessment was based on setting the effective sample sizes at pre-specified fractions of the observed numbers of striped marlin measured using the approach of McAllister and Ianelli (1997) (TA1.1 in Francis (2011)), which compared the variance of the standardized residuals about the fits to the data with the variance of the expected standardized residuals under a multinomial distribution. This approach has been criticized by Francis (2011) who noted that the residuals about the fits to length data tend to be correlated between length-classes. In this update assessment, we improved the previous assessment by using the Francis (2011) approach in which the effective sample size was based on how well the model fit the mean lengths. The result suggested that the adjusted mean sample sizes were smaller than the 2011 assessment except L2_JPN_DWLL_A2, L8_TWN_LL and L9_HW_LL, implying that the composition data in the previous assessment may have been over-weighted.

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Table 1. Descriptions of fisheries included in the base-case model for the stock assessment update including fishing countries, gear types, catch units (biomass (B) or numbers (#)), and reference sources for catch data.

Fishery number	Reference Code	Fishing Countries	Gear Types	Units	Source
F1	JPN_DWLL_A1	Japan	Offshore and distant-water longline in area 1	#	Yokawa et al. (2015)
F2	JPN_DWLL_A2	Japan	Offshore and distant-water longline in area 2	#	Yokawa et al. (2015)
F3	JPN_DWLL_A3	Japan	Offshore and distant-water longline in area 3	#	Yokawa et al. (2015)
F4	JPN_CLL	Japan	Coastal longline	B	Yokawa et al. (2015)
F5	JPN_DRIFT	Japan	High-sea large-mesh driftnet and coastal driftnet	B	Yokawa et al. (2015)
F6	JPN_OLL	Japan	Other longline	B	Yokawa et al. (2015)
F7	JPN_SQUID	Japan	Squid drift net	B	Yokawa et al. (2015)
F8	JPN_BAIT	Japan	Bait fishing	B	Yokawa et al. (2015)
F9	JPN_NET	Japan	Net fishing	B	Yokawa et al. (2015)
F10	JPN_TRAP	Japan	Trap fishing	B	Yokawa et al. (2015)
F11	JPN_OTHER_Q12	Japan	Harpoon and trolling in quarters 1 and 2	B	Yokawa et al. (2015)
F12	JPN_OTHER_Q34	Japan	Harpoon and trolling in quarters 3 and 4	B	Yokawa et al. (2015)
F13	TWN_LL	Taiwan	Distant-water longline	B	Su et al. (2015)
F14	TWN_OSLL	Taiwan	Offshore longline	B	Su et al. (2015)
F15	TWN_CF	Taiwan	Offshore & coastal gillnet, coastal harpoon, coastal set net and other	B	Su et al. (2015)
F16	HW_LL	USA	Longline	B	Ito (2015)
F17	WCPO_OTHER	See text for full list	Miscellaneous longline	B	Yau and Chang (2015); Tagami and Wang (2015)
F18	KOR_LL	Korea	Longline	B	Sang Chul Yoon, pers. comm., Jan 6, 2015

Table 2. Descriptions of standardized relative abundance indices (catch-per-unit-effort, CPUE) for striped marlin from the Western and Central North Pacific Ocean used in the stock assessment update including whether the index was used in the base case, sample size (n), years of coverage, and reference source. For all indices, catch was in numbers.

Reference Code	**Used**	**Fishery Description**	***n***	**Time series**	**Source**
S2_JPN_DWLL1_A1	Yes	Japanese offshore and distant-water longline area 1	12	1975-1986	Kanaiwa et al. (2015)
S3_JPN_DWLL2_A1	Yes		13	1987-1999	Kanaiwa et al. (2015)
S4_JPN_DWLL3_A1	Yes		14	2000-2013	Kanaiwa et al. (2015)
S6_JPN_DWLL1_A2	Yes	Japanese offshore and distant-water longline area 2	12	1975-1986	Kanaiwa et al. (2015)
S7_JPN_DWLL2_A2	Yes		13	1987-1999	Kanaiwa et al. (2015)
S5_JPN_DWLL3_A2	Yes		14	2000-2013	Kanaiwa et al. (2015)
S8_JPN_DWLL1_A3	Yes	Japanese offshore and distant-water longline area 3	12	1975-1986	Kanaiwa et al. (2015)
S9_JPN_DWLL2_A3	Yes		13	1987-1999	Kanaiwa et al. (2015)
S10_JPN_DWLL3_A3	Yes		14	2000-2013	Kanaiwa et al. (2015)
S11_JPN_CLL	Yes	Japanese coastal longline	20	1994-2013	Oshimo et al. (2015)
S12_JPN_DRIFT1	No	Japanese high-sea large-mesh driftnet	17	1977-1993	Yokawa (2005)
S13_JPN_DRIFT2	No	Japanese coastal driftnet	11	2001-2002; 2004-2011; 2013	Yokawa and Shiozaki (2015)
S14_TWN_LL1	No	Taiwanese distant-water longline	16	1975-1984, 1987, 1989-1993	Sun et al. (2011c)
S15_TWN_LL2	Yes	Taiwanese distant-water longline	19	1995-2013	Sun et al. (2015)
S16_HW_LL	Yes	Hawaiian longline	18	1996-2013	Walsh and Chang (2015)

Table 3. Description of size composition data (eye-fork lengths, EFL, cm) for striped marlin from the Western and Central North Pacific Ocean used in the stock assessment update, including number of observations (n), years of coverage, and reference sources.

Reference Code	Fishery Description	*n*	Time series	Source
L1_JPN_DWLL_A1	Japanese offshore and distant-water longline in area1	71	1975-1990 1992-2000 2002; 2004; 2006; 2011; 2012	Yokawa et al. (2015)
L2_JPN_DWLL_A2	Japanese offshore and distant-water longline in area2	148	1975-2003; 2005-2013	Yokawa et al. (2015)
L3_JPN_DWLL_A3	Japanese offshore and distant-water longline in area3	151	1975-2013	Yokawa et al. (2015)
L4_JPN_CLL	Japanese coastal longline	106	1986-2013	Yokawa et al. (2015)
L5_JPN_DRIFT	Japanese high-sea large-mesh driftnet and coastal driftnet	30	1980-1983; 1991; 2000; 2004; 2005; 2008-2013	Yokawa et al. (2015)
L6_JPN_OTHER_Q12	Japanese harpoon and trolling in quarters 1 and 2	37	1976-1990; 1992-1995; 2000	Yokawa et al. (2015)
L7_JPN_OTHER_Q34	Japanese harpoon and trolling in quarters 3 and 4	14	1977-1979; 1982-1987; 1992	Yokawa et al. (2015)
L8_TWN_LL	Taiwanese distant-water longline	29	2006-2013	Su et al. (2015)
L9_HW_LL	Hawaii longline	77	1994-2013	Eric Fletcher, pers. comm., Jan 13, 2015
L10_WCPO_OTHER	Miscellaneous longline	54	1993-2010	Yau and Chang (2015)
L11_KOR_LL	Korean longline	13	2005; 2009-2013	Sang Chul Yoon, pers. comm., Jan 6, 2015

Table 4. Key life history parameters and model structures for striped marlin from the Western and Central North Pacific Ocean used in the stock assessment update including values, pertinent comments, and references.

Parameter	**Value**	**Comments**	**Source**
Gender	1	Female only	ISC(2012)
Natural mortality	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (age 4-15)	Age-specific natural mortality	Piner and Lee (2011)
Reference age (a1)	0.3	Fixed parameter	Refit from Sun et al. (2011a); ISC(2012)
Maximum age (a2)	15	Fixed parameter	
Length at a1 (L1)	104	Fixed parameter	Refit from Sun et al. (2011a); ISC(2012)
Length at a2 (L2)	214	Fixed parameter	Refit from Sun et al. (2011a); ISC(2012)
Growth rate (K)	0.24	Fixed parameter	Refit from Sun et al. (2011a); ISC(2012)
CV of L1 (CV=f(LAA))	0.14	Fixed parameter	ISC (2012)
CV of L2	0.08	Fixed parameter	ISC (2012)
Weight-at-length	$W=4.68e\text{-}006\times L^{3.16}$	Fixed parameter	Sun et al. (2011a)
Size-at-50% Maturity	177	Fixed parameter	Sun et al. (2011b)
Slope of maturity ogive	-0.064	Fixed parameter	Sun et al. (2011b)
Fecundity	Proportional to spawning biomass	Fixed parameter	Sun et al. (2011b)
Spawning season	2	Model structure	Sun et al. (2011b)
Spawner-recruit relationship	Beverton-Holt	Model structure	Brodziak et al. (2011); Brodziak et al. (2015)
Spawner-recruit steepness (*h*)	0.87	Fixed parameter	Brodziak et al. (2011); Brodziak et al. (2015)
Log of Recruitment at virgin biomass log(R_0)	6.31642	Estimated	ISC (2012)
Recruitment variability (σ_R)	0.6	Fixed parameter	ISC (2012)
Initial age structure	5 yrs	Estimated	ISC (2012)
Main recruitment deviations	1975-2008	Estimated	ISC (2012)

Table 5. Fishery-specific selectivity assumptions for striped marlin from the Western and Central North Pacific Ocean. The selectivity curves for fisheries lacking size composition data were assumed to be the same as (i.e., mirror gear) closely related fisheries or fisheries operating in the same area

Fishery number	Reference Code	Selectivity assumption	Mirror gear
F1	JPN_DWLL_A1	Double-normal	
F2	JPN_DWLL_A2	Double-normal for 1975-1986; 1987-1999; 2000-2013	
F3	JPN_DWLL_A3	Double-normal for 1975-1986; 1987-1999; 2000-2013	
F4	JPN_CLL	Double-normal	
F5	JPN_DRIFT	Logistic	
F6	JPN_OLL	Double-normal	F4
F7	JPN_SQUID	Logistic	F5
F8	JPN_BAIT	Double-normal	F4
F9	JPN_NET	Double-normal	F4
F10	JPN_TRAP	Double-normal	F4
F11	JPN_OTHER_Q12	Logistic	
F12	JPN_OTHER_Q34	Double-normal	
F13	TWN_LL	Double-normal	
F14	TWN_OSLL	Double-normal	F13
F15	TWN_CF	Double-normal	F13
F16	HW_LL	Double-normal	
F17	WCPO_OTHER	Double-normal	
F18	KOR_LL	Double-normal	F2

Table 6. Standardized catch-per-unit-effort (CPUE) indices for striped marlin from the Western and Central North Pacific Ocean used in the stock assessment update. Season refers to the calendar quarter(s) in which most of the catch was taken by each fishery, where 1 = Jan-Mar, 2 = Apr-June, 3 = July-Sept, and 4 = Oct-Dec.

Year	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
Season	1	1	1	2	2	2	1	1	1	2	3	3	2	2	2
1975	0.0015				0.0063		0.1400						0.6547		
1976	0.0018				0.0060		0.0911						1.2102		
1977	0.0009				0.0026		0.0538				0.2857		1.0415		
1978	0.0008				0.0025		0.0904				0.1876		1.2697		
1979	0.0016				0.0063		0.1370				0.1458		1.4185		
1980	0.0017				0.0128		0.1230				0.1487		1.2002		
1981	0.0015				0.0045		0.1170				0.1321		1.2697		
1982	0.0010				0.0044		0.0872				0.0715		1.9839		
1983	0.0011				0.0033		0.0651				0.0685		0.6547		
1984	0.0012				0.0039		0.1460				0.0993		0.6051		
1985	0.0011				0.0135		0.1300				0.0959				
1986	0.0033				0.0154		0.1340				0.0991				
1987		0.0014				0.0064		0.1640			0.1094		0.2976		
1988		0.0020				0.0060		0.2300			0.1377				
1989		0.0017				0.0067		0.1850			0.1321		0.7539		
1990		0.0010				0.0056		0.0903			0.1625		0.6249		
1991		0.0007				0.0074		0.0865			0.1732		1.1209		
1992		0.0013				0.0084		0.1380			0.1587		0.6348		
1993		0.0018				0.0181		0.1570			0.2065		1.2598		
1994		0.0018				0.0100		0.1180		0.1210					
1995		0.0010				0.0130		0.1410		0.2190				0.1650	
1996		0.0014				0.0107		0.0882		0.1560				0.1240	1.6200
1997		0.0007				0.0140		0.0738		0.1400				0.1040	1.1100
1998		0.0019				0.0247		0.0987		0.1890				0.0660	1.1600
1999		0.0025				0.0140		0.0892		0.1110				0.1130	1.1200
2000			0.0010	0.0130					0.0320	0.0960				0.1070	0.5500

2001	0.0009	0.0095	0.0495	0.1510	0.8948	0.1080	1.7000
2002	0.0012	0.0074	0.0241	0.1090	1.1741	0.1260	0.6600
2003	0.0009	0.0040	0.0374	0.0650		0.1120	2.2100
2004	0.0012	0.0046	0.0333	0.1020	1.3441	0.1630	0.9300
2005	0.0008	0.0024	0.0203	0.0810	1.0680	0.1650	0.9200
2006	0.0010	0.0014	0.0172	0.0520	1.1235	0.1300	1.1500
2007	0.0003	0.0034	0.0060	0.0690	1.3138	0.1170	0.3100
2008	0.0003	0.0027	0.0134	0.0330	1.2955	0.1050	0.8200
2009	0.0003	0.0028	0.0076	0.0510	0.9752	0.0940	0.3900
2010	0.0013	0.0037	0.0022	0.0500	1.3216	0.1140	0.1900
2011	0.0032	0.0031	0.0151	0.0710	1.2859	0.1090	1.0500
2012	0.0012	0.0054	0.0145	0.0730		0.1170	0.5500
2013	0.0012	0.0060	0.0094	0.0710	1.9176	0.1340	0.7700

Table 7. Input coefficients of variations (CVs) for the catch-per-unit-effort (CPUE) series for striped marlin from the Western and Central North Pacific Ocean used in the stock assessment update. Lognormal errors were assumed. Season refers to the calendar quarter(s) in which most of the catch was taken by each fishery, where 1 = Jan-Mar, 2 = Apr-June, 3 = July-Sept, and 4 = Oct-Dec.

Year	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**
Season	1	1	1	2	2	2	1	1	1	2	3	3	2	2	2
1975	0.17				0.16		0.12						0.40		
1976	0.09				0.16		0.12						0.40		
1977	0.12				0.17		0.15				0.30		0.40		
1978	0.11				0.18		0.10				0.08		0.40		
1979	0.09				0.18		0.10				0.11		0.40		
1980	0.09				0.16		0.12				0.08		0.40		
1981	0.10				0.17		0.10				0.05		0.40		
1982	0.10				0.18		0.11				0.07		0.40		
1983	0.11				0.18		0.12				0.07		0.40		
1984	0.09				0.18		0.10				0.07		0.40		
1985	0.10				0.20		0.11				0.07				
1986	0.10				0.16		0.10				0.08				
1987		0.19				0.19		0.09			0.11		0.40		
1988		0.20				0.20		0.07			0.07				
1989		0.20				0.22		0.08			0.08		0.40		
1990		0.20				0.26		0.10			0.05		0.40		
1991		0.22				0.20		0.11			0.06		0.40		
1992		0.20				0.24		0.10			0.07		0.40		
1993		0.19				0.19		0.10			0.12		0.40		
1994		0.19				0.19		0.09		0.06					
1995		0.20				0.19		0.09		0.06				0.14	
1996		0.19				0.21		0.10		0.06				0.12	0.08
1997		0.22				0.24		0.11		0.06				0.12	0.08
1998		0.19				0.20		0.10		0.06				0.14	0.08

1999	0.17				0.25		0.10		0.06				0.11	0.07
2000		0.23	0.19					0.13	0.06				0.12	0.06
2001		0.26	0.22					0.12	0.06		0.32		0.09	0.03
2002		0.24	0.23					0.14	0.06		0.23		0.09	0.03
2003		0.30	0.21					0.12	0.07				0.09	0.02
2004		0.26	0.24					0.13	0.06		0.13		0.08	0.03
2005		0.35	0.26					0.14	0.06		0.12		0.08	0.02
2006		0.36	0.28					0.15	0.07		0.12		0.08	0.03
2007		0.61	0.24					0.21	0.06		0.12		0.08	0.03
2008		0.67	0.23					0.18	0.51		0.13		0.09	0.03
2009		0.66	0.23					0.20	0.12		0.13		0.09	0.03
2010		0.34	0.26					0.32	0.09		0.12		0.09	0.04
2011		0.31	0.25					0.21	0.07		0.18		0.09	0.03
2012		0.38	0.22					0.19	0.07				0.09	0.03
2013		0.40	0.21					0.21	0.06		0.13		0.09	0.03

Table 8. Fishery-specific initial multinomial effective sample sizes (N) and re-weighted effective sample sizes as derived from Francis (2011)'s TA1.8 for size composition data of striped marlin from the Western and Central North Pacific Ocean as used in the stock assessment update.

Reference code	Initial mean N	Iteration 1	Iteration 2	Iteration 3
L1_JPN_DWLL_A1	9.56	9.84	9.45	9.26
L2_JPN_DWLL_A2	36.66	39.16	42.75	43.85
L3_JPN_DWLL_A3	40.28	18.49	16.19	15.55
L4_JPN_CLL	39.13	25.12	23.87	23.36
L5_JPN_DRIFT	33.62	24.91	18.83	17.86
L6_JPN_OTHER_Q12	44.5	7.21	5.56	5.38
L7_JPN_OTHER_Q34	37.57	7.78	8.27	8.42
L8_TWN_LL	12.01	15.22	13.31	12.17
L9_HW_LL	25.99	40.2	49.87	54.91
L10_WCPO_OTHER	3.26	3.5	3.6	3.72

Table 9. Relative negative log-likelihoods of abundance index data components in the base-case model over a range of fixed levels of virgin recruitment in log-scale (log(R0)). Likelihoods are relative to the minimum negative log-likelihood (best-fit) for each respective data component. Colors indicate relative likelihood (green: low negative log-likelihood, better-fit; red: high negative log-likelihood, poorer-fit). Maximum likelihood estimate of log(R0) was 6.32. See Table 2 for a description of the abundance indices.

log(R0)	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S15	S16
5.5	0.41	2.88	0.77	3.15	0.68	6.20	2.80	1.81	2.20	1.21	4.97	0.71
5.55	0.40	2.89	0.75	3.10	0.67	6.21	2.74	1.81	2.19	1.18	4.80	0.69
5.6	0.28	2.89	0.74	3.01	0.58	6.20	2.59	1.80	2.19	1.07	4.63	0.67
5.65	0.27	2.90	0.72	2.95	0.59	6.22	2.55	1.79	2.19	1.01	4.45	0.66
5.7	0.35	2.90	0.69	2.87	0.60	6.14	2.59	1.79	2.17	0.94	4.28	0.65
5.75	0.78	2.92	0.67	2.81	0.64	6.51	2.14	1.79	2.12	0.58	4.40	0.58
5.8	1.65	2.66	0.60	2.83	1.23	6.68	2.80	1.72	1.97	0.86	3.93	0.49
5.85	0.51	2.86	0.66	2.73	0.48	6.42	1.76	1.73	2.11	0.55	4.16	0.57
5.9	0.26	2.53	0.63	2.68	0.70	5.80	2.37	1.33	2.21	0.94	3.60	0.66
5.95	0.21	2.48	0.61	2.63	0.71	5.74	2.32	1.28	2.23	1.01	3.39	0.68
6	0.18	2.46	0.59	2.58	0.71	5.75	2.23	1.24	2.24	1.04	3.16	0.68
6.05	0.22	2.44	0.57	2.55	0.77	5.78	2.21	1.20	2.25	1.17	2.92	0.69
6.1	0.18	2.43	0.54	2.49	0.77	5.78	2.12	1.17	2.28	1.24	2.69	0.71
6.15	0.18	2.55	0.66	2.56	0.80	6.21	2.06	1.13	2.06	0.00	3.95	0.56
6.2	0.13	2.41	0.47	2.37	0.77	5.83	1.92	1.11	2.37	1.41	2.23	0.77
6.25	0.13	2.41	0.43	2.31	0.78	5.89	1.81	1.08	2.44	1.53	1.98	0.82
6.3	0.09	2.42	0.35	2.21	0.77	5.93	1.66	1.04	2.62	1.60	1.74	0.93
6.35	0.18	2.37	0.27	2.14	0.89	5.87	1.63	0.96	2.83	1.98	1.45	1.10
6.4	0.60	2.50	0.16	2.10	1.15	6.54	1.48	1.01	2.87	2.73	0.96	1.17
6.45	0.94	2.58	0.10	1.89	1.38	7.05	1.42	1.01	2.67	3.63	0.36	1.15
6.5	0.88	2.43	0.13	1.45	1.26	6.92	1.15	0.98	2.10	4.06	0.00	0.92
6.55	0.69	2.12	0.19	1.07	1.05	6.26	0.86	0.98	1.65	4.26	0.09	0.75
6.6	0.53	1.78	0.25	0.78	0.86	5.45	0.64	1.01	1.33	4.41	0.36	0.62
6.65	0.42	1.47	0.30	0.55	0.71	4.64	0.48	1.09	1.08	4.54	0.69	0.53
6.7	0.02	1.00	0.55	0.42	0.20	3.21	0.17	1.39	0.48	3.97	1.90	0.18
6.75	0.00	0.80	0.59	0.31	0.13	2.64	0.12	1.52	0.33	4.02	2.29	0.12
6.8	2.83	1.23	0.00	3.36	2.98	4.34	4.16	0.00	5.68	7.12	4.11	3.87
6.85	0.33	0.26	0.60	0.32	0.44	0.69	0.26	2.05	0.49	5.83	3.02	0.17
6.9	0.01	0.38	0.70	0.06	0.00	1.31	0.01	1.92	0.00	4.11	3.25	0.00
6.95	0.10	0.10	0.69	0.05	0.13	0.39	0.02	2.14	0.09	5.22	3.46	0.12
7	0.10	0.00	0.71	0.00	0.10	0.00	0.00	2.31	0.02	5.25	3.72	0.09

Table 10. Relative negative log-likelihoods of size composition data components in the base-case model over a range of fixed levels of virgin recruitment in log-scale (log(R0)). Likelihoods are relative to the minimum negative log-likelihood (best-fit) for each respective data component. Colors indicate relative likelihood (green: low negative log-likelihood, better-fit; red: high negative log-likelihood, poorer-fit). Maximum likelihood estimate of log(R0) was 6.32. See Table 3 for a description of the composition data.

log(R0)	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
5.5	5.14	15.12	15.19	5.66	1.41	0.93	0.41	1.90	0.96	2.56
5.55	5.02	14.29	14.43	5.47	1.44	0.95	0.45	1.83	0.65	2.44
5.6	4.78	14.94	13.59	5.17	1.66	0.33	0.54	1.79	0.40	2.31
5.65	4.70	13.95	12.90	4.95	1.74	0.39	0.56	1.69	0.25	2.16
5.7	5.33	13.40	12.73	4.58	1.60	0.00	0.59	1.59	0.25	2.01
5.75	8.47	17.20	18.47	5.22	5.14	3.16	0.48	1.69	0.00	2.14
5.8	54.27	0.00	11.26	6.08	3.43	6.48	0.00	1.14	0.07	2.12
5.85	5.18	17.12	14.58	4.61	5.30	2.75	0.47	1.58	0.09	1.97
5.9	4.86	5.99	10.45	2.31	2.15	0.87	0.32	1.36	0.58	1.55
5.95	4.93	5.33	10.07	1.59	1.81	0.68	2.63	1.29	0.87	1.42
6	4.89	4.77	9.28	1.13	1.76	0.78	0.36	1.23	1.23	1.29
6.05	4.84	3.64	8.52	0.97	1.35	1.30	0.36	1.13	1.69	1.15
6.1	4.68	3.59	7.76	0.66	1.21	1.29	0.39	1.09	2.17	1.03
6.15	4.60	3.72	6.55	1.66	0.46	1.36	0.40	1.17	3.83	9.16
6.2	4.28	3.90	6.21	0.29	0.96	1.43	0.46	1.05	3.30	0.78
6.25	4.17	3.97	5.58	0.26	0.84	1.75	0.49	1.05	4.03	0.63
6.3	4.45	5.45	5.57	0.00	0.80	1.45	0.57	1.24	5.01	0.46
6.35	5.20	5.78	6.38	0.19	0.00	1.82	10.56	1.37	6.58	0.65
6.4	4.89	1.40	3.76	2.38	0.92	6.71	0.61	1.10	8.16	0.00
6.45	4.01	0.51	1.44	4.64	2.71	10.63	0.72	0.33	10.27	0.25
6.5	2.48	1.99	0.23	6.22	5.35	12.55	0.80	0.00	12.17	1.92
6.55	1.62	3.65	0.00	7.18	7.53	13.27	0.86	0.72	13.56	3.98
6.6	1.12	4.91	0.07	7.88	9.28	13.69	0.90	1.81	14.54	5.90
6.65	0.80	5.81	0.21	8.43	10.73	14.04	0.93	2.98	15.22	7.63
6.7	0.82	7.00	0.79	8.69	13.06	13.13	0.95	2.04	15.01	0.57
6.75	0.68	7.26	0.83	9.04	14.05	13.58	0.97	2.23	15.28	0.65
6.8	16.84	9.82	20.44	14.49	83.55	14.83	0.02	9.03	32.37	4.14
6.85	0.48	7.28	7.94	8.58	15.53	15.90	0.91	3.30	16.21	13.30
6.9	0.33	7.53	0.85	9.80	16.34	14.86	1.02	2.64	15.78	0.82
6.95	0.09	7.64	0.92	9.65	16.67	15.67	1.03	2.79	15.93	14.91
7	0.00	7.64	0.93	9.81	17.24	16.02	1.05	2.89	15.98	15.69

Table 11. Mean input coefficients of variation (CVs), root-mean-square-errors (RMSE), and standard deviations of the normalized residuals (SDNR) for the relative abundance indices for striped marlin from the Western and Central North Pacific Ocean used in the 2011 stock assessment and in this stock assessment update.

Reference code	2011 assessment			2015 update				
	n	**Input CV**	**RMSE**	***n***	**Input CV**	**RMSE**	**SDNR**	χ^2
S2_JPN_DWLL1_A1	12	0.31	0.31	12	0.33	0.3	0.96	1.34
S3_JPN_DWLL2_A1	13	0.41	0.48	13	0.36	0.44	1.25	1.32
S4_JPN_DWLL3_A1	10	0.16	0.24	14	0.76	0.64	0.74	1.31
S5_JPN_DWLL3_A2	10	0.62	0.7	14	0.39	0.63	1.65	1.31
S6_JPN_DWLL1_A2	12	0.39	0.41	12	0.55	0.46	0.88	1.34
S7_JPN_DWLL2_A2	13	0.55	0.64	13	0.32	0.6	1.98	1.32
S8_JPN_DWLL1_A3	12	0.26	0.26	12	0.3	0.3	1.05	1.34
S9_JPN_DWLL2_A3	13	0.22	0.26	13	0.25	0.25	1.05	1.32
S10_JPN_DWLL3_A3	10	0.45	0.55	14	0.59	0.73	1.22	1.31
S11_JPN_CLL	16	0.47	0.45	16	0.61	0.54	1.66	1.26
S15_TWN_LL2	15	0.23	0.2	19	0.2	0.18	0.95	1.27
S16_HW_LL	14	0.48	0.47	18	0.52	0.47	0.93	1.27

Table 12. Mean input multinomial effective sample sizes (N) and model estimated effective sample sizes (effN) in the 2011 stock assessment and the stock assessment update.

Reference code	2011 assessment		2015 update	
	Input mean N	**Mean effN**	**Input mean N**	**Mean effN**
L1_JPN_DWLL_A1	9.79	13.13	9.28	12.66
L2_JPN_DWLL_A2	33.22	33.18	44	34.91
L3_JPN_DWLL_A3	42.16	47.55	15.71	42.46
L4_JPN_CLL	39.04	47.93	23.48	50.05
L5_JPN_DRIFT	18.32	39.72	3.46	71.66
L6_JPN_OTHER_Q12	32.26	31.49	5.34	29.98
L7_JPN_OTHER_Q34	34.02	33.86	8.27	32.75
L8_TWN_LL	10.05	33.82	12.13	55.51
L9_HW_LL	26.79	25.78	54.83	27.68
L10_WCPO_OTHER	3.3	26.05	3.72	24.66

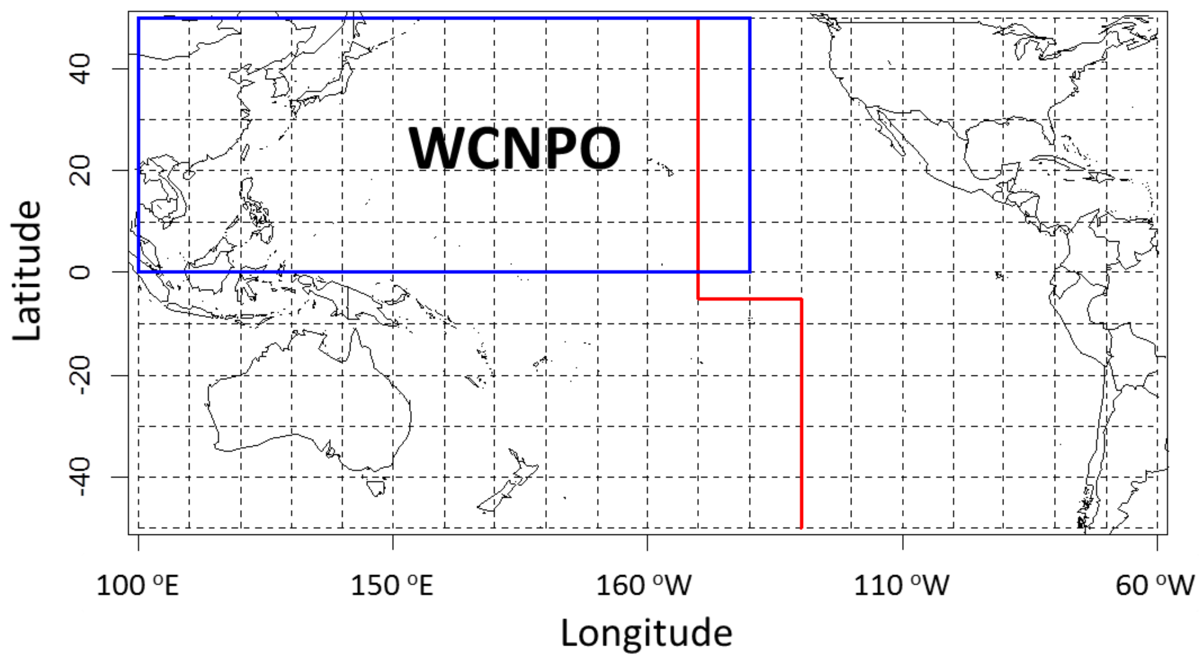

Figure 1. Stock boundary for the stock assessment update of Western and Central North Pacific Ocean striped marlin (WCNPO) as indicated by the blue lines. Red lines indicates the WCPFC convention area.

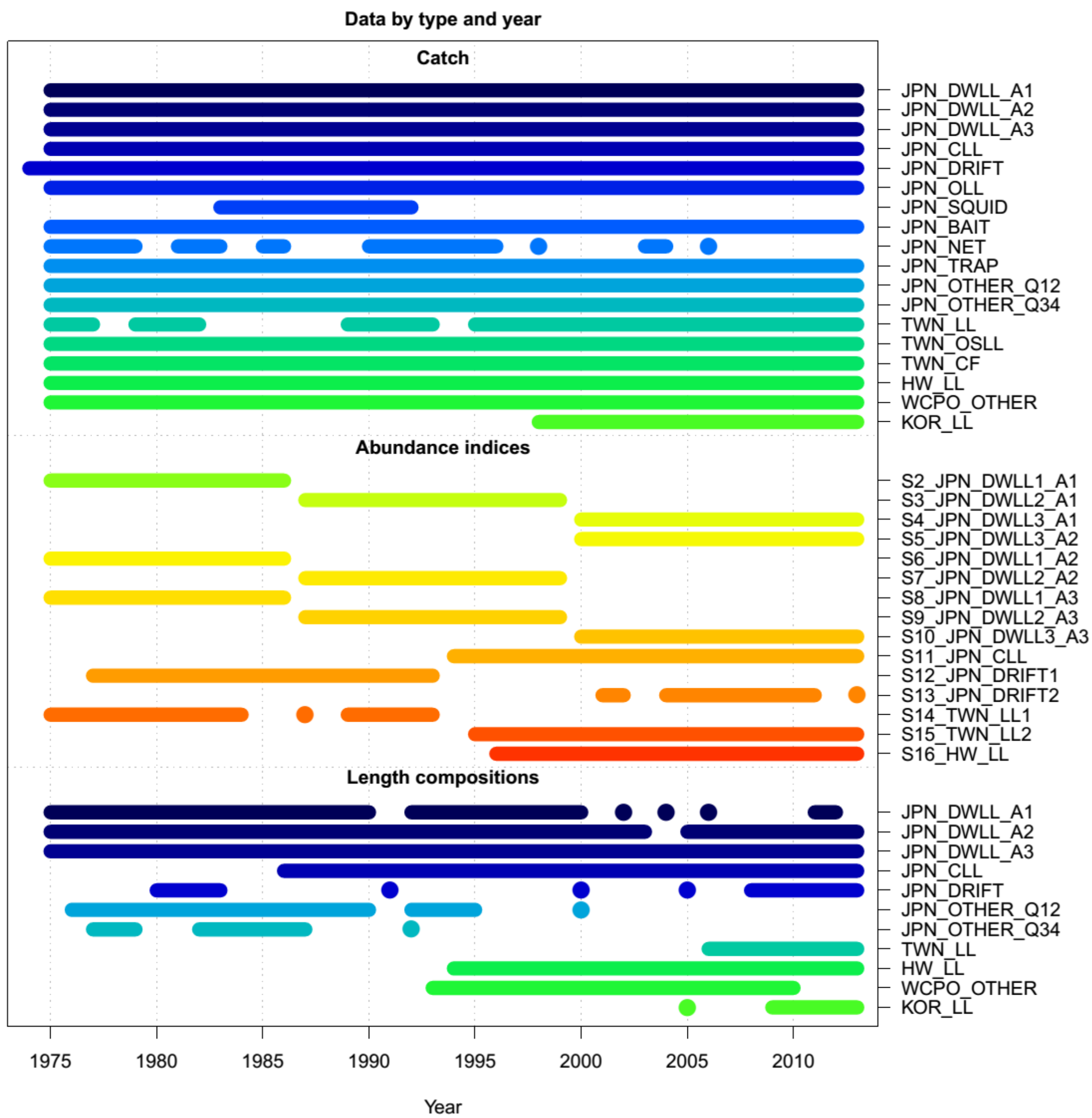

Figure 2. Available temporal coverage and sources of catch, CPUE (abundance indices), and length composition for the stock assessment update of Western and Central North Pacific Ocean striped marlin.

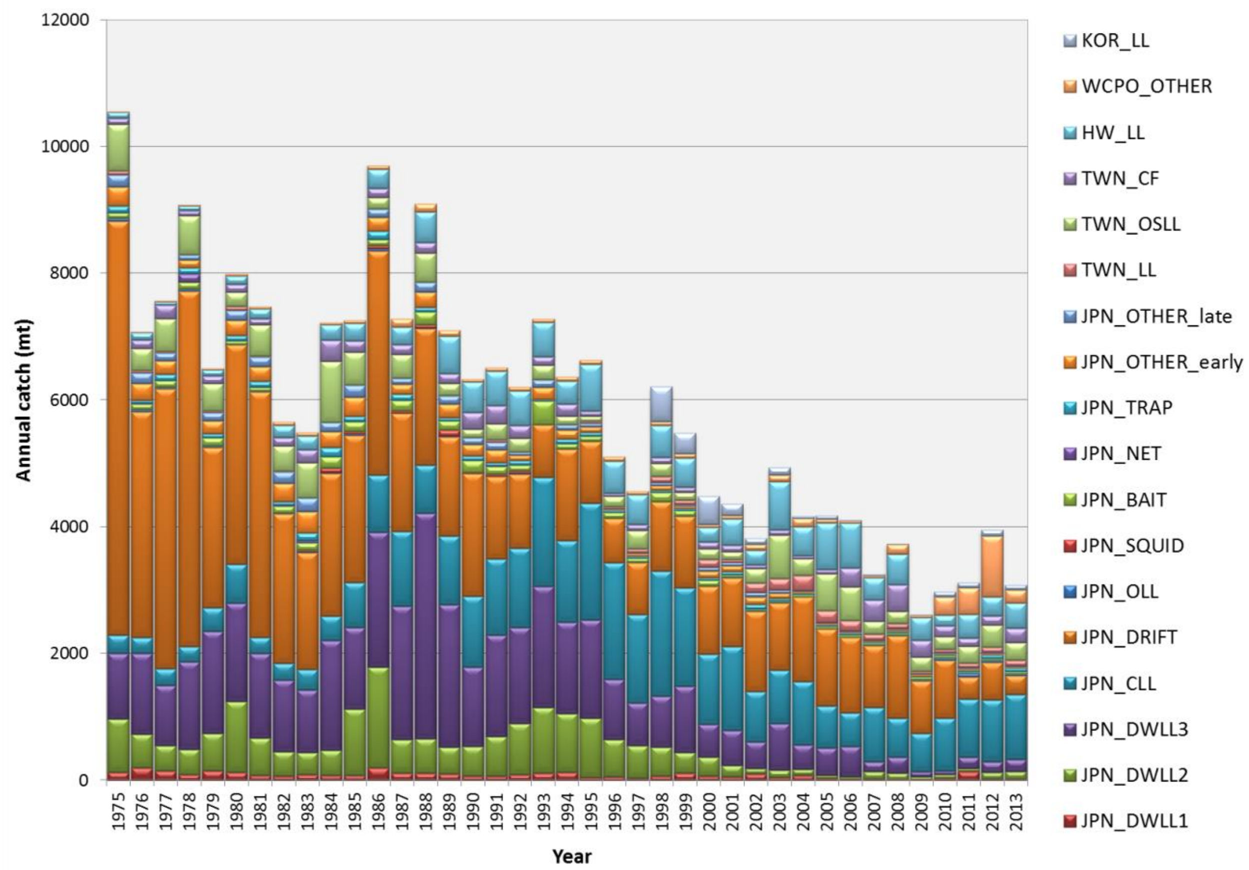

Figure 3. Total annual catch of Western and Central North Pacific Ocean striped marlin by all fisheries harvesting the stock during 1975-2013. See Table 1 for the reference code for each fishery.

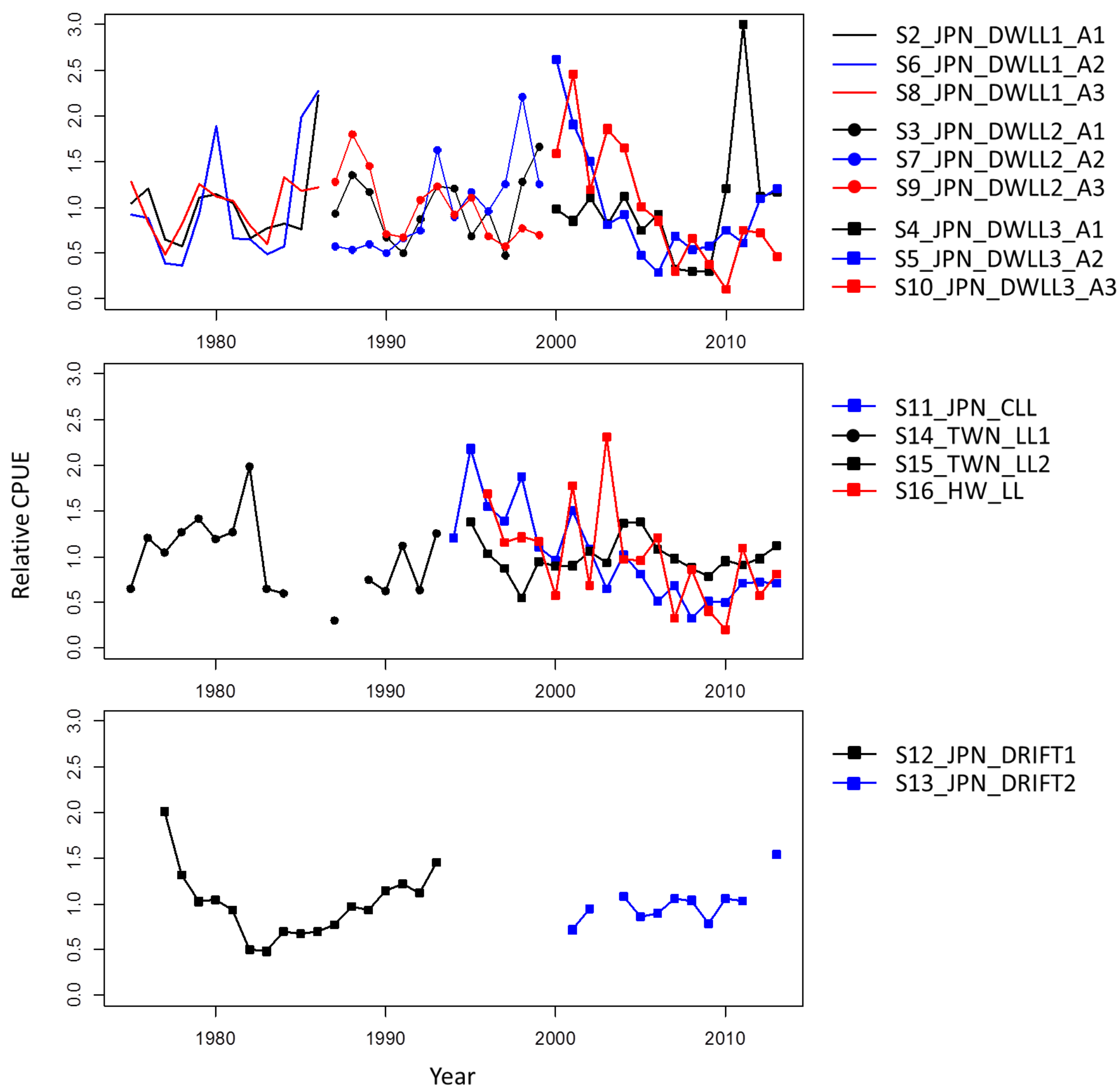

Figure 4. Time series of annual standardized indices of catch-per-unit-effort (CPUE) for the Japanese distant water longline fisheries (top panel); Japanese coastal longline, Taiwan distant water longline, and Hawaii-based longline fisheries (middle panel); and Japan driftnet fisheries (bottom panel) for Western and Central North Pacific Ocean striped marlin as described in Table 2. Index values in the figures were rescaled by the mean of each index for comparison purposes.

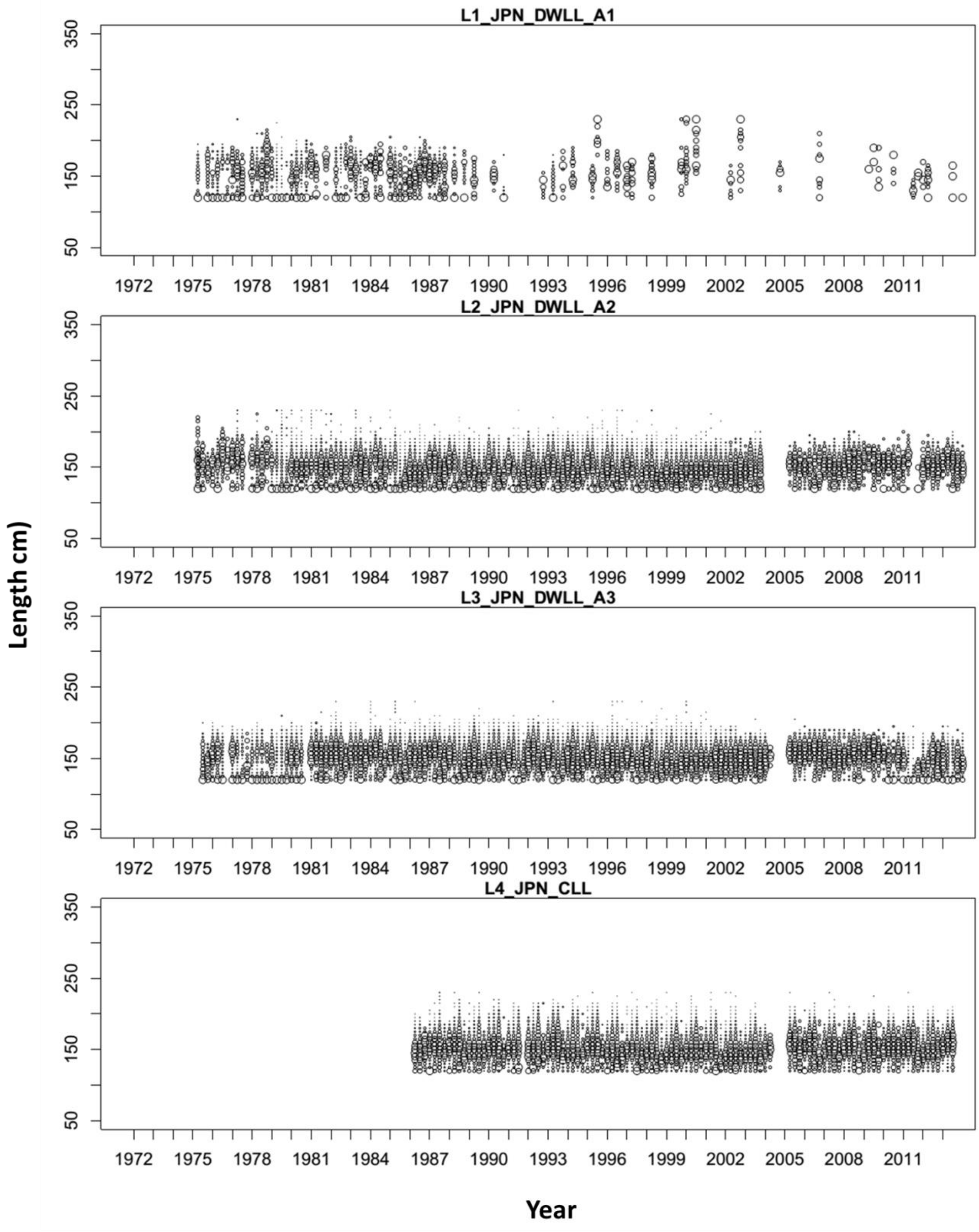

Figure 5. Quarterly length composition data by fishery used in the stock assessment update (see Table 3). The sizes of the circles are proportional to the number of observations. All measurements were eye- fork lengths (EFL, cm).

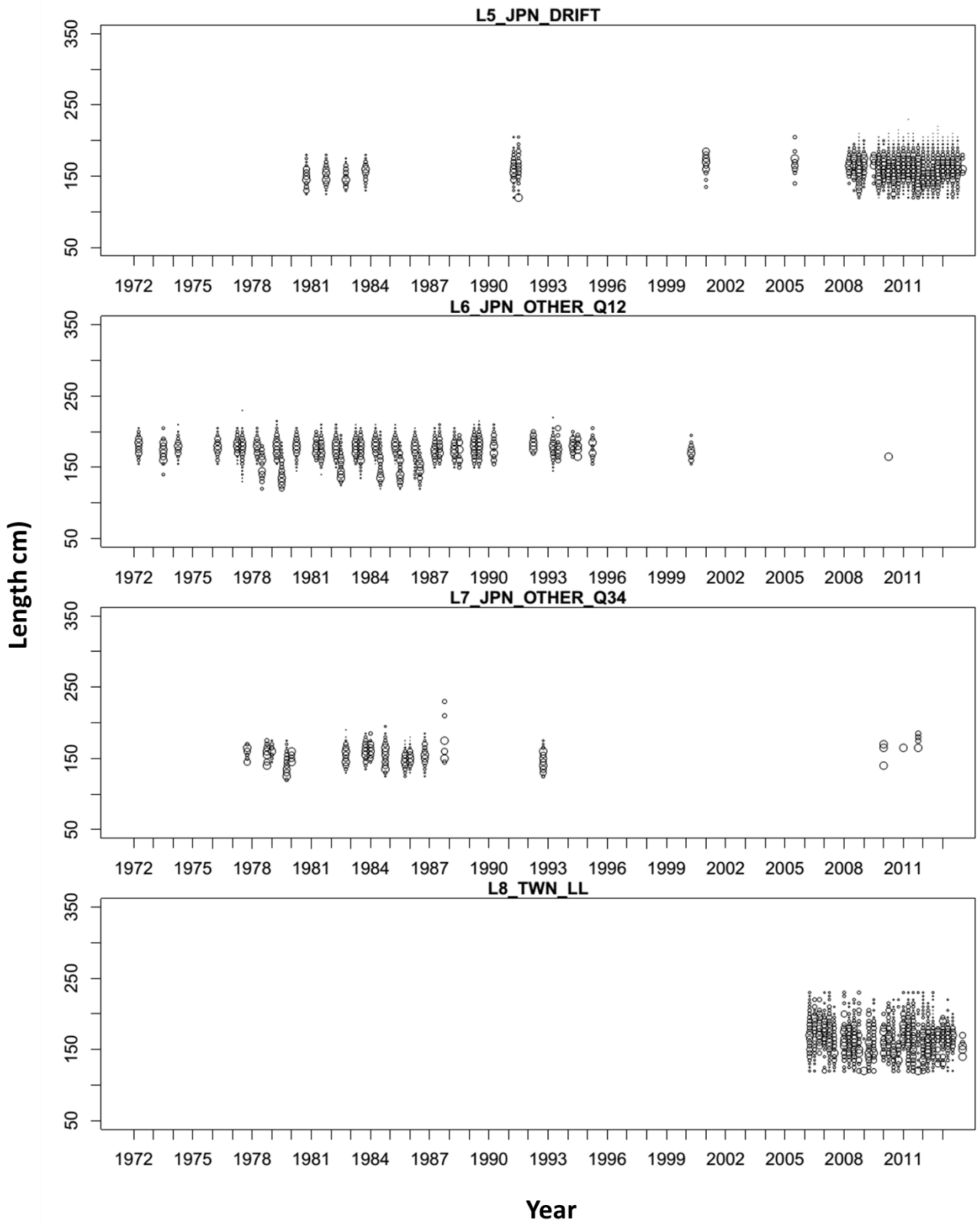

Figure 5. Continued.

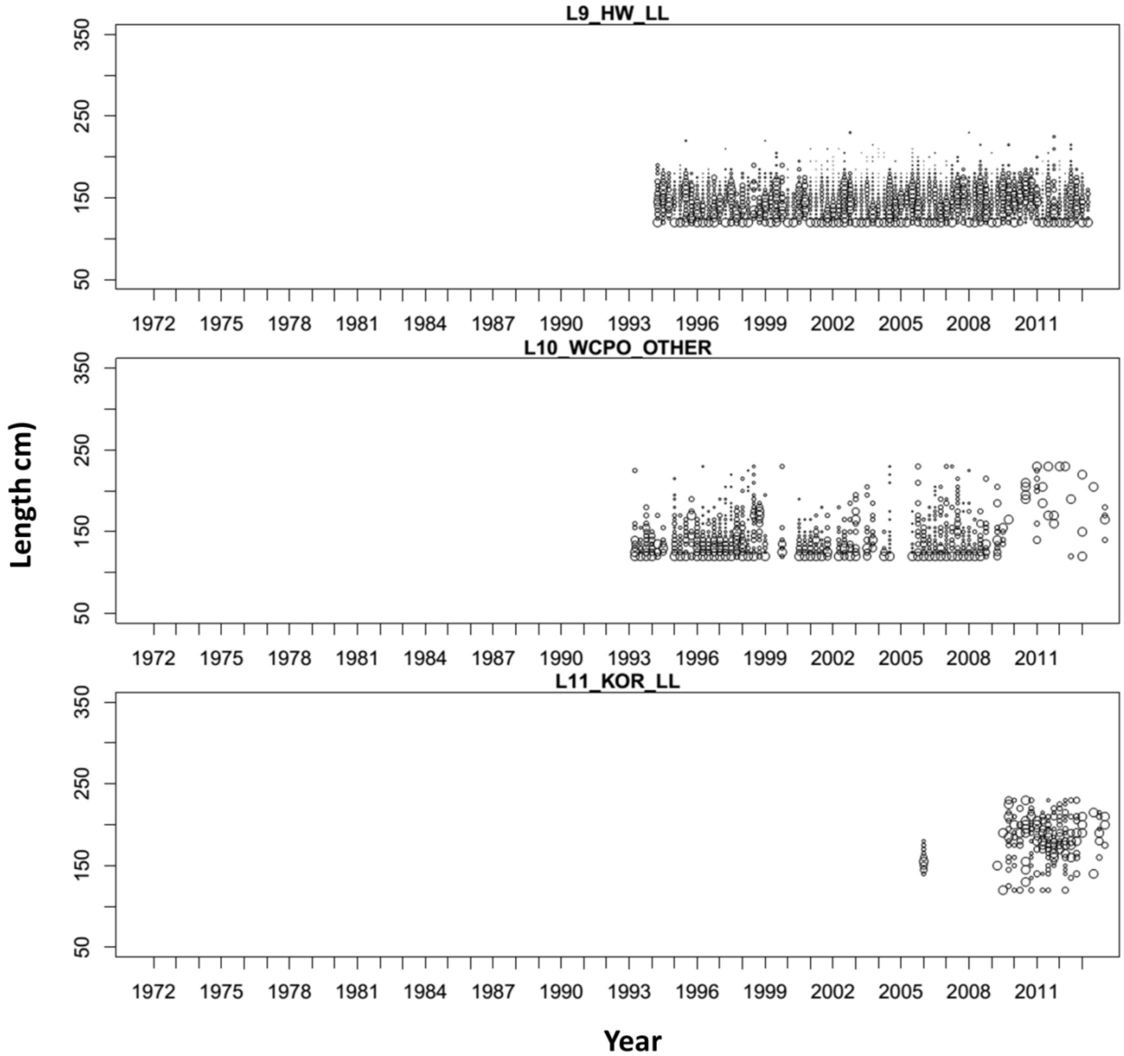

Figure 5. Continued.

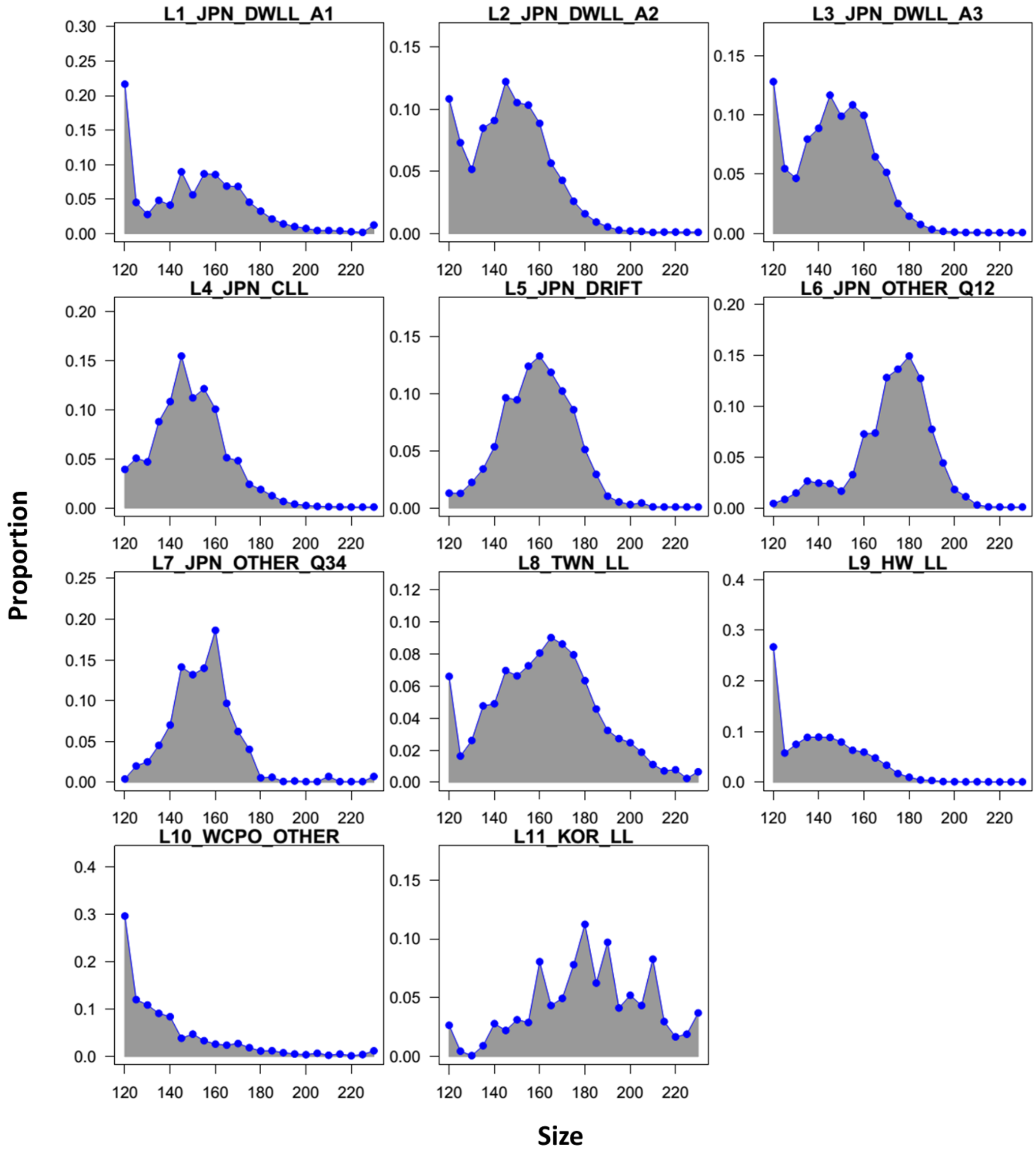

Figure 6. Aggregated length compositions used in the stock assessment update (see Table 3 for descriptions of the composition data). Data were compiled using 5-cm size bins from 120 to 230 cm, where the lower boundary of each bin (blue point) was used to define each bin.

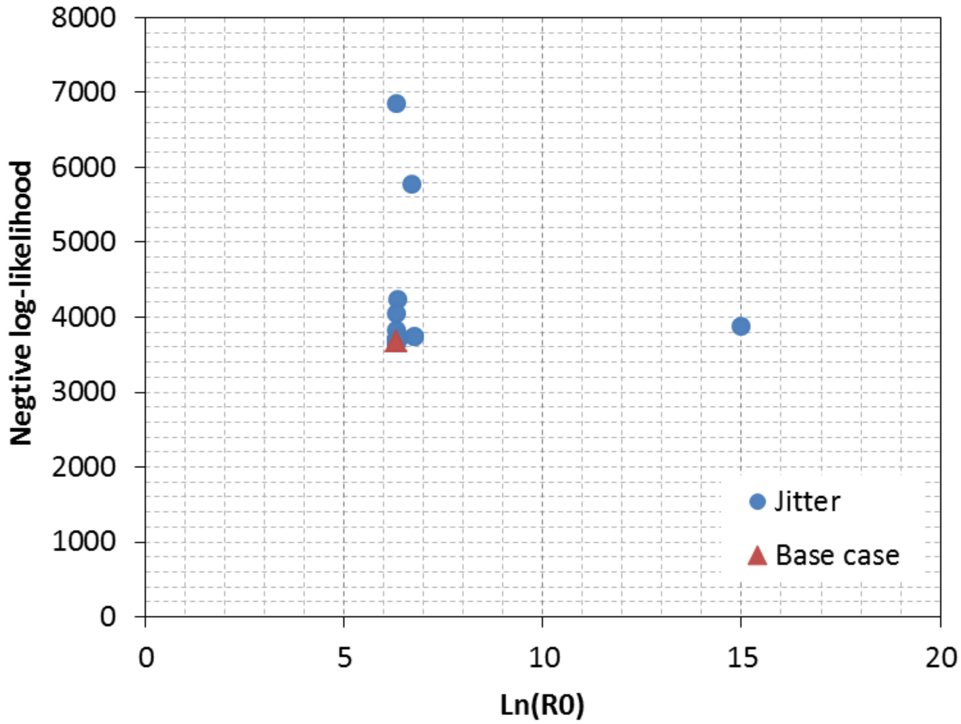

Figure 7. Total negative log-likelihood and estimated virgin recruitment in log-scale (log(R0)) from 50 model runs with different initial values of log(R0) and other important parameters in the base-case model. Red triangle indicates results from model run using initial parameters from the updated base case model, which has the lowest total negative log-likelihood (3683.54) of all 50 model runs.

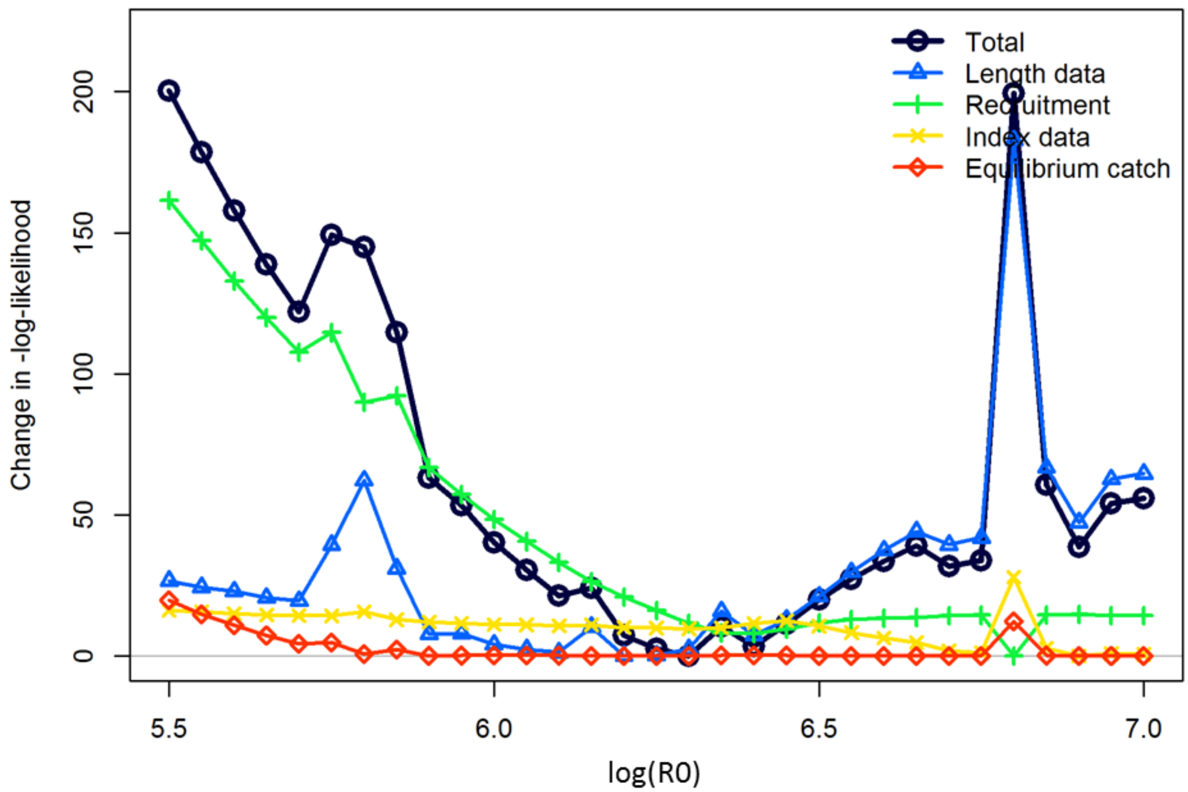

Figure 8. Profiles of the relative-negative log likelihoods by different likelihood components for the virgin recruitment in log-scale (log(R0)) of the base case scenario.

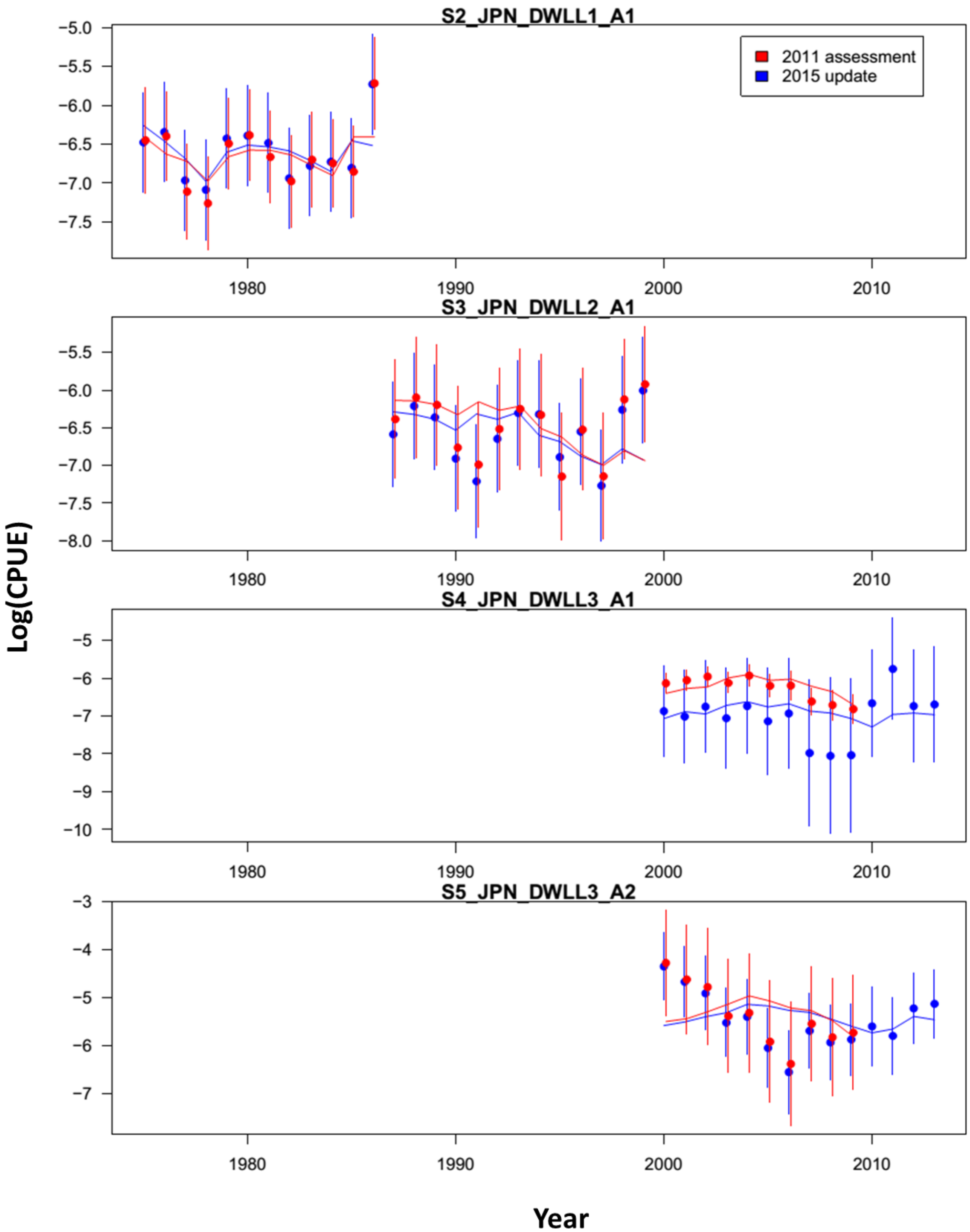

Figure 9. Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. Red color = 2011 assessment, blue color = 2015 update.

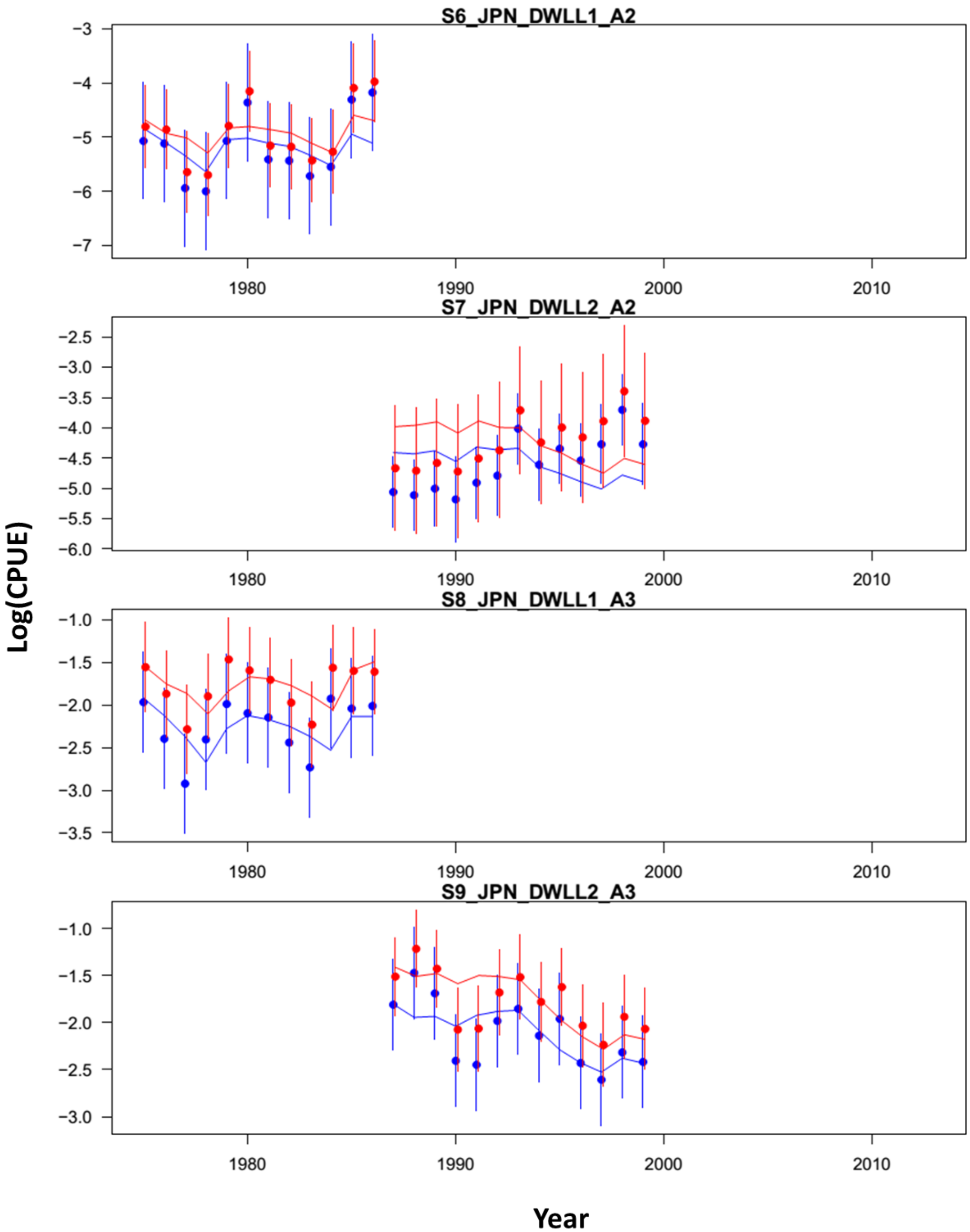

Figure 9. Continued.

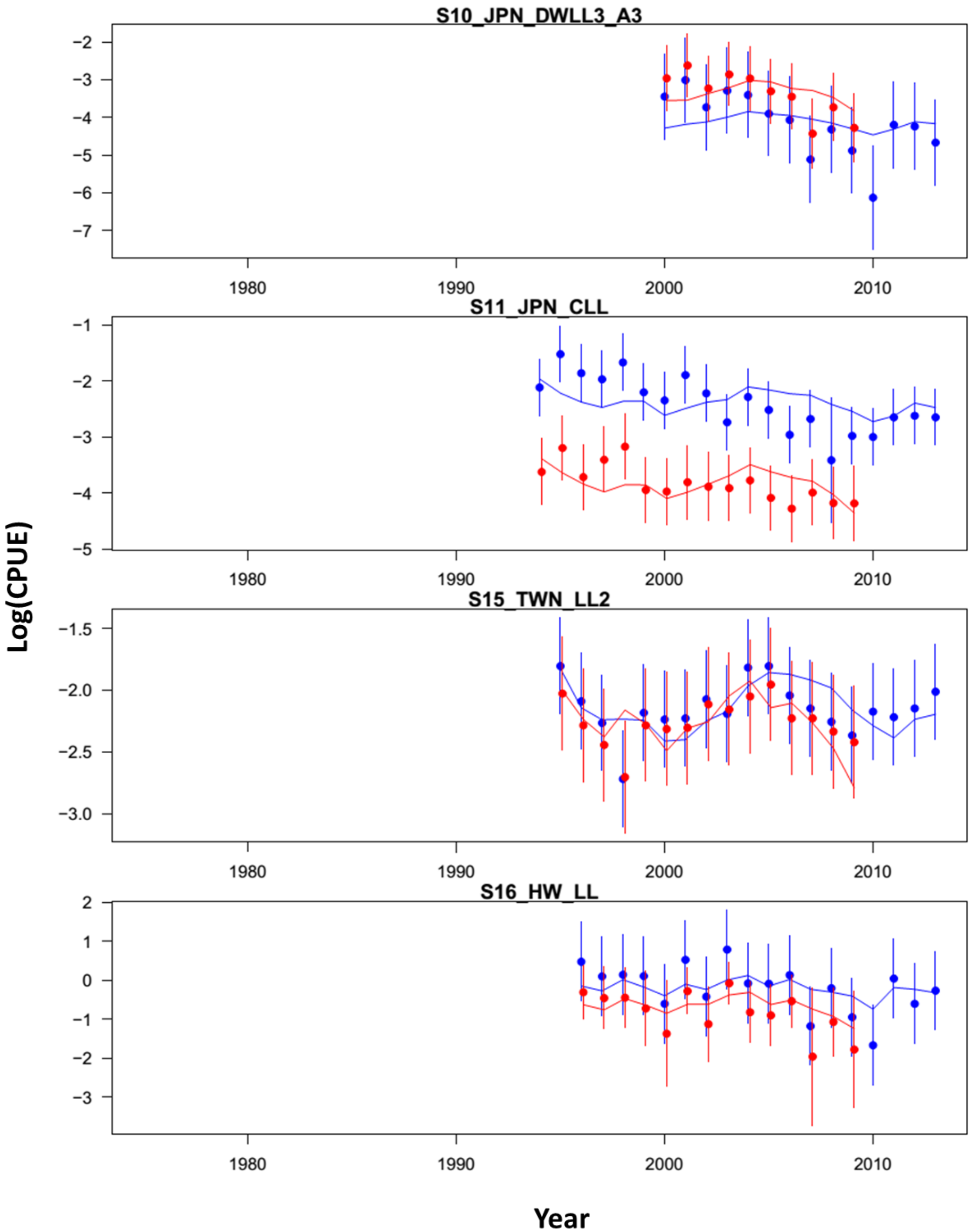

Figure 9. Continued.

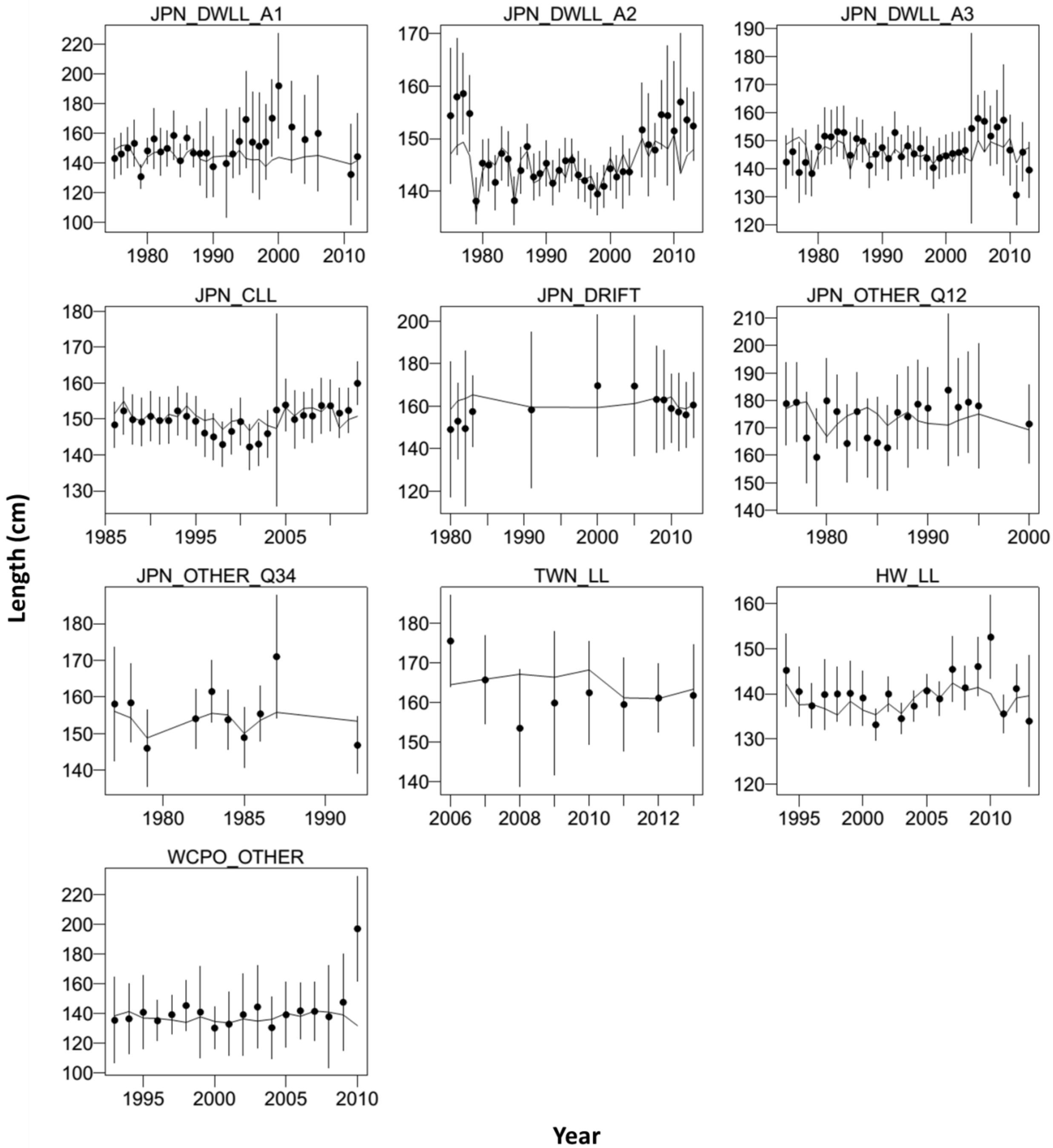

Figure 10. Model fit (lines) to mean size of the composition data (points, showing the observed mean age and 95% credible limits around mean age with the re-weighted multinomial effective sample sizes (vertical lines). See Table 3 for descriptions of the data.

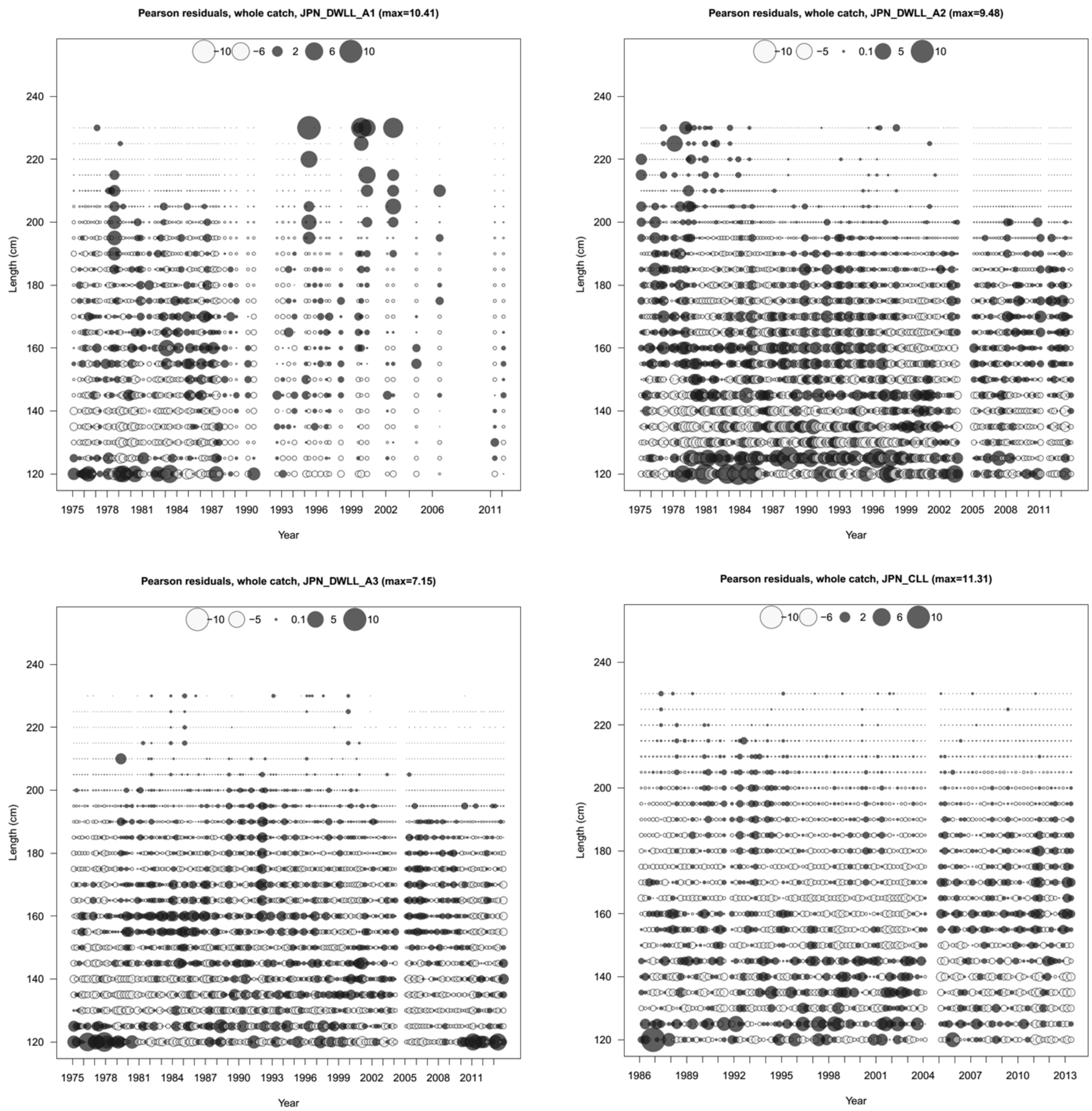

Figure 11. Pearson residual plots of model fits to the length-composition data for the Western and Central North Pacific Ocean striped marlin fisheries used in the assessment model.

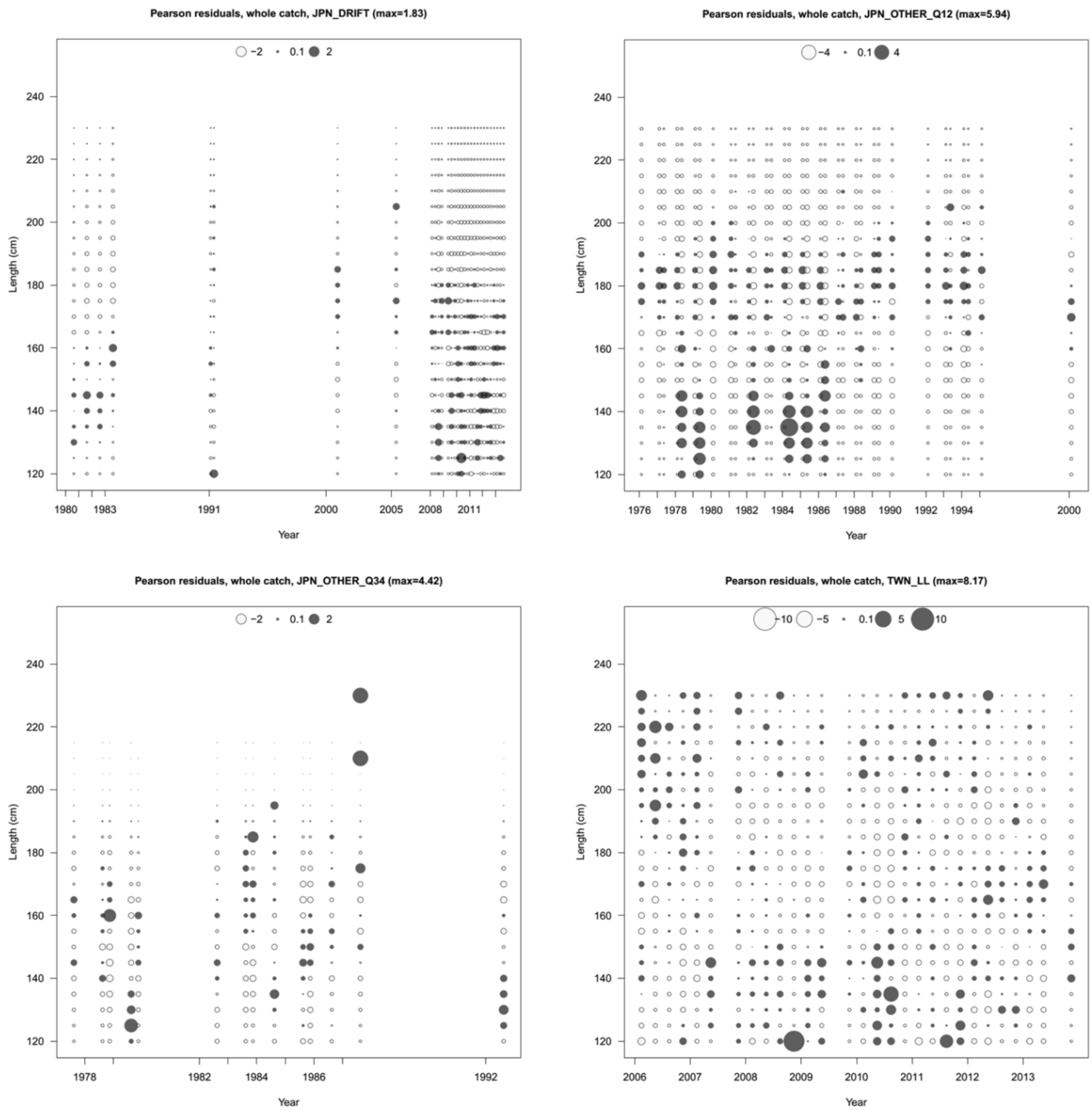

Figure 11. Continued.

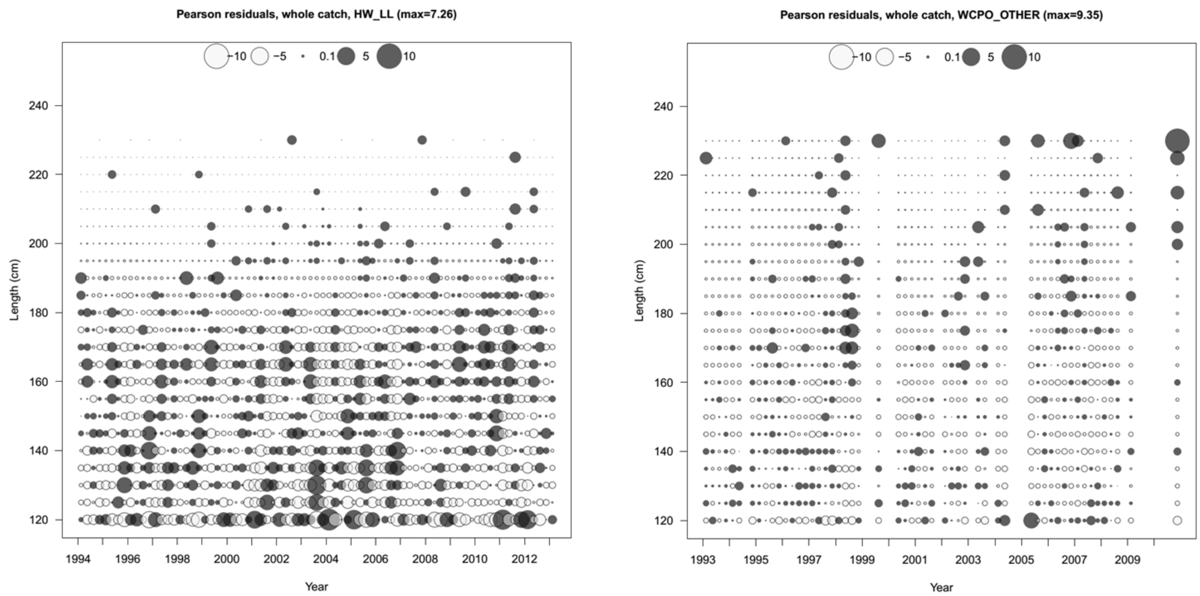

Figure 11. Continued.

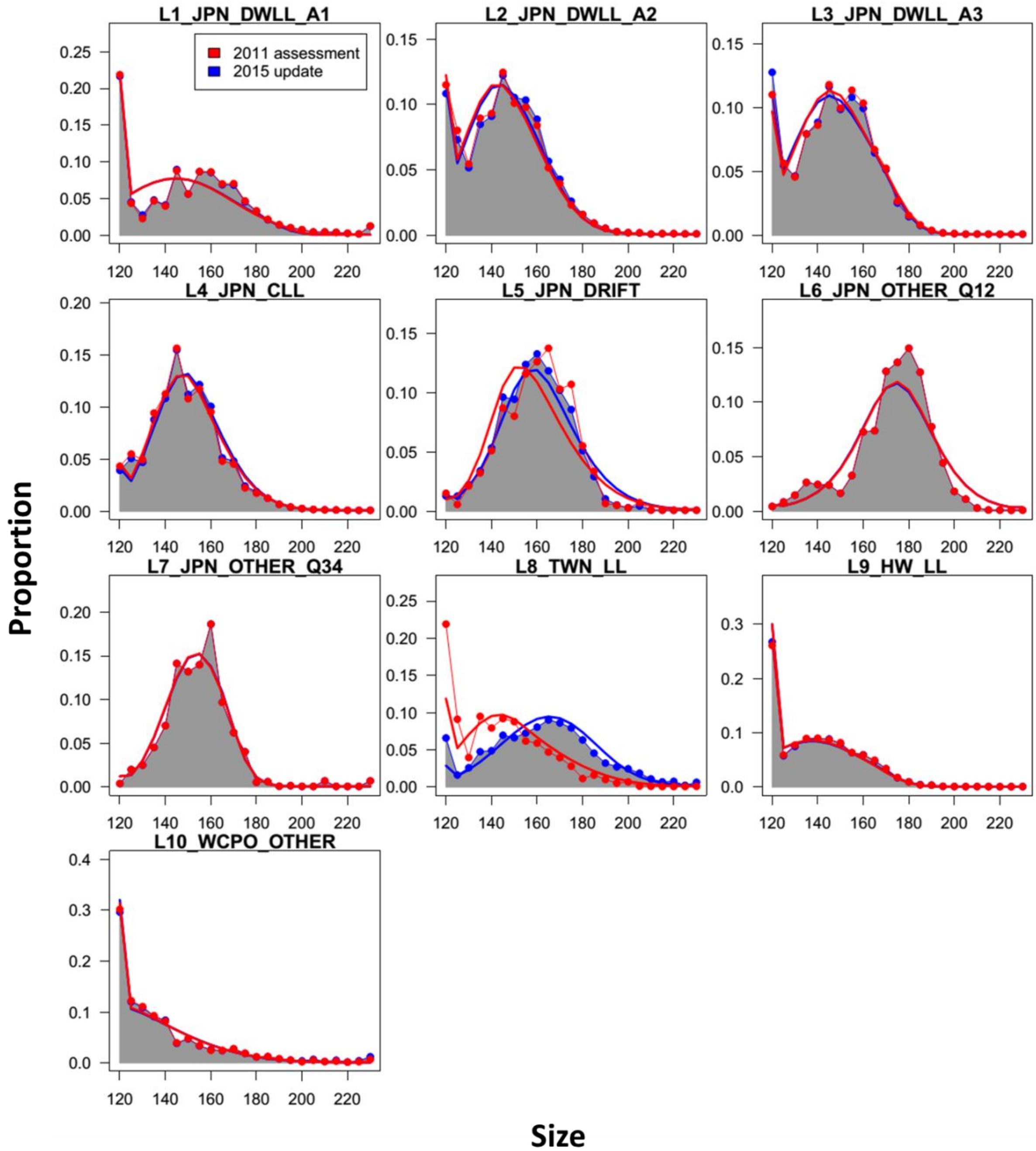

Figure 12. Comparison of observed (gray shaded area and blue bots) and model predicted (blue solid line) length compositions for fisheries used in the updated stock assessment for the Western and Central North Pacific Ocean striped marlin. Red colors indicate observed (dots) and predicted (line) length compositions from the 2011 assessment.

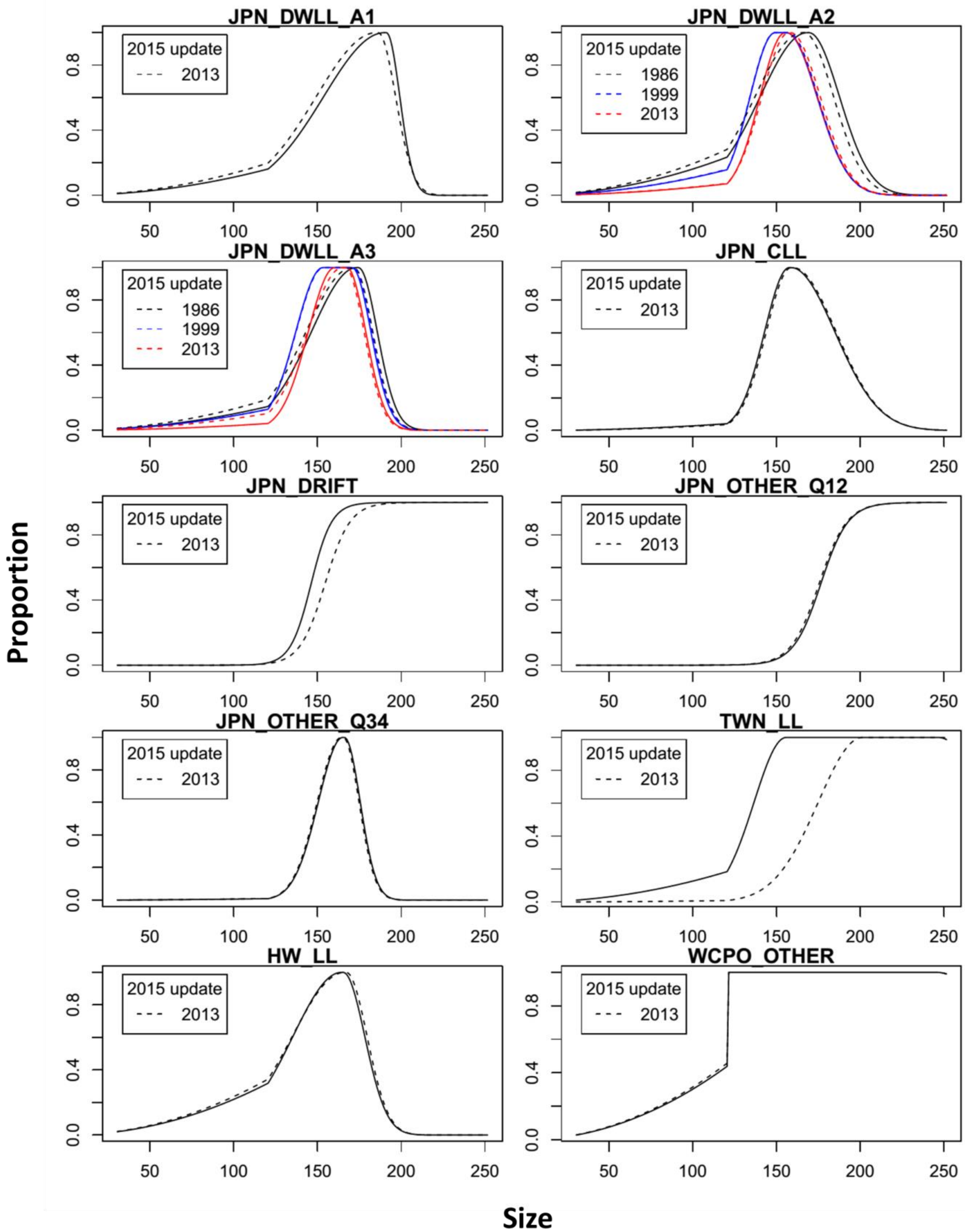

Figure 13. Comparison of length-based selectivity of fisheries for the Western and Central North Pacific Ocean striped marlin between the 2011 stock assessment (dashed lines) and the 2015 update (solid lines).Different colors denote the selectivity curves by time blocks.

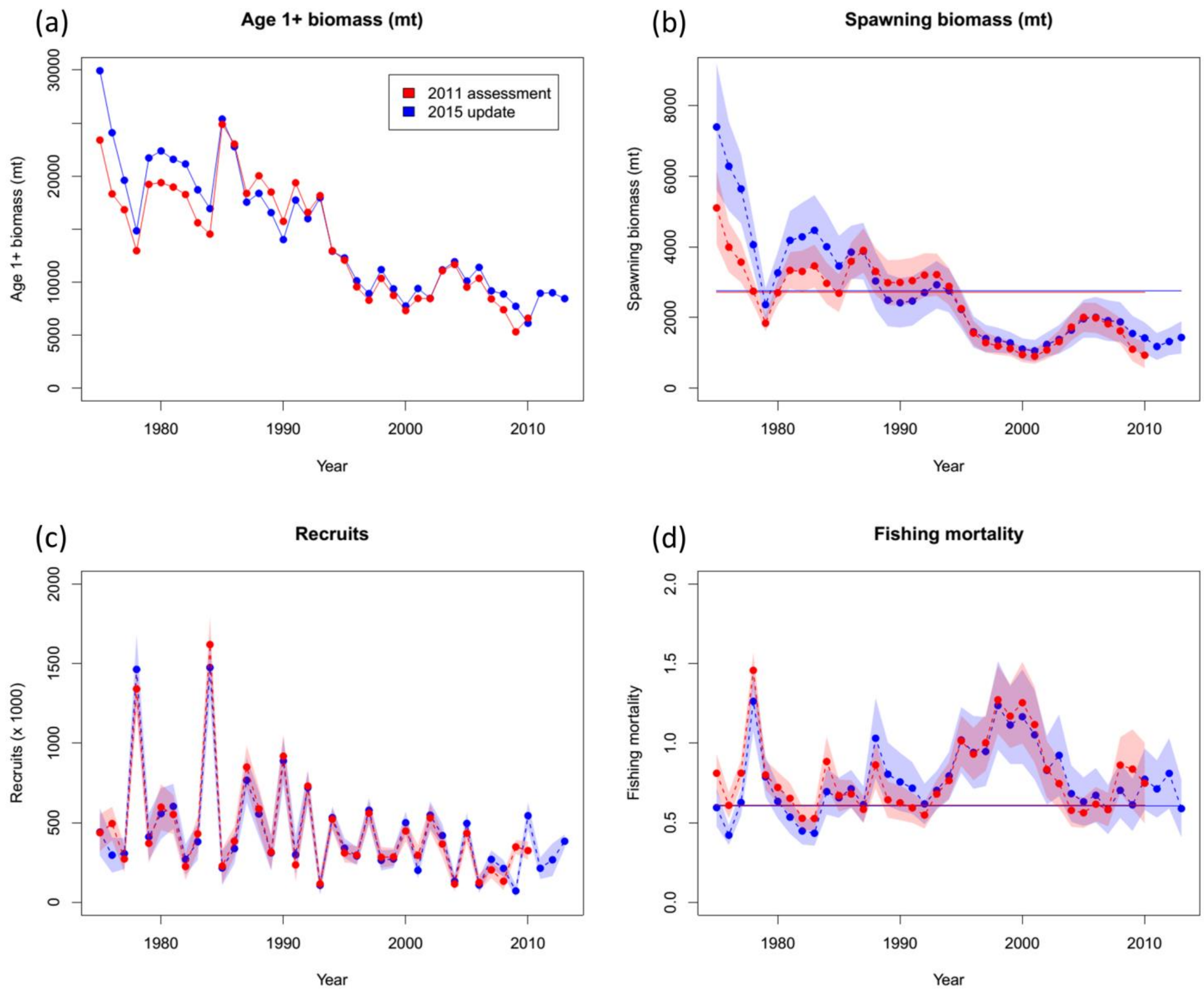

Figure 14. Comparison of time series of total biomass (age 1 and older) (a), spawning biomass (b), age-0 recruitment (c), and instantaneous fishing mortality (year^{-1}) (d) for the Western and Central North Pacific Ocean striped marlin between the 2011 stock assessment (red) and the 2015 update (blue). The solid line with circles represents the maximum likelihood estimates for each quantity and the shadowed area represents the 95% asymptotic intervals of the estimates (± 1.96 standard deviations). The solid horizontal lines indicated the MSY-based reference points.

Appendix I

Table A1. Correlation matrices of various abundance indices for time periods of 1975-1986 (a), 1987-1999 (b), and 2000-2013 (c). Colors indicate levels of correlation (blue: high positive correlation, red: high negative correlation). See Table 2 for descriptions of each abundance index.

(a) 1975 – 1986

	S6	S8	S12	S14
S2	0.68	0.44	-0.23	-0.09
S6		0.53	-0.29	0.09
S8			-0.40	-0.17
S12				-0.04

(b) 1987 – 1999

	S7	S9	S11	S12	S14	S15	S16
S3	0.29	0.36	-0.44	-0.12	0.08	-0.38	-0.14
S7		-0.33	0.39	0.76	0.70	-0.77	-0.49
S9			0.56	-0.43	-0.21	0.63	0.13
S11				-	-	0.30	0.22
S12					0.87	-	-
S14						-	-
S15							0.52

(c) 2000 – 2013

	S5	S10	S11	S13	S15	S16
S4	0.03	0.01	0.13	0.21	0.04	0.11
S5		0.55	0.69	-0.01	-0.20	0.02
S10			0.76	-0.42	0.11	0.74
S11				-0.28	0.21	0.31
S13					0.22	-0.29
S15						0.04

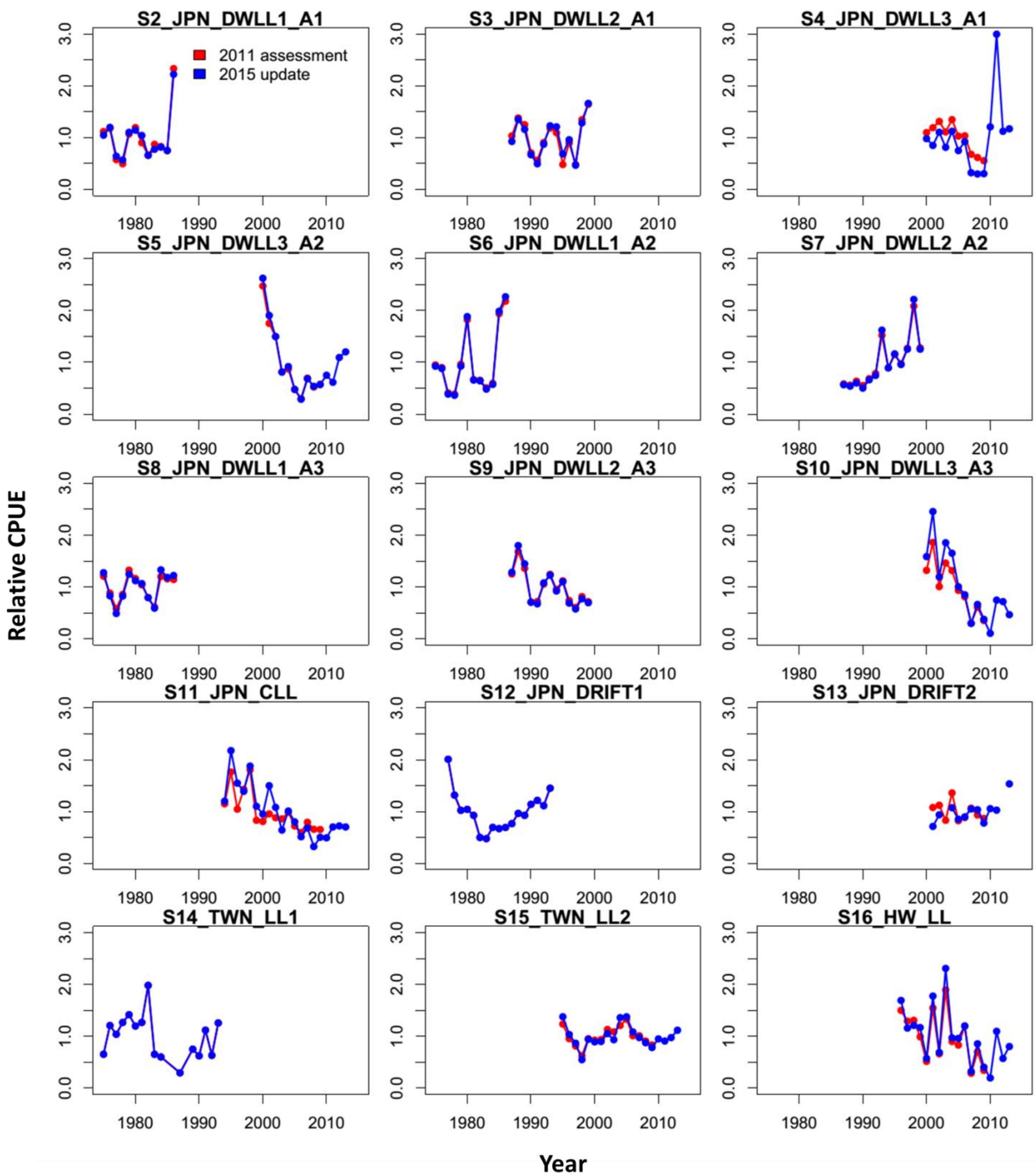

Figure A1. Comparison of relative abundance indices (in relative scale) of catch-per-unit-effort (CPUE) for Western and Central North Pacific Ocean striped marlin *Kajikia audax* used in the 2011 stock assessment and the 2015 update. The red line represents the 2011 stock assessment; the blue line represents the 2015 update.

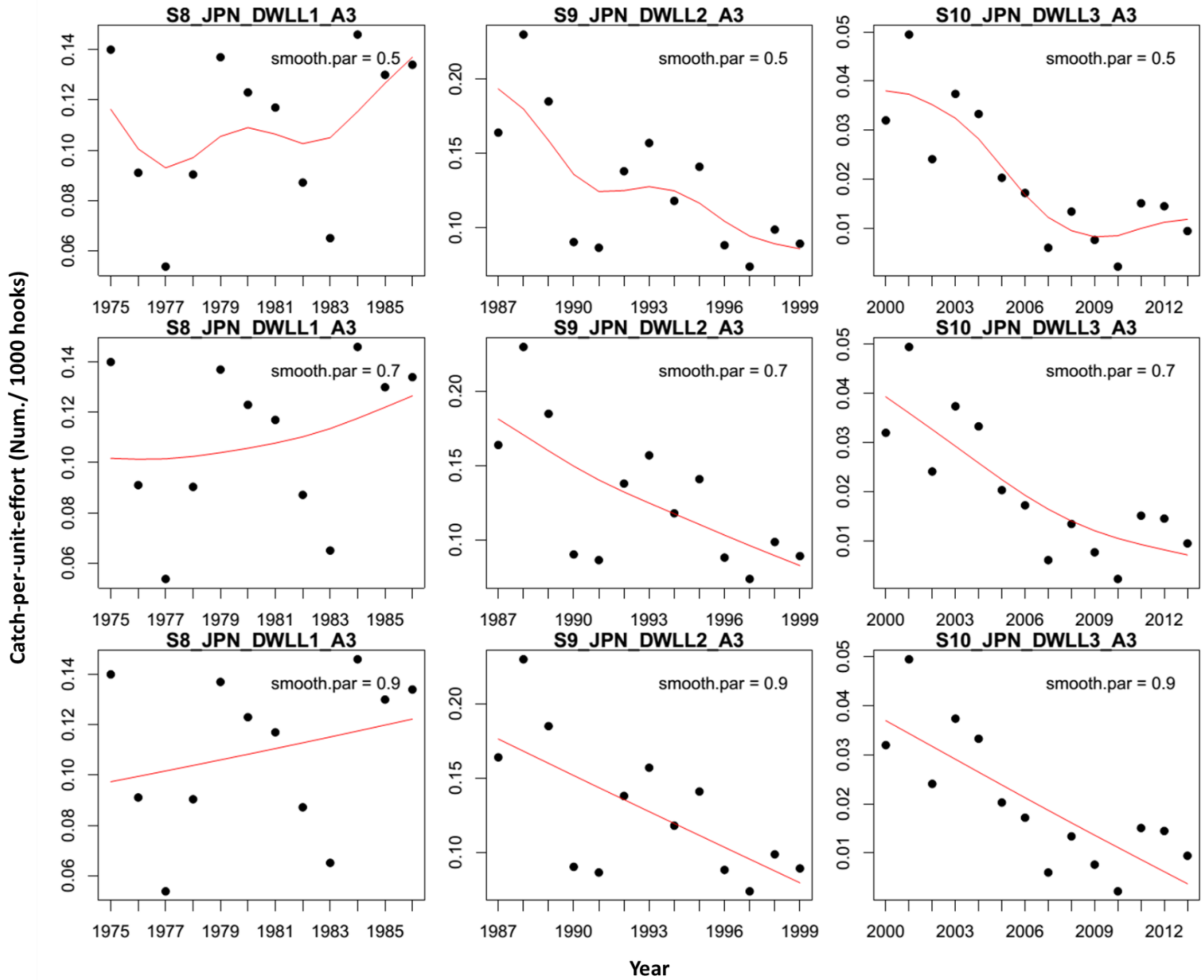

Figure A2. Examples of fits of a data smoother to Japanese distant water longline catch-per-unit-effort (CPUE) indices in area 3 (see Table 2 for definitions). Three smooth parameter values (0.5, 0.7, 0.9) were used with each of three fisheries (S8, S9, S10) in order to estimate the total error of the abundance data set.

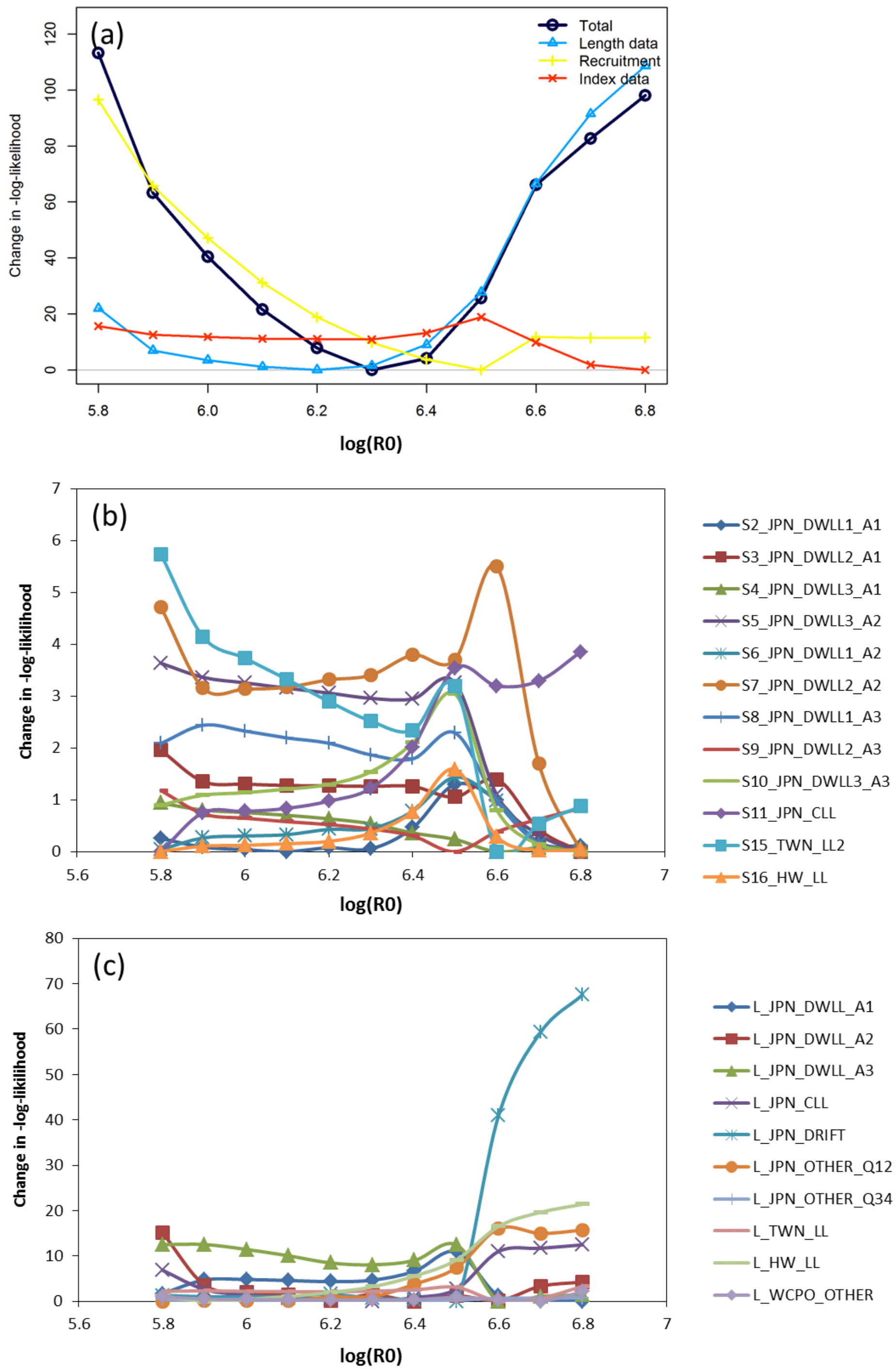

Figure A3. Profiles of the relative-negative log likelihoods for the different main likelihood components: (a) relative abundance indices; (b) size composition of the catch data; and (c) for the virgin recruitment in log-scale (log(R0)). See Tables 2 and 3 for the definitions of abundance and size composition data sets by fishery.