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Report of the Billfish Working Group
(Stock Assessment Update for Blue Marlin (*Makaira nigricans*) in the Pacific Ocean through 2014)

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ISC[1]

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[1] International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

Annex 10

Stock Assessment Update for Blue Marlin (*Makaira nigricans*) in the Pacific Ocean through 2014[1]

REPORT OF THE BILLFISH WORKING GROUP

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

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[1] Prepared for the Sixteenth Meeting of the International Scientific committee on Tuna and Tuna-like Species in the North Pacific Ocean (ISC), 13-18 July, 2016, Sapporo, Japan. Document should not be cited without permission of the authors.

Stock Assessment Update for Blue Marlin (*Makaira nigricans*) in the Pacific Ocean through 2014

ISC Billfish Working Group

June 3, 2016

Abstract

We present an update of the benchmark stock assessment for the Pacific blue marlin (*Makaira nigricans*) stock conducted in 2013 by the ISC Billfish Working Group (BILLWG). The 2016 assessment update consisted of applying a Stock Synthesis model with newly available catch, abundance index, and length and size composition data for 1971-2014. We used the same model structure and parameters as were used in the base case run from the 2013 stock assessment. The results indicated that biomass (age 1 and older) for the Pacific blue marlin stock fluctuated around 120,000 metric tons from 1971 until 1984, thereafter exhibited a long-term decline to the lowest level of 69,720 metric tons in 2009, and then increased to around 78,000 metric tons during the last three years of the assessment (2012-2014). Estimated fishing mortality gradually increased from the early 1970s to the mid-2000s, peaked at 0.38 $year^{-1}$ in 2005 in response to higher catches, and declined to 0.28 $year^{-1}$ in the most recent years (2012-2014). Compared to MSY-based reference points, the current spawning biomass (average for 2012-2014) was 23% above SSB_{MSY} and the current fishing mortality (average for ages 2 and older in 2012-2014) was 14% below F_{MSY}. The base case model indicated that under current conditions the Pacific blue marlin stock was not overfished and was not subject to overfishing relative to MSY-based reference points.

Executive Summary: Pacific Blue Marlin Stock Assessment

Stock Identification and Distribution: The Pacific blue marlin (*Makaira nigricans*) stock area consisted of all waters of the Pacific Ocean and all available fishery data from this area were used for the stock assessment. For the purpose of modeling observations of CPUE and size composition data, it was assumed that there was an instantaneous mixing of fish throughout the stock area on a quarterly basis.

Catches: Pacific blue marlin catches exhibited an increasing trend from the 1950's to the 1980's and thereafter fluctuated without trend. In the 1990's the catch by Japanese fleets decreased while the catch by Taiwanese, WCPFC, and some IATTC member countries increased (Figure S1). Overall, longline gear has accounted for the vast majority of Pacific blue marlin catches since the 1950's (Figure S2).

Data and Assessment: Catch and size composition data were collected from ISC countries (Japan, Taiwan, and USA), IATTC member countries, and the WCPFC (Table S1). Standardized catch-per-unit effort data used to measure trends in relative abundance were provided by Japan, USA, and Chinese Taipei. The Pacific blue marlin stock was assessed using an age-, length-, and sex-structured assessment Stock Synthesis model fit to time series of standardized CPUE and size composition data. Sex-specific growth curves and natural mortality rates were used to account for the sexual dimorphism of adult blue marlin. The value for stock-recruitment steepness used for the base case model was $h = 0.87$. The assessment model was fit to relative abundance indices and size composition data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived outputs, and their variances were used to characterize stock status and to develop stock projections. Several sensitivity analyses were conducted to evaluate the effects of changes in model parameters, including the data series used in the analyses, the natural mortality rate, the stock-recruitment steepness, the growth curve parameters, and the female age at 50% maturity.

Status of Stock: Estimates of total stock biomass show a long term decline. Population biomass (age-1 and older) averaged roughly 130,965 mt in 1971-1975, the first 5 years of the assessment time frame, and has declined by approximately 40% to 78,082 mt in 2014 (Figure S3). Female spawning biomass was estimated to be 24,809 mt in 2014, or about 25% above SSB_{MSY} (Tables S1 and S2). Fishing mortality on the stock (average F, ages 2 and older) averaged roughly F = 0.28 during 2012-2014, or about 12% below F_{MSY}. The estimated spawning potential ratio of the stock (SPR, the predicted spawning output at the current F as a fraction of unfished spawning output) is currently $SPR_{2012\text{-}2014} = 21\%$. Annual recruitment averaged about $854 \cdot 10^3$ recruits during 2010-2014, and no long-term trend in recruitment was apparent. Overall, the time series of spawning stock biomass and recruitment estimates indicate a long-term decline in spawning stock biomass and suggest a fluctuating pattern without trend for recruitment (Figure S3). The Kobe plot depicts the stock status relative to MSY-based reference points for the base case model (Figure S4) and shows that spawning stock biomass decreased to roughly the MSY level in the mid-2000's, and has increased slightly in recent years (Table S1). Results from the base case assessment model indicate that the Pacific blue marlin stock is currently not overfished and is not experiencing overfishing relative to either MSY-based or $F_{20\%}$-based biological reference points.

Table S1. Reported catch (mt) used in the stock assessment along with annual estimates of population biomass (age-1 and older, mt), female spawning biomass (mt), relative female spawning biomass (*SSB/SSB$_{MSY}$*), recruitment (thousands of age-0 fish), fishing mortality (average F, ages-2 and older), relative fishing mortality (*F/F$_{MSY}$*), and spawning potential ratio of Pacific blue marlin.

Year	2008	2009	2010	2011	2012	2013	2014	Mean[1]	Min[1]	Max[1]
Reported Catch	17,828	18,282	20,086	18,165	19,407	20,727	20,356	18,232	9,160	25,589
Population Biomass	71,768	69,720	72,696	72,995	76,697	78,761	78,082	101,149	69,720	135,623
Spawning Biomass	22,706	23,065	22,392	23,182	23,432	24,771	24,809	41,717	20,972	71,807
Relative Spawning Biomass	1.14	1.16	1.13	1.17	1.18	1.25	1.25	2.10	1.06	3.62
Recruitment (age 0)	687	1031	702	1061	763	909	839	897	589	1181
Fishing Mortality	0.27	0.29	0.30	0.26	0.27	0.28	0.28	0.22	0.09	0.38
Relative Fishing Mortality	0.82	0.88	0.92	0.82	0.83	0.87	0.87	0.67	0.26	1.17
Spawning Potential Ratio	22%	21%	20%	22%	22%	21%	21%	31%	15%	57%

[1] During 1971-2014

Biological Reference Points: Biological reference points were computed for the base case model with Stock Synthesis (Table S2). The point estimate of maximum sustainable yield was MSY = 19,901 mt. The point estimate of the spawning biomass to produce MSY (adult female biomass) was SSB$_{MSY}$ = 19,853 mt. The point estimate of F$_{MSY}$, the fishing mortality rate to produce MSY (average fishing mortality on ages 2 and older) was F$_{MSY}$ = 0.32 and the corresponding equilibrium value of spawning potential ratio at MSY was SPR$_{MSY}$ = 18%. The point estimate of F$_{20\%}$ was 0.30 and the corresponding estimate of SSB$_{20\%}$ was 22,727 mt.

Projections: Deterministic stock projections were conducted with Stock Synthesis to evaluate the impact of alternative future levels of harvest intensity on female spawning stock biomass and yield for Pacific blue marlin. Future recruitment was predicted based on the stock-recruitment curve. These projections used all the multi-fleet, multi-season, size- and age-selectivity, and complexity in the assessment model to produce consistent results. The stock projections started in 2015 and continued through 2024 under 4 levels of constant fishing mortality: (1) constant fishing mortality equal to the 2003-2005 average ($F_{2003-2005} = F_{16\%}$); (2) constant fishing mortality equal to $F_{MSY} = F_{18\%}$; (3) constant fishing mortality equal to the 2012-2014 average defined as current ($F_{21\%}$); and (4) constant fishing mortality equal to $F_{30\%}$ (F$_{30\%}$ corresponds to the fishing mortality that produces 30% of the spawning potential ratio). Results show the projected female spawning stock biomasses and the catch biomasses under each of the four harvest scenarios (Table S3 and Figure S5).

Conservation Advice: To avoid overfishing of this nearly fully exploited stock (F/FMSY = 0.88) fishing mortality should not be increased from the current (2012-2014) level.

Special Comments: The lack of sex-specific size data and the simplified treatment of the spatial structure of Pacific blue marlin population dynamics were important sources of uncertainty in the 2016 stock assessment update.

Table S2. Estimates of biological reference points along with estimates of fishing mortality (F), spawning stock biomass (SSB), recent average yield (C), and spawning potential ratio (SPR) of Pacific blue marlin, derived from the base case model assessment model, where “MSY” and “20%” indicate reference points based on maximum sustainable yield and a spawning potential ratio of 20%, respectively.

Reference Point	**Estimate**
F_{MSY} (age 2+)	0.32
$F_{20\%}$ (age 2+)	0.30
$F_{2012-2014}$ (age 2+)	0.28
SSB_{MSY}	19,853 mt
$SSB_{20\%}$	22,727 mt
SSB_{2014}	24,809 mt
MSY	19,901 mt
$C_{2012-2014}$	20,163 mt
SPR_{MSY}	0.18
$SPR_{2012-2014}$	0.21

Table S3. Projected values of Pacific blue marlin spawning stock biomass (SSB, mt) and catch (mt) under four constant fishing mortality rate (F) scenarios during 2015-2024.

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Scenario 1: F = $F_{2003-2005}$										
SSB	24,545	22,683	21,163	20,014	19,167	18,546	18,086	17,741	17,481	17,283
Catch	25,688	24,044	22,890	22,089	21,522	21,111	20,806	20,576	20,402	20,268
Scenario 2: F = F_{MSY}										
SSB	24,810	23,850	22,972	22,260	21,710	21,295	20,982	20,745	20,564	20,426
Catch	23,194	22,336	21,693	21,234	20,905	20,667	20,491	20,359	20,259	20,182
Scenario 3: F = $F_{2012-2014}$										
SSB	25,114	25,242	25,217	25,144	25,063	24,995	24,942	24,901	24,869	24,845
Catch	20,267	20,162	20,047	19,958	19,895	19,852	19,822	19,800	19,785	19,774
Scenario 4: F = $F_{30\%}$										
SSB	25,638	27,797	29,585	31,042	32,212	33,151	33,903	34,506	34,985	35,367
Catch	15,015	15,802	16,386	16,833	17,177	17,442	17,648	17,808	17,932	18,028

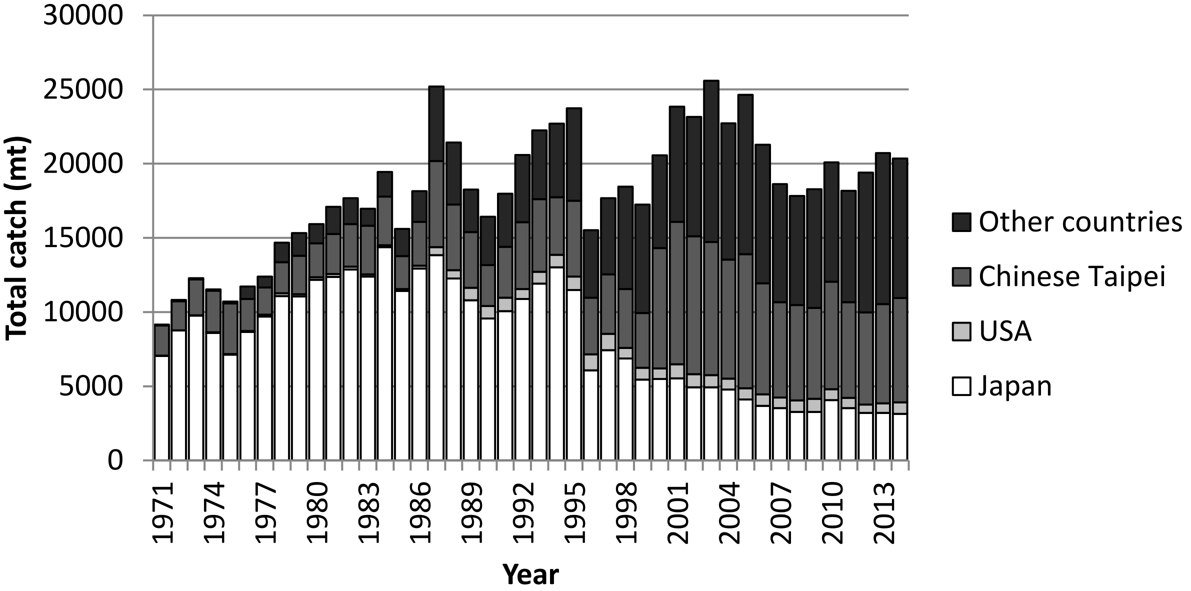

Figure S1. Annual catch biomass (mt) of Pacific blue marlin (*Makaira nigricans*) by country for Japan, Chinese Taipei, the U.S.A., and all other countries during 1971-2014.

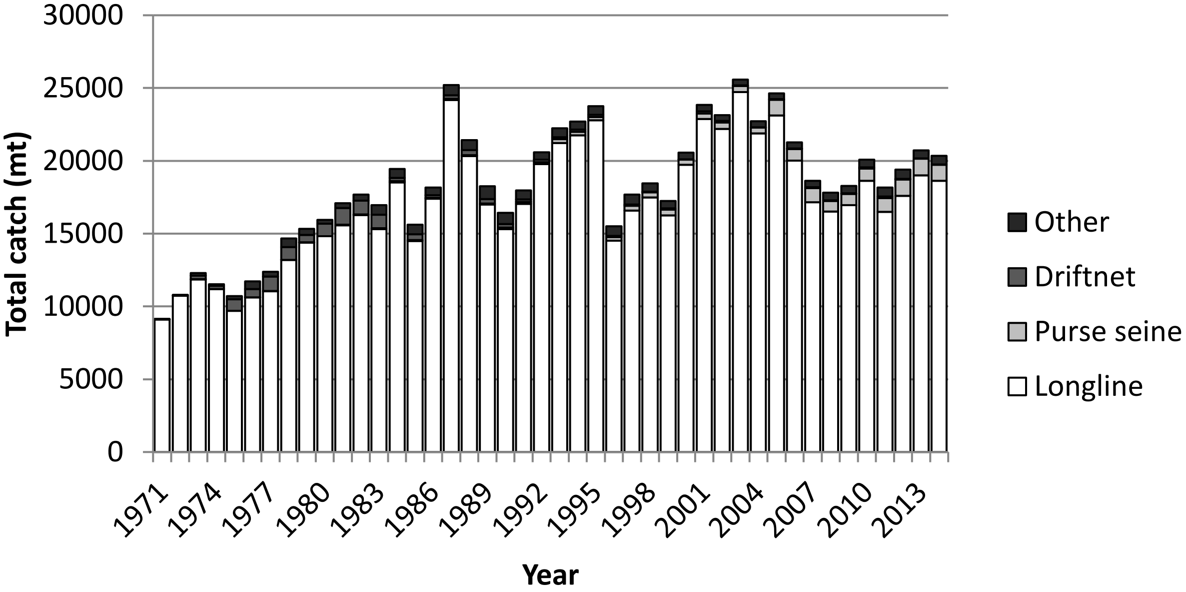

Figure S2. Pacific blue marlin (*Makaira nigricans*) annual catch biomass (mt) by fishing gear from 1952-2014.

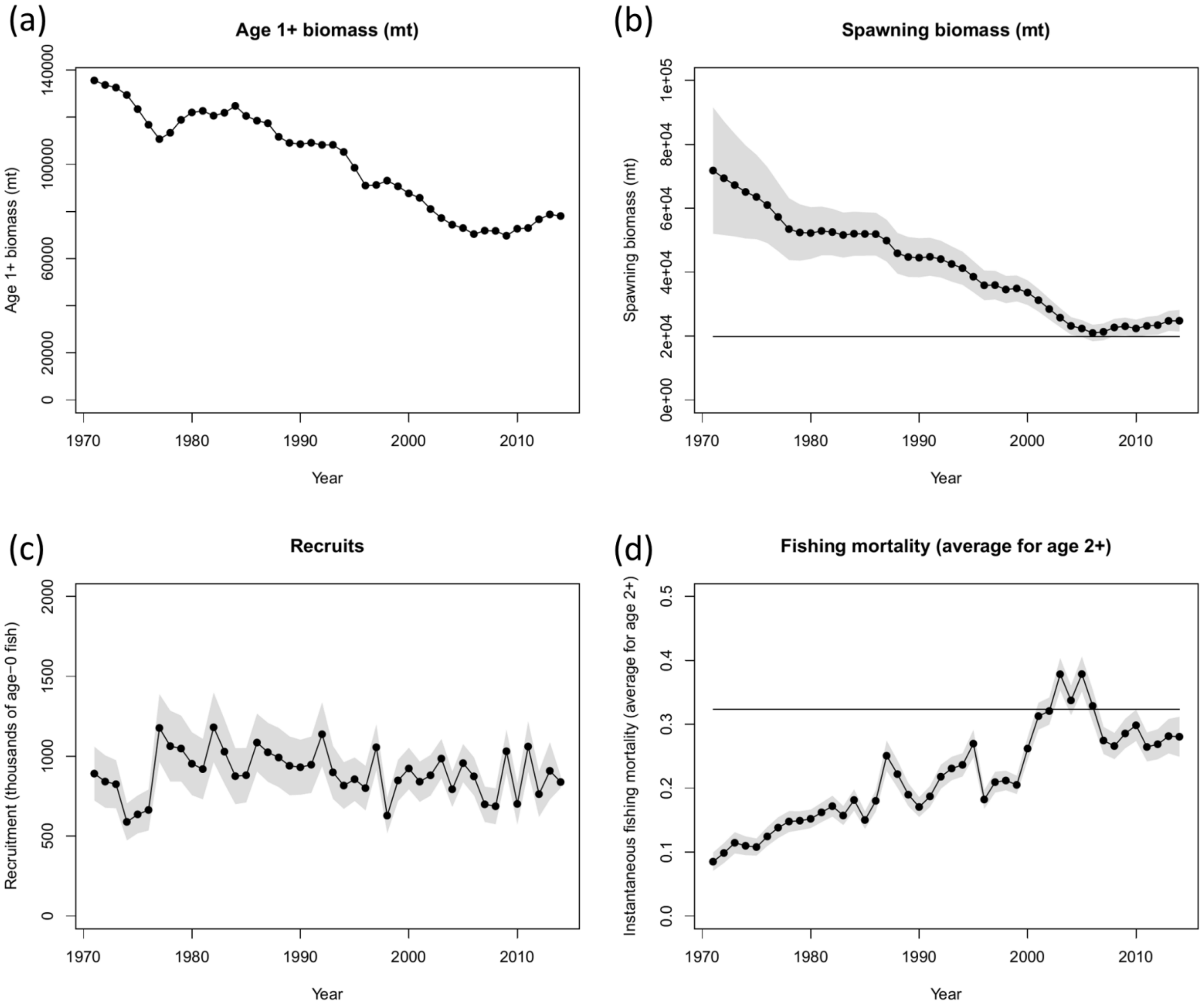

Figure S3. Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) recruitment (age-0 fish), and (d) instantaneous fishing mortality (average for age 2+, year^{-1}) for Pacific blue marlin (*Makaira nigricans*) derived from the 2016 stock assessment update. The solid circles represents the maximum likelihood estimates by year for each quantity and the shadowed area represents the uncertainty of the estimates (± 1 standard deviation), except for the total biomass time series. The solid horizontal lines indicate the MSY-based reference points for spawning biomass and fishing mortality.

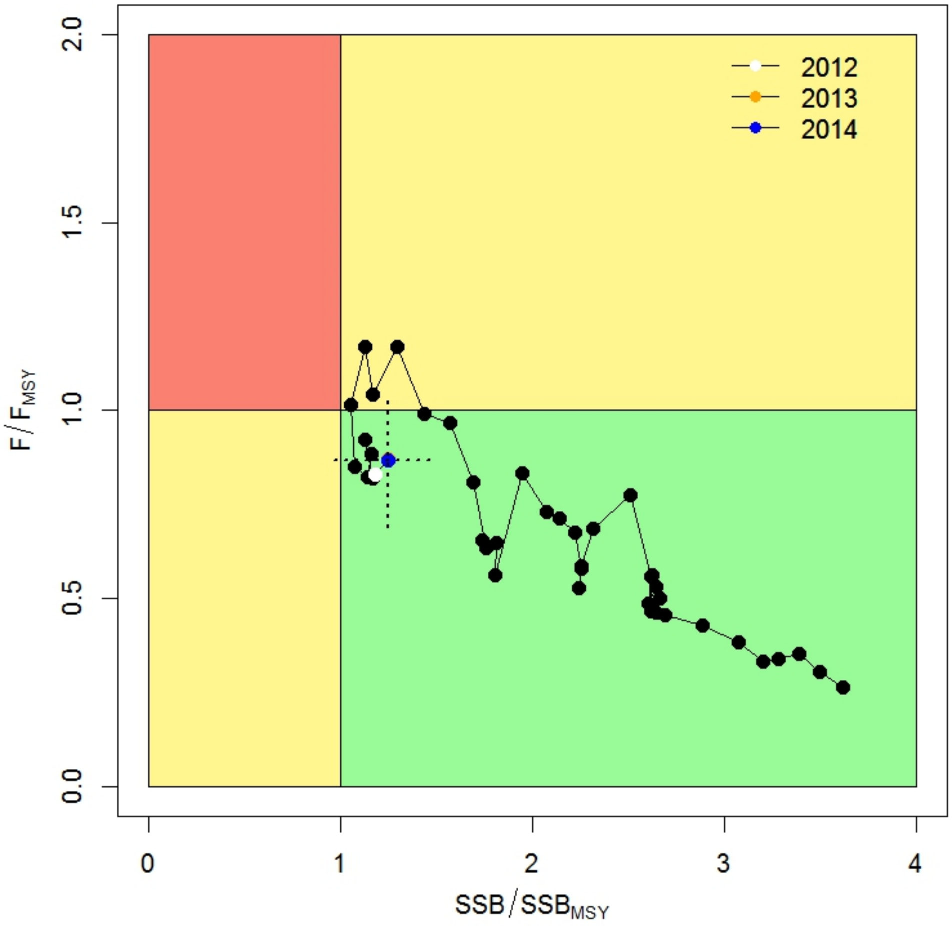

Figure S4. Kobe plot of the time series of estimates of relative fishing mortality (average of age 2+) and relative spawning stock biomass of Pacific blue marlin (*Makaira nigricans*) during 1971-2014. The dashed lines denote the 95% confidence intervals for the estimates in the year 2014.

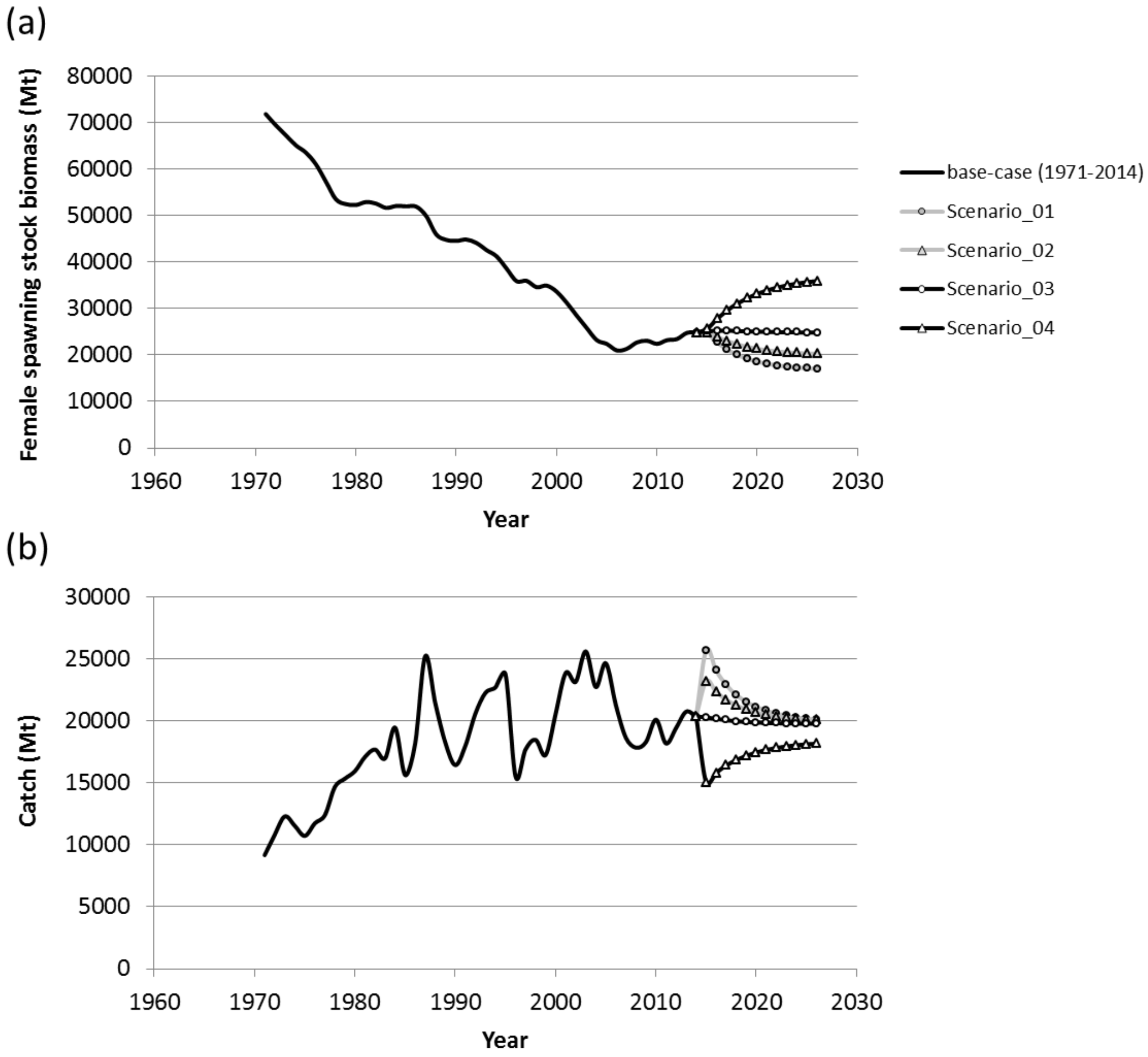

Figure S5. Historical and projected trajectories of (a) spawning stock biomass and (b) total catch from the Pacific blue marlin base case model. Stock projection results are shown for four constant fishing mortality rate scenarios during 2015-2024: Scenario 1, F equal to the average fishing mortality during 2003-2005 ($F_{2003-2005}= F_{16\%}$); Scenario 2, F equal to F_{MSY} ($F_{18\%}$); Scenario 3, F equal to the average fishing mortality during 2012-2014 ($F_{2012-2014}= F_{21\%}$); Scenario 4, F equal to $F_{30\%}$.

Introduction

The Billfish Working Group (BILLWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) completed a benchmark stock assessment for blue marlin (*Makaira nigricans*) in the Pacific Ocean in 2013 (ISC, 2013). The 2013 assessment included data from 1971-2011, and showed a long term decline in blue marlin biomass. Spawning stock biomass (SSB) was 24,990 metric tons in 2011 or 129% of SSB at maximum sustainable yield (SSB_{MSY}), and fishing mortality (F) on the stock (average on ages 2 and older) was F = 0.26 during 2009-2011 or 81% of *F* at maximum sustainable yield (F_{MSY}). Overall trends in SSB and recruitment indicated a long-term decline in SSB and suggested a fluctuating pattern without trend for recruitment. Kobe plots indicated that the Pacific blue marlin SSB decreased to the MSY level in the mid-2000s, and since then has increased slightly. The base case assessment model indicated that the Pacific blue marlin stock was not overfished and was not subject to overfishing relative to MSY-based reference points. There is a three year cycle for assessments in the BILLWG, so an update assessment of the 2013 blue marlin benchmark was scheduled for 2016.

This report describes the updated 2016 stock assessment for the Pacific blue marlin stock. The best available scientific information including the up-to-date catch, catch-per-unit-effort (CPUE), and composition data from 1971-2014 were provided by individual ISC countries, the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), and the Secretariat of the Pacific Community (SPC). The 2016 assessment used the same modeling platform (Stock synthesis, SS) and version (3.24f) as were used in the 2013 assessment. Overall, very similar model structure and parameters were used for the 2016 assessment update in comparison to the 2013 assessment.

Materials and Methods

Spatial and Temporal Stratification

The geographic area encompassed in the assessment for blue marlin was the entire Pacific Ocean. Three types of data were used: fishery-specific catches, relative abundance indices, and length and size measurements. The fishery data were compiled for 1971-2014, noting that the catch data, and length and weight composition data were compiled and modeled on a quarterly basis. Available data, sources of data, and temporal coverage of the datasets used in the updated stock assessment were summarized (Figure 1). Further details are presented below.

Definition of Fisheries

As in the 2013 assessment, a total of 16 fisheries that impacted blue marlin were defined on the basis of country, gear type, location, and time period where each fishery was considered to represent a distinct mode of fishing. These fisheries consisted of: eight country-specific longline fisheries which were the Japanese offshore and distant-water longline early- (JPNEarlyLL) and late-period (JPNLateLL), the Japanese coastal longline (JPNCLL), the Hawaii longline (HWLL), the American Samoa longline (ASLL), the Taiwanese distant-water longline (TWNLL) , various flags other longline (OthLL), and the French Polynesia longline (PYFLL); one Japanese driftnet fishery (JPNDRIFT); one Japanese bait fishery (JPNBait); two purse seine fisheries which were the eastern Pacific purse seine (EPOPS) and the western and central Pacific purse seine (WCPFCPS); two small-scale troll and handline fisheries which were the Hawaii troll and handline (HWOth) and the eastern Pacific troll and handline and also harpoon (EPOOth); and two mixed gear fisheries which were the Japanese other fishing gears (JPNOth) and Taiwanese other fishing gears (TWNOth). Descriptions and data sources to characterize these sixteen fisheries that impact Pacific blue marlin were also summarized (Table 1).

Catch

Catch was input into the model on a quarterly basis (i.e., by calendar year and quarter) from 1971 to 2014 for the 16 individual fisheries. Catch was reported in terms of catch biomass (live-weight, kg) for all fisheries, with the exception of the American Samoa longline fishery (ASLL) and the Eastern Pacific Ocean purse seine fishery (EPOPS), for which catch was reported as numbers of fish caught along with a mean weight estimate. Because 2011 catch data were incomplete for the last assessment, updated catch data from 2011-2014 for all fisheries except JPNEarlyLL were used for the assessment update. In addition, updated time series of catch prior to 2011 were used for the OthLL, WCPFCPS, JPNDrift, JPNOth, ASLL, JPNCLL, PYFLL, and the EPOPS fisheries.

Three countries (i.e., Japan, Taiwan, and the USA) provided updated national catch data (Ijima and Shiozaki, 2016; Nan-Jay Su personal communication, Jan 15, 2016; Ito 2016). Logbook catch data for the year 2014 from the JPNCLL, JPNDRIFT, JPNBait, and JPNOth fisheries were incomplete, and as a result, the best available catch data from yearbook catches from 2013 were imputed for the 2014 catch. Blue marlin catches for all other fishing countries were collected from WCPFC and IATTC category I and II data (Chang et al. 2016). Overall, use of the updated catch data led to a small increase of 1.6% in reported blue marlin catch from 1971 to 2011 in comparison to the 2013 assessment. Individual differences in catch biomass estimates between this update and the 2013 assessment are shown in Appendix (Figure A1).

The resulting best available data on blue marlin catches by fishery from 1971-2014 were tabulated and are shown in Figure 2. The historical maximum and minimum annual blue marlin catches were 25,588 metric tons in 2003 and 9,160 metric tons in 1971, respectively. It is notable that the JPNEarlyLL fishery harvested most of the blue marlin catch during the early assessment period, but yields for this fishery declined after 1995 (as JPNLateLL). For the overall fishery catch of Pacific blue marlin, it is notable that since reaching a maximum in 2003, annual catches have declined and with the exception of 2010, were stable during 2012-2014. The average annual catch of blue marlin in the Pacific Ocean was about 19,663 metric tons during the assessment update period (2011-2014) and it is notable that the TWNOth and OthLL fisheries produced 27% and 39% of the yield during this recent time period, respectively.

Abundance Indices

Relative abundance indices for Pacific blue marlin based on standardized CPUE were prepared for this assessment update and are shown in Figure 3 and Table 4. All of the standardized CPUE indices were updated except for S1_JPNEarlyLL (1975-1993). It is notable that set-by-set logbook data was used in the CPUE standardization for Japanese distant water and offshore longline fisheries (Kai et al., 2016). A deterministic habitat-based standardization model (HBS; Hinton and Nakano 1996) using the same data filtering and assumptions as the CPUE standardization for the last 2013 assessment was used to standardize CPUE for the important Japanese distant water and offshore longline fisheries

Operational fishing data collected in the deep-set sector of the Hawaiian longline fishery by fishery observers in 1995-2014 were used for CPUE standardization of S3_ HW_LL (Carvalho et al. 2016). Similar patterns of the standardized CPUE indices were produced by the delta-lognormal and zero-inflated negative binomial models. The same approach used in the last assessment (the zero-inflated negative binomial generalized linear model (GLM)) was used to develop the relative abundance index for S3_HW_LL.

Data aggregated by 5°×5° grids, with quarters, latitude, longitude, and year information from 1967 to 2014, and those with hooks per basket (HPB) information for 2000-2014 were standardized using GLM for the Taiwanese distant-water longline fishery (Su et al., 2016). The CPUE standardization models were conducted based on three periods, 1967-1978 (S4_TWNLL), 1979-1999 (S5_TWNLL) and 2000-2014 (S6_TWNLL), due to the changes in the fishery such as targeting. Given the timeframe of the model was limited to 1971-2014, the early years (1967-1970) of the CPUE time series for S4_TWNLL were removed.

Visual inspection of all indices grouped by fishery type showed a stable trend over time with the exception of an increasing trend of S1_JPNEarlyLL (1975-1984), a large decreasing trend of S3_HWLL, and a minor decreasing trend of S5_TWNLL (Figure 3). Updated CPUE indices on a relative scale were compared to the indices used in the 2013 assessment (Appendix Figure A2). In general, the updated CPUE indices showed a consistent trend to the previous CPUE indices, although the updated CPUE of S2_JPNLateLL and S3_HWLL showed higher variability. The updated S4_TWNLL and S6_TWNLL were less variable compared to the previous indices used in the 2013 assessment.

Correlations among CPUE indices were analyzed in the 2013 assessment. Similarly, correlations among the updated CPUE indices were also examined (Appendix Table A1). Pearson correlation coefficients (ρ) were interpreted as measuring the association among pairs of CPUE series.

Patterns in correlations among CPUE indices for the update assessment were similar to those in the last assessment. S1_JPNEarlyLL and S4_TWNLL (n=4) and S1_JPNEarlyLL and S5_TWNLL (n=15) showed a consistent trend (ρ ranged from 0.11 to 0.38). S2_JPNLateLL and S3_HWLL (n=20, ρ = 0.24), S2_JPNLateLL and S5_TWNLL (n=6, ρ = 0.23), and

S2_JPNLateLL and S6_TWNLL (n=15, ρ = 0.22) were also positively correlated. However, negative correlations were found between the S3_HWLL and S5_TWNLL (n=5, ρ = -0.14) and S3_HWLL and S6_TWNLL (n=15, ρ = -0.24). Based on the graphical inspection of relative CPUEs and the correlation analysis, the updated data supported the use of a similar base case model (i.e., S1, S2, S4, S5, and S6 were fitted and contributed to the total likelihood) to the one used for the 2013 assessment.

Size Composition Data

Quarterly fish length or weight composition data from 1971–2014 for eight fisheries were used in the update assessment, and were summarized in Table 6. Updated length frequency data were available for six fisheries, and weight frequency data for one. An updated time-series of length composition data for TWNLL was not available, so composition data from the last assessment were used. Since not all samples were known by sex, all compositions were assumed to be for a single gender.

As was done in the previous assessment, length frequency data were compiled using 5-cm length bins from 80 to 320 cm for JPNEarlyLL (F1), JPNLateLL (F2), HWLL (F7), TWNLL (F10), and EPOPS (F14), and using 10-cm bins from 80 to 320 cm for OthLL (F12) and PYFLL (F13). Weight frequency data for JPNDRIFT (F4) were compiled using varying binning structure from 10 to 300 kg according to the allometric length-weight relationship by using 10-cm bins from 80 to 320 cm. OthLL, PYFLL, and JPNDRIFT were inputted as generalized-size composition data in SS. The lower boundary of each bin was used to define each bin for all composition data, and each observation consisted of the actual number of blue marlin measured.

There were some differences between the updated and previously used compositional data, as shown in Figure A3. The differences in mean length or size between the updated and the previous dataset were generally less than 5%, with the exception of smaller mean for JPNDRIFT in all years and for OthLL in 2011. Despite the differences, the new composition data were agreed upon at the BILLWG data workshop as the best available scientific information for the 2016 stock assessment.

Figure 4 shows the updated quarterly length and size compositions. Most of the fisheries exhibited consistent, clear seasonal cycles in their composition data. There were some variations in the distributions within a fishery; e.g., JPNLateLL in 2003, HWLL after 2000, EPOPS before 1992, and OthLL before 1997. The PYFLL size distributions also varied considerably between 1996-2002 and 2003-2014.

There was also considerable variation in both the length and size distributions and modal positions among fisheries (Figure 5). Length distributions for JPNEarlyLL, JPNLateLL, and HWLL were generally skewed to lengths less than 200 cm EFL and typically exhibited a single mode near 150 cm EFL. Length distributions for TWNLL, and size distributions for EPOPS, JPNDRIFT, and OthLL were less skewed. The TWNLL and OthLL exhibited a single mode near 160 cm EFL, and the JPNDRIFT had a mode around 100 kg. The EPOPS exhibited a single mode at around 200 cm EFL, meaning that this fleet caught larger blue marlin. Two modes were observed for PYFLL, one near 100 cm EFL and the second near 180 cm EFL.

Model Description

This stock assessment update for blue marlin was conducted using the same stock assessment model (SS, version 3.24f; Methot and Wetzel, 2013) as used previously. The model structure and parameters were similar to the base case run used in the 2013 stock assessment. Biological and demographic assumptions and fishery dynamics are summarized in Table 6 and Table 7, respectively.

Data Observation Models

The assessment model fit three data components: 1) total catch; 2) relative abundance indices; and 3) 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 (log(SE)) which was approximated as sqrt(log(1+CV^2)), where CV is the standard error of the observation divided by the mean value of the observation and sqrt is the square root function.

The log(SE) of each candidate index was first estimated by the statistical model used to standardize the index in the various BILLWG working papers (Table 4). Input CPUE values and the reported log(SE) for all indices are shown in Tables 6 and 7, respectively.

The reported log(SE) 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. Following the previous assessment, a minimum average log(SE) for indices of 0.14 was assumed for each series. Series with average log(SE) < 0.14 were scaled to log(SE) = 0.14 through the addition of a constant. Series with average log(SE) > 0.14 were input as given.

The composition data were assumed to have multinomial error distributions with the error variances determined by the effective sample sizes. Measurements of fish are usually not random samples 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.

To obtain random samples from the population, approximations of the amount of clustering were taken from an analysis of the relationship with number of trips sampled in the HWLL fleet which found around 10 fish per trip for marlin (Courtney, unpublished). Thus for all longline fisheries (F1, F2, F7, F10, F12, F13), sample size was assumed to be number of fish measured/10. For JPNDRIFT and EPOPS (F4, F14), sample size was assumed to be the number of fish measured.

The minimum quarterly sample size was fixed at 2.5 (i.e. 25 samples/10) for all longline fisheries and was fixed at 25 for JPNDRIFT and EPOPS, so as to remove unrepresentative observations. Length or size composition records with effective sample sizes > 50 were set to 50 for all fisheries.

Data Weighting

Index data were prioritized in the previous assessment. To maintain consistency with the previous assessment, index data were also prioritized in this assessment based on the principles 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 composition data should not induce poor fits to the abundance indices (Francis, 2011).

It is common practice to re-weight some or all data sets in two stages (Francis, 2011). In the last assessment, samples sizes of the composition data were 50 for F1, F2, F4, F10, and F14 after following the procedures for stage 1 weighting described in the 'Data observation models' section. These samples therefore exhibited little within-fishery variability. In order to retain the relative among-sample variability when fitting the models, a single iteration of the model was made. The effective sample sizes estimated in this tuning fit were then re-scaled by a scalar (i.e., stage 2 weighting).

The value of the scalar used in the last assessment was not reproducible, and so for this update assessment, we used a similar stage-1 weighting scheme for the length or size composition data of fleets F1, F2, F4, F10, and F14, but a different stage-2 scalar. The process used to calculate the stage-2 scalar for fleets F1, F2, F4, F10, and F14 in this update assessment was to:

1) Estimate the effective sample size for compositional data using a single iteration of SS3;
2) Replace input sample size of each fleet with the estimated effective sample size relative to its mean, and re-scale to have a mean value of 30, which was based on the values in Table 5.3 from the last assessment (ISC, 2013); and
3) If the new input sample size > 50, set the sample size to 50.

Goodness-of-Fit to Abundance Indices

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 fitted well, 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.

Stock Projections

As were done in the previous assessment, deterministic stock projections were conducted in SS to evaluate the impact of various levels of fishing mortality on future SSB and yield. No recruitment deviations and log-bias adjustment were applied to the future projection in this study. Instead, the absolute future recruitments were based on the expected stock-recruitment relationship. The future projection routine calculated the future SSB and yield that would occur while the specific fishing mortality, selectivity patterns and relative fishing mortality proportions depended on the specific harvest scenarios. In this study, the last three model years' (2012-2014) selectivity patterns and relative fishing mortality rates were used in population future projection. The projection started in 2015 and continued through 2024 under four different harvest scenarios:

1. **High F Scenario**: Select the 3-year time period with the highest average F (age 2+) and apply this fishing mortality rate to the stock estimates beginning in 2015;
2. **F_{MSY} Scenario**: Apply the estimate of the F_{MSY} fishing mortality rate to the stock estimates beginning in 2015;
3. **Status Quo F Scenario**: This will be the average F (age 2+) during 2012-2014 ($F_{2012-2014}$);
4. **Low F Scenario**: Apply an $F_{30\%}$ fishing mortality rate to the stock estimates beginning in 2015.

Results

Base Case Model

Our exploration of the updated data supported the use of a similar base case to the one for the 2013 assessment. Although there were some variations in indices used in the update assessment compared to the 2013 assessment (i.e., S2_JPNLateLL), the correlation analyses supported the choice to utilize the same abundance indices in this update assessment (i.e., exclude S3_HWLL from the total likelihood; Table A1).

The proposed weighting method for the composition data produced similar input values and variation among year compared to the previous weighting method (Figure A4). The initial mean input sample sizes, mean estimated sample sizes, and re-scaled mean estimated sample sizes were shown in Table 8. The proposed weighting method produced relatively smaller sample sizes compared to the initial N and estimated N, thus down-weighting the composition data. The mean effective sample sizes for F1, F2, F4, F10, and F14 scaled down the initial N by factors between 0.55 and 0.6 (with mean sample sizes ranging from 24.6 and 29.27), with the greatest effect being on JPNEarlyLL and JPNDRIFT.

Recruitment variability (σ_R, the standard deviation of log-recruitment) was iteratively rescaled in the final model to match the expected variability and set to 0.28 based on the RMSE of the recruitment deviations. This followed the same approach as was used in the 2013 assessment, but resulted in a different value than what was used in the 2013 assessment, which was 0.32.

Model Convergence

All estimated parameters in the base case model were within the set bounds, and the final gradient of the model was approximately $4.159 \cdot 10^{-5}$ and the hessian matrix for the parameter estimates was positive definite, which indicated that the model had converged to a local or global minimum. Results from 30 model runs with different random initial starting values for estimated parameters using the internal "jitter" routine in SS supported the result that a global minimum was obtained (i.e., there was no evidence of a lack of convergence to a global minimum) (Figure 6). In addition, the log(R0) values were similar from runs with total negative log-likelihoods similar to the base case model.

Model Diagnostics

Figure 7.1 presents the results of the likelihood profiling on the logarithm of the unfished recruitment parameter R0, i.e. log(R0), for each data component. Detailed information on changes in negative log-likelihoods among the various fishery data sources are shown in Tables 9 and 10 and Figure 7.2.

Changes in the likelihood of each data component indicated how informative that data component was to the overall estimated model fit. 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 (Figure 7.1).

S1_JPNEarlyLL (max 20.72) and S2_JPNLateLL (max 19.37) showed the largest changes in negative log-likelihood values across values of R0 among abundance indices (Table 9). Changes in the negative log-likelihood were also high for S3_HWLL, but S3_HWLL was not included in the model likelihood for the base case. The MLE for log(R0) matched a local minimum between 6.5 and 7.0 in the fleet combined likelihood profile for index data. The likelihood profile of individual fleets was similar to the overall MLE for S4_TWNLL and S5_TWNLL, was similar to the fleet combined likelihood pattern for S2_JPNLateLL and S6_TWNLL, and was different than the MLE for S1_JPNEarlyLL (Figure 7.2). S1_JPNEarlyLL may provide conflicting information compared to other fleets' indices based on its lower fleet-specific MLE (Table 9).

In general, the changes in the negative log-likelihoods among eight composition data were small over a range of log(R0) values except for the JPNEarlyLL and JPNLateLL (Table 10). The maximum changes in negative log-likelihoods for F1_JPNEarlyLL and F2_JPNLateLL are 75.21 and 41.80, respectively. Five of eight fleets had minimum relative negative log-likelihoods that occurred between 6.7-6.9.

This implies that length data (F1, F2, F7, F10, and F14) are informative in the fitting process. The MLE also matched well with the likelihood profile of individual fleets except F7_HWLL (Figure 7.2). This implies F7_HWLL may provide conflicting information compared to other fleets' length composition. The MLE did not match the fleet combined likelihood profile for generalized-size data very well. A similar pattern was found in the likelihood profile of individual fleet's generalized-size data, with the exception of F13_PYFLL. Generalized-size data for F12_OthLL and F4_JPNDRIFT may provide conflicting information compared to the length composition data from other fleets.

The magnitude of change in the negative log-likelihoods for the abundance indices were similar to length composition and generalized-size composition data within the log(R0) range of 6.6-7.0, and were within 5 units of likelihood at the MLE of log(R0) (6.88; Figure 7.3). Minor conflicts in the shape of the likelihood profiles between index, length composition and generalized-size composition data were observed. The likelihood profile analysis suggested that the generalized-size composition data indicated a smaller log(R0) value than the index and length composition data, and therefore was possibly uninformative with respect to population scale in the base case assessment model. There was greater agreement between the length composition data and the abundance indices for the maximum likelihood estimate of log(R0) within the range of 6.6-7.0 based on log(R0) likelihood profiles, but less agreement with the generalized-size composition. In other words, the generalized-size composition data did not stop the model from fitting abundance data for the base case model.

Residual Analysis of Abundance Indices

Goodness-of-fit diagnostics were presented in Table 11, and plots of predicted and observed CPUE by fishery for the base case model were shown in Figure 8. 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 < 0.2) being indicative of a good fit. As in the 2013 assessment, the model fit all abundance indices that were incorporated into the total likelihood well, with RMSE < 0.2. Although not included in the likelihood of the fitted models, index HWLL (S3) was included in the model to allow comparison of the fitted and observed trends.

Although the input log(SE) of S4_TWNLL and S5_TWNLL in the update assessment (0.14 and 0.14) were smaller than the 2013 assessment (0.64 and 0.45), the input log(SE) were comparable with the RMSE of residuals for the base case. Similar uncertainty between input log(SE) and the RMSE of residuals were found in other indices in the base case model. This suggested that the input log(SE) were appropriate for observation error.

The fits to abundance indices were generally within the 95 percent CIs. The residuals pattern of the assessment update was similar to the 2013 assessment (Figure 8). There was a trend of negative residuals in the early time period (1975-1977) and of positive residuals in the late time period (1984-1993) in S1_JPNEarlyLL for both assessments (Figure 8).

In contrast to the 2013 assessment, the model fit the S5_TWNLL well. There was a trend of negative residuals in 1995-1999 for the 2013 assessment, but this was not observed in the update assessment. The RMSE of residuals also showed an improved fit, 0.12 for the update assessment compared to 0.21 for the 2013 assessment. The improved performance was most likely caused by a slightly lower variability in CPUE values later (1995−1999) in the S5_TWNLL time-series for the update assessment. Although not included in the total likelihood, and therefore not fit, showing diagnostics for HWLL (S3) revealed that HWLL was inconsistent with fits to other indices.

The SDNR of the CPUE fit was used as another goodness-of-fit diagnostic (Table 11). The SDNR diagnostics also indicated that the update model did not fit S2_JPNLateLL (1.28 > 1.25) well compared to the 2013 assessment (1.16 < 1.27). It should be noted the number of observations were different for S2_JPNLateLL between two assessments (18 and 21).

Residuals Analysis of Size Composition Data

Comparisons between the observed and expected mean values of composition data from Francis (2011) were used for model diagnostics. Figure 9 shows the 95% credible intervals for mean value for the five length composition data sets and the three generalized-size composition data sets. The reweighted model fit passed through almost all of the credible intervals (Figure 9), although there was a poor fit between the observed and predicted mean values for the EPOPS in 1990, OthLL in 1993 and 2010, and PYFLL in 1997, 2002 and 2009. The results suggested that our stage-2 weighting approach accounted for expected correlations analogous to recommended methods from Francis (2011).

Model misfit of composition data was found in four fisheries, JPNEarlyLL (F1), JPNLateLL (F2), HWLL (F7), and PYFLL (F13) (Figure 10). Patterns of positive residuals occurred around 100 cm EFL during 1971-1977 and above 200 cm EFL during 1971-1979 for JPNEarlyLL, around 150 cm EFL during 1994-2014 for JPNLateLL, and below 160 cm EFL during 2000-2006 and above 200 cm EFL during 2002-2014 for HWLL. Negative residuals occurred around 135 cm EFL during 1971-1982 and 1984-1993 for JPNEarlyLL, around 130 and 170 cm EFL during 1994-2014 for JPNLateLL, and below 150 cm EFL during 2007-2014 for HWLL. Outliers (extreme positive residuals) were found in 1997, 2002 and 2005 for PYFLL.

Assuming standardized residuals were normally distributed, 95% of the measurements would fall within 2 standard deviations of the mean. JPNLateLL, HWLL, EPOPS, OthLL, PYFLL, and JPNDRIFT were found with 0.1%, 0.3%, 0.1%, 0.8%, 2.2%, and 0.3% of their Pearson residuals greater than 2 or smaller than -2, indicating appropriate distributional assumptions (Figure 10). Nonetheless, the observations with extreme standardized residuals might need further investigation**.**

The model fit the length modes in composition data aggregated by fishery fairly well using the input effective sample sizes (Figure 11). The precision of the model predictions was greater than that of the observations, and indirectly related to effective sample size. Estimated effective sample size was used for the goodness-of-fit diagnostics for the composition data in the 2013 assessment. In this updated stock assessment, the effective sample sizes as derived from our stage-2 weighting process were slightly smaller than the input effective sample sizes used in the 2013 assessment (Table 12).

Estimation of Fishery Selectivity

The same selectivity configurations were used in this update stock assessment as were used for the 2013 assessment. The results of the estimated selectivity patterns were consistent with the assumed selectivity patterns (Figure 12). There was a significant change for JPNDRIFT with higher selectivity for the smaller fish and lower selectivity for the larger fish (i.e., the selectivity curve shifted left). There was also a minor change in selectivity during the second time block for PYFLL and the selectivity for EPOPS. There was lower selectivity for fish around 120-170 cm EFL for PYFLL in 2003-2014 and higher selectivity for fish greater than 250 cm EFL for EPOPS.

Stock Assessment Results

Estimates of population biomass (estimated biomass of age 1 and older fish at the beginning of the year) declined from a high of 135,623 mt in 1971 until 1977, increased to 124,812 mt in 1984, decreased again to the lowest level of 69,720 mt in 2009, and increased to around 78,000 metric tons during the final three years of the 2016 stock assessment time horizon (2012−2014) (Table 13 and Figures 13a and 14.1). Compared to the 2013 stock assessment, the population biomass estimates were higher in 1971-1990, and were slightly lower in 1991-1993, 1997-1998, and 2010-2011 (Figure 13a). Overall, population biomass declined from an average of roughly 130 thousand metric tons in the early 1970s to an average of roughly 80 thousand metric tons in the early 2010s (Figure 14.1).

Spawning stock biomass estimates also exhibited a decline during 1971−1979, was stable during 1980-1986, declined to the lowest level of 20,972 metric tons in 2006, and increased to 24,809 in 2014 (Table 13 and Figures 13b and 14.2). The time-series of SSB at the beginning of the spawning cycle (quarter 2) averaged 62,368 metric tons during 1971-1979, or 50% of unfished SSB; 50,577 metric tons (34% of unfished SSB) during 1980−1989; 39,715 metric tons (28% of unfished SSB) during 1990−1999; 25,272 metric tons (19% of unfished SSB) during 2000−2009, and 23,717 metric tons (21% of unfished SSB) in 2010−2014. Compared to the 2013 stock assessment, the SSB estimates were higher in 1971−1991 (Figure 13b). Precision of SSB estimates gradually improved over time. Overall, SSB exhibited a long-term decline from the early 1970s to the 2000s and has since exhibited a moderate increase.

Recruitment (age-0 fish) estimates indicated a long-term fluctuation around a mean of approximately 897,000 (Table 13 and Figures 13c and 14.3). Recruitment was low in the early part of time series (1971-1976) with an average of 741,000 recruits. The model estimated that several strong year classes (> 1000 thousand recruits) recruited to the fisheries in 1977-1979, 1982-1983, 1986-1987, 1992, 1997, 2009, and 2011 followed by several weak year classes. Compared to the 2013 stock assessment, the recruitment estimates were higher in 1977-1978, 1992, 1997 and 2011, but lower in 2009. Uncertainty in recruitment estimates in the update assessment was smaller than the 2013 assessment during 1985-1997, and comparable in other years. While the overall pattern of recruitment from 1971-2014 was variable, there was no apparent long-term trend in recruitment strength (Table 13 and Figure 14.3).

Over the course of the assessment time horizon, estimated fishing mortality (arithmetic average of F for ages 2 and older) gradually increased from the early 1970s to the 1990s, peaked at 0.38 $year^{-1}$ in 2005 in response to higher catches, and afterward declined to 0.28 $year^{-1}$ in the most recent years (2012-2014) (Table 13 and Figures 13d and 14.4). Compared to the 2013 stock assessment, fishing mortality estimates were slightly higher in 2005 and 2010-2014, but overall the trends in fishing mortality were very similar between the 2013 and 2016 assessments.

Biological Reference Points

Biological reference points were computed from the Stock Synthesis base case model using the most recent three-year averages of fishery selectivity patterns. Since most life history parameters for Pacific blue marlin, including steepness, were considered to be reasonably well defined, MSY-based biological reference points were used to assess relative stock status (Table 13.2), noting that reference points based on $SSB_{20\%}$ were also calculated. The point estimate of maximum sustainable yield was MSY = 19,901 metric tons. The point estimate of the spawning stock biomass to produce MSY was SSB_{MSY} = 19,853 metric tons. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY on ages 2 and older fish was F_{MSY} = 0.32 and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

Stock Status

Compared to MSY-based reference points, the current spawning biomass (average for 2012-2014) was 23% above SSB_{MSY} and the current fishing mortality (average for ages 2 and older in 2012-2014) was 14% below F_{MSY}. The Kobe plot indicates that the Pacific blue marlin spawning stock biomass decreased to the MSY level in the mid-2000's, and since then has increased slightly (Figure 15). The base case assessment model indicates that the Pacific blue marlin stock is currently not overfished and is not subject to overfishing relative to MSY-based reference points.

Sensitivity Analyses

In the January 2016 BILLWG workshop, it was agreed that at least 13 sensitivity analyses were to be conducted in the 2016 assessment update (Table 14) in order to examine the effects of plausible alternative model assumptions and data input. The WG agreed that the same sensitivity analyses conducted in the 2013 benchmark assessment (ISC 2013, see Table 4.5) would be conducted for this 2016 assessment update. The WG agreed that the first priority would be to conduct the same 13 sensitivity analyses. In addition, 6 new sensitivity analyses were proposed, for a total of 19 sensitivity analyses (Table 14). During the March 2016 BILLWG workshop, all 19 sensitivity analyses were completed and the results were presented and reviewed. The WG noted that 6 of the sensitivity runs were from the WCPFC SC9's request for sensitivity runs at 3 alternative levels of steepness; another was for the inclusion of the Hawaii longline CPUE series as a relative abundance index; and the other two were for alternative adult natural mortality rates, one using a high and one using a low natural mortality rate (WCPFC 2013).

For each sensitivity run, comparisons of spawning stock biomass and fishing intensity (1-SPR) trajectories were completed (Figures 16.1). Additionally, the WG produced a Kobe plot, as requested by WCPFC SC9, that showed the patterns of the base case and terminal year estimates for the key sensitivity runs (Figure 16.2).

For 4 of the 19 sensitivity runs, the stock status was estimated to be in the red section of the Kobe plot indicating that the stock was overfished and experiencing overfishing (Figure 16.2). These were: Run 1 (S1 and S3 CPUE only), Run 9 (lower natural mortality rate), Run 11 (lowest stock recruitment steepness value), and Run 12 (lower middle stock recruitment steepness value). For all the other sensitivity analyses, the stock was estimated at MSY or in the green section of the Kobe plot, indicating stock was not overfished and not experiencing overfishing (Figure 16.2).

It was notable that 3 of the 4 sensitivity analyses resulting in a poor stock status (Runs 9, 11, and 12) used life history parameter values that were unlikely to be biologically reasonable for blue marlin. Since assuming a lower natural mortality was expected to increase fishing mortality, and assuming a lower steepness was expected to decrease stock productivity, the pessimistic stock status results were not surprising. However, the base case model parameters for natural mortality and steepness were expected to be more reliable than the values assumed in these sensitivity runs (i.e., natural mortality was estimated from several empirical equations, and steepness was estimated from life history parameters).

Overall, the results of the sensitivity analyses confirmed the robustness of the base case model, and it was concluded that other sensitivity runs were not necessary for this stock assessment update.

Retrospective Analysis

A retrospective analysis of the base case Pacific blue marlin stock assessment model was conducted for the last 5 years of the assessment time horizon to evaluate whether there were any strong changes in parameter estimates through time. This retrospective analysis was conducted during the March 2016 BILLWG workshop. The results of the retrospective analysis are shown in Figure 17. The trajectories of estimated spawning stock biomass and the index of fishing intensity (i.e., one minus the spawning potential ratio, or 1-SPR) showed no appreciable retrospective pattern and there was no consistent trend of over- or under-estimating spawning stock biomass or fishing intensity. It was noted that the 1971-2013 retrospective peel showed a somewhat different pattern than the other 4 peels and it was not known why this occurred. Given the small magnitude of the retrospective pattern, it was concluded that the base case model was robust to the inclusion of recent assessment data and did not have an important retrospective pattern for estimates of spawning biomass or fishing intensity.

Stock Projections

Deterministic stock projections were also conducted using the Stock Synthesis software platform and the base case model to evaluate the impact of various levels of fishing intensity on future spawning stock biomass and yield for blue marlin in the Pacific Ocean. The future recruitment pattern was based on the estimated stock-recruitment curve. The projection calculations employed model estimates for the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Projections started in 2015 and continued through 2024 under 4 levels of fishing mortality. The four stock projection scenarios were: (1) the high F scenario; (2) the F_{MSY} scenario; (3) the status quo F scenario; and (4) the low F scenario.

Results showed projected spawning stock biomass and the catch for each of the four harvest scenarios (Tables 15.1 and 15.2 and Figure 18). When the current fishing level was maintained (Scenario 3: $F_{2012-2014}$, equivalent to $F_{21\%}$), the SSB was projected to be stable at roughly 24,800 metric tons by 2024, which was above SSB at MSY level (19,852 metric tons). If fishing increased to the MSY level (Scenario 2: equivalent to $F_{18\%}$), the projected SSB was estimated to gradually decrease, and by 2024 it approached but remained above the SSB at MSY level. If fishing further increased to the 2003-2005 level (Scenario 1: $F_{16\%}$), the SSB was projected to be below SSB at MSY level by 2019. Conversely, if fishing mortality was reduced to be equivalent to $F_{30\%}$ (Scenario 4), the projected SSB would gradually increase to about 35,400 metric tons by 2024.

Fishing at the current level ($F_{21\%}$) and F_{MSY} ($F_{18\%}$) provided an expected safe/optimal level of harvest, where the average projected catches between 2015 and 2024 were near MSY at approximately 20,200 and 19,800 metric tons. Fishing at the 2003-2005 level ($F_{16\%}$) and $F_{30\%}$ provided average projected catches between 2015 and 2024 of about 21,900 and 17,000 metric tons, respectively.

Special Comments

The lack of sex-specific size data and the simplified treatment of the spatial structure of Pacific blue marlin population dynamics were important sources of uncertainty in the 2016 stock assessment update. It was recommended that sex-specific fishery data be collected and management strategy evaluation research be conducted to address these issues for improving future stock assessments.

Conservation Advice

To avoid overfishing of this nearly fully exploited stock (F/FMSY = 0.88) fishing mortality should not be increased from the current (2012-2014) level.

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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	JPNEarlyLL	Japan	Offshore and distant-water longline (early period)	B	Ijima and Shiozaki (2016)
F2	JPNLateLL	Japan	Offshore and distant-water longline (late period)	B	Ijima and Shiozaki (2016)
F3	JPNCLL	Japan	Coastal longline	B	Ijima and Shiozaki (2016)
F4	JPNDRIFT	Japan	High-sea large-mesh driftnet and coastal driftnet	B	Ijima and Shiozaki (2016)
F5	JPNBait	Japan	Bait fishing	B	Ijima and Shiozaki (2016)
F6	JPNOth	Japan	Other gears	B	Ijima and Shiozaki (2016)
F7	HWLL	USA (Hawaii)	longline	B	Ito (2016)
F8	ASLL	USA (American Samoa)	longline	#	Russell Ito, pers. comm., Jan 13, 2016
F9	HWOth	USA (Hawaii)	Troll and handline	B	Ito (2016)
F10	TWNLL	Taiwan	Distant-water longline	B	Nan-Jay Su, pers. comm., Jan 13, 2016
F11	TWNOth	Taiwan	Offshore longline, coastal longline, gillnet, harpoon, and others	B	Nan-Jay Su, pers. comm., Jan 13, 2016
F12	OthLL	Various flags	Longline	B	Chang et al. (2016); Tagami and Wang (2016)
F13	PYFLL	French Polynesia	Longline	B	Chang et al. (2016)
F14	EPOPS	Various flags	Purse seine	#	Chang et al. (2016)
F15	WCPFCPS	Various flags	Purse seine	B	Chang et al. (2016)

F16	EPOOth	French Polynesia	Troll, handline, and harpoon	B	Chang et al. (2016)

Table 2. Blue marlin catches (metric ton) in the Pacific Ocean by fisheries, 1971-2014; “0” indicates less than 1 metric ton. See Table 1 for the reference code for each fishery.

Year	JPNEarlyLL	JPNLateLL	JPN CLL	JPNDRIFT	JPN Bait	JPN Oth	HW LL	AS LL	HW Oth	TW NLL	TWN Oth	Oth LL	PYF LL	EP OPS	WCP FCPS	EPO Oth
1971	6864	0	113	0	6	49	21	0	0	104	1935	60	0	0	8	0
1972	8493	0	211	8	7	52	1	0	0	203	1759	63	0	0	9	0
1973	9125	0	211	264	23	134	15	0	0	225	2202	75	0	0	14	0
1974	8073	0	181	226	61	52	35	0	0	161	2650	87	0	0	7	0
1975	5657	0	464	782	146	82	33	0	0	148	3259	139	0	0	7	0
1976	7145	0	424	572	200	323	60	0	0	176	1973	850	0	0	6	0
1977	7849	0	517	982	191	154	124	0	0	145	1687	730	0	0	9	0
1978	8794	0	827	870	197	394	194	0	0	63	2020	1302	0	0	8	0
1979	9364	0	748	505	165	266	159	0	0	422	2174	1519	0	0	13	0
1980	10387	0	683	854	138	118	174	0	0	490	1783	1299	0	0	13	0
1981	10104	0	798	1146	185	145	190	0	0	463	2231	1795	0	0	30	0
1982	10818	0	703	940	169	247	180	0	0	304	2562	1712	0	0	42	0
1983	9786	0	1030	916	227	440	143	0	0	272	3015	1067	0	0	67	0
1984	12253	0	1271	239	183	428	137	0	0	382	2882	1589	0	0	86	0

1985	9352	0	1010	395	298	363	136	0	0	212	1997	1784	0	0	69	0
1986	11355	0	874	173	366	153	209	0	0	184	2763	2015	0	0	66	0
1987	11700	0	1486	252	281	128	240	0	283	198	5613	4949	0	0	73	0
1988	10108	0	1416	357	229	151	264	0	296	320	4097	4112	0	0	71	0
1989	8748	0	1228	288	389	133	477	0	365	445	3317	2779	0	0	86	0
1990	7714	0	1172	248	250	177	517	0	337	437	2327	3148	3	0	95	0
1991	8336	0	1307	175	169	67	535	0	387	720	2696	3431	23	0	135	0
1992	8908	0	1613	158	151	57	368	0	301	122	4380	4309	77	0	141	0
1993	9465	0	2037	144	187	88	467	0	339	449	4443	4155	205	126	142	0
1994	0	11134	1511	154	140	70	524	0	334	603	3262	4377	349	93	141	0
1995	0	9317	1786	140	171	67	569	0	351	326	4771	5597	416	92	144	0
1996	0	4659	1097	105	177	42	620	7	441	187	3626	3892	422	81	160	0
1997	0	6145	951	75	233	34	656	16	422	104	3910	4463	337	157	179	0
1998	0	5422	1089	54	282	29	425	20	264	209	3762	6250	307	166	182	0
1999	0	4088	1090	76	170	12	458	22	332	131	3552	6568	355	235	153	0
2000	0	4024	1208	21	194	32	457	33	235	114	7989	5655	261	156	184	0

2001	0	4062	1155	159	136	22	541	103	294	585	9030	7142	265	171	189	0
2002	0	3789	853	104	149	28	397	255	231	495	8799	7349	255	237	205	0
2003	0	3708	977	36	175	21	435	187	210	1207	7760	10142	303	213	214	0
2004	0	3395	1139	20	192	33	408	138	188	1456	6572	8545	243	162	226	0
2005	0	2886	980	36	192	24	440	114	187	1506	7540	9411	251	224	848	0
2006	0	2506	988	31	139	22	429	170	160	1678	5808	8174	266	182	611	105
2007	0	2165	1104	75	159	32	339	236	129	1271	5161	6562	327	132	824	106
2008	0	1843	1147	31	200	47	418	180	181	910	5523	6284	224	133	592	114
2009	0	1927	1094	57	157	34	469	225	181	1338	4787	6903	223	175	579	131
2010	0	2237	1482	93	222	33	398	193	150	1490	5742	6836	260	180	644	126
2011	0	1963	1192	100	234	43	373	111	201	1331	5112	6223	201	185	752	144
2012	0	1838	998	47	242	79	298	113	143	1284	4940	7877	241	213	918	177
2013	0	1789	1155	14	173	80	406	90	140	1055	5631	8629	243	208	946	168
2014	0	1717	1155	14	173	80	535	70	163	1225	5806	7890	240	244	859	186

Table 3. Descriptions of standardized relative abundance indices (catch-per-unit-effort, CPUE) of Pacific blue marlin 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 and effort was in 1000 hooks.

Reference Code	**Used**	**Fishery Description**	***n***	**Time series**	**Source**
S1_JPNEarlyLL (F1)	Yes	Japanese offshore and distant-water longline (early period)	19	1975-1993	Kanaiwa et al. (2013)
S2_JPNLateLL (F2)	Yes	Japanese offshore and distant-water longline (late period)	21	1994-2014	Kai et al. (2016)
S3_HWLL (F7)	No	Hawaiian longline	20	1995-2014	Carvalho et al. (2016)
S4_TWNLL (F10)	Yes	Taiwanese distant-water longline (early period)	8	1971-1978	Su et al. (2016)
S5_TWNLL (F10)	Yes	Taiwanese distant-water longline (middle period)	21	1979-1999	Su et al. (2016)
S6_TWNLL (F10)	Yes	Taiwanese distant-water longline (late period)	15	2000-2014	Su et al. (2016)

Table 4. Standardized catch-per-unit-effort (CPUE; in number per 1000 hooks) indices and input standard error (SE) in log-scale (i.e., log(SE)) of lognormal error of CPUE for the blue marlin from the 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.

Index	**S1_JPNEarlyLL**		**S2_JPNLateLL**		**S3_HWLL**		**S4_TWNLL**		**S5_TWNLL**		**S6_TWNLL**	
	CPUE	**log(SE)**	**CPUE**	**log(SE)**	**CPUE**	**log(SE)**	**CPUE**	**log(SE)**	**CPUE**	**log(SE)**	**CPUE**	**log(SE)**
Season	1	1	1	1	3	3	1	1	1	1	1	1
1971							0.076	0.063				
1972							0.08	0.064				
1973							0.082	0.063				
1974							0.079	0.059				
1975	0.333	0.015					0.073	0.069				
1976	0.329	0.019					0.081	0.068				
1977	0.247	0.015					0.07	0.065				
1978	0.399	0.023					0.074	0.07				
1979	0.456	0.027							0.153	0.065		
1980	0.468	0.027							0.129	0.066		
1981	0.548	0.032							0.136	0.064		
1982	0.546	0.032							0.124	0.067		
1983	0.439	0.026							0.118	0.073		
1984	0.697	0.041							0.127	0.071		
1985	0.476	0.028							0.138	0.077		
1986	0.492	0.029							0.115	0.079		
1987	0.482	0.028							0.103	0.071		
1988	0.459	0.027							0.118	0.077		
1989	0.476	0.028							0.113	0.077		
1990	0.463	0.027							0.102	0.091		
1991	0.443	0.026							0.123	0.082		

1992	0.454	0.027							0.084	0.079		
1993	0.567	0.033							0.103	0.069		
1994			12.455	0.011					0.127	0.072		
1995			15.023	0.013	0.51	0.464			0.106	0.085		
1996			8.237	0.014	0.57	0.394			0.103	0.072		
1997			11.338	0.014	0.48	0.349			0.081	0.075		
1998			10.845	0.013	0.47	0.275			0.088	0.078		
1999			8.8	0.013	0.14	0.159			0.102	0.068		
2000			9.1	0.012	0.45	0.256					0.092	0.051
2001			7.611	0.011	0.3	0.179					0.099	0.042
2002			8.282	0.012	0.14	0.129					0.089	0.041
2003			10.174	0.014	0.23	0.149					0.108	0.04
2004			12.472	0.012	0.17	0.129					0.094	0.04
2005			10.816	0.015	0.12	0.129					0.127	0.04
2006			10.682	0.017	0.23	0.129					0.114	0.041
2007			8.864	0.013	0.05	0.07					0.111	0.044
2008			7.998	0.017	0.12	0.1					0.095	0.045
2009			11.265	0.022	0.11	0.1					0.095	0.045
2010			10.35	0.013	0.07	0.08					0.101	0.044
2011			7.487	0.016	0.1	0.09					0.094	0.044
2012			11.4	0.013	0.16	0.11					0.094	0.046
2013			9.457	0.016	0.07	0.1					0.111	0.05

2014			10.828	0.018	0.11	0.11					0.105	0.078

Table 5. Description of length composition data (eye-fork lengths, EFL, cm) and size composition data (kg) for Pacific blue marlin used in the stock assessment update, including bin size definitions, number of observations (n), years of coverage, and reference sources.

Reference Code	**Fleet**	**Fishery Description**	**Unit**	**Bin**	***n***	**Time series**	**Source**
JPNEarlyLL	F1	Japanese offshore and distant-water longline (early period)	cm	5	92	1971-1993	Ijima and Shiozaki (2016)
JPNLateLL	F2	Japanese offshore and distant-water longline (late period)	cm	5	84	1994-2014	Ijima and Shiozaki (2016)
JPNDRIFT	F4	High-sea large-mesh driftnet and coastal driftnet	kg	Proportional to length	19	1977-1989; 1993; 1998	Ijima and Shiozaki (2016)
HWLL	F7	Hawaiian longline	cm	5	70	1994-2014	Langseth and Fletcher (2016)
TWNLL	F10	Taiwanese distant-water longline	cm	5	23	2005-2010	ISC (2013)
OthLL	F12	Various flags longline	cm	10	83	1992-2014	Chang et al. (2016)
PYFLL	F13	French Polynesia longline	cm	10	52	1996-2014	Chang et al. (2016)
EPOPS	F14	Various flags purse seine	cm	5	95	1990-2014	Chang et al. (2016)

Table 6. Key life history parameters and model structures for Pacific blue marlin used in the stock assessment update including values, comments, and sources.

Parameter	Value		Comments	Source
Gender	2		Two genders model	ISC (2013)
Natural mortality	Female: 0.42 (age 0) 0.37 (age 1) 0.32 (age 2) 0.27 (age 3) 0.22 (age 4-25)	Male: 0.42 (age 0) 0.37 (age 1+)	Age-specific natural mortality	Lee and Chang (2013)
Reference age (a1)	1		Fixed parameter	Refit from Chang et al. (2013); ISC (2013)
Maximum age (a2)	26		Fixed parameter	
Length at a1 (L1)	144 (Female); 144 (Male)		Fixed parameter	Refit from Chang et al. (2013); ISC (2013)
Length at a2 (L2)	304.18 (Female) 226 (Male)		Fixed parameter	Refit from Chang et al. (2013); ISC (2013)
Growth rate (K)	0.107 (Female) 0.211 (Male)		Fixed parameter	Refit from Chang et al. (2013); ISC (2013)
CV of L1 (CV=f(LAA))	0.14 (Female); 0.14 (Male);		Fixed parameter	Chang et al. (2013); ISC (2013)
CV of L2	0.15 (Female); 0.1 (Male);		Fixed parameter	Chang et al. (2013); ISC (2013)
Weight-at-length	$W=1.844 \times 10^{-5}L^{2.956}$ (Female); $W=1.37 \times 10^{-5}L^{2.975}$ (male)		Fixed parameter	Brodziak 2013

Length-at-50% Maturity	179.76	Fixed parameter	Sun et al. (2009); Shimose et al. (2009)
Slope of maturity ogive	-0.2039	Fixed parameter	Sun et al. (2009); Shimose et al. (2009)
Fecundity	Proportional to spawning biomass	Fixed parameter	Sun et al. (2009)
Spawning season	2	Model structure	Sun et al. (2009)
Spawner-recruit relationship	Beverton-Holt	Model structure	Brodziak and Mangel (2011); Brodziak et al. (2015)
Spawner-recruit steepness (*h*)	0.87	Fixed parameter	Brodziak and Mangel (2011); Brodziak et al. (2015)
Recruitment variability (σ_R)	0.28	Fixed parameter	
Initial age structure	5 yrs (1966-1970)	Estimated	
Main recruitment deviations	1971-2013	Estimated	
Bias adjustment	1971-2013	Fixed	ISC (2013)

Table 7. Fishery-specific selectivity assumptions for the Pacific blue marlin stock assessment. The selectivity curves for fisheries lacking length 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	JPNEarlyLL	Cubic Spline (nodes=4)	
F2	JPNLateLL	Double-normal	
F3	JPNCLL	Double-normal	F2
F4	JPNDRIFT	Double-normal	
F5	JPNBait	Double-normal	F4
F6	JPNOth	Double-normal	F2
F7	HWLL	Cubic Spline (nodes=3)	
F8	ASLL	Double-normal	F7
F9	HWOth	Double-normal	F7
F10	TWNLL	Double-normal	
F11	TWNOth	Double-normal	F10
F12	OthLL	Double-normal	
F13	PYFLL	Double-normal for 1971-2002; 2003-2014	
F14	EPOPS	Double-normal	
F15	WCPFCPS	Double-normal	F14
F16	EPOOth	Double-normal	F14

Table 8. Fishery-specific initial multinomial effective sample sizes (N) and re-scaled effective sample sizes for length composition data of Pacific blue marlin as used in the stock assessment update. Estimated mean N was the effective sample size from the initial run of SS3.

Reference Code	**Fleet**	**Initial Mean N**	**Estimated Mean N**	**Re-scaled Mean N**
JPNEarlyLL	F1	49.65	269.25	27.11
JPNLateLL	F2	44.97	114.21	26.98
JPNDRIFT	F4	45.11	107.03	24.60
HWLL	F7	13.19	57.61	No rescaling
TWNLL	F10	48.89	423.39	29.27
OthLL	F12	27.25	85.90	No rescaling
PYFLL	F13	6.91	22.74	No rescaling
EPOPS	F14	49.32	213.36	27.58

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 6.88. See Table 3 for a description of the abundance indices. S3_HWLL was not included in the total likelihood.

log(R0)	**S1_JPNEarly LL**	**S2_JPNLate LL**	**S3_HWL L**	**S4_TWNL L**	**S5_TWNL L**	**S6_TWNL L**
6	20.72	19.37	0.00	1.80	13.67	7.71
6.1	8.01	14.91	20.47	0.97	6.70	5.90
6.2	1.56	14.27	19.57	0.96	4.58	5.46
6.3	7.51	13.76	17.97	0.78	3.72	5.27
6.4	0.00	11.68	16.79	1.01	2.92	4.46
6.5	2.88	9.77	13.24	1.19	2.61	3.80
6.6	1.04	7.67	8.85	1.40	1.40	3.06
6.7	1.69	4.72	3.67	0.68	1.34	1.74
6.8	3.75	2.55	4.14	0.04	0.91	0.78
6.9	5.50	1.62	9.43	0.00	0.25	0.50
7	6.60	1.20	15.62	0.11	0.00	0.50
7.1	6.28	0.73	19.60	0.24	0.22	0.33
7.2	5.97	0.41	22.10	0.32	0.35	0.14
7.3	6.14	0.29	27.26	0.39	0.39	0.27
7.4	5.38	0.07	27.67	0.24	0.59	0.04
7.5	5.05	0.00	29.78	0.16	0.71	0.00

Table 10. Relative negative log-likelihoods of length 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 6.88. See Table 5 for a description of the composition data.

log(R0)	JPNEarlyLL	JPNLateLL	HWLL	TWNLL	EPOPS	JPNDRIFT	OthLL	PYFLL
6	75.21	41.70	2.76	7.96	11.95	1.45	8.64	3.75
6.1	40.09	29.17	11.64	6.29	6.91	1.87	6.10	2.86
6.2	42.17	23.28	6.62	4.12	5.45	2.43	2.40	2.33
6.3	37.92	20.38	4.15	2.82	5.23	2.49	0.46	2.12
6.4	25.44	14.93	3.15	1.32	3.39	1.69	0.00	1.39
6.5	11.57	11.25	3.17	0.77	2.41	0.81	0.41	0.91
6.6	4.28	7.75	3.50	0.44	1.55	0.65	1.19	0.53
6.7	0.59	3.23	3.73	0.00	0.54	0.28	2.22	0.17
6.8	0.00	0.25	3.33	0.15	0.00	0.17	3.46	0.00
6.9	1.14	0.00	1.54	0.52	0.42	0.12	4.86	0.00
7	1.73	3.60	0.43	0.85	1.10	0.07	6.31	0.77
7.1	1.58	4.35	0.00	1.20	2.11	0.05	8.07	2.40
7.2	1.53	6.97	0.13	1.60	2.70	0.02	10.15	1.08
7.3	1.70	9.06	0.58	1.84	3.32	0.00	12.00	5.83
7.4	2.19	11.49	0.96	2.16	3.72	0.01	13.93	1.69
7.5	2.64	13.46	1.39	2.38	4.11	0.01	15.58	1.95

Table 11. Mean input standard error (SE) in log-space (i.e., log(SE)) of lognormal error, root-mean-square-errors (RMSE), and standard deviations of the normalized residuals (SDNR) for the relative abundance indices for Pacific blue marlin used in the 2013 stock assessment and in this stock assessment update. S3_HWLL was not included in the total likelihood. An SDNR value greater than the chi-squared statistic (χ^2) indicates a statistically poor fit.

Reference code	**2013 assessment**					**2016 update**				
	N	**Input log(SE)**	**RMSE**	**SDNR**	χ^2	***n***	**Input log(SE)**	**RMSE**	**SDNR**	χ^2
S1_JPNEarlyLL (F1)	19	0.14	0.14	1.05	1.27	19	0.14	0.14	1.07	1.27
S2_JPNLateLL (F2)	18	0.14	0.16	1.16	1.27	21	0.14	0.17	1.28	1.25
S3_HWLL (F7)	17	0.14	0.48	3.39	1.28	20	0.18	0.83	4.36	1.26
S4_TWNLL (F10)	8	0.64	0.09	0.18	1.42	8	0.14	0.06	0.45	1.42
S5_TWNLL (F10)	21	0.45	0.21	0.39	1.25	21	0.14	0.12	0.89	1.25
S6_TWNLL (F10)	12	0.14	0.17	1.29	1.34	15	0.14	0.11	0.86	1.30

Table 12. Mean input multinomial effective sample sizes (N) and model estimated effective sample sizes (effN) in the 2013 stock assessment and this stock assessment update.

Reference code	**Fleet**	**2013 assessment**		**2016 update**	
		Input mean N	**Mean effN**	**Input mean N**	**Mean effN**
JPNEarlyLL	1	30.00	249.59	27.11	261.22
JPNLateLL	2	30.00	122.38	26.98	112.96
JPNDRIFT	4	30.00	121.68	24.60	116.58
HWLL	7	14.50	61.35	13.19	58.36
TWNLL	10	30.00	408.63	29.27	407.60
OthLL	12	26.49	85.14	27.25	86.09
PYFLL	13	6.95	19.38	6.91	22.44
EPOPS	14	30.00	209.53	27.58	210.63

Table 13.1. Time series of total biomass (age 1 and older, metric ton), spawning biomass (metric ton), age-0 recruitment (thousands of fish), instantaneous fishing mortality (year^{-1}), spawning potential ratio, fishing intensity (1- spawning potential ratio) for the Pacific blue marlin estimated in the base-case model. SE = standard error.

Year	**Age 1+ biomass (mt)**	**Spawning biomass (mt)**		**Recruitment (1000 age-0 fish)**		**Instantaneous fishing mortality**		**Spawning potential ratio**		**1-spawning potential ratio**	
	Mean	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
1971	135623.00	71806.50	19780.70	891.36	168.41	0.09	0.01	0.57	0.05	0.43	0.05
1972	133709.00	69410.40	17793.10	841.41	163.75	0.10	0.02	0.52	0.04	0.48	0.04
1973	132589.00	67252.40	16063.40	825.18	150.42	0.11	0.02	0.48	0.04	0.52	0.04
1974	129445.00	65101.30	14553.20	589.30	115.84	0.11	0.01	0.50	0.04	0.50	0.04
1975	123457.00	63538.20	13194.70	636.27	118.48	0.11	0.01	0.50	0.04	0.50	0.04
1976	116813.00	61014.00	11904.10	663.81	128.59	0.12	0.01	0.45	0.04	0.55	0.04
1977	110720.00	57275.00	10713.30	1176.94	212.03	0.14	0.02	0.41	0.04	0.59	0.04
1978	113412.00	53483.60	9673.90	1063.48	221.60	0.15	0.02	0.39	0.03	0.61	0.03
1979	118900.00	52426.70	8804.21	1048.29	206.08	0.15	0.01	0.40	0.03	0.60	0.03
1980	122042.00	52251.40	8101.66	953.28	196.94	0.15	0.01	0.40	0.03	0.60	0.03
1981	122708.00	52895.10	7625.90	919.69	188.98	0.16	0.02	0.38	0.03	0.62	0.03
1982	120641.00	52545.90	7284.46	1181.18	218.24	0.17	0.02	0.36	0.03	0.64	0.03
1983	121913.00	51632.00	7040.13	1028.63	201.99	0.16	0.01	0.38	0.03	0.62	0.03
1984	124812.00	52040.00	6904.71	875.43	175.19	0.18	0.02	0.34	0.03	0.66	0.03
1985	120559.00	51964.70	6800.38	881.30	170.44	0.15	0.01	0.40	0.03	0.60	0.03
1986	118554.00	51909.30	6694.74	1085.58	181.21	0.18	0.02	0.34	0.03	0.66	0.03
1987	117466.00	49865.90	6546.65	1024.75	184.58	0.25	0.02	0.24	0.03	0.76	0.03
1988	111698.00	45912.40	6368.19	992.11	185.31	0.22	0.02	0.27	0.03	0.73	0.03
1989	109115.00	44752.10	6235.93	940.20	183.66	0.19	0.02	0.32	0.03	0.68	0.03
1990	108599.00	44531.80	6100.03	931.47	171.90	0.17	0.02	0.36	0.03	0.64	0.03
1991	109152.00	44821.90	5940.22	946.97	176.46	0.19	0.02	0.33	0.03	0.67	0.03
1992	108265.00	44088.60	5747.45	1137.68	199.70	0.22	0.02	0.28	0.03	0.72	0.03
1993	108287.00	42563.40	5524.00	899.15	165.93	0.23	0.02	0.26	0.02	0.74	0.02
1994	105265.00	41234.10	5192.05	816.74	146.08	0.24	0.02	0.25	0.02	0.75	0.02

1995	98567.50	38589.30	4890.91	856.11	136.22	0.27	0.02	0.21	0.02	0.79	0.02
1996	91013.90	35884.20	4647.35	800.70	139.50	0.18	0.01	0.32	0.03	0.68	0.03
1997	91267.60	35948.70	4478.24	1056.28	143.15	0.21	0.02	0.28	0.02	0.72	0.02
1998	93107.00	34572.70	4273.84	628.63	110.72	0.21	0.02	0.28	0.02	0.72	0.02
1999	90677.80	34912.90	4052.85	848.77	129.44	0.21	0.01	0.28	0.02	0.72	0.02
2000	87674.70	33608.00	3843.25	923.38	130.08	0.26	0.02	0.23	0.02	0.77	0.02
2001	85808.10	31235.60	3553.67	840.92	126.28	0.31	0.02	0.19	0.02	0.81	0.02
2002	81061.90	28457.90	3273.39	880.83	127.32	0.32	0.02	0.18	0.01	0.82	0.01
2003	77238.40	25771.80	2996.42	985.46	122.97	0.38	0.03	0.15	0.01	0.85	0.01
2004	74393.70	23187.60	2758.55	793.43	111.27	0.34	0.02	0.17	0.01	0.83	0.01
2005	72970.40	22374.00	2636.61	956.88	119.43	0.38	0.03	0.15	0.01	0.85	0.01
2006	70419.20	20972.00	2576.58	874.14	119.44	0.33	0.03	0.18	0.02	0.82	0.02
2007	71872.30	21341.10	2623.27	699.28	110.74	0.27	0.02	0.21	0.02	0.79	0.02
2008	71767.70	22705.80	2697.06	687.05	112.41	0.27	0.02	0.22	0.02	0.78	0.02
2009	69720.10	23065.30	2729.60	1031.00	135.69	0.29	0.02	0.21	0.02	0.79	0.02
2010	72696.00	22391.80	2757.74	701.74	128.39	0.30	0.02	0.20	0.02	0.80	0.02
2011	72995.40	23181.80	2832.15	1060.95	156.88	0.26	0.02	0.22	0.02	0.78	0.02
2012	76697.10	23432.20	2946.78	763.04	142.62	0.27	0.02	0.22	0.02	0.78	0.02
2013	78760.70	24770.90	3125.30	908.75	179.42	0.28	0.03	0.21	0.02	0.79	0.02
2014	78082.00	24808.70	3372.22	838.53	37.27	0.28	0.03	0.21	0.03	0.79	0.03

Table 13.2. Estimated biological reference points derived from the Stock Synthesis base case model for Pacific blue marlin where F is the instantaneous annual fishing mortality rate, SPR is the annual spawning potential ratio, SSB is 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
$F_{2012\text{-}2014}$ (age 2+)	0.28
$SPR_{2012\text{-}2014}$	0.21
F_{MSY} (age 2+)	0.32
$F_{20\%}$ (age 2+)	0.30
SPR_{MSY}	0.18
SSB_{2014}	24,809
SSB_{MSY}	19,853
$SSB_{20\%}$	22,727
MSY	19,901

Table 14. Complete list of sensitivity runs conducted for the 2016 stock assessment update of Pacific blue marlin. Sensitivity analyses listed in italicized text were added and conducted at the March 2016 workshop, and other runs were from the sensitivity analyses completed for the 2013 benchmark assessment.

RUN	**NAME**	**DESCRIPTION**
ALTERNATIVE INPUT DATA		
1	01_base_case_S1S3only	Alternative CPUE trends, S1 and S3 only
2	02_base_case_dropF4size	Drop F4 weight composition data
3	03_base_case_dropF13size	Drop F13 length composition data
4	*04_base_case_newTWsize_reW30*	*Include the updated F10 length composition data*
5	*05_base_case_oldTWcv*	*Alternative S4 and S5 input log(SE)*
6	*06_base_case_scalar10*	*Alternative mean input effective sample size for F1, F2, F4, F10, and F14, rescale by a scalar of 10*
7	*07_base_case_scalar40*	*Alternative mean input effective sample size for F1, F2, F4, F10, and F14, rescale by a scalar of 40*
8	*08_base_case_scalar20*	*Alternative mean input effective sample size for F1, F2, F4, F10, and F14, rescale by a scalar of 20*
19	*19_base_case_S1S6only*	*Alternative CPUE trends, S1 and S6 only*
ALTERNATIVE LIFE HISTORY PARAMETERS: NATURAL MORTALITY RATES		
9	09_base_case_lowM	Alternative natural mortality rates, lower M, adult female M=0.12, adult male M=0.27, juvenile M rescaled
10	10_base_case_highM	Alternative natural mortality rates, higher M, adult female M=0.32, adult male M=0.47, juvenile M rescaled
ALTERNATIVE LIFE HISTORY PARAMETERS: STOCK-RECRUITMENT STEEPNESS		
11	11_base_case_h065	Alternative stock-recruitment steepness, lower h, h = 0.65
12	12_base_case_h075	Alternative stock-recruitment steepness, lower h, h = 0.75

13	13_base_case_h095	Alternative stock-recruitment steepness, higher h, h = 0.95
ALTERNATIVE LIFE HISTORY PARAMETERS: GROWTH CURVES		
14	14_base_case_small_Amax	Alternative growth curves, 10% smaller maximum size for each sex, change K to be consistent with size at age-1 from the base case model
15	15_base_case_large_Amax	Alternative growth curves, 10% larger maximum size for each sex, change K to be consistent with size at age-1 from the base case model
16	16_base_case_ChangGrowth	Alternative growth parameters, based on Chang et al. (2013)
ALTERNATIVE LIFE HISTORY PARAMETERS: MATURITY OGIVES		
17	17_base_case_high_L50	Alternative maturity ogives, L_{50} = 197.7 cm
18	18_base_case_low_L50	Alternative maturity ogives, L_{50} = 161.8 cm

Table 15.1. Projected trajectory of spawning stock biomass (SSB in metric tons) for alternative harvest scenarios. Fishing intensity ($F_{x\%}$) alternatives are based on $F_{16\%}$ (average 2003-2005), F_{MSY} ($F_{18\%}$), $F_{2012-2014}$ ($F_{21\%}$) (average 2012-2014 defined as current), and $F_{30\%}$. Green blocks indicate the projected SSB is greater than MSY level (SSB_{MSY} =19,853 metric tons).

Run	**Harvest scenario**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**Average**
1	$F_{2003-2005}$ ($F_{16\%}$)	24,545	22,683	21,163	20,014	19,167	18,546	18,086	17,741	17,481	17,283	19,671
2	F_{MSY} ($F_{18\%}$)	24,810	23,850	22,972	22,260	21,710	21,295	20,982	20,745	20,564	20,426	21,961
3	$F_{2012-2014}$ ($F_{21\%}$)	25,114	25,242	25,217	25,144	25,063	24,995	24,942	24,901	24,869	24,845	25,033
4	$F_{30\%}$	25,638	27,797	29,585	31,042	32,212	33,151	33,903	34,506	34,985	35,367	31,819

Table 15.2. Projected trajectory of yield (metric tons) for alternative harvest scenarios. Fishing intensity ($F_{x\%}$) alternatives are based on $F_{16\%}$ (average 2003-2005), F_{MSY} ($F_{18\%}$), $F_{2012-2014}$ ($F_{21\%}$) (average 2012-2014 defined as current), and $F_{30\%}$. MSY = 19,901 metric tons.

Harvest scenario	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**Average**
1: $F_{2003-2005}$ ($F_{16\%}$)	25,688	24,044	22,890	22,089	21,522	21,111	20,806	20,576	20,402	20,268	21,940
2: F_{MSY} ($F_{18\%}$)	23,194	22,336	21,693	21,234	20,905	20,667	20,491	20,359	20,259	20,182	21,132
3: $F_{2012-2014}$ ($F_{21\%}$)	20,267	20,162	20,047	19,958	19,895	19,852	19,822	19,800	19,785	19,774	19,936
4: $F_{30\%}$	15,015	15,802	16,386	16,833	17,177	17,442	17,648	17,808	17,932	18,028	17,007

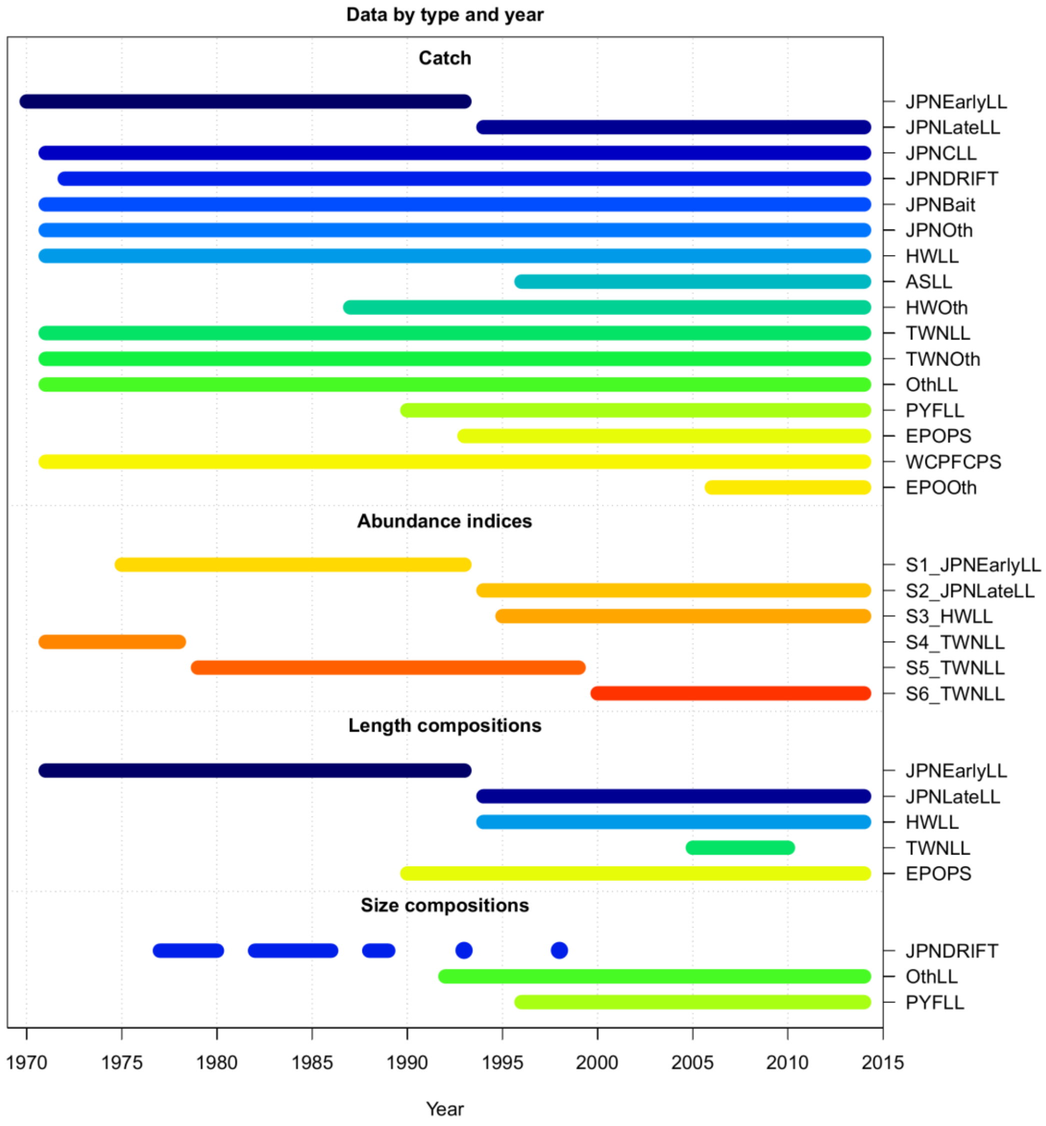


Figure 1. Available temporal coverage and sources of catch, CPUE (abundance indices), and length and size composition for the stock assessment update of the Pacific blue marlin.

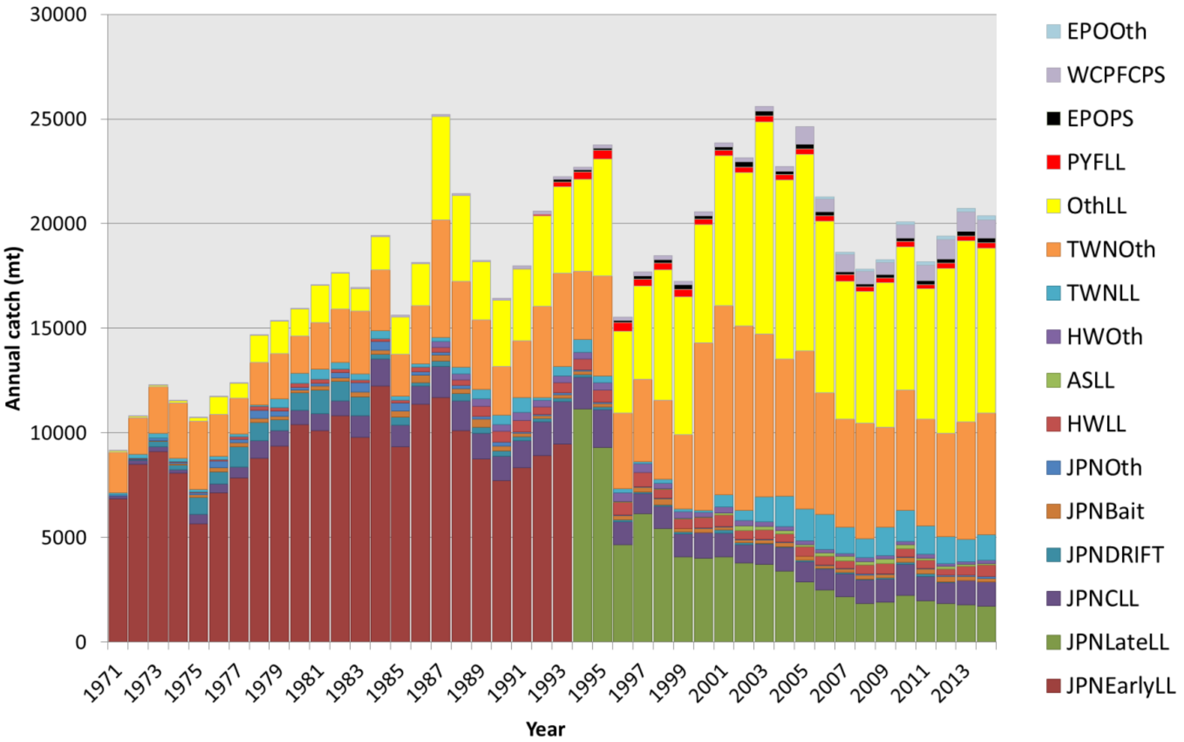


Figure 2. Total annual catch of the Pacific blue marlin by all fisheries harvesting the stock during 1971-2014. See Table 1 for the reference code for each fishery.

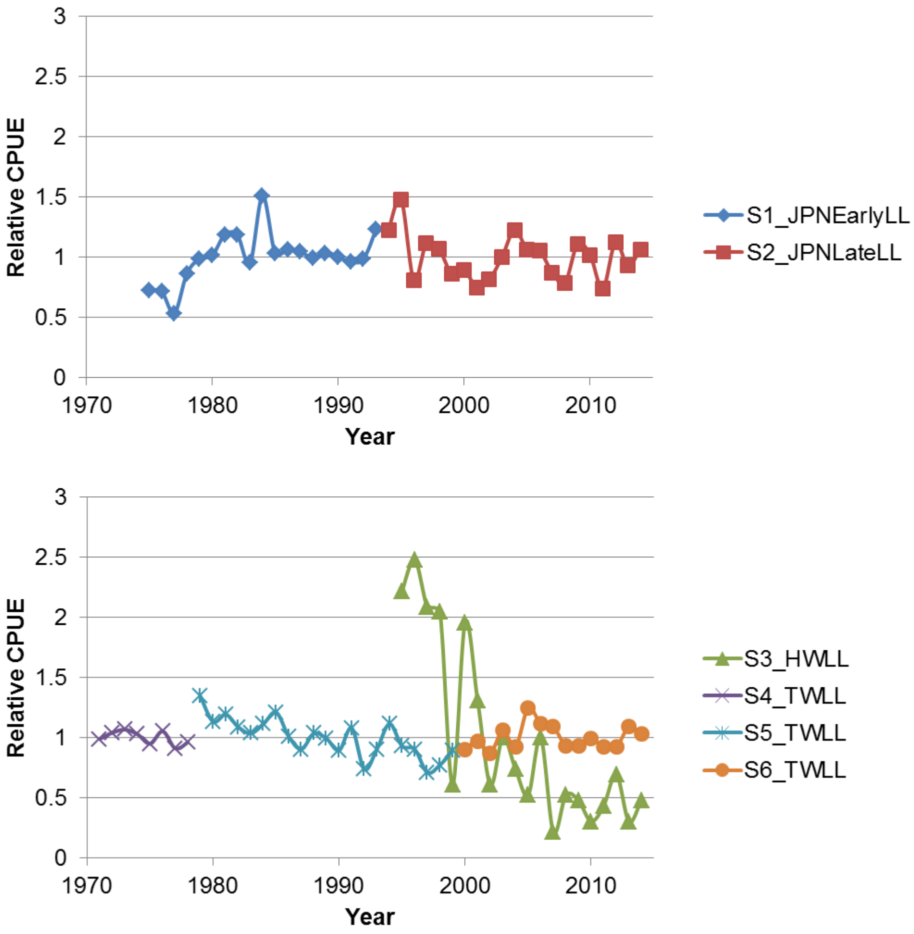


Figure 3. Time series of annual standardized indices of catch-per-unit-effort (CPUE) for the Japanese distant water longline fisheries (top panel); Hawaii-based longline and Taiwan distant water longline fisheries (bottom panel) for the Pacific blue marlin as described in Table 3. Index values were rescaled by the mean of each index for comparison purposes.

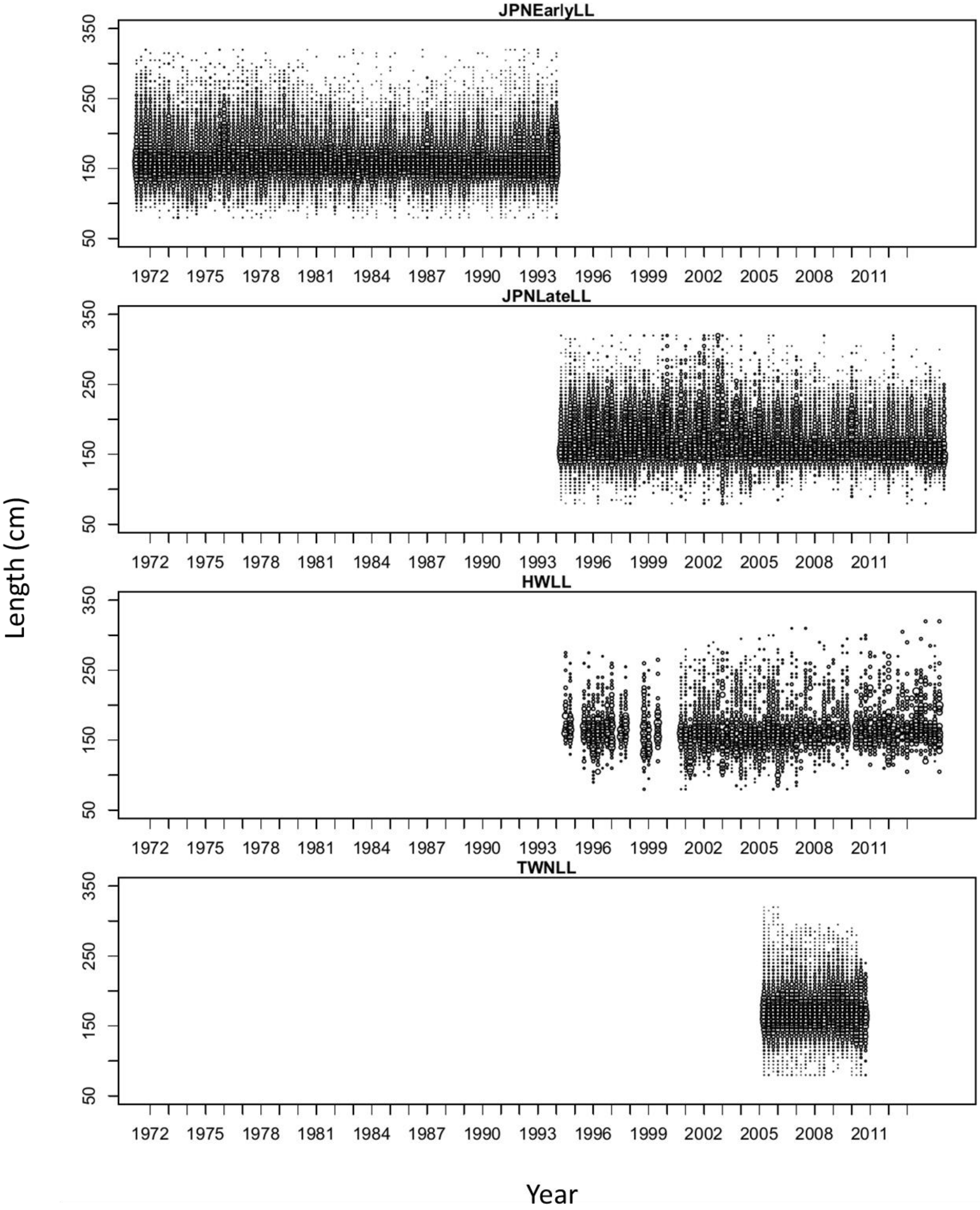


Figure 4. Quarterly length and size composition data by fishery used in the stock assessment update (see Table 5). The sizes of the circles are proportional to the number of observations. All measurements were eye- fork lengths (EFL, cm) except JPNDRIFT (kg).

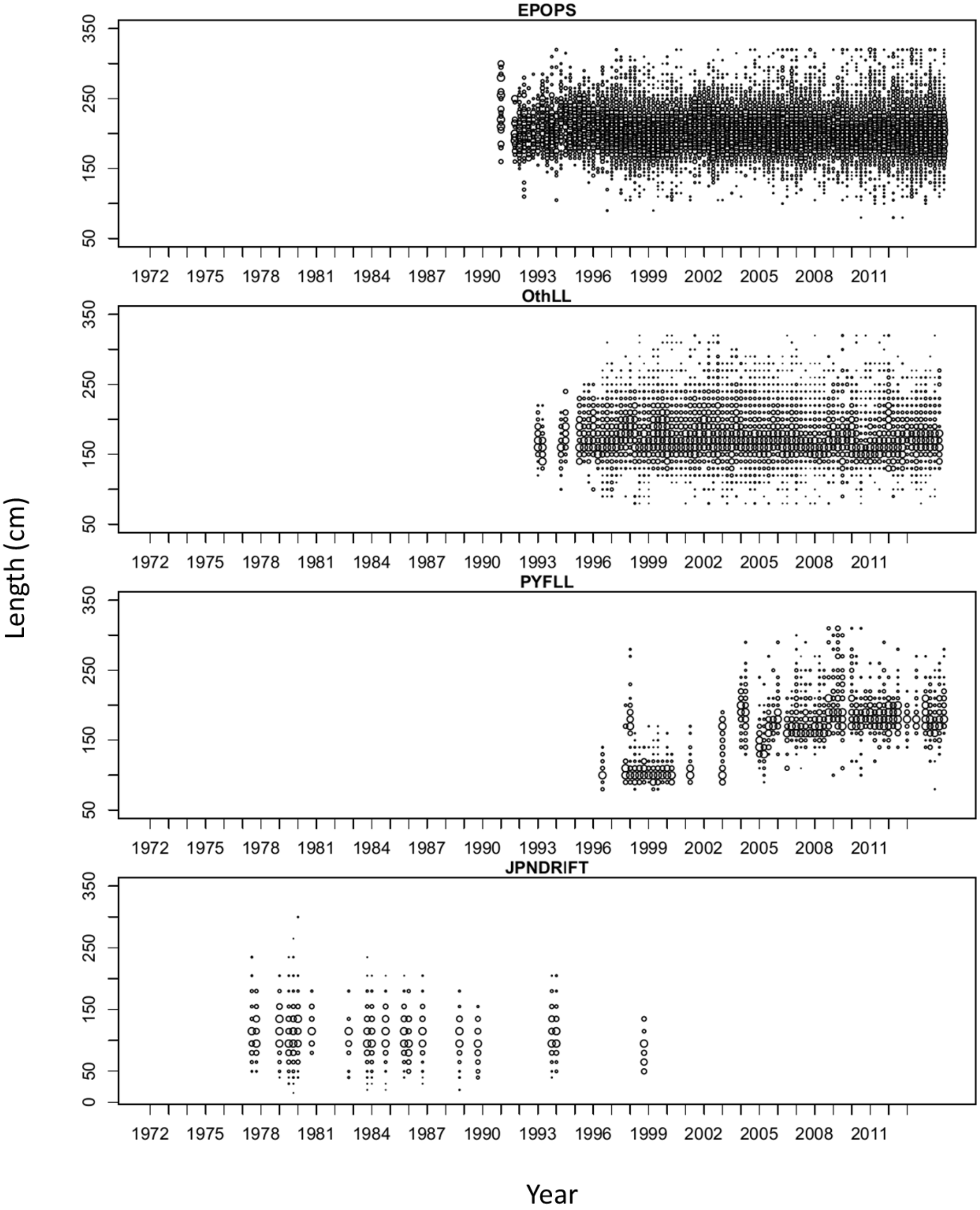


Figure 4. Continued.

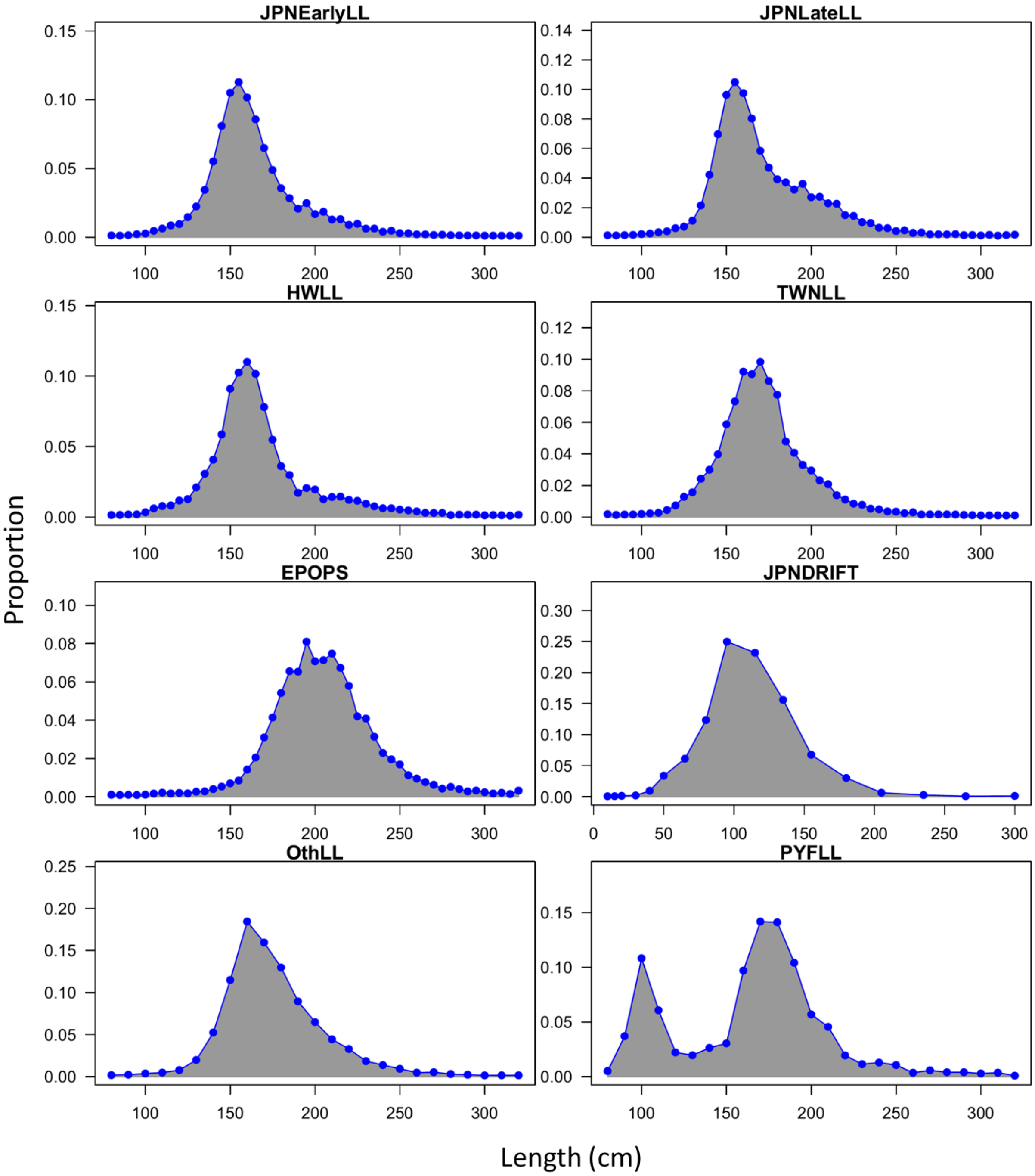


Figure 5. Aggregated length and size compositions used in the stock assessment update (see Table 5 for descriptions of the composition data). All measurements were eye- fork lengths (EFL, cm) except JPNDRIFT (kg).

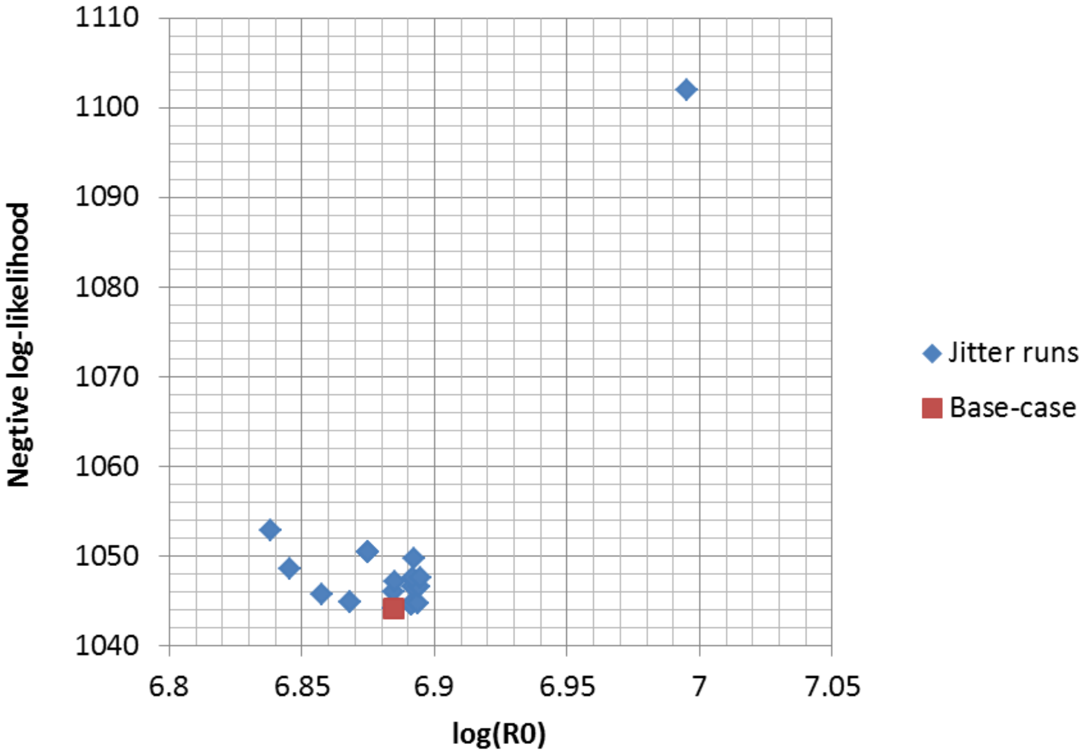


Figure 6. Total negative log-likelihood and estimated virgin recruitment in log-scale (log(R0)) from 30 model runs with different random initial values (jitter runs) based on estimated parameters in the base case model. The red triangle indicates results from the updated base case model, which had the lowest total negative log-likelihood (1044.2) of all of the 30 model runs with randomized initial parameter values.

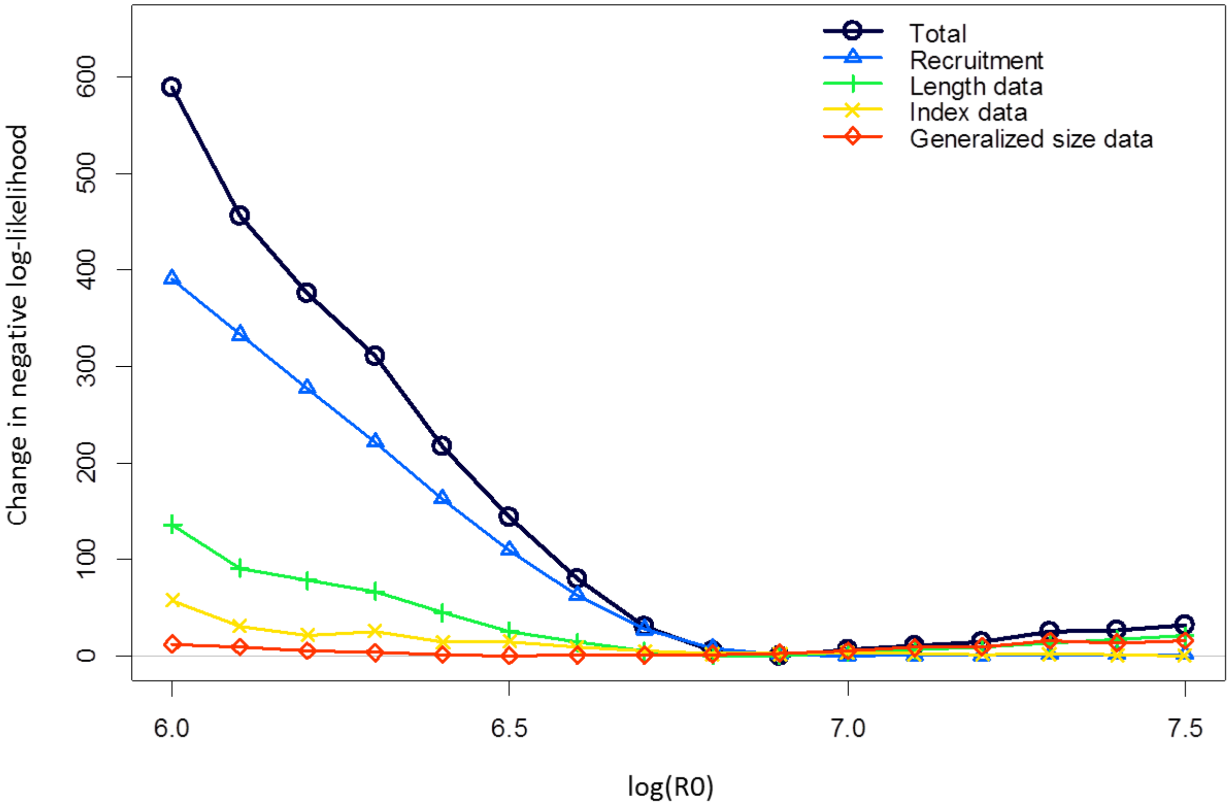


Figure 7.1. Profiles of the negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter R0 in log-scale (i.e., the x-axis is log(R0)) ranging from 6.0 to 7.5 for the base case model, where recruitment represents the likelihood component based on the deviations from the stock-recruitment curve, length data represents the joint likelihood component for combined fleets based on the fish length composition data, index data represents the joint likelihood component for combined fleets based on the relative abundance, or CPUE indices, and generalized size data represents the joint likelihood component for combined fleets based on the fish weight composition data.

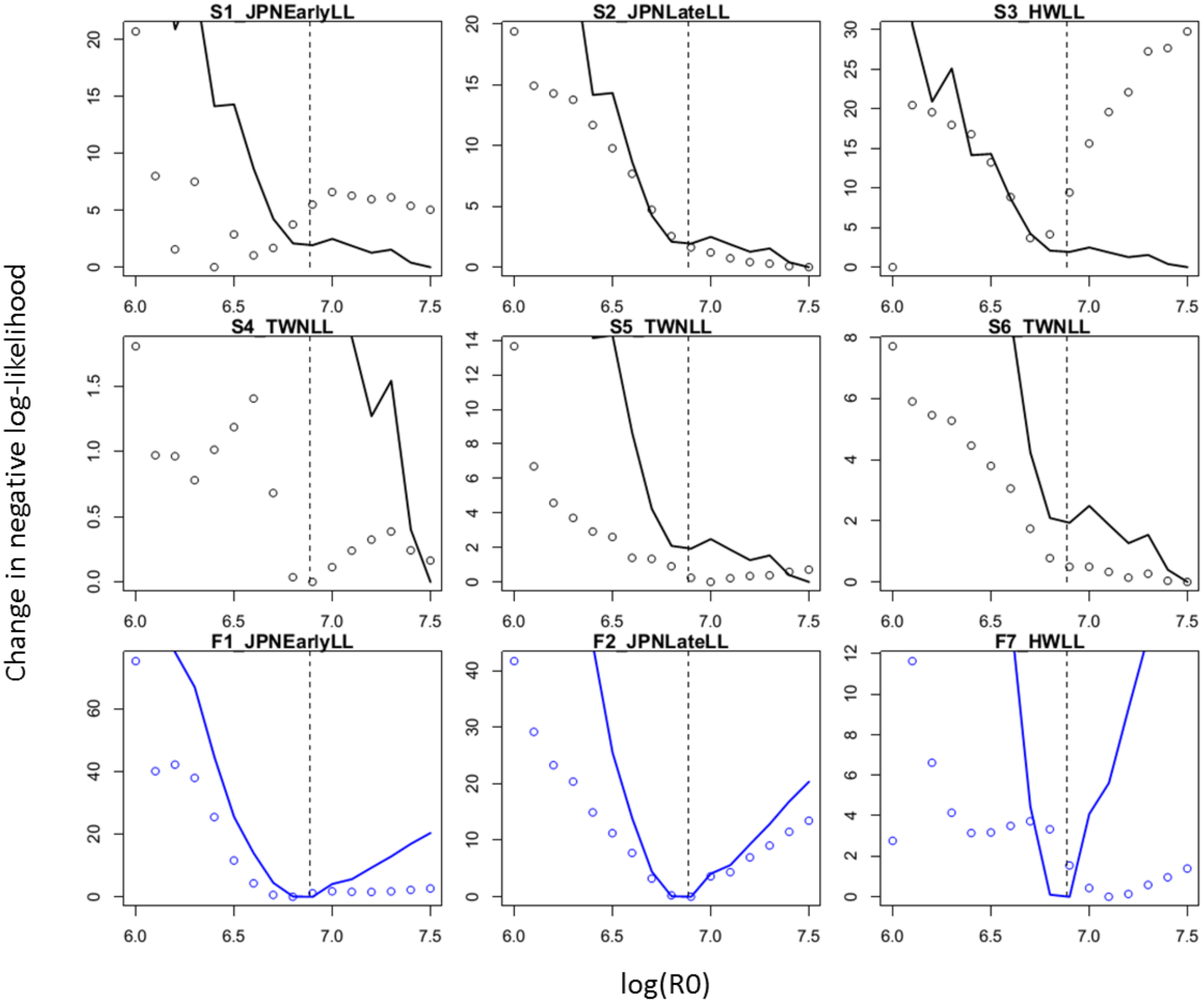


Figure 7.2. Profiles of the relative negative log-likelihoods by index (black circles), length composition (blue circles), generalized-size composition (red circles) likelihood components for the virgin recruitment in log-scale (log(R0)) ranged from 6.0 to 7.5 of the base case scenario. Black, blue, and red lines denote the changes in the joint likelihoods components for combined fleets for the index, length composition, and generalized-size composition data, respectively. See Tables 2 and 3 for descriptions of the index and composition data. S3_HWLL was not included in the total likelihood.

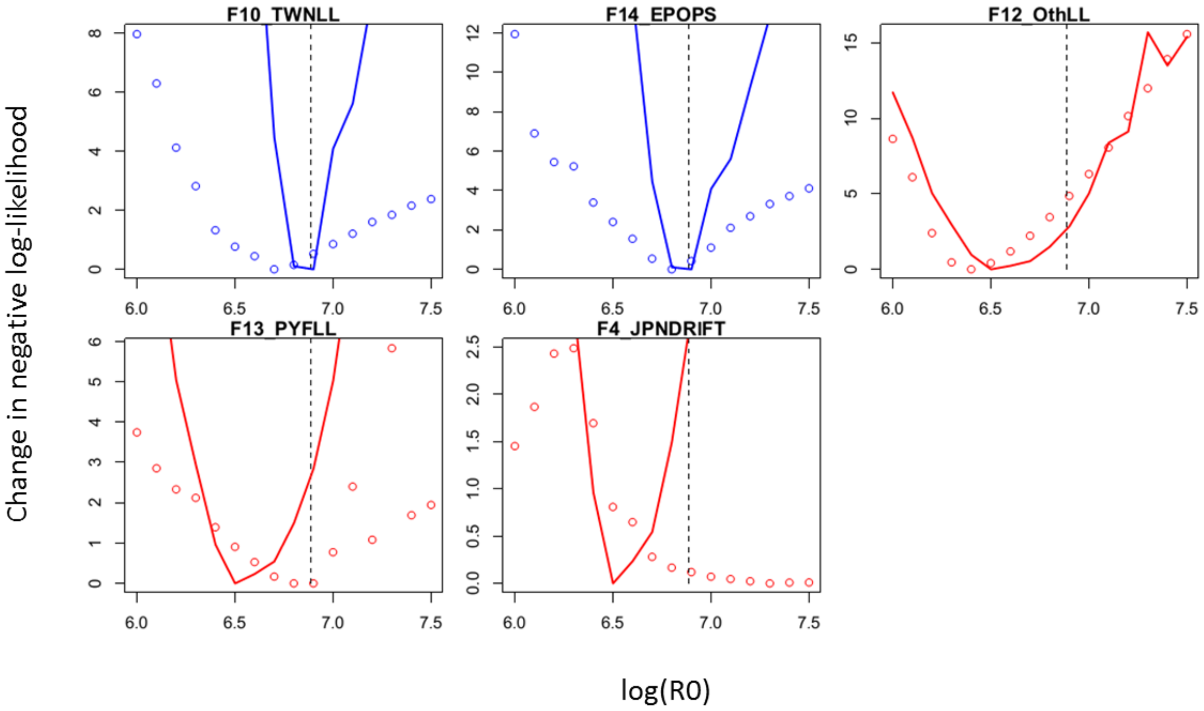


Figure 7.2 Continued.

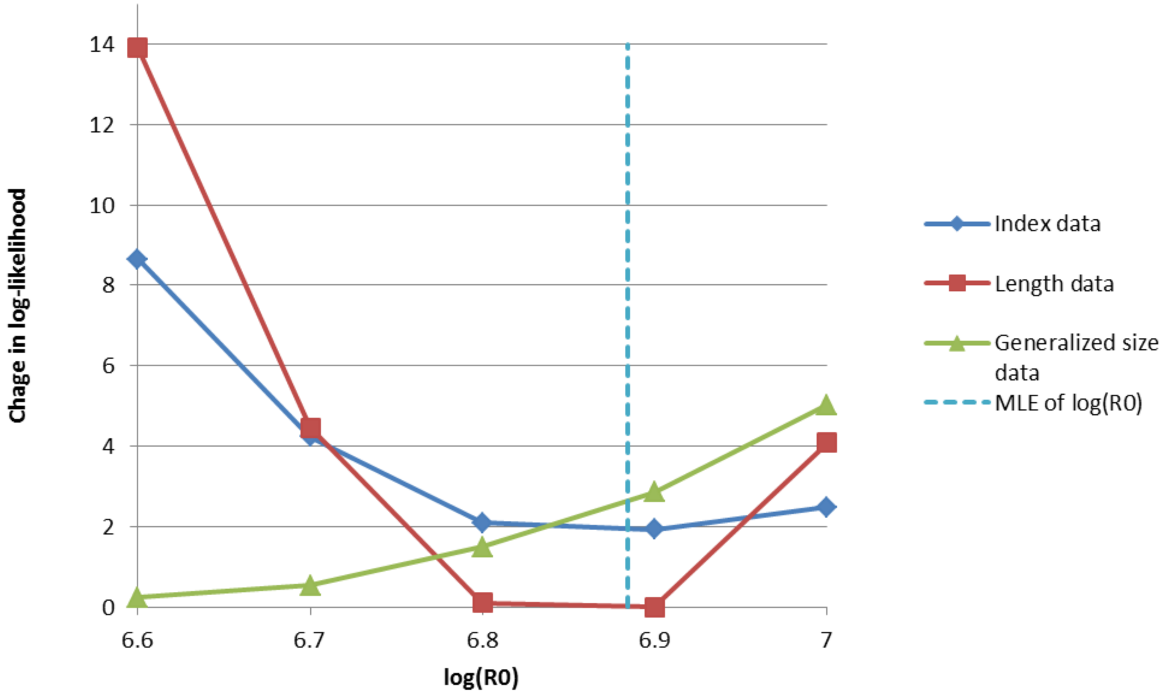


Figure 7.3. Zoomed in profiles of the relative negative log-likelihoods by index, length composition, and generalized-size composition data for combined fleets of the unfished recruitment parameter R0 in log-scale (log(R0)) ranged from 6.6 to 7.0 of the base case scenario.

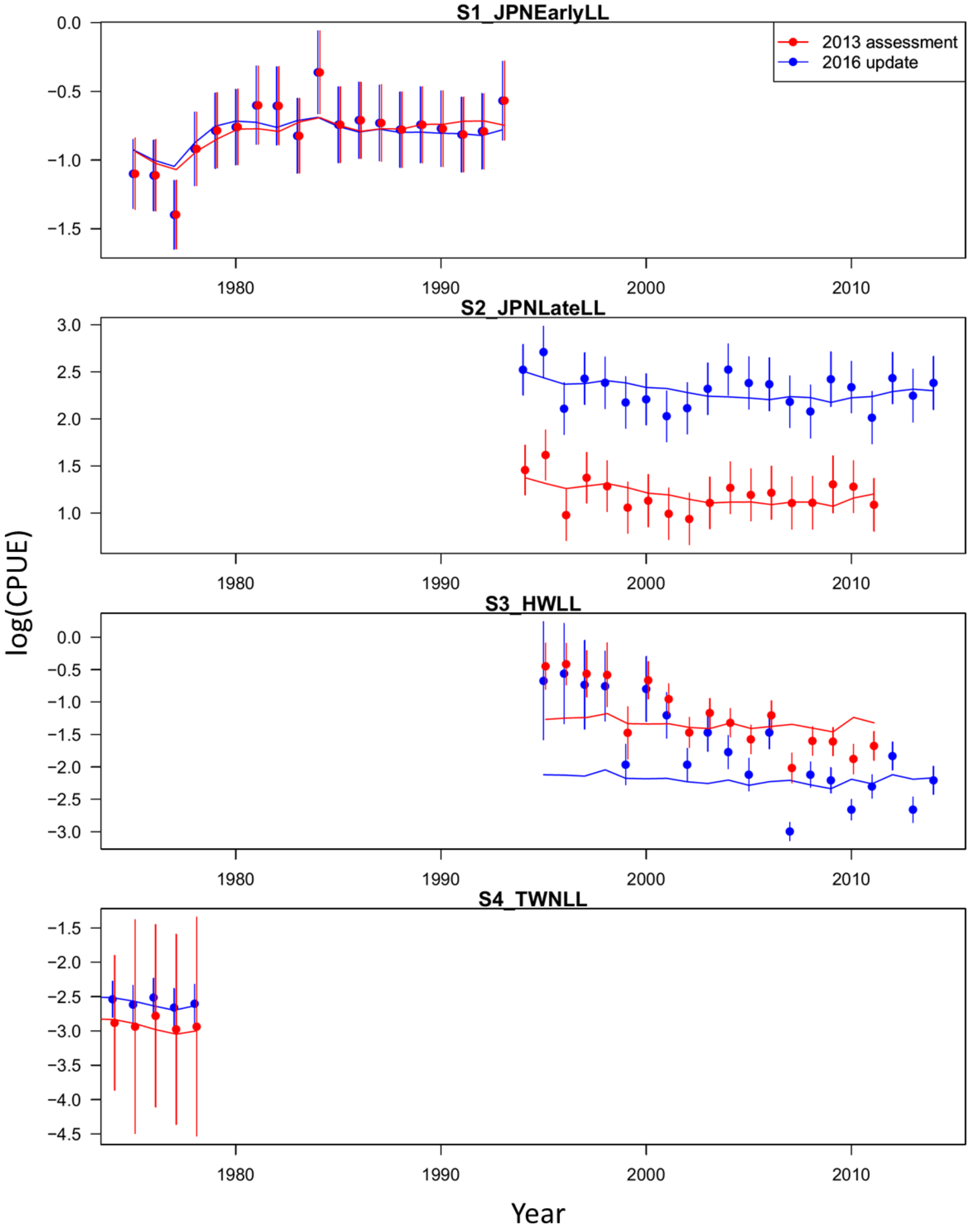


Figure 8. Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. Red color = 2013 assessment, blue color = 2016

update. S3_HWLL was not included in the total likelihood

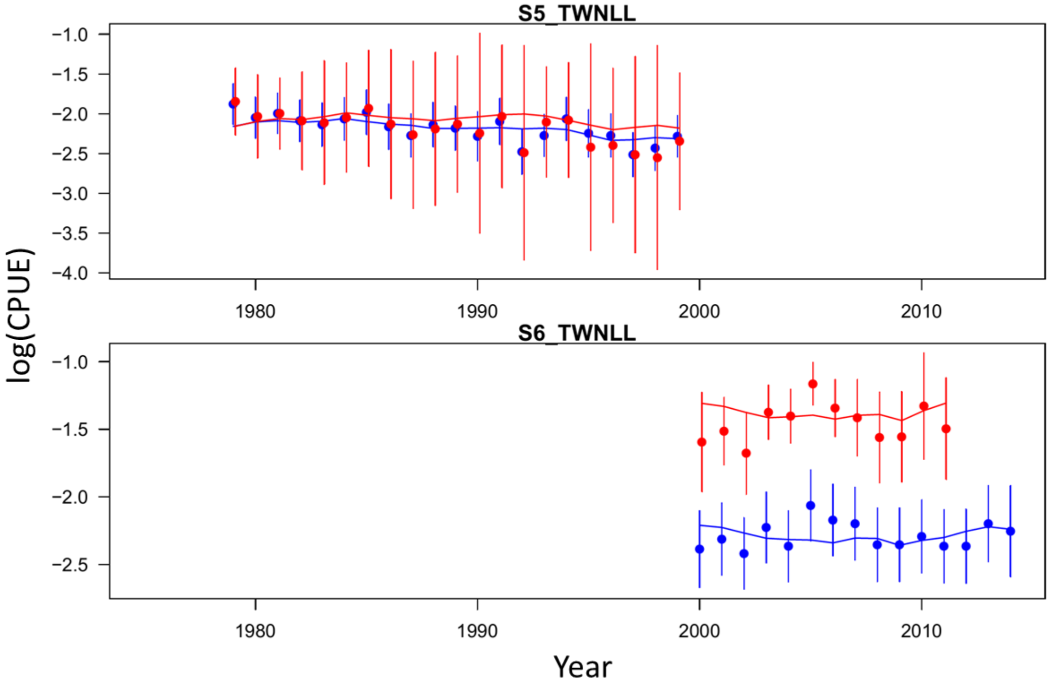


Figure 8. Continued.

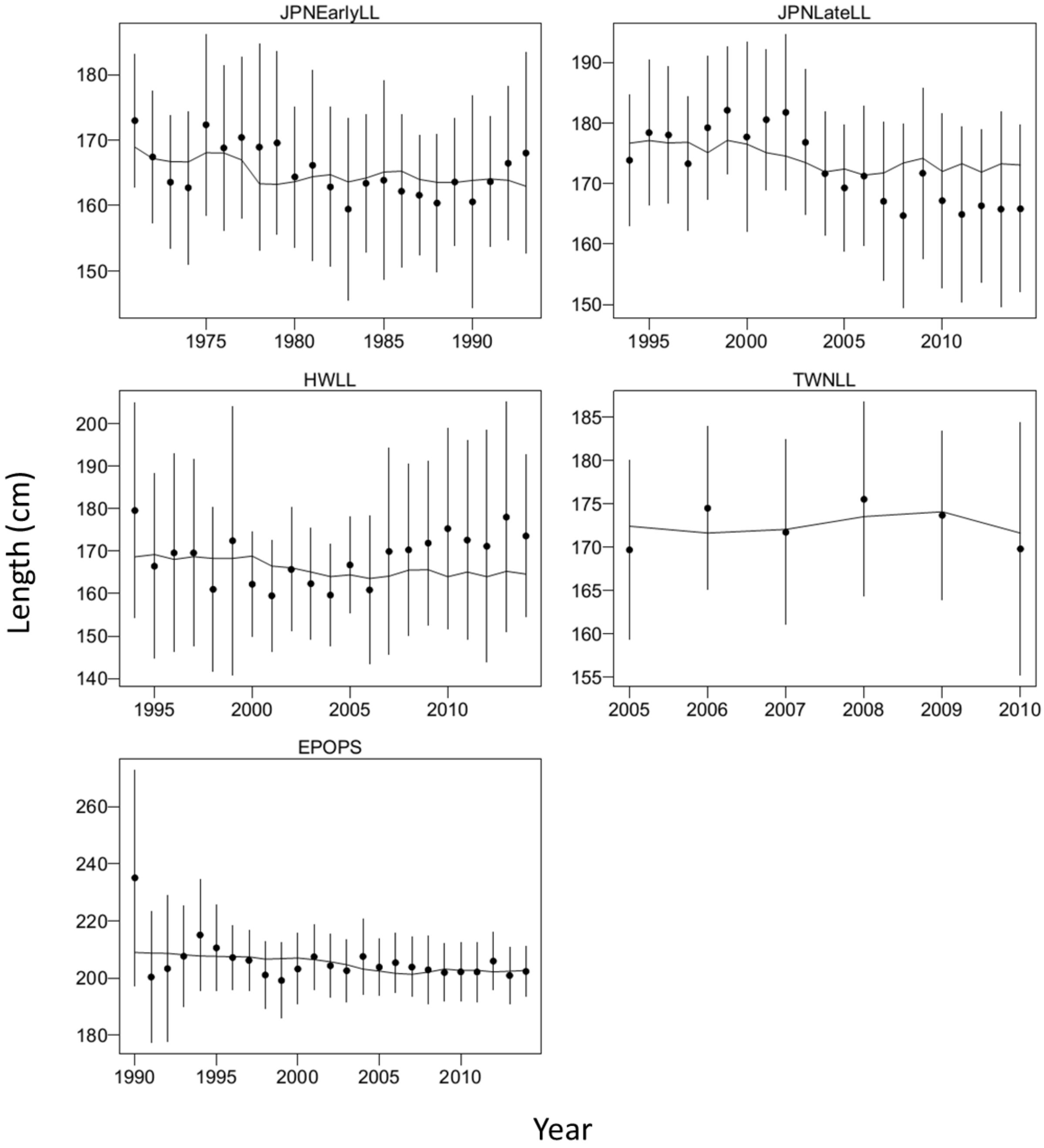
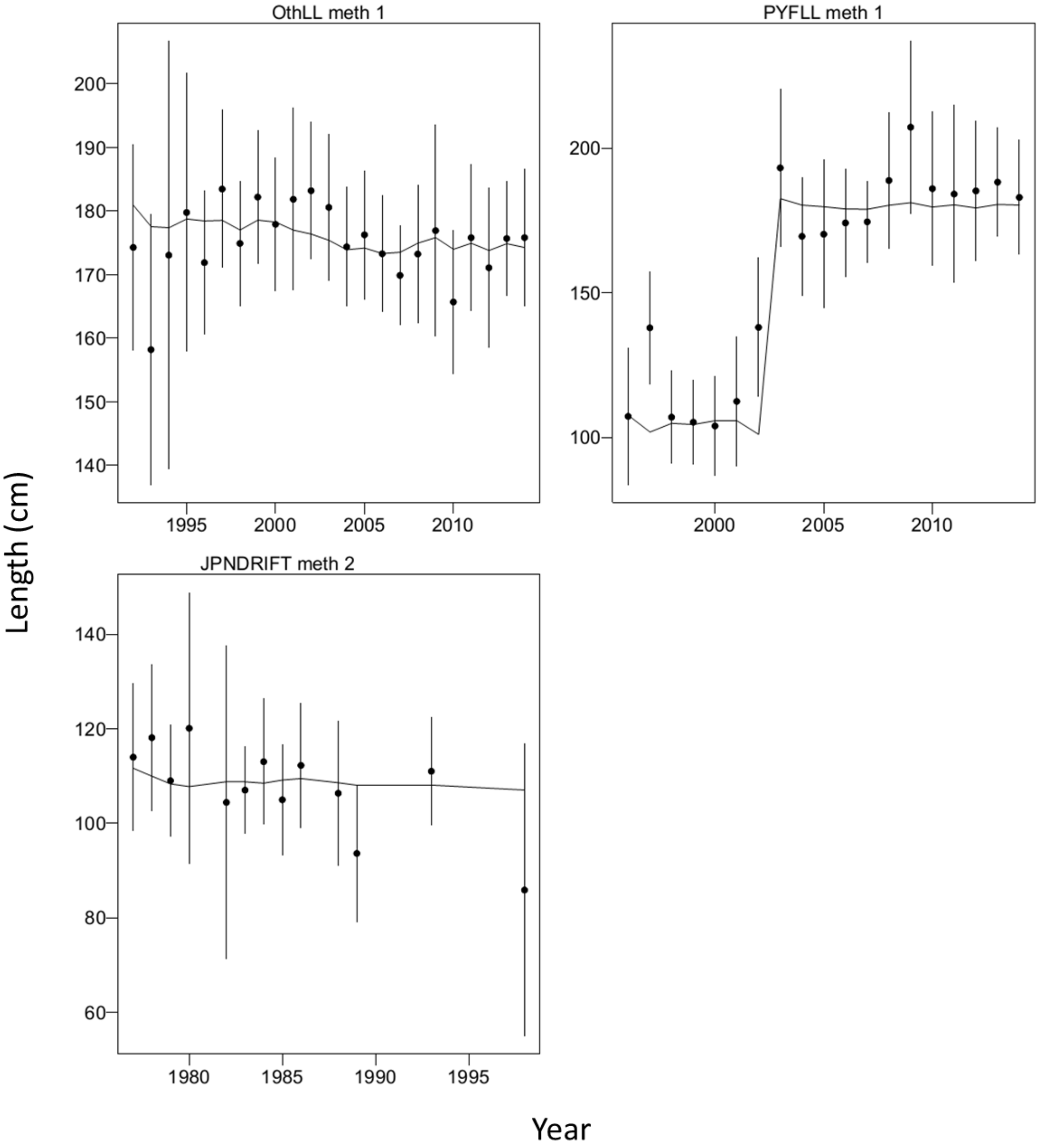


Figure 9. Model fit (lines) to mean length of the composition data (points, showing the observed mean age and 95% credible limits around mean age (vertical lines)). See Table 5 for descriptions of the data. All measurements were eye-to-fork lengths (EFL, cm) except JPNDRIFT (kg).



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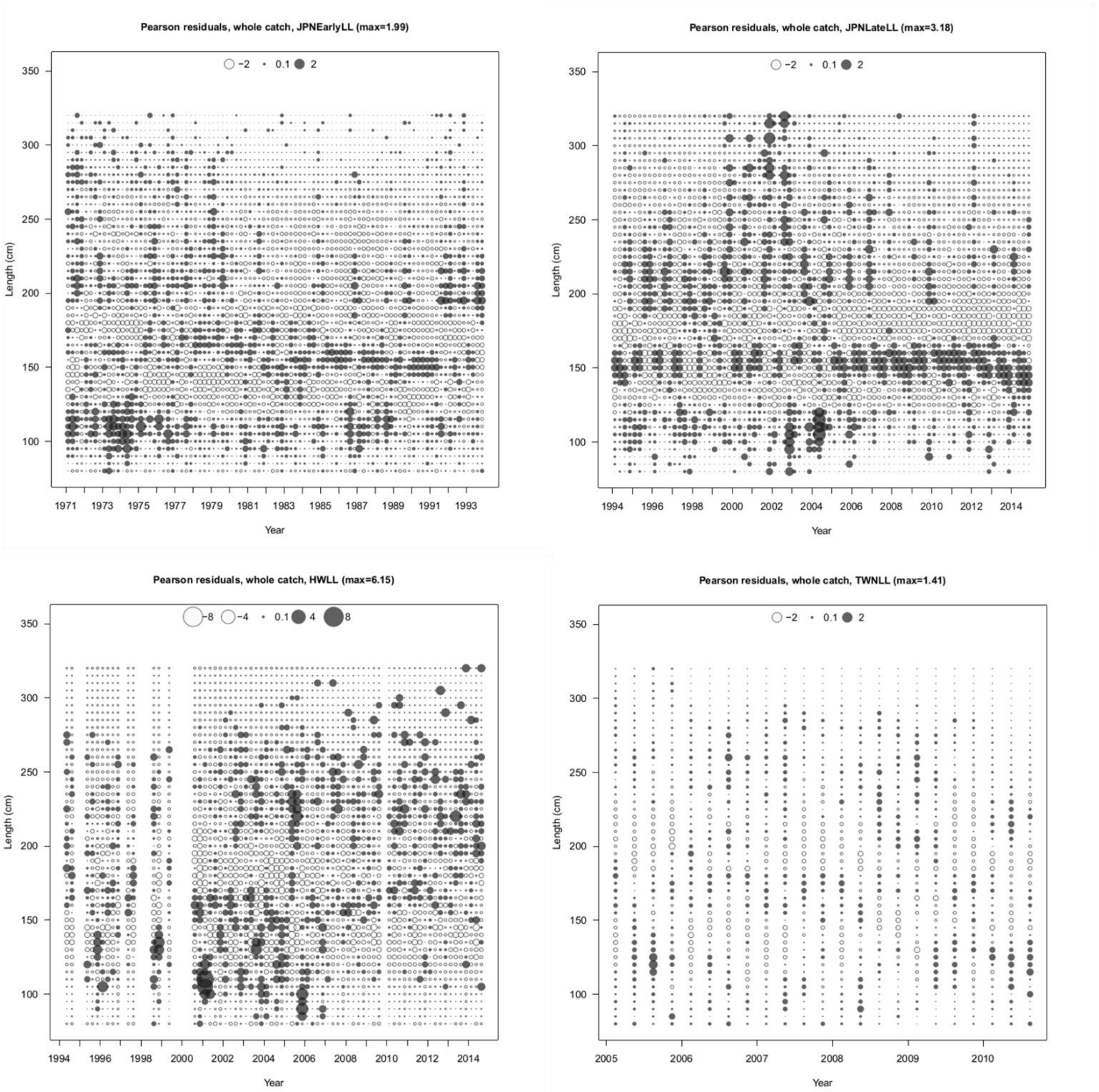


Figure 10. Pearson residual plots of model fits to the various length-composition data for the Pacific blue marlin fisheries used in the assessment model.

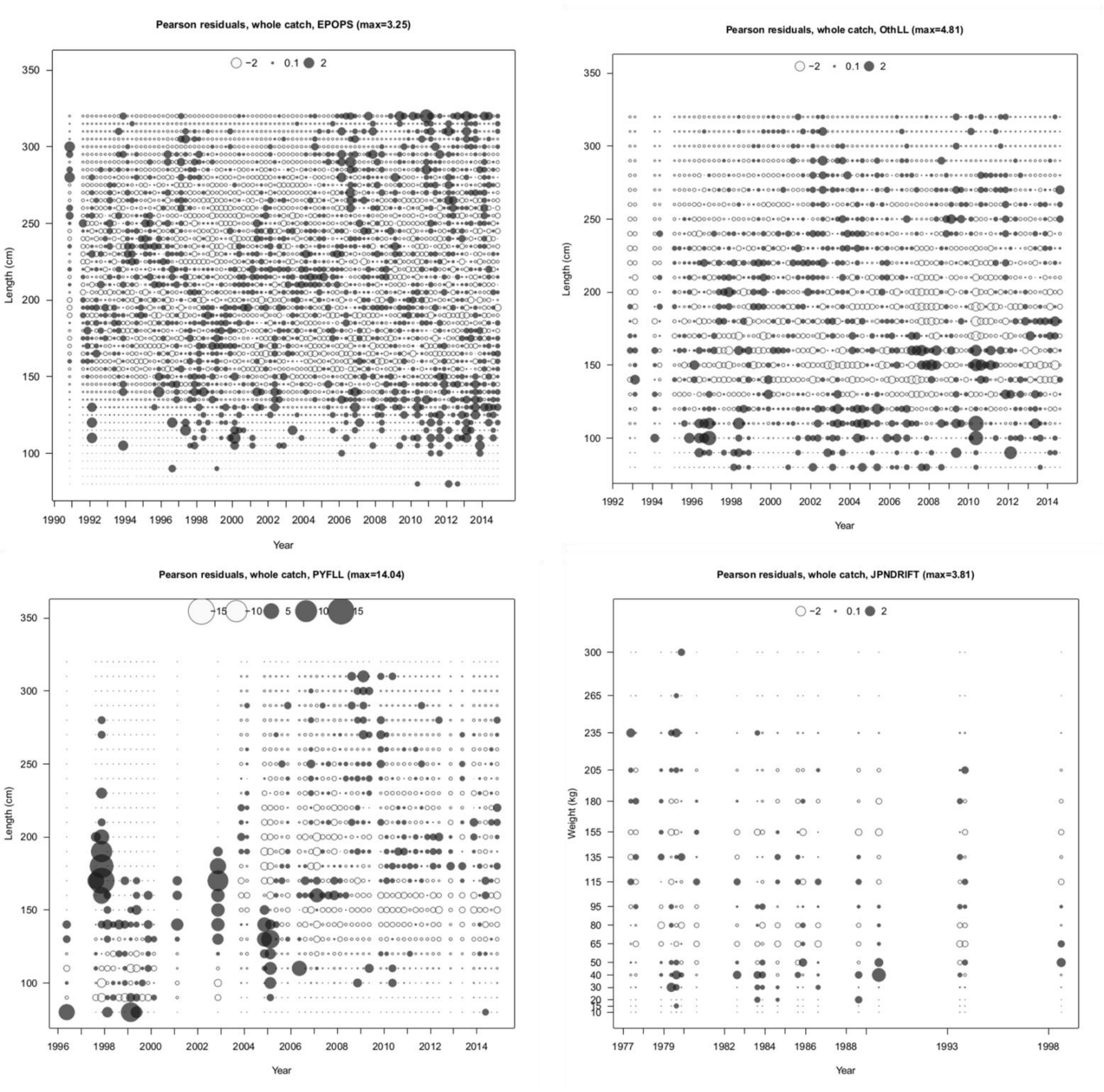


Figure 10. Continued.

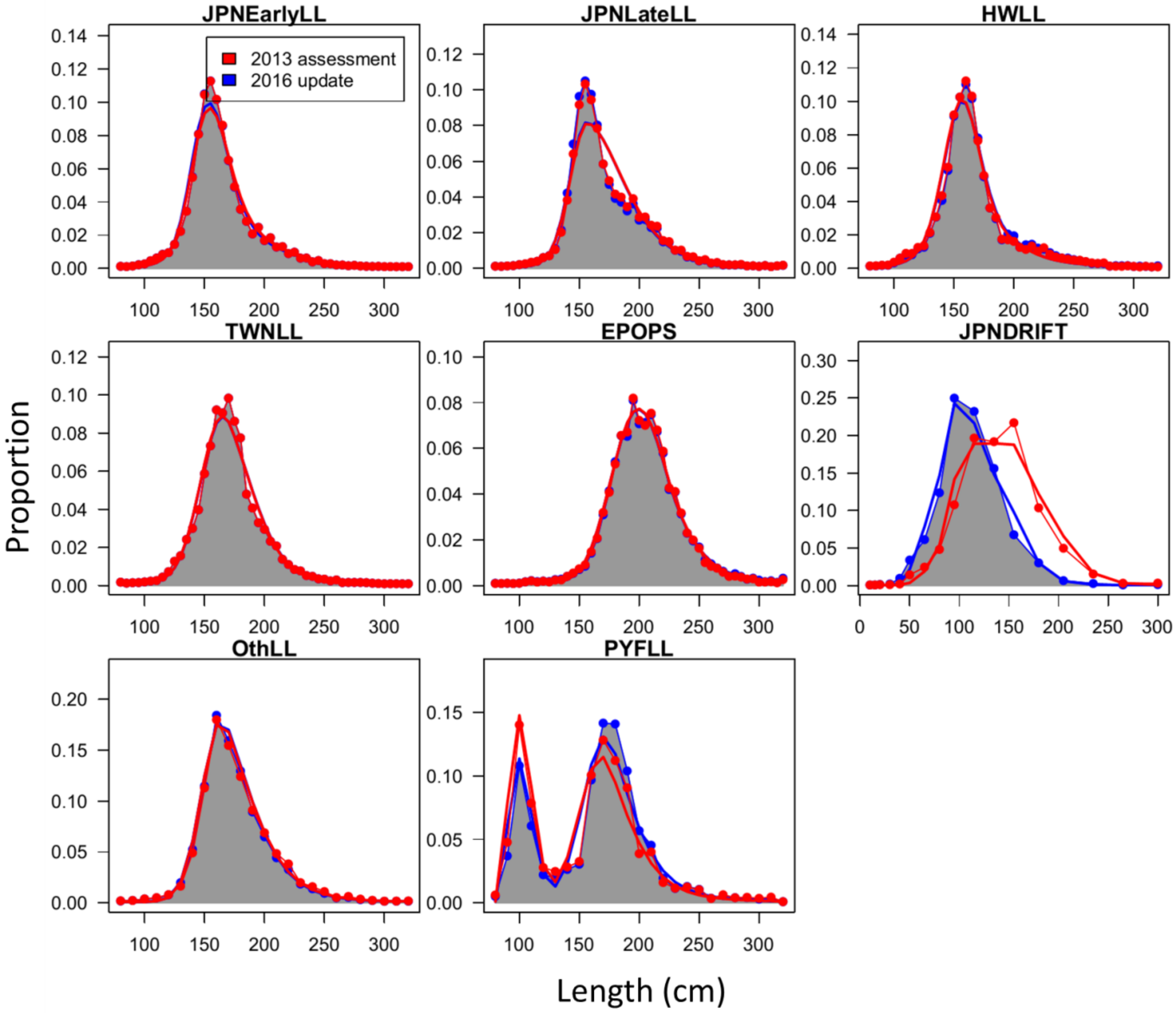


Figure 11. Comparison of observed (gray shaded area and blue dots) and model predicted (blue solid line) length compositions for fisheries used in the updated stock assessment for the Pacific blue marlin. Red colors indicate observed (dots) and predicted (line) length compositions from the 2013 assessment. All measurements were eye-to-fork lengths (EFL, cm) except JPNDRIFT (kg).

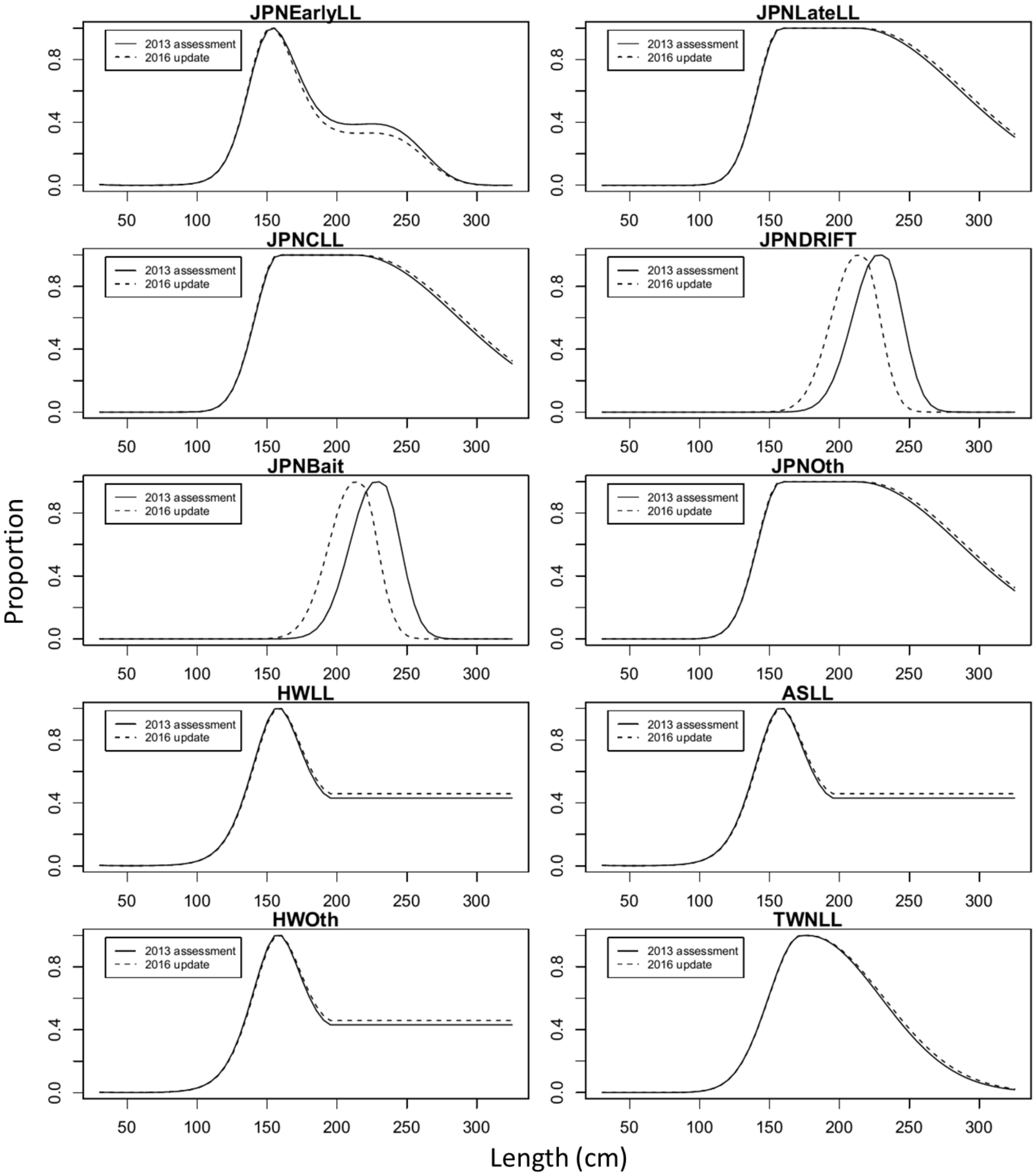
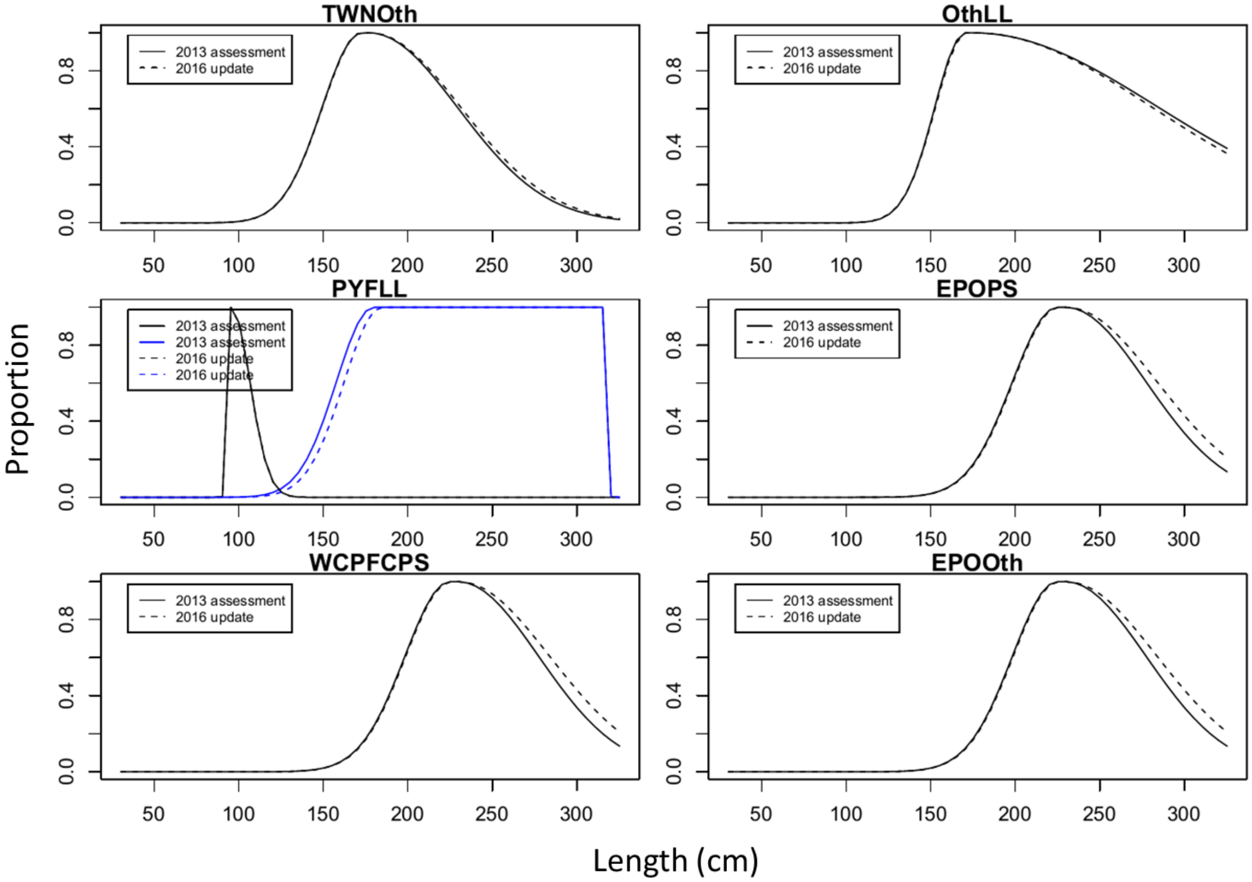


Figure 12. Comparison of length-based selectivity of fisheries for Pacific blue marlin between the 2013 stock assessment (solid lines) and the 2016 update (dash lines). Different colors denote the selectivity curves by time blocks.



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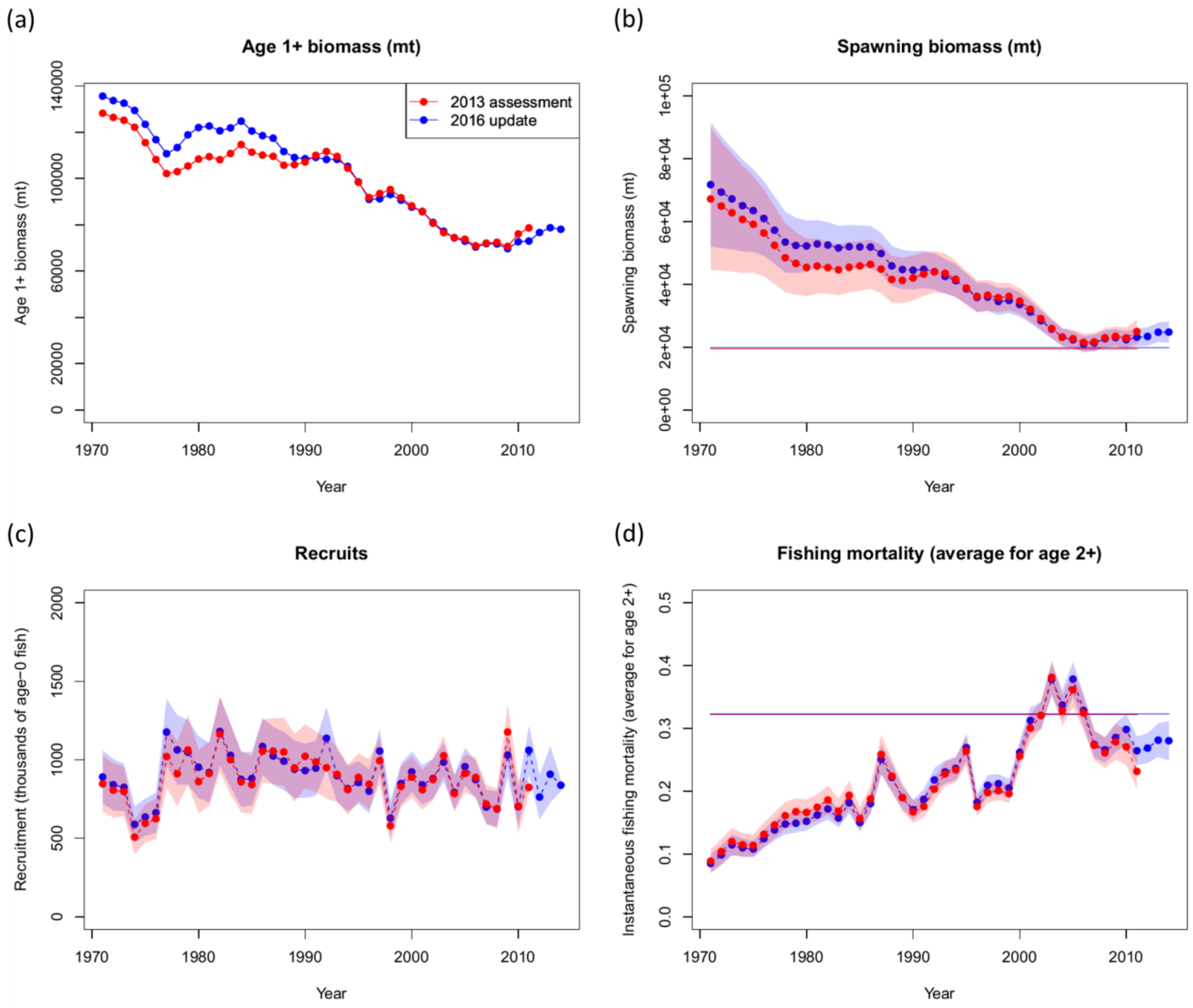

Figure 13. Comparison of time series of (a) total biomass (age 1+), (b) spawning biomass, (c) age-0 recruitment, and (d) instantaneous fishing mortality (year^{-1}) for Pacific blue marlin between the 2013 stock assessment (red) and the 2016 update (blue). The solid line with circles represents the maximum likelihood estimates for each quantity and the shadowed area represents the uncertainty of the estimates (± 1 standard deviation), noting that no estimates of standard deviations were available from the SS3 software for the total biomass time series. The solid horizontal lines indicated the MSY-based reference points.

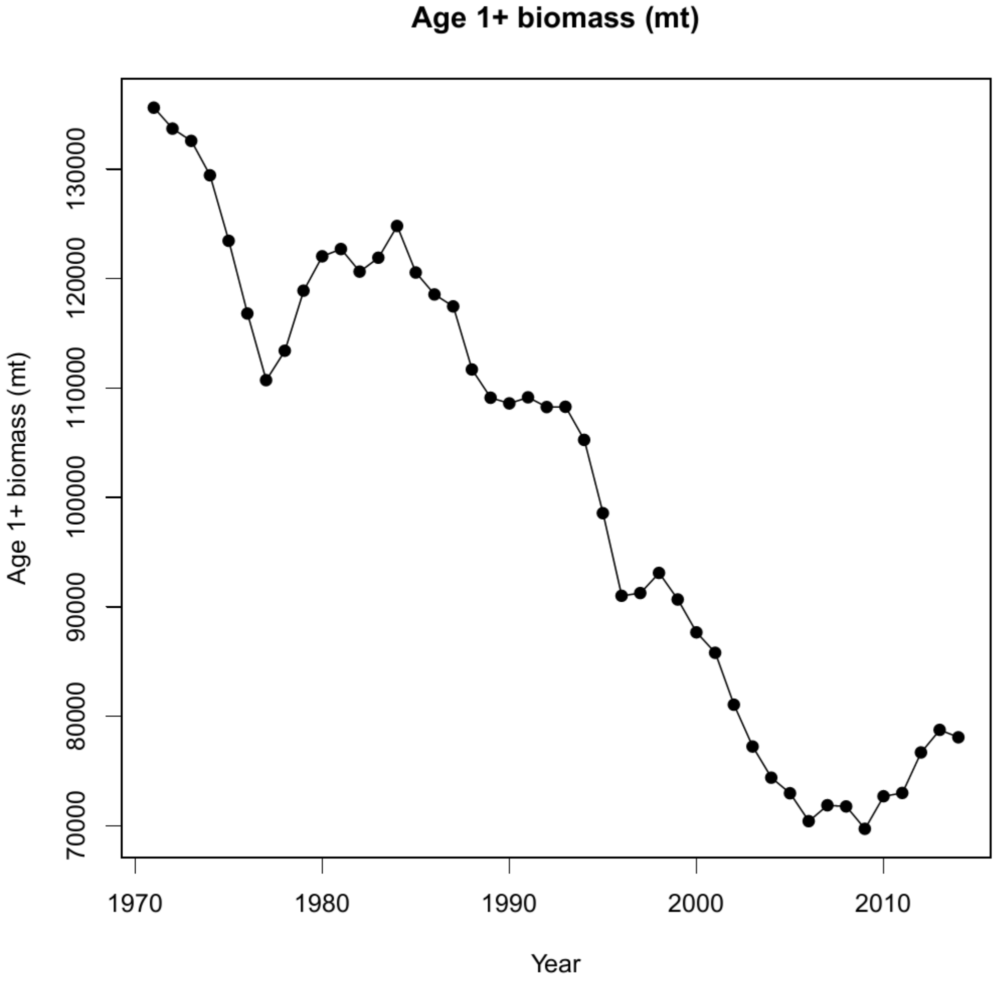

Figure 14.1. Time series of total biomass (age 1 and older, metric ton) for the Pacific blue marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates.

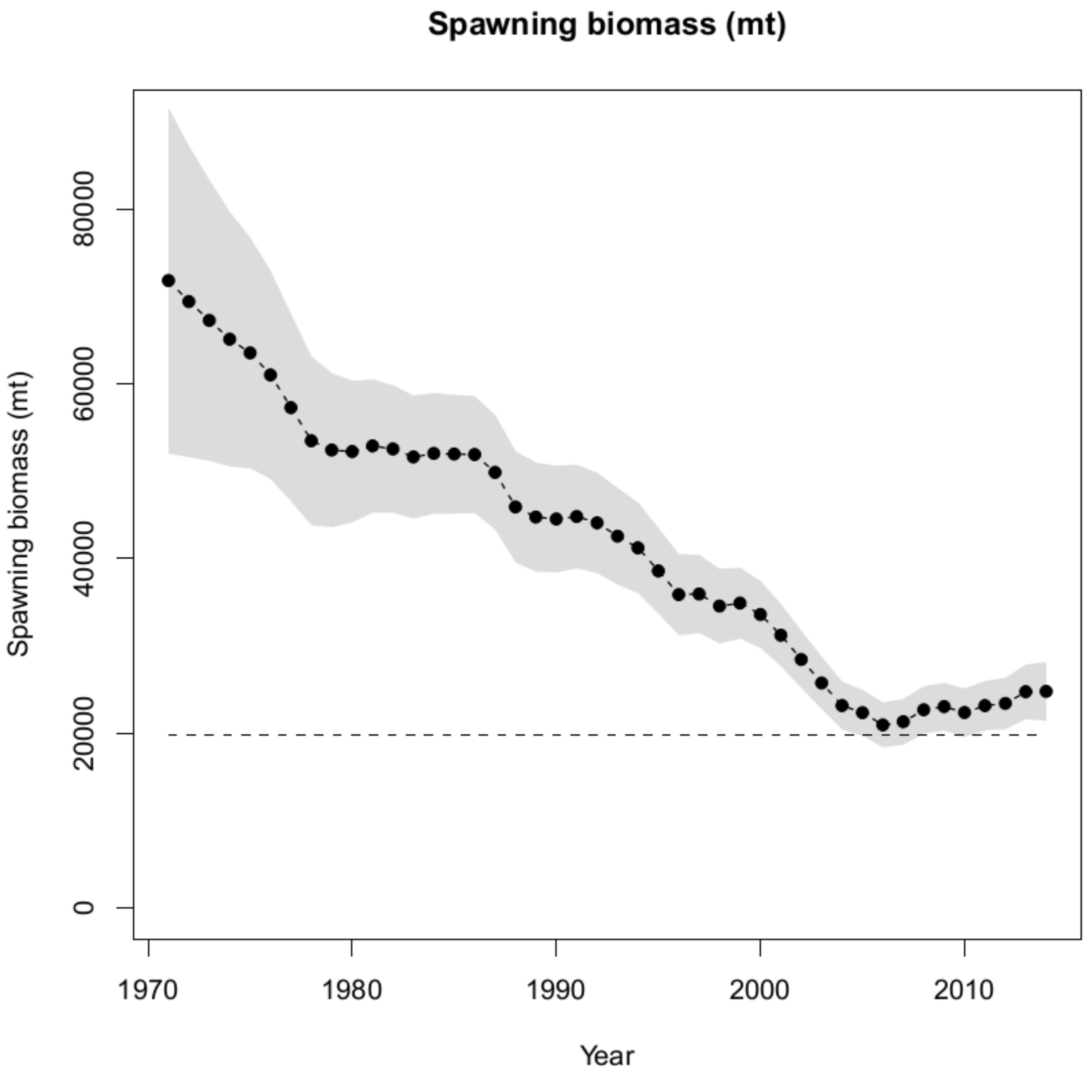

Figure 14.2. Time series of spawning biomass (metric ton) for the Pacific blue marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the shadowed area represents the uncertainty of the estimates (± 1 standard deviations). The dashed horizontal line shows the spawning biomass to produce MSY reference point.

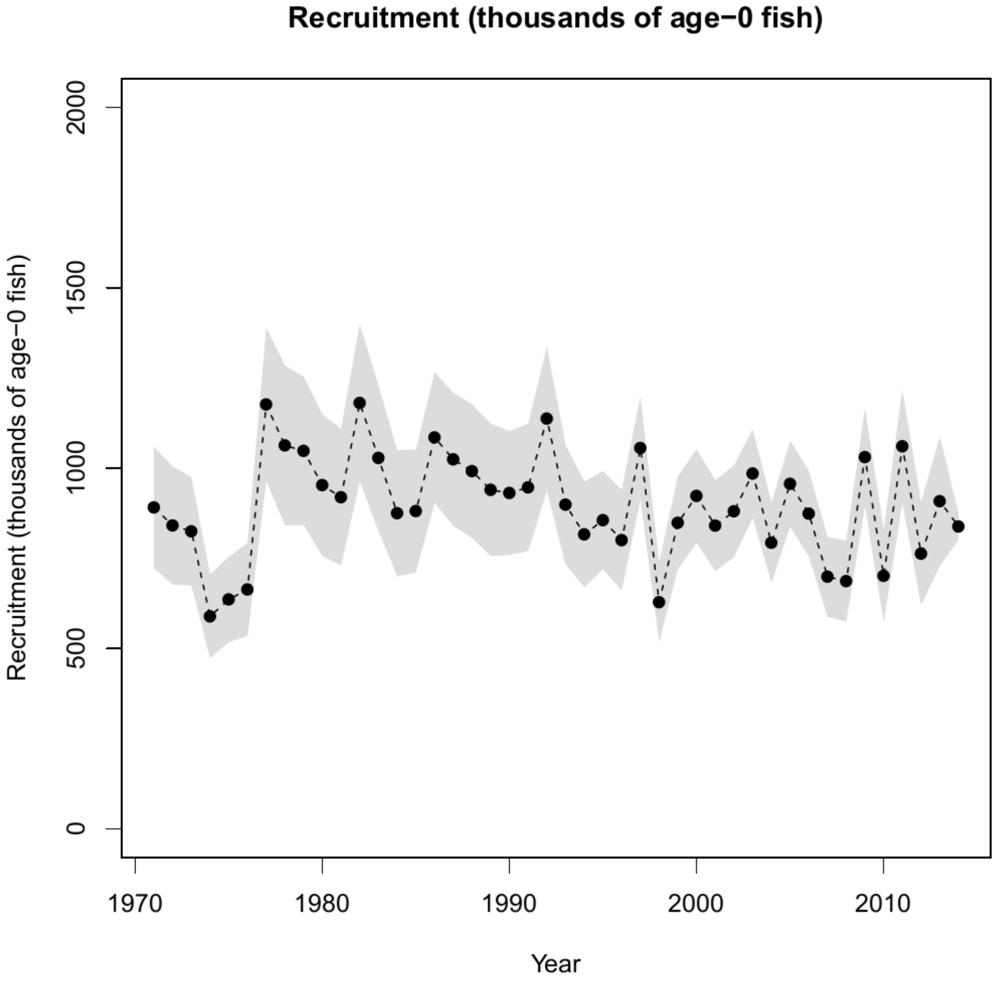

Figure 14.3. Time series of recruitment (thousands of age-0 fish) for the Pacific blue marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the shadowed area represents the uncertainty of the estimates (± 1 standard deviation).

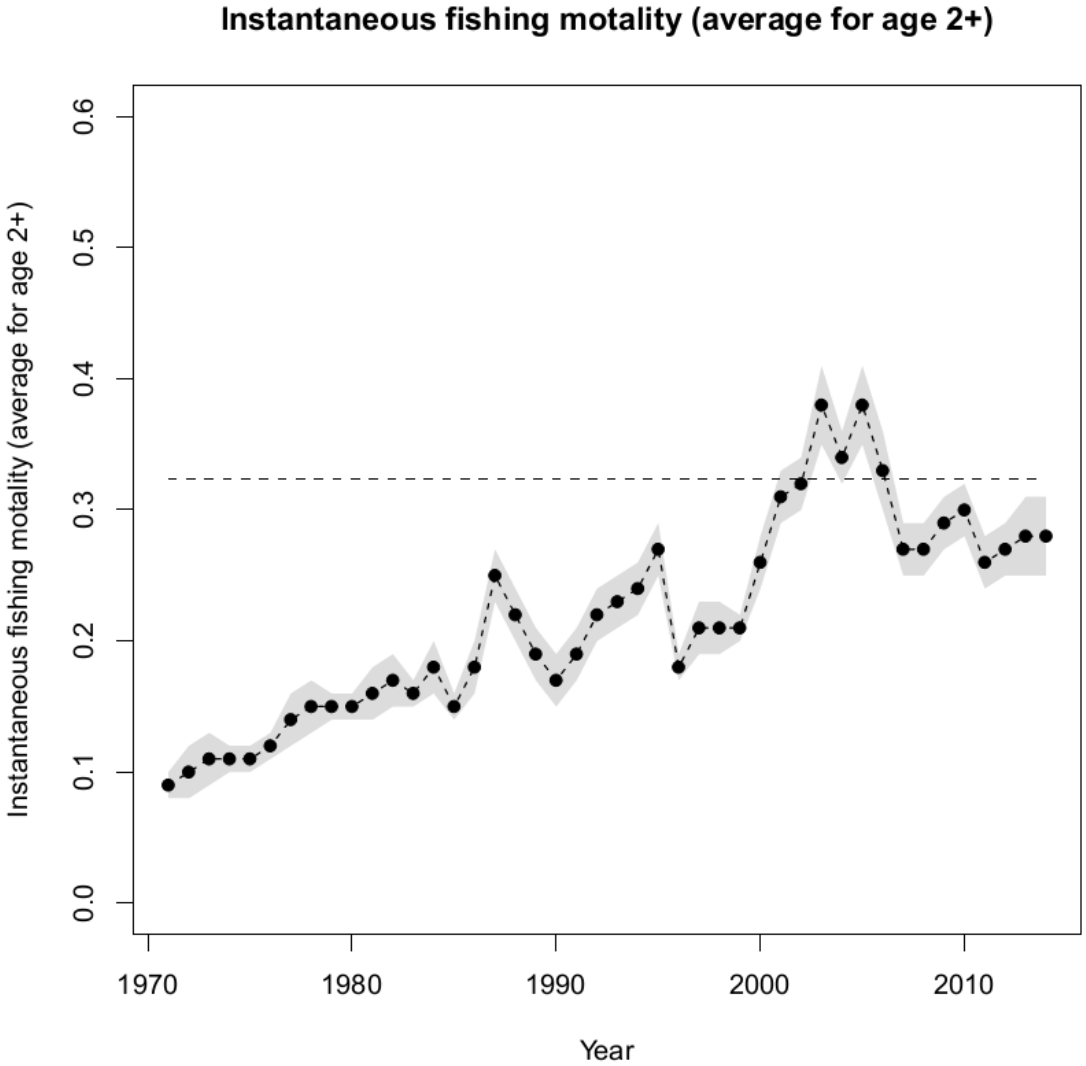

Figure 14.4. Time series of instantaneous fishing mortality (average for age 2+) for the Pacific blue marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the shadowed area represents the uncertainty of the estimates (± 1 standard deviations). The dashed horizontal line shows the fishing mortality to produce MSY reference point.

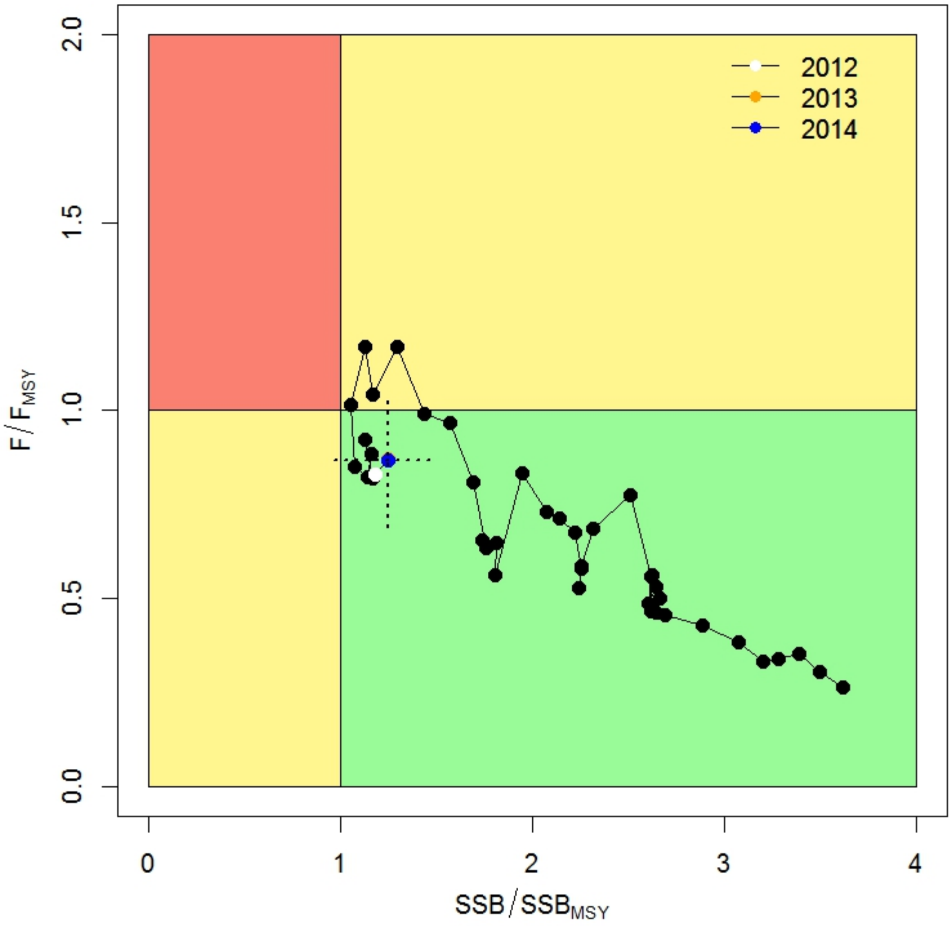

Figure 15. Kobe plot of the trends in estimates of relative fishing mortality (average of age 2+) and spawning stock biomass of Pacific blue marlin (*Makaira nigricans*) during 1971-2014. The dashed lines denote the 95% confidence intervals for the estimates in the year 2014.

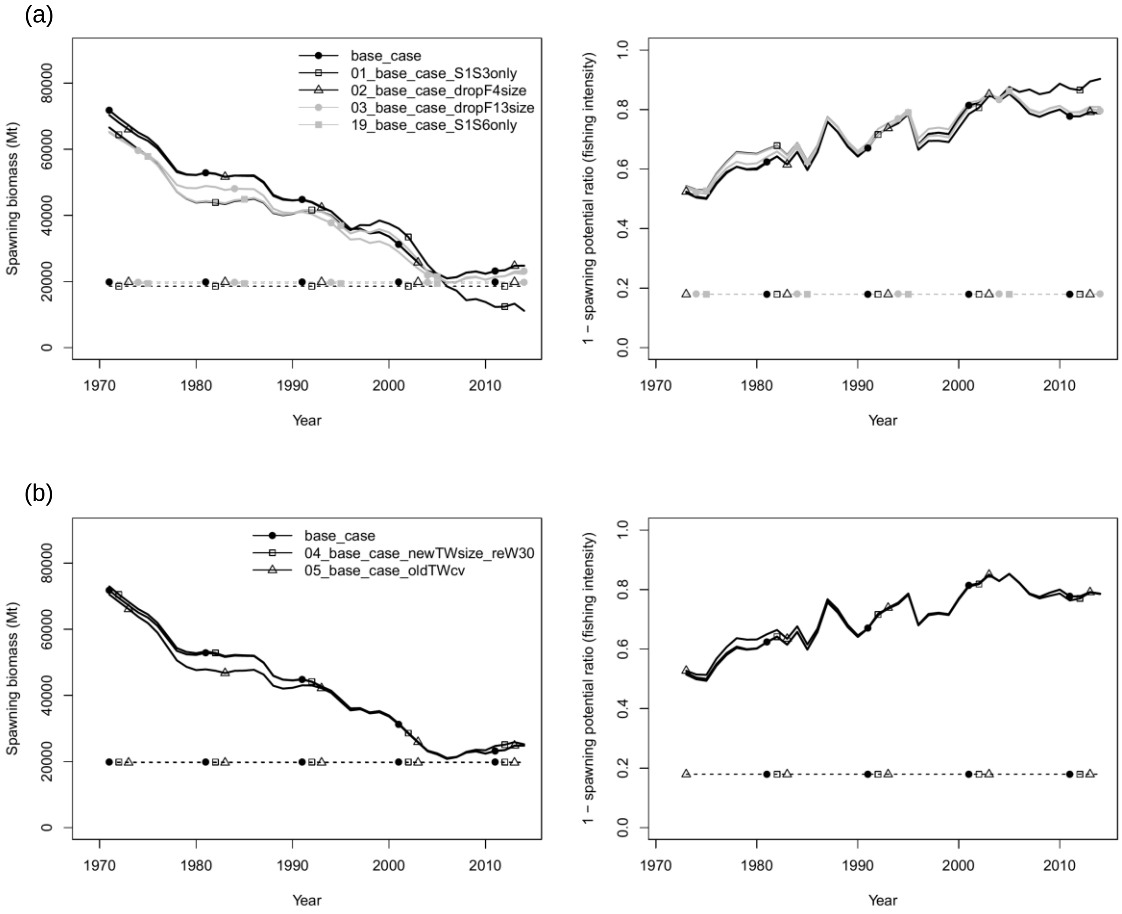

Figure 16.1. Trajectories of spawning stock biomass and an index of fishing intensity (1-spawning potential ratio) from 19 sensitivity analyses listed in Table 14, compared to the base case model. Dashed-lines and symbols denote MSY-based reference points and identify trajectory values. (a) Runs 1, 2, 3, and 19 use alternative input data; (b) Runs 4 and 5 use alternative input data for Taiwan; (c) Runs6, 7, and 8 use alternative input data size compositions data weighting; (d) Run runs 9 and 10 use alternative natural mortality rates; (e) Runs11, 12 and 13 use alternative stock-recruitment steepness; (f) Runs14,15, and 16 use alternative growth curves; (g) Runs 17 and 18 use alternative maturity ogives.

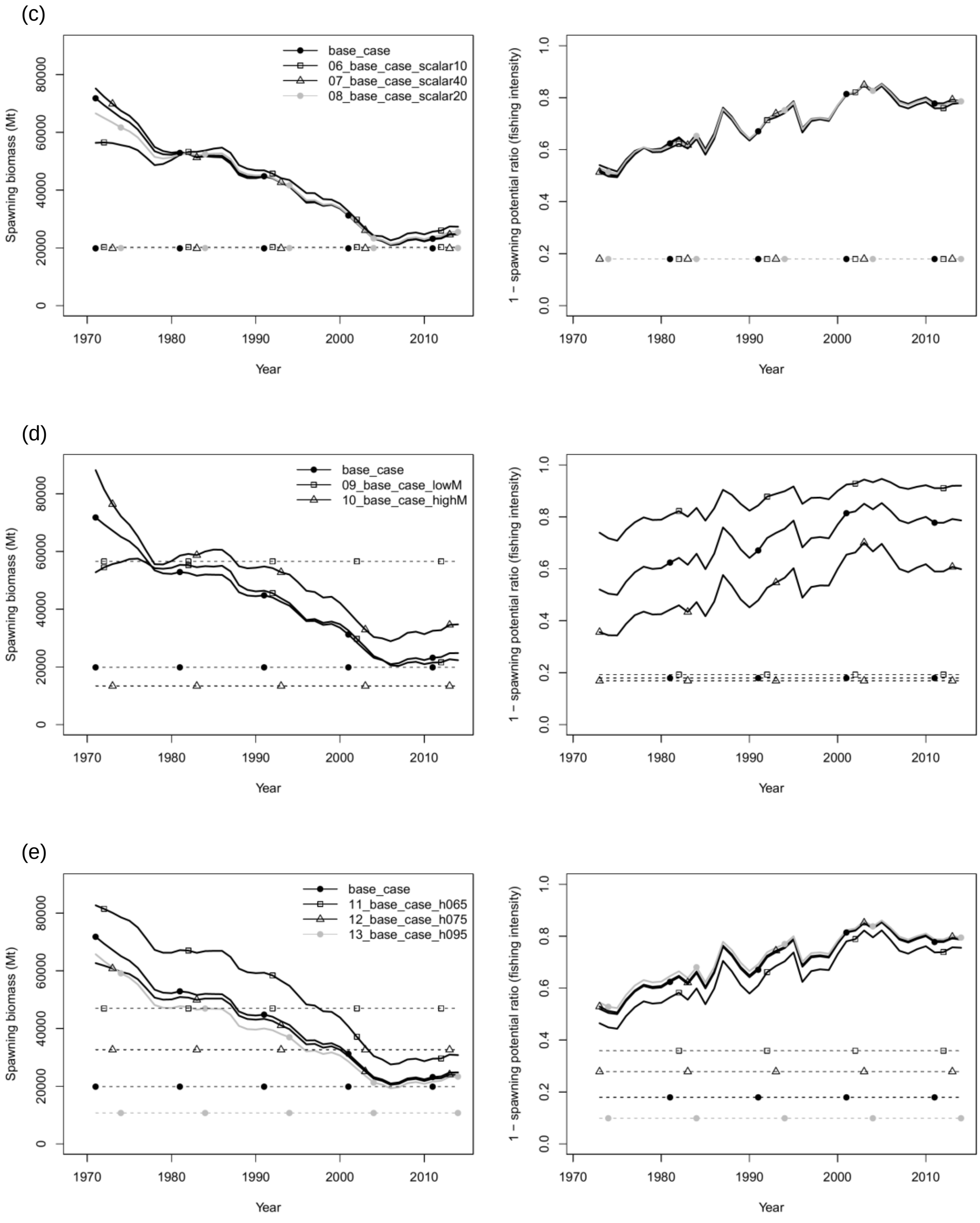

Figure 16.1 Continued.

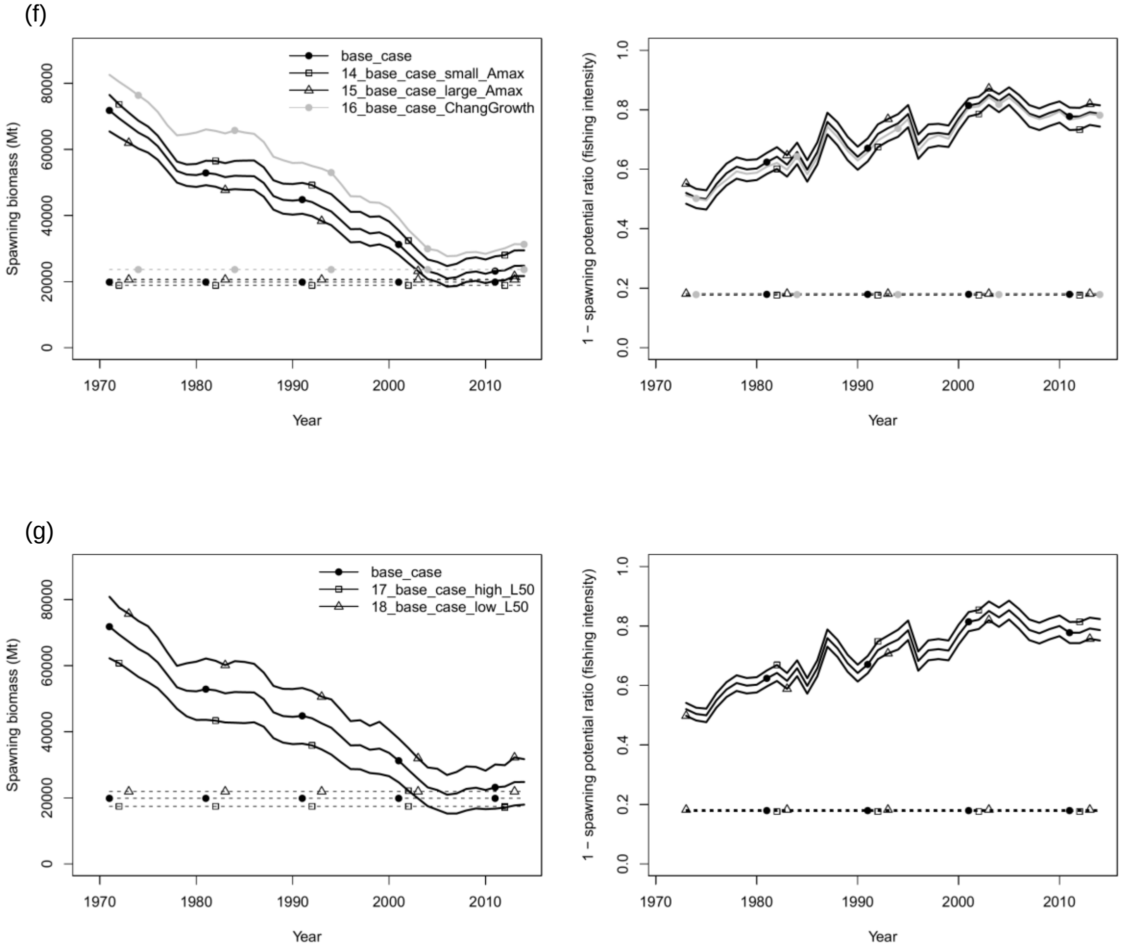

Figure `16.1. Continued.

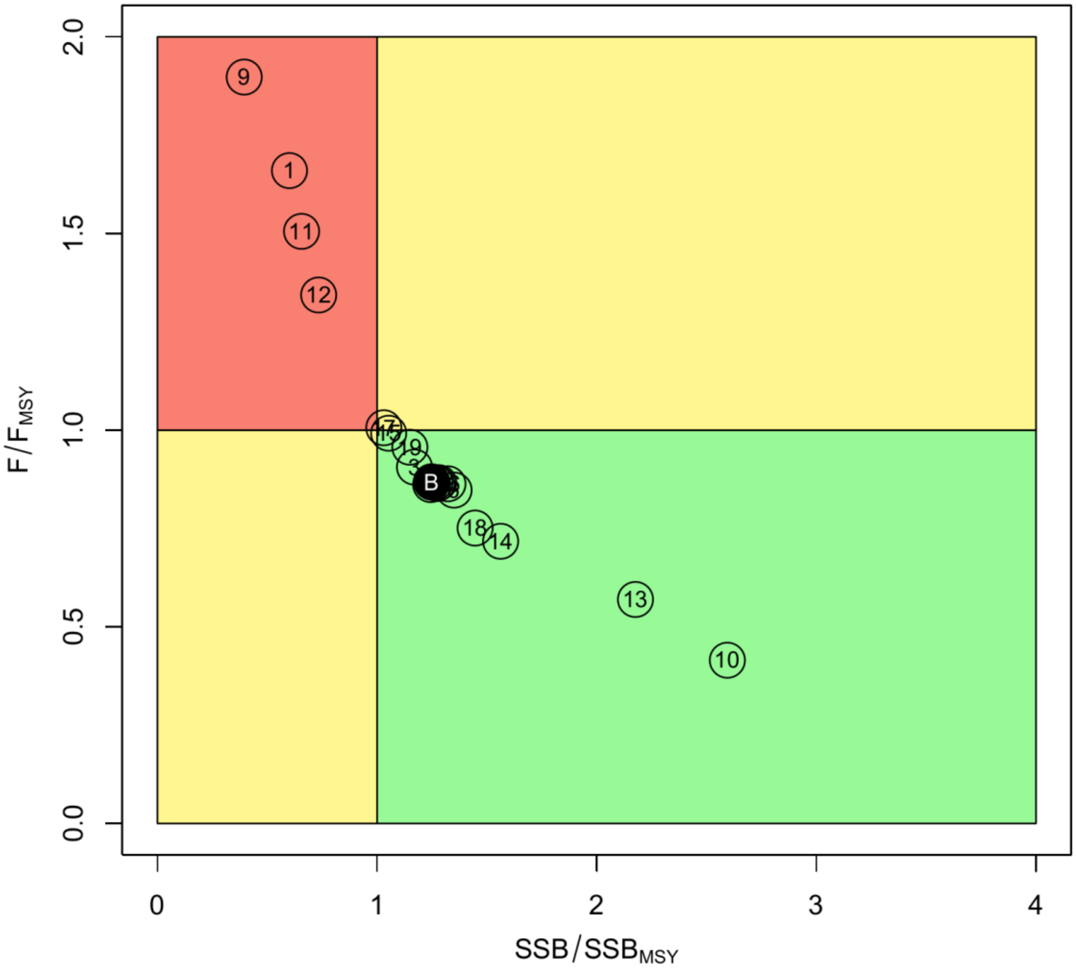

Figure 16.2. Kobe plot showing the terminal year stock status for the base case model (B) and the sensitivity analyses as indicated by the run numbers. For the list of sensitivity runs, please see Table 14.

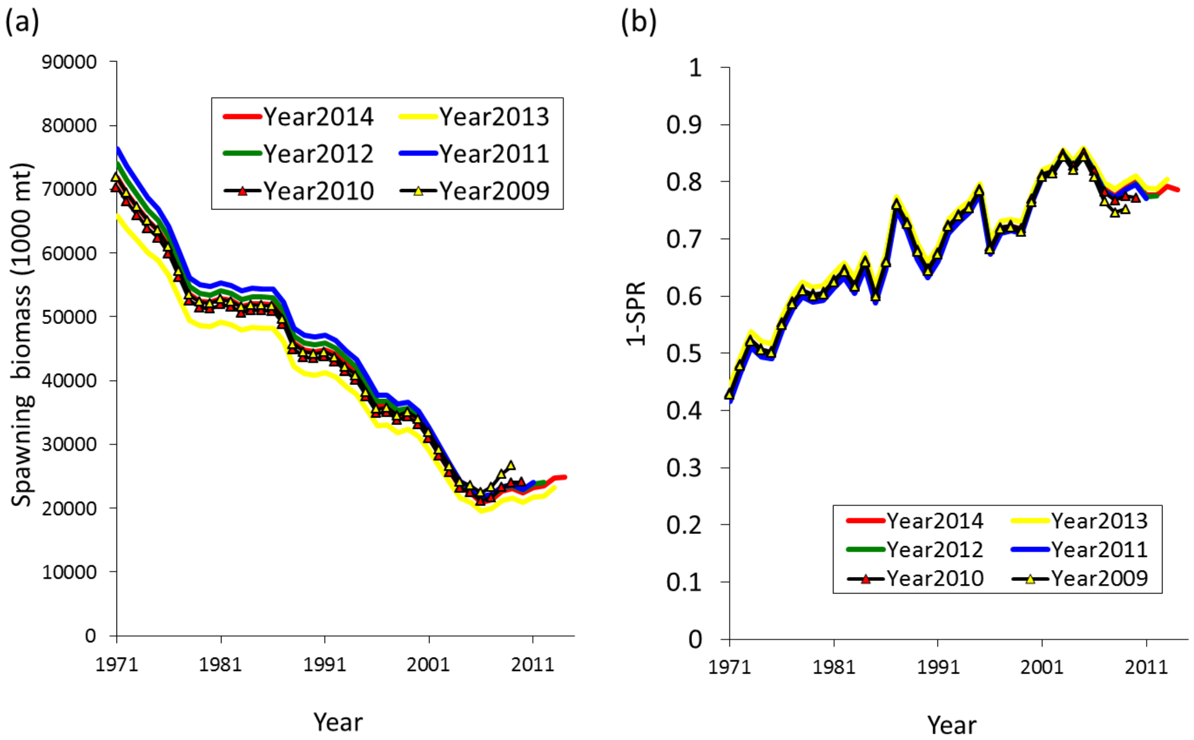

Figure 17. A 5-year retrospective analysis of (a) spawning biomass and (b) an index of fishing intensity for the base case model for Pacific blue marlin as conducted in the 2016 stock assessment update. The label “Year2014” indicates the base case model results. The label “YearYYYY” indicate the retrospective results from the retrospective peel that includes data through the year “YYYY”.

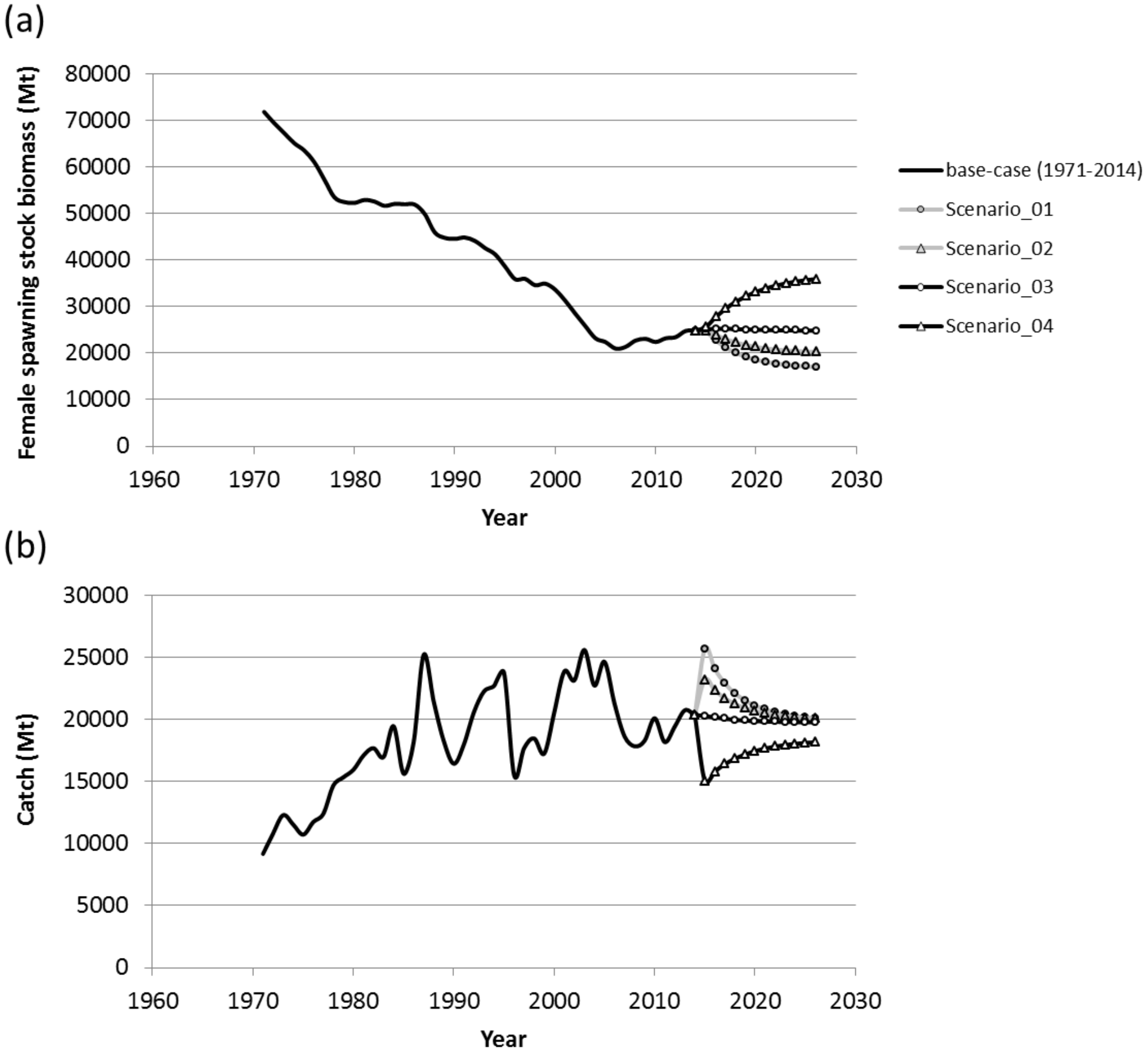

Figure 18. Historical and projected trajectories of (a) spawning biomass and (b) total catch from the Pacific blue marlin base case model. Stock projection results are shown for Scenario_01 = average fishing intensity during 2003-2005 ($F_{2003-2005}= F_{16\%}$); Scenario_02 = F_{MSY} ($F_{18\%}$); Scenario_03 = average fishing intensity during 2012-2014 ($F_{2012-2014}= F_{21\%}$); Scenario_04 = $F_{30\%}$.

Appendix I

Table A1. Correlation matrix of abundance indices. Lower diagonal values are correlation coefficient and upper diagonal values indicate number of overlapped years. Colors indicate levels of correlation (blue: high positive correlation, red: high negative correlation). See Table 3 for descriptions of each abundance index.

	S1	S2	S3	S4	S5	S6
S1 (1975-1993)	19	0	0	4	15	0
S2 (1994-2014)	NA	21	20	0	6	15
S3 (1995-2014)	NA	0.24	20	0	5	15
S4 (1971-1978)	0.38	NA	NA	8	0	0
S5 (1979-1999)	0.11	0.23	-0.14	NA	21	0
S6 (2000-2014)	NA	0.22	-0.24	NA	NA	15

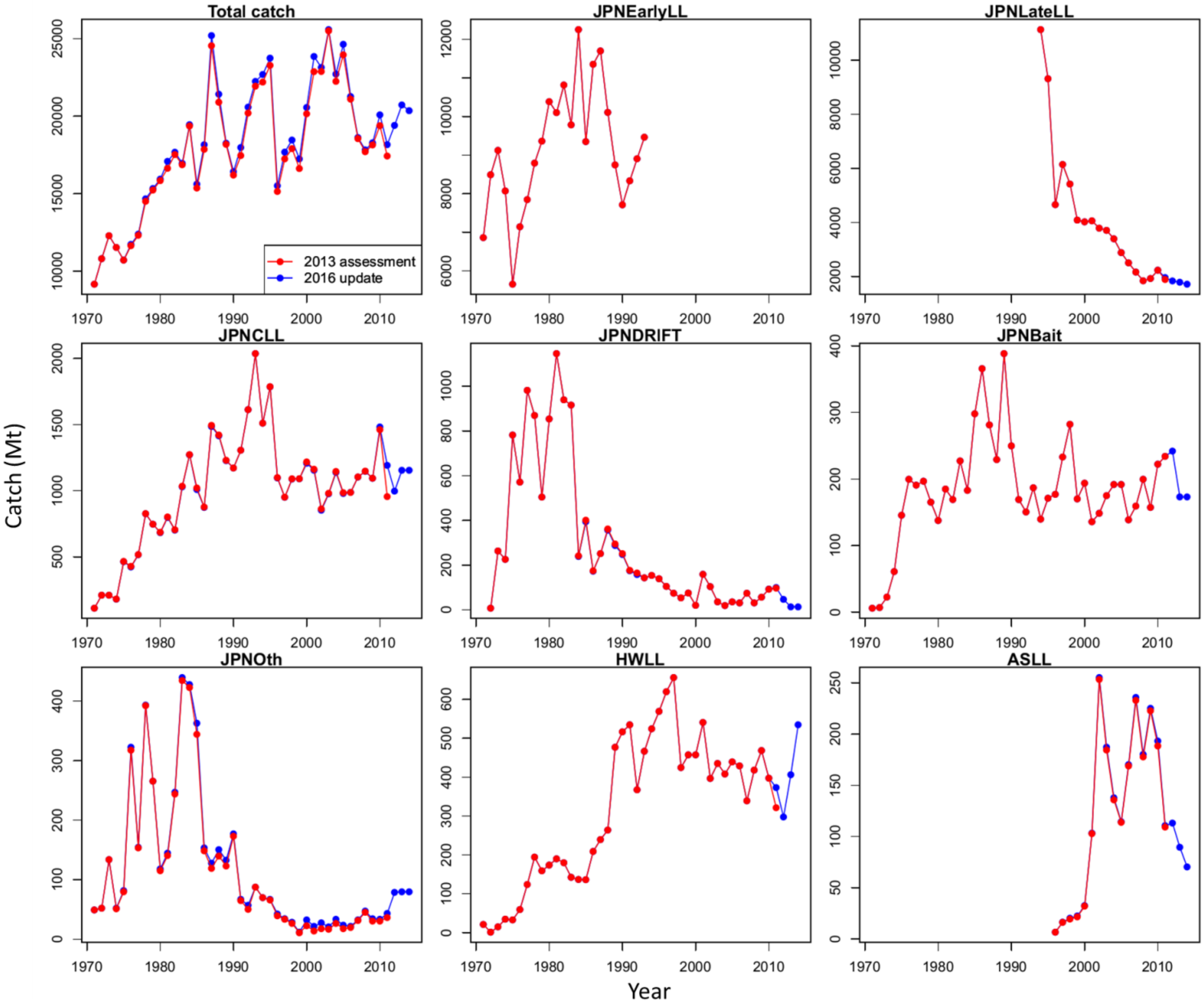

Figure A1. Comparison of time-series of catch of Pacific blue marlin used in the 2013 stock assessment (red line) and the 2016 update (blue line).

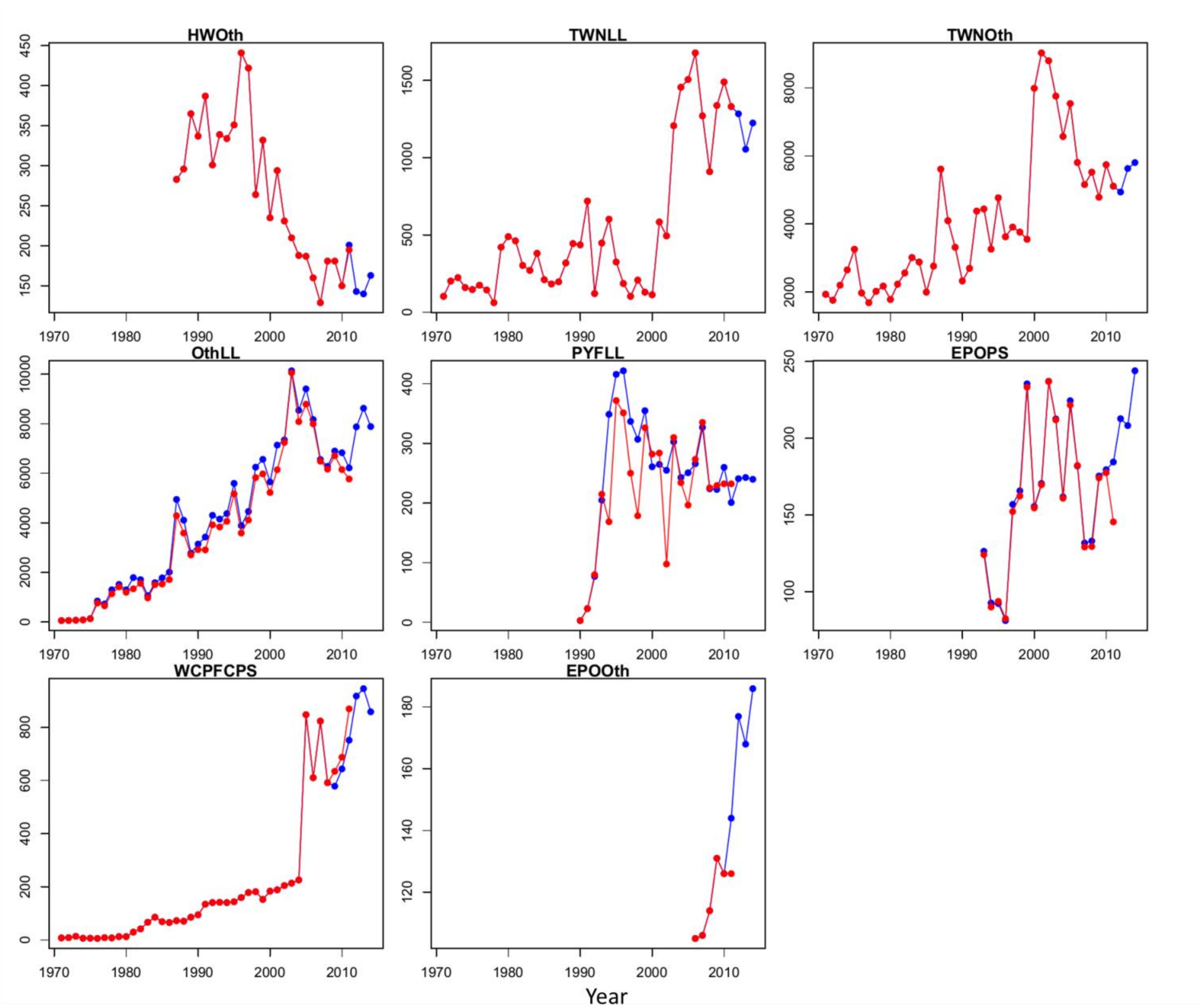

Figure A1. Continued.

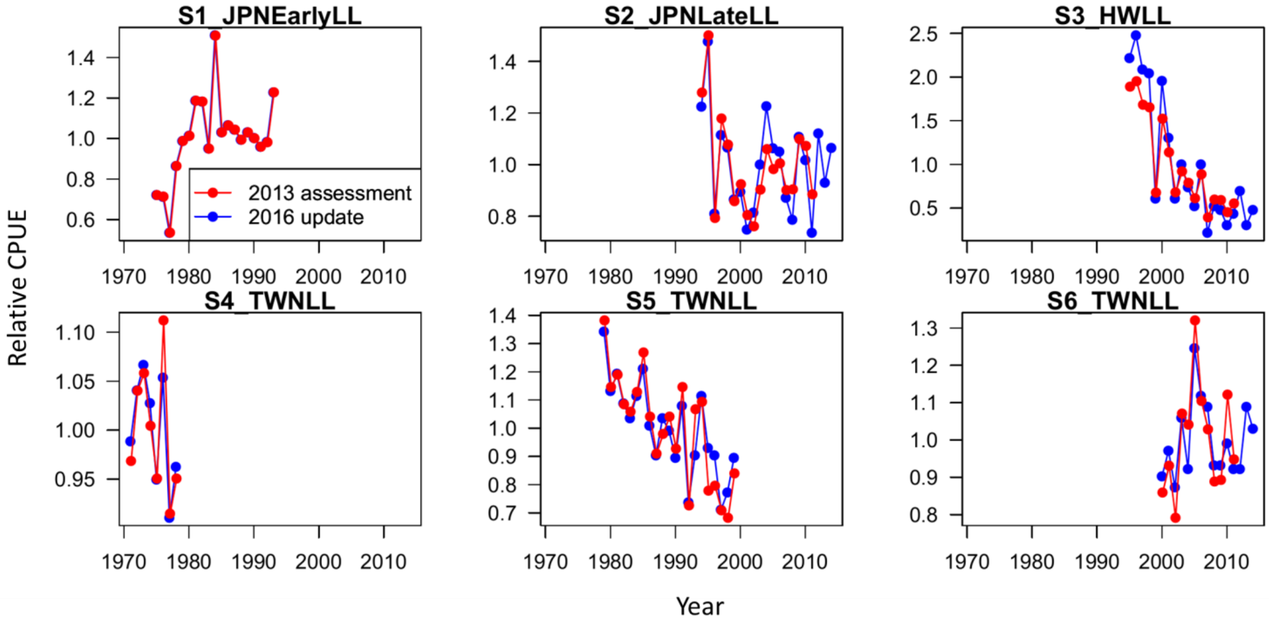

Figure A2. Comparison of relative abundance indices (in relative scale) of catch-per-unit-effort (CPUE) for Pacific blue marlin in the 2013 stock assessment (red line) and the 2016 update (blue line).

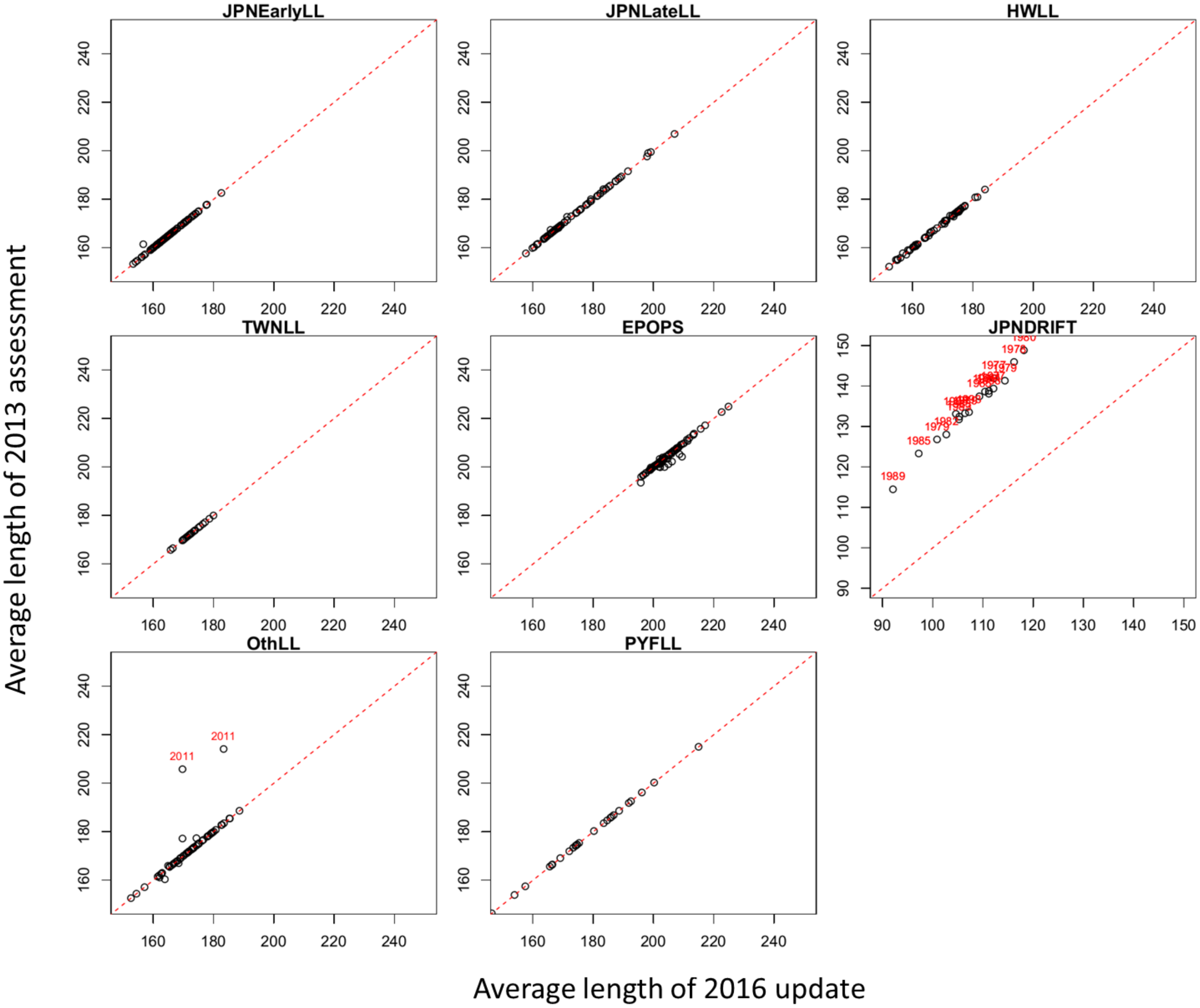

Figure A3. Comparison of average length of the input composition data for the Pacific blue marlin in the 2013 stock assessment and the 2016 update. All measurements were eye-to-fork lengths (EFL, cm) except JPNDRIFT (kg). The red labels denote the years with differences larger than 5%.

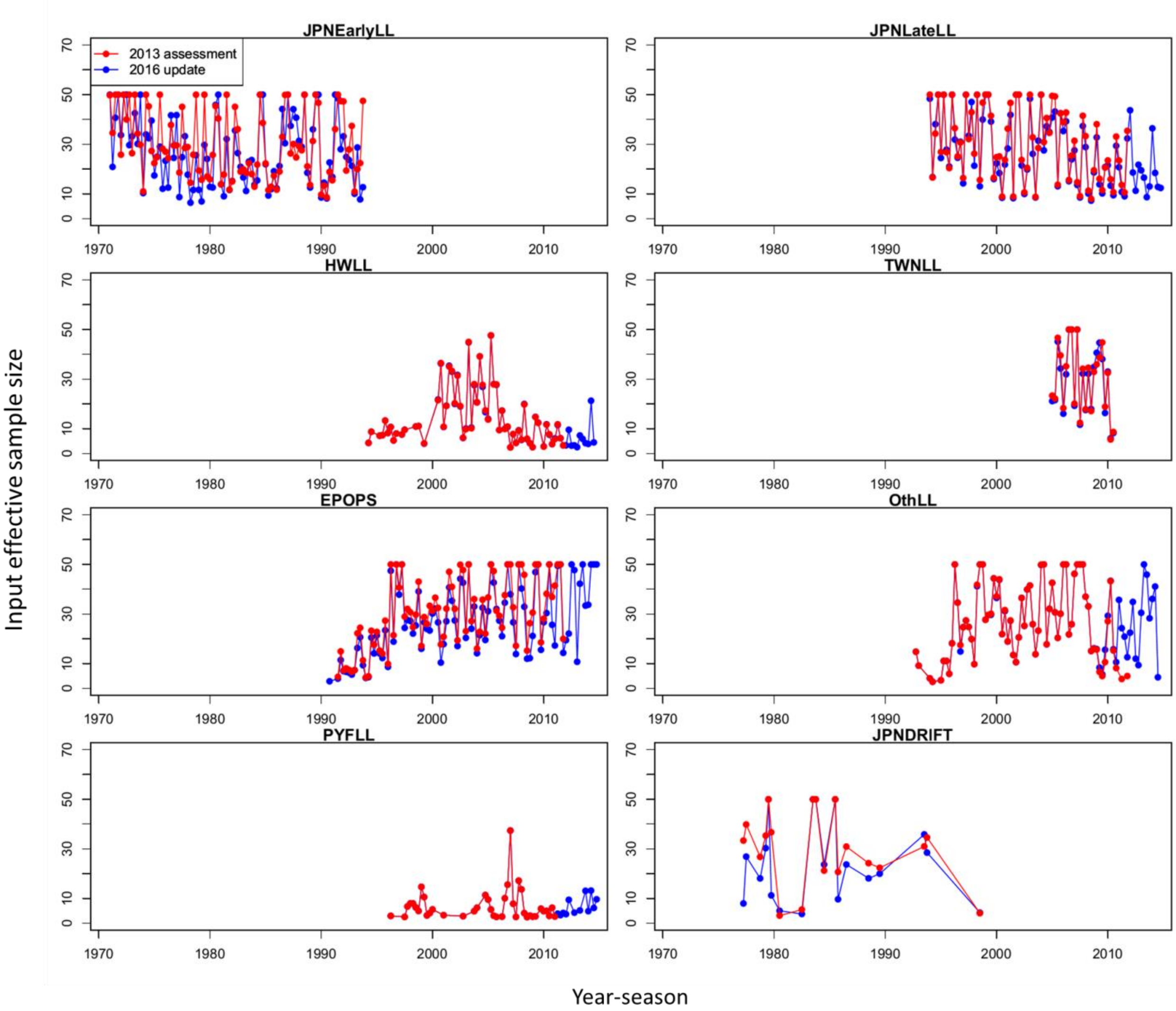

Figure A4. Comparison of the input effective sample size of the multinomial length composition for the Pacific blue marlin in the 2013 stock assessment (red line) and the 2016 update (blue line).