SCIENTIFIC COMMITTEE
FIFTEENTH REGULAR SESSION

Pohnpei, Federated States of Micronesia
12-20 August 2019

Stock Assessment Report for Striped Marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2017

WCPFC-SC15-2019/SA-WP-09

ISC[1]

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

FINAL

ISC/19/ANNEX/11

ANNEX 11

19th Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Taipei, Taiwan
July 11-15, 2019

STOCK ASSESSMENT REPORT FOR STRIPED MARLIN (KAJIKIA AUDAX) IN THE WESTERN AND CENTRAL NORTH PACIFIC OCEAN THROUGH 2017

July 2019

Left Blank for Printing

TABLE OF CONTENTS

ABSTRACT

We present the benchmark stock assessment for the Western and Central North Pacific Ocean striped marlin (*Kajikia audax*) stock conducted in 2019 by the ISC Billfish Working Group (BILLWG). The 2019 assessment consisted of applying a Stock Synthesis model with the best-available catch, abundance index, and length composition data for 1975-2017. The results indicated that biomass (age 1 and older) for the Western and Central North Pacific striped marlin stock decreased from 17,000 metric tons in 1975 to 6,000 metric tons in 2017. Estimated fishing mortality averaged F=0.97 during 1975-1994 with a range of 0.60 to 1.59, peaked at F=1.71 $year^{-1}$ in 2001, and declined sharply to F=0.64 $year^{-1}$ in the most recent years (2015-2017). Fishing mortality has fluctuated around F_{MSY} since 2013. Compared to MSY-based reference points, the current spawning biomass (average for 2015-2017) was 76% below SSB_{MSY} and the current fishing mortality (average for ages 3 – 12 in 2015-2017) was 7% above F_{MSY}. The base case model indicated that under current conditions the Western and Central North Pacific striped marlin stock was overfished and was subject to overfishing relative to MSY-based reference points.

EXECUTIVE SUMMARY: WESTERN AND CENTRAL NORTH PACIFIC OCEAN STRIPED MARLIN STOCK ASSESSMENT

Stock Identification and Distribution

The Western and Central North Pacific Ocean (WCNPO) striped marlin (*Kajikia audax*) stock area consisted of waters of the North Pacific Ocean contained in the Western and Central Pacific Fisheries Commission management area bounded by the equator and 150°W. 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

North Pacific striped marlin catches were high from the 1970's to the 1990's, and has decreased to the present. The catch by Japanese fleets has decreased and catch from the US and Chinese Taipei has varied without trend, while the catch by other Western and Central Pacific Fisheries Commission (WCPFC) countries has increased (Figure S1). Overall, longline gear has accounted for the vast majority of Western and Central North Pacific striped marlin catches since the 1990's and the driftnet catch dominated from 1975 to 1993.

Data and Assessment

Catch and size composition data were collected from ISC countries (Japan, Chinese Taipei, and USA) and the WCPFC. Standardized catch-per-unit effort data used to measure trends in relative abundance were provided by Japan, USA, and Chinese Taipei. The Western and Central North Pacific striped marlin stock was assessed using an age- and length-structured assessment Stock Synthesis model fit to time series of standardized CPUE and size composition data. 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 natural mortality rate, the stock-recruitment steepness, the growth curve parameters, and the female age at 50% maturity, as well as uncertainty in the input data and model structure.

Status of Stock

Estimates of population biomass of the WCNPO striped marlin stock (*Kajikia audax*) fluctuated without trend between 1975 and 1993. The population deceased substantially in 1994 and fluctuated without trend until the present year. Population biomass (age-1 and older) averaged roughly 17,969 t, or 54% below unfished biomass during 1975-1993 and declined to 4,508 t, or 89% below unfished biomass in 2008. The minimum spawning stock biomass is estimated to be 618 t in 2011 (76% below SSB_{MSY}, the spawning stock biomass to produce MSY, Figure S2a). In 2017, SSB = 981 mt and $SSB/SSB_{MSY} = 0.38$. Fishing mortality on the stock (average F on ages 3-12) is currently around F_{MSY} (Figure S2b). It averaged roughly $F = 0.64$ during 2015-2017, or 7% above F_{MSY} and in 2017, F=0.80 with a relative fishing mortality of $F/F_{MSY} = 1.33$. Fishing mortality has been above F_{MSY} in every year except 1984, 1992, and 2016. The predicted value of the spawning potential ratio (SPR, the predicted spawning output at current F as a fraction of unfished spawning output) is currently $SPR_{2015-2017}$ = 17% and is approximately equal to the SPR required to produce MSY. Recruitment averaged about 263,000 age-0 recruits during 1994-2016, which was 34% below the 1975-2016 average. No target or limit reference points have been established for the WCNPO striped marlin stock under the auspices of the WCPFC. Despite the relative large L_{50}/L_{inf} ratio for WCNPO striped marlin, the stock is expected to be highly productive due to its rapid growth and high resilience to reductions in spawning potential. Recent recruitments have been lower than expected and have been below the long-term trend since 2005. Although fishing mortality has decreased since 2000, due to the prolonged low recruitment and landings of juvenile fish, the biomass of the stock has remained below MSY. When the status of striped marlin is evaluated relative to MSY-based reference points, the 2017 spawning stock biomass of 981 mt is 62% below SSB_{MSY} (2,604 t) and the 2015-2017 fishing mortality exceeds F_{MSY} by 7%. Therefore, relative to MSY-based reference points, overfishing is occurring and the WCNPO striped marlin stock is overfished (Figure S3).

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-3 – 12), relative fishing mortality (F/F_{MSY}), and spawning potential ratio of Western and Central North Pacific striped marlin.

Year	2011	2012	2013	2014	2015	2016	2017	Mean[1]	Min[1]	Max[1]
Reported Catch	2,690	2,757	2,534	1,879	2,072	1,892	2,487	5,643	1,879	10,862
Population Biomass	5,874	6,057	4,937	6,241	5,745	5,832	6,196	12,153	4,509	22,303
Spawning Biomass	618	809	743	864	1,073	1,185	981	1,765	618	3,999
Relative Spawning Biomass	0.24	0.31	0.29	0.33	0.41	0.46	0.38	0.68	0.24	1.54
Recruitment (age 0)	196,590	87,956	330,550	77,274	185,438	195,069	354,391	396,218	77,274	1,049,460
Fishing Mortality	1.11	1.06	0.86	0.63	0.62	0.51	0.80	1.06	0.51	1.71
Relative Fishing Mortality	1.85	1.76	1.42	1.05	1.03	0.85	1.33	1.76	0.85	2.85
Spawning Potential Ratio	9%	11%	11%	16%	17%	20%	14%	12%	20%	6%

[1] During 1975-2017

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 = 4,947 mt. The point estimate of the spawning biomass to produce MSY (adult female biomass) was SSB_{MSY} = 2,604 mt. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY (average fishing mortality on ages 3 – 12) was F_{MSY} = 0.60 and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

Projections

Stock projections for WCNPO striped marlin were conducted using the age-structured projection model software AGEPRO. Stochastic projections were conducted using results from the base case model to evaluate the probable impacts of alternative fishing intensities or constant catch quotas on future spawning stock biomass and yield for striped marlin in the Western and Central North Pacific Ocean. For fishing mortality projections, a standard set of F-based projections were conducted. For catch quota projections, the set of rebuilding projection analyses requested by the 14th Regular Session of the WCPFC Northern Committee were conducted. Two future recruitment scenarios were evaluated: (1) a short-term recruitment scenario based on resampling the empirical cumulative distribution function of recruitment observed during 2012-2016 and (2) a long-term recruitment scenario based on resampling the empirical cumulative distribution function of recruitment observed during 1975-2016. The short-term recruitment scenario had an average recruitment of 134,020 age-1 fish and the long-term recruitment mean was 306,989 age-1 fish. The stochastic projections employed model estimates of the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Fishing mortality-based projections started in 2018 and continued through 2037 under 5 levels of fishing mortality and the two recruitment scenarios. The five fishing mortality stock projection scenarios were: (1) F status quo (average F during 2015-2017), (2) F_{MSY}, (3) F at $0.2 \cdot SSB_{(F=0)}$, (4) F_{High} at the highest 3-year average during 1975-2017, and (5) F_{Low} at $F_{0.30\%}$. For the F-based scenarios, fishing mortality in 2018-2019 was set to be F status quo (0.64) and fishing mortality during 2020-2037 was set to the projected level of F. Catch-based projections also ran from 2018 to 2037 and included 7 levels of constant catch for the long-term recruitment scenario and 10 levels of catch for the short-term recruitment scenario. For the catch-based scenarios, catch biomass in 2018-2019 was set to be the status quo catch during 2015-2017 (2150.6 mt) and annual catches during 2020-2037 were set to the projected catch quota. The ten constant catch stock projection scenarios were: (1) Quota based upon CMM10-01, (2) 90% of the quota, (3) 80% of the quota, (4) 70% of the quota, (5) 60% of the quota, (6) 50% of the quota, (7) 40% of the quota, (8) 30% of the quota, (9) 20% of the quota, and (10) 10% of the quota. Results show the projected female spawning stock biomasses and the catch biomasses under each of the scenarios (Table S3 and Figure S4).

Conservation Advice

The WCNPO striped marlin stock has produced annual yields of around 2,173 mt per year since 2012, or about 40% of the MSY catch amount. Striped marlin stock status shows evidence of substantial depletion of spawning potential ($SSB_{Current}$ is 62% below SSB_{MSY}), however fishing mortality has fluctuated around F_{MSY} in the last 4 years. It was also noted that retrospective analyses show that the assessment model appears to underestimate spawning potential in recent years.

Special Comments

WG achieved a base-case model using best available data and biological information. However, the WG recognized has uncertainty in input catch data including drift gillnet and initial catch amounts, life history parameters including maturation and growth, and stock structure. The WG considered an extensive suite of model formulations and associated diagnostics for developing the base-case assessment model. Overall, we found issues with the base case model diagnostics and sensitivity runs that indicated some data conflicts exist (see Assessment Challenges and Sensitivity Analyses). To improve the stock assessment, the WG also recommends continuing model development work to reduce data conflicts and modeling uncertainties, and reevaluating and improving input assessment data. When developing a CMM to rebuild the resource, the WG recommends that these issues be recognized and carefully considered.

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 Western and Central North Pacific striped marlin, derived from the base case model assessment model, where "MSY" indicates reference points based on maximum sustainable yield.

Reference Point	Estimate
F_{MSY} (age 3-12)	0.60
F_{2017} (age 3-12)	0.80
$F_{20\%SSB(F=0)}$	0.47
SSB_{MSY}	2,604 mt
SSB_{2017}	981 mt
$SSB_{20\%(F=0)}$	3,610 mt
MSY	4,946 mt
$C_{2015-2017}$	2,151 mt
SPR_{MSY}	18%
SPR_{2017}	14%
$SPR_{20\%SSB(F=0)}$	23%

Table S3. Projected median values of Western and Central North Pacific striped marlin spawning stock biomass (SSB, mt), catch (mt), and probability of reaching 20%$SSB_{F=0}$ under five constant fishing mortality rate (F) and ten constant catch scenarios during 2018-2037. For scenarios which have a 60% probability of reaching the target of 20%$SSB_{F=0}$, the year in which this occurs is provided; NA indicates projections that did not meet this criterion. Note that 20%$SSB_{F=0}$ is 3610 mt and SSB_{MSY} is 2604 mt.

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2027**	**2037**	**Year when target achieved with 60% probability**
Scenario 1: $F_{status\ quo}$; Long-Term Recruitment								
SSB	1931.3	2605.3	3591	4288.3	4639.4	4893.4	4884.4	
Catch	2229.8	3089.8	3911.6	4412.8	4644.9	4797.2	4790.9	
Probability of reaching 20% SSB	0%	4%	44%	70%	79%	84%	84%	2021
Scenario 2: $F_{status\ quo}$; Short-Term Recruitment								
SSB	1932.4	2556.5	3080	2786.9	2422.3	2071.4	2072.1	
Catch	2224.6	2827	2871.7	2535.9	2260.7	2029.6	2030.4	
Probability of reaching 20% SSB	0%	4%	21%	9%	2%	<0.5%	<0.5%	NA
Scenario 3: FMSY; Long-Term Recruitment								
SSB	1935.1	2611.8	3650.5	4444	4860.6	5158.9	5203.5	
Catch	2228.1	3092.7	3705.2	4241.6	4498.9	4666.4	4711.5	
Probability of reaching 20% SSB	0%	4%	47%	75%	83%	89%	89%	2021
Scenario 4: FMSY; Short-Term Recruitment								
SSB	1932.9	2557.7	3126.3	2895.5	2552.2	2207	2197	
Catch	2230.8	2829.6	2724.6	2450.7	2209.9	1994.1	1984.9	
Probability of reaching 20% SSB	0%	4%	23%	12%	4%	<0.5%	<0.5%	NA
Scenario 5: F 20%$SSB_{F=0}$; Long-Term Recruitment								
SSB	1933.7	2611.9	3813.4	4943.7	5631	6358.1	6348.5	
Catch	2227.6	3091.3	2996.4	3588.7	3933.2	4271.7	4266.7	
Probability of reaching 20% SSB	0%	4%	55%	85%	93%	97%	98%	2021
Scenario 6: F 20%$SSB_{F=0}$; Short-Term Recruitment								
SSB	1934	2560.5	3276.3	3274.8	3030.2	2697	2690.2	
Catch	2224.9	2828.8	2211.6	2115.4	1969.7	1809.1	1804.7	
Probability of reaching 20% SSB	0%	4%	29%	28%	17%	6%	7%	NA
Scenario 7: Highest F (Average F 1975-1977); Long-Term Recruitment								
SSB	1932.8	2611.8	2739.8	2299.1	2102	2028.4	2036.2	
Catch	2226.4	3088.5	7520.7	6557.5	6184.4	6058	6084.1	
Probability of reaching 20% SSB	0%	4%	9%	4%	2%	1%	1%	NA
Scenario 8: Highest F (Average F 1975-1977); Short-Term Recruitment								
SSB	1933.5	2559.4	2289.2	1330.7	968.3	858.7	859.2	
Catch	2225.9	2827.6	5362.9	3399.3	2751.6	2564.6	2570.9	

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2027**	**2037**	**Year when target achieved with 60% probability**
Probability of reaching 20% SSB	0%	3%	2%	<0.5%	0%	0%	0%	NA
<u>Scenario 9: Low F ($F_{30\%}$); Long-Term Recruitment</u>								
SSB	1933.6	2612.5	4009.5	5603.2	6742.4	8287.5	8353	
Catch	2228.6	3093.5	2117.6	2693.6	3075	3558.2	3577.8	
Probability of reaching 20% SSB	0%	4%	63%	93%	98%	>99.5%	>99.5%	2020
<u>Scenario 10: Low F ($F_{30\%}$); Short-Term Recruitment</u>								
SSB	1932.5	2555.6	3453.8	3788.4	3747.4	3537.4	3525.3	
Catch	2228.4	2832	1572.9	1623.8	1589	1515.8	1511.6	
Probability of reaching 20% SSB	0%	4%	37%	54%	54%	44%	42%	NA
<u>Scenario 11: Quota; Long-Term Recruitment</u>								
SSB	1946.7	2823	4141.1	5220.9	6074.7	8147.5	8715.3	
Catch	2150.6	2150.6	3396.8	3396.7	3396.3	3396.1	3396.8	
Probability of reaching 20% SSB	<0.5%	17%	61%	76%	83%	93%	95%	2020
<u>Scenario 12: Quota; Short-Term Recruitment</u>								
SSB	1948.8	2737.1	3279.8	2592.9	1781.9	524.2	436.7	
Catch	2150.6	2150.6	3393.7	3377.1	3319.7	2954.7	2903	
Probability of reaching 20% SSB	<0.5%	15%	36%	20%	7%	<0.5%	<0.5%	NA
<u>Scenario 13: 10% Reduction; Long-Term Recruitment</u>								
SSB	1947.9	2826.1	4225.3	5467.3	6492.5	9096.5	9798.7	
Catch	2150.6	2150.6	3057.1	3057.1	3056.8	3057.1	3057.1	
Probability of reaching 20% SSB	<0.5%	17%	63%	81%	87%	96%	97%	2020
<u>Scenario 14: 10% Reduction; Short-Term Recruitment</u>								
SSB	1948.6	2738	3390.9	2886.8	2162.9	763	587	
Catch	2150.6	2150.6	3054.6	3052.8	3032.5	2846.7	2780.1	
Probability of reaching 20% SSB	<0.5%	15%	40%	26%	12%	<0.5%	<0.5%	NA
<u>Scenario 15: 20% Reduction; Long-Term Recruitment</u>								
SSB	1949.9	2829.1	4317.7	5750.4	6954.1	9928.4	10806.2	
Catch	2150.6	2150.6	2717.4	2717.4	2717.4	2717.4	2717.4	
Probability of reaching 20% SSB	<0.5%	18%	65%	84%	90%	98%	99%	2020
<u>Scenario 16: 20% Reduction; Short-Term Recruitment</u>								
SSB	1949.3	2739.2	3495.1	3176.4	2570.8	1175.5	883.3	
Catch	2150.6	2150.6	2716.8	2714.3	2710.8	2648.8	2610.7	
Probability of reaching 20% SSB	<0.5%	15%	43%	34%	19%	1%	<0.5%	NA
<u>Scenario 17: 30% Reduction; Long-Term Recruitment</u>								
SSB	1947.6	2824.5	4381.5	5981.7	7356.2	10856.1	11783.5	
Catch	2150.6	2150.6	2377.8	2377.8	2377.8	2377.8	2377.8	

Year	2018	2019	2020	2021	2022	2027	2037	Year when target achieved with 60% probability
Probability of reaching 20% SSB	<0.5%	17%	67%	87%	94%	99%	>99.5%	2020
Scenario 18: 30% Reduction; Short-Term Recruitment								
SSB	1947.4	2733.8	3594	3479.2	3018.1	1736.6	1383.5	
Catch	2150.6	2150.6	2377.8	2377.1	2377.1	2365.6	2355.3	
Probability of reaching 20% SSB	<0.5%	15%	45%	42%	29%	5%	2%	NA
Scenario 19: 40% Reduction; Long-Term Recruitment								
SSB	1949.2	2831.8	4486.8	6295.8	7868.9	11749.2	12851.3	
Catch	2150.6	2150.6	2038.1	2038.1	2038.1	2038.1	2038.1	
Probability of reaching 20% SSB	<0.5%	18%	70%	90%	95%	>99.5%	>99.5%	2020
Scenario 20: 40% Reduction; Short-Term Recruitment								
SSB	1949.9	2737.3	3689.5	3756	3445.9	2444.2	2124.2	
Catch	2150.6	2150.6	2038.1	2038.1	2037.9	2037.6	2036.4	
Probability of reaching 20% SSB	<0.5%	15%	48%	49%	41%	16%	10%	NA
Scenario 21: 50% Reduction; Long-Term Recruitment								
SSB	1950.4	2829.7	4548.9	6512.1	8259.1	12654	13799.3	
Catch	2150.6	2150.6	1698.4	1698.4	1698.4	1698.4	1698.4	
Probability of reaching 20% SSB	<0.5%	17%	71%	92%	97%	>99.5%	>99.5%	2020
Scenario 22: 50% Reduction; Short-Term Recruitment								
SSB	1949.1	2737.4	3791.4	4065.7	3916.3	3214.4	3021.3	
Catch	2150.6	2150.6	1698.4	1698.4	1698.4	1698.4	1698.4	
Probability of reaching 20% SSB	<0.5%	15%	51%	57%	53%	35%	29%	NA
Scenario 23: 60% Reduction; Long-Term Recruitment								
SSB	1949.9	2829.1	4631.3	6798.1	8741.1	13605.2	14857.1	
Catch	2150.6	2150.6	1358.7	1358.7	1358.7	1358.7	1358.7	
Probability of reaching 20% SSB	<0.5%	18%	73%	94%	98%	>99.5%	>99.5%	2020
Scenario 24: 60% Reduction; Short-Term Recruitment								
SSB	1948.6	2737.7	3888.1	4364.3	4396.6	4110.1	3970.5	
Catch	2150.6	2150.6	1358.7	1358.7	1358.7	1358.7	1358.7	
Probability of reaching 20% SSB	<0.5%	15%	53%	65%	67%	63%	59%	2021*
Scenario 25: 70% Reduction; Short-Term Recruitment								
SSB	1948.7	2736.4	3979.8	4667.7	4886	4960.9	4977	
Catch	2150.6	2150.6	1019	1019	1019	1019	1019	
Probability of reaching 20% SSB	<0.5%	15%	56%	72%	78%	85%	86%	2021
Scenario 26: 80% Reduction; Short-Term Recruitment								
SSB	1948.7	2736.2	4071.1	4971.3	5380.3	5909.1	5977.5	
Catch	2150.6	2150.6	679.4	679.4	679.4	679.4	679.4	

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2027**	**2037**	**Year when target achieved with 60% probability**
Probability of reaching 20% SSB	<0.5%	15%	58%	79%	88%	97%	97%	2021
<u>Scenario 27: 90% Reduction; Short-Term Recruitment</u>								
SSB	1950.6	2740.5	4170.3	5284.1	5881.7	6836.7	7009.4	
Catch	2150.6	2150.6	339.7	339.7	339.7	339.7	339.7	
Probability of reaching 20% SSB	<0.5%	15%	61%	85%	94%	>99.5%	>99.5%	2020

* This scenario has a 60% probability of being at or above 20%$SSB_{F=0}$ in 2020 but drops slightly below 60% starting in 2035.

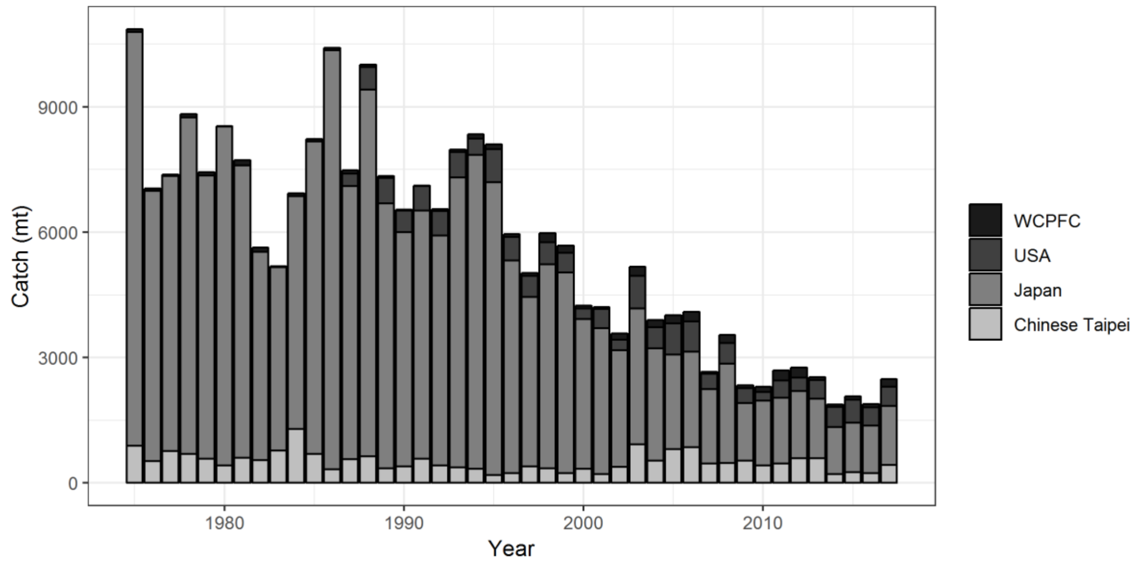


Figure S1. Annual catch biomass (mt) of Western and Central North Pacific striped marlin (*Kajikia audax*) by country for Japan, Chinese Taipei, the U.S.A., and all other countries during 1975-2017.

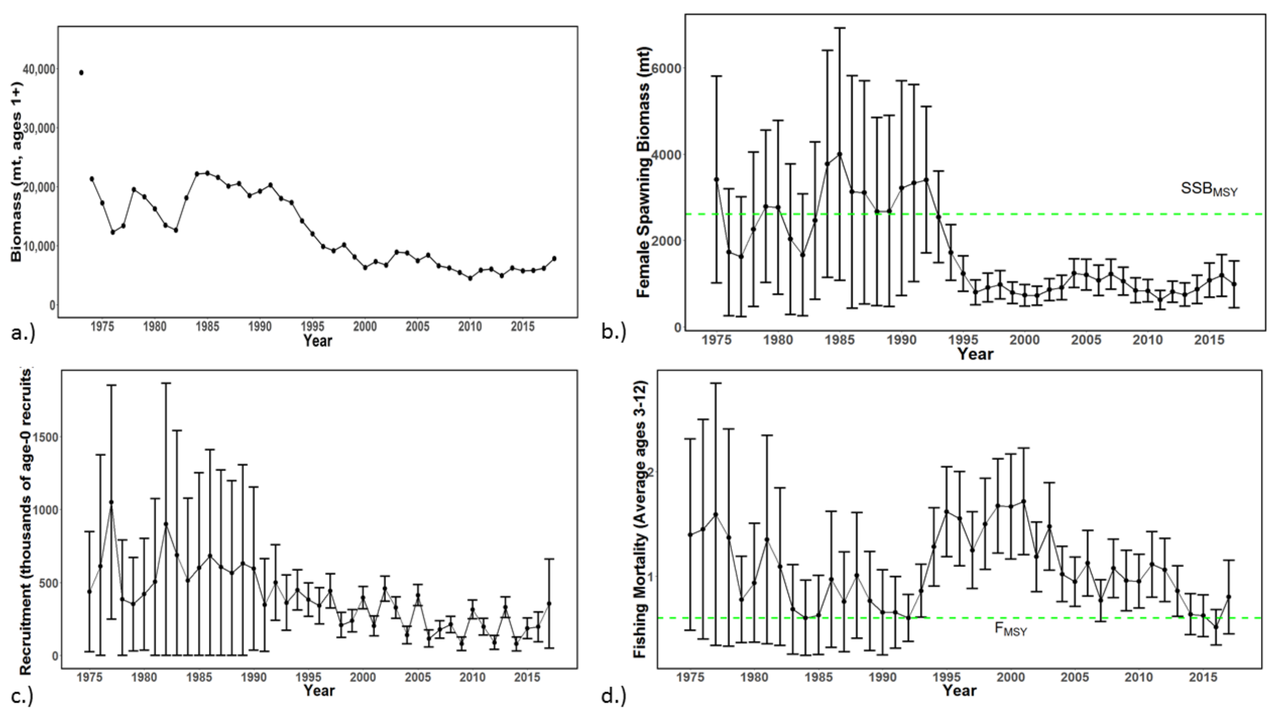


Figure S2. Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) recruitment (age-0 fish), and (d) instantaneous fishing mortality (average for age 3-12, year^{-1}) for Western and Central North Pacific striped marlin (*Kajikia audax*) derived from the 2019 stock assessment. The circles represent the maximum likelihood estimates by year for each quantity and the error bars represent the uncertainty of the estimates (95% confidence intervals), green dashed lines indicate SSB_{MSY} and F_{MSY}.

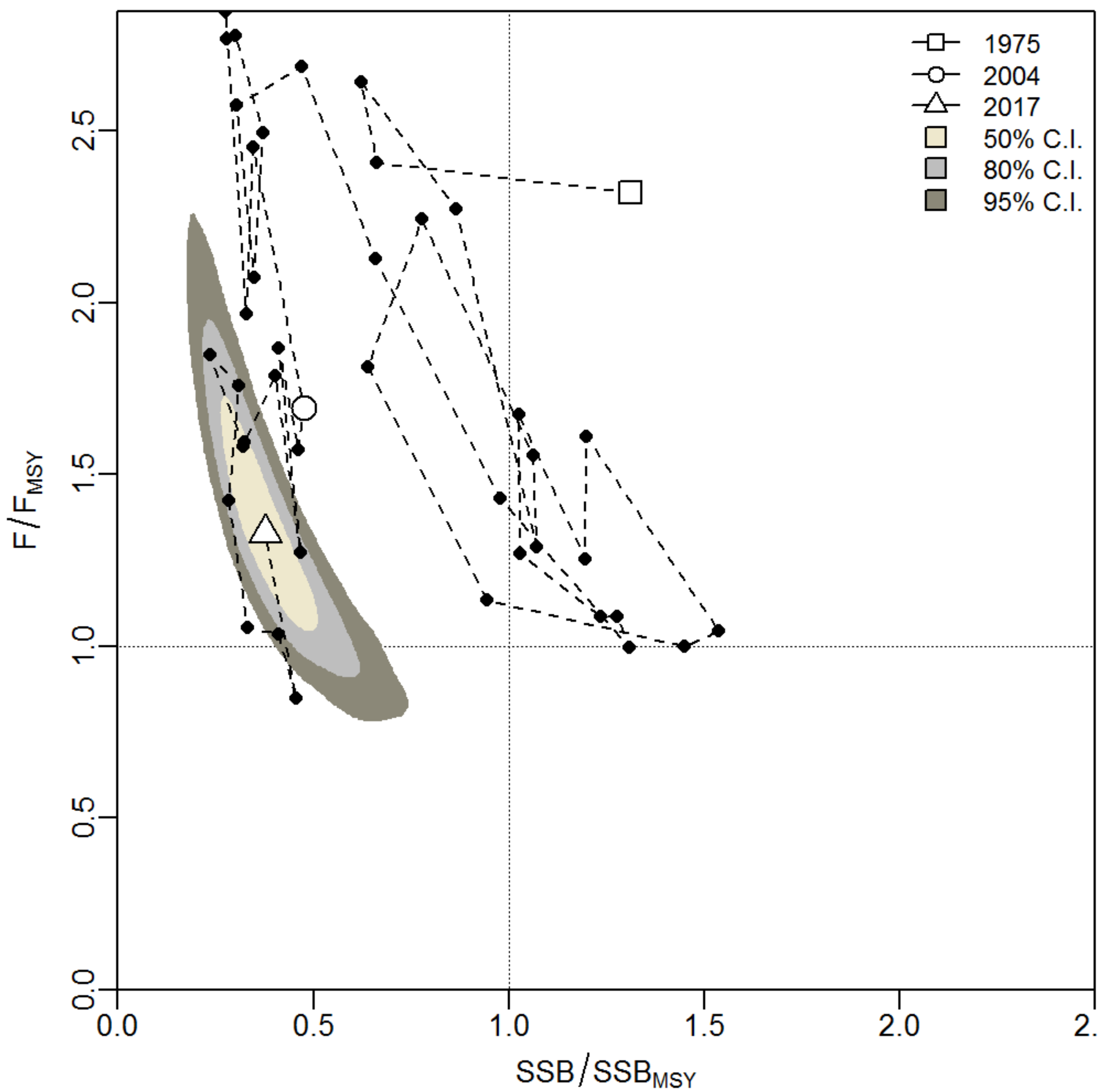
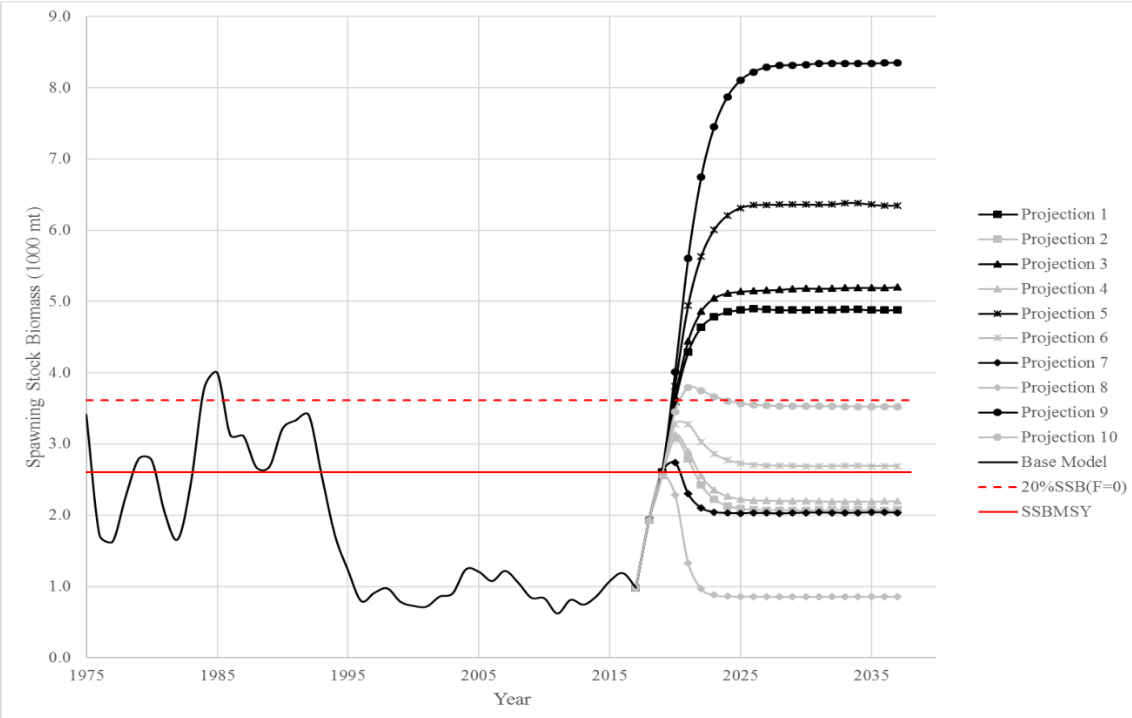
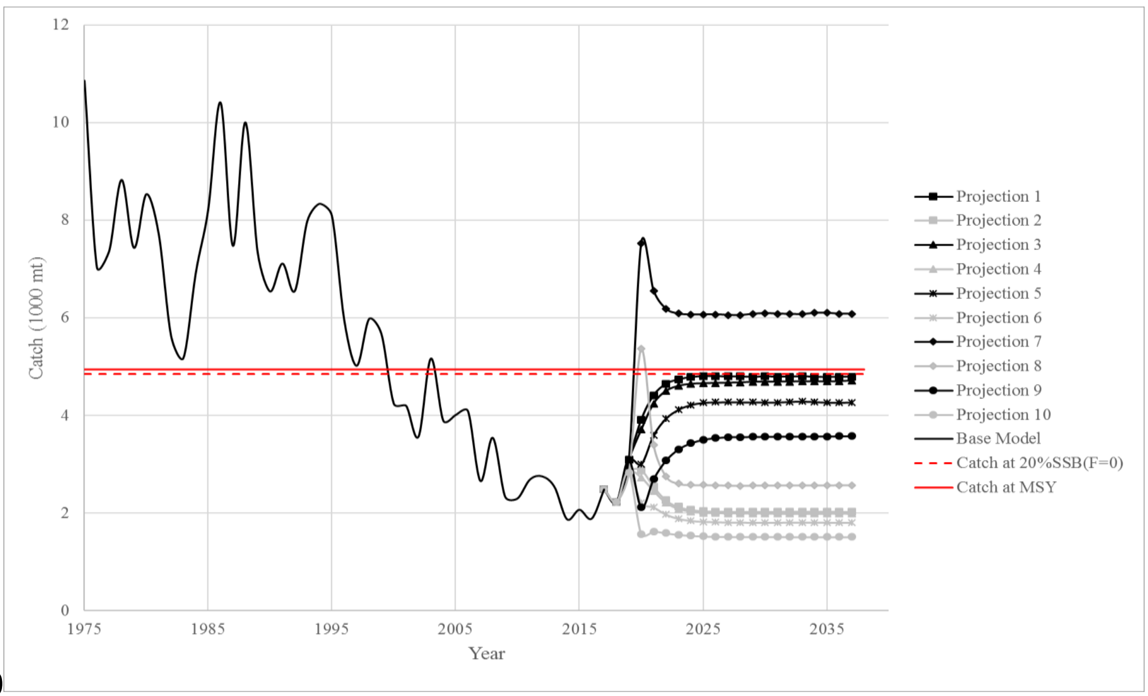


Figure S3. Kobe plot of the time series of estimates of relative fishing mortality (average of age 3-12) and relative spawning stock biomass of Western and Central North Pacific striped marlin (*Kajikia audax*) during 1975-2017. The white square denotes the first (1975) year of the assessment, the white circle denotes 2004, and the white triangle denotes the last (2017) year of the assessment.

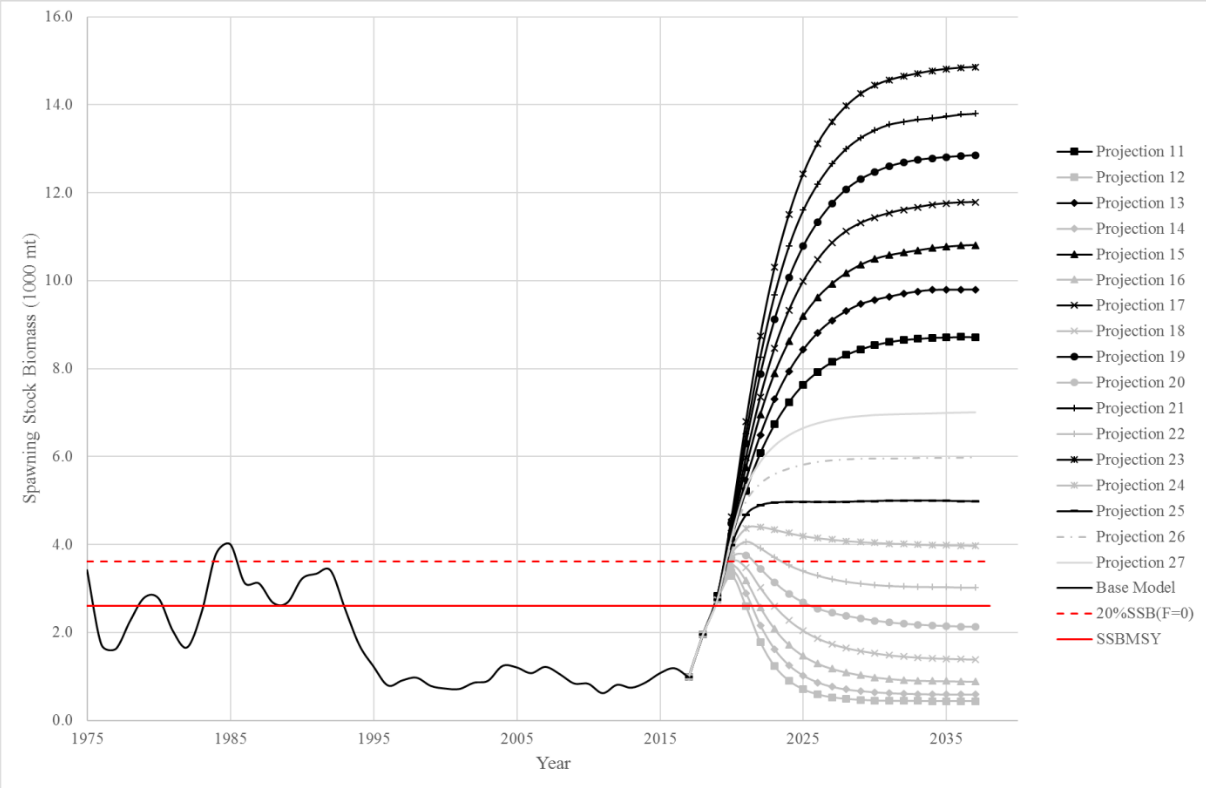


a.)

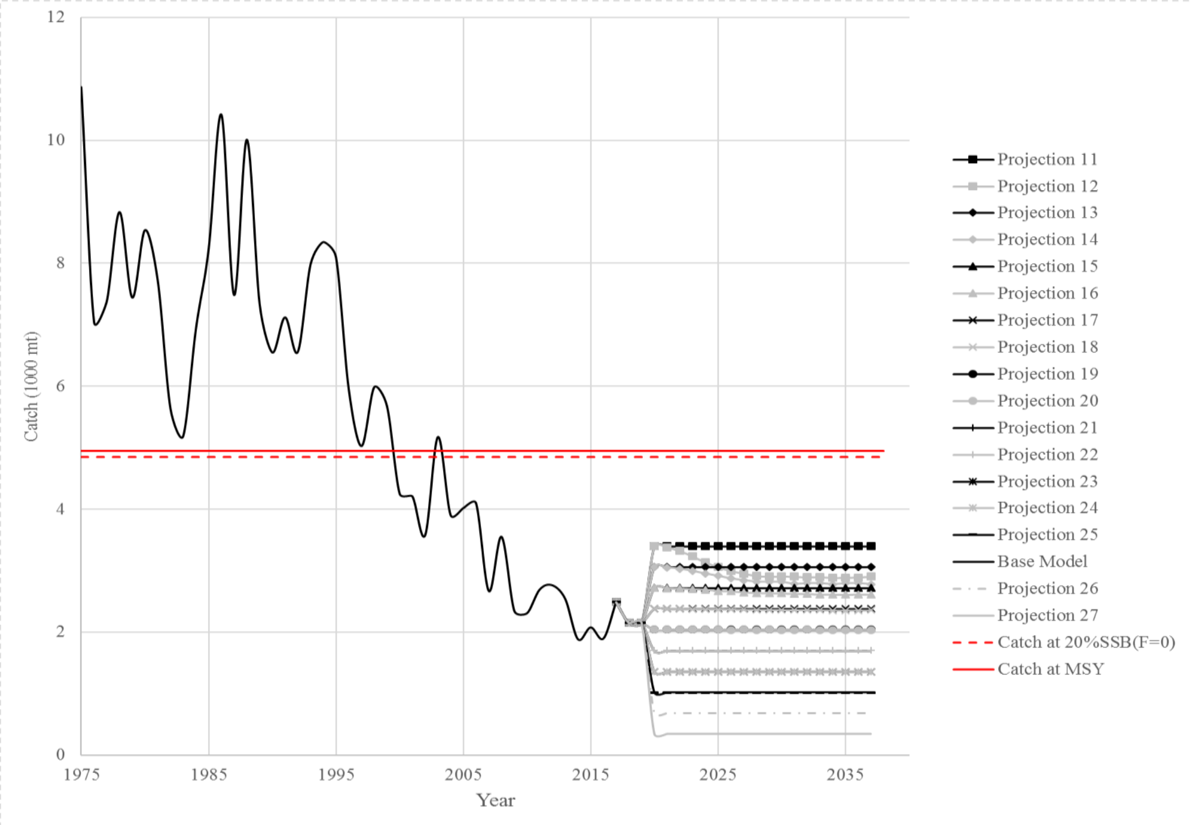


b.)

Figure S4. Historical and projected trajectories of spawning biomass and total catch from the Western and Central North Pacific striped marlin base case model based upon F and constant catch scenarios: (a) F scenarios projected spawning biomass; (b) F scenarios projected catch; (c) constant catch scenarios projected spawning biomass; and (d) constant catch scenarios projected catch. Black lines indicate the long-term recruitment scenarios; grey lines indicate the short-term recruitment scenarios. Red dashed line indicates the catch or spawning stock biomass at 20%$SSB_{F=0}$. Red solid line indicates the catch or spawning stock biomass at SSB_{MSY}. The list of projection scenarios can be found in Table S3.



c.)



d.)

Figure S4. Continued.

1. 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 striped marlin (*Kajikia audax*) in the Western and Central Pacific Ocean (WCNPO) in 2011 (ISC, 2012) and updated the assessment in 2015 (ISC, 2015). The ISC BILLWG proposed to run a benchmark assessment on western and central North Pacific (WCNPO) striped marlin in 2019. The status of the WCNPO striped marlin stock was overfished and overfishing was occurring relative to MSY-based reference points in the 2015 updated assessment using a Stock Synthesis (SS) assessment model. The ISC BILLWG data preparatory meeting was held in January 2019 to evaluate new stock structure, life history, catch, length composition, and CPUE data and strategize for the assessment (ISC, 2019).

This report describes the 2019 stock assessment for the WCNPO striped marlin stock. The best available scientific information including the up-to-date catch, catch-per-unit-effort (CPUE), and composition data from 1975-2017 were provided by individual ISC countries, the Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC). The 2019 assessment was an integrated age-structured assessment model with a quarterly time step using the modeling platform Stock Synthesis (SS) version 3.30.08 (Methot and Wetzel 2013).

2. MATERIALS AND METHODS

2.1. Spatial and Temporal Stratification

The geographic area encompassed in the assessment for striped marlin was the Western and Central North Pacific Ocean bounded by the equator and the Western and Central Pacific Fisheries Commission management boundary at 150°W. The eastern stock boundary was changed from 140°W used in the 2015 assessment after review of the available information on striped marlin stock structure. Lacking conclusive evidence of a clearly defined stock boundary, the management unit with an eastern boundary of 150°W longitude was used as the definition of the stock for this assessment. Over 90% of the catch was accounted for using the 150°W boundary compared to the 140°W boundary. Three types of data were used: fishery-specific catches, relative abundance indices, and length measurements. The fishery data were compiled for 1975-2017, noting that the catch data and length composition data were compiled and modeled on a quarterly basis. Several CPUE indices were also modeled as a quarterly index from the Japanese longline fleet. Available data, sources of data, and temporal coverage of the datasets used in the updated stock assessment are summarized in Figure 1. Further details are presented below.

2.2. Definition of Fisheries

A total of 23 fisheries that caught striped marlin were defined on the basis of country, gear type, location, and time period, where each fishery was assumed to target a distinct component of the stock. These fisheries included fourteen longline fisheries from Japan. Thirteen of these fleets are the results of the flexmix model applied to the Japanese offshore and distant-water longline data, which divided the data into areas and quarters based upon mean weight and CPUE. Nine quarter-area combinations were identified and two of these, Japan quarter 1 area 1 and quarter 3 area 1 were divided into the early and late periods. An additional longline fleet (JPNLL_Others) accounted for any other striped marlin longline catches. Three additional fleets from Japan included the driftnet catches in two fleets divided by quarter: quarters one and four and quarters two and three (JPNDF_Q14 and JPNDF_Q23) and a fleet to encompass all other Japanese striped marlin catches (JPN_Others). There were also three fleets from Chinese Taipei: one for their distant water longline fleet (TWN_DWLL), one for their small-scale tuna longline fleet (TWN_STLL) and one other fleet for any additional catches (TWN_Others). There were two fleets from the United States: a single fleet for the Hawaii-based longline fleet (US_LL) and one other fleet (US_Others) which included handline and troll catches. Finally, there was one fleet for the various flags contained in the WCPFC management region not otherwise accounted for (WCPFC_Others). Descriptions and data sources to characterize the twenty-three fisheries that catch WCNPO striped marlin are also summarized in Table 1.

2.3. Catch

Catch was input into the model on a quarterly basis (i.e., by calendar year and quarter) from 1975 to 2017 for the 23 individual fisheries. Catch was reported in terms of catch biomass (mt) for all fisheries, with the exception of the Japanese offshore and distant water longline fleets (JPNLL F1-13) for which catch was reported as numbers of fish caught.

Three countries (i.e., Japan, Chinese Taipei, and the USA) provided national catch data (Hirotaka Ijima, NRIFSF, personal communication; Yi-Jay Chang, NTU, personal communication; Ito 2019). Striped marlin catches for all other fishing countries were collected from WCPFC category I and II data (Peter Williams, SPC, personal communication).

The resulting best available data on striped marlin catches by fishery from 1975-2017 were tabulated and are shown in Figure 2 and Table 2. The historical maximum and minimum annual striped marlin catches were 10,862 metric tons in 1976 and 1,879 metric tons in 2014, respectively. From 1975 to 1993, the Japanese driftnet fishery harvested approximately half of the total annual catch. However, it is possible that these catches have large uncertainty and sensitivity runs to evaluate how future adjustments to these reported catches were explored in this assessment. Overall, annual catches of WCNPO striped marlin have generally declined since 1975. The annual catch of striped marlin in the WCNPO averaged about 2,151 metric tons in the period since the last assessment (2015-2017).

2.4. Abundance Indices

Relative abundance indices for WCNPO striped marlin based on standardized CPUE were prepared for this assessment and are shown in Figure 3 and Tables 3 and 4. A finite mixture model analysis was used to identify nine different area-quarter combinations based upon the weight and CPUE of striped marlin caught in the Japanese offshore and distant water longline fleets. Japanese CPUE data were standardized in two area-quarters (area one quarter one and area one quarter 3) as well as pre- and post-1993 when Japanese logbook reporting requirements were changed (Ijima and Kanaiwa, 2019a; Ijima and Kanaiwa, 2019b).

Operational fishing data collected in the Hawaiian longline fishery by fishery observers in 1995-2017 were used for CPUE standardization of US longline fleets (Sculley, 2019). The fishery operates in two sectors; a shallow-set sector targeting swordfish and a deep-set sector targeting tunas. Striped marlin is caught as bycatch in both sectors. These data were standardized into a single CPUE time series including factors that accounted for much of the variability between sectors.

Two CPUE standardizations were put forward from Taiwanese fisheries. The distant-water longline fleet was standardized from 1995-2017 (Chang *et al.*, 2019). A new index was presented by Chinese Taipei from the small-scale tuna fishery from 2008-2017 (Chang *et al.*, 2019).

Visual inspection of all indices showed an overall decreasing trend with the last 5-10 years showing a relatively flat trend. Both of the early Japanese LL indices are increasing through 1993 and the Chinese Taipei small-scale tuna index has a peak around 2012 (Figure 3).

Correlations among CPUE indices were analyzed in the 2019 assessment using the diags component of the FLCore package (Version 2.6.6, Kell *et al.* 2007) in R (version 3.4.0, R Core Team, 2018). These packages provide a standardized method to plot and summarize CPUE data so that modelers can better evaluate their input data into assessment models. Each CPUE index was fit using a Loess smoother with only year as an explanatory variable using the default phase and number of nodes in the R package gam (Hastie, 2018), and the residuals from that smoother were examined graphically. Patterns in correlations among CPUE indices for the assessment were generally positive. Based on the graphical inspection of relative CPUEs and the correlation analysis, the data supported the use of all the CPUE indices in the base case model. However, S1 (JPNLL Q1A1 Late), S5 (TWN STLL) and S6 (JPNLL Q1A1 Early) were ultimately excluded from the model likelihood due to conflicts in the indices identified when profiling the likelihood based upon R_0.

2.5. Size Composition Data

Quarterly fish length composition data from 1975–2016 for seventeen fisheries were available for the assessment; nine were ultimately used, and are summarized in Table 3. Length composition data for the Japanese fleets F3 and F7-F11 were not included because it accounted for <0.5% of the total catch in the fishery. Length composition data for fleet F1, F6, and F12 were not included in the likelihood because they had a conflicting trend in the profile of $\log(R_0)$ compared to the other length composition data and CPUE indices or the data were determined to be too sparse to be informative.

Length frequency data were compiled using 5-cm length bins from 50 to 230 cm. 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 striped marlin measured. The new composition data were agreed upon at the BILLWG data workshop as the best available scientific information for the 2019 stock assessment.

Figure 4 shows the quarterly length compositions. Most of the fisheries caught small (<150cm) individuals. The longline fleets caught fish with a mean of 150 cm EFL while the driftnet fleets caught slightly larger fish, mean 157 cm EFL. The US longline fleet (US_LL) caught smaller fish on average than any of the other fleets (mean size 136cm EFL).

The aggregate length composition distributions were relatively consistent between fleets, with the exception of the US Longline fleet (Figure 5). Most longline size distributions had a single mode around 150-160cm. The US longline fleet was bimodal with peaks around 110cm and 140cm EFL.

2.6. Model Description

The assessment was conducted with Stock Synthesis (SS) version 3.30.08.03-SAFE released 09/29/2017 using Otter Research ADMB 11.6 (Methot and Wetzel 2013). The WCNPO model was set up as a single area model with a single sex and four seasons (quarters). Spawning was assumed to occur in quarter two while recruitment was assumed to occur in July (month 7). Age at recruitment was calculated based upon the model estimated average selectivity at age based upon the quarterly selectivity at length. The maximum age of striped marlin was set to 15 years. Age-specific natural mortality was used (Table 5) as agreed upon in the BILLWG data preparatory meeting (ISC, 2019). In addition, the CV of the growth curve was set to 0.3, and the sex ratio at birth was assumed to be 1:1. The model used a Beverton-Holt spawner-recruit relationship with steepness (h) fixed at 0.87 and sigmaR (σ_r) fixed at 0.6.

2.7. 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 $\log(SE)=\text{sqrt}(\log(1+CV^2))$, where CV is the standard error of the observation divided by the mean value of the observation and sqrt is the square root function.

Annual CPUEs (S3-5) were assigned to quarter one. Japanese longline fleets (S1, S2, S6 and S7) were quarterly indices representing quarters one and three. Of these, fleets S1, S5, and S6 were excluded from the base-case model. These three CPUE indices were excluded from the base-case model because they were shown to be in conflict with the other input data based upon the R0 likelihood profile. The CPUE indices were assumed to be linearly proportional to biomass where catchability (*q*) was assumed to be constant and occur in the first month of the quarter assigned.

The CVs for each CPUE index were assumed to be equal to their respective calculated SEs on the log scale (Table 6). The minimum CV was scaled to a minimum of 0.2 and then reweighted based upon the Francis method using the root-mean-square error (RMSE, i.e., square root of the residual variance, Francis 2011).

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. The effective sample size for Japanese DWLL fleets were given effective sample sizes calculated by Japan. All other fleets had effective sample sizes equal to 1/10 of the total number of samples in each quarter, in alignment with previous assessments (ISC 2015). In addition, quarters with fewer than 15 total samples were removed from the time series due to limited sample size and the maximum number of samples was set to 50, as agreed upon by the modeling sub-group.

2.8. Estimation of Fishery Selectivity

Selectivity was estimated as a double-normal curve for all fleets, except for F13 and F14, the Japan drift gillnet fisheries, and were assumed as asymptotic lognormal (Figure 6). All other fleets were mirrored to the fleet that was believed to have the most similar selectivity pattern (Table 7).

2.9. Data Weighting

Index data were 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). However, because the model was sensitive to reweighting of the length composition and CPUE data, input sample sizes were not iteratively re-weighted in stage 2.

2.10. Model Diagnostics

Several diagnostics have been evaluated for their utility to identify data conflicts and model misspecification within integrated stock assessment models (Carvalho *et al.* 2017). However, Carvalho *et al.* (2017) determined that there was no single diagnostic that worked well in all of the cases they evaluated. Instead, they recommend the use of a carefully selected range of diagnostics that proved to increase the ability to detect model misspecification.

Key stock assessments diagnostics identified by Carvalho *et al*. (2017) were implemented to evaluate the base case model.

Retrospective analysis

Retrospective analysis is a way to detect bias and model misspecification (Hurtado-Ferro et al. 2014). A retrospective analysis was applied to the base-case model results. The diagnostic was implemented here by sequentially eliminating the five most recent years of data from the full stock assessment base case model (a 5 year “peel”) and then re-estimating all stock assessment model parameters from each peel and from the full model.

R0 likelihood profile

An R0 likelihood component profile (Lee *et al.* 2014) was applied to the base-case model results.

The diagnostic was implemented here by sequentially fixing the equilibrium recruitment parameter, R_0, on the natural log scale, $\log(R_0)$, to a range of values. The relative change in negative log-likelihood units over the range of fixed values for $\log(R_0)$ (the R_0 profile) was compared among the Stock Synthesis model likelihood components for CPUE, length-composition, and recruitment deviations using two diagnostic tests. First, a relatively large change in negative log-likelihood units along the R_0 profile was diagnostic of a relatively informative data source for that particular model. Second, a difference in the location of the minimum negative log-likelihood along the R_0 profile among data sources was diagnostic of either conflict in the data or model misspecification (or both).

Age-structured production model

An age-structured production model (ASPM; Maunder and Piner 2015; Carvalho *et al*. 2017) was applied to the base-case model results.

The diagnostic was implemented here by fixing selectivity to its estimated values in the fully integrated stock assessment model, fixing recruitment equal to the stock recruitment curve obtained from the fully integrated stock assessment model, and then estimating the remaining parameters of the stock assessment model. Trends in relative spawning stock size were compared from the fully integrated stock assessment model and the ASPM.

Carvalho *et al.* (2017) suggest that if the ASPM is able to fit well to the indices of abundance that have good contrast (i.e. those that have declining and/or increasing trends), then this is evidence of the existence of a production function, and the indices will likely provide information about absolute abundance. On the other hand, Carvalho *et al*. (2017) suggest that if there is not a good fit to the indices, then the catch data alone cannot explain the trajectories depicted in the indices of relative abundance. This can have several causes: (i) the stock is recruitment-driven; (ii) the stock has not yet declined to the point at which catch is a major factor influencing abundance; (iii) the base-case model is incorrect; or (iv) the indices of relative abundance are not proportional to abundance.

Goodness-of-Fit Indices of Abundance

Residuals are examined for patterns to evaluate whether the model assumptions have been met. Many statistics exist to evaluate the residuals for desirable properties. One way is to calculate, for each abundance index, the root-mean-square-error (RSME) was used as a goodness-of-fit diagnostic, with relatively low RMSE values (i.e., RMSE < 0.3) being indicative of a good fit.

Goodness-of-Fit Size Composition Data

Comparisons between the observed and expected mean values of composition data from Francis (2011) were used for model diagnostics. Pearson residuals for size composition data fits were also used as a model diagnostic.

2.11. Stock Projections

Stock projections for WCNPO striped marlin were conducted using the age-structured projection model software AGEPRO (Brodziak et al. 1998). Stochastic projections were conducted using results from the base-case model to evaluate the probable impacts of alternative fishing intensities or constant catch quotas on future spawning stock biomass and yield for striped marlin in the Western and Central North Pacific Ocean. For fishing mortality projections, a standard set of F-based were conducted (c.f., ISC BILLWG 2018). For catch quota projections, the set of rebuilding projection analyses requested by the 14th Regular Session of the WCPFC Northern Committee was conducted (NC14 2018). Technical descriptions of the F-based and catch-based projection analyses are provided below (Table 8).

Initial conditions for the stochastic projections were based on the estimated initial population size at age in year 2018 from the base case model. A total of 100 bootstrap replicates of the 2018 striped marlin population size at age were calculated in SS3 to characterize the uncertainty in the initial population size. In each projection, 100 total simulations were run for each bootstrap replicate to characterize the effects of process errors in future recruitment, life history and fishery parameters. This gave 10,000 total simulated trajectories to evaluate the central tendency and variability of population and fishery quantities of interest, such as spawning biomass and catch, in each projection.

Recruitment for the stochastic projections was based on two hypotheses about future recruitment. The first hypothesis was that future recruitment would be similar to recent short-term recruitment. This hypothesis was based on the observation that recruitment estimates had remained relatively low in recent years and one may not expect this to change in the future. In particular, the short-term recruitment scenario was based on resampling the empirical cumulative distribution function of recruitment observed during 2012-2016 (AGEPRO, recruitment sub-model 14). Under the short-term recruitment scenario, the average recruitment was 134,020 age-1 fish with a CV of 58%. The second hypothesis was that future recruitment would be similar to the long-term recruitment pattern. This hypothesis was based on the observation that the average of the bootstrap distribution of recruitment in 2018 (294,574 age-1 fish with a CV of 44%) was more than two-fold higher than the recent 5-year average, suggesting that achieving higher recruitment was a possibility. In particular, the long-term recruitment scenario was based on resampling the empirical cumulative distribution function of recruitment observed during 1975-2017 (AGEPRO, recruitment sub-model 14). Under the long-term recruitment scenario, the average recruitment was 360,989 age-1 fish with a CV of 54%. Thus, the long-term recruitment scenario would be expected to produce over twice as many recruits as the short-term scenario on average although both scenarios had similar levels of observed recruitment variability.

Fishery selectivity for the stochastic projections was based on the estimated selectivities in the base case model. It was noted that all of the longline and other fleet-specific estimates of fishery selectivity as a function of age were dome-shaped in the base case model, with the exception of the Japanese drift gillnet fleet, which had a flat-topped selectivity at age. To characterize the fishery selectivity of both the dome-shaped and flat-topped selectivity fleets, an aggregate fishery selectivity was calculated as a weighted average of the two fleet types. In this case, the catch biomass percentages in 2017 by dome-shaped (95%) and flat-topped (5%) were used to weight the representative dome-shaped fleet (Japanese longline fleet in area 1 in quarter 3) and the representative flat-topped fleet (Japanese gillnet fleet in quarters 2 and 3) fishery selectivities to produce the fishery selectivity at age. Here it was noted that the differences in comparable projection results using the two representative fleets versus using the single fleet were negligible. As a result, projections were conducted using the single fishery aggregate fleet selectivity for parsimony and tractability, and also noting that projections with two fleets requires annual assumptions about the magnitude of the relative catch by each fleet going into the future. For stochastic projections, fishery selectivity at age were sampled with a multiplicative lognormal process error with a mean of unity and a CV of 10% to represent uncertainty about future selectivity.

Life history parameters for the projections were based on the exact same values as were used in the base case model. This included natural mortality at age, maturity at age, and mean spawning weights at age. Mean fishery catch weights at age were calculated as a weighted average of the catch weights at age for the representative dome-shaped (95%) and flat-topped (5%) selectivity fleets. For stochastic projections, life history parameters at age were sampled with a multiplicative lognormal process error with a mean of unity and a CV of 10% to represent uncertainty about future values, with the exception of maturity at age, which was sampled with a CV of 1%.

The stochastic projections employed model estimates of the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Fishing mortality-based projections started in 2018 and continued through 2037 under 5 levels of fishing mortality and two recruitment scenarios (Table 8). The five fishing mortality stock projection scenarios were: (1) F status quo (average F during 2015-2017), (2) F_{MSY}, (3) F at $0.2 \cdot SSB_{(F=0)}$, (4) F_{High} at the highest 3-year average during 1975-2016, and (5) F_{Low} at $F_{0.30\%}$. For the F-based scenarios, fishing mortality in 2018-2019 was set to be F status quo (0.64) and fishing mortality during 2020-2037 was set to the projected level of F. Catch-based projections also ran from 2018 to 2037 and included 7 levels of constant catch for the long-term recruitment scenario and 10 levels of catch for the short-term recruitment scenario. For the catch-based scenarios, catch biomass in 2018-2019 was set to be the status quo catch during 2015-2017 (2150.6 mt) and annual catches during 2020-2037 were set to the projected catch quota. The ten constant catch stock projection scenarios were: (1) Quota based upon CMM10-01, (2) 90% of the quota, (3) 80% of the quota, (4) 70% of the quota, (5) 60% of the quota, (6) 50% of the quota, (7) 40% of the quota, (8) 30% of the quota, (9) 20% of the quota, and (10) 10% of the quota. The alternative constant catch projections were requested by the WCPFC Northern Committee (NC) in order to provide information for the development of a rebuilding plan for WCNPO striped marlin (NC14, 2018). This request was to provide the probability of rebuilding to 20%$SSB_{F=0}$ within 20 years and continue reducing catches by 10% until the probability of achieving the rebuilding target of 3610.4 mt of spawning biomass was at least 60%.

3. RESULTS

3.1. Base Case Model

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

3.2. Model Convergence

All estimated parameters in the base case model were within the set bounds, and the final gradient of the model was approximately 0.0001 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 100 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 7).

3.3. Model Diagnostics

Figure 8 presents the results of the likelihood profiling on the logarithm of the unfished recruitment parameter R_0, i.e. log(R_0), 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 9 and 10.

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).

There was a relatively large change in the R_0 profile for estimated recruitment deviations (Recruitment) relative to the data likelihood components for survey (CPUE) and length composition data (Figure 8). This result indicated that the estimation of the recruitment deviations was relatively informative within the likelihood. The changes in negative log-likelihood of abundance indices was relatively flat and the local minimum value (5.7) was lower to that of total likelihood $\log(R_0) = 6.22$. Index S7 (max 6.25) showed the largest changes in negative log-likelihood values across values of R_0 among abundance indices, followed by S3 (max 0.75), S2 (max 0.37), and S4 (max 0.19; Table 9, Figure 9).

Similar to the abundance indices data, the changes in the negative log-likelihoods from the nine length composition data included were small, with a local minimum at 6.0 (Figure 8). The U.S. longline fleet (F16) showed the largest changes in negative log-likelihood values (max 2.69) across values of R_0 among the nine size composition data (Table 10, Figure 10).

Another large component of the change in R_0 was driven by the initial equilibrium catch. There were also differences in the location of the minimum negative log-likelihood along the R_0 profile observed among data likelihood components for the base case model. The two-stage Francis approach seemed to have reduced the conflict, but did not eliminate it.

Goodness-of-Fit Indices of Abundance

Goodness-of-fit diagnostics were presented in Table 6, and plots of predicted and observed CPUE by fishery for the base case model were shown in Figure 11.

The fit to the CPUE indices were summarized into two groups: (1) those in which indices contributed to the total likelihood (S2, S3, S4, S7), and those in which indices did not contribute to the total likelihood (S1, S5, and S6). Results showed that the Japan early abundance index (S1) had RMSE < 0.3, which indicates that the model fit this CPUE index well. However, all the other indices included in the total likelihood had values for RMSE > 0.3.

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 12 shows the 95% credible intervals for mean value for the nine length composition data sets. The model fit passed through almost all of the credible intervals.

Fits to the annual length compositions by fleet could be improved (Figure 13), with few obvious systematic patterns observed in the residuals (e.g., patterns of positive or negative residuals) making it difficult to objectively determine how to improve the fits. This is an important area for future model development. For example, more flexible selectivity curves (or time blocks) in combination with alternative binning of length composition data could be examined in the future to account for the jagged distributions observed in seasonal length compositions. Alternatively, different area stratification of fleets could be explored in the future to either increase sample size or smooth the length-frequency distributions.

Assuming standardized residuals were normally distributed, 95% of the measurements would fall within 2 standard deviations of the mean. The majority of Pearson residuals did not meet this criteria (Figure 13), in particular F16 U.S. longline and F18 Chinese Taipei distant water longline showed stronger residual patterns when compared to the other fleets**.**

Overall, the model fit the length modes in composition data aggregated by fishery fairly well using the input effective sample sizes (Figure 14). However, F16 showed some misfit.

Retrospective Analysis

A retrospective analysis of the base case Western and Central North Pacific striped 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 May 2019 BILLWG workshop. The results of the retrospective analysis are shown in Figure 15. 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 there was a tendency for the base case model to underestimate spawning biomass in recent years and overestimate fishing intensity.

Age-structured production model

ASPM results are provided in Figure 16. The models showed different trends in SSB during the first 20 years of modeled timeframe. However, after 1995 the ASPM showed a similar stabilized trend than the fully integrated stock assessment model. After 2013, the ASPM showed a steep increase in SSB, while the fully integrated stock assessment model continued to show stabilization. The asymptotic 95% confidence interval from the fully integrated stock assessment did not overlap with the SSB trend from the ASPM for most of the modeled years.

3.4. 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 22,303 mt in 1985 to 4,509 mt in 2010, and increased to around 5,904 metric tons during the final three years of the 2019 stock assessment time horizon (2015−2017, Table 11 and Figure 17). Overall, population biomass declined from an average of roughly 22 thousand metric tons in the mid-1980s to an average of roughly 5 thousand metric tons in the 2010s (Figure 17).

Spawning stock biomass (SSB) estimates exhibited an initial oscillation around 2 thousand metric tons in the late 1970s. SSB reached its highest level of 3,999 metric tons in 1985, and declined to 794 metric tons in 1996 (Table 11 and Figure 18). The time-series of SSB during the past decade averaged 5,710 metric tons, or 31% of unfished SSB. Overall, SSB exhibited a strong decline during the early 1990s and has stabilized since. However, SSB showed signs of increase in recent years going from 743 metric tons in 2013 to 981 metric tons in 2017.

Recruitment (age-0 fish) estimates indicated a long-term fluctuation around a mean of approximately 764,000 (Table 11 and Figures 19). The model estimated a strong year class (> 1000 thousand recruits) recruited to the fisheries in 1977 and weak year classes in 2009 and 2014. While the overall pattern of recruitment from 1975-2017 was variable, there was an apparent declining trend in recruitment strength over time (Table 11 and Figure 19).

Over the course of the assessment time horizon, estimated fishing mortality (arithmetic average of F for ages 3 – 12) decreased from 1.4 $year^{-1}$ in 1975s to 0.6 $year^{-1}$ in 1992, increased to 1.71 $year^{-1}$ in 2001, and afterward declined to an all-time low of 0.51 $year^{-1}$ in 2016 (Table 11 and Figure 20).

3.5. Biological Reference Points

Biological reference points were computed from the Stock Synthesis base case model. Since most life history parameters for Western and Central North Pacific striped marlin, including steepness, were considered reasonably well defined, MSY-based biological reference points were used to assess relative stock status (Table 12). The point estimate of maximum sustainable yield was MSY = 4,946 metric tons. The point estimate of the spawning stock biomass to produce MSY was SSB_{MSY} = 2,604 metric tons. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY on ages 3-12 fish was F_{MSY} = 0.6 and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

3.6. Stock Status

Compared to MSY-based reference points, the current spawning biomass (average of 2015-2017) was 62% below SSB_{MSY} and the current fishing mortality (average for ages 3-12 in 2015-2017) was 7% above F_{MSY}. The Kobe plot indicates that the Western and Central North Pacific striped marlin stock is currently overfished and is subject to overfishing relative to MSY-based reference points (Figure 14).

3.7. Sensitivity Analyses

In the May 2019 BILLWG workshop, it was agreed that at least five life history parameters would be evaluated in sensitivity analyses in the 2019 assessment (Table 13) in order to examine the effects of plausible alternative model assumptions and data input. These analyses were:

(1) **Sensitivity analysis on growth**: The WG agreed to conduct two sensitivity analyses for growth. These were an alternative growth curve with L_{Amax} set to the mean from Fitchett (2019, 184 cm EFL) and an alternative growth curve with a 10% larger maximum size (225 cm EFL).

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

(3) **Sensitivity analysis on recruitment variability**: The WG agreed to run a sensitivity run on recruitment variability by assuming a larger σ_R (0.9).

(4) **Sensitivity analysis on steepness**: The WG agreed to run three additional sensitivity runs on steepness. Steepness was fixed at h=0.95, h=0.79, and h=0.70.

(5) **Sensitivity analysis on maturity**: The group agreed to run three sensitivity analyses for the maturity ogive. These were an alternative maturity ogives with L_{50} = 171 cm, Alternative maturity ogives with L_{50}=177 cm (used in the 2015 assessment), and an alternative maturity ogives with converted L_{50} = 181cm from Chang et al. (2019).

(6) **Sensitivity analysis on initial equilibrium catch**: The group agreed to run four sensitivity analyses for the initial equilibrium catch. These were assuming alternative values for the initial equilibrium catch; the values were 1000 mt, 25000 mt, 75000 mt, and 10000 mt.

(7) **Sensitivity analysis on uncertainty in the Japanese drift gillnet catch**: The group agreed to run four sensitivity analyses on uncertainty in the Japanese drift gillnet catch. These were assuming that the catches for these fisheries were 90%, 50%, 30%, and 10% lower than the catches used in the base case model. In addition, a fifth sensitivity analysis were conducted assuming a CV of 10% around the Japanese drift gillnet catch, which is higher than the 5% assumed in the base case.

(8) **Sensitivity analysis on assessment model time frame**: The group agreed to run a sensitivity analyses on the stock assessment time frame. This was assuming the same parametrization of the base case model, however excluding all the data prior 1994. This particular sensitivity analysis was conducted to explore the impact of removing historical data on the stock assessment results.

During the May 2019 BILLWG workshop, all 22 sensitivity analyses were completed and the results were presented and reviewed.

For each sensitivity run, comparisons of spawning stock biomass and fishing intensity (1-SPR) trajectories were completed (Figure 22). Additionally, the WG produced a Kobe plot, that showed the patterns of the base case and terminal year estimates for the key sensitivity runs (Figure 23).

For one of the 22 sensitivity runs, the stock status was estimated to be in the yellow section of the Kobe plot indicating that the stock was overfished but not experiencing overfishing (Figure 23). This was Run 7 (steepness = 0.95). For Run 2 (L_{Amax} set to 184 cm EFL), the stock was estimated to be in the green section of the Kobe plot, indicating stock was not overfished and not experiencing overfishing (Figure 23).

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.

3.8. Stock Projections

Projection results showed the average spawning stock biomass the average catch, and the probability of achieving the spawning stock biomass target in 2018-2022, 2027, and 2037 for each of the twenty-seven scenarios (Table 14 and Figures 24 and 25). For the constant F scenarios, the recruitment scenario substantially influenced the probability of rebuilding the stock to $20\%SSB_{F=0}$. Under the long-term recruitment scenario, which had a higher mean recruitment of 307 thousand age-1 fish, it was predicted that all of the constant F projections (scenarios 1, 3, 5, and 9) would recover the stock by 2021 with the exception of the high F scenario 7. Under the short-term recruitment scenario, none of the constant F projections were expected to rebuild the stock with 60% probability although the low F scenario 10 would be expected to achieve the rebuilding target with a 54% probability in 2021. Thus, for the constant F scenarios, the projections indicated that stock rebuilding was unlikely to occur unless recruitment increased from recent low levels.

All of the projections show an increasing trend in spawning stock biomass during 2018-2020, with the exception of the high F scenario 8 under short-term recruitment. This increasing trend in SSB is due to the 2018 recruitment which averaged about 295 thousand age-1 fish, or more than twice as large as the average recruitment under the short-term recruitment scenario (134 thousand age-1 fish). Thus, the initial population size for the projections includes a large year class that improves the chances for rebuilding in the early years of the projection time horizon.

For the constant catch projection scenarios, it was notable that all of the projections under the long-recruitment scenario (scenarios 11, 13, 15, 17, 19, 21, and 23) would be expected to achieve the spawning biomass target by 2020 with probabilities ranging from 61% to 73% and catch quotas ranging from 1359 to 3397 mt. In contrast, under the short-term recruitment scenario, the projection scenarios that rebuilt the stock with at least 60% probability (scenarios 24, 25, 26, and 27) required substantial catch reductions to achieve the target. The smallest quota reduction that would be expected to rebuild the stock was scenario 24 with a 60% reduction in the CM2011-11 quota to 1359 mt with a rebuilding probability of 65% in 2021. This corresponds to a reduction of roughly 37% from the recent average yield of 2151 mt. Quota reductions of 70% to 90% from the CM2011-11 level (scenarios 25, 26, and 27) would produce higher rebuilding probabilities ranging from 72% to 85%. Overall, the catch-based projections show that reducing total catch biomass by 60% from the CM2011-11 levels would be required to rebuild the stock if future recruitment follows the short-term recruitment scenario.

3.9. Assessment Challenges

The WG identified several challenges in developing the base-case stock assessment model that contributed to uncertainty in the assessment results. The six major sources of uncertainty were detailed by the WG and should be carefully evaluated in the future.

Stock structure

The WG noted that there is considerable uncertainty in the stock structure for Pacific striped marlin. Several genetic studies suggest there are at least three genetically distinct populations, one including Japan, Hawaii, and California, one including Equator and Peru, and one including Australia and New Zealand (Graves and McDowell 1994, Sipple *et al.* 2007, McDowell and Graves 2008, Purcell and Edmands 2011, Sipple *et al.* 2011). Evidence from Purcell and Edmands (2011) and more recently Mamoozadeh et al. (2018) also suggested a fourth genetically distinct group, which separates adults in Hawaii into a distinct group indicating that adults caught around Hawaii may not be from the same genetic stock as juveniles caught around Hawaii. Lam *et al.* (WP1 from this meeting) also indicated there is mixing between the NP, Eastern Pacific, and SW Pacific Ocean based upon conventional, PSAT, and data archival storage tagging. There also appears to be differences in life history parameters between striped marlin in the eastern and western Pacific Ocean (see below, Chang *et al.*, 2018; Humphreys and Brodziak, 2019). In addition, previous analyses of patterns of longline CPUE data suggested alternative eastern stock boundaries (ISC 2019). The flexmix analysis provided by Japan also suggested seasonal spatio-temporal patterns of fisheries CPUE and catch size composition (Ijima and Kanaiwa, 2019b). Overall, noting that there was ambiguity in the evidence to support the eastern stock boundary at 140ºW, the WG elected to assess the WCNPO striped marlin stock management unit based upon the boundaries of the convention area of the RFMO in this stock assessment; however, the WG noted that tag-recovery data indicated that there was some mixing of striped marlin stock between the WCPFC and IATTC convention areas. Population dynamics may be more complex than can be modeled in this stock assessment (e.g., a meta-population model could be considered in the future).

Driftnet catch

The WG noted that the Japanese driftnet catch before the moratorium on gillnets in the high seas (i.e., before 1993) might be smaller than reported for this assessment. The catch provided by Japan in January was used in this assessment since alternative catch data were not available for the group to consider. Additional time will be required to update and correct the driftnet catch data. The driftnet fishery comprises the majority of the catch until 1993, and the WG expressed concern about how this uncertainty would influence the stock assessment results. The WG ran a series of sensitivity analyses to evaluate the consequences of any potential changes in driftnet catch. The results show that the spawning biomass and fishing mortality trends are consistent with the base-case model for all of the alternative driftnet catch time-series from 1994 to 2017 and overall stock status is the same (Figure 22g). The different levels of driftnet catch changed the estimate of virgin biomass and the trend of spawning stock biomass and fishing mortality at the beginning of the assessment (1975-1993).

Life History Parameters

The WG noted that there were substantially different estimates for length at 50% maturity (L_{50}) for individuals caught by the Chinese Taipei (L_{50} =181 cm EFL, Chang *et al.*, 2018) and US longline fleets (L_{50}=161 cm EFL, Humphreys and Brodziak, 2019). The WG agreed that it should use peer-reviewed results from Chang *et al.* (2018). However, model convergence was not achieved when L_{50}=181 cm EFL was used in the assessment model. Therefore, the WG elected to use the lower value of the 50% maturity at length (L_{50}=161 cm EFL). The WG noted that the value of L_{50}/L_{inf} is 0.85 for L_{50}=181 cm EFL and is 0.75 for L_{50} =161 cm EFL. These values are relatively higher than other Pacific billfish species (about 0.6). Furthermore, Fitchett (2019) presented in the striped marlin data preparatory meeting provided some additional estimates of L_{inf} between 170 and 190 cm EFL based upon tagging data around Hawaii, which would be biologically inconsistent with an L_{50} of 181 cm EFL. The WG noted that changing the length at A_{max} changed the trajectories of spawning biomass and fishing mortality, but changing the L_{50} has less of an impact (Figure 22a, e). However, the models with different L_{50} parameters did not always converge with a positive definite Hessian. Additional work would be necessary to obtain a converged model and evaluate the impact of the different life history parameters.

Initial equilibrium catch

Initial conditions for this assessment are another major source of uncertainty. Initial equilibrium catch was fixed in the base-case model in order to estimate initial F. The WG pointed out that there was striped marlin landings before 1975, but these are highly uncertain (due to double counting between oceans, etc.). Historical catches range from 4,000 to 18,000 mt. The WG agreed to use 5,000 mt in the base case to be consistent with the previous assessment. It was noted that while the WG was able to estimate initial equilibrium catch in model runs starting in 1994, the 2015 stock assessment also fit to the initial equilibrium catch. The WG agreed that there was not sufficient evidence to change the initial equilibrium catch from the 2015 level. Sensitivity analyses fitted to different levels of initial equilibrium catch showed slightly different levels of estimated fishing intensity and female SSB compared to the base-case model (Figure 22f).

R_0 Profile

The WG discussed the information provided to estimate the equilibrium recruitment parameter, R_0, on the natural log scale, log(R_0), in this stock assessment. The WG observed that there was a much larger change in the R_0 profile for estimated recruitment deviations (recruitment, Figure 8) relative to the likelihood components for CPUE and length composition. The WG also noted that a large portion of the change in R_0 was determined by the initial equilibrium catch. Differences in the location of the minimum value along the R_0 profile were observed among likelihood components for estimated recruitment deviations and the likelihood components for CPUE and length composition. A two-stage Francis approach was applied aiming to reduce this conflict. After one iteration of CPUE reweighting, the conflict between individual CPUE time-series was reduced, but the conflict between CPUE and length composition data increased. The information provided by the initial equilibrium catch and the recruitment deviation remained dominant. The WG elected not to reweight the CPUE indices in order to reduce the conflict between the CPUE and length composition data, noting that reweighting the CPUE indices did not change the overall assessment results or the estimated value of R_0. It is important to note that it is desirable that the information provided to estimate R_0 come from data sources such as the CPUE indices and length composition.

ASPM diagnostic

Overall, the ASPM for the base case model does not follows the trend from the fully integrated stock assessment during the early part of the time series (1975-1995), and during the most recent years (2014-2017). However, for the period around 1995-2014, it seems that the changes in the abundance indices can be explained by the catches alone. These results indicate that during about 50% of the modeled time frame the abundance information, both absolute and relative, contained in the CPUE indices cannot be interpreted without accounting for the fluctuations in recruitment.

3.10. Special Comments

WG achieved a base-case model using best available data and biological information. However, the WG recognized that there is considerable uncertainty in input catch data including drift gillnet and initial catch amounts, life history parameters including maturation and growth, and stock structure. The WG considered an extensive suite of model formulations and associated diagnostics for developing the base-case assessment model. Overall, we found issues with the base case model diagnostics and sensitivity runs that indicated some data conflicts exist (see sections Assessment Challenges and Sensitivity Analyses). To improve the stock assessment, the WG also recommends continuing model development work, to reduce data conflicts and modeling uncertainties , and reevaluating and improving input assessment data. When developing a CMM to rebuild the resource, the WG recommends that these issues be recognized and carefully considered.

3.11. Conservation Advice

The WCNPO striped marlin stock has produced annual yields of around 2,173 mt per year since 2012, or about 40% of the MSY catch amount; however the majority of the catch are immature fish. Striped marlin stock status shows evidence of substantial depletion of spawning potential ($SSB_{Current}$ is 62% below SSB_{MSY}), however fishing mortality has fluctuated around F_{MSY} in the last 4 years. It was also noted that retrospective analyses show that the assessment model appears to underestimate spawning potential in recent years.

4. ACKNOWLEDGMENTS

We thank the fishery stakeholders, data providers, and participants in the ISC Billfish Working Group meetings for their help in preparing and providing information for this assessment of Western and Central North Pacific striped marlin.

5. REFERENCES

Brodziak, J. and Mangel, M. (2011). Probable values of stock-recruitment steepness for north Pacific striped marlin. ISC/11/BILLWG-2/11. Available at: http://isc.fra.go.jp/pdf/BILL/ISC11_BILL_2/ISC11BILLWG2_WP11.pdf

Brodziak, J., Mangel, M., and Sun, C.-L. (2015). Stock-recruitment resilience of North Pacific striped marlin based on reproductive ecology. Fisheries Research, 166:140-150. Available at: http://dx.doi.org/10.1016/j.fishres.2014.08.008

Brodziak, J., Rago, P. and Conser. R. (1998). A general approach for making short-term stochastic projections from an age-structured fisheries assessment model. In F. Funk, T. Quinn II, J. Heifetz, J. Ianelli, J. Powers, J. Schweigert, P. Sullivan, and C.-I. Zhang (eds), Proceedings of the International Symposium on Fishery Stock Assessment Models for the 21st Century. Alaska Sea Grant College Program, Univ. of Alaska, Fairbanks. Available at: https://www.researchgate.net/publication/267682539_A_General_Approach_for_Making_Short-Term_Stochastic_Projections_from_an_Age-Structured_Fisheries_Assessment_Model

Carvalho, F., Punt, A. E., Chang, Y.-J., Maunder, M. N., and Piner, K. R. (2017). Can diagnostic tests help identify model misspecification in integrated stock assessments? Fisheries Research, 192: 28-40.

Chang, Y., Yeh, S., Hsu, J., and Sun, C. (2019). Catch rate standardization of striped marlin in the Western and Central North Pacific Ocean by the Taiwanese tuna longline fisheries during 1989-2017. ISC/19/BILLWG-1/8.

Chang, H.-Y., Sun, C.-L., Yeh, S.-Z., Chang, Y.-J., Su, N.-J., and DiNardo, G. (2018). Reproductive biology of female striped marlin *Kajikia audax* in the western Pacific Ocean. Journal of Fish Biology, 92:105–130.

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

Graves, J.E., and McDowell, J.R. (1994). Genetic analysis of striped marlin (*Tetrapturus audax*) population structure in the Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences, 51:1762-1968.

Hastie, T. (2018) gam: Generalized Additive Models, Version 1.15. Available at: https://CRAN.R-project.org/package=gam

Humphreys, R. and Brodziak, J. (2019). Reproductive maturity of striped marlin, (*Kajikia audax*), in the central North Pacific off Hawaii. ISC/19/BILLWG-2/2.

Hurtado-Ferro, F., Szuwalski, C. S., Valero, J. L., Anderson, S. C., Cunningham, C. J., Johnson, K. F., Licandeo, R., McGilliard, C.R., Monnahan, C.C., Muradian, M.L., Ono, K., Vert-Pre, K.A. Whitten, A.R., and Punt, A.E. (2015). Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES Journal of Marine Science, 72: 99-110.

Ijima, H., and Kanaiwa, M. (2019a). Japanese longline CPUE of striped marlin (*Kajika audax*) in the WCNPO. ISC/19/BILLWG-1/7.

Ijima, H., and Kanaiwa, M. (2019b). Size-dependent distribution of Pacific striped marlin (*Kajikia audax*): The analysis of Japanese longline fishery data using the finite mixture model. ISC/19/BILLWG-1/9.

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC]. (2012). Stock assessment of striped marlin in the Western and Central North Pacific Ocean in 2011, Report of the Billfish Working Group Stock Assessment Workshop. July, Sapporo, Japan. ISC/SAR/MLS/2012. Available at: http://isc.ac.affrc.go.jp/pdf/Stock_assessment/ISC-BILLWG%202011%20Stock%20Assess ment%20of%20Striped%20Marlin.pdf

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. (2015). Annex 11: Report of the Billfish Working Group Workshop, Stock assessment update for striped marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2013, 15-20 July 2015. Kona, HI, USA. ISC/15/Annex11. Available at: http://isc.fra.go.jp/pdf/ISC15/Annex11_WCNPO_STM_ASSESSMENT_REPORT_2015.pdf

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. (2018). Annex 16: Stock assessment for swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean through 2016, 11-16 July 2018. Yeosu, Korea. ISC/18/Annex16. Available at: http://isc.fra.go.jp/pdf/ISC18/ISC_18_ANNEX_16_Stock_Assessment_of_WCNPO_Swordfish_through_2016_FINAL.pdf

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. (2019). Report of the Billfish Working Group Workshop, 14-21 January 2019. Honolulu, HI, USA. ISC/19/BILLWG-01/REPORT.

Ito, R. (2019). U.S. commercial fisheries for marlins in the North Pacific Ocean. ISC/19/BILLWG-1/01.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., Scott, F., and Scott, R.D. (2007). FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science, 64 (4): 640-646. Doi: 10.1093/icesjms/fsm012

Lee, H.-H., Piner, K. R., Methot Jr., R. D., and Maunder, M. N. (2014). Use of likelihood profiling over a global scaling parameter to structure the population dynamics model: An example using blue marlin in the Pacific Ocean. Fisheries Research 158: 138-146.

Mamoozadeh, N., McDowell, J., and Graves, J. 2018. Genetic population structure of striped marlin (*Kajikia audax*) in the Indian Ocean, with relationship to Pacific Ocean populations. Indian Ocean Tuna Commission, 16th Working Party on Billfish, IOTC-2018-WPB16-20, 23 p.

McDowell, J.R., and Graves, J.E. (2008). Population structure of striped marlin (*Kajikia audax*) in the Pacific Ocean based on analysis of microsatellite and mitochondrial DNA. Canadian Journal of Fisheries and Aquatic Sciences, 65:1307–1320.

Maunder, M. N., and Piner, K. R. (2015). Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science, 72: 7-18.

Methot, R.D. and Wetzel, C.R. (2013). Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142, 86–99.

Northern Committee Fourteenth Regular Session [NC14]. (2018). NC14 Summary Report, revision 1. Western and Central Pacific Fisheries Commission, Northern Committee Fourteenth Regular Session, Fukuoka, Japan 4 – 7 September 2018. Available at: https://www.wcpfc.int/meeting-folders/northern-committee .

Pennington, M., Burmeister, L. M., and Hjellvik, V. (2002). Assessing the precision of frequency distributions estimated from trawl-survey samples. Fishery Bulletin, US, 100: 74–81.

Piner, K.R. and Lee, H.H. 2011. Correction to meta-analysis of striped marlin natural mortality. ISC/11/BILLWG-2/08. Available at: http://isc.ac.affrc.go.jp/pdf/BILL/ISC11_BILL_2/ISC11BILLWG2_WP08.pdf

Purcell, C.M., and Edmands, S. (2011). Resolving the genetic structure of striped marlin, *Kajikia audax*, in the Pacific Ocean through spatial and temporal sampling of adult and immature fish. Canadian Journal of Fisheries and Aquatic Sciences, 68:1861–1875.

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sculley, M. (2019). Standardization of the striped marlin *Kajikia audax c*atch per unit effort data caught by the Hawaii-based longline fishery from 1994-2017 using generalized linear models. ISC/19/BILLWG-01/06.

Sippel, T.J., Davie, P.S., Holdsworth, J.C., and Block, B.A. (2007). Striped marlin (*Tetrapturus audax*) movements and habitat utilization during a summer and autumn in the Southwest Pacific Ocean. Fisheries Oceanography, 16:459–472.

Sippel, T., Holdsworth, J., Dennis, T., and Montgomery, J. (2011). Investigating behavior and population dynamics of striped marlin (*Kajikia audax*) from the southwest Pacific Ocean with satellite tags. PLoS One 6, e21087.

Sun, C.L., Hsu, W.S., Chang, Y.J., Yeh, S.Z., Chiang, W.C., and Su, N.J. (2011a). Age and growth of striped marlin (*Kajikia audax*) in waters off Taiwan: A revision. Working paper submitted to the ISC Billfish Working Group Meeting, 24 May-1 June 2011, Taipei, Taiwan. ISC/11/BILLWG-2/07: 12p. Available at: http://isc.ac.affrc.go.jp/pdf/BILL/ISC11_BILL_2/ISC11BILLWG2_WP07.pdf

Sun, C.L., Hsu, W.S., Chang, Y.J., Yeh, S.Z., Chiang, W.C., and Su, N.J. (2011b). Reproductive biology of male striped marlin, Kajikia audax, in the waters off Taiwan. Working paper submitted to the ISC Billfish Working Group Meeting, 24 May-1 June 2011, Taipei, Taiwan. ISC/11/BILLWG-2/09.

6. TABLES

Table 1. Descriptions of fisheries catch and abundance indices included in the base case model for the stock assessment including fishing countries, time-period, and reference sources for CPUE standardizations.

Catch Index	Abundance Index	Fleet Name	Time Period	Source
F1	S1	JPNLL_Q1A1_Late	1994-2017	Ijima and Kanaiwa (2019)
F2	-	JPNLL_Q1A2	1975-2017	
F3	-	JPNLL_Q1A3	1975-2017	
F4	-	JPNLL_Q2A1	1975-2017	
F5	S2	JPNLL_Q3A1_Late	1994-2017	Ijima and Kanaiwa (2019)
F6	-	JPNLL_Q4A1	1975-2017	
F7	-	JPNLL_Q1A4	1975-2017	
F8	-	JPNLL_Q2A2	1975-2017	
F9	-	JPNLL_Q3A2	1975-2017	
F10	-	JPNLL_Q4A2	1975-2017	
F11	-	JPNLL_Q4A3	1975-2017	
F12	-	JPNLL_Others	1975-2017	
F13	-	JPNDF_Q14	1975-2017	
F14	-	JPNDF_Q23	1975-2017	
F15	-	JPN_Others	1975-2017	
F16	S3	US_LL	1987-2017	Sculley (2019)
F17	-	US_Others	1987-2017	Chang *et al.* (2019)
F18	S4	TWN_DWLL	1967-2017	
F19	S5	TWN_STLL	1958-2017	
F20	-	TWN_Others	1958-2017	
F21	-	WCPFC_Others	1975-2017	
F22	S6	JPNLL_Q1A1_Early	1975-1993	Ijima and Kanaiwa (2019)
F23	S7	JPNLL_Q3A1_Early	1975-1993	Ijima and Kanaiwa (2019)

Table 2. Time series of catch by fleet submitted for the 2018 North Pacific striped marlin stock assessment Fleets 1-11 and 22-23 are in numbers of fish, fleets 12-21 are in metric tons. See Table 1 for and explanation of fleet numbers

		Fleet											
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1975	1	-	8100	8628	-	-	-	195	-	-	-	-	81
1975	2	-	-	-	12285	-	-	-	439	-	-	-	81
1975	3	-	-	-	-	-	-	-	-	297	-	-	81
1975	4	-	-	-	-	-	11013	-	-	-	675	264	81
1976	1	-	10524	6635	-	-	-	260	-	-	-	-	69.5
1976	2	-	-	-	11119	-	-	-	987	-	-	-	69.5
1976	3	-	-	-	-	-	-	-	-	374	-	-	69.5
1976	4	-	-	-	-	-	12176	-	-	-	1942	347	69.5
1977	1	-	8005	4006	-	-	-	58	-	-	-	-	67.75
1977	2	-	-	-	8691	-	-	-	569	-	-	-	67.75
1977	3	-	-	-	-	-	-	-	-	124	-	-	67.75
1977	4	-	-	-	-	-	7456	-	-	-	2095	168	67.75
1978	1	-	6689	3309	-	-	-	81	-	-	-	-	67.5
1978	2	-	-	-	13233	-	-	-	1096	-	-	-	67.5
1978	3	-	-	-	-	-	-	-	-	191	-	-	67.5
1978	4	-	-	-	-	-	11592	-	-	-	3925	156	67.5
1979	1	-	11708	11827	-	-	-	360	-	-	-	-	96.75
1979	2	-	-	-	32730	-	-	-	1115	-	-	-	96.75
1979	3	-	-	-	-	-	-	-	-	378	-	-	96.75
1979	4	-	-	-	-	-	13646	-	-	-	3257	265	96.75
1980	1	-	14348	21479	-	-	-	594	-	-	-	-	153
1980	2	-	-	-	22548	-	-	-	692	-	-	-	153
1980	3	-	-	-	-	-	-	-	-	149	-	-	153
1980	4	-	-	-	-	-	12889	-	-	-	622	164	153
1981	1	-	10297	10837	-	-	-	171	-	-	-	-	67.75
1981	2	-	-	-	14692	-	-	-	476	-	-	-	67.75
1981	3	-	-	-	-	-	-	-	-	418	-	-	67.75
1981	4	-	-	-	-	-	11809	-	-	-	245	95	67.75
1982	1	-	8491	10546	-	-	-	147	-	-	-	-	70.75
1982	2	-	-	-	12399	-	-	-	484	-	-	-	70.75
1982	3	-	-	-	-	-	-	-	-	117	-	-	70.75
1982	4	-	-	-	-	-	5461	-	-	-	168	89	70.75
1983	1	-	5726	4747	-	-	-	254	-	-	-	-	82.5
1983	2	-	-	-	11098	-	-	-	327	-	-	-	82.5
1983	3	-	-	-	-	-	-	-	-	194	-	-	82.5
1983	4	-	-	-	-	-	8888	-	-	-	86	65	82.5
1984	1	-	8796	4280	-	-	-	164	-	-	-	-	98.75
1984	2	-	-	-	13655	-	-	-	254	-	-	-	98.75
1984	3	-	-	-	-	-	-	-	-	274	-	-	98.75

		Fleet											
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1984	4	-	-	-	-	-	17912	-	-	-	211	172	98.75
1985	1	-	9227	8269	-	-	-	234	-	-	-	-	183.75
1985	2	-	-	-	35272	-	-	-	708	-	-	-	183.75
1985	3	-	-	-	-	-	-	-	-	122	-	-	183.75
1985	4	-	-	-	-	-	10070	-	-	-	549	173	183.75
1986	1	-	17703	16378	-	-	-	488	-	-	-	-	233.5
1986	2	-	-	-	47991	-	-	-	458	-	-	-	233.5
1986	3	-	-	-	-	-	-	-	-	93	-	-	233.5
1986	4	-	-	-	-	-	15907	-	-	-	607	126	233.5
1987	1	-	8607	7807	-	-	-	172	-	-	-	-	298.25
1987	2	-	-	-	25529	-	-	-	626	-	-	-	298.25
1987	3	-	-	-	-	-	-	-	-	247	-	-	298.25
1987	4	-	-	-	-	-	15723	-	-	-	1308	113	298.25
1988	1	-	9421	26842	-	-	-	135	-	-	-	-	189.75
1988	2	-	-	-	43422	-	-	-	329	-	-	-	189.75
1988	3	-	-	-	-	-	-	-	-	135	-	-	189.75
1988	4	-	-	-	-	-	22434	-	-	-	3539	42	189.75
1989	1	-	7813	14446	-	-	-	139	-	-	-	-	273.5
1989	2	-	-	-	29436	-	-	-	320	-	-	-	273.5
1989	3	-	-	-	-	-	-	-	-	98	-	-	273.5
1989	4	-	-	-	-	-	11305	-	-	-	2363	98	273.5
1990	1	-	4774	9562	-	-	-	38	-	-	-	-	282
1990	2	-	-	-	16998	-	-	-	179	-	-	-	282
1990	3	-	-	-	-	-	-	-	-	240	-	-	282
1990	4	-	-	-	-	-	6787	-	-	-	1395	139	282
1991	1	-	6825	14061	-	-	-	118	-	-	-	-	300
1991	2	-	-	-	24026	-	-	-	216	-	-	-	300
1991	3	-	-	-	-	-	-	-	-	501	-	-	300
1991	4	-	-	-	-	-	11545	-	-	-	1093	48	300
1992	1	-	4309	11271	-	-	-	213	-	-	-	-	314.25
1992	2	-	-	-	23584	-	-	-	432	-	-	-	314.25
1992	3	-	-	-	-	-	-	-	-	732	-	-	314.25
1992	4	-	-	-	-	-	8842	-	-	-	1527	137	314.25
1993	1	-	7723	16814	-	-	-	81	-	-	-	-	431
1993	2	-	-	-	28776	-	-	-	328	-	-	-	431
1993	3	-	-	-	-	-	-	-	-	153	-	-	431
1993	4	-	-	-	-	-	19100	-	-	-	2369	129	431
1994	1	2268	10394	23330	-	-	-	390	-	-	-	-	91.9
1994	2	-	-	-	37664	-	-	-	464	-	-	-	91.9
1994	3	-	-	-	-	12086	-	-	-	732	-	-	91.9
1994	4	-	-	-	-	-	32594	-	-	-	2352	248	91.9
1995	1	2604	8838	18128	-	-	-	142	-	-	-	-	64.5

		Fleet											
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1995	2	-	-	-	33438	-	-	-	276	-	-	-	64.5
1995	3	-	-	-	-	22252	-	-	-	178	-	-	64.5
1995	4	-	-	-	-	-	41026	-	-	-	6272	138	64.5
1996	1	2066	6112	14918	-	-	-	320	-	-	-	-	173.7
1996	2	-	-	-	36874	-	-	-	602	-	-	-	173.7
1996	3	-	-	-	-	8978	-	-	-	1228	-	-	173.7
1996	4	-	-	-	-	-	15502	-	-	-	1178	378	173.7
1997	1	1370	4432	12460	-	-	-	186	-	-	-	-	61.3
1997	2	-	-	-	24946	-	-	-	324	-	-	-	61.3
1997	3	-	-	-	-	10346	-	-	-	336	-	-	61.3
1997	4	-	-	-	-	-	15206	-	-	-	604	84	61.3
1998	1	950	3484	8012	-	-	-	252	-	-	-	-	78.1
1998	2	-	-	-	29796	-	-	-	544	-	-	-	78.1
1998	3	-	-	-	-	18038	-	-	-	652	-	-	78.1
1998	4	-	-	-	-	-	15084	-	-	-	1628	548	78.1
1999	1	1874	5824	13622	-	-	-	476	-	-	-	-	138.7
1999	2	-	-	-	24776	-	-	-	632	-	-	-	138.7
1999	3	-	-	-	-	11240	-	-	-	306	-	-	138.7
1999	4	-	-	-	-	-	11124	-	-	-	1988	240	138.7
2000	1	442	4658	9348	-	-	-	142	-	-	-	-	85.8
2000	2	-	-	-	7240	-	-	-	392	-	-	-	85.8
2000	3	-	-	-	-	12534	-	-	-	148	-	-	85.8
2000	4	-	-	-	-	-	10064	-	-	-	1550	116	85.8
2001	1	616	5004	9950	-	-	-	158	-	-	-	-	88.9
2001	2	-	-	-	7154	-	-	-	506	-	-	-	88.9
2001	3	-	-	-	-	12840	-	-	-	282	-	-	88.9
2001	4	-	-	-	-	-	9878	-	-	-	1566	226	88.9
2002	1	386	4770	6610	-	-	-	114	-	-	-	-	3.0
2002	2	-	-	-	8062	-	-	-	500	-	-	-	3.0
2002	3	-	-	-	-	4596	-	-	-	202	-	-	3.0
2002	4	-	-	-	-	-	4962	-	-	-	586	194	3.0
2003	1	430	5600	12152	-	-	-	160	-	-	-	-	49.2
2003	2	-	-	-	7010	-	-	-	128	-	-	-	49.2
2003	3	-	-	-	-	10510	-	-	-	578	-	-	49.2
2003	4	-	-	-	-	-	7756	-	-	-	1400	132	49.2
2004	1	974	3952	7252	-	-	-	96	-	-	-	-	31.1
2004	2	-	-	-	3084	-	-	-	138	-	-	-	31.1
2004	3	-	-	-	-	5406	-	-	-	196	-	-	31.1
2004	4	-	-	-	-	-	6842	-	-	-	1044	122	31.1
2005	1	424	1844	4170	-	-	-	44	-	-	-	-	27.6
2005	2	-	-	-	3882	-	-	-	166	-	-	-	27.6
2005	3	-	-	-	-	3318	-	-	-	110	-	-	27.6

		Fleet											
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2005	4	-	-	-	-	-	4548	-	-	-	1378	56	27.6
2006	1	250	1848	3810	-	-	-	20	-	-	-	-	19.9
2006	2	-	-	-	6210	-	-	-	80	-	-	-	19.9
2006	3	-	-	-	-	4592	-	-	-	58	-	-	19.9
2006	4	-	-	-	-	-	3850	-	-	-	1100	50	19.9
2007	1	680	1672	2370	-	-	-	12	-	-	-	-	30.9
2007	2	-	-	-	2168	-	-	-	68	-	-	-	30.9
2007	3	-	-	-	-	2070	-	-	-	114	-	-	30.9
2007	4	-	-	-	-	-	4560	-	-	-	872	6	30.9
2008	1	556	2328	2676	-	-	-	6	-	-	-	-	38.6
2008	2	-	-	-	2432	-	-	-	130	-	-	-	38.6
2008	3	-	-	-	-	2008	-	-	-	60	-	-	38.6
2008	4	-	-	-	-	-	7658	-	-	-	1240	208	38.6
2009	1	180	712	2516	-	-	-	4	-	-	-	-	44.2
2009	2	-	-	-	666	-	-	-	30	-	-	-	44.2
2009	3	-	-	-	-	1020	-	-	-	20	-	-	44.2
2009	4	-	-	-	-	-	1612	-	-	-	182	28	44.2
2010	1	210	830	1274	-	-	-	22	-	-	-	-	53.8
2010	2	-	-	-	1326	-	-	-	574	-	-	-	53.8
2010	3	-	-	-	-	1420	-	-	-	406	-	-	53.8
2010	4	-	-	-	-	-	1482	-	-	-	80	312	53.8
2011	1	200	10632	3660	-	-	-	130	-	-	-	-	63.4
2011	2	-	-	-	1594	-	-	-	520	-	-	-	63.4
2011	3	-	-	-	-	1686	-	-	-	46	-	-	63.4
2011	4	-	-	-	-	-	2950	-	-	-	432	422	63.4
2012	1	600	3392	5296	-	-	-	50	-	-	-	-	53.4
2012	2	-	-	-	2594	-	-	-	66	-	-	-	53.4
2012	3	-	-	-	-	1940	-	-	-	26	-	-	53.4
2012	4	-	-	-	-	-	3016	-	-	-	272	22	53.4
2013	1	420	2306	3332	-	-	-	32	-	-	-	-	65.2
2013	2	-	-	-	6200	-	-	-	376	-	-	-	65.2
2013	3	-	-	-	-	1418	-	-	-	24	-	-	65.2
2013	4	-	-	-	-	-	2182	-	-	-	684	34	65.2
2014	1	362	1468	6740	-	-	-	20	-	-	-	-	58.6
2014	2	-	-	-	2886	-	-	-	112	-	-	-	58.6
2014	3	-	-	-	-	1516	-	-	-	104	-	-	58.6
2014	4	-	-	-	-	-	2614	-	-	-	120	98	58.6
2015	1	318	2272	3802	-	-	-	28	-	-	-	-	67.3
2015	2	-	-	-	3064	-	-	-	64	-	-	-	67.3
2015	3	-	-	-	-	1282	-	-	-	172	-	-	67.3
2015	4	-	-	-	-	-	1396	-	-	-	50	46	67.3
2016	1	822	838	1518	-	-	-	12	-	-	-	-	54.3

		Fleet											
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2016	2	-	-	-	2510	-	-	-	58	-	-	-	54.3
2016	3	-	-	-	-	3076	-	-	-	162	-	-	54.3
2016	4	-	-	-	-	-	2026	-	-	-	32	44	54.3
2017	1	3877	2280	2353	-	-	-	7	-	-	-	-	53.3
2017	2	-	-	-	4757	-	-	-	25	-	-	-	53.3
2017	3	-	-	-	-	1475	-	-	-	87	-	-	53.3
2017	4	-	-	-	-	-	2301	-	-	-	38	53	53.3

		Fleet										
Year	**Quarter**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1975	1	1058	-	171.5	24.2	0	16	183	24	5.2	854	-
1975	2	-	446	171.5	11.0	0	16	183	24	36.7	-	-
1975	3	-	3549	171.5	42.8	0	16	183	24	15.7	-	7954
1975	4	1482	-	171.5	15.3	0	16	183	24	19.6	-	-
1976	1	577	-	146.25	15.8	0	8	86.75	35	10.2	1778	-
1976	2	-	243	146.25	23.2	0	8	86.75	35	6.4	-	-
1976	3	-	1934	146.25	43.3	0	8	86.75	35	9.1	-	3261
1976	4	807	-	146.25	27.2	0	8	86.75	35	27.6	-	-
1977	1	716	-	136.75	7.6	0	4.25	131	54.75	11.5	1319	-
1977	2	-	302	136.75	16.0	0	4.25	131	54.75	9.7	-	-
1977	3	-	2403	136.75	4.7	0	4.25	131	54.75	5.9	-	2289
1977	4	1003	-	136.75	18.4	0	4.25	131	54.75	2.9	-	-
1978	1	906	-	136.5	22.0	0	0	154.5	19.5	21.9	625	-
1978	2	-	381	136.5	22.0	0	0	154.5	19.5	9.9	-	-
1978	3	-	3038	136.5	7.3	0	0	154.5	19.5	16.9	-	2838
1978	4	1268	-	136.5	22.0	0	0	154.5	19.5	33.1	-	-
1979	1	410	-	131.5	29.6	0	6.5	108	30.5	28.3	961	-
1979	2	-	173	131.5	29.6	0	6.5	108	30.5	14.7	-	-
1979	3	-	1375	131.5	9.9	0	6.5	108	30.5	11.5	-	5720
1979	4	574	-	131.5	29.6	0	6.5	108	30.5	23.8	-	-
1980	1	561	-	134	39.5	0	15.25	55.75	32.875	5.7	891	-
1980	2	-	236	134	39.5	0	15.25	55.75	32.875	2.9	-	-
1980	3	-	1883	134	13.2	0	15.25	55.75	32.875	0	-	5943
1980	4	786	-	134	39.5	0	15.25	55.75	32.875	1.8	-	-
1981	1	626	-	135.5	47.2	0	4	122.75	23.75	52.0	1333	-
1981	2	-	264	135.5	47.2	0	4	122.75	23.75	24.2	-	-
1981	3	-	2100	135.5	15.7	0	4	122.75	23.75	16.6	-	3462
1981	4	877	-	135.5	47.2	0	4	122.75	23.75	32.5	-	-
1982	1	381	-	164	55.8	0	1.75	99.25	34.5	43.6	791	-
1982	2	-	160	164	55.8	0	1.75	99.25	34.5	23.5	-	-

									Fleet			
Year	**Quarter**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1982	3	-	1277	164	18.6	0	1.75	99.25	34.5	21.0	-	3240
1982	4	533	-	164	55.8	0	1.75	99.25	34.5	13.8	-	-
1983	1	298	-	212.25	65.0	0	0	138.75	53.5	12.9	874	-
1983	2	-	126	212.25	65.0	0	0	138.75	53.5	0.7	-	-
1983	3	-	1000	212.25	21.7	0	0	138.75	53.5	1.3	-	2725
1983	4	418	-	212.25	65.0	0	0	138.75	53.5	2.5	-	-
1984	1	358	-	198.75	74.2	0	0	241.25	82.5	35.3	1540	-
1984	2	-	151	198.75	74.2	0	0	241.25	82.5	4.8	-	-
1984	3	-	1200	198.75	24.8	0	0	241.25	82.5	6.3	-	5502
1984	4	501	-	198.75	74.2	0	0	241.25	82.5	26.0	-	-
1985	1	374	-	193.25	82.2	0	0	128.25	45.25	13.1	1666	-
1985	2	-	157	193.25	82.2	0	0	128.25	45.25	5.5	-	-
1985	3	-	1253	193.25	27.4	0	0	128.25	45.25	24.1	-	15561
1985	4	523	-	193.25	82.2	0	0	128.25	45.25	13.8	-	-
1986	1	568	-	156.25	91.1	0	0	44.75	37	11.7	1280	-
1986	2	-	239	156.25	91.1	0	0	44.75	37	3.8	-	-
1986	3	-	1906	156.25	30.4	0	0	44.75	37	6.9	-	9714
1986	4	796	-	156.25	91.1	0	0	44.75	37	38.9	-	-
1987	1	300	-	136.25	35.6	7.75	7.75	95.75	37.75	26.4	1357	-
1987	2	-	126	136.25	85.8	7.75	7.75	95.75	37.75	20.3	-	-
1987	3	-	1007	136.25	15.2	7.75	7.75	95.75	37.75	11.9	-	6846
1987	4	420	-	136.25	140.0	7.75	7.75	95.75	37.75	15.0	-	-
1988	1	334	-	180.5	130.3	13.75	1.75	114.25	42.25	45.0	2544	-
1988	2	-	141	180.5	177.2	13.75	1.75	114.25	42.25	1.7	-	-
1988	3	-	1119	180.5	8.5	13.75	1.75	114.25	42.25	6.3	-	13879
1988	4	467	-	180.5	166.6	13.75	1.75	114.25	42.25	7.3	-	-
1989	1	217	-	159.75	174.7	6	1.5	46	39.25	18.4	1382	-
1989	2	-	92	159.75	257.3	6	1.5	46	39.25	3.4	-	-
1989	3	-	729	159.75	17.5	6	1.5	46	39.25	7.0	-	8640
1989	4	305	-	159.75	137.4	6	1.5	46	39.25	11.9	-	-
1990	1	300	-	141	114.5	6.75	0.5	34.25	64	16.4	1460	-
1990	2	-	126	141	205.8	6.75	0.5	34.25	64	5.3	-	-
1990	3	-	1005	141	35.4	6.75	0.5	34.25	64	2.0	-	6174
1990	4	419	-	141	128.0	6.75	0.5	34.25	64	5.7	-	-
1991	1	211	-	133.5	103.1	10	9	63.5	71.5	8.1	667	-
1991	2	-	89	133.5	239.6	10	9	63.5	71.5	0.6	-	-
1991	3	-	707	133.5	61.9	10	9	63.5	71.5	0.2	-	7676
1991	4	295	-	133.5	145.2	10	9	63.5	71.5	3.1	-	-
1992	1	189	-	84.5	134.3	9.75	0.25	54.75	49.25	19.4	769	-
1992	2	-	80	84.5	181.5	9.75	0.25	54.75	49.25	16.0	-	-
1992	3	-	635	84.5	69.8	9.75	0.25	54.75	49.25	5.9	-	8629
1992	4	265	-	84.5	159.9	9.75	0.25	54.75	49.25	8.0	-	-

		Fleet										
Year	**Quarter**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1993	1	134	-	177	104.7	17.25	1.25	55.25	35.5	35.4	917	-
1993	2	-	56	177	202.8	17.25	1.25	55.25	35.5	16.6	-	-
1993	3	-	450	177	55.3	17.25	1.25	55.25	35.5	4.0	-	9876
1993	4	188	-	177	169.8	17.25	1.25	55.25	35.5	6.9	-	-
1994	1	234	-	95.75	108.6	8.5	0.25	34.25	49	40.6	-	-
1994	2	-	98	95.75	142.4	8.5	0.25	34.25	49	15.4	-	-
1994	3	-	784	95.75	32.4	8.5	0.25	34.25	49	21.6	-	-
1994	4	327	-	95.75	79.9	8.5	0.25	34.25	49	23.7	-	-
1995	1	157	-	70.75	105.3	13	6.75	20.75	20.5	46.8	-	-
1995	2	-	66	70.75	201.1	13	6.75	20.75	20.5	27.2	-	-
1995	3	-	527	70.75	96.5	13	6.75	20.75	20.5	12.0	-	-
1995	4	220	-	70.75	335.3	13	6.75	20.75	20.5	24.0	-	-
1996	1	114	-	38	156.4	13.75	6.5	40.5	11.75	18.4	-	-
1996	2	-	48	38	167.4	13.75	6.5	40.5	11.75	6.7	-	-
1996	3	-	382	38	63.7	13.75	6.5	40.5	11.75	8.1	-	-
1996	4	159	-	38	127.7	13.75	6.5	40.5	11.75	30.7	-	-
1997	1	132	-	40.75	95.8	9.75	14.75	72.5	11.75	12.9	-	-
1997	2	-	55	40.75	246.6	9.75	14.75	72.5	11.75	5.5	-	-
1997	3	-	442	40.75	32.1	9.75	14.75	72.5	11.75	9.7	-	-
1997	4	184	-	40.75	93.5	9.75	14.75	72.5	11.75	36.5	-	-
1998	1	177	-	76	79.3	6.5	22.5	51.25	12.5	38.4	-	-
1998	2	-	74	76	116.1	6.5	22.5	51.25	12.5	22.0	-	-
1998	3	-	593	76	64.3	6.5	22.5	51.25	12.5	48.1	-	-
1998	4	248	-	76	239.3	6.5	22.5	51.25	12.5	112.5	-	-
1999	1	182	-	46	118.5	7.25	16.5	32	10.5	63.9	-	-
1999	2	-	77	46	133.9	7.25	16.5	32	10.5	43.2	-	-
1999	3	-	612	46	69.7	7.25	16.5	32	10.5	26.9	-	-
1999	4	255	-	46	129.0	7.25	16.5	32	10.5	31.3	-	-
2000	1	172	-	74.25	69.8	3.75	22.5	40.25	13.75	18.5	-	-
2000	2	-	72	74.25	90.6	3.75	22.5	40.25	13.75	11.2	-	-
2000	3	-	577	74.25	21.5	3.75	22.5	40.25	13.75	26.9	-	-
2000	4	241	-	74.25	51.3	3.75	22.5	40.25	13.75	18.8	-	-
2001	1	174	-	59.25	71.9	11	5.25	32.25	12.75	5.0	-	-
2001	2	-	73	59.25	95.4	11	5.25	32.25	12.75	14.2	-	-
2001	3	-	585	59.25	31.1	11	5.25	32.25	12.75	8.9	-	-
2001	4	244	-	59.25	217.0	11	5.25	32.25	12.75	7.7	-	-
2002	1	205	-	72.5	72.5	7.5	12.75	56.5	7.25	35.3	-	-
2002	2	-	86	72.5	56.4	7.5	12.75	56.5	7.25	56.0	-	-
2002	3	-	686	72.5	13.9	7.5	12.75	56.5	7.25	19.5	-	-
2002	4	287	-	72.5	89.3	7.5	12.75	56.5	7.25	28.8	-	-
2003	1	172	-	50.75	288.2	7.5	43	170.25	10.75	105.9	-	-
2003	2	-	73	50.75	113.0	7.5	43	170.25	10.75	34.2	-	-

									Fleet			
Year	**Quarter**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
2003	3	-	578	50.75	55.8	7.5	43	170.25	10.75	13.3	-	-
2003	4	241	-	50.75	302.2	7.5	43	170.25	10.75	58.4	-	-
2004	1	217	-	22.5	185.2	8.75	57	65.25	6	65.8	-	-
2004	2	-	91	22.5	89.2	8.75	57	65.25	6	13.2	-	-
2004	3	-	727	22.5	48.0	8.75	57	65.25	6	23.7	-	-
2004	4	304	-	22.5	137.6	8.75	57	65.25	6	76.2	-	-
2005	1	197	-	24.5	317.7	5	44	146	8	122.7	-	-
2005	2	-	83	24.5	240.2	5	44	146	8	10.1	-	-
2005	3	-	659	24.5	68.2	5	44	146	8	15.5	-	-
2005	4	275	-	24.5	107.0	5	44	146	8	44.7	-	-
2006	1	193	-	23.75	154.9	5.25	33.5	134.25	36.75	57.4	-	-
2006	2	-	81	23.75	164.0	5.25	33.5	134.25	36.75	28.7	-	-
2006	3	-	646	23.75	138.3	5.25	33.5	134.25	36.75	52.1	-	-
2006	4	270	-	23.75	247.4	5.25	33.5	134.25	36.75	90.8	-	-
2007	1	157	-	19.75	139.9	3.25	22.25	49.75	42.5	28.6	-	-
2007	2	-	66	19.75	110.0	3.25	22.25	49.75	42.5	4.1	-	-
2007	3	-	527	19.75	53.8	3.25	22.25	49.75	42.5	1.9	-	-
2007	4	220	-	19.75	44.6	3.25	22.25	49.75	42.5	18.6	-	-
2008	1	211	-	24.25	83.5	3.5	18	48	53.25	87.4	-	-
2008	2	-	89	24.25	212.0	3.5	18	48	53.25	34.1	-	-
2008	3	-	707	24.25	58.8	3.5	18	48	53.25	25.3	-	-
2008	4	295	-	24.25	122.5	3.5	18	48	53.25	57.0	-	-
2009	1	133	-	22.5	92.1	2.5	7.5	56.25	34.5	26.5	-	-
2009	2	-	56	22.5	114.3	2.5	7.5	56.25	34.5	21.2	-	-
2009	3	-	446	22.5	66.5	2.5	7.5	56.25	34.5	7.3	-	-
2009	4	186	-	22.5	79.2	2.5	7.5	56.25	34.5	14.5	-	-
2010	1	148	-	20.5	45.9	4.75	8	50	44	13.1	-	-
2010	2	-	62	20.5	45.9	4.75	8	50	44	12.8	-	-
2010	3	-	496	20.5	45.9	4.75	8	50	44	52.4	-	-
2010	4	207	-	20.5	45.9	4.75	8	50	44	48.7	-	-
2011	1	56	-	22	100.38	4	13.25	67.25	31.75	79.5	-	-
2011	2	-	24	22	100.38	4	13.25	67.25	31.75	99.3	-	-
2011	3	-	188	22	100.38	4	13.25	67.25	31.75	29.6	-	-
2011	4	79	-	22	100.38	4	13.25	67.25	31.75	24.9	-	-
2012	1	97	-	29.75	77.55	2.75	18.25	88	37.5	112.6	-	-
2012	2	-	41	29.75	77.55	2.75	18.25	88	37.5	55.0	-	-
2012	3	-	324	29.75	77.55	2.75	18.25	88	37.5	36.5	-	-
2012	4	135	-	29.75	77.55	2.75	18.25	88	37.5	31.1	-	-
2013	1	54	-	23	109.73	2	16.75	71.25	55	39.6	-	-
2013	2	-	23	23	109.73	2	16.75	71.25	55	18.8	-	-
2013	3	-	182	23	109.73	2	16.75	71.25	55	8.1	-	-
2013	4	76	-	23	109.73	2	16.75	71.25	55	8.9	-	-

		Fleet										
Year	**Quarter**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
2014	1	28	-	14.25	117.15	3	4.2	28.75	17.45	22.9	-	-
2014	2	-	12	14.25	117.15	3	4.2	28.75	17.45	15.6	-	-
2014	3	-	94	14.25	117.15	3	4.2	28.75	17.45	14.8	-	-
2014	4	39	-	14.25	117.15	3	4.2	28.75	17.45	10.3	-	-
2015	1	46	-	25.25	134.75	2.75	8.325	45.25	8.23	32.5	-	-
2015	2	-	20	25.25	134.75	2.75	8.325	45.25	8.23	14.1	-	-
2015	3	-	156	25.25	134.75	2.75	8.325	45.25	8.23	5.2	-	-
2015	4	65	-	25.25	134.75	2.75	8.325	45.25	8.23	28.4	-	-
2016	1	50	-	24.5	106.15	3	14.5	33.75	6.08	37.5	-	-
2016	2	-	21	24.5	106.15	3	14.5	33.75	6.08	20.7	-	-
2016	3	-	167	24.5	106.15	3	14.5	33.75	6.08	9.2	-	-
2016	4	70	-	24.5	106.15	3	14.5	33.75	6.08	17.6	-	-
2017	1	50	-	24.5	113.03	1.5	18	72.75	12.08	85.0	-	-
2017	2	-	21	24.5	113.03	1.5	18	72.75	12.08	21.2	-	-
2017	3	-	167	24.5	113.03	1.5	18	72.75	12.08	16.7	-	-
2017	4	70	-	24.5	113.03	1.5	18	72.75	12.08	68.5	-	-

Table 3. List of fleets with catch used in the base-case assessment model along with CPUE indices provided for the 2019 Western Central North Pacific Ocean striped marlin stock assessment, their source and whether the indices were used in the base-case assessment model.

Length Comp – Used?	Relative Abundance Index – Used?	Fleet Name	Time Series	Source
F1 – Y	S1 – N	JPNLL_Q1A1_Late	1994-2017	Ijima and Kanaiwa (2019)
F2 - Y	-	JPNLL_Q1A2	1975-2017	Hirotaka Ijima, pers. comm.
F3 - N	-	JPNLL_Q1A3	1975-2017	Hirotaka Ijima, pers. comm.
F4 – Y	-	JPNLL_Q2A1	1975-2017	Hirotaka Ijima, pers. comm.
F5 – Y	S2 – Y	JPNLL_Q3A1_Late	1994-2017	Ijima and Kanaiwa (2019)
F6 – Y	-	JPNLL_Q4A1	1975-2017	Hirotaka Ijima, pers. comm.
F7 – N	-	JPNLL_Q1A4	1975-2017	Hirotaka Ijima, pers. comm.
F8 – N	-	JPNLL_Q2A2	1975-2017	Hirotaka Ijima, pers. comm.
F9 – N	-	JPNLL_Q3A2	1975-2017	Hirotaka Ijima, pers. comm.
F10 – N	-	JPNLL_Q4A2	1975-2017	Hirotaka Ijima, pers. comm.
F11 – N	-	JPNLL_Q4A3	1975-2017	Hirotaka Ijima, pers. comm.
F12 – N	-	JPNLL_Others	1975-2017	Hirotaka Ijima, pers. comm.
F13 – Y	-	JPNDF_Q14	1975-2017	Hirotaka Ijima, pers. comm.
F14 – Y	-	JPNDF_Q23	1975-2017	Hirotaka Ijima, pers. comm.
F15	-	JPN_Others	1975-2017	Hirotaka Ijima, pers. comm.
F16 – Y	S3 - Y	US_LL	1987-2017	Sculley (2019)
F17	-	US_Others	1987-2017	Ito (2019)
F18-Y	S4 – Y	TWN_DWLL	1967-2017	Chang *et al.* (2019)
F19	S5 – N	TWN_STLL	1958-2017	Yi-Jay Chang, pers. comm.
F20	-	TWN_Others	1958-2017	Yi-Jay Chang, pers. comm.
F21	-	WCPFC_Others	1975-2017	Peter Williams, pers. comm.
F22 – N	S6 – N	JPNLL_Q1A1_Early	1975-1993	Ijima and Kanaiwa (2019)
F23 – N	S7 – Y	JPNLL_Q3A1_Early	1975-1993	Ijima and Kanaiwa (2019)

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 striped marlin from the Western and Central North Pacific Ocean used in the stock assessment. Index descriptions can be found in Table 3.

Fleet	**S1**		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1976	-	-	-	-	-	-	-	-	-	-	0.67	0.46	0.87	0.34
1977	-	-	-	-	-	-	-	-	-	-	0.74	0.47	0.74	0.35
1978	-	-	-	-	-	-	-	-	-	-	0.34	0.51	0.78	0.38
1979	-	-	-	-	-	-	-	-	-	-	0.6	0.47	2.01	0.32
1980	-	-	-	-	-	-	-	-	-	-	0.96	0.50	2.41	0.32
1981	-	-	-	-	-	-	-	-	-	-	0.7	0.47	1.07	0.32
1982	-	-	-	-	-	-	-	-	-	-	0.42	0.46	0.85	0.32
1983	-	-	-	-	-	-	-	-	-	-	0.64	0.47	0.97	0.32
1984	-	-	-	-	-	-	-	-	-	-	0.82	0.46	1.56	0.32
1985	-	-	-	-	-	-	-	-	-	-	0.33	0.45	3.25	0.31
1986	-	-	-	-	-	-	-	-	-	-	0.45	0.46	2.12	0.31
1987	-	-	-	-	-	-	-	-	-	-	0.61	0.46	1.5	0.32
1988	-	-	-	-	-	-	-	-	-	-	0.5	0.45	1.98	0.31
1989	-	-	-	-	-	-	-	-	-	-	0.61	0.46	1.64	0.31
1990	-	-	-	-	-	-	-	-	-	-	0.49	0.45	1.67	0.32
1991	-	-	-	-	-	-	-	-	-	-	0.38	0.49	1.83	0.31
1992	-	-	-	-	-	-	-	-	-	-	0.65	0.48	1.72	0.31
1993	-	-	-	-	-	-	-	-	-	-	0.62	0.49	2.14	0.31
1994	0.51	0.37	1.84	0.43	-	-	-	-	-	-	-	-	-	-
1995	0.62	0.36	3.96	0.43	1.19	0.86	0.22	0.27	-	-	-	-	-	-
1996	1.22	0.36	1.72	0.43	0.98	0.74	0.13	0.35	-	-	-	-	-	-
1997	0.63	0.38	2.70	0.43	0.74	0.58	0.13	0.43	-	-	-	-	-	-
1998	0.74	0.39	3.54	0.43	0.83	0.64	0.05	0.58	-	-	-	-	-	-
1999	0.68	0.37	2.06	0.43	0.70	0.55	0.18	0.36	-	-	-	-	-	-
2000	0.29	0.46	2.37	0.43	0.55	0.43	0.10	0.39	-	-	-	-	-	-
2001	0.73	0.44	2.10	0.43	0.72	0.57	0.08	0.43	-	-	-	-	-	-
2002	0.43	0.49	1.71	0.43	0.42	0.32	0.16	0.32	-	-	-	-	-	-
2003	0.86	0.44	2.53	0.43	0.90	0.69	0.16	0.36	-	-	-	-	-	-
2004	0.48	0.42	1.23	0.44	0.55	0.43	0.22	0.32	-	-	-	-	-	-
2005	0.46	0.42	1.45	0.44	0.53	0.42	0.25	0.30	-	-	-	-	-	-
2006	0.47	0.53	1.14	0.44	0.54	0.43	0.14	0.34	-	-	-	-	-	-
2007	0.52	0.43	0.77	0.45	0.30	0.21	0.11	0.37	-	-	-	-	-	-
2008	0.30	0.41	1.04	0.45	0.39	0.30	0.10	0.38	0.05	0.35	-	-	-	-
2009	0.25	0.51	0.78	0.49	0.25	0.17	0.08	0.41	0.08	0.30	-	-	-	-
2010	0.35	0.48	0.49	0.52	0.18	0.12	0.11	0.41	0.07	0.30	-	-	-	-
2011	0.17	0.49	1.27	0.46	0.33	0.24	0.10	0.38	0.07	0.30	-	-	-	-
2012	0.74	0.40	0.57	0.49	0.28	0.19	0.15	0.31	0.13	0.26	-	-	-	-

Fleet	S1		S2		S3		S4		S5		S6		S7	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
2013	0.46	0.45	0.97	0.47	0.25	0.17	0.15	0.34	0.07	0.30	-	-	-	-
2014	0.28	0.45	1.17	0.45	0.35	0.26	0.07	0.48	0.06	0.31	-	-	-	-
2015	0.22	0.44	1.67	0.45	0.31	0.22	0.09	0.42	0.07	0.31	-	-	-	-
2016	0.27	0.40	1.35	0.45	0.30	0.21	0.10	0.42	0.05	0.32	-	-	-	-
2017	0.46	0.39	0.67	0.48	0.26	0.18	0.1	0.44	0.06	0.3	-	-	-	-

Table 5. Key life history parameters and model structures for Western and Central North Pacific striped marlin used in the stock assessment. The column labeled "Estimated ?" identifies if the parameters are expected to be estimated within the assessment model (Estimated), fixed at a specific value, i.e., not estimated (Fixed) from Table 9.0 in the BILLWG Data Preparatory report (ISC 2019).

Parameter	**Value**	**Comments**	**Source**
Gender	1	Structure	
Natural mortality	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)	Fixed	Piner and Lee (2011)
Reference age (A_{min})	0.3	Structure	ISC (2012)
Maximum age (A_{max})	15	Structure	ISC (2012)
Length at A_{min} (cm, EFL)	104	Fixed	Refit from Sun et al. (2011a); ISC (2012)
Length at A_{max} (cm, EFL)	214	Fixed	Refit from Sun et al. (2011a); ISC (2012)
Growth rate (k)	0.24	Fixed	Refit from Sun et al. (2011a); ISC (2012)
CV of Length at A_{min}	0.14	Fixed	ISC (2012)
CV of Length at A_{max}	0.08	Fixed	ISC (2012)
Weight-at-length	$W=4.68e\text{-}006\times L^{3.16}$	Fixed	Sun et al. (2011a)
Size-at-50% Maturity	161	Fixed	Humphries and Brodziak (2019)
Slope of maturity ogive	-0.082	Fixed	Chang et al. (2018)
Fecundity	Proportional to spawning biomass	Structure	
Spawning season (quarter)	2	Structure	Sun et al. (2011b)
Spawner-recruit relationship	Beverton-Holt	Structure	I
Spawner-recruit steepness (*h*)	0.87	Fixed	Brodziak et al. (2011); Brodziak et al. (2015)
Logarithm of Recruitment at virgin biomass $\log(R_0)$	-	Estimated	
Recruitment variability (σ_R)	0.6	Fixed	
Initial age structure (5 yr)	-	Estimated	
Recruitment deviations 1975-2017	-	Estimated	

Table 6. Mean input standard error (SE) in log-space (i.e., log(SE)) of lognormal error and root-mean-square-errors (RMSE) for the relative abundance indices for Western and Central North Pacific striped marlin used in the base-case model. S1 (JPNLL_Q1A1_late), S5 (TWN_STLL) and S6 (JPNLL_Q1A1_Early) were not included in the total likelihood.

Fleet	***N***	**Input log(SE)**	**RMSE**
S1_JPNLL_Q1A1_Late	24	0.43	0.44
S2_JPNJPNLL_Q3A1_Late	24	0.45	0.32
S3_US_LL	23	0.39	0.40
S4_TWN_DWLL	23	0.38	0.37
S5_TWN_STLL	10	0.31	0.30
S6_JPNLL_Q1A1_Early	18	0.47	0.45
S7_JPNLL_Q3A1_Early	18	0.32	0.18

Table 7. Fishery-specific selectivity assumptions for the Western and Central North Pacific striped 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.

Fleet	**Selectivity Function**
F1	Double-normal
F2	Double-normal
F3	Mirror F2
F4	Double-normal
F5	Double-normal
F6	Double-normal
F7	Mirror F2
F8	Mirror F4
F9	Mirror F5
F10	Mirror F6
F11	Mirror F6
F12	Mirror F4
F13	Asymptotic lognormal
F14	Asymptotic lognormal
F15	Mirror F4
F16	Double-normal
F17	Mirror F16
F18	Double-normal
F19	Mirror F18
F20	Mirror F14
F21	Mirror F12
F22	Mirror F1
F23	Mirror F5
S1	Mirror F1
S2	Mirror F5
S3	Mirror F16
S4	Mirror F18
S5	Mirror F18
S6	Mirror F1
S7	Mirror F5

Table 8. Stochastic projections conducted for the 2019 WCNPO striped marlin stock assessment.

Projection	Scenario		Value	Target	Years	Recruitment Scenario
1	**F-Based**	$F_{status\ quo}$ (Average F 2015-2017)	0.64	20% SSB	20	Long term
2		$F_{status\ quo}$ (Average F 2015-2017)	0.64	20% SSB	20	Short term
3		F_{MSY}	0.60	20% SSB	20	Long term
4		F_{MSY}	0.60	20% SSB	20	Short term
5		$F_{20\%SSB(F=0)}$	0.47	20% SSB	20	Long term
6		$F_{20\%SSB(F=0)}$	0.47	20% SSB	20	Short term
7		Highest F (Average F 1975-1977)	1.48	20% SSB	20	Long term
8		Highest F (Average F 1975-1977)	1.48	20% SSB	20	Short term
9		Low F ($F_{30\%}$)	0.32	20% SSB	20	Long term
10		Low F ($F_{30\%}$)	0.32	20% SSB	20	Short term
11	**Catch-Based**	Quota	3396.8	20% SSB	20	Long term
12		Quota	3396.8	20% SSB	20	Short term
13		10% Reduction	3057.1	20% SSB	20	Long term
14		10% Reduction	3057.1	20% SSB	20	Short term
15		20% Reduction	2717.4	20% SSB	20	Long term
16		20% Reduction	2717.4	20% SSB	20	Short term
17		30% Reduction	2377.8	20% SSB	20	Long term
18		30% Reduction	2377.8	20% SSB	20	Short term
19		40% Reduction	2038.1	20% SSB	20	Long term
20		40% Reduction	2038.1	20% SSB	20	Short term
21		50% Reduction	1698.4	20% SSB	20	Long term
22		50% Reduction	1698.4	20% SSB	20	Short term
23		60% Reduction	1358.7	20% SSB	20	Long term
24		60% Reduction	1358.7	20% SSB	20	Short term
25		70% Reduction	1019.0	20% SSB	20	Short term
26		80% Reduction	679.4	20% SSB	20	Short term
27		90% Reduction	339.7	20% SSB	20	Short term

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(R_0)). 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(R_0) was 6.22. See Table 3 for a description of the abundance indices. S1, S5, and S6 were not included in the total likelihood.

log(R0)	S2	S3	S4	S7
5.1	0.35	0.30	0.00	0.29
5.2	0.11	0.00	0.16	0.13
5.3	0.07	0.03	0.15	0.85
5.4	0.28	0.34	0.04	0.13
5.5	0.03	0.06	0.18	0.13
5.6	0.03	0.08	0.21	0.06
5.7	0.01	0.14	0.21	0.00
5.8	0.02	0.18	0.24	0.20
5.9	0.02	0.27	0.24	0.12
6	0.00	0.37	0.23	0.03
6.1	0.03	0.43	0.25	0.44
6.2	0.03	0.49	0.27	0.48
6.22	0.04	0.50	0.27	0.55
6.3	0.08	0.55	0.29	0.89
6.4	0.09	0.59	0.30	1.38
6.5	0.13	0.64	0.32	1.94

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 ($\log(R_0)$). 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 $\log(R_0)$ was 6.22. See Table 3 for a description of the composition data.

ln(R0)	F01	F02	F04	F05	F06	F13	F14	F16	F18
5.1	0.00	0.10	0.11	0.32	0.05	4.73	0.05	1.45	0.09
5.2	0.36	0.04	0.23	0.19	0.04	4.61	0.33	0.00	0.08
5.3	0.48	0.03	0.25	0.17	0.04	4.21	0.16	0.00	0.07
5.4	0.07	0.04	0.00	0.08	0.04	3.39	0.11	1.75	0.05
5.5	0.40	0.04	0.43	0.24	0.04	3.21	0.14	0.09	0.05
5.6	0.43	0.04	0.42	0.17	0.03	2.49	0.31	0.28	0.04
5.7	0.47	0.03	0.44	0.20	0.03	1.94	0.11	0.31	0.03
5.8	0.45	0.03	0.43	0.15	0.03	1.15	0.29	0.45	0.02
5.9	0.51	0.02	0.36	0.14	0.03	0.54	0.08	0.51	0.02
6	0.60	0.02	0.49	0.20	0.03	0.03	0.09	0.36	0.01
6.1	0.72	0.01	0.30	0.00	0.03	0.07	0.07	0.81	0.00
6.2	0.46	0.01	0.50	0.17	0.02	0.01	0.05	0.67	0.00
6.22	0.44	0.01	0.50	0.17	0.02	0.01	0.05	0.71	0.00
6.3	0.37	0.00	0.36	0.08	0.01	0.00	0.02	1.03	0.00
6.4	0.23	0.00	0.49	0.13	0.01	0.01	0.02	1.14	0.00
6.5	0.13	0.00	0.49	0.12	0.00	0.00	0.00	1.40	0.00

Table 11. 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}), and fishing intensity (1- spawning potential ratio) for Western and Central North Pacific striped 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		1-spawning potential ratio	
	Mean	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1975	17263	3412	1226	436	210	1.40	0.47	0.88	0.03
1976	12304	1723	751	611	390	1.45	0.54	0.90	0.03
1977	13389	1623	710	1049	409	1.59	0.64	0.91	0.03
1978	19520	2255	915	383	208	1.37	0.53	0.90	0.04
1979	18305	2789	900	351	164	0.77	0.21	0.87	0.04
1980	16266	2768	1028	419	195	0.94	0.29	0.87	0.04
1981	13483	2028	892	505	290	1.35	0.51	0.89	0.04
1982	12654	1662	721	899	493	1.09	0.38	0.88	0.04
1983	18108	2459	932	686	437	0.68	0.22	0.83	0.05
1984	22166	3776	1343	512	288	0.60	0.18	0.81	0.05
1985	22303	3999	1493	599	333	0.63	0.19	0.83	0.05
1986	21593	3123	1377	681	372	0.97	0.33	0.88	0.04
1987	20113	3112	1321	604	340	0.75	0.24	0.85	0.05
1988	20541	2669	1115	565	322	1.01	0.31	0.90	0.03
1989	18504	2680	1132	631	345	0.76	0.24	0.87	0.04
1990	19259	3214	1271	594	285	0.65	0.21	0.83	0.05
1991	20289	3329	1168	345	162	0.65	0.17	0.84	0.04
1992	18028	3404	866	499	132	0.60	0.11	0.82	0.03
1993	17318	2545	543	360	97	0.86	0.13	0.88	0.02
1994	14215	1718	330	447	70	1.28	0.19	0.92	0.01
1995	12019	1224	210	382	58	1.62	0.22	0.94	0.01
1996	9867	794	146	339	63	1.55	0.23	0.94	0.01
1997	9161	908	169	441	60	1.25	0.19	0.93	0.01
1998	10148	971	169	208	44	1.50	0.22	0.93	0.01
1999	8114	783	127	237	39	1.67	0.23	0.94	0.01
2000	6304	725	126	395	39	1.66	0.26	0.93	0.01
2001	7320	716	113	201	35	1.71	0.26	0.93	0.01
2002	6719	856	131	457	44	1.18	0.17	0.91	0.01
2003	8934	902	145	327	38	1.48	0.21	0.93	0.01
2004	8783	1238	168	138	30	1.02	0.14	0.88	0.01
2005	7462	1203	180	412	37	0.94	0.12	0.89	0.01
2006	8418	1074	179	114	30	1.12	0.16	0.90	0.01
2007	6606	1217	177	176	31	0.76	0.10	0.84	0.02
2008	6231	1051	166	211	28	1.07	0.14	0.89	0.01
2009	5480	840	147	80	24	0.96	0.15	0.87	0.02

Year	Age 1+ biomass (mt)	Spawning biomass (mt)		Recruitment (1000 age-0 fish)		Instantaneous fishing mortality		1-spawning potential ratio	
	Mean	Mean	SE	Mean	SE	Mean	SE	Mean	SE
2010	4509	831	131	313	33	0.95	0.13	0.86	0.02
2011	5874	618	111	197	29	1.11	0.16	0.91	0.01
2012	6057	809	125	88	24	1.06	0.15	0.89	0.01
2013	4937	743	136	331	36	0.86	0.12	0.89	0.02
2014	6241	864	168	77	24	0.63	0.10	0.84	0.03
2015	5745	1073	202	185	36	0.62	0.10	0.83	0.03
2016	5832	1185	246	195	52	0.51	0.09	0.80	0.03
2017	6196	981	278	354	155	0.80	0.18	0.86	0.03

Table 12. Estimated biological reference points derived from the Stock Synthesis base case model for Western and Central North Pacific striped marlin where F is the instantaneous annual fishing mortality rate, SPR is the annual spawning potential ratio, SSB is spawning stock biomass, and MSY indicates maximum sustainable yield.

Reference Point	**Estimate**
F_{MSY} (age 3-12)	0.60
F_{2017} (age 3-12)	0.80
$F_{20\%SSB(F=0)}$	0.47
SSB_{MSY}	2,604 mt
SSB_{2017}	981 mt
$SSB_{20\%(F=0)}$	3,610 mt
MSY	4,946 mt
$C_{2015-2017}$	2,151 mt
SPR_{MSY}	18%
SPR_{2017}	14%
$SPR_{20\%SSB(F=0)}$	23%

Table 13. Complete list of sensitivity runs conducted for the 2019 stock assessment of Western and Central North Pacific striped marlin.

RUN	NAME	DESCRIPTION
	Alternative Life History Parameters: Growth	
2	base_case_large_Amax	Alternative growth curve with L_{Amax} set to the mean from Fitchett 2019 (184 cm EFL).
3	base_case_large_Amax	Alternative growth curve with a 10% larger maximum size (225 cm EFL).
	Alternative Life History Parameters: Natural Mortality	
4	base_case_highM	Alternative natural mortality rates are 10% higher than in the base case
5	base_case_lowM	Alternative natural mortality rates are 10% lower than in the base case
	Alternative Life History Parameters: Recruitment Variability (σ_R)	
6	base_case_large_SigR	Alternative growth curve with a larger σ_R (0.9).
	Alternative Life History Parameters: Stock-Recruitment Steepness	
7	base_case_h095	Alternative higher steepness with h=0.95
8	base_case_h079	Alternative lower steepness with h=0.79
9	base_case_h070	Alternative lower steepness with h=0.70
Alternative Life History Parameters: Maturity Ogive		
10	base_case_L50_171	Alternative maturity ogives with L_{50} set to 171 cm
11	base_case_L50_177	Alternative maturity ogives with L_{50} 177 cm (Used in the 2015 assessment)
12	base_case_L50_181	Alternative maturity ogives with converted L_{50} from Chang *et al*. (2019)
Alternative Model Configuration: Initial Equilibrium Catch		
13	base_case_EC1000	Alternative model with Initial Equilibrium Catch set to 1000mt
14	base_case_EC2500	Alternative model with Initial Equilibrium Catch set to 2500mt
15	base_case_EC7500	Alternative model with Initial Equilibrium Catch set to 7500mt
16	base_case_EC10000	Alternative model with Initial Equilibrium Catch set to 10000mt
Alternative Data Inputs: Uncertainty in Japanese Drift Gillnet Catch		
17	base_case_F13_90	Input catch for F13 is 90% lower than base case
18	base_case_F13_50	Input catch for F13 is 50% lower than base case
19	base_case_F13_30	Input catch for F13 is 30% lower than base case
20	base_case_F13_10	Input catch for F13 is 10% lower than base case
21	base_case_F13_cv10	Input catch CV for F13 is 10%
Alternative Model Configuration: Start in 1994		
22	Base_case_S1994	Start the assessment model in 1994 instead of 1975

Table 14. Projected median values of Western and Central North Pacific striped marlin spawning stock biomass (SSB, mt), catch (mt), and probability of reaching 20%$SSB_{F=0}$ under five constant fishing mortality rate (F) and ten constant catch scenarios during 2018-2037. For scenarios which have a 60% probability of reaching the target of 20%$SSB_{F=0}$, the year in which this occurs is provided; NA indicates projections that did not meet this criterion. Note that 20%$SSB_{F=0}$ is 3610 mt and SSB_{MSY} is 2604 mt.

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2027**	**2037**	**Year when target achieved with 60% probability**
Scenario 1: $F_{status\ quo}$; Long-Term Recruitment								
SSB	1931.3	2605.3	3591	4288.3	4639.4	4893.4	4884.4	
Catch	2229.8	3089.8	3911.6	4412.8	4644.9	4797.2	4790.9	
Probability of reaching 20% SSB	0%	4%	44%	70%	79%	84%	84%	2021
Scenario 2: $F_{status\ quo}$; Short-Term Recruitment								
SSB	1932.4	2556.5	3080	2786.9	2422.3	2071.4	2072.1	
Catch	2224.6	2827	2871.7	2535.9	2260.7	2029.6	2030.4	
Probability of reaching 20% SSB	0%	4%	21%	9%	2%	<0.5%	<0.5%	NA
Scenario 3: FMSY; Long-Term Recruitment								
SSB	1935.1	2611.8	3650.5	4444	4860.6	5158.9	5203.5	
Catch	2228.1	3092.7	3705.2	4241.6	4498.9	4666.4	4711.5	
Probability of reaching 20% SSB	0%	4%	47%	75%	83%	89%	89%	2021
Scenario 4: FMSY; Short-Term Recruitment								
SSB	1932.9	2557.7	3126.3	2895.5	2552.2	2207	2197	
Catch	2230.8	2829.6	2724.6	2450.7	2209.9	1994.1	1984.9	
Probability of reaching 20% SSB	0%	4%	23%	12%	4%	<0.5%	<0.5%	NA
Scenario 5: F 20%$SSB_{F=0}$; Long-Term Recruitment								
SSB	1933.7	2611.9	3813.4	4943.7	5631	6358.1	6348.5	
Catch	2227.6	3091.3	2996.4	3588.7	3933.2	4271.7	4266.7	
Probability of reaching 20% SSB	0%	4%	55%	85%	93%	97%	98%	2021
Scenario 6: F 20%$SSB_{F=0}$; Short-Term Recruitment								
SSB	1934	2560.5	3276.3	3274.8	3030.2	2697	2690.2	
Catch	2224.9	2828.8	2211.6	2115.4	1969.7	1809.1	1804.7	
Probability of reaching 20% SSB	0%	4%	29%	28%	17%	6%	7%	NA
Scenario 7: Highest F (Average F 1975-1977); Long-Term Recruitment								

Year	2018	2019	2020	2021	2022	2027	2037	Year when target achieved with 60% probability
SSB	1932.8	2611.8	2739.8	2299.1	2102	2028.4	2036.2	
Catch	2226.4	3088.5	7520.7	6557.5	6184.4	6058	6084.1	
Probability of reaching 20% SSB	0%	4%	9%	4%	2%	1%	1%	NA
Scenario 8: Highest F (Average F 1975-1977); Short-Term Recruitment								
SSB	1933.5	2559.4	2289.2	1330.7	968.3	858.7	859.2	
Catch	2225.9	2827.6	5362.9	3399.3	2751.6	2564.6	2570.9	
Probability of reaching 20% SSB	0%	3%	2%	<0.5%	0%	0%	0%	NA
Scenario 9: Low F ($F_{30\%}$); Long-Term Recruitment								
SSB	1933.6	2612.5	4009.5	5603.2	6742.4	8287.5	8353	
Catch	2228.6	3093.5	2117.6	2693.6	3075	3558.2	3577.8	
Probability of reaching 20% SSB	0%	4%	63%	93%	98%	>99.5%	>99.5%	2020
Scenario 10: Low F ($F_{30\%}$); Short-Term Recruitment								
SSB	1932.5	2555.6	3453.8	3788.4	3747.4	3537.4	3525.3	
Catch	2228.4	2832	1572.9	1623.8	1589	1515.8	1511.6	
Probability of reaching 20% SSB	0%	4%	37%	54%	54%	44%	42%	NA
Scenario 11: Quota; Long-Term Recruitment								
SSB	1946.7	2823	4141.1	5220.9	6074.7	8147.5	8715.3	
Catch	2150.6	2150.6	3396.8	3396.7	3396.3	3396.1	3396.8	
Probability of reaching 20% SSB	<0.5%	17%	61%	76%	83%	93%	95%	2020
Scenario 12: Quota; Short-Term Recruitment								
SSB	1948.8	2737.1	3279.8	2592.9	1781.9	524.2	436.7	
Catch	2150.6	2150.6	3393.7	3377.1	3319.7	2954.7	2903	
Probability of reaching 20% SSB	<0.5%	15%	36%	20%	7%	<0.5%	<0.5%	NA
Scenario 13: 10% Reduction; Long-Term Recruitment								
SSB	1947.9	2826.1	4225.3	5467.3	6492.5	9096.5	9798.7	
Catch	2150.6	2150.6	3057.1	3057.1	3056.8	3057.1	3057.1	
Probability of reaching 20% SSB	<0.5%	17%	63%	81%	87%	96%	97%	2020
Scenario 14: 10% Reduction; Short-Term Recruitment								

Year	2018	2019	2020	2021	2022	2027	2037	Year when target achieved with 60% probability
SSB	1948.6	2738	3390.9	2886.8	2162.9	763	587	
Catch	2150.6	2150.6	3054.6	3052.8	3032.5	2846.7	2780.1	
Probability of reaching 20% SSB	<0.5%	15%	40%	26%	12%	<0.5%	<0.5%	NA
Scenario 15: 20% Reduction; Long-Term Recruitment								
SSB	1949.9	2829.1	4317.7	5750.4	6954.1	9928.4	10806.2	
Catch	2150.6	2150.6	2717.4	2717.4	2717.4	2717.4	2717.4	
Probability of reaching 20% SSB	<0.5%	18%	65%	84%	90%	98%	99%	2020
Scenario 16: 20% Reduction; Short-Term Recruitment								
SSB	1949.3	2739.2	3495.1	3176.4	2570.8	1175.5	883.3	
Catch	2150.6	2150.6	2716.8	2714.3	2710.8	2648.8	2610.7	
Probability of reaching 20% SSB	<0.5%	15%	43%	34%	19%	1%	<0.5%	NA
Scenario 17: 30% Reduction; Long-Term Recruitment								
SSB	1947.6	2824.5	4381.5	5981.7	7356.2	10856.1	11783.5	
Catch	2150.6	2150.6	2377.8	2377.8	2377.8	2377.8	2377.8	
Probability of reaching 20% SSB	<0.5%	17%	67%	87%	94%	99%	>99.5%	2020
Scenario 18: 30% Reduction; Short-Term Recruitment								
SSB	1947.4	2733.8	3594	3479.2	3018.1	1736.6	1383.5	
Catch	2150.6	2150.6	2377.8	2377.1	2377.1	2365.6	2355.3	
Probability of reaching 20% SSB	<0.5%	15%	45%	42%	29%	5%	2%	NA
Scenario 19: 40% Reduction; Long-Term Recruitment								
SSB	1949.2	2831.8	4486.8	6295.8	7868.9	11749.2	12851.3	
Catch	2150.6	2150.6	2038.1	2038.1	2038.1	2038.1	2038.1	
Probability of reaching 20% SSB	<0.5%	18%	70%	90%	95%	>99.5%	>99.5%	2020
Scenario 20: 40% Reduction; Short-Term Recruitment								
SSB	1949.9	2737.3	3689.5	3756	3445.9	2444.2	2124.2	
Catch	2150.6	2150.6	2038.1	2038.1	2037.9	2037.6	2036.4	
Probability of reaching 20% SSB	<0.5%	15%	48%	49%	41%	16%	10%	NA
Scenario 21: 50% Reduction; Long-Term Recruitment								

Year	2018	2019	2020	2021	2022	2027	2037	Year when target achieved with 60% probability
SSB	1950.4	2829.7	4548.9	6512.1	8259.1	12654	13799.3	
Catch	2150.6	2150.6	1698.4	1698.4	1698.4	1698.4	1698.4	
Probability of reaching 20% SSB	<0.5%	17%	71%	92%	97%	>99.5%	>99.5%	2020
Scenario 22: 50% Reduction; Short-Term Recruitment								
SSB	1949.1	2737.4	3791.4	4065.7	3916.3	3214.4	3021.3	
Catch	2150.6	2150.6	1698.4	1698.4	1698.4	1698.4	1698.4	
Probability of reaching 20% SSB	<0.5%	15%	51%	57%	53%	35%	29%	NA
Scenario 23: 60% Reduction; Long-Term Recruitment								
SSB	1949.9	2829.1	4631.3	6798.1	8741.1	13605.2	14857.1	
Catch	2150.6	2150.6	1358.7	1358.7	1358.7	1358.7	1358.7	
Probability of reaching 20% SSB	<0.5%	18%	73%	94%	98%	>99.5%	>99.5%	2020
Scenario 24: 60% Reduction; Short-Term Recruitment								
SSB	1948.6	2737.7	3888.1	4364.3	4396.6	4110.1	3970.5	
Catch	2150.6	2150.6	1358.7	1358.7	1358.7	1358.7	1358.7	
Probability of reaching 20% SSB	<0.5%	15%	53%	65%	67%	63%	59%	2021*
Scenario 25: 70% Reduction; Short-Term Recruitment								
SSB	1948.7	2736.4	3979.8	4667.7	4886	4960.9	4977	
Catch	2150.6	2150.6	1019	1019	1019	1019	1019	
Probability of reaching 20% SSB	<0.5%	15%	56%	72%	78%	85%	86%	2021
Scenario 26: 80% Reduction; Short-Term Recruitment								
SSB	1948.7	2736.2	4071.1	4971.3	5380.3	5909.1	5977.5	
Catch	2150.6	2150.6	679.4	679.4	679.4	679.4	679.4	
Probability of reaching 20% SSB	<0.5%	15%	58%	79%	88%	97%	97%	2021
Scenario 27: 90% Reduction; Short-Term Recruitment								
SSB	1950.6	2740.5	4170.3	5284.1	5881.7	6836.7	7009.4	
Catch	2150.6	2150.6	339.7	339.7	339.7	339.7	339.7	
Probability of reaching 20% SSB	<0.5%	15%	61%	85%	94%	>99.5%	>99.5%	2020

* This scenario has a 60% probability of being at or above 20%$SSB_{F=0}$ in 2020 but drops slightly below 60% starting in 2035.

7. FIGURES

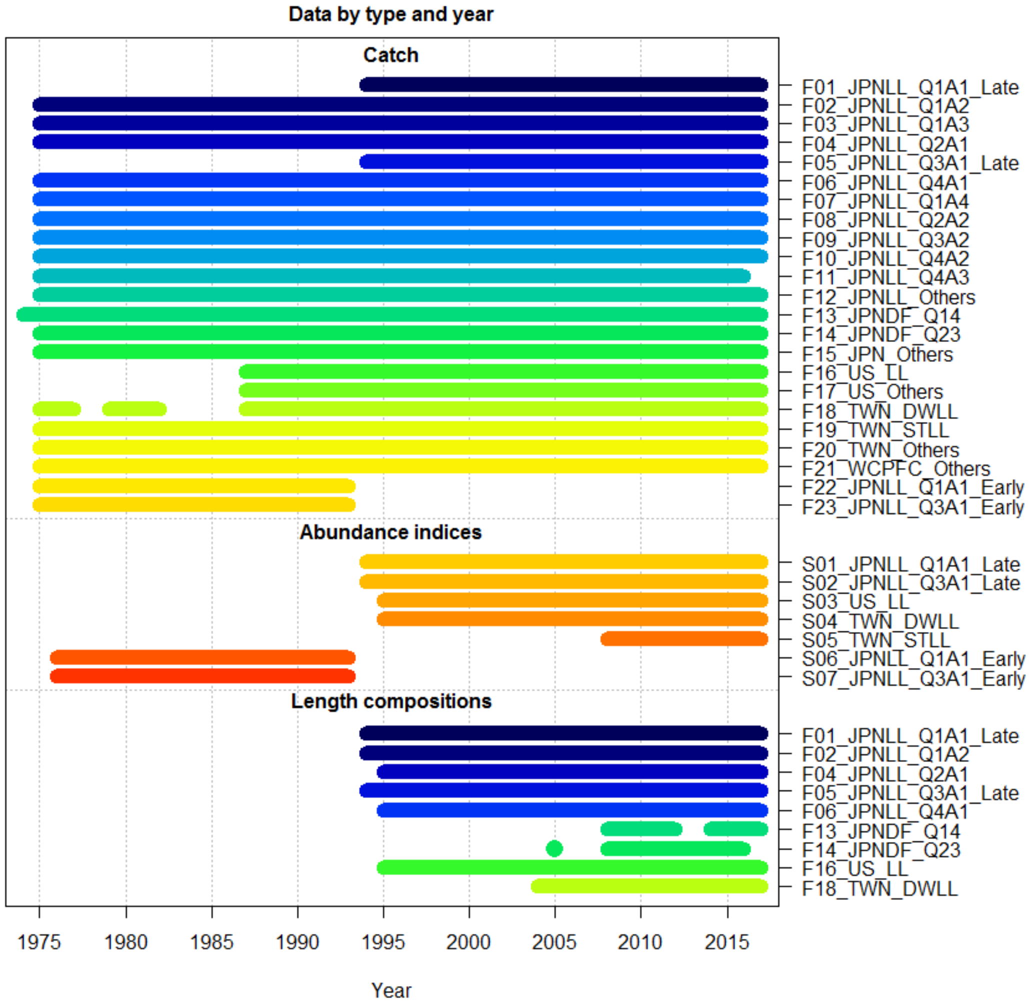


Figure 1. Available temporal coverage and sources of catch, CPUE (abundance indices), and length and size composition for the 2019 stock assessment of the Western and Central North Pacific striped marlin.

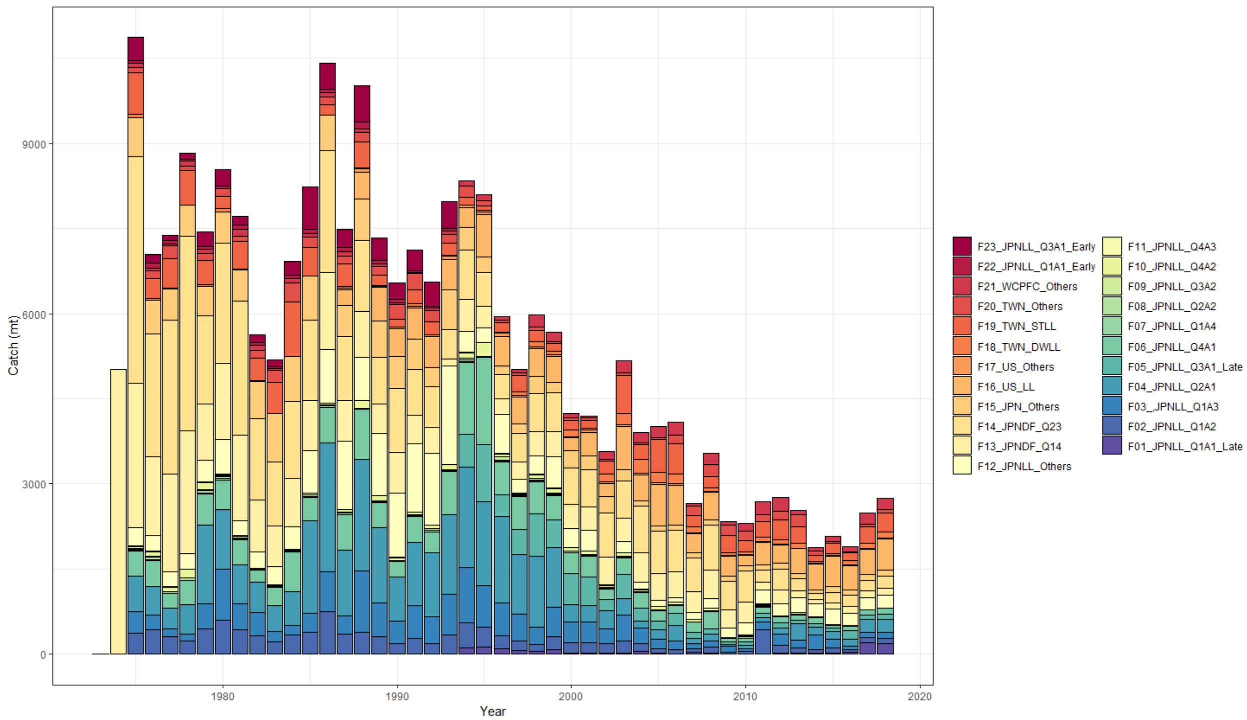


Figure 2. Total annual catch of the Western and Central North Pacific striped marlin by all fisheries harvesting the stock during 1975-2017. See Table 1 for the reference code for each fishery.

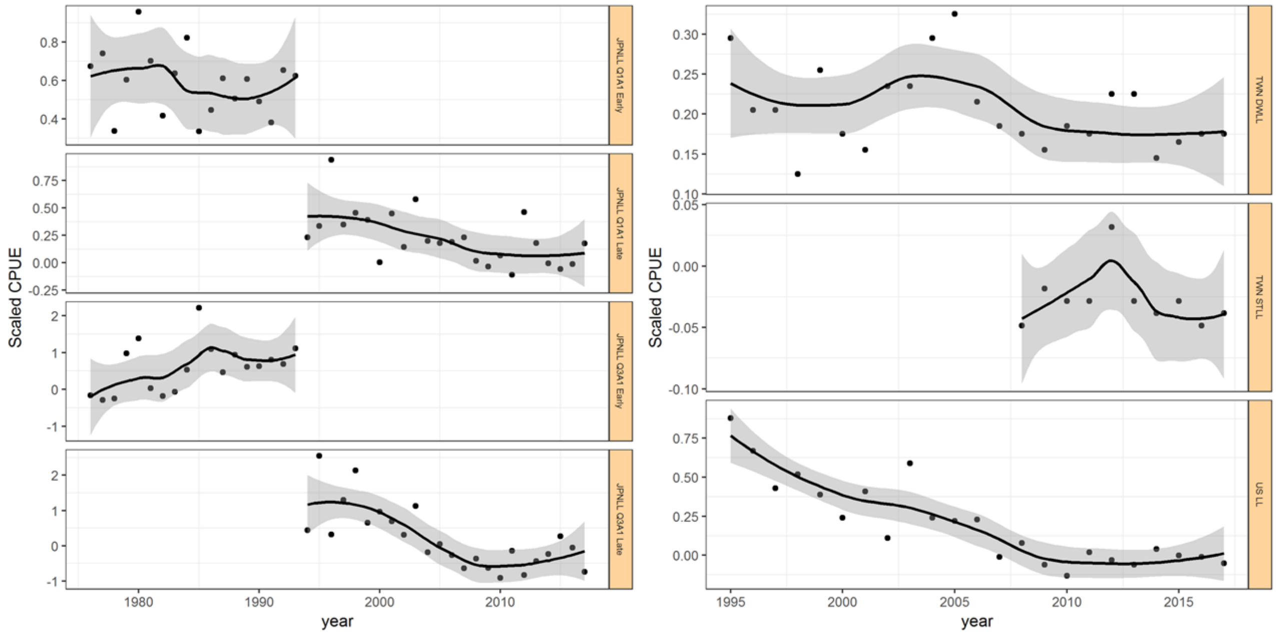


Figure 3. Time series of annual standardized indices of catch-per-unit-effort (CPUE) for the for each fleet in the base-case assessment model for the Western and Central North Pacific striped marlin as described in Table 3. Index values were rescaled by the mean of each index for comparison purposes. A loess curve was fit to the data to show the general trend with shaded area representing 95% confidence intervals.

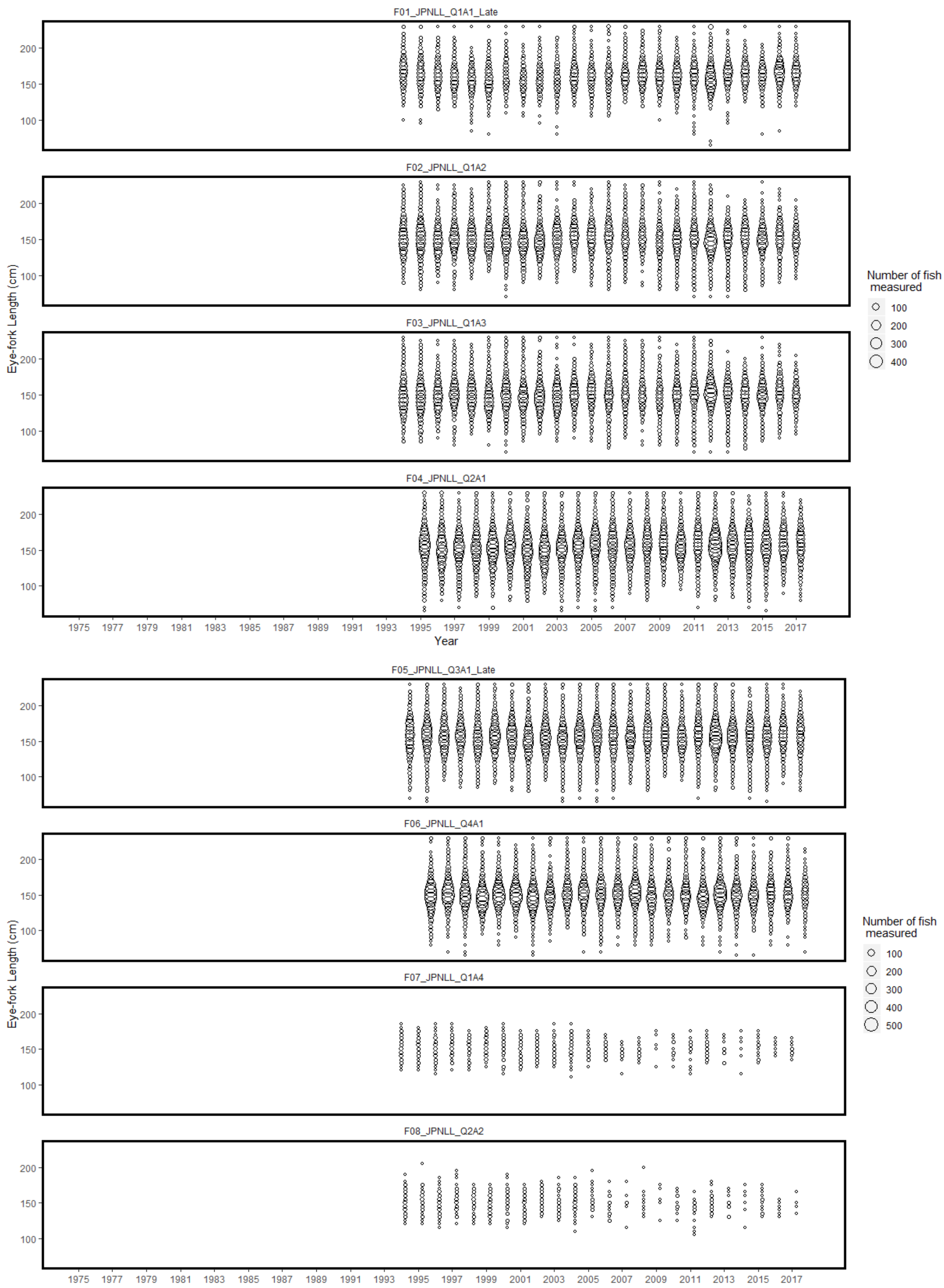


Figure 4. Quarterly length and size composition data by fishery used in the stock assessment (see Table 3). The sizes of the circles are proportional to the number of observations. All measurements were eye- fork lengths (EFL, cm).

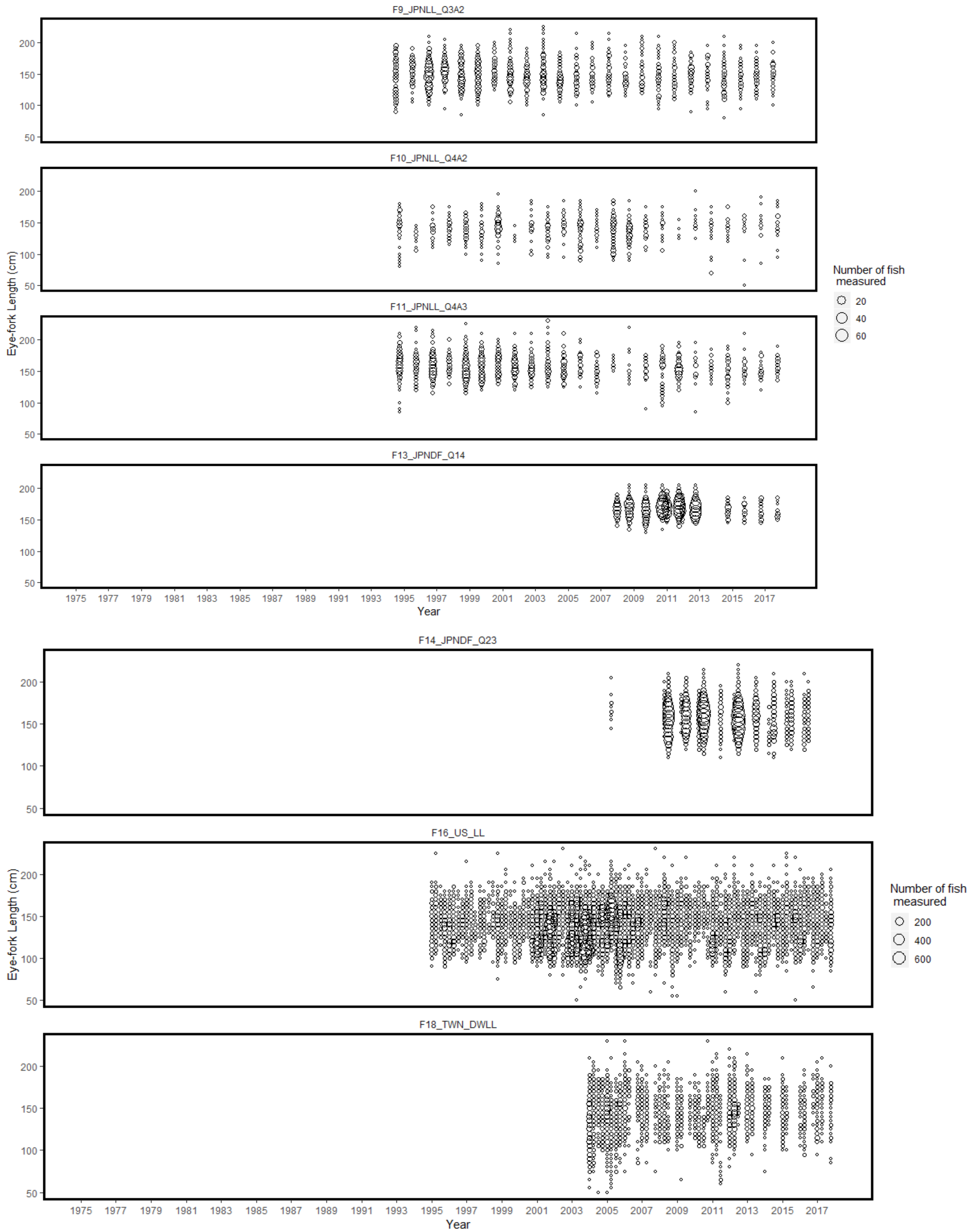


Figure 4. Continued

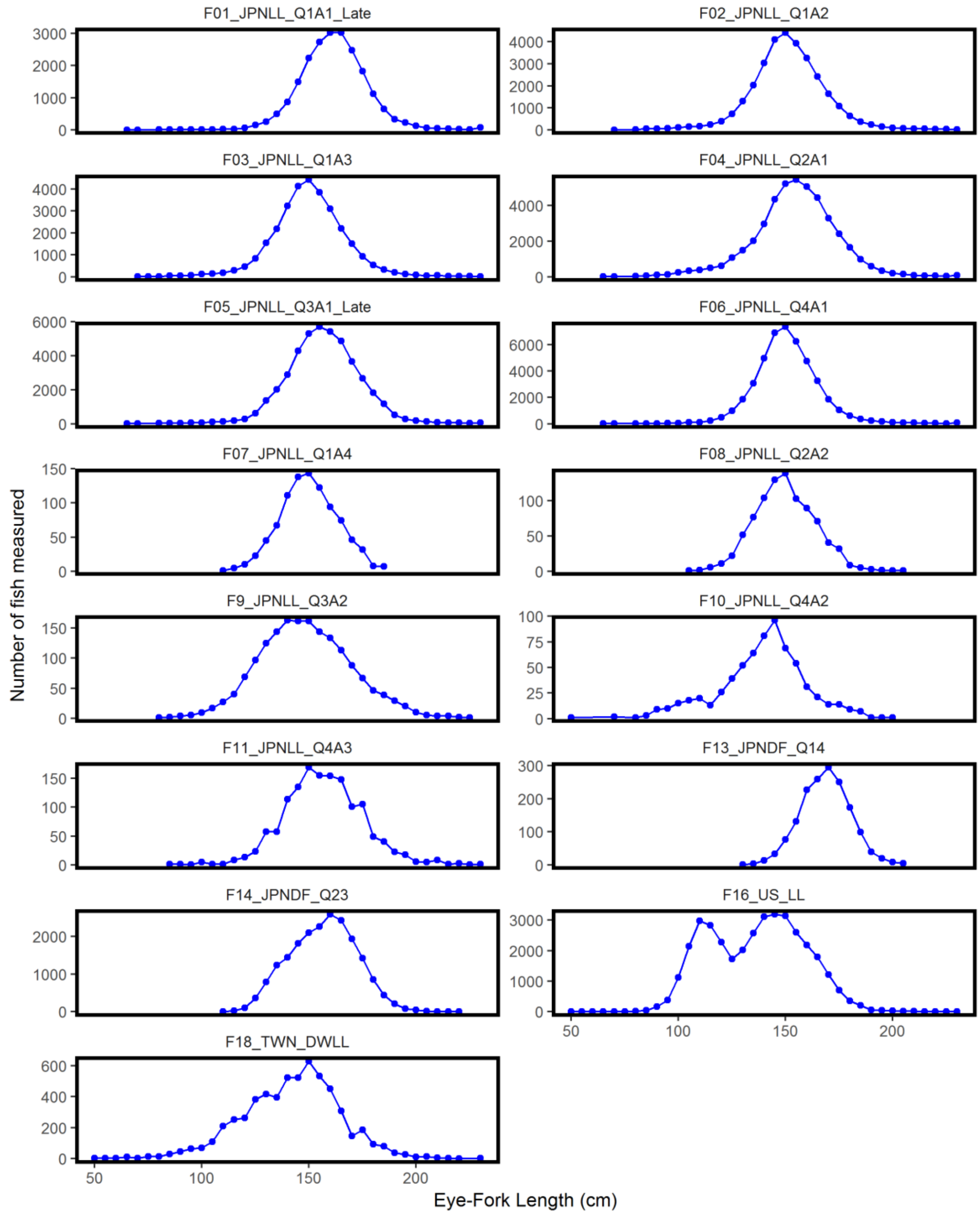


Figure 5. Aggregated length and size compositions used in the stock assessment (see Table 3 for descriptions of the composition data). All measurements were eye-fork lengths (EFL, cm).

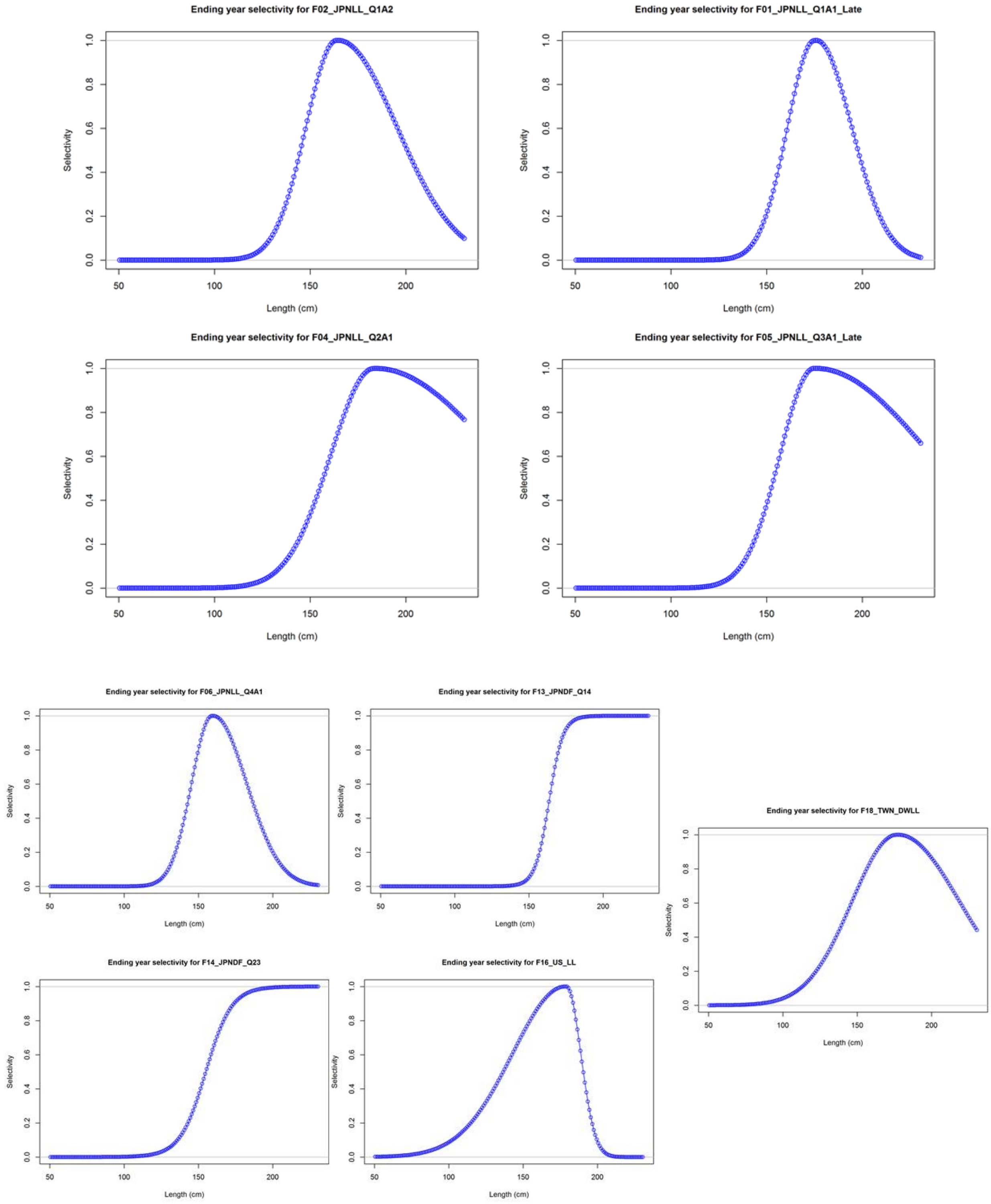


Figure 6. Length-based selectivity of fisheries for Western and Central North Pacific striped marlin estimated for the 2019 assessment.

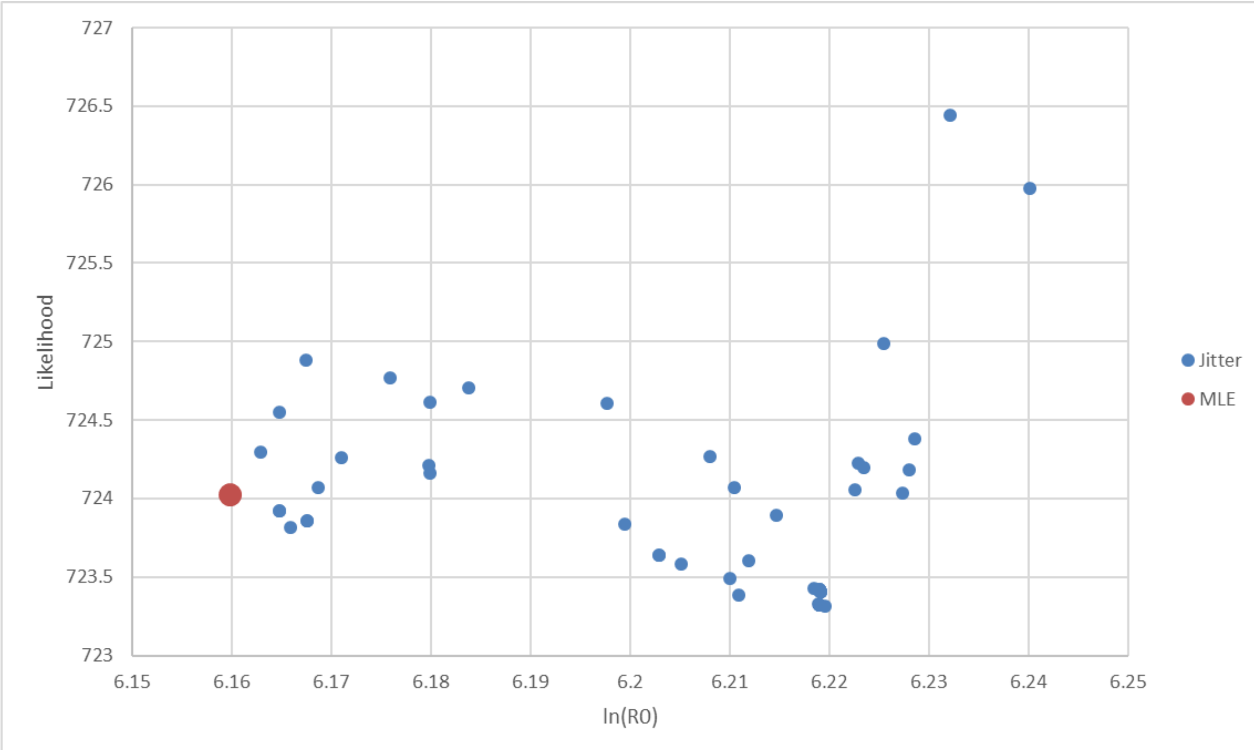


Figure 7. Results of a randomized initial parameter value diagnostic for the base case model where 100 randomized initial conditions were used with a CV of 10% assigned to each parameter. Results are shown for the base case model (MLE, solid red circle) and for the base case model with randomized initial parameter values (Jitter runs, solid blue circle).

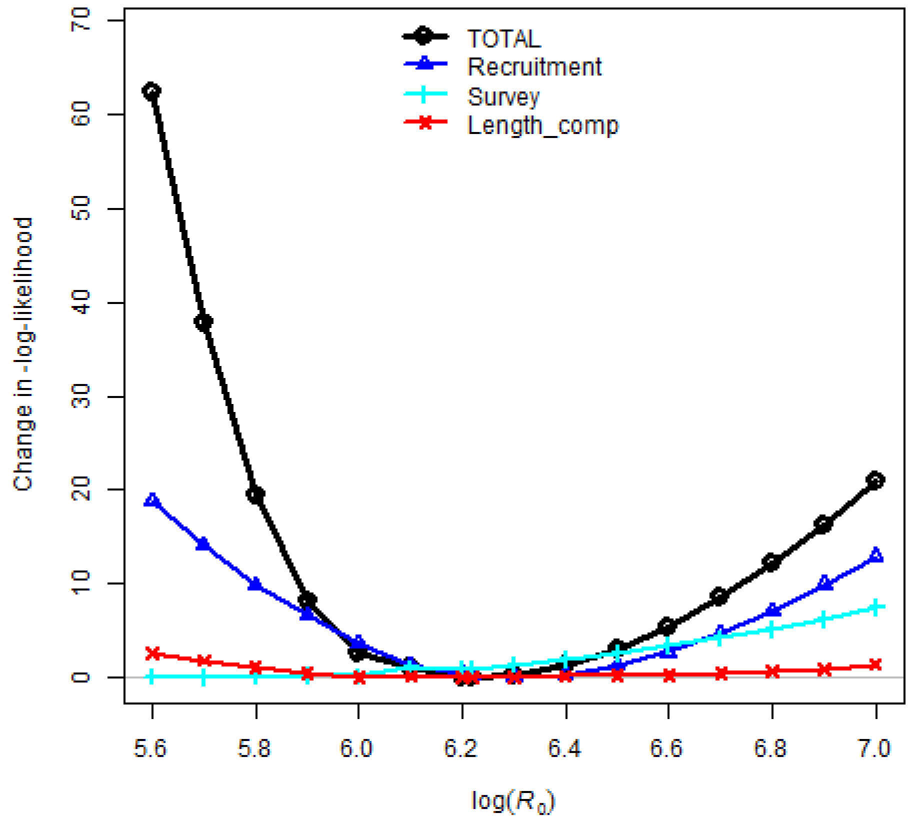


Figure 8. Profiles of the negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter R_0 in log-scale (i.e., the x-axis is $\log(R_0)$) ranging from 5.6 to 7.0 for the base case model, where recruitment represents the likelihood component based on the deviations from the stock-recruitment curve and length data represents the joint likelihood component for combined fleets based on the fish length composition data.

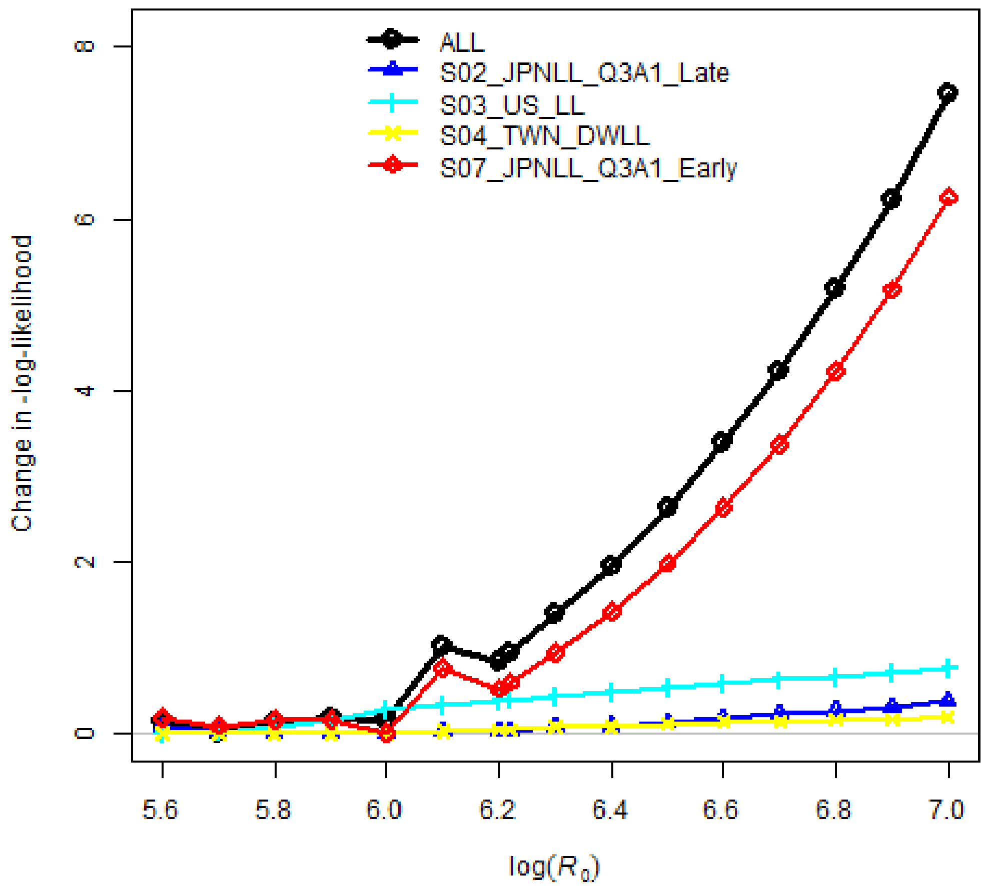


Figure 9. Profiles of the relative negative log-likelihoods by fleet-specific index likelihood components for the virgin recruitment in log-scale ($\log(R_0)$) ranged from 5.6 to 7.0 of the base case scenario. See Table 3 for descriptions of the index data. S1, S5, and S6 were not included in the total likelihood.

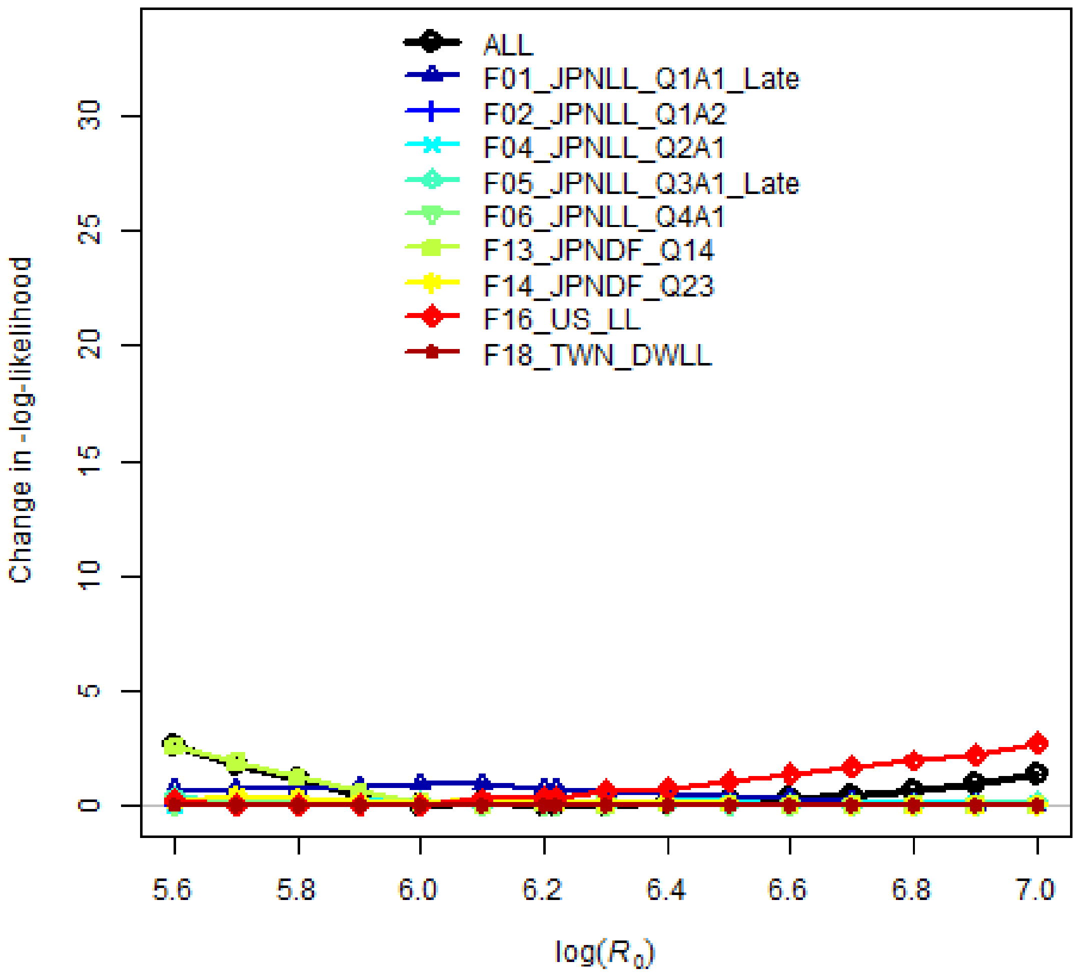


Figure 10. Profiles of the relative negative log-likelihoods by fleet-specific length composition likelihood components for the virgin recruitment in log-scale ($\log(R_0)$) ranged from 5.6 to 7.0 of the base case scenario. See Table 3 for descriptions of the length composition data.

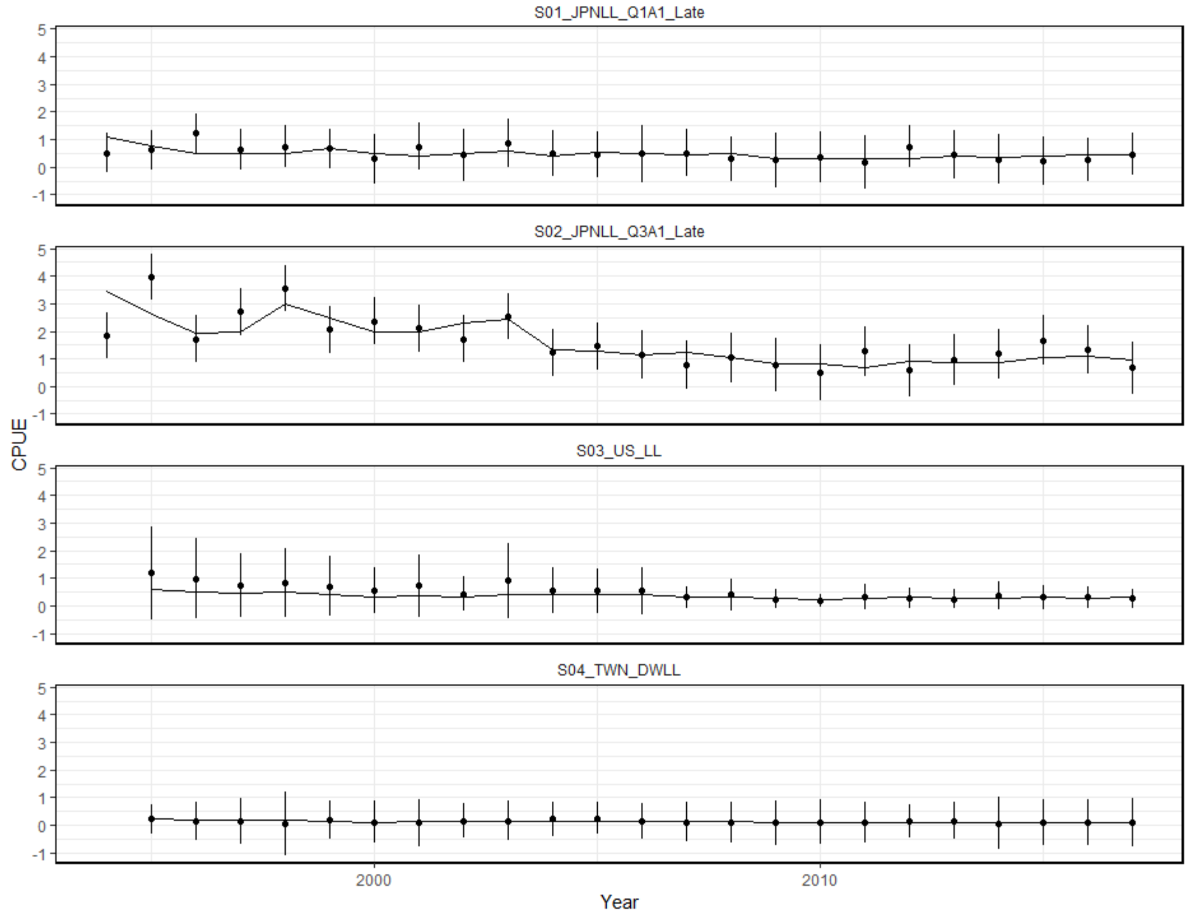


Figure 11. Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. S1, S5, and S6 were not included in the total likelihood.

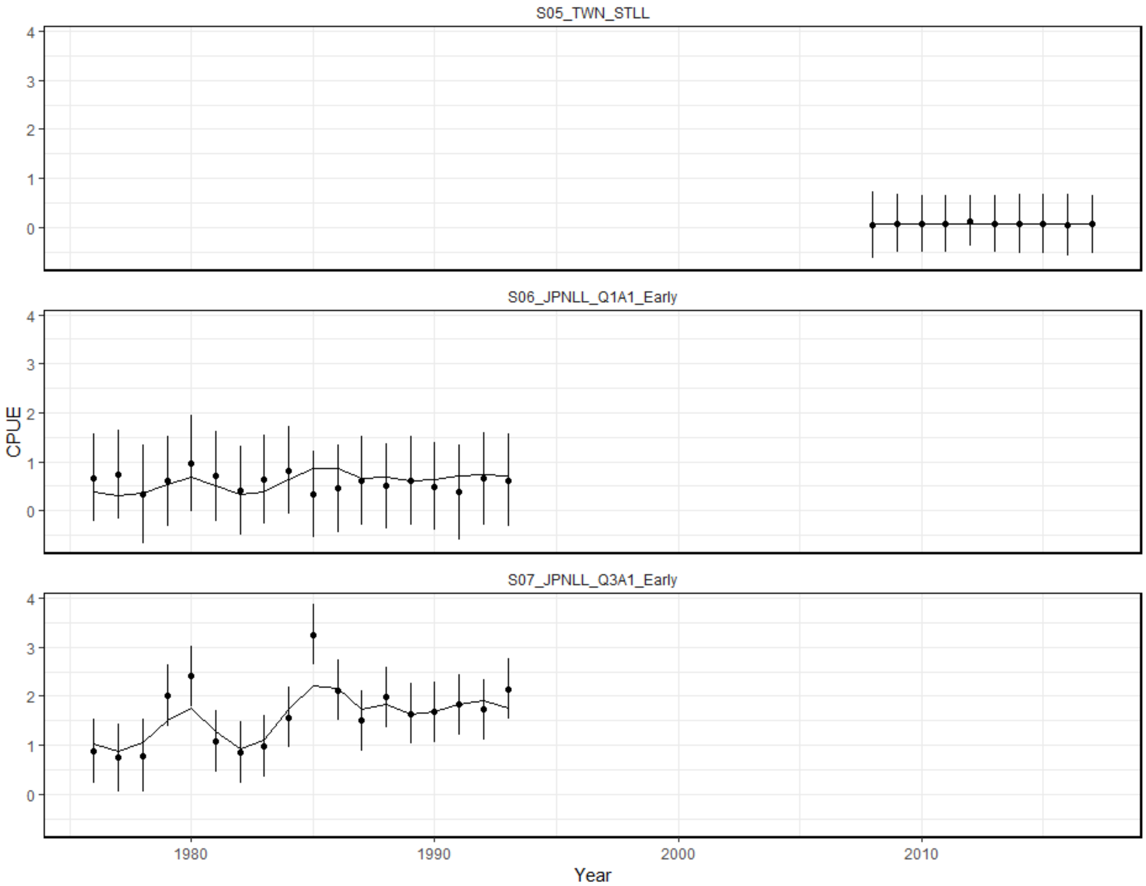


Figure 11. Continued

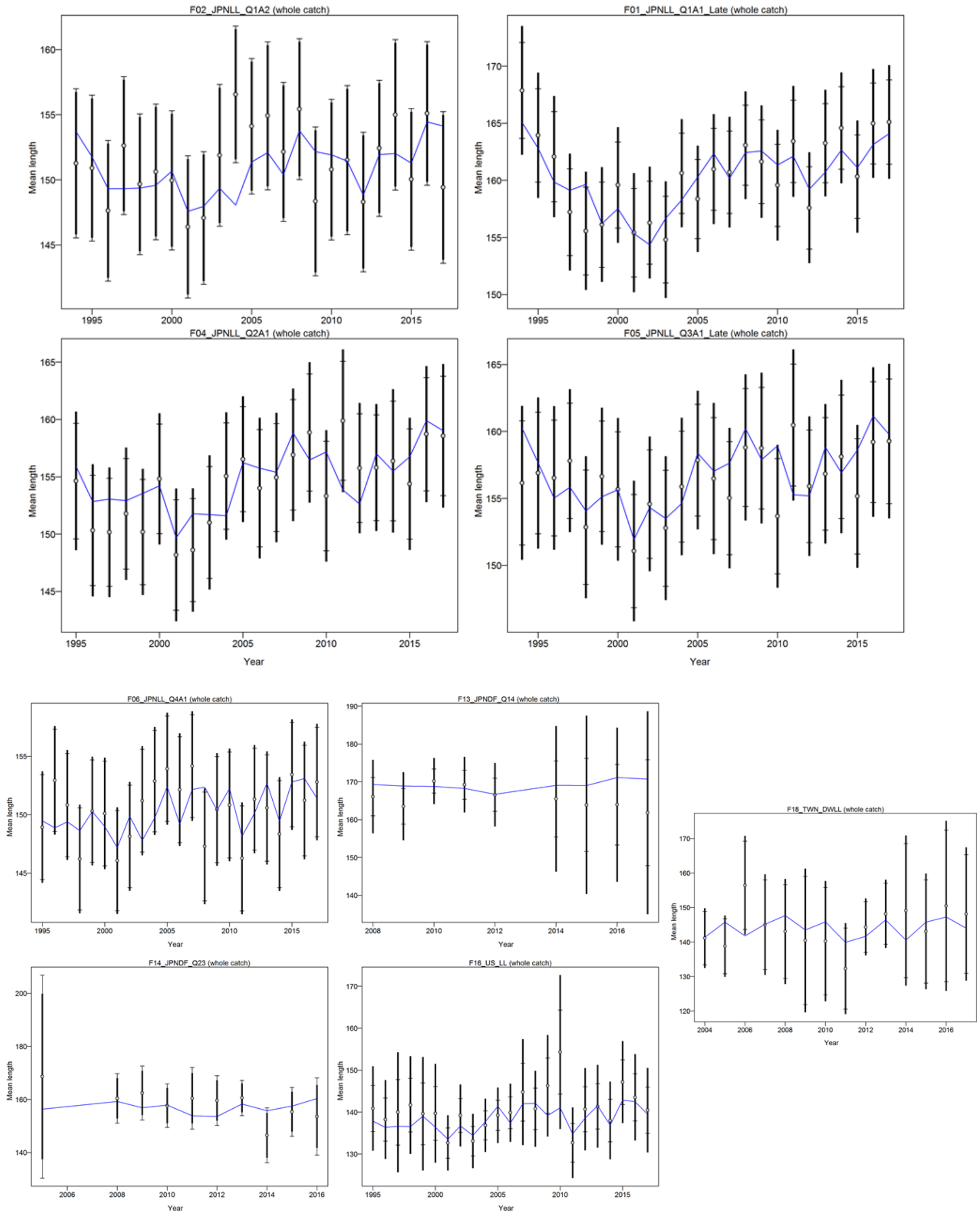


Figure 12. Model fit (lines) to mean length of the composition data (points, showing the observed mean age and 95% credible limits around mean age (vertical lines)). See Table 3 for descriptions of the data. All measurements were eye-fork lengths (EFL, cm).

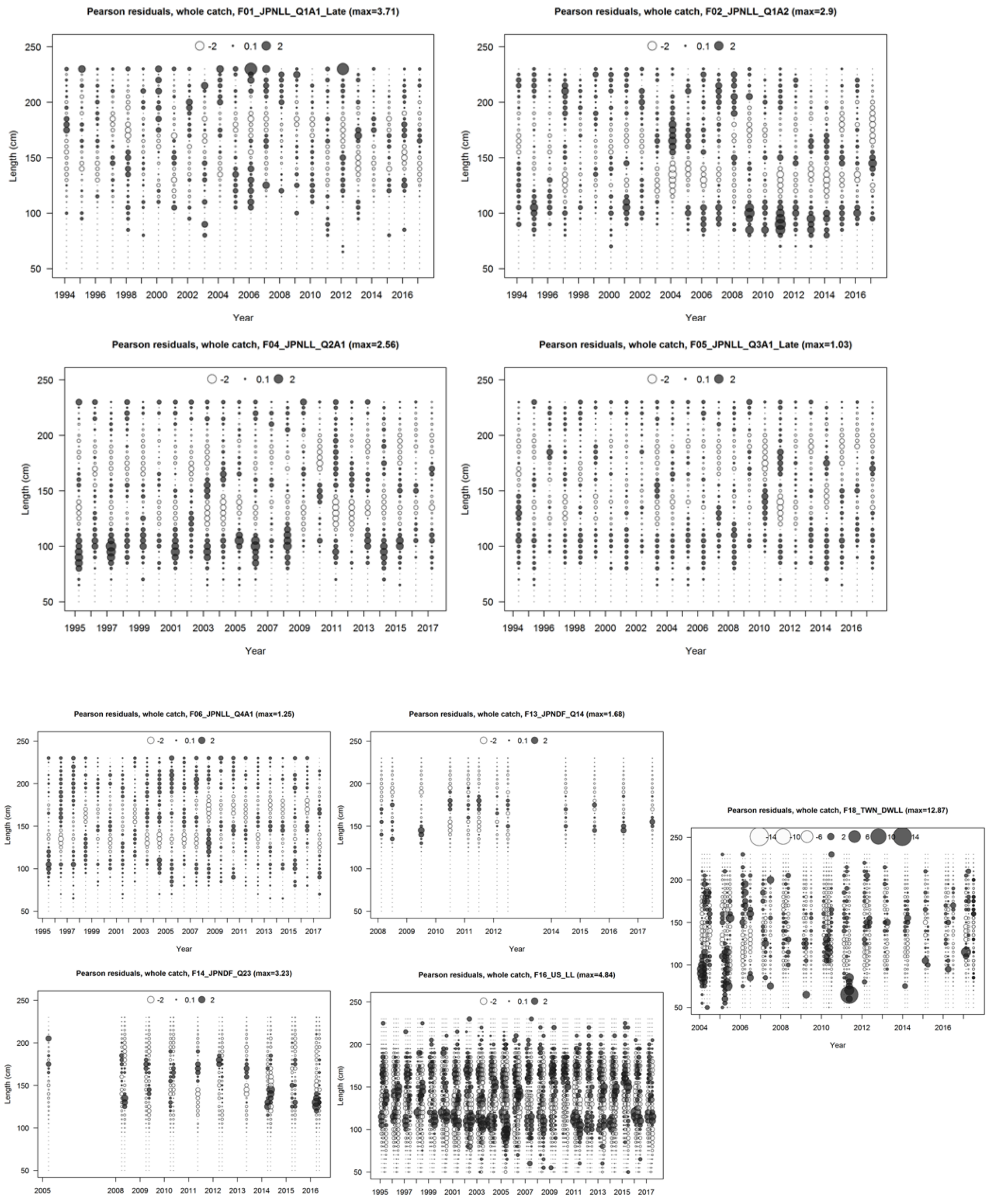


Figure 13. Pearson residual plots of model fits to the various length-composition data for the Western and Central North Pacific striped marlin fisheries used in the assessment model.

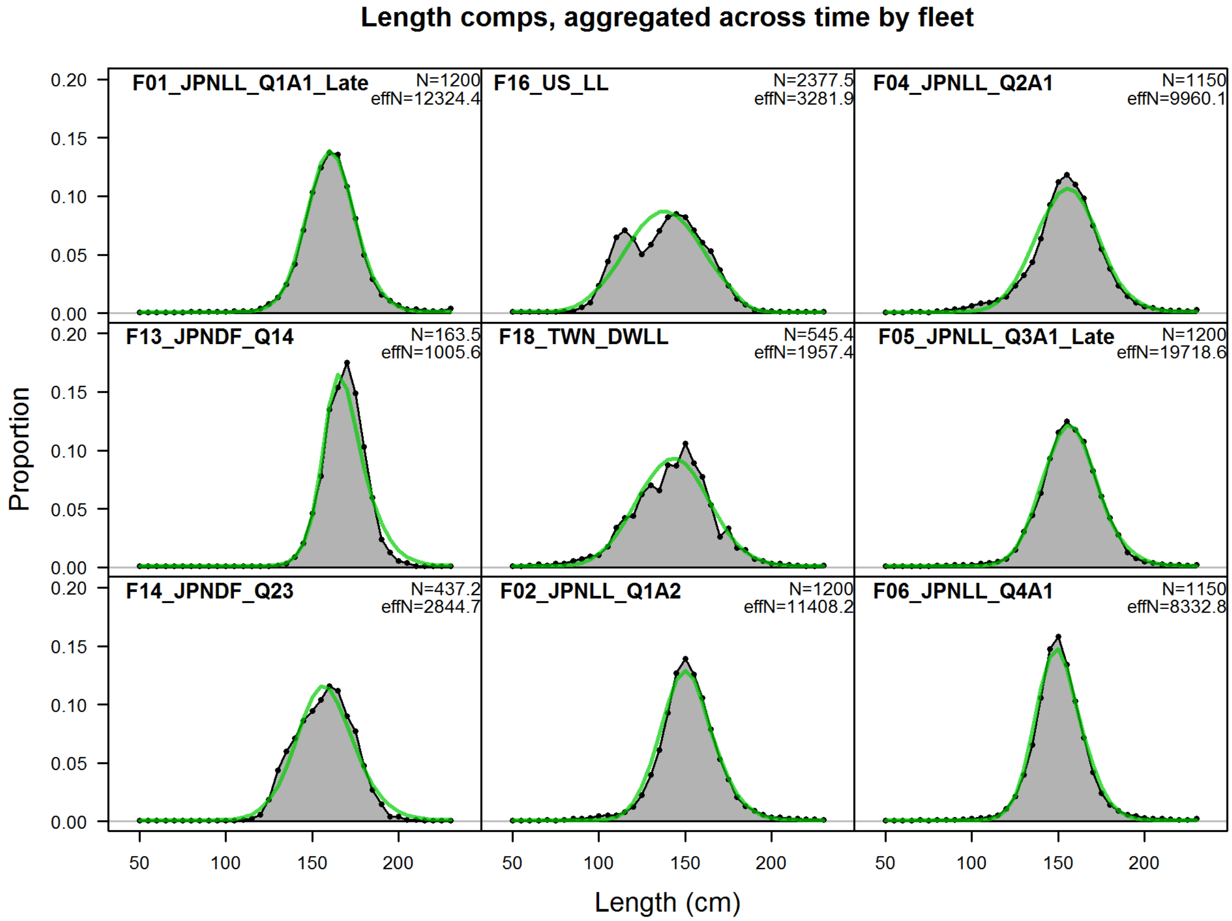


Figure 14. Comparison of observed (gray shaded area and blue dots) and model predicted (blue solid line) length compositions for fisheries used in the stock assessment for the Western and Central North Pacific striped marlin. Observed (black circles) and predicted (green line) length compositions. All measurements were eye-to-fork lengths (EFL, cm).

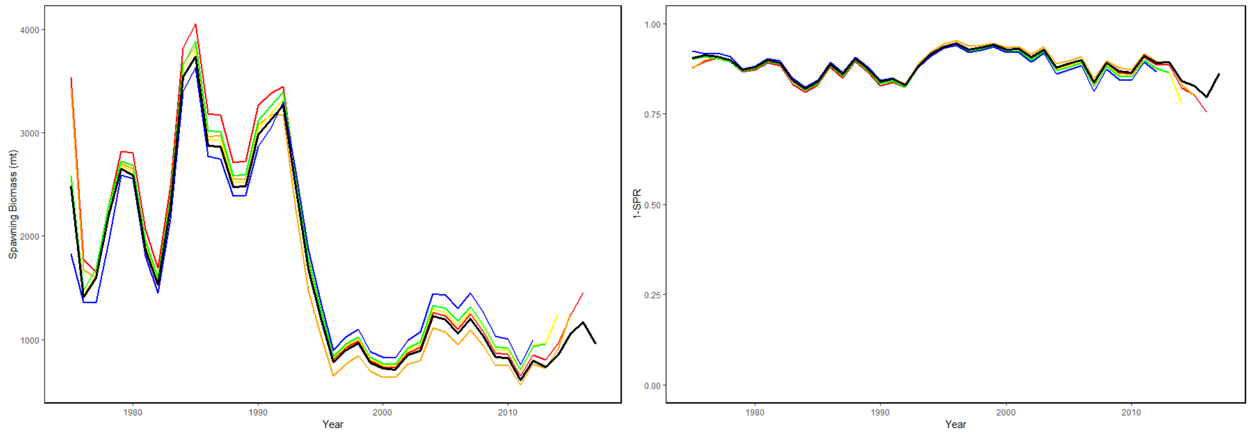


Figure 15. Retrospective analysis of spawning biomass (left) and fishing intensity (1-SPR, one minus the spawning potential ratio, right) consisting of 5 reruns of the base case model each fitted with one more year of data removed from the base case model (black line, 1975-2017).

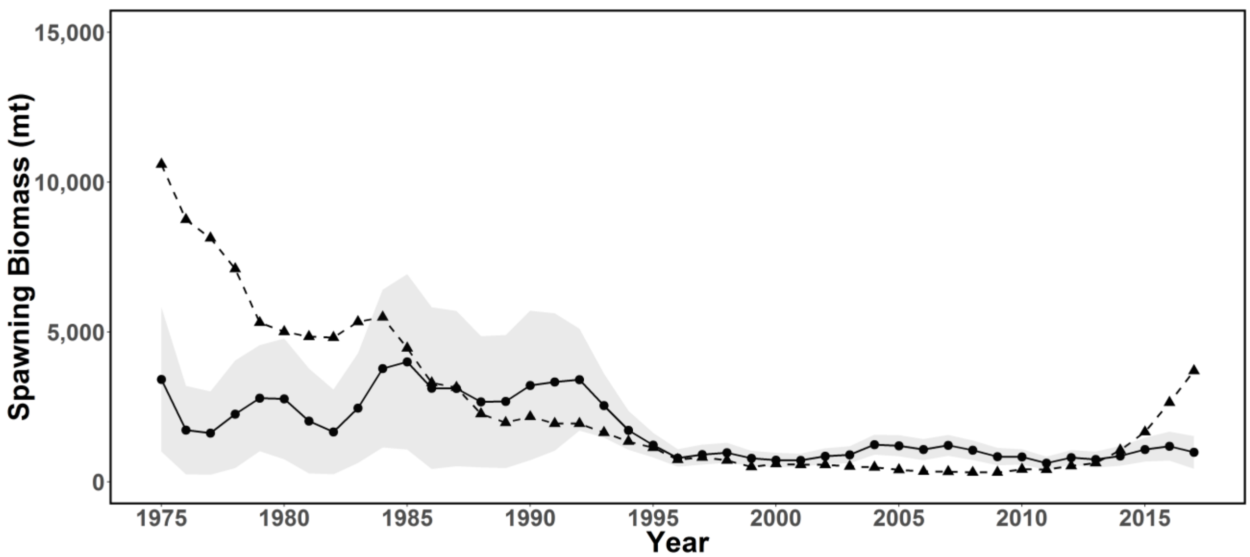


Figure 16. Age structured production model diagnostic for Stock Synthesis base case model. Spawning stock biomass estimates from the base-case model (black circles, solid line; grey shading indicates 95% confidence interval) and ASPM model diagnostic (black triangles, dashed line).

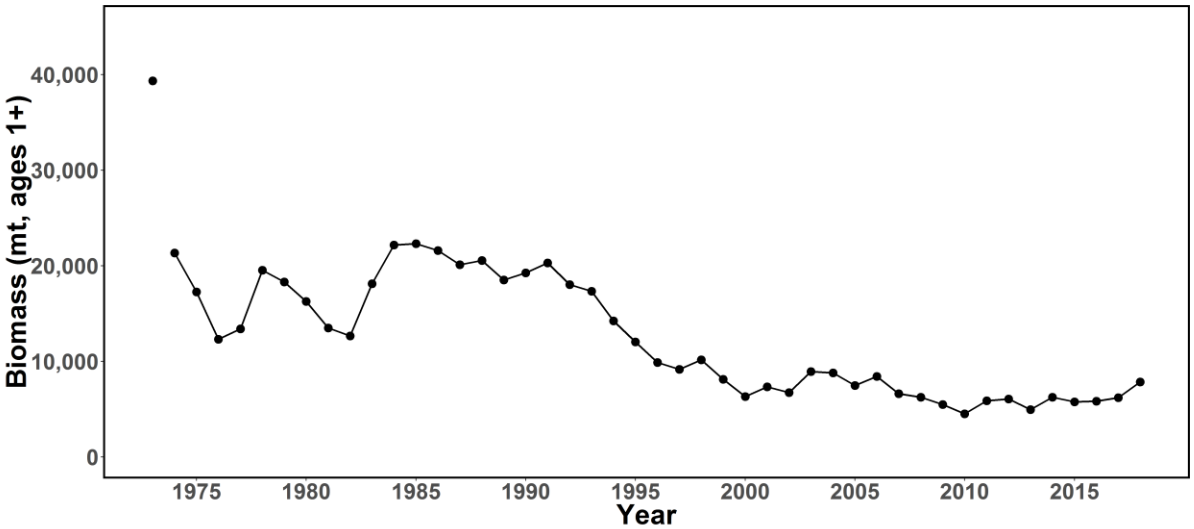


Figure 17. Time series of total biomass (age 1 and older, metric ton) for the Western and Central North Pacific striped marlin estimated in the base-case model. The first year indicates virgin biomass levels.

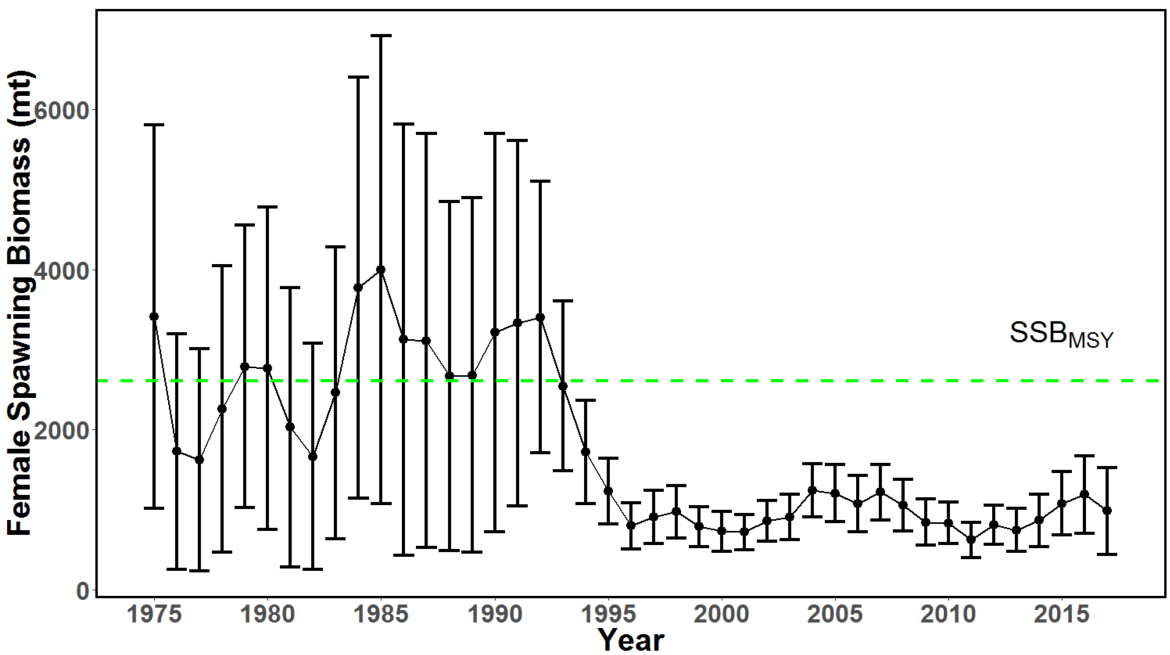


Figure 18. Time series of spawning biomass (metric ton) for the Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence intervals). The dashed horizontal line shows the spawning biomass to produce MSY reference point.

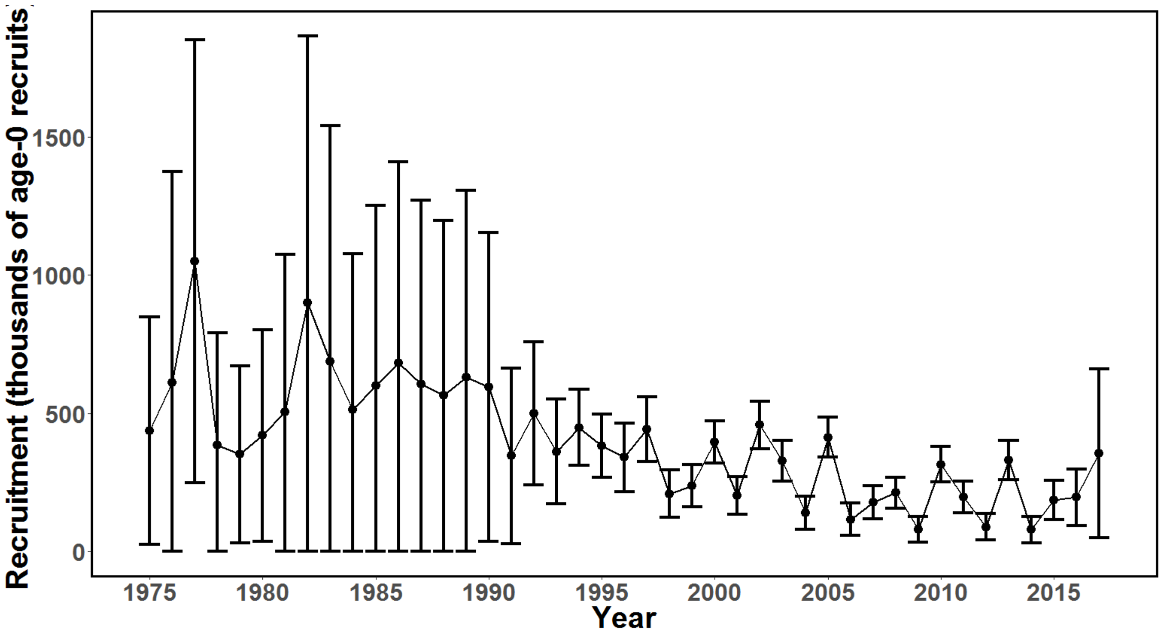


Figure 19. Time series of recruitment (thousands of age-0 fish) for Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence intervals).

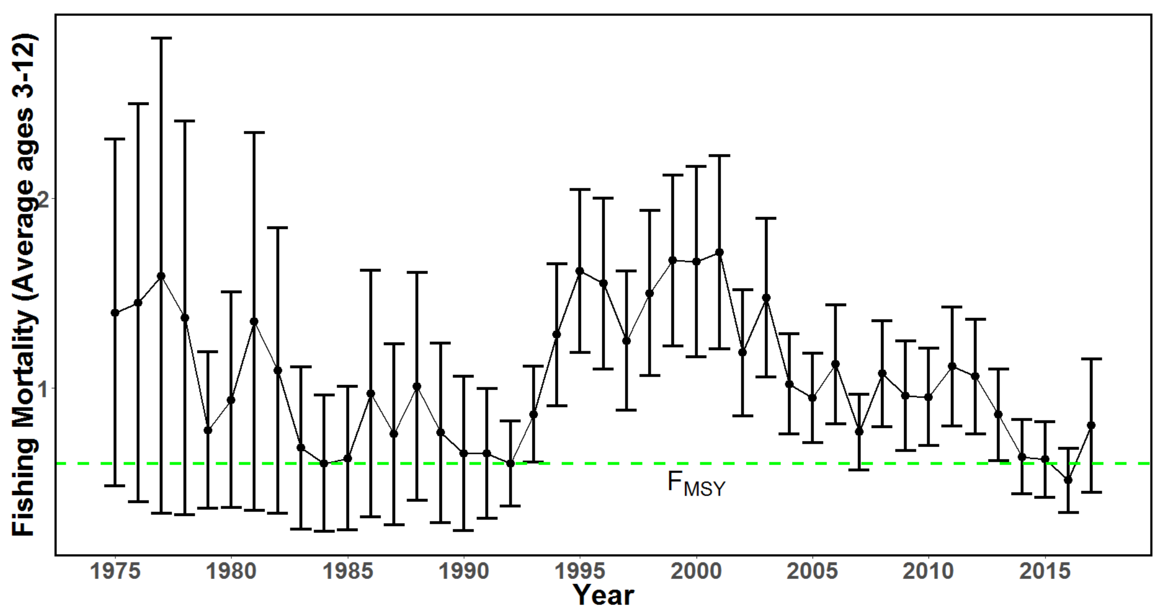


Figure 20. Time series of instantaneous fishing mortality (average for age 3-12) for the Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence interval). The dashed horizontal line shows the fishing mortality to produce MSY reference point.

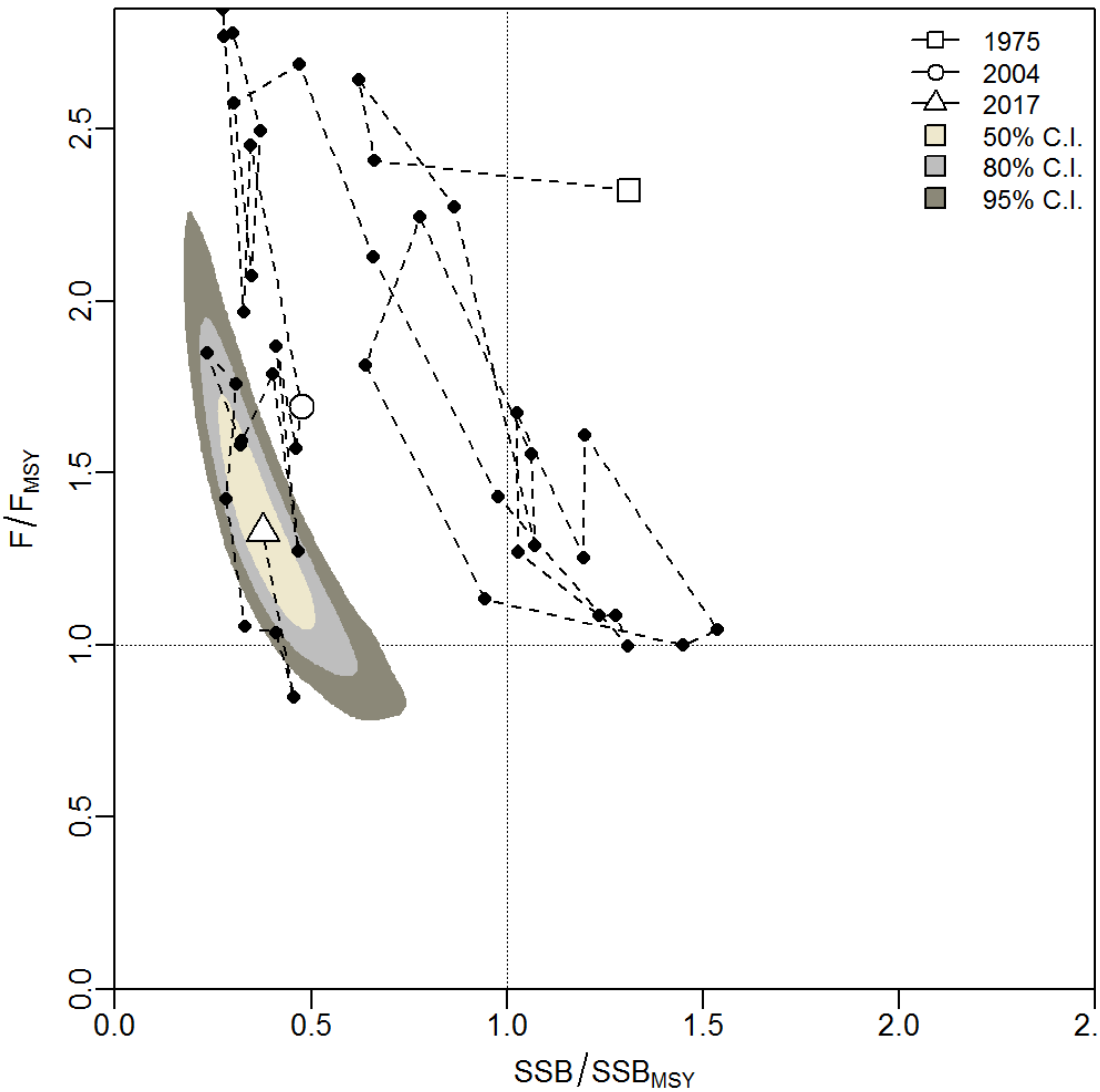


Figure 21. Kobe plot of the trends in estimates of relative fishing mortality (average of age 3-12) and spawning stock biomass of Western and Central North Pacific striped marlin (*Kajikia audax)* during 1975-2017.

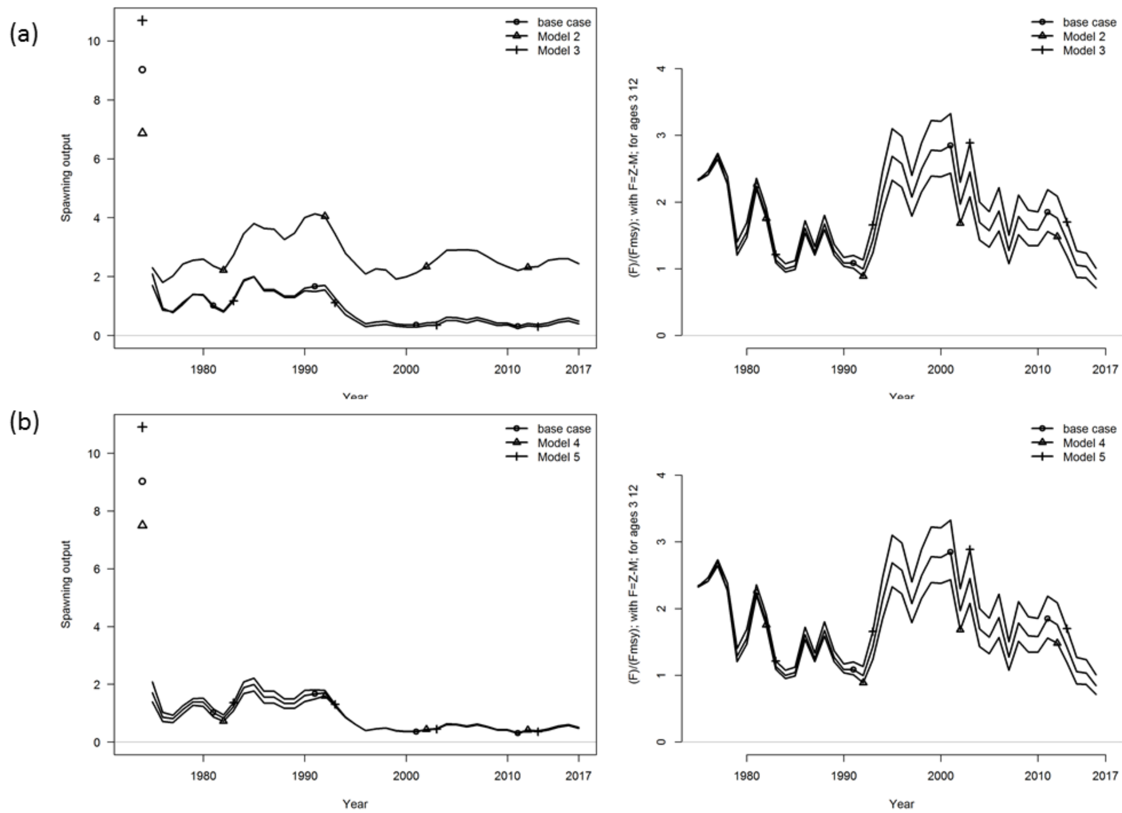


Figure 22. Trajectories of spawning stock biomass and fishing mortality as F/F_{MSY} from 21 sensitivity analyses listed in Table 13, compared to the base case model: (a) Runs 2 and 3 use alternative growth curve parameters; (b) Runs 3, and 4 use alternative natural mortality; (c) Run 6 uses alternative recruitment variability; (d) Runs 7, 8, and 9 use alternative steepness parameters; (e) Runs 10, 11, and 12 use alternative maturity ogives; (f) runs 13, 14, 15, and 16 use alternative initial equilibrium catches; (g) Runs 17, 18, 19, 20, and 21 use alternative Japanese drift gillnet catches; (h) Run 22 starts in 1994 rather than 1975.

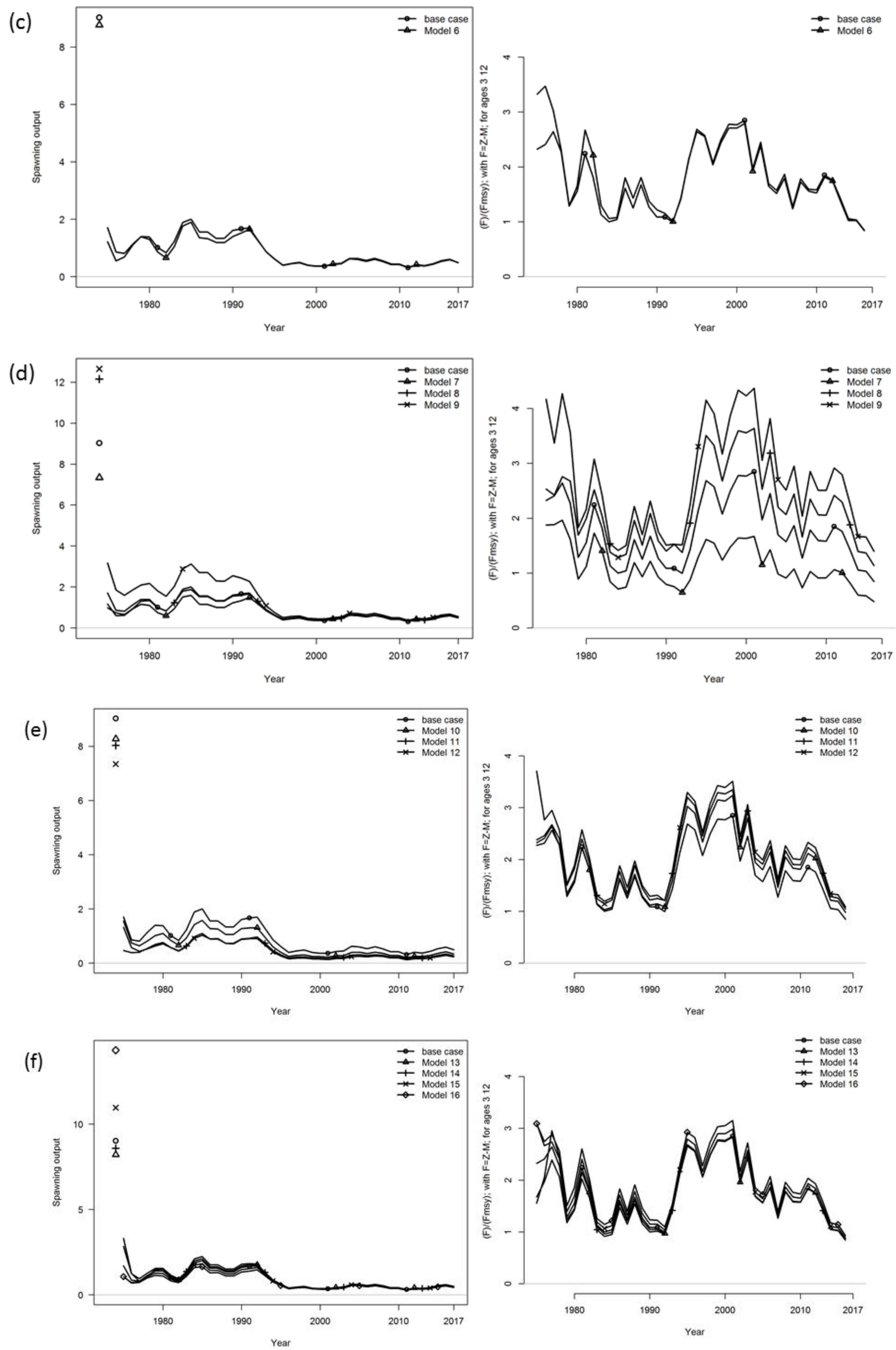


Figure 22. Continued

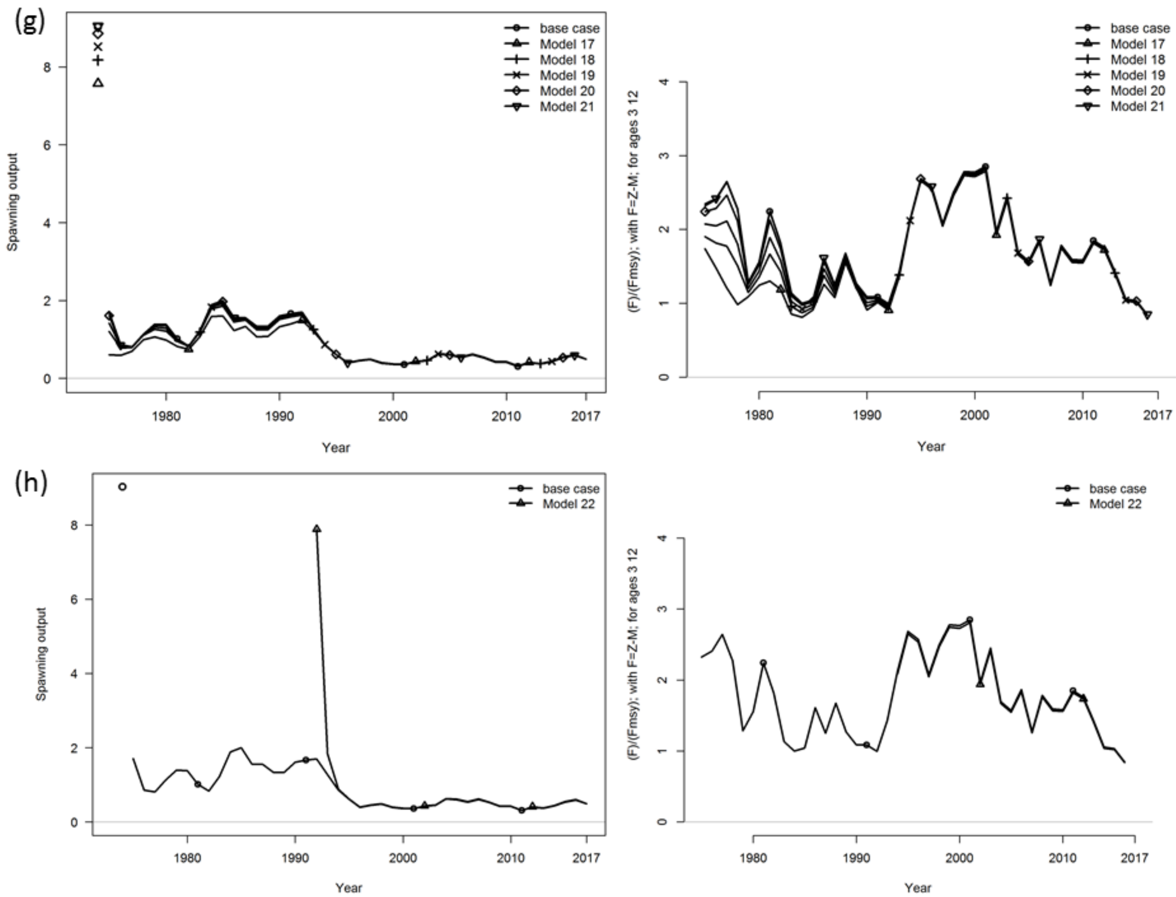


Figure 22. Continued

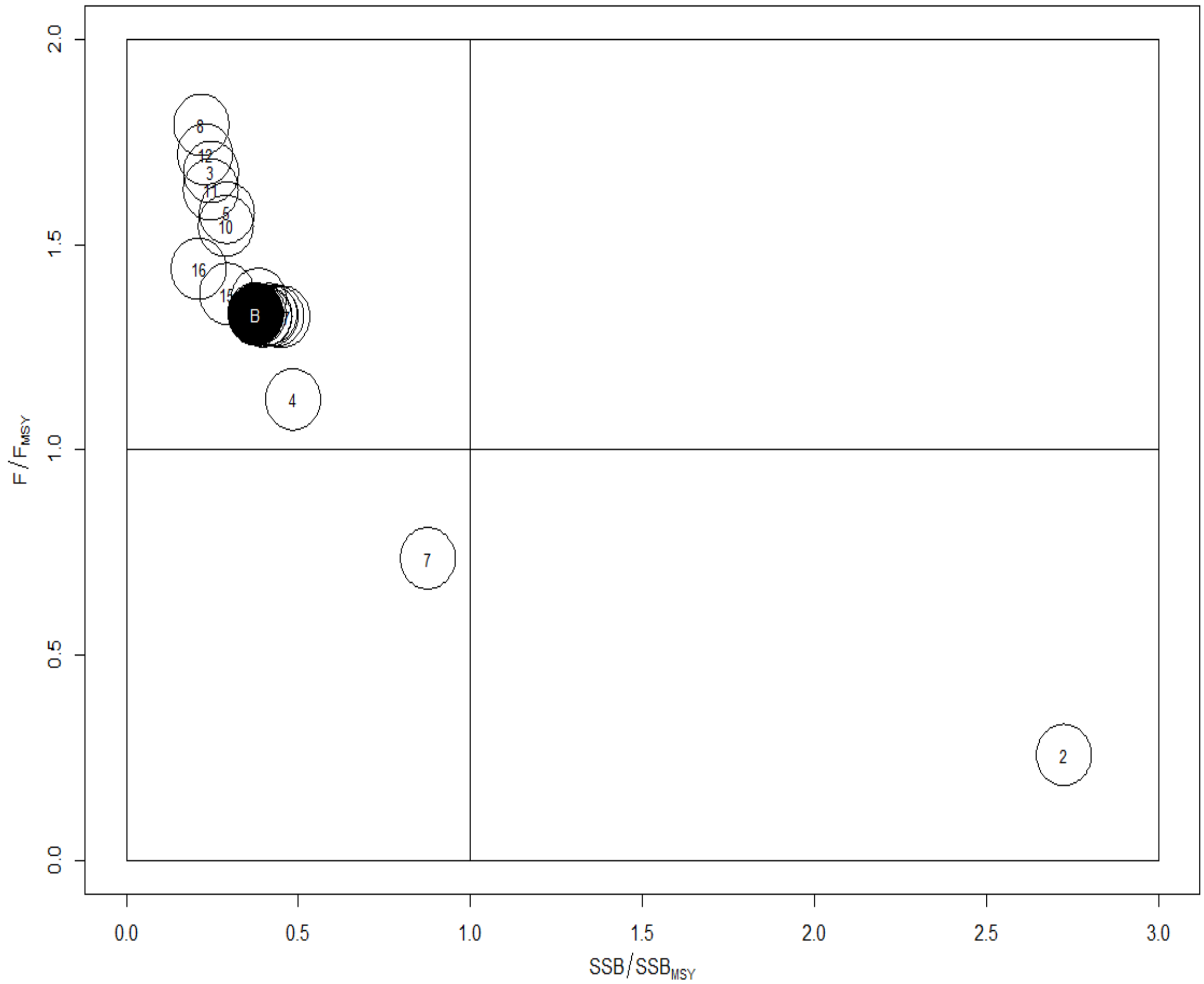


Figure 23. Kobe plot showing the terminal-year stock status for the base case model (B) and the sensitivity analyses as indicated by the run numbers. For the list of sensitivity runs, please see Table 13.

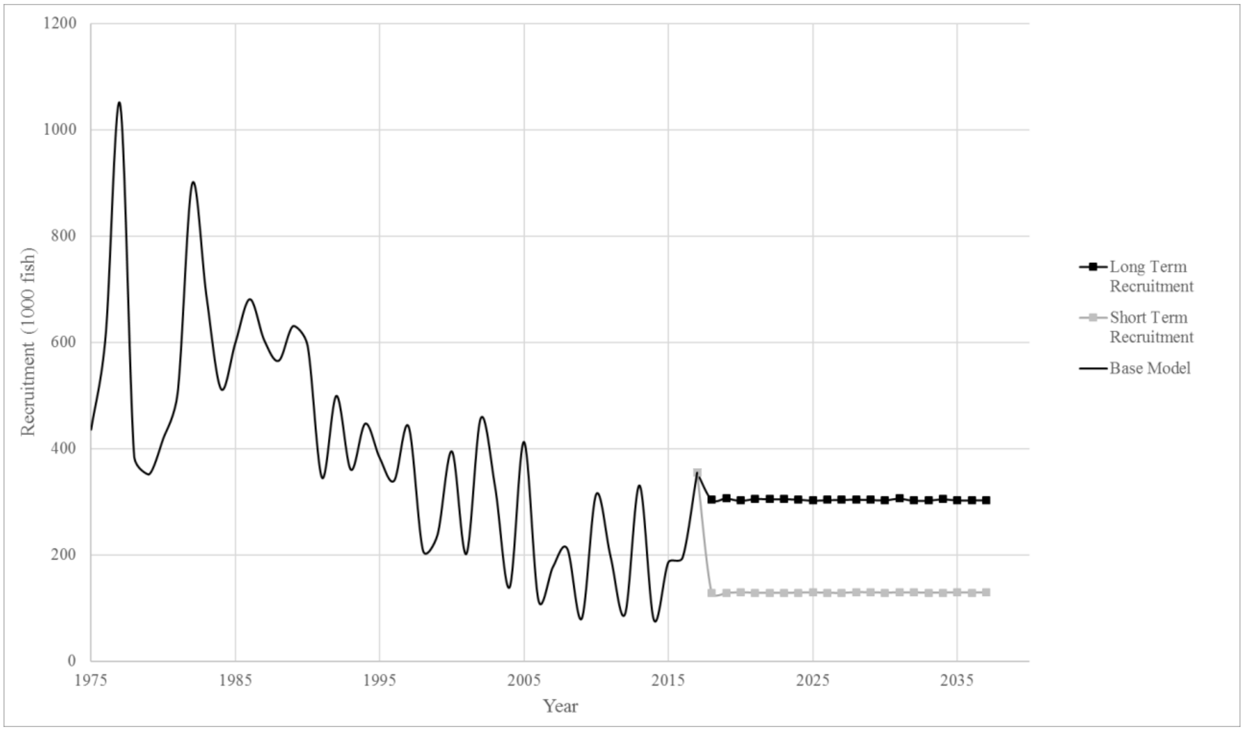
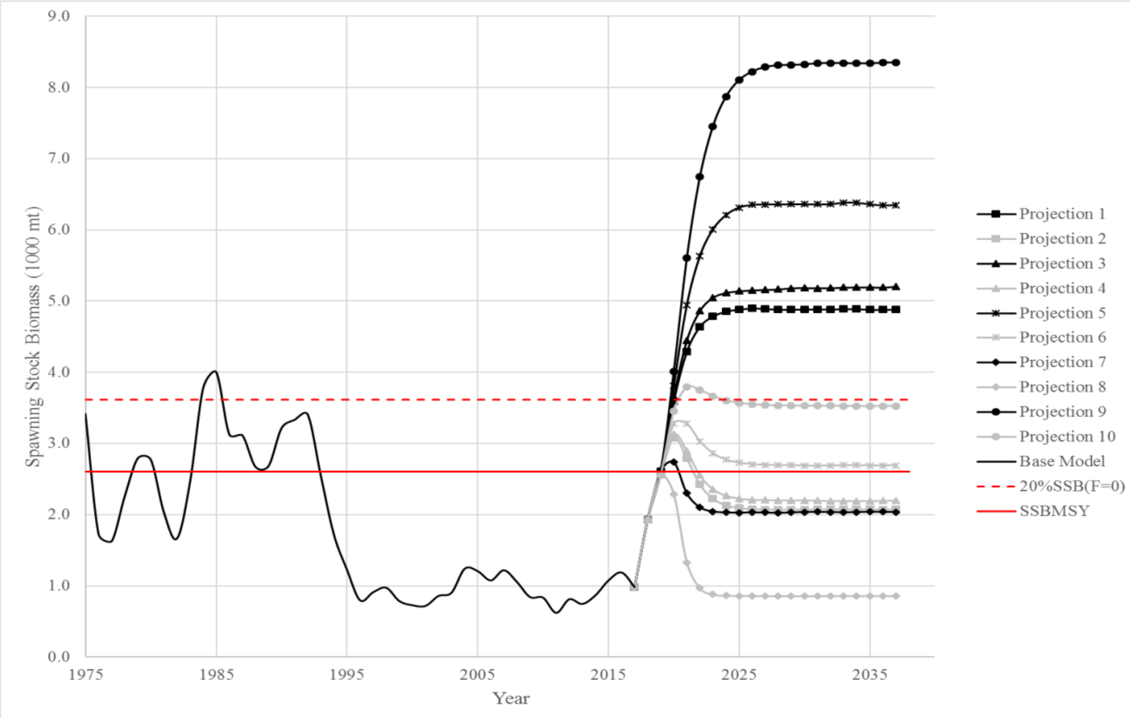
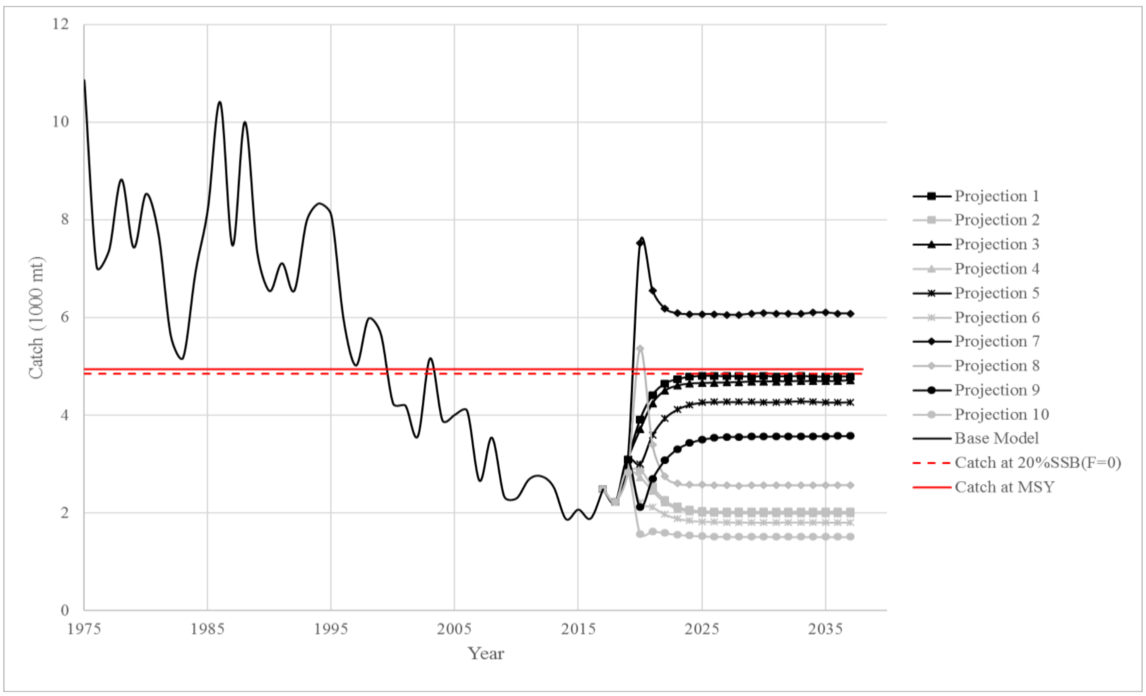


Figure 24. Recruitment trajectories used in the projections: Average short-term recruitment estimates (grey squares); average long-term recruitment estimates (black squares); and base-case model estimated recruitment (black solid line)

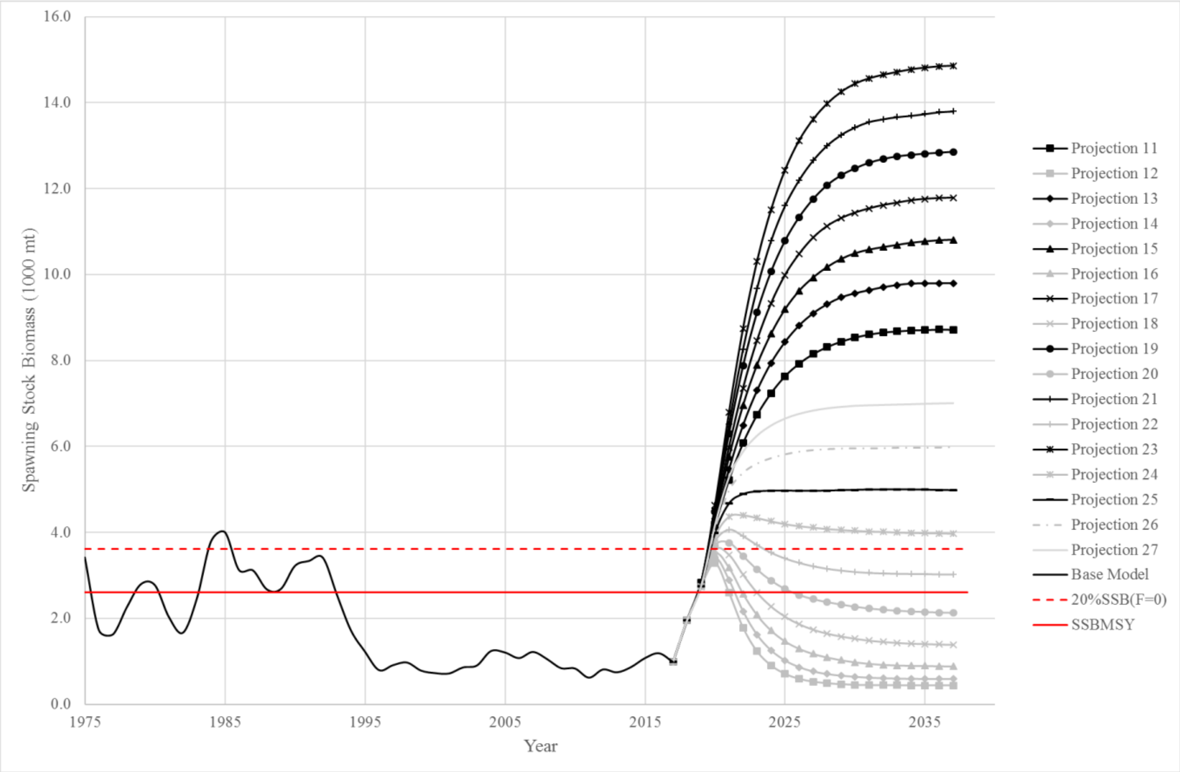


a.)

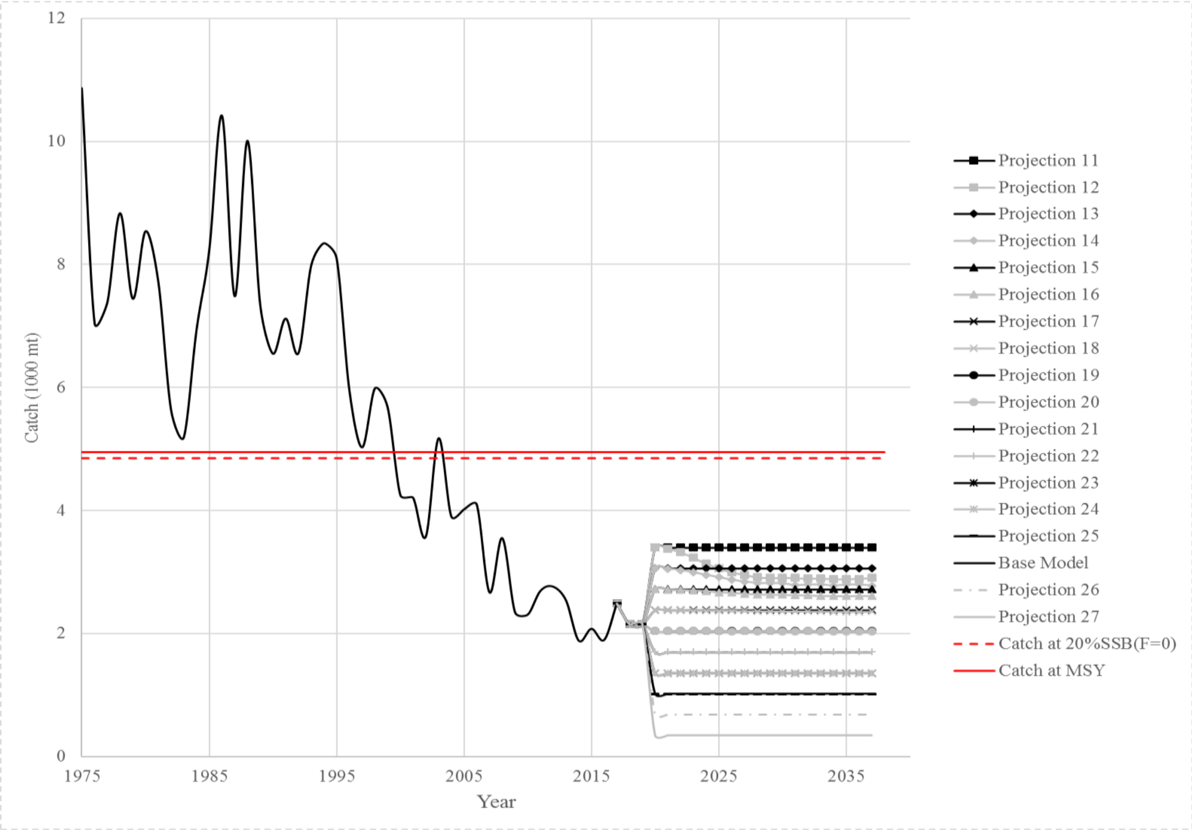


b.)

Figure 25. Historical and projected trajectories of spawning biomass and total catch from the Western and Central North Pacific striped marlin base case model based upon F and constant catch scenarios: (a) F scenarios projected spawning biomass; (b) F scenarios projected catch; (c) Constant catch scenarios projected spawning biomass; and (d) constant catch scenarios projected catch. Black lines indicate the long-term recruitment scenarios; grey lines indicate the short-term recruitment scenarios. Red dashed line indicates the catch or spawning stock biomass at 20%$SSB_{F=0}$. Red solid line indicates the catch or spawning stock biomass at MSY. The list of projection scenarios can be found in Table 8.



c.)



d.)

Figure 25. Continued