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Modeling improvements for the Western and Central north Pacific Ocean striped marlin (*kajikia audax*) to be implemented in the benchmark stock assessment in 2023

WCPFC-SC18-2022/SA-WP-07 (Rev.01)

ISC[1]

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

ANNEX 14

22nd Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Kona, Hawai'i, U.S.A.
July 12-18, 2022

MODELING IMPROVEMENTS FOR THE WESTERN AND CENTRAL NORTH PACIFIC OCEAN STRIPED MARLIN (KAJIKIA AUDAX) TO BE IMPLEMENTED IN THE BENCHMARK STOCK ASSESSMENT IN 2023

July 2022

NOTE TO READERS

The ISC22 Plenary reviewed new modelling and data improvements for the WCNPO MLS stock and concluded that this report is a work in progress, but it is not a benchmark assessment. The new work reviewed includes some important improvements to address previously recognized uncertainties in the data and model and model parameterization, but a significant issue was identified with the choice of growth curve employed that affects the perception of stock status. Until this issue is resolved, the ISC22 Plenary has concluded that it cannot provide stock status and conservation information based on the 2022 modelling and will bring forward information from the 2019 assessment with some updates, in the interim. The ISC22 Plenary approved a BILLWG workplan to explore the growth curve and complete a benchmark WCNPO MLS assessment for approval at ISC23.

This document describes the methodology for the upcoming WCNPO MLS assessment and contains information on improvements to input data, model structure improvements, and parameterization improvements completed by the BILLWG. The base-case model results and estimates, and sensitivity runs are shown to judge the performance of the improvements implemented by the BILLFISH Working Group. These results cannot and should not be used to determine stock status and conservation of WCNPO MLS. The improvements described here will be incorporated into a new benchmark assessment expected to be delivered in 2023 which will form the basis for new stock status and conservation information for this stock.

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EXECUTIVE SUMMARY

Stock Identification and Distribution

The Western and Central North Pacific Ocean striped marlin (*Kajikia audax*) stock area was defined to be the waters of the North Pacific Ocean contained in the Western and Central Pacific Fisheries Commission Convention Area bounded by the equator and 150°W. All available fishery data from the stock 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 averaging about 7,200 mt per year during 1977-1999, and have decreased to an annual average of 2,500 mt during 2018-2020. Catches by Japanese fleets have decreased and catches from the US and Chinese Taipei have varied without trend, while minor catches by other WCPFC countries have generally increased (Figure S1). Overall, longline fishing gear has accounted for the vast majority of WCNPO striped marlin catches since the 1990's while catches by the Japanese driftnet fleet were predominant during 1977 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. Life history parameters for growth and maturity were updated for this benchmark stock assessment. 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 natural mortality rate at age, stock-recruitment steepness, growth curve parameters, and female length at 50% maturity, as well as uncertainty in the input data and model structure.

Estimates of population biomass fluctuated around an average of 18,900 mt during 1977-2020 and was estimated to be 22,500 t in 2020 (Figure S2a). Initial estimates of female spawning stock biomass averaged around 7,200 t in the late 1970s. SSB was at its highest level of 7,849 metric tons in 1977, and declined to 2,546 t in 1999. The time-series of SSB during 2011-2020 averaged about 3,300 metric tons, or about 92% of the dynamic 20-year $SSB_{F=0}$ and about 90% of SSB_{MSY}. Overall, SSB exhibited a strong decline during 1995-2001 and has stabilized to an average of about 3,400 mt since then. SSB has fluctuated at or slightly below the dynamic 20-year 20%$SSB_{F=0}$ reference biomass since 1996, despite declining fishing mortality (Figure S2b). Estimated fishing mortality (arithmetic average of F for ages 3 – 12) increased from 0.36 year^{-1} in 1977 to a peak of 0.76 year^{-1} in 1998, and subsequently declined to 0.34 year^{-1} in 2020 (Figure S2c). It averaged roughly F=0.35 during 2018-2020 or about 40% below $F_{20\%SSB(F=0)}$, with a relative fishing mortality of $F/F_{20\%SSB(F=0)}$ = 0.58 in 2020. Fishing mortality has been below $F_{20\%SSB(F=0)}$ since 2003 and has had a declining trend since 1998. Recruitment (age-0 fish) estimates averaged approximately 425,000 during 1977-2020. While the overall pattern of recruitment from 1977-2020 varied, there was an apparent declining trend in recruitment strength over time with higher recruitments observed in the 1980s and lower recruitments from 2000 to the present (Figure S2d). Recruitment from 2001-2020 averaged about 277,000 age-0 fish, which was 65% of the 1977-2020 average. The WCPFC has request the BILLWG to provide estimates of stock status for WCNPO striped marlin relative to biological reference points based on 20% of a dynamic SSB_0 estimate ($SSB_{F=0}$), where SSB_0 is the moving average of the last 20 years of SSB_0 estimates. 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 average since 2000 (Figure S2d). Although fishing mortality has decreased since 2000, the two decades of low recruitment combined with consistent landings of immature fish have inhibited increases in spawning biomass since 2001. Thus, while spawning biomass of the stock is near the $20\%SSB_{F=0}$ reference biomass in 2020, spawning potential has not recovered as quickly as might be expected given the fishing mortality estimates. When the status of striped marlin is evaluated relative to dynamic $20\%SSB_{F=0}$-based reference points, the 2020 spawning stock biomass of 3,439 mt is 4% below $20\%SSB_{F=0}$ (3,596 mt) and the 2018-2020 fishing mortality is about 40% below $F_{20\%SSB(F=0)}$.

Biological Reference Points

Biological reference points were computed for the base case model with Stock Synthesis (Table S2). The reference points were based upon 20% of the dynamic B_0 ($SSB_{F=0}$) averaged over the last 20 years (2001-2020), which corresponds to about 4 mean generation times for WCNPO striped marlin. The point estimate of annual catch at the dynamic $20\%SSB_{(F=0)}$ was calculated to be 5,446 t. The point estimate of the spawning biomass to produce $20\%SSB_{(F=0)}$ (adult female biomass) was 3,596 t. The point estimate of $F_{20\%SSB(F=0)}$, the fishing mortality rate to produce 20% of $SSB_{(F=0)}$ (average fishing mortality on ages 3 – 12) was 0.59 and the corresponding equilibrium value of spawning potential ratio at $20\%SSB_{(F=0)}$ was 18%.

Projections

Stock projections for WCNPO striped marlin will be conducted using SS3.30. No recruitment deviations and log-bias adjustment will be applied to the future projections. The absolute future recruitments will be based on two recruitment scenarios: the expected stock-recruitment relationship and the average recruitment in the last 20 years. Projections started in 2020 and continued through 2040 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 2018-2020), (2) F_{MSY}, (3) F at $20\%SSB_{(F=0)}$, (4) F_{High} at the highest 3-year average during 1975-2017 (1998-2000), and (5) F_{Low} at $F_{30\%}$.

Special Comments

The WG achieved a base-case model using best available data and biological information. However, the WG recognized that there is still uncertainty in drift gillnet catch data, life history parameters including maturation and growth, and stock structure due to some apparent stock mixing in the WCNPO area as indicated by recent genetic analyses (Lam et al. 2022). The WG considered an extensive suite of model formulations and life history parameters and the corresponding diagnostics for developing the base-case assessment model. Overall, we believe the 2022 assessment is an improvement over the 2019 assessment. To improve the stock assessment in the future, the WG also recommends continuing model development work, reducing data conflicts and modeling uncertainties, supporting the ISC billfish sampling program to provide current estimates of growth parameters, and reevaluating and improving input assessment data. When developing a CMM to conserve the spawning potential of this bycatch species, the WG recommends that these issues be recognized and carefully considered.

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 ($SSB/20\%SSB_{F=0}$), recruitment (thousands of age-0 fish), fishing mortality (average F, ages-3 – 12), relative fishing mortality ($F/F_{20\%SSB(F=0)}$), and spawning potential ratio of Western and Central North Pacific striped marlin.

Year	2014	2015	2016	2017	2018	2019	2020	Mean[1]	Min[1]	Max[1]
Reported Catch	2,743	3,271	2,460	2,261	2,180	2,695	2,413	5,222	2,180	10,577
Population Biomass	12,170	11,205	10,394	9,613	9,008	10,608	10,460	16,311	8,900	24,759
Spawning Biomass	3,243	3,584	3,647	3,401	3,218	2,902	3,449	4,321	2,533	7,825
Relative Spawning Biomass	0.90	1.00	1.01	0.95	0.89	0.81	0.96	2.18	0.70	1.20
Recruitment (age 0)	98,163	252,706	172,440	179,387	376,376	200,369	297,709	424,638	98,163	984,205
Fishing Mortality	0.35	0.40	0.33	0.34	0.33	0.38	0.33	0.50	0.33	0.76
Relative Fishing Mortality	0.59	0.68	0.55	0.57	0.57	0.65	0.55	0.84	0.55	1.30
Spawning Potential Ratio	0.31	0.26	0.33	0.32	0.32	0.28	0.32	0.23	0.34	0.12

[1] During 1977-2020

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 $SSB_{F=0}$ indicates the average 20-year dynamic B_0 estimate, $20\%SSB_{F=0}$ is the associated reference point, and MSY indicates the maximum sustainable yield reference point.

Reference Point	Estimate
$F_{20\%SSB(F=0)}$ (age 3-12)	0.59
F_{MSY} (age 3-12)	0.57
F_{2020} (age 3-12)	0.33
$F_{2018-2020}$	0.35
$SSB_{F=0}$	17,978 mt
$20\%SSB_{F=0}$	3,596 mt
SSB_{MSY}	3,689 mt
SSB_{2020}	3,449 mt
$SSB_{2018-2020}$	3,190 mt
$C_{20\%SSB(F=0)}$	5,446 mt
C_{MSY}	5,407 mt
$C_{2018-2020}$	2,429 mt
$SPR_{20\%SSB(F=0)}$	18%
SPR_{MSY}	19%
SPR_{2020}	32%
$SPR_{2018-2020}$	30%

Table S3. Projected median values of Western and Central North Pacific striped marlin spawning stock biomass (SSB, mt) and catch (mt) under five constant fishing mortality rate (F) and two recruitment scenarios during 2021-2040. For scenarios which have a 50% 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 3596 mt.

Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2030**	**2040**	**Year when target achieved**
Scenario 1: $F_{20\%SSB(F=0)}$; Stock – Recruitment Curve								
SSB	2938	2723	2953	3179	3320	3564	3596	2037
Catch	4175	4186	4596	4920	5107	5408	5446	
Scenario 2: Highest F (Average $F_{1998-2000}$); Stock – Recruitment Curve								
SSB	2820	2445	2551	2662	2723	2830	2845	NA
Catch	4749	4586	4897	5098	5200	5364	5387	
Scenario 3: Low F ($F_{30\%}$); Stock – Recruitment Curve								
SSB	3630	3928	4648	5375	5920	6950	1097	2021
Catch	2614	2979	3525	3996	4319	4867	4938	
Scenario 4: F_{MSY}; Stock – Recruitment Curve								
SSB	2975	2770	3005	3242	3392	3653	3688	2028
Catch	4080	4139	4552	4874	5062	5367	5407	
Scenario 5: $F_{Status\ Quo}$ (Average $F_{2018-2020}$); Stock – Recruitment Curve								
SSB	3557	3789	4425	5069	5550	6459	6590	2022
Catch	2760	3121	3652	4097	4398	4911	4979	
Scenario 6: $F_{20\%SSB(F=0)}$; 20-year Average Recruitment								
SSB	2938	2626	2478	2398	2359	2329	2328	NA
Catch	4172	3817	3662	3584	3550	3526	3526	
Scenario 7: Highest F (Average $F_{1998-2000}$); 20-year Average Recruitment								
SSB	2820	2352	2129	2022	1975	1942	1941	NA
Catch	4747	4132	3863	3748	3703	3675	3675	
Scenario 8: Low F ($F_{30\%}$); 20-year Average Recruitment								
SSB	3630	3812	3967	4048	4089	4133	4135	2021
Catch	2613	2727	2809	2846	2861	2876	2877	
Scenario 9: F_{MSY}; 20-year Average Recruitment								
SSB	2975	2674	2530	2452	2414	2382	2382	NA
Catch	4077	3756	3615	3545	3514	3491	3491	
Scenario 10: $F_{Status\ Quo}$ (Average $F_{2018-2020}$); 20-year Average Recruitment								
SSB	3557	3676	3779	3828	3850	3872	3873	2022
Catch	2757	2837	2891	2911	2919	2926	2926	

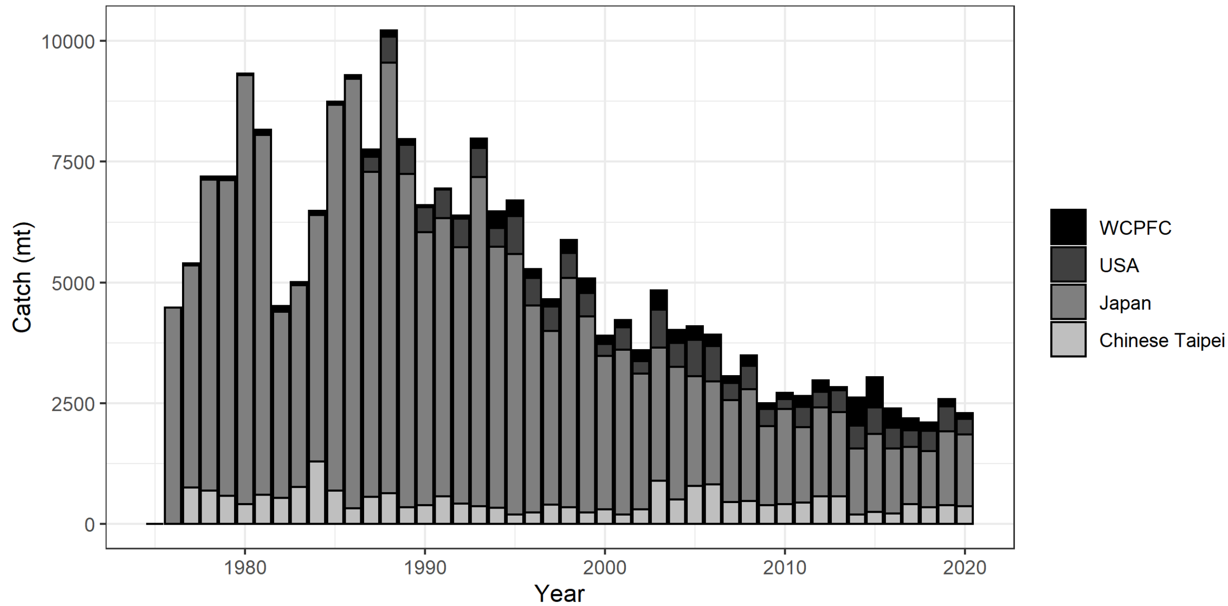

Figure S1. Annual catch biomass (mt) of Western and Central North Pacific striped marlin (*Kajikia audax*) by country for Japan, Chinese Taipei, the U.S.A., and all other countries during 1977-2020.

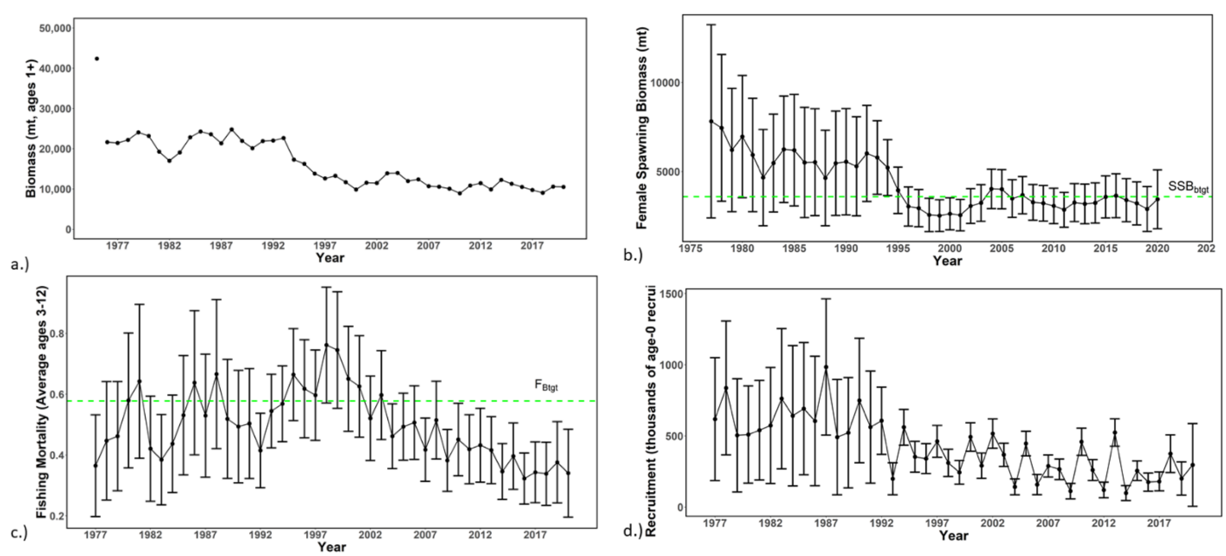

Figure S2. Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) instantaneous fishing mortality (average for age 3-12, year^{-1}), and (d) recruitment (age-0 fish) for Western and Central North Pacific striped marlin (*Kajikia audax*) derived from the 2022 stock assessment. The circles represents 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 $20\%SSB_{(F=0)}$ and $F_{20\%SSB(F=0)}$.

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 2019 and noted several important concerns with the model (ISC, 2019). In addition, member of the Western and Central Pacific Fisheries Commission requested the BILLWG to provide stock status based upon a dynamic B0 estimate and requested the WG to provide the best time-frame for the calculation of these reference points. Therefore, the BILLWG agreed to produce a new benchmark assessment in 2022, with stock status reported based upon a 20%$SSB_{F=0}$ reference point where the $SSB_{F=0}$ was based upon a dynamic B0. The status of the WCNPO striped marlin stock was overfished and overfishing was occurring relative to MSY-based reference points in the 2019 assessment using a Stock Synthesis (SS) assessment model. The ISC BILLWG data preparatory meeting was held virtually in December 2021 to evaluate new stock structure, life history, catch, length composition, and CPUE data and strategize for the assessment (ISC, 2022).

This report describes the 2022 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 1975-2020 were provided by individual ISC countries and the Western and Central Pacific Fisheries Commission (WCPFC), however modeling choices during the development of the model resulted in a change of the start year for the assessment from 1975 to 1977. The 2022 assessment was an integrated age-structured assessment model with a quarterly time step using the modeling platform Stock Synthesis (SS) version 3.30.18 (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. Three types of data were used: fishery-specific catches, relative abundance indices, and length measurements. The fishery data were compiled for 1975-2020, noting that the catch data and length composition data were compiled and modeled on a quarterly basis and only data from 1977-2020 were ultimately used in the model. 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 stock assessment are summarized in Figure 1. Further details are presented below.

2.2. Definition of Fisheries

A total of 25 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 which are consistent with the fleets used in the 2019 assessment. 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. Five additional fleets from Japan included the driftnet catches in four fleets divided by time-period and quarter: quarters one and four and quarters two and three (JPNDF_Q14 and JPNDF_Q23) and 1977-1993 (Mid) and 1975-1976, 1994-2020 (EarlyLate) and a fleet to encompass all other Japanese striped marlin catches (JPN_Others). The change in the Japanese driftnet fleets from two to four fleets was to reflect a re-estimation of the Japanese driftnet catch from 1977-1993 where the new catch data are reported in numbers. 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-five 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 1977 to 2020 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) and the Japanese driftnet mid fisheries (F24 and F25) 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; Russell Ito, NOAA NMFS, personal communication). Striped marlin catches for all other fishing countries were collected from WCPFC category I and II data (WCPFC Yearbook).

The resulting best available data on striped marlin catches by fishery from 1977-2020 were tabulated and are shown in Figure 2 and Table 2. The historical maximum and minimum annual striped marlin catches were 10,577 metric tons in 1988 and 2,180 metric tons in 2018, respectively. From 1975 to 1993, the Japanese driftnet fishery harvested approximately half of the total annual catch. However, these catches likely have large uncertainty due to incomplete logbook records and limited port sampling. Overall, annual catches of WCNPO striped marlin have generally declined since 1988. The annual catch of striped marlin in the WCNPO averaged about 2,430 metric tons in the period since the last assessment (2018-2020).

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; Ijima and Koike, 2022).

Operational fishing data collected in the Hawaiian longline fishery by fishery observers in 1995-2020 were used for CPUE standardization of US longline fleets (Sculley, 2022). The fishery operates in two sectors; a shallow-set sector targeting swordfish and a deep-set sector targeting tunas. Striped marlin are 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.

The distant-water longline fleet from Chinese Taipei was standardized from 1995-2020 using a spatio-temporal model (Lee *et al.*, 2022).

Visual inspection of all indices showed an overall decreasing trend with the last 10-20 years showing a relatively flat trend. Both of the early Japanese LL indices and the Chinese Taipei LL index are relatively variable without trend (Figure 3). However, S2 (JPNLL Q1A3 Late), S3 (US HI LL) and S4 (TWN DWLL) 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 1977–2020 for seventeen fisheries were used for the assessment and are summarized in Table 3. 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 2020 stock assessment.

Figure 4 shows the quarterly length compositions. Most of the fisheries caught small (mean size caught 153 cm) individuals. The longline fleets caught fish with a mean of 154 cm EFL while the driftnet fleets caught slightly larger fish, mean 163 cm EFL. The US longline fleet (US_LL) caught smaller fish on average than any of the other fleets (mean size 143cm 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 3.30.18.00-SAFE released 09/30/2021 using Otter Research ADMB 12.3 (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, 2022). The age at length L1 was set to age 0.5, the CV of the growth curve was set to 0.14 for young fish and 0.08 for old fish, and the sex ratio at birth was assumed to be 1:1. The growth curve used a von Bertalanffy growth curve for ages 0.5-15 with a K = 0.34 and an L_{inf} = 203 cm EFL with the size at age 0.5 = 110 cm EFL. In 2011, the Billfish Working Group agreed with Sun et al.'s (2011) conclusion that the Richards growth curve is the best representation of WCNPO striped marlin growth. However, the BILLWG had to convert the Richard's curve parameters to the standard von Bertalanffy curve parameters in order to use them in the stock assessment because the SS3 model did not have the option to choose Richard's growth curve. Prior to the last data-preparation meeting, the BILLWG reviewed the growth curve parameters used in 2019. The BILLWG could not reproduce the parameters from past stock assessments, and therefore agreed to use in this stock assessment the same growth-curve form as for EPO and SWPO. The latter growth curves are of the standard von Bertalanffy form, meaning that reproducibility across all regions is ensured. The growth-curve parameters were taken from Sun et al. 2011 and converted for use in SS3. The converted parameter values were reported in Ijima 2021 and agreed upon at the data-preparation meeting. A Beverton-Holt spawner-recruit relationship was used with steepness (h) set at 0.87 and sigmaR (σ_r) set 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 $\log(SE)=\mathrm{sqrt}(\log(1+CV^2))$, 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 (S3-4) were assigned to quarter one. Japanese longline fleets (S1, S2, S5 and S6) were quarterly indices representing quarters one and three. Of these, only fleets S1, S5, and S6 were included in the base-case model. The other 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 all fleets was set equal to 1/10 of the total number of samples in each quarter, in alignment with previous assessments (ISC 2019). 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 F18, the Chinese Taipei longline fishery 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). Input length composition sample sizes and CPUE data iteratively re-weighted in stage 2, but only if the re-weighting decreased the sample size or increased the CPUE CV.

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) and Carvalho *et al.* (2021) were implemented to evaluate the base case model.

2.10.1. 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. Then Mohn's rho was calculated for the biomass and fishing mortality peels, which measures the severity of the retrospective pattern (Hurtado-Ferro *et al.* 2014). Values higher than 0.20 and lower than -0.15 can indicate problematic retrospective patterns and may point to model misspecification, data conflicts, or poor fits to the data.

2.10.2. Prediction skill

In addition to evaluating the retrospective patterns of the model, understanding how well a model predicts future years is key to evaluating projections. To do so, hindcasting cross-validation was used to predict the next years' observed data from the retrospective peel (Carvalho *et al.* 2021). Then the forecast bias is estimated by comparing the forecasted values from the retrospective peel to the full model. To evaluate the predictive skill, the mean absolute scaled error (MASE) is used to determine if the predicted value improves the model forecast compared to the baseline (Carvalho *et al.* 2021). A MASE score of >1 indicates that the average model forecasts are worse than a random walk model, and a value of 0.5 indicates the model has prediction skill. The hindcasting cross-validation and MASE scores were calculated for the CPUE indices and size composition data in the last five years of the assessment.

2.10.3. 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).

2.10.4. 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.

2.10.5. 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.

2.10.6. 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.

2.10.7. Runs Test

The runs test evaluates the residuals of the CPUE indices and size composition mean length trends. This is a nonparametric test for randomness in the sequence of residuals (Carvalho *et al.* 2021, Wald and Wolfowitz 1940). In other words, this test uses a 2-sided p-value to estimate the number of positive or negative residuals in a row (a "run"). CPUE or size composition data that fail the runs test indicate that there may be a pattern in the residuals and the model is unable to fit the data well or is mis-specified.

2.11. Stock Projections

Deterministic stock projections were conducted in SS to evaluate the impact of various levels of fishing mortality on future SSB and yield. No recruitment deviations and log-bias adjustment were applied to the future projections in this study. Instead, the absolute future recruitments were based on two recruitment scenarios: the expected stock-recruitment relationship and the average recruitment in the last 20 years. The future projection routine calculated the future SSB and yield that would occur while the specific fishing mortality, selectivity patterns, and relative fishing mortality proportions depended on the specific harvest scenarios. The last three model years' (2018-2020) selectivity patterns and relative fishing mortality rates were used in the population future projections. The projections started in 2021 and continued through 2040 under five different harvest scenarios:

1. **High F Scenario ($F_{1998\text{-}2000}$)**: Select the 3 years with the highest average F (age 3-12) and apply this fishing mortality rate to the stock estimates beginning in 2021; this corresponds to 1998-2000;

2. **F_{MSY} Scenario (F_{MSY})**: Apply the estimate of the FMSY fishing mortality rate to the stock estimates beginning in 2021;

3. **Status Quo F Scenario ($F_{18\text{-}20}$)**: This will be the average F (age 3-12) during 2018-2020;

4. **Low F Scenario (F_{30})**: Apply an $F_{30\%}$ fishing mortality rate to the stock estimates beginning in 2021;
5. **$F_{20\%SSBF=0}$ Scenario:** Apply the estimate of F which produces $20\%SSB_{F=0}$ based upon the dynamic B0, which roughly corresponds to $F_{15\%}$.

Recruitment for the 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. The time period chosen to average the recruitment was 20 years, consistent with the time-period from which the dynamic B0 was calculated. The second hypothesis was that future recruitment would be similar to the stock recruitment curve.

3. RESULTS

***NOTE**: Because of an issue with the growth curve, stock status and conservation information cannot be based on the current 2022 model results. Results are shown here in order to be able to judge the performance of the model improvements. A new benchmark assessment of the WCNPO stock will be completed in 2023 and will be the basis for new stock status and conservation information for the WCNPO MLS stock.*

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 200 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 8 and 9 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 (6.4) was slightly higher than that of total likelihood log(R_0) = 6.30. The contribution to the likelihood for all CPUE indices was minimal (Table 8, 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 5.9 (Figure 8). The U.S. longline fleet (F16) showed the largest changes in negative log-likelihood values (max 38.0) across values of R_0 among the nine size composition data (Table 9, Figure 10).

There were 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.

3.3.1. 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 (S1, S5, and S6), and those in which indices did not contribute to the total likelihood (S2, S3, and S4). Results showed that four of the indices (S1, S2, S5, and S6) had RMSE < 0.3, which indicates that the model fit these CPUE indices well. Fleets S3 and S4 had RSME = 0.3, but these were not included in the likelihood.

3.3.2. 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. In this assessment both of these options were explored for several of the fleets, including the F01 Japanese LL Q1A1 data and the F16 US LL data, however the WG ultimately selected a simpler model as improving the fit to the size data often required additional parameters, while accepting a slightly degraded fit to the data allowed the focus to remain on improving the CPUE fit and maintaining as many degrees of freedom in the model as possible.

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 for F16 U.S. longline and F18 Chinese Taipei distant water longline, which showed stronger residual patterns when compared to the other fleets (Figure 13)**.**

Overall, the model fit the length modes in composition data aggregated by fishery fairly well using the input effective sample sizes (Figure 14). However, F13, F14, and F16 all showed some misfit.

3.3.3. Runs test

All three of the CPUE indices included in the model passed the runs test (S1, S5, and S6, Figure 15). This indicates that in general, the model can fit the CPUE indices well. Of the nine length composition data time series available, seven passed the runs test (Figure 16). The size data for F01 Japanese LL Q1A1 passes the runs test if an additional time block is included in the selectivity estimates for that fleet. However, this also increase the number of parameters estimated by 6 and degrades the fit to the S1 Japanese LL Q1A1 CPUE index. The WG agreed that the priority was to fit the CPUE data and therefore estimated the F01 size data without a time block. Additionally, the size data for F13 Japanese DF Q14 was down-weighted according to the Francis weighting, thereby degrading the fit to that dataset. Overall, additional work must be done to improve the fit to the size data within the model, while ensuring that the fit to the CPUE data are prioritized.

3.3.4. Retrospective Analysis

A retrospective analysis of the WCNPO 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. The results of the retrospective analysis are shown in Figure 17. The trajectories of estimated spawning stock biomass and fishing mortality showed there was a slight tendency for the base case model to overestimate spawning biomass in recent years and underestimate fishing intensity. In addition, the Mohn's rho for biomass (-0.08) and fishing mortality (0.11) fall within the range of acceptable values (-0.15 to 0.20), suggesting that the retrospective pattern is not substantial.

3.3.5. Predictive Skill

Four CPUE indices and eight length composition time series had at least one data point within the last five years of the assessment, the hindcasting evaluation period. Only one of the CPUE indices were included in the model likelihood, S01, which had a MASE score of 1.91 (Figure 18). The only CPUE index with a MASE score <1 was S4, indicating a poor predictive ability of the model. However, for all four CPUE indices, the predicted value was within the 95% confidence intervals of the input index.

Predictive skill for the length composition data was much better than the CPUE data (Figure 19). Four length composition time series had MASE scores below one, Japanese longline Q1A2 (MASE=0.59), Japanese longline Q4A1 (MASE=0.68), US longline (MASE = 0.66) and Chinese Taipei deep water longline data (MASE = 0.45). All of the other length composition data had MASE >1, although the MASE for F01 Japanese longline Q1A1 was very close to 1 (1.06). Like the CPUE data hindcast, all of the predicted length composition data points were within the 95% confidence intervals of the original input data.

3.3.6. Age-structured production model

ASPM results are provided in Figure 20. The models showed different trends in SSB during the modeled timeframe. The ASPM model population declined from the beginning of the assessment to the 1980s. After 1987, the ASPM showed a flat trend which was lower than the fully integrated model. 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 after 1987.

3.4. Stock Assessment Results

***NOTE**: Because of an issue with the growth curve, stock status and conservation information cannot be based on the current 2022 model results. Results are shown here in order to be able to judge the performance of the model improvements. A new benchmark assessment of the WCNPO stock will be completed in 2023 and will be the basis for new stock status and conservation information for the WCNPO MLS stock.*

Estimates of population biomass (estimated biomass of age 1 and older fish at the beginning of the year) declined from a high of 24,758 mt in 1988 to 8,900 mt in 2010, and increased to around 10,000 metric tons during the final three years of the 2022 stock assessment time horizon (2018−2020, Table 10 and Figure 21). Overall, population biomass declined from an average of roughly 22 thousand metric tons in the mid-1980s to an average of roughly 10 thousand metric tons in the 2010s (Figure 21).

Spawning stock biomass (SSB) estimates exhibited an initial oscillation around 6 thousand metric tons in the late 1970s. SSB was at its highest level of 7,825 tonnes in 1977, and declined to 2,532 t in 1999 (Table 10 and Figure 22). The time-series of SSB during the past decade averaged 3,200 t, or 18% of $SSB_{F=0}$. Overall, SSB exhibited a strong decline during the early 1990s and has stabilized since. SSB has hovered at or just below 20%$SSB_{F=0}$ since 1996, despite declining fishing mortality.

Recruitment (age-0 fish) estimates indicated a long-term fluctuation around a mean of approximately 424,000 (Table 10 and Figure 23). While the overall pattern of recruitment from 1977-2020 was variable, there was an apparent declining trend in recruitment strength over time with average recruitment higher in the 1980 than after 2020 (Table 10 and Figure 23).

Over the course of the assessment time horizon, estimated fishing mortality (arithmetic average of F for ages 3 – 12) increased from 0.36 $year^{-1}$ in 1977 to an all-time high of 0.76 $year^{-1}$ in 1998, and afterward declined to a low of 0.33 $year^{-1}$ in 2020 (Table 10 and Figure 24).

3.5. Biological Reference Points

Biological reference points were computed from the Stock Synthesis base case model. Based upon a request from WCPFC18, dynamic B_0 reference points ($SSB_{F=0}$) will be used to assess relative stock status (Table 11). This value is 20% of the 20-year average $SSB_{F=0}$. The point estimate of 20%$SSB_{F=0}$ was 3,595 t with a $SSB_{F=0}$ point estimate of 17,978 t. The point estimate of $F_{20\%SSBF=0}$, the fishing mortality rate to produce 20% of $SSB_{F=0}$ on ages 3-12 fish was F = 0.59.

3.6. Sensitivity Analyses

***NOTE**: Because of an issue with the growth curve, stock status and conservation information cannot be based on the current 2022 model results. Results are shown here in order to be able to judge the performance of the model improvements. A new benchmark assessment of the WCNPO stock will be completed in 2023 and will be the basis for new stock status and conservation information for the WCNPO MLS stock.*

In the April 2022 BILLWG workshop, it was agreed that at least five parameters would be evaluated in sensitivity analyses in the 2022 assessment (Table 12) 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 fully explore alternative growth curves in the development of this assessment. Growth curves and associated maturity and natural mortality parameters from the Eastern Pacific Ocean and Southwest Pacific Ocean striped marlin stocks were explored with full diagnostics. Ultimately both growth curves were discarded as base-case model options. The results of the EPO growth model can be found in the ISCBILLWG stock assessment workshop report (ISC 2022), but is not included as a sensitivity analysis because the WG determined that the biological parameters were incompatible with the WCNPO data and produced biologically unrealistic results. An iteration of the SWPO growth model is included as a sensitivity run, as the model results were biologically plausible but the model diagnostics were too poor to consider for a base-case model.

(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 two sensitivity analyses for the maturity ogive. These were an 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. (2018).

(6) **Sensitivity analysis on assessment model time frame**: The group agreed to run two sensitivity analyses on the stock assessment time frame. This was assuming the same parametrization of the base case model, but starting the model in 1975 or 1994. This 1994 sensitivity analysis was conducted to explore the impact of removing historical data on the stock assessment results.

(7) **Sensitivity analysis on modeling choices:** The WG agreed to run three additional sensitivity analyses on modeling choices made during the assessment workshop to

explore how changes from the 2019 model effects the 2022 model results. These three models are a model run excluding catch from China and Vietnam (newly included in the 2022 model), a model using the same biological parameters as the 2019 assessment base-case model, and a model using the same selectivity pattern for Japanese driftnet catch prior to 1994 as the 2019 assessment model.

During the April 2022 BILLWG workshop, all 14 sensitivity analyses were completed and the results were presented and reviewed.

For each sensitivity run, comparisons of spawning stock biomass and fishing mortality trajectories were completed (Figure 25).

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.

3.7. Assessment Challenges

The WG identified several challenges in developing the 2019 base-case stock assessment model that contributed to uncertainty in the assessment results. The WG attempted to address several of these issues in the 2022 assessment, although some uncertainties still remain. The six major sources of uncertainty were detailed by the WG and their consideration in this assessment are as follows.

3.7.1. Stock structure

The 2019 WG noted that there is considerable uncertainty in the stock structure for Pacific striped marlin, and that this important uncertainty is unlikely to be resolved without substantial resource dedicated to research. 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, 2020) 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.* (2022) 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, 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). This uncertainty is still a concern for the 2022 assessment.

3.7.2. Driftnet catch

The 2019 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. Sensitivity runs in the 2019 assessment evaluated how changing the driftnet catch may effect assessment results. For the 2022 assessment, the Japanese driftnet catch from 1977 to 1993 were revised by Japanese scientists, although the WG noted that this catch should still be considered highly uncertain (Figure 30). Paper-based landing notebooks on the six major ports made by the prefecture government and logbook data of high seas driftnet fishery were used to estimate Japanese driftnet catch. The six major ports are Choshi, Kamaishi, Kesennuma, Miyako, Nagasaki, and Shiogama. There is no landings notebook other than the six major ports, and the billfish species have been reported with the number of fish caught and the catchweight. Although the logbook data has a number of catch data for the other ports, the reporting rate is not 100%. Both data sets have been available since 1977, and there were no catches in the first and second quarters of 1977 and 1978. It was assumed that the number of catches at six major ports was correct and estimated the other port's landing. Specifically, the logbook data was used to calculate the catch ratio between six ports and the other ports. The total catch number was estimated by the landing number in six ports and the catch ratio of the other ports. In addition, catches from the southern hemisphere were excluded using the catch rate of North and South. From 1977 to 1978, catches in the 2019 stock assessment were larger than the estimated six major port catches (Figure 26). It was assumed that the prefecture government did not survey the ports in these two years because of the lack of landings. However, somebody may have estimated the catch in the first and second quarters by some method in 1977-1978. Between 1980 and 1981, the catches of the 2019 stock assessment were also smaller than the major ports' total catch (Figure 26). It was considered that the total catch during this period was affected by the catch ratio between the North and South Pacific.

3.7.3. Life History Parameters

The WG noted that there were substantially different estimates for growth, maturity, and subsequently natural mortality for the three Pacific striped marlin stock areas. The WG agreed to explore using a model ensemble with biological parameters from each of the three Pacific stocks for the 2022 assessment. This included the updated life history parameters for growth and maturation used for the WCNPO stock in the 2022 benchmark assessment (Table 5). The assessment model using the life history parameters from the EPO stock were found to be biologically incompatible with the data from the WCNPO stock, and was removed from consideration without additional exploration. The model using SWPO stock life history parameters was fully explored during the 2022 assessment meeting, but ultimately the WG decided that the problems highlighted by the diagnostics were to substantial to allow for the model to be put forward for management advice. In addition, the life history parameters for the WCNPO were re-estimated during 2022 data prep meeting (ISC, 2022), which resulted in fairly different model results (Figure 25k-l). Due to this full exploration of the life history parameters for Pacific striped marlin, the WG feels as though the life history parameters used for this assessment are the best available scientific information available, until the biological sampling program for billfish is completed and new parameters have been estimated.

3.7.4. Initial equilibrium catch

Initial conditions for the 2019 assessment were fixed in the base-case model in order to estimate initial F. The 2022 assessment was able to estimate initial equilibrium catch, therefore removing a substantial source of uncertainty and a strong assumption about the WCNPO stock prior to 1977.

3.7.5. ASPM diagnostic

Overall, the ASPM for the 2022 base case model was consistent with the 2019 base-case model concerns, as it does not follows the trend from the fully integrated stock assessment during the early part of the time series (1977-1995), and SSB was much lower than the base-case after 1995. These results indicate that during the majority 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.

4. COMPARISON TO THE 2019 BASE-CASE MODEL

The WG noted that the 2022 biomass and fishing mortality trends were significantly different than the 2019 assessment model (Figures 27 and 28). In light of this result, the WG undertook to better understand how the changes in the 2022 assessment model affected the results compared to the 2019 model. The three major changes to this assessment from the 2019 assessment are the change in biological parameters, revised Japanese driftnet catch, and the change in Japanese driftnet selectivity. The Japanese driftnet fleets 1977-1993 selectivity was changed from mirroring the Japanese driftnet selectivity in 1994-2020 to mirroring the Japanese longline area 1 fleets (Table 7). This change in selectivity reflects the fact that the fishing area for the 1977-1993 Japanese driftnet fleet overlapped in the high seas with the Japanese longline fleet while the driftnet fleet in 1994-2020 only occurred in coastal waters within the Japanese EEZ. Changing the selectivity of the Japanese driftnet fleets did cause the SSB trend to change in 1977-1993 and decreased the estimated fishing mortality during this time period compared to the 2019 assessment (Figure 29). Changing the Japanese driftnet catch changed the SSB and fishing mortality during 1977-1993 only slightly. The largest change from the 2019 assessment is the change in biological parameters (Table 5). This caused the SSB to be higher in 2022, but virgin SSB to be lower. The Fishing mortality was also higher for the entire time series with the biggest change observed in 1994-2020. This is primarily driven by the change in intrinsic growth rate (Brody’s k) which is 40% higher (0.24 vs 0.34) in the 2022 assessment which means the fish grow faster at smaller sizes. The change in SSB was primarily driven by the size at 50% maturity, which was 9 cm smaller in the 2022 assessment, which means that smaller fish mature earlier than in the 2019 assessment.

5. CONCLUSIONS

5.1. Special Comments

Although the 2022 model has been improved relative to the 2019 model, the WG recognized that there is still uncertainty in drift gillnet catch data, life history parameters including maturation and growth, and stock structure due to some apparent stock mixing in the WCNPO area as indicated by recent genetic analyses (Lam et al. 2022). The WG considered an extensive suite of model formulations and life history parameters and the corresponding diagnostics for developing the base-case assessment model. To improve the stock assessment in the future, the WG also recommends continuing model development work, reducing data conflicts and modeling uncertainties, supporting the ISC billfish sampling program to provide current estimates of growth parameters, and reevaluating and improving input assessment data. When developing a CMM to conserve the spawning potential of this bycatch species, the WG recommends that these issues be recognized and carefully considered.

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REFERENCES

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.

Carvalho, F., Winker, H., Courtney, D., Kapur, M., Kell, L., Cardinale, M. Schirripa, M., Kitakado, T., Yemane, D., Piner, K.R., Maunder, M.N., Taylor, I., Wetzel C.R., Doering, K. Johnson, K.F. and Methot, R.D. (2021). A cookbook for using model diagnostics in integrated stock assessments. Doi: 10.1016/j.fishres.2021.105959

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.

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., (2021). Update Japanese data set for striped marlin stock assessment in the Western and Central North Pacific Ocean. ISC/21/BILLWG-02/04.

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.

Ijima, H. and Koike, H. (2022). CPUE Standardization for Striped Marlin (Kajikia audax) using Spatio-Temporal Model using INLA. (ISC/21/BILLWG-02/01).

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC]. (2019). Stock assessment of striped marlin in the Western and Central North Pacific Ocean in 2019, Report of the Billfish Working Group Stock Assessment Workshop.

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. (2022). Report of the Billfish Working Group Workshop, 14-17 December 2021.

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. (2022). Report of the Billfish Working Group Workshop, 28 March and 1-6 April 2022.

Lam, C.-H., Tam, C., and Lutcavage, M.E. (2022) Connectivity of striped marlin from the Central North Pacific Ocean. Front. Mar. Sci. 9:879463. doi: 10.3389/fmars.2022.879463

Lee, K., Yi, C-H., Wang, W-J., Lu, C-Y., and Chang, Y-J. (2021a). Catch and size data of striped marlin (Kajikia audax) by the Taiwanese fisheries in the Western and Central North Pacific Ocean during 1958-2020. ISC/21/BILLWG-02/05.

Lee, K., Hsu, J., Chang, Y-J. (2021b). CPUE standardization of stripe marlin caught by Taiwanese distant-water longline fishery in the Western and Central North Pacific Ocean during 1995 – 2020. ISC/21/BILLWG-02/02.

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.

Mamoozadeh, N., Graves, J., and McDowell, J. 2020. Genome-wide SNPs resolve spatiotemporal patterns of connectivity within striped marlin (Kajikia audax), a broadly distributed and highly migratory pelagic species. Evolutionary applications, 13(4): 677-698.

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.

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.

Sculley M. (2022). Standardization of the Striped Marlin (Kajikia audax) Catch per Unit Effort Data Caught by the Hawaii-based Longline Fishery from 1994-2020 Using Generalized Linear Models ISC/21/BILLWG-02/03.

Sun C.-L., Hsu W.-S., Su N.-J., Yeh S.-Z., Chang Y.-J. and Chiang W.-C. (2011) Age and growth of striped marlin (*Kajikia audax*) in the waters off Taiwan: A revision. ISC/11/BILLWG-2/07

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.

Wald, A., and Wolfowitz, J. (1940). On a test whether two samples are from the same population. Annals of Mathematical Statistics, Institute of Mathematical Statistics11: 147-162.

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	1994-2020	Ijima and Koike 2021
F2	-	JPNLL_Q1A2	1975-2020	
F3	-	JPNLL_Q1A3	1975-2020	
F4	-	JPNLL_Q2A1	1975-2020	
F5	S2	JPNLL_Q3A1_Late	1994-2020	Ijima and Koike 2021
F6	-	JPNLL_Q4A1	1975-2020	
F7	-	JPNLL_Q1A4	1975-2020	
F8	-	JPNLL_Q2A2	1975-2020	
F9	-	JPNLL_Q3A2	1975-2020	
F10	-	JPNLL_Q4A2	1975-2020	
F11	-	JPNLL_Q4A3	1975-2020	
F12	-	JPNLL_Others	1975-2020	
F13	-	JPNDF_Q14_EarlyLate	1975-1976, 1994-2020	
F14	-	JPNDF_Q23_EarlyLate	1975-1976, 1994-2020	
F15	-	JPN_Others	1975-2020	
F16	S3	US_LL	1987-2020	Sculley 2021
F17	-	US_Others	1987-2020	
F18	S4	TWN_DWLL	1967-2020	Lee et al., 2021a; Lee et al., 2021b
F19	-	TWN_STLL	1958-2020	
F20	-	TWN_Others	1958-2020	
F21	-	WCPFC_Others	1975-2020	
F22	S5	JPNLL_Q1A1_Early	1975-1993	Ijima and Koike 2021
F23	S6	JPNLL_Q3A1_Early	1975-1993	Ijima and Koike 2021
F24	-	JPNDF_Q14_Mid	1977-1993	
F25	-	JPNDF_Q23_Mid	1977-1993	

Table 2. Time series of catch by fleet submitted for the 2022 North Pacific striped marlin stock assessment Fleets 1-11 and 22-25 are in numbers of fish, fleets 12-21 are in metric tons. See Table 1 for and explanation of fleet numbers.

		Fleet												
Year	Qtr	1	2	3	4	5	6	7	8	9	10	11	12	13
1975	1	-	8097	8628	-	-	-	195	-	-	-	-	81	1058.09
1975	2	-	-	-	12336	-	-	-	388	-	-	-	81	-
1975	3	-	-	-	-	-	-	-	-	297	-	-	81	-
1975	4	-	-	-	-	-	11118	-	-	-	570	264	81	1481.62
1976	1	-	10441	6635	-	-	-	260	-	-	-	-	69.5	576.65
1976	2	-	-	-	11136	-	-	-	970	-	-	-	69.5	-
1976	3	-	-	-	-	-	-	-	-	374	-	-	69.5	-
1976	4	-	-	-	-	-	12556	-	-	-	1562	347	69.5	807.48
1977	1	-	7997	4006	-	-	-	58	-	-	-	-	67.75	-
1977	2	-	-	-	8704	-	-	-	556	-	-	-	67.75	-
1977	3	-	-	-	-	-	-	-	-	124	-	-	67.75	-
1977	4	-	-	-	-	-	7610	-	-	-	1941	168	67.75	-
1978	1	-	6689	3309	-	-	-	81	-	-	-	-	67.5	-
1978	2	-	-	-	13236	-	-	-	1093	-	-	-	67.5	-
1978	3	-	-	-	-	-	-	-	-	191	-	-	67.5	-
1978	4	-	-	-	-	-	11649	-	-	-	3868	156	67.5	-
1979	1	-	11680	11827	-	-	-	360	-	-	-	-	96.75	-
1979	2	-	-	-	32828	-	-	-	1017	-	-	-	96.75	-
1979	3	-	-	-	-	-	-	-	-	378	-	-	96.75	-
1979	4	-	-	-	-	-	13987	-	-	-	2916	265	96.75	-
1980	1	-	14348	21479	-	-	-	594	-	-	-	-	153	-
1980	2	-	-	-	22550	-	-	-	690	-	-	-	153	-
1980	3	-	-	-	-	-	-	-	-	149	-	-	153	-
1980	4	-	-	-	-	-	13116	-	-	-	395	164	153	-
1981	1	-	10271	10837	-	-	-	171	-	-	-	-	67.75	-
1981	2	-	-	-	14692	-	-	-	476	-	-	-	67.75	-
1981	3	-	-	-	-	-	-	-	-	418	-	-	67.75	-
1981	4	-	-	-	-	-	11920	-	-	-	134	95	67.75	-
1982	1	-	8458	10546	-	-	-	147	-	-	-	-	70.75	-
1982	2	-	-	-	12404	-	-	-	479	-	-	-	70.75	-
1982	3	-	-	-	-	-	-	-	-	117	-	-	70.75	-
1982	4	-	-	-	-	-	5454	-	-	-	175	89	70.75	-
1983	1	-	5726	4747	-	-	-	254	-	-	-	-	82.5	-
1983	2	-	-	-	11174	-	-	-	251	-	-	-	82.5	-
1983	3	-	-	-	-	-	-	-	-	194	-	-	82.5	-
1983	4	-	-	-	-	-	8885	-	-	-	89	65	82.5	-
1984	1	-	8796	4280	-	-	-	164	-	-	-	-	98.75	-
1984	2	-	-	-	13686	-	-	-	223	-	-	-	98.75	-

1984	3	-	-	-	-	-	-	-	-	274	-	-	98.75	-
1984	4	-	-	-	-	-	17970	-	-	-	153	172	98.75	-
1985	1	-	9220	8269	-	-	-	234	-	-	-	-	183.75	-
1985	2	-	-	-	35283	-	-	-	697	-	-	-	183.75	-
1985	3	-	-	-	-	-	-	-	-	122	-	-	183.75	-
1985	4	-	-	-	-	-	10389	-	-	-	230	173	183.75	-
1986	1	-	17697	16378	-	-	-	488	-	-	-	-	233.5	-
1986	2	-	-	-	47996	-	-	-	453	-	-	-	233.5	-
1986	3	-	-	-	-	-	-	-	-	93	-	-	233.5	-
1986	4	-	-	-	-	-	16045	-	-	-	469	126	233.5	-
1987	1	-	8607	7807	-	-	-	172	-	-	-	-	298.25	-
1987	2	-	-	-	25580	-	-	-	575	-	-	-	298.25	-
1987	3	-	-	-	-	-	-	-	-	247	-	-	298.25	-
1987	4	-	-	-	-	-	15928	-	-	-	1103	113	298.25	-
1988	1	-	9419	26842	-	-	-	135	-	-	-	-	189.75	-
1988	2	-	-	-	43430	-	-	-	321	-	-	-	189.75	-
1988	3	-	-	-	-	-	-	-	-	135	-	-	189.75	-
1988	4	-	-	-	-	-	23905	-	-	-	2068	42	189.75	-
1989	1	-	7789	14446	-	-	-	139	-	-	-	-	273.5	-
1989	2	-	-	-	29438	-	-	-	318	-	-	-	273.5	-
1989	3	-	-	-	-	-	-	-	-	98	-	-	273.5	-
1989	4	-	-	-	-	-	12006	-	-	-	1662	98	273.5	-
1990	1	-	4774	9562	-	-	-	38	-	-	-	-	282	-
1990	2	-	-	-	17004	-	-	-	173	-	-	-	282	-
1990	3	-	-	-	-	-	-	-	-	240	-	-	282	-
1990	4	-	-	-	-	-	7589	-	-	-	593	139	282	-
1991	1	-	6821	14061	-	-	-	118	-	-	-	-	300	-
1991	2	-	-	-	24028	-	-	-	214	-	-	-	300	-
1991	3	-	-	-	-	-	-	-	-	501	-	-	300	-
1991	4	-	-	-	-	-	12350	-	-	-	288	48	300	-
1992	1	-	4309	11271	-	-	-	213	-	-	-	-	314.25	-
1992	2	-	-	-	23631	-	-	-	385	-	-	-	314.25	-
1992	3	-	-	-	-	-	-	-	-	732	-	-	314.25	-
1992	4	-	-	-	-	-	8765	-	-	-	1604	137	314.25	-
1993	1	-	7682	16814	-	-	-	81	-	-	-	-	431	-
1993	2	-	-	-	28854	-	-	-	250	-	-	-	431	-
1993	3	-	-	-	-	-	-	-	-	153	-	-	431	-
1993	4	-	-	-	-	-	19565	-	-	-	1904	129	431	-
1994	1	2040	6983	11956	-	-	-	282	-	-	-	-	91.93	233.67
1994	2	-	-	-	28388	-	-	-	356	-	-	-	91.93	-
1994	3	-	-	-	-	10161	-	-	-	521	-	-	91.93	-
1994	4	-	-	-	-	-	21457	-	-	-	1046	191	91.93	327.21

1995	1	2297	7471	9404	-	-	-	120	-	-	-	-	64.52	157.08
1995	2	-	-	-	25455	-	-	-	293	-	-	-	64.52	-
1995	3	-	-	-	-	22729	-	-	-	279	-	-	64.52	-
1995	4	-	-	-	-	-	36711	-	-	-	3871	107	64.52	219.95
1996	1	2340	6047	8387	-	-	-	218	-	-	-	-	173.74	113.84
1996	2	-	-	-	30281	-	-	-	353	-	-	-	173.74	-
1996	3	-	-	-	-	8008	-	-	-	816	-	-	173.74	-
1996	4	-	-	-	-	-	17525	-	-	-	458	271	173.74	159.41
1997	1	2670	6027	8132	-	-	-	151	-	-	-	-	61.29	131.65
1997	2	-	-	-	22605	-	-	-	346	-	-	-	61.29	-
1997	3	-	-	-	-	8792	-	-	-	320	-	-	61.29	-
1997	4	-	-	-	-	-	16723	-	-	-	169	67	61.29	184.35
1998	1	2271	5878	4691	-	-	-	155	-	-	-	-	78.08	176.83
1998	2	-	-	-	31951	-	-	-	466	-	-	-	78.08	-
1998	3	-	-	-	-	19523	-	-	-	396	-	-	78.08	-
1998	4	-	-	-	-	-	20336	-	-	-	487	290	78.08	247.62
1999	1	3097	5732	7671	-	-	-	263	-	-	-	-	138.69	182.34
1999	2	-	-	-	20969	-	-	-	339	-	-	-	138.69	-
1999	3	-	-	-	-	8631	-	-	-	238	-	-	138.69	-
1999	4	-	-	-	-	-	14550	-	-	-	586	157	138.69	255.33
2000	1	983	4754	6004	-	-	-	111	-	-	-	-	85.79	171.98
2000	2	-	-	-	9022	-	-	-	273	-	-	-	85.79	-
2000	3	-	-	-	-	8754	-	-	-	126	-	-	85.79	-
2000	4	-	-	-	-	-	12368	-	-	-	575	104	85.79	240.81
2001	1	1096	5386	5963	-	-	-	94	-	-	-	-	88.92	174.40
2001	2	-	-	-	10028	-	-	-	265	-	-	-	88.92	-
2001	3	-	-	-	-	15310	-	-	-	244	-	-	88.92	-
2001	4	-	-	-	-	-	15026	-	-	-	362	136	88.92	244.22
2002	1	1069	5750	3805	-	-	-	67	-	-	-	-	3.04	204.69
2002	2	-	-	-	11783	-	-	-	338	-	-	-	3.04	-
2002	3	-	-	-	-	7459	-	-	-	142	-	-	3.04	-
2002	4	-	-	-	-	-	7570	-	-	-	140	106	3.04	286.62
2003	1	1138	6310	7378	-	-	-	100	-	-	-	-	49.16	172.30
2003	2	-	-	-	9778	-	-	-	101	-	-	-	49.16	-
2003	3	-	-	-	-	8165	-	-	-	316	-	-	49.16	-
2003	4	-	-	-	-	-	6822	-	-	-	607	106	49.16	241.27
2004	1	2703	4889	4677	-	-	-	153	-	-	-	-	31.09	216.83
2004	2	-	-	-	7867	-	-	-	90	-	-	-	31.09	-
2004	3	-	-	-	-	6610	-	-	-	320	-	-	31.09	-
2004	4	-	-	-	-	-	8082	-	-	-	214	83	31.09	303.63
2005	1	1867	2581	2190	-	-	-	67	-	-	-	-	27.59	196.59
2005	2	-	-	-	6760	-	-	-	122	-	-	-	27.59	-

2005	3	-	-	-	-	3740	-	-	-	101	-	-	27.59	-
2005	4	-	-	-	-	-	4804	-	-	-	455	48	27.59	275.28
2006	1	1230	2329	1993	-	-	-	32	-	-	-	-	19.90	192.70
2006	2	-	-	-	6476	-	-	-	68	-	-	-	19.90	-
2006	3	-	-	-	-	4422	-	-	-	66	-	-	19.90	-
2006	4	-	-	-	-	-	5162	-	-	-	282	35	19.90	269.84
2007	1	2141	1985	1725	-	-	-	15	-	-	-	-	30.92	157.08
2007	2	-	-	-	5287	-	-	-	58	-	-	-	30.92	-
2007	3	-	-	-	-	4046	-	-	-	116	-	-	30.92	-
2007	4	-	-	-	-	-	9319	-	-	-	303	11	30.92	219.95
2008	1	2867	2493	1606	-	-	-	18	-	-	-	-	22.27	210.84
2008	2	-	-	-	4700	-	-	-	67	-	-	-	22.27	-
2008	3	-	-	-	-	3222	-	-	-	68	-	-	22.27	-
2008	4	-	-	-	-	-	7091	-	-	-	483	150	22.27	295.24
2009	1	2325	1506	1675	-	-	-	13	-	-	-	-	34.09	132.95
2009	2	-	-	-	3537	-	-	-	40	-	-	-	34.09	-
2009	3	-	-	-	-	3283	-	-	-	63	-	-	34.09	-
2009	4	-	-	-	-	-	3490	-	-	-	85	30	34.09	186.17
2010	1	2984	2556	932	-	-	-	17	-	-	-	-	40.28	147.85
2010	2	-	-	-	8146	-	-	-	280	-	-	-	40.28	-
2010	3	-	-	-	-	2558	-	-	-	294	-	-	40.28	-
2010	4	-	-	-	-	-	3614	-	-	-	22	165	40.28	207.03
2011	1	1994	7200	2575	-	-	-	108	-	-	-	-	45.68	56.19
2011	2	-	-	-	4164	-	-	-	297	-	-	-	45.68	-
2011	3	-	-	-	-	6397	-	-	-	63	-	-	45.68	-
2011	4	-	-	-	-	-	9390	-	-	-	30	221	45.68	78.68
2012	1	3099	6452	4020	-	-	-	49	-	-	-	-	20.64	96.68
2012	2	-	-	-	9450	-	-	-	55	-	-	-	20.64	-
2012	3	-	-	-	-	2553	-	-	-	66	-	-	20.64	-
2012	4	-	-	-	-	-	6597	-	-	-	46	28	20.64	135.37
2013	1	3906	4395	2263	-	-	-	31	-	-	-	-	43.31	54.41
2013	2	-	-	-	12783	-	-	-	198	-	-	-	43.31	-
2013	3	-	-	-	-	1835	-	-	-	49	-	-	43.31	-
2013	4	-	-	-	-	-	4895	-	-	-	80	20	43.31	76.19
2014	1	2596	3208	3816	-	-	-	16	-	-	-	-	66.19	28.01
2014	2	-	-	-	6130	-	-	-	75	-	-	-	66.19	-
2014	3	-	-	-	-	3720	-	-	-	81	-	-	66.19	-
2014	4	-	-	-	-	-	5475	-	-	-	33	50	66.19	39.23
2015	1	2271	5953	3211	-	-	-	24	-	-	-	-	72.74	46.48
2015	2	-	-	-	11727	-	-	-	60	-	-	-	72.74	-
2015	3	-	-	-	-	1984	-	-	-	105	-	-	72.74	-
2015	4	-	-	-	-	-	2470	-	-	-	63	26	72.74	65.08

2016	1	3772	1683	841	-	-	-	21	-	-	-	-	58.45	49.88
2016	2	-	-	-	5750	-	-	-	46	-	-	-	58.45	-
2016	3	-	-	-	-	2371	-	-	-	118	-	-	58.45	-
2016	4	-	-	-	-	-	3254	-	-	-	33	28	58.45	69.84
2017	1	3533	1859	1488	-	-	-	5	-	-	-	-	69.03	39.03
2017	2	-	-	-	4653	-	-	-	17	-	-	-	69.03	-
2017	3	-	-	-	-	1354	-	-	-	69	-	-	69.03	-
2017	4	-	-	-	-	-	2277	-	-	-	28	30	69.03	54.65
2018	1	2421	1949	1036	-	-	-	8	-	-	-	-	66.95	45.02
2018	2	-	-	-	3874	-	-	-	21	-	-	-	66.95	-
2018	3	-	-	-	-	1342	-	-	-	54	-	-	66.95	-
2018	4	-	-	-	-	-	2819	-	-	-	25	23	66.95	63.04
2019	1	3369	2713	1073	-	-	-	5	-	-	-	-	62.77	39.03
2019	2	-	-	-	8363	-	-	-	97	-	-	-	62.77	-
2019	3	-	-	-	-	3901	-	-	-	37	-	-	62.77	-
2019	4	-	-	-	-	-	5729	-	-	-	22	29	62.77	54.65
2020	1	7419	2896	566	-	-	-	4	-	-	-	-	55.40	39.03
2020	2	-	-	-	5577	-	-	-	88	-	-	-	55.40	-
2020	3	-	-	-	-	1898	-	-	-	52	-	-	55.40	-
2020	4	-	-	-	-	-	5288	-	-	-	0	29	55.40	54.65

		Fleet											
Year	**Qtr**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1975	1	-	171.5	0	0	16	183	24	6	857	-	-	-
1975	2	445.63	171.5	0	0	16	183	24	6	-	-	-	-
1975	3	3548.66	171.5	0	0	16	183	24	6	-	7954	-	-
1975	4	-	171.5	0	0	16	183	24	6	-	-	-	-
1976	1	-	146.3	0	0	8	86.75	35	14	1861	-	-	-
1976	2	242.87	146.3	0	0	8	86.75	35	14	-	-	-	-
1976	3	1934.00	146.3	0	0	8	86.75	35	14	-	3261	-	-
1976	4	-	146.3	0	0	8	86.75	35	14	-	-	-	-
1977	1	-	136.8	0	0	4.25	131	54.75	11.25	1327	-	12	-
1977	2	-	136.8	0	0	4.25	131	54.75	11.25	-	-	-	445
1977	3	-	136.8	0	0	4.25	131	54.75	11.25	-	2289	-	38640
1977	4	-	136.8	0	0	4.25	131	54.75	11.25	-	-	28798	-
1978	1	-	136.5	0	0	0	154.5	19.5	15	625	-	1056	-
1978	2	-	136.5	0	0	0	154.5	19.5	15	-	-	-	705
1978	3	-	136.5	0	0	0	154.5	19.5	15	-	2838	-	83349
1978	4	-	136.5	0	0	0	154.5	19.5	15	-	-	28961	-
1979	1	-	131.5	0	0	6.5	108	30.5	20	989	-	588	-
1979	2	-	131.5	0	0	6.5	108	30.5	20	-	-	-	1520
1979	3	-	131.5	0	0	6.5	108	30.5	20	-	5720	-	49968
1979	4	-	131.5	0	0	6.5	108	30.5	20	-	-	26289	-
1980	1	-	134	0	0	15.25	55.75	32.875	7.5	891	-	2742	-
1980	2	-	134	0	0	15.25	55.75	32.875	7.5	-	-	-	3915
1980	3	-	134	0	0	15.25	55.75	32.875	7.5	-	5943	-	106911
1980	4	-	134	0	0	15.25	55.75	32.875	7.5	-	-	28494	-
1981	1	-	135.5	0	0	4	122.75	23.75	27	1359	-	6324	-
1981	2	-	135.5	0	0	4	122.75	23.75	27	-	-	-	2537
1981	3	-	135.5	0	0	4	122.75	23.75	27	-	3462	-	101706
1981	4	-	135.5	0	0	4	122.75	23.75	27	-	-	25615	-
1982	1	-	164	0	0	1.75	99.25	34.5	29.25	824	-	3905	-
1982	2	-	164	0	0	1.75	99.25	34.5	29.25	-	-	-	5399
1982	3	-	164	0	0	1.75	99.25	34.5	29.25	-	3240	-	24505
1982	4	-	164	0	0	1.75	99.25	34.5	29.25	-	-	9937	-
1983	1	-	212.3	0	0	0	138.75	53.5	16	874	-	3682	-
1983	2	-	212.3	0	0	0	138.75	53.5	16	-	-	-	5935
1983	3	-	212.3	0	0	0	138.75	53.5	16	-	2725	-	33401
1983	4	-	212.3	0	0	0	138.75	53.5	16	-	-	9238	-
1984	1	-	198.8	0	0	0	241.25	82.5	20.75	1540	-	3330	-
1984	2	-	198.8	0	0	0	241.25	82.5	20.75	-	-	-	7398
1984	3	-	198.8	0	0	0	241.25	82.5	20.75	-	5502	-	33499
1984	4	-	198.8	0	0	0	241.25	82.5	20.75	-	-	16839	-

		Fleet											
Year	**Qtr**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1985	1	-	193.3	0	0	0	128.25	45.25	17.25	1673	-	3084	-
1985	2	-	193.3	0	0	0	128.25	45.25	17.25	-	-	-	16236
1985	3	-	193.3	0	0	0	128.25	45.25	17.25	-	15561	-	59910
1985	4	-	193.3	0	0	0	128.25	45.25	17.25	-	-	22225	-
1986	1	-	156.3	0	0	0	44.75	37	18.5	1286	-	3857	-
1986	2	-	156.3	0	0	0	44.75	37	18.5	-	-	-	2428
1986	3	-	156.3	0	0	0	44.75	37	18.5	-	9714	-	72717
1986	4	-	156.3	0	0	0	44.75	37	18.5	-	-	22260	-
1987	1	-	136.3	35.64	7.75	7.75	95.75	37.75	37	1357	-	2420	-
1987	2	-	136.3	85.84	7.75	7.75	95.75	37.75	37	-	-	-	6691
1987	3	-	136.3	15.17	7.75	7.75	95.75	37.75	37	-	6846	-	60180
1987	4	-	136.3	140.03	7.75	7.75	95.75	37.75	37	-	-	8294	-
1988	1	-	180.5	130.27	13.75	1.75	114.25	42.25	31.75	2546	-	9907	-
1988	2	-	180.5	177.15	13.75	1.75	114.25	42.25	31.75	-	-	-	13384
1988	3	-	180.5	8.53	13.75	1.75	114.25	42.25	31.75	-	13879	-	62371
1988	4	-	180.5	166.62	13.75	1.75	114.25	42.25	31.75	-	-	8662	-
1989	1	-	159.8	174.73	6	1.5	46	39.25	27.25	1406	-	4449	-
1989	2	-	159.8	257.26	6	1.5	46	39.25	27.25	-	-	-	11802
1989	3	-	159.8	17.48	6	1.5	46	39.25	27.25	-	8640	-	41940
1989	4	-	159.8	137.37	6	1.5	46	39.25	27.25	-	-	11310	-
1990	1	-	141	114.52	6.75	0.5	34.25	64	10.75	1460	-	8288	-
1990	2	-	141	205.75	6.75	0.5	34.25	64	10.75	-	-	-	11198
1990	3	-	141	35.38	6.75	0.5	34.25	64	10.75	-	6174	-	18461
1990	4	-	141	128.04	6.75	0.5	34.25	64	10.75	-	-	18588	-
1991	1	-	133.5	103.13	10	9	63.5	71.5	6	671	-	4854	-
1991	2	-	133.5	239.63	10	9	63.5	71.5	6	-	-	-	4459
1991	3	-	133.5	61.87	10	9	63.5	71.5	6	-	7676	-	18160
1991	4	-	133.5	145.23	10	9	63.5	71.5	6	-	-	16220	-
1992	1	-	84.5	134.29	9.75	0.25	54.75	49.25	17.5	769	-	4422	-
1992	2	-	84.5	181.45	9.75	0.25	54.75	49.25	17.5	-	-	-	5787
1992	3	-	84.5	69.77	9.75	0.25	54.75	49.25	17.5	-	8629	-	18358
1992	4	-	84.5	159.91	9.75	0.25	54.75	49.25	17.5	-	-	11225	-
1993	1	-	177	104.66	17.25	1.25	55.25	35.5	48.5	958	-	4160	-
1993	2	-	177	202.79	17.25	1.25	55.25	35.5	48.5	-	-	-	1918
1993	3	-	177	55.31	17.25	1.25	55.25	35.5	48.5	-	9876	-	18315
1993	4	-	177	169.76	17.25	1.25	55.25	35.5	48.5	-	-	8663	-
1994	1	-	95.75	108.55	8.5	0.25	34.25	49	84.75	-	-	-	-
1994	2	98.42	95.75	142.44	8.5	0.25	34.25	49	84.75	-	-	-	-
1994	3	783.70	95.75	32.39	8.5	0.25	34.25	49	84.75	-	-	-	-
1994	4	-	95.75	79.91	8.5	0.25	34.25	49	84.75	-	-	-	-

		Fleet											
Year	**Qtr**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1995	1	-	70.75	105.31	13	6.75	20.75	20.5	80	-	-	-	-
1995	2	66.16	70.75	201.13	13	6.75	20.75	20.5	80	-	-	-	-
1995	3	526.81	70.75	96.49	13	6.75	20.75	20.5	80	-	-	-	-
1995	4	-	70.75	335.31	13	6.75	20.75	20.5	80	-	-	-	-
1996	1	-	38	156.35	13.75	6.5	40.5	11.75	45.75	-	-	-	-
1996	2	47.95	38	167.4	13.75	6.5	40.5	11.75	45.75	-	-	-	-
1996	3	381.80	38	63.66	13.75	6.5	40.5	11.75	45.75	-	-	-	-
1996	4	-	38	127.65	13.75	6.5	40.5	11.75	45.75	-	-	-	-
1997	1	-	40.75	95.81	9.75	14.75	72.5	11.75	37.5	-	-	-	-
1997	2	55.45	40.75	246.58	9.75	14.75	72.5	11.75	37.5	-	-	-	-
1997	3	441.55	40.75	32.14	9.75	14.75	72.5	11.75	37.5	-	-	-	-
1997	4	-	40.75	93.48	9.75	14.75	72.5	11.75	37.5	-	-	-	-
1998	1	-	76	79.29	6.5	22.5	51.25	12.5	65	-	-	-	-
1998	2	74.48	76	116.14	6.5	22.5	51.25	12.5	65	-	-	-	-
1998	3	593.07	76	64.26	6.5	22.5	51.25	12.5	65	-	-	-	-
1998	4	-	76	239.29	6.5	22.5	51.25	12.5	65	-	-	-	-
1999	1	-	46	118.54	7.25	16.5	32	10.5	76.5	-	-	-	-
1999	2	76.80	46	133.86	7.25	16.5	32	10.5	76.5	-	-	-	-
1999	3	611.54	46	69.65	7.25	16.5	32	10.5	76.5	-	-	-	-
1999	4	-	46	129.03	7.25	16.5	32	10.5	76.5	-	-	-	-
2000	1	-	74.25	69.81	3.75	22.5	40.25	13.75	42.5	-	-	-	-
2000	2	72.43	74.25	90.55	3.75	22.5	40.25	13.75	42.5	-	-	-	-
2000	3	576.78	74.25	21.5	3.75	22.5	40.25	13.75	42.5	-	-	-	-
2000	4	-	74.25	51.28	3.75	22.5	40.25	13.75	42.5	-	-	-	-
2001	1	-	59.25	71.89	11	5.25	32.25	12.75	38.75	-	-	-	-
2001	2	73.45	59.25	95.43	11	5.25	32.25	12.75	38.75	-	-	-	-
2001	3	584.93	59.25	31.1	11	5.25	32.25	12.75	38.75	-	-	-	-
2001	4	-	59.25	217.03	11	5.25	32.25	12.75	38.75	-	-	-	-
2002	1	-	72.5	72.47	7.5	12.75	56.5	7.25	55.75	-	-	-	-
2002	2	86.21	72.5	56.36	7.5	12.75	56.5	7.25	55.75	-	-	-	-
2002	3	686.49	72.5	13.85	7.5	12.75	56.5	7.25	55.75	-	-	-	-
2002	4	-	72.5	89.34	7.5	12.75	56.5	7.25	55.75	-	-	-	-
2003	1	-	50.75	288.2	7.5	43	170.25	10.75	99.75	-	-	-	-
2003	2	72.57	50.75	113.04	7.5	43	170.25	10.75	99.75	-	-	-	-
2003	3	577.87	50.75	55.83	7.5	43	170.25	10.75	99.75	-	-	-	-
2003	4	-	50.75	302.19	7.5	43	170.25	10.75	99.75	-	-	-	-
2004	1	-	22.5	185.2	8.75	57	65.25	6	68.25	-	-	-	-
2004	2	91.32	22.5	89.2	8.75	57	65.25	6	68.25	-	-	-	-
2004	3	727.22	22.5	47.96	8.75	57	65.25	6	68.25	-	-	-	-
2004	4	-	22.5	137.61	8.75	57	65.25	6	68.25	-	-	-	-

		Fleet											
Year	**Qtr**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
2005	1	-	24.5	317.68	5	44	146	8	70.5	-	-	-	-
2005	2	82.80	24.5	240.16	5	44	146	8	70.5	-	-	-	-
2005	3	659.33	24.5	68.24	5	44	146	8	70.5	-	-	-	-
2005	4	-	24.5	106.95	5	44	146	8	70.5	-	-	-	-
2006	1	-	23.75	154.91	5.25	33.5	134.25	36.75	60	-	-	-	-
2006	2	81.16	23.75	163.96	5.25	33.5	134.25	36.75	60	-	-	-	-
2006	3	646.30	23.75	138.26	5.25	33.5	134.25	36.75	60	-	-	-	-
2006	4	-	23.75	247.35	5.25	33.5	134.25	36.75	60	-	-	-	-
2007	1	-	19.75	139.9	3.25	22.25	49.75	42.5	35.25	-	-	-	-
2007	2	66.16	19.75	109.97	3.25	22.25	49.75	42.5	35.25	-	-	-	-
2007	3	526.81	19.75	53.8	3.25	22.25	49.75	42.5	35.25	-	-	-	-
2007	4	-	19.75	44.62	3.25	22.25	49.75	42.5	35.25	-	-	-	-
2008	1	-	24.25	83.45	3.5	18	48	53.25	52.75	-	-	-	-
2008	2	88.80	24.25	211.98	3.5	18	48	53.25	52.75	-	-	-	-
2008	3	707.13	24.25	58.8	3.5	18	48	53.25	52.75	-	-	-	-
2008	4	-	24.25	122.5	3.5	18	48	53.25	52.75	-	-	-	-
2009	1	-	22.5	92.13	2.5	7.5	56.25	34.5	29.75	-	-	-	-
2009	2	55.99	22.5	114.32	2.5	7.5	56.25	34.5	29.75	-	-	-	-
2009	3	445.89	22.5	66.45	2.5	7.5	56.25	34.5	29.75	-	-	-	-
2009	4	-	22.5	79.21	2.5	7.5	56.25	34.5	29.75	-	-	-	-
2010	1	-	20.5	45.93	4.75	8	50	44	31.75	-	-	-	-
2010	2	62.27	20.5	45.93	4.75	8	50	44	31.75	-	-	-	-
2010	3	495.86	20.5	45.93	4.75	8	50	44	31.75	-	-	-	-
2010	4	-	20.5	45.93	4.75	8	50	44	31.75	-	-	-	-
2011	1	-	22	100.38	4	13.25	67.25	31.75	55	-	-	-	-
2011	2	23.67	22	100.38	4	13.25	67.25	31.75	55	-	-	-	-
2011	3	188.46	22	100.38	4	13.25	67.25	31.75	55	-	-	-	-
2011	4	-	22	100.38	4	13.25	67.25	31.75	55	-	-	-	-
2012	1	-	29.75	77.55	2.75	18.25	88	37.5	57.25	-	-	-	-
2012	2	40.72	29.75	77.55	2.75	18.25	88	37.5	57.25	-	-	-	-
2012	3	324.23	29.75	77.55	2.75	18.25	88	37.5	57.25	-	-	-	-
2012	4	-	29.75	77.55	2.75	18.25	88	37.5	57.25	-	-	-	-
2013	1	-	23	109.73	2	16.75	71.25	55	16.75	-	-	-	-
2013	2	22.92	23	109.73	2	16.75	71.25	55	16.75	-	-	-	-
2013	3	182.48	23	109.73	2	16.75	71.25	55	16.75	-	-	-	-
2013	4	-	23	109.73	2	16.75	71.25	55	16.75	-	-	-	-
2014	1	-	14.25	117.15	3	4.2	28.75	17.45	144	-	-	-	-
2014	2	11.80	14.25	117.15	3	4.2	28.75	17.45	144	-	-	-	-
2014	3	93.96	14.25	117.15	3	4.2	28.75	17.45	144	-	-	-	-
2014	4	-	14.25	117.15	3	4.2	28.75	17.45	144	-	-	-	-

		Fleet											
Year	**Qtr**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
2015	1	-	25.25	134.75	2.75	8.325	45.25	8.23	156.3	-	-	-	-
2015	2	19.57	25.25	134.75	2.75	8.325	45.25	8.23	156.3	-	-	-	-
2015	3	155.87	25.25	134.75	2.75	8.325	45.25	8.23	156.3	-	-	-	-
2015	4	-	25.25	134.75	2.75	8.325	45.25	8.23	156.3	-	-	-	-
2016	1	-	24.5	106.15	3	14.5	33.75	6.08	98.5	-	-	-	-
2016	2	21.01	24.5	106.15	3	14.5	33.75	6.08	98.5	-	-	-	-
2016	3	167.28	24.5	106.15	3	14.5	33.75	6.08	98.5	-	-	-	-
2016	4	-	24.5	106.15	3	14.5	33.75	6.08	98.5	-	-	-	-
2017	1	-	19.75	113.03	1.5	18	72.75	12.08	59.75	-	-	-	-
2017	2	16.44	19.75	113.03	1.5	18	72.75	12.08	59.75	-	-	-	-
2017	3	130.89	19.75	113.03	1.5	18	72.75	12.08	59.75	-	-	-	-
2017	4	-	19.75	113.03	1.5	18	72.75	12.08	59.75	-	-	-	-
2018	1	-	29	113.03	1.5	13.5	64.75	8.21	41.25	-	-	-	-
2018	2	18.96	29	113.03	1.5	13.5	64.75	8.21	41.25	-	-	-	-
2018	3	150.98	29	113.03	1.5	13.5	64.75	8.21	41.25	-	-	-	-
2018	4	-	29	113.03	1.5	13.5	64.75	8.21	41.25	-	-	-	-
2019	1	-	32.25	113.03	1.5	9.75	78.5	8.47	38.75	-	-	-	-
2019	2	16.44	32.25	113.03	1.5	9.75	78.5	8.47	38.75	-	-	-	-
2019	3	130.89	32.25	113.03	1.5	9.75	78.5	8.47	38.75	-	-	-	-
2019	4	-	32.25	113.03	1.5	9.75	78.5	8.47	38.75	-	-	-	-
2020	1	-	32.25	113.03	1.5	7.875	76.75	8.35	29.75	-	-	-	-
2020	2	16.44	32.25	113.03	1.5	7.875	76.75	8.35	29.75	-	-	-	-
2020	3	130.89	32.25	113.03	1.5	7.875	76.75	8.35	29.75	-	-	-	-
2020	4	-	32.25	113.03	1.5	7.875	76.75	8.35	29.75	-	-	-	-

Table 3. List of fleets with catch used in the base-case assessment model along with CPUE indices provided for the 2022 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 – Y	JPNLL_Q1A1_Late	1994-2020	Ijima and Koike 2021
F2 - Y	-	JPNLL_Q1A2	1975-2020	Ijima 2021
F3 - N	-	JPNLL_Q1A3	1975-2020	Ijima 2021
F4 – Y	-	JPNLL_Q2A1	1975-2020	Ijima 2021
F5 – Y	S2 – Y	JPNLL_Q3A1_Late	1994-2020	Ijima and Koike 2021
F6 – Y	-	JPNLL_Q4A1	1975-2020	Ijima 2021
F7 – N	-	JPNLL_Q1A4	1975-2020	Ijima 2021
F8 – N	-	JPNLL_Q2A2	1975-2020	Ijima 2021
F9 – N	-	JPNLL_Q3A2	1975-2020	Ijima 2021
F10 – N	-	JPNLL_Q4A2	1975-2020	Ijima 2021
F11 – N	-	JPNLL_Q4A3	1975-2020	Ijima 2021
F12 – N	-	JPNLL_Others	1975-2020	Ijima 2021
F13 – Y	-	JPNDF_Q14_EarlyLate	1975-1976, 1994-2020	Ijima 2021
F14 – Y	-	JPNDF_Q23_EarlyLate	1975-1976, 1994-2020	Ijima 2021
F15 – N	-	JPN_Others	1975-2020	Ijima 2021
F16 – Y	S3 – N	US_LL	1987-2020	Sculley 2021
F17 – N	-	US_Others	1987-2020	Russ Ito, pers. comm.
F18 – Y	S4 – N	TWN_DWLL	1975-2020	Russ Ito, pers. comm.
F19 – N	-	TWN_STLL	1975-2020	Lee et al., 2021a, b
F20 – N	-	TWN_Others	1975-2020	Lee et al., 2021a, b
F21 – N	-	WCPFC_Others	1975-2020	WCPFC yearbook
F22 – N	S5 – N	JPNLL_Q1A1_Early	1975-1993	Ijima and Koike 2021
F23 – N	S6 – Y	JPNLL_Q3A1_Early	1975-1993	Ijima and Koike 2021
F24 – N	-	JPNDF_Q13_Mid	1977-1993	Ijima 2021
F25 – N	-	JPNDF_Q13_Mid	1977-1993	Ijima 2021

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**	
Year	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV
1976	-	-	-	-	-	-	-	-	0.73	0.2	0.92	0.2
1977	-	-	-	-	-	-	-	-	0.7	0.2	0.86	0.2
1978	-	-	-	-	-	-	-	-	0.87	0.2	0.96	0.2
1979	-	-	-	-	-	-	-	-	0.76	0.2	1.21	0.2
1980	-	-	-	-	-	-	-	-	0.92	0.2	1.15	0.2
1981	-	-	-	-	-	-	-	-	0.67	0.2	0.92	0.2
1982	-	-	-	-	-	-	-	-	0.54	0.2	0.86	0.2
1983	-	-	-	-	-	-	-	-	0.56	0.2	0.85	0.2
1984	-	-	-	-	-	-	-	-	0.81	0.2	1.08	0.2
1985	-	-	-	-	-	-	-	-	1.01	0.2	1.23	0.2
1986	-	-	-	-	-	-	-	-	0.76	0.2	1.14	0.2
1987	-	-	-	-	-	-	-	-	0.7	0.2	0.93	0.2
1988	-	-	-	-	-	-	-	-	0.8	0.2	1.36	0.2
1989	-	-	-	-	-	-	-	-	0.77	0.2	1.12	0.2
1990	-	-	-	-	-	-	-	-	0.68	0.2	0.85	0.2
1991	-	-	-	-	-	-	-	-	0.7	0.2	0.94	0.2
1992	-	-	-	-	-	-	-	-	0.8	0.2	1.06	0.2
1993	-	-	-	-	-	-	-	-	0.86	0.2	0.98	0.2
1994	0.97	0.2	1.14	0.2	-	-	-	-	-	-	-	-
1995	1.18	0.2	1.4	0.2	1.47	0.63	1.25	0.26	-	-	-	-
1996	0.81	0.2	1.08	0.2	1.07	0.76	0.77	0.2	-	-	-	-
1997	0.88	0.2	0.89	0.2	0.85	0.89	0.72	0.22	-	-	-	-
1998	1.21	0.2	1.05	0.2	0.89	0.87	1.12	0.31	-	-	-	-
1999	0.83	0.2	1.03	0.2	0.89	0.84	0.93	0.26	-	-	-	-
2000	0.75	0.2	0.78	0.2	0.62	1.1	0.46	0.21	-	-	-	-
2001	0.73	0.2	0.86	0.2	0.94	0.8	0.9	0.19	-	-	-	-
2002	0.62	0.2	0.75	0.2	0.53	1.21	1	0.22	-	-	-	-
2003	0.76	0.2	0.83	0.2	1.05	0.74	1.73	0.18	-	-	-	-
2004	0.6	0.2	0.72	0.2	0.72	0.96	1.87	0.14	-	-	-	-
2005	0.58	0.2	0.67	0.2	0.68	0.98	1.77	0.13	-	-	-	-
2006	0.59	0.2	0.67	0.2	0.69	0.98	1.14	0.15	-	-	-	-
2007	0.58	0.2	0.63	0.2	0.38	1.54	0.99	0.14	-	-	-	-
2008	0.69	0.2	0.7	0.2	0.51	1.2	0.95	0.16	-	-	-	-
2009	0.55	0.2	0.7	0.2	0.34	1.64	0.66	0.16	-	-	-	-
2010	0.56	0.2	0.71	0.2	0.23	2.25	0.81	0.17	-	-	-	-
2011	0.59	0.2	0.81	0.2	0.49	1.22	0.93	0.17	-	-	-	-
2012	0.58	0.2	0.72	0.2	0.36	1.51	1.01	0.19	-	-	-	-
2013	0.58	0.2	0.7	0.2	0.35	1.54	1.67	0.18	-	-	-	-
2014	0.61	0.2	0.74	0.2	0.43	1.32	0.63	0.18	-	-	-	-
2015	0.61	0.2	0.74	0.2	0.39	1.41	0.6	0.17	-	-	-	-
2016	0.63	0.2	0.72	0.2	0.35	1.52	0.54	0.15	-	-	-	-
2017	0.55	0.2	0.67	0.2	0.38	1.42	1	0.16	-	-	-	-
2018	0.57	0.2	0.7	0.2	0.37	1.47	0.68	0.15	-	-	-	-
2019	0.66	0.2	0.8	0.2	0.42	1.32	0.72	0.14	-	-	-	-
2020	0.58	0.2	0.69	0.2	0.34	1.55	1.14	0.13	-	-	-	-

Table 5. Key life history parameters and model structures for the three Pacific striped marlin stock areas Western and Central North Pacific Ocean [WCNPO], Southwest Pacific Ocean [SWPO], and Eastern Pacific Ocean [EPO]) as well as the life history parameters used in the 2019 WCNPO striped marlin stock assessment.

Parameter	**2019 Value**	**2022 Value**		
	WCNPO	**WCNPO**	**SWPO**	**EPO**
Gender	1	1	1	1
Natural mortality	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)
Reference age (A_{min})	0.3	0.5	0.5	0.5
Maximum age (A_{max})	15	15	15	15
Length at A_{min} (cm, EFL)	104	110	115	74
Length at A_{max} (cm, EFL)	214	203	212	184
Growth rate (k)	0.24	0.34	0.64	0.23
CV of Length at A_{min}	0.14	0.14	0.14	0.14
CV of Length at A_{max}	0.08	0.08	0.08	0.08
L_{inf} (cm, EFL)	217.3	203.7	212.0	188.1
t_0	-2.413	-1.784	-0.722	-1.674
Weight-at-length	$W=4.68e\text{-}006\times L^{3.16}$	$W=4.68e\text{-}006\times L^{3.16}$	$W=4.68e\text{-}006\times L^{3.16}$	$W=4.68e\text{-}006\times L^{3.16}$
Size-at-50% Maturity	161	152.2	178.4	166.5
Age-at-50% Maturity	3.2	2.3	2.2	7.7
L_{50}/L_{inf}	74%	75%	84%	89%
Size-at-95% Maturity	196.9	166.6	192.8	180.9
Age-at-95% Maturity	7.4	3.2	3.0	12.6
L_{95}/L_{inf}	91%	82%	91%	96%
Slope of maturity ogive	-0.082	-0.204	-0.204	-0.204
Fecundity	Proportional to spawning biomass	Proportional to spawning biomass	Proportional to spawning biomass	Proportional to spawning biomass
Spawning season (quarter)	2	2	2	2
Spawner-recruit relationship	Beverton-Holt	Beverton-Holt	Beverton-Holt	Beverton-Holt
Spawner-recruit steepness (*h*)	0.87	0.87	0.87	0.87
Recruitment variability (σ_R)	0.6	0.6	0.6	0.6

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. S3 (US_LL), S4 (TWN_DWLL) and S5 (JPNLL_Q1A1_Early) were not included in the total likelihood.

Fleet	*N*	Input log(SE)	RMSE
S1_JPNLL_Q1A1_Late	27	0.2	0.16
S2_JPNJPNLL_Q3A1_Late	27	0.2	0.16
S3_US_LL	26	0.21	0.20
S4_TWN_DWLL	26	0.31	0.33
S5_JPNLL_Q1A1_Early	18	0.2	0.07
S6_JPNLL_Q3A1_Early	18	0.2	0.08

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 – Time Varying
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 – Time Varying
F17	Mirror F16
F18	Asymptotic lognormal
F19	Mirror F18
F20	Mirror F14
F21	Mirror F12
F22	Mirror F1
F23	Mirror F5
F24	Mirror F1
F25	Mirror F5
S1	Mirror F1
S2	Mirror F5
S3	Mirror F16
S4	Mirror F18
S5	Mirror F1
S6	Mirror F5

Table 8. 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 6.298. See Table 3 for a description of the abundance indices. S2, S3, and S4 were not included in the total likelihood.

log(R0)	S1	S5	S6
5.5	0.31	0.20	0.05
5.6	0.26	0.21	0
5.7	0.25	0.16	0.03
5.8	0.19	0.13	0.05
5.9	0	0.10	0.09
6	0.02	0.08	0.11
6.1	0.03	0.08	0.11
6.2	0.01	0.06	0.15
6.298	0.01	0.03	0.18
6.3	0.66	0.02	0.16
6.4	0.66	0	0.20
6.5	0.66	0.18	0.24
6.6	0.67	0.16	0.28
6.7	0.68	0.14	0.30
6.8	0.69	0.11	0.33
6.9	0.68	0.07	0.34
7	0.67	0.03	0.35

Table 9. 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 6.298. See Table 3 for a description of the composition data.

ln(R0)	F01	F02	F04	F05	F06	F13	F14	F16	F18
5.5	0.08	0	0.46	0.21	0	0	0	38.00	0.05
5.6	0.23	0.15	0.45	0	0.15	0.30	0.40	28.32	0.30
5.7	0.13	0.34	0.14	0.17	0.30	0.61	0.86	33.97	0.09
5.8	0.13	0.38	0.10	0.22	0.31	0.61	0.88	34.09	0.06
5.9	0	0.31	0	0.30	0.28	0.31	0.90	35.53	0.05
6	0.11	0.42	0.01	0.30	0.31	0.56	0.85	34.57	0
6.1	0.23	1.09	0.26	0.21	1.06	2.00	2.82	28.99	0.90
6.2	0.21	1.08	0.20	0.25	1.05	1.93	2.74	29.43	0.10
6.298	0.18	1.06	0.50	0.29	1.03	1.84	2.63	29.99	0.11
6.3	1.21	3.31	1.36	0.52	4.05	9.20	12.36	0	0.30
6.4	1.14	1.01	1.02	0.33	1.01	1.72	2.48	0.30	0.40
6.5	1.23	3.38	1.28	0.60	4.05	9.20	12.43	0.45	0.55
6.6	1.21	3.36	1.20	0.64	4.04	9.07	12.28	1.14	0.53
6.7	1.15	3.29	1.09	0.67	4.01	8.84	11.97	2.24	0.51
6.8	1.05	3.17	0.93	0.70	3.97	8.47	11.49	3.87	0.50
6.9	0.92	3.00	0.73	0.73	3.92	7.98	10.80	6.10	0.48
7.0	0.76	2.76	0.49	0.76	3.86	7.35	9.94	9.01	0.48

Table 10. Time series of total biomass (age 1 and older, metric ton), spawning biomass (metric ton), age-0 recruitment (thousands of fish), and instantaneous fishing mortality (age 3-12, year^{-1}) for the 2022 Western and Central North Pacific striped marlin estimated in the base-case model. SD = standard deviation.

Year	Age 1+ biomass (mt)	Spawning biomass (mt)		Recruitment (1000 age-0 fish)		Instantaneous fishing mortality	
	Mean	Mean	SE	Mean	SE	Mean	SE
1977	7825	7825	2765	618	220	0.37	0.09
1978	22145	7456	2101	837	240	0.45	0.10
1979	24007	6215	1765	504	203	0.46	0.09
1980	23144	6967	1747	510	174	0.58	0.11
1981	19243	5938	1623	540	178	0.64	0.13
1982	16965	4663	1379	573	208	0.42	0.09
1983	19041	5483	1400	761	251	0.39	0.08
1984	22800	6252	1523	642	251	0.44	0.08
1985	24216	6205	1597	691	237	0.53	0.10
1986	23557	5513	1578	605	232	0.64	0.12
1987	21327	5532	1531	984	244	0.53	0.10
1988	24759	4644	1367	492	207	0.67	0.13
1989	21914	5468	1493	522	197	0.52	0.10
1990	20078	5555	1522	749	223	0.49	0.09
1991	21854	5300	1418	561	200	0.50	0.09
1992	21976	6021	1377	607	121	0.42	0.06
1993	22626	5792	1055	199	57	0.55	0.06
1994	17257	5223	800	561	64	0.57	0.06
1995	16201	3952	664	354	55	0.67	0.08
1996	13793	3044	559	341	54	0.62	0.08
1997	12590	2951	532	462	57	0.60	0.08
1998	13252	2571	476	311	49	0.76	0.10
1999	11668	2533	453	244	42	0.75	0.10
2000	9830	2634	460	492	51	0.65	0.09
2001	11530	2559	449	291	45	0.63	0.09
2002	11460	3069	496	516	53	0.52	0.07
2003	13872	3243	525	367	42	0.60	0.07
2004	13942	4031	564	143	28	0.46	0.05
2005	11945	4012	562	446	44	0.49	0.06
2006	12365	3489	538	159	36	0.51	0.06
2007	10664	3680	533	288	39	0.42	0.05
2008	10541	3280	511	266	37	0.52	0.07
2009	10041	3225	511	112	28	0.38	0.05
2010	8900	3076	505	458	49	0.45	0.06
2011	10819	2862	498	260	37	0.42	0.06

Year	Age 1+ biomass (mt)	Spawning biomass (mt)		Recruitment (1000 age-0 fish)		Instantaneous fishing mortality	
	Mean	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
2012	11400	3264	544	120	28	0.43	0.06
2013	9841	3191	567	521	49	0.42	0.06
2014	12170	3243	576	98	27	0.35	0.05
2015	11205	3584	601	253	35	0.40	0.06
2016	10394	3647	628	172	32	0.33	0.04
2017	9613	3401	616	179	34	0.34	0.05
2018	9008	3218	616	376	67	0.33	0.05
2019	10608	2902	644	200	59	0.38	0.07
2020	10460	3449	843	298	149	0.33	0.07

Table 11. 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 $SSB_{(F=0)}$ indicates the average 20-year SSB_0 estimate, $20\%SSB_{(F=0)}$ is the associated reference point, and MSY is the maximum sustainable yield reference point.

Reference Point	**Estimate**
$F_{20\%SSB(F=0)}$ (age 3-12)	0.59
F_{MSY} (age 3-12)	0.57
F_{2020} (age 3-12)	0.33
$F_{2018-2020}$	0.35
$SSB_{(F=0)}$	17,978 mt
$20\%SSB_{(F=0)}$	3,596 mt
SSB_{MSY}	3,689 mt
SSB_{2020}	3,449 mt
$SSB_{2018-2020}$	3,190 mt
$C_{20\%SSB(F=0)}$	5,446 mt
C_{MSY}	5,407 my
$C_{2018-2020}$	2,429 mt
$SPR_{20\%SSB(F=0)}$	18%
SPR_{MSY}	19%
SPR_{2020}	12%
$SPR_{2018-2020}$	13%

Reference Point	**Estimate**
$F_{20\%SSB(F=0)}$ (age 3-12)	0.59
F_{MSY} (age 3-12)	0.57
F_{2020} (age 3-12)	0.33
$F_{2018-2020}$	0.35
$SSB_{(F=0)}$	17,978 mt
$20\%SSB_{(F=0)}$	3,596 mt
SSB_{MSY}	3,689 mt
SSB_{2020}	3,449 mt
$SSB_{2018-2020}$	3,190 mt
$C_{20\%SSB(F=0)}$	5,446 mt
C_{MSY}	5,407 my
$C_{2018-2020}$	2,429 mt
$SPR_{20\%SSB(F=0)}$	18%
SPR_{MSY}	19%
SPR_{2020}	12%
$SPR_{2018-2020}$	13%

Table 12. Complete list of sensitivity runs conducted for the 2022 stock assessment of Western and Central North Pacific striped marlin.

RUN	NAME	DESCRIPTION
Alternative Life History Parameters: Natural Mortality		
1	base_case_highM	Alternative natural mortality rates are 10% higher than in the base case
2	base_case_lowM	Alternative natural mortality rates are 10% lower than in the base case
Alternative Life History Parameters: Recruitment Variability (σ_R)		
3	base_case_large_σ_R	A larger σ_R (0.9).
Alternative Life History Parameters: Stock-Recruitment Steepness		
4	base_case_h095	Alternative higher steepness with h=0.95
5	base_case_h079	Alternative lower steepness with h=0.79
6	base_case_h070	Alternative lower steepness with h=0.70
Alternative Life History Parameters: Maturity Ogive		
7	base_case_L50_177	Alternative maturity ogives with L_{50} 177 cm (Used in the 2015 assessment)
8	base_case_L50_181	Alternative maturity ogives with converted L_{50} from Chang et al. (2018)
Alternative Model Configuration		
9	Base_case_S1994	Start the assessment model in 1994 instead of 1977
10	Base_case_S1975	Start the assessment model in 1975 instead of 1977
Alternative catch assumption		
11	Drop_VNCN_catch	Drop the Vanuatu and Chinese catch
12	SWPO_SA9	SW Pacific Growth model
13	Growth_2019	Use biological parameters from 2019 base-case model
14	base-case_DFselect	Alternative mirroring for F24 (F13) and F25 (F14)

Table 13. Projected median values of Western and Central North Pacific striped marlin spawning stock biomass (SSB, t), catch (t), and probability of reaching 20%$SSB_{F=0}$ under ten constant fishing mortality rate (F) 2021-2040. For scenarios reach 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 3596 t.

Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2030**	**2040**	**Year when target achieved**
Scenario 1: $F_{20\%SSB(F=0)}$; Stock – Recruitment Curve								
SSB	2938	2723	2953	3179	3320	3564	3596	2037
Catch	4175	4186	4596	4920	5107	5408	5446	
Scenario 2: Highest F (Average $F_{1998-2000}$); Stock – Recruitment Curve								
SSB	2820	2445	2551	2662	2723	2830	2845	NA
Catch	4749	4586	4897	5098	5200	5364	5387	
Scenario 3: Low F ($F_{30\%}$); Stock – Recruitment Curve								
SSB	3630	3928	4648	5375	5920	6950	1097	2021
Catch	2614	2979	3525	3996	4319	4867	4938	
Scenario 4: F_{MSY}; Stock – Recruitment Curve								
SSB	2975	2770	3005	3242	3392	3653	3688	2028
Catch	4080	4139	4552	4874	5062	5367	5407	
Scenario 5: $F_{Status\ Quo}$ (Average $F_{2018-2020}$); Stock – Recruitment Curve								
SSB	3557	3789	4425	5069	5550	6459	6590	2022
Catch	2760	3121	3652	4097	4398	4911	4979	
Scenario 6: $F_{20\%SSB(F=0)}$; 20-year Average Recruitment								
SSB	2938	2626	2478	2398	2359	2329	2328	NA
Catch	4172	3817	3662	3584	3550	3526	3526	
Scenario 7: Highest F (Average $F_{1998-2000}$); 20-year Average Recruitment								
SSB	2820	2352	2129	2022	1975	1942	1941	NA
Catch	4747	4132	3863	3748	3703	3675	3675	
Scenario 8: Low F ($F_{30\%}$); 20-year Average Recruitment								
SSB	3630	3812	3967	4048	4089	4133	4135	2021
Catch	2613	2727	2809	2846	2861	2876	2877	
Scenario 9: F_{MSY}; 20-year Average Recruitment								
SSB	2975	2674	2530	2452	2414	2382	2382	NA
Catch	4077	3756	3615	3545	3514	3491	3491	
Scenario 10: $F_{Status\ Quo}$ (Average $F_{2018-2020}$); 20-year Average Recruitment								
SSB	3557	3676	3779	3828	3850	3872	3873	2022
Catch	2757	2837	2891	2911	2919	2926	2926	

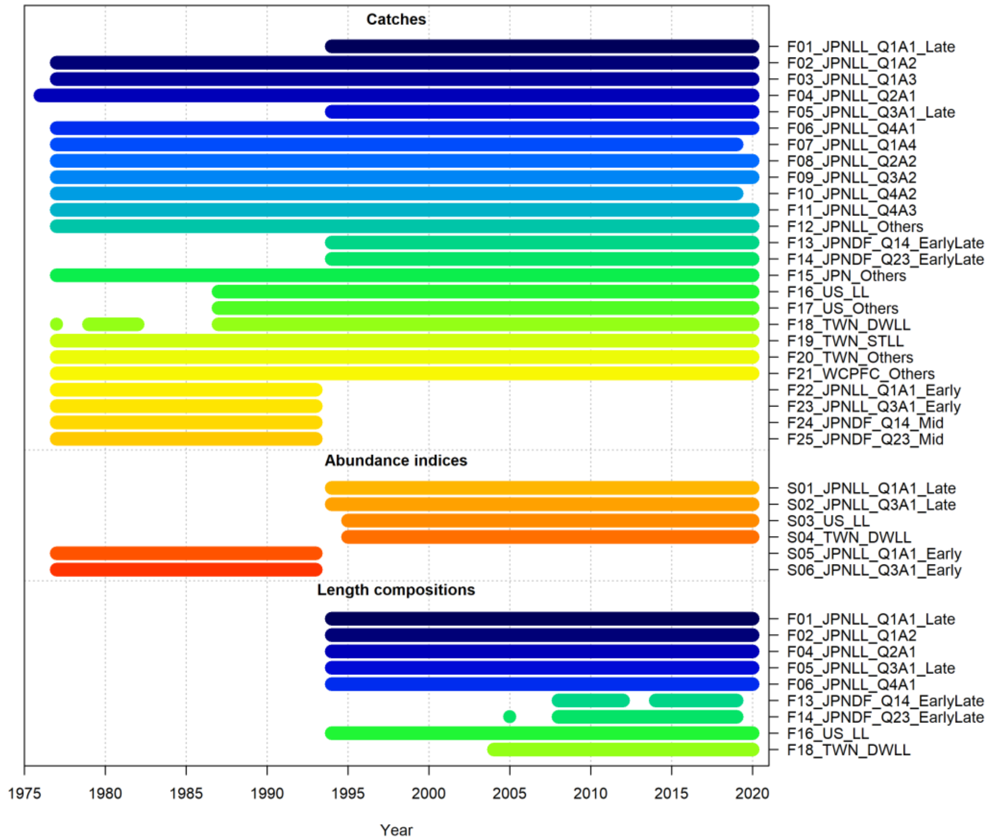


Figure 1. Available temporal coverage and sources of catch, CPUE (abundance indices), and length and size composition for the 2022 stock assessment of the Western and Central North Pacific striped marlin.

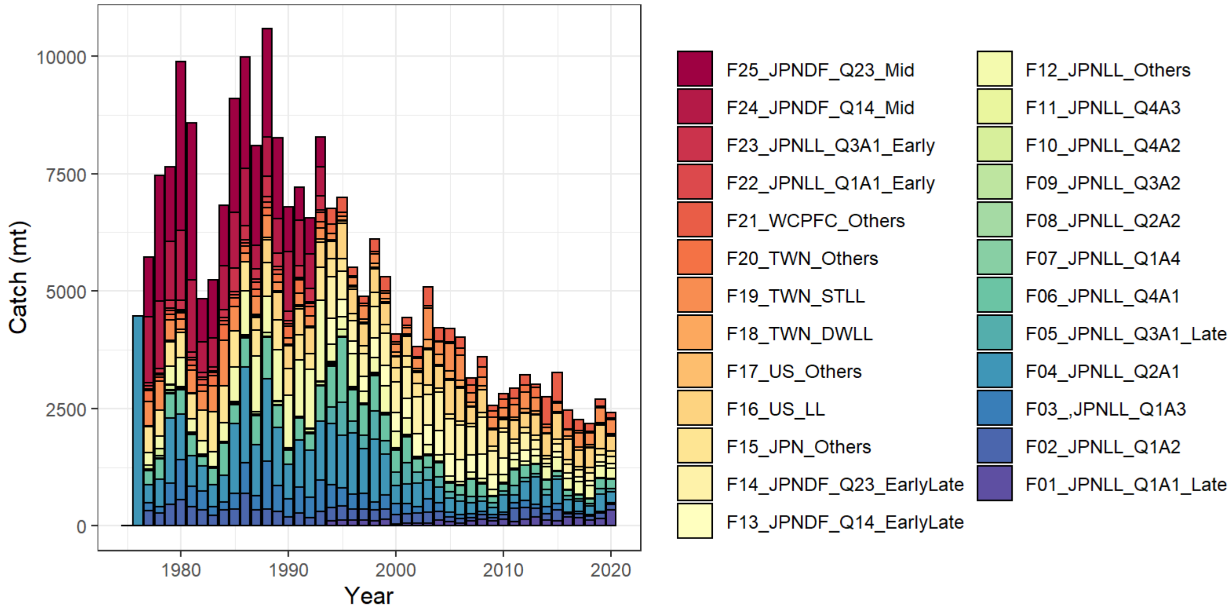


Figure 2. Total annual catch of the Western and Central North Pacific striped marlin by all fisheries harvesting the stock during 1977-2020. See Table 1 for the reference code for each fishery.

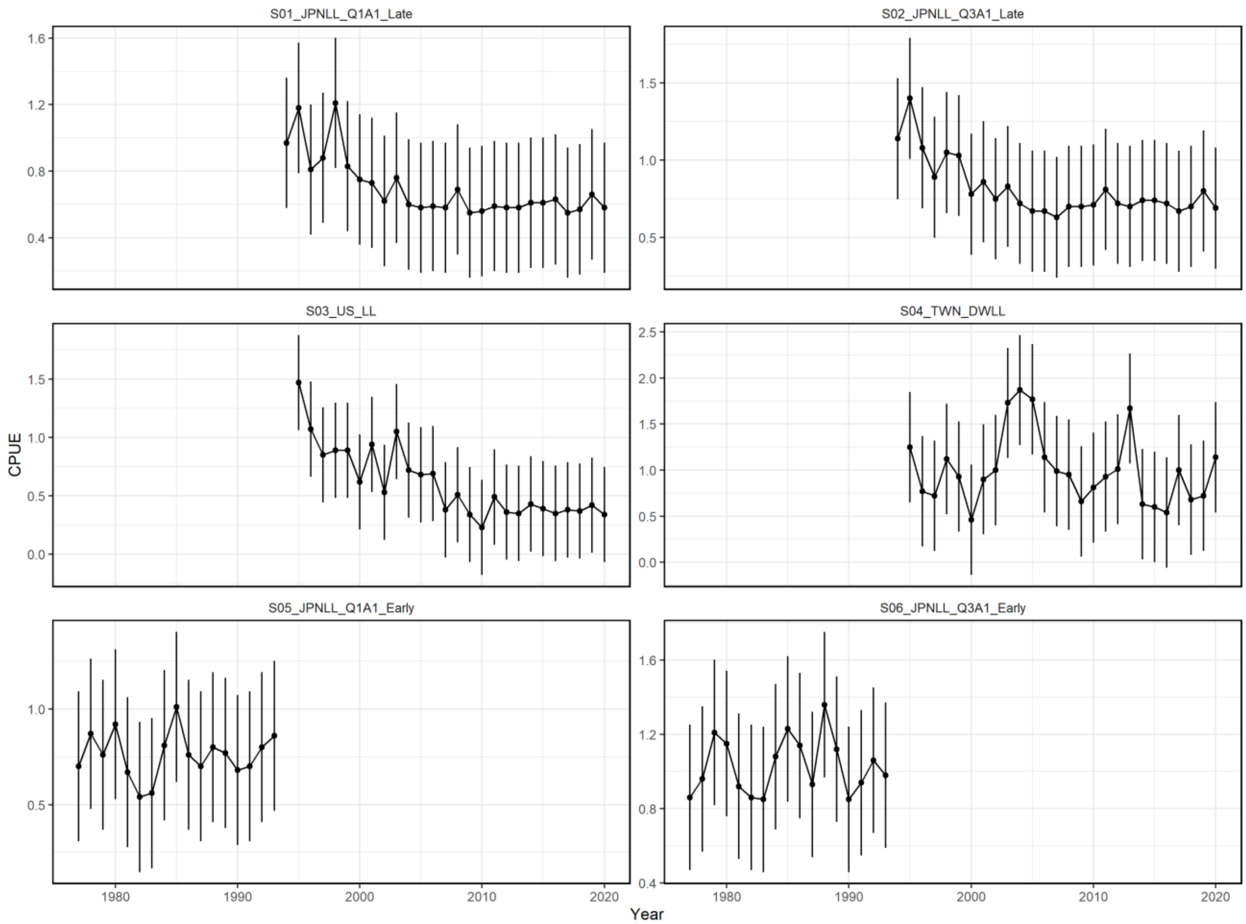


Figure 3. Time series of annual standardized indices of catch-per-unit-effort (CPUE) for the for each fleet in the base-case assessment model for the Western and Central North Pacific striped marlin as described in Table 1. Index values were rescaled by the mean of each index for comparison purposes.

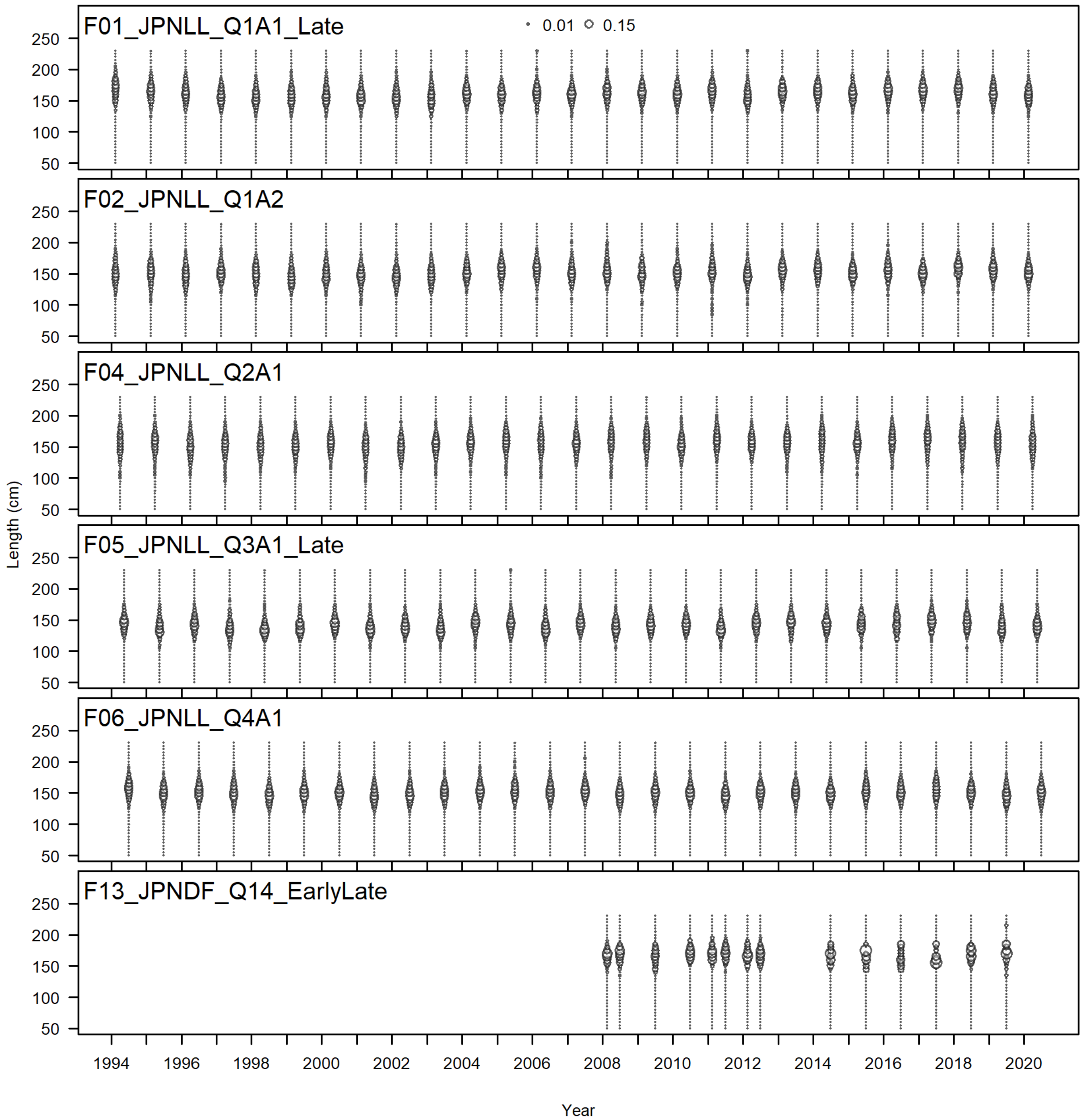


Figure 4. Quarterly length and size composition data by fishery used in the stock assessment (see Table 3). The sizes of the circles are proportional to the number of observations. All measurements were eye- fork lengths (EFL, cm).

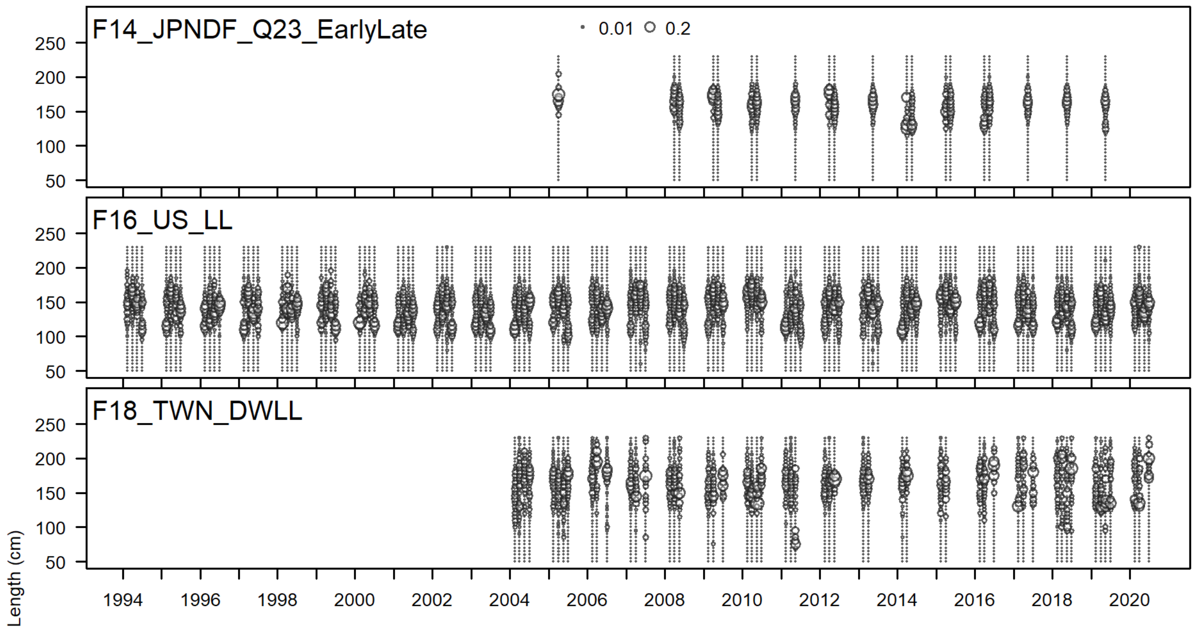


Figure 4. (Continued)

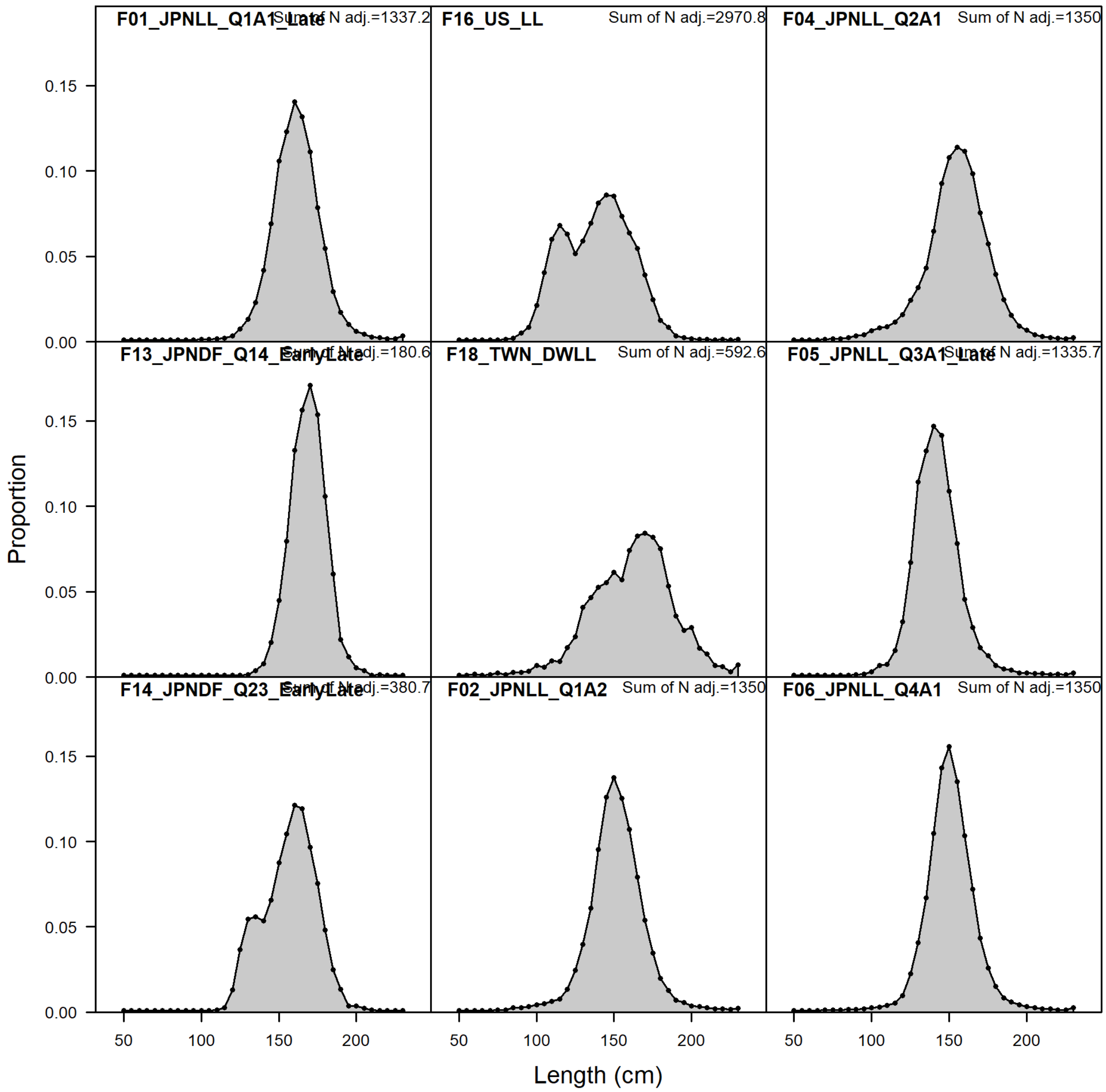


Figure 5. Aggregated length and size compositions used in the stock assessment (see Table 3 for descriptions of the composition data). All measurements were eye-fork lengths (EFL, cm).

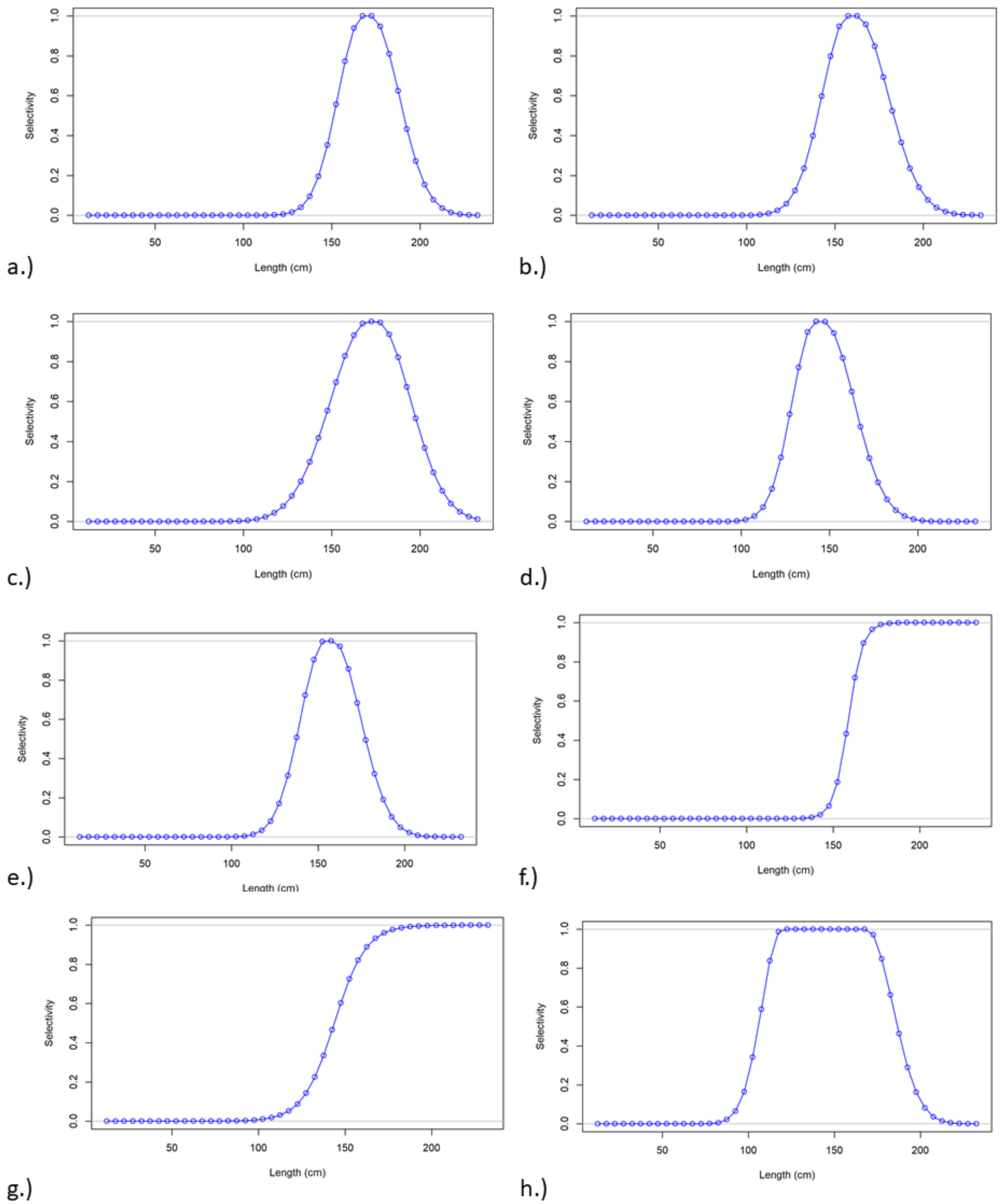
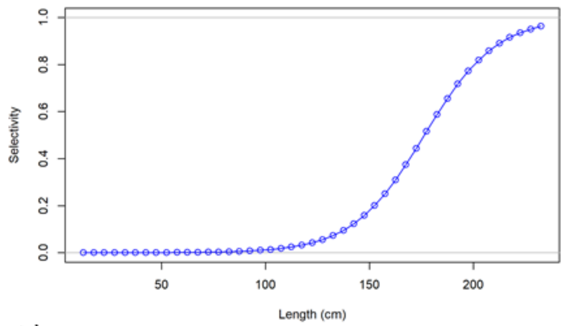


Figure 6. Final year length-based selectivity of fisheries for Western and Central North Pacific striped marlin estimated for the 2022 assessment: a.) F01_JPNLL_Q1A1_Late; b.) F02_JPNLL_Q1A2; c.) F04_JPNLL_Q2A1; d.) F05_JPNLL_Q3A1_Late; e.) F06_JPNLL_Q4A1; f.) F13_JPNDF_Q14_EarlyLate; g.) F14_JPNDF_Q23_EarlyLate; h.) F16_US_LL; i.) F18_TWN_DWLL.



i.)

Figure 6. (Continued.)

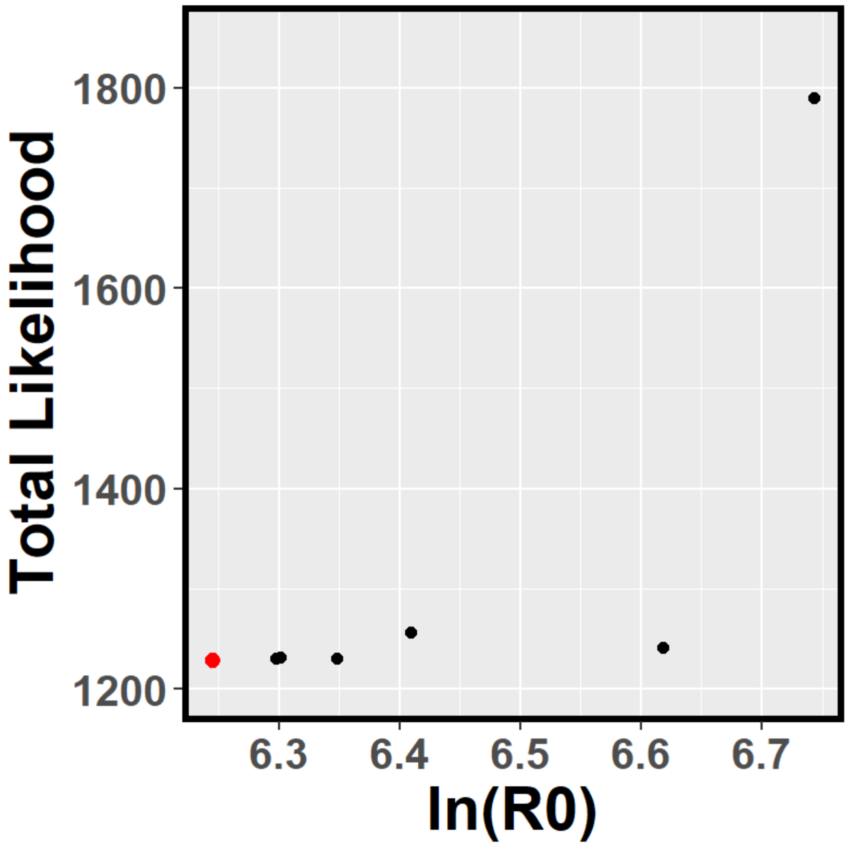


Figure 7. Results of a randomized initial parameter value diagnostic for the base case model where 200 randomized initial conditions were used with a CV of 10% assigned to each parameter. Results are shown for the base case model (MLE, solid red circle) and for the base case model with randomized initial parameter values (Jitter runs, solid black circles).

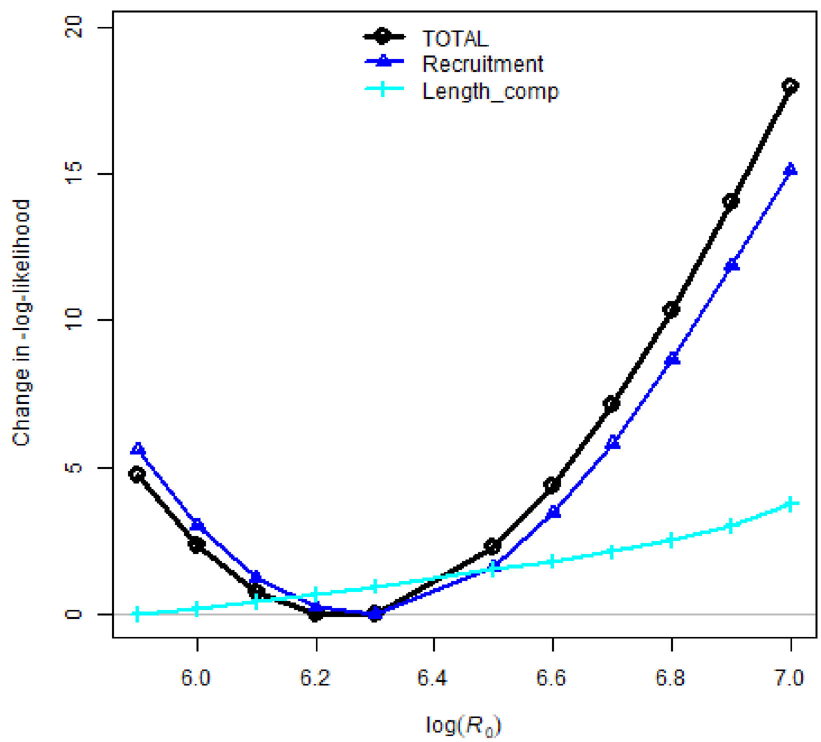


Figure 8. Profiles of the negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter R_0 in log-scale (i.e., the x-axis is log(R_0)) ranging from 5.8 to 7.0 for the base case model, where recruitment represents 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.

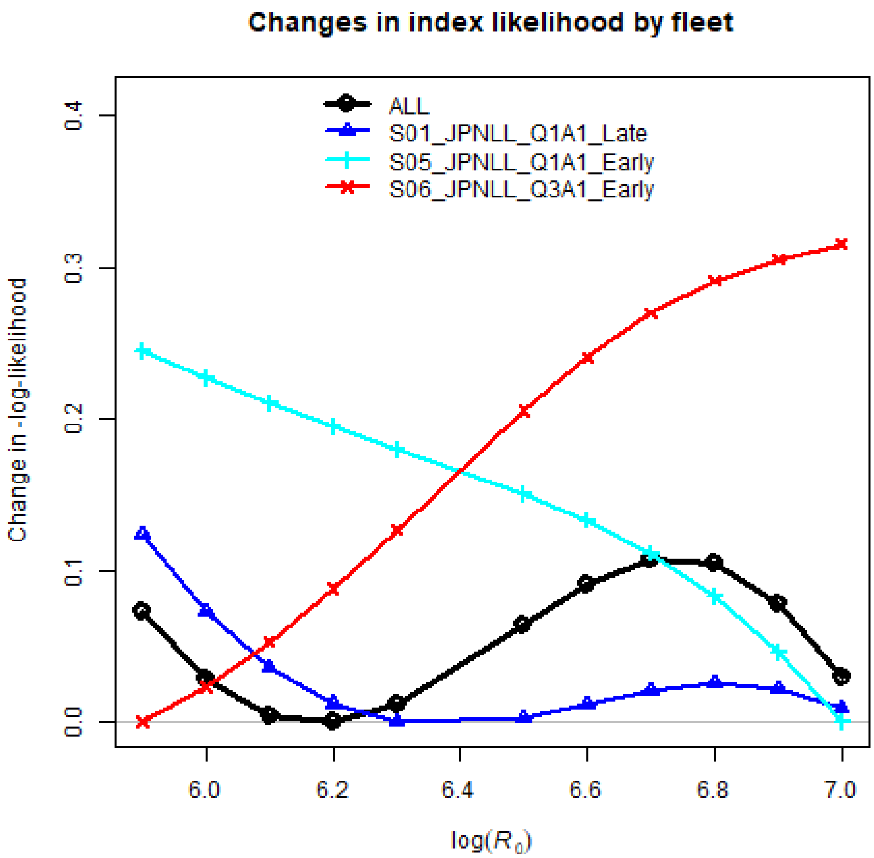


Figure 9. Profiles of the relative negative log-likelihoods by fleet-specific index likelihood components for the virgin recruitment in log-scale ($\log(R_0)$) ranged from 5.8 to 7.0 of the base case scenario. See Table 1 for descriptions of the index data. S2, S3, and S4 were not included in the total likelihood.

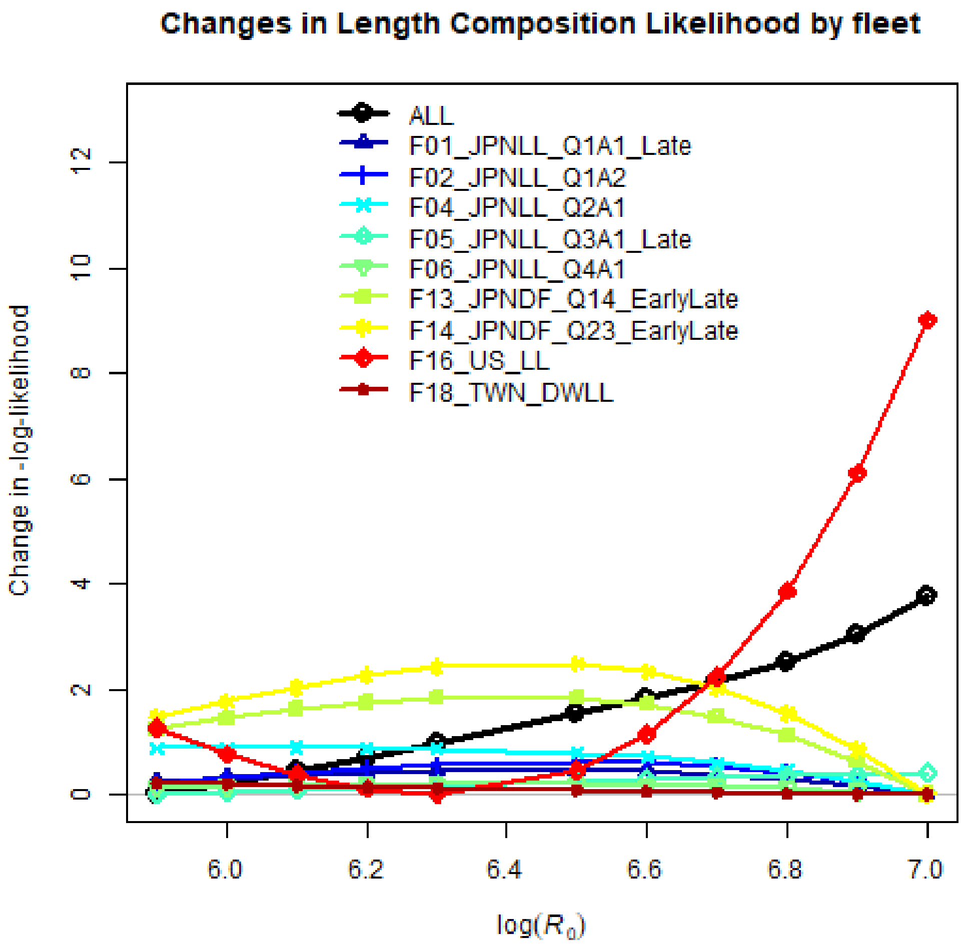


Figure 10. Profiles of the relative negative log-likelihoods by fleet-specific length composition likelihood components for the virgin recruitment in log-scale ($\log(R_0)$) ranged from 5.8 to 7.0 of the base case scenario. See Table 3 for descriptions of the length composition data.

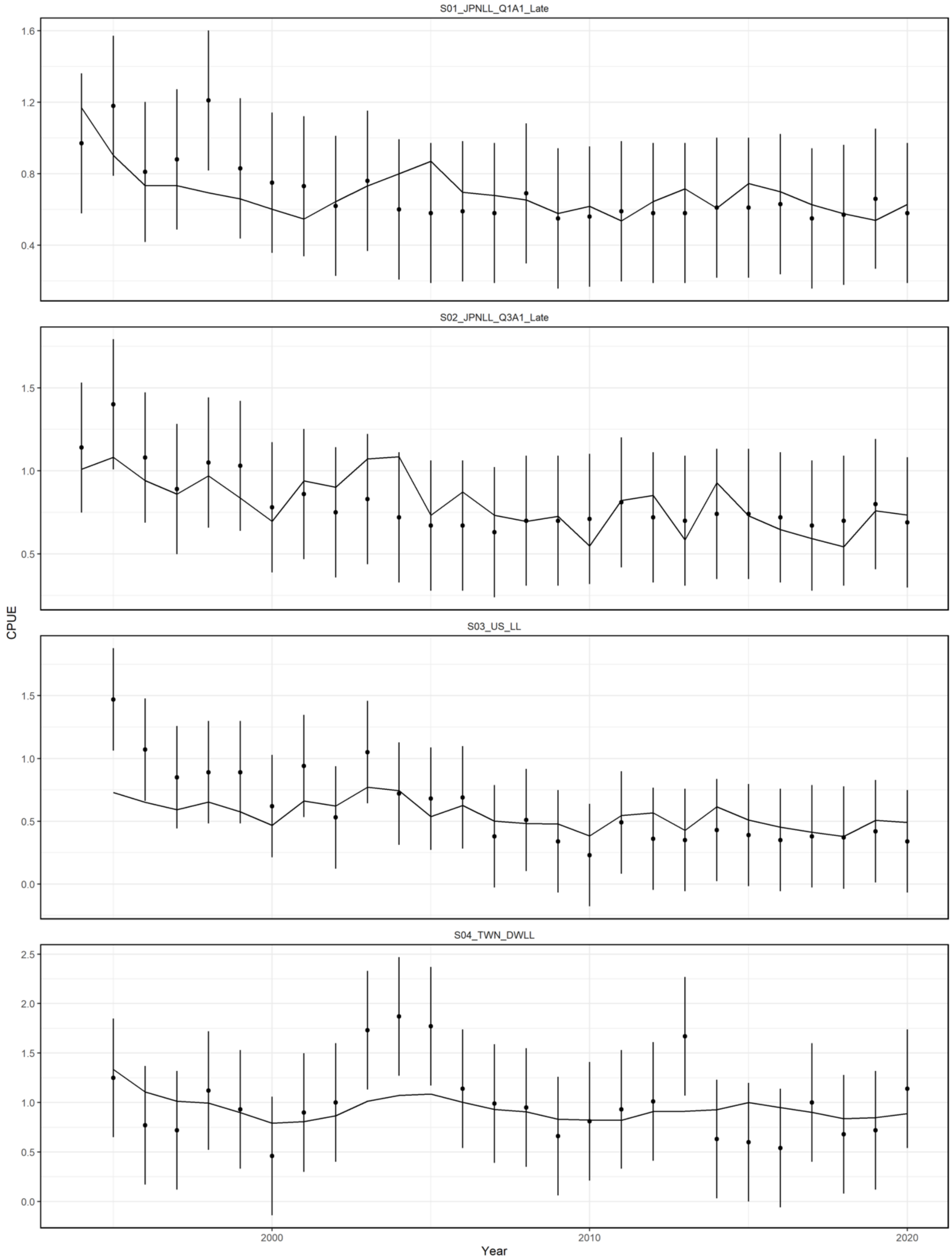


Figure 11. Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. S2, S3, and S4 were not included in the total likelihood.

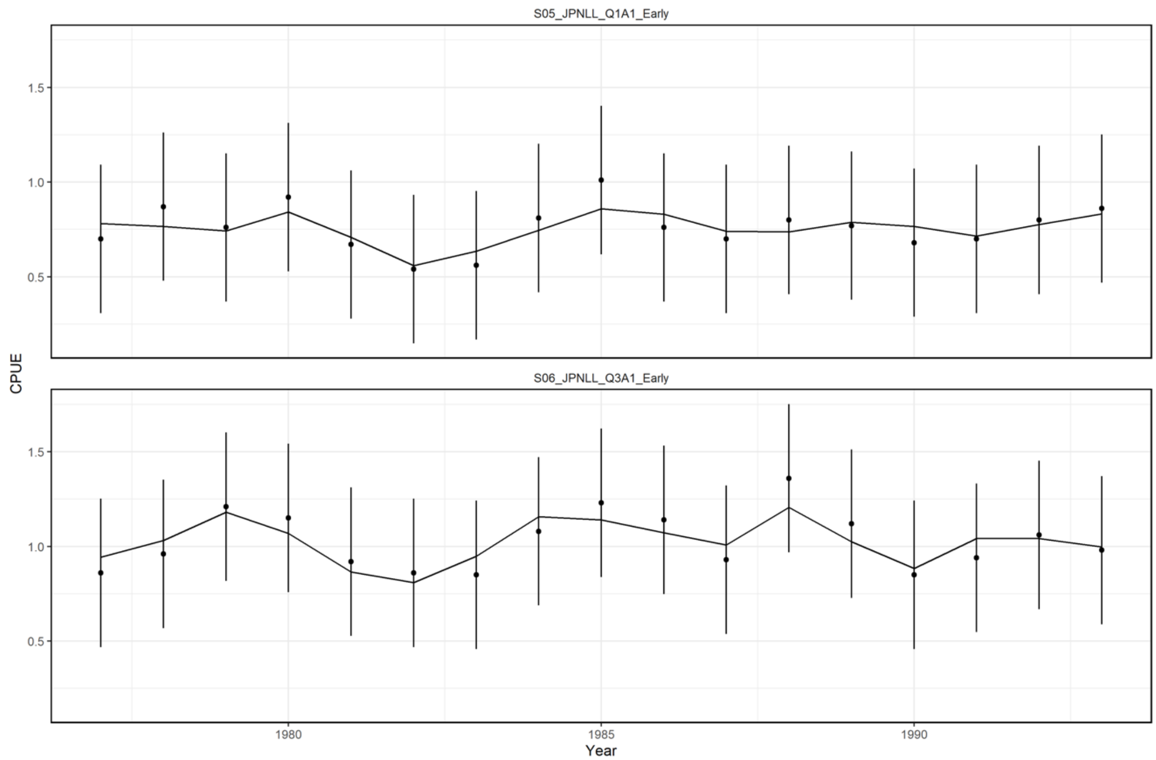


Figure 11. Continued

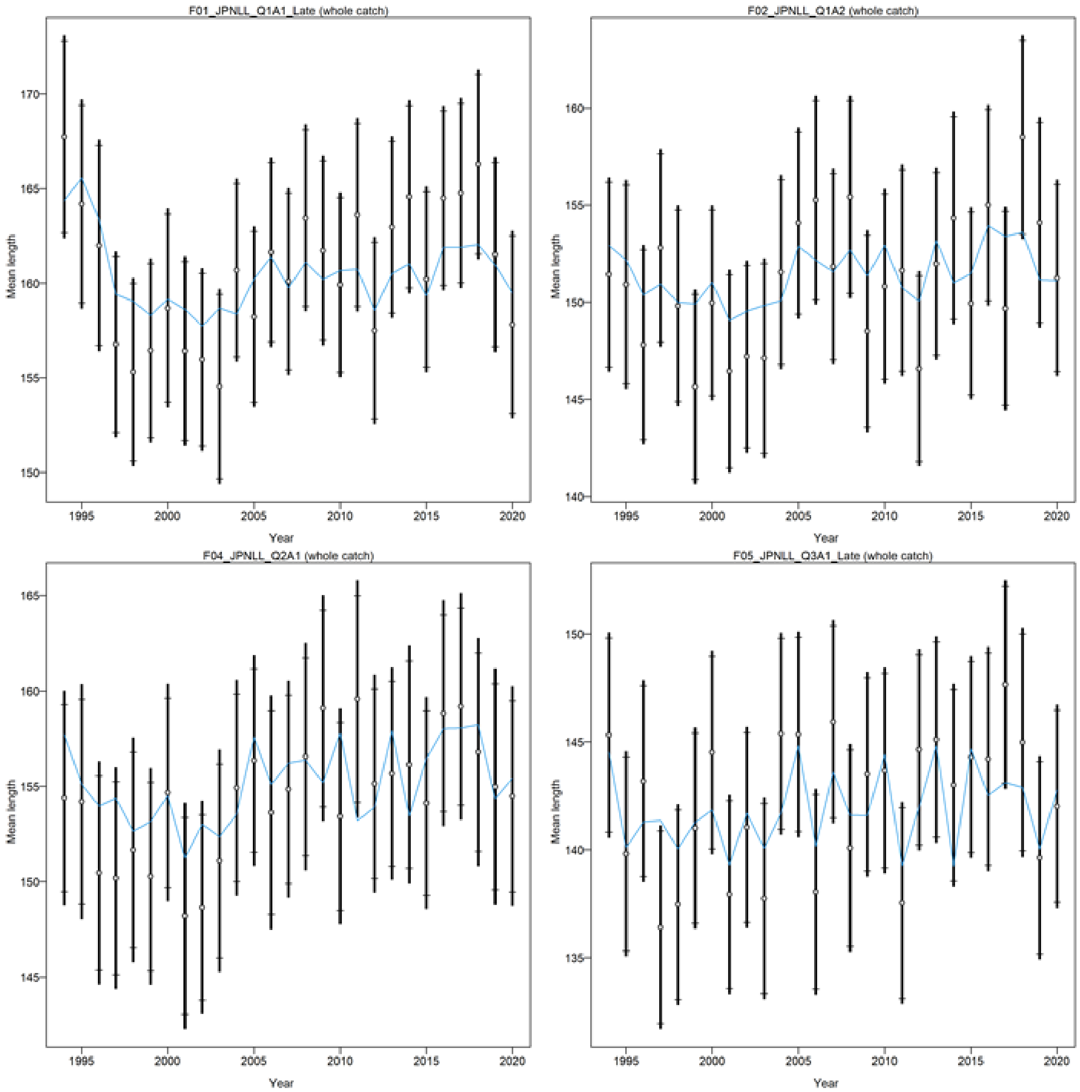


Figure 12. Model fit (lines) to mean length of the composition data (points, showing the observed mean age and 95% credible limits around mean age (vertical lines)). See Table 3 for descriptions of the data. All measurements were eye-fork lengths (EFL, cm).

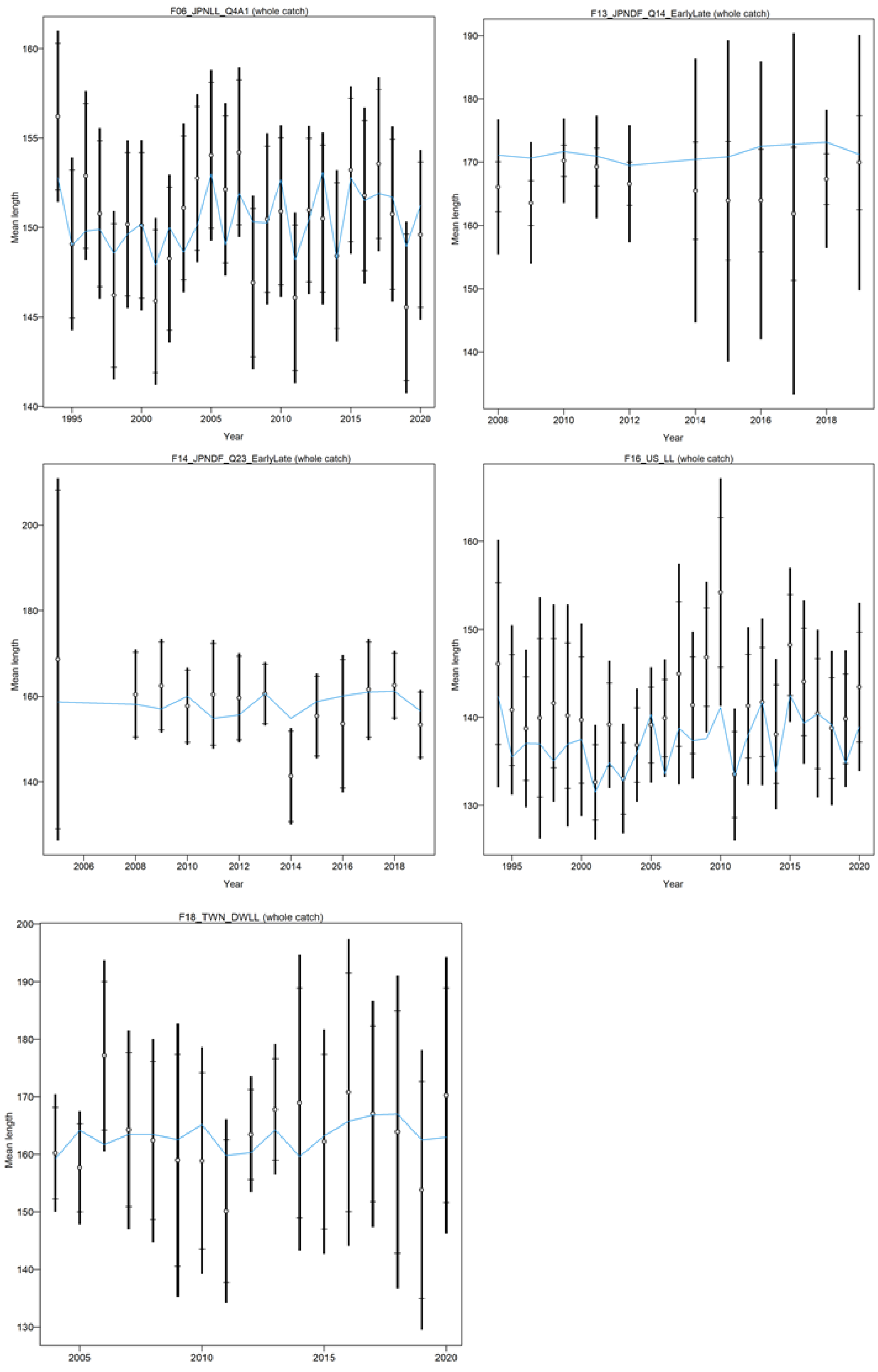


Figure 12. Continued.

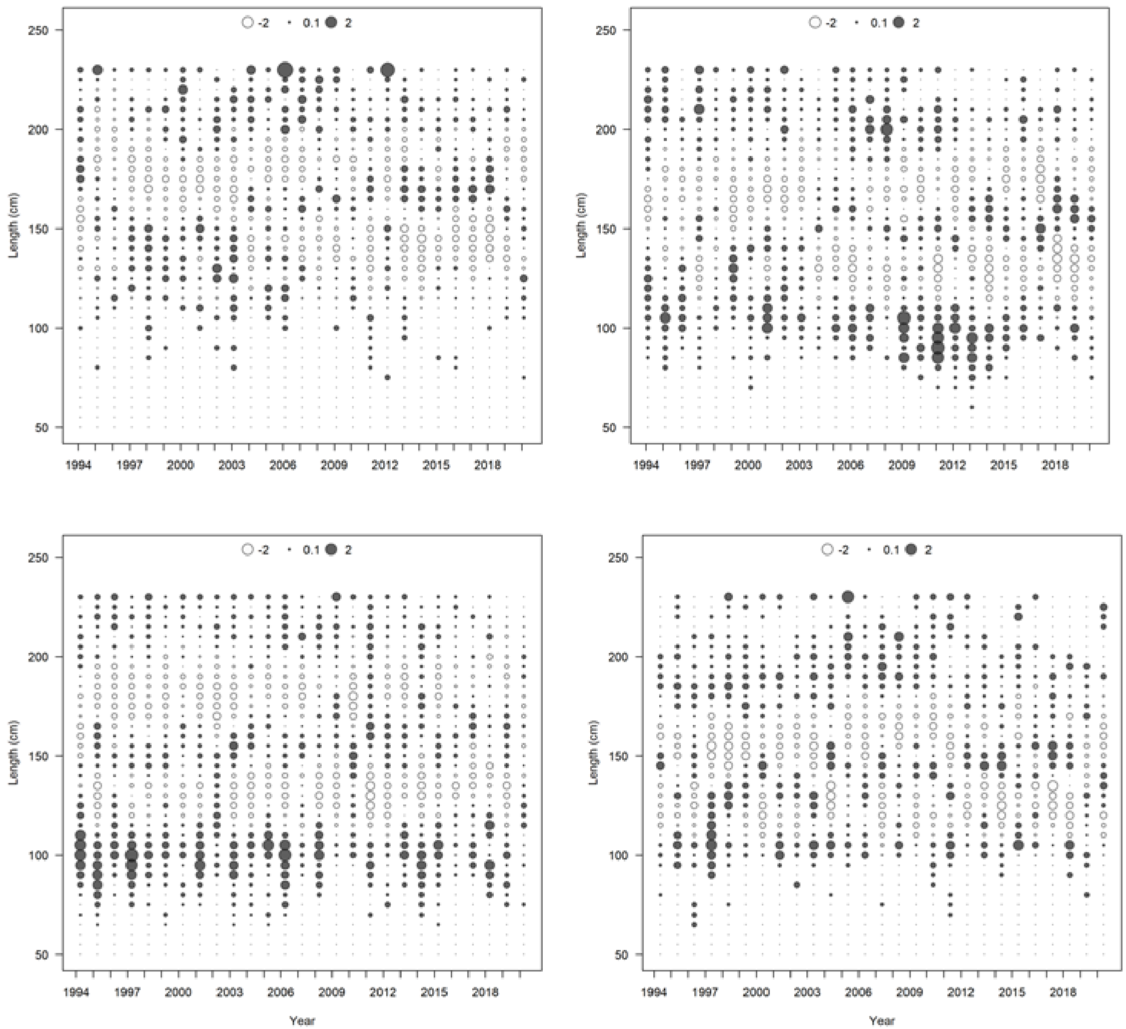


Figure 13. Pearson residual plots of model fits to the various length-composition data for the Western and Central North Pacific striped marlin fisheries used in the assessment model.

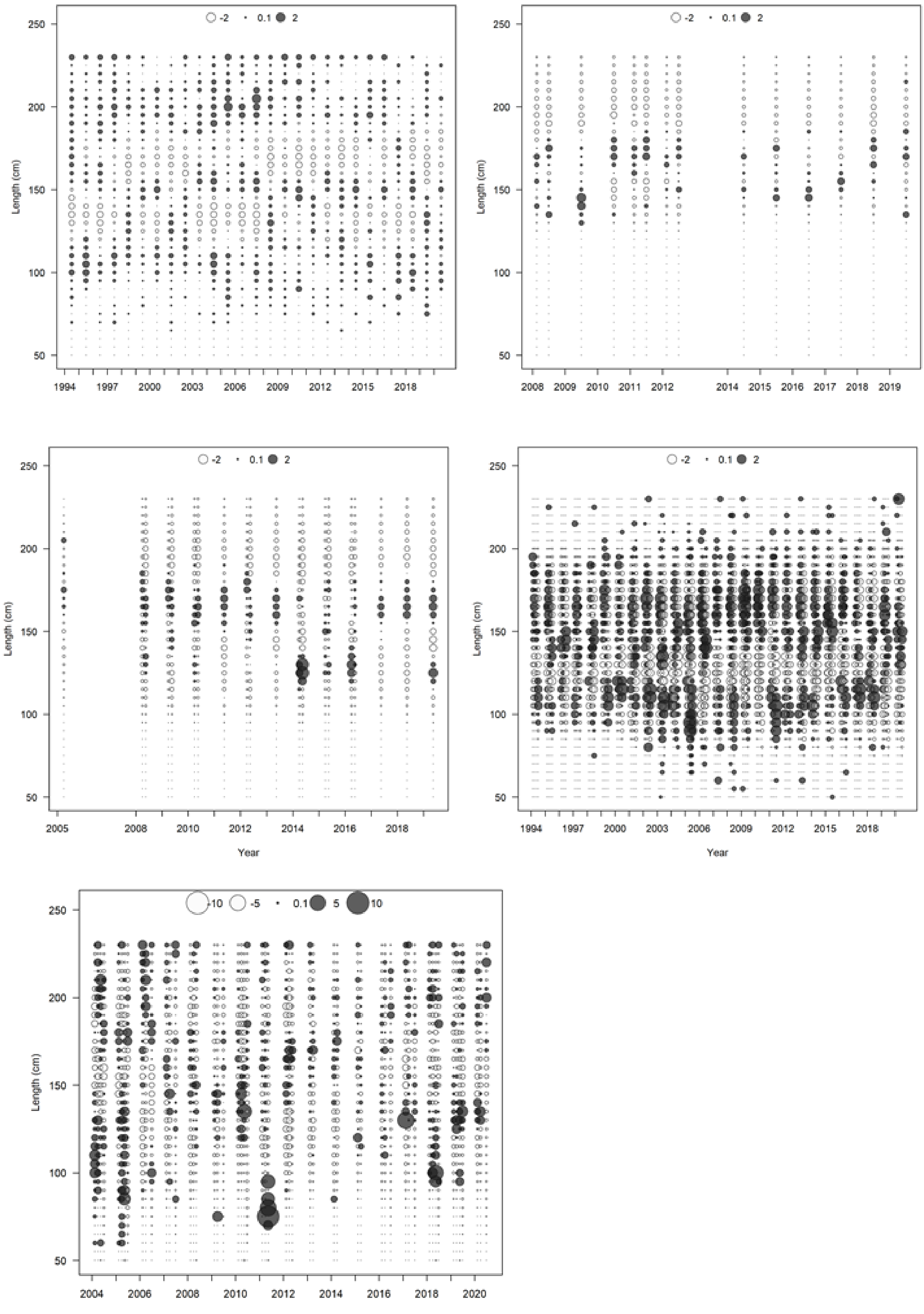


Figure 13. Continued

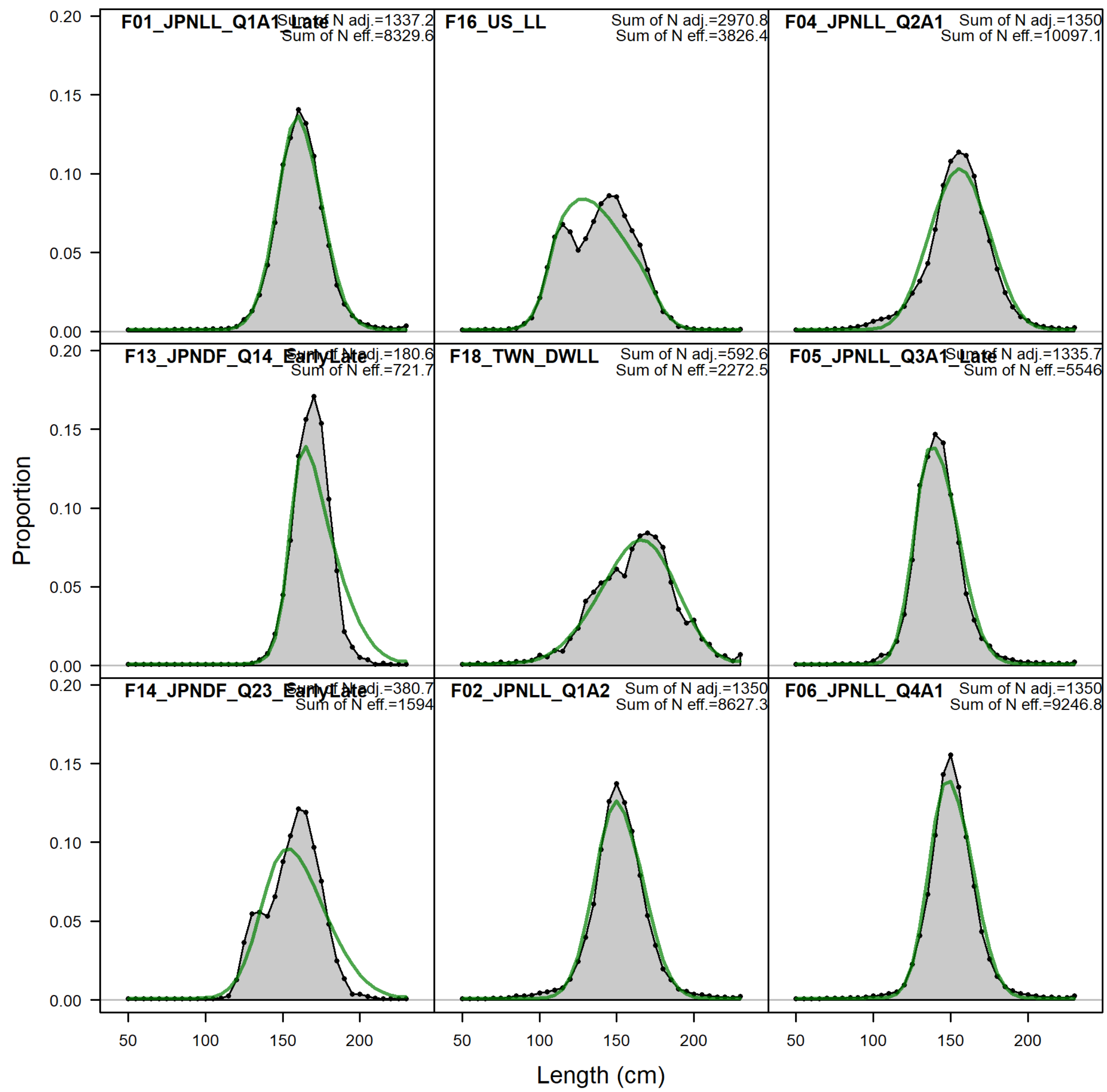


Figure 14. Comparison of observed (gray shaded area and blue dots) and model predicted (blue solid line) length compositions for fisheries used in the stock assessment for the Western and Central North Pacific striped marlin. Observed (black circles) and predicted (green line) length compositions. All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

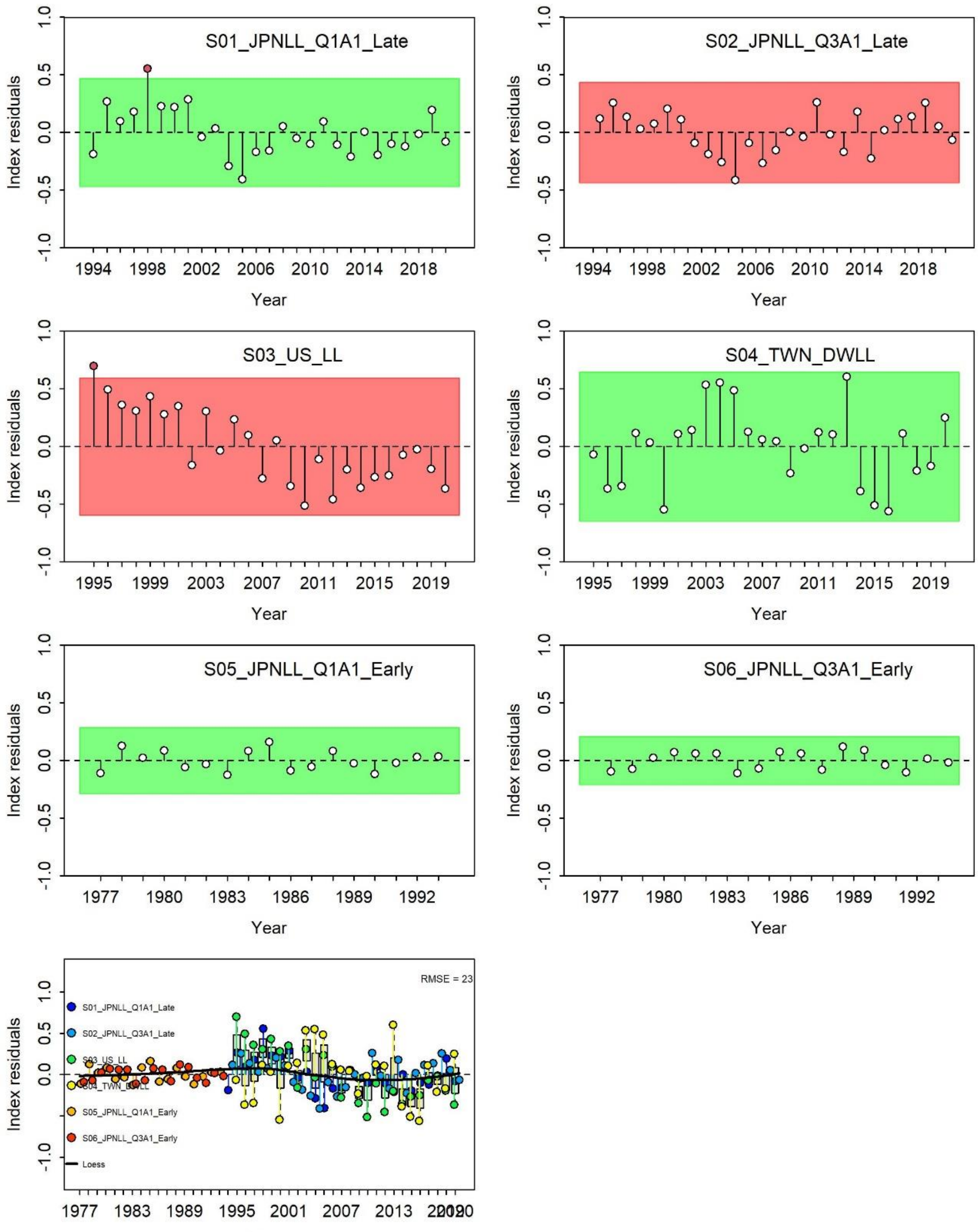


Figure 15. Runs test results for the CPUE fits. Green shading indicates no evidence (p≥0.05) and red shading indicates evidence (p<0.05) to reject the hypothesis of a randomly distributed time-series of residuals. The red/green shaded areas span three residual standard deviations to either side from zero, the red points outside of the shading violate the "three-sigma limits" for that series. Note that S2, S3, and S4 were not included in the assessment likelihood.

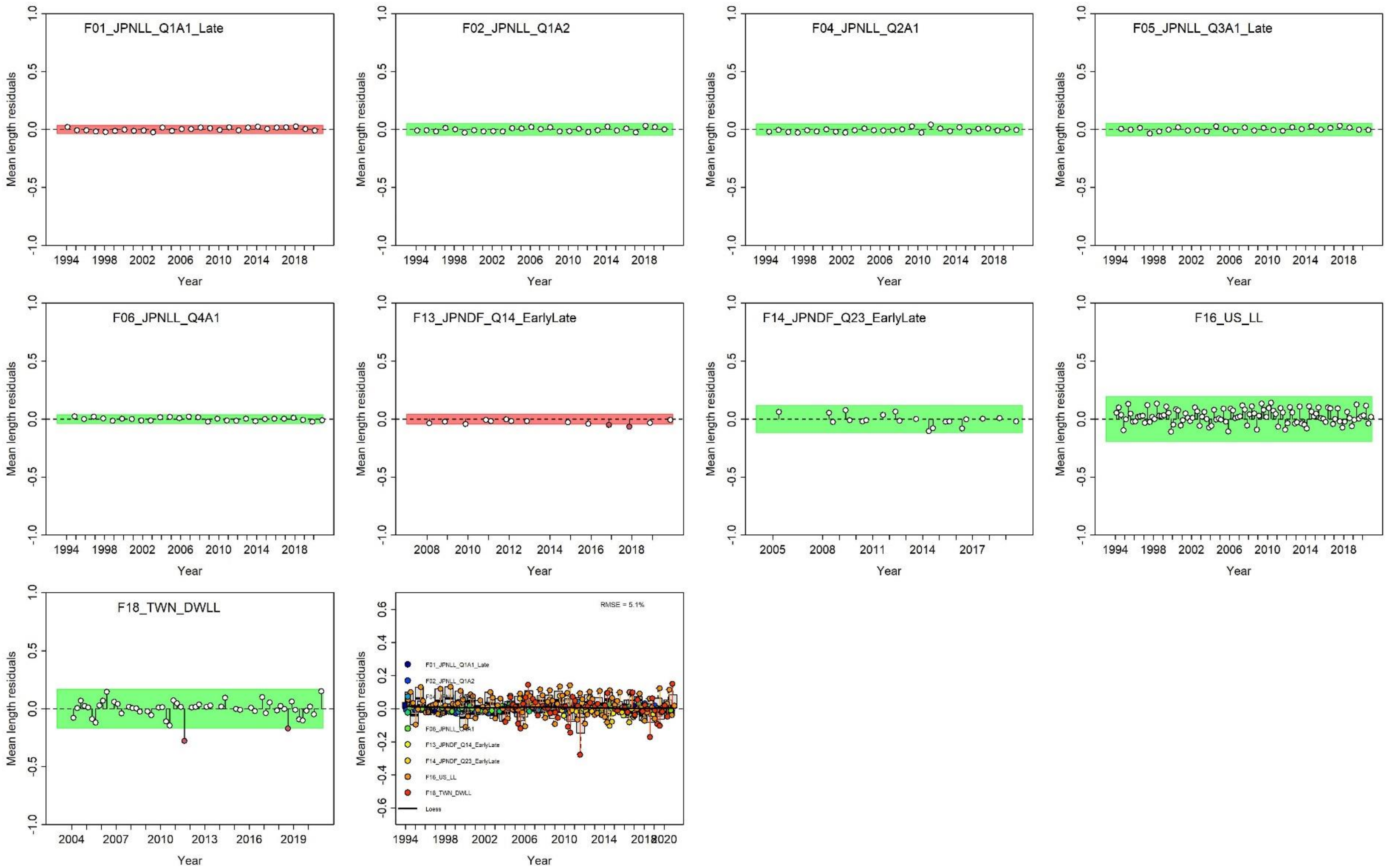


Figure 16. Runs test results for the mean lengths of size composition data. Green shading indicates no evidence (p≥0.05) and red shading indicates evidence (p<0.05) to reject the hypothesis of a randomly distributed time-series of residuals. The red/green shaded areas span three residual standard deviations to either side from zero, the red points outside of the shading violate the "three-sigma limits" for that series.

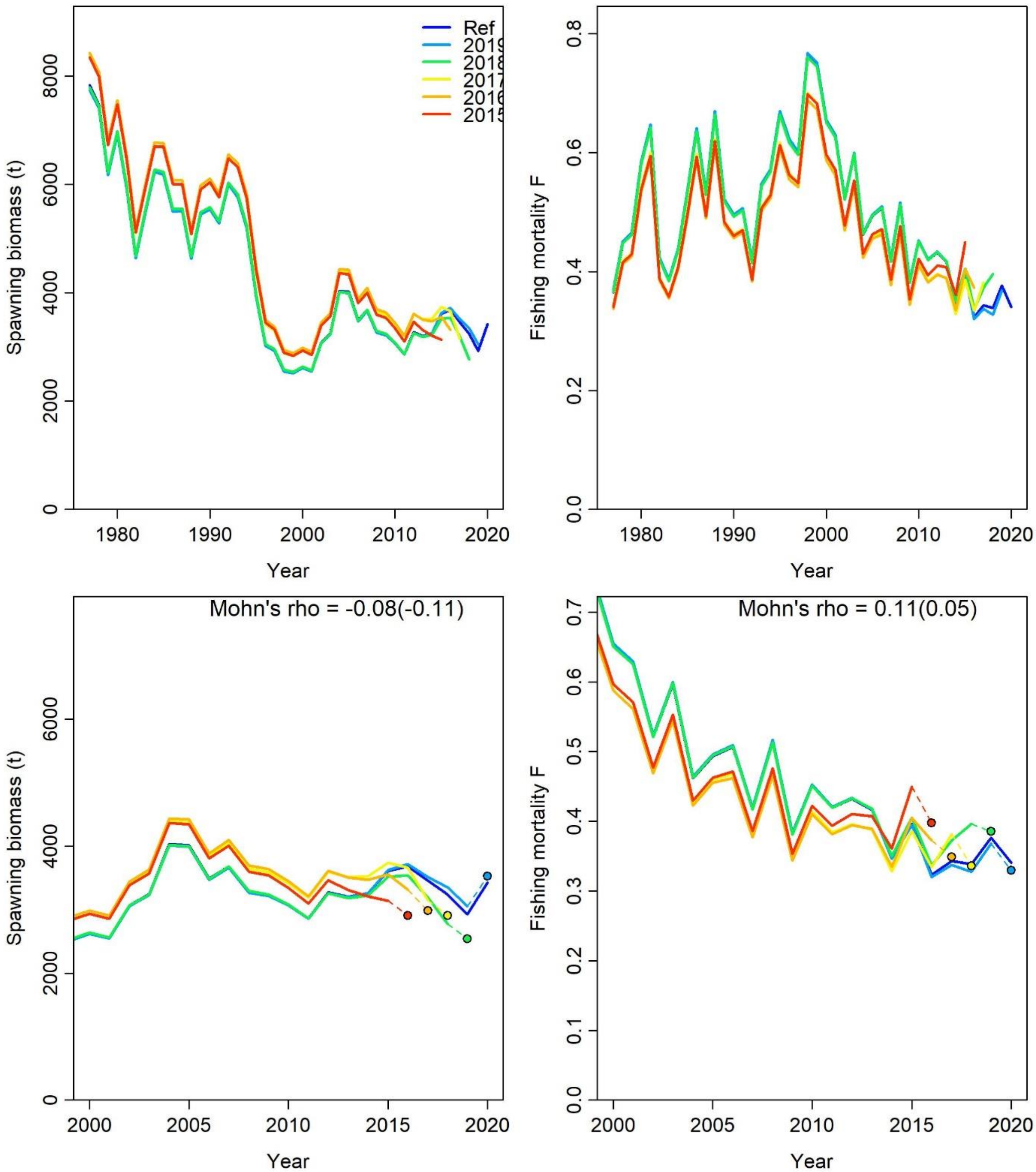


Figure 17. Retrospective analysis of spawning biomass (left) and fishing mortality (right) for the whole time series (top) and the last 20 years (bottom) consisting of 5 reruns of the base case model each fitted with one more year of data removed from the base case model (blue line, 1977-2020).

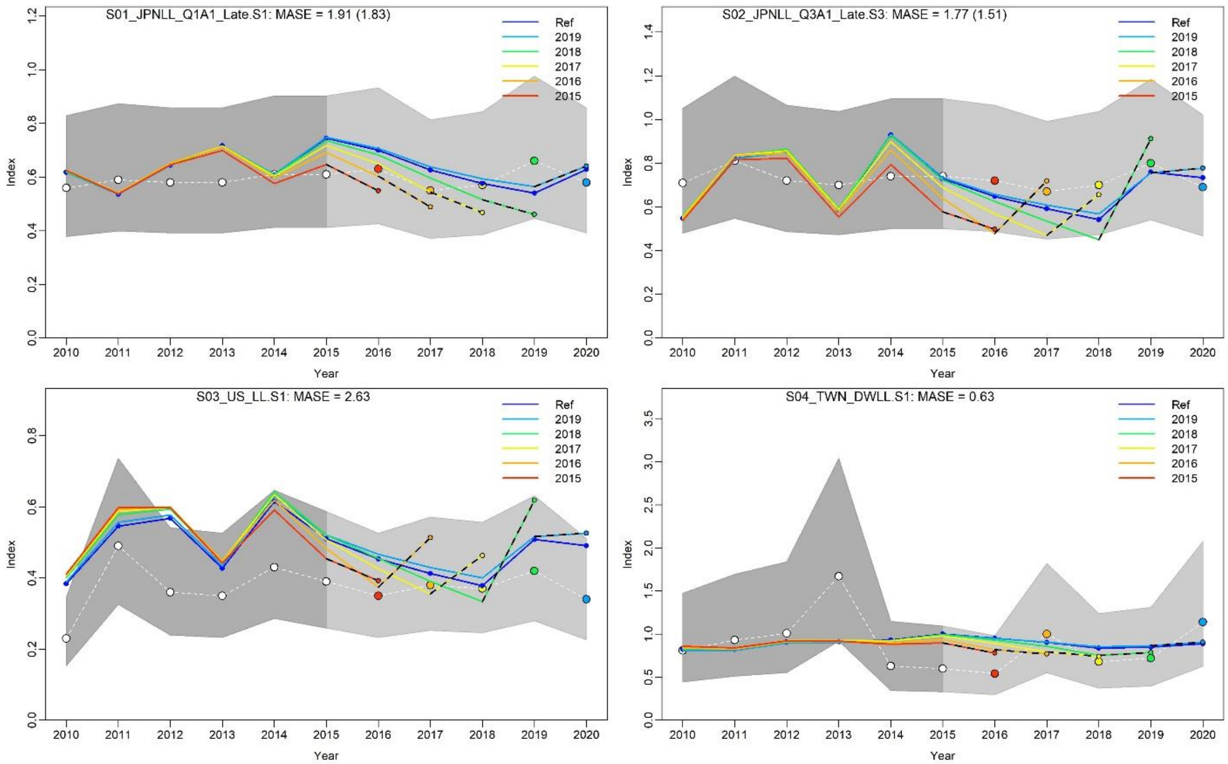


Figure 18. Hind casting cross-validation (HCxval) results for the four CPUE fits, showing observed (large points with dashed line), fitted (solid lines), and one-year-ahead forecast values (small terminal points) in the old growth model. The observations used for cross-validation are highlighted as color-coded solid circles with associated 95% confidence intervals (light-grey shading). The model reference year refers to the endpoint of each one-year-ahead forecast and the corresponding observation. The mean absolute scaled error (MASE) score associated with each CPUE time series is denoted in each panel.

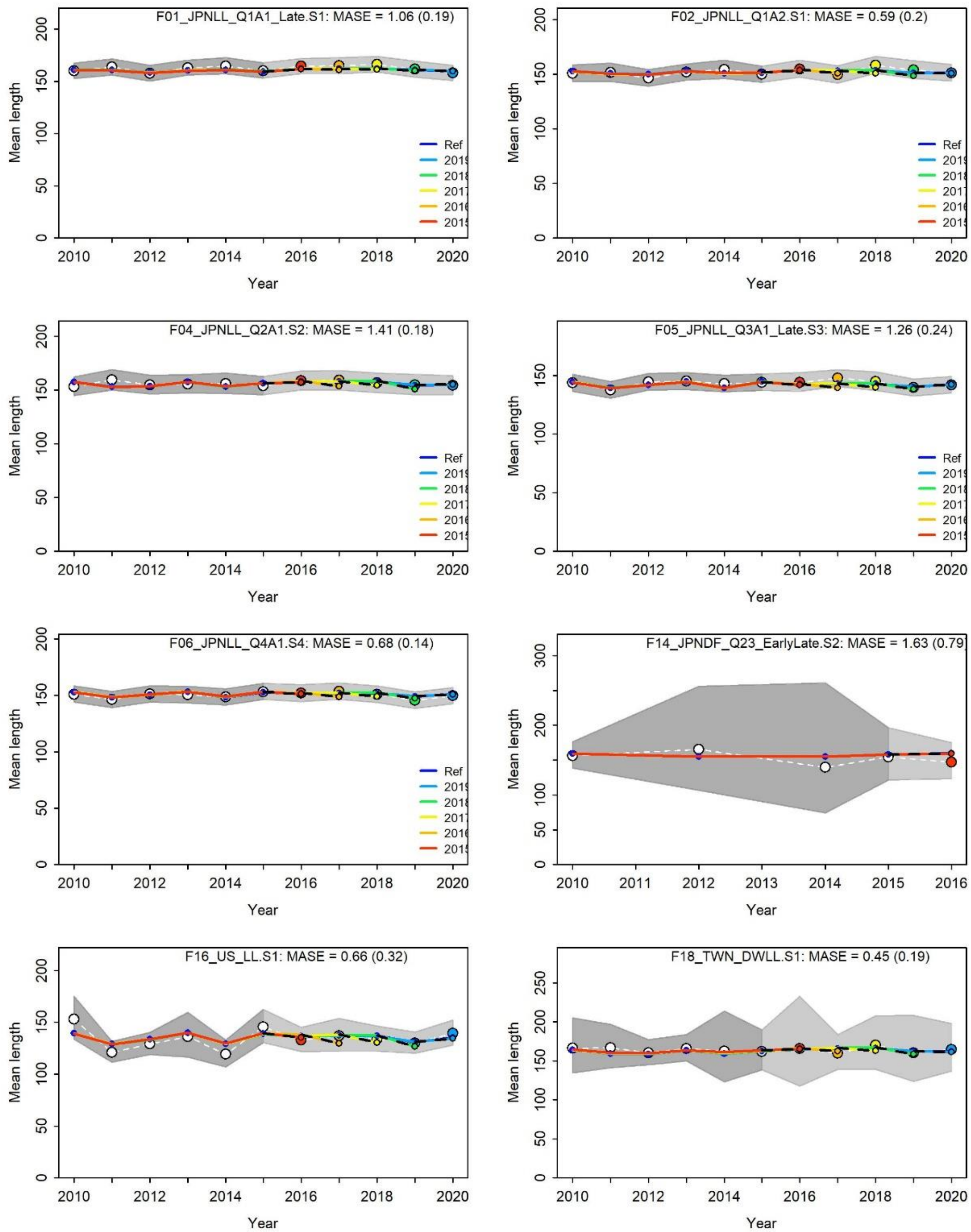


Figure 19. Hind casting cross-validation (HCxval) results for the eight size composition mean lengths, showing observed (large points with dashed line), fitted (solid lines), and one-year-ahead forecast values (small terminal points) in the old growth model. The observations used for cross-validation are highlighted as color-coded solid circles with associated 95% confidence intervals (light-grey shading). The model reference year refers to the endpoint of each one-year-ahead forecast and the corresponding observation. The mean absolute scaled error (MASE) score associated with each size composition time series is denoted in each panel.

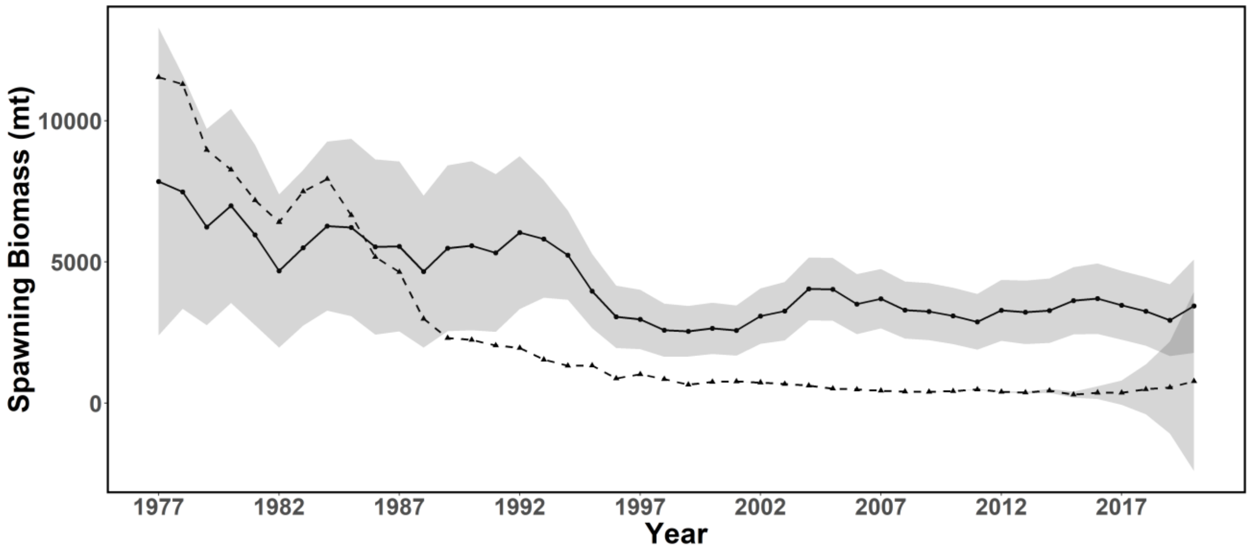


Figure 20. Age structured production model (ASPM) diagnostic for Stock Synthesis base case model. Spawning stock biomass estimates from the base-case model (circles, solid line; grey shading indicates 95% confidence interval) and ASPM model diagnostic (triangles, dashed line).

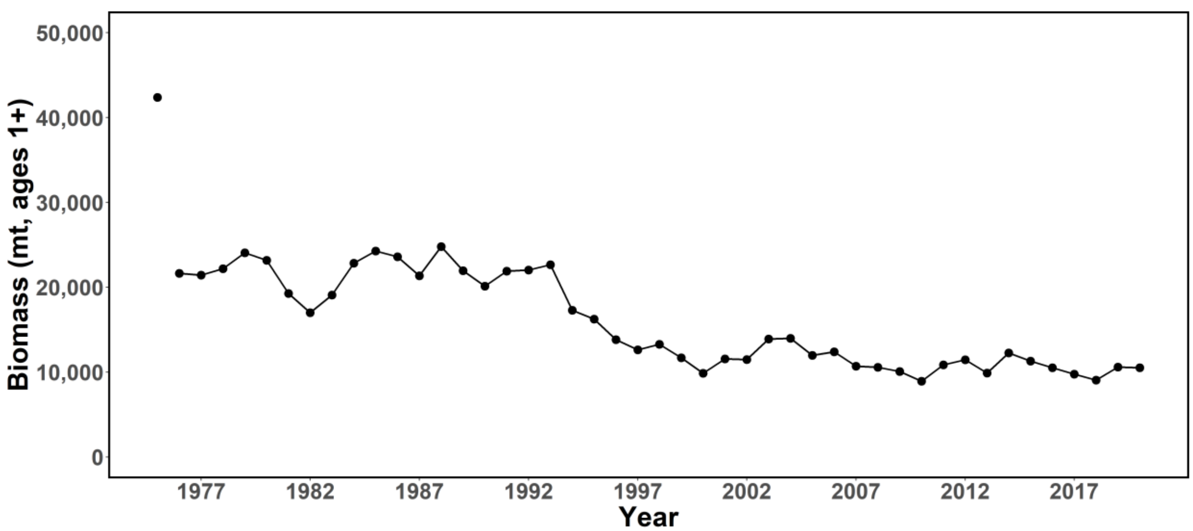


Figure 21. Time series of total biomass (age 1 and older, metric ton) for the Western and Central North Pacific striped marlin estimated in the base-case model. The first year indicates virgin biomass levels.

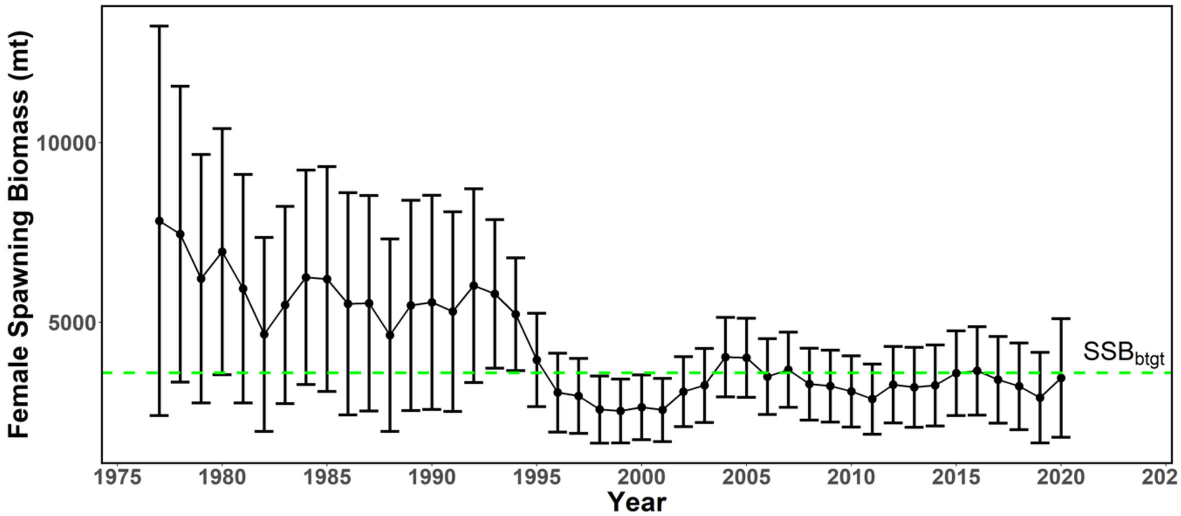


Figure 22. Time series of spawning biomass (metric ton) for the Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence intervals). The dashed horizontal line shows the spawning biomass to produce 20% $SSB_{F=0}$ (btgt) reference point.

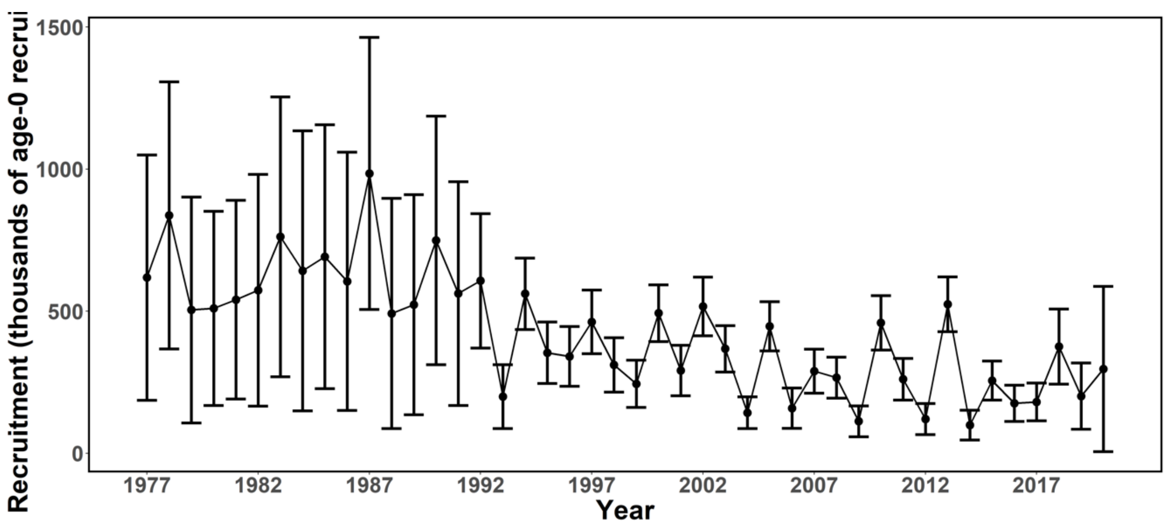


Figure 23. Time series of recruitment (thousands of age-0 fish) for Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence intervals).

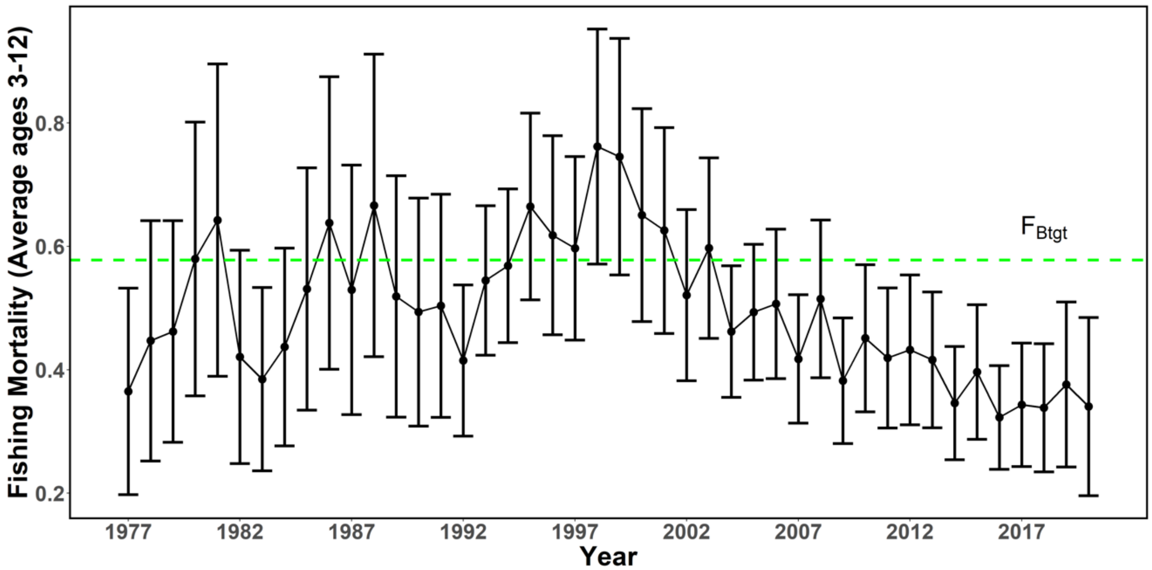


Figure 24. Time series of instantaneous fishing mortality (average for age 3-12) for the Western and Central North Pacific striped marlin estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (95% confidence interval). The dashed horizontal line shows the fishing mortality to produce 20%$SSB_{F=0}$ (btgt) reference point.

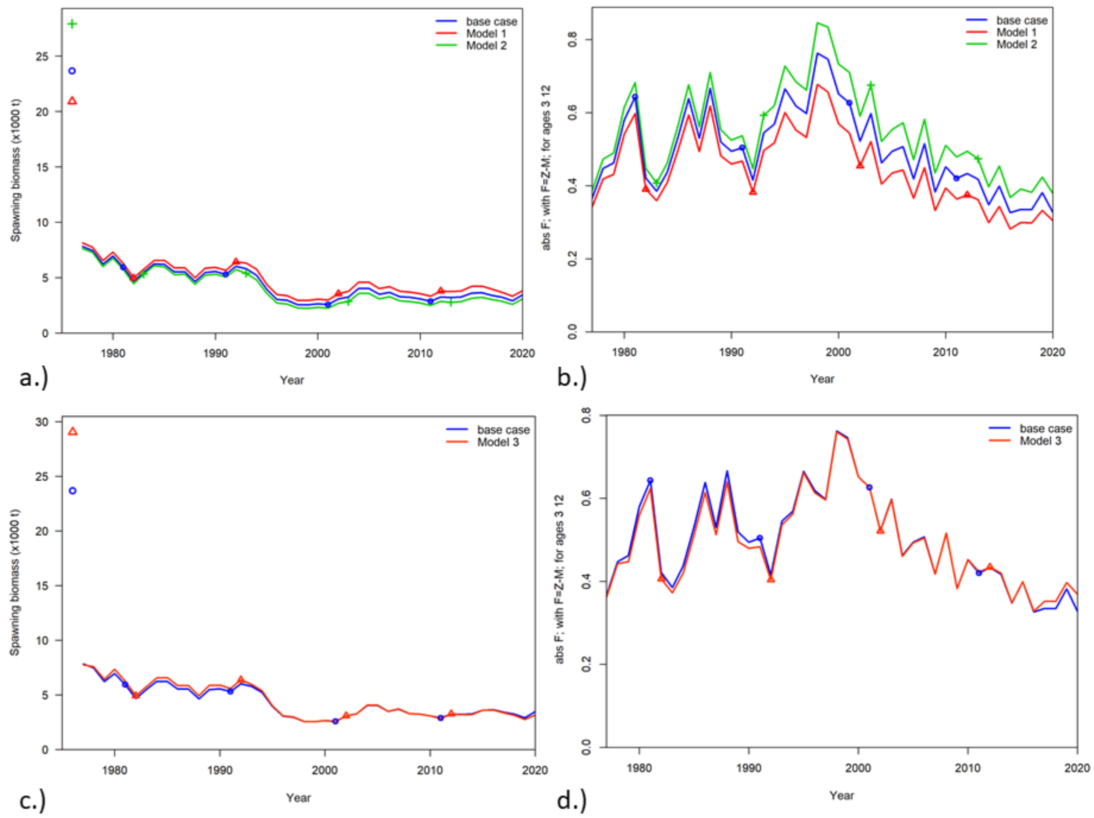
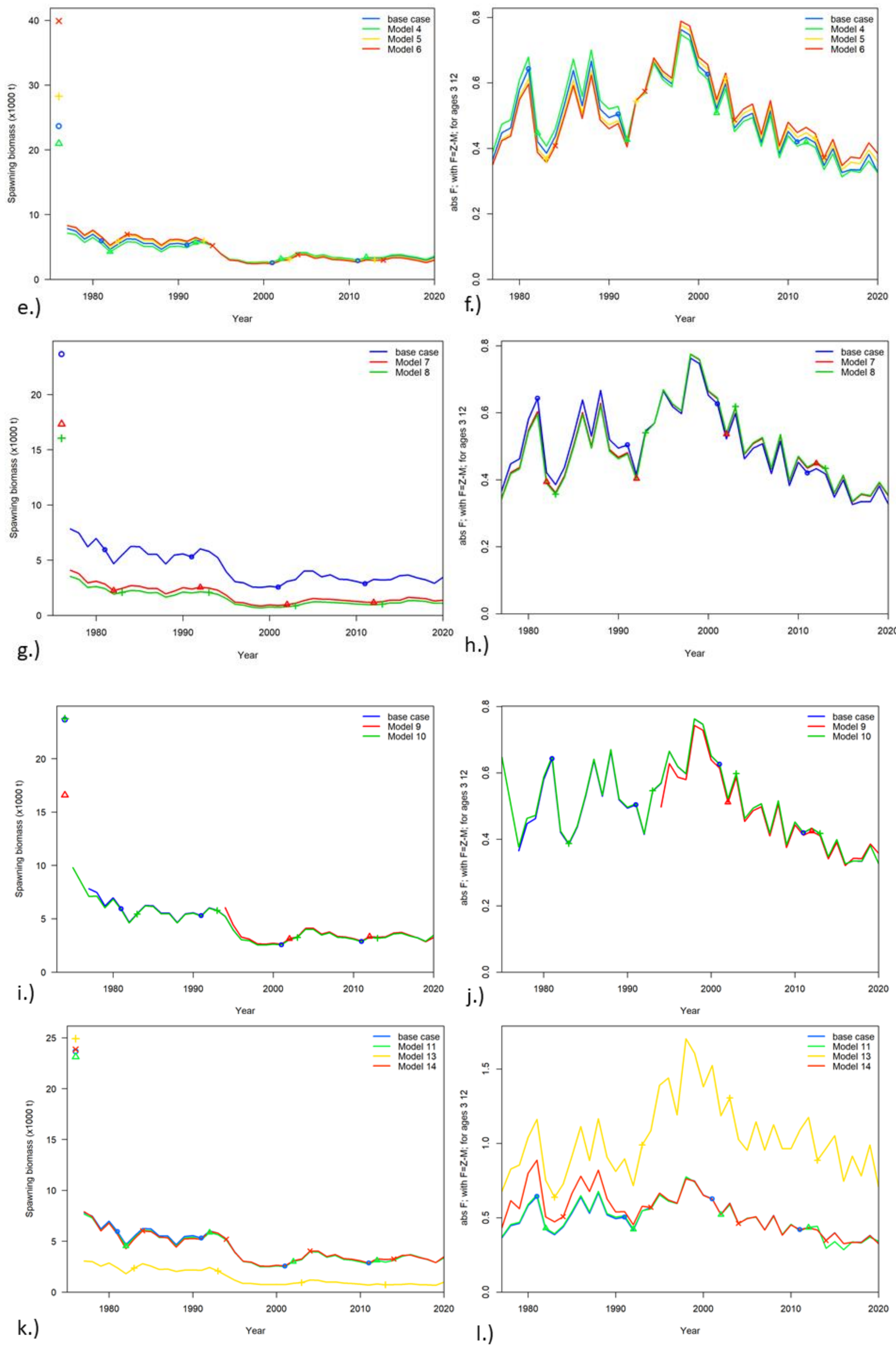


Figure 25. Trajectories of spawning stock biomass and fishing mortality from 14 sensitivity analyses listed in Table 12, compared to the base case model: (a-b) Runs 1 and 2 use alternative natural mortality parameters; (c-d) Run 3 uses alternative recruitment variability; (e-f) Runs 4, 5, and 6 use alternative steepness parameters; (g-h) Runs 7 and 8 use alternative maturity ogives; (i-j) Runs 9 and 10 use alternative model start years; (k-l) Runs 11, 13, and 14 use alternative model configurations and (m-n) Run 12 uses SWPO growth parameters.



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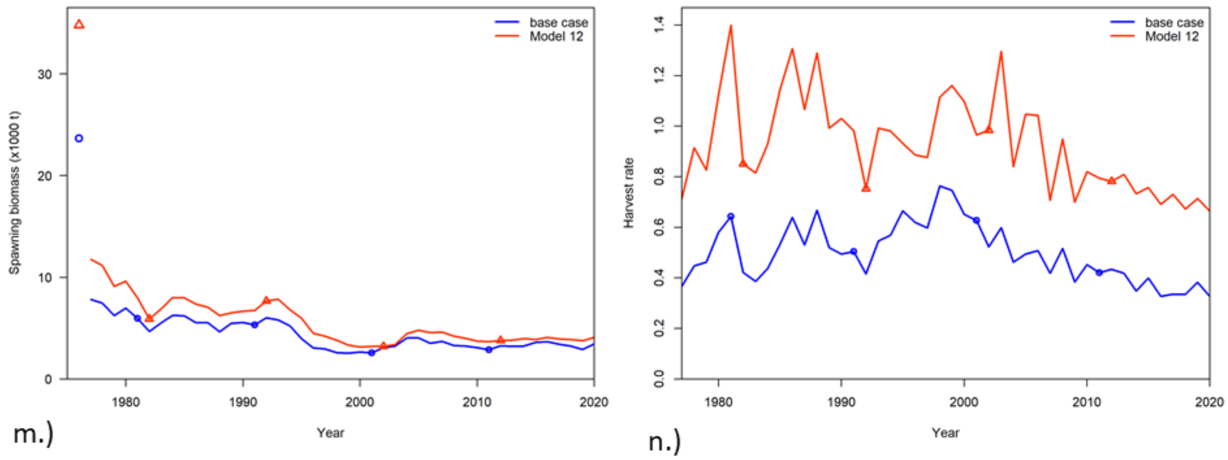

Figure 25. Continued

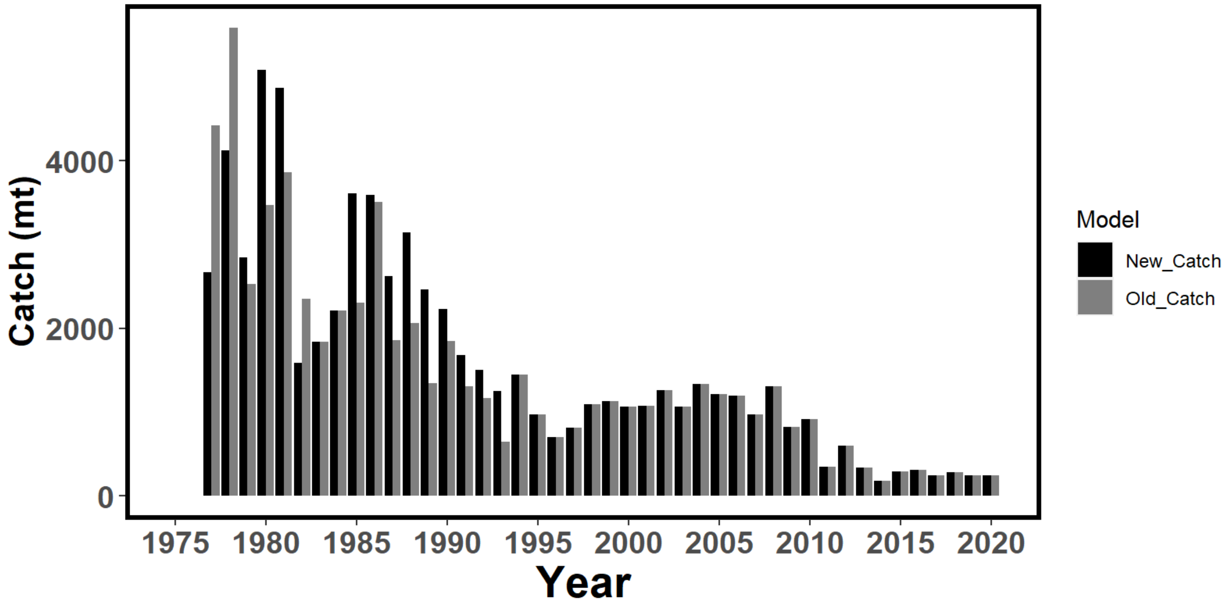

Figure 26. Comparison of Japanese driftnet catch in the 2019 (old) base-case model and the 2022 (new) base-case model. Catch was revised from 1977-1993 and input as numbers of fish for the 2022 model, therefore catch is estimated for this fleet internally in the model.

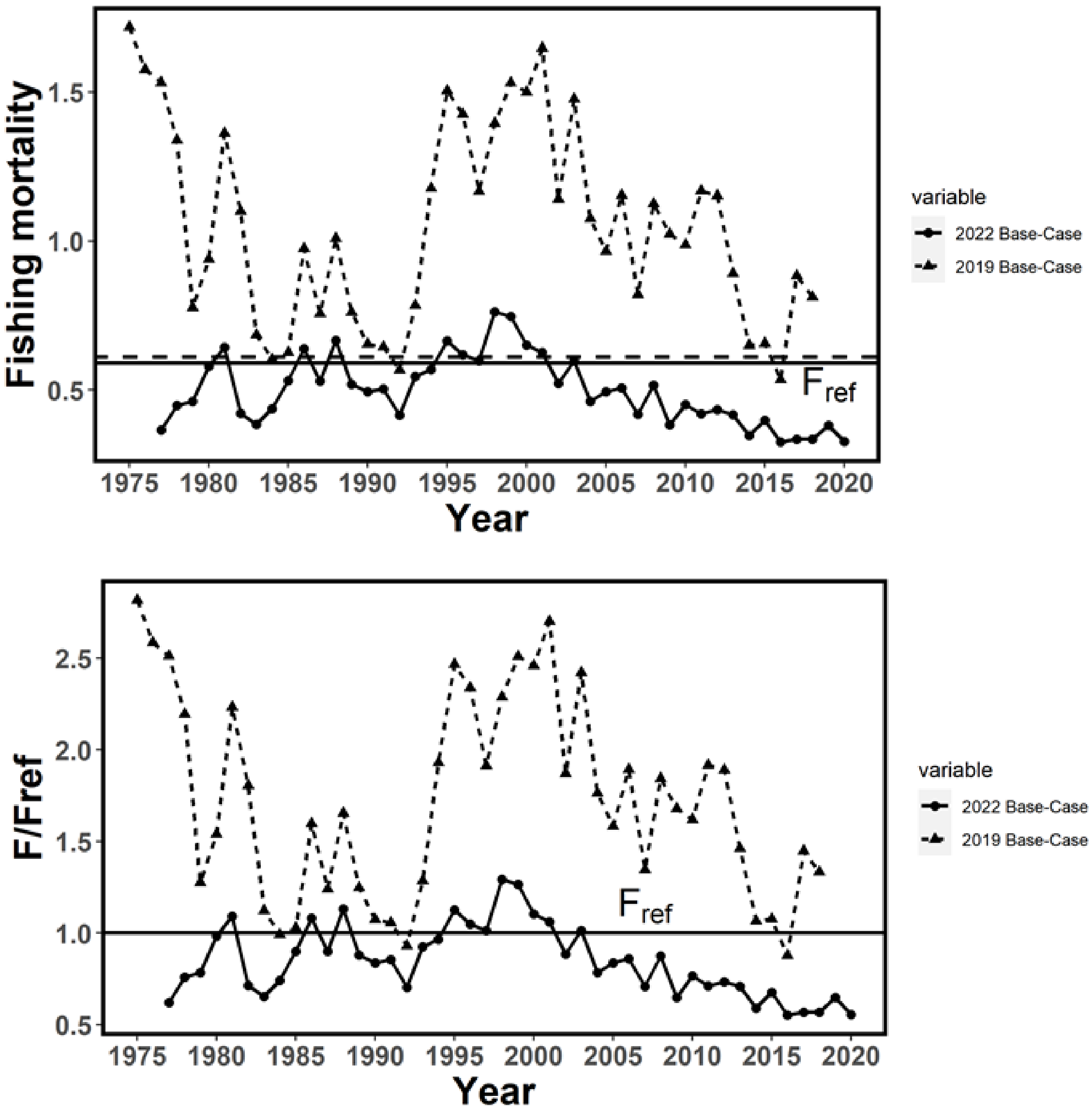

Figure 27. Comparison of the annual fishing mortality (top) and relative fishing mortality (bottom) for the 2019 and 2022 WCNPO striped marlin base-case models. F_{ref} refers to the respective reference points for each model: 2019 is F_{MSY} and 2022 is $F_{20\%SSB(F=0)}$.

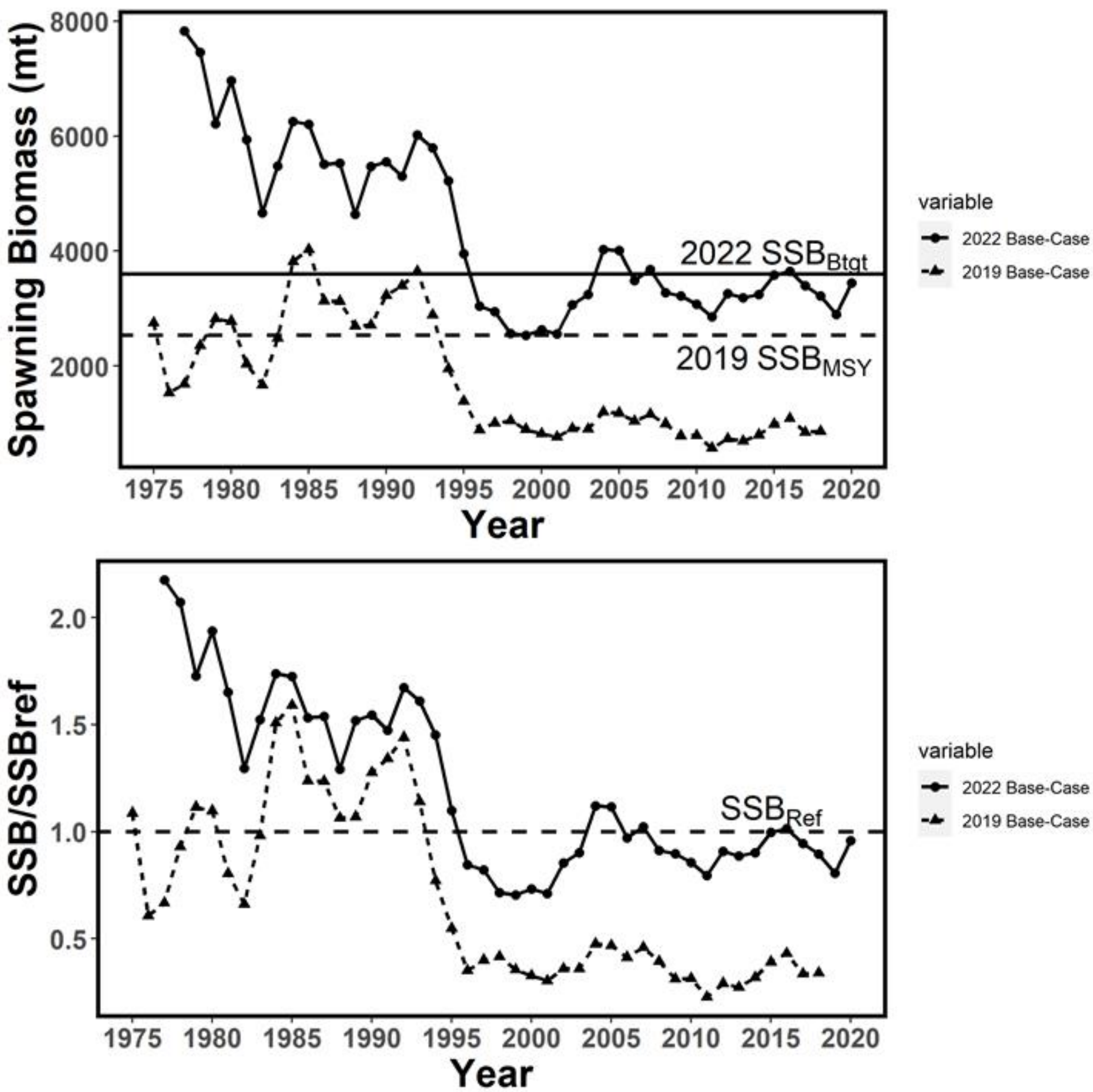

Figure 28. Comparison of the annual spawning stock biomass (SSB, top) and relative SSB (bottom) for the 2019 and 2022 WCNPO striped marlin base-case models. SSB_{ref} refers to the respective reference points for each model: 2019 is SSB_{MSY} and 2022 is $20\%SSB_{(F=0)}$ or SSB_{btgt}.

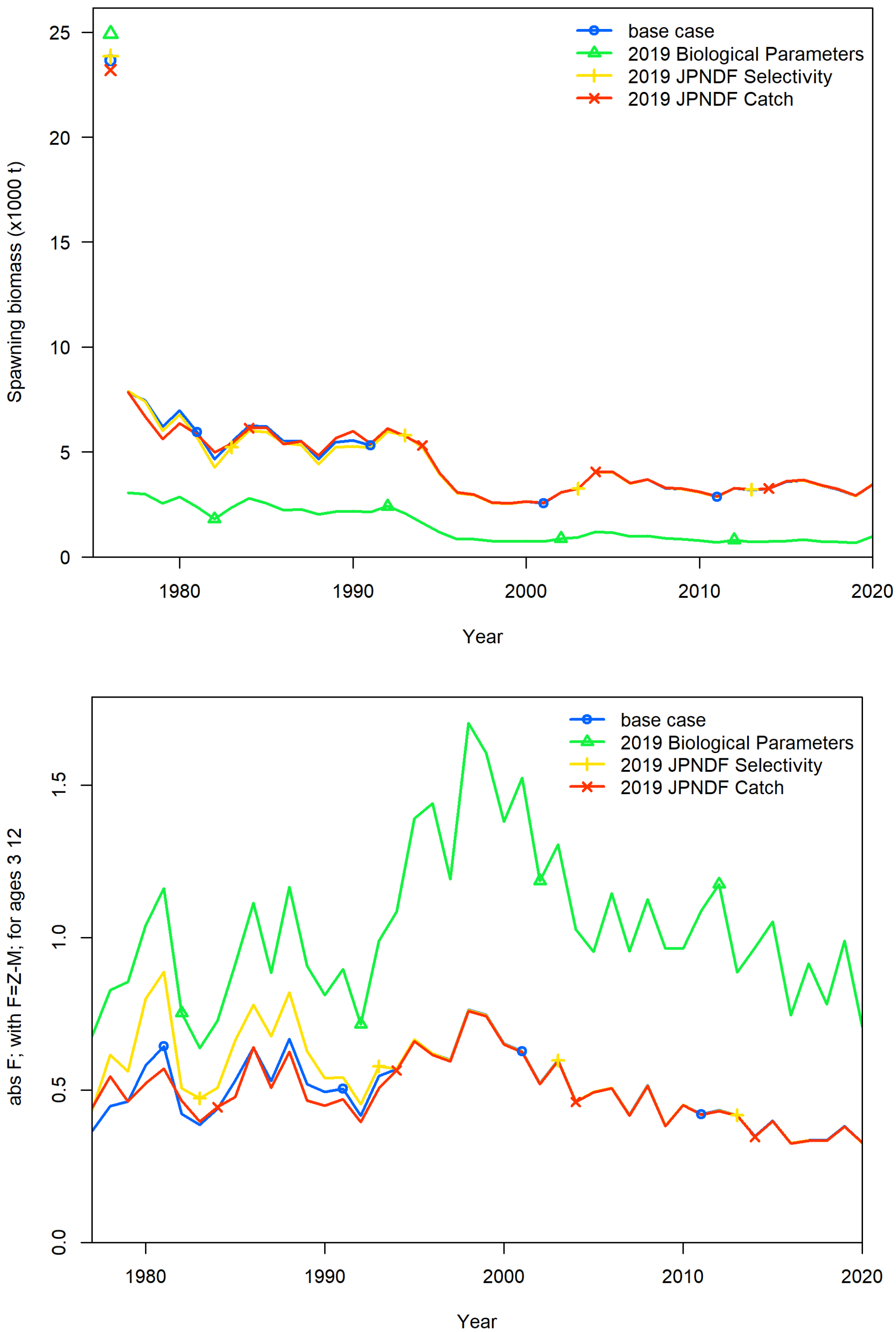

Figure 29. Comparison of the three major changes between the 2019 base-case assessment model and the 2022 base-case assessment model for spawning biomass (left) and fishing mortality (right).