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Stock Assessment Report for Swordfish (*Xiphias Gladius*) in the North Pacific through 2021

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ISC[1] Billfish Working Group

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

ANNEX 11

23^{rd} Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Kanazawa, Japan
July 12-17, 2023

STOCK ASSESSMENT REPORT FOR SWORDFISH (*XIPHIAS GLADIUS*) IN THE NORTH PACIFIC THROUGH 2021

July 2023

ACKNOWLEDGMENTS

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ANNEX 11

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the North Pacific Ocean

12 - 17 July 2023
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ABSTRACT

We present the benchmark stock assessment for the North Pacific swordfish (*Xiphias gladius*, NP SWO) stock conducted in 2023 by the ISC Billfish Working Group (BILLWG). The 2023 assessment consisted of applying a Stock Synthesis model with the best-available life history parameters and catch, abundance index, and length composition data for 1975-2021. The results indicated that population biomass (age 1 and older) for the NP SWO stock fluctuated around an average of 83000 mt during 1975-2021 and was estimated to be 88,755 mt in 2021. Estimated fishing mortality (F) has generally declined from the 1970s to the late-1990s, slightly increased again to the 2001, and then continued declining to average 0.09 year^{-1} in 2018-2021. Fishing mortality has been below F_{MSY} for the entire assessment period. There are no defined reference points for NP SWO in the Western and Central Pacific Fisheries Commission (WCPFC), therefore stock status is based upon maximum sustainable yield (MSY) reference points. The current or recent 3-year average spawning biomass of 34,900 mt (average for 2019-2021) was almost 2.5 times greater than SSB_{MSY} and the current F (average for ages 1 – 10 during 2019-2021) was 49% above F_{MSY}. The base case model indicated that under current conditions the NP SWO stock was very likely not overfished (>99% probability) and was very likely not subject to overfishing (>99% probability) relative to MSY-based reference points.

EXECUTIVE SUMMARY

Stock Identification and Distribution

The North Pacific swordfish (*Xiphias gladius,* NP SWO) stock area was defined to be the waters of the North Pacific Ocean contained in the Western and Central Pacific Fisheries Commission (WCPFC) Convention Area bounded by the equator and the waters of the Inter-American Tropical Tuna Commission (IATTC) Convention Area north of 10°N (Figure S1). All available fishery data from the stock area were used for the stock assessment. For the purpose of modeling observations of catch-per-unit effort (CPUE) and size composition data, it was assumed that there was an instantaneous mixing of fish throughout the stock area on a quarterly basis. The stock was modeled using a fleets-as-areas approach with separate catch and index fleets for the Western and Central North Pacific Ocean (WCNPO) and Eastern Pacific Ocean (EPO) region delineated in (Figure S1).

Catches

The NP SWO catches were high from the 1970’s to the 1980’s averaging about 14000 mt per year during 1975-1990, peaked with unusually high catches in 1998 -2000, and then generally declined to the current levels around 11000. Catches by most fleets have generally declined, while minor catches by other WCPFC countries have generally increased, except in in the last three years (Figure S2). Overall, longline fishing gear has accounted for the vast majority of NP SWO catch.

Data and Assessment

Catch and size composition data were collected from International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean (ISC) countries (Chinese Taipei, Japan, and USA) and the WCPFC and IATTC. Standardized CPUE data used to measure trends in relative abundance were provided by Chinese Taipei, Japan, and USA. The NP SWO stock was assessed using an age- and length-structured assessment Stock Synthesis (SS3) 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 $h = 0.9$. 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.

Stock Status

Estimates of population biomass fluctuated around an average of 80,800 mt during 1975-2021 and was estimated to be 88,800 mt in 2021 (Figure S3a and Table S1). Initial estimates of female spawning stock biomass (SSB) averaged around 27,600 mt in the late 1970s. SSB was at its highest level of 35,778 metric tons in 2021, and was at its minimum of 22,415 mt in 1981. Overall, spawning stock biomass has been relatively stable for the entirety of the assessment period (Figure S3b). Estimated F (arithmetic average of F for ages 1 – 10) decreased from 0.17 year^{-1} in 1978 to a minimum of 0.09 year^{-1} in 2021 (Figure S3c). It averaged roughly F=0.09 during 2019-2021 or about 51% of F_{MSY} with a relative fishing mortality of $F/F_{MSY} = 0.09$ in 2021. Fishing mortality has been below F_{MSY} since the beginning of the assessment time period and has had a declining trend with the exception of a high peak in 1998 coinciding with high catch by the US LL fleet. Recruitment (age-0 fish) estimates averaged approximately 838,000 individuals during 1975-2021. While the overall pattern of recruitment varied, there was no apparent trend in recruitment strength over time (Figure S3d). Overall, total annual catch is declining, CPUE is increasing, and recruitment is relatively stable. When the status of NP SWO is evaluated relative to MSY-based reference points, the 2021 SSB of 35,778 mt is 220% above SSB_{MSY} (16,000 mt) and the 2019-2021 F is about 49% above F_{MSY}. Therefore, relative to MSY-based reference points, overfishing is very likely not occurring (>99% probability) and the NP SWO stock is very likely not overfished (>99% probability, Figure S4).

Table S1: Reported catch (mt) used in the stock assessment along with annual estimates of population biomass (age-1 and older, mt), female spawning biomass (mt), relative female spawning biomass (SSB/SSB_{MSY}), recruitment (thousands of age-0 fish), fishing mortality (average F, ages 1–10), relative fishing mortality (F/F_{MSY}), and spawning potential ratio of North Pacific swordfish (Xiphias gladius).

Year	2016	2017	2018	2019	2020	2021	Mean[1]	Min[1]	Max[1]
Reported Catch	12,648	11,831	12,730	11,093	10,731	10,136	12,876	9,539	19,230
Population Biomass	83,200	86,835	89,418	89,617	89,992	88,755	80,762	65,722	89,992
Spawning Biomass	28,205	29,785	31,661	33,761	35,159	35,778	28,777	22,415	35,778
Relative Spawning Biomass	1.72	1.82	1.93	2.06	2.15	2.18	1.76	1.37	2.18
Recruitment (age 0)	964,401	746,962	783,354	739,400	624,962	633,046	838,473	595,771	1,430,430
Fishing Mortality	0.10	0.09	0.10	0.09	0.09	0.09	0.12	0.09	0.19
Relative Fishing Mortality	0.55	0.52	0.57	0.49	0.50	0.49	0.68	0.49	1.09
Spawning Potential Ratio	0.34	0.37	0.37	0.42	0.43	0.44	0.33	0.24	0.44

[1] During 1975-2021

Biological Reference Points

MSY-based biological reference points were computed for the base case model with SS (Table S2). The point estimate of annual catch at F_{MSY} was calculated to be 14924 mt. The point estimate of the spawning biomass to produce MSY (adult female biomass) was 16,388 mt. The point estimate of F_{MSY}, the fishing mortality rate to produce SSB_{MSY} (average fishing mortality on ages 1 – 10) was 0.18 and the corresponding equilibrium value of spawning potential ratio at SSB_{MSY} was 19%.

Projections

Stock projections for NP SWO were conducted using SS3. No recruitment deviations nor log-bias adjustment were applied to the future projections. Projections are reported as the mean and standard deviation around 100 bootstrapped model runs for each scenario. Projections started in 2022 and continued through 2031 under 5 levels of fishing mortality. The five fishing mortality stock projection scenarios were: (1) F at $20\%SSB_{(F=0)}$ which was calculated from the mean dynamic SSB in the five years, (2) $F_{(2008\text{-}2010)}$ which is the reference years for the proposed CMM for NP SWO, (3) F_{Low} at $F_{30\%SPR}$, (4) F_{MSY}, and (5) F status quo (average F during 2019-2021). Results show the projected female spawning stock biomass and the catch biomass under each of the scenarios (Table S3 and Figures S5 - S6).

Conservation Information

The NP SWO stock has produced annual yields of around 11,500 mt per year since 2016, or about 2/3 of the MSY catch amount. This suggests the stock may be able to support somewhat higher yields. Swordfish stock status is positive with no evidence of excess F above F_{MSY} or substantial depletion of spawning potential. It was also noted that retrospective analyses show that the assessment model appears to underestimate spawning potential in recent years.

Special Comments

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

Table S2: Estimated biological reference points derived from the Stock Synthesis base case model for North Pacific swordfish 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 5-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 1-10)	0.16
F_{MSY} (age 1-10)	0.18
F_{2021}	0.09
$F_{2019-2021}$	0.09
$SSB_{F=0}$	95,732
$20\%SSB_{F=0}$	19,146
SSB_{MSY}	16,388
SSB_{2021}	35,778
$SSB_{2019-2021}$	34,899
$C_{20\%SSB(F=0)}$	14,815
C_{MSY}	14,924
$C_{2019-2021}$	10,653
$SPR_{20\%SSB(F=0)}$	22%
SPR_{MSY}	19%
SPR_{2021}	44%
$SPR_{2019-2021}$	43%

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.

Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Scenario 1: $F_{20\%SSB(F=0)}$										
SSB	40,457	38,288	36,295	35,452	35,425	35,611	36,064	36,387	36,264	36,478
Catch	16,906	14,986	13,531	13,120	13,298	13,612	13,875	14,053	14,161	14,220
Scenario 2: $F_{1998-2000}$										
SSB	41,567	40,422	38,952	38,309	38,371	38,565	39,133	39,534	39,336	39,625
Catch	14,302	13,389	12,608	12,428	12,656	12,967	13,224	13,399	13,509	13,572
Scenario 3: Low F ($F_{SPR30\%}$)										
SSB	42,268	42,368	41,811	41,756	42,235	42,712	43,610	44,300	44,162	44,705
Catch	11,370	11,249	11,096	11,255	11,623	11,990	12,263	12,445	12,557	12,631
Scenario 4: F_{MSY}										
SSB	38,291	34,051	31,164	29,979	29,800	29,894	30,225	30,452	30,322	30,473
Catch	23,395	17,817	14,992	14,169	14,264	14,565	14,812	14,966	15,052	15,095
Scenario 5: $F_{Status\ Quo}$ (Average $F_{2019-2021}$)										
SSB	38,828	35,056	32,339	31,201	31,036	31,138	31,489	31,733	31,602	31,765
Catch	21,803	17,218	14,723	13,981	14,082	14,379	14,627	14,785	14,875	14,921

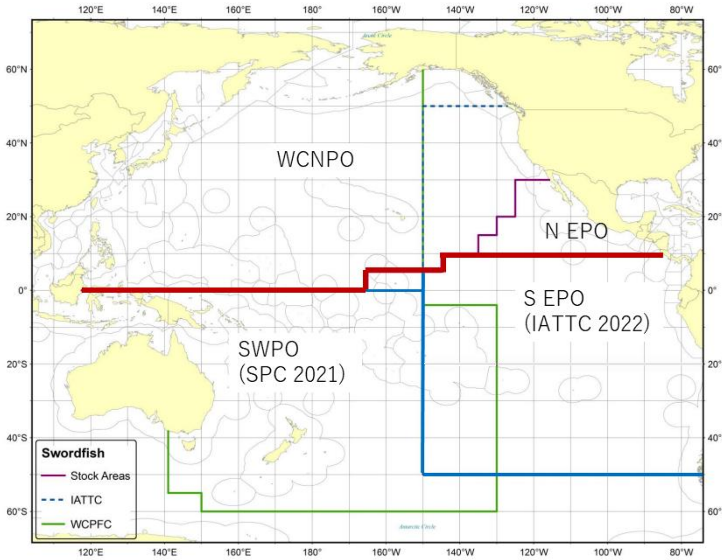


Figure 1: Western and Central North Pacific Ocean and North Eastern Pacific Ocean swordfish stock boundaries for the 2023 North Pacific swordfish assessment. Spatial structure is treated implicitly using fleets as areas.

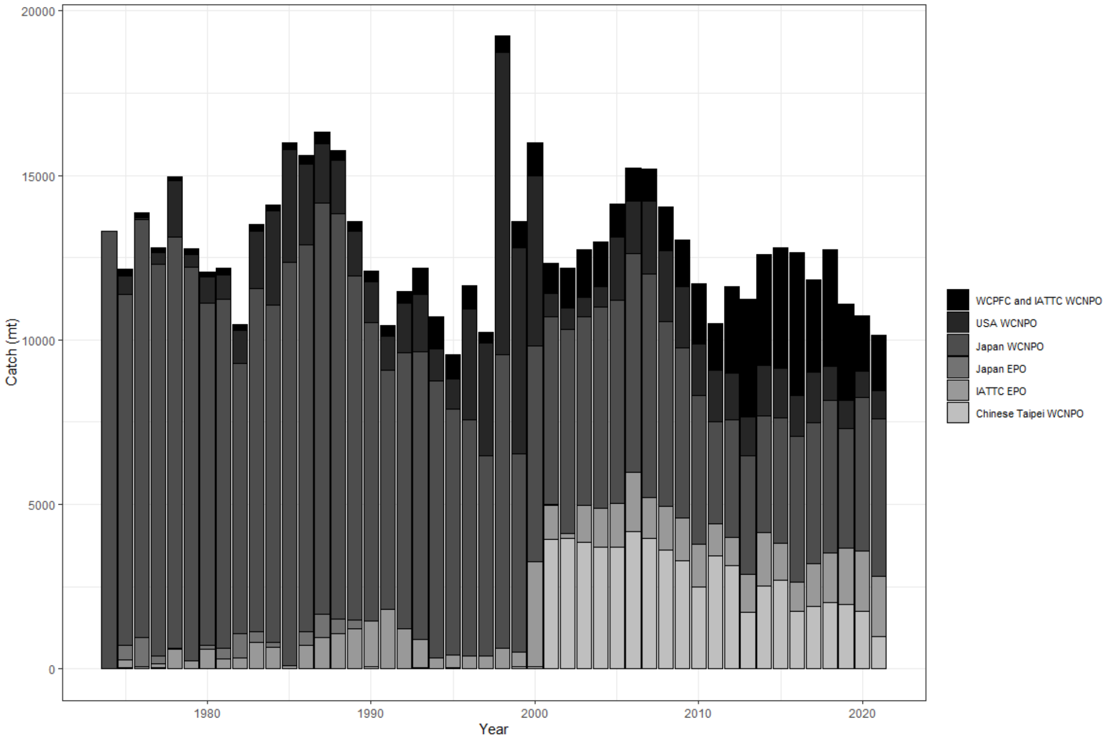
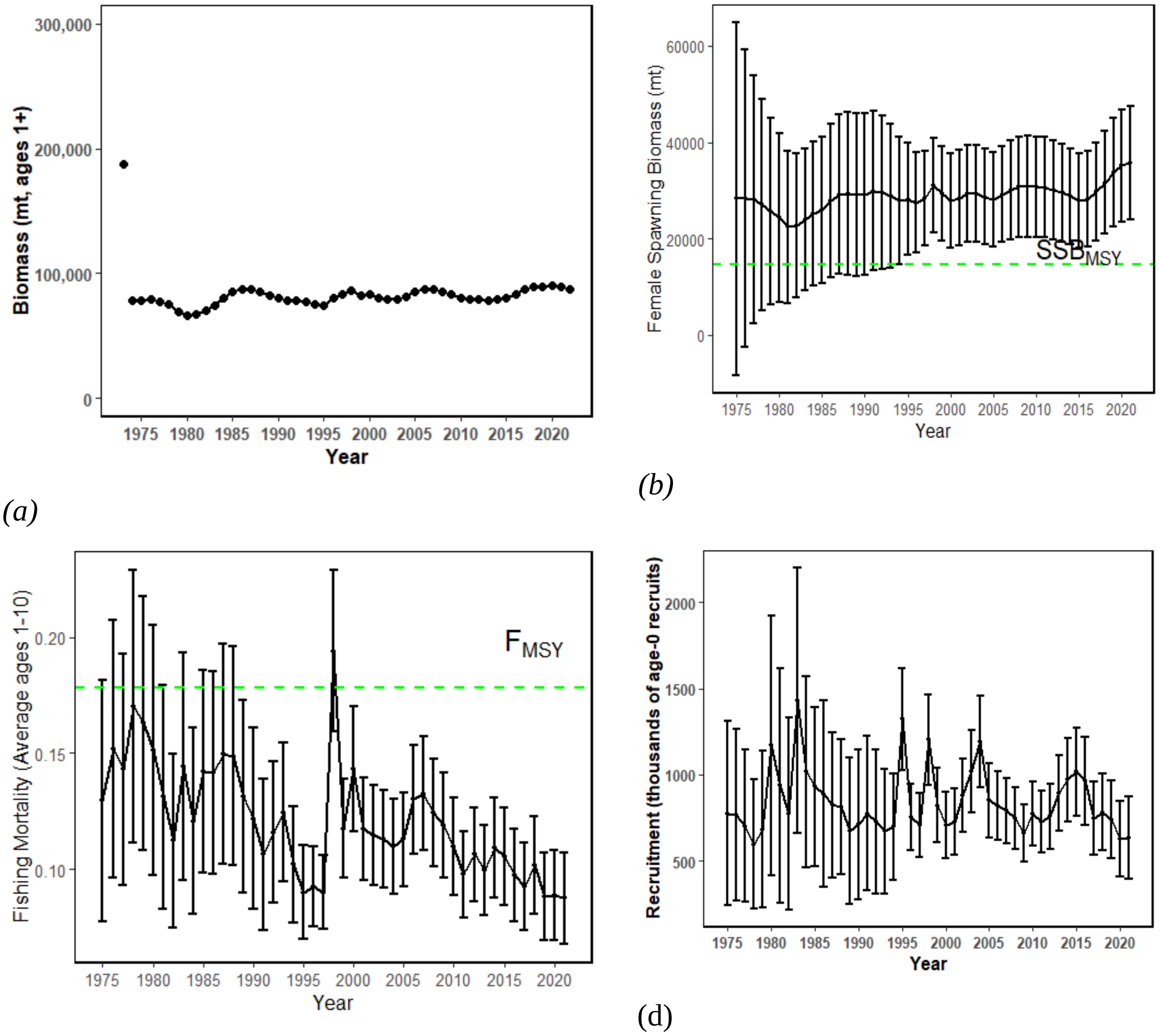


Figure S2: Annual catch of NP swordfish by country or commission and area.



(a) *(b)*

(c) (d)

Figure S3: Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) instantaneous fishing mortality (average for age 1-10, year^{-1}), and (d) recruitment (age-0 fish) for North Pacific swordfish (Xiphias gladius) derived from the 2023 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 the dynamic SSB_{MSY} and F_{MSY} reference points.

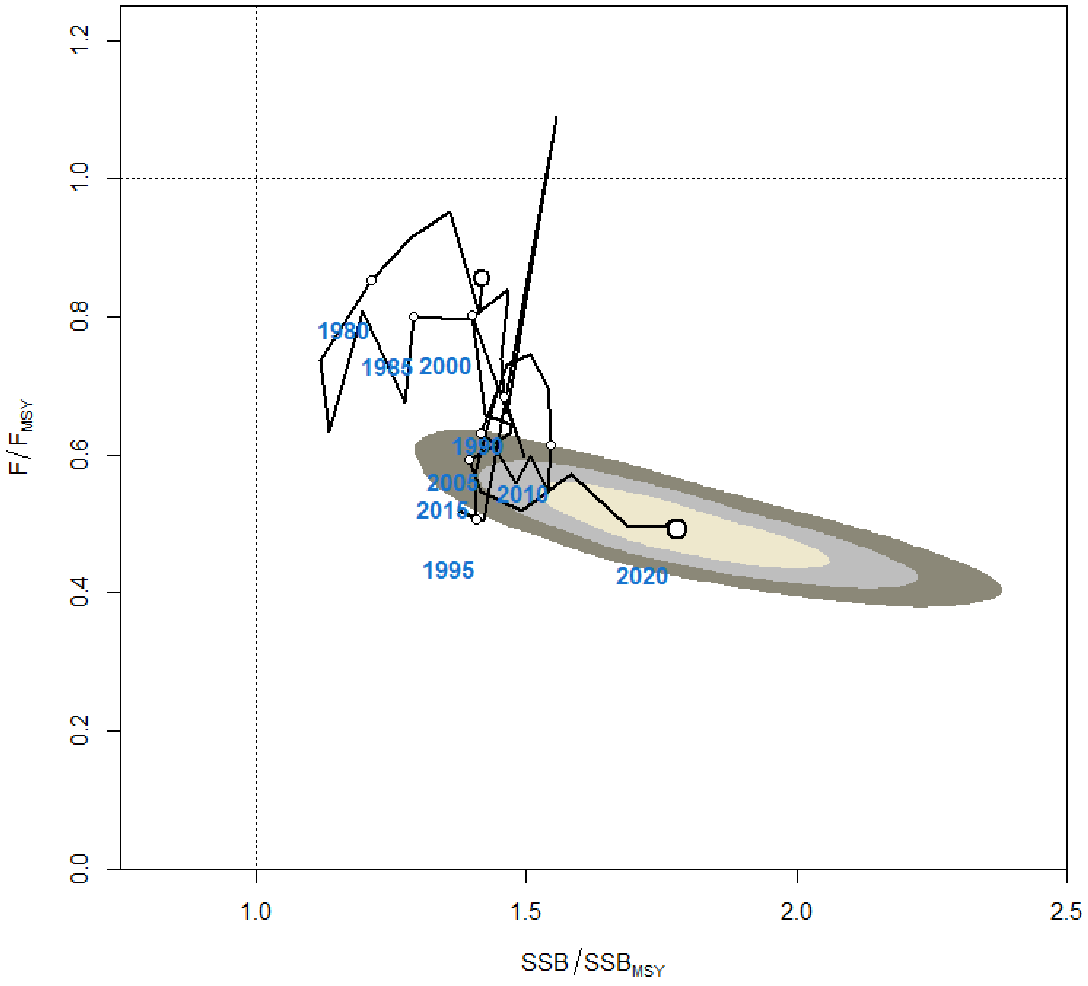


Figure S4: Kobe plot of the time series of estimates of relative fishing mortality (average of age 1-10) and relative spawning stock biomass of North Pacific swordfish (Xiphias gladius) during 1977-2020. The first white dot indicates 1975, subsequent dots are in 5-year increments. Shading indicates 50%, 80%, and 95% confidence intervals, respectively.

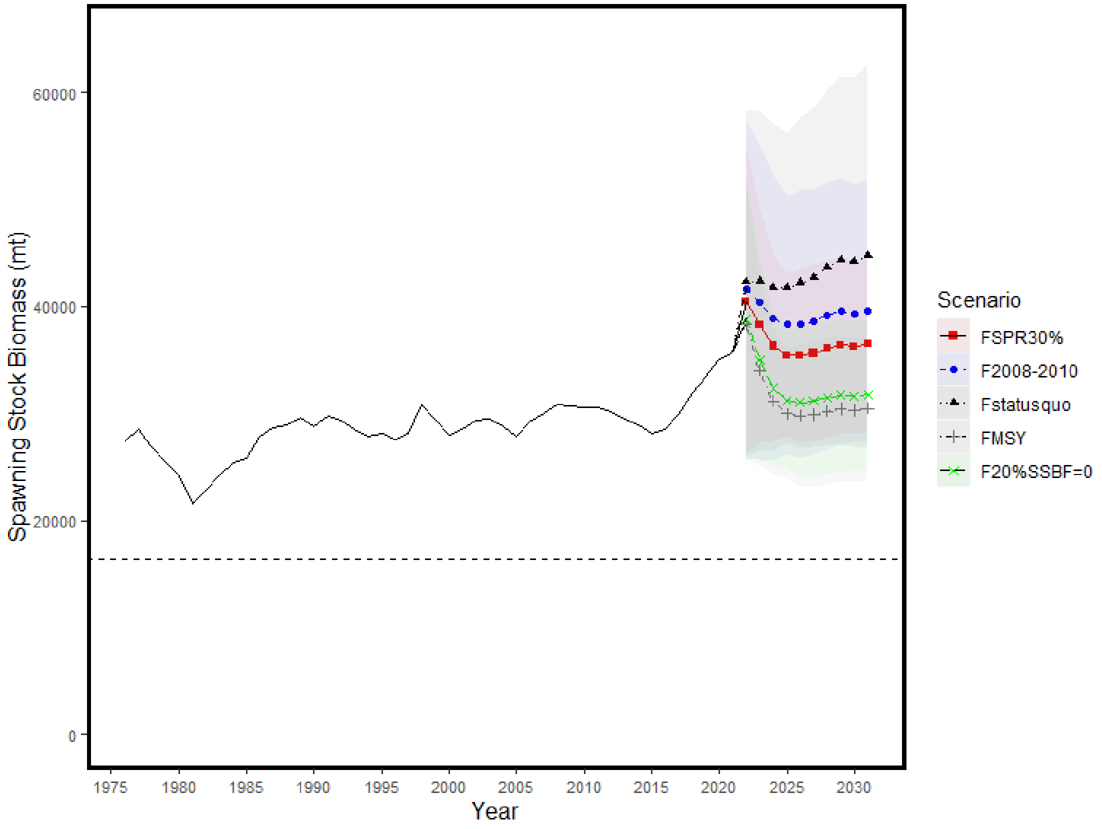


Figure S5: Historical and projected trajectories of spawning biomass from the North Pacific swordfish base case model based upon F scenarios. Dashed line indicates the spawning stock biomass at SSB_{MSY}. The list of projection scenarios can be found in Table S3.

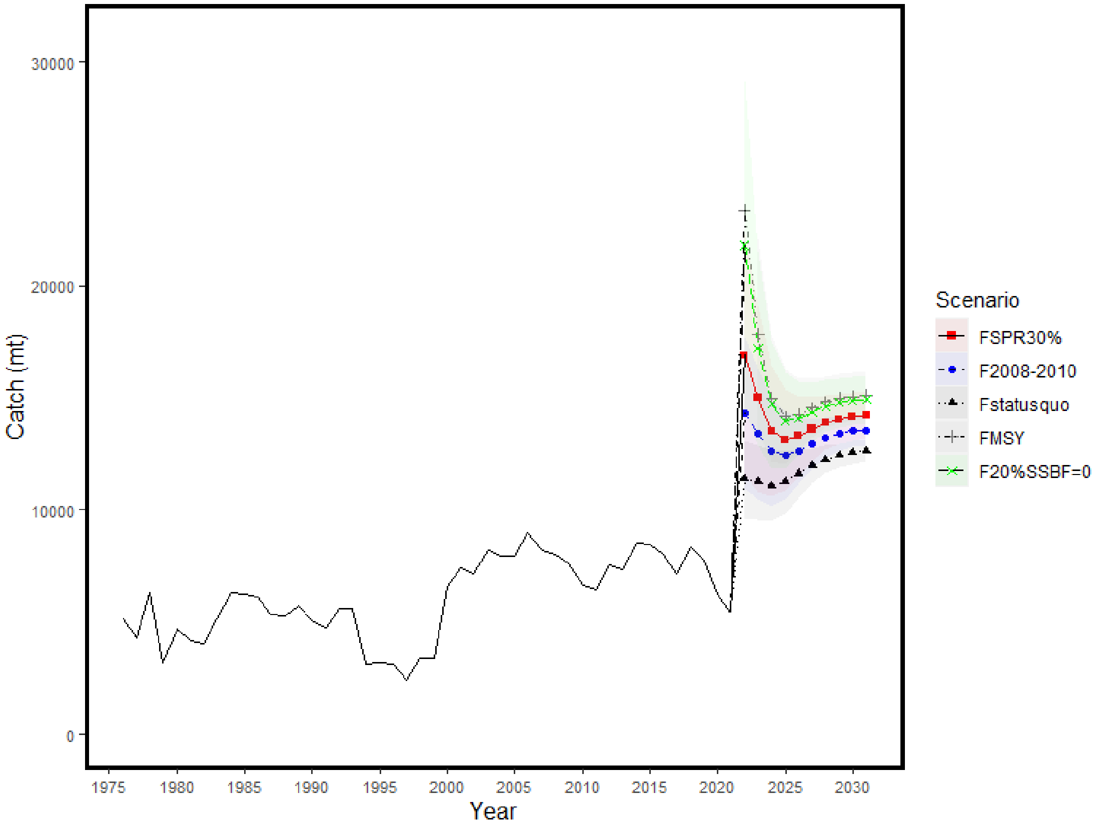


Figure S6: Historical and projected trajectories of catch from the North Pacific swordfish base case model based upon F scenarios. The list of projection scenarios can be found in Table S3.

1. INTRODUCTION

The Billfish Working Group (BILLWG or WG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) completed a benchmark stock assessment for North Pacific swordfish (*Xiphias gladius*, NP SWO) in 2018 (ISC, 2018). The assessment results indicated that the stock status was not overfished and overfishing was not occurring relative to MSY-based reference points. The BILLWG agreed to conduct a new benchmark stock assessment in 2023. The BILLWG held a hybrid data preparatory meeting in Yokohama, Japan December 2022 to evaluate any new information on stock structure, life history parameters, and fishery data (ISC, 2023). Then the BILLWG conducted the stock assessment at a hybrid meeting in Honolulu, in HI April 2023. This report describes the 2023 stock assessment for the NP SWO stock. The best available scientific information including the up-to-date catch, catch-per-unit-effort (CPUE), and composition data from 1975-2021 were provided by individual ISC countries, the Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC). The 2023 assessment was an age-structured integrated-assessment model using the modeling platform Stock Synthesis (SS3) version 3.30.20.

2. MATERIALS AND METHODS

2.1. Spatial and Temporal Stratification

The geographic area encompassed in the assessment for NP SWO was the North Pacific Ocean bounded by the equator in the WCPFC convention area, and 10°N in the IATTC convention area (Figure 1). Three types of data were used: fishery-specific catches, relative abundance indices, and length measurements. The fishery data were compiled for 1975-2021, noting that the catch data and length composition data were compiled and modeled on a quarterly basis. Available data, sources of data, and temporal coverage of the datasets used in the stock assessment are summarized in Figure 2. Further details are presented below.

2.2. Definition of Fisheries

A total of 19 fleets catching NP SWO were defined based on country, gear type, location, and time period, where each fishery was assumed to target a distinct component of the stock. Descriptions and data sources to characterize the 19 fisheries that catch NP SWO are summarized in Table 1. These fisheries included five longline fleets from Japan, three longline fleets from the USA, and two longline fleets from Chinese Taipei. Four additional fleets from Japan included the driftnet catches for two time periods: 1975-1993 and 1994-2021 and two fleets to encompass all other Japanese NP SWO catches in the early and late periods. There was one fleet for any additional catches and two fleets from the US for gillnet and all other catches which included handline and troll catches. Finally, there was one fleet for each region containing the the various flags not otherwise included, one for the Eastern Pacific Ocean (IATTC) and one for the Western and Central Pacific Ocean (WCPFC).

2.3. Catch

Catch was input into the model on a quarterly basis (i.e., by calendar year and quarter) from 1975 to 2021 for the 19 individual fleets. Catch was reported in terms of thousands of fish for Japanese and US longline fleets, all others reported catch in biomass (metric tons, mt).

Three countries (i.e., Chinese Taipei, Japan, and the USA) provided national catch data (Hirotaka Ijima, NRIFSF, personal communication; Yi-Jay Chang, NTU, personal communication; Russell Ito, NOAA NMFS, personal communication). The NP SWO catches for all other fishing countries were collected from WCPFC category I and II data (WCPFC Yearbook 2021) and IATTC category I and II data (need reference).

The resulting best available data on NP SWO catch by fishery from 1975-2021 were tabulated and are shown in Figure 3 and Table 2. The historical maximum and minimum annual NP SWO catches were 19230 mt in 1998 and 9539 mt in 1995, respectively. Overall, annual catch of NP SWO generally declined since 1998 and 9539. The mean annual catch of NP SWO during 2019-2021 was 10653 mt.

2.4. Abundance Indices

Relative abundance indices for NP SWO based on standardized CPUE were prepared for this assessment and are shown in Figure 4 and Tables 1 and 3. A generalized linear mixed model (GLMM) using R-INLA was used to produce a spatio-temporal model for areas one and two as identified in the 2018 assessment (Kanaiwa and Ijima, 2018). Japanese CPUE data were also standardized in two-time periods (Early: 1975-1993 and Late: 1994-2021) due to the change of Japanese logbook reporting requirements (Jusup *et al.,* 2023).

Operational fishing data collected by observers in the Hawaiian longline fishery during 1995-2021 were used in the CPUE standardization for US longline fleets (Bohaboy and Sculley, 2023). The fishery operates in two sectors: a shallow-set sector targeting swordfish and a deep-set sector targeting tunas. The NP SWO are non-targeted catch in the deep-set sector and a target species in the shallow-set sector. These data were standardized into a three CPUE time series using generalized additive mixed models (GAMM), with a continuous index for the deep-set sector and two indices for shallow-set: 1995-2000 and 2004-2021, to account for the fishery closure from 2001 to 2004. As the majority of the fish caught in the deep-set sector are young of the year, this CPUE index is treated as a recruitment index in the model and not fit as a traditional CPUE index.

The distant-water longline fleet from Chinese Taipei was standardized from 2000-2021 using a spatio-temporal GLMM (VAST, Thorson and Barnett, 2017) model (Hsu and Chang, 2023).

Visual inspection of four indices of late period (S2, S4, S5, and S8) showed three of the indices indicated a generally increasing trend in the last 5-10 years, with the exception of the US LL shallow-set index (Figure 4). After consideration of the limited area in the Central North Pacific that the US index represents, the WG agreed that the trend of the US LL shallow-set index may not be representative of the overall abundance of adult swordfish in the North Pacific. This fishery targets a small area of the Pacific north of the Hawaiian Islands, has historically be subject to partial-year closures due to interactions with protected species, and fishing captains react to changing fuel costs, market price, etc. when determining when and where to target swordfish. In addition, the model did not fit to the Chinese Taipei index well. Due to these reasons, and conflicts in the indices identified when profiling the likelihood based upon virgin recruitment (R_0), S5 and S8 were ultimately excluded from the model.

2.5. Size Composition Data

Quarterly fish length composition data from 1975 - 2021 for nine fleets were used for the assessment and are summarized in Table 3. Length frequency data were compiled using 5-cm length bins from 10 to 260 cm. The lower boundary of each bin was used to define each bin for all length-composition data, and each observation consisted of the actual number of NP SWO measured. The length composition data were agreed upon at the BILLWG data preparatory meeting as the best available scientific information for the 2023 stock assessment.

Figure 5 shows the quarterly length compositions. Most of the fisheries caught adult individuals. The longline fleets caught fish with a mean of around 140-150 cm eye-fork length (EFL) while F2 caught slightly larger fish, with a mean around 160 cm EFL. F7 caught the largest fish on average, 180cm EFL, and the US longline deep-set sector fleet caught smaller fish on average than any of the other fleets (mean size 130cm EFL, with a median at ~55 cm EFL).

The aggregate length composition distributions were relatively consistent between fleets, with the exception of the US Longline fleet (Figure 6). Most longline length composition distributions had a single mode around 150-160cm EFL, while the US deep-set fleet had a large peak around 55 cm EFL and a long and fat tail. Ultimately, due to challenges fitting the US deep-set fleet (F9) and the small component of catch it represented, it was not included in the final base-case model. Similarly, JPN_EPO_OSDWLL (F5) was not included in the final base-case model due to conflict with the other size composition data and low sample size.

2.6. Model Description

The stock assessment for NP SWO was conducted using SS3 version 3.30.20.00-SAFE released 09/30/2022 programed via Otter Research ADMB 13.0 (Methot and Wetzel, 2013). The model was set up as a single area model with a single sex and four seasons (quarters), with the WCNPO and EPO regions modeled implicitly using fleets-as-areas. Spawning was assumed to occur in quarter two while recruitment was assumed to occur in July (month 7). The maximum age of NP SWO was set to 15 years based upon the observed maximum size caught in the fishery. Age-specific natural mortality was used (Table 4) as agreed upon in the BILLWG data preparatory meeting (ISC, 2023). The age at length L1 was set to age 0.5, the coefficient of variation (CV) of length at age of the growth curve was set to 0.1 for both the young fish (Ages 0-0.5) and the old fish (ages 0.5+) and these were assumed to be the same for both sexes. The sex ratio at birth was assumed to be 1:1. The growth curve used was a von Bertalanffy growth curve for ages 0.5-15 with a K = 0.246 for females and 0.271 for males, a length at age 15 (L_2) = 226.3 cm EFL for females and 206.4 cm EFL for males, and the size at age 0.5 (L_1) = 80.1 cm EFL for females and 83.4 cm EFL for males. A Beverton-Holt spawner-recruit relationship was used with steepness (h) set at 0.9 and sigmaR (σ_r) rescaled to 0.42using the estimates from SS3.

2.7. Data Observation Models

The assessment model fit three data components: 1) total catch; 2) relative abundance indices; and 3) length 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 lognormally distributed errors with SE in log-space (log(SE)) which was $log(SE) = \sqrt{log(1 + CV^2)}$, where CV is the standard error of the observation divided by the mean value of the observation.

Five CPUEs (S1, S2, S3, S4, and S8) were assigned to quarter one. S5 was assigned to quarter three and S6 and S7 were assigned to quarter two, which roughly coincided with the quarters in which the most catch was reported for each fleet. 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 5). The minimum CV was scaled to a minimum of 0.2 and then re-weighted if the suggested variance was greater than the input variance based upon the Francis method using the root-mean-square error (RMSE, i.e., square root of the residual variance, Francis, 2011).

The length 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, 2018). 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 to reduce the influence of very large sample sizes, 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 F2, the Chinese Taipei longline fishery, and F4, other IATTC fleets in the EPO, which were estimated as asymptotic lognormal (Figure 9). Two fleets had time varying selectivity: F1 (Figure 7) and F2 (Figure 8). All other fleets were mirrored to the fleet that was believed to have the most similar selectivity pattern (Table 6).

2.9. Data Weighting

Index data were prioritized in this assessment based on the principles that relative abundance indices (CPUEs) 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 CV of the CPUE index.

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. R_0 likelihood profile

An R_0 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 SS3 model likelihood components for CPUE, length-composition, initial equilibrium catch, 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).

2.10.2. 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.

2.10.3. 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.

2.10.4. 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.

2.10.5. 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.

2.10.6. 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 five CPUE indices in the last five years of the assessment.

2.10.7. 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) suggests 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) suggests 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.

2.11. Sensitivity Analyses

In the April 2023 BILLWG workshop, the BILLWG agreed to conduct a series of sensitivity analyses (Table 7) to examine the effects of plausible alternative model assumptions and data input to the stock status. These analyses were:

(1) **Sensitivity analysis on natural mortality**: The BILLWG conducted two sensitivity analyses for natural mortality (M)-at-age. These were a low M scenario where Ms-at-ages were 10% lower than those of the base-case model and a high M scenario where Ms-at-ages were 10% higher than those of the base case model.

(2) **Sensitivity analysis on steepness**: The BILLWG conducted three additional sensitivity runs on steepness (h). Steepness was fixed at higher value (h=0.99), lower value (h=0.81), and much lower value (h=0.70) compared to the base-case value (h=0.9).

(3) **Sensitivity analysis on growth**: Two sensitivity runs on growth were conducted, one increasing the size at age Amax by 10% and one using an alternative growth curve from Sun *et al.,* (2002).

(4) **Sensitivity analysis on maturity**: The BILLWG conducted three sensitivity runs on the maturity ogive. The maturity ogive was fixed at the values 10% higher and lower than the base-case value and used an alternative ogive from Wang *et al.*, (2003).

(5) **Sensitivity analysis on catch**: The BILLWG conducted three sensitivity runs on catch and stock structure. One removed the Vietnam and Chinese catch. Two others addressed stock structure concerns, one including all catch in the North Pacific including between the equator and 10°N in the EPO and one including the “orphan” catch between 165°W adn 150°W and the equator and 5°N that is not included in any base-case assessment for the three Pacific swordfish stocks.

(6) **Sensitivity analysis on modeling structure**: The BILLWG conducted eleven additional sensitivity runs to explore the effects of changes in the model assumptions made during the

model development: 1) a model setting A_{min} to 1 which was used in the 2018 assessment; 2) a model without the inclusion of the S8 US deep-set LL recruitment index (S6); 3) a model with the selectivity pattern for Chinese Taipei longline size data (F2) set as double normal; 4.) a model including the size data from the US deep-set LL fleet (F8); 5.) six models using a single CPUE index to inform relative abundance, and 7.) a model including all the CPUE indicies available.

2.12. Future Projections

Deterministic future 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. Projections were based upon 100 bootstrap runs to estimate the uncertainty around future stock status. 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' (2019-2021) selectivity patterns and relative fishing mortality rates were used in the population future projections. It was assumed that future recruitment would be similar to the stock recruitment curve (S/R Curve).The projections started in 2022 and continued through 2031 under five different harvest scenarios:

1. **$F_{20\%SSBF=0}$Scenario** (**F_{Btgt}**): Apply the estimate of F which produces 20%$SSB_{F=0}$ based upon the average of the last five years dynamic B0, which roughly corresponds to $F_{19\%}$.
2. **2008-2010 F Scenario** (**$F_{2008\text{-}2010}$**): Use the average fishing intensity (SPR) from 2008-2010 and apply the corresponding fishing mortality rate to the stock estimates beginning in 2022; this corresponds to the proposed NP SWO CMM;
3. **Low F Scenario** (**F_{Low}**): Apply an $F_{SPR30\%}$ fishing mortality rate to the stock estimates beginning in 2022;
4. **F_{MSY} Scenario** (**F_{MSY}**): Apply the estimate of the F_{MSY} fishing mortality rate to the stock estimates beginning in 2022;
5. **Status Quo F Scenario** (**$F_{StatusQuo}$**): This is the average F (age 1-10) during 2019-2021;

3. RESULTS

3.1. Base Case Model

Results for the base case model provided estimates of biological reference points for NP SWO and included trends in estimates of total stock biomass, female SSB, recruitment, and F, 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 <0.0001 and the hessian matrix for the parameter estimates was positive definite, which indicated that the model had converged to a local or global minimum. Results from 100 model runs with different random initial starting values for estimated parameters using the internal "jitter" routine in SS3 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 10).

3.3. Model Diagnostics

Figure 11 showed the results of the likelihood profile on virgin recruitment (ln(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 Figures 12 and 13.

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 reasonable about of information in the size data and survey (CPUE) data to inform the lower bound of R_0, but only the size composition data contributed to an estimate of the upper bound of R_0 (Figure 11). Generally, all the data agreed upon the maximum likelihood estimate of ln(R_0) = 6.84. The Chinese Taipei size composition data contributed the most to the estimate of ln(R_0) (Figure 13), and the Japanese longline late CPUE index in area 1 and the US longline deep-set sector CPUE index contributed to most to the survey estimate of ln(R_0) (Figure 12).

There were some 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 5, and plots of predicted and observed CPUE by fishery for the base case model were shown in Figure 14.

The fit to the CPUE indices can be summarized into two groups by the contribution to the total likelihood (contributed group of S1, S2, S3, S4, S6, and S7; uncontributed group of S5 and S8). Table 5 showed that RMSE was smaller than 0.3 for all indices except for S5. This result indicates that the model fit to these CPUE indices were good.

3.3.2. Residuals Analysis of Size Composition Data

Comparisons between the observed and expected mean values of length composition data from Francis (2011) were used for model diagnostics. Figure 15 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 16), 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 IATTC EPO size data and the US LL data, especially the deep-set sector which was ultimately excluded from the base-case model, however the BILLWG 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 meet this criteria, although F3 and F8, the U.S. longline shallow-set data in the early and late periods showed stronger residual patterns when compared to the other fleets (Figure 16).

Overall, the model fit the length modes in length composition data aggregated by fishery fairly well using the input effective sample sizes (Figure 6). However, F4 still showed some misfit.

3.3.3. Runs test

The CPUE indices for all fleets included in the likelihood (S1 - S4, and S7) passed runs test (Figure 17) that indicated the model fitted well. S5 and S8 were not fit in the likelihood, so we expect some mis-fit. S6 is not fit as a survey/CPUE index, so the interpretation of the runs test for this fleet is less straightforward as there are many data sources that contribute to estimating recruitment. The length composition data for five fleets passed the runs test (Figure 18). The length-composition data for F1 Japanese LL area 1 late could pass the runs test if an additional time block is included in the selectivity estimates. However, this also increased the number of parameters estimated and did not change the overall model result. The BILLWG agreed that the priority was to fit the CPUE data and therefore estimated the F1 size data without the second time block. F4 IATTC size data also failed the runs test. This fleet is an aggregate of many fleets and gears catching swordfish in the EPO. This means that the selectivity of the fleet is unlikely to be consistent between years or quarters and would cause problems when fitting. In adddition, the aggreate distribution of the size composition data for this fleet has sharp peaks at a few size classes, which causes issues in estimating selectivity and indicates that these data should be evaluated more closely for inclusion in the future.

3.3.4. Retrospective Analysis

A retrospective analysis 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 19. The trajectories of estimated SSB and F showed that there was a slight tendency of overestimation for SSB in recent years and underestimation for F. In addition, the Mohn’s rho for SSB (-0.14) and F (0.14) fell within the range of acceptable values (-0.15 to 0.20), suggesting that the retrospective pattern is not substantial.

3.3.5. Prediciton skill

Results of the hindcast with cross-validation indicate that of the five CPUE indices at the end of the assessment horizon, only the Japanese LL area 2 fleet had reasonable predictive ability (MASE = 0.85), with all other fleets MASE > 1 (Figure 20). Comparing the predictive ability of the size composition data, two fleets had good predictive ability (MASE <0.5, F3 and F9), one had moderate predictive ability (MASE <1 and >0.5, F2) and two had poor predictive ability (MASE <1, F1 and F7, Figure 21).

3.3.6. Age-structured production model

Results from the ASPM model showed a similar population trend as the full model although the scale of the ASPM is larger than the base-case model (Figure 22). This suggests that while the Catch and CPUE data do provide information for the production function, the size composition data provide information about the overall scale of the population.

4. STOCK ASSESSMENT RESULTS

Estimates of population biomass (estimated biomass of age 1 and older fish at the beginning of the year) fluctuated around an average of 80,800 mt during 1975-2021 and was estimated to be 88,800 mt in 2021 (Table 11 and Figure 23a). Overall, population biomass has increased slightly over time.

Initial estimates of female SSB averaged around 27,600 mt in the late 1970s. SSB was at its highest level of 35,778 metric tons in 2021, and was at its minimum of 22,415 mt in 1981. Overall, spawning stock biomass has been relatively stable and above SSB_{MSY} for the entirety of the assessment period (Table 11 and Figure 23b).

Estimated F (arithmetic average of F for ages 1 – 10) decreased from 0.17 $year^{-1}$ in 1978 to a minimum of 0.087 $year^{-1}$ in 2021 (Table 11 and Figure 23c). It averaged roughly F=0.09 during 2019-2021 or about 51% of F_{MSY} with a relative fishing mortality of $F/F_{MSY} = 0.09$ in 2021. Fishing mortality has been below F_{MSY} since the beginning of the assessment time period and has had a declining trend with the exception of a high peak in 1998 coinciding with high catch by the US LL fleet.

Recruitment (age-0 fish) estimates averaged approximately 838,000 during 1975-2021. While the overall pattern of recruitment varied, there was no apparent trend in recruitment strength over time (Table 11 and Figure 23d). Overall, total annual catches are declining, catch per unit effort is increasing, and recruitment is relatively stable.

4.1. Biological Reference Points

MSY-based biological reference points were computed for the base case model with SS (Table 11). The point estimate of MSY (C_{MSY}: annual catch at F_{MSY}) was calculated to be 14924 mt. The point estimate of the SSB to produce MSY (adult female biomass) was 16388 mt. The point estimate of F_{MSY}, the fishing mortality rate to produce SSB_{MSY} (average fishing mortality on ages 1 – 10) was 0.18 and the corresponding equilibrium value of spawning potential ratio at SSB_{MSY} was 19%.

4.2. Stock Status

There are no defined reference points for North Pacific swordfish in the Western and Central Pacific Fisheries Commission (WCPFC), therefore stock status is based upon maximum sustainable yeild (MSY) refernce points. The current or recent 3-year average spawning biomass of 34,900 mt (average for 2019-2021) was almost 2.5 times greater than SSB_{MSY} and the current fishing mortality (average for ages 1 – 10 during 2019-2021) was 49% above F_{MSY}. The base case model indicated that under current conditions the NP SWO stock was very likely not overfished (>99% probability) and was very likely not subject to overfishing (>99% probability) relative to MSY-based reference points (Figure 24).

4.3. Sensitivity Analyses

The BILLWG completed all 24 sensitivity runs and compared the SSB and the F trajectories to those of the base-case model (Figure 25). The BILLWG also produced a Kobe plot to compare the stock status of the recent years among 24 sensitivity runs. The result showed that there was clear pattern of the stock status (improvement or deterioration, Figure 26).

The sensitivity analyses run for this assessment indicated that the model is not very sensitive to alternative parameterizations, alternative catch time series, and alternative model configurations.

All of the sensitivities run indicated the stock was not overfished and overfishing was not occuring, with the majority of the runs overlapping considerably with the base-case model (Figure 26).

4.4. Stock Projections

Future projection showed the trajectories of SSB and catch as well as mean values during 2022-2031 for five scenarios (Table 12 and Figures 27 and 28). For each scenario, intial SSB and catch increase as all projections use higher Fs than the F in the final year of the assessment. For scenario 5, $F_{status\ quo}$, SSB continues to increase until 2031. For all other scenarios, catch begins to decrease then stabilize, but projections suggest that the stock can withstand additional fishing pressure in the next 10 years without decreasing SSB below MSY levels. In all scenarios, catch would increase due to the increase in fishing mortality.

5. CONCLUSIONS

5.1. Conservation information

The NP SWO stock has produced annual yields of around 11,500 mt per year since 2016, or about 2/3 of the MSY catch amount. This suggests the stock may be able to support somewhat higher yields. Swordfish stock status is positive with no evidence of excess fishing mortality above F_{MSY} or substantial depletion of spawning potential. It was also noted that retrospective analyses show that the assessment model appears to underestimate spawning potential in recent years.

6. SWORDFISH CATCH DISTRIBUTION

In response to a request from the WCPFC Northern committee, the BILLWG used WCPFC and IATTC public domain data and yearbooks to compile catch and effort north and south of 20°N (**Figure 29**). The WG did not use 2021 data because the data sets were preliminary. Much of the swordfish catch is from longlines, and only longlines are available for effort. The effort south of 20°N includes and accounts for a large proportion of the statistics for Vietnam and Indonesia. However, the longline effort for Indonesia and Vietnam has been estimated because the logbook coverage for these fleets could be much higher or less coverage over time. Recently, catches of longline fishery in the 0°-10°N area of the eastern Pacific have increased. The Gillnet fishing conducted in the waters around Vietnam is also responsible for the increase in catch south of 20°N.

7. REFERENCES

Bohaboy, E. and Sculley M. (2023). Standardization of Western and Central North Pacific swordfish (*Xiphias gladius*) Catch Per Unit Effort in the Hawai'i longline fishery from 1995-2021. ISC/22/BILLWG-02/02.

Brodziak, J. (2020). On the probably distribution of stock-recruitment steepness for Western and Central North Pacific swordfish. ISC/20/BILLWG-01/06.

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

DeMartini, E.E., Uchiyama, J.H., Humphreys Jr., R.L., Sampaga, J.D. and Williams, H.A. (2007). Age and growth of swordfish (*Xiphias gladius*) caught by the Hawaii-based pelagic longline fishery. Fish. Bull. 105:356-367.

Francis, R. I. C. C. (2011). Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68(6): 1124-1138.

Hsu, J. and Chang, Y-J. (2023). Catch, length data and standardized CPUE of swordfish caught by the Taiwanese fisheries in North Pacific Ocean. ISC/22/BILLWG-02/07.

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.

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC]. (2018). Stock assessment of swordfish in the North Pacific Ocean in 2018, Report of the Billfish Working Group Stock Assessment Workshop.

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC]. (2023). Report of the Billfish Working Group Workshop. 13, 15-18 December 2023.

Jusup, M., Koike, H. and Ijima, H. (2023). CPUE Standardization for Pacific Swordfish (*Xiphias gladius*) caught by the Japanese longline fishery: A GLMM analysis using the R software package R-INLA. ISC/22/BILLWG-02/06

Kanaiwa M. and Ijima H. (2018). Abundance indices of Swordfish (*Xiphias gladius*) by the Japanese offshore and distant-water longline fishery in the North-Western Central Pacific. ISC/18/BILLWG-01/07.

Kapur, M., Brodziak, J. Fletcher, E. and Yau, A. (2017). Summary of Life History and Stock Assessment Results for Pacific Blue Marlin, Western and Central North Pacific Striped Marlin, and North Pacific Swordfish. ISC/17/BILLWG-01/02.

Lee, H.-H., K. R. Piner, R. D. Methot Jr and M. N. Maunder (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.

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 Jr, R. D. and C. R. Wetzel (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142: 86-99.

Nishikawa, Y., M. Honma , S. Ueyanagi , S. Kikkawa. (1985). Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. Far Seas Fish. Res. Lab., S Series 12, 99p.

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.

Sun, C-L., Wang, S-P. and Yeh, S-Z. (2002). Age and growth of the swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays. Fishery Bulletin, 100(4), pp. 822-835.

Thorson, J.T., and Barnett, L.A.K., (2017). Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES J. Mar. Sci. 74, 1311–1321. https://doi.org/10.1093/icesjms/fsw193

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.

Wang, S-P., Sun, C-L., Yeh, S-Z. (2003). Sex ratios and sexual maturity of swordfish (*Xiphias* gladius L.) in the waters of Taiwan. Zoological Studies. 42(4): 529-539.

TABLES

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

Catch Index	Abundance Index	Fleet Name	Time Period	Len Comp used?	Source
F1	S1 - Y	JPN_WCNPO_OSDWLL_late_Area 1	1994-2021	Y	Jusup et al., 2023
F2	S5 - N	TWN_WCNPO_DWLL_late	2000-2021	Y	Hsu and Chang, 2023
F3	S8 - N	US_WCNPO_LL_shallow_late	2004-2021	Y	Bohaboy and Sculley, 2023
F4	-	IATTC	1975-2021	Y	-
F5	-	JPN_EPO_OSDWLL	1975-2016	N	-
F6	S2 - Y	JPN_WCNPO_OSDWLL_early_area 1	1975-1993	Y	Jusup et al., 2023
F7	-	JPN_WCNPO_CODF	1993-2021	Y	-
F8	S7 - Y	US_WCNPO_LL_shallow_early	1993-2021	Y	Bohaboy and Sculley, 2023
F9	S6 - Y	US_WCNPO_LL_deep	1996-2021	N	Bohaboy and Sculley, 2023
F10	-	JPN_WCNPO_OSDF	1975-1992	-	-
F11	-	JPN_WCNPO_Other_early	1975-1993	-	-
F12	-	JPN_WCNPO_Other_late	1994-2021	-	-
F13	-	TWN_WCNPO_DWLL_early	1975-1999	-	-
F14	-	TWN_WCNPO_Other	2001-2021	-	-
F15	-	US_WCNPO_GN	1980-2021	-	-
F16	-	US_WCNPO_Other	1975-2021	-	-
F17	S3 - Y	JPN_WCNPO_OSDWLL_early_area 2	1975-1993	-	Jusup et al., 2023
F18	S4 - Y	JPN_WCNPO_OSDWLL_late_area2	1994-2021	-	Jusup et al., 2023
F19	-	WCPFC	1975-2021	-	-

Table 2: Time series of catch by fleet submitted for the 2023 North Pacific swordfish stock assessment. Starred fleets are in numbers of fish, all others are in metric tons. See Table 1 for and explanation of fleet numbers.

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
1975	1	0	0	0	59.6	134	30770	0	0	0	668
1975	2	0	0	0	59.6	2440	17705	0	0	0	668
1975	3	0	0	0	59.6	1615	12619	0	0	0	668
1975	4	0	0	0	59.6	1565	41163	0	0	0	668
1976	1	0	0	0	12.2	5557	38251	0	0	0	872
1976	2	0	0	0	12.2	2304	18186	0	0	0	872
1976	3	0	0	0	12.2	1197	13094	0	0	0	872
1976	4	0	0	0	12.2	2449	33783	0	0	0	872
1977	1	0	0	0	32.5	684	49038	0	0	0	586
1977	2	0	0	0	32.5	2231	22981	0	0	0	586
1977	3	0	0	0	32.5	107	10027	0	0	0	586
1977	4	0	0	0	32.5	26	34195	0	0	0	586
1978	1	0	0	0	153.1	52	43277	0	0	0	618.75
1978	2	0	0	0	153.1	32	24013	0	0	0	618.75
1978	3	0	0	0	153.1	31	10488	0	0	0	618.75
1978	4	0	0	0	153.1	3	35618	0	0	0	618.75
1979	1	0	0	0	58.3	13	42977	0	0	0	245.75
1979	2	0	0	0	58.3	88	23783	0	0	0	245.75
1979	3	0	0	0	58.3	134	16868	0	0	0	245.75
1979	4	0	0	0	58.3	13	35079	0	0	0	245.75
1980	1	0	0	0	145	0	25886	0	0	0	436.5
1980	2	0	0	0	145	159	18370	0	0	0	436.5
1980	3	0	0	0	145	246	7342	0	0	0	436.5
1980	4	0	0	0	145	1386	18055	0	0	0	436.5
1981	1	0	0	0	78.6	326	31977	0	0	0	462
1981	2	0	0	0	78.6	592	26258	0	0	0	462
1981	3	0	0	0	78.6	201	7085	0	0	0	462
1981	4	0	0	0	78.6	3389	19099	0	0	0	462
1982	1	0	0	0	84	2876	24296	0	0	0	314.25
1982	2	0	0	0	84	1530	18874	0	0	0	314.25
1982	3	0	0	0	84	1302	5932	0	0	0	314.25
1982	4	0	0	0	84	4785	26181	0	0	0	314.25
1983	1	0	0	0	200.5	2914	45609	0	0	0	240.5
1983	2	0	0	0	200.5	84	28709	0	0	0	240.5

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
1983	3	0	0	0	200.5	365	8857	0	0	0	240.5
1983	4	0	0	0	200.5	1313	25184	0	0	0	240.5
1984	1	0	0	0	166.7	914	29375	0	0	0	242.75
1984	2	0	0	0	166.7	395	20684	0	0	0	242.75
1984	3	0	0	0	166.7	201	14954	0	0	0	242.75
1984	4	0	0	0	166.7	793	28957	0	0	0	242.75
1985	1	0	0	0	23	1	40738	0	0	0	256.5
1985	2	0	0	0	23	0	40438	0	0	0	256.5
1985	3	0	0	0	23	2	20984	0	0	0	256.5
1985	4	0	0	0	23	8	34442	0	0	0	256.5
1986	1	0	0	0	181.6	1877	48762	0	0	0	292.5
1986	2	0	0	0	181.6	1280	32783	0	0	0	292.5
1986	3	0	0	0	181.6	812	15570	0	0	0	292.5
1986	4	0	0	0	181.6	1896	33316	0	0	0	292.5
1987	1	0	0	0	240	3967	57744	0	0	0	227.5
1987	2	0	0	0	239.8	1316	29781	0	0	0	227.5
1987	3	0	0	0	239.8	291	13396	0	0	0	227.5
1987	4	0	0	0	240.4	3869	30346	0	0	0	227.5
1988	1	0	0	0	265.6	1261	56695	0	0	0	262
1988	2	0	0	0	265.6	194	31357	0	0	0	262
1988	3	0	0	0	265.6	1144	10481	0	0	0	262
1988	4	0	0	0	266.2	3476	19719	0	0	0	262
1989	1	0	0	0	298.1	2725	33352	0	0	0	349.25
1989	2	0	0	0	298.1	648	23892	0	0	0	349.25
1989	3	0	0	0	298.1	88	8249	0	0	0	349.25
1989	4	0	0	0	298.5	121	18244	0	0	0	349.25
1990	1	0	0	0	344.2	37	36962	0	0	0	256.5
1990	2	0	0	0	344.2	12	23450	0	0	0	256.5
1990	3	0	0	0	344.3	43	6777	0	0	0	256.5
1990	4	0	0	0	344.3	0	12224	0	0	0	256.5
1991	1	0	0	0	451.3	0	22310	0	0	0	106
1991	2	0	0	0	451.2	3	19652	0	0	0	106
1991	3	0	0	0	451.2	42	7672	0	0	0	106
1991	4	0	0	0	451.2	14	17279	0	0	0	106

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
1992	1	0	0	0	305.1	0	27527	0	0	0	210
1992	2	0	0	0	305.4	1	24231	0	0	0	210
1992	3	0	0	0	305.4	2	9727	0	0	0	210
1992	4	0	0	0	305.9	7	12483	0	0	0	210
1993	1	0	0	0	211.5	1	29415	73	0	0	0
1993	2	0	0	0	212	0	29960	73	0	0	0
1993	3	0	0	0	211.7	0	11229	73	0	0	0
1993	4	0	0	0	211.8	0	19258	73	0	0	0
1994	1	34547	0	0	81.3	0	0	105.25	0	0	0
1994	2	26453	0	0	81.4	0	0	105.25	0	0	0
1994	3	8556	0	0	82.2	0	0	105.25	0	0	0
1994	4	23342	0	0	84.5	0	0	105.25	0	0	0
1995	1	27886	0	0	93.5	0	0	140.25	0	0	0
1995	2	21059	0	0	93.7	0	0	140.25	0	0	0
1995	3	7541	0	0	93.8	21	0	140.25	0	0	0
1995	4	21734	0	0	93.8	198	0	140.25	0	0	0
1996	1	30962	0	0	98.5	151	0	107	11831	117	0
1996	2	23750	0	0	97.7	0	0	107	13928	270	0
1996	3	7590	0	0	97.8	0	0	107	3162	118	0
1996	4	15239	0	0	98.5	1	0	107	10648	115	0
1997	1	31260	0	0	92.8	0	0	91.25	17341	57	0
1997	2	17006	0	0	92.6	0	0	91.25	16864	220	0
1997	3	5509	0	0	92.7	97	0	91.25	2474	134	0
1997	4	19071	0	0	96.8	23	0	91.25	5413	185	0
1998	1	28378	0	0	155.5	0	0	117.75	15790	157	0
1998	2	16626	0	0	155.6	0	0	117.75	17850	424	0
1998	3	48130	0	0	153.7	0	0	117.75	44411	248	0
1998	4	15686	0	0	153.8	0	0	117.75	44496	416	0
1999	1	22310	0	0	112.3	0	0	181	16332	242	0
1999	2	15843	0	0	112.4	0	0	181	13714	426	0
1999	3	6029	0	0	112.7	0	0	181	43933	442	0
1999	4	18573	0	0	112.9	0	0	181	11325	455	0
2000	1	27538	21.48	0	789	0	0	202	16659	137	0
2000	2	14112	21.48	0	788.9	0	0	202	17268	415	0

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
2000	3	7651	21.48	0	795.1	0	0	202	34469	223	0
2000	4	21135	21.48	0	791	0	0	202	678	290	0
2001	1	24407	28.27	0	260.6	199	0	183	1597	152	0
2001	2	10468	28.27	0	264	0	0	183	880	432	0
2001	3	9113	28.27	0	265.3	0	0	183	0	429	0
2001	4	16518	28.27	0	259	0	0	183	0	679	0
2002	1	22057	48.25	0	38.7	1	0	291	0	1468	0
2002	2	9737	48.25	0	35.2	0	0	291	0	775	0
2002	3	9579	48.25	0	35.2	1	0	291	0	496	0
2002	4	18673	48.25	0	38.1	0	0	291	0	879	0
2003	1	18649	106.8	0	252.9	0	0	282.5	0	303	0
2003	2	7495	106.8	0	310.9	1	0	282.5	0	895	0
2003	3	5907	106.8	0	337.6	0	0	282.5	0	1060	0
2003	4	21308	106.8	0	226.8	0	0	282.5	0	1266	0
2004	1	20930	150.03	0	324.2	0	0	263.75	0	758	0
2004	2	4682	150.03	0	291.2	0	0	263.75	0	1279	0
2004	3	6765	150.03	0	284.9	0	0	263.75	0	690	0
2004	4	25366	150.03	1324	284.6	0	0	263.75	0	1012	0
2005	1	27767	67.47	8944	344.2	0	0	238.75	0	373	0
2005	2	7049	67.47	11003	336.1	0	0	238.75	0	1143	0
2005	3	5149	67.47	0	337.7	0	0	238.75	0	681	0
2005	4	24261	67.47	1313	333.3	0	0	238.75	0	893	0
2006	1	20221	65.8	13435	452.4	0	0	199	0	448	0
2006	2	8960	65.8	0	449.9	0	0	199	0	1221	0
2006	3	8540	65.8	0	449.9	0	0	199	0	611	0
2006	4	32613	65.8	0	449.9	0	0	199	0	864	0
2007	1	30939	58.2	15170	331.4	0	0	207	0	386	0
2007	2	10286	58.2	4727	306.4	0	0	207	0	1381	0
2007	3	5693	58.2	183	302.1	0	0	207	0	783	0
2007	4	25850	58.2	763	304.3	0	0	207	0	878	0
2008	1	20548	58.38	11651	330.1	0	0	162	0	478	0
2008	2	6804	58.38	4380	334.9	0	0	162	0	2034	0
2008	3	5519	58.38	503	329.3	0	0	162	0	634	0
2008	4	22764	58.38	3808	329.7	0	0	162	0	502	0

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
2009	1	18926	43.23	7769	322.2	0	0	170.25	0	509	0
2009	2	5692	43.23	8436	322.4	0	0	170.25	0	1550	0
2009	3	7225	43.23	823	320.1	0	0	170.25	0	704	0
2009	4	20683	43.23	1480	316	0	0	170.25	0	571	0
2010	1	13092	61.6	9238	304.2	0	0	123.5	0	707	0
2010	2	4282	61.6	5090	328.5	0	0	123.5	0	1049	0
2010	3	7625	61.6	392	337.9	0	0	123.5	0	675	0
2010	4	19457	61.6	2406	330.1	0	0	123.5	0	485	0
2011	1	9469	96.97	9530	256.8	0	0	48.25	0	554	0
2011	2	3498	96.97	4530	240.9	0	0	48.25	0	1175	0
2011	3	4694	96.97	0	235.4	0	0	48.25	0	829	0
2011	4	16139	96.97	2120	244.3	0	0	48.25	0	574	0
2012	1	12241	72.88	7898	223.1	0	0	97.25	0	554	0
2012	2	4745	72.88	4741	207	0	0	97.25	0	1555	0
2012	3	4163	72.88	0	209.8	0	0	97.25	0	775	0
2012	4	15592	72.88	1598	207.7	0	0	97.25	0	665	0
2013	1	12647	60.25	5730	286.9	0	0	77.25	0	502	0
2013	2	7097	60.25	1994	278.2	0	0	77.25	0	1635	0
2013	3	3981	60.25	0	280.5	0	0	77.25	0	1331	0
2013	4	14080	60.25	3005	285	0	0	77.25	0	781	0
2014	1	11480	37.17	8421	416.4	0	0	67	0	674	0
2014	2	5868	37.17	3930	397.6	0	0	67	0	1713	0
2014	3	3789	37.17	724	388.9	0	0	67	0	1293	0
2014	4	15885	37.17	2374	411.6	0	0	67	0	883	0
2015	1	15586	93.75	10670	271.2	0	0	69.25	0	904	0
2015	2	5499	93.75	3546	296.8	0	0	69.25	0	2336	0
2015	3	5058	93.75	0	270.4	0	0	69.25	0	1202	0
2015	4	16280	93.75	772	274	0	0	69.25	0	947	0
2016	1	18777	128.43	5220	266.5	0	0	75.75	0	1101	0
2016	2	7547	128.43	3344	211.9	0	0	75.75	0	2167	0
2016	3	7134	128.43	447	196.1	37	0	75.75	0	966	0
2016	4	20562	128.43	719	208.1	27	0	75.75	0	885	0
2017	1	15374	88.9	5584	314.8	0	0	72.75	0	1134	0
2017	2	9219	88.9	6068	307.1	0	0	72.75	0	2793	0

		Fleet									
Year	Quarter	1*	2	3*	4	5*	6*	7	8*	9*	10
2017	3	6499	88.9	0	333.2	0	0	72.75	0	834	0
2017	4	18618	88.9	2276	336	0	0	72.75	0	815	0
2018	1	18985	130.15	5750	396.7	0	0	57.5	0	1075	0
2018	2	8524	130.15	360	402.6	0	0	57.5	0	3010	0
2018	3	7829	130.15	0	375.7	0	0	57.5	0	773	0
2018	4	15925	130.15	0	356	0	0	57.5	0	1256	0
2019	1	11842	91.25	3435	457.9	0	0	60.5	0	774	0
2019	2	8858	91.25	0	419.1	0	0	60.5	0	2533	0
2019	3	4382	91.25	0	418.8	0	0	60.5	0	685	0
2019	4	13367	91.25	0	431.2	0	0	60.5	0	909	0
2020	1	14105	100.12	2933	470	0	0	72.5	0	687	0
2020	2	10003	100.12	0	464.3	0	0	72.5	0	1890	0
2020	3	7436	100.12	0	443.1	0	0	72.5	0	629	0
2020	4	19566	100.12	1661	451	0	0	72.5	0	657	0
2021	1	14105	69.28	3575	470	0	0	72.5	0	503	0
2021	2	10003	69.28	2350	464.3	0	0	72.5	0	1956	0
2021	3	7436	69.28	0	443.1	0	0	72.5	0	860	0
2021	4	19566	69.28	412	451	0	0	72.5	0	793	0

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
1975	1	225.75	0	7.25	0	0	142.5	7122	0	35.5
1975	2	225.75	0	7.25	0	0	142.5	2734	0	33
1975	3	225.75	0	7.25	0	0	142.5	1098	0	70.6
1975	4	225.75	0	7.25	0	0	142.5	1913	0	60.9
1976	1	314.75	0	5.75	0	0	13.75	10648	0	47.3
1976	2	314.75	0	5.75	0	0	13.75	4813	0	49.4
1976	3	314.75	0	5.75	0	0	13.75	1682	0	36.3
1976	4	314.75	0	5.75	0	0	13.75	4703	0	33.4
1977	1	290.25	0	9	0	0	84.25	6793	0	55.9
1977	2	290.25	0	9	0	0	84.25	3626	0	35.9
1977	3	290.25	0	9	0	0	84.25	1252	0	43.7
1977	4	290.25	0	9	0	0	84.25	3551	0	36.9
1978	1	323.5	0	0	0	0	428	12176	0	37.7
1978	2	323.5	0	0	0	0	428	4715	0	20.9
1978	3	323.5	0	0	0	0	428	1552	0	23.1
1978	4	323.5	0	0	0	0	428	2935	0	27.5
1979	1	315.75	0	1.73	0	0	96.5	17810	0	46.7
1979	2	315.75	0	1.73	0	0	96.5	5343	0	47.3
1979	3	315.75	0	1.73	0	0	96.5	2204	0	32.7
1979	4	315.75	0	1.73	0	0	96.5	3133	0	32.2
1980	1	323	0	2.5	0	40	157	21348	0	49.4
1980	2	323	0	2.5	0	40	157	5293	0	36.7
1980	3	323	0	2.5	0	40	157	2030	0	27.7
1980	4	323	0	2.5	0	40	157	11503	0	36.8
1981	1	231.5	0	0.35	0	115.25	71.75	31031	0	50.4
1981	2	231.5	0	0.35	0	115.3	71.75	6211	0	50.4
1981	3	231.5	0	0.35	0	115.3	71.75	3901	0	49.6
1981	4	231.5	0	0.35	0	115.3	71.75	3102	0	57.5
1982	1	283.75	0	0.25	0	227.75	19.9	16726	0	51.3
1982	2	283.75	0	0.25	0	227.75	19.9	3850	0	52.7
1982	3	283.75	0	0.25	0	227.75	19.9	1282	0	50.4
1982	4	283.75	0	0.25	0	227.75	19.9	4322	0	48.6
1983	1	319.25	0	0	0	330.25	109	20451	0	50.6
1983	2	319.25	0	0	0	330.25	109	3025	0	44.1

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
1983	3	319.25	0	0	0	330.25	109	1106	0	46.3
1983	4	319.25	0	0	0	330.25	109	5680	0	47.3
1984	1	371.75	0	0	0	525.25	193.5	28619	0	49.3
1984	2	371.75	0	0	0	525.25	193.5	4102	0	40.8
1984	3	371.75	0	0	0	525.25	193.5	1788	0	40.7
1984	4	371.75	0	0	0	525.25	193.5	5205	0	51.8
1985	1	344	0	0	0	747.5	103.25	24213	0	51.9
1985	2	344	0	0	0	747.5	103.25	4014	0	47.9
1985	3	344	0	0	0	747.5	103.25	1706	0	56.7
1985	4	344	0	0	0	747.5	103.25	6300	0	59.9
1986	1	327.5	0	0	0	517.25	101	15201	0	62.6
1986	2	327.5	0	0	0	517.25	101	3686	0	60.4
1986	3	327.5	0	0	0	517.25	101	2050	0	63.7
1986	4	327.5	0	0	0	517.25	101	4365	0	66.9
1987	1	286	0	0.5	0	382.25	67.5	19566	0	94.3
1987	2	286	0	0.5	0	382.25	67.5	4473	0	81.6
1987	3	286	0	0.5	0	382.25	67.5	2237	0	87.2
1987	4	286	0	0.5	0	382.25	67.5	10187	0	73.4
1988	1	266	0	0	0	344	67	23634	0	86.5
1988	2	266	0	0	0	344	67	3702	0	63.4
1988	3	266	0	0	0	344	67	1658	0	64.5
1988	4	266	0	0	0	344	67	11571	0	63.5
1989	1	336	0	3.98	0	310.75	31.25	24255	0	82.1
1989	2	336	0	3.98	0	310.75	31.25	4637	0	70
1989	3	336	0	3.98	0	310.75	31.25	1237	0	68.6
1989	4	336	0	3.98	0	310.75	31.25	4487	0	75.4
1990	1	220.75	0	19.77	0	282.75	28	20917	0	115.9
1990	2	220.75	0	19.77	0	282.75	28	3130	0	84.8
1990	3	220.75	0	19.77	0	282.75	28	1326	0	78.4
1990	4	220.75	0	19.77	0	282.75	28	3355	0	65.4
1991	1	264.75	0	4	0	236	17.5	11474	0	91.2
1991	2	264.75	0	4	0	236	17.5	2871	0	98.4
1991	3	264.75	0	4	0	236	17.5	1284	0	76.7
1991	4	264.75	0	4	0	236	17.5	3662	0	63

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
1992	1	407.75	0	3.5	0	339	30.75	8819	0	99.2
1992	2	407.75	0	3.5	0	339	30.75	2756	0	110.4
1992	3	407.75	0	3.5	0	339	30.75	1520	0	88.1
1992	4	407.75	0	3.5	0	339	30.75	2567	0	61.7
1993	1	437.75	0	13.5	0	353	83.25	6548	0	105.5
1993	2	437.75	0	13.5	0	353	83.25	2495	0	211.9
1993	3	437.75	0	13.5	0	353	83.25	1394	0	318
1993	4	437.75	0	13.5	0	353	83.25	2838	0	150.3
1994	1	0	87.25	0	0	198	46.25	0	5089	157.4
1994	2	0	87.25	0	0	198	46.25	0	2452	378.4
1994	3	0	87.25	0	0	198	46.25	0	1191	279.2
1994	4	0	87.25	0	0	198	46.25	0	1462	159.3
1995	1	0	116.25	11.47	0	192.75	33	0	3701	192
1995	2	0	116.25	11.47	0	192.75	33	0	2110	241.4
1995	3	0	116.25	11.47	0	192.75	33	0	999	183.3
1995	4	0	116.25	11.47	0	192.75	33	0	1580	122.8
1996	1	0	162.5	1.6	0	190.25	25.25	0	3847	182.5
1996	2	0	162.5	1.6	0	190.25	25.25	0	1869	189.6
1996	3	0	162.5	1.6	0	190.25	25.25	0	845	156.8
1996	4	0	162.5	1.6	0	190.25	25.25	0	2567	163.6
1997	1	0	103.5	3.75	0	177	25.5	0	2351	89
1997	2	0	103.5	3.75	0	177	25.5	0	1742	72.9
1997	3	0	103.5	3.75	0	177	25.5	0	787	72.7
1997	4	0	103.5	3.75	0	177	25.5	0	1319	84.9
1998	1	0	137.5	5	0	232.75	18.5	0	1832	139.3
1998	2	0	137.5	5	0	232.75	18.5	0	1831	129.5
1998	3	0	137.5	5	0	232.75	18.5	0	857	110.1
1998	4	0	137.5	5	0	232.75	18.5	0	1412	126.9
1999	1	0	117.5	14.8	0	151.5	29.25	0	3312	149.8
1999	2	0	117.5	14.8	0	151.5	29.25	0	1908	226.6
1999	3	0	117.5	14.8	0	151.5	29.25	0	1252	204.8
1999	4	0	117.5	14.8	0	151.5	29.25	0	2088	218.6
2000	1	0	140	0	0	162.25	30.75	0	3282	260.4
2000	2	0	140	0	0	162.25	30.75	0	2441	280.7

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
2000	3	0	140	0	0	162.25	30.75	0	962	264.7
2000	4	0	140	0	0	162.25	30.75	0	1731	223.4
2001	1	0	71	0	953.25	93.75	17.75	0	2818	218.1
2001	2	0	71	0	953.25	93.75	17.75	0	2336	256.6
2001	3	0	71	0	953.25	93.75	17.75	0	1339	214.6
2001	4	0	71	0	953.25	93.75	17.75	0	2124	237.5
2002	1	0	62.75	0	941.5	75.5	23.25	0	3192	348.1
2002	2	0	62.75	0	941.5	75.5	23.25	0	2748	379.8
2002	3	0	62.75	0	941.5	75.5	23.25	0	948	226.7
2002	4	0	62.75	0	941.5	75.5	23.25	0	1551	242.1
2003	1	0	63.5	0	856.23	54	32	0	2402	485.9
2003	2	0	63.5	0	856.23	54	32	0	3649	364.3
2003	3	0	63.5	0	856.23	54	32	0	1158	240.9
2003	4	0	63.5	0	856.23	54	32	0	1490	356.4
2004	1	0	68.5	0	777.62	45.5	30	0	5808	361.7
2004	2	0	68.5	0	777.62	45.5	30	0	5102	350.2
2004	3	0	68.5	0	777.62	45.5	30	0	1056	300
2004	4	0	68.5	0	777.62	45.5	30	0	875	345.2
2005	1	0	133.5	0	855.25	55	21.75	0	3459	357.4
2005	2	0	133.5	0	855.25	55	21.75	0	1682	260.6
2005	3	0	133.5	0	855.25	55	21.75	0	1442	177.3
2005	4	0	133.5	0	855.25	55	21.75	0	1657	205.6
2006	1	0	148.75	0	976.77	110.75	20	0	5029	286
2006	2	0	148.75	0	976.77	110.75	20	0	2794	260.9
2006	3	0	148.75	0	976.77	110.75	20	0	1326	210.4
2006	4	0	148.75	0	976.77	110.75	20	0	845	258.4
2007	1	0	123.75	0	934.52	122.5	16.25	0	2700	277.1
2007	2	0	123.75	0	934.52	122.5	16.25	0	2939	245.5
2007	3	0	123.75	0	934.52	122.5	16.25	0	986	214.9
2007	4	0	123.75	0	934.52	122.5	16.25	0	1295	257.8
2008	1	0	132	0	843.38	101.25	18.25	0	4361	359.6
2008	2	0	132	0	843.38	101.25	18.25	0	2250	340.8
2008	3	0	132	0	843.38	101.25	18.25	0	760	285.9
2008	4	0	132	0	843.38	101.25	18.25	0	551	321.3

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
2009	1	0	134.75	0	782.38	63.25	14	0	975	374.1
2009	2	0	134.75	0	782.38	63.25	14	0	1341	347.4
2009	3	0	134.75	0	782.38	63.25	14	0	425	292.7
2009	4	0	134.75	0	782.38	63.25	14	0	482	392.7
2010	1	0	87.75	0	564.48	15.5	10	0	3019	576.7
2010	2	0	87.75	0	564.48	15.5	10	0	2192	487.3
2010	3	0	87.75	0	564.48	15.5	10	0	660	395.3
2010	4	0	87.75	0	564.48	15.5	10	0	445	364
2011	1	0	62	0	759.85	29.75	7.25	0	902	335.5
2011	2	0	62	0	759.85	29.75	7.25	0	1160	460.1
2011	3	0	62	0	759.85	29.75	7.25	0	709	304.7
2011	4	0	62	0	759.85	29.75	7.25	0	423	321.8
2012	1	0	90.25	0	712.92	29.5	3.25	0	958	718.9
2012	2	0	90.25	0	712.92	29.5	3.25	0	1217	769.8
2012	3	0	90.25	0	712.92	29.5	3.25	0	444	568.7
2012	4	0	90.25	0	712.92	29.5	3.25	0	389	582.8
2013	1	0	118	0	373.9	23.75	5	0	668	953.1
2013	2	0	118	0	373.9	23.75	5	0	1196	940.5
2013	3	0	118	0	373.9	23.75	5	0	322	821.8
2013	4	0	118	0	373.9	23.75	5	0	463	855.6
2014	1	0	133.5	0	592.48	31.75	4.75	0	894	848.7
2014	2	0	133.5	0	592.48	31.75	4.75	0	1029	970.9
2014	3	0	133.5	0	592.48	31.75	4.75	0	650	754.6
2014	4	0	133.5	0	592.48	31.75	4.75	0	539	783.9
2015	1	0	122.25	0	584.6	24.75	6.25	0	998	1104.8
2015	2	0	122.25	0	584.6	24.75	6.25	0	1507	1001.5
2015	3	0	122.25	0	584.6	24.75	6.25	0	432	744.1
2015	4	0	122.25	0	584.6	24.75	6.25	0	440	825.3
2016	1	0	107.5	0	309.4	43.25	20.5	0	616	1232.8
2016	2	0	107.5	0	309.4	43.25	20.5	0	1772	1261.6
2016	3	0	107.5	0	309.4	43.25	20.5	0	209	918.9
2016	4	0	107.5	0	309.4	43.25	20.5	0	179	928.7
2017	1	0	142.75	0	386.5	44.75	19.75	0	556	802.4
2017	2	0	142.75	0	386.5	44.75	19.75	0	1108	767.8

		Fleet								
Year	Quarter	11	12	13	14	15	16	17*	18*	19
2017	3	0	142.75	0	386.5	44.75	19.75	0	350	599.3
2017	4	0	142.75	0	386.5	44.75	19.75	0	242	640.3
2018	1	0	188.75	0	372.02	37	20.25	0	561	1000.7
2018	2	0	188.75	0	372.02	37	20.25	0	1020	1198.5
2018	3	0	188.75	0	372.02	37	20.25	0	245	653.6
2018	4	0	188.75	0	372.02	37	20.25	0	233	668.6
2019	1	0	139.75	0	396.62	13	50.25	0	409	754.5
2019	2	0	139.75	0	396.62	13	50.25	0	648	947.5
2019	3	0	139.75	0	396.62	13	50.25	0	274	588.8
2019	4	0	139.75	0	396.62	13	50.25	0	214	651.7
2020	1	0	124	0	339.38	8.75	33.5	0	1291	556.3
2020	2	0	124	0	339.38	8.75	33.5	0	909	581.1
2020	3	0	124	0	339.38	8.75	33.5	0	77	262.6
2020	4	0	124	0	339.38	8.75	33.5	0	105	282.1
2021	1	0	124	0	181.1	3.25	15.75	0	1291	556.3
2021	2	0	124	0	181.1	3.25	15.75	0	909	581.1
2021	3	0	124	0	181.1	3.25	15.75	0	77	262.6
2021	4	0	124	0	181.1	3.25	15.75	0	105	282.1

Table 3: 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 1.

	S1		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**		**S8**	
Year	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
1976	0.44	0.19	-	-	0.33	0.2	-	-	-	-	-	-	-	-	-	-
1977	0.38	0.19	-	-	0.31	0.21	-	-	-	-	-	-	-	-	-	-
1978	0.39	0.18	-	-	0.26	0.19	-	-	-	-	-	-	-	-	-	-
1979	0.36	0.17	-	-	0.25	0.19	-	-	-	-	-	-	-	-	-	-
1980	0.25	0.14	-	-	0.46	0.22	-	-	-	-	-	-	-	-	-	-
1981	0.26	0.14	-	-	0.26	0.19	-	-	-	-	-	-	-	-	-	-
1982	0.47	0.22	-	-	0.29	0.2	-	-	-	-	-	-	-	-	-	-
1983	0.45	0.18	-	-	0.34	0.2	-	-	-	-	-	-	-	-	-	-
1984	0.36	0.17	-	-	0.36	0.2	-	-	-	-	-	-	-	-	-	-
1985	0.44	0.2	-	-	0.35	0.2	-	-	-	-	-	-	-	-	-	-
1986	0.54	0.28	-	-	0.36	0.21	-	-	-	-	-	-	-	-	-	-
1987	0.61	0.33	-	-	0.43	0.21	-	-	-	-	-	-	-	-	-	-
1988	0.49	0.23	-	-	0.41	0.21	-	-	-	-	-	-	-	-	-	-
1989	0.43	0.21	-	-	0.34	0.2	-	-	-	-	-	-	-	-	-	-
1990	0.34	0.16	-	-	0.34	0.2	-	-	-	-	-	-	-	-	-	-
1991	0.42	0.18	-	-	0.28	0.2	-	-	-	-	-	-	-	-	-	-
1992	0.42	0.2	-	-	0.26	0.2	-	-	-	-	-	-	-	-	-	-
1993	0.47	0.25	-	-	0.23	0.2	-	-	-	-	-	-	-	-	-	-
1994	-	-	0.42	0.18	-	-	0.27	0.19	-	-	-	-	-	-	-	-
1995	-	-	0.36	0.19	-	-	0.21	0.18	-	-	0.26	0.21	6.13	0.2	-	-
1996	-	-	0.41	0.22	-	-	0.32	0.2	-	-	0.16	0.2	6.78	0.2	-	-
1997	-	-	0.46	0.22	-	-	0.28	0.2	-	-	0.1	0.21	7.83	0.2	-	-
1998	-	-	0.36	0.19	-	-	0.28	0.2	-	-	0.14	0.2	7.84	0.2	-	-
1999	-	-	0.37	0.2	-	-	0.3	0.2	-	-	0.13	0.2	7.48	0.2	-	-
2000	-	-	0.44	0.24	-	-	0.32	0.2	0.59	0.38	0.11	0.2	7.91	0.2	-	-
2001	-	-	0.4	0.22	-	-	0.35	0.21	1.13	0.34	0.12	0.2	-	-	-	-
2002	-	-	0.38	0.22	-	-	0.32	0.2	1.43	0.32	0.15	0.2	-	-	-	-
2003	-	-	0.27	0.18	-	-	0.28	0.19	1.01	0.33	0.14	0.2	-	-	-	-
2004	-	-	0.28	0.16	-	-	0.25	0.18	1.12	0.31	0.18	0.2	-	-	-	-
2005	-	-	0.3	0.16	-	-	0.24	0.19	0.95	0.3	0.13	0.2	-	-	14.96	0.2
2006	-	-	0.33	0.17	-	-	0.3	0.2	0.69	0.3	0.13	0.2	-	-	16.54	0.2
2007	-	-	0.39	0.19	-	-	0.33	0.21	0.72	0.32	0.13	0.2	-	-	13.71	0.2
2008	-	-	0.26	0.15	-	-	0.33	0.21	0.56	0.32	0.12	0.2	-	-	12.84	0.2
2009	-	-	0.35	0.18	-	-	0.32	0.21	0.71	0.32	0.12	0.2	-	-	10.42	0.2

	S1		S2		S3		S4		S5		S6		S7		S8	
Year	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
2010	-	-	0.32	0.18	-	-	0.25	0.19	0.72	0.32	0.11	0.2	-	-	9.52	0.2
2011	-	-	0.3	0.19	-	-	0.22	0.18	0.62	0.32	0.1	0.2	-	-	10.43	0.2
2012	-	-	0.3	0.2	-	-	0.2	0.18	0.84	0.32	0.11	0.2	-	-	9.07	0.2
2013	-	-	0.29	0.19	-	-	0.21	0.18	0.84	0.32	0.11	0.2	-	-	9.09	0.2
2014	-	-	0.3	0.19	-	-	0.2	0.18	0.79	0.33	0.14	0.2	-	-	9.35	0.2
2015	-	-	0.31	0.18	-	-	0.31	0.21	1.09	0.3	0.15	0.19	-	-	10.44	0.2
2016	-	-	0.43	0.21	-	-	0.3	0.21	1.08	0.31	0.13	0.2	-	-	12.07	0.2
2017	-	-	0.51	0.24	-	-	0.22	0.19	1.32	0.31	0.13	0.2	-	-	12.01	0.2
2018	-	-	0.67	0.32	-	-	0.27	0.2	1.68	0.29	0.13	0.19	-	-	10.06	0.2
2019	-	-	0.49	0.25	-	-	0.27	0.2	1.14	0.3	0.1	0.2	-	-	8.81	0.2
2020	-	-	0.47	0.24	-	-	0.31	0.22	1.42	0.29	0.08	0.2	-	-	9.15	0.2
2021	-	-	0.4	0.21	-	-	0.39	0.24	1.55	0.28	0.09	0.2	-	-	7.32	0.2

Table 4: Key life history parameters and model structures for the North Pacific swordfish stock assessment.

Parameter	Female	Male	Reference
Growth age for L1	0.5	0.5	-
Growth age for L2	15	15	-
Natural mortality	0.42 (0)	0.4 (0)	Kapur et al. 2017
	0.37 (1)	0.38 (1)	
	0.32 (2)	0.37 (2)	
	0.27 (3)	0.37 (3)	
	0.22 (4+)	0.37 (4)	
		0.37 (5)	
		0.36 (6+)	
L at Amin GP 1	80.1	83.2	DeMartini et al. 2007
L at Amax GP 1	226.3	206.4	DeMartini et al. 2007
VonBert K GP 1	0.246	0.271	DeMartini et al. 2007
CV young GP 1	0.1	0.1	
CV old GP 1	0.1	0.1	
Weight – length par 1	1.30E-05	1.30E-05	DeMartini et al. 2007
Weight – length par 2	3.07	3.07	DeMartini et al. 2007
50% maturity length	143.68	-	Kapur et al. 2017
Mat slope	-0.1034	-	
Fecundity	Proportional to spawning biomass	-	
Spawning season	July		Nishikawa 1985
R_0	0.42		
Steepness	0.9		Brodziak 2020

Table 5: 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 North Pacific swordfish used in the base-case model. S5 (TWN LL) and S8 (US LL shallow-late) were not included in the total likelihood.

Fleet	***N***	**Input log(SE)**	**RMSE**
S1_JPN_WCNPO_OSDWLL_early_Area1	18	0.201	0.15
S2_JPN_WCNPO_OSDWCOLL_late_Area1	28	0.203	0.18
S3_JPN_WCNPO_OSDWLL_early_Area2	18	0.202	0.17
S4_JPN_WCNPO_OSDWLL_late_Area2	28	0.198	0.16
S5_TWN_WCNPO_DWLL_late	22	0.205	0.32
S6_US_WCNPO_LL_deep	27	0.20	0.13
S7_US_WCNPO_LL_shallow_early	6	0.20	0.03
S8_US_WCNPO_LL_shallow_late	17	0.20	0.19

Table 6: Fishery-specific selectivity assumptions for the North Pacific swordfish 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	Asymptotic lognormal - Time Varying
F3	Double normal
F4	Asymptotic lognormal
F5	Mirror F4
F6	Double-normal
F7	Double-normal
F8	Double-normal
F9	Mirror F8
F10	Mirror F6
F11	Mirror F6
F12	Mirror F1
F13	Mirror F2
F14	Mirror F1
F15	Mirror F2
F16	Mirror F2
F17	Mirror F3
F18	Mirror F3
F19	Mirror F2
S1	Mirror F6
S2	Mirror F1
S3	Mirror F3
S4	Mirror F3
S5	Mirror F2
S6	None
S7	Mirror F8
S8	Mirror F3

Table 7: Complete list of sensitivity runs conducted for the 2023 stock assessment of North Pacific swordfish.

RUN	NAME	DESCRIPTION
Alternative Life History Parameters: Natural Mortality		
1	base_case_highM	Alternative natural mortality rates are 10% lower than in the base case
2	base_case_lowM	Alternative natural mortality rates are 10% higher than in the base case
Alternative Life History Parameters: Stock-Recruitment Steepness		
3	base_case_h070	Alternative lower steepness with h=0.70
4	base_case_h081	Alternative lower steepness with h=0.81
5	base_case_h099	Alternative higher steepness with h=0.99
Alternative Life History Parameters: Growth Curves		
6	base_case_large_Amax	Alternative growth curve with a 10% larger maximum size for each sex.
7	base_case_Sun_Growth	Alternative growth curves using growth parameters from Sun et al. (2002)
Alternative Life History Parameters: Maturity Ogive		
8	base_case_high_L50	Alternative maturity ogives with L50 set 10% higher than base case
9	base_case_low_L50	Alternative maturity ogives with L50 set 10% lower than base case
10	base_case_Wang2003	Alternative maturity ogives with converted L50 from Wang et al. (2003)
Alternative catch assumption		
11	Drop_VNCN_catch	Drop the Vanuatu and Chinese catch
12	NP_all_catch	Use all catches in North Pacific Ocean
13	Orphan catch	Use the catch of unclaimed area between 3 Pacific sword fish stocks
Alternative model setting assumption		
14	Change Amin to 1.0	Alternative setting of Amin
15	Fit to S6	Lambda of US Deep CPUE change to 0
16	Alternative selectivity of TW	Alternative selectivity of Taiwanese to double normal
17	Add F9 of size data	Add the size data of US Deep LL
18a	S1 and S2	Include only the S1 and S2 CPUE indices
18b	S3 and S4	Include only the S3 and S4 CPUE indices
18c	S5 only	Include only on S5 CPUE index
18d	S7 only	Include only the S7 CPUE index
18e	S8 only	Include only the S8 CPUE index
18f	S7 and S8	Include only the S7 and S8 CPUE indices
19	All CPUE scenario	Use all CPUEs including the dropped CPUE

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(R0)). Likelihoods are relative to the minimum negative log-likelihood (best-fit) for each respective data component. Colors indicate relative likelihood (green: low negative log-likelihood, better-fit; red: high negative log-likelihood, poorer-fit). Maximum likelihood estimate of log(R0) was 6.84. See Table 1 for a description of the abundance indices. S5 and S8 were not included in the total likelihood.

ln(R0)	S1	S2	S3	S4	S6
6.2	3.04	8.83	0.66	3.70	9.18
6.3	3.16	8.83	1.07	3.03	8.03
6.4	3.36	7.36	0.02	2.58	6.19
6.5	1.37	15.13	0.81	2.50	3.55
6.6	2.30	4.70	0	1.27	2.11
6.7	0.70	2.53	0.28	0.32	0.04
6.8	0.04	0.61	0.89	0	0
6.84	0	0.36	1.01	0.05	0.21
6.9	0	0.15	1.07	0.11	0.45
7	0.04	0.02	1.08	0.19	0.71
7.1	0.09	0	1.04	0.25	0.86
7.2	0.14	0.05	0.99	0.28	0.96
7.3	0.19	0.11	0.94	0.31	1.03
7.4	0.23	0.18	0.89	0.32	1.09
7.5	0.27	0.25	0.85	0.33	1.14
7.6	0.30	0.31	0.81	0.34	1.18
7.7	0.33	0.37	0.78	0.35	1.21
7.8	0.36	0.43	0.76	0.36	1.24

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 6.84. See Table 1 for a description of the composition data.

ln(R0)	F1	F2	F3	F4	F6	F7	F8
6.2	2.65	14.23	0	2.11	27.94	2.31	6.94
6.3	5.87	13.58	0.10	2.02	14.20	2.20	4.21
6.4	1.45	12.10	0.14	1.89	11.83	2.04	3.30
6.5	9.85	8.15	0.39	1.56	7.27	1.64	6.27
6.6	0	8.50	0.44	1.53	2.18	1.61	1.27
6.7	0.05	4.57	0.96	1.13	0.06	1.21	0.82
6.8	0.87	0.62	1.88	0.65	0	1.03	0.56
6.84	1.04	0	2.18	0.55	0.08	1.01	0.49
6.9	1.28	0.06	2.50	0.47	0.20	0.99	0.41
7	1.67	1.63	2.89	0.35	0.36	0.92	0.30
7.1	2.04	4.03	3.16	0.26	0.49	0.81	0.22
7.2	2.36	6.67	3.36	0.19	0.59	0.65	0.15
7.3	2.66	9.27	3.50	0.13	0.67	0.46	0.10
7.4	2.92	11.73	3.61	0.09	0.72	0.31	0.08
7.5	3.15	14.02	3.70	0.06	0.77	0.24	0.06
7.6	3.34	16.10	3.78	0.03	0.81	0.14	0.04
7.7	3.51	18.00	3.84	0.01	0.84	0.06	0.02
7.8	3.66	19.72	3.89	0	0.87	0	0

Table 10: Time series of total biomass (age 1 and older, metric ton), spawning stock biomass (metric ton), age-0 recruitment (thousands of fish), and instantaneous fishing mortality (age 1-10, year^{-1}) for the 2023 North Pacific swordfish estimated in the base-case model. SD = standard deviation.

Year	**Age 1+ biomass (mt)**	**Spawning stock biomass (mt)**		**Recruitment (1000 age-0 fish)**		**Instantaneous fishing mortality**	
	Mean	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1975	78466	28295	18702	777	273	0.13	0.03
1976	79051	28426	15741	768	255	0.15	0.03
1977	76981	28165	13091	704	226	0.14	0.03
1978	74911	27121	11181	596	192	0.17	0.03
1979	69354	25744	9889	683	233	0.16	0.03
1980	65723	24384	8950	1169	383	0.15	0.03
1981	67123	22415	8108	937	346	0.13	0.02
1982	70283	22796	7620	772	284	0.11	0.02
1983	74496	23978	7521	1430	394	0.14	0.03
1984	79859	25288	7632	1017	283	0.12	0.02
1985	85036	25899	7787	933	235	0.14	0.02
1986	86914	27908	8164	888	275	0.14	0.02
1987	87231	29242	8482	825	214	0.15	0.02
1988	85070	29278	8614	813	201	0.15	0.02
1989	82207	29180	8620	675	217	0.13	0.02
1990	79792	29174	8563	711	222	0.12	0.02
1991	78010	29914	8418	777	230	0.11	0.02
1992	78049	29519	8113	727	212	0.12	0.02
1993	76954	28766	7630	673	185	0.12	0.02
1994	74709	27973	6730	698	157	0.10	0.01
1995	74073	28180	5921	1323	150	0.09	0.01
1996	79740	27529	5303	752	99	0.09	0.01
1997	82983	28322	5003	708	94	0.09	0.01
1998	85797	31019	5004	1202	134	0.19	0.02
1999	81786	29254	5001	822	109	0.12	0.01
2000	82916	27872	4967	707	99	0.14	0.01
2001	80057	28485	5022	729	98	0.12	0.01
2002	79474	29426	5100	881	108	0.11	0.01
2003	79614	29287	5106	1019	121	0.11	0.01
2004	81089	28684	5064	1192	134	0.11	0.01

Year	Age 1+ biomass (mt)	Spawning stock biomass (mt)		Recruitment (1000 age-0 fish)		Instantaneous fishing mortality	
	Mean	Mean	SD	Mean	SD	Mean	SD
2005	85253	28137	5032	851	110	0.11	0.01
2006	87537	29204	5096	819	101	0.13	0.01
2007	87127	30073	5217	791	96	0.13	0.01
2008	85142	30776	5326	746	91	0.12	0.01
2009	83044	30795	5368	660	84	0.12	0.01
2010	80447	30722	5365	774	93	0.11	0.01
2011	79212	30696	5322	728	92	0.10	0.01
2012	79056	30022	5231	758	96	0.11	0.01
2013	78097	29510	5138	896	112	0.10	0.01
2014	78997	28759	5053	971	123	0.11	0.01
2015	80374	27947	5003	1016	130	0.11	0.01
2016	83200	28205	5046	964	130	0.10	0.01
2017	86835	29785	5211	747	109	0.09	0.01
2018	89418	31661	5455	783	113	0.10	0.01
2019	89617	33761	5713	739	116	0.09	0.01
2020	89992	35159	5896	625	112	0.09	0.01
2021	88755	35778	6009	633	122	0.09	0.01

Table 11: Estimated biological reference points derived from the Stock Synthesis base case model for North Pacific swordfish 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 5-year SSB0 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 1-10)	0.16
F_{MSY} (age 1-10)	0.18
F_{2021}	0.09
$F_{2019-2021}$	0.09
$SSB_{F=0}$	95,732
$20\%SSB_{F=0}$	19,146
SSB_{MSY}	16,388
SSB_{2021}	35,778
$SSB_{2019-2021}$	34,899
$C_{20\%SSB(F=0)}$	14,815
C_{MSY}	14,924
$C_{2019-2021}$	10,653
$SPR_{20\%SSB(F=0)}$	22%
SPR_{MSY}	19%
SPR_{2021}	44%
$SPR_{2019-2021}$	43%

Table 12: Projected median values of North Pacific swordfish spawning stock biomass (SSB, mt) and catch (mt) in 2022-2031.

Year	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Scenario 1: $F_{20\%SSB(F=0)}$										
SSB	40,457	38,288	36,295	35,452	35,425	35,611	36,064	36,387	36,264	36,478
Catch	16,906	14,986	13,531	13,120	13,298	13,612	13,875	14,053	14,161	14,220
Scenario 2: $F_{1998-2000}$										
SSB	41,567	40,422	38,952	38,309	38,371	38,565	39,133	39,534	39,336	39,625
Catch	14,302	13,389	12,608	12,428	12,656	12,967	13,224	13,399	13,509	13,572
Scenario 3: Low F ($F_{SPR30\%}$)										
SSB	42,268	42,368	41,811	41,756	42,235	42,712	43,610	44,300	44,162	44,705
Catch	11,370	11,249	11,096	11,255	11,623	11,990	12,263	12,445	12,557	12,631
Scenario 4: F_{MSY}										
SSB	38,291	34,051	31,164	29,979	29,800	29,894	30,225	30,452	30,322	30,473
Catch	23,395	17,817	14,992	14,169	14,264	14,565	14,812	14,966	15,052	15,095
Scenario 5: $F_{Status\ Quo}$ (Average $F_{2019-2021}$)										
SSB	38,828	35,056	32,339	31,201	31,036	31,138	31,489	31,733	31,602	31,765
Catch	21,803	17,218	14,723	13,981	14,082	14,379	14,627	14,785	14,875	14,921

FIGURES

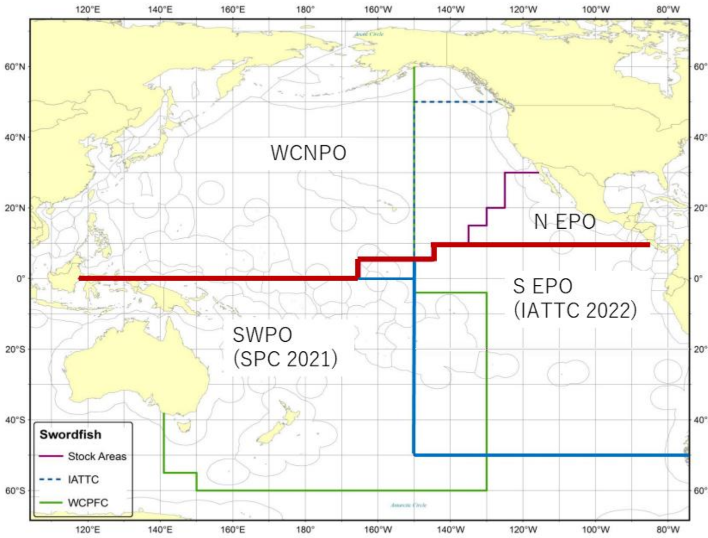


Figure 1: Western and Central North Pacific Ocean and North Eastern Pacific Ocean swordfish stock boundaries for the 2023 North Pacific swordfish assessment. Spatial structure is treated implicitly using fleets as areas.

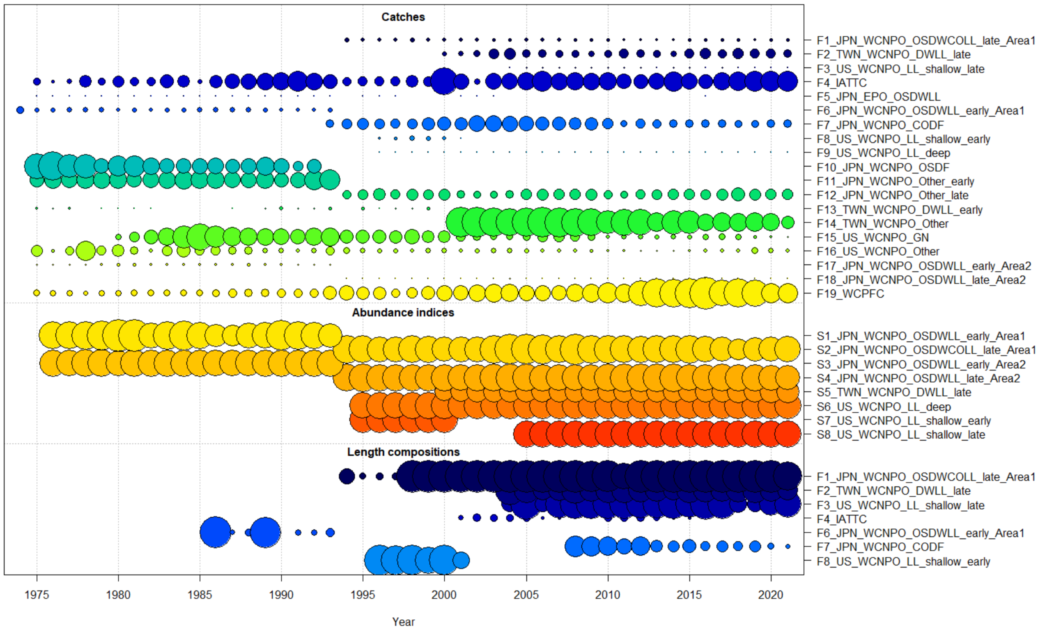


Figure 2: Catch, CPUE index, and size composition data included in the 2023 NP swordfish stock assessment. The size of the bubble indicates the relative number of observations available.

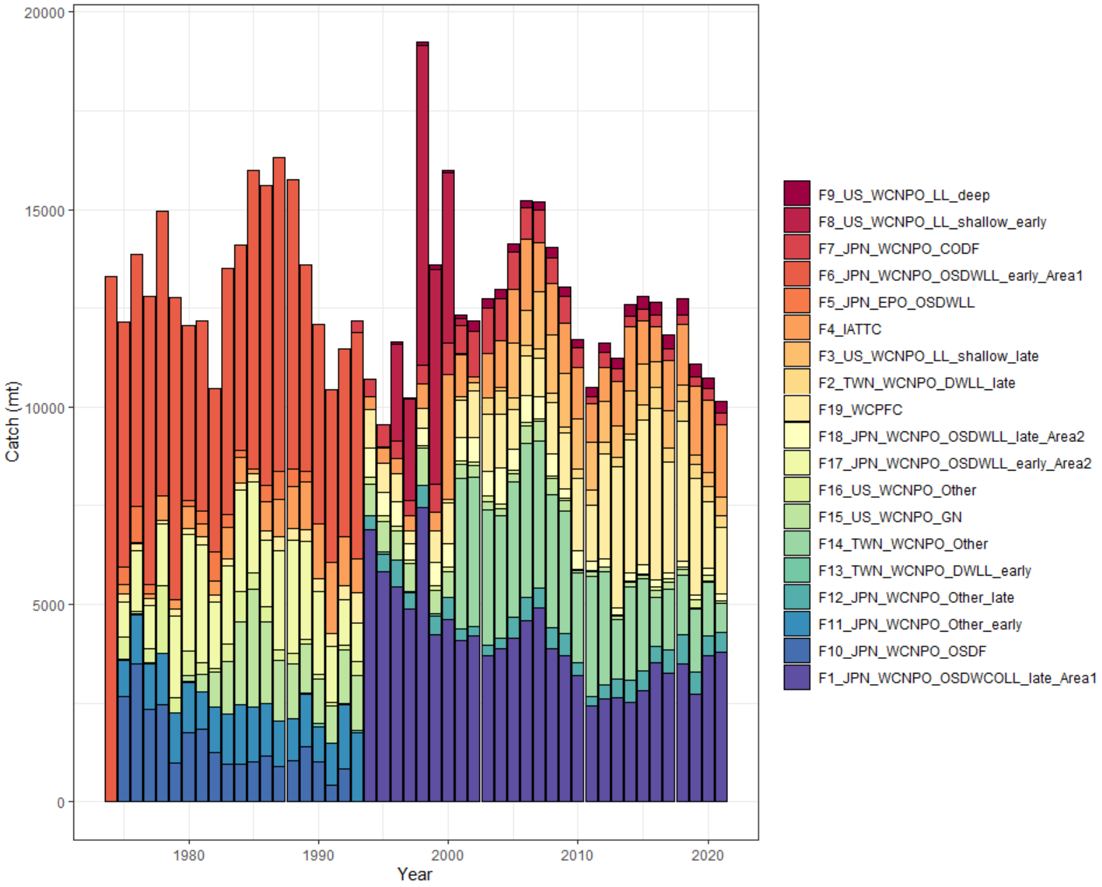


Figure 3: Total annual catch of the North Pacific swordfish by all fisheries harvesting the stock during 1975-2021. See Table 1 for the reference code for each fishery.

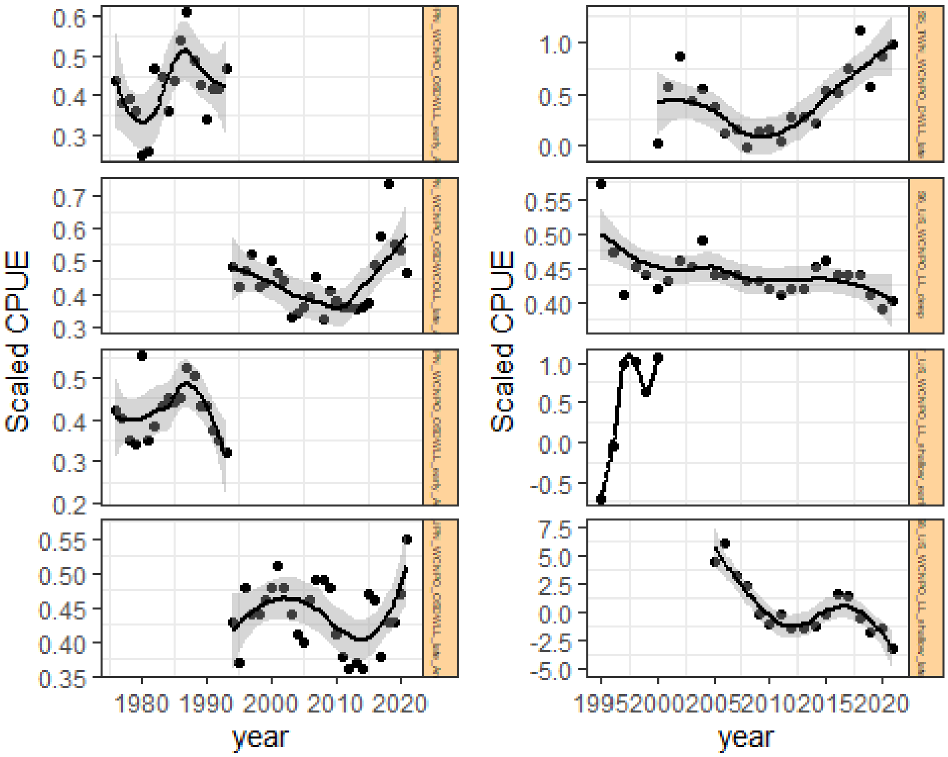


Figure 4: Plot of CPUE index by fleet with a simple loess smoother fit to each time series. This provides information on the general trend of the indices considered for inclusion in the model and identifies potential conflict between indices.

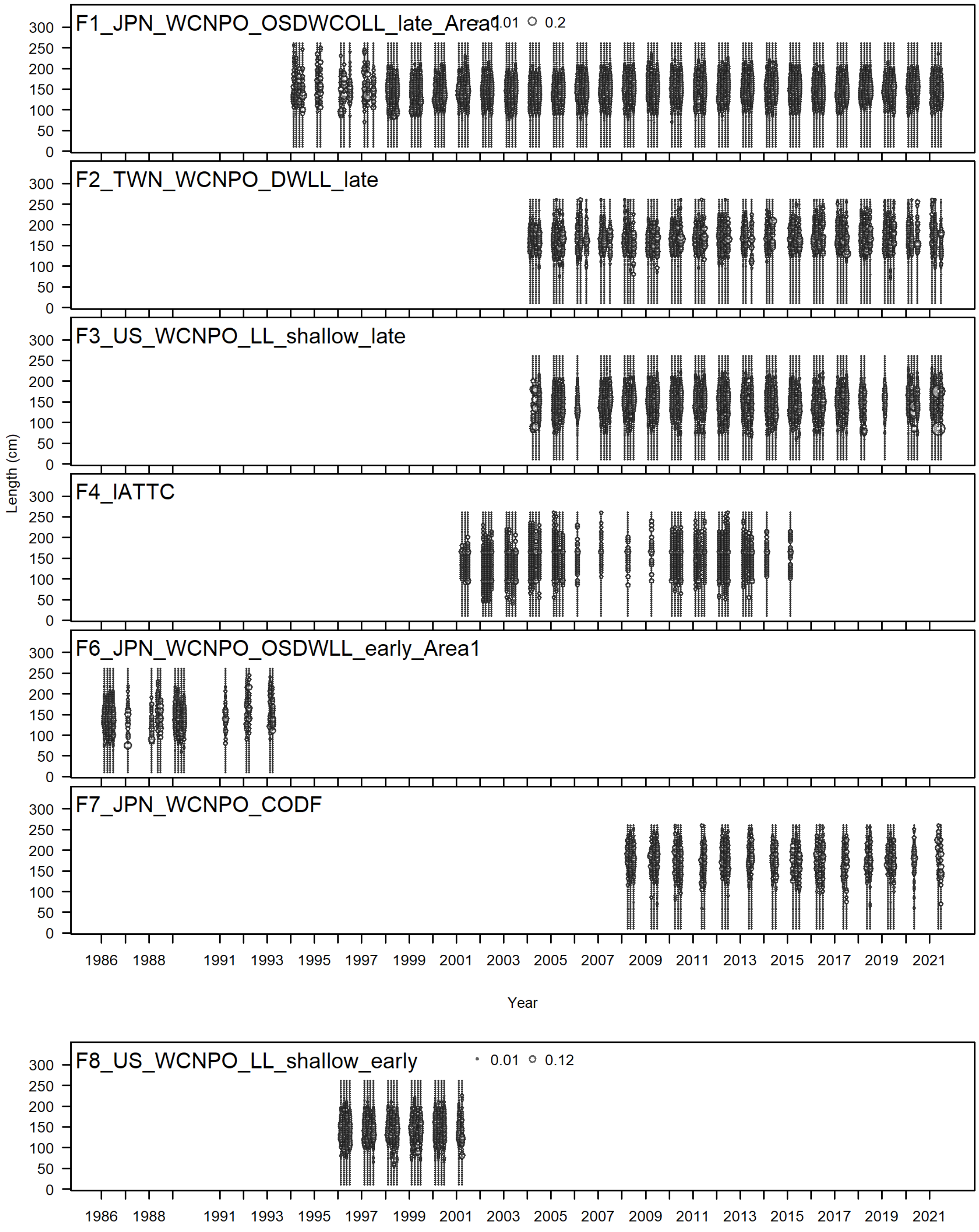


Figure 5: Length Composition data available in 5cm size bins for the 2023 North Pacific swordfish (Xiphias gladius) stock assessment.

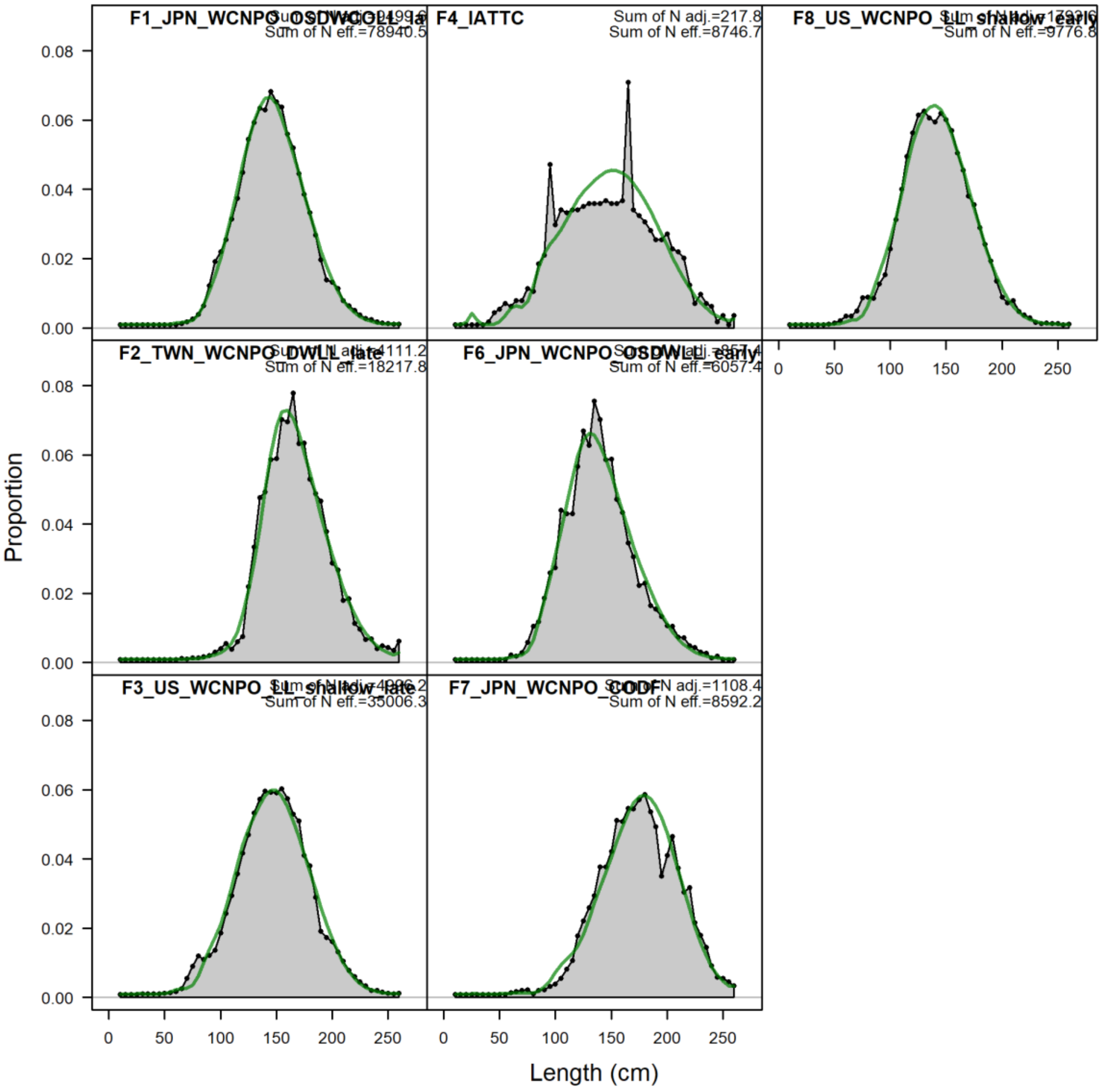


Figure 6: Aggregated Size comp data (grey) and model fit (green)

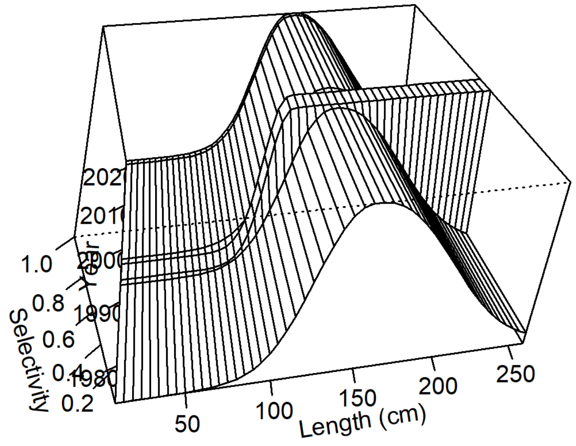


Figure 7: Time-varying selelctivity estimated for F01 Japanese LL Area 1 Late.

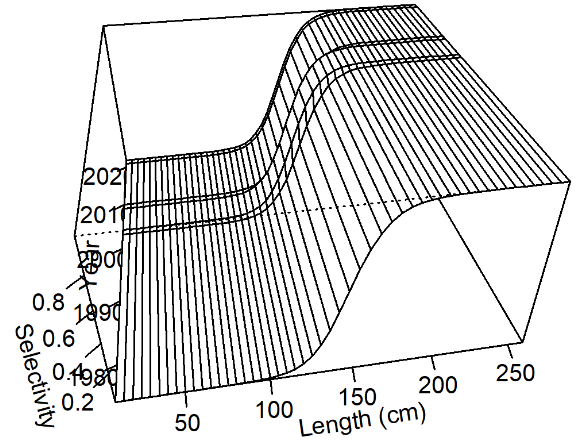
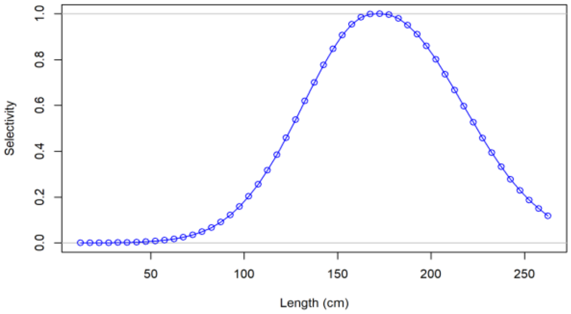
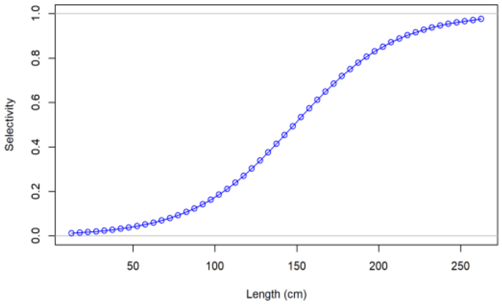


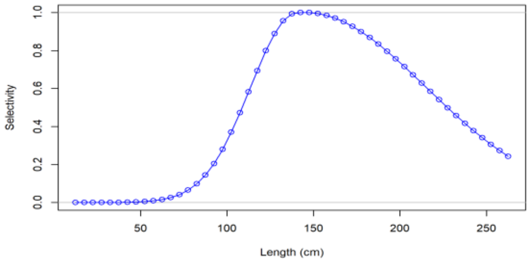
Figure 8: Time-varying selectivity estimated for F02 Chinese Taipei LL late.



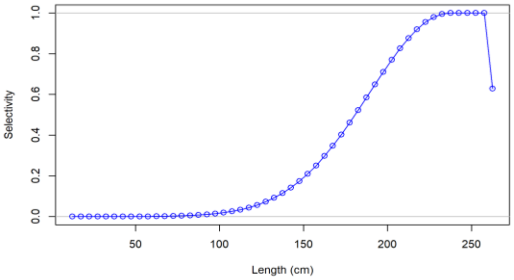
F03_US_WCNPO_LL_shallow_late



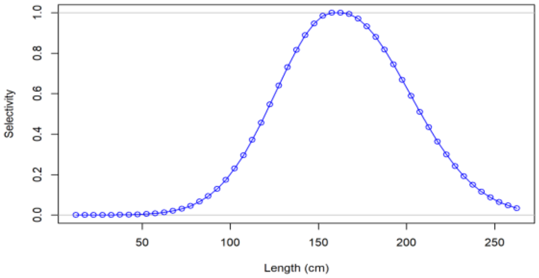
F04_IATTC



F06_JPN_WCNPO_OSDWLL_early_Area1



F07_JPN_WCNPO_CODF



F08_US_WCNPO_LL_shallow_early

Figure 9: Selectivity estimates for each of the five fleets without time-varying parameters.

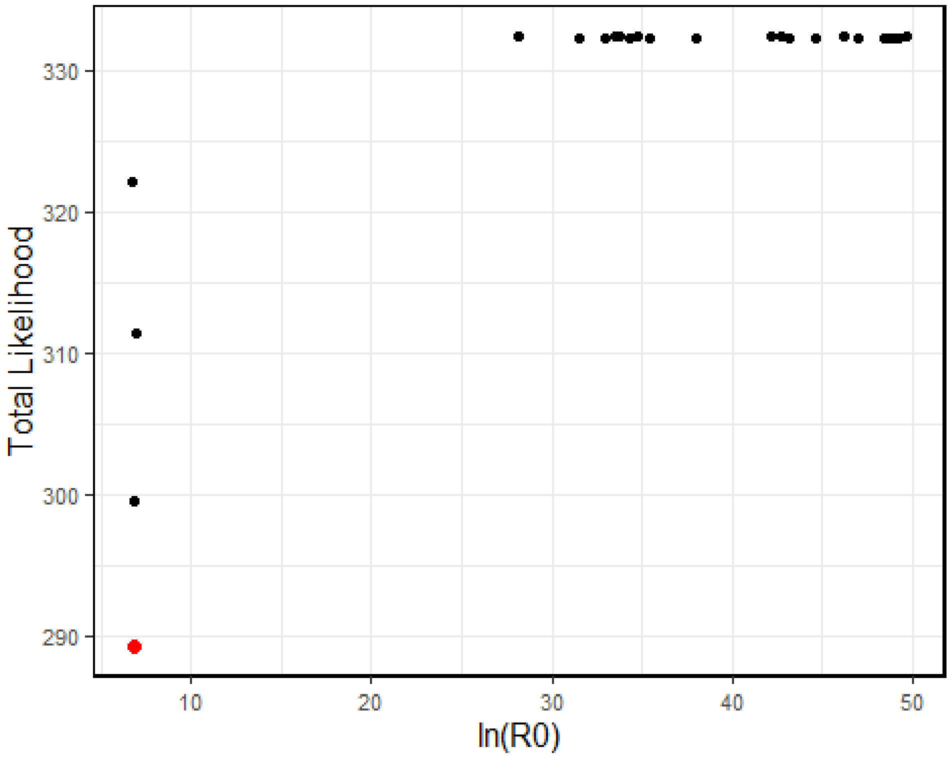


Figure 10: Plot of RO versus total likelihood for 100 jitter runs for the base-case model (black points). The base-case model is indicated by the red point.

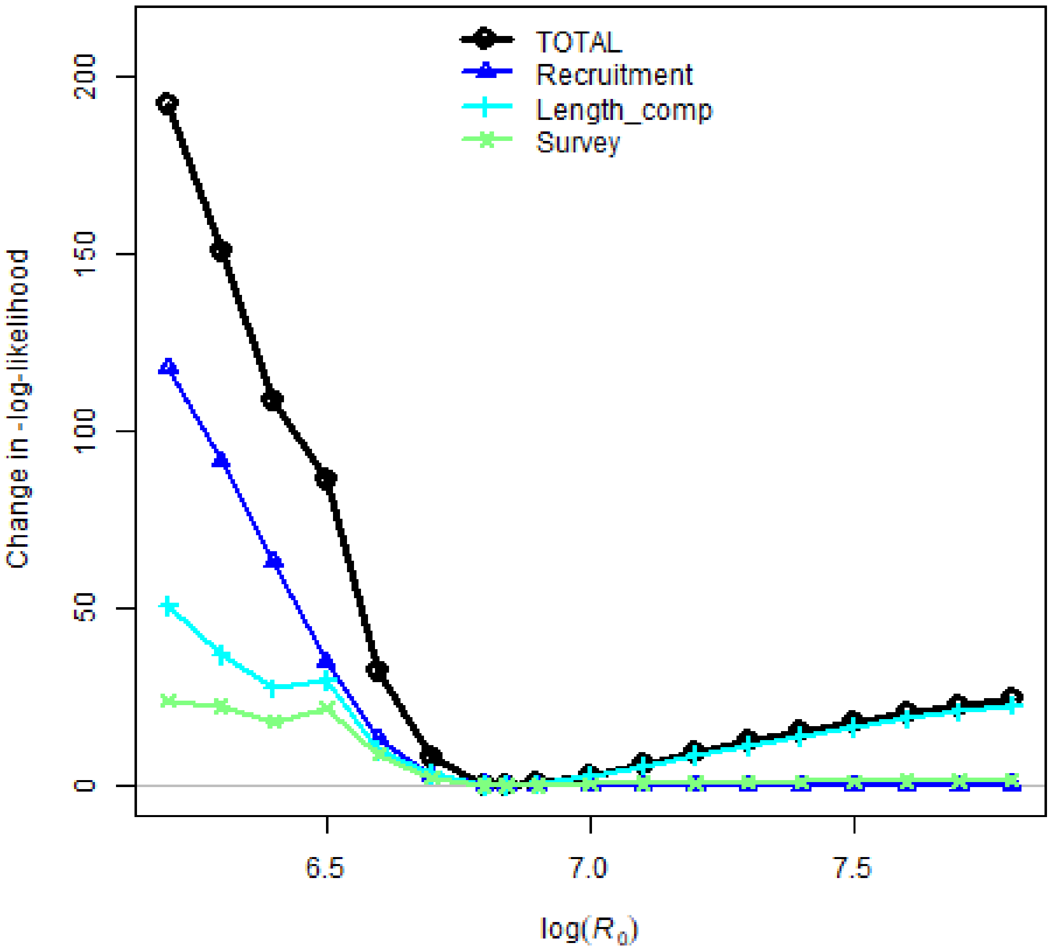


Figure 11: Likelihood profile over R0 for the base-case model: total likelihood (black circles), recruitment (blue triangles), length composition data (light blue crosses), and survey/CPUE indices (yellow x).

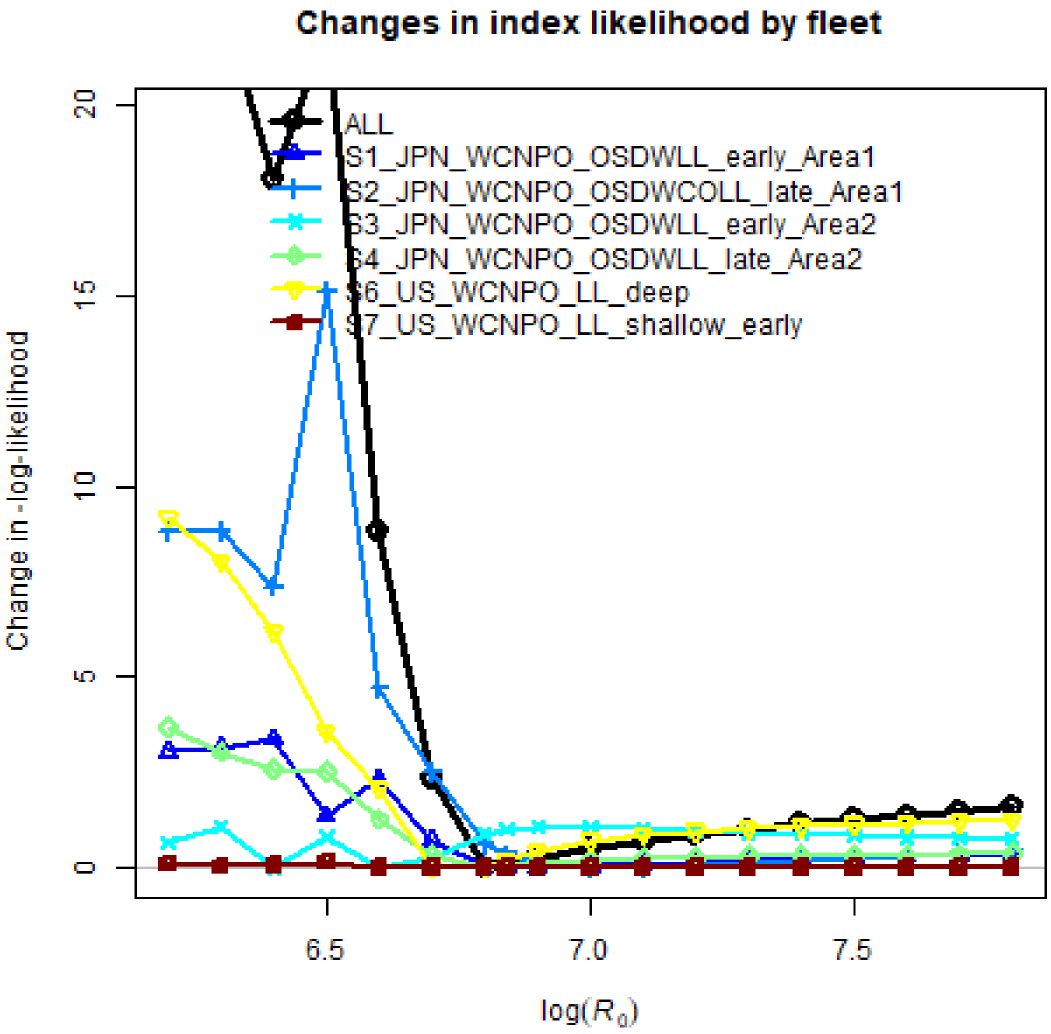


Figure 12: Likelihood profile over R0 by CPUE index for the base-case model.

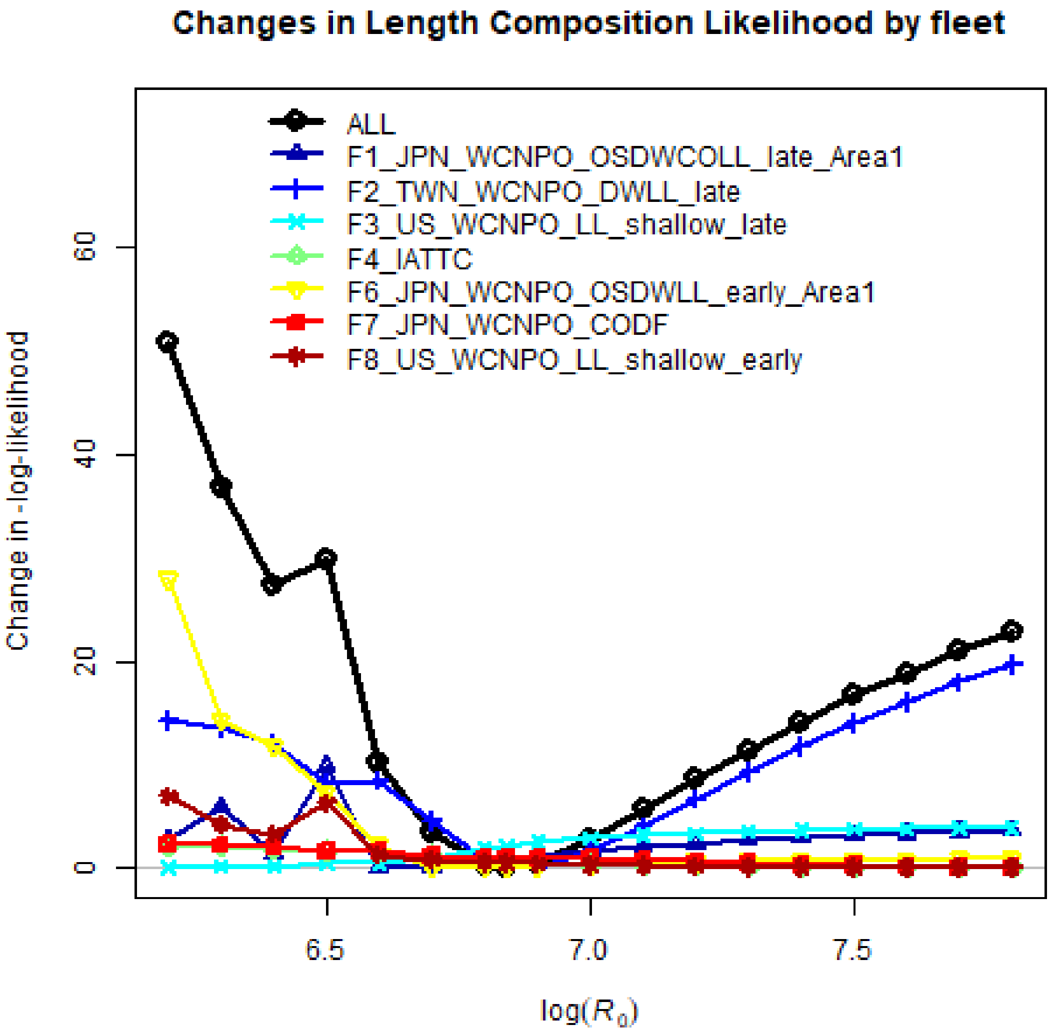


Figure 13: Likelihood profile over R0 for each length composition time series for the base-case model.

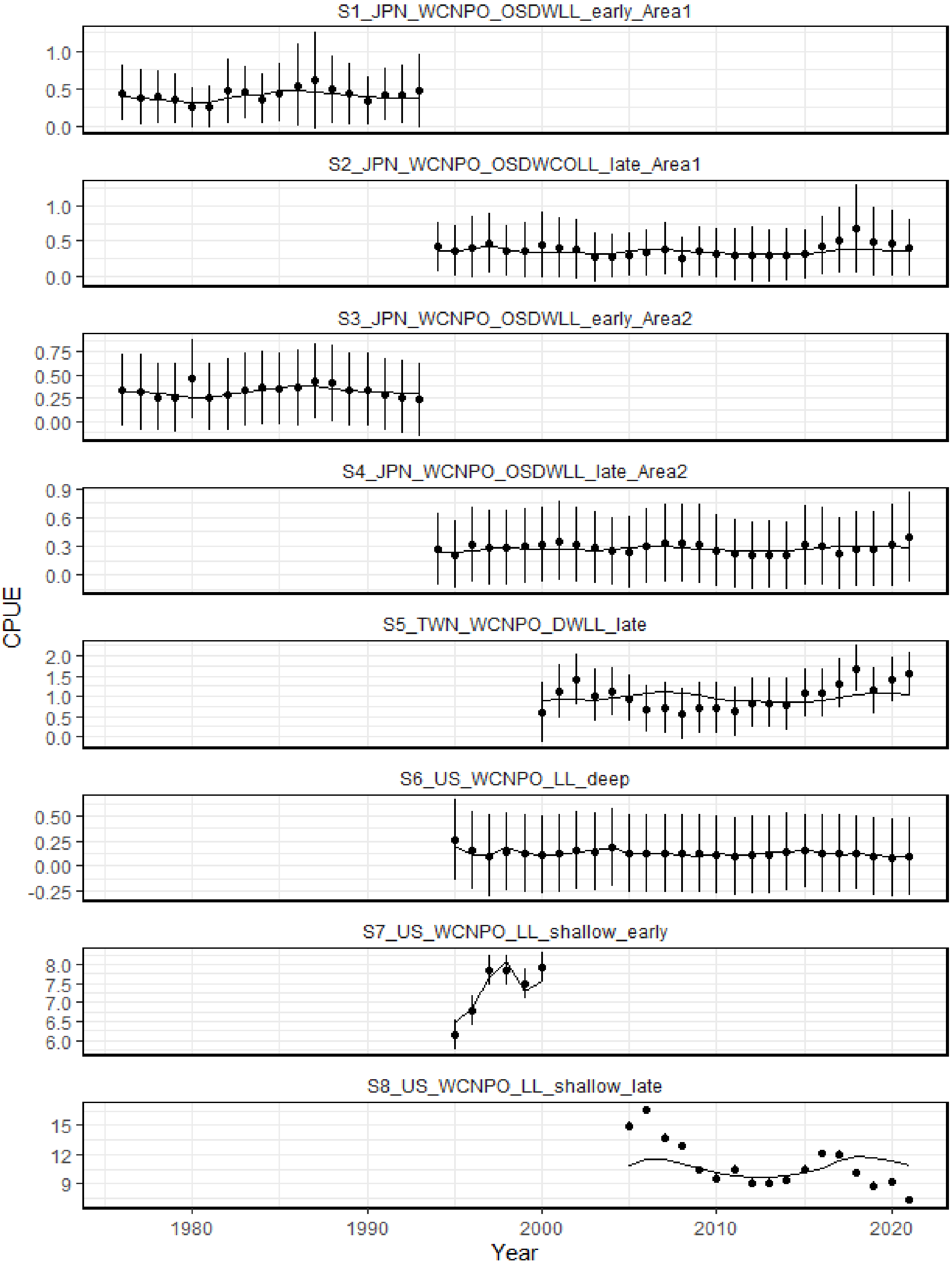


Figure 14: Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. S5 and S8 were not included in the total likelihood.

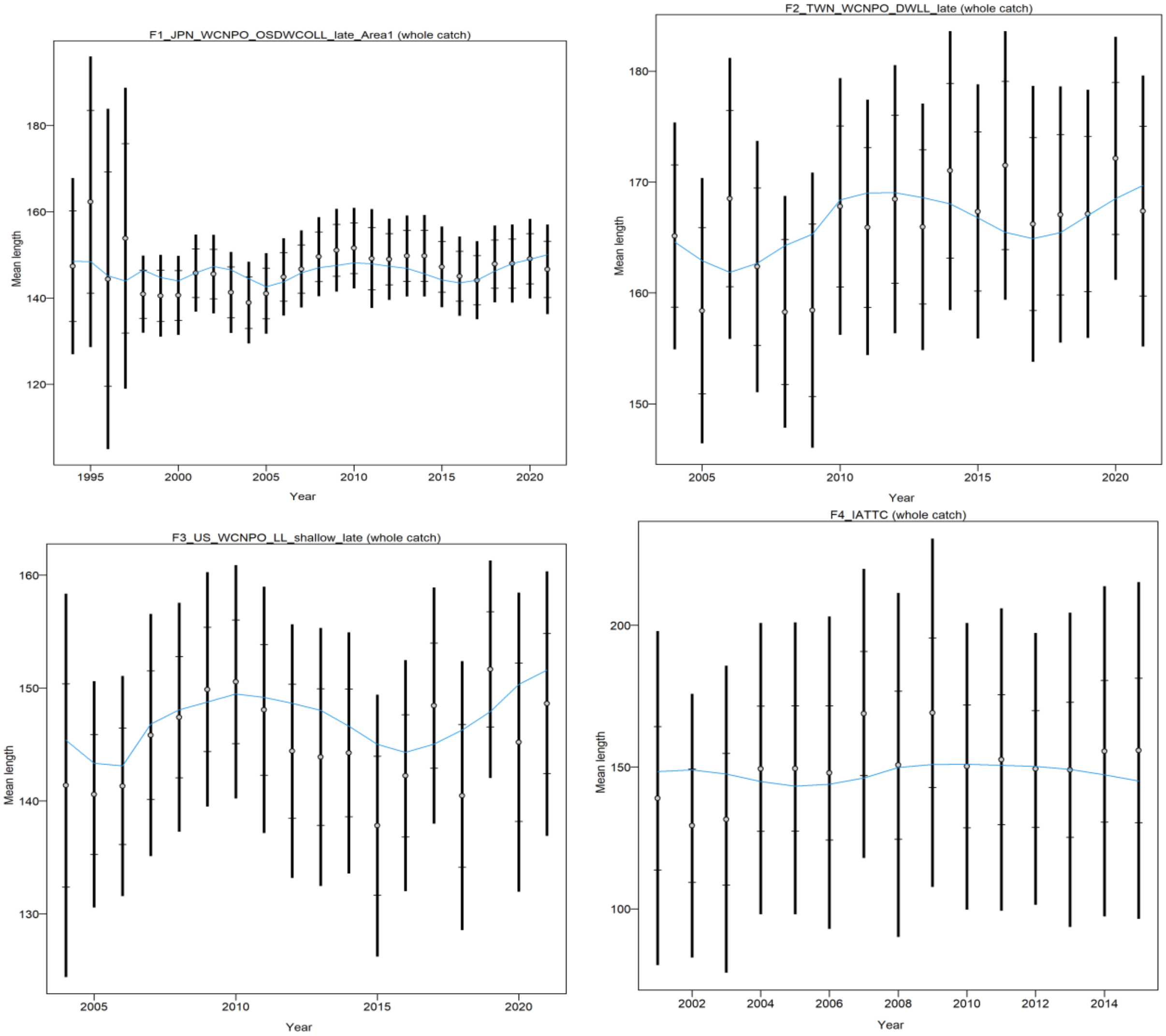


Figure 15: Fits to the annual mean length composition data. The blue line indicates the estimated mean length, open dots indicate input mean length with black bars indicating the distribution of the length data with the added variance.

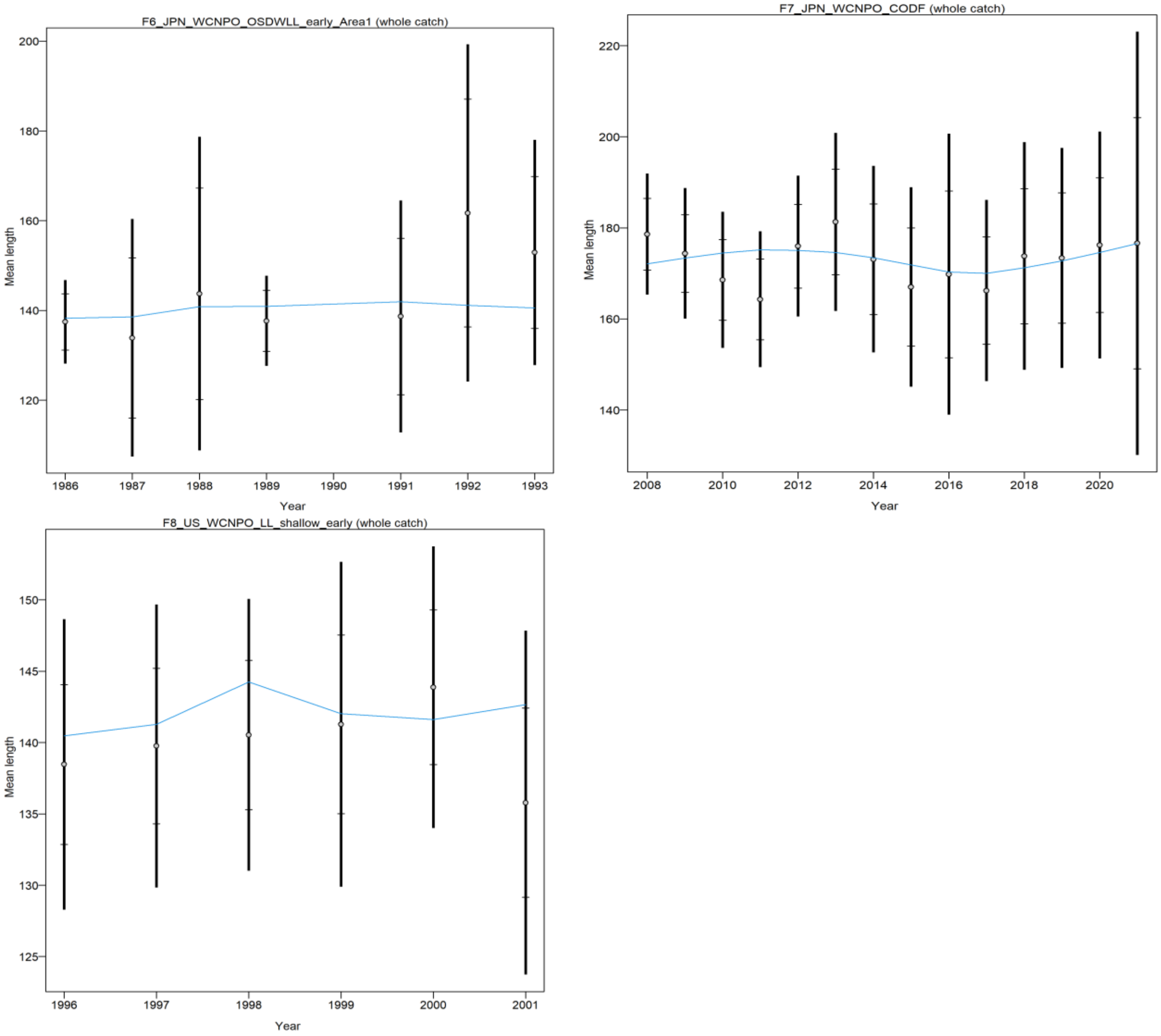


Figure 15: Continued.

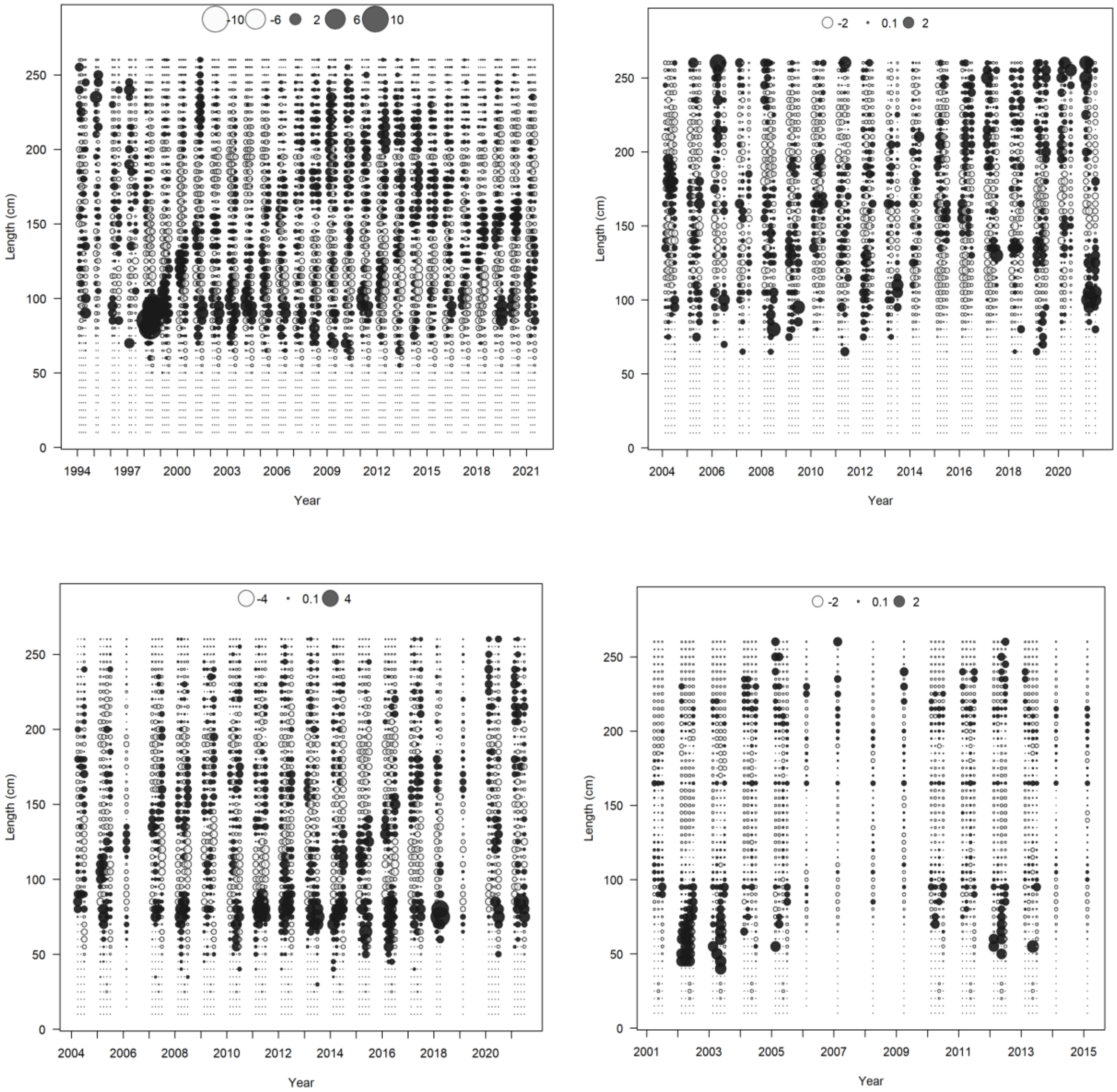


Figure 16: Quarterly residual plots the length composition data by fleet. Open circles indicate negative residuals and closed circles indicate positive residuals.

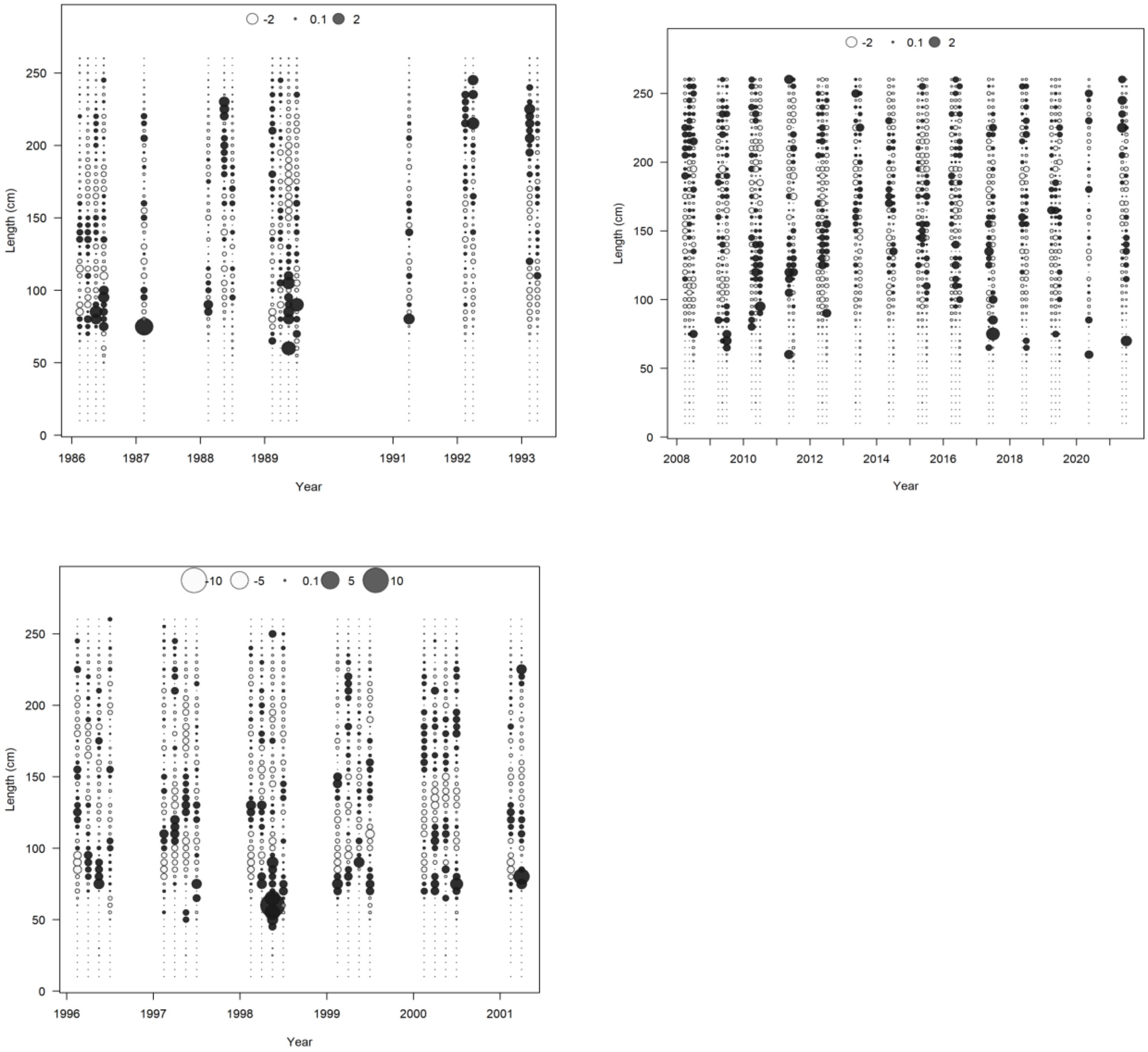


Figure 16: Continued.

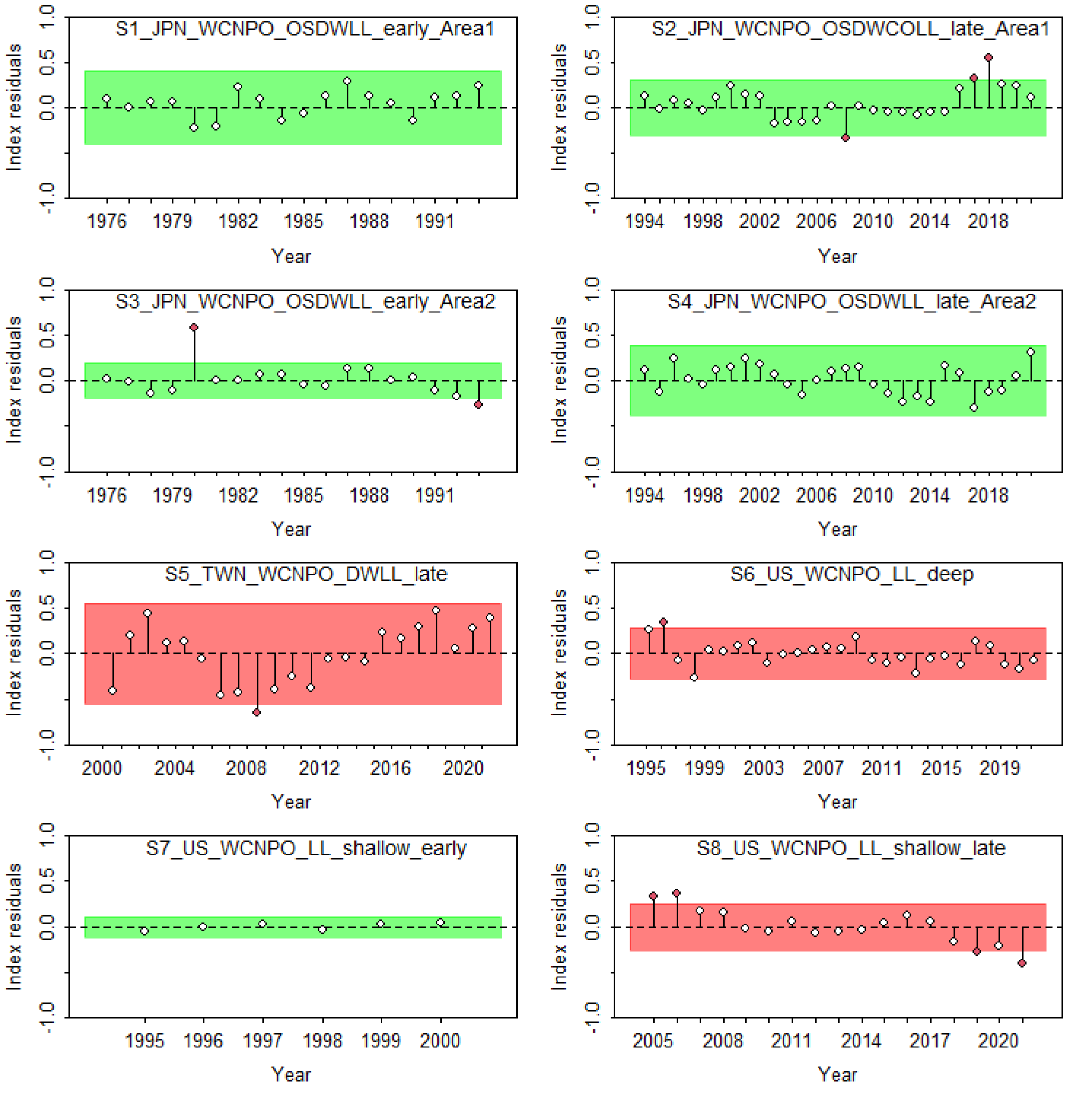


Figure 17: Results from a runs test for each CPUE index. Red indicates the index failed the test (residuals are not random), green indicates the index passed the test.

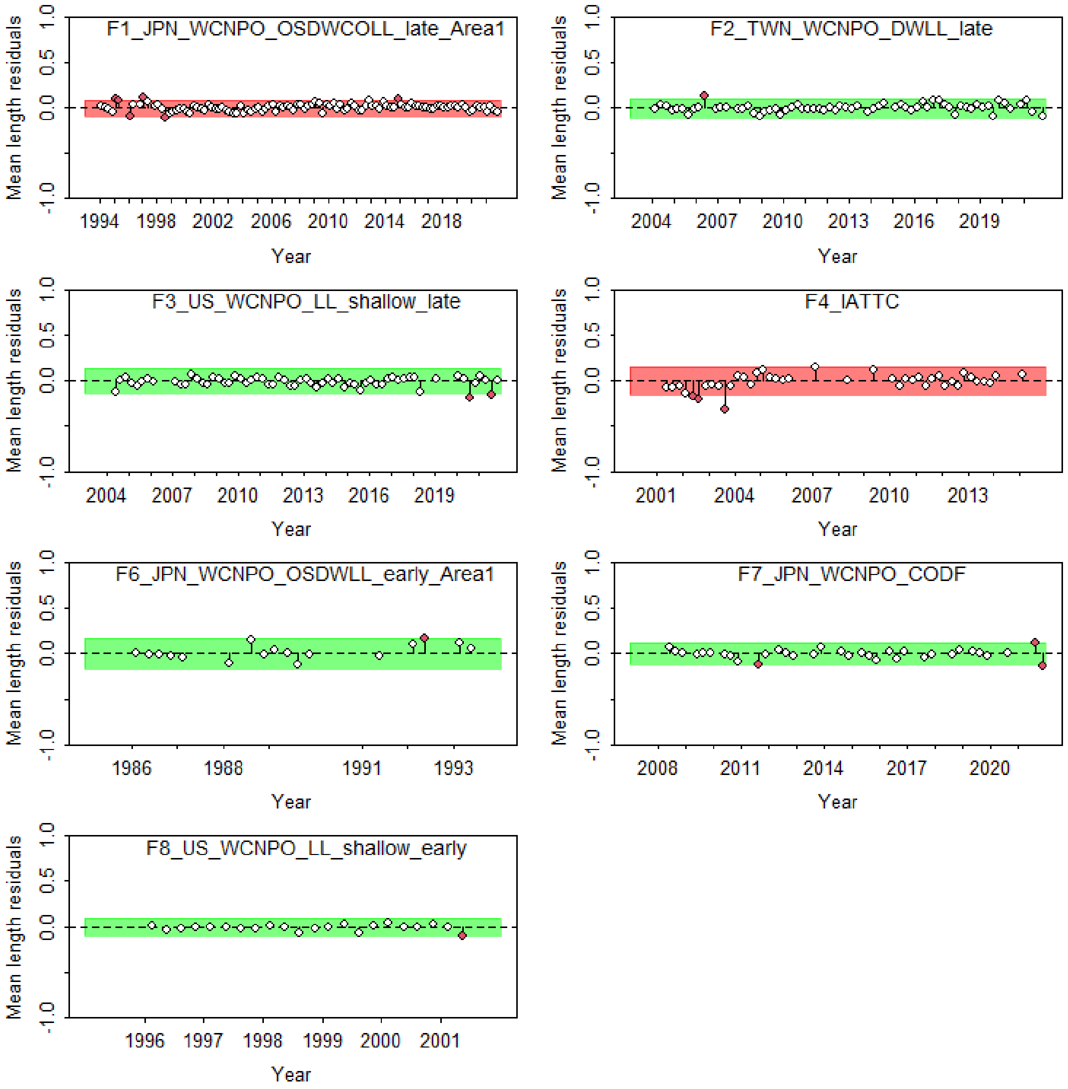


Figure 18: Results from a runs test for each size composition time series. Red indicates the time series failed the test (residuals are not random), green indicates the time series passed the test.

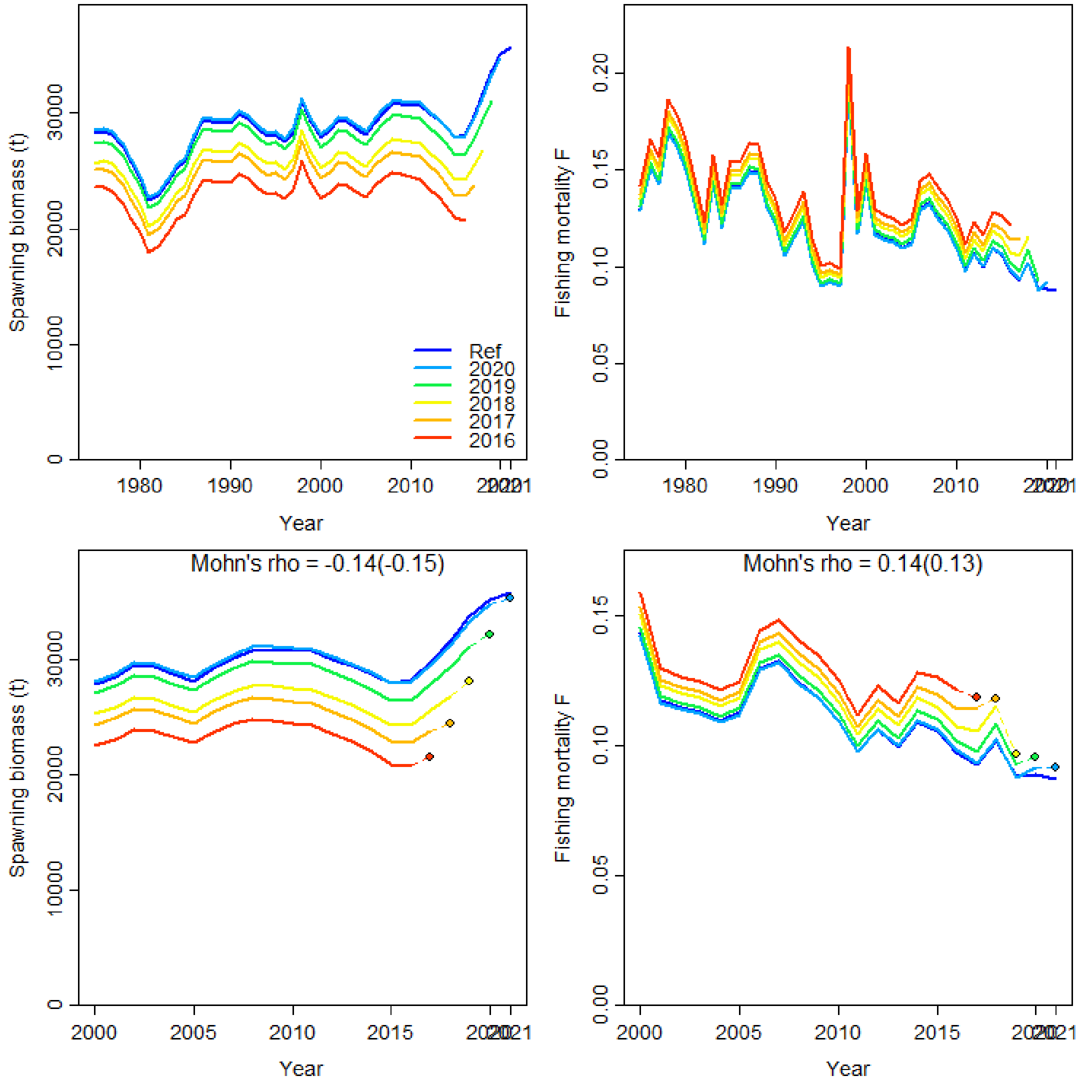


Figure 19: Retrospective analysis of spawning biomass (left) and fishing mortality (right) for the whole time series (top) and the last 20 years (bottom) consisting of 5 reruns of the base case model each fitted with one more year of data removed from the base case model (blue line).

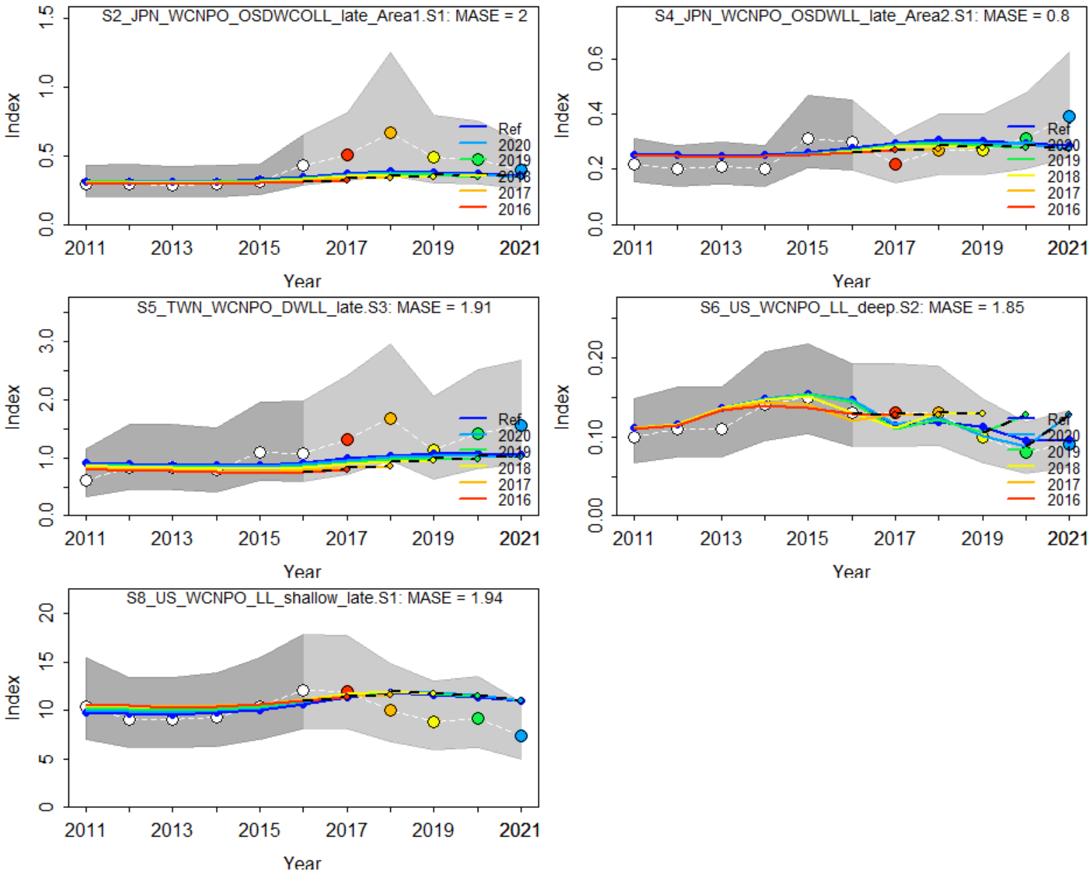


Figure 20: Hind casting cross-validation (HCxval) results for Japanese longline late area 1 (top right), Japanese LL late area 2 (top left), Chinese Taipei deep water longline late (center right), US Hawaii deep-set longline (center left) CPUE, and US Hawaii deep-set longline (bottom left) fits, showing 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.

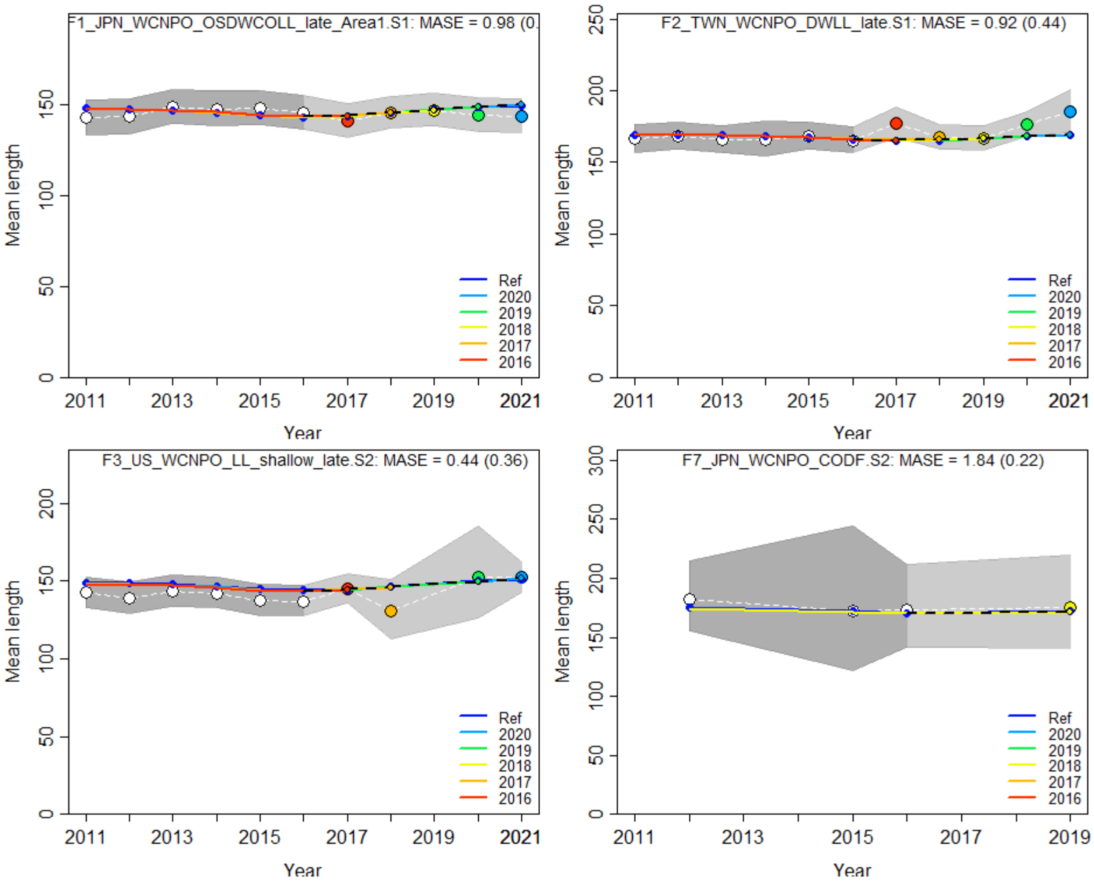


Figure 21: Hind casting cross-validation (HCxval) results for size composition mean lengths, showing observed (large points with dashed line), fitted (solid lines), and one-year-ahead forecast values (small terminal points) in the old growth model. The observations used for cross-validation are highlighted 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.

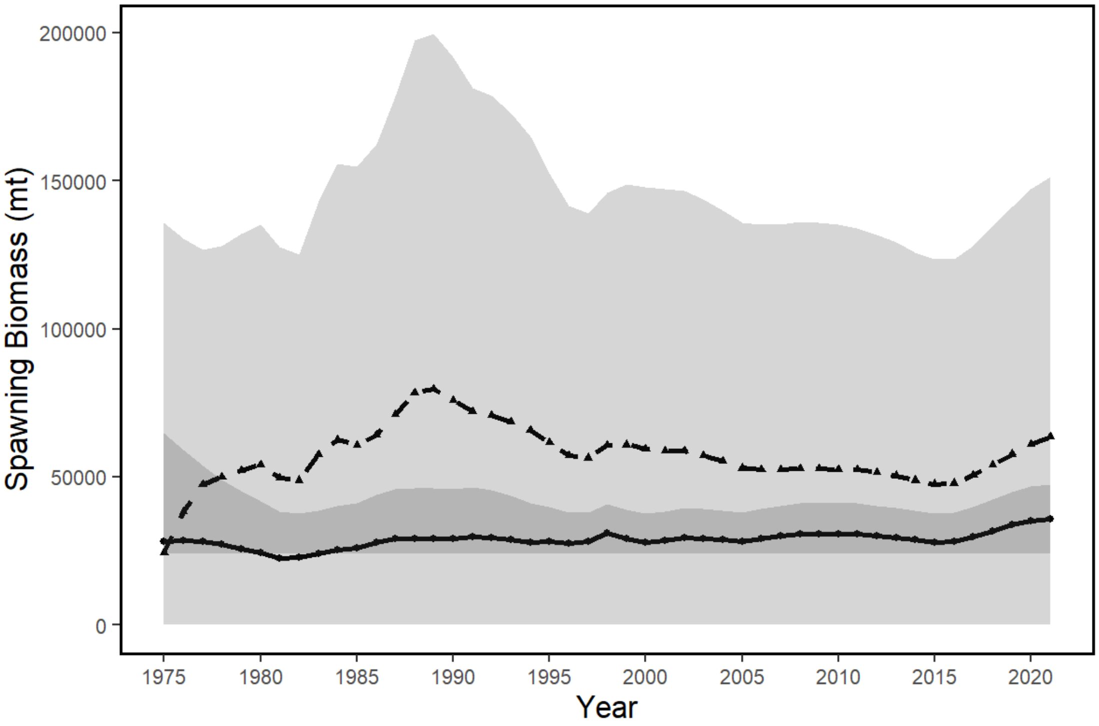
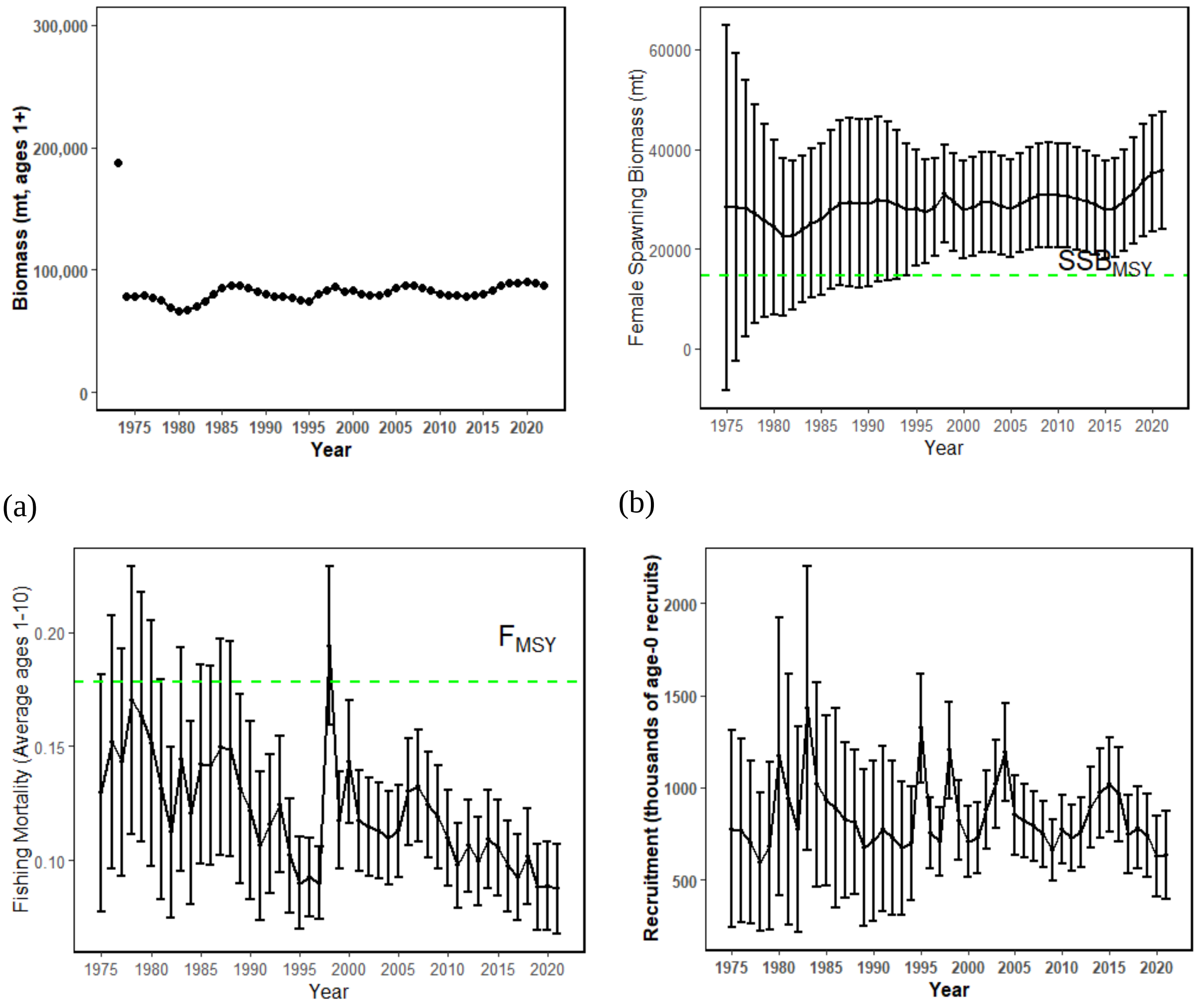


Figure 22: Spawning stock biomass trend for the ASPM model run (dashed line, triangles) and the base-case model (solid line, circles). Grey shading indicates 95% confidence intervals for each model.



(a) (b)

(c) (d)

Figure 23: Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) instantaneous fishing mortality (average for age 1-10, year^{-1}), and (d) recruitment (age-0 fish) for North Pacific swordfish (Xiphias gladius) derived from the 2023 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 the dynamic SSB$_{MSY}$ and F$_{MSY}$ reference points.

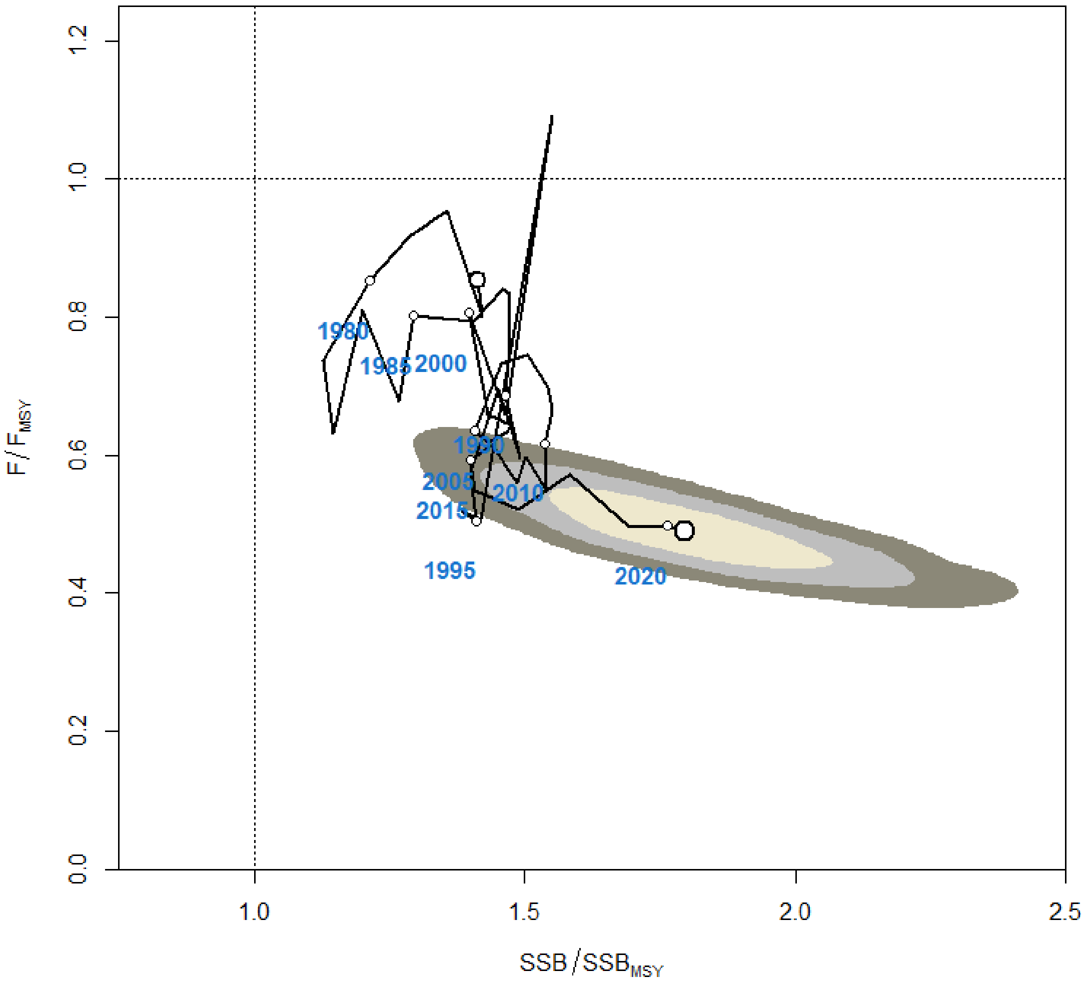
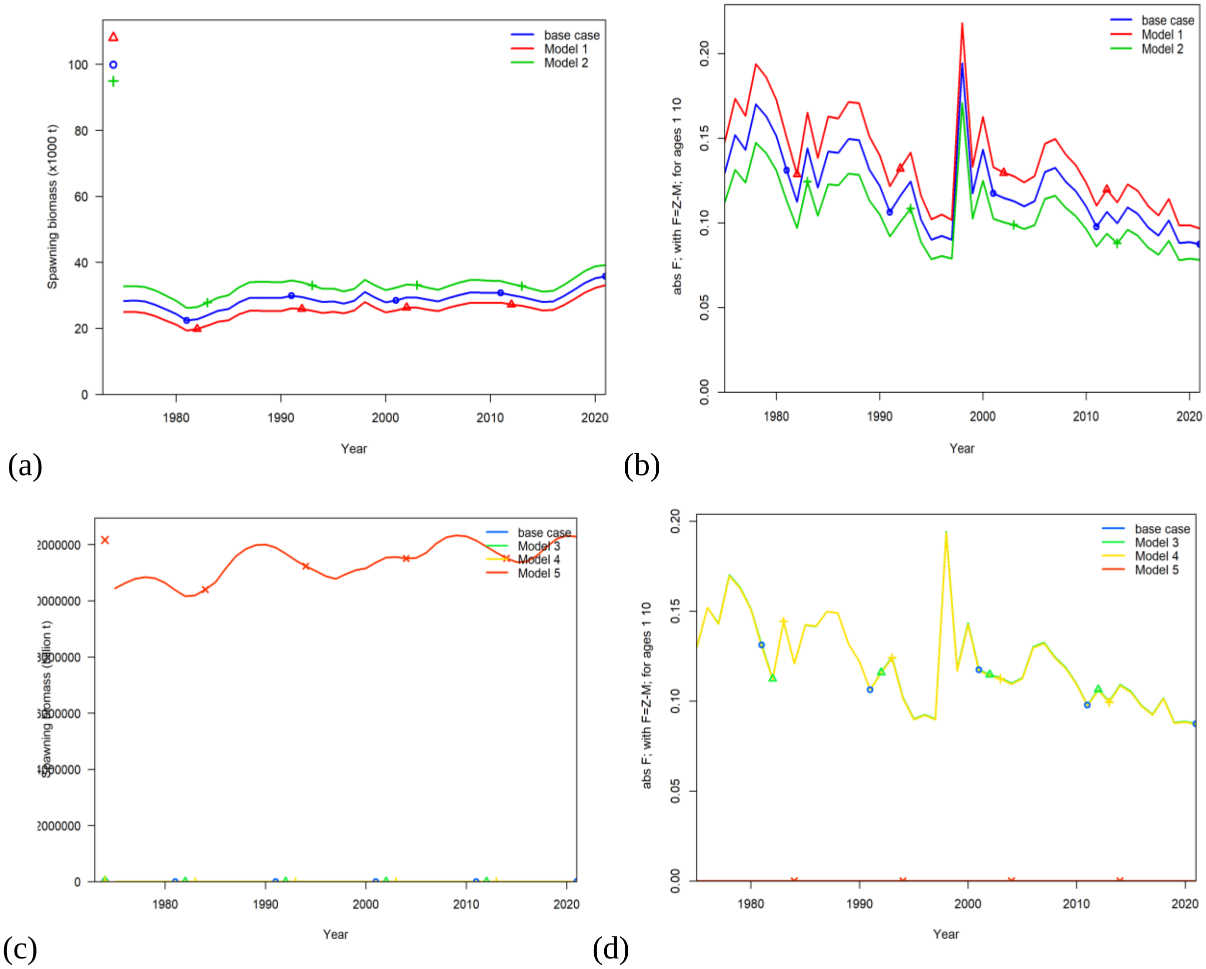


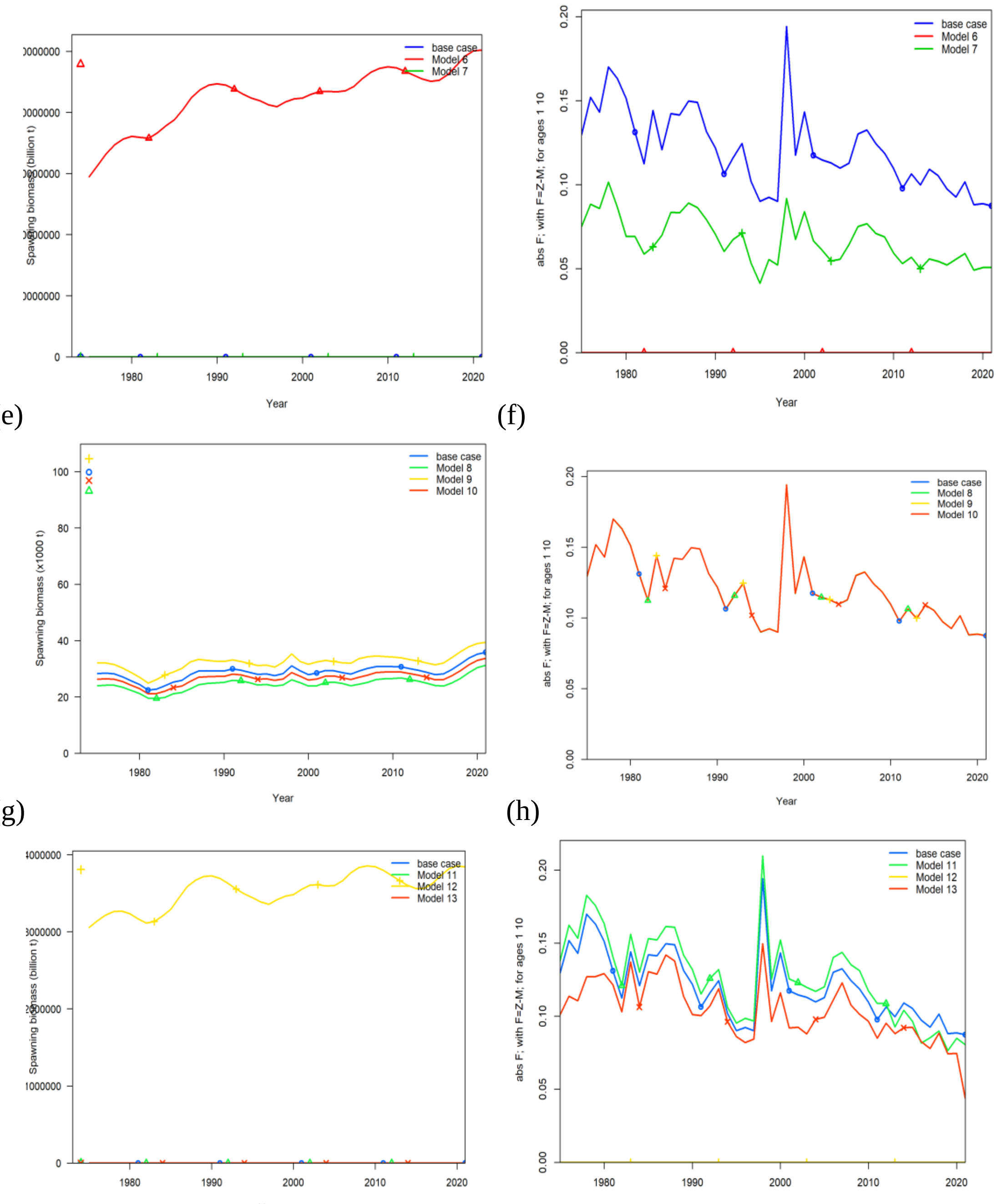
Figure 24: Kobe plot of the time series of estimates of relative fishing mortality (average of age 1-10) and relative spawning stock biomass of North Pacific swordish (Xiphias gladius) during 1977-2020. The first white dot indicates 1975, subsequent dots are in 5-year increments. Shading indicates 50%, 80%, and 95% confidence intervals, respectively.



(a) (b)

(c) (d)

Figure 25: Trajectories of spawning stock biomass (left) and fishing mortality (right) for the 24 sensitivity analyses listed in Table 14, compared to the base-case model: (a -b) Runs 1 and 2 use alternative natural mortality parameters; (c-d) Runs 3-5 use alternative steepness parameters; (e-f) Runs 6 and 7 use alternative growth parameters; (g-h) Runs 8-10 use alternative maturity ogives; (i-j) Runs 11-13 use alternative catch scenarios; (k-l) runs 14-17 use alternative model assumptions; and (m-n) Runs 18a-f and 19 use alternative CPUE configurations.

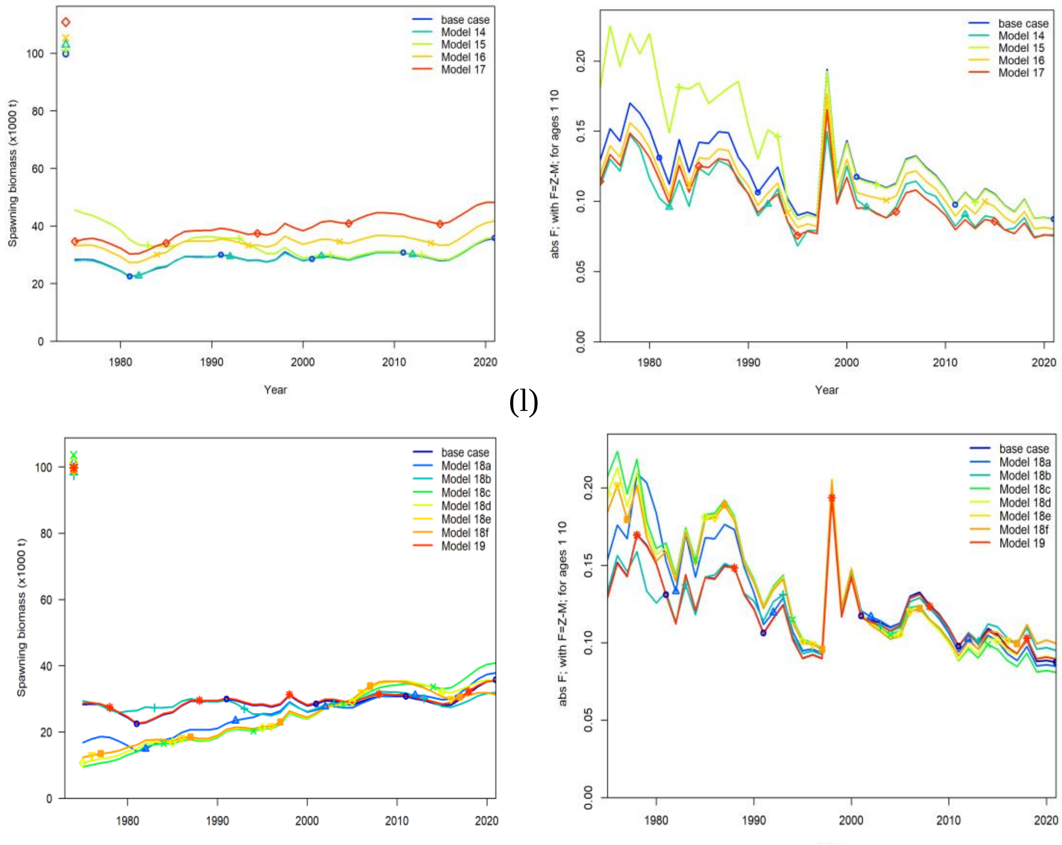


(e) (f)

(g) (h)

(i) (j)

Figure 25: Continued.



(k) (l)

(m) (n)

Figure 25: Continued.

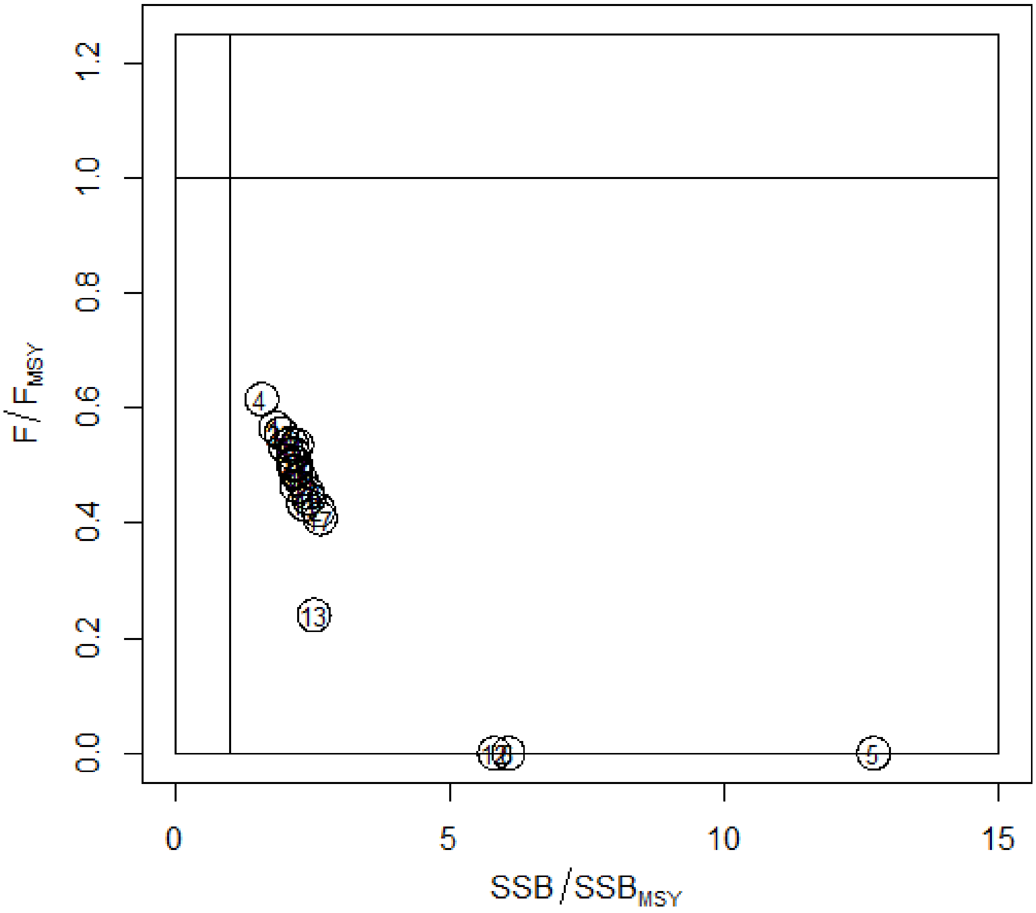


Figure 26: Kobe plot showing the terminal-year stock status for the base case model (grey B) and the sensitivity analyses as indicated by the run numbers. For the list of sensitivity runs, please see Table 12.

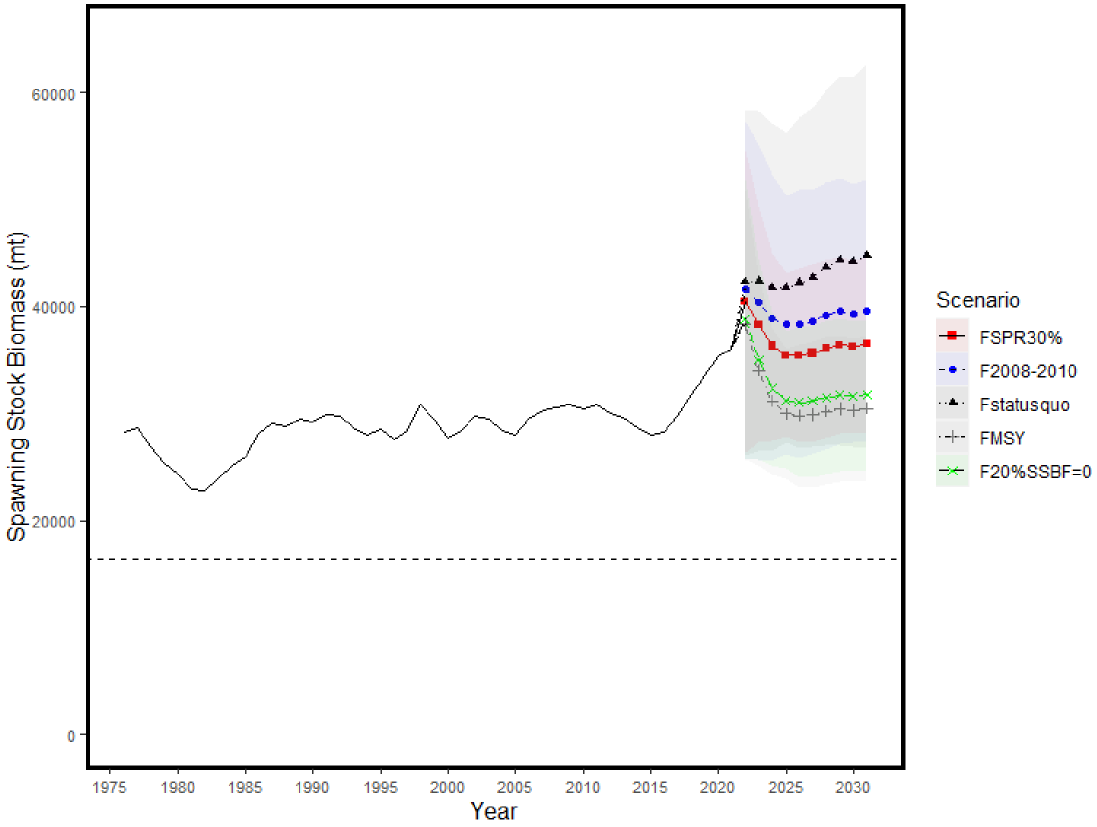


Figure 27: Historical and projected trajectories of spawning biomass from the North Pacific swordfish base case model based upon F scenarios. Dashed line indicates the spawning stock biomass at SSB_{MSY}. The list of projection scenarios can be found in Table 7.

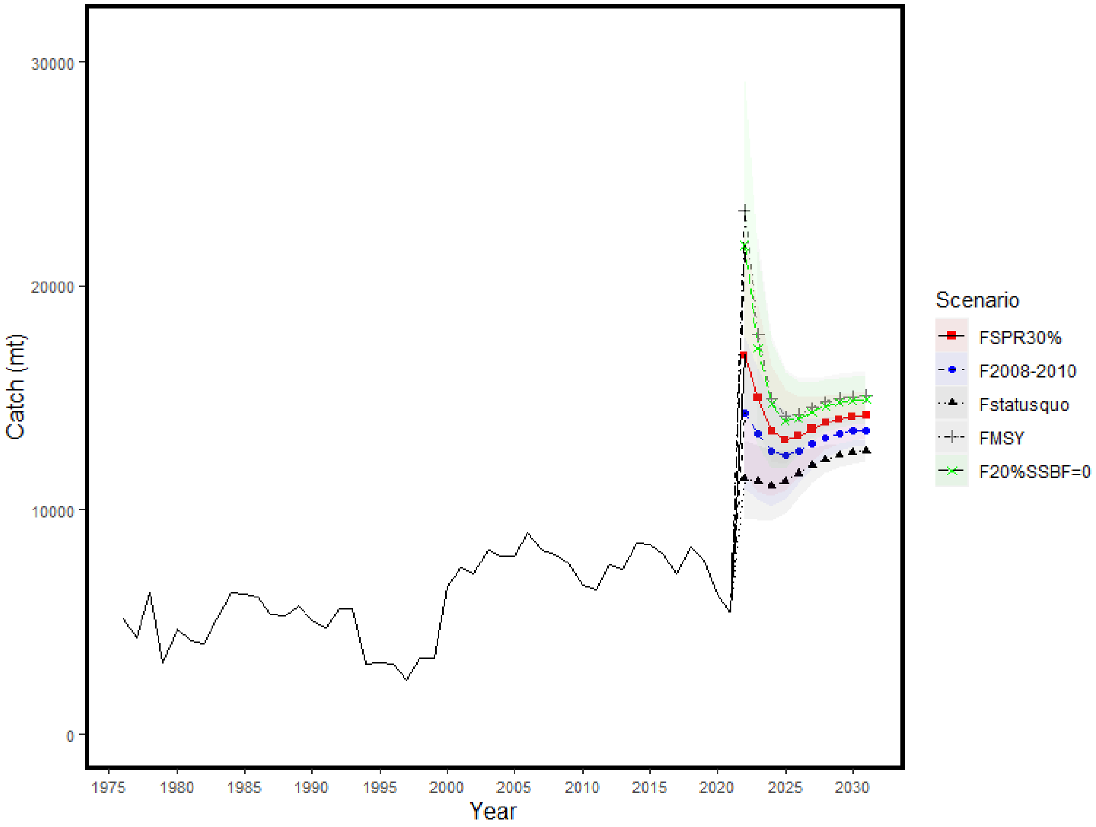


Figure 28: Historical and projected trajectories of catch from the North Pacific swordfish base case model based upon F scenarios. The list of projection scenarios can be found in Table 7.

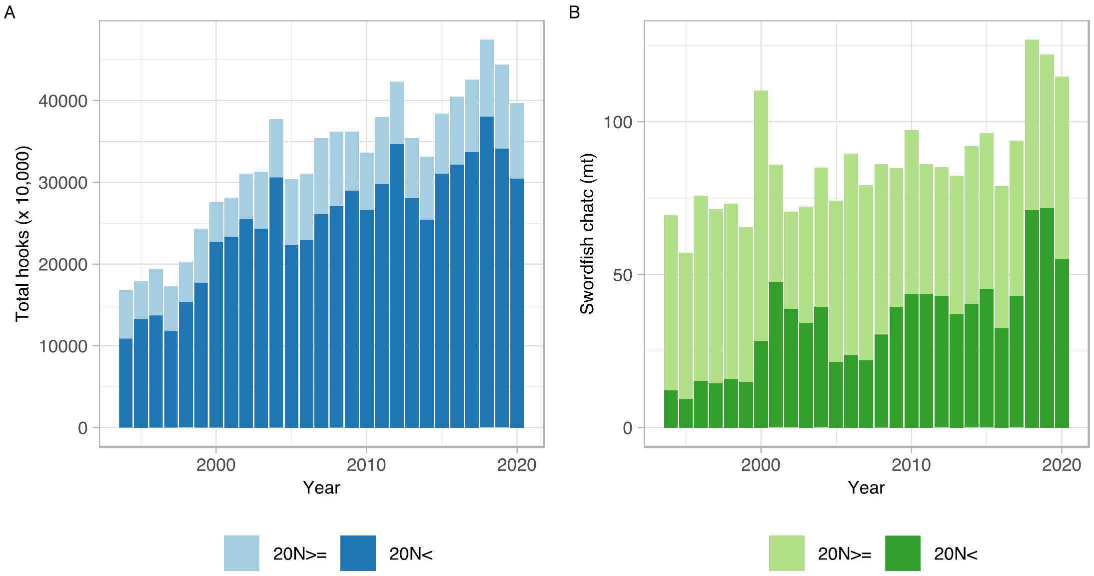


Figure 29. The proportion of swordfish catch and effort north and south of 20˚N. A: total hooks of a longline fishery. B: Total catch weight of swordfish on the North Pacific Ocean.