NORTHERN COMMITTEE
EIGHTEENTH REGULAR SESSION

ELECTRONIC MEETING
8am-12am, 4-6 October 2022, Japan Standard Time

Stock Assessment for Swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean through 2016

WCPFC-NC18-2022/IP-06
(WCPFC-NC14-2018/IP-05)

ISC[1] Billfish Working Group

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

Stock Assessment for Swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean through 2016

ISC Billfish Working Group

May 2018

Abstract

We present the benchmark stock assessment for the Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) stock conducted in 2018 by the ISC Billfish Working Group. The 2018 assessment consisted of applying a Stock Synthesis model with the best-available catch, abundance index, and length composition data for 1975-2016. The results indicated that population biomass (age 1 and older) for the Western and Central North Pacific Ocean swordfish stock decreased from 97,000 metric tons in 1975 to 51,000 metric tons in 1998, thereafter increasing to around 71,000 metric tons during the last three years of the assessment (2014-2016). Estimated fishing mortality gradually increased from the 1970s to the mid-1990s, peaked at 0.18 yr^{-1} in 1993, and declined to average 0.09 yr^{-1} since 2007. Compared to MSY-based reference points, the spawning stock biomass in 2016 was 87% above SSB_{MSY} and the current fishing mortality (average for ages 1 to 10 during 2013-2015) was 45% below F_{MSY}. Overall, the base case model indicated that the WCNPO swordfish stock is not likely overfished and is not likely experiencing overfishing relative to MSY-based or 20% of unfished spawning biomass-based reference points.

Executive Summary: Western and Central North Pacific Ocean Swordfish Stock Assessment

Stock Identification and Distribution: The Western and Central North Pacific Ocean (WCNPO) swordfish (*Xiphias gladius*) stock area consisted of waters of the North Pacific Ocean contained in the boundaries north of the equator and west of the diagonal purple line in Figure S1 labeled stock area 1. All available fishery data from this area were used for the stock assessment. For the purpose of modeling observations of CPUE and size composition data, it was assumed that there was an instantaneous mixing of fish throughout the stock area on a quarterly basis.

Catch: WCNPO swordfish catches exhibited a variable trend and averaged about 12,933 mt during 1975-1999. Annual catches increased to an average of 14,343 mt during 2000-2009 and have declined to an average of 10,498 mt since 2010. Since the 1980s catches by the Japanese and Chinese Taipei fleets have decreased while catches by the US and other Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC) countries have increased (Figure S2). Overall, longline gear has accounted for the vast majority of Western and Central North Pacific Ocean swordfish catches since the 1970s.

Data and Assessment: Catch and size composition data were collected from ISC countries (Japan, Taiwan, and USA), IATTC member countries, and the WCPFC (Table S1). Standardized catch-per-unit effort data used to measure trends in relative abundance were provided by Japan, USA, and Chinese Taipei. The Western and Central North Pacific Ocean swordfish stock was assessed using an age-, length-, and sex-structured assessment Stock Synthesis model fit to time series of standardized CPUE and size composition data. Sex-specific growth curves and natural mortality rates were used to account for the sexual dimorphism of adult swordfish. 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 the natural mortality rate, the stock-recruitment steepness, the growth curve parameters, and the female age at 50% maturity.

Biological Reference Points: Biological reference points were computed for the base case model with Stock Synthesis (Table S2). The point estimate of maximum sustainable yield was MSY =14,941 mt. The point estimate of the spawning stock biomass to produce MSY (adult female biomass) was SSB_{MSY} = 15,702 mt. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY (average fishing mortality on ages 1 to 10) was F_{MSY} = 0.17 yr^{-1} and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

Status of Stock: Estimates of total stock biomass show a relatively stable population, with a slight decline until the mid-1990s followed by a slight increase since 2000. Population biomass (age-1 and older) averaged roughly 97,919 mt in 1974-1978, the first 5 years of the assessment time frame, and has declined by only 20% to 71,979 mt in 2016 (Figure S3). Female spawning stock biomass was estimated to be 29,403 mt in 2016, or about 90% above SSB_{MSY} (Tables S1 and S2). Fishing mortality on the stock (average F, ages 1 – 10) averaged roughly F = 0.08 yr^{-1} during 2013-2015, or about 45% below F_{MSY}. The estimated spawning potential ratio of the stock (SPR, the predicted spawning output at the current F as a fraction of unfished spawning output) is currently SPR_{2016} = 45%. Annual recruitment averaged about 717 $\cdot 10^3$ recruits during 2012-2016, and no long-term trend in recruitment was apparent. Overall, the time series of spawning stock biomass and recruitment estimates indicate a stable spawning stock biomass and suggest a fluctuating pattern without trend for recruitment (Figure S3). The Kobe plot depicts the stock status relative to MSY-based reference points for the base case model (Figure S4) and shows that spawning stock biomass declined to almost the MSY level in the mid-1990s, but SSB has remained above SSB_{MSY} throughout the time series (Table S1).

For this 2018 benchmark assessment, note that biomass status is based on female spawning stock biomass, whereas for the 2014 update assessment, biomass status was based on exploitable biomass (effectively age-2+ biomass). It is also important to note that there are no currently agreed upon reference points for the WCNPO swordfish stock and that retrospective analyses show that the assessment model appears to underestimate spawning stock biomass in recent years.

The WCNPO swordfish stock has produced annual yields of around 10,200 mt per year since 2012, or about 2/3 of the MSY catch amount. There is no evidence of excess fishing mortality above F_{MSY} ($F_{2013-2015}$ is 45% of F_{MSY}) or substantial depletion of spawning potential (SSB_{2016} is 87% above SSB_{MSY}). Overall, the WCNPO swordfish stock is not likely overfished and is not likely experiencing overfishing relative to MSY-based or 20% of unfished spawning biomass-based reference points.

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

Year	2010	2011	2012	2013	2014	2015	2016	Mean[1]	Min[1]	Max[1]
Reported Catch	12,716	9,971	10,608	9,241	9,211	11,672	10,068	12,863	9,211	17,793
Population Biomass	66,417	66,087	68,117	67,885	69,560	71,951	71,979	67,487	51,856	97,919
Spawning Biomass	26,136	26,448	26,569	27,546	28,580	28,865	29,404	24,442	17,191	44,100
Relative Spawning Biomass	1.66	1.68	1.69	1.75	1.82	1.84	1.87	1.56	1.09	2.81
Recruitment (age 0)	789	565	671	710	683	742	781	761	401	1241
Fishing Mortality (yr^{-1})	0.10	0.08	0.09	0.07	0.07	0.09	0.07	0.12	0.07	0.18
Relative Fishing Mortality	0.57	0.46	0.51	0.44	0.40	0.51	0.44	0.72	0.40	1.05
Spawning Potential Ratio	38%	41%	39%	45%	47%	39%	45%	29%	17%	47%

[1] During 1975-2016

Conservation Information: Stock projections were conducted using a two-gender projection model. The five stock projection scenarios were: (1) F status quo, (2) F_{MSY}, (3) F at 0.2*SSB(F=0), (4) $F_{20\%}$, and (5) $F_{50\%}$. These projection scenarios were applied to the base case model results to evaluate the impact of alternative levels of fishing intensity on future spawning biomass and yield for swordfish in the Western and Central North Pacific Ocean. The projected recruitment pattern was generated by stochastically sampling the estimated stock-recruitment model from the base case model. The projection calculations employed model estimates for the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. The results show that projected female spawning biomasses would be expected to increase under all of the harvest scenarios (Table S3 and Figure S5), with greater increases expected under lower fishing mortality rates. Similarly, projected catch biomasses are expected to increase under each of the five harvest scenarios, with greater increases expected under higher fishing mortality rates (Table S3 and Figure S5).

Research Recommendations: The lack of sex-specific size composition data and the simplified treatment of the spatial structure of swordfish population dynamics remained as two important sources of uncertainty for this benchmark assessment.

Table S2. Estimates of biological reference points along with estimates of fishing mortality (F), spawning stock biomass (SSB), recent average yield (C), and spawning potential ratio (SPR) of Western and Central North Pacific Ocean swordfish, derived from the base case model assessment model, where "MSY" indicates reference points based on maximum sustainable yield.

Reference Point	Estimate
F_{MSY}	0.17 yr^{-1}
$F_{0.2*SSB(F=0)}$	0.16 yr^{-1}
$F_{2013-2015}$	0.08 yr^{-1}
SSB_{MSY}	15,702 mt
SSB_{2016}	29,403 mt
$SSB_{F=0}$	97,286 mt
MSY	14,941 mt
$C_{2012-2016}$	10,160 mt
SPR_{MSY}	18%
SPR_{2016}	45%

Table S3. Projected values of WCNPO swordfish spawning stock biomass (SSB, mt) and catch (mt) under five constant fishing mortality rate scenarios during 2017-2026.

Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Scenario 1: F = $F_{2013-2015}$										
SSB	32,118	33,207	34,599	35,476	36,270	37,082	37,951	38,967	40,083	41,087
Catch	8,851	9,135	9,407	9,599	9,794	10,022	10,275	10,595	11,053	11,142
Scenario 2: F = F_{MSY}										
SSB	28,267	23,963	21,443	19,458	18,303	17,618	17,293	17,197	17,253	17,263
Catch	20,885	18,323	16,509	15,294	14,666	14,353	14,308	14,520	14,650	14,348
Scenario 3: F = F20%SSB(F=0)										
SSB	28,425	24,384	21,800	19,735	18,530	17,874	17,496	17,586	17,818	17,779
Catch	20,691	18,122	16,454	15,261	14,653	14,361	14,319	14,554	14,665	14,384
Scenario 4: F = $F_{20\%}$										
SSB	29,007	25,431	23,527	21,763	20,736	20,131	19,893	19,883	19,981	20,066
Catch	18,680	16,933	15,657	14,726	14,242	14,033	14,050	14,292	14,496	14,253
Scenario 5: F = $F_{50\%}$										
SSB	32,559	34,334	36,290	37,666	38,836	39,984	41,148	42,490	44,049	45,625
Catch	7,556	7,973	8,343	8,605	8,847	9,101	9,366	9,692	10,087	10,223

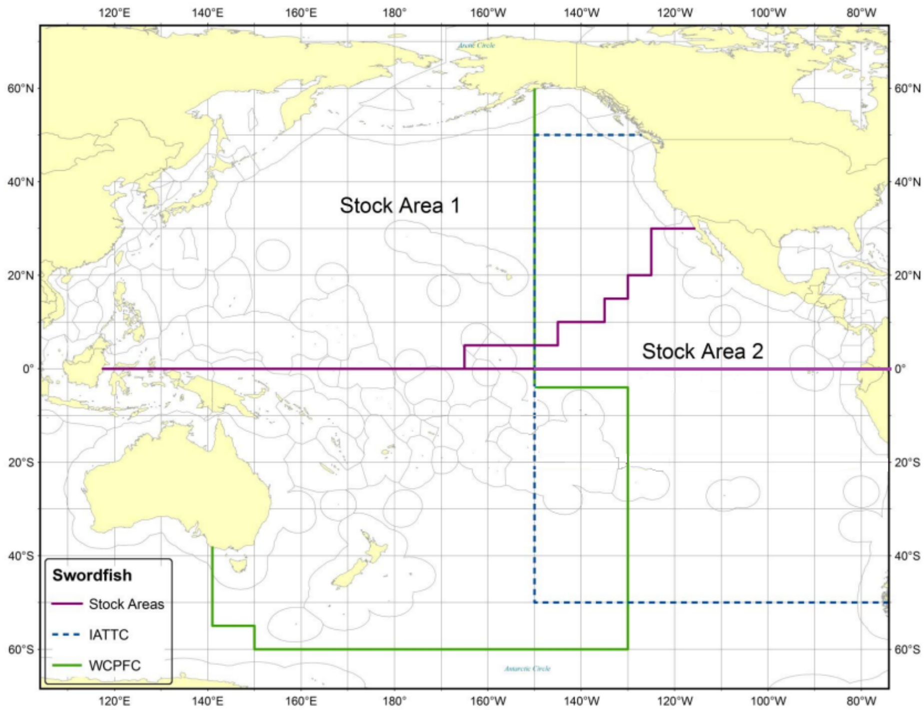


Figure S1. Stock boundaries used for this assessment of North Pacific Ocean swordfish: purple lines indicate stock area divisions; stock area 1 was assessed as the Western and Central North Pacific Ocean stock, stock area 2 contains the Eastern Pacific Ocean stock, the green line indicates Western Central Pacific Fisheries Commission convention area, blue dashed line indicates Inter-American Tropical Tuna Commission convention area.

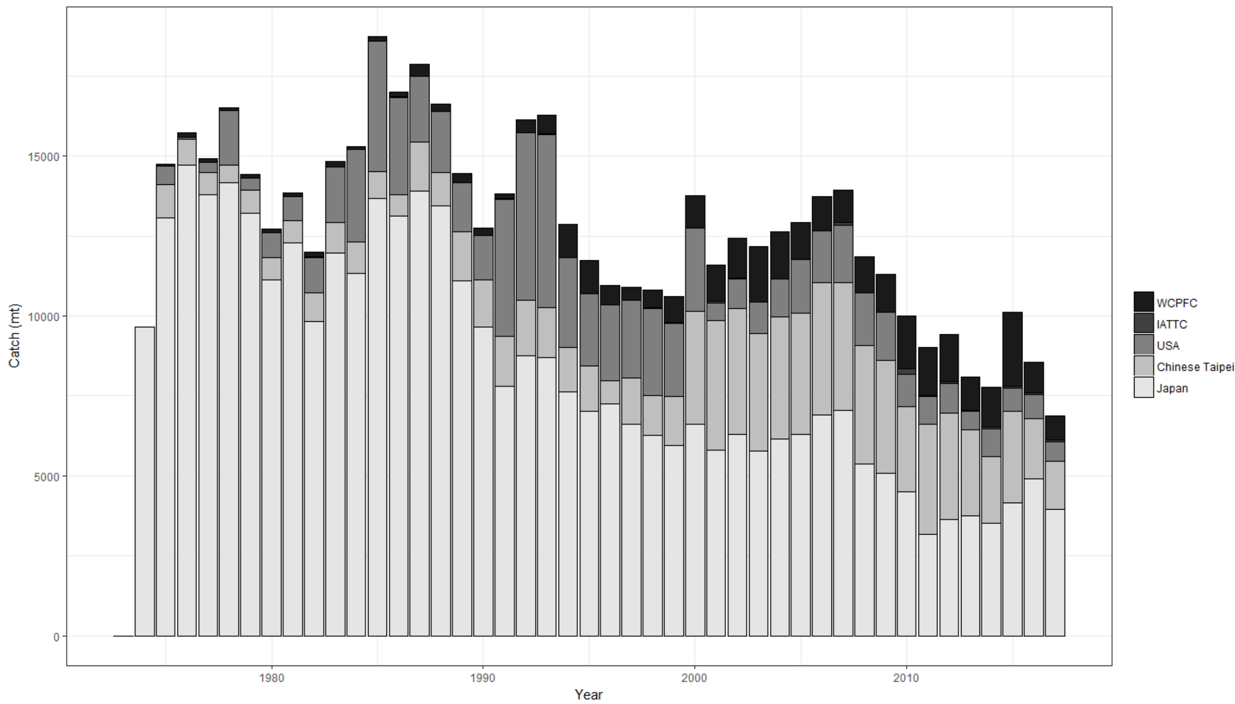


Figure S2. Annual catch biomass (mt) of Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) by country for Japan, Chinese Taipei, the USA, and all other countries during 1975-2016.

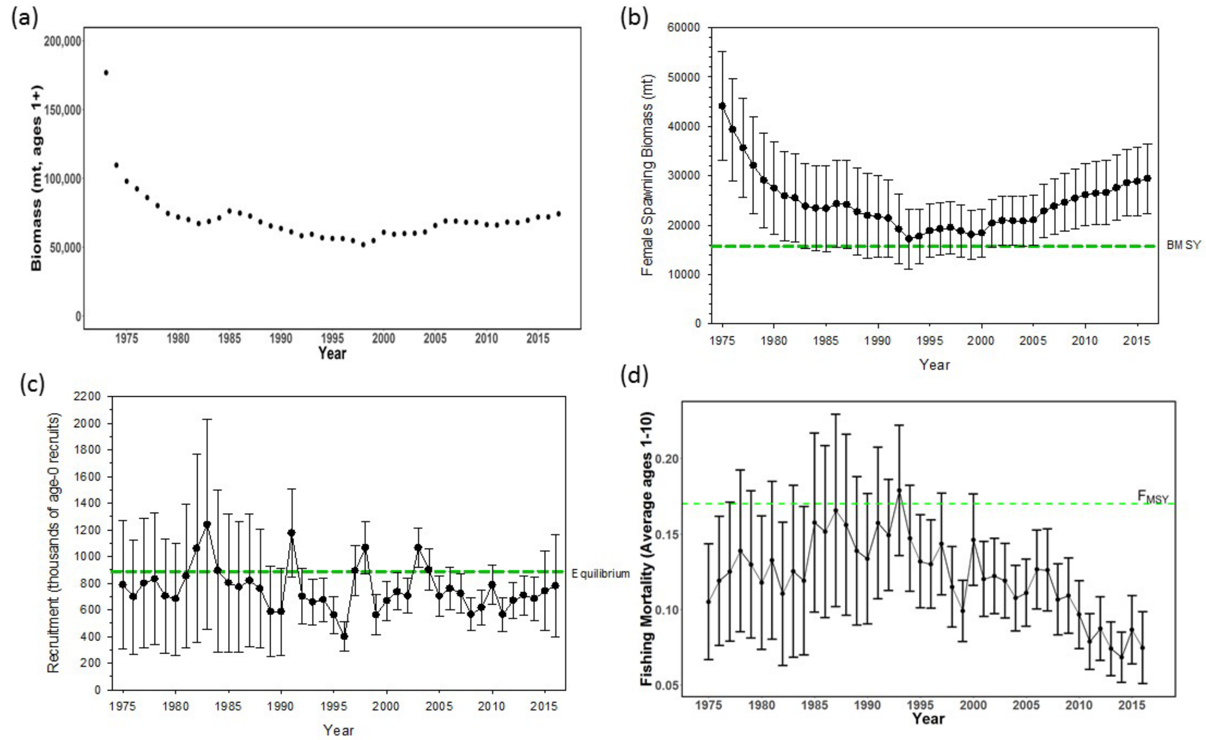


Figure S3. Time series of estimates of (a) population biomass (age 1+), (b) spawning biomass, (c) recruitment (age-0 fish), and (d) instantaneous fishing mortality (average for ages 1 to 10, units are yr^{-1}) for Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) derived from the 2018 stock assessment. The solid circles are the maximum likelihood estimates by year for each quantity and the error bars represent the uncertainty of the estimates (80% confidence intervals), green dashed lines indicate B_{MSY}, equilibrium recruitment, and F_{MSY} except for the population biomass time series.

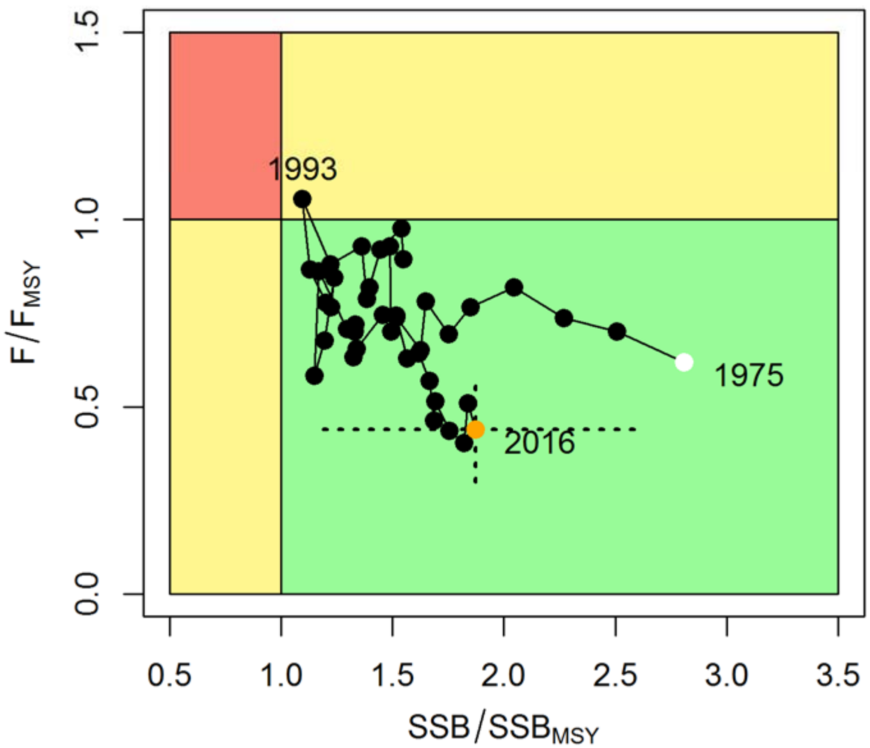


Figure S4. Kobe plot of the time series of estimates of relative fishing mortality (average of age 1-10) and relative spawning stock biomass of Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) during 1975-2016. The white circle denotes the first year (1975) and the orange circle denotes the last year (2016) of the assessment time horizon.

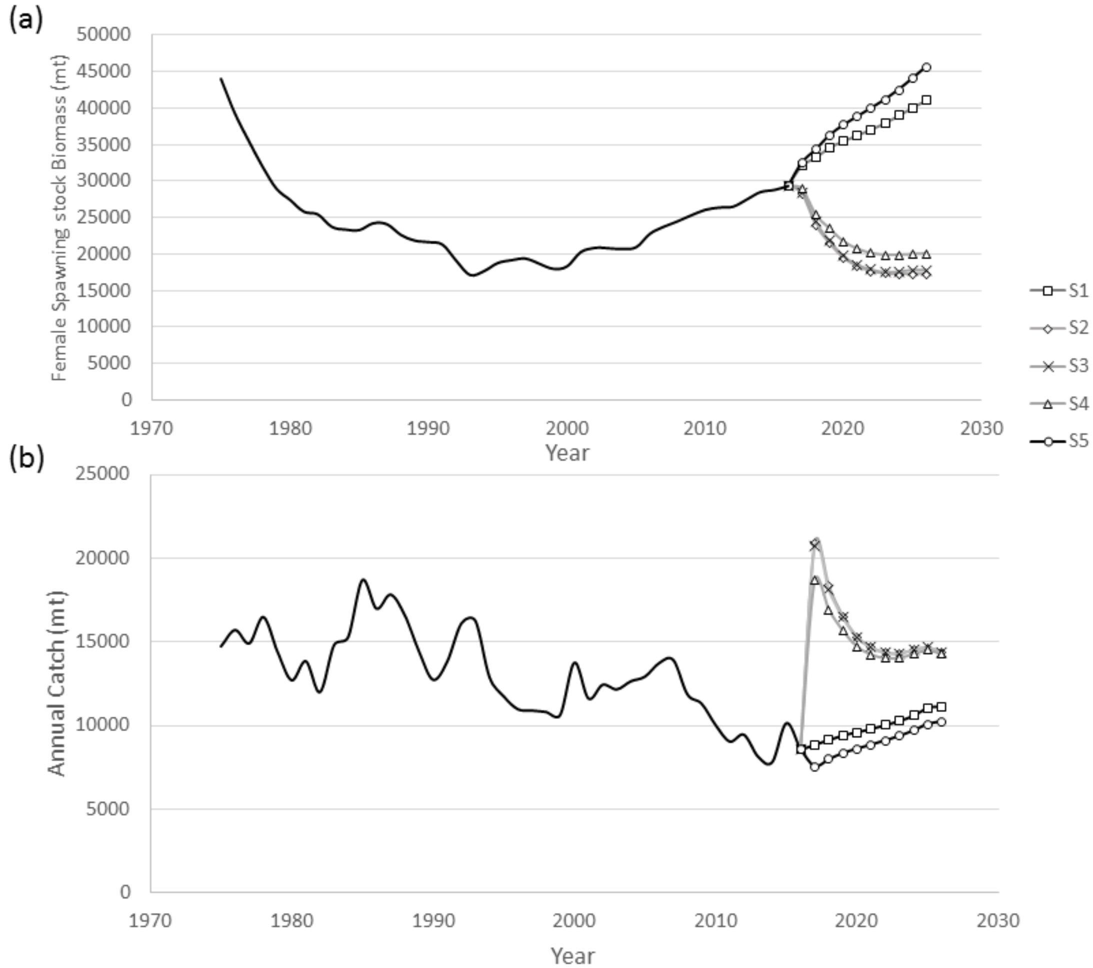


Figure S5 Historical and projected trajectories of (a) spawning biomass and (b) total catch from the Western and Central North Pacific Ocean swordfish base case model. Stock projection results are shown for five fishing mortality scenarios: S1 = the status quo or average fishing intensity during 2013-2015 ($F_{2013-2015}$= $F_{43\%}$); S2 = F_{MSY} ($F_{18\%}$); S3 = F to produce 20% of unfished spawning biomass or $F_{0.2*SSB(F=0)}$ ($F_{22\%}$); S4 = the highest 3-year average F during 1975-2016 or High F ($F_{20\%}$); S5 = Low F ($F_{50\%}$).

Introduction

The Billfish Working Group (BILLWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) completed a benchmark stock assessment for swordfish (*Xiphias gladius*) in the Western and Central Pacific Ocean (WCNPO) in 2009 (ISC 2009) and updated the assessment in 2014 (ISC 2014). The ISC BILLWG proposed to produce a benchmark assessment on North Pacific swordfish in 2018. The status of the WCNPO swordfish stock was not overfished and overfishing was not occurring relative to MSY-based reference points in the 2009 updated assessment using a Bayesian Surplus Production assessment model. The ISC BILLWG data preparatory meeting was held in January 2018 to evaluate new life history, catch, length, and CPUE data and strategize for the assessment (ISC 2018).

This report describes the 2018 benchmark stock assessment for the WCNPO swordfish stock. The best available scientific information including up-to-date catch, catch-per-unit-effort (CPUE), and composition data from 1975-2016 were provided by individual ISC countries, the Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC). The 2018 assessment was an age-structured two-gender population model based on the modeling platform Stock Synthesis (SS) version 3.30.

Materials and Methods

Spatial and Temporal Stratification

The geographic area encompassed in the assessment for swordfish was the Western and Central North Pacific Ocean as defined by the ISC Billfish Working Group (Ichinokawa and Brodziak 2009, ISC 2009, Ichinokawa and Brodziak 2010). Three types of data were used for this benchmark stock assessment: fishery-specific catches, relative abundance indices, and length measurements. The fishery data were compiled for 1975-2016, 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 data sets used in the updated stock assessment were summarized (Figure 1). Further details are presented below (ISC 2018).

Definition of Fisheries

A total of 18 fisheries that impacted swordfish were defined on the basis of country, gear type, location, and time period where each fishery was considered to target a distinct component of the stock. These fisheries consisted of eleven longline fisheries which were:

- the Japanese offshore and distant-water longline early- (JPN_WCNPO_OSDWLL_early) and late-period (JPN_WCNPO_OSDWLL_late) in areas 1 and 2
- the Hawaii longline (US_WCNPO_LL) deep-set sector, early shallow-set sector, and late shallow-set sector
- the Taiwanese distant-water longline (TWN_WCNPO_DWLL) early- and late-period
- the various country flags contained in the WCPFC management region (WCPFC_LL)
- the various country flags contained in the IATTC management region (IATTC_LL_Overlap)
- the two Japanese driftnet fisheries early- (JPN_WCNPO_OSDF) and late-periods (JPN_WCNPO_CODF)
- the USA gillnet fishery (US_WCNPO_GN)
- four mixed gear fisheries which included the Japanese other fishing gears (JPN_Other) early- and late-period, the Taiwanese other fishing gears (TWN_WCNPO_Other) and the US other fishing gears (US_WCNPO_Other).

  Descriptions and data sources to characterize these eighteen fisheries that impact WCNPO swordfish are summarized in Table 1.

Catch

Swordfish catch by fleet was input into the model on a quarterly basis (i.e., by calendar year and quarter) from 1975 to 2016 for the 18 individual fisheries (Table 2). Catch was reported in terms of catch biomass (mt) for all fisheries, with the exception of the Japanese offshore and distant water longline fleets (JPN_WCNPO_OSDWLL) and IATTC fleet for which catch was reported as numbers of fish caught.

Three countries (i.e., Japan, Taiwan, and the USA) provided national catch data (Ijima personal communication; Yi-Jay Chang personal communication; Ito 2018).

Swordfish catches for all other fishing countries were collected from WCPFC and IATTC category I and II data (Shane Griffiths, personal communication; Darryl Tagami, personal communication).

The resulting best available data on swordfish catches by fishery from 1975-2016 were tabulated and are shown in Figure 2. The historical maximum and minimum annual swordfish catches were 17,793 mt in 1993 and 9,211 mt in 2014, respectively. It is notable that the JPN_WCNPO_OSDWLL_early_area1 fishery harvested most of the swordfish catch during the early assessment period, but yields for this fishery declined after 1989 (i.e., the late period fishery or JPN_WCNPO_OSDWLL_late_area1). For the overall fishery catch of WCNPO swordfish, it is notable that since reaching a maximum in 1993, annual catches have generally declined. The recent average yield of swordfish in the WCNPO was about 10,160 mt during 2012-2016.

Abundance Indices

Relative abundance indices for WCNPO swordfish based on standardized CPUE were prepared for this assessment update and are shown in Figure 3 and Table 4. All of the standardized CPUE indices were updated except for US_WCNO_GN index (1990-2006), for which the index developed for the 2009 Swordfish assessment was used (Courtney and Fletcher 2009). A finite mixture model analysis was used to identify areas 1 and 2 based upon the Japanese operational data caught in the Japanese off-shore and distant water longline fleets. Japanese CPUE data were standardized in these two areas as well as pre- and post-1993 when Japanese logbook reporting requirements were changed (Ijima and Kanaiwa 2018).

Operational fishing data collected in the Hawaiian longline fishery by fishery observers in 1995-2014 were used for CPUE standardization of US longline fleets (Sculley *et al*. 2018). The data were divided into three components, a deep-set sector which targeted primarily small young-of-the-year swordfish and was used as an index of recruitment (S7_US_WCNPO_LL_deep), a shallow-set sector from 1995-2000 (S8_US_WCNPO_LL_shallow_early) and from 2004-2016 (S8_US_WCNPO_LL_shallow_late) which primarily targeted adult swordfish. The CPUE time series were divided by a fishery closure during which substantial changes to the fishing regulations were implemented.

Year, quarter, fishing region, and the two-way interactions between quarter and fishing region were used as predictors in the standardization models for two separate periods of 1964-1999, and 2000-2016 (with and without hooks-per-basket) due to changes in targeting species and fishing ground for the Taiwanese distant-water longline fishery (Chang *et al*. 2018).

Visual inspection of all indices showed an overall trend for each index of increasing in the last 5-10 years with the exception of the Taiwanese LL CPUE, which is flat to slightly decreasing (Figure 3). The US indices all have a peak in the mid-2000s followed by a slight decrease and subsequent increase in CPUE. Japan has a similar peak in the mid 1980s0s followed by a dip and increase after 2004 in area 1, which is the swordfish targeted fleet. The trend in area 2 shows a general decrease in CPUE until 1995 and an increase in CPUE until present. The Taiwanese LL CPUE is relatively flat until the 2000s and peaks in around 2010 (Figure 3).

Correlations among CPUE indices were analyzed in the 2018 assessment using the diags() function of the FLCore package (Version 2.6.6, Kell *et al.* 2007) in R (version 3.4.0, R Core Team, 2017). These packages provide a standardized method to plot and summarize CPUE data so that modelers can better evaluate their input data into assessment models (Sculley and Yau 2018). Each CPUE index was fit using a Loess smoother with only year as an explanatory variable using the default phase and number of nodes in the R package gam (Hastie 2018), and the residuals from that smoother were examined graphically. A pairwise correlation analysis was used to evaluate similarities and discrepancies in the trends of each pair of indices. Pearson correlation coefficients (ρ) were used to measure the association among pairs of CPUE series.

Patterns in Pearson correlations among the various CPUE indices considered for the swordfish stock assessment were generally positive. The positive correlations for pairs of CPUE indices (Table 4) were:

- S1 and S3 (ρ=0.32, n=19)
- S1 and S10 (ρ = 0.74, n=4)
- S2 and S5 (ρ=0.99, n=5)
- S2 and S7 (ρ = 0.34, n=22)
- S2 and S10 (ρ=0.18, n=13)
- S3 and S10 (ρ=0.73, n=4)
- S4 and S6 (ρ=0.21, n=17)
- S4 and S8 (ρ = 0.53, n=6)

- S4 and S10 (ρ=0.17, n=13)
- S5 and S7 (ρ = 0.82, n=5)
- S6 and S10 (ρ=0.13, n=7)
- S7 and S9 (ρ = 0.34, n=11)
- S9 and S10 (ρ = 0.65, n=4).

The negative correlations for pairs of CPUE indices (Table 4) were:

- S1 and S5 (n=12, ρ=-0.31)
- S2 and S8 (n=6, ρ=-0.75)
- S3 and S5 (n=12, ρ=-0.41)
- S4 and S7 (n = 22, ρ = -0.15)
- S4 and S9 (n=12, ρ=-0.43)
- S5 and S8 (n=5, ρ=-0.70)
- S6 and S9 (n=12, ρ=-0.41)
- S7 and S8 (n=6, ρ=-0.34)
- S7 and S10 (n=12, ρ=-0.12)
- S8 and S10 (n=6, ρ=-0.56).

Based on the graphical inspection of relative CPUEs and the correlation analysis, the data supported the use of all the CPUE indices in the base case model. However, the CPUE indices S5 (Taiwanese early longline fleet) and S10 (US gillnet fleet) were ultimately excluded from the model likelihood due to poor data quality and low area coverage for each index, respectively.

Size Composition Data

Quarterly fish length composition data from 1975–2016 for eight fisheries were available for the assessment, four were ultimately used, and were summarized in Table 3. Length composition data for fleet F12_US_WCNPO_LL_deep was not included because it accounted for <0.5% of the total catch in the fishery. Length composition data for fleet F1, F6, and F13 were not included in the likelihood because they had a conflicting trend in the profile of log(R0) compared to the other length composition data and CPUE indices.

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 composition data, and each observation consisted of the actual number of swordfish measured. The new composition data were agreed upon at the BILLWG data workshop as the best available scientific information for the 2018 benchmark stock assessment.

Figure 4 shows the quarterly length compositions. Most of the fisheries exhibited consistent, clear seasonal cycles in their composition data. There were some variations in the distributions within a fishery; e.g., F1 and F2 JPN_OSDWLL from 1985-1999 had a different composition than the rest of the time series. Strong year classes can also be seen through the time series of length composition data.

There was also considerable variation in both the length and size distributions and modal positions among fisheries (Figure 5). The length distribution data for fleet F6 were generally skewed to lengths greater than 150 cm EFL and exhibited a single mode near 180 cm EFL. The length distribution data for fleet F12 were highly skewed to lengths less than 100 cm with a model near 80 cm. Length distribution data for fleets F1, F2, F10, F13, F14, and F18 were less skewed and typically had modes around 150 cm.

Model Description

The assessment was conducted with Stock Synthesis (SS) version 3.30.08.03-SAFE released 09/29/2017 (Methot and Wetzel 2013). The WCNPO model was set up as a single area model with two sexes and four seasons (quarters). Spawning was assumed to occur in May (month 5) while recruitment was assumed to occur in July (month 7). Age at recruitment was calculated based upon the model estimated average selectivity at age based upon the quarterly selectivity at length. The maximum age of swordfish was set to 15 years. Sex specific biological parameters were used, with sex- and age-specific natural mortality (Table 5) as agreed upon in the BILLWG data preparatory meeting (ISC, 2018). In addition, the CV of the growth curve was set to 0.1 for males and females, and the sex ratio at birth was assumed to be 1:1. The model used a Beverton-Holt spawner-recruit relationship with steepness (h) fixed at 0.9 and sigmaR (σ_r) fixed at 0.6.

Data Observation Models

The assessment model fit three data components: 1) total catch; 2) relative abundance indices; and 3) composition data. The observed total catches were assumed to be unbiased and relatively precise, and were fitted assuming a lognormal error distribution with standard error (SE) of 0.05. The relative abundance indices were assumed to have log-normally distributed errors with SE in log-space (log(SE)) which was calculated as the value of $(\log(1+CV^2))^{1/2}$, where CV is the standard error of the observation divided by the mean value of the observed index.

The CPUE data were assigned to a specific quarter within each year based upon the recommendations of the country providing the index and are assumed to represent the quarter in which the highest catches take place for each fishery. Japanese longline fleets (S1-4) were all assigned to quarter 1; Taiwanese longline fleets (S5 and S6) were assigned to quarter 3; US longline deep-set (S7) was assigned to quarter 2, US longline shallow-set (S8 and S9) were assigned to quarter 2, and US gillnet (S10) was assigned to quarter 4. Of these, fleets S5 and S10 were excluded from the base-case model. In the base-case model, Taiwanese fleet S5 (longline early) was excluded from the likelihood estimation (but included in the model along with a selectivity) because of poor data quality (Chang, pers. comm.). The US gillnet fleet S10 was similarly excluded from the likelihood estimation but included in the model because the area covered by S10 was very small compared to the WCNPO region and it was suggested that it represented the dynamics of a small fraction of the swordfish population. The USA longline deep-set fleet S7 was included as an index of recruitment (i.e.,Fleet type 33) because the fishery catches large numbers of young-of-the-year fish (Sculley *et al*. 2018). The CPUE indices were assumed to be linearly proportional to biomass where catchability (q) was assumed to be constant and occur in the first month of the quarter assigned.

The CVs for each CPUE index were assumed to be equal to their respective calculated SEs on the log scale (Table 6). The minimum CV was scaled to a minimum of 0.25 or the root-mean-square error (RMSE) (i.e., square root of the residual variance) of what we would expect the assessment model to fit the CPUE index best by adding a constant to each CV value. This was calculated as the square root of the residual variance of a loess smoother fit to each index (Francis 2011, Lee *et al.,* 2014).

$$RMSE_{smoother} = \sqrt{(\frac{1}{N})\sum_{t=1}^{N}(Y_t - \hat{Y}_t)^2}$$

where Y_t is the observed CPUE in year *t* on the log scale, $\hat{Y}_t$ is the predicted CPUE in year *t* from the smoother fit to the data on the log scale, and *N* is the number of CPUE observations. RMSE values for each index are listed in Table 6. If the input SE was greater than these values, it was left unchanged.

The composition data were assumed to have multinomial error distributions with the error variances determined by the effective sample sizes. Measurements of fish are usually not random samples from the entire population. Rather, they tend to be highly correlated within a set or trip (Pennington *et al*. 2002). The effective sample size is usually substantially lower than the actual number of fish measured because the variance within each set or trip is substantially lower than the variance within a population. The effective sample size for all fleets was scaled to have a mean of 25. Quarters with fewer than 15 total samples were removed from the time series due to limited sample size, as agreed upon by the modeling sub-group. In addition, the length composition data for F5 were excluded as they only represented two time periods and were sparse.

Data Weighting

Index data were prioritized in this assessment based on the principles that relative abundance indices should be fitted well because abundance indices are a direct measure of population trends and scale, and that other data components such as composition data should not induce poor fits to the abundance indices (Francis 2011).

It is common practice to re-weight some or all data sets in two stages (Francis 2011). However, because the model was sensitive to reweighting of the length composition data, input sample sizes were not iteratively re-weighted in stage 2.

Goodness-of-Fit to Abundance Indices

For each abundance index, the standard deviation of the normalized (or standardized) residuals (SDNR) was used to examine the goodness-of-fit (Francis 2011). For an abundance data set to be fitted well, the SDNR should be less than

$\left[\chi^2_{0.95,\,m-1}/(m-1)\right]^{0.5}$ where $\chi^2_{0.95,\,m-1}$ is the 95th percentile of a χ^2 distribution with m–1 degrees of freedom. Various residuals plots, including the observed and expected abundances, were also examined to assess goodness-of-fit.

Stock Projections

Deterministic stock projections were conducted using a two-gender projection model. Projections were applied to the base case model results to evaluate the impact of various levels of fishing mortality on future SSB and yield. The projections account for uncertainty in the initial swordfish population size at age in 2017 based on Markov chain Monte Carlo samples of the population size estimator. The projections also account for uncertainty in future recruitment based on stochastic sampling of the estimated stock-recruitment model from the SS3.30 base case model. The future projection routine calculated the future SSB and yield that would occur while the specific fishing mortality and relative fishing mortality proportions depended on the specific harvest scenarios. Three year averages (2013-2015) of the selectivity patterns and relative fishing mortality rates were used in the future projection. The projections were run from 2017 to 2026 under five different harvest scenarios:

(1) F=F status quo
Use the 3-year average F for 2013-2015. This is equivalent to $F_{43\%}$.

(2) F=F_{MSY}
Use the estimate of F_{MSY}. This is equivalent to $F_{18\%}$.

(3) F=F at 0.2SSB(F=0).
Use the potential limit reference point based on 20% of unfished spawning biomass similar to the LRPs used for skipjack, bigeye and yellowfin tunas in the WCPFC. This is equivalent to $F_{22\%}$.

(4) High F
This scenario applies the highest 3-year average F from the 1975-2016 time series of F estimates. This is equivalent to $F_{20\%}$.

(5) Low F=0.20
This scenario applies a low value of F to the stock and is roughly equivalent to $F_{50\%}$.

Results

Base Case Model

Results for the base case model provided estimates of biological reference points for WCNPO swordfish and included trends in estimates of total stock biomass, spawning stock biomass, recruitment, and fishing mortality (units are yr^{-1}), along with a Kobe plot indicating stock status over time.

Model Convergence

All estimated parameters in the base case model were within the set bounds, and the final gradient of the model was approximately 0.04 and the hessian matrix for the parameter estimates was positive definite, which indicated that the model had converged to a local or global minimum. Results from 100 model runs with different random initial starting values for estimated parameters using the internal "jitter" routine in SS supported the result that a global minimum was obtained (i.e., there was no evidence of a lack of convergence to a global minimum) (Figure 6).

Model Diagnostics

Figure 7.1 presents the results of the likelihood profiling on the logarithm of the unfished recruitment parameter R0, i.e. log(R0), for each data component. Detailed information on changes in negative log-likelihoods among the various fishery data sources are shown in Tables 6 and 7 and Figure 7.2 and 7.3.

Changes in the likelihood of each data component indicated how informative that data component was to the overall estimated model fit. Ideally, relative abundance indices should be the primary sources of information on the population scale in a model (Francis 2011). In general, the changes in negative log-likelihoods of abundance indices were small over the range of R0 (Figure 7.1).

In general, the changes in the negative log-likelihoods among the four length composition data included were small over 6.7 of log(R0) values (Table 7, Figure 7.3). All four fleets had minimum relative negative log-likelihoods that occurred between 6.8-6.9. This implies that length data (F2, F10, F14, and F18) are informative in the fitting process. The MLE also matched well with the likelihood profile of individual fleets.

The magnitude of change in the negative log-likelihoods for the abundance indices were similar to length composition and generalized-size composition data within the log(R0) range of 6.8-7.0, and were within 5 units of likelihood at the MLE of log(R0), 6.81. There was good agreement between the length composition data and the abundance indices for the maximum likelihood estimate of log(R0) within the range of 6.6-7.0 based on log(R0) likelihood profiles.

Residual Analysis of Abundance Indices

Goodness-of-fit diagnostics were presented in Table 6, and plots of predicted and observed CPUE by fishery for the base case model were shown in Figure 8. The model fits to all abundance indices that were incorporated into the total likelihood well, with input log(SE) < estimated RMSE. Indices of S5 and S10 were included in the model to allow comparison of the fitted and observed trends. The estimated RMSE of S5 is larger than its input log(SE). The fits to abundance indices were generally within the 95 percent CIs. There was a trend of negative residuals in the early time period (1975-1982) and of positive residuals in the late time period (1985-1993) in S1_JPN_WCNPO_OSDWLL_early_Area1. Trend of negative residuals in the early time period (1994-2002) and of positive residuals in the late time period (2003-2013) in S2_JPN_WCNPO_OSDWLL_late_Area1.

The SDNR of the CPUE fit was used as another goodness-of-fit diagnostic (Table 6). The SDNR diagnostics also indicated that the model did not fit S5 (4.416 > 1.282) well.

Residuals Analysis of Size Composition Data

Comparisons between the observed and expected mean values of composition data from Francis (2011) were used for model diagnostics. Figure 9 shows the 95% credible intervals for mean value for the five length composition data sets and the three generalized-size composition data sets. The model fit passed through almost all of the credible intervals (Figure 9), although there was a poor fit between the observed and predicted mean values for F2 after 2005 and F14 after 2012.

The length composition data from F2 shows residual patterns which suggest the periodic presence of strong year classes (Figure 9). Also, length composition data from 1994-1998 were converted from weight data observations, therefore there is likely some uncertainty around the data in this time period. There were some large residuals for the fleet F14 US HI LL Shallow Late length composition data which primarily occurred in quarters one and two (Figure 9). This suggests some seasonal changes in the selectivity of the fleet. It may be useful to explore seasonal selectivity patterns in future work. There were minimal residual patterns in the length composition data from F10 and F18 (Figure 9).

Assuming standardized residuals were normally distributed, 95% of the measurements would fall within 2 standard deviations of the mean. The majority of Pearson residuals met this criterion (Figure 10), however there were patterns of large residuals for fleets F1 and F14 that warrant further investigation**.**

The model fit the length modes in composition data aggregated by fishery fairly well using the input effective sample sizes (Figure 11). Fits to fleets F1, F6, and F13 are shown although not fit in the total likelihood, therefore some misfitting is expected.

Estimation of Fishery Selectivity

Selectivity was estimated as a double-normal curve for fleets F2_JPN_WCNPO_OSDWLL_early_area1 and F14_US_WCNPO_LL_shallow_late and as asymptotic lognormal for fleets F10_TWN_WCNPO_DWLL_late and F18_IATTC_LL_Overlap (Figure 12). All other fleets were mirrored to the fleet which was believed to have the most similar selectivity pattern (Table 8).

Stock Assessment Results

The time series of estimates of population biomass show a relatively stable population. Estimates of population biomass (estimated biomass of age 1 and older fish at the beginning of the year) declined from a high of 97,919 mt in 1975 decreased to the lowest level of 51,856 mt in 1998, and increased to around 71,000 mt during the final three years of the 2018 stock assessment time horizon (2014−2016) (Table 10 and Figure 13.1). Overall, population biomass declined from an average of roughly 97 thousand mt in the late 1970s to an average of roughly 71 thousand mt in the 2010s (Table 10 and Figure 13.1).

Spawning stock biomass estimates also exhibited an initial decline and reached its lowest level of 17,191 metric tons in 1993. Since then spawning stock biomass has increased to 29,403 in 2016 (Table 10 and Figure 13.2). The time-series of SSB at the beginning of the spawning cycle (quarter 2) averaged 36,048 metric tons during 1975-1979, or 37% of unfished SSB; 24,251 metric tons (25% of unfished SSB) during 1980−1989; 19,144 metric tons (20% of unfished SSB) during 1990−1999; 21,883 metric tons (22% of unfished SSB) during 2000−2009, and 27,650 metric tons (28% of unfished SSB) in 2010−2016. Overall, SSB exhibited a decline from the early 1970s to the 1990s and has since increased to a similar level seen in the late 1970s.

Recruitment estimates indicated a long-term fluctuation around a mean of approximately 761,000 age-0 fish (Table 10 and Figures 13.3). The model estimated that several strong year classes (> 1000 thousand recruits) recruited to the fisheries in 1981-1982, 1991, 1998, and 2003 followed by several weak year classes. While the overall pattern of recruitment from 1971-2014 was variable, there was no apparent long-term trend in recruitment strength (Table 10 and Figure 13.3).

Over the course of the assessment time horizon, estimated fishing mortality (arithmetic average of F for ages 1 to 10, units are yr^{-1}) gradually increased from the early 1970s to the 1990s, peaked at 0.18 yr^{-1} in 1993 in response to higher catches, and afterward declined to F=0.08 yr^{-1} in recent years (2013-2015), or about 45% below F_{MSY} (Table 10 and Figure 13.4).

Biological Reference Points

Biological reference points were computed from the Stock Synthesis base case model using the most recent three-year averages of fishery selectivity patterns. Since most life history parameters for Western and Central North Pacific Ocean swordfish, including steepness, were considered to be reasonably well defined, MSY-based biological reference points were used to assess relative stock status (Table 11). The point estimate of maximum sustainable yield was MSY = 14,941 metric tons. The point estimate of the spawning stock biomass to produce MSY was SSB_{MSY} = 15,702 metric tons. The point estimate of F_{MSY}, the fishing mortality rate to produce MSY on ages 2 and older fish was F_{MSY} = 0.17 yr^{-1} and the corresponding equilibrium value of spawning potential ratio at MSY was SPR_{MSY} = 18%.

Stock Status

The Kobe plot depicts the stock status relative to MSY-based reference points for the base case model (Figure 14) and shows that spawning stock biomass declined to almost the MSY level in the mid-1990s, but SSB has remained above SSB_{MSY} throughout the time series (Tables 10 and 11). Overall, results from the base case assessment model indicate that the WCNPO swordfish stock is not likely overfished and is not likely experiencing overfishing relative to MSY-based or 20% of unfished spawning biomass-based reference points (Tables 10 and 11).

Sensitivity Analyses

In the January 2018 BILLWG workshop, it was agreed that at least four parameters would be evaluated in sensitivity analyses in the 2018 assessment (Table 12) in order to examine the effects of plausible alternative model assumptions and data input. These analyses were:

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

(2) Sensitivity analysis on steepness: The WG agreed to run two additional sensitivity runs on steepness, steepness was fixed at ± 10% of the value in the base-case model, or *h*=0.81 and *h*=0.99. In addition the WG agreed to use a steepness of *h*=0.7 which reflected a lower bound on stock resilience that was consistent with the reproductive longevity of swordfish of approximately $1/M_{4+} \approx 4.5$ years (i.e., Myers *et al*. 2002, Figure 5).

(3) Sensitivity analysis on growth: The group agreed to use an alternative growth curve described in Sun *et al.* (2002). This growth curve estimates a smaller maximum size for females and males. The new input parameters for SS3.30 were L_1 = 78.42 EFL (males) and 79.7 EFL (females); k = 0.198 (males) and 0.13 (females); L_{15} = 179.7 (males) and 216 (females). A 10% increase in L_1 and L_{15} was used for a second sensitivity run, setting k equal to the base-case value to explore the results if growth was underestimated.

The 10% larger parameters for L_1 = 108.9 (males) 107.7 (females) and for L_{15} = 226 (males) and 248.7 (females).

(4) Sensitivity analysis on maturity: The group agreed to run sensitivity analyses using the maturity ogive in Wang *et al*. (2003) and also using the length at 50% maturity (L_{50}) set to ± 10% than the value in the base-case model.

For each sensitivity run, comparisons of spawning stock biomass and relative fishing mortality trajectories were completed (Figures 15.1). Additionally, the WG produced a Kobe plot, similar to that requested by WCPFC SC9, that showed the patterns of the base case and terminal year estimates for the sensitivity runs (Figure 15.2).

For 2 of the 10 sensitivity runs, the stock status was estimated to be in the yellow section of the Kobe plot indicating that the stock was overfished but not experiencing overfishing (Figure 15.2). These were: Run 3 (steepness = 0.7) and Run 7 (using growth parameters from Sun *et al*. 2002). For all the other sensitivity analyses, the stock was estimated at MSY or in the green section of the Kobe plot, indicating stock was not overfished and not experiencing overfishing (Figure 15.2).

It was notable that Run 3 sensitivity analyses resulting in a poor stock status used a steepness parameter value that was unlikely to be biologically reasonable for swordfish. Since assuming a lower steepness was expected to decrease stock productivity, the pessimistic stock status results was not surprising. However, the base case model parameter steepness was expected to be more reliable than the values assumed in these sensitivity runs.

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

Retrospective Analysis

A retrospective analysis of the base case Western and Central North Pacific Ocean swordfish stock assessment model was conducted for the last 5 years of the assessment time horizon to evaluate whether there were any substantial changes in parameter estimates through time. This retrospective analysis was conducted during the April 2018 BILLWG workshop. The results of the retrospective analysis are shown in Figure 16. The trajectories of estimated spawning stock biomass and the spawning potential ratio (SPR) showed there was a tendency for the base case model to underestimate spawning biomass in recent years but there was no clear pattern for spawning potential ratio.

Stock Projections

Stock projections were conducted using a two-gender projection model. Projections were applied to the base case model results to evaluate the impact of various levels of fishing intensity on future spawning stock biomass and yield for swordfish in the Pacific Ocean. The future recruitment pattern was stochastic sampling of the estimated stock-recruitment model from the base case model. The projection calculations employed model estimates for the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Projections started in 2017 and continued through 2026 under 5 levels of fishing mortality in units of yr^{-1}. The five stock projection scenarios were: (1) F status quo, (2) F_{MSY}, (3) F at 0.2SSB(F=0), (4) High $F=F_{20\%}$, and (5) Low $F=F_{50\%}$.

Results showed projected spawning stock biomass and the catch for each of the five harvest scenarios (Tables 13.1 and 13.2 and Figure 17). The central tendency of the future spawning potential of WCNPO swordfish was projected to be above the level needed to produce MSY under each harvest scenario (Table 13.1). For fishery yield, the central tendency of the future catch biomass of WCNPO swordfish was projected to be above the pretty good yield level (at least 80% of MSY) under the F_{MSY}, F at 20% of unfished spawning biomass, and the high F scenarios (Table 13.2).

When the current fishing level was maintained (Scenario 1: $F_{2013-2015}$, equivalent to $F_{43\%}$) or increased (Scenario 5: F_{Low}, equivalent to $F_{50\%}$), the SSB was projected to be increase to over 40,000 metric tons by 2026, which was above SSB at MSY level (15,702 metric tons). If fishing increased to the MSY level (Scenario 2: equivalent to $F_{18\%}$), 20% SSB (Scenario 3: equivalent to $F_{22\%}$) or a High F (Scenario 4: equivalent to $F_{20\%}$), the projected SSB was estimated to gradually decrease, and by 2024 it approached but remained above the SSB at MSY level.

Fishing at the $F_{20\%SSB(F=0)}$ ($F_{22\%}$), F_{MSY} ($F_{18\%}$), and F_{High} ($F_{20\%}$) provided an expected low-risk level of harvest, where the average projected catches between 2015 and 2024 were above 80% of MSY at approximately 15,000 metric tons. Fishing at the current level ($F_{43\%}$) and $F_{50\%}$ provided average projected catches between 2015 and 2024 of about 9,900 and 8,900 metric tons, respectively.

Conservation Information

For this 2018 benchmark assessment, note that biomass status is based on female spawning stock biomass, whereas for the 2014 update assessment, biomass status was based on exploitable biomass (effectively age-2+ biomass). It is also important to note that there are no currently agreed upon reference points for the WCNPO swordfish stock and that retrospective analyses show that the assessment model appears to underestimate spawning stock biomass in recent years.

The WCNPO swordfish stock has produced annual yields of around 10,200 mt per year since 2012, or about 2/3 of the MSY catch amount. There is no evidence of excess fishing mortality above FMSY ($F_{2013-2015}$ is 45% of F_{MSY}) or substantial depletion of spawning potential (SSB_{2016} is 87% above SSB_{MSY}). Overall, the WCNPO swordfish stock is not likely overfished and is not likely experiencing overfishing relative to MSY-based or 20% of unfished spawning biomass-based reference points.

Research Recommendations

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. It was recommended that sex-specific fishery data be collected and management strategy evaluation research be conducted to address these issues for improving future stock assessments.

Acknowledgments

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

References

Chang, Y., Sun, C., Hsu, J., Yeh, S. (2018). Standardized catch-rates of swordfish (*Xiphias gladius*) for the Taiwanese distant-water tuna longline fishery in the North Pacific Ocean for 1964-2016. ISC/18/BILLWG-01/06. Available at: http://isc.fra.go.jp/pdf/BILL/ISC18_BILL_1/ISC18_BILLWG_WP1-6.pdf

Courtney, D., Fletcher, E. (2009). Input data for a North Pacific swordfish stock assessment using Stock Synthesis. ISC/09/BILLWG-02/04. Available at: http://isc.fra.go.jp/pdf/BILL/ISC09_BILL_2/WP04.pdf

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

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

Ichinokawa, M., Brodziak, J. (2008). Stock boundary between possible swordfish stocks in the northwest and southeast Pacific judged from fisheries data of Japanese longliners. ISC/08/Special Session on Billfish Stock Structure, 4, 14.

Ichinokawa, M., Brodziak, J. 2010. Using adaptive area stratification to standardize catch rates with application to North Pacific swordfish (*Xiphias gladius*). Fisheries Research 106:249:260.

Ijima, H., Kanaiwa, M. 2018. Pattern recognition of population dynamics for North Pacific swordfish (*Xiphias gladius*). ISC/18/BILLWG-1/09. Available at: http://isc.fra.go.jp/pdf/BILL/ISC18_BILL_1/ISC18_BILLWG_WP1-9.pdf

ISC Billfish Working Group. (2009). Report of the Billfish Working Group Workshop, 19-26 May 2009. Busan, Korea. ISC/09/BILLWG-02/REPORT. Available at: http://isc.fra.go.jp/pdf/ISC09/Annex_7_ISC9_BILLWG_May09.pdf

ISC Billfish Working Group. (2014). Report of the Billfish Working Group Workshop, 11-19 February 2014. Honolulu, HI, USA. ISC/14/BILLWG-01/REPORT. Available at: http://isc.fra.go.jp/pdf/ISC14/Annex8-BILLWG_Report_Feb_2014_final.pdf

ISC Billfish Working Group. (2018). Report of the Billfish Working Group Workshop, 17-23 January 2018. Honolulu, HI, USA. ISC/18/BILLWG-01/REPORT.

Ito, R., Childers, J., and Gu, Y. 2018. U.S. swordfish fisheries in the North Pacific Ocean. ISC/18/BILLWG-1/01.

Kanaiwa, M. 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-1/07. Available at: http://isc.fra.go.jp/pdf/BILL/ISC18_BILL_1/ISC18_BILLWG_WP1-7.pdf

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. Available at: http://isc.fra.go.jp/pdf/BILL/ISC17_BILL_1/ISC17_BILLWG_WP1-1.pdf

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

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

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

Myers, R., Barrowman, N., Hilborn, H., Kehler, D. 2002. Inferring Bayesian priors with limited direct data: Applications to risk analysis. North American Journal of Fisheries Management 22:351–364.

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

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sculley, M., Yau, A. (2018). Input data available for the North Pacific swordfish stock assessment in Stock Synthesis. ISC/18/BILLWG-01/01.

Sculley, M., Yau, A., Kapur, M. (2018). Standardization of the swordfish *Xiphias gladius c*atch per unit effort data caught by the Hawaii-based longline fishery from 1994-2016 using generalized linear models. ISC/18/BILLWG-01/05.

Sun, C-L., Wang, S-P., 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.

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.

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

Catch Index	Abundance Index	Fleet Name	Time Period	Source
F1	S1	JPN_WCNPO_OSDWLL_early_Area1	1975-1993	Kanaiwa 2018
F2	S2	JPN_WCNPO_OSDWLL_late_Area1	1994-2016	Kanaiwa 2018
F3	S3	JPN_WCNPO_OSDWLL_early_Area2	1975-1993	Kanaiwa and Ijima 2018
F4	S4	JPN_WCNPO_OSDWLL_late_Area2	1994-2016	Kanaiwa and Ijima 2018
F5	-	JPN_WCNPO_OSDF	1960-1992	
F6	-	JPN_WCNPO_CODF	1993-2014	
F7	-	JPN_WCNPO_Other_Early	1952-1993	
F8	-	JPN_WCNPO_Other_Late	1994-2016	
F9	S5	TWN_WCNPO_DWLL _early	1975-1999	Chang *et al*. 2018
F10	S6	TWN_WCNPO_DWLL _late	2000-2016	Chang *et al*. 2018
F11	-	TWN_WCNPO_Other	1959-2016	
F12	S7	US_WCNPO_LL_deep	1995-2016	Sculley *et al*. 2018
F13	S8	US_WCNPO_LL_shallow_early	1995-2000	Sculley *et al*. 2018
F14	S9	US_WCNPO_LL_shallow_late	2005-2016	Sculley *et al*. 2018
F15	S10	US_WCNPO_GN	1985-2006	Courtney *et al.* 2009
F16	-	US_WCNPO_Other	1970-2016	
F17	-	WCPFC_LL	1970-2016	
F18	-	IATTC_LL_Overlap	1975-2016	

Table 2. Time series of catch by fleet submitted for the 2018 WCNPO swordfish stock assessment. Catches for fleets 1-4 and 18 are in numbers of fish, while catches for fleets 5-17 are in metric tons. See Table 1 for and explanation of fleet numbers

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1952	1	90494	-	333	-	-	-	700.2	-	-	-	-	-	-	-	-	-	-	
1952	2	20310	-	544	-	-	-	700.2	-	-	-	-	-	-	-	-	-	-	-
1952	3	15498	-	143	-	-	-	700.2	-	-	-	-	-	-	-	-	-	-	-
1952	4	48794	-	445	-	-	-	700.2	-	-	-	-	-	-	-	-	-	-	-
1953	1	83749	-	2589	-	-	-	403.0	-	-	-	-	-	-	-	-	-	-	-
1953	2	37093	-	333	-	-	-	403.0	-	-	-	-	-	-	-	-	-	-	-
1953	3	10707	-	307	-	-	-	403.0	-	-	-	-	-	-	-	-	-	-	-
1953	4	79050	-	587	-	-	-	403.0	-	-	-	-	-	-	-	-	-	-	-
1954	1	118319	-	874	-	-	-	261.8	-	-	-	-	-	-	-	-	-	-	-
1954	2	66616	-	261	-	-	-	261.8	-	-	-	-	-	-	-	-	-	-	-
1954	3	15233	-	59	-	-	-	261.8	-	-	-	-	-	-	-	-	-	-	-
1954	4	51442	-	926	-	-	-	261.8	-	-	-	-	-	-	-	-	-	-	-
1955	1	103859	-	3130	-	-	-	261.7	-	-	-	-	-	-	-	-	-	-	-
1955	2	68962	-	632	-	-	-	261.7	-	-	-	-	-	-	-	-	-	-	-
1955	3	2982	-	185	-	-	-	261.7	-	-	-	-	-	-	-	-	-	-	-
1955	4	81541	-	1468	-	-	-	261.7	-	-	-	-	-	-	-	-	-	-	-
1956	1	145031	-	2392	-	-	-	222.4	-	-	-	-	-	-	-	-	-	-	-
1956	2	57667	-	1853	-	-	-	222.4	-	-	-	-	-	-	-	-	-	-	-
1956	3	1411	-	169	-	-	-	222.4	-	-	-	-	-	-	-	-	-	-	-
1956	4	83341	-	652	-	-	-	222.4	-	-	-	-	-	-	-	-	-	-	-
1957	1	145143	-	2567	-	-	-	245.7	-	-	-	-	-	-	-	-	-	-	-
1957	2	54342	-	1015	-	-	-	245.7	-	-	-	-	-	-	-	-	-	-	-
1957	3	1702	-	532	-	-	-	245.7	-	-	-	-	-	-	-	-	-	-	-
1957	4	77685	-	1844	-	-	-	245.7	-	-	-	-	-	-	-	-	-	-	-
1958	1	179317	-	2631	-	-	-	302.3	-	-	-	-	-	-	-	-	-	-	-
1958	2	64187	-	2110	-	-	-	302.3	-	-	-	-	-	-	-	-	-	-	-

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1958	3	8468	-	1023	-	-	-	302.3	-	-	-	-	-	-	-	-	-	-	-
1958	4	111146	-	1028	-	-	-	302.3	-	-	-	-	-	-	-	-	-	-	-
1959	1	136471	-	2254	-	-	-	257.8	-	106.75	-	22.75	-	-	-	-	-	-	-
1959	2	47736	-	3964	-	-	-	257.8	-	106.75	-	22.75	-	-	-	-	-	-	-
1959	3	50421	-	446	-	-	-	257.8	-	106.75	-	22.75	-	-	-	-	-	-	-
1959	4	98626	-	1779	-	-	-	257.8	-	106.75	-	22.75	-	-	-	-	-	-	-
1960	1	182427	-	5635	-	0.35	-	335.0	-	130	-	31.75	-	-	-	-	-	-	-
1960	2	49834	-	5331	-	0.35	-	335.0	-	130	-	31.75	-	-	-	-	-	-	-
1960	3	28858	-	456	-	0.35	-	335.0	-	130	-	31.75	-	-	-	-	-	-	-
1960	4	122952	-	1160	-	0.35	-	335.0	-	-	-	31.75	-	-	-	-	-	-	-
1961	1	151311	-	7477	-	0.42	-	357.7	-	79.5	-	18.25	-	-	-	-	-	-	-
1961	2	45065	-	10257	-	0.42	-	357.7	-	79.5	-	18.25	-	-	-	-	-	-	-
1961	3	35099	-	3113	-	0.42	-	357.7	-	79.5	-	18.25	-	-	-	-	-	-	-
1961	4	125754	-	3717	-	0.42	-	357.7	-	130	-	18.25	-	-	-	-	-	-	-
1962	1	57544	-	21566	-	0	-	377.1	-	123.5	-	15.5	-	-	-	-	-	-	-
1962	2	12678	-	15863	-	0	-	377.1	-	123.5	-	15.5	-	-	-	-	-	-	-
1962	3	8474	-	1152	-	0	-	377.1	-	123.5	-	15.5	-	-	-	-	-	-	-
1962	4	61014	-	14956	-	0	-	377.1	-	79.5	-	15.5	-	-	-	-	-	-	-
1963	1	27431	-	36430	-	0	-	230.4	-	85.75	-	4.5	-	-	-	-	-	-	-
1963	2	8686	-	5104	-	0	-	230.4	-	85.75	-	4.5	-	-	-	-	-	-	-
1963	3	8460	-	2043	-	0	-	230.4	-	85.75	-	4.5	-	-	-	-	-	-	-
1963	4	66700	-	29414	-	0	-	230.4	-	123.5	-	4.5	-	-	-	-	-	-	-
1964	1	38594	-	6240	-	1	-	294.75	-	89.5	-	2.5	-	-	-	-	-	-	-
1964	2	13141	-	2162	-	1	-	294.75	-	89.5	-	2.5	-	-	-	-	-	-	-
1964	3	9056	-	917	-	1	-	294.75	-	89.5	-	2.5	-	-	-	-	-	-	-
1964	4	36933	-	2469	-	1	-	294.75	-	85.75	-	2.5	-	-	-	-	-	-	-
1965	1	45909	-	4563	-	0	-	562.25	-	82.75	-	6.75	-	-	-	-	-	-	-
1965	2	12798	-	3896	-	0	-	562.25	-	82.75	-	6.75	-	-	-	-	-	-	-
1965	3	15858	-	1635	-	0	-	562.25	-	82.75	-	6.75	-	-	-	-	-	-	-

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1965	4	60335	-	1438	-	0	-	562.25	-	89.5	-	6.75	-	-	-	-	-	-	-
1966	1	59819	-	3091	-	0	-	474.25	-	122.25	-	7.75	-	-	-	-	-	-	-
1966	2	16929	-	2714	-	0	-	474.25	-	122.25	-	7.75	-	-	-	-	-	-	-
1966	3	21020	-	535	-	0	-	474.25	-	122.25	-	7.75	-	-	-	-	-	-	-
1966	4	66868	-	1519	-	0	-	474.25	-	205	-	7.75	-	-	-	-	-	-	-
1967	1	87043	-	3874	-	0	-	281.25	-	161.5	-	8.75	-	-	-	-	-	-	-
1967	2	16528	-	4799	-	0	-	281.25	-	161.5	-	8.75	-	-	-	-	-	-	-
1967	3	11717	-	1303	-	0	-	281.25	-	161.5	-	8.75	-	-	-	-	-	-	-
1967	4	64978	-	1289	-	0	-	281.25	-	161.5	-	8.75	-	-	-	-	-	-	-
1968	1	56379	-	7275	-	0	-	459.75	-	190.75	-	3	-	-	-	-	-	-	-
1968	2	10519	-	3077	-	0	-	459.75	-	190.75	-	3	-	-	-	-	-	-	-
1968	3	22762	-	708	-	0	-	459.75	-	190.75	-	3	-	-	-	-	-	-	-
1968	4	53632	-	2414	-	0	-	459.75	-	190.75	-	3	-	-	-	-	-	-	-
1969	1	67510	-	4579	-	0	-	480	-	210.75	-	1.75	-	-	-	-	-	-	-
1969	2	9549	-	1597	-	0	-	480	-	210.75	-	1.75	-	-	-	-	-	-	-
1969	3	16523	-	967	-	0	-	480	-	210.75	-	1.75	-	-	-	-	-	-	-
1969	4	41571	-	3531	-	0	-	480	-	210.75	-	1.75	-	-	-	-	-	-	-
1970	1	40007	-	5603	-	0	-	555.75	-	226	-	1.25	-	-	-	-	155.5	7.5	-
1970	2	7927	-	3960	-	0	-	555.75	-	226	-	1.25	-	-	-	-	155.5	7.5	-
1970	3	12427	-	1516	-	0	-	555.75	-	226	-	1.25	-	-	-	-	155.5	7.5	-
1970	4	28713	-	3041	-	0	-	555.75	-	226	-	1.25	-	-	-	-	155.5	7.5	-
1971	1	38940	-	6723	-	0.25	-	227	-	248	-	0.75	-	-	-	-	25.5	8.25	-
1971	2	7281	-	2581	-	0.25	-	227	-	248	-	0.75	-	-	-	-	25.5	8.25	-
1971	3	10421	-	2486	-	0.25	-	227	-	248	-	0.75	-	-	-	-	25.5	8.25	-
1971	4	32500	-	3346	-	0.25	-	227	-	248	-	0.75	-	-	-	-	25.5	8.25	-
1972	1	36894	-	9744	-	13.75	-	209	-	215.5	-	2.75	-	-	-	-	43.75	8.5	-
1972	2	7666	-	4382	-	13.75	-	209	-	215.5	-	2.75	-	-	-	-	43.75	8.5	-
1972	3	5541	-	1291	-	13.75	-	209	-	215.5	-	2.75	-	-	-	-	43.75	8.5	-
1972	4	22771	-	4401	-	13.75	-	209	-	215.5	-	2.75	-	-	-	-	43.75	8.5	-

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1973	1	34532	-	10764	-	180	-	146.75	-	215	-	29.75	-	-	-	-	100.75	10.25	-
1973	2	8965	-	3821	-	180	-	146.75	-	215	-	29.75	-	-	-	-	100.75	10.25	-
1973	3	4900	-	3180	-	180	-	146.75	-	215	-	29.75	-	-	-	-	100.75	10.25	-
1973	4	22081	-	4135	-	180	-	146.75	-	215	-	29.75	-	-	-	-	100.75	10.25	-
1974	1	20358	-	9775	-	326	-	222.25	-	220	-	34	-	-	-	-	107	12	-
1974	2	8753	-	5058	-	326	-	222.25	-	220	-	34	-	-	-	-	107	12	-
1974	3	9884	-	2793	-	326	-	222.25	-	220	-	34	-	-	-	-	107	12	-
1974	4	34990	-	3178	-	326	-	222.25	-	220	-	34	-	-	-	-	107	12	-
1975	1	30770	-	7324	-	668	-	225.75	-	227.5	-	38.25	-	-	-	-	142.5	14.25	0
1975	2	17705	-	2854	-	668	-	225.75	-	227.5	-	38.25	-	-	-	-	142.5	14.25	0
1975	3	12619	-	1221	-	668	-	225.75	-	227.5	-	38.25	-	-	-	-	142.5	14.25	0
1975	4	41163	-	1918	-	668	-	225.75	-	227.5	-	38.25	-	-	-	-	142.5	14.25	5
1976	1	38251	-	10662	-	872	-	314.75	-	155.75	-	48.5	-	-	-	-	13.75	38.25	0
1976	2	18186	-	5049	-	872	-	314.75	-	155.75	-	48.5	-	-	-	-	13.75	38.25	0
1976	3	13094	-	2003	-	872	-	314.75	-	155.75	-	48.5	-	-	-	-	13.75	38.25	5
1976	4	33783	-	4718	-	872	-	314.75	-	155.75	-	48.5	-	-	-	-	13.75	38.25	0
1977	1	49038	-	6841	-	586	-	290.25	-	136.25	-	35.25	-	-	-	-	84.25	27.25	11
1977	2	22981	-	3941	-	586	-	290.25	-	136.25	-	35.25	-	-	-	-	84.25	27.25	7
1977	3	10027	-	1542	-	586	-	290.25	-	136.25	-	35.25	-	-	-	-	84.25	27.25	0
1977	4	34195	-	3568	-	586	-	290.25	-	136.25	-	35.25	-	-	-	-	84.25	27.25	0
1978	1	43277	-	12209	-	618.75	-	323.5	-	136.5	-	3	-	-	-	-	428	19.75	0
1978	2	24013	-	4892	-	618.75	-	323.5	-	136.5	-	3	-	-	-	-	428	19.75	0
1978	3	10488	-	1741	-	618.75	-	323.5	-	136.5	-	3	-	-	-	-	428	19.75	5
1978	4	35618	-	2947	-	618.75	-	323.5	-	136.5	-	3	-	-	-	-	428	19.75	1
1979	1	42977	-	17880	-	245.75	-	315.75	-	167	-	8.25	-	-	-	-	96.5	26	1
1979	2	23783	-	5415	-	245.75	-	315.75	-	167	-	8.25	-	-	-	-	96.5	26	0
1979	3	16868	-	2254	-	245.75	-	315.75	-	167	-	8.25	-	-	-	-	96.5	26	0
1979	4	35079	-	3142	-	245.75	-	315.75	-	167	-	8.25	-	-	-	-	96.5	26	0
1980	1	25886	-	21356	-	436.5	-	323	-	153.5	-	19	-	-	-	40	157	25	8

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1980	2	18370	-	5314	-	436.5	-	323	-	153.5	-	19	-	-	-	40	157	25	2
1980	3	7342	-	2042	-	436.5	-	323	-	153.5	-	19	-	-	-	40	157	25	0
1980	4	18055	-	11514	-	436.5	-	323	-	153.5	-	19	-	-	-	40	157	25	5
1981	1	31977	-	31033	-	462	-	231.6	-	164.25	-	6.25	-	-	-	115.25	71.75	29	113
1981	2	26258	-	6244	-	462	-	231.6	-	164.25	-	6.25	-	-	-	115.25	71.75	29	0
1981	3	7085	-	3975	-	462	-	231.6	-	164.25	-	6.25	-	-	-	115.25	71.75	29	0
1981	4	19099	-	3143	-	462	-	231.6	-	164.25	-	6.25	-	-	-	115.25	71.75	29	6
1982	1	24296	-	16750	-	314.25	-	283.8	-	214	-	12.25	-	-	-	227.75	49.75	37	80
1982	2	18874	-	3863	-	314.25	-	283.8	-	214	-	12.25	-	-	-	227.75	49.75	37	6
1982	3	5932	-	1328	-	314.25	-	283.8	-	214	-	12.25	-	-	-	227.75	49.75	37	2
1982	4	26181	-	4326	-	314.25	-	283.8	-	214	-	12.25	-	-	-	227.75	49.75	37	52
1983	1	45609	-	20459	-	240.5	-	319.2	-	195.75	-	41.5	-	-	-	330.25	109	37.25	47
1983	2	28709	-	3029	-	240.5	-	319.2	-	195.75	-	41.5	-	-	-	330.25	109	37.25	0
1983	3	8857	-	1108	-	240.5	-	319.2	-	195.75	-	41.5	-	-	-	330.25	109	37.25	0
1983	4	25184	-	5681	-	240.5	-	319.2	-	195.75	-	41.5	-	-	-	330.25	109	37.25	9
1984	1	29375	-	28640	-	242.75	-	371.7	-	183.25	-	66	-	-	-	525.25	193.5	25.5	2
1984	2	20684	-	4133	-	242.75	-	371.7	-	183.25	-	66	-	-	-	525.25	193.5	25.5	0
1984	3	14954	-	1830	-	242.75	-	371.7	-	183.25	-	66	-	-	-	525.25	193.5	25.5	0
1984	4	28957	-	5222	-	242.75	-	371.7	-	183.25	-	66	-	-	-	525.25	193.5	25.5	23
1985	1	40738	-	24261	-	256.5	-	344	-	141.5	-	64.75	-	-	-	747.5	274.25	31.75	29
1985	2	40438	-	4051	-	256.5	-	344	-	141.5	-	64.75	-	-	-	747.5	274.25	31.75	0
1985	3	20984	-	1801	-	256.5	-	344	-	141.5	-	64.75	-	-	-	747.5	274.25	31.75	0
1985	4	34442	-	6308	-	256.5	-	344	-	141.5	-	64.75	-	-	-	747.5	274.25	31.75	0
1986	1	48762	-	15217	-	292.5	-	327.5	-	114	-	52.75	-	-	-	517.25	246.75	42.75	22
1986	2	32783	-	3732	-	292.5	-	327.5	-	114	-	52.75	-	-	-	517.25	246.75	42.75	7
1986	3	15570	-	2062	-	292.5	-	327.5	-	114	-	52.75	-	-	-	517.25	246.75	42.75	0
1986	4	33316	-	4382	-	292.5	-	327.5	-	114	-	52.75	-	-	-	517.25	246.75	42.75	2
1987	1	57744	-	19627	-	227.5	-	286.0	-	332.25	-	47.5	-	-	-	382.25	133.75	89.25	10
1987	2	29781	-	4489	-	227.5	-	286.0	-	332.25	-	47.5	-	-	-	382.25	133.75	89.25	23

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1987	3	13396	-	2297	-	227.5	-	286.0	-	332.25	-	47.5	-	-	-	382.25	133.75	89.25	0
1987	4	30346	-	10205	-	227.5	-	286.0	-	332.25	-	47.5	-	-	-	382.25	133.75	89.25	24
1988	1	56695	-	23635	-	262	-	266.0	-	194.25	-	65.75	-	-	-	344	135	55.5	8
1988	2	31357	-	3716	-	262	-	266.0	-	194.25	-	65.75	-	-	-	344	135	55.5	1
1988	3	10481	-	1789	-	262	-	266.0	-	194.25	-	65.75	-	-	-	344	135	55.5	1
1988	4	19719	-	11592	-	262	-	266.0	-	194.25	-	65.75	-	-	-	344	135	55.5	15
1989	1	33352	-	24261	-	349.25	-	336.0	-	373.75	-	9.5	-	-	-	310.75	71.5	75.25	2
1989	2	23892	-	4689	-	349.25	-	336.0	-	373.75	-	9.5	-	-	-	310.75	71.5	75.25	4
1989	3	8249	-	1278	-	349.25	-	336.0	-	373.75	-	9.5	-	-	-	310.75	71.5	75.25	1
1989	4	18244	-	4509	-	349.25	-	336.0	-	373.75	-	9.5	-	-	-	310.75	71.5	75.25	15
1990	1	36962	-	20968	-	256.5	-	220.75	-	328.5	-	38.5	-	0	-	282.75	50.25	52	7
1990	2	23450	-	3179	-	256.5	-	220.75	-	328.5	-	38.5	-	0	-	282.75	50.25	52	7
1990	3	6777	-	1336	-	256.5	-	220.75	-	328.5	-	38.5	-	0	-	282.75	50.25	52	0
1990	4	12224	-	3360	-	256.5	-	220.75	-	328.5	-	38.5	-	72.8	-	282.75	50.25	52	2
1991	1	22310	-	11481	-	106	-	264.75	-	350	-	45	-	866.2	-	236	39.25	39.75	14
1991	2	19652	-	2895	-	106	-	264.75	-	350	-	45	-	1466.8	-	236	39.25	39.75	0
1991	3	7672	-	1291	-	106	-	264.75	-	350	-	45	-	460.5	-	236	39.25	39.75	0
1991	4	17279	-	3664	-	106	-	264.75	-	350	-	45	-	383.1	-	236	39.25	39.75	0
1992	1	27527	-	8928	-	210	-	407.75	-	368.75	-	60.75	-	1153.8	-	339	29.75	97.2	35
1992	2	24231	-	2846	-	210	-	407.75	-	368.75	-	60.75	-	1235.9	-	339	29.75	97.2	10
1992	3	9727	-	1528	-	210	-	407.75	-	368.75	-	60.75	-	608.3	-	339	29.75	97.2	3
1992	4	12483	-	2571	-	210	-	407.75	-	368.75	-	60.75	-	768.1	-	339	29.75	97.2	28
1993	1	29415	-	6608	-	-	73	437.75	-	308	-	77.5	-	1335.8	-	353	51	144.5	96
1993	2	29960	-	2538	-	-	73	437.75	-	308	-	77.5	-	1177.4	-	353	51	144.5	141
1993	3	11229	-	1452	-	-	73	437.75	-	308	-	77.5	-	716.7	-	353	51	144.5	12
1993	4	19258	-	2840	-	-	73	437.75	-	308	-	77.5	-	571.2	-	353	51	144.5	9
1994	1	-	34547	-	5118	-	105.25	-	87.25	288.75	-	54.75	-	861.9	-	197.75	41.25	262.25	155
1994	2	-	26453	-	2467	-	105.25	-	87.25	288.75	-	54.75	-	602.2	-	197.75	41.25	262.25	3
1994	3	-	8556	-	1292	-	105.25	-	87.25	288.75	-	54.75	-	146.7	-	197.75	41.25	262.25	14

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1994	4	-	23342	-	1491	-	105.25	-	87.25	288.75	-	54.75	-	239.5	-	197.75	41.25	262.25	0
1995	1	-	27886	-	3728	-	140.25	-	116.25	301.5	-	56.25	0.0	271.9	-	192.75	32	256.6	38
1995	2	-	21059	-	2136	-	140.25	-	116.25	301.5	-	56.25	0.7	707.1	-	192.75	32	256.6	12
1995	3	-	7541	-	1031	-	140.25	-	116.25	301.5	-	56.25	11	206.6	-	192.75	32	256.6	8
1995	4	-	21734	-	1591	-	140.25	-	116.25	301.5	-	56.25	12.1	140.4	-	192.75	32	256.6	25
1996	1	-	30962	-	3912	-	107	-	162.5	177.75	-	8	5.4	467.6	-	190.25	22.75	154.2	32
1996	2	-	23750	-	1977	-	107	-	162.5	177.75	-	8	11.1	596.7	-	190.25	22.75	154.2	17
1996	3	-	7590	-	881	-	107	-	162.5	177.75	-	8	3.8	123.4	-	190.25	22.75	154.2	0
1996	4	-	15239	-	2594	-	107	-	162.5	177.75	-	8	4.1	294.6	-	190.25	22.75	154.2	2
1997	1	-	31260	-	2433	-	91.25	-	103.5	344.5	-	15.25	2.6	654.4	-	177	21	98.75	0
1997	2	-	17006	-	1780	-	91.25	-	103.5	344.5	-	15.25	10	782.2	-	177	21	98.75	8
1997	3	-	5509	-	792	-	91.25	-	103.5	344.5	-	15.25	4	111.7	-	177	21	98.75	0
1997	4	-	19071	-	1331	-	91.25	-	103.5	344.5	-	15.25	3.6	66.4	-	177	21	98.75	2
1998	1	-	28378	-	2006	-	117.75	-	137.5	300	-	10.25	6.7	458.7	-	232.75	15.25	137.5	13
1998	2	-	16626	-	1851	-	117.75	-	137.5	300	-	10.25	17.4	888.2	-	232.75	15.25	137.5	52
1998	3	-	4813	-	894	-	117.75	-	137.5	300	-	10.25	7.6	204	-	232.75	15.25	137.5	1
1998	4	-	15686	-	1453	-	117.75	-	137.5	300	-	10.25	9.9	138	-	232.75	15.25	137.5	2
1999	1	-	22310	-	3388	-	181	-	117.5	362	-	15.25	10.8	687.7	-	151.5	20.75	207.3	29
1999	2	-	15843	-	1929	-	181	-	117.5	362	-	15.25	21.2	673.9	-	151.5	20.75	207.3	1
1999	3	-	6029	-	1401	-	181	-	117.5	362	-	15.25	11.4	155.1	-	151.5	20.75	207.3	33
1999	4	-	18573	-	2584	-	181	-	117.5	362	-	15.25	10.9	49.2	-	151.5	20.75	207.3	35
2000	1	-	27538	-	3462	-	202	-	140	-	863.5	21.5	4.3	534.2	-	162.25	24.75	252.4	3
2000	2	-	14112	-	2620	-	202	-	140	-	863.5	21.5	25.3	1098.2	-	162.25	24.75	252.4	1
2000	3	-	7651	-	1081	-	202	-	140	-	863.5	21.5	11	143.3	-	162.25	24.75	252.4	120
2000	4	-	21135	-	2219	-	202	-	140	-	863.5	21.5	9.8	18.7	-	162.25	24.75	252.4	22
2001	1	-	24407	-	2981	-	183	-	71	-	983.3	22.75	5.9	-	20.7	93.75	14.25	282.25	21
2001	2	-	10468	-	2522	-	183	-	71	-	983.3	22.75	33.1	-	31.6	93.75	14.25	282.25	167
2001	3	-	9113	-	1459	-	183	-	71	-	983.3	22.75	20.9	-	0	93.75	14.25	282.25	136
2001	4	-	16518	-	2185	-	183	-	71	-	983.3	22.75	26.7	-	0	93.75	14.25	282.25	253

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
2002	1	-	22057	-	3406	-	291	-	62.75	-	980.3	6.75	81	-	217.3	75.5	23.25	314	81
2002	2	-	9737	-	2970	-	291	-	62.75	-	980.3	6.75	52.2	-	144.1	75.5	23.25	314	32
2002	3	-	9579	-	1003	-	291	-	62.75	-	980.3	6.75	19.2	-	0	75.5	23.25	314	0
2002	4	-	18673	-	1564	-	291	-	62.75	-	980.3	6.75	14.5	-	0	75.5	23.25	314	3
2003	1	-	18649	-	2466	-	299.5	-	46.5	-	921.8	2.75	14.7	-	247.6	54	26.75	434.3	0
2003	2	-	7495	-	3700	-	299.5	-	46.5	-	921.8	2.75	71.7	-	208	54	26.75	434.3	0
2003	3	-	5907	-	1161	-	299.5	-	46.5	-	921.8	2.75	26.1	-	0	54	26.75	434.3	0
2003	4	-	21308	-	1498	-	299.5	-	46.5	-	921.8	2.75	16.9	-	49.4	54	26.75	434.3	0
2004	1	-	20930	-	5840	-	265.5	-	66.75	-	953.3	4	23	-	643.6	45.5	26.5	375.25	0
2004	2	-	4682	-	5196	-	265.5	-	66.75	-	953.3	4	80.2	-	59.2	45.5	26.5	375.25	0
2004	3	-	6765	-	1113	-	265.5	-	66.75	-	953.3	4	28.0	-	0	45.5	26.5	375.25	0
2004	4	-	25366	-	916	-	265.5	-	66.75	-	953.3	4	19.9	-	15.3	45.5	26.5	375.25	0
2005	1	-	27767	-	3472	-	239	-	133.25	-	947	6.5	17.2	-	576.1	55	19.25	293.75	0
2005	2	-	7049	-	1686	-	239	-	133.25	-	947	6.5	99.3	-	619	55	19.25	293.75	0
2005	3	-	5149	-	1445	-	239	-	133.25	-	947	6.5	21.1	-	0	55	19.25	293.75	0
2005	4	-	24261	-	1661	-	239	-	133.25	-	947	6.5	20.7	-	0	55	19.25	293.75	0
2006	1	-	20221	-	5069	-	199	-	148.75	-	1020	15.25	21.1	-	929.1	110.75	17.75	266.5	31
2006	2	-	8960	-	2814	-	199	-	148.75	-	1020	15.25	96.3	-	0	110.75	17.75	266.5	18
2006	3	-	8540	-	1345	-	199	-	148.75	-	1020	15.25	29.5	-	0	110.75	17.75	266.5	5
2006	4	-	32613	-	845	-	199	-	148.75	-	1020	15.25	27.8	-	0	110.75	17.75	266.5	0
2007	1	-	30939	-	2814	-	207.25	-	123.5	-	991.5	6.5	17.4	-	758	122.5	14.75	253.3	556
2007	2	-	10286	-	2973	-	207.25	-	123.5	-	991.5	6.5	112.2	-	269.8	122.5	14.75	253.3	89
2007	3	-	5693	-	1007	-	207.25	-	123.5	-	991.5	6.5	36	-	10.3	122.5	14.75	253.3	7
2007	4	-	25850	-	1295	-	207.25	-	123.5	-	991.5	6.5	28.6	-	24.5	122.5	14.75	253.3	0
2008	1	-	19598	-	4304	-	162	-	131.75	-	918.5	12	22.1	-	574.6	101.25	12.25	279.2	10
2008	2	-	6216	-	2128	-	162	-	131.75	-	918.5	12	179.8	-	305.4	101.25	12.25	279.2	84
2008	3	-	4906	-	727	-	162	-	131.75	-	918.5	12	16.9	-	30.2	101.25	12.25	279.2	1
2008	4	-	18967	-	556	-	162	-	131.75	-	918.5	12	18.4	-	39.3	101.25	12.25	279.2	7
2009	1	-	17277	-	999	-	170.5	-	123	-	846.8	30.25	25.6	-	346.7	62.75	12.5	295.6	13

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
2009	2	-	5335	-	1371	-	170.5	-	123	-	846.8	30.25	101.3	-	624.5	62.75	12.5	295.6	77
2009	3	-	6996	-	424	-	170.5	-	123	-	846.8	30.25	35.9	-	51.8	62.75	12.5	295.6	60
2009	4	-	20061	-	478	-	170.5	-	123	-	846.8	30.25	16.5	-	0	62.75	12.5	295.6	18
2010	1	-	12442	-	3017	-	123.5	-	87.5	-	649.3	13	34.8	-	397.5	15.25	9.25	411.6	38
2010	2	-	3936	-	2196	-	123.5	-	87.5	-	649.3	13	82.4	-	322.2	15.25	9.25	411.6	516
2010	3	-	6817	-	660	-	123.5	-	87.5	-	649.3	13	31	-	25.6	15.25	9.25	411.6	1088
2010	4	-	18219	-	446	-	123.5	-	87.5	-	649.3	13	10.8	-	0	15.25	9.25	411.6	114
2011	1	-	9176	-	997	-	48.25	-	61.75	-	841.5	19.5	21.9	-	291.3	29.5	6	374.3	87
2011	2	-	3360	-	1165	-	48.25	-	61.75	-	841.5	19.5	98.1	-	283.1	29.5	6	374.3	65
2011	3	-	4574	-	761	-	48.25	-	61.75	-	841.5	19.5	20.8	-	0	29.5	6	374.3	165
2011	4	-	15902	-	428	-	48.25	-	61.75	-	841.5	19.5	11.9	-	0	29.5	6	374.3	0
2012	1	-	11833	-	1000	-	97.5	-	90	-	819.8	12	25.8	-	344.1	24.25	3.25	370.3	131
2012	2	-	4460	-	1215	-	97.5	-	90	-	819.8	12	118.4	-	285.6	24.25	3.25	370.3	171
2012	3	-	3955	-	436	-	97.5	-	90	-	819.8	12	40.3	-	0	24.25	3.25	370.3	96
2012	4	-	14580	-	380	-	97.5	-	90	-	819.8	12	17.7	-	0	24.25	3.25	370.3	51
2013	1	-	12131	-	660	-	77.25	-	118	-	673.3	2.75	24.5	-	149.3	23.75	5	262.4	24
2013	2	-	6882	-	1155	-	77.25	-	118	-	673.3	2.75	126.1	-	116.3	23.75	5	262.4	173
2013	3	-	3821	-	304	-	77.25	-	118	-	673.3	2.75	26.4	-	0	23.75	5	262.4	81
2013	4	-	13649	-	454	-	77.25	-	118	-	673.3	2.75	17.6	-	0	23.75	5	262.4	36
2014	1	-	11176	-	891	-	67.25	-	75.25	-	514.3	2	27	-	247	31	3.25	312.4	280
2014	2	-	5648	-	1019	-	67.25	-	75.25	-	514.3	2	106.8	-	252.9	31	3.25	312.4	129
2014	3	-	3622	-	637	-	67.25	-	75.25	-	514.3	2	36.6	-	42.1	31	3.25	312.4	53
2014	4	-	15427	-	537	-	67.25	-	75.25	-	514.3	2	26.6	-	0	31	3.25	312.4	48
2015	1	-	15277	-	994	-	69.25	-	122.25	-	709.8	2	41.1	-	169.7	24.25	6.5	580.1	287
2015	2	-	5298	-	1509	-	69.25	-	122.25	-	709.8	2	157	-	186.6	24.25	6.5	580.1	197
2015	3	-	4883	-	425	-	69.25	-	122.25	-	709.8	2	25	-	0	24.25	6.5	580.1	18
2015	4	-	16073	-	437	-	69.25	-	122.25	-	709.8	2	31	-	0	24.25	6.5	580.1	5
2016	1	-	18236	-	620	-	75.75	-	107.5	-	466.8	1.25	54.7	-	48.4	44	17.75	237.7	227.8
2016	2	-	7258	-	1734	-	75.75	-	107.5	-	466.8	1.25	174.5	-	155.2	44	17.75	237.7	125.8

		Fleet																	
Year	**Quarter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
2016	3	-	6868	-	201	-	75.75	-	107.5	-	466.8	1.25	27.4	-	19.9	44	17.75	237.7	39.5
2016	4	-	20272	-	163	-	75.75	-	107.5	-	466.8	1.25	28.7	-	0	44	17.75	237.7	89.25

Table 3. List of fleets with catch used in the base case assessment model along with CPUE indices provided for the 2018 Western Central North Pacific Ocean swordfish stock assessment, their source and whether the indices were used in the base case assessment model. Catch estimates for fleets F5 – F8 and F11 were provided to the BILLWG after the January 2018 data preparation meeting.

Length Comp – Used?	Relative Abundance Index – Used?	Fleet Name	Time Series	Source
F1 – N	S1 – Y	JPN_WCNPO_OSDWLL_early_Area1	1975-1993	Kanaiwa and Ijima 2018
F2-Y	S2 – Y	JPN_WCNPO_OSDWLL_late_Area1	1994-2016	Kanaiwa and Ijima 2018
F3	S3 – Y	JPN_WCNPO_OSDWLL_early_Area2	1975-1993	Kanaiwa and Ijima 2018
F4	S4 – Y	JPN_WCNPO_OSDWLL_late_Area2	1994-2016	Kanaiwa and Ijima 2018
F5	-	JPN_WCNPO_OSDF	1960-1992	Hirotaka Ijima, pers. comm.
F6 – N	-	JPN_WCNPO_CODF	1993-2014	Hirotaka Ijima, pers. comm.
F7	-	JPN_WCNPO_Other_Early	1952-1993	Hirotaka Ijima, pers. comm.
F8	-	JPN_WCNPO_Other_Late	1994-2016	Hirotaka Ijima, pers. comm.
F9	S5 – N	TWN_WCNPO_DWLL _early	1975-1999	Chang *et al*. 2018
F10-Y	S6 – Y	TWN_WCNPO_DWLL _late	2000-2016	Chang *et al.* 2018
F11	-	TWN_WCNPO_Other	1959-2016	Yi-Jay Chang, pers. comm
F12 – N	S7 – Y	US_WCNPO_LL_deep	1995-2016	Sculley *et al*. 2018
F13 – N	S8 – Y	US_WCNPO_LL_shallow_early	1995-2000	Sculley *et al*. 2018
F14-Y	S9 – Y	US_WCNPO_LL_shallow_late	2005-2016	Sculley *et al*. 2018
F15	S10 – N	US_WCNPO_GN	1985-2006	Courtney *et al*. 2009
F16	-	US_WCNPO_Other	1970-2016	Ito *et al*. 2018
F17	-	WCPFC_LL	1970-2016	Darryl Tagami, pers. comm.
F18-Y	-	IATTC_LL_Overlap	1975-2016	Shane Griffiths, pers. comm.

Table 4. Standardized catch-per-unit-effort (CPUE; in number per 1000 hooks) indices and input standard error (SE) in log-scale (i.e., log(SE)) of lognormal error of CPUE for the swordfish from the Western and Central North Pacific Ocean used in the stock assessment update. Index descriptions can be found in Table 3.

Fleet	S1		S2		S3		S4		S5	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1975	1.82	0.01	-	-	0.13	0.019	-	-	0.2	0.04
1976	1.77	0.008	-	-	0.14	0.016	-	-	0.36	0.04
1977	1.7	0.008	-	-	0.17	0.017	-	-	0.02	0.03
1978	1.45	0.008	-	-	0.13	0.018	-	-	-	-
1979	1.58	0.008	-	-	0.11	0.017	-	-	0.1	0.09
1980	1.46	0.009	-	-	0.14	0.016	-	-	0.05	0.14
1981	1.45	0.008	-	-	0.14	0.016	-	-	0.03	0.15
1982	1.44	0.009	-	-	0.1	0.017	-	-	-	-
1983	1.71	0.009	-	-	0.1	0.019	-	-	-	-
1984	1.68	0.008	-	-	0.11	0.017	-	-	-	-
1985	2.13	0.009	-	-	0.14	0.017	-	-	-	-
1986	1.9	0.009	-	-	0.14	0.018	-	-	-	-
1987	2.04	0.009	-	-	0.12	0.018	-	-	0.02	0.7
1988	1.73	0.009	-	-	0.11	0.019	-	-	-	-
1989	1.6	0.009	-	-	0.1	0.019	-	-	0.11	0.22
1990	1.75	0.009	-	-	0.11	0.019	-	-	0.2	0.27
1991	1.57	0.01	-	-	0.1	0.021	-	-	0.18	0.09
1992	1.4	0.01	-	-	0.09	0.022	-	-	0.44	0.38
1993	1.47	0.01	-	-	0.11	0.02	-	-	0.7	0.14
1994	-	-	1.69	0.031	-	-	0.09	0.033	-	-
1995	-	-	1.7	0.028	-	-	0.09	0.03	0.23	0.26
1996	-	-	1.44	0.027	-	-	0.11	0.03	0.05	0.36
1997	-	-	1.44	0.028	-	-	0.08	0.032	0.04	0.2
1998	-	-	1.4	0.029	-	-	0.08	0.032	0.01	0.24
1999	-	-	1.42	0.03	-	-	0.11	0.031	0.05	0.27
2000	-	-	1.36	0.029	-	-	0.13	0.03	-	-

2001	-	-	1.59	0.029	-	-	0.14	0.031	-	-
2002	-	-	1.22	0.03	-	-	0.12	0.032	-	-
2003	-	-	1.3	0.03	-	-	0.11	0.034	-	-
2004	-	-	1.25	0.029	-	-	0.1	0.035	-	-
2005	-	-	1.33	0.029	-	-	0.09	0.037	-	-
2006	-	-	1.4	0.028	-	-	0.11	0.037	-	-
2007	-	-	1.33	0.029	-	-	0.1	0.038	-	-
2008	-	-	1.1	0.031	-	-	0.13	0.038	-	-
2009	-	-	1.42	0.034	-	-	0.13	0.04	-	-
2010	-	-	1.23	0.035	-	-	0.11	0.042	-	-
2011	-	-	1.14	0.037	-	-	0.12	0.044	-	-
2012	-	-	1.35	0.037	-	-	0.12	0.045	-	-
2013	-	-	1.33	0.037	-	-	0.12	0.048	-	-
2014	-	-	1.66	0.037	-	-	0.11	0.052	-	-
2015	-	-	1.95	0.038	-	-	0.13	0.059	-	-
2016	-	-	1.49	0.044	-	-	0.13	0.07	-	-

Fleet	**S6**		**S7**		**S8**		**S9**		**S10**	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1975	-	-	-	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-	-	-	-
1982	-	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-

1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	0.137	0.022
1991	-	-	-	-	-	-	-	-	0.052	0.012
1992	-	-	-	-	-	-	-	-	0.097	0.02
1993	-	-	-	-	-	-	-	-	0.09	0.017
1994	-	-	-	-	-	-	-	-	0.063	0.013
1995	-	-	0.37	0.6	2.82	1.49	-	-	0.106	0.018
1996	-	-	0.22	0.5	2.97	1.55	-	-	0.085	0.019
1997	-	-	0.17	0.44	3.24	1.63	-	-	0.141	0.045
1998	-	-	0.26	0.5	3.55	1.69	-	-	0.025	0.2
1999	-	-	0.26	0.5	3.68	1.67	-	-	0.105	0.034
2000	0.19	0.35	0.23	0.48	4.09	1.75	-	-	0.04	0.017
2001	0.36	0.3	0.22	0.48	-	-	-	-	0.272	0.296
2002	0.39	0.34	0.28	0.51	-	-	-	-	0.008	0.001
2003	0.36	0.36	0.26	0.49	-	-	-	-	-	-
2004	0.34	0.37	0.3	0.52	-	-	-	-	-	-
2005	0.23	0.42	0.25	0.49	-	-	11.92	0.37	0.106	0.2
2006	0.44	0.22	0.26	0.5	-	-	12.59	0.37	0.359	0.043
2007	0.46	0.19	0.25	0.49	-	-	10.57	0.37	0.207	0.038
2008	0.52	0.17	0.24	0.48	-	-	10.2	0.37	0.078	0.039
2009	0.48	0.2	0.25	0.49	-	-	8.33	0.37	-	-
2010	0.49	0.21	0.24	0.48	-	-	7.25	0.37	-	-
2011	0.45	0.22	0.2	0.45	-	-	8.4	0.37	-	-
2012	0.46	0.27	0.24	0.48	-	-	8.07	0.37	-	-
2013	0.4	0.25	0.23	0.47	-	-	7.44	0.37	-	-
2014	0.45	0.22	0.26	0.49	-	-	8.62	0.37	-	-
2015	0.45	0.27	0.28	0.5	-	-	8.7	0.37	-	-
2016	0.45	0.35	0.26	0.48	-	-	10.19	0.38	-	-

Table 5. Key life history parameters and model structures for WCNPO swordfish used in the stock assessment. The column labeled "Estimated ?" identifies if the parameters are expected to be estimated within the assessment model (Estimated), fixed at a specific value, i.e., not estimated (Fixed) from Table 9.0 in the BILLWG swordfish data preparation report (ISC 2018).

Parameter (units)	**Value**	**Estimated?**
Natural mortality (M, age-specific^{-yr})	Female: M_0 = 0.42, M_1 = 0.37, M_2 = 0.32, M_3 = 0.27, M_{4+} = 0.22 Male: M_0 = 0.40, M_{1-2} = 0.38, M_{3-5} = 0.37, M_{4+} = 0.36	Fixed
Length_at_min_age (EFL cm)	Female: $L(A_{min})$ = 97.7 Male: $L(A_{min})$ = 99.0	Fixed
Length_at_max_age (EFL cm)	Female: $L(A_{max})$ = 226.3 Male: $L(A_{max})$ = 206.4	Fixed
Von Bertalanffy_K	Female: k = 0.246 Male: k = 0.271	Fixed
$W=aL^b$ (kg)	Both genders: a = 1.299 ×10-5 b = 3.0738	Fixed
Size at 50-percent maturity (EFL cm) and maturity ogive slope parameter	Female: L_{50} = 143.6, β = -0.103 Male: L_{50} = 102.0, β = -0.141	Fixed
Stock-recruitment steepness (h)	h= 0.9	Fixed
Unfished log-scale recruitment (Ln($R0$))	-	Estimated
Standard deviation of recruitment (σR)	σR = 0.6	Fixed
Initial age structure	-	Estimated
Recruitment deviations	-	Estimated
Selectivity	-	Estimated
Catchability		Estimated

Table 6. Mean input standard error (SE) in log-space (i.e., log(SE)) of lognormal error, root-mean-square-errors (RMSE), and standard deviations of the normalized residuals (SDNR) for the relative abundance indices for Western and Central North Pacific Ocean swordfish used in the base-case model. CPUE indices S5 (TWN_WCNPO_DWLL_early) and S10 (US_WCNPO_GN) were not included in the total likelihood. An SDNR value greater than the chi-squared statistic (χ^2) indicates a statistically poor fit.

Fleet	***N***	**Input log(SE)**	**RMSE**	**SDNR**	χ^2
S1_JPN_WCNPO_OSDWLL_early_Area1	19	0.250	0.083	0.340	1.266
S2_JPN_WCNPO_OSDWCOLL_late_Area1	23	0.250	0.173	0.706	1.242
S3_JPN_WCNPO_OSDWLL_early_Area2	19	0.250	0.109	0.447	1.266
S4_JPN_WCNPO_OSDWLL_late_Area2	23	0.250	0.134	0.547	1.242
S5_TWN_WCNPO_DWLL_early	17	0.294	1.185	4.416	1.282
S6_TWN_WCNPO_DWLL_late	17	0.296	0.218	0.616	1.282
S7_US_WCNPO_LL_deep	22	0.492	0.258	0.535	1.247
S8_US_WCNPO_LL_shallow_early	6	1.630	0.145	0.144	1.488
S9_US_WCNPO_LL_shallow_late	12	0.371	0.143	0.405	1.337
S10_US_WCNPO_GN	17	0.817	0.586	0.735	1.282

Table 7. 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 6.81. See Table 3 for a description of the abundance indices. S5 and S10 were not included in the total likelihood. S8 is not listed below as it contributed <0.01 to the change in negative log-likelihood.

log(R0)	S1	S2	S3	S4	S6	S7	S9
6.6	11.39	0.21	13.12	4.26	2.04	11.91	0.33
6.7	6.51	0.00	2.36	3.40	3.05	1.02	0.00
6.8	0.00	0.36	0.00	0.08	0.45	0.08	0.39
6.81	0.01	0.40	0.01	0.05	0.43	0.04	0.41
6.9	0.07	0.84	0.10	0.00	0.30	0.00	0.52
7	0.00	1.20	0.27	0.02	0.22	0.09	0.59
7.1	0.14	1.73	0.18	0.16	0.16	0.07	0.65
7.2	0.16	2.16	0.16	0.25	0.10	0.11	0.68
7.3	0.12	2.19	0.16	0.32	0.13	0.20	0.64
7.4	0.23	2.79	0.10	0.41	0.06	0.19	0.72
7.5	0.22	3.02	0.07	0.45	0.05	0.23	0.73
7.6	0.23	3.22	0.09	0.50	0.04	0.26	0.74
7.7	0.33	3.55	0.12	0.58	0.00	0.21	0.76
7.8	0.23	3.62	0.04	0.60	0.03	0.33	0.75
7.9	0.26	3.78	0.03	0.64	0.02	0.36	0.76
8	0.34	3.81	0.03	0.69	0.02	0.34	0.75

Table 8. Relative negative log-likelihoods of length composition data components in the base case model over a range of fixed levels of virgin recruitment in log-scale (log(R0)). Likelihoods are relative to the minimum negative log-likelihood (best-fit) for each respective data component. Colors indicate relative likelihood (green: low negative log-likelihood, better-fit; red: high negative log-likelihood, poorer-fit). Maximum likelihood estimate of log(R0) was 6.81. See Table 3 for a description of the composition data.

log(R0)	F2_JPN_WCNPO_OSDWCOLL_late_Area1	F10_TWN_WCNPO_DWLL_late	F14_US_WCNPO_LL_shallow_late	F18_IATTC_LL_Overlap
6.6	53.17	1.37	11.67	4.16
6.7	96.32	125.12	62.83	40.95
6.8	0.00	0.10	0.00	0.06
6.81	0.14	0.00	0.03	0.03
6.9	0.95	0.45	0.21	0.00
7	4.66	2.61	0.44	0.51
7.1	2.47	5.82	0.53	0.35
7.2	2.90	9.18	0.57	0.61
7.3	3.53	13.14	0.67	0.95
7.4	3.47	15.40	0.70	1.11
7.5	3.59	18.25	0.83	1.34
7.6	3.95	20.74	0.88	1.54
7.7	4.60	22.66	0.79	1.67
7.8	3.89	24.96	0.95	1.92
7.9	3.89	26.76	1.01	2.04
8	4.38	28.65	0.93	2.21

Table 9. Fishery-specific selectivity assumptions for the Western and Central North Pacific Ocean 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	Mirror F2
F2	Double-normal
F3	Mirror F14
F4	Mirror F14
F5	Mirror F10
F6	Mirror F18
F7	Mirror F2
F8	Mirror F2
F9	Mirror F10
F10	Asymptotic lognormal
F11	Mirror F2
F12	Mirror F14
F13	Mirror F14
F14	Double-normal
F15	Mirror F10
F16	Mirror F10
F17	Mirror F10
F18	Asymptotic lognormal
S1	Mirror F2
S2	Mirror F2
S3	Mirror F14
S4	Mirror F14
S5	Mirror F10
S6	Mirror F10
S7	Mirror F14
S8	Mirror F14
S9	Mirror F14
S10	Mirror F10

Table 10. Time series of total biomass (age 1 and older, metric ton), spawning biomass (metric ton), age-0 recruitment (thousands of fish), instantaneous fishing mortality (average ages 1 to 10, yr^{-1}), fishing intensity (1-spawning potential ratio) and spawning potential ratio for the Western and Central North Pacific Ocean swordfish estimated in the base-case model. SE = standard error.

Year	Age 1+ biomass (mt)	Spawning biomass (mt)		Recruitment (1000 age-0 fish)		Instantaneous fishing mortality		1 - Spawning potential ratio		Spawning potential ratio	
	Mean	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1975	97919	44100	8638	789	377	0.10	0.02	0.64	0.05	0.36	0.05
1976	92360	39375	8115	697	334	0.12	0.02	0.68	0.05	0.32	0.05
1977	85998	35617	7816	803	378	0.12	0.02	0.69	0.05	0.31	0.05
1978	80177	32091	7697	833	387	0.14	0.03	0.74	0.05	0.26	0.05
1979	74580	29057	7489	705	335	0.13	0.02	0.72	0.05	0.28	0.05
1980	71937	27485	7253	682	329	0.12	0.02	0.69	0.06	0.31	0.06
1981	70091	25871	7008	854	422	0.13	0.03	0.73	0.05	0.27	0.05
1982	67168	25512	6953	1061	552	0.11	0.02	0.69	0.06	0.31	0.06
1983	68703	23811	6753	1241	615	0.13	0.03	0.76	0.05	0.24	0.05
1984	71310	23426	6730	894	474	0.12	0.03	0.75	0.05	0.25	0.05
1985	76361	23356	6763	803	403	0.16	0.03	0.79	0.05	0.21	0.05
1986	74806	24286	6946	772	381	0.15	0.03	0.76	0.05	0.24	0.05
1987	72630	24154	7029	820	390	0.17	0.03	0.78	0.05	0.22	0.05
1988	68402	22691	6876	760	349	0.16	0.03	0.78	0.05	0.22	0.05
1989	65398	21921	6708	587	265	0.14	0.03	0.76	0.05	0.24	0.05
1990	63602	21709	6454	586	255	0.13	0.02	0.73	0.05	0.27	0.05
1991	61184	21373	6116	1178	256	0.16	0.03	0.76	0.05	0.24	0.05
1992	58264	19156	5522	702	164	0.15	0.02	0.82	0.04	0.18	0.04
1993	59383	17191	4768	658	133	0.18	0.02	0.83	0.03	0.17	0.03
1994	56829	17716	4320	677	129	0.15	0.02	0.77	0.04	0.23	0.04
1995	56300	18832	4219	563	107	0.13	0.02	0.74	0.04	0.26	0.04
1996	56272	19224	4191	401	86	0.13	0.01	0.72	0.04	0.28	0.04

1997	54792	19451	4163	894	145	0.14	0.02	0.72	0.04	0.28	0.04
1998	51856	18745	4081	1068	153	0.11	0.01	0.73	0.04	0.27	0.04
1999	54820	18039	3936	564	116	0.10	0.01	0.73	0.04	0.27	0.04
2000	60870	18365	3815	669	115	0.15	0.02	0.77	0.03	0.23	0.03
2001	59366	20322	3857	737	108	0.12	0.01	0.71	0.04	0.29	0.04
2002	59948	20911	3889	706	101	0.12	0.01	0.73	0.04	0.27	0.04
2003	60113	20866	3908	1066	117	0.12	0.01	0.72	0.04	0.28	0.04
2004	61065	20767	3939	901	121	0.11	0.01	0.73	0.04	0.27	0.04
2005	65727	20990	4025	703	121	0.11	0.01	0.73	0.04	0.27	0.04
2006	68991	22848	4215	762	123	0.13	0.01	0.72	0.04	0.28	0.04
2007	68884	23811	4404	723	115	0.13	0.01	0.72	0.04	0.28	0.04
2008	68131	24557	4573	567	97	0.11	0.01	0.68	0.04	0.32	0.04
2009	68144	25392	4743	617	101	0.11	0.01	0.66	0.04	0.34	0.04
2010	66417	26136	4891	789	117	0.10	0.01	0.62	0.04	0.38	0.04
2011	66087	26448	4987	565	101	0.08	0.01	0.59	0.05	0.41	0.05
2012	68177	26569	5056	671	106	0.09	0.01	0.61	0.05	0.39	0.05
2013	67885	27546	5179	710	115	0.07	0.01	0.55	0.05	0.45	0.05
2014	69560	28580	5295	683	129	0.07	0.01	0.53	0.05	0.47	0.05
2015	71951	28865	5393	742	232	0.09	0.01	0.61	0.05	0.39	0.05
2016	71979	29404	5533	781	303	0.07	0.01	0.55	0.05	0.45	0.05

Table 11. Estimates of biological reference points along with estimates of fishing mortality (F), spawning stock biomass (SSB), recent average yield (C), and spawning potential ratio (SPR) of Western and Central North Pacific Ocean swordfish, derived from the base case model assessment model, where "MSY" indicates reference points based on maximum sustainable yield.

Reference Point	**Estimate**
F_{MSY}	0.17 yr^{-1}
$F_{0.2*SSB(F=0)}$	0.16 yr^{-1}
$F_{2013-2015}$	0.08 yr^{-1}
SSB_{MSY}	15,702 mt
SSB_{2016}	29,403 mt
$SSB_{F=0}$	97,286 mt
MSY	14,941 mt
$C_{2012-2016}$	10,160 mt
SPR_{MSY}	18%
SPR_{2016}	45%

Table 12. Complete list of sensitivity runs conducted for the 2018 stock assessment of Western and Central North Pacific Ocean swordfish.

RUN	NAME	DESCRIPTION
	Alternative Life History Parameters: Natural Mortality Rates	
1	base_case_lowM	Alternative natural mortality rates are 10% lower than in the base case
2	base_case_highM	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 Ogives	
8	base_case_high_L50	Alternative maturity ogives with L_{50} set 10% higher than base case
9	base_case_low_L50	Alternative maturity ogives with L_{50} set 10% lower than base case
10	base_case_Wang2003	Alternative maturity ogives with converted L_{50} from Wang *et al*. (2003)

Table 13.1. Projected trajectory of spawning stock biomass (SSB in metric tons) for alternative harvest scenarios. Green blocks indicate the projected SSB is greater than MSY level (SSB_{MSY} =15,704 metric tons).

Harvest scenario	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**Average**
1. $F_{Status\ quo}$ ($F_{43\%}$)	32118	33207	34599	35476	36270	37082	37951	38967	40083	41087	36684
2. F_{MSY} ($F_{18\%}$)	28267	23963	21443	19458	18303	17618	17293	17197	17253	17263	19806
3. $F_{20\%SSB(F=0)}$ ($F_{22\%}$)	28425	24384	21800	19735	18530	17874	17496	17586	17818	17779	20143
4. F_{High} ($F_{20\%}$)	29007	25431	23527	21763	20736	20131	19893	19883	19981	20066	22042
5. F_{Low} ($F_{50\%}$)	32559	34334	36290	37666	38836	39984	41148	42490	44049	45625	39298

Table 13.2. Projected trajectory of yield (metric tons) for alternative harvest scenarios. Green blocks indicate the projected catch is greater than 80% of MSY or at the pretty good yield level (0.8*MSY=11,954 metric tons).

Harvest scenario	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Average
1. $F_{Status\ quo}$ ($F_{43\%}$)	8851	9135	9407	9599	9794	10022	10275	10595	11053	11142	9987
2. F_{MSY} ($F_{18\%}$)	20885	18323	16509	15294	14666	14353	14308	14520	14650	14348	15786
3. $F_{20\%SSB(F=0)}$ ($F_{22\%}$)	20691	18122	16454	15261	14653	14361	14319	14554	14665	14384	15747
4. F_{High} ($F_{20\%}$)	18680	16933	15657	14726	14242	14033	14050	14292	14496	14253	15136
5. F_{Low} ($F_{50\%}$)	7556	7973	8343	8605	8847	9101	9366	9692	10087	10223	8979

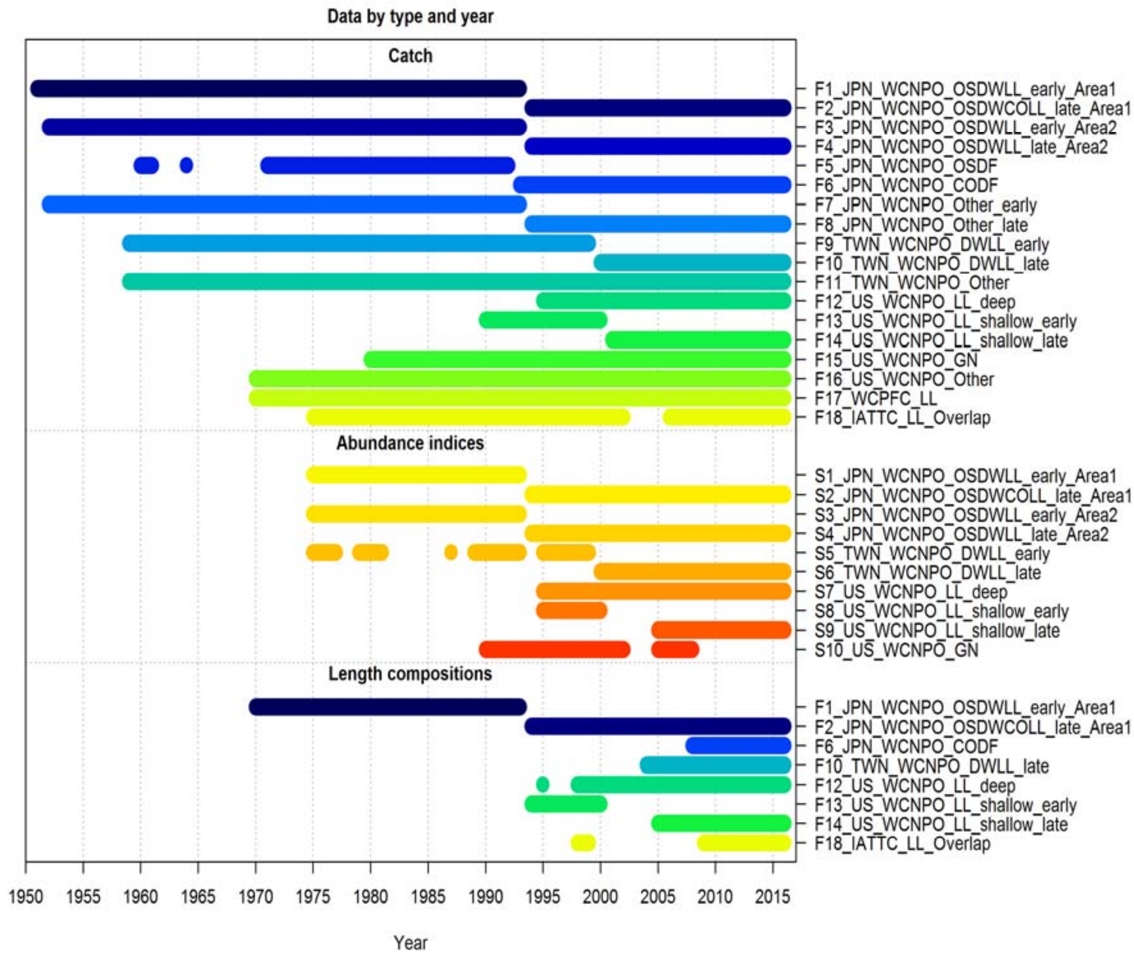


Figure 1. Available temporal coverage and sources of catch, CPUE (abundance indices), and length and size composition for the stock assessment of the Western and Central North Pacific Ocean swordfish.

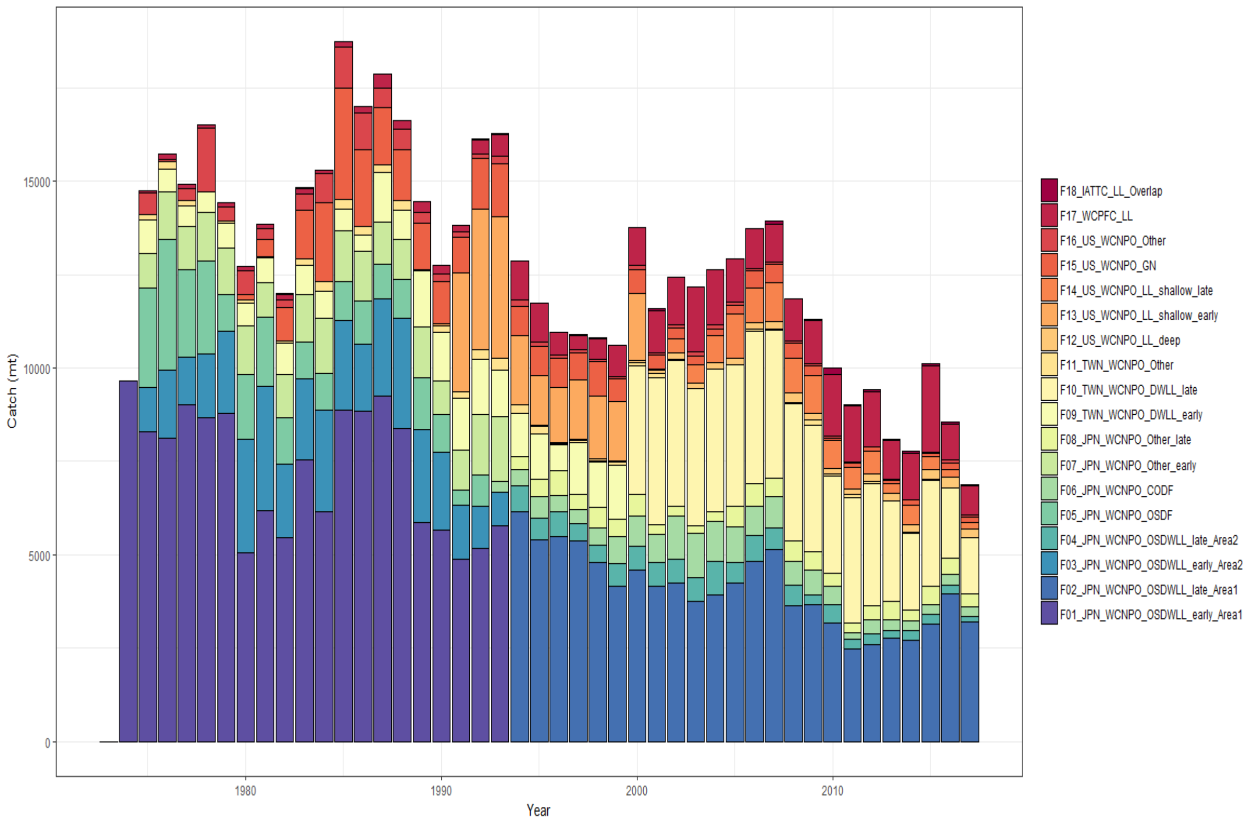


Figure 2. Total annual catch of the Western and Central North Pacific Ocean swordfish by all fisheries harvesting the stock during 1975-2016. See Table 1 for the reference code for each fishery.

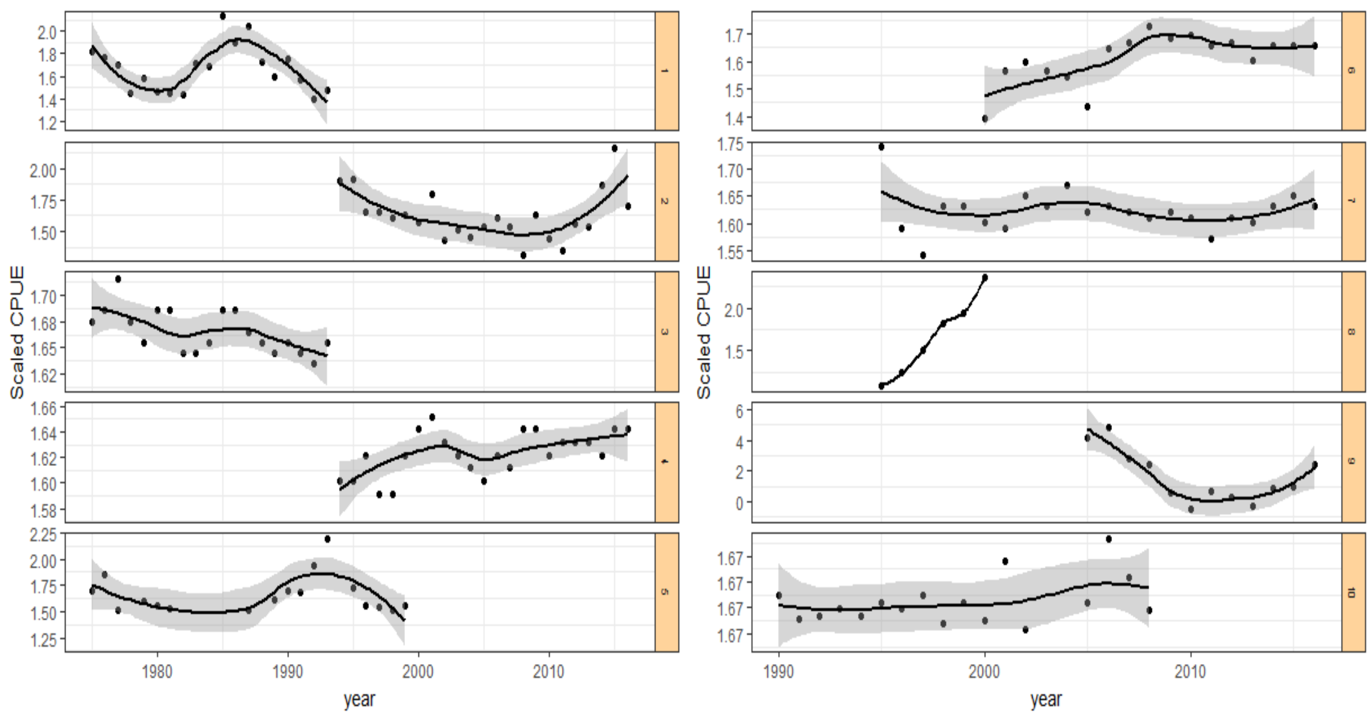


Figure 3. Time series of annual standardized indices of catch-per-unit-effort (CPUE) for the for each fleet in the base-case assessment model for WCNPO swordfish, where the CPUE time series for index fleets S1 to S5 are shown on the left from top to bottom and the CPUE time series for index fleets S6 to S10 are shown on the right from top to bottom. See Table 3 for the reference code for each index fleet. Index values were rescaled by the mean of each index for comparison purposes. A loess curve was fit to the data to show the general trend with shaded area representing 95% confidence intervals.

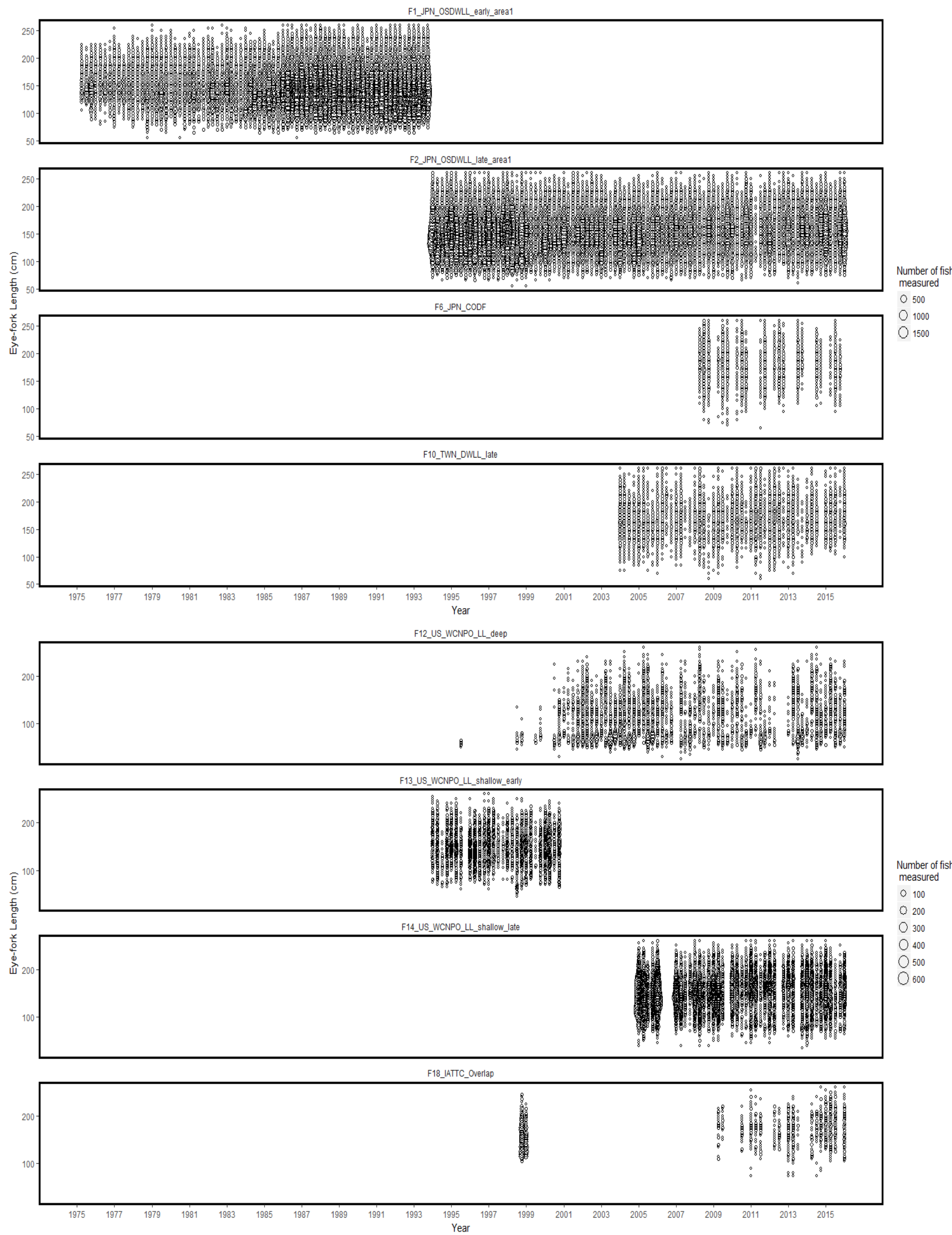


Figure 4. Quarterly length and size composition data by fishery used in the stock assessment (see Table 3). The sizes of the circles are proportional to the number of observations. All measurements were eye- fork lengths (EFL, cm).

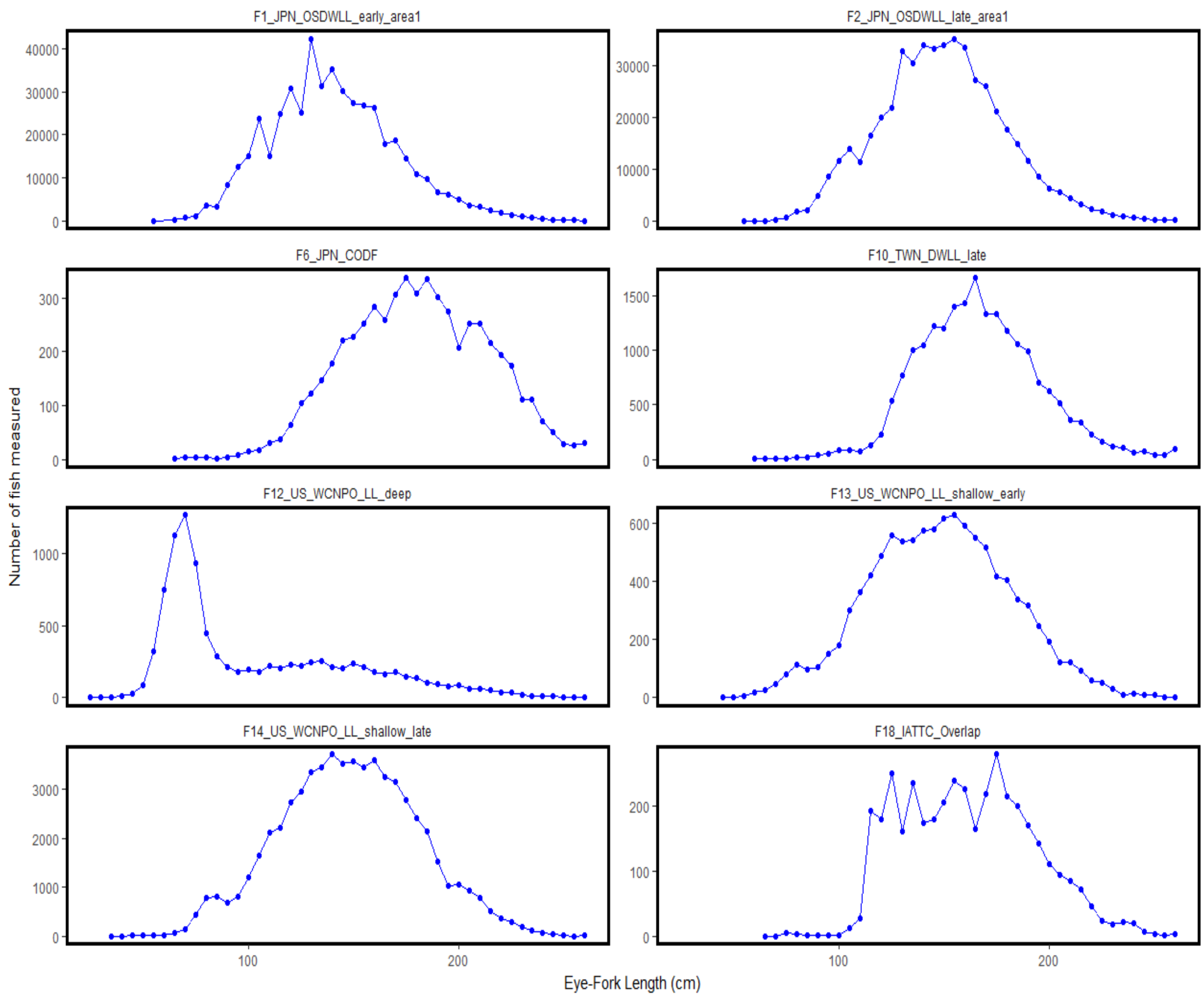


Figure 5. Aggregated length and size compositions used in the stock assessment (see Table 3 for descriptions of the composition data). All measurements were eye- fork lengths (EFL, cm).

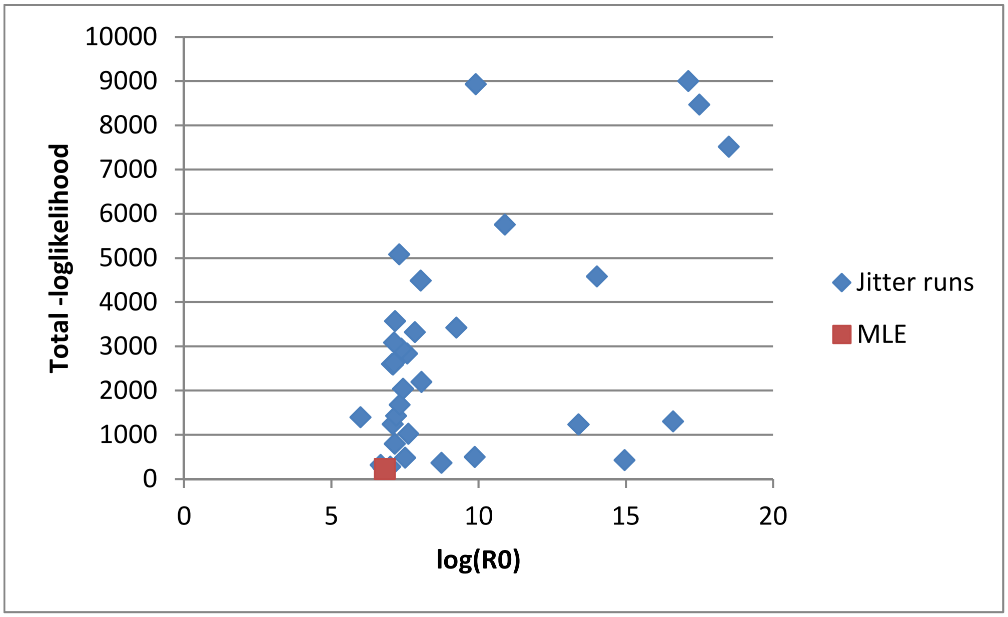


Figure 6. Results of a randomized initial parameter value diagnostic for the base case model where 100 randomized initial conditions were used with a CV of 20% assigned to each parameter. Results are shown for the base case model (MLE, solid red square) and for the base case model with randomized initial parameter values (Jitter runs, solid blue diamond) that had a fitted total negative log-likelihood value of less than 9,000.

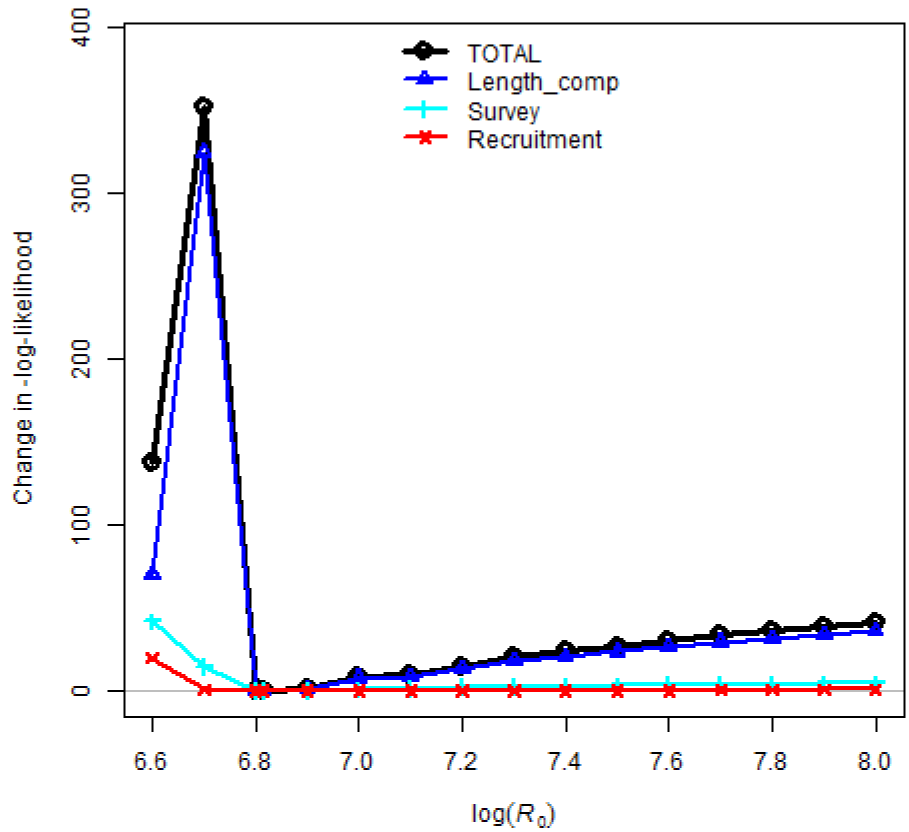


Figure 7.1. Profiles of the negative log-likelihoods relative to the minimum value of each component for the different likelihood components affecting the unfished recruitment parameter R0 in log-scale (i.e., the x-axis is log(R0)) ranging from 6.6 to 8.0 for the base case model, where recruitment represents the likelihood component based on the deviations from the stock-recruitment curve, length data represents the joint likelihood component for combined fleets based on the fish length composition data, and index data represents the joint likelihood component for combined fleets based on the relative abundance, or CPUE indices.

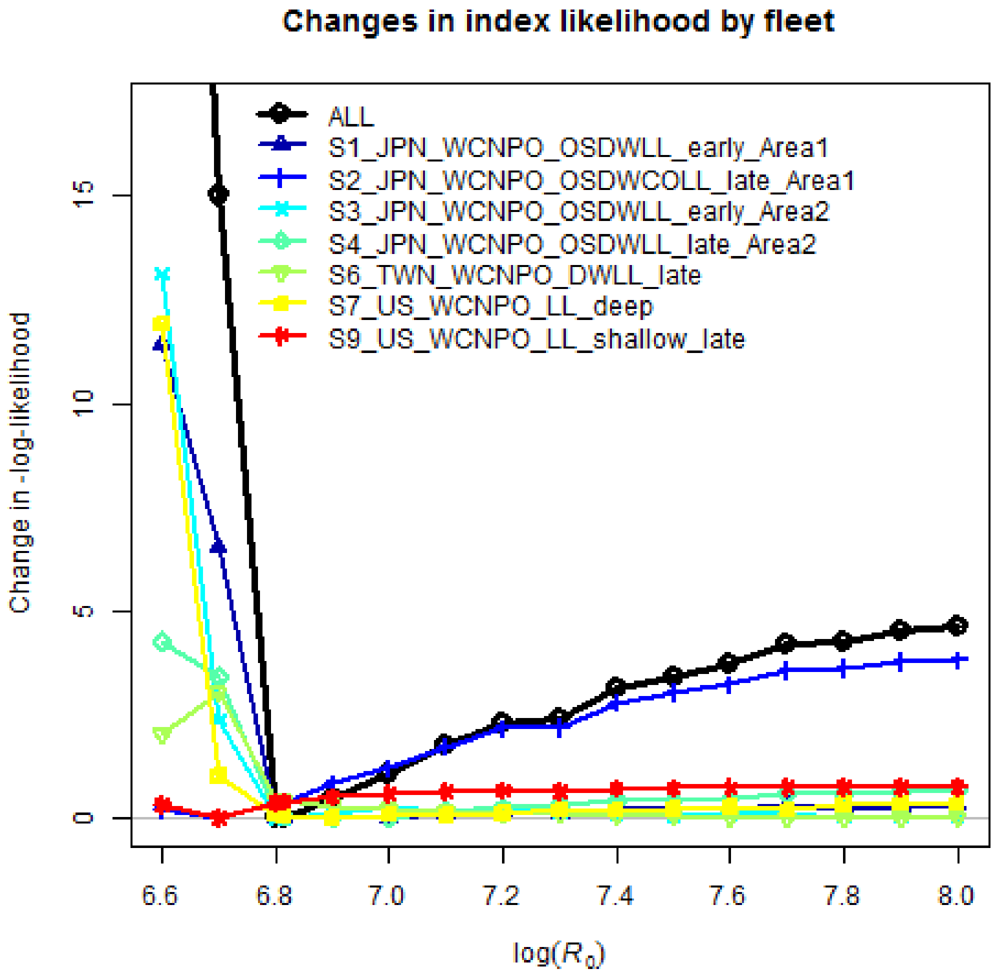


Figure 7.2. Profiles of the relative negative log-likelihoods by fleet-specific index likelihood components for the virgin recruitment in log-scale (log(R0)) ranged from 6.6 to 8.0 of the base case scenario. See Table 3 for descriptions of the index data. S5 and S10 were not included in the total likelihood, S8 is not drawn because it contributed to less than 0.01 of the change in total negative log-likelihood.

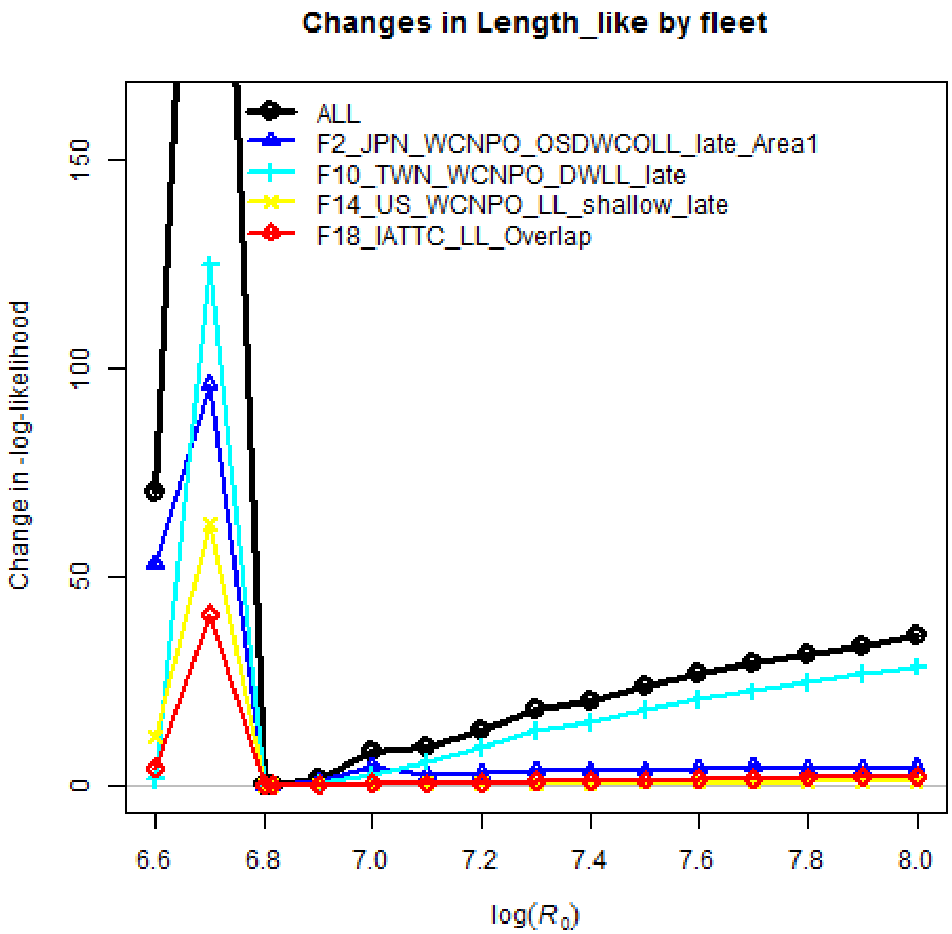


Figure 7.3. Profiles of the relative negative log-likelihoods by fleet-specific length composition likelihood components for the virgin recruitment in log-scale (log(R0)) ranged from 6.6 to 8.0 of the base case scenario. See Table 3 for descriptions of the length composition data. F1, F6, F12, and F13 were not included in the total likelihood.

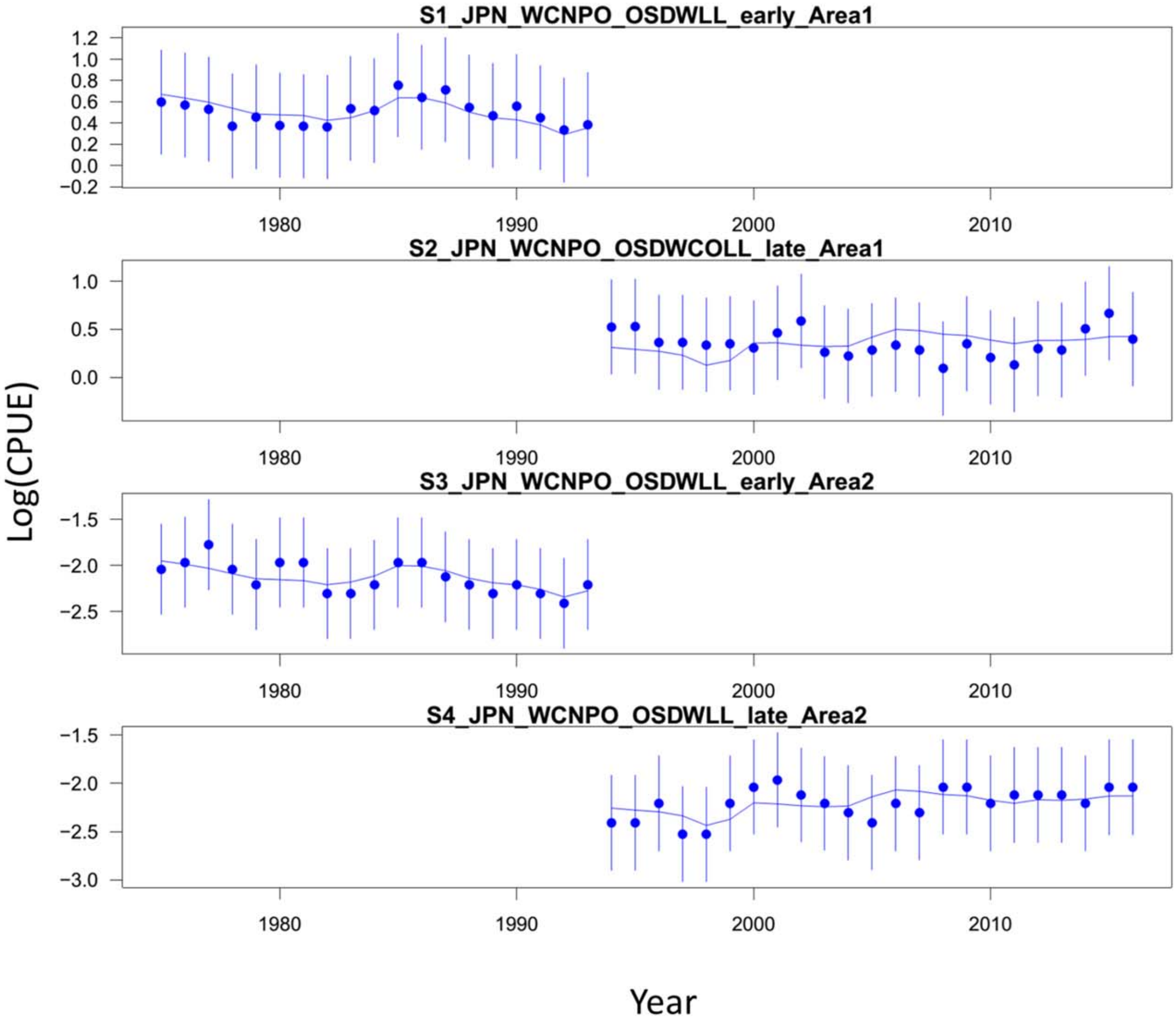


Figure 8. Model fits to the standardized catch-per-unit-effort (CPUE) data sets from different fisheries for the base case scenario. The line is the model predicted value and the points are observed (data) values. The vertical lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. S5 (TWN_WCNPO_DWLL_early) and S10 (US_WCNPO_GN) were not included in the total likelihood.

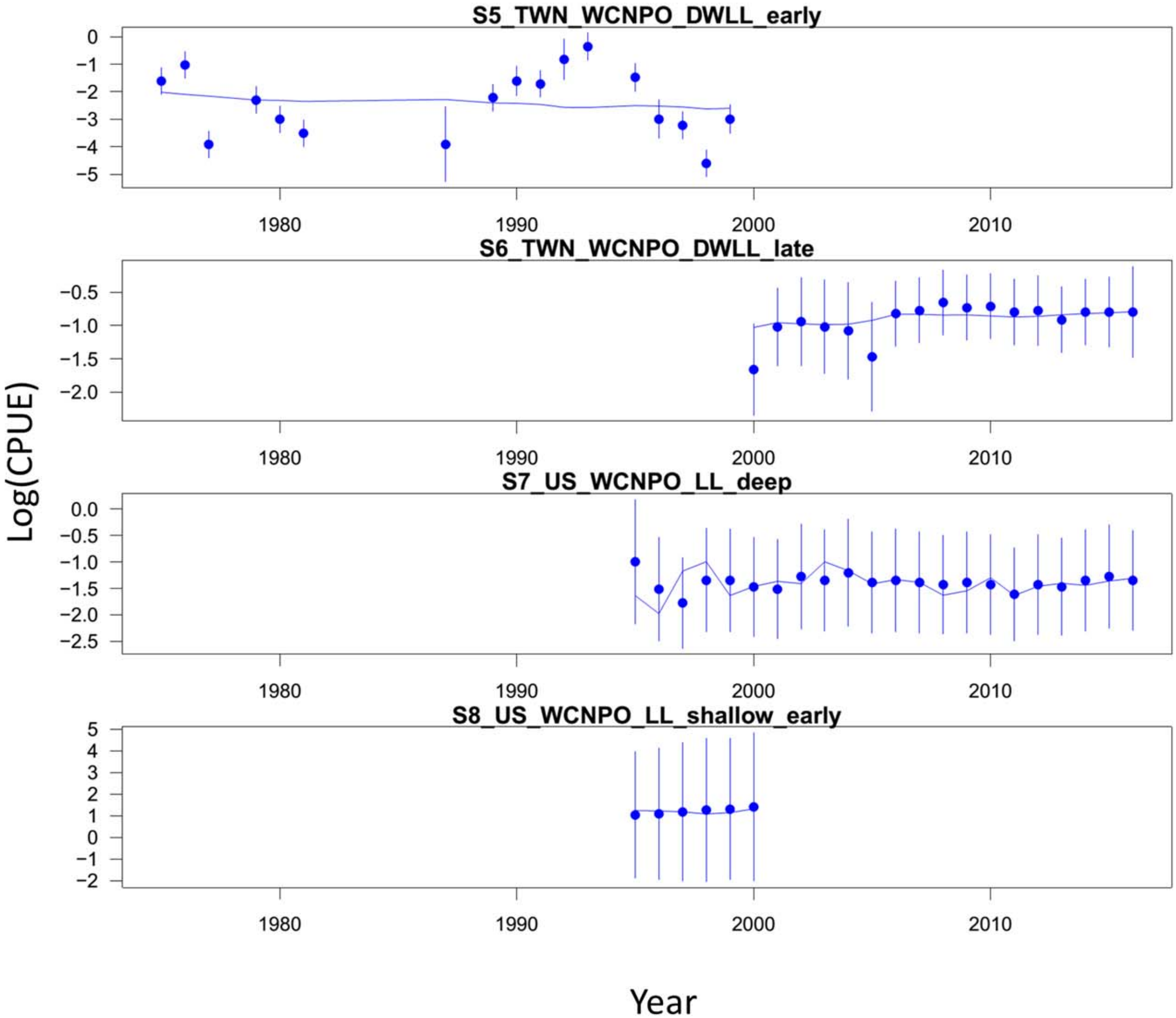


Figure 8. Continued

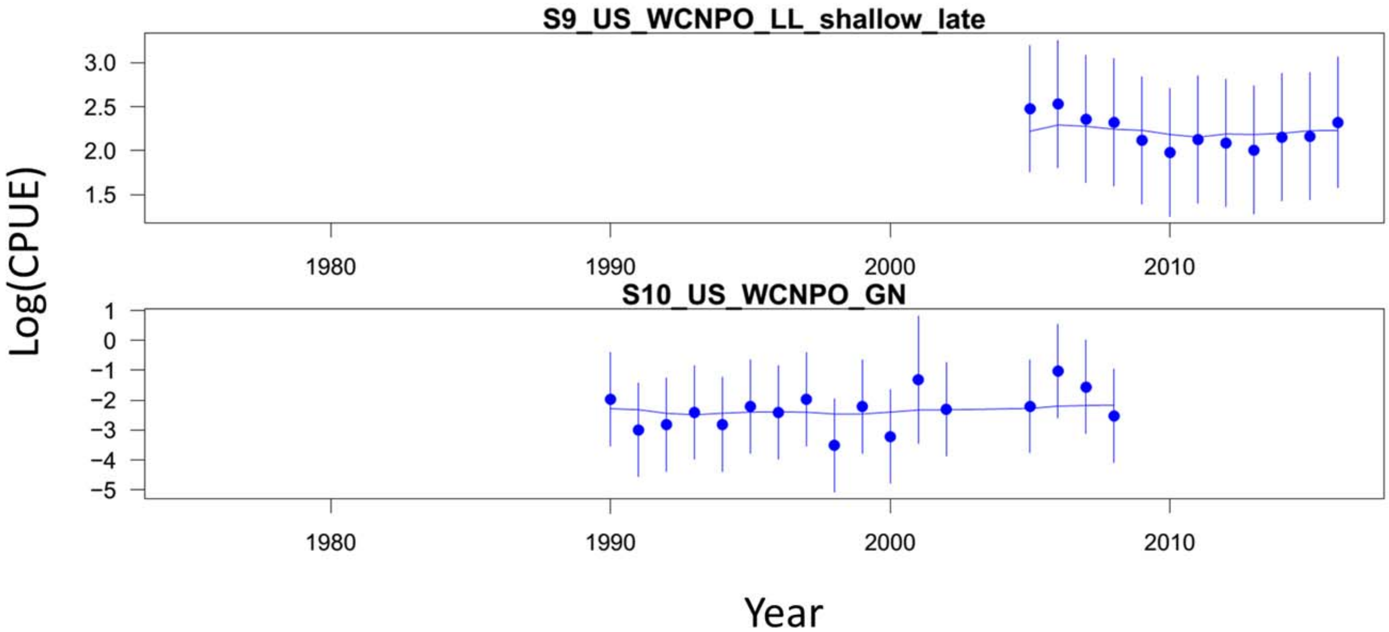


Figure 8. Continued

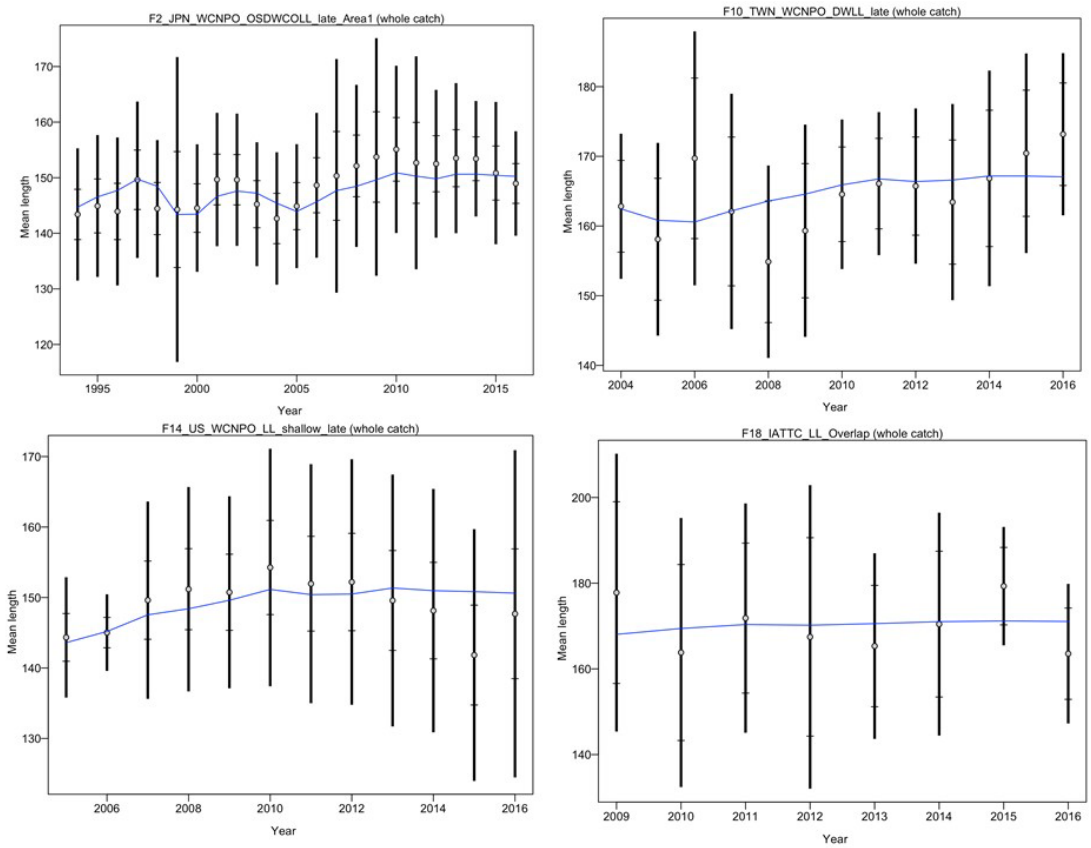


Figure 9. Model fit (lines) to mean length of the composition data (points, showing the observed mean age and 95% credible limits around mean age (vertical lines)). See Table 3 for descriptions of the data. All measurements were eye-to-fork lengths (EFL, cm).

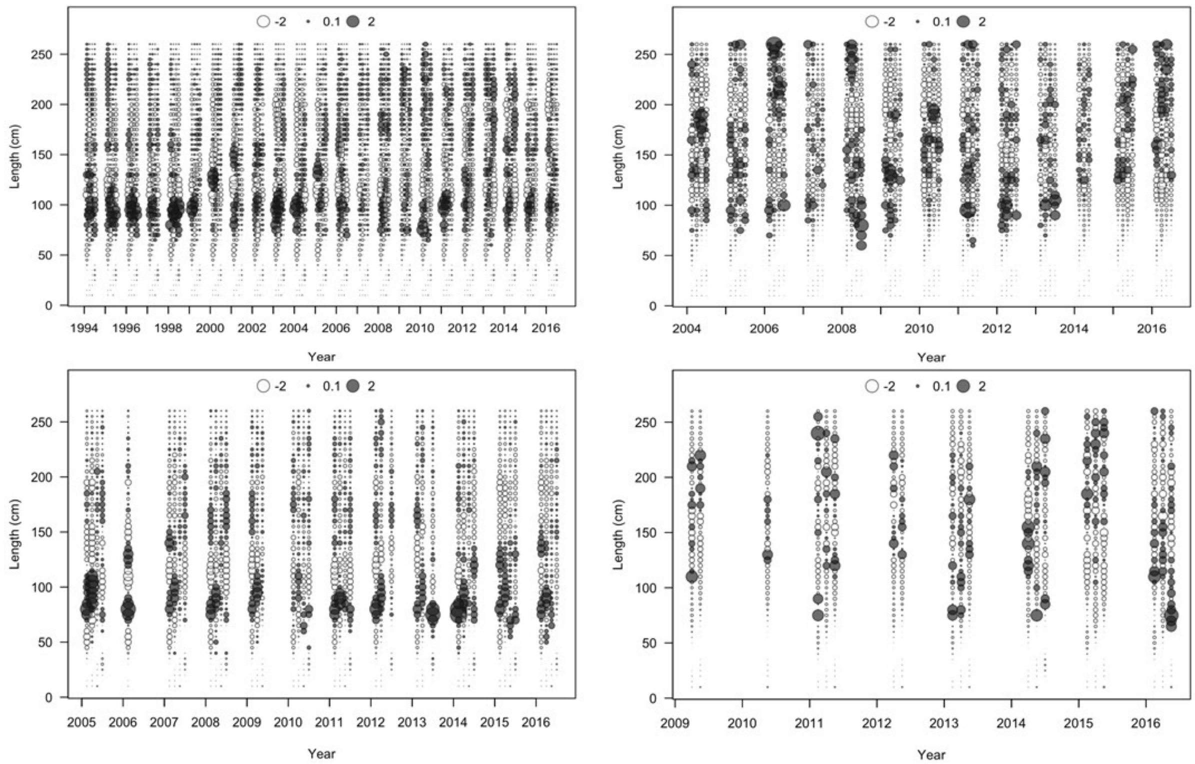


Figure 10. Pearson residual plots of model fits to the various length-composition data for the Western and Central North Pacific Ocean swordfish fisheries used in the assessment model: F2_JPN_WCNPO_OSDWLL_late_area1 (top left); F10_TWN_WCNPO_DWLL_late (top right); F14_US_WCNPO_LL_shallow_late (bottom left); F18_IATTC_Overlap (bottom right).

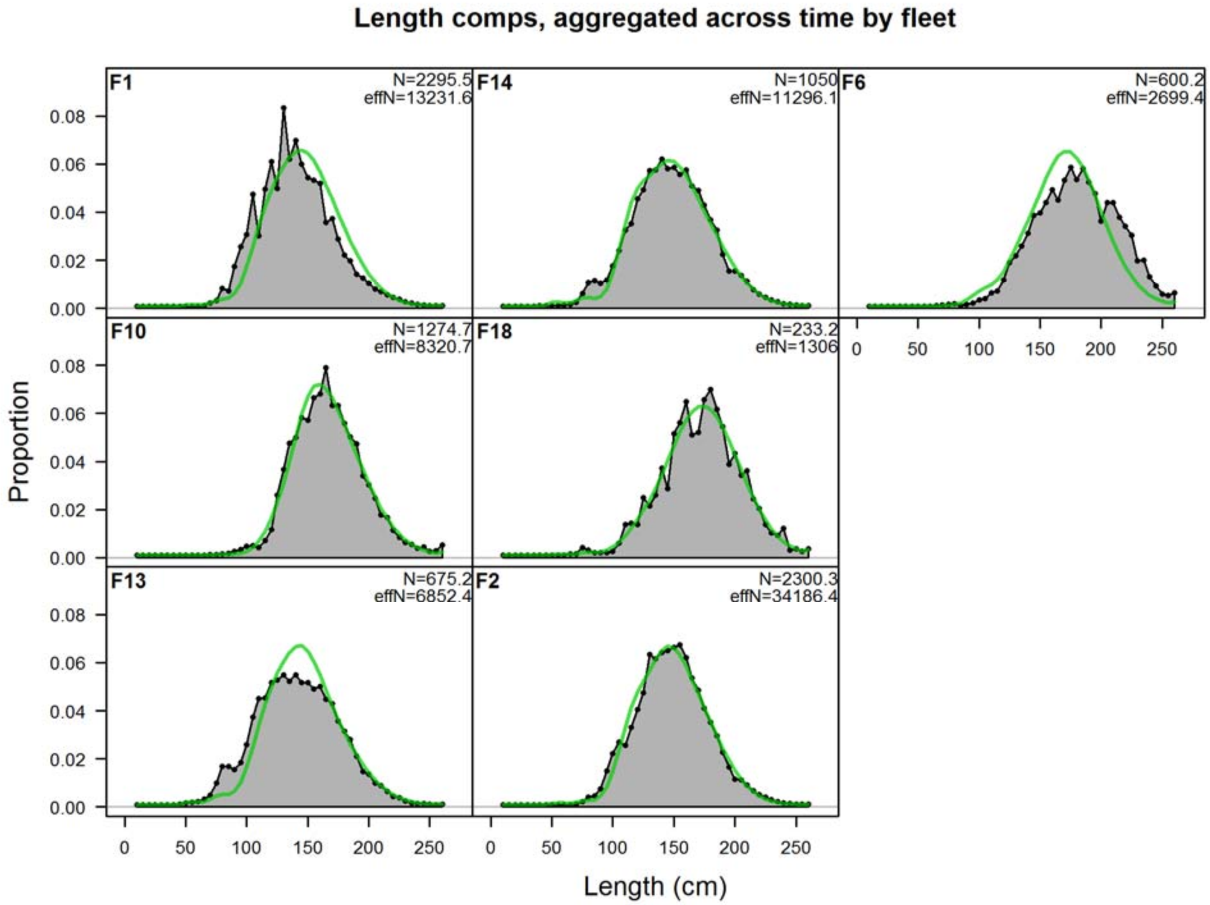


Figure 11. Comparison of observed (gray shaded area and blue dots) and model predicted (blue solid line) length compositions for fisheries used in the stock assessment for the Western and Central North Pacific Ocean swordfish. Observed (black circles) and predicted (green line) length compositions. All measurements were eye-to-fork lengths (EFL, cm). F1, F6, and F13 were not fit in the total likelihood.

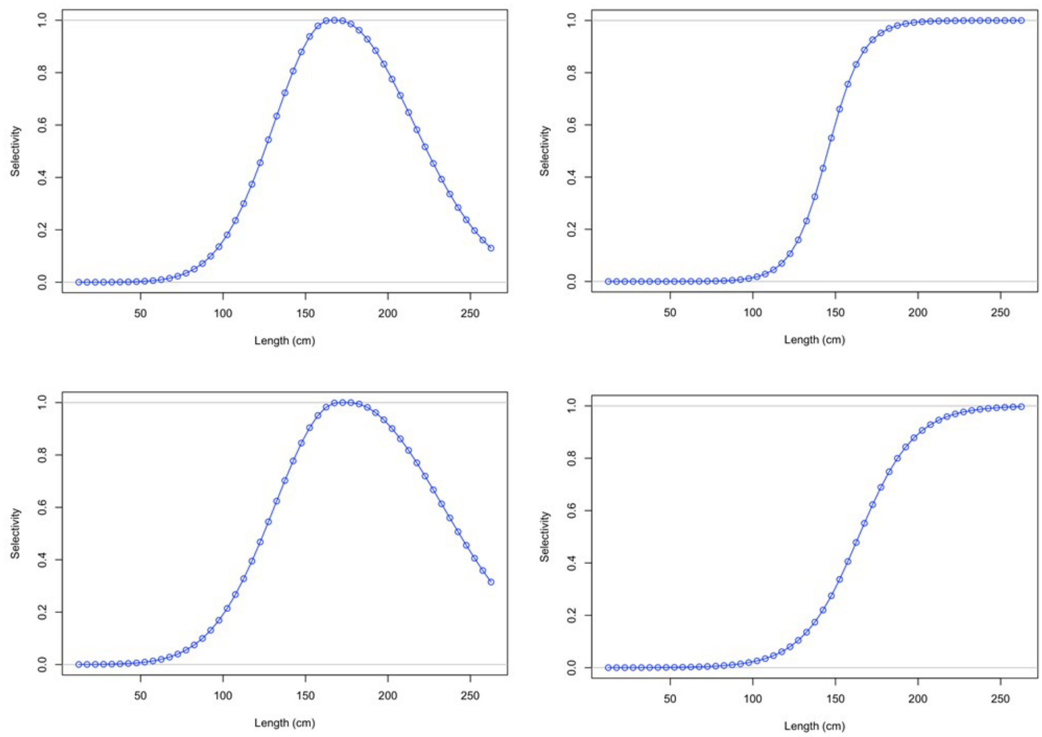


Figure 12. Length-based selectivity of fisheries for Western and Central North Pacific Ocean swordfish estimated for the 2018 assessment.

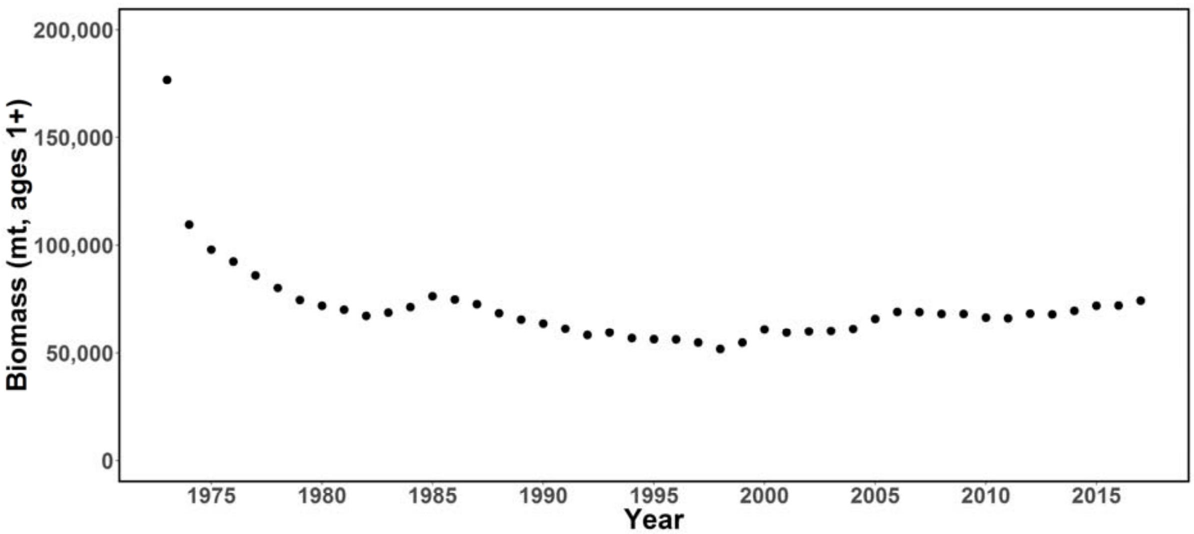


Figure 13.1. Time series of total biomass (age 1 and older, metric ton) for the Western and Central North Pacific Ocean swordfish estimated in the base-case model. The first year indicates the unfished equilibrium biomass level.

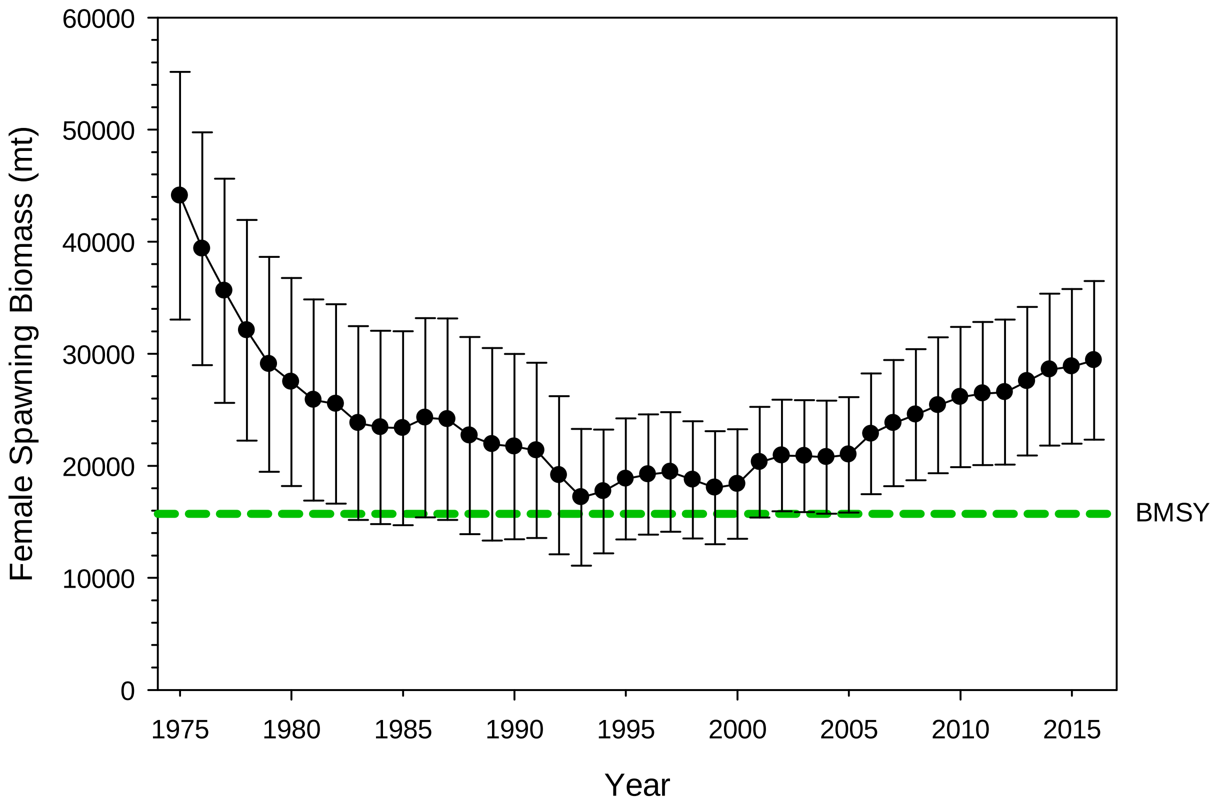


Figure 13.2. Time series of spawning biomass (metric ton) for the Western and Central North Pacific Ocean swordfish estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (80% confidence intervals). The dashed horizontal line shows the spawning biomass to produce MSY reference point.

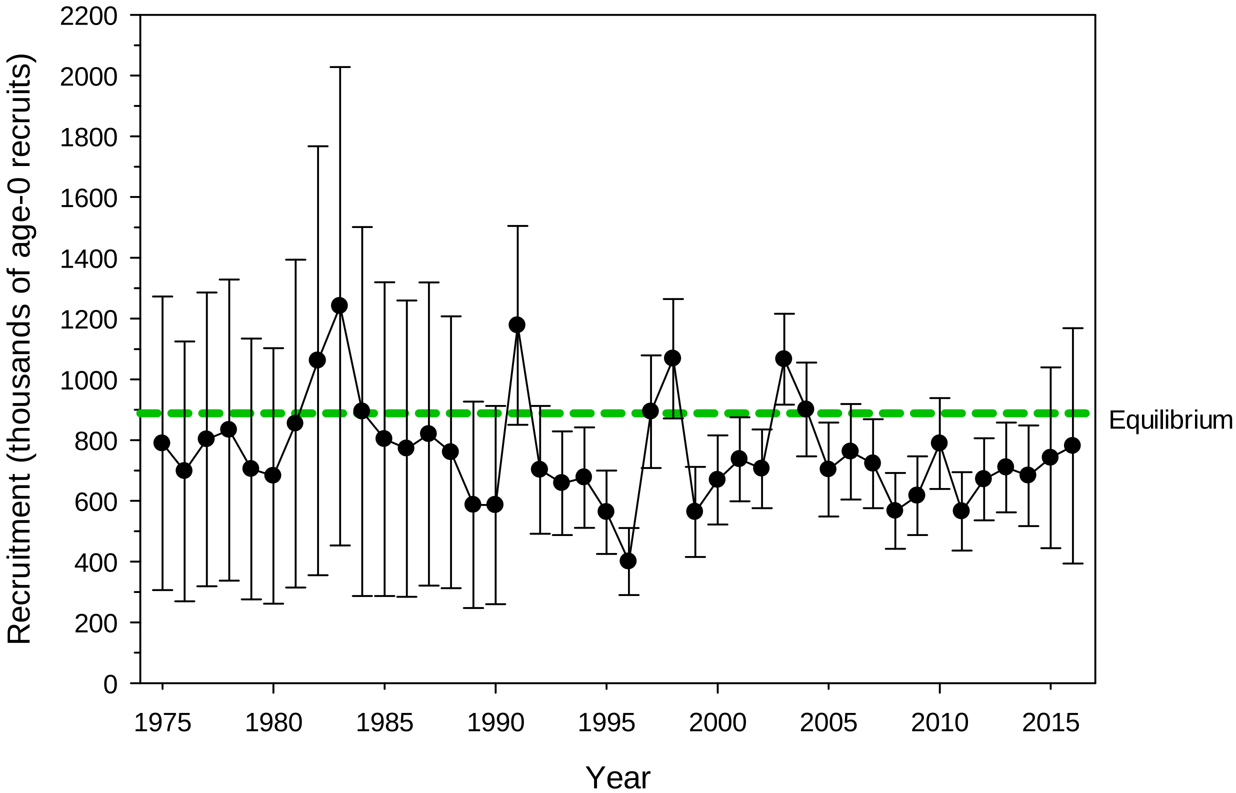


Figure 13.3. Time series of recruitment (thousands of age-0 fish) for the Western and Central North Pacific Ocean swordfish estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (80% confidence intervals).

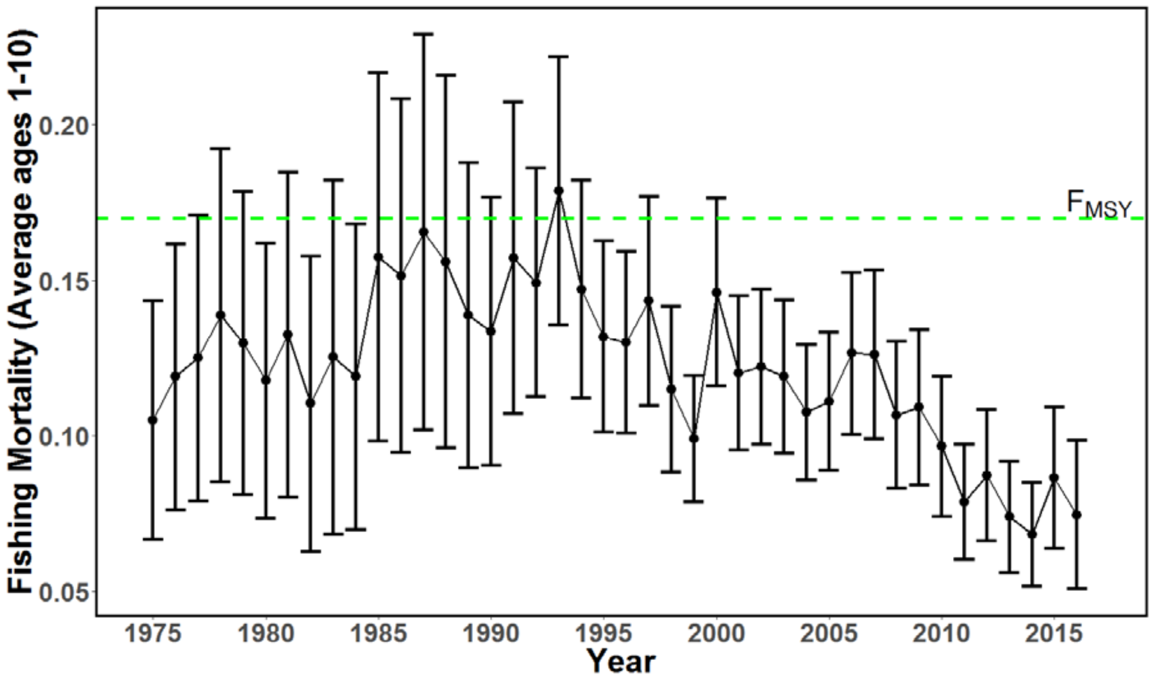


Figure 13.4. Time series of instantaneous fishing mortality (average for age 1-10, units are yr^{-1}) for the Western and Central North Pacific Ocean swordfish estimated in the base-case model. The solid line with circles represents the maximum likelihood estimates and the error bars represent the uncertainty of the estimates (80% confidence interval). The dashed horizontal line shows the fishing mortality to produce MSY reference point.

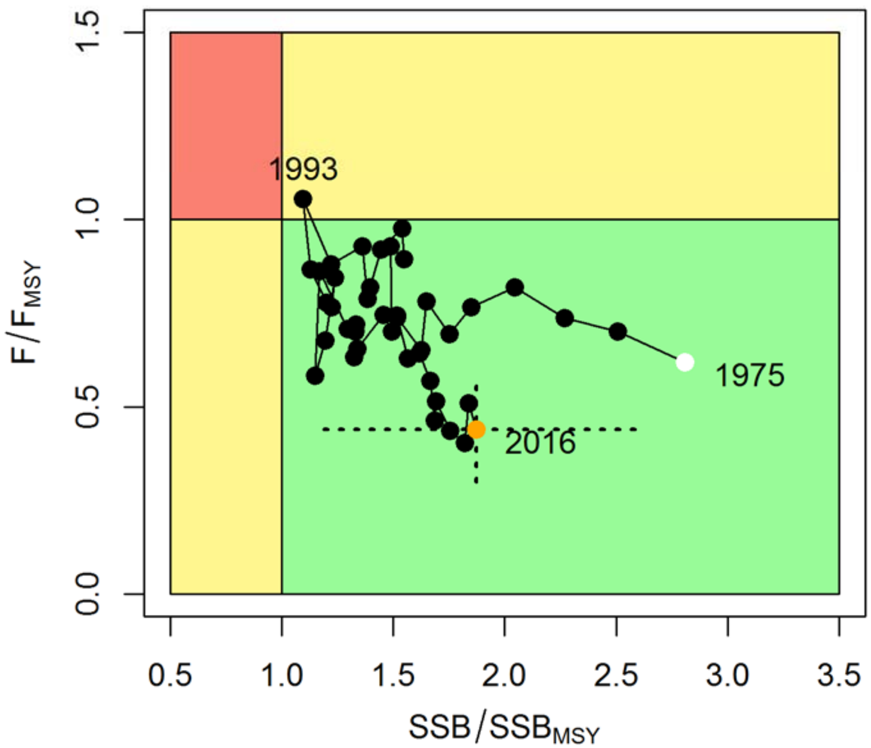
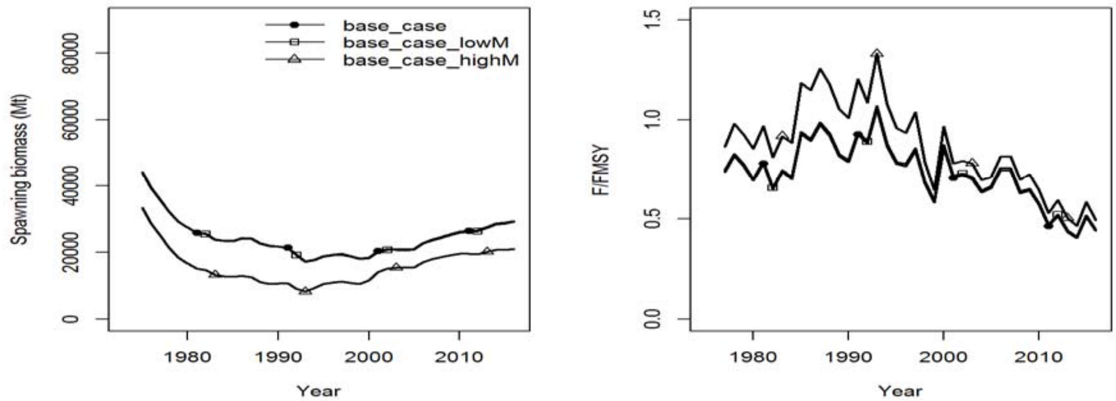


Figure 14. Kobe plot of the trends in estimates of relative fishing mortality (average of age 1-10) and spawning stock biomass of Western and Central North Pacific Ocean swordfish (*Xiphias gladius*) during 1975-2016.

(a)



(b)

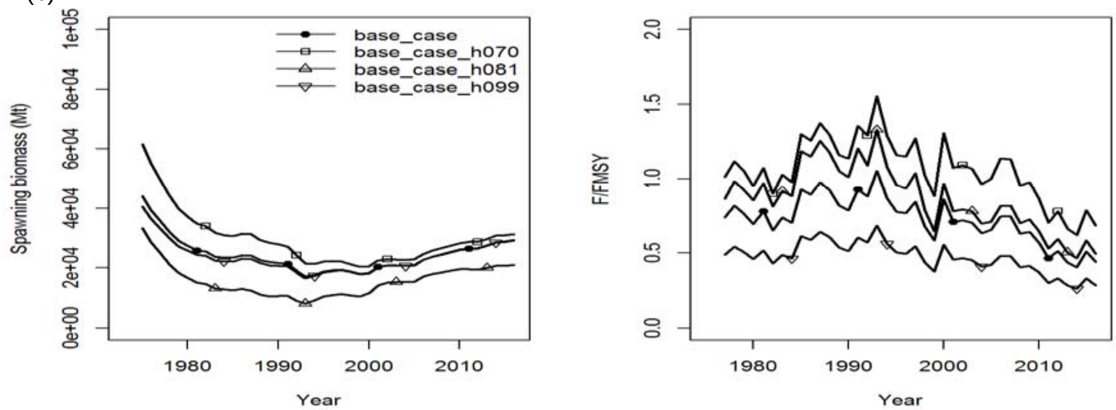


Figure 15.1. Trajectories of spawning stock biomass and an index of fishing intensity (1-spawning potential ratio) from 10 sensitivity analyses listed in Table 12, compared to the base case model: (a) Runs 1 and 2 use alternative natural mortality parameters; (b) Runs 3, 4, and 5 use alternative steepness parameters; (c) Runs 6 and 7 use alternative growth curves; (d) Run runs 8, 9, and 10 use alternative maturity ogives.

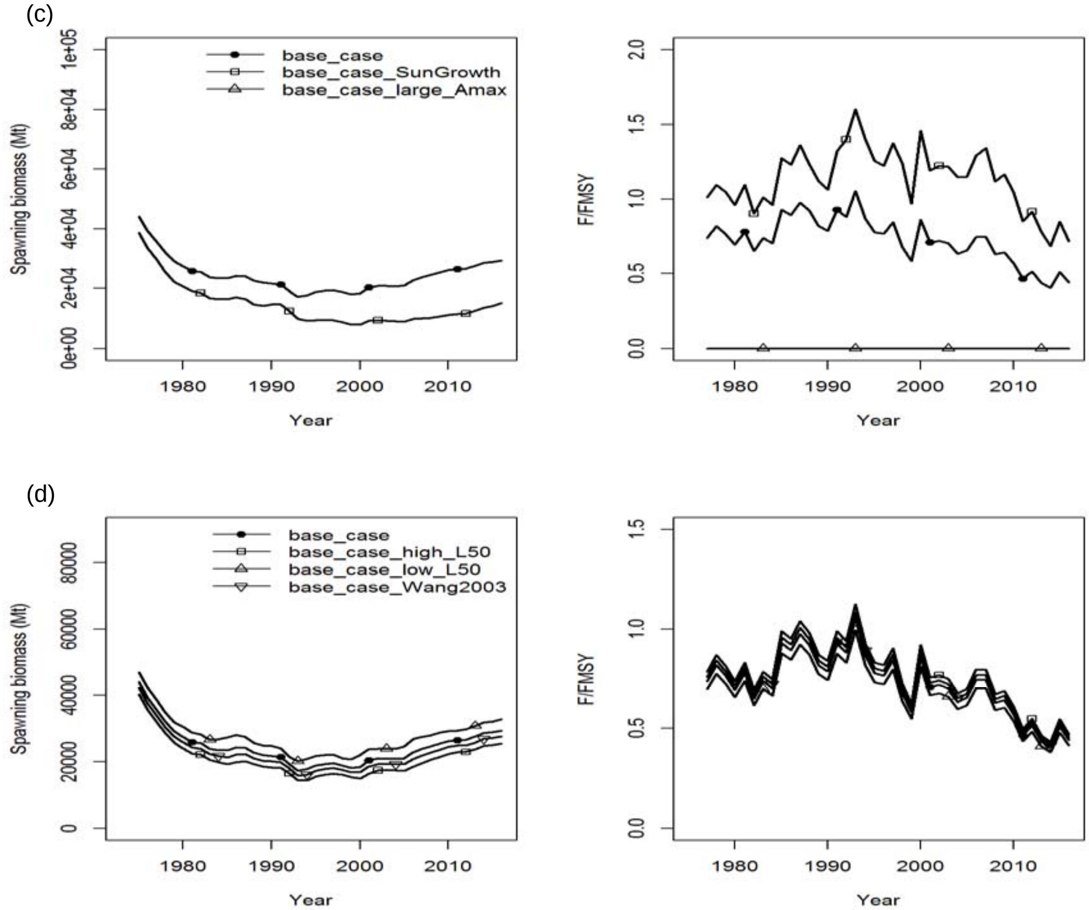


Figure 15.1. Continued.

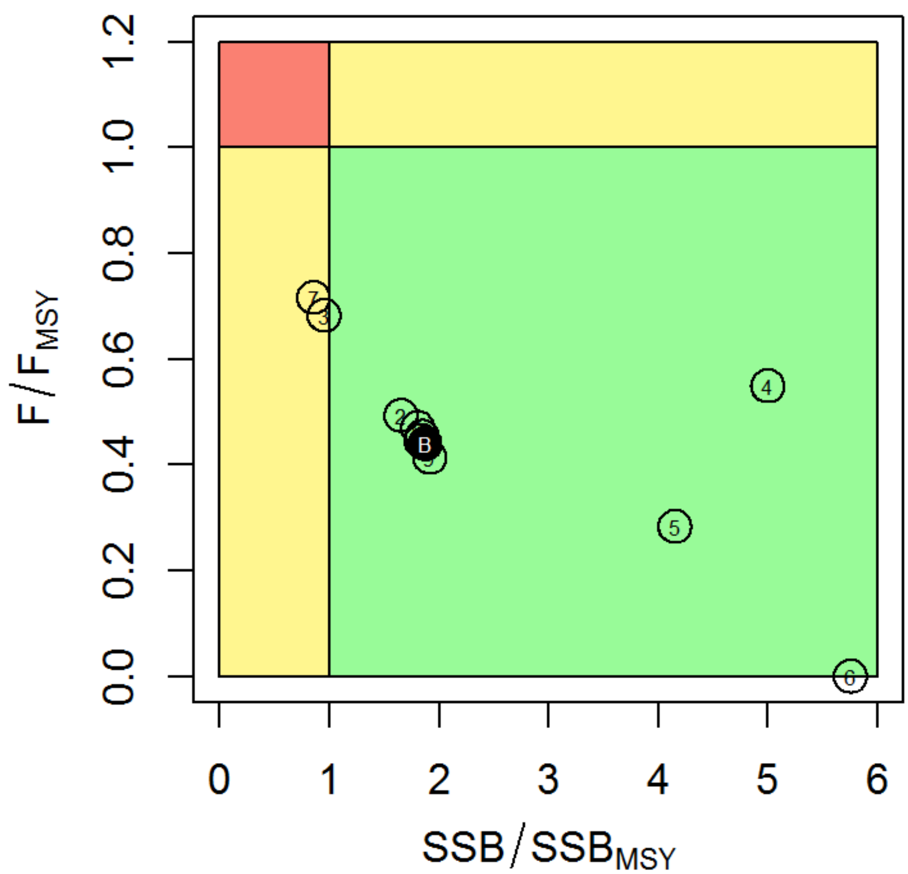


Figure 15.2. Kobe plot showing the terminal year stock status for the base case model (B) and the sensitivity analyses as indicated by the run numbers listed in Table 12.

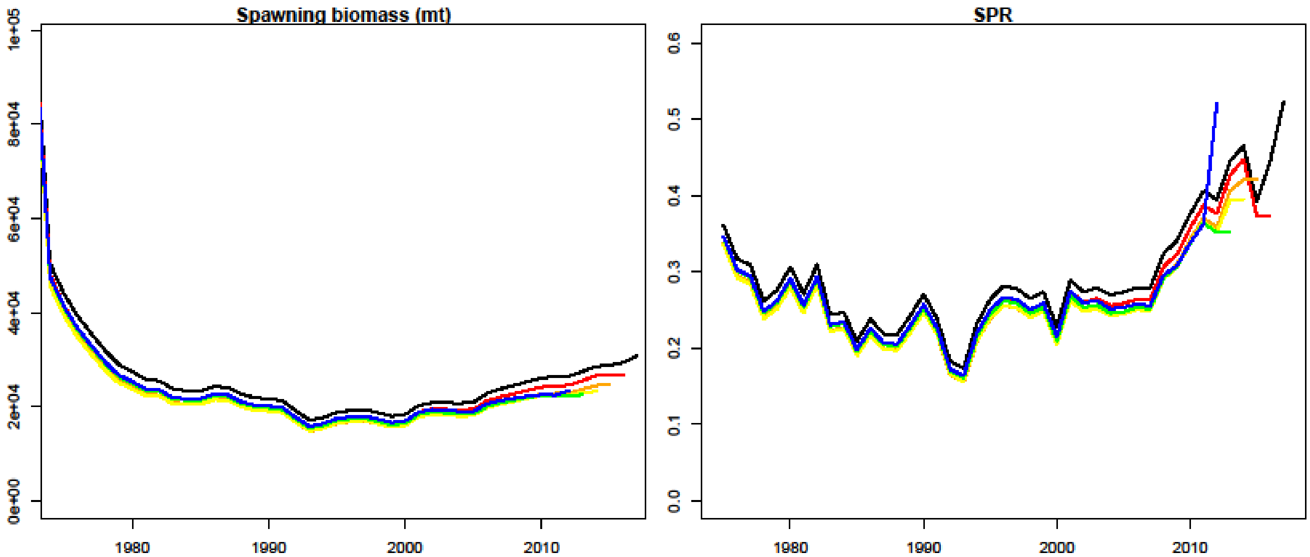


Figure 16. Retrospective analysis of spawning biomass (left panel) and spawning potential ratio (right panel) consisting of 5 reruns of the base case model each fitted with one more year of data removed from the base case model (black line, 1975-2016).

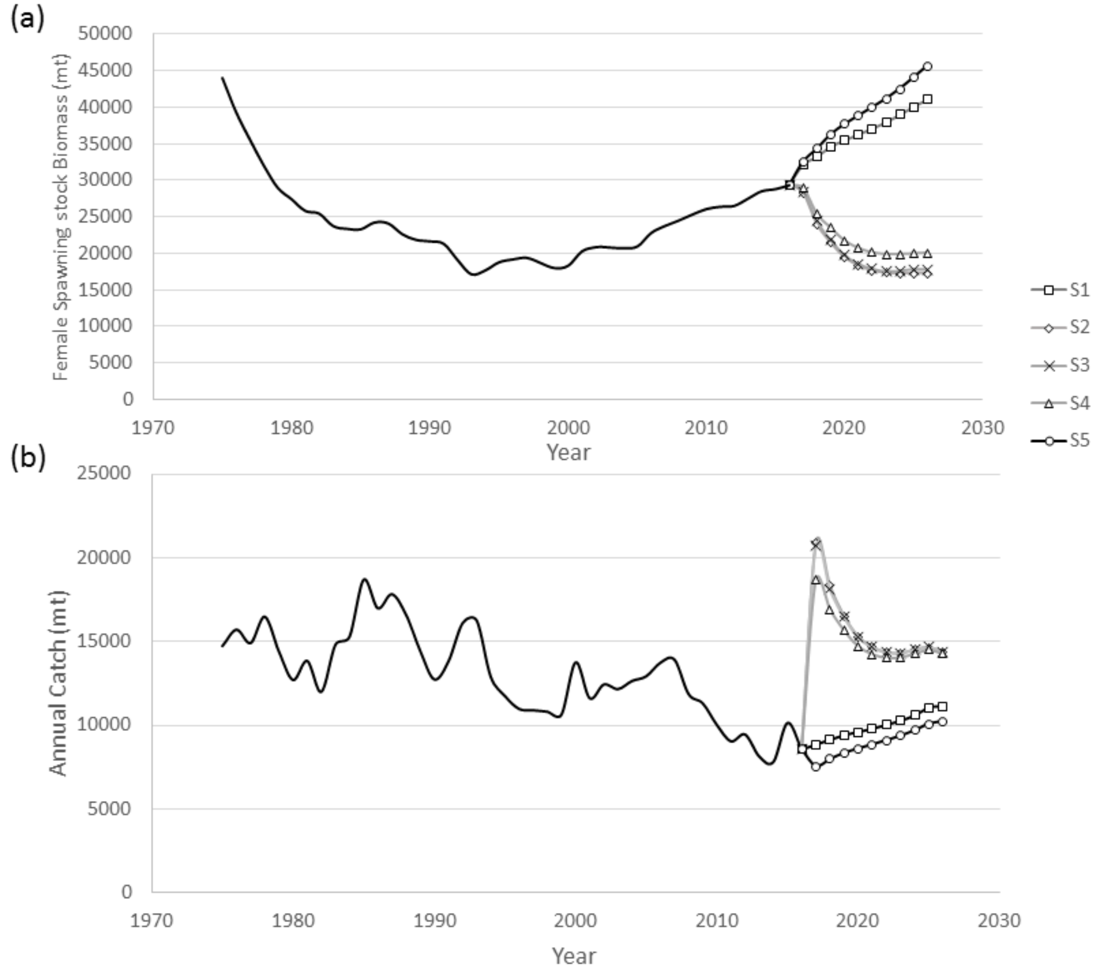


Figure 17. Historical and projected trajectories of (a) spawning biomass and (b) total catch from the Western and Central North Pacific Ocean swordfish base case model. Stock projection results are shown for harvest scenarios S1 = average fishing intensity during 2013-2015 scenario ($F_{2013-2015}$= $F_{43\%}$); S2 = F_{MSY} scenario ($F_{18\%}$); S3 = F at level to produce 20% of unfished spawning biomass or $F_{0.2*SSB(F=0)}$ scenario (F= $F_{22\%}$); S4 = High F scenario ($F_{20\%}$); S5 = Low F scenario ($F_{50\%}$).