**FINAL**

**ISC/18/ANNEX/15**

# ANNEX 15

*18th Meeting of the*
*International Scientific Committee for Tuna*
*and Tuna-Like Species in the North Pacific Ocean*
*Yeosu, Republic of Korea*
*July 11-16, 2018*

# Stock Assessment of Shortfin Mako Shark in the North Pacific Ocean Through 2016

**ISC SHARK Working Group**

**July 2018**

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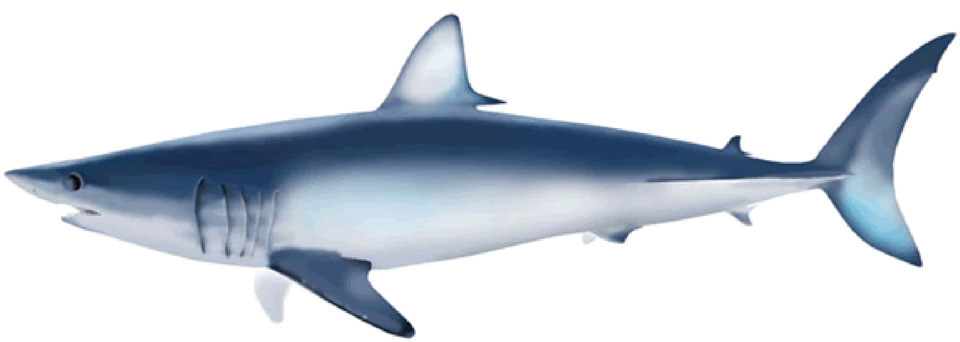
Annex 15

# STOCK ASSESSMENT OF SHORTFIN MAKO SHARK IN THE NORTH PACIFIC OCEAN THROUGH 2016

## REPORT OF THE SHARK WORKING GROUP

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



07-16 July 2018
Yeosu, Korea

## Table of Contents

# Executive Summary

This document presents the results of the ISC SHARKWG's first full stock assessment of shortfin mako shark (SFM, *Isurus oxyrinchus*) in the North Pacific Ocean (NPO) conducted in 2018. Due to a lack of biological and fisheries information, an indicator-based analysis was conducted in 2015. For the present analysis, time-series of catch, relative abundance, and sex-specific length composition from multiple fisheries were developed for the modeling period (1975 – 2016). In addition, new biological information, and research into parameterization of the Beverton-Holt stock recruitment relationship enabled the development of a size-based, age-structured model using the Stock Synthesis modeling platform.

**Stock Identification and Distribution**

SFMs are distributed throughout the pelagic, temperate NPO. Nursery areas are found along the continental margins in both the western and eastern Pacific Ocean (WPO and EPO), and larger subadults and adults are observed in greater proportions in the Central Pacific Ocean (CPO). A single stock of SFMs is assumed in the NPO based on evidence from genetics, tagging studies, and lower catch rates of SFM near the equator compared to temperate areas. However, within the NPO some regional substructure is apparent as the majority of tagged SFMs have been recaptured within the same region where they were originally tagged, and examination of catch records by size and sex demonstrates some regional and seasonal segregation across the NPO.

**Catches**

Catch data for this stock could be divided into early (1975 – 1993) and late (1994 – 2016) periods. The catch for the early period (1975-1993) was highly uncertain because species-specific SFM catch was not reported for major fisheries, and were instead estimated from blue shark (BSH) catch using BSH to SFM ratios. On the other hand, species-specific SFM catch was available for all major fisheries after 1993. The total estimated catch of North Pacific SFMs reached a peak of 7,068 metric tons (mt) in 1981 and then declined in the early 1990s, with catches fluctuating between 1,948 mt and 2,395 mt since the early 1990s (**Figure ES1**). Drift gill nets accounted for the highest catches of SFM during the early period but the catches have been predominantly from longline fisheries since 1993.

**Data and Assessment**

Annual catch estimates were derived for a variety of fisheries by nation and gear. Catch and size composition data were grouped into 17 fisheries. Standardized catch-per-unit-effort (CPUE) data used to represent trends in relative abundance were provided by Japan, USA, Taiwan, and Mexico.

The North Pacific SFM stock was assessed using a length-based statistical catch-at-age Stock Synthesis model (SS Version 3.24U), that was fit to time series of standardized CPUE and sex-specific size composition data. Sex-specific growth curves and weight-at-length were used to account for the sexual dimorphism of SFMs. A Beverton-Holt stock recruitment relationship was used to characterize productivity of the stock based on plausible life history information available for North Pacific SFMs. Models were 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 of the base case model were used to characterize stock status.

Input parameter values and model structure for the base case model were chosen based on the best available information regarding the life history of SFMs, knowledge of the historical catch time series and existing fishery data, and model fit and diagnostics. Standardized CPUE from the Japan offshore distant water longline shallow-set fleet (S9_JPN_SS_I; 1975-1993), Hawaii longline shallow-set fleet (S1_US_SS; 2005-2016), Taiwan large scale longline fleet (S3_TW_LL_LRG; 2005-2016), Japan research and training vessels (S5_JPN_RTV; 1994-2016), and Mexico longline fleet (S8_MEX_LL; 2006-2016) were used as measures of relative population abundance in the base case model (**Figure ES2**).

**Future Projections**

Using the base case model, future projections over a 10-year period (2017-2026) were performed under three constant fishing intensity scenarios: 1) average of 2013-2015 (F2013-2015); 2) F2013-2015 + 20%; and 3) F2013-2015 - 20%. Future recruitment was based on the assumed stock-recruitment relationship without stochastic resampling of historical recruitment deviates and future selectivity of each fishery was assumed to be the average of 2013 – 2015. It should be noted that, given the uncertainty in fishery data and key biological processes within the model, especially the stock recruitment relationship, the models' ability to project into the future is highly uncertain.

**Key Uncertainties**

Due to uncertainty in the input data and life history parameters, multiple models were run with alternative data and/or parameters including the abundance indices used in the analyses, initial catch level, natural mortality schedule, and the stock recruitment relationship. Numerous models representing different combinations of input datasets and structural model hypotheses were used to assess the influence of these uncertainties on biomass trends and fishing intensity levels for the North Pacific SFM. The key uncertainties in this assessment were related to the catch time series, especially in the early period (1975-1993), the precision of the early Japan shallow-set CPUE index (1975-1993), initial conditions, and the stock recruitment relationship. Six models representing these key uncertainties were developed to examine the status of the North Pacific SFM stock under alternative states of nature:

1. Higher catch: Total catch is 50% and 20% higher for the early (1975-1993) and late (1993-2016) periods, respectively;
2. Lower catch: Total catch is 50% and 20% lower for the early (1975-1993) and late (1993-2016) periods, respectively;
3. Higher uncertainty on index: Average CV of Japan shallow-set CPUE index (1975-1993) is 0.3;
4. Initial conditions: Initial conditions were estimated without fitting to initial equilibrium catch estimated outside the model, and fit to S9_JPN_SS_I and S1_US_SS indices;
5. Lower steepness: A lower value was assumed for the steepness parameter (0.260);

6. Higher steepness: A higher value was assumed for the steepness parameter (0.372).

**Status of the Stock**

The current assessment provides the best scientific information available on North Pacific shortfin mako shark stock status. Results from this assessment should be considered with respect to the management objectives of the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC), the organizations responsible for management of pelagic sharks caught in international fisheries for tuna and tuna-like species in the Pacific Ocean. Target and limit reference points have not been established for pelagic sharks in the Pacific Ocean. In this assessment, stock status is reported in relation to maximum sustainable yield (MSY).

In this assessment, the reproductive capacity of this population was calculated as spawning abundance (SA; i.e. number of mature female sharks) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups). Spawning potential ratio (SPR) was used to describe the impact of fishing on this stock. The SPR of this population is the ratio of SA per recruit under fishing to the SA per recruit under virgin (or unfished) conditions. Therefore, 1-SPR is the reduction in the SA per recruit due to fishing and can be used to describe the overall impact of fishing on a fish stock.

Recruitment was estimated on average to be 1.1 million age-0 sharks during the modeling timeframe (1975-2016) (Figure ES3). During the same period, the SA was estimated, on average, to be 910,000 sharks (Figure ES4). The current SA (SA2016) was estimated to be 860,200 sharks (CV=46%) (Table ES1) and was 36% (CV=30%) higher than the estimated SA at MSY (SAMSY) (Table ES2, Figure ES4). The recent annual fishing intensity (1-SPR2013-2015) was estimated to be 0.16 (CV=38%) and was 62% (CV=38%) of fishing intensity at MSY (1-SPRMSY; 0.26) (Table ES2; Figure ES5). The results from the base case model show that, relative to MSY, the North Pacific shortfin mako stock is likely (>50%) not in an overfished condition (i.e. $\frac{\mathrm{SA}_{2016}}{\mathrm{SA}_{\mathrm{MSY}}} > 1$) and overfishing is likely (>50%) not occurring (i.e. $\frac{1-\mathrm{SPR}_{2013-2015}}{1-\mathrm{SPR}_{\mathrm{MSY}}} < 1$) (**Figure ES6**).

Besides the base case model, stock status was also examined under the six alternative states of nature outlined above, which represent the most important sources of uncertainty in the assessment. Results of these models with alternative states of nature were consistent with the base case model and showed that, relative to MSY, the stock is likely (>50%) not in an overfished condition and overfishing is likely (>50%) not occurring (**Figure ES7**, **Table ES3**).

**Conservation Information**

Future projections over a 10-year period (2017-2026) were performed under three constant fishing intensity scenarios: 1) average of 2013-2015 ($F_{2013-2015}$); 2) $F_{2013-2015}$ + 20%; and 3) $F_{2013-2015}$ - 20%. Based on these future projections, the SA is expected to increase gradually under scenarios 1 and 3, however, in scenario 2, the SA drops in the final years of the projection (**Figure ES8)**. Based on these results, the SA is expected to increase gradually if fishing intensity remains constant or is decreased moderately relative to 2013-2015 levels. However, given the uncertainty in fishery data and key biological processes within the model, especially the stock recruitment relationship, the models' ability to project into the future is limited and highly uncertain.

**Research needs**

**There is substantial uncertainty** in the estimated historical catches of SFMs. Substantial time and effort was spent on estimating historical catch and more work remains to be conducted. In particular, the SHARKWG identified two future improvements that are critical: 1) identify all fisheries that catch SFMs in the NPO, such as are there any fisheries that catch SFM that may not have been identified by the SHARKWG; and 2) methods to estimate SFM catches should be improved, especially for the early period from 1975 to 1993.

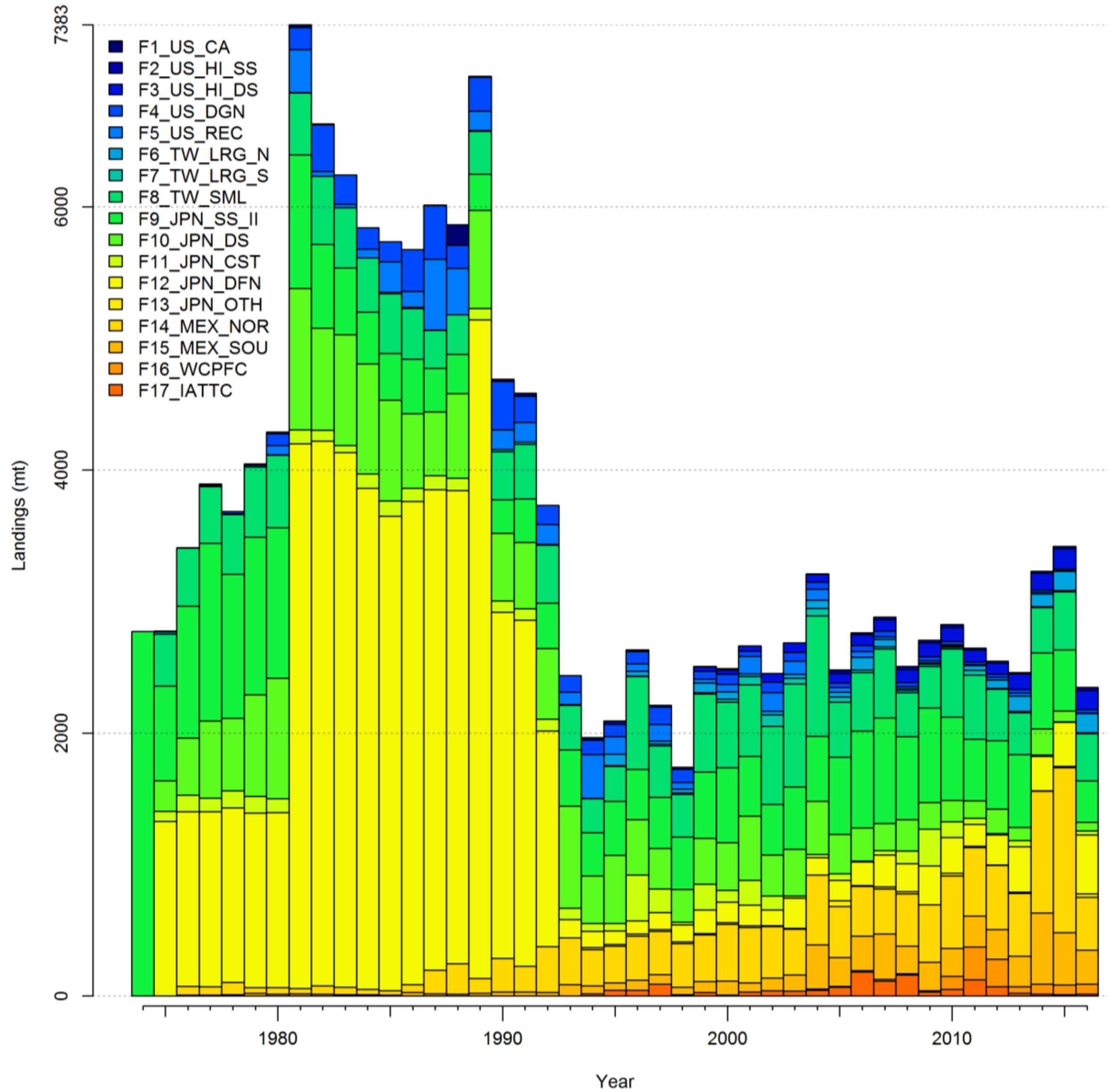



**Figure ES1**. Total catch (total dead removals) of North Pacific shortfin mako shark by fishery (1975-2016).

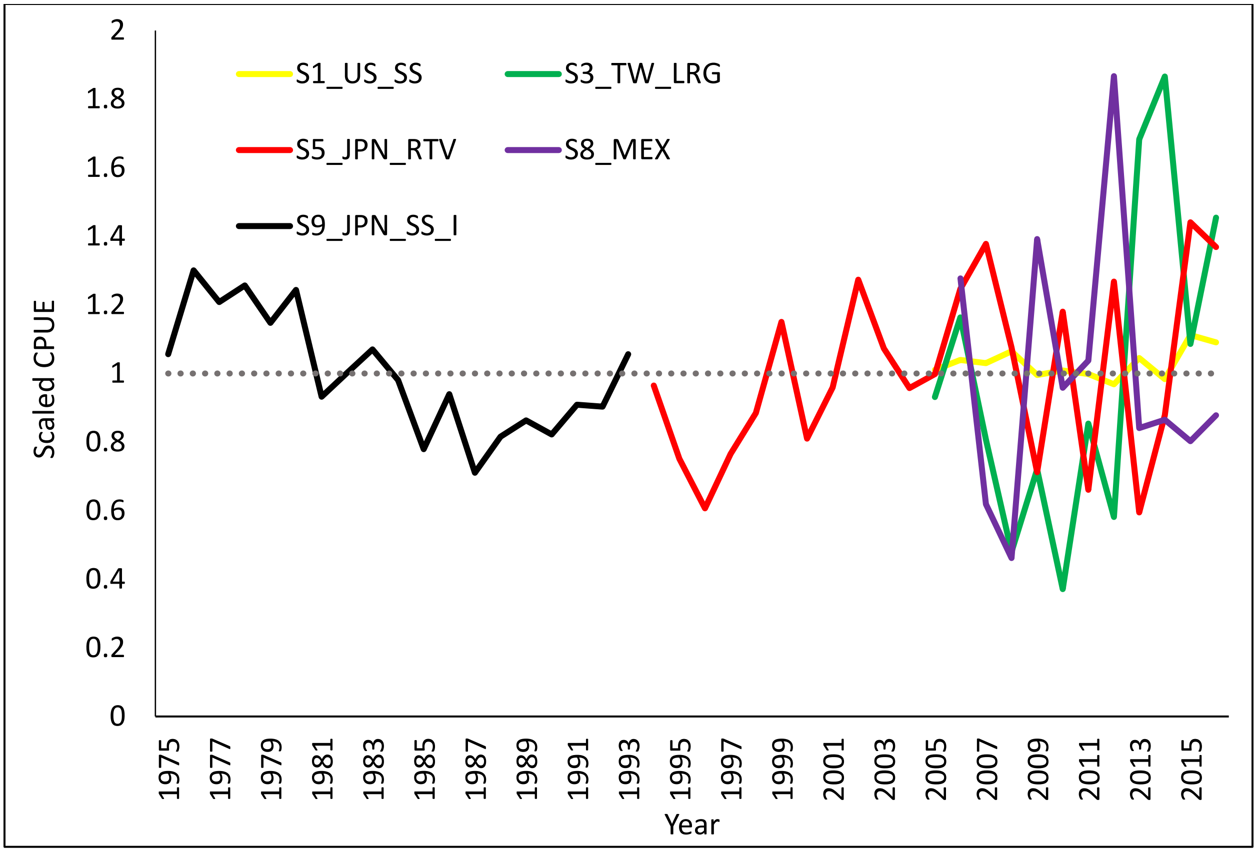



**Figure ES2**. Yearly changes in standardized CPUE of North Pacific shortfin mako shark (1975-2016) used in the base case stock assessment model. All indices are normalized to a mean value of one (horizontal dotted line). S1_US_SS (Hawaii longline shallow-set fleet), S3_TWN_LRG (Taiwan large scale longline fleet), S5_JPN_RTV (Japan research and training vessels), S8_MEX (Mexico longline fleet), and S9_JPN_SS_I (Japan longline shallow-set fleet).

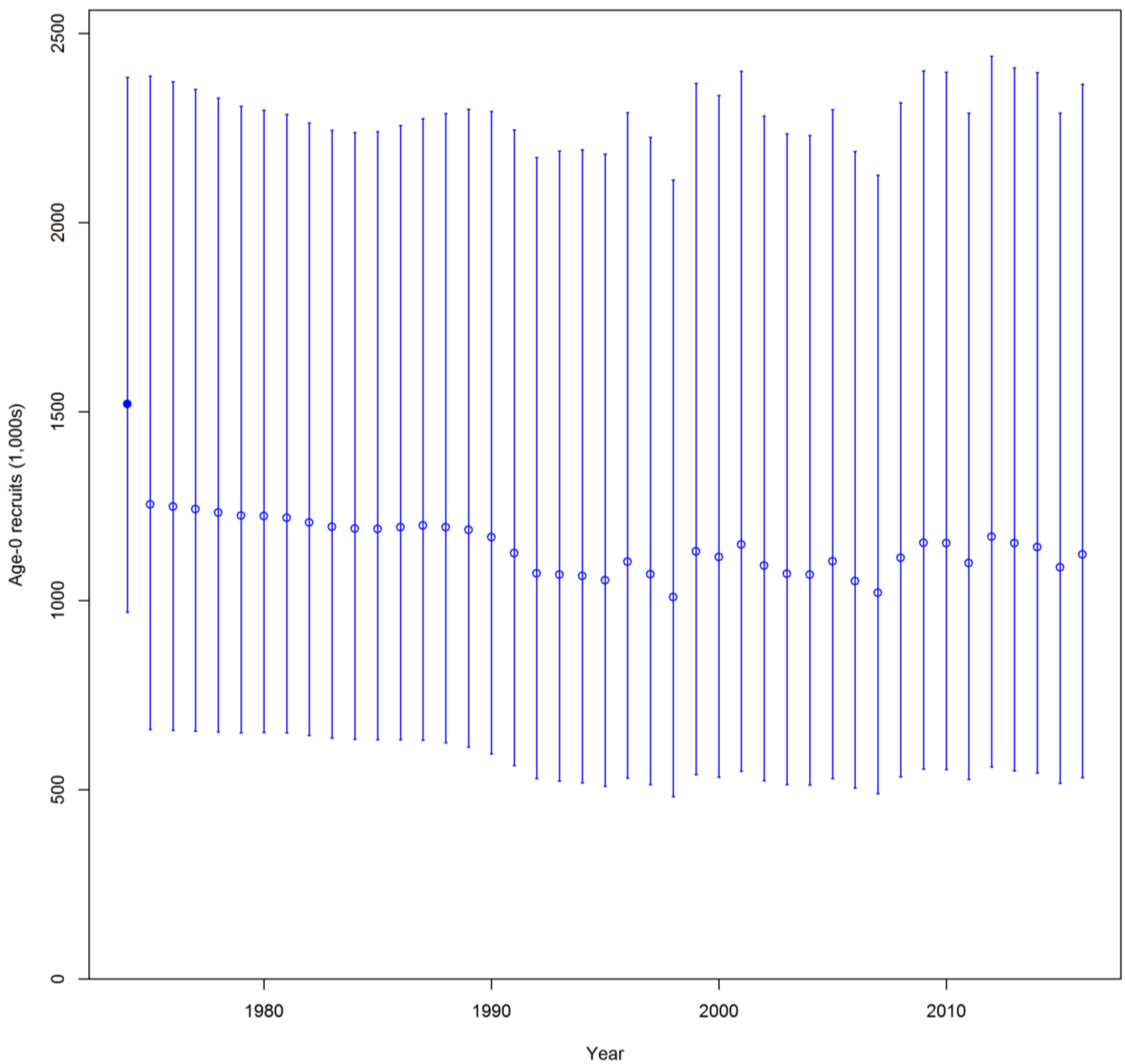



**Figure ES3.** Estimated age-0 recruitment in the base case model. Error bars indicate the 95% confidence intervals; the closed circle indicates recruitment under unfished conditions.

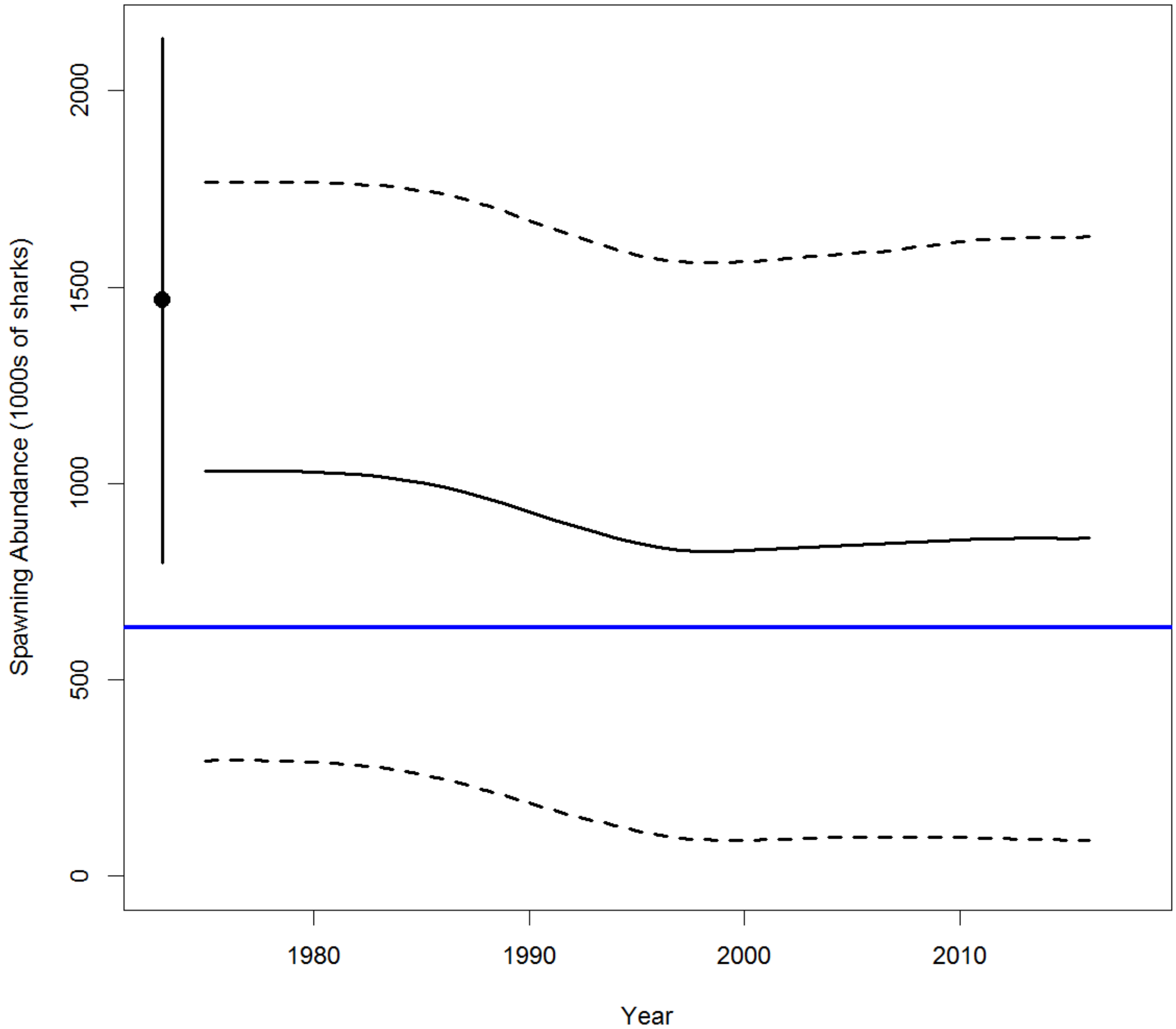



**Figure ES4.** Estimated spawning abundance (SA; number of mature female sharks) of shortfin mako sharks in the North Pacific Ocean during the modeling time frame (1975-2016). Dashed lines indicate 95% confidence intervals; and closed circle and error bars indicate the estimated SA and 95% confidence intervals under unfished conditions ($SA_0$). Blue solid line indicates the estimate of SA at maximum sustainable yield (MSY) ($SA_{MSY}$).

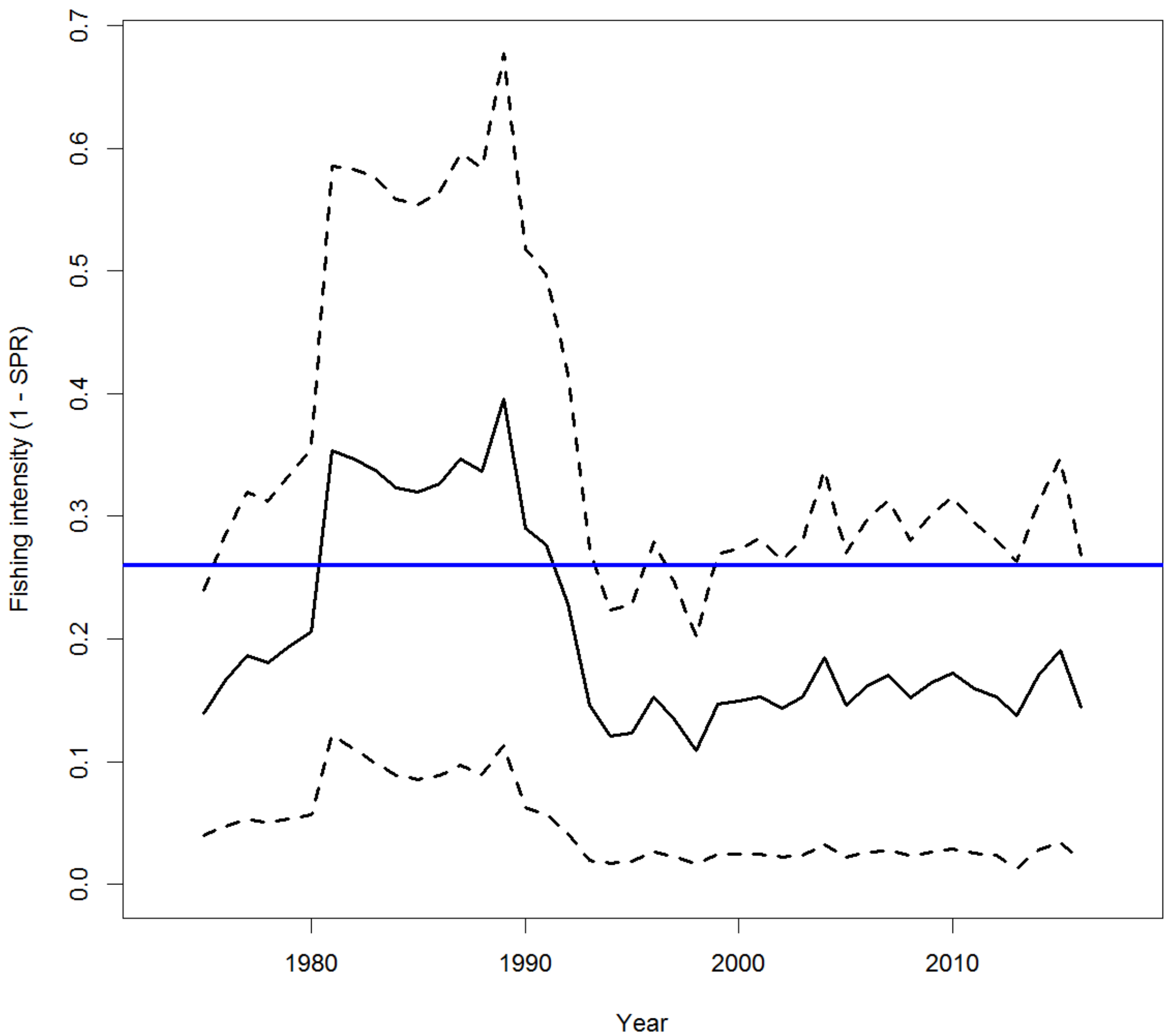



**Figure ES5.** Estimated fishing intensity (1-SPR) on the North Pacific shortfin mako shark stock. Dashed lines indicate 95% confidence intervals. Blue solid line indicates the estimate of (1-SPR) at maximum sustainable yield (MSY) ($1\text{-}SPR_{MSY}$).

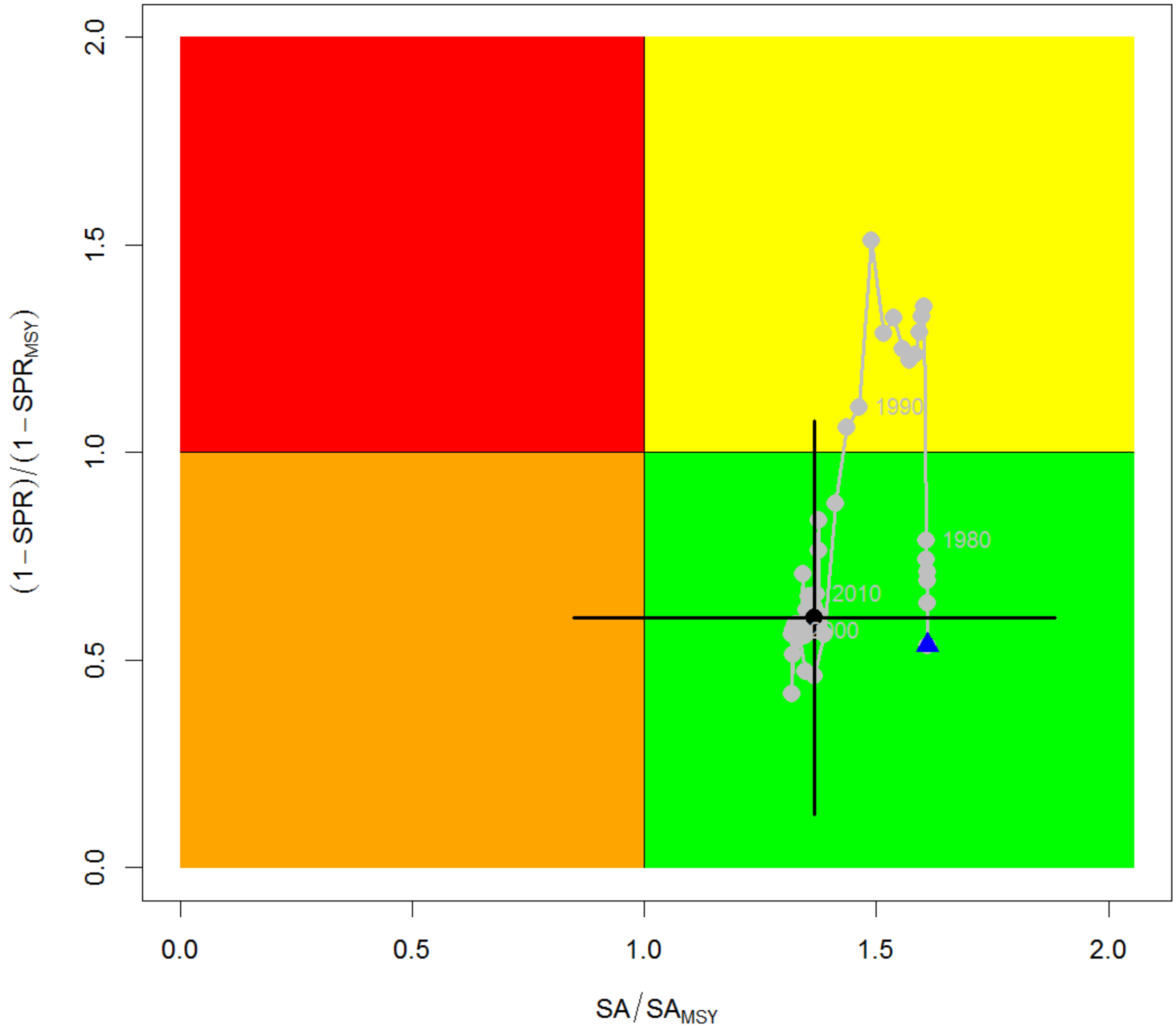



**Figure ES6.** Kobe time series plot of shortfin mako sharks in the North Pacific Ocean indicating the ratio of spawning abundance (SA; number of mature female sharks) relative to SA at maximum sustainable yield ($SA_{MSY}$), and the ratio of fishing intensity (1-SPR) relative to fishing intensity at maximum sustainable yield ($1\text{-}SPR_{MSY}$) for the base case model. Values for the start (1975) and end (2016) years are indicated by the blue triangle and black circle, respectively. Black error bars indicate 95% confidence intervals. Gray numbers indicate selected years.

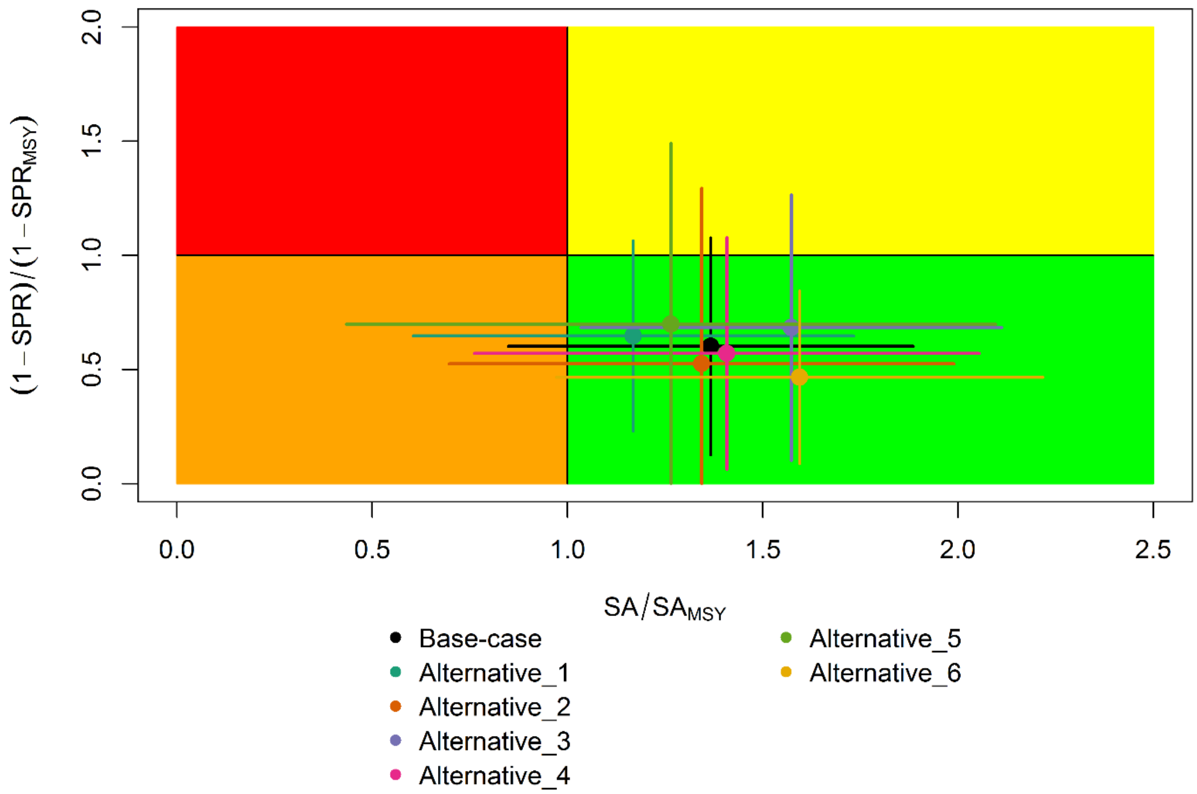



**Figure ES7.** Kobe plot of shortfin mako sharks in the North Pacific Ocean indicating the ratio of spawning abundance (SA; number of mature female sharks) relative to SA at maximum sustainable yield (MSY) ($SA_{MSY}$), and the ratio of fishing intensity (1-SPR) relative to fishing intensity at MSY (1-$SPR_{MSY}$) for the end year (2016) of the base case model and six alternative states of nature: Alternative_1) higher catch, Alternative_2) lower catch; Alternative_3) higher uncertainty on Japan shallow-set CPUE index (1975-1993) (CV=0.3); Alternative_4) fit to Japan offshore distant water longline shallow-set fleet (JPN_SS_I; 1975-2016) and Hawaii longline shallow-set fleet (US_SS; 2005-2016), and no fit to initial equilibrium catch; Alternative_5) low steepness, h=0.260; and Alternative_6) high steepness, h=0.372. Solid lines indicate 95% confidence intervals.

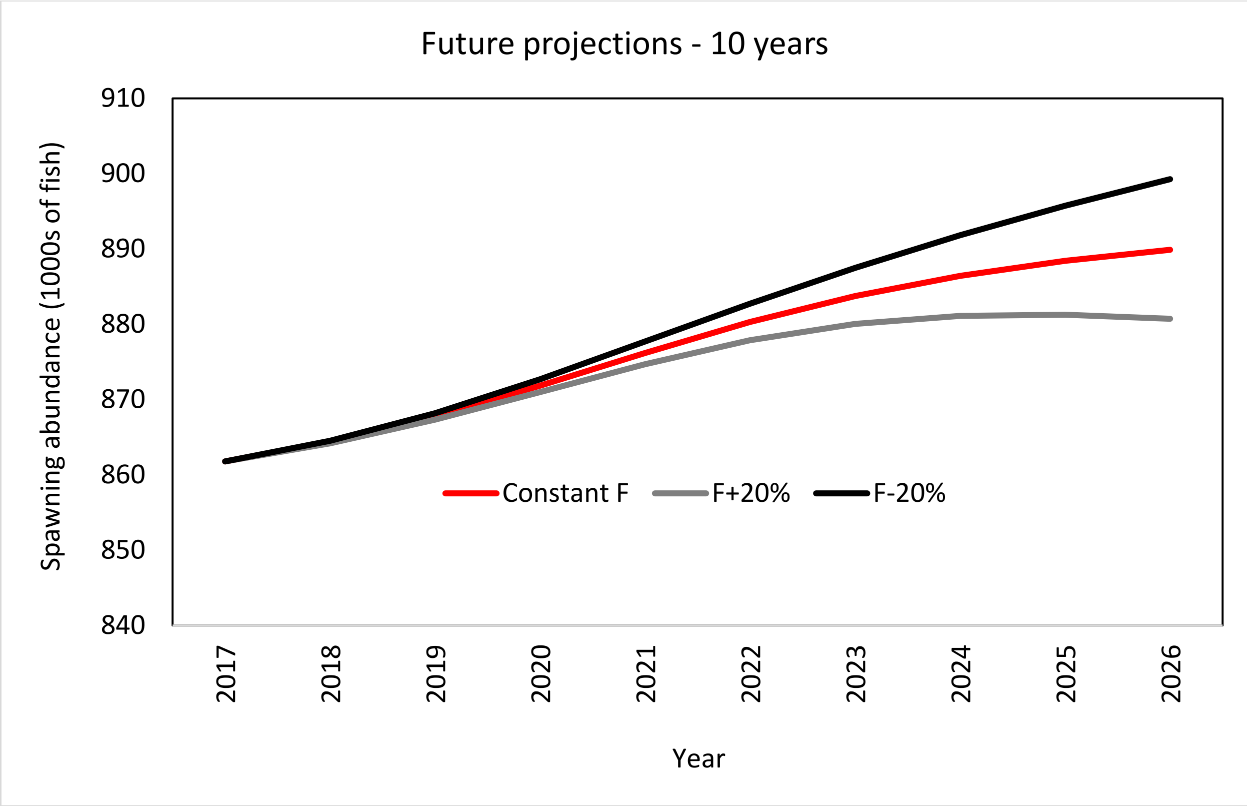



**Figure ES8.** Future projections of spawning abundance for shortfin mako sharks in the North Pacific Ocean from 2017 to 2026 under three constant fishing intensity (*F*) harvest scenarios ($F_{2013\text{-}2015}$, $F_{2013\text{-}2015}$+20%, $F_{2013\text{-}2015}$-20%) using the base case model.

**Table ES1**. Recent estimates of catch, biomass, and spawning abundance (SA; number of mature female sharks), recruitment estimated, and fishing intensity (1-SPR) in the base case model.

| Year | Estimated catch (mt) | Spawning abundance (1000s) | Number of recruits (1000s) | 1-SPR |
|---|---|---|---|---|
| 2007 | 2882.4 | 847.3 | 1020.6 | 0.17 |
| 2008 | 2506.5 | 850.4 | 1112.8 | 0.15 |
| 2009 | 2704.6 | 853.7 | 1153.6 | 0.16 |
| 2010 | 2824.6 | 856.8 | 1152.3 | 0.17 |
| 2011 | 2646.1 | 858.9 | 1099.0 | 0.16 |
| 2012 | 2545.0 | 860.0 | 1169.0 | 0.15 |
| 2013 | 2329.1 | 860.4 | 1151.8 | 0.13 |
| 2014 | 2460.3 | 860.3 | 1141.7 | 0.17 |
| 2015 | 2519.9 | 859.9 | 1087.9 | 0.19 |
| 2016 | 2346.8 | 860.2 | 1122.0 | 0.14 |

**Table ES2**. Estimated reference points for the base case model.

| Reference points | Symbol | Estimate (CV) | Units |
|---|---|---|---|
| **Unfished conditions** | | | |
| Spawning abundance (number of mature female sharks) | $SA_0$ | 1465.8 (23.3%) | 1000s of sharks |
| Recruitment at age-0 | $R_0$ | 1520.4 (23.3%) | 1000s of sharks |
| **MSY-based reference points** | | | |
| Maximum Sustainable Yield (MSY) | $C_{MSY}$ | 3127.1 (22.2%) | Metric tons |
| Spawning abundance at MSY | $SA_{MSY}$ | 633.7 (23.3%) | 1000s of sharks |
| Fishing intensity at MSY | $1\text{-}SPR_{MSY}$ | 0.26 | NA |

**Table ES3**. Summary of reference points and management quantities for the base case and six alternative states of nature: Alternative_1) higher catch, Alternative_2) lower catch; Alternative_3) higher uncertainty on Japan shallow-set CPUE index (1975-1993) (CV=0.3); Alternative_4) fit to Japan offshore distant water longline shallow-set fleet (JPN_SS_I; 1975-2016) and Hawaii longline shallow-set fleet (US_SS; 2005-2016), and no fit to initial equilibrium catch; Alternative_5) low steepness, h=0.260; and Alternative_6) high steepness, h=0.372. Values in parentheses represent the coefficient of variation (CV) when available.

| Reference points | Symbol | Units | Base-case | Alternative_1 | Alternative_2 | Alternative_3 | Alternative_4 | Alternative_5 | Alternative_6 |
|---|---|---|---|---|---|---|---|---|---|
| Spawning abundance (number of mature female sharks) | $SA_0$ | 1000s of sharks | 1465.8 (23.3%) | 1898.8 (14.6%) | 826.8 (27.5%) | 1240.6 (70%) | 1727.6 (32%) | 2366.5 (30%) | 1327.1 (32%) |
| Maximum Sustainable Yield (MSY) | $C_{MSY}$ | Metric tons | 3127.1 (22.2%) | 3951.8 (13.0%) | 1725.4 (26%) | 2558.2 (68%) | 3175.3 (31%) | 2731 (29%) | 3759 (28%) |
| Spawning abundance at MSY | $SA_{MSY}$ | 1000s of sharks | 633.7 (23.3%) | 821.3 (14.1%) | 371.5 (27%) | 536.6 (70%) | 759 (32%) | 1095 (30%) | 539.8 (30%) |
| Fishing intensity at MSY | $1\text{-}SPR_{MSY}$ | NA | 0.26 | 0.26 | 0.26 | 0.26 | 0.24 | 0.16 | 0.34 |
| Current spawning abundance relative to MSY | $SA_{2016}/SA_{MSY}$ | NA | 1.36 | 1.16 | 1.34 | 1.57 | 1.40 | 1.26 | 1.59 |
| Current spawning abundance relative to unfished level | $SA_{2016}/SA_0$ | NA | 0.58 | 0.51 | 0.58 | 0.68 | 0.61 | 0.59 | 0.64 |
| Recent fishing intensity relative to MSY | $\frac{1-SPR_{2013-2015}}{1-SPR_{MSY}}$ | NA | 0.62 | 0.66 | 0.53 | 0.68 | 0.57 | 0.69 | 0.47 |

# 1 Introduction

The Shark Working Group (SHARKWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) was established in 2010 and is responsible for providing regular stock status assessments of pelagic sharks that interact with international tuna and billfish fisheries in the North Pacific Ocean (NPO). The focus of the SHARKWG to date has been on the two most commonly encountered pelagic sharks, the blue shark (BSH, *Prionace glauca*) and shortfin mako shark (SFM, *Isurus oxyrinchus*). In order to assess population status, SHARKWG members have been collecting biological and fisheries information on these key shark species in coordination and collaboration with regional fishery management organizations, national scientists and observers.

The SFM is a highly migratory shark species and is one of the fastest of the pelagic sharks. Unlike commercially targeted species of higher value, such as tunas and billfish, a greater portion of fishing intensity on sharks is the result of bycatch or incidental catch. Due to their lower reproductive potential as a result of slower growth, larger adult size, later reproduction, and fewer offspring, sharks are generally more susceptible to overfishing than teleosts and higher fecundity species (Branstetter 1990; Hoenig and Gruber 1990; Au et al. 2008). As largely non-targeted species, records of shark catches (retained and discarded) are often of lower quality and quantity than for targeted species.

The SHARKWG conducted its first assessment of SFM stock status in the NPO in 2015 using an indicator-based analysis. The 2015 analysis used a series of fishery indicators, such as catch per unit of effort (CPUE) and average length (AL), to assess the response of the population to fishing pressure. Such indicators are usually straightforward to compute and track over time, thus providing the opportunity to observe trends which can serve as early signals of overexploitation. Interpreted as a suite, indicators of stock status can be useful for initial assessments and/or for prioritizing future data collection or analytical work.

After reviewing a suite of fishery indicators information, the ISC SHARKWG concluded that stock status (overfishing and overfished) of North Pacific SFM could not be determined in 2015 because information on important fisheries were missing, validity of indicators for determining stock status was untested, and there were conflicts in the available data. The ISC SHARKWG recommended that missing data (e.g. total catch) for all fisheries be developed for use in the next stock assessment scheduled for 2018.

Extensive improvements in the available fishery and biological information over the last two years have allowed the ISC SHARKWG to develop the first full stock assessment of the SFM in the NPO using a fully integrated size-based, age-structured model.

# 2 Background

## 2.1 Biology

### 2.1.1 Stock structure and movement

A single stock of SFM is assumed in the NPO based on evidence from genetics, tagging studies, and lower catch rates of SFMs near the equator relative to temperate areas. All but one SFM tagged in the North and South Pacific Ocean (NPO and SPO) have been recaptured within the same hemisphere (Sippel et al. 2011; Bruce 2013; Urbisci et al. 2013), and there is a distinct signal in mitochondrial DNA heterogeneity between the NPO and SPO (Michaud et al. 2011; Taguchi et al. 2015). However, within the NPO, some regional substructure is apparent as the majority of tagged SFMs have been recaptured within the same region where they were originally tagged, and examination of catch records by size and sex demonstrates some regional and seasonal segregation across the NPO (Semba and Yokawa 2011; Sippel et al. 2015).

However, there remain uncertainties about SFM stock structure. Microsatellite DNA analyses reveal no differentiation between the NPO and SPO, although the results are still being examined in order to determine the significance of the findings with respect to population connectivity (Taguchi et al. 2015). In addition, one SFM tagged in the southwestern Pacific Ocean (PO) off Australia was reportedly recaptured east of the Philippines (Bruce 2013). Given the preponderance of current evidence supporting limited connection of SFM populations between NPO and SPO, the SHARKWG assumes distinct North and South Pacific stocks, although stock structure should be reconsidered in the future, if there is further information supporting alternative hypotheses.

### 2.1.2 Habitat

SFM are distributed throughout the pelagic, tropical to temperate NPO, within which there are regions where young-of-the-year SFMs are more abundant, suggestive of pupping and/or nursery areas. These areas are distributed along the continental margins of the NPO, off the coast of U.S. and Mexico between about 27-35 degrees N in the eastern NPO (EPO, Holts and Bedford 1993; Sippel et al. 2015) and off the coast of Japan between about 30-40 degrees N (Semba and Yokawa 2011; Kai et al. 2015a; Sippel et al. 2015). Larger subadults and adults are observed in greater proportions in the central NPO (CPO, Semba and Yokawa 2011; Sippel et al. 2015). However, these observations are based on fishery data and the effect of gear selectivity on the size composition of the catch is unclear. Nevertheless, the data are suggestive that larger sharks tend to use more oceanic habitats in the CPO perhaps for mating purposes, and that large females move toward the coastal areas to pup. From the limited number of electronic tagging studies conducted in the NPO, SFMs appear to spend most of their time in epipelagic waters remaining predominately in the upper 100-150 m of the water column with occasional excursions below 500 m (Sepulveda et al. 2004; Vetter et al. 2008; Stevens et al. 2010; Abascal et al. 2011; Musyl et al. 2011). They exhibit diurnal behavior, generally remaining closer to the surface at night. The majority of individuals studied have been juveniles and subadults.

### 2.1.3 Reproduction

The occurrence of adult-sized SFMs in fishery catch is rare and studies of the reproductive biology of Pacific SFMs have therefore been few (Mollet et al. 2000; Joung and Hsu 2005; Semba et al. 2011). However, these studies have suggested SFMs reproduce every two to three years, with an estimated gestation of 12 to 25 months (Mollet et al. 2000; Juong and Hsu 2005; Semba et al. 2011), followed by a “rest period” before the next pregnancy begins. Combined Japanese and Taiwanese data suggested that females on average give birth to ~12 pups per litter (ISC 2017a). In the northern hemisphere, SFMs are thought to pup from late winter to mid spring (Cailliet and Bedford 1983; Mollet et al. 2000; Juong and Hsu 2005; Semba et al. 2011; Kai et al. 2015a).

### 2.1.4 Growth

It was assumed that pups are born at ~60 cm pre-caudal length (PCL), and adults reach a maximum length of between 232 – 244 cm PCL for males and 293 – 315 cm PCL for females (Takahashi et al. 2017). Sex-specific maturity ogives developed from a combined Japanese and Taiwanese dataset suggested that lengths at 50% maturity for male and female SFMs are 166 cm PCL and 233 cm PCL respectively (Semba et al. 2017).

Age determination for SFMs has been hampered by uncertainty in growth band pair deposition rates across regions, ages, and sexes. The periodicity of band pair deposition for SFM in the Northeast PO up to age five has been validated at two band pairs per year based on oxytetracycline tagging (Wells et al. 2013), and one per year for a single adult male shark after age five (Kinney et al. 2016). Validation studies based on radio-bomb carbon in the Atlantic suggest that one band pair is deposited in vertebrae per year (Ardizzone et al. 2006), but the data in the Pacific are not inconsistent with a deposition rate of two per year for a few years. Due to these uncertainties, a meta-analytic approach for estimating growth was adopted by the SHARKWG (Takahashi et al. 2017). This approach treated data from the western NPO (WPO) as having a constant band pair deposition rate and data from the EPO as having a band pair deposition rate that changes from 2 to 1 band pairs per year after age 5. This approach allowed the SHARKWG to produce a single growth model for the northern stock that included data collected from across the basin (ISC 2017b).

## 2.2 Fisheries

Currently, the primary source of known SFM fishing intensity is oceanic longline fisheries targeting swordfish and tuna, including mostly shallow-set longline fisheries in temperate waters, and deep-set longline fisheries in more tropical area. Sharks are targeted less often than tunas and swordfish by these fisheries. However, Asian shark markets, which have been developing for over a decade, provide economic value to SFM bycatch in these fisheries.

# 3 Material and methods

Available time series of catch, abundance, and length composition data considered for use in this stock assessment model were assigned to "fleets" and "surveys" as summarized in Table 1 and Figure 1. The start and end years of the model were 1975 and 2016, respectively.

## 3.1 Spatial stratification

This assessment assumes a single stock in the NPO, north of the equator.

## 3.2 Temporal stratification

An annual (Jan 1-Dec 31) time-series of fishery data for 1975-2016 was used for the assessment.

## 3.3 Catch data

Catches (metric tons and/or numbers of sharks) were provided by ISC member nations and cooperating collaborators (Table 2 and Figure 2). The highest catches came from Japan, Taiwan, and Mexico. The primary sources of catch were from longline and drift gillnet fisheries, with smaller catches also estimated from purse seine, trap, troll, trawl and recreational fisheries. Catches comprised of total dead removals, which include landings and discards.

Major fishing fleets in the NPO (i.e. Japan and Taiwan) lacked species-specific catch data for SFMs prior to 1994. Therefore, SFM catches for these major fishing fleets during 1975 – 1993 were estimated from BSH catch and SFM to BSH ratios (Kai and Liu 2018; Section 3.3.7).

### 3.3.1 USA

A multitude of US fisheries operating in the NPO, both along the US West Coast and out of Hawaii, catch SFM sharks (Kinney et al. 2017). These fisheries include: 1) California longline fishery (F1_US_CA); 2) Hawaiian shallow-set longline fishery targeting swordfish (F2_US_HI_SS); 3) Hawaiian deep-set longline fishery targeting bigeye tuna (F3_US_HI_DS); 4) US West Coast drift gillnets targeting swordfish and thresher sharks within the US EEZ (F4_US_DGN), and 5) Recreational fisheries and other fisheries that periodically catch SFM (F5_US_REC).

The majority of SFM catches in US fisheries were from the Hawaii longline and US West Coast drift gillnets. Catches from both F2_US_HI_SS and F3_US_HI_DS sectors displayed a generally increasing trend since 1995. The F4_US_DGN showed a large oscillation in the catches from 1975 to 2002, followed by a decline, with the lowest catches recorded in the most recent years, 2015 and 2016.

### 3.3.2 Taiwan

Taiwanese fisheries data were obtained primarily from two sources (Tsai and Liu 2017): 1) logbook data of the large-scale tuna longline fishery and 2) logbook data of the small-scale tuna longline fishery. The large-scale tuna longline fishery operates in two areas: north of 25°N (F6_TW_LRG_N) and south of 25°N (F7_TW_LRG_S), with F6_TW_LRG_N catching mainly albacore tuna, *Thunnus alalunga*, in more temperate waters, while F7_TW_LRG_S targets bigeye tuna, *Thunnus obesus*, in equatorial waters. The small-scale tuna longline fishery operates mainly in coastal waters (F8_TW_SML) (Tsai and Liu 2017). The large majority of SFMs are caught by F8_TW_SML (90%) followed by F6_TW__LRG_N (7%) and F7_TW_LRG_S (3%). Trends of SFM catches by F8_TW_SML were relatively stable over-time with a peak in 2004.

### 3.3.3 Japan

SFM is incidentally caught by Japanese coastal and high seas (i.e., offshore and distant waters) fisheries. The majority of SFM catch in Japanese fisheries is from either the high seas longlines or large mesh drift gill-net (Kimoto et al. 2012). Offshore and distant water longline vessels were split into two fisheries based on vessel tonnage, with smaller vessels (20 -120 mt) designated as offshore, and larger vessels (>120 mt) deemed distant water. These two-longline fisheries were further categorized as shallow-set (SS) and deep-set (DS) based on the gear configuration (number of hooks between floats; HBF, with shallow-set - HBF ≤5 and deep-set - HBF ≥6). In 1993, the large-mesh drift gill-net fishery was banned in international waters (Yokawa 2012). However, the Japanese large mesh drift gill-net fishery is still operating within Japans economic exclusive zone (EEZ), and therefore is still considered part of the Japanese fisheries.

Japan provided estimated catch for five sectors of their fisheries, categorized by the vessel tonnage and gear configurations: 1) offshore and distant water longline shallow-set (F9_JPN_SS); 2) offshore and distant water longline deep-set (F10_JPN_DS); 3) coastal waters longline (F11_JPN_CST); 4) offshore and distant waters drift gillnet (F12_JPN_DFN); and 5) trap and other fisheries (F13_JPN_OTH) (Kai and Yano 2017; Kai and Semba 2017). Note that it is not operated in the distant water after 1993 for F12 but the name is used in this document.

Estimated annual catches of SFM in Japanese fisheries were predominantly from F12_JPN_DFN (54%), followed by F9_JPN_SS (23%), F10_JPN_DS (18%), F11_JPN_CST (4%), and F13_JPN_OTH (1%). The highest catches of SFM in the NPO were observed in F12_JPN_DFN during the 1980’s, before it was banned in international waters. For F9_JPN_SS, the total catches of SFM gradually increased from 1992 to 2007, followed by a decrease until 2016. The estimated catches of F10_JPN_DS has shown a decreasing trend since 1992. F11_JPN_CST and F13_JPN_OTH had relatively stable catches over time.

### 3.3.4 Mexico

Aggregated shark catches from Mexico’s Pacific waters were provided by the Mexican National Institute of Fisheries and Aquaculture (INAPESCA) for the states of Sinaloa, Nayarit and Colima, from 1976-2016. Catches were aggregated into two distinct fisheries: 1) the fisheries from Baja California and Baja California Sur as northern catches (F14_MEX_NOR), and 2) those from those from Sinaloa, Nayarit, and Colima as southern catches (F15_MEX_SOU). The northern fisheries were responsible for most of the SFM catches (72%). Both fisheries showed an increasing trend in catches over time, with catches peaking in 2015 and 2014 for the northern and southern fisheries, respectively (Sosa-Nishizaki et al. 2017).

### 3.3.5 Inter-American Tropical Tuna Commission (IATTC)

The number of SFMs caught in tuna purse seine fisheries was available for the period between 1994-2016 and was estimated from observer bycatch data (Appendix A). Some assumptions regarding the relative bycatch rates of SFMs were applied based on their temperate distribution, catch composition information, and estimates of BSH bycatch in tuna purse seine fisheries in the north EPO which were provided by IATTC. Estimates were calculated separately by set type, year and area. Small purse seine vessels, for which there are no observer data, were assumed to have the same SFM bycatch rates by set type, year and area, as those of large vessels.

### 3.3.6 Western Central Pacific Fisheries Commission (WCPFC)

SFM longline catches for non-ISC member countries in the WCPFC area north of the equator were estimated from SPC observer data (personal communication with Peter Williams). Catches from 2002-2016 were estimated based on standardized CPUE values calculated for 5 x 5 degree cells multiplied by the effort reported in that cell summed on an annual basis. The non-ISC countries represented in this dataset include 12 countries, many of which likely fish only south of the equator, thus it is believed that the SFM catch in the NPO of non-ISC member countries represented in the WCPFC database is attributed only to the Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea and Vanuatu.

### 3.3.7 Korea

Landings of SFM by the Korea longline fishery for 2008 – 2017 were submitted to the SHARKWG. However, the SHARKWG decided not to use these data for this assessment because: 1) the catch data was incomplete because a substantial proportion of SFM were likely landed as “Other sharks” and were not included in the submitted data, especially for data prior to 2013; 2) the catch data were highly inconsistent with other major fisheries operating in similar areas and using similar gear; and 3) the data was submitted late and not enough time was available to review and correct the data. It is therefore important to note that the catch for this assessment is likely incomplete and highly uncertain but the impact of this on the assessments are currently unclear. The improvement and inclusion of catch data from the Korean longline and historical drift gillnet fisheries will be an important improvement for the next assessment.

### 3.3.8 Early period catch data (1975-1993)

Prior to 1994, shark catch data for Japanese and Taiwanese fisheries were reported in a single species-aggregated "sharks" category. SFM catches for these major fishing fleets during 1975 – 1993 were estimated using SFM to BSH catch ratios from the period 1994-2016 (Kai and Liu 2018). In summary, the procedure to generate SFM catches followed a two-stage process:

I. Estimate the fleet specific average catch ratios of SFM to BSH for the period 1994-2016 for five major fleets (F8, F9, F10, F12, and F13);
II. Calculate the fleet specific annual catches of SFM from 1975-1993 through multiplying the annual catches of BSH by the average catch ratio of SFM to BSH from 1994 to 2016.

The average catch ratio of SFM to BSH ranged from 0.035 to 0.211 across all five major fleets, with the majority of estimated catches obtained from F12_JPN_DFN (60%) followed by F10_JPN_DS (15%), F9_JPN_SS (14%), F8_TW_SML (9%), and F13_JPN_CST (2%). To address the considerable uncertainty about annual SFM/BSH ratios, we applied a sensitivity analysis wherein the fleet-specific yearly catch was set to +/- 50% of those calculated in stage II (see section 5.2).

### 3.4 Indices of relative abundance

Indices of relative abundance (CPUE) for SFM in the NPO and their corresponding coefficients of variation (CV) were developed with fishery data from four nations (Japan, USA, Taiwan, and Mexico) (Figure 3; Tables 3 and 4). The SHARKWG considered all available abundance indices, and rated each for consideration in this assessment using the same criteria established in the 2017 BSH stock assessment, including spatio-temporal coverage of the data, statistical soundness and other characteristics.

Based on this evaluation, the SHARKWG decided which indices should be included in the base case model. The CPUE series used in the base case model were: S1_US_SS, S3_TWN_LRG, S5_JPN_RTV, S8_MEX, and S9_JPN_SS_I. However, sensitivity analyses were conducted with those indices that were not included in the base case model.

The R package "diags' was used for plotting and summarizing all standardized CPUEs available for this stock assessment. These analyses included, for example, pairwise scatterplots to illustrate correlations among all indices, and cluster analysis to identify dissimilarities among the indices (Appendix B).

#### 3.4.1 Hawaii longline

Abundance indices for the Hawaii deep-set and shallow-set longline fisheries were developed with delta lognormal models using observer data. The shallow-set fishery was impacted by closures from 2001-2004 due to bycatch concerns, but the deep-set fishery was not similarly affected.

Catch and effort data from the Hawaii-based pelagic longline fishery operating in the NPO were analyzed to estimate indices of relative abundance for the SFM between 1995 and 2016. The data came from the records of the Pacific Islands Regional Observer Program (PIROP) submitted to the Pacific Islands Fisheries Science Center (PIFSC). Standardized CPUEs were estimated separately for shallow-set (target: swordfish) (S1_US_SS) and deep-set (target: bigeye tuna) (S2_US_DS) sectors using Generalized Linear Models (GLM).

The index of relative abundance for the shallow-set fishery (S1_US_SS) was considered high priority and therefore was included in the base case model. This decision was based on the statistical soundness of the standardized CPUE, as well as the fact that this fishery has 100% observer coverage. The standardized CPUE for the deep-set fishery (S2_US_DS) was considered valuable because of its long timespan (1994-2016), and statistical soundness. However, the catch rates of SFM for this fishery were much lower when compared to the shallow-set fishery. This difference is probably associated with the spatial distribution and habitat preference of SFMs in the waters off the Hawaiian archipelago. Therefore, the index of relative abundance for S2_US_DS was not included in the base case model.

### 3.4.2 Taiwan longline

The SFM catch and effort data from the logbook records of the Taiwanese large-scale tuna longline fishing vessels operating in the NPO from 2005 to 2016 were analyzed to create an index of relative abundance for Taiwanese longline fishery (S3_TWN_LRG) (Tsai and Liu. 2017). Due to the large percentage of sets with zero SFM catches, the nominal CPUE for SFM was standardized using a zero-inflated negative binomial model.

The S3_TWN_LRG index was considered high priority and therefore was included in the base case model. This decision was based on the statistical soundness of the standardized CPUE, and the extensive spatial coverage of this fishery.

### 3.4.3 Japan longline

#### *Offshore and distant water longline shallow-set*

Set-by-set logbook data from Japanese offshore and distant water longline fishery were used to estimate the standardized CPUE over the period from 1994-2016 (Kai 2017a). Available data included information on catch number, amount of effort (number of hooks), number of branch lines between floats (hooks per basket: HPB) as a proxy for gear configuration, location (longitude and latitude) of set in a 1 by 1 degree square, vessel identity, fishery type (offshore or distant water), and the prefecture in Japan where the longline boats were registered. From this data, an index of relative abundance was estimated using GLM (S4_JPN_SS).

Based on the statistical soundness, long timespan, extensive spatial coverage, and relatively high catch rates, this index was considered as a high priority. However, further explorations showed that the steep increasing trend of this index was inconsistent with all the other indices available, as well as biologically implausible given the current understanding of SFM's population dynamics. Consequently, the SHARKWG decided not to include this index in the base case model.

#### *Training and research vessels*

The National Research Institute of Far Seas Fisheries in Japan has been collecting data from research and training vessels (RTV) since 1992. The RTV fleet commonly operates in the waters around Hawaii. The catch data for SFM showed evidence of excess zeros (15%). To account for the occurrence of excess zeros, a two-part model (Zuur et al. 2009) was used to standardize CPUE of SFM for the RTV (Kai 2017b). A binomial GLM was used for the first stage and a Poisson model was used for the second stage (S5_JPN_RTV).

Based on the statistical soundness, long timespan, extensive spatial coverage, and reliability of record, this index was considered as a high priority and therefore was included in the base case model.

*Observer data*

Observer data of Japanese longline fisheries operating in the NPO from 2011-2016 were used to standardize CPUE for this fishery (S6_JPN_OBS). This standardized CPUE was estimated using a Generalized Additive Mixed model (GAMM) (Kanaiwa et al. 2017).

Given the short time span of this index, it was not included in the base case model.

*Geostatistical spatial-temporal model*

Generalized linear mixed models with spatio-temporal effects have become state of the art in modelling spatial data (Lewy and Kristensen 2009; Kristensen et al. 2014; Nielsen et al. 2014; Thorson et al. 2015). Kai et al. (2017) presented a GLMM framework that integrates spatio-temporal catch, effort and length composition data into a standardized CPUE of SFM catch for the Japanese shallow-set longline fishery operating in the WPO and CPO from 2006-2014. The value of this method is that the resultant index accounts for spatio-temporal changes in both fishing operation and species abundance by size class. This standardized index was considered for inclusion in the present stock assessment (S7_JPN_SPT). However, this index was not ultimately used in the base case model due to concern of dual inference of the length composition data, which is already incorporated into the assessment model as a separate data source (section 3.5.1).

A similar GLMM framework was used to standardize CPUE of SFM caught in the Japanese shallow-set longline fishery operating in the WPO and CPO from 1975-1993. However, for the development of this model, length composition data was not available (S9_JPN_SS_I) (Kai and Kanaiwa. 2018), and therefore this standardized CPUE could be incorporated as-is into the base case model.

### 3.4.4 Mexico longline

Standardized CPUE of SFM caught in Mexican pelagic longline fishery operating in the northwest PO was estimated for the period between 2006 and 2016 (S8_MEX). The analysis used data obtained through the Mexican pelagic longline observer program and a GLM approach (González-Ania et al. 2017).

Based on the statistical soundness, and the fact that this is the only index available for the EPO, this index was considered as a high priority and therefore was included in the base case model.

## 3.5 Catch-at-length

The length frequency observations were the estimated catch-at-size (i.e., size compositions were raised to the catch) for different fisheries from Japan, USA and Mexico. Sex-specific data were reported in the observed measurement units (FL – fork length, TL – total length, AL – alternate length, which is the length from the leading edge of the first dorsal fin to the leading edge of the second dorsal fin) which were subsequently converted to PCL using fishery specific conversion equations (Figure 4). The majority of size length composition data were provided by Japan (90%), followed by USA (7%), and Mexico (3%). For the assessment, sex-specific size data were grouped by fishery as follows.

A 5 cm PCL bin width was chosen for the length composition data bin width and 55 data length bins (60 – 330+ cm PCL) were defined for use in the model. Due to aliasing of length data from length-length conversions, size composition data from US drift gillnet (F4_US_DGN) used 7 cm length bins.

### 3.5.1 Japan

Japan provided SFM size data from several sources including port sampling and research data (Semba 2017). Port sampling data comes from the offshore and distant waters longline fishery, and the coastal small-scale longline and offshore and distant waters drift gill-net fishery, while research data comes from shallow-set longline surveys, research and training vessels, and an observer program.

Size data from longline gear comprised 91% of all Japanese size data, they were divided into shallow-set longline (F9_JPN_SS), and deep-set longline (F10_JPN_DS) based on operational patterns. The shallow-set fishery included data from shallow-set research and training vessels, a shallow-set longline observer program, offshore and distant water shallow-set longline fishery, and small scale coastal shallow-set longlines. Size data categorized as deep-set included data from deep-set research and training vessels, deep-set longline observers, offshore and distant water deep-set longline fishery, and small scale coastal deep-set longlines (Figure 4). Size data from the offshore and distant water shallow-set longline fishery were separated into two periods: 1) from 2005 to 2013, and 2) from 2014 to 2016, due to changes in sampling regulations. The full understanding of the impact of changing regulations in the size samples was not possible this time, therefore it was decided not to include the size data from 2014 to 2016 in this stock assessment (Figure 2). Size data from coastal longline fisheries were available from 2006 to 2016 (F11_JPN_CST), while size data from Japanese drift gill-net fisheries (F12_JPN_DFN) were available from 2005-2006, and 2008-2016, respectively (Figure 2).

### 3.5.2 USA

Length composition data for the drift gill-net fishery (F4_USA_DGN) have been collected by observers and port based sampling. These data were previously described in Sippel et al. (2014), and have been updated for this stock assessment (Kinney et al. 2017) (Figure 5). For the Hawaii longline fishery, sex and size of caught sharks have been recorded by observers in both the shallow-set (F2_US_HI_SS) and deep-set (F3_US_HI_DS) fisheries. These data were also previously described in Walsh and Teo (2012) and Sippel et al. (2014), and have been updated for this stock assessment (Figure 4). The majority of USA length composition data were obtained from F4_USA_DGN (79%), followed by F2_US_HI_SS (12%), and F3_US_HI_DS (9%).

### 3.5.3 Mexico

Length composition data were collected by onboard observers in longline fisheries from Baja California and Baja California Sur (F14_MEX_NOR), and from Sinaloa, Nayarit, and Colima (F15_MEX_SOU) between 2006 and 2014 (Castillo-Geniz et al. 2017) (Figures 2 and 4).

# 4 Integrated model description

## 4.1 Stock Synthesis software

For the integrated modelling efforts, the SHARKWG agreed to use a length-based, age-structured, forward-simulation population model conducted using Stock Synthesis (SS), version 3.24U to examine the stock status of SFM in the NPO. The underlying integrated analysis approach of SS is similar to other commonly-used statistical age-structured models such as Multifan-CL (Fournier et al. 1998) and CASAL (Doonan et al. 2016). SS is designed to accommodate age-structure in the population. Some SS features include incorporation of ageing error, growth estimation, a spawner-recruitment relationship, sex-specific biological parameters and sex-specific fishery data. In fitting the model, the SS code searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian matrices.

## 4.2 Biological assumptions

In addition to assumptions regarding stock structure, the other critical information on the biology of SFMs necessary for the SS assessment relates to sex-specific growth, natural mortality, maturity and fecundity. Biological assumptions and parameter values used in the SS models are summarized in Table 5.

### 4.2.1 Growth

Sex-specific estimates of growth from Takahashi et al. (2017) were assumed in this assessment. The relationships of length at age were based on results of estimating a growth curve for SFMs in the NPO using a meta-analysis of age and growth data provided by the ISC SHARKWG members (US, Mexico, Taiwan, and Japan). Seven data sets of length and age (five from vertebrae observation and two from length frequency analysis) were compiled. Each data set represents a different individual age and growth study and was treated as random effect in the meta-analysis.

Standard assumptions concerning age and growth in the SS model were made: 1) lengths-at-age were assumed to be normally distributed for each age-class; 2) mean lengths-at-age were assumed to follow a von Bertalanffy growth equation:

$$L_2 = L_\infty + (L_1 - L_\infty)e^{-K(A_2 - A_1)}$$

where $L_1$ and $L_2$ are the sizes associated with ages near a first age ($A_1$) and second age ($A_2$), $L_\infty$ is the theoretical maximum length, and K is the growth coefficient. K and $L_\infty$ can be solved for based on the length-at-age; $L_\infty$ was thus re-parameterized as:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-K(A_2 - A_1)}}$$

The growth parameters K, $L_1$ and $L_2$ were fixed in the SS model, with K at 0.128 (0.174) $y^{-1}$ for female (male) and $L_1$ and $L_2$ at 60.0 (60.0) cm and 293.1 (232.8) cm PCL for $A_1$ (age 1) and $A_2$ (age 31), respectively (Takahashi et al. 2017). A CV of 0.10 was assumed to model variation in length-at-age for all ages. No attempt was made to estimate growth due to the uninformative nature of the size data to track cohorts through time (Figure 6).

### 4.2.2 Plus group

For any age-specific model, it is necessary to assume the number of significant age-classes in the exploited population, with the last age-class being defined as a "plus group", i.e. all fish of the designated age and older. For the results presented here, 31 yearly age-classes have been assumed, as age 31 approximates to the age at the theoretical maximum length of an average fish.

### 4.2.3 Weight-at-length

The whole body weight (W, kg) and precaudal length (PCL, cm) relationships of the SFM in the NPO was estimated based on the data provided by Japan, US, and Taiwan (Su et al. 2017). The majority of Japanese and US length data ranged from 60 cm to 200 cm PCL with weight ranging from 1.36 to 162 kg. While Taiwanese data covered wider ranging from 60 cm to 313 cm PCL with weight ranging from 3 to 441 kg. Since the sex-specific weight at length relationships were significantly different for combined data, sex-specific weight-at-length relationships were used:

$W = 4.62 \times 10^{-5} \times PCL^{2.77}$ , for female and

$W = 3.40 \times 10^{-5} \times PCL^{2.84}$ , for male.

These weight-at-length relationships were applied as fixed parameters in the model (Figure 7).

### 4.2.4 Natural mortality

Natural mortality rates for both sexes were fixed at 0.128 $y^{-1}$ for all ages, based on life history invariant methods. The natural mortality (M) is estimated from an empirical equation for cetaceans (Hoenig 1983):

$$M = \exp(0.941) {a_{max}}^{-0.873}$$

where $a_{max}$ is the maximum age and 31 years is given based on the method of bomb-radiocarbon (Ardizzone 2006).

### 4.2.5 Maturity and fecundity

For a shark stock assessment, it is critically important to estimate the correct units of spawning potential. This assessment assumed a single maturity ogive and did not consider age/length specific changes in fecundity in the final set of model runs. In Section 4.3.4 we describe a relationship between pre-recruit survival and spawning potential (essentially the spawner-recruitment relationship) that was used in the assessment.

For the purpose of computing the SA, we assumed a logistic maturity schedule based on length with the size-at-50% maturity for females equal to 233.6 PCL in cm (Semba et al. 2017) (Figure 8). We also assumed that the sex ratio at birth is 1:1. Pup production was fixed at 12 pups per litter, with a two-year reproductive cycle (i.e., 6 pups per year), in the base case model (Figure 9). A three-year reproductive cycle (i.e., 4 pups per year) was used in the sensitivity analysis.

## 4.3 Model structure

### 4.3.1 Population and fishery dynamics

The model partitions the population into 31 yearly age-classes in a single, well-mixed region, defined as the NPO. The last age-class comprises a "plus group" in which mortality and other characteristics are assumed constant. The population is "monitored" in the model at yearly time steps, extending through a time window of 1975-2016. The main population dynamics processes are indicated below.

### 4.3.2 Initial population state

It was not assumed that the SFM population was at an unfished state at the start of the model (1975) because significant longline fishing occurred in the NPO in the 1950s and in Japanese coastal waters prior to 1975 (Okamoto 2004). SS has several approaches to start the model from a fished state and two of these were considered for this assessment.

The first approach involves estimating an initial equilibrium F and early recruitment deviates, without fitting to poorly known initial equilibrium catch, to allow the model substantial flexibility to start from initial conditions that best match the data in the main modelling period. The second approach, involves fitting to the initial equilibrium catch estimated outside the model. Whichever approach is used, it is necessary to specify a selectivity curve to apply either to the F or the equilibrium catch.

Implementation of initial F is described in the manual for SS (Methot 2015). Preliminary attempts to estimate initial F using the first approach resulted in poor model performance and diagnostics. Given this, the base case model used the second approach of fitting to the initial equilibrium catch estimated outside the model.

In this assessment, three initial equilibrium catch values were estimated outside the model – 1385, 2770 (base case model) and 4155 mt. These values represent 50%, 100% and 150% of the 1975 total calculated catch.

The selectivity of the initial equilibrium catch was assumed to be one of the Japanese longline fleets (F9_JPN_SS) because that fishery had large catches of sharks in the early years.

The population age structure and overall size in the first year was determined as a function of the estimate of the first year's recruitment ($R_1$) offset from virgin recruitment ($R_0$) - the initial 'equilibrium' F discussed above - and the initial recruitment deviations. As the size composition data were only available after 1993, the size composition data was relatively uninformative in terms of initial depletion and recruitment variation, only a small number (five) of the initial recruitment deviates were estimated.

### 4.3.3 Stock recruitment

A Beverton-Holt stock-recruitment relationship was assumed and implemented in SS. In the assessment model, the Beverton-Holt stock-recruitment model is parameterized with three parameters, the log of unexploited equilibrium recruitment ($R_0$), the steepness parameter (h) and a parameter representing the standard deviation in recruitment ($\sigma_R$) (Methot and Wetzel 2013). The steepness parameter ($h$) describes the fraction of the unexploited recruits produced at 20% of the equilibrium spawning biomass level. For this stock assessment, the steepness parameter was fixed at a value obtained analytically based on life history, $h$ = 0.317, as described in Kai et al. (2018).

Annual recruitment deviations were estimated based on the information available in the data and the central tendency that penalizes the log (recruitment) deviations. A log-bias adjustment factor was used to assure that the estimated log-normally distributed recruitments were mean unbiased (Methot and Taylor 2011).

The parameter representing the standard deviation in recruitment, $\sigma_R$, was fixed at 0.1. Higher values for the standard deviation in recruitment (e.g. 0.3), evaluated in preliminary model runs resulted in a noticeable trend in recruitment (matching the trend in CPUE), which did not seem plausible.

### 4.3.4 Selectivity curves

A parametric "double-normal" length selectivity function (SS selectivity pattern 24; Methot, 2015) was used for all fleets (Figure 10). The double-normal selectivity function includes six parameters: p1) peak value, p2) width of the top, p3) width of ascending limb, p4) width of descending limb, p5) selectivity at initial size bin, and p6) selectivity at final size bin.

Selectivity was non-sex specific. The parameters for p1, p3, and p4 were estimated for all selectivity curves. The selectivity of the initial and final size bin was assumed to be controlled by p4 and therefore not estimated for all selectivity curves. The value of p2 was assumed to be negligible and fixed at a very small value for all selectivity curves because preliminary models indicated that this parameter was always estimated to be a very small value and at the lower bound for all selectivity curves.

The size of SFM caught by the F2_US_HI_SS fishery was relatively small compared to the other fleets, and the "double-normal" selectivity for this fishery was modified to improve model fits to the size data of this fishery. Instead of a standard "double-normal" selectivity described above, the "double-normal" selectivity parameterization was modified such that the selectivity shape was similar to a logistic curve with full selectivity occurring for fish that were smaller than the peak parameter.

Selectivity for fisheries with poor, limited or missing length data were not estimated. Instead, these fisheries were assumed to have a selectivity of another fishery (i.e., mirrored selectivity) with similar operational characteristics (Table 1).

### 4.3.5 Parameter estimation and uncertainty

Model parameters were estimated by minimizing the negative log-likelihoods of the model fit, and penalties on various model processes (e.g., recruitment deviates). For the catch and CPUE series, lognormal likelihood functions were assumed while a multinomial function was assumed for the size data. The catch data were assumed unbiased and relatively precise, as such, a standard error of 0.01 was assigned for all fleets. The maximization was performed by an efficient optimization using exact numerical derivatives with respect to the model parameters (Fournier et al. 2012). Estimation was conducted in a series of phases. A quality control procedure (i.e., jitter analysis) to ensure that the model was not converging only on a local minimum was conducted by perturbing the starting values of all parameters and by assigning different estimation phases of 50 models, especially for scaling parameters. If any of these 50 models had an improved model fit relative to the base case model, it would indicate that the base case model had not converged to the global minimum. The SS control file (SFM.ctl) which documents the phased procedure, initial starting values, and model assumptions, is included in Appendix C.

The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix. This was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

### 4.3.6 Data weighting

Many of the time series of sex-specific size compositions had low sample sizes and inconsistencies across years. An annual sample size was assumed to be proportional to the number of fishing trips in which at least one SFM was measured, with a maximum of 100.

$ESS_{j,y}$ is the annual effective sample size for fleet $j$ in year $y$, and it is calculated as:

$$ESS_{j,y} = max\ (n, 100),$$

where $n$ is the number of fishing trips.

It is well known that the results of fishery stock assessments based on integrated models can be sensitive to the values used to weight each of the data types included in the objective function. The weight given to each data point in a stock assessment model is determined by a measure of the assumed size of the error associated with that point: typically a coefficient of variation (CV) for abundance indices, and a sample size for composition data.

For the abundance indices the Francis (2011) data weighting approach was implemented. A minimum average standard error (SE; on the natural log scale) was implemented in SS for each CPUE series. The minimum SE was based on fitting a simple smoother to the CPUE data (on the natural log scale) outside the model and estimating the residual variance (e.g. Francis 2011, Carvalho and Winker 2015).

The CVs for each CPUE series were obtained externally to the SS before being input as follows. The annual CVs for each CPUE series were assumed to be equal to the SE on the log scale and adjusted based on our expectation that the stock assessment model would fit each CPUE series at least as well as a smoother (e.g., Francis 2011). The average annual SE (SE.in; on the log scale) was calculated for each CPUE series. The square root of the residual variance was calculated based on the fit of a simple smoother to each CPUE series on the log scale as:

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

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—rather than the degrees of freedom used in the estimation of the smoother fit— (e.g. Francis 2011; Carvalho and Winker 2015). For these model runs, a LOESS smoother was fit to each CPUE series on the log scale. If input SE ($SE_{in}$) for a CPUE series was less than $RMSE_{Smoother}$ for that CPUE series, then the input SE for the CPUE series was adjusted ($SE_{adj}$) in SS before running the model so that the new average SE was equal to $RMSE_{Smoother}$ ($SE_{in} + SE_{adj} = RMSE_{Smoother}$). If $SE_{in}$ for a CPUE series was greater than or equal to the $RMSE_{Smoother}$ for that CPUE series then the SE of the CPUE series was not adjusted in SS. In addition, a minimum average CV of 0.2 was also assumed for each index. The resulting adjustment factors for indices S1 – S9 were 0.04, 0.01, 0.13, 0.14, 0.14, 0.0, 0.08, 0.09, and 0.11.

The method proposed by Francis (2011) (Method TA1.8) was also used to weight the size composition data, using the SSMethod.TA1.8 function in the 'r4ss' package. In his stock assessment, all estimated Francis weights of the size composition for all fleets were > 1, which suggested that the size composition data did not have to be down-weighted. A $R_0$ profile of the data components also suggested that the size composition data were relatively consistent with abundance indices with respect to estimated population scale (Section 5.1.2).

### 4.3.7 Assessment strategy

The development of a stock assessment model is comprised of the model processes, data and statistical methods for comparing data to predictions. Systematic misfit to data or conflict between data within an assessment model should be considered as a sign of model misspecification.

Unacceptable model fit (i.e. model predictions do not match the data) can be detected by either the magnitude of the residuals being larger than implied by the observation error, or trends in residuals indicating systematic misfit. Data conflicts occur when different data series, given the model structure, provide different information about important aspects of the dynamics. Unacceptable model misfit or conflict between data can be dealt with by either data weighting or model process changes/flexible model parametrization.

Because it is difficult to determine the underlying cause of the model misfit and conflict, it is often assumed that some data are more reliable than other data for determining particular aspects of the population dynamics (Francis 2011). The goal here was to develop a dynamic model that fit the data well, had biological parameters consistent with the best available biological studies, and was internally consistent. Internal consistency implies all data are fit as well as their observational errors and trends in residuals are minimized. Important aspects of the dynamics (scale, trend and relative scale) should be derived from the most trusted data sources.

The modeling approach is summarized as follows:

1. Selection of the data and estimation of the true sampling error;
2. Development of the initial model with original sampling error;
3. Determine if CPUE indices have information on scale and prioritize data;
4. Run stock assessment model;
5. Apply model diagnostics;
6. Modify or add additional process based on diagnostics and complete steps 4-6 again until internally consistent model is achieved;
7. Re-weight the data as needed.

### 4.3.8 Base case model

The model selected as the base case used: the CPUE series recommended by the SHARKWG (S1_US_SS, S3_TWN_LRG, S5_JPN_RTV, S8_MEX, and S9_JPN_SS_I); the best practice approach for weighting size frequency data to ensure that the data did not overwhelm the abundance indices; sigma R of 0.1; initial catch fixed at 2,770 mt, and the steepness parameter $h$ = 0.317.

### 4.3.9 Sensitivity analyses

Several sensitivity analyses were conducted to evaluate the effects of changes in the base case model. A selected number of the most relevant alternate model configurations are described in the sensitivity analyses section. These configurations include alternative assumptions regarding historical commercial removals of SFMs, life history (e.g. growth, reproductive cycle, and mortality), SS model structure (e.g. fit to a single index at a time, and estimate initial equilibrium catch freely), and changes in the stock-recruitment relationship.

Sensitivity analysis were also developed to explore the impact of starting the stock assessment in 1994 (the year when catches were species specific) and fitting to each one the CPUE indices available, except S9_JPN_SS_I. The values assumed for the initial equilibrium catch were based on 50%, 100%, and 150% of total catches in 1994.

## 4.4 Stock assessment model diagnostics

There are limited diagnostics available for assessing the goodness of fit and identifying model misspecification in integrated fishery stock assessment models (Carvalho et al. 2017). The model diagnostics below were applied to the base case model.

### 4.4.1 Residual analysis

Residuals were examined for patterns to evaluate whether the model assumptions have been met. Many statistics exist to evaluate the residuals for desirable properties. One way is to calculate, for each abundance index, the standard deviation of the normalized (or standardized) residuals divided by the sampling (or assumed) standard deviation (SDNR) (Breen et al. 2003; Francis 2011; Carvalho et al. 2017). The SDNR is a measure of the fit to the data that is independent of the number of data points. A relatively good model fit will be characterized by smaller residuals (i.e. close to zero) and a SDNR close to one. In addition, the root-mean-square-error (RSME) was used as a goodness-of-fit diagnostic, with relatively low RMSE values (i.e., RMSE < 0.3) being indicative of a good fit.

### 4.4.2 Age-structured production model (ASPM)

The ASPM diagnostic is intended to evaluate the influence of catch and abundance indices on estimating absolute abundance (Maunder and Piner 2015; Carvalho et al. 2017). The ASPM was also used to determine whether information on temporal recruitment variability is needed to interpret the information about absolute abundance contained in the index of relative abundance. To conduct the ASPM diagnostic, the following protocol was used:

1. run the SS base case model;
2. fix selectivity parameters at the maximum likelihood estimate (MLE) from the base case model,
3. turn off the estimation of all parameters except the scaling parameters and the parameters representing the initial conditions (a parameter for the equilibrium recruitment and a parameter for the equilibrium fishing intensity), set the recruitment deviates to zero (early recruitment and model period recruitments), and set the recruitment bias correction to zero;
4. fit the model to only the catch and indices of abundance;
5. compare the estimated SA trajectory to the one obtained in the fully integrated model.

### 4.4.3 $R_0$ profile

Likelihood profiles are used to check that a solution has actually been found and to evaluate the information content of the various data components on the estimated population scale. It is not uncommon for indices to contain insufficient information to estimate the population scale of a stock assessment model. Indices may also be conflicting with other indices and/or other data components, therefore fitting results in weighting averages of contradictory trends. This generally produces parameter estimates intermediate to those obtained from the data sets individually. Likelihood profiles on the average recruitment $R_0$ by data component were plotted to evaluate the information in each series in relation to the estimated population scale.

#### 4.4.4 Retrospective analysis

Retrospective analysis was conducted based on the base case with the same model configuration and parameter specifications to examine the consistency of the stock assessment results when sequentially eliminating the final year of data. The data were removed for each year up to five years from 2016 to 2011 using the retrospective function of SS. The estimates of spawning biomass were compared to elucidate the potential biases and uncertainty in the terminal year estimates.

In stock assessment, the "$\rho$"; statistic proposed by Mohn (1999) is commonly used to evaluate the severity of retrospective patterns (Carvalho et al. 2017). This statistic measures the average of relative difference between an estimated quantity from an assessment (e.g., biomass in final year) with a reduced time-series and the same quantity estimated from an assessment using the full time-series. Retrospective patterns generally arise from two main causes: time-varying processes unaccounted for in the assessment (i.e., model misspecification), or incomplete data.

### 4.5 Future projections

Future projections from 2017 to 2026 were conducted on the base case output assuming three harvest policies:

1. Status-Quo *F* scenario: fishing intensity is maintained at the current level (average *F* for 2013-2015)
2. High *F* scenario: relative fishing intensity increases by 20% from the current level (average *F* for 2013-2015).
3. Low *F* scenario: relative fishing intensity decreases by 20% from the current level (average *F* for 2013-2015).

Projections were run using the *Forecast* option available in SS. Future selectivities for all fisheries were fixed at the average of 2013-2015. Future recruitment was based on the Beverton-Holt stock recruitment relationship in the base case model, without stochastic resampling of estimated recruitment deviates.

## 5 Results

### 5.1 Base case model

#### 5.1.1 Estimated parameters and model performance

All estimated parameters in the base case model were within the set bounds, and the final maximum gradient of the model (3.52061E-5) indicated that the model had converged onto a local or global minimum. The results of the jitter analysis (Section 4.3.5) indicated that there is no evidence of other models with different starting values and/or estimation phases having substantial differences in the scaling parameter ($R_0$) and total likelihood showing a better fit than the base case model. Based on these results, it is concluded that the model is relatively stable with no evidence of lack of convergence to the global minimum. The performance of the base case model was assessed by comparing input data with predictions for two data types: abundance indices and size compositions. Abundance indices provide direct information about stock trends and composition data inform about strong and weak year classes and the shape of selectivity curves (Francis 2011).

The model fits to the CPUE indices by fishery are provided in Figure 11. Results showed that the S1_US_SS, S5_JPN_RTV, and S9_JPN_SS_I indices had RMSE < 0.3 and SDNR values < 1, which indicates that the models fit those CPUE indices reasonably well. However, S3_TWN_LRG and S8_MEX had values for RMSE > 0.3 and SDNR > 1, which indicates that those indices were not consistent with the other data included in the model (Table 6). All late indices (after 1994) showed a relative flat predicted CPUE trend.

Model predicted and observed length compositions are provided in Figure 12. Overall fits to length compositions appeared to be reasonably good – indicating that the estimated selectivity curves removed sharks from the modelled population in aggregate at comparable lengths to that observed in the data. Predicted annual mean lengths of the catch by fleet are comparable to the observed annual mean lengths (Figure 13).

Figure 14 presents the results of the likelihood profiling on log ($R_0$) for each data component. Changes in negative log-likelihood over the range of $R_0$ examined was relatively small, which means that the estimated population scale was relatively uncertain, which was reflected in the uncertainty in SA estimates (presented below). The $R_0$ profile of the abundance indices was asymmetrical, with increasing negative log-likelihoods when $R_0$ was low and moderate change when $R_0$ was high. This finding is particularly useful for providing information on whether the population is lower than a certain minimum level but less informative on the upper limit to the population scale (i.e., uncertainty was primarily on the high $R_0$ side).

Overall, the changes in negative log-likelihoods among the eight length composition data sources were smaller than those from the abundance indices over the range of log ($R_0$) values (Figure 14). There was a slight level of disagreement between the length composition data and the abundance indices. However, interpreting these results in conjunction with those obtained from other diagnostics (see ASPM results section), the length composition data did not stop the model from fitting the abundance indices well. Importantly, the abundance indices were the primary sources of information on the population scale in this model, which indicates that the results of this assessment are relatively robust (Francis 2011). The S9_JP_SS_I and the S5_JP_RTV indices were the most important indices in this assessment for the early and late periods respectively.

### 5.1.2 Model results

#### 5.1.2.1 Spawning abundance

In this assessment, the reproductive capacity of the population was calculated as the number of mature female sharks (i.e. spawning abundance; SA) rather than spawning biomass, because the size of mature female sharks did not appear to affect the number of pups produced (i.e., larger female sharks did not produce more pups).

The SA was estimated, on average, to be 910,000 sharks (Figure 15). The current SA ($SA_{2016}$) was estimated to be 860,200 sharks (CV=46%) (Table 7) and was 36% (CV=30%) higher than the estimated SA at MSY ($SA_{MSY}$) (Table 8). Estimated SA has slightly increasing since 1999 (Table 7). The maximum likelihood estimate of SA has been above MSY throughout the entire assessment period (Figure 15).

Uncertainty in the estimated SA was relatively large and the 95% confidence intervals overlapped the MSY throughout the assessment period. Uncertainties in the SA estimates were relatively large because the virgin recruitment parameter log ($R_0$), which determines the population scale, was estimated with considerably uncertainty.

#### 5.1.2.2 Recruitment

Estimated recruitment was generally consistent with the biology of the stock and assumptions in the base case model. Recruitment estimates did not show a substantial trend with respect to SA (Figure 16). The estimated recruitments have fluctuated moderately during the assessment period, ranging from a low of 1.1 million fish in 1998 to a high of 1.3 million sharks in 1975 (Figure 16). The average recruitment during the stock assessment period was 1.1 million sharks, which was below virgin recruitment (1.5 million sharks). Uncertainty in the recruitment estimates was relatively large due to the large uncertainty for the estimated log ($R_0$) parameter.

The estimated annual recruitment deviates from the assumed stock-recruitment relationship, expected recruitment from the stock-recruitment relationship and the bias adjustment applied to the stock-recruitment relationship are provided in Figures 17, 18 and 19, respectively.

#### 5.1.2.3 Fishing intensity

Spawning potential ratio (SPR) was used to describe the impact of fishing on this stock. The SPR of this population is the ratio of SA per recruit under fishing to the SA per recruit under virgin (or unfished) conditions. Therefore, 1-SPR is the reduction in the SA per recruit due to fishing and can be used to describe the overall impact of fishing on a fish stock (Goodyear 1993). The fishing intensity (1-SPR) on the SFM stock in the NPO has fluctuated between 0.1 and 0.4 during the assessment period, and was 0.16 in recent years (2013-2015) (Table 7 and Figure 20).

#### 5.1.2.4 Biological reference points

Target and limit reference points of SFMs in the NPO have not been adopted by either the IATTC or WCPFC. In this assessment, stock status is reported in relation to MSY. $SA_{MSY}$ was estimated to be 633,700 sharks (CV=23.3%) (Table 8). Fishing intensity at MSY ($1\text{-}SPR_{MSY}$) was estimated to be 0.26 (Table 8).

A Kobe plot of the base case model is presented in Figure 21 to illustrate stock status of the SFM in the NPO in relation to $SA_{MSY}$ and the equivalent fishing intensity (1-$SPR_{MSY}$) over the modeling period. The Kobe plot showed that SFM in the NPO have likely (>50%) experienced overfishing (1-SPR/1-$SPR_{MSY}$ > 1) in the past but the stock is likely (>50%) not in an overfished condition over the past two decades.

### 5.1.3 ASPM and retrospective analysis

The age-structure production model (ASPM) diagnostic can be used as an indicator of the presence of a production function for indices in an integrated stock assessment model. If an ASPM is able to fit the abundance indices with good contrast, then this finding is considered evidence that the indices will likely be able to provide information on the scale of the population.

In this stock assessment, the ASPM produced similar estimates of abundance to the fully integrated model suggesting that there is information about absolute abundance in the indices of relative abundance and how it is depleted by the catch (Figure 22). Similar to the fully integrated base case model, the ASPM showed a good fit to the early CPUE index (S9_JPN_SS_I) (Figure 11). However, for the late period, the ASPM was not able to fit three of the CPUE indices well (S3_TWN_LRG; S5_JPN_RTV; S8_MEX), with only the U.S. longline index (S1_US_SS) showing a good fit. In addition, the predicted trends for the CPUE indices in the late period were flat. These findings can be considered as evidence that most of the indices available for the late period were likely not able to provide information on the scale of the population. In contrast, the only CPUE index available for the early period (S9_JPN_SS_I) was likely informative on both population trend and scale.

The results of the retrospective analysis are shown in Figure 23. The trajectories of SA showed no appreciable retrospective pattern and there was no consistent trend of over- or under-estimating SA. Given the small magnitude of the retrospective pattern ($\rho = 0.039$), it was concluded that the base case model was robust to the inclusion of recent assessment data and did not have a retrospective pattern of concern for estimates of SA.

## 5.2 Sensitivity analyses

The SHARKWG identified four major groups of sensitivity analyses to examine the effects of: 1) uncertainty in total catch estimates and initial conditions; 2) the use of a single CPUE index in combination with S9; 3) uncertainty in biological assumptions; and 4) stock assessment period on the assessment results.

Model sensitivity was evaluated by comparing density plots (based on standard error of parameter estimates obtained from the inverted Hessian matrix with r4ss; Taylor et al. 2014) for the main scaling parameter in the model (virgin recruitment; log($R_0$)), and the resulting equilibrium unfished spawning abundance ($SA_0$).

Key MSY-related quantities and time series of the SA, and 1-SPR were also provided for all sensitivity analysis.

### 5.2.1 Uncertainty in catch estimates and initial conditions

Because of the uncertainty in the estimates of total catches, especially for the early period, the SHARKWG decided to explore the sensitivity of model results under alternative scenarios of catch estimates. The catches were assumed the same as those used in the base case (status quo), or 50% and 20% higher or lower in the period of 1975-1993 and 1994-2016, respectively. A combination of different assumptions on catch estimates generated eight different alternative scenarios (Sensitivity models 1-8; Table 9). In addition, because of the uncertainty in the only CPUE index available for the early period (S9_JPN_SS_I), the working group also decided to explore the impact of increasing the CV (~0.3) for this CPUE index in the stock assessment results (Sensitivity model 10; Table 9).

One potential criticism of the base case model is that the initial conditions of the model was heavily constrained by fitting to an initial equilibrium catch (2770 mt) that was estimated outside of the model. Another potential improvement for future assessments is to fit to only a single representative abundance index in the late period (1994-2016) instead of fitting to four abundance indices that appear to conflict. Therefore, a sensitivity model was developed where the model was not fit to the estimated initial equilibrium catch and the model was fit only to the S9_JPN_SS_I and S1_US_SS in the early and late periods respectively (Sensitivity model 9; Table 9). The S1_US_SS was chosen as the only index for the late period because this was the best-fitting index that was the most consistent with the rest of the model and data (Sections 5.1.1 and 5.1.3).

Major differences were observed in equilibrium recruitment, log($R_0$) and the resulting equilibrium unfished spawning abundance ($SA_0$) (Figure 24). Time-series of SA and fishing intensity showed major differences among model runs (Figure 24). Similarly to the base case model uncertainty on estimates of SA and fishing intensity were relatively large.

### 5.2.2 Alternative CPUE indices

In the base case model, four available indices were fitted in the late period. However, using four potentially conflicting indices may be inappropriate and may lead to biased estimates. Sensitivity models were developed that fit to a combination of S9_JPN_SS_I, and one other available late period index at a time, instead of all four (Sensitivity models 11-14; Table 9).

Major differences were observed in virgin recruitment, log($R_0$) and the resulting unfished spawning abundance ($SA_0$) (Figure 25). Time-series of SA and fishing intensity showed major differences among model runs (Figure 25). Similarly to the base case model uncertainty on estimates of SA and fishing intensity were relatively large.

### 5.2.3 Biology

A series of sensitivity models were developed under different biological assumptions (Table 9), including:

- Higher and lower steepness values, correspondent to + or - one standard deviation from the value used in the base case model (Sensitivity models 19 – 20);
- Natural mortality and steepness similar to those used in the 2017 ICCAT North Atlantic SFM stock assessment (Sensitivity model 18);
- Alternative growth curve produced using only age and growth data provided by Taiwan. In comparison to the one used in the base case model, the growth curve from Taiwan suggests that SFMs in the NPO grow slower (Sensitivity model 17);
- A low fecundity stock recruitment (LFSR) relationship used to characterize productivity of the stock based on plausible life history information available for SFM in the NPO. Parametrization of the LFSR was based on the most plausible life history information available for SFM in the NPO with $s_{Frac}$ = 1 and $\beta$ = 4 (Sensitivity model 16);
- Reproductive cycle assumed to be three years instead of two, as used in the base case model (Sensitivity model 15).

Major differences were observed in virgin recruitment, log($R_0$) and the resulting unfished spawning abundance ($SA_0$) (Figure 26). Time-series of SA and fishing intensity showed major differences among model runs (Figure 26). Similar to the base case model uncertainty on estimates of SA and fishing intensity were relatively large.

### 5.2.4 Start year of model

Data from the early period (1975 – 1993) was considered to be highly uncertain because a substantial portion of the catches and the abundance index (S9_JPN_SS_I) were derived from non-species-specific data (Section 3.3.7). Therefore, a sensitivity model was developed to illustrate the effect of not using the data from the early period and starting the model in 1994 (Sensitivity model 21; Table 9).

Starting the stock assessment model in 1994 resulted in models with lack of convergence and poor model diagnostics, and were not further considered.

## 5.3 Key uncertainties and limitations

Based on the above sensitivity analyses, key uncertainties of this assessment were identified and used to illustrate stock status under six alternative states of nature. The key uncertainties in this assessment were related to the catch time series, especially in the early period (1975-1993), the precision of the early Japan shallow-set CPUE index (1975-1993), initial conditions, and the stock recruitment relationship. Six models representing these key uncertainties were developed to examine the status of the North Pacific SFM stock under alternative states of nature:

1. Higher catch: Total catch is 50% and 20% higher for the early (1975-1993) and late (1993-2016) periods, respectively;

2. Lower catch: Total catch is 50% and 20% lower for the early (1975-1993) and late (1993-2016) periods, respectively;
3. Higher uncertainty on index: Average CV of Japan shallow-set CPUE index (1975-1993) is 0.3;
4. Initial conditions: Initial conditions were estimated without fitting to initial equilibrium catch estimated outside the model, and fit to S9_JPN_SS_I and S1_US_SS indices;
5. Lower steepness: A lower value was assumed for the steepness parameter (0.260);
6. Higher steepness: A higher value was assumed for the steepness parameter (0.372).

All six alternative states of nature were consistent with the base case model (Figure 27, Table 10).

## 5.4 Future projections

Future projections were performed under three constant fishing intensity scenarios: 1) average of 2013-2015 ($F_{2013-2015}$); 2) $F_{2013-2015}$ + 20%; and 3) $F_{2013-2015}$ - 20% for a 10-year period (2017-2026). Based on these future projections the SA is expected to increase gradually under scenarios 1 and 3, however in scenario 2 SA drops in the final years of the projection (Figure 28).

## 5.5 Stock status and conservation information

### 5.5.1 Status of the stock

Results from this assessment should be considered with respect to the management objectives of WCPFC and IATTC, the organizations responsible for management of pelagic sharks caught in international fisheries for tuna and tuna-like species in the Pacific Ocean. Target and limit reference points have not been established for pelagic sharks in the Pacific Ocean. In this assessment, stock status is reported in relation to MSY.

Recruitment was estimated on average to be 1.1 million age-0 sharks during the modeling timeframe (1975-2016) (Figure 16). During the same period, the SA was estimated, on average, to be 910,000 (Figure 15). The current SA ($SA_{2016}$) was estimated to be 860,200 (CV=46%) (Table 7) and was 36% (CV=30%) higher than the estimated SA at MSY ($SA_{MSY}$) (Table 8, Figure 15). The recent annual fishing intensity ($1\text{-}SPR_{2013-2015}$) was estimated to be 0.16 (CV=38%) and was 62% (CV=38%) of fishing intensity at MSY ($1\text{-}SPR_{MSY}$; 0.26) (Table 8; Figure 20). The results from the base case model show that, relative to MSY, the SFM stock in the NPO is likely (>50%) not in an overfished condition and overfishing is likely (>50%) not occurring (Figure 21).

Besides the base case model, stock status was also examined under the six alternative states of nature outlined above, which represent the most important sources of uncertainty in the assessment. Results of these models with alternative states of nature were consistent with the base case model (Figure 27, Table 10).

### 5.5.2 Conservation information

Based on the results of future projection (Figure 28), SA is expected to increase gradually if F remains constant or is decreased moderately relative to 2013-2015 levels. However, given the uncertainty in fishery data and key biological processes within the model, especially the stock recruitment relationship, the models' ability to project into the future is highly uncertain.

## 5.6 Research needs

### 5.6.1 Catch

There is substantial uncertainty in the estimated historical catches of SFMs. Substantial time and effort was spent on estimating historical catch, but more work remains to be done. In particular, the SHARKWG have identified two future improvements that are critical: 1) identify all fisheries that catch SFMs in the NPO (i.e., are there any fisheries that catch SFM that may not have been identified by the SHARKWG?); and 2) methods to estimate SFM catches should be improved, especially for the early period from 1975 to 1993.

### 5.6.2 Abundance indices

It is important to improve the development of the abundance indices, especially in the early period (1975-1993) and for the drift-net fishery (F12_JPN_DFN). In addition, the application of the spatial-temporal model to the CPUE data of each longline fleet is essential to improving the standardized abundance index. Further, there should be an exploration into the reasons for the steep increase trends of the CPUE for Japanese shallow-set longline fishery (F9_JPN_SS).

### 5.6.3 Length and sex composition

Improvement of the quantity and quality of size data (i.e. increase the number of sample with random sampling) is important to further improvements in the assessment model.

### 5.6.4 Biological parameters

Further investigations into the biological parameters of SFM will be important for future assessments. In particular, sex-specific length at ages, reproductive cycle, number of fecundity, sex-and age- specific M schedules. These parameters currently include large uncertainties.

### 5.6.5 Stock-recruitment relationship

It is essential to perform further research into the use of the LFSR relationship for SFM. In addition, further investigation into the parameterization of the LFSR relationship is useful for future assessments.

## 6 Acknowledgements

Completion of the SFM stock assessment was a collaborative effort by the ISC Shark Working Group. Those who contributed included Carvalho, F., Castillo-Geniz, L., Clarke, S., Fernandez-Mendez, I., Fujinami, Y., Gonzalez-Ania, L., Kai, M. (SHARKWG Chair), Kanaiwa, M., Kapur, M., King, J., Kinney, M. (SHARKWG Vice-Chair), Kohin, S., Liu, K.M., Maunder, M., Piner, K., Semba, Y., Sosa-Nishizaki, O., Takahashi, N., Teo, S., Tsai, W.P. and Yokoi, H. Carvalho, F. and Teo, S. were the lead Stock Synthesis modelers.

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# 8 Tables and Figures

**Table 1**. Time series of catch, relative abundance, length composition data, and selectivity considered for the assessment of shortfin mako (SFM) in the North Pacific Ocean (NPO).

| Time series # | Symbol | Catch (metric tons) and abundance (numbers or biomass) | Name | Definition | Length composition availability (5 cm PCL bins, unless stated otherwise) | Selectivity |
|---|---|---|---|---|---|---|
| 1 | F1 | Catch (metric tons) | F1_US_CA | US California longline | NA | Mirror F2 |
| 2 | F2 | Catch (numbers) | F2_US_HI_SS | US Hawaii longline shallow-set + California longline | (2005-2016) | Estimated |
| 3 | F3 | Catch (in numbers) | F3_US_HI_DS | US Hawaii longline deep-set (Catch in 1000s fish) | (2005-2016) | Estimated |
| 4 | F4 | Catch (metric tons) | F4_US_DGN | US Drift Gillnet | (1994-2016; 7 cm bin) | Estimated |
| 5 | F5 | Catch (numbers) | F5_US_REC | US Recreational (Catch in 1000s fish) | | Mirror F2 |
| 6 | F6 | Catch (metric tons) | F6_TW_LRG_N | TW longline large-scale (North) | (1994-2016; not fit) | Mirror F9 |
| 7 | F7 | Catch (metric tons) | F7_TW_LRG_S | TW longline large-scale (South) | | Mirror F9 |
| 8 | F8 | Catch (metric tons) | F8_TW_SML | TW longline small-scale | | Mirror F9 |
| 9 | F9 | Catch (metric tons) | F9_JPN_SS | JP offshore & distant water longline shallow-set | (2005-2013) | Estimated |
| 10 | F10 | Catch (metric tons) | F10_JPN_DS | JP offshore & distant water longline deep-set | (2000-2016) | Estimated |
| 11 | F11 | Catch (metric tons) | F11_JPN_CST | JP coastal longline | (2006-2016) | Mirror F9 |
| 12 | F12 | Catch (metric tons) | F12_JPN_DFN | JP drift gillnet | (2005-2016) | Estimated |
| 13 | F13 | Catch (metric tons) | F13_JPN_OTH | JP trap and others | | Mirror F9 |
| 14 | F14 | Catch (metric tons) | F14_MEX_NOR | MX north all fisheries | (2007-2016) | Estimated |
| 15 | F15 | Catch (metric tons) | F15_MEX_SOU | MX south all fisheries | (2006-2016) | Estimated |
| 16 | F16 | Catch (metric tons) | F16_WCPFC | WCPFC observer other longlines | | Mirror F2 |
| 17 | F17 | Catch (metric tons) | F17_IATTC | IATTC purse seine | | Mirror F2 |
| 18 | F18 | Catch (numbers) | F18_JPN_SSII | JP F9 (last 3 years of size comp) | (2014-2016; not fit) | Mirror F9 |
| 19 | S1 | Relative abundance (numbers) | S1_US_SS | INDEX US Hawaii longline shallow-set | | Mirror F2 |
| 20 | S2 | Relative abundance (numbers) | S2_US_DS | INDEX US Hawaii longline deep-set | | Mirror F3 |
| 21 | S3 | Relative abundance (numbers) | S3_TW_LRG | INDEX TW longline large-scale | | Mirror F6 |
| 22 | S4 | Relative abundance (numbers) | S4_JPN_SS | INDEX JP longline shallow-set (Primary index) | | Mirror F9 |
| 23 | S5 | Relative abundance (numbers) | S5_JPN_RTV | INDEX JP research & training vessels | | Mirror F9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 24 | S6 | Relative abundance (numbers) | S6_JPN_OBS | INDEX JP observer | | Mirror F9 |
| 25 | S7 | Relative abundance (numbers) | S7_JPN_GEO | INDEX JP longline shallow-set spatio-temporal model | | Mirror F9 |
| 26 | S8 | Relative abundance (numbers) | S8_MEX | INDEX MEX longline | | Mirror F14 |
| 27 | S9 | Relative abundance (numbers) | S9_JPN_SS_I | INDEX JP longline shallow-set (1975-1993) | | Mirror F9 |

**Table 2.** Catch time series of shortfin mako sharks in the North Pacific Ocean from 1975 to 2016 assigned to "fleets" F1 – F18 as defined below. Each column indicates the fleet's catch either in numbers (1000s of fish) or metric tons. See Table 1 for catch units.

| | Fleet | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | F13 | F14 | F15 | F16 | F17 | F18 |
| 1975 | 0.07 | 0 | 0 | 6.65 | 0 | 0 | 15 | 396 | 721 | 232 | 75 | 1329 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1976 | 0.46 | 0 | 0 | 1.09 | 0 | 0 | 0 | 443 | 1002 | 433 | 126 | 1329 | 0 | 66 | 7 | 0 | 0 | 0 |
| 1977 | 1.16 | 0 | 0 | 12.28 | 0 | 3 | 2 | 431 | 1351 | 588 | 103 | 1329 | 0 | 64 | 8 | 0 | 0 | 0 |
| 1978 | 1.8 | 0 | 0 | 16.73 | 0 | 2 | 4 | 454 | 1097 | 550 | 128 | 1329 | 0 | 92 | 11 | 0 | 0 | 0 |
| 1979 | 10.39 | 0 | 0 | 13.46 | 0 | 0 | 1 | 532 | 1200 | 774 | 123 | 1329 | 0 | 43 | 21 | 0 | 0 | 0 |
| 1980 | 13.7 | 0 | 0 | 91.17 | 2.72 | 0 | 3 | 551 | 1144 | 918 | 106 | 1329 | 0 | 51 | 14 | 0 | 0 | 0 |
| 1981 | 19.11 | 0 | 0 | 168.24 | 13.03 | 0 | 3 | 471 | 1013 | 1076 | 106 | 4142 | 0 | 38 | 19 | 0 | 0 | 0 |
| 1981 | 6.39 | 0 | 0 | 354.22 | 1.5 | 0 | 0 | 517 | 637 | 774 | 85 | 4142 | 0 | 61 | 15 | 0 | 0 | 0 |
| 1983 | 0.56 | 0 | 0 | 222.54 | 1.08 | 0 | 0 | 456 | 510 | 842 | 53 | 4064 | 0 | 58 | 10 | 0 | 0 | 0 |
| 1984 | 2.43 | 0 | 0 | 161.61 | 2.63 | 0 | 0 | 410 | 397 | 836 | 109 | 3810 | 0 | 40 | 10 | 0 | 0 | 0 |
| 1985 | 0.02 | 0 | 0 | 153.06 | 9.34 | 0 | 8 | 457 | 352 | 769 | 114 | 3607 | 0 | 35 | 7 | 0 | 0 | 0 |
| 1986 | 1.27 | 0 | 0 | 318.71 | 4.84 | 0 | 10 | 384 | 416 | 565 | 101 | 3674 | 0 | 57 | 29 | 0 | 0 | 0 |
| 1987 | 3.5 | 0 | 0 | 409.94 | 21.89 | 0 | 4 | 288 | 333 | 486 | 104 | 3655 | 0 | 177 | 19 | 0 | 0 | 0 |
| 1988 | 156.34 | 0 | 0 | 174.13 | 14.47 | 0 | 1 | 300 | 299 | 645 | 94 | 3595 | 0 | 231 | 16 | 0 | 0 | 0 |
| 1989 | 4.76 | 0 | 0 | 257.55 | 6.14 | 0 | 4 | 328 | 274 | 747 | 86 | 5007 | 0 | 114 | 20 | 0 | 0 | 0 |
| 1990 | 15.2 | 0 | 0 | 368.25 | 6.27 | 0 | 16 | 365 | 257 | 512 | 88 | 2630 | 0 | 257 | 30 | 0 | 0 | 0 |
| 1991 | 23.26 | 0 | 0 | 201.31 | 6.17 | 0 | 17 | 412 | 333 | 505 | 86 | 2630 | 0 | 198 | 30 | 0 | 0 | 0 |
| 1992 | 2.16 | 0 | 0 | 143.69 | 6.17 | 0 | 6 | 443 | 344 | 538 | 90 | 1639 | 0 | 350 | 26 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 0.8 | 0 | 0 | 124.55 | 3.91 | 0 | 4 | 338 | 431 | 775 | 86 | 139 | 0 | 354 | 89 | 0 | 0 | 0 |
| 1994 | 20.78 | 0 | 0 | 110.61 | 13.59 | 0 | 1 | 262 | 325.78 | 364.18 | 57.91 | 123 | 17.64 | 274 | 61 | 0 | 17 | 0 |
| 1995 | 0 | 0.23 | 0.59 | 90.81 | 5.49 | 84 | 7 | 268 | 408.37 | 520.72 | 56.16 | 103.06 | 13.19 | 276 | 58 | 0 | 44 | 0 |
| 1996 | 0 | 0.14 | 0.32 | 93.62 | 2.24 | 36 | 3 | 707 | 382.7 | 421.38 | 348.32 | 101.06 | 14 | 337 | 76 | 0 | 44 | 0 |
| 1997 | 0 | 0.12 | 0.31 | 132.91 | 5.21 | 23 | 13 | 390 | 387.53 | 309.09 | 180.65 | 127.49 | 15.05 | 328 | 73 | 0 | 91 | 0 |
| 1998 | 0 | 0.11 | 0.4 | 98.7 | 1.91 | 31 | 10 | 325 | 399.53 | 249.42 | 18.07 | 130.23 | 12.14 | 332 | 56 | 0 | 12 | 0 |
| 1999 | 0 | 0.12 | 1 | 57.97 | 1.18 | 76 | 9 | 592 | 507.3 | 348.25 | 195.81 | 176.44 | 12.91 | 353 | 85 | 0 | 26 | 0 |
| 2000 | 0 | 0.3 | 0.97 | 75.33 | 2.39 | 56 | 24 | 498 | 568.11 | 362.23 | 89.33 | 155.58 | 13.67 | 431 | 108 | 0 | 7 | 0 |
| 2001 | 0 | 0 | 1.13 | 40.83 | 5.41 | 21 | 62 | 543 | 456.85 | 487.88 | 186.95 | 155.75 | 13.67 | 422 | 70 | 0 | 31 | 0 |
| 2002 | 0 | 0 | 1.87 | 81.52 | 5.84 | 25 | 88 | 592 | 384.56 | 311.93 | 106.5 | 121.94 | 4.69 | 392 | 96 | 0.31 | 41 | 0 |
| 2003 | 0 | 0 | 2.02 | 68 | 3.99 | 31 | 42 | 782 | 476.58 | 355.81 | 16.53 | 228.74 | 5.68 | 348 | 124 | 0.76 | 36 | 0 |
| 2004 | 0 | 0.15 | 1.71 | 53.21 | 3.27 | 64 | 57 | 917 | 491.37 | 406.39 | 22.2 | 133.5 | 0.79 | 530 | 334 | 12.59 | 43 | 0 |
| 2005 | 0 | 1.04 | 2.09 | 33.46 | 1.42 | 36 | 39 | 418 | 587.23 | 301.62 | 48.87 | 154.89 | 42.85 | 388 | 220 | 6.21 | 68 | 0 |
| 2006 | 0 | 0.6 | 2.27 | 45.18 | 1.72 | 99 | 20 | 444 | 736.14 | 251.95 | 7.97 | 177.88 | 5.65 | 380 | 260 | 12.86 | 182 | 0 |
| 2007 | 0 | 0.81 | 2.37 | 43.46 | 0.84 | 57 | 16 | 525 | 801.92 | 205.04 | 33.55 | 243.83 | 14.63 | 344 | 345 | 11.1 | 115 | 0 |
| 2008 | 0 | 0.97 | 2.73 | 32 | 0.6 | 12 | 18 | 334 | 631.79 | 239.13 | 97.12 | 212.49 | 13.69 | 400 | 209 | 8.91 | 161 | 0 |
| 2009 | 0 | 0.8 | 2.94 | 29.61 | 0.7 | 10 | 16 | 316 | 718 | 204.39 | 278.44 | 294.17 | 1.48 | 438 | 214 | 11.95 | 30 | 0 |
| 2010 | 0 | 0.88 | 3.05 | 20.55 | 0.39 | 12 | 13 | 518 | 632.6 | 163.78 | 120.32 | 272 | 19.65 | 550 | 211 | 99.51 | 52 | 0 |
| 2011 | 0 | 0.61 | 2.61 | 17.39 | 0.36 | 36 | 35 | 489 | 469.15 | 131.46 | 47.77 | 162.98 | 11.47 | 520 | 238 | 246.11 | 125 | 0 |
| 2012 | 0 | 0.43 | 2.51 | 21.68 | 0.87 | 63 | 6 | 392 | 521.71 | 185.07 | 9.49 | 229.46 | 1.83 | 488 | 226 | 207.81 | 72 | 0 |
| 2013 | 0 | 0.37 | 3.36 | 29.06 | 0.88 | 116 | 9 | 320 | 554.05 | 98.55 | 47.27 | 344.68 | 9.41 | 478 | 234 | 49.04 | 21 | 0 |
| 2014 | 0 | 0.57 | 3.57 | 16.44 | 0.58 | 98 | 6 | 345 | 578.01 | 199.16 | 7.22 | 263.22 | 3.31 | 925 | 542 | 77.69 | 13 | 0 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | 0 | 0.78 | 4.26 | 13.15 | 0.23 | 147 | 9 | 440 | 465.52 | 85.04 | 2.22 | 334.13 | 11.45 | 1253 | 400 | 72.52 | 10 | 0 |
| 2016 | 0 | 0.99 | 4.03 | 25.69 | 0.23 | 145 | 5 | 360 | 314.43 | 65.55 | 32.52 | 448.29 | 25.68 | 401 | 259 | 76.4 | 14 | 0 |

**Table 3**. Time series of indices of relative abundance from 1975 to 2016 (CPUE of each year relative to average CPUE of whole period) for shortfin mako sharks in the North Pacific Ocean. The available abundance indices were assigned to "surveys" S1 – S9 for use in the assessment model, as defined in Table 1.

| Year | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
|---|---|---|---|---|---|---|---|---|---|
| 1975 | | | | | | | | | 1.05 |
| 1976 | | | | | | | | | 1.30 |
| 1977 | | | | | | | | | 1.20 |
| 1978 | | | | | | | | | 1.25 |
| 1979 | | | | | | | | | 1.14 |
| 1980 | | | | | | | | | 1.24 |
| 1981 | | | | | | | | | 0.93 |
| 1982 | | | | | | | | | 1.00 |
| 1983 | | | | | | | | | 1.07 |
| 1984 | | | | | | | | | 0.98 |
| 1985 | | | | | | | | | 0.77 |
| 1986 | | | | | | | | | 0.93 |
| 1987 | | | | | | | | | 0.71 |
| 1988 | | | | | | | | | 0.81 |
| 1989 | | | | | | | | | 0.86 |
| 1990 | | | | | | | | | 0.82 |
| 1991 | | | | | | | | | 0.90 |
| 1992 | | | | | | | | | 0.90 |
| 1993 | | | | | | | | | 1.05 |
| 1994 | | | | 0.36 | 0.96 | | | | |
| 1995 | | 0.70 | | 0.47 | 0.75 | | | | |
| 1996 | | 0.69 | | 0.49 | 0.60 | | | | |
| 1997 | | 0.82 | | 0.50 | 0.76 | | | | |
| 1998 | | 0.79 | | 0.50 | 0.88 | | | | |
| 1999 | | 0.95 | | 0.66 | 1.15 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2000 | | 0.69 | | 0.67 | 0.81 | | | |
| 2001 | | 0.75 | | 0.55 | 0.95 | | | |
| 2002 | | 0.91 | | 0.50 | 1.27 | | | |
| 2003 | | 0.83 | | 0.72 | 1.07 | | | |
| 2004 | | 0.87 | | 0.68 | 0.95 | | | |
| 2005 | 1.01 | 0.92 | 0.93 | 0.95 | 0.99 | | | |
| 2006 | 1.03 | 0.96 | 1.16 | 1.17 | 1.24 | | 0.78 | 1.27 |
| 2007 | 1.03 | 0.98 | 0.80 | 1.13 | 1.37 | | 0.73 | 0.61 |
| 2008 | 1.06 | 1.01 | 0.47 | 0.99 | 1.07 | | 0.66 | 0.46 |
| 2009 | 0.99 | 0.95 | 0.72 | 1.32 | 0.71 | | 1.03 | 1.39 |
| 2010 | 1.00 | 0.95 | 0.37 | 1.19 | 1.18 | | 1.01 | 0.95 |
| 2011 | 0.99 | 1.04 | 0.85 | 1.63 | 0.66 | 1.19 | 1.02 | 1.03 |
| 2012 | 0.96 | 0.98 | 0.58 | 1.52 | 1.26 | 1.20 | 1.16 | 1.86 |
| 2013 | 1.04 | 1.10 | 1.68 | 1.46 | 0.59 | 1.18 | 1.06 | 0.84 |
| 2014 | 0.98 | 1.17 | 1.86 | 1.64 | 0.87 | 0.64 | 1.53 | 0.86 |
| 2015 | 1.11 | 1.21 | 1.08 | 1.66 | 1.44 | 0.91 | | 0.80 |
| 2016 | 1.09 | 1.19 | 1.45 | 2.13 | 1.36 | 0.85 | | 0.87 |

**Table 4**. Time series of coefficients of variation (CV) from 1975 to 2016 corresponding to indices of relative abundance for shortfin mako sharks in the North Pacific Ocean in Table 3.

| Year | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
|---|---|---|---|---|---|---|---|---|---|
| 1975 | | | | | | | | | 0.10 |
| 1976 | | | | | | | | | 0.13 |
| 1977 | | | | | | | | | 0.12 |
| 1978 | | | | | | | | | 0.12 |
| 1979 | | | | | | | | | 0.11 |
| 1980 | | | | | | | | | 0.12 |
| 1981 | | | | | | | | | 0.09 |
| 1982 | | | | | | | | | 0.10 |
| 1983 | | | | | | | | | 0.10 |
| 1984 | | | | | | | | | 0.09 |
| 1985 | | | | | | | | | 0.07 |
| 1986 | | | | | | | | | 0.09 |
| 1987 | | | | | | | | | 0.07 |
| 1988 | | | | | | | | | 0.08 |
| 1989 | | | | | | | | | 0.08 |
| 1990 | | | | | | | | | 0.08 |
| 1991 | | | | | | | | | 0.09 |
| 1992 | | | | | | | | | 0.09 |
| 1993 | | | | | | | | | 0.10 |
| 1994 | | | | 0.06 | 0.04 | | | | |
| 1995 | | 0.37 | | 0.05 | 0.04 | | | | |
| 1996 | | 0.24 | | 0.05 | 0.04 | | | | |
| 1997 | | 0.22 | | 0.05 | 0.04 | | | | |
| 1998 | | 0.19 | | 0.05 | 0.04 | | | | |
| 1999 | | 0.21 | | 0.05 | 0.07 | | | | |
| 2000 | | 0.18 | | 0.04 | 0.05 | | | | |
| 2001 | | 0.3 | | 0.05 | 0.06 | | | | |
| 2002 | | 0.19 | | 0.05 | 0.05 | | | | |
| 2003 | | 0.14 | | 0.06 | 0.10 | | | | |
| 2004 | | 0.07 | | 0.05 | 0.06 | | | | |
| 2005 | 0.23 | 0.04 | 0.04 | 0.05 | 0.06 | | | | |
| 2006 | 0.11 | 0.16 | 0.03 | 0.05 | 0.05 | | 0.10 | 0.20 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2007 | 0.15 | 0.15 | 0.04 | 0.04 | 0.06 | | 0.08 | 0.16 |
| 2008 | 0.19 | 0.19 | 0.06 | 0.05 | 0.09 | | 0.08 | 0.20 |
| 2009 | 0.24 | 0.18 | 0.08 | 0.05 | 0.11 | | 0.09 | 0.18 |
| 2010 | 0.31 | 0.13 | 0.08 | 0.05 | 0.10 | 0.61 | 0.10 | 0.16 |
| 2011 | 0.23 | 0.09 | 0.06 | 0.06 | 0.15 | 0.90 | 0.12 | 0.19 |
| 2012 | 0.25 | 0.14 | 0.07 | 0.06 | 0.09 | 0.43 | 0.11 | 0.30 |
| 2013 | 0.29 | 0.16 | 0.03 | 0.05 | 0.11 | 0.41 | 0.18 | 0.18 |
| 2014 | 0.28 | 0.1 | 0.05 | 0.08 | 0.05 | 0.47 | 0.17 | 0.18 |
| 2015 | 0.17 | 0.13 | 0.04 | 0.06 | 0.05 | 0.27 | | 0.18 |
| 2016 | 0.14 | 0.11 | 0.03 | 0.06 | 0.10 | 0.36 | | 0.22 |

**Table 5.** Life history inputs for North Pacific shortfin mako sharks used in this assessment.

| **Parameter** | **Value** |
|---|---|
| Natural mortality rates | 0.128 $y^{-1}$ for both male and female and all ages |
| Reference age (a1) | 1 |
| Maximum age (a2) | 31 |
| Length at a1 (L1) | 60 (Female) |
| | 60 (Male) |
| Length at a2 (L2) | 293.1 (Female) |
| | 232.8 (Male) |
| Growth rate (K) | 0.128 (Female) |
| | 0.174 (Male) |
| CV of L1 | 0.1 (Female); 0.1 (Male) |
| CV of L2 | 0.1 (Female); 0.1 (Male) |
| Weight-at-length | $W=4.62 \times 10^{-5}L^{2.77}$ (Female) |
| | $W=3.40 \times 10^{-5}L^{2.84}$ (Male) |
| Length-at-50% Maturity | 233.65 cm PCL (Female) |
| Slope of maturity ogive | - 0.34 (Female) |
| Fecundity | Fixed at 12 pups per litter based on a two-year reproductive cycle (i.e., 6 pups per year) |
| Breeding periodicity | 2 years |
| Spawner-recruit steepness (BH) | $h$ = 0.317 |

| | |
|---|---|
| Log of Recruitment at virgin biomass log(R0) | Estimated (initial value 7.05) |
| Recruitment variability ($\sigma_R$) | Fixed at 0.1 |
| Main recruitment deviations | 1975-2016 |

**Table 6.** Root-mean-square-errors (RMSE), and standard deviations of the normalized residuals (SDNR) for the relative abundance indices used in the SS model.

| Index | RMSE | SDNR | $\chi^2$ |
|---|---|---|---|
| S1_US_SS | 0.05 | 0.454 | 1.337 |
| S3_TW_LRG | 0.46 | 1.182 | 1.059 |
| S5_JPN_RTV | 0.29 | 0.830 | 1.241 |
| S8_MEX | 0.31 | 1.218 | 1.353 |
| S_JPN_SS_I | 0.11 | 0.751 | 1.258 |

**Table 7**. Estimates of catch, biomass and spawning abundance (SA; number of mature female sharks), recruitment, and fishing intensity (1-SPR) estimated in the base case model from 1975 to 2016.

| Year | Estimated catch (mt) | Spawning abundance (1000s) | Number of recruits (1000s) | 1-SPR |
|---|---|---|---|---|
| 1975 | 2774.7 | 1031.3 | 1254.3 | 0.14 |
| 1976 | 3407.5 | 1031.4 | 1249.2 | 0.17 |
| 1977 | 3892.4 | 1031.3 | 1241.4 | 0.19 |
| 1978 | 3685.5 | 1030.8 | 1232.5 | 0.18 |
| 1979 | 4046.8 | 1030.2 | 1225.0 | 0.19 |
| 1980 | 4289.3 | 1028.8 | 1223.2 | 0.21 |
| 1981 | 7384.5 | 1026.3 | 1219.2 | 0.35 |
| 1982 | 6629.6 | 1022.2 | 1206.4 | 0.35 |
| 1983 | 6243.3 | 1017.4 | 1194.7 | 0.34 |
| 1984 | 5842.0 | 1011.0 | 1190.5 | 0.32 |
| 1985 | 5734.4 | 1002.8 | 1189.7 | 0.32 |
| 1986 | 5675.3 | 991.9 | 1194.3 | 0.33 |
| 1987 | 6015.4 | 978.9 | 1198.1 | 0.35 |
| 1988 | 5863.2 | 963.1 | 1194.5 | 0.34 |
| 1989 | 6990.9 | 945.6 | 1186.0 | 0.40 |
| 1990 | 4689.3 | 927.7 | 1168.0 | 0.29 |
| 1991 | 4584.2 | 910.1 | 1125.5 | 0.28 |
| 1992 | 3731.7 | 893.0 | 1072.0 | 0.23 |
| 1993 | 2436.6 | 876.7 | 1069.1 | 0.15 |
| 1994 | 2266.6 | 861.5 | 1065.7 | 0.12 |
| 1995 | 2290.6 | 848.2 | 1053.9 | 0.12 |
| 1996 | 2633.6 | 837.7 | 1102.9 | 0.15 |
| 1997 | 2212.5 | 830.6 | 1069.5 | 0.13 |
| 1998 | 2238.7 | 827.1 | 1009.1 | 0.11 |
| 1999 | 2507.5 | 826.7 | 1130.7 | 0.15 |
| 2000 | 2488.9 | 828.3 | 1116.0 | 0.15 |
| 2001 | 2662.8 | 831.0 | 1148.2 | 0.15 |
| 2002 | 2454.9 | 833.9 | 1093.2 | 0.14 |
| 2003 | 2685.6 | 837.1 | 1070.9 | 0.15 |
| 2004 | 2911.2 | 840.0 | 1069.2 | 0.19 |
| 2005 | 2480.1 | 842.5 | 1103.5 | 0.15 |
| 2006 | 2762.2 | 844.8 | 1051.1 | 0.16 |
| 2007 | 2882.4 | 847.3 | 1020.6 | 0.17 |

| | | | | |
|---|---|---|---|---|
| 2008 | 2506.5 | 850.4 | 1112.8 | 0.15 |
| 2009 | 2704.6 | 853.7 | 1153.6 | 0.16 |
| 2010 | 2824.6 | 856.8 | 1152.3 | 0.17 |
| 2011 | 2646.1 | 858.9 | 1099.0 | 0.16 |
| 2012 | 2545.0 | 860.0 | 1169.0 | 0.15 |
| 2013 | 2329.1 | 860.4 | 1151.8 | 0.13 |
| 2014 | 2460.3 | 860.3 | 1141.7 | 0.17 |
| 2015 | 2519.9 | 859.9 | 1087.9 | 0.19 |
| 2016 | 2346.8 | 860.2 | 1122.0 | 0.14 |

**Table 8**. Estimated reference points for the base case model.

| Reference points | Symbol | Estimate (CV) | Units |
| --- | --- | --- | --- |
| **Unfished conditions** | | | |
| Spawning abundance (number of mature female sharks) | $SA_0$ | 1465.8 (23.3%) | 1000s of sharks |
| Recruitment at age-0 | $R_0$ | 1520.4 (23.3%) | 1000s of sharks |
| **MSY-based reference points** | | | |
| Maximum Sustainable Yield (MSY) | $C_{MSY}$ | 3127.1 (22.2%) | Metric tons |
| Spawning abundance at MSY | $SA_{MSY}$ | 633.7 (23.3%) | 1000s of sharks |
| Fishing intensity at MSY | $1\text{-}SPR_{MSY}$ | 0.26 | NA |

**Table 9.** Estimates of key management quantities for shortfin mako sharks in the North Pacific Ocean in the base case model and sensitivity analysis.

| | $\frac{SA_{2016}}{SA_0}$ | $\frac{SA_{2016}}{SA_{MSY}}$ | $\frac{1-SPR_{2013-2015}}{1-SPR_{MSY}}$ | **Description** |
|---|---|---|---|---|
| | 0.58 | 1.36 | 0.62 | Base case model |
| Sensitivity model | | | | **Uncertainty in catch estimates** |
| 1 | 0.51 | 1.16 | 0.66 | 50% higher catches in 1975-1993 and 20% higher catches in 1994-2016 |
| 2 | 0.53 | 1.22 | 0.59 | 50% higher catches in 1975-1993 and 20% lower catches in 1994-2016 |
| 3 | 0.58 | 1.34 | 0.52 | 50% lower catches in 1975-1993 and 20% lower catches in 1994-2016 |
| 4 | 0.70 | 1.52 | 0.63 | 50% lower catches in 1975-1993 and 20% higher catches in 1994-2016 |
| 5 | 0.52 | 1.21 | 0.64 | Status quo catches in 1975-1993 and 20% higher catches in 1994-2016 |
| 6 | 0.51 | 1.27 | 0.57 | Status quo catches in 1975-1993 and 20% lower catches in 1994-2016 |
| 7 | 0.51 | 1.20 | 0.63 | 50% higher catches in 1975-1993 and status quo catches in 1994-2016 |
| 8 | 0.64 | 1.32 | 0.58 | 50% lower catches in 1975-1993 and status quo catches in 1994-2016 |
| 9 | 0.61 | 1.40 | 0.61 | Initial equilibrium catch of F9_JPN_SS was freely estimated from the data |
| 10 | 0.68 | 1.57 | 0.68 | Average CV of Japan shallow-set CPUE index (S9_JPN_SS_I; 1975-1993) is 0.3 |
| | | | | **Alternative CPUE indices** |
| 11 | 0.51 | 1.20 | 0.74 | S9_JPN_SS_I + S1_US_SS |
| 12 | 0.53 | 1.23 | 0.71 | S9_JPN_SS_I + S3_TWN_LRG |
| 13 | 0.61 | 1.42 | 0.58 | S9_JPN_SS_I + S5_JPN_RTV |
| 14 | 0.50 | 1.16 | 0.81 | S9_JPN_SS_I + S8_MEX |
| | | | | **Biology** |
| 15 | 0.61 | 1.36 | 0.58 | Reproductive cycle assumed to be three years |
| 16 | 0.66 | 1.53 | 0.73 | A low fecundity stock recruitment (LFSR) relationship was used to characterize productivity |
| 17 | 0.72 | 1.67 | 0.42 | Alternative growth curve produced using only age and growth data provided by Taiwan |
| 18 | 0.65 | 1.53 | 0.55 | Natural mortality and $h$ similar to those used in the 2017 ICCAT North Atlantic shortfin mako shark stock assessment |
| 19 | 0.59 | 1.26 | 0.60 | Beverton-Holt model ($h$ - 1SD = 0.260) |
| 20 | 0.64 | 1.59 | 0.47 | Beverton-Holt model ($h$ + 1SD = 0.372) |

**Table 10**. Summary of reference points and management quantities for the base case and six alternative states of nature: Alternative_1) higher catch, Alternative_2) lower catch; Alternative_3) higher uncertainty on Japan shallow-set CPUE index (1975-1993) (CV=0.3); Alternative_4) fit to Japan longline shallow-set fleets (S9_JPN_SS_I; 1975-1993) and Hawaii longline shallow-set fleet (S1_US_SS; 2005-2016), and no fit to initial equilibrium catch; Alternative_5) low steepness, h=0.260; and Alternative_6) high steepness, h=0.372. Values in parentheses represents the coefficient of variation (CV) when available.

| **Reference points** | **Symbol** | **Units** | **Base-case** | **Alternative_1** | **Alternative_2** | **Alternative_3** | **Alternative_4** | **Alternative_5** | **Alternative_6** |
|---|---|---|---|---|---|---|---|---|---|
| Spawning abundance (number of mature female sharks) | $SA_0$ | 1000s of sharks | 1465.8 (23.3%) | 1898.8 (14.6%) | 826.8 (27.5%) | 1240.6 (70%) | 1727.6 (32%) | 2366.5 (30%) | 1327.1 (32%) |
| Maximum Sustainable Yield (MSY) | $C_{MSY}$ | Metric tons | 3127.1 (22.2%) | 3951.8 (13.0%) | 1725.4 (26%) | 2558.2 (68%) | 3175.3 (31%) | 2731 (29%) | 3759 (28%) |
| Spawning abundance at MSY | $SA_{MSY}$ | 1000s of sharks | 633.7 (23.3%) | 821.3 (14.1%) | 371.5 (27%) | 536.6 (70%) | 759 (32%) | 1095 (30%) | 539.8 (30%) |
| Fishing intensity at MSY | $1\text{-}SPR_{MSY}$ | NA | 0.26 | 0.26 | 0.26 | 0.26 | 0.24 | 0.16 | 0.34 |
| Current spawning abundance relative to MSY | $SA_{2016}/SA_{MSY}$ | NA | 1.36 | 1.16 | 1.34 | 1.57 | 1.40 | 1.26 | 1.59 |
| Current spawning abundance relative to unfished level | $SA_{2016}/SA_0$ | NA | 0.58 | 0.51 | 0.58 | 0.68 | 0.61 | 0.59 | 0.64 |
| Recent fishing intensity relative to MSY | $\frac{1-SPR_{2013-2015}}{1-SPR_{MSY}}$ | NA | 0.62 | 0.66 | 0.53 | 0.68 | 0.57 | 0.69 | 0.47 |

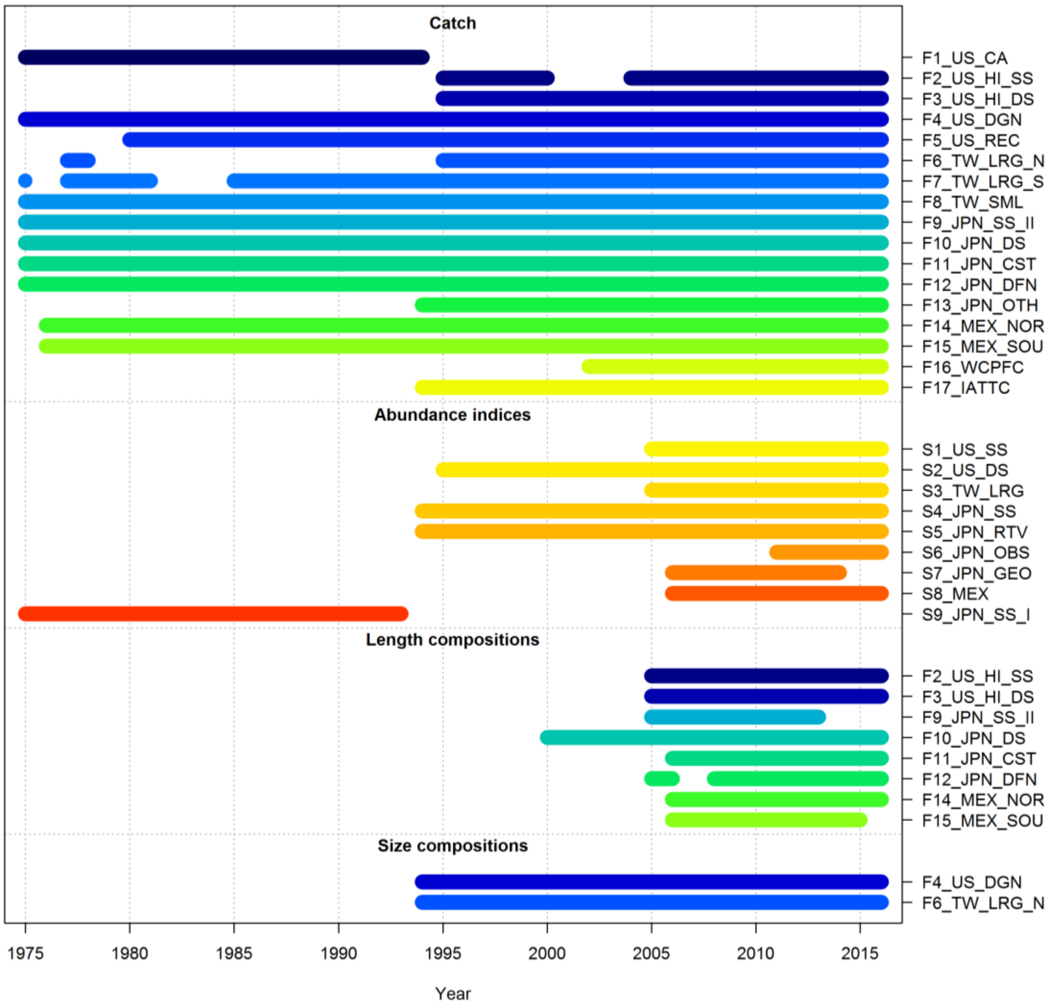


**Figure 1**. Time series of catch, relative abundance, and length composition data of shortfin mako sharks in the North Pacific Ocean available for this stock assessment. See Table 1 for the reference of the fleet's name.

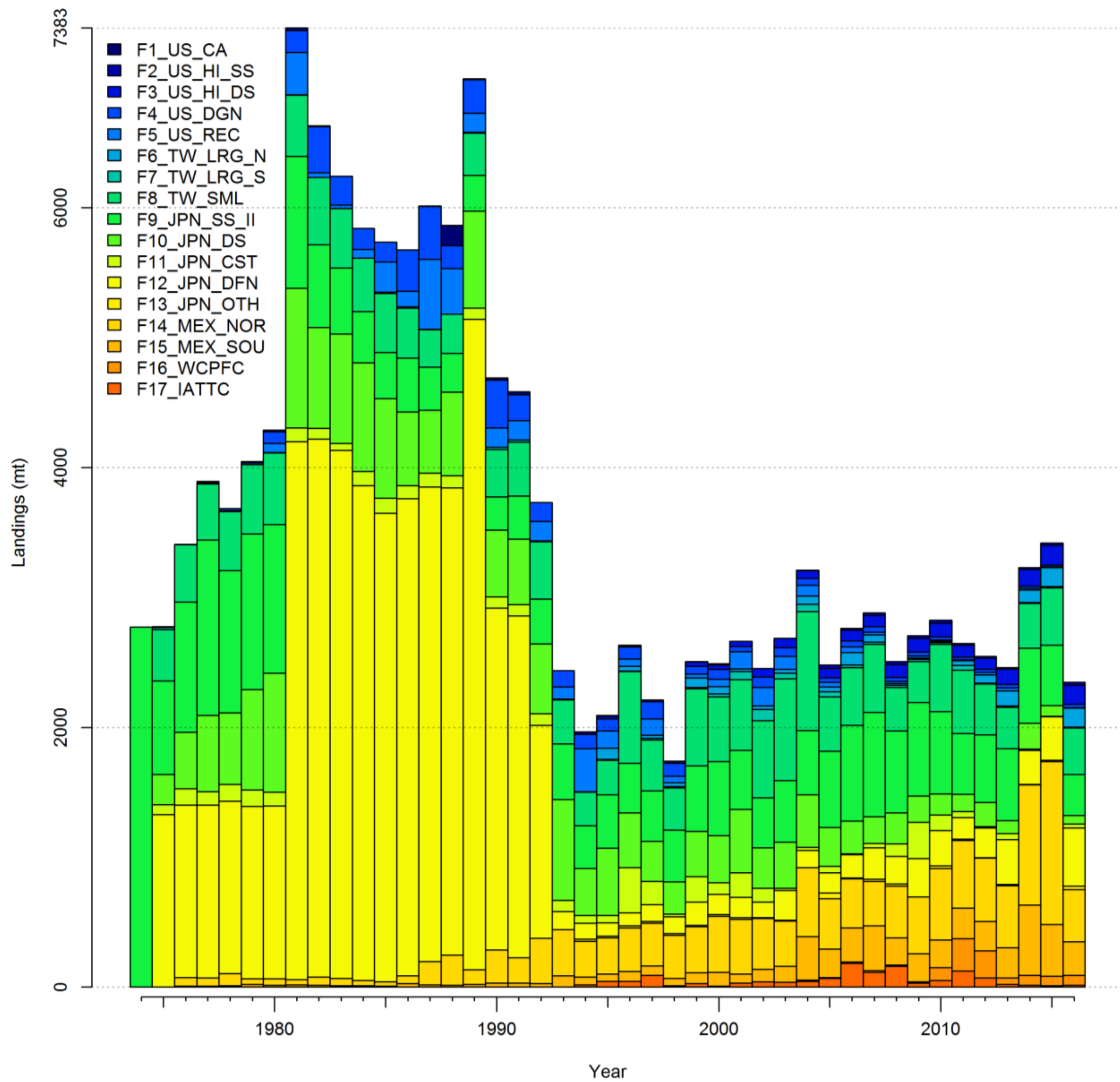


**Figure 2.** Catches by fishery (fleet) from 1975 to 2016. Note: Catch in 1974 is an assumed level of catch used to derive equilibrium conditions (i.e., initial equilibrium catch). See Table 1 for the reference of the fleet's name.

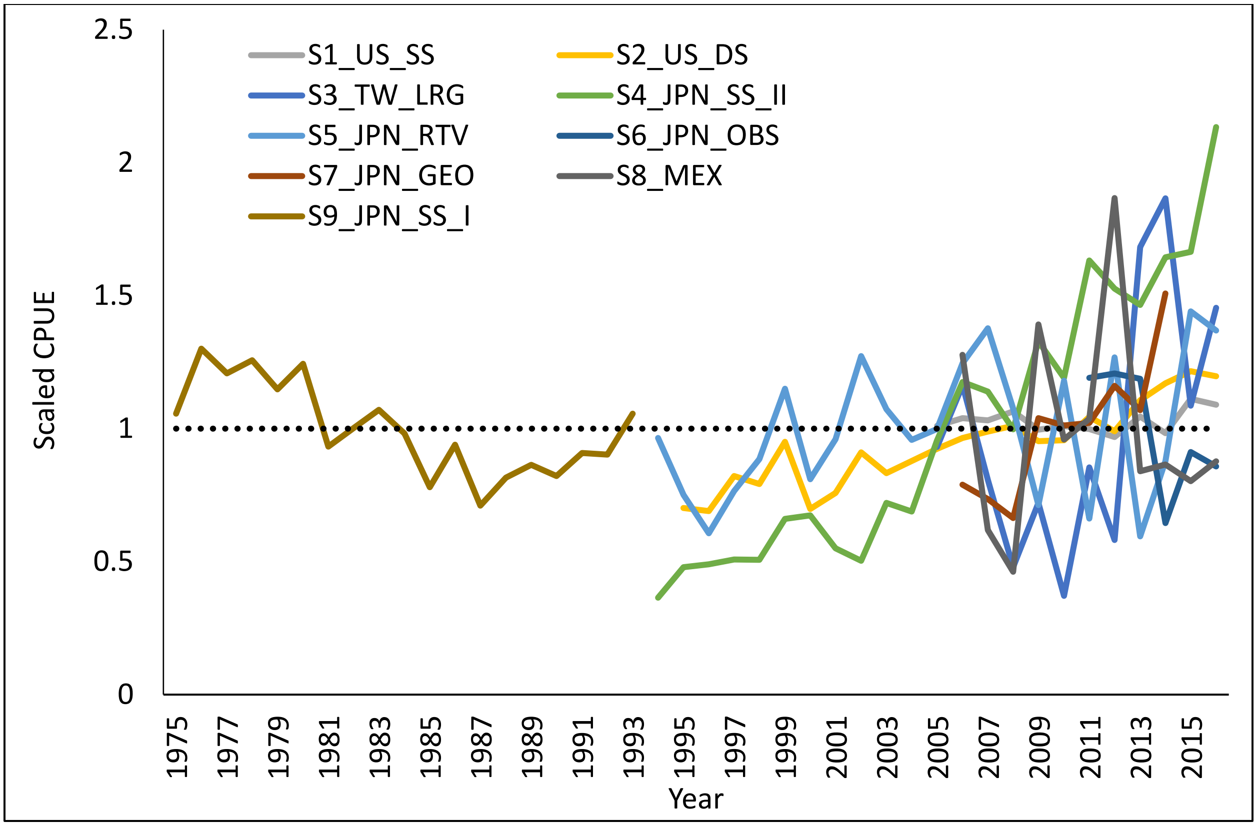


**Figure 3.** Yearly changes in standardized CPUE of shortfin mako sharks in the North Pacific Ocean (1975-2016). All indices are normalized to a mean value of one (horizontal dotted line). See Table 1 for the reference of the fleet's name. The CPUE series used in the base case model were: S1_US_SS, S3_TWN_LRG, S5_JPN_RTV, S8_MEX, and S9_JPN_SS_I.

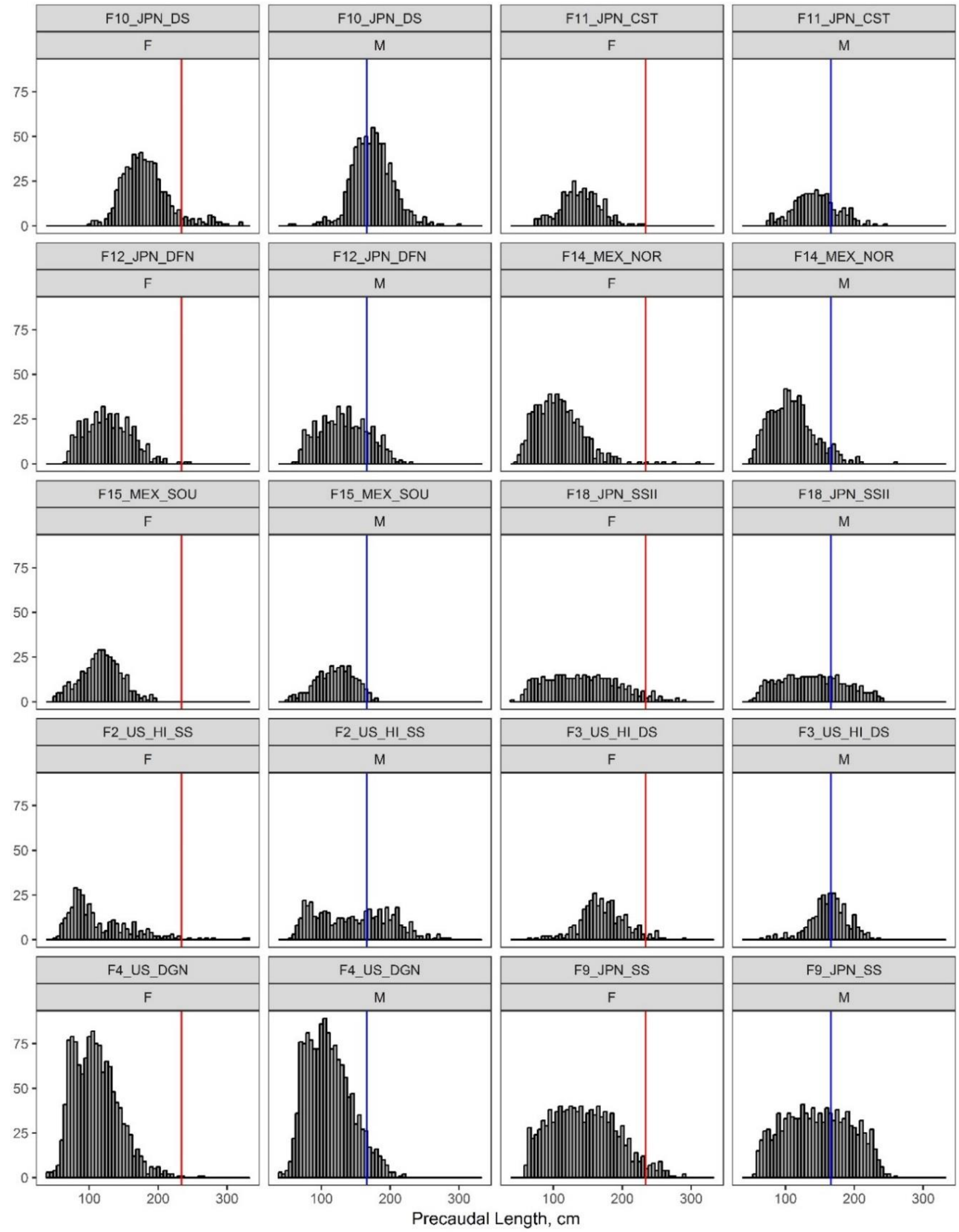


**Figure 4.** Frequency of sex-specific size data (Pre-caudal length; PCL in cm) by fleet. Colored solid vertical lines indicate size-at-50% maturity. F and M denotes female and male, respectively. See Table 1 for the reference of the fleet's name.

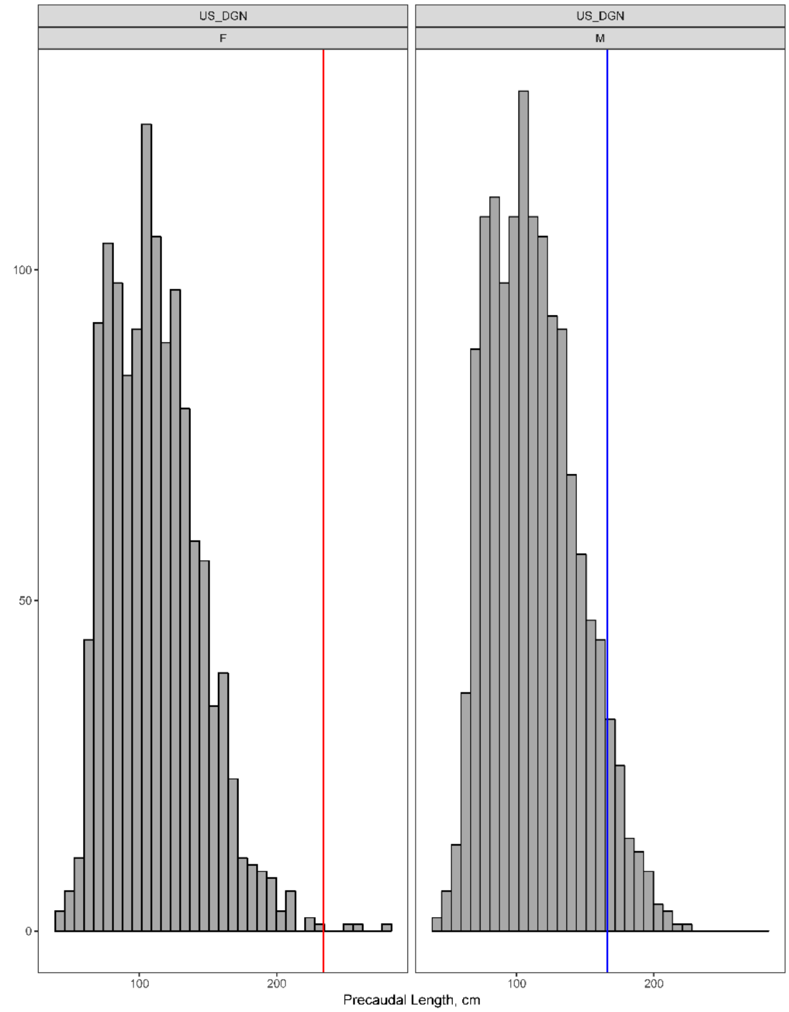


**Figure 5.** Frequency of sex-specific size data (Pre-caudal length; PCL in cm) for F4_US_DGN. Colored solid vertical lines indicate size-at-50% maturity. F and M denotes female and male, respectively.

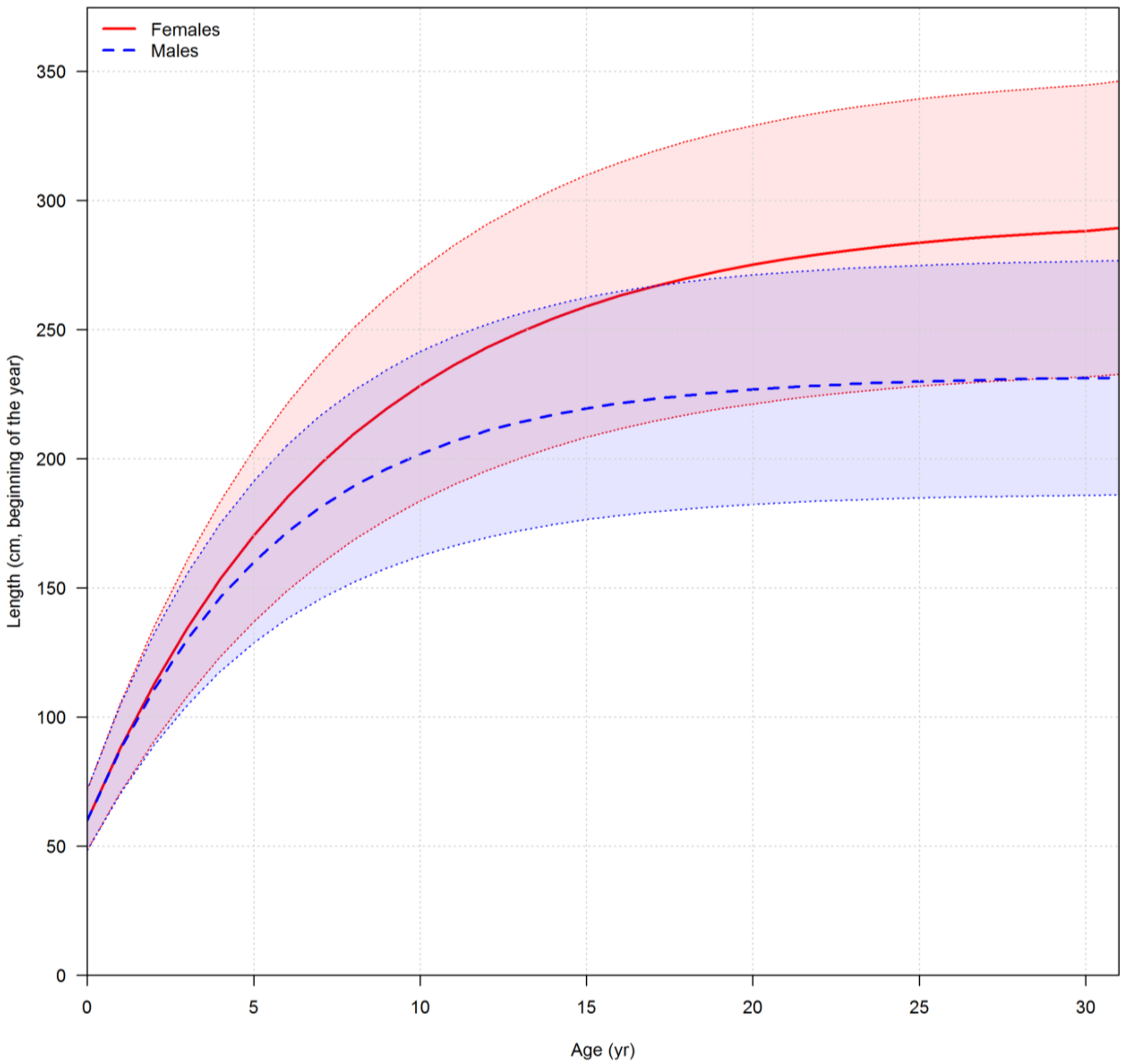


**Figure 6**. Sex-specific growth curves of shortfin mako sharks in the North Pacific Ocean assumed in the base case model. Shaded area represents 95% confidence intervals. Length is in pre-caudal length (PCL in cm).

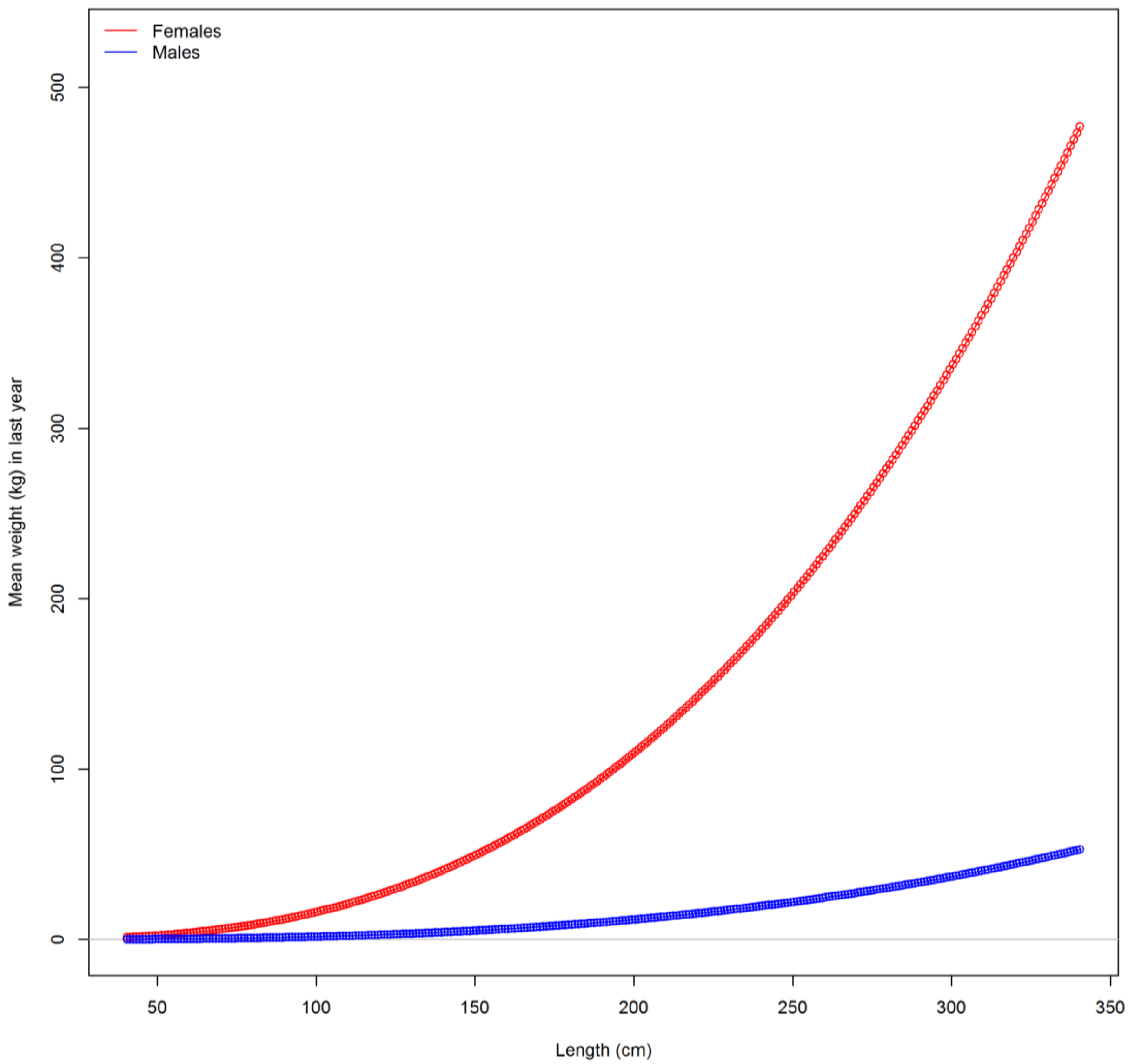


**Figure 7.** Sex-specific whole weight (kg)-at-length (PCL in cm) of shortfin mako sharks in the North Pacific Ocean assumed in the base case model.

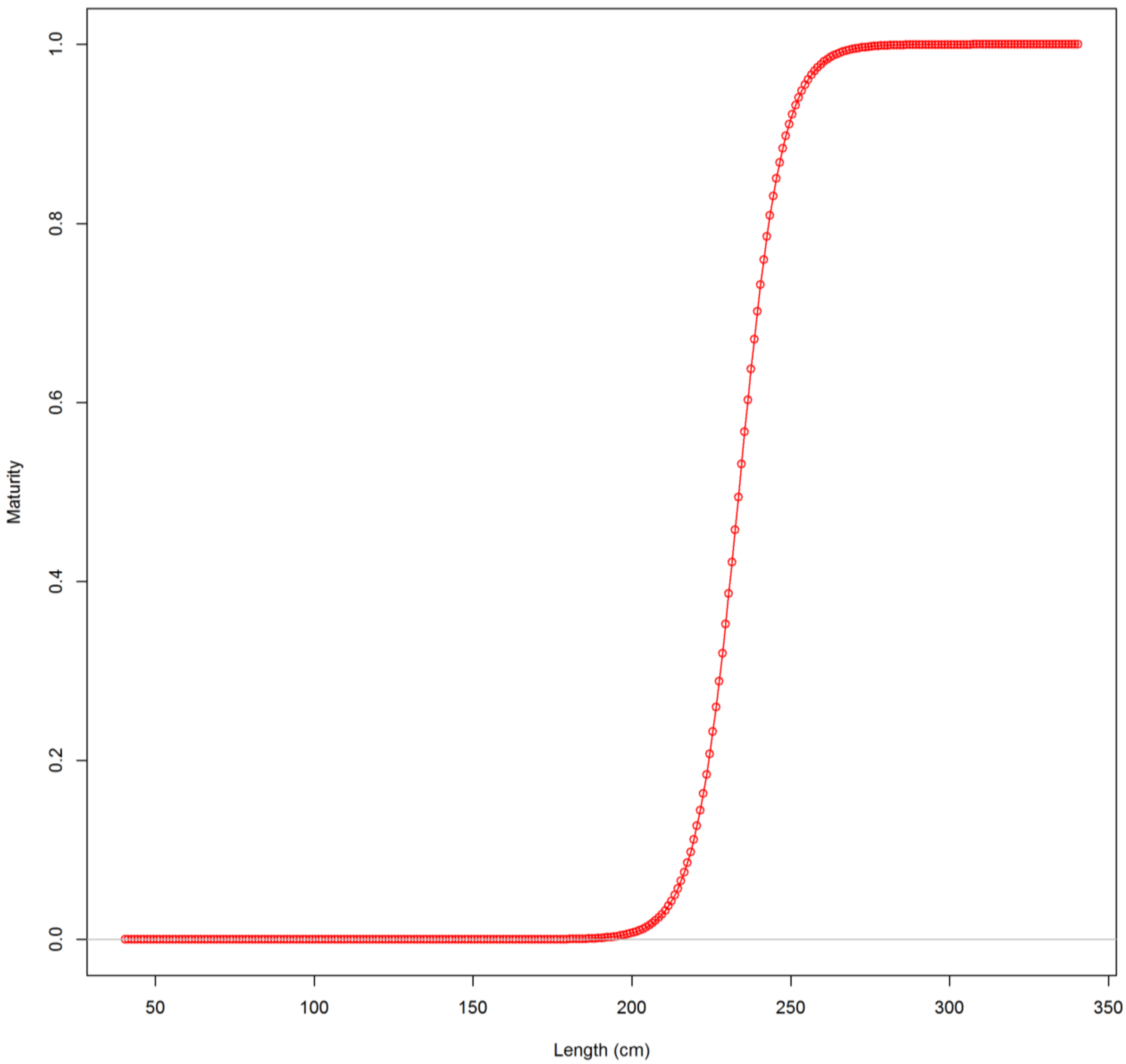


**Figure 8.** Logistic maturity schedule (Maturity rate against length in pre-caudal length) of female shortfin mako sharks in the North Pacific Ocean assumed in the base case model.

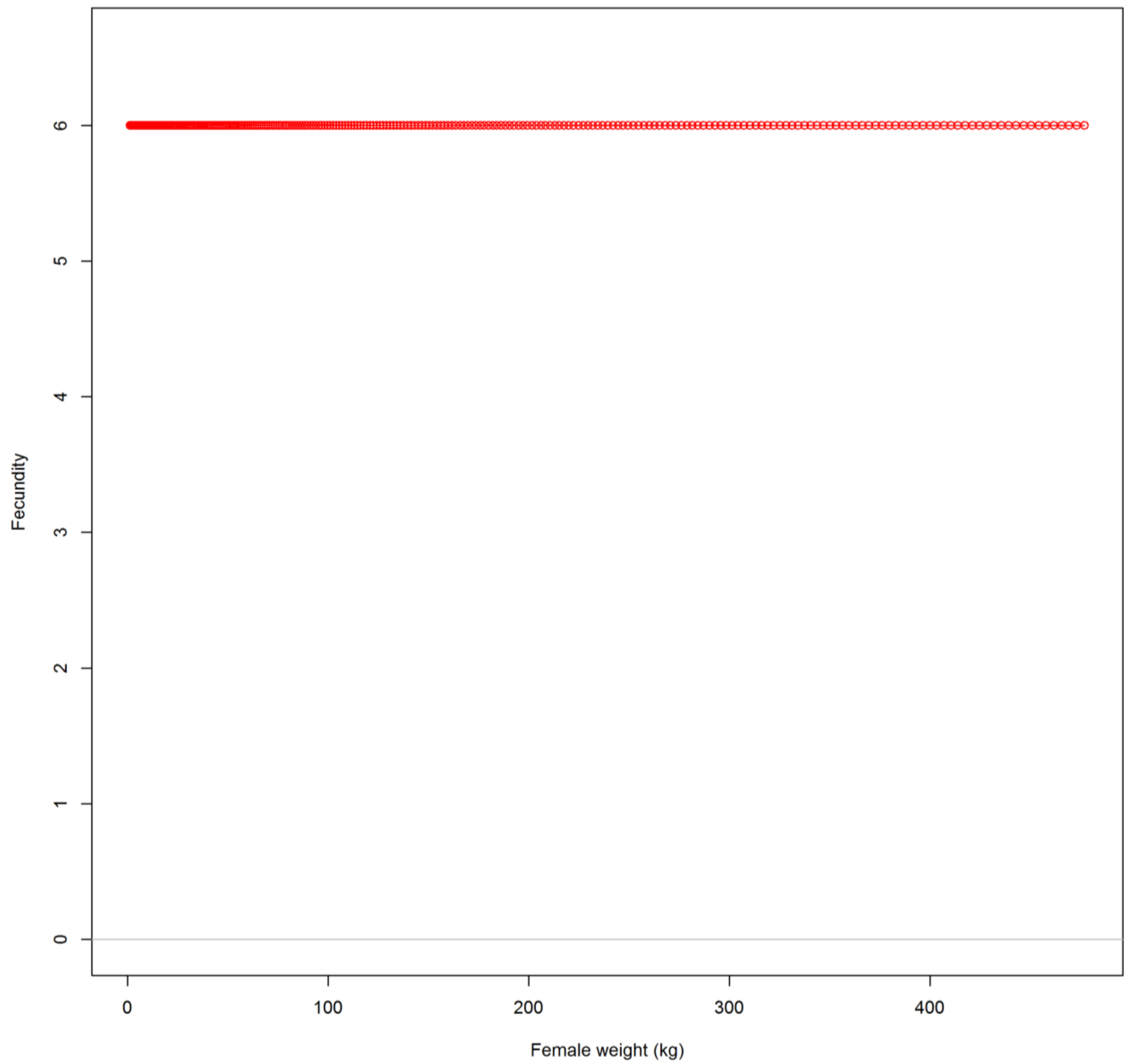


**Figure 9.** Annual pup production (number of fecundity) of shortfin mako sharks in the North Pacific Ocean assumed in the base case model.

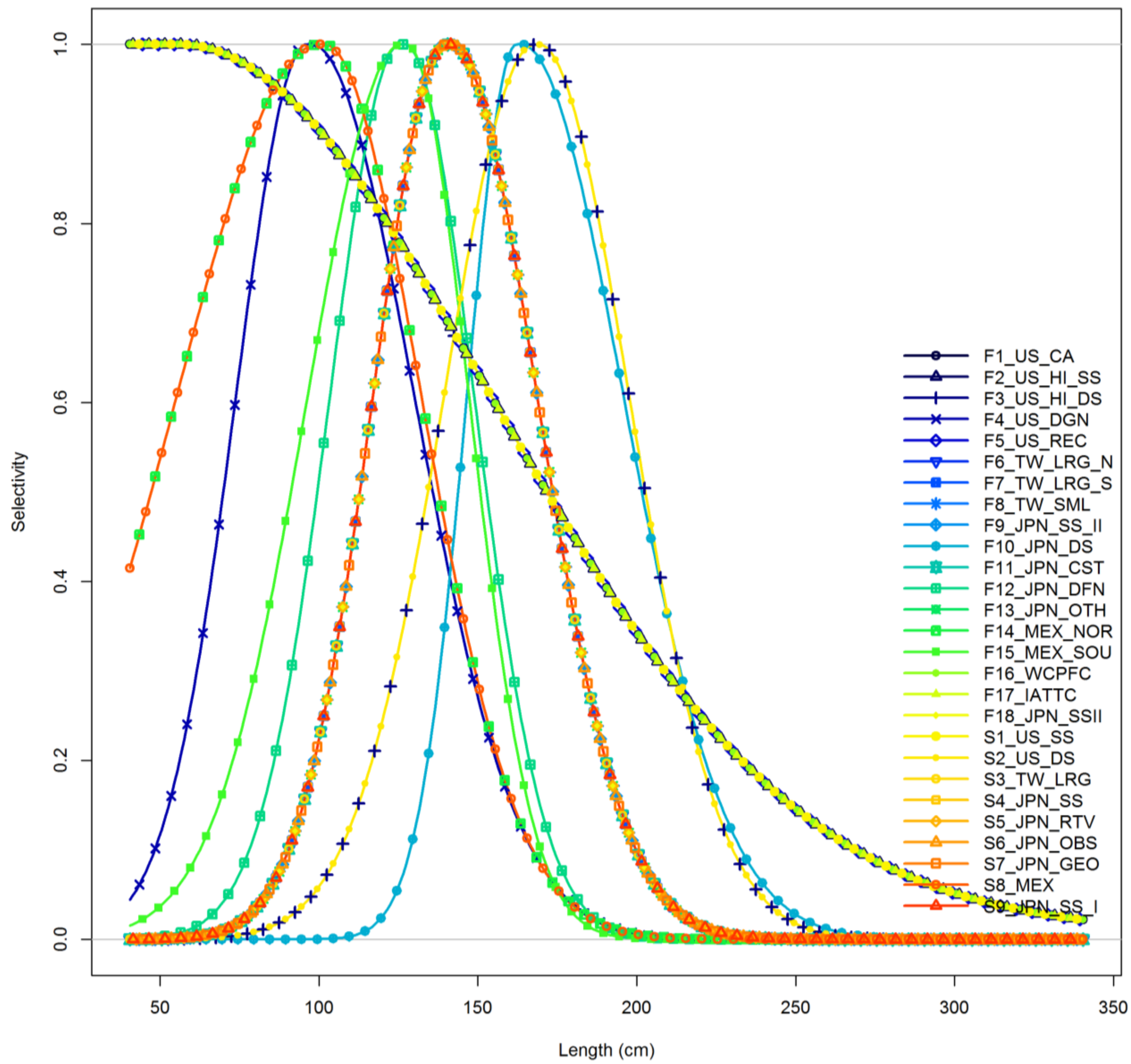


**Figure 10.** Selectivity at length (pre-caudal length in cm) based on fit to length composition data of shortfin mako sharks in the North Pacific Ocean estimated in the base case model. See Table 1 for the reference of the fleet's name.

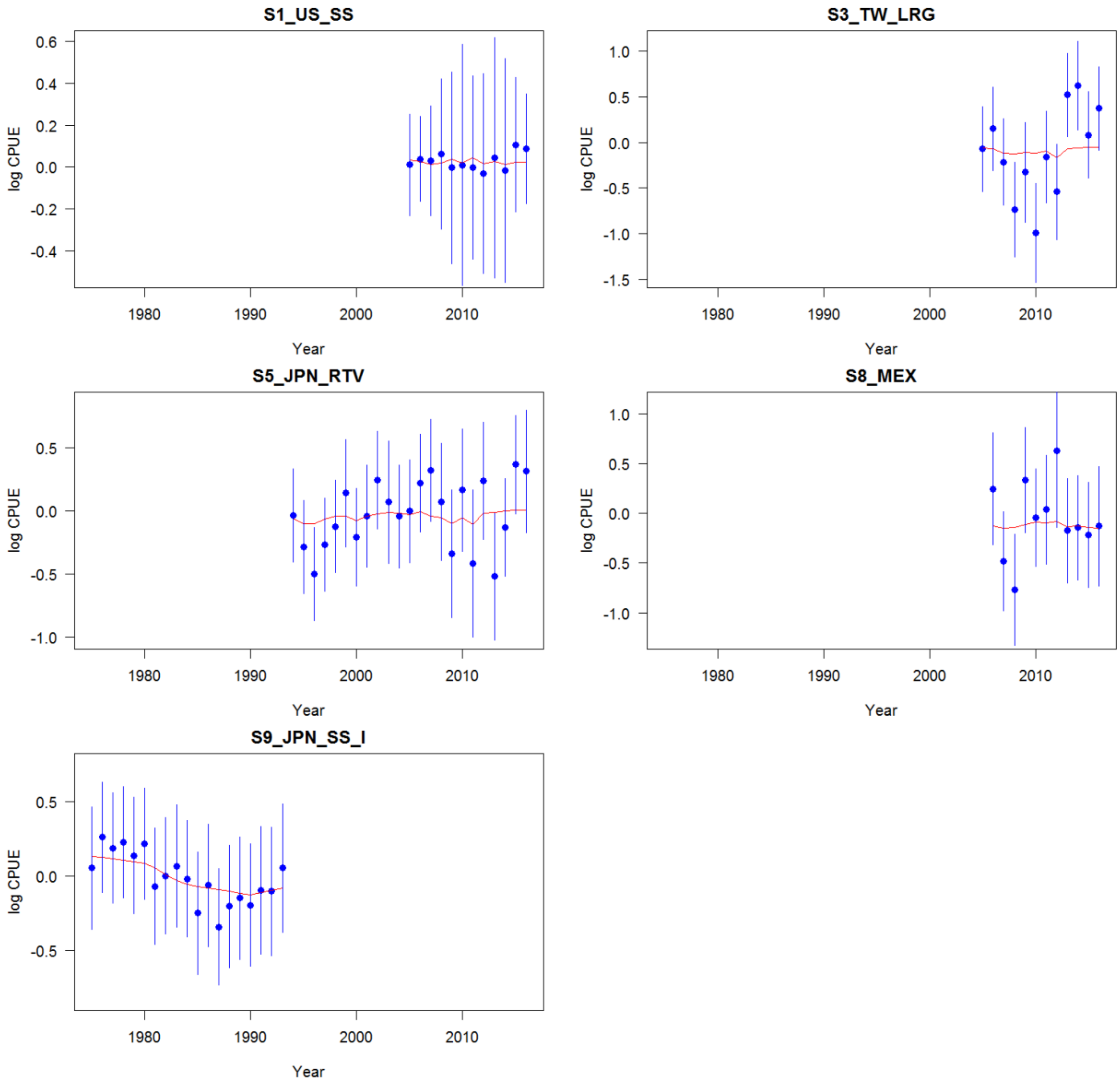


**Figure 11**. Model fits to the standardized catch-per-unit-effort (CPUE) (in log scale) data sets from different fleets in the base case model. Solid red line denotes the model predicted value and Solid circles denote observed data values. Vertical blue lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. See Table 1 for the reference of the fleet's name.

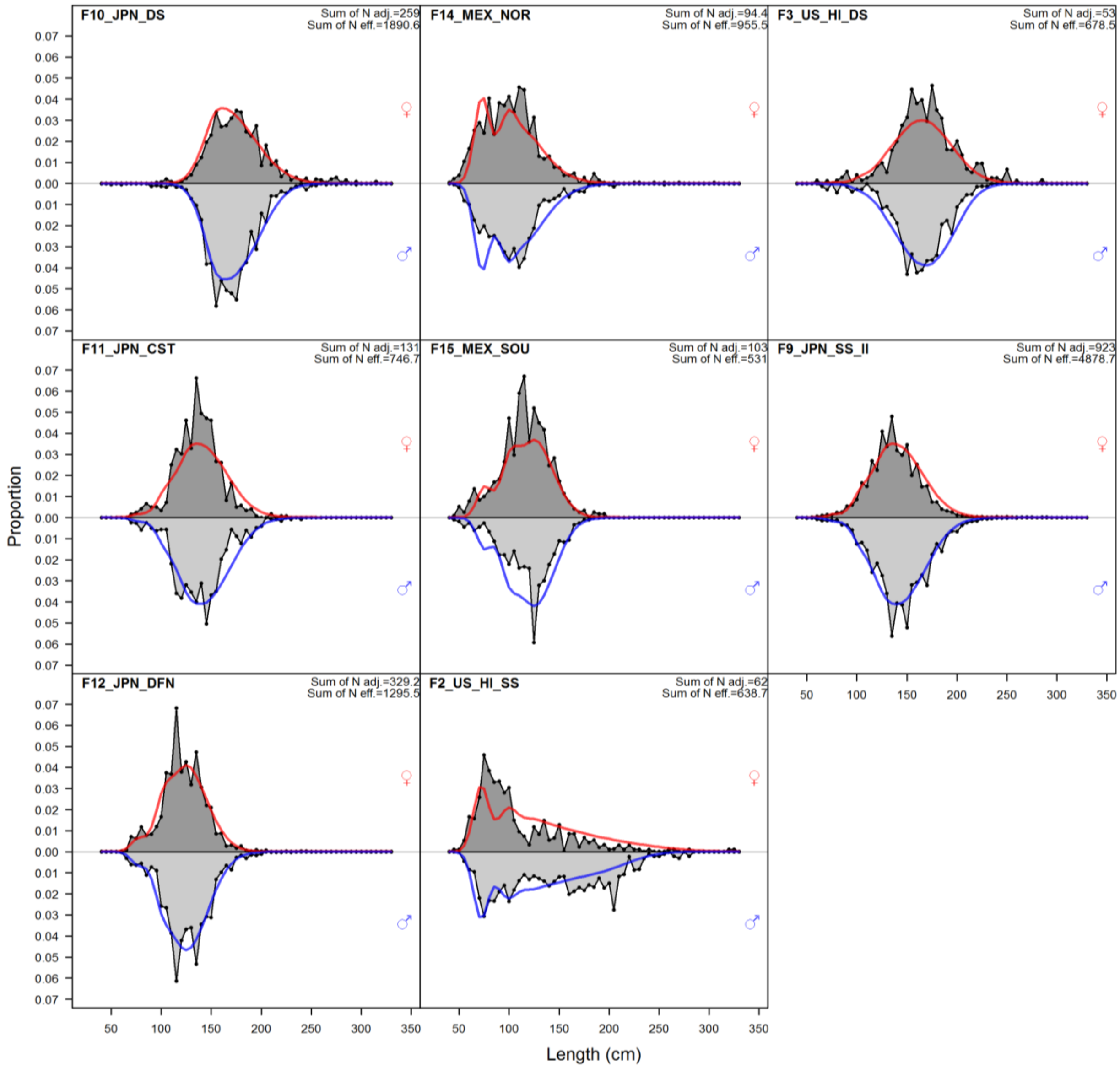


**Figure 12.** Sex specific comparison of observed (gray shaded area) and model predicted (colored solid lines; blue=male and red=female) length compositions (pre-caudal length in cm) for different fleets in the base case model. See Table 1 for the reference of the fleet's name.

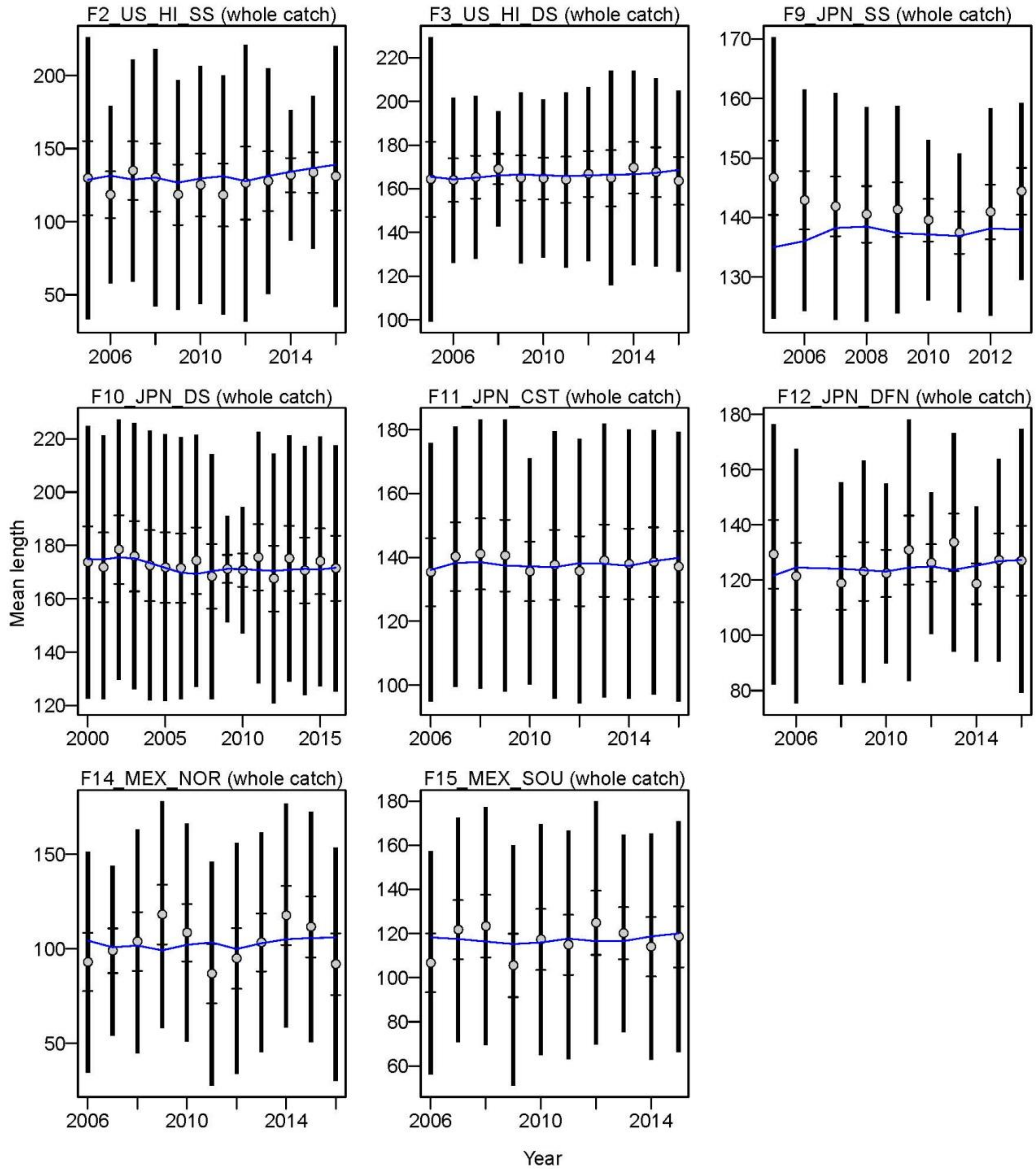


**Figure 13.** Model fit (blue solid lines) to mean observed length (pre-caudal length in cm) of the composition data for the base case model. The vertical black solid lines are 95% credible limits around mean length. See Table 1 for the reference of the fleet's name.

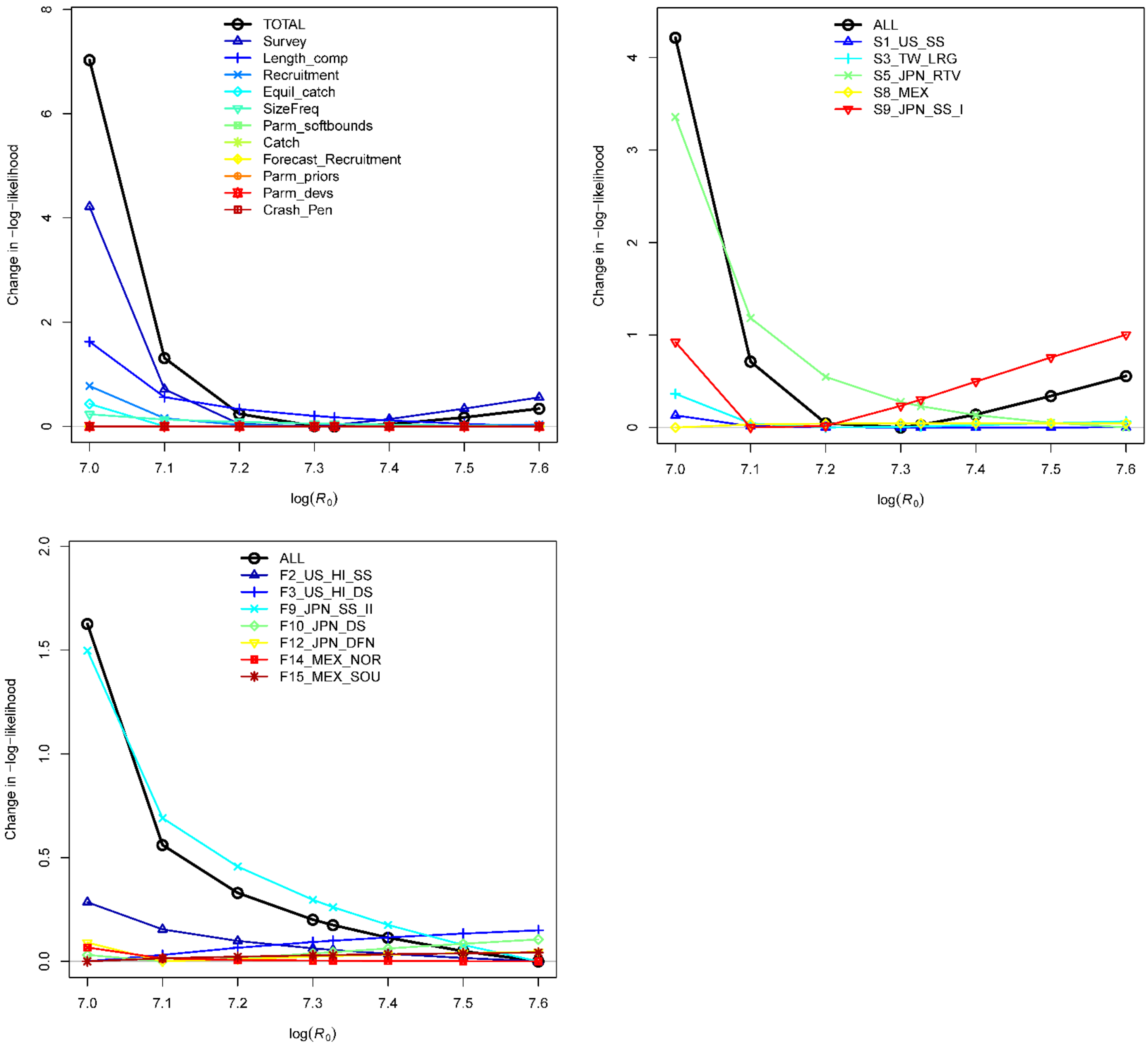


**Figure 14.** Likelihood profiles with respect to virgin recruitment on logscale; log ($R_0$) for the main data components (upper left), abundance indices (upper right), and length compositions (lower left) in the base case model. See Table 1 for the reference of the fleet's name.

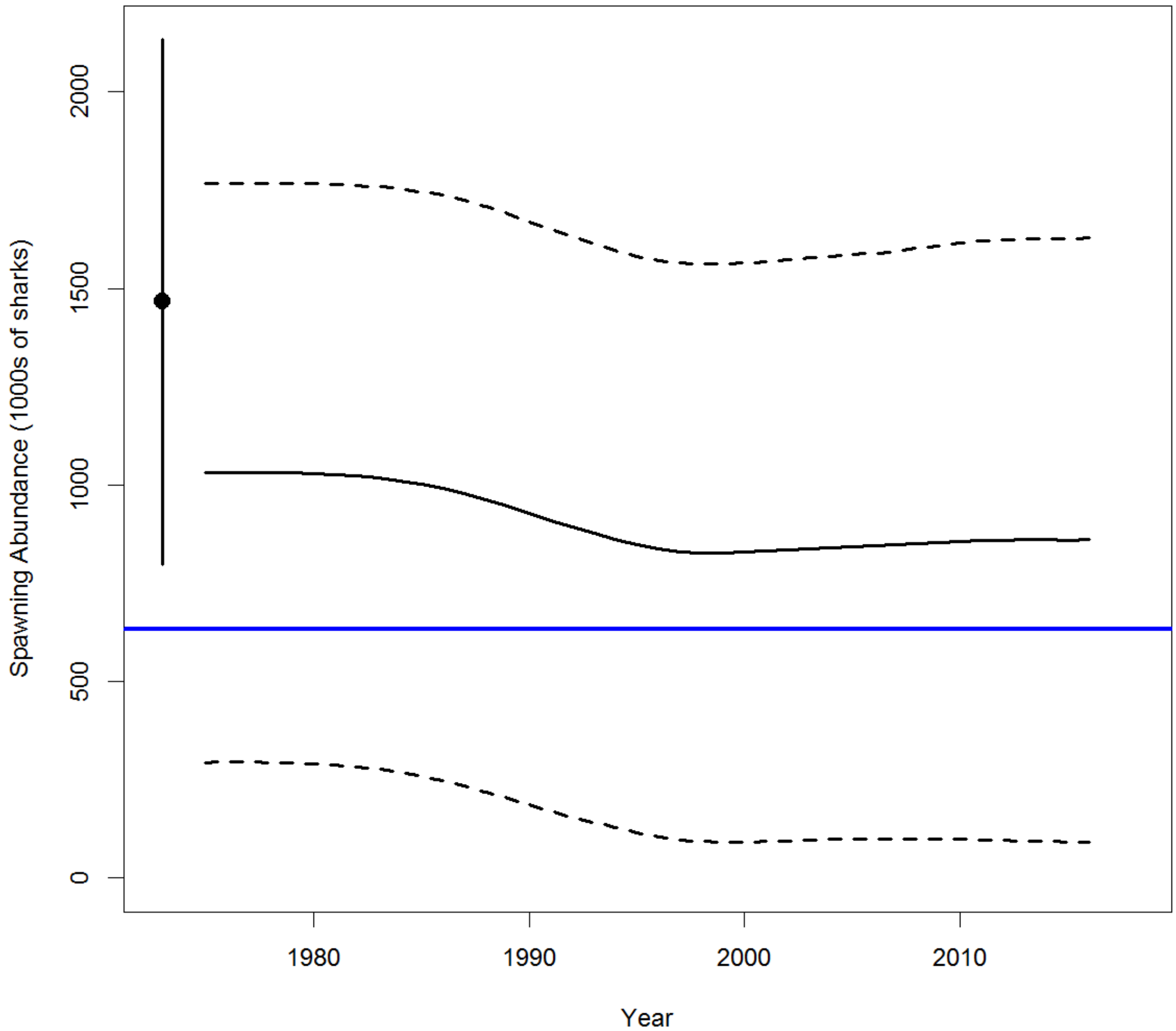


**Figure 15.** Yearly changes in the estimated spawning abundance (SA; number of mature female sharks) of shortfin mako sharks in the North Pacific Ocean during the modeling period (1975-2016). Dashed lines indicate 95% confidence intervals; the closed circle and error bars indicate the estimated SA and 95% confidence intervals under unfished conditions ($SA_0$). Blue solid line indicates the estimate of SA at maximum sustainable yield (MSY) ($SA_{MSY}$).

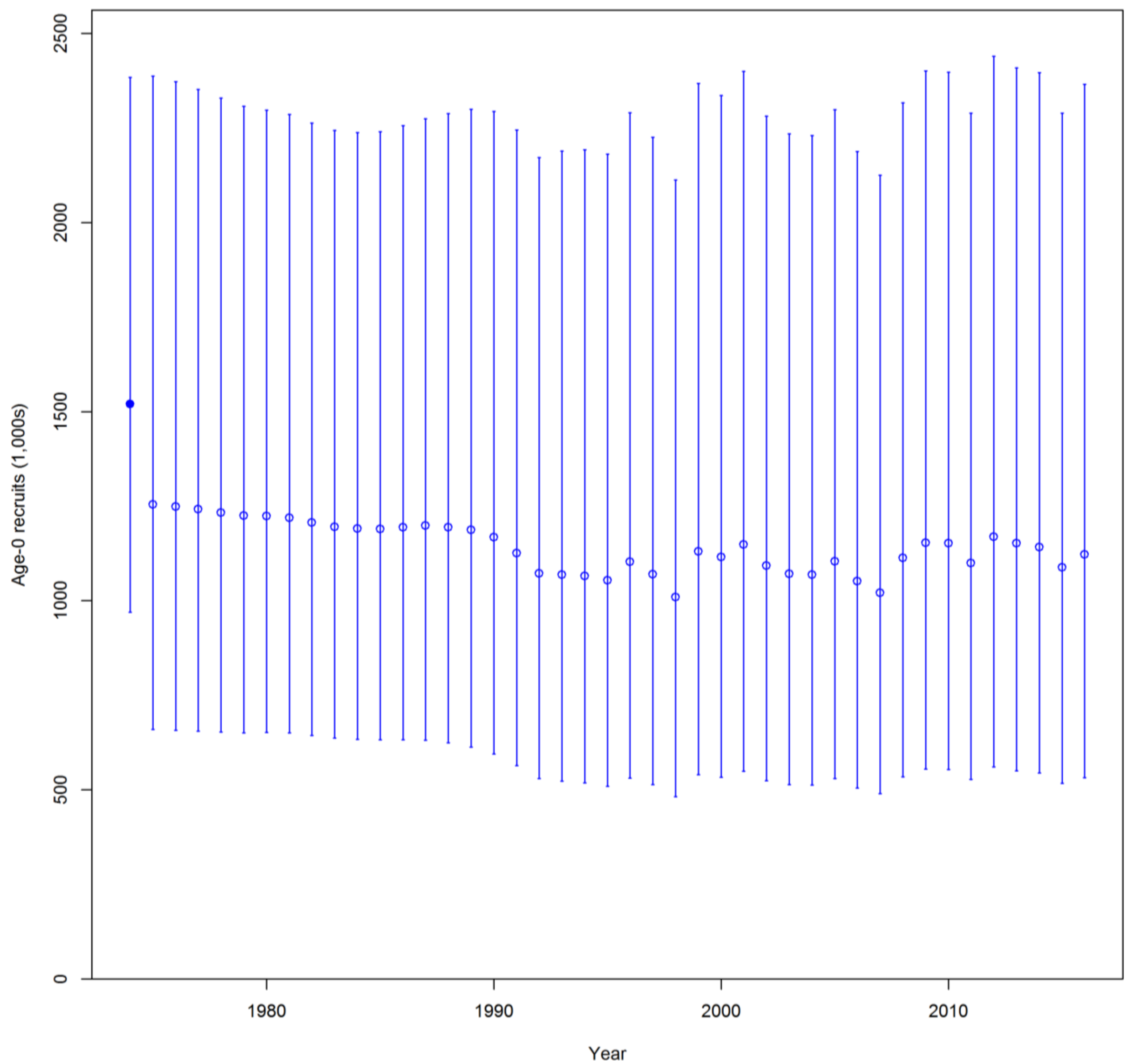


**Figure 16.** Yearly changes in the estimated age-0 recruitment in the base case model. Error bars indicate the 95% confidence intervals; and closed circle indicates recruitment under unfished conditions.

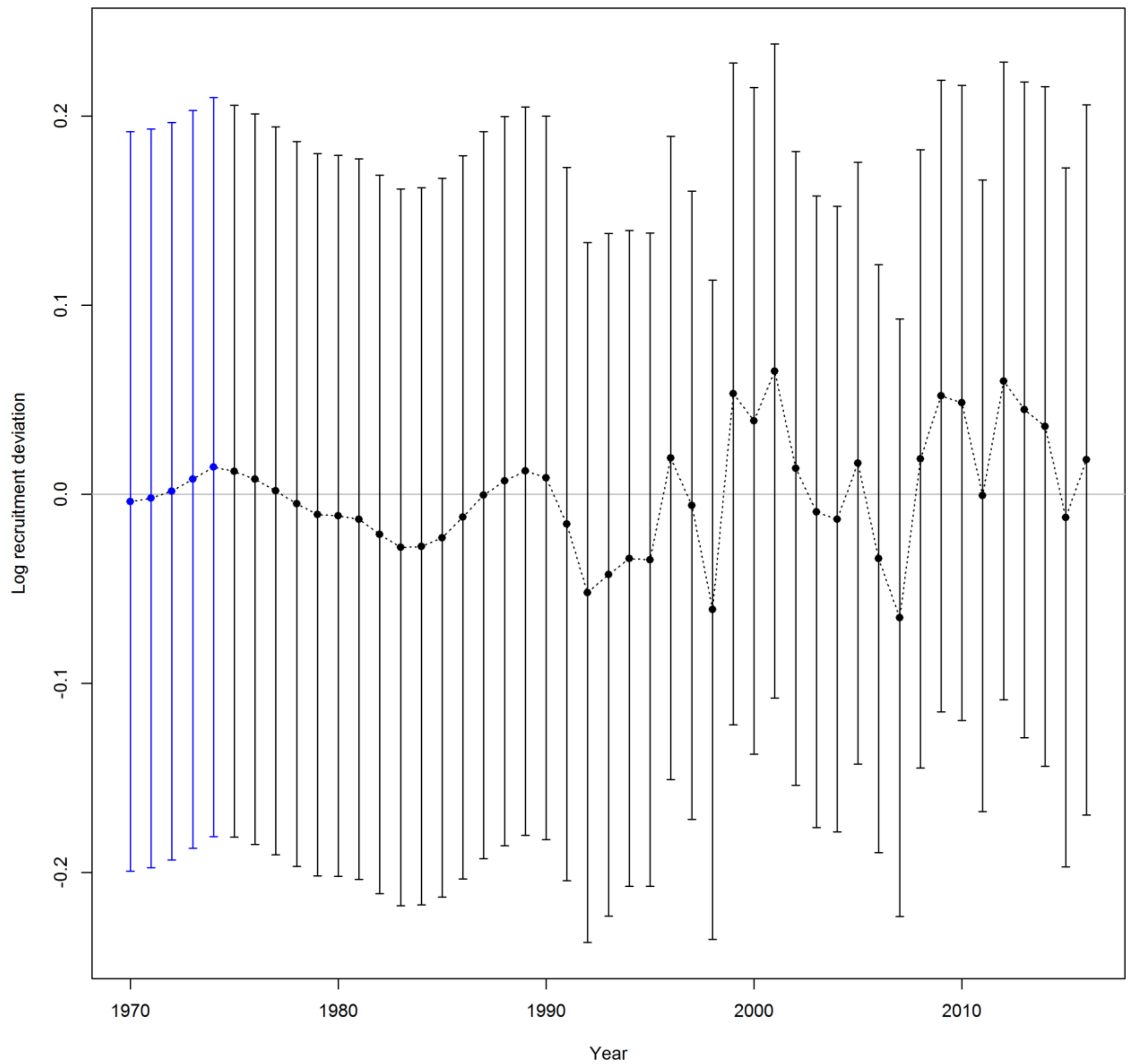


**Figure 17.** Yearly changes in the estimated log recruitment deviations for the early (1970 – 1975, blue) and main (1975 – 2016, black) recruitment periods. Error bars indicate the 95% confidence intervals.

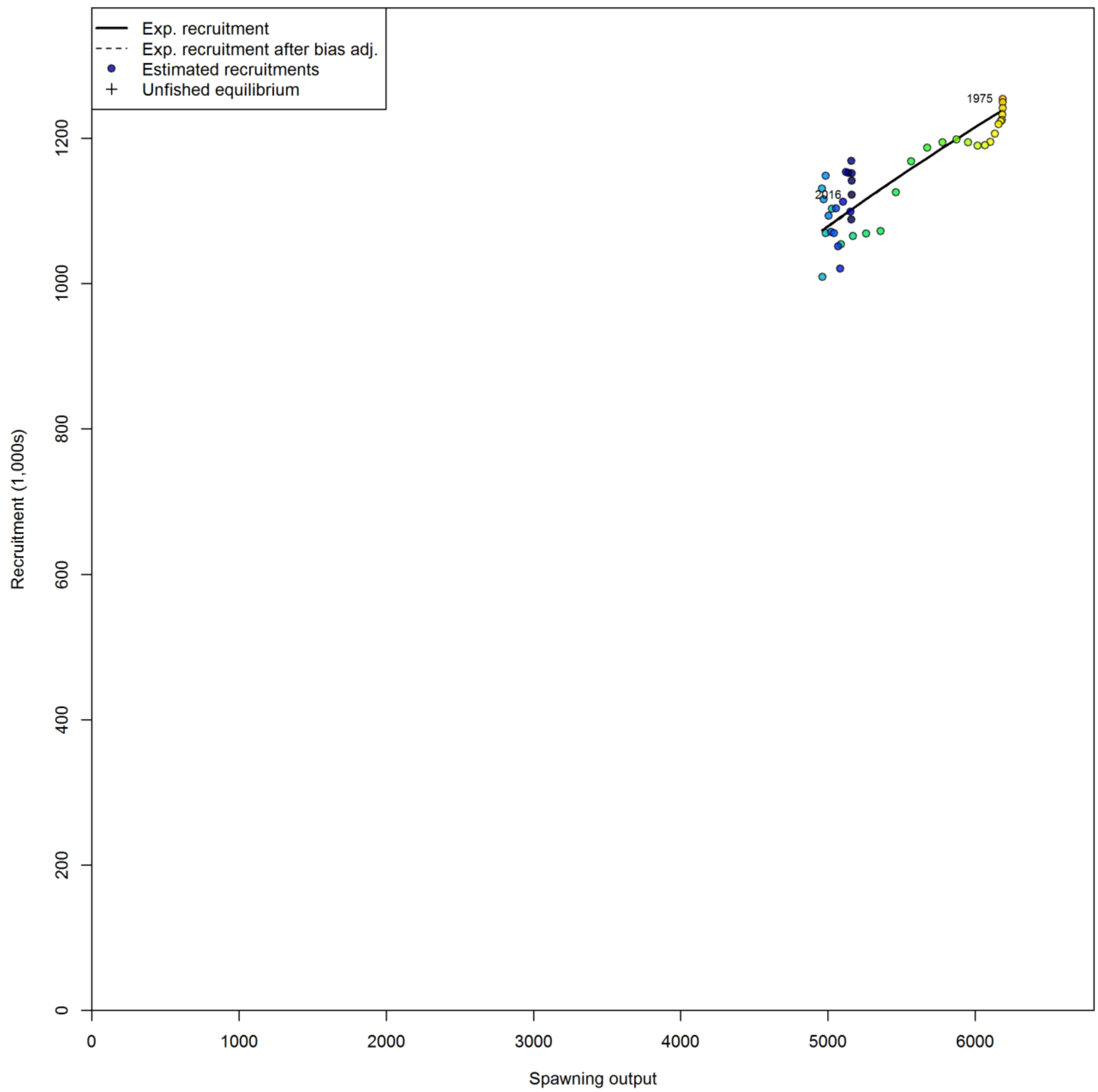


**Figure 18.** Expected recruitment from the stock-recruitment relationship (black line), expected recruitment after implementing the bias adjustment correction (dashed line – not visible), and estimated annual recruitments from 1975 to 2016 (circles) against annual spawning output (i.e., spawning abundance * 6 pups per year).

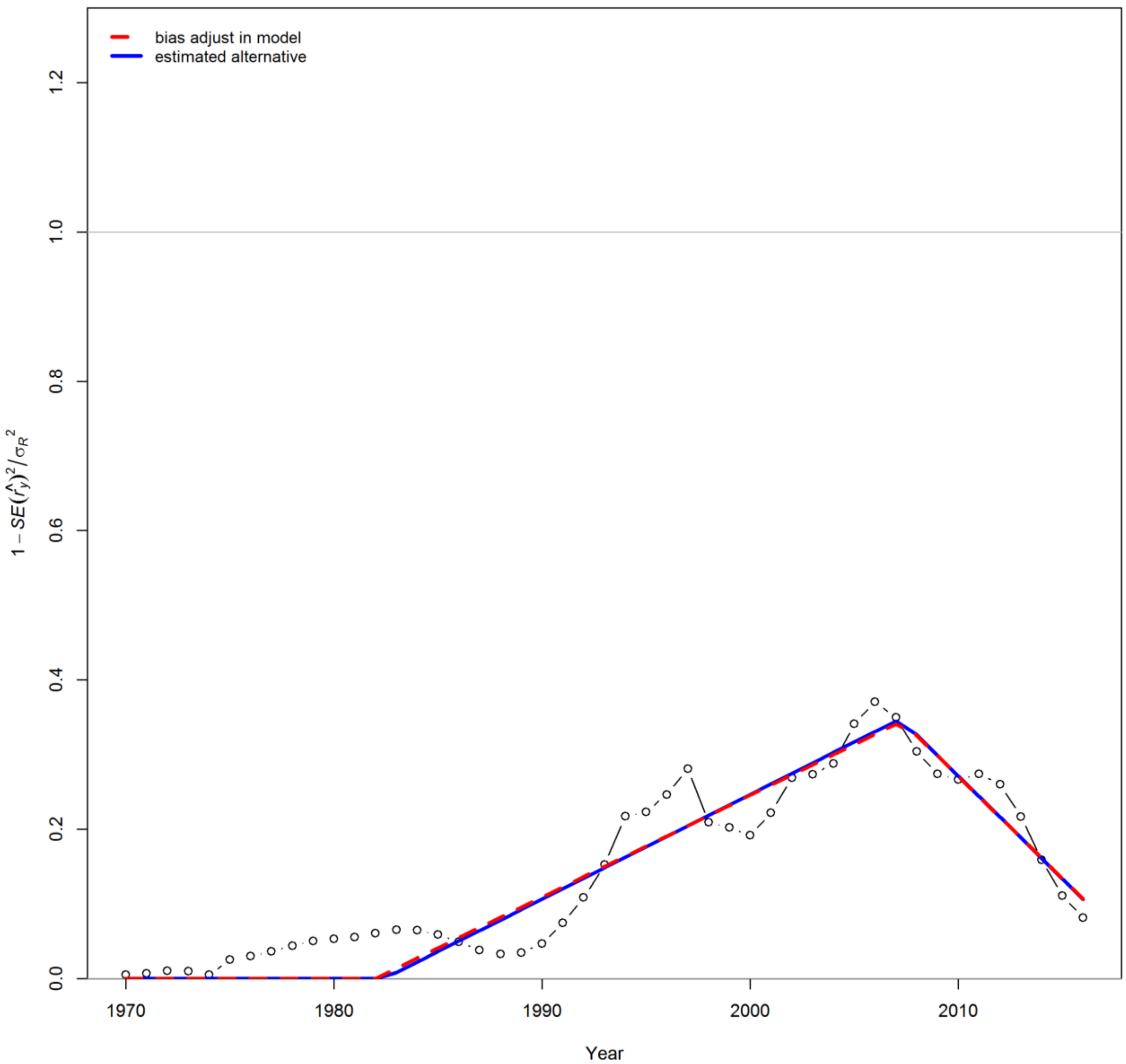


**Figure 19.** Bias adjustment applied to the stock-recruitment relationship (red stippled line) and the estimated alternative (blue line) obtained from the r4ss output.

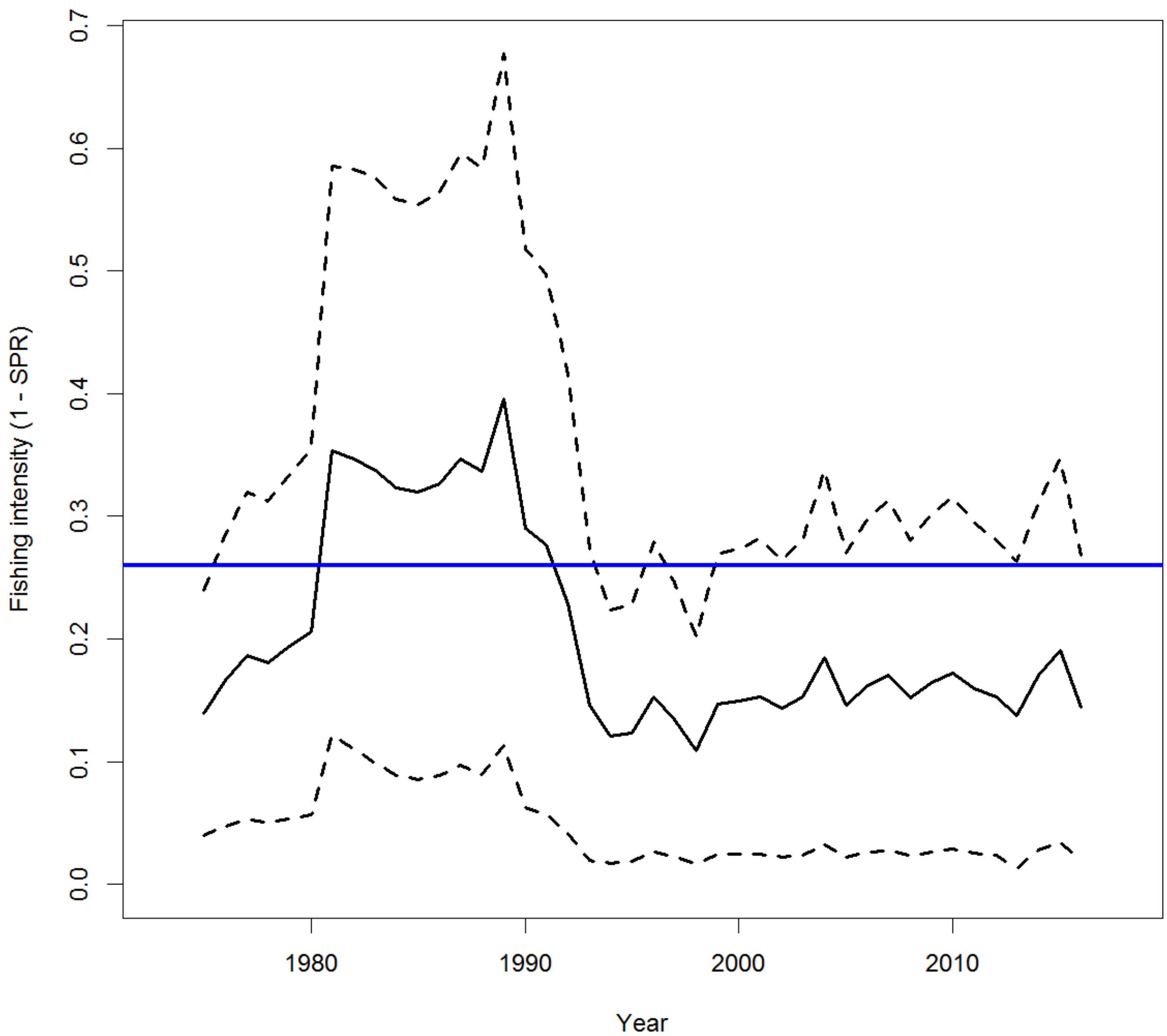


**Figure 20.** Yearly changes in the estimated fishing intensity (1-SPR) of shortfin mako sharks in the North Pacific Ocean (Black solid line). Dashed lines indicate 95% confidence intervals. Blue solid line indicates the estimates of 1-SPR at maximum sustainable yield (MSY) (1- $SPR_{MSY}$).

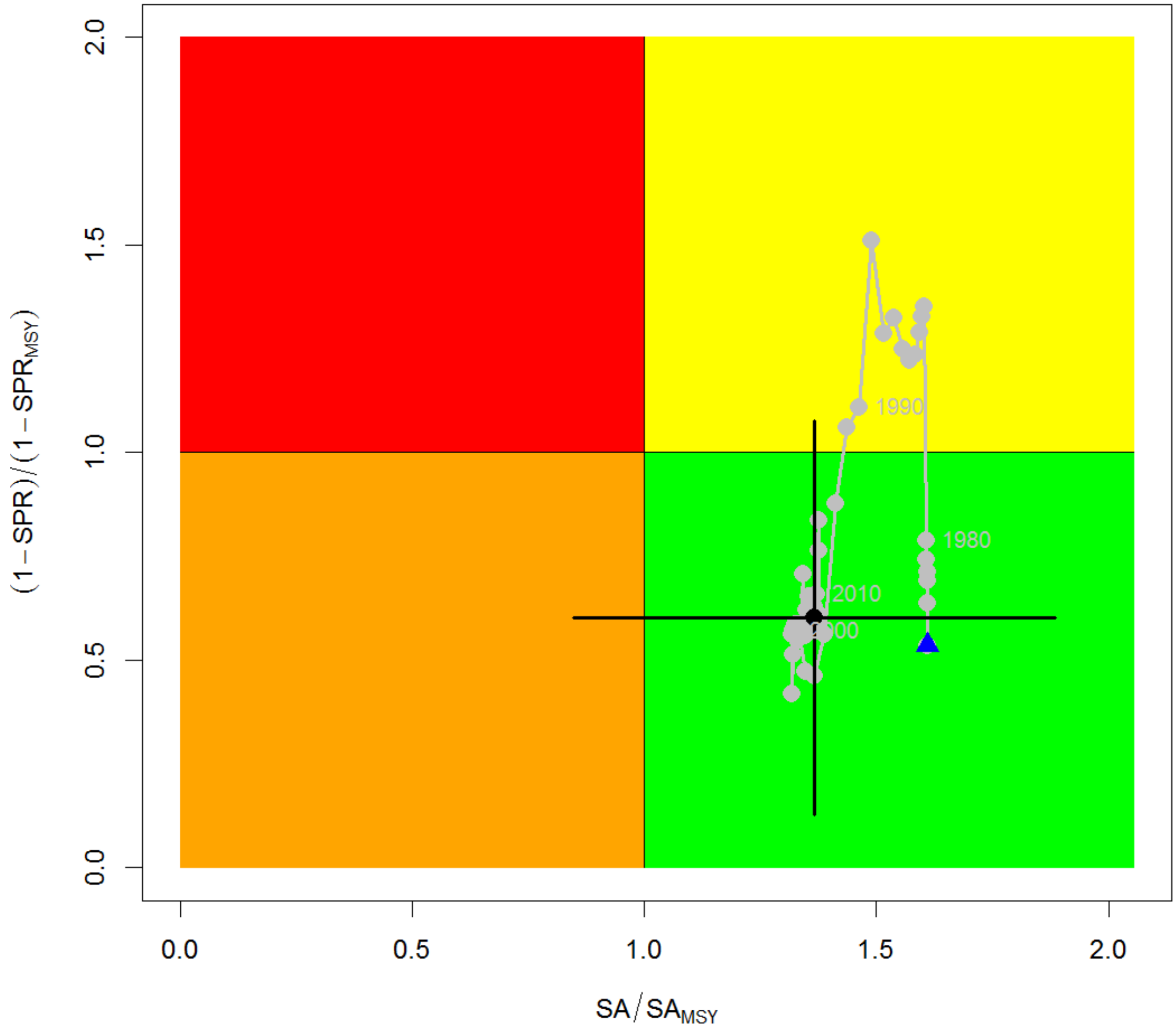


**Figure 21.** Kobe time series plot of shortfin mako sharks in the North Pacific Ocean indicating the ratio of spawning abundance (SA; number of mature female sharks) relative to spawning abundance at maximum sustainable yield (MSY) ($SA_{MSY}$), and the ratio of fishing intensity (1-SPR) relative to fishing intensity at MSY ($1\text{-}SPR_{MSY}$) for the base case model. Blue triangle and black circle denote the values of the start (1975) and end (2016) years, respectively. Black lines indicate 95% confidence intervals (2016) of the end year. Gray numbers indicate selected years.

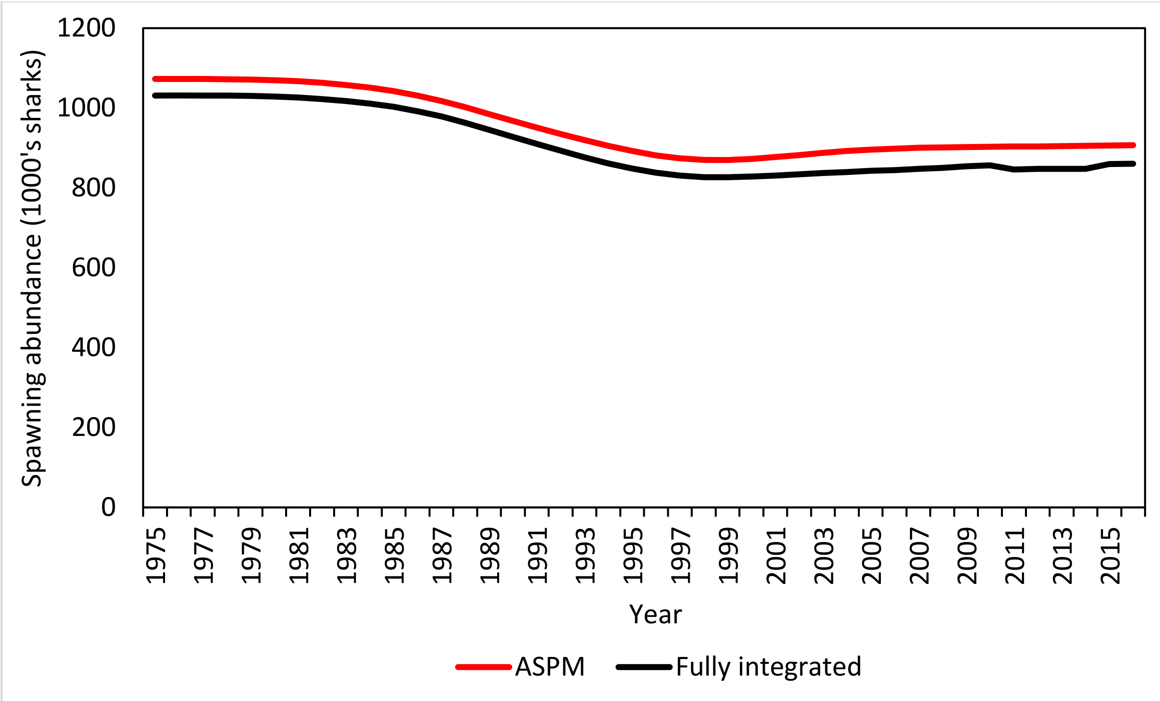


**Figure 22.** Yearly changes in the estimated spawning abundance (SA; number of mature female sharks) during the modeling period (1975-2016) from the age-structured production model (ASPM) and fully integrated base case model.

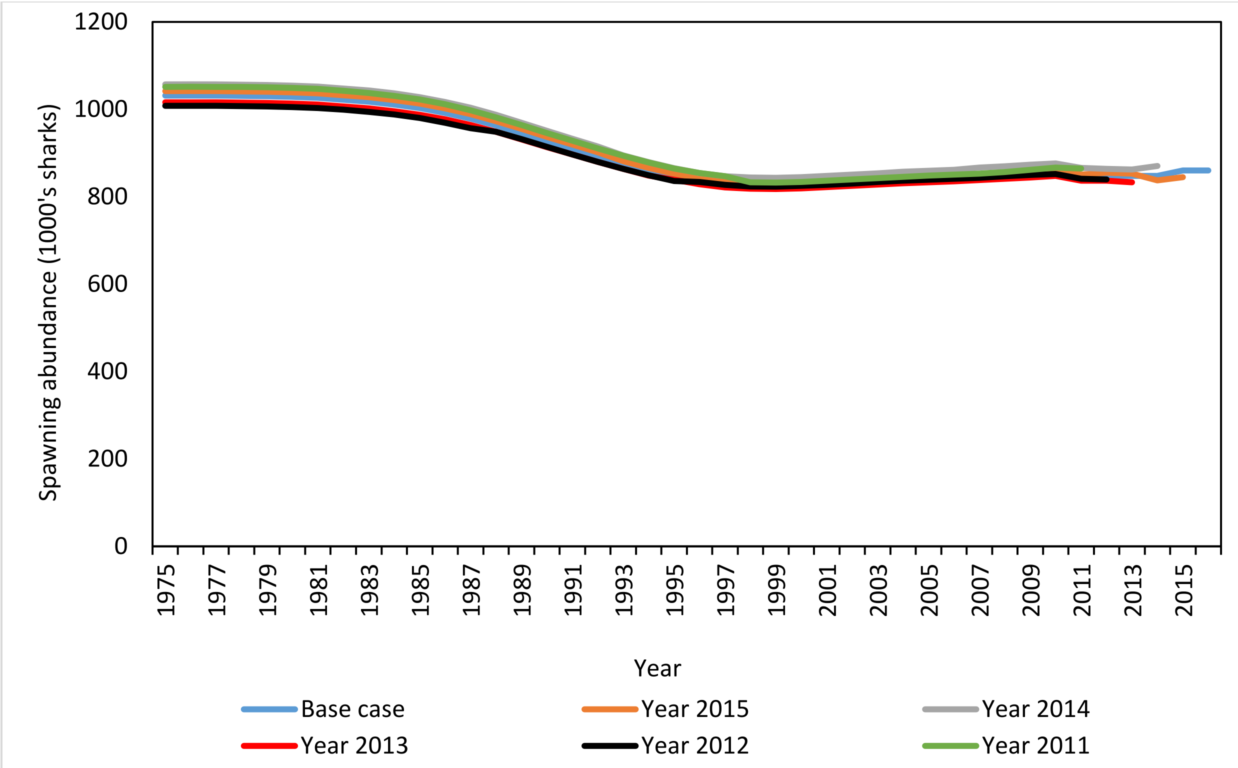


**Figure 23.** A 5-year retrospective analysis of spawning abundance (SA; number of mature female sharks) for the base case model.

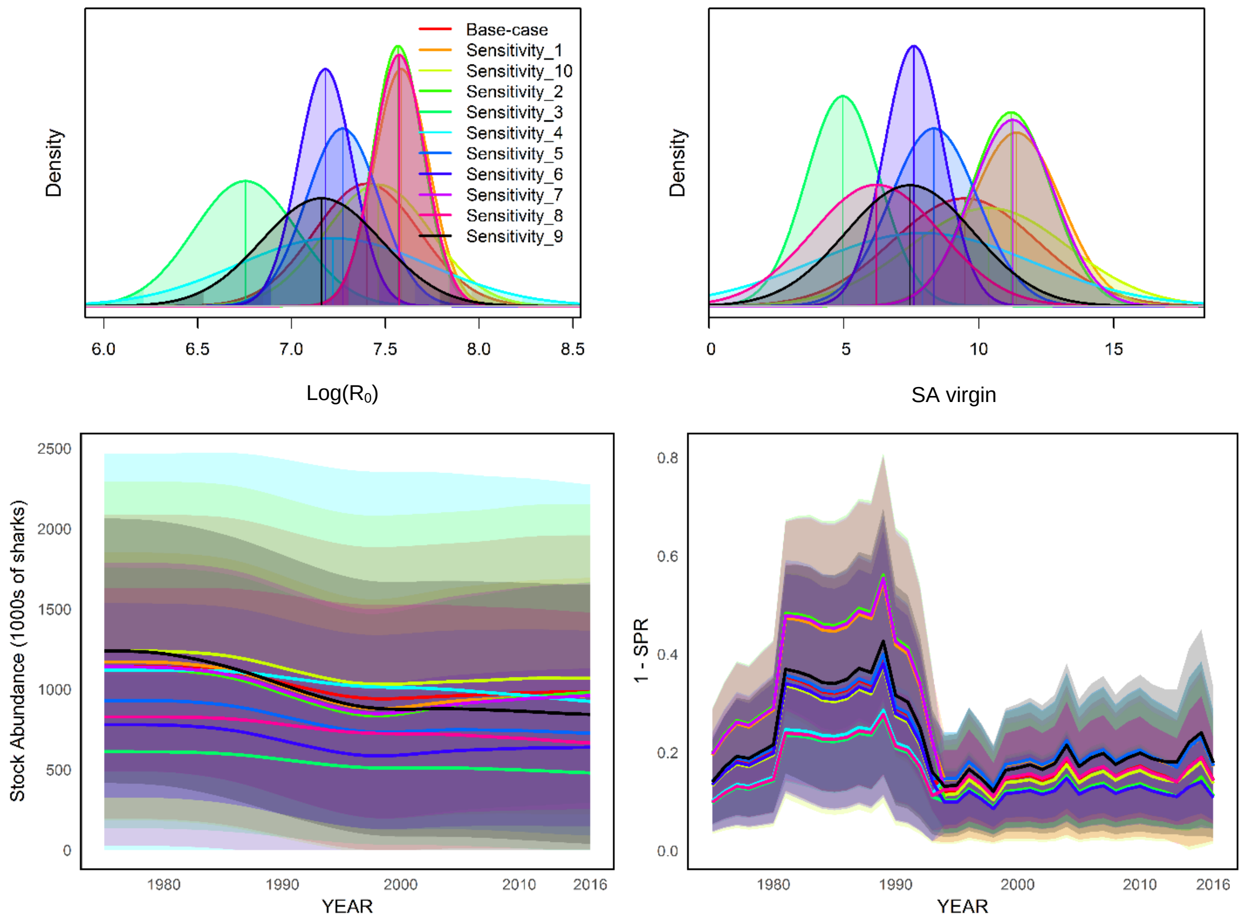


**Figure 24**. Density plots for the main scaling parameter in the model (equilibrium unfished recruitment; Log($R_0$)) and equilibrium unfished spawning abundance (SA virgin or $SA_0$) for the base case model and ten sensitivity models (Top panel). Yearly changes in the estimated SA and the fishing intensity (1-SPR) for the base case model and ten sensitivity models (Bottom panel). See Table 9 for the details of the sensitivity models.

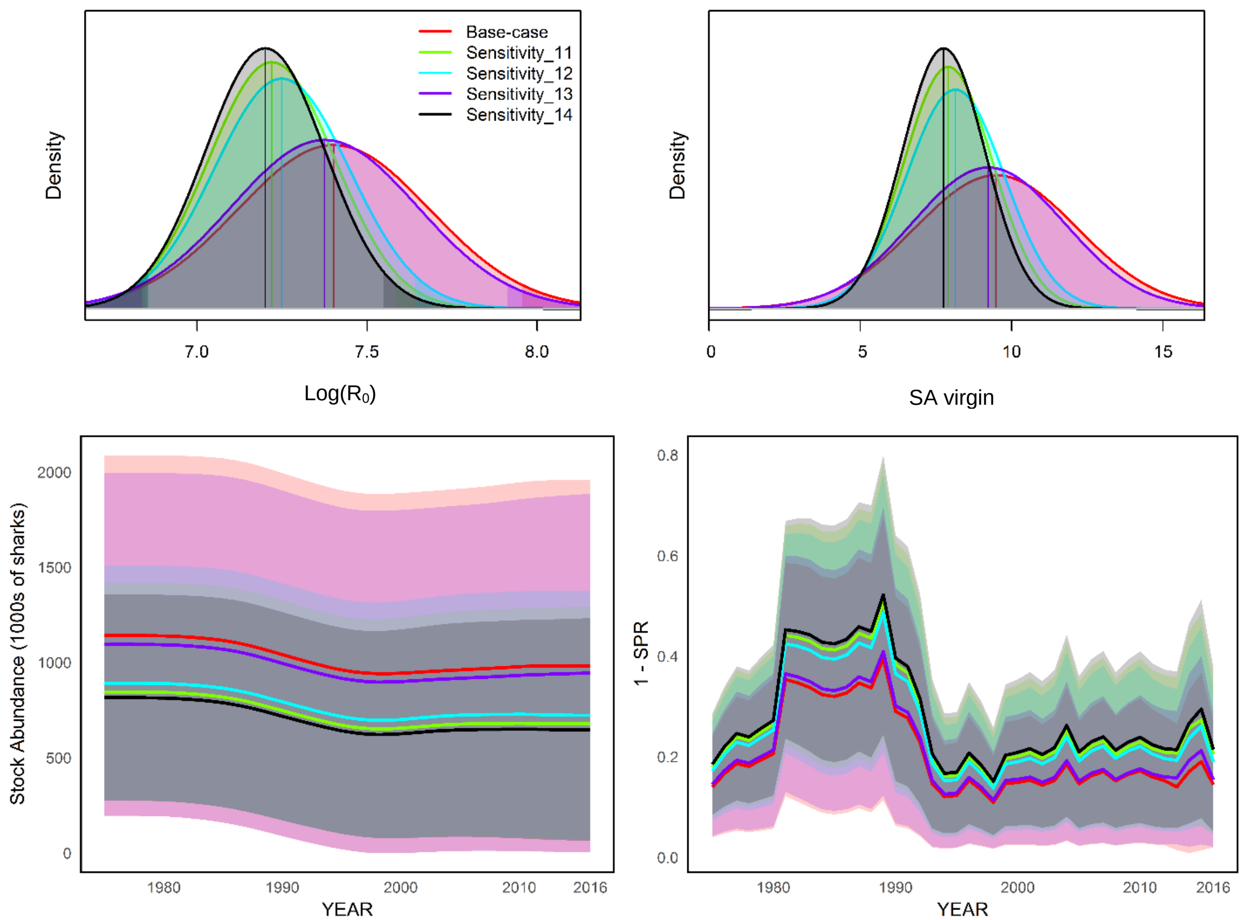


**Figure 25**. Density plots for the main scaling parameter in the model (equilibrium unfished recruitment; Log(R0)) and equilibrium unfished spawning abundance (SA virgin or $SA_0$) for the base case model and four sensitivity models (Top panel). Yearly changes in the estimated SA and the fishing intensity (1-SPR) for the base case model and four sensitivity models (Bottom panel). See Table 9 for the details of the sensitivity models.

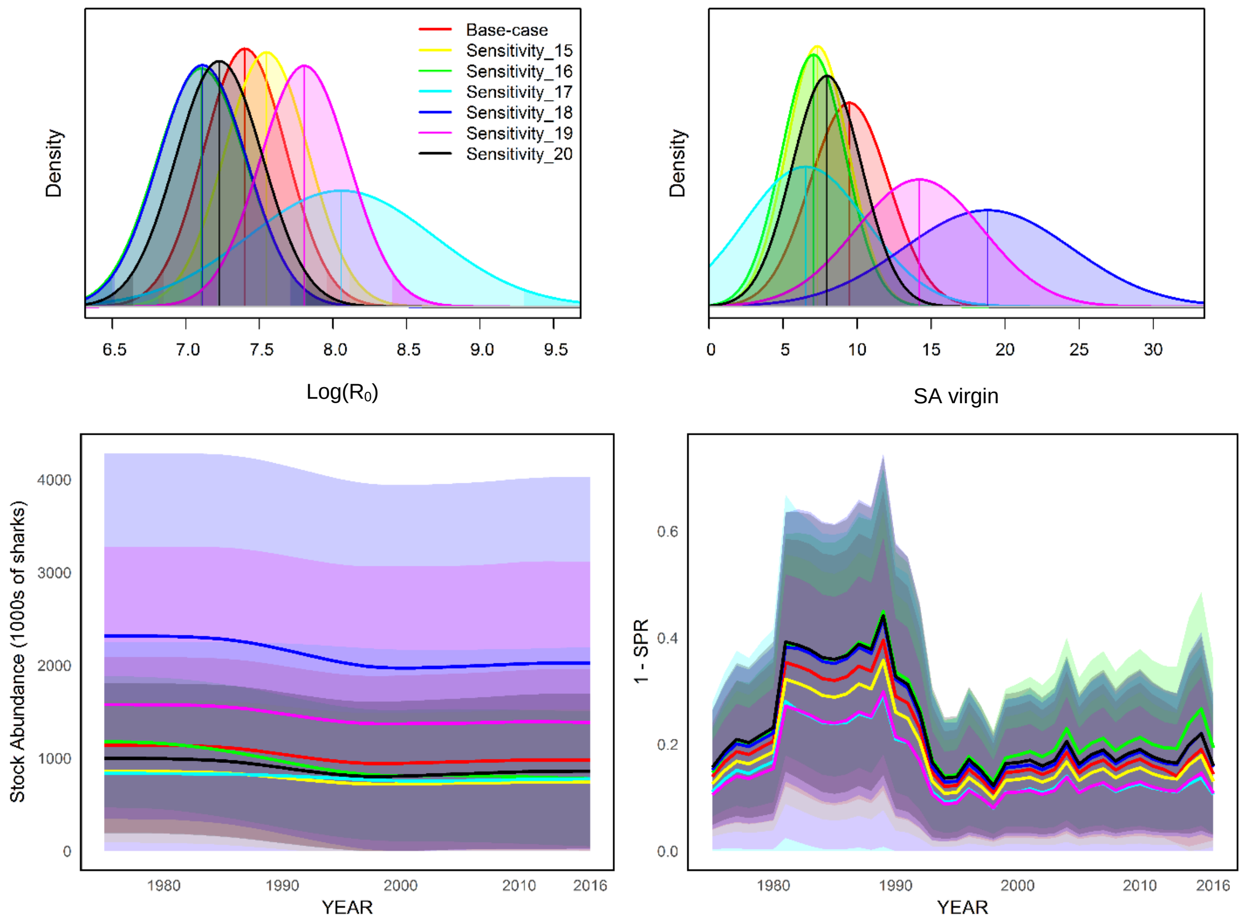


**Figure 26**. Density plots for the main scaling parameter in the model (equilibrium unfished recruitment; log($R_0$)) and equilibrium unfished spawning abundance (SA virgin or $SA_0$) for the base case model and six sensitivity models (Top panel). Yearly changes in the estimated SA and the fishing intensity (1-SPR) for the base case model and six sensitivity models (Bottom panel). See Table 9 for the details of the sensitivity models.

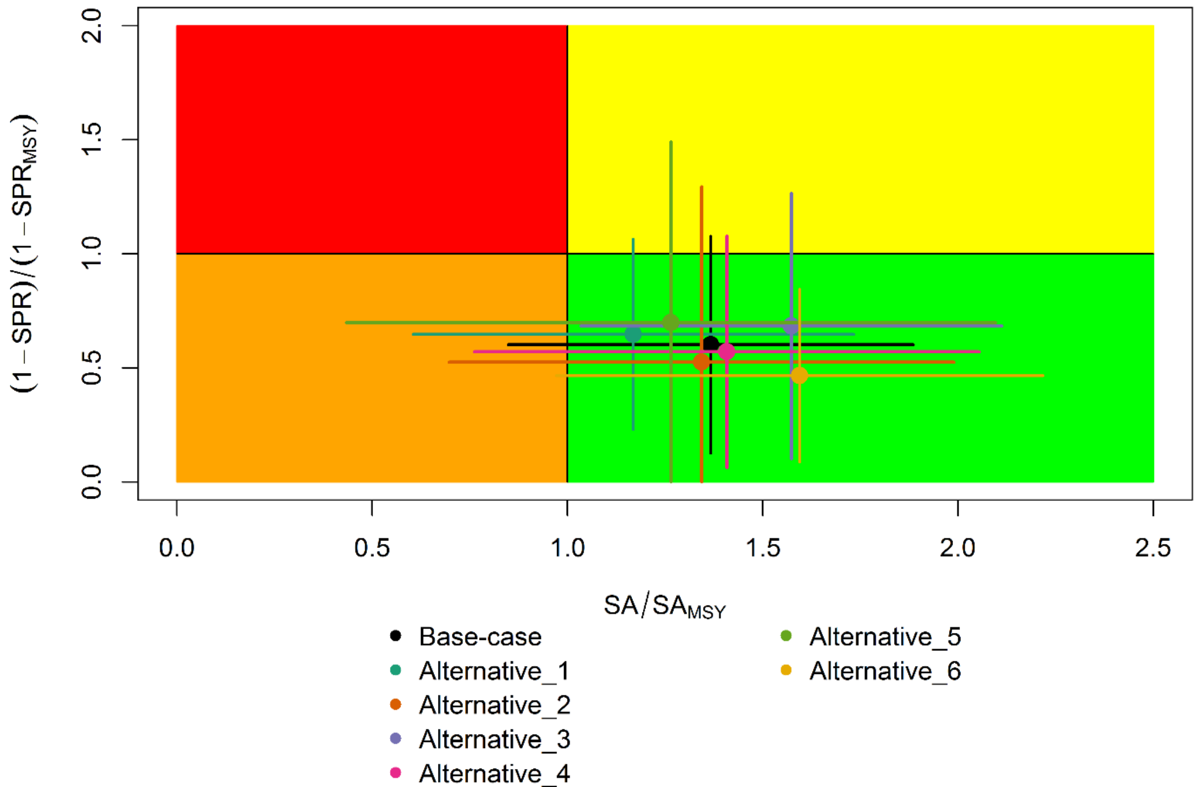


**Figure 27**. Kobe plot of shortfin mako sharks in the North Pacific Ocean indicating the ratio of spawning abundance (SA; number of mature female sharks) relative to spawning abundance at maximum sustainable yield (MSY) ($SA_{MSY}$), and the ratio of fishing intensity (1-SPR) relative to fishing intensity at MSY (1-$SPR_{MSY}$) for the end year (2016) of the base case model and six alternative states of nature detailed in Table 10.

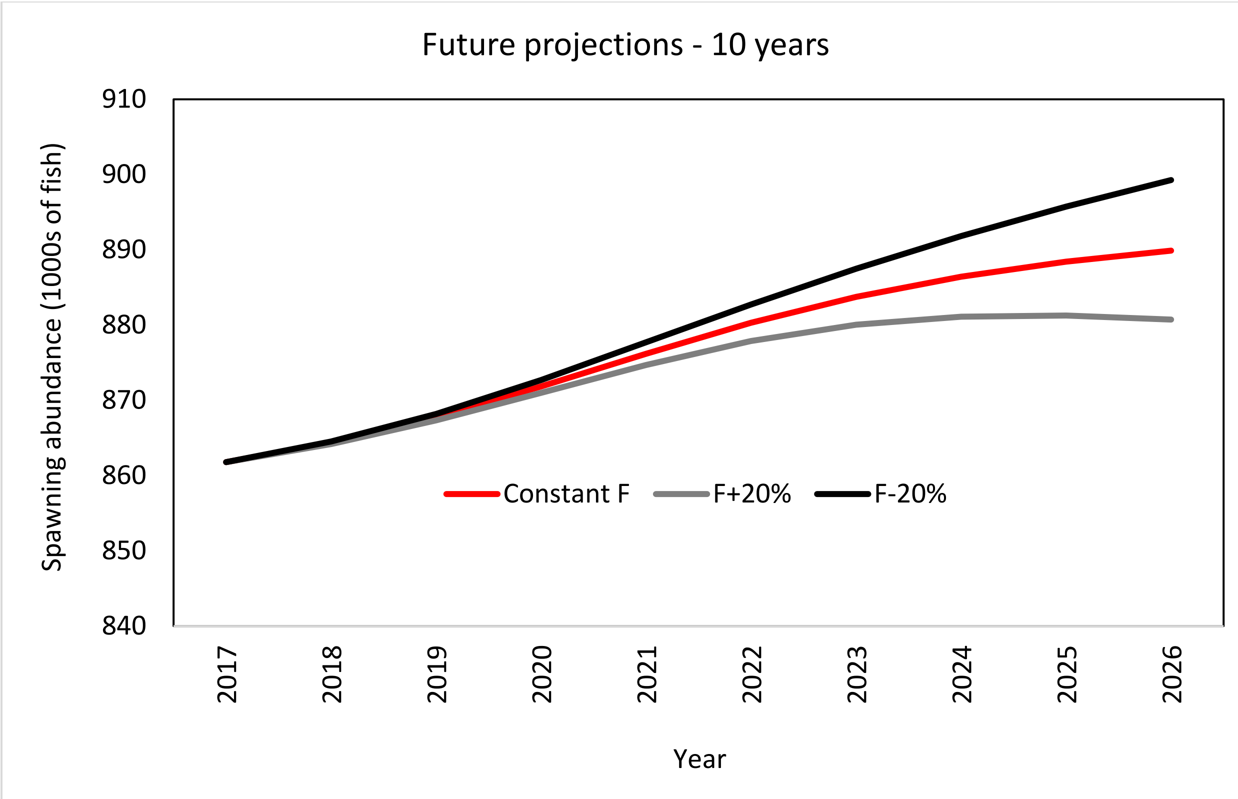


**Figure 28.** Future projections of spawning abundance for shortfin mako sharks in the North Pacific Ocean from 2017 to 2026 under three constant fishing intensity (*F*) harvest scenarios ($F_{2013\text{-}2015}$, $F_{2013\text{-}2015}$+20%, $F_{2013\text{-}2015}$-20%) using the base case model.

# 9 Appendix

## A) Notes on catch estimation of mako sharks caught by purse seine fishery in the EPO

- Estimates were computed separately for 0°-15°N and north of 15°N, by purse-seine set type and year, because of the different spatial distributions of three purse-seine set types and the different bycatch rates by set type.
- Total estimated numbers of sets for 1971-1986 were based on tallies from the IATTC Catch and Effort (CAE) database, with a global annual correction for database coverage (=sum of species-composition catch/sum of CAE catch; catches are the sum of yellowfin tuna, bigeye tuna, skipjack tuna), then prorated to area within the northern EPO (0°-15°N and north of 15°N) with CAE data on number of sets by 5° area.
- Total estimated numbers of sets for 1987-2016 are from the IATTC Fisheries Status Report tables, prorated to area within the northern EPO (0°-15°N and north of 15°N) with CAE data on numbers of sets.
- Total bycatch estimates were computed separately by purse-seine set type, area and year.
- The annual estimates in the table (Table A1) are the sum over purse-seine set types (for all size classes of vessels) and areas, by year.
- Estimates include a proration for unidentified sharks.
- For 2005-2016, bycatch data used to estimate bycatch-per-set include “live release” (live release information was not collected prior to 2005).
- Prior to the introduction of the shark data form in late 2004/2005, only one code was available for mako sharks (*i.e*., species were not distinguished in the code table used by observers). Several years ago, an attempt was made to recover species ids for mako sharks prior to 2005, but this was only possible for sets for which the observer’s notes indicated the species of mako shark.
- For consistency, IATTC observer data were used to estimate bycatch rates. However, because the bycatch of mako sharks in the purse-seine fishery appears to be rare, in some cases the estimated total bycatch was less than that reported by all purse-seine observer programs (IATTC and national programs combined). If the estimated total bycatch was less than the observed bycatch for all observer programs, the estimated bycatch was replaced with the observed bycatch. This was the case in 6 years for 0°-15°N (2005, 2007, 2009, 2011, 2015, 2016) and in 3 years for north of 15°N (2012, 2014, 2015).
- The formula used to estimate total bycatch by set type and year (within each of the two areas) was as follows:

Total bycatch = {bycatch-per-set_all mako x Total sets } +
{(sum bycatch of all mako/ sum bycatch of all identified sharks) * (bycatch-per-set_unidentified sharks x Total sets) },

where the bycatch data were collected by onboard observers.

- Very little bycatch data are available for small purse-seine vessels (IATTC size classes 1-5; defined as vessels with < 364 mt fish-carrying capacity) and no formal sampling program for such vessels exists. Therefore, it was assumed that the bycatch rate of small purse-seine vessels was the same as that of large (IATTC class 6) purse-seine vessels (vessels with ≥ 364 mt fish-carrying capacity), by set type x year x area. Large purse-seine vessels carry observers.

- No bycatch data for sharks are available for any purse-seine vessels prior to 1993. The average bycatch rate (by set type x area) from 1993-1995 was used for the period 1971-1992 because it is closest in time, but the choice of the number of years (3) was arbitrary.

**Table A1**. Preliminary estimates of total purse-seine bycatch of all mako sharks (in numbers of sharks; shortfin mako, longfin mako, and unidentified mako combined), 1971-2016, for the northern eastern Pacific Ocean (EPO) (*i.e.*, EPO north of 0°).

| Year | Total bycatch |
|---|---|
| 1971 | 47 |
| 1972 | 38 |
| 1973 | 47 |
| 1974 | 55 |
| 1975 | 62 |
| 1976 | 71 |
| 1977 | 62 |
| 1978 | 93 |
| 1979 | 88 |
| 1980 | 88 |
| 1981 | 77 |
| 1982 | 61 |
| 1983 | 45 |
| 1984 | 47 |
| 1985 | 33 |
| 1986 | 39 |
| 1987 | 41 |
| 1988 | 55 |
| 1989 | 51 |
| 1990 | 44 |
| 1991 | 35 |
| 1992 | 34 |
| 1993 | 72 |
| 1994 | 17 |
| 1995 | 44 |
| 1996 | 44 |
| 1997 | 91 |
| 1998 | 12 |
| 1999 | 26 |
| 2000 | 7 |
| 2001 | 31 |

| | |
|---|---|
| 2002 | 41 |
| 2003 | 36 |
| 2004 | 43 |
| 2005 | 68 |
| 2006 | 182 |
| 2007 | 115 |
| 2008 | 161 |
| 2009 | 30 |
| 2010 | 52 |
| 2011 | 125 |
| 2012 | 72 |
| 2013 | 21 |
| 2014 | 13 |
| 2015 | 10 |
| 2016 | 14 |

**B) SFM CPUE diagnostic plots**

The CPUE time series are plotted in Figure A1 to compare trends in SFM by fleet. The overall trend for the indices is a general increase or stabilization from 2005 to present, with high values for Japan, Taiwan and Mexico evident in recent years. Each panel includes a Loess smoother with attendant confidence intervals determined via a generalized additive model that treats year as a linear predictor and fleet as a factor.

Residuals from the Loess fit are plotted for each fleet in Figure A2. This allows inspection of conflicts or trends in residuals across and between fleets throughout the time series. Japanese series S4_JPN_SS and S5_JPN_RTV stand out for a switch from negative to positive residuals and a potentially cyclic residual pattern, respectively.

Figure A3 illustrates the correlation between indices; the lower triangle displays the pairwise scatter plots between the indices with a regression line, the upper triangle the correlation coefficients and the diagonal the range of observations. A single influential point may cause a strong spurious correlation therefore it is important to look at the plots as well as the correlation coefficients. For example, the correlation between S5_JPN_RTV and S2_US_SS is moderate at 0.45.

If indices represent the same stock components then it is reasonable to expect them to be correlated. If indices are in conflict (negatively correlated, or showing weak correlation), the model may struggle to reconcile both indices and produced biased and/or poor-fitting estimates. Therefore, correlations plots as in Figure A4 can be used to identify groups that represent common or agreeing hypotheses about the stock trend. While many series appear to be correlated, the S6_JPN_OBS is in complete conflict with all other indices except for Mexico.

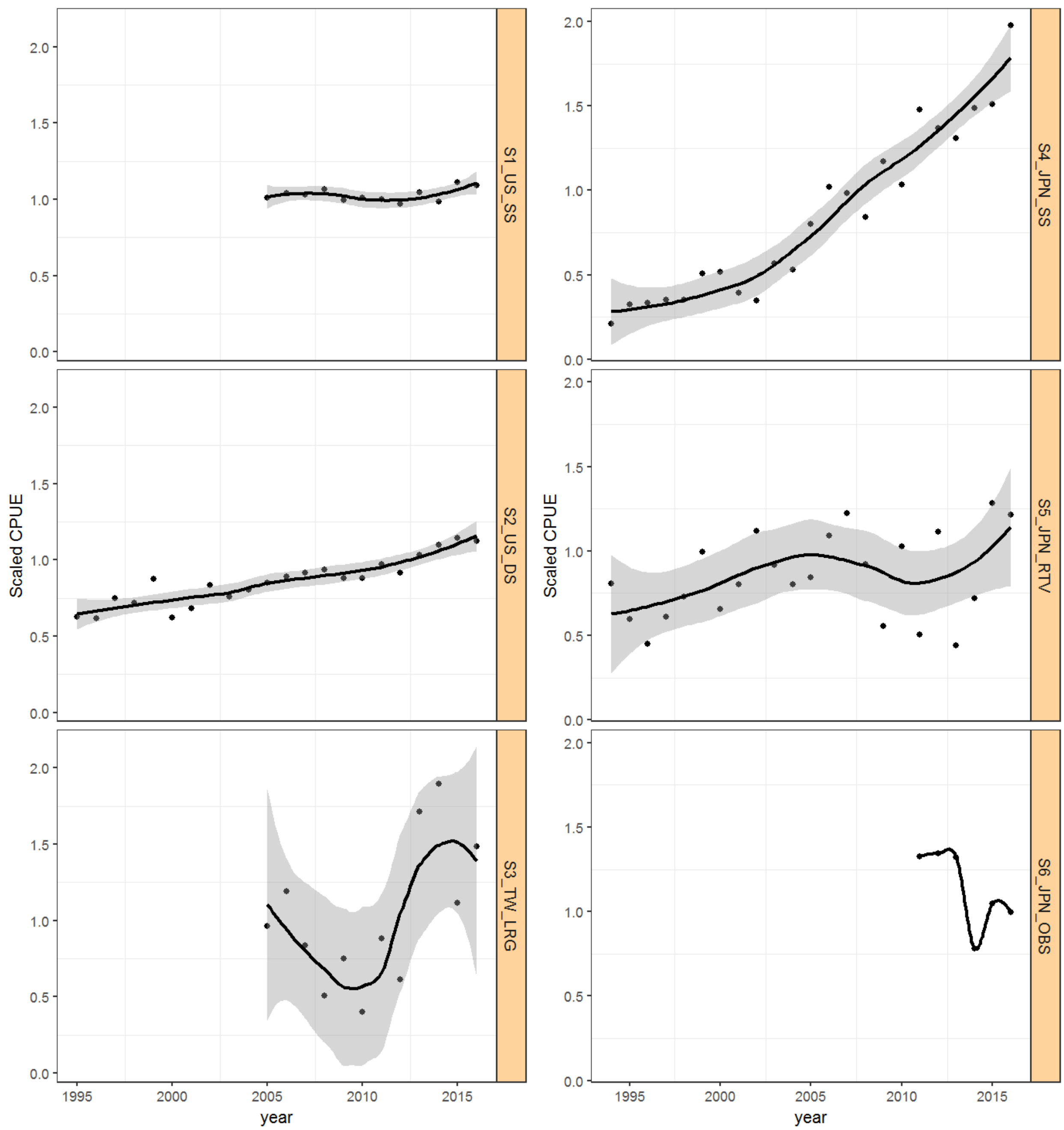


**Figure A1**. Time series of CPUE indices, continuous black line is a Loess smother showing the average trend by fleet (i.e. fitted across the year range with Fleet as factor.)

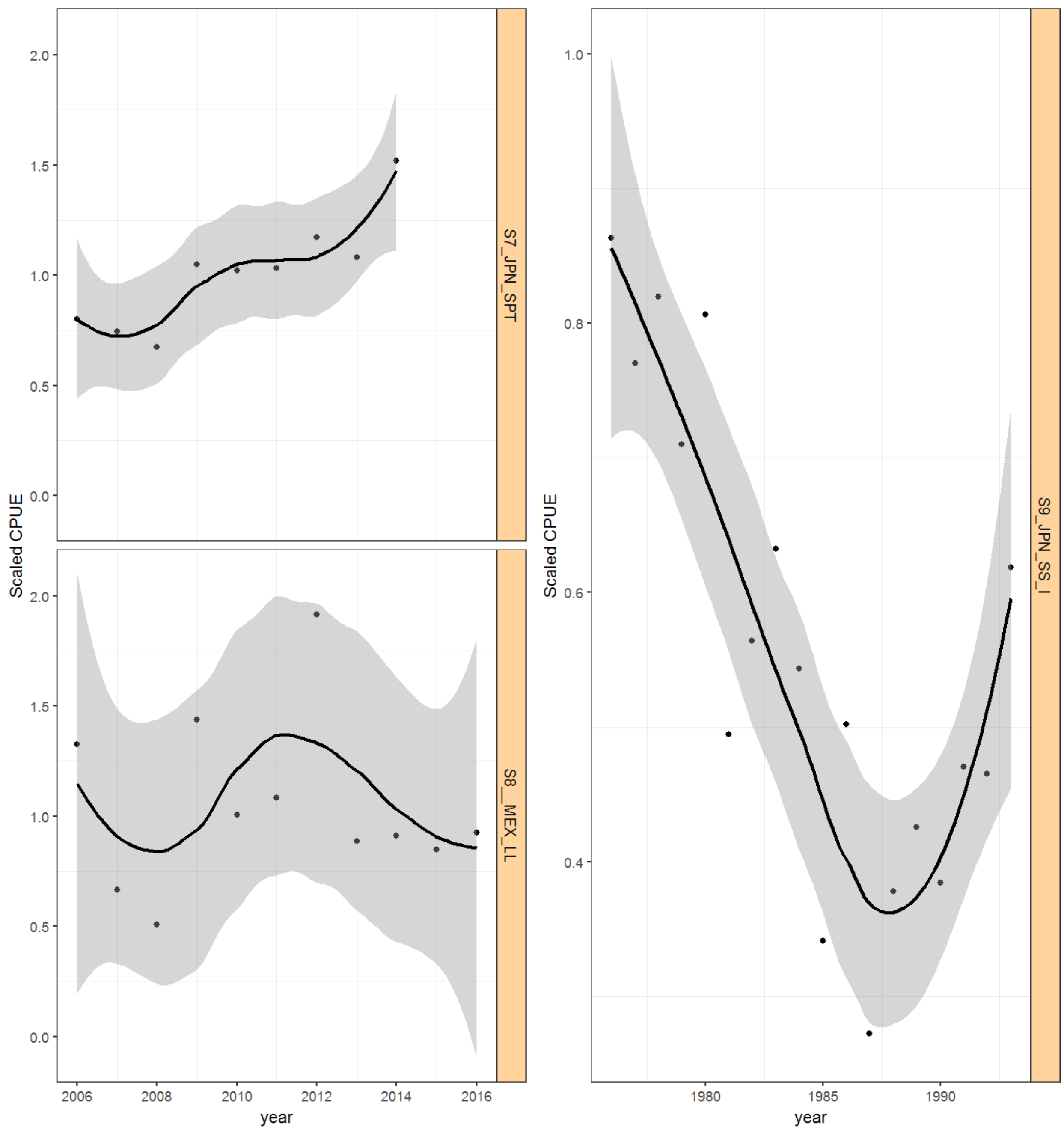


**Figure A1 (cont.)**. Time series of CPUE indices, continuous black line is a Loess smother showing the average trend by fleet (i.e. fitted across the year range with Fleet as factor.)

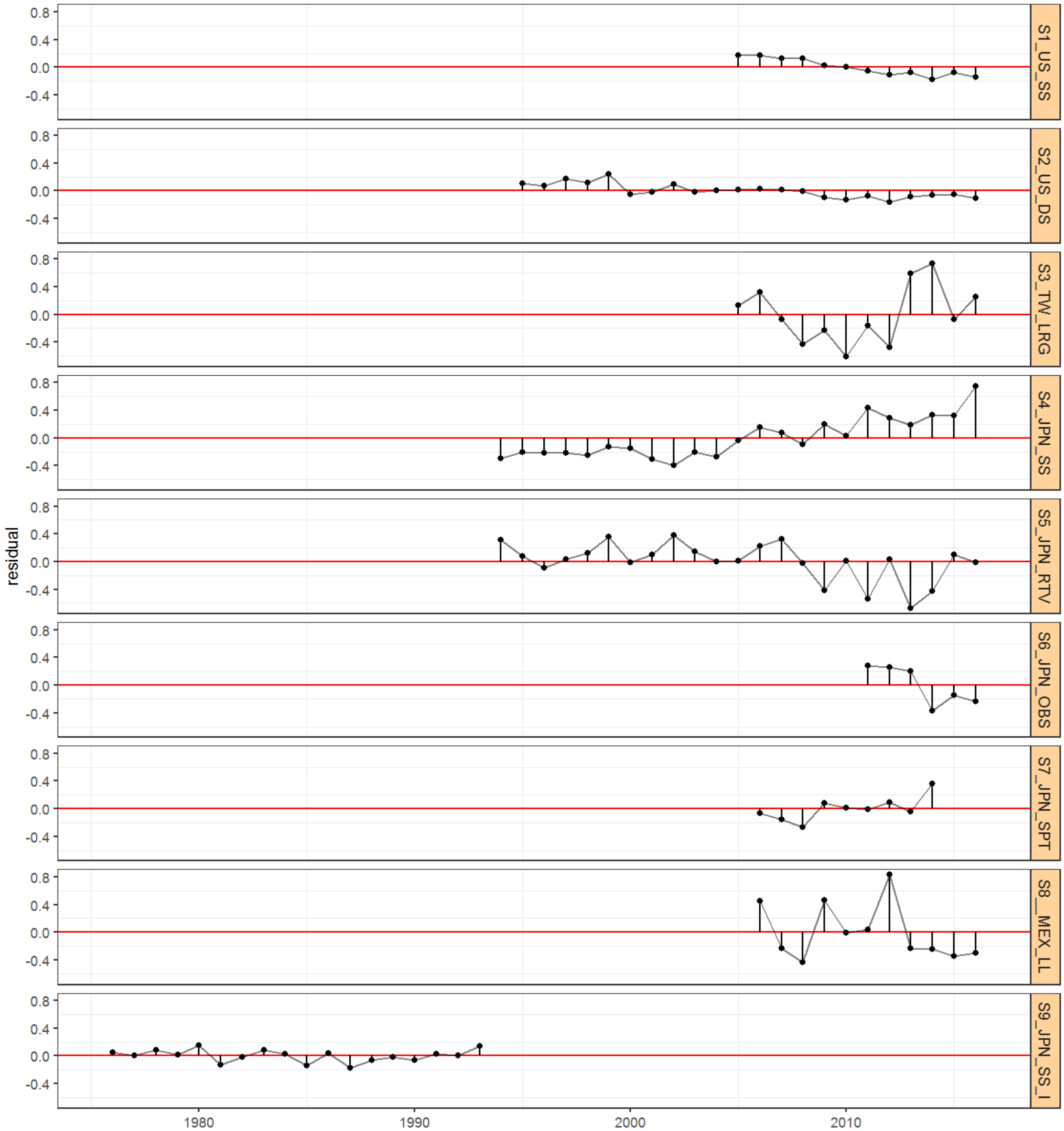


**Figure A2.** Time series of residuals from the Loess fit. Red line is set at zero.

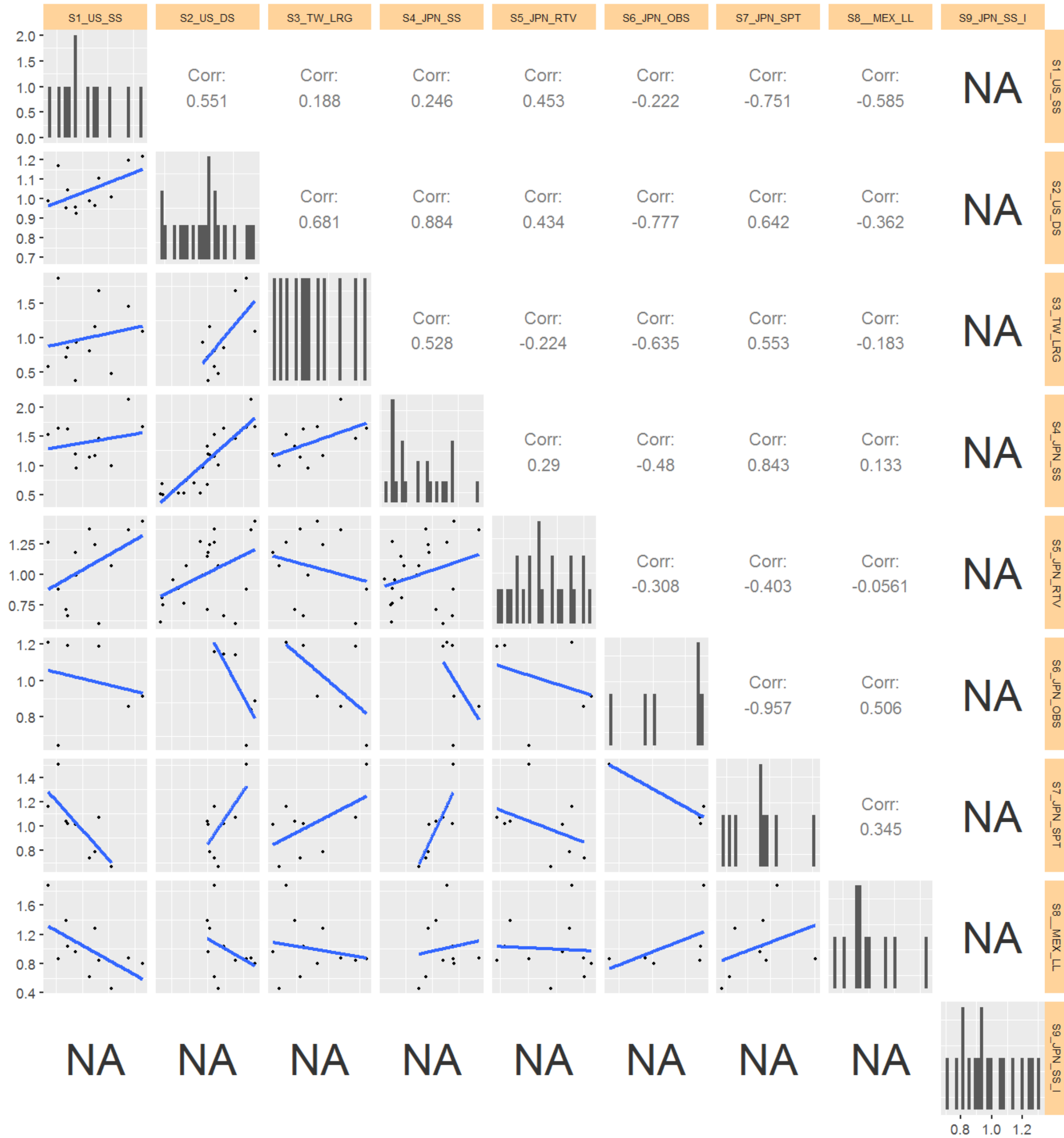


**Figure A3.** Pairwise scatterplots to illustrate correlations among all indices.

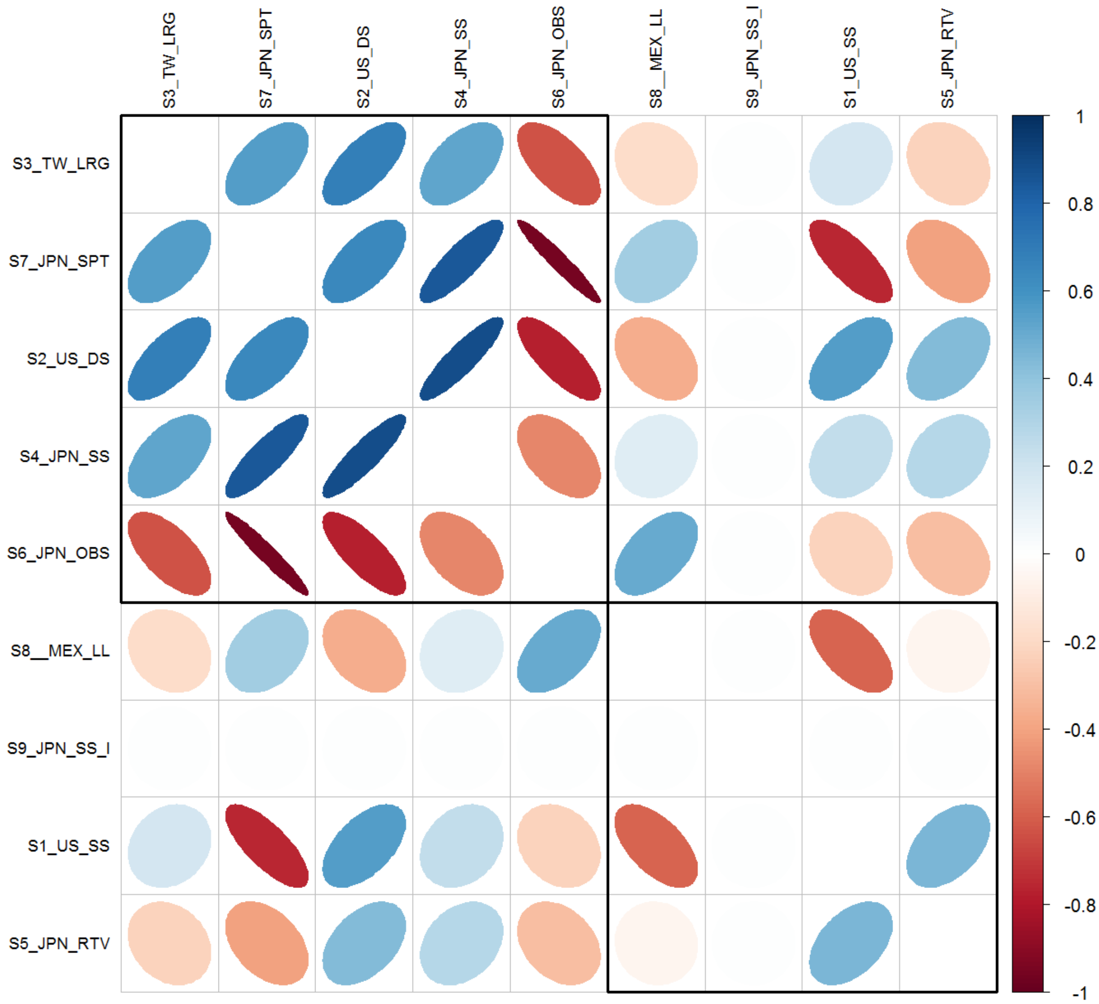


**Figure A4.** Plot of the correlation matrix for CPUE indices. Blue indicates a positive correlation, and red negative. The order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities for the indices being clustered.

**C) SFM.ctl file**

## North Pacific Shortfin Mako Shark Stock Assessment Using Stock Synthesis

## ISC Shark Working Group

Felipe Carvalho, NOAA Pacific Islands Fisheries Science Center, Hawaii, USA

Steven Teo, NOAA Southwest Fisheries Science Center, California, USA

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V3.24U Data & Control Files: C SS3_Control_NP_MAK.xlsx DATA.ss // CONTROL.ss _SS-V3.24Ufast;_08/29/2014;*Stock_Synthesis_by_Richard_Methot*(NOAA)_using_ADMB_11.2_Linux64_compiled_on_RHEL6.6

SS Control File

```
1  #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond  1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
#_Cond 0  #  N recruitment designs goes here if N_GP*nseas*area>1
#_Cond 0  #  placeholder for recruitment interaction request
#_Cond 1 1 1  # example recruitment design element for GP=1, seas=1, area=1
#
#_Cond 0 # N_movement_definitions goes here if N_areas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also con
d on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, a
ge1=4, age2=10
#
0 #_Nblock_Patterns
#_Cond 0 #_blocks_per_pattern
# begin and end years of blocks
#
0.5 #_fracfemale
4 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withsea
sinterpolate
 #_Age_natmort_by gender x growthpattern
0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0
.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.
128 0.128 0.128 0.128  0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.
128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.128 0.1
28 0.128 0.128 0.128 0.128 0.128 0.128 0.128
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_speciific_K; 4=no
t implemented
0 #_Growth_Age_for_L1
999 #_Growth_Age_for_L2 (999 to use as Linf)
```

```
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
1 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity by GP; 4=read age-fecundity by GP; 5=read fec and wt from wtatage.ss; 6=read length-maturity by GP
#_placeholder for empirical age- or length- maturity by growth pattern (female only)
2 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=age-specific fxn
1 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm bounds; 3=standard w/ no bound check)

#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 5 100 60 60 -1 99 -3 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
 50 600 293.1 293.1 -1 99 -4 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
 0.01 0.7 0.128 0.128 -1 99 -5 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
 0.01 0.3 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
 0.01 0.3 0.1 0.1 -1 99 -3 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
 5 100 60 60 -1 99 -3 0 0 0 0 0 0 0 # L_at_Amin_Mal_GP_1
 50 600 232 232 -1 99 -4 0 0 0 0 0 0 0 # L_at_Amax_Mal_GP_1
 0.01 0.7 0.174 0.174 -1 99 -5 0 0 0 0 0 0 0 # VonBert_K_Mal_GP_1
 0.01 0.3 0.1 0.1 -1 99 -2 0 0 0 0 0 0 0 # CV_young_Mal_GP_1
 0.01 0.3 0.1 0.1 -1 99 -3 0 0 0 0 0 0 0 # CV_old_Mal_GP_1
 -3 3 4.62e-05 4.62e-05 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_1_Fem
 -3 5 2.77 2.77 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_2_Fem
 1 300 233.654 233.654 -1 99 -3 0 0 0 0 0 0 0 # Mat50%_Fem
 -200 3 -0.14652 -0.14652 -1 99 -3 0 0 0 0 0 0 0 # Mat_slope_Fem
 -3 20 6 6 0 0.5 -3 0 0 0 0 0.5 0 0 # Eggs_scalar_Fem
 -3 3 0 0 0 0.5 -3 0 0 0 0 0.5 0 0 # Eggs_exp_len_Fem
 -3 5 3.4e-06 3.4e-06 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_1_Mal
 -3 5 2.84 2.84 -1 99 -3 0 0 0 0 0 0 0 # Wtlen_2_Mal
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_GP_1
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Area_1
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 # RecrDist_Seas_1
 -4 4 0 1 -1 99 -3 0 0 0 0 0 0 0 # CohortGrowDev
#_Cond 0  #custom_MG-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-environ parameters
#
#_Cond 0  #custom_MG-block_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no MG-block parameters
#_Cond No MG parm trends
#
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm; 8=Shepard_3Parm
```

```
#_LO HI INIT PRIOR PR_type SD PHASE
 2 15 7.32667 7 -1 99 1 # SR_LN(R0)
 0.2 0.99 0.317 0.317 0 1000 -2 # SR_BH_steep
 0.2 1.9 0.1 0.1 0 1000 -4 # SR_sigmaR
 -5 5 0 0 -1 99 -3 # SR_envlink
 -4 4 0 0 -999 99 -1 # SR_R1_offset
 0 0 0 0 -1 99 -1 # SR_autocorr
0 #_SR_env_link
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
1 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1975 # first year of main recr_devs; early devs can preceed this era
2016 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options
 -5 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 2 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 1982.0 #_last_early_yr_nobias_adj_in_MPD
 2007.1 #_first_yr_fullbias_adj_in_MPD
 2007.4 #_last_yr_fullbias_adj_in_MPD
 2019.9 #_first_recent_yr_nobias_adj_in_MPD
 0.3421 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estima
ted recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -5 #min rec_dev
 5 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
# read specified recr devs
#_Yr Input_value
#
# all recruitment deviations
#DisplayOnly -0.00379823 # Early_InitAge_5
#DisplayOnly -0.00211381 # Early_InitAge_4
#DisplayOnly 0.00156702 # Early_InitAge_3
#DisplayOnly 0.0078997 # Early_InitAge_2
#DisplayOnly 0.0143381 # Early_InitAge_1
#DisplayOnly 0.0121099 # Main_RecrDev_1975
#DisplayOnly 0.00798203 # Main_RecrDev_1976
#DisplayOnly 0.00183501 # Main_RecrDev_1977
#DisplayOnly -0.00510561 # Main_RecrDev_1978
#DisplayOnly -0.0108527 # Main_RecrDev_1979
#DisplayOnly -0.0114458 # Main_RecrDev_1980
#DisplayOnly -0.0132213 # Main_RecrDev_1981
#DisplayOnly -0.021242 # Main_RecrDev_1982
#DisplayOnly -0.0280077 # Main_RecrDev_1983
#DisplayOnly -0.0275443 # Main_RecrDev_1984
#DisplayOnly -0.0229661 # Main_RecrDev_1985
#DisplayOnly -0.0121834 # Main_RecrDev_1986
#DisplayOnly -0.000465674 # Main_RecrDev_1987
#DisplayOnly 0.00695653 # Main_RecrDev_1988
#DisplayOnly 0.0122247 # Main_RecrDev_1989
```

```
#DisplayOnly 0.00870006 # Main_RecrDev_1990
#DisplayOnly -0.0158376 # Main_RecrDev_1991
#DisplayOnly -0.0520176 # Main_RecrDev_1992
#DisplayOnly -0.0425158 # Main_RecrDev_1993
#DisplayOnly -0.0340211 # Main_RecrDev_1994
#DisplayOnly -0.0347133 # Main_RecrDev_1995
#DisplayOnly 0.0191475 # Main_RecrDev_1996
#DisplayOnly -0.00586221 # Main_RecrDev_1997
#DisplayOnly -0.0610691 # Main_RecrDev_1998
#DisplayOnly 0.0530947 # Main_RecrDev_1999
#DisplayOnly 0.038808 # Main_RecrDev_2000
#DisplayOnly 0.0651651 # Main_RecrDev_2001
#DisplayOnly 0.0137704 # Main_RecrDev_2002
#DisplayOnly -0.00927031 # Main_RecrDev_2003
#DisplayOnly -0.0131561 # Main_RecrDev_2004
#DisplayOnly 0.0164646 # Main_RecrDev_2005
#DisplayOnly -0.0339647 # Main_RecrDev_2006
#DisplayOnly -0.0653094 # Main_RecrDev_2007
#DisplayOnly 0.0186935 # Main_RecrDev_2008
#DisplayOnly 0.0519834 # Main_RecrDev_2009
#DisplayOnly 0.0483342 # Main_RecrDev_2010
#DisplayOnly -0.000803603 # Main_RecrDev_2011
#DisplayOnly 0.0599198 # Main_RecrDev_2012
#DisplayOnly 0.0446563 # Main_RecrDev_2013
#DisplayOnly 0.0358322 # Main_RecrDev_2014
#DisplayOnly -0.0122877 # Main_RecrDev_2015
#DisplayOnly 0.0181852 # Main_RecrDev_2016
#Fishing intensity info
0.2 # F ballpark for annual F (=Z-M) for specified year
-2010 # F ballpark year (neg value to disable)
3 # F_Method:  1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
4 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
# if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
5  # N iterations for tuning F in hybrid method (recommend 3 to 7

#_LO HI INIT PRIOR PR_type SD PHASE
 0 5 0 0.01 -1 99 -1 # InitF_1F1_US_CA
 0 5 0 0.01 -1 99 -1 # InitF_2F2_US_HI_SS
 0 5 0 0.01 -1 99 -1 # InitF_3F3_US_HI_DS
 0 5 0 0.01 -1 99 -1 # InitF_4F4_US_DGN
 0 5 0 0.01 -1 99 -1 # InitF_5F5_US_REC
 0 5 0 0.01 -1 99 -1 # InitF_6F6_TW_LRG_N
 0 5 0 0.01 -1 99 -1 # InitF_7F7_TW_LRG_S
 0 5 0 0.01 -1 99 -1 # InitF_8F8_TW_SML
 0 5 0.0403419 0.2 -1 99 1 # InitF_9F9_JPN_SS_II
 0 5 0 0.01 -1 99 -1 # InitF_10F10_JPN_DS
 0 5 0 0.01 -1 99 -1 # InitF_11F11_JPN_CST
 0 5 0 0.01 -1 99 -1 # InitF_12F12_JPN_DFN
 0 5 0 0.01 -1 99 -1 # InitF_13F13_JPN_OTH
 0 5 0 0.01 -1 99 -1 # InitF_14F14_MEX_NOR
 0 5 0 0.01 -1 99 -1 # InitF_15F15_MEX_SOU
 0 5 0 0.01 -1 99 -1 # InitF_16F16_WCPFC
 0 5 0 0.01 -1 99 -1 # InitF_17F17_IATTC
```

```
 0 5 0 0.01 -1 99 -1 # InitF_18F18_JPN_SSII
#
#_Q_setup
 # Q_type options:  <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=parm_nobiasadj,
3=parm_w_random_dev, 4=parm_w_randwalk, 5=mean_unbiased_float_assign_to_parm
#_for_env-var:_enter_index_of_the_env-var_to_be_linked
#_Den-dep  env-var  extra_se  Q_type
 0 0 0 0 # 1 F1_US_CA
 0 0 0 0 # 2 F2_US_HI_SS
 0 0 0 0 # 3 F3_US_HI_DS
 0 0 0 0 # 4 F4_US_DGN
 0 0 0 0 # 5 F5_US_REC
 0 0 0 0 # 6 F6_TW_LRG_N
 0 0 0 0 # 7 F7_TW_LRG_S
 0 0 0 0 # 8 F8_TW_SML
 0 0 0 0 # 9 F9_JPN_SS_II
 0 0 0 0 # 10 F10_JPN_DS
 0 0 0 0 # 11 F11_JPN_CST
 0 0 0 0 # 12 F12_JPN_DFN
 0 0 0 0 # 13 F13_JPN_OTH
 0 0 0 0 # 14 F14_MEX_NOR
 0 0 0 0 # 15 F15_MEX_SOU
 0 0 0 0 # 16 F16_WCPFC
 0 0 0 0 # 17 F17_IATTC
 0 0 0 0 # 18 F18_JPN_SSII
 0 0 0 0 # 19 S1_US_SS
 0 0 0 0 # 20 S2_US_DS
 0 0 0 0 # 21 S3_TW_LRG
 0 0 0 0 # 22 S4_JPN_SS
 0 0 0 0 # 23 S5_JPN_RTV
 0 0 0 0 # 24 S6_JPN_OBS
 0 0 0 0 # 25 S7_JPN_GEO
 0 0 0 0 # 26 S8_MEX
 0 0 0 0 # 27 S9_JPN_SS_I
#
#_Cond 0 #_If q has random component, then 0=read one parm for each fleet with random
 q; 1=read a parm for each year of index
#_Q_parms(if_any);Qunits_are_ln(q)

#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_
dead
#_Pattern Discard Male Special
 24 0 0 0 # 1 F1_US_CA
 5 0 0 1 # 2 F2_US_HI_SS
 24 0 0 0 # 3 F3_US_HI_DS
 24 0 0 0 # 4 F4_US_DGN
 5 0 0 2 # 5 F5_US_REC
 24 0 0 0 # 6 F6_TW_LRG_N
 5 0 0 6 # 7 F7_TW_LRG_S
 5 0 0 6 # 8 F8_TW_SML
 5 0 0 6 # 9 F9_JPN_SS_II
 24 0 0 0 # 10 F10_JPN_DS
 5 0 0 9 # 11 F11_JPN_CST
 24 0 0 0 # 12 F12_JPN_DFN
 5 0 0 9 # 13 F13_JPN_OTH
```

```
 24 0 0 0 # 14 F14_MEX_NOR
 24 0 0 0 # 15 F15_MEX_SOU
 5 0 0 1 # 16 F16_WCPFC
 5 0 0 1 # 17 F17_IATTC
 5 0 0 9 # 18 F18_JPN_SSII
 5 0 0 2 # 19 S1_US_SS
 5 0 0 3 # 20 S2_US_DS
 5 0 0 6 # 21 S3_TW_LRG
 5 0 0 9 # 22 S4_JPN_SS
 5 0 0 9 # 23 S5_JPN_RTV
 5 0 0 9 # 24 S6_JPN_OBS
 5 0 0 9 # 25 S7_JPN_GEO
 5 0 0 14 # 26 S8_MEX
 5 0 0 6 # 27 S9_JPN_SS_I
#
#_age_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F1_US_CA
 11 0 0 0 # 2 F2_US_HI_SS
 11 0 0 0 # 3 F3_US_HI_DS
 11 0 0 0 # 4 F4_US_DGN
 11 0 0 0 # 5 F5_US_REC
 11 0 0 0 # 6 F6_TW_LRG_N
 11 0 0 0 # 7 F7_TW_LRG_S
 11 0 0 0 # 8 F8_TW_SML
 11 0 0 0 # 9 F9_JPN_SS_II
 11 0 0 0 # 10 F10_JPN_DS
 11 0 0 0 # 11 F11_JPN_CST
 11 0 0 0 # 12 F12_JPN_DFN
 11 0 0 0 # 13 F13_JPN_OTH
 11 0 0 0 # 14 F14_MEX_NOR
 11 0 0 0 # 15 F15_MEX_SOU
 11 0 0 0 # 16 F16_WCPFC
 11 0 0 0 # 17 F17_IATTC
 11 0 0 0 # 18 F18_JPN_SSII
 11 0 0 0 # 19 S1_US_SS
 11 0 0 0 # 20 S2_US_DS
 11 0 0 0 # 21 S3_TW_LRG
 11 0 0 0 # 22 S4_JPN_SS
 11 0 0 0 # 23 S5_JPN_RTV
 11 0 0 0 # 24 S6_JPN_OBS
 11 0 0 0 # 25 S7_JPN_GEO
 11 0 0 0 # 26 S8_MEX
 11 0 0 0 # 27 S9_JPN_SS_I
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Bl
ock Block_Fxn
 55 297.5 55 148.87 -1 99 -2 0 0 0 0 0 0 0 # SizeSel_1P_1_F1_US_CA
 -9 4 -7.80104 -4.56 -1 99 3 0 0 0 0 0 0 0 # SizeSel_1P_2_F1_US_CA
 -1 99 99 7.25 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_1P_3_F1_US_CA
 -1 12 9.85594 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_1P_4_F1_US_CA
 -999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_1P_5_F1_US_CA
 -9 9 -3.79134 -5 -1 99 4 0 0 0 0 0 0 0 # SizeSel_1P_6_F1_US_CA
 -99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_2P_1_F2_US_HI_SS
 -99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_2P_2_F2_US_HI_SS
 62.5 297.5 167.796 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_3P_1_F3_US_HI_DS
```

```
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_3P_2_F3_US_HI_DS
-1 9 7.39283 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_3P_3_F3_US_HI_DS
-1 9 7.38943 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_3P_4_F3_US_HI_DS
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_3P_5_F3_US_HI_DS
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_3P_6_F3_US_HI_DS
62.5 297.5 96.1097 148.87 -1 99 2 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F4_US_DGN
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_4P_2_F4_US_DGN
-1 9 6.89979 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_4P_3_F4_US_DGN
-1 9 7.64549 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_4P_4_F4_US_DGN
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_4P_5_F4_US_DGN
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_4P_6_F4_US_DGN
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_5P_1_F5_US_REC
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_5P_2_F5_US_REC
62.5 297.5 140.095 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_6P_1_F6_TW_LRG_N
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_6P_2_F6_TW_LRG_N
-1 9 6.97814 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_6P_3_F6_TW_LRG_N
-1 9 7.2941 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_6P_4_F6_TW_LRG_N
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_6P_5_F6_TW_LRG_N
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_6P_6_F6_TW_LRG_N
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_7P_1_F7_TW_LRG_S
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_7P_2_F7_TW_LRG_S
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_8P_1_F8_TW_SML
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_8P_2_F8_TW_SML
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_9P_1_F9_JPN_SS_II
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_9P_2_F9_JPN_SS_II
62.5 297.5 162.155 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_10P_1_F10_JPN_DS
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_10P_2_F10_JPN_DS
-1 9 6.18826 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_10P_3_F10_JPN_DS
-1 9 7.64278 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_10P_4_F10_JPN_DS
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_10P_5_F10_JPN_DS
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_10P_6_F10_JPN_DS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_11P_1_F11_JPN_CST
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_11P_2_F11_JPN_CST
62.5 297.5 125.491 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_12P_1_F12_JPN_DFN
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_12P_2_F12_JPN_DFN
-1 9 6.88431 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_12P_3_F12_JPN_DFN
-1 9 6.86102 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_12P_4_F12_JPN_DFN
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_12P_5_F12_JPN_DFN
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_12P_6_F12_JPN_DFN
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_13P_1_F13_JPN_OTH
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_13P_2_F13_JPN_OTH
62.5 297.5 100.104 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_14P_1_F14_MEX_NOR
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_14P_2_F14_MEX_NOR
-1 9 8.30395 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_14P_3_F14_MEX_NOR
-1 9 7.53315 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_14P_4_F14_MEX_NOR
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_14P_5_F14_MEX_NOR
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_14P_6_F14_MEX_NOR
62.5 297.5 126.021 148.87 -1 99 2 0 0 0 0 0 0 0 # SizeSel_15P_1_F15_MEX_SOU
-6 4 -6 -4.56 -1 99 -3 0 0 0 0 0 0 0 # SizeSel_15P_2_F15_MEX_SOU
-1 9 7.46986 7.25 -1 99 3 0 0 0 0 0 0 0 # SizeSel_15P_3_F15_MEX_SOU
-1 9 6.65527 7.61 -1 99 3 0 0 0 0 0 0 0 # SizeSel_15P_4_F15_MEX_SOU
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_15P_5_F15_MEX_SOU
-999 9 -999 -5 -1 99 -4 0 0 0 0 0 0 0 # SizeSel_15P_6_F15_MEX_SOU
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_16P_1_F16_WCPFC
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_16P_2_F16_WCPFC
```

```
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_17P_1_F17_IATTC
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_17P_2_F17_IATTC
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_18P_1_F18_JPN_SSII
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_18P_2_F18_JPN_SSII
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_19P_1_S1_US_SS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_19P_2_S1_US_SS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_20P_1_S2_US_DS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_20P_2_S2_US_DS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_21P_1_S3_TW_LRG
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_21P_2_S3_TW_LRG
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_22P_1_S4_JPN_SS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_22P_2_S4_JPN_SS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_23P_1_S5_JPN_RTV
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_23P_2_S5_JPN_RTV
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_24P_1_S6_JPN_OBS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_24P_2_S6_JPN_OBS
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_25P_1_S7_JPN_GEO
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_25P_2_S7_JPN_GEO
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_26P_1_S8_MEX
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_26P_2_S8_MEX
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_27P_1_S9_JPN_SS_I
-99 10 -99 1 -1 99 -99 0 0 0 0 0 0 0 # SizeSel_27P_2_S9_JPN_SS_I
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_1P_1_F1_US_CA
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_1P_2_F1_US_CA
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_2P_1_F2_US_HI_SS
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_2P_2_F2_US_HI_SS
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_3P_1_F3_US_HI_DS
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_3P_2_F3_US_HI_DS
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_4P_1_F4_US_DGN
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_4P_2_F4_US_DGN
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_5P_1_F5_US_REC
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_5P_2_F5_US_REC
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_6P_1_F6_TW_LRG_N
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_6P_2_F6_TW_LRG_N
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_7P_1_F7_TW_LRG_S
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_7P_2_F7_TW_LRG_S
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_8P_1_F8_TW_SML
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_8P_2_F8_TW_SML
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_9P_1_F9_JPN_SS_II
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_9P_2_F9_JPN_SS_II
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_10P_1_F10_JPN_DS
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_10P_2_F10_JPN_DS
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_11P_1_F11_JPN_CST
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_11P_2_F11_JPN_CST
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_12P_1_F12_JPN_DFN
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_12P_2_F12_JPN_DFN
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_13P_1_F13_JPN_OTH
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_13P_2_F13_JPN_OTH
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_14P_1_F14_MEX_NOR
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_14P_2_F14_MEX_NOR
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_15P_1_F15_MEX_SOU
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_15P_2_F15_MEX_SOU
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_16P_1_F16_WCPFC
10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_16P_2_F16_WCPFC
0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_17P_1_F17_IATTC
```

```
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_17P_2_F17_IATTC
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_18P_1_F18_JPN_SSII
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_18P_2_F18_JPN_SSII
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_19P_1_S1_US_SS
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_19P_2_S1_US_SS
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_20P_1_S2_US_DS
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_20P_2_S2_US_DS
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_21P_1_S3_TW_LRG
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_21P_2_S3_TW_LRG
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_22P_1_S4_JPN_SS
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_22P_2_S4_JPN_SS
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_23P_1_S5_JPN_RTV
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_23P_2_S5_JPN_RTV
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_24P_1_S6_JPN_OBS
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_24P_2_S6_JPN_OBS
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_25P_1_S7_JPN_GEO
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_25P_2_S7_JPN_GEO
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_26P_1_S8_MEX
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_26P_2_S8_MEX
 0 10 0.01 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_27P_1_S9_JPN_SS_I
 10 100 31 0 -1 99 -99 0 0 0 0 0 0 0 # AgeSel_27P_2_S9_JPN_SS_I
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
#_Cond 0 #_custom_sel-blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
#_Cond No selex parm trends
#_Cond -4 # placeholder for selparm_Dev_Phase
#_Cond 0 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in base
parm bounds; 3=standard w/ no bound check)
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
1 #_Variance_adjustments_to_input_values
#_fleet: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.04333 0.010455 0.2 0.146852 0.147 0 0.085795
0.09 0.1 #_add_to_survey_CV
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_discard_stddev
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_add_to_bodywt_CV
  1 1 1 1 1 1 1 1 1 1 1 0.38 1 0.4 1 1 1 1 1 1 1 1 1 1 1 1 1 #_mult_by_lencomp_N
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_mult_by_agecomp_N
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 #_mult_by_size-at-age_N

1 #_maxlambdaphase
1 #_sd_offset
#
61 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8
=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=
Tag-negbin; 17=F_ballpark
#like_comp fleet/survey  phase  value  sizefreq_method
 1 1 1 0 1
 1 2 1 0 1
```

```
1 3 1 0 1
1 4 1 0 1
1 5 1 0 1
1 6 1 0 1
1 7 1 0 1
1 8 1 0 1
1 9 1 0 1
1 10 1 0 1
1 11 1 0 1
1 12 1 0 1
1 13 1 0 1
1 14 1 0 1
1 15 1 0 1
1 16 1 0 1
1 17 1 0 1
1 18 1 0 1
1 19 1 1 1
1 20 1 0 1
1 21 1 1 1
1 22 1 0 1
1 23 1 1 1
1 24 1 0 1
1 25 1 0 1
1 26 1 1 1
1 27 1 1 0
4 1 1 0 0
4 2 1 1 0
4 3 1 1 0
4 4 1 0 0
4 5 1 0 0
4 6 1 0 0
4 7 1 0 0
4 8 1 0 0
4 9 1 1 0
4 10 1 1 0
4 11 1 0 0
4 12 1 1 0
4 13 1 0 0
4 14 1 1 0
4 15 1 1 0
4 16 1 0 0
4 17 1 0 0
4 18 1 0 0
4 19 1 0 0
4 20 1 0 0
4 21 1 0 0
4 22 1 0 0
4 23 1 0 0
4 24 1 0 0
4 25 1 0 0
4 26 1 0 0
4 27 1 0 0
6 4 1 1 2
6 6 1 0 1
7 4 1 0 0
```

```
 7 6 1 0 0
 9 9 1 1 0
 11 1 1 0 0
 12 1 1 1 0
#
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  0 #_CPUE/survey:_2
#  0 #_CPUE/survey:_3
#  0 #_CPUE/survey:_4
#  0 #_CPUE/survey:_5
#  0 #_CPUE/survey:_6
#  0 #_CPUE/survey:_7
#  0 #_CPUE/survey:_8
#  0 #_CPUE/survey:_9
#  0 #_CPUE/survey:_10
#  0 #_CPUE/survey:_11
#  0 #_CPUE/survey:_12
#  0 #_CPUE/survey:_13
#  0 #_CPUE/survey:_14
#  0 #_CPUE/survey:_15
#  0 #_CPUE/survey:_16
#  0 #_CPUE/survey:_17
#  0 #_CPUE/survey:_18
#  1 #_CPUE/survey:_19
#  0 #_CPUE/survey:_20
#  1 #_CPUE/survey:_21
#  0 #_CPUE/survey:_22
#  1 #_CPUE/survey:_23
#  0 #_CPUE/survey:_24
#  0 #_CPUE/survey:_25
#  1 #_CPUE/survey:_26
#  1 #_CPUE/survey:_27
#  0 #_lencomp:_1
#  1 #_lencomp:_2
#  1 #_lencomp:_3
#  0 #_lencomp:_4
#  0 #_lencomp:_5
#  0 #_lencomp:_6
#  0 #_lencomp:_7
#  0 #_lencomp:_8
#  1 #_lencomp:_9
#  1 #_lencomp:_10
#  0 #_lencomp:_11
#  1 #_lencomp:_12
#  0 #_lencomp:_13
#  1 #_lencomp:_14
#  1 #_lencomp:_15
#  0 #_lencomp:_16
#  0 #_lencomp:_17
#  0 #_lencomp:_18
#  0 #_lencomp:_19
#  0 #_lencomp:_20
#  0 #_lencomp:_21
#  0 #_lencomp:_22
```

```
#  0 #_lencomp:_23
#  0 #_lencomp:_24
#  0 #_lencomp:_25
#  0 #_lencomp:_26
#  0 #_lencomp:_27
#  1 #_sizefreq:_1
#  0 #_sizefreq:_2
#  1 #_init_equ_catch
#  1 #_recruitments
#  0 #_parameter-priors
#  1 #_parameter-dev-vectors
#  1 #_crashPenLambda
#  0 # F_ballpark_lambda
0 # (0/1) read specs for more stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex bins, Gro
wth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
 # placeholder for vector of selex bins to be reported
 # placeholder for vector of growth ages to be reported
 # placeholder for vector of NatAges ages to be reported
999
```

### SS Forecast File

```
#V3.24U
#C SS3_Control                             =
# for all year entries except rebuilder; enter either: actual year, -999 for styr, 0
for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.68894 # SPR target (e.g. 0.40)
0.407912 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actu
al year, or values of 0 or -integer to be rel. endyr)
 -10 -1 -10 -1 -10 -1
#  2005 2014 2005 2014 2005 2014 # after processing
1 #Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
#
0 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (uses first-last relF yrs
); 5=input annual F scalar
0 # N forecast years
0 # F scalar (only used for Do_Forecast==5)
#_Fcast_years:  beg_selex, end_selex, beg_relF, end_relF  (enter actual year, or valu
es of 0 or -integer to be rel. endyr)
0 0 0 0
#  1180631112 1667592815 7631713 1936290657 # after processing
0 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be
 > the no F level below)
0 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
0 # Control rule target as fraction of Flimit (e.g. 0.75)
74 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with alloca
tions applied)
0 #_First forecast loop with stochastic recruitment
0 #_Forecast loop control #3 (reserved for future bells&whistles)
0 #_Forecast loop control #4 (reserved for future bells&whistles)
0 #_Forecast loop control #5 (reserved for future bells&whistles)
0  #FirstYear for caps and allocations (should be after years with fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause ac
tive impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
0 # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 199
9)
0 # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1 # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) bel
ow
# Note that fleet allocation is used directly as average F if Do_Forecast=4
0 # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio;
 3=retainbio; 5=deadnum; 6=retainnum)
# Conditional input if relative F choice = 2
# Fleet relative F:  rows are seasons, columns are fleets
#_Fleet:
#
# max totalcatch by fleet (-1 to have no max) must enter value for each fleet
# max totalcatch by area (-1 to have no max); must enter value for each fleet
# fleet assignment to allocation group (enter group ID# for each fleet, 0 for #not in
cluded in an alloc group)
#_Conditional on >1 allocation group
```

```
# allocation fraction for each of: 0 allocation groups
# no allocation groups
0 # Number of forecast catch levels to input (else calc catch from forecastF)
-1 # code means to read fleet/time specific basis (2=dead catch; 3=retained #catch; 9
9=F)  as below (units are from fleetunits; note new codes in SSV3.20)
# Input fixed catch values
#Year Seas Fleet Catch(or_F) Basis
#
999 # verify end of input
```

SS Starter File

```
#V3.24U
#C SS3_Control_NA_SMA_2017_12.xlsx
DATA.ss
CONTROL.ss
0 # 0=use init values in control file; 1=use ss3.par
2 # run display detail (0,1,2)
1 # detailed age-structured reports in REPORT.SSO (0,1)
0 # write detailed info from first call to echoinput.sso (0,1)
3 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; #3=every_iter
,all_parms; 4=every,active)
2 # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0 # Include prior_like for non-estimated parameters (0,1)
1 # Use Soft Boundaries to aid convergence (0,1) (recommended)
1 # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and #higher a
re bootstrap
10 # Turn off estimation for parameters entering after this phase
10 # MCeval burn interval
2 # MCeval thin interval
0 # jitter initial parm value by this fraction
-1 # min yr for sdreport outputs (-1 for styr)
-1 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values
1e-005 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
1 # min age for calc of summary biomass
2 # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel #X*B_styr
1 # Fraction (X) for Depletion denominator (e.g. 0.4)
2 # SPR_report_basis:  0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); #3=(1-SP
R)/(1-SPR_Btarget); 4=rawSPR
3 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); #3=sum(Frates);
 4=true F for range of ages
#COND 10 15 #_min and max age over which average F will be calculated with #F_reporti
ng=4
2 # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999 # check value for end of file
```