Annex 13

STOCK ASSESSMENT AND FUTURE PROJECTIONS OF BLUE SHARK IN THE NORTH PACIFIC OCEAN THROUGH 2015

REPORT OF THE SHARK WORKING GROUP

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

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Table of Contents

Executive Summary

This document presents the results of the ISC SHARKWG's assessment of blue shark in the North Pacific Ocean using a fully-integrated size-structured model. The last assessment was conducted in 2014. Time-series data updated through 2015 (catch, relative abundance, and sex-specific length composition from multiple fisheries), new biological information, and research into parameterization of a low-fecundity stock recruitment relationship (LFSR) enabled the development of an improved size-structured model. A Bayesian State-Space Surplus Production reference case model was also conducted to facilitate comparison with the 2014 assessment.

Stock Identification and Distribution

Blue shark (BSH) are widely distributed throughout temperate and tropical waters of the Pacific Ocean. The ISC SHARKWG recognizes two stocks in the North and South Pacific, respectively, based on biological and fishery evidence. Relatively few BSH are encountered in the tropical equatorial waters separating the two stocks. Tagging data demonstrate long distance movements and a high degree of mixing of BSH across the North Pacific, although there is evidence of spatial and temporal structure by size and sex.

Catch History

Catch records for BSH in the North Pacific are limited and, where lacking, have been estimated using statistical models and information from a combination of historical landings data, fishery logbooks, observer records and research surveys. In these analyses, estimated BSH catch data refer to total dead removals, which includes retained catch and dead discards. Estimated catch data in the North Pacific date back to 1971, although longline and driftnet fisheries targeting tunas and billfish earlier in the 20th century likely caught BSH. The nations catching most BSH in the North Pacific include Japan, Chinese Taipei, Mexico, and USA which account for more than 90% of the estimated catch (Figure 1E). Estimated catches of BSH were highest from 1976 to 1989 with a peak estimated catch of approximately 88,000 mt in 1981. Over the past decade BSH estimated catches in the North Pacific have shown a gradual decline from ~52,000 mt in 2005 to an average of ~35,000 mt annually in 2013-2015. While a variety of fishing gears catch BSH, most are caught in longline fisheries (Figure 2E).

Data and Assessment

Annual catch estimates were derived for a variety of fisheries by nation. Catch and size composition data were grouped into 18 fisheries for the period 1971 to 2015. Standardized catch-per-unit-effort (CPUE) data used to measure trends in relative abundance were provided by Japan, USA, Chinese Taipei, Mexico, and SPC (Figure 3E).

The north Pacific blue shark stock was assessed using an age-based statistical catch-at-length model, Stock Synthesis (SS), fit to time series of standardized CPUE and sex-specific size composition data. Sex-specific growth curves and natural mortality rates were used to account for the sexual dimorphism of adult blue sharks. A low fecundity stock recruitment (LFSR) relationship was used to characterize productivity of the stock based on plausible life history information available for north Pacific blue sharks. 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 were used to characterize stock status based on a reference case and to develop stock projections.

Input parameter values for the reference case run was chosen based on the best available information regarding the life history of Pacific blue sharks, and knowledge of the historical catch time series and existing fishery data. For example, for the reference case, initial catch was set at 40,000 mt because Japan longline fishing effort increased and spread rapidly in the 1950s with effort stabilizing by the late 1950s into the 1960s. Standardized CPUE from the Japanese shallow longline fleet that operates out of Hokkaido and Tohoku ports for the periods 1976-1993 and 1994-2015 were used as measures of relative population abundance in the reference case assessment. Parametrization of the LFSR was based on the most plausible life history information available for north Pacific blue sharks with s_{Frac} = 0.391 and β = 2.

Stock projections of biomass and catch of BSH in the North Pacific from 2015 to 2024 were conducted assuming alternative harvest scenarios. Status quo F was based on the average over the recent 3 years (2012-2014).

Due to uncertainty in the input data and life history parameters, multiple models were run with alternative data/parameters including the abundance indices used in the analyses, initial catch level, natural mortality schedule, and the stock recruitment relationship and shape. In addition, a Bayesian State-Space Surplus Production model based on the SS reference case was conducted to facilitate comparison with the 2014 assessment. In total, 14 SS 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 mortality levels for North Pacific BSH.

Status of the Stock

The current assessment provides the best available scientific information on North Pacific Blue shark stock status. The assessment uses a fully integrated approach in Stock Synthesis with model inputs that have been greatly improved since the previous assessment. The main differences between the present assessment and the 2014 assessment are: 1) use of SS with a thorough examination of the size composition data and the relative weighting of CPUE and composition data; 2) improved life history information, such as growth and reproductive biology, and their contribution to productivity assumptions; 3) an improved understanding and parametrization of the LFSR; 4) catch, CPUE and size time series updated through 2015; 5) a suite of model diagnostics including implementation of an Age Structured Production Model implemented in SS. There remain some uncertainties in the time series based on the quality (observer vs. logbook) and timespans of catch and relative abundance indices, limited size composition data for several fisheries, the potential for additional catch not accounted for in the assessment, and regarding life history parameters. Continued improvements in the monitoring of BSH catches, including recording the size and sex of sharks retained and discarded for all fisheries, as well as continued research into the biology and ecology of BSH in the North Pacific are recommended.

While the results varied depending upon the input assumptions, extensive model explorations showed that the reference run had the best model performance and showed fits most consistent with the data. The CPUE indices used in the reference case were considered most representative of the north Pacific blue shark stock due to their broader spatial temporal coverage in the core distribution of the stock and the statistical soundness of the standardizations. Alternate CPUE series for the latter part of the time series produced different stock trajectories depending upon the index used, but in each case, median SSB during the last 3 years exceeded MSY. Using alternate assumptions on stock productivity (i.e. form of the stock recruitment relationship) also resulted in variation in the stock trajectories. For example, assuming stock productivity lower than supported by current biological studies, resulted in lowered spawning stock biomass relative to MSY.

Results of the reference case model showed that the spawning stock biomass was near a time-series high in the late 1970s, fell to its lowest level between 1990 to 1995, subsequently increased gradually to reach the time-series high again in 2005, and has since shown small fluctuations close to the time-series high. Recruitment has fluctuated around 37,000,000 age-0 sharks annually (Figure 4E). Stock status is reported in relation to maximum sustainable yield (MSY). Benchmark results are shown based on female spawning stock biomass. Female spawning biomass in 2015 (SB_{2015}) was 71% higher than at MSY and estimated to be 308,286 mt (Table E1; Figure 4E). The recent annual fishing mortality ($F_{2012\text{-}2014}$) was estimated to be well below F_{MSY} at approximately 37% of F_{MSY} (Table E1; Figure 4E). The reference run produced terminal conditions that were predominately in the green quadrant (not overfished and overfishing not occurring) of the Kobe plot (Figure 5E).

Conservation Information

These results 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 yet been established for pelagic sharks in the Pacific. Relative to MSY, the reference case with input parameter values considered most probable suggest that the North Pacific blue shark stock is not overfished and overfishing is not occurring.

Future projections under different fishing mortality (F) harvest policies (status quo, +20%, -20%, F_{MSY}) show that median BSH biomass in the North Pacific will likely remain above B_{MSY} in the foreseeable future (Table E2; Figure 6E).

Improvements in the monitoring of blue shark catches and discards, through carefully designed observer programs and species-specific logbooks, as well as continued research into the fisheries, biology and ecology of blue shark in the North Pacific are recommended.

Table 1E. Estimates of key management quantities for the North Pacific blue shark SS stock assessment reference case model and the range of values for 13 sensitivity runs.

Management Quantity	Reference Case Model	Range for Sensitivity Runs
SB_{1971}	311,312	174,381 - 980,878
SB_{2015}	308,286	140,742 - 1,082,300
SB_{MSY}	179,539	100,984 - 482,638
F_{1971}	0.13	0.01 - 0.15
$F_{2012\text{-}2014}$	0.13	0.06 - 0.15
F_{MSY}	0.35	0.26 - 0.66
SB_{2015}/SB_{MSY}	1.71	1.39 - 2.59
$F_{2012\text{-}2014}/F_{MSY}$	0.37	0.15 - 0.50

Table 2E. Projected trajectory of spawning biomass (in metric tons) for alternative harvest scenarios.

Year	Average F + 20%	F_{MSY}	Average F - 20%	Average F (2012-2014)
2015	308,286	308,286	308,286	308,286
2016	319,292	319,292	319,292	319,291
2017	328,679	324,591	330,693	329,683
2018	334,827	324,839	339,339	337,069
2019	337,305	323,009	344,621	340,929
2020	339,267	319,719	349,439	344,292
2021	340,833	316,419	353,720	347,185
2022	342,133	313,352	357,498	349,691
2023	343,229	310,601	360,796	351,859
2024	344,166	308,173	363,648	353,728

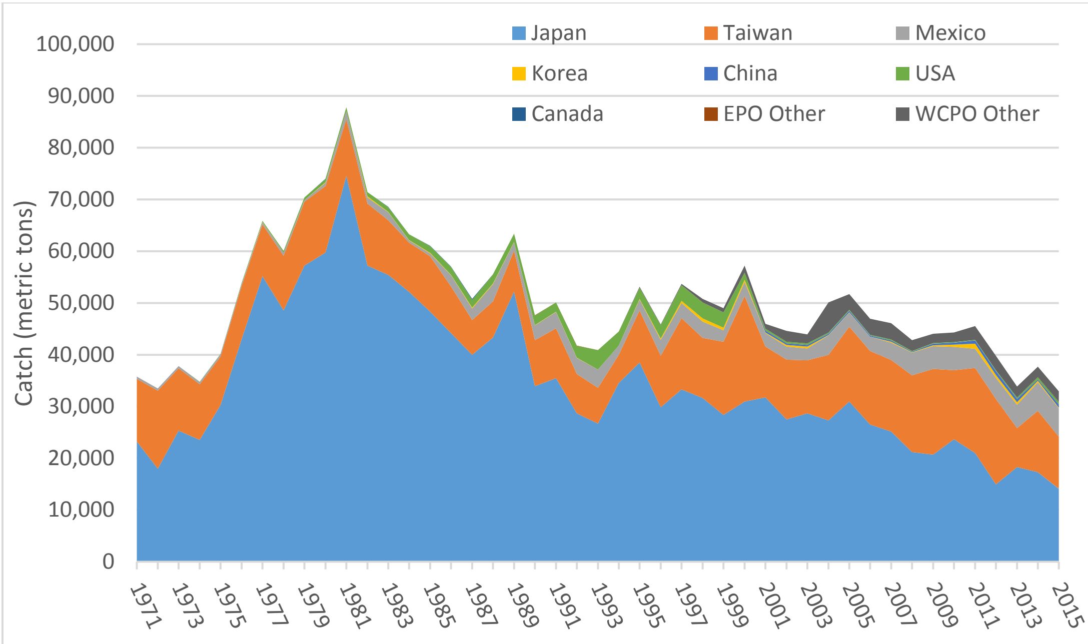

Figure 1E. Total catch (total dead removals) of North Pacific blue shark by nation or region.

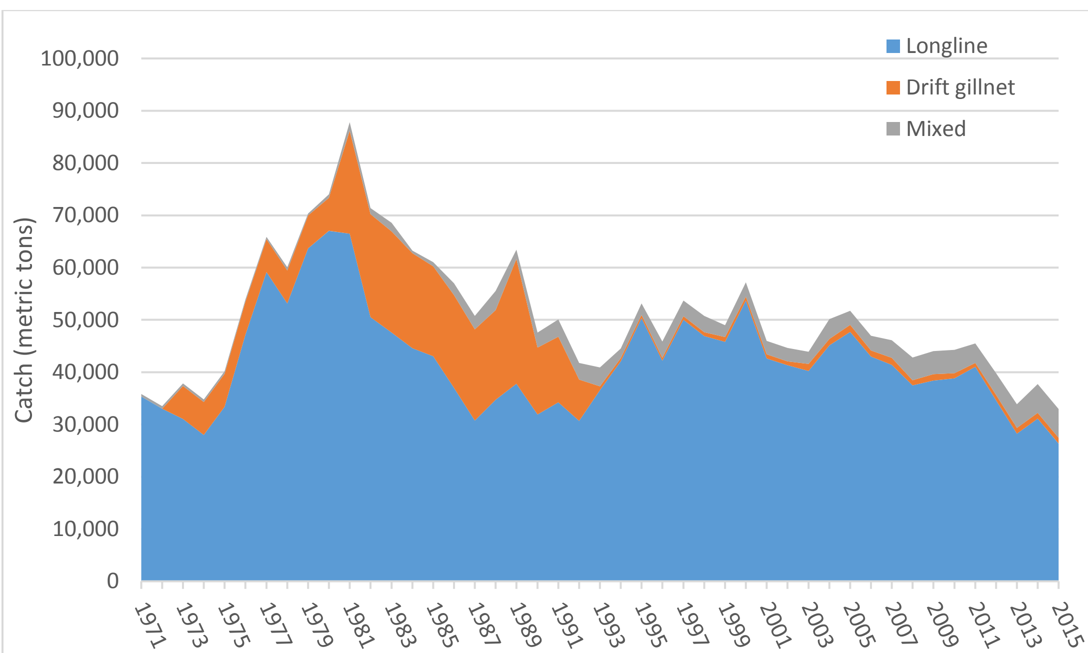

Figure 2E. Total catch (total dead removals) of North Pacific blue shark by gear type. Note: the mixed gear category includes purse seine, trap, troll, trawl and recreational.

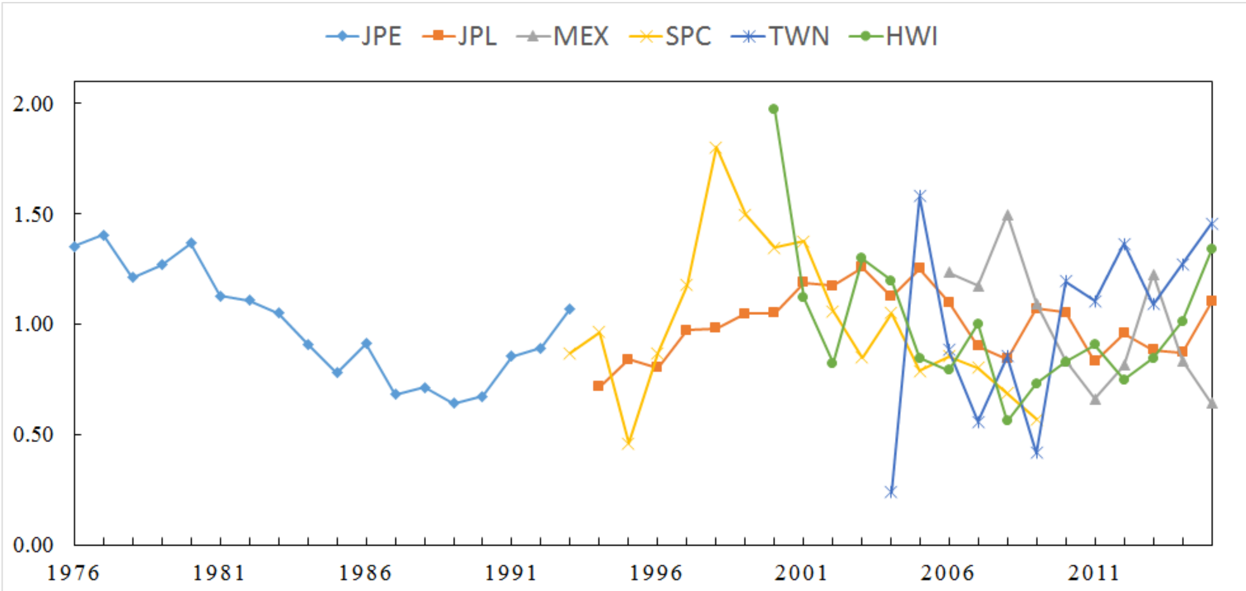

Figure 3E. Yearly changes in standardized CPUE of north Pacific blue shark during 1976 through 1993 (Japanese offshore shallow-set longline: **JPE**), and five standardized CPUE time series of blue shark between 1992 and 2015 (Japanese offshore shallow-set longline: **JPL**, Mexico longline: **MEX**, SPC observed longline: **SPC**, Taiwan large-scale longline: **TWN,** and Hawaii deep-set longline: **HWI**). All indices are normalized to a mean value of 1.

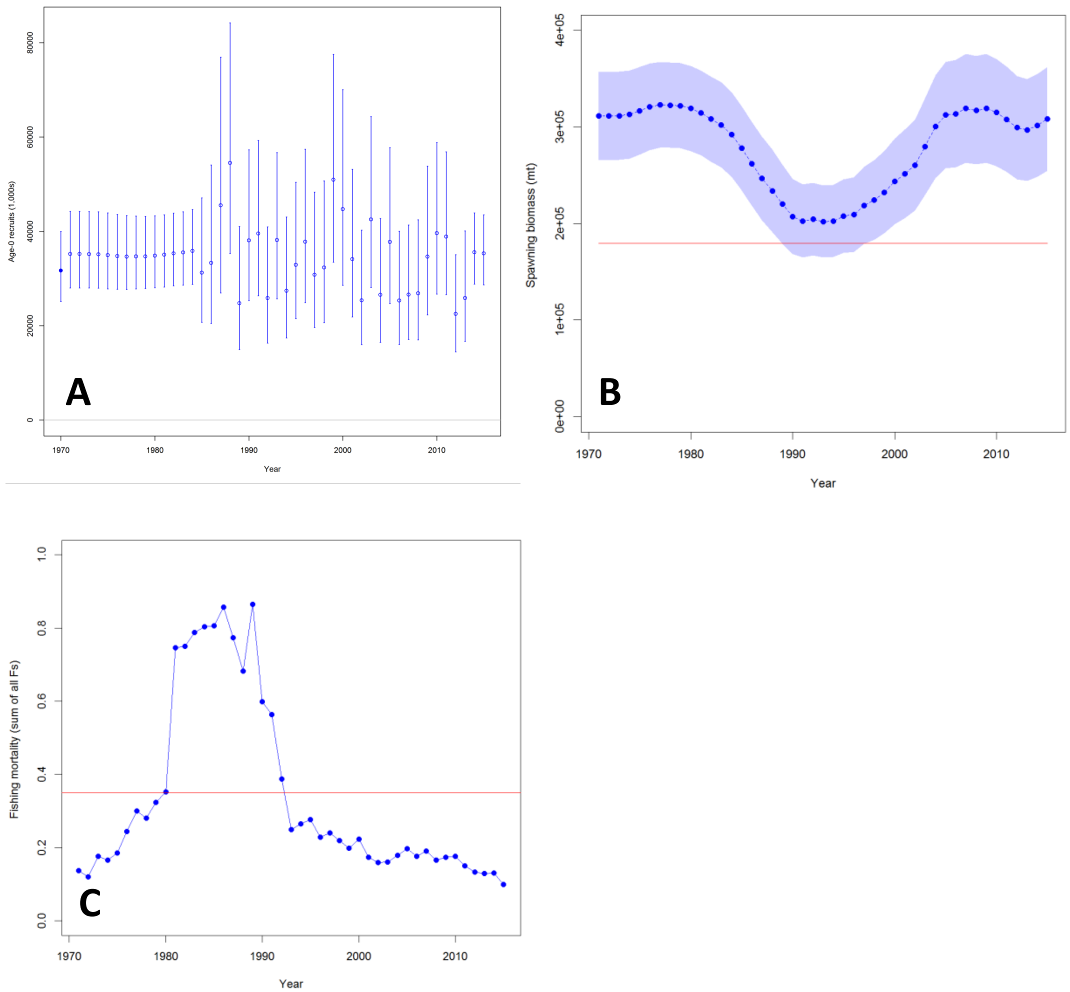

Figure 4E. Results of the SS stock assessment reference case model: (A) estimated age-0 recruits (circles) and 95% confidence intervals (vertical bars); (B) estimated female spawning biomass and 95% confidence intervals (blue shaded area); (C) estimated fishing mortality (sum of F's across all fishing fleets). Red solid lines indicate the estimates of SB_{MSY} and F_{MSY} in (B) and (C), respectively.

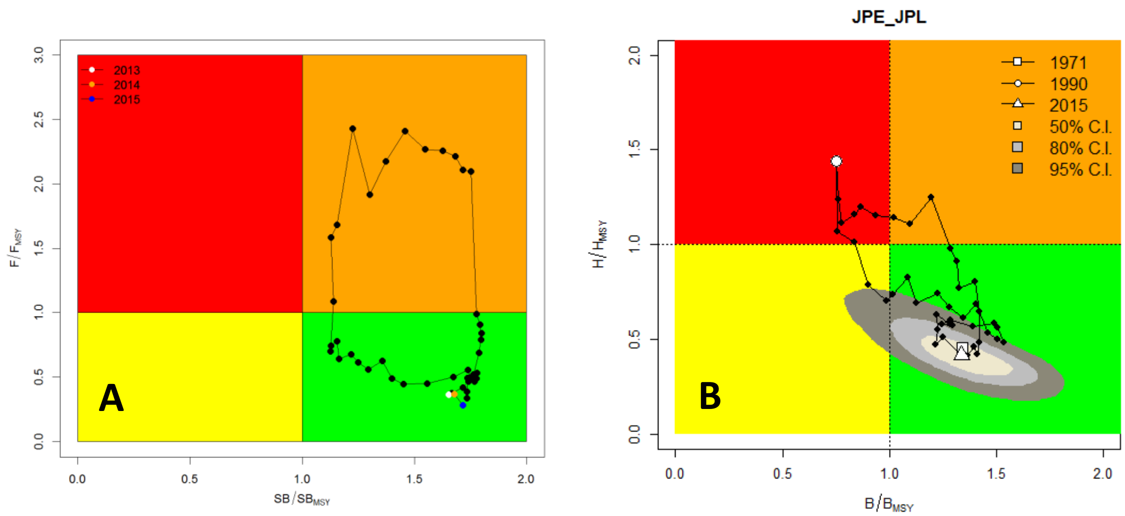

Figure 5E. Kobe plots of the trends in estimates of relative fishing mortality and biomass of North Pacific blue shark between 1971-2015 for the reference case of (A) the SS stock assessment model, and (B) the BSSPM stock assessment model.

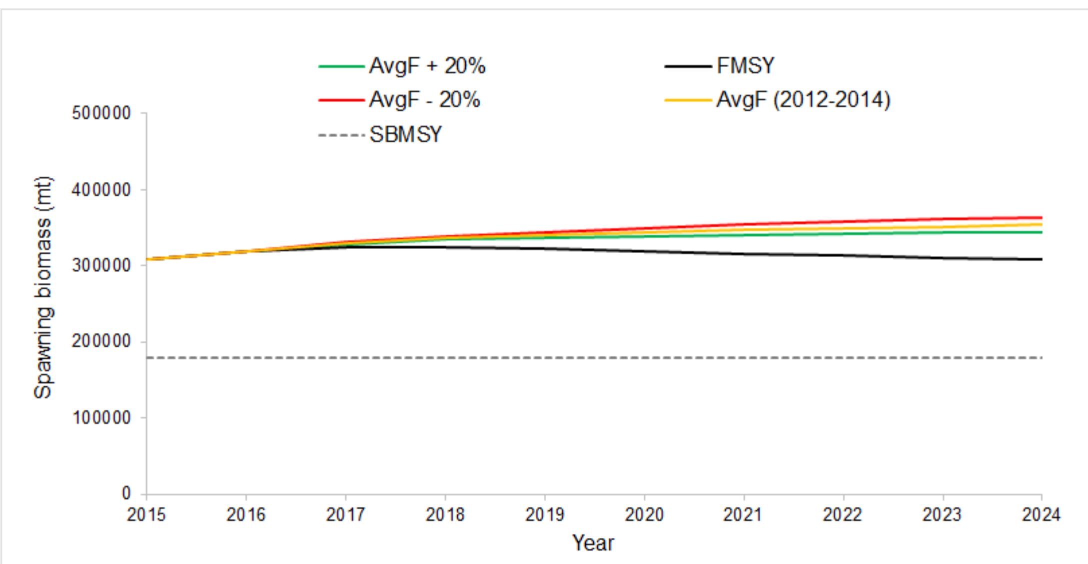

Figure 6E. Comparison of future projected north Pacific blue shark spawning biomass under different *F* harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* fishing mortality was based on the average from 2012-2014.

1 Introduction

Blue shark (*Prionace glauca*) is considered a highly migratory species (HMS) under the United Nations Convention on the Law of the Sea (ANNEX I)[1]. They are a commonly occurring species found primarily in the photic zone of temperature and tropical waters around the world. Blue shark populations are impacted by many fisheries as both a target and non-target component of catches, and their flesh is commonly consumed.

Historically, blue shark were caught as bycatch in fisheries targeting other species, primarily high seas tuna and swordfish fisheries. However, as new processing techniques have developed, it has led to new markets, particularly in Asia (Clarke et al., 2007) and Mexico (Sosa-Nishizaki et al., 2002). As a result of new food products like surimi, fishing fleets have probably been targeting blue shark for at least a decade. Up through the 1980's shark catch was only loosely monitored and often aggregated as "shark" in vessel logbooks and landings receipts, but starting in the 1990's conservation concerns about fisheries bycatch motivated the development and expansion of fishery observer programs and better record keeping.

To address uncertainty about the conservation status of high seas shark stocks in the North Pacific Ocean the International Scientific Committee for Tuna and Tuna-like Species (ISC) created a Shark Working Group (SHARKWG) in 2011 to begin compiling the necessary information to conduct stock assessments. The SHARKWG conducted its first assessment of blue shark stock status in the North Pacific in 2013 and followed up with an update in 2014 to address requests from the Western and Central Pacific Fisheries Commission (WCPFC) about the former assessment. Upon adopting the 2014 assessment, the ISC and WCPFC concluded that the stock was well above B_{MSY} and fishing mortality below F_{MSY} as of 2011, and had been since the mid-1990s. The 2014 assessment was conducted using both a fully-integrated size-structured assessment model and a surplus production model. The surplus production model was the primary assessment model from which stock status conclusions were drawn due to uncertainty about the quality of size composition data available at the time, and the need to conduct more biological research on the stock-recruitment relationship. The SHARKWG had not fully examined the size data and explored fishery definitions and selectivities. In addition, due to a lack of understanding of the low fecundity stock recruitment relationship and its application to blue sharks, there was incomplete specification of the model with respect to stock-recruitment relationships. Thus, the primary objective moving forward from that assessment was to improve data and model fitting and conduct biological research to support the development of a more defensible size-structured assessment using a fully-integrated model in 2017.

This document presents the results of the ISC SHARKWG's stock assessment of blue shark in the North Pacific Ocean using a fully integrated size-structured model. Time-series data updated through 2015 (catch, relative abundance, and sex-specific length composition from multiple fisheries), new biological information, and research into parameterization of a low-fecundity stock recruitment relationship (LFSR) were available and enabled development of an improved size-structured model. The SHARKWG also conducted a series of models using a Bayesian Surplus Production Model to facilitate comparison with the 2014 assessment.

[1] United Nations Convention of the Law of the Sea as of 10 December 1982.
http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm

2 Background

Blue shark relative abundance is highest in temperate pelagic zones and decreases in neritic and warmer tropical waters, as well as cooler waters at latitudes higher than approximately 50 degrees. In the eastern North Pacific, they spend most of their time in the mixed layer, with forays as deep as 400 m while occupying temperatures from 14-27 °C predominantly (Weng et al., 2005). In the southwest Pacific, they have shown a similar preference for surface waters but with occasional dives in excess of 980 m, while occupying comparable water temperatures to those in the eastern North Pacific (Stevens et al., 2010). Within the North Pacific, males and females smaller than 50 cm precaudal length (PCL) co-occur on the parturition grounds between approximately 35 and 40 °N. The habitat for subadults diverges between subadult females (35 and 50 °N) and males (30 and 40 °N) at around 100-150 cm PCL. The subadult sharks occur in the lower latitudes and adult habitat is believed to be more southerly with mating thought to occur in pelagic waters between 20-30 °N (Nakano, 1994).

2.1 Biology

2.1.1 Stock structure

Within the Pacific Ocean blue sharks are found in both hemispheres, with no genetic evidence of distinct hemispheric populations (King et al., 2015; Taguchi et al., 2015). However, their abundance is low in the tropics, and mark-recapture data have not documented movements across the equator (Sippel et al., 2011; Stevens et al., 2010; Weng et al., 2005). The SHARKWG concurs that current evidence justifies consideration of two distinct populations in the northern and southern hemisphere for stock assessment purposes.

2.1.2 Reproduction

Sex-specific length-frequency data suggests mating occurs in middle latitudes (20-30 °N) and pupping occurs between 35-45 °N in the western Pacific and 25-50 °N in the eastern Pacific (Sippel et al., 2016). Mating scars and fertilized eggs suggest mating occurs from June to August (Suda, 1953), and this is corroborated by monthly changes in the observed gonadosomatic index (GSI) and maximum ova diameter from Nakano (1994) and Fujinami et al. (2017). Litter size ranging from 15-112 (mean 35.5) has been observed in the western North Pacific (Fujinami et al., 2017) and was larger than that ranging from 1-62 (mean 25.6) reported previously in the North Pacific (Nakano, 1994). Fujinami et al. (2017) also estimated an annual cycle of female reproduction, with the potential for a small percentage of females to reproduce less frequently, although prior research indicated a biannual cycle (Joung et al., 2011). Different gestation estimates range from 9-12 months (Cailliet and Bedford, 1983) and 11-12 months (Nakano, 1994; Fujinami et al., 2017). Overall, blue sharks are considered to be highly productive relative to other pelagic sharks based on their maturation time and fecundity (Cortés, 2002; Smith et al., 1998).

2.1.3 Growth

Pups are born at an estimated 40-50 cm fork length (FL; ~36 cm PCL) (Joung et al., 2011; Fujinami et al., 2017), and adults reach a maximum length of 380 cm total length (TL) (Hart et al., 1973). Fifty percent of females are considered mature at 156.6 cm PCL (Fujinami et al., 2017), at around 5-6 years old (Yokoi et al., 2017) and the size and age at 50% maturity for males is 161 cm PCL and about 6 years old, respectively (Cailliet and Bedford, 1983; Fujinami et al., 2017; Nakano, 1994; Yokoi et al., 2017). Growth models for blue shark in the North Pacific have been estimated by the SHARKWG (Hsu et al., 2011; Yokoi et al., 2017) and others (Cailliet and Bedford, 1983; Tanaka et al., 1990; Nakano, 1994; Blanco-Parra et al., 2008). Factors including sample size and ageing techniques varied across the earlier attempts, but recent efforts of the SHARKWG are focusing on corroborating age reading across studies, standardizing ageing techniques, increasing sample sizes and collecting samples across a wider geographic range.

2.2 Fisheries

The primary source of known blue shark fishing mortality 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, although new Asian shark markets have been developing for over a decade and they are a common bycatch in these fisheries (Clarke et al., 2013). Blue shark bycatch is often discarded at sea, and the survivorship of those released depends on the condition of the released animals and environmental conditions. Factors including condition at release including capture methods, capture duration before fishing gear is retrieved, animal size, and handling at the boat affect survivorship of discards (FAO, 2017) although post-release mortality of blue sharks released alive from longline fisheries is reported to be low in the central Pacific Ocean (Musyl et al., 2011). A recent study of the Canadian pelagic longline fishery also showed that more than 85% of blue sharks survive after being hooked by a longline, and estimates of the post-release mortality rate based on pop-off tagging was 9.8% (Campana et al., 2016).

2.3 Previous stock assessments

The SHARKWG has conducted two previous stock assessments. Most recently, an assessment was conducted using two different assessment models, a Bayesian Surplus Production (BSP) model and a catch-at-length analysis using Stock Synthesis (SS) (ISC, 2014). The last assessment was the first assessment of the population using data from the entire North Pacific Ocean and was accepted as the best available information on north Pacific blue shark status and adopted for management. That assessment was an update to another analysis conducted by the SHARKWG previously using only a BSP model, which was not adopted for management and subsequently updated (ISC, 2013). Prior to these assessments, Kleiber et al. (2009) assessed the stock using data from the Western and Central North Pacific (excluding the eastern Pacific) also using a BSP model and a catch-at-length model.

3 Data

3.1 Spatial stratification

This assessment assumes a single stock in the North Pacific Ocean, north of the equator (Figure 1).

3.2 Temporal stratification

An annual (Jan 1-Dec 31) time-series of fishery data for 1971-2015 was used for the assessment.

3.3 Definition of fisheries

The SHARKWG estimated catches of many fisheries from different nations and member sources in an effort to understand the nature of fishing mortality. Eighteen different fisheries are defined (Figure 2).

3.4 Catch data

Catches (metric tons) were provided by ISC member nations and cooperating partners (Figure 3, Table 1). As in the previous assessment, 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 (Figure 3). Catches were comprised of total dead removals, which includes landings and discard mortalities.

3.4.1 Japan

Japan (JPN) provided estimated catch for four sectors of their longline fisheries categorized by the vessel tonnage and gear configurations (F4_JPN_KK_SH; F5_JPN_KK_DP; F6_JPN_ENY_SHL; F7_JPN_ENY_DP). Offshore (Kinkai; KK) and Distant-water (Enyo; ENY) longline was categorized as the vessels between 20 and 120 mt and larger than 120 mt respectively, and these two-longline catches were further categorized as shallow-set (SH) and deep-set (DP) based on the gear configuration (number of hook between floats; HBF, shallow-set - HBF < 7 and deep-set - HBF > 6). Since the landings of sharks were frequently underestimated due to the lower catches and the proportion discarded, when compared to teleost species such as tunas and billfishes, total catches including retained and discard/released catches were estimated using a product of the yearly standardized CPUEs and fishing effort. The estimates were separated into two time-series (1976-1993 and 1994-2015) because species disaggregated shark catch data is only available after 1993. In the estimation of the CPUE for the early period, season-area specific ratio of blue shark catch to the total shark catch was assumed to be the same for the period before 1994 as after 1993. The former CPUE (1976-1993) was estimated by Hiraoka et al. (2013a) and the latter CPUE (1994-2015) was updated by Kai and Shiozaki (2016). The former and latter catches were converted to biomass using the mean weight by season and area (Hiraoka et al., 2013a). The estimation methods and estimated catch amount can be found in Kai et al. (2014) and Kai (2016), respectively.

Japan also provided two driftnet catch time series (F8_JPN_LG_MESH; F10_JPN_SM_MESH) and catch for a miscellaneous coastal fishery (F9_JPN_CST_Oth). Prior to the United Nations moratorium on high seas, large-scale, pelagic drift net fisheries, implemented on 31 December 1992, Japanese high seas drift net fisheries in the North Pacific consisted of a large mesh fishery (F8_JPN_LG_MESH) targeting striped marlin and later albacore, and a small mesh fishery (F10_JPN_SM_MESH) targeting flying squid. The small mesh fishery was closed after December 1992, but Japan's large mesh driftnet fishery continues to operate within Japan's Exclusive Economic Zone. Japanese Large Mesh driftnet and coastal catches (coastal and other longline, set-net, bait fishing, others; F9_JPN_CST_Oth) were updated from 1994 to 2014 (Kai and Yano, 2016). Most of the Japanese shark catch data was reported in species aggregated form as "sharks", thus the ratios of the catch of blue shark to all, sharks by fishing gear were calculated using available species-specific landings data, and used to estimate the catch of blue shark. The Japanese coastal fishery catches prior to 1994 were provided in Yokawa (2012) and Kimoto et al. (2012).

3.4.2 Taiwan

Taiwan small scale longline catches were updated in Liu et al. (2016a). Large scale longline catch was estimated in two areas (0-25 degrees north of equator; and northwards of 25 degrees) using catch rates multiplied by effort in the two separate areas (Tsai and Liu, 2016).

3.4.3 South Korea

The Korean annual reports for the 2010 and 2011 WCPFC SC meetings indicated that the catch of major shark species reported in logbooks includes only blue and “other” sharks (reported as “porbeagle” sharks but since corrected to “other” sharks, Y. Kwon pers. comm.). Observer records for one year showed that 65% of the catches of major shark species was comprised of blue shark. The Korean annual report to the WCPFC in 2010 indicated that the average CPUE of blue shark caught by Korean longliners was 0.07 (number/100 hooks) based on observer data. Using the annual aggregated shark catch and effort data submitted to the ISC, and an average blue shark size of 30 kg, the average size caught in a comparable Japanese longline fishery, estimated CPUE by year in number of blue sharks per 1000 hooks caught by Korean longliners ranged from 0.0 to 0.89 which is comparable to the average CPUE obtained by the Korean observer data. For this assessment, Korean blue shark catch was assumed to be equal to North Pacific species-aggregated shark catch reported to the ISC (various shark species, code SHK). Beginning in 2013, a small amount of shark catch was reported as blue shark, which was added to the species-aggregated shark catch for the assessment time series. Kwon et al. (2017) developed an independent estimate of Korean longline blue shark catch for the period 1973-2015. Catch estimates were derived by applying area-specific CPUE based on observer data to Korean longline fishing effort recorded in logbooks. Careful review of the catch estimation methodologies and time series provided in Kwon et al. (2017)was not possible in time for the assessment; however, the magnitude and trends in the catch time series were quite similar to those developed by the SHARKWG.

3.4.4 China

China longline species-specific catch and effort were available for 2007-2015 and effort data were available back to 2001. The mean annual CPUE for 2007-2015 was applied to effort data for 2001-2006 to estimate catch for those years. It was assumed that effort of Chinese longliners in the North Pacific was minimal prior to 2001.

3.4.5 Canada

Blue shark bycatch in Canadian fisheries were estimated from a combination of observer and logbook records from 1979-2015 for groundfish, salmon, sardine, albacore, hake and squid fisheries (King and Surry, 2016). Minor adjustments to previous estimates were based on newly available information.

3.4.6 USA

Blue shark catch in US fisheries including the Hawaii-based longline fleet, as well as west coast drift gillnet, recreational, albacore troll fleets and small longline fisheries were provided in Kohin et al. (2016). Estimation methods were consistent with those used in the 2014 assessment, except the discard mortality rate estimate used for the Hawaii based longline fishery was updated, and catches from the albacore troll fishery (less than 1 mt annually) had not been previously estimated.

3.4.7 Mexico

Total blue shark catches were calculated from artisanal, commercial longline, and historical drift gillnet fisheries. Catches were sourced from annual fishery statistics yearbooks of SAGARPA (the Mexican fishery authority - provided by INAPESCA) from five Mexican States (Baja California, Baja California Sur, Sinaloa, Nayarit and Colima), published articles and reports (including grey literature) (Castillo-Geniz et al., 2017; Sosa-Nishizaki and Castillo-Geniz, 2016).

3.4.8 IATTC

IATTC provided estimates of blue shark bycatch in tuna purse seine fisheries in the north EPO. The methods were the same as for the last stock assessment (IATTC, 2013). The number of blue sharks caught in number from 1971-2015 was estimated from observer bycatch data, and observer and logbook effort data. Some assumptions regarding the relative bycatch rates of blue sharks were applied based on their temperate distribution and catch composition information. 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 blue shark bycatch rates by set type, year and area, as those of large vessels. Prior to 1993, when shark bycatch data were not available, blue shark bycatch rates assumed to be equal to the average of 1993-1995 rates were applied to the available effort information by set type, area and year. Numbers of sharks were converted to mt by applying an average annual weight estimate derived from blue sharks measured through the IATTC observer program.

3.4.9 SPC

Blue shark longline catches for non-ISC member countries in the WCPFC area north of the equator were estimated from SPC observer data holdings. Catches during 1995-2010 were estimated based on standardized CPUE values for each 5 x 5 degree cell multiplied by the effort reported in that cell summed on an annual basis. The non-ISC countries represented in the dataset include 12 countries, many of them that likely fish only south of the equator, thus it is believed that the north Pacific blue shark catch of non-ISC member countries represented in the WCPFC database is attributed to Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea and Vanuatu. Total dead removals are assumed to be the same as longline catches. For 2011-2014 the reported effort in the North Pacific (publically available Category 1 data; https://www.wcpfc.int/node/4648) was multiplied by the 2000-2010 average CPUE based on the estimated catch for non-ISC members divided by total effort data for the North Pacific.

3.5 Indices of relative abundance

Indices of relative abundance that were used in this assessment were developed with fishery data from five nations or information sources (Figure 4, Table 2). Three of these abundance indices were used in the previous assessment and updated with data through 2015, one was used in the 2014 assessment but and an update was not available, and one new index was developed by Mexico. The SHARKWG considered all available abundance indices including others developed by SHARKWG members and some from published documents, and rated each for consideration in this assessment using the same criteria established in the 2014 assessment, including spatio-temporal coverage of the data, statistical soundness and other characteristics (Table 3).

3.5.1 Reference case abundance indices

The reference case abundance indices were based on the Japan shallow-set longline fishery for “early” and “late” time periods, 1975-1993 and 1994-2015, respectively. The early abundance index was estimated by Hiraoka et al. (2013b), and unchanged from what was used in the 2014 BSH assessment. The index for the late period was updated to include data though 2015 (Kai and Shiozaki, 2016). CPUE was standardized using a generalized linear model (glm) with negative binomial error distributions. Standardization of the late index including investigation of the effects of the 2011 Great East Japan Earthquake and resulting tsunami and found little concern with continuing to use it as a continuous index, and no reason to break up the late time-series. As in the 2014 assessment, the SHARKWG considered these indices to be the best indicators of stock abundance based on their broad spatio-temporal coverage, statistical soundness of the standardization process, size and sex composition, and larger catch relative to other fisheries.

3.5.2 Alternative abundance indices

As in the 2014 assessment, only one abundance index for the early period was available, but multiple alternative indices for the late period were used in this assessment.

3.5.2.1 Hawaii longline

Abundance indices for the Hawaii deep-set and shallow-set longline fisheries were developed with delta lognormal models using observer data. Indices from the 2014 assessment (Walsh and DiNardo, 2014; Walsh and Teo, 2012) were updated through 2015 (Carvalho, 2016). The shallow-set fishery was impacted by closures from 2001-2004 due to bycatch concerns, but the deep-set fishery was not similarly affected. The index for the deep-set fishery was regarded a better option as an alternative abundance index.

3.5.2.2 Taiwan longline

This index was updated through 2015 using the same delta lognormal glm model with observer data from the Taiwanese large scale longline fisheries (Tsai and Liu, 2016).

3.5.2.3 Mexico longline

An abundance index was developed with glm models using observer data from the Mexican longline fishery in the Pacific (Fernandez-Mendez et al., 2016). The proportion of zero catch was relatively small (~4%), so commonly used zero-inflated methods were not considered necessary and the index was developed using a Gaussian link function.

3.5.2.4 SPC longline

The same relative abundance index developed with longline observer data during 1993-2009 for the 2014 assessment was included (Rice and Harley, 2014).

3.6 Catch-at-length

Length composition data were provided for different fisheries from Japan, Taiwan, South Korea, China, USA and Mexico. Sex-specific data (including unknown sex) 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 precaudal length (PCL) using fishery specific conversion equations if available, or the following agreed upon conversion equations.

PCL = (FL x 0.894) + 2.547

PCL = (TL x 0.748) + 1.063

PCL = (AL x 2.462702) + 12.7976

The coordinates of where the samples were taken was reported when possible in order to investigate spatially-explicit size and sex structure. Some data were provided with exact coordinates whereas some were summarized into spatial blocks (1° x 1° , 5° x 5° , or 20° x 10°) (Sippel et al., 2016). For the assessment, sex-specific size data were grouped by fishery.

3.6.1 Japan

Japan provided blue shark size data from the following fishery data sources: Kinkai shallow-set longline (Hiraoka et al., 2011), research and training longline (Ohshimo et al., 2014, 2016), small scale coastal longline (Kimoto et al., 2012), the longline observer program, and drift gillnets (Yokawa, 2012). Size data from longline gear comprised 97% of all Japanese size data and they were divided into shallow-set longline (shallow LL) and deep-set longline (deep LL) based on operational patterns (e.g., fishing at night or during the day, target species, fishing depth). Size data categorized as "Kinkai shallow" included data from shallow-set research and training vessels, a shallow-set longline observer program, small scale coastal shallow-set longlines, and Kinkai-shallow longliners that fished at night and targeted sharks and swordfish. Size data categorized as "Kinkai deep" included data from deep-set research and training vessels, deep-set longline observers, and deep-set small scale longliners that fished during the day for tunas. Size data from other Japanese fisheries were categorized as "Enyo-deep". Size data from the large mesh drift gillnet fishery was also provided.

3.6.2 Taiwan

Size data of large scale (distant water) longliners collected by observers were available for 2004 to 2014 (Liu et al., 2016b), as were size data of small scale longliners collected by observers from 2014-2015 (Liu et al., 2016a).

3.6.3 South Korea

Lengths measured by observers on South Korean longline vessels were provided from 2005-2008 and 2013-2014. The majority of sampling prior to 2008 was from the WCPO, but starting in 2008 sampling effort moved to the EPO (Kim et al., 2016).

3.6.4 China

Size data for 2146 blue sharks measured by observers on Chinese longline vessels during 2009-2015 were provided.

3.6.5 USA

Size and sex composition data collected by observers in the Hawaii-based longline fisheries (deep- and shallow-set) as described in Walsh and Teo (2012) and Sippel et al. (2014), and the US West Coast drift gillnet fishery (Teo et al., 2012) were included in the assessment.

3.6.6 Mexico

Size data were collected by observers opportunistically deployed in Mexico's Ensenada and San Carlos based longline fleets during 2006-2014 (Castillo-Geniz et al., 2017).

4 Integrated model description

4.1 Stock Synthesis software

For the integrated modeling efforts, the SHARKWG agreed to use a length-based, age-structured, forward-simulation population model conducted using Stock Synthesis (SS), version 3.24F (Methot, 2009; Methot and Wetzel, 2013) in addition to a BSP model to examine the north Pacific blue shark stock status. 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 both age- and size-structure in the population. Some SS features include incorporating ageing error, growth estimation, a spawner-recruitment relationship, sex-specific biological parameters and sex-specific fishery data. However, SS is currently the only model offering a stock-recruitment relationship specifically designed for low-fecundity species (Taylor et al., 2013) such as sharks. 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 blue shark 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 4.

4.2.1 Growth

Sex-specific estimates of growth from Yokoi et al. (2017) were assumed in the assessment. The length at age relationships were based on reading vertebrae samples from 620 females and 659 males, ranging from about 33 to 258 cm PCL (Yokoi et al., 2017). The standard assumptions made concerning age and growth in the SS model are; (i) the lengths-at-age are assumed to be normally distributed for each age-class; (ii) the mean lengths-at-age are assumed to follow a von Bertalanffy growth equation used in SS:

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

where L1 and L2 are the sizes associated with ages near a first age (A1) and second age (A2), L_∞ is the theoretical maximum length, and K is the growth coefficient. K and L_∞ can be solved for based on the length-at-age; L_∞ 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, L1 and L2 were fixed in the SS model, with K at 0.147 (0.117) y^{-1} for female (male) and L1 and L2 at 64.4 (68.2) cm and 244.6 (261.3) cm for A1 (age 1) and A2 (age 20), respectively (Yokoi et al., 2017). A CV of 0.25 was used to model variation in length-at-age. The value of CV was fixed to the common value used in other tuna and tuna-like species stock assessments. No attempt was made to estimate growth due to the uninformative nature of the size data to track cohorts through time.

All lengths listed are precaudal length (PCL) unless otherwise specified.

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, 24 yearly age-classes have been assumed, as age 24 approximates to the age at the theoretical maximum length of an average fish.

4.2.3 Weight-at-length

Sex-specific weight-at-length relationships were used to convert body length (PCL) in cm to body weight (W) in kg (Nakano 1994). The sex-specific weight-length relationships are:

$W = 5.388 \times 10^{-6} PCL^{3.102}$, for female and

$W = 3.293 \times 10^{-6} PCL^{3.225}$, for male.

These weight-at-length relationships were applied as fixed parameters in the model (Figure 5).

4.2.4 Natural mortality

Age and sex-specific natural mortality ogives were considered in the assessment. They were calculated based on the Method II proposed by Walter et al. (2016) and described in Semba and Yokoi (2016) (Table 5).

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 considered 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 spawning biomass, we assumed a logistic maturity schedule based on length with the size-at-50% maturity for females equal to 156.6 cm (Fujinami et al., 2017) (Figure 6). There is no information which indicates that sex ratio differs from parity throughout the lifecycle of blue shark.

4.3 Model structure

4.3.1 Input fishery data

The input fisheries and survey data consist of catch, catch/effort (CPUE) and sex-specific length-composition data (Figure 7). An annual (Jan 1-Dec 31) time-series of fishery data for 1971-2015 was used in this assessment.

4.3.2 Population and fishery dynamics

The model partitions the population into 24 yearly age-classes in one 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 1971-2015. The main population dynamics processes are indicated below.

4.3.3 Initial population state

It is not assumed that the blue shark population was at an unfished state of equilibrium at the start of the model (1971) as significant longline fishing occurred in the region from the 1950s and in Japanese coastal waters prior to that. SS has several approaches to start from a fished state and two of these were considered for this and the previous assessments.

The first approach involves assuming an initial equilibrium fishing mortality, while the second approach, that was used in this assessment, involved assuming an initial equilibrium catch. Whichever approach is used, it is necessary to specify a selectivity curve to apply either to the fishing mortality or the equilibrium catch. The SHARKWG decided that catch was easier to fix in a pragmatic way, i.e., if *F* was fixed, then catch can differ depending upon estimated abundance resulting in an unintended discontinuity (Carvalho et al., 2017). In this assessment, three values for equilibrium catch were assumed - 20,000, 40,000 and 60,000 mt. These values represent approximately 50%, 100% and 150% of the first four years' estimated catch.

The selectivity estimated for one of the Japanese fleets (F4 JPN_KK_SH) was used for the equilibrium catches as it dominated catches in the early years and its selectivity was not extreme towards small or large fish.

The population age structure and overall size in the first year is determined as a function of the estimate of the first year's recruitment (R_1) offset from virgin recruitment (R_0) - the initial 'equilibrium' fishing mortality discussed above - and the initial recruitment deviations. As the size data were found to be uninformative about initial depletion and recruitment variation, only a small number (five) of initial recruitment deviates was estimated.

4.3.4 Recruitment and Low-fecundity spawner-recruitment relationship (LFSR)

In this model "recruitment" is the appearance of age-class 1 fish. The results were derived using one recruitment episode per year, which is assumed to occur at the start of each year. Annual recruitment deviates from the recruitment relationship were estimated, but constrained reflecting the limited scope for compensation given estimates of fecundity. As in the previous ISC blue shark stock assessment, a survival based spawner-recruitment function was used (Taylor et al., 2013) which is referred to as the Low Fecundity Spawner Recruitment relationship (LFSR).

Recruitment (R_y) in each year is then defined as:

$$R_y = S_y B_y$$

where B_y is the spawning output in year y and S_y is the pre-recruit survival given by:

$$S_y = \exp\left(-z_0 + (z_0 - z_{min})\left(1 - \left(\frac{B_y}{B_0}\right)^{\beta}\right)\right),$$

and where:

$$z_0 = -\log\left(\frac{B_y}{B_0}\right),$$

and where R_0 is the recruitment at equilibrium, resulting from the exponential of the estimated $\log(R_0)$ parameter, and $B_0$is the equilibrium spawning output.

$z_{min} = z_0(1 - s_{Frac})$ is the limit of the pre-recruit mortality as depletion approaches 0, parameterized as a function of s_{Frac} (which represents the reduction in mortality as a fraction of z_0); and, Beta (β) is a parameter controlling the shape of density-dependent relationship between spawning depletion and pre-recruit survival. During the previous ISC blue shark stock assessment, little information regarding the choice of the parameters to define the stock recruitment relationship was available.

In the way that the LFSR is set up in SS, values of β < 1 has survival increasing fastest at low spawning output (concave decreasing survival), whereas β > 1 has the increase in survival occurring fastest closer to the unfished equilibrium (convex decreasing survival). As observed by Rice et al. (2014) it is unlikely that blue shark survival would decrease fastest at low stock size; instead it is reasonable to expect that for a low-fecundity species, offspring survival would decrease faster due to competition when the population approaches carrying capacity (β > 1). Then, in the previous stock assessment Rice et al. (2014) considered a wide range of LFSR shapes which gave similar productivity to that assumed in the production model developed simultaneously at that time. The selected values were 0.1, 0.3 and 0.5, for s_{Frac} and 1, 2 and 3 for β.

Kai and Fujinami (2017) applied the simulation method developed by Mangel et al. (2010) to estimate probable values of stock-recruitment steepness (h) for a Beverton-Holt stock-recruitment curve for north Pacific blue shark. Results indicated that the mean steepness (h) was μ_h = 0.670 with a standard deviation of σ = 0.073 (Figure 8). In the reference case model, the SHARKWG did not attempt to estimate β or s_{Frac} inside the stock assessment model because it is a task harder than estimating h due to the extra parameter involved. However, using equations from Taylor et al. (2013) and the information presented in Kai and Fujinami (2017), s_{Frac} and β were calculated as s_{Frac}= 0.391 and β = 2 (Figure 8). These values match the steepness of the Beverton and Holt model with h = 0.670, and are most consistent with the life history information available for blue sharks. In addition, the model assuming these values for s_{Frac} and β had better fit when compared to models that used other possible combinations (e.g. s_{Frac}= 0.391 and β = 3) (Carvalho et al., 2017).

In order to examine the effects of assuming an alternative stock recruitment relationship, sensitivity analyses were conducted using alternative stock recruitment relationship assumptions (see section 5.2.5).

Annual recruitment deviations were estimated from the information available in the data. The central tendency that penalizes the log (recruitment) deviations for deviating from zero was assumed to sum to zero over the estimated period. Recruitment variability (Sigma-R) - the standard deviation of log recruitment - was fixed at 0.3. A log-bias adjustment factor was used to assure that the estimated mean log-normally distributed recruitments were mean-unbiased. SS allows for a user-defined fraction of the log bias adjustment implied by the specified Sigma-R to be consistent with the estimated variability of the recruitment deviates.

The log of R_0 and annual recruitment deviates were estimated by the model. The offset for the initial recruitment relative to R_0 was estimated in the model. The deviations from the stock-recruitment relationships were estimated in two parts: (1) early period recruitment deviates for the 5 years prior to the period before the bulk of the length composition information (1985-1989); and (2) the main recruitment deviates that covered the period 1990-2014.

4.3.5 Selectivity curves

A double-normal functional form was assumed for all selectivity curves with an offset of the peak and scale estimated for sex-specific differences in selectivity that were evident in the data. Selectivity is fishery-specific and temporal variations in selectivity were captured by time blocks employed for F8 (2011; 2006-2014; 2015), F14 (1990-2005; 2006-2015), and F16 (1995-2005; 2006-2015). Time blocks were used to account for differences in data fishery operations, data collection procedures or apparent changes in composition across time. A cubic spline was used for fitting to size composition data for F17, since it was not possible to obtain model solutions using the double-normal functional form due to extreme peaks in the size-composition data. The parameterization of the cubic spline function estimates a starting and ending gradient and a selectivity value at each node using a smoothing function to connect the nodes (cubic spline selectivity curve). Given its flexibility, the benefit of this function is not just to increase additional process but also reduce the potential misfit of size compositions without introducing too many highly-correlated nodes. Selectivity patterns of fisheries without size composition data were mirrored to (assumed equal to) the selectivity patterns of fisheries with similar operations and areas for which a selectivity pattern was estimated. Mirrored selectivity patterns were based on expert opinions of members of the Working Group (Table 6).

4.3.6 Parameter estimation and uncertainty

Model parameters were estimated by minimizing the negative log-likelihoods of the data plus the log of the probability density functions of the priors, and the normalized sum of the recruitment deviates estimated in the model. For the catch and CPUE series, lognormal likelihood functions were assumed while a multinomial function was assumed for the size data. The catch data are assumed to be unbiased and relatively precise, so that the standard error of 0.05 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, the first of which used arbitrary starting values for most parameters. This analysis (i.e. likelihood profile tests) was conducted as a quality control procedure to ensure that the model was not converging on a local minimum. The SS control file, BSH.ctl, documenting the phased procedure, initial starting values and model assumptions is included in Appendix A.

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.

4.3.7 Data weighting

Many of the time series of size compositions by sex suffered from low sample sizes and inconsistencies across years. An annual sample size proportional to the number of fishing trips was assumed, with a max 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. If the data weighting is changed, the balance between the different data sets is changed, and thus the parameter estimates change. Punt (2017) provided a comprehensive review and a comparison of various iterative re-weighting methods for length composition data. The iterative re-weighting approach attempts to reduce the potential for particular data sources to have a disproportionate effect on total model fit, while creating estimates of uncertainty that are commensurate with the uncertainty inherent in the input data.

In this stock assessment a two stage Francis (2011) data weighting approach was used. In stage one, a minimum average standard error (SE; on the natural log scale) for each CPUE series was assumed. In stage two, the McAllister and Ianelli (1997) 2 method (using the harmonic mean) was applied to estimate the effective sample size of each length composition data from the residuals of the SS model fit to the data.

Stage 1. The relative CPUE to its mean was assumed to have log-normally distributed errors with standard error (SE) in log-space (log(SE)) which was approximated as sqrt (log(1+CV^2)). The log(SE) of each CPUE was estimated by the statistical model in the standardization process. The estimated log(SE) only captures observation error within the statistical model but it does not reflect the inherent process error between the unobserved vulnerable population and the observed CPUE. Therefore, a minimum average log(SE) for each CPUE of 0.1 was assumed. If the average log(SE) for each CPUE was smaller than 0.1, the estimated log(SE) was scaled to 0.1 by adding a constant value to the time series of estimated log(SE). If the average estimated log(SE) was larger than 0.1 the value was not changed.

Stage 2. After an initial model run with the input CVs adjusted for each CPUE as described above, the input sample sizes for the length composition data for fleets F1, F3, F4, F5, F7, F8, F14, F16, and F17 were adjusted one time with variance adjustment multiplication factors so that the sample size entered for each length composition data set was equal to the effective sample size obtained using the McAllister and Ianelli (1997) 2 method.

4.3.8 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 diagnostic 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 create a dynamic model of all the available data that fit the data well 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 to 6 again until internally consistent model is achieved;
7. Re-weight the data as needed.

The model selected as the reference case used: the CPUE series recommended by the SHARKWG (JPN-early and JPN-late); the best practice approach for weighting size frequency data to ensure that the data did not overwhelm the abundance indices; sigma R of 0.3; initial catch fixed at 40,000 mt, and the combination of parameters for the LFSR of s_{Frac} = 0.391 and β=2.

4.3.9 Sensitivity analyses

A large number of alternative model configurations of different levels of complexity were explored in order to formulate a base model that would realistically describe the population dynamics of this stock and would balance realism and parsimony. A selected number of the most relevant alternate model configurations are described in the sensitivity analyses section (Section 5.2). These configurations include alternative assumptions regarding historical commercial removals of blue sharks, fishery selectivity, alternate values for natural mortality (M), SS parameterizations used in previous stock assessment, and using a different stock-recruitment relationship (Beverton-Holt model) or different LFSR parameters.

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).

4.4.1 Residual analysis

Residuals are examined for patterns to evaluate whether the model assumptions have been met. Many statistics exist to evaluate the residuals for desirable properties. One way is to calculate, for each abundance index, the 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 < 0.2) being indicative of a good fit.

4.4.2 Age-structured production model (ASPM)

The ASPM diagnostic is intended to evaluate the influence of data sets on absolute abundance (Maunder and Piner, 2015; Carvalho et al., 2017). This diagnostic may also be used to determine if a stock is recruitment-driven, fishery-driven, or a combination of both. The ASPM was 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 protocol provided in Minte-Vera et al. (2017) was followed:

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 mortality), set the recruitment deviates to zero (early recruitment and model period recruitments), and set the recruitment bias correction to zero (in order to achieve this in SS V3.24f the estimation phase of the recruitment deviates needs to be set to a large number, e.g. 50, and the maximum estimation phase needs to be set to a smaller value, e.g. 10);
4. fit the model to the indices of abundance only;
5. compare the estimated 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 data. It is not uncommon for indices to contain insufficient information to estimate the parameters of a stock assessment model. Indices may also be conflicting, and fitting therefore involves 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 parameters.

4.4.4 Retrospective analysis

Retrospective analysis was conducted based on the reference case with the same model configuration and parameter specifications to examine the consistency of the stock assessment results when sequentially eliminated the final year of data. The data were removed for each year up to four years from 2015 to 2012 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.

4.5 Future projections

Future projections from 2015 to 2024 were conducted on the reference case output assuming four harvest policies:

1. Low *F* scenario: relative fishing mortality rate decreases by 20% from the current level (average *F* for 2012-2014).
2. F_{MSY} scenario: relative fishing mortality rate is sustained at MSY level.
3. High *F* scenario: relative fishing mortality rate increases by 20% from the current level (average *F* for 2012-2014).

4. Status-Quo *F* scenario: fishing mortality rate is maintained at the current level (average *F* for 2012-2014).

Projections were run using the *Forecast* option available in SS. For the F_{MSY} scenario, the estimated value of F_{MSY} for the reference case was used. Time horizons of the projections were set at 5 and 10 years beginning with the terminal year (2015).

4.6 Bayesian surplus production model

A Bayesian State-Space Surplus Production Model (BSSPM) was also fitted to total catch and abundance indices included in the SS reference model. The BSSPM model was developed by Carvalho et al., (2016a) using Markov Chain Monte Carlo (MCMC) parameter estimation methods as opposed to the Sampling Importance Resampling (SIR) parameter estimation technique implemented by McAllister and Babcock (2006) to fit the Surplus Production Model (BSP2) used in the previous assessment. The objectives of running the BSSPM model were to; 1) facilitate comparison to the 2014 assessment, 2) to compare to the trend and scale of biomass estimated by the SS model in this assessment, and 3) to compare inferences about stock status with the SS model in this assessment. In addition to using the catch and abundance indices updated for this assessment, hyper-parameters of the BSSPM were initialized with the latest biological information. Details of the BSSPM modeling including exploration of alternate scenarios can be found in Kai et al. (2017a).

5 Results

5.1 Reference case model

The reference case model chosen was the one with the JPN-early and JPN-late CPUE series along with s_{Frac} = 0.391 and β = 2, natural mortality based on the Walter et al. (2016) method II using data from Yokoi et al. (2017), Sigma-R of 0.3 and initial catch fixed at 40,000 mt.

5.1.1 Estimated parameters and model performance

All estimated parameters in the reference case model were within the set bounds, and the final gradients of the model indicated that the model had converged onto a local or global minimum. Convergence to a global minimum was examined by randomly perturbing the starting values of all parameters by 10 percent and by randomly assigning the estimated phase (jitter option in SS). Improved fit would confirm that the models had not converged to the global solution. There is no evidence of substantial differences in the scaling parameter (R_0) and total likelihood showing a better fit in the reference 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 reference 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 9 and Table 7. The fit to the CPUE indices were summarized into two groups: (1) those in which indices contributed to the total likelihood (Japan-Early and Japan-Late), and (2) those in which indices did not contribute to the total likelihood (Hawaii, Taiwan, SPC, and Mexico). Results showed that the Japan-Early and Japan-Late abundance indices had RMSE < 0.2 and SDNR values < 1, which indicates that the models fit those CPUE indices well. However, all the other indices had values for RMSE > 0.2 and SDNR > 1, which indicates that those indices were not consistent with the other data included in the model.

The model fit the length modes in data aggregated by fishery and season fairly well given the estimated effective sample sizes (effN) (Figure 10), and the results of the estimated selectivity patterns were consistent with the assumed selectivity patterns (Figure 11).

Figure 12 presents the results of the likelihood profiling on log (R_0) for each data component. Detailed information on the changes in negative log-likelihoods (NLL) among the various fisheries' data are shown in Tables 8 and 9. Changes in NLL for each data component indicated how informative that data component was to the overall estimated model fit. Ideally, relative abundance indices should be the primary sources of information on the population scale in a model (Francis, 2011). The changes in NLL of abundance indices showed a reasonably concave shape and the minimum value (0) was close to that of total likelihood $\log(R_0)$ = 11.3.

Japan-Early and Japan-Late index fits showed the largest changes in NLL across values of $\log(R_0)$ among the abundance indices (Table 8). The changes in NLL were also high for Taiwan, although this index was not included in the total likelihood of the model. Japan-Early showed the largest change in likelihood across values of R_0, while Mexico showed the lowest change in likelihood across values of R_0 among all indices. The MLE estimate for log(R_0) of Japan-Early and Japan-Late matched a local minimum of 11.3 observed in the fleet combined likelihood profile for index data.

Overall, the changes in log-likelihoods among the nine length composition data sources were smaller than those from the abundance indices, over the range of log (R_0) values (Table 9). Two out of the nine fleets (Japan Kinkai-shallow and Japan Enyo-deep) had minimum relative negative log-likelihoods that occurred at 11.3.

There was a significant level of agreement between the length composition data and the abundance indices based on log (R_0) likelihood profiles. In other words, the generalized-size composition data did not stop the model from fitting the abundance data.

5.1.2 Estimated stock status and other quantities

In the reference case model, annual recruitment varied around 37,000,000 recruits during the assessment time period (Figure 13).

SS provides estimates of the MSY-related quantities. These and other quantities of interest for the reference case model and all one-change sensitivity analysis are provided in Table 10.

In the reference case model, estimates of female spawning biomass (SB) declined from 1971 to 1991, followed by an increase between 1995 and 2007 (Figure 14). More recently, SB slightly declined from 2009-2013, followed by an increase in the final two years (2014-2015). Over the course of the modelled time series, estimated fishing mortality increased abruptly in the late 1970s and early 1980s with a peak around 1989, in response to higher catches. For the last two decades, F showed a declining trend, with recent values being close to those observed in the beginning of the time series (Figure 15).

Degrees of stock depletion and overfishing in the reference case model were illustrated using the "Kobe plot" (Figure 16). Compared to MSY-based reference points, the current spawning biomass (SB_{2015}) is 71%

above SB_{MSY}, and the current fishing mortality ($F_{2012-2014}$) is 64% below F_{MSY}. The historical trajectories of stock status revealed that North Pacific blue shark had experienced some level of depletion and overfishing in previous years showing that the trajectories moved through the orange (overfishing) zone in the Kobe plots. However, in the last two decades, the stock condition returned into the Kobe green zone. By the standard terminology, this would indicate that the stock is not in an overfished state, and that overfishing is not occurring.

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 17).

5.2 Sensitivity analyses

5.2.1 Alternative assumptions about mortality schedule

In the previous ISC blue shark stock assessment, the estimator by Peterson and Wroblewski (1984) and the growth equation by Nakano (1994) were used in the reference case model, with the assumption of maximum age of 30. However, in the calculation by Rice and Semba (2014), the coefficient assigned for the dry weight (1.92) was mistakenly applied to wet weight of North Pacific blue shark, instead of that for the wet weight (1.28). The assessment presented here corrects this mistake and calculates age and sex-specific natural mortality based on the length-based method II from Walters et al. (2016) as described in Semba and Yokoi (2016).

We explored the sensitivity of the reference case model to alternative assumptions about the method used to calculate age and sex-specific natural mortality, specifically the Peterson and Wroblewski (1984) method using data from Yokoi et al. 2017 (Table 11). The results show that the model is sensitive to this assumption, with noticeably higher estimates of SB when using the alternate natural mortality schedules (see S1 in Table 10).

5.2.2 Alternative assumptions regarding initial catch

The results show that the model is only slightly sensitive to the value assumed to fix the initial equilibrium catch, and neither SSB nor depletion levels noticeably changed when alternative initial catches were assumed (see S2 and S3 in Table 10).

5.2.3 Alternative late CPUE series

Annual changes in SB varied among all four sensitivity analyses using the Japan-Early index in combination with alternative late CPUE series. However, all models showed that SB has increased in recent years (2013-2015) (Figure 18), and that the current stock status is in the green zone of the Kobe plot (Figure 19; and S4-S7 in Table 10).

5.2.4 Alternative SS model configuration (mimic 2014 blue shark SS model)

The sensitivity analysis using the SS model parameterization from the previous ISC blue shark stock assessment, showed similar trends in stock status when compared to the reference case model. However, the scale of estimated SB over time was higher (see S8 in Table 10)

5.2.5 Alternative assumptions of spawner-recruit relationship

The relationship used in the reference case model for this stock assessment is parameterized in terms pre-recruit survival (Section 3.4.2). The parameters governing the relationship, which may be estimated or fixed, are equilibrium recruitment (R_0), s_{Frac}, and β.

The sensitivity analysis with s_{Frac} = 0.391 and β estimated internally (estimated value = 2.122) shows similar stock status to that of the reference case model (see S9 on Table 9). The sensitivity analyses using a Beverton-Holt relationship assumed the following values for steepness: h = 0.459 (Maximum age=24 and 2 year reproductive cycle), h = 0.503 (Maximum age=20 and 2 year reproductive cycle), and h = 0.622 (Maximum age=20 and 2 year reproductive cycle). Overall, the results showed that under all the assumed values for the steepness parameter (h), the stock condition is in the green zone of the Kobe plot for at least the last two decades (Figure 20; see S10-S12 on Table 10).

5.2.6 Alternative assumptions of fishery selectivity

Selectivity misspecification can impact estimates of management quantities. It is common practice in stock assessments to assume asymptotic selectivity for at least one fishery to stabilize parameter estimation. If dome-shape selectivity is estimated for all gears, a 'cryptic' biomass phenomenon may arise, which may translate to population estimates of older fish that are not proportional to those observed through sampling efforts. For these cases, if one assumes that selectivity for one fleet is asymptotic, then estimates will likely be more precautionary (but generally producing poorer fits to the data).

In this assessment a sensitivity analysis was conducted to explore the impact of assuming asymptotic selectivity for one fishery (F17) on the MSY-related quantities and overall model performance.

Results showed that the model is slightly sensitive to assuming an asymptotic selectivity for one fishery. The estimates of the MSY-related quantities were very similar to those obtained in the reference case model (see S13 on Table 10). However, model fits to the size composition data were poorer than in the reference case model.

5.3 Retrospective analysis

The results of the retrospective analysis are shown in Figure 21. The trajectories of estimated spawning biomass showed no appreciable retrospective pattern and there was no consistent trend of over- or under-estimating spawning biomass. Given the small magnitude of the retrospective pattern, it was concluded that the reference case model was robust to the inclusion of recent assessment data and did not have a retrospective pattern of concern for estimates of spawning biomass.

5.4 Bayesian surplus production model

The reference case models from BSSPM (Kai et al., 2017a) and BSP2 (ISC, 2014) produced similar results, including estimated reference points and stock status (Figure 23). The BSSPM B and H trajectories showed that the stock was in an overfished state and overfishing was occurring from the early 1980's through early 1990's (Figure 22), and has since recovered and remained near 1971 levels of B and H since the early 2000's. B_{2015}/B_{MSY} was 1.34 and H_{2015}/H_{MSY} was 0.41 (Figure 23).

5.5 Future projections

Future projections showed that maintaining current fishing mortality levels results in much higher levels of SB than SB_{MSY} throughout the future projection periods (Figure 24; Table 12). Since F is currently much lower that F_{MSY}, increasing F to F_{MSY} results in a decreasing SB trend, as expected.

6 Stock status and conservation conclusions

6.1 Status of the stock

The current stock assessment provides the best available scientific information on North Pacific Blue shark stock status. The assessment uses a fully integrated approach in Stock Synthesis with model inputs that have been greatly improved since the previous assessment. The main differences between the present assessment and the 2014 assessment are: 1) use of SS with a thorough examination of the size composition data and the relative weighting of CPUE and composition data; 2) improved life history information, such as growth and reproductive biology, and their contribution to productivity assumptions; 3) an improved understanding and parametrization of the LFSR; 4) catch, CPUE and size time series updated through 2015; 5) a suite of model diagnostics including implementation of an Age Structured Production Model implemented in SS. There remain some uncertainties in the time series based on the quality (observer vs. logbook) and timespans of catch and relative abundance indices, limited size composition data for several fisheries, the potential for additional catch not accounted for in the assessment, and regarding life history parameters. Continued improvements in the monitoring of BSH catches, including recording the size and sex of sharks retained and discarded for all fisheries, as well as continued research into the biology and ecology of BSH in the North Pacific are recommended.

While the results varied depending upon the input assumptions, extensive model explorations showed that the reference run had the best model performance and showed fits most consistent with the data. The CPUE indices used in the reference case were considered most representative of the north Pacific blue shark stock due to their broader spatial temporal coverage in the core distribution of the stock and the statistical soundness of the standardizations. Alternate CPUE series for the latter part of the time series produced different stock trajectories depending upon the index used, but in each case, median SSB during the last 3 years exceeded MSY. Using alternate assumptions on stock productivity (i.e. form of the LFSR relationship) also resulted in variation in the stock trajectories. For example, assuming stock productivity lower than supported by current biological studies, resulted in lowered spawning stock biomass relative to MSY.

Results of the reference case model showed that the spawning stock biomass was near a time-series high in the late 1970s, fell to its lowest level between 1990 to 1995, subsequently increased gradually to reach the time-series high again in 2005, and has since shown small fluctuations close to the time-series high (Figure 14). Stock status is reported in relation to maximum sustainable yield (MSY). Benchmark results are shown based on female spawning stock biomass. Spawning biomass in 2015 (SB_{2015}) was 72% higher than at MSY (Table 10; Figure 14). Female spawning stock biomass of blue shark in 2015 (SB_{2015}) was estimated to be 308,286 mt (Table 10; Figure 14). The recent annual fishing mortality ($F_{2012-2014}$) was estimated to be well below F_{MSY} at approximately 37% of F_{MSY}. The reference run produced terminal conditions that were predominantly in the green quadrant (not overfished and overfishing not occurring) of the Kobe plot (Figure 16).

6.2 Conservation information

These results 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 yet been established for pelagic sharks in the Pacific. Relative to MSY, the reference case with input parameter values considered most probable suggest that the North Pacific blue shark stock is not overfished and overfishing is not occurring.

Future projections under different fishing mortality (F) harvest policies (status quo, +20%, -20%, F_{MSY}) show that median BSH biomass in the North Pacific will likely remain above B_{MSY} (Table 12; Figure 24).

Improvements in the monitoring of blue shark catches and discards, through carefully designed observer programs and species-specific logbooks, as well as continued research into the fisheries, biology and ecology of blue shark in the North Pacific are recommended.

6.3 Limitations and research needs

6.3.1 Catch

There is substantial uncertainty in the amount of historical catches of blue shark. The SHARKWG spent substantial time and effort estimating historical catch, but more work remains to be done. In particular, two improvements were deemed important by the SHARKWG: 1) identify all fisheries that catch blue shark in the North Pacific (i.e., are there any fisheries that catch blue shark that may not have been identified by the SHARKWG); and 2) methods to estimate blue shark catches should be improved.

6.3.2 Abundance indices

Assessment results are highly dependent on the relative abundance indices used. All abundance indices used in this assessment were derived from fisheries-dependent information. Therefore, the SHARKWG recognizes the importance of continuing to work on improving the data sources and standardization methods used to develop these abundance indices.

A spatio-temporal (geo-statistical) model may provide an improvement over conventional time-series and spatially stratified models by yielding more precise and biologically interpretable estimates of abundance (Thorson et al., 2015). Kai et al. (2017b) applied a spatio-temporal model to analyze the seasonal spatio-temporal distribution of blue shark in the western North Pacific and showed significant variation across time and space. Kai et al. (2017c) also applied a spatio-temporal model to estimate length-disaggregated abundance indices of shortfin mako in the western North Pacific. Application of the spatio-temporal model to the standardization of the abundance indices for north Pacific blue shark has a high potential to improve the abundance index estimates. In future work, it is recommended that geo-statistical methods be explored and compared with the current models for abundance indices.

For the stock assessment presented here, the Working Group extensively discussed if there was any clear evidence of changes in fishing strategies in Japan's Kinkai shallow fishery data, and how to treat them properly in the standardization. There was consensus that targeting/fishing strategy shifts have probably occurred in the Kinkai shallow fleet, but the timing and magnitude of these shifts remains unclear. The group acknowledged Japan's in depth research efforts on this issue; however, further study regarding the existing standardization model's explanatory variable for targeting should be a priority for future work.

6.3.3 Length and sex composition

Preliminary information reviewed by the SHARKWG indicated that blue shark exhibit substantial size and sex structure patterns through space and time. Therefore, collection of composition data, including sex, is needed from all fleets.

6.3.4 Biological parameters

This assessment used updated biological parameters regarding the reproductive biology (Fujinami et al., 2017) to improve the accuracy of the stock assessment. However, there is still room for further improvements. For example, samples of large male and female sharks are insufficient to accurately estimate the growth parameters. Estimation errors of the growth curve may lead to incorrect natural mortality schedules and longevity, resulting in incorrect estimation of the intrinsic rate of increase (*r*) and steepness (*h*). In addition, too few samples for large females may result in an underestimation of the litter size, because litter size increases with maternal size (Fujinami et al., 2017).

Fujinami et al. (2017) concluded that most female blue sharks reproduce annually but a small portion of mature females may rest after parturition. Therefore, it is necessary to verify the annual reproductive cycle using other methods, such as by monitoring reproductive hormone levels.

Large-scale tagging studies throughout the North Pacific could help to provide estimates of age-specific natural mortality and a clearer understanding of migration patterns of blue sharks.

Finally, meta-analyses of the biological parameters in the North Pacific among ISC Members may be useful to improve accuracy of the estimated biological parameters. For all estimated life history parameters, research should be conducted on how these parameters vary in space and time.

6.3.5 Stock-recruitment relationship

Kai and Fujinami (2017) estimated the steepness of the North Pacific blue shark using updated biological parameters. However, estimation of the biological parameters is still highly uncertain due in large part to uncertain natural mortality pre- and post-recruitment. Lack of knowledge regarding natural mortality may cause an under-estimation or over-estimation of the steepness. Direct estimates of the natural mortality derived through a tagging study could help reduce the uncertainty.

In this assessment, steepness was estimated outside of the assessment model, based on the best available biological information. The low-fecundity stock recruitment relationships used were based on those steepness estimates, which in turn relied primarily on a few fundamental ecological assumptions surrounding the pre-recruit mortality and age-specific mortality of adults. The size (cohort) data included in the model served to verify the quantitative hypothesis regarding stock-recruitment relationships; however, the assessment model could not adequately estimate the parameters of the stock-recruitment relationship because of insufficient information on the stock depletion. Therefore, it is necessary to improve the accuracy of the estimation of the steepness outside of the assessment model until better information on age-specific natural mortality and stock depletion are available.

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9 Tables

Table 1. Time series of catch (total dead removals; metric tons) for different countries/data sources. The total catch time series was used in the BSSPM.

Year	Canada	China	IATTC	Japan	Korea	Mexico	Non-ISC	Taiwan	USA	Total
1,971	0	0	7	23,252	0	440	0	12,070	30	35,799
1,972	0	0	5	17,977	0	440	0	15,056	30	33,508
1,973	0	0	5	25,328	0	440	0	12,025	30	37,828
1,974	0	0	5	23,546	0	440	0	10,742	30	34,763
1,975	0	0	7	30,277	5	440	0	9,392	33	40,154
1,976	0	0	7	43,026	32	374	0	10,286	129	53,854
1,977	0	0	6	55,144	55	386	0	10,045	225	65,861
1,978	0	0	8	48,550	17	561	0	10,603	329	60,068
1,979	1	0	10	57,193	0	338	0	12,360	466	70,368
1,980	11	0	10	59,773	114	624	0	12,840	630	74,002
1,981	0	0	9	74,573	0	1,593	0	10,961	669	87,805
1,982	0	0	6	57,189	242	1,181	0	12,003	784	71,405
1,983	25	0	6	55,408	27	1,548	0	10,586	954	68,554
1,984	0	0	6	52,161	88	390	0	9,509	1,112	63,266
1,985	60	0	3	48,314	145	528	0	10,712	1,291	61,053
1,986	90	0	2	44,165	95	2,128	0	9,048	1,496	57,024
1,987	159	0	2	39,996	159	2,205	0	6,729	1,508	50,758
1,988	0	0	6	43,321	140	3,337	0	6,966	1,783	55,553
1,989	0	0	5	52,206	49	1,643	0	7,897	1,607	63,407
1,990	4	0	3	33,933	58	2,865	0	8,885	1,855	47,603
1,991	0	0	2	35,452	65	3,197	0	9,619	1,763	50,098
1,992	0	0	3	28,655	49	3,085	0	7,615	2,328	41,735
1,993	0	0	3	26,667	28	3,517	0	6,919	3,747	40,881
1,994	0	0	2	34,519	33	1,758	0	5,470	2,723	44,505
1,995	0	0	10	38,478	104	2,100	161	10,100	2,165	53,118
1,996	1	0	2	29,843	231	3,117	165	9,917	2,586	45,862
1,997	1	0	4	33,276	433	2,948	261	13,773	3,020	53,716
1,998	2	0	2	31,621	623	3,134	634	11,640	3,103	50,759
1,999	1	0	1	28,379	471	2,261	782	14,118	2,960	48,973
2,000	1	0	2	30,928	433	2,719	1,350	20,391	1,378	57,202
2,001	5	340	0	31,738	163	2,587	944	9,831	381	45,989
2,002	5	334	3	27,485	293	2,524	2,126	11,582	273	44,625
2,003	17	305	1	28,661	399	2,307	1,708	10,244	281	43,923
2,004	4	282	1	27,285	50	3,781	5,846	12,668	201	50,118
2,005	0	343	0	30,929	44	2,721	3,081	14,478	146	51,742
2,006	20	201	3	26,526	21	2,765	3,111	14,175	143	46,965
2,007	9	234	2	25,134	203	3,324	3,153	13,848	182	46,089
2,008	6	134	3	21,201	75	4,355	2,066	14,824	138	42,802
2,009	8	298	2	20,688	146	4,423	1,778	16,559	122	44,024
2,010	7	357	1	23,670	470	4,469	1,808	13,349	150	44,281
2,011	13	613	1	21,006	952	3,719	2,624	16,451	142	45,521
2,012	9	758	2	14,975	551	4,108	2,778	16,451	145	39,777
2,013	26	598	2	18,319	491	4,494	2,131	7,534	268	33,863
2,014	9	251	0	17,306	328	5,502	2,059	11,856	396	37,707
2,015	23	627	0	14,111	121	5,502	2,059	10,042	471	32,956

Table 2. CPUE time series (relative value to its mean) for different fleets and the coefficient of variations (CV). **JPE:** Japanese offshore shallow-set longline (1976-1993), **JPL**: Japanese offshore shallow-set longline (1994-2015), **HWI**: Hawaii deep-set longline (2000-2015), **MEX:** Mexico longline (2006-2015), **SPC:** SPC observed longline (1993-2009), and **TWN:** Taiwan large-scale longline (2004-2015).

Year	JPE-JPL		HWI		MEX		SPC		TWN	
	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV
1976	1.35	0.10								
1977	1.40	0.10								
1978	1.21	0.10								
1979	1.27	0.10								
1980	1.36	0.10								
1981	1.13	0.10								
1982	1.11	0.10								
1983	1.05	0.10								
1984	0.91	0.10								
1985	0.78	0.10								
1986	0.91	0.10								
1987	0.68	0.10								
1988	0.71	0.10								
1989	0.64	0.10								
1990	0.67	0.10								
1991	0.85	0.10								
1992	0.89	0.10								
1993	1.07	0.10					0.87	0.14		
1994	0.72	0.10					0.96	0.14		
1995	0.84	0.10					0.46	0.14		
1996	0.80	0.10					0.87	0.14		
1997	0.97	0.10					1.18	0.14		
1998	0.98	0.10					1.80	0.14		
1999	1.05	0.10					1.50	0.14		
2000	1.05	0.10	1.97	0.29			1.35	0.14		
2001	1.19	0.10	1.12	0.29			1.37	0.14		
2002	1.17	0.10	0.82	0.29			1.06	0.14		
2003	1.26	0.10	1.30	0.29			0.85	0.14		
2004	1.12	0.10	1.20	0.29			1.05	0.14	0.24	0.10
2005	1.25	0.10	0.84	0.29			0.79	0.14	1.58	0.10
2006	1.10	0.10	0.79	0.29	1.23	0.12	0.85	0.14	0.88	0.10
2007	0.90	0.10	1.00	0.29	1.17	0.12	0.80	0.14	0.56	0.10
2008	0.84	0.10	0.56	0.29	1.49	0.12	0.69	0.14	0.85	0.10
2009	1.07	0.10	0.73	0.29	1.09	0.12	0.57	0.14	0.42	0.10
2010	1.05	0.10	0.83	0.29	0.83	0.12			1.19	0.10
2011	0.83	0.10	0.91	0.29	0.66	0.12			1.10	0.10
2012	0.96	0.10	0.75	0.29	0.81	0.12			1.36	0.10
2013	0.88	0.10	0.84	0.29	1.22	0.12			1.09	0.10
2014	0.87	0.10	1.01	0.29	0.83	0.12			1.27	0.10
2015	1.10	0.10	1.34	0.29	0.64	0.12			1.45	0.10

Table 3: Characteristics of candidate abundance indices proposed to represent relative abundance of north Pacific blue shark (*Prionace glauca*) and criteria used to evaluate the indices.

	Hawaii Deep-set Tuna Longline	**Hawaii Shallow-set Swordfish Longline**	**Taiwan Large-scale Tuna Longline**	**Taiwan Small-scale Longline**	**Japan Early Offshore Shallow Longline (Hokkaido & Tohoku)**	**Japan Late Offshore & Distant Water (Hokkaido & Tohoku)**	**Japan Research and Training Vessel (Region 2)**	**SPC Observed Longline**	**Mexico Longline**
Use in 2017	**yes**	**no**	**yes**	**no**	**yes**	**yes**	**no**	**yes**	**yes**
Qualilty of Observations	Good because using observer data and has 10-20% coverage and discards recorded.	Good because using observer data with 100% coverage and discards recorded.	Good because based on observer data but the number of sets observed is low.	Catch data are representative but effort data were estimated. Based only on landed catch and not discards.	Relatively reliable because 94.6% reporting ratio filter applied; logbook data were more reliable after filtering. Data are based on self-reported information and blue shark catch was derived from aggregated shark catch.	Relatively reliable because 94.6% reporting ratio filter applied. Logbook reporting rates were validated using available research data.	Concerns about reporting rate post 2000 addressed by filtering.	Good because it was observer measured, but coverage low.	Good because it was observer measured, but coverage not uniform over time.
Spatial distribution	Relatively small (Areas 4 & 5)	Relatively Small (Areas 2 & 5)	Large geographic area (Areas 1-5)	Large geographic area (Areas 1-5)	Medium (Area 1 & 3)	Large (Area 1, 2, 3 and 4)	Relatively Small (Areas 2)	Southwest North Pacific (140E-180, 0-15N)	Relatively Small - Northeast Pacific off Baja California
Size range (approx. upper)	207 PCL (F); 225 PCL (M)	207 PCL (F); 225 PCL (M)	302 PCL (M and F)	240 PCL	no information	170 PCL	180 PCL	181 PCL	190 PCL
Size range (approx. lower)	132 PCL (M and F)	76 PCL (M and F)	40 PCL (F); 52 PCL (M)	68 PCL	no information	90 PCL	120 PCL, median 160 PCL	114 PCL	70 PCL
Statistical soundness	Yes. Diagnostics provided.	Yes. Diagnostics provided.	Yes. Diagnostics provided.	Yes. Diagnostics provided.	Yes. Diagnostics provided.	Yes. Diagnostics provided.	No. Strong patterns in residuals and departure from normality in qq plot; lacking some diagnostics (e.g. deviance table, CV's).	Diagnostics provided but some concerns raised.	Yes. Diagnostics provided.
Temporal coverage	2000-2015	2005-2015	2004-2015	2001-2010 (except 2004) - not updated	1976-1993	1994-2015	1993-2008 - not updated	1993-2009 - not updated	2006-2015

Table 3. Continued

Q Changes (due to management, fishing practices, etc.)	Not likely great because no major regulatory changes after the ban on finning in 2000. Shallow-set closure may have affected some deepset fishery effort during 2000-2003.	Likely due to the regulatory requirements to avoid reaching turtle take caps.	Ban finning from 2005 (probably limited effect on Q)	Ban finning from 2005 (probably limited effect on Q)	No regulation or gear changes.	No notable regulation and gear changes; potential targeting change.	Uncertain, changes in catchability are hard to determine.	Not likely but catchability changes hard to determine.	Not likely, but there was a summer closure imposed starting in 2012 that covers ~30% of the high blue shark catch season.
Fishery relative catch contribution	<1500 to 2000 mt annually (for deep and shallow sectors combined)		<500 mt/yr before 1999, ~800 mt annually since	>10000 mt/yr from 2004	19000-55000 mt/yr	13000-24000 mt/yr	~50 mt/yr	low	Ensenada:~1500 mt/yr
Comments		Closures in 2006, 2011 due to turtle take caps.	2015 observer coverage low in northern area.	No discard data; more confidence in late than early time series due to higher coverage.	Blue shark targeting may have changed over time. Standardization and filtering may have addressed these concerns.	Blue shark is a primary target species. Continued research recommended about capturing targeting practice in the CPUE.	Filtering may have addressed data quality issue. Spatio-temproal coverage may have been patchy. Further efforts to develop an index for this fishery are recommended.	In area of relatively lower blue shark density.	Spatio-temporal observer coverage could affect data aquality and should be explored. Considered best EPO index available. NEPO had anomalous warm conditions in 2014 and 2015.

Table 4. Key life history parameters used in the Stock Synthesis North Pacific blue shark stock assessment.

Parameter	**Value**
Natural mortality	Sex specific (see Table 5)
Reference age (a1)	1
Maximum age (a2)	20
Female at first age	4
Length at a1 (L1)	64.4 (Female)
	68.2 (Male)
Length at a2 (L2)	244.6 (Female)
	261.3 (Male)
Growth rate (K)	0.147 (Female)
	0.117 (Male)
CV of L1	0.25 (Female); 0.25 (Male);
CV of L2	0.1 (Female); 0.1 (Male);
Weight-at-length	$W=5.388 \times 10^{-6}L^{3.102}$ (Female);
	$W=3.293 \times 10^{-6}L^{3.225}$ (Male)
Length-at-50% Maturity	156.6 (Female)
Slope of maturity ogive	- 0.16 (Female)
Fecundity (Litter size; (4)eggs=a+b*L)	Proportional to body length
Slope of fecundity (b)	0.46
Intercept of fecundity (a)	-45.54
Spawner-recruit steepness (LFSR)	s_{Frac}= 0.391 and β = 2
Log of Recruitment at virgin biomass log(R0)	11.1358 (Initial value)
Recruitment variability (σ_R)	0.3
Initial age structure	5 yrs (1985-1989)
Main recruitment deviations	1990-2013
Bias adjustment	1990-2013
F ballpark for tuning early phases	0.2
F ballpark year	2013
F-Method	3 (hybrid)
Initial-F	0.315485 (Initial value) only Kinkai shallow (F4)

Table 5. Estimates of age-specific natural mortality used in the SS modeling reference case. The schedules are based on Method II proposed by Walter et al. (2016) and the Yokoi et al. 2017 life history data.

Age	Male	Female
0	0.728187	0.784575
1	0.491939	0.488427
2	0.382625	0.369896
3	0.319682	0.306121
4	0.278942	0.266551
5	0.250568	0.239827
6	0.229791	0.220739
7	0.214012	0.206556
8	0.201696	0.195705
9	0.191875	0.187217
10	0.183911	0.180461
11	0.177364	0.175011
12	0.171919	0.170564
13	0.16735	0.166903
14	0.163485	0.163867
15	0.160194	0.161334
16	0.157376	0.15921
17	0.154951	0.15742
18	0.152856	0.155907
19	0.151039	0.154625
20	0.149459	0.153534
21	0.148081	0.152605
22	0.146877	0.151812
23	0.145821	0.151134
24	0.144895	0.150553

Table 6. Fishery-specific selectivity assumptions used in the North Pacific blue shark stock assessment. The selectivity curves for fisheries lacking length composition data were assumed to be the same as (i.e., mirror gear) a related fishery operating in the manner or area.

Fishery reference	Reference Code	Selectivity assumption	Mirror gear
F1	MEX	Double-normal	Estimated
F2	CAN	Double-normal	F1
F3	CHINA	Double-normal	Estimated
F4	JPN_KK_SH	Double-normal	Estimated
F5	JPN_KK_DP	Double-normal	Estimated
F6	JPN_ENY_SHL	Double-normal	F4
F7	JPN_ENY_DP	Double-normal	F5
F8	JPN_LG_MESH	Double-normal	Estimated
F9	JPN_CST_Oth	Double-normal	F7
F10	JPN_SM_MESH	Double-normal	Estimated
F11	IATTC	Double-normal	F1
F12	KOREA	Double-normal	F3
F13	NON_ISC	Double-normal	F3
F14	USA_GILL	Double-normal	Estimated
F15	USA_SPORT	Double-normal	F14
F16	USA_Longline	Double-normal	Estimated
F17	TAIW_LG	Double-normal	Estimated
F18	TAIW_SM	Double-normal	F17
S1	HW_DP	Double-normal	F16
S2	HW_SH	Double-normal	F16
S3	TAIW_LG	Double-normal	F17
S4	TAIW_SM	Double-normal	F18
S5	JPN_EARLY	Double-normal	F4
S6	JPN_LATE	Double-normal	F5
S7	JPN_RTV	Double-normal	F16
S8	SPC_OBS	Double-normal	F13
S9	SPC_OBS_TROPIC	Double-normal	F13
S10	Mex_LG	Double-normal	Estimated

Table 7. Input CV, root-mean-square-errors (RMSE), and standard deviations of the normalized residuals (SDNR) for the relative abundance indices used in the North Pacific blue shark stock assessment. Hawaii, Taiwan, SPC, and Mexico were not included in the total likelihood.

Reference code	n	Input CV	RMSE	SDNR	χ^2
Hawaii	16	0.28	0.46	1.69	1.29
Taiwan	12	0.10	0.67	7.01	1.33
Japan Early	18	0.10	0.08	0.89	1.27
Japan Late	22	0.10	0.09	0.99	1.24
SPC	17	0.14	0.39	2.85	1.28
Mexico	10	0.12	0.24	2.15	1.37

Table 8. Relative negative log-likelihoods of abundance index data components for the stock assessment reference case model over a range of fixed levels of virgin recruitment in log-scale (log(R_0)). Likelihoods are relative to the minimum negative log-likelihood for each respective data component. Colors indicate relative likelihood (red: high negative log-likelihood; green: low negative log-likelihood). Hawaii, Taiwan, SPC, and Mexico were not included in the total likelihood.

R_0	Hawaii	Taiwan	Japan Early	Japan Late	SPC	Mexico
10.8	3.192665	20	135.979	46.06176	6.0495	0.653301
10.9	2.156205	11.0447	89.681	27.5769	5.3626	1.478125
11	1.343675	7.7786	44.269	14.1025	4.183	2.505805
11.1	1.346335	4.4135	20.935	7.2711	0.867	1.435678
11.2	1.217195	1.1	4.026	1.164	0.7812	1.289124
11.3	1.186075	0.72	0	0	0.4507	0.807215
11.4	0.942685	0.0021	6.804	3.6564	0.2557	0.511986
11.5	0.664265	0	14.969	6.5903	0.1344	0.316444
11.6	0.41626	1.0491	27.604	11.5687	0.0586	0.173947
11.7	0.195376	5.312	37.161	22.7597	0.0161	0.072241
11.8	0	7.6273	45	34.0496	0	0

Table 9. Relative negative log-likelihoods of abundance index data components for the stock assessment reference case model over a range of fixed levels of virgin recruitment in log-scale (log(R_0)). Likelihoods are relative to the minimum negative log-likelihood for each respective data component. Colors indicate relative likelihood (red: high negative log-likelihood; green: low negative log-likelihood).

R_0	MEX	CHINA	JPN KK_SH	JPN KK_DP	JPN ENY_DP	JPN LG_MESH	USA GILL	USA Longline	TAIW_LG
10.8	0.592059	3.708873	25.21644	2.605106	19.83565	0.281332	8.612634	3.708873	0.25496
10.9	0.399855	2.04817	16.63077	2.309306	11.87549	0.636527	4.756198	2.04817	0.17219
11	0.249176	1.442492	8.209405	1.801332	6.072983	1.079079	3.349712	1.442492	0.107303
11.1	0.249669	0.818456	3.882263	0.373358	3.131166	0.618248	1.900593	0.818456	0.107516
11.2	0.225721	0.203988	0.746596	0.336409	0.501255	0.555138	0.473695	0.203988	0.097203
11.3	0.21995	0.133519	0	0.194086	0	0.347612	0.310055	0.133519	0.094717
11.4	0.174815	0.000389	1.261759	0.110113	1.574562	0.220477	0.000904	0.000389	0.075281
11.5	0.123184	0	2.775906	0.057877	2.837992	0.136271	0	0	0.053047
11.6	0.077193	0.194549	5.118987	0.025235	4.981849	0.074907	0.451776	0.194549	0.033242
11.7	0.036231	0.985077	6.891272	0.006933	9.801048	0.031109	2.287516	0.985077	0.015602
11.8	0	1.414434	8.344965	0	14.66284	0	3.284557	1.414434	0

Table 10. Estimates of key management quantities for the North Pacific blue shark stock assessment reference case model and sensitivity analysis.

	SB_{1971}	SB_{2015}	SB_{MSY}	F_{1971}	$F_{2012-2014}$	F_{MSY}	SB_{2015}/SB_{MSY}	$F_{2012-2014}/F_{MSY}$	Description
Ref.	311,312	308,286	179,539	0.13	0.13	0.35	1.71	0.37	Reference case model
S1	980,878	1,082,300	482,638	0.05	0.06	0.40	2.24	0.15	Natural mortality schedule based on the Peterson and Wroblewski (1984).
S2	330,220	296,037	175,222	0.126	0.14	0.35	1.68	0.40	Initial equilibrium catch fixed at 20,000 mt
S3	283,977	316,255	182,132	0.15	0.13	0.35	1.73	0.37	Initial equilibrium catch fixed at 60,000 mt
S4	183,443	167,184	105,336	0.11	0.11	0.27	2.59	0.40	CPUE combination: JPN_EARLY + HWI
S5	183,052	232,396	105,296	0.11	0.07	0.27	2.20	0.26	CPUE combination: JPN_ EARLY + TAIW
S6	174,381	140,742	100,984	0.12	0.14	0.28	1.39	0.50	CPUE combination: JPN_ EARLY + SPC
S7	202,488	190,581	114,567	0.01	0.10	0.26	1.66	0.38	CPUE combination: JPN_ EARLY + MEX
S8	596,335	595,485	318,388	0.07	0.06	0.30	1.87	0.20	2014 SS stock assessment parameterization
S9	309,144	304,207	178,009	0.12	0.12	0.34	1.70	0.35	LFSR (S_{Frac} =0.391 and β= estimated)
S10	285,083	407,052	181,098	0.10	0.15	0.45	1.57	0.33	Beverton-Holt model (h = 0.503)
S11	393,099	298,964	155,390	0.11	0.14	0.60	1.92	0.23	Beverton-Holt model (h = 0.622)
S12	413,197	277,188	190,050	0.10	0.15	0.39	1.45	0.38	Beverton-Holt model (h = 0.459)
S13	307,722	303,028	181,422	0.14	0.14	0.36	1.71	0.38	Asymptotic selectivity on F17

Table 11. Estimates of age-specific natural mortality based on Peterson and Wroblewski (1984) method using data from Yokoi et al. 2017.

Age	Male	Female
0	0.250371	0.302307
1	0.173235	0.184636
2	0.138899	0.14179
3	0.119228	0.11934
4	0.106441	0.105521
5	0.097472	0.096203
6	0.090853	0.089538
7	0.085788	0.084574
8	0.081807	0.080767
9	0.078612	0.077781
10	0.076006	0.075398
11	0.073853	0.073472
12	0.072054	0.071897
13	0.070539	0.070598
14	0.069252	0.069519
15	0.068153	0.068617
16	0.067209	0.06786
17	0.066395	0.067222
18	0.06569	0.066682
19	0.065078	0.066224
20	0.064545	0.065531
21	0.064078	0.064935
22	0.06367	0.064338
23	0.063313	0.063741
24	0.062998	0.063145

Table 12. Projected trajectory of spawning biomass (in metric tons) for alternative harvest scenarios.

Year	Average F + 20%	F_{MSY}	Average F - 20%	Average F (2012-2014)
2015	308,286	308,286	308,286	308,286
2016	319,292	319,292	319,292	319,291
2017	328,679	324,591	330,693	329,683
2018	334,827	324,839	339,339	337,069
2019	337,305	323,009	344,621	340,929
2020	339,267	319,719	349,439	344,292
2021	340,833	316,419	353,720	347,185
2022	342,133	313,352	357,498	349,691
2023	343,229	310,601	360,796	351,859
2024	344,166	308,173	363,648	353,728

10 Figures

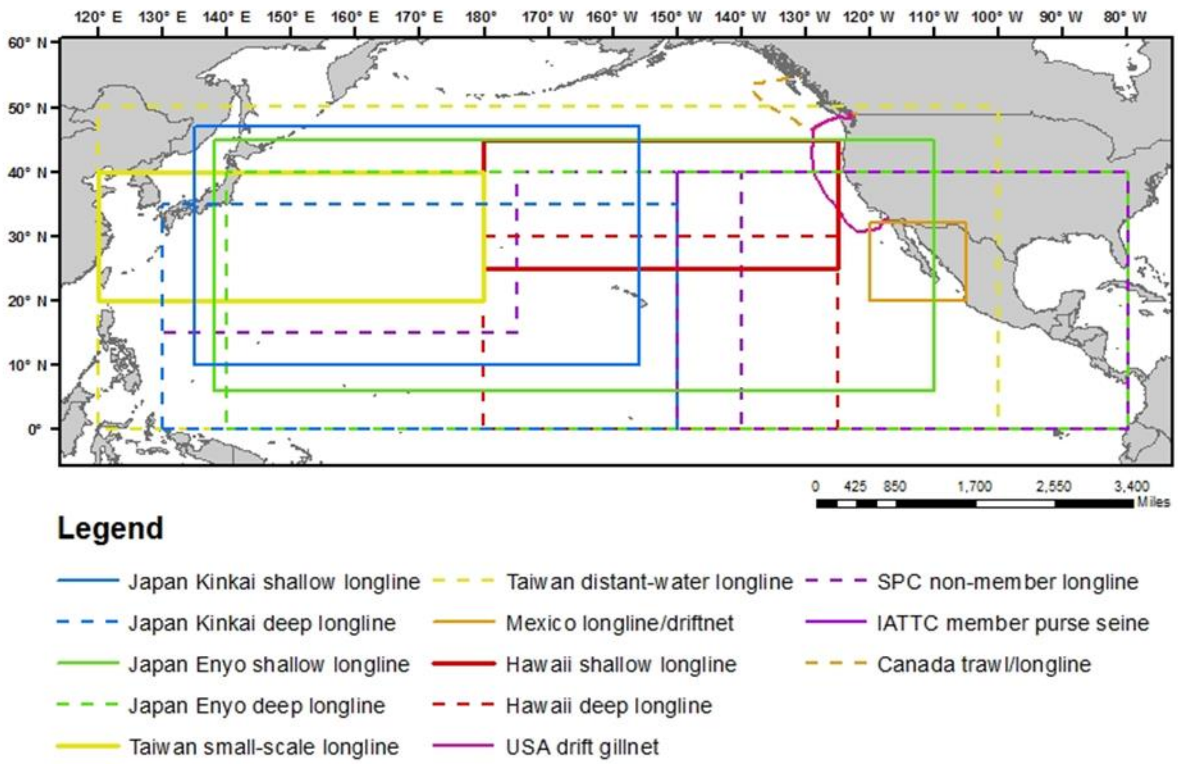

Figure 1. Blue shark (*Prionace glauca*) stock boundaries and approximate spatial extent of the primary fisheries contributing catch for this assessment.

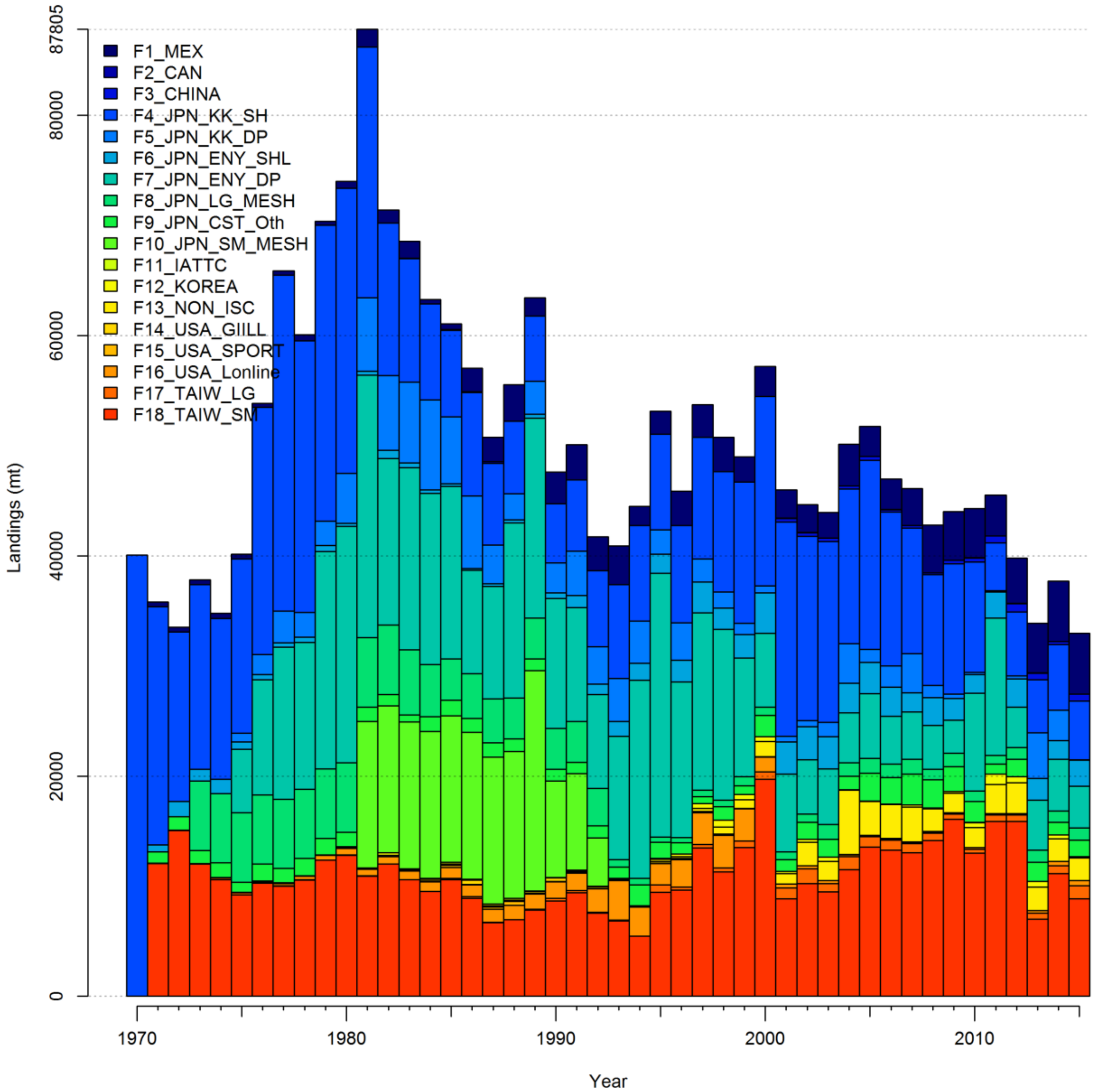

Figure 2. Catches by fishery from 1971-2015. Note: Catch in 1970 is an assumed level of catch used to derive equilibrium conditions.

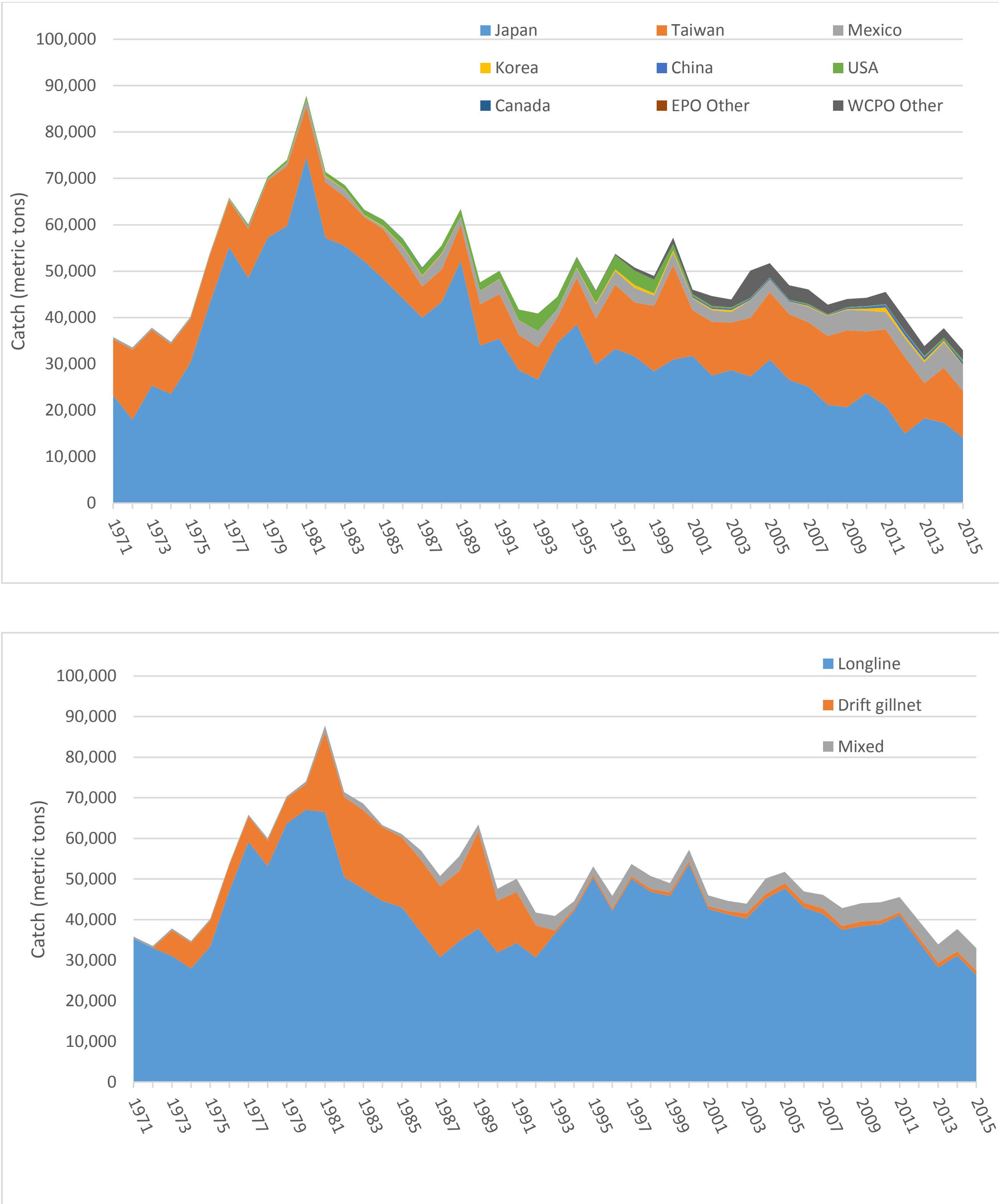

Figure 3. Total catch (total dead removals) of North Pacific blue shark by nation or region (top panel), and by gear type (bottom panel). Note: the mixed gear category in the bottom panel includes purse seine, trap, troll, trawl and recreational.

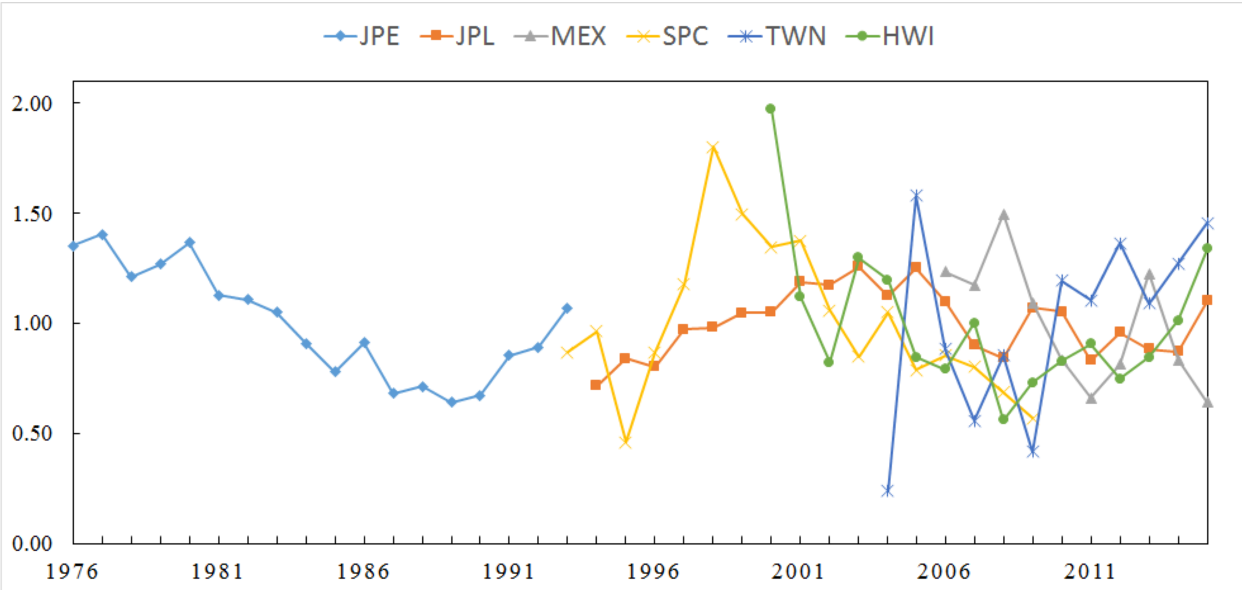

Figure 4. Yearly changes in standardized CPUE of north Pacific blue shark during 1976 and 1993 (Japanese offshore shallow-set longline: **JPE**), and five standardized CPUE time series of blue shark between 1993 and 2015 (Japanese offshore shallow-set longline: **JPL**, Mexico longline: **MEX**, SPC observed longline: **SPC**, Taiwan large-scale longline: **TWN,** and Hawaii deep-set longline: **HWI**). All indices are normalized to a mean value of 1.

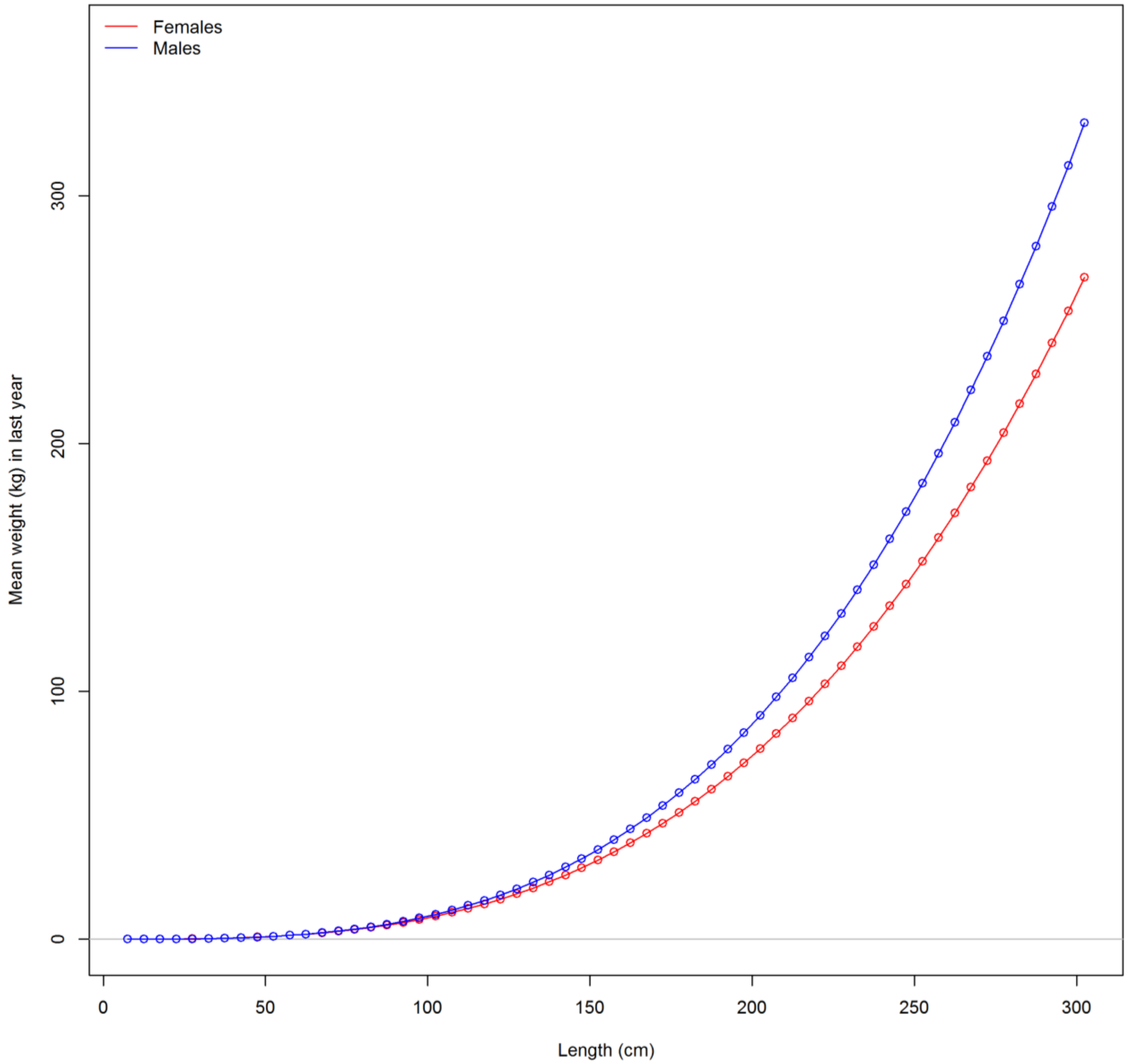

Figure 5. The sex-specific weight-at-length (from Nakano 1994) for female (red solid line) and male (blue solid line) blue sharks used in the SS analysis.

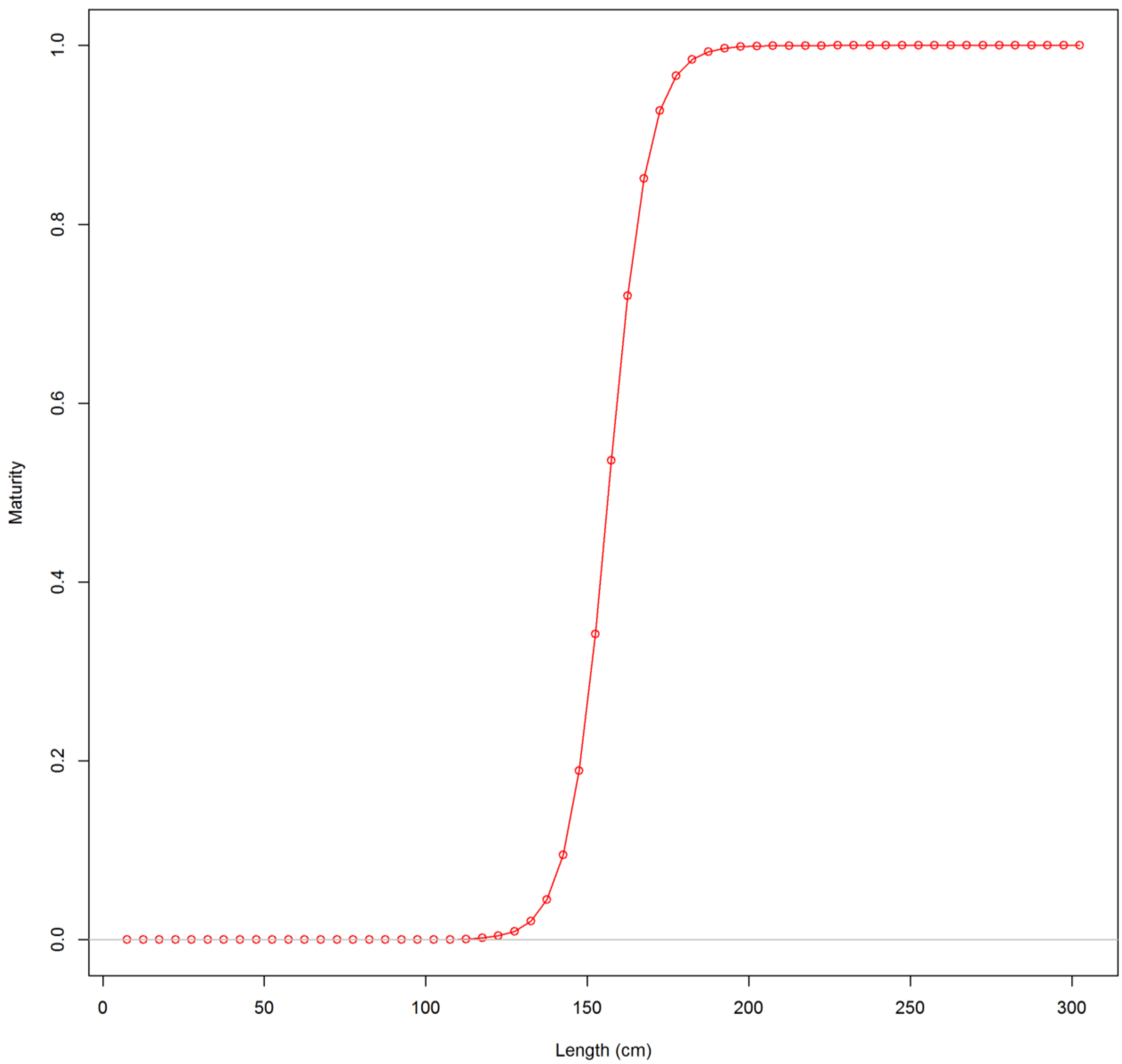

Figure 6. Assumed a logistic maturity schedule based on length and the age-at-50% maturity (from Fujinami et al. 2017) for females used in the stock assessment.

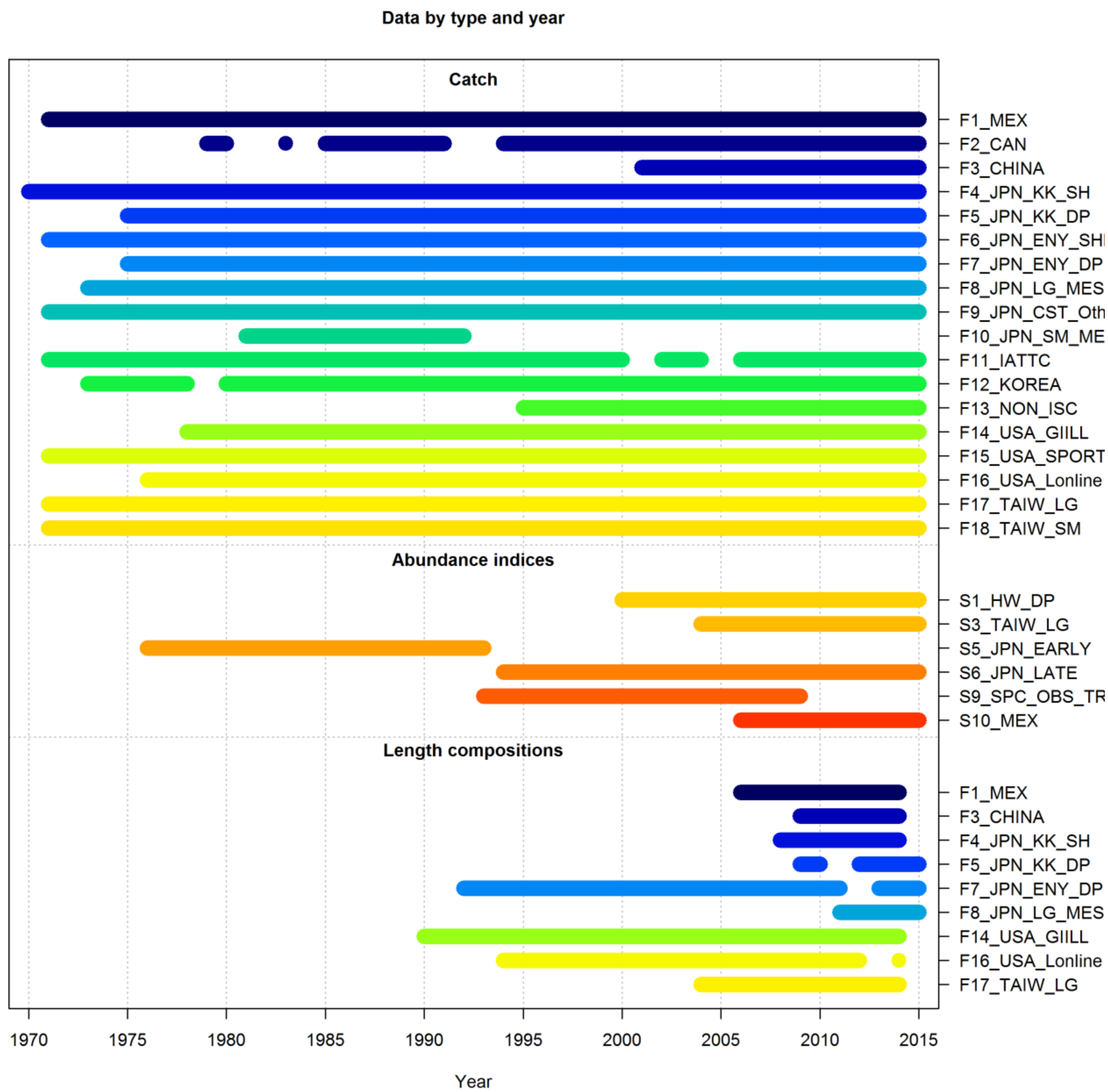

Figure 7. Coverage of catch, effort, and length composition data by year and fleet for the SS reference case.

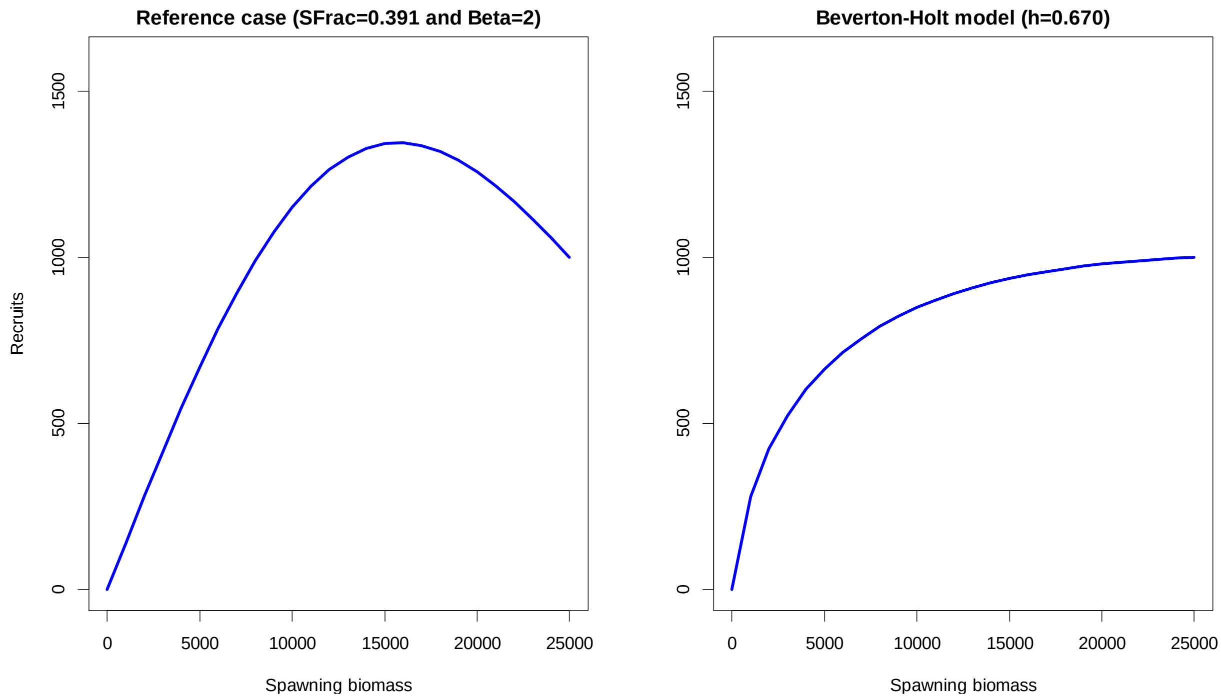

Figure 8. Spawner recruitment curve for the Low Fecundity Spawner Recruitment (LFSR) relationship used in the reference case analysis (left panel), and the Beverton-Holt model with steepness estimated based on the most plausible life history information for north Pacific blue sharks used in an alternate model run (right panel).

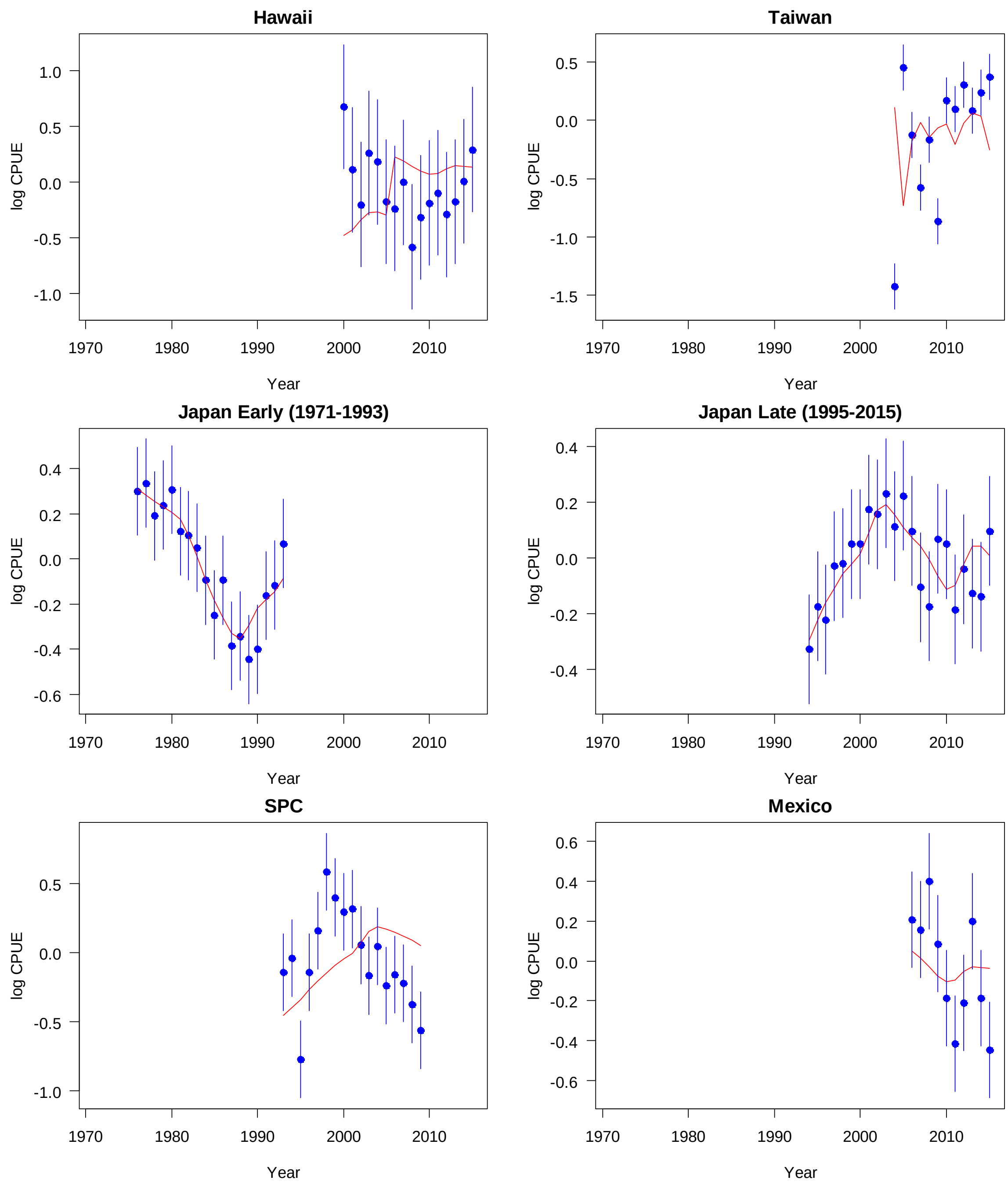

Figure 9. Model fits to the standardized catch-per-unit-effort (CPUE) (in log scale) data sets from different fisheries for the reference case model. The solid red line is the model predicted value and the solid circles are observed data values. Vertical blue lines represent the estimated confidence intervals (± 1.96 standard deviations) around the CPUE values. Hawaii, Taiwan, SPC, and Mexico were not included in the total likelihood.

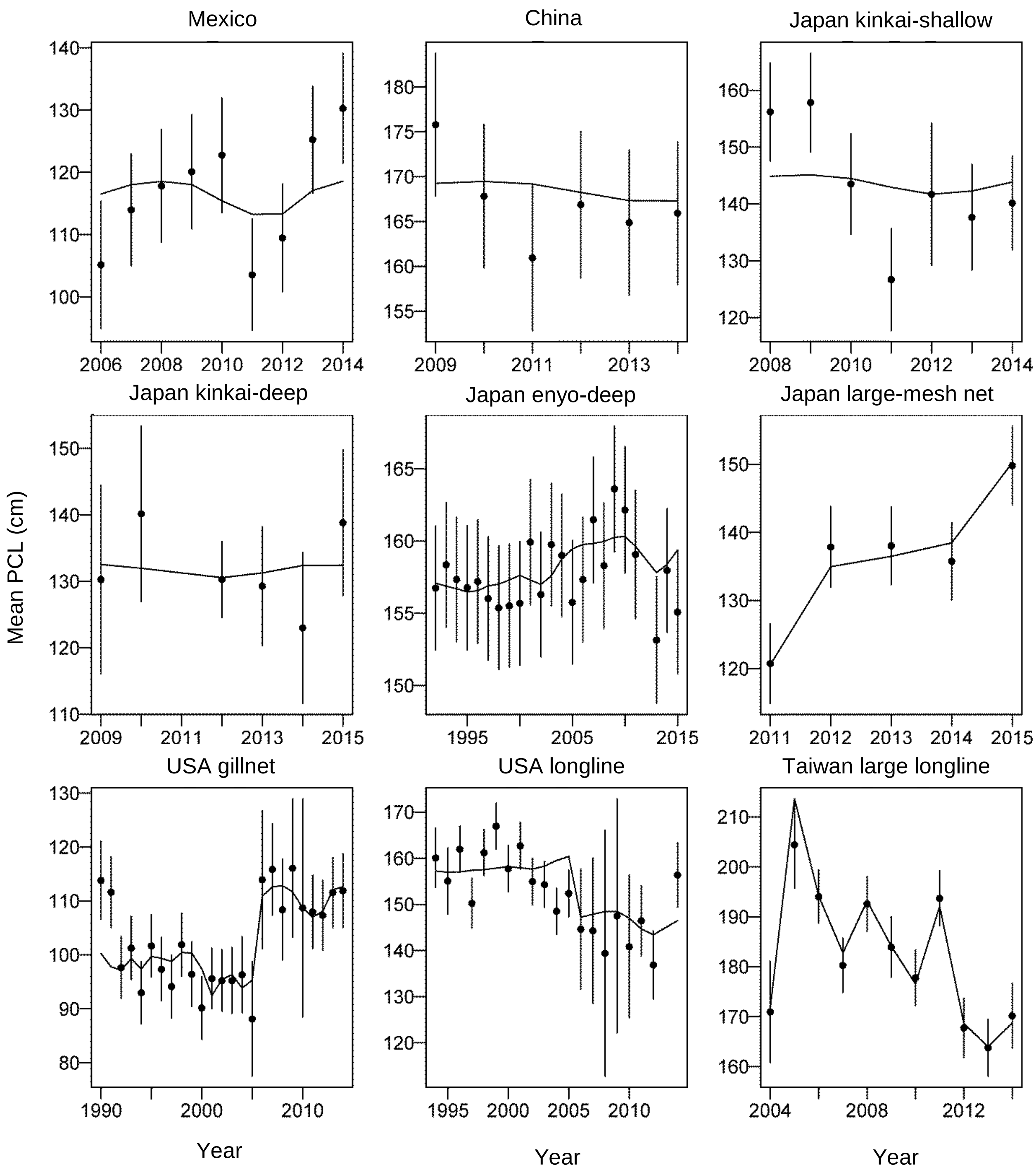

Figure 10. Model fit (black solid lines) to mean PCL (in cm) of the composition data for the reference case. The solid circles are the observed mean length and the vertical black solid lines are 95% credible limits around mean length.

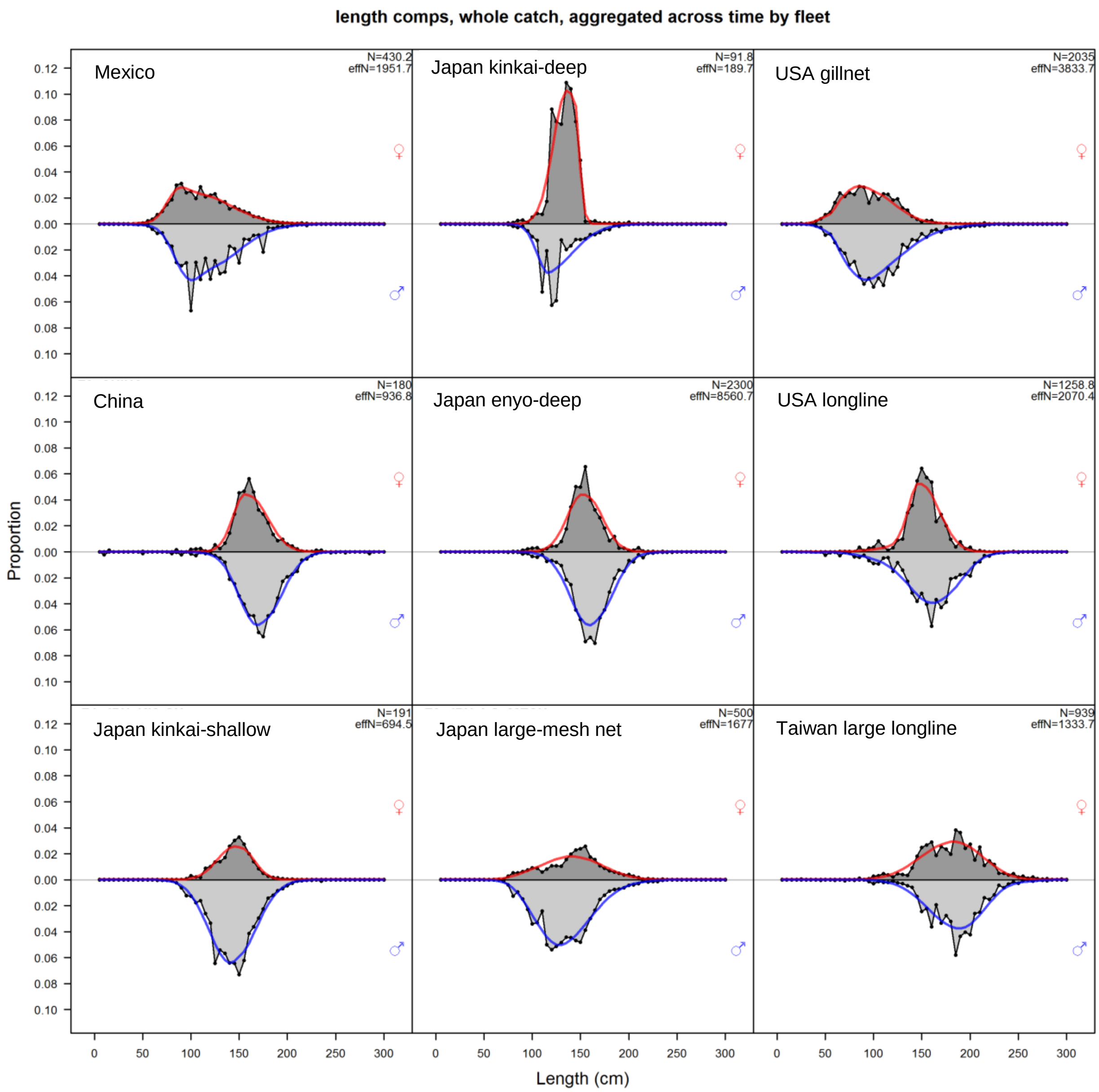

Figure 11. Sex specific comparison of observed (gray shaded area) and model predicted (blue and red solid lines) length compositions for different fisheries in the stock assessment reference case model.

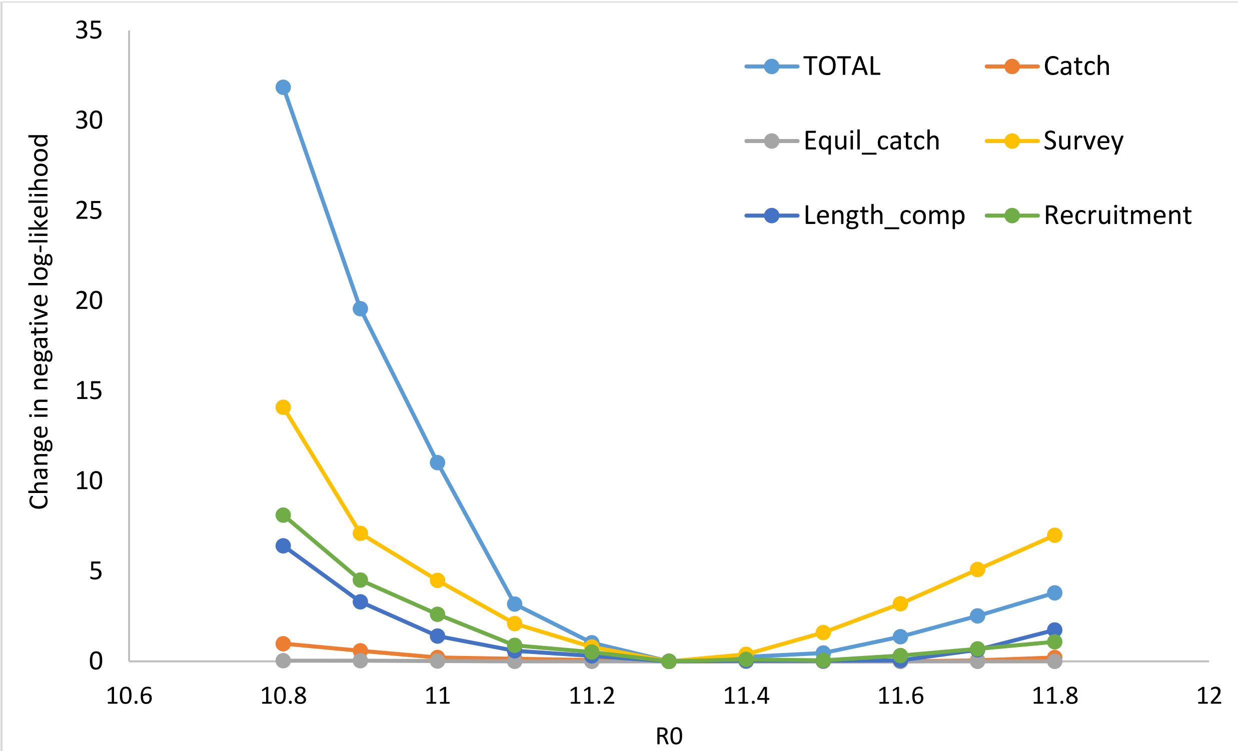

Figure 12. Profiles of the relative-negative log likelihoods by different data components for the virgin recruitment in log-scale (log(R0)) for the stock assessment reference case model.

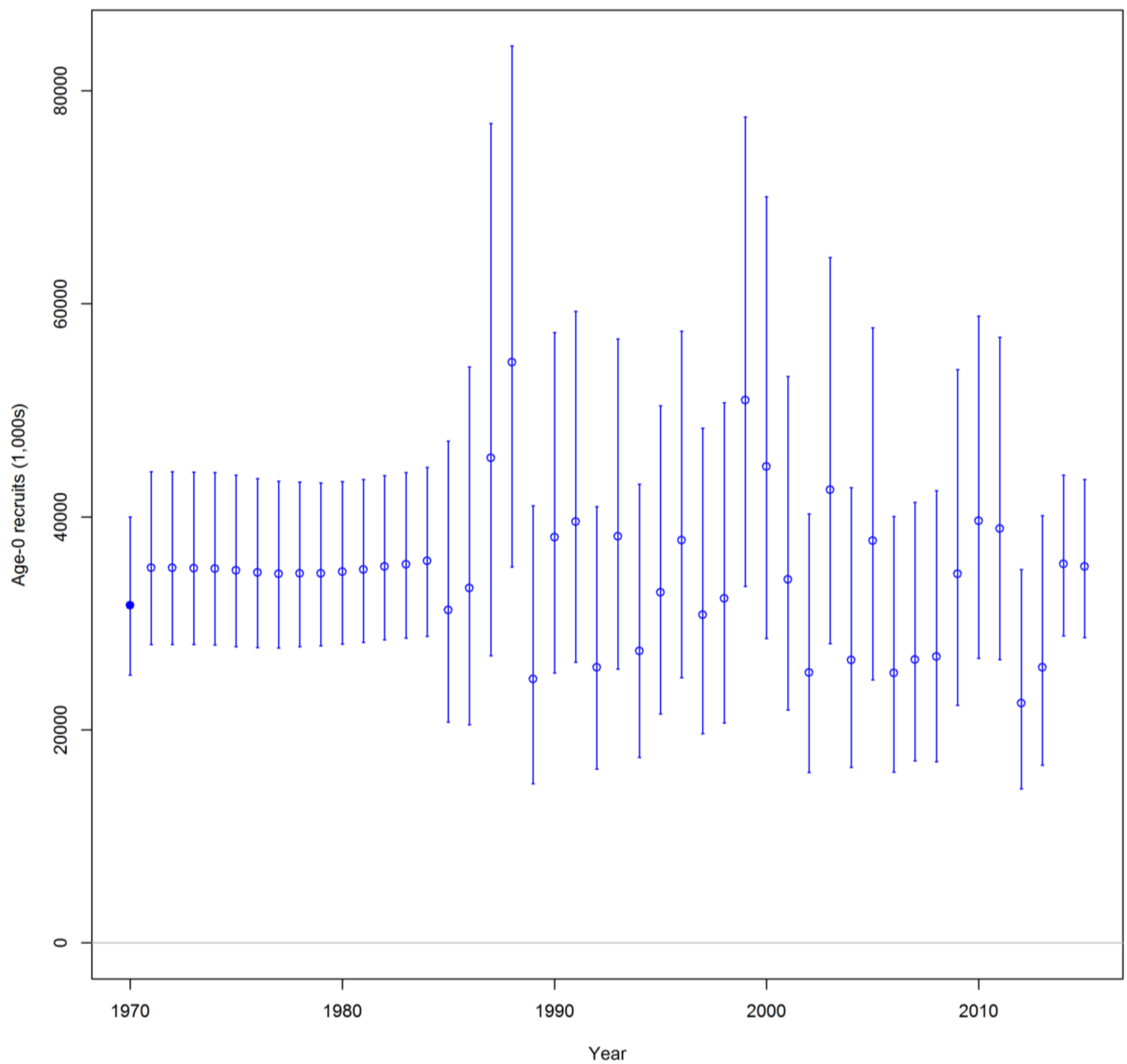

Figure 13. Estimated age-0 recruits (circles) and 95% confidence intervals (vertical bars) from the stock assessment reference case model.

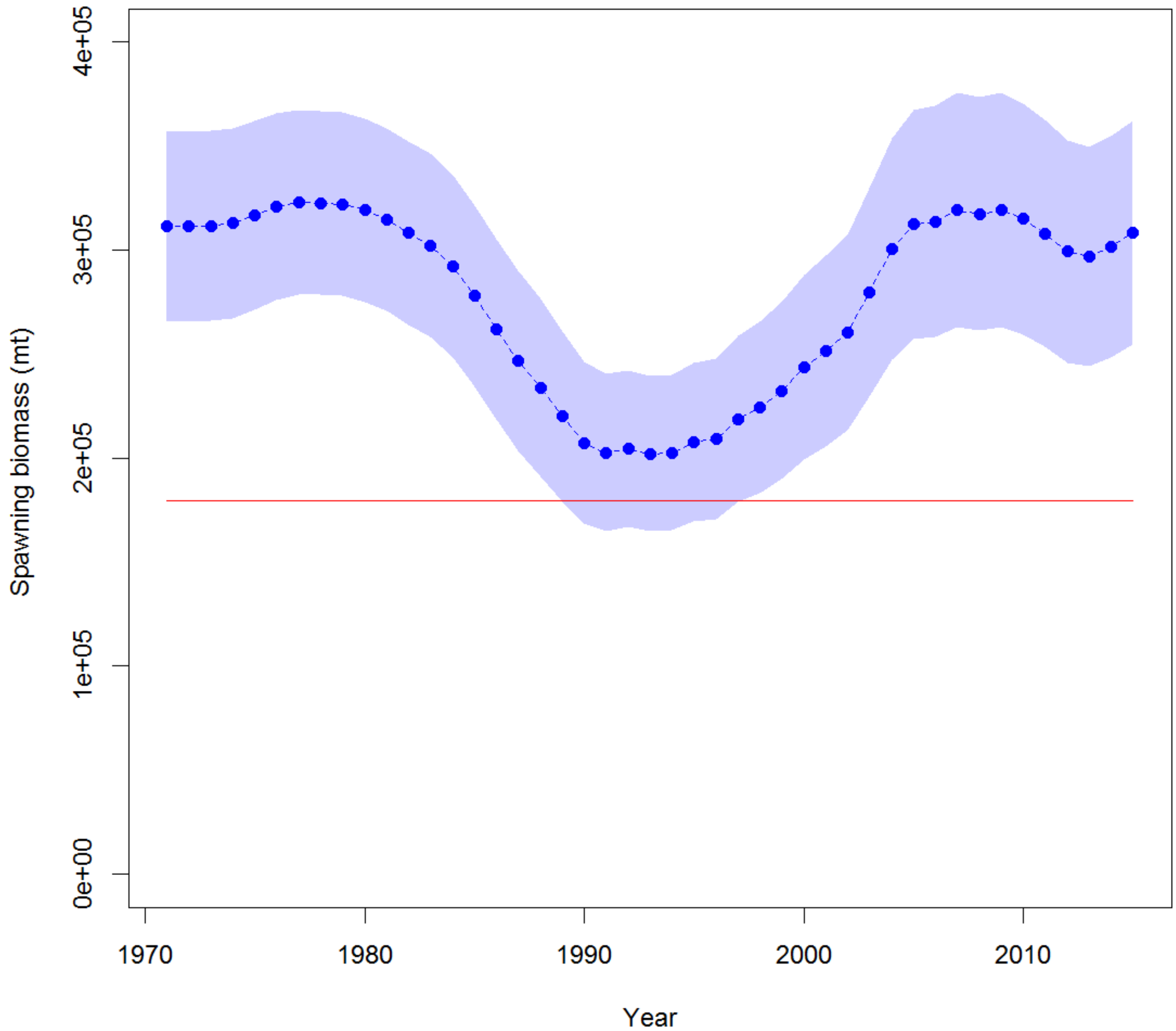

Figure 14. Time series of estimated female spawning biomass and 95% confidence intervals (blue shaded area) for the stock assessment reference case model. Red solid lines indicate the estimates of MSY.

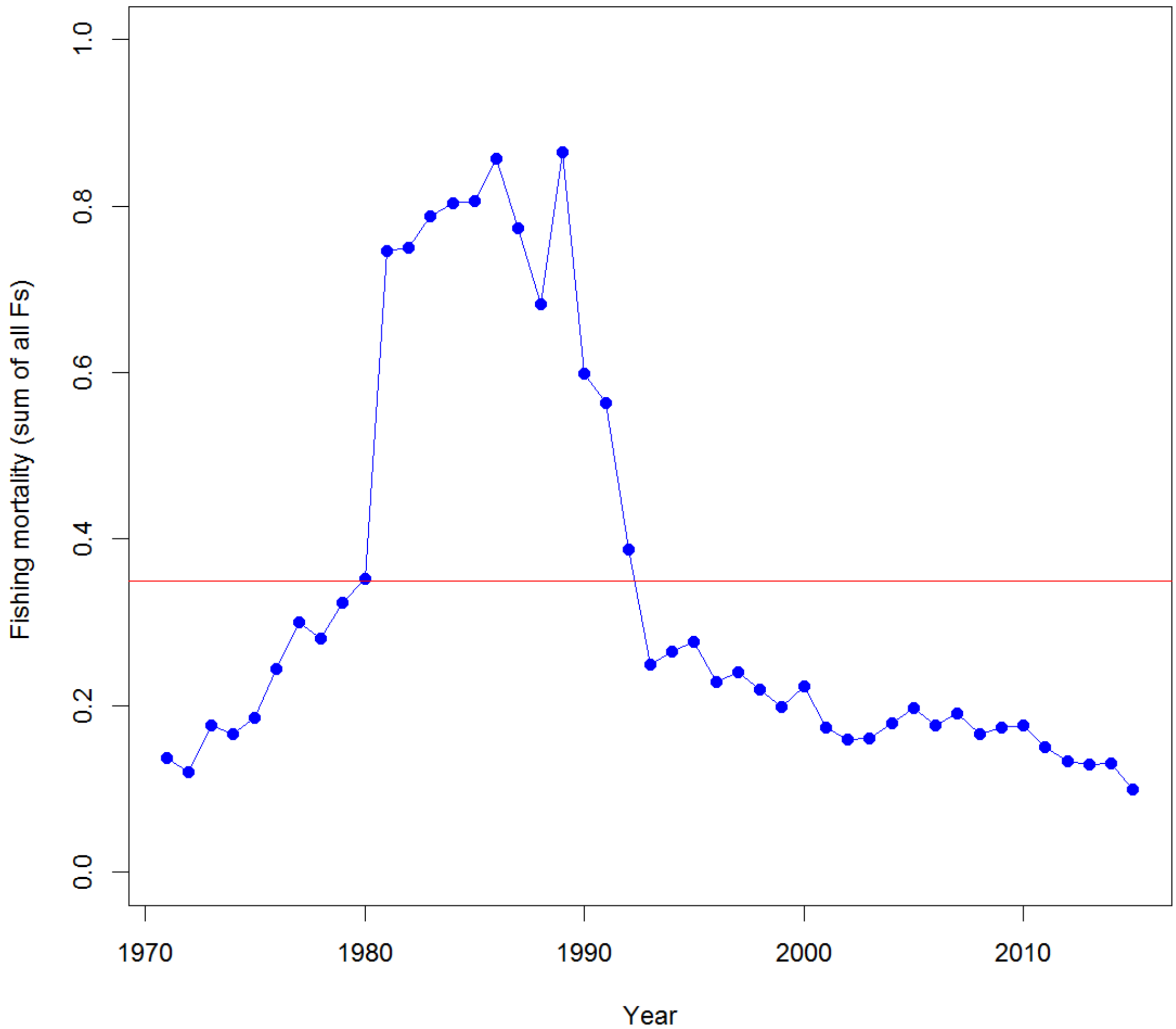

Figure 15. Time series of estimated fishing mortality (sum of F's across all fishing fleets) for the stock assessment reference case model. Red solid lines indicate the estimates of MSY.

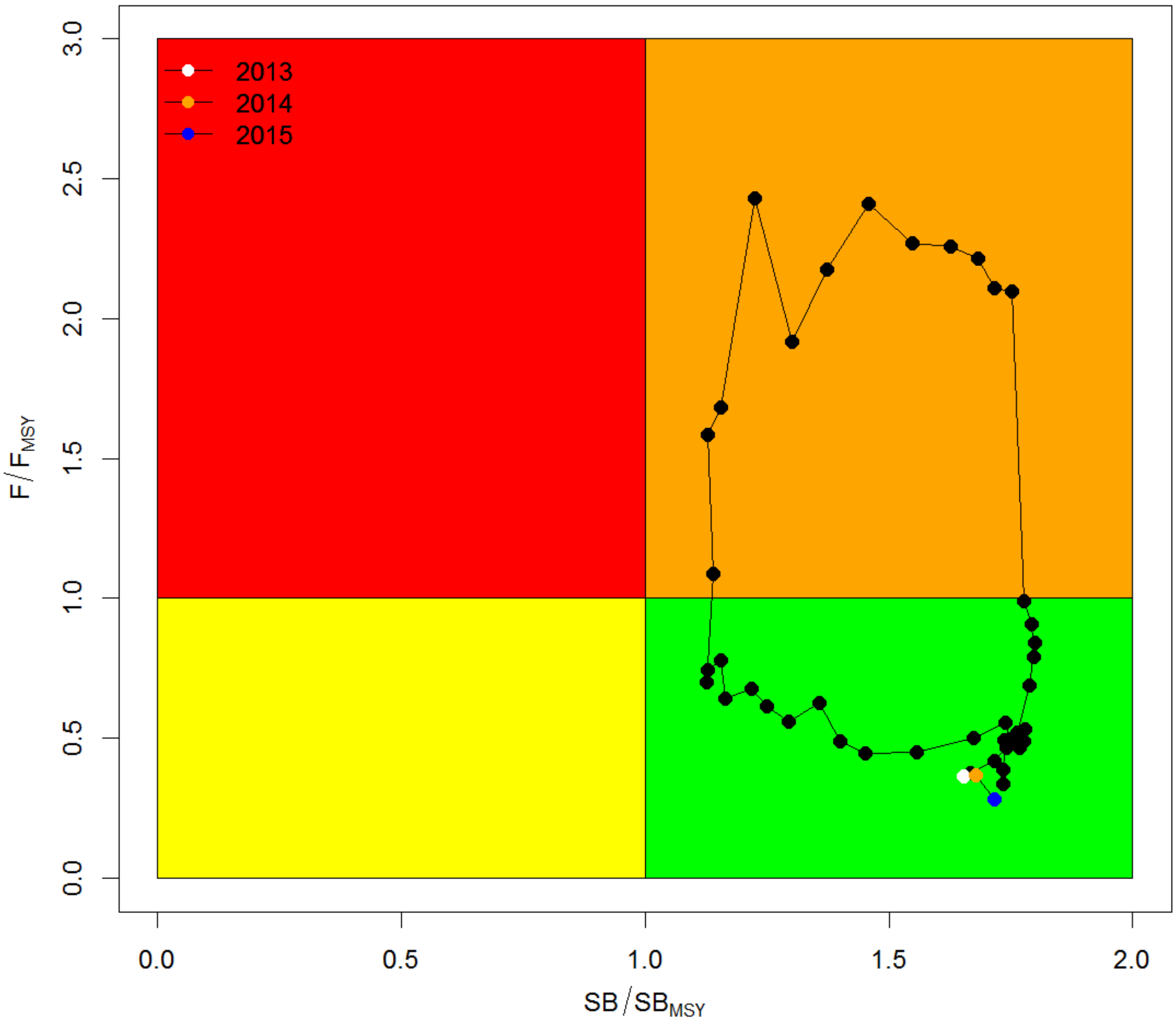

Figure 16. Kobe plot of the trends in estimates of relative fishing mortality and spawning biomass of North Pacific blue shark between 1971-2015 for the reference case stock assessment model.

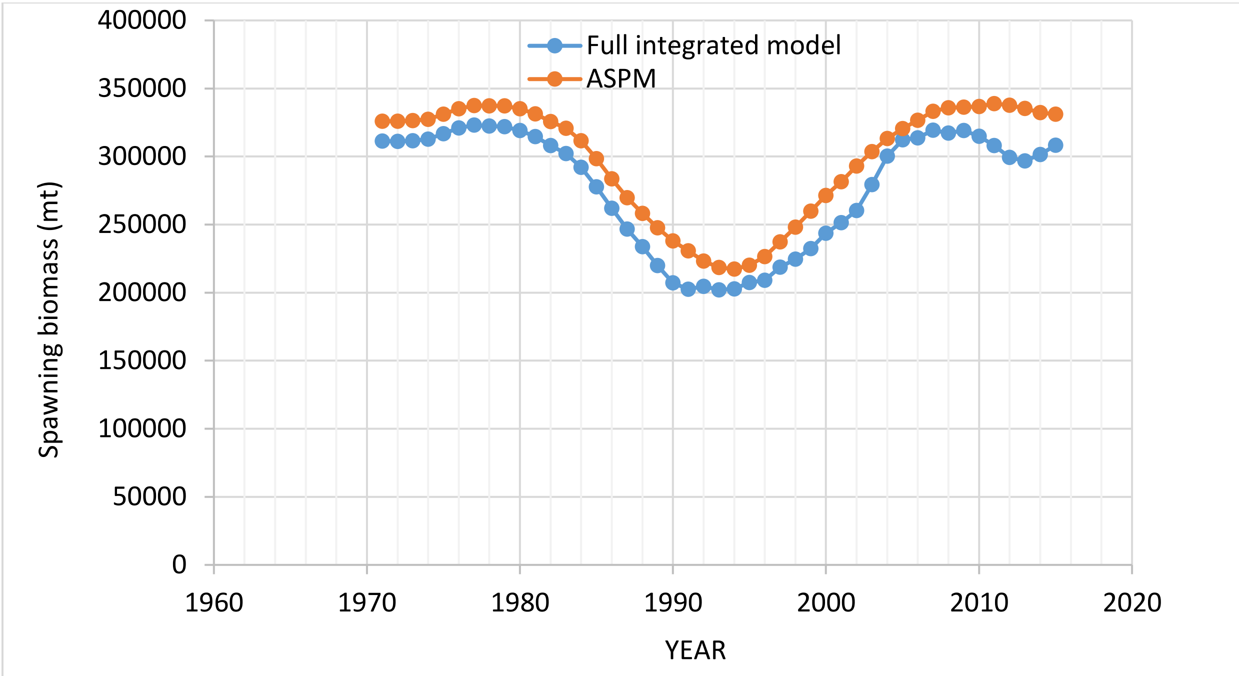

Figure 17. Age-Structured Production Model diagnostic (ASPM).

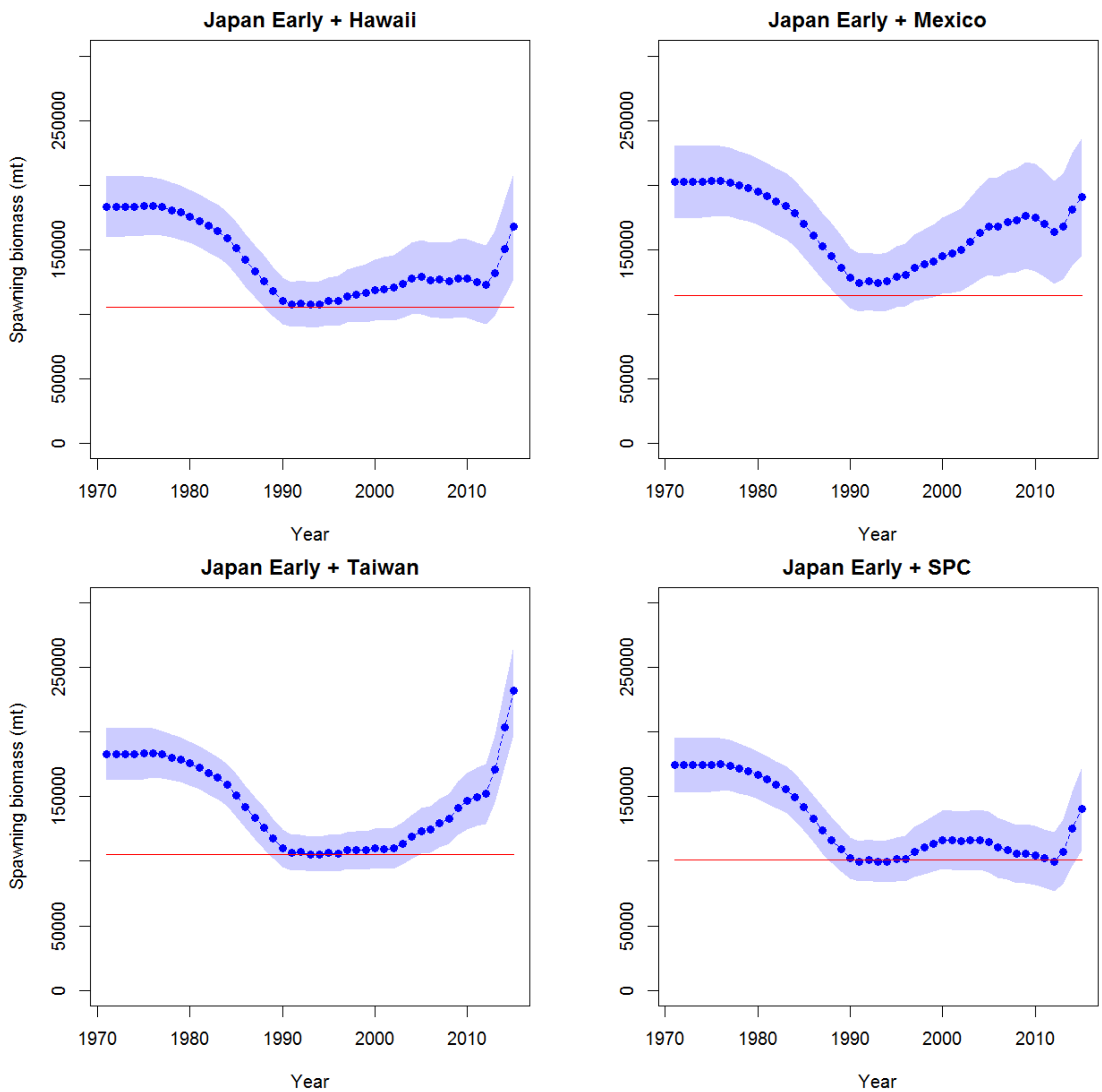

Figure 18. Time series of estimated spawning biomass and 95% confidence intervals (blue shaded area) for the sensitivity analysis using the Japan-Early CPUE series in combination with alternative late CPUE series (Hawaii, Mexico, Taiwan, and SPC). Red solid lines indicate the estimates of MSY.

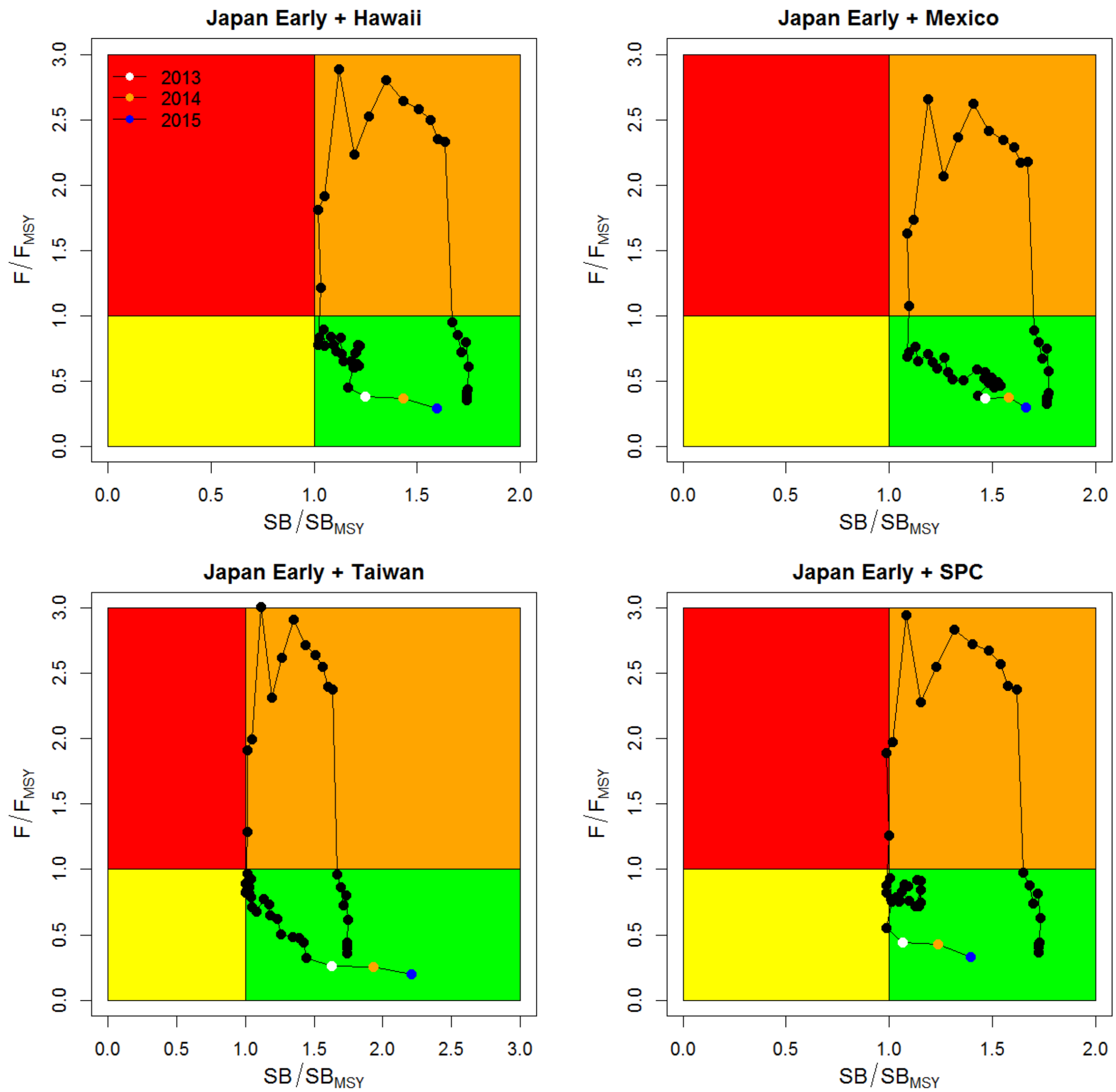

Figure 19. Kobe plot of the trends in estimates of relative fishing mortality and spawning biomass of North Pacific blue shark between 1971-2015 for the sensitivity analysis using the CPUE series Japan Early in combination with alternative late CPUE series (Hawaii, Mexico, Taiwan, and SPC).

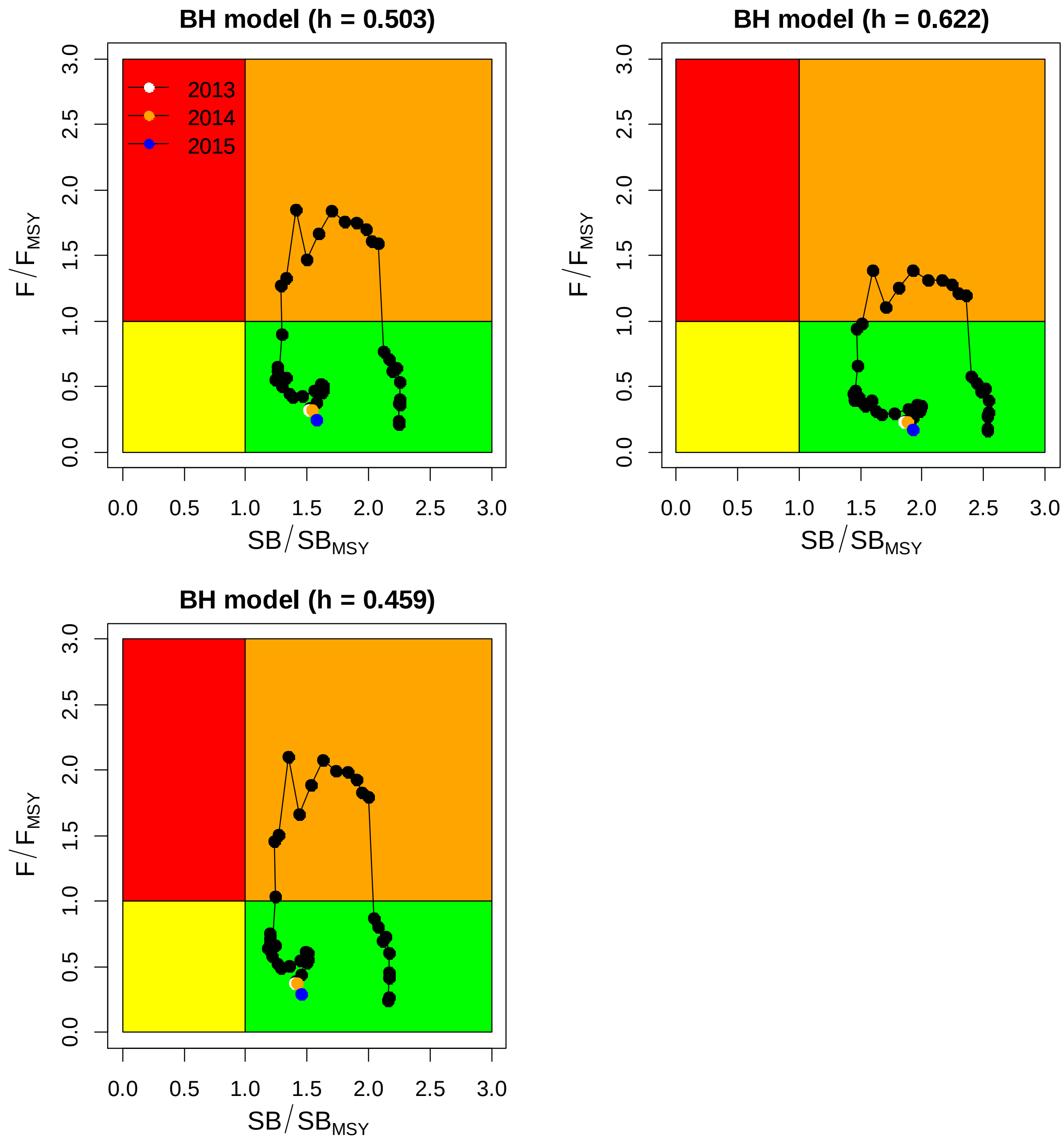

Figure 20. Kobe plot of the trends in estimates of relative fishing mortality and spawning biomass of North Pacific blue shark between 1971-2015 for the sensitivity analysis using the Beverton-Holt stock-recruitment relationship.

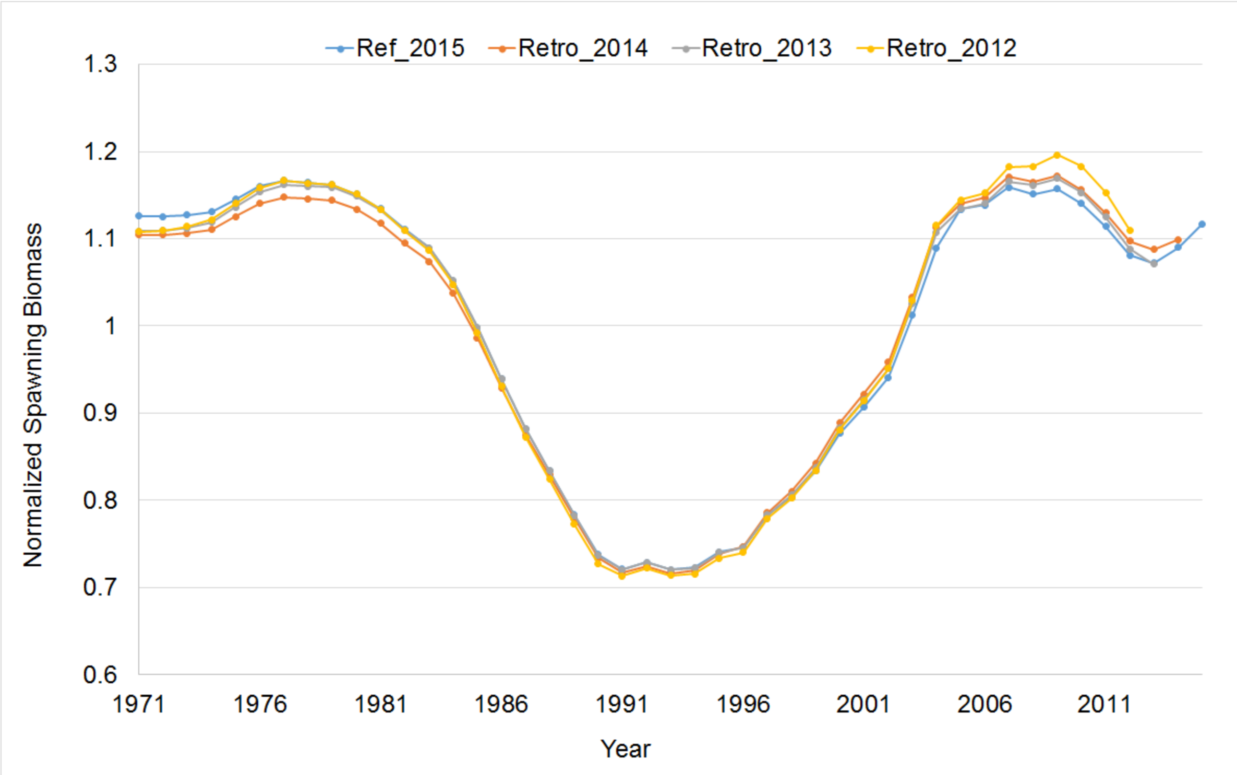

Figure 21. A 4-year retrospective analysis of spawning biomass for the reference case. The label “Ref_2015” indicates the reference case model results. The label “Retro_Y” indicates the retrospective results from the retrospective peel that includes data through the year “Y”.

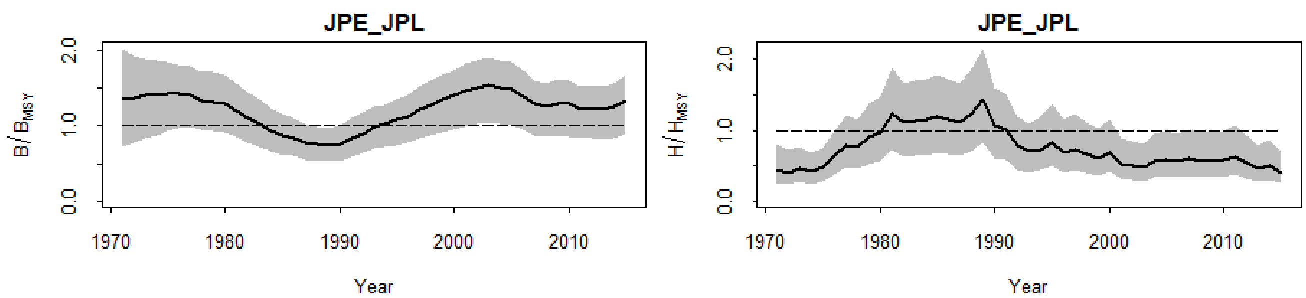

Figure 22. BSSPM historical trajectories of median estimate based on base-parameter model and the 95% credible intervals (grey shadow) for 5 reference cases. The horizontal dashed line indicates the median estimate for the biomass and harvest rate at the maximum sustainable yield (B_{MSY} and H_{MSY}).

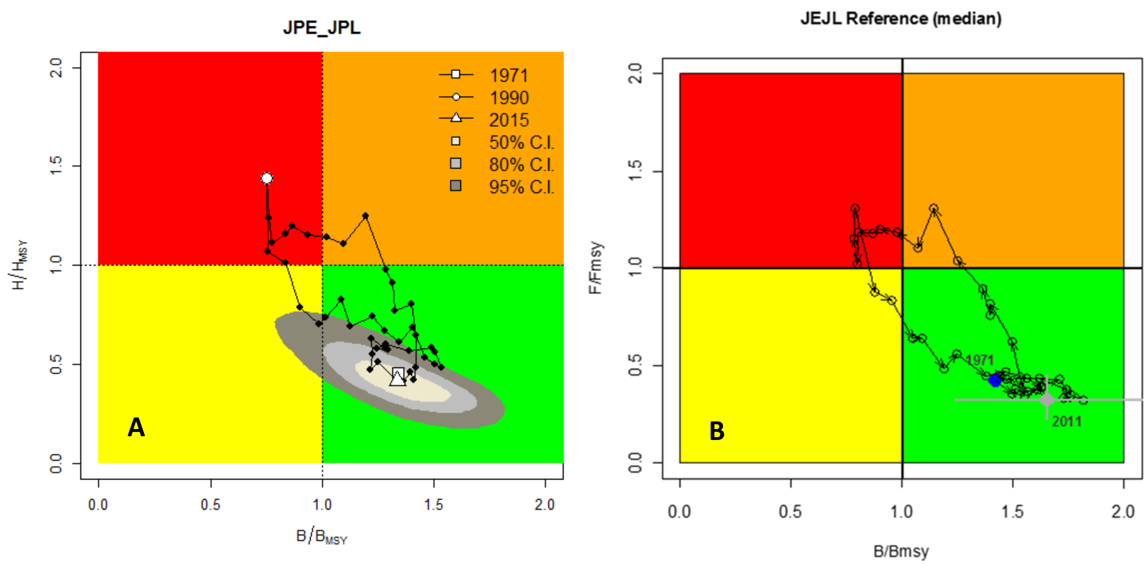

Figure 23. A) BSSPM Kobe plot based on the median trajectories of B/B$_{MSY}$ and H/H$_{MSY}$ for base-parameter model. Note that the values of B_{MSY} and H_{MSY} are fixed to the medians of posterior distributions. B) BSP Kobe plot from the 2104 assessment.

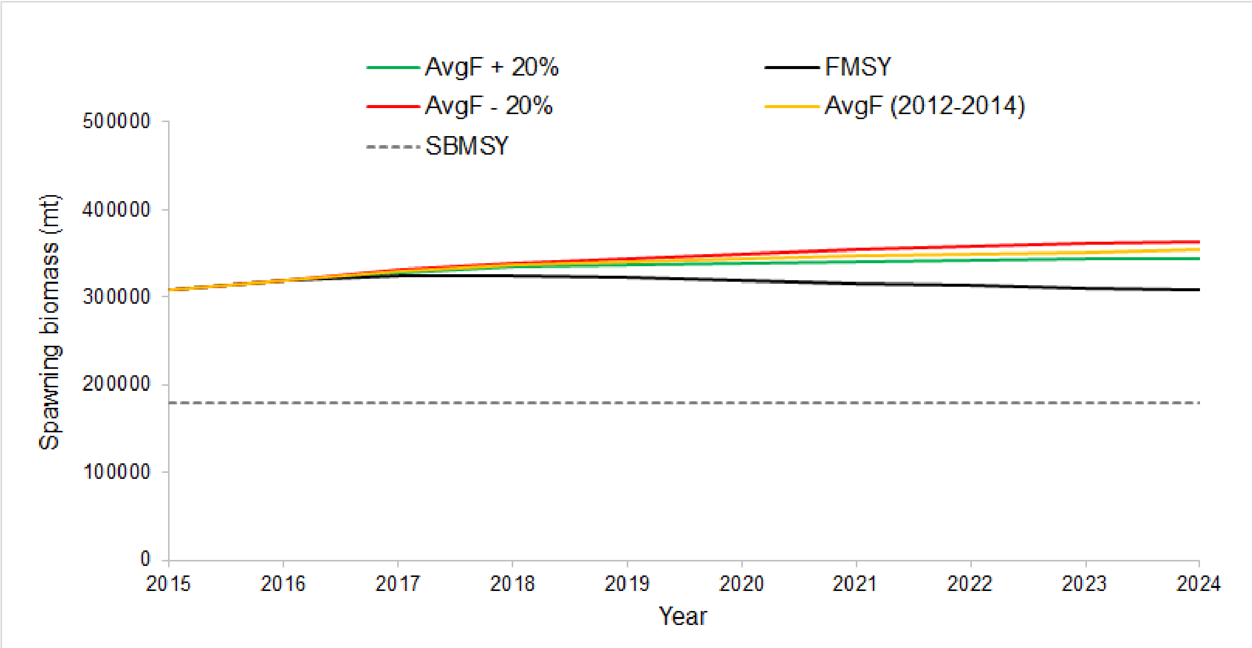

Figure 24. Comparison of future projected blue shark spawning biomass under different *F* harvest policies (*status quo*, +20%, -20%, and F_{MSY}) using the SS reference case model. *Status quo* fishing mortality was based on the average from 2012-2014.

11 Appendix

North Pacific Blue shark Stock Assessment Using Stock Synthesis

ISC Shark Working Group

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

Contact: felipe.carvalho@noaa.gov

V3.24f Data & Control Files: BSH_n.dat // BSH_n.ctl _SS-V3.24f-safe-Win64; Stock Synthesis by Richard Methot (NOAA) using ADMB 11

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, a
rea=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 in
teger) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, sou
rce=1 dest=2, age1=4, age2=10

3 #_Nblock_Patterns
1 2 3 #_Cond 0 #_blocks_per_pattern

# begin and end years of blocks
2006 2015
2001 2005 2006 2015
2011 2011 2012 2014 2015 2015

0.5 #_fracfemale
3 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=
agespec_withseasinterpolate
0.785 0.488 0.370 0.306 0.267 0.240 0.221 0.207 0.196 0.187 0.180 0.17
5 0.171 0.167 0.164 0.161 0.159 0.157 0.156 0.155 0.154 0.153 0.152 0.
151 0.151
```

```
0.728 0.492 0.383 0.320 0.279 0.251 0.230 0.214 0.202 0.192 0.184 0.17
7 0.172 0.167 0.163 0.160 0.157 0.155 0.153 0.151 0.149 0.148 0.147 0.
146 0.145

2 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_sp
eciific_K; 4=not implemented
1 #_Growth_Age_for_L1
20 #_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-ma
turity matrix by growth_pattern; 4=read age-fecundity; 5=read fec and
wt from wtatage.ss
#_placeholder for empirical age-maturity by growth pattern
4 #_First_Mature_Age
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
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from fe
male-GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=logistic transform keep
s in base parm bounds; 3=standard w/ no bound check)
```

Growth Parameters

```
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxy
r dev_stddev Block Block_Fxn
 10 120 64.4 65 0 10 -4 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
 40 410 244.6 400 0 10 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
 0.1 0.25 0.147 0.15 0 0.8 -4 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
 -10 10 1 1 0 0.8 -4 0 0 0 0 0.5 0 0 # Richards_Fem_GP_1
 0.01 1 0.25 0.0834877 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1
 -3 3 -1.06443 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Fem_GP_1
 -3 3 0.059011 0 0 0.8 -3 0 0 0 0 0.5 0 0 # L_at_Amin_Mal_GP_1
 -3 3 0.068275 0 0 0.8 -2 0 0 0 0 0.5 0 0 # L_at_Amax_Mal_GP_1
 -3 3 -0.200 0 0 0.8 -3 0 0 0 0 0.5 0 0 # VonBert_K_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Richards_Mal_GP_1
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_young_Mal_GP_1
 -3 3 -1.4381 0 0 0.8 -3 0 0 0 0 0.5 0 0 # CV_old_Mal_GP_1
 -3 3 5.388e-006 5.388e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Fem
 -3 3.5 3.102 3.102 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Fem
 -3 300 156.6 55 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat50%_Fem
 -3 3 -0.16 -0.16 0 0.8 -3 0 0 0 0 0.5 0 0 # Mat_slope_Fem
 -3 50 45 45 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_scalar_Fem
 -3 3 0 0 0 0.8 -3 0 0 0 0 0.5 0 0 # Eggs_exp_len_Fem
 -3 3 3.293e-006 3.293e-006 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_1_Mal
```

```
 -3 3.5 3.225 3.225 0 0.8 -3 0 0 0 0 0.5 0 0 # Wtlen_2_Mal
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_GP_1
 -4 4 0 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Area_1
 -4 4 4 0 -1 99 -3 0 0 0 0 0.5 0 0 # RecrDist_Seas_1
 1 1 1 1 -1 99 -3 0 0 0 0 0.5 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,Malewtl
en1,malewtlen2,L1,K
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Cond -4 #_MGparm_Dev_Phase
#
#_Spawner-Recruitment
7 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop;
7=survival_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
 3 20 11.1358 9 0 10 1 # SR_LN(R0)
 0.01 1 0.391 0.5 0 0.2 -4 # SR_surv_Sfrac
 0.01 10 2 1 0 0.2 -4 # SR_surv_Beta
 0 2 0.3 0.6 0 0.8 -3 # SR_sigmaR
 -5 5 0 0 0 1 -3 # SR_envlink
 -5 5 0.00172569 0 0 1 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
2 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1990 # first year of main recr_devs; early devs can preceed this era
2013 # last year of main recr_devs; forecast devs start in following y
ear
1 #_recdev phase
1 # (0/1) to read 13 advanced options
 -5 #_recdev_early_start (0=none; neg value makes relative to recdev_s
tart)
 1 #_recdev_early_phase
 0 #_forecast_recruitment phase (incl. late recr) (0 value resets to m
axphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 1979.0929 #_last_early_yr_nobias_adj_in_MPD
```

```
 1992.3346 #_first_yr_fullbias_adj_in_MPD
 2012.4720 #_last_yr_fullbias_adj_in_MPD
 2019.5047 #_first_recent_yr_nobias_adj_in_MPD
 0.6081 #_max_bias_adj_in_MPD (1.0 to mimic pre-2009 models)
 0 #_period of cycles in recruitment (N parms read below)
 -10 #min rec_dev
 10 #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
#
#Fishing Mortality info
0.2 # F ballpark for tuning early phases
2013 # F ballpark year (neg value to disable)
3 # F_Method:  1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
5 # 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
4  # N iterations for tuning F in hybrid method (recommend 3 to 7)
```

Initial F Parameters

```
#_LO HI INIT PRIOR PR_type SD PHASE
 0.1 5 0 0.01 0 99 -1 # InitF_1F1_MEX
 0.1 5 0 0.01 0 99 -1 # InitF_2F2_CAN
 0.1 5 0 0.01 0 99 -1 # InitF_3F3_CHINA
 0.001 5 0.315485 0.01 0 99 1 # InitF_4F4_JPN_KK_SH
 0.1 5 0 0.01 0 99 -1 # InitF_5F5_JPN_KK_DP
 0.1 5 0 0.01 0 99 -1 # InitF_6F6_JPN_ENY_SHL
 0.1 5 0 0.01 0 99 -1 # InitF_7F7_JPN_ENY_DP
 0.1 5 0 0.01 0 99 -1 # InitF_8F8_JPN_LG_MESH
 0.1 5 0 0.01 0 99 -1 # InitF_9F9_JPN_CST_Oth
 0.1 5 0 0.01 0 99 -1 # InitF_10F10_JPN_SM_MESH
 0.1 5 0 0.01 0 99 -1 # InitF_11F11_IATTC
 0.1 5 0 0.01 0 99 -1 # InitF_12F12_KOREA
 0.1 5 0 0.01 0 99 -1 # InitF_13F13_NON_ISC
 0.1 5 0 0.01 0 99 -1 # InitF_14F14_USA_GIILL
 0.1 5 0 0.01 0 99 -1 # InitF_15F15_USA_SPORT
 0.1 5 0 0.01 0 99 -1 # InitF_16F16_USA_Lonline
 0.1 5 0 0.01 0 99 -1 # InitF_17F17_TAIW_LG
 0.1 5 0 0.01 0 99 -1 # InitF_18F18_TAIW_SM
```

Q Setup

```
# Q_type options:  <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=pa
rm_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_MEX
 0 0 0 0 # 2 F2_CAN
 0 0 0 0 # 3 F3_CHINA
 0 0 0 0 # 4 F4_JPN_KK_SH
 0 0 0 0 # 5 F5_JPN_KK_DP
 0 0 0 0 # 6 F6_JPN_ENY_SHL
 0 0 0 0 # 7 F7_JPN_ENY_DP
 0 0 0 0 # 8 F8_JPN_LG_MESH
 0 0 0 0 # 9 F9_JPN_CST_Oth
 0 0 0 0 # 10 F10_JPN_SM_MESH
 0 0 0 0 # 11 F11_IATTC
 0 0 0 0 # 12 F12_KOREA
 0 0 0 0 # 13 F13_NON_ISC
 0 0 0 0 # 14 F14_USA_GIILL
 0 0 0 0 # 15 F15_USA_SPORT
 0 0 0 0 # 16 F16_USA_Lonline
 0 0 0 0 # 17 F17_TAIW_LG
 0 0 0 0 # 18 F18_TAIW_SM
 0 0 0 0 # 19 S1_HW_DP
 0 0 0 0 # 20 S2_HW_SH
 0 0 0 0 # 21 S3_TAIW_LG
 0 0 0 0 # 22 S4_TAIW_SM
 0 0 0 0 # 23 S5_JPN_EARLY
 0 0 0 0 # 24 S6_JPN_LATE
 0 0 0 0 # 25 S7_JPN_RTV
 0 0 0 0 # 26 S8_SPC_OBS
 0 0 0 0 # 27 S9_SPC_COMB
 0 0 0 0 # 28 S10__MEX

#_Cond 0 #_If q has random component, then 0=read one parm for each fl
eet with random q; 1=read a parm for each year of index
#_Q_parms(if_any)
```

Size Selection Types

```
#discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3
=all_discarded_dead
#_Pattern Discard Male Special
 24 0 4 0 # 1 F1_MEX
 5 0 0 1 # 2 F2_CAN
 24 0 4 0 # 3 F3_CHINA
```

```
 24 0 4 0 # 4 F4_JPN_KK_SH
 24 0 3 0 # 5 F5_JPN_KK_DP
 5 0 0 4 # 6 F6_JPN_ENY_SHL
 24 0 4 0 # 7 F7_JPN_ENY_DP
 24 0 4 0 # 8 F8_JPN_LG_MESH
 5 0 0 8 # 9 F9_JPN_CST_Oth
 #5 0 0 4 # 10 F10_JPN_SM_MESH
 24 0 0 0
 5 0 0 1 # 11 F11_IATTC
 5 0 0 3 # 12 F12_KOREA
 5 0 0 3 # 13 F13_NON_ISC
 24 0 4 0 # 14 F14_USA_GIILL
 5 0 0 14 # 15 F15_USA_SPORT
 24 0 4 0 # 16 F16_USA_Lonline
 24 0 4 0 # 17 F17_TAIW_LG
 5 0 0 17 # 18 F18_TAIW_SM
 5 0 0 16 # 19 S1_HW_DP
 5 0 0 16 # 20 S2_HW_SH
 5 0 0 17 # 21 S3_TAIW_LG
 5 0 0 18 # 22 S4_TAIW_SM
 5 0 0 4 # 23 S5_JPN_EARLY
 5 0 0 4 # 24 S6_JPN_LATE
 5 0 0 16 # 25 S7_JPN_RTV
 5 0 0 13 # 26 S8_SPC_OBS
 5 0 0 13 # 27 S9_SPC_COMB
 5 0 0 16 # 28 S10_MEX
#
#_age_selex_types
#_Pattern ___ Male Special
 11 0 0 0 # 1 F1_MEX
 11 0 0 0 # 2 F2_CAN
 11 0 0 0 # 3 F3_CHINA
 11 0 0 0 # 4 F4_JPN_KK_SH
 11 0 0 0 # 5 F5_JPN_KK_DP
 11 0 0 0 # 6 F6_JPN_ENY_SHL
 11 0 0 0 # 7 F7_JPN_ENY_DP
 11 0 0 0 # 8 F8_JPN_LG_MESH
 11 0 0 0 # 9 F9_JPN_CST_Oth
 11 0 0 0 # 10 F10_JPN_SM_MESH
 11 0 0 0 # 11 F11_IATTC
 11 0 0 0 # 12 F12_KOREA
 11 0 0 0 # 13 F13_NON_ISC
 11 0 0 0 # 14 F14_USA_GIILL
 11 0 0 0 # 15 F15_USA_SPORT
 11 0 0 0 # 16 F16_USA_Lonline
 11 0 0 0 # 17 F17_TAIW_LG
```

```
 11 0 0 0 # 18 F18_TAIW_SM
 11 0 0 0 # 19 S1_HW_DP
 11 0 0 0 # 20 S2_HW_SH
 11 0 0 0 # 21 S3_TAIW_LG
 11 0 0 0 # 22 S4_TAIW_SM
 11 0 0 0 # 23 S5_JPN_EARLY
 11 0 0 0 # 24 S6_JPN_LATE
 11 0 0 0 # 25 S7_JPN_RTV
 11 0 0 0 # 26 S8_SPC_OBS
 11 0 0 0 # 27 S9_SPC_COMB
 11 0 0 0 # 28 S10_MEX
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxy
r dev_stddev Block Block_Fxn
35 250 105.958 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_1P_1_F1_MEX
 -15 15 -1.81495 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_2_F1_MEX
 -15 15 6.71486 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_3_F1_MEX
 -15 15 7.81557 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_1P_4_F1_MEX
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_5_F1_MEX
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_1P_6_F1_MEX
 -20 200 -16.9636 125 -1 50 4 0 0 0 0 0 0 0 # SzSel_1Fem_Peak_F1_MEX
 -15 15 -0.65966 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_1Fem_Ascend_F1_MEX
 -15 15 0.178666 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_1Fem_Descend_F1_MEX
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_1Fem_Final_F1_MEX
 -15 15 0.63211 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_1Fem_Scale_F1_MEX
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_2P_1_F2_CAN
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_2P_2_F2_CAN
 35 250 168.201 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_3P_1_F3_CHINA
 -15 15 -8.15178 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_2_F3_CHINA
 -15 15 6.31774 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_3_F3_CHINA
 -15 15 6.9276 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_3P_4_F3_CHINA
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_5_F3_CHINA
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_3P_6_F3_CHINA
 -20 200 0 125 -1 50 4 0 0 0 0 0 0 0 # SzSel_3Male_Peak_F3_CHINA
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_3Male_Ascend_F3_CHINA
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_3Male_Descend_F3_CHINA
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_3Male_Final_F3_CHINA
 -15 15 0.85 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_3Male_Scale_F3_CHINA
 35 250 157.718 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_4P_1_F4_JPN_KK_SH
 -15 15 -11.7328 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_4P_2_F4_JPN_KK_SH
 -15 15 7.25747 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_4P_3_F4_JPN_KK_SH
 -15 15 5.87368 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_4P_4_F4_JPN_KK_SH
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_5_F4_JPN_KK_SH
 -999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_4P_6_F4_JPN_KK_SH
 -20 200 -2.8058 0 -1 50 4 0 0 0 0 0 0 0 # SzSel_4Fem_Peak_F4_JPN_KK_S
H
 -15 15 -0.929099 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_4Fem_Ascend_F4_JPN_K
```

```
K_SH
 -15 15 -1.14884 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_4Fem_Descend_F4_JPN_K
K_SH
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_4Fem_Final_F4_JPN_KK_SH
 -15 15 0.62 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_4Fem_Scale_F4_JPN_KK_SH
 35 250 139.613 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_5P_1_F5_JPN_KK_DP
 -15 15 -7.62908 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_F5_JPN_KK_DP
 -15 15 6.58699 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_5P_3_F5_JPN_KK_DP
 -15 15 6.49612 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_5P_4_F5_JPN_KK_DP
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_5_F5_JPN_KK_DP
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_5P_6_F5_JPN_KK_DP
 -80 200 4 125 -1 50 4 0 0 0 0 0 0 0 # SzSel_5Fem_Peak_F5_JPN_KK_DP
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_5Fem_Ascend_F5_JPN_KK_DP
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_5Fem_Descend_F5_JPN_KK_DP
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_5Fem_Final_F5_JPN_KK_DP
 -15 15 0.675664 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_5Fem_Scale_F5_JPN_KK_
DP
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_6P_1_F6_JPN_ENY_SHL
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_6P_2_F6_JPN_ENY_SHL
 35 250 156.714 50 -1 0 2 0 0 0 0 0.5 0 0 # SizeSel_7P_1_F7_JPN_ENY_DP
 -15 15 -11.681 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_7P_2_F7_JPN_ENY_DP
 -15 15 5.85889 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_7P_3_F7_JPN_ENY_DP
 -15 15 5.86717 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_7P_4_F7_JPN_ENY_DP
 -999 -999 -999 0 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_5_F7_JPN_ENY_DP
 -999 -999 -999 0 -1 5 -2 0 0 0 0 0.5 0 0 # SizeSel_7P_6_F7_JPN_ENY_DP
 -20 200 8.44256 125 -1 50 4 0 0 0 0 0 0 0 # SzSel_7Male_Peak_F7_JPN_E
NY_DP
 -15 15 0.893434 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_7Male_Ascend_F7_JPN_E
NY_DP
 -15 15 0.988553 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_7Male_Descend_F7_JPN_
ENY_DP
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_7Male_Final_F7_JPN_ENY_DP
 -15 15 0.85 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_7Male_Scale_F7_JPN_ENY_DP
 35 250 138.027 120 -1 0 2 0 0 0 0 0.5 3 2 # SizeSel_8P_1_F8_JPN_LG_ME
SH
 -15 15 -7.85384 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_8P_2_F8_JPN_LG_MES
H
 -15 15 7.13516 5 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_8P_3_F8_JPN_LG_MESH
 -15 15 7.74822 5 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_8P_4_F8_JPN_LG_MESH
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_5_F8_JPN_LG_MES
H
 -999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_8P_6_F8_JPN_LG_MES
H
 -20 260 3 125 -1 50 4 0 0 0 0 0 3 2 # SzSel_8Male_Peak_F8_JPN_LG_MESH
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_8Male_Ascend_F8_JPN_LG_MESH
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_8Male_Descend_F8_JPN_LG_MESH
```

```
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_8Male_Final_F8_JPN_LG_MESH
 -15 15 0.6 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_8Male_Scale_F8_JPN_LG_MESH
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_9P_1_F9_JPN_CST_Oth
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_9P_2_F9_JPN_CST_Oth
 35 250 50 120 -1 0 -2 0 0 0 0 0.5 0 0 # SizeSel_10P_1_F10_JPN_SM_MESH
 -15 15 -9 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_2_F10_JPN_SM_MESH
 -15 15 5.5 5 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_10P_3_F10_JPN_SM_MESH
 -15 15 6.85 5 -1 0 -4 0 0 0 0 0.5 0 0 # SizeSel_10P_4_F10_JPN_SM_MESH
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_5_F10_JPN_SM_M
ESH
 -999 -999 -999 0 -1 4 -3 0 0 0 0 0.5 0 0 # SizeSel_10P_6_F10_JPN_SM_M
ESH
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_11P_1_F11_IATTC
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_11P_2_F11_IATTC
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_12P_1_F12_KOREA
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_12P_2_F12_KOREA
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_13P_1_F13_NON_ISC
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_13P_2_F13_NON_ISC
 28 250 82.289 50 -1 0 3 0 0 0 0 0.5 2 2 # SizeSel_14P_1_F14_USA_GIILL
 -15 15 -2.30759 0 -1 0 3 0 0 0 0 0.5 2 2 # SizeSel_14P_2_F14_USA_GIIL
L
 -15 15 5.90339 0 -1 0 3 0 0 0 0 0.5 2 2 # SizeSel_14P_3_F14_USA_GIILL
 -15 15 8.33466 0 -1 0 3 0 0 0 0 0.5 2 2 # SizeSel_14P_4_F14_USA_GIILL
 #-10 10 -6.33109 0 -1 0 4 0 0 0 0 0.5 0 0 # SizeSel_14P_5_F14_USA_GII
LL
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_14P_6_F14_USA_GIIL
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_14P_6_F14_USA_GIIL
L
 -20 200 -10 0 -1 50 4 0 0 0 0 0 2 2 # SzSel_14Fem_Peak_F14_USA_GIILL
 -15 15 0 4 -1 50 4 0 0 0 0 0 2 2 # SzSel_14Fem_Ascend_F14_USA_GIILL
 -15 15 0 4 -1 50 4 0 0 0 0 0 2 2 # SzSel_14Fem_Descend_F14_USA_GIILL
 -15 15 0 4 -1 50 4 0 0 0 0 0 2 2 # SzSel_14Fem_Final_F14_USA_GIILL
 -15 15 0.520265 4 -1 50 5 0 0 0 0 0 2 2 # SzSel_14Fem_Scale_F14_USA_G
IILL
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_15P_1_F15_USA_SPORT
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_15P_2_F15_USA_SPORT
 35 250 150 50 -1 0 3 0 0 0 0 0.5 1 2 # SizeSel_16P_1_F16_USA_Lonline
 -15 15 -10.2074 0 -1 0 3 0 0 0 0 0.5 1 2 # SizeSel_16P_2_F16_USA_Lonl
ine
 -15 15 7.25299 0 -1 0 3 0 0 0 0 0.5 1 2 # SizeSel_16P_3_F16_USA_Lonli
ne
 -15 15 6.66187 0 -1 0 3 0 0 0 0 0.5 1 2 # SizeSel_16P_4_F16_USA_Lonli
ne
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_5_F16_USA_Lonl
ine
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_16P_6_F16_USA_Lonl
```

```
ine
 -80 200 19.6238 0 -1 50 4 0 0 0 0 0 1 2 # SzSel_16Fem_Peak_F16_USA_Lo
nline
 -15 15 1.07867 4 -1 50 4 0 0 0 0 0 1 2 # SzSel_16Fem_Ascend_F16_USA_L
online
 -15 15 -0.854555 4 -1 50 4 0 0 0 0 0 1 2 # SzSel_16Fem_Descend_F16_US
A_Lonline
 -15 15 0 4 -1 50 4 0 0 0 0 0 1 2 # SzSel_16Fem_Final_F16_USA_Lonline
 -15 15 0.642424 4 -1 50 5 0 0 0 0 0 1 2 # SzSel_16Fem_Scale_F16_USA_L
online
 35 280 200 50 -1 0 2 0 1 2004 2014 0.6 0 0 # SizeSel_17P_1_F17_TAIW_L
G
 -15 15 -2.6 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_17P_2_F17_TAIW_LG
 -15 15 7.5 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_17P_3_F17_TAIW_LG
 -15 15 5.5 0 -1 0 3 0 0 0 0 0.5 0 0 # SizeSel_17P_4_F17_TAIW_LG
 -999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_5_F17_TAIW_LG
 -999 -999 -999 0 -1 5 -3 0 0 0 0 0.5 0 0 # SizeSel_17P_6_F17_TAIW_LG
 -80 200 9.5 9 -1 50 4 0 1 2004 2014 0.6 0 0 # SzSel_17Fem_Peak_F17_TA
IW_LG
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_17Fem_Ascend_F17_TAIW_LG
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_17Fem_Descend_F17_TAIW_LG
 -15 15 0 4 -1 50 4 0 0 0 0 0 0 0 # SzSel_17Fem_Final_F17_TAIW_LG
 -15 15 0.62 4 -1 50 5 0 0 0 0 0 0 0 # SzSel_17Fem_Scale_F17_TAIW_LG
 #28 250 118.194 50 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_1_F18_TAIW_S
M
 #-15 15 -9.7791 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_2_F18_TAIW_SM
 #-15 15 6.82267 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_3_F18_TAIW_SM
 #-15 15 8.17439 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_4_F18_TAIW_SM
 #-10 10 -5.22115 0 -1 0 -5 0 0 0 0 0.5 0 0 # SizeSel_18P_5_F18_TAIW_S
M
 #-999 -999 -999 0 -1 0 -3 0 0 0 0 0.5 0 0 # SizeSel_18P_6_F18_TAIW_SM
 #-20 200 -10 0 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Peak_F18_TAIW_SM
 #-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Ascend_F18_TAIW_SM
 #-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Descend_F18_TAIW_SM
 #-15 15 0 4 -1 50 -4 0 0 0 0 0 0 0 # SzSel_18Fem_Final_F18_TAIW_SM
 #-15 15 0.51336 4 -1 50 -5 0 0 0 0 0 0 0 # SzSel_18Fem_Scale_F18_TAIW
_SM
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_9P_1_F18
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_9P_2_F18
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_19P_1_S1_HW_DP
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_19P_2_S1_HW_DP
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_20P_1_S2_HW_SH
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_20P_2_S2_HW_SH
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_21P_1_S3_TAIW_LG
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_21P_2_S3_TAIW_LG
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_22P_1_S4_TAIW_SM
```

```
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_22P_2_S4_TAIW_SM
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_23P_1_S5_JPN_EARLY
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_23P_2_S5_JPN_EARLY
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_24P_1_S6_JPN_LATE
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_24P_2_S6_JPN_LATE
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_25P_1_S7_JPN_RTV
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_25P_2_S7_JPN_RTV
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_26P_1_S8_SPC_OBS
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_26P_2_S8_SPC_OBS
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_27P_1_S9_SPC_OBS_TROPI
C
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_27P_2_S9_SPC_OBS_TROPI
C
 -1 200 -1 50 0 99 -2 0 0 0 0 0.5 0 0 # SizeSel_28P_1_S10_MEX
 -1 239 -1 50 0 99 -3 0 0 0 0 0.5 0 0 # SizeSel_28P_2_S10_MEX
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_1_F1_MEX
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_1P_2_F1_MEX
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_1_F2_CAN
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_2P_2_F2_CAN
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_1_F3_CHINA
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_3P_2_F3_CHINA
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_1_F4_JPN_KK_SH
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_4P_2_F4_JPN_KK_SH
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_1_F5_JPN_KK_DP
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_5P_2_F5_JPN_KK_DP
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_1_F6_JPN_ENY_SHL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_6P_2_F6_JPN_ENY_SHL
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_1_F7_JPN_ENY_DP
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_7P_2_F7_JPN_ENY_DP
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_1_F8_JPN_LG_MESH
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_8P_2_F8_JPN_LG_MESH
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_1_F9_JPN_CST_Oth
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_9P_2_F9_JPN_CST_Oth
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_1_F10_JPN_SM_MESH
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_10P_2_F10_JPN_SM_MESH
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_1_F11_IATTC
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_11P_2_F11_IATTC
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_1_F12_KOREA
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_12P_2_F12_KOREA
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_13P_1_F13_NON_ISC
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_13P_2_F13_NON_ISC
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_14P_1_F14_USA_GIILL
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_14P_2_F14_USA_GIILL
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_15P_1_F15_USA_SPORT
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_15P_2_F15_USA_SPORT
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_16P_1_F16_USA_Lonline
```

```
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_16P_2_F16_USA_Lonline
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_17P_1_F17_TAIW_LG
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_17P_2_F17_TAIW_LG
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_18P_1_F18_TAIW_SM
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_18P_2_F18_TAIW_SM
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_19P_1_S1_HW_DP
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_19P_2_S1_HW_DP
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_20P_1_S2_HW_SH
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_20P_2_S2_HW_SH
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_21P_1_S3_TAIW_LG
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_21P_2_S3_TAIW_LG
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_22P_1_S4_TAIW_SM
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_22P_2_S4_TAIW_SM
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_23P_1_S5_JPN_EARLY
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_23P_2_S5_JPN_EARLY
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_24P_1_S6_JPN_LATE
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_24P_2_S6_JPN_LATE
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_25P_1_S7_JPN_RTV
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_25P_2_S7_JPN_RTV
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_26P_1_S8_SPC_OBS
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_26P_2_S8_SPC_OBS
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_27P_1_S9_SPC_OBS_TROPIC
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_27P_2_S9_SPC_OBS_TROPIC
 0 40 0 1 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_28P_1_S10_MEX
 1 40 36 3 0 99 -1 0 0 0 0 0.5 0 0 # AgeSel_28P_2_S10_MEX
#_Cond 0 #_custom_sel-env_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
1 #_Cond 0 #_custom_sel-blk_setup (0/1)
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no block usage
 35 250 138.027 120 -1 0 4
 35 250 138.027 120 -1 0 4
 35 250 138.027 120 -1 0 4
 -80 200 3 125 -1 50 4
 -80 200 3 125 -1 50 4
 -80 200 3 125 -1 50 4
 28 250 82.289 50 -1 0 4 # SizeSel_14P_1_F14_USA_GIILL
 28 250 82.289 50 -1 0 4 # SizeSel_14P_1_F14_USA_GIILL
 -15 15 -2.30759 0 -1 0 4 # SizeSel_14P_2_F14_USA_GIILL
 -15 15 -2.30759 0 -1 0 4 # SizeSel_14P_2_F14_USA_GIILL
 -15 15 5.90339 0 -1 0 4 # SizeSel_14P_3_F14_USA_GIILL
 -15 15 5.90339 0 -1 0 4 # SizeSel_14P_3_F14_USA_GIILL
 -15 15 8.33466 0 -1 0 4 # SizeSel_14P_4_F14_USA_GIILL
 -15 15 8.33466 0 -1 0 4 # SizeSel_14P_4_F14_USA_GIILL
 -20 200 -10 0 -1 50 4 # SzSel_14Fem_Peak_F14_USA_GIILL
 -20 200 -10 0 -1 50 4 # SzSel_14Fem_Peak_F14_USA_GIILL
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Ascend_F14_USA_GIILL
```

```
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Ascend_F14_USA_GIILL
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Descend_F14_USA_GIILL
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Descend_F14_USA_GIILL
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Final_F14_USA_GIILL
 -15 15 0 4 -1 50 4 # SzSel_14Fem_Final_F14_USA_GIILL
 -15 15 0.520265 4 -1 50 5 # SzSel_14Fem_Scale_F14_USA_GIILL
 -15 15 0.520265 4 -1 50 5 # SzSel_14Fem_Scale_F14_USA_GIILL
 35 250 150 50 -1 0 4 # SizeSel_16P_1_F16_USA_Lonline
 -15 15 -10.2074 0 -1 0 4 # SizeSel_16P_2_F16_USA_Lonline
 -15 15 7.25299 0 -1 0 4 # SizeSel_16P_3_F16_USA_Lonline
 -15 15 6.66187 0 -1 0 4 # SizeSel_16P_4_F16_USA_Lonline
 -20 200 19.6238 0 -1 50 4 # SzSel_16Fem_Peak_F16_USA_Lonline
 -15 15 1.07867 4 -1 50 4 # SzSel_16Fem_Ascend_F16_USA_Lonline
 -15 15 -0.854555 4 -1 50 4 # SzSel_16Fem_Descend_F16_USA_Lonline
 -15 15 0 4 -1 50 4 # SzSel_16Fem_Final_F16_USA_Lonline
 -15 15 0.642424 4 -1 50 5 # SzSel_16Fem_Scale_F16_USA_Lonline

#_Cond No selex parm trends
6 #_Cond -4 # placeholder for selparm_Dev_Phase
1 #_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 parameter
s

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 2
4 25 26 27 28
  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 0#_add_to_surv
ey_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 0#_add_to_disc
ard_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 0#_add_to_body
wt_CV
  0.49 1 1 1 0.408 1 1 1 1 1 1 1 1 1 1 0.85 1 1 1 1 1 1 1 1 1 1 1 1#
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1#_mult_by_age
comp_N
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1#_mult_by_siz
e-at-age_N

1 #_maxlambdaphase
1 #_sd_offset

58 # 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=SizeFre
q; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPe
n; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin
#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 0 1
 1 20 1 0 1
 1 21 1 0 1
 1 22 1 0 1
 1 23 1 1 1
 1 24 1 1 1
 1 25 1 0 1
 1 26 1 0 1
 1 27 1 0 1
 1 28 1 0 1
 4 1 1 1 0
 4 2 1 0 0
 4 3 1 1 0
 4 4 1 1 0
 4 5 1 1 0
 4 6 1 0 0
 4 7 1 1 0
 4 8 1 1 0
 4 9 1 0 0
 4 10 1 0 0
 4 11 1 0 0
 4 12 1 0 0
```

```
 4 13 1 0 0
 4 14 1 1 0
 4 15 1 0 0
 4 16 1 1 0
 4 17 1 1 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
 4 28 1 0 0
 9 1 1 1 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
#  0 #_CPUE/survey:_19
#  0 #_CPUE/survey:_20
#  0 #_CPUE/survey:_21
#  0 #_CPUE/survey:_22
#  1 #_CPUE/survey:_23
```

```
#  1 #_CPUE/survey:_24
#  0 #_CPUE/survey:_25
#  0 #_CPUE/survey:_26
#  0 #_CPUE/survey:_27
#  1 #_lencomp:_1
#  0 #_lencomp:_2
#  1 #_lencomp:_3
#  0 #_lencomp:_4
#  1 #_lencomp:_5
#  0 #_lencomp:_6
#  0 #_lencomp:_7
#  1 #_lencomp:_8
#  0 #_lencomp:_9
#  0 #_lencomp:_10
#  0 #_lencomp:_11
#  0 #_lencomp:_12
#  0 #_lencomp:_13
#  1 #_lencomp:_14
#  0 #_lencomp:_15
#  1 #_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 #_init_equ_catch
#  1 #_recruitments
#  1 #_parameter-priors
#  1 #_parameter-dev-vectors
#  1 #_crashPenLambda
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, Growth 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

```
# Forecast_SS file
# for all year entries except rebuilder; enter either: actual year, -9
99 for styr, 0 for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 0=none; 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=
set to F(endyr)
0.4 # SPR target (e.g. 0.40) # old value was 0.349641857 possibly a ea
rly calc of % bio
0.4 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_r
elF (enter actual year, or values of 0 or -integer to be rel. endyr)
 0 0 0 0 2005 2013
 #  2001 2001 2001 2001 2001 2001 # 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 firs
t-last relF yrs); 5=input annual F scalar
0 # N forecast years
1 # F scalar (only used for Do_Forecast==5)
#_Fcast_years:  beg_selex, end_selex, beg_relF, end_relF  (enter actua
l year, or values of 0 or -integer to be rel. endyr)
 0 0 2006 2014
#  2001 2001 1991 2001 # after processing
1 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.4 # Control rule Biomass level for constant F (as frac of Bzero, e.g
. 0.40)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10
)
0.75 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1-3) (fixed at 3 for now)
3 #_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 fixe
d inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>
0.0 to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
-1 # Rebuilder:  first year catch could have been set to zero (Ydecl)(
-1 to set to 1999)
```

```
-1 # 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) below
# Note that fleet allocation is used directly as average F if Do_Forecast=4
2 # 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:  FISHERY1
#  1
# max totalcatch by fleet (-1 to have no max)
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
# max totalcatch by area (-1 to have no max)
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
# fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)
 0
#_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 forecast F)
2 # basis for input Fcast catch:  2=dead catch; 3=retained catch; 99=input Hrate(F) (units are from fleetunits; note new codes in SSV3.20)
# Input fixed catch values
#Year Seas Fleet Catch(or_F)

#
999 # verify end of input
```

SS Starter File

```


0 # 0=use init values in control file; 1=use ss2.par
1 # run display detail (0,1,2)
1 # detailed age-structured reports in REPORT.SSO (0,1)
0 # write detailed checkup.sso file (0,1)
0 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)
0 # 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)
0 # Number of bootstrap datafiles to produce
```

```
100 # Turn off estimation for parameters entering after this phase
10 # MCMC burn interval
2 # MCMC thin interval
0 # jitter initial parm value by this fraction
-1 # min yr for sdreport outputs (-1 for styr)
-2 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecast
yrs)
0 # N individual STD years
# vector of year values
# 1973 1976

1e-004 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
0 # min age for calc of summary biomass
1 # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=re
l 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-SPR)/(1-SPR_Btarget); 4=rawSPR
3 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num);
3=sum(Frates)
2 # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999 # check value for end of file
```