ISC/19/SHARKWG-2/1

Stock synthesis projections of blue shark in the North Pacific Ocean through 2028[1]

Mikihiko Kai[2] and Felipe Carvalho[3]
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[2]National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN

[3]NOAA Pacific Islands Fisheries Science Center,
1845 Wasp Boulevard, Honolulu, Hawaii 96818, USA

Email: kaim@affrc.go.jp

[1] Working document submitted to the ISC Shark Working Group Webinar, 5 March, 2020, National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan. **Document not to be cited without author's permission.**

Abstract

Stock Synthesis projections were conducted from 2019 to 2028 at pre-specified constant F scenarios (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$) and a deterministic recruitment after updating the annual catch data of blue shark caught in the North Pacific Ocean through 2018 to assess not only the stock status in recent three years (2016-2018) but also future trajectories of the spawning stock biomass through 2028. The specifications of the stock synthesis (SS) model were the same as those used in the previous benchmark stock assessment in 2017. All the parameters of SS were fixed except for the R0 and recruitment deviations. The future projections with status-quo showed that the spawning stock biomass (SSB) in 2018 exceeded the MSY level (SSB_{2018}/SSB_{MSY}=1.65) and the mean current fishing mortality (F) from 2015 to 2017 was below MSY level ($F_{2015\text{-}2017}/F_{MSY}$=0.29), and the future trajectories of spawning stock biomass gradually increased because current catch is much lower than MSY level. These results continuously suggested that the stock status is not overfished, and overfishing is not occurring.

Introduction

Blue shark (*Prionace glauca*) is a highly migratory species and widely distributed throughout temperate and tropical waters globally (Nakano and Stevens, 2008). Blue shark is mainly caught by longline fisheries as well as drift-net fisheries in the North Pacific Ocean (NPO) as bycatch and occasionally as target species (Nakano and Seki, 2003). The ISC shark working group (SHARKWG) recognizes that there are two stocks in the North and South Pacific, respectively, based on biological and fishery evidence (ISC, 2017). The stock assessment and future projection for blue shark in the NPO was conducted in 2017 using the stock synthesis 3 (SS3; Methot and Wetzel, 2013) with the biological parameters and fishery data from 1971 and 2015. The results of stock assessment for the reference case model showed that (1) the spawning stock biomass (SSB) in 2015 (SSB_{2015}) was 69% higher than at maximum sustainable yields (MSY) (SSB_{MSY}) and estimated to be 295,774 mt, and (2) the annual fishing mortality during 2012 and 2014 ($F_{2012\text{-}2014}$) was estimated to be well below F_{MSY} at approximately 38% of F_{MSY} (ISC, 2017). Therefore, the reference run produced terminal conditions that were predominantly in the green quadrant of the Kobe plot that means the stock status is not overfished and the overfishing is not occurring. The results of future projections from 2015 to 2024 under different F harvest policies ($F_{status\ quo}$, $F_{20\%plus}$, $F_{20\%minus}$, F_{MSY}) showed that the median SSB in the NPO will likely remain above SSB_{MSY} in the foreseeable future (ISC, 2017).

ISC SHARKWG has been conducting the benchmark stock assessment for blue shark and shortfin mako shark (*Isurus oxyrinchus*) in the NPO, respectively, every three years (ISC, 2014, ISC, 2015, ISC, 2017 and ISC, 2018). At the ISC plenary meeting in July, 2019, in Chinese Taipei,

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some member countries (Japan, Taiwan and USA) of ISC SHARKWG proposed to change the stock assessment cycle of these species from 3 years to 5 years. The motivation of the 5 years cycle was a recommendation that was first proposed by the Western and Central Pacific Fisheries Commission (WCPFC). The proposal was accepted by ISC plenary under the condition that the update stock assessment for both species shall be conducted between the benchmark assessments. All the member countries of ISC SHARKWG agreed the proposals by the end of webinar in November 2019. ISC SHARKWG also determined to conduct an update stock assessment every five years using the future projection with update of the annual catch data in recent three years.

The objective of this working document paper is to conduct the update stock assessment for blue shark in the NPO using the function of future projection of SS with the updated catch data from 2016-2018 to assess the current stock status and future trajectories of SSB for ten years until 2028.

Materials and Methods

The annual catch data of each fleet used in the SS was updated for 3 years until 2018 (**Fig. 1**). Thereafter, future projection was conducted using SS3 (version 3.24f; Methot, 2015) under the conditions of pre-specified constant F scenarios (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$) and a deterministic recruitment (Low-fecundity stock recruitment relationships; LFSR, Taylor *et al*., 2013) after updating the annual catch data of each fleets through 2018 (**Table 1**). Time period of the projections were set at 10 years beginning in 2019 until 2028.We used the input SS files including control file (control.ss), data file (data.ss), starter file (starter.ss) and forecast file (forecast.ss) of the reference case used in the previous stock assessment in 2017. For the control file, we fix all the parameters except for the parameters of R0 and recruitment deviations using the output file (control.ss_new) of SS reference case in 2017. For the forecast file, we use the selectivity from 2012 to 2014 and changed the relative F value by the scenarios of status quo. The value of 0.111666 was used as the F-multiplier of status-quo for $F_{2015\text{-}2017}$ when $F_{20\%plus}$ and $F_{20\%minus}$ were calculated.

Annual spawning stock biomass (SSB) under different F scenarios was estimated from maximum likelihood estimation (MLE) and the estimates from 1971 to 2028 were compared with MSY and unfished levels (SSB/SSB_{MSY} and SSB/SSB_0). Management quantities were summarized in **Tables 2** and **3**.

Results

The relative values of $F(F/F_{MSY})$ for the status quo (2015 – 2017) were the lowest level in the stock assessment periods (**Fig. 2**) due to the reduction of the recent annual catch compared to that of last three decades (**Table 1, Fig. 1**). Compared to MSY-based reference points, the current spawning

biomass (SSB_{2018}) was 65% above SSB_{MSY}, and the current fishing mortality ($F_{2015\text{-}2017}$) was 29% of F_{MSY} (**Table 2**). These results suggested that the current stock is not in an overfished state, and that overfishing is not occurring (**Fig. 3**). The healthy conditions of the stock status had a large influence on the results of future projections.

The results of the future projection under the different constant F policies (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$) indicated that the SSBs could continuously increase above the SSB_{MSY} until 2028 except for the scenario of F_{MSY} and maintain above 70% of unfished level for all strategies during the forecast period (**Table 3**, **Fig. 4, 5**).

The stock status and conservation information for the update assessment report of NP blue shark are summarized in **Appendix A**.

Discussions

Our results of future projection revealed that the stock status of blue shark in NPO was a healthy condition, even if the relative F of blue shark in the NPO increases by 20% compared to the current level for 2015-2017. The total annual catch of blue shark has been decreasing since mid-2000s and recent total catch is the lowest level in the stock assessment period and stable approximately 30,000 tons (**Table 1, Fig. 1**). In addition, there is no tendency to significantly increase the catch in recent years because the total catches of major Japanese and Taiwanese fleets are stable (Kai, 2019; Tsai and Liu, 2019). Further, the abundance indices of Japanese shallow-set longline fishery and Taiwanese large-scale longline fishery had increased in recent three years for 2016-2018 (Kai, 2019; Tsai and Liu, 2019). These results support that the abundance of blue shark in NPO has increased in recent years due to decrease of total fishing effort.

The stock synthesis projection indicated that it is possible to maintain the SSB above the MSY level until 2028. In consideration with the difficulties in the sales of pelagic sharks in the global market due to the CITES listing of major pelagic sharks and regulations for the shark's fishery, longline fisheries targeting the blue shark in the NPO have a low possibility to increase their catches for pelagic sharks such as a blue shark.

The ten-year period of future projection is likely enough because the stock status in recent years was healthy conditions (ISC, 2017) and the generation time of blue shark is approximately 7 years (Cortés, 2002).

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Table 1. Annual catch for 1971-2018 used in the stock synthesis forecast.

Year	#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SH	F7_JPN_ENY_DP	F8_JPN_LG_MES	F9_JPN_CST_Oth	F10_JPN_SM_ME	F11_IATTC	F12_KOREA	F13_NON_ISC	F14_USA_GIILL	F15_USA_SPORT	F16_USA_Lonline	F17_TAIW_LG	F18_TAIW_SM	Total
1971	440	0	0	21604.7	0	650.8	0	0	996.4	0	7	0	0	0	30	0	5	12065	35,799
1972	440	0	0	15359	0	1416.9	0	0	1201.4	0	5	0	0	0	30	0	5	15051	33,508
1973	440	0	0	16760.9	0	1098.6	0	6296.9	1172	0	5	0.01	0	0	30	0	1	12024	37,828
1974	440	0	0	14607	0	1304.5	0	6296.9	1337.3	0	5	0.05	0	0	30	0	134	10608	34,763
1975	440	0	0	15821.8	798.5	671.1	5774.4	6296.9	913.9	0	7	4.7	0	0	33	0	200	9192	40,153
1976	374	0	0	22434.2	1819.8	494.5	10442.1	6296.9	1538.3	0	7	31.8	0	0	31	98	8	10278	53,854
1977	386	0	0	30495.3	2866.2	429.4	13790.6	6296.9	1265.1	0	6	55.5	0	0	29	196	48	9997	65,861
1978	561	0	0	24642.8	2254	456.9	13340.9	6296.9	1558.8	0	8	17.3	0	2	33	294	60	10543	60,069
1979	338	1	0	26898.2	2200	566.6	19721.5	6296.9	1509.7	0	10	0	0	5	33	428	14	12346	70,368
1980	624	11	0	25899.7	4530.5	270	21482.9	6296.9	1293.1	0	10	114.2	0	12	29	589	45	12795	74,002
1981	1593	0	0	22794.5	6641.5	378.1	23839.6	6296.9	1290.9	13331.3	9	0.3	0	55	27	587	40	10921	87,805
1982	1181	0	0	13861	6794.2	724	15146.9	6296.9	1034.4	13331.3	6	241.9	0	84	15	685	5	11998	71,405
1983	1548	25	0	11228.6	7312.6	432.7	16534	5926.8	642	13331.3	6	27.3	0	125	46	783	5	10581	68,554
1984	390	0	0	8741.6	8137.3	345.5	15544.3	4727.5	1333.1	13331.3	6	87.8	0	135	96	881	1	9508	63,265
1985	528	60	0	7846.2	6093.6	207.9	15683.9	3763.6	1387.8	13331.3	3	145.4	0	119	193	979	115	10597	61,054
1986	2128	90	0	9373.7	6603.2	143.6	9393	4081.1	1239.4	13331.3	2	95.4	0	376	43	1077	138	8910	57,025
1987	2205	159	0	7406.6	3538.8	222.9	10229.9	3990.5	1276.3	13331.3	2	158.8	0	152	181	1175	56	6673	50,758
1988	3337	0	0	6582.2	2383.7	267.5	15896.2	3707.7	1152.5	13331.3	6	139.8	0	125	346	1312	10	6956	55,553
1989	1643	0	0	5902.1	3013.9	358.5	18148.8	3707.7	1052.7	20022	5	49.5	0	128	99	1380	54	7843	63,407
1990	2865	4	0	5394.4	2717.7	484.6	11799.3	3707.7	1070.4	8758.4	3	58.2	0	299	64	1492	216	8669	47,603
1991	3197	0	0	6479.3	4007.2	1140.1	10305.7	3707.7	1053.7	8758.4	2	64.8	0	94	97	1572	230	9389	50,098
1992	3085	0	0	6902.1	3408.7	958.5	8519.6	3387.7	1099	4379.2	3	49.1	0	135	47	2146	75	7540	41,735
1993	3517	0	0	8518.4	3889.7	1340.3	11211	660.5	1047	0	3	27.8	0	105	47	3595	60	6859	40,881
1994	1758	0	0	8665.3	3857.7	1515.0	18004.9	576.9	1899.1	0	2	33.0	0	37	43	2643	12	5458	44,505
1995	2100	0	0	8679.6	2206.9	1716.7	23951.4	483.4	1439.8	0	10	103.5	161	160	50	1955	638	9462	53,117
1996	3117	1	0	8841.7	3399.5	1959.0	14109.9	474.0	1059.3	0	2	230.9	165	85	26	2475	275	9642	45,862
1997	2948	1	0	11055.8	2073.9	2821.0	16095.7	598.0	631.8	0	4	432.9	261	64	61	2895	320	13453	53,716
1998	3134	2	0	10908.7	1447.4	1959.3	15478.5	610.9	1216.6	0	2	623.2	634	105	11	2987	337	11303	50,760
1999	2261	1	0	12856.1	1019.6	2113.9	10789.6	827.6	772.2	0	1	470.8	782	54	20	2886	623	13495	48,973
2000	2719	1	0	17230.7	626.6	3652.3	6718.8	729.8	1969.7	0	2	433.0	1350	27	36	1315	684	19707	57,202

Table 1. Continued.

Year	#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SH	F7_JPN_ENY_DP	F8_JPN_LG_MES	F9_JPN_CST_Oth	F10_JPN_SM_ME	F11_IATC	F12_KOREA	F13_NON_ISC	F14_USA_GIILL	F15_USA_SPORT	F16_USA_Lonline	F17_TAIW_LG	F18_TAIW_SM	Total
2001	2587	5	340.4	19457.9	506.9	2931.8	7027.7	730.5	1083.6	0	0	162.7	944	18	13	350	984	8847	45,989
2002	2524	5	333.6	16745.8	547.8	2979.1	4930.1	767.7	1514.7	0	3	293.5	2126	12	5	256	1357	10225	44,626
2003	2307	17	305.1	16423.2	1297.1	2937.0	5029.0	1350.3	1623.9	0	1	398.8	1708	15	11	255	777	9467	43,923
2004	3781	4	282.2	14025.3	3600.8	2685.4	4536.9	1202.4	1234.2	0	1	49.6	5846	10	4	187	1189	11479	50,118
2005	2721	0	343.3	17184.4	1169.3	2863.4	5869.4	1321.2	2520.8	0	0	44.0	3081	3	3	140	915	13563	51,742
2006	2765	20	200.6	13986.9	1902.8	2680.2	4332.9	1204.1	2418.7	0	3	21.4	3111	3	4	136	884	13291	46,965
2007	3324	9	234.2	11418.8	3540.6	1741.9	4308.9	1322.6	2801.1	0	2	203.3	3153	27	5	150	818	13030	46,090
2008	4355	6	133.6	10095.0	1071.8	2544.8	3999.0	943.7	2546.7	0	3	74.6	2066	14	3	121	680	14144	42,801
2009	4423	8	297.8	11841.6	412.4	1954.7	3023.1	1207.7	2248.3	0	2	146.0	1778	5	3	114	478	16081	44,024
2010	4469	7	357.3	10018.0	204.4	1717.4	8857.0	962.5	1910.2	0	1	470.0	1808	3	3	144	334	13015	44,281
2011	3719	13	612.5	4335.5	122.1	2358.0	12492.6	764.5	933.6	0	1	952.0	2624	3	1	138	594	15,857	45,520
2012	4108	9	757.7	5798.9	284.3	2544.8	3675.3	1076.3	1595.6	0	1.9	551.0	2778	5	2.1	138	594	15,857	39,777
2013	4494	26	598.4	4807.9	4157.5	1954.7	4536.7	1103.4	1759.1	0	1.6	491.0	2131	2	1.3	265	551	6983	33,863
2014	5502	9	250.6	5972.5	2741.8	1717.4	4674.2	1059.6	1140.6	0	0.4	328.0	2059	2	1.6	392	700	11156	37,707
2015	5502	23	626.9	5312.3	57.4	2358.0	3804.8	1079.8	1498.4	0	0.3	121.0	2059	1	1.9	468	1186	8856	32,956
2016	3880	12	569.2	4841.6	166.4	4421.0	4453.3	1832.3	628.1	0	2.0	0.1	321	9.7	2.9	401.0	449	11,700	33,689
2017	3384	25	569.2	5384.7	236.3	4458.5	4152.6	1365.7	560.1	0	0.0	4.438	1062	4.5	2.5	356	431	11,309	33,306
2018	2852	46	569.2	4348.6	438.1	4168.7	1543.0	1365.7	560.1	0	0.1	2.098	1279	0.3	1.0	379	878	10,787	29,219

Table 2. Estimates of key management quantities for the North Pacific blue shark update stock assessment.

Management quantities	Basecase in 2017	Forecast
SSB_{1971}	293,537	293,459
SSB_{2015}	291,205	290,234
SSB_{2018}		285,385
SSB_{MSY}	170,251	173,207
SSB_0	348,947	348,854
F_{MSY}	0.35	0.39
SSB_{2015}/SSB_{MSY}	1.71	1.68
SSB_{2018}/SSB_{MSY}		1.65
SSB_{2015}/SSB_0	0.83	0.83
SSB_{2018}/SSB_0		0.82
$F_{2012\text{-}2014}/F_{MSY}$	0.38	0.35
$F_{2015\text{-}2017}/F_{MSY}$		0.29
MSY	79,142	78,366

Table 3. Estimates of key management quantities in the forecast for the North Pacific blue shark update stock assessment.

Management quantities	$F_{2012\text{-}2014}$	$F_{2015\text{-}2017}$	$F_{20\%plus}$	$F_{20\%minus}$	F_{MSY}
SSB_{2028}	317,593	327,485	319,028	330,616	259,727
SSB_{2028}/SSB_{MSY}	1.83	1.89	1.84	1.91	1.50
SSB_{2028}/SSB_0	0.91	0.94	0.91	0.95	0.74

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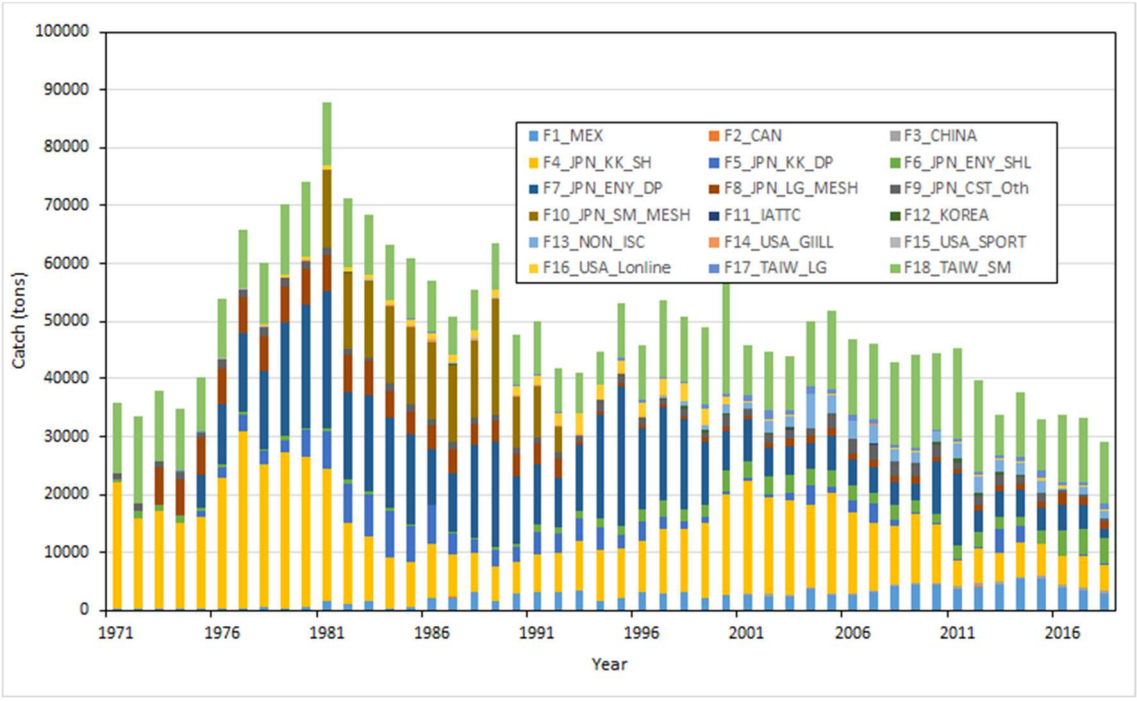

Fig. 1 Annual catch for 1971-2018 used in the stock synthesis forecast.

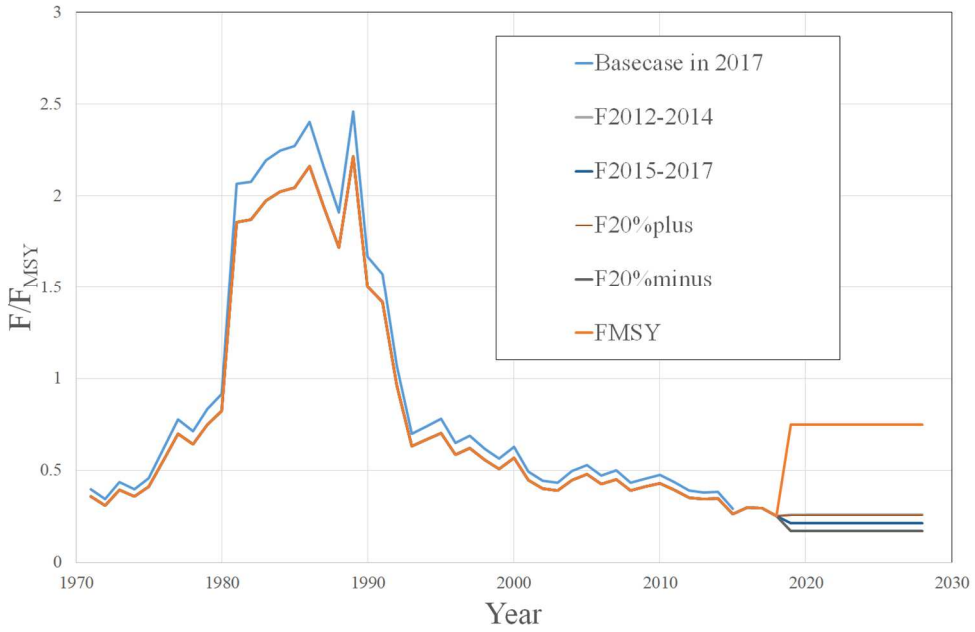

Fig.2 Trajectories of Fishing mortality (F) relative to MSY level (F_{MSY}) under five constant F strategies (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$).

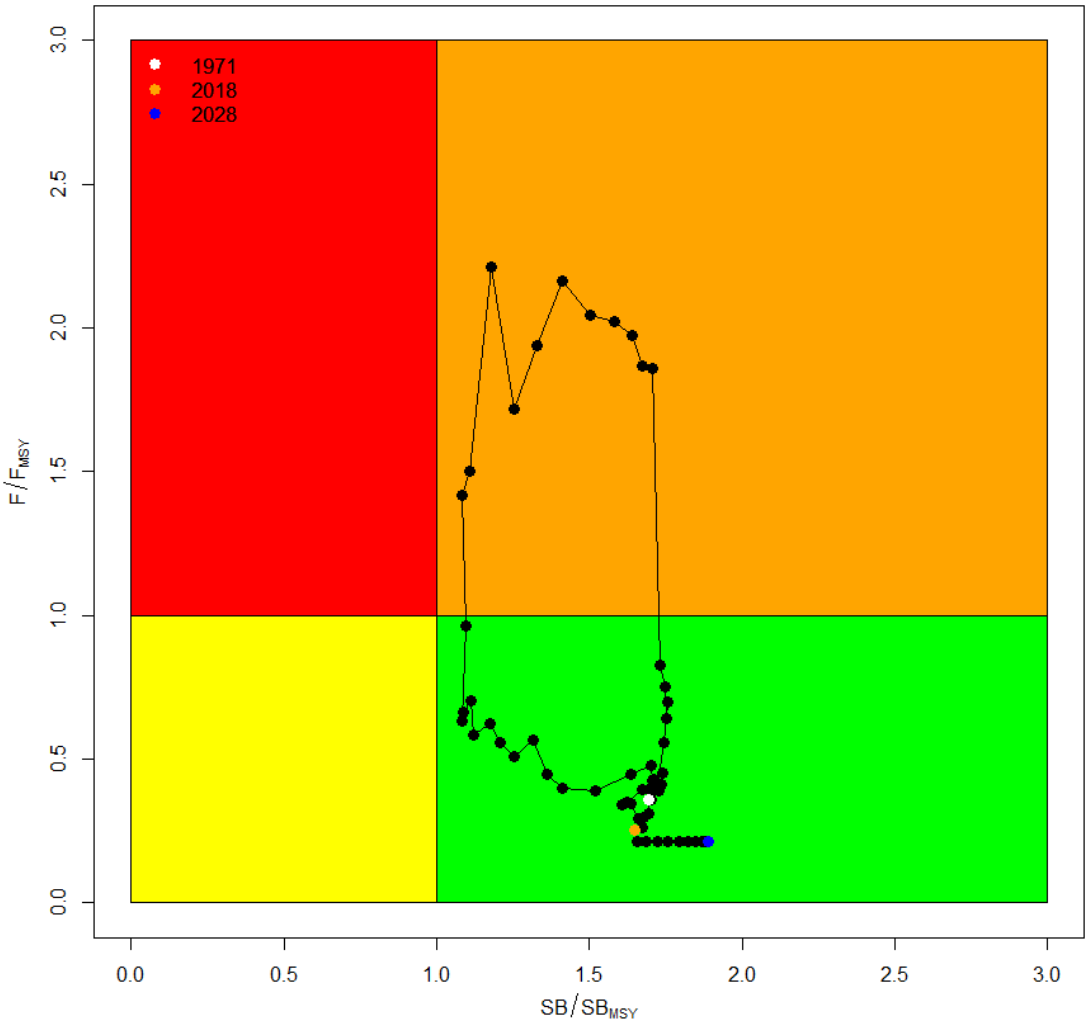

Fig.3 Kobe plot of the trends in estimates of relative fishing mortality and female spawning biomass of north Pacific blue shark between 1971-2028 for the reference case of SS with updated catch data.

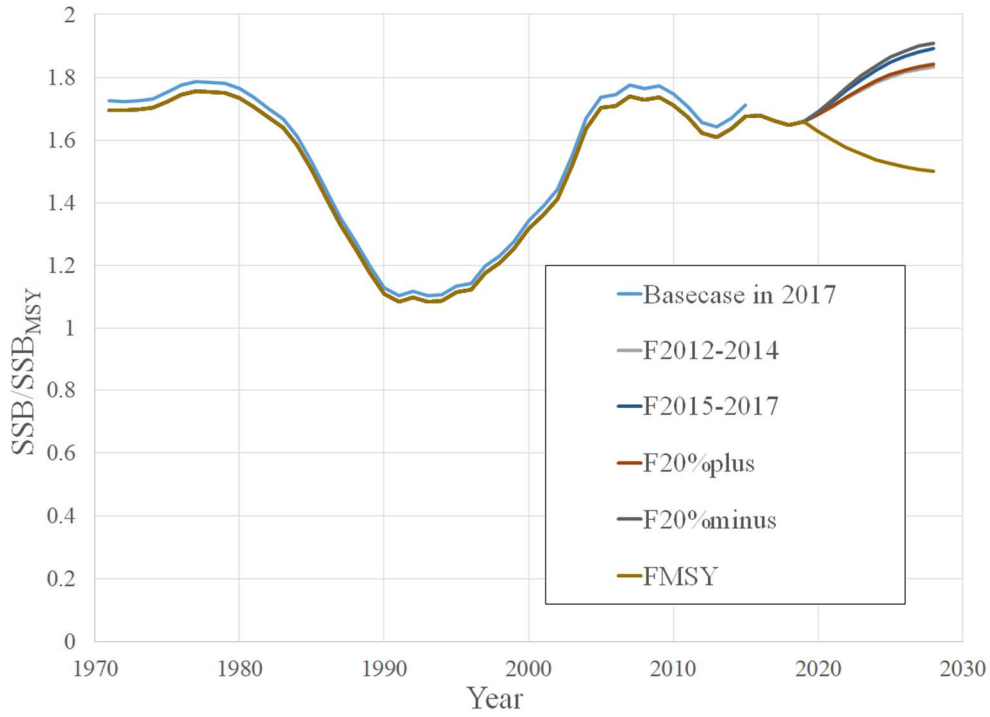

Fig.4 Trajectories of spawning stock biomass (SSB) relative to MSY level (SSB_{MSY}) under five constant F strategies (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$).

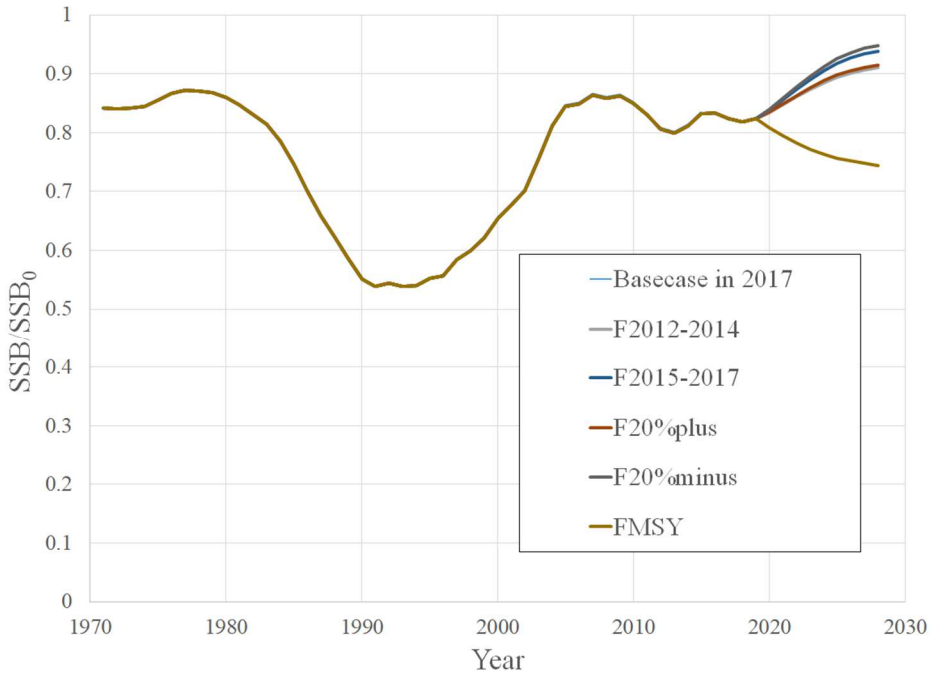

Fig.5 Trajectories of spawning stock biomass (SSB) relative to unfished level (SSB_0) under five constant F strategies (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$).

Appendix A Stock status and conservation information

Target and limit reference points have not yet been established for pelagic sharks in the Pacific Ocean by either the WCPFC or the IATTC. Stock status is reported in relation to MSY-based reference points. The following information on the status of NP BSH is provided.

Status of stock

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 2018 (SB_{2018}) was 65% higher than at MSY and estimated to be 285,385 mt (**Table 2**; **Fig. 4**). The recent annual fishing mortality ($F_{2015\text{-}2017}$) was estimated to be well below F_{MSY} at approximately 29% of F_{MSY} (**Table 2**; **Fig. 2**). The reference run produced terminal conditions that were predominantly in the lower right quadrant of the Kobe plot (not overfished and overfishing not occurring) (**Fig. 3**).

Conservation information

Future projections under different fishing mortality (F) harvest policies (F_{MSY}, $F_{2012\text{-}2014}$, $F_{2015\text{-}2017}$, $F_{20\%plus}$, $F_{20\%minus}$) show that median BSH biomass in the North Pacific will likely remain above B_{MSY} in the foreseeable future (**Table 3**; **Fig. 4**).

Appendix B Alternative setting of SS for the future projection

To satisfy the consistency of the parameters in the control file of the previous benchmark assessment in 2017 and those of newly updated stock assessment, we attempted to do the alternative runs of the future projection without estimating all the parameters except for the initial fishing mortality for fleet 4 (Japanese coastal and offshore shallow-set longline fishery). If we fixed the parameters of R0 and recruitment deviations, female spawning biomass and fishing mortality rates relative to MSY level largely differed from those of other scenarios (**Fig. A1** and **A2**). The differences were caused by the fixation of the recruitment deviations (**Fig. A3**). In our conclusion, the estimation of initial F without estimating other parameters including R0 is unreasonable to reproduce the same trajectory as shown in the reference run in the benchmark assessment in 2017.

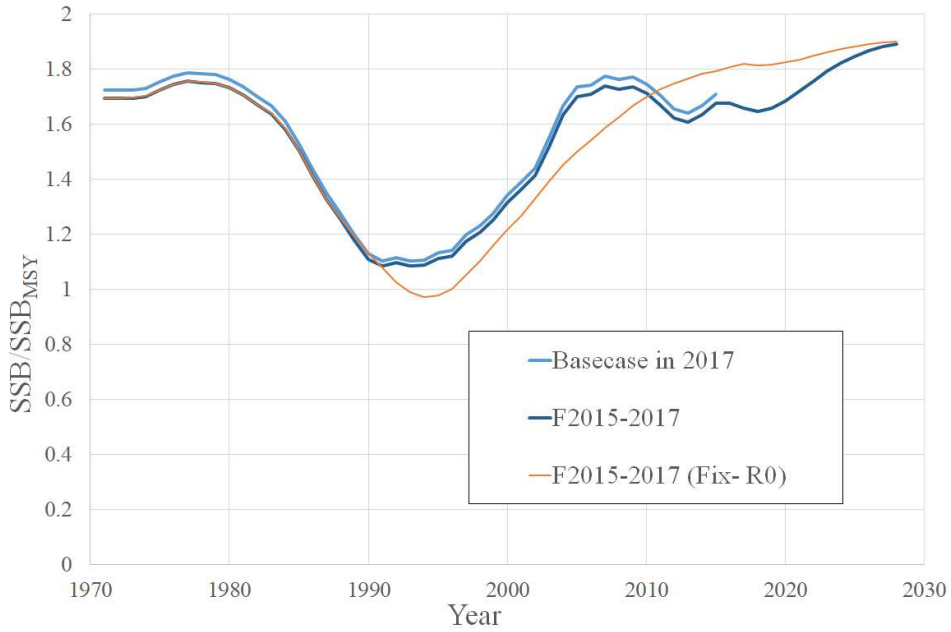

Fig.A1 Trajectories of spawning stock biomass (SSB) relative to MSY level (SSB_{MSY}) under status-quo strategies for the reference case in 2017, updated data with estimation of R0 and updated data with fixation of R0.

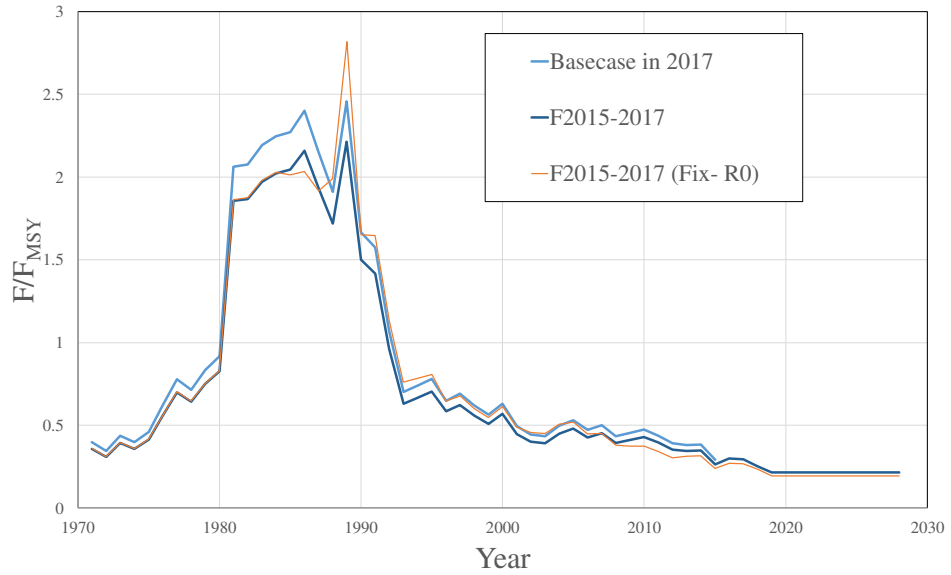

Fig.A2 Trajectories of Fishing mortality (F) relative to MSY level (F_{MSY}) under status-quo strategies for the reference case in 2017, updated data with estimation of R0 and updated data with fixation of R0.

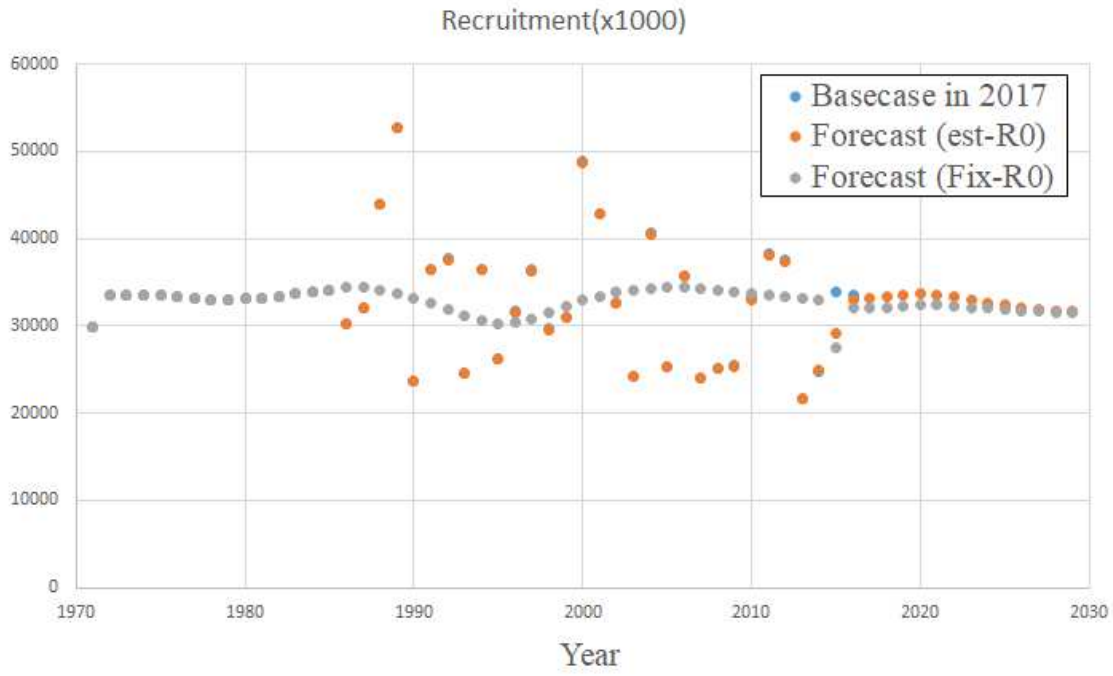

Fig. A3 Trajectories of recruitment under status-quo strategies for the reference case in 2017, updated data with estimation of R0 and updated data with fixation of R0.