ISC/19/SHARKWG-1/07

Preliminary results of stock synthesis projections of blue shark in the North Pacific Ocean through 2025[1]

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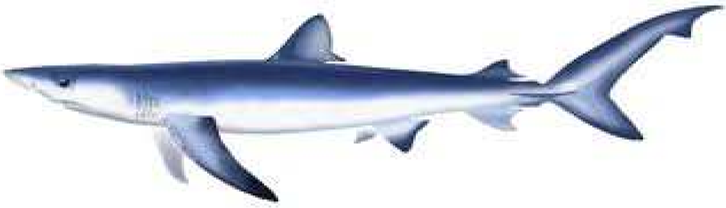

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Abstract

Stock Synthesis projections were conducted from 2016 to 2025 at pre-specified three constant harvest policies ($C_{status\ quo}$; Status quo, $C_{+20\%}$; 20% increase of catch, $C_{-20\%}$; 20% decrease of catch) 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 but also future trajectories of the spawning stock biomass through 2025. The biological parameters, the other fisheries data such as CPUE and size composition data and the specifications of the model such as data weighting were the same as those used in the reference-run of previous full stock assessment in 2017. The future projections with status-quo showed that the spawning stock biomass (SSB) in 2018 exceeded the MSY level (SSB_{2018}/SSB_{MSY}=1.67) and the mean current fishing mortality (F) from 2015 to 2017 was below MSY level ($F_{2015-2017}/F_{MSY}$=0.33), 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 ($F_{2012-2014}$) 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 ($F_{status\ quo}$, $F_{+20\%}$, $F_{-20\%}$, 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 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, 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 intermediate stock assessment for both species shall be conducted between the full 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 intermediate 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 preliminary intermediate stock assessment for blue shark in the NPO to assess the current stock status and future trajectories of SSB for ten years through 2025.

Materials and Methods

Future projection was conducted using SS3 (version 3.24f; Methot, 2015) under the conditions of pre-specified constant harvest policies ($C_{status\ quo}$, $C_{+20\%}$, $C_{-20\%}$) 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 with the terminal year in 2015 of the previous stock assessments in 2017.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 were used with a minor changes in the values of annual catches in the data file and harvest scenarios in forecast file.

Fundamentally, the annual catch data of each fleet was updated for 2016-2018 (**Fig. 1**). The annual catch data of Japanese fleets and Taiwanese large-scale longline fleets were updated for 1994-2018 (see Kai, 2019; Kai and Yano, 2019) and for 1971-2018 (Tsai and Liu, 2019), respectively. The annual catches of China for 2016-2018 were given using a mean value of annual catches for 2011-2015 due to large uncertainty in the reported catches in recent three years based on the SPC database. The annual catch of Republic of South Korea was updated for 1971-2015 using the new estimation method based on the nominal CPUE of tuna longline fishery in the NPO (Kwon, *et al*., 2017) and the catches of recent three years were given from the average catch for 2011-2015. The annual catch of Non-ISC in the North Pacific Ocean above equator was updated for 2015-2018 after summing the reported annual catch of multiple countries in the WCPFC jurisdiction except the catches of ISC member countries (China, Chinese Taipei, Japan, Republic of South Korea and USA). The details of the fleet definition and derivation methods of annual catch for each fleet were described in the previous stock assessment report (ISC, 2017; WCPFC, 2017).

The proportion of catch among fleets in the projection period was assumed to be constant and the value was calculated as the average proportion of catch by each fleet for the most recent 10 years for 2009-2018 (**Table 2**). Projected total catch, mean catch of recent three years, was allocated to each fleet based on these proportions (**Table 3**).

Annual SSB and F under the specified constant harvest policy ($C_{status\ quo}$, $C_{+20\%}$, $C_{-20\%}$) were estimated from maximum likelihood estimation (MLE) and the estimates from 1971 to 2025 were compared with MSY level (SSB/SSB_{MSY} and $F/\ F_{MSY}$), respectively. Future projection results were summarized using a package of R language for statistical computing version 3.6.0 (R Core Team, 2019), and the R library package "r4ss" version 1.34.0 (Taylor *et al.*, 2018). The annual fishing mortality (F) during the projection period was not considered in this analysis because F is largely affected by the assumptions of selectivity.

Additional two runs were conducted to compare the effect of changes in the catch table with previous one used in the stock assessment in 2017 (SA2017). The assessment period of first run was from 1971 to 2015 with updated data (SA2017_New_Catch_until 2015) and that of the second run was from 1971-2018 with updated data (SA2019).

Result

The updated total annual catch after 1994 was slightly different with previous one used in the stock assessment in 2017 (**Fig. 2**) because the annual catches of Japanese offshore and distant water longline fisheries as well as the coastal fisheries were updated for the period (Kai, 2019; Kai and Yano, 2019).

The results of the future projection under the different constant harvest policies ($C_{status\ quo}$, $C_{+20\%}$, $C_{-20\%}$) indicated that the SSBs could continuously increase above the SSB_{MSY} (**Fig.3**) due to the reduction of the recent annual catch compared to that of last three decades (**Table 1, Fig. 1**). Meanwhile, the relative values of F for 2016 – 2018 were the lowest level in the stock assessment periods for all the scenarios (**Fig. 4**).

The key management quantities were also summarized in **Table 4**. Compared to MSY-based reference points, the current spawning biomass (SSB_{2018}) is 68% above SSB_{MSY}, and the current fishing mortality ($F_{2015\text{-}2017}$) is 67% below FMSY in the status quo of the reference case model. The historical trajectories of stock status revealed that North Pacific blue shark had experienced some level of depletion and overfishing in previous years for 1981-1992 showing that the trajectories moved through the overfishing (**Fig. 4**). However, in the last two decades, the stock condition returned into the healthy conditions. These results mean that the stock is not in an overfished state, and that overfishing is not occurring.

The results of additional two runs were compared with the output of the previous stock assessment in 2017. The update of annual catches for 1971-2015 had a small impact on the trajectories of SSBs and Fs, while those for 1971-2018 had a large impact (**Figs. A1 and A2**).

Discussions

Our preliminary results of future projection revealed that the stock status of blue shark in NPO was a healthy condition, even if the total annual catch of blue shark in the NPO increases by 20% compared to the current level for 2016-2018. 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. 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 2025 if the current total catch of blue shark around 30,000 tons is continued. 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).

Reference

Cortés, E. 2002. Incorporating uncertainty into demographic modeling: application to shark populations and their conservation. Conserv. Biol. 16, 1048–1062.

ISC, 2014. Stock assessment and future projections of blue shark in the North Pacific Ocean (Report of the Shark Working Group No. Annex 13). International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Taipei, Chinese-Taipei.

ISC, 2015. Indicator-based analysis of the status of shortfin mako shark in the North Pacific Ocean (Report of the Shark Working Group No. Annex 12). International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Kona, Hawaii, USA.

ISC, 2017. Stock assessment and future projections of blue shark in the North Pacific Ocean through 2015 (Report of the Shark Working Group No. Annex 13). International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Vancouver, Canada.

ISC, 2018. Stock assessment of shortfin mako shark in the North Pacific Ocean through 2016 (Report of the Shark Working Group No. Annex 15). International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Yeosu, Republic of Korea.

Kai, M. 2019. Update of Japanese annual catches for blue shark caught by Japanese offshore and distant-water longliner in the North Pacific Ocean from 1994 to 2018. ISC/19/SHARKWG-1/3.

Kai, M., and Yano, T. 2019. Update of annual catches for blue shark caught by Japanese coastal fisheries in the North Pacific Ocean from 1994 to 2017. ISC/19/SHARKWG-1/4.

King, J.R., and Surry, A.M. 2019. Blue shark (*Prionace glauca*) bycatch statistics in Canadian fisheries. ISC/19/SHARKWG-1/6.

Kwon, Y., Kim, D.N., Lee, S.I., Cho, H.J., Ku, J.E., and Lee, M.K. 2017. Fishery data and catch estimation of blue shark by Korean tuna longline fishery in the North Pacific Ocean. ISC/17/SHARKWG-1/06.

Methot, R.D. 2015. User manual for Stock Synthesis model version 3.24s, Updated February 11, 2015. NOAA Fisheries, Seattle, WA.

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

Nakano, H., and M. P. Seki. 2003. Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus. Bull. Fish. Res. Agen. No 6, 18-55, 2003.

Nakano, H., and Stevens, J. D. 2008. The biology and ecology of the blue shark, *Prionace glauca*. In 'Sharks of the Open Ocean: Biology, Fisheries and Conservation'. (Eds M. D. Camhi, E. K. Pikitch, and E. A. Babcock.) pp. 140–151. (Blackwell Publishing: Oxford, UK.)

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Taylor, I.G., Gertseva, V., Methot, R.D., Maunder, M.N., 2013. A stock–recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fish. Res. 142, 15–21.

Taylor, *et al*. 2018. r4ss: R code for Stock Synthesis. R package version 1.30.2. https://github.com/r4ss.

Tsai, W.P, and Liu, K.M. 2019. Updated information on standardized CPUE and catch estimation of the blue shark from Taiwanese large scale tuna longline fishery in the North Pacific Ocean. ISC/19/SHARKWG-1/5.

WCPFC. 2017. Stock assessment and future projections of blue shark in the North Pacific Ocean through 2015 (Report of the Shark Working Group). Northern Committee Thirteenth Regular Session, Busan, Republic of South Korea.

Table 1. Annual catch data of each fleet from 1971 to 2018 used in the stock synthesis projection.

Year	#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SHL	F7_JPN_ENY_DP	F8_JPN_LG_MESH	F9_JPN_CST_Oth	F10_JPN_SM_MESH	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	0	21604.7	0	650.8	0	0	996.4	0	7	0	0	0	30	0	5	12065	23733.9
1972	440	0.0	0	15359	0	1416.9	0	0	1201.4	0	5	0	0	0	30	0	4	15051	18456.3
1973	440	0.0	0	16760.9	0	1098.6	0	6296.9	1172	0	5	1.00	0	0	30	0	0.8	12024	25805.2
1974	440	0.0	0	14607	0	1304.5	0	6296.9	1337.3	0	5	13.0	0	0	30	0	129	10608	24162.7
1975	440	0.0	0	15821.8	798.5	671.1	5774.4	6296.9	913.9	0	7	17.0	0	0	33	0	194	9192	30967.6
1976	374	0.0	0	22434.2	1819.8	494.5	10442.1	6296.9	1538.3	0	7	218.0	0	0	31	98	8	10278	43761.8
1977	386	0.0	0	30495.3	2866.2	429.4	13790.6	6296.9	1265.1	0	6	52.0	0	0	29	196	47	9997	55859.5
1978	561	0.0	0	24642.8	2254	456.9	13340.9	6296.9	1558.8	0	8	18.0	0	2	33	294	58	10543	49524.3
1979	338	0.9	0	26898.2	2200	566.6	19721.5	6296.9	1509.7	0	10	16	0	5	33	428	14	12346	58037.79
1980	624	11.0	0	25899.7	4530.5	270	21482.9	6296.9	1293.1	0	10	114.0	0	12	29	589	44	12795	61206.07
1981	1593	0.0	0	22794.5	6641.5	378.1	23839.6	6296.9	1290.9	13331.3	9	16.0	0	55	27	587	38	10921	76897.8
1982	1181	0.0	0	13861	6794.2	724	15146.9	6296.9	1034.4	13331.3	6	505.0	0	84	15	685	5	11998	59669.7
1983	1548	24.6	0	11228.6	7312.6	432.7	16534	5926.8	642	13331.3	6	156.0	0	125	46	783	5	10581	58101.57
1984	390	0.9	0	8741.6	8137.3	345.5	15544.3	4727.5	1333.1	13331.3	6	158.0	0	135	96	881	0.8	9508	53828.29
1985	528	60.4	0	7846.2	6093.6	207.9	15683.9	3763.6	1387.8	13331.3	3	117.0	0	119	193	979	111	10597	50424.73
1986	2128	90.3	0	9373.7	6603.2	143.6	9393	4081.1	1239.4	13331.3	2	64.0	0	376	43	1077	133	8910	48078.61
1987	2205	159.1	0	7406.6	3538.8	222.9	10229.9	3990.5	1276.3	13331.3	2	123.0	0	152	181	1175	55	6673	44048.44
1988	3337	0.5	0	6582.2	2383.7	267.5	15896.2	3707.7	1152.5	13331.3	6	102.0	0	125	346	1312	10	6956	48559.56
1989	1643	0.2	0	5902.1	3013.9	358.5	18148.8	3707.7	1052.7	20022	5	26.0	0	128	99	1380	52	7843	55538.9
1990	2865	4.4	0	5394.4	2717.7	484.6	11799.3	3707.7	1070.4	8758.4	3	31.0	0	299	64	1492	209	8669	38899.91
1991	3197	0.4	0	6479.3	4007.2	1140.1	10305.7	3707.7	1053.7	8758.4	2	27.0	0	94	97	1572	223	9389	40664.51
1992	3085	0.0	0	6902.1	3408.7	958.5	8519.6	3387.7	1099	4379.2	3	28.0	0	135	47	2146	73	7540	34171.8
1993	3517	0.0	0	8518.4	3889.7	1340.3	11211	660.5	1047	0	3	13.0	0	105	47	3595	58	6859	34004.9
1994	1758	0.1	0	9800.5	2911.1	918.8	18277.3	599.1	1357.3	0	2	25.0	0	37	43	2643	12	5458	38384.11
1995	2100	0.0	0	10695.3	1590.6	1607.6	24082.3	501.9	1033.9	0	10	110.0	161	160	50	1955	619	9462	44676.68
1996	3117	0.7	0	9463.4	2577.1	1560.5	14064.3	492.2	734.7	0	2	277.0	165	85	26	2475	266	9642	35305.89
1997	2948	0.7	0	12169.5	1369.5	1912.4	16335.4	620.9	433.8	0	4	578.0	261	64	61	2895	311	13453	39964.19
1998	3134	2.1	0	11985.9	960.3	2468.9	15542.4	634.3	832.4	0	2	979.0	634	105	11	2987	326	11303	40604.38
1999	2261	0.9	0	13602.7	542.3	2690.6	10856.8	859.3	506.7	0	1	588.0	782	54	20	2886	604	13495	36255.43
2000	2719	1.5	0	18195.5	488.5	2463.5	6717.0	757.7	1360.7	0	2	571.0	1350	27	36	1315	663	19707	36667.43
2001	2587	4.8	340.4	20104.7	310.2	3318.8	7023.5	758.5	710.4	0	0	155.0	944	18	13	350	953	8847	37591.36
2002	2524	5.5	333.6	17556.4	272.9	2414.5	4921.0	767.7	1000.0	0	3	265.0	2126	12	5	256	1315	10225	33777.47
2003	2307	17.5	305.1	17405.0	874.6	3077.9	5110.5	1350.3	1114.2	0	1	360.0	1708	15	11	255	753	9467	34665.11
2004	3781	4.4	282.2	14848.7	1785.0	4794.6	4591.0	1202.4	853.5	0	1	42.0	5846	10	4	187	1152	11479	39384.82
2005	2721	0.7	343.3	17959.9	1192.1	4460.7	5924.2	1321.2	2410.4	0	0	40.0	3081	3	3	140	887	13563	40487.5
2006	2765	22.0	200.6	14707.6	2228.8	4881.5	4364.4	1204.1	2212.3	0	3	17.0	3111	3	4	136	857	13291	36717.37
2007	3324	9.6	234.2	11742.2	3522.5	4723.2	4277.8	1322.6	2740.9	0	2	175.0	3153	27	5	150	793	13030	36202.05
2008	4355	6.2	133.6	10095.0	763.4	4281.6	4012.8	943.7	2419.6	0	3	82.0	2066	14	3	121	674	14144	29973.96
2009	4423	9.4	297.8	11821.4	195.5	3977.9	2932.1	1207.7	2103.5	0	2	140.0	1778	5	3	114	469	16081	29479.14
2010	4469	8.5	357.3	9989.4	96.9	3760.4	8464.0	962.5	1825.5	0	1	429.0	1808	3	3	144	643	13015	32964.47
2011	3719	14.2	612.5	3859.2	57.9	2097.4	12169.7	793.8	934.1	0	1	765.0	2624	3	1	138	899	14,707	28688.72
2012	4108	10.1	757.7	5592.2	37.3	3251.3	3603.9	1117.6	1595.6	0	1.9	459.0	2778	5	2.1	138	664	8,647	24121.7
2013	4494	29.7	598.4	4543.2	337.7	2547.5	4494.0	1103.4	1759.1	0	1.6	490.0	2131	2	1.3	265	551	6983	23348.83
2014	5502	10.4	250.6	5218.1	265.0	2020.5	4597.4	1059.6	1140.6	0	0.4	413.0	2059	2	1.6	392	700	11156	23632.04
2015	3985	26.7	626.9	5105.8	158.8	3315.9	4060.5	697.4	960.5	0	0.3	310.0	340	1	1.9	468	1186	8856	21245.23
2016	3880	12.2	569.2	4841.6	166.4	4421.0	4453.3	1832.3	628.1	0	1.0	487.4	321	9.7	2.9	280.2	449	11,700	22354.91
2017	3384	24.7	569.2	5384.7	236.3	4458.5	4152.6	1365.7	560.1	0	1.0	487.4	1062	4.5	2.5	280.2	431	11,309	22404.89
2018	2852	46.4	569.2	4348.6	438.1	4168.7	1543.0	1365.7	560.1	0	1.0	487.4	1279	0.3	1.0	280.2	878	10,787	18819.2

	Updated
	No-catch
	Tentatively given
	Mean value for 2011-2015

Table 2. Proportion of annual catch weight by fleet and the average proportions for 10 years from 2009 to 2018.

Year	#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SHL	F7_JPN_ENY_DP	F8_JPN_LG_MESH	F9_JPN_CST_Oth	F10_JPN_SM_MESH	F11_IATTC	F12_KOREA	F13_NON_ISC	F14_USA_GIILL	F15_USA_SPORT	F16_USA_Lonline	F17_TAIW_LG	F18_TAIW_SM
2009	0.0971	0.0002	0.0065	0.2595	0.0043	0.0873	0.0644	0.0265	0.0462	0.0000	0.0000	0.0031	0.0390	0.0001	0.0001	0.0025	0.0103	0.3530
2010	0.0972	0.0002	0.0078	0.2173	0.0021	0.0818	0.1841	0.0209	0.0397	0.0000	0.0000	0.0093	0.0393	0.0001	0.0001	0.0031	0.0140	0.2831
2011	0.0857	0.0003	0.0141	0.0889	0.0013	0.0483	0.2804	0.0183	0.0215	0.0000	0.0000	0.0176	0.0605	0.0001	0.0000	0.0032	0.0207	0.3389
2012	0.1254	0.0003	0.0231	0.1707	0.0011	0.0992	0.1100	0.0341	0.0487	0.0000	0.0001	0.0140	0.0848	0.0002	0.0001	0.0042	0.0203	0.2639
2013	0.1482	0.0010	0.0197	0.1498	0.0111	0.0840	0.1482	0.0364	0.0580	0.0000	0.0001	0.0162	0.0703	0.0001	0.0000	0.0087	0.0182	0.2302
2014	0.1582	0.0003	0.0072	0.1500	0.0076	0.0581	0.1322	0.0305	0.0328	0.0000	0.0000	0.0119	0.0592	0.0001	0.0000	0.0113	0.0201	0.3207
2015	0.1324	0.0009	0.0208	0.1696	0.0053	0.1102	0.1349	0.0232	0.0319	0.0000	0.0000	0.0103	0.0113	0.0000	0.0001	0.0155	0.0394	0.2942
2016	0.1139	0.0004	0.0167	0.1422	0.0049	0.1298	0.1308	0.0538	0.0184	0.0000	0.0000	0.0143	0.0094	0.0003	0.0001	0.0082	0.0132	0.3436
2017	0.1004	0.0007	0.0169	0.1597	0.0070	0.1322	0.1232	0.0405	0.0166	0.0000	0.0000	0.0145	0.0315	0.0001	0.0001	0.0083	0.0128	0.3354
2018	0.0963	0.0016	0.0192	0.1469	0.0148	0.1408	0.0521	0.0461	0.0189	0.0000	0.0000	0.0165	0.0432	0.0000	0.0000	0.0095	0.0297	0.3643
Average	0.1155	0.0006	0.0152	0.1654	0.0060	0.0972	0.1360	0.0330	0.0333	0.0000	0.0000	0.0128	0.0448	0.0001	0.0001	0.0075	0.0199	0.3127

Table 3. Fixed annual catch (tons) of each fleet during the future projection.

Year	#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SHL	F7_JPN_ENY_DP	F8_JPN_LG_MESH	F9_JPN_CST_Oth	F10_JPN_SM_MESH	F11_IATTC	F12_KOREA	F13_NON_ISC	F14_USA_GIILL	F15_USA_SPORT	F16_USA_Lonline	F17_TAIW_LG	F18_TAIW_SM
2016	3879.7	12.2	569.2	4841.6	166.4	4421.0	4453.3	1832.3	628.1	0.0	1.0	487.4	320.9	9.7	2.9	280.2	449.0	11700.0
2017	3384.1	24.7	569.2	5384.7	236.3	4458.5	4152.6	1365.7	560.1	0.0	1.0	487.4	1062.3	4.5	2.5	280.2	431.0	11309.0
2018	2852.4	46.4	569.2	4348.6	438.1	4168.7	1543.0	1365.7	560.1	0.0	1.0	487.4	1279.1	0.3	1.0	280.2	878.0	10787.0
2019-202	3372.1	27.8	569.2	4858.3	280.2	4349.4	3382.9	1521.2	582.7	0.0	1.0	487.4	887.5	4.9	2.1	280.2	586.0	11265.3

Table 4 Estimates of key management quantities for the North Pacific blue shark intermediate stock assessment.

Management quantities	SA2017	SA2017_NEW_Catch_until 2015	SA2019	SA_2019_Projection_SQ	SA_2019_Projection_20plus	SA_2019_Projection_20minus
SSB1971	293,538	293,171	293,172	293,070	293,070	293,070
SSB2015	291,206	293,553	293,554	289,914	289,914	289,914
SSB2018			291,190	284,049	281,835	286,252
SSBMSY	170,251	170,510	173,559	170,563	170,563	170,563
F1971	0.14	0.14	0.14	0.14	0.14	0.14
F2012-2014	0.14	0.11	0.11	0.14	0.14	0.14
F2015-2017			0.11	0.11	0.12	0.09
FMSY	0.35	0.36	0.40	0.32	0.32	0.32
SSB2015/SSBMSY	1.71	1.72	1.69	1.70	1.70	1.70
SSB2018/SSBMSY			1.68	1.67	1.65	1.68
F2012-2014/FMSY	0.38	0.31	0.28	0.42	0.42	0.42
F2015-2017/FMSY			0.27	0.33	0.38	0.29

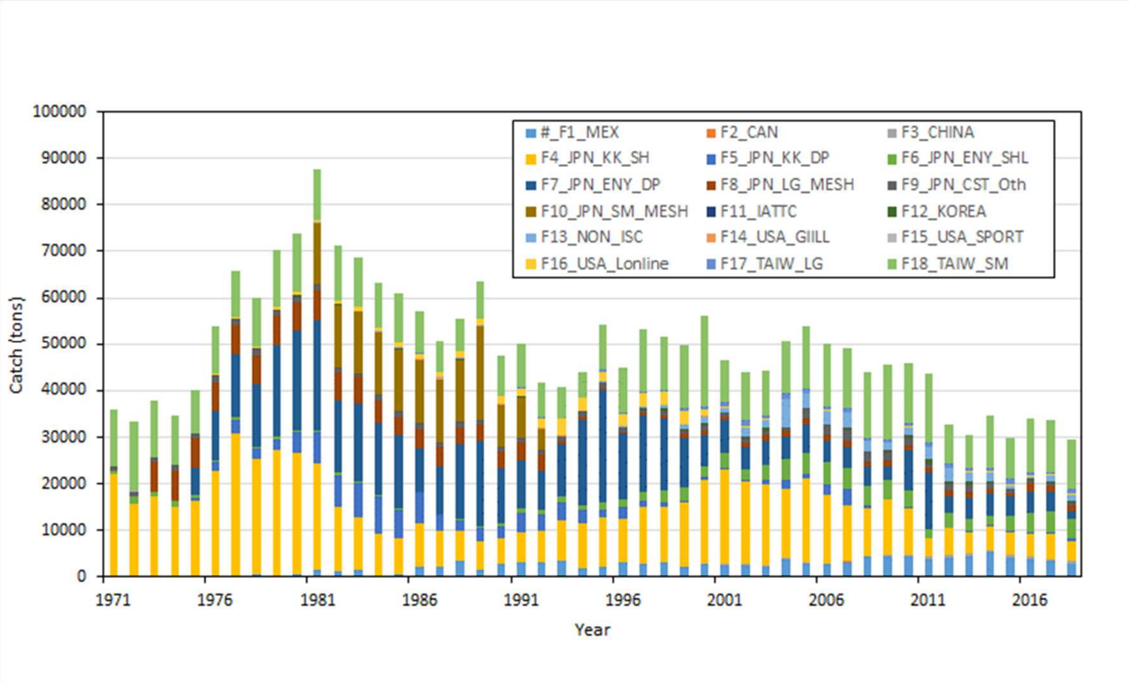

Fig. 1 Annual catch of each fleet from 1971 to 2018 used in the stock synthesis projection.

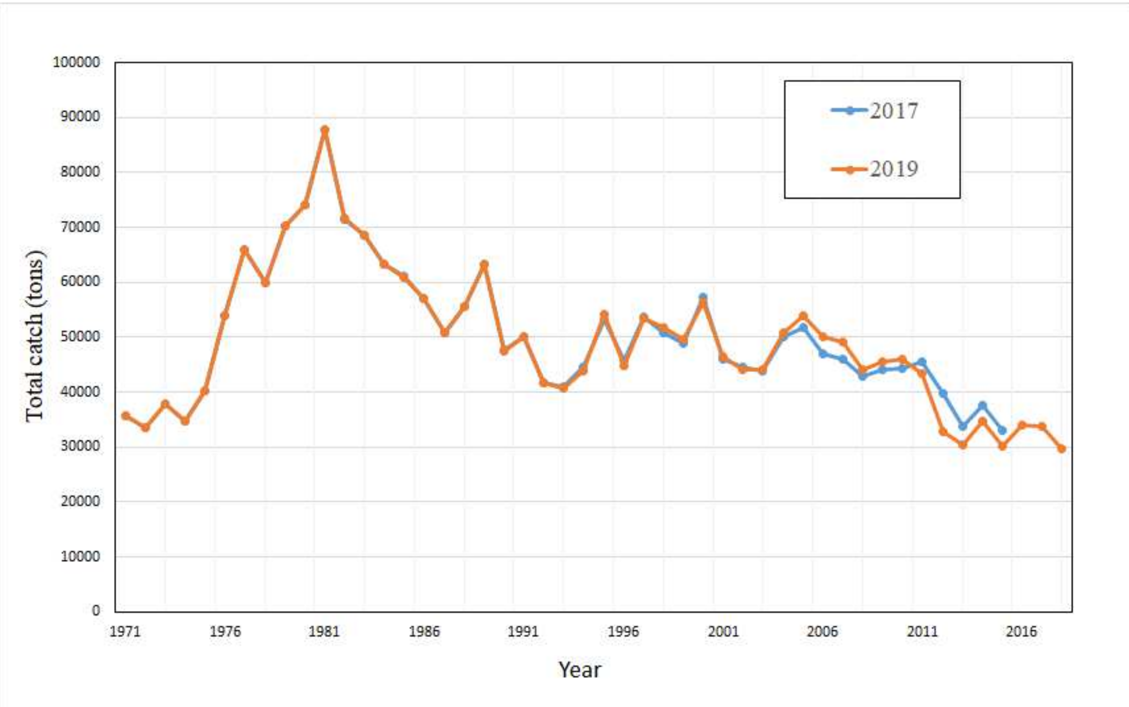

Fig. 2 A companion of total annual catch used in the stock assessment in 2017 with those used in future projection in this study.

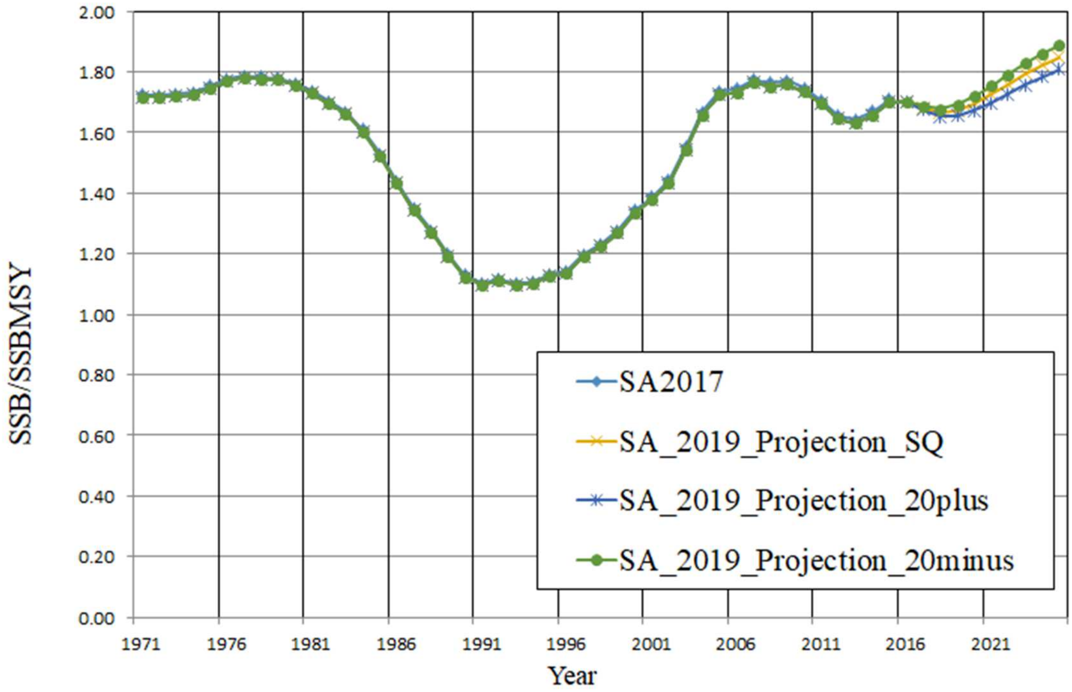

Fig.3 Trajectories of spawning stock biomass (SSB) relative to MSY level (SSB_{MSY}) under three harvest strategies ($C_{status\ quo}$, $C_{+20\%}$, $C_{-20\%}$).

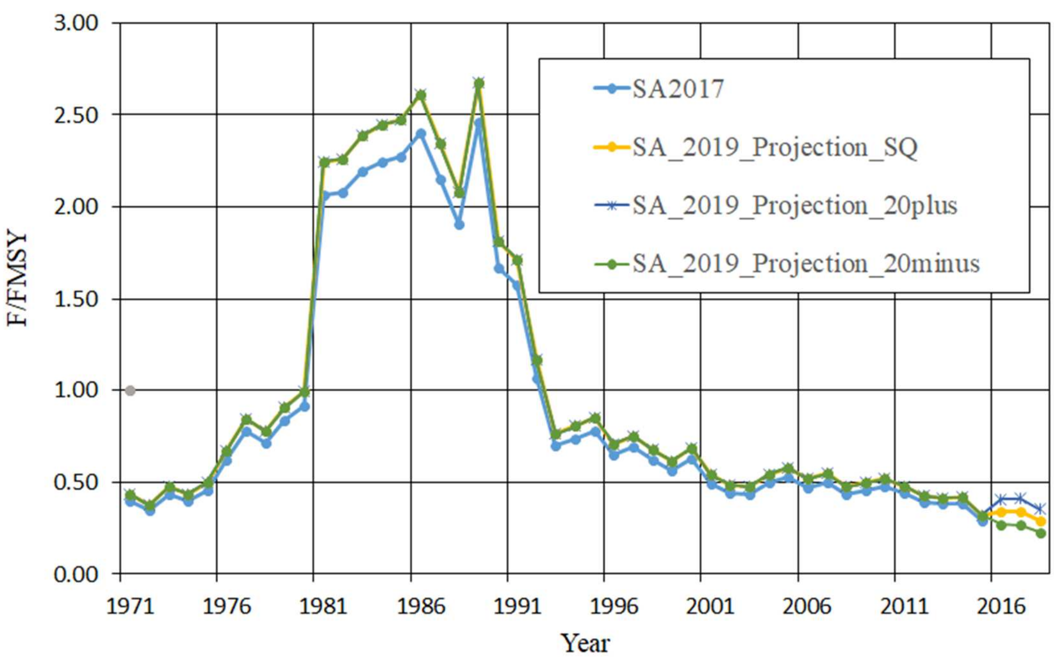

Fig.4 Trajectories of Fishing mortality rate (F) relative to MSY level (F_{MSY}) under three harvest strategies ($C_{status\ quo}$, $C_{+20\%}$, $C_{-20\%}$).

Table A1. Annual catch data of each fleet from 1971 to 2015 used in the stock assessment in 2017.

#_F1_MEX	F2_CAN	F3_CHINA	F4_JPN_KK_SH	F5_JPN_KK_DP	F6_JPN_ENY_SHL	F7_JPN_ENY_DP	F8_JPN_LG_MESH	F9_JPN_CST_Oth	F10_JPN_SM_MESH	F11_IATTC	F12_KOREA	F13_NON_ISC	F14_USA_GIILL	F15_USA_SPORT	F16_USA_Lonline	F17_TAIW_LG	F18_TAIW_SM	year	seas	Total
440	0.0	0	21604.7	0	650.8	0	0	996.4	0	7	0.0	0	0	30	0	5	12065	1971	1	35799
440	0.0	0	15359	0	1416.9	0	0	1201.4	0	5	0.0	0	0	30	0	5	15051	1972	1	33508
440	0.0	0	16760.9	0	1098.6	0	6296.9	1172	0	5	0.0	0	0	30	0	1	12024	1973	1	37828
440	0.0	0	14607	0	1304.5	0	6296.9	1337.3	0	5	0.0	0	0	30	0	134	10608	1974	1	34763
440	0.0	0	15821.8	798.5	671.1	5774.4	6296.9	913.9	0	7	4.7	0	0	33	0	200	9192	1975	1	40153
374	0.0	0	22434.2	1819.8	494.5	10442.1	6296.9	1538.3	0	7	31.8	0	0	31	98	8	10278	1976	1	53854
386	0.0	0	30495.3	2866.2	429.4	13790.6	6296.9	1265.1	0	6	55.5	0	0	29	196	48	9997	1977	1	65861
561	0.0	0	24642.8	2254	456.9	13340.9	6296.9	1558.8	0	8	17.3	0	2	33	294	60	10543	1978	1	60069
338	0.9	0	26898.2	2200	566.6	19721.5	6296.9	1509.7	0	10	0.0	0	5	33	428	14	12346	1979	1	70368
624	11.0	0	25899.7	4530.5	270	21482.9	6296.9	1293.1	0	10	114.2	0	12	29	589	45	12795	1980	1	74002
1593	0.0	0	22794.5	6641.5	378.1	23839.6	6296.9	1290.9	13331.3	9	0.3	0	55	27	587	40	10921	1981	1	87805
1181	0.0	0	13861	6794.2	724	15146.9	6296.9	1034.4	13331.3	6	241.9	0	84	15	685	5	11998	1982	1	71405
1548	24.6	0	11228.6	7312.6	432.7	16534	5926.8	642	13331.3	6	27.3	0	125	46	783	5	10581	1983	1	68554
390	0.0	0	8741.6	8137.3	345.5	15544.3	4727.5	1333.1	13331.3	6	87.8	0	135	96	881	1	9508	1984	1	63265
528	60.4	0	7846.2	6093.6	207.9	15683.9	3763.6	1387.8	13331.3	3	145.4	0	119	193	979	115	10597	1985	1	61054
2128	90.3	0	9373.7	6603.2	143.6	9393	4081.1	1239.4	13331.3	2	95.4	0	376	43	1077	138	8910	1986	1	57025
2205	158.7	0	7406.6	3538.8	222.9	10229.9	3990.5	1276.3	13331.3	2	158.8	0	152	181	1175	56	6673	1987	1	50758
3337	0.5	0	6582.2	2383.7	267.5	15896.2	3707.7	1152.5	13331.3	6	139.8	0	125	346	1312	10	6956	1988	1	55553
1643	0.2	0	5902.1	3013.9	358.5	18148.8	3707.7	1052.7	20022	5	49.5	0	128	99	1380	54	7843	1989	1	63407
2865	4.4	0	5394.4	2717.7	484.6	11799.3	3707.7	1070.4	8758.4	3	58.2	0	299	64	1492	216	8669	1990	1	47603
3197	0.4	0	6479.3	4007.2	1140.1	10305.7	3707.7	1053.7	8758.4	2	64.8	0	94	97	1572	230	9389	1991	1	50098
3085	0.0	0	6902.1	3408.7	958.5	8519.6	3387.7	1099	4379.2	3	49.1	0	135	47	2146	75	7540	1992	1	41735
3517	0.0	0	8518.4	3889.7	1340.3	11211	660.5	1047	0	3	27.8	0	105	47	3595	60	6859	1993	1	40881
1758	0.1	0	8665.3	3857.7	1515	18004.9	576.9	1899.1	0	2	33.0	0	37	43	2643	12	5458	1994	1	44505
2100	0.0	0	8679.6	2206.9	1716.7	23951.4	483.4	1439.8	0	10	103.5	161	160	50	1955	638	9462	1995	1	53117
3117	0.7	0	8841.7	3399.5	1959	14109.9	474	1059.3	0	2	230.9	165	85	26	2475	275	9642	1996	1	45862
2948	0.7	0	11055.8	2073.9	2821	16095.7	598	631.8	0	4	432.9	261	64	61	2895	320	13453	1997	1	53716
3134	2.0	0	10908.7	1447.4	1959.3	15478.5	610.9	1216.6	0	2	623.2	634	105	11	2987	337	11303	1998	1	50760
2261	0.7	0	12856.1	1019.6	2113.9	10789.6	827.6	772.2	0	1	470.8	782	54	20	2886	623	13495	1999	1	48973
2719	1.4	0	17230.7	626.6	3652.3	6718.8	729.8	1969.7	0	2	433.0	1350	27	36	1315	684	19707	2000	1	57202
2587	4.7	340	19457.9	506.9	2931.8	7027.7	730.5	1083.6	0	0	162.7	944	18	13	350	984	8847	2001	1	45989
2524	5.5	334	16745.8	547.8	2979.1	4930.1	767.7	1514.7	0	3	293.5	2126	12	5	256	1357	10225	2002	1	44626
2307	17.5	305	16423.2	1297.1	2937	5029	1350.3	1623.9	0	1	398.8	1708	15	11	255	777	9467	2003	1	43923
3781	3.8	282	14025.3	3600.8	2685.4	4536.9	1202.4	1234.2	0	1	49.6	5846	10	4	187	1189	11479	2004	1	50118
2721	0.3	343	17184.4	1169.3	2863.4	5869.4	1321.2	2520.8	0	0	44.0	3081	3	3	140	915	13563	2005	1	51742
2765	19.9	201	13986.9	1902.8	2680.2	4332.9	1204.1	2418.7	0	3	21.4	3111	3	4	136	884	13291	2006	1	46965
3324	9.1	234	11418.8	3540.6	1741.9	4308.9	1322.6	2801.1	0	2	203.3	3153	27	5	150	818	13030	2007	1	46090
4355	5.6	134	10095	1071.8	2544.8	3999	943.7	2546.7	0	3	74.6	2066	14	3	121	680	14144	2008	1	42801
4423	8.2	298	11841.6	412.4	1954.7	3023.1	1207.7	2248.3	0	2	146.0	1778	5	3	114	478	16081	2009	1	44024
4469	7.3	357	10018	204.4	1717.4	8857	962.5	1910.2	0	1	470.0	1808	3	3	144	334	13015	2010	1	44281
3719	12.5	613	4335.5	122.1	2358	12492.6	764.5	933.6	0	1	952.0	2624	3	1	138	594	15857	2011	1	45520
4108	8.9	758	5798.9	284.3	2544.8	3675.3	1076.3	1595.6	0	1.9	551.0	2778	5	2.1	138	594	15857	2012	1	39777
4494	25.6	598	4807.9	4157.5	1954.7	4536.7	1103.4	1759.1	0	1.6	491.0	2131	2	1.3	265	551	6983	2013	1	33863
5502	9.2	251	5972.5	2741.8	1717.4	4674.2	1059.6	1140.6	0	0.4	328.0	2059	2	1.6	392	700	11156	2014	1	37707
5502	22.9	627	5312.3	57.4	2358	3804.8	1079.8	1498.4	0	0.3	121.0	2059	1	1.9	468	1186	8856	2015	1	32956

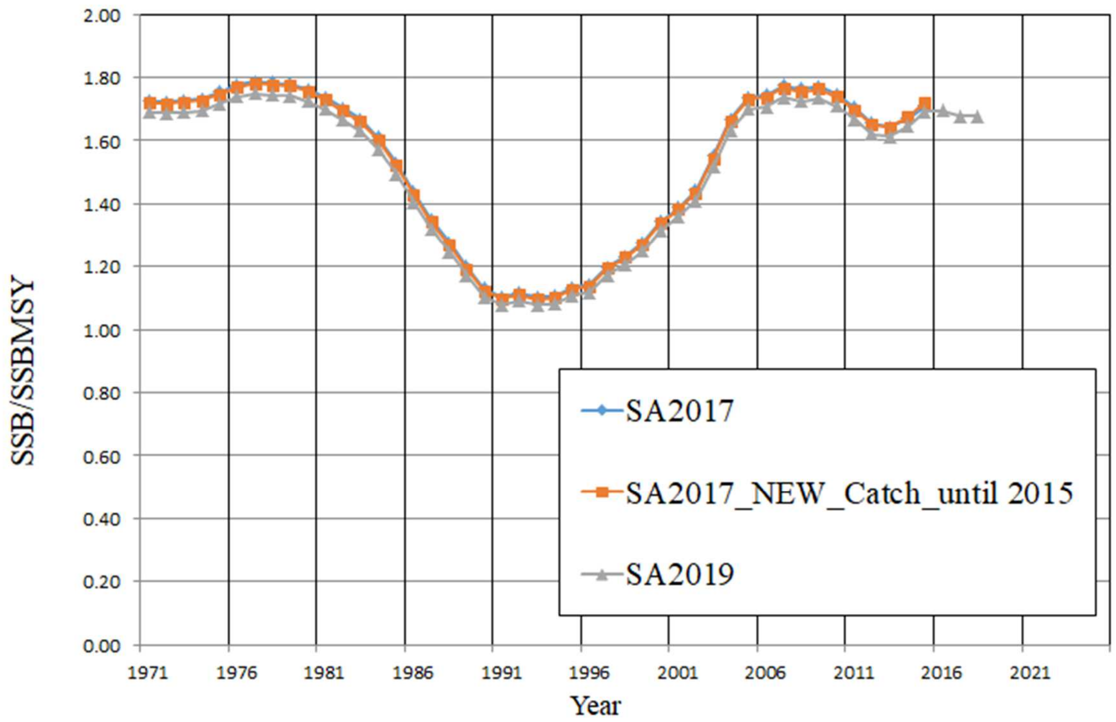

Fig.A1 Trajectories of spawning stock biomass (SSB) relative to MSY level (SSB_{MSY}) under three different scenarios (SA2017, SA2017 with the catch data until 2015, SA2019).

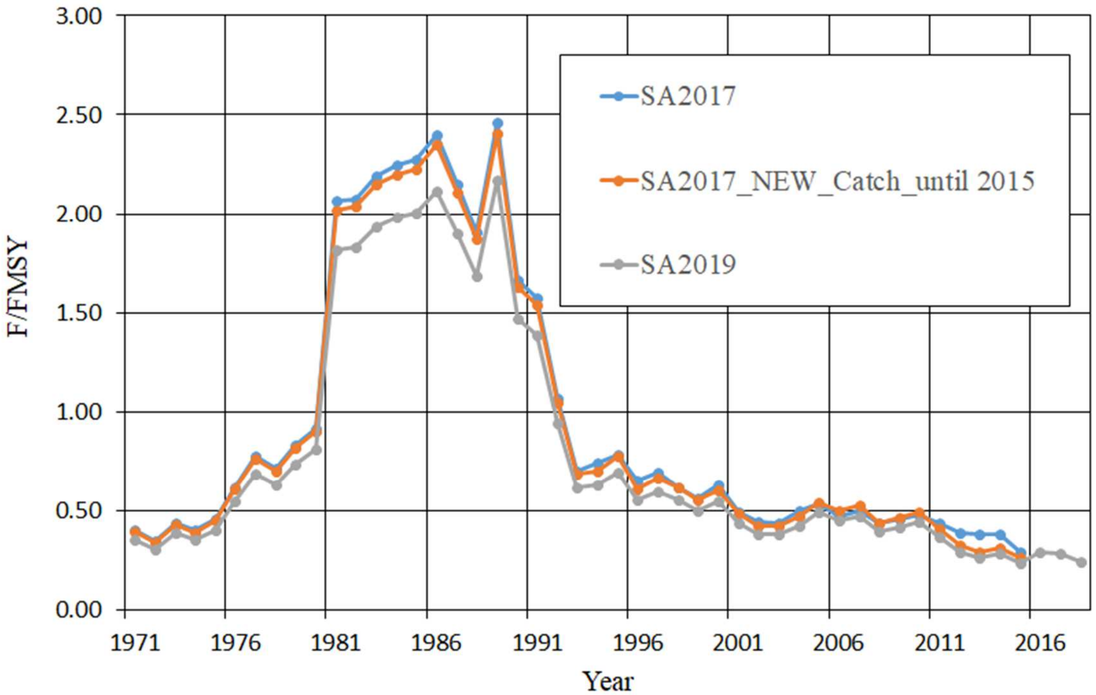

Fig.A2 Trajectories of Fishing mortality rate (F) relative to MSY level (F_{MSY}) under three different scenarios (SA2017, SA2017 with the catch data until 2015, SA2019).