Stock assessment of Blue Mackerel East China Sea stock (2019)

Responsible Institute: National Research Institute of Fisheries Science,
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Summary

The stock biomass stayed around 100,000 to 200,000 tons since 1992 and estimated as 204,000 tons in 2018. The SSB was historical high of 87,000 tons in 2018. The Hockey Stick (HS) model of reproduction curve was recommended in the 'Research Institute meeting on Reference points for the East China Sea Stock of Blue Mackerel' held in April, 2019. The SBmsy was estimated as 109,000 tons (Hayashi et al. 2019). Following the reference based on MSY standard, SSB2018 was below SBmsy. Recently the F tended to decrease, but it rapidly increased over Fmsy in 2018. The status of SSB was considered "increasing" referencing the past five years trend (2014-2018). The stock was also caught by South Korea and China, and it is considered that hundreds of Chinese fishing vessels operating in the area might have strong influence, but not included in the analysis.

Summary table of reference relating to MSY

Reference	Values
Regarding MSY	
SBmsy	109,000 tons
Fmsy	0yr, 1yr, 2yr, 3yr and above=0.36, 0.47, 0.66, 0.66
%SPR(Fmsy)	26.4%
MSY	76,000 tons
SSB and Fishing pressure in 2018	
SB2018	87,000 tons
F2018	0yr, 1yr, 2yr, 3yr and above=0.88, 1.05, 1.62, 1.62
%SPR(F2018)	9.3%
%SPR(F2016-F2018)	18.4%
Ratio to MSY	
SB2018/SBmsy	0.80
F2018/Fmsy	2.40

S-R relationship assumption: Hockey stick (without autocorrelation)

Summary of stock status:

Status of current SSB	Below SBmsy
Status of F	Above Fmsy
Status of SSB	increasing

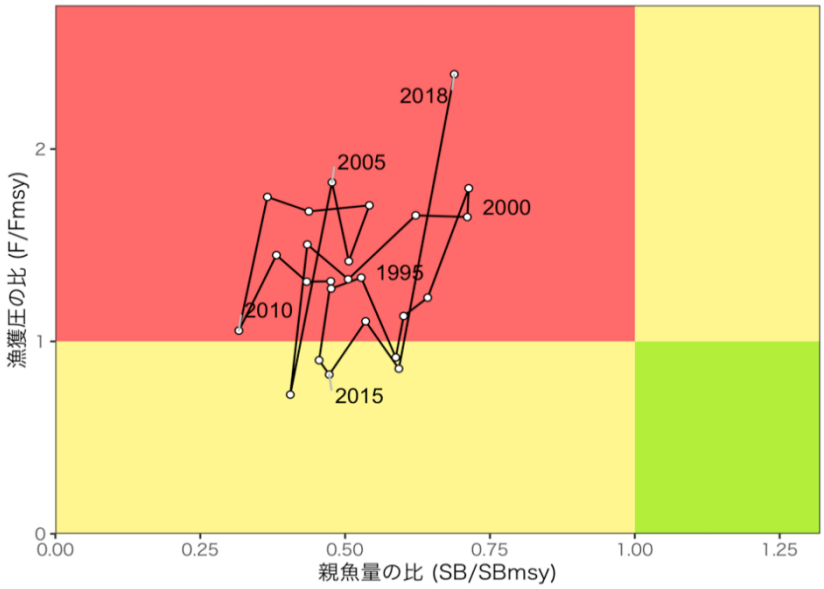

Figure. The relationship between SB/SBmsy and F/Fmsy.

The values of three years moving average were used for both SB and Fishing intensity.

1. Data set

The data set used for the stock assessment is as follows.

Data set	Data source and research
Catch number by age and year	National statistics of Ministry of agriculture, forestry and fisheries Landing at major ports (Fukuoka-Kagoshima [5] prefecture) Landing in number at Kyusyu major ports (National Fisheries institute) Logbook report of purse seine fisheries (Fishery agency) Length composition by month (NRIFS, Fukuoka-Kagoshima [5] prefectures); market measurement National Fisheries statistics of South Korea (http://www.fips.go.kr, March, 2019)
Index of the stock	Logbook report of purse seine fisheries (Fishery agency) * Landing statistics by size of purse seine at Makurazaki port (Kagoshima prefecture) * Neuston-net larval survey (Feb-Jun) Acoustic and midwater trawl biomass survey (Aug-Sep) Bottom trawl survey (East china sea) (May-Jun)
Natural mortality	Assuming M = 0.4 per year

* Tuning index for cohort analysis

Birth date was assumed at 1st of January.

2. Ecology of the species

1) Distribution and migration

Blue mackerel distribute relatively high temperature area than chub mackerel (Collette and Nauen 1983, Yamada et al. 2007, Fig. 2-1). Blue mackerel spawn at the area from Uotsuri Island to Kuchiminose during January to April, after grown up it appears in the southern waters of East china sea to western water of Kyusyu, with a portion reaches in the Japan sea. In the southern Kyusyu area spawning occurs January to May, juvenile reaches to the western water of Kyusyu to Pacific coastal waters of Japan. It migrates to the north for feeding during spring and summer, and migrates down south for wintering at fall and winter (Tsujita and Kondo 1957, Tanoue 1966).

2) Age and growth

The detail of growth is unknown. However, in the report, blue mackerels is assumed to be 28cm FL at age 1, 32cm at age 2, 36cm at age 3, 38cm at age 4, and 39cm at age 5 (Fig. 2-2). The longevity is considered as around 6 years.

3) Reproduction

Main spawning grounds are formed in the central and southern waters of East china sea in January to April, and in the central East china sea to southern water of Kyusyu in May (Yukami et al. 2009, Sassa and Tsukamoto 2010). Although the exact maturation age is unknown, it is assumed that it proportion of maturation as 60% at age 1, 85% at age 2, and 100% at age 3 above considering study results of chub mackerel (Shiraishi et al. 2008) and observation of biological measurements (Fig. 2-3).

4) Prey-predator relationships

Blue mackerel mainly feeds copepod and appendicularia at larval stage, anchovy and sardine larvae at juvenile, and planktonic crustacean and small teleost at adult stage (Tsujita and Kondo 1957, Sassa et al. 2008). Larvae may be eaten by ichthyophagous fish (Tanoue 1966).

3. Fisheries on the species

1) Outline of fisheries

Most of the catches of blue mackerel are made by purse seine fisheries. Main fishing grounds are from the East china sea to the southern water of Kyusyu.

2) Historical catch and size compositions

In the official statistics, chub and blue mackerel catches has been reported as mackerels and not separated by species. In this report, blue mackerel catches were estimated from official statistics (See Appendix 2-1-notes 1, Table 3-1). The Japanese blue mackerel catch from the East china sea and the Japan sea stayed around 50,000 tons since 1970s with fluctuations (Fig. 3-1, Table 3-1). Recently it decreased from the peak of 49,000 tons in 2011, but the catch in 2018 increased from previous year to 41,000 tons.

Korean blue mackerel catch was 11,000 tons in 2017, but it increased historical high of 74,000 tons in 2018 (See Appendix 2 for the ratio of chub and blue mackerel in

Korean catch). Chinese catch increased up to 500,000 tons since 2010, and was 440,000 tons in 2017（FAO Fishery and Aquaculture Statistics. Global capture production 1950-2017, March 2019 http://www.fao.org/fishery/statistics/software/fishstatj/en）. However, it is unknown for catches by species.

The 2018 catch mainly consists with age 0 and 1 fish as usual (Fig. 3-2, Appendix 4).

3) Annual fishing effort by fisheries

The number of nets of purse seine fishery operating in the East china sea and western waters of Japan sea is shown in Fig. 3-3. It reached at peak in 1980s, then continued to decrease after 1990. It recorded the lowest (4,710 nets) in 2018 due to the shift of fishing operations in the Pacific.

4. Stock status

（1）Stock assessment methods

We conducted cohort type analysis using the data of catch, effort, catch by age by year with biological information (Appendix 1 and 2). In the analysis, using catch by age data for Japanese and Korean during 1992-2018, F was estimated by fitting the trends between the abundance index by age of Japanese purse seine fishery and abundance index of Makurazaki landing data. Additionally, estimating methods using penalty to avoid overestimate of terminal F was used from the assessment of 2017 (ridge VPA; Okamura et al. 2017). The Chinese catch data was not used due to the mixture of chub and blue mackerels catches and lack of latest catch (2018).

The surveys were conducted using neuston net (Feb-Jun) to estimate recruitment, bottom trawl (May-Jun) for biomass, bottom trawl and acoustic survey (Aug-Sep) to estimate biomass (Appendix 3). However, all survey results were used as qualitative reference information due to the lack of reliable information of blue mackerel recruitment index. We will continue to improve methods of surveys and analysis.

（2）Changes in the biomass indices

The density index (tons/net) was estimated using statistics of purse seine fishery operating in the East china sea and western waters of Japan sea as an index of long-term

trends of stock since 1973. The indices stayed at low level as average 6 tons/net during 1970s and 1980s, but it increased from late 1990s and reached 18 tons/net in 2005 (Fig. 4-1). Thereafter, it decreased to 9 tons/net in 2018. The effective efforts increased during 1995 to 2001, and decreased from 2002 to 2010, then stayed at same level after increased in 2011 (Fig. 4-1). The density index is the average value of catch per net at 30 minutes of grid where blue mackerel caught in 2018.

Stock abundance index at age calculated from the landing data by size of purse seine operating at the East china sea and the Japan sea after 2003 were used for cohort analysis (Fig. 4-2, Appendix 2-note3). When the abundance indices of 2018 are compared to the past 15 years, values were low at age 0 and 1, but maintained the same level at age 2 and 3. The abundance index calculated from the landing data at Makurazaki port was used for analysis as an index representing abundance of coastal waters of southern Kyusyu (Fig. 4-3, Appendix 2-note3). From the 2018 assessment, the new classification of data was introduced to estimate more accurate age composition which classified small size as for age 0-1 and middle and large size as age 2 above. Both abundance indices of age indicated gradual fluctuations since 2003. The abundance indices for age 0-1 and 2 above in 2018 indicated near average figures of past 16 years.

（3）Trends in biomass and fishing ratio

The stock biomass estimated by cohort model stayed ranging 100,000 to 200,000 tons since 1992 and is relatively stable (Fig. 4-4, Table 4-1). The abundance estimated for 2018 was 204,000 tons. Fishing ratio was around 40% until 2012, then it continued to be 40%, but it rapidly increased to 57% in 2018.

The recruitment (abundance of age 0) fluctuated between 200 to 400 million fish since 1992, it became 390 million in 2018 (Fig.4-5, Table 4-1). The SSB (abundance of adult) fluctuated between 30 to 80 thousand tons until 2014, then increased up to 87 thousand tons in 2018 (Fig. 4-5, Table 4-1).

As sensitivity test of natural mortality (M) used for cohort analysis, M=0.3 and 0.5 were used for analysis. The biomass, SSB and recruitment in 2018 increased according increase of M, it affected around 10% of estimated values if M changed 0.1 (Fig.4-5).

Fishery coefficient F (average of F at each age) fluctuated between 0.5 to 1.0 during 1992 to 2017 (Fig. 4-7). After 2012, F indicated gradually decreased, it became 0.47 in 2017, then rapidly increased to 1.29 in 2018.

Item	Value	Remarks
SB2018	87,000 tons	SSB in 2018
F2018	(age 0, 1, 2, 3+)=(0.88, 1.05, 1.62, 1.62)	
U2018	57%	Fishing ratio in 2018

(4) Yield per recruitment (YPR), spawning per recruitment (SPR) and current fishing pressure

In order to compare the fishing pressure considering the influence of selectivity, Figure 4-8 shows the %SPR (ratio of SPR which assumes no fishing divided by the SPR with current catch) calculated by converting the *F* value of each year. The lower the fishing pressure, the higher the %SPR. The %SPR fluctuated and tended to increase since late 2000s, but the value of 2018 was low as 9.3%.

The relation between average fishing pressure in recent five years selectivity (2014 to 2018) and %SPR are shown in Fig. 4-9. The current fishing pressure (F2016-F2018) is higher than Fmed, F30%SPR and F0.1. Figure 4-9 also indicates the relation between average fishing pressure at MSY and %SPR which was presented at the 'Research Institute meeting on Reference points for the East China Sea Stock of Blue Mackerel ' held at April, 2019. The current F (F2016-2018) and F2018 are higher than Fmsy.

Item	Value	Remarks
%SPR (F2018)	9.3%	%SPR in 2018
%SPR (F2016-2018)	18.4%	%SPR corresponding to current fishing pressure (F2016-F2018)

(5) Stock-recruitment relationship

Figure 4-10 shows the Stock-recruitment (S-R) relationship between SSB (in weight) and recruitment (in numbers). According to the 'Research Institute meeting on Reference points for the East China Sea Stock of Blue Mackerel ' mentioned above, it is suggested to use the Hockey-Stick functional response type for the S-R relationship of this stock (Hayashi *et al*. 2019). Parameters for the S-R relationship is estimated based on the SSB and recruitment which are estimated by the stock assessment conducted in 2018, and as for the optimization method, least-squares method is used. The model does not consider auto-correlation between the residuals of the recruitment. Estimated

parameters for the S-R relationship are shown below.

S-R relationship	Optimization method	Auto-correlation	*a*	*b*	S.D.
Hockey-Stick (HS) type	Least square	No	0.00493	84,935	0.33

Here, parameter *a* is the steepness of the HS S-R curve (numbers / kg) from the origin to the break point, and *b* is the SSB (ton) at the break point.

(6) Level of SSB and fishing pressure that will achieve MSY under the current environmental condition.

The table below shows the SSB and *F* that will achieve MSY (SBmsy, Fmsy) under the current environmental condition since 1992, which was suggested at the 'Research Institute meeting on Reference points for the East China Sea Stock of Blue Mackerel ' (Hayashi *et al*. 2019).

Item	Suggested value	Remarks
SBmsy	109,000 tons	SSB that will obtain MSY
Fmsy	(age 0, 1, 2, 3+)=(0.36, 0.47, 0.66, 0.66)	
%SPR(Fmsy)	26%	%SPR corresponding to Fmsy
MSY	76,000 tons	MSY

(7) Stock status, stock trend and level of fishing pressure

A Kobe-plot shows the relationship between SSB and its corresponding fishing pressure in Fig. 4-11. A Kobe-plot based on fishing ratio is also shown in Appendix 8. F/Fmsy shows the yearly ratio between F and F under the current selectivity that gives Fmsy which was converted to %SPR. The fishing ratio and SSB were calculated as three years moving average. The fishing pressure in recent years has been above the level of MSY. The fishing pressure in 2018 was 2.40 times larger than Fmsy. The SSB is considered to be lower than the SBmsy since 1992. The SSB in 2018 is 0.80 times the SBmsy. The trend of SSB is classified "increasing" considering trend of recent five years (2014-2018).

Item	Value	Remarks
SB2018/ SBmsy	0.80	Ratio between the SSB that gives MSY and the SSB in 2018
F2018/ Fmsy	2.40	Ratio between the fishing pressure that gives MSY and the fishing pressure in 2018 *

* Ratio between *F* in 2018 and *F* under the current selectivity that gives Fmsy which was converted to %SPR.

Level of SSB	below SBmsy
Level of *F*	above Fmsy
Trends in SSB	Increasing

5. Stock assessment summary

Biomass of this stock stayed in ranging 100 to 200 thousand tons, and it was estimated 204 thousand tons in 2018 (Fig. 4-4, Table 4-1). The SSB (abundance of adult) fluctuated between 30 to 80 thousand tons until 2014, thereafter it increased up to historical high of 87 thousand tons (Fig. 4-5, Table 4-1). The SSB in 2018 was below SBmsy. The trends of SSB was considered "increasing" based on the trends of recent five years (2014-2018). Fishing pressure were high from Fmsy in the most years, it stayed around Fmsy during 2014 to 2017. However, F of 2018 rapidly increased to 1.29 which is below Fmsy. Recruitment (abundance of age 0 fish) fluctuated between 200 to 400 million fish, and it became 390 million fish in 2018 (Fig. 4-5, Table 4-1).

6. Other matters

It is possible that different interpretation of rapid increase of Korean catch in 2018 and different methods of assessment may provide uncertainty for the assessment results. The Korean catch largely increased in 2018, but such change did not appear in Japanese catch and abundance index (Fig. 4-2, 4-3). If we use same method of assessment used in previous year, estimate value may be largely changed by the influence of large catch by Korea (Appendix 9-14). Or if we assume Korean catch is not rapid change but gradual, the estimated abundance is 30% smaller than the assessment of this year (Appendix 15-20).

It is considered that other cause of large uncertainty of assessment is that the information of Chinese vessels is not used (Kuroda et al. 2019b). It is difficult to

include both Korean and Chinese information for future projection due to the unknown situation for their fishery management. There are practical issues that TAC is managed as “mackerels” both chub and blue mackerel together in Japan. It should be noted that those uncertainty mentioned above are not included in the future projection of this study.

7. References

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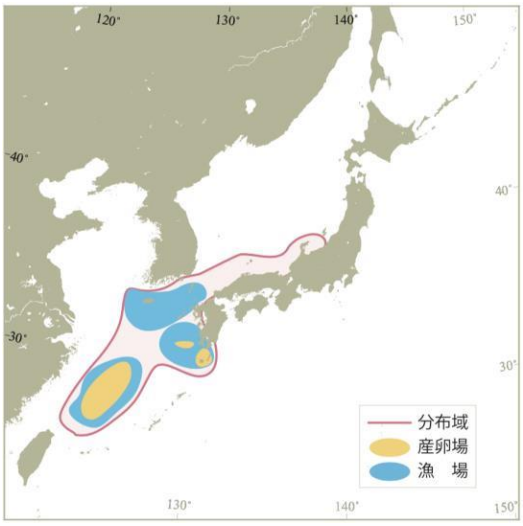


Figure 2-1. Distribution and migration of blue mackerel East china sea stock.

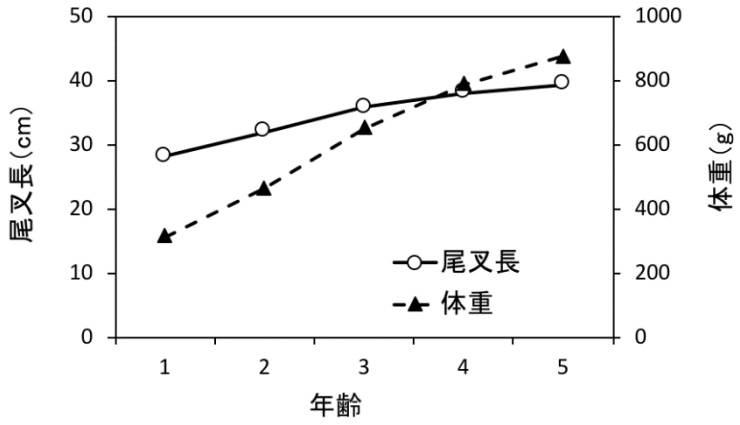


Fig. 2-2. Age and growth.

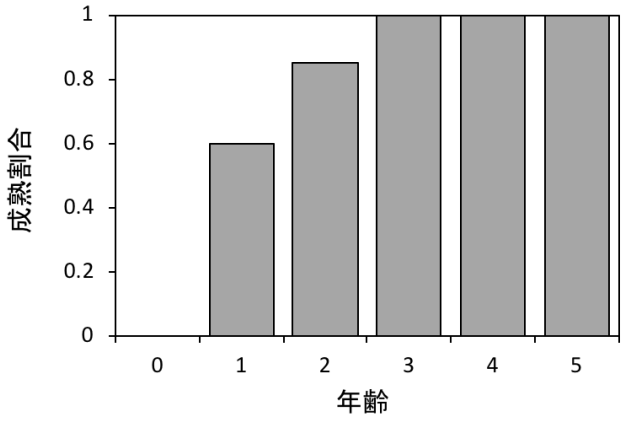


Figure 2-3. Maturity rate by age.

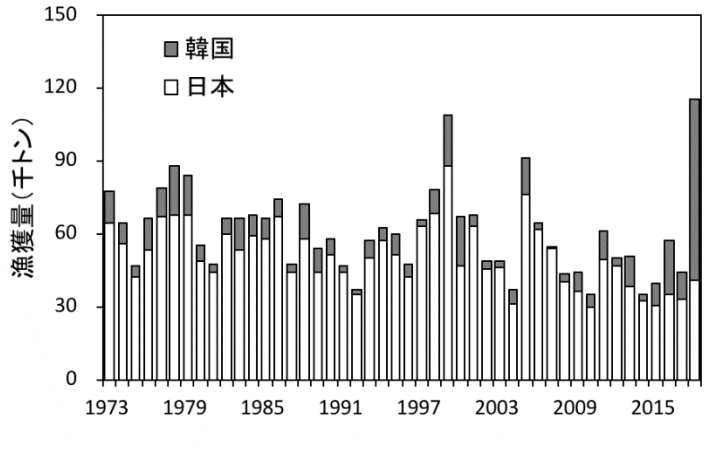


Figure 3-1. Annual catches of blue mackerel by fisheries (in thousand tons). (Grey: Korea, white: Japan).

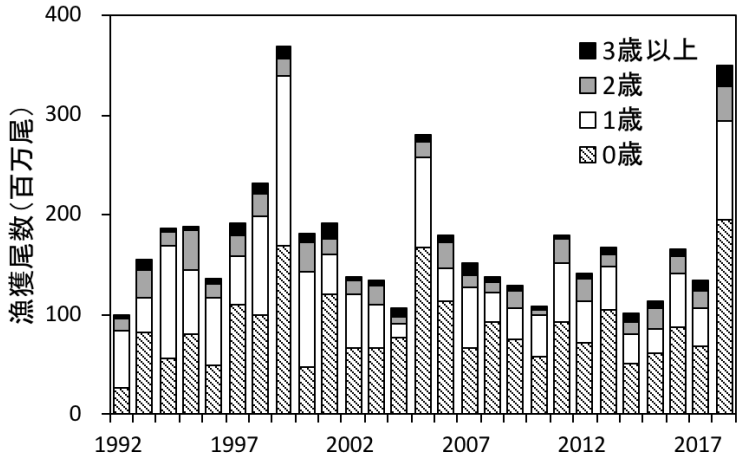


Figure 3-2. Annual age composition in catch (in million fishes). Each color represents age (0, 1, 2, 3+).

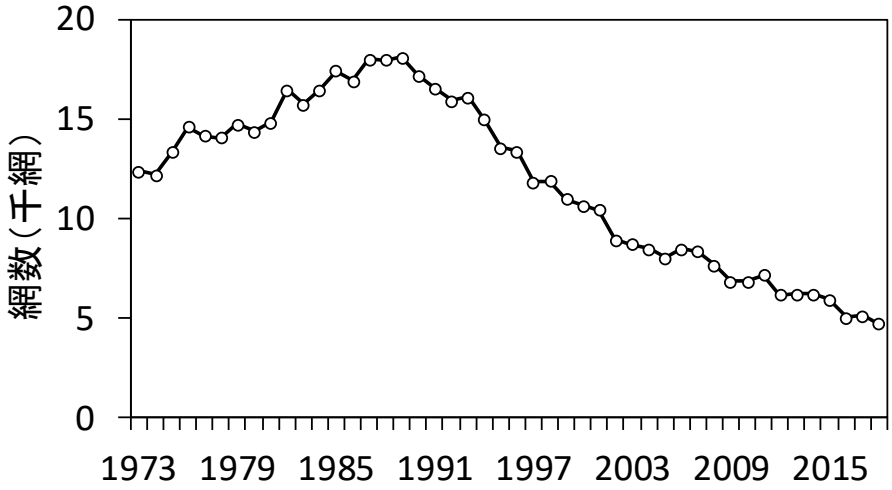


Fig. 3-3. Annual number of nets of purse seine operating in the East china sea and Japan sea (in thousand nets).

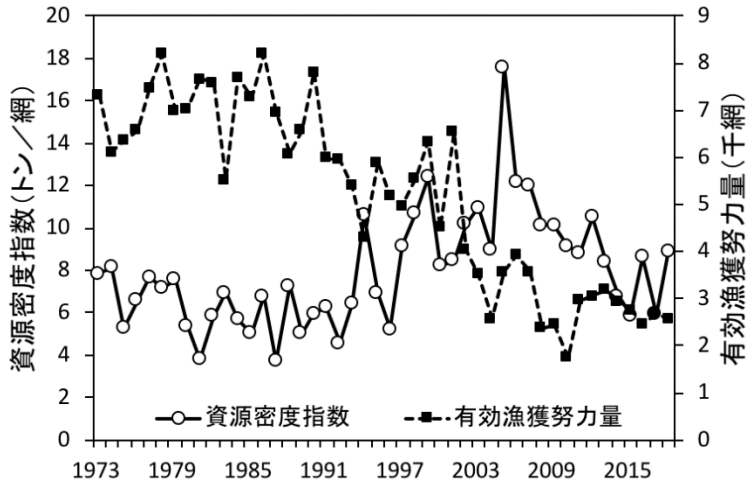


Figure 4-1. Density indices by year and annual effective effort on blue mackerel by purse seine fishery.

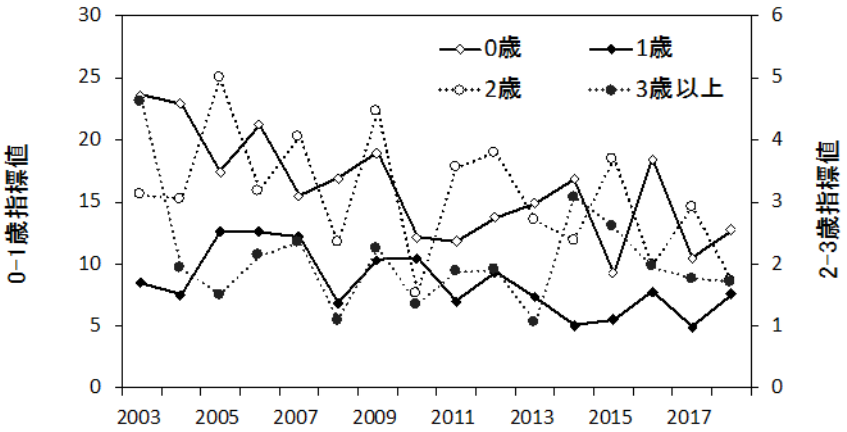


Fig. 4-2. Abundance indices by age calculated by catch by size of purse seine operating in the East china sea and Japan sea. The left axis represents index scale for 0 and 1 years old, and the right axis represents index scale for 2 and 3+ year old.

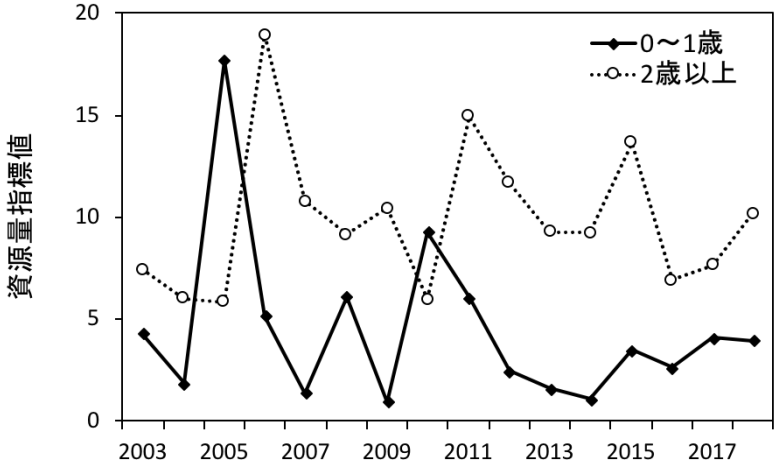


Fig. 4-3. The estimated abundances indices by age from landing data at Makurazaki port, Kagoshima prefecture.

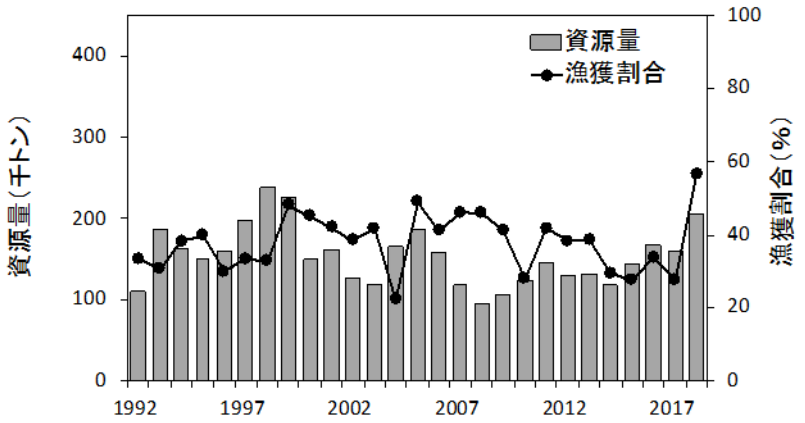


Fig. 4-4. The estimated blue mackerel abundance and fishing ratio by year. The left axis and right axis represent stock abundance (in thousand tons) and fishing ratio, respectively.

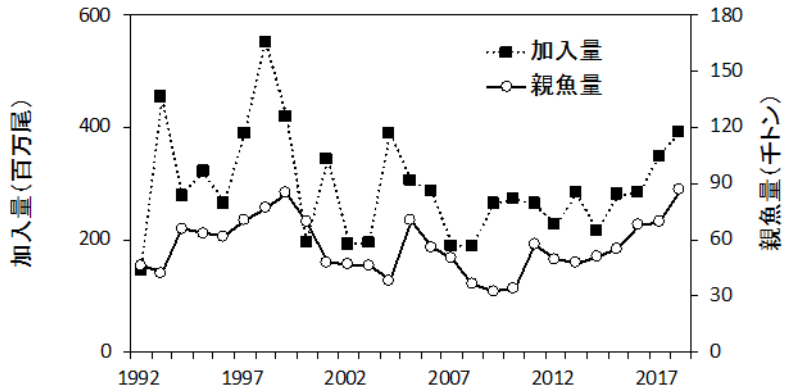


Fig. 4-5. Fluctuations of SSB and recruitment of blue mackerel East china sea stock. The black line with open circle represent SSB (left axis) and dotted line with black square represent recruitment (left axis).

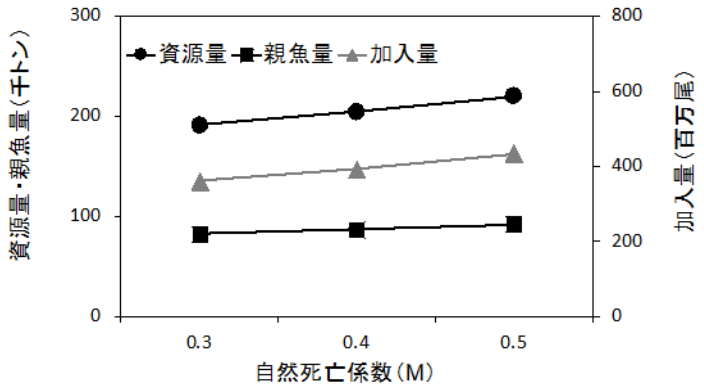


Fig 4-6. Change in stock abundance (circle), SSB (square), and recruitment (grey triangle) with various value of natural mortality coefficient M. The left axis represents stock abundance and SSB (in thousand ton) and the right axis represents recruitment (in million fish).

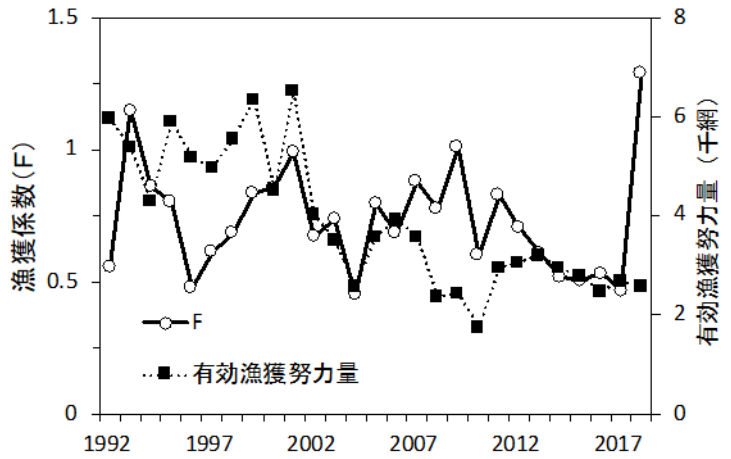


Fig. 4-7. The average of F at age (black line with open circle, left axis), and effective efforts by year (dotted line with solid square, right axis in thousand nets).

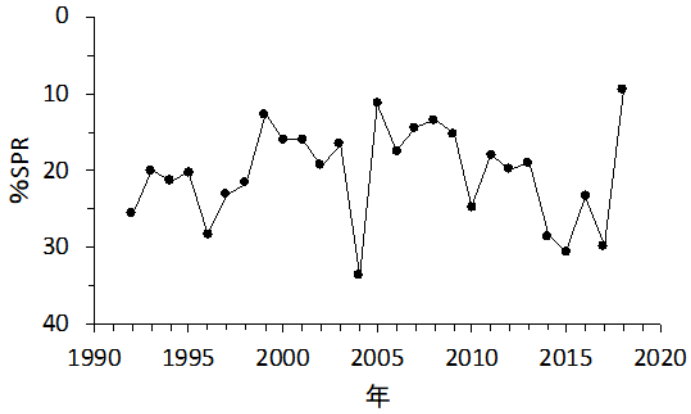


Fig. 4-8. Fluctuations in %SPR by years. %SPR shows the ratio of SSB when no fishing to the SSB when there is fishing, and %SPR becomes low with high *F* and vice versa.

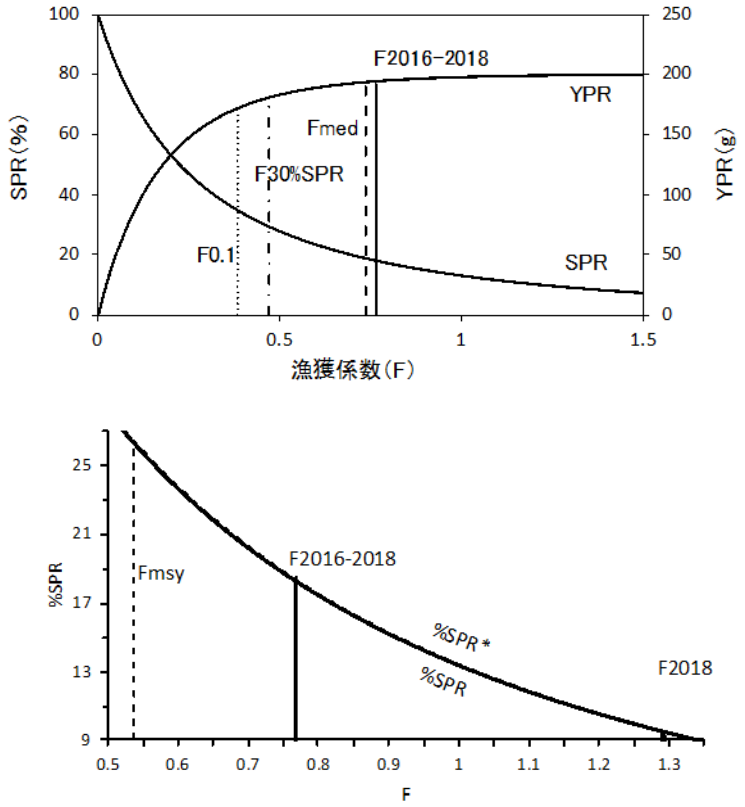


Fig. 4-9. Relationship between the fishing mortality (F2016-2018) and %SPR, YPR (above). Relationship between F and %SPR (below). %SPR* (dotted line) is the relationship between %SPR and average F under MSY.

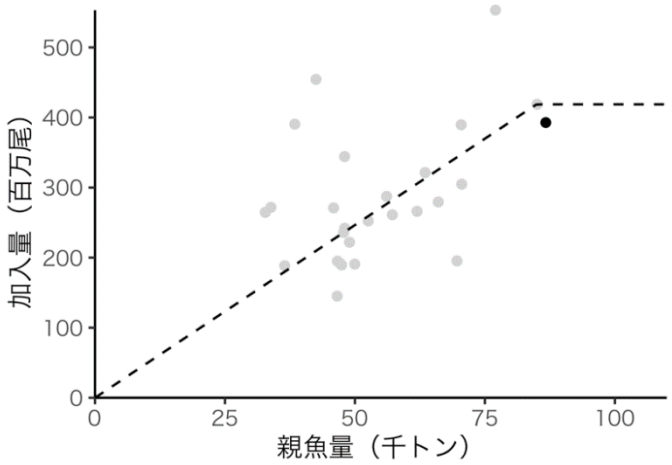


Fig. 4-10. Relationship between SSB and recruitment. The dotted line shows the S-R relationship suggested at the 'Research Institute meeting on Reference points for the East China Sea Stock of Blue Mackerel ' held in April 2019 (Hayashi et al. 2019). Black dot indicates value of 2018.

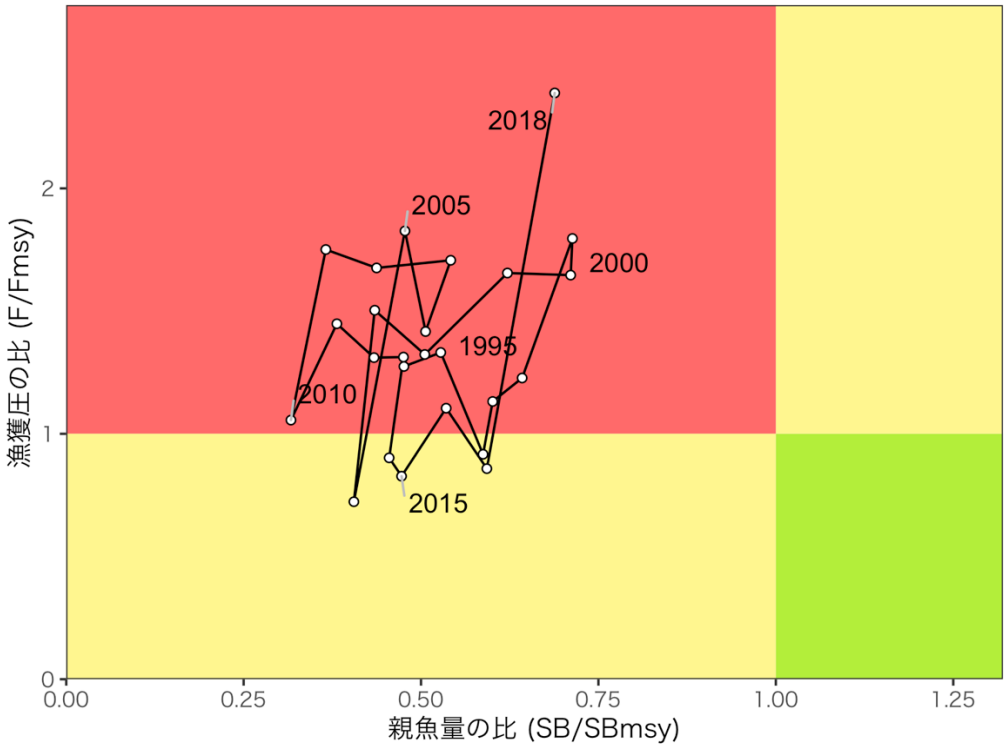


Fig. 4-11. Relationship between the SSB/SBmsy and F/Fmsy (Kobe plot). The *F* and SSB is the three-year moving average.

Table 3-1. Annual catch of blue mackerel (tons) by purse seine and by prefecture. The captions in the table below are from the left: Calendar year, catch by purse seine, Kagoshima, Kumamoto, Nagasaki, Saga, Fukuoka, Yamaguchi, Shimane and Tottori, respectively.

暦年	大中まき	鹿児島	熊本	長崎	佐賀	福岡	山口	島根	鳥取
1973	215,160	966	942	2,414	34	764	1,911	38,598	9
1974	295,856	746	575	1,716	17	676	2,821	33,423	487
1975	237,859	1,361	828	2,132	14	662	1,619	38,432	212
1976	215,601	1,789	889	2,138	24	332	772	36,709	868
1977	250,593	1,749	863	3,647	41	674	1,338	21,241	247
1978	257,417	959	1,197	9,622	51	648	587	18,498	262
1979	212,769	2,542	1,093	7,102	106	705	1,069	38,385	118
1980	255,753	2,100	623	4,595	84	617	1,378	25,388	171
1981	203,333	2,740	2,106	7,098	140	549	1,477	19,952	260
1982	233,390	2,848	2,883	6,753	182	1,016	2,094	25,179	630
1983	197,112	2,863	1,268	5,590	266	1,440	2,235	24,158	377
1984	150,995	2,952	1,308	5,063	77	789	2,150	28,426	24
1985	152,021	3,853	2,784	12,803	42	743	2,957	21,189	233
1986	144,646	2,082	551	4,902	107	1,060	1,778	30,167	893
1987	124,383	2,307	2,358	25,887	370	1,623	2,863	25,006	266
1988	158,964	1,782	1,050	10,914	316	1,409	3,738	52,260	255
1989	213,583	1,524	1,019	7,711	613	1,625	1,485	47,890	13
1990	104,467	696	254	3,490	75	798	4,035	14,554	21
1991	111,700	867	1,454	4,227	65	571	6,687	25,152	3
1992	111,697	1,208	1,242	4,849	163	883	3,639	17,885	0
1993	175,995	2,240	1,457	10,058	489	3,518	3,202	33,375	5
1994	265,917	1,143	610	8,742	452	2,453	5,394	44,236	6
1995	154,712	1,051	1,933	9,467	187	1,483	5,683	28,748	2
1996	358,199	1,742	2,106	9,232	149	1,814	5,244	26,246	0
1997	173,610	2,297	2,748	11,288	275	786	3,900	12,204	11
1998	125,813	1,137	472	7,321	152	1,194	6,260	18,756	11
1999	79,681	1,372	671	8,745	149	1,373	2,713	10,555	12
2000	65,284	1,400	286	6,046	70	519	4,649	7,797	9
2001	54,132	1,157	50	7,580	145	1,142	3,602	7,824	8
2002	62,323	345	76	7,822	25	988	3,360	9,877	5
2003	62,440	1,135	7	8,046	11	1,177	939	7,850	0
2004	58,008	959	131	14,251	37	953	319	6,648	0
2005	61,858	2,331	117	10,843	20	879	928	10,252	1
2006	55,971	2,326	125	13,799	231	962	1,579	11,929	12
2007	71,649	1,771	282	12,065	51	2,353	1,728	13,451	2
2008	82,358	2,793	313	13,478	146	743	1,606	16,412	4
2009	92,412	1,744	59	14,416	13	578	2,005	17,123	5
2010	89,528	2,476	126	11,666	83	844	1,416	9,000	7
2011	62,842	4,164	290	19,802	19	1,282	1,528	15,684	2
2012	70,195	2,515	108	14,034	69	860	818	14,772	75
2013	41,032	2,172	117	9,062	45	69	557	6,818	114
2014	46,591	1,946	192	14,736	17	201	856	15,081	1
2015	76,914	2,390	301	14,489	20	614	1,763	9,917	6
2016	47,860	2,134	278	13,326	52	193	2,580	23,633	5
2017	60,078	3,881	548	21,230	35	445	1,504	19,358	7
2018	84,054	13,229	348	32,640	92	845	2,284	27,587	3

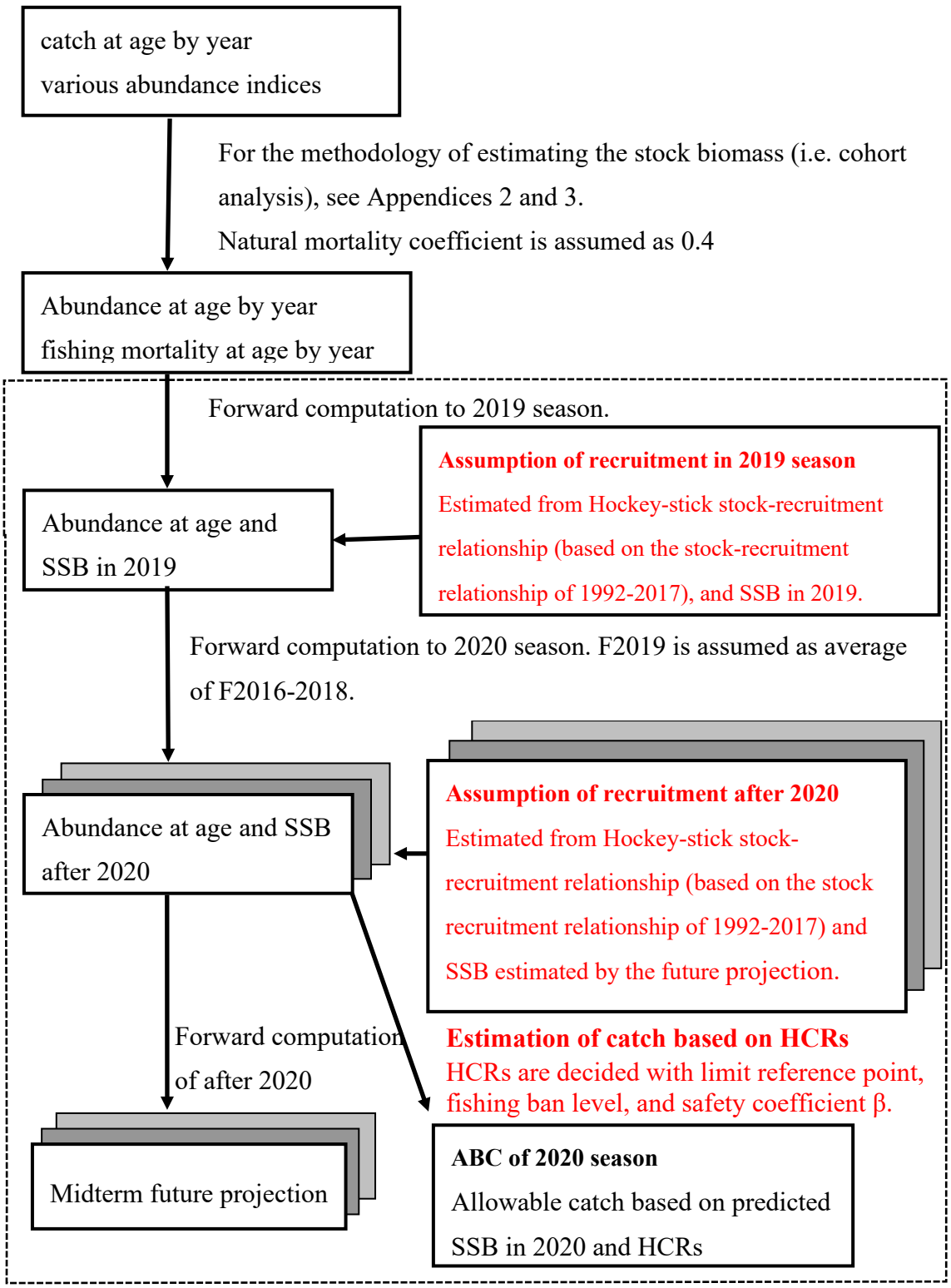
Table 3-1 (continued). Annual catch of blue mackerel (tons) by purse seine and by prefecture. The captions in the table below are from the left: Calendar year, catch by Hyogo, Kyoto, Fukui, Ichikawa, Toyama, Niigata, Yamagata, Akita and Total, respectively.

暦年	兵庫	京都	福井	石川	富山	新潟	山形	秋田	合計
1973	340	1,235	2,252	1,254	539	2,039	10	84	268,551
1974	1,486	477	2,520	3,172	1,205	1,500	6	144	346,826
1975	279	130	1,937	1,916	519	1,881	5	147	289,932
1976	678	169	2,070	3,356	1,120	2,041	2	227	268,787
1977	1,725	80	1,481	3,646	1,689	2,494	9	233	291,750
1978	1,676	61	979	3,415	1,419	1,495	0	153	298,439
1979	377	503	1,235	1,816	465	1,225	7	352	269,867
1980	43	295	894	2,492	1,000	1,446	7	215	297,101
1981	650	153	903	2,665	1,010	405	1	101	243,544
1982	1,772	95	791	2,579	402	603	1	140	281,358
1983	942	97	2,045	2,406	330	1,054	3	79	242,265
1984	557	106	1,504	2,224	239	905	6	204	197,530
1985	393	333	2,199	2,988	223	799	11	98	203,670
1986	383	93	1,164	3,382	465	1,059	15	110	192,858
1987	722	100	1,984	4,920	207	622	5	78	193,701
1988	369	140	2,179	5,408	316	838	4	102	240,043
1989	474	692	1,340	3,678	216	638	7	73	282,580
1990	187	301	494	1,510	134	184	0	29	131,228
1991	69	146	390	1,233	172	216	0	37	152,991
1992	70	120	190	1,047	230	140	0	24	143,385
1993	76	447	835	1,916	665	249	2	26	234,555
1994	746	632	1,334	5,180	1,357	498	3	50	338,751
1995	373	388	478	2,237	1,039	250	0	48	208,078
1996	283	298	516	4,255	764	335	2	31	411,217
1997	54	409	405	1,802	509	280	5	37	210,618
1998	10	472	183	1,257	1,306	144	4	32	164,524
1999	167	294	409	564	842	337	3	34	107,839
2000	113	409	265	1,028	1,134	178	1	59	89,249
2001	2	202	147	990	319	144	1	68	77,514
2002	6	276	151	630	117	85	1	33	86,121
2003	24	363	164	765	192	102	0	4	83,219
2004	2	180	51	1,144	525	112	6	51	83,377
2005	81	88	146	3,665	390	193	7	70	91,870
2006	35	1,399	602	878	348	232	27	58	90,514
2007	10	348	258	1,714	310	338	11	43	106,384
2008	57	279	188	1,316	764	545	16	53	121,073
2009	16	306	142	984	365	344	5	44	130,559
2010	14	86	199	1,368	495	339	4	26	117,678
2011	26	275	164	3,212	1,004	382	14	109	110,798
2012	18	53	162	2,870	1,193	283	1	23	108,048
2013	7	146	137	2,826	994	246	4	28	64,373
2014	4	514	29	3,156	3,201	447	3	15	86,990
2015	57	263	268	3,529	4,018	547	5	50	115,149
2016	4	217	249	2,989	754	456	3	32	94,765
2017	5	257	193	2,762	808	305	3	25	112,668
2018	11	141	204	5,353	1,251	567	4	55	150,659

Table 3-2. Annual catch by countries and results of the cohort-analysis. The captions in the table are from the left: fishing year, catch (thousand tons) by Japan, Korea and Total, estimated abundance (thousand tons), SSB (thousand tons), recruitment (million fish), fishing ratio (%), and RPS (numbers/kg).

	漁獲量（千トン）			資源量	親魚量	加入量	漁獲割合	再生産成功率
年	日本	韓国	計	（千トン）	（千トン）	（100万尾）	（%）	（尾／kg）
1973	269	61	330	1,026	312	2,078	32	6.667
1974	347	72	419	1,029	380	1,749	41	4.608
1975	290	65	355	946	327	1,759	38	5.373
1976	269	95	364	976	316	1,911	37	6.052
1977	292	101	393	1,070	325	2,202	37	6.777
1978	298	79	378	1,044	360	1,906	36	5.286
1979	270	104	374	1,123	363	2,229	33	6.144
1980	297	57	354	921	415	1,203	38	2.900
1981	244	105	348	985	329	2,026	35	6.162
1982	281	93	374	1,116	343	2,295	34	6.684
1983	242	110	352	1,050	408	1,714	34	4.202
1984	198	93	291	902	406	1,283	32	3.163
1985	204	60	264	926	380	1,647	28	4.332
1986	193	97	290	866	388	1,252	33	3.229
1987	194	98	292	1,255	339	2,992	23	8.816
1988	240	149	389	1,219	533	1,576	32	2.957
1989	283	154	437	876	521	762	50	1.463
1990	131	91	222	636	256	1,187	35	4.631
1991	153	89	242	735	236	1,559	33	6.616
1992	143	114	258	917	265	1,963	28	7.397
1993	235	168	403	1,098	377	2,100	37	5.570
1994	339	205	544	1,118	400	2,145	49	5.366
1995	208	192	400	1,292	295	3,287	31	11.152
1996	411	410	821	1,370	468	2,456	60	5.247
1997	211	158	368	832	247	1,775	44	7.183
1998	165	163	328	715	245	1,349	46	5.507
1999	108	157	265	617	213	1,286	43	6.048
2000	89	126	215	446	190	1,046	48	5.490
2001	78	199	277	559	159	1,166	50	7.341
2002	86	139	225	467	137	972	48	7.076
2003	83	119	202	459	116	991	44	8.539
2004	83	178	262	627	125	1,497	42	11.934
2005	92	120	212	509	183	830	42	4.529
2006	91	99	189	443	165	887	43	5.387
2007	106	143	249	522	138	1,132	48	8.224
2008	121	187	308	696	131	1,779	44	13.580
2009	131	168	298	551	188	955	54	5.079
2010	118	94	212	511	112	1,237	41	11.073
2011	111	139	250	516	143	1,326	48	9.260
2012	108	125	233	487	144	1,057	48	7.336
2013	64	102	166	371	125	804	45	6.412
2014	87	127	214	555	109	1,487	39	13.686
2015	115	132	247	570	173	1,144	43	6.607
2016	95	133	228	480	157	1,023	47	6.502
2017	111	104	215	640	130	1,986	34	15.262
2018	151	142	292	654	238	1,329	45	5.580

Appendix 1. The workflow of stock assessment



NOTE : Workflows in the dashed box are developed based on the discussions of stock-recruitment relationship and reference points (written in red) at the Committee of Stock Management Policy (http://www.jfa.maff.go.jp/j/press/sigen/190612.html, [in Japanese])

Appendix 2. Methodology of stock estimation

1. Cohort analysis

The abundance of blue mackerel was estimated by cohort analysis using catch at age by year calculated from catch (Notes 1). Average fork length and weight in 2018 and maturity rate used for analysis are as below. The age 3+ means age 3 and above. Natural mortality M was assumed 0.4 (M=2.5/max age 6≒0.4) with maximum age 6 (Tanaka 1960).

Age	0	1	2	3+
Fork length（cm）	25.2	29.6	34.2	37.8
weight（g）	222	363	571	772
Maturity ratio（%）	0	60	85	100

Catch at age was estimated catch by size caught by coastal fisheries around Kyusyu (Notes 2). Annual catch by age (January to December) during 1992 to 2018 was estimated by Japanese catch and raised by total catch of Japan and Korea. The blue mackerel ratio in Korean catch before 2007 was assumed same as Japanese one calculated from the catch data of large purse seine. After 2008, Korea reported chub and blue mackerel catch separately then those were used. However, in 2009 Korean blue mackerel catch was extremely high, and suggested reliability was low, then same method used before 2007 was adapted. Chinese catch was not included.

The abundance at age was estimated by the equations of cohort analysis shown below.

$$N_{a,y} = N_{a+1,y+1}\exp\left(F_{a,y} + M\right) \quad (1)$$

$$C_{a,y} = \frac{F_{a,y}}{F_{a,y} + M} N_{a+1,y+1}\left(\exp\left(F_{a,y} + M\right) - 1\right) \quad (2)$$

where N is the number of fish, C is the catch of fish, a is age (0 to 3+), and y is year. The F was estimated by iteration of the equation of Ishioka and Kishida (1985), and plus group was treated as following Hiramatsu (2000). The F for 3+ group was assumed same as age 2.

$$F_{3+,y} = F_{2,y} \quad (3)$$

The terminal F for age 0, 1, 2 were estimated by ridge VPA (Okamura et al. 2017). Ridge VPA is a method reducing instability of F estimation using the penalty according to F value. The penalty was decided by minimizing retrospective bias (trend of over estimation on latest B) of estimated abundance. Specifically, F was estimated by minimizing objective function (equation 4) which relates likelihood L of goodness of fit on abundance index and penalty of F.

$$\text{minimize} \qquad -(1-\lambda)lnL + \lambda \sum_{a=0}^{2} \left(\hat{F}_{a,(Y-5,Y-1)} - F_{a,Y}\right)^2 \tag{4}$$

The penalty term of terminal F (2018) estimation was F square until last year, but residual sum of square of past five years average $\hat{F}_{a,(Y-5,Y-1)}$ was used this analysis. If same method of last year was adapted, estimated abundance increased rapidly in recent years and it over the maximum value in the past due to the large increase of catch in 2018 (Appendix 9). However, fishing status of 2019 (catch until September was 37 thousand tons) was rather low, and not suggested rebulbing stock. Furthermore, there is no evidence to revise estimated stock abundance. Considering such situation, the penalty of ridge VPA was defined as equation (4).

The weighting coefficient λ ($0 <= \lambda <= 1$) of F estimation was set to minimize retrospective bias ρ of B (abundance) (equation 5).

$$\rho = \frac{1}{P} \sum_{i=1}^{P} \frac{B'^{R_i}_{Y-i} - B'_{Y-i}}{B'_{Y-i}} \tag{5}$$

$$B'_Y = \sum_{a=0}^{3+} B_{a,Y} \tag{6}$$

The retrospective bias ρ of B is average of B, estimated abundance of recent assessment by year and relative value of assessment lacking data of *i* years (Y-*i* years): B^R (Mohn 1999). The number of years go back was 5 in previous assessment, but used 7 this time. Because if take 5, λ became 0.10 and estimation of F over 4×10^7 of unrealistic value.

Likelihood (equation 7) examined degree of fit between (1) CPUE at age of large purse seine catch (catch/net Notes 3) and trend of abundance at age and (2) mid-size purse seine CPUE of age 0-1, and 2 and above landing Makurazaki port (Landing/vessel; Notes 3), and trend of abundance at age. The period examined were from 2003 to 2018 when operational status and fishing efficiency are same. The negative log likelihood has to be minimized is defined below (Hashimoto et al. 2018).

$$-\ln L = \sum_a \sum_y \frac{\left[\ln I_{a,y} - \left(b_a \ln B_{a,y} + \ln q_a\right)\right]^2}{2{\sigma_a}^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma_a}\right) + \sum_g \sum_y \frac{\left[\ln J_{g,y} - \left(b'_g \ln B'_{g,y} + \ln q'_g\right)\right]^2}{2{\sigma'_g}^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma'_g}\right) \quad (7)$$

Here, $I_{a,y}$ is large puse seine CPUE at age a, $J_{g,y}$ is mid-size purse seine CPUE at age group g (age 0-1, 2+) by year y, $B_{a,y}$ is abundance of age a at year y, $B'_{g,y}$ is abundance age group g at year y, $s_{a,y}$ is selectivity of mid-size purse seine by age a at year y, q_a, b_a, σ_a, q'_g, b'_g, σ'_g are estimated parameters (estimated with terminal F). The abundance by age was estimated that abundance in number at age and year multiplied by average weight by age and year $w_{a,y}$.

$$B_{a,y} = N_{a,y} w_{a,y} \quad (8)$$

It also following relations assumed between $I_{a,y}$ and $B_{a,y}$, and $J_{g,y}$ and $B'_{g,y}$.

$$I_{a,y} = q_a {B_{a,y}}^{b_a} \quad (9)$$

$$J_{0-1,y} = q'_{0-1}\left(\sum_{a=0}^{1} s_{a,y} B_{a,y}\right)^{b'_{0-1}} \quad (10)$$

$$J_{2+,y} = q'_{2+}\left(\sum_{a=2}^{3+} s_{a,y} B_{a,y}\right)^{b'_{2+}} \quad (11)$$

However, b_a and b' are fixed as 1 in the analysis. Furthermore, because of the estimation of F and selectivity by fishery is difficult in the current model, selectivity of mid-size purse seine $s_{a,y}$ is assumed same among same age group, and the indices of mid-size purse seine at age group 0-1 and 2+ supposed to indicate abundance at age group.

The F at age in 2018 are estimated $F_{0,2018}$ = 0.88, $F_{1,2018}$ = 1.05, $F_{2,2018}$ =

$F_{3+,2018}$ = 1.62, respectively. The λ was estimated as 0.76. The other parameters were estimated as follows: q_0 = 0.23, q_1 =0.22, q_2 =0.16, q_3 =0.17, q'_{0-1} =0.03, q'_{2+}=0.30, σ_0 =0.33, σ_1 =0.47, σ_2 =0.49, σ_3 =0.55, σ'_{0-1} =0.71, σ'_{2+} =0.38. When tuning VPA run assuming λ =0, F became unrealistic value of over $4x10^7$.

The future projection was made based on the abundance estimated by cohort analysis. The management reference points are shown in Appendix 6 and the method of projection is described in Appendix 7.

The abundance indices at age (tons/net)

year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Large PS										
Age 0	23.61	22.93	17.42	21.27	15.49	16.93	19.01	12.16	11.8	13.81
1	8.51	7.56	12.64	12.60	12.22	6.91	10.37	10.50		9.36
2	3.11	3.05	4.99	3.18	4.06	2.34	4.47	1.54		3.80
3+	4.62	1.93	1.51	2.15	2.36	1.09	2.25	1.35		1.91
Middele										
0-1	4.29	1.87	17.71	5.17	1.37	6.11	0.95	9.28		2.43
2+	7.42	6.03	5.83	18.94	10.78	9.17	10.43	5.99	14.9	11.67

year	2013	2014	2015	2016	2017	2018
Large PS						
Age 0	14.9	16.8		18.4	10.4	12.7
1					4.93	7.60
2					2.93	1.72
3+					1.76	1.71
Middele						
0-1					4.10	3.95
2+			13.6		7.65	10.1

Notes 1. The catch was estimated as below. The ratio of chub and blue mackerel caught by large purse seine were reported, then chub mackerel catch from the East china sea and Japan sea were summarized. The blue mackerel catch from the area Kagoshima to Akita prefecture except large purse seine catch were added. Those catch were calculated by the mackerel catch multiplied with the ration of blue mackerel by prefecture (Kagoshima 80%, Kumamoto and Nagasaki 20%, Saga and Fukuoka 10%, Yamaguchi

to Fukui 5%, and north of Ishikawa 0%). For 2017 and 2018, blue mackerel ratio of Kagoshima was determined based on the landing by chub and blue mackerel of middle purse seine at the major ports (Makurazaki and Akune).

Notes 2. The catch number at age by year was estimated as below. The large purse seine catches at age were estimated by box number (number per box 18kg). For small fish (age 0 to 1), number were estimated catch weight and average weight per fish. For the coastal fishery (middle purse seine and set net), catch number at age by year was estimated by length measurement data in each prefecture (6606 fish in 2018) and catch by month. Age classification for size were mini size of July to December into age 0, mini of January to June and small of July to December into age 1, small of January to June and middle of July to December into age 2, and middle of January to June and all large into age 3+.

Notes 3. For the fishing operation targeting blue mackerel from January to May and from August to December, abundance indices were calculated as catch by size (Notes 2) per net (CPUE). From the assessment of 2017, the fishing data from north and central Japan sea was used with the data of East china sea and south of Japan sea. The catch data which over 10% of blue mackerel catch per total catch were extracted from the logbook data by day and vessels, then CPUE at age by day and vessels were calculated. The 10% threshold was used for excluding obvious mixed catch with chub mackerel and extract blue mackerel catch data as much as possible. Then average CPUE at age was calculated as abundance indices at age. From the relation between size in the box data and length, size classification of mini and small were assumed age 0-1, middle and large size categorized as age 2+.

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Appendix 3. Results of various surveys on mackerels.

(1) The abundance indices obtained from the distribution survey "Pelagic fish acoustic survey using quantitate fish detector" conducted western Kyusyu and eastern water of Tsushima are shown below. The chub and blue mackerels are shown as mackerels. The separation by species has been examined.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
mackerels	0.2	2.2	1.6	0.9	0.3	0.3	0.05	1.0	2.7
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
mackerels	1.7	0.9	8.3	0.8	0.4	0.8	7.8	1.6	1.7
Year	2015	2016	2017	2018					
mackerels	1.3	2.3	4.8	4.6					

(2) The estimated abundance (tons) obtained by biomass survey using bottom trawl conducted in the continental shelf break of East china sea in May to June "The biomass survey of bottom fish in the East china sea" are shown below. (The survey area was 138 thousand km^2, fishing efficiency assumed 1). Because of the nature of bottom survey, it is considered the survey is not cover all distribution depth of mackerels. Therefore, the survey results used as reference.

Year	2000	2001	2002	2003	2004	2005	2006	2007
blue mackerel	31,300	67,230	6,417	4,515	873	501	11,063	251
Year	2008	2009	2010	2011	2012	2013	2014	2015
blue mackerel	3,694	78	327	11,479	11,813	141	604	9,065
Year	2016	2017	2018	2019				
blue mackerel	18,568	10,165	13,632	419				

(3) Recruitment survey "recruitment survey using neuston net" has been conducted in February to June at the East china sea and coastal waters of Kyusyu since 2000. The survey results are shown in the appendix 5 of the assessment report of anchovy Tsushima stock in 2019 (Kurota et al. 2020).

Reference

黒田啓行・髙橋素光・依田真里 (2020) 令和元（2019）年度カタクチイワシ対馬暖流系群の資源評価. 令和元（2019）年度我が国周辺水域の漁業資源評価(魚種別系群別資源評価), 印刷中

Appendix 4. Details of cohort analysis results (Fishing season 1992-2018).

Captions of table are from left Catch in number (million fish), Catch in weight (thousand tons) and F in the top line. In the second line from left, Year, Age 0 to 3+.

年＼年齢	漁獲尾数（百万尾）				漁獲重量（千トン）				漁獲係数F			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	27	57	12	3	8	21	6	2	0.25	0.77	0.60	0.60
1993	82	34	29	11	24	12	14	8	0.24	0.76	1.80	1.80
1994	56	112	14	4	12	41	7	2	0.28	0.81	1.17	1.17
1995	80	65	39	3	15	24	18	2	0.36	0.78	1.03	1.03
1996	48	69	13	5	13	25	6	4	0.25	0.77	0.44	0.44
1997	110	48	21	12	29	18	11	9	0.41	0.53	0.75	0.75
1998	100	98	23	10	24	36	12	7	0.25	1.09	0.70	0.70
1999	169	170	18	12	42	51	9	8	0.65	1.16	0.76	0.76
2000	48	94	30	10	13	32	14	7	0.35	1.38	0.85	0.85
2001	120	40	16	15	34	14	8	11	0.54	0.71	1.36	1.36
2002	66	55	13	4	20	20	6	3	0.53	0.66	0.75	0.75
2003	67	42	20	5	19	16	10	4	0.53	1.04	0.69	0.69
2004	77	14	7	8	23	5	4	5	0.27	0.26	0.64	0.64
2005	167	90	17	6	46	33	9	4	1.03	0.76	0.70	0.70
2006	114	32	26	7	34	12	14	5	0.64	0.72	0.69	0.69
2007	67	60	12	14	18	21	6	9	0.54	1.16	0.91	0.91
2008	93	29	10	6	23	10	6	5	0.87	0.61	0.81	0.81
2009	75	31	16	6	18	12	9	5	0.42	1.19	1.22	1.22
2010	57	42	5	3	16	14	3	3	0.29	0.56	0.77	0.77
2011	93	58	25	3	22	24	13	2	0.54	0.70	1.03	1.03
2012	71	42	22	6	20	15	11	4	0.47	0.67	0.85	0.85
2013	105	43	12	6	25	15	7	4	0.58	0.77	0.54	0.54
2014	50	30	12	8	12	11	7	6	0.33	0.41	0.67	0.67
2015	61	25	20	7	15	9	11	5	0.30	0.34	0.68	0.68
2016	88	53	17	8	24	19	9	5	0.46	0.60	0.53	0.53
2017	68	38	18	10	13	13	10	7	0.27	0.48	0.56	0.56
2018	195	100	35	21	43	36	20	16	0.88	1.05	1.62	1.62

Appendix 4 (continued). Details of cohort analysis results (Fishing season 1992-2018).

Captions of table are from left, average weight (g), abundance in number (million fish), and abundance in weight (thousand tons) in the top line. In the second line from left, Year, Age 0 to 3+.

年＼年齢	平均体重(g)				資源尾数（百万尾）				資源量（千トン）			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	296	373	462	692	145	126	32	8	43	47	15	6
1993	287	357	474	703	454	76	39	15	130	27	19	10
1994	219	365	487	659	279	238	24	6	61	87	12	4
1995	188	374	454	687	321	142	71	6	61	53	32	4
1996	270	361	474	641	266	151	43	18	72	54	21	12
1997	262	370	505	731	390	139	47	27	102	52	24	20
1998	238	365	508	667	553	173	55	23	132	63	28	15
1999	247	298	489	655	419	290	39	26	103	86	19	17
2000	280	343	487	700	195	146	61	20	55	50	30	14
2001	285	362	519	729	344	92	25	23	98	33	13	17
2002	299	360	475	690	192	135	30	8	57	49	14	6
2003	284	388	508	721	195	76	47	12	55	29	24	9
2004	295	362	520	693	390	77	18	20	115	28	9	14
2005	274	366	505	710	305	200	40	13	84	73	20	10
2006	296	367	524	685	287	73	62	18	85	27	33	12
2007	276	345	534	672	191	102	24	27	53	35	13	18
2008	243	342	597	754	188	74	21	14	46	25	13	10
2009	240	376	567	749	265	53	27	10	64	20	15	8
2010	272	327	581	755	273	117	11	7	74	38	6	6
2011	237	404	533	712	264	137	45	6	63	55	24	4
2012	280	347	519	688	226	103	46	12	63	36	24	8
2013	239	345	557	668	284	95	35	17	68	33	20	11
2014	233	359	560	701	215	106	29	20	50	38	16	14
2015	247	352	546	680	281	104	47	17	70	37	26	12
2016	270	356	539	709	283	139	50	22	76	50	27	15
2017	198	354	540	738	350	119	51	28	69	42	28	21
2018	222	363	571	772	393	180	50	30	87	65	28	23

Appendix 5. The values of References, Stock status and Fishing intensity.

The estimated value of Biological reference points and results of cohort model.

Items	Values	Remarks
SBtarget	109,000 tons	SBmsy
SBlimit	51,000 tons	SB 0.6msy
SBban	8,000 tons	SB 0.1msy
Umsy	31%	Catch ratio at MSY
MSY	76,000 tons	
β	NA	The constant multiplied to Fishing intensity to maintain stock certain level.
SB2018	87,000 tons	SSB at 2018
U2018	57%	Fishing ratio at 2018
F2018/Fmsy	2.40	

*It is recommended that SBmsy=109,000 tons as SBtarget, SB0.6msy=51,000 tons as SBlimit, and SB0.1msy=8,000 tons as SBban, respectively at the stock assessment meeting in 2019.

*SBcurrent=87,000 tons estimated by cohort model is below SBtarget, but is above SBlimit and SBban. F2018 is above Fmsy (F2018/Fmsy=2.40), and U2018 is also above Umsy.

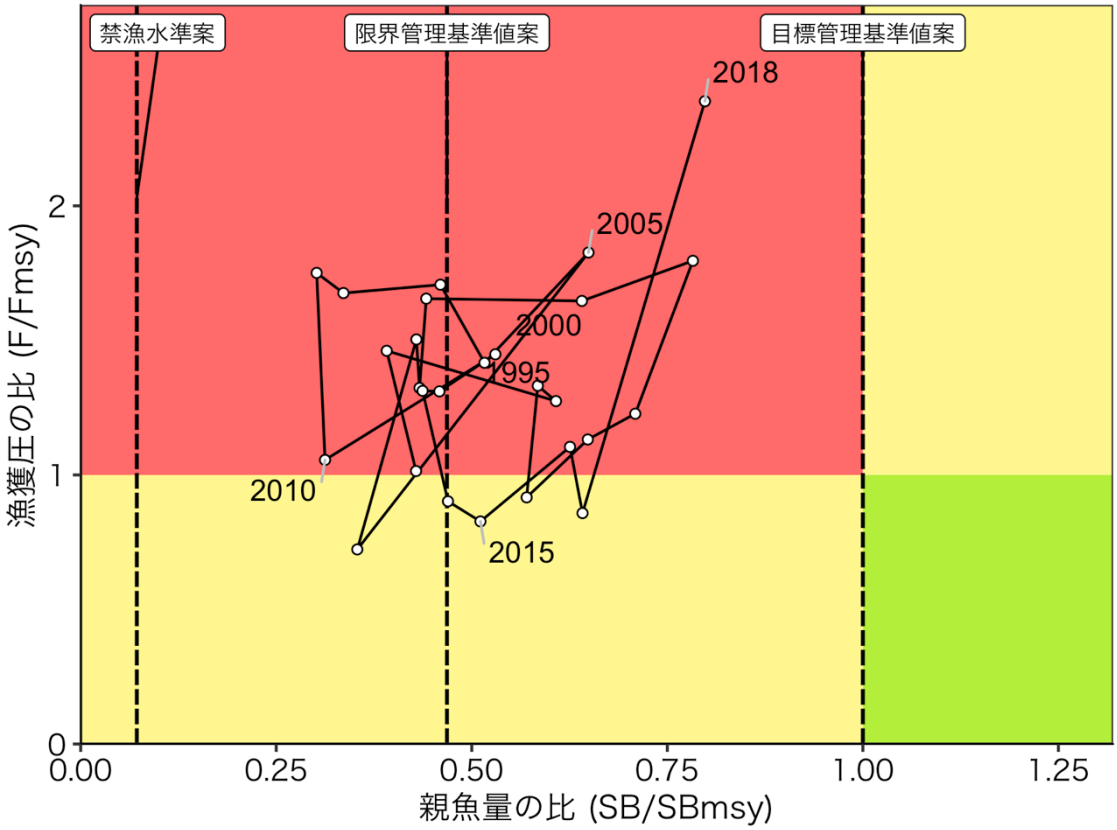
*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 5-1. Fishing intensity on the species has been over the level of Fmsy. The SSB has been low from SBtarget recently.

*The status of SSB and Fishing pressure are considered using Kobe plots. It is defined if SSB above SBtarget as “appropriate”, SSB below SBtarget and above SBlimit as “warning”, and SSB below SBlimit and above SBban as “rebuilt required”, and SSB below SBban as “fishery ban”.

*For Fishing pressure, it is defined if it below Fmsy as “appropriate”, it over Fmsy as “over fishing”.

*SB2018 is below SBtarget and above SBlimit, then considered as “warning”. F2018 is over Fmsy, then considered as “over fishing”. The status of SSB is considered “increasing” from the transition of past five years (2014-2018).

Status of SSB	warning
Status of fishing pressure	Over fishing
Status of SSB transition	increasing



Appendix Fig. 5-1. Kobe plots of chub mackerel Tsushima stock. The values in each year indicate it of single year.

Appendix 6. Estimations of catch under HCR.

The HCR is a rule which determine Fishing mortality and ABC level to maintain SSB above SBtarget. If the SSB decreased below SBlimit, fishing mortality was decreased until SBban along straight line. Fmsy should be multiplied with β. The recommended HCR was shown in Appendix Fig. 6-1. For instance, it is shown in the case of β=0.8. It is suggested by the 'Research Institute meeting on Reference points for the East China Sea Stock of blue Mackerel'.

The 2020 catch was estimated by the projection following the HCR. The projection was made using forward cohort model and recruitment predicted by reproductive relation with SSB (Appendix 7). Five thousand of iteration was made for the estimation considering uncertainty of recruitments. The current catch of 2019 (F2019) was F during 2016-2018. The F used to predict catch in 2020 is the value calculated with projected SSB in 2020 and HCR.

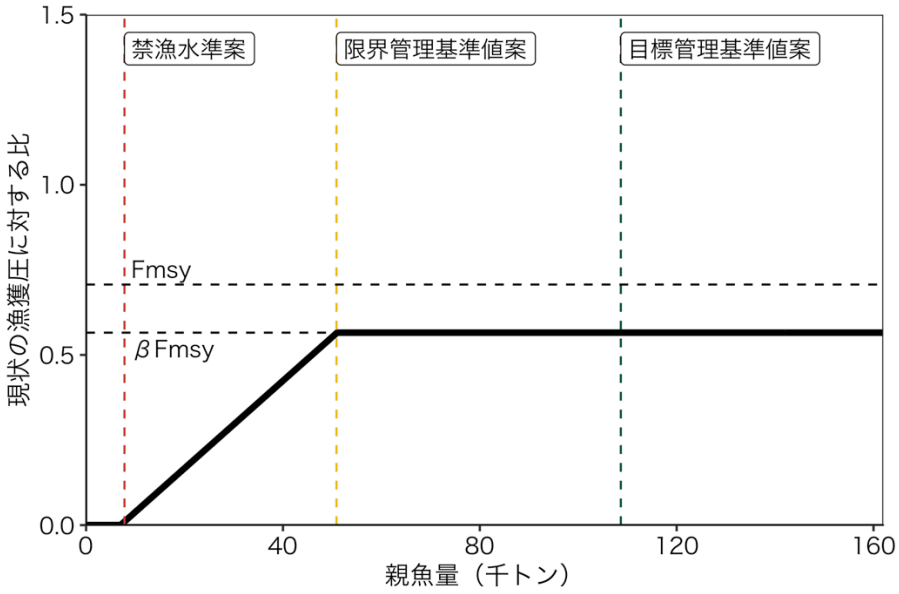
In the projection results, average catch following HCR in 2020 is 29,000 tons at β=0.8 and 35,000 tons at β=1.0. Predicted SSBs in 2020 is 48,000 tons in average exceeding SBlimit in any iterated calculations.

SSB in 2020（average of prediction）：48,000 tons			
Items	predicted catch in 2020 (thousand tons)	（F/F2016-2018）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β=<0.9	=<32	=<0.64	=<26
Other suggested catch (using differentβin HCR)			
β=1.0	35	0.71	28
β=0.8	29	0.57	24
β=0.6	23	0.42	18
β=0.4	16	0.28	13
β=0.2	8	0.14	7

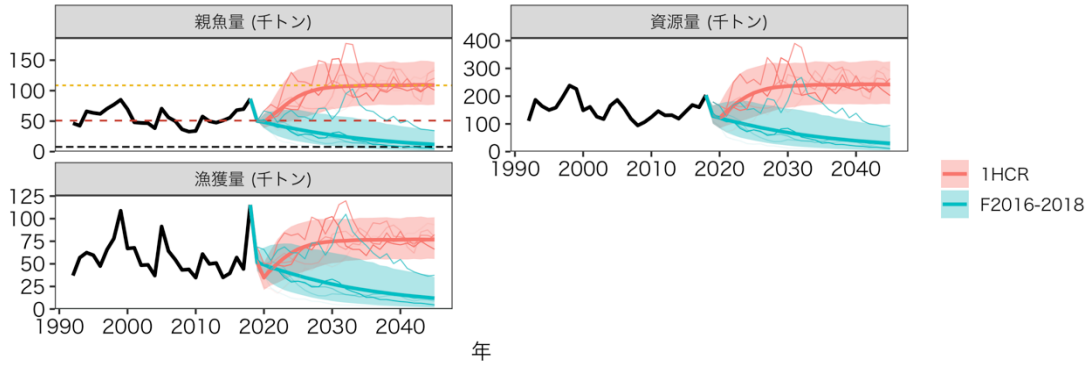
β=0	0	0.00	0
F2016-2018	46	1	40

The mid and long term projection results based on HCR (Appendix 6-1) were shown in Appendix table 6-1, 6-2 and Fig.6-2. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 106,000 tons in average using β=1.0 (80% confidence limit ranged 77,000-135,000 tons), and 133,000 tons in average using β=0.8 (80% confidence limit ranged 104,000-166,000 tons). The probability of SB above SBtarget is more than 50% usingβ<= 0.9. The probabilities above SBlimit and SBban are above 99% in all cases.

Uncertainty considered: Recruitment					
Items	predicted SSB in 2030 (thousands tons)	80% confidence limits (thousands tons)	Probability of SSB above References below in 2030 (%)		
			SBtarget	SBlimit	SBban
Fishing pressure scientifically suggested					
β=<0.9	>=120	>=92->=150	>=67	100	100
Other suggested catch (using differentβin HCR)					
β=1.0	106	77 - 135	43	99	100
β=0.8	133	104 - 166	85	100	100
β=0.6	167	132 - 204	99	100	100
β=0.4	214	172 - 259	100	100	100
β=0.2	287	234 - 343	100	100	100
β=0	405	339 - 476	100	100	100
F2016-2018	27	11 - 49	0	9	97



Appendix Figure 6-1. HCR for blue mackerel East china sea stock. Current fishing pressure is F2019 (F2016-2018).



Appendix Figure 6-2. Comparison of the projection results between HCR adapted case and to keep fishing pressure F2019 case. The bold line indicates average values of 5,000 iterations, shadow zone shown 80% confidence limits, solid lines indicate five trials.

Explanation of figure: Top left is projection of SSB (thousand tons), top right is stock biomass (thousand tons), and bottom left is catch projection (thousand tons).

Appendix Table 6-1. Probabilities of (a) SSB over SBtarget and (b) SSB over SBban. Catch in 2019 is assumed catch under F2016-2018.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	0	0	0	3	8	16	24	30	34	38	41	43	47	46
0.9	0	0	0	4	15	30	43	53	59	64	66	67	69	69
0.8	0	0	0	8	27	49	65	76	82	84	85	85	86	87
0.7	0	0	1	14	43	70	85	92	95	96	96	96	96	96
0.6	0	0	1	23	61	86	96	98	99	99	99	99	99	100
0.5	0	0	2	33	77	95	99	100	100	100	100	100	100	100
0.4	0	0	4	46	89	99	100	100	100	100	100	100	100	100
0.3	0	0	5	60	95	100	100	100	100	100	100	100	100	100
0.2	0	0	7	73	99	100	100	100	100	100	100	100	100	100
0.1	0	0	11	83	100	100	100	100	100	100	100	100	100	100
0.0	0	0	15	90	100	100	100	100	100	100	100	100	100	100

(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	0	30	70	83	90	94	97	98	99	99	99	99	100	100
0.9	0	30	78	91	96	98	99	100	100	100	100	100	100	100
0.8	0	30	84	95	99	100	100	100	100	100	100	100	100	100
0.7	0	30	89	98	100	100	100	100	100	100	100	100	100	100
0.6	0	30	93	99	100	100	100	100	100	100	100	100	100	100
0.5	0	30	96	100	100	100	100	100	100	100	100	100	100	100
0.4	0	30	98	100	100	100	100	100	100	100	100	100	100	100
0.3	0	30	99	100	100	100	100	100	100	100	100	100	100	100
0.2	0	30	100	100	100	100	100	100	100	100	100	100	100	100
0.1	0	30	100	100	100	100	100	100	100	100	100	100	100	100
0.0	0	30	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 6-2. Projection results of (a) average SSB and (b) catch. Catch in 2019 is assumed catch under F2016-2018.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	50	48	58	66	75	84	90	96	99	102	104	106	109	109
0.9	50	48	60	72	84	96	105	111	115	118	119	120	121	121
0.8	50	48	63	78	95	110	120	127	130	132	133	133	134	134
0.7	50	48	66	85	106	124	136	143	146	148	149	149	149	149
0.6	50	48	69	92	118	140	154	161	164	166	167	167	167	167
0.5	50	48	72	101	132	158	173	182	185	187	188	188	189	189
0.4	50	48	75	109	147	177	195	205	210	213	214	214	215	215
0.3	50	48	78	119	163	199	221	234	240	244	245	246	248	248
0.2	50	48	81	129	181	224	251	268	276	282	285	287	289	290
0.1	50	48	85	140	201	252	287	309	322	330	335	338	344	344
0.0	50	48	89	152	223	286	330	359	378	391	400	405	417	418

(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	51	35	44	51	57	62	66	69	72	73	74	75	77	77
0.9	51	32	42	50	58	64	68	71	73	74	75	75	76	76
0.8	51	29	40	49	58	64	69	71	72	73	73	74	74	74
0.7	51	26	38	47	56	63	67	69	70	71	71	71	71	71
0.6	51	23	34	44	53	60	64	66	67	67	67	67	68	68
0.5	51	19	30	40	49	56	60	61	62	63	63	63	63	63
0.4	51	16	26	35	44	50	53	55	56	57	57	57	57	57
0.3	51	12	21	29	36	42	45	47	48	48	49	49	49	49
0.2	51	8	15	21	27	31	34	36	37	37	37	38	38	38
0.1	51	4	8	11	15	18	19	21	21	22	22	22	22	22
0.0	51	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7 Stock projection method

Based on the abundance estimate obtained, we conducted future projection of the stock by applying the HCR. The parameters estimated by Hockey-stick type model （a=0.0049, b=84,935, SD=0.33） which was recommended at the Scientific meeting of stock management were used for projection of future recruitments. The data used for parameter estimation were SSB and recruitment calculated at the 2019 sock assessment, and least square means are used for optimization. The autocorrelation among residuals of recruitments were not considered. See detail in the report of 'Research Institute meeting on Reference points for the East china sea stock of Blue Mackerel' held in April, 2019.

The *F* used for the projection is estimated based on the HCR set for the first group of stocks (group of data rich species) which is detailed in 'Basic guidelines for the harvest control rules and the estimation of the Allowable Biological Catch (ABC)'. The parameters used for the future projections are shown in Appendix Table 7-1. As for the selectivity and average weight of the catch, we used the values that was suggested at the research institute meeting mentioned above. As for the S-R relationship parameters, these values of selectivity and average weight of catch are based on the stock assessment of this species in 2018. The %SPR estimated by the current fishing pressure (F2016-2018) under this selectivity was set to be same as the %SPR estimated by the average *F* of 2016-2018. The catch of 2019 was predicted as 51,000 tons from the current F (F2016-2018).

As for the projection of the numbers at age, we used forward calculation method for the cohort-analysis (equation 1-3).

$$N_{a+1,y+1} = N_{a,y}\exp(-F_{a,y} - M) \quad (1)$$

$$N_{3+,y+1} = N_{3+,y}\exp(-F_{3+,y} - M) + N_{2,y}\exp(-F_{2,y} - M) \quad (2)$$

$$C_{a,y} = N_{a,y}\frac{F_{a,y}}{F_{a,y} + M}(1 - \exp(-F_{a,y} - M)) \quad (3)$$

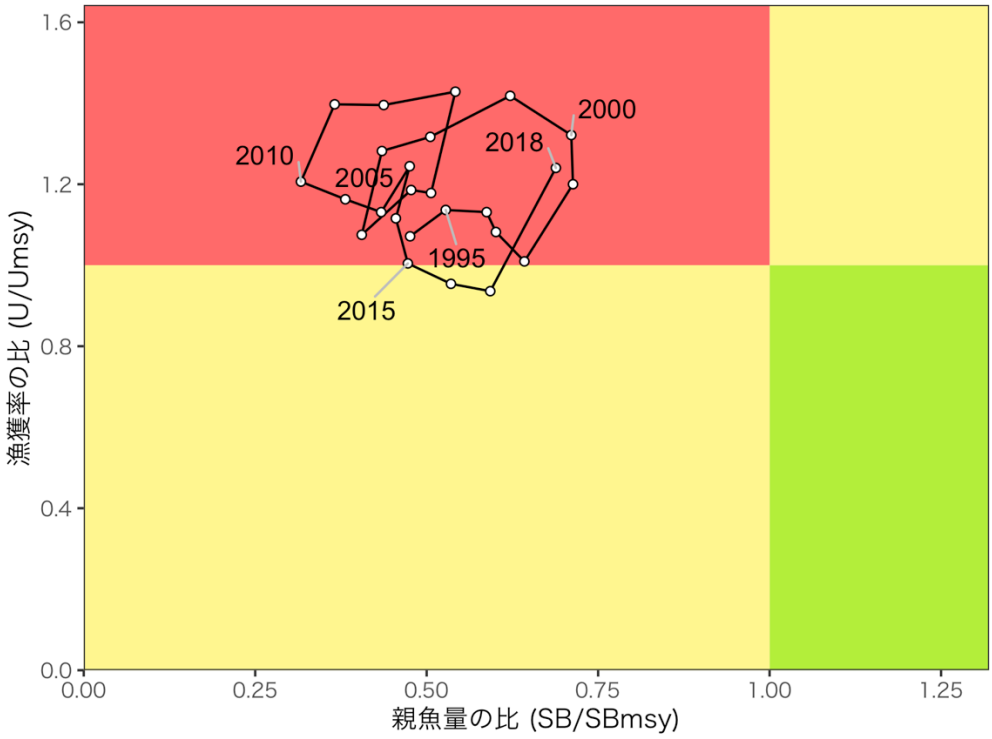
Appendix Table 7-1. Parameters used for future projection.

Age	selectivity	Fmsy	F2019	Average weight（g）	M	Maturity rate
0	0.54	0.36	0.51	238	0.4	0.00
1	0.71	0.47	0.67	354	0.4	0.60
2	1.00	0.66	0.94	542	0.4	0.85
3+	1.00	0.66	0.94	709	0.4	1.00

Appendix 8. Kobe plot based on fishing proportion

Below shows a Kobe plot based on the SSB and its corresponding fishing rate (U) in Appendix figure 8-1. The SSB is considered below the level which attains MSY during 1992 to 2018. The ratio of the fishing rate (U/Umsy) were higher than that which attains MSY during 1992 to 2014, but it declined recently. Fishing ratio (U2018/Umsy) was 1.78 in 2018.

Item	Suggested value	Remarks
SBmsy	109 thousand tons	SSB that attains MSY
Umsy	32%	Fishing rate that attains MSY
U2018	57%	Fishing rate in 2018
U2018/ Umsy	1.78	Ratio of the fishing rate in 2018 to MSY



Appendix Figure 8-1. The relationship between past SSB and fishing rate to that which gives MSY (SBmsy and Umsy) (Kobe plot). The fishing rate and SSB is the three year moving average.

Appendix 9. Assessment results of ridge VPA using penalty term as F square.

The ridge VPA assessment was conducted checking the variation of results using different penalty of F square in the equation (4) in Appendix 2. The same condition was used assessment of 2018. However retrospective bias was examined based on biomass instead of F.

(1) Transition of abundance and fishing rates

The estimated biomass was relatively stable around 100 to 200 thousand tons in 1999 to 2014, then it increased since 2015, drastically increased to 347 thousand tons in 2018 (Appendix Fig. 9-1, Appendix 10). The estimated fishing rate by ridge VPA with penalty of F square stayed around 40% until 2000s, then decline in 2014 and down to 33% in 2018.

The estimated recruitment of same ridge VPA stayed 200 to 400 million fish since 1992, but increased from 2015, and 700 million in 2018 (Appendix Fig. 9-2, Appendix 10). The variation of SSB estimated by ridge VPA was similar to that of abundance, it fluctuated between 30 to 80 thousand tons until 2013, then increased to the historical highest of 141 thousand tons in 2018 (Appendix Fig. 9-2, Appendix 10).

Additional assessment as sensitivity test of M used for cohort analysis was conducted using 0.3 and 0.5 against assumed M (0.4). The estimated abundance, SSB and recruitment tend to increase according with increase of M, and increasing of M at 0.1 affect around 5% of results (Appendix 9-3).

The estimated F (average of F at ages) fluctuates between 0.5 to 1 (Appendix Fig. 9-4, Appendix 11). Since 2012, F continually decrease to 0.33 in 2017, then rapidly increase 0.61 in 2018.

Item	values	Remarks
SB2018	141 thousand tons	SSB that attains MSY
F2018	Age 0, 1, 2, 3+= 0.41, 0.47, 0.78, 0.78	
U2018	33%	Fishing rate in 2018

(2) YPR, SPR, and the current fishing pressure

The values of %SPR (the ratio of %SPR with catch per %SPR without catch) converted from F by year to compare fishing pressure with effect of selectivity, were shown in Appendix Figure 9-5. The lower F leads the higher %SPR. The %SPR estimated

by ridge VPA having penalty of F square fluctuated, tended to increase since late 2000s, but was low as 23.5% in 2018.

The relation between %SPR and average fishing pressure under selectivity of past five years (2014 to 2018) were shown in Appendix Figure 9-6. The current fishing pressure estimated by ridge VPA were close to F30%SPR, was lower than Fmed and higher than F0.1. The relation between %SPR and average fishing pressure with the condition of MSY estimated at the scientific meeting held at April of 2019 is also shown in Appendix 9-6. Such estimated values were lower than Fmsy, but F2018 was higher than Fmsy.

Items	Value	Remarks
%SPR （F2018）	23.5%	%SPR at 2018
%SPR（F2016-2018）	30.9%	%SPR at Fcurrent (F2016-2018)

(3) S-R relationship

The relation with estimated SSB (weight) and recruitment (number of fish) by ridge VPA with penalty of F square were shown in Appendix Figure 9-7. The Hockey-stick type reproductive function was recommended at the scientific meeting mentioned above (Hayashi et al. 2019). Here, the data used to estimate S-R relationship were SSB and recruitment estimated at 2018 stock assessment, and least absolute method was used for optimization. Each parameters of S-R relation were shown below.

S-R relationship	optimization	autoregression	a	b	S.D.
Hokey-stick	Least absolute method	none	0.00493	84,935	0.33

Here, ‘a’ is slope (number of fish/Kg) of HS to the break point, ‘b’ is SSB (tons) at the break point of HS.

(4) The level that attains MSY under current environment.

The level of SBmsy and Fmsy which give MSY under current environment suggested at the scientific meeting mentioned above (Hayashi et al. 2019) are shown below.

Items	Suggested values	
SBmsy	109,000 tons	
Fmsy	(Age 0, 1, 2, 3+) ＝ (0.36, 0.47, 0.66, 0.66)	
%SPR (Fmsy)	26%	
MSY	76,000 tons	

(5) The level of abundance, trend and fishing pressure

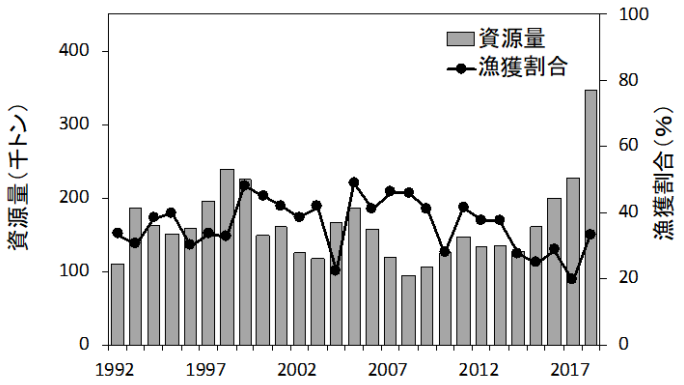
The Kobe plots of SSB and fishing pressure based on the values estimated by ridge VPA was shown in Appendix Figure 9-8. Here, the ratio of fishing pressure (F/Fmsy) used the ratio between F at %SPR converted to Fmsy and F at each year, and three years average were used for SSB and fishing ratio. Recent fishing pressure were considered above Fmsy. F2018 was 1.13 times of Fmsy. The SSB were below SBmsy during 1992 to 2017, it was above SBmsy in 2018 as 1.30 times.

Items	values	備考
SB2018/SBmsy	1.30	Ratio of SB2018 estimated by ridge VPA to SBmsy
F2018/Fmsy	1.13	Estimated by ridge VPA*

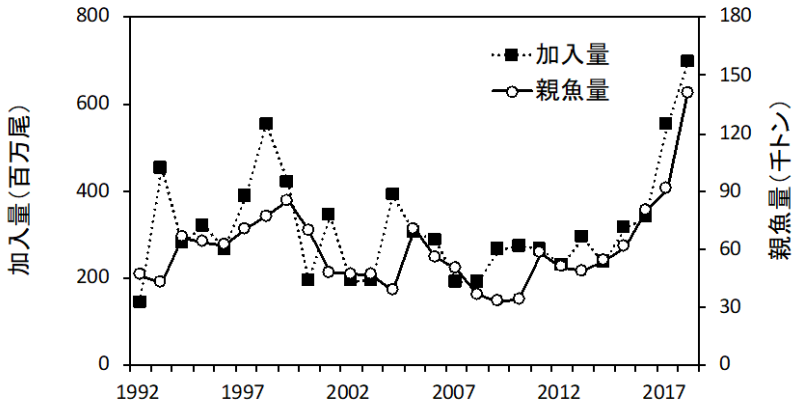
*F2018 was estimated under the selectivity of 2018 to convert Fmsy to %SPR

Status of SSB*	Above SBmsy
Status of fishing pressure*	Above Fmsy
Status of SSB transition*	increasing

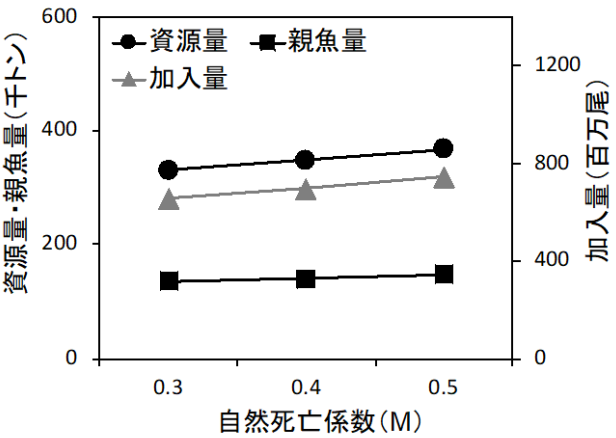
*estimated by ridge VPA



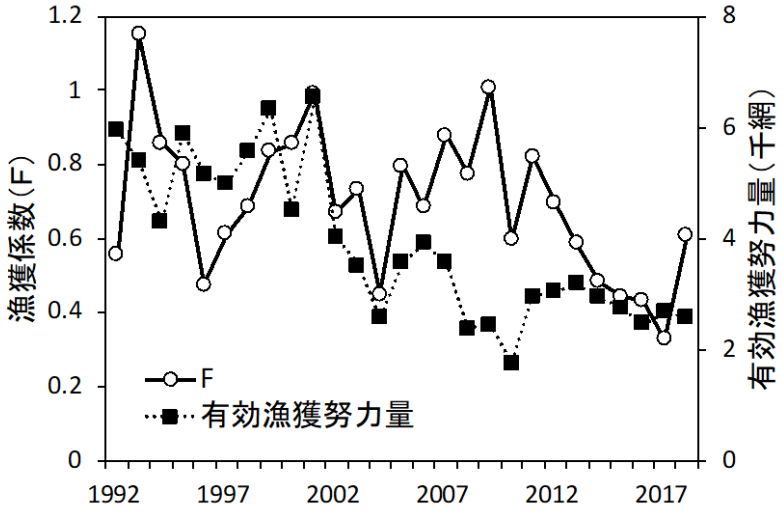
Appendix Figure 9-1. Annual abundance and fishing ration estimated by ridge VPA.



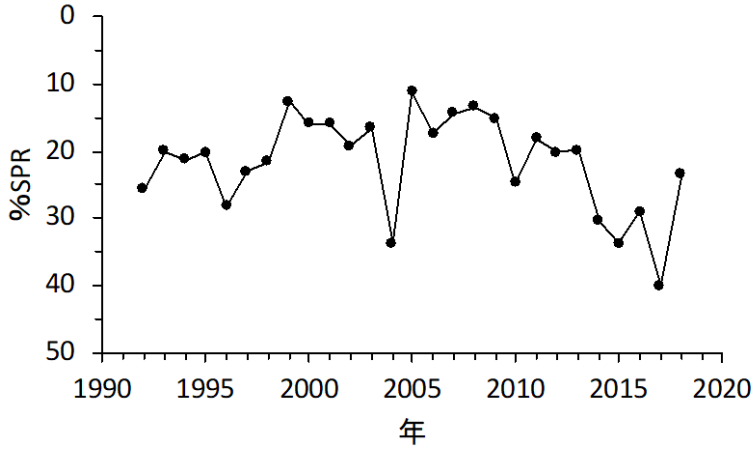
Appendix Figure 9-2. Annual SSB and recruitment estimated by ridge VPA using penalty F square.



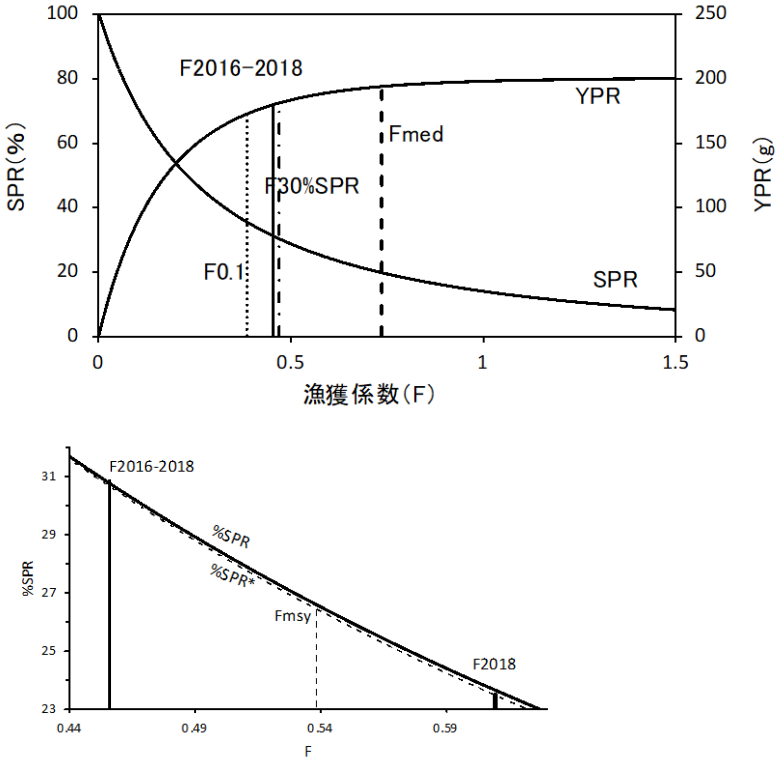
Appendix Figure 9-3. Variation of abundance, SSB and recruitment estimated by ridge VPA using penalty of F square according with various M. Black circles: abundance, black square: SSB, triangles: recruitment.



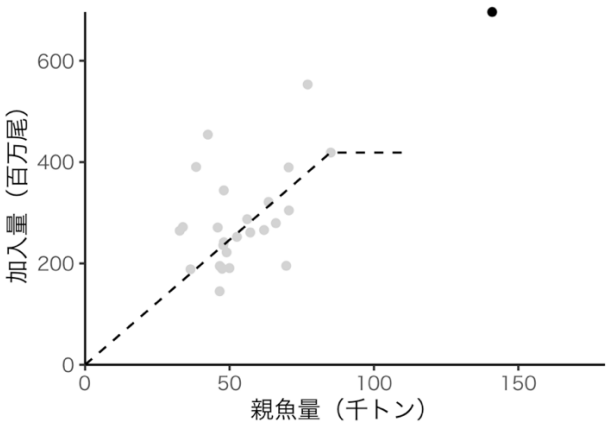
Appendix Figure 9-4. Average F at age (white circle), and effective efforts estimated by ridge VPA (black square).



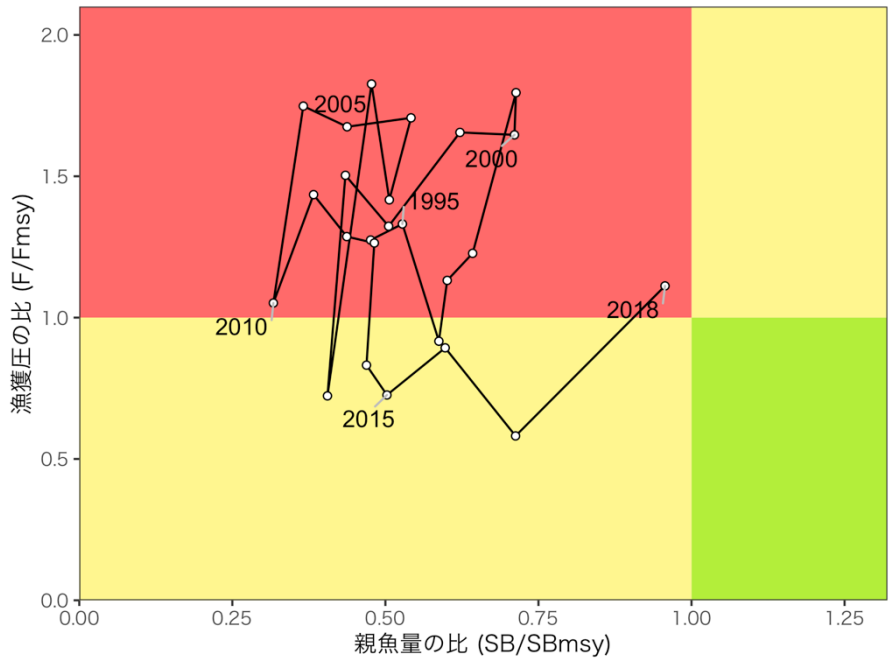
Appendix Figure 9-5. Annual variation of %SPR estimated by ridge VPA. The %SPR indicate ratio of SSB with catch to without catch. The higher F, the lower %SPR.



Appendix Figure 9-6. The relationship of YPR and %SPR under current F (F2016-2018) estimated by ridge VPA (top figure). The dotted line in the bottom figure indicate the relationship of average fishing pressure and %SPR under the condition estimated MSY.



Appendix Figure 9-7. S-R relations estimated by ridge VPA. The break line indicates S-R relationship suggested at scientific meeting held at April, 2019 mentioned above (Hayashi et al. 2019). Black dot indicates the value of 2018.



Appendix Figure 9-8. The Kobe plots of SB/SBmsy and F/Fmsy estimated by ridge VPA. Both SB and F values are calculated by three years moving average

Appendix 10. Estimated catch and results of cohort analysis using ridge VPA.

	Catch (thousand tons)			abundance	SSB	recruitment	Fishing ratio	RPS
Year	Japan	Korea	Total	Thousand tons	Thousand tons	Million fish	(%)	(fish/kg)
1992	35	2	37	111	47	145	33	3.112
1993	50	7	57	187	43	454	30	10.687
1994	57	6	62	164	66	279	38	4.232
1995	51	8	60	150	63	321	40	5.059
1996	42	5	48	159	62	266	30	4.294
1997	63	3	66	197	70	390	33	5.531
1998	68	10	78	238	77	553	33	7.182
1999	88	21	109	226	85	419	48	4.925
2000	47	20	67	149	70	195	45	2.804
2001	63	5	68	161	48	344	42	7.169
2002	45	3	48	126	47	192	38	4.085
2003	46	3	49	117	47	195	42	4.178
2004	31	6	37	166	38	390	22	10.161
2005	76	16	91	186	71	305	49	4.320
2006	61	3	64	157	56	287	41	5.122
2007	54	1	55	119	50	191	46	3.818
2008	40	3	43	94	37	188	46	5.162
2009	36	7	44	107	33	266	41	8.097
2010	30	5	35	125	34	275	28	8.072
2011	49	12	61	147	58	266	41	4.598
2012	47	3	50	133	50	229	38	4.541
2013	38	13	51	135	49	293	38	6.026
2014	33	2	35	127	54	235	28	4.379
2015	31	9	40	160	61	316	25	5.145
2016	35	22	57	200	80	341	29	4.281
2017	33	11	44	228	91	552	19	6.050
2018	41	74	115	347	141	696	33	4.941

Appendix 11. Results of cohort analysis using ridge VPA (1992-2018). Captions in the table are from left year/age, catch in number (million fish), catch weight (thousand tons), and fishing intensity F.

年＼年齢	漁獲尾数（百万尾）				漁獲重量（千トン）				漁獲係数F			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	27	57	12	3	8	21	6	2	0.25	0.77	0.60	0.60
1993	82	34	29	11	24	12	14	8	0.24	0.76	1.80	1.80
1994	56	112	14	4	12	41	7	2	0.28	0.81	1.17	1.17
1995	80	65	39	3	15	24	18	2	0.36	0.78	1.03	1.03
1996	48	69	13	5	13	25	6	4	0.25	0.77	0.44	0.44
1997	110	48	21	12	29	18	11	9	0.41	0.53	0.75	0.75
1998	100	98	23	10	24	36	12	7	0.25	1.09	0.70	0.70
1999	169	170	18	12	42	51	9	8	0.65	1.16	0.76	0.76
2000	48	94	30	10	13	32	14	7	0.35	1.38	0.85	0.85
2001	120	40	16	15	34	14	8	11	0.54	0.71	1.36	1.36
2002	66	55	13	4	20	20	6	3	0.53	0.66	0.75	0.75
2003	67	42	20	5	19	16	10	4	0.53	1.04	0.69	0.69
2004	77	14	7	8	23	5	4	5	0.27	0.26	0.64	0.64
2005	167	90	17	6	46	33	9	4	1.03	0.76	0.70	0.70
2006	114	32	26	7	34	12	14	5	0.64	0.72	0.69	0.69
2007	67	60	12	14	18	21	6	9	0.54	1.16	0.91	0.91
2008	93	29	10	6	23	10	6	5	0.87	0.61	0.81	0.81
2009	75	31	16	6	18	12	9	5	0.42	1.18	1.22	1.22
2010	57	42	5	3	16	14	3	3	0.29	0.56	0.77	0.77
2011	93	58	25	3	22	24	13	2	0.54	0.70	1.03	1.03
2012	71	42	22	6	20	15	11	4	0.46	0.65	0.83	0.83
2013	105	43	12	6	25	15	7	4	0.56	0.75	0.52	0.52
2014	50	30	12	8	12	11	7	6	0.30	0.38	0.63	0.63
2015	61	25	20	7	15	9	11	5	0.27	0.29	0.61	0.61
2016	88	53	17	8	24	19	9	5	0.37	0.49	0.43	0.43
2017	68	38	18	10	13	13	10	7	0.16	0.34	0.40	0.40
2018	195	100	35	21	43	36	20	16	0.41	0.47	0.78	0.78

Appendix 11 (continued) Results of cohort analysis using ridge VPA (1992-2018).

Captions in the table are from left year/age, average weight (g), abundance in number (million fish) and abundance (thousand tons).

年＼年齢	平均体重(g)				資源尾数（百万尾）				資源量（千トン）			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	296	373	462	692	145	126	32	8	43	47	15	6
1993	287	357	474	703	454	76	39	15	130	27	19	10
1994	219	365	487	659	279	238	24	6	61	87	12	4
1995	188	374	454	687	321	142	71	6	61	53	32	4
1996	270	361	474	641	266	151	43	18	72	54	21	12
1997	262	370	505	731	390	139	47	27	102	52	24	20
1998	238	365	508	667	553	173	55	23	132	63	28	15
1999	247	298	489	655	419	290	39	26	103	86	19	17
2000	280	343	487	700	195	146	61	20	55	50	30	14
2001	285	362	519	729	344	92	25	23	98	33	13	17
2002	299	360	475	690	192	135	30	8	57	49	14	6
2003	284	388	508	721	195	76	47	12	55	29	24	9
2004	295	362	520	693	390	77	18	20	115	28	9	14
2005	274	366	505	710	305	200	40	13	84	73	20	10
2006	296	367	524	685	287	73	62	18	85	27	33	12
2007	276	345	534	672	191	102	24	27	53	35	13	18
2008	243	342	597	754	188	74	21	14	46	25	13	10
2009	240	376	567	749	266	53	27	10	64	20	15	8
2010	272	327	581	755	275	118	11	7	75	38	6	6
2011	237	404	533	712	266	138	45	6	63	56	24	4
2012	280	347	519	688	229	104	46	12	64	36	24	8
2013	239	345	557	668	293	97	36	17	70	33	20	11
2014	233	359	560	701	235	113	31	21	55	40	17	15
2015	247	352	546	680	316	117	52	19	78	41	28	13
2016	270	356	539	709	341	162	59	26	92	58	32	18
2017	198	354	540	738	552	158	66	37	109	56	36	27
2018	222	363	571	772	696	315	75	46	154	114	43	36

Appendix 12. The values of References, Stock status and Fishing intensity estimated by ridge VPA.

The estimated value of Biological reference points and results of cohort model.

Items	**Values**	**Remarks**
SBtarget	109,000 tons	SBmsy
SBlimit	51,000 tons	SB 0.6msy
SBban	8,000 tons	SB 0.1msy
Umsy	31%	Catch ratio at MSY
MSY	76,000 tons	
β	NA	The constant multiplied to Fishing intensity to maintain stock certain level.
SB2018	141,000 tons	SSB at 2018
U2018	33%	Fishing ratio at 2018
F2018/Fmsy	1.13	

*SBcurrent=141,000 tons estimated by ridge VPA is above SBtarget, SBlimit and SBban. F2018 is above Fmsy (F2018/Fmsy=1.13), and U2018 is also above Umsy.

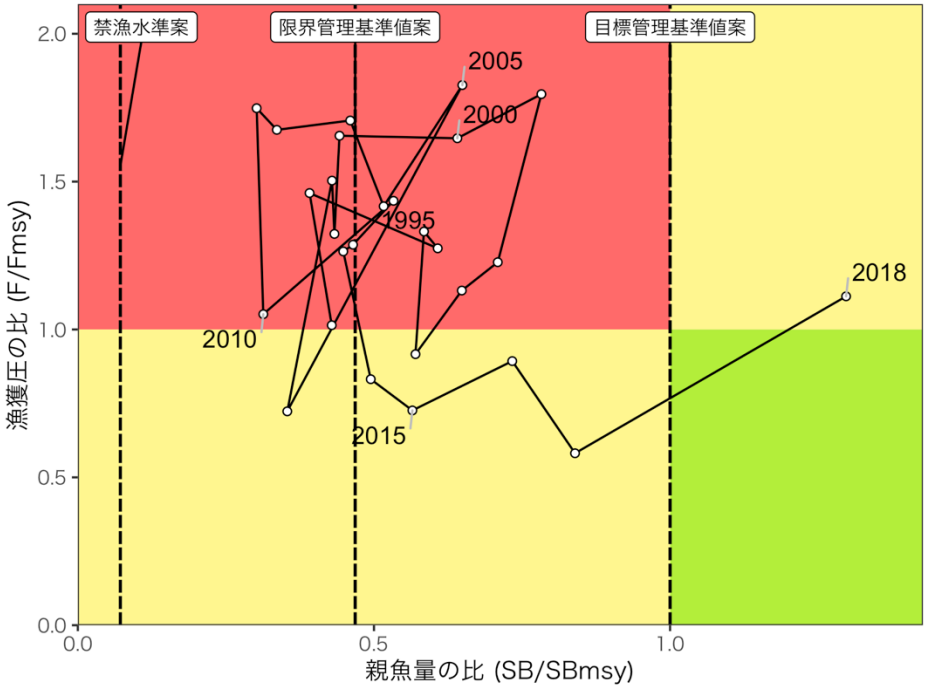
*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 12-1. Fishing intensity on the species has been over the level of Fmsy. The SB2018 is above SBtarget.

*The status of SSB and Fishing pressure are considered using Kobe plots. It is defined if SSB above SBtarget as “appropriate”, SSB below SBtarget and above SBlimit as “warning”, and SSB below SBlimit and above SBban as “rebuilt required”, and SSB below SBban as “fishery ban”.

*For Fishing pressure, it is defined if it below Fmsy as “appropriate”, it over Fmsy as “over fishing”.

*SB2018 was above SBtarget, then considered as “appropriate”. F2018 is over Fmsy, then considered as “over fishing”. The status of SSB is considered “increasing” from the transition of past five years (2014-2018).

Status of SSB	appropriate
Status of fishing pressure	Over fishing
Status of SSB transition	increasing



Appendix Fig. 12-1. Kobe plots of SB/SBmsy and F/Fmsy estimated by ridge VPA. The values in each year indicate it of single year.

Appendix 13. Estimations of catch under HCR based on the assessment results using ridge VPA.

The 2020 catch was predicted using the results of ridge VPA described in Appendix 12 and parameters shown Appendix Table 13-1. The methods of prediction was described in Appendix 7.

Appendix Table 13-1. The parameters used for future projection.

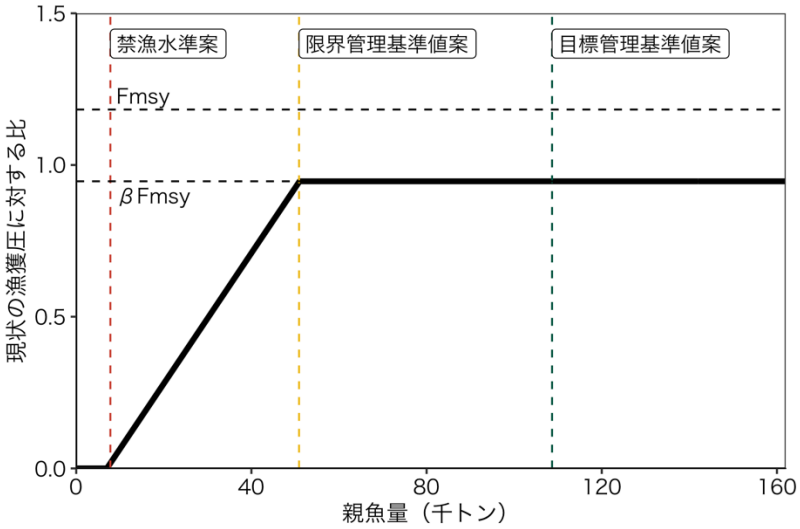
Age	selectivity	Fmsy	F2016-2018	Average weight(g)	M	Maturity rate
0	0.54	0.36	0.30	238	0.4	0.00
1	0.71	0.47	0.40	354	0.4	0.60
2	1.00	0.66	0.56	542	0.4	0.85
3+	1.00	0.66	0.56	709	0.4	1.00

In the projection results using ridge VPA, average catch following HCR in 2020 is 82,000 tons at β=0.8 and 98,000 tons at β=1.0. Predicted SSBs in 2020 is 153,000 tons in average exceeding SBlimit in any iterated calculations.

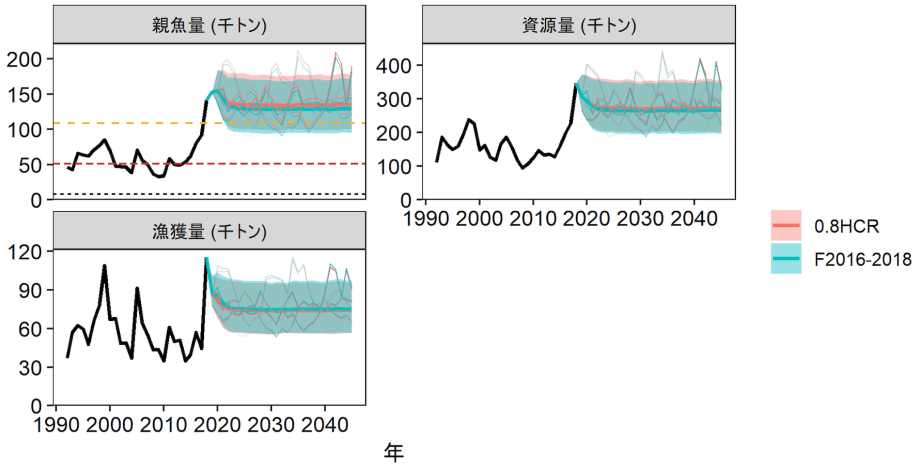
SSB in 2020（average of prediction）：153,000 tons			
Items	predicted catch in 2020 (thousand tons)	（F/F2016-2018）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β =<0.9	=<90	=<1.07	=<31
Other suggested catch (using differentβin HCR)			
β =1.0	97	1.18	33
β =0.8	81	0.95	28
β =0.6	64	0.71	22
β =0.4	45	0.47	15
β =0.2	23	0.24	8
β =0	0	0.00	0
F2016-2018	79	1	29

The mid and long-term projection results using ridge VPA with following HCR (Appendix Fig. 13-1) were shown in Appendix Fig. 13-2 and Appendix Table 13-2 and 13-3. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 109,000 tons in average using β=1.0 (80% confidence limit ranged 83,000-137,000 tons), and 134,000 tons in average using β=0.8 (80% confidence limit ranged 105,000-166,000 tons). The probability of SB above SBtarget is more than 50% using β<= 0.9. The probabilities above SBlimit and SBban are above 100% in all cases.

Uncertainty considered: Recruitment					
Items	predicted SSB in 2030 (thousands tons)	80% confidence limits (thousands tons)	Probability of SSB above References below in 2030 (%)		
			SBtarget	SBlimit	SBban
Fishing pressure scientifically suggested					
β=<0.9	>=121	>=93->=151	>=68	100	100
Other suggested catch (using differentβin HCR)					
β=1.0	109	83 - 137	48	100	100
β=0.8	134	105 - 166	86	100	100
β=0.6	167	132 - 205	99	100	100
β=0.4	215	173 - 260	100	100	100
β=0.2	288	236 - 344	100	100	100
β=0	411	345 - 482	100	100	100
F2016-2018	125	100 - 159	80	100	100



Appendix Figure 13-1. HCR for blue mackerel East china sea stock. Current fishing pressure is F2019 (F2016-2018) estimated by ridge VPA.



Appendix Figure 13-2. Comparison of the projection results between HCR adapted case and to keep Fishing pressure F2019 case. The calculation is based on ridge VPA. The bold line indicates average values of 5,000 iterations, shadow zone shown 80% confidence limits, solid lines indicate five trials.

Explanation of figure: Top left is projection of SSB (thousand tons), top right is stock biomass (thousand tons), and bottom left is catch projection (thousand tons).

Appendix Table 13-2. Probabilities of (a) SSB over SBtarget, and (b) SSB over SBlimit. Catch in 2019 is assumed catch under F2016-2018. The calculation is based on ridge VPA.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	100	100	88	63	53	50	50	48	48	48	47	48	47	46
0.9	100	100	94	79	74	71	70	70	70	69	69	68	69	69
0.8	100	100	98	91	88	88	87	88	87	87	86	86	86	87
0.7	100	100	100	97	97	97	97	97	96	96	96	96	96	96
0.6	100	100	100	99	99	100	99	99	100	99	99	99	99	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 13-3. Projection results of (a) average SSB and (b) catch. Catch in 2019 is assumed catch under F2016-2018. The calculation is based on ridge VPA.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	153	153	130	117	112	111	110	110	109	109	109	109	109	109
0.9	153	153	137	127	123	122	122	122	121	121	121	121	121	121
0.8	153	153	144	137	135	135	135	135	134	134	134	134	134	134
0.7	153	153	152	149	149	150	150	150	149	149	149	149	149	149
0.6	153	153	160	162	165	167	167	168	167	167	167	167	167	167
0.5	153	153	168	176	183	186	188	189	189	189	189	188	189	189
0.4	153	153	177	192	203	210	213	214	214	215	215	215	215	215
0.3	153	153	187	210	227	237	242	245	246	247	247	247	248	248
0.2	153	153	196	229	254	269	278	283	286	287	288	288	289	290
0.1	153	153	207	251	285	308	322	330	335	339	340	341	344	344
0.0	153	153	218	275	322	354	375	390	399	405	409	411	417	418

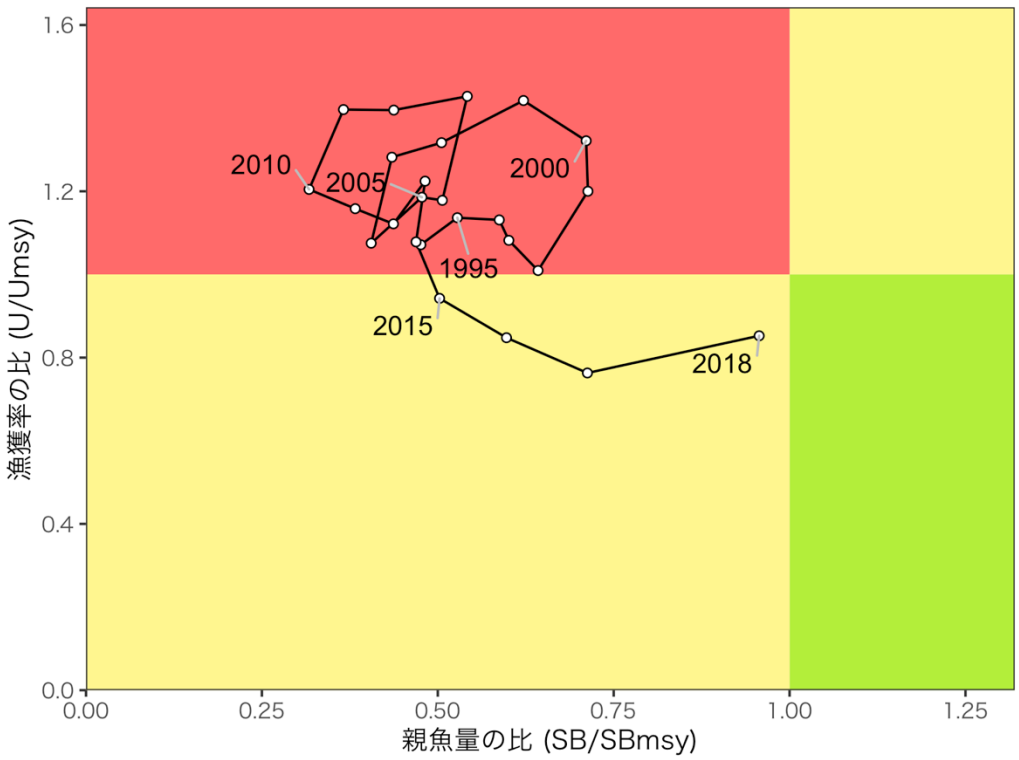
(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	89	97	86	80	79	78	78	77	77	77	77	77	77	77
0.9	89	89	82	78	77	76	76	76	76	76	76	76	76	76
0.8	89	81	77	75	74	74	74	74	74	74	74	74	74	74
0.7	89	73	72	71	71	71	71	71	71	71	71	71	71	71
0.6	89	64	65	66	67	68	68	68	68	68	68	68	68	68
0.5	89	54	58	60	62	63	63	63	63	63	63	63	63	63
0.4	89	45	49	53	55	56	57	57	57	57	57	57	57	57
0.3	89	34	39	43	46	47	48	49	49	49	49	49	49	49
0.2	89	23	28	32	34	36	37	37	38	38	38	38	38	38
0.1	89	12	15	18	19	21	21	22	22	22	22	22	22	22
0.0	89	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 14. Kobe plot based on fishing proportion estimated by ridge VPA

Below shows a Kobe plot based on the SSB and its corresponding fishing rate (U) in Appendix figure 14-1. The SSB is considered below the level which attains MSY during 1992 to 2018. The ratio of the fishing rate (U/Umsy) were higher than that which attains MSY during 1992 to 2014, but it declined recently. Fishing ratio (U2018/Umsy) was 1.05 in 2018.

Item	Suggested value	Remarks
SBmsy	109 thousand tons	SSB that attains MSY
Umsy	32%	Fishing rate that attains MSY
U2018	33%	Fishing rate in 2018
U2018/ Umsy	1.05	Ratio of the fishing rate in 2018 to MSY



Appendix Figure 14-1. The relationship between past SB/SBmsy and fishing rate U/Umsy (Kobe plot). The fishing rate and SSB is the three year moving average. The calculation is based on ridge VPA.

Appendix 15. Estimation of Korean catch using mixture ratio of blue and chub mackerel

Reported Korean catch in 2018 was 74 thousand tons, it drastically exceeds the maximum catch in the past (Appendix Fig. 15-1). While Japanese catch was slightly larger than catch of previous year Figure 3-1). The ratio of blue mackerel to mackerels in Japanese catch was larger than it of Korea, but Korea exceeds the ratio in 2018(Appendix Fig. 15-2). Fishing condition in 2018 was never observed in the past. It was assumed that the ration of blue mackerel of Korean mackerels catch in 2018 is same as three years average (2015 to 2017). Then abundance was estimated using estimated 2018 catch using the assumption (estimated catch, Appendix Fig. 15-3). Using the estimated catch, F of 2018 (F2018') was 0.82, F at age were estimated as follows: $F_{0,2018'}=0.52$、$F_{1,2018'}=0.62$、$F_{2,2018'}=F_{3+,2018'}=1.07$. Other parameters were estimated as follows: $q_{0'}=0.24$、$q_{1'}=0.23$、$q_{2'}=0.17$、$q_{3'}=0.18$、$q'_{0\text{-}1'}=0.03$、$q'_{2+'}=0.32$、$\sigma_{0'}=0.30$、$\sigma_{1'}=0.42$、$\sigma_{2'}=0.42$、$\sigma_{3'}=0.50$、$\sigma'_{0\text{-}1'}=0.71$、$\sigma'_{2+'}=0.33$. Total blue mackerel catch of Japan and Korea was 63 thousand tons (Appendix 16). Catch number at age estimated using total catch were 110 million at age 0, 50 million at age 1, 20 million at age 2 and 10 million at age 3+ (Appendix Fig. 15-4, Appendix 17). It became relatively high abundance but in the range since 1992.

(1) Variation of abundance and fishing ratio

The results of cohort analysis using Korean estimate catch in 2018 were shown in Appendix Figure 15-5 and Appendix 16. Fishing ratio in 2018 (U2018') estimated with Korean estimated catch was 41% (Appendix Figure 15-5).

The fluctuation of recruitment and SSB estimated with Korean estimated catch were shown in Appendix Figure 15-6. The estimated values of recruitment and SSB (SB2018') with Korean estimated catch were 310 million and 63 thousand tons, respectively.

As sensitivity test of natural mortality (M=0.4) used for cohort analysis, M=0.3 and 0.5 were used for test. The biomass, SSB and recruitment in 2018 increased according increase of M, it affects around 10% of estimated values if M changed 0.1 (Appendix Fig.

15-7).

The estimated Fishery coefficient F (F2018') using Korean estimated catch was 0.82 as middle level during the period used analysis (Appendix Figure 15-8).

Item	Value	Remarks
SB2018	63,000 tons	SSB in 2018
F2018	（age 0, 1, 2, 3+）=（0.52, 0.62, 1.07, 1.07）	
U2018	41%	Fishing ratio in 2018

（2）Yield per recruitment（YPR）, spawning per recruitment（SPR）and current fishing pressure

The estimated %SPR with Korean estimated catch was shown in Appendix Figure 15-9.The relationship between the average fishing pressure under the selectivity of recent five years (2014 to 2018) and %SPR using Korean estimated catch was shown in Appendix Figure 15-10. The estimated current fishing intensity (F2016-2018') was similar to Fmed rather than F30%SPR. The estimated F2018 and the current fishing pressure (F2016-2018') were high than Fmsy under the same condition suggested at the 'Research Institute meeting on Reference points for the East China Sea Stock of blue Mackerel' held at April, 2019.

Item	Value	Remarks
%SPR（F2018'）	17.7%	%SPR in 2018
%SPR（F2016-2018'）	20.1%	%SPR corresponding to current fishing pressure (F2016-F2018)

（3）Stock-recruitment relationship

Appendix Figure 15-11 shows the Stock-recruitment (S-R) relationship estimated using Korean estimated catch.

（4）Stock status, stock trend and level of fishing pressure

A Kobe-plot shows the relationship between SSB and its corresponding fishing

pressure in Fig. 15-12. The estimated SSB is 0.58 times the SBmsy. The trend of SSB is classified “increasing”. The fishing pressure in 2018 was 1.52 times larger than Fmsy.

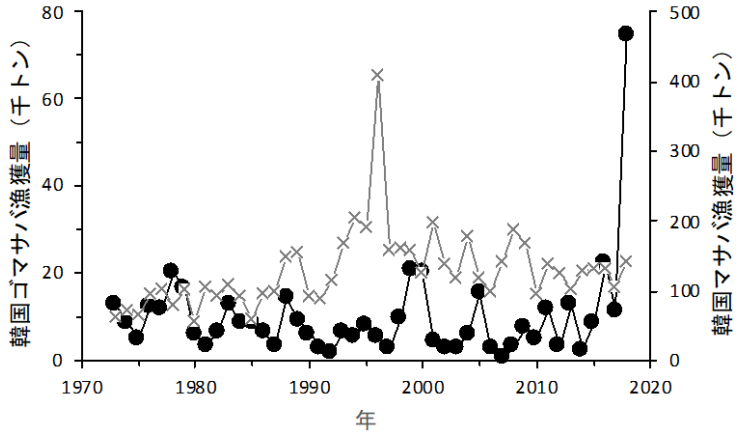
Item	Value	Remarks
SB2018’/ SBmsy	0.58	Ratio between the SSB that gives MSY and the SSB in 2018
F2018’/ Fmsy	1.52	Ratio between the fishing pressure that gives MSY and the fishing pressure in 2018 *

* Ratio between *F* in 2018 and *F* under the current selectivity that gives Fmsy which was converted to %SPR.

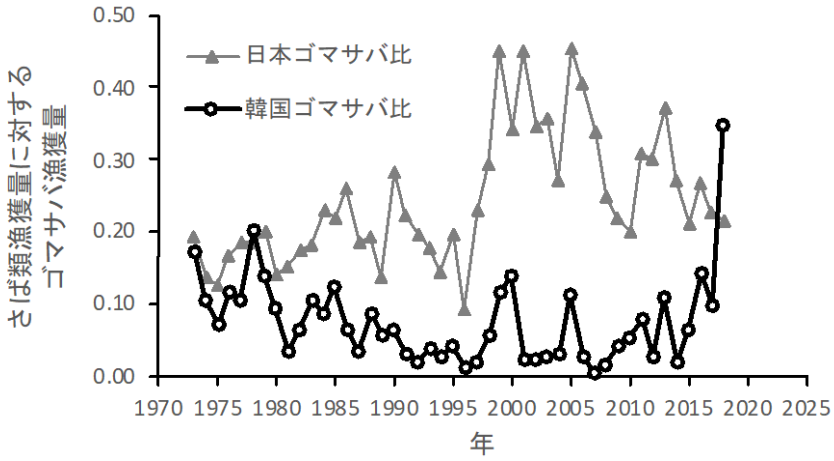
Level of SSB*	warning
Level of *F**	Over fishing
Trends in SSB*	Increasing

*Estimated using Korean estimated catch

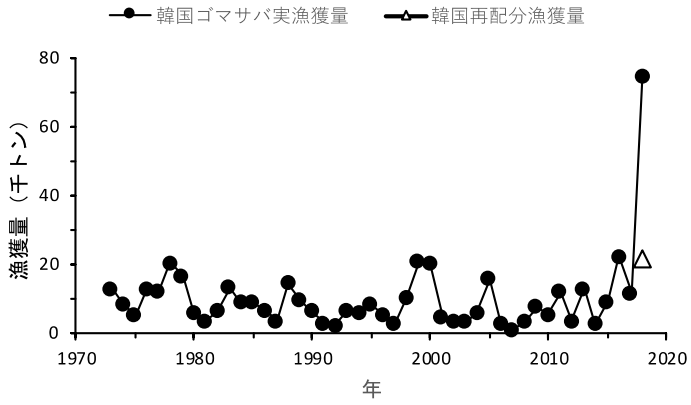
The analysis conducted to estimate effect of drastic increase of Korean blue mackerel catch in 2018, recent abundance, SB and recruitment 30% estimated smaller than the analysis conducted this year, and 40% smaller than the analysis using the penalty of F square (Appendix 9). It is concluded that drastic increase of Korean blue mackerel catch largely affect on the analysis.



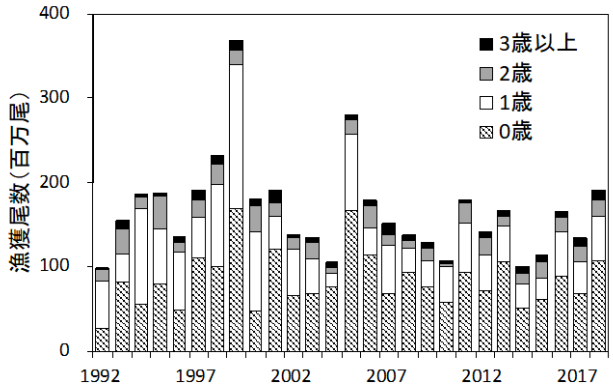
Appendix Figure 15-1. Korean catch of blue and chub mackerels. Black dots indicate blue and × indicate chub mackerels.



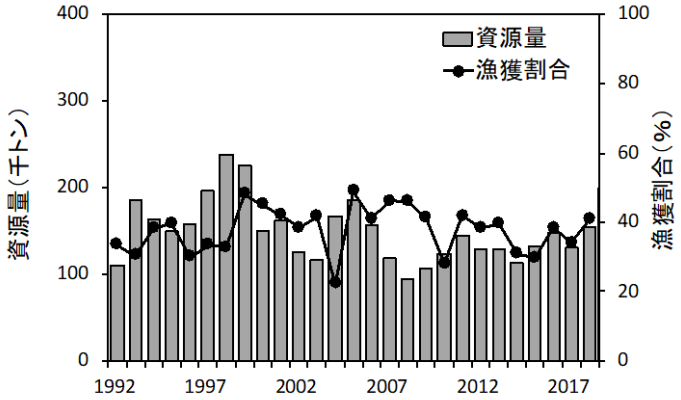
Appendix Figure 15-2. Ratio of blue catch to total mackerels catch in Japan (triangle) and Korea (white circle).



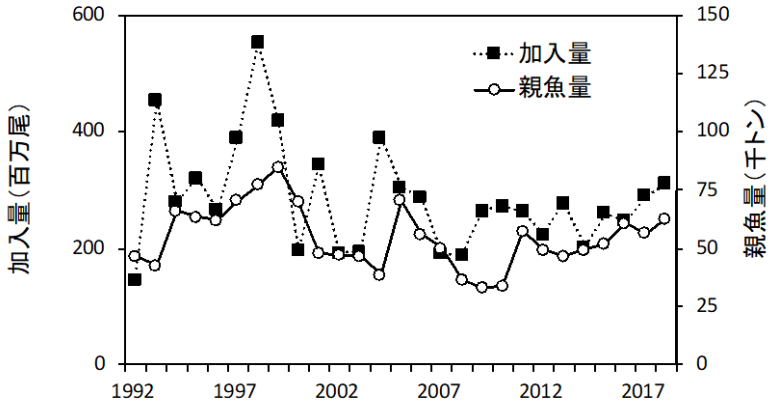
Appendix Figure 15-3. Korean blue mackerel catch (Black circles) by year and estimated blue catch (triangle).



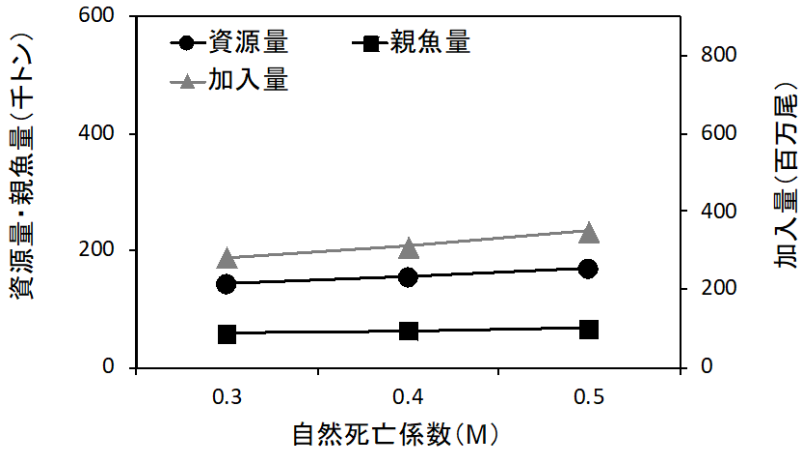
Appendix Figure 15-4. Korean blue mackerel catch at age converted to estimated catch.



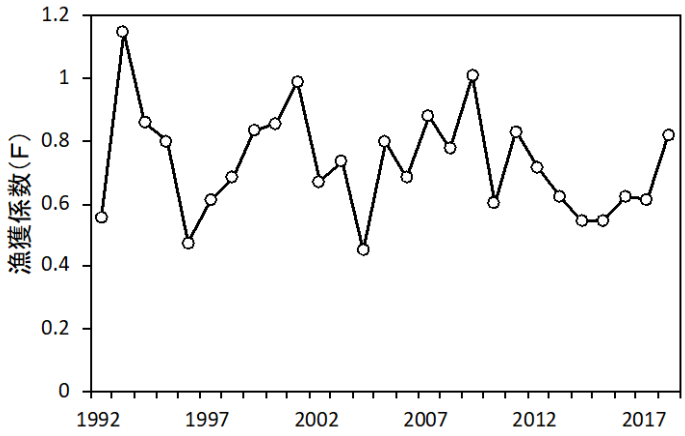
Appendix Figure 15-5. Annual blue mackerel abundance (bar graph) and fishing ratio (black circles) calculated by cohort analysis which converted the Korean catch in 2018 to a calculated value.



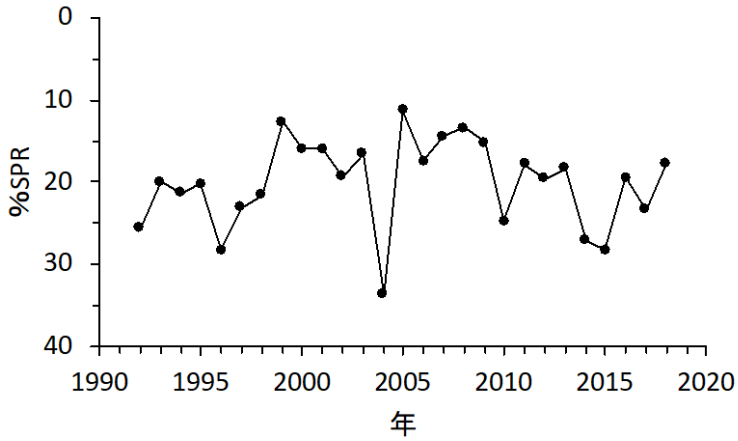
Appendix Figure 15-6. Variation of SB and recruitment estimated with Korean catch including estimated value in 2018. Left axis is recruitment (million fish), right axis is SB (thousand tons), black square is recruitment, and white circle is SB.



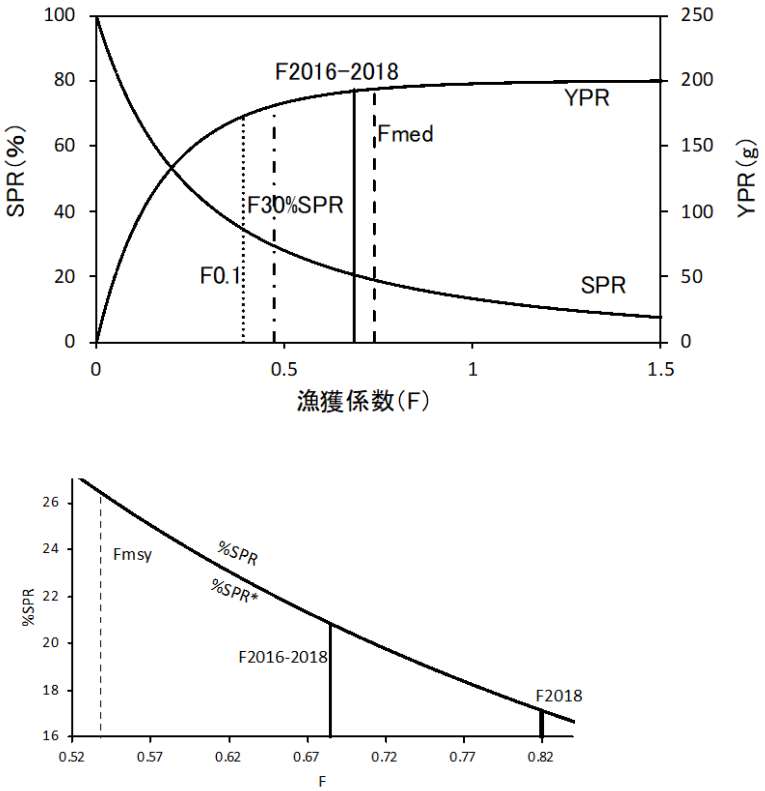
Appendix Figure 15-7. Biomass, SSB and recruitment for 2018 depending on the value of *M*. black circle represents the biomass, square represents SSB and triangle represents the recruitment. Left y-axis is the biomass and SSB (thousand tons), right y-axis is the recruitment (million in numbers). Results of analysis using Korean estimated catch in 2018.



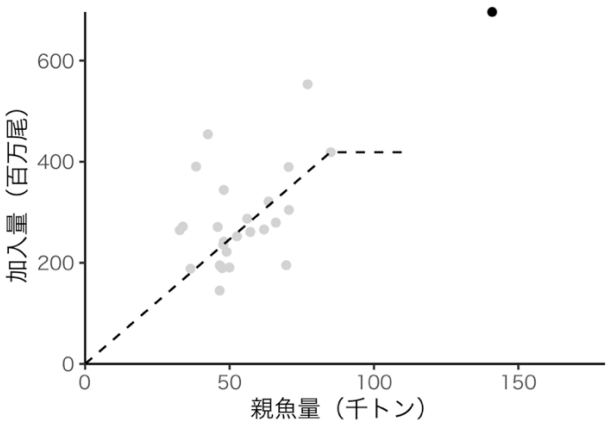
Appendix Figure 15-8. Variation of F using Korean estimated catch in 2018 in the analysis.



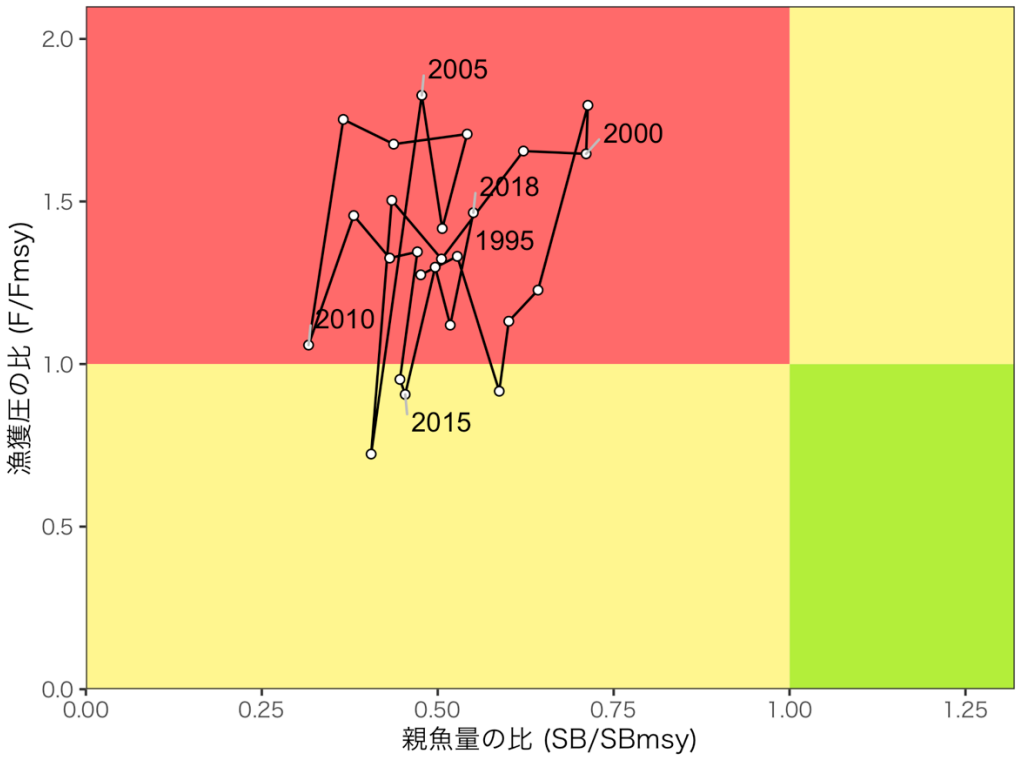
Appendix Figure 15-9. Variation of %SPR using Korean estimated catch in 2018 in the analysis.



Appendix Figure 15-10. The relationship of YPR and %SPR under current F (F2016-2018) including Korean estimated catch in 2018 in the analysis. The dotted line in the bottom figure indicate the relationship of average fishing pressure and %SPR under the condition estimated MSY.



Appendix Figure 15-11. S-R relations estimated with Korean estimated catch in 2018 in the analysis. The break line indicates reproductive relationship suggested at scientific meeting held at April, 2019 mentioned above (Hayashi et al. 2019). Black dot indicates the value of 2018.



Appendix Fig. 15-12. Kobe plots of SB/SBmsy and F/Fmsy estimated with Korean estimated catch in 2018 in the analysis. The values in each year indicate it of single year.

Appendix 16. Estimated catch and results of cohort analysis (1992 to 2018) with Korean estimated catch in 2018 in the analysis. Captions from left; catch (thousand tons), abundance (thousand tons), SB (thousand tons), recruitment (million fish), fishing ratio (%) and RPS (fish/kg). In the second line from left; year, Japan, Korea, total, (thousand tons), (thousand tons), (million fish), (%), (fish/kg)

	漁獲量（千トン）			資源量	親魚量	加入量	漁獲割合	再生産成功率
年	日本	韓国	計	（千トン）	（千トン）	（100万尾）	（%）	（尾／kg）
1992	35	2	37	111	47	145	33	3.112
1993	50	7	57	187	43	454	30	10.687
1994	57	6	62	164	66	279	38	4.232
1995	51	8	60	150	63	321	40	5.059
1996	42	5	48	159	62	266	30	4.294
1997	63	3	66	197	70	390	33	5.531
1998	68	10	78	238	77	553	33	7.182
1999	88	21	109	226	85	419	48	4.925
2000	47	20	67	149	70	195	45	2.804
2001	63	5	68	161	48	344	42	7.169
2002	45	3	48	126	47	192	38	4.085
2003	46	3	49	117	47	195	42	4.178
2004	31	6	37	166	38	390	22	10.161
2005	76	16	91	186	71	305	49	4.320
2006	61	3	64	157	56	287	41	5.122
2007	54	1	55	119	50	191	46	3.817
2008	40	3	43	94	36	188	46	5.163
2009	36	7	44	106	33	265	41	8.083
2010	30	5	35	124	34	273	28	8.044
2011	49	12	61	145	57	263	42	4.576
2012	47	3	50	130	49	224	38	4.535
2013	38	13	51	129	47	278	39	5.941
2014	33	2	35	114	49	203	31	4.118
2015	31	9	40	133	52	260	30	5.006
2016	35	22	57	148	61	247	38	4.070
2017	33	11	44	130	56	289	34	5.138
2018	41	22	63	155	63	312	41	4.987

Appendix 17. Results of cohort analysis using Korean estimated catch in 2018 (1992-2018). Captions in the table are from left year/age, catch in number (million fish), catch weight (thousand tons), and fishing intensity F.

年＼年齢	漁獲尾数（百万尾）				漁獲重量（千トン）				漁獲係数F			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	27	57	12	3	8	21	6	2	0.25	0.77	0.60	0.60
1993	82	34	29	11	24	12	14	8	0.24	0.76	1.80	1.80
1994	56	112	14	4	12	41	7	2	0.28	0.81	1.17	1.17
1995	80	65	39	3	15	24	18	2	0.36	0.78	1.03	1.03
1996	48	69	13	5	13	25	6	4	0.25	0.77	0.44	0.44
1997	110	48	21	12	29	18	11	9	0.41	0.53	0.75	0.75
1998	100	98	23	10	24	36	12	7	0.25	1.09	0.70	0.70
1999	169	170	18	12	42	51	9	8	0.65	1.16	0.76	0.76
2000	48	94	30	10	13	32	14	7	0.35	1.38	0.85	0.85
2001	120	40	16	15	34	14	8	11	0.54	0.71	1.36	1.36
2002	66	55	13	4	20	20	6	3	0.53	0.66	0.75	0.75
2003	67	42	20	5	19	16	10	4	0.53	1.04	0.69	0.69
2004	77	14	7	8	23	5	4	5	0.27	0.26	0.64	0.64
2005	167	90	17	6	46	33	9	4	1.03	0.76	0.70	0.70
2006	114	32	26	7	34	12	14	5	0.64	0.72	0.69	0.69
2007	67	60	12	14	18	21	6	9	0.54	1.16	0.91	0.91
2008	93	29	10	6	23	10	6	5	0.87	0.61	0.81	0.81
2009	75	31	16	6	18	12	9	5	0.42	1.19	1.22	1.22
2010	57	42	5	3	16	14	3	3	0.29	0.56	0.77	0.77
2011	93	58	25	3	22	24	13	2	0.55	0.71	1.04	1.04
2012	71	42	22	6	20	15	11	4	0.47	0.68	0.86	0.86
2013	105	43	12	6	25	15	7	4	0.60	0.79	0.55	0.55
2014	50	30	12	8	12	11	7	6	0.35	0.43	0.70	0.70
2015	61	25	20	7	15	9	11	5	0.33	0.37	0.74	0.74
2016	88	53	17	8	24	19	9	5	0.55	0.70	0.62	0.62
2017	68	38	18	10	13	13	10	7	0.33	0.64	0.74	0.74
2018	106	54	19	12	24	20	11	9	0.52	0.62	1.07	1.07

Appendix 17 (continued). Results of cohort analysis using Korean estimated catch in 2018 (1992-2018). Captions in the table are from left year/age, catch in number (million fish), catch weight (thousand tons), and fishing intensity F.

年＼年齢	平均体重(g)				資源尾数（百万尾）				資源量（千トン）			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1992	296	373	462	692	145	126	32	8	43	47	15	6
1993	287	357	474	703	454	76	39	15	130	27	19	10
1994	219	365	487	659	279	238	24	6	61	87	12	4
1995	188	374	454	687	321	142	71	6	61	53	32	4
1996	270	361	474	641	266	151	43	18	72	54	21	12
1997	262	370	505	731	390	139	47	27	102	52	24	20
1998	238	365	508	667	553	173	55	23	132	63	28	15
1999	247	298	489	655	419	290	39	26	103	86	19	17
2000	280	343	487	700	195	146	61	20	55	50	30	14
2001	285	362	519	729	344	92	25	23	98	33	13	17
2002	299	360	475	690	192	135	30	8	57	49	14	6
2003	284	388	508	721	195	76	47	12	55	29	24	9
2004	295	362	520	693	390	77	18	20	115	28	9	14
2005	274	366	505	710	305	200	40	13	84	73	20	10
2006	296	367	524	685	287	73	62	18	85	27	33	12
2007	276	345	534	672	191	102	24	27	53	35	13	18
2008	243	342	597	754	188	74	21	14	46	25	13	10
2009	240	376	567	749	265	53	27	10	63	20	15	8
2010	272	327	581	755	273	117	11	7	74	38	6	6
2011	237	404	533	712	263	137	45	6	62	55	24	4
2012	280	347	519	688	224	102	45	12	63	35	23	8
2013	239	345	557	668	278	93	35	16	66	32	19	11
2014	233	359	560	701	203	102	28	20	47	37	16	14
2015	247	352	546	680	260	96	45	16	64	34	24	11
2016	270	356	539	709	247	125	44	19	67	44	24	14
2017	198	354	540	738	289	95	42	23	57	34	22	17
2018	222	363	571	772	312	139	34	21	69	51	19	16

Appendix 18. The values of References, Stock status and Fishing intensity estimated using Korean estimated catch in 2018.

The estimated value of Biological reference points and results of cohort model.

Items	Values	Remarks
SBtarget	109,000 tons	SBmsy
SBlimit	51,000 tons	SB 0.6msy
SBban	8,000 tons	SB 0.1msy
Umsy	31%	Catch ratio at MSY
MSY	76,000 tons	
β	NA	The constant multiplied to Fishing intensity to maintain stock certain level.
SB2018’	63,000 tons	SSB at 2018
U2018’	41%	Fishing ratio at 2018
F2018’/Fmsy	1.52	

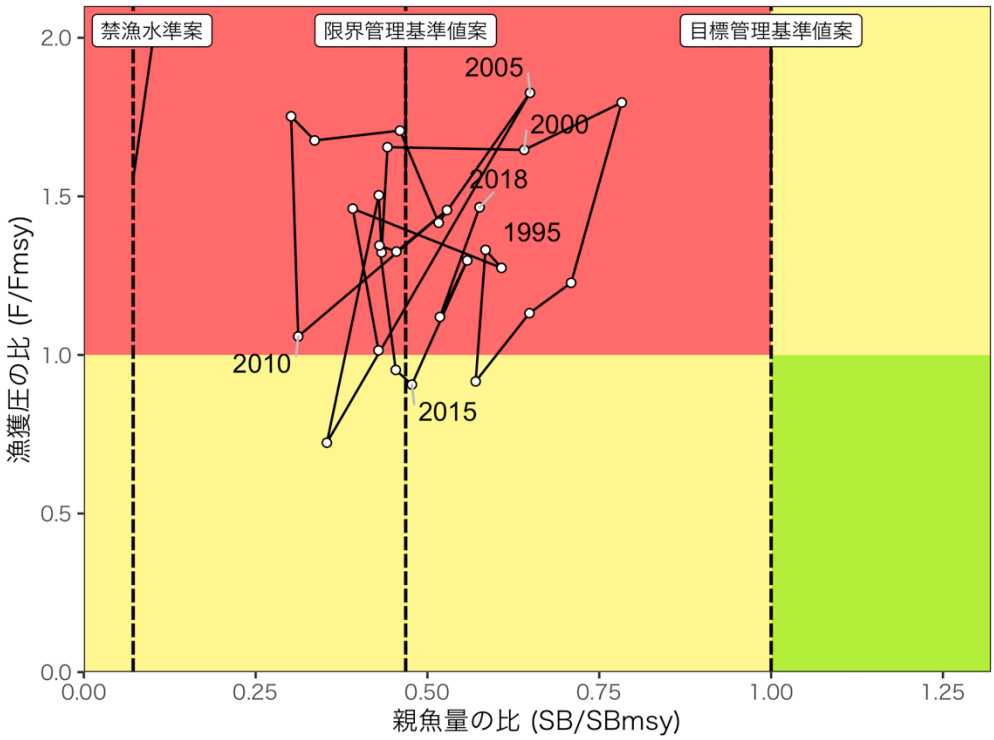
* Estimated SB in 2018 (SB2018’: 63,000 tons) using Korean estimated catch in 2018 is above SBlimit and SBban but low from SBtarget. F2018’ is above Fmsy (F2018’/Fmsy=1.52), and U2018’ is also above Umsy.

*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 18-1. Fishing intensity using Korean estimated catch in 2018 is over the level of Fmsy. The SB2018’ is lower than SBtarget.

*The status of SSB and Fishing pressure are considered using Kobe plots.

*SB2018’ was below SBtarget, then considered as “warning”. F2018’ is over Fmsy, then considered as “over fishing”. The status of SSB is considered “increasing” from the transition of past five years (2014-2018).

Status of SSB	warning
Status of fishing pressure	Over fishing
Status of SSB transition	increasing



Appendix Fig. 18-1. Kobe plots of SB/SBmsy and F/Fmsy estimated using Korean estimated catch in 2018. The values in each year indicate it of single year.

Appendix 19. Estimations of catch under HCR based on the assessment results using Korean estimated catch in 2018.

The 2020 catch was predicted using the results using Korean estimated catch in 2018 described in Appendix 15 and parameters shown Appendix Table 19-1. The methods of prediction was described in Appendix 7.

Appendix Table 19-1. The parameters used for future projection.

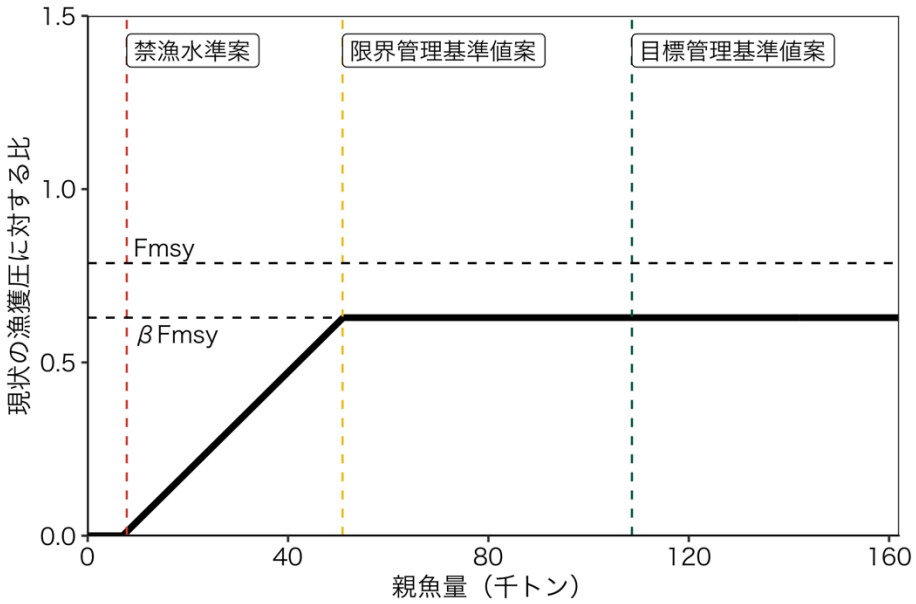
Age	selectivity	Fmsy	F2016-2018	Average weight(g)	M	Maturity rate
0	0.54	0.36	0.46	238	0.4	0.00
1	0.71	0.47	0.60	354	0.4	0.60
2	1.00	0.66	0.84	542	0.4	0.85
3+	1.00	0.66	0.84	709	0.4	1.00

In the projection results using Korean estimated catch in 2018, average catch following HCR in 2020 is 39,000 tons at β=0.8 and 46,000 tons at β=1.0. Predicted SSBs in 2020 is 60,000 tons in average exceeding SBlimit in any iterated calculations.

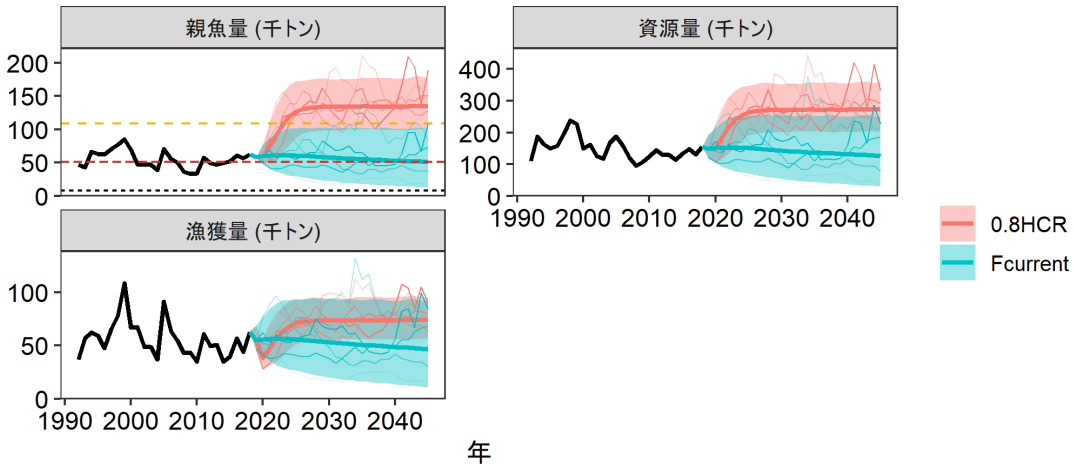
SSB in 2020（average of prediction）：60,000 tons			
Items	catch in 2020 (thousand tons)	（F/F2016-2018’）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β =<0.9	=<43	=<0.70	=<28
Other suggested catch (using differentβin HCR)			
β =1.0	46	0.79	31
β =0.8	38	0.63	26
β =0.6	30	0.47	20
β =0.4	21	0.31	14
β =0.2	11	0.16	7
β =0.0	0	0.00	0
F2016-2018’	55	1	38

The mid and long-term projection results using ridge VPA with following HCR (Appendix Fig. 19-1) were shown in Appendix Fig. 19-2 and Appendix Table 19-2 and 19-3. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 107,000 tons in average using β=1.0 (80% confidence limit ranged 80,000-136,000 tons), and 134,000 tons in average using β=0.8 (80% confidence limit ranged 104,000-166,000 tons). The probability of SB above SBtarget is more than 50% usingβ<= 0.9. The probabilities above SBlimit and SBban are above 100% in all cases.

Uncertainty considered: Recruitment					
Items	predicted SSB in 2030 (thousand tons)	80% confidence limits (thousand tons)	Probability of SSB above References below in 2030 (%)		
			SBtarget	SBlimit	SBban
Fishing pressure scientifically suggested					
β=<0.9	>=120	>=93->=151	>=67	100	100
Other suggested catch (using differentβin HCR)					
β=1.0	107	80 - 136	45	100	100
β=0.8	134	104 - 166	86	100	100
β=0.6	167	132 - 205	99	100	100
β=0.4	214	173 - 259	100	100	100
β=0.2	287	235 - 343	100	100	100
β=0.0	407	340 - 478	100	100	100
F2016-2018’	58	27 - 92	3	56	100



Appendix Figure 19-1. HCR for blue mackerel East china sea stock. Current fishing pressure is F2019 (F2016-2018) estimated using Korean estimated catch in 2018.



Appendix Figure 19-2. Comparison of the projection results between HCR adapted case including Korean estimated catch in 2018. The bold line indicates average values of 5,000 iterations, shadow zone shown 80% confidence limits, solid lines indicate five trials.

Explanation of figure: Top left is projection of SSB (thousand tons), top right is stock biomass (thousand tons), and bottom left is catch projection (thousand tons).

Appendix Table 19-2. Probabilities of (a) SSB over SBtarget and (b) SSB over SBlimit. Catch in 2019 is assumed catch under F2016-2018. The calculation is including Korean estimated catch in 2018.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	0	0	2	7	15	24	32	36	39	42	43	45	47	46
0.9	0	0	3	13	28	42	53	59	64	66	67	67	69	69
0.8	0	0	4	21	44	63	74	82	84	86	86	86	86	87
0.7	0	0	6	31	63	82	90	94	96	96	96	96	96	96
0.6	0	0	8	45	79	93	98	99	99	99	99	99	99	100
0.5	0	0	11	59	90	98	100	100	100	100	100	100	100	100
0.4	0	0	16	72	96	100	100	100	100	100	100	100	100	100
0.3	0	0	20	83	99	100	100	100	100	100	100	100	100	100
0.2	0	0	27	91	100	100	100	100	100	100	100	100	100	100
0.1	0	0	34	96	100	100	100	100	100	100	100	100	100	100
0.0	0	0	42	98	100	100	100	100	100	100	100	100	100	100

(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	100	84	88	92	95	97	98	99	99	99	99	100	100	100
0.9	100	84	93	96	98	99	100	100	100	100	100	100	100	100
0.8	100	84	96	99	100	100	100	100	100	100	100	100	100	100
0.7	100	84	98	99	100	100	100	100	100	100	100	100	100	100
0.6	100	84	99	100	100	100	100	100	100	100	100	100	100	100
0.5	100	84	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	84	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	84	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	84	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	84	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	84	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 19-3. Projection results of (a) average SSB and (b) average catch. Catch in 2019 is assumed catch under F2016-2018. The calculation is including Korean estimated catch in 2018.

(a)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	58	59	67	76	85	92	97	101	103	105	106	107	109	109
0.9	58	59	71	83	95	105	111	115	117	119	120	120	121	121
0.8	58	59	74	90	106	118	126	130	132	133	134	134	134	134
0.7	58	59	78	99	118	133	142	146	148	149	149	149	149	149
0.6	58	59	81	107	132	149	159	164	165	166	167	167	167	167
0.5	58	59	85	117	146	167	178	184	186	188	188	188	189	189
0.4	58	59	89	127	162	187	201	208	211	213	214	214	215	215
0.3	58	59	94	138	180	210	227	237	242	245	246	247	248	248
0.2	58	59	98	150	199	236	259	272	279	283	286	287	289	290
0.1	58	59	103	163	221	267	296	314	325	332	336	339	344	344
0.0	58	59	108	176	246	302	341	367	383	395	402	407	417	418

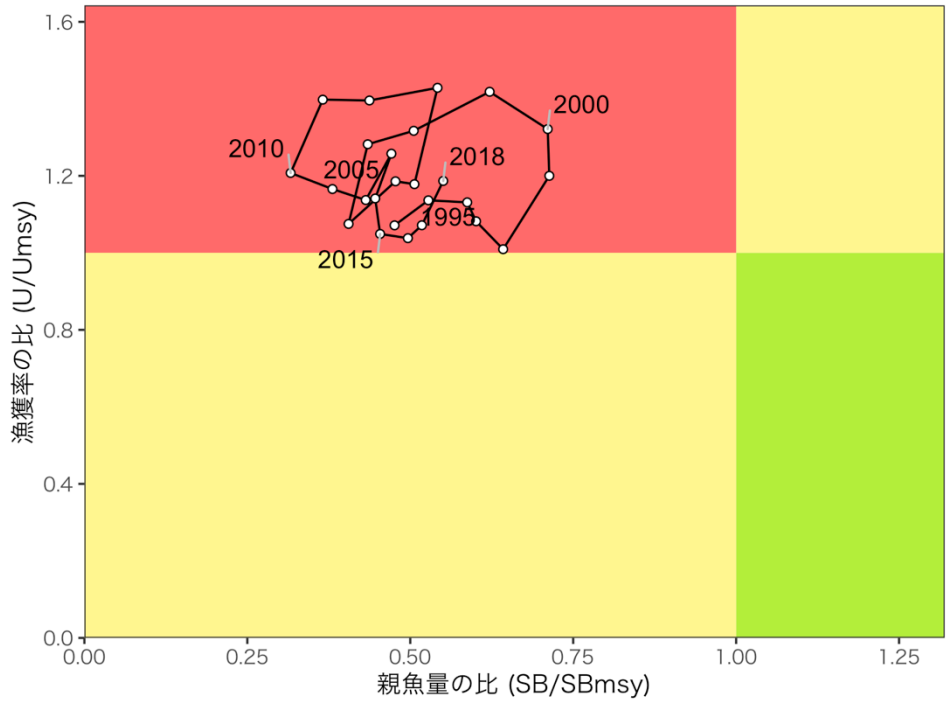
(b)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	56	46	52	58	63	67	70	72	74	74	75	75	77	77
0.9	56	42	50	57	64	68	71	73	74	75	75	75	76	76
0.8	56	38	47	56	63	68	71	72	73	73	74	74	74	74
0.7	56	34	44	53	61	66	69	70	71	71	71	71	71	71
0.6	56	30	40	50	58	63	65	67	67	67	67	67	68	68
0.5	56	25	35	45	53	58	61	62	63	63	63	63	63	63
0.4	56	21	30	39	47	52	54	56	56	57	57	57	57	57
0.3	56	16	24	32	39	43	46	47	48	49	49	49	49	49
0.2	56	11	17	23	29	33	35	36	37	37	38	38	38	38
0.1	56	6	9	13	16	18	20	21	21	22	22	22	22	22
0.0	56	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 20. Kobe plot based on fishing proportion estimated with Korean estimated catch in 2018

Below shows a Kobe plot based on the SSB described in Appendix Table 15 and its corresponding fishing rate (U') in Appendix figure 20-1. The SSB is considered below the level which attains MSY during 1992 to 2018. The ratio of the fishing rate (U'/Umsy) were lower than that which attains MSY during the period. Fishing ratio (U'/Umsy) was higher than at many years.

Item	Suggested value	Remarks
SBmsy	109 thousand tons	SSB that attains MSY
Umsy	32%	Fishing rate that attains MSY
U2018'	41%	Fishing rate in 2018
U2018'/ Umsy	1.28	Ratio of the fishing rate in 2018 to MSY



Appendix Figure 20-1. The relationship between past SB/SBmsy and fishing rate U/Umsy (Kobe plot). The fishing rate and SSB is the three year moving average. The calculation is including Korean estimated catch in 2018.