Stock assessment of Chub Mackerel Tsushima stock (2019)

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Summary

The stock biomass was estimated by cohort model considering abundance index. The biomass stayed around one million tons during 1973 to 1996 except a few years, but it decreased around 500,000 tons after 2000. However, after 2004, it increased around 600,000 tons supported by strong recruitments, and it became 650,000 tons in 2018. The SSB in 2018 was estimated 240,000 tons.

For this stock, we propose the Hockey Stick (HS) model of reproduction curve, and SBmsy was estimated as 310,000 tons. Following the reference, SSB in 2018 is below MSY. Recently fishing pressure on the stock stay at similar level and is above Fmsy. The trend of SSB is considered “increasing” by the transition of past five years (2014-2018). The stock is caught by South Korea and China, and it is considered that Chinese fishing operations by more than hundreds of boats may have strong effect on the stock, especially. However, it is not including in the analysis.

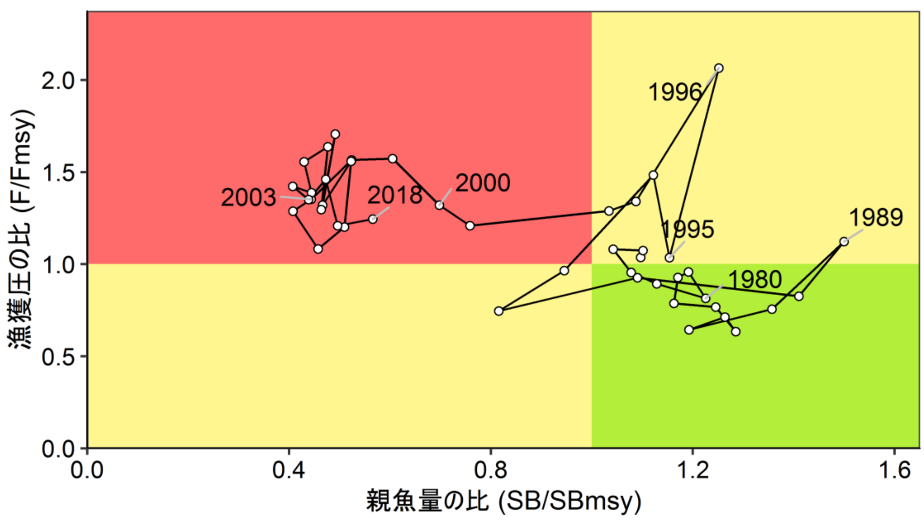
Summary table of reference relating to MSY

Reference	Values
Regarding MSY	
SBmsy	310,000 tons
Fmsy	0.33, 1.07, 0.69, 0.69=0yr, 1yr, 2yr, 3yr and above
%SPR(Fmsy)	20%
SSB and Fishing pressure at 2018	
SB2018	238,000 tons
F2018	0.30, 1.34, 1.01, 1.01=0yr, 1yr, 2yr, 3yr and above
%SPR(F2018)	16.7%
%SPR(F2016-F2018)	15.6%
Ratio to MSY	
SB2018/SBmsy	0.77
F2018/Fmsy	1.24

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



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 (Hokkaido-Miyazaki [17] prefectures, JAFIC, Northern Purse Seine Fisheries Association) Landing in number at Kyusyu major ports (National Fisheries institute) Logbook report of purse seine fisheries (Fishery agency) Length composition by month (NRIFS, Hokkaido-Miyazaki [17] prefectures, JAFIC); 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 Sakai port (Tottori prefecture) Neuston-net larval survey (Feb-Jun) Acoustic biomass survey (Aug-Sep) Bottom trawl survey (East china sea) (May-Jun) NORPAC net larval survey (all the year round)
Natural mortality	Assuming M = 0.4 per year (Limbong et al., 1988)

Birth day was assumed at 1st of January.

2. Ecology of the species

1) Distribution and migration

Chub mackerel Tsushima stock distributes from the southern part of East china sea, northern part of the Japan sea to the Yellow sea Bo Hai (Yamada et al. 2007, Fig. 2-1). It migrates to north for feeding during spring and summer, and down south for spawning and wintering at fall to winter. There are some schools stay at the northern part of Japan sea for wintering (Limbong et al. 1991, Yasuda et al. 2014).

2) Age and growth

Although growth differ by area and year, it grows to 25-28cm in fork length one year after hatch, 29-32cm at two years, 33-35cm at three years, 36cm at four years, and 37cm at five years (Shiraishi et al. 2008, Fig. 2-2). The longevity is around six years.

3) Reproduction

Main spawning grounds are found in the waters of Chinese coast in the East china sea, coastal waters of Korean peninsula, coastal waters of Kyusyu and Sanin districts of Japan (Yamada et al. 2007, Sassa and Tsukamoto 2010). The spawning season is early in the southern region (Jan-Apr) and late in the northern region (May-Jun) (Ouchi and Hamazaki 1979, Yukami et al. 2009). The age of maturity range one to two year old, and rates of maturity are 60% for one year old, 85% for two, and 100% for three and above (Shiraichi unpublished data, Fig. 2-3).

4) Prey-predator relationships

It is considered that the adults feed mainly planktonic crustaceans including krill, opossum shrimps and copepods, and small teleost like anchovy (Yamada et al. 2007 and Moriwaki and Miyabe 2012). Larvae may be eaten by ichthyophagous fish.

3. Fisheries on the species

1) Outline of fisheries

Chub mackerel of Tsushima stock are mainly caught by various size of purse seine fisheries. Main fishing grounds are the East china sea, coastal water of South Korea, northwest coast of Kyusyu, and western water of the Japan sea, but after 2016 catches from northwestern Kyusyu and western waters of the Japan sea fishing grounds increased. After 2016, fishing effort for the stock decreased at the lowest level due to the shift of fishing operations to the Pacific fishing grounds.

2) Historical catch and size compositions

In the official statistics, chub mackerel catch has been reported with blue mackerel as mackerels. In this report, chub mackerel catches were estimated from official statistics (See Appendix 2-1-notes 1, Table 3-1). The chub mackerel catch of Tsushima stock stayed around 300,000 tons at the late 1970s, and it decreased around 150,000 tons in the early 1990s (Fig. 3-1, Table 3-2). Thereafter it increased up to 410,000 tons in 1996, and stayed at the low level of around 80,000-120,000 tons after 2000. The catch of 2013 was 60,000, the lowest after 1973, then it increased to 150,000 tons in 2018. Korean catch in 2018 was 140,000 tons, and it increased from 100,000 tons of previous year (See Appendix 2-1 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 chub and blue mackerel.

The Japanese catch are mainly consisted with 0- and 1-year old fish (Fig. 3-2, Appendix 4). The ratio of zero-year fish increased and two and above decreased after 1990s. It of one-year fish was high in 2018. The age composition of Korean and Chinese catches are unknown.

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 at the lowest (4,710 nets) in 2018 due to the shift of fishing operations in the Pacific. The effective efforts also revealed decreasing trend since 1998 (Fig.4-1).

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, 2-1). In the analysis, using catch by age for Japanese and Korean catch data, F was estimated for fitting the trends between the abundance index by age of Japanese purse seine fishery and estimated abundance by age. The Chinese catch data was not used due to the mixture of chub and blue mackerels catches.

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). The larval survey was conducted all over the year. However, all research results were used as qualitative information, because the accuracy of estimates was not enough. 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 decreased from the early 1970s to the late 1980s, but were high at middle of 1990s and around 2009 (Fig. 4-1). Recently, it decreased from 2011 to 2013, then it stayed high level after 2015. The effective efforts stayed at the same level until 1994, it gradually decreased thereafter (Fig. 4-1).

The density index is the average value of catch per net at 30 minutes of grid where chub mackerel caught in 2018. The effective effort was calculated by the catch in each grid in 2018 divided by density index.

The abundance index by age (0 - 3+) calculated by 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 2-1-note3). The abundance indices of 2018 are high at age 1 and low at age 2 comparing with past 14 years. The indices of age 0 and 3 are average level in 2018. From 2018, new abundance for age 0 and 1 calculated with size data of landing statistics at Sakai port were used for analysis (Kuroda et al. 2019, Fig. 4-2, Appendix 2-1-note3). The abundance indices in 2018 were slightly low at age 0 and very high at age 1 comparing with past 14 years. It is considered that each index well indicates the status of stock at age from fitting of indices and model projection in cohort model.

(3) Trends in biomass and fishing pressure

The stock biomass estimated by cohort model were around 1,000,000 tons during 1973 to 1989 and relatively stable (Fig. 4-3, Table 3-2). It rapidly decreased to 640,000 tons in 1990, then increased again, and it became 1,370,000 tons in 1996. Thereafter, it again rapidly down to 500,000 tons after 2000. Recently it became the lowest of 370,000 tons in 2013, then after 2014 it increased around 600,000 tons and 650,000 tons in 2018. Fishing ratio rapidly increased in 1996, then stayed in high level of 40 to 50%, and decreased at 2014 and 2017. The ratio of 2018 was 45% (Fig. 4-3, Table 3-2).

The recruitment (abundance of age 0) indicated high number of 3,300 million individuals in 1995, then decreased around 1,000 to 1,500 million after 2000s (Fig.4-4, Table 3-2). Recently it decreased 800 million in 2013, then became high level of 1,500 million in 2014 and 2,000 million in 2017. The number of 2018 was 1,300 million.

The SSB (abundance of adult) increased up to 470,000 tons during 1993 to 1996, it rapidly decreased in 1997, it down to 120,000 tons in 2003 (Fig. 4-4, Table 3-2). Thereafter it fluctuated ranging 110,000 to 190,000 tons until 2014, it increased from 110,000 at 2014 to 170,000 tons in 2015 by high recruitment of 2014. Then it decreased, but it increased again up to 240,000 tons in 2018.

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 increased according increase of M, it affect around 10% od estimated values if M changed 0.1 (Fig.4-5).

Fishery coefficient F (average of F at each age) decreased during 1973 to 1984, then gradually increased until 1995, then rapidly increased in 1996 (Fig. 4-6). After 2009, F indicated gradually decreased, it stayed around same level past five years. F of age 0 tended to increase after 1990, but it decreased after 2009 (Fig. 4-6). Although the effective effort of purse seine decreased, but F did not decrease. It may be due to the Korean catch.

Item	Value	Remarks
SB2018	238,000 tons	SSB in 2018
F2018	（age 0, 1, 2, 3+）=（0.30, 1.34, 1.01, 1.01）	
U2018	45%	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 4-7 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 was the lowest in 1996, then it tended to increase.

The relation between average fishing pressure in recent five years selectivity (2014 to 2018) and %SPR are shown in Fig. 4-8. The current fishing pressure (F2016-F2018) is higher than Fmed, F30%SPR and F0.1 as biological reference point. Figure 4-8 also indicates the relation between average fishing pressure at MSY and %SPR. The current F (F2016-2018) and F2018 are higher than Fmsy.

Item	Value	Remarks
%SPR（F2018）	16.7%	%SPR in 2018
%SPR（F2016-2018）	15.6%	%SPR corresponding to current fishing pressure (F2016-F2018)

（5）Stock-recruitment relationship

Figure 4-9 shows the Stock-recruitment (S-R) relationship between SSB (in biomass) and recruitment (in numbers). According to the ‘Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel’ mentioned above, it is suggested to use the Hockey-Stick functional response type for the S-R relationship of this stock (Yasuda *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（Kuroda et al. 2019）, 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 in the Table below.

S-R relationship	Optimization method	Auto-correlation	*a*	*b*	S.D.
Hockey-Stick (HS) type	Least square	No	0.00755	237,192	0.31

Here, parameter *a* is the steepness (numbers / g) of the HS S-R curve 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 1973, which was suggested at the 'Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel' suggested above (Yasuda *et al.* 2019).

Item	Suggested value	Remarks
SBmsy	310,000 tons	SSB that will obtain MSY
Fmsy	（age 0, 1,2,3+）=（0.33, 1.07, 0.69, 0.69）	
%SPR（Fmsy）	20%	%SPR corresponding to Fmsy
MSY	323 thousand tons	MSY

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

Figure 4-10 shows a Kobe-plot which shows the relationship between SSB and its corresponding fishing pressure. F/Fmsy shows the yearly ratio between F and F under the current selectivity that gives Fmsy which was converted to %SPR. The fishing pressure of this stock in recent years has been above the level of MSY. The fishing pressure in 2018 was 1.24 times larger than Fmsy. Moreover, the SSB is considered to be lower than the SBmsy since 1997 (Table 3-2), and the SSB in 2018 is 0.77 times the SBmsy. The values used in Fig. 4-10 are calculated by three years moving average.

Item	Value	Remarks
SB2018/ SBmsy	0.77	Ratio between the SSB that gives MSY and the SSB in 2018
F2018/ Fmsy	1.24	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 were around 1 million tons during 1973 to 1996, and it decreased around 500,000 tons since 2000. After 2014, it increased around 600,000 tons due to the high recruitment, and it became 650,000 tons in 2018. The SSB (abundance of adult) increased 470,000 tons during 1993 to 1996, it rapidly decreased in 1997, and it down to 120,000 tons in 2003. Thereafter the SSB fluctuated between 110,000 and 190,000 tons until 2014. It increased to 240,000 tons in 2018.

The SSB in 2018 is considered as "warning" level due to the lower level of SBmsy, but its trend is considered "increasing" because of the trends of past five years (2014-2018). Fishing pressure in recent years stays in same level, and it is above Fmsy level.

6. Other matters

So far, management of the stock was conducted by effort control including limitation of licensed vessels for purse seine. It is also conducted the management based on TAC of "mackerels" including blue mackerel since 1997. In addition, the stock rebuilding plan for Jack mackerel (including chub mackerel and pacific sardine) in western Japan sea and western water of Kyusyu was conducted during 2009 to 2011. The plan aimed to protect small juvenile, it required shift of fishing ground for large purse seine and reducing fishing and landing days for small purse seine when they have the concentration of small fish catch. Those trials are continued under new guideline of fishery stock management after 2012.

It is considered that the cause of large uncertainty of assessment is the lack of the information of Chinese vessels. Other cause of uncertainty for future projections are less accuracy of Chinese and Korean predicted catches, and the difficulty of Japanese catch projection caused by the TAC including both chub and blue mackerels. Those causes may afect on stock-recruitment relationship, biological reference points and probability of achievement management goals. For more effective stock management, it needs study for mechanism of recruitment fluctuation and migrating pattern, and conducting international cooperation of monitoring fisheries (Kuroda et al. 2019).

7. References

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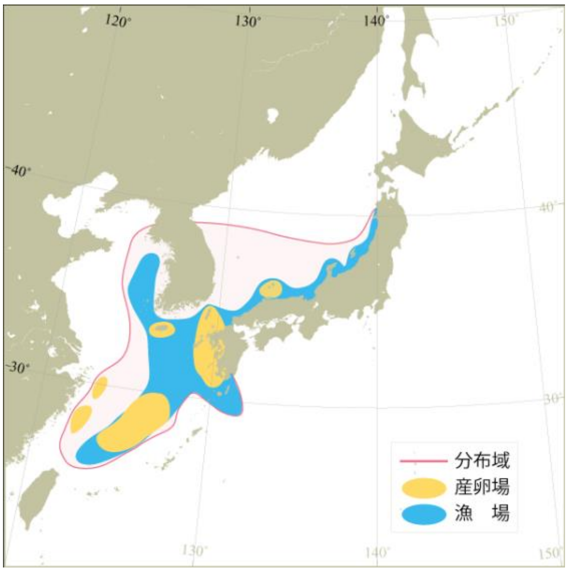


Figure 2-1. Distribution and migration of chub mackerel Tsushima stock. Yellow indicate spawning grounds, blue indicates fishing grounds.

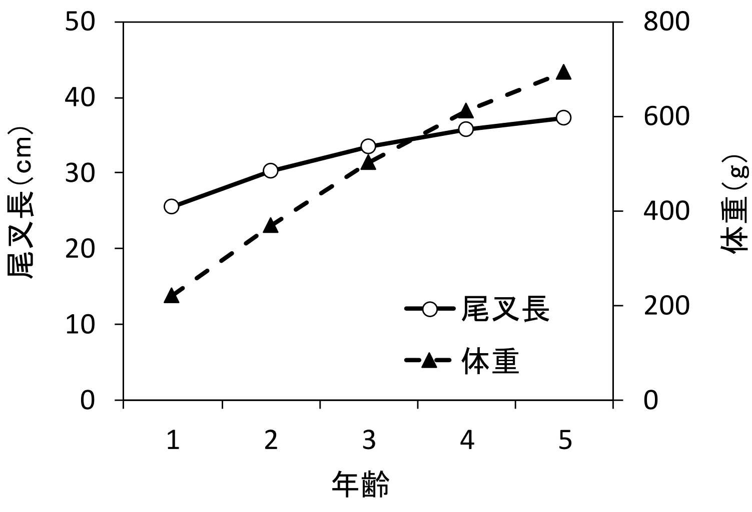


Fig. 2-2. Age and growth. Bold line indicates length (FL) by age, dotted line indicates weight by age.

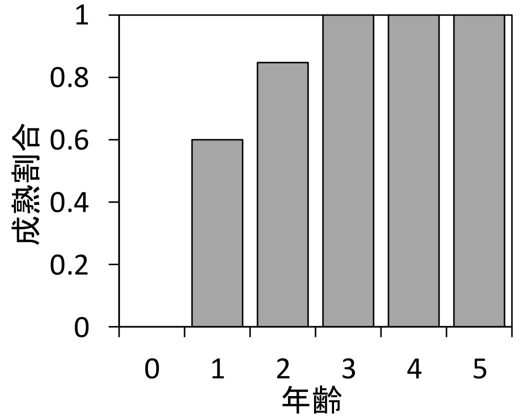


Figure 2-3. Maturity rate by age.

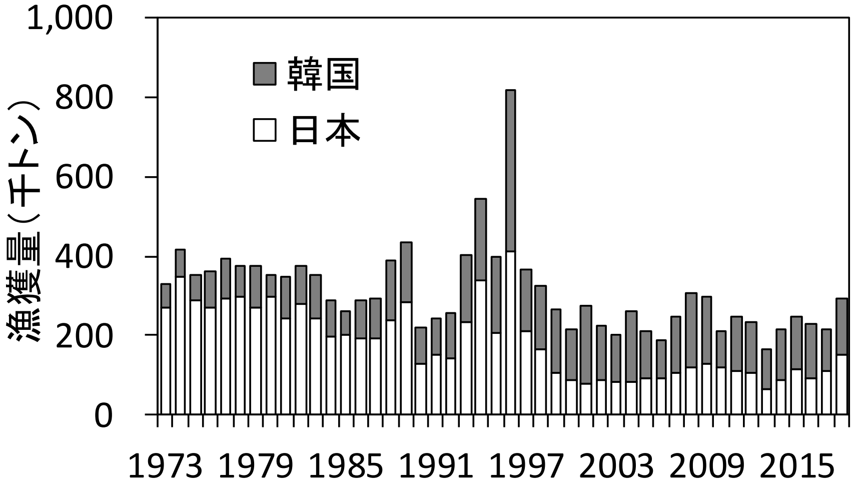


Figure 3-1. Annual catches of chub mackerel by fisheries. (Grey: Korea, white: Japan).

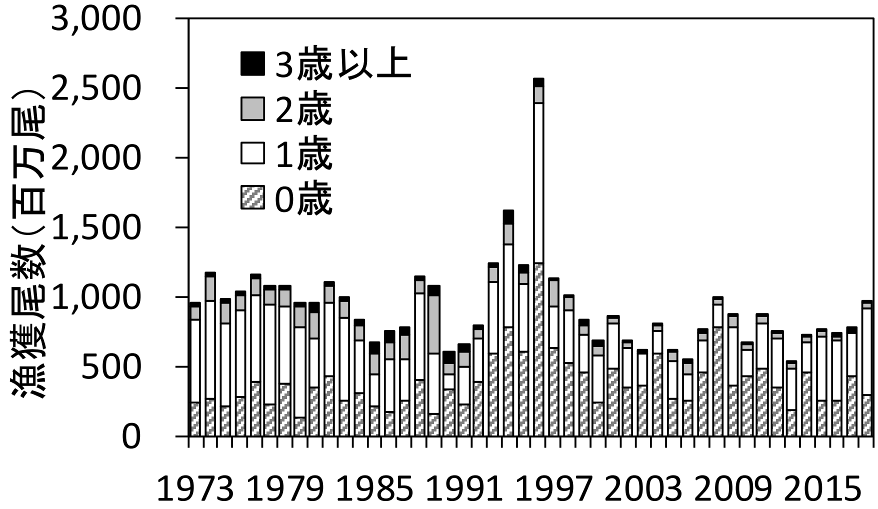


Figure 3-2. Annual age composition in catch.

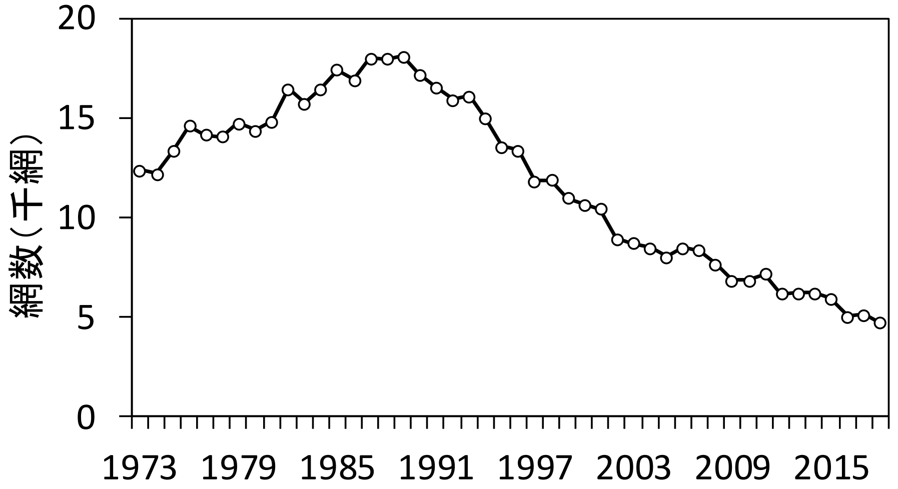


Fig. 3-3. Annual number of purse seine nets (thousands) operating in the East china sea and Japan sea.

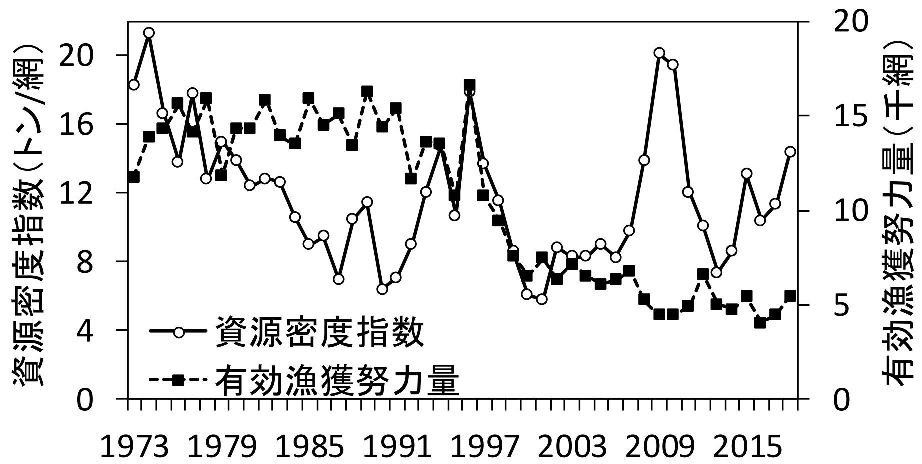
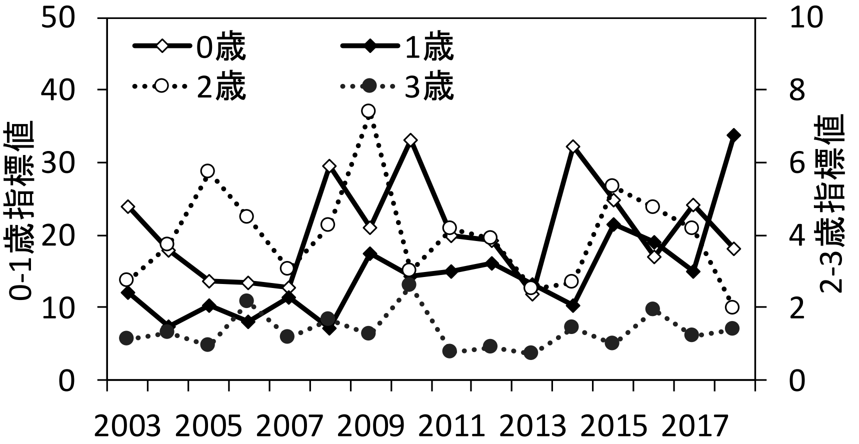


Figure 4-1. Density indices by year (bold line) and annual effective effort (dotted line) on chub mackerel by purse seine fishery. The left axis is density (ton/net), and the right axis is effective efforts (thousand nets).



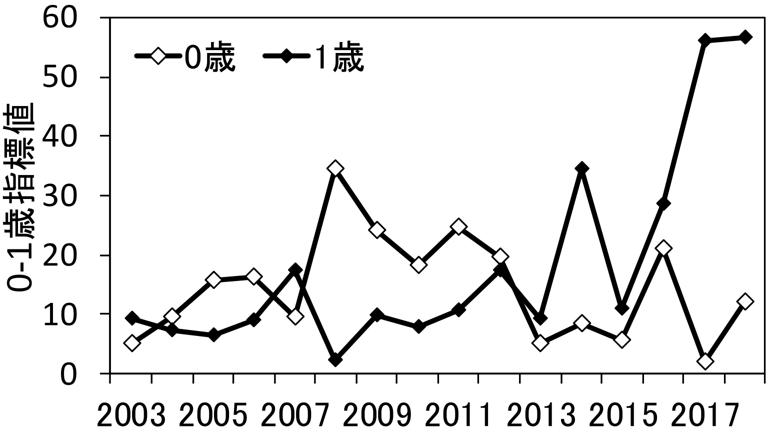


Fig. 4-2. Abundance indices by age calculated by catch by size of purse seine operating in the East china sea and Japan sea (above) and abundance indices for age 0 and 1 fish calculated by catch by size of purse seine landed at Sakai port (below).

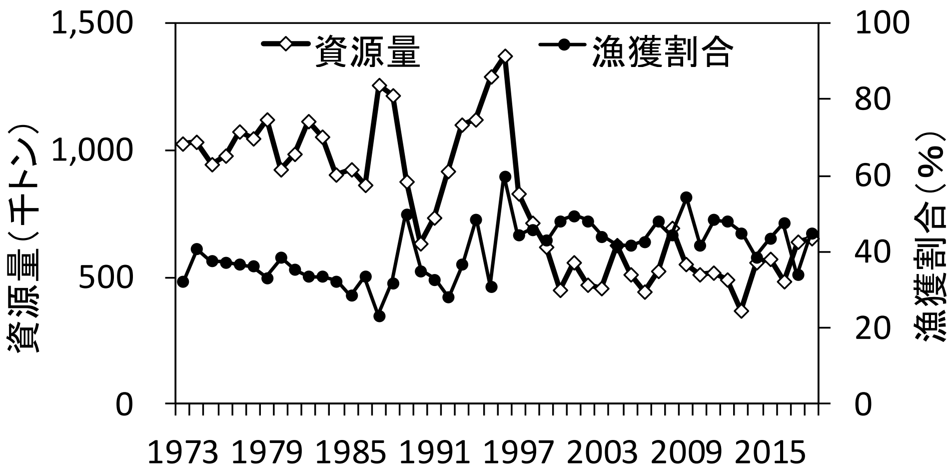


Fig. 4-3. The estimated abundances (white square) and fishing ratios (black dots) by year. The left axis is abundance (thousand tons), the right axis is fishing ratio (%).

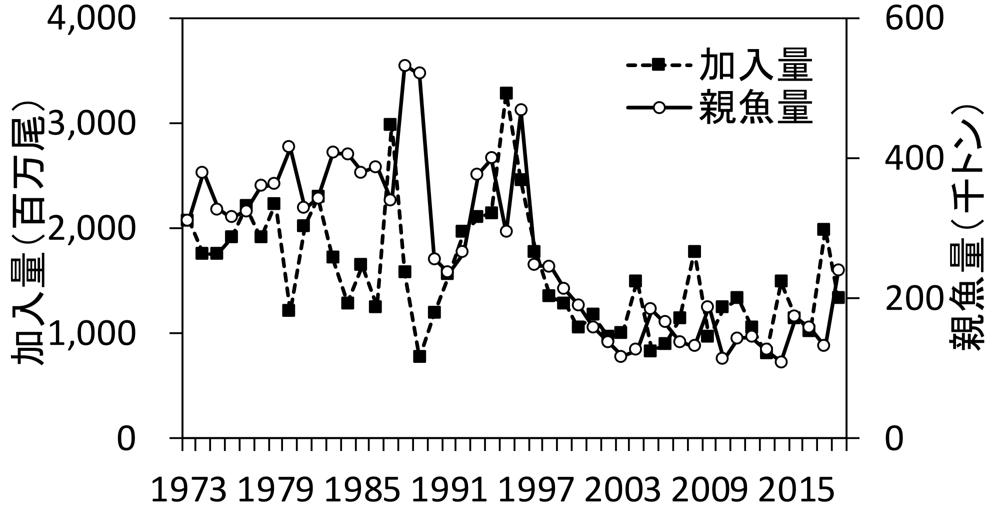


Fig. 4-4. Estimated SSB (bold line) and recruitments (dotted line) by year. The left axis is recruitment (million fish), and the right axis is SSB (thousand tons).

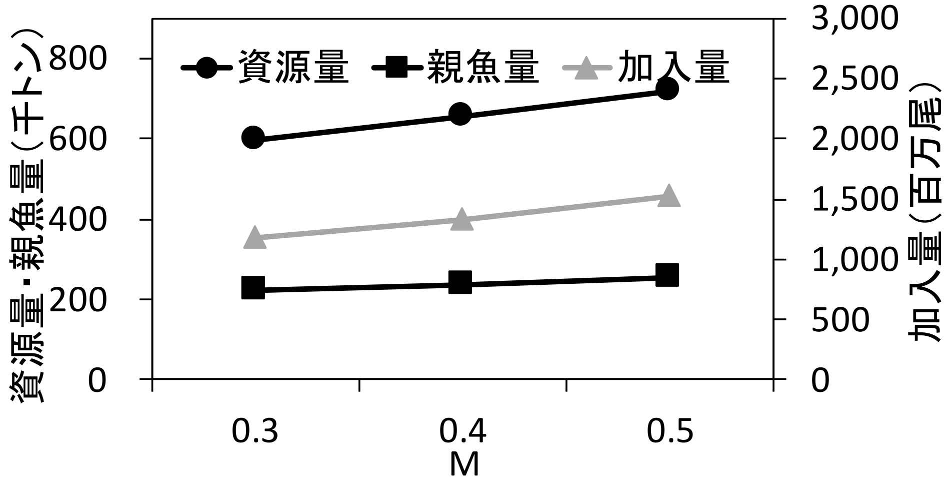


Fig. 4-5. Fluctuations of stock abundance (circle), SSB (square) and recruitment (triangle) according to changes of natural mortality M.

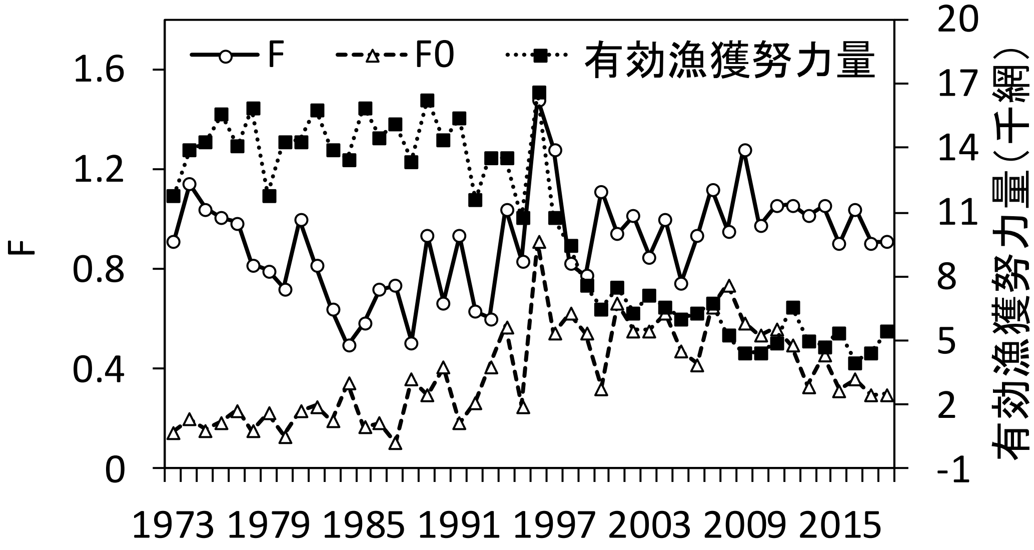


Fig. 4-6. The average of F at age (white circle), F of age 0 (triangle), and effective efforts (square) by year. The left axis indicates F, and the right indicates effective effort (thousand nets).

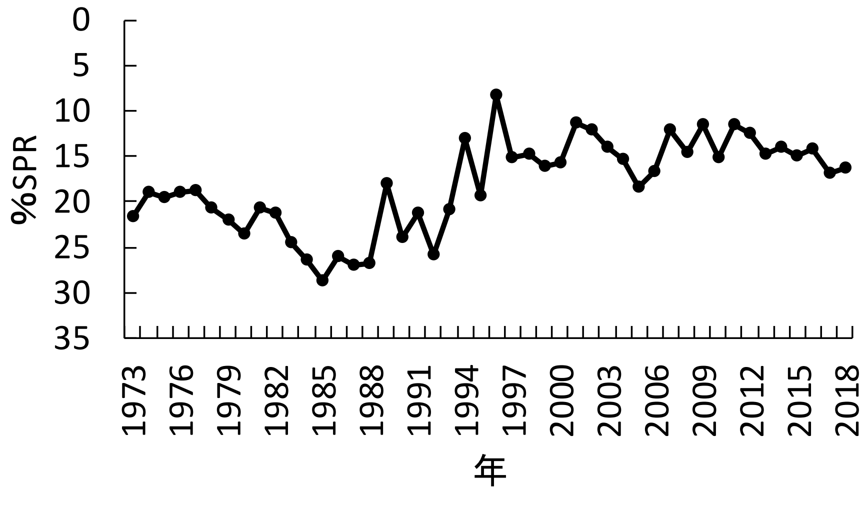


Fig. 4-7. Fluctuations in %SPR by years. %SPR shows the ratio of SSB when no fishing to the SSB when there is fishing, and %SPR becomes low with high *F* and vice versa.

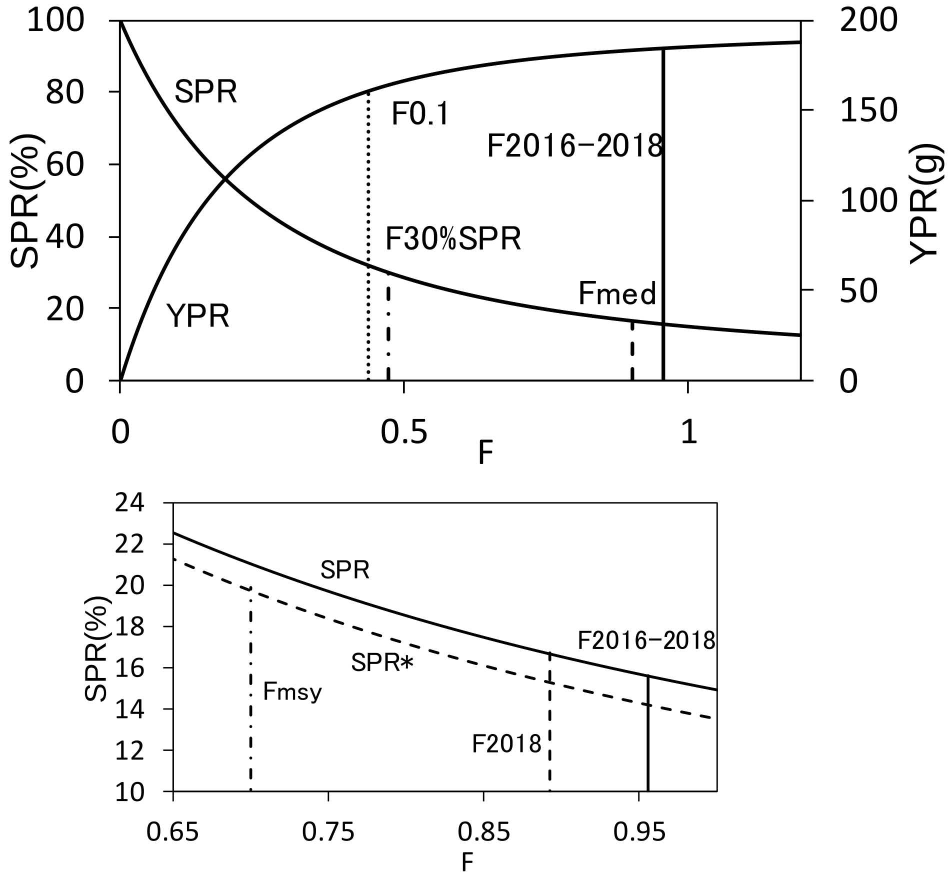


Fig. 4-8. Relationship between the fishing mortality (F, simple average) and %SPR, YPR (above). Relationship between F and %SPR (below).

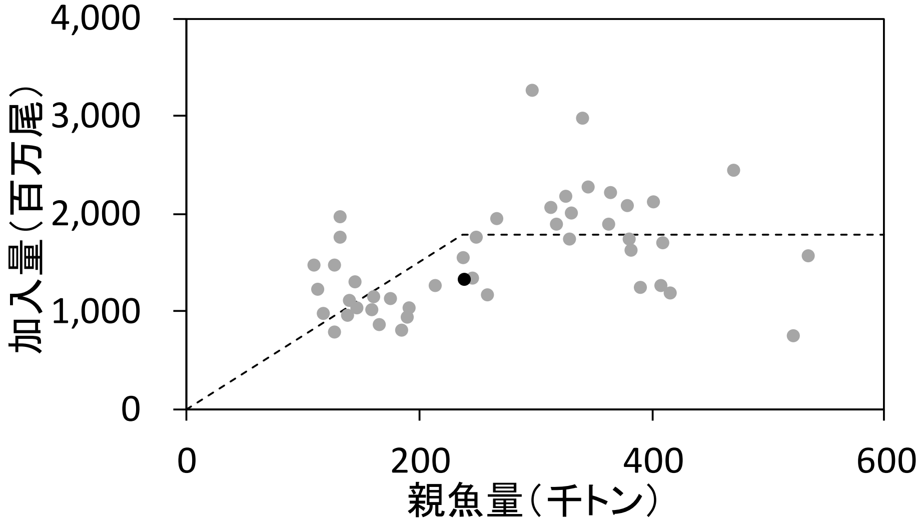


Fig. 4-9. Relationship between SSB (thousand tons) and recruitment (million fish). The dotted line shows the S-R relationship suggested at the 'Research Institute meeting on Reference points' held in April 2019 (Yasuda et al. 2019). Black dot indicates value of 2018.

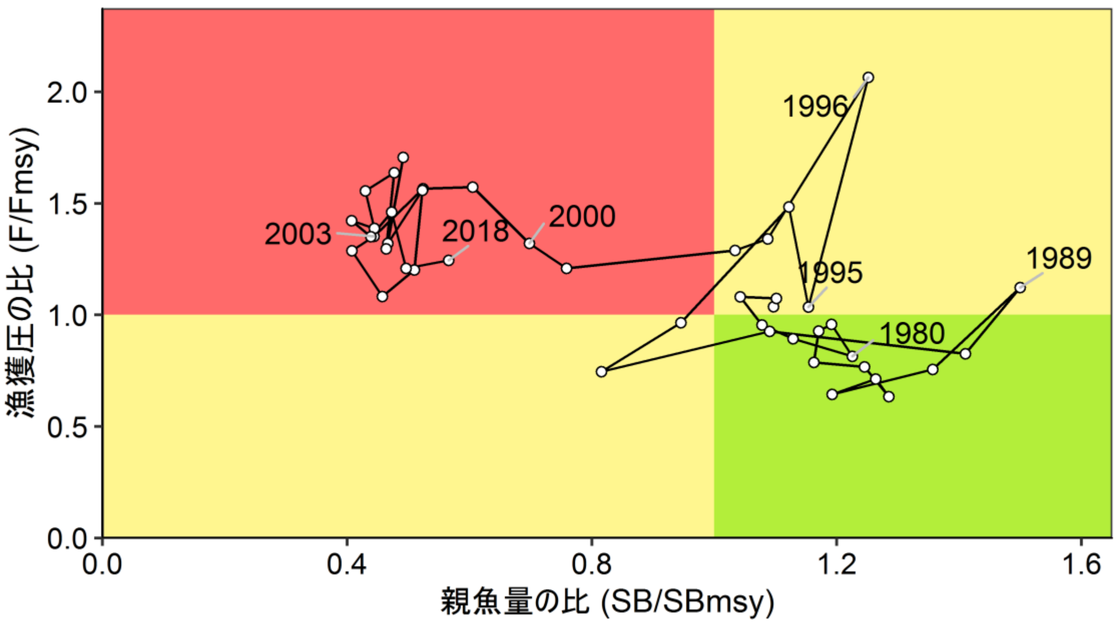


Fig. 4-10. Relationship between the SSB/SBmsy and F/Fmsy (Kobe plot). The *F* and SSB is the three-year moving average.

Table 3-1. Annual chub mackerel catch (tons) by purse seine and by prefecture. The captions in the table below are from the left: Fishing 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

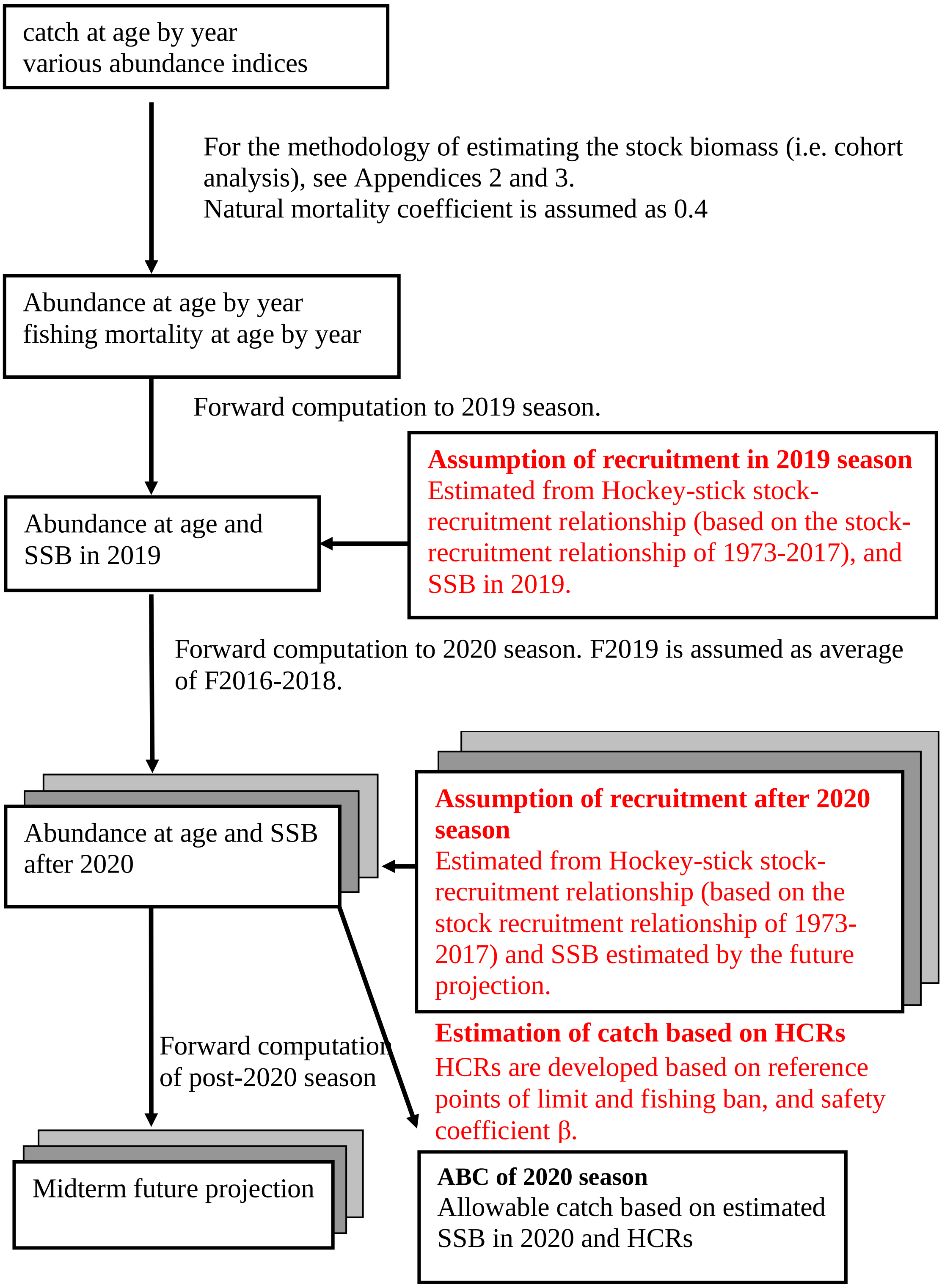
Table 3-1 (continued). Annual chub mackerel catch (tons) by purse seine and by prefecture. The captions in the table below are from the left: Fishing year, catch by Hyogo, Kyoto, Fukui, Ichikawa, Toyama, Niigata, Yamagata, Akita and Total, respectively.

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 chub mackerel was estimated by cohort analysis using catch at age by year calculated from catch (Notes 1-2). 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 (Limbong et al. 1988).

Age	0	1	2	3+
Fork length（cm）	24.9	28.5	32.6	36.2
weight（g）	213	323	486	673
Maturity ratio（%）	0	60	85	100

Catch at age and average weight (January to December) during 1973 to 2018 was estimated catch by size of purse seine operating in the East china sea and Japan sea, form landing by size of major fishing ports of Kyusyu, and length composition in coastal fishery (Notes 2).

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 most recent F for age 0, 1, 2 were tuned by fitting trends of each age between the trends of abundance indices at age (0 to 3+) of purse seine and abundance indices of middle size purse seine landing at Sakai port (age 0 to 1, notes 3). Tuning period was determined as from 2003 to 2018 considering that fishery operation and fishery efficiency are similar to present. For the fitting, negative likelihood was defined as below (Hashimoto et al. 2018).

$$-\ln L = \sum_{f}\sum_{a}\sum_{y} \frac{\left[\ln I_{f,a,y} - \left(b_{f,a}\ln B_{a,y} + \ln q_{f,a}\right)\right]^2}{2{\sigma_{f,a}}^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma_{f,a}}\right) \quad (4)$$

Here, $I_{f,a,y}$ is CPUE of fishery f (1: large purse seine, 2: middle size purse seine), age a and year y, $B_{a,y}$ is abundance at age a, and year y, $q_{f,a}$、$b_{f,a}$、$\sigma_{f,a}$ are parameters (estimated with terminal F). The abundance at age by year are estimated from number at age by year multiplied by $w_{a,y}$: average weight of catch.

$$B_{a,y} = N_{a,y} w_{a,y} \quad (5)$$

Furthermore, $I_{f,a,y}$ and $B_{a,y}$ were assumed having an exponential relations shown below.

$$I_{f,a,y} = q_{f,a} B_{a,y}^{b_{f,a}} \quad (6)$$

However, $b_{f,a}$ is fixed as 1 to any indices. As results of estimating F by minimizing equation 4, it were estimated as follows: $F_{0,2018}=0.30$、$F_{1,2018}=1.34$、$F_{2,2018}=F_{3+,2018}=1.01$. Other parameters were estimated as follows: $q_{1,0}$=0.065、$q_{1,1}$=0.084、$q_{1,2}$=0.102、$q_{1,3}$=0.082、$q_{2,0}$=0.038、$q_{2,1}$=0.082、$\sigma_{1,0}$=0.236、$\sigma_{1,1}$=0.257、$\sigma_{1,2}$=0.306、$\sigma_{1,3}$=0.328、$\sigma_{2,0}$=0.810、$\sigma_{2,1}$=0.760.

The uncertainty of estimated F was diagnosed by profile likelihood. The 80% confidence intervals of F at ages were F_0 [0.21, 0.30]、F_1 [1.21, 2.23]、$F_{2,3+}$ [1.00, 1.50].

The abundance indices at age (tons/net)

year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Large PS										
Age 0	24.0	17.92	13.61	13.39	12.69	29.67	21.03	33.17	19.90	19.25
1	12.2	7.37	10.31	8.01	11.45	7.26	17.57	14.43	15.09	16.13
2	2.72	3.73	5.73	4.46	3.07	4.26	7.38	3.02	4.17	3.89
3+	1.11	1.31	0.96	2.16	1.18	1.67	1.26	2.61	0.77	0.92
Middele PS										
0	4.97	9.58	15.77	16.32	9.59	34.46	24.18	18.18	24.64	19.76
1	9.20	7.21	6.35	8.87	17.50	2.38	9.69	7.98	10.68	17.29

year	2013	2014	2015	2016	2017	2018
Large PS						
Age 0	11.95	32.18	24.98	16.95	24.28	18.15
1	13.23	10.31	21.46	19.14	15.03	33.93
2	2.51	2.70	5.35	4.77	4.16	1.96
3+	0.74	1.43	0.98	1.94	1.21	1.39
Middele PS						
0	4.98	8.52	5.49	20.95	1.85	11.93
1	9.32	34.55	10.95	28.73	56.19	56.57

2. Future projection

Projection was made using abundance estimated by cohort analysis and HCR. MSYtarget is described in Appendix 6, HCR and projection results are in Appendix 7 and the method of projection is described in Appendix 8.

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 chub mackerel catch from the Kagoshima to Akita prefecture except large purse seine catch were added. Those catch were calculated by the mackerel catch multiplied with the ration of chub mackerel by prefecture (Kagoshima 20%, Kumamoto and Nagasaki 80%, Saga and Fukuoka 90%, Yamaguchi to Fukui 95%, and north of Ishikawa 100%). From 2017, chub mackerel ration of Kagoshima was determined based on the landing by chub and blue mackerel of middle purse seine landing at the major ports (Makurazaki and Akune).

Notes 2. The catch number at age by year was estimated as below. There is difference between before 1991 and after 1992. The large purse seine catches at age in 1992 to 2017 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 (20,626 fish in 2018) and catch by month. Different length range at age by month were used between south of Fukui and north of Ishikawa considering different growth by area. Age composition of Korean catch was assumed same as large purse seine catch landed at major ports in Kyusyu. The ratio of chub mackerel in Korean catch before 2007 was assumed same as Japanese large purse seine catch. After 2008, Korea reported chub and blue mackerel catch separately, then Korean chub mackerel catch data was used. However, in the data of 2009 the ration of blue mackerel was extremely high and less reliable, then same method used for 2007 was used. Chinese catch was not included. Age composition of Japanese other fisheries was assumed same as it of whole catch.

Before 1991, large purse seine catch by size in 1973 to 2007 was converted into each age, such ratio were adapted to the catch of 1992 to 2007, age composition was corrected by average values of 1992 to 2007. 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+.

Average weight at age of catch were calculated with catch number at age by month and catch weight.

Notes 3. The abundance indices at age of large purse seine operating in the East china sea and Japan sea were estimated as follows. For the fishing operation targeting chub mackerel from January to May and from September to December, abundance indices were calculated as catch by size (Notes 2) per net (CPUE). From the assessment of 2017, the fishing data form north and central Japan sea was used with East china sea and south of Japan sea to estimate indices from wider area (Kurota et al. 2019). The catch data which over 10% of chub mackerel catch per total catch were extracted from the logbook data by day and vessels and CPUE at age by day and vessels were calculated. The 10% threshold was used for excluding obvious mixed catch with blue mackerel and extract chub mackerel catch data as much as possible. Then average CPUE at age was calculated as abundance indices at age.

The landing of mini size chub mackerel per vessels at Sakai port were used as abundance indices for age 0 and 1. The catch of ripe fishing season during October to December was assumed for age 0, and the landing of next January to March as age 1. The abundance indices by year is calculated average of indices at landing days.

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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 km2, 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
Chub mackerel	26,100	14,513	4,951	2,715	3,645	1,062	9,363	213
Year	2008	2009	2010	2011	2012	2013	2014	2015
Chub mackerel	22,479	515	12,553	57,162	29,869	257	3,351	3,630
Year	2016	2017	2018	2019				
Chub mackerel	4,701	2,692	23,733	2,279				

(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).

(4) The annual total eggs spawn (trillion eggs) estimated by egg and larvae survey conducted in the East china sea and Japan sea from January to June are shown below by the area. Although chub and blue mackerels are treated as mackerels, the eggs collected in the Japan sea are considered of chub mackerel. After 2015, amount of eggs spawn tends to be high level, and it of 2018 is also high.

Year	2006	2007	2008	2009	2010	2011	2012	2013
East china sea	30.7	32.6	12.1	9.7	10.4	7.6	8.3	5.1
Northwest Kyusyu	0.5	4.3	0.6	0.7	0.1	3.6	2.6	2.3
Japan sea	1.8	7.6	1.1	7.2	1.0	2.3	8.4	2.6
Year	2014	2015	2016	2017	2018			
East china sea	4.1	6.1	11.6	20.6	25.4			
Northwest Kyusyu	1.2	3.1	3.3	7.8	2.7			
Japan sea	2.7	24.4	30.0	14.9	55.6			

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 1973-2018).

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

	漁獲尾数（百万尾）				漁獲重量（千トン）			
年＼年齢	0	1	2	3+	0	1	2	3+
1973	240	598	97	19	64	208	46	12
1974	267	706	179	26	71	245	86	17
1975	211	590	161	26	56	205	77	17
1976	275	626	112	31	73	217	54	20
1977	389	624	116	27	103	217	55	17
1978	222	720	113	22	59	250	54	14
1979	376	552	119	39	100	192	57	25
1980	124	660	146	34	33	229	70	22
1981	352	350	184	69	94	122	88	45
1982	424	539	110	34	113	187	53	22
1983	249	594	130	27	66	206	63	17
1984	313	379	109	37	83	132	52	24
1985	212	230	153	83	56	80	73	54
1986	177	369	123	86	47	128	59	56
1987	252	296	185	51	67	103	89	33
1988	399	631	84	35	106	219	40	23
1989	162	433	409	73	43	151	196	47
1990	332	109	79	91	88	38	38	59
1991	219	282	104	55	58	98	50	35
1992	385	317	64	23	102	110	31	15
1993	595	509	117	18	158	177	56	12
1994	786	587	158	86	209	204	76	55
1995	611	477	87	47	162	166	42	30
1996	1,246	1,154	122	47	331	401	59	30
1997	626	305	187	20	169	103	84	12
1998	527	379	96	13	140	133	46	8
1999	452	276	71	30	114	97	35	19
2000	241	333	68	48	42	111	33	29
2001	476	336	37	15	132	116	17	11
2002	348	284	40	16	96	99	19	11
2003	356	230	23	14	104	79	11	9
2004	584	164	45	15	172	59	20	10
2005	262	280	58	8	75	103	29	5
2006	255	188	82	25	63	66	44	17
2007	454	231	53	24	131	78	25	16
2008	787	152	49	13	223	53	24	9
2009	356	419	92	13	102	145	44	7
2010	432	193	35	17	121	64	16	10
2011	480	334	48	10	109	112	22	7
2012	346	355	37	14	88	118	17	9
2013	190	297	37	12	44	98	17	8
2014	457	217	38	13	121	68	17	9
2015	258	460	39	6	69	155	19	4
2016	259	425	35	16	62	141	16	10
2017	425	308	27	15	95	100	13	9
2018	289	627	44	11	61	203	21	7

Appendix 4 (continued). Details of cohort analysis results (Fishing season 1973-2018).

Captions of table are Fishery coefficient F and average weight (g) in the top line. In the second line from left, Year, Age 0 to 3+, %SPR and Age 0 to 3+.

	漁獲係数F				%SPR	平均体重(g)			
年＼年齢	0	1	2	3+		0	1	2	3+
1973	0.15	1.03	1.23	1.23	21.68	266	348	479	645
1974	0.20	1.17	1.60	1.60	18.87	266	348	479	645
1975	0.16	1.27	1.37	1.37	19.49	266	348	479	645
1976	0.19	1.28	1.28	1.28	18.94	266	348	479	645
1977	0.24	1.17	1.27	1.27	18.79	266	348	479	645
1978	0.15	1.28	0.92	0.92	20.73	266	348	479	645
1979	0.23	0.90	1.03	1.03	21.97	266	348	479	645
1980	0.13	1.05	0.86	0.86	23.45	266	348	479	645
1981	0.23	0.88	1.44	1.44	20.66	266	348	479	645
1982	0.25	0.90	1.06	1.06	21.33	266	348	479	645
1983	0.19	0.88	0.75	0.75	24.57	266	348	479	645
1984	0.35	0.64	0.50	0.50	26.46	266	348	479	645
1985	0.17	0.60	0.78	0.78	28.78	266	348	479	645
1986	0.19	0.64	1.03	1.03	25.95	266	348	479	645
1987	0.11	0.70	1.07	1.07	26.94	266	348	479	645
1988	0.36	0.54	0.57	0.57	26.70	266	348	479	645
1989	0.30	1.17	1.14	1.14	18.05	266	348	479	645
1990	0.41	0.42	0.92	0.92	24.00	266	348	479	645
1991	0.19	0.99	1.29	1.29	21.17	266	348	479	645
1992	0.27	0.57	0.85	0.85	25.91	266	348	479	645
1993	0.41	0.91	0.55	0.55	20.82	266	348	479	645
1994	0.57	1.32	1.14	1.14	12.96	266	348	479	645
1995	0.25	1.16	0.96	0.96	19.40	266	348	479	645
1996	0.91	1.51	1.75	1.75	8.31	266	348	479	645
1997	0.55	0.79	1.90	1.90	15.20	270	338	447	615
1998	0.63	1.04	0.82	0.82	14.74	266	351	477	631
1999	0.54	1.10	0.73	0.73	16.04	252	352	488	624
2000	0.32	1.47	1.33	1.33	15.70	173	334	481	613
2001	0.66	1.46	0.83	0.83	11.36	278	345	474	699
2002	0.56	1.68	0.92	0.92	12.11	276	348	481	653
2003	0.56	1.26	0.80	0.80	14.06	291	343	456	655
2004	0.62	0.71	1.33	1.33	15.27	295	360	455	654
2005	0.47	0.95	0.79	0.79	18.34	286	368	505	638
2006	0.42	1.01	1.16	1.16	16.65	247	349	530	672
2007	0.65	1.18	1.33	1.33	12.14	288	336	474	646
2008	0.74	0.61	1.24	1.24	14.47	283	350	488	654
2009	0.59	1.87	1.34	1.34	11.59	287	346	475	572
2010	0.54	1.01	1.18	1.18	15.19	281	334	456	604
2011	0.56	1.59	1.03	1.03	11.48	228	334	452	692
2012	0.49	1.65	1.05	1.05	12.53	256	334	470	647
2013	0.33	1.58	1.08	1.08	14.72	229	330	468	657
2014	0.46	1.07	1.35	1.35	13.99	265	311	449	697
2015	0.32	1.81	0.74	0.74	14.92	267	336	494	653
2016	0.36	2.01	0.90	0.90	14.09	238	331	467	580
2017	0.30	1.38	0.98	0.98	16.77	224	323	473	626
2018	0.30	1.34	1.01	1.01	16.24	213	323	486	673

Appendix 4 (continued). Details of cohort analysis results (Fishing season 1973-2018).

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

	資源尾数（百万尾）				資源量（千トン）			
年＼年齢	0	1	2	3+	0	1	2	3+
1973	2,078	1,089	160	31	552	378	76	20
1974	1,749	1,199	259	37	465	417	124	24
1975	1,759	957	250	40	467	333	120	26
1976	1,911	1,008	181	49	507	350	87	32
1977	2,202	1,059	188	43	585	368	90	28
1978	1,906	1,162	221	44	506	404	106	28
1979	2,229	1,098	217	71	592	382	104	46
1980	1,203	1,191	299	69	319	414	143	45
1981	2,026	706	280	105	538	246	134	68
1982	2,295	1,074	197	61	609	373	94	39
1983	1,714	1,197	294	60	455	416	141	39
1984	1,283	947	333	112	341	329	160	73
1985	1,647	609	333	182	437	212	160	117
1986	1,252	932	224	158	333	324	107	102
1987	2,992	697	331	92	795	242	159	59
1988	1,576	1,802	232	97	418	626	111	63
1989	762	736	703	125	202	256	337	81
1990	1,187	380	154	178	315	132	74	115
1991	1,559	529	167	88	414	184	80	57
1992	1,963	868	132	47	521	302	63	31
1993	2,100	1,006	329	52	558	350	158	33
1994	2,145	930	272	147	570	323	130	95
1995	3,287	811	166	90	873	282	80	58
1996	2,456	1,711	170	65	652	595	81	42
1997	1,775	663	252	27	479	224	113	17
1998	1,349	689	202	28	359	242	96	18
1999	1,286	484	164	68	324	170	80	42
2000	1,046	501	107	75	181	168	52	46
2001	1,166	507	77	32	324	175	37	23
2002	972	402	79	32	268	140	38	21
2003	991	374	50	30	288	128	23	20
2004	1,497	380	71	24	442	137	32	16
2005	830	538	125	17	237	198	63	11
2006	887	347	140	43	219	121	74	29
2007	1,132	390	84	39	326	131	40	25
2008	1,779	397	80	22	503	139	39	14
2009	955	568	145	20	274	197	69	11
2010	1,237	356	59	29	348	119	27	18
2011	1,326	484	87	18	302	162	39	13
2012	1,057	506	66	25	271	169	31	16
2013	804	432	65	21	184	142	31	14
2014	1,487	386	60	20	394	120	27	14
2015	1,144	631	88	14	306	212	44	9
2016	1,023	559	69	33	244	185	32	19
2017	1,986	478	50	28	445	154	24	17
2018	1,329	989	81	20	282	319	39	13

Appendix 5. Fishing operation for chub mackerel by foreign fishing vessels in the East china sea.

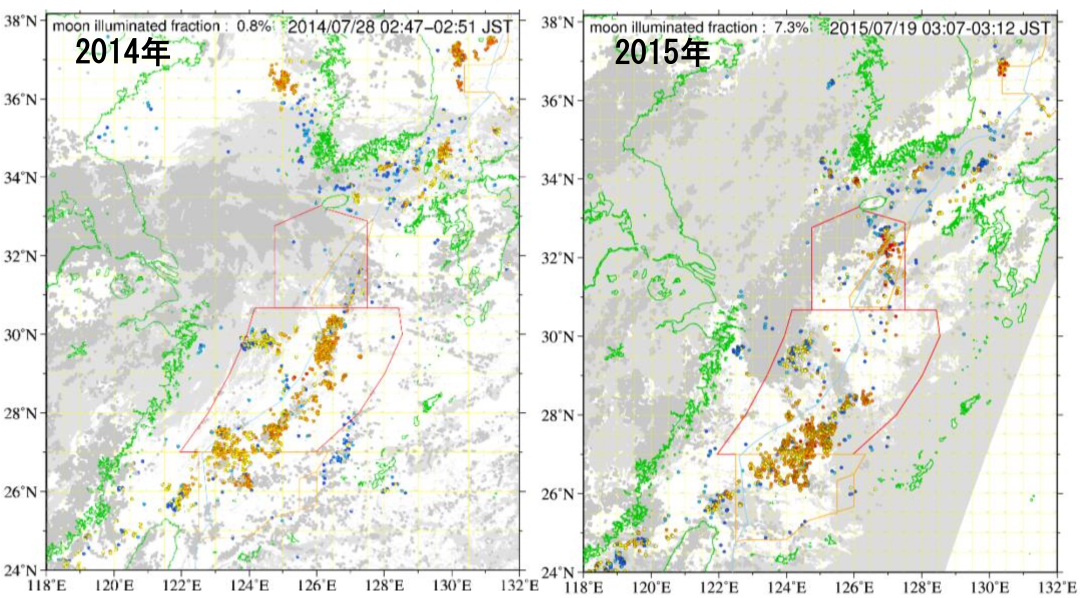
The chub mackerel catch by Chinese fishing vessels and its effort were not included in the analysis due to the lack of reliable information. However, following the FAO statistics, Chinese chub mackerel catch in the northwest Pacific Ocean is large as 500,000 tons (2016). Therefore, it is possible that it affect on the stock status in the East china sea.

Considering the situation, monitoring trial using satellite night vision on the activity of Chinese fishing vessels was started from 2014. In this year, the operating positions of fishing vessels continued to be detected by the light of fishing using night vision of US satellite (Suomi NPP) (Miller et al. 2012) (Appendix Fig. 5-1). The kind of fishery at each spot also can be classified by luminance level, position, water temperature and eye observing data by research vessels (Yoko-maru).

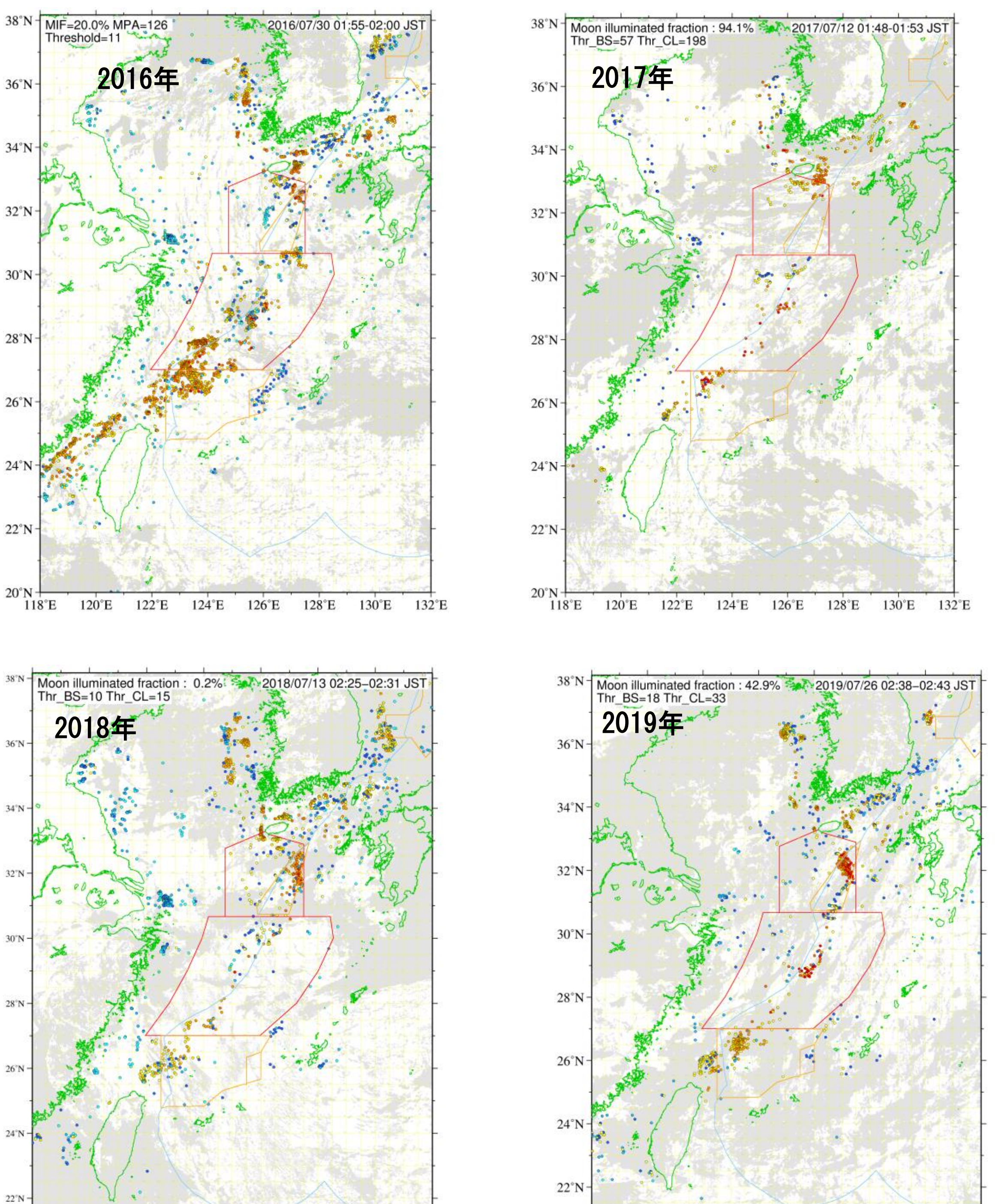
The index monitoring relative change of fishing efforts might be given by collecting position data of fishing operations by year. It is expected that such estimated effort data is going to be included to the analysis when China provide detailed fishery statistics in the future.

Reference:

Miller, S.D., S.P. Mills, C.D. Elvidge, D.T. Lindsey, T.F. Lee, and J.D. Hawkins (2012) Suomi satellite brings to light a unique frontier of nighttime environmental sensing capabilities. Proc. Natl. Acad. Sci. USA, 109, 15706-15711.



Appendix Fig. 5-1. The positions of fishing operation obtained satellite night vision in the East china sea at July of 2014 to 2019.



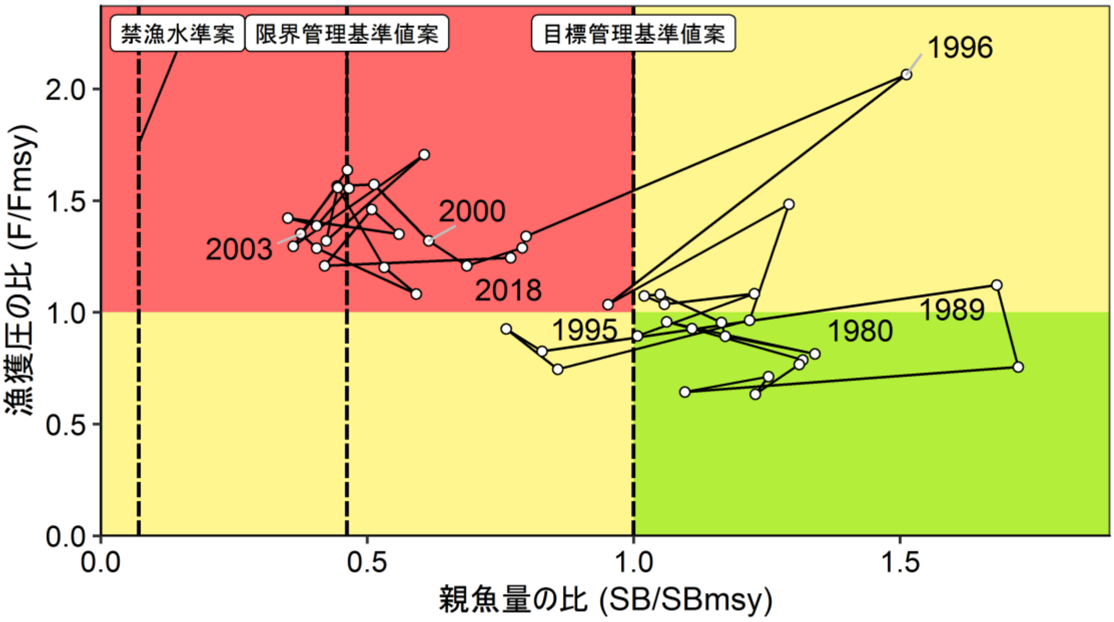
Appendix Fig. 5-1 (continued). The positions of fishing operation obtained satellite night vision in the East china sea at July of 2014 to 2019.

Appendix 6. 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	310,000 tons	SBmsy
SBlimit	143,000 tons	SB 0.6msy
SBban	22,000 tons	SB 0.1msy
Umsy	37%	Catch ratio at MSY
MSY	323,000 tons	
β	NA	The constant multiplied to Fishing intensity to maintain stock certain level.
SB2018	238,000 tons	SSB at 2018
U2018	45%	Fishing ratio at 2018
F2018/Fmsy	1.24	

*It is recommended that SBmsy=310,000 tons as SBtarget, SB0.6msy=143,000 tons as SBlimit, and SB0.1msy=22,000 tons as SBban, respectively at the stock assessment meeting in 2019.
*SBcurrent=238,000 tons estimated by cohort model is below SBtarget, but is above SBlimit and SBban. F2018 is above Fmsy (F2018/Fmsy=1.24), and U2018 is also above Umsy.
*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 6-1. Fishing intensity on the species has been over the level of Fmsy. The SSB has been low from SBtarget recently. The values of each year in Fig. 6-1 are differ from Fig. 4-10 and indicate single year.
*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. 6-1. Kobe plots of chub mackerel Tsushima stock. The values in each year indicate it of single year.

Appendix 7. 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 multifield with β. The recommended HCR was shown in Appendix Fig. 7-1. 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 Pacific Stock of Chub Mackerel' that if βbelow 0.9, the stock may exceed SBtarget with more than 50% probability.

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 8). Five thousand of iteration was made for the estimation considering uncertainty of recruitments. The current catch of 2019 (F2019) was estimated as F which given %SPR(15.6) corresponding to the average of F during 2016-2018 (Fig. 4-8). In the results of projection, Average F of F2019 was 0.88. The F used to predict catch in 2020 is the value calculated with projected SSB in 2020 and HCR.

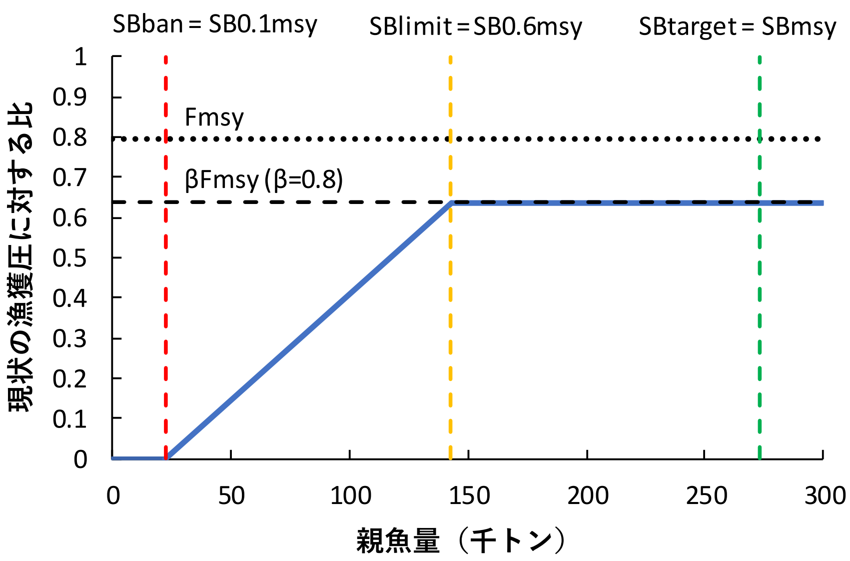
In the projection results, average catch following HCR in 2020 is 222,000 tons at β=0.8 and 261,000 tons at β=1.0. Predicted SSBs in 2020 is 224,000 tons in average exceeding SBlimit in any iterated calculations.

SSB in 2020（average of prediction）：224,000 tons			
Items	predicted catch in 2020 (thousand tons)	（F/F2016-2018）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β=<0.9	=<242	=<0.71	=<34
Other suggested catch (using differentβin HCR)			
β=1.0	261	0.79	37
β=0.8	222	0.63	31
β=0.6	178	0.48	25
β=0.4	127	0.32	18
β=0.2	68	0.16	10
β=0	0	0	0
F2016-2018	306	1.00	43

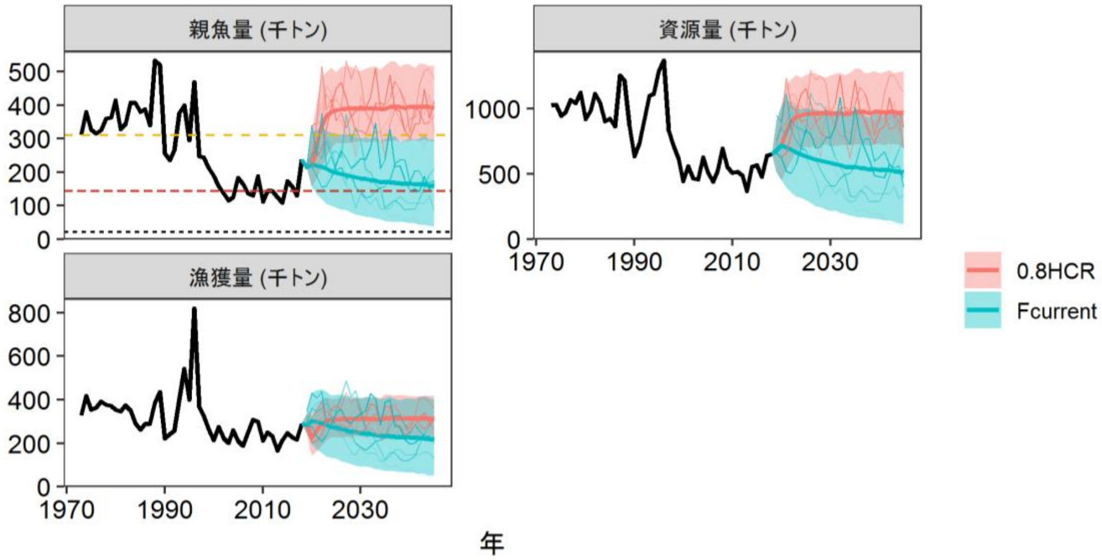
*Calendar year

The mid and long term projection results based on HCR (Appendix 7-1) were shown in Appendix table 7-1, 7-2 and Fig.7-2. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 310,000 tons in average usingβ=1.0 (80% confidence limit ranged 234,000-391,000 tons), and 391,000 tons in average usingβ=0.8 (80% confidence limit ranged 306,000-481,000 tons). The probability of SB above SBtarget is more than 50% usingβ<= 0.9. The probabilities above SBlimit and SBban are 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 (%)		
			SBtarget	SBlimit	SBban
Fishing pressure scientifically suggested					
β=<0.9	>=348	>=269->=433	>=70	100	100
Other suggested catch (using differentβin HCR)					
β=1.0	310	234-391	46	100	100
β=0.8	391	306-481	88	100	100
β=0.6	506	405-614	100	100	100
β=0.4	689	561-824	100	100	100
β=0.2	997	823-1168	100	100	100
β=0	1576	1309-1790	100	100	100
F2016-2018	185	94-277	4	69	100



Appendix Figure 7-1. HCR for chub mackerel Tsushima stock. Current fishing pressure is F2019.



Appendix Figure 7-2. 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. Years are calendar year.

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 7-1. The probability of SSB above SBtarget (a) and above SBlimit (b).
The F of 2019 was assumed by the catch of F2019. Years are calendar year.

(a) The probabilities SSB above SBtarget.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1	0	5	17	28	35	42	43	44	45	46	46	46	46	46
0.9	0	5	25	44	57	64	67	69	70	70	69	70	70	70
0.8	0	5	33	62	78	84	87	90	89	89	89	88	89	89
0.7	0	5	44	78	92	96	98	98	98	98	98	98	98	98
0.6	0	5	53	89	98	100	100	100	100	100	100	100	100	100
0.5	0	5	64	95	100	100	100	100	100	100	100	100	100	100
0.4	0	5	73	98	100	100	100	100	100	100	100	100	100	100
0.3	0	5	81	100	100	100	100	100	100	100	100	100	100	100
0.2	0	5	87	100	100	100	100	100	100	100	100	100	100	100
0.1	0	5	92	100	100	100	100	100	100	100	100	100	100	100
0	0	5	96	100	100	100	100	100	100	100	100	100	100	100

(b) The probabilities SSB above SBlimit.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1	100	97	98	98	99	99	100	100	100	100	100	100	100	100
0.9	100	97	99	99	100	100	100	100	100	100	100	100	100	100
0.8	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	97	100	100	100	100	100	100	100	100	100	100	100	100
0	100	97	100	100	100	100	100	100	100	100	100	100	100	100

Appendix table 7-2. The projection results for SSB (a) and future catch (b).
The catch in 2019 was assumed as catch projected by F2019. Years are calendar year.

(a) Predicted SSB in thousands tons (average of 5,000 iterations)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1	216	224	255	277	292	301	305	308	308	310	310	310	310	311
0.9	216	224	270	305	327	339	344	348	347	349	348	348	348	348
0.8	216	224	287	335	365	381	388	391	390	392	391	391	391	391
0.7	216	224	304	369	409	430	438	442	442	443	443	442	443	443
0.6	216	224	324	407	459	487	499	505	505	507	507	506	507	507
0.5	216	224	345	450	518	556	573	582	584	586	587	586	587	587
0.4	216	224	367	499	587	639	665	678	683	687	688	688	689	690
0.3	216	224	392	554	669	741	779	800	809	815	818	819	821	822
0.2	216	224	418	617	767	865	921	955	971	983	988	991	997	998
0.1	216	224	447	690	885	1019	1102	1155	1184	1205	1216	1223	1237	1238
0	216	224	479	774	1026	1209	1332	1415	1467	1504	1527	1543	1576	1578

(b) Predicted future catch in thousands tons (average of 5,000 iterations)

（千トン）

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1	300	261	284	301	312	317	320	322	322	324	323	323	324	324
0.9	300	242	274	297	310	316	319	320	320	321	320	320	320	320
0.8	300	222	262	289	303	310	312	313	312	313	312	312	313	313
0.7	300	201	246	276	292	299	302	302	302	303	302	302	303	303
0.6	300	178	226	259	277	285	288	289	289	290	289	289	290	290
0.5	300	153	203	237	256	265	269	271	271	272	272	272	272	272
0.4	300	127	175	209	229	239	244	246	247	248	248	248	248	249
0.3	300	98	141	173	193	204	209	213	214	215	215	215	216	216
0.2	300	68	102	128	145	156	162	165	167	168	169	169	170	170
0.1	300	35	55	71	83	90	95	98	99	100	101	101	102	102
0	300	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 8 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=0.0075、b=237,192、SD=0.31）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 Pacific Stock of Chub 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 8-1. As for the selectivity and average weight of the catch, we used the values that was suggested at the research institute meeting on reference point held in 2019. 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, those are average of 2013 to 2017. The %SPR estimated by the current fishing pressure (F2016-2018) under this selectivity was set to be same as the %SPR (15.6) estimated by the average *F* of 2016-2018.

As for the projection of the numbers at age, we used forward calculation method for the cohort-analysis (equation 7-9).

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M) \tag{7}$$

$$N_{3+,y+1} = N_{3+,y} \exp(-F_{3+,y} - M) + N_{2,y} \exp(-F_{2,y} - M) \tag{8}$$

$$C_{a,y} = N_{a,y} \frac{F_{a,y}}{F_{a,y} + M} (1 - \exp(-F_{a,y} - M)) \tag{9}$$

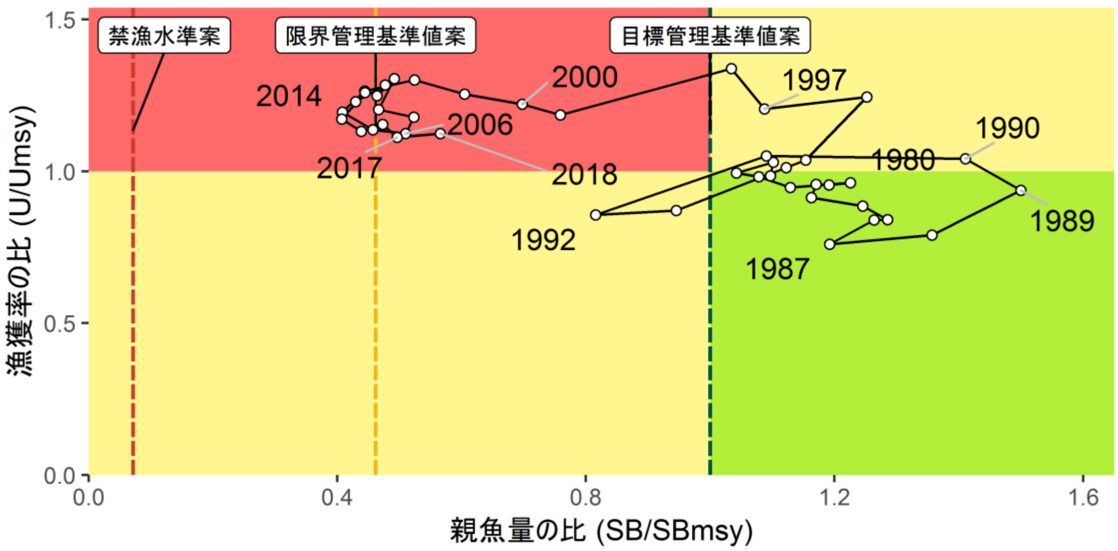
Appendix Table 8-1. Parameters used for future projection.

Age	selectivity	Fmsy	F2019	Average weight（g）	M	Maturity rate
0	0.31	0.33	0.42	243	0.4	0
1	1.00	1.07	1.34	330	0.4	0.6
2	0.65	0.69	0.87	478	0.4	0.8
3+	0.65	0.69	0.87	619	0.4	1.00

Appendix 9　Kobe plot based on fishing proportion

Below shows a Kobe plot based on the SSB and its corresponding fishing rate (U). The SSB is considered below the level which attains MSY since 2000. The ratio of the fishing rate (U/Umsy) were higher than that which attains MSY

Item	Suggested value	Remarks
SBmsy	310 thousand tons	SSB that attains MSY
Umsy	37%	Fishing rate that attains MSY
U2018	45%	Fishing rate in 2018
U2018/ Umsy	1.22	Ratio of the fishing rate in 2018 to MSY



Appendix Figure 9-1. 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.