Stock assessment of Blue Mackerel Pacific stock (2019)

Responsible Institute: National Research Institute of Fisheries Science

Summary

The stock biomass was estimated by cohort model considering abundance index. Although the biomass fluctuated between 254 to 378 thousand tons during 1995 to 2003, it largely increased over 700 thousand tons in 2009 and 2010 fishing season by extremely high recruitment of 2004 and 2009. However, it decreased after 2011 by no significant high recruitment after 2010, it was 124 thousand tons in 2018 fishing season. The SSB increased same as the stock biomass between 165 and 340 thousand tons during 2006 to 2014 fishing seasons, then it decreased 53 thousand tons in 2018. Fishing pressure (average of fishery coefficient at age) revealed relatively stay at same level except high levels of 1995 to 1997, 2002 and 2003 fishing season.

For this population stock, we propose the Ricker (RI) model of reproduction curve for the stock-recruitment relationship equation, SBmsy is estimated 158 thousand tons (Yukami et al. 2019a). Following the reference, SSB at 2018 is below SBmsy. The fishing pressure on the stock are above Fmsy since 2014. The status of SSB was considered at "decreasing" level by the past five years trend between 2014 to 2018.

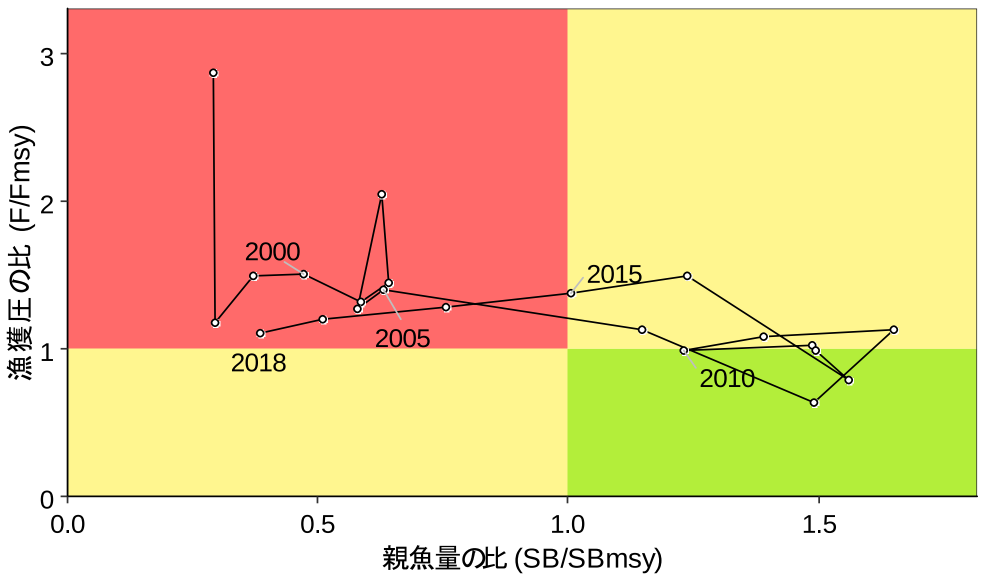
- Summary table of reference relating to MSY

References	Values
Regarding MSY	
SBmsy	158,000 tons
Fmsy	0yr, 1yr, 2yr, 3yr, 4yr above= 0.22, 0.31, 0.48, 0.87, 0.87
%SPR(Fmsy)	27%
MSY	105,000 tons
SSB and Fishing pressure at 2018	
SB2018	53,000 tons
F2018	0yr, 1yr, 2yr, 3yr, 4yr above= 0.28, 0.34, 0.48, 0.83, 0.83
%SPR(F2018)	24%
%SPR(F2016-F2018)	21%
Ratio to MSY	
SB2018/SBmsy	0.33
F2018/Fmsy	1.09

- S-R relationship assumption: Ricker (without autocorrelation)

- Summary of stock status

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



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	Landing at major ports (Hokkaido-Miyazaki [17] prefectures, JAFIC, Northern Purse Seine Fisheries Association) Length composition by month (NRIFS, Hokkaido-Miyazaki [17] prefectures, JAFIC); market measurement Length, weight, age, and maturity data by month (NRIFS, Hokkaido-Miyazaki [17] prefectures, JAFIC); market measurement, fisheries testing Mixing rate research of chub and blue mackerel by month and fisheries (NRIFS, Hokkaido-Miyazaki [17] Prefectures); at sample ports, market samples, and fisheries research
Index of the stock	
Recruitment index	East Hokkaido-Sanriku Waters drift-net fishing survey CPUE (Hokkaido); drift net Mid water trawl survey at Northwestern Pacific(May-July, NRIFS); mid water trawl* Mid water trawl survey at Northwestern Pacific (September/October, NRIFS); mid water trawl*
SSB index	Izu Islands waters dip-net fishing CPUE (Kanagawa Prefecture) *
Spawning volume	Egg and larvae survey (NRIFS, Aomori-Miyazaki [18] prefectures); NORPAC net
Natural mortality	Assuming $M = 0.4$ per year (Tanaka 1960)

*: used as the tuning index for the cohort analysis.

2. Ecology of the species

1) Distribution and migration

Blue mackerel tends to distribute warm offshore waters (Ochiai and Tanaka 1998). The main distribution area for adults is around water of the Kuroshio current.

The distribution and migration are shown in Fig. 2-1. The larvae hatched around the Kuroshio current and distributes from the coastal water of southern Honsyu to the transition water between Kuroshio and Oyashio currents at located 165 to 170 East longitude as same as the chub mackerel larvae (Watanabe et al. 1999, Nishida et al. 2000, Kawabata et al. 2006a). The juveniles sized at 5 to 15cm FL transferred to transition water, migrate to north with growing, feed at the area from coastal water of eastern Hakkaido and Krill Islands to the subarctic water around 165 degree East longitude where the surface temperature around 13℃ in summer to fall (Savinykh et al. 2004, Kawabata et al. 2006a and 2007). It reached 20 to 25cm FL in fall to winter, and down south to the coastal waters of Joban and Boso to offshore water around Kuroshio current for wintering (Kawabata et al. 2009b). The wintering ground at the water near Emperor Sea mounts was found for 2004 year class which had high recruitment (Kawabata et al. 2008 and 2009a). Age one fish did not appear the water north of Sanriku district after wintering until 1980, but it became migrating to the water from Tohoku to Hokkaido according to the increase of surface temperature since 2001 (Kawabata et al. 2006b and 2008). It down south for wintering and migrate to the Izu Islands water for spawning in spring (Meguro et al. 2002). Many schools distribute near Kuroshio current at the coastal water of southern Honshu all the year to be targeted by many fisheries, which are different from the schools largely migrate from near the Kuroshio current at the Izu Island to Tohoku and Hokkaido waters. It is suggested that many fish above age three does not migrate north of Sanriku district and stay at the western water near the cape Ashizuri with small migrations or stay near the spawning grounds (Nashida et al. 2006). Furthermore, it is considered that the observation of schools mainly consisting with age 8 fish at the Emperor sea mount area in 2008 to 2015 were due to the dominant recruitment spawned at the water south of Hachijo Island (Kamimura et al 2017).

2) Age and growth

The larvae grow 1mm per day until 5cm FL after hatching observed by otolith reading (Watanabe et al. 2002), then it grows 15cm after 80days, and over 20cm of 120 days after hatching (Takahashi et al. 2010). The scale annuli reading is practical for the fish after subadult stage (Kondo and Kuroda 1966, Watanabe et al. 2002), it is used the survey. Otolith annuli and daily ring readings are also effective for age determination (Higuchi 1999, Kimura et al. 2002, Nashida et al. 2003, Katayama and Ishii 2009). Recent analysis for age and growth from sampling of catch indicates fish becoming 20-25cm FL at age 0 in fall, 28-31cm at age 1 in summer, 30-34cm at age 2, 33-36cm at age 3, around 37cm at age 4, and 45cm at the maximum. The longevity was estimated around age 6 from size composition of catch, but the oldest age 11 was reported. The growths at younger ages are different by area, and it in the western area of offshore Kumano tends to faster than fish occur in the water north of Izu Islands. The average length (FL), weight (average weight in catch in 2014 to 2018) by age used for future projection are shown in Fig. 2-2.

3) Reproduction

The blue mackerel mature and spawn above 30cm FL from the observation of ovary tissue (Hanai and Meguro 1997). The mature age was considered age 2 and above, then it is assumed that all the fish age 2 and above are mature and spawn (Fig. 2-2, 2-3). The spawning grounds are found from the waters southern Kyusyu and cape Ashizuri to the Kuroshio current water near Izu Islands (Tanoue 1966, Fig 2-1). The recruitments hatched at the larger spawning ground in the East china sea supposed to migrate into the Pacific waters (Tanoue 1966, Niiya 2007). A spawning season are from December to June next year at the western waters of cape Ashizuri, January to March in the East china sea, and February to March near the water of cape Ashizuri (Tanoue 1966, Nashida et al.

2006). The spawning season of main spawning ground of blue mackerel near Izu Island are March to June, but it considered that it is not suitable as spawning grounds by the short spawning season from the ovary tissue observation and small amount of spawning eggs sampled (Watanabe et al. 2000, Hashimoto et al. 2005). However, it is supposed that larvae and juvenile occur in the north of transition area consist by the fish hatched at the Izu Island spawning grounds in March to June as same as chub mackerel (Takahashi et al. 2010).

4) Prey-predator relationships

Larvae feed on planktonic crustaceans and larvae of anchovy or sardines (Ochiai and Tanaka 1998). After juvenile, it feed small teleost and cephalopods with preys mentioned above. It feeds fishes including anchovy, benttooth and lantern fishes, crustaceans like krill and cephalopods at the Kumano Nada fishing ground, horned krill and anchovy at Sanriku fishing ground and copepod, krill, anchovy, lantern fishes, cephalopod like Enoploteuthidae and salpa in the transition area between Kuroshio and Oyashio where located offshore of Joban and Sanriku (Hotta 1957 and Yokota et al. 1961). Feeding by whales are observed at the high abundance periods (Matsuoka et al. 2008).

3. Fisheries on the species

1) Outline of fisheries

The major fisheries for blue mackerel are middle scale purse seine, large scale purse seine, dip-net fishing and stick-held dip-net fishing (mid-area), set net and line fishing (Fig. 3-1). Fishing grounds are formed in the water on continental shelves and slops, around water of Islands and slows. Targeted fish are below age 2 and elder fishes larger than 40cm are rare in the catch. In the firelight mackerel fishing, main target are age 1 and 2 fishes. Line fishing operated at the southern waters targets adults staying at shallows, therefore it catches elder fishes. In the set net fishery, catches differ by area and season, and juveniles are caught in the southern area. The mixer catch with chub mackerels frequently occurs in the northern areas. The purse seine catch is the largest in various fisheries.

2) History of catch

The blue mackerel catch was estimated from the mixing ratio survey of landing. Chub and blue mackerels are caught together by the fisheries and summed together as “mackerels” in fishery statistics. The identification of each species by external form are relatively easy which blue has clear black spots in side body, and fin base distance of first dorsal spine is narrower than chub mackerel (Fishery Agency 1999). Natural hybrid between blue and chub mackerels are found, but it is not considered a big issue for stock assessment because occurrence rate is only 0.3% of total (Taniguchi et al. 1989 and Saito 2001).

For the assessment, fishing season, July to June next year was used as an unit of year, catch was summed by fishing year, and stock abundance was defined as the value of July. The catch by fishery fluctuated between one (1982) to 89 thousand tons (2006) for mid-scale purse seine, 4 (2018) to 62 thousand tons (1985) for firelight mackerel fishing, one (1991) to 32 thousand tons (2010) for set net, 0 (1994) to 64 thousand tons (2009) for northern purse seine, respectively (Fig. 3-1, Table 3-1). Especially for the northern purse seine, it decreased from 41 thousand tons in 2014 to 16 thousand in 2015, 3 thousand in 2016 and finally 490 tons in 2018. In total, catch increased high level from 100 thousand in 1995, to historical highest 193 thousand tons in 2006 by high recruitment of 2004. Thereafter, it remained high level at 191 thousand tons in 2010, then it decreased since 2011 and catch recorded at 34 thousand tons in 2018 as the lowest since 1995.

Before 1981, catch records as blue mackerel was not remained, but catch by the northern purse seine and set net were fairly small (Sou et al. 1980, TNFRI unpublished). Purse seine catch was small in the mid-area of Pacific coast, catch of dip net fishing mainly consisted with chub mackerel, and blue mackerel catch increased after the decreasing of chub mackerel since 1982 (Meguro 1999). Estimated blue mackerel catch was relatively smaller than that of after 1982 in the southern area of Pacific coast. It is supposed that the blue mackerel abundance before 1981 was largely smaller than that after 1995 which abundance was estimated (Fig. 3-1).

Recently, China and Russia catch chub mackerel at the high sea of North Pacific and 200 EEZ, respectively. They reported their catch after 2014 to the North Pacific Fisheries Commission (NPFC). Since the catch of both countries included blue and chub mackerel together, the blue mackerel catch by each country were estimated assuming the same mixture ratios of Japanese purse seine catch in July to December (Fig.3-1, Table 3-1). In the results, the ratios of blue mackerel were estimated at 21% in 2014, 9% in 2015, 2% in 2016, 1% in 2017, and 0.5% in 2018. The difference of statistical unit of catch, e.g. calendar year used by NPFC and fishing year used for analysis was supposed not an issue, because fishing season of both countries were July to November.

Age composition of catch mainly consist with age 1 and 2 fish with yearly large fluctuation due to the large contribution of purse seine fishery (Fig. 3-2, Appendix 3). When strong recruitment occurs, it appears in the catch as age 0 and 1 fish. The proportion of age 0 fish in the catch is relatively small except dominant year class. It is considered that the difference of the migration route and fishing grounds caused the less catchability of age 0 fish.

4. Stock status

1) Stock assessment methods

We estimated the numbers at age by years 1995-2018 using the tuning-VPA method (cohort analysis) which applies the Pope's approximation formula with taking fishing season (July to next June) as year and age 4 and above fish as age plus group (Pope, 1972) (Table 4-1, Appendices 1,2,3 and 4). The natural mortality coefficient (*M*) was set at 0.4 per year estimated by the statistical relation between longevity and natural mortality, M=2.5/longevity, here longevity is 6 years then M became 0.4 (Equation of Tauchi and Tanaka, Tanaka 1960). Japanese catch at age was made by summing up catch at age of each prefecture where converted from catch at size calculated by length composition and length-weight relation of each three month of landing at major fishing port of Pacific coast. The catch at age of Russia and China were obtained assuming same as it of Japanese one came from north of Ensyu Nada area in July to December. Terminal F (2018) was determined with recruitment index obtained from stock held dip net fishery at Shizuoka prefecture (Fig. 4-1, Table 4-2) and SB index from standardized amount of spawning eggs (Appendix 3, Fig.4-2, Table 4-2) using as tuning index.

2) Changes in the biomass indices

The yearly fluctuation of recruitment index is shown in Fig. 4-1 and Table 4-2. All indices are revealing same trends of recruitment level with high abundance in 1996, 2004 and 2009, and low level in 2006 and 2008. However, the results of cohort analysis do not indicate high level of recruitment in 2013, 2016, 2017 and 2018, but indices of northern migration and survey in fall indicated high recruitment. The assessment results and indices tend to be not fit recently.

The yearly fluctuations of amounts of eggs spawn as index of adults are shown in Fig. 4-2 and Table 4-2. After 2005, it indicated high values in 2007 and 2011 reflecting increase of mature fish in 2004 and 2009. Thereafter, it stayed around 25 trillion eggs until 2014, then it decreased to 8.9 trillion eggs. It increased again to 109.6 trillion eggs in 2018 then suddenly dropped to 10.9 trillion eggs in 2019 (only January to June). The 102.2 trillion eggs of 2018 total eggs suggested to be spawn at Area III (Hyuga Nada, Tosa bay, Cape Shionomisaki). It is considered that the total egg amount was over estimated considering frequency distribution of egg diameter, and fishing status of adult fish (Yukami et al. 2019b). It is considered that spawning condition in 2019 is similar of 2018, then concluded that the value of total eggs spawn cannot be used as tuning index, then the values are standardized (Appendix 3). The standardized values of amount eggs spawn peaked at 2008, then decreased to the lowest value in 2019 since 2005 (Fig. 4-2, Table 4-2).

3) Trends in biomass and fishing pressure

Biomass increased from around 300 thousand tons in 1995 to 600 thousand tons in 2004 by high recruitments of 1996 and 2004, then up to 700 thousand tons in 2009 and 2010 with high recruitment of 2009 (Fig.4-3, Table 4-1, Appendix 4). After 2011, it decreased to 113 thousand tons in 2017, the lowest after 1995, then increased to 124 thousand tons in 2018. The SB revealed same trend of biomass, in high level of 165 to 340 thousand tons in 2006 to 2014, then decreased to 53 thousand tons in 2018 (Fig. 4-3, Table 4-1, Appendix 4). The recruitment per spawning (RPS) stayed in stable except high value of 2004 since 1996, it decreased and stay low level after 2010 (Fig. 4-4).

As a sensitivity test on *M*, we used 0.3 and 0.5 as alternatives to the base value of 0.4 and estimated the biomass, SSB and recruitment for the most recent year 2018 (Fig. 4-5). The biomass ranged from 80% to 128%, SSB from 83% to 122% and recruitment from 77% to 134% compared to the base value, resulting in higher value as *M* increases.

Average *F* among all ages (simple average of *F* at age) fluctuated among years at a range of 0.44 and 1.15, and show relatively stable status except the high values of 1995 to 1997 and 2002 and 2003 (Figure 4-6, Appendix 4). The fishing ratio fluctuated ranging 21 to 56%, but stayed around 30% except high values of 1995 to 1997 (Fig. 4-7, Table 4-1, Appendix 4).

Item	Value	Remarks
SB2018	53 thousand tons	SSB in 2018
F2018	(age 0, 1, 2, 3, 4+)=(0.28, 0.34, 0.48, 0.83, 0.83)	
U2018	28%	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 were low during 1995 to 1997, then stayed around 25% during 1998 to 2013, and it slightly decreased in 2014. It gradually increased since 2015.

Figure 4-9 shows the relationship between YPR and %SPR for the current fishing pressure. As for the selectivity in *F*, we use the selectivity which was used to estimate *F* that gives MSY (*Fmsy*) which was suggested at the 'Research Institute meeting on Reference points' held in April, 2019. *Fmsy* corresponds to 27% in %SPR. Current fishing pressure (F2014-F2018) is higher than *Fmsy* and F30%SPR.

Item	Value	Remarks
%SPR (F2018)	24%	%SPR in 2018
%SPR (F2016-2018)	21%	%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 biomass) and recruitment (in numbers). According to the 'Research Institute meeting on Reference points' mentioned above, it is suggested to use the Ricker type model for the S-R relationship of this stock (Yukami *et al*. 2019a). 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 in the Table below.

S-R relationship	Optimization method	Auto-correlation	*a*	*b*	S.D.
Ricker (RI) type	Least square	No	13.5	0.00558	0.507

Here, *a* and *b* are parameters of Ricker type reproduction model shown below. R is recruitment (million fish) and E is SB (thousand tons).

$$R=aEe^{-bE}$$

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

The table below shows the SSB and *F* that will achieve MSY (SBmsy, Fmsy) under the current environmental condition since 1995, which was suggested at the 'Research Institute meeting on Reference points' (Yukami *et al*. 2019a).

Item	Suggested value	Remarks
SBmsy	158 thousand tons	SSB that will obtain MSY
Fmsy	（age 0, 1,2,3,4+）=（0.22, 0.31, 0.48, 0.87, 0.87）	
%SPR（Fmsy）	27%	%SPR corresponding to Fmsy
MSY	105 thousand tons	MSY

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

Figure 4-11 and Appendix 5 shows a Kobe-plot which shows the relationship between SSB and fishing pressure. F/Fmsy shows the yearly ratio between F and F under the current selectivity that gives Fmsy which was converted to %SPR. It is regarded that the fishing pressure of this stock has been above the level that gives MSY until 2006. It stayed around Fmsy during 2007 to 2013, then it became above Fmsy again after 2014, it gradually decreased but was 1.09 times of Fmsy in 2018. Although, the SSB were above SBmsy during 2006 to 2014, it was below SBmsy except that period. The SSB in 2018 was 0.33 times of the SBmsy. The condition of SSB is considered "decreasing" by the five years trend of SB (2014 to 2018).

Item	Value	Remarks
SB2018/ SBmsy	0.33	Ratio between the SSB that gives MSY and the SSB in 2018
F2018/ Fmsy	1.09	Ratio between the fishing pressure that gives MSY and the fishing pressure in 2018 *

* Ratio between *F*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	decreasing

5. Stock assessment summary

Biomass fluctuated between 254 and 378 thousand tons during 1995 to 2003, it reached over 700 thousand level in 2009 and 2010 by the strong recruitments of 2004 and 2009. However, no strong recruitment occurred after 2010, the biomass rapidly down to 124 thousand tons in 2018. The SB showed similar trend of biomass, it stayed between 165 to 340 thousand tons during 2006 to 2014, then decreased and down to 53 thousand tons in 2018. Fishing pressure (average of F at age) were relatively stable except high level during 1995 to 1997, and 2002 to 2003.

The SB2018 is below the level of SBmsy. *F* has been higher than the Fmsy since 2014. Trends in SSB is considered to be “decreasing” based on the recent five-year trends (2014-2018).

6. Other matters

It is considered that the effect of catch regulation on age 0 fish to increase abundance of stock might be small, because fishing pressure on age 0 fish is not high and is less reliable increasing recruitment by increasing SB. However, it is valuable to consider HCR by age in terms of economy effects because fish age one and above having higher price than age 0 fish.

The stock conditions are different between chub and blue mackerels, for instance dominant year class occurs in chub mackerel recently but not for blue mackerel. While the blue mackerel is managed in the same TAC of chub mackerel due to the mixed catch with chub. Therefore it is important that monitoring of the stock should be conducted with chub mackerel stocks.

7. References

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（執筆者：由上龍嗣、井須小羊子、上村泰洋、古市　生、渡部亮介、金森由妃）

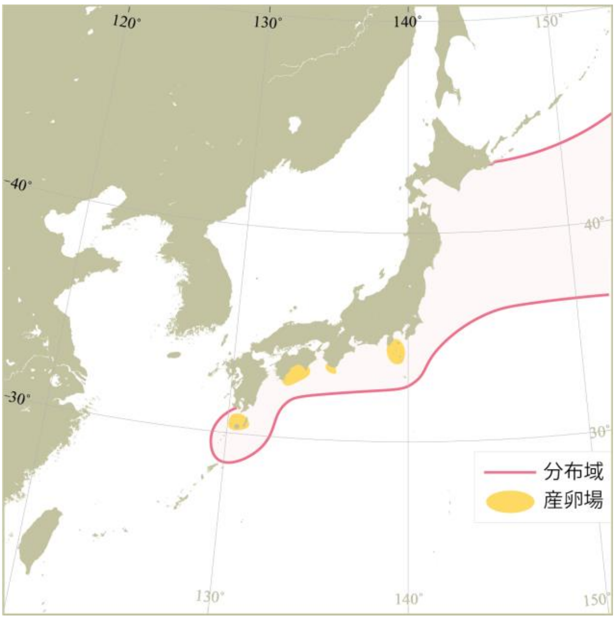


Figure 2-1. Distribution and migration of blue mackerel Pacific stock.

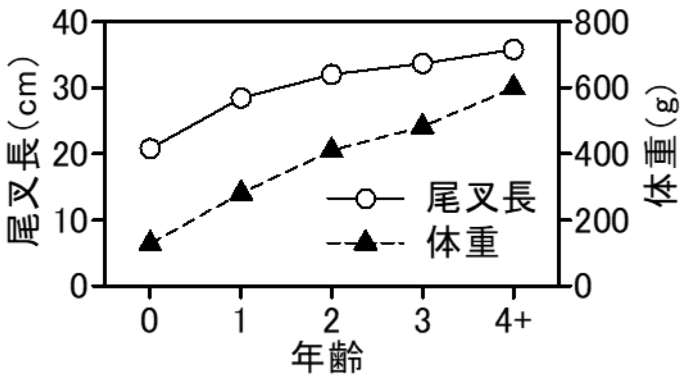


Figure 2-2. Relationship between age and length (fork length), and between age and weight. Black triangle shows that of weight and white circle shows that of length.

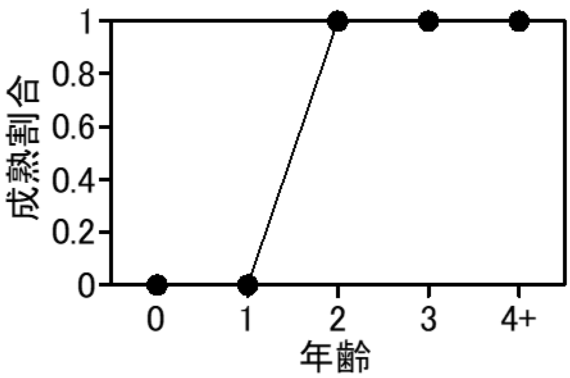


Figure 2-3. Maturity rate by age.

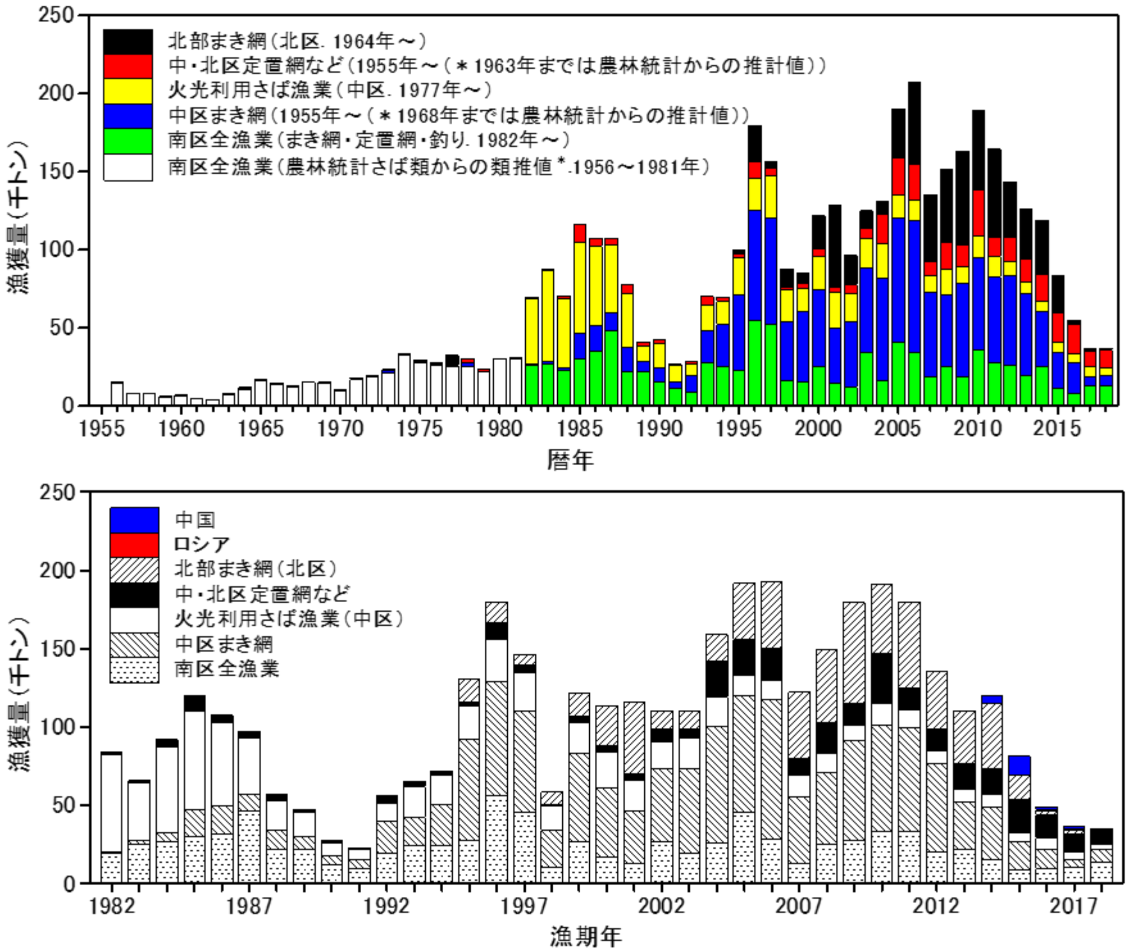


Figure 3-1. Annual catches of blue mackerel by fisheries. Calendar year only Japan (above: January to December) and Fishing year including foreign countries (below: July to next June). The values for China and Russia are estimated values.

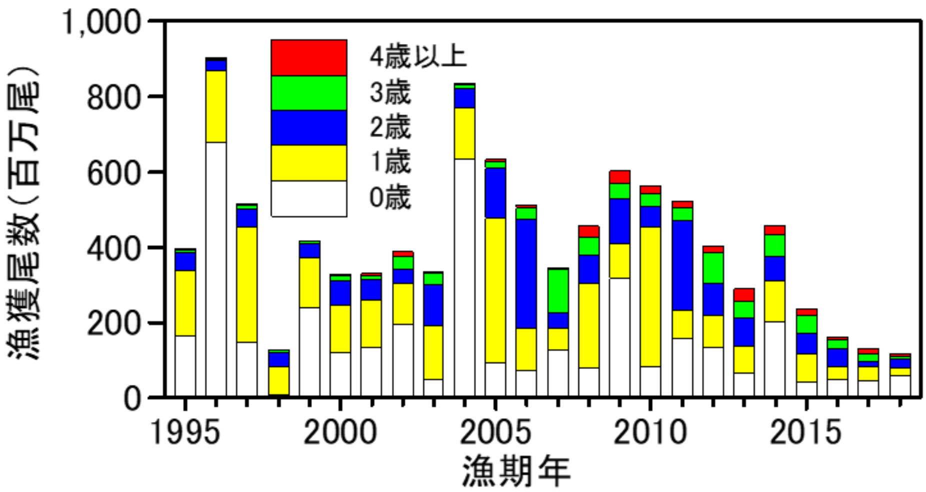


Figure 3-2. Annual age composition in catch. (Red: above 4 years old, green: 3 years old, blue: 2 years old, yellow: 1 year old, white: age 0).

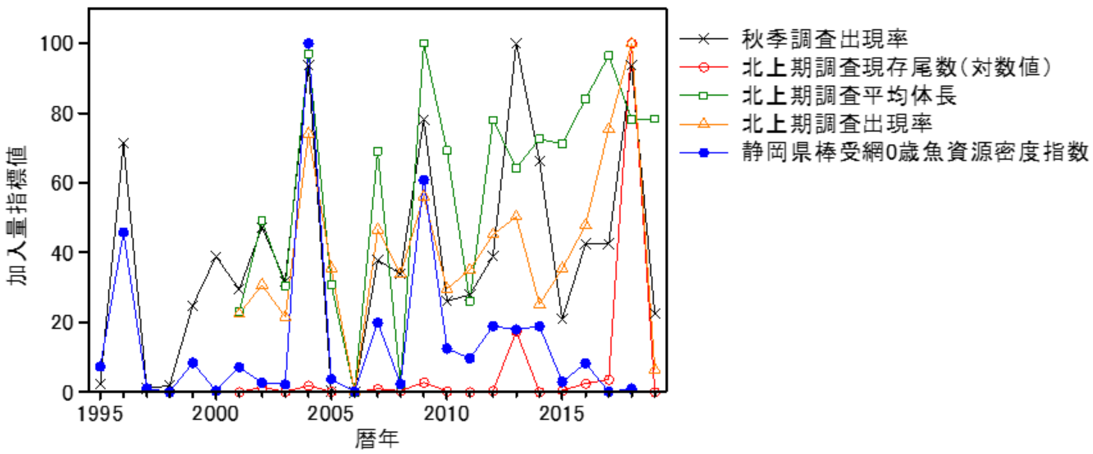


Figure 4-1. Fluctuations in the recruitment index in various surveys. The indices are relative values with the index maximum and minimum set at 100 and 0, respectively.

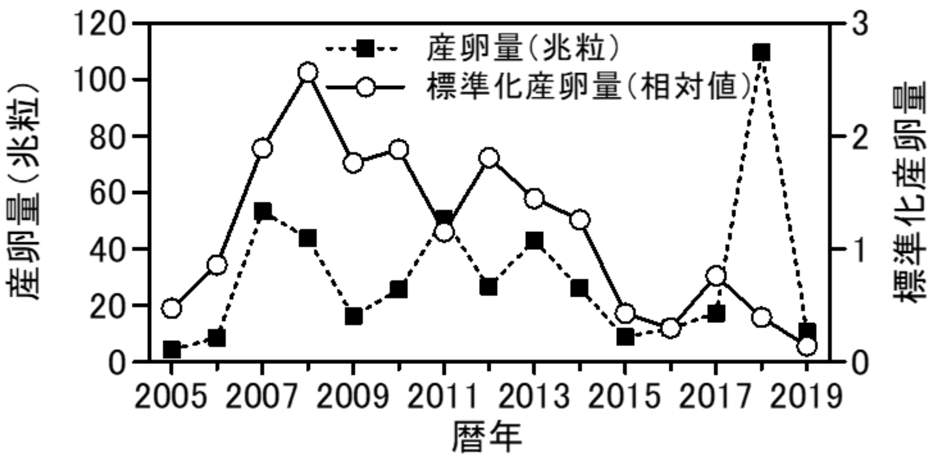


Figure 4-2. Spawning eggs of blue mackerels in the Pacific waters off Japan. Values for 2019 is for January to June. Left axis is the number of spawning eggs (in trillion) and right axis is the standardized spawning eggs. Black square shows the spawning eggs and white circle shows the standardized spawning eggs.

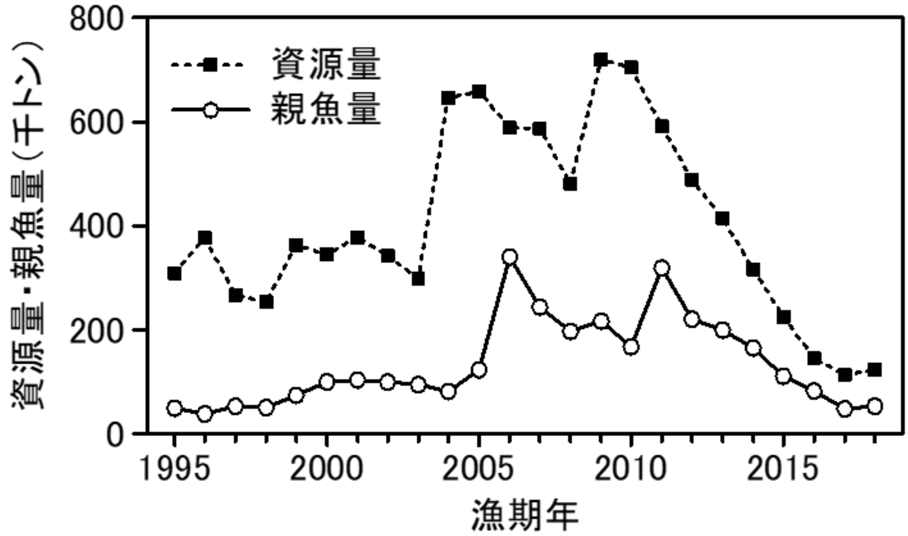


Figure 4-3. Fluctuations in biomass and SSB. The white dots show SSB, and the black dots show biomass.

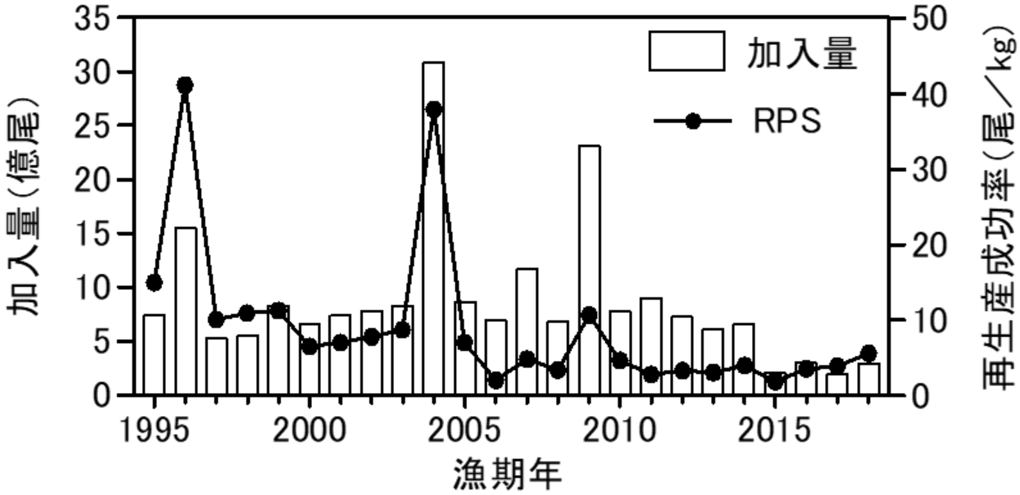


Figure 4-4. Fluctuations in recruitment and recruitment per spawning (RPS). White bar plot shows recruitment and black dots indicate RPS. Left y-axis is recruitment (100 million in numbers), right y-axis is the RPS (numbers/kg).

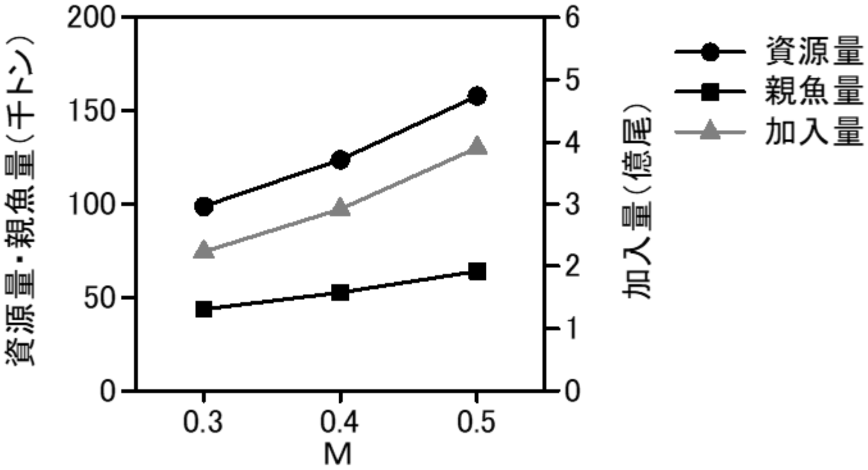


Figure 4-5. Biomass, SSB and recruitment for 2018 depending on the value of *M*. Black circle represents the biomass, square represents SSB and triangle represents the recruitment. Left y-axis is the biomass and SSB (thousand tons), right y-axis is the recruitment (100 million in numbers).

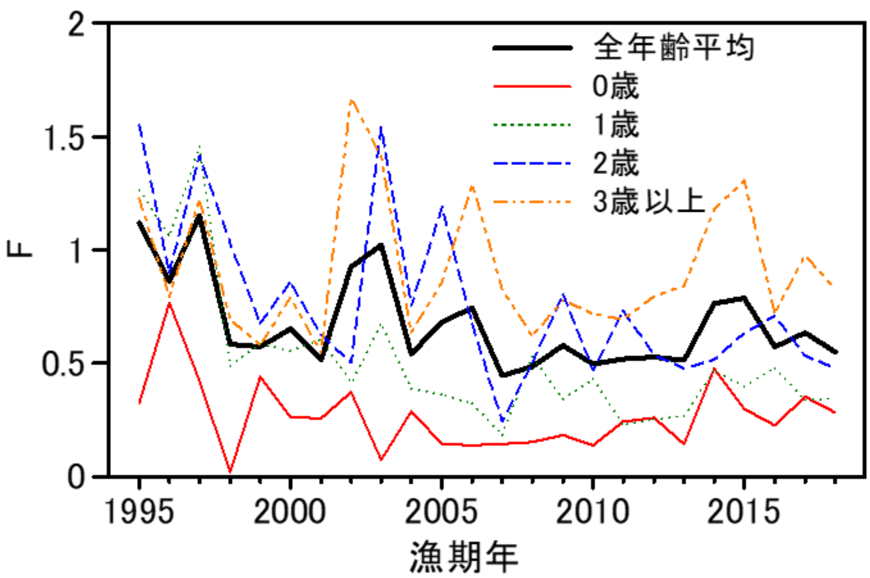


Figure 4-6. Fluctuations in *F* at age. The black solid line shows the average of all ages.

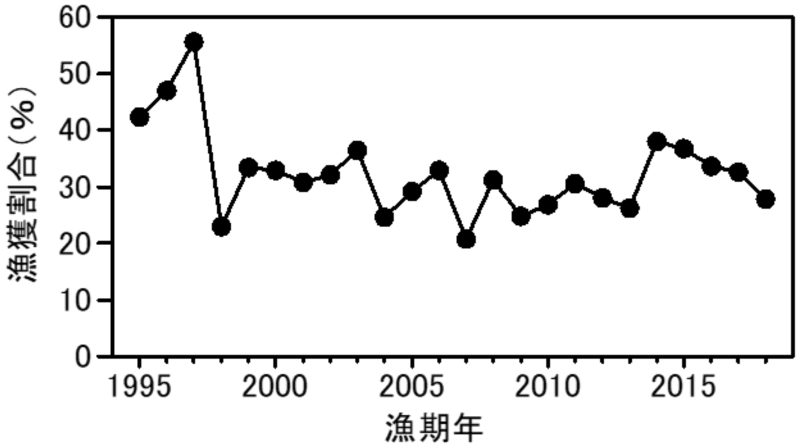


Figure 4-7. Fluctuations in catch proportion. Y-axis is the catch proportion (%).

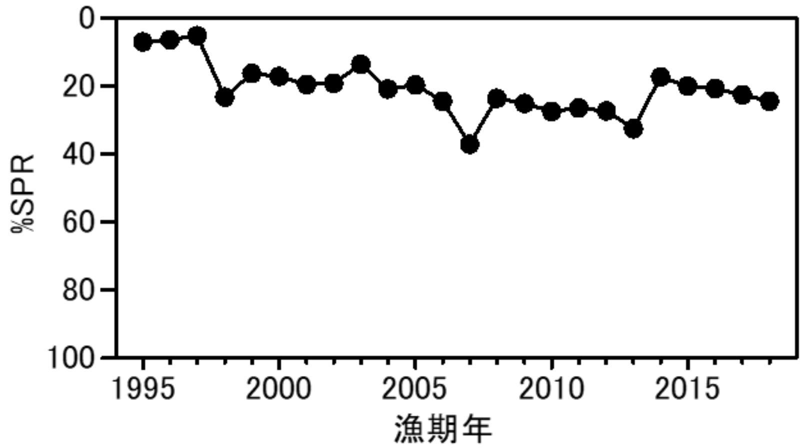


Figure 4-8. Fluctuations in %SPR by years. %SPR shows the ratio of SSB when no fishing to the SSB when there is fishing, and %SPR becomes low with high *F* and vice versa.

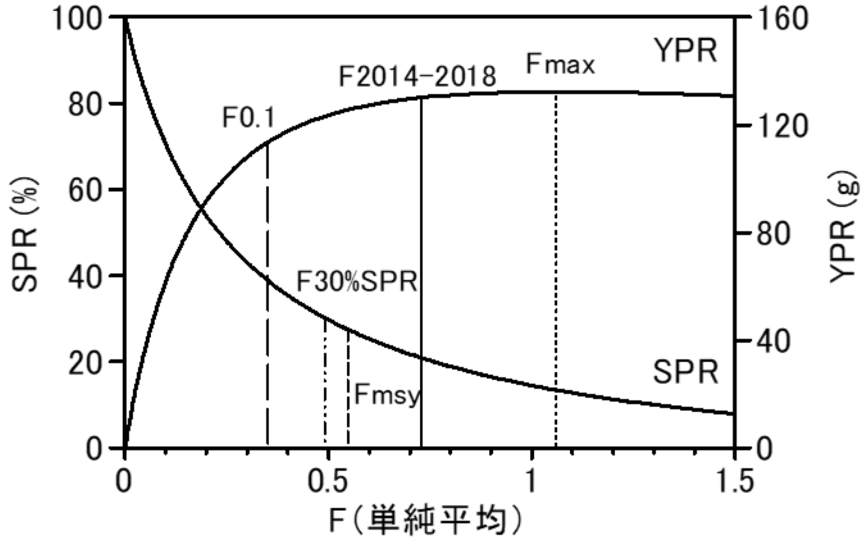


Figure 4-9. Relationship between the fishing mortality (F, simple average) and %SPR, YPR.

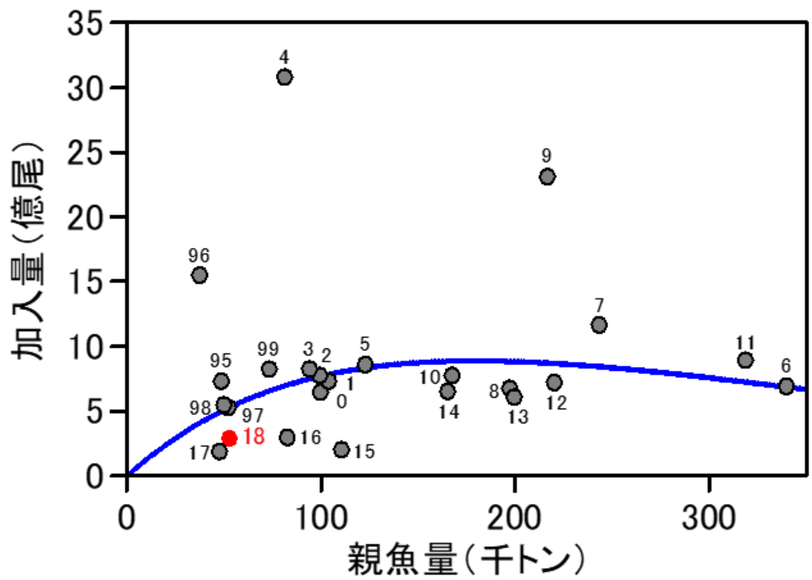


Figure 4-10. Relationship between SSB and recruitment. The blue line shows the S-R relationship suggested at the 'Research Institute meeting on Reference points' held in April 2019 (Yukami et al. 2019a).

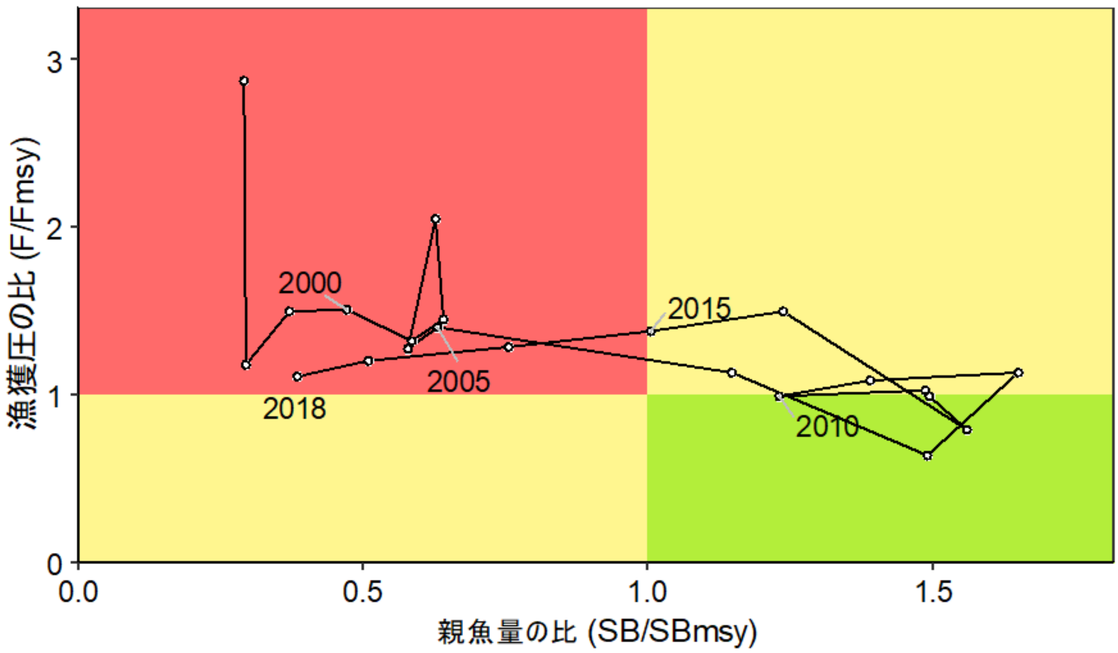


Figure 4-11. Relationship between the SSB and F that gives MSY (SBmsy, Fmsy) to the current SSB and F (Kobe plot). The *F* and SSB is the three-year moving average. The value in 2018 is the average of 2016 to 2018.

Table 3-1. Annual blue mackerel catch by country, region and fisheries (ton). The captions in the table below are from the left: Fishing year (July to next June), Total, Total of Japan, Russia, China, Northern purse-seine, Set net, firelight mackerel fishing, Mid-area purse-seine fishery, various fisheries catch at southern area.

漁期年 7月～ 翌年 6月	合計	日本 合計	太平洋北・中区						南区
			ロシア	中国	北区 まき網	定置網 等	火光利 用さば 漁業*	中区 まき網	全漁業
1982	84,023	84,023	-	-	0	1,354	61,917	826	19,927
1983	65,833	65,833	-	-	0	1,721	36,552	2,308	25,252
1984	92,096	92,096	-	-	0	4,667	55,088	5,816	26,525
1985	120,123	120,123	-	-	0	10,287	62,420	17,092	30,325
1986	107,583	107,583	-	-	532	3,925	53,655	18,010	31,460
1987	97,262	97,262	-	-	0	4,097	35,929	10,532	46,704
1988	57,242	57,242	-	-	0	4,579	18,240	12,067	22,356
1989	47,458	47,458	-	-	0	2,082	15,331	8,034	22,011
1990	27,864	27,864	-	-	47	2,070	7,767	5,678	12,302
1991	23,024	23,024	-	-	113	692	7,164	5,070	9,984
1992	56,060	56,060	-	-	10	4,434	11,870	20,284	19,463
1993	65,231	65,231	-	-	0	3,335	19,511	18,327	24,058
1994	71,962	71,962	-	-	0	2,348	18,718	26,894	24,002
1995	131,067	131,067	-	-	14,824	3,040	21,057	64,498	27,647
1996	179,832	179,832	-	-	13,184	10,938	26,514	72,788	56,408
1997	146,324	146,324	-	-	6,589	5,008	24,871	63,903	45,953
1998	58,385	58,385	-	-	7,641	1,334	15,348	23,544	10,518
1999	121,315	121,315	-	-	14,238	4,381	19,607	56,695	26,393
2000	113,597	113,597	-	-	25,548	3,830	23,365	44,230	16,624
2001	116,056	116,056	-	-	46,230	4,022	18,847	33,817	13,140
2002	110,135	110,135	-	-	11,746	7,802	16,760	46,575	27,252
2003	110,413	110,413	-	-	11,464	5,686	19,948	53,951	19,365
2004	158,927	158,927	-	-	16,673	23,107	18,631	74,934	25,582
2005	191,870	191,870	-	-	35,965	23,182	12,705	73,986	46,032
2006	192,976	192,976	-	-	42,643	20,777	11,890	89,427	28,239
2007	122,171	122,171	-	-	42,627	10,319	13,579	42,525	13,121
2008	149,584	149,584	-	-	46,848	19,624	12,572	45,411	25,129
2009	179,244	179,244	-	-	64,200	13,488	10,643	62,853	28,060
2010	190,993	190,993	-	-	44,136	32,121	13,732	68,058	32,947
2011	180,014	180,014	-	-	54,986	13,537	11,676	66,234	33,580
2012	135,075	135,075	-	-	35,991	14,278	8,015	56,504	20,288
2013	109,998	109,998	-	-	33,088	16,855	7,545	30,294	22,216
2014	120,382	115,192	9	5,180	41,393	17,005	7,568	33,608	15,619
2015	81,431	68,925	43	12,463	15,565	20,473	5,597	18,155	9,134
2016	49,215	46,892	141	2,182	2,907	14,998	7,048	12,500	9,440
2017	36,658	34,345	594	1,720	2,392	11,877	4,584	4,972	10,520
2018	34,879	33,862	439	579	490	8,139	3,640	7,793	13,801

Table4-1. Results of the cohort-analysis. The captions in the table are from the left: fishing year, catch (thousand tons), biomass (thousand tons), SSB (thousand tons), recruitment (million fish), catch proportion (%), and RPS (numbers/kg).

漁期年	漁獲量（千トン）	資源量（千トン）	親魚量（千トン）	加入量（百万尾）	漁獲割合（%）	再生産成功率（尾／kg）
1995	131	309	49	732	42	15.0
1996	177	377	38	1,549	47	41.2
1997	149	268	52	528	56	10.1
1998	58	254	50	548	23	11.0
1999	121	363	73	826	33	11.3
2000	114	345	100	649	33	6.5
2001	116	378	104	733	31	7.0
2002	110	342	100	774	32	7.8
2003	109	299	94	825	37	8.8
2004	159	646	81	3,079	25	37.9
2005	192	659	123	858	29	7.0
2006	194	589	340	691	33	2.0
2007	122	587	243	1,166	21	4.8
2008	150	481	197	676	31	3.4
2009	179	720	217	2,314	25	10.7
2010	189	704	168	778	27	4.6
2011	181	591	319	893	31	2.8
2012	137	489	220	720	28	3.3
2013	109	414	200	606	26	3.0
2014	120	316	165	654	38	4.0
2015	83	225	111	204	37	1.8
2016	49	146	83	297	34	3.6
2017	37	113	48	187	33	3.9
2018	34	124	53	292	28	5.6

Table 4-2. The abundance indices by various survey. r: regression coefficient between recruitment and SSB. No.1, 2, 5, and 6 indicate regression coefficients using recruitment of beginning year to 2018. No.3 is regression coefficient of recruitment during 2010 to 2018. No. 4 and 4' are it of 2007 to 2019. No.3 and 4' are tuning index of cohort analysis.

	①	②	③	④	④'	⑤	⑥
1995			2,235				5.00
1996			13,870				53.57
1997			321				4.17
1998			8				4.76
1999			2,560				20.83
2000			109				30.77
2001	21.98	14.08	2,142			0.04	24.14
2002	26.98	16.12	813			8.11	36.67
2003	21.52	14.67	692			1.01	25.81
2004	52.73	19.90	30,269			11.11	69.23
2005	29.79	14.69	1,146	4.35	0.48	0.62	3.70
2006	8.70	12.27	59	8.52	0.86	0.01	3.45
2007	36.36	17.70	6,038	53.25	1.89	5.34	30.00
2008	28.85	12.45	716	43.89	2.56	2.13	27.27
2009	42.11	20.14	18,386	16.27	1.76	16.59	58.33
2010	26.32	17.72	3,774	25.56	1.88	1.48	21.74
2011	29.55	14.32	2,939	50.79	1.15	0.22	23.08
2012	35.56	18.41	5,700	26.37	1.81	1.97	30.77
2013	38.64	17.33	5,423	43.12	1.45	104.14	73.68
2014	23.64	17.98	5,718	25.98	1.26	0.14	50.00
2015	29.73	17.86	892	8.87	0.43	2.98	18.18
2016	37.14	18.88	2,505	11.98	0.30	15.00	33.33
2017	53.57	19.86	35	17.27	0.76	21.57	33.33
2018	68.18	18.42	296	109.59	0.39	601.11	69.23
2019	12.50	18.44		10.87	0.14	0.02	19.23
r	0.40	0.02	0.71	0.00	0.55	-0.04	0.40

① CPUE of YOY caught by midwater trawl from the spring survey in Northwestern Pacific (number of fish / net / 60 min).

② Average length of age 0 fish caught by midwater trawl from the fall survey in Northwestern Pacific

③ CPUE of dip-net fishery at the Izu Islands waters (kg / person / hour).

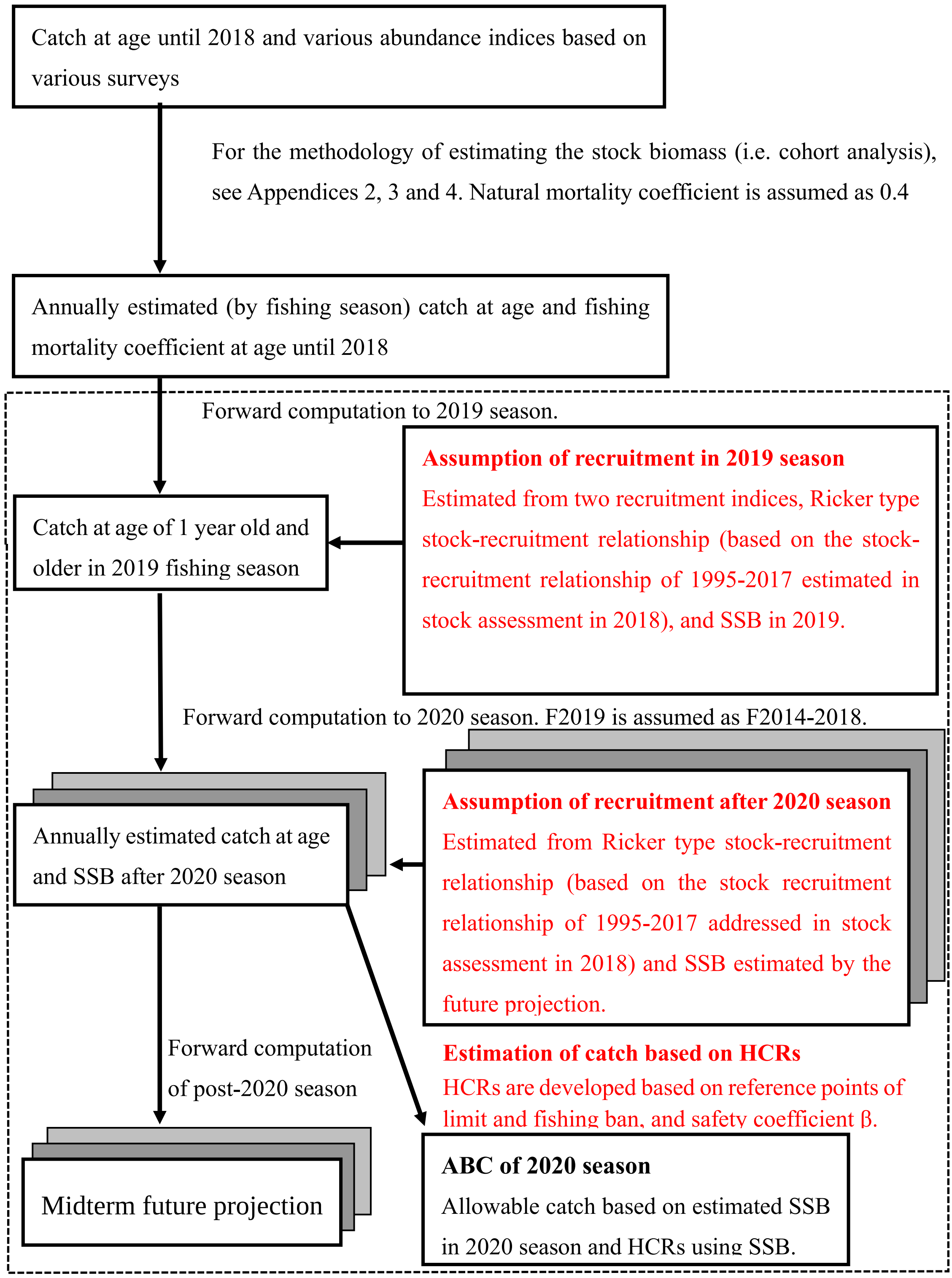
④ Number of eggs in region I – III (entire Pacific coast, by 100 billion).

④' Standardized number of eggs spawn (Appendix 3).

⑤ Estimated abundance of age 0 fish in number (billion fish) from midwater trawl survey in Northwestern Pacific.

⑥ Occurrence ration (%) of midwater trawl survey at Northwestern Pacific and drift net survey at offshore Tohoku area.

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

Catch at age, biomass, fishing mortality coefficient, and total catch are estimated by the cohort analysis using the equation by Pope (1972) (See detail in Hiramatsu 2001, Appendix 4). Fishing season is defined as July to June of the following year. Age composition was assumed age 0 to 3 and four and above (4+; plus group). The calculation for plus group was followed of Hiramatsu (2001). Natural mortality coefficient (M) is assumed as 0.4 year^{-1} based on Tauchi and Tanaka (longevity 6 year old, Tanaka 1960). The calculation used for analysis as follows:

<u>Step 1</u>

Catch at age is calculated based on equations (1).

$$N_{a,y} = N_{a+1,y+1}\, exp(M) + C_{a,y}\, exp(\tfrac{M}{2}) \quad (1)$$

where $N_{a,y}$ is the number of fish of age *a* in year *y*, $C_{a,y}$ is the catch of fish of age *a* in year *y*.

However, the fish age one and above of the most recent year (year t, 2018 fishing season), the eldest age group (age p, here 4+) of previous year (year t-1, 2017 fishing season) were calculated following equations (2), (3) and (4).

$$N_{a,t} = \frac{C_{a,t}\, exp(\frac{M}{2})}{(1-exp(-F_{a,t}))} \quad (2)$$

$$N_{p,y} = \frac{C_{p,y}}{C_{p,y}+C_{p-1,y}} N_{p,y+1}\, exp(M) + C_{p,y}\, exp(\tfrac{M}{2}) \quad (3)$$

$$N_{p-1,y} = \frac{C_{p-1,y}}{C_{p,y}+C_{p-1,y}} N_{p,y+1}\, exp(M) + C_{p-1,y}\, exp(\tfrac{M}{2}) \quad (4)$$

Fishing mortality coefficient F except for the terminal F are calculated based on the equation (5).

$$F_{a,y} = -\,ln\left\{1 - \frac{C_{a,y}}{N_{a,y}} exp(\tfrac{M}{2})\right\} \quad (5)$$

The most recent F (F2018) was assumed an average of past four years (2014 to 2017). Equation (6).

$$F_{a,t} = \tfrac{1}{4}\textstyle\sum_{y=t-4}^{t-1} F_{a,y} \quad (6)$$

The F of plus group is assumed to equal to the F of the age group which is 1 year younger than the oldest age group observed ($F_{p,\,y} = F_{p-1,\,y}$).

The selectivity at age (F at age divided by the maximum F) was calculated from the terminal F and used for Step 2.

Step 2

The terminal F are estimated exploratory by tuning. Two indices that is predicted to represent recruitment and SSB are used for tuning (Appendix table 2-1).

① Density index of age 0 fish observe stick-held dip-net in Shizuoka prefecture.

② Standardized number of eggs spawn in area I, II and III (East of Miyazaki prefecture) (Appendix 3).

No.1 was used for tuning of Age 0 fish abundance (N_0), No.2 was used for SSB. The period such indices used were the period of 2010 to 2018 for index No.1 and after 2007 for No.2.

Although number of eggs spawn without standardized was used as tuning index of SSB, considering mixed catch with chub mackerel and extreme high catch at one sampling station of Tosa bay in 2018, the indices of 2007 to 2017 were used for tuning without 2018 (Yukami et al. 2019). Considering standardization could minimize the issues of mixed catch and extreme sampling, the standardized number of eggs spawn was use for tuning (Appendix 3, Appendix Table 2-1).

The exponential relation was observed between density index of Age 0 fish caught by stick-held dip-net in Shizuoka prefecture and stock abundance in number. The log transformation (ln(Y)) was used as tuning index (I) (Appendix Table 2-1). The objective function used as follows:

$$\sum_y (ln(I_y) - ln(qX_y))^2 \tag{7}$$

Here X is target (recruitment and SSB) of tuning estimated by cohort analysis with $F_{a,t}$. The q is proportional coefficient obtained by equation (8) with various parameters (Geometric mean of I/X).

$$q = exp\left\{\frac{1}{n}\sum_{y=1}^{n} ln\left(\frac{I_y}{X_y}\right)\right\} \tag{8}$$

Terminal F are estimated exploratory which minimize the total sum of objective function under the selectivity obtained Step 1.

The stock biomass was estimated by catch number at age multiplied by average weight at age until 2018.

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Appendix Table 2-1. Tuning indices.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
①$\ln(Y_1)$				8.24	7.99	8.65	8.60	8.65	6.79	7.83	3.56	5.69	
②Y_2	1.89	2.56	1.76	1.88	1.15	1.81	1.45	1.26	0.43	0.30	0.76	0.39	0.14

①静岡県地先棒受網漁業CPUEによる資源密度指数：Y_1

②海区Ⅰ・Ⅱ・Ⅲ（宮崎県以東の太平洋）の標準化産卵量：Y_2

No.1 Density indices of stick-held dip net in the Shizuoka Prefecture: Y_1

No.2 Standardized number of eggs spawn in the area I, II and III: Y_2

Appendix 3. Standardization of number of eggs spawn using Vector Autoregressive Spatio-Temporal model (VAST)

The blue mackerel number of eggs spawn drastically increased in 2018, but most of them were sampled offshore water of Shikoku (Appendix Fig. 3-1). It is pointed out by Yukami et al. (2019) that it could be overestimated due to the large portion of mixture with chub mackerel eggs analyzed by egg diameter frequency distribution and mixed catch of adult fish. The same situation might continue considering the mixed catch of adults in 2019. Then it is considered that nominal number of eggs spawn in 2018 (not standardized) cannot be used as tuning index.

To solve the issue, standardization of number of blue mackerel eggs spawn has been done using the average egg density of both species obtained egg survey conducted in the area I to III by 30' grid from January to June during 2005 to 2019 (Kanamori et al. in prep.). The Vector Autoregressive Spatio-Temporal (VAST) model was used for standardization (Thorson and Barnett 2017). The VAST is a model for standardization method which can treat time-space fluctuation of relative density flexibly by considering autoregression of space. It is reported that the VAST revealed the highest performance comparing standardization with GLM and GAM (Gruss et al. 2019). Furthermore, a northern shift of chub mackerel spawning ground was reported by the study which the VAST was applied to distribution of average egg density (Kanamori et al. 2019). Regarding the location of survey, see Kanamori et al. (2019).

Model structure

VAST express egg density with the relation of encounter probability ($p_1(i)$ of sample i and egg density ($p_2(i)$) of sample i as following two equations below.

$$p_1(i) = \beta_1(t_i) + \omega_1(s_i) + \varepsilon_1(s_i, t_i) + \eta_1(v_i) + \lambda_1 Q(i)$$
$$p_2(i) = \beta_2(t_i) + \omega_2(s_i) + \varepsilon_2(s_i, t_i) + \eta_2(v_i) + \lambda_2 Q(i)$$

The first item of right side $\beta(t_i)$ is fixed effect of research year t, it assumed independent by year. The second item $\omega(s_i)$ is random effect of space at year t, third item $\varepsilon_2(s_i, t_i)$ is random effect of time and space at year t and area s. The fourth item $\eta(v_i)$ is random effect of factor v_i rising over dispersion of sampling year. Factor v_i includes interaction between sampling year and month. The fifth item $\lambda Q(i)$ is fixed effect of covariate $Q(i)$ effect on sampling rate, and egg density of chub mackerel sampled at same location was used as $Q(i)$; $Q(i) = \log(\text{egg density of Chub}(s_i) + 0.1)$ It means that the model considers the sampling rate of blue mackerel eggs is affected by number of chub eggs spawn by overlapping of egg diameter distribution of both species according with increasing eggs spawn. There was no change in the result when log transformation adding 1.

Estimation of parameters

The VAST make model of time-space fluctuation of relative density by knot, by calculating knot of space distribution using k-average method, kind of clustering. It is recommended that number of knots is over 100 (Thorson 2019). Following the recommendation, number of knots decided as 100. The probability distribution of space effect was expressed by Multivariate normal distribution (MVN) as below.

$$\omega_1(\cdot,f)\sim MVN(0,\boldsymbol{R_1}),\qquad \omega_2(\cdot,f)\sim MVN(0,\boldsymbol{R_2})$$

Here, $\boldsymbol{R_1}$, $\boldsymbol{R_2}$ are Matérn correlation function. Here $\varphi = 1$.

$$\boldsymbol{R_1}(s_n,s_m) = \frac{1}{2^{\varphi-1}\Gamma(\varphi)} \times (\kappa_1|\boldsymbol{d}(s_n,s_m)\boldsymbol{H}|)^{\varphi} \times K_v(\kappa_1|\boldsymbol{d}(s_n,s_m)\boldsymbol{H}|),$$

$$\boldsymbol{R_2}(s_n,s_m) = \frac{1}{2^{\varphi-1}\Gamma(\varphi)} \times (\kappa_2|\boldsymbol{d}(s_n,s_m)\boldsymbol{H}|)^{\varphi} \times K_v(\kappa_2|\boldsymbol{d}(s_n,s_m)\boldsymbol{H}|)$$

Γ is Gamma function. K_v is modified Bessel function, $\kappa_1 and\ \kappa_2$ are decorrelation rate, $\boldsymbol{d}(s_n,s_m)$ is distance between knots, H is matrix expressed anisotropy (degree of regression differs by direction). Probability density function of spatio-temporal effect are expressed below.

$$\varepsilon_1(\cdot,f,t)\sim\begin{cases} MVN(0,\boldsymbol{R_1}) & if\ t=1 \\ MVN(\rho_{\varepsilon1}\varepsilon_1(\cdot,f,t-1),\boldsymbol{R_1}) & if\ t>1\end{cases}$$

$$\varepsilon_2(\cdot,f,t)\sim\begin{cases} MVN(0,\boldsymbol{R_2}) & if\ t=1 \\ MVN(\rho_{\varepsilon2}\varepsilon_2(\cdot,f,t-1),\boldsymbol{R_2}) & if\ t>1\end{cases}$$

Such are assumed independent by year. ($\rho_{\varepsilon1} = \rho_{\varepsilon2} = 0$) The parameter of equations above are estimated by maximum likelihood using fast optimization software Temperate Model Builder (Kristensen et al. 2016) due to the necessity of fast calculation with many random noises.

The predicted encounter rate ($r_1(i)$) and predicted egg density ($r_2(i)$) are expressed by Delta type model with using binominal distribution and log normal distribution which the equations shown below (Thorson 2017).

$$r_1(i) = \text{logit}^{-1}p_1(i)$$

$$r_2(i) = a_i \times \log^{-1}p_2(i)$$

The a_i is offset item, and is assumed 1 because average egg density is objective variable. The probability of egg density B observed is expressed the equation below, a parameter is estimated by maximum likelihood.

$$\Pr(b_i = B) = \begin{cases} 1-r_1(i) & \text{if } B=0 \\ r_1(i)\times g\{B|r_2(i),\sigma_m^2(c)\} & \text{if } B>0\end{cases}$$

The index of number of eggs spawn is obtained by sum of relative egg density multiplied by area of knots, calculating relative egg density by $d(x,c,t) = r_1^*(x,c,t) \times r_2^*(x,c,t)$ with parameters given.

$$I(c,t,l) = \sum_{x=1}^{n_x}\big(a(x,l)\times d(x,c,t)\big)$$

The average correction of random effect has been done (Thorson and Kristensen 2016). The details structure of VAST, see Thorson (2019) and GitHub (https://github.com/James-Thorson-

NOAA/VAST）.

Results

The standardized index number of eggs spawn showed pattern like smoothing was done comparing with nominal index (Appendix Fig. 3-2). The rapid increase observed in nominal index in 2018 was revised downward significantly. In the comparison between models with chub mackerel effect and without it, it with chub effect had lower AIC more than 600. It is suggested that chub mackerel effect should be included for standardization. The effect λ is 0.16 which is chub egg density effect on blue egg sampling rate in the model with chub effect. The standardized index of number of eggs spawn tends to decrease since 2008 in the model with chub effect, and the index of 2019 is the lowest after 2005 (Appendix Fig. 4-2, Table 4-1).

The relative egg density by year especially high at offshore of Kagoshima, Shikoku and Izu islands, and slightly high in offshore of Miyagi. It suggests multiple spawning grounds (Appendix Fig. 3-3). There is no area where shows significant fluctuation in relative egg density, and no trends of spawning grounds change.

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由上龍嗣・井須小羊子・渡邊千夏子・上村泰洋・古市　生 (2019) 平成 30（2018）年度ゴマ

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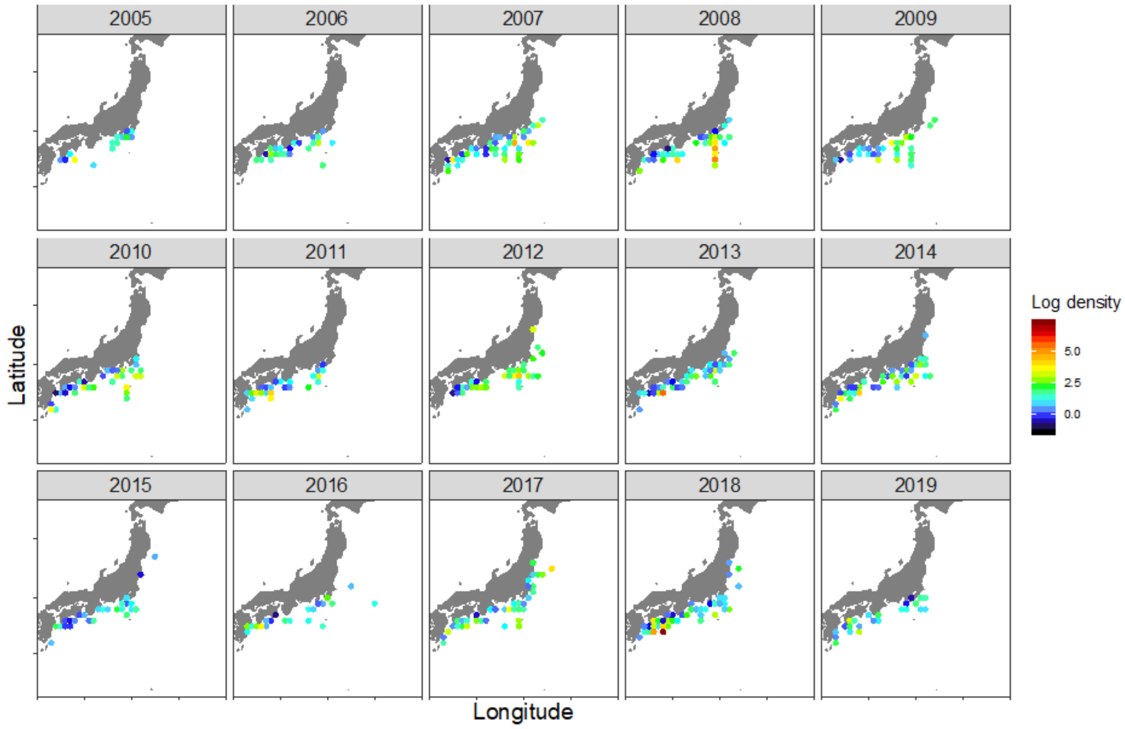
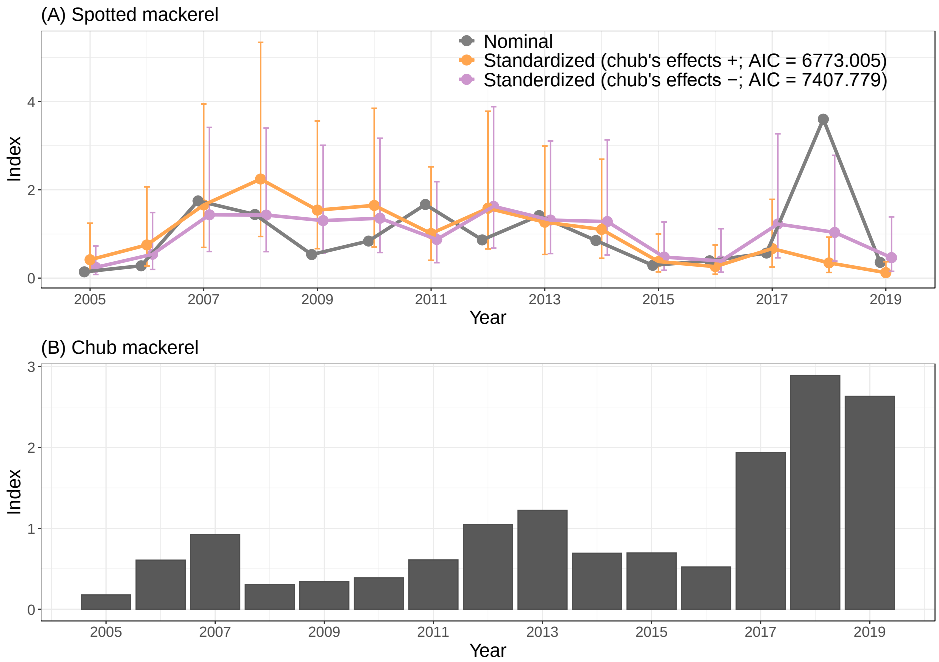
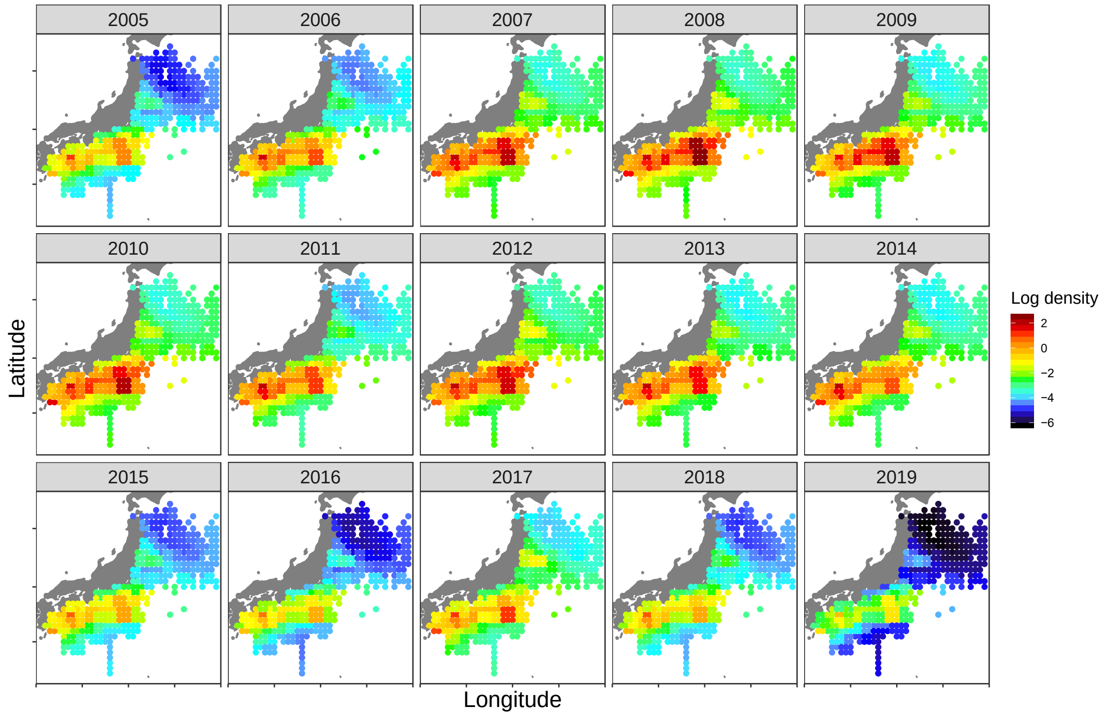


Appendix Fig. 3-1. Distribution map of sampling points and number of blue mackerel egg sampled. The sampling points with no egg are not shown. The colors indicate amounts.



Appendix Fig. 3-2. (A) Annual variation of nominal number of eggs spawn (black line) and standardized index of number of eggs spawn (orange) estimated by VAST for blue mackerel (described as Spotted mackerel). The values were normalized as average into 1 and bar indicated 95% confidence intervals obtained by delta method. The standardized value without chub mackerel effect and 95% confidence intervals were also shown as reference (purple). (B) annual variation of nominal number of eggs for chub mackerel. The values were normalized as average into 1.



Appendix Fig. 3-3. Annual spatial distribution of relative egg density estimated by VAST. The colors indicate degrees of density.

Appendix 4: Details of cohort analysis results of blue mackerel (Fishing season 1995-2006). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾） ※0歳魚について発生年の1～6月分をその後の7月～翌年6月の漁期年へ加えている。

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳	166.0	679.8	149.2	8.7	240.0	122.7	135.9	196.9	48.1	633.3	93.9	73.3
1歳	172.4	190.1	302.5	73.5	130.3	124.0	124.2	105.3	143.1	135.1	383.2	112.2
2歳	47.6	27.0	51.1	39.8	38.4	63.5	52.5	39.7	108.5	53.3	133.2	290.3
3歳	7.6	4.7	8.8	5.5	6.5	14.5	13.3	32.8	30.8	9.3	18.2	28.2
4歳以上	1.8	1.4	2.4	1.5	2.1	4.0	4.4	13.1	5.4	3.7	5.6	8.5
計	395.4	902.9	514.0	129.0	417.3	328.7	330.3	387.9	335.8	834.6	634.0	512.5

年齢別漁獲量（千トン） ※0歳魚について発生年の1～6月分をその後の7月～翌年6月の漁期年へ加えている。

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳	33.1	101.7	14.8	1.6	49.5	21.4	23.9	30.2	5.6	85.5	6.2	4.8
1歳	67.1	57.4	102.1	31.6	43.1	45.9	53.7	34.5	43.7	39.2	118.9	46.0
2歳	25.1	14.0	25.1	20.5	22.3	33.7	27.4	19.7	41.9	25.1	53.0	122.4
3歳	4.4	2.8	5.2	3.4	4.7	9.1	7.7	16.8	14.2	6.1	10.0	15.1
4歳以上	1.3	1.1	1.7	1.2	1.8	3.4	3.4	9.0	3.8	2.9	4.0	5.7
計	131.0	177.1	149.0	58.3	121.4	113.6	116.1	110.0	109.2	158.9	192.1	194.0
漁獲割合	42%	47%	56%	23%	33%	33%	31%	32%	37%	25%	29%	33%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳	0.32	0.77	0.42	0.02	0.44	0.26	0.26	0.37	0.07	0.29	0.14	0.14
1歳	1.26	1.06	1.45	0.49	0.58	0.55	0.60	0.41	0.67	0.39	0.36	0.32
2歳	1.55	0.90	1.42	1.03	0.68	0.86	0.63	0.50	1.54	0.76	1.19	0.67
3歳	1.23	0.79	1.23	0.69	0.58	0.79	0.55	1.67	1.41	0.64	0.86	1.29
4歳以上	1.23	0.79	1.23	0.69	0.58	0.79	0.55	1.67	1.41	0.64	0.86	1.29
平均	1.12	0.86	1.15	0.59	0.57	0.65	0.52	0.93	1.02	0.54	0.68	0.74
%SPR	6.97	6.23	5.12	23.28	16.19	17.08	19.46	19.11	13.54	20.77	19.67	24.41

年齢別資源尾数（百万尾）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳（加入量）	732	1,549	528	548	826	649	733	774	825	3,079	858	691
1歳	293	355	482	232	360	357	335	380	358	513	1,546	498
2歳	74	56	82	75	95	135	138	123	168	122	234	722
3歳	13	10	15	13	18	32	38	49	50	24	39	48
4歳以上	3	3	4	4	6	9	13	20	9	10	12	14
計	1,116	1,974	1,112	873	1,305	1,182	1,256	1,346	1,409	3,749	2,688	1,974

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率：RPS（尾/kg）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳	146	232	52	104	170	113	129	119	96	416	57	45
1歳	114	107	163	100	119	132	145	124	109	149	480	204
2歳	39	29	41	39	55	72	72	61	65	58	93	305
3歳	8	6	9	8	13	20	22	25	23	16	21	25
4歳以上	2	3	3	3	5	8	10	14	6	8	9	10
計	309	377	268	254	363	345	378	342	299	646	659	589
親魚量（SSB）	49	38	52	50	73	100	104	100	94	81	123	340
RPS	15.0	41.2	10.1	11.0	11.3	6.5	7.0	7.8	8.8	37.9	7.0	2.0

年齢別漁獲物平均体重（g）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0歳	199	150	99	190	206	175	176	153	116	135	66	65
1歳	389	302	338	429	331	370	432	327	305	290	310	410
2歳	527	519	492	516	580	532	522	496	387	471	398	422
3歳	588	599	597	615	727	627	583	511	463	660	552	536
4歳以上	687	793	697	746	851	854	774	685	704	794	716	672

Appendix 4 (continued): Details of cohort analysis results of blue mackerel (Fishing season 2007-2018). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾） ※0歳魚について発生年の1～6月分をその後の7月～翌年6月の漁期年へ加えている。

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	128.7	78.2	317.4	82.8	157.9	135.6	66.7	203.3	43.1	49.1	45.6	58.6
1歳	55.2	227.1	92.2	369.4	75.8	84.9	71.1	107.2	73.0	31.5	37.1	20.8
2歳	42.6	72.9	121.0	56.7	239.2	82.7	76.1	63.2	56.7	51.1	14.3	23.7
3歳	113.6	48.2	40.4	33.8	31.9	81.6	44.0	57.8	45.6	22.2	20.6	7.6
4歳以上	5.2	28.6	32.5	21.2	17.5	18.1	31.2	26.5	18.3	8.2	12.0	7.4
計	345.2	455.0	603.5	563.9	522.2	402.9	289.0	458.0	236.7	162.0	129.6	118.2

年齢別漁獲量（千トン） ※0歳魚について発生年の1～6月分をその後の7月～翌年6月の漁期年へ加えている。

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	21.7	8.1	51.9	14.8	19.6	18.5	10.8	17.7	7.4	5.9	4.7	9.3
1歳	20.2	71.8	29.4	113.7	27.1	30.7	22.4	28.6	21.3	8.6	10.8	5.9
2歳	19.9	27.0	55.6	27.1	103.8	35.4	35.1	28.0	21.8	19.9	5.8	10.2
3歳	56.5	25.6	21.6	19.2	18.9	41.3	22.8	29.9	21.5	9.7	8.9	4.2
4歳以上	3.5	17.5	20.0	14.0	11.5	11.2	17.6	15.8	10.7	4.9	6.6	4.9
計	121.7	150.1	178.6	188.8	180.9	137.1	108.6	120.0	82.7	49.0	36.9	34.5
漁獲割合	21%	31%	25%	27%	31%	28%	26%	38%	37%	34%	33%	28%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	0.14	0.15	0.18	0.14	0.24	0.26	0.14	0.48	0.30	0.23	0.35	0.28
1歳	0.18	0.53	0.34	0.43	0.23	0.25	0.27	0.47	0.40	0.48	0.34	0.34
2歳	0.24	0.50	0.80	0.47	0.73	0.54	0.48	0.52	0.63	0.71	0.53	0.48
3歳	0.83	0.62	0.78	0.72	0.69	0.80	0.84	1.18	1.31	0.72	0.98	0.83
4歳以上	0.83	0.62	0.78	0.72	0.69	0.80	0.84	1.18	1.31	0.72	0.98	0.83
平均	0.44	0.48	0.58	0.50	0.52	0.53	0.51	0.76	0.79	0.57	0.64	0.55
%SPR	37.02	23.58	25.06	27.36	26.43	27.27	32.50	17.29	19.93	20.74	22.49	24.34

年齢別資源尾数（百万尾）

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳（加入量）	1,166	676	2,314	778	893	720	606	654	204	297	187	292
1歳	403	676	389	1,291	454	469	372	351	272	101	159	88
2歳	242	225	268	185	563	242	245	191	148	123	42	76
3歳	247	127	91	80	78	182	95	102	76	53	40	17
4歳以上	11	76	73	51	43	40	67	47	31	19	23	16
計	2,070	1,781	3,135	2,385	2,030	1,654	1,384	1,345	731	593	452	489

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率：RPS（尾/kg）

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	196	70	379	139	111	98	98	57	35	36	19	46
1歳	147	214	124	397	162	170	117	94	79	28	46	25
2歳	113	83	123	88	244	104	113	85	57	48	17	33
3歳	123	68	49	46	46	92	49	53	36	23	17	9
4歳以上	8	46	45	33	28	25	38	28	18	12	13	11
計	587	481	720	704	591	489	414	316	225	146	113	124
親魚量（SSB）	243	197	217	168	319	220	200	165	111	83	48	53
RPS	4.8	3.4	10.7	4.6	2.8	3.3	3.0	4.0	1.8	3.6	3.9	5.6

年齢別漁獲物平均体重（g）

年齢＼漁期年	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	168	104	164	179	124	137	161	87	171	120	103	159
1歳	366	316	319	308	357	362	315	267	292	272	291	282
2歳	467	371	459	477	434	428	461	443	384	389	408	430
3歳	498	531	534	570	594	506	518	516	472	439	433	552
4歳以上	660	610	616	661	658	615	563	596	585	601	555	665

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	158,000 tons	SBmsy
SBlimit	50,000 tons	SB 0.6msy
SBban	6,000 tons	SB 0.1msy
Umsy	27%	Catch ratio at MSY
MSY	105,000 tons	
β	0.9	The constant multiplied to F to keep below upper limit. In the case of β=0.9, the stock will increase above the management target at 2030.
SB2018	53,000 tons	SSB at 2018
U2018	28%	Fishing ratio at 2018
F2018/Fmsy	1.09	

*It is recommended that SBmsy=158,000 tons as SBtarget, SB0.6msy=50,000 tons as SBlimit, and SB0.1msy=6,000 tons as SBban, respectively at the stock assessment meeting in 2019. See in detail: 'Research Institute meeting on Reference points for the Pacific Stock of Blue Mackerel' held at April, 2019.

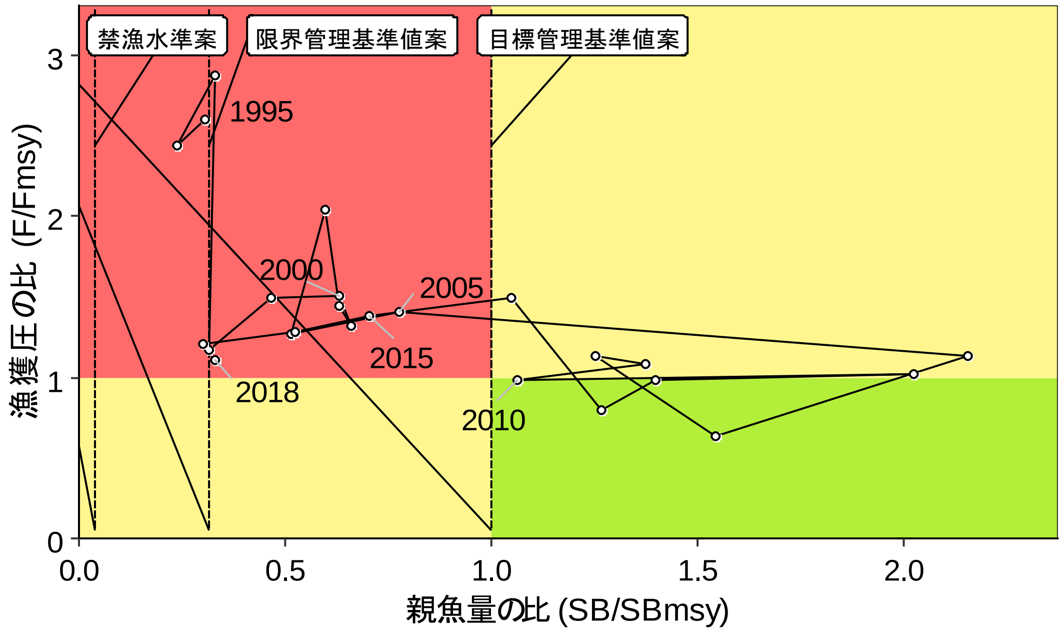
*SBcurrent=53,000 tons estimated by cohort model is below SBtarget, but is above SBlimit and SBban. F2018 is above Fmsy (F2018/Fmsy=1.09), and U2018 is also above Umsy.

*The Kobe plot using SBtarget and Fmsy is shown in appendix Fig. 5-1. Fishing intensity on the species has been over the level of Fmsy before 2006. It stayed around Fmsy during 2006 to 2014, but increased again after 2014. The SSB has been low from SBtarget except during 2006 to 2014.

*The status of SSB and Fishing pressure are examined 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 "decreasing" from the transition of past five years (2014-2018).

Status of SSB	warning
Status of fishing pressure	over fishing
Status of SSB transition	decreasing



Appendix Fig. 5-1. Kobe plots of blue mackerel pacific stock. The values of SSB and F are 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=0.9.

The desirable catch of 2020 was estimated by the projection following the HCR. The projection was made using forward cohort model and recruitment predicted by reproductive relation with SSB. Ten thousand of iteration was made for the estimation considering uncertainty of recruitments. The Fcurrent (F2014-2018) is defined the value calculated that estimated %SPR by average F of 2014 to 2018 is same as estimated %SPR by same selectivity of Fmsy. The catch of 2019 was assumed 41,000 tons predicted by the fishing pressure (F2014-F2018). The expected fishing pressure in 2020 by projection using SSB2020 was assumed fishing pressure to estimate expected catch in 2020.

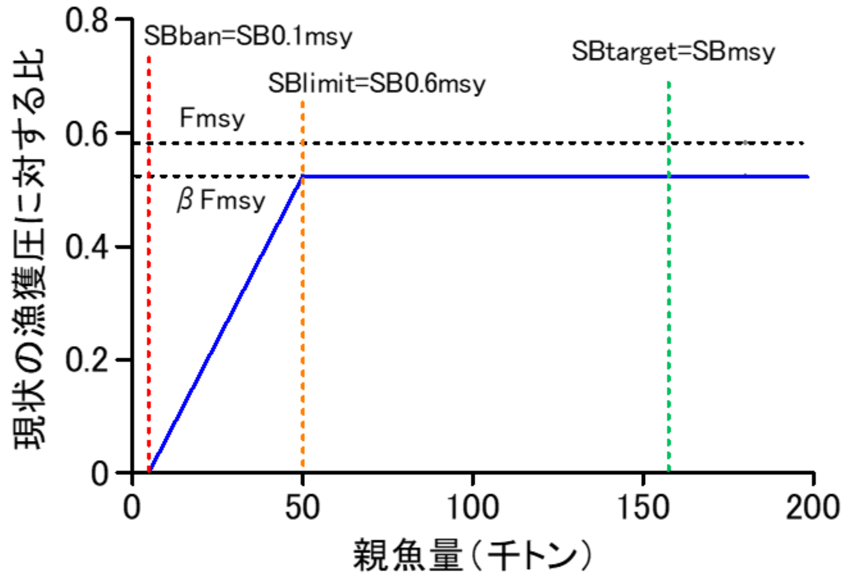
In the results of projection, expected catch in 2020 is 27,000 tons using β=0.9, and 29,000 tons assuming β=1.0. The predicted SSB in 2020 was 40,000 tons in average, and all estimation were below SBtarget. The F used for catch projection was calculated coefficient according to SSB multiplied to SB: γ(SBt)×β Fmsy due to the SB below SBtarget. Here, γ(SBt) of 2020 was calculated as 0.77 following management rules based on "guideline of fishery management and ABC rules".

$$\gamma(\mathrm{SB_t}) = \frac{\mathrm{SB_t} - \mathrm{SB_{ban}}}{\mathrm{SB_{limit}} - \mathrm{SB_{ban}}}$$

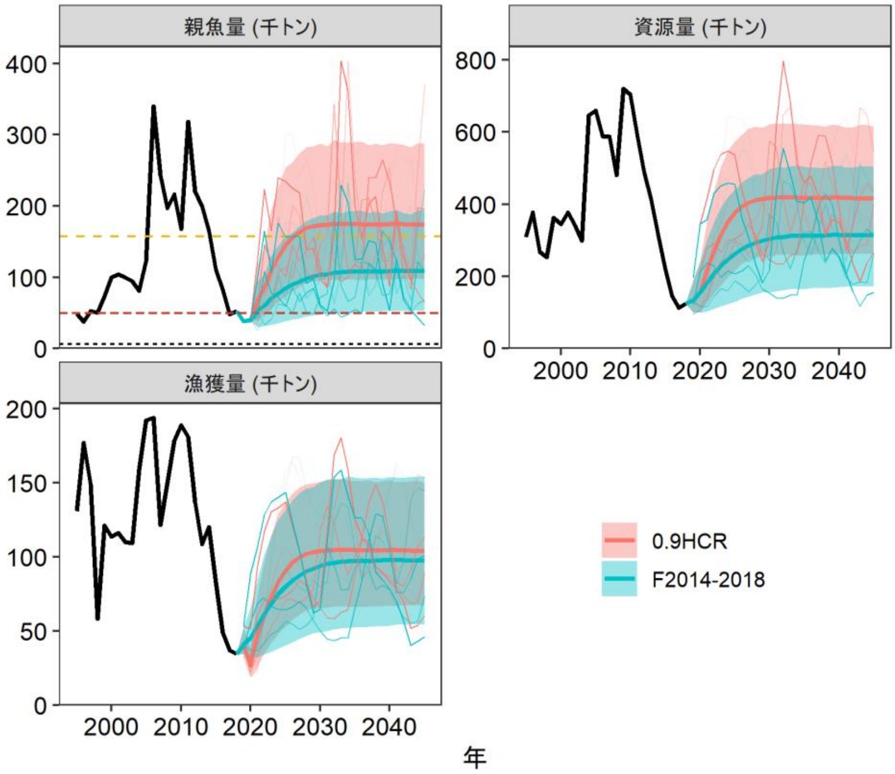
SSB in 2020（average of prediction）: 40,000 tons			
Items	Predicted catch in 2020 (thousand tons)	（F/F2014-2018）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β=0.9	27	0.53	17
Other suggested catch (using differentβin HCR)			
β=1.0	29	0.58	19
β=0.8	24	0.47	15
β=0.6	19	0.35	12
β=0.4	13	0.23	8
β=0.2	7	0.12	4
β=0	0	0	0
F2014-2018	45	1.00	29

The mid and long term projection results were shown in Appendix table 6-1, 6-2. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 155,000 tons usingβ=1.0 (80% confidence limit ranged 93,000-229,000 tons), and 173,000 tons using β=0.9 (80% confidence limit ranged 107,000-252,000 tons). The probability of SB above SBtarget is 41% using β=1.0, and 54% using β=0.9. The probability of SB above SBlimit is 41% using β=1.0, and 54% using β=0.9. The probabilities above SBban are 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	173	107-252	54	100	100
Other suggested catch (using differentβin HCR)					
β=1.0	155	93-229	41	100	100
β=0.8	192	121-275	67	100	100
β=0.6	232	153-324	88	100	100
β=0.4	276	191-375	98	100	100
β=0.2	329	240-433	100	100	100
β=0	395	309-494	100	100	100
F2014-2018	103	55-160	11	94	100



Appendix Fig. 6-1. HCR for blue mackerel Pacific stock. Fcurrent is F2014-2018. The value of β is 0.9.



Appendix Figure 6-2. Comparison of the projection results between HCR adapted and to keep Fishing pressure F2014-2018. The bold line indicates average values, shadow zone shown 80% confidence limits, solid lines are some example of projection. The yellow dotted line indicates SBtarget, red dotted is SBlimit, and Black dotted is SBban, respectively. The catch in 2019 was predicted 41,000 tons by Fcurrent (F2014-2018) and β=0.9 of HCR. The Fcurrent (F2014-2018) was determined by assuming %SPR at average F during 2014-2018 is equal to the %SPR at Fmsy.

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

Appendix table 6-1. The probability of SSB above SBtarget (table a) and above SBlimit (table b) are estimated by future projection under β values from 0 to 1.0. The catch in 2019 was assumed as 41,000 tons projected by Fcurrent (F2014-2018), and the catch from 2020 was calculated by HCR.

(a) The probabilities SSB above SBtarget.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	0	0	1	2	9	16	24	30	34	38	39	41	42	42
0.9	0	0	1	3	13	23	34	42	47	51	52	54	55	55
0.8	0	0	1	4	17	32	46	56	61	65	66	67	67	68
0.7	0	0	1	5	23	42	58	69	75	77	78	79	79	79
0.6	0	0	2	7	30	54	71	81	86	88	88	88	88	89
0.5	0	0	2	10	39	66	83	91	94	95	95	95	95	95
0.4	0	0	2	13	49	78	91	96	98	98	99	98	98	98
0.3	0	0	3	17	60	87	96	99	100	100	100	100	100	100
0.2	0	0	3	21	70	94	99	100	100	100	100	100	100	100
0.1	0	0	3	28	80	97	100	100	100	100	100	100	100	100
0.0	0	0	4	35	88	99	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
1.0	0	0	72	89	96	98	99	99	100	100	100	100	100	100
0.9	0	0	75	92	98	99	100	100	100	100	100	100	100	100
0.8	0	0	79	95	99	100	100	100	100	100	100	100	100	100
0.7	0	0	82	97	99	100	100	100	100	100	100	100	100	100
0.6	0	0	85	98	100	100	100	100	100	100	100	100	100	100
0.5	0	0	87	99	100	100	100	100	100	100	100	100	100	100
0.4	0	0	90	100	100	100	100	100	100	100	100	100	100	100
0.3	0	0	92	100	100	100	100	100	100	100	100	100	100	100
0.2	0	0	94	100	100	100	100	100	100	100	100	100	100	100
0.1	0	0	96	100	100	100	100	100	100	100	100	100	100	100
0.0	0	0	97	100	100	100	100	100	100	100	100	100	100	100

Appendix table 6-2. The projection results for SSB (a) and future catch (b) were estimated by future projection under β values from 0 to 1.0. The catch in 2019 was assumed as 41,000 tons projected by Fcurrent (F2014-2018), and the catch from 2020 was calculated by HCR.

(a) Predicted SSB in thousand tons (average of 10,000 iterations)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	1,472	1,984	3,032	2,761	2,581	2,231	1,977	1,870	1,829	1,807	1,784	1,768	1,623	1,614
0.9	1,472	1,984	3,073	2,844	2,691	2,351	2,087	1,973	1,927	1,904	1,884	1,871	1,737	1,733
0.8	1,472	1,984	3,114	2,929	2,807	2,479	2,208	2,086	2,034	2,010	1,991	1,981	1,860	1,860
0.7	1,472	1,984	3,156	3,017	2,929	2,617	2,341	2,210	2,153	2,126	2,108	2,100	1,991	1,995
0.6	1,472	1,984	3,199	3,109	3,058	2,767	2,486	2,348	2,285	2,255	2,236	2,229	2,132	2,139
0.5	1,472	1,984	3,243	3,204	3,195	2,928	2,645	2,501	2,433	2,398	2,378	2,372	2,284	2,294
0.4	1,472	1,984	3,287	3,302	3,338	3,102	2,820	2,672	2,598	2,559	2,537	2,531	2,450	2,461
0.3	1,472	1,984	3,332	3,404	3,491	3,290	3,013	2,862	2,784	2,742	2,717	2,710	2,633	2,645
0.2	1,472	1,984	3,378	3,510	3,651	3,493	3,226	3,076	2,995	2,949	2,921	2,913	2,838	2,849
0.1	1,472	1,984	3,424	3,619	3,821	3,713	3,461	3,315	3,234	3,186	3,157	3,147	3,071	3,082
0.0	1,472	1,984	3,471	3,733	4,001	3,952	3,721	3,585	3,507	3,460	3,429	3,418	3,340	3,350

(b) Predicted future catch in thousand tons (average of 10,000 iterations)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	794	523	633	566	625	540	478	453	440	433	428	425	391	386
0.9	794	474	582	529	592	516	457	433	421	414	410	408	380	376
0.8	794	424	529	488	554	488	434	410	398	392	389	387	365	362
0.7	794	374	473	444	512	456	406	383	372	366	363	362	345	343
0.6	794	323	415	395	463	417	373	352	342	336	334	333	319	318
0.5	794	271	354	343	407	372	334	316	306	301	299	298	288	287
0.4	794	218	290	285	345	319	288	273	264	260	258	257	250	249
0.3	794	165	222	223	274	257	234	222	215	211	210	209	204	203
0.2	794	111	152	155	193	184	169	161	156	153	152	152	148	148
0.1	794	56	78	81	102	99	92	88	85	84	83	83	81	81
0.0	794	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7 Stock projection method

Based on the abundance estimated, we conducted future projection of the stock by applying the HCR.

For the projection of the recruitment, the values estimated Ricker type model (a=13.5, b=0.00558, SD=0.507) agreed by the meeting 'Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel' held at April, 2019, were used. The data used for parameter estimate of reproduction function were SB and recruitment estimated stock assessment of 2018 which uses least-squares method as optimization method, and autocorrelation of the recruitment residuals is not considered. See details in "Technical notes on estimation of S-R relation, calculation of BRP and future projection" (https://github.com/ichimomo/future-text/blob/master/technical_document.pdf).

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 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, and was used in the projection there. The %SPR estimated by the current fishing pressure (F2014-2018) under this selectivity was set to be same as the %SPR estimated by the average *F* of 2014-2018. The catch in 2019 was estimated to be 41 thousand tons based on the current fishing pressure (F2014-2018).

The forward cohort calculation (equations 9) were used for projection.

$$N_{a+1,y+1} = N_{a,y}\, exp(-F_{a,y} - M) \quad *a < p\text{-}1 \qquad (9a)$$

$$N_{p,y+1} = (N_{p,y} + N_{p-1,y})\, exp(-F_{p,y} - M) \quad *\text{plus group} \qquad (9b)$$

The number of catch was estimated by equation below using abundance estimated above equations and F determined by catch scenario.

$$C_{a,y} = N_{a,y}\left(1 - exp(-F_{a,y})\right) exp(-\frac{M}{2}) \qquad (10)$$

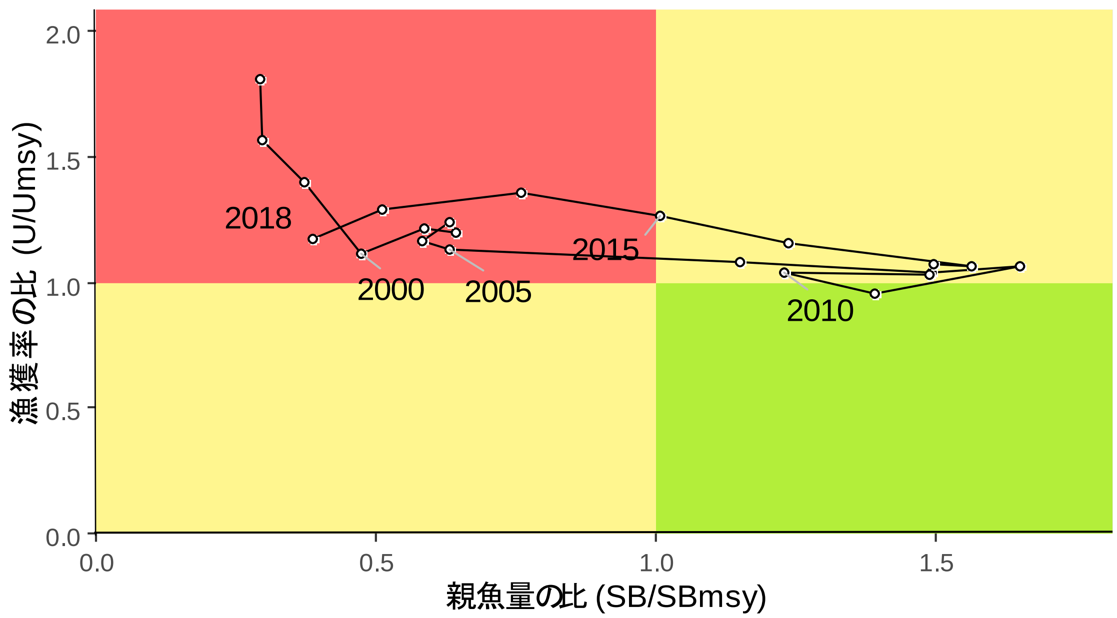
Appendix Table 7-1. Parameters used for future projection.

Age	Selectivity	Fmsy	F2014-2018	Average weight (g)	*M*	Proportion
0	0.25	0.22	0.28	129	0.40	0.00
1	0.36	0.31	0.41	287	0.40	0.00
2	0.54	0.48	0.62	417	0.40	1.00
3	1.00	0.87	1.15	476	0.40	1.00
4+	1.00	0.87	1.15	580	0.40	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). The SSB for the entire period considered is below the level which attains MSY. The ratio of the fishing rate (U/Umsy) during the 1970s to the 2000s were higher than that which attains MSY except for year 1991; however, since 2013, the ratio is around the level which attains MSY.

Item	Suggested value	Remarks
SBmsy	158,000 tons	SSB that attains MSY
Umsy	27%	Fishing rate that attains MSY
U2018	28%	Fishing rate in 2018
U2018/ Umsy	1.051	Ratio of the fishing rate in 2018 to that which attains 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. For year 2018, it is the average of 2016-2018.