Stock Assessment of Japanese Sardine Tsushima Stock in 2020

Fisheries Stock Assessment Center, Fisheries Resources Institute, Japan Fisheries Research and Education Agency

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Summary

The biomass of the present stock for the period up to 2018 was estimated by a VPA model considering the abundance index, and the biomass in 2019 was estimated by forward computation considering the amount and age composition of the catch up to the point of the 2020 stock assessment. The catch of Japanese sardines was small in 2019. Presuming that this was because Japanese sardines did not migrate to coastal waters, which are the main fishing grounds, we did not use the 2019 data of catch and abundance indices in the VPA analysis. The biomass of the present stock started to increase in the 1970s and was estimated to have reached 10 million tons in 1988. However, it sharply declined in 1990, and shifted around 5 thousand tons, the lowest level ever, from 2001 to 2003. The biomass has been on an increase since 2004. The stock biomass in 2019 was estimated at 329 thousand tons and the spawning biomass at 194 thousand tons.

At the "Research Institute Meeting on Reference Points" held in March 2020, it was proposed that the hockey stick (HS) model for the normal recruitment period (1960 to 1975 and 1988 to 2017), which is considered to reflect the recent recruitment conditions, be used for estimating the stock-recruitment (S-R) relationship of the present stock. SBmsy, which is the level of the spawning biomass that produces MSY, estimated based on this model is 1,093 thousand tons. According to this basis, the spawning biomass of the present stock for 2019 is below SBmsy. In addition, fishing mortality (F) on the stock in 2019 is extremely low, at a level below the level that produces MSY (Fmsy). The trend of the spawning biomass is determined to be "increasing" in light of the transition over the past five years (2015 to 2019).

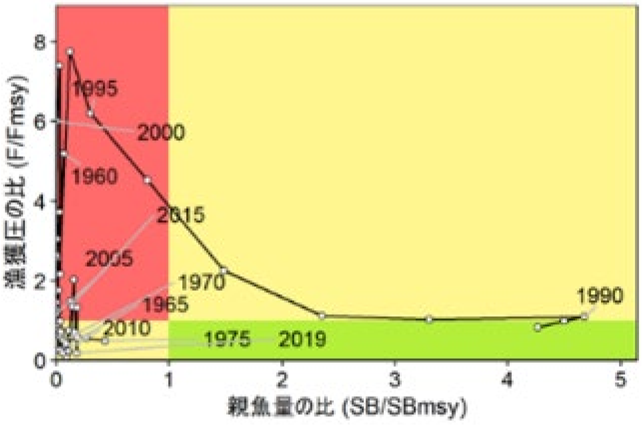
(With regard to the items that are to be developed based on discussions at the Committee of Stock Management Policy, such as reference points and future projection, we tentatively indicated the values proposed at the Research Institute Meeting on Reference Points. * For reference points, we used values that were updated in September 2020.)

Item	Value	Remarks
Level that produces MSY under the current environment		
SBmsy	1,093 thousand tons	Spawning biomass that produces MSY
Fmsy	(Ages 0, 1, 2, 3, 4 and above) = (0.25, 0.14, 0.24, 0.42, 0.42)	
%SPR (Fmsy)	41.1%	%SPR corresponding to Fmsy
Spawning biomass and fishing mortality in 2019		
SB2019	194 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3, 4 and above) = (0.01, 0.07, 0.05, 0.07, 0.05)	
%SPR (F2019)	82.2%	%SPR in 2019
%SPR (F2014-2018)	35.9%	%SPR corresponding to the average fishing mortality (F) in 2014 to 2018
Ratio to MSY		
SB2019/SBmsy	0.18	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	0.19	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

* Ratio between F in 2019 and F under the selectivity in 2019 that gives Fmsy which has been converted into %SPR.

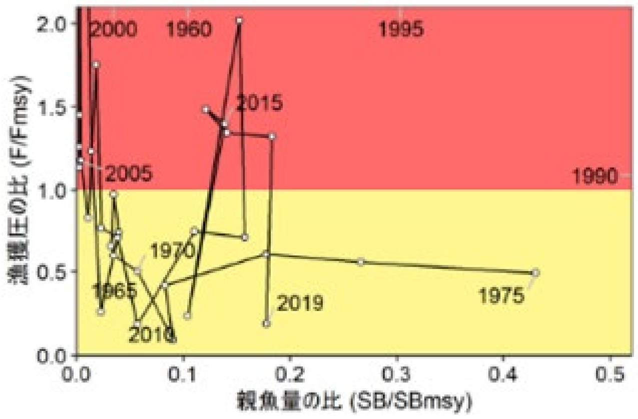
S-R relationship: HS model (no autocorrelation)

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Below Fmsy
Trend in spawning biomass	Increasing



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Enlarged view



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Year	Stock biomass (thousand tons)	Spawning biomass (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2016	268	133	62	1.48	23
2017	263	154	54	1.35	21
2018	293	200	71	1.32	24
2019	329	194	14	0.19	4
2020	463	240	98	1.20	21
2021	521	286	-	-	-

Values for 2020 and 2021 are estimates based on future projection.

1. Data set

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

Data set	Data source and research
Catch in number at age and by year	Annual Statistics on Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landing at major ports (Aomori-Kagoshima [17] prefectures) Logbook report of large- and medium-scale purse seine fisheries (Fisheries Agency of Japan) Monthly length composition survey (National Research Institute of Fisheries Science [NRIFS], Aomori-Kagoshima [17] prefectures) ・Market measurement Length-age measurement survey (NRIFS) ・Market measurement, age determination

Abundance index ・Spawning volume	Egg and larvae survey (year-round, NRIFS, Aomori-Kagoshima [17] prefectures) ・NORPAC net*
・Abundance index	Catch in purse seine fishery at Sakai Port (Tottori Prefecture, FRA-SA2020-SC01-102)* Catch in purse seine fishery in Ishikawa Prefecture (Ishikawa Prefecture, FRA-SA2020-SC01-103)*
Natural mortality (M)	Assuming M = 0.4 per year (Wada and Jacobson 1998)

Asterisk (*) denotes data used as the tuning index for the VPA analysis.

2. Ecology of the stock

(1) Distribution and migration

The present stock is widely distributed from the northern part of the East China Sea to the Sea of Japan, and the distribution range is considered to change according to the biomass (Figure 2-1). The stock had also been distributed in the offshore areas of the Sea of Japan in the 1980s, when the biomass was high, but the distribution range was limited to coastal areas from 2000 onward, when the biomass decreased (Hiyama 1998, Muko et al. 2018). Japanese sardines are considered to be seasonally migrating within this distribution range in various scales (Ito 1961, Kuroda 1991). However, scientific knowledge on migration of the present stock is lacking.

(2) Age and growth

The growth rate of the Japanese sardine is affected by not only environmental factors, such as the water temperature and food, but also intrinsic factors, such as age, and growth slows down as the fish ages. It has also been pointed out that the growth rate changes in synchronization with the stock status, and that the growth is fast in a stock increase period and the growth is slow in a high abundance period (Hiyama et al. 1995). As for the growth of the present stock in recent years, the body length reaches about 16 cm in 1 full year, about 19 cm in 2 years, and about 20 cm in 3 years, although it varies by the growing grounds. The longevity is estimated to be approximately 7 years. Figure 2-2 shows the average values of the scaled body length and body weight of catch at age from 2015 to 2019.

(3) Maturity and spawning

The age at maturity of Japanese sardines in Japan is known to change depending on the biomass (Morimoto 2010). While there are geographical differences, in the high abundance period in the past, spawning at age 1 fish was rare, and the spawning population mainly consisted of fish of age 2 and above. In the low abundance period, mature age 1 fish were observed. It has also been reported that many of age 1 fish were found to be mature, from 2008 to 2010, when abundance was low (Yoneda et al. 2013). However, whether an individual becomes mature and capable of spawning is considered to be determined by how much nutrition was accumulated before the spawning season (Morimoto 2010). Also, as environmental factors, such as the water temperature, promote or restrain maturation (Matsuyama et al. 1991), the age at maturity is considered to be also affected by short-term changes in environmental factors. Based on such information, we assumed that the age at maturity to be used in the assessment of the present stock takes an equivalent value in periods with a similar stock status (such as 1960 to 1970, 1994 to 1999, and 2016 to 2019) (Figure 2-3). The maturity rate at age used in the past assessment of the present stock was 0 to 50% for age 1, 50 to 100% for age 2, and 100% for age 3 and above. The appropriateness of the assumption concerning the maturity rate is examined based on precision measurement of individuals and histological observation of the gonad. From these observation results, a decline in the maturity rate of age 1 fish was found in 2016 (Yasuda et al. 2018). This decline in maturity rate is considered to have reflected an increase in abundance, and we assumed the maturity rate of age 1 fish in 2019 to be the same as that in 2016. The maturity rate at age in 2019 was 0% for age 0 fish, 25% for age 1 fish, and 100% for age 2 and above.

The spawning season of the present stock is from winter to spring (January to June), and the spawning tends to be earlier in waters at low latitude. The spawning grounds are formed in coastal waters from Noto Peninsula to the western coast of Kyushu (Figure 2-1), but the waters constituting the main spawning grounds change by year. Until 1986, which was a stock increase period, the egg abundance was high in waters of northern Kyushu and the western part of the Sea of Japan, but from 1990 onward, which is a stock decrease period, the egg abundance has been high in the northern part of the Sea of Japan (Hiyama 1998, Goto 1998, Furuichi et al. 2020). Looking at the coastal waters of Kyushu alone, a large amount of eggs have tended to be collected in waters of the Satsunan area in years with high stock abundance, and in waters to the north of Goto in years with low stock abundance (Matsuoka and Konishi 2001). When the sea surface temperature was lower, the spawning tended to decrease in the northern part of the Sea of Japan and it tended to increase in offshore areas of Kyushu (Furuichi et al. 2020).

(4) Prey-predator relationships

In the juvenile stage, Japanese sardines feed on zooplankton, such as copepods (Nakai 1962). In the adult stage, they feed on not only zooplankton, but also phytoplankton, such as diatoms, and anchovy eggs by filter feeding (Nakai 1962, Baba et al. 2018). Their feeding period is mainly from spring to autumn. It has been pointed out that the timing of the spring phytoplankton bloom affects recruitment of the present stock (Kodama et al. 2018). Predators of the this stock are considered to include large zooplankton and small fish in the juvenile stage, and large fish, mammals, and sea birds in the adult stage.

(5) Special notes

It has been pointed out that the biomass of Japanese sardines is affected by the ocean environment, which changes in the medium to long term (Yatsu et al. 2005). Historically, the this stock shows fluctuations at a cycle of several decades, and such fluctuation had been recognized as being a response to regime shifts in marine ecosystems (Ohshimo et al. 2009). The biomass of this stock had been low from the 1960s to the beginning of the 1970s, but showed a sudden increase from the mid-1970s. After peaking in the second half of the 1980s, the biomass sharply decreased (see 4. (2)). This stock fluctuation is considered to have been affected by changes in the ocean environment associated with the winter monsoon index (Ohshimo et al. 2009). Changes in the biomass and the ocean environment affect the growth, maturation, and successful recruitment of individuals, and could cause changes in the stock-recruitment (S-R) relationship.

3. Status of fisheries

(1) Outline of fisheries

Japanese sardines that inhabit the Tsushima Warm Current region are caught by purse seine, set net, stick-held dip net, and other fisheries. In the 1980s, when the abundance was high, fishing grounds were formed in wide areas from coastal waters to offshore waters. However, fishing grounds have mainly been formed in coastal areas in recent years.

(2) Changes in the amount and age composition of catch

With regard to the catch amount in this assessment, we totaled the catch data in the Annual Statistics on Fishery and Aquaculture Production for the area from the Sea of Japan and the East China Sea side of Aomori Prefecture to Kagoshima Prefecture, after which we added the catch in the waters of the Sea of Japan and the East China Sea by fishing vessels that belong to areas other than the Sea of Japan and the East China Sea areas, and deducted the catch in the Pacific waters by fishing vessels that belong to the Sea of Japan and the East China Sea areas, obtained from the logbook report (Figure 3-1, Table 3-1).

The catch exceeded 1 million tons in 1983, and remained above 1 million tons until 1991, but then decreased sharply, falling to 1 thousand tons by 2001. Subsequently, it turned to an increase from 2004, recording the highest catch since 2000 in 2013 at 85 thousand tons. In 2014, the catch suddenly fell to 9 thousand tons, but increased again in 2015 to 69 thousand tons. The sudden catch decrease in 2014 is considered to be due to a smaller number of individuals migrating to coastal areas which serve as fishing grounds, rather than to a decline in biomass, because a large number of older fish of age 2 and above were included in the catch in 2015. From 2015 to 2018, the catch shifted between 54 thousand tons to 71 thousand tons, but it decreased to 14 thousand tons in 2019. Looking at the catch in 2019 by sea area, the catch decreased to approximately one-third of the level in the previous year in the northern part of the Sea of Japan (Fukui Prefecture to Ishikawa Prefecture) and to approximately one-tenth of the level in the previous year in the western part of the Sea of Japan (Fukui Prefecture to Yamaguchi Prefecture). The catch in the East China Sea (Fukui Prefecture to Kagoshima Prefecture) was extremely small (Figure 3-1).

Figure 3-2 and Appendix 7 show the catch in number at age and by year. From the second half of the 1990s to 2010, the main age group composing the catch was age 0 fish. Since 2011, the proportion of fish of age 1 and above has been increasing in the catch in number.

In the Tsushima Warm Current region, Japanese sardines are caught not only by Japan, but also by South Korea, and in the past, they had also been caught by Russia. South Korea's catch recorded 190 thousand tons in 1987, but it decreased thereafter. The catch shifted between 0 and 4 thousand tons from 2000 to 2015, and between 5 thousand and 8 thousand tons from 2016 onward, but it decreased to 2 thousand tons in 2019 (Fisheries statistics (Ministry of Oceans and Fisheries, South Korea); http://www.fips.go.kr:7001/index.jsp; March 2020). Russia's catch had exceeded 200 thousand tons until 1991, but it decreased to 70 thousand tons in 1992, and there has been hardly any catch thereafter (Zhigalin (unpublished document)). China's catch of Japanese pilchard stayed between 110 thousand and 170 thousand tons from 2007 to 2018 (FAO Fishery and Aquaculture Statistics. Global capture production 1950-2018; http://www.fao.org/fishery/statistics/software/fishstatj/en; July 2020). As it is unclear whether these catches by foreign countries are catches of the present stock, we used these data as reference information, and did not include them in calculations for this stock assessment.

(3) Fishing effort

The main fishing grounds of the present stock in recent years are waters in the southwestern part of the Sea of Japan, and Japanese sardines in this sea area are mainly caught by medium-scale purse seine fishery. Medium-scale purse seine fishing vessels mainly catch pelagic fishes, such as Japanese jack mackerel, chub mackerel, and Japanese sardine, and their main landing port is Sakai Port in Tottori Prefecture. During 2000-2004, when the abundance was extremely low, Japanese sardines were often caught as by-catch by vessels targeting other fish species, and it was difficult to identify the fishing effort for Japanese sardines. In recent years, however, Japanese sardines have come to be landed in large quantities, so it is considered that the annual total of the daily number of fleets of medium-scale purse seine fishing vessels that land catch at Sakai Port can be used as a fishing effort index for the present stock (Figure 3-3, Table 3-2). The annual total of the daily number of fleets stayed stable between 1.2 to 1.6 thousand fleets from 2004 to 2018, and the total for 2019 was 1.2 thousand fleets.

4. Stock status

(1) Stock assessment method

We calculated the catch at age and by year based on the catch amount, the biological measurements of the catch, and age determination using age characteristics, such as scales, and conducted cohort analysis for the period from 1960 to 2018. In the cohort analysis, we tuned the fishing mortality (F) of 2018 using the abundance indices for 2004 to 2018 (egg production; the standardized catch per fleet of Japanese sardines landed at Sakai Port by purse seine fishery; and the catch per vessel of Japanese sardines landed in Ishikawa Prefecture by purse seine fishery based on sampled data) (Appendices 1 to 4).

According to the amount and age composition of the catch as of the time of stock assessment for 2020, 2019 was considered to be a year with an extremely small number of Japanese sardines migrating to Japan's coastal waters, which serve as fishing grounds and spawning grounds (Appendices 4 and 6). Therefore, we did not use the 2019 data of catch and egg production in the cohort analysis, considering that they did not reflect the stock biomass. The stock biomass in 2019 was estimated using forward computation based on the cohort analysis results for the period up to 2018 (Appendix 2). The recruitment in 2019 was obtained based on the estimated spawning biomass in 2019 and the hockey-stick (HS) S-R model applied to the normal recruitment period (1960 to 1975 and 1988 to 2017), which is indicated in (5) (Appendices 2 and 6).

(2) Changes in abundance indices

Appendix Table 2-4 shows the abundance indices used for tuning the fishing mortality (F), and Figure 4-1 shows changes in the index values that were normalized by dividing them by the mean values for 2004 to 2019. The egg production of the present stock based on the egg and larvae survey conducted from the western coastal waters of Kyushu to the Sea of Japan shifted between 1 trillion to 10 trillion eggs during 2005-2009, but it increased to 10 trillion to 100 trillion eggs from 2010 onward, marking 90 trillion eggs in 2018 and 31 trillion eggs in 2019 (Appendix Table 2-4). The standardized CPUE of Japanese sardines landed at Sakai Port by purse seine fishery (tons/fleet) was low during 2000-2004, but it increased from 2011 onward and maintained a high level (Appendix Table 2-4, Appendix 4-1). The amount was extremely high in 2017, but was low in 2014 and 2019 (Figure 4-1). The CPUE of Japanese sardines landed in Ishikawa Prefecture (tons/vessel) increased from 2011 onward, and without showing a large decrease in 2014, continued to indicate a gradual increase (Appendix Table 2-4, Appendix 4-2). However, in 2019, the amount substantially decreased from the previous year (Figure 4-1).

The abundance indices based on operation records of the purse seine fishery catch landed at Sakai Port and at major ports in Ishikawa Prefecture are likely to be affected not only by fluctuations in the stock density of the entire stock, but also by formation of fishing grounds. It is necessary to further study the factors that affect the migration of the present stock in the future and to continue to assess the reliability and consider accuracy improvement of the abundance indices.

Appendix 5 shows the sampling status of Japanese sardines in the fish distribution survey "Pelagic fish survey using a quantitative echo sounder" conducted in summer. As the survey area is limited compared to the distribution range of Japanese sardines in summer, we considered that a reliable abundance index for Japanese sardines has not been derived from the survey results at this point, so we did not use those data in the stock calculation, but used it as a reference material. We intend to continue to conduct the survey, accumulate data, and work on improvement of the survey and the analysis method.

(3) Trends in biomass and fishing mortality

The stock biomass obtained by cohort analysis was estimated to have increased from the 1970s and reached 10 million tons in 1988 (Figure 4-2, Table 3-1). Then the stock biomass decreased, falling below 1 million tons in 1995, and below 10 thousand tons in 2001. The biomass started to increase in 2004, and exceeded 100 thousand tons in 2010. Although it temporarily decreased in 2014, it increased to 330 thousand tons in 2019. The spawning biomass (the biomass of mature fish in stock calculation) has been increasing since 2005, and it exceeded 100 thousand tons in 2011. After that, it shifted between 110 thousand and 200 thousand tons, and was estimated at 190 thousand tons in 2019.

The recruitment (the number of age 0 fish in stock calculation) started to increase in 1971, and reached above 100 billion individuals in some years in the 1980s (Figure 4-3, Table 3-1). It turned to a decrease in 1987, falling to 42 million individuals by 2002. Then it showed an increasing trend, and shifted between 1.9 billion and 4.4 billion individuals from 2010 onward. The recruitment for 2019 was assumed to be 5.4 billion individuals based on the S-R relationship.

In stock biomass at age, the biomass of age 1 to age 3 fish constitutes a large proportion (Figure 4-4, Appendix 7). In particular, the biomass of age 1 fish constitutes the highest proportion in most of the years. The biomass of age 0 fish has stayed about the same level since 2011.

The recruitment per spawning fluctuates wildly. It shifted at low levels from the second half of the 1980s to the first half of the 1990s (Figure 4-5). This coincides with the period when the recruitment peaked and then suddenly declined. The recruitment per spawning increased in the mid-1990s, and has leveled off with some fluctuations. Relatively high values were observed in 2004, 2005, and 2010.

In the stock biomass calculation, we assumed the natural mortality (M) to be 0.4, but we also calculated the stock biomass and the spawning biomass for 2019 while changing this value to 0.3 and 0.5 (Figure 4-6). When M was larger, the estimated stock biomass and spawning biomass also became larger. When M was 0.3 and 0.5, the values were 72% and 149%, respectively, compared to when M was 0.4.

The fishing mortality (F) at age showed a gradual increase at a relatively low level from 1965 to the first half of the 1990s (Figure 4-7, Appendix 7). It sharply increased from the mid-1990s, indicating larger yearly changes. Since 2005, it has shifted at a relatively low level while rising and falling. The fishing mortality for age 0 and age 1 fish has been stable over time, but that for fish of age 3 and above has fluctuated significantly. The fishing mortality for 2019 was low for all age groups, but this is considered to have been an exceptional situation.

The exploitation rate was low from the second half of the 1960s to the first half of the 1970s, but then rose high, and showed a decreasing trend from the 1990s onward, while fluctuating wildly (Figure 4-8). The exploitation rate in 2010 was 3%, but it increased after that, and shifted between 15% and 34% until 2018, except for marking 4% in 2014. The exploitation rate in 2019 was low, at 4%.

Item	Value	Explanation
SB2019	194 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3, 4 and above) = (0.01, 0.07, 0.05, 0.07, 0.05)	
U2019	4%	Exploitation rate in 2019

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

In order to compare the fishing mortality considering the difference in selectivity, Figure 4-9 shows the value of F for each year, which has been converted into %SPR (the ratio of SPR corresponding to the catch in each year to SPR assuming no catch). The lower the fishing mortality, the higher the %SPR. The %SPR changes substantially by year, and it indicated low values from 1994 to 1996 and from 1998 to 2000. While the %SPR shifted between 20% and 53% from 2000 onward, the value was high in 2010, 2014, and 2019.

The fishing mortality in 2019 is considered to be low and very uncertain. Therefore, the current fishing mortality was given by the average value of 5 years from 2014 to 2018. Figure 4-10 shows the relationship between YPR and %SPR for the current fishing mortality. As for the selectivity in F, we used the selectivity value which was used to estimate F that produces the maximum sustainable yield (MSY) (Fmsy) (Takahashi et al. 2020b*) at the "Research Institute Meeting on Reference Points" held in March 2020. For the body weight at age and the maturity rate, we also used the values which were used to calculate Fmsy. Fmsy corresponds to 41.1% in %SPR. F that produces 35.9%SPR under the same conditions was set as the current fishing mortality (F2014-F2018). F2014-F2018 was above Fmsy, F40%SPR, and F0.1.

Item	Value	Explanation
%SPR (F2019)	82.1%	%SPR in 2019
%SPR (F2014-2018)	35.9%	%SPR corresponding to the current fishing mortality (F2014 -2018)

(5) S-R relationship

Figure 4-11 shows the relationship between spawning biomass (in weight) and recruitment (in number) (S-R relationship). At the abovementioned "Research Institute Meeting on Reference Points," it was proposed that the S-R relationship can be divided into the normal recruitment period (1960 to 1975 and 1988 to 2017) and the high recruitment period (1976 to 1987) according to the recruitment levels, and that the HS S-R relationship be applied to the respective periods (Takahashi et al. 2020b*). The recruitment status in 2019 is considered to belong to the normal recruitment period (1960 to 1975 and 1988 to 2017), which includes the S-R relationship in recent years. The parameters for the HS S-R relationship in the normal recruitment period are shown in the table below. Here, the data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment, which were obtained by modifying the plus group in the stock assessment conducted in 2019 (Takahashi et al. 2020a) (Appendix 3), and as for the optimization method, the least absolute value method is used. The model does not consider autocorrelation between the residuals of the recruitment.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey stick	Least squares method	No	0.0276	7.36e+05	0.683

Here, parameter a is the steepness (individuals/g) of the HS S-R curve from the origin to the break point, and b is the spawning biomass (tons) at the break point.

(6) Level that produces MSY under the current environment

As the current environment, the values proposed at the abovementioned "Research Institute Meeting on Reference Points" as the spawning biomass that produces MSY (SBmsy) and the fishing mortality that produces MSY (Fmsy) under the conditions in the normal recruitment period (1960 to 1975 and 1988 to 2017) (Takahashi et al. 2020b*) are shown in the table below.

Item	Proposed value	Explanation
SBmsy	1,093 thousand tons	Spawning biomass that produces MSY
Fmsy	(Ages 0, 1, 2, 3, 4 and above) = (0.25, 0.14, 0.24, 0.42, 0.42)	
%SPR (Fmsy)	41.1%	%SPR corresponding to Fmsy
MSY	338 thousand tons	Maximum sustainable yield

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

Figure 4-12 shows a Kobe plot based on the spawning biomass that produces MSY and the corresponding fishing mortality at that time. The fishing mortality on the present stock in recent years is considered to be slightly above the level that produces MSY. The fishing mortality (F) in 2019 was 0.19 times the level that produces MSY (Fmsy). Meanwhile, the spawning biomass of the present stock was lower than the level that produces SMY (SBmsy) from 1994 to 2019 (Table 3-1). The ratio of F (F/Fmsy) shows the yearly ratio between F and F where %SPR becomes a value corresponding to Fmsy under the selectivity in that year. The trend of the spawning biomass is considered to be "increasing" in light of the transition over the past 5 years (2015 to 2019).

Item	Value	Explanation
SB2019/SBmsy	0.18	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	0.19	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

* Ratio between F in 2019 and F under the selectivity in 2019 that gives Fmsy which has been converted into %SPR.

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Below SBmsy
Trend in spawning biomass	Increasing

5. Stock assessment summary

The spawning biomass of the present stock was lower than the level that produces MSY (SBmsy) from 1994 to 2019. In recent years, the fishing mortality remained slightly above Fmsy, but it fell below Fmsy in 2019. The trend of the spawning biomass is considered to be "increasing" in light of the transition over the past 5 years (2015 to 2019).

6. Others

The current stock biomass has increased to 6 to 7 times the level seen during 2000-2004, but it is still low compared to the biomass in the 1980s. Meanwhile, the recruitment per spawning of the present stock fluctuates notably year by year (Figure 4-5), and there is a possibility in the future that the recruitment will increase along with an increase in the biomass, and the S-R relationship in a high recruitment period will be realized. In using and managing the present stock, it is necessary to sufficiently take into consideration how harvest control rules (HCRs) should be reviewed in line with a review of the S-R relationship, and how we should shift to the revised HCRs. A stock rebuilding plan for Japanese jack mackerel (including chub mackerel and Japanese sardine) in the western Sea of Japan and western waters of Kyushu was implemented during the period from 2009 to 2011. Under this plan, which aimed to conserve small juveniles, if a fishing vessel's catch mainly consisted of small juveniles, the vessel was required to promptly shift to another fishing ground to avoid imposing concentrated fishing mortality in the case of large- to medium-scale purse seine fishery, and the fishery organization of the vessel became subject to fishing regulations, such as a reduced number of fishing and landing days, in the case of medium- to small-scale purse seine fishery. These initiatives have been continued to date under the Resource Management Guidelines and resource management plans, and it is considered desirable to continue them in the future.

7. References

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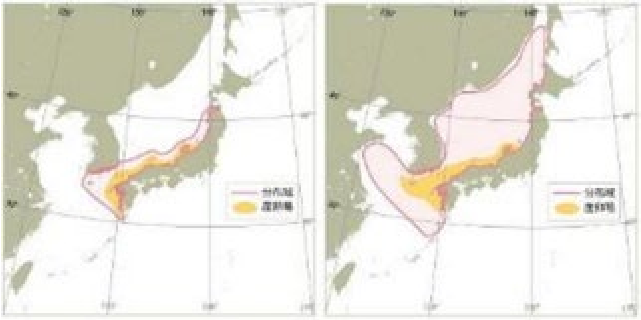
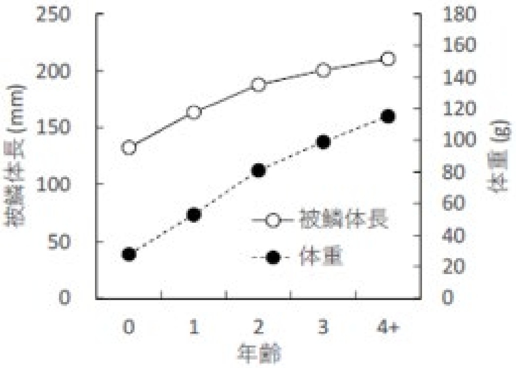
(Authors: Soyoka Muko, Motomitsu Takahashi, Hiroyuki Kurota, Mari Yoda, and Haruhiko Hino)



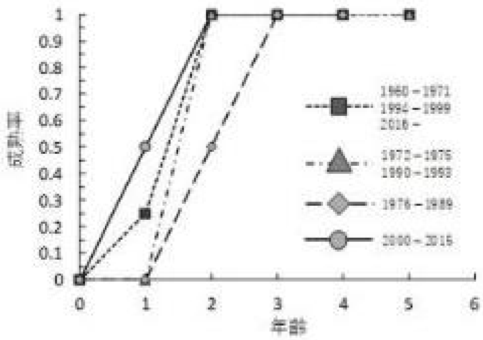
分布域	Distribution range
産卵場	Spawning grounds

Figure 2-1. Schematic of distribution, migration, life history, and fishing ground formation of Japanese sardine Tsushima stock (left: low abundance period; right: high abundance period)



被鱗体長（mm）	Scaled body length (mm)
体重（g）	Body weight (g)
年齢	Age

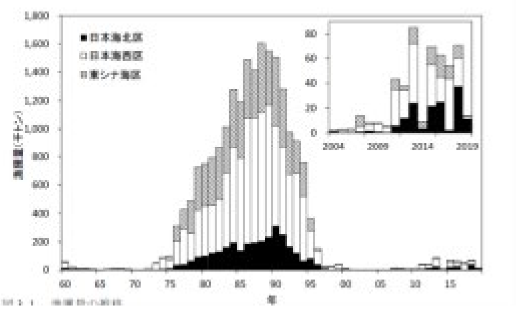
Figure 2-2. Age and growth



成熟率	Maturity rate

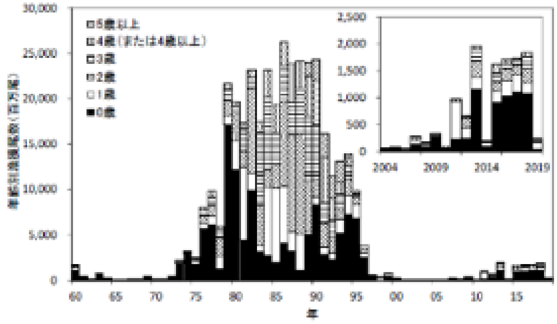
年齢	Age in years

Figure 2-3. Age and maturity rate



年	Year
漁獲量（千トン）	Catch (thousand tons)
日本海北区	Northern Sea of Japan region
日本海西区	Western Sea of Japan region
東シナ海区	East China Sea region

Figure 3-1. Changes in catch

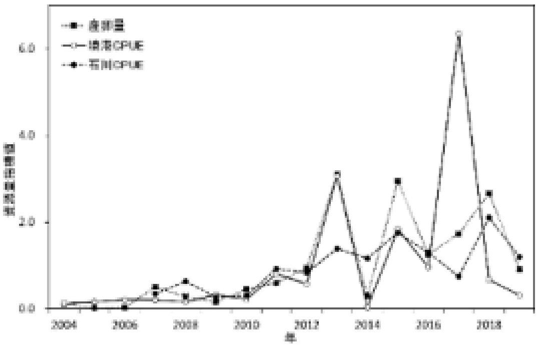


年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
5 歳以上	Age 5 and above
4 歳（または 4 歳以上）	Age 4 (or age 4 and above)
3 歳	Age 3
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

Figure 3-2. Changes in catch in number at age

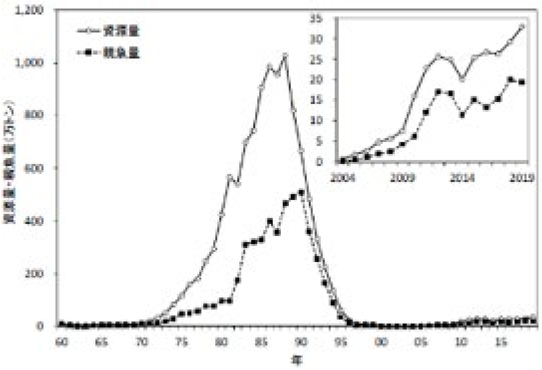
延べ日別水揚げ統数（千統）	Annual total of the daily number of fleets landing catch (thousand fleets)
年	Year
境港まき網延べ日別水揚げ統数	Annual total of the daily number of fleets of purse seine fishing vessels landing catch at Sakai Port

Figure 3-3. Changes in the fishing effort of medium-scale purse seine fishery at Sakai Port (annual total of the daily number of fleets landing catch)



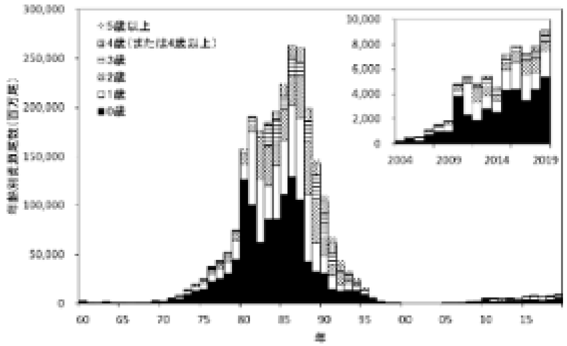
資源量指標値	Abundance indices
年	Year
産卵量	Egg production
境港 CPUE	Sakai Port CPUE
石川 CPUE	Ishikawa Prefecture CPUE

Figure 4-1. Changes in abundance indices (values normalized by dividing them by the mean values)



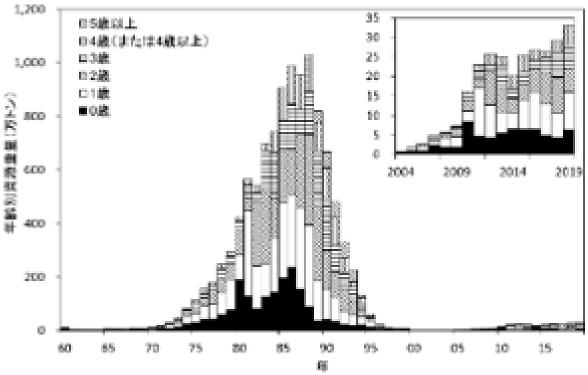
資源量・親魚量（万トン）	Stock biomass / spawning biomass (10 thousand tons)
年	Year
資源量	Stock biomass
親魚量	Spawning biomass

Figure 4-2. Changes in stock biomass and spawning biomass



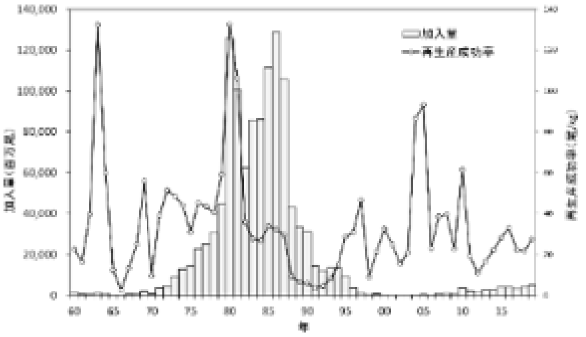
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)
年	Year
5 歳以上	Age 5 and above
4 歳（または 4 歳以上）	Age 4 (or age 4 and above)
3 歳	Age 3
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

Figure 4-3. Changes in the number of fish at age



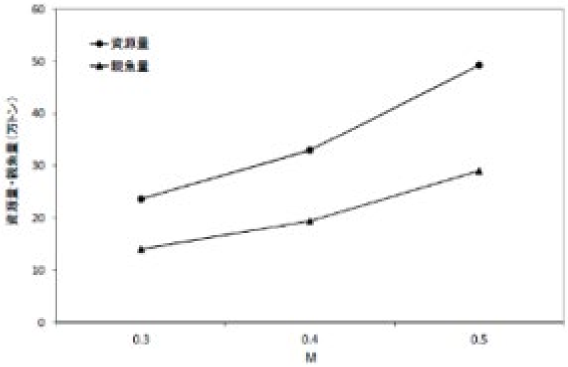
年齢別資源重量（万トン）	Stock biomass atat age (10 thousand tons)
年	Year
5 歳以上	Age 5 and above
4 歳（または 4 歳以上）	Age 4 (or age 4 and above)
3 歳	Age 3
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

Figure 4-4. Changes in stock biomass at age



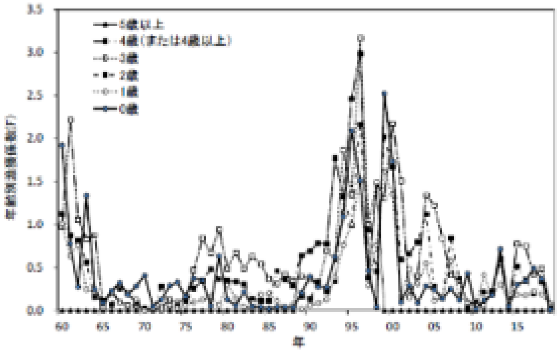
加入量（百万尾）	Recruitment (million individuals)
年	Year
再生産成功率（尾/kg）	Recruitment per spawning (individuals/kg)
加入量	Recruitment
再生産成功率	Recruitment per spawning

Figure 4-5. Changes in recruitment and recruitment per spawning



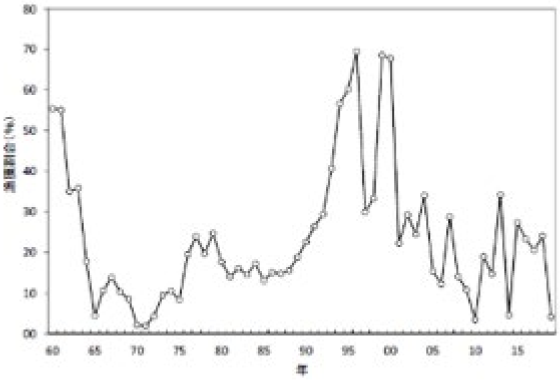
資源量・親魚量（万トン）	Stock biomass, spawning biomass (10 thousand tons)
資源量	Stock biomass
親魚量	Spawning biomass

Figure 4-6. Influence of natural mortality (M) on estimation of stock biomass and spawning biomass



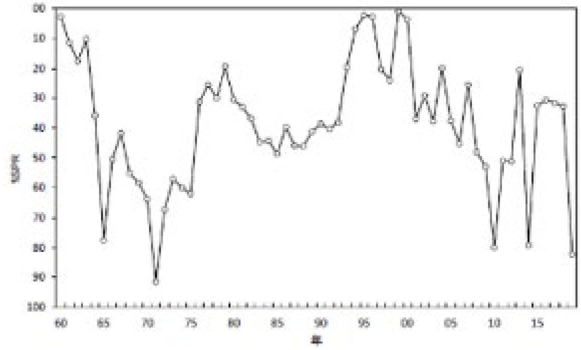
年齢別漁獲係数(F)	Fishing mortality at age (F)
年	Year
5 歳以上	Age 5 and above
4 歳（または 4 歳以上）	Age 4 (or age 4 and above)
3 歳	Age 3
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

Figure 4-7. Changes in fishing mortality (F) at age



漁獲割合（%）	Exploitation rate (%)
年	Year

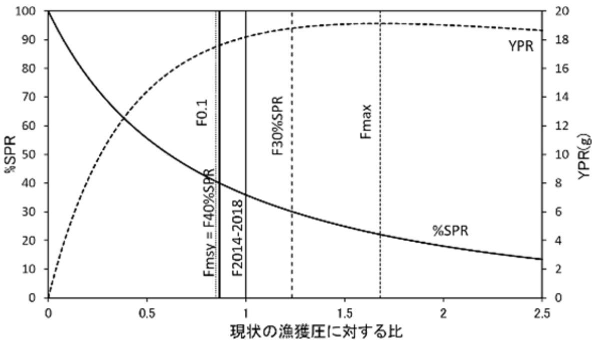
Figure 4-8. Changes in exploitation rate



年	Year

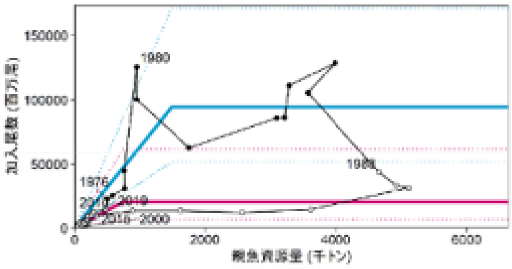
Figure 4-9. Changes in %SPR values

The %SPR indicates the ratio of spawning biomass with catch to spawning biomass assuming no catch. The higher (lower) the fishing mortality (F), the lower (higher) the %SPR.



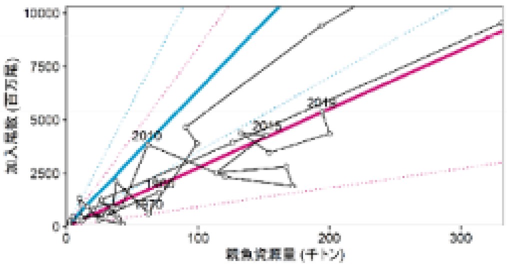
現状の漁獲圧に対する比	Ratio to the current fishing mortality

Figure 4-10. Relationship between YPR and %SPR for the current fishing mortality (F2014-2018)



加入尾数（百万尾）	Recruitment (million individuals)
親魚資源量（千トン）	Spawning biomass (thousand tons)

Enlarged view

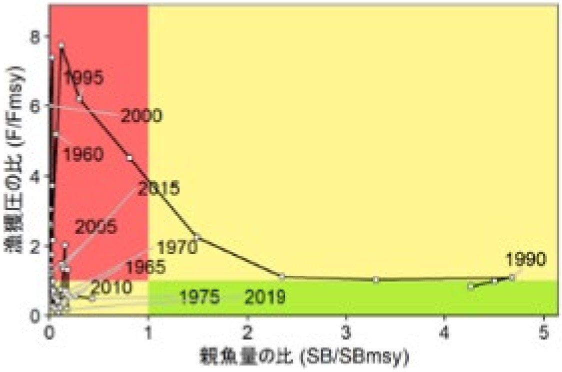


加入尾数（百万尾）	Recruitment (million individuals)
親魚資源量（千トン）	Spawning biomass (thousand tons)

Figure 4-11. Relationship between spawning biomass and recruitment (S-R relationship)

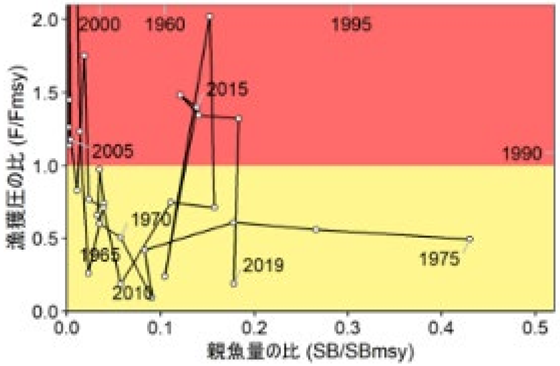
The S-R relationship proposed at the "Research Institute Meeting on Reference Points" held in March 2020 (Takahashi et al. 2020b*)

The red line shows the S-R relationship in the normal recruitment period (1960 to 1975 and 1988 to 2017) and the blue line shows the S-R relationship in the high recruitment period (1976 to 1987). The circles are actual measurement data (1960 to 2019), and the white circles indicate values for the normal recruitment period, while black circles indicate values for the high recruitment period. The dotted lines above and below the S-R relationship show the range that is estimated to cover 90% of the observation data under the assumed S-R relationship. Numbers in the figure denote the year class.



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Enlarged view

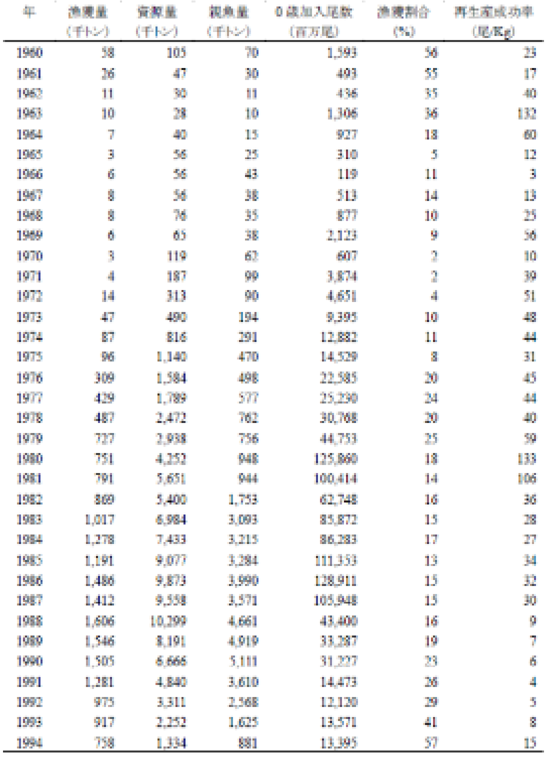


漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Figure 4-12. Relationship of the past spawning biomass and fishing mortality (F) to the spawning biomass that produces the maximum sustainable yield MSY (SBmsy) and F that produces MSY (Fmsy) (Kobe plot) and its enlarged view

SBmsy and Fmsy assume the normal recruitment period (1960 to 1975 and 1988 to 2017), and the plots of the spawning biomass and F are also limited to that period.

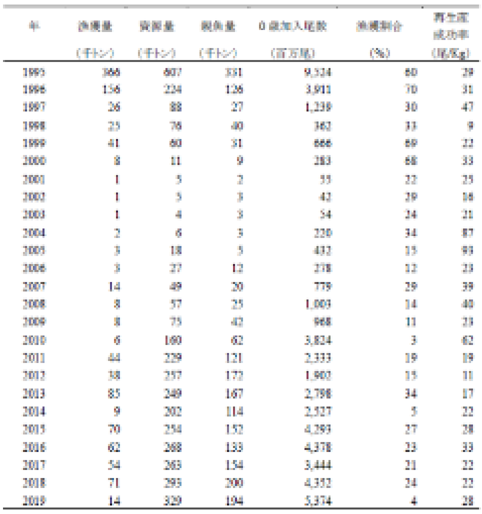
Table 3-1. Catch and stock analysis results (1960-1994)



年	漁獲量（千トン）	資源量（千トン）	親魚量（千トン）	0 歳加入尾数（百万尾）	漁獲割合（%）	再生産成功率（尾/Kg）
1960	58	105	70	1,593	56	23
1961	26	47	30	493	55	17
1962	11	30	11	436	35	40
1963	10	28	10	1,306	36	132
1964	7	40	15	927	18	60
1965	3	56	25	310	5	12
1966	6	56	43	119	11	3
1967	8	56	38	513	14	13
1968	8	76	35	877	10	25
1969	6	65	38	2,123	9	56
1970	3	119	62	607	2	10
1971	4	187	99	3,874	2	39
1972	14	313	90	4,651	4	51
1973	47	490	194	9,395	10	48
1974	87	816	291	12,882	11	44
1975	96	1,140	470	14,529	8	31
1976	309	1,584	498	22,585	20	45
1977	429	1,789	577	25,230	24	44
1978	487	2,472	762	30,768	20	40
1979	727	2,938	756	44,753	25	59
1980	751	4,252	948	125,860	18	133
1981	791	5,651	944	100,414	14	106
1982	869	5,400	1,753	62,748	16	36
1983	1,017	6,984	3,093	85,872	15	28
1984	1,278	7,433	3,215	86,283	17	27
1985	1,191	9,077	3,284	111,353	13	34
1986	1,486	9,873	3,990	128,911	15	32
1987	1,412	9,558	3,571	105,948	15	30
1988	1,606	10,299	4,661	43,400	16	9
1989	1,546	8,191	4,919	33,287	19	7
1990	1,505	6,666	5,111	31,227	23	6
1991	1,281	4,840	3,610	14,473	26	4
1992	975	3,311	2,568	12,120	29	5
1993	917	2,252	1,625	13,571	41	8
1994	758	1,334	881	13,395	57	15

年	Year
漁獲量（千トン）	Catch (thousand tons)
資源量（千トン）	Stock biomass (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
0 歳加入尾数（百万尾）	Age 0 recruitment (million individuals)
漁獲割合	Exploitation rate (%)
再生産成功率（尾/kg）	Recruitment per spawning (individuals/kg)

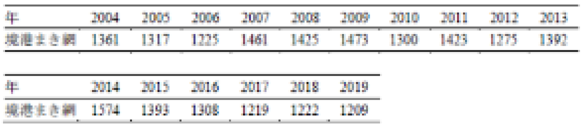
Table 3-1. Catch and stock analysis results (1995-2019)



年	漁獲量（千トン）	資源量（千トン）	親魚量（千トン）	0 歳加入尾数（百万尾）	漁獲割合（%）	再生産成功率（尾/Kg）
1995	366	607	331	9,324	60	29
1996	156	224	126	3,911	70	31
1997	26	88	27	1,239	30	47
1998	25	76	40	362	33	9
1999	41	60	31	666	69	22
2000	8	11	9	283	68	33
2001	1	5	2	55	22	25
2002	1	5	3	42	29	18
2003	1	4	3	54	24	21
2004	2	6	3	220	34	87
2005	3	18	5	432	15	93
2006	3	27	12	278	12	23
2007	14	49	20	779	29	39
2008	8	57	25	1,003	14	40
2009	8	75	42	968	11	23
2010	6	160	62	3,824	3	62
2011	44	229	121	2,333	19	19
2012	38	257	172	1,902	15	11
2013	85	249	167	2,798	34	17
2014	9	202	114	2,527	5	22
2015	70	254	152	4,293	27	28
2016	62	268	133	4,378	23	33
2017	54	263	154	3,444	21	22
2018	71	293	200	4,352	24	22
2019	14	329	194	5,374	4	28

年	Year
漁獲量（千トン）	Catch (thousand tons)
資源量（千トン）	Stock biomass (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
0 歳加入尾数（百万尾）	Age 0 recruitment (million individuals)
漁獲割合	Exploitation rate (%)
再生産成功率（尾/kg）	Recruitment per spawning (individuals/kg)

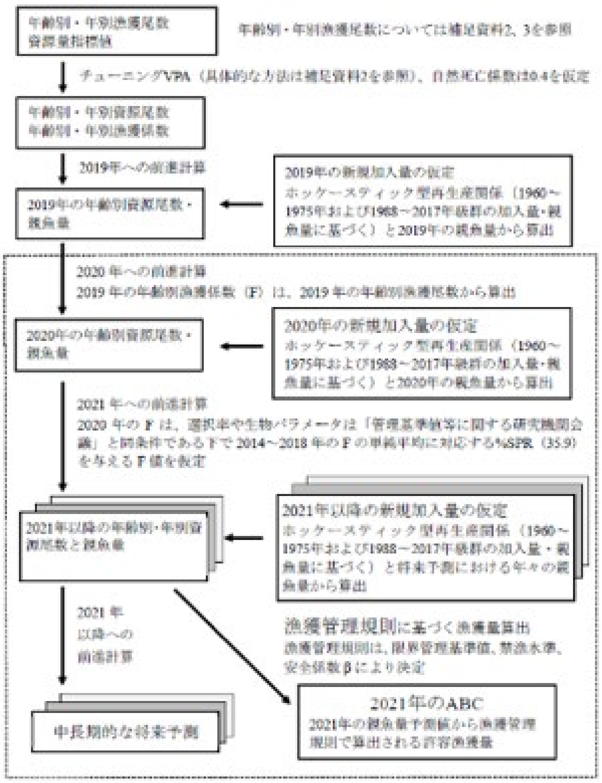
Table 3-2. Fishing effort (annual total of the daily number of fleets of medium-scale purse seine fishing vessels landing catch at Sakai Port)



年	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
境港まき網	1361	1317	1225	1461	1425	1473	1300	1423	1275	1392	1574	1393	1308	1219	1222	1209

年	Year
境港まき網	Sakai Port purse seine fishery

Appendix 1. The workflow of stock assessment



年齢別・年別漁獲尾数	Catch in number at age and by year
資源量指標値	Abundance indices
年齢別・年別漁獲尾数については補足資料 2、3 を参照	For details of the catch in number at age and by year, see Appendices 2 and 3.
チューニング VPA（具体的な方法は補足資料 2 を参照）、自然死亡係数は 0.4 を仮定	Tuned VPA (for the specific method, see Appendix 2); natural mortality is assumed as 0.4
年齢別・年別資源尾数	Number of fish at age and by year
年齢別・年別漁獲係数	Fishing mortality at age and by year
2019 年への前進計算	Forward computation to 2019
2019 年の年齢別資源尾数・親魚量	Number of fish and spawning biomass at age in 2019
2019 年の新規加入量の仮定	Assumption of new recruitment in 2019
ホッケー スティック型再生産関係（1960～1975 年および 1988～2017 年 級群の加入量・親魚量に基づく）と 2019 年の親魚 量から算出	Estimated from HS S-R relationship (based on recruitment /spawning biomass of 1960-1975 and 1988-2017 year classes) and the spawning biomass in 2019
2020 年への前進計算	Forward computation to 2020

2019 年の年齢別漁獲係数（F）は、2019 年の年齢別漁獲尾数から算出	Fishing mortality (F) at age in 2019 is estimated from catch in number at age in 2019
2020 年の年齢別資源尾数・親魚量	Number of fish and spawning biomass at age in 2020
2020 年の新規加入量の仮定	Assumption of new recruitment in 2020
ホッケー スティック型再生産関係（1960〜1975 年および 1988〜2017 年 級群 の加入量・親魚量に基づく）と 2020 年の親魚 量から算出	Estimated from HS S-R relationship (based on recruitment / spawning biomass of 1960-1975 and 1988-2017 year classes) and the spawning biomass in 2020
2021 年への前進計算	Forward computation to 2021
2020 年の F は、選択率や生物パラメータは「管理基準値等に関する研究機関会議」と同条件である下で 2014〜2018 年の F の単純平均に対応する%SPR（35.9）を与え る F 値を仮定	F for 2020 is assumed to be the F value that gives the %SPR (35.9) that corresponds to the simple average of F in 2014 to 2018 where the selectivity and biological parameters are the same as those proposed at the "Research Institute Meeting on Reference Points."
2021 年以降の年齢別・年別資源尾数と親魚量	Number of fish and spawning biomass at age and by year in 2021 onward
2021 年以降の新規加入量の仮定	Assumption of new recruitment in 2021 onward
ホッケー スティック型再生産関係（1960〜1975 年および 1988〜2017 年 級群 の加入量・親魚量に基づく）と将来予測における年々の親魚量から算出	Estimated from HS S-R relationship (based on recruitment / spawning biomass of 1960-1975 and 1988-2017 year classes) and the spawning biomass projected for each year
2021 年以降への前進計算	Forward computation to 2021 onward
漁獲管理規則に基づく漁獲量算出	Estimation of catch based on HCRs
漁獲管理規則は、限界管理基準値、禁漁水準、安全係数 β により決定	HCRs are decided based on the limit reference point, fishing ban level, and safety coefficient β.
中長期的な将来予測	Medium- to long-term future projection
2021 年の ABC	ABC of 2021
2021 年の親魚量予測値から漁獲管理規則で算出される許容漁獲量	Allowable catch based on the predicted spawning biomass in 2021 and HCRs

* Workflows in the dashed box are created based on discussions on reference points and HCRs at the Committee of Stock Management Policy.
(http://www.fra.affrc.go.jp/ shigen_hyoka/SCmeeting/2019-1/detail_maiwashi_tc.pdf)

Appendix 2. Calculation method

(1) Stock calculation method (cohort analysis)

We estimated the number of fish at age and by year based on tuned VPA (cohort analysis) by using the catch in number at age and by year and abundance indices for years up to 2018. The number of fish at age in 2019 was estimated by forward computation from the abundance at age in 2018 and the catch in number at age in 2019 that were obtained by cohort analysis. We performed future projection for 2020 onward based on HCRs.

The catch in number at age and by year used for the cohort analysis was calculated based on data of the catch in the northern Sea of Japan region, the western Sea of Japan region, and the East China Sea region, and the landing volume and body length composition of catch at major ports on the Sea of Japan to East China Sea side of Japan in the Annual Statistics on Fishery and Aquaculture Production (Appendix 7). With regard to the catch, we added the catch in the East China Sea by vessels registered in prefectures on the Pacific side of Japan and deducted the catch in the Pacific Ocean by vessels registered in prefectures on the Sea of Japan to East China Sea side of Japan, obtained from the logbook report of large- and medium-scale purse seine fisheries. For the age-length relationship, we used the results of scale-based age determination. Appendix Table 2-1 shows the average body weight at age in 2019, Appendix Table 2-2 shows the natural mortality (M) used for the stock calculation, and Appendix Table 2-3 shows the maturity rate.

We set the start of the fishing season for the VPA to January, used the approximate equation by Pope for the calculation of the number of fish at age and by year, and followed the method by Hiramatsu (2000; calculation of the plus group in an unsteady case, $\alpha = 1$) for the calculation of the number of fish of the plus group. We classified the age groups as follows: age 0, age 1, age 2, age 3, and age 4+ for 1953 to 1988 and 1999 to 2018; and age 0, age 1, age 2, age 3, age 4, and age 5+ for 1989 to 1998 (age 4 and above and age 5 and above are collectively indicated as age 4+ and age 5+ (plus group), respectively).

1. Calculation of thenumber of fish using the approximate equation by Pope (step 1)

The number of fish at age and by year was calculated based on equation (1).

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

Here, $N_{a,y}$ is the number of age a fish in year y, $C_{a,y}$ is the catch in number of age a fish in year y, and M is the natural mortality (0.4).

However, for the calculation of the number of the most recent year, for the oldest age (age p) and a year younger than that (age p-1), were calculated based on equations (2) to (4).

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

$$N_{p-1,y} = \frac{C_{p-1,y}}{C_{p,y}+C_{p-1,y}} N_{p,y+1} \times \exp(M) + C_{p-1,y} \times \exp\left(\frac{M}{2}\right) \qquad (3)$$

$$N_{p,y} = \frac{C_{p,y}}{C_{p-1,y}} N_{p-1,y} = \frac{C_{p,y}}{C_{p,y}+C_{p-1,y}} N_{p,y+1} \times \exp(M) + C_{p,y} \times \exp\left(\frac{M}{2}\right) \qquad (4)$$

The year in which the age of the plus group changes was estimated as follows according to age.

The number of age 3 fish and age 4 fish in 1988, $N_{3,1988}$ and $N_{4,1988}$, were estimated by the following equations, reviewing the conventional stock calculation method (Appendix 3). At the "Research Institute Meeting on Reference Points" held in March 2020, results obtained by the following corrected equations were used (Takahashi et al. 2020b*).

$$N_{3,1988} = \frac{C_{3,1988} \times (N_{4,1989} + N_{5+,1989}) \times \exp(M)}{C_{3,1988} + C_{4+,1988}} + C_{3,1988} \times \exp\left(\frac{M}{2}\right) \qquad (5)$$

$$N_{4+,1988} = N_{3,1988} \times \frac{C_{4+,1988}}{C_{3,1988}} \qquad (6)$$

The number of age 3 fish and age 4 fish in 1998, $N_{3,1998}$ and $N_{4,1998}$, were estimated by the following equations.

$$N_{3,1998} = \frac{C_{3,1998} \times N_{4+,1999} \times \exp(M)}{C_{3,1998} + C_{4,1998} + C_{5+,1998}} + C_{3,1998} \times \exp\left(\frac{M}{2}\right) \qquad (7)$$

$$N_{4,1998} = N_{3,1998} \times \frac{C_{4,1998}}{C_{3,1998}} \qquad (8)$$

F is the fishing mortality, and it is calculated by equation (9), except for that in the most recent year (terminal F).

$$F_{a,y} = -\ln\left\{1 - \frac{C_{a,y} \times \exp\left(\frac{M}{2}\right)}{N_{a,y}}\right\} \qquad (9)$$

Where F for the plus group was set to be equal to F of one year old younger than the oldest age group minus. F in 2018, which was the most recent year in the cohort analysis, (terminal F) was set to be the average of F for each age in the past 5 years with regard to fish of age 0 to age 3. Regarding the plus group (4+), F was obtained to become equal to F for the oldest age group − age 1 (age 3). Then, F in the most recent year was further tuned by the method in step 2.

2. Tuning of F in the most recent year (step 2)

We obtained terminal F in an exploratory manner by tuning, using abundance indices. In step 1, the terminal F for each age was the average value of the past 5 years (from 2013 to 2017). In step 2, we assumed the selectivity calculated from the fishing mortality at age obtained in step 1 to be the selectivity for terminal F, and estimated the size of F to be multiplied by the selectivity, by tuning.

The abundance indices used for tuning F were the egg production, the daily catch per fleet of Japanese sardines landed at Sakai Port by purse seine fishery (hereinafter, Sakai Port CPUE), and the catch per vessel of Japanese sardines landed in Ishikawa Prefecture by medium-scale purse seine fishery (hereinafter, Ishikawa Prefecture CPUE) (Appendix Table 2-4). The egg production was calculated based on the number of eggs of Japanese sardines collected using the NORPAC net from January to June from waters off Kagoshima Prefecture in western Kyushu to waters off the Sea of Japan coast of Aomori Prefecture. For the Sakai Port CPUE, we used standardized CPUE in which the month effect is eliminated by using a two-level generalized linear mixed model (delta-lognormal GLMM) (Appendix 4). For the Ishikawa Prefecture CPUE, in order to consider the data of fisheries targeting Japanese sardines, which became clear for 2007 onward, we used directed CPUE, which was calculated by extracting operations that accounted for 90% of the year's total catch in descending order of the Japanese sardine fishing rate per operation (Appendix 4).

The period subject to the indices was, for the Sakai Port CPUE and the egg production, from 2004 to 2018, when the stock biomass exceeded 5 thousand tons. For the Ishikawa Prefecture CPUE, the period was from 2007 to 2018, when the proportion of the data of operations with catch exceeded 0.5. The catch amount of the Japanese sardine Tsushima stock was extremely small in 2014. As the catch in 2015 included a large number of older fish of age 2 and above, it was considered that the number of fish migrating to the coastal areas, which serve as fishing grounds, was extremely small in 2014. Since abundance indices based on the catch data at Sakai Port and the egg and larvae survey, with small landing volumes, may not properly indicate the stock biomass and the spawning biomass, 2014 was excluded from the tuning period with regard to the Sakai Port CPUE and egg production. On the other hand, no significant decrease was observed in the 2014 catch in Ishikawa Prefecture, so 2014 was included in making the adjustment with regard to the Ishikawa Prefecture CPUE.

We estimated terminal F in a manner that the spawning biomass obtained by cohort analysis best fits the egg production, the stock biomass of all ages best fits the Sakai Port CPUE, and the stock biomass of fish of age 1 and above best fits the Ishikawa Prefecture CPUE, by the maximum likelihood method. For these three types of biomass indices, the negative log-likelihood to be minimized was defined as below (Hashimoto et al. 2018).

$$-\ln L = \sum_f \sum_y \frac{\left[\ln I_{f,y} - \left(b_f \ln B_{f,y} + \ln q_f\right)\right]^2}{2\sigma_f{}^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma_f}\right) \qquad (10)$$

Here, $I_{f,y}$ is index f (1: egg production; 2: Sakai Port CPUE; 3: Ishikawa Prefecture CPUE) in year y, $B_{f,y}$ is the biomass (1: spawning biomass; 2: stock biomass; 3: biomass of fish of age 1 and above) to be applied to index f in year y, and q_f, b_f, and σ_f are estimated parameters (estimated simultaneously with terminal F). We assumed that $I_{f,y}$ and $B_{f,y}$ have the allometric relationship shown below.

We also assumed that $I_{f,k}$ and $N_{a,y}$ have the allometric relationship shown below.

$$I_{f,y} = q_f B_y^{b_f} \tag{11}$$

Where bf was fixed at 1 for all indices in this stock assessment. This is because, when bf was estimated, the bias in abundance estimation became high. As a result of obtaining F that minimizes (equation 10) in an exploratory manner, the following was estimated: $F_{0,2018} = 0.36$, $F_{1,2018} = 0.19$, F2,2018 = 0.33, $F_{3,2018} = 0.49$, and $F_{4+,2018} = 0.49$. Other parameters were $q_1 = 3.255$, $q_2 = 0.101$, $q_3 = 1.841$, $\sigma_1 = 0.774$, $\sigma_2 = 0.814$, and $\sigma_3 = 0.479$.

We conducted cohort analysis for a period up to 2018 because we determined that the stock biomass in 2019 would clearly be underestimated if it were estimated by cohort analysis using the catch amount and other data for a period up to 2019. When we used the catch amount and other data for a period up to 2019, the projected biomass of fish of age 1 and above in 2020, obtained by multiplying the projected number of fish at age of fish of age 1 and above by the body weight of catch at age for 2015 to 2019, was 99 thousand tons, and the projected catch amount, obtained by multiplying that projected abundance by the fishing mortality at age for 2015 to 2019, was 43 thousand tons. However, the amount of Japanese sardines caught in the Sea of Japan and the East China Sea from January to May 2020 was 47 thousand tons (Appendix 6), already exceeding the projected catch amount. The ratio of the catch for January to May to the annual catch was 54.4% (±17.8S.D.) on average in 2015 to 2019, and the catch in 2020 is expected to increase further. Also, it is unlikely that the fishing mortality in 2020 suddenly increased due to a change in the mode of operation or other factors. Due to these reasons, we considered that Japanese sardines' migration in 2019 was peculiar, and although the stock existed in offshore waters, they did not migrate to the coastal waters, which are the main fishing grounds, and were therefore not caught; thus, we did not use the catch amount and abundance indices for 2019 in the cohort analysis.

3. Calculation of the number of fish and fishing mortality in 2019

The number of fish of age 1 and above was estimated by forward computation using the results in 2.

$$N_{a+1,y+1} = N_{a,y} \exp\left(-F_{a,y} - M\right) \tag{12}$$

However, the following equation was used for the number of fish of the plus group (age 4+).

$$N_{4+,y+1} = \left(N_{3,y} + N_{4+,y}\right) \times \exp\left(-F_{3,y} - M\right) \tag{13}$$

We calculated the number of age 0 fish in 2019, $N_{0,2019}$, based on the S-R relationship given by the spawning biomass in 2019 (SSB_{2019}) and equation (14). This S-R relationship was proposed at the "Research Institute Meeting on Reference Points" held in March 2020 as the HS S-R relationship (Clark et al. 1985) based on the recruitment and spawning biomass in the normal recruitment period (1960 to 1975 and 1988 to 2017), which is considered to reflect the recent recruitment conditions (Takahashi et al. 2020b*).

$$N_{0,y} = \begin{cases} 0.0276 \times 7.36e+05 & \text{if } SSB_y \geq 7.36e+05 \\ 0.0276 \times SSB_y & \text{if } SSB_y < 7.36e+05 \end{cases} \tag{14}$$

The fishing mortality of age a fish (including the plus group) in 2019, $F_{a,2019}$, was calculated by equation (9), using the catch in number at age and the number of fish at age in 2019. The fishing mortality in 2019 is highly uncertain, so we did not include it in the period for considering the current fishing mortality, and set 2014 to 2018 as the period for determining the current fishing mortality.

(2) Future projection

(1) We performed future projection from the stock biomass obtained by cohort analysis, based on HCRs. The proposed reference points are explained in detail in Appendix 9, and the proposed HCRs and the method of calculation of the future catch are explained in Appendices 10 and 11.

(3) Uncertainty of the number of age 0 fish in 2019

In the number of fish at age in 2019, the number of age 0 fish based on the S-R relationship is considered to be the most uncertain. Therefore, we confirmed the uncertainty level of the estimation based on the age composition of the catch in number of fish of age 1 and above in 2020. The projected catch in number of fish of age 1 and above in 2020 obtained in (2) under the current F (F2014-2018) accounted for 43% of the abundance of fish of age 1 and above in 2020. On the other hand, when we calculated the proportion of fish that were age 1 in the period from January to December 2000 based on the body length composition of the catch landed from January to May 2020, the proportion was 39% (Appendix 6). As the proportion of age 1 fish in 2020 projected based on the S-R relationship approximated the proportion of age 1 fish in the catch observed in 2020, we considered the stock assessment method adopted this year to be appropriate.

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Appendix Table 2-1. Average body weight at age

Age	0	1	2	3	4+
Body weight (g)	11.8	47.2	77.6	108.6	132.5

Appendix Table 2-2. Natural mortality (M)

Age	0	1	2	3	4+
Natural mortality	0.4	0.4	0.4	0.4	0.4

Appendix Table 2-3. Maturity rate at age

Age	0	1	2	3	4+
Maturity rate	0	0.25	1	1	1

Appendix Table 2-4. Tuning indices

年	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
産卵量	3.88	0.72	1.05	16.98	9.62	5.34	15.34	20.56	31.87	105.53
境港 CPUE	0.24	0.30	0.40	0.39	0.31	0.62	0.41	1.57	1.12	5.89
石川 CPUE				9.38	17.26	7.25	8.15	25.24	22.68	37.63

年	2014*	2015	2016	2017	2018	2019
産卵量	10.27	99.82	42.8	58.7	90.2	31.3
境港 CPUE	0.05	3.55	1.87	12.22	1.31	0.50
石川 CPUE	31.63	47.48	35.25	20.37	56.87	32.56

年	Year
産卵量	Egg production
境港 CPUE	Sakai Port CPUE
石川 CPUE	Ishikawa Prefecture CPUE

* The egg production and Sakai Port CPUE for 2014 and all indices for 2019 are not included in the tuning.

Appendix 3. Change of the biomass calculation method (cohort analysis)

In the stock assessment of the Japanese sardine Tsushima stock, the number of fish at age and by year was estimated by cohort analysis using the catch in number at age and by year. The age groups considered were age 0, age 1, age 2, age 3, and age 4+ (age 4 and above is collectively indicated as age 4+ (plus group)), but for the period from 1989 to 1998, age 0, age 1, age 2, age 3, age 4, and age 5+ were considered.

In the cohort analysis in the stock assessment in 2019, the number of age a fish in 1988, $N_{a,1988}$, was estimated based on the following equations using the number of fish in 1989, $N_{a,1989}$, the catch in number in 1988, $C_{a,1988}$, and natural mortality, M (Takahashi et al. 2020a).

Age 3

$$N_{3,1988} = N_{4,1989} \times exp(M) + C_{3,1988} \times \exp\left(\frac{M}{2}\right)$$

Age 4+

$$N_{4+,1988} = N_{5+,1989} \times exp(M) + C_{4+,1988} \times \exp\left(\frac{M}{2}\right)$$

Here, the fishing mortality of age a fish, $F_{a,1998}$, is calculated by the following equation. F for the plus group was set to be equal to F for the oldest age group − age 1.

$$F_{a,1988} = -ln\left\{1 - C_{a,1988} \times exp\left(\frac{M}{2}\right)/N_{a,1988}\right\}$$

However, the number of age 5+ fish in 1989, which was estimated by forward computation using the approximate equation by Pope and the obtained $N_{4+,1988}$ and $F_{4+,1988}$, did not coincide with the number, $N_{5+,1989}$, obtained by cohort analysis. Thus, we changed the equations for calculating the number of age a fish in 1988, $N_{a,1988}$, to the equations below.

Age 3

$$N_{3,1988} = \frac{C_{3,1988} \times (N_{4,1989} + N_{5+,1989}) \times \exp(M)}{C_{3,1988} + C_{4+,1988}} + C_{3,1988} \times \exp\left(\frac{M}{2}\right)$$

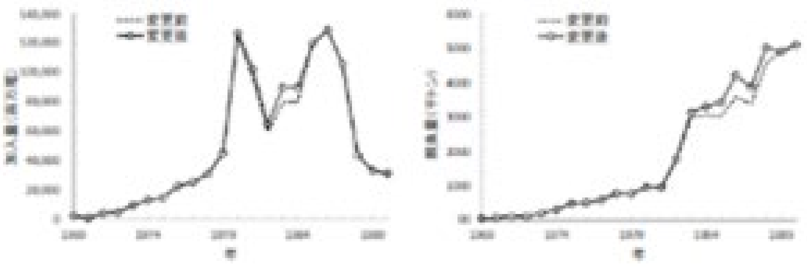
Age 4+

$$N_{4+,1988} = N_{3,1988} \times \frac{C_{4+,1988}}{C_{3,1988}}$$

The total number of age 4 and ages 5+ fish in 1989, which was estimated by forward computation based on the obtained results, coincided with the total of $N_{4,1989}$ and $N_{5+,1989}$ obtained by cohort analysis.

In association with the abovementioned change in equations, the values of the number at age for 1969 to 1988 were changed from those in the 2019 stock assessment. In line with this, the values of the recruitment and spawning biomass were also changed (Appendix Figure 3-1, Appendix Tables 3-1 and 3-2). Both the recruitment and the spawning biomass increased by a maximum of 8%. This has not caused a change to the ABC of 2020.

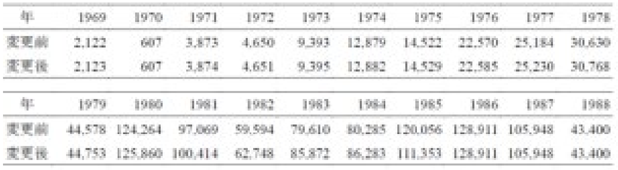
At the "Research Institute Meeting on Reference Points" held in March 2020, estimation of the S-R relationship and calculation of the proposed reference points were conducted using the results obtained by the corrected equations (Takahashi et al. 2020b*). Therefore, there is no change to the proposed target reference points or the proposed limit reference points.



加入量（百万尾）	Recruitment (million individuals)
年	Year
変更前	Before the change
変更後	After the change
親魚量（千トン）	Spawning biomass (thousand tons)

Appendix Figure 3-1. Recruitment (left) and spawning biomass (right) for 1969 to 1988 before and after the change

Appendix Table 3-1. Recruitment for 1969 to 1988 (million individuals)

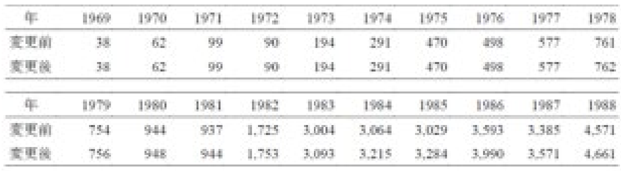


年	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
変更前	2,122	607	3,873	4,650	9,393	12,879	14,522	22,570	25,184	30,630
変更後	2,123	607	3,874	4,651	9,395	12,882	14,529	22,585	25,230	30,768

年	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
変更前	44,578	124,264	97,069	59,594	79,610	80,285	120,056	128,911	105,948	43,400
変更後	44,753	125,860	100,414	62,748	85,872	86,283	111,353	128,911	105,948	43,400

年	Year
変更前	Before the change
変更後	After the change

Appendix Table 3-2. Spawning biomass for 1969 to 1988 (thousand tons)



年	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
変更前	38	62	99	90	194	291	470	498	577	761
変更後	38	62	99	90	194	291	470	498	577	762

年	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
変更前	754	944	937	1,725	3,004	3,064	3,029	3,593	3,385	4,571
変更後	756	948	944	1,753	3,093	3,215	3,284	3,990	3,571	4,661

年	Year
変更前	Before the change
変更後	After the change

Appendix 4. CPUE standardization method

(1) Sakai Port medium-scale purse seine fishery CPUE

We standardized the abundance index based on landing at Sakai Port by medium-scale purse seine fishery. The data used was the daily number of fleets of medium-scale purse seine fishing vessels landing catch at Sakai Port and the catch amount of Japanese sardines landed at Sakai Port. For the water temperature at 50 m depth that was taken into consideration as an environmental factor, we used FRA-ROMS reanalysis values (released on April 3, 2020), and for CPUE, we used the daily catch per fleet of Japanese sardines (tons/fleet, daily CPUE).

The delta-lognormal method was used for standardizing CPUE. This is a method to separately analyze a model for predicting the probability of catch and a model for predicting the log CPUE (natural log) for a case where there is catch. We used the generalized linear mixed model (GLMM) for analysis, used binomial distribution for the error distribution of the former model, and used normal distribution for that of the latter model.

As explanatory variables for predicting the CPUE, we used year (categorical variable), month (categorical variable), and water temperature at 50 m depth (rounded to the nearest lower degree; categorical variable). The interaction between year and month was incorporated as a random effect, as there were year-month combinations with no data. We confirmed the absence of multicollinearity, using GVIF as an indicator. When we took into consideration all variable combinations and selected a model that minimizes the Akaike information criterion (AIC), the following equations were selected.

Probability of operation with catch: binomial distribution model

$$\mathrm{Log}\left[\frac{p_{ij}}{1-p_{ij}}\right] = \alpha + Year_i + Month_j + \beta_{i|j} + \varepsilon_{ij}$$

CPUE for dates with catch: lognormal distribution model

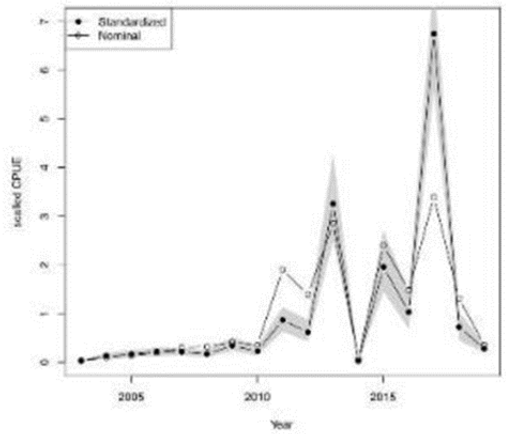
$$\mathrm{Log}\left[CPUE_{ij}\right] = \gamma + Year_i + Month_j + \delta_{i|j} + \theta_{ij}$$

p_{ij} is the probability of operation with catch, $CPUE_{ij}$ is the daily CPUE, α and γ are constants, $Year_i$ is year, $Month_j$ is month, $\beta_{i|j}$ and $\delta_{i|j}$ are the interaction between year and month, ε_{ij} and θ_{ij} are residuals in year i and year j. The effect of the water temperature at 50 m depth was excluded from explanatory variables.

In order to check the appropriateness of the selected models, we confirmed the distribution of residuals qualitatively. For both the binomial distribution model and the lognormal distribution model, the frequency distribution of residuals did not substantially deviate from the normal distribution, and dispersion of residuals did not show a biased trend against response variables. Due to these results, the models were considered to be appropriate as CPUE standardization models.

We calculated the least squares mean (LSmean) of the year effect based on the above models, and by multiplying the year effect of the binomial distribution model by the year effect of the lognormal distribution, we calculated the year trend of the standardized CPUE (Table 4). We obtained the 95% confidence intervals by using bootstrapping allowing overlaps (300 iterations). For details of the analysis, see Document (FRA-SA2020-SC01-102).

When the standardized CPUE and the nominal CPUE were compared, the fluctuations of their year trends were the same, but the standardized CPUE was higher than the nominal CPUE in 2017 (Appendix Figure 4-1). As the catch amount was constant throughout the year in 2017, with catch being observed even in months when Japanese sardines are hardly caught in normal years, the CPUE is considered to have become high as a result of eliminating the month effect through standardization. On the other hand, the standardized CPUE was lower than the nominal CPUE in 2011 and 2012 (Appendix Figure 4-1). In these two years, there were large catches in April, the peak fishing month, so the CPUE is considered to have become low as a result of standardization that eliminates the month effect.



Appendix Figure 4-1. Changes in the nominal CPUE and the ±95% confidence interval of the standardized CPUE

The values were normalized by dividing them by the mean values for 2003 to 2019.

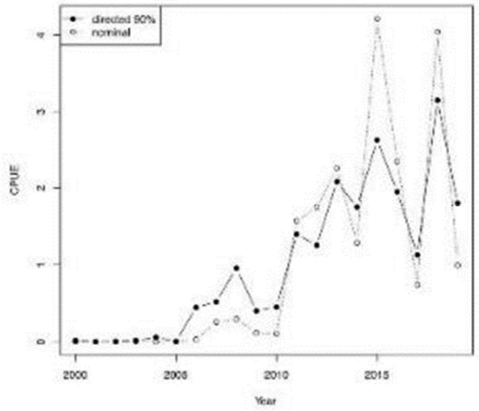
(2) Ishikawa Prefecture medium-scale purse seine fishery CPUE

We calculated the abundance index for fish of age 1 and above based on landing in Ishikawa Prefecture by medium-scale purse seine fishery. The data used was the daily catch per vessel of Japanese sardines, Japanese jack mackerels, chub mackerels, and round herrings landed at major ports in Ishikawa Prefecture. For CPUE, we used the daily catch per vessel of Japanese sardines (tons/vessel).

We used the directed CPUE method whereby the CPUE is calculated from a data set that has extracted operations targeting Japanese sardines (Biseau 1998). It is a method to extract data of operations in descending order of the daily Japanese sardine fishing rate (Japanese sardine catch / total catch) per vessel, until the cumulative Japanese sardine catch in each year reaches 90% of the year's total Japanese sardine catch. The annual average of the CPUE in the extracted data set is called the directed CPUE, and it is regarded as CPUE that takes into consideration operations that target specific species (Biseau 1998). For details of the method, see Document (FRA-SA2020-SC01-103).

In years with little data on operations with catch of Japanese sardines, there is a risk that the directed CPUE will be calculated relying on a small number of operations. Therefore, it was considered appropriate to use the data for 2007 onward, for which the proportion of the data of operations with catch has exceeded 0.5 and the presence of operations targeting Japanese sardines has been suggested.

Both the directed CPUE and the nominal CPUE (annual average of the Japanese sardine catch per vessel including data with no catch of Japanese sardines) indicated an increasing trend from 2010 onward (Appendix Figure 4-2). The fluctuations of their year trends generally coincided with each other, but the fluctuation range was narrower for the directed CPUE.



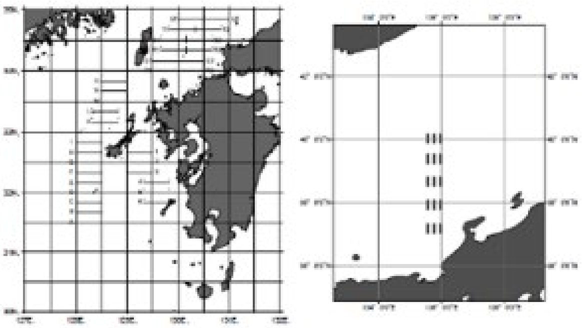
Appendix Figure 4-2. Changes in the nominal CPUE and the directed CPUE (90%)

References

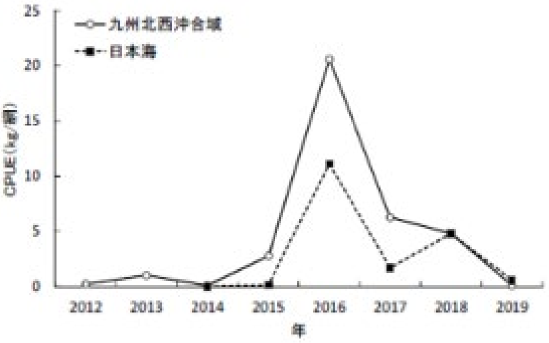
Biseau, A. (1998) Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquat. Living. Resour. 11, 119-136.

Appendix 5. Outline of vessel survey: Pelagic fish survey in summer

Since 1997, an abundance survey using a midwater trawl has been conducted in summer (from mid-August to mid-September) in northwestern offshore waters of Kyushu (Appendix Figure 5-1 left) in order to identify the standing stock of small pelagic fishes. A research vessel navigated along a fixed survey line, using an echo sounder, in daytime, and sampled fish schools at nighttime by midwater trawling in waters where fish schools had been observed. Since 2014, a survey sea area has also been set in the Sea of Japan (Appendix Figure 5-1 right). Appendix Figure 5-2 shows the Japanese sardine CPUE for 2012 onward based on data using the same fishing gear. The secular changes in the CPUE were similar in both the Sea of Japan and the northwestern offshore waters of Kyushu. The CPUE increased notably in 2016, decreased in 2017, and approximated the 2017 level in 2018. However, the CPUE in 2019 was low in both sea areas.



Appendix Figure 5-1. The lines drawn in the survey sea areas of the pelagic fish survey conducted in the Sea of Japan and the northwestern offshore waters of Kyushu in summer indicate the fixed survey lines.



CPUE（kg／網）	CPUE (kg/net)
年	Year
九州北西沖合域	Northwestern offshore waters of Kyushu
日本海	Sea of Japan

Appendix Figure 5-2. CPUE of Japanese sardines in midwater trawl sampling

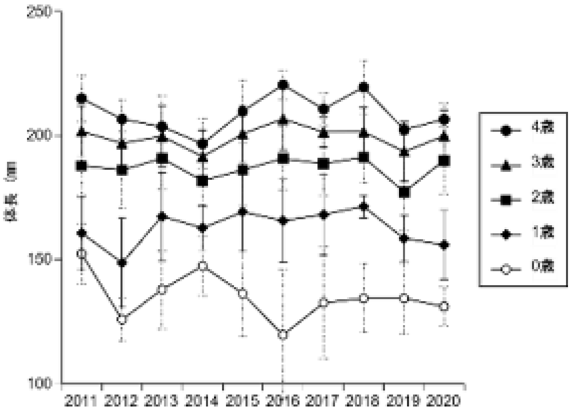
Appendix 6. Amount and age composition of catch in January to May 2020

We totaled the catch amount of the present stock for January to May 2020 based on the daily reports of the total allowable catch (TAC) for governor managed fishery in 2020 (provided by the Japan Fisheries Information Service Center on July 20, 2020), the total values provided by each prefecture, and the basic summary table of fishery results in 2020 for large- to medium-scale purse seine fishery operating in the Sea of Japan and the East China Sea (January to May) (provided by the Kyushu Fisheries Management Office, Fisheries Agency, on June 23, 2020). The catches in Aomori, Hyogo, and Yamaguchi Prefectures were all regarded as catches on the Sea of Japan side of the prefectures. The totaled catch was 47 thousand tons.

We calculated the catch in number at age based on the body length composition data of Japanese sardines landed in Toyama, Ishikawa, Kyoto, and Tottori Prefectures in January to May 2020 (5,999 individuals) and the total catch in these prefectures, which was 45 thousand tons. In the catch in number of fish of age 1 and above, age 1 fish (2019 year class) accounted for 35%. When we calculated the ratio of the proportion of age 1 fish in the catch in number of fish of age 1 and above caught in the Sea of Japan in January to December to the same proportion for fish caught in January to May, for each year from 2015 to 2019, the average ratio was 1.12 (average for 2015 to 2019 ± 0.07S.E.). According to the progress of the past fishery conditions, the proportion of age 1 fish in January to December 2020 can be expected to be 39% (the 95% confidence interval is 37 to 42%).

In order to check the secular changes in the average body length at age of catch, we totaled the results of the age determination using scales, which was conducted for the present stock between 2011 and 2020. The age determination had been conducted for a total of 7,263 Japanese sardine individuals, and the annual number ranged from 316 to 1,288 individuals. The samples were landed at ports in Aomori, Ishikawa, Toyama, Kyoto, Tottori, Shimane, Yamaguchi, Fukuoka, and Nagasaki Prefectures. For 2020, out of the 331 scale samples of Japanese sardines landed in Aomori, Ishikawa, and Tottori Prefectures in January to April, we used 316 samples for which age could be determined.

Appendix Figure 6-1 shows secular changes in the average body length at age of catch in 2011 to 2020. The average body lengths of fish of age 2 and above show similar secular changes, and they gradually decreased from 2011 to 2014, but then increased until 2016. The average body lengths in 2019 were smaller compared to 2018 and 2020. The smaller body lengths observed in 2014 and 2019 are considered to be possibly reflecting the result of fewer adult fish migrating to fishing grounds and low-growth individuals remaining in fishing grounds. The average body lengths of age 0 and age 1 fish showed a trend that differs from fish of age 2 and above, but as the age 0 and age 1 fish caught show a rapid growth in length from early summer every year, the average body lengths of age 0 and age 1 fish in 2020 are expected to be corrected in the future. Therefore, when we focus on the age-length relationship over the latest 5 years, the average body length of each age group has slightly minimized in 2019, but it is considered to show no notable differences by year in the other years. The age groups of the catch in number based on the body length composition data were set on the basis of the abovementioned observation results.

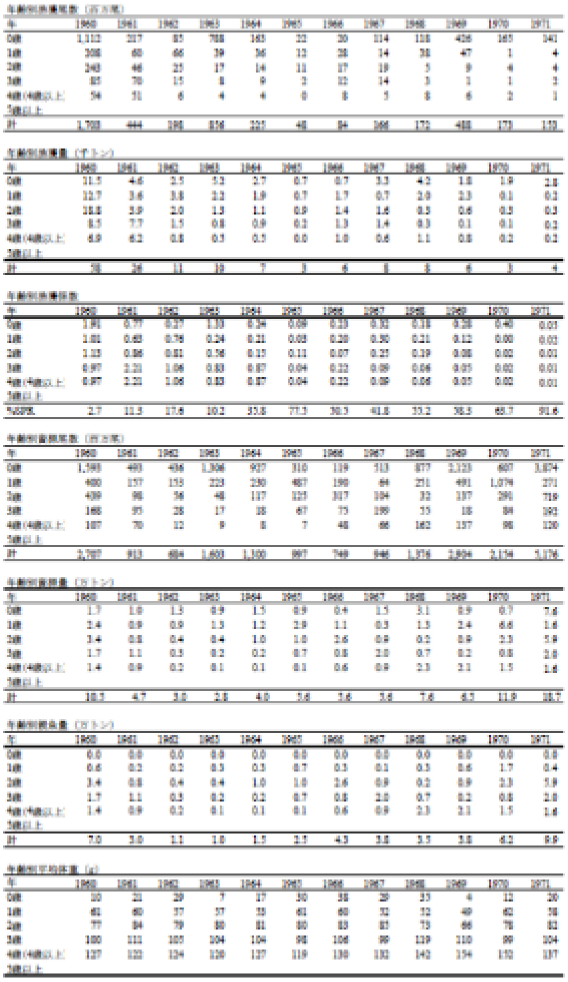


体長（mm）	Body length (mm)
4 歳	Age 4
3 歳	Age 3
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

Appendix Figure 6-1. Secular changes in the age-length relationship in 2011 to 2020
The vertical lines indicate standard deviations.

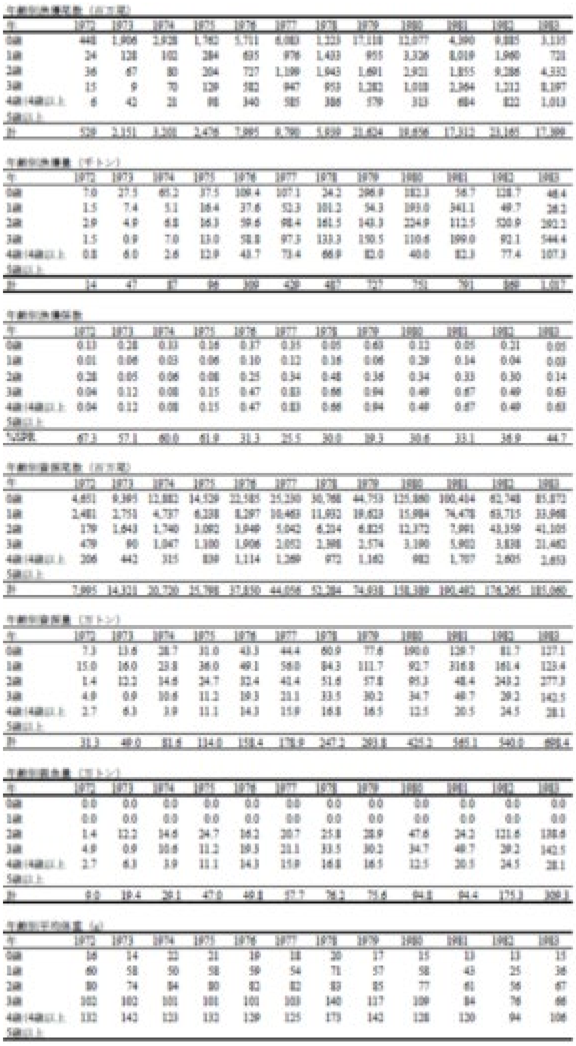
Next, we checked the age composition based on the results of the age determination of the catch in January to April 2020. Here, we regarded the samples in Aomori Prefecture to represent the catch of Japanese sardines in Aomori Prefecture, the samples in Ishikawa Prefecture to represent the catch in Ishikawa and Toyama Prefectures, and the samples in Tottori Prefecture to represent the catch in Tottori and Shimane Prefectures, and the age composition by month of the respective samples was weighted by the catch amount by prefecture and by month. The catch was estimated to mainly consist of age 2 and age 3 fish, with age 1 fish (2019 year class) accounting for 7%. The samples used for the age determination using scales were mostly individuals with a body length of 180 mm or more, so the proportion of age 1 fish is likely to have been underestimated.

Appendix 7. Details of stock analysis results (1960-1971)



年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳（4 歳以上）	Age 4 (or age 4 and above)
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量（千トン）	Catch at age (thousand tons)
年齢別漁獲係数	Fishing mortality at age
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)
年齢別資源量（万トン）	Stock biomass at age (10 thousand tons)
年齢別親魚量（万トン）	Spawning biomass at age (10 thousand tons)
年齢別平均体重（g）	Average body weight at age (g)

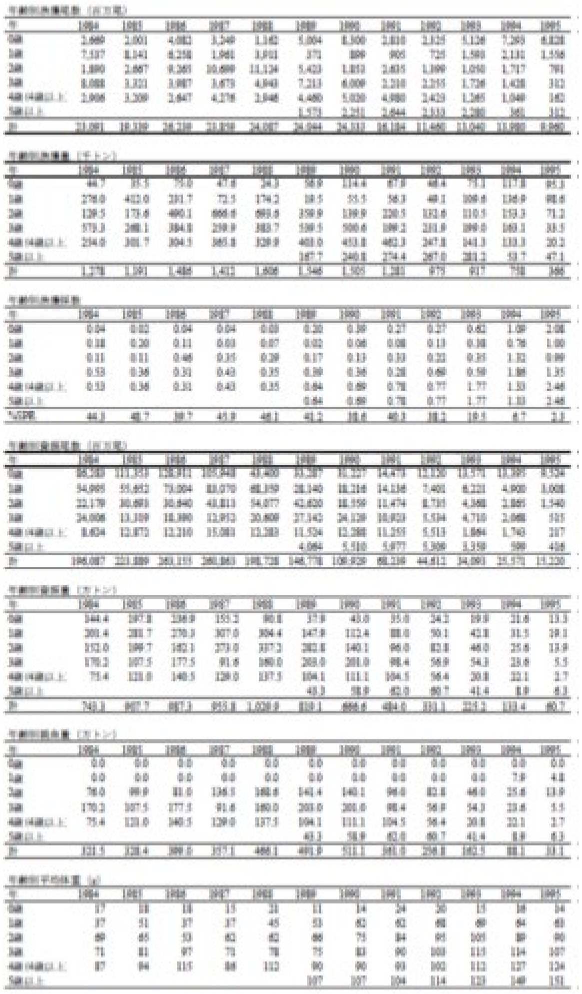
Appendix 7 (continued). Details of cohort analysis results (1972-1983)



年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳（4 歳以上）	Age 4 (or age 4 and above)
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量（千トン）	Catch at age (thousand tons)
年齢別漁獲係数	Fishing mortality at age
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)
年齢別資源量（万トン）	Stock biomass at age (10 thousand tons)

年齢別親魚量（万トン）	Spawning biomass at age (10 thousand tons)
年齢別平均体重（g）	Average body weight at age (g)

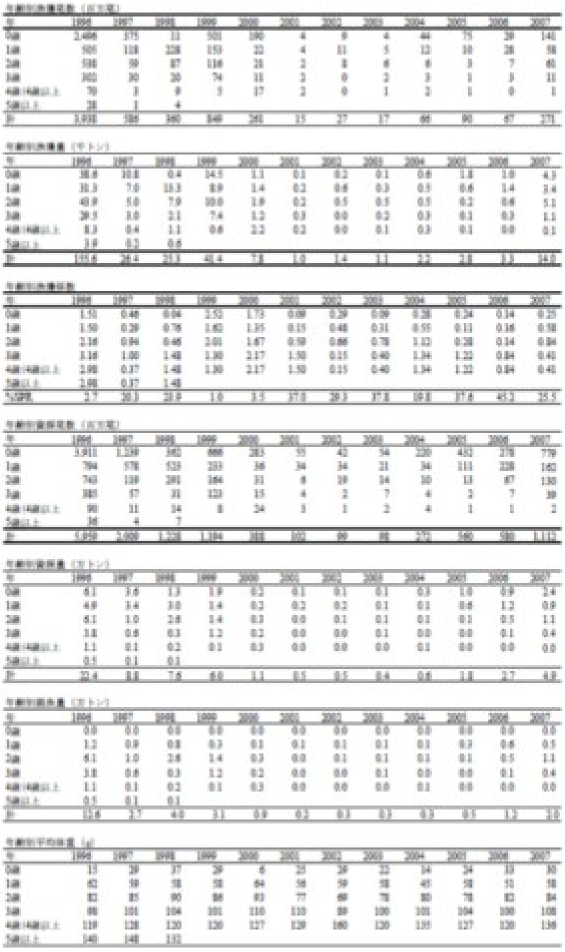
Appendix 7 (continued). Details of cohort analysis results (1984-1995)



年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳（4 歳以上）	Age 4 (or age 4 and above)
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量（千トン）	Catch at age (thousand tons)
年齢別漁獲係数	Fishing mortality at age
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別資源量（万トン）	Stock biomass at age (10 thousand tons)
年齢別親魚量（万トン）	Spawning biomass at age (10 thousand tons)
年齢別平均体重（g）	Average body weight at age (g)

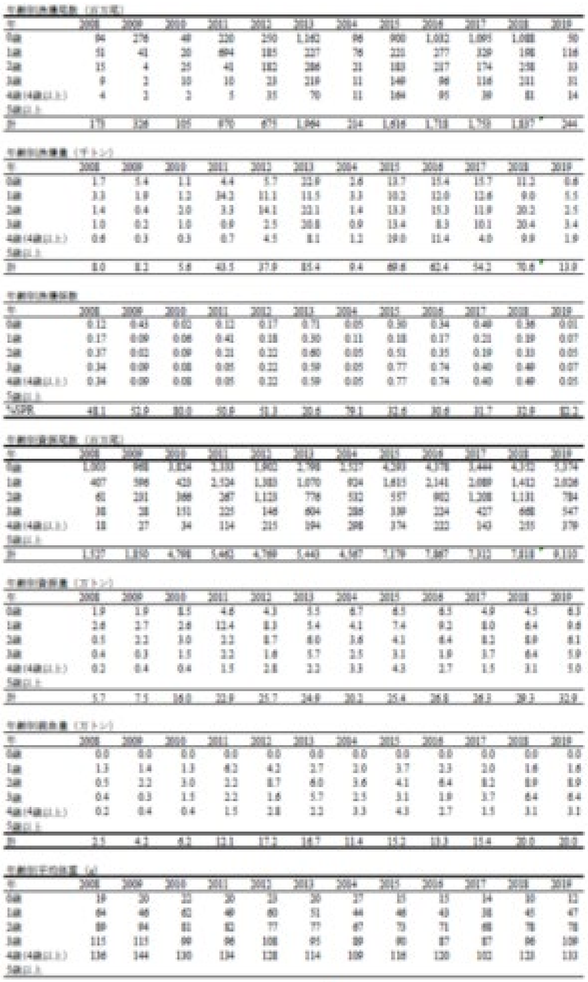
Appendix 7 (continued). Details of cohort analysis results (1996-2007)



年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳（4 歳以上）	Age 4 (or age 4 and above)
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量（千トン）	Catch at age (thousand tons)
年齢別漁獲係数	Fishing mortality at age
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別資源量（万トン）	Stock biomass at age (10 thousand tons)
年齢別親魚量（万トン）	Spawning biomass at age (10 thousand tons)
年齢別平均体重（g）	Average body weight at age (g)

Appendix 7 (continued). Details of cohort analysis results (2008-2019)



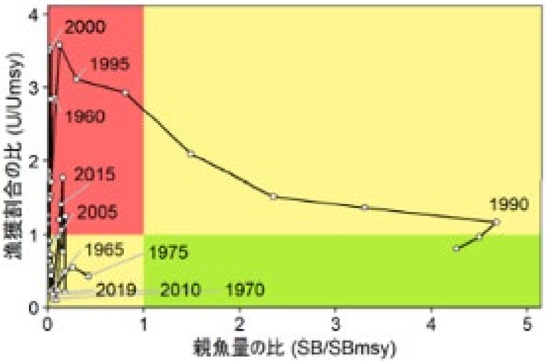
年齢別漁獲尾数（百万尾）	Catch in number at age (million individuals)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳（4 歳以上）	Age 4 (or age 4 and above)
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量（千トン）	Catch at age (thousand tons)
年齢別漁獲係数	Fishing mortality at age

年齢別資源尾数（百万尾）	Number of fish at age (million individuals)
年齢別資源量（万トン）	Stock biomass at age (10 thousand tons)
年齢別親魚量（万トン）	Spawning biomass at age (10 thousand tons)
年齢別平均体重（g）	Average body weight at age (g)

Appendix 8. Kobe plot based on exploitation rate

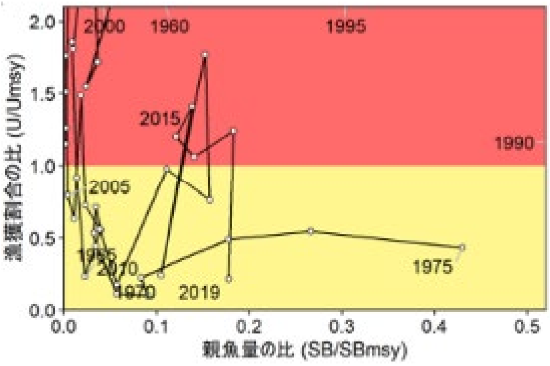
Appendix Figure 8-1 shows a Kobe plot based on the spawning biomass and exploitation rate (U) at that time. It is based on proposed reference points assuming the conditions in the normal recruitment period (1960 to 1975 and 1988 to 2017). The spawning biomass of the present stock has been below the level that produces MSY since 1994, but the ratio of the exploitation rate (U/Umsy) has been above the level that produces MSY since 2013, except in 2014 and 2019.

Item	Value	Explanation
SBmsy	1,093 thousand tons	Spawning biomass that produces MSY
Umsy	19%	Exploitation rate that produces MSY
U2019	4%	Exploitation rate in 2019
U2019/Umsy	0.22	Ratio of the exploitation rate in 2019 to the exploitation rate that produces MSY



漁獲割合の比（U/Umsy）	U/Umsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Enlarged view



漁獲割合の比（U/Umsy）	U/Umsy
親魚量の比（SB/SBmsy）	SB/SBmsy

Appendix Figure 8-1. Relationship between the spawning biomass and the exploitation rate (U) (Kobe plot) and its enlarged view

SBmsy and Umsy assume the normal recruitment period (1960 to 1975 and 1988 to 2017), and the plots of the spawning biomass and U are also limited to that period.

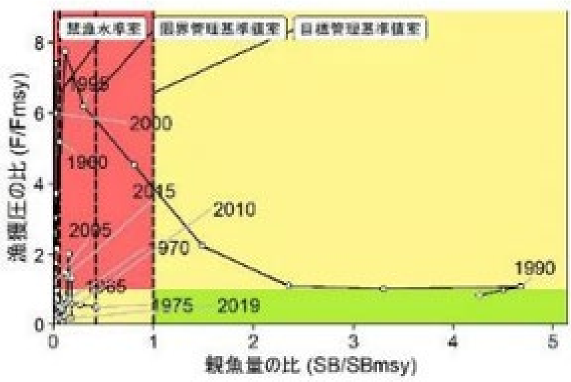
Appendix 9. Proposed reference points and fishing ban level, etc.

The reference points and fishing ban level, etc. proposed for the present stock are as shown below.

Item	Value	Explanation
Proposed SBtarget	1,093 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	465 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	66 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

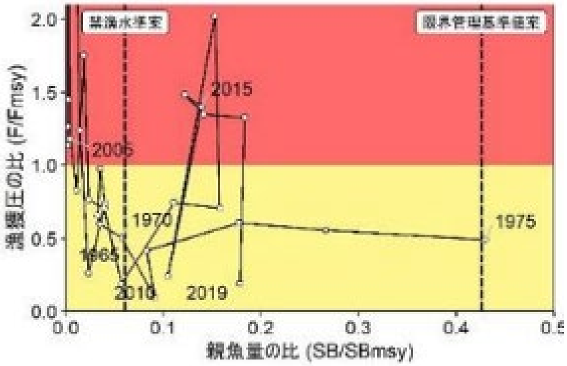
It was proposed at the Research Institute Meeting held in March 2020 that, assuming the conditions in the normal recruitment period (1960 to 1975 and 1988 to 2017), the spawning biomass that produces MSY (SBmsy: 1,093 thousand tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 465 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 66 thousand tons) be used for the fishing ban level (SBban). For details, see "Report of the Research Institute Meeting on Reference Points of Japanese sardine Tsushima stock (2020) (Takahashi et al. 2020b*)."

Appendix Figure 9-1 shows a Kobe plot based on the proposed SBtarget and F at that time. The spawning biomass in 2019 (SB2019: 194 thousand tons) obtained by cohort analysis was below the proposed SBlimit. The F is determined to have been above Fmsy since 2013, except in 2014 and 2019.



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

Enlarged view



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Appendix Figure 9-1. Relationship between the proposed reference points and the spawning biomass and F (Kobe plot) and its enlarged view

SBmsy and Fmsy assume the normal recruitment period (1960 to 1975 and 1988 to 2017), and the plots of the spawning biomass and the exploitation rate are also limited to that period.

Appendix 10. Future projection compliant with the proposed HCRs

(1) Setting of future projection

We calculated the future projection for 2020 to 2051 using forward computation of cohort analysis based on the stock biomass (B) in 2019 estimated in stock assessment (Appendix 11). For recruitment in the future projection, we used the value predicted from the spawning biomass in each year based on the S-R relationship. We assumed error following a lognormal distribution as uncertainty in recruitment, and made 10,000 iterations. For the fishing mortality in 2020 (F2020), which indicates the current fishing mortality, we used the F value that gives %SPR (35.9) corresponding to the simple average of F in 2014 to 2018 as estimated in this year's assessment (Figure 4-9). As a result, the ratio of F2020 to Fmsy was 1.20. As the fishing mortality in 2019 involved high uncertainties, we did not include it in the period that considers the current fishing mortality. For the fishing mortality in 2021 onward, we used the fishing mortality specified in the proposed HCRs below based on the spawning biomass projected for each year.

(2) Proposed HCRs

The proposed HCRs represent a proposed fishing scenario that specifies the fishing mortality (F) corresponding to spawning biomass, taking into consideration the probability of maintaining/managing spawning biomass above the proposed target reference point (SBtarget). If spawning biomass is below the proposed limit reference point (SBlimit), the fishing mortality is to be reduced in a linear manner to the proposed fishing ban level. Fmsy, which will be the upper limit of fishing mortality, is multiplied by tuning parameter β, which will be the safety coefficient. Appendix Figure 10-1 shows the HCRs proposed at the Research Institute Meeting held in March 2020 (Takahashi et al. 2020b*). Here, we present a case where safety coefficient β is the standard value 0.8, as an example. Meanwhile, it was proposed at the Research Institute Meeting that "if β is 0.8 or less, spawning biomass is estimated to exceed SBtarget in 10 years with a probability of 50% or more."

(3) Projected values for 2021

The catch in 2021 estimated according to the future projection using the proposed HCRs was 46 thousand tons where β was 0.8, and 56 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 286 thousand tons on average, and the estimation was below the proposed SBlimit in all iterations, so fishing mortality in 2021 was calculated by multiplying βFmsy by the coefficient corresponding to the spawning biomass, γ(SBt). Here, γ(SBt) was calculated as 0.55 by the equation below, based on the HCRs set for the first group of stocks detailed in the "2020 Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC) (FRA-SA2020-ABCWG02-01)."

$$\frac{SB_t - SB_{ban}}{SB_{limit} - SB_{ban}}$$

Spawning biomass in 2021 (average projection value): 286 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2014-2018)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β = 0.8	46	0.37	9
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	56	0.46	11
β = 0.9	51	0.41	10
β = 0.7	40	0.32	8
β = 0.6	35	0.28	7
β = 0	0	0	0
F2014-2018	110	1.00	21

Appendix Figure 10-2 and Appendix Tables 10-1 and 10-2 show the medium- to long-term future projection results based on the proposed HCRs (Appendix Figure 10-1). If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in 2031 is 1,001 thousand tons on average where β is 1.0 (the 80% confidence interval is 514 thousand to 1,564 thousand tons), and 1,213 thousand tons on average where β is 0.8 (the 80% confidence interval is 676 thousand to 1,836 thousand tons). The probability of the projected spawning biomass being above the proposed target reference point (SBtarget) exceeded 50% where β is 0.8 or less. The probability of the projected spawning biomass being above the proposed limit reference point (SBlimit) and the probability of the projected spawning biomass being above the proposed fishing ban level (SBban) were 100% where β is 0.6 or less.

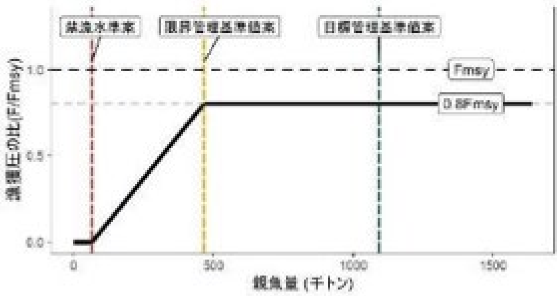
Uncertainty considered: recruitment					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points below (%)		
			SBtarget	SBlimit	SBban
Scientifically proposed fishing mortality					
β = 0.8	1213	676-1836	54	98	100
Other strategy (when using different β in the proposed HCRs)					
β = 1.0	1001	514-1564	34	93	100
β = 0.9	1103	587-1701	44	96	100
β = 0.7	1331	773-1985	64	99	100
β = 0.6	1459	877-2150	74	100	100

β = 0	2597	1717-3633	100	100	100
F2014-2018	641	202-1175	13	59	100

If management based on the proposed HCRs is continued, the year in which spawning biomass will be above the proposed SBtarget with a probability of 50% or more was projected to be in or after 2031 where β is 0.8. Also, the year in which spawning biomass will be above the SBlimit with a probability of 50% or more was projected to be 2024. Even if the fishing mortality is set at zero (β = 0), the year in which spawning biomassSB will be above the proposed SBtarget with a probability of 50% or more was predicted to be 2025.

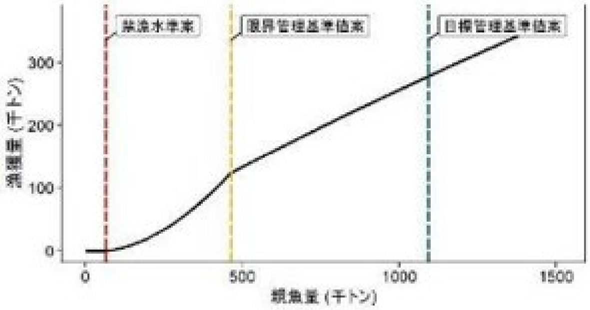
Uncertainty considered: recruitment			
	Year in which spawning biomass will be above the reference points with a probability of 50% or more		
	Proposed SBtarget	Proposed SBlimit	Proposed SBban
β used in the HCRs			
β = 0.8	2030	2024	2019
Other strategy (when using different β from the HCRs)			
β = 1.0	2051 onward	2024	2019
β = 0.9	2041	2024	2019
β = 0.7	2029	2024	2019
β = 0.6	2028	2024	2019
β = 0	2025	2023	2019
F2014-2018	2051 onward	2029	2019

a) When the vertical axis is fishing mortality



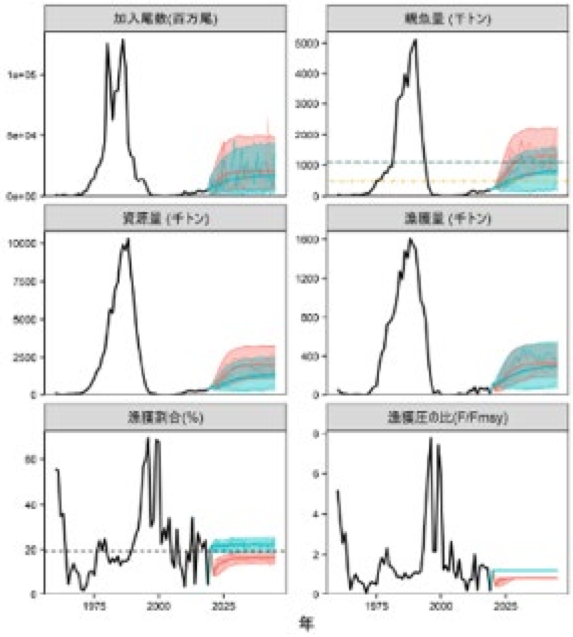
漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

b)



漁獲量（千トン）	Catch (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

Appendix Figure 10-1. Proposed HCRs
(a) When vertical axis is fishing mortality, and (b) When vertical axis is catch



加入尾数（百万尾）	Recruitment (million individuals)
資源量（千トン）	Stock biomass (thousand tons)
漁獲割合（%）	Exploitation rate (%)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲圧の比（F/Fmsy）	F/Fmsy
年	Year

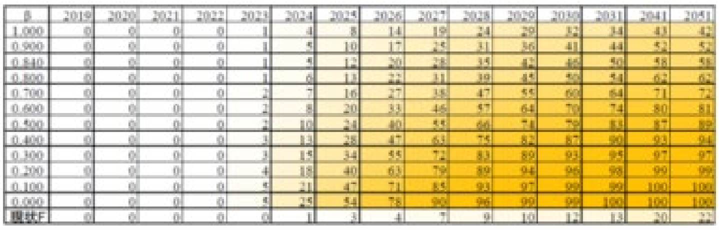
（塗り：5-95%予測区間，太い実線：平均値，細い実線：シミュレーションの１例）	(Shaded: 5-95% prediction interval; thick solid line: average value; thin solid line: simulation example)

Appendix Figure 10-2. Future projection using the proposed HCRs (in red) and future projection in the case of continuing fishing with the current fishing mortality (in green)

The thick solid line indicates the average value, the shaded part indicates the 90% prediction interval that covers 90% of the simulation results, the thin lines indicate 5 patterns of future projection examples. In the figure of spawning biomass, the green broken line indicates the proposed target reference point, and the yellow dotted line indicates the proposed limit reference point. In the figure of exploitation rate, the broken line indicates Umsy. Safety coefficient β is 0.8. 1e+05 means 10^5.

Appendix Table 10-1. Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	1	4	8	14	19	24	29	32	34	43	42
0.900	0	0	0	0	1	5	10	17	25	31	36	41	44	52	52
0.840	0	0	0	0	1	5	12	20	28	35	42	46	50	58	58
0.800	0	0	0	0	1	6	13	22	31	39	45	50	54	62	62
0.700	0	0	0	0	2	7	16	27	38	47	55	60	64	71	72
0.600	0	0	0	0	2	8	20	33	46	57	64	70	74	80	81
0.500	0	0	0	0	2	10	24	40	55	66	74	79	83	87	89
0.400	0	0	0	0	3	13	28	47	63	75	82	87	90	93	94
0.300	0	0	0	0	3	15	34	55	72	83	89	93	95	97	97
0.200	0	0	0	0	4	18	40	63	79	89	94	96	98	99	99
0.100	0	0	0	0	5	21	47	71	85	93	97	99	99	100	100
0.000	0	0	0	0	5	25	54	78	90	96	99	99	100	100	100
現状F	0	0	0	0	0	1	3	4	7	9	10	12	13	20	22

現状 F	Fcurrent

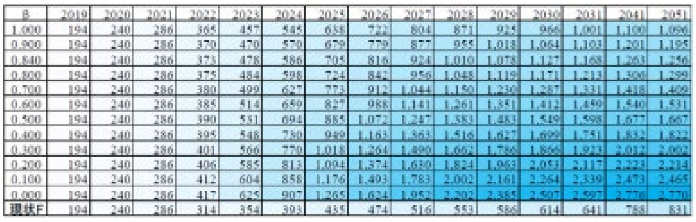
b) Probability of being above the proposed limit reference point (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	14	37	54	67	76	81	86	89	92	93	97	98
0.900	0	0	0	15	40	59	72	81	86	90	93	95	96	99	99
0.840	0	0	0	16	42	61	75	83	89	92	95	96	98	99	99
0.800	0	0	0	16	43	63	77	85	90	94	96	97	98	100	100
0.700	0	0	0	17	46	68	81	89	93	96	98	99	99	100	100
0.600	0	0	0	18	50	72	85	92	96	98	99	99	100	100	100
0.500	0	0	0	19	53	76	88	94	97	99	99	100	100	100	100
0.400	0	0	0	20	57	80	91	96	98	99	100	100	100	100	100
0.300	0	0	0	22	61	83	93	98	99	100	100	100	100	100	100
0.200	0	0	0	23	64	86	95	99	100	100	100	100	100	100	100
0.100	0	0	0	24	68	89	97	99	100	100	100	100	100	100	100
0.000	0	0	0	25	71	92	98	100	100	100	100	100	100	100	100
現状F	0	0	0	8	18	26	33	39	44	49	53	56	59	76	82

現状 F	Fcurrent

Appendix Table 10-2. Changes in average values of future spawning biomass and catch

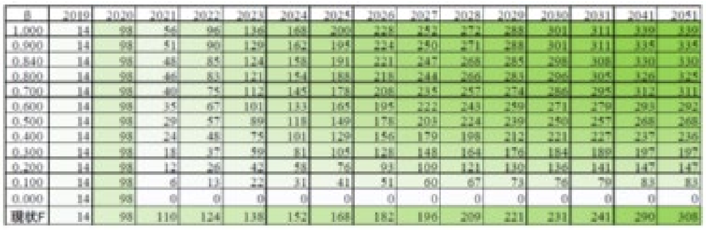
a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	365	457	545	638	722	804	871	925	966	1,001	1,100	1,096
0.900	194	240	286	370	470	570	679	779	877	955	1,018	1,064	1,103	1,201	1,195
0.840	194	240	286	373	478	586	705	816	924	1,010	1,078	1,127	1,168	1,263	1,256
0.800	194	240	286	375	484	598	724	842	956	1,048	1,119	1,171	1,213	1,306	1,299
0.700	194	240	286	380	499	627	773	912	1,044	1,150	1,230	1,287	1,331	1,418	1,409
0.600	194	240	286	385	514	659	827	988	1,141	1,261	1,351	1,412	1,459	1,540	1,531
0.500	194	240	286	390	531	694	885	1,072	1,247	1,383	1,483	1,549	1,598	1,677	1,667
0.400	194	240	286	395	548	730	940	1,163	1,363	1,516	1,627	1,699	1,751	1,832	1,822
0.300	194	240	286	401	566	770	1,018	1,264	1,490	1,662	1,786	1,866	1,923	2,012	2,002
0.200	194	240	286	406	585	813	1,094	1,374	1,630	1,824	1,963	2,053	2,117	2,223	2,214
0.100	194	240	286	412	604	858	1,176	1,493	1,783	2,002	2,161	2,264	2,339	2,473	2,465
0.000	194	240	286	417	625	907	1,265	1,624	1,952	2,202	2,385	2,507	2,597	2,776	2,770
現状F	194	240	286	314	354	393	435	474	516	553	586	614	641	788	831

現状 F	Fcurrent

b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	56	96	136	168	200	228	252	272	288	301	311	339	339
0.900	14	98	51	90	129	162	195	224	250	271	288	301	311	335	335
0.840	14	98	48	85	124	158	191	221	247	268	285	298	308	330	330
0.800	14	98	46	83	121	154	188	218	244	266	283	296	305	326	325
0.700	14	98	40	75	112	145	178	208	235	257	274	286	295	312	311
0.600	14	98	35	67	101	133	165	195	222	243	259	271	279	293	292
0.500	14	98	29	57	89	118	149	178	203	224	239	250	257	268	268
0.400	14	98	24	48	75	101	129	156	179	198	212	221	227	237	236
0.300	14	98	18	37	59	81	105	128	148	164	176	184	189	197	197
0.200	14	98	12	26	42	58	76	93	109	121	130	136	141	147	147
0.100	14	98	6	13	22	31	41	51	60	67	73	76	79	83	83
0.000	14	98	0	0	0	0	0	0	0	0	0	0	0	0	0
現状F	14	98	110	124	138	152	168	182	196	209	221	231	241	290	308

現状 F	Fcurrent

Appendix 11. Method of future projection of the stock

We performed future projection from the obtained stock biomass, according to HCRs. We used R package “frasyr” (version 2.1.1.0) for the analysis. For projection of recruitment in 2020 onward, we used values estimated based on the HS S-R relationship estimated for the normal recruitment period (1960 to 1975 and 1988 to 2017) (a = 0.0276, b = 7.36e+05, SD = 0.683) proposed at the "Research Institute Meeting on Reference Points" held in March 2020 (Takahashi et al. 2020b*). The data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment, which were obtained by modifying the plus group in the stock assessment conducted in 2019 (Takahashi et al. 2020a) (Appendix 3), and as for the optimization method, the least-squares method is used. The model does not consider autocorrelation between the residuals of the recruitment.

For fishing mortality (F) in future projection, we used the values calculated based on the HCRs set for the first group of stocks detailed in the "2020 Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC) (FRA-SA2020-ABCWG02-01)." The parameters used for the future projection are shown in Appendix Table 11-1. As for the selectivity and the average body weight of the catch, etc., we again used the values used for estimating the reference points proposed at the abovementioned "Research Institute Meeting on Reference Points" (Takahashi et al. 2020b*). These values are based on the 2019 stock assessment (Takahashi et al. 2020a), similar to the S-R relationship, and the average values of 2014 to 2018 obtained by this calculation were used for the selectivity and the average body weight of catch. The fishing mortality in 2020 (F2020), which indicates the current fishing mortality, was assumed to be the F value that gives the %SPR (35.9) that corresponds to the simple average of F in 2014 to 2018 in the assessment for this year (Figure 4-9). As the fishing mortality in 2019 involved high uncertainties, we did not include it in the period that considers the current fishing mortality.

For estimation of the number of fish, we used forward computation of cohort analysis (Appendix 2. equations (12) and (13)).

$$N_{a+1,y+1} = N_{a,y} \exp\left(-F_{a,y} - M\right) \tag{12}$$

$$N_{4+,y+1} = \left(N_{3,y} + N_{4+,y}\right) \times \exp\left(-F_{3,y} - M\right) \tag{13}$$

We obtained the catch in number from the number of fish obtained by the above equations and the F value assumed from each fishing scenario, based on equation (15).

$$C_{a,y} = N_{a,y}\{1 - exp(-F_{a,y})\}exp\left(-\frac{M}{2}\right) \tag{15}$$

Appendix Table 11-1. Parameters used for calculating the future projection

	Selectivity	Fmsy	F2014-2018	Average body weight (g)	Natural mortality	Maturity rate
Age 0	0.59	0.25	0.30	16	0.40	0

Age 1	0.34	0.14	0.17	43	0.40	0.25
Age 2	0.58	0.24	0.29	71	0.40	1.00
Age 3	1.00	0.42	0.51	90	0.40	1.00
Age 4 and above	1.00	0.42	0.51	114	0.40	1.00

Note 1: Selectivity used for estimating the level that produces MSY at the 2020 Research Institute Meeting (i.e., selectivity of Fcurrent in the 2019 stock assessment).

Note 2: Fmsy estimated at the 2020 Research Institute Meeting (i.e., the Fcurrent in the 2019 stock assessment multiplied by Fmsy/Fcurrent).

Note 3: F value under the selectivity above that gives the same fishing mortality as the average F at age for 2014 to 2018 estimated in the present stock assessment, which has been converted into %SPR. This F value was used for assuming the catch in 2020.

Appendix 12. Results based on S-R relationship using data for the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017)

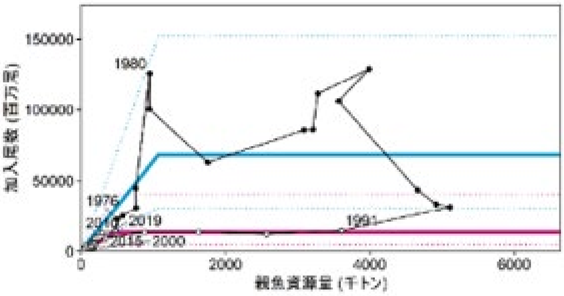
At the "Research Institute Meeting on Reference Points" held in March 2020, the S-R relationship for a case of excluding 1988 to 1990 as the transition period involving rapid changes in the stock status, and the proposed reference points based on that relationship were published in Appendix 4 (Takahashi et al. 2020b*). In response to discussions at the Committee of Stock Management Policy on Japanese sardine and Japanese jack mackerel held in Fukuoka City on July 30 and 31, 2020 (the Stakeholder Meeting [SH Meeting]), the Stock Assessment Meeting requested us to conduct trial calculation of the following scenario.

・The Stock Assessment Meeting in August requests that a scenario excluding the S-R relationship for 1988 to 1990 be presented at the next session of the SH Meeting.

Therefore, we summarized the results of future projection for a case of considering the current environment to be the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017).

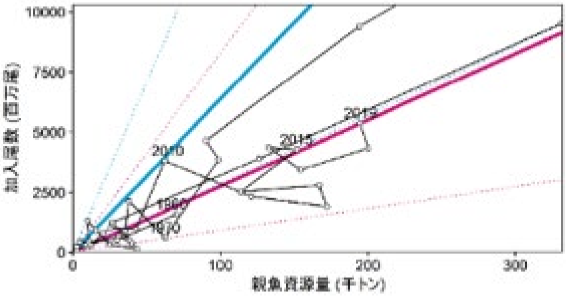
HS model is used as the S-R relationship, and the parameters used are indicated in the table below (Appendix Figure 12-1). The optimization method is the least-squares method, and the model does not consider autocorrelation between the residuals of the recruitment. Here, parameter a is the steepness (individuals/g) of the HS S-R curve from the origin to the break point, and b is the spawning biomass (tons) at the break point.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey stick	Least squares method	No	0.0276	4.84e+05	0.678



加入尾数（百万尾）	Recruitment (million individuals)
親魚資源量（千トン）	Spawning biomass (thousand tons)

Enlarged view



加入尾数（百万尾）	Recruitment (million individuals)
親魚資源量（千トン）	Spawning biomass (thousand tons)

Appendix Figure 12-1. The red line shows the S-R relationship in the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017) and the blue line shows the S-R relationship in the high recruitment period including the transition period (1976 to 1990). The circles are actual measurement data (1960 to 2019), and the white circles indicate values for the normal recruitment period excluding the transition period, while black circles indicate values for the high recruitment period including the transition period. The dotted lines above and below the S-R relationship show the range that is estimated to cover 90% of the observation data under the assumed S-R relationship. Numbers in the figure denote the year class.

By the forward computation in Appendix 2, the recruitment of age 0 fish in 2019 was estimated to be 5,374 million individuals, the fishing mortality for age 0 fish to be 0.01, and the stock biomass to be 329 thousand tons, showing only slight differences from the proposed estimate values. There was no change in the spawning biomass. The stock status in 2019 can be summarized as follows.

Item	Value	Explanation
Level that produces MSY under the current environment		
SBmsy	716 thousand tons	Spawning biomass that produces MSY
Fmsy	(Ages 0, 1, 2, 3, 4 and above) = (0.25, 0.14, 0.25, 0.42, 0.42)	
%SPR (Fmsy)	40.9%	%SPR corresponding to Fmsy
Spawning biomass and fishing mortality in 2019		
SB2019	194 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3, 4 and above) = (0.01, 0.07, 0.05, 0.07, 0.05)	
%SPR (F2019)	82.2%	%SPR in 2019
%SPR (F2014-2018)	35.9%	%SPR corresponding to the average fishing mortality (F) in 2014 to 2018
Ratio to MSY		

SB2019/SBmsy	0.27	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	0.19	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

* Ratio between F in 2019 and F under the selectivity in 2019 that gives Fmsy which has been converted into %SPR.

Year	Stock biomass (thousand tons)	Spawning biomass (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2016	268	133	62	1.48	23
2017	263	154	54	1.35	21
2018	293	200	71	1.32	24
2019	329	194	14	0.19	4
2020	463	240	98	1.19	21
2021	521	286	-	-	-

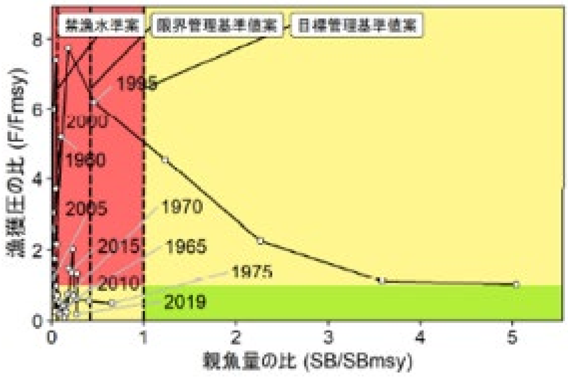
Values for 2020 and 2021 are estimates based on future projection.

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Below SBmsy
Trend in spawning biomass	Increasing

The proposed reference points and fishing ban level, etc. are as shown below.

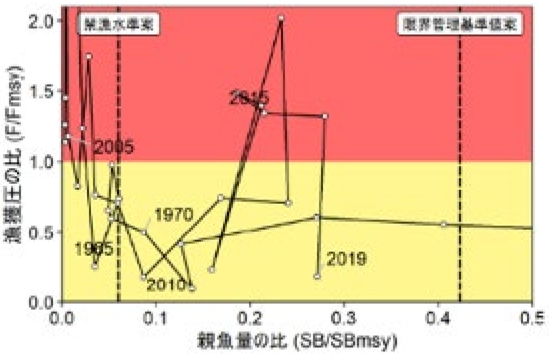
Item	Value	Explanation
Proposed target reference point	716 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed limit reference point	303 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed fishing ban level	43 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

Appendix Figure 12-2 shows a Kobe plot based on the proposed target reference point and fishing mortality (F) at that time. The spawning biomass in 2019 (SB2019: 194 thousand tons) obtained by cohort analysis was below the proposed limit reference point. The fishing mortality is determined to have been above Fmsy since 2013, except in 2019.



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

Enlarged view



漁獲圧の比（F/Fmsy）	F/Fmsy
親魚量の比（SB/SBmsy）	SB/SBmsy
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point

Appendix Figure 12-2. Relationship between the proposed reference points and the spawning biomass and fishing mortality (Kobe plot) and its enlarged view

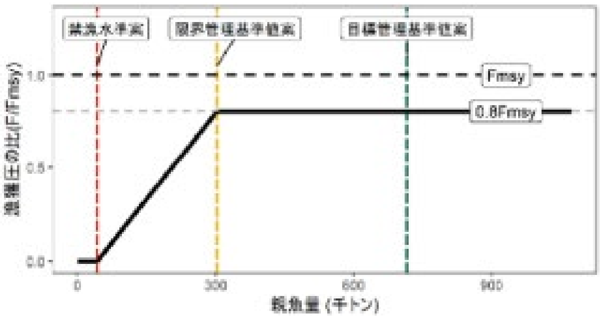
SBmsy and Fmsy assume the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017), and the plots of the spawning biomass and the exploitation rate are also limited to that period.

(1) Setting of future projection

We calculated the future projection for 2020 to 2051 using forward computation of cohort analysis based on the stock biomass (B) in 2019 estimated in stock assessment (Appendices 10 and 11). The parameters used for the future projection are shown in the table below. Other settings are the same as those in Appendix 10. The ratio of the fishing mortality in 2020 (F2020), which indicates the current fishing mortality, to Fmsy was 1.19. For the fishing mortality in 2021 onward, we used the fishing mortality specified in the proposed HCRs (Appendix Figure 12-3) based on the spawning biomass projected for each year.

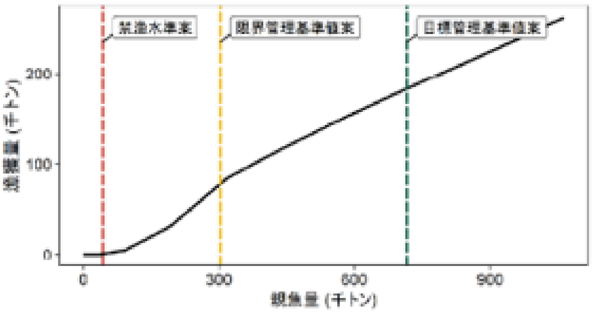
	Selectivity	Fmsy	F2014-2018	Average body weight (g)	Natural mortality	Maturity rate
Age 0	0.59	0.25	0.30	16	0.40	0
Age 1	0.34	0.14	0.17	43	0.40	0.25
Age 2	0.58	0.25	0.29	71	0.40	1.00
Age 3	1.00	0.42	0.51	90	0.40	1.00
Age 4 and above	1.00	0.42	0.51	114	0.40	1.00

a)



漁獲圧の比	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

b)



漁獲量（千トン）	Catch (thousand tons)

親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

Appendix Figure 12-3. Proposed HCRs

(a) When the vertical axis is fishing mortality, and (b) When the vertical axis is catch

(3) Projected values for 2021

The catch in 2021 estimated according to the future projection using the proposed HCRs was 72 thousand tons where β was 0.8, and 88 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 286 thousand tons on average, and the estimation was below the proposed limit reference point in all iterations, so F in 2021 was calculated by multiplying βFmsy by the coefficient corresponding to spawning biomass, γ (γ = 0.93).

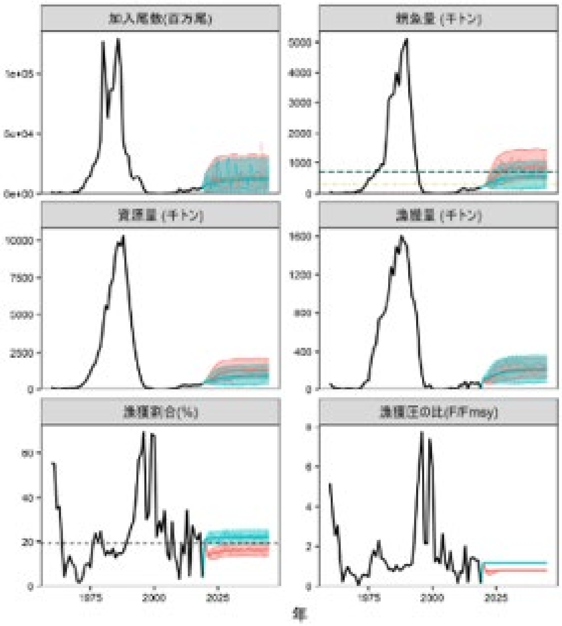
Spawning biomass in 2021 (average projection value): 286 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2014-2018)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β = 0.8	72	0.61	14
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	88	0.77	17
β = 0.9	80	0.69	15
β = 0.7	64	0.54	12
β = 0.6	56	0.46	11
β = 0	0	0	0
F2014-2018	110	1.00	21

Appendix Figure 12-4 and Appendix Tables 12-1 and 12-2 show the medium- to long-term future projection results based on the proposed HCRs. If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in 2031 is 684 thousand tons on average where β is 1.0 (the 80% confidence interval is 368 thousand to 1,050 thousand tons), and 824 thousand tons on average where β is 0.8 (the 80% confidence interval is 486 thousand to 1,224 thousand tons). The probability of the projected spawning biomass being above the proposed target reference point (SBtarget) exceeded 50% where β is 0.8 or less. The probability of the projected spawning biomass being above the proposed limit reference point (SBlimit) and the probability of the projected spawning biomass being above the proposed fishing ban level (SBban) were 100% where β is 0.7 or less.

Uncertainty considered: recruitment					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points below (%)		
			SBtarget	SBlimit	SBban
Scientifically proposed fishing mortality					
β = 0.8	824	486–1224	58	99	100
Other strategy (when using different β in the proposed HCRs)					
β = 1.0	684	368–1050	38	96	100
β = 0.9	752	426–1133	48	98	100
β = 0.7	901	548–1323	68	100	100
β = 0.6	984	612–1434	78	100	100
β = 0	1752	1177–2428	100	100	100
F2014-2018	516	203–862	20	77	100

If management based on the proposed HCRs is continued, the year in which spawning biomass will be above the proposed SBtarget with a probability of 50% or more was projected to be in or after 2029 where β is 0.8. Also, the year in which spawning biomass will be above the SBlimit with a probability of 50% or more was projected to be in 2022. Even if the fishing mortality is set at zero (β = 0), the year in which spawning biomass will be above the proposed SBtarget with a probability of 50% or more was predicted to be in 2024.

Uncertainty considered: recruitment			
	Year in which spawning biomass will be above the proposed reference points with a probability of 50% or more		
	Proposed SBtarget	Proposed SBlimit	Proposed SBban
β used in the HCRs			
β = 0.8	2029	2022	2019
Other strategy (when using different β from the proposed HCRs)			
β = 1.0	2051 onward	2022	2019
β = 0.9	2041	2022	2019
β = 0.7	2027	2022	2019
β = 0.6	2026	2022	2019
β = 0	2024	2022	2019
F2014-2019	2051 onward	2023	2019



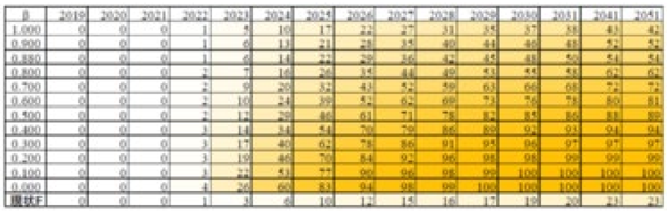
加入尾数（百万尾）	Recruitment (million individuals)
資源量（千トン）	Stock biomass (thousand tons)
漁獲割合（%）	Exploitation rate (%)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲圧の比（F/Fmsy）	Ratio of the fishing mortality to MSY (F/Fmsy)
年	Year
（塗り：5-95%予測区間，太い実線：平均値，細い実線：シミュレーションの１例）	(Shaded: 5-95% prediction interval; thick solid line: average value; thin solid line: simulation example)

Appendix Figure 12-4. Future projection using the proposed HCRs (in red) and future projection in the case of continuing fishing with the current fishing mortality (in green)

The thick solid line indicates the average value, the shaded part indicates the 90% prediction interval that covers 90% of the simulation results, the thin lines indicate 5 patterns of future projection examples. In the figure of spawning biomass, the green broken line indicates the proposed target reference point, and the yellow dotted line indicates the proposed limit reference point. In the figure of exploitation rate, the broken line indicates Umsy. Safety coefficient β is 0.8. 1e+05 means 10^5.

Appendix Table 12-1. Probability of future spawning biomass being above the proposed target reference point and limit reference point

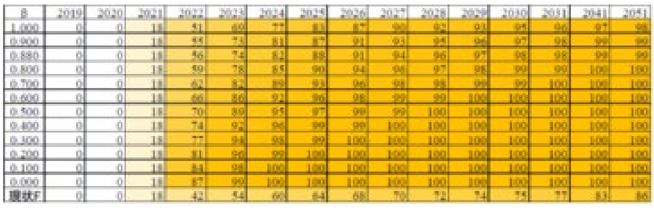
a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	1	5	10	17	22	27	31	35	37	38	43	42
0.900	0	0	0	1	6	13	21	28	35	40	44	46	48	52	52
0.880	0	0	0	1	6	14	22	29	36	42	45	48	50	54	54
0.800	0	0	0	2	7	16	26	35	44	49	53	55	58	62	62
0.700	0	0	0	2	9	20	32	43	52	59	63	66	68	72	72
0.600	0	0	0	2	10	24	39	52	62	69	73	76	78	80	81
0.500	0	0	0	2	12	29	46	61	71	78	82	85	86	88	89
0.400	0	0	0	3	14	34	54	70	79	86	89	92	93	94	94
0.300	0	0	0	3	17	40	62	78	86	91	95	96	97	97	97
0.200	0	0	0	3	19	46	70	84	92	96	98	98	99	99	99
0.100	0	0	0	3	22	53	77	90	96	98	99	100	100	100	100
0.000	0	0	0	4	26	60	83	94	98	99	100	100	100	100	100
現状F	0	0	0	1	3	6	10	12	15	16	17	19	20	23	23

現状 F	Fcurrent

b) Probability of being above the proposed limit reference point (%)

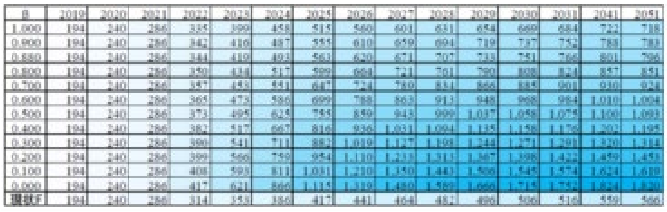


β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	51	69	77	83	87	90	92	93	95	96	97	98
0.900	0	0	18	55	73	81	87	91	93	95	96	97	98	99	99
0.880	0	0	18	56	74	82	88	91	94	96	97	98	98	99	99
0.800	0	0	18	59	78	85	90	94	96	97	98	99	99	100	100
0.700	0	0	18	62	82	89	93	96	98	98	99	99	100	100	100
0.600	0	0	18	66	86	92	96	98	99	99	100	100	100	100	100
0.500	0	0	18	70	89	95	97	99	99	100	100	100	100	100	100
0.400	0	0	18	74	92	96	99	99	100	100	100	100	100	100	100
0.300	0	0	18	77	94	98	99	100	100	100	100	100	100	100	100
0.200	0	0	18	81	96	99	100	100	100	100	100	100	100	100	100
0.100	0	0	18	84	98	100	100	100	100	100	100	100	100	100	100
0.000	0	0	18	87	99	100	100	100	100	100	100	100	100	100	100
現状F	0	0	18	42	54	60	64	68	70	72	74	75	77	83	86

現状 F	Fcurrent

Appendix Table 12-2. Changes in average values of future spawning biomass and catch

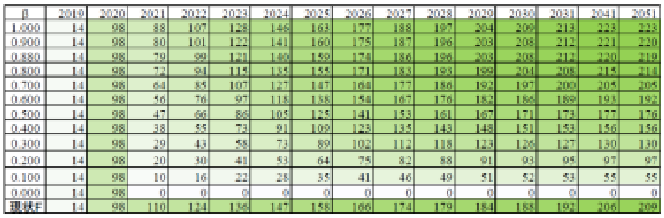
a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	335	399	458	515	560	601	631	654	669	684	722	718
0.900	194	240	286	342	416	487	555	610	659	694	719	737	752	788	783
0.880	194	240	286	344	419	493	563	620	671	707	733	751	766	801	796
0.800	194	240	286	350	434	517	599	664	721	761	790	808	824	857	851
0.700	194	240	286	357	453	551	647	724	780	834	866	885	901	930	924
0.600	194	240	286	365	473	586	699	788	863	913	948	968	984	1,010	1,004
0.500	194	240	286	373	495	625	755	859	943	999	1,037	1,058	1,075	1,100	1,093
0.400	194	240	286	382	517	667	816	936	1,031	1,094	1,135	1,158	1,176	1,202	1,195
0.300	194	240	286	390	541	711	882	1,019	1,127	1,198	1,244	1,271	1,291	1,320	1,314
0.200	194	240	286	399	566	759	954	1,110	1,233	1,313	1,367	1,398	1,422	1,459	1,453
0.100	194	240	286	408	593	811	1,031	1,210	1,350	1,443	1,506	1,545	1,574	1,624	1,619
0.000	194	240	286	417	621	866	1,115	1,319	1,480	1,589	1,660	1,715	1,752	1,824	1,820
現状F	194	240	286	314	353	386	417	441	464	482	496	506	516	559	566

現状 F	Fcurrent

b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	88	107	128	146	163	177	188	197	204	209	213	223	223
0.900	14	98	80	101	122	141	160	175	187	196	203	208	212	221	220
0.880	14	98	79	99	121	140	159	174	186	196	203	208	212	220	219
0.800	14	98	72	94	115	135	155	171	183	193	199	204	208	215	214
0.700	14	98	64	85	107	127	147	164	177	186	192	197	200	205	205
0.600	14	98	56	76	97	118	138	154	167	176	182	186	189	193	192
0.500	14	98	47	66	86	105	125	141	153	161	167	171	173	177	176
0.400	14	98	38	55	73	91	109	123	135	143	148	151	153	156	156
0.300	14	98	29	43	58	73	89	102	112	118	123	126	127	130	130
0.200	14	98	20	30	41	53	64	75	82	88	91	93	95	97	97
0.100	14	98	10	16	22	28	35	41	46	49	51	52	53	55	55
0.000	14	98	0	0	0	0	0	0	0	0	0	0	0	0	0
現状F	14	98	110	124	136	147	158	166	174	179	184	188	192	206	209

現状 F	Fcurrent

Appendix 13. Study on a scenario that eases the decrease in the catch upon introduction of the HCRs

In response to discussions at the Committee of Stock Management Policy on Japanese sardine and Japanese jack mackerel held in Fukuoka City on July 30 and 31, 2020 (the SH Meeting), the SH Meeting requested us to conduct trial calculation of a scenario that eases the decrease in the catch upon introduction of HCRs.

(1) The SH Meeting requests indication of a scenario where: the immediate catch is set within a range where β does not exceed 1, aiming at a value as close as possible to about 80 thousand tons, and the catch in 2031 is set at about 200 thousand tons; β can be small, such as 0.6 or 0.7; and a stock biomass that produces MSY is achieved with a probability of 50% or more in 10 years.

(2) The SH Meeting requests indication of the projected stock biomass and the probability of achieving a stock biomass that produces MSY in the case of fixing the catch at around 80 thousand to 90 thousand tons in the immediate future, and subsequently using catch at lower β.

Therefore, we studied the following two corresponding scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment period (1960 to 1975 and 1988 to 2017) (Appendix Figure 10-1).

[13-1] Scenario assuming catch at 0.8 times the fishing mortality that produces MSY (0.8Fmsy) from 2021 to 2023, and catch under the proposed HCRs from 2024 onward

[13-2] Scenario assuming catch with fishing mortality that gives a constant catch (85 thousand tons) from 2021 to 2023 and catch under the proposed HCRs from 2024 onward

The outline of the results are as follows.

[13−1] 0.8Fmsy from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 13-1)

The catch shifts from 77 thousand tons on average in 2021, 97 thousand tons on average in 2022, and 118 thousand tons on average in 2023. Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed target reference point (SBtarget) (1,093 thousand tons) with a probability of 50%. The year in which spawning biomass will be above the proposed limit reference point (SBlimit) (465 thousand tons) with a probability of 50% or more is 2025, and the SBlimit was projected to be reached one year later than in the case of introducing the proposed HCRs in 2021. The catch in 2024 will be 128 thousand tons on average, increasing by 10 thousand tons on average from 2023.

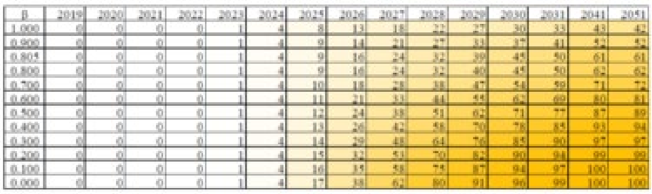
[13−2] Constant catch (85 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 13-2)

Where β is 0.7, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50%. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2025, and the SBlimit was projected to be reached one year later than in the case of introducing the proposed HCRs in 2021. The catch in 2024 is 118 thousand tons on average, increasing by 33 thousand tons on average from 2023.

In the case of fishing with a fishing mortality that gives a constant catch, the stock status is not considered in deciding the catch amount. In the case of introducing the proposed HCRs in 2021, the catch amount where β is 0.8 is low, at 46 thousand tons on average in 2021, but it is projected to be 83 thousand tons on average in 2022 and 121 thousand tons on average in 2023 (Appendix Table 10-2). Therefore, in the third year after the start, the catch amount in this scenario will be lower. In other words, in scenario 13-2, stronger fishing restrictions will be imposed from 2023 onward. If the stock biomass happens to decrease, there will be a delay in management, so there could be a risk of extinction of the stock.

Appendix Table 13-1-1. [13-1] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



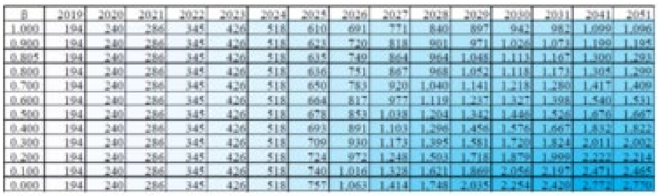
β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	1	4	8	13	18	22	27	30	33	43	42
0.900	0	0	0	0	1	4	9	14	21	27	33	37	41	52	52
0.805	0	0	0	0	1	4	9	16	24	32	39	45	50	61	61
0.800	0	0	0	0	1	4	9	16	24	32	40	45	50	62	62
0.700	0	0	0	0	1	4	10	18	28	38	47	54	59	71	72
0.600	0	0	0	0	1	4	11	21	33	44	55	62	69	80	81
0.500	0	0	0	0	1	4	12	24	38	51	62	71	77	87	89
0.400	0	0	0	0	1	4	13	26	42	58	70	78	85	93	94
0.300	0	0	0	0	1	4	14	29	48	64	76	85	90	97	97
0.200	0	0	0	0	1	4	15	32	53	70	82	90	94	99	99
0.100	0	0	0	0	1	4	16	35	58	75	87	94	97	100	100
0.000	0	0	0	0	1	4	17	38	62	80	91	96	99	100	100

b) Probability of being above the proposed limit reference point (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	12	31	47	60	70	77	83	87	90	92	97	98
0.900	0	0	0	12	31	47	62	73	80	87	90	93	95	99	99
0.805	0	0	0	12	31	47	63	75	84	89	93	96	97	100	100
0.800	0	0	0	12	31	47	63	75	84	89	93	96	97	100	100
0.700	0	0	0	12	31	47	65	78	86	92	95	97	98	100	100
0.600	0	0	0	12	31	47	67	80	89	94	97	98	99	100	100
0.500	0	0	0	12	31	47	68	82	91	95	98	99	100	100	100
0.400	0	0	0	12	31	47	70	84	92	97	99	99	100	100	100
0.300	0	0	0	12	31	47	71	86	94	97	99	100	100	100	100
0.200	0	0	0	12	31	47	73	87	95	98	99	100	100	100	100
0.100	0	0	0	12	31	47	74	89	96	99	100	100	100	100	100
0.000	0	0	0	12	31	47	75	90	97	99	100	100	100	100	100

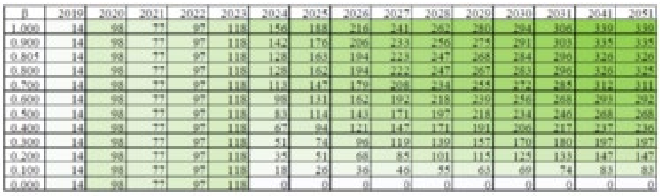
Appendix Table 13-1-2. [13-1] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	345	426	518	610	691	771	840	897	942	982	1,099	1,096
0.900	194	240	286	345	426	518	623	720	818	901	971	1,026	1,073	1,199	1,195
0.805	194	240	286	345	426	518	635	749	864	964	1,048	1,113	1,167	1,300	1,293
0.800	194	240	286	345	426	518	636	751	867	968	1,052	1,118	1,173	1,304	1,299
0.700	194	240	286	345	426	518	650	783	920	1,040	1,141	1,218	1,280	1,417	1,409
0.600	194	240	286	345	426	518	664	817	977	1,119	1,237	1,327	1,398	1,540	1,531
0.500	194	240	286	345	426	518	678	853	1,038	1,204	1,342	1,446	1,526	1,676	1,667
0.400	194	240	286	345	426	518	693	891	1,103	1,296	1,456	1,576	1,667	1,832	1,822
0.300	194	240	286	345	426	518	709	930	1,173	1,395	1,581	1,720	1,824	2,011	2,002
0.200	194	240	286	345	426	518	724	972	1,248	1,503	1,718	1,879	1,999	2,222	2,214
0.100	194	240	286	345	426	518	740	1,016	1,328	1,621	1,868	2,056	2,197	2,471	2,465
0.000	194	240	286	345	426	518	757	1,063	1,414	1,748	2,035	2,254	2,420	2,772	2,770

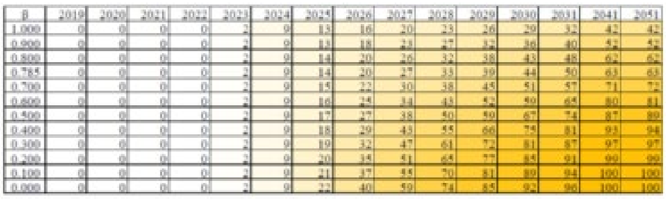
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	77	97	118	156	188	216	241	262	280	294	306	339	339
0.900	14	98	77	97	118	142	176	206	233	256	275	291	303	335	335
0.805	14	98	77	97	118	128	165	194	223	247	268	284	296	326	326
0.800	14	98	77	97	118	128	162	194	222	247	267	283	296	326	325
0.700	14	98	77	97	118	113	147	179	208	234	255	272	285	312	311
0.600	14	98	77	97	118	98	131	162	192	218	239	256	268	293	292
0.500	14	98	77	97	118	83	114	143	171	197	218	234	246	268	268
0.400	14	98	77	97	118	67	94	121	147	171	191	206	217	237	236
0.300	14	98	77	97	118	51	74	96	119	139	157	170	180	197	197
0.200	14	98	77	97	118	35	51	68	85	101	115	125	133	147	147
0.100	14	98	77	97	118	18	26	36	46	55	63	69	74	83	83
0.000	14	98	77	97	118	0	0	0	0	0	0	0	0	0	0

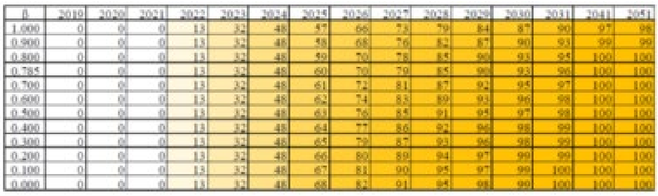
Appendix Table 13-2-1. [13-2] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	2	9	13	16	20	23	26	29	32	42	42
0.900	0	0	0	0	2	9	13	18	23	27	32	36	40	52	52
0.800	0	0	0	0	2	9	14	20	26	32	38	43	48	62	62
0.785	0	0	0	0	2	9	14	20	27	33	39	44	50	63	63
0.700	0	0	0	0	2	9	15	22	30	38	45	51	57	71	72
0.600	0	0	0	0	2	9	16	25	34	43	52	59	65	80	81
0.500	0	0	0	0	2	9	17	27	38	50	59	67	74	87	89
0.400	0	0	0	0	2	9	18	29	43	55	66	75	81	93	94
0.300	0	0	0	0	2	9	19	32	47	61	72	81	87	97	97
0.200	0	0	0	0	2	9	20	35	51	65	77	85	91	99	99
0.100	0	0	0	0	2	9	21	37	55	70	81	89	94	100	100
0.000	0	0	0	0	2	9	22	40	59	74	85	92	96	100	100

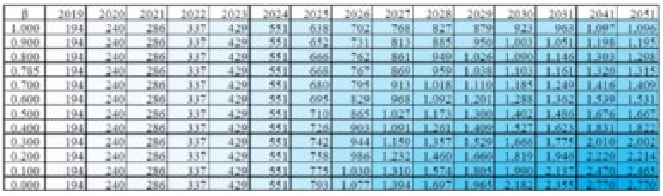
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	13	32	48	57	66	73	79	84	87	90	97	98
0.900	0	0	0	13	32	48	58	68	76	82	87	90	93	99	99
0.800	0	0	0	13	32	48	59	70	78	85	90	93	95	100	100
0.785	0	0	0	13	32	48	60	70	79	85	90	93	96	100	100
0.700	0	0	0	13	32	48	61	72	81	87	92	95	97	100	100
0.600	0	0	0	13	32	48	62	74	83	89	93	96	98	100	100
0.500	0	0	0	13	32	48	63	76	85	91	95	97	98	100	100
0.400	0	0	0	13	32	48	64	77	86	92	96	98	99	100	100
0.300	0	0	0	13	32	48	65	79	87	93	96	98	99	100	100
0.200	0	0	0	13	32	48	66	80	89	94	97	99	99	100	100
0.100	0	0	0	13	32	48	67	81	90	95	97	99	100	100	100
0.000	0	0	0	13	32	48	68	82	91	95	98	99	100	100	100

Appendix Table 13-2-2.[13-2] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	337	429	551	638	702	768	827	879	923	963	1,097	1,096
0.900	194	240	286	337	429	551	652	731	813	885	950	1,003	1,051	1,198	1,195
0.800	194	240	286	337	429	551	666	762	861	949	1,026	1,090	1,146	1,303	1,298
0.785	194	240	286	337	429	551	668	767	869	959	1,038	1,103	1,161	1,320	1,315
0.700	194	240	286	337	429	551	680	795	913	1,018	1,110	1,184	1,249	1,416	1,409
0.600	194	240	286	337	429	551	695	829	968	1,092	1,201	1,288	1,362	1,539	1,531
0.500	194	240	286	337	429	551	710	865	1,027	1,173	1,300	1,402	1,486	1,676	1,667
0.400	194	240	286	337	429	551	726	903	1,091	1,261	1,409	1,527	1,623	1,831	1,822
0.300	194	240	286	337	429	551	742	944	1,159	1,357	1,529	1,666	1,775	2,010	2,002
0.200	194	240	286	337	429	551	758	986	1,232	1,460	1,660	1,819	1,946	2,220	2,214
0.100	194	240	286	337	429	551	775	1,030	1,310	1,574	1,805	1,990	2,137	2,470	2,465
0.000	194	240	286	337	429	551	793	1,077	1,394	1,697	1,965	2,182	2,355	2,770	2,770

b) Changes in average values of catch (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	85	85	85	162	191	216	237	256	273	287	300	338	339
0.900	14	98	85	85	85	148	178	205	229	250	268	284	296	334	335
0.800	14	98	85	85	85	133	164	193	218	240	260	276	289	325	325
0.785	14	98	85	85	85	131	162	191	216	239	258	275	288	324	324
0.700	14	98	85	85	85	118	149	178	204	228	248	264	278	312	311
0.600	14	98	85	85	85	103	133	162	188	212	232	248	262	293	292
0.500	14	98	85	85	85	87	115	142	168	191	211	227	240	268	268
0.400	14	98	85	85	85	70	96	121	144	166	185	200	211	237	236
0.300	14	98	85	85	85	54	74	96	116	135	152	165	175	197	197
0.200	14	98	85	85	85	36	52	67	83	98	111	121	129	147	147
0.100	14	98	85	85	85	18	27	36	45	53	61	67	72	83	83
0.000	14	98	85	85	85	0	0	0	0	0	0	0	0	0	0

Appendix 14. Study on a scenario that eases the decrease in the catch upon introduction of HCRs 2

At the Stock Assessment Meeting of Japanese Sardine and Japanese Jack Mackerel held in August 11, 2020, we were requested to conduct additional trial calculation of scenarios that ease the decrease in the catch upon introduction of the HCRs. The contents of the trial calculations are as follows.

- Scenario that increases the catch in 2021 as much as possible and assumes a gradual increase in future catch
- Scenario that conducts fishing with the current fishing mortality for 1 or 2 years
- Scenario that increases the catch in 2021 based on the S-R relationship for the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017)

We sorted out the above requests and assumed a total of 12 scenarios, including the scenarios studied so far. We created (1) scenarios 1-1 to 1-6 based on the S-R relationship for the normal recruitment period (1960 to 1975 and 1988 to 2017) and (2) scenarios 2-1 to 2-6 based on the S-R relationship for the normal recruitment period excluding the transition period (1960 to 1975 and 1991 to 2017) (Appendix Table 14-1).

Appendix Table 14-1. Harvest control scenarios for the Japanese sardine Tsushima stock

Fishing mortality before introduction of HCRs	Year of introduction of HCRs	Normal recruitment period	Normal recruitment period excluding the transition period
-	2021	1-1 (Appx. 10)	2-1* (Appx. 12)
0.8Fmsy	2024	1-2* (Appx. 13-1)	2-2 (Appx. 14-5)
Constant catch (85 thousand tons)	2024	1-3* (Appx. 13-2)	2-3 (Appx. 14-6)
Constant catch (100 thousand tons)	2024	1-4 (Appx. 14-2)	2-4 (Appx. 14-7)
Constant catch (100 thousand tons)	2022	1-5 (Appx. 14-3)	2-5 (Appx. 14-8)
Current fishing mortality	2022	1-6 (Appx. 14-4)	2-6 (Appx. 14-9)

The asterisk (*) indicates scenarios corresponding to the requests from the SH Meeting. Scenarios excluding 1-1 and those marked with * are those requested at the Stock Assessment Meeting.

(1) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment period (Appendix Figure 10-1)

[1-1] Proposed HCRs from 2021 (Appendix 10)

[1-2*] Catch at 0.8 times the fishing mortality that produces MSY (0.8Fmsy) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 13-1)

[1-3*] Fishing mortality that gives constant catch (85 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 13-2)

[1-4] Fishing mortality that gives constant catch (100 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-2)

[1-5] Fishing mortality that gives constant catch (100 thousand tons) in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-3)

[1−6] Current fishing mortality in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-4)

(2) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment excluding the transition period (Appendix Figure 12-3)

[2-1*] Proposed HCRs from 2021 (Appendix 12)

[2-2] Catch at 0.8 times the fishing mortality that produces MSY (0.8Fmsy) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-5)

[2-3] Fishing mortality that gives constant catch (85 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-6)

[2-4] Fishing mortality that gives constant catch (100 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-7)

[2-5] Fishing mortality that gives constant catch (100 thousand tons) in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-8)

[2−6] Current fishing mortality in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-9)

In all scenarios, there was β for which the spawning biomass in 2031 will be above the proposed target reference point (SBtarget) with a probability of 50% or more.

Appendix 14 shows the results for scenarios 1-4 to 1-6 and 2-2 to 2-6, which correspond to the requests at the Stock Assessment Meeting. Appendix 15 compares the results of all scenarios studied.

(1) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment period (1960 to 1975 and 1988 to 2017) (Appendix Figure 10-1)

[1-4] Constant catch (100 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-2)

Where β is 0.7, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed limit reference point (SBlimit) with a probability of 50% or more is 2025, and the SBlimit was projected to be reached one year later compared to scenario 1-1. The catch in 2024 is 101 thousand tons on average, and is expected to increase by 10 thousand tons on average from 2023. However, with a probability of 3%, the spawning biomass in 2024 will be below the proposed fishing ban level (SBban) (66 thousand tons), and the fishing will be banned.

[1-5] Constant catch (100 thousand tons) in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-3)

Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2024, which is the same as in scenario 1-1. The catch in 2022 is 63 thousand tons on average, decreasing by 37 thousand tons on average from 2021.

[1-6] Current fishing mortality in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-4)

Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2025, and the SBlimit was projected to be reached one year later compared to scenario 1-1. The catch will shift from 110 thousand tons on average in 2021 to 59 thousand tons on average in 2022, and is expected to decrease by 51 thousand tons on average from the previous year in 2022, when the projected HCRs are introduced.

[2-2] 0.8Fmsy from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-5)

The catch shifts from 78 thousand tons on average in 2021, 96 thousand tons on average in 2022, and 115 thousand tons on average in 2023. Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2022, which is the same as in scenario 2-1. The catch in 2024 will be 131 thousand tons on average, increasing by 16 thousand tons on average from 2023.

[2-3] Constant catch (85 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-6)

Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2022, which is the same as in scenario 2-1. The catch in 2024 is 133 thousand tons on average, increasing by 48 thousand tons on average from 2023.

[2-4] Constant catch (100 thousand tons) from 2021 to 2023, and the proposed HCRs from 2024 onward (Appendix Table 14-7)

Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2023, and the SBlimit was projected to be reached one year later compared to scenario 2-1. The catch in 2024 is 116 thousand tons on average, increasing by 16 thousand tons on average from 2023. However, with a probability of 2%, the spawning biomass in 2024 will be below the proposed SBban (43 thousand tons), and the fishing will be banned.

[2-5] Constant catch (100 thousand tons) in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-8)

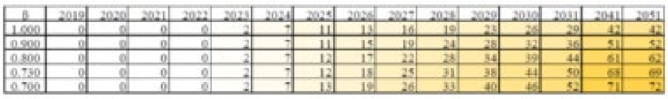
Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2023, and the SBlimit was projected to be reached one year later compared to scenario 2-1. The catch in 2022 is 82 thousand tons on average, decreasing by 18 thousand tons on average from 2021.

[2-6] Current fishing mortality in 2021, and the proposed HCRs from 2022 onward (Appendix Table 14-9)

Where β is 0.8, the projected spawning biomass in 2031 will be above the proposed SBtarget with a probability of 50% or more. The year in which spawning biomass will be above the proposed SBlimit with a probability of 50% or more is 2023, and the SBlimit was projected to be reached one year later compared to scenario 2-1. The catch will shift from 110 thousand tons on average in 2021, to 80 thousand tons on average in 2022, and to 104 thousand tons on average in 2023, and is expected to decrease by 30 thousand tons on average from the previous year in 2022, when the projected HCRs are introduced.

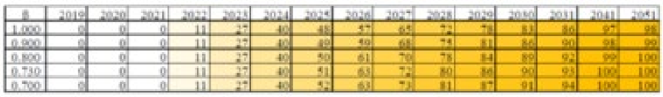
Appendix Table 14-2-1. [1-4] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	2	7	11	13	16	19	23	26	29	42	42
0.900	0	0	0	0	2	7	11	15	19	24	28	32	36	51	52
0.800	0	0	0	0	2	7	12	17	22	28	34	39	44	61	62
0.750	0	0	0	0	2	7	12	18	25	31	38	44	50	68	69
0.700	0	0	0	0	2	7	13	19	26	33	40	46	52	71	72

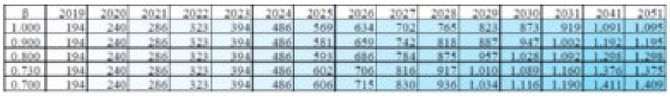
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	11	27	40	48	57	65	72	78	83	86	97	98
0.900	0	0	0	11	27	40	49	59	68	75	81	86	90	98	99
0.800	0	0	0	11	27	40	50	61	70	78	84	89	92	99	100
0.750	0	0	0	11	27	40	51	63	72	80	86	90	93	100	100
0.700	0	0	0	11	27	40	52	63	73	81	87	91	94	100	100

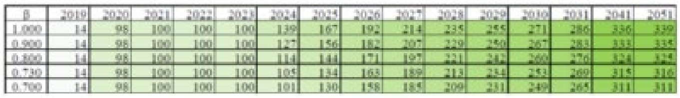
Appendix Table 14-2-2. [1-4] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	323	394	486	569	634	702	765	823	873	919	1,091	1,095
0.900	194	240	286	323	394	486	581	659	742	818	887	947	1,002	1,192	1,195
0.800	194	240	286	323	394	486	593	686	784	875	957	1,028	1,092	1,298	1,298
0.730	194	240	286	323	394	486	602	706	816	917	1,010	1,089	1,160	1,376	1,375
0.700	194	240	286	323	394	486	606	715	830	936	1,034	1,116	1,190	1,411	1,409

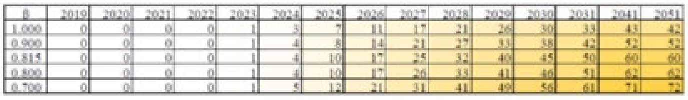
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	100	100	100	139	167	192	214	235	255	271	286	336	339
0.900	14	98	100	100	100	127	156	182	207	229	250	267	283	333	335
0.800	14	98	100	100	100	114	144	171	197	221	242	260	276	324	325
0.730	14	98	100	100	100	105	134	163	189	213	234	253	269	315	316
0.700	14	98	100	100	100	101	130	158	185	209	231	249	265	311	311

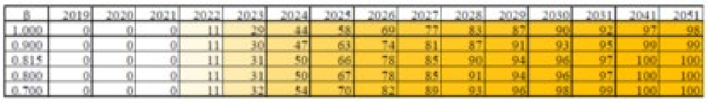
Appendix Table 14-3-1. [1-5] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	1	3	7	11	17	21	26	30	33	43	42
0.900	0	0	0	0	1	4	8	14	21	27	33	38	42	52	52
0.815	0	0	0	0	1	4	10	17	25	32	40	45	50	60	60
0.800	0	0	0	0	1	4	10	17	26	33	41	46	51	62	62
0.700	0	0	0	0	1	5	12	21	31	41	49	56	61	71	72

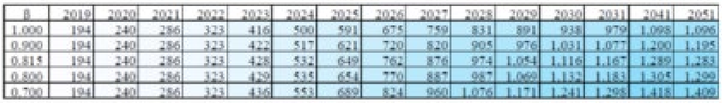
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	11	29	44	58	69	77	83	87	90	92	97	98
0.900	0	0	0	11	30	47	63	74	81	87	91	93	95	99	99
0.815	0	0	0	11	31	50	66	78	85	90	94	96	97	100	100
0.800	0	0	0	11	31	50	67	78	85	91	94	96	97	100	100
0.700	0	0	0	11	32	54	70	82	89	93	96	98	99	100	100

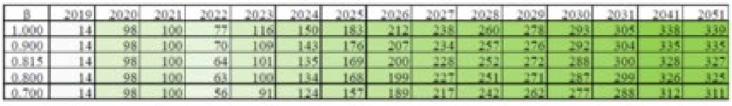
Appendix Table 14-3-2. [1-5] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	323	416	500	591	675	759	831	891	938	979	1,098	1,096
0.900	194	240	286	323	422	517	621	720	820	905	976	1,031	1,077	1,200	1,195
0.815	194	240	286	323	428	532	649	762	876	974	1,054	1,116	1,167	1,289	1,283
0.800	194	240	286	323	429	535	654	770	887	987	1,069	1,132	1,183	1,305	1,299
0.700	194	240	286	323	436	553	689	824	960	1,076	1,171	1,241	1,298	1,418	1,409

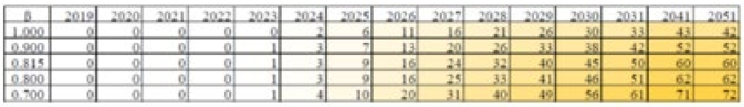
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	100	77	116	150	183	212	238	260	278	293	305	338	339
0.900	14	98	100	70	109	143	176	207	234	257	276	292	304	335	335
0.815	14	98	100	64	101	135	169	200	228	252	272	288	300	328	327
0.800	14	98	100	63	100	134	168	199	227	251	271	287	299	326	325
0.700	14	98	100	56	91	124	157	189	217	242	262	277	288	312	311

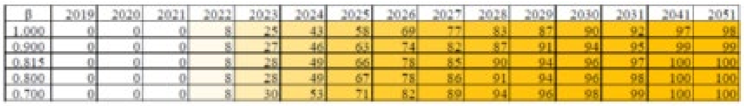
Appendix Table 14-4-1. [1-6] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	0	0	2	6	11	16	21	26	30	33	43	42
0.900	0	0	0	0	1	3	7	13	20	26	33	38	42	52	52
0.815	0	0	0	0	1	3	9	16	24	32	40	45	50	60	60
0.800	0	0	0	0	1	3	9	16	25	33	41	46	51	62	62
0.700	0	0	0	0	1	4	10	20	31	40	49	56	61	71	72

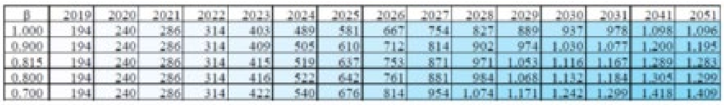
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	8	25	43	58	69	77	83	87	90	92	97	98
0.900	0	0	0	8	27	46	63	74	82	87	91	94	95	99	99
0.815	0	0	0	8	28	49	66	78	85	90	94	96	97	100	100
0.800	0	0	0	8	28	49	67	78	86	91	94	96	98	100	100
0.700	0	0	0	8	30	53	71	82	89	94	96	98	99	100	100

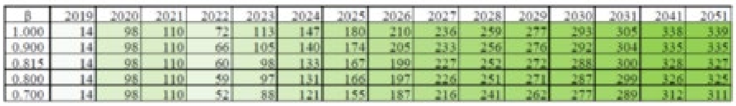
Appendix Table 14-4-2. [1-6] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	314	403	489	581	667	754	827	889	937	978	1,098	1,096
0.900	194	240	286	314	409	505	610	712	814	902	974	1,030	1,077	1,200	1,195
0.815	194	240	286	314	415	519	637	753	871	971	1,053	1,116	1,167	1,289	1,283
0.800	194	240	286	314	416	522	642	761	881	984	1,068	1,132	1,184	1,305	1,299
0.700	194	240	286	314	422	540	676	814	954	1,074	1,171	1,242	1,299	1,418	1,409

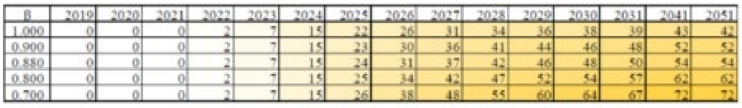
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	110	72	113	147	180	210	236	259	277	293	305	338	339
0.900	14	98	110	66	105	140	174	205	233	256	276	292	304	335	335
0.815	14	98	110	60	98	133	167	199	227	252	272	288	300	328	327
0.800	14	98	110	59	97	131	166	197	226	251	271	287	299	326	325
0.700	14	98	110	52	88	121	155	187	216	241	262	277	289	312	311

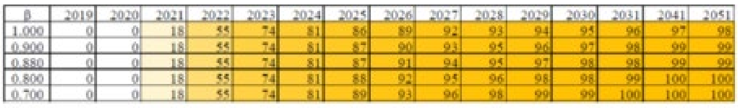
Appendix Table 14-5-1. [2-2] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	2	7	15	22	26	31	34	36	38	39	43	42
0.900	0	0	0	2	7	15	23	30	36	41	44	46	48	52	52
0.880	0	0	0	2	7	15	24	31	37	42	46	48	50	54	54
0.800	0	0	0	2	7	15	25	34	42	47	52	54	57	62	62
0.700	0	0	0	2	7	15	26	38	48	55	60	64	67	72	72

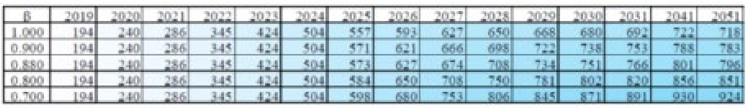
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	55	74	81	86	89	92	93	94	95	96	97	98
0.900	0	0	18	55	74	81	87	90	93	95	96	97	98	99	99
0.880	0	0	18	55	74	81	87	91	94	95	97	98	98	99	99
0.800	0	0	18	55	74	81	88	92	95	96	98	98	99	100	100
0.700	0	0	18	55	74	81	89	93	96	98	99	99	100	100	100

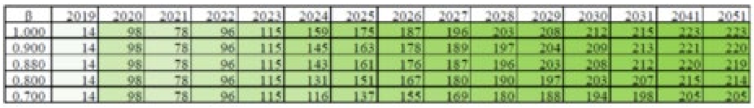
Appendix Table 14-5-2. [2-2] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	345	424	504	557	593	627	650	668	680	692	722	718
0.900	194	240	286	345	424	504	571	621	666	698	722	738	753	788	783
0.880	194	240	286	345	424	504	573	627	674	708	734	751	766	801	796
0.800	194	240	286	345	424	504	584	650	708	750	781	802	820	856	851
0.700	194	240	286	345	424	504	598	680	753	806	845	871	891	930	924

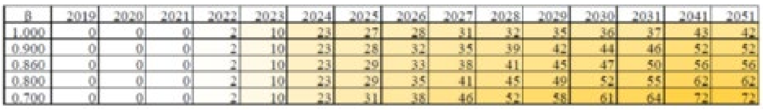
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	78	96	115	159	175	187	196	203	208	212	215	223	223
0.900	14	98	78	96	115	145	163	178	189	197	204	209	213	221	220
0.880	14	98	78	96	115	143	161	176	187	196	203	208	212	220	219
0.800	14	98	78	96	115	131	151	167	180	190	197	203	207	215	214
0.700	14	98	78	96	115	116	137	155	169	180	188	194	198	205	205

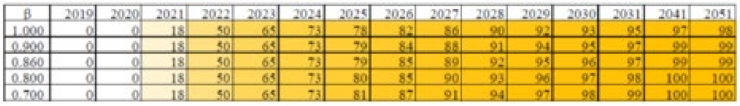
Appendix Table 14-6-1. [2-3] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	2	10	23	27	28	31	32	35	36	37	43	42
0.900	0	0	0	2	10	23	28	32	35	39	42	44	46	52	52
0.860	0	0	0	2	10	23	29	33	38	41	45	47	50	56	56
0.800	0	0	0	2	10	23	29	35	41	45	49	52	55	62	62
0.700	0	0	0	2	10	23	31	38	46	52	58	61	64	72	72

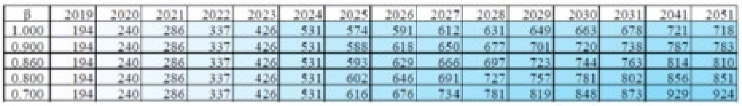
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	50	65	73	78	82	86	90	92	93	95	97	98
0.900	0	0	18	50	65	73	79	84	88	91	94	95	97	99	99
0.860	0	0	18	50	65	73	79	85	89	92	95	96	97	99	99
0.800	0	0	18	50	65	73	80	85	90	93	96	97	98	100	100
0.700	0	0	18	50	65	73	81	87	91	94	97	98	99	100	100

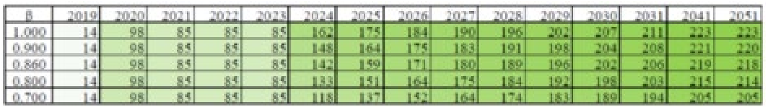
Appendix Table 14-6-2. [2-3] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	337	426	531	574	591	612	631	649	663	678	721	718
0.900	194	240	286	337	426	531	588	618	650	677	701	720	738	787	783
0.860	194	240	286	337	426	531	593	629	666	697	723	744	763	814	810
0.800	194	240	286	337	426	531	602	646	691	727	757	781	802	856	851
0.700	194	240	286	337	426	531	616	676	734	781	819	848	873	929	924

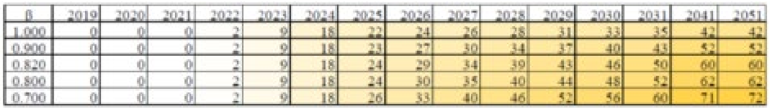
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	85	85	85	162	175	184	190	196	202	207	211	223	223
0.900	14	98	85	85	85	148	164	175	183	191	198	204	208	221	220
0.860	14	98	85	85	85	142	159	171	180	189	196	202	206	219	218
0.800	14	98	85	85	85	133	151	164	175	184	192	198	203	215	214
0.700	14	98	85	85	85	118	137	152	164	174	183	189	194	205	205

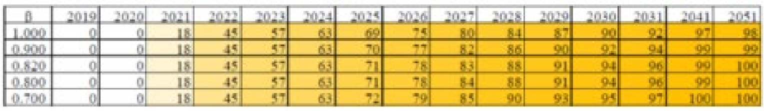
Appendix Table 14-7-1. [2-4] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	2	9	18	22	24	26	28	31	33	35	42	42
0.900	0	0	0	2	9	18	23	27	30	34	37	40	43	52	52
0.820	0	0	0	2	9	18	24	29	34	39	43	46	50	60	60
0.800	0	0	0	2	9	18	24	30	35	40	44	48	52	62	62
0.700	0	0	0	2	9	18	26	33	40	46	52	56	60	71	72

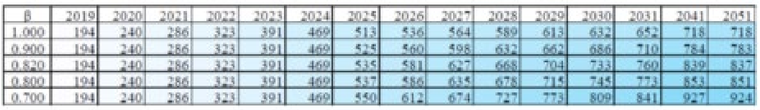
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	45	57	63	69	75	80	84	87	90	92	97	98
0.900	0	0	18	45	57	63	70	77	82	86	90	92	94	99	99
0.820	0	0	18	45	57	63	71	78	83	88	91	94	96	99	100
0.800	0	0	18	45	57	63	71	78	84	88	91	94	96	99	100
0.700	0	0	18	45	57	63	72	79	85	90	93	95	97	100	100

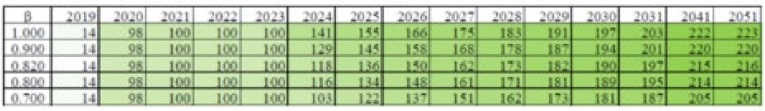
Appendix Table 14-7-2. [2-4] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	323	391	469	513	536	564	589	613	632	652	718	718
0.900	194	240	286	323	391	469	525	560	598	632	662	686	710	784	783
0.820	194	240	286	323	391	469	535	581	627	668	704	733	760	839	837
0.800	194	240	286	323	391	469	537	586	635	678	715	745	773	853	851
0.700	194	240	286	323	391	469	550	612	674	727	773	809	841	927	924

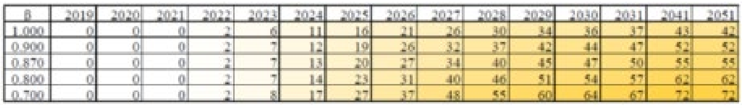
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	100	100	100	141	155	166	175	183	191	197	203	222	223
0.900	14	98	100	100	100	129	145	158	168	178	187	194	201	220	220
0.820	14	98	100	100	100	118	136	150	162	173	182	190	197	215	216
0.800	14	98	100	100	100	116	134	148	161	171	181	189	195	214	214
0.700	14	98	100	100	100	103	122	137	151	162	173	181	187	205	205

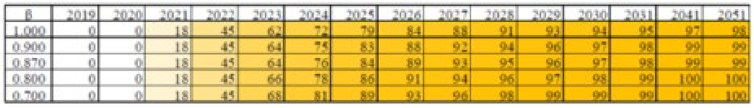
Appendix Table 14-8-1. [2-5] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	2	6	11	16	21	26	30	34	36	37	43	42
0.900	0	0	0	2	7	12	19	26	32	37	42	44	47	52	52
0.870	0	0	0	2	7	13	20	27	34	40	45	47	50	55	55
0.800	0	0	0	2	7	14	23	31	40	46	51	54	57	62	62
0.700	0	0	0	2	8	17	27	37	48	55	60	64	67	72	72

b) Probability of being above the proposed limit reference point (%)



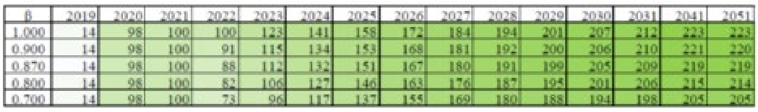
β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	45	62	72	79	84	88	91	93	94	95	97	98
0.900	0	0	18	45	64	75	83	88	92	94	96	97	98	99	99
0.870	0	0	18	45	64	76	84	89	93	95	96	97	98	99	99
0.800	0	0	18	45	66	78	86	91	94	96	97	98	99	100	100
0.700	0	0	18	45	68	81	89	93	96	98	99	99	99	100	100

Appendix Table 14-8-2. [2-5] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	323	391	447	502	546	588	620	644	662	678	721	718
0.900	194	240	286	323	400	466	532	587	638	677	706	726	744	787	783
0.870	194	240	286	323	402	472	542	600	654	695	725	747	765	808	803
0.800	194	240	286	323	408	487	565	632	693	738	772	795	815	856	851
0.700	194	240	286	323	417	508	600	680	752	805	844	870	891	930	924

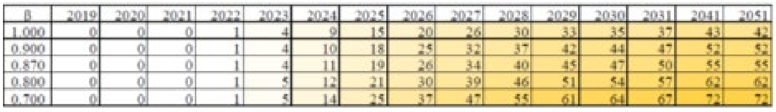
b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	100	100	123	141	158	172	184	194	201	207	212	223	223
0.900	14	98	100	91	115	134	153	168	181	192	200	206	210	221	220
0.870	14	98	100	88	112	132	151	167	180	191	199	205	209	219	219
0.800	14	98	100	82	106	127	146	163	176	187	195	201	206	215	214
0.700	14	98	100	73	96	117	137	155	169	180	188	194	198	205	205

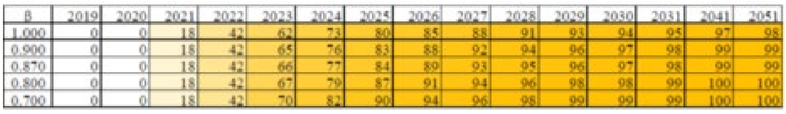
Appendix Table 14-9-1. [2-6] Probability of future spawning biomass being above the proposed target reference point and limit reference point

a) Probability of being above the proposed target reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	0	1	4	9	15	20	26	30	33	35	37	43	42
0.900	0	0	0	1	4	10	18	25	32	37	42	44	47	52	52
0.870	0	0	0	1	4	11	19	26	34	40	45	47	50	55	55
0.800	0	0	0	1	5	12	21	30	39	46	51	54	57	62	62
0.700	0	0	0	1	5	14	25	37	47	55	61	64	67	72	72

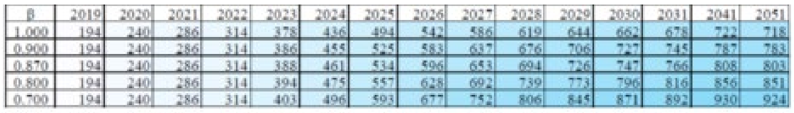
b) Probability of being above the proposed limit reference point (%)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	0	0	18	42	62	73	80	85	88	91	93	94	95	97	98
0.900	0	0	18	42	65	76	83	88	92	94	96	97	98	99	99
0.870	0	0	18	42	66	77	84	89	93	95	96	97	98	99	99
0.800	0	0	18	42	67	79	87	91	94	96	98	98	99	100	100
0.700	0	0	18	42	70	82	90	94	96	98	99	99	99	100	100

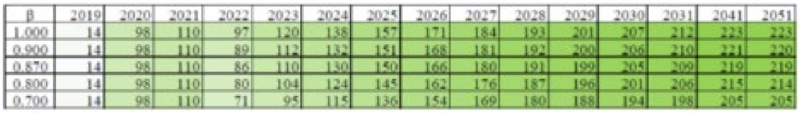
Appendix Table 14-9-2. [2-6] Changes in average values of future spawning biomass and catch

a) Changes in average values of spawning biomass (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	194	240	286	314	378	436	494	542	586	619	644	662	678	722	718
0.900	194	240	286	314	386	455	525	583	637	676	706	727	745	787	783
0.870	194	240	286	314	388	461	534	596	653	694	726	747	766	808	803
0.800	194	240	286	314	394	475	557	628	692	739	773	796	816	856	851
0.700	194	240	286	314	403	496	593	677	752	806	845	871	892	930	924

b) Changes in average values of catch (thousand tons)



β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.000	14	98	110	97	120	138	157	171	184	193	201	207	212	223	223
0.900	14	98	110	89	112	132	151	168	181	192	200	206	210	221	220
0.870	14	98	110	86	110	130	150	166	180	191	199	205	209	219	219
0.800	14	98	110	80	104	124	145	162	176	187	196	201	206	215	214
0.700	14	98	110	71	95	115	136	154	169	180	188	194	198	205	205

Appendix 15. Comparison of the results of scenarios that ease the decrease in the catch upon introduction of HCRs

We studied 12 catch scenarios for harvest control of the Japanese sardine Tsushima stock (Appendix Table 14-1). In order to clarify the characteristics of the scenarios, we compared the average catch and the average spawning biomass of 2020 to 2031. We also studied the risk that the average spawning biomass will decrease to a level below the spawning biomass in 2020. All values are those where β is the maximum value for which the spawning biomass in 2031 will be above the proposed target reference point with a probability of 50% (Appendix Table 15-1).

Average catch (Appendix Figure 15-1)

In the scenarios based on the proposed HCRs from 2021 onward (1-1 and 2-1), the scenarios with a constant catch of 100 thousand tons in 2021 (1-5 and 2-5), and scenarios that conduct fishing with the current fishing mortality (1-6 and 2-7), a substantial catch decrease from the previous year was seen upon introduction of the HCRs. In the scenarios that conduct fishing at 0.8Fmsy from 2021 to 2023 (1-2 and 2-2) and scenarios with a constant catch (1-3 to 1-4 and 2-3 to 2-4), there is no decrease in the catch in 2024, when the HCRs are introduced. However, in scenarios with a constant catch, the catch from 2023 onward is lower than the scenarios based on the proposed HCRs from 2021 (1-1 and 2-1) and scenarios that conduct fishing at 0.8Fmsy (1-2 and 2-2). From 2024 onward, when the HCRs are introduced in all scenarios, the catch will be the lowest in the scenarios with a constant catch of 100 thousand tons from 2021 to 2023 (1-4 and 2-4). There were no notable differences in the catch among other scenarios, except for the scenario that introduces the proposed HCRs using the S-R relationship for the normal recruitment period in 2021 (1-1).

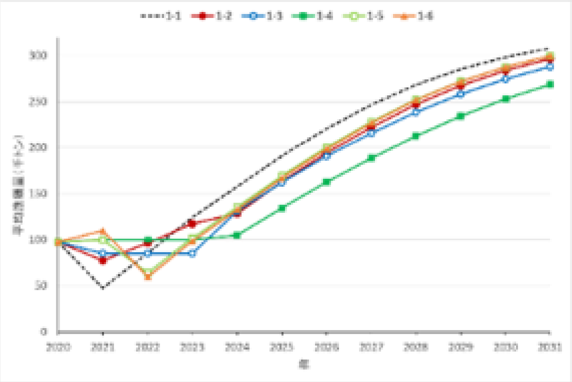
Average spawning biomass (Appendix Figure 15-2)

In the scenarios with a constant catch of 100 thousand tons from 2021 to 2023 (1-4 and 2-4), the recovery of spawning biomass was gradual. In the scenario that introduced the proposed HCRs using the S-R relationship for the normal recruitment period (1-1), the spawning biomass was constantly high from 2022 onward. In other scenarios, there were no notable differences in the changes in spawning biomass.

Risk for a decrease in spawning biomass (Appendix Table 15-1)

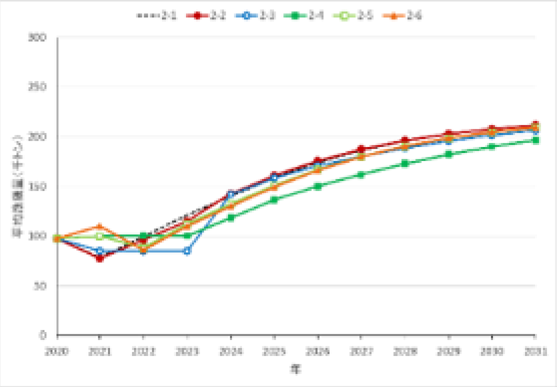
Considering the uncertainty in recruitment, if fishing mortality that does not comply with the proposed HCRs is applied, there would be a risk of a decrease in spawning biomass (B). Thus, in the 10,000 iterations for future projection simulation, we obtained a probability with which the spawning biomass in each year from 2021 to 2025 will be below the spawning biomass in 2020 (240 thousand tons). In the scenario that introduces the proposed HCRs based on the normal recruitment period in 2021 (1-1), the probability was 3% or less, and in the scenario that introduces the proposed HCRs based on the normal recruitment period excluding the transition period in 2021 (2-1), the probability was 9% or less. When the introduction of the proposed HCRs was delayed, the probability that the spawning biomass in each year will be below the spawning biomass in 2020 increased in all scenarios. In the scenarios that conduct fishing at 0.8Fmsy (1-2 and 2-2), the probability was relatively low, at 11% or less. In the scenarios with a constant catch (1-3 to 1-5 and 2-3 to 2-5) and scenarios that conduct fishing with the current fishing mortality (1-6 and 2-6), the probability was 20% to 28% at the stage of 2022. In the scenarios with a constant catch of 100 thousand tons from 2021 to 2023 (1-4 and 2-4), the spawning biomass in 2024 was below the proposed fishing ban level with a probability of 3% (1-4) and 2% (2-4), respectively.

(1) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment period (1960 to 1975 and 1988 to 2017) (Appendix Figure 10-1)



平均漁獲量（千トン）	Average catch (thousand tons)
年	Year

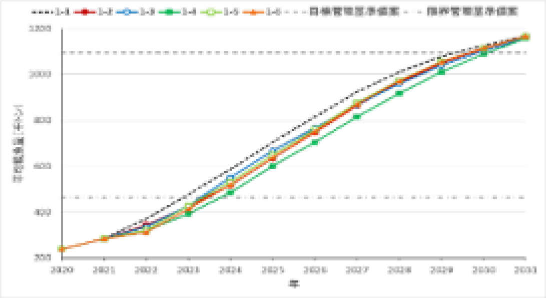
(2) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment excluding the transition period (1960 to 1975 and 1991 to 2017) (Appendix Figure 12-3)



平均漁獲量（千トン）	Average catch (thousand tons)
年	Year

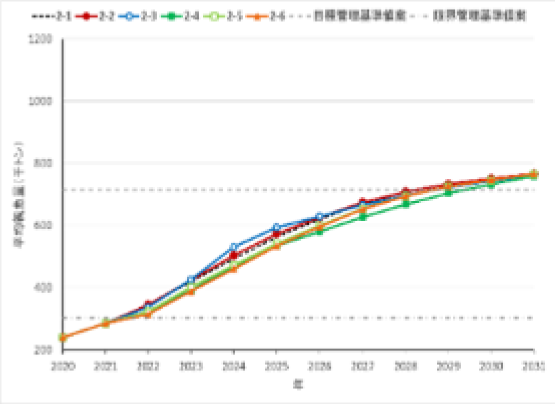
Appendix Figure 15-1. Average catch of 2020 to 2031

(1) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment period (1960 to 1975 and 1988 to 2017) (Appendix Figure 10-1)



平均漁獲量（千トン）	Average catch (thousand tons)
年	Year
目標管理基準値案	Proposed target reference point
限界管理基準値案	Proposed limit reference point

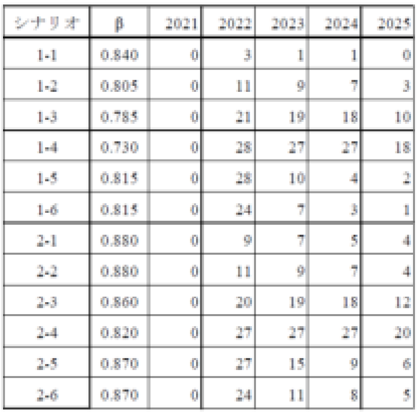
(2) Scenarios based on the proposed HCRs using the S-R relationship for the normal recruitment excluding the transition period (1960 to 1975 and 1991 to 2017) (Appendix Figure 12-3)



平均漁獲量（千トン）	Average catch (thousand tons)
年	Year
目標管理基準値案	Proposed target reference point
限界管理基準値案	Proposed limit reference point

Appendix Figure 15-2. Average spawning biomass of 2020 to 2031

Appendix Table 15-1. β for which the spawning biomass in 2031 will be above the proposed target reference point with a probability of 50% and the probability of future spawning biomass being below the spawning biomass in 2020 (%)



シナリオ	β	2021	2022	2023	2024	2025
1-1	0.840	0	3	1	1	0
1-2	0.805	0	11	9	7	3
1-3	0.785	0	21	19	18	10
1-4	0.730	0	28	27	27	18
1-5	0.815	0	28	10	4	2
1-6	0.815	0	24	7	3	1
2-1	0.880	0	9	7	5	4
2-2	0.880	0	11	9	7	4
2-3	0.860	0	20	19	18	12
2-4	0.820	0	27	27	27	20
2-5	0.870	0	27	15	9	6
2-6	0.870	0	24	11	8	5

シナリオ	Scenario