

Stock Assessment of Japanese Jack Mackerel Tsushima Stock in 2020

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Summary

The stock biomass was estimated by a cohort model considering the abundance index. The biomass of the present stock was low in the second half of the 1970s, but it increased from 1980 to the first half of the 1990s and exceeded 500 thousand tons from 1993 to 1998. Then, the biomass decreased, fluctuating between 300 thousand to 400 thousand tons from 1999 to 2002, but it turned to an increase in 2003 and 2004, and exceeded 500 thousand tons again. From 2005 onward, the biomass stayed around 400,000 tons, and the biomass in 2019 was estimated at 420 thousand tons.

At the "Research Institute Meeting on Reference Points" held in March 2020, it was proposed that the hockey stick (HS) model be used for estimating the stock-recruitment (S-R) relationship of the present stock, and that the spawning biomass that produces the maximum sustainable yield (MSY) (SB_{msy}) be set at 250 thousand tons. According to this basis, the spawning biomass of the present stock for 2019 (280 thousand tons) is above the level that produces MSY. In addition, the fishing mortality of the stock has been on a declining trend in recent years, falling below the level that produces MSY (F_{msy}). The trend of spawning biomass is determined to be "increasing" in light of the transition over the past five years (2015-2019). The present stock is caught also by South Korea and China. In particular, the hundreds of Chinese fishing vessels operating in the East China Sea are expected to be strongly influencing the present stock, but we have not been able to take such influence into

consideration in this stock assessment.

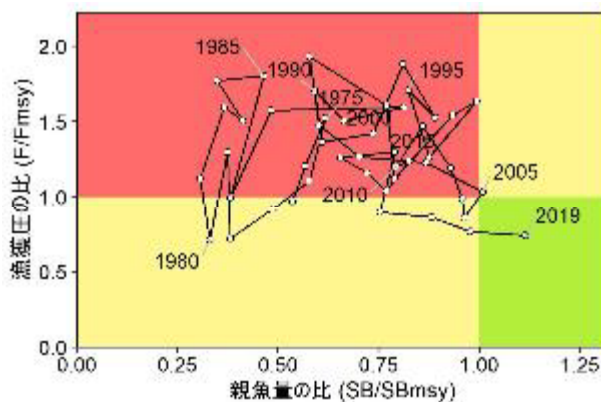
With regard to the items that are to be developed based on discussions at the Committee of Stock Management Policy, such as reference points and future projections, we tentatively indicated the values proposed at the Research Institute Meeting on Reference Points.

Item	Value	Explanation
Level that produces MSY under the current environment		
SBmsy	254 thousand tons	Spawning biomass that produces MSY
Fmsy	(Ages 0, 1, 2, 3 and above) = (0.11, 1.10, 0.82, 0.24)	
%SPR (Fmsy)	20%	%SPR corresponding to Fmsy
Spawning biomass and fishing mortality in 2019		
SB2019	283 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3 and above) = (0.13, 0.78, 0.61, 0.18)	
%SPR (F2019)	28.2%	%SPR in 2019
%SPR (F2017-2019)	26.1%	%SPR corresponding to the average fishing mortality in 2017-2019
Ratio to MSY		
SB2019/SBmsy	1.11	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	0.74	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 (no autocorrelation)

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



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Year	Stock biomass (thousand tons)	Spawning biomass (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2016	386	191	128	0.99	33
2017	423	224	140	0.86	33
2018	430	248	125	0.77	29
2019	418	283	121	0.74	29
2020	453	268	113	0.80	25
2021	495	277	-	-	-

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

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) Landing volume by number of individuals per fish box at major ports in Kyushu (National Research Institute of Fisheries Science [NRIFS]) Logbook report of large- and medium-scale purse seine fisheries (Fisheries Agency of Japan) Monthly length composition survey (NRIFS, Aomori-Kagoshima [17] prefectures) • Market measurement Fisheries statistics (Ministry of Oceans and Fisheries, South Korea) (http://www.fips.go.kr ; March 2020)
Abundance index • Recruitment index	Logbook report of large- and medium-scale purse seine fisheries (Fisheries Agency of Japan)* Logbook report of medium-scale purse seine fisheries (Shimane Prefecture)* Landing of mini size fish at the Nagasaki fish market (Nagasaki Prefecture)* Survey on new recruitment "Pelagic fish survey using a midwater trawl" (May to June; NRIFS, Tottori Prefecture, Shimane Prefecture, and Yamaguchi Prefecture)

	<ul style="list-style-type: none"> • Midwater trawl* Direct biomass estimation survey "Bottom fish standing stock survey (East China Sea)" (May to June; NRIFS) <ul style="list-style-type: none"> • Bottom trawl* Fish distribution survey "Pelagic fish survey using a quantitative echo sounder" (August to September; NRIFS) <ul style="list-style-type: none"> • Midwater trawl / quantitative echo sounder*
• Abundance index at age	Logbook report of large- and medium-scale purse seine fisheries (Fisheries Agency of Japan)* Logbook report of medium-scale purse seine fisheries (Shimane Prefecture)* Direct biomass estimation survey "Bottom fish standing stock survey (East China Sea)" (May to June; NRIFS) <ul style="list-style-type: none"> • Bottom trawl*
Natural mortality (M)	Assuming $M = 0.5$ per year

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

2. Ecology of the stock

(1) Distribution and migration

The present stock is distributed over a wide area from the southern part of the East China Sea to Kyushu and along the coast of the Sea of Japan (Figure 2-1). The stock migrates northward in spring and summer for feeding and migrates southward in fall and winter for wintering and spawning. Some age 0 fish emerging from spawning sites in the East China Sea are considered to be recruited along the Pacific coast. However, it is unknown what percentage of the Pacific stock are recruits from the East China Sea, and there has been no information that spawning adults of the Pacific stock migrate to the East China Sea for spawning.

(2) Age and growth

Although growth varies slightly by area and year, the fork length reaches 16 to 18 cm at age 1, 22 to 24 cm at age 2, and 26 to 28 cm at age 3 (Yoda et al. 2014, etc. (Figure 2-2)). The life span is considered to be around 5 years.

(3) Maturity and spawning

Spawning takes place in extensive sea areas including the southern part of the East China Sea and from areas along the coast of the Kyushu and Sanin districts to coastal waters in the northern part of the Sea of Japan. Dense distribution of larvae and juveniles is observed in the southern part of the East China Sea from February to March (Sassa et al. 2006). The spawning season tends to be earlier in the southern regions (January to March) and later in the northern regions (May to June) (the main season is from March to May). The maturity rate of age 1 fish

is about 50%, and most individuals become mature at age 2 (Figure 2-3).

(4) Prey-predator relationships

The stock mainly feed on zooplankton, such as krill, opossum shrimps and copepods, and small fish (Tanaka et al. 2006). Larvae and juveniles are eaten by piscivorous fish, such as yellowtail.

3. Status of fisheries

(1) Outline of fisheries

Approximately 80% of Japanese jack mackerel caught in the Tsushima Warm Current region are caught by large- to medium-scale purse seine fishery and medium- to small-scale purse seine fishery. The main fishing grounds are from the East China Sea to areas along the northern to western coast of Kyushu and the western part of the Sea of Japan.

(2) Changes in catch volume and age composition of catch

Japan's catch volume of Japanese jack mackerel in the Tsushima Warm Current region had fluctuated between 93 thousand and 150 thousand tons from 1973 to 1976, but then turned to a decrease, and fell below 41 thousand tons in 1980. It showed an increasing trend from the 1980s to the 1990s, and exceeded 200 thousand tons from 1993 to 1998, but declined to a level between 135 thousand and 159 thousand tons from 1999 to 2002. The catch volume started to increase again in 2003, reaching 192 thousand tons in 2004. It stayed around the same level from 2006 onward, but then fell below 100 thousand tons in 2018 and marked 78 thousand tons in 2019 (Figure 3-1, Table 3-1).

South Korea catches tens of thousands of tons of jack mackerels every year, catching 43 thousand tons in 2019. Jack mackerels caught by South Korea include mackerel scads, but most are estimated to be Japanese jack mackerel. China's catch of Japanese jack mackerel has been reported since 2003. The catch exceeded 100 thousand tons from 2005 to 2007, but decreased to 59 thousand tons in 2008, and has shifted between 200 thousand to 400 thousand tons from 2009 onward, marking 400 thousand tons in 2018 (FAO Fishery and Aquaculture Statistics. Global capture production 1950-2018 (Release date: March 2020; <http://www.fao.org/fishery/statistics/software/fishstatj/en>)).

Figure 3-2 shows changes in the catch in number at age. Japan's catch mainly consists of age 1 and age 2 fish. Since 2015, the catch in number of age 0 fish has been below 1 billion individuals, with age 1 fish accounting for a larger proportion of the catch (Figure 3-2, Appendix 4).

(3) Fishing effort

Figure 3-3 shows the number of nets of large- to medium-scale purse seine fishery operating in the East China Sea and the western part of the Sea of Japan. The number of nets peaked in the second half of the 1980s but has been on a decline since 1990. The number of nets in 2019

was low at about 5 thousand nets. The principal reason is an increase in operation in the Pacific, mainly in fall. The later-discussed effective fishing effort has also generally shown a declining trend since 1998 (Figure 4-1).

4. Stock status

(1) Stock assessment method

We collected information including the catch volume and fishing effort, and conducted a stock analysis using the biological measurement results of the catch as well as the catch in number at age and by year (Appendices 1 and 2). The calculation of the stock analysis was conducted based on the catch in number at age for Japan's and South Korea's catch from 1973 to 2019. We did not consider China's catch in the stock calculation as the catch volume data is only available for 2003 onward, and the data is not available for the most recent year (2019).

Mainly targeting age 0 fish, we conducted a survey on new recruitment using a midwater trawl in waters around Tsushima to the western part of the Sea of Japan from May to June, a direct biomass estimation survey using a bottom trawl in the East China Sea from May to June, and a fish distribution survey using a midwater trawl and a quantitative echo sounder along the western coast of Kyushu to the Sea of Japan from August to September. We used the collected data as index values for age 0 and age 1 fish (Appendix 3).

(2) Changes in abundance indices

As the abundance index for having an overview of long-term fluctuations in stock for 1973 onward, we obtained the density index (tons/net) based on statistic values of large- to medium-scale purse seine fishery operating in the East China Sea and the western part of the Sea of Japan. The index declined from the first half of the 1970s to the first half of the 1980s, but then turned to an increase, and stayed high in the middle of the 1990s and from 2009 onward (Figure 4-1). After an increase from 2008 to 2011, the index has shifted at a relatively high level. The effective fishing effort had stayed at an almost constant level until 1994, but it has been on a gradual downward trend since then (Figure 4-1). The density index is the average catch per net in 30-minute latitude-longitude grid cells where Japanese jack mackerel were caught in 2019. We obtained the effective fishing effort by dividing the catch in the grid cells where fishery of Japanese jack mackerel was operated in 2019 by the density index. As an index value that shows detailed stock fluctuations by age from 2003 onward, we calculated the abundance index at age (age 0, age 1, age 2, and age 3+) based on the catch volume by fish size of large- to medium-scale purse seine fishery operating in the East China Sea and the western part of the Sea of Japan, used it in the cohort analysis (Figures 4-2, 4-3, and 4-4; Appendix Figure 2-1, Appendix Note 3). The abundance index in 2019 was low for age 1 and high for age 2 and above as compared to levels in the past 15 years. The abundance of age 0 and age 1 fish was estimated by also using the index values obtained by the abovementioned research vessel surveys, in addition to these index values (Appendix 2-1, Appendix Notes 2 and 3). We standardized the CPUE for the abundance index in the large- to medium-scale purse

seine fishery and the survey of juveniles in the Sea of Japan (Appendix 5, Document FRA-SA2020-SC01-107).

(3) Trends in biomass and fishing mortality

Figure 4-5 and Table 3-1 show the stock biomass obtained by cohort analysis (for details, see Appendix 4). The stock biomass decreased from 260 thousand to 340 thousand tons in 1973 to 1976 to 130 thousand to 180 thousand tons in 1977 to 1980 (Figure 4-5). After that, it showed an increase and stayed high at 500 thousand to 540 thousand tons from 1993 to 1998. The biomass remained slightly lower from 1999 onward, decreasing to 280 thousand tons in 2001, but then it turned to an increase and reached 540 thousand tons in 2004. The level gradually decreased from 2005 to 2012, marking 350 thousand tons in 2012 and 2013. It shifted between 380 thousand and 430 thousand tons from 2014 onward and was 420 thousand tons in 2019.

The recruitment (number of age 0 fish in stock calculation) reached above 8 billion individuals in some years from the second half of the 1980s to the first half of the 2000s. It shifted between 3 billion to 6 billion individuals from 2005 onward, but then increased again in 2014 to 7.4 billion individuals. The recruitment in 2019 was estimated at 3 billion individuals (Figure 4-6).

The ratio of recruitment to spawning biomass (recruitment per spawning [RPS]) generally showed a similar fluctuation pattern as the recruitment (Figure 4-6).

The spawning biomass (biomass of mature fish in stock calculation) exceeded 250 thousand tons in 2005, but it decreased to 170 thousand tons by 2014. It shifted around 200 thousand tons again from 2015 onward and increased to 250 thousand tons in 2018 and 280 thousand tons in 2019 (Figure 4-5, Table 3-1).

As a sensitivity analysis of natural mortality (M) used in cohort analysis, we conducted stock assessment using 0.4 and 0.6 for M as alternatives to the assumed base value (0.5). The stock biomass, spawning biomass, and recruitment became larger and F became lower as M increased. When M changed by 0.1, it affected the estimate values by around 20% (Figure 4-7).

The fishing mortality (F) was high overall from the second half of the 1980s to the first half of the 1990s, but then turned to a decrease. By age, F for age 1 and age 2 fish has been relatively high, and F for age 1 fish tended to be high from 2003 onward. On the other hand, F for age 0 fish decreased from 2014, and has stayed at a low level (Figure 4-8).

The exploitation rate was at a high level above 50% in 2001, but it decreased thereafter and has shifted around 30% since 2016 (Figure 4-9).

Item	Value	Explanation
SB2019	283 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3 and above) = (0.13, 0.78, 0.61, 0.18)	
U2019	29%	Exploitation rate in 2019

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

In order to compare the fishing mortality considering the influence of selectivity, we made a comparison with the case with no fishing mortality, based on the SPR. Figure 4-10 shows the ratio of SPR with catch to SPR assuming no catch (%SPR) for each year. The lower the fishing mortality, the higher the %SPR. The %SPR had been low from the 1990s to the beginning of the 2000s, declining below 10% in some years, but has been on an increase since then, and was 28.1% in 2019. The current fishing mortality, which is the %SPR calculated from the average F value of the latest 3 years (from 2017 to 2019), was 26%.

Figure 4-11 shows the relationship between %SPR and YPR for the current fishing mortality. As for the selectivity in F, we used the selectivity value which was used to estimate F that produces MSY (Fmsy) (Yoda et al. 2020) at the "Research Institute Meeting on Reference Points" held in March 2020. Current fishing mortality (F2017-F2019) is above F30%SPR and F0.1, and it is below Fmsy.

Item	Value	Explanation
%SPR (F2019)	28.2%	%SPR in 2019
%SPR (F2017-2019)	26.1%	%SPR corresponding to the current fishing mortality (F2017 to F2019)

(5) Stock-recruitment relationship

Figure 4-12 shows the relationship between spawning biomass (in weight) and recruitment (in the number of individuals) (stock-recruitment (S-R) relationship). At the abovementioned "Research Institute Meeting on Reference Points," it was proposed that the hockey stick (HS) model be used for estimating the S-R relationship of the present stock (Yoda et al. 2020). Here, the data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment based on the stock assessment conducted in 2019 (Yoda et al. 2020), 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. The parameters for the S-R relationship are shown in the table below.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey stick	Least absolute value method	No	0.0271	1.67e + 05	0.486

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

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 current environment (1973 onward) (Yoda et al. 2020)) are shown in the table below.

Item	Proposed value	Explanation
SBmsy	254 thousand tons	Spawning biomass that produces MSY
Fmsy	(Ages 0, 1, 2, 3 and above) = (0.11, 1.10, 0.82, 0.24)	
%SPR (Fmsy)	20%	%SPR corresponding to Fmsy
MSY	158 thousand tons	Maximum sustainable yield (MSY)

(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 fishing mortality at that time. The fishing mortality of the present stock in recent years is determined to be below the level that produces MSY. The fishing mortality in 2019 was 0.74 times the level that produces MSY (Fmsy). Meanwhile, the spawning biomass of the present stock was lower than the level that produces MSY (SBmsy) from 1973 to 2018, except for 2005, (Table 3-1), but it increased to above SBmsy in 2019. The ratio of the fishing mortality (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 spawning biomass is determined to be "increasing" in light of the transition over the past five years (2015 to 2019).

Item	Value	Explanation
SB2019/SBmsy	1.11	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	0.74	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	Above 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 SBmsy from 1973 to 2018, except for 2005, but showed an increasing trend over the past 5 years (from 2015 to 2019), and it reached above SBmsy in 2019. The fishing mortality fell below Fmsy in 2016 and has stayed at the same level since then.

6. Others

To date, management of the present stock has been conducted in the form of effort control, including limitation in the number of vessels licensed to operate in the fishing grounds of large- to medium-scale purse seine fishery (sea area system). Also, stock management based on the total allowable catch (TAC) has been conducted since 1997. In addition, a stock rebuilding plan for Japanese jack mackerel (including chub mackerel and Japanese sardine) in western Sea of Japan and western waters of Kyushu was implemented during the period from 2009 to 2011. Under this plan, which aimed to protect 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 restrictions, 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 in and after 2012 under the new framework based on the Resource Management Guidelines and resource management plans.

A factor that brings large uncertainty to the stock assessment results and future projections of the present stock is the lack of sufficient consideration of the influence of the catch by foreign fishing vessels. This factor could affect the S-R relationship, reference points, and the probability of achievement of management objectives. For conducting stock management of this species, it is necessary to elucidate the factors that cause fluctuations in recruitment and the migration routes, and to advance efforts to understand the actual status of fisheries through international cooperation.

7. References

- Hotta, H. and H. Mako (1970) Nishi Nihon kaiiki ni okeru maaji no gun kozo ni kansuru kenkyu (Study on the population structure of Japanese jack mackerel in waters of western Japan) I. Gyokyo hendo ni yoru kaiseki (Analysis based on changes in fishery conditions). Bulletin of Seikai National Fisheries Research Institute, 38, 87-100.
- Sassa, C., Y. Konishi and K. Mori (2006) Distribution of jack mackerel (*Trachurus japonicus*) larvae and juveniles in the East China Sea, with special reference to the larval transport by the Kuroshio Current. Fish. Oceanogr., 15, 508-518.7.
- Fisheries Research Agency (2013) Heisei 24 nendo shigen hendo yoin bunseki chosa hokokusho "maaji tsushima danryu keigun" (Report on analysis and survey of causes of stock fluctuations (2012) "Japanese jack mackerel Tsushima stock"). 39-52.
- Fisheries Research Agency (2016) Heisei 27 nendo shigen hendo yoin bunseki chosa hokokusho "maaji tsushima danryu keigun" (Report on analysis and survey of causes of stock fluctuations (2015) "Japanese jack mackerel Tsushima stock"). 55-64.
- Tanaka, H., I. Aoki and S. Ohshimo (2006) Feeding habits and gill raker morphology of three planktivorous pelagic fish species off the coast of northern and western Kyusyu in summer.

J. Fish. Biol., 68, 1041-1061.

Yoda, Y., T. Shiraishi, R. Yukami and S. Ohshimo (2014) Age and maturation of jack mackerel *Trachurus japonicus* in the East China Sea. Fish. Sci., 80, 61-68.

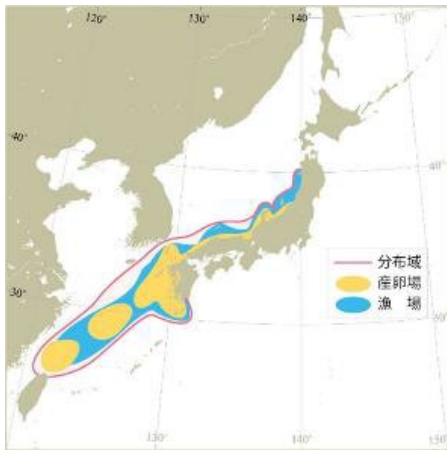
Yoda, M., H. Kurota, and M. Takahashi (2020) Reiwa gan (2019) nendo maaji tsushima danryu keigun no shigen hyoka (Stock assessment of Japanese jack mackerel Tsushima stock in 2019).

<http://abchan.fra.go.jp/digests2019/details/201904.pdf>, last accessed on July 20, 2020

Yoda, M., H. Kurota • M. Takahashi (2020) Reiwa 2 (2020) nendo maaji tsuhima danryu keigun no kanri kijunchi to ni kansuru kenkyu kikan kaigi hokokusho (Report of the Research Institute Meeting on Reference Points of Japanese jack mackerel Tsushima stock in 2020).

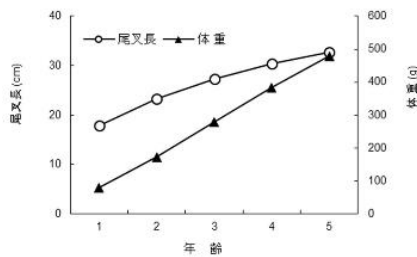
http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_maaji_tc.pdf, last accessed on July 20, 2020

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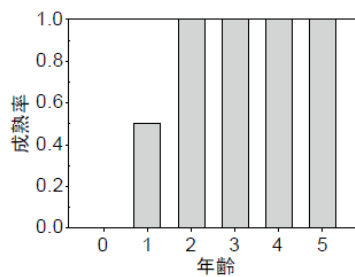
分布域	Distribution range
産卵場	Spawning grounds
漁場	Fishing grounds

Figure 2-1. Distribution range and spawning grounds of Japanese jack mackerel Tsushima stock



尾叉長	Fork Length
体重	Body weight
年齢	Age

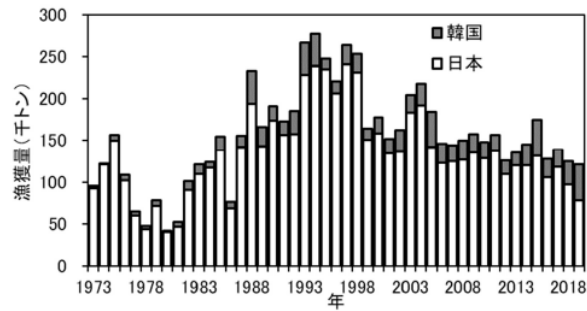
Figure 2-2. Age and growth



成熟率	Maturity rate
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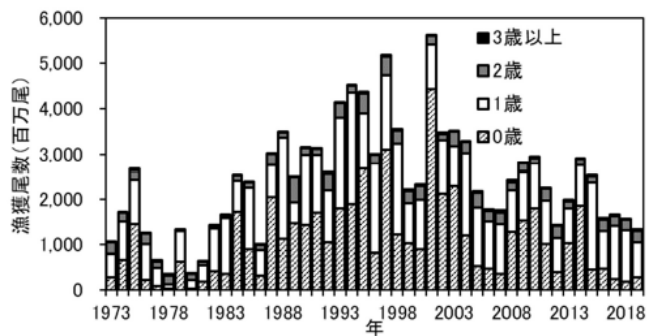
年齢	Age
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Figure 2-3. Age and maturity rate



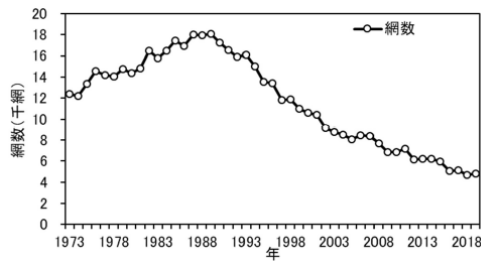
漁獲量 (千トン)	Catch (thousand tons)
年	Year
韓国	South Korea
日本	Japan

Figure 3-1. Changes in catch volume



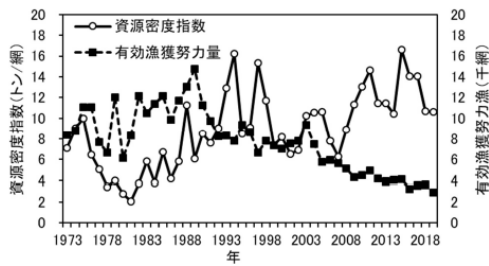
漁獲尾数 (百万尾)	Catch in number (million individuals)
年	Year
3歳以上	Age 3 and above
2歳	Age 2
1歳	Age 1
0歳	Age 0

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



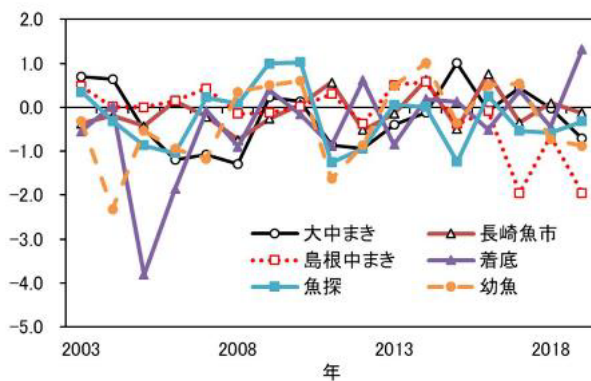
網数 (千網)	Number of nets (thousand nets)
網数	Number of nets
年	Year

Figure 3-3. Changes in the number of nets of large- to medium-scale purse seine fishery operating in the East China Sea and the western part of the Sea of Japan



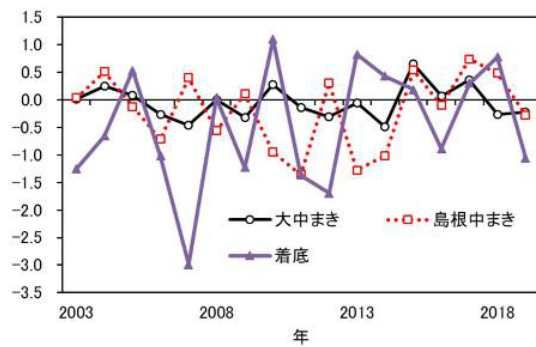
資源密度指数 (トン/網)	Density index (tons/net)
有効漁獲努力量 (千網)	Effective fishing effort (thousand nets)
年	Year
資源密度指数	Density index
有効漁獲努力量	Effective fishing effort

Figure 4-1. Changes in the density index of and effective fishing effort for Japanese jack mackerel in large- to medium-scale purse seine fishery operating in the East China Sea and the western part of the Sea of Japan



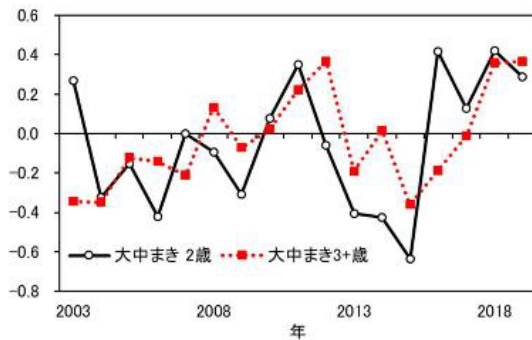
年	Year
大中まき	Large- to medium-scale purse seine
島根中まき	Medium-scale purse seine in Shimane
魚探	Echo sounder
長崎魚市	Nagasaki fish market
着底	Bottom trawl
幼魚	Juveniles

Figure 4-2. Index values for age 0 fish (see Appendix Note 2; the data has been log-transformed after being normalized by the mean value)



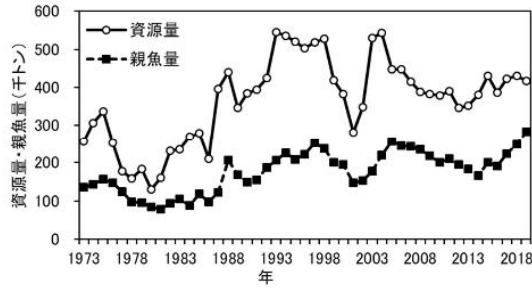
年	Year
大中まき	Large- to medium-scale purse seine
着底	Bottom trawl
島根中まき	Medium-scale purse seine in Shimane

Figure 4-3. Index values for age 1 fish (see Appendix Note 2; the data has been log-transformed after being normalized by the mean value)



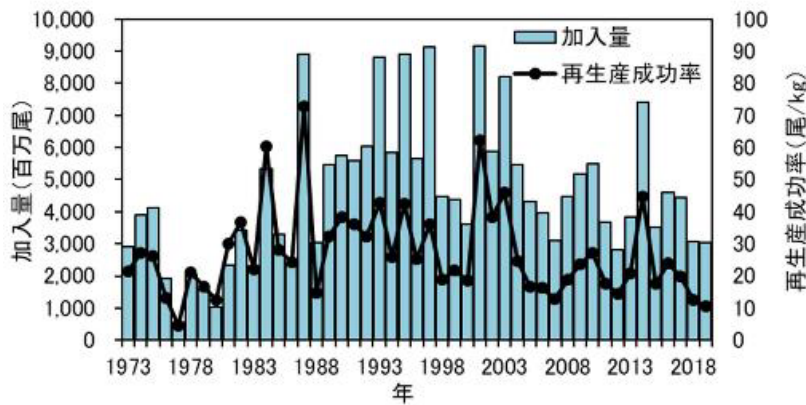
大中まき 2歳	Large- to medium-scale purse seine; Age 2
大中まき 3+歳	Large- to medium-scale purse seine; Age 3+

Figure 4-4. Index values for age 2 fish (see Appendix Note 2; the data has been log-transformed after being normalized by the mean value)



資源量・親魚量 (千トン)	Stock biomass, spawning biomass (thousand tons)
年	Year
資源量	Stock biomass
親魚量	Spawning biomass

Figure 4-5. Changes in stock biomass and spawning biomass



加入量 (百万尾)	Recruitment (million individuals)
再生産成功率 (尾/g)	RPS (individuals/g)
年	Year

Figure 4-6. Changes in recruitment and RPS

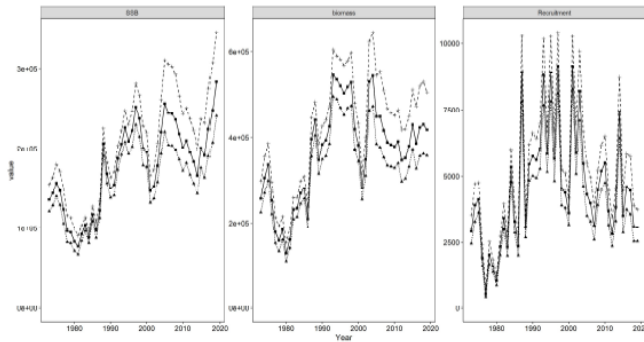
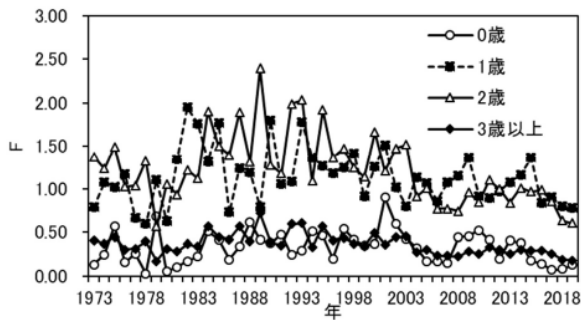


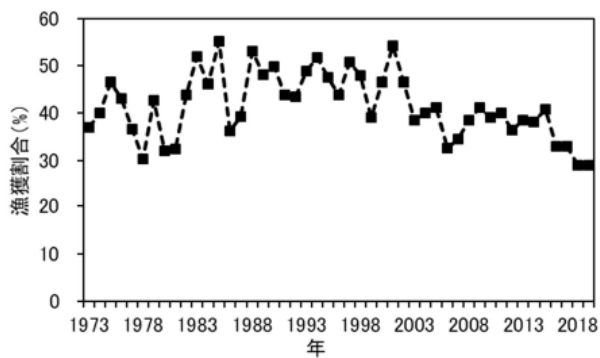
Figure 4-7. Changes in spawning biomass, stock biomass, and recruitment when the M value is changed

Solid lines indicate M = 0.5, broken lines indicate M = 0.6, and dotted lines indicate M = 0.4.



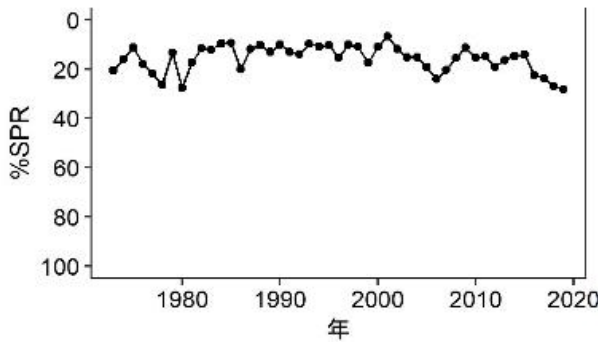
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above

Figure 4-8. Changes in fishing mortality (F) at age



漁獲割合(%)	Exploitation rate (%)
年	Year

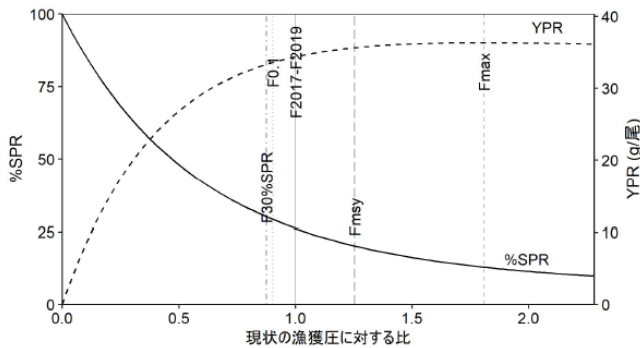
Figure 4-9. Changes in exploitation rate



年	Year
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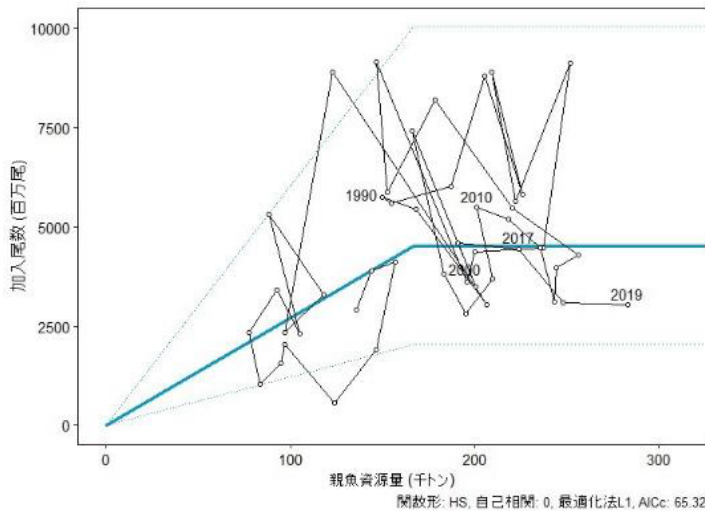
Figure 4-10. Changes in %SPR values

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



現状の漁獲圧に対する比	Ratio to the current fishing mortality
(g/尾)	(g/individuals)

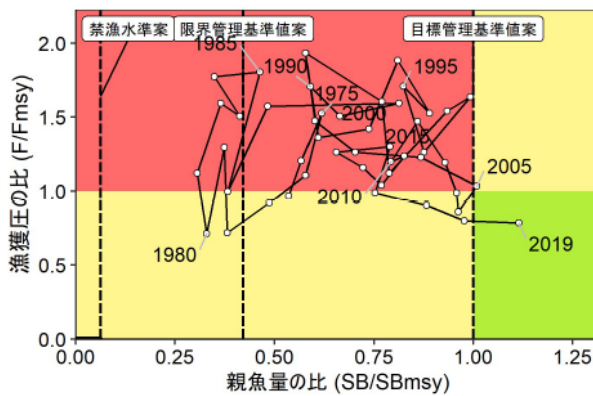
Figure 4-11. Relationship between YPR and %SPR for the current fishing mortality (F2017-F2019)



加入尾数 (百万尾)	Recruitment (million individuals)
親魚資源量 (千トン)	Spawning biomass (thousand tons)
関数形 : HS, 自己相関 : 0, 最適化法 L1, AICc; 65.32	Model: HS; autocorrelation:0; optimization method: L1, AICc: 65.32

Figure 4-12. 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 (Yoda et al. 2020). The dotted lines above and below the S-R relationship (blue solid line) in the figure show the range that is estimated to cover 90% of the observation data under the assumed S-R relationship.



漁獲圧の比	F/Fmsy
親魚量の比	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

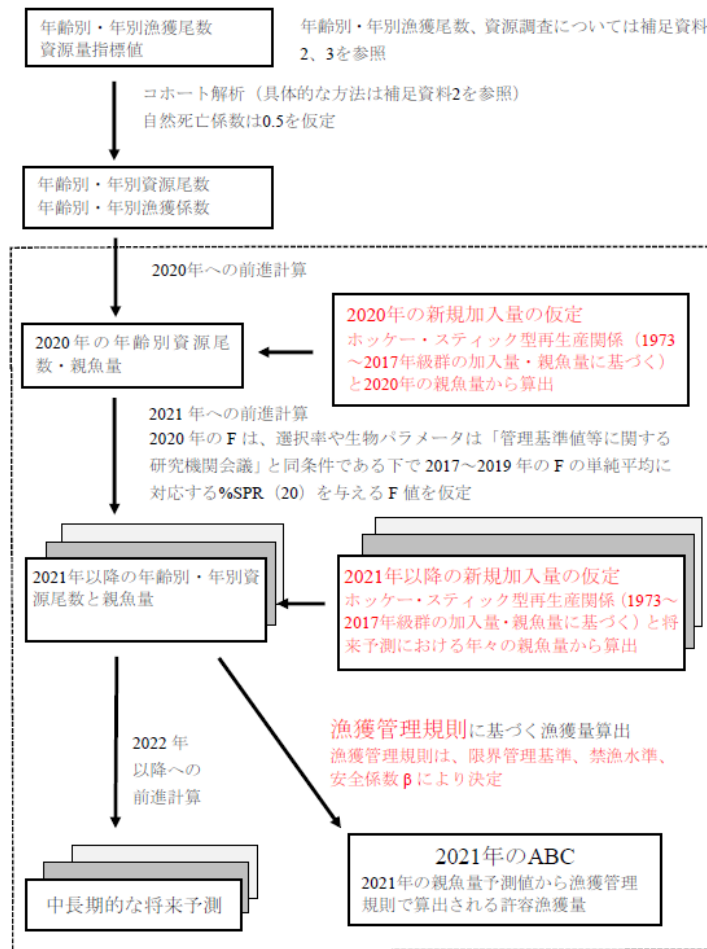
Figure 4-13. Relationship of the past spawning biomass and fishing mortality to the spawning biomass that produces MSY (SB_{msy}) and fishing mortality that produces MSY (F_{msy}) (Kobe plot)

Table 3-1. Catch and cohort analysis results

年	漁獲量 (千トン)			資源量 (千トン)	親魚量 (千トン)	0歳加入量 (百万尾)	漁獲割合 (%)	再生産成功率 (尾/kg)
	日本	韓国	計					
1973	93	2	95	256	136	2,913	37	21.43
1974	121	2	122	305	144	3,900	40	27.09
1975	150	7	157	336	157	4,113	47	26.23
1976	102	7	109	253	147	1,927	43	13.13
1977	60	5	65	178	124	553	37	4.47
1978	44	4	48	159	97	2,034	30	21.03
1979	72	7	79	184	95	1,570	43	16.52
1980	41	1	42	130	84	1,043	32	12.45
1981	47	6	52	161	78	2,338	32	30.08
1982	91	11	101	231	93	3,414	44	36.81
1983	110	12	122	234	105	2,320	52	22.14
1984	117	7	124	269	89	5,334	46	60.24
1985	139	16	155	280	118	3,299	55	28.02
1986	69	7	76	210	97	2,354	36	24.24
1987	142	14	156	396	123	8,920	39	72.76
1988	194	40	233	440	206	3,045	53	14.76
1989	144	23	167	347	168	5,451	48	32.37
1990	174	17	191	384	150	5,739	50	38.29
1991	156	16	173	393	155	5,601	44	36.19
1992	157	28	185	426	187	6,035	43	32.25
1993	228	38	266	545	206	8,799	49	42.79
1994	239	38	277	535	226	5,838	52	25.84
1995	235	12	248	520	209	8,908	48	42.60
1996	207	15	221	503	222	5,643	44	25.39
1997	241	23	263	518	252	9,140	51	36.27
1998	231	22	253	528	237	4,485	48	18.91
1999	150	14	164	419	200	4,369	39	21.83
2000	159	20	178	382	195	3,610	47	18.47
2001	135	18	152	280	147	9,149	54	62.36
2002	136	26	162	348	153	5,863	47	38.41
2003	184	20	204	530	178	8,197	39	45.98
2004	192	26	218	543	220	5,464	40	24.80
2005	142	43	184	448	256	4,302	41	16.80
2006	123	23	146	448	244	3,977	33	16.28
2007	125	19	144	416	243	3,113	35	12.81
2008	127	23	150	389	236	4,467	39	18.95
2009	136	22	158	383	218	5,189	41	23.79
2010	129	19	148	379	201	5,488	39	27.29
2011	138	19	157	391	210	3,689	40	17.59
2012	109	17	126	346	195	2,809	37	14.40
2013	121	15	136	351	183	3,825	39	20.87
2014	121	24	145	380	166	7,419	38	44.64
2015	132	43	175	429	200	3,503	41	17.47
2016	106	22	128	386	191	4,589	33	24.02
2017	118	21	140	423	224	4,452	33	19.86
2018	98	27	125	430	248	3,085	29	12.44
2019	78	43	121	418	283	3,035	29	10.73

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歳加入量 (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)
日本	Japan
韓国	South Korea
計	Total

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、資源調査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 and surveys, see Appendices 2 and 3.
コホート解析（具体的な方法は補足資料 2 を参照）	Cohort analysis (for the specific method, see Appendix 2)
自然死亡係数は 0.5 を仮定	Natural mortality is assumed as 0.5.
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
2020 年への前進計算	Forward computation to 2020
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(1973～2017 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 the HS S-R relationship (based on recruitment / spawning biomass of 1973-2017 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 2017～2019 年の F の単純平均に対応する %SPR (20) を与える F 値を仮定	F for 2020 is assumed to be the F value that gives the %SPR (20) that corresponds to the simple average of F in 2017 to 2019 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(1973～2017 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 1973-2017 year classes) and the spawning biomass projected for each year
2022 年以降への前進計算	Forward computation to 2022 onward
漁獲管理規則に基づく漁獲量算出	Estimation of catch based on harvest control rules (HCRs)
漁獲管理規則は、限界管理基準、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 prepared based on discussions on the S-R relationship and reference points (red text) at the Committee of Stock Management Policy. (http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/)

Appendix 2. Calculation method

(1) Stock calculation method

We estimated the catch in number at age and by year of Japanese jack mackerel based on the catch volume of the present stock (Appendix Note 1-2), and calculated the number of fish by cohort analysis. The average fork length and body weight in 2019 and the maturity rate used for the stock calculation are as shown below. Age 3+ means age 3 and above. Natural mortality (M) was obtained base on the equation by Tauchi and Tanaka (Tanaka 1960), assuming the oldest age to be age 5 ($M = 2.5 \div \text{oldest age (age 5)} = 0.5$).

Age	0	1	2	3+
Fork Length (1 cm)	11.6	18.1	22.7	29.7
Body weight (g)	21.5	80.8	160	359
Maturity rate (%)	0	50	100	100

The catch in number at age and by year and the average body weight (January to December) from 1973 to 2019 were estimated based on the catch volume by size for large- to medium-scale purse seine fishery operating in the East China Sea and the Sea of Japan, the catch volume by number of individuals per fish box at major ports in Kyushu, and body length composition of Japanese jack mackerel caught in coastal areas (Appendix Note 2).

The number of fish at age was calculated by using cohort analysis based on the survival equation (equation 1) and the catch equation (equation 2).

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

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

where N is the number of fish, C is the catch in number, a is age (0 to 3+), and y is year. F was calculated by iteration of the equation of Ishioka and Kishida (1985), and the plus group was treated according to Hiramatsu (2000; treatment of the plus group in an unsteady case). We assumed the early fishing mortality (F) for the oldest age group of age 3 and above (3+) to be proportionate to that for age 2 and treated α as constant (0.3) (Yoda et al. 2007).

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

We obtained F for ages 1 and 2 in the most recent year (2019) in an exploratory manner by tuning. For the tuning, we used 11 indices that are considered to reflect recruitment and stock biomass at age of fish of age 1 and above (Appendix Table 2-1). The tuning period was set from 2003 to 2019, for which results of research vessel surveys are available. The negative log-likelihood to be minimized was defined as below (Hashimoto et al. 2018).

$$-\ln L = \sum_k \sum_y \left[\frac{[\ln I_{k,y} - (b_k \ln N_{a(k),y} + \ln q_k)]^2}{2\sigma_k^2} - \ln \left(\frac{1}{\sqrt{2\pi}\sigma_k} \right) \right] \quad (4)$$

Here, $I_{k,y}$ is the observation value of index k in year y , N is the number of age 0 fish and

biomass for fish of age 1 and above, and I is the index value by fishing method or survey at age (Appendix 2, Appendix Notes 2 and 3). q_k , b_k , and σ_k are parameters (defined for each index) to be estimated (estimated simultaneously with terminal F). The biomass at age and by year was obtained by multiplying the number of fish at age and by year by the average body weight of catch $w_{a,y}$ at age and by year.

In addition, we assumed that $I_{f,k}$ and $N_{a,y}$ have the exponential relationship shown below.

$$I_{k,y} = q_k E_{a(k),y}^{b_k} \quad (5)$$

However, in this stock assessment, b_k was fixed as 1 to any of the indices. As the number of operating fleets of large- to medium-scale purse seine fishery vessels has been decreasing in recent years, and effective effort on Japanese jack mackerel has substantially decreased since 2003, we set a separate fishing-efficiency-related parameter q for the period from 2003 to 2007 and the period from 2008 to 2019 for the abundance index in large- to medium-scale purse seine fishery of age 1 fish and age 2 fish (Appendix Table 2-2). As a result of exploring F , which minimizes equation 4, the following was estimated: $F_{0,2019} = 0.13$, $F_{1,2019} = 0.78$, $F_{2,2019} = 0.61$, and $F_{3+,2019} = 0.18$.

Appendix Note 1. We estimated the catch in number at age and by year as follows. For the period from 1997 to 2019, we made monthly estimations of the body length composition of the catch in large- to medium-scale purse seine fishery landed at major ports in Kyushu based on the catch volume by number of individuals per fish box, and the body length composition of the catch in Kyushu's coastal fishery and in the Sea of Japan based on body length measurement data and the catch volume. By using these and the body length range at age specified for each month, we estimated the catch in number at age and by year. For the period up to 1996, we simply allocated the monthly catch by size in large- to medium-scale purse seine fishery for the period from 1973 to 2009 to the respective age groups, obtained the ratio of each age group to the estimation results above for the period from 1997 to 2009, and corrected the catch in number at age and by year by using the average values for 1997 to 2009. We classified the sizes into the following age groups: the mini size in June to December and the very small ("zengo") size in September to December into age 0; the mini size in January to May, the very small size in January to August, and the small size in September to December into age 1; the small size in January to August and the medium size in June to December into age 2; and the medium size in January to May and the large size in January to December into age 3+. The catch in number at age and by year for 2018 was updated in line with the updating of the provisional values for catch in that year.

Appendix Note 2. For age 0 fish, we used the following as indices on fishery conditions: the standardized CPUE for fish sizes corresponding to age 0 fish in large- to medium-scale purse seine fishery (June to December); the landing volume of mini size fish per vessel at the Nagasaki fish market (September to November); and the catch of mini size fish per net in

medium-scale purse seine fishery in Shimane Prefecture (August to January). In addition, we used the following as indices based on research vessel surveys: the standing stock value of Japanese jack mackerel in waters to the depth of 125 m obtained in the direct biomass estimation survey using a bottom trawl (bottom trawl; Appendix 3 (1)) in May to June; and the standing stock index of age 0 Japanese jack mackerel obtained in the survey on new recruitment using a midwater trawl in May to June (juveniles; Appendix 3 (2)) and the fish distribution survey using a quantitative echo sounder, etc. in August to September (echo sounder; Appendix 3 (3)).

Appendix Note 3. For age 1 fish, we used the following indices: the standardized CPUE for fish sizes corresponding to age 1 fish in large- to medium-scale purse seine fishery (January to December); the catch of mini size fish per net in medium-scale purse seine fishery in Shimane Prefecture in March to May that are considered to correspond to age 1 fish; and the standing stock value of age 1 fish in the direct biomass estimation survey using a bottom trawl (Appendix 3 (1)) (year 2003 was set as 1).

For age 2 and age 3 and above, we used the standardized CPUE for fish sizes corresponding to age 2 fish and fish of age 3 and above, in large- to medium-scale purse seine fishery (January to December) as indices.

(2) Future projection

We performed future projection from the stock biomass obtained by cohort analysis, based on the harvest control rules (HCRs). The proposed reference points are explained in detail in Appendix 6, the proposed HCRs and calculation of the future catch in Appendix 7, and the method of future projection in Appendix 8.

References

- Hashimoto, M., H. Okamura, M. Ichinokawa, K. Hiramatsu and T. Yamakawa (2018) Impacts of the nonlinear relationship between abundance and its index in a tuned virtual population analysis. *Fish. Sci.* 84(2), 335-347.
- Hiramatsu, K. (2000) VPA. 2000 Shigen hyoka taisei kakuritsu suishin jigyo hokokusho - Shigen hyoka kyokasho - (Report of the project for promotion of establishment of a stock assessment framework: Stock assessment textbook), 104-127.
- Ishioka, K. and T. Kishida (1985) Studies on the Algorithm for Solving the Catch Equation and Its Accuracy. *Bulletin of the Nansei Regional Fisheries Research Laboratory*, 19, 111-120.
- Oshimo, S. (2000) Higashi shina kai ni okeru maaji no seijuku tokusei ni kansuru kenkyu (Study on maturation characteristics of Japanese jack mackerel in the East China Sea), *Memoirs of a conference for forecasting oceanic and fishing conditions in the East China Sea and the western Sea of Japan (Seikai Block)*, 8, 27-33.
- Tanaka, S. (1960) Suisan seibutsu no Population Dynamics to gyogyo shigen kanri (Population Dynamics of fishery organisms and fishery resource management). *Bulletin of Tokai*

Regional Fisheries Research Laboratory, 28, 1-200.

Yoda, M., Y. Hiyama, S. Oshimo, and R. Yukami (2007) Heisei 18 nendo maaji tsushima danryu keigun no shigen hyoka (Stock assessment of Japanese jack mackerel Tsushima stock (2006)). Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2006/2007), (Vol. 1) Fisheries Agency/Fisheries Research Agency, pp.93-117.

Appendix Table 2-1. Indices and estimated parameter values used for tuning (recruitment)

指標値	漁況			調査		
	大中まき	長崎魚市	島根中まき	着底	幼魚	魚探
対象	N ₀	N ₀	N ₀	N ₀	N ₀	N ₀
2003	2.03	1.59	9.62	8,487	0.73	20.5
2004	1.89	1.90	6.00	15,161	0.10	10.6
2005	0.61	1.50	5.93	324	0.58	6.1
2006	0.30	2.64	6.86	2,265	0.39	5.1
2007	0.34	1.86	9.12	13,569	0.31	18.1
2008	0.28	1.10	5.14	5,934	1.43	15.8
2009	1.27	1.78	5.24	21,712	1.65	39.0
2010	1.15	2.47	6.07	12,375	1.83	40.4
2011	0.42	4.08	8.05	6,062	0.20	4.1
2012	0.40	1.37	4.09	27,122	0.42	5.7
2013	0.67	2.00	9.82	6,237	1.64	15.3
2014	0.90	4.25	10.55	17,625	2.75	14.5
2015	2.76	1.41	4.05	16,593	0.70	4.2
2016	0.93	4.92	5.42	8,819	1.67	18.5
2017	1.57	1.62	0.84	21,411	1.71	8.5
2018	0.99	2.55	3.08	9,310	0.48	8.1
2019	0.50	2.04	0.84	54,603	0.42	10.5
q	0.000184	0.000488	0.00114	2.25	0.000166	0.00264
σ	0.61	0.46	0.67	1.17	0.82	0.59

指標値	Index
漁況	Fishery conditions
調査	Survey
大中まき	Large- to medium-scale purse seine
長崎魚市	Nagasaki fish market
島根中まき	Medium-scale purse seine in Shimane
着底	Bottom trawl
幼魚	Juveniles
魚探	Echo sounder
対	Target

Appendix Table 2-2. Indices and estimated parameter values used for tuning (fish of age 1 and above)

指標値	調査					漁況				
	着底	大中まき	島根中まき	大中まき	大中まき	B ₁	B ₁	B ₁	B ₂	B ₃₊
対象	B ₁	B ₁	B ₁	B ₂	B ₃₊	B ₁	B ₁	B ₁	B ₂	B ₃₊
2003	1.00	1.01	7.96	1.31	0.71	1.00	1.01	7.96	1.31	0.71
2004	1.81	1.29	12.78	0.72	0.71	1.81	1.29	12.78	0.72	0.71
2005	5.95	1.08	6.78	0.86	0.89	5.95	1.08	6.78	0.86	0.89
2006	1.25	0.77	3.76	0.66	0.87	1.25	0.77	3.76	0.66	0.87
2007	0.18	0.63	11.44	1.00	0.81	0.18	0.63	11.44	1.00	0.81
2008	3.61	0.99	4.38	0.91	1.14	3.61	0.99	4.38	0.91	1.14
2009	1.02	0.72	8.52	0.74	0.93	1.02	0.72	8.52	0.74	0.93
2010	10.43	1.32	2.96	1.08	1.02	10.43	1.32	2.96	1.08	1.02
2011	0.89	0.87	1.98	1.42	1.25	0.89	0.87	1.98	1.42	1.25
2012	0.64	0.74	10.38	0.94	1.45	0.64	0.74	10.38	0.94	1.45
2013	7.94	0.94	2.14	0.67	0.83	7.94	0.94	2.14	0.67	0.83
2014	5.37	0.61	2.78	0.65	1.02	5.37	0.61	2.78	0.65	1.02
2015	4.19	1.93	13.15	0.53	0.70	4.19	1.93	13.15	0.53	0.70
2016	1.43	1.08	6.92	1.52	0.83	1.43	1.08	6.92	1.52	0.83
2017	4.71	1.43	16.07	1.14	0.99	4.71	1.43	16.07	1.14	0.99
2018	7.58	0.77	12.45	1.52	1.43	7.58	0.77	12.45	1.52	1.43
2019	1.22	0.80	5.84	1.33	1.44	1.22	0.80	5.84	1.33	1.44
q	0.0137	0.00500	0.00644	0.0397	0.0110	0.0137	0.00500	0.00644	0.0397	0.0110
σ	1.04	0.19	0.61	0.24	0.32	1.04	0.19	0.61	0.24	0.32

指標値	Index
調査	Survey

漁況	Fishery conditions
着底	Bottom trawl
大中まき	Large- to medium-scale purse seine
島根中まき	Medium-scale purse seine in Shimane

Appendix 3. Results of research vessel surveys

(1) Direct biomass estimation survey (bottom trawl): The distributions estimated based on the survey using a bottom trawl conducted in the continental shelf break of the East China Sea in May to June are shown below (the survey area was 138 thousand km²; the fishing efficiency was assumed as 1).

年	2000	2001	2002	2003	2004	2005	2006
現存量推定値 (トン)	26,700	70,907	34,945	9,422	23,535	7,098	2,693
年	2007	2008	2009	2010	2011	2012	2013
現存量推定値 (トン)	13,700	9,544	25,290	23,536	7,041	28,570	13,335
年	2014	2015	2016	2017	2018	2019	
現存量推定値 (トン)	21,077	20,590	10,302	24,909	15,436	58,753	

年	Year
現存量推定値 (トン)	Estimated standing stock (tons)

(2) Survey on new recruitment (juveniles): A survey on new recruitment using a midwater trawl and a quantitative echo sounder has been conducted from May to June in waters around Tsushima to the western part of the Sea of Japan since 2002. The recruitment index values that have been calculated since 2003 are shown below.

年	2003	2004	2005	2006	2007	2008	2009
加入量指標値	1.00	0.07	0.10	0.23	0.28	1.24	1.45
年	2010	2011	2012	2013	2014	2015	2016
加入量指標値	1.92	0.21	0.42	2.02	3.03	0.34	2.20
年	2017	2018	2019	2020			
加入量指標値	2.74	0.76	0.70	1.35*			

*2020 年は速報値。

年	Year
加入量指標値	Recruitment index

*Value for 2020 is a preliminary value.

(3) Biomass survey using a quantitative echo sounder, etc. (echo sounder): The standing stock index values obtained in the biomass survey conducted along the western coast of Kyushu and the eastern waters of Tsushima in summer (August to September) are shown below. The target fish is mainly age 0 Japanese jack mackerel.

年	1997	1998	1999	2000	2001	2002	2003
現存量指標値	8.0	3.3	18.4	12.1	89.8	5.7	20.5
年	2004	2005	2006	2007	2008	2009	2010
現存量指標値	10.6	6.1	5.1	18.1	15.8	39.0	40.4
年	2011	2012	2013	2014	2015	2016	2017
現存量指標値	4.1	5.7	15.3	14.5	4.2	18.5	8.5
年	2018	2019					
現存量指標値	8.1	10.5					

年	Year
現存量指標値	Standing stock index

(4) Survey on new recruitment "Survey on new recruitment using a Newston net": The survey has been conducted from February to May in the East China Sea and coastal waters of Kyushu since 2000. As the survey targets larvae that are distributed in the surface waters and does not fully cover the habitat water depth of Japanese jack mackerel larvae, so the obtained results were treated as reference values and presented in Kurota et al. (2020).

References

Kurota,H., M. Takahashi, M. Yoda, and C. Sassa (2020) Reiwa 2 (2020) nendo katakuchi iwashi tsushima danryu keigun no shigen hyoka (Stock assessment of Japanese anchovy Tsushima stock in2020). Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2020/2021) (stock assessment by species and by stock)), printing underway.

Appendix 4. Details of cohort analysis results (1973-2019)

年\年齢	漁獲尾数 (百万尾)				漁獲重量 (千トン)				漁獲係数 F			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1973	286	310	255	20	7	41	39	7	0.13	0.79	1.38	0.41
1974	677	841	187	23	17	68	29	8	0.25	1.08	1.24	0.37
1975	1,451	971	206	27	37	79	32	9	0.38	1.02	1.49	0.45
1976	222	798	212	17	6	65	33	6	0.16	1.17	1.03	0.31
1977	99	393	140	26	3	32	22	9	0.26	0.67	1.04	0.31
1978	41	94	190	29	1	8	29	10	0.03	0.60	1.33	0.40
1979	631	662	30	12	16	54	5	4	0.69	1.11	0.57	0.17
1980	43	181	129	17	1	15	20	6	0.05	0.63	1.06	0.32
1981	180	368	77	17	5	30	12	6	0.10	1.35	0.94	0.28
1982	428	931	55	19	11	76	8	6	0.17	1.95	1.22	0.37
1983	369	1,217	62	11	9	99	9	4	0.22	1.76	1.13	0.34
1984	1,716	684	131	15	43	56	20	5	0.51	1.32	1.91	0.57
1985	907	1,355	118	9	23	110	18	3	0.42	1.77	1.50	0.45
1986	324	553	126	10	8	45	19	3	0.19	0.73	1.40	0.42
1987	2,037	695	275	16	51	57	42	5	0.34	1.25	1.89	0.57
1988	1,136	2,223	125	13	29	181	19	5	0.62	1.19	1.32	0.40
1989	1,481	442	555	23	37	36	85	8	0.41	0.79	2.40	0.72
1990	1,441	1,535	163	14	36	125	25	5	0.38	1.79	1.28	0.38
1991	1,704	1,283	126	16	43	104	19	6	0.48	1.06	1.18	0.35
1992	1,042	1,147	367	25	26	93	57	9	0.24	1.08	1.99	0.60
1993	1,799	2,007	320	24	45	163	49	8	0.30	1.78	2.03	0.61
1994	1,897	2,458	161	12	48	200	25	4	0.52	1.37	1.10	0.33
1995	2,652	1,256	442	30	67	102	68	10	0.46	1.27	1.92	0.58
1996	820	1,946	222	22	21	158	34	8	0.20	1.19	1.37	0.41
1997	3,094	1,652	405	25	51	137	66	9	0.55	1.25	1.47	0.44
1998	1,218	2,020	286	31	46	154	43	10	0.41	1.41	1.25	0.37
1999	1,037	878	267	31	33	80	42	10	0.35	0.91	1.14	0.34
2000	891	1,106	298	47	27	90	43	18	0.37	1.26	1.66	0.50
2001	4,436	965	185	26	35	80	28	9	0.90	1.51	1.21	0.36
2002	2,131	1,182	130	29	38	95	21	9	0.60	1.02	1.48	0.44
2003	2,301	878	320	20	76	72	49	7	0.43	0.80	1.51	0.45
2004	1,205	1,809	260	18	45	132	35	6	0.32	1.14	0.91	0.27
2005	526	1,297	327	36	11	112	49	12	0.17	1.07	1.01	0.30
2006	480	1,038	218	35	14	86	35	12	0.17	0.86	0.77	0.23
2007	353	1,109	248	40	11	82	37	14	0.15	1.08	0.77	0.23
2008	1,284	913	179	44	23	83	29	15	0.44	1.15	0.74	0.22
2009	1,533	1,077	156	51	29	82	27	20	0.46	1.37	0.96	0.29
2010	1,805	974	125	34	30	85	21	12	0.53	0.92	0.85	0.25
2011	1,009	953	266	36	29	73	42	13	0.42	0.90	1.11	0.33
2012	403	752	251	34	13	64	37	12	0.20	0.98	1.00	0.30
2013	1,034	758	156	32	28	71	26	11	0.41	1.08	0.84	0.25
2014	1,856	873	150	36	38	70	24	12	0.38	1.17	1.01	0.30
2015	451	1,911	148	28	17	124	23	11	0.18	1.36	0.97	0.29
2016	480	823	247	27	13	69	37	9	0.14	0.84	0.99	0.30
2017	240	1,172	220	30	6	89	34	11	0.07	0.90	0.86	0.26
2018	194	1,124	226	27	6	73	36	10	0.08	0.80	0.64	0.19
2019	286	760	252	38	6	61	40	14	0.13	0.78	0.61	0.18

年\年齢	Year\Age
漁獲尾数 (百万尾)	Catch in number (million individuals)
漁獲重量 (千トン)	Catch in weight (thousand tons)
漁獲係数 F	Fishing mortality (F)

Appendix 4 (continued). Details of cohort analysis results (1973-2019)

年\年齢	平均体重 (g)				資源尾数 (百万尾)				資源量 (千トン)			
	0	1	2	3+	0	1	2	3+	0	1	2	3+
1973	25	81	154	345	2,913	1,152	411	75	74	94	63	26
1974	25	81	154	345	3,900	1,547	318	93	99	126	49	32
1975	25	81	154	345	4,113	1,849	318	95	104	150	49	33
1976	25	81	154	345	1,927	1,402	403	80	49	114	62	28
1977	25	81	154	345	553	999	264	123	14	81	41	43
1978	25	81	154	345	2,034	260	311	111	51	21	48	38
1979	25	81	154	345	1,570	1,202	87	95	40	98	13	33
1980	25	81	154	345	1,043	480	241	78	26	39	37	27
1981	25	81	154	345	2,338	599	155	85	59	49	24	29
1982	25	81	154	345	3,414	1,280	94	76	86	104	15	26
1983	25	81	154	345	2,320	1,744	111	49	59	142	17	17
1984	25	81	154	345	5,334	1,126	181	43	135	92	28	15
1985	25	81	154	345	3,299	1,940	183	31	83	158	28	11
1986	25	81	154	345	2,354	1,314	201	37	59	107	31	13
1987	25	81	154	345	8,920	1,180	384	45	225	96	59	15
1988	25	81	154	345	3,045	3,862	206	51	77	314	32	17
1989	25	81	154	345	5,451	994	709	54	138	81	109	19
1990	25	81	154	345	5,739	2,184	273	55	145	178	42	19
1991	25	81	154	345	5,601	2,387	221	69	142	194	34	24
1992	25	81	154	345	6,035	2,109	500	70	153	172	77	24
1993	25	81	154	345	8,799	2,865	433	65	222	233	67	22
1994	25	81	154	345	5,838	3,967	294	56	148	323	45	19
1995	25	81	154	345	8,908	2,109	612	84	225	172	94	29
1996	25	81	154	345	5,643	3,398	359	83	143	276	55	29
1997	16	83	164	369	9,140	2,796	630	89	150	231	103	33
1998	38	76	149	343	4,485	3,212	485	123	168	246	72	42
1999	31	91	156	328	4,369	1,797	476	136	137	163	74	44
2000	31	82	143	376	3,610	1,863	438	151	110	152	63	57
2001	8	81	154	345	9,149	1,513	319	106	73	122	49	37
2002	18	80	158	300	5,863	2,252	202	102	106	180	32	31
2003	33	82	154	328	8,197	1,954	492	68	271	161	76	22
2004	38	73	133	348	5,464	3,230	530	92	205	236	71	32
2005	21	87	151	337	4,302	2,398	627	171	88	208	95	58
2006	28	83	159	344	3,977	2,206	497	215	112	183	79	74
2007	31	74	149	342	3,113	2,045	566	242	97	152	84	83
2008	18	91	162	342	4,467	1,618	422	275	79	147	68	94
2009	19	76	173	386	5,189	1,738	310	255	99	132	54	98
2010	16	88	166	370	5,488	1,988	268	188	90	174	45	69
2011	29	76	158	372	3,689	1,967	482	158	106	150	76	59
2012	32	85	148	365	2,809	1,473	485	165	89	125	72	60
2013	27	94	164	342	3,825	1,396	336	183	103	131	55	63
2014	20	81	162	332	7,419	1,536	287	174	152	124	47	58
2015	37	65	158	384	3,503	3,091	290	141	128	201	46	54
2016	26	84	150	344	4,589	1,780	480	130	121	149	72	45
2017	24	76	154	362	4,452	2,415	466	167	107	184	72	61
2018	33	65	157	371	3,085	2,516	594	197	101	163	93	73
2019	21	81	160	359	3,035	1,722	687	289	65	139	110	104

年\年齢	Year\Age
平均体重 (g)	Average body weight (g)
資源尾数 (百万尾)	Number of fish (million individuals)
資源量 (千トン)	Biomass (thousand tons)

Appendix 5. CPUE standardization method

(1) Large- to medium-scale purse seine fishery

We standardized the abundance index at age (by size) in large- to medium-scale purse seine fishery. The data used was the catch result reports of large- to medium-scale purse seine fishery in which catch by vessel, by date, by species, and by size and the number of nets in a 10-minute latitude-longitude grid cell are recorded. 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 catch at age of Japanese jack mackerel per vessel and per net (tons/net).

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 additive model (GAM) for analysis, used binomial distribution for the error distribution of the former model, and used normal distribution for that of the latter mode. As explanatory variables for predicting the CPUE, we used year (categorical variable), month (categorical variable), latitude and longitude (smoothing spline), water temperature at 50 m depth (continuous variable, smoothing spline), tonnage group (categorical variable), and fishing vessel ID (categorical variable). The fishing vessel ID was treated as a random effect. We calculated the standardized CPUE by taking into consideration all variable combinations and setting a model that minimizes the BIC as the best model.

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 in all ages, 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 estimate value of 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.

(2) Survey on new recruitment (juveniles)

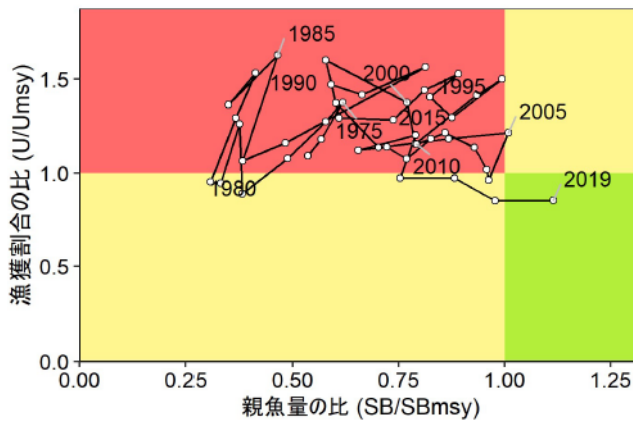
We standardized the abundance index with regard to the results of the survey of Japanese jack mackerel juveniles conducted by using a midwater trawl in May to June from the western coast of Kyushu to the southwestern part of the Sea of Japan (Appendix 3 (2) Survey on new recruitment (juveniles)). The data used was the abundance of Japanese jack mackerel juveniles per net from 2003 to 2019. As the fixed survey points where Japanese jack mackerel was not collected accounted for less than 20% of the total, we used the generalized linear model (GLM) for the analysis. Since overdispersion was found in a preliminary study, we used negative binomial distribution as error distribution. As explanatory variables for predicting the CPUE, we used year (categorical variable), sea area (categorical variable), organization conducting

the survey (categorical variable), and day-night difference (categorical variable). We calculated the standardized CPUE by taking into consideration all variable combinations and setting a model that minimizes the BIC as the best model. For details, see the document (FRA-SA2020-SC01-107).

Appendix 6. Kobe plot based on exploitation rate

The figure below shows a Kobe plot based on the spawning biomass and exploitation rate (U) at that time. The spawning biomass of the present stock has been below the level that produces MSY, except in 2005 and 2019, and recently the ratio of the exploitation rate (U/Umsy) has been lower than the level that produces MSY since 2016.

Item	Value	Explanation
SBmsy	254 thousand tons	Spawning biomass that produces MSY
Umsy	32.4%	Exploitation rate that produces MSY
U2019	29.1%	Exploitation rate in 2019
U2019 Umsy	0.90	Ratio of the exploitation rate in 2019 to the exploitation rate that produces MSY



漁獲割合の比	U/Umsy
親魚量の比	SB/SBmsy

Appendix Figure 6-1. Relationship of the past spawning biomass and exploitation rate to the spawning biomass that produces MSY (SBmsy) and exploitation rate that produces MSY (Umsy) (Kobe plot)

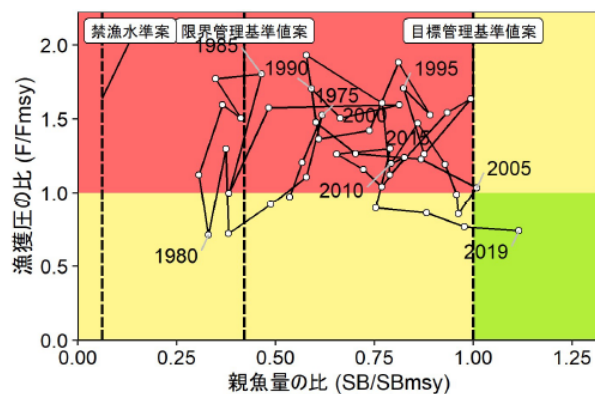
Appendix 7. Proposed reference points and fishing ban level, etc.

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

Item	Value	Explanation
Proposed SBtarget	254 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	107 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	16 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

It was proposed at the Research Institute Meeting held in March 2020 that the spawning biomass that produces MSY (SBmsy: 254 thousand tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 107 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 16 thousand tons) be used for the fishing ban level (SBban). For details, see "Report of the Research Institute Meeting on Reference Points of Japanese jack mackerel Tsushima stock (2020)."

Appendix Figure 7-1 shows a Kobe plot based on the proposed SBtarget and fishing mortality (F) at that time. The spawning biomass in 2019 (SB2019: 283 thousand tons) obtained by cohort analysis was slightly above the proposed SBtarget. The fishing mortality is determined to have been below Fmsy since 2016.



漁獲圧の比	F/Fmsy
親魚量の比	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

Appendix Figure 7-1. Relationship between the proposed reference points / fishing ban level and spawning biomass / fishing mortality (Kobe plot)

Appendix 8. Future projection compliant with the proposed HCRs

(1) Setting of future projection

We calculated the future projection for 2020 to 2051 using forward calculation of cohort analysis based on the stock biomass in 2019 estimated in stock assessment (Appendix 9). 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. The catch in 2020 was assumed from the projected stock biomass and the current fishing mortality (F2017-2019). For the current fishing mortality, we used the F value that gives %SPR corresponding to the fishing mortality in 2017 to 2019 as estimated in this year's assessment, under the same conditions of selectivity and biological parameters (average body weight, etc.) as those for calculating the proposed reference points. 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

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 Figures 8-1 and 8-2 show the HCRs proposed at the Research Institute Meeting held in March 2020. Here, we present a case where safety coefficient β is the standard values 0.8 and 0.9, as an example. Meanwhile, it was proposed at the Research Institute Meeting that "if β is 0.9 or less, spawning biomass is estimated to exceed SBtarget in 10 years at a probability of 50% or more." The same conclusion was obtained also in the future projection using data that has been updated by 1 year.

(3) Projected values for 2021

We estimated the catch in 2021 according to the future projection using the proposed HCRs. As a result of the future projection, the average catch in 2021, which was estimated based on the proposed HCRs, was 152 thousand tons where β was 0.9, and 140 thousand tons where β was 0.8. The projected spawning biomass in 2021 was estimated at 279 thousand tons at average, and the estimation was above SBlimit in all iterations.

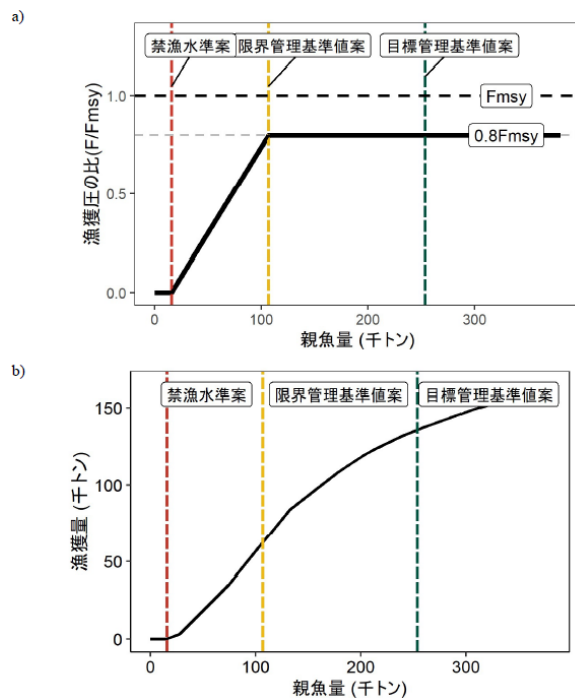
Spawning biomass in 2021 (average projection value): 277 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality	Exploitation rate in 2021 (%)

		(F/F2017-2019)	
When using β proposed by the Research Institute Meeting in the proposed HCRs			
$\beta = 0.9$	151	1.13	30.2
Other strategy (when using different β in the proposed HCRs)			
$\beta = 1.0$	162	1.25	32.4
$\beta = 0.8$	139	1.00	27.7
$\beta = 0$	0	0	0
F2017-2019	139	1.00	27.7

(4) Projection for 2022 onward

Appendix Figures 8-3 and 8-4 and Appendix Tables 8-1 and 8-2 show the medium- to long-term future projection results based on the proposed HCRs (Appendix Figures 8-1 and 8-2). If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in 2031 is 257 thousand tons on average where β is 1.0 (the 80% confidence interval is 180 thousand to 345 thousand tons), and 292 thousand tons on average where β is 0.9 (the 80% confidence interval is 209 thousand to 388 thousand tons). The probability of the projected spawning biomass being above the proposed SBtarget exceeded 50% where β is 0.9 or less. When β was changed at 0.01 intervals, the probability of the projected spawning biomass in 2031 being above the proposed SBtarget was 50% where $\beta=0.98$. When $\beta=0.98$, the average catch in 2021 was 160 thousand tons. The probability of the projected spawning biomass being above the proposed SBlimit and the probability of the projected spawning biomass being above the proposed SBban were 100% in all strategies.

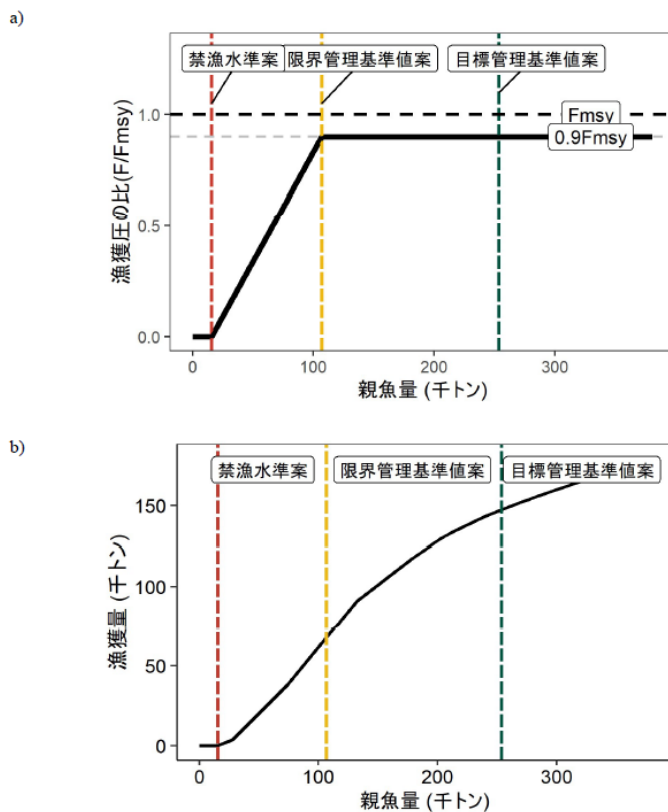
Uncertainty considered: recruitment					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points below (%)		
			SBtarget	SBlimit	SBban
When using β proposed by the Research Institute Meeting in the proposed HCRs					
$\beta = 0.9$	292	209–388	67.0	100	100
Other strategy (when using different β in the proposed HCRs)					
$\beta = 1.0$	257	180–345	45.9	100	100
$\beta = 0.8$	334	240–438	85.3	100	100
$\beta = 0$	1270	963–1613	100	100	100
F2017-2019	335	241–440	85.6	100	100



漁獲圧の比	F/Fmsy
親魚量 (千トン)	Spawning biomass (thousand tons)
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
漁獲量 (千トン)	Catch (thousand tons)

Appendix Figure 8-1. Proposed HCRs (where $\beta = 0.8$)

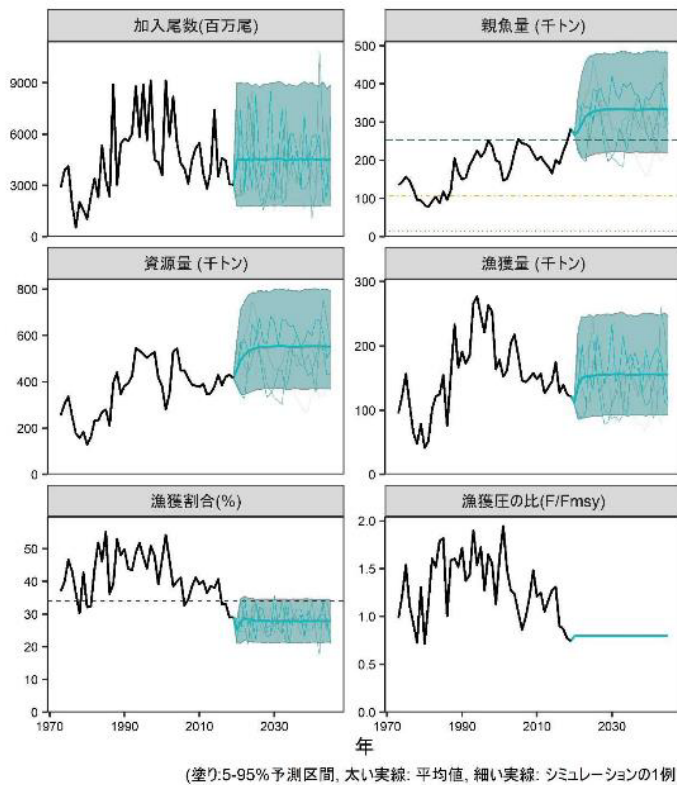
The proposed target reference point (SBtarget) is SBmsy calculated based on the HS S-R relationship. Standard values were used for the proposed limit reference point (SBlimit) and the proposed fishing ban level (SBban). Here, standard value 0.8 was used as safety coefficient β . The black broken line indicates Fmsy, the gray broken line indicates 0.8Fmsy, the black bold line indicates HCRs, the red broken line indicates the proposed SBban, the yellow broken line indicates the proposed SBlimit, and the green broken line indicates the proposed SBtarget. a) shows the case where the vertical axis is the fishing mortality, and b) shows the case where the vertical axis is catch. Whereas the actual catch volume slightly varies depending on the age composition in the year of the catch, b) shows the catch volume in the case of average age composition in an equilibrium state.



漁獲圧の比	F/Fmsy
親魚量 (千トン)	Spawning biomass (thousand tons)
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
漁獲量 (千トン)	Catch (thousand tons)

Appendix Figure 8-2. Proposed HCRs (where $\beta = 0.9$)

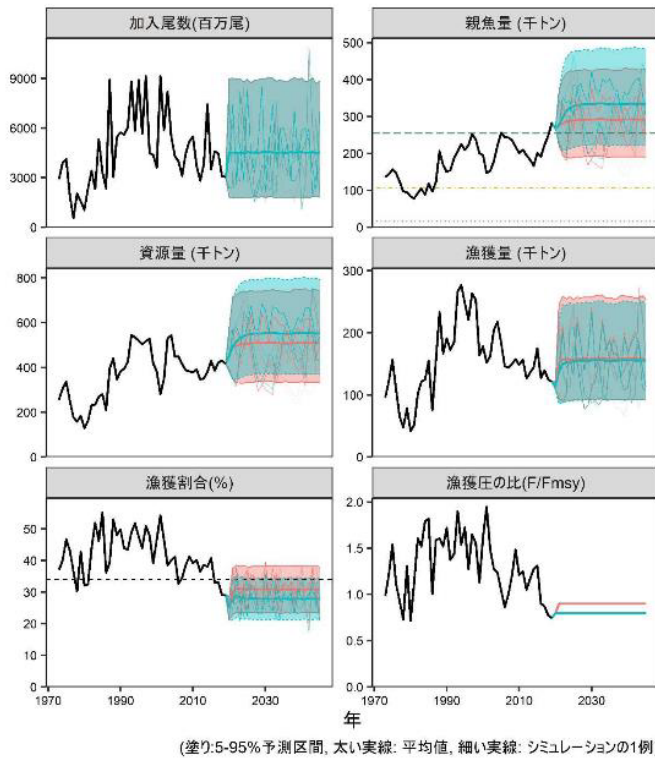
The proposed target reference point (SBtarget) is SBmsy calculated based on the HS S-R relationship. Standard values were used for the proposed limit reference point (SBlimit) and the proposed fishing ban level (SBban). Here, safety coefficient β was set at 0.9, as it was estimated that spawning biomass will be above the SBtarget in 10 years with a probability of 50% or higher, if β was 0.9 or lower. The black broken line indicates Fmsy, the gray broken line indicates 0.8Fmsy, the black bold line indicates HCRs, the red broken line indicates the proposed SBban, the yellow broken line indicates the proposed SBlimit, and the green broken line indicates the proposed SBtarget. a) shows the case where the vertical axis is the fishing mortality, and b) shows the case where the vertical axis is catch. Whereas the actual catch volume slightly varies depending on the age composition in the year of the catch, b) shows the catch volume in the case of average age composition in an equilibrium state.



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	Ratio of the fishing mortality to MSY
年	Year
(塗り : 5-59%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 slid line: simulation example)

Appendix Figure 8-3. Results of medium- to long-term future projection based on the proposed HCRs (Appendix Figure 8-1) (where $\beta = 0.8$)

The thick line indicates the average value of 10,000 iterations, the thin line indicates the result of 5 trials, and the shaded part indicates the 90% prediction interval that covers 90% of the simulation results. In the figure of spawning biomass, the green broken line indicates the proposed target reference point, the yellow dash-dotted line indicates the proposed limit reference point, and the red dotted line indicates the proposed fishing ban level. In the figure of exploitation rate, the broken line indicates U_{msy} . The catch in 2020 was assumed based on the projected stock biomass and $F_{2017-2019}$.



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	Ratio of the fishing mortality to MSY
年	Year
(塗り : 5-59%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 8-4. Results of medium- to long-term future projection based on the proposed HCRs (Appendix Figure 8-2) (where $\beta = 0.9$)

The thick line indicates the average value of 10,000 iterations, the thin line indicates the result of 5 trials, and the shaded part indicates the 90% prediction interval that covers 90% of the simulation results. In the figure of spawning biomass, the green broken line indicates the proposed target reference point, the yellow dash-dotted line indicates the proposed limit reference point, and the red dotted line indicates the proposed fishing ban level. In the figure of exploitation rate, the broken line indicates U_{msy} . The catch in 2020 was assumed based on the predicted stock biomass and $F_{2017-2019}$.

Appendix Table 8-1. Probability for spawning biomass to exceed (a) the proposed target reference point and (b) the proposed limit reference point

The fishing mortality in 2020 was assumed based on the catch under F2017-2019. Years are calendar years.

(a) (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	100	100	64	51	49	48	46	46	47	46	46	46	46	47	45
0.98	100	100	64	53	52	51	50	50	51	51	50	50	50	51	50
0.9	100	100	64	61	64	65	65	66	67	67	67	67	67	67	67
0.8	100	100	64	70	77	81	83	84	85	85	85	85	85	85	85
0.7	100	100	64	80	88	92	94	95	95	96	96	96	96	96	96
0.6	100	100	64	87	95	98	98	99	99	99	99	100	99	99	99
0.5	100	100	64	93	98	100	100	100	100	100	100	100	100	100	100
0.4	100	100	64	97	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	64	98	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	64	99	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	64	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	64	100	100	100	100	100	100	100	100	100	100	100	100

(b) (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.98	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 8-2. Changes in average values of future spawning biomass (a) and catch (b)

The fishing mortality in 2020 was assumed based on the catch under F2017-2019. Years are calendar years.

(a)
(thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	283	268	277	266	261	259	257	257	257	257	256	257	257	257	256
0.98	283	268	277	269	266	265	263	263	263	264	263	263	264	264	262
0.9	283	268	277	280	286	289	289	290	291	292	291	292	292	293	291
0.8	283	268	277	297	314	323	327	330	331	333	332	333	334	334	332
0.7	283	268	277	314	347	364	372	377	380	382	382	383	384	384	382
0.6	283	268	277	334	385	413	426	434	439	442	443	444	445	445	443
0.5	283	268	277	355	429	470	491	504	511	516	517	518	520	521	519
0.4	283	268	277	378	480	539	570	589	599	606	609	611	612	614	612
0.3	283	268	277	404	539	621	666	692	707	717	722	725	727	730	727
0.2	283	268	277	432	609	719	782	818	840	855	862	866	869	874	871
0.1	283	268	277	463	690	837	922	974	1,005	1,025	1,036	1,043	1,047	1,054	1,051
0	283	268	277	497	785	978	1,094	1,164	1,208	1,237	1,254	1,263	1,270	1,281	1,278

(b)

(thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	121	113	162	163	161	161	159	161	160	160	160	160	161	161	160
0.98	121	113	160	162	161	160	159	160	160	160	160	160	161	161	160
0.9	121	113	151	157	158	158	157	159	159	159	158	159	160	159	158
0.8	121	113	139	150	153	154	154	155	155	156	155	156	156	156	155
0.7	121	113	126	142	146	148	148	150	151	151	150	151	151	151	150
0.6	121	113	112	131	137	140	141	143	144	144	144	144	145	145	144
0.5	121	113	97	119	126	130	131	133	134	134	134	135	135	135	134
0.4	121	113	80	103	111	116	118	120	121	121	121	121	122	122	121
0.3	121	113	63	84	93	97	100	102	103	103	103	103	104	104	103
0.2	121	113	43	61	69	73	75	77	78	78	79	79	79	79	79
0.1	121	113	23	34	39	41	43	44	45	45	45	45	46	46	46
0	121	113	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 9. Method of future projection of the stock

We performed future projection from the stock biomass obtained, based on the HCRs.

The values estimated by the HS model ($a = 0.0271$, $b = 1.67e + 05$, $SD = 0.486$), which was agreed at the Committee of Stock Management Policy held in 2020, were used for estimating the future recruitment. The data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment based on the stock assessment conducted in 2019, 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. For details, see "Report of the Research Institute Meeting on Reference Points of Japanese jack mackerel Tsushima stock in 2020" (Yoda et al. 2020).

For fishing mortality (F) in future projection, we used the value calculated based on the HCRs set for the first group of stocks detailed in the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)." The parameters used for the future projection are shown in Appendix Table 9-1. As for the selectivity and average body weight of the catch, etc., we again used the values used for estimating the reference points agreed at the Committee of Stock Management Policy held in 2020. These values are based on the 2019 stock assessment, similar to the S-R relationship, and the selectivity and average body weight of catch are the average values of the calculation results for 2016-2018. For the fishing mortality in 2020 (F2020), we used the F value that gives %SPR corresponding to the fishing mortality in 2017-2019 as estimated in this year's assessment, under the same conditions of selectivity and biological parameters (average body weight, etc.) as those for calculating the proposed reference points. The body weight is the average value of the results for 2017-2019.

For projection of the number of fish, we used forward calculation of cohort analysis (equations (6 to 8)).

$$N_{a-1,y+1} = N_{a,y} \exp(-F_{a,y} - M) \quad (6)$$

$$N_{3+,y+1} = N_{3+,y} \exp(-F_{3+,y} - M) + N_{2,y} \exp(-F_{2,y} - M) \quad (7)$$

$$C_{a,y} = N_{a,y} \frac{F_{a,y}}{F_{a,y} + M} (1 - \exp(-F_{a,y} - M)) \quad (8)$$

We used the values in the table below as the settings for the future projection. We projected the number of fish and catch using the calculation package frasyr (version 2.1.1.0) for statistics software R (version 3.6.1) based on ABCWG (2020).

Appendix Table 9-1. Parameters used for calculating the future projection

	選択率 (注1)	Fmsy (注2)	F2017-2019 (注3)	平均体重 (g)	自然死亡 係数	成熟率
0歳	0.10	0.11	0.091	27.6	0.5	0
1歳	1.00	1.10	0.878	74.8	0.5	0.5
2歳	0.74	0.82	0.651	153.6	0.5	1.0
3歳以上	0.22	0.24	0.195	359.0	0.5	1.0

選択率 (注1)	Selectivity (Note 1)
(注2)	(Note 2)

(注 3)	(Note 3)
平均体重(g)	Average body weight (g)
自然死亡係数	Natural mortality
成熟率	Maturity rate
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above

Note 1: Selectivity used for estimating the level that produces MSY at the 2020 Research Institute Meeting.

Note 2: Fmsy estimated at the 2020 Research Institute Meeting.

Note 3: F value under the selectivity above that gives the same fishing mortality as the average F at age for 2017-2019 estimated in the present stock assessment, which has been converted into %SPR. This F value was used for assuming the catch in 2020.

Reference

ABCWG (2020) Technical Note on Estimation of stock-recruitment relationship, reference point calculation and future prediction simulation (2020 Research Institute Meeting Version). FRA-SA2020-ABCWG01-02.

Yoda, M., H. Kurota, and M. Takahashi (2020) Reiwa 2 (2020) nendo maaji taiheiyokeigun no kanri kijunchi to ni kansuru kenkyu kikan kaigi hokokusho (Report of the Research Institute Meeting on Reference Points of Japanese jack mackerel Tsushima stock in 2020). http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_maaji_tc.pdf, last accessed on July 20, 2020