Stock Assessment of Japanese Jack Mackerel Pacific Stock in 2020

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

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Summary

The stock biomass was estimated by a cohort analysis using the abundance index as the tuning index. The biomass of the present stock increased since the 1980s and changed around 143 thousand to 162 thousand tons in the middle of the 1990s. Since 1997, it turned to a decrease and it had been lower than 100 thousand tons since 2006, then it decreased to 56 thousand tons in 2009. Afterward, the biomass turned to an increase again to 69 thousand tons in 2013 and then it remained at around 40 thousand tons in 2015-2018. The biomass in 2019 was estimated to be 38 thousand tons and spawning was estimated to be 20 thousand tons.

At the "Research Institute Meeting on Reference Points" held in March 2020, the weighted average model of Ricker (RI) and Beverton-Holt (BH) models considering autocorrelation was applied as the stock-recruitment (S-R) relationship of this stock. Based on this model, the spawning biomass that produces the maximum sustainable yield (MSY) (SBmsy) is estimated to be 60 thousand tons. Based on this, the spawning biomass of this stock in 2019 will be below the level that produces MSY. Also, the fishing mortality in 2019 will exceed the pressure of the level that produces MSY (Fmsy).

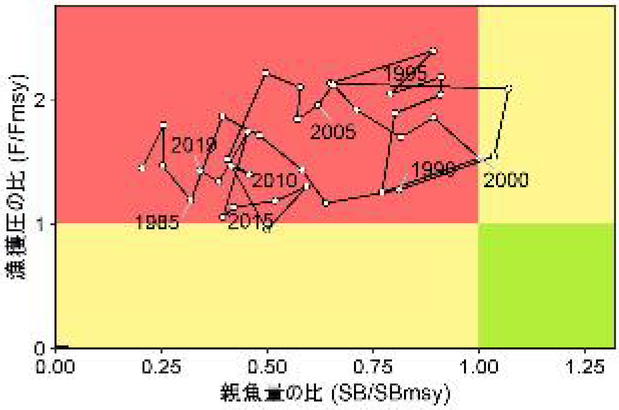
With regard to the items that are to be finalized based on discussions at the Study Meeting on Stock Management Policy, such as reference points and future projections, we tentatively indicated the values suggested at the "Research Institute meeting on Reference points."

Item	Value	Explanation
Level that produces MSY under the current environment		
SBmsy	60 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3 and above) = (0.40,0.58,0.77,0.77)	
%SPR(Fmsy)	22%	%SPR corresponding to Fmsy
MSY	38 thousand tons	Maximum sustainable yield
Spawning biomass and fishing mortality in 2019		
SB2019	20 thousand tons	Spawning biomass in 2019
F2019	Fishing mortality in 2019 (ages 0, 1, 2, 3 and above) = (0.48, 0.83, 1.12, 1.12)	
%SPR (F2019)	14.2%	%SPR in 2019
%SPR (F2017-2019)	13.7%	%SPR corresponding to the current fishing mortality (2017-2019)
Ratio to MSY		
SB2019/SBmsy	0.34	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.43	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: Weighed average models of the RI and BH relationships (with autocorrelation)

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Above Fmsy
Trend in spawning biomass	Decreasing



漁獲圧の比	Ratio of the fishing mortality to MSY
親魚量の比	Ratio of the spawning biomass to MSY

年	資源量（千トン）	親魚量（千トン）	漁獲量（千トン）	F/Fmsy	漁獲割合（%）
2016	49	24	16	1.05	33
2017	49	27	24	1.74	49
2018	44	23	18	1.34	42
2019	38	20	16	1.43	43
2020	40	19	17	1.44	43
2021	41	18	–	–	–

年	Year
資源量（千トン）	Stock biomass (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲割合	Exploitation Rate

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 (Miyazaki-Aomori [17] prefectures) Data collection survey on biological information (National Research Institute of Fisheries Science [NRIFS], Miyazaki-Aomori [17] prefectures, Japan Fisheries Information Service Center [JAFIC])
Abundance index ・Recruitment index	CPUE for set net fishery in the southern Miyazaki Prefecture* (Miyazaki Prefecture)

	CPUE for purse seine fishery in Uwajima port* (Ehime Prefecture) CPUE for medium-scale purse seine fishery in Sukumo Bay* (Kochi Prefecture) Catch of age 0 fish in stick-held dip net fishery at Kushimoto* (Wakayama Prefecture) Catch of age 0 fish in small-scale trawl net fishery in Ise Bay* (Aichi Prefecture) Catch of age 0 fish in set net fishery in Chiba Prefecture* (Chiba Prefecture)
Natural mortality (M)	Assuming M = 0.5 per year (Tanaka 1960)
Fishing effort	Annual Statistics on Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Northern Pacific purse seine efforts (JAFIC)

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

2. Ecology of the stock

(1) Distribution and migration

The distribution range of Japanese jack mackerel Pacific stock and a schematic view of forming main fishing ground are shown in Figures 2-1 and 2-2, respectively. As for Japanese jack mackerel distributing in the Sea of Japan (in the Pacific and neighboring sea areas), it is presumed that there are groups whose main spawning ground is the East China Sea and those whose spawning ground is the mid mainland and southward. In the sea area of the Pacific coast of the mid mainland and eastward, some groups of different seasons of recruitment are mixed. It is supposed that they consist of those born from February to April in the East Sea of Japan and those born after May offshore the coast of the Pacific (Kohata 1972). Also, it is thought that the amount of recruitment from the East China Sea (Yokota and Mita 1958) dominates the stock status (Koto 1990).

(2) Age and growth

The fork length of a Japanese jack mackerel grows to 18 cm in a year and to 24 cm in two years (Figure 2-3). As the growing speed is thought to be different depending on the sea area in which they live (Taga and Yamashita 2018), it is desirable to conduct a survey widely to research the growing process of this stock. The catch of fish of age 4 and above in this stock is very small, but it is reported that individuals that show more than ten ring patterns in the otolith in the catch (Taga and Yamashita 2018, Katayama et al. 2019, Takamura et al. 2019).

(3) Maturity and spawning

The farther south Japanese jack mackerel live, the earlier the spawning season is. In Bungo

Channel and outside of Kii Strait, the spawning season is from winter to early summer (Sakamoto et al. 1986, Yakushiji 2001, Sakachi 2001), and in Sagami Bay, it is from spring to early summer (Kohata 1972, Sawada 1974). It is thought that 50% of those of age 1 and 100% of those of the age 2 are mature (Figure 2-4).

(4) Prey-predator relationships

Juveniles take large zooplankton and become more ichtyophagous as they grow (Mitani et al. 2001). This type of fish is preyed on by large fish (Mitani et al. 2001).

(5) Special notes

As is mentioned above, it is presumed that two groups generated in the mid mainland and southward and in the East China Sea are mixed in the offshore fishing ground of the Pacific coast. At present, a scientific survey is being conducted in each distributing area to distinguish the origin of individuals that comprise the group from the features such as history of growth and inherited characters. From this survey, it is expected that the contribution ratio of those generated in the East China Sea to the biomass of the Pacific stock and its annual change will be elucidated.

3. Status of fisheries

(1) Outline of fisheries

The catch by purse seine fishery consists of about 60% of the total catch, and then the catch in set net fishery consists of about 30% of the total. In Sagami Bay, the main fishing season is spring, while that in Hyuuganada, Bungo Channel, Kii Strait, and Kumanonada is from spring until autumn. In these sea areas, age 0 fish are caught from spring and age 1 fish are caught from the beginning of the year. The catch of age 1 and 2 fish is large in the sea areas in Chiba and northward.

(2) Changes in catch amount

Changes in catch from the Northern Pacific to the Southern Pacific (north of the Pacific offshore of Hokkaido-Miyazaki Prefectures) are shown in Table 3-1 and Figure 3-1.The catch was less than 20 thousand tons during the period of 1982-1985, but it began to increase rapidly to 37 thousand tons in 1986. Since 1990, it increased again and during the period of 1993-1997, it remained at a high level of 70 thousand to 80 thousand tons. The catch began to decrease in 1997, and it remained less than 30 thousand tons. It remained at a very low level of 16 thousand to 17 thousand tons in 2015-2016. Since July 2017, the total catch was 24 thousand tons, mainly due to the high yield of age 0 fish in the fishing ground west of Kochi, which was higher than in 2015 and 2016. However, it remained at a low level again — 18 thousand tons in 2018 and 16 thousand tons in 2019. As for the exploitation rate by sea area, it was 50% in the Southern Pacific, 40% in the Middle Pacific, and about 10% in the Northern Pacific in the latter half of 1990s, when the biomass of this stock decreased. The exploitation rates in 2019 were almost the same as these. The catch by foreign fishing vessels of this stock was zero.

Here, the catch shown in Figure 3-1 and Table 3-1 is based on the figures summarized in the Annual Statistics of Fishery and Aquaculture Production, and subtracts the catch determined to be caught in the East China Sea from the Logbook report of large- and medium-scale purse seine fisheries (offered by the Fisheries Agency of Japan, summed by the Saikai National Fisheries Research Institute) from the catch added up to each prefecture of the Pacific side. The catch in the Sea of Japan by the vessels belong to the Pacific coast in 2014-2019, which was added because the catch in the Pacific has been corrected. The catch of fish caught together (mainly mackerel) in 1989-2001, which was added to the catch of Japanese jack mackerel in the Annual Statistics on Fishery and Aquaculture Production, is subtracted.

The changes in catch in number at age is shown in Figure 3-2. The main target of the fishery is age 0 and 1 fish. The catch in number of age 0 fish in 2015 was 66 million individuals, which was the lowest since 1982, but it increased to twice that figure, 123 million individuals, in 2016. The catch in number of age 0 fish in 2018 and 2019 was 117 million and 102 million individuals, respectively. However, it was at a low level compared with those in 1990s-2008, when the catch in number of age 0 fish was large (218 million to 867 million individuals) (Figure3-2, Appendix Table 2-1). The catch in number of age 0 fish was large in Miyazaki and Kochi Prefectures.

(3) Fishing effort

The main fishery is purse seine and set net. The changes in the number of fishing units of large-scale set net fishery and the effective effort of northern purse seine fishery in 2000-2008 are shown in Figure 3-3. As for the Northern Pacific purse seine fishery among those fishing in the Northern Pacific, the annual effective effort summarized by the Japan Fisheries Information Center (JAFIC) tended to decrease until 2000-2005, and afterward it remained at a low level. The number of fishing units of large-scale set net fishery since 2000 remained unchanged in the Southern Pacific and decreased moderately in the Middle Pacific. As for the Northern Pacific, the changes are unknown, as the statistics of 2007-2016 were not published.

4. Stock status

(1) Stock assessment method

We calculated the number of fish at age, biomass, and fishing mortality (F) by cohort analysis (Appendices 1 and 2) based on the catch in number at age since 1982 (Figure 3-1, Appendix Table 2-1) and the relationship between age and fork length (Appendix Table 2-2). In the calculation used in the stock assessment, as was the case in the last year, we assumed that the selectivity of the most recent year is equivalent to the average of the selectivity of the past 5 years. As for the recruitment index, the figures of 2005-2019 shown in the "changes in the abundance index" were used for tuning (Appendix 2, Appendix Table 2-3). We set the natural mortality (M) to 0.5 according to Tanaka (1960), assuming the lifespan to be around 5 years, as the catch of fish of age 4 and above is very small.

(2) Changes in abundance indices

As for the recruitment index, there are six kinds of data on each fishery in each prefecture that targets age 0 fish. (Figure 4-1, Appendix Table 2-3, Nakagami et al. 2020).

(i) CPUE for set net fishery in the southern Miyazaki Prefecture: The value of catch of Japanese jack mackerel of juveniles (age 0) caught in the set net of the Nango fishermen's cooperative in Miyazaki Prefecture from April to June, which was divided by the total number of landing days of the set net.

(ii) CPUE for purse seine fishery in Uwajima port: The geometric mean of CPUE (monthly catch / total number of landing) of Japanese horse mackerel (age 0) caught by the medium-scale purse seine landed at Uwajima port in Ehime Prefecture from April to March of next year.

(iii) CPUE for medium-scale purse seine fishery in Sukumo Bay: The geometric mean of CPUE (daily catch / number of fishing vessels) of Japanese horse mackerel (age 0) caught by the medium-scale purse seine in Sukumo Bay in Kochi Prefecture from April to March of the following year.

(iv) Catch of age 0 in stick-held dip net fishery at Kushimoto: The catch in the stick-held dip net fishery which targets Japanese jack mackerel of age 0 at Kushimoto, Wakayama Prefecture, from May to June.

(v) Catch of age 0 in small-scale trawl net fishery in Ise Bay: The catch of age 0 fish in the small-scale trawl net fishery in Ise Bay in Aichi Prefecture from April to March of the following year.

(vi) Catch of age 0 in set net fishery in Chiba Prefecture: The monthly catch of mini size fish in the set net fishery offshore and in the open sea of Kamogawa, and in the set net in Chikura, in Chiba Prefecture from October to March of the following year.

Focusing on these six indices, the values of (i), (iii) and (iv) were high in 2008 and since 2009, they tended to decrease with some variance of up and down. The values of (vi) were high in 2010 but tended to decrease in recent years as did the other induces. Each index remained unchanged in 2019, except that the value of (iii) decreased (Figure 4-1, Appendix Table 2-3).

(3) Trends in biomass and fishing mortality

Though the biomass increased since 1982 until the beginning of 1990s, it turned to decrease after peaking at 162 thousand tons in 1996 (Figure 4-2, Table 3-1). Afterward, from 2000 until 2013, it repeated an increase and decrease. In 2015-2018, it stayed at 40 thousand to 50 thousand tons, but it decreased to 38 thousand ton in 2019. The spawning biomass increased since 1984 and reached a peak of 64 thousand tons in 1992. It remained at around 50 thousand tons during 1993-2000, then decreased during 2001-2008, and remained at around 24 thousand to 35 thousand tons during 2009-2013. Afterward, it decreased moderately and the estimated spawning biomass in 2019 was 20 thousand tons. The recruitment (number of age 0 fish) tended to decrease after the peak of 2.4 billion in 1993, and it was 340 million in 2019 (Figure 4-3, Table 3-1). Recruitment per spawning was high in 1986 (47.0 individuals/kg) and in 1993 (61.3 individuals/kg), and it remained at roughly 20 individuals/kg during 1982-2011 (Table 3-1). On the other hand, the recruitment per spawning remained below 20 individuals/kg since 2012 except for 2016, and that in 2019 was 16.8 individuals/kg.

The stock biomass and spawning biomass when natural mortality (M) is assumed to be 0.4 and 0.6 are shown in Figure4-4. The higher M becomes, the higher all the estimated values become.

The changes in exploitation coefficient (F) are shown in Figure 4-5. Generally, the value of F of age 0 fish is relatively lower than that of age 1 fish, and in the year when the F of fish of age 1 and above decreases, the F of age 0 fish slightly increases. It was assumed that the F of age 0 fish in 2019 was 0.48, that of age 1 fish was 0.83, that of age 2 and 3 and above was 1.12 (Appendix Table 2-1). The exploitation rate changes in the range of 33 to 53% (Figure 4-6), and it was 43% in 2019.

Item	Value	Explanation
SB2019	20 thousand tons	Spawning biomass in 2019
F2019	Fishing mortality in 2019 (ages 0, 1, 2, 3 and above) = (0.48, 0.83, 1.12, 1.12)	
U2019	43%	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 influence of selectivity, we made a comparison with the case with no fishing mortality, based on SPR. Figure 4-7 and Table 3-1 show 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 value of %SPR remained at around 7.5 to 23.1% since 1982 and was 14.2% in 2019. The %SPR calculated from the average F value of the most recent three years (2017-2019) as the current fishing mortality and its selectivity and average weight at age of 2006-2019 (Appendix 2-4) was 13.7%.

Figure 4-8 shows the relationship between YPR and %SPR for the current fishing mortality. Here, the selectivity of F is the same value that was used in estimation of F that produces maximum sustainable yield (Fmsy) (Isu et al. 2020) at the "Research Institute Meeting on Reference Points" held in March 2020. As for the averaged weight at age and maturity rate, we applied the same values as those in the estimation of Fmsy. Fmsy corresponds to 21.6% in %SPR. Under the same condition, the F value that would obtain 13.7%SPR is used as the present fishing mortality (F2017-2019). F2017-2019 is higher than Fmsy and F30%SPR. From the viewpoint of YPR management, F2017-2019 exceeds both F0.1 and Fmax.

Item	Value	Explanation

%SPR (F2019)	14.2%	%SPR in 2019
%SPR (F2017-2019)	13.7%	%SPR corresponding to the current fishing mortality (2017 to 2019)

(5) Stock-recruitment relationship

Figure 4-9 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," the weighted average model of the Ricker (RI) and Beverton-Holt (BH) relationships was applied as the S-R relationship for this stock (Isu et el. 2020). Here, the data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment of 1982-2017 based on the stock assessment conducted in 2019 (Nakagami et al. 2020), and as for the optimization method, the least-squares method is used. The recruitment of the group generated in the East Sea of Japan mentioned before was treated as annual variation of recruitment by taking the autocorrelation of the residuals of the recruitment into both the models. The parameters for the S-R relationship are shown in the table below.

再生産関係式	最適化法	自己相関	a	b	S.D.	ρ
リッカー型	最小二乗法	有	0.0588	2.58×10^{-5}	0.306	0.805
ベバートン・ホルト型	最小二乗法	有	0.0667	5.11×10^{-5}	0.315	0.698

再生産関係式	S-R relationship
最適化法	Optimization method
自己相関	Autocorrelation
リッカー型	Ricker
ベバートン・ホルト型	Beverton-Holt
最小二乗法	Least squares method
有	Yes

Here, a and b are estimated parameters of each S-R relationship, S.D. is the standard deviation of recruitment, and ρ is an autocorrelation coefficient.

(6) Level that produces the maximum sustainable yield (MSY) under the current environment

The spawning biomass that produces MSY under the current (since 1982) environment (SBmsy) and the F value that produces MSY estimated at the "Research Institute Meeting on Reference Points" (Isu et al. 2020) are shown in the table below.

Item	Value	Explanation
SBmsy	60 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY	

	(ages 0, 1, 2, 3 and above) = (0.40, 0.58, 0.77, 0.77)	
%SPR (Fmsy)	22%	%SPR corresponding to Fmsy
MSY	38 thousand tons	Maximum sustainable yield

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

Figure 4-10 shows a Kobe plot based on the spawning biomass that produces MSY and fishing mortality that produces MSY. The spawning biomass of this stock in 2019 was below the level of spawning biomass that produces MSY (SBmsy), and the spawning biomass in 2019 was 0.34 times larger than SBmsy. Also, the fishing mortality in 2019 exceeds the fishing mortality that produces MSY (Fmsy), and comparing the fishing mortality in 2019 in %SPR, it is 1.43 times Fmsy. The ratio of the fishing mortality (F/Fmsy) indicated on the Kobe plot shows the yearly ratio between F and F under the current selectivity that produces Fmsy, which was converted to %SPR. The trend of spawning biomass is determined to be "decreasing" in light of the transition over the past five years (2015 to 2019). The fishing mortality of this stock remained above Fmsy except for 2012, and spawning biomass remained below SBmsy, except for 1991 and 1992.

Item	Value	Explanation
SB2019/SBmsy	0.34	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.43	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

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

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Above Fmsy
Trend in spawning biomass	Decreasing

5. Stock assessment summary

The biomass in 2019 was 38 thousand tons and the spawning biomass was 20 thousand tons. The spawning biomass was lower than the level that produces MSY (60 thousand tons). The fishing mortality in 2019 exceeded the level that produces MSY.

6. Others

It is supposed that the current fishing mortality (F2017-2019) is not so large that would decrease the spawning biomass to a level lower than the current level, assuming that the average recruitment expected from the S-R relationship for this stock (Figure 4-9) could be obtained every year (Appendix Figure 5-2). However, as the current fishing mortality is higher than the fishing mortality (Fmsy) that produces MSY (Figure 4-8), it is necessary to increase spawning biomass to the level that produces MSY, keeping fishing mortality lower than the present, in order to use and control biomass to produce MSY (Appendix 5). Also, the current fishing mortality is too large compared with the reference points in light of the YPR management, such as F0.1 and Fmax (Figure 4-8). Moreover, because the recruitment in recent years continue to be lower than the average expected from the S-R relationship (Figure 4-9), it is necessary to note that the biomass in recent years tends to decrease (Figure 4-2).

It is expected to be effective to restore biomass to protect immature age 0 fish. However, this biomass is used as food mainly in west Japan even if they are immature and the logistics and form of consumption are different depending on the body length. Therefore, it is important to discuss the appropriate catch considering each need.

It is expected that scientific knowledge will be gathered on such as biological properties and ecologies concerning the assessment of this stock, especially age and growth by sea area, distribution pattern of the group generated in the East China Sea and change of lifestyle by age.

7. References

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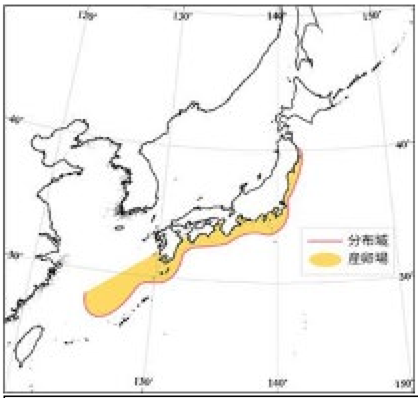
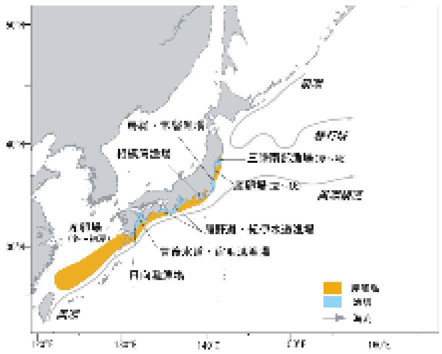


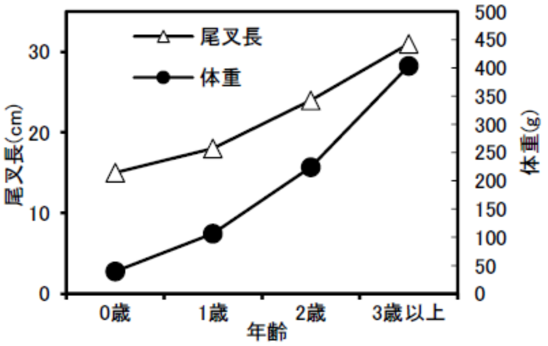
分布域	Distribution range
産卵場	Spawning grounds

Figure 2-1. Distribution and migratory of Japanese jack mackerel Pacific stock



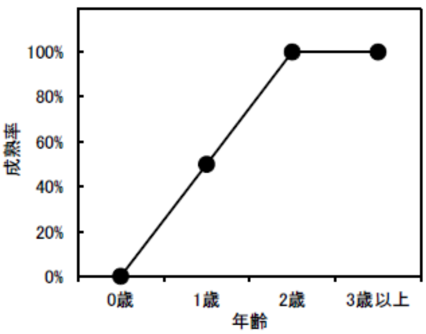
親潮	Oyashio Current
移行域	Transition area
三陸南部漁場（夏～秋）	South Sanriku fishing ground (summer to autumn)
産卵場（夏～秋）	Spawning grounds(summer to autumn)
房総・常総漁場	Bousou Jyousou fishing ground
黒潮続流	Kuroshio extension
相模湾漁場	Sagami Bay fishing ground
熊野灘・紀伊水道漁場	Kumanonada / Kii Strait fishing ground
豊後水道・宿毛湾漁場	Bungo Channel / Sukumo Bay fishing ground
日向灘漁場	Hyuuganada fishing ground
産卵場（冬～初夏）	Spawning grounds (winter to early summer)
黒潮	Kuroshio Current
産卵場	Spawning grounds
漁場	Fishing ground
海流	Current

Figure 2-2. Schematic view of life cycle and formation of fishing ground



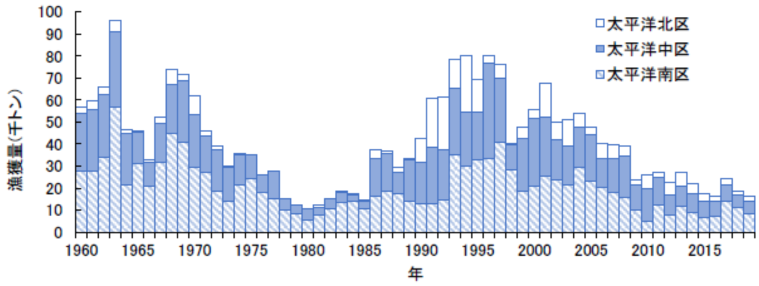
尾叉長	Fork Length
体重	Body weight
年齢	Age
0 歳	Age 0
1 歳	Age 1
3 歳以上	Age 3 and above

Figure 2-3. Age and growth



成熟率	Maturity rate (%)
年齢	Age
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above

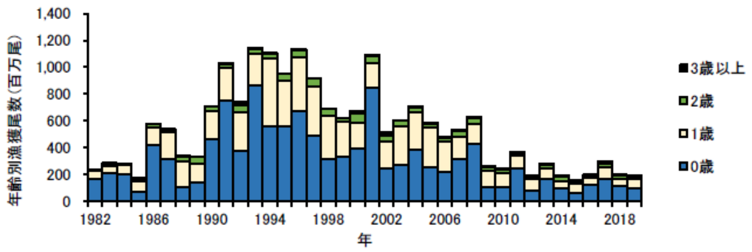
Figure 2-4. Age and maturity rate



漁獲量（千トン）	Catch (thousand tons)
年	Year
太平洋北区	Northern Pacific
太平洋中区	Middle Pacific
太平洋南区	Southern Pacific

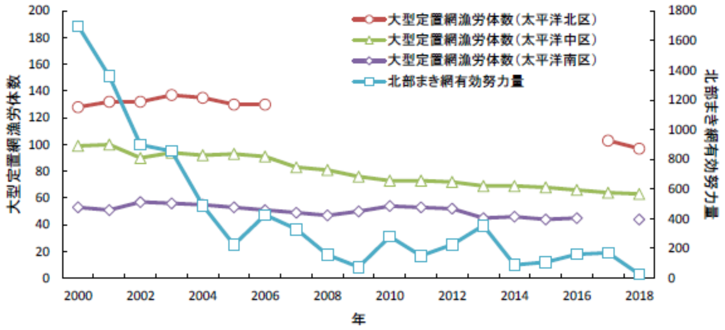
Figure 3-1. Changes in catch

The values are calculated from the value of catch in the Pacific area in the Annual Statistics on Fishery and Aquaculture Production by subtracting the amount of the catch in other fishery areas and the catch of mixed fishing that was added as Japanese jack mackerel.



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

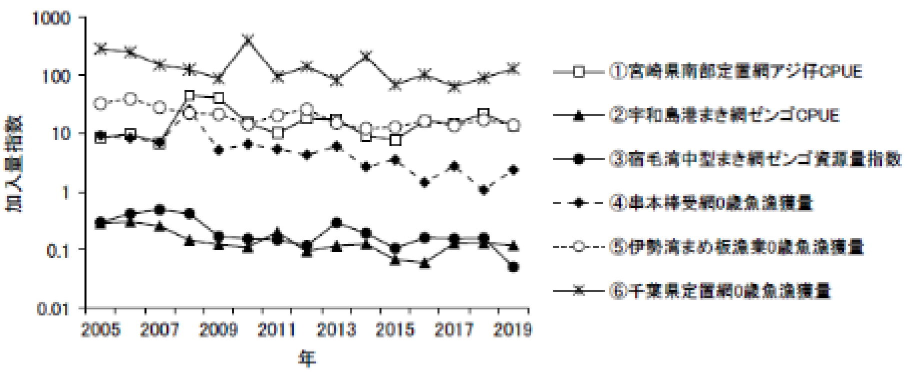
Figure 3-2. Changes in catch in number at age



大型定置網漁労体数	Number of fishing units of large-scale set net
北部まき網有効努力量	Effective effort of the northern purse seine fishery
大型定置網漁労体数（太平洋北区）	Number of fishing units of large-scale set net fishery (Northern Pacific)
大型定置網漁労体数（太平洋中区）	Number of fishing units of large-scale set net fishery (Middle Pacific)
大型定置網漁労体数（太平洋南区）	Number of fishing units of large-scale set net fishery (Southern Pacific)
北部まき網有効努力量	Effective effort of the northern purse seine fishery

Figure 3-3. Changes in the number of fishing units of large-scale set net fishery and the effective effort of the northern purse seine fishery in 2000-2018

The number of fishing units of large-scale set net fishery in the Northern Pacific from 2007 to 2016 is not published.

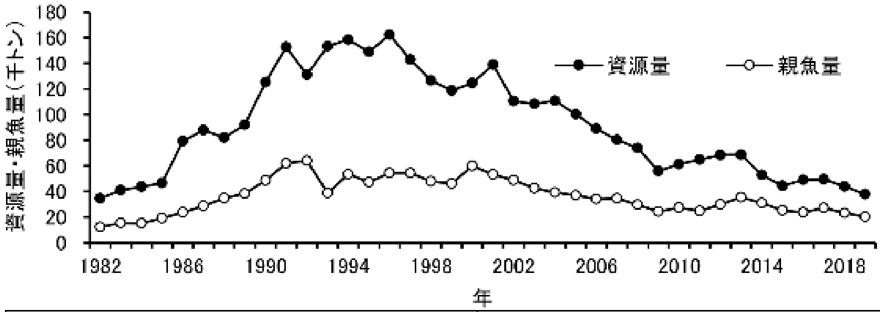


加入量指数	Recruitment index
年	Year
①宮崎県南部定置網アジ仔 CPUE	(i) CPUE for juveniles of Japanese jack mackerel in set net fishery in the south of Miyazaki Prefecture
②宇和島港まき網ゼンゴ CPUE	(ii) CPUE for horse mackerel in purse seine fishery in Usashima port

③宿毛湾中型まき網ゼンゴ資源量指数	(iii) Biomass index of horse mackerel in medium-scale purse seine fishery in Sukumo Bay
④串本棒受網 0 歳魚漁獲量	(iv) Catch of age 0 in stick-held dip net fishery at Kushimoto
⑤伊勢湾まめ板漁業 0 歳魚漁獲量	(v) Catch of age 0 in small scale trawl net fishery in Ise Bay
⑥千葉県定置網 0 歳魚漁獲量	(vi) Catch of age 0 in set net fishery in Chiba Prefecture

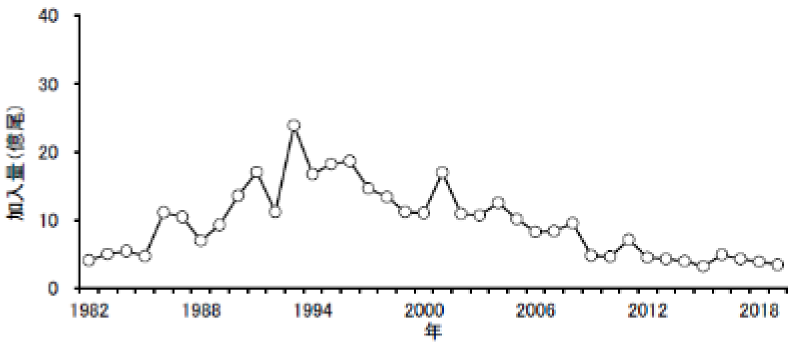
Figure 4-1. Changes in recruitment index

The vertical axis is a logarithmic scale to indicate the annual change of each index in different unit relatively.



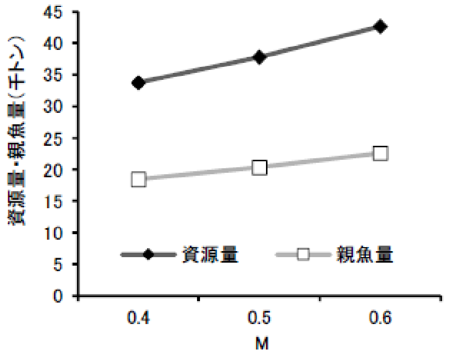
資源量・親魚量（千トン）	Stock biomass,spawning biomass (thousand tons)
年	Year
資源量	Stock biomass
親魚量	Spawning biomass

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



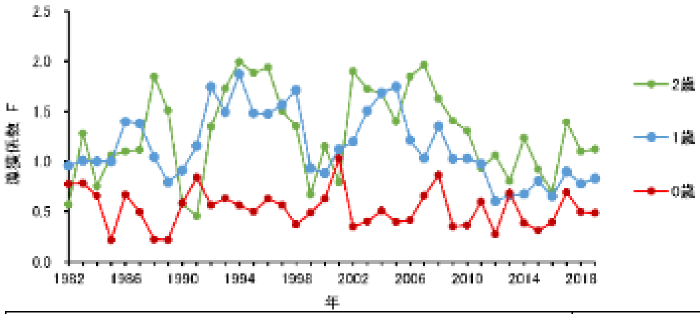
加入量（億尾）	Recruitment (100 million individuals)
年	Year

Figure 4-3. Changes in recruitment



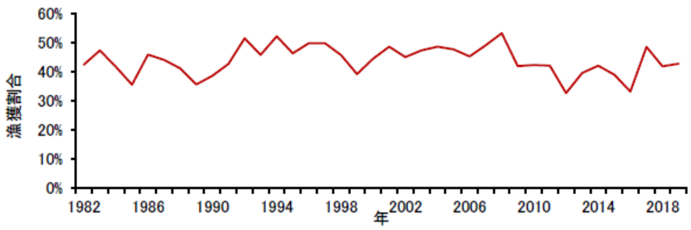
資源量・親魚量（千トン）	Stock biomass, spawning biomass (thousand tons)
資源量	Stock biomass
親魚量	Spawning biomass

Figure 4-4. Stock biomass and spawning biomass when natural mortality (M) is changed



漁獲係数　F	Fishing mortality (F)
年	Year
2 歳	Age 2
1 歳	Age 1
0 歳	Age 0

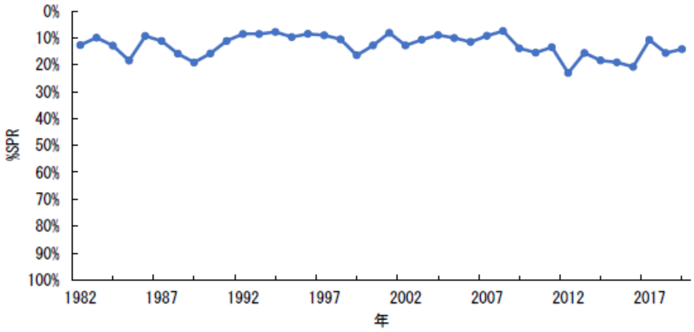
Figure 4-5. Changes in fishing mortality (F) at age



漁獲割合	Exploitation rate

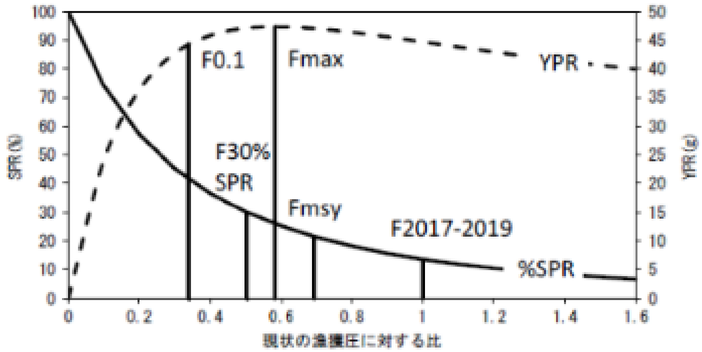
年	Year

Figure 4-6. Changes in exploitation rate



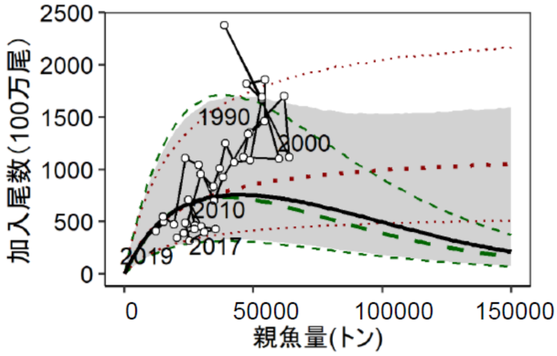
年	Year

Figure 4-7. Changes in %SPR value



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

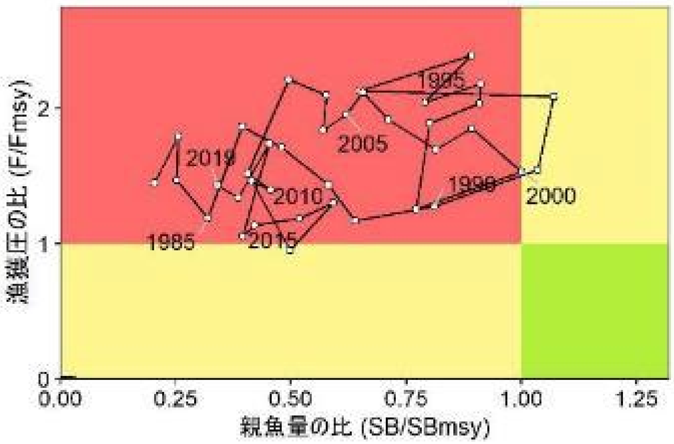
Figure 4-8. Relationship between YPR and %SPR for the current fishing mortality



加入尾数（100 万尾）	Recruitment (million individuals)
親魚量（トン）	Spawning biomass (tons)

Figure 4-9. Relationship between spawning biomass and recruitment (circle:1982-2019) and predicted value (black curve) and the 90% confidence interval (grey region) by the S-R relationship applied to this stock

The thick lines and thin lines represent the predicted value and the 90% confidence interval, respectively, of the RI model (green) and BH model (red). Parameters of each S-R relationship are based on the values proposed at the "Research Institute Meeting on Reference Points" held in March 2020 (Isu et al. 2020).



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Figure 4-10. Kobe plot

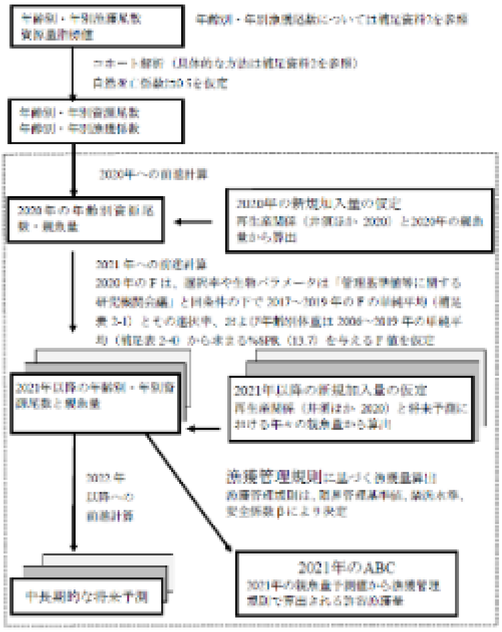
Table 3-1. Catch and cohort analysis results

年	漁獲量（千トン）	資源量（千トン）	親魚量（千トン）	加入量（百万尾）	漁獲割合（%）	再生産成功率（尾/kg）	%SPR
1982	13	34	12	406	43	33.3	12.7
1983	18	41	15	499	47	32.7	9.9
1984	17	44	15	544	42	36.1	12.9
1985	14	46	19	470	36	24.6	18.4
1986	37	79	24	1,107	46	47.0	9.3
1987	37	88	29	1,043	44	36.3	11.2
1988	30	82	35	697	41	20.0	15.9
1989	33	92	38	924	36	24.2	19.2
1990	42	125	49	1,353	39	27.9	15.8
1991	61	153	62	1,699	43	27.4	11.1
1992	62	131	64	1,118	52	17.5	8.6
1993	79	153	39	2,381	46	61.3	8.6
1994	80	159	53	1,669	52	31.3	7.8
1995	70	149	47	1,818	46	38.4	9.7
1996	80	162	54	1,858	50	34.1	8.5
1997	76	143	54	1,459	50	26.8	9.1
1998	40	127	48	1,335	46	27.9	10.5
1999	48	119	46	1,117	39	24.2	16.5
2000	56	125	60	1,100	45	18.4	12.8
2001	68	139	53	1,693	49	31.7	8.2
2002	50	111	49	1,087	45	22.3	12.9
2003	51	108	43	1,065	48	25.1	10.7
2004	54	111	39	1,249	49	31.9	9.0
2005	48	100	37	1,009	48	27.2	10.1
2006	40	89	34	825	45	24.2	11.5
2007	40	80	35	836	49	24.2	9.3
2008	39	74	30	953	53	32.2	7.5
2009	24	56	24	479	42	19.7	13.9
2010	26	61	27	462	42	16.9	15.5
2011	27	65	25	709	42	28.6	13.5
2012	22	68	30	450	33	15.1	23.1
2013	27	69	35	426	40	12.0	15.6
2014	22	53	31	396	42	12.8	18.4
2015	17	44	25	316	39	12.6	19.1
2016	16	49	24	488	33	20.7	20.8
2017	24	49	27	428	49	15.8	10.7
2018	18	44	23	387	42	16.8	15.6
2019	16	38	20	343	43	16.8	14.2

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)
加入量（百万尾）	Recruitment (million individuals)
漁獲割合（%）	Exploitation rate (%)
再生産成功率（尾/kg）	Recruitment per spawning (individuals/kg)

Note: The values are calculated from the value of catch in the Pacific area in the Annual Statistics on Fishery and Aquaculture Production by subtracting the amount of the catch in other fishery area and the catch of mixed fishing that was added as Japanese jack mackerel. The exploitation rate is that indicated in Appendix Table 2-1.

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 を参照	For details of the catch in number at age and by year, see Appendix 2.
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
再生産関係（井須ほか 2020）と 2020 年の親魚量から算出	Calculated from the S-R relationship (Isu et al. 2020) 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」と同条件の下で 2017-2019 年の F の単純平均（補足表 2-1）とその選択率、および年齢別体重は 2006-2019 年の単純平均（補足表 2-4）から求まる%SPR（13.7）を与える F 値を仮定	As for F value in 2020, the selectivity and biological parameter are the simple average of F of 2017-2019 (Appendix Table 2-1) and the selectivity under the same condition as the "Research Institute Meeting on Reference Points," and the body weight at age is assumed from the F value that

	gives %SPR (13.7) obtained from the simple average of 2006-2019 (Appendix Table 2-4).
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
再生産関係（井須ほか 2020）と将来予測における年々の親魚量から算出	Calculated from the S-R relationship (Isu et al. 2020) and spawning biomass for each year in future prediction.
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 prepared based on discussions on the S-R relationship and reference points and HCRs at the Committee of Stock Management Policy. (http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/).

Appendix 2. Calculation method

1) Catch in number at age

The catch in number at age and by year was calculated using the landing at main ports of each prefecture and their composition of body length that the research institute of each prefecture along the Pacific coast surveyed. We divided the Pacific coast into five areas: Kochi Prefecture and westward, Tokushima and Wakayama Prefectures, Mie and Aichi Prefectures, Shizuoka-Tokyo Prefectures, and Chiba Prefecture and northward. We calculated the catch in number by class of body length for every month, using the landing and composition of body length at the main port in each area. Since 2013, we have considered the difference of main fishery by prefecture in and north of Chiba Prefecture, and further divided it into two areas: Chiba-Ibaraki Prefectures, where purse seine is the main fishery; and Fukushima Prefecture and northward, where set net and trawl are the main fishery. The catch in number by the class of body length was converted to the catch in number at age using the method of section based on the relationship between age by month and fork length shown in Appendix Table 2-2. The catch in number at age of the whole group was calculated by extending the ratio of catch in number at main ports at age calculated in the above manner, in order that it equals to the value subtracting the catch in the East China Sea and the Sea of Japan from the total sum of the catch (personal statistics) in the Southern, Middle, and Northern Pacific in the Annual Statistics on Fishery and Aquaculture Production. Here, fish of age 3 and above, for which is difficult to decompose the age by the method of section, were all included together in a plus group.

2) Estimation of biomass

We estimated the number of fish at age, biomass, exploitation coefficient etc. by cohort analysis. Based on the lifecycle of Japanese jack mackerel, the starting point of calculation was January. The biological parameters used are shown in Figures 2-3 and 2-4. The results of analysis were obtained at age of 0 to 3+ (here, the group of age 3 and above is indicated as 3+ (the plus group all together) (Appendix Table 2-1). In calculation of the number of fish at age (N), we used the approximation of Pope (1972), and we used the method in Hiramatsu (1999) to obtain the number of fish of the plus group. The natural mortality was obtained as 0.5 according to Tanai-Tanaka equation (Tanaka 1960) by assuming M = 2.5 / lifetime (here, lifetime is assumed to be 5). For the period of 38 years of 1982-2019, abundance $N_{a,y}$ and exploitation coefficient $F_{a,y}$ in year y were obtained by the catch in number at age and by year ($C_{a,y}$), applying the following equations.

$$N_{a,y} = N_{a+1,y+1} \exp(M) + C_{a,y} \exp(M/2) \quad \text{(a=0,1, y=1982,…,Y-1)} \qquad (1)$$

$$F_{a,y} = -\ln\left(1 - \frac{C_{a,y}\exp(M/2)}{N_{a,y}}\right) \quad \text{(a=0,1,2, y=1982,…,Y-1)} \qquad (2)$$

Here, Y is the most recent year of 2019. Fish of age 3 and above were included in the plus group, and we assumed that the exploitation coefficients of age 2 and 3+ were the same. The number of fish were obtained from the following equations.

$$N_{2,y}=\frac{C_{2,y}}{C_{2,y}+C_{3+,y}}N_{3+,y+1}\exp(M)+C_{2,y}\exp(M/2)\quad (y=1982,\ldots,Y-1)\qquad (3)$$

$$N_{3+,y}=\frac{C_{3+,y}}{C_{2,y}+C_{3+,y}}N_{3+,y+1}\exp(M)+C_{3+,y}\exp(M/2)\quad (y=1982,\ldots,Y-1)\qquad (4)$$

The number of fish in the most recent year is obtained from the following equation.

$$N_{a,Y}=\frac{C_{a,Y}}{1-\exp(-F_{a,Y})}\exp(M/2)\qquad (a=0,\ldots,3+)\qquad (5)$$

The exploitation coefficient in 2019 was estimated by tuning the $F_{3+,Y}$ of the oldest in the most recent years, using indices of each recruitment shown in Appendix Table 2-3. The value of $F_{3+,Y}$, which minimizes the residual between the observed value of the recruitment index $\ln(I_{j,y})$ and the calculated value $\ln(\hat{I}_{j,y})$ in year y, for the jth (j = 1, …,6) index that were logarithmically transformed, were estimated by the least-squares method.

$$\ln(\hat{I}_{j,y})=\ln q_j N_{0,y}\qquad (6)$$

$$RSS=\sum_{j=1}^{6}\sum_{y=2005}^{Y}(\ln(\hat{I}_{j,y})-\ln(I_{j,y}))^2\qquad (7)$$

Where q_j is the catchability coefficient that was calculated as follows.

$$q_j=\exp\left(\frac{1}{n}\left(\sum_{y=2005}^{Y}\ln\frac{I_{j,y}}{N_y}\right)\right)\qquad (8)$$

The exploitation coefficient of age 0 to 2 in 2019 was estimated by the following equation, assuming that the selectivity was equal to the value averaged for the past five years, $s_{a,y}$.

$$F_{a,Y}=\frac{\frac{1}{5}\sum_{y=Y-5}^{Y-1}s_{a,y}}{\frac{1}{5}\sum_{y=Y-5}^{Y-1}s_{3+,y}}F_{3+,Y}\qquad (a=0,\ldots,2)\qquad (9)$$

$$S_{a,y}=F_{a,y}/max(F_y)\qquad (10)$$

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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.

Appendix Table 2-1. Results of biomass analysis

年齢別漁獲尾数（百万尾）

年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	170	211	204	70	420	317	108	140	466	750	375	867
1歳	57	56	68	84	135	200	194	144	210	244	287	233
2歳	7	16	10	16	20	18	35	50	32	31	51	30
3歳以上	1	5	3	5	4	5	6	4	4	10	32	15
計	236	287	285	175	579	541	342	338	712	1,035	746	1,145

年齢別漁獲量（千トン）

年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	7	8	8	3	17	13	4	6	19	30	15	35
1歳	6	6	7	8	13	20	19	14	21	24	29	23
2歳	2	4	2	4	5	4	8	12	7	7	12	7
3歳以上	1	2	1	2	2	2	2	1	2	4	12	6
計	15	19	18	17	37	39	34	33	48	65	68	70

年齢別資源尾数（百万尾）

年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	406	499	544	470	1,107	1,043	697	924	1,353	1,699	1,118	2,381
1歳	120	114	139	172	230	344	386	339	452	458	447	385
2歳	20	28	25	31	38	35	53	83	93	110	88	47
3歳以上	4	8	6	9	8	9	9	6	12	36	56	23
計	550	649	714	681	1,384	1,432	1,144	1,351	1,910	2,303	1,708	2,837

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 歳以上	Age 3 and above
計	Total
年齢別漁獲量（千トン）	Catch amount at age (thousand tons)
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別漁獲係数、%SPR、漁獲割合

年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	0.77	0.78	0.65	0.21	0.67	0.49	0.22	0.22	0.58	0.84	0.56	0.63
1歳	0.95	1.00	1.00	1.00	1.40	1.38	1.04	0.79	0.91	1.15	1.74	1.49
2歳	0.57	1.28	0.75	1.05	1.10	1.11	1.85	1.51	0.58	0.45	1.34	1.73
3歳以上	0.57	1.28	0.75	1.05	1.10	1.11	1.85	1.51	0.58	0.45	1.34	1.73
%SPR	12.71	9.95	12.92	18.42	9.32	11.16	15.89	19.15	15.80	11.13	8.55	8.56
漁獲割合	43%	47%	42%	36%	46%	44%	41%	36%	39%	43%	52%	46%

年齢別漁獲係数、%SPR、漁獲割合	Fishing mortality at age, %SPR, exploitation rate
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
漁獲割合	Exploitation rate

年齢別資源量と親魚量（千トン）および再生産成功率RPS（0歳魚尾数/親魚量，尾/kg）

年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	16.2	20.0	21.8	18.8	44.3	41.7	27.9	37.0	54.1	68.0	44.7	95.2
1歳	12.0	11.4	13.9	17.2	23.0	34.4	38.6	33.9	45.2	45.8	44.7	38.5
2歳	4.5	6.4	5.8	7.1	8.8	7.9	12.1	19.0	21.4	25.4	20.2	10.9
3歳以上	1.7	3.1	2.3	3.4	3.2	3.6	3.3	2.2	4.5	13.6	21.4	8.7
資源量	34.4	40.9	43.8	46.5	79.3	87.7	81.9	92.1	125.2	152.7	131.0	153.4
親魚量	12.2	15.3	15.1	19.1	23.5	28.8	34.8	38.2	48.5	61.9	64.0	38.8
RPS	33.3	32.7	36.1	24.6	47.0	36.3	20.0	24.2	27.9	27.4	17.5	61.3

年齢別資源量と親魚量（千トン）および再生産成功率 RPS（0 歳魚尾数/親魚量, 尾/kg）	Stock biomass at age and spawning biomass (thousand tons) and recruitment per spawning (RPS) (abundance of age 0 fish / spawning biomass, individuals/kg)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
資源量	Stock biomass
親魚量	Spawning biomass

*The average weight at age before 2005 was assumed as 40 g for age 0 fish, 100 g for age 1 fish, 230 g for age 2 fish, 380 g for age 3 and above for each year. For 2006-2009, the average body weight of the catch at age were used (Appendix Table 2-4). As for 1982-2000, the abundance was calculated without correcting the difference between the actual average body weight, so the catch in number and the sum of the catch obtained by multiplying the average body weight mentioned above does not correspond to the catch indicated in Table 3-1.

Appendix Table 2-1 (continued). Results of biomass analysis

年齢別漁獲尾数（百万尾）

年	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0歳	558	556	672	489	320	335	398	847	249	274	387	257
1歳	507	348	403	372	322	264	190	187	200	282	274	293
2歳	35	47	53	56	44	21	71	45	47	43	40	29
3歳以上	5	3	5	5	8	5	11	13	25	6	5	5
計	1,105	955	1,132	921	694	625	671	1,091	520	606	706	584

年齢別漁獲量（千トン）

年	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0歳	22	22	27	20	13	13	16	34	10	11	15	10
1歳	51	35	40	37	32	26	19	19	20	28	27	29
2歳	8	11	12	13	10	5	16	10	11	10	9	7
3歳以上	2	1	2	2	3	2	4	5	9	2	2	2
計	83	69	81	71	58	47	56	68	50	51	54	48

年齢別資源尾数（百万尾）

年	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0歳	1,669	1,818	1,858	1,459	1,335	1,117	1,100	1,693	1,087	1,065	1,249	1,009
1歳	769	578	670	603	504	560	417	357	367	465	433	456
2歳	52	72	80	93	76	55	134	105	71	68	62	49
3歳以上	8	5	7	8	13	14	22	30	37	10	8	8
計	2,498	2,473	2,614	2,163	1,929	1,746	1,673	2,185	1,562	1,608	1,753	1,522

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 歳以上	Age 3 and above
計	Total
年齢別漁獲量（千トン）	Catch amount at age (thousand tons)
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別漁獲係数、%SPR、漁獲割合

年	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0歳	0.56	0.50	0.62	0.56	0.37	0.49	0.63	1.03	0.35	0.40	0.51	0.40
1歳	1.87	1.48	1.48	1.57	1.71	0.93	0.88	1.12	1.19	1.51	1.68	1.75
2歳	1.99	1.88	1.94	1.51	1.35	0.67	1.14	0.79	1.90	1.72	1.68	1.39
3歳以上	1.99	1.88	1.94	1.51	1.35	0.67	1.14	0.79	1.90	1.72	1.68	1.39
%SPR	7.83	9.70	8.54	9.06	10.54	16.48	12.83	8.16	12.86	10.70	8.99	10.06
漁獲割合	52%	46%	50%	50%	46%	39%	45%	49%	45%	48%	49%	48%

年齢別漁獲係数、%SPR、漁獲割合	Fishing mortality at age, %SPR, exploitation rate
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
漁獲割合	Exploitation rate

年齢別資源量と親魚量（千トン）および再生産成功率RPS（0歳魚尾数/親魚量，尾/kg）

年	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0歳	66.8	72.7	74.3	58.4	53.4	44.7	44.0	67.7	43.5	42.6	50.0	40.4
1歳	76.9	57.8	67.0	60.3	50.4	56.0	41.7	35.7	36.7	46.5	43.3	45.6
2歳	12.1	16.5	18.3	21.3	17.6	12.7	30.8	24.1	16.3	15.5	14.4	11.2
3歳以上	2.9	1.9	2.7	2.9	5.1	5.4	8.2	11.4	14.1	3.7	3.2	3.0
資源量	158.6	149.0	162.3	142.9	126.5	118.8	124.7	138.9	110.6	108.4	110.8	100.3
親魚量	53.4	47.3	54.5	54.4	47.9	46.1	59.8	53.4	48.7	42.5	39.2	37.1
RPS	31.3	38.4	34.1	26.8	27.9	24.2	18.4	31.7	22.3	25.1	31.9	27.2

年齢別資源量と親魚量（千トン）および再生産成功率 RPS（0 歳魚尾数/親魚量，尾/kg）	Stock biomass at age and spawning biomass (thousand ton) and RPS (abundance of age 0 fish / spawning biomass, individuals/kg)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
資源量	Stock biomass
親魚量	Spawning biomass

*The average weight at age before 2005 were assumed as 40 g for age 0 fish, 100 g for age 1 fish, 230 g for age 2 fish, 380 g for age 3 and above for each year. For 2006-2009, the average body weight of the catch at age were used (Appendix Table 2-4). As for 1982-2000, the abundance was calculated without correcting the difference between the actual average body weight, so the catch in number and the sum of the catch obtained by multiplying the average body weight mentioned above does not correspond to the catch indicated in Table 3-1.

Appendix Table 2-1 (continued). Results of biomass analysis

年齢別漁獲尾数（百万尾）

年	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0歳	218	313	429	110	109	248	84	164	98	66	123	166
1歳	225	166	151	122	102	95	83	78	50	71	52	92
2歳	32	50	45	24	30	21	23	34	36	19	17	26
3歳以上	6	4	4	5	4	5	7	5	14	7	5	10
計	480	533	629	262	246	368	197	282	198	163	198	295

年齢別漁獲量（千トン）

年	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0歳	9	10	14	5	5	10	5	8	4	2	5	5
1歳	23	18	15	11	13	11	10	9	5	7	5	8
2歳	7	9	9	6	7	5	5	8	8	5	4	6
3歳以上	2	2	2	2	2	2	3	2	5	3	2	4
計	40	40	39	24	26	27	22	27	22	17	16	24

年齢別資源尾数（百万尾）

年	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0歳	825	836	953	479	462	709	450	426	396	316	488	428
1歳	412	331	263	244	205	195	237	208	130	164	141	200
2歳	48	75	72	41	53	44	45	79	65	40	44	45
3歳以上	9	5	7	9	8	10	13	12	25	16	14	18
計	1,293	1,247	1,294	773	727	959	745	724	617	536	687	690

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 歳以上	Age 3 and above
計	Total
年齢別漁獲量（千トン）	Catch amount at age (thousand tons)
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別漁獲係数、%SPR、漁獲割合

年	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0歳	0.41	0.66	0.86	0.35	0.36	0.60	0.27	0.69	0.38	0.31	0.39	0.69
1歳	1.21	1.03	1.35	1.02	1.03	0.97	0.60	0.66	0.67	0.80	0.65	0.90
2歳	1.85	1.96	1.63	1.40	1.30	0.93	1.05	0.80	1.23	0.92	0.70	1.39
3歳以上	1.85	1.96	1.63	1.40	1.30	0.93	1.05	0.80	1.23	0.92	0.70	1.39
%SPR	11.52	9.27	7.47	13.88	15.52	13.49	23.07	15.64	18.42	19.12	20.76	10.74
漁獲割合	45%	49%	53%	42%	42%	42%	33%	40%	42%	39%	33%	49%

年齢別漁獲係数、%SPR、漁獲割合	Fishing mortality at age, %SPR, exploitation rate
年	Year
0 歳	Age 0

1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
漁獲割合	Exploitation rate

年齢別資源量と親魚量（千トン）および再生産成功率RPS（0歳魚尾数/親魚量，尾/kg）

年	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
0歳	34.1	27.7	31.0	20.6	21.3	28.7	24.3	20.7	15.4	10.6	18.3	13.1
1歳	41.5	36.2	26.3	22.1	25.5	22.4	28.6	25.1	12.8	17.0	14.2	18.4
2歳	9.9	14.0	14.0	9.5	11.6	9.7	10.4	17.8	15.3	10.0	10.5	10.7
3歳以上	3.4	2.4	2.4	3.8	3.0	3.9	5.1	5.0	9.3	6.7	6.0	7.2
資源量	88.9	80.4	73.8	55.9	61.4	64.7	68.4	68.7	52.8	44.3	49.0	49.4
親魚量	34.1	34.5	29.6	24.3	27.3	24.8	29.8	35.4	31.0	25.2	23.6	27.1
RPS	24.2	24.2	32.2	19.7	16.9	28.6	15.1	12.0	12.8	12.6	20.7	15.8

年齢別資源量と親魚量（千トン）および再生産成功率 RPS（0 歳魚尾数/親魚量，尾/kg）	Stock biomass at age and spawning biomass (thousand ton) and RPS (abundance of age 0 fish / spawning biomass, individuals/kg)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
資源量	Stock biomass
親魚量	Spawning biomass

*The average weight at age before 2005 were assumed as 40 g for age 0 fish, 100 g for age 1 fish, 230 g for age 2 fish, 380 g for age 3 and above for each year. For 2006-2009, the average body weight of the catch at age were used (Appendix Table 2-4). As for 1982-2000, the abundance was calculated without correcting the difference between the actual average body weight, so the catch in number and the sum of the catch obtained by multiplying the average body weight mentioned above does not correspond to the catch indicated in Table 3-1.

Appendix Table 2-1 (continued). Results of biomass analysis

年齢別漁獲尾数（百万尾）

年	2018	2019
0歳	117	102
1歳	55	63
2歳	26	19
3歳以上	5	6
計	203	190

年齢別漁獲量（千トン）

年	2018	2019
0歳	4	3
1歳	6	5
2歳	6	5
3歳以上	2	3
計	18	16

年齢別資源尾数（百万尾）

年	2018	2019
0歳	387	343
1歳	130	143
2歳	50	36
3歳以上	9	12
計	575	534

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 歳以上	Age 3 and above
計	Total
年齢別漁獲量（千トン）	Catch amount at age (thousand tons)
年齢別資源尾数（百万尾）	Number of fish at age (million individuals)

年齢別漁獲係数、%SPR、漁獲割合

年	2018	2019
0歳	0.49	0.48
1歳	0.78	0.83
2歳	1.10	1.12
3歳以上	1.10	1.12
%SPR	15.64	14.23
漁獲割合	42%	43%

年齢別漁獲係数、%SPR、漁獲割合	Fishing mortality at age, %SPR, exploitation rate
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
漁獲割合	Exploitation rate

年齢別資源量と親魚量（千トン）および再生産成功率RPS（0歳魚尾数/親魚量，尾/kg）

年	2018	2019
0歳	13.8	11.3
1歳	14.0	12.4
2歳	12.1	9.0
3歳以上	3.9	5.1
資源量	43.8	37.8
親魚量	23.1	20.3
RPS	16.8	16.8

年齢別資源量と親魚量（千トン）および再生産成功率 RPS（0 歳魚尾数/親魚量，尾/kg）	Stock biomass at age and spawning biomass (thousand ton) and RPS (abundance of age 0 fish / spawning biomass, individuals/kg)
年	Year
0 歳	Age 0
1 歳	Age 1
2 歳	Age 2
3 歳以上	Age 3 and above
資源量	Stock biomass
親魚量	Spawning biomass

*The average weight at age before 2005 were assumed as 40 g for age 0 fish, 100 g for age 1 fish, 230 g for age 2 fish, 380 g for age 3 and above for each year. For 2006-2009, the average body weight of the catch at age were used (Appendix Table 2-4). As for 1982-2000, the abundance was calculated without correcting the difference between the actual average body weight, so the catch in number and the sum of the catch obtained by multiplying the average body weight mentioned above does not correspond to the catch indicated in Table 3-1.

Appendix Table 2-2. Relationship between age and fork length (body length)

体長階級 (cm)	1月	2月	3月	4月	5月	6月	7月	8月	9月	10月	11月	12月
13以下	1	1	0	0	0	0	0	0	0	0	0	0
14	1	1	1	1	0	0	0	0	0	0	0	0
15	1	1	1	1	1	0	0	0	0	0	0	0
16	1	1	1	1	1	1	0	0	0	0	0	0
17	1	1	1	1	1	1	1	0	0	0	0	0
18	1	1	1	1	1	1	1	1	0	0	0	0
19	1	1	1	1	1	1	1	1	1	0	0	0
20	2	1	1	1	1	1	1	1	1	1	1	1
21	2	2	1	1	1	1	1	1	1	1	1	1
22	2	2	2	1	1	1	1	1	1	1	1	1
23	2	2	2	2	2	2	1	1	1	1	1	1
24	2	2	2	2	2	2	2	1	1	1	1	1
25	2	2	2	2	2	2	2	2	2	1	1	1
26	2	2	2	2	2	2	2	2	2	2	2	2
27	3	3	2	2	2	2	2	2	2	2	2	2
28	3	3	3	2	2	2	2	2	2	2	2	2
29	3	3	3	3	3	2	2	2	2	2	2	2
30	3	3	3	3	3	3	3	3	3	3	3	2
31以上	3	3	3	3	3	3	3	3	3	3	3	3

体長階級(cm)	Class of body length (cm)
1 月	January
2 月	February

3 月	March
4 月	April
5 月	May
6 月	June
7 月	July
8 月	August
9 月	September
10 月	October
11 月	November
12 月	December
13 以下	13 and below
31 以上	31 and above

Appendix Table 2-3. Parameters used for calculation of recruitment index

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
①宮崎県南部定置アジ仔CPUE	9.8	7.0	45.2	40.9	15.0	10.1	18.3	17.2	9.2	7.8
②宇和島港まき網ゼンゴ漁獲量	0.3	0.3	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
③宿毛湾ゼンゴ資源量指数	0.4	0.5	0.4	0.2	0.2	0.1	0.1	0.3	0.2	0.1
④串本棒受網当歳魚漁獲量	8.4	7.0	25.7	5.2	6.6	5.4	4.3	6.0	2.7	3.6
⑤伊勢湾まめ板漁業当歳魚漁獲量	39.5	27.9	22.2	21.5	14.4	20.4	26.1	15.0	12.1	12.8
⑥千葉県定置網0歳魚漁獲量	251.9	151.3	124.8	87.7	405.2	94.8	140.7	81.9	211.3	68.4

	2016	2017	2018	2019
①宮崎県南部定置アジ仔CPUE	16.5	14.7	21.7	13.5
②宇和島港まき網ゼンゴ漁獲量	0.1	0.1	0.1	0.1
③宿毛湾ゼンゴ資源量指数	0.2	0.2	0.2	0.1
④串本棒受網当歳魚漁獲量	1.4	2.8	1.1	2.4
⑤伊勢湾まめ板漁業当歳魚漁獲量	16.5	13.6	17.1	14.0
⑥千葉県定置網0歳魚漁獲量	101.4	63.8	89.5	128.8

①宮崎県南部定置アジ仔 CPUE	(i) CPUE for Japanese jack mackerel of juveniles in set net fishery in the south of Miyazaki Prefecture
②宇和島港まき網ゼンゴ漁獲量	(ii) Catch of Japanese horse mackerel in purse seine fishery in Uwajima port
③宿毛湾ゼンゴ資源量指数	(iii) Biomass index of Japanese horse mackerel in Sukumo Bay
④串本棒受網当歳魚漁獲量	(iv) Catch of age 1 in stick-held dip net fishery in Kushimoto
⑤伊勢湾まめ板漁業当歳魚漁獲量	(v) Catch of age 0 in small scale trawl net fishery in Ise Bay
⑥千葉県定置網 0 歳魚漁獲量	(vi) Catch of age 0 in set net fishery in Chiba Prefecture

Appendix Table 2-4. Average body weight of catch at age (g)

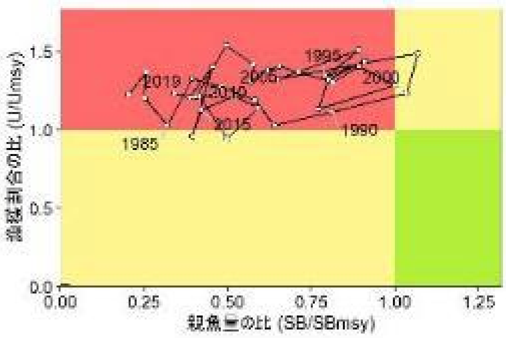
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	06～19平均*
0歳	41.4	33.2	32.6	43.0	46.2	40.5	54.1	48.7	38.7	33.6	37.5	30.6	35.6	32.9	39.2
1歳	100.8	109.4	100.3	90.5	124.4	114.7	120.5	121.1	98.4	103.6	100.9	91.7	108.0	86.6	105.1
2歳	205.2	187.5	195.5	228.3	217.6	219.0	232.6	226.4	235.0	247.6	237.1	241.4	244.7	248.9	226.2
3+歳	398.1	443.7	355.1	402.9	400.0	388.1	393.6	406.1	376.2	420.8	439.7	411.4	416.8	429.2	405.8

0 歳	Age 0
2 歳	Age 2
3+歳	Age 3 and above
06～19 平均	Average of 2006-2019

Appendix 3. 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 for 1991 and 1992, and the exploitation rate has been higher than the level that produces MSY, except for 2012 and 2016. The exploitation rate in 2019 is 42.9%, while the exploitation rate that produces MSY (Umsy) is 34.7%.

Item	Value	Explanation
SBmsy	60 thousand tons	Spawning biomass that produces MSY
Umsy	34.7%	Exploitation rate that produces MSY
U2019	42.9%	Exploitation rate in 2019
U2019/Umsy	1.24	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 3-1. 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)

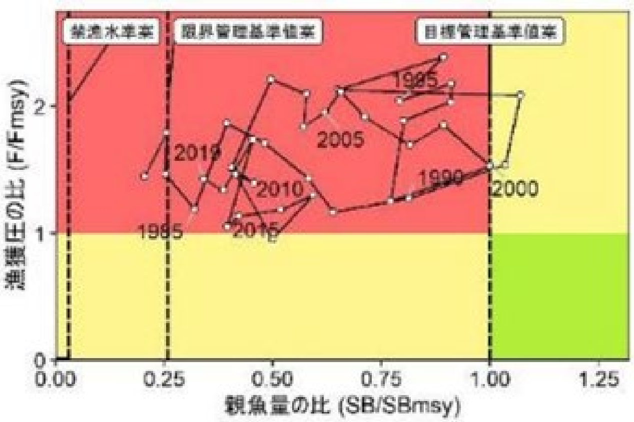
Appendix 4. Proposed reference points and fishing ban level, etc.

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

Item	Value	Explanation
Proposed SBtarget	60 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	15 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	1.7 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

It was proposed at the "Research Institute Meeting on Reference Points" held in March 2020 that the spawning biomass that produces MSY (SBmsy: 60 thousand tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 15 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 1.7 thousand tons) be used for the fishing ban level (SBban).

Appendix Figure 4-1 shows a Kobe plot based on the proposed SBtarget and fishing mortality that produces MSY (Fmsy). Although the spawning biomass in 2019 (SB2019: 20 thousand ton) obtained by cohort analysis was below the proposed target reference point, it was higher than the proposed limit reference point and fishing ban level. The fishing mortality is determined to have been above Fmsy, except for 2012.



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 4-1. Relationship between the proposed reference points / fishing ban level and spawning biomass / fishing mortality (Kobe plot)

Appendix 5. 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 6). 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 (13.7) 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), etc. corresponding to spawning biomass, taking into consideration the probability of maintaining/recovering spawning biomass to a level above the proposed target reference point (SBtarget). The "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)" provide that, 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, and if it is above SBlimit, the value obtained by multiplying Fmsy by safety coefficient β should be the upper limit of fishing mortality. Appendix Figure 5-1 shows the HCRs proposed at the "Research Institute Meeting on Reference Points" for the present stock. Here, we present a case where safety coefficient β is 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 at a probability of 50% or more."

(3) Projected values for 2021

The average catch in 2021 estimated based on the HCRs was 11 thousand tons where β was 0.8, and 13 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 18 thousand tons on average, and the estimation was above SBlimit in all iterations (Appendix Tables 5-1 and 5-2).

Spawning biomass in 2021 (average projection value): 18 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2017-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β = 0.8	11	0.55	28

Other strategy (when using different β in the proposed HCRs)			
β = 1.0	13	0.69	33
β = 0.9	12	0.62	30
β = 0	0	0	0
F2017-2019	17	1.00	42

(4) Projection for 2022 onward

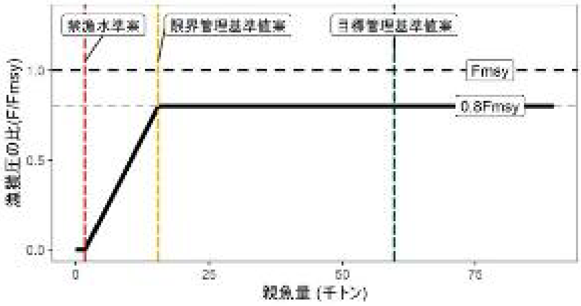
Appendix Figure 5-2 and Appendix Tables 5-1 and 5-2 show the future projection results including 2022 onward. If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in 2031 is 71 thousand tons where β is 0.8 (the 80% confidence interval is 38 thousand to 110 thousand tons), and 57 thousand tons where β is 1.0 (the 80% confidence interval is 29 thousand to 88 thousand tons). If β is 0.8 or less, the probability that the predicted spawning biomass would exceed the proposed target reference point is above 50%. The probability that it would exceed the limit reference point is as high as 99%, even when β is 1.0. If the current fishing mortality (F2017-2019) is continued, the projected spawning biomass in 2031 is 34 thousand tons (the 80% confidence interval is 12 thousand to 58 thousand tons), and the probability of the projected spawning biomass being above the proposed target reference point and limit reference point is 9% and 84%, respectively.

考慮している不確実性：加入量					
項目	2031 年の親魚量（千トン）	80%信頼区間（千トン）	2031 年に親魚量が以下の管理基準値を上回る確率(%)		
			SBtarget 案	SBlimit 案	SBban 案
漁獲管理規則案にて研究機関会議が提案した β を使用した場合					
β=0.8	71	38 – 110	58	100	100
その他の方策（漁獲管理規則案にて異なる β を使用した場合）					
β=1.0	57	29 – 88	38	99	100
β=0.9	64	33 – 98	48	100	100
β=0	197	89 – 430	100	100	100
F2017-2019	34	12 – 58	9	84	100

考慮している不確実性：加入量	Uncertainty considered: recruitment
項目	Item
2031 年の親魚量（千トン）	Spawning biomass in 2031 (thousand tons)]
80%信頼区間（千トン）	80% confidence interval (thousand tons)
2031 年に親魚量が以下の 管理基準値を上回る確率（%）	Probability of the spawning biomass in 2031 being above the reference points below (%)
SBtarget 案	Proposed target reference point
SBlimit 案	Proposed limit reference point
SBban 案	Proposed fishing ban level
漁獲管理規則案にて研究機関会議が提案した β を使用した場合	When using β proposed by the Research Institute Meeting in the proposed HCRs

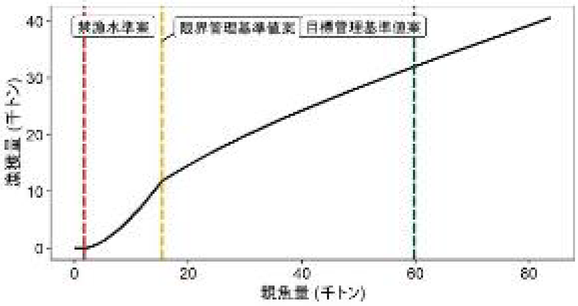
その他の方策（漁獲管理規則案にて異なるβを使用した場合）	Other strategy (when using different β in the proposed HCRs)

a) When the vertical axis is fishing mortality



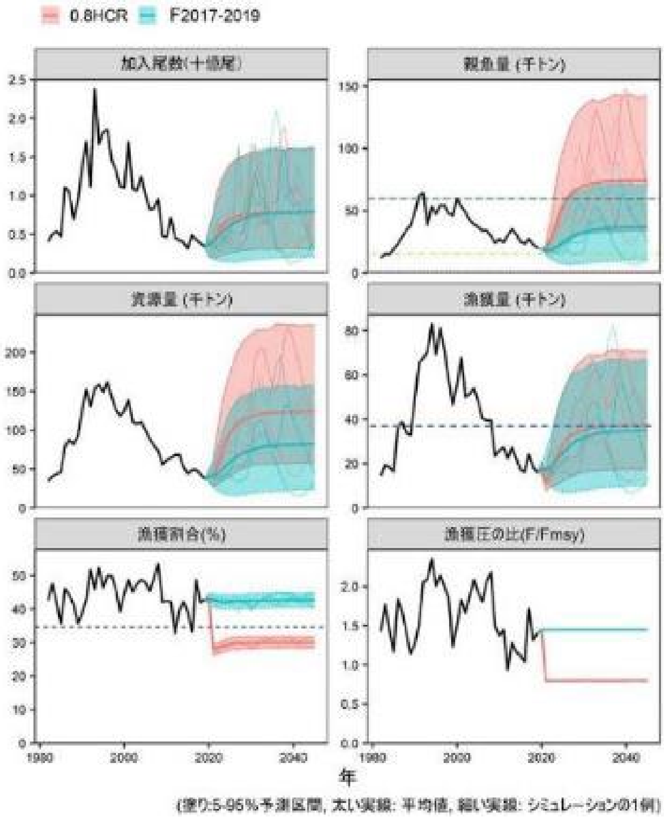
漁獲圧の比	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

b) When the vertical axis is catch



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 5-1. Proposed HCRs for Japanese jack mackerel Pacific stock (when β is 0.8)



加入尾数（十億尾）	Recruitment (billion individuals)
親魚量（千トン）	Spawning biomass (thousand tons)
資源量（千トン）	Stock biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲割合	Exploitation rate (%)
漁獲圧の比	Ratio of the fishing mortality to MSY
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 slid line: simulation example)

Appendix Figure 5-2. Future projection using 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 prediction interval that covers 90% of the simulation results, the thin lines indicate 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 catch, the broken line indicates MSY. In the figure of exploitation rate, the broken line indicates Umsy. Safety coefficient β in the proposed HCRs is 0.8.

Appendix Table 5-1. Probability for future spawning biomass to exceed the proposed target reference point and limit reference point

a) Probability for future spawning biomass to exceed the proposed target reference point (%)

beta	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	0	0	0	2	10	18	24	29	31	34	36	38	42	43
0.9	0	0	0	4	15	26	33	37	41	44	46	48	52	53
0.8	0	0	0	6	22	35	43	48	51	53	56	58	61	62
0.7	0	0	0	10	30	46	54	58	61	64	66	67	71	71
0.6	0	0	0	15	40	57	66	68	71	73	75	76	79	80
0.5	0	0	1	21	52	69	76	78	79	81	83	84	86	86
0.4	0	0	1	29	64	79	85	86	87	88	89	90	91	91
0.3	0	0	1	39	75	88	91	92	92	93	94	95	95	95
0.2	0	0	2	51	84	94	96	96	96	97	97	98	98	98
0.1	0	0	3	62	91	97	99	99	98	99	99	99	99	99
0	0	0	5	73	96	99	99	100	100	100	100	100	100	100

b) Probability for future spawning biomass to exceed the proposed limit reference point (%)

beta	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	100	92	93	95	96	97	98	98	98	99	99	99	99	99
0.9	100	92	96	97	98	98	99	99	99	99	100	100	100	100
0.8	100	92	98	99	99	99	99	99	100	100	100	100	100	100
0.7	100	92	99	100	100	100	100	100	100	100	100	100	100	100
0.6	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	92	100	100	100	100	100	100	100	100	100	100	100	100
0	100	92	100	100	100	100	100	100	100	100	100	100	100	100

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

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

beta	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	19	18	23	30	37	43	47	51	53	55	56	57	60	60
0.9	19	18	24	33	41	48	53	57	59	61	63	64	67	67
0.8	19	18	26	36	46	55	60	64	66	68	70	71	74	74
0.7	19	18	27	40	52	61	67	71	74	76	78	79	83	83
0.6	19	18	29	44	58	69	76	80	83	85	87	88	92	92
0.5	19	18	31	48	65	78	85	89	93	96	98	99	103	104
0.4	19	18	32	53	73	88	95	100	104	108	111	112	116	117
0.3	19	18	34	58	83	99	108	112	116	122	125	127	132	132
0.2	19	18	36	64	93	113	122	126	131	138	143	145	151	151
0.1	19	18	38	70	105	128	138	143	149	157	165	168	175	175
0	19	18	41	77	119	147	159	164	171	181	191	197	206	206

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

beta	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	17	13	17	22	26	29	31	33	34	35	36	36	38	38
0.9	17	12	17	21	26	29	31	33	34	35	36	36	38	38
0.8	17	11	16	21	25	29	31	33	34	35	35	36	37	37
0.7	17	10	15	20	25	28	30	32	33	34	34	35	36	36
0.6	17	9	14	19	24	27	29	31	32	32	33	34	35	35
0.5	17	8	12	18	22	25	27	29	30	30	31	31	33	33
0.4	17	6	11	15	20	23	25	26	27	28	28	28	30	30
0.3	17	5	9	13	17	20	21	22	23	24	24	24	25	25
0.2	17	3	6	10	13	15	16	17	17	18	19	19	20	20
0.1	17	2	3	5	7	9	9	10	10	10	11	11	11	11
0	17	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 6. Method of future projection

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 2.1.0) for statistics software R (version 3.6.1) based on ABCWG (2020). The recruitment in the future prediction was obtained from the weighted average model (Isu et al. 2020, Ichinokawa et al. 2020) of the RI and BH S-R relationships (ABCWG2020) that were proposed at the "Research Institute Meeting on Reference Points" held in March 2020 and the estimated spawning biomass for each year.

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)." As for the selectivity and average body weight of the catch, etc., we again used the values used for estimating the reference points proposed at the abovementioned "Committee of Stock Management Policy" held in 2020 (Isu et al. 2020). These values are based on the 2019 stock assessment, similar to the S-R relationship, and the average body weight of catch are the average values of the calculation results for 2006-2018.

For projection of the number of fish, we used forward calculation of cohort analysis (equations (11) to (13)).

$$N_{a+1,y+1} = N_{a,y}\exp(-F_{a,y} - M) \quad (11)$$

$$N_{3+,y+1} = N_{3+,y}\exp(-F_{3+,y} - M) + N_{2,y}\exp(-F_{2,y} - M) \quad (12)$$

$$C_{a,y} = N_{a,y}\{1 - exp(-F_{a,y})\}exp\left(-\frac{M}{2}\right) \quad (13)$$

	選択率 (注 1)	Fmsy (注 2)	F2017-2019 (注 3)	平均体重 (g)	自然死亡係数	成熟割合
0 歳	0.52	0.40	0.58	40	0.5	0
1 歳	0.75	0.58	0.83	106	0.5	0.5
2 歳	1.00	0.77	1.11	224	0.5	1.0
3 歳以上	1.00	0.77	1.11	404	0.5	1.0

選択率（注 1）	Selectivity (Note 1)
Fmsy（注 2）	Fmsy (Note 2)
F2017-2019（注 3）	F2017-2019 (Note 3)
平均体重	Average body weight
自然死亡係数	Natural mortality
成熟割合	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 (i.e., selectivity of Fcurrent in the 2019 stock assessment).

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

Noe 3: F value under the selectivity above that gives the same fishing mortality as the average F at age for 2015 to 2019 estimated in the present stock assessment, which has been converted into %SPR. This F value was used for assuming the catch in 2020 (Appendix 1)

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