

Stock Assessment of Japanese Sardine Pacific Stock in 2020

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Summary

The stock biomass was estimated by a cohort model using the abundance index as the tuning index. Although the biomass remained high at over 10 million tons in the 1980s, it sharply declined on entering the 1990s, and stayed low at around 100 thousand tons from 2002 to 2009. Then, from 2010 to 2014, the biomass turned to an increase due to continuous, relatively favorable recruitment and a decline in fishing mortality, exceeding 1 million tons in 2014. The biomass further increased after that as favorable recruitment continued, and was estimated to be 3.415 million tons in 2019. The spawning biomass remained below 100 thousand tons from 2002 onward, but increased from 2011, reaching an estimate of 1.585 million tons in 2019.

At the "Research Institute Meeting on Reference Points" held in March 2020, it was proposed that the hockey stick model for the normal recruitment period (1988 to 2018) be used for estimating the current stock-recruitment relationship of the present stock. SB_{msy}, which is the level of spawning biomass that produces the maximum sustainable yield (MSY), estimated based on this model is 1.187 million tons. According to this basis, the spawning biomass of the present stock for 2019 exceeds the level that produces MSY. In addition, the fishing mortality of the stock in 2019 is approximately the same as the level of fishing mortality 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 to 2019).

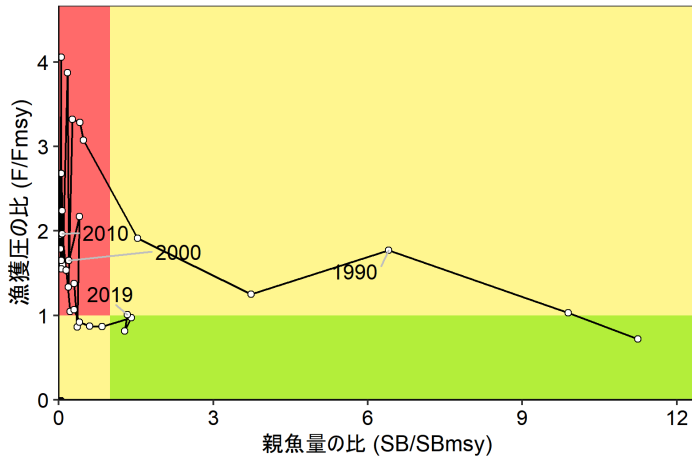
(With regard to the items that are to be finalized based on discussions at the Study Meeting on Stock Management Policy, such as reference points and future projections, we tentatively indicated the values proposed at the "Research Institute Meeting on Reference Points.")

Item	Value	Explanation
Level that produces MSY under the current environment		
SBmsy	1.187 million tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3, 4, 5 and above) = (0.18, 0.18, 0.24, 0.50, 0.50, 0.50)	
%SPR (Fmsy)	40.0%	%SPR corresponding to Fmsy
MSY	389 thousand tons	Maximum sustainable yield
Spawning biomass and fishing mortality in 2019		
SB2019	1.585 million tons	Spawning biomass in 2019
F2019	Fishing mortality in 2019 (ages 0, 1, 2, 3, 4, 5 and above) = (0.05, 0.12, 0.81, 0.32, 0.20, 0.20)	
%SPR (F2019)	39.8%	%SPR in 2019
%SPR (F2015-2019)	41.8%	%SPR corresponding to the current fishing mortality (2015 to 2019)
Ratio to MSY		
SB2019/SBmsy	1.33	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.01	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.

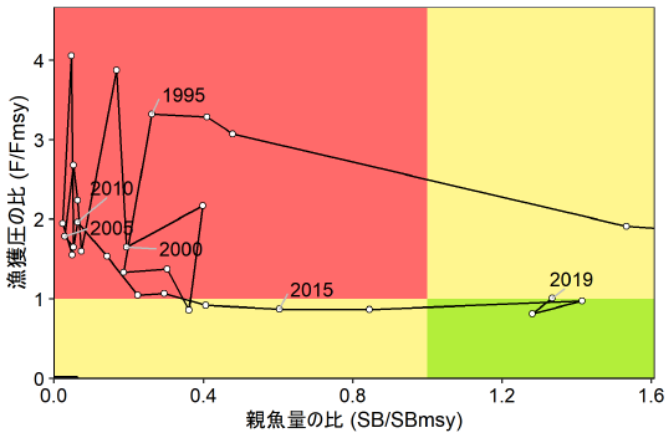
Stock-recruitment relationship: hockey stick model for the normal recruitment period (1988 to 2018) (no autocorrelation)

Level of spawning biomass	Above SBmsy
Level of fishing mortality	Approx. the same as Fmsy
Trend in spawning biomass	Increasing



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Enlarged view



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

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	2,100	1,003	316	0.87	15.0
2017	2,647	1,680	446	0.97	16.8
2018	3,137	1,521	452	0.82	14.4
2019	3,415	1,585	521	1.01	15.3
2020	4,103	2,876	742	0.94	18.1
2021	3,617	2,882	—	—	—

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 based on future projections (see Appendix 6).

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 (Hokkaido-Kagoshima [20] prefectures) Length composition survey (National Research Institute of Fisheries Science [NRIFS], Hokkaido-Kagoshima [20] prefectures, Japan Fisheries Information Service Center [JAFIC]): market measurement Length-weight survey; length-age measurement survey (NRIFS, Hokkaido-Kagoshima [20] prefectures, JAFIC): market measurement, catch for research
Abundance index	
• Spawning volume	Egg and larvae survey (year-round, NRIFS, relevant prefectures): NORPAC net*
• Distribution in offshore areas	Transitional area larva/juvenile survey (May/June, NRIFS): midwater trawl, quantitative echo sounder Pelagic fish survey in Northwestern Pacific in the northward migration period (May-July, NRIFS): midwater trawl, quantitative echo sounder Pelagic fish survey in Northwestern Pacific in fall (September/October, NRIFS): midwater trawl, quantitative echo sounder*
• Index for wintering juveniles	Conditions of large- and medium-scale purse seine fisheries in the Boso-Joban sea area (Chiba Prefectural Fisheries Experimental Station, Ibaraki Prefectural Fisheries Experimental Station)*
• Abundance index	Northern Pacific purse seine catch per unit of effort (CPUE) / abundance index based on fishing ground distribution (JAFIC)
Natural mortality (M)	Assuming $M = 0.4$ per year (Tanaka 1960)
Fishing effort	Northern Pacific purse seine efforts (JAFIC, fisheries status survey by fishing ground)

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

2. Ecology of the stock

(1) Distribution and migration

The Japanese sardine Pacific stock is distributed widely from Japan's coast to offshore areas in the Northwestern Pacific (Figure 2-1). The distribution and migration of larvae and juveniles are largely divided into two patterns depending on how they are transported by ocean currents in the early stage of growth. After hatching around the Kuroshio Current, some larvae are taken into the current flowing toward coastal areas, grow in Japan's coastal waters, and become fishery targets in their whitebait (shirasu) to juvenile stage in coastal fishing grounds (hereafter, the "coastal recruitment group"), while some larvae are transported eastward by the Kuroshio Current, grow in the Kuroshio-Oyashio transition area from waters near Japan to 165 to 170 degrees east longitude, spend the summer feeding period in the subarctic waters off eastern Hokkaido to off the east of the Kuril Islands, and move south in fall to winter to be recruited to the fishing grounds (hereafter, the "offshore recruited group") (Kawabata et al. 2011). The distribution range of the offshore recruited group depends on transportation by ocean currents, so it does not reflect the amount of recruitment, and the group is distributed in a wide area even with low recruitment. Whether larvae become a coastal recruitment group or an offshore recruitment group is considered to be decided by chance according to the oceanic conditions around the spawning grounds. The two groups have differences in their hatch date distribution. In the coastal recruitment group, individuals of various hatch dates appear, reflecting the long spawning period (Ochiai 2009, Hasegawa and Higoshi 2011), but in the offshore recruitment group, individuals hatching from March to May (mainly in April) appear, with their larval period coinciding with the spring blooming season (Ochiai 2009, Takagi et al. 2010, Sahara 2014). However, individuals hatching in or before early March have increased in the offshore recruitment group in recent years, which have seen an increase in the stock biomass, particularly since 2013. The relationship between early-hatching individuals and growth in biomass and recruitment has drawn attention and has been studied (report of the 2018 high-accuracy biomass estimation project). The coastal recruitment group and the offshore recruited group are not independent groups, but their recruitment trends do not necessarily coincide due to differences in their main occurrence periods and growing grounds.

The fish of ages 1 and above winter around the Kuroshio Current and spawn. Then, in summer to fall, some stay in coastal areas around the Kuroshio Current and migrate in a small area for feeding, while some migrate northward for feeding. The range of northward migration for feeding changes substantially based on the abundance level. During the high abundance period in the 1980s, they migrated over an extensive subarctic area from the waters off Sanriku to eastern Hokkaido to waters off the east of the Kuril Islands from near the Emperor Seamount Chain to the area reaching the western hemisphere (Ito 1991, Kuroda 1991). In the 1990s, when the abundance decreased to below 1 million tons, the migration range was reduced to the area from northern Sanriku to the Oyashio Current region off eastern Hokkaido. In the 2000s, when

the abundance further fell below 500 thousand tons, the range shrank to the area around the Kuroshio Extension in the Joban sea area to near the southern edge of the Oyashio Current in southern Sanriku. Recently, the abundance increased due to the high recruitment in 2010, and migration to the waters off northern Sanriku to eastern Hokkaido has been observed since 2011. In addition, expansion of the distribution to offshore areas has been observed in recent years. In the pelagic fish survey in the Northwestern Pacific in the northward migration period conducted in June to July, Japanese sardines of age 1 and above have been confirmed in waters reaching around 170 degrees east longitude since 2018.

(2) Age and growth

The life span of Japanese sardines is about 7 years, and their maximum body length (scaled body length) is about 22 to 24 cm. The relationship between the age and body length changes substantially based on abundance, while it is also affected by the sea area. Among the population migrating in the Oyashio Current region for feeding, the growth speed of those aged 1 and above declined during the high abundance period in the 1980s, with the body length becoming 14-15 cm at age 1 (at full age), 15-16 cm at age 2, 17-18 cm at age 3, 18-19 cm at age 4, 19-20 cm at age 5, and 20 cm or more at age 6, but during the low/medium abundance period in the 2000s, the body length was 15-16 cm at age 1, 18-19 cm at age 2, and 20 cm or more at age 3 and above. Figure 2-2 shows the average body length and body weight at age for the latest three years (2017-2019). The average body weight at age has tended to be smaller in recent years (Appendix Table 2-1), and there is a possibility that the increase in the stock biomass has caused poor growth. It is necessary to keep watch on the relationship between the stock biomass and growth.

(3) Maturity and spawning

Figure 2-3 shows the relationship between age and maturity rate. Although the growth speed declined and maturity delayed in the high abundance period, in recent years, maturity starts at age 1, and most individuals become mature at age 2. In this assessment, we assumed the maturity rate at age for 1998 to 2015 to be 50% for age 1 and 100% for ages 2 and above. Considering the recent increase in the stock biomass, we assumed the maturity rate for age 1 fish for 2016 onward to be 20%, which is equal to the rate for 1994 to 1997, when the spawning biomass temporarily recovered after the regime shift.

The status of appearance and distribution of eggs suggest that the spawning season is from November to the following June, and the main spawning season is February to April (Figure 2-1). The spawning grounds have changed according to the stock status. In the 1950s to 1960s, when the abundance was low, the spawning grounds were formed in waters on the onshore side of the Kuroshio Current from Hyuga Nada to areas near Kanto (Kuroda 1991). In the first half of the 1970s, when the biomass started to increase, spawning increased in the Tosa Bay and its surroundings and areas near Kanto. From 1976, spawning grounds were also formed in the Satsunan sea area, and during the high abundance period from 1980 until around 1990, large-

scale spawning grounds were formed in the Kuroshio Current region from the Satsunan sea area to off Kii Peninsula. In line with the decrease in stock in the 1990s, the spawning grounds in the Satsunan sea area disappeared, and thereafter, spawning grounds have been formed in waters on the onshore side of the Kuroshio Current from off Shikoku to areas near Kanto.

(4) Prey-predator relationships

Larvae and juveniles feed on small zooplankton, and then come to feed on larger zooplankton as they grow. Adults have developed gill rakers and feed on not only zooplankton, but also diatoms by filtering them. They are eaten by medium- and large-sized fish, cephalopods, marine mammals, and seabirds. Large amounts of Japanese sardines were found in the stomach contents of baleen whales in the 1980s high abundance period, suggesting that they were the whales' main prey items (Kasamatsu and Tanaka 1992). The presence of Japanese sardines in the stomach contents decreased along with the decline in abundance from the 1990s onward (Tamura and Fujise 2002). From 2012 onward, however, mackerels and Japanese sardines increased while anchovy decreased in the stomach contents. In particular, Japanese sardines became the main prey items for sei whales from 2014 to 2016 (Konishi et al. 2017). The abundance of Japanese sardines is considered to have increased to such an extent that they have become prey items for baleen whales.

(5) Special notes

The biomass of the present stock is known to change dramatically in synchronization with the interdecadal global shift in the structure of systems including the atmospheric system and marine ecosystems (regime shift) (Kawasaki 1992, Klyashtorin 1998, Chavez et al. 2003). The biomass increased synchronously with the 1976/77 regime shift (Yasunaka and Hanawa 2002), and then remained high at over 10 million tons in the 1980s. After that, the recruitment per spawning successively declined from 1988 to 1991 in synchronization with the 1988/89 regime shift (Watanabe et al. 1995), resulting in a sharp decline in recruitment and biomass. The changes in the ocean environment and other elements are likely to have affected the environmental carrying capacity and recruitment success (Tanaka 2003, Yatsu et al. 2005), and have also changed the stock-recruitment relationship.

2. Status of fisheries

(1) Outline of fisheries

The major types of fisheries for Japanese sardines are large- to medium-scale purse seine fishery, medium-scale purse seine fishery, and set net fishery targeting juveniles and adults. Their whitebait (shirasu) are also caught by boat seine fishery, etc. About 70% to 90% of the total catch in recent years have been caught in areas east of Mie Prefecture (Northern and Middle Pacific). The catch in areas west of Wakayama Prefecture (Southern Pacific and Seto Inland Sea) is relatively small compared to areas east of Mie Prefecture, and although it showed an increase in 2015, it subsequently turned to a decline (Figure 3-1, Table 3-1). The catch by

large- to medium-scale purse seine fishery in areas north of Boso (northern purse seine fishery) accounts for most of the total catch regardless of the stock abundance. In the 1980s high abundance period, large-scale fishing grounds were formed in the waters from Joban to Sanriku as well as in the eastern Hokkaido region from summer to fall, and more than 2 million tons were caught. On entering the 1990s, the range of migration for feeding shrank in line with a decrease in stock, and the eastern Hokkaido fishing ground was no longer formed in and after 1994. As the stock further decreased in the 2000s due to high fishing mortality, fishing grounds also became scarce in the northern Sanriku region, and the catch mainly targeting age 0 and age 1 fish in the Boso-Joban sea area became predominant. In recent years, the range of migration for feeding has expanded due to an increase in stock. From 2012 onward, fishing grounds have been formed in the eastern Hokkaido region, and the catch in that region increased from 6 thousand tons in 2012 to 218 thousand tons in 2019.

(2) Changes in catch volume

For the catch volume in this assessment, we used the value obtained by totaling the catch data in the Annual Statistics on Fishery and Aquaculture Production for the area from the Pacific side of Hokkaido to Miyazaki Prefecture and the Seto Inland Sea area, adding to it the catch in the Pacific waters by fishing vessels that belong to areas other than the Pacific area, and deducting from it the catch in waters other than the Pacific by fishing vessels that belong to the Pacific area (based on logbook data) (Figure 4-1, Table 3-1). The catch volume was below 500 thousand tons in 1975, but it later increased and remained extremely high at levels above 2.5 million tons from 1983 to 1989. However, it began to decrease from 1990, falling below 1 million tons in 1993, and stayed around 100 thousand to 300 thousand tons from 1995 to 2001. The catch remained below 100 thousand tons from 2002 to 2010, but turned to an increase from 2011, growing above 100 thousand tons, and marked 521 thousand tons in 2019. Since the migration range has expanded in recent years due to an increase in the stock biomass, the catch by Russia and China has increased. According to reports made to the North Pacific Fisheries Commission (NPFC), the catch by Russia in 2019 was 133 thousand tons, and the catch by China was 46 thousand tons. The stock assessment for this year was made without taking into consideration the catch by foreign countries, as many points remain unclear at this stage. Although we used many assumptions, we also made an estimation that considers the catch by foreign countries, and showed the result in Appendix 9.

(3) Fishing effort

Figure 3-3 shows changes in the annual and monthly effective efforts of the northern purse seine fishery based on data from the Japan Fisheries Information Service Center (JAFIC). The efforts had been on a decline in and after 2000 in line with a decrease in the stock biomass but have increased since 2009 in line with an increase in the biomass (Figure 3-3). The monthly effective efforts have increased mainly from spring to summer every year since 2000 (Figure 3-4).

3. Stock status

(1) Stock assessment method

Appendix 1 shows a flow chart of the stock assessment. We obtained the catch in number at age for 1976 onward based on analytical data of the catch volume, the length composition of catch, the length-weight relationship, and length-age relationship derived from data collected in the stock assessment surveys conducted by related experimental and research institutions (Appendix 3), and performed tuned virtual population analysis (VPA) (cohort analysis) (Appendix 2). As tuning indices, we used the standing stock of age 0 fish in the subarctic region in fall and the egg production in waters east of Cape Shionomisaki based on the pelagic fish surveys in the Northwestern Pacific in fall conducted in 2005 onward, and the index for wintering juveniles based on the conditions of large- and medium-scale purse seine fisheries in 2006 onward (Figures 4-1 and 4-2, Appendix 3), and exploratorily obtained F at age for 2019 in a manner that fits these tuning indices. The data values used for the calculation and the estimation results of the stock biomass, etc. are shown in Table 3-1 and Appendix Table 2-1.

(2) Changes in abundance indices

The egg production, which serves as an index for spawning biomass, was low at a level below 100 trillion eggs in the entire Pacific Ocean side in the early 2000s, when the spawning biomass was extremely low. However, the egg production has been on an increase recently in line with the increase in the spawning biomass, particularly in areas east of Cape Shionomisaki (Figure 4-1, Table 4-1). On the other hand, an increase in the egg production in the waters from Kii Strait to Hyuga Nada that was observed in the 1980s has not been observed as of 2020.

Figure 4-2 and Tables 4-2 to 4-5 show the abundance indices based on various surveys, which serve as indices for recruitment (the details of the surveys are described in Appendix 3). All indices have shown relatively high values since 2010, when recruitment was estimated to be at one of the highest levels in recent years. The index for wintering juveniles is based on the conditions of purse seine fisheries during the wintering period (December to the following April), and the index for 2000 and earlier is considered to be indicating higher levels overall than the trend in recent years, reflecting the high fishing mortality at the time. Therefore, the index level for 2000 and earlier cannot be directly compared with that for recent years in which the fishing mortality has declined.

Among these indices, indices based on offshore surveys, such as the recruitment index for the transition area based on the transitional area larva/juvenile survey, the distribution of age 0 fish in the northward migration period based on the pelagic fish survey in the Northwestern Pacific in the northward migration period, and the standing stock of age 0 fish in the subarctic region in fall based on the pelagic fish survey in the Northwestern Pacific in fall, are based on surveys in offshore growing grounds and feeding grounds, so only the values for the aforementioned offshore recruited group are used as indicators. For example, in 2008, there

was a large catch of whitebait in coastal areas and a large catch of juveniles by set nets, etc., but the indices based on offshore surveys were not high, and recruitment was estimated to be high in the coastal recruitment group, but not particularly high in the offshore recruited group. In contrast, in 2010, recruitment was low in coastal areas, but was outstandingly high compared to previous years in the offshore recruited group.

(3) Trends in biomass and fishing mortality

The stock biomass increased in the 1970s, and stayed high at over 10 million tons in the 1980s, but turned to a decline on entering the 1990s (Figure 4-3, Table 3-1, Appendix Table 2-1). The biomass fell below 1 million tons in 1994, and fluctuated around 700 thousand to 900 thousand tons until 1999. Then it further declined and stayed low at around 100 thousand tons from 2002 to 2009. However, from 2010 onward, the biomass turned to an increase due to continuous, relatively favorable recruitment and a decline in the exploitation rate, exceeding 1 million tons in 2014. The biomass further increased after that as favorable recruitment continued, and was estimated to be 3.415 million tons in 2019. The spawning biomass remained below 100 thousand tons from 2002 onward, but increased from 2011, reaching an estimate of 1.585 million tons in 2019 (Figure 4-3, Table 3-1, Appendix Table 2-1).

The exploitation rate rose to 40% to 50% levels from the 1990s to the beginning of the 2000s in correspondence with changes in fishing effort, leading to a decrease in stock biomass (Figure 4-3, Table 3-1). After that, the exploitation rate trended down, except for rising to 58% in 2007, and has stayed at a low level around 15% recently.

Figure 4-4 and Table 3-1 show fluctuations in recruitment and recruitment per spawning (RPS). From 1976 to 1981, the RPS was high at 36.0 to 65.6 individuals/kg, except in 1979, and the spawning biomass increased along with the increase in recruitment. From 1982 to 1987, the RPS was around 20 individuals/kg, and a high recruitment level continued due to high spawning biomass. Immediately after the regime shift, from 1988 to 1991, the RPS became extremely low at 0.9 to 1.7 individuals/kg, with the recruitment level substantially declining and the spawning biomass sharply decreasing. From 1992 to the first half of the 2000s, the RPS shifted between 12 to 24 individuals/kg, except becoming low at 5.4 individuals/kg in 1999 and high at 60.7 individuals/kg in 1996. From the second half of the 2000s onward, a high RPS above 30 individuals/kg has been observed frequently, and the RPS has not fallen below 10 individuals/kg in any year.

As a sensitivity analysis of natural mortality (M) in cohort analysis, we used 0.3 and 0.5 as alternatives to the base value of 0.4 assumed in this assessment, and estimated the stock biomass and spawning biomass for 2019 (Figure 4-5). When M was larger (smaller), the estimated stock biomass and spawning biomass also became larger (smaller). When M was 0.3 and 0.5, the stock biomass was 84% and 125%, and the spawning biomass was 91% and 114%, respectively, compared to when M was 0.4.

Item	Value	Explanation
SB2019	1.585 thousand tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3, 4, 5 and above) = (0.05, 0.12, 0.81, 0.32, 0.20, 0.20)	
U2019	15.3%	Exploitation rate in 2019

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

In order to compare the fishing mortality (F) considering the influence of selectivity, we made a comparison with the case with no fishing mortality, based on the SPR. Figure 4-6 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 declined from the end of the 1980s through the 1990s to the beginning of the 2000s, and the fishing mortality increased as the stock biomass decreased, showing a relationship where fishing mortality was causing a decrease in resources. From 2008 onward, the %SPR has been on an increase, and fishing mortality has maintained a relatively low level. The %SPR in 2019 was 39.8%. The current fishing mortality, which is the %SPR calculated from the average F value of the latest 5 years (from 2015 to 2019), was 41.8%.

Figure 4-7 shows the relationship between YPR and %SPR for the current fishing mortality. As for the selectivity in F, we used the selectivity value which was used to estimate F that produces the maximum sustainable yield (MSY) (F_{msy}) (Furuichi et al. 2020a) at the "Research Institute Meeting on Reference Points" held in March 2020. For the average body weight at age and the maturity rate, we also used the values which were used to calculate F_{msy} . F_{msy} corresponds to 40.0% in %SPR. Current fishing mortality (F2016-F2019) is lower than $F_{30\%SPR}$, and is approximately the same as $F_{0.1}$.

Item	Value	Explanation
%SPR (F2019)	39.8%	%SPR in 2019
%SPR (F2015-2019)	41.8%	%SPR corresponding to the current fishing mortality (2015 to 2019)

(5) Stock-recruitment relationship

Figure 4-8 shows the relationship between spawning biomass (in weight) and recruitment (in the number of individuals) (stock-recruitment [S-R] relationship). The biomass of the present stock is known to change dramatically in synchronization with the interdecadal global shift in the structure of systems including the atmospheric system and marine ecosystems (regime shift) (Kawasaki 1992, Klyashtorin 1998, Chavez et al. 2003). The changes in the ocean environment and other elements are likely to have affected the environmental carrying capacity and recruitment success (Tanaka 2003, Yatsu et al. 2005), and have also changed the S-R relationship. Thus, at the abovementioned "Research Institute Meeting on Reference

Points," it was assumed that the S-R relationship of the present stock can be divided into two modes based on the recruitment level: the normal recruitment period (from 1988 to 2018) and the high recruitment period (from 1976 to 1987). The present stock may be shifting to a high recruitment period as favorable recruitment has continued in recent years, but the expansion of spawning grounds to Satsunan, which was observed in the past high recruitment period, still cannot be found, and there are many differences from the past high recruitment period also from the ocean environment aspect, such as the Oyashio Current area being small in spring. It is quite uncertain whether the same scale of recruitment as that in the past high recruitment period will occur under the current environment. Therefore, at the abovementioned "Research Institute Meeting on Reference Points," it was proposed that the hockey stick S-R relationship estimated for the normal recruitment period (from 1988 to 2018) should be used for estimating the S-R relationship of the present stock (Furuichi et al. 2020a). 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 (Furuichi et al. 2020b), and as for the optimization method, the least squares 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.	ρ
Hockey stick	Least squares method	No	0.026	764,050	0.705	-

Here, parameter a is the steepness (thousand individuals/kg) of the hockey stick (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 present stock may be shifting to a high recruitment period, as favorable recruitment has continued in recent years, but the current environment has many differences from the past high recruitment period, and it is quite uncertain whether the same scale of recruitment as that in the past high recruitment period will occur. Therefore, it is assumed that the current status is a normal recruitment period. The values estimated at the abovementioned "Research Institute Meeting on Reference Points" as the spawning biomass that produces MSY (SBmsy) and the catch that produces MSY under the environment in a normal recruitment period (Furuichi et al. 2020a) are shown in the table below.

Item	Value	Explanation
SBmsy	1.187 million tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3, 4, 5 and above) = (0.18, 0.18, 0.24, 0.50, 0.50, 0.50)	

%SPR (Fmsy)	40.0%	%SPR corresponding to Fmsy
MSY	389 thousand tons	Maximum sustainable yield

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

Figure 4-9 shows a Kobe plot based on the spawning biomass that produces MSY and fishing mortality that produces MSY. The spawning biomass of the present stock in 2019 was above the level of spawning biomass that produces MSY (SBmsy), and the spawning biomass in 2019 was 1.33 larger than SBmsy. The fishing mortality in 2019 was below the fishing mortality (F) that produces MSY (Fmsy), and F in 2019 was 1.01 times larger than Fmsy. The ratio of F (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 "increasing" in light of the transition over the past five years (2015 to 2019). The spawning biomass of the present stock was below SBmsy from the second half of the 1990s to the first half of the 2010s, but from 2014 onward, F declined below or to approximately the same level as Fmsy, and BS from 2017 onward has been recovered to and maintained at a level above SBmsy.

Item	Value	Explanation
SB2019/SBmsy	1.33	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.01	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	Approx. the same as Fmsy
Trend in spawning biomass	Increasing

4. Stock assessment summary

Although the stock biomass remained high at over 10 million tons in the 1980s, it sharply declined on entering the 1990s, and stayed low at around 100 thousand tons from 2002 to 2009. Then, from 2010 to 2014, the biomass turned to an increase due to continuous, relatively favorable recruitment and a decline in the fishing mortality, exceeding 1 million tons in 2014. The biomass further increased after that as favorable recruitment continued, and was estimated to be 3.415 million tons in 2019. The spawning biomass remained below 100 thousand tons from 2002 onward, but increased from 2011, reaching an estimate of 1.585 million tons in 2019.

The fishing mortality declined in the second half of the 2000s, and has maintained a level below or approximately the same level as the level that produces MSY (F_{msy}) in recent years. The spawning biomass increased in line with the decline in fishing mortality, exceeding the level that produces MSY (SB_{msy}) from 2017 onward. The trend of spawning biomass is determined to be "increasing" in light of the transition over the past five years (2015 to 2019).

5. Others

In the Japanese sardine Pacific stock, all individuals are estimated to become mature at age 2. Because of this, in order to secure more than a certain level of spawning biomass that is necessary for increasing or maintaining the stock, it is considered to be essential to examine the harvest strategy for each age so as to prevent excessive fishing mortality of juveniles. Looking at past developments, a shift to a high abundance period has involved changes in marine ecosystems, and has also had a large impact on society, such as the fishery industry. Therefore, it is desirable to identify the timing of the shift to a high abundance period as early as possible. As we have been able to identify the recruitment in the current year with a certain level of accuracy under the current survey framework, it is considered to be possible to make a projection to some extent of the stock trend in a few years' time, when the recruits become the main fishery targets. Also for further improving the projection accuracy and elucidating the mechanism of changes in biomass, it is necessary to continue to advance related investigations and studies, and to keep a close watch on changes in the environment and associated stock trends, such as an outbreak of recruitment groups or a rapid decrease in stock.

6. References

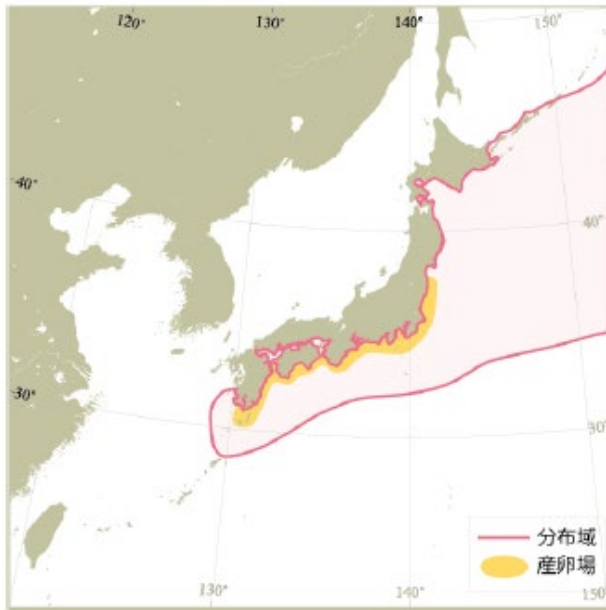
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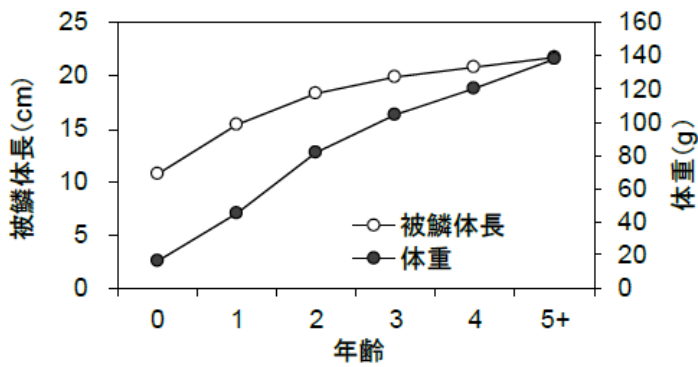
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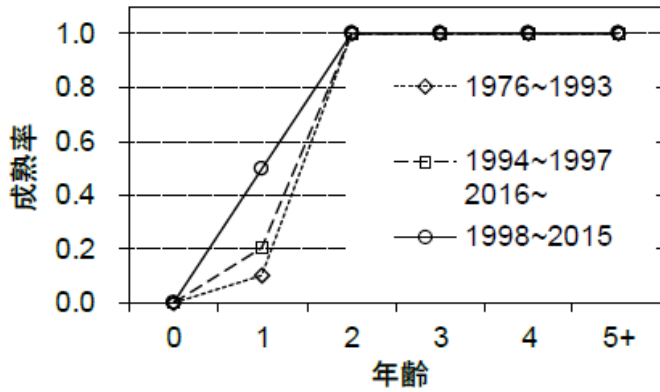
分布域	Distribution range
産卵場	Spawning grounds

Figure 2-1. Distribution range and spawning grounds of Japanese sardine Pacific stock



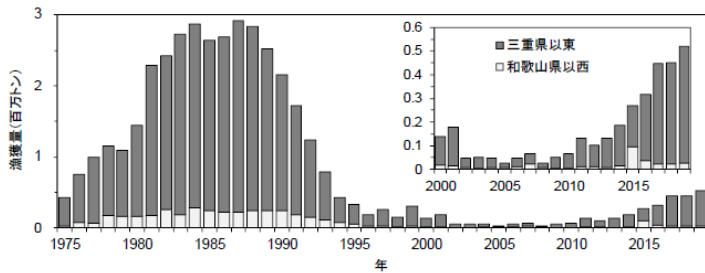
被鱗体長 (cm)	Scaled body length (cm)
年齢	Age
体重 (g)	Body weight (g)
被鱗体長	Scaled body length
体重	Body weight

Figure 2-2. Age and growth (average of catches in 2017 to 2019)



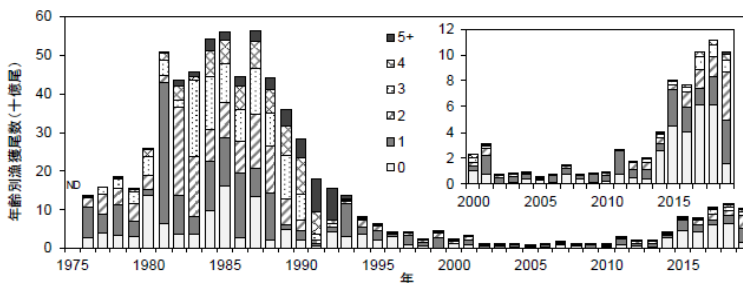
成熟率	Maturity rate
年齢	Age

Figure 2-3. Age and maturity rate



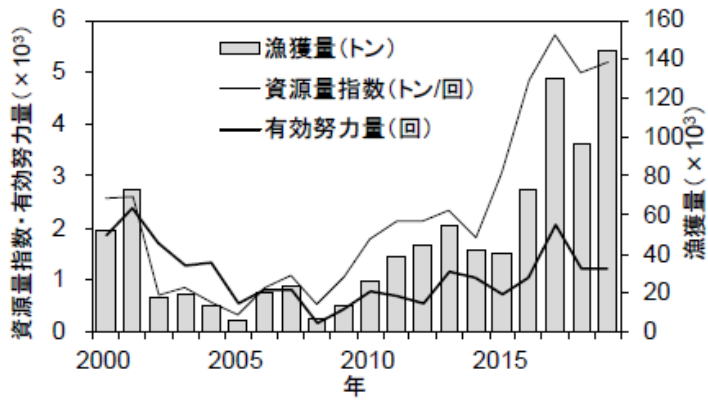
漁獲量 (百万トン)	Catch (million tons)
年	Year
三重県以東	Areas east of Mie Prefecture
和歌山県以西	Areas west of Wakayama Prefecture

Figure 3-1. Changes in catch volume



年齢別漁獲尾数 (十億尾)	Catch in number at age (billion individuals)
年	Year

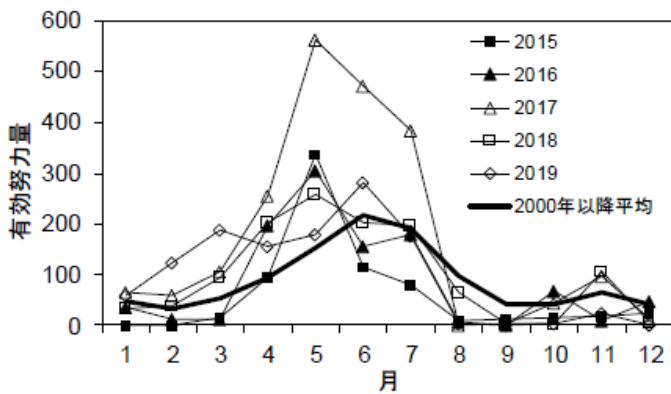
Figure 3-2. Changes in catch in number at age



資源量指数・有効努力量 (×10 ³)	Abundance index, effective effort (×10 ³)
漁獲量 (×10 ³)	Catch (×10 ³)
年	Year
漁獲量 (トン)	Catch (tons)
資源量指数 (トン/回)	Abundance index (tons/haul)
有効努力量 (回)	Effective effort (hauls)

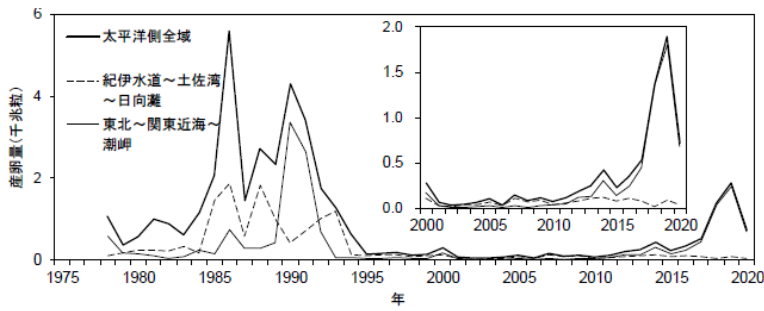
Figure 3-3. Changes in the effective effort and catch of the northern purse seine fishery and the abundance index (JAFIC data; not including eastern Hokkaido)

Effort = number of hauls, abundance index = CPUE per 30-minute Σ latitude-longitude grid, effective effort = catch/density index, density index = abundance index/number of grids with no significant catch.



有効努力量	Effective effort
月	Month
2000 年以降平均	Average of 2000 onward

Figure 3-4. Monthly changes in the effective effort of the northern purse seine fishery

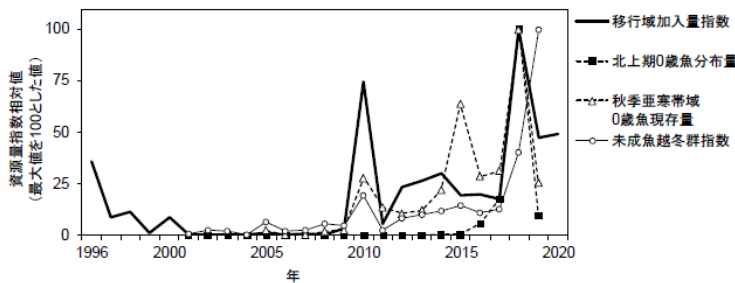


産卵量 (千兆粒)	Egg production (thousand trillion eggs)
年	Year
太平洋側全域	Entire Pacific Ocean side
紀伊水道～土佐湾～日向灘	Kii Strait - Tosa Bay - Hyuga Nada
東北～関東近海～潮岬	Tohoku - waters near Kanto - Cape Shionomisaki

Figure 4-1. Changes in egg production

Values for October of the previous year to September of the current year provided by the Egg and Larvae Survey Association

Values for 2020 are provisional values for the period until May. Values for the entire Pacific Ocean side are the values for Regions I to IV under the association's classification, the values for Kii Strait - Tosa Bay - Hyuga Nada are the values for Region III, and the values for Tohoku - waters near Kanto - Cape Shionomisaki are the values for Regions I and II.

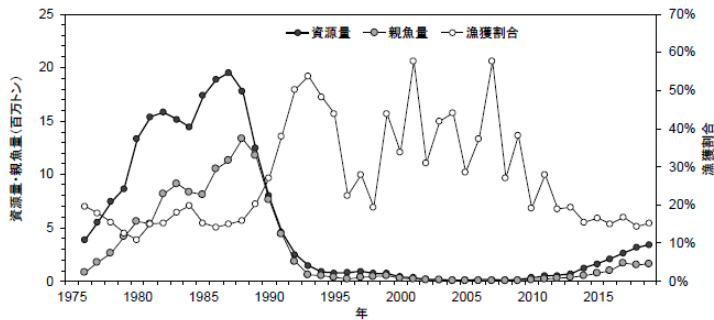


資源量指数相対値 (最大値を 100 とした値)	Relative values of abundance indices (with the index maximum set at 100)
年	Year
移行域加入量指数	Recruitment index for the transition area
北上期 0 歳魚分布量	Distribution of age 0 fish in the northward migration period
秋季亜寒帯域 0 歳魚現存量	Standing stock of age 0 fish in the subarctic region in fall
未成魚越冬群指数	Index for wintering juveniles

Figure 4-2. Changes in abundance indices that serve as indicators for recruitment

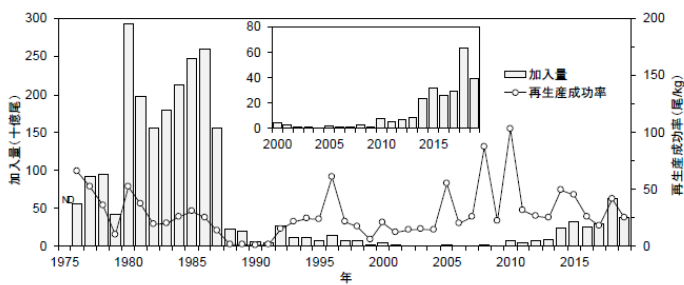
For details of the indices, see Appendix 3.

As the index for wintering juveniles corresponds to the recruitment in the previous year, the value is shown for the corresponding previous year, and values for 2002 onward are shown. Values of the recruitment index for the transition area for 2018 onward are based on a different survey period from the values up to 2017, so caution is required when making a comparison.



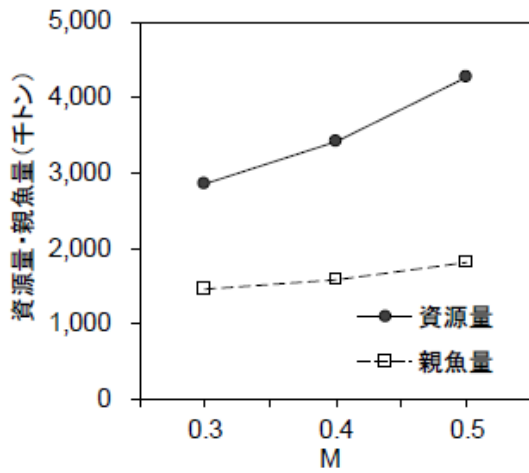
資源量・親魚量 (百万トン)	Stock biomass, spawning biomass (million tons)
漁獲割合	Exploitation rate
年	Year
資源量	Stock biomass
親魚量	Spawning biomass
漁獲割合	Exploitation rate

Figure 4-3. Changes in stock biomass, spawning biomass, and exploitation rate



加入量 (十億尾)	Recruitment (billion individuals)
再生産成功率 (尾/kg)	Recruitment per spawning (individuals/kg)
年	Year
加入量	Recruitment
再生産成功率	Recruitment per spawning

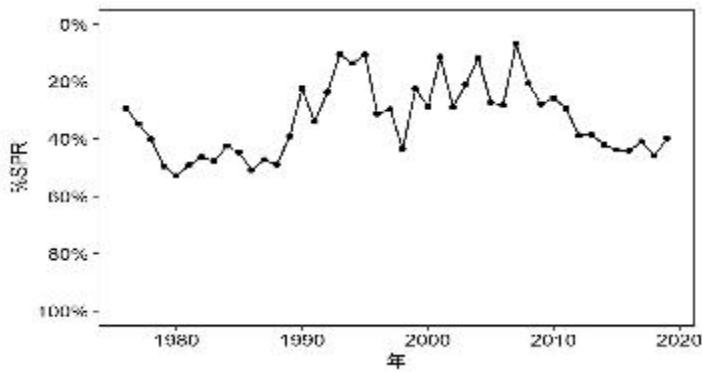
Figure 4-4. Changes in recruitment and RPS



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 4-5. Relationship between natural mortality (M) and the stock biomass and spawning biomass

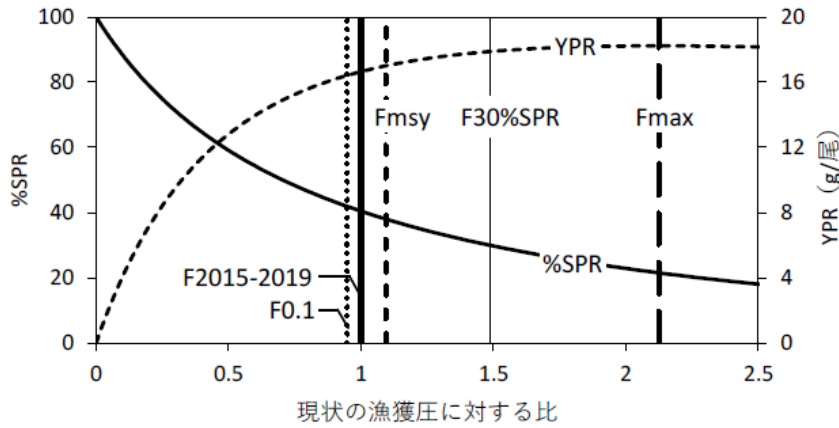
Sensitivity analysis of estimate values for 2019 against changes in M.



年	Year
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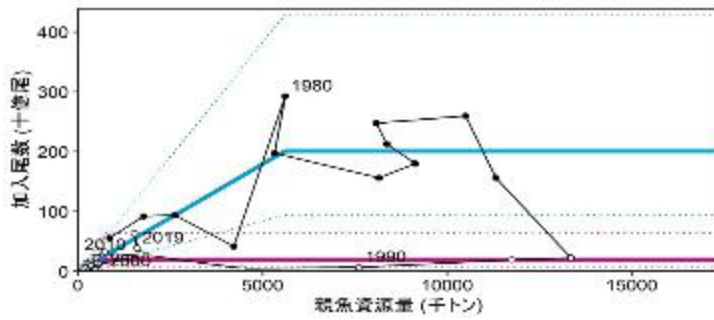
Figure 4-6. Changes in %SPR values

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.



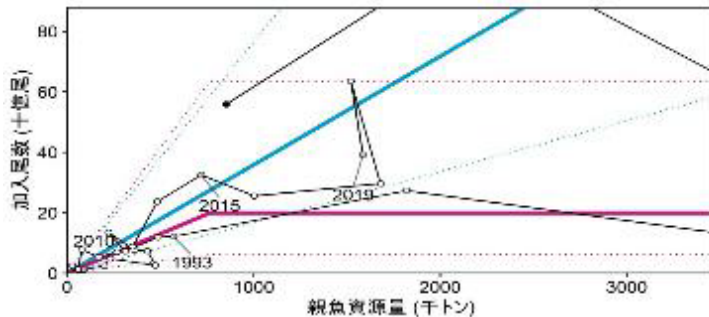
現状の漁獲圧に対する比	Ratio to the current fishing mortality
YPR (g/尾)	YPR (g/individual)

Figure 4-7. Relationship between YPR and %SPR for the current fishing mortality (F2015-2019)



加入尾数 (十億尾)	Recruitment (billion individuals)
親魚資源量 (千トン)	Spawning biomass (thousand tons)

Enlarged view

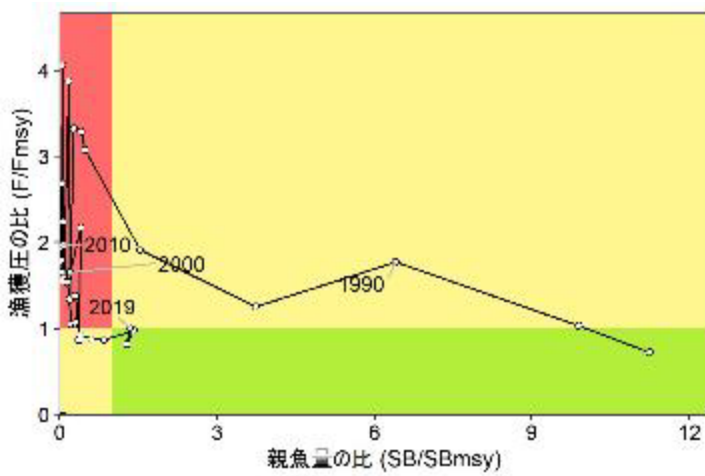


加入尾数 (十億尾)	Recruitment (billion individuals)
親魚資源量 (千トン)	Spawning biomass (thousand tons)

Figure 4-8. Relationship between spawning biomass and recruitment (S-R relationship)

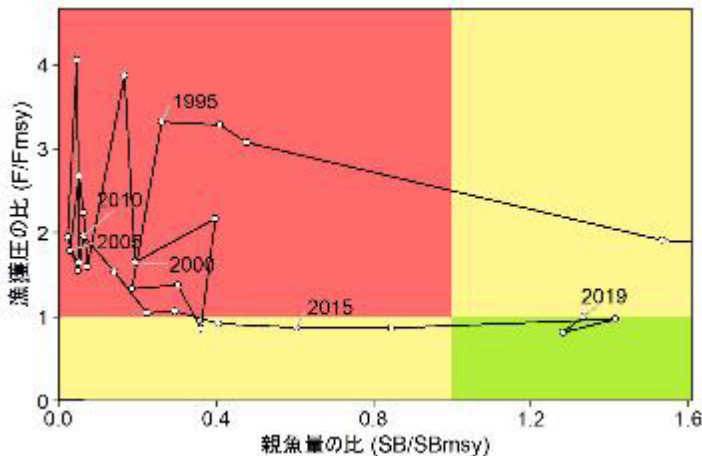
The S-R relationship proposed at the "Research Institute Meeting on Reference Points" held in March 2020 (Furuichi et al. 2020a)

The blue line shows the S-R relationship in the high recruitment period (from 1976 to 1987) and the red line shows the S-R relationship in the normal recruitment period (from 1988 to 2018). The circles are actual measurement data (from 1976 to 2019), and the black circles indicate values for the high recruitment period, white while circles indicate values for the normal recruitment period. The dotted lines above and below the S-R relationship show the range that is estimated to cover 90% of the observation data under the assumed S-R relationship. Numbers in the figure denote the year class.



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Enlarged view



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Figure 4-9. Relationship of the past spawning biomass and fishing mortality to the spawning biomass that produces MSY (SBmsy) and fishing mortality that produces MSY (Fmsy) (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 (億尾)	漁獲割合 (%)	再生産成功率 (尾/kg)
	太平洋合計	三重県以東	和歌山県以西					
1975	430	400	30					
1976	756	677	79	3,862	852	559	19.6	65.6
1977	991	934	56	5,553	1,774	923	17.8	52.0
1978	1,149	975	174	7,440	2,620	942	15.5	36.0
1979	1,089	933	156	8,647	4,219	419	12.6	9.9
1980	1,445	1,286	159	13,366	5,613	2,930	10.8	52.2
1981	2,296	2,129	167	15,415	5,325	1,978	14.9	37.1
1982	2,419	2,158	261	15,830	8,158	1,562	15.3	19.2
1983	2,725	2,539	186	15,151	9,140	1,802	18.0	19.7
1984	2,870	2,589	281	14,419	8,368	2,128	19.9	25.4
1985	2,644	2,397	247	17,392	8,079	2,479	15.2	30.7
1986	2,685	2,471	214	18,881	10,499	2,600	14.2	24.8
1987	2,916	2,696	220	19,542	11,322	1,565	14.9	13.8
1988	2,838	2,593	244	17,774	13,355	228	16.0	1.7
1989	2,524	2,280	243	12,507	11,754	194	20.2	1.7
1990	2,162	1,916	246	7,981	7,609	69	27.1	0.9
1991	1,724	1,544	180	4,546	4,440	53	37.9	1.2
1992	1,240	1,089	152	2,465	1,819	273	50.3	15.0
1993	791	675	116	1,467	569	121	53.9	21.3
1994	425	357	68	879	487	119	48.3	24.4
1995	332	277	55	756	310	73	43.9	23.6
1996	181	150	31	805	221	134	22.5	60.7
1997	255	228	27	916	360	78	27.9	21.6
1998	142	124	18	727	429	74	19.5	17.2
1999	308	281	27	701	473	26	43.9	5.4
2000	139	122	17	411	231	48	33.8	21.0
2001	177	162	15	305	199	25	57.9	12.4
2002	49	43	6	157	87	12	31.1	14.1
2003	51	46	5	121	75	11	42.0	15.0
2004	48	41	7	109	63	9	44.1	14.3
2005	25	16	9	87	35	19	28.6	55.4
2006	49	40	10	131	62	12	37.4	20.1
2007	65	42	23	112	56	14	57.9	25.4
2008	27	18	9	99	28	24	27.1	87.4
2009	49	46	3	129	59	13	38.2	22.3
2010	65	62	3	338	76	78	19.1	103.2
2011	132	122	10	471	169	53	28.0	31.6
2012	102	92	9	534	266	70	19.0	26.4
2013	130	124	6	666	351	88	19.5	25.1
2014	186	172	14	1,211	483	237	15.4	49.2
2015	270	175	95	1,635	718	325	16.5	45.2
2016	316	278	38	2,100	1,003	255	15.0	25.5
2017	446	423	23	2,647	1,680	297	16.8	17.7
2018	452	430	22	3,137	1,521	635	14.4	41.8
2019	521	495	26	3,415	1,585	391	15.3	24.7

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 (億尾)	Recruitment (100 million individuals)
漁獲割合	Exploitation rate (%)

再生産成功率 (尾/kg)	Recruitment per spawning (individuals/kg)
太平洋合計	Pacific Ocean total
三重県以東	Areas east of Mie Prefecture
和歌山県以西	Areas west of Wakayama Prefecture

Table 4-1. Egg production (trillion eggs)

Values for October of the previous year to September of the current year (values for 2020 are provisional values for the period until May). Underlined values in bold are values used for tuning of the cohort analysis.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
I・II区	150	109	43	79	244	153	734	285	277	420	3,379	2,632	697	48
I~IV区	562	989	892	622	1,158	2,052	5,614	1,462	2,727	2,328	4,304	3,423	1,754	1,280
	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
I・II区	61	26	22	49	42	35	170	32	12	7	18	31	<u>7</u>	32
I~IV区	638	143	148	172	121	145	283	63	33	44	62	101	38	148
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
I・II区	<u>13</u>	<u>24</u>	<u>37</u>	<u>52</u>	<u>116</u>	<u>134</u>	<u>306</u>	<u>146</u>	<u>241</u>	<u>452</u>	<u>1,354</u>	<u>1,804</u>	<u>682</u>	
I~IV区	84	118	75	120	192	245	426	228	347	531	1,378	1,892	723	

I・II区	Regions I and II
I~IV区	Regions I to IV

Table 4-2. Recruitment index for the transition area based on the transitional area larva/juvenile survey (May to June)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
移行域	187.4	45.0	60.1	6.1	45.7	0.1	0.8	0.1	0.6	5.0
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
移行域 加入量指数	0.4	3.2	1.2	16.8	391.4	28.8	123.2	139.1	158.0	101.5
	2016	2017	2018	2019	2020					
	102.6	91.9	524.8	248.1	257.1					

移行域加入量指数	Recruitment index for the transition area
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Table 4-3. Distribution of age 0 fish in the northward migration period (100 million individuals) and distribution of fish of age 1 and above (100 million individuals) in the transition area to the Oyashio Current region based on the pelagic fish survey in the Northwestern Pacific in the northward migration period (May to July)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
0歳魚	0	5	1	0	1	0	1	1	5	78	19
1歳以上	19	2	8	1	0	0	0	0	0	5	10
	2012	2013	2014	2015	2016	2017	2018	2019			
0歳魚	18	8	259	313	4,791	15,107	85,559	8,383			
1歳以上	14	14	11	14	3	7	22	583			

0歳魚	Age 0 fish
1歳以上	Fish of age 1 and above

Table 4-4. Standing stock of age 0 fish in the subarctic region in fall (million individuals) and distribution density (individuals/km²) based on the pelagic fish surveys in the Northwestern Pacific in fall (September to October)

Underlined values in bold are values used for tuning of the cohort analysis.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
現存量	<u>1,203</u>	<u>63</u>	60	<u>1,018</u>	<u>1,415</u>	<u>15,258</u>	<u>7,359</u>	<u>5,715</u>	<u>6,601</u>
分布密度	1,284	62	70	1,236	1,792	19,645	9,199	5,569	7,765
	2014	2015	2016	2017	2018	2019			
現存量	<u>11,892</u>	<u>34,764</u>	<u>15,551</u>	<u>17,092</u>	<u>54,528</u>	<u>13,870</u>			
分布密度	13,140	32,159	22,002	14,098	98,409	23,183			

現存量	Standing stock
分布密度	Distribution density

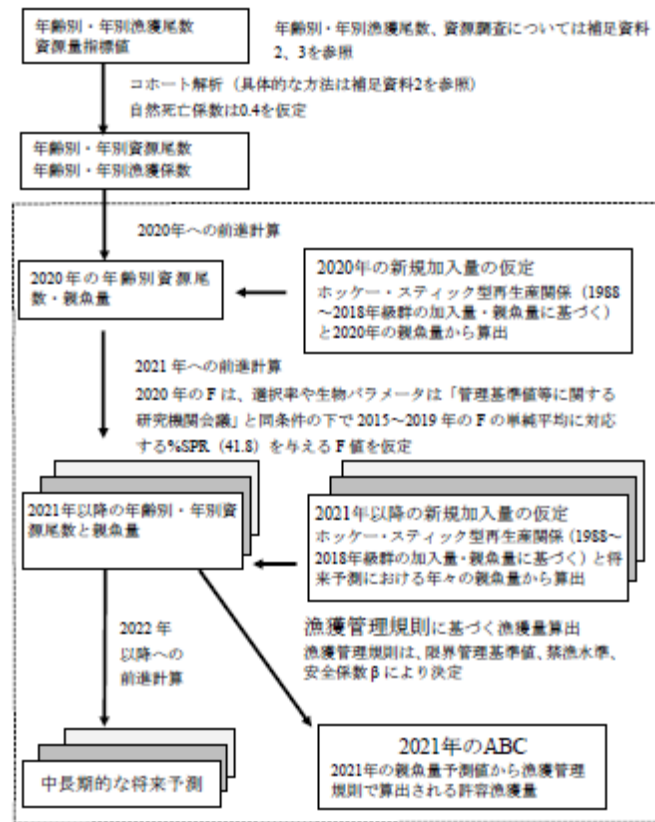
Table 4-5. Index for wintering juveniles (Chiba Prefectural Fisheries Experimental Station, Ibaraki Prefectural Fisheries Experimental Station)

Underlined values in bold are values used for tuning of the cohort analysis.

	1976	1977	1978	1979	1980	1981	1982	1983	1984
	7,592	4,109	16,840	11,653	2,853	53,698	41,207	6,740	50,085
	1985	1986	1987	1988	1989	1990	1991	1992	1993
	41,197	62,928	42,986	39,659	1,588	5,944	224	30	30,541
未成魚 越冬群指数	1994	1995	1996	1997	1998	1999	2000	2001	2002
	5,802	5,054	239	8,481	1,136	5,763	0	8,480	122
	2003	2004	2005	2006	2007	2008	2009	2010	2011
	404	342	28	<u>1,093</u>	<u>371</u>	<u>385</u>	<u>921</u>	<u>780</u>	<u>3,374</u>
	2012	2013	2014	2015	2016	2017	2018	2019	2020
	<u>408</u>	<u>1,397</u>	<u>1,757</u>	<u>2,065</u>	<u>2,480</u>	<u>1,855</u>	<u>2,178</u>	<u>6,991</u>	<u>17,329</u>

未成魚越冬群指数	Index for wintering juveniles
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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 0.4 を仮定	Natural mortality is assumed as 0.4.
年齢別・年別資源尾数	Number of fish at age and by year
年齢別・年別漁獲係数	Fishing mortality at age and by year
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（1988～2018 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 hockey stick S-R relationship (based on recruitment / spawning biomass of 1988-2018 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」と同条件の下で2015-2019年のF単純平均に対応するSPR(41.8)を与えるF値を仮定	F for 2020 is assumed to be the F value that gives the %SPR (41.8) that corresponds to the simple average of F in 2015 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(1988～2018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 hockey stick S-R relationship (based on recruitment / spawning biomass of 1988-2018 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 decided based on discussions on reference points and HCRs at the Committee of Stock Management Policy. (https://www.jfa.maff.go.jp/j/press/sigen/200529_29.html)

Appendix 2. Calculation method

(1) Stock calculation method

We estimated the catch in number at age, the number of fish, and biomass using tuned VPA (cohort analysis) (the results are shown in Appendix Table 2-1). Considering the life history and the seasonality of catches, we set the start of the fishing season to January and categorized the ages into the following six groups: age 0, age 1, age 2, age 3, age 4, and the oldest age group comprising ages 5 and above ("age 5+"; plus group). Although the spawning season extends from fall to spring, we assumed adults spawning in fall of year $y-1$ to spring of year y to be spawning adults in year y . The approximate equation by Pope (1972) was used. The method by Hiramatsu (1999) was used for the calculation of the oldest age group. We set natural mortality (M) at 0.4 based on the equation indicated by Tanaka (1960), $M = 2.5/\text{longevity}$, and longevity of 7 years.

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

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

Here, $N_{a,y}$ and $C_{a,y}$ are the number of fish and catch in number, respectively, of age a fish in year y . However, the abundance in the most recent year (year t ; here, 2019) and the number of fish for the oldest age group (subscript p ; here, age 5+) and fish of the oldest age-1 ($p-1$; here, age 4) were based on equations (2), (3), and (4), respectively.

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

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

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

We calculated fishing mortality F based on equation (5), except for F in the most recent year and F for the oldest age group.

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

F for the oldest age group was assumed to be equal to F for the oldest age-1 in all years (Hiramatsu 1999; equation (6)).

$$F_{p,y} = F_{p-1,y} \quad (6)$$

We obtained F for ages 0 to 4 in the most recent year (terminal F) in an exploratory manner by tuning. As it has been pointed out that the stock's selectivity at age varies substantially by year, and that accurate assessment cannot be made by setting terminal F under an assumption that "selectivity at age has been stable in recent years" (Hiramatsu 2009), we explored the F values for ages 0 to 4 in 2019 without assuming stable selectivity. The indices and the corresponding estimate values used for the tuning are the three types below (Appendix Table 2-2). The period subject to the indices was in and after 2005, when the survey of pelagic fish in fall started (in an after 2006 for the index for wintering juveniles, as it is the index for abundance of age 1 fish and corresponds to recruitment in the previous year).

- (i) Standing stock of age 0 fish in the subarctic region in fall based on the pelagic fish survey in the Northwestern Pacific in fall for 2005 to 2019 (I_1) / the number of age 0 fish (N_0)
- (ii) Index for wintering juveniles for 2006 to 2020 (Chiba Prefectural Fisheries Experimental Station, Ibaraki Prefectural Fisheries Experimental Station, I_2) / stock biomass of age 1 fish (B_1)
- (iii) Egg production in sea areas to the east of Cape Shionomisaki (Regions I and II) for 2005 to 2020 (I_3) / spawning biomass (SB)

However, we excluded the standing stock of age 0 fish based on the survey of pelagic fish in fall for 2007 from the tuning as its survey area only covered a small part of the sea area subject to the estimation and the estimation accuracy was considered to be low (underestimation). In order to ensure stability in the estimation values of terminal F , we applied ridge VPA (Okamura et al. 2017) to the cohort analysis. It is a technique to obtain terminal F by minimizing a function that has added a penalty parameter to the residual sum of squares. The penalty size is decided to minimize the retrospective bias (Mohn's ρ ; Mohn 1999). In the present stock, however, a trade-off relationship was observed where a lower bias in spawning biomass resulted in a higher negative bias in recruitment. As a normal penalty parameter for ridge VPA is the sum of squares of F at age in the terminal year, there was a possibility that F for age 0 fish became excessively large due to the influence of F for older fish. Thus, in this assessment, we used a technique to change the weight of penalty for fish of age 1 and above and age 0 fish as shown in equation (7). As a result, the trade off was eliminated to a certain extent.

$$(1 - \lambda) \sum_{k=1}^3 \sum_y [\ln(I_{k,y}) - \ln(q_k X_{k,y}^{b_k})]^2 + \lambda \left[(1 - \eta) \sum_{a=1}^4 F_{a,2019}^2 + \eta F_{0,2019}^2 \right] \quad (7)$$

Here, λ is the penalty size in ridge regression, and η is the relative weight of F for age 0 fish to F for fish of age 1 and above in the penalty parameter, both taking a value between 0 to 1. $I_{k,y}$ is the value of index k in year y . q_k is the proportional constant for index k , $X_{k,y}$ is the

objective value (recruitment, biomass of age 1 fish, and spawning biomass) for index k in year y calculated from the cohort analysis, and b_k is a coefficient that represents the non-linear relationship between index and estimated VPA values. q_k and b_k were estimated based on equation (8) below.

$$q_k = \exp \left\{ \frac{1}{n_k} \sum_y \ln \left(\frac{I_{k,y}}{X_y^{b_k}} \right) \right\} \quad (8a)$$

$$b_k = \frac{Cov[\ln(I_k), \ln(X_k)]}{V[\ln(X_k)]} \quad (8b)$$

Here, n_k is the length of years used in tuning of index k . V and Cov are variance and covariance, respectively. For the standing stock of age 0 fish in the subarctic region in fall ($k = 1$) and index for wintering juveniles ($k = 2$), we assumed a nonlinear relationship ($b_k \neq 1$). Egg production ($k = 3$) showed a roughly proportional relationship with spawning biomass, so we fixed the relationship at $b_k = 1$.

The retrospective bias (Mohn's ρ) is the average of relative values between the estimate value for each year based on full data up to terminal year Y (2019) in the latest stock assessment and the estimate value for terminal year where data for i years are lacking from latest data (year $Y-i$). The number of years to be removed was set at 5 years. We selected λ and η by the following method. We changed λ and η at 0.01 intervals between 0 and 1, and selected combinations of λ and η for which the retrospective bias fell within $\pm 20\%$ ($\rho = \pm 0.2$) for all of stock biomass, spawning biomass, the number of fish, recruitment, and average F . From those combinations, we selected a combination that minimized the sum of absolute values of retrospective bias. λ was 0.93 and η was 0.99. The estimate values of the parameters were $F_{0,2019} = 0.05$, $F_{1,2019} = 0.12$, $F_{2,2019} = 0.81$, $F_{3,2019} = 0.32$, $F_{4,2019} = F_{5+,2019} = 0.20$, $q_1 = 0.13$, $q_2 = 38.2$, $q_3 = 0.41$, $b_1 = 1.17$, and $b_2 = 0.68$.

We assessed the uncertainty of the estimated recruitment, stock biomass, and spawning biomass by nonparametric bootstrapping (Appendix Figure 2-1). We created new abundance indices by resampling the residuals between the observation values and projected values in the tuning, and performed iterations of the VPA using those indices. We performed 10,000 iterations to obtain confidence intervals. The 90% confidence intervals for the respective estimate values for 2019 were recruitment (100 million individuals) [149, 1,094], stock biomass (thousand tons) [2,426, 6,986], spawning biomass (thousand tons) [1,161, 3,219], F_0 [0.02, 0.14], F_1 [0.05, 0.36], F_2 [0.21, 1.54], F_3 [0.10, 1.16], and F_4 [0.07, 0.82].

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Appendix Table 2-1. Details of cohort analysis results

年齢別漁獲尾数 (百万尾)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	2,688	3,838	3,043	2,828	13,733	6,276	3,578	3,601	9,656
1歳	7,763	5,052	8,106	4,208	1,500	36,761	10,028	4,538	12,952
2歳	2,542	5,224	4,401	4,714	3,591	1,964	22,951	15,526	8,377
3歳	278	1,636	2,353	2,750	4,998	3,654	2,007	20,050	13,665
4歳	98	53	346	745	1,790	1,845	3,494	874	6,671
5歳以上	1	1	27	19	324	348	1,365	1,358	2,958
計	13,370	15,803	18,276	15,264	25,937	50,849	43,422	45,946	54,278
年齢別漁獲量 (千トン)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	67.2	80.6	66.9	96.1	288.4	119.2	68.0	43.2	77.2
1歳	434.7	293.0	421.5	231.4	103.5	1,396.9	411.1	190.6	531.0
2歳	213.5	438.8	369.7	381.8	290.9	167.0	1,216.4	916.0	452.4
3歳	29.2	171.8	247.1	288.8	509.8	354.5	182.7	1,343.4	929.2
4歳	11.6	6.2	40.8	87.9	211.3	214.1	370.4	81.2	560.3
5歳以上	0.1	0.1	3.4	2.5	41.2	44.2	170.6	150.7	319.4
計	756	991	1,149	1,089	1,445	2,296	2,419	2,725	2,870
漁獲割合	19.6%	17.8%	15.5%	12.6%	10.8%	14.9%	15.3%	18.0%	19.9%
年齢別漁獲係数 (F)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	0.06	0.05	0.04	0.09	0.06	0.04	0.03	0.02	0.06
1歳	0.35	0.19	0.18	0.09	0.07	0.28	0.10	0.06	0.14
2歳	0.57	0.55	0.32	0.19	0.13	0.16	0.35	0.28	0.17
3歳	1.06	1.31	0.68	0.44	0.41	0.23	0.31	0.81	0.56
4歳	3.50	0.76	1.94	0.61	0.76	0.33	0.45	0.27	0.96
5歳以上	3.50	0.76	1.94	0.61	0.76	0.33	0.45	0.27	0.96
単純平均	1.51	0.60	0.85	0.34	0.37	0.23	0.28	0.29	0.47
年齢別資源尾数 (百万尾)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	55,898	92,251	94,204	41,921	292,971	197,812	156,249	180,202	212,801
1歳	31,999	35,269	58,696	60,655	25,786	185,141	127,459	101,808	117,844
2歳	7,185	15,094	19,506	32,709	37,214	16,056	94,007	77,228	64,528
3歳	520	2,735	5,841	9,472	18,066	22,005	9,155	44,224	39,056
4歳	123	121	494	1,989	4,097	8,018	11,759	4,493	13,228
5歳以上	1	3	39	52	742	1,512	4,592	6,982	5,866
計	95,727	145,473	178,779	146,797	378,875	430,545	403,220	414,937	453,324
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS, 尾/尾)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	1,397	1,937	2,072	1,425	6,152	3,758	2,969	2,182	1,702
1歳	1,792	2,046	3,052	3,336	1,779	7,035	5,226	4,276	4,832
2歳	604	1,268	1,638	2,649	3,014	1,365	4,982	4,556	3,485
3歳	55	287	613	995	1,843	2,134	833	2,963	2,656
4歳	15	14	58	235	483	930	1,246	418	1,111
5歳以上	0	0	5	7	94	192	574	775	633
計	3,862	5,553	7,440	8,647	13,366	15,415	15,830	15,151	14,419
親魚量	852	1,774	2,620	4,219	5,613	5,325	8,158	9,140	8,368
RPS	65.6	52.0	36.0	9.9	52.2	37.1	19.2	19.7	25.4
年齢別平均体重 (g)									
年齢\年	1976	1977	1978	1979	1980	1981	1982	1983	1984
0歳	25	21	22	34	21	19	19	12	8
1歳	56	58	52	55	69	38	41	42	41
2歳	84	84	84	81	81	85	53	59	54
3歳	105	105	105	105	102	97	91	67	68
4歳	118	118	118	118	118	116	106	93	84
5歳以上	127	127	127	127	127	127	125	111	108

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

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾/kg）	Stock biomass at age (thousand tons), spawning biomass (thousand tons),RPS (individuals/kg)
親魚量	Spawning biomass
年齢別平均体重（g）	Average body weight at age (g)

Appendix Table 2-1. Details of cohort analysis results (continued)

年齢別漁獲尾数（百万尾）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	16,152	2,612	13,293	1,857	4,733	1,831	482	4,003	2,806
1歳	12,648	16,897	7,413	12,465	1,176	2,798	775	1,190	8,933
2歳	8,947	8,340	13,945	12,176	6,865	2,632	944	363	317
3歳	10,192	8,256	12,206	8,351	11,210	6,753	1,373	738	321
4歳	6,217	5,976	6,746	6,310	7,801	9,491	5,685	768	329
5歳以上	2,039	2,452	2,929	3,073	4,185	4,655	8,525	8,352	932
計	56,194	44,531	56,532	44,231	35,970	28,180	17,784	15,414	13,637
年齢別漁獲量（千トン）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	290.7	26.1	79.8	22.3	47.3	9.2	1.9	72.1	16.8
1歳	505.9	709.7	348.4	610.8	52.9	114.7	23.2	64.3	544.9
2歳	438.4	492.1	753.0	706.2	405.0	152.6	82.1	30.1	25.1
3歳	682.8	619.2	817.8	626.3	840.8	533.5	133.2	70.9	35.9
4歳	516.0	555.7	600.4	561.6	725.5	863.7	562.8	76.0	44.1
5歳以上	210.0	281.9	316.4	310.4	452.0	488.8	920.7	927.1	124.0
計	2,644	2,685	2,916	2,838	2,524	2,162	1,724	1,240	791
漁獲割合									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	15.2%	14.2%	14.9%	16.0%	20.2%	27.1%	37.9%	50.3%	53.9%
年齢別漁獲係数（F）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	0.08	0.01	0.11	0.10	0.35	0.39	0.12	0.20	0.33
1歳	0.12	0.14	0.05	0.18	0.11	0.47	0.36	0.62	1.29
2歳	0.17	0.14	0.21	0.15	0.17	0.49	0.36	0.36	0.41
3歳	0.42	0.30	0.38	0.24	0.24	0.32	0.68	0.69	0.84
4歳	0.71	0.61	0.57	0.45	0.47	0.43	0.66	1.68	1.09
5歳以上	0.71	0.61	0.57	0.45	0.47	0.43	0.66	1.68	1.09
年齢平均	0.37	0.30	0.32	0.26	0.30	0.42	0.47	0.87	0.84
年齢別資源尾数（百万尾）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	247,911	259,954	156,475	22,847	19,437	6,923	5,308	27,329	12,127
1歳	134,739	152,955	172,114	94,005	13,794	9,154	3,142	3,163	15,042
2歳	68,389	79,963	88,695	109,303	52,808	8,283	3,845	1,472	1,146
3歳	36,396	38,518	46,773	48,037	63,299	29,778	3,398	1,805	690
4歳	14,992	16,053	19,060	21,359	25,363	33,252	14,432	1,153	605
5歳以上	4,916	6,586	8,276	10,402	13,608	16,310	21,641	12,546	1,716
計	507,343	554,029	491,392	305,952	188,309	103,701	51,765	47,467	31,326
年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾/kg）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	4,462	2,600	939	274	194	35	21	492	73
1歳	5,390	6,424	8,089	4,606	621	375	94	171	918
2歳	3,351	4,718	4,790	6,340	3,116	480	335	122	91
3歳	2,439	2,889	3,134	3,603	4,747	2,352	330	173	77
4歳	1,244	1,493	1,696	1,901	2,359	3,026	1,429	114	81
5歳以上	506	757	894	1,051	1,470	1,713	2,337	1,393	228
計	17,392	18,881	19,542	17,774	12,507	7,981	4,546	2,465	1,467
親魚量	8,079	10,499	11,322	13,355	11,754	7,609	4,440	1,819	569
RPS	30.7	24.8	13.8	1.7	1.7	0.9	1.2	15.0	21.3
年齢別平均体重（g）									
年齢\年	1985	1986	1987	1988	1989	1990	1991	1992	1993
0歳	18	10	6	12	10	5	4	18	6
1歳	40	42	47	40	45	41	30	54	61
2歳	49	59	54	58	59	58	87	83	79
3歳	67	75	67	75	75	79	97	96	112
4歳	83	93	89	89	93	91	99	99	134
5歳以上	103	115	108	101	108	105	108	111	133

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

計	Total
年齢別漁獲量 (千トン)	Catch at age (thousand tons)
漁獲割合	Exploitation rate
年齢別漁獲係数 (F)	Fishing mortality (F) at age
単純平均	Simple average
年齢別資源尾数 (百万尾)	Number of fish at age (million individuals)
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)	Stock biomass at age (thousand tons), spawning biomass (thousand tons), RPS (individuals/kg)
親魚量	Spawning biomass
年齢別平均体重 (g)	Average body weight at age (g)

補足表 2-1. コホート解析結果の詳細 (つづき)

年齢別漁獲尾数 (百万尾)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	3,517	1,973	2,948	725	451	61	1,071	753	24
1歳	2,089	2,533	651	2,638	993	2,606	255	1,466	471
2歳	1,788	1,231	336	449	490	1,108	377	564	137
3歳	319	193	128	139	148	421	320	196	50
4歳	125	42	28	30	142	174	235	103	27
5歳以上	328	60	12	10	71	59	89	71	17
計	8,168	6,033	4,103	3,990	2,295	4,428	2,347	3,154	725

年齢別漁獲量 (千トン)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	38.7	66.8	99.9	20.3	10.8	2.2	31.7	12.7	0.8
1歳	117.0	123.3	31.7	168.8	51.7	155.6	11.1	79.2	26.9
2歳	168.1	103.8	28.3	44.4	38.7	85.0	28.7	44.7	10.9
3歳	38.3	22.8	15.1	16.1	14.9	39.9	30.9	19.0	5.1
4歳	16.9	6.1	3.9	4.0	16.6	17.6	25.3	11.8	3.0
5歳以上	46.0	9.4	1.8	1.5	8.7	7.6	11.0	9.2	2.2
計	425	332	181	255	142	308	139	177	49
漁獲割合	48.3%	43.9%	22.5%	27.9%	19.5%	43.9%	33.8%	57.9%	31.1%

年齢別漁獲係数 (F)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	0.45	0.40	0.31	0.12	0.08	0.03	0.32	0.46	0.02
1歳	0.58	0.94	0.28	0.67	0.30	1.19	0.20	1.41	0.80
2歳	1.56	1.15	0.37	0.40	0.31	0.90	0.68	1.39	0.57
3歳	1.45	0.92	0.41	0.32	0.27	0.62	0.99	1.38	0.50
4歳	1.45	1.05	0.39	0.19	0.85	0.81	1.24	1.65	0.92
5歳以上	1.45	1.05	0.39	0.19	0.85	0.81	1.24	1.65	0.92
単純平均	1.16	0.92	0.36	0.32	0.44	0.72	0.78	1.32	0.62

年齢別資源尾数 (百万尾)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	11,889	7,312	13,445	7,777	7,388	2,580	4,838	2,483	1,220
1歳	5,832	5,090	3,286	6,599	4,619	4,583	1,679	2,366	1,047
2歳	2,769	2,199	1,338	1,669	2,263	2,283	938	917	386
3歳	509	392	466	622	752	1,116	624	320	153
4歳	200	80	104	207	303	383	404	156	54
5歳以上	524	114	46	68	152	131	154	108	34
計	21,722	15,185	18,685	16,942	15,478	11,076	8,636	6,350	2,895

年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	131	248	455	218	177	91	143	42	41
1歳	327	248	160	422	241	274	73	128	60
2歳	260	185	113	165	179	175	71	73	31
3歳	61	46	55	72	76	106	60	31	16
4歳	27	11	15	28	36	39	43	18	6
5歳以上	73	18	7	11	19	17	19	14	4
計	879	756	805	916	727	701	411	305	157
親魚量	487	310	221	360	429	473	231	199	87
RPS	24.4	23.6	60.7	21.6	17.2	5.4	21.0	12.4	14.1

年齢別平均体重 (g)									
年齢\年	1994	1995	1996	1997	1998	1999	2000	2001	2002
0歳	11	34	34	28	24	35	30	17	33
1歳	56	49	49	64	52	60	44	54	57
2歳	94	84	84	99	79	77	76	79	79
3歳	120	118	118	116	101	95	96	97	102
4歳	135	143	143	134	118	102	107	115	112
5歳以上	140	156	150	154	122	127	123	129	132

年齢別漁獲尾数 (百万尾)	Catch in number at age (million individuals)
年齢\年	Age \ Year
0歳	Age 0

1 歳	Age 1
2 歳	Age 2
3 歳	Age 3
4 歳	Age 4
5 歳以上	Age 5 and above
計	Total
年齢別漁獲量 (千トン)	Catch at age (thousand tons)
漁獲割合	Exploitation rate
年齢別漁獲係数 (F)	Fishing mortality (F) at age
単純平均	Simple average
年齢別資源尾数 (百万尾)	Number of fish at age (million individuals)
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)	Stock biomass at age (thousand tons), spawning biomass (thousand tons), RPS (individuals/kg)
親魚量	Spawning biomass
年齢別平均体重 (g)	Average body weight at age (g)

補足表 2-1. コホート解析結果の詳細 (つづき)

年齢別漁獲尾数 (百万尾)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	152	375	260	172	750	459	121	209	760	
1歳	410	399	101	464	430	178	620	406	1,769	
2歳	127	71	22	43	206	36	29	206	76	
3歳	73	13	35	23	20	16	11	14	15	
4歳	31	9	46	13	7	2	6	10	6	
5歳以上	12	5	22	3	3	1	2	8	8	
計	904	872	486	718	1,416	692	788	852	2,634	
年齢別漁獲量 (千トン)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	2.9	10.2	6.2	3.7	20.2	11.7	2.6	6.2	23.2	
1歳	25.2	27.3	4.1	37.5	22.7	9.8	41.9	30.9	97.0	
2歳	9.9	7.2	1.9	3.6	19.0	2.9	2.7	23.9	8.3	
3歳	7.8	1.6	3.8	2.7	2.0	1.9	1.1	1.6	1.8	
4歳	3.6	1.0	5.6	1.5	0.8	0.3	0.7	1.1	0.6	
5歳以上	1.6	0.6	3.2	0.3	0.3	0.2	0.2	0.9	0.9	
計	51	48	25	49	65	27	49	65	132	
漁獲割合	42.0%	44.1%	28.6%	37.4%	57.9%	27.1%	38.2%	19.1%	28.0%	
年齢別漁獲係数 (F)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	0.18	0.72	0.18	0.19	1.04	0.26	0.12	0.03	0.19	
1歳	0.99	1.45	0.54	0.75	1.42	1.03	0.93	1.01	0.55	
2歳	0.67	0.57	0.31	0.62	1.35	0.50	0.59	1.42	0.68	
3歳	0.94	0.16	0.83	0.83	0.91	0.39	0.33	0.84	0.42	
4歳	0.92	0.33	2.45	1.24	1.01	0.32	0.30	0.78	1.51	
5歳以上	0.92	0.33	2.45	1.24	1.01	0.32	0.30	0.78	1.51	
単純平均	0.77	0.59	1.13	0.81	1.12	0.47	0.43	0.81	0.81	
年齢別資源尾数 (百万尾)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	1,134	895	1,919	1,241	1,420	2,427	1,309	7,838	5,335	
1歳	798	636	293	1,074	691	338	1,251	779	5,083	
2歳	317	199	100	114	340	112	80	331	190	
3歳	146	108	76	49	41	59	45	30	53	
4歳	62	38	62	22	14	11	27	22	9	
5歳以上	24	23	30	5	5	5	8	17	12	
計	2,481	1,900	2,479	2,505	2,512	2,951	2,720	9,016	10,681	
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	21	24	46	26	38	62	28	233	163	
1歳	49	43	12	87	37	19	85	59	279	
2歳	25	20	9	9	31	9	8	38	21	
3歳	16	13	8	6	4	7	5	3	7	
4歳	7	4	8	2	2	1	3	2	1	
5歳以上	3	3	4	1	1	1	1	2	1	
計	121	109	87	131	112	99	129	338	471	
親魚量	75	63	35	62	56	28	59	76	169	
RPS	15.0	14.3	55.4	20.1	25.4	87.4	22.3	103.2	31.6	
年齢別平均体重 (g)										
年齢\年	2003	2004	2005	2006	2007	2008	2009	2010	2011	
0歳	19	27	24	21	27	26	21	30	31	
1歳	61	68	41	81	53	55	68	76	55	
2歳	78	102	88	83	92	82	93	116	109	
3歳	107	124	109	118	99	123	108	117	122	
4歳	117	111	122	113	111	123	115	109	108	
5歳以上	138	118	143	108	110	142	127	119	119	

年齢別漁獲尾数 (百万尾)	Catch in number at age (million individuals)
年齢\年	Age\Year
0歳	Age 0
1歳	Age 1
2歳	Age 2
3歳	Age 3
4歳	Age 4
5歳以上	Age 5 and above
計	Total
年齢別漁獲量 (千トン)	Catch at age (thousand tons)
漁獲割合	Exploitation rate
年齢別漁獲係数 (F)	Fishing mortality (F) at age
単純平均	Simple average
年齢別資源尾数 (百万尾)	Number of fish at age (million individuals)
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)	Stock biomass at age (thousand tons), spawning biomass (thousand tons),RPS

	(individuals/kg)
親魚量	Spawning biomass
年齢別平均体重 (g)	Average body weight at age (g)

年齢別漁獲尾数 (百万尾)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	515	330	2,554	4,523	4,036	6,088	6,096	1,569
1歳	612	813	567	2,783	1,897	1,378	2,236	3,374
2歳	570	544	483	398	1,252	1,402	1,545	3,698
3歳	25	240	297	211	345	1,078	892	950
4歳	4	8	83	43	138	268	348	479
5歳以上	1	5	3	65	30	86	130	155
計	1,727	1,939	3,987	8,022	7,698	10,299	11,247	10,226

年齢別漁獲量 (千トン)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	13.6	7.4	62.0	89.1	75.8	83.0	108.1	25.4
1歳	34.2	44.6	30.8	111.8	81.1	70.2	91.9	134.1
2歳	50.2	48.9	47.0	34.9	99.1	129.0	112.8	212.2
3歳	3.0	26.9	35.4	22.1	38.7	116.4	83.8	82.5
4歳	0.6	1.0	10.5	5.0	16.9	35.0	38.0	48.7
5歳以上	0.1	0.8	0.5	7.6	4.2	12.3	17.1	18.4
計	102	130	186	270	316	446	452	521
漁獲割合	19.0%	19.5%	15.4%	16.5%	15.0%	16.8%	14.4%	15.3%

年齢別漁獲係数 (F)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	0.09	0.05	0.14	0.19	0.21	0.29	0.12	0.05
1歳	0.29	0.26	0.13	0.28	0.14	0.13	0.20	0.12
2歳	0.44	0.60	0.31	0.16	0.25	0.18	0.26	0.81
3歳	0.64	0.42	1.09	0.27	0.25	0.45	0.20	0.32
4歳	0.26	0.51	0.32	0.55	0.36	0.40	0.32	0.20
5歳以上	0.26	0.51	0.32	0.55	0.36	0.40	0.32	0.20
単純平均	0.33	0.39	0.39	0.33	0.26	0.31	0.24	0.28

年齢別資源尾数 (百万尾)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	7,031	8,796	23,717	32,462	25,546	29,679	63,514	39,147
1歳	2,954	4,292	5,626	13,807	18,057	13,820	14,910	37,584
2歳	1,959	1,479	2,212	3,306	6,976	10,551	8,136	8,163
3歳	65	846	545	1,087	1,891	3,651	5,925	4,189
4歳	24	23	371	123	556	985	1,565	3,241
5歳以上	3	14	15	188	121	316	582	1,048
計	12,035	15,449	32,485	50,973	53,146	59,001	94,631	93,372

年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS, 尾/kg)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	185	197	576	640	480	404	1,126	635
1歳	165	236	305	555	772	704	613	1,494
2歳	173	133	215	290	552	971	594	468
3歳	8	95	65	114	212	394	557	364
4歳	3	3	47	15	68	129	171	330
5歳以上	1	2	2	22	17	45	77	124
計	534	666	1,211	1,635	2,100	2,647	3,137	3,415
親魚量	266	351	483	718	1,003	1,680	1,521	1,585
RPS	26.4	25.1	49.2	45.2	25.5	17.7	41.8	24.7

年齢別平均体重 (g)

年齢\年	2012	2013	2014	2015	2016	2017	2018	2019
0歳	26	22	24	20	19	14	18	16
1歳	56	55	54	40	43	51	41	40
2歳	88	90	97	88	79	92	73	57
3歳	119	112	119	105	112	108	94	87
4歳	128	128	127	118	122	130	109	102
5歳以上	175	181	162	117	139	143	132	119

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

年齢別漁獲量 (千トン)	Catch at age (thousand tons)
漁獲割合	Exploitation rate
年齢別漁獲係数 (F)	Fishing mortality (F) at age
単純平均	Simple average
年齢別資源尾数 (百万尾)	Number of fish at age (million individuals)
年齢別資源量 (千トン)、親魚量 (千トン)、再生産成功率 (RPS、尾/kg)	Stock biomass at age (thousand tons), spawning biomass (thousand tons), RPS (individuals/kg)
親魚量	Spawning biomass
年齢別平均体重 (g)	Average body weight at age (g)

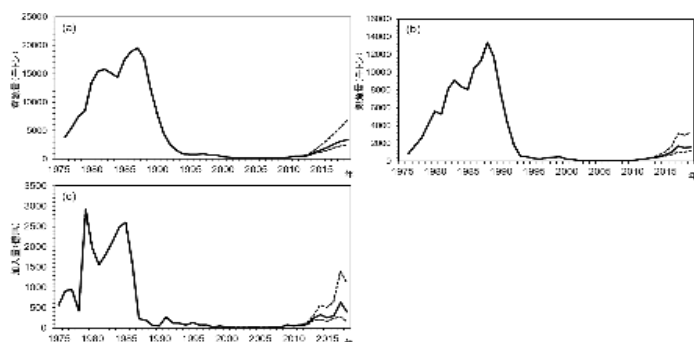
Appendix Table 2-2. Values of indices used for tuning

*The standing stock of age 0 fish in the subarctic region in fall for 2007 was excluded from the tuning as the survey area was too small to fully cover the estimated main distribution area of age 0 fish of Japanese sardines and the estimation accuracy was considered to be low (underestimation).

	2005	2006	2007	2008	2009	2010	2011	2012
① 秋季亜寒帯域0歳魚現存量(百万尾)	1,202.8	63.0	59.8*	1,018.1	1,414.8	15,258.2	7,358.6	5,714.6
② 未成魚越冬群指数		1,093.5	370.9	385.4	921.2	780.3	3,373.9	408.3
③ 潮岬以東海域産卵量(海区I・II)	31.4	7.2	32.1	12.9	24.1	37.5	52.0	115.9

	2013	2014	2015	2016	2017	2018	2019	2020
① 秋季亜寒帯域0歳魚現存量(百万尾)	6,600.8	11,891.7	34,764.1	15,550.9	17,091.6	54,528.3	13,870.3	
② 未成魚越冬群指数	1,396.7	1,757.4	2,064.8	2,480.0	1,855.0	2,178.1	6,990.8	17,329.1
③ 潮岬以東海域産卵量(海区I・II)	133.9	306.3	146.1	240.6	451.6	1,354.2	1,803.8	681.5

① 秋季亜寒帯域 0 歳魚現存量 (百万尾)	(i) Standing stock of age 0 fish in the subarctic region in fall (million individuals)
② 未成魚越冬群指数	(ii) Index for wintering juveniles
③ 潮岬以東海域産卵量 (海区 I・II)	(iii) Egg production in sea areas to the east of Cape Shionomisaki (Regions I and II)



資源量 (千トン)	Stock biomass (thousand tons)
親魚量 (千トン)	Spawning biomass (thousand tons)
加入量 (億尾)	Recruitment (100 million individuals)

年	Year
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Appendix Figure 2-1. Estimate values and 90% confidence intervals of (a) stock biomass, (b) spawning biomass, and (c) recruitment

Solid lines indicate estimate values, and broken lines indicate 90% confidence intervals.

Appendix 3. Outline of surveys conducted for stock assessment

(1) Surveys of catch and surveys of fishery conditions at major ports and fishing grounds

Related experimental and research institutions collect data on the catch volume as well as the body length, body weight, age, maturity and other attributes of the catch landed at major ports. They analyze the length-weight, length-age, age-maturity, and other relationships based on the collected data, and estimate catch at age based on catch data of agricultural and forestry statistics. In addition, institutions conduct fisheries status surveys and sampling vessel surveys at various fishing grounds, and survey distribution and recruitment in adjacent waters. In the Boso-Joban sea area in winter, Chiba Prefectural Fisheries Experimental Station and Ibaraki Prefectural Fisheries Experimental Station survey the CPUE, fishing grounds distribution, and catch composition of large- to medium-scale purse seine fishery, and obtain the index for wintering juveniles, which serves as an indicator for stock biomass. The index for wintering juveniles is a value obtained by deriving the daily abundance index for "koba" (small) and "kochuba" (small to medium) brands, which correspond to age 1 fish, and totaling it for the period of their arrival from December of the previous year to April of the current year (Uchiyama 1998).

(2) Egg and larval survey

In order to identify the status of spawning, related experimental and research institutions conduct a sampling survey by vertical hauling of modified NORPAC plankton net (45 cm mouth diameter; 0.335 mm mesh). Prefectural experimental and research institutions set fixed lines along an adjacent coast, and conduct the survey all year round on an approximately monthly basis. The NRIFS conducts a large-scale survey from areas near Kanto to areas around the Kuroshio Current in Satsunan in the spawning season from February to March, and also conducts sampling through other offshore oceanic/resource surveys as needed. The Egg and Larvae Survey Association compiles the obtained results and estimates egg production by sea area. The association classifies sea areas as follows: Region I - area to the north of Joban; Region II - Boso to Kumano Nada; Region III - area outside Kii Strait to Hyuga Nada; and Region IV - Satsunan.

(3) Recruitment survey / offshore distribution survey

The following surveys are conducted to identify the status of resources in offshore areas outside fishing grounds.

- (i) Transitional area larva/juvenile survey: Since 1996, the Japan Fisheries Research and Education Agency (FRA) has conducted sampling of larvae and juveniles using a midwater trawl for larvae and juveniles (25 m net mouth, 10 mm cod mesh) in part of the Kuroshio-Oyashio transition area at 35 to 42 degrees north latitude and 143 to 165 degrees east longitude in May to June, and calculates the recruitment index by the following method that has modified Nishida et al. (2001).

Recruitment index = Σ [the median value of CPUE for catch points in each water temperature area with sea surface temperature of 1°C (individuals/net)] \times [the ratio of catch points in each water temperature area with sea surface temperature of 1°C] \times [the ratio of each water temperature area with sea surface temperature of 1°C to the entire sea area surveyed]

- (ii) Pelagic fish survey in the Northwestern Pacific in the northward migration period (stock survey of saury in western part of the North Pacific, stock survey of pelagic fishes in the northward migration period): Since 2001, the FRA has conducted surveys of catch using a midwater trawl (30 m net mouth, 17 mm cod mesh) in the transition area to the Oyashio Current region from May to July, and has estimated the distribution of fish.
- (iii) Pelagic fish survey in the Northwestern Pacific in fall: Since 2005, the FRA has conducted stock surveys using a quantitative echo sounder and surveys of catch using a midwater trawl (30 m net mouth, 17 mm cod mesh) in waters off Sanriku to eastern Hokkaido and to the east of the Kuril Islands from September to October. Based on the results, the agency has identified the distribution status of fish of age 1 and above and has estimated the standing stock of age 0 fish in the area with a sea surface temperature of 10 to 15°C in the subarctic region at 145 to 170 degrees east longitude.
- (iv) Drift-net fishing survey in waters from Sanriku to eastern Hokkaido: Kushiro Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization conducts a drift-net fishing survey in waters from Sanriku to eastern Hokkaido from spring to fall, and identifies the distribution status, body length, age composition, etc. of fish schools in offshore areas outside fishing grounds.

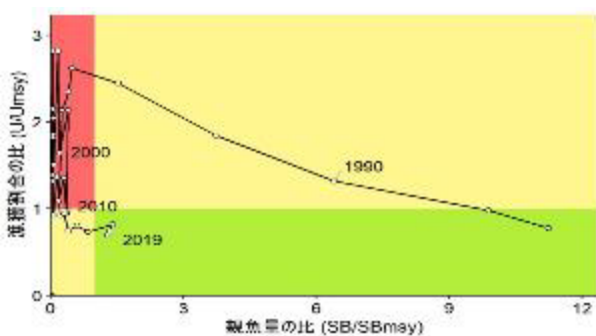
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- H. Nishida, C. Watanabe, and A. Yatsu (2001) Forecasting the recruitment abundance of Japanese sardine and chub mackerel based on the juvenile abundance in the Kuroshio-Oyashio transition regions. *Fisheries biology and oceanography in the Kuroshio*, 2, 77-82.
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Appendix 4. Kobe plot based on exploitation rate

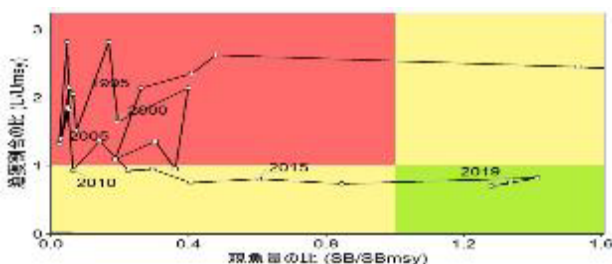
The figure below shows a Kobe plot based on the spawning biomass and exploitation rate (U). The U for the present stock has been lower than the level that produces MSY (U_{msy}) since 2012. In line with this, the spawning biomass has increased and has exceeded the level that produces MSY (SB_{msy}) since 2017.

Item	Value	Explanation
SB _{msy}	1.187 million tons	Spawning biomass that produces MSY
U _{msy}	20.6%	Exploitation rate that produces MSY
U ₂₀₁₉	15.3%	Exploitation rate in 2019
U ₂₀₁₉ /U _{msy}	0.74	Ratio of the exploitation rate in 2019 to the exploitation rate that produces MSY



漁獲割合の比	U/U _{msy}
親魚量の比	SB/SB _{msy}

Enlarged view



漁獲割合の比	U/U _{msy}
親魚量の比	SB/SB _{msy}

Appendix Figure 4-1. Relationship of the past spawning biomass and exploitation rate to the spawning biomass that produces MSY (SB_{msy}) and exploitation rate that produces MSY (U_{msy}) (Kobe plot)

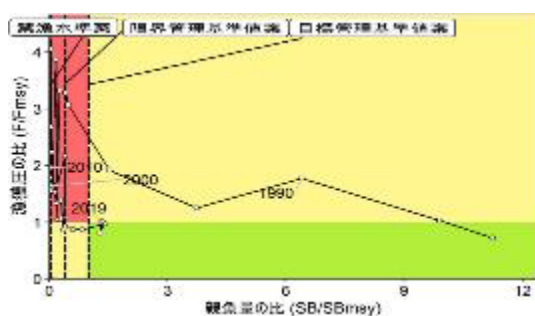
Appendix 5. Proposed reference points and fishing ban level, etc.

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

Item	Value	Explanation
Proposed target reference point	1.187 million tons	Spawning biomass that produces MSY (SBmsy)
Proposed limit reference point	487 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed fishing ban level	69 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

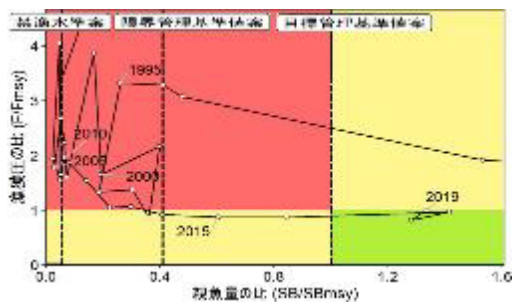
It was proposed at the "Research Institute Meeting on Reference Points" held in March 2020 that the spawning biomass that produces MSY (SBmsy: 1.187 million tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 487 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 69 thousand tons) be used for the fishing ban level (SBban).

Appendix Figure 5-1 shows a Kobe plot based on the proposed SBtarget and fishing mortality that produces MSY (Fmsy). The spawning biomass in 2019 (SB2019: 1.585 million tons) obtained by cohort analysis was above the proposed SBtarget. The fishing mortality of the present stock had been below Fmsy since 2014, but it is found to be about the same level as Fmsy in 2019.



漁獲割合の比	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

Enlarged view



漁獲割合の比	U/U_{msy}
親魚量の比	SB/SB_{msy}
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. Relationship between the proposed reference points and spawning biomass / fishing mortality (Kobe plot)

Appendix 6. Future projection compliant with the proposed harvest control rules

(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 (B) in 2019 estimated in stock assessment (Appendix 7). 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. In addition, although study on the appropriateness of the method and the uncertainty in the case where the S-R relationship was erroneous is still insufficient, we also calculated a future projection reflecting the recent favorable recruitment trend and presented it in Appendix 8.

The catch in 2020 was assumed from the projected B and the current fishing mortality (F₂₀₁₅₋₂₀₁₉). For the current fishing mortality, we used the F value that gives %SPR corresponding to the fishing mortality in 2015 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 harvest control rules (HCRs) below based on the spawning biomass projected for each year.

(2) Proposed HCRs

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 (SB_{target}). 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 (SB_{limit}), the fishing mortality is to be reduced in a linear manner to the proposed fishing ban level, and if it is above SB_{limit}, the value obtained by multiplying F_{msy} by safety coefficient β should be the upper limit of fishing mortality. Appendix Figure 6-1 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 the standard value 0.8 is desirable for β , as a result of considering uncertainties, such as the case of shifting to a high recruitment period or a case where the S-R relationship stays the same throughout the entire period without being clearly divided according to the period.

(3) Projected values for 2021

The average catch in 2021 estimated based on the proposed HCRs was 698 thousand tons where β was 0.8, and 841 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 2.882 million tons on average, and the estimation was above SB_{limit} in all iterations (Appendix Table 6-2).

Spawning biomass in 2021 (average projection value): 2.882 million tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
$\beta = 0.8$	698	0.85	19
Other strategy (when using different β in the proposed HCRs)			
$\beta = 1.0$	841	1.07	23
$\beta = 0.9$	771	0.96	21
$\beta = 0.7$	622	0.75	17
$\beta = 0.6$	544	0.64	15
$\beta = 0$	0	0	0
F2015-2019	797	1.00	22

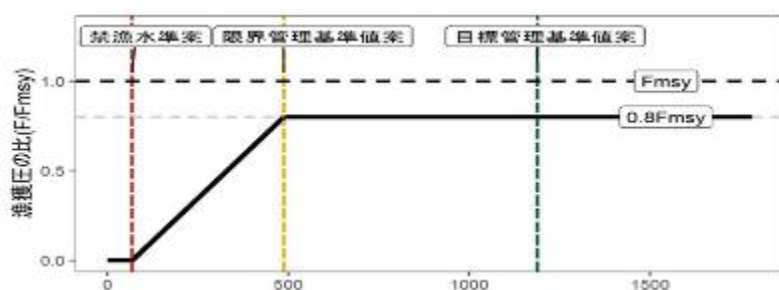
(4) Projection for 2022 onward

Appendix Figure 6-2 and Appendix Tables 6-1 and 6-2 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 1.416 million tons where β is 0.8 (the 80% confidence interval is 0.839 million to 2.118 million tons), and 1.209 million tons where β is 1.0 (the 80% confidence interval is 0.688 million to 1.840 million tons). The probability of the projected spawning biomass being above the proposed target reference point exceeds 50% where β is 0.9 or less. The probability of the projected spawning biomass being above the proposed limit reference point is 98% where β is 1, 99% where β is 0.9, and 100% in any other case. If the current fishing mortality (F2015-2019) is continued, the projected spawning biomass in 2031 is 1.271 million tons (the 80% confidence interval is 0.732 million to 1.930 million tons), and the probability of the projected spawning biomass being above the proposed target reference point is 48%, and the probability of the projected spawning biomass being above the proposed limit reference point is 99%.

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 reference points below (%)		
			Proposed target reference point	Proposed limit reference point	Proposed fishing ban level
When using β proposed by the Research Institute Meeting in the proposed HCRs					

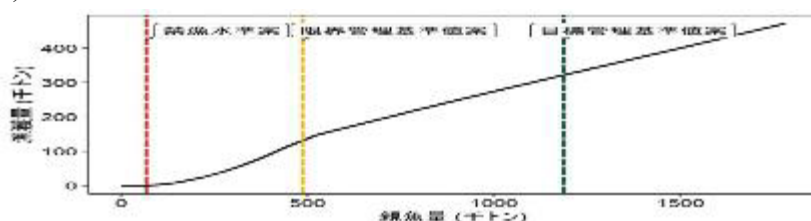
$\beta = 0.8$	1,416	839-2,118	60	100	100
Other strategy (when using different β in the proposed HCRs)					
$\beta = 1.0$	1,209	688-1,840	43	98	100
$\beta = 0.9$	1,309	761-1,978	51	99	100
$\beta = 0.7$	1,533	924-2,278	70	100	100
$\beta = 0.6$	1,664	1,017-2,451	79	100	100
$\beta = 0$	3,090	2,071-4,279	100	100	10
F2015-2019	1,271	732-1,930	48	99	100

a) When the vertical axis is fishing mortality



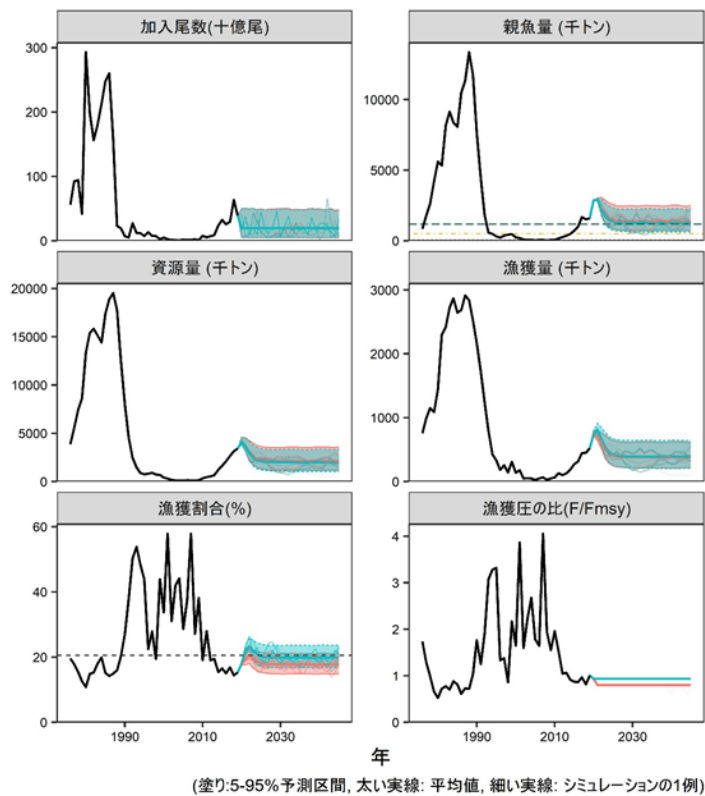
漁獲圧の比	F/Fmsy
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

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 6-1. Proposed HCRs



(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)

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 solid line: simulation example)

Appendix Figure 6-2. Future projection using proposed HCRs based on proposed reference points (red) and future projection in the case of continuing fishing with the current fishing mortality (green)

The thick solid line indicates the average value, the shaded part indicates the 90% prediction interval that covers 90% of the simulation results, the thin lines indicate three 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 U_{msy} . Safety coefficient β is 0.8.

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

a) Probability of being above the proposed target reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	100	100	100	89	62	51	47	45	45	44	43	43	43
0.9	100	100	100	95	71	60	55	53	53	52	51	51	51
0.8	100	100	100	98	80	70	64	62	62	61	60	60	60
0.7	100	100	100	100	88	78	74	72	71	70	69	70	69
0.6	100	100	100	100	94	86	82	80	80	79	78	79	78
0.5	100	100	100	100	98	92	90	88	87	86	86	86	85
0.4	100	100	100	100	100	97	95	94	93	93	93	93	92
0.3	100	100	100	100	100	99	98	98	97	97	97	97	96
0.2	100	100	100	100	100	100	100	99	99	99	99	99	99
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100

b) Probability of being above the proposed limit reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	100	100	100	100	100	100	99	99	99	99	98	98	98
0.9	100	100	100	100	100	100	100	100	99	99	99	99	99
0.8	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
0.6	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
0.4	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
0.2	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

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

a) Changes in average values of spawning biomass

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	2,876	2,882	2,136	1,655	1,416	1,305	1,253	1,237	1,226	1,218	1,210	1,209	1,205
0.9	2,876	2,882	2,205	1,754	1,519	1,403	1,348	1,332	1,321	1,315	1,308	1,309	1,308
0.8	2,876	2,882	2,276	1,861	1,631	1,512	1,454	1,437	1,426	1,421	1,414	1,416	1,418
0.7	2,876	2,882	2,350	1,975	1,755	1,634	1,572	1,553	1,543	1,537	1,531	1,533	1,537
0.6	2,876	2,882	2,427	2,098	1,891	1,771	1,707	1,686	1,674	1,668	1,662	1,664	1,668
0.5	2,876	2,882	2,506	2,230	2,042	1,925	1,860	1,837	1,824	1,818	1,811	1,814	1,818
0.4	2,876	2,882	2,585	2,372	2,209	2,100	2,035	2,013	1,998	1,991	1,984	1,986	1,990
0.3	2,876	2,882	2,676	2,526	2,394	2,298	2,238	2,217	2,202	2,195	2,187	2,189	2,193
0.2	2,876	2,882	2,765	2,691	2,600	2,523	2,473	2,456	2,444	2,438	2,430	2,432	2,436
0.1	2,876	2,882	2,858	2,869	2,829	2,780	2,746	2,739	2,732	2,729	2,723	2,727	2,732

b) Changes in average values of catch

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	742	841	693	539	462	427	411	404	401	398	397	396	394
0.9	742	771	656	521	452	418	403	396	394	392	391	391	389
0.8	742	698	613	499	437	405	391	384	382	381	380	380	380
0.7	742	622	564	470	417	389	375	369	367	365	365	365	365
0.6	742	544	509	435	392	366	354	348	346	345	344	344	345
0.5	742	462	446	392	358	337	327	321	319	318	318	318	318
0.4	742	377	376	340	316	300	291	286	285	283	283	283	283
0.3	742	288	298	276	261	250	245	241	240	239	238	238	238
0.2	742	196	209	200	193	187	184	182	181	180	180	180	180
0.1	742	100	110	109	107	105	104	104	103	103	103	103	103

Appendix 7. Method of future projection

We performed future projection from the obtained stock biomass, based on the proposed HCRs. For projection of recruitment in the 2020 fishing season onward, we used values estimated based on the HS S-R relationship estimated for the normal recruitment period (from 1988 to 2018) ($a = 0.026$, $b = 764,050$, $SD = 0.705$) proposed at the "Research Institute Meeting on Reference Points" held in March 2020 (Furuichi et al. 2020a). 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 (Furuichi et al. 2020b), and as for the optimization method, the least-squares method is used. The model does not consider autocorrelation between the residuals of the recruitment.

For fishing mortality F in future projection, we used the 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 7-1. 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 "Research Institute Meeting on Reference Points." These values are based on the 2019 stock assessment, similar to the S-R relationship, and the values set for future projection in that assessment were used for the selectivity and average body weight of catch in the present assessment. The current fishing mortality ($F_{2015-2019}$) was assumed to be the fishing mortality in 2020.

For projection of the number of fish, we used forward calculation of cohort analysis (equation (9)).

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M) \quad \text{※}a < 4 \text{ の場合} \quad (9a)$$

$$N_{5+y+1} = (N_{5+y} + N_{4,y}) \exp(-F_{4,y} - M) \quad \text{※最高齢グループ} \quad (9b)$$

We obtained the catch in number from the number of fish obtained above and the F value assumed from each fishing scenario, based on equation (10).

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

References

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gan (2019) nendo maiwashi taiheiyoikeigun no shigen hyoka. wagakuni shuhen suiiki no gyogyo shigen hyoka (Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2020/2021)), Fisheries Agency/Japan Fisheries Research and Education Agency, Tokyo.

Appendix Figure 7-1. Parameters used for calculating the future projection

	選択率 (注1)	Fmsy (注2)	F2015-2019 (注3)	平均体重 (g)	自然死亡 係数	成熟 割合
0歳	0.36	0.18	0.17	16.7	0.4	0.0
1歳	0.37	0.18	0.17	44.9	0.4	0.2
2歳	0.49	0.24	0.23	81.4	0.4	1.0
3歳	1.00	0.50	0.47	104.8	0.4	1.0
4歳	1.00	0.50	0.47	120.5	0.4	1.0
5歳以上	1.00	0.50	0.47	138.1	0.4	1.0

選択率 (注1)	Selectivity (Note 1)
Fmsy (注2)	Fmsy (Note 2)
F2015-2019 (注3)	F2015-2019 (Note 3)
平均体重 (g)	Average body weight (g)
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	Age 3
4歳	Age 4
5歳以上	Age 5 and above

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

Note 2: Fmsy estimated at 2020 Research Institute Meeting (i.e., the $F_{current}$ in the 2019 stock assessment multiplied by $F_{msy}/F_{current}$).

Note 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 8. Future projection in the case of incorporating the recent favorable recruitment trend

As recruitment in 2014 onward has been higher than the S-R relationship in the normal recruitment period, we also estimated the future projection in the case of incorporating the recent favorable recruitment trend. However, caution is required in handling this result because study on the appropriateness of the method and the uncertainty in the case where the S-R relationship was erroneous is still insufficient. As uncertainty of recruitment, we gave future recruitment by random resampling of residuals between observation values and the S-R relationship, and performed 10,000 iterations. In order to reflect the recent favorable recruitment trend, we adopted backward resampling that resamples residuals by dividing the time backwards. The backward resampling is conducted through the following procedure (Appendix Figure 8-1).

- 1st to 5th year of the future projection: perform resampling, allowing duplicates only from residuals in the latest 5 years (from 2015 to 2019) of stock assessment.
- 6th to 10th year of the future projection: randomly select either residuals in the latest 5 years (from 2015 to 2019) or residuals in the 5 years prior (from 2000 to 2014), and perform resampling, allowing duplicates from residuals in the selected 5 years.
- 11th year onward of the future projection: further add 5-year resampling periods in the same manner as the procedure above.

The conditions are the same as those for Appendix 6, except for the adoption of backward resampling of residuals for uncertainty of recruitment.

●Projected values for 2021

The average catch in 2021, which was estimated based on the proposed HCRs by applying backward resampling of residuals for recruitment errors, was 747 thousand tons where β was 0.8, and 901 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 2.935 million tons at average, and the estimation was above SBlimit in all iterations (Appendix Table 8-2).

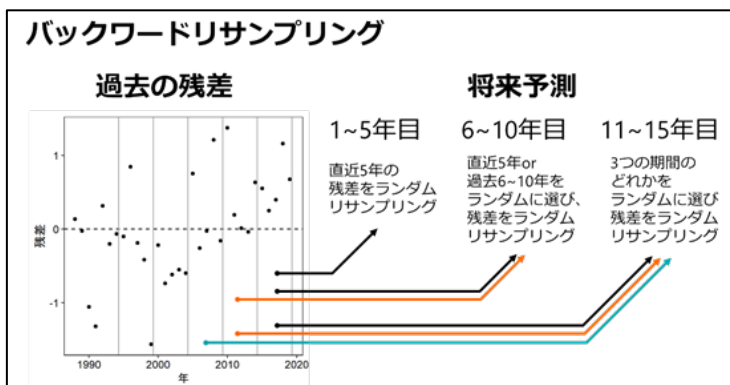
Spawning biomass in 2021 (average projection value): 2.935 million tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
$\beta = 0.8$	747	0.85	18
Other strategy (when using different β in the proposed HCRs)			
$\beta = 1.0$	901	1.07	22

$\beta = 0.9$	826	0.96	20
$\beta = 0.7$	666	0.75	16
$\beta = 0.6$	581	0.64	14
$\beta = 0$	0	0	0
F2015-2019	853	1.00	21

●Projection for 2022 onward

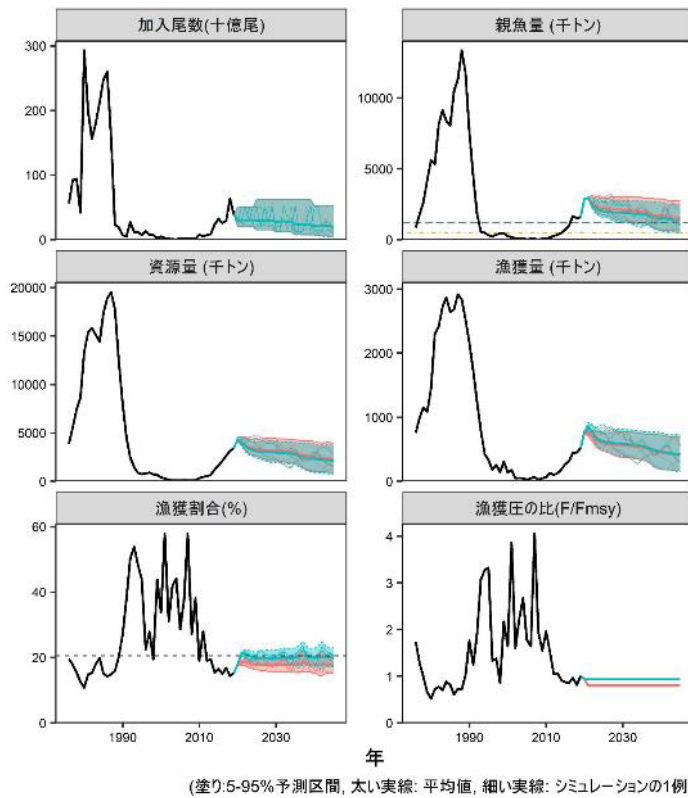
Appendix Figure 8-2 and Appendix Tables 8-1 and 8-2 show the future projection results including 2022 onward in the case of applying backward resampling of residuals for recruitment errors. If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in 2031 is 2.096 million tons where β is 0.8 (the 80% confidence interval is 1.460 million to 2.795 million tons), and 1.819 million tons where β is 1.0 (the 80% confidence interval is 1.248 million to 2.459 million tons). As backward resampling that reflects the recent favorable recruitment has been adopted, the projected spawning biomass is above the proposed target reference point at a probability of over 50%, even where β is 1.0. If the current fishing mortality (F2015-2019) is continued, the projected spawning biomass in 2031 is 1.900 million tons (the 80% confidence interval is 1.310 million to 2.559 million tons), the probability of the projected spawning biomass being above the proposed target reference point is 95%, and the probability of the projected spawning biomass being above the proposed limit reference point is 100%.

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 reference points below (%)		
			Proposed target reference point	Proposed limit reference point	Proposed fishing ban level
When using β proposed by the Research Institute Meeting in the proposed HCRs					
$\beta = 0.8$	2,096	1,460-2,795	99	100	100
Other strategy (when using different β in the proposed HCRs)					
$\beta = 1.0$	1,819	1,248-2,459	93	100	100
$\beta = 0.9$	1,950	1,348-2,617	96	100	100
$\beta = 0.7$	2,263	1,589-3,001	100	100	100
$\beta = 0.6$	2,452	1,741-3,225	100	100	100
$\beta = 0$	4,544	3,430-5,689	100	100	100
F2015-2019	1,900	1,310-2,559	95	100	100



バックワードリサンプリング	Backward resampling
過去の残差	Past residuals
残差	Residuals
年	Year
1~5年目	1st to 5th year
直近5年の残差をランダムリサンプリング	Perform random resampling of errors in the latest 5 years.
6~10年目	6th to 10th year
直近5年 or 過去6~10年をランダムに選び、残差をランダムリサンプリング	Randomly select between the latest 5 years or the 5 years earlier, and perform random resampling of residuals.
11~15年目	11th to 15th year
3つの期間のどれかをランダムに選び残差をランダムリサンプリング	Randomly select from the three periods, and perform random resampling of residuals.

Appendix Figure 8-1. Schematic of backward resampling of residuals



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 solid line: simulation example)

Appendix Figure 8-2. Future projection using proposed HCRs based on proposed reference points (in red) and future projection in the case of continuing fishing with the current fishing mortality (in green) in the case of applying backward resampling of residuals for recruitment errors.

The thick solid line indicates the average value, the shaded part indicates the 90% prediction interval that covers 90% of the simulation results, and the thin lines indicate three patterns of future projection examples. In the figure of spawning biomass, the green broken line indicates the proposed target reference point, and the yellow dotted line indicates the proposed limit reference point. In the figure of exploitation rate, the broken line indicates

Umsy. Safety coefficient β is 0.8.

Appendix Table 8-1. Probability of future spawning biomass being above the proposed target reference point and limit reference point (in the case of applying backward resampling of residuals for recruitment errors)

a) Probability of being above the proposed target reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	100	100	100	100	100	100	100	100	96	93	93	93	63
0.9	100	100	100	100	100	100	100	100	99	97	96	96	67
0.8	100	100	100	100	100	100	100	100	100	100	99	99	70
0.7	100	100	100	100	100	100	100	100	100	100	100	100	72
0.6	100	100	100	100	100	100	100	100	100	100	100	100	74
0.5	100	100	100	100	100	100	100	100	100	100	100	100	77
0.4	100	100	100	100	100	100	100	100	100	100	100	100	82
0.3	100	100	100	100	100	100	100	100	100	100	100	100	91
0.2	100	100	100	100	100	100	100	100	100	100	100	100	99
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100

b) Probability of being above the proposed limit reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	100	100	100	100	100	100	100	100	100	100	100	100	98
0.9	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
0.7	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
0.5	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
0.3	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
0.1	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 and catch (in the case of applying backward resampling of residuals for recruitment errors)

a) Changes in average values of spawning biomass

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	2,876	2,935	2,458	2,157	2,003	1,932	1,899	1,863	1,847	1,839	1,826	1,819	1,434
0.9	2,876	2,935	2,533	2,275	2,136	2,068	2,035	1,997	1,980	1,972	1,958	1,950	1,545
0.8	2,876	2,935	2,610	2,401	2,281	2,219	2,187	2,148	2,129	2,120	2,105	2,096	1,667
0.7	2,876	2,935	2,690	2,536	2,439	2,386	2,357	2,318	2,298	2,288	2,272	2,263	1,804
0.6	2,876	2,935	2,773	2,680	2,613	2,571	2,548	2,510	2,491	2,480	2,463	2,452	1,958
0.5	2,876	2,935	2,859	2,834	2,802	2,779	2,764	2,730	2,711	2,700	2,682	2,671	2,137
0.4	2,876	2,935	2,949	2,999	3,011	3,011	3,010	2,982	2,965	2,965	2,936	2,925	2,346
0.3	2,876	2,935	3,042	3,176	3,240	3,272	3,291	3,273	3,262	3,254	3,236	3,224	2,595
0.2	2,876	2,935	3,138	3,366	3,493	3,566	3,613	3,611	3,610	3,608	3,592	3,581	2,896
0.1	2,876	2,935	3,238	3,569	3,772	3,899	3,984	4,007	4,023	4,030	4,020	4,013	2,268

b) Changes in average values of catch

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041
1.0	764	901	801	705	656	631	619	611	604	602	597	590	459
0.9	764	826	755	677	636	615	603	596	589	587	582	576	452
0.8	764	747	703	644	612	593	583	577	570	568	563	557	440
0.7	764	666	645	603	580	566	558	552	546	543	539	533	423
0.6	764	581	580	554	540	530	524	520	514	512	508	503	400
0.5	764	493	507	496	491	485	482	479	474	472	468	464	370
0.4	764	402	426	427	429	428	427	425	422	420	418	414	331
0.3	764	307	336	345	352	355	357	357	355	354	352	349	280
0.2	764	209	235	248	258	263	266	268	267	267	266	264	213
0.1	764	106	124	134	142	147	150	152	152	152	152	151	123

Appendix 9. Estimation that considers the catch by foreign countries

The present stock assessment was made without taking into consideration the catch by foreign countries. However, we estimated the case that considers the catch by foreign countries, while using a number of assumptions. The age composition and body weight at age of catch by foreign vessels are unknown, as we do not have access to such information, but considering the fishing waters and seasons as well as the migration routes of Japanese sardine, we assumed their catch to be equal to the catch by purse seine fisheries in areas to the north of Miyagi Prefecture from July to December. Appendix Table 9-1 and Appendix Figures 9-1 and 9-2 show the catch volume and catch in number at age including the catch by foreign countries. Catch by Russia substantially increased in 2019, so the catch in number at age of fish of age 1 and above increased mainly in 2019 as a result of considering the catch by foreign vessels.

We estimated the stock biomass based on the obtained catch in number at age. The method is the same as in the main document. As a result of considering the catch by foreign countries, the recent stock biomass increased slightly, but no change was observed in the overall trend (Appendix Table 9-1, Appendix Figures 9-3 and 9-4). On the other hand, the recent exploitation rate and fishing mortality showed an increasing trend (Appendix Figures 9-3 and 9-5).

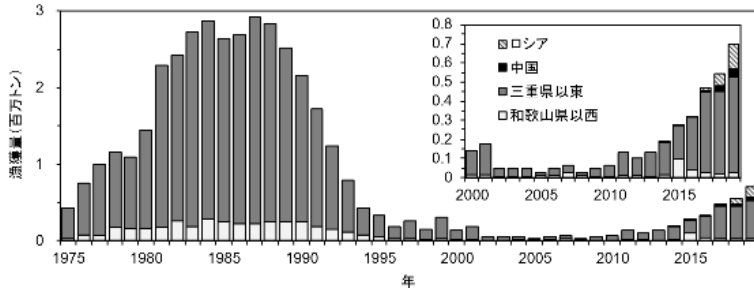
Item	Value	Explanation
SB2019	1.719 million tons	Spawning biomass in 2019
F2019	(Ages 0, 1, 2, 3, 4, 5 and above) = (0.05, 0.15, 1.02, 0.48, 0.22, 0.22)	
U2019	18.9%	Exploitation rate in 2019

Item	Value	Explanation
%SPR (F2019)	33.8%	%SPR in 2019
%SPR (F2015-2019)	40.3%	%SPR corresponding to the current fishing mortality (2015 to 2019)

Compared to the level that produces MSY, the fishing mortality in 2019 was above the fishing mortality that produces MSY (F_{msy}) in the estimation result considering the catch by foreign countries (Appendix Figure 9-6). Except for that, there was no major change in the overall trend, and the spawning biomass in 2019 was above the spawning biomass that produces MSY (SB_{msy}).

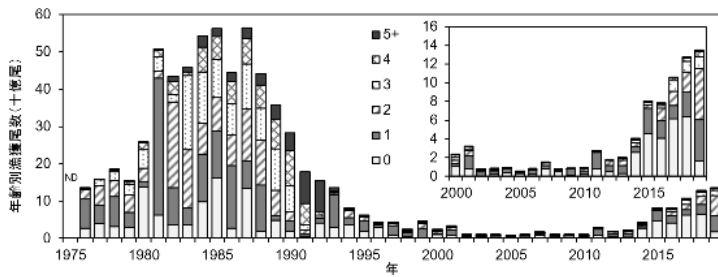
Item	Value	Explanation
SB2019/ SB_{msy}	1.45	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY

F2019/Fmsy	1.27	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*
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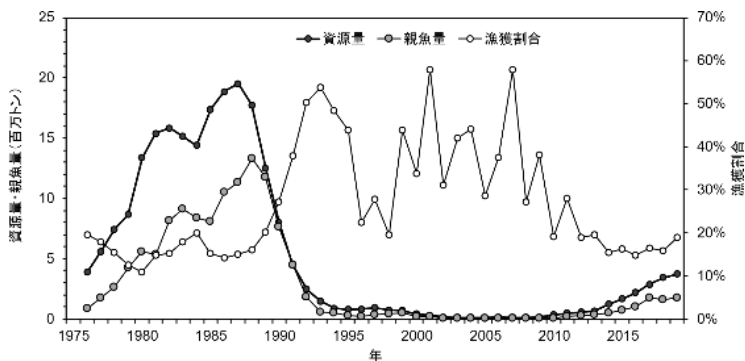
漁獲量 (百万トン)	Catch (million tons)
年	Year
ロシア	Russia
中国	China
三重県以東	Areas east of Mie Prefecture
和歌山県以西	Areas west of Wakayama Prefecture

Appendix Figure 9-1. Changes in catch volume



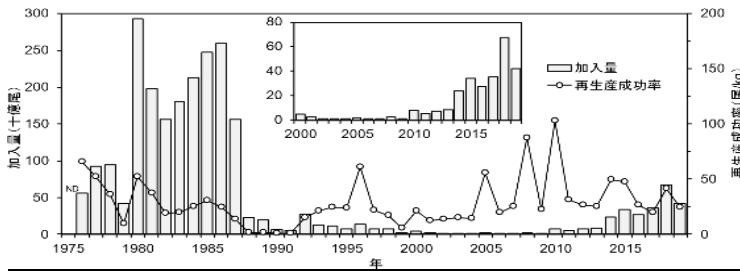
年齢別漁獲尾数 (十億尾)	Catch in number at age (billion individuals)
年	Year

Appendix Figure 9-2. Changes in catch in number at age



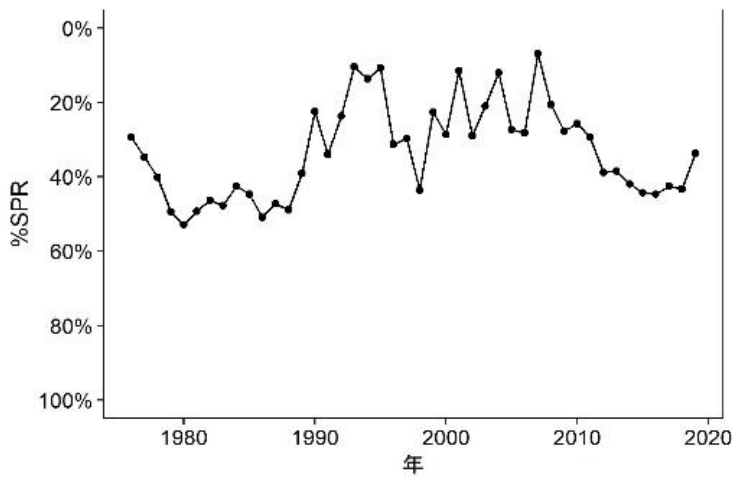
資源量・親魚量 (百万トン)	Stock biomass / spawning biomass (million tons)
漁獲割合	Exploitation rate
年	Year
資源量	Stock biomass
親魚量	Spawning biomass
漁獲割合	Exploitation rate

Appendix Figure 9-3. Changes in stock biomass, spawning biomass, and exploitation rate



加入量 (十億尾)	Recruitment (billion individuals)
再生産成功率 (尾/kg)	RPS (individuals/kg)
年	Year
加入量	Recruitment
再生産成功率	RPS

Appendix Figure 9-4. Changes in recruitment and RPS

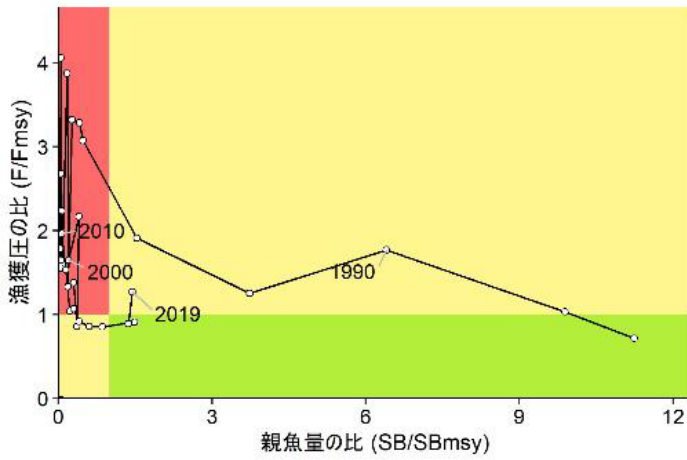


年	Year
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Appendix Figure 9-5. Changes in %SPR values

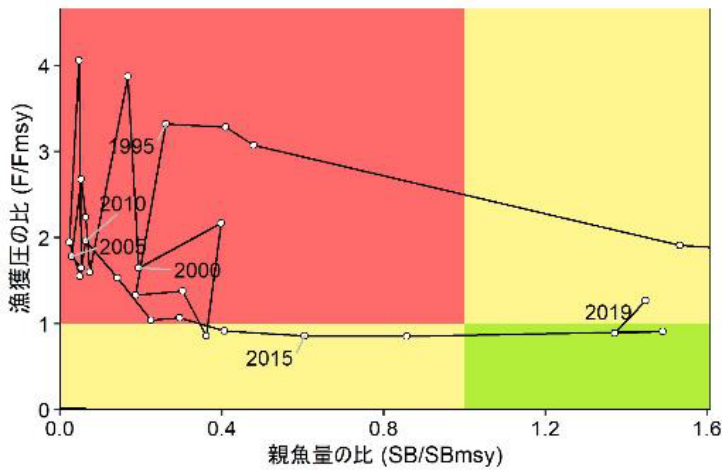
The %SPR indicates the ratio of spawning biomass with catch to spawning biomass

assuming no catch. The higher (lower) the F, the lower (higher) the %SPR.



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Enlarged view



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy

Appendix Figure 9-6. Relationship of the past spawning biomass and fishing mortality to the spawning biomass that produces MSY (SBmsy) and fishing mortality that produces MSY (Fmsy) (Kobe plot)

Appendix Table 9-1. 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 (億尾)	漁獲 割合 (%)	再生産 成功率 (尾/kg)
	太平洋 合計	ロシア	中国	日本 合計	三重県 以東					
1975	430			430	400	30				
1976	756			756	677	79	3,862	852	559	19.6
1977	991			991	934	56	5,553	1,774	923	17.8
1978	1,149			1,149	975	174	7,440	2,620	942	15.5
1979	1,089			1,089	933	156	8,647	4,219	419	12.6
1980	1,445			1,445	1,286	159	13,366	5,613	2,930	10.8
1981	2,296			2,296	2,129	167	15,415	5,325	1,978	14.9
1982	2,419			2,419	2,158	261	15,830	8,158	1,562	15.3
1983	2,725			2,725	2,539	186	15,151	9,140	1,802	18.0
1984	2,870			2,870	2,589	281	14,419	8,368	2,128	19.9
1985	2,644			2,644	2,397	247	17,392	8,079	2,479	15.2
1986	2,685			2,685	2,471	214	18,881	10,499	2,600	14.2
1987	2,916			2,916	2,696	220	19,542	11,322	1,565	14.9
1988	2,838			2,838	2,593	244	17,774	13,355	228	16.0
1989	2,524			2,524	2,280	243	12,507	11,754	194	20.2
1990	2,162			2,162	1,916	246	7,981	7,609	69	27.1
1991	1,724			1,724	1,544	180	4,546	4,440	53	37.9
1992	1,240			1,240	1,089	152	2,465	1,819	273	50.3
1993	791			791	675	116	1,467	569	121	53.9
1994	425			425	357	68	879	487	119	48.3
1995	332			332	277	55	756	310	73	43.9
1996	181			181	150	31	805	221	134	22.5
1997	255			255	228	27	916	360	78	27.9
1998	142			142	124	18	727	429	74	19.5
1999	308			308	281	27	701	473	26	43.9
2000	139			139	122	17	411	231	48	33.8
2001	177			177	162	15	305	199	25	57.9
2002	49			49	43	6	157	87	12	31.1
2003	51			51	46	5	121	75	11	42.0
2004	48			48	41	7	109	63	9	44.1
2005	25			25	16	9	87	35	19	28.6
2006	49			49	40	10	131	62	12	37.4
2007	65			65	42	23	112	56	14	57.9
2008	27			27	18	9	99	28	24	27.1
2009	49			49	46	3	129	59	13	38.2
2010	65			65	62	3	339	76	78	19.1
2011	132			132	122	10	471	169	53	28.0
2012	102			102	92	9	534	266	70	19.0
2013	130			130	124	6	665	351	87	19.5
2014	186	0		186	172	14	1,212	482	238	15.4
2015	271	0		270	175	95	1,670	718	342	16.2
2016	322	7		316	278	38	2,187	1,018	272	14.7
2017	473	17	10	446	423	23	2,866	1,769	354	16.5
2018	541	63	26	452	430	22	3,417	1,628	676	15.8
2019	700	133	46	521	495	26	3,706	1,719	419	18.9

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 (億尾)	Recruitment (100 million individuals)
漁獲割合 (%)	Exploitation rate (%)
再生産成功率 (尾/kg)	Recruitment per spawning (individuals/kg)
太平洋合計	Pacific Ocean total
ロシア	Russia
中国	China
日本合計	Japan total
三重県以東	Areas east of Mie Prefecture
和歌山県以西	Areas west of Wakayama Prefecture