Stock Assessment for Tsushima Current Stock of Japanese Anchovy (Fiscal Year 2022)

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Environment and Fisheries Applied Techniques Research Department, Fisheries Technology Institute

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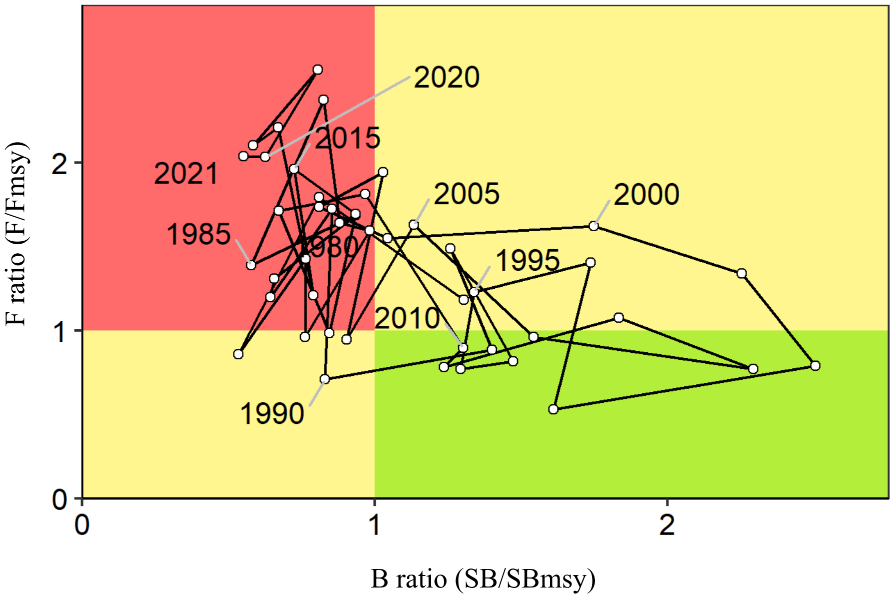
Summary

The biomass of this stock was estimated by cohort analysis using spawning volume and standardized CPUE (catch per unit effort) from small to medium-scale purse seine fisheries in Nagasaki Prefecture as tuning indices. The biomass of this stock has fluctuated in cycles, ranging from 113,000 to 426,000 tons from 1977 to 2020. Since 2009, it has been in an decreasing trend, and was estimated to be a record low of 104,000 tons in 2021. Likewise, SSB (spawning stock biomass) fluctuated in cycles, ranging from 45,000 to 210,000 tons. Since 2010, SSB has been in an decreasing trend, and was estimated to be 46,000 tons in 2021.

In the Research Institute Meeting held in September 2021, a hockey-stick model was applied to the stock-recruitment relationship of this stock, and based on this, the maximum sustainable yield (MSY) was estimated, and the level of SSB required for MSY (SBmsy) was calculated to be 84,000 tons. Following these criteria, SSB of this stock in 2021 is below the level required for MSY. In addition, the fishing pressure for this stock in the 2021 was higher than the fishing pressure level required for MSY (Fmsy). Based on trends seen in the previous 5 years (2017 to 2021), the SSB is judged to be in a “flat” trend.

In this stock, the reference points, future projections, and other items are provisional values as proposed at the Research Institute Meeting, which will be finalized based on discussions of the stakeholder meeting.

Summary Figures and Tables



MSY, SSB Levels and Trends, and ABC	
SSB required for MSY	84,000 tons
Level of SSB in 2021	Under the level required for MSY
Level of fishing pressure in 2021	Over the level required for MSY
Changes in SSB in 2021	Flat
Maximum Sustainable Yield (MSY)	51,000 tons
ABC for 2023	-
Comments: ・ABC is estimated after Harvest Control Rules (HCRs) for this stock are compiled by the stakeholder meeting, and set through the Fishery Policy Council.	

Recent Stock Biomass, Catch, Fishing Pressure, and Exploitation Rate

Year	Biomass (thousand tons)	SSB (thousand tons)	Catch in Weight (thousand tons)	F/Fmsy	Exploitation Rate (%)
2017	130	56	50	2.21	39
2018	130	49	44	2.10	34
2019	135	68	54	2.55	40
2020	113	53	46	2.03	41
2021	104	46	41	2.04	39
2022	144	65	41	0.96	28
2023	167	90	-	-	-

・The values for 2022 and 2023 are estimates based on future projections.

・ The catch in weight in 2021 was used as catch in weight for 2022.

1. Data Sets

The data sets used for this stock assessment are as follows:

Data Sets	Basic Information & Related Surveys
Catch in number at age and by year	Annual Statistics of Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landings at major ports (Niigata to Kagoshima (14 prefectures)) Monthly length composition surveys (Fisheries Resources Institute, Niigata to Kagoshima (14 prefectures))
Stock abundance index ・ School size	School distribution survey “Pelagic Fish School Size Survey Using Quantitative Echo Sounders” (August to September, Fisheries Resources Institute) ・ Quantitative echo sounder, midwater trawl
・Distribution density of juveniles	Recruitment survey “Recruitment Survey Using Neuston Nets” (April, Fisheries Resources Institute) ・ Neuston Net Recruitment survey “Pelagic Fish School Size Survey Using Midwater Trawls” (May to June, Fisheries Resources Institute) ・ Neuston Net
・ Stock abundance	Catch in weight from small to medium-scale purse seine fisheries in Nagasaki Prefecture (FRA-SA2022-SC06-05)*
・ Spawning volume	Egg and larvae survey (annual, Fisheries Resources Institute, Aomori to Kagoshima (17 prefectures)) ・ NORPAC nets
Natural mortality (M)	Assumed to be 1.0 per year (Ohshimo and Tanaka 2009)

* Indicates the tuning index for cohort analysis.

2. Ecology

(1) Distribution / Migration

The distribution of Japanese anchovy in the Sea of Japan is known to be concentrated along the coasts of Japan, the Korean Peninsula, and Primorsky Krai (near Vladivostok) (Ochiai and Tanaka 1986). In addition, this species has also been reported to be distributed in the central regions of the Sea of Japan, and in the northwestern waters south of the Straight of Tartary (Belyaev and Schershenkov, unpublished), suggesting that the distribution area of this stock in the Sea of Japan extensively spans from coastal areas to offshore waters. There are also reports that distribution of this species in the East China Sea is concentrated along the coasts of Japan, the Korean Peninsula, and China, and some offshore regions (Fig. 2-1, Iversen et al. 1993, Ohshimo 1996). The main fishing grounds for Japanese fishing vessels in the Sea of Japan and the East China Sea are the Western half of the Sea of Japan and the Northwest coast of Kyushu, therefore, the stock assessment for the Tsushima current stock of Japanese anchovy will analyze distribution in these coastal regions. The details of migration patterns of Japanese anchovy in the Sea of Japan and the East China Sea are unknown, and we believe that uncovering the truth about stock interactions between coastal and offshore regions is essential to understanding the ecology of this species.

(2) Age / Growth

Growth patterns of this stock are known to vary according to the timing of emergence. We assumed that individuals reach a standard (scaled) body length of up to 9 cm within 6 months after hatching, based on results from analysis of daily growth increments in otoliths, and changes in body length composition over months. Growth patterns were identified for spring emergence and autumn emergence based on changes in body length composition over months, and the results are expressed below (Fig. 2-2, Ohshimo 2009).

$$\text{Spring Emergence Stock: } BL_t = 143.96\{1 - \exp(-0.15(t + 0.44))\}$$

$$\text{Autumn Emergence Stock: } BL_t = 158.59\{1 - \exp(-0.09(t + 0.74))\}$$

In these equations, BL_t is the standard (scaled) body length (mm) at t months after hatching. The lifespan of this species is said to be around 3 years.

(3) Maturation / Spawning

Spawning of this stock occurs throughout all regions of the Tsushima current region, spanning from the west coast of Kagoshima Prefecture to the west coast of Hokkaido. West of the Noto Peninsula, spawning is nearly year-round, except for winter, and north of the Noto Peninsula, spawning occurs in the warm seasons, concentrated in summer (Uchida and Dohtsu 1958). Histological observations of the ovaries of wild-caught individuals indicate that along the coast of Tottori Prefecture, most individuals with a body length of 11.9 cm or longer are capable of spawning (Shimura et al. 2008). Combining these results with the growth equations above leads us to believe that most fish in the spring emergence stock are capable of spawning by the start of the spawning season of the following year. Meanwhile, mature individuals of 8.5 cm in length have been reported in Wakasa Bay (Funamoto et al. 2004), suggesting that this species can be capable of spawning even at age 0 if the environmental conditions are suitable. In this stock assessment, the spawning volume from age 0 fish is believed to be an extremely low proportion of the total spawning volume, so we assumed that the threshold for maturity was 1 year of age (Fig. 2-3).

(4) Predator-Prey Relationships

Japanese anchovy feed mainly on copepod species of zooplankton (Tanaka et al. 2006). This species is preyed upon by a diverse number of animal species, including predation by piscivorous fish like Japanese jack mackerel and chub mackerel, and predation by carnivorous zooplankton, during the larval and juvenile stage, and predation by piscivorous fish, marine mammals like whales and dolphins, and sea birds, as immature and mature fish.

3. Fishery Status

(1) Fishery Overview

Mature fish of this stock are mainly caught using set nets in the northern Sea of Japan (from Aomori to Ishikawa Prefectures), and set nets and large to medium-scale/medium-scale purse seine nets in the western Sea of Japan (from Fukui to Yamaguchi Prefectures). In the East China Sea (from Fukuoka to Kagoshima Prefectures), it is mainly caught using small to medium-scale purse seine nets. Juveniles (late larval stage, also known as whitebait or “shirasu”) are caught by shirasu fisheries in coastal regions from Kumamoto to Kagoshima Prefectures.

(2) Trends in Catch in Weight

Aggregated catch in weight was calculated by adding the catch in weight of this stock from Aomori to Kagoshima Prefectures from the Annual Statistics of Fishery and Aquaculture Production, to the catch in weight in the East China Sea (aggregated from catch performance reports) by Pacific-based fishing vessels, and subtracted the catch in weight in the Pacific (aggregated from catch performance reports) by East China Sea-based fishing vessels (Table 3-1, Fig. 3-1). In addition, all shirasu in the Annual Statistics of Fishery and Aquaculture Production were considered to be juvenile Japanese anchovy.

Catch of this stock, excluding shirasu, exceeded 100,000 tons from 1996 to 2000 (except in 1997), but decreased sharply in 2001, and fell to 61,000 tons in 2004 (Table 3-1, Fig. 3-1). Next, catch increased to 97,000 tons from 2005 to 2008, but has been in a decreasing trend since 2009. Catch was 41,000 tons in 2021.

Sorting by area shows that in the northern Sea of Japan region, catch increased to 9,000 tons in 1995, and then fluctuated around 1,000 to 7,000 tons (except in 2001), and was 2,000 tons in 2021 (Table 3-1, Fig. 3-1).

Catch in the western Sea of Japan increased to 70,000 tons from 1991 to 1998, and then decreased, and remained around 20,000 tons from 2001 to 2011 (Table 3-1, Fig. 3-1). Since then, the catch has been in a decreasing trend, and was 8,000 tons in 2021.

Catch in the East China Sea area was in an increasing trend from 1990 to 2000, reaching 65,000 tons in 2000 and surpassing the western Sea of Japan (Table 3-1, Fig. 3-1). Since then, catch has remained around 26,000 to 70,000 tons, and was 31,000 tons in 2021.

Catch of shirasu in the coastal regions of the Tsushima current regions fluctuated from 2,000 to 7,000 tons from 1977 to 1987, and then remained around 6,000 tons for 10 years (Table 3-1). Catch surpassed 10,000 tons in 1999 and 2000, and then decreased sharply in 2002, falling below 5,000 tons. Since then, catch increased to return to around 10,000 tons in 2005, but decreased since 2008, and was 3,000 tons in 2021.

Japanese anchovy are also caught by South Korea, along the southern and eastern coasts (National Fisheries Research and Development Institute, South Korea 2000). Although it has fluctuated, catch in South Korea continued to exceed 200,000 tons from 1995 to 2015 (Table 3-1, Fisheries Statistics (Ministry of Oceans and Fisheries, South Korea), https://www.fips.go.kr/p/Main/, August 2022). Catch fell to 140,000 tons in 2016, and then remained around 200,000 tons, and was 140,000 tons in

2021.

Meanwhile, catch of Japanese anchovy by China was greater than Japan or South Korea, exceeding 500,000 tons in 1993, and remaining around 1 million tons from 1996 to 2004 (Table 3-1, FAO, Fishery and Aquaculture Statistics: Global capture production 1950-2020, http://www.fao.org/fishery/statistics/ (software/fishstatj/en, August 2022). Catch by China decreased temporarily up to 2009, and then increased again to reach 960,000 tons in 2015. However, catch has been in a decreasing trend since 2016, and was 610,000 tons in 2020, the most recent year for which data is available.

Catch in number at age for this stock is shown in Fig. 3-2 and Supplementary Table 2-2. In this stock, age 0 fish comprised 38 to 78% of catch. Since 1977, the catch in number of age 0 fish has fluctuated in cycles while being in an increasing trend, reaching a record high of 13.4 billion in 2005, then decreasing to 3.5 billion in 2009. Catch in number of age 0 fish ranged from 3.2 billion to 6.5 billion from 2010 to 2020, and was estimated to be 7.1 billion in 2021, which was the highest level since 2010. Catch in number in 2021 was estimated to be 3.1 billion for age 1 fish, and 50 million for age 2 fish.

(3) Fishing Effort

We believe that the total number of fishing vessels entering port in Nagasaki Prefecture each day is an index of fishing effort, because these small to medium-scale purse seine fisheries have accounted for around half of the catch of this stock since 2001. The number of fishing vessels entering port is in a decreasing trend, after remaining around 8,000 vessels from 2001 to 2008, it declined to 5,615 vessels in 2021 (Fig. 3-3).

4. Stock Status

(1) Stock Assessment Methods

Up to FY 2020, stock assessment for this stock included shirasu in the base case, but in order to ensure consistency with the Pacific stock and Seto Inland Sea stock, which do not consider the catch of shirasu, in the FY 2021 stock assessment, the abundance (biomass) was estimated using cohort analysis based on Catch in number at age and by year, without inclusion of shirasu (Hino et al. 2022). Catch in weight of this stock has been in a decreasing trend since 2009. In order to determine whether this reflects a decline in stock, or is the result of less fishing due to changes in fishing rules, the FY 2022 stock assessment adopted a base case of performing stock assessment based on cohort analysis using abundance indices (hereinafter referred to as “VPA with tuning”). In accordance with the VPA with tuning that was trialed last year (Hino et al. 2022), the fishing mortality F in 2021 was adjusted based on the standardized catch per day per vessel from small to medium-scale purse seine fisheries in Nagasaki Prefecture from 2009 to 2021 (hereinafter referred to as “Nagasaki CPUE”), and the spawning volume in the Sea of Japan and the East China Sea from 2001 to 2021 (Appendix 1 and 2). Stock assessment results for scenarios including shirasu, and using different natural mortality, are shown in Appendix 8.

(2) Trends in Abundance Indices

The tuning indices used to adjust fishing mortality F are shown in Supplementary Table 2-1. Spawning volume in the Sea of Japan (March to June) and the East China Sea (March to April) was high from 1998 to 2000, low in 2001, and reached 10.084 quadrillion (10^{16}) eggs in 2004, the record high since 1979 (Fig. 4-1). Since 2009, spawning volume has ranged between 789 trillion and 3.835 quadrillion eggs. Spawning volume in 2021 was 3.824 quadrillion eggs, which is nearly double the levels in 2020 (1.991 quadrillion eggs). The Nagasaki CPUE has fluctuated between 2,612 and 5,949 since 2009, and has been in a gentle decreasing trend since 2019, reaching 2,876 in 2021 (Supplementary Table 2-1). Values for each index, scaled by dividing by average, are shown in Fig. 4-2. Trends in scaled Nagasaki CPUE values were more stable than spawning volume values.

Results of spring/summer pelagic fish school size surveys using quantitative echo sounders and midwater trawls are shown in Appendix 7. It is still being debated exactly how abundance indices calculated in each survey reflect the abundance of the whole stock, so these values are only included as a reference for judging trends in this stock.

(3) Trends in Biomass and Fishing Pressure

Stock abundance (biomass) estimated using VPA with tuning remained around 170,000 tons up to 1994, then was in an increasing trend since 1995, reaching a record high of 426,000 tons in 1998 (Fig. 4-3, Table 4-1). Next, it decreased and remained around 19,000 tons from 2001 to 2005, and then increased to 302,000 tons in 2007. Since 2007, it has been in a gentle decreasing trend, and was estimated to be a record low of 104,000 tons in 2021.

SSB remained steady around 70,000 tons in the 1980s, and then exceeded 100,000 tons in 1991, and increased to reach a peak of 210,000 tons in 1998 (Fig. 4-3, Table 4-1). Afterwards, SSB decreased to 68,000 tons in 2002, and then increased to 192,000 tons until 2007, and is estimated to have declined to 46,000 tons in 2021.

Fish age 0 to 1 comprised for the majority of stock population at age. In 2021, the stock population of age 0 fish and age 2 fish was higher than in the previous year, but for age 1 fish, it was lower than in the previous year (Fig. 4-4 and Supplementary Table 2-2).

Likewise, fish age 0 comprised 36 to 65% of stock weight at age, and fish age 0 to 1 comprised the majority of stock weight at age. In 2021, stock weight at age of fish age 0 to 1 was lower than in the previous year, but for age 2 fish, it was higher than in the previous year (Fig. 4-5).

Recruitment volume remained around 24.0 billion until the early 1990s, and has exceeded 40.0 billion since 1995, reaching a record high of 51.9 billion in 1998 (Fig. 4-6, Table 4-1). Next, recruitment volume decreased, but still exceeded 40.0 billion in 2005 and 2006. Afterwards, it declined and ranged between 20.1 billion to 35.2 billion in 2007 and onwards, but was estimated to be 31.8 billion in 2021, which was the second highest level since 2008.

Recruitment per spawning was highly variable, and fluctuated between 152 ind./kg and 719 ind./kg. In 2021, recruitment per spawning was 689 ind./kg, which was the second highest level since 1977 (Fig. 4-6, Table 4-1).

Estimated abundance (biomass) and SSB with natural mortality (M) varied to 0.5 times, 1.0 times

–(reference value), and 1.5 times are shown in Fig. 4-7. Biomass was 65% of the reference value when M was assumed to be 0.5, and was 173% when M was assumed to be 1.5.

Changes in fishing mortality (F) by age over time are shown in Fig. 4-8. The F of age 0 fish fluctuated in cycles but remained between 0.2 and 0.7, and was estimated to be 0.5 in 2021. Meanwhile, the F of fish age 1 to 2 fluctuated between 1.2 and 4.3 from 1977 to 2005, and reached a record low of 0.7 in 2006. Subsequently, the F of fish age 1 to 2 was in an increasing trend, and reached a record high of 5.2 in 2017. Afterwards, the F of fish age 1 to 2 remained around 4.4, and was estimated to be 4.6 in 2021.

The exploitation rate has remained around 35% continuously since 1977, and was 39% in 2021 (Fig. 4-9).

(4) Yield Per Recruit (YPR), Spawning Per Recruit (SPR), and Current Fishing Pressure

In order to compare fishing pressures with consideration for selectivity, we compared findings for spawning per recruit (SPR) in scenarios with and without fishing pressure. Fig. 4-10 shows changes in the SPR ratio (%SPR), which compares SPR in a scenario without fishing pressure against SPR in a scenario with fishing for each year. Lower fishing pressure means higher %SPR levels. Results show that %SPR has fluctuated between 27% to 58%, and was 33% in 2021. Calculations showed that %SPR was 31% using the average F value of the 3 previous years (2019 to 2021) for the current fishing pressure.

The relationship between current fishing pressure and YPR and %SPR is shown in Fig. 4-11. The selection probability of F was defined as the value used to estimate the level of F required for maximum sustainable yield (Fmsy) (Hino et al. 2021) at the Research Institute Meeting held in September 2021. In addition, the values used to calculate Fmsy were also used for average body weight at age and the maturity rate. Fmsy is equivalent to 45% when converted to %SPR. The current fishing pressure (F2019 to 2021) is above Fmax and F40%SPR, but below F30%SPR.

(5) Stock-Recruitment Relationship

The relationship (stock-recruitment relationship) between SSB (in weight) and recruitment volume (individuals) is shown in Figure 4-12. The Research Institute Meeting, as described in previous sections, proposed to apply a hockey-stick model for stock-recruitment relationships to the stock-recruitment relationship model of this stock (Hino et al. 2021). The data used to estimate the parameters of this stock-recruitment relationship was based on SSB and recruitment volume reported in the FY 2020 stock assessment (Kuroda et al. 2021), and the optimization method was the least squares method. In addition, autocorrelation was considered regarding residuals in recruitment. The parameters of the stock-recruitment relationship model are shown in Supplementary Table 6-1.

(6) Levels Required for MSY Under Current Environmental Conditions

The SSB required for maximum sustainable yield (SBmsy) and the catch in weight required for maximum sustainable yield, under current environmental conditions (1977 and onward), were defined as the values estimated at the Research Institute Meeting (Hino et al. 2021), and are shown in

Supplementary Table 6-2.

(7) Stock Levels/Trends and Fishing Pressure Levels

Reference values for SSB and fishing pressure required for MSY are shown in a Kobe plot in Fig. 4-13. In addition, a summary of SSB and fishing pressure in 2021 is shown in Supplementary Table 6-3. SSB of this stock in the 2021 fishing season was lower than the SSB required for MSY (SBmsy), specifically, SSB in the 2021 fishing season was 0.55 times the value of SBmsy. In addition, the fishing pressure in 2021 was higher than the fishing pressure required for MSY (Fmsy), specifically, it was 2.04 times the value of Fmsy. The F ratios (F/Fmsy) shown in the Kobe plot are the ratio between F values in each year, and the value of F that gives the fishing pressure of Fmsy under the selectivity of F in each year, converted to %SPR. Based on trends seen in the previous 5 years (2017 to 2021), SSB was judged to be in a “flat” trend. SSB of this stock exceeded SBmsy in 1977, 1991 to 2001, 2003, and 2005 to 2010, but was below SBmsy in 2011 and onwards. The fishing pressure of this stock has been higher than Fmsy since 2011 (except in 2013).

5. Summary of Stock Assessment

Stock abundance (biomass) remained around 170,000 tons up to 1994, then was in an increasing trend since 1995, reaching a record high of 426,000 tons in 1998. Next, it decreased and remained around 19,000 tons from 2001 to 2005, and then increased to 302,000 tons in 2007. Since 2007, biomass has been in a decreasing trend, and was estimated to be a record low of 104,000 tons in 2021, however, recruitment volume was estimated to be 31.8 billion, which was the second highest level since 2008.

6. Additional Comments

In order to ensure stable utilization of this stock, we believe that it will be effective to maintain SSB above a certain level, in consideration of the relationship between SSB and recruitment volume in this stock. In this stock, age 0 fish comprise the majority of most catches, and recruitment volume has a large impact on SSB of the following year and the year after, therefore, it is essential to understand the mechanism of changes in recruitment volume. In contrast with the data from the most recent 10-year period, it has become empirically clear that recruitment volume in this stock shows a positive correlation with winter surface water temperatures in the Tsushima current region (Kuroda et al. 2021). Therefore, we believe that measures must be taken against low recruitment, such as avoiding catches of age 0 fish in years when water temperature is lower than normal.

Although Japanese anchovy distributed in the Tsushima current region are also caught by China and South Korea, this stock assessment defines the Tsushima current stock of Japanese anchovy as being “schools distributed from the northern and western Sea of Japan to the west coast of Kyushu, caught by Japanese fishing vessels”, and does not consider the catch in those countries. Although the catches by China (50,000 to 1,220,000 tons) and South Korea (50,000 to 290,000 tons) surpass the catch by Japan since 1977 (30,000 to 130,000 tons), they are not considered in this assessment for the following reasons: China and South Korea do not measure catches with the same level of precision, and statistics released by China and South Korea only report catch without inclusion of biological data (body length composition, growth patterns, age of maturity, etc.). Accordingly, there is no guarantee that the precision of stock assessments will be improved by the inclusion of these reports. Japanese anchovy distributed in the Yellow Sea are considered to be a different stock than the Tsushima current stock, because the body shape, body color, and frequency of Anisakidae parasitic worms is significantly different compared to anchovies distributed in the western Sea of Japan and the west coast of Kyushu. There are also reports of genetic differentiation between populations in the central Sea of Japan and populations in the Bohai Sea and Yellow Sea (Zhang et al. 2020). Accordingly, we presume that our decision to not consider the catch by China will not have a very large impact on the precision of stock assessments for this stock.

However, there are no reports that compare the biological characteristics of the stock caught by South Korea and the stock living along the coasts of Japan. In addition, the fishing grounds of South Korean vessels and the fishing grounds of Japanese vessels are geographically close. Therefore, we cannot rule out the possibility that the South Korean stock is actually the same as the Tsushima current stock. Accordingly, we also performed a stock assessment that considers the catch by South Korea, and the results are presented in Appendix 9. Moving forward, in order to consider the catch by South Korea in stock assessments, further research into biological and ecological findings regarding the interaction of Japanese anchovy distributed along the coast of Kyushu and schools distributed along the coast of South Korea is required.

7. References

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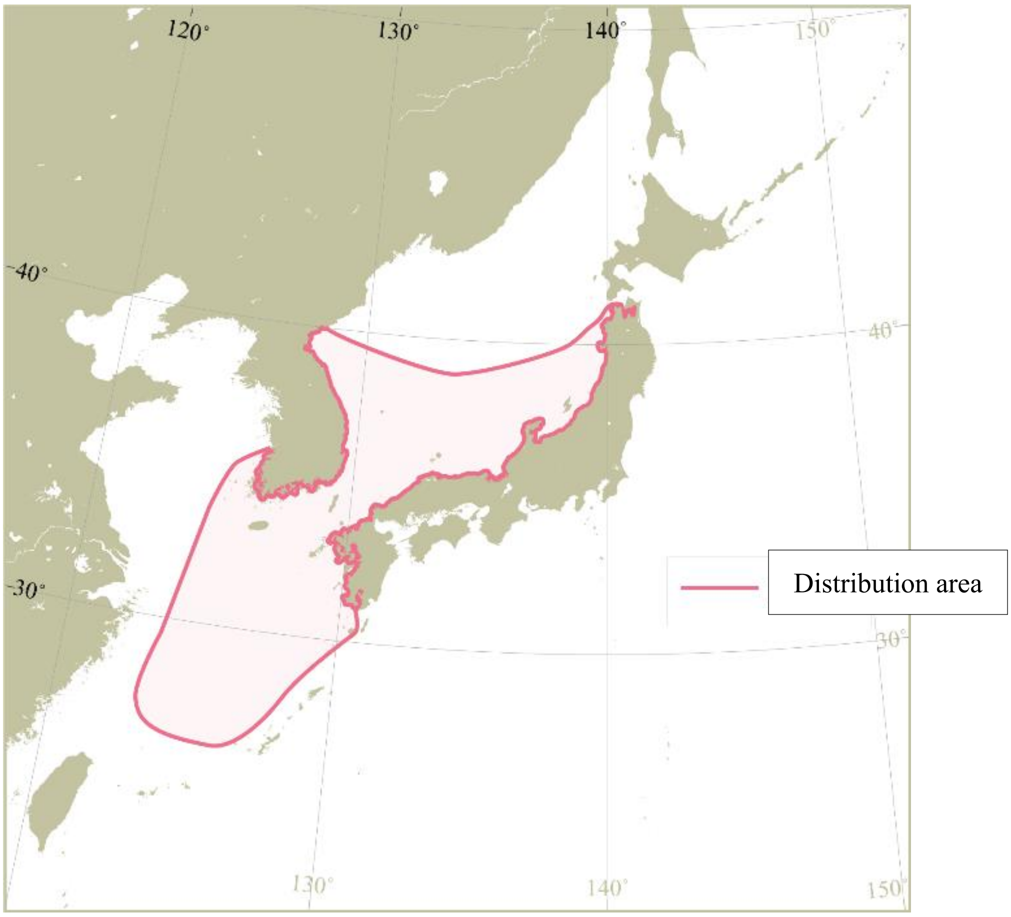


Fig. 2-1. Distribution area of the Tsushima current stock of Japanese Anchovy

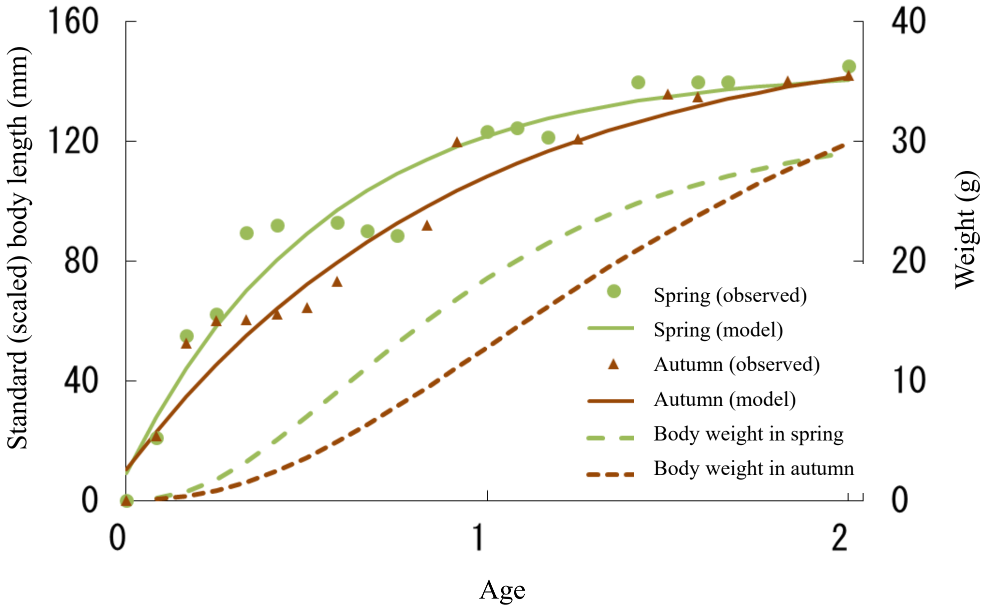


Fig. 2-2. Growth pattern of Japanese anchovy. Circles indicate observed values and solid lines indicate model values.

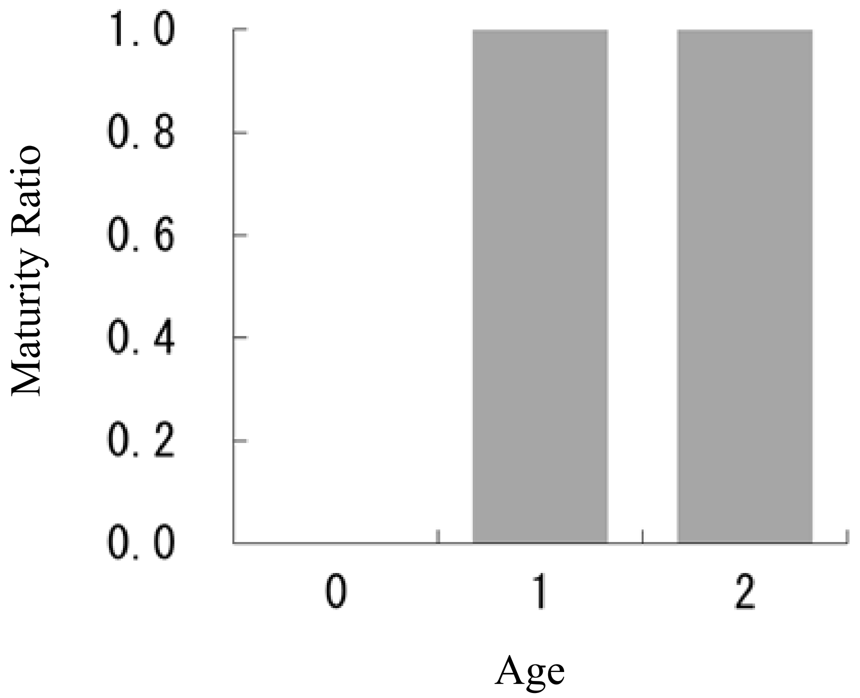


Fig. 2-3. Maturity ratio at age

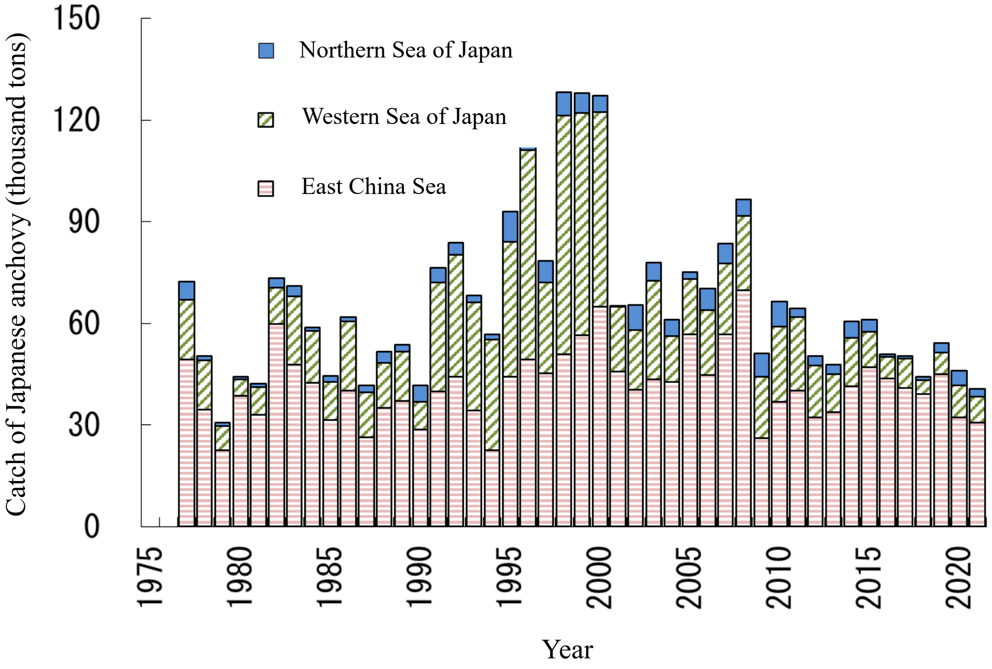


Fig. 3-1. Trends in catch in weight

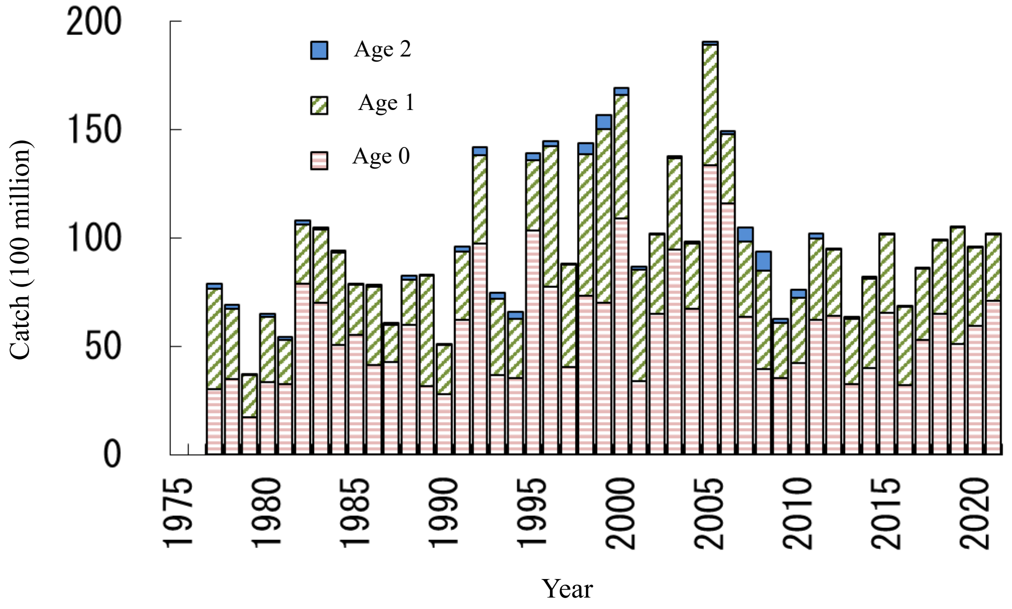


Fig. 3-2. Trends in catch in number at age

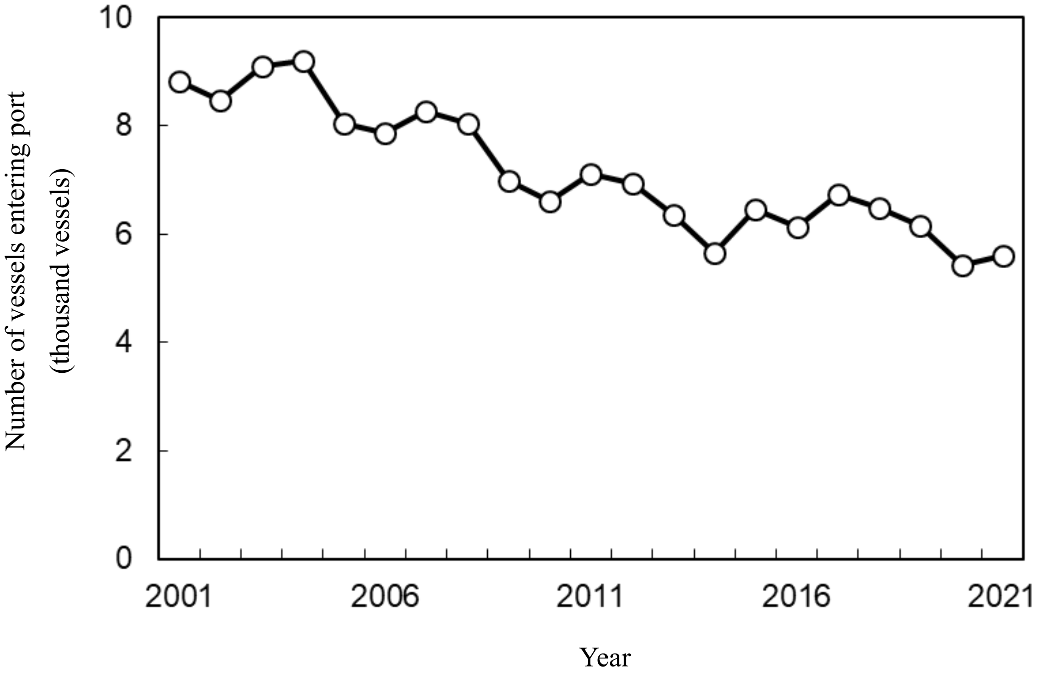


Fig. 3-3. Trends in fishing effort (number of vessels entering port) of small to medium-scale purse seine fisheries in Nagasaki Prefecture

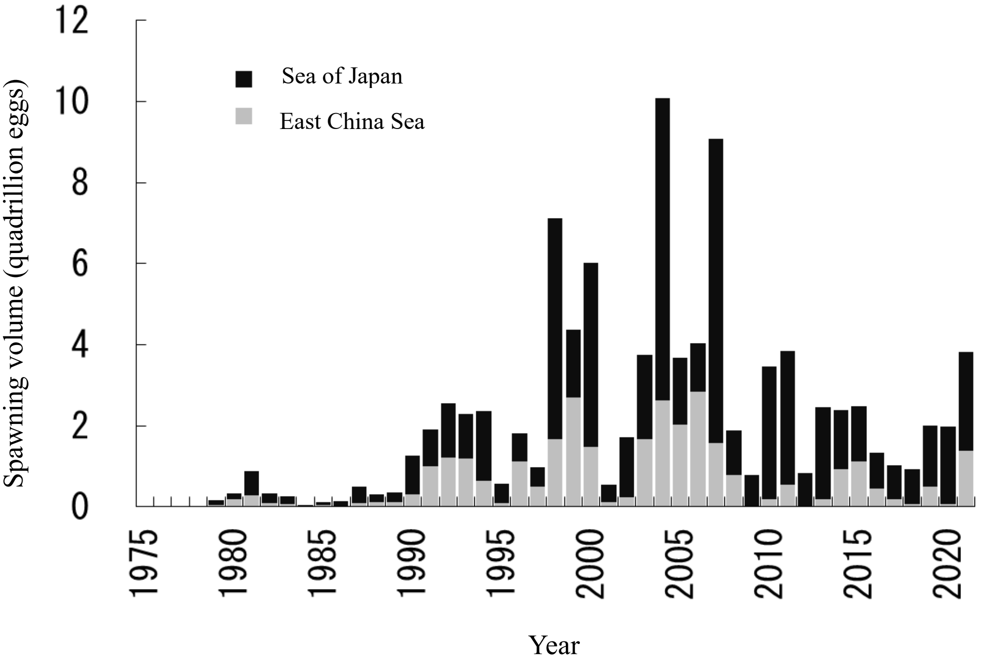


Fig. 4-1. Trends in spawning volume

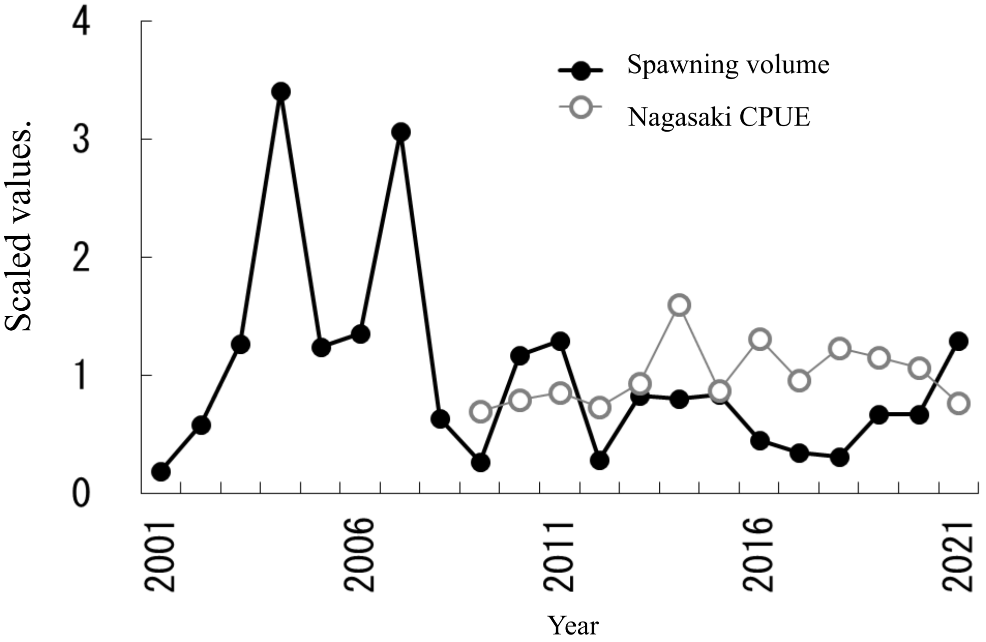


Fig. 4-2. Trends in tuning indices

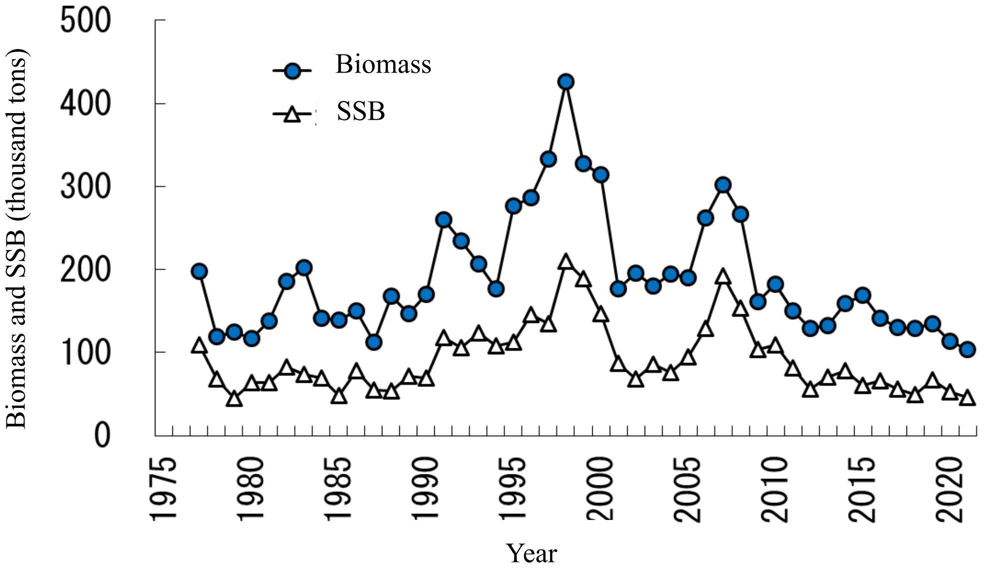


Fig. 4-3. Trends in biomass and SSB

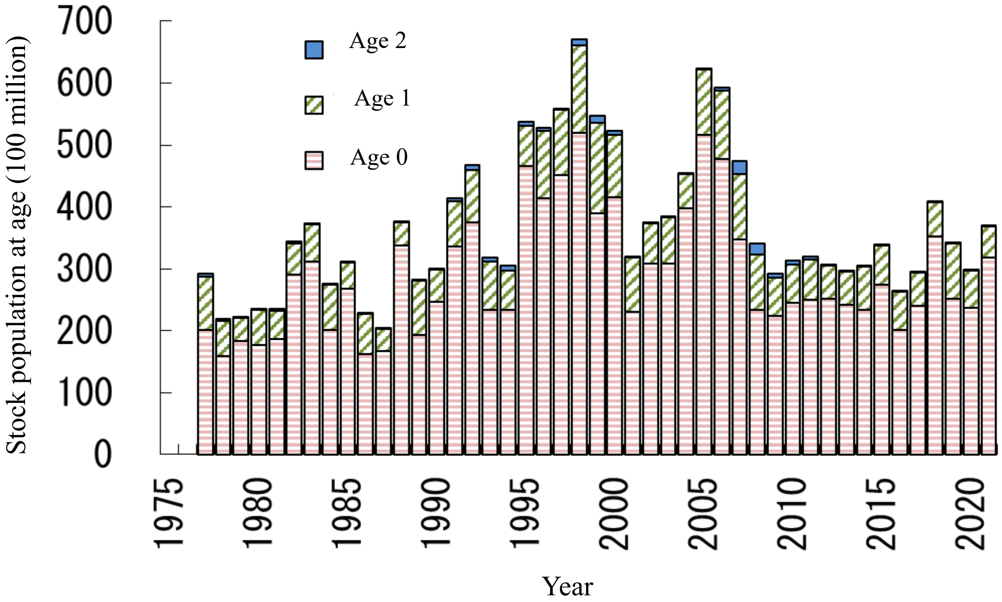


Fig. 4-4. Trends in stock population at age

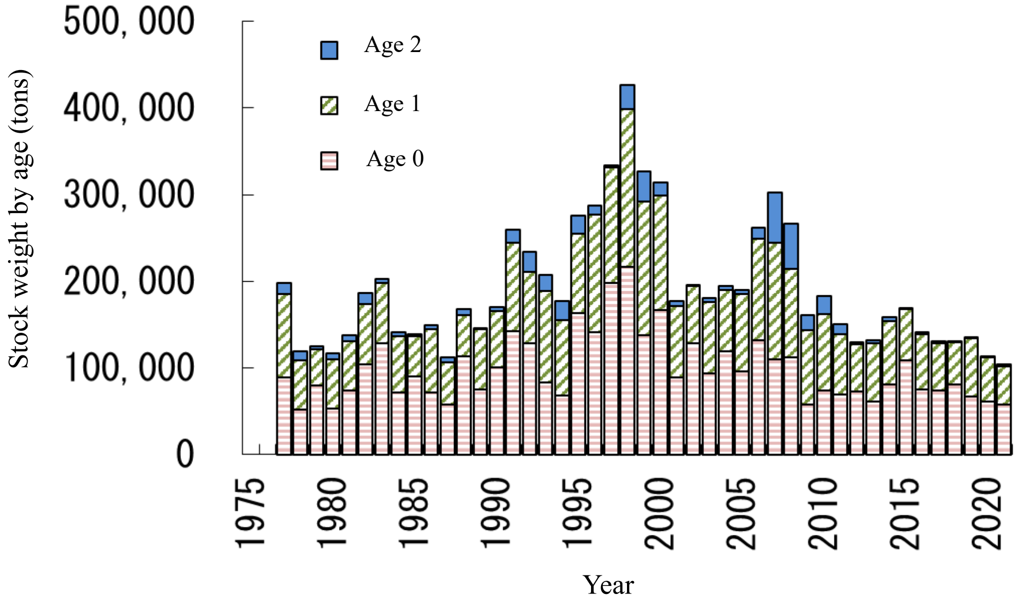


Fig. 4-5. Trends in stock weight by age

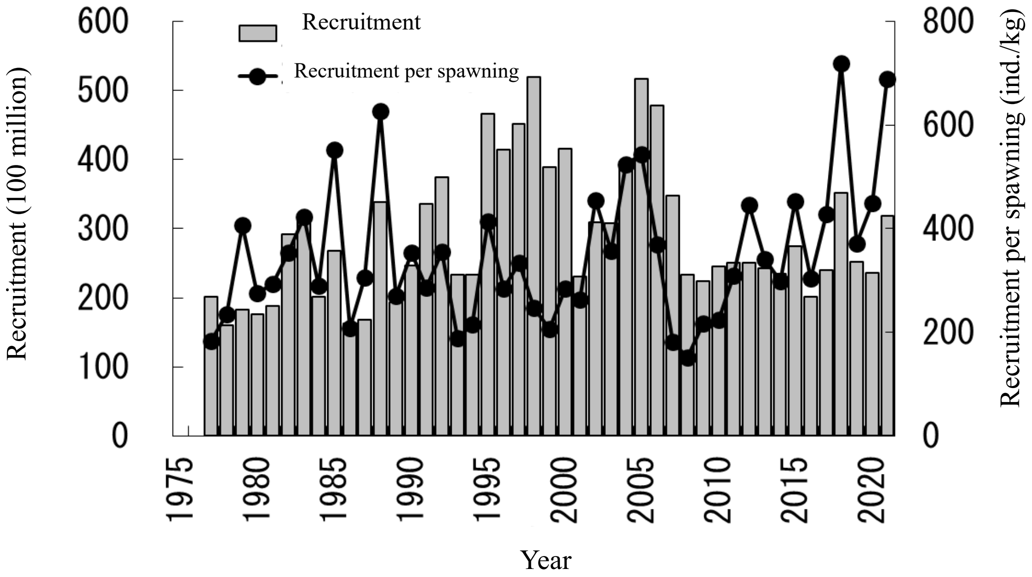


Fig. 4-6. Trends in recruitment volume and recruitment per spawning

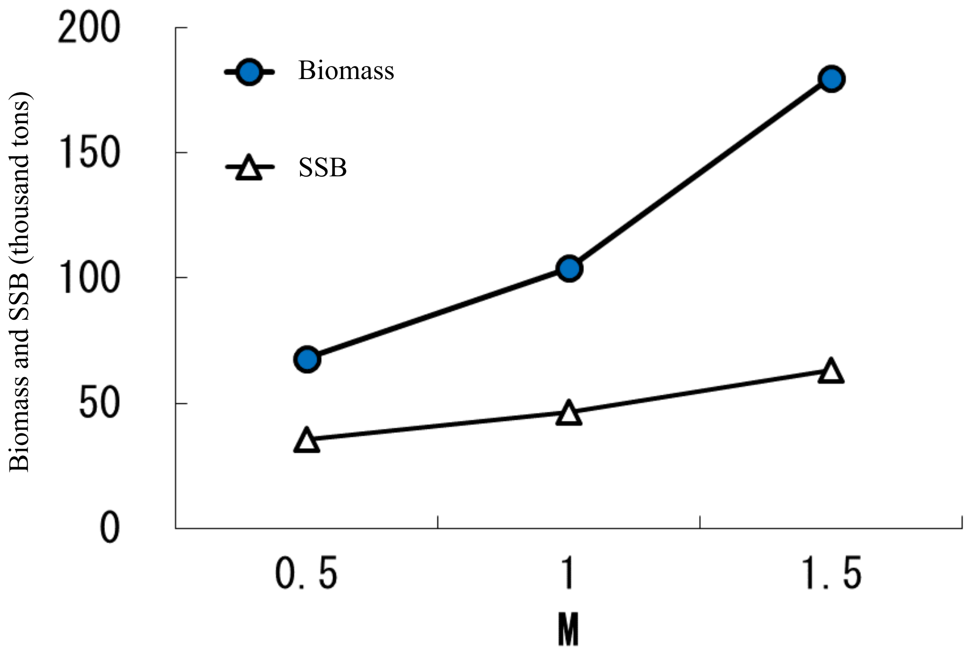


Fig. 4-7. Impact of natural mortality M on biomass and SSB

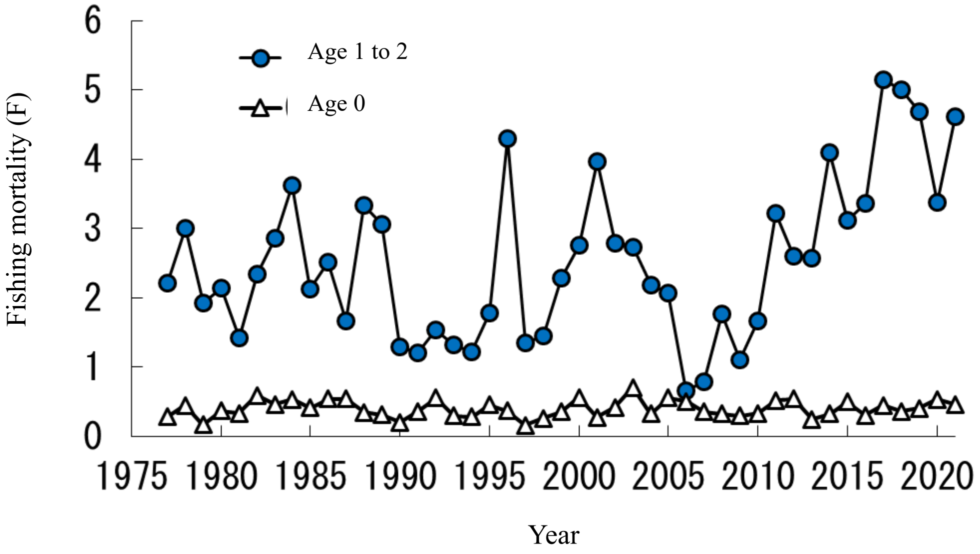


Fig. 4-8. Trends in fishing mortality F at age

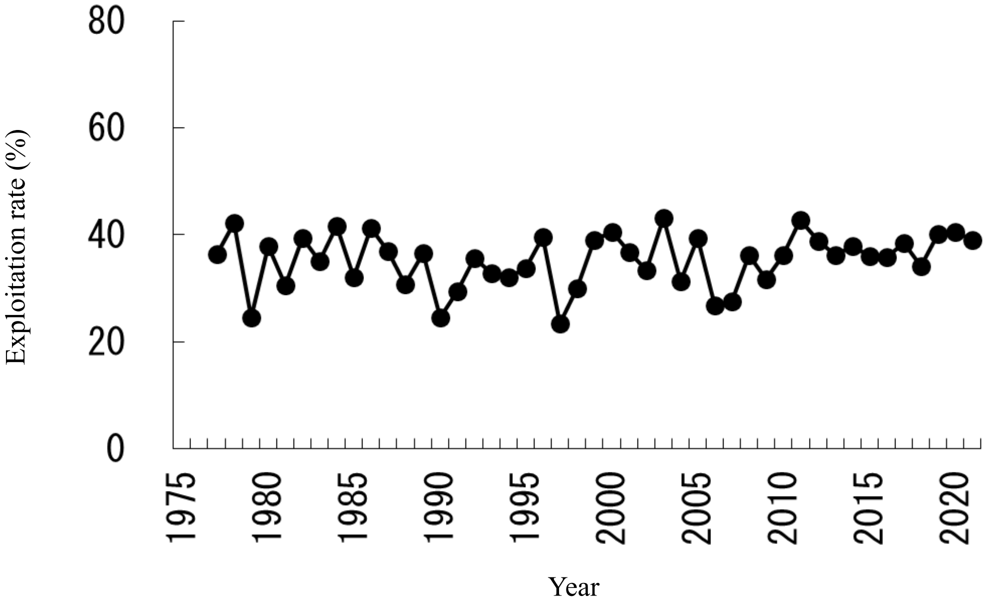


Fig. 4-9. Trends in exploitation rate

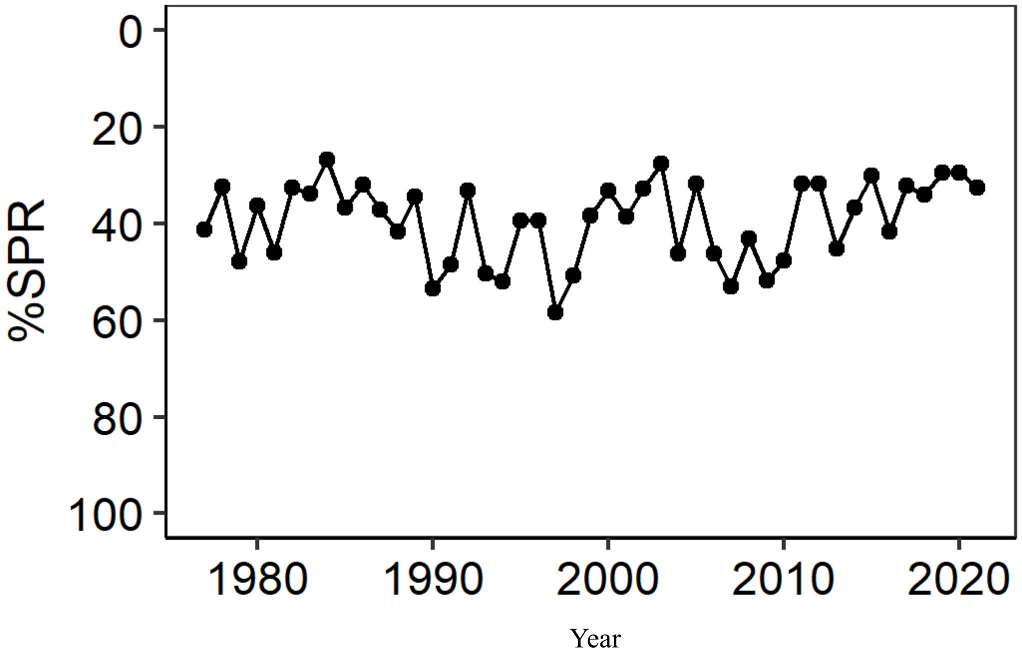


Fig. 4-10. Trends in %SPR of F by year

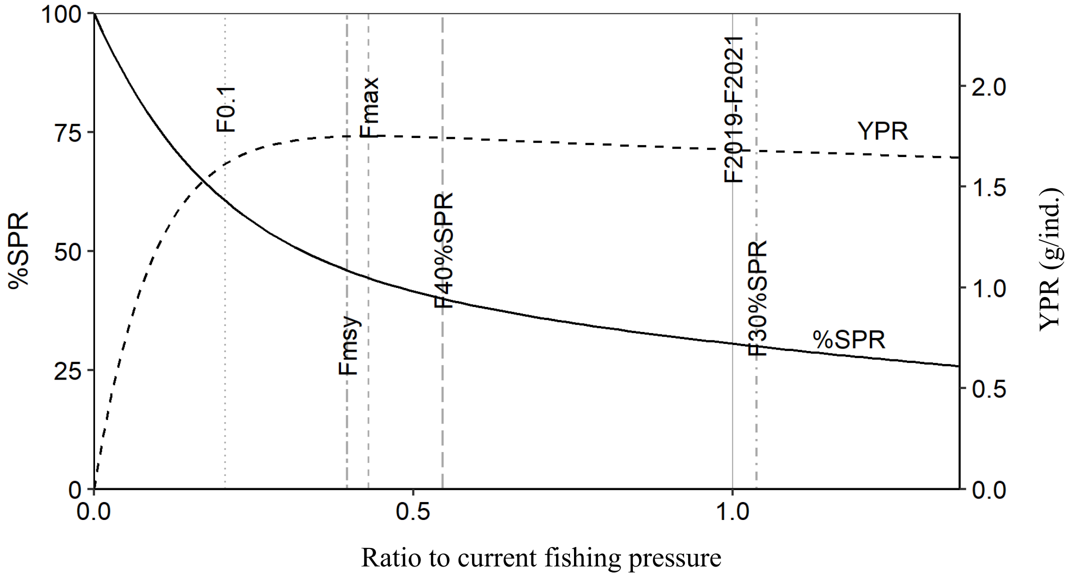
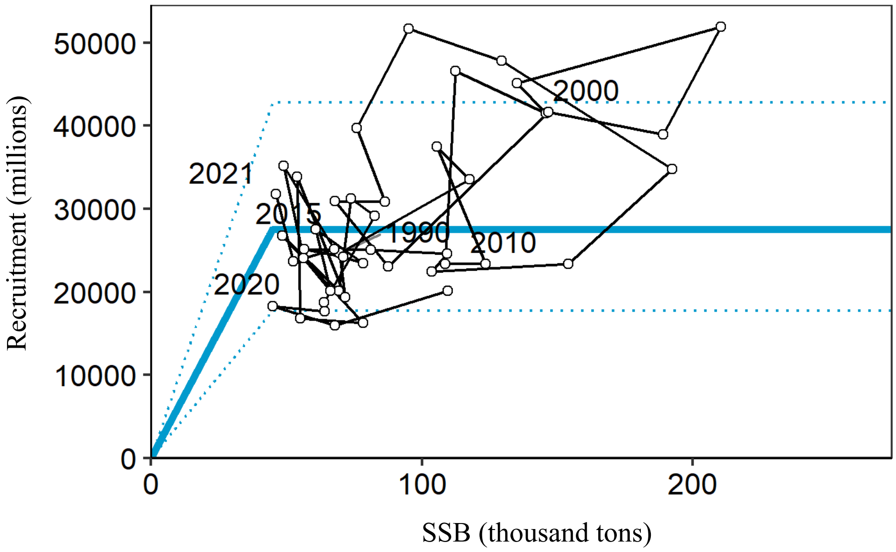


Fig. 4-11. Relationship between current fishing pressure (F2019 to 2021) and YPR and %SPR



Function: HS, autocorrelation: 1, optimization method L2, AICc: 17.95

Fig. 4-12. Relationship between SSB and recruitment volume (stock-recruitment relationship)

This stock-recruitment relationship model (blue solid line) was proposed at the Research Institute Meeting held in September 2021 (Hino et al. 2021). The dotted lines above and below the stock-recruitment relationship model (solid blue line) in the figure represent the interval estimated to contain 90% of observed data in the assumed stock-recruitment relationship. The solid lines and white circles plot the stock-recruitment relationship obtained from the FY 2022 stock assessment (1977 to 2021).

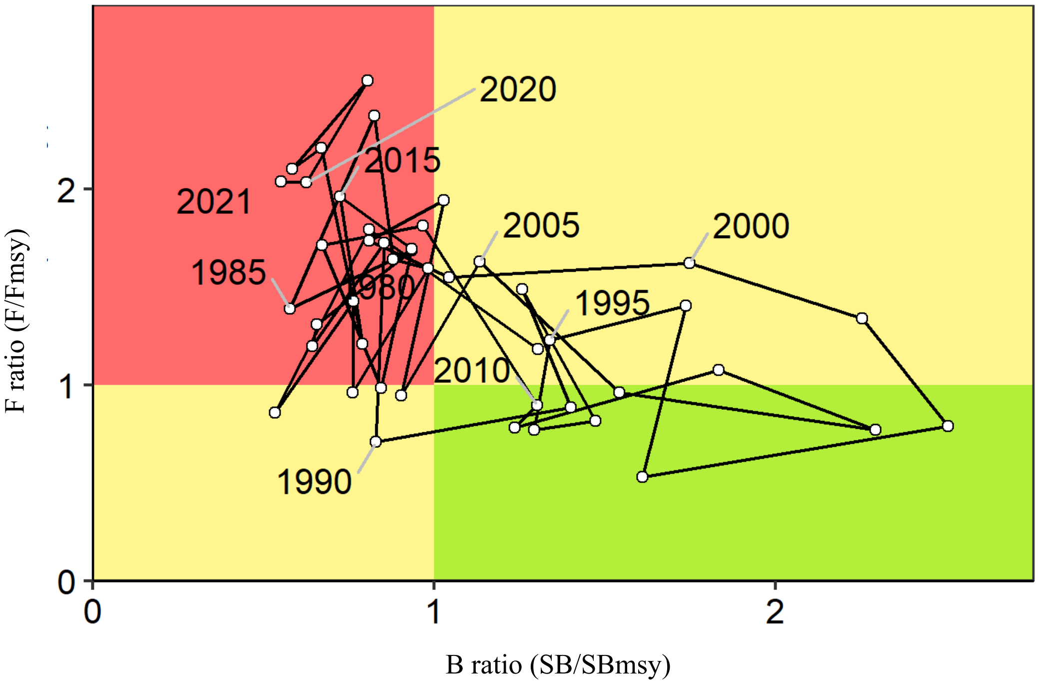


Fig. 4-13. Relationship of SSB required for MSY (SBmsy) and fishing pressure required for MSY (Fmsy) against levels of SSB and fishing pressure from 1977 to 2021 (Kobe plot).

Table 3-1. Catch (thousand tons) of Japanese anchovy (Japan, South Korea, China) and shirasu (Japan) Northern Sea of Japan: Aomori to Ishikawa Prefectures, Western Sea of Japan: Fukui to Yamaguchi Prefectures, East China Sea: Fukuoka to Kagoshima Prefectures.

Year	Sea of Japan Northern	Sea of Japan Western	East China Sea	Tsushima Current Stock Total	South Korea	China	Shirasu
1977	5.3	17.5	49.5	72.3	140.8		4.9
1978	1.4	14.5	34.5	50.4	183.2		5.1
1979	0.9	7.3	22.5	30.7	171.5		6.5
1980	0.8	4.9	38.5	44.2	169.7		4.5
1981	1.1	8.0	33.1	42.2	184.4		4.0
1982	2.7	10.8	59.9	73.3	162.3		3.8
1983	3.1	20.2	47.8	71.1	131.9		3.1
1984	1.2	15.3	42.3	58.9	155.1		2.1
1985	2.0	11.1	31.5	44.6	143.5		2.5
1986	1.3	20.4	40.2	61.9	201.6		3.5
1987	2.0	13.3	26.5	41.8	167.7		5.7
1988	3.3	13.4	35.0	51.7	126.1		5.9
1989	2.0	14.6	37.1	53.7	131.9		6.5
1990	5.1	8.0	28.8	41.8	130.2	54.1	6.5
1991	4.5	32.1	39.9	76.4	124.5	113.1	7.1
1992	3.4	36.0	44.3	83.8	116.9	192.7	6.0
1993	2.0	32.0	34.2	68.2	249.2	557.2	6.0
1994	1.5	32.8	22.5	56.8	193.4	439.0	7.1
1995	9.0	40.0	44.2	93.1	230.7	489.1	6.0
1996	2.5	61.8	49.2	113.5	237.1	671.4	5.7
1997	6.5	26.6	45.4	78.4	230.9	1,110.9	6.5
1998	7.1	70.3	50.9	128.3	249.5	1,217.2	6.7
1999	5.9	65.8	56.4	128.0	238.9	951.4	11.1
2000	4.8	57.5	64.9	127.2	201.2	980.5	12.1

Table 3-1. Catch of Japanese anchovy (Japan, South Korea, China) and shirasu (Japan) (thousand tons) (continued)

Year	Northern Sea of Japan	Western Sea of Japan	East China Sea	Total of Tsushima Current Stock	South Korea	China	Shirasu
2001	0.4	18.9	45.9	65.2	273.9	1,075.6	6.7
2002	7.4	17.7	40.4	65.5	236.3	998.1	4.6
2003	5.3	29.0	43.6	77.9	250.1	1,106.5	5.2
2004	4.8	13.6	42.7	61.0	196.6	935.4	8.8
2005	2.0	16.2	56.9	75.1	249.0	882.6	9.9
2006	6.4	19.0	44.8	70.2	265.3	826.8	8.2
2007	5.8	20.9	56.7	83.4	221.1	806.5	9.3
2008	4.9	22.0	69.7	96.6	261.5	658.7	7.2
2009	6.9	18.1	26.2	51.2	203.7	521.9	5.9
2010	7.4	22.0	36.9	66.4	249.6	598.1	7.1
2011	2.7	21.5	40.3	64.4	292.7	766.6	4.7
2012	2.7	15.4	32.2	50.3	222.0	824.2	4.2
2013	2.8	11.3	33.8	47.9	209.1	866.8	4.3
2014	4.6	14.3	41.5	60.5	221.2	926.5	4.1
2015	3.5	10.6	47.0	61.2	211.6	955.8	5.0
2016	0.8	6.3	43.7	50.8	141.0	816.2	4.8
2017	0.7	8.5	41.1	50.3	210.9	703.7	4.6
2018	1.0	4.1	39.2	44.4	188.5	658.4	3.9
2019	2.9	6.4	45.0	54.3	171.7	625.4	2.7
2020	4.4	9.4	32.4	46.1	216.8	609.9	3.7
2021	2.2	7.7	30.7	40.6	143.4		2.5

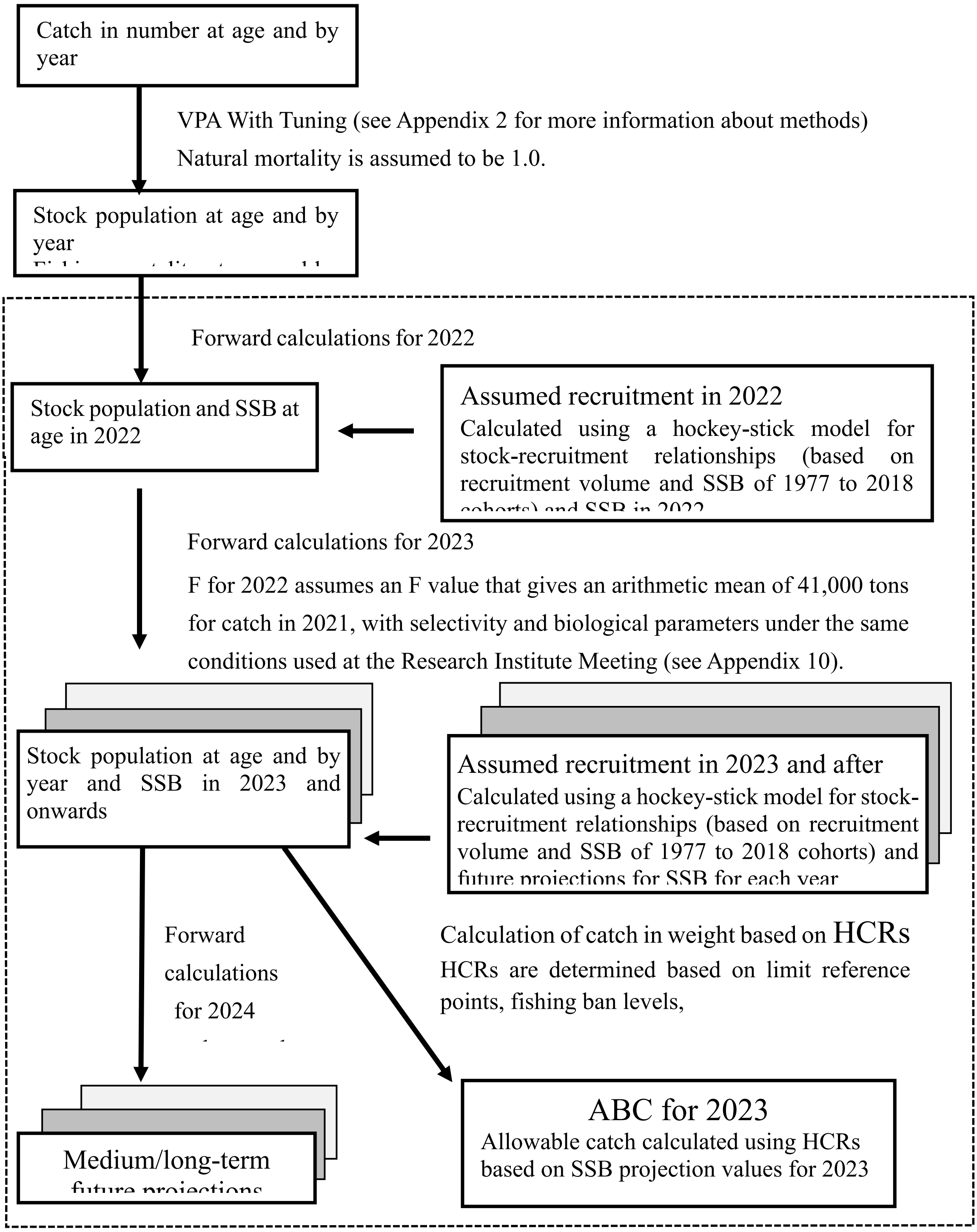
Catch in the northern Sea of Japan is based on aggregated statistics by area (Niigata: 1995 to 2000, Ishikawa: 2000 and onwards).

Table 4-1. Results of VPA With Tuning

Year	Biomass (thousand tons)	SSB (thousand tons)	Recruitment volume (ten million ind.)	Recruitment per spawning (ind./kg)	Exploitation rate (%)	F/Fmsy
1977	198	109	2,014	184	37	1.18
1978	120	68	1,596	235	42	1.79
1979	125	45	1,827	407	25	0.86
1980	117	64	1,764	275	38	1.43
1981	138	64	1,875	294	31	0.96
1982	186	82	2,914	353	39	1.60
1983	203	74	3,124	423	35	1.64
1984	141	69	2,012	291	42	2.37
1985	139	48	2,674	552	32	1.39
1986	150	78	1,625	207	41	1.69
1987	113	55	1,680	305	37	1.31
1988	168	54	3,385	627	31	1.20
1989	146	72	1,935	270	37	1.72
1990	170	70	2,467	355	25	0.71
1991	259	118	3,356	286	29	0.88
1992	234	106	3,744	355	36	1.49
1993	207	124	2,333	189	33	0.82
1994	177	108	2,339	216	32	0.77
1995	276	112	4,657	414	34	1.23
1996	287	146	4,146	284	40	1.40
1997	333	135	4,514	334	24	0.53
1998	426	210	5,189	247	30	0.79
1999	327	189	3,890	206	39	1.34
2000	314	147	4,162	284	40	1.62
2001	177	88	2,308	264	37	1.55
2002	196	68	3,091	455	33	1.73
2003	180	86	3,081	357	43	1.94
2004	195	76	3,972	524	31	0.94
2005	191	95	5,165	544	39	1.63
2006	262	129	4,782	369	27	0.96
2007	302	192	3,480	181	28	0.77
2008	266	154	2,337	152	36	1.08
2009	161	104	2,242	216	32	0.78
2010	183	109	2,455	225	36	0.89
2011	150	81	2,508	309	43	1.81
2012	130	56	2,512	445	39	1.71
2013	132	71	2,421	342	36	0.98
2014	159	78	2,346	300	38	1.69
2015	169	61	2,751	453	36	1.96
2016	141	66	2,010	303	36	1.21
2017	130	56	2,402	427	39	2.21
2018	130	49	3,519	719	34	2.10
2019	135	68	2,513	372	40	2.55

2020	113	53	2,363	450	41	2.03
2021	104	46	3,180	689	39	2.04

Appendix 1 Flow of Stock Assessment



※ Information inside the dotted line box is based on discussion of reference points, HCRs, etc., by the stakeholder meeting. (http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/index.html)

Appendix 2 Calculation Methods

(1) Stock Calculation Methods

Japanese anchovy have a long spawning season, so if we assume that age is counted up on the 1st of January, then the autumn emergence stock will become age 1 a few months after emergence. Accordingly, a length-age key was created for each ocean area (East China Sea and Sea of Japan) by month based on the growth patterns described by Ohshimo (2009), and age composition was determined according to body length composition. In addition, we determined body weight composition by age based on the length-weight relationship, then estimated catch in number by age and by year by stretching results according to catch in weight. In order to accurately reflect selectivity of fisheries in catch in number at age, we aggregated body length composition and catch in the Sea of Japan after dividing the area into the region of Yamaguchi to Tottori Prefectures, and the region of Hyogo to Aomori Prefectures. Then, we performed VPA with tuning using Pope's approximation formula based on the results for catch in number at age and by year to estimate abundance (population size). In these calculations, the lifespan was presumed to be 3 years. Calculations were performed using R package frasyr (version 2.2.2.0). Stock calculation methods are shown below.

1. Calculation of stock population using Pope's approximation formula (Step 1)

The following equation (1) was used to calculate the stock population at age and by year of fish age 0 and 1 up to 2020, excluding the most recent year (2021).

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

In these equations, $N_{a,y}$ is the stock population of fish age *a* in year *y*, and $C_{a,y}$ is the catch in number of fish age *a* in year *y*, and M is natural mortality (1.0).

In addition, the following equation (2) was used to calculate the stock population of the oldest fish (age 2) and of each age group in the most recent year, using fishing mortality F.

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

The following equation (3) was used to calculate the stock population of fish age 0 and 1, excluding the most recent year.

$$F_{a,y} = -\ln\left\{1 - \frac{C_{a,y} \times \exp\left(\frac{M}{2}\right)}{N_{a,y}}\right\} \tag{3}$$

In these calculations, F of fish age 2 was set equal to F of fish age 1. F of fish age 0 and 1 in the most recent year was set equal to the average value for fish the same age in the previous 3-year period (2018 to 2020), and equation (1) was used to estimate the stock population. F of fish age 2 in the most recent year was set equal to F of fish age 1. Next, we further adjusted F in the most recent year following the methods in Step 2.

2. Adjustment of F in the most recent year (Step 2)

We obtained terminal F in an exploratory manner using tuning based on abundance indices. In Step 2, the selectivity that was calculated based on fishing mortality at age in Step 1 was assumed to be the selectivity of terminal F, then value of F, which is multiplied by selectivity, was estimated using tuning.

The abundance indices used for tuning of F were spawning volume and Nagasaki CPUE (Supplementary Table 2-1). Spawning volume is the total quantity of Japanese anchovy eggs collected using NORPAC nets in the Sea of Japan (March to June) and the East China Sea (March to April) (Fig. 4-1). We used catch analysis data from April to December for Nagasaki CPUE, because it is an index for the biomass of fish age 0 (January to March is excluded because catch of fish age 1 and older is relatively higher in these months in most years) (Appendix 8).

Terminal F (the value that is the best fit for SSB and spawning volume obtained from cohort analysis, and the best fit for biomass of age 0 fish according to the Nagasaki CPUE) was estimated using the maximum likelihood method. Based on the two abundance indices above, the negative log-likelihood function to be minimized was defined as shown below (Hashimoto et al. 2018).

$$-\ln L = \sum_f \sum_y \frac{\left[\ln I_{f,y} - \left(b_f \ln B_{f,y} + \ln q_f\right)\right]^2}{2\sigma_f{}^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma_f}\right) \qquad (4)$$

In this equation, $I_{f,y}$ is the index *f* in year *y* (1: spawning volume, 2: Nagasaki CPUE), $B_{f,y}$ is the biomass that fits index *f* in year *y* (1. SSB, 2. biomass of fish age 0), and q_f, b_f and σ_f are estimated parameters (estimated at the same time as terminal F).

In addition, we assumed that $I_{f,y}$ and $B_{f,y}$ are in a relationship that is expressed by the following exponentiation equation.

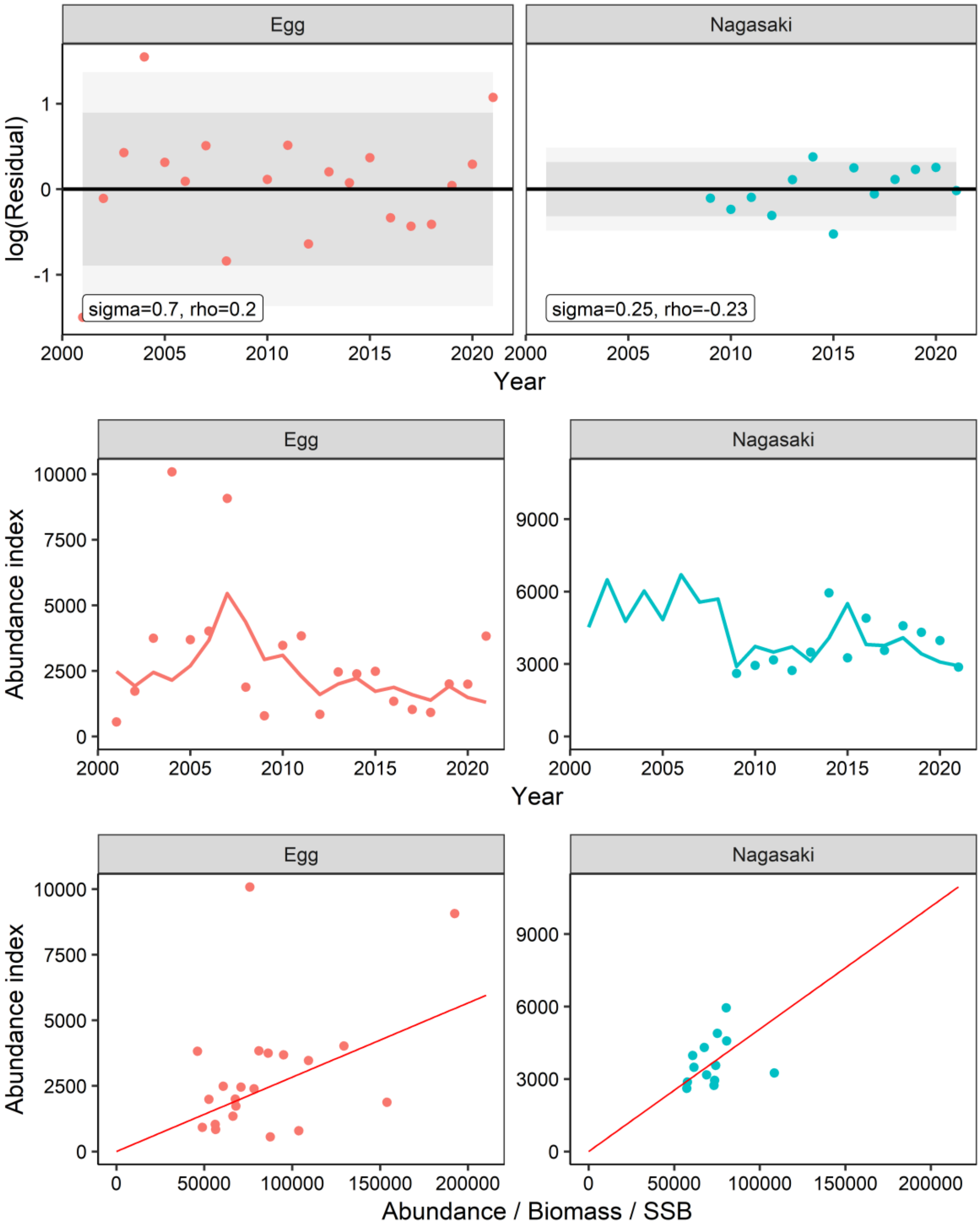
$$I_{f,y} = q_f B_{f,y}^{b_f} \qquad (5)$$

However, b_f was fixed at 1 for both index values in this stock assessment.

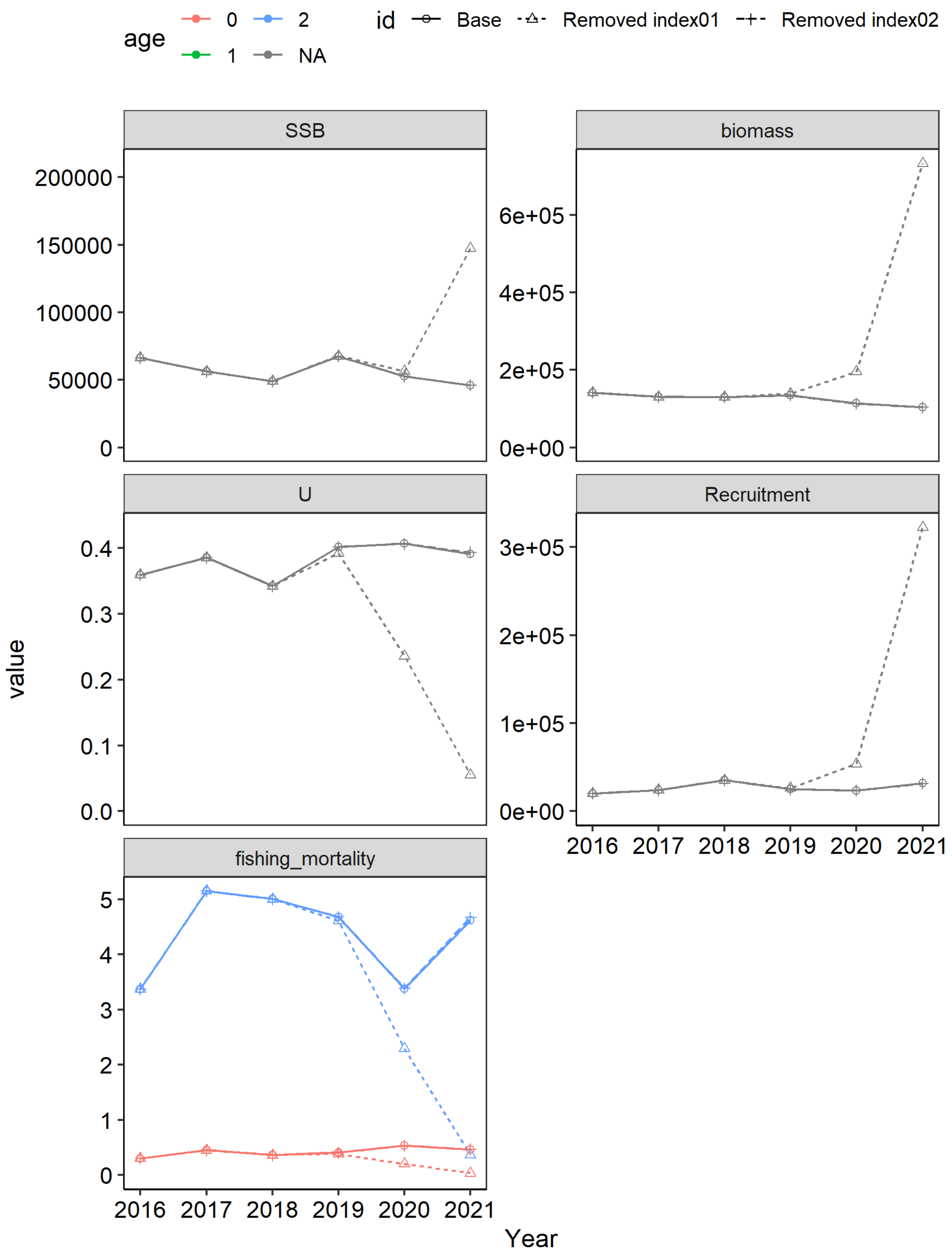
The periods that were fitted to index values were 2001 and onwards for spawning volume, and 2009 and onwards for Nagasaki CPUE. Exploratory results for the F that would minimize equation (4) under these conditions gave the following estimates: $F_{0,2021} = 0.46$, $F_{1,2021} = 4.62$, and $F_{2,2021} = 4.62$. Estimates for other parameters were $q_1 = 28.3$, $q_2 = 50.7$, $\sigma_1 = 0.70$, and $\sigma_2 = 0.25$.

The robustness of the statistical validity of the VPA and assumptions used for this stock assessment were diagnosed according to the Stock Assessment Model Diagnostic Procedures and Data Provision Guidelines (FY 2022) (FRA-SA2022-ABCWG02-03). Residuals of observed values of indices and projected values in the model are shown in Supplementary Figure 2-1. Spawning volume showed greater variability by year than Nagasaki CPUE, resulting in large residuals and lesser weight of indices in years that didn’t fit VPA results. The results of the jackknife analysis showed that exclusion of Nagasaki CPUE (index01) gave higher estimates for biomass, SSB, and recruitment volume in 2020 and onwards (Supplementary Fig. 2-2).

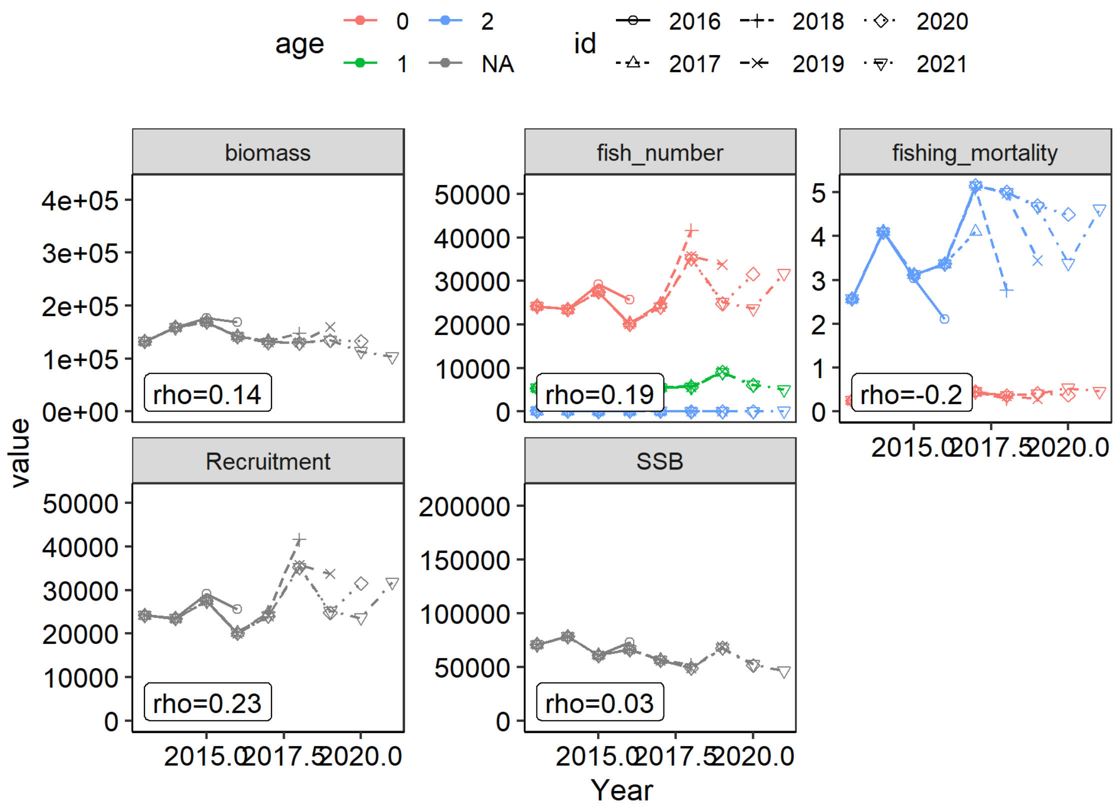
We performed a retrospective analysis of the 5-year period, which revealed that estimates for F and biomass changed after the data was expanded and updated (Supplementary Fig. 2-3). In the results, we observed that biomass, stock population, and recruitment volume continued to be revised downward, while fishing mortality continued to be revised upward. However, retrospective bias (Mohn's ρ, Mohn 1999) was not very large, with 0.14 for biomass, 0.19 for stock population, -0.20 for fishing mortality, 0.23 for recruitment in number, and 0.03 for SSB



Supplementary Fig. 2-1. (Top) Residuals of observed values of indices and projected values in the model, (Middle and Bottom) Observed values of indices (circles) and projected values in the model (solid lines)



Supplementary Fig. 2-2. Model analysis of VPA with tuning. Jackknife analysis of SSB, biomass, exploitation rate, recruitment in number, and fishing mortality. Indices (index01: Nagasaki CPUE, index02: spawning volume)



Supplementary Fig. 2-3. Retrospective analysis of 5-year period (from top left: biomass, stock population, fishing mortality, recruitment in number, SSB). In these graphs, 1e+05 means 10^5.

Supplementary Table 2-1. Tuning Indices

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Spawning volume (trillion eggs)	555	1,728	3,748	10,084	3,688	4,024	9,072	1,880	789	3,469	3,835
Nagasaki CPUE									2,612	2,947	3,172

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Spawning volume (trillion eggs)	842	2,458	2,391	2,484	1,345	1,032	918	2,000	1,991	3,824
Nagasaki CPUE	2,734	3,490	5,949	3,254	4,896	3,563	4,582	4,309	3,974	2,876

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Mohn, R (1999) The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci., **56**, 473-488.

Supplementary Table 2-2. Results of VPA With Tuning

Year	Catch in number at age (millions)			Average weight (g)		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1977	3,009	4,643	228	4.4	11.2	31.2
1978	3,486	3,220	200	3.2	10.3	30.3
1979	1,698	1,945	52	4.4	11.1	31.1
1980	3,330	3,046	109	3.0	10.1	31.7
1981	3,239	2,058	114	4.0	12.6	30.2
1982	7,904	2,704	217	3.6	14.2	31.7
1983	6,996	3,389	100	4.1	11.6	30.1
1984	5,044	4,281	73	3.6	9.0	30.9
1985	5,526	2,319	38	3.4	10.7	29.1
1986	4,142	3,617	106	4.4	11.2	29.1
1987	4,271	1,706	95	3.4	14.2	30.5
1988	5,996	2,101	140	3.4	13.3	26.7
1989	3,174	5,096	27	3.9	8.0	26.9
1990	2,762	2,280	67	4.1	12.5	30.9
1991	6,234	3,153	225	4.2	13.9	28.2
1992	9,721	4,086	387	3.4	9.5	29.5
1993	3,662	3,514	300	3.6	13.3	28.0
1994	3,515	2,729	329	2.9	13.6	28.7
1995	10,327	3,270	346	3.5	14.0	31.7
1996	7,730	6,502	238	3.4	12.5	26.1
1997	4,042	4,745	25	4.4	12.7	25.3
1998	7,311	6,582	469	4.2	12.9	27.6
1999	7,022	7,990	662	3.6	10.5	29.1
2000	10,901	5,710	310	4.0	13.1	28.3
2001	3,384	5,177	139	3.9	9.4	25.6
2002	6,479	3,663	35	4.1	10.3	31.7
2003	9,478	4,218	83	3.1	11.1	26.3
2004	6,732	3,010	96	3.0	12.8	23.5
2005	13,377	5,577	122	1.8	8.5	24.0
2006	11,581	3,210	145	2.8	10.7	25.8
2007	6,345	3,484	678	3.2	12.8	27.7
2008	3,963	4,509	894	4.8	11.4	29.0
2009	3,544	2,515	227	2.6	14.0	30.5
2010	4,228	2,997	370	3.0	14.5	27.5
2011	6,200	3,767	248	2.7	10.8	27.0
2012	6,387	3,069	53	2.9	9.9	25.7
2013	3,256	3,005	84	2.5	12.4	27.9
2014	3,973	4,134	90	3.4	10.7	28.8
2015	6,542	3,607	25	3.9	9.6	29.0

2016	3,206	3,602	59	3.7	10.4	23.0
2017	5,300	3,286	47	3.1	9.9	26.5
2018	6,489	3,387	7	2.3	8.7	24.7
2019	5,085	5,414	8	2.7	7.5	26.1
2020	5,945	3,610	18	2.6	8.4	23.9
2021	7,115	3,055	46	1.8	8.7	22.5

Supplementary Table 2-2. Results of VPA With Tuning (continued)

Year	Stock population (millions)			Fishing mortality			%SPR
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	
1977	20,141	8,598	422	0.28	2.21	2.21	41%
1978	15,965	5,585	347	0.45	3.01	3.01	32%
1979	18,272	3,759	101	0.17	1.92	1.92	48%
1980	17,635	5,692	203	0.37	2.14	2.14	36%
1981	18,751	4,468	247	0.34	1.42	1.42	46%
1982	29,138	4,933	396	0.59	2.34	2.34	33%
1983	31,245	5,925	175	0.46	2.86	2.86	34%
1984	20,119	7,251	124	0.53	3.63	3.63	27%
1985	26,739	4,342	71	0.42	2.12	2.12	37%
1986	16,248	6,485	191	0.55	2.52	2.52	32%
1987	16,802	3,465	192	0.54	1.67	1.67	37%
1988	33,845	3,590	240	0.35	3.34	3.34	42%
1989	19,348	8,814	47	0.32	3.06	3.06	34%
1990	24,672	5,193	152	0.20	1.29	1.29	53%
1991	33,559	7,401	527	0.37	1.21	1.21	49%
1992	37,442	8,564	810	0.56	1.54	1.54	33%
1993	23,328	7,878	672	0.30	1.33	1.33	50%
1994	23,391	6,361	767	0.28	1.23	1.23	52%
1995	46,571	6,473	685	0.46	1.79	1.79	39%
1996	41,462	10,869	398	0.37	4.29	4.29	40%
1997	45,136	10,565	55	0.16	1.35	1.35	58%
1998	51,892	14,153	1,009	0.26	1.46	1.46	51%
1999	38,900	14,656	1,215	0.35	2.29	2.29	38%
2000	41,621	10,052	546	0.57	2.76	2.76	33%
2001	23,075	8,700	234	0.28	3.96	3.96	39%
2002	30,908	6,436	61	0.42	2.79	2.79	33%
2003	30,814	7,441	146	0.71	2.73	2.73	28%
2004	39,723	5,587	179	0.33	2.19	2.19	46%
2005	51,648	10,530	230	0.56	2.06	2.06	32%
2006	47,820	10,887	491	0.51	0.67	0.67	46%
2007	34,800	10,568	2,058	0.36	0.78	0.78	53%
2008	23,366	8,954	1,775	0.33	1.77	1.77	43%
2009	22,422	6,192	559	0.30	1.11	1.11	52%
2010	24,554	6,099	752	0.33	1.66	1.66	48%
2011	25,082	6,469	426	0.52	3.22	3.22	32%
2012	25,118	5,467	95	0.54	2.60	2.60	32%
2013	24,208	5,367	150	0.25	2.57	2.57	45%
2014	23,462	6,931	152	0.33	4.10	4.10	37%

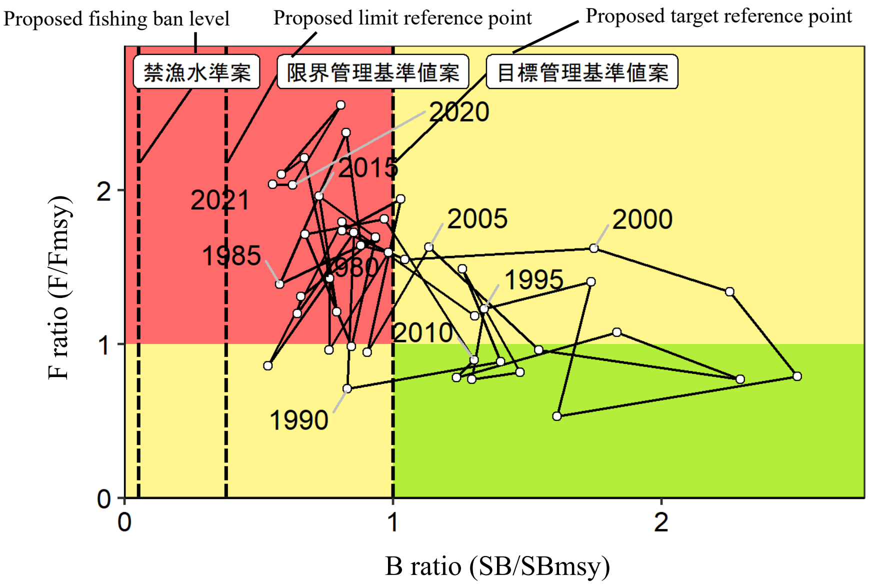
2015	27,506	6,221	42	0.50	3.12	3.12	30%
2016	20,099	6,151	101	0.31	3.37	3.37	42%
2017	24,021	5,449	78	0.45	5.15	5.15	32%
2018	35,190	5,622	12	0.36	5.00	5.00	34%
2019	25,131	9,010	14	0.41	4.68	4.68	30%
2020	23,628	6,161	31	0.54	3.38	3.38	30%
2021	31,796	5,086	77	0.46	4.62	4.62	33%

Appendix 3 Proposed Reference Points and Proposed Fishing Ban Level

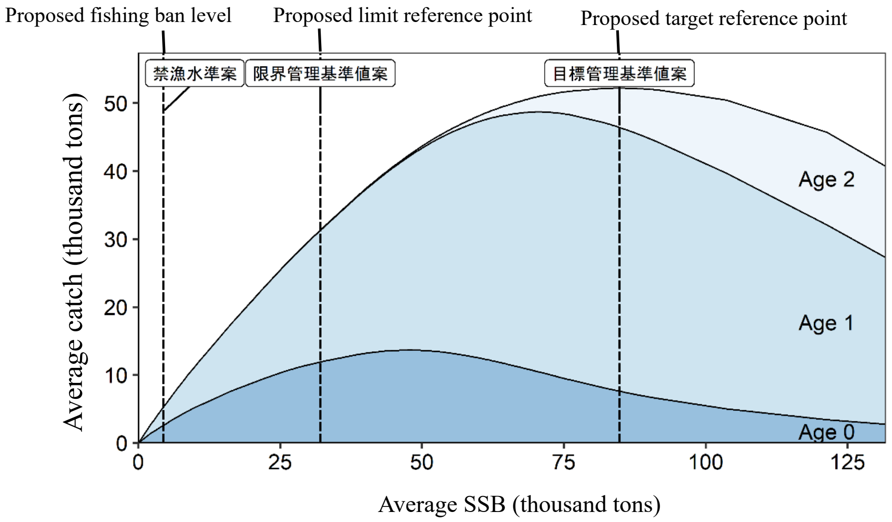
The Research Institute Meeting held in September 2021 proposed adoption of the following: SSB required for MSY (SBmsy: 84,000 tons) as a target reference point (SBtarget), SSB required for 60% MSY (SB0.6msy: 32,000 tons) as a limit reference point (SBlimit), and SSB required for 10% MSY (SB0.1msy: 4,000 tons) as a fishing ban level (SBban) (Hino et al. 2021, Supplementary Table 6-2).

The proposed target reference points and fishing pressure (F) required for MSY are shown in the Kobe plot in Supplementary Fig. 3-1. SSB in 2021 (SB2021: 46,000 tons) obtained from cohort analysis is lower than the proposed target reference points, but above the proposed limit reference point and proposed fishing ban level. Fishing pressure of this stock since 2014 was judged to be above the fishing pressure required for MSY (Fmsy).

The relationship of average SSB and average catch in weight at age at equilibrium is shown in Supplementary Fig. 3-2. When average SBB is below the limit reference point, catches are dominated by age 0 and age 1 fish. However, the proportion of older fish tends to increase in correlation with increase of SSB.



Supplementary Fig. 3-1. Relationship of proposed reference points and SSB/fishing pressure (Kobe plot)



Supplementary Fig. 3-2. Relationship of average SSB and average catch in weight at age at equilibrium (catch in weight curve)

Appendix 4 Future Projections Based on Proposed HCRs

(1) Setting Future Projections

Future projection calculations were performed for the 2022 to 2053 fishing seasons using a progression method for cohort analysis applied to estimates for stock abundance in 2021 (Appendix 5). Recruitment volume in future projections was predicted based on values for SSB in each year using the stock-recruitment relationship model. Calculations were replicated 10,000 times assuming errors which follow log-normal distribution to account for uncertainty in recruitment. Catch in 2022 was assumed to be the value in 2021 (41,000 tons) under recent fishing conditions (Appendix 10). The current fishing pressure is the F value that gives the %SPR corresponding to fishing pressure from 2019 to 2021 in this assessment, under the same selectivity and biological parameters (average body weight, etc.) as the calculations for proposed reference points. Fishing pressure in 2023 and onwards was set as the fishing pressure established in the following proposed HCRs, which are based on SSB projections for each year.

(2) Proposed Harvest Control Rules

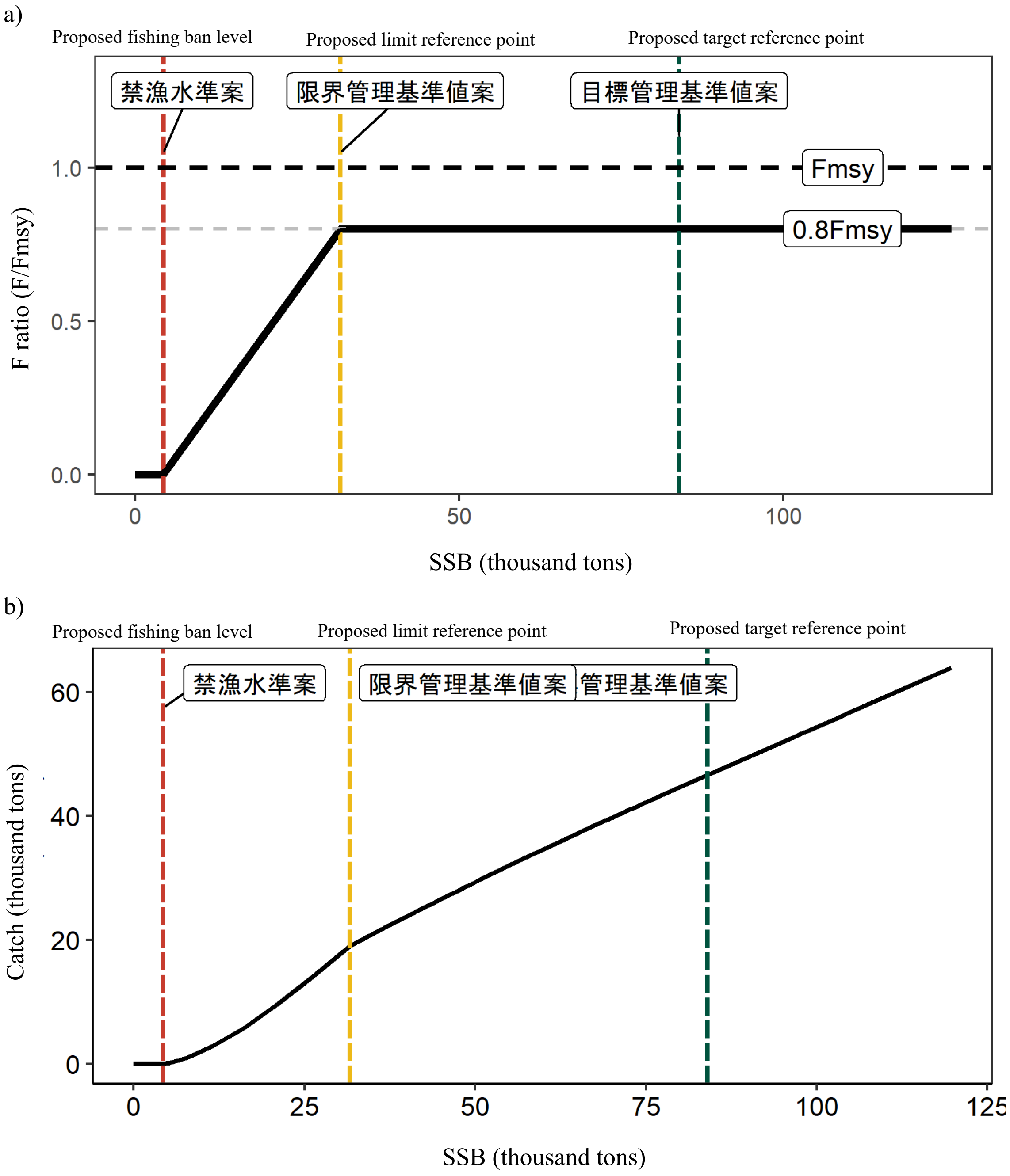
Proposed HCRs guidelines which aim for better results than proposed target reference points in consideration of the probability of success for both maintenance and recovery of SSB, which set fishing pressure (F) and other factors that correspond to SSB. The Basic Guidelines for Harvest Control Rules and ABC Calculation describe linear reduction of fishing pressure down to the proposed fishing ban level when SSB falls below the proposed limit reference point, and an upper limit for fishing pressure equal to Fmsy multiplied by adjustment coefficient β when SSB is above the limit reference point. Supplementary Figure 4-1 shows the proposed HCRs from the Research Institute Meeting for this stock. This figure includes an example showing when the adjustment coefficient β is set to 0.8. The Research Institute Meeting proposals state that “when β is lower than 0.8, then there is a 50% or higher probability that values will exceed proposed target reference points in 10 years.”

(3) Projected Values for 2023

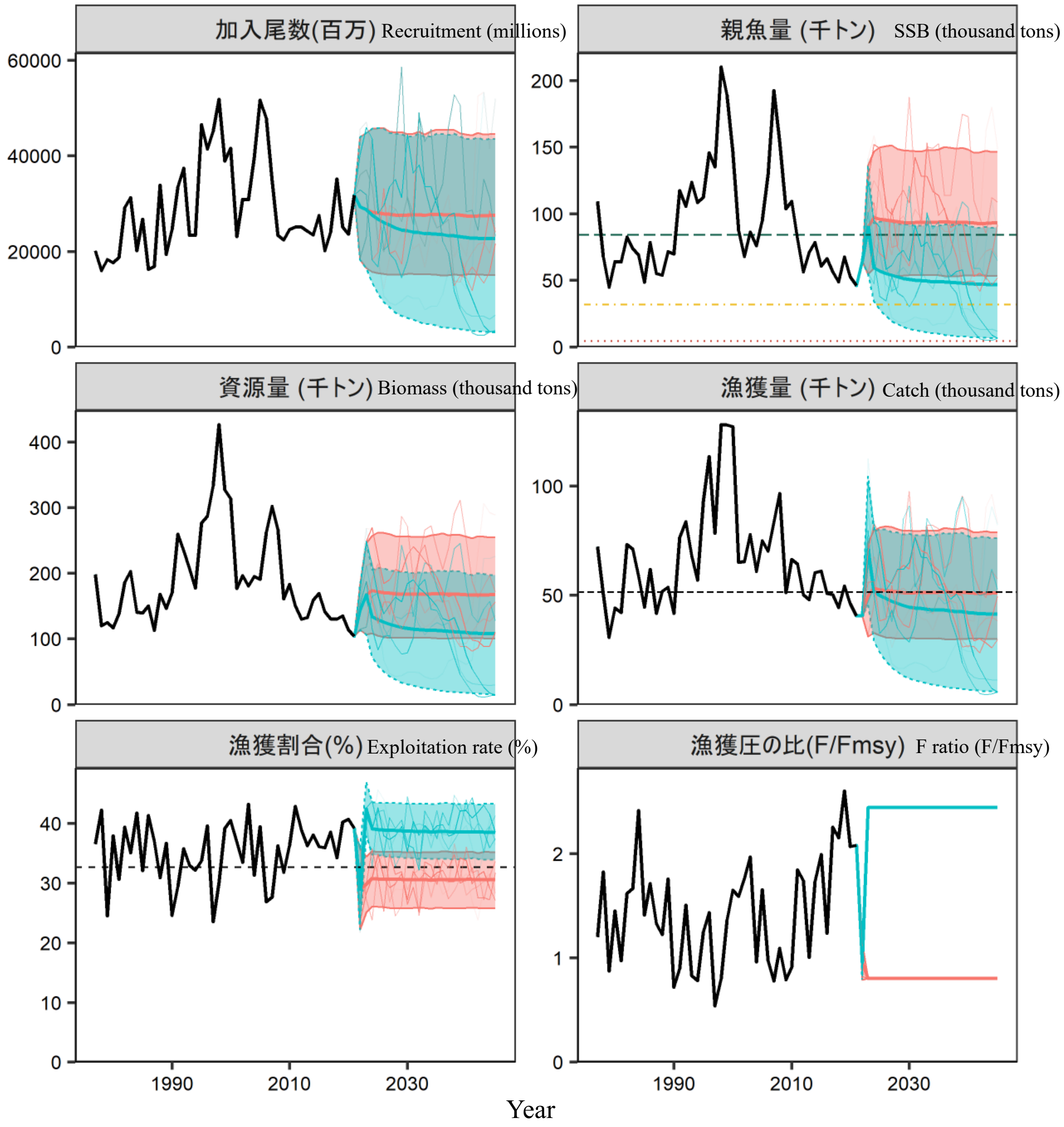
The average catch in 2023, as calculated based on proposed HCRs, will be 50,000 tons if β is set to 0.8, and 55,000 tons if β is set to 1.0 (Supplementary Table 6-4). Projected SSB in 2023 is forecast to be an average of 90,000 tons, which exceeds limit reference points in replicated calculations using both values.

(4) Projections for 2024 and Onwards

Results of future projections, including 2024 and onwards, are shown in Supplementary Figure 4-2 and Supplementary Tables 4-1 and 4-2. If management based on these proposed HCRs is continued for 10 years, then projected values for average SSB in 2033 will be 94,000 tons if β is set to 0.8 (90% prediction interval: 54,000 to 149,000 tons), and 85,000 tons if β is set to 1.0 (90% prediction interval: 47,000 to 135,000 tons) (Supplementary Table 6- 5). If β is 0.9 or lower, then there is a 50% or higher probability that the projected value will exceed the proposed target reference point. If the current fishing pressure (F2019 to 2021) is continued, then projected values for SSB in 2033 will be 50,000 tons (90% prediction interval of 11,000 to 92,000 tons), with a 8% probability that the value will exceed the proposed target reference point, and a 76% probability that it will exceed the proposed limit reference point.



Supplementary Fig. 4-1. Proposed HCRs (β = 0.8) (a) is the scenario when the vertical axis shows fishing pressure, and (b) is the scenario when the vertical axis shows catch in weight



(Shaded areas: 5 to 95% prediction interval, thick solid lines: average value, thin solid lines: simulation results)

Supplementary Fig. 4-2. Future projections based on proposed HCRs (red line), and future projections if the current fishing pressure is continued (green line)

The solid line indicates average values, the shaded area indicates the prediction interval which contains 90% of simulation results, and the thin lines indicate 5 future projections. In the SSB graph, the green dashed line is the proposed target reference point, the yellow dotted line is the proposed limit reference point, and the red dotted line is the proposed fishing ban level. In the exploitation rate graph, the dashed line indicates Umsy. These graphs use results for constant fishing pressure and adjustment coefficient β = 0.8.

Supplementary Table 4-1. Probability (%) that future SSB will exceed proposed target/limit reference points. Values in bold indicate values in the target year, which is 10 years after starting management based on HCRs.

These tables show results with β varied from 0.0 to 1.0 in 2023 and onwards, and future projections if the current fishing pressure (F2019 to 2021) is continued.

a) Probability of exceeding the proposed target reference point (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
1.0	0	0	55	52	48	46	46	46	45	44	44	45	**45**	44	44
0.9	0	0	55	59	55	53	52	52	51	50	50	51	**51**	51	50
0.8	0	0	55	65	62	60	59	59	58	58	57	58	**58**	57	57
0.7	0	0	55	72	69	67	67	67	66	65	65	65	**65**	65	65
0.6	0	0	55	79	77	75	74	74	73	73	73	74	**73**	72	73
0.5	0	0	55	86	84	83	82	82	81	80	81	81	**81**	80	81
0.4	0	0	55	91	90	89	88	88	88	87	88	88	**88**	87	87
0.3	0	0	55	95	95	94	93	93	93	93	93	93	**93**	93	93
0.2	0	0	55	98	98	97	97	97	97	97	97	97	**96**	96	96
0.1	0	0	55	99	99	99	99	99	99	99	99	99	**99**	98	98
0.0	0	0	55	100	100	100	99	99	99	100	100	100	**100**	99	100
F2019-2021	0	0	55	10	10	9	9	8	8	8	8	8	**8**	8	7

b) Probability of exceeding the proposed limit reference point (%)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
1.0	100	100	100	100	100	100	100	100	99	100	100	100	**100**	99	99
0.9	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
F2019-2021	100	100	100	97	92	87	84	82	80	79	77	76	**76**	71	70

Supplementary Table 4-2. Trends in future SSB and average catch in weight Values in bold indicate values in the target year, which is 10 years after starting management based on proposed HCRs. These tables show results with β varied from 0.0 to 1.0 in 2023 and onwards, and future projections if the current fishing pressure (F2019 to 2021) is continued.

a) Trends in average SSB (thousand tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
1.0	46	65	90	89	87	86	85	85	84	84	84	84	**85**	84	84
0.9	46	65	90	93	91	90	90	89	89	88	89	89	**89**	88	88
0.8	46	65	90	97	96	95	95	94	94	93	93	93	**94**	93	93
0.7	46	65	90	103	102	101	100	100	99	99	99	99	**99**	98	99
0.6	46	65	90	109	109	108	107	107	106	106	106	106	**106**	105	105
0.5	46	65	90	116	117	116	115	115	114	113	114	114	**114**	113	113
0.4	46	65	90	125	127	126	125	124	124	123	123	123	**123**	122	123
0.3	46	65	90	135	139	137	136	136	135	135	135	135	**135**	134	134
0.2	46	65	90	148	153	152	151	150	149	149	149	149	**149**	148	148
0.1	46	65	90	162	171	169	168	167	166	166	166	166	**166**	165	165
0.0	46	65	90	180	193	190	189	188	187	186	186	187	**187**	185	186
F2019-2021	46	65	90	60	57	55	54	53	51	51	50	50	**49**	47	46

b) Trends in average catch (thousand tons)

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
1.0	41	41	55	54	53	53	52	52	52	52	52	52	**52**	51	51
0.9	41	41	53	54	53	52	52	52	52	51	52	52	**52**	51	51
0.8	41	41	50	53	53	52	52	52	51	51	51	51	**51**	51	51
0.7	41	41	47	52	52	51	51	51	51	50	51	51	**51**	50	50
0.6	41	41	43	51	51	50	50	50	49	49	49	49	**49**	49	49
0.5	41	41	38	49	49	48	48	48	47	47	47	47	**47**	47	47
0.4	41	41	33	45	45	45	45	45	44	44	44	44	**44**	44	44
0.3	41	41	27	39	40	40	40	39	39	39	39	39	**39**	39	39
0.2	41	41	20	31	32	32	32	31	31	31	31	31	**31**	31	31
0.1	41	41	11	19	20	19	19	19	19	19	19	19	**19**	19	19
0.0	41	41	0	0	0	0	0	0	0	0	0	0	**0**	0	0
F2019-2021	41	41	71	52	50	48	47	46	45	45	44	44	**44**	42	41

Appendix 5 Future Projection Methods

Future projections were performed based on proposed HCRs using the SSB estimates. The values used for recruitment volume projections for 2022 and onwards were values estimated using the hockey-stick model for relationships (a = 0.614, b = 4.48e+04, SD = 0.268) proposed at the Research Institute Meeting held in September 2021 (Hino et al. 2021). The data used to estimate the parameters of this stock-recruitment relationship was based on SSB and recruitment volume reported in the FY 2020 stock assessment (Kuroda et al. 2021, Appendix 3), and the optimization method was the least squares method. We believe there is autocorrelation regarding residuals in recruitment volume.

The fishing mortality F used in the future projections were values estimated based on control rules for Stock Group 1 according to Basic Guidelines for Harvest Control Rules and ABC Calculation at FY 2022 (FRA-SA2022-ABCWG02-01). We used the same values for selectivity and average body weight in catches as were used to estimate the various proposed reference points which were proposed at the Research Institute Meeting (Supplementary Table 5-1). These values are based on the FY 2020 stock assessment, same as for the stock-recruitment relationship. Fishing pressure in 2022 (F2022) was assumed to be the value that makes catch in 2022 equal to catch in 2021, which was 41,000 tons (Appendix 10).

Projections for stock population were made using progression method cohort analysis.

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

$$N_{2,y+1} = \left(N_{1,y} + N_{2,y}\right)\exp\left(-F_{1,y} - M\right) \tag{7}$$

Catch in number was determined using the equation below with catch in number results from the equation above (8) and F value assumptions based on each catch strategy

$$C_{a,y} = N_{a,y}\left\{1 - \exp\left(-F_{a,y}\right)\right\}\exp\left(-\frac{M}{2}\right) \tag{8}$$

Supplementary Table 5-1. Average weight by age

	Selectivity (Note 1)	Fmsy (Note 2)	F2022 (Note 3)	Average weight (g)	Natural mortality coefficient	Maturity ratio
Age 0	0.09	0.18	0.17	2.70	1.00	0
Age 1	1.00	1.99	1.91	8.67	1.00	1.00
Age 2	1.00	1.99	1.91	26.3	1.00	1.00

Note 1: Selectivity used to estimate the level required for MSY at the FY 2021 Research Institute Meeting (i.e., selectivity of Fcurrent in the FY2020 stock assessment).

Note 2: Fmsy estimated at the FY 2021 Research Institute Meeting (i.e., Fmsy/Fcurrent multiplied by Fcurrent in the FY2020 stock assessment).

Note 3: Average F was assumed to be the value that makes catch in 2022 equal to the catch in 2021, which was 41,000 tons, based on biomass in 2022 as estimated in this stock assessment, under the selectivity described above (Appendix 10).

References

Kurot H., Takahashi M., Yoda M., Muko S., Sasa C., Hino H. (2021) Stock Assessment for Tsushima Current Stock of Japanese Anchovy (Fiscal Year 2020). Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2020), Japan Fisheries Research and Education Agency, Fisheries Agency.

Hino H., Kurot H., Muko Y., Sassa C., Kunimatsu S. (2021) Materials for the Research Institute Meeting on Reference Points of Tsushima current stock of Japanese anchovy (FY 2021). Japan Fisheries Research and Education Agency

Appendix 6: Summary of Various Parameters and Assessment Results

Supplementary Table 6-1. Parameters for stock-recruitment relationship model

Stock-recruitment relationship model	Optimization method	Autocorrelation	a	b	S.D.	ρ
Hockey-stick model	Least squares method	Yes	0.614	4.48×10^4	0.268	0.579

In this table, a and b are the estimated parameters of the stock-recruitment relationship model, S.D. is the standard deviation of recruitment volume, and ρ is the autocorrelation coefficient.

Supplementary Table 6-2. Proposed reference points and MSY

Item	Value	Description
SBtarget (proposed)	84 thousand tons	A proposed target reference point. SSB required for MSY (SBmsy).
SBlimit (proposed)	32,000 tons	A proposed limit reference point. SSB required for catch of 60% of MSY (SB0.6msy).
SBban (proposed)	4 thousand tons	Proposed fishing ban level. SSB required for catch of 10% of MSY (SB0.1msy).
Fmsy	Fishing pressure required for MSY (fishing mortality F) (Age 0, Age 1, Age 2) = (0.18, 1.99, 1.99)	
%SPR (Fmsy)	45%	%SPR corresponding to Fmsy
MSY	51,000 tons	Maximum Sustainable Yield

Supplementary Table 6-3. SSB and fishing pressure in most recent year

Item	Value	Description
SB2021	46,000 tons	SSB in 2021
F2021	Fishing pressure in 2021 (fishing mortality F) (Age 0, Age 1, Age 2) = (0.46, 4.62, 4.62)	
U2021	39%	Exploitation rate in 2021
%SPR (F2021)	32.7%	%SPR in 2021
%SPR (F2019 to 2021)	30.6%	%SPR corresponding to current fishing pressure (2019 to 2021 fishing seasons)*
Compared against proposed reference points		
SB2021 / SBmsy (SBtarget)	0.55	B ratio required for MSY (proposed target reference point) to SSB in 2021 fishing season
F2021 / Fmsy	2.04	F ratio required for MSY to fishing pressure in 2021*
Level of SSB	Under the level required for MSY	
Level of fishing pressure	Over the level required for MSY	
Changes in SSB	Flat	

*Ratio calculated based on F converted to %SPR, which gives the fishing pressure of Fmsy under the selectivity of 2021.

Supplementary Table 6-4. Projected catch in weight and projected SSB

SSB in 2023 fishing season (average projected value): 90,000 tons			
Item	Catch (thousand tons) in 2023	Ratio to current fishing pressure (F/F2019 to 2021)	Exploitation rate in 2023 (%)
β = 1.0	55	0.41	33
β = 0.8	50	0.33	30
β = 0.6	43	0.25	26
β = 0.4	33	0.16	20
β = 0.2	20	0.08	12
β = 0	0	0	0
F2019 to 2021	71	1.00	42

Supplementary Table 6-5. Results of future projections using various β

Uncertainty under consideration: recruitment					
β	SSB in 2033 (thousand tons)	90% prediction interval (thousand tons)	Probability (%) that SSB will exceed the following proposed reference points in 2033		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
β = 1.0	85	47 – 135	45	100	100
β = 0.8	94	54 – 149	58	100	100
β = 0.6	106	62 – 166	73	100	100
β = 0.4	123	72 – 192	88	100	100
β = 0.2	149	88 – 231	96	100	100
β = 0	187	111 – 289	100	100	100
F2019 to 2021	49	11 – 92	8	76	99

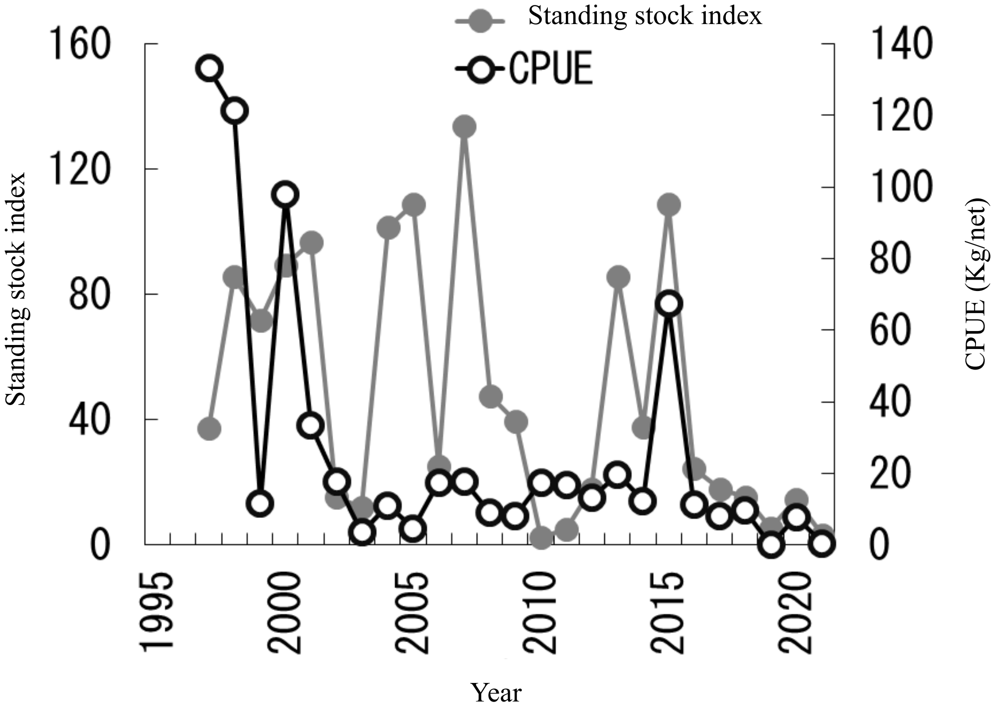
Appendix 7 Summary of Pelagic Fish School Size Surveys

Results of spring/summer pelagic fish school size surveys using quantitative echo sounders and midwater trawls are summarized here. It is still being debated exactly how abundance indices calculated in each survey reflect the abundance of the whole stock, so these values are only included as a reference for judging trends in this stock.

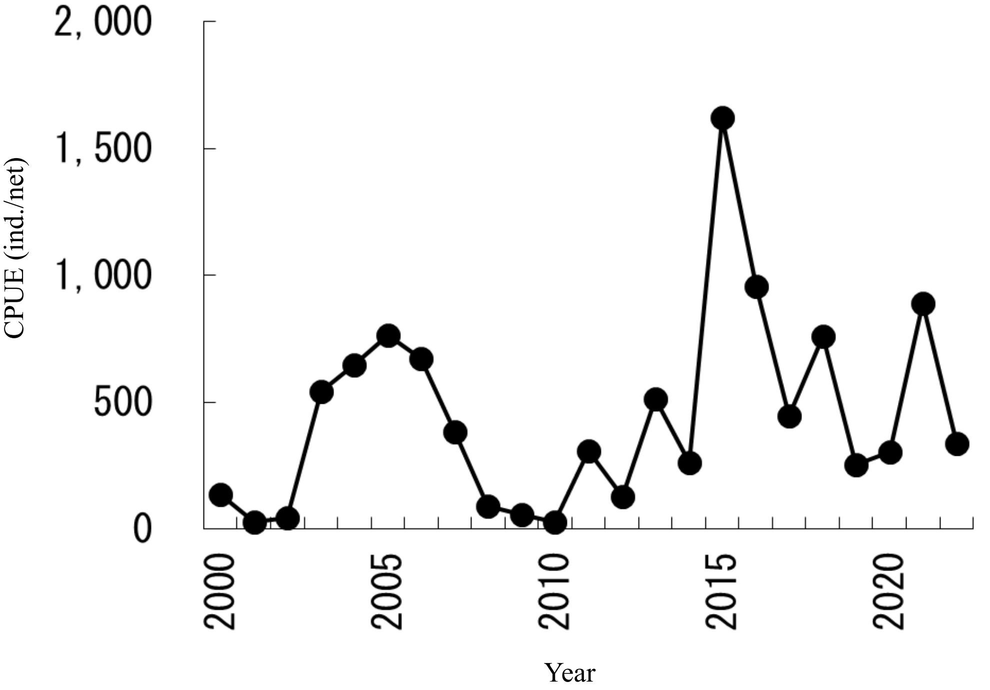
Pelagic fish school size surveys were conducted along the northwestern coast of Kyushu in summer (August to September) using quantitative echo sounders and other equipment. The standing stock index based on the results of surveys using quantitative echo sounders (Ohshimo 2004) and CPUE (ind./net) based on midwater trawls are shown in Supplementary Figure 7-1. The standing stock index has fluctuated in cycles, reaching 134.0 (relative value) in 2007, which was the highest level since 1997. Since 2016, the standing stock index has remained low, and was 3.3 in 2021. Meanwhile, the CPUE of Japanese anchovy based on midwater trawls was around 130 kg/net from 1997 to 1998. Since 1999, CPUE has ranged between 0.01 and 33.4 kg/net, except for unusually high levels in 2000 and 2015, and was 0.6 kg/net in 2021.

Recruitment surveys were performed using Neuston nets in the East China Sea in spring (April). Trends in the CPUE of Japanese anchovy juveniles from these surveys are shown in Supplementary Figure 7-2. CPUE ranged between 26 and 138 ind./net from 2000 to 2002, and then increased sharply to range between 385 and 765 ind./net from 2003 to 2007. From 2008 to 2014, CPUE levels declined temporarily, and were frequently less than 262 ind./net. In 2015, CPUE increased sharply to 1,622 ind./net, and was in a decreasing trend in 2016 and onwards, but it increased to 891 ind./net in 2021 and 339 ind./net in 2022.

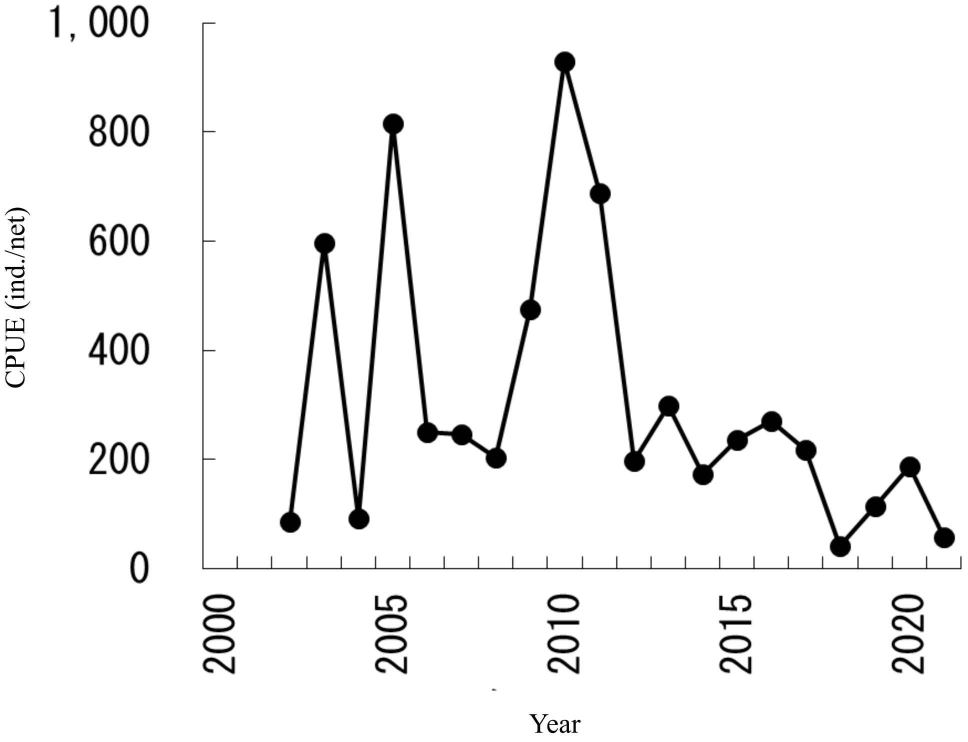
Trends in the CPUE of juveniles captured in Neuston nets, based on pelagic fish school size surveys using midwater trawls and other equipment along the northwestern coast of Kyushu (May to June) are shown in Supplementary Figure 7-3. CPUE was particularly high in 2003 (598 ind./net), 2005 (815 ind./net), and from 2009 to 2011 (475 to 928 ind./net), and fluctuated between 85 and 299 ind./net in other years (2002 to 2017). In 2018, CPUE declined sharply to a record low of 43 ind./net, and it was 59 ind./net in 2021.



Supplementary Fig. 7-1. CPUE of Japanese anchovy (August to September) based on standing stock index (quantitative echo sounder surveys) and midwater trawls



Supplementary Fig. 7-2. CPUE of juveniles (April) based on surveys in the East China Sea



Supplementary Fig. 7-3. CPUE of juveniles (May to June) based on surveys along the northwest coast of Kyushu

Appendix 8 Standardized CPUE of Small to Medium-Scale Purse Seine Fisheries in Nagasaki Prefecture

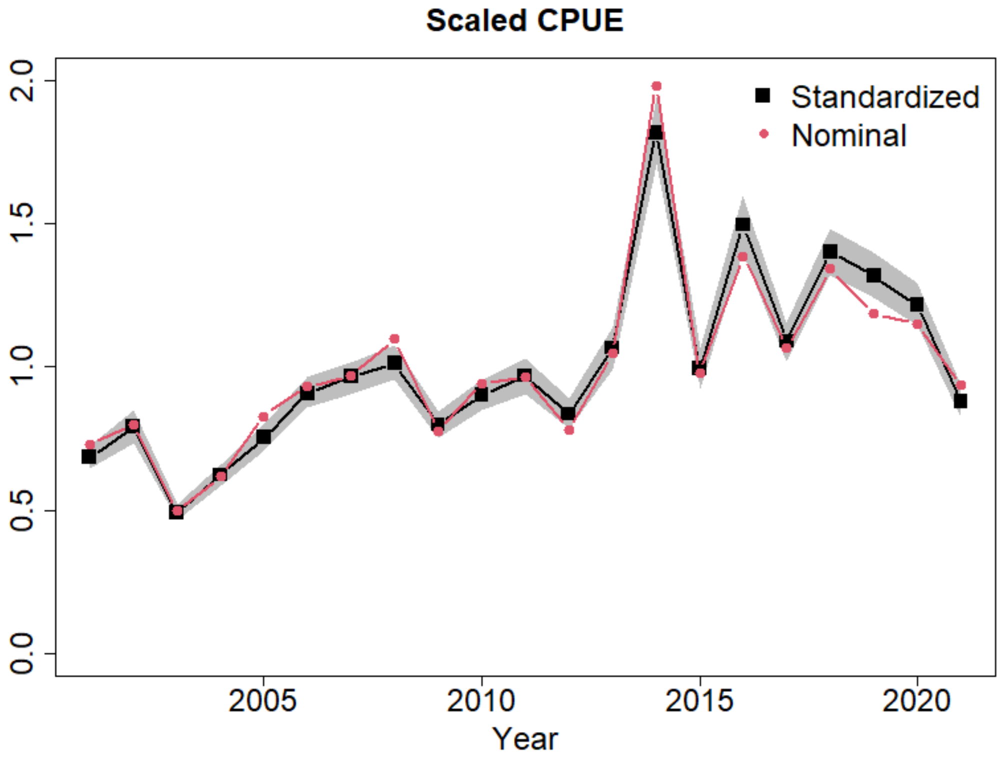
The CPUE of small to medium-scale purse seine fisheries in Nagasaki Prefecture, which have accounted for around half of the catch of this stock since 2001, was standardized. When the results which were standardized using the methods from the previous fiscal year were used as abundance indices of fish age 0 to 2 in VPA with tuning, there were problems with overestimation in retrospective bias for recruitment volume. One solution for this problem was to perform standardization of data from April to December, excluding data from January to March when fish age 1 and older comprise a relatively higher portion of catches, because these standardized results are only used as an abundance index of fish age 0, which compromise the majority of catch. Catch (kg) of Japanese anchovy per vessel per day was used for CPUE. Data for water temperature at 50 m depth, which was adopted as an environmental factor, was taken from FRA-ROMS II reanalysis data (downloaded on July 15, 2022).

Because operations of small to medium-scale purse seine fisheries are focused on Japanese anchovy, targeting operations were not considered, and only data from non-zero catches was used for analysis (zero-catch data was excluded). We constructed a model which sets the response variable as the natural log converted CPUE, and sets the explanatory variables as the water temperature at 50 m depth (Temp50 m), ocean area (Area), month (Month), and year (Year), and which assumes that model error follows a normal distribution. All explanatory variables were categorical variables, and water temperature at 50 m depth was categorized in increments of 1°C. The following full model was selected through a best subset approach based on the Bayesian Information Criterion (BIC).

Ln (CPUE) ~ Intercept + Year + Month + Area +Temp50 m + error term

We confirmed that there were no problems with multicollinearity when using VIF as an index in the selected model. The frequency distribution of residuals did not deviate significantly from normal distribution. Standardized CPUE was calculated based on the selected model.

The standardized CPUE, which was scaled according to the average from 2001 to 2021, fluctuated following generally similar trends as the nominal CPUE, remaining flat from 2001 to 2013, and reaching a record high of 1.9 in 2014. Afterwards, it fluctuated in cycles from 2015 to 2020, and then decreased in 2021. Details of this standardization methodology are presented in a separate document (FRA-SA2022-SC06-05).



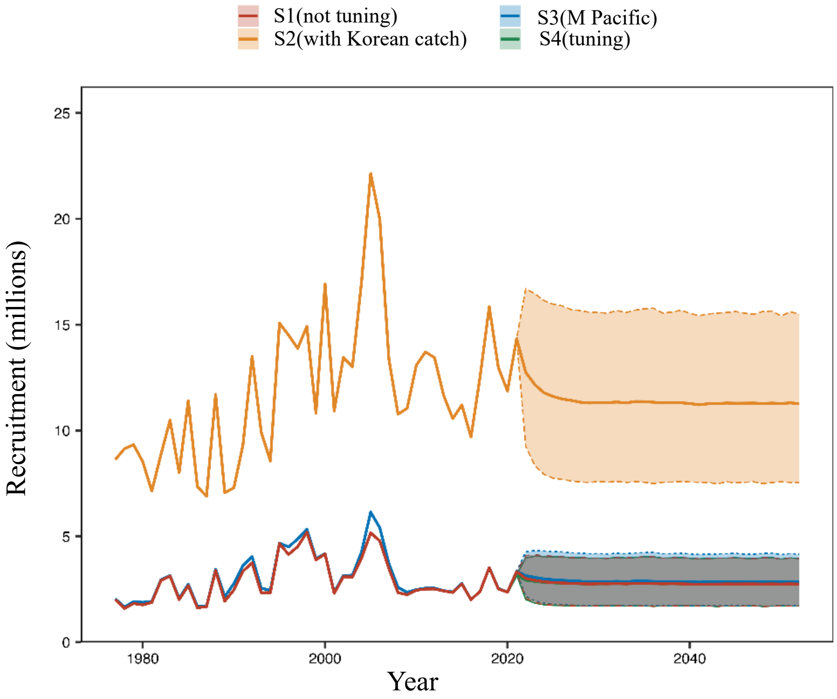
Supplementary Fig. 8-1. Trends in nominal CPUE and standardized CPUE, scaled by average
The shaded area indicates the 95% confidence interval for standardized CPUE

Appendix 9 Stock Assessment Results & Future Projections in Alternative Scenarios

Stock assessment results under different conditions (shown in Supplementary Table 9-1), and future projections results assuming β = 0.8, are summarized here. We performed calculations for scenarios that don't consider the catch of shirasu (S1 to S4) and scenarios that do (S5 to S7). Calculations were also performed for different natural mortality, and for a scenario that considers the catch by South Korea. In these scenarios, S4 represents the base case in the stock assessment, and F in 2022 was assumed to be the value that makes catch equal to the catch in the most recent year, which was 41,000 tons in 2021. In addition to S4, other scenarios also assumed that F in 2022 was equal to the F value that makes catch in weight the same as in 2021. Future projections with different assumptions for F in 2022 in S4 are shown in Appendix 10.

Estimate results for recruitment volume, biomass, SSB, and exploitation rate in each scenario are separated by whether they consider the catch of shirasu, or not (Supplementary Fig. 9-1 and 9-2, Supplementary Tables 9-2 and 9-3). SSB and fishing pressure in 2021 are summarized in a Kobe plot (Supplementary Fig. 9-3). In all scenarios, SSB in 2021 was lower than SBmsy, and fishing pressure was higher than Fmsy.

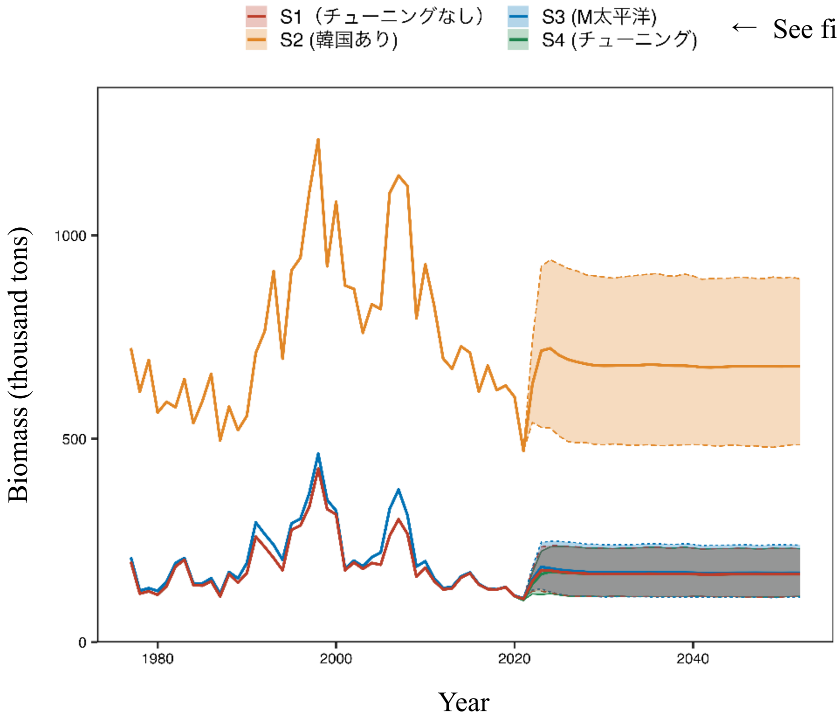
(a) Recruitment in number



Supplementary Fig. 9-1. Scenarios without catch of shirasu. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate

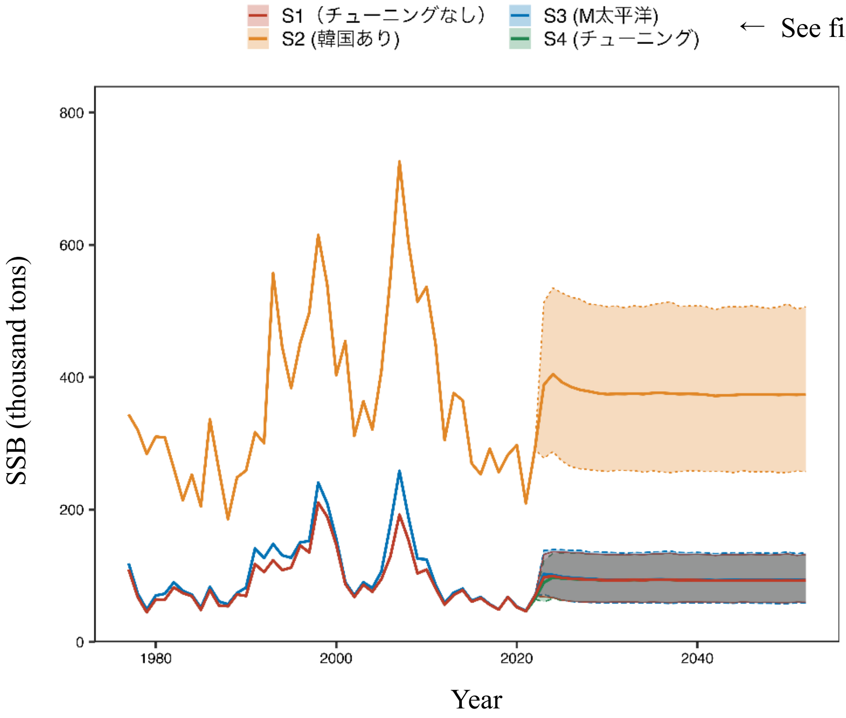
(S4 is the base case, shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average)

(b) Stock abundance



← See figure (a)

(c) SSB

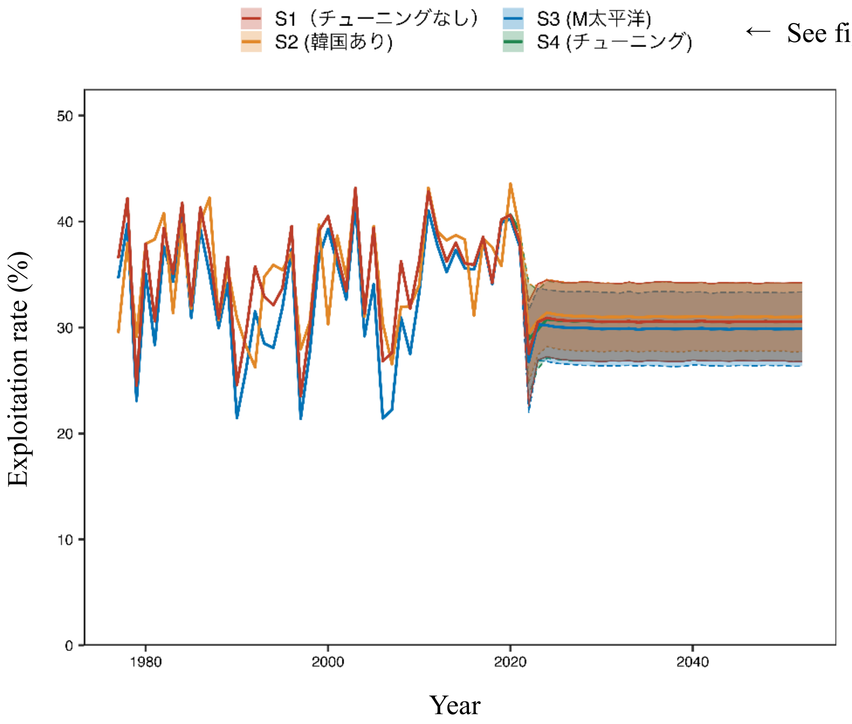


← See figure (a)

Supplementary Fig. 9-1. Scenarios without catch of shirasu. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate

(S4 is the base case, shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average) (continued)

(d) Exploitation rate

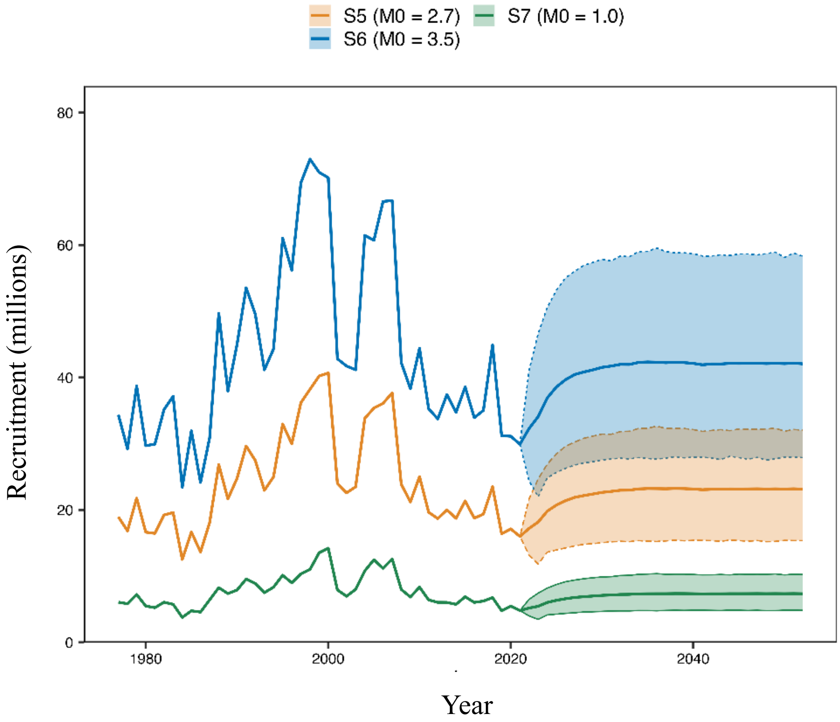


← See figure (a)

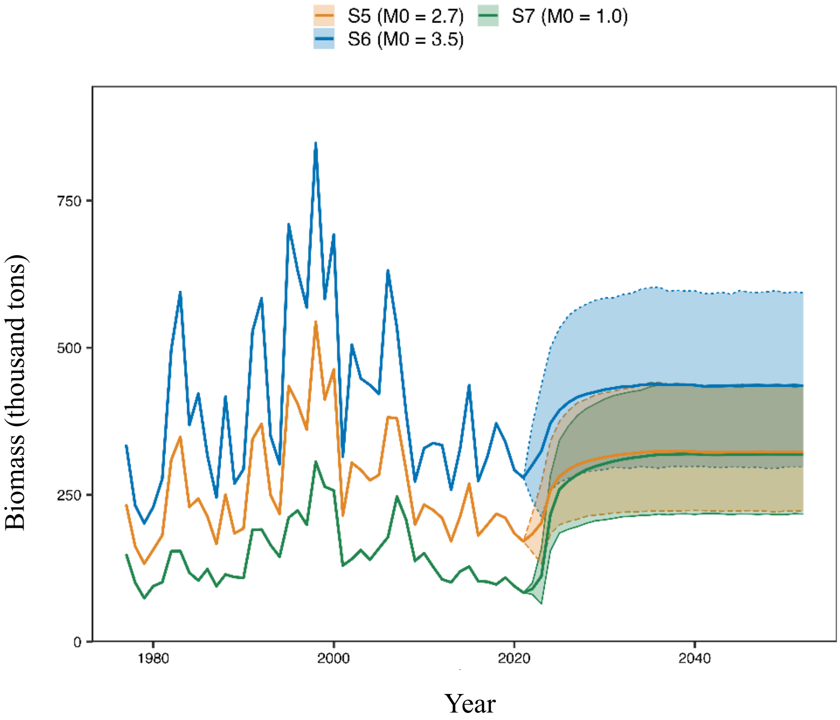
Supplementary Fig. 9-1. Scenarios without catch of shirasu. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate

(S4 is the base case, shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average) (continued)

(a) Recruitment in number



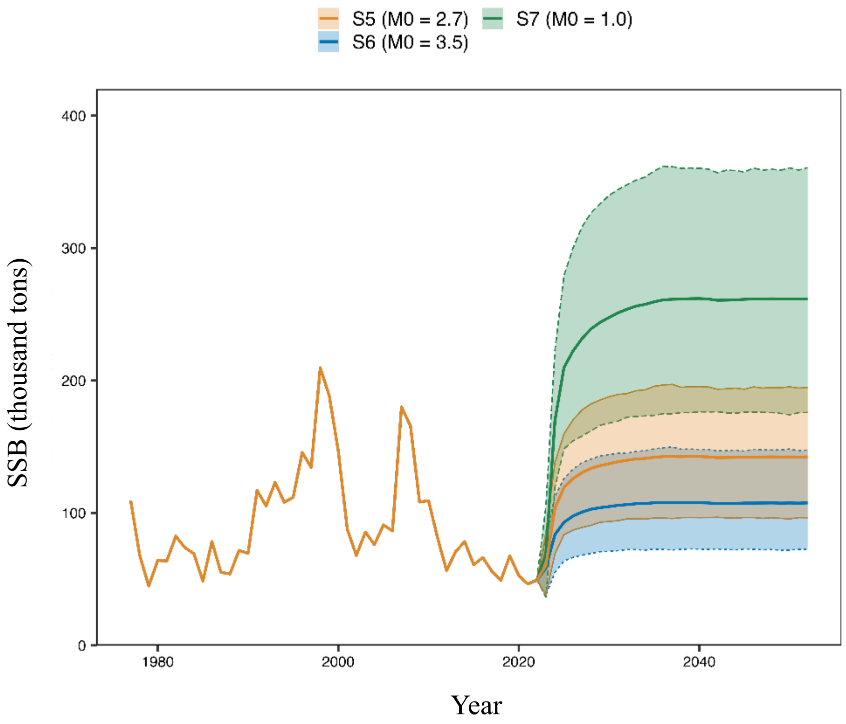
(b) Stock abundance



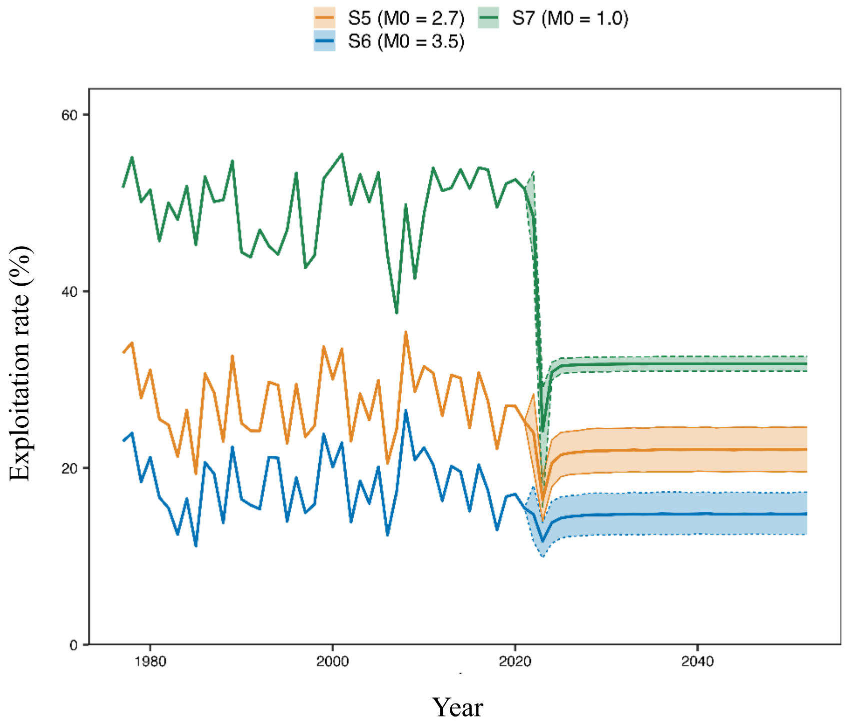
Supplementary Fig. 9-2. Scenarios with catch of shirasu. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate

(Shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average)

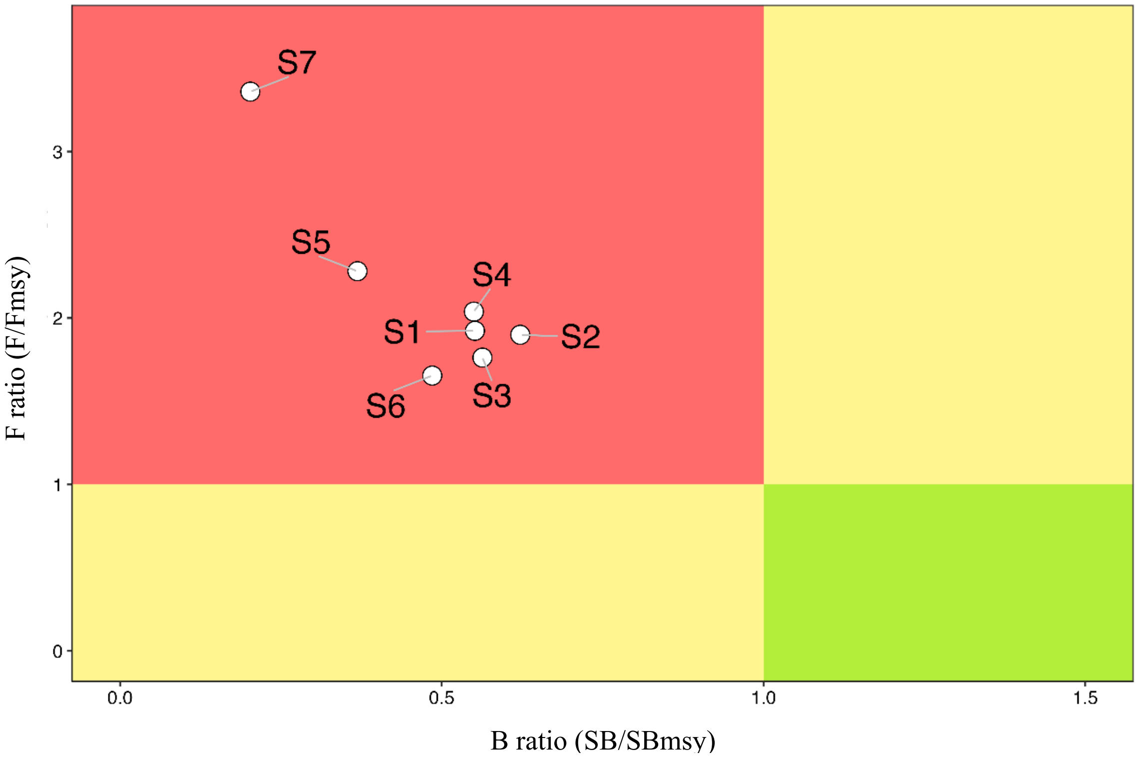
(c) SSB



(d) Exploitation rate



Supplementary Fig. 9-2. Scenarios with catch of shirasu. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate
(Shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average) (continued)



Supplementary Fig. 9-3. Kobe plot for 2021 in all scenarios (Scenario conditions are shown in Supplementary Table 9-1)

Supplementary Table 9-1. Scenario conditions

Scenario Name	Shirasu	M (Age 0, Age 1, Age 2)	Other Conditions	Remarks
S1	No	1.0, 1.0, 1.0		Base case of FY 2021
S2	No	1.0, 1.0, 1.0	Considers catch by South Korea	
S3	No	1.0, 1.0, 1.6		Same M as the Pacific stock
S4	No	1.0, 1.0, 1.0	With tuning	Base case of FY 2022
S5	Yes	2.7, 1.0, 1.0		
S6	Yes	3.5, 1.0, 1.0		
S7	Yes	1.0, 1.0, 1.0		Base case used up to FY 2020

Supplementary Table 9-2. Probability (β = 0.8) that future SSB will exceed proposed target/limit reference points in each scenario S4 is the base case, values in bold indicate values in the target year, which is 10 years after starting management based on HCRs.

a) Probability of exceeding the target reference point (%)

Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
S1	0	0	68	68	63	61	60	59	58	58	58	58	**58**	57	57
S2	0	0	68	74	68	65	63	63	61	60	60	61	**61**	60	60
S3	0	0	75	70	64	62	61	60	59	58	58	59	**58**	58	57
S4	0	0	55	65	62	60	59	59	58	58	57	58	**58**	57	57
S5	0	0	0	20	38	45	50	54	56	57	59	60	**61**	62	62
S6	0	0	3	28	41	48	52	55	57	58	59	60	**60**	61	61
S7	0	0	0	8	32	40	46	51	54	56	58	59	**61**	63	63

b) Probability of exceeding the limit reference point (%)

Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
S1	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
S2	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
S3	100	100	100	100	100	100	100	100	99	100	100	100	**100**	99	100
S4	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100	100
S5	100	100	90	100	100	100	100	100	100	100	100	100	**100**	100	100
S6	100	100	96	100	100	100	100	100	100	100	100	100	**100**	100	100
S7	0	0	55	99	100	100	100	100	100	100	100	100	**100**	100	100

Supplementary Table 9-3. Trends in future average SSB and catch in weight in each scenario (β = 0.8). S4 is the base case, values in bold indicate values in the target year, which is 10 years after starting management based on HCRs.

a) Trends in average SSB (thousand tons)

Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
S1	46	69	98	99	97	96	95	94	94	93	93	93	**94**	93	93
S2	210	291	389	405	392	385	381	379	376	374	375	375	**375**	373	373
S3	47	70	103	101	99	97	96	95	95	94	94	94	**94**	93	94
S4	46	65	90	97	96	95	95	94	94	93	93	93	**94**	93	93
S5	46	49	60	103	119	126	130	134	136	137	139	140	**141**	142	142
S6	46	49	58	84	93	98	101	103	104	105	106	106	**107**	107	107
S7	46	49	69	170	210	222	232	239	244	248	251	254	**256**	261	261

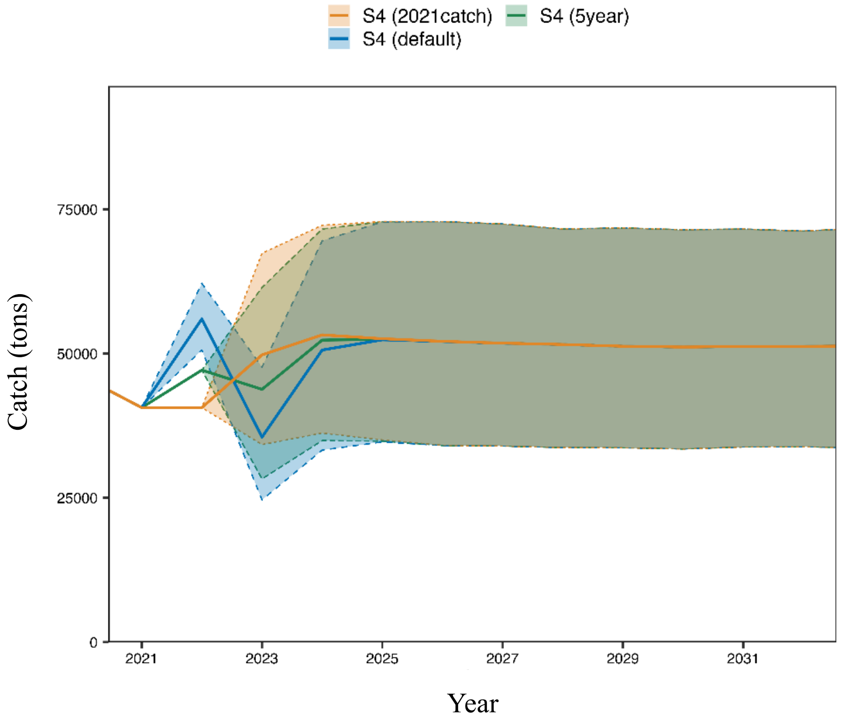
b) Trends in average catch (thousand tons)

Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	2043	2053
S1	41	41	54	54	53	52	52	52	51	51	51	51	**51**	51	51
S2	184	184	219	226	220	216	214	213	211	210	211	211	**211**	210	210
S3	41	41	56	55	53	53	52	52	51	51	51	51	**51**	51	51
S4	41	41	50	53	53	52	52	52	51	51	51	51	**51**	51	51
S5	43	43	33	53	60	63	65	67	68	69	69	70	**70**	71	71
S6	43	43	38	51	56	59	60	61	62	63	63	63	**64**	64	64
S7	43	43	29	67	82	87	90	93	95	96	98	99	**100**	101	102

Appendix 10 Future Projections With Different Assumptions for F in 2022

Future projection results (β = 0.8) with different assumptions for F in 2022 are summarized here. If the current fishing pressure (F2019-2021) is used for F in 2022, then catch in 2022 was projected to be 56,000 tons. However, in Nagasaki Prefecture, which accounted for around half of the catch of this stock, catch of small to medium-scale purse seine fisheries from January to June 2022 was around the same level as January to June in the previous year, which was only 16,000 tons. Accordingly, F in 2022 was assumed to be the value that makes catch equal to the catch in the most recent year, which was 41,000 tons in 2021(age 0 = 0.17, age 1 to 2 = 1.91, Appendix 5). For reference, we also graphed future projections for catch, recruitment volume, biomass, SSB, and exploitation rate if F in 2022 was assumed to be the value that makes catch equal to the average catch (47,000 tons) of the most recent 5-year period (2017 to 2021), under current fishing pressure (F2019-2021) (default).

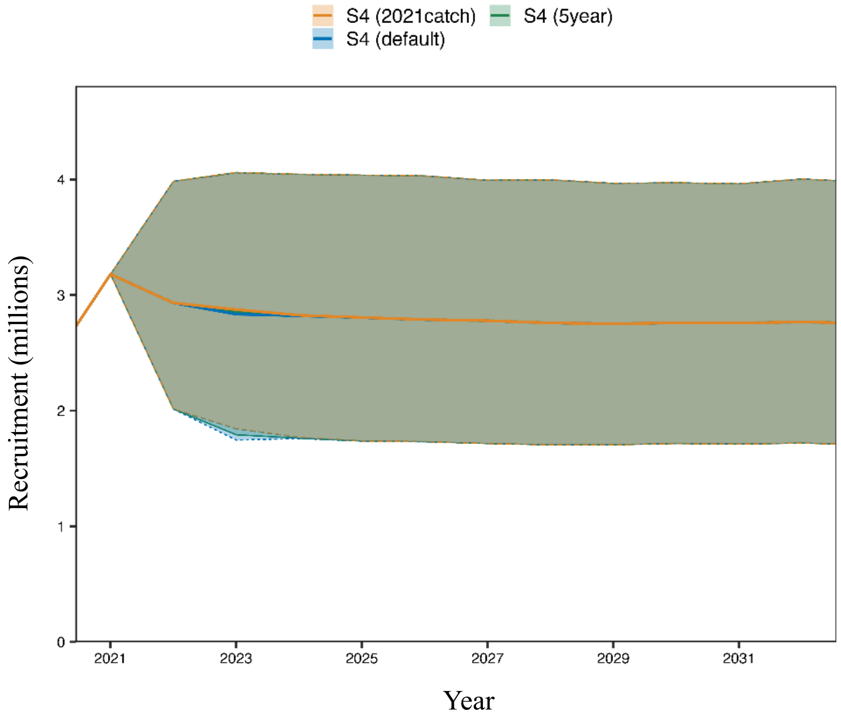
If F in 2022 was used as the current fishing pressure, then catch was estimated to be 56,000 tons in 2022, and 36,000 tons in 2023, and to remain around 50,000 tons onwards (Supplementary Fig. 10-1). However, if F in 2022 was assumed to be equal to F in 2021, or the value that makes catch equal to the average catch of the most recent 5-year period, then catch in 2023 was estimated to be 50,000 tons or 44,000 tons, respectively (Supplementary Fig. 10-2).



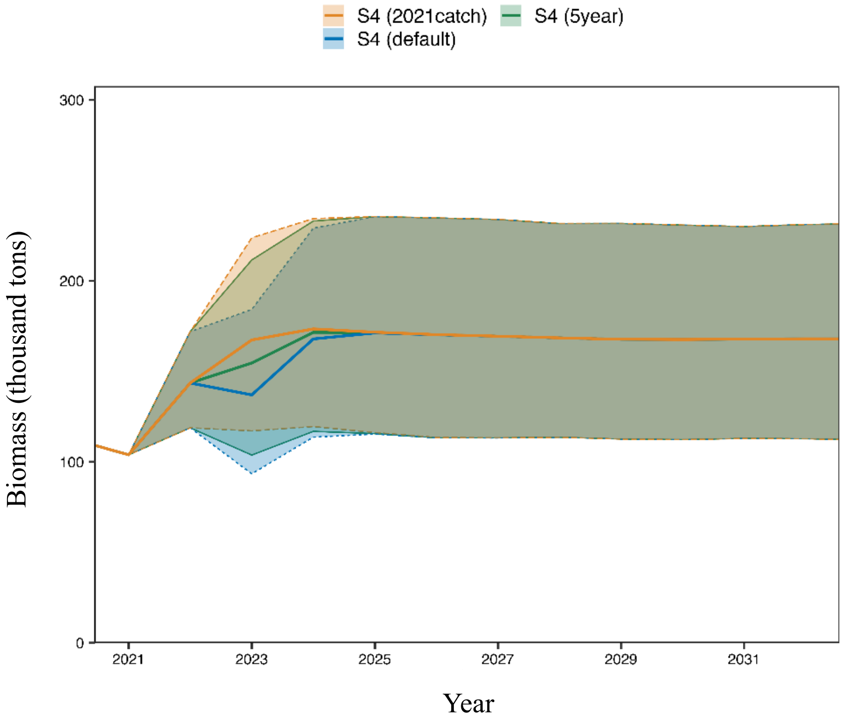
Supplementary Fig. 10-1. Future projections of catch for different assumptions for F in 2022

In these graphs, 2021catch indicates the base case, and shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average.

(a) Recruitment in number



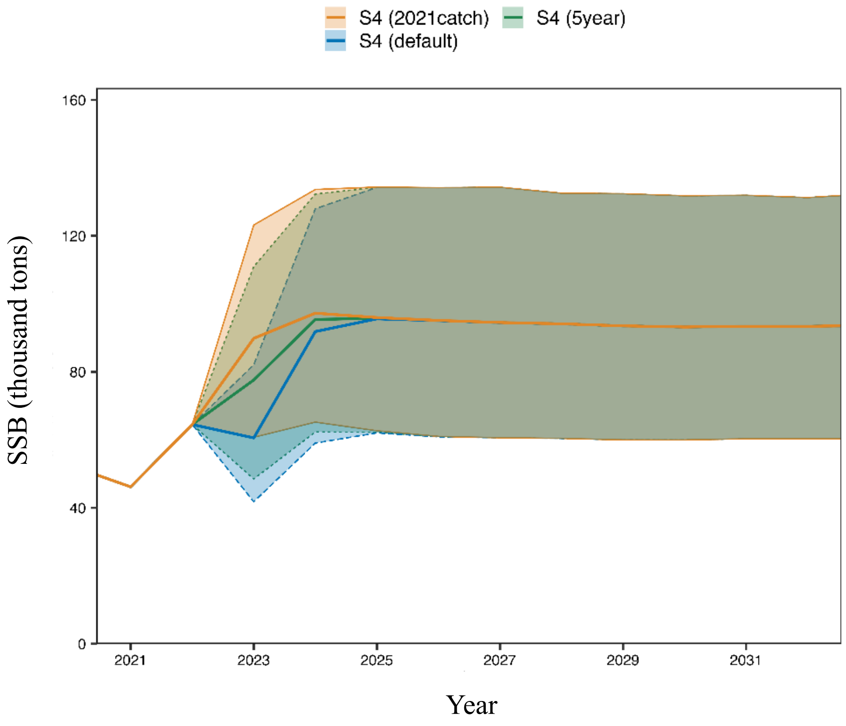
(b) Stock abundance



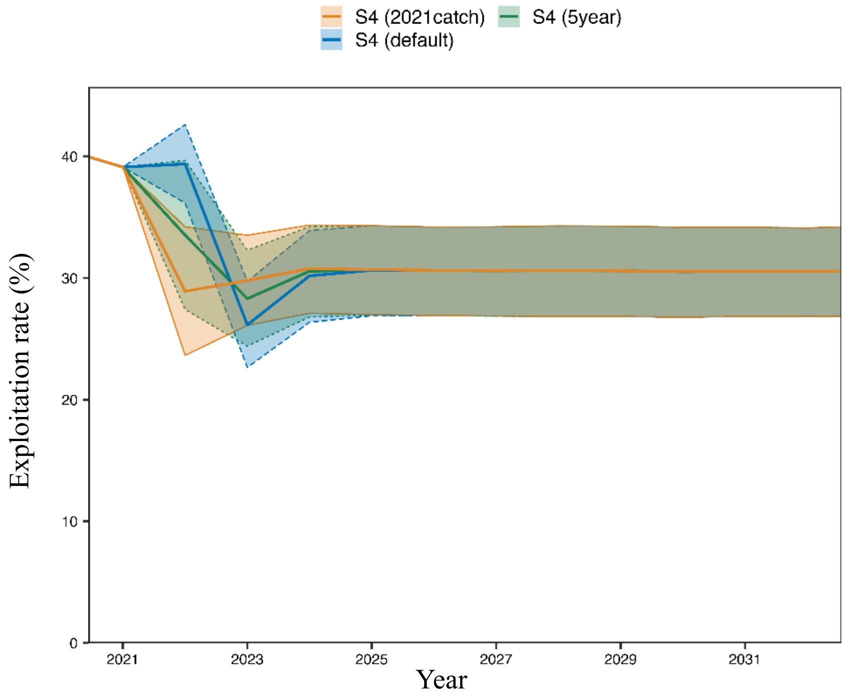
Supplementary Fig. 10-2. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate in scenarios with different assumptions for F in 2022

(Shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average)

(c) SSB



(d) Exploitation rate



Supplementary Fig. 10-2. Trends in (a) recruitment in number, (b) biomass, (c) SSB, and (d) exploitation rate in scenarios with different assumptions for F in 2022

(Shaded areas indicate the prediction interval which contains 90% of simulation results, and the thick solid lines indicate the average) (continued)