Stock assessment for western Sea of Japan and East China Sea stock of Japanese seabream (*Pagrus major*) in Fiscal Year 2022

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

Participating Organizations: Tottori Prefectural Fish Farming Center; Shimane Prefectural Fisheries Technology Center; Yamaguchi Prefectural Fisheries Research Center; Fukuoka Fisheries and Marine Technology Research Center; Saga Prefectural Genkai Fisheries Research and Development Center; Nagasaki Prefectural Institute of Fisheries; Kumamoto Prefectural Fisheries Research Center; Kagoshima Prefectural Fisheries Technology Development Center; and National Association for Promotion of Productive Seas (NAPPS)

Summary

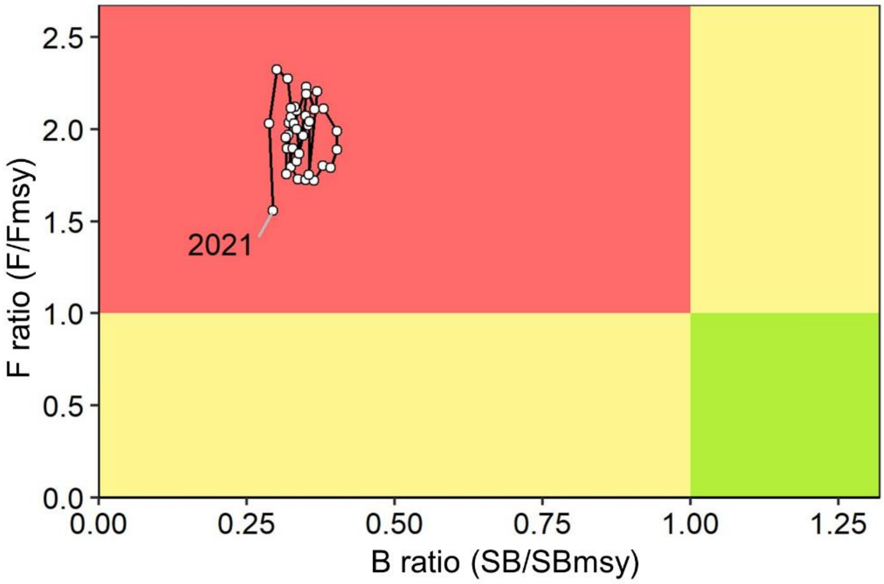
The biomass of this stock since 1986 was calculated using tuning cohort analysis with the catch per unit effort (CPUE) of large set net fisheries in Shimane Prefecture since 2007 as the abundance index. The catch of this stock decreased from 11,200 tons in 1969 to 6,400 tons in 1985, and then remained between 5,100 to 7,100 tons from 1986 and onwards, with 5,217 tons in 2021 (approximate value). The biomass increased from 19,800 tons in 1988 to 23,800 tons in 1996, and then decreased to 19,900 tons in 2001 before increasing to 22,700 tons in 2007. It then entered a slight decreasing trend, but increased to 21,000 tons in 2021. The SB (spawning stock biomass) remained at 63 to 70% of the biomass until 2018, but this ratio has been in a decreasing trend since 2019, reaching 57% (12,100 tons) in 2021.

This species is also a target species of stock enhancement, and 2.73 million hatchery-reared fish were released in 2020. The contribution rate of hatchery-released fish in the 2021 catch was 2.4% and survival to recruitment (survival rate of released fish until recruitment at age 1) was 0.21. Wild fish recruitment (age 1 stock abundance) for this stock ranged between 12.82 million and 19.08 million.

In the Research Institute Meeting held in November 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 SB required for MSY (SBmsy) was calculated to be 39,300 tons. Following these criteria, SB of this stock in 2021 is significantly below the level required for MSY. In addition, the fishing mortality for this stock in 2021 was higher than the fishing mortality level required for MSY (Fmsy). Based on trends seen in the previous 5 years (2017 to 2021 fishing seasons), SB is judged to be in a "declining" 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, SB levels and trends, and ABC	
SB required for MSY	39,300 tons
Level of SB in 2021	Under the level required for MSY (SB/SBmsy = 0.31)
Level of fishing mortality in 2021	Over the level required for MSY (F/Fmsy = 1.66)
Trends in SB in 2021	Decrease
Maximum Sustainable Yield (MSY)	6,720 tons
ABC for 2023	-
Comments: ・ABC is estimated after Harvest Control Rules (HCRs) for this stock compiled by the stakeholder meeting, and set through the Fishery Policy Council.	

Recent biomass, SB, catch, fishing mortality, and exploitation rate					
Year	Biomass (hundred tons)	SB (hundred tons)	Catch (tons)	F/Fmsy	Exploitation rate (%)
2017	210	133	6,188	2.15	29
2018	208	131	6,582	2.32	32
2019	204	124	6,629	2.37	32
2020	200	118	5,889	2.07	29
2021	210	121	5,217	1.64	25
2022	231	141	6,317	1.85	27
2023	239	155	-	-	-

・Catch for 2021 is approximate value.
・The values for 2022 and 2023 are estimates based on future projections.

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	・ 2020 catch in weight by prefecture, Approximate values for 2021 catch in weight by prefecture (Fisheries Agency, 8 prefectures from Tottori to Kagoshima) ・ Age composition in catches
Natural mortality (M)	M = 0.24/year (age 1) and 0.17/year (age 2 and older) (Shimamoto 1999).
Abundance indices	Catch per day per management entity for large set net fishery in Shimane Prefecture
Number of hatchery-released fish	Results of Hatchling Release for Stock Enhancement (National Association for Promotion of Productive Seas (NAPPS)) Catch in number by age for wild and hatchery-released fish (Kagoshima Prefecture) Contribution rate by year and age (Saga and Kumamoto prefectures) Contribution rate by year (Shimane Prefecture)

2. Ecology

(1) Distribution / Migration

This stock of Japanese seabream *Pagrus major* is distributed in the western area of the Sea of Japan west of Tottori Prefecture and the western coast of Kyushu from Fukuoka to Kagoshima prefectures (Fig. 2-1). It is known to have several spawning grounds around the Oki Islands in Shimane Prefecture, as well as in the western Kyushu area from Yamaguchi to Kagoshima prefectures, primarily around islands. Fish age 1 to 3 migrate seasonally, staying near the coast in spring, then leaving the coast in autumn (wintering off the coast). Mature fish age 4 and older migrate along trenches and are believed to migrate over a wide area.

(2) Age / Growth

Fork length after hatching is 14 cm at age 1, 22 cm at age 2, and 30 cm at age 3 (Fig. 2-2), and lifespan is estimated to be approximately 20 years. The growth and fork length-weight relationships used in this stock are expressed in the following equations.

Age-fork length equation $FLt = 78.14 \times (1 - \exp(-0.1423 \times (t+0.35)))$

Fork length-weight equation $BW = 0.0382 \times FL^{2.825}$

FLt is fork length at age t (cm), BW is body weight (g), and FL is fork length (cm).

Body weight at each age was calculated by adding 0.5 year to obtain the value at the midpoint for each year.

(3) Maturation / Spawning

The spawning season is earlier farther south, and is from February to May in Kagoshima Prefecture, from early March to late May off the western coast of Goto and Ajisone in Nagasaki Prefecture, from

April to June in Iki and Tsushima in Nagasaki Prefecture, and from March to the end of May in Fukuoka Prefecture. Hatched larvae spend 30 to 40 days in a pelagic stage then enter the benthic stage, and juveniles are widely distributed along the coast in April and May (Tanaka 1986). Half of fish at age 3 and all fish at age 4 and older reproduce (Fig. 2-3).

(4) Predator-prey relationships

Juveniles feed mainly on zooplankton such as amphipods and tunicates, young of the year fish feed on amphipods and mysids, and mature fish feed on crustaceans, mollusks, and polychaetes (Kiso 1980). Predators of this species include large fish.

3. Fishery status

(1) Fishery overview

Fisheries targeting this stock are diverse and include boat seine fishing (53%), anglings/long line fishery (12%), small trawl fishery (6%), offshore bottom trawl fishery (5%), and gill net fishery (6%) (percentages are for 2021). Nagasaki (33%) and Fukuoka (29%) were the prefectures with the highest catch in weight in 2021, followed by Shimane and Kagoshima (10%) (Fig. 3-1). The recreational catch for this area was estimated at between 213 to 327 tons (Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries, 1998 and 2003), or 4 to 5% of the catch for the year. The total recreational catch in 2008 for the six prefectures of Tottori, Shimane, Yamaguchi (including the Seto Inland Sea), Nagasaki, Kumamoto, and Kagoshima was estimated to be 677 tons (Recreational Catch Survey, 2008). Although the current report does not take recreational fishing into account, it is necessary to consider the impact of recreational fishing on fish stock in the future. The current report also does not take catch by foreign vessels into account.

(2) Trends in catch in weight

The catch of this stock decreased from 11,200 tons in 1969 to 6,400 tons in 1985, and then remained between 5,100 to 7,100 tons from 1986 and onwards, with 5,217 tons in 2021 (approximate value) (Fig. 3-2, Table 3-1). This catch accounted for 33% of the total catch of Japanese seabream in Japan.

From 1986 to the present, the catch in number has undergone repeated short-term fluctuations between 8.35 to 13 million, and in 2021 it was 10.05 million (Fig. 3-3). Based on age, fish age 1 to 3 accounted for the majority of the catch, with age 1 accounting for 34.1%, age 2 for 38.3%, and age 3 for 17.6% in 2021. In terms of catch weight, there were more fish age 2 to 3 (Fig. 3-4).

4. Stock status

(1) Stock assessment methods

The abundance at age, fishing mortality (F) at age, biomass, and SB were estimated through a cohort analysis using the catch in number at age and catch in weight for the entire stock since 1986 (Appendix 2). Here, the standardized CPUE (catch in weight per day per management entity) from large set net fishery in Shimane Prefecture since 2007 was used as the tuning index. Pope's approximation formula (Pope 1972), which assumes that fishing takes place in the middle of fishing season, was used.

Recruitment in 2021 was assumed to be the average from 2018 to 2020.

(2) Trends in abundance indices

The standardized CPUE (catch in weight per day per management entity) from large set net fishery in Shimane Prefecture declined in 2008, and then increased in 2009 before declining again in 2014. It increased once in 2017 but showed low values again after 2018 and increased in 2021 (Fig. 4-1, Table 4-1).

(3) Trends in biomass and fishing mortality

Biomass increased from 19,800 tons in 1988 to 23,800 tons in 1996, and then decreased to 19,900 tons in 2001 before increasing to 22,700 tons in 2007. It then entered a slight decreasing trend, but increased in 2021 to 21,000 tons (Fig. 4-2, Table 4-2). The SB remained between 13,000 to 16,500 tons (63 to 70% of biomass) until 2018, but this ratio has been in a decreasing trend since 2019, reaching 12,100 tons (57% of biomass) in 2021 (Fig. 4-3).

Recruitment of wild fish (age 1 stock biomass) increased from 12.97 million in 1989 to 18.15 million in 1997, and then decreased to 12.82 million in 2001. Since then, the number of fish has generally been in an increasing trend, reaching 17.58 million in 2021 (Table 4-2).

F by age showed repeated short-term fluctuations but was particularly high at age 2 and 3 throughout the period (Fig. 4-4). In 2020 and 2021, F entered a decreasing trend. The exploitation rate ranged from 24 to 32%, and was 25% in 2021 (Fig. 4-2).

A sensitivity analysis of biomass, SB, and stock abundanceat age 1 when the natural mortality (M) value is adjusted by 30% resulted in a change of 85 to 123% for biomass, 83 to 124% for SB, and 85 to 122% for the age 1 stock abundance (Fig. 4-5).

(4) Hatchling release and recruitment

This species is a target species for stock enhancement, and hatchery-reared fish have been released in this stock's target area since 1977. The number of released fish has increased since the start of release, reaching a maximum of 9.14 million fish released in 1999, but has since declined, remaining around 3 million since 2013 (Fig. 4-6). A total of 2.73 million fish were released in Shimane, Yamaguchi, Nagasaki, Kumamoto, and Kagoshima prefectures in 2020 (data for 2021 has not yet been aggregated).

Estimates for contribution rates by age for released fish corrected using tag rate are provided annually by three of the prefectures, while data from the other prefectures is unclear, age combined contribution rate are provided, or years are missing. For this reason, the contribution rate was estimated using the value for all ages. Survival rate to recruitment was calculated by multiplying the age 1 stock abundance by the contribution rate for each year, and dividing that by the number of released fish in the previous year. Results showed that the contribution rate of hatchery-released fish in the 2021 catch was 2.4% and survival rate to recruitment was 0.16 (Table 4-3).

In this area, 179,000 to 2,011,000 hatchery-released Japanese seabream were recruited at age 1, and this is believed to have a certain effect on supporting wild recruitment. The number of released fish recruited at age 1 in 2021 was estimated to be 432,000 and the average for the five most recent years (2017 to 2021) was estimated at 374,000.

(5) Yield per recruit (YPR), spawning per recruit (SPR), and current fishing mortality

In order to assess the current fishing mortality, we compared spawning per recruit (SPR) to that without fishing mortality. Fig. 4-7 show changes in the SPR ratio (%SPR), which compares SPR in a scenario without fishing mortality against SPR in a scenario with fishing for each year. Lower fishing mortality means higher %SPR levels. The %SPR in 2021 was 13%.

Relative YPR and %SPR curves to current fishing mortality are shown in Fig. 4-8. The current fishing mortality (F2022), the value used to estimate the F required for maximum sustainable yield (MSY) (Fmsy) at the Research Institute Meeting held in November 2021 (Shimose et al. 2021) was used for selectivity, and the 2021 value (13%) was used for %SPR. In addition, the values used to calculate Fmsy were also used for average body weight at age and the maturation rate. Fmsy is equivalent to 26% when converted to %SPR. The current fishing mortality (F2022) is above Fmsy, F0.1 and F30%SPR.

(6) Stock-recruitment relationship

The relationship (stock-recruitment relationship) between SB (in weight) and recruitment (number of individuals) is shown in Fig. 4-9. The Research Institute Meeting mentioned earlier has applied the hockey-stick model to the stock-recruitment relationship model for this stock (Shimose et al. 2021). The data used to estimate the parameters of the stock-recruitment relationship are SB and recruitment from 1986 to 2019 based on the FY 2021 stock assessment (Shimose et al. 2022). Only recruitment of wild fish was used for recruitment. The least squares method was used for optimization method, and autocorrelation of the residuals in recruitment was taken into account. In accordance with the Guidelines for Determining the Stock-Recruitment Relationship (FY2021) (FRA-SA2021-ABCWG01-03), the inflection point was set as the minimum SB level in the observation range. The parameters of the stock-recruitment relationship model are shown in Supplementary Table 6-1.

(7) Levels required for MSY under current environmental conditions

The SB required for MSY (SBmsy) and the catch required for MSY were defined as the values estimated at the Research Institute Meeting (Shimose et al. 2021), and are shown in Supplementary Table 6-2.

(8) Stock levels/trends and fishing mortality levels

Kobe plot showing reference values for SB and fishing mortality required for MSY are shown in Fig. 4-10. In addition, a summary of SB and fishing mortality in 2021 is shown in Supplementary Table 6-3. SB of this stock in the 2021 fishing season was lower than the SB required for MSY (SBmsy), specifically, SB in the 2021 fishing season was 0.31 times the value of SBmsy. In addition, the fishing mortality in 2021 was higher than the fishing mortality required for MSY (Fmsy), specifically, it was 1.66 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 Fmsy under the selectivity of F in each year, converted to %SPR. SB was determined to be in a declining trend based on the trends seen over the previous 5 years (2017 to 2021).

5. Summary of stock assessment

In 2021, biomass was 21,000 tons and SB was 12,100 tons, which is below the SB required for MSY (SBmsy), and it is in a decreasing trend. While fishing mortality in 2021 has decreased from the previous year, it still exceeds the fishing mortality required for MSY (Fmsy).

6. Additional comments

Currently, fishing mortality is high among fish age 2 to 3, and the proportion of small, immature fish is high, indicating a need to significantly reduce fishing mortality to recover to levels required for MSY; however, continued investigation into calculation methods for the catch in number at age, which forms the basis of stock assessment, is required.

7. References

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Fig. 2-1. Distribution area of the western Sea of Japan and East China Sea stock of Japanese seabream

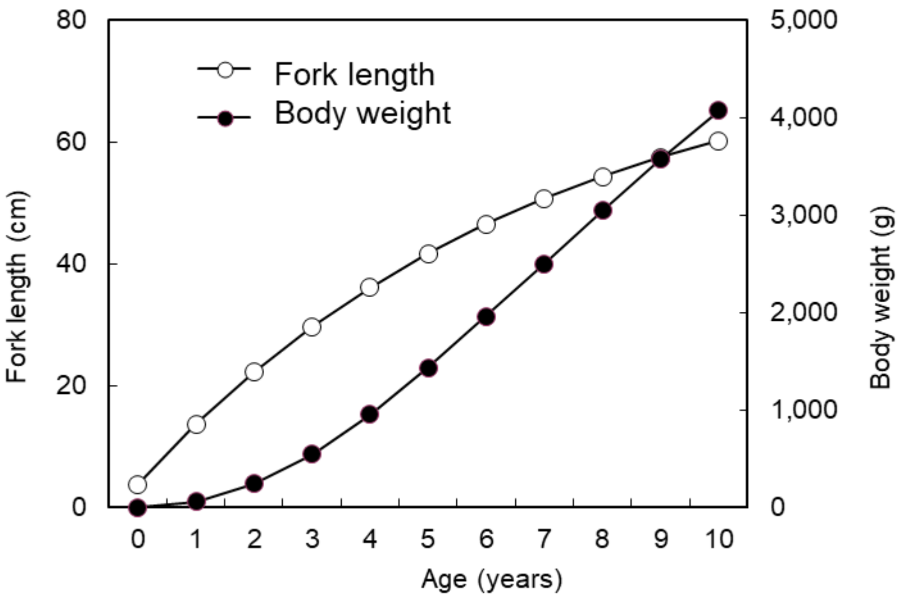


Fig. 2-2. Growth of the western Sea of Japan and East China Sea stock of Japanese seabream

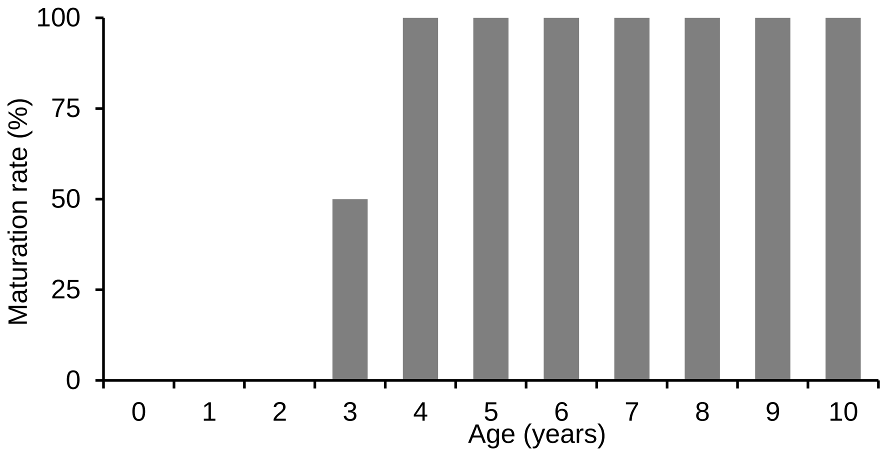


Fig. 2-3. Maturation rate at age of the western Sea of Japan and East China Sea stock of Japanese seabream

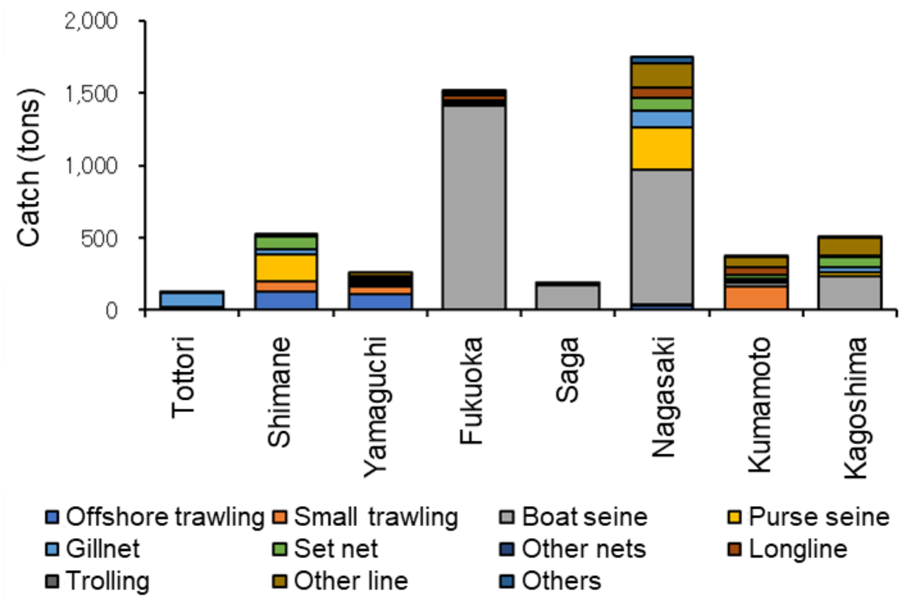


Fig. 3-1. Catch in weight of the western Sea of Japan and East China Sea stock of Japanese seabream by prefecture by fishery type (2021)

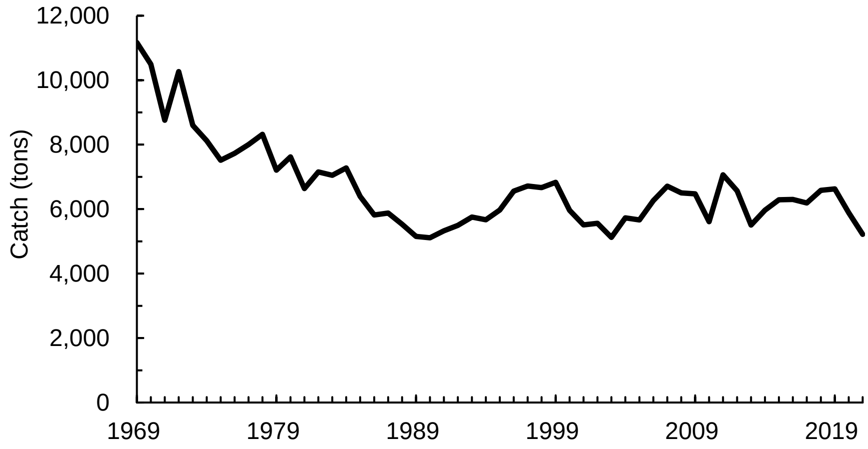


Fig. 3-2. Trends in catch in weight of the western Sea of Japan and East China Sea stock of Japanese seabream

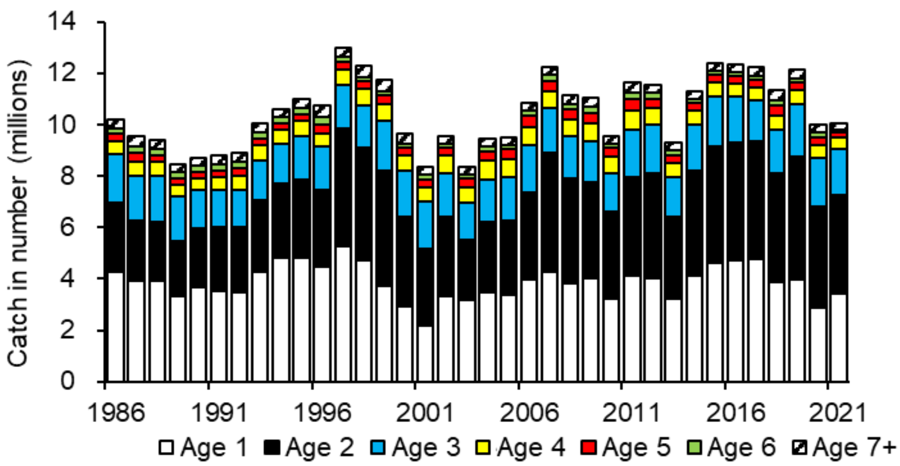


Fig. 3-3. Changes in catch in number at age over time

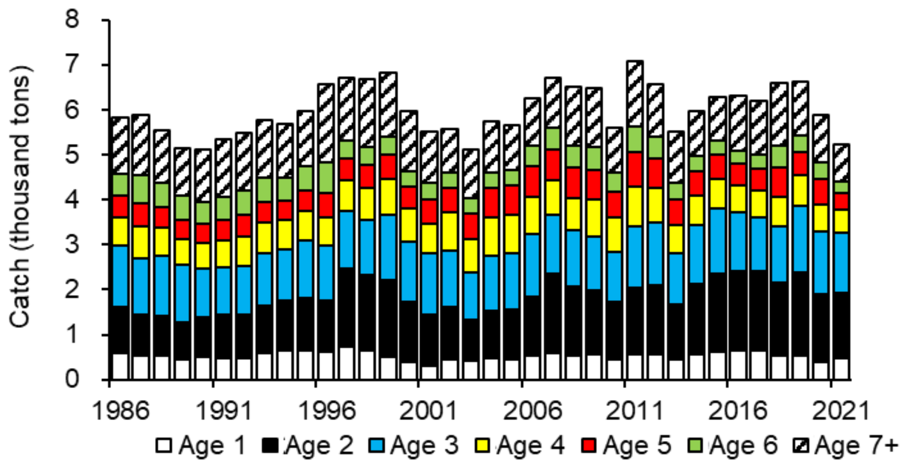


Fig. 3-4. Changes in catch in weight at age over time

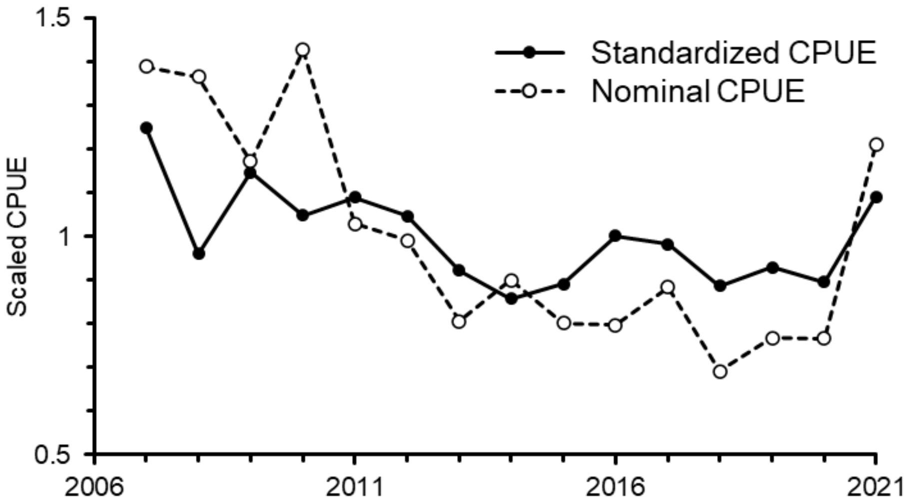


Fig. 4-1. Scaled nominal CPUE and standardized CPUE for large set net fishery in Shimane Prefecture

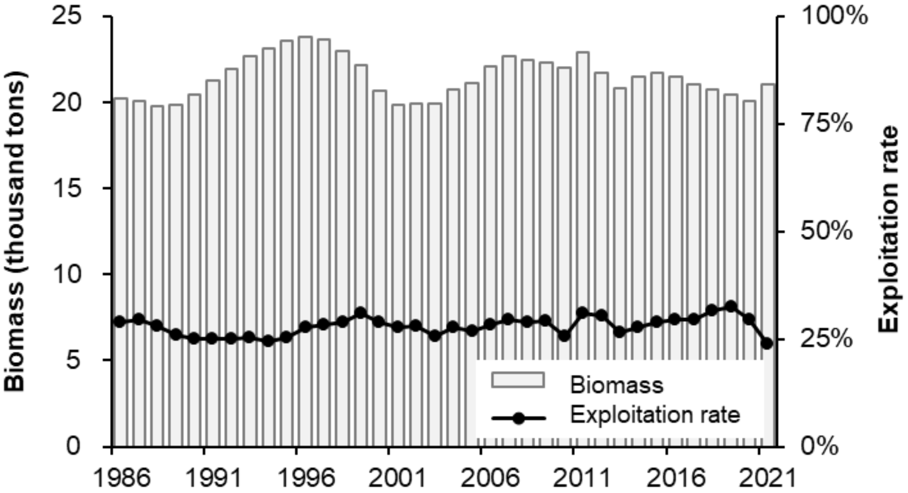


Fig. 4-2. Trends in biomass and exploitation rate

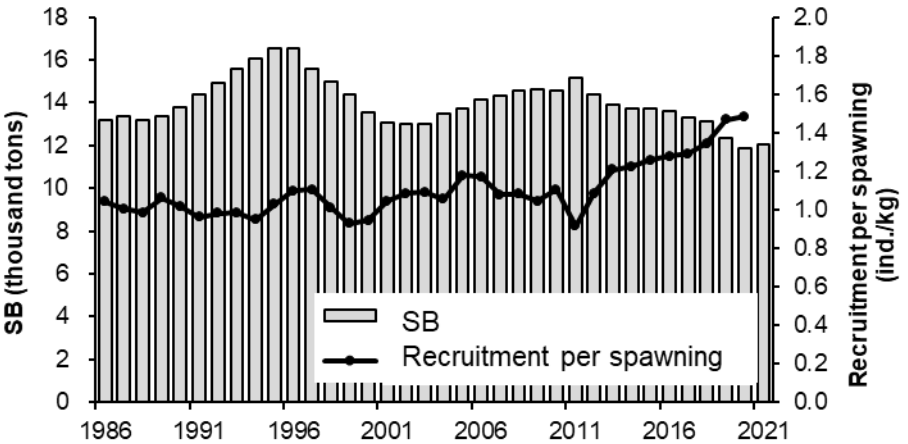


Fig. 4-3. Trends in SB and recruitment per spawning (age 1 stock abundance of the following year)

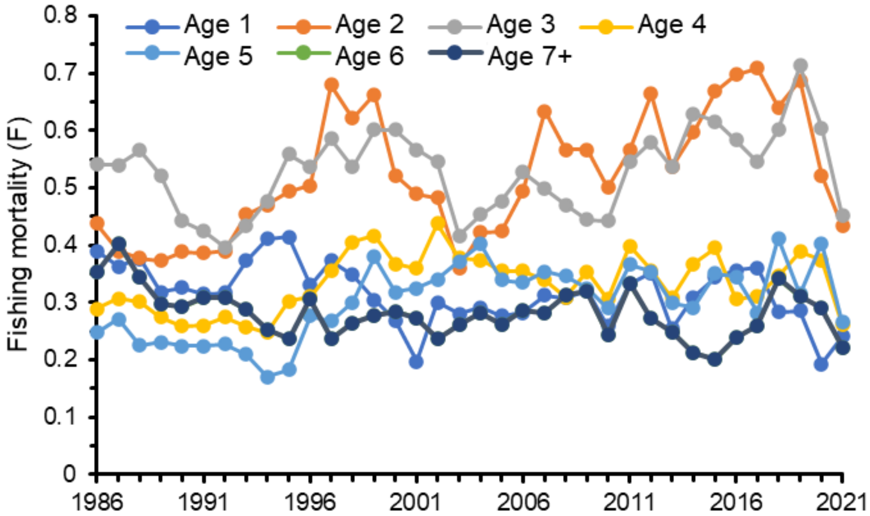


Fig. 4-4. Trends in fishing mortality (F) at age

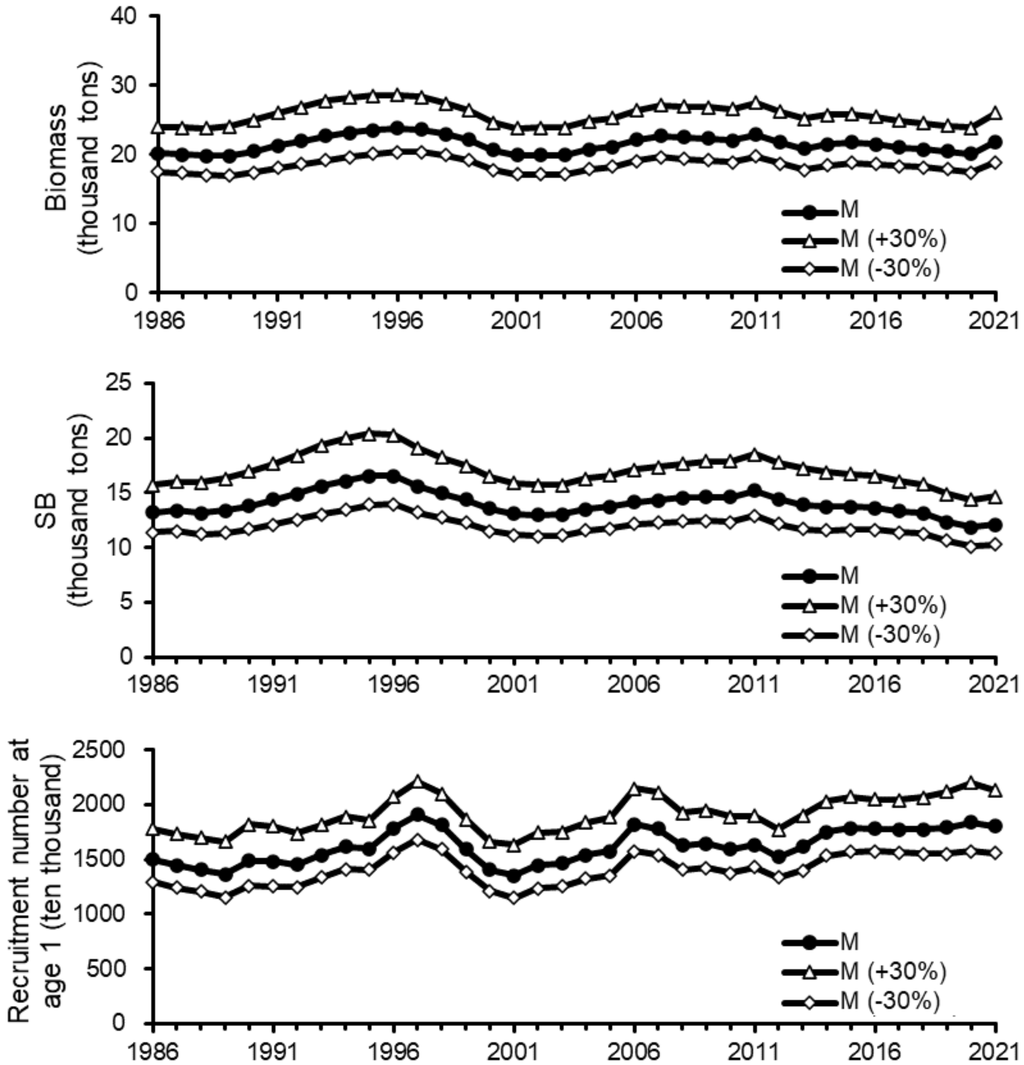


Fig. 4-5. Sensitivity analysis of stock abundance, SB, and recruitment with natural mortality (M)

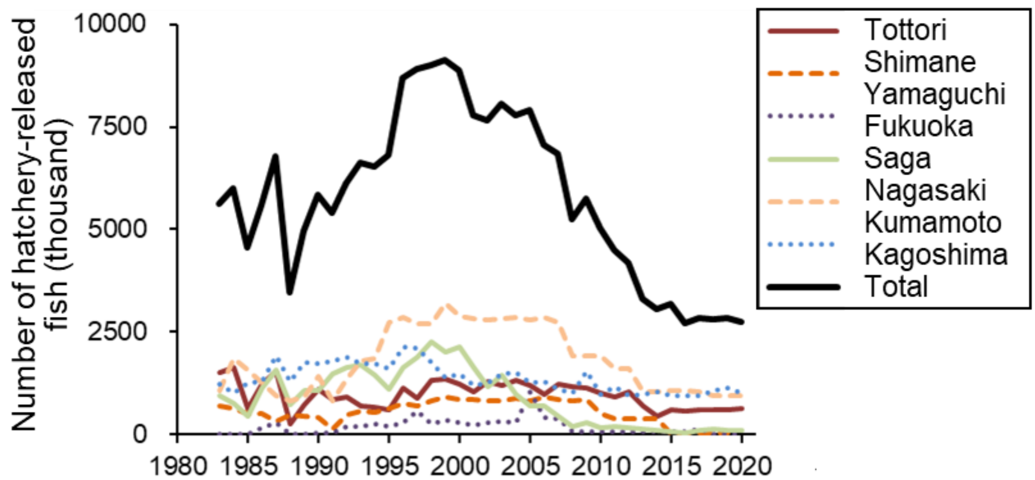


Fig. 4-6. Trends in the number of hatchlings released since 1983

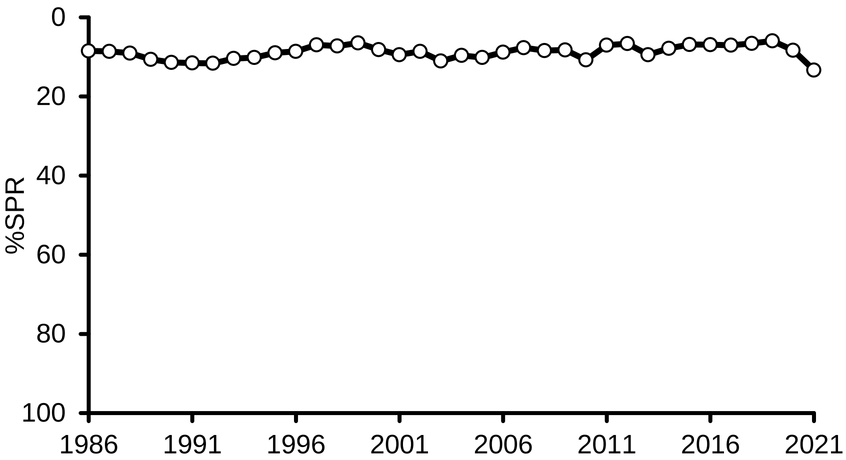


Fig. 4-7. Trends in %SPR

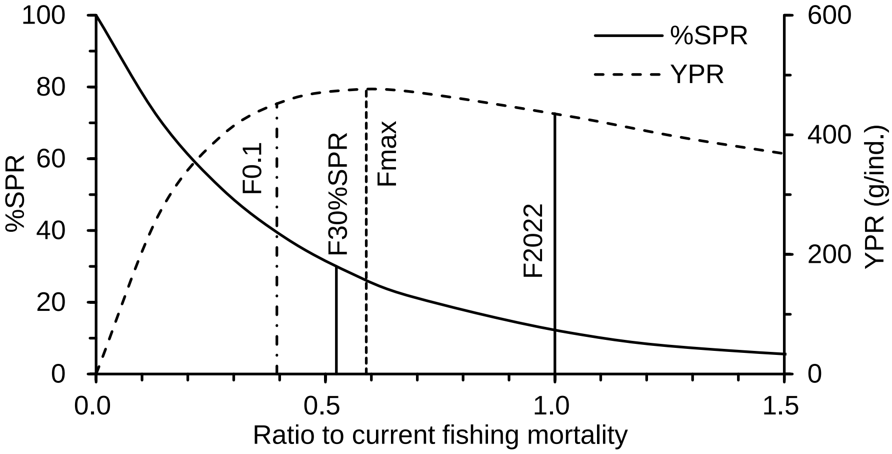


Fig. 4-8. Relationship between current fishing mortality (F2022) and YPR and %SPR

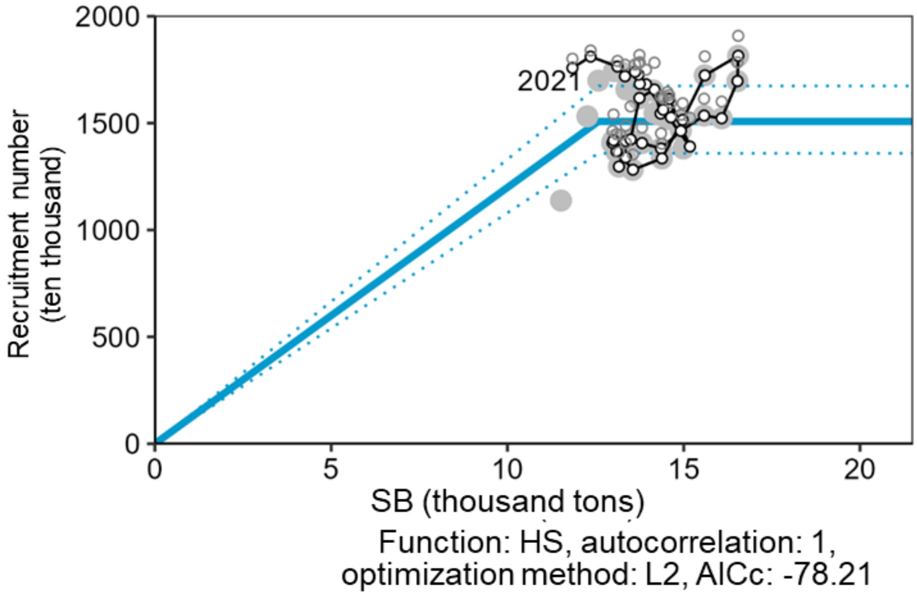


Fig. 4-9. Relationship between SB and recruitment. The solid blue line is the stock-recruitment relationship for this stock and the dotted lines above and below represent the interval estimated to contain 90% of observed data in the assumed stock-recruitment relationship. The parameters for stock-recruitment relationship model are based on values presented at the Research Institute Meeting held in November 2021 (Shimose et al. 2021). The white circles indicate estimated SB and recruitment between 1986 and 2021 used in this stock assessment, black represents wild only, and gray represents the recruitment when released stock is taken into account. The numbers in the figure indicate the recruitment year of the recruited stock.

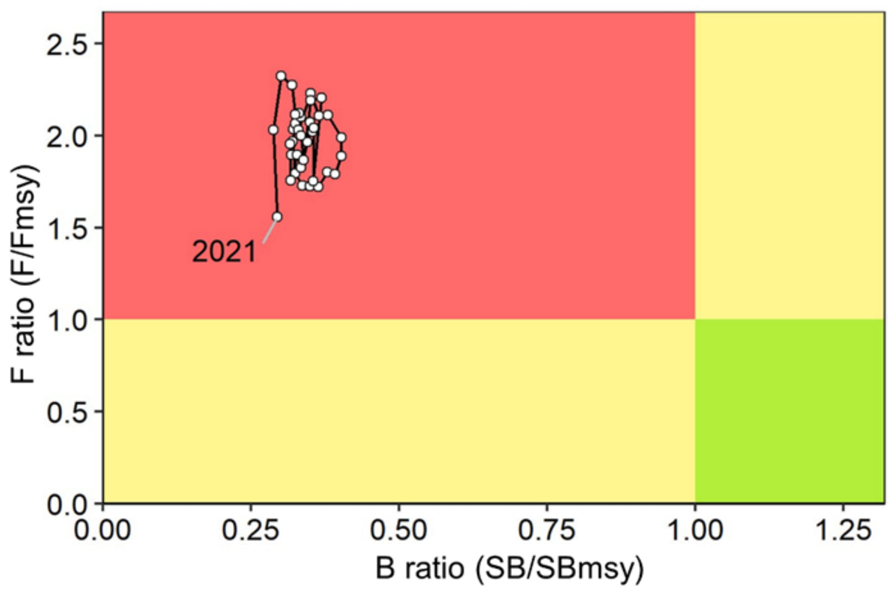


Fig. 4-10. Kobe plot

Table 3-1. Trends in catch (tons) of the western Sea of Japan and East China Sea stock of Japanese seabream

Year	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Catch	11,166	10,493	8,759	10,268	8,596	8,121	7,517	7,729	8,000	8,320

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Catch	7,206	7,622	6,638	7,154	7,050	7,279	6,392	5,819	5,879	5,532

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Catch	5,154	5,111	5,327	5,495	5,754	5,669	5,973	6,555	6,716	6,666

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Catch	6,830	5,964	5,512	5,561	5,123	5,729	5,665	6,265	6,710	6,505

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Catch	6,472	5,610	7,065	6,568	5,506	5,965	6,291	6,297	6,188	6,582

Year	2019	2020	2021
Catch	6,629	5,889	5,217

*Catch for 2021 is approximate value

Table 4-1. CPUE (kg/day per management entity) and scaled CPUE (relative value when the average is set as 1) from large set net fishery in Shimane Prefecture since 2007

Year	Effort (day · management entity)	Catch (kg)	CPUE (kg/day per management entity) Nominal	CPUE Standardized	Scaled CPUE Nominal	Scaled CPUE Standardized
2007	2,912	109,748	37.69	13.24	1.39	1.25
2008	2,578	95,499	37.04	10.17	1.37	0.96
2009	2,914	92,590	31.77	12.15	1.17	1.15
2010	2,403	93,031	38.71	11.12	1.43	1.05
2011	2,681	74,819	27.91	11.54	1.03	1.09
2012	2,542	68,307	26.87	11.10	0.99	1.05
2013	2,390	52,276	21.87	9.77	0.81	0.92
2014	2,658	64,878	24.41	9.09	0.90	0.86
2015	2,669	58,061	21.75	9.45	0.80	0.89
2016	2,807	60,666	21.61	10.61	0.80	1.00
2017	2,334	56,007	24.00	10.41	0.88	0.98
2018	2,264	42,502	18.77	9.39	0.69	0.89
2019	2,360	49,150	20.83	9.85	0.77	0.93
2020	2,195	45,659	20.80	9.49	0.77	0.90
2021	2,326	76,325	32.81	11.57	1.21	1.09

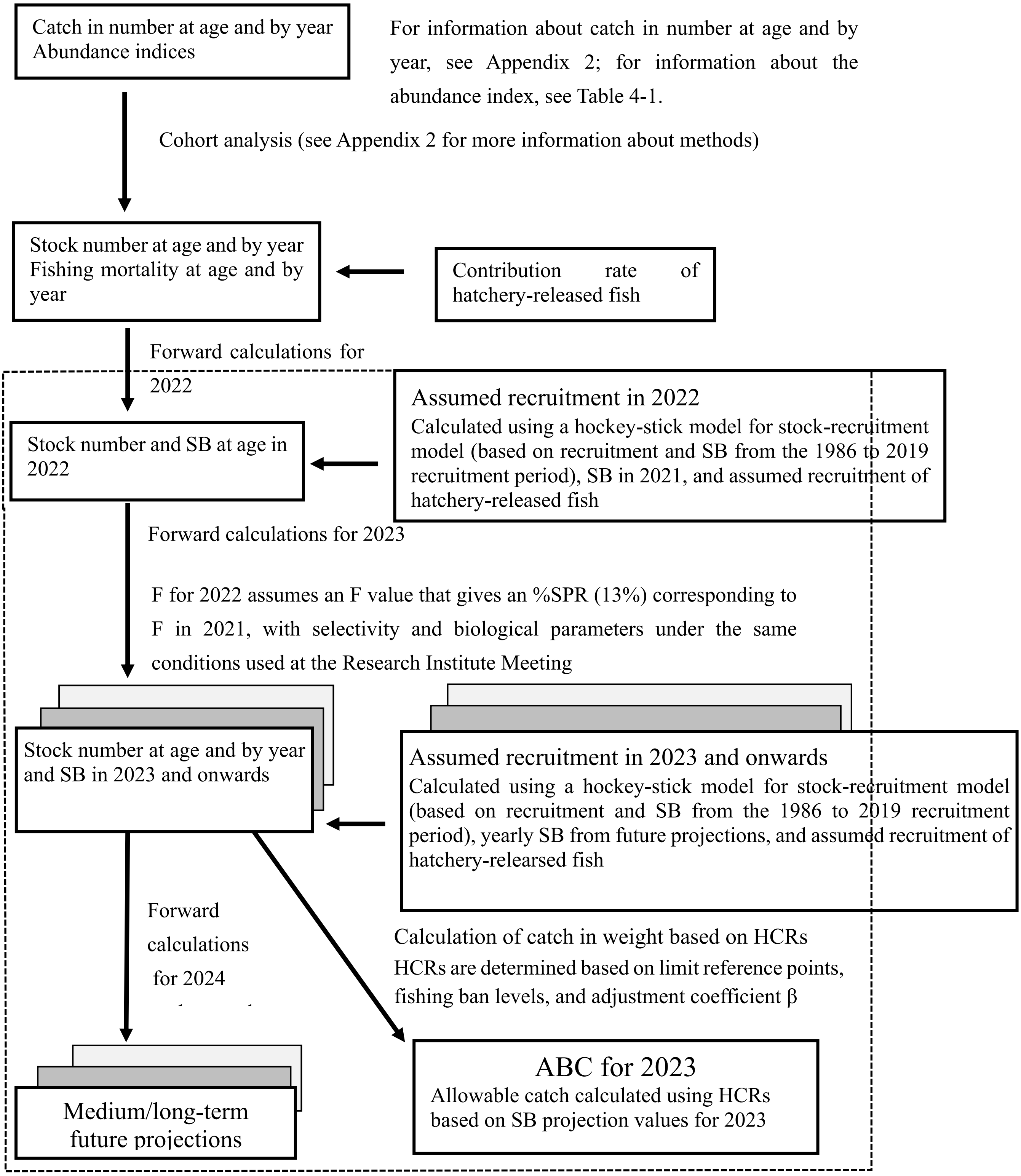
Table 4-2. Stock analysis results for the western Sea of Japan and East China Sea stock of Japanese seabream

Year	Catch (tons)	Biomass (tons)	SB (tons)	Recruitment in number (thousands) Wild fish	Hatchery-released fish	Exploitation rate (%)	%SPR	F/Fmsy
1986	5,819	20,176	13,205	14239	733	29	8.50	2.08
1987	5,879	20,026	13,354	13749	707	29	8.61	2.11
1988	5,532	19,789	13,161	13395	689	28	9.06	2.01
1989	5,154	19,817	13,359	12966	667	26	10.64	1.83
1990	5,111	20,462	13,817	14154	728	25	11.40	1.76
1991	5,327	21,252	14,356	14067	724	25	11.55	1.76
1992	5,495	21,936	14,918	13810	711	25	11.62	1.76
1993	5,754	22,652	15,578	14637	753	25	10.40	1.84
1994	5,669	23,111	16,076	15352	790	25	10.17	1.83
1995	5,973	23,548	16,526	15226	783	25	8.97	1.93
1996	6,555	23,758	16,545	16968	873	28	8.61	2.03
1997	6,716	23,620	15,598	18149	934	28	6.96	2.15
1998	6,666	22,986	14,970	17236	887	29	7.26	2.15
1999	6,830	22,134	14,383	15149	779	31	6.47	2.28
2000	5,964	20,620	13,559	13349	687	29	8.17	2.07
2001	5,512	19,871	13,093	12820	712	28	9.47	1.93
2002	5,561	19,908	12,983	13681	802	28	8.61	1.99
2003	5,123	19,912	13,008	14075	559	26	11.05	1.79
2004	5,729	20,754	13,493	14193	1,211	28	9.61	1.94
2005	5,665	21,136	13,744	14234	1,547	27	10.18	1.86
2006	6,265	22,095	14,168	16174	2,011	28	8.82	2.01
2007	6,710	22,689	14,344	16571	1,256	30	7.69	2.12
2008	6,505	22,461	14,538	15448	809	29	8.40	2.06
2009	6,472	22,287	14,638	15717	732	29	8.25	2.09
2010	5,610	22,009	14,586	15268	688	25	10.77	1.79
2011	7,065	22,879	15,177	16130	179	31	7.05	2.25
2012	6,568	21,726	14,416	13902	1,346	30	6.66	2.23
2013	5,506	20,832	13,929	15625	525	26	9.45	1.91
2014	5,965	21,441	13,752	16816	678	28	7.84	2.04
2015	6,291	21,703	13,716	16834	1,012	29	6.88	2.14
2016	6,297	21,463	13,618	17266	531	29	6.91	2.16
2017	6,188	21,046	13,333	17397	345	29	7.06	2.16
2018	6,582	20,764	13,123	17191	543	32	6.59	2.32
2019	6,629	20,414	12,359	17645	264	32	5.96	2.37
2020	5,889	20,043	11,843	18112	284	29	8.34	2.07
2021	5,217	21,049	12,075	17581	432	25	12.51	1.64

Table 4-3. Number of hatchery-released fish and their contribution rate and survival rate to recruitment

		The following year			
Release year	Number of released fish (ten thousands)	Age 1 stock abundance (ten thousands)	Contribution rate (%)	Recruitment of released fish (ten thousands)	Survival rate to recruitment (Recruitment at age 1)
1985	456.4	1497.1			
1986	558.4	1445.6			
1987	679.7	1408.4			
1988	345.3	1363.3			
1989	495.3	1488.2			
1990	583.3	1479.0			
1991	540.0	1452.1			
1992	611.5	1539.0			
1993	663.3	1614.1			
1994	651.9	1600.9			
1995	681.4	1784.1			
1996	869.1	1908.2			
1997	890.4	1812.3			
1998	900.0	1592.8			
1999	913.6	1403.5			
2000	888.7	1353.2	5.3	71.2	0.08
2001	777.3	1448.4	5.5	80.2	0.10
2002	767.3	1463.4	3.8	55.9	0.07
2003	807.5	1540.3	7.9	121.1	0.15
2004	779.0	1578.1	9.8	154.7	0.20
2005	789.5	1818.5	11.1	201.1	0.25
2006	706.5	1782.7	7.0	125.6	0.18
2007	684.2	1625.7	5.0	80.9	0.12
2008	523.6	1644.9	4.5	73.2	0.14
2009	575.5	1595.5	4.3	68.8	0.12
2010	501.7	1630.9	1.1	17.9	0.04
2011	449.0	1524.8	8.8	134.6	0.30
2012	418.8	1615.1	3.3	52.5	0.13
2013	330.6	1749.4	3.9	67.8	0.21
2014	307.4	1784.7	5.7	101.2	0.33
2015	317.4	1779.7	3.0	53.1	0.17
2016	272.4	1774.2	1.9	34.5	0.13
2017	285.6	1773.4	3.1	54.3	0.19
2018	280.4	1791.0	1.5	26.4	0.09
2019	285.0	1839.5	1.5	28.4	0.10
2020	273.2	1801.3	2.4	43.2	0.16
2021	Uncounted	-	-	-	-

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) Estimated catch in number by age and by year and parameters used in the cohort analysis

The catch in number by age and by year for Tottori, Shimane, Yamaguchi, Fukuoka, Saga, Nagasaki, Kumamoto, and Kagoshima prefectures were estimated by each prefecture. Because the maximum ages in the age compositions estimated differ by prefectures, the catch in number for fish age 7 and older was aggregated (age 7+). Moreover, since the harvest of age 0 fish has been prohibited in many areas since 1993, the recruitment age for fishery was set to 1, and age 0 fish were excluded from the analysis. The natural mortality (M) was set at 0.24 for age 1 and 0.17 for age 2 and older based on Shimamoto (1999). Parameters related to growth were based on the following equation, which has conventionally been used for this stock.

Growth formula: $FL_t = 78.14\times(1 - e^{-0.1423\times(t + 0.35)})$

Fork length-weight equation: $BW = 0.0382\times FL^{2.825}$

In this formula, FLt is fork length at age t (cm), BW is body weight (g), and FL is fork length (cm).

Body weight at age was calculated by adding 0.5 to each age to obtain the value at the midpoint for each year. Body weight of age 7+ was fixed to 3,531 g based on the proportion of age 7 to 20 years old fish assuming total mortality of 0.5. While the body weight assigned to this age group should be updated annually to account for variations in age composition, a constant figure was used regardless of the year due to the fact that, at the present moment, the accuracy of age composition estimates is inconsistent and retroactively scrutinizing the data is impossible.

(2) Biomass estimation method

Cohort analysis was performed using the catch in number at age since 1986 and the catch in weight in the area of this stock. The biological parameters used in the cohort calculations are shown in Supplementary Table 2-1.

The stock abundance ($N_{a,y}$) and fishing mortality ($F_{a,y}$) of fish age (0 to 5) in year y, excluding the most recent year, were calculated using the following equations (Hiramatsu 2001).

$$N_{a,y} = N_{a+1,y+1}\exp(M_a) + C_{a,y}\exp\left(\frac{M_a}{2}\right) \qquad (1\le a\le 5) \qquad (1)$$

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

$C_{a,y}$ is the catch in number in year y at age a.

Fish age 7 and older were deemed the plus group (7+), and, assuming fishing mortality to be equal for the age 6 and age 7+ groups, and stock abundance for fish age 6 and 7+ was obtained using the following equations.

$$N_{6,y} = \left(\frac{C_{6,y}}{(C_{6,y}+C_{7+,y})}\right) N_{7+,y+1}\exp(M_6) + C_{6,y}\exp\left(\frac{M_6}{2}\right) \quad (3)$$

$$N_{7+,y} = \left(\frac{C_{7+,y}}{C_{6,y}}\right) N_{6,y} \quad (4)$$

The stock abundance in the most recent year was obtained using the following equation.

$$N_{a,y} = \frac{C_{a,y}}{1-\exp(-F_{a,y})} \exp\left(\frac{M_a}{2}\right) \quad (1 \leq a \leq 7^{+}) \quad (5)$$

$F_{6,y}$ was estimated through a tuning cohort analysis using the observed value of CPUE in year y (uy) (see Table 4-1 for values of standardized CPUE (kg/day/company) for Japanese seabream caught by large set net fishery in Shimane Prefecture) (Hiramatsu 2001). For uy that has undergone log transformation, the following random variables for normal distribution were assumed.

$$\ln(u_y) = \ln q \sum_a (N_{a,y} W_a) + \varepsilon_y \quad \text{In this equation, } \varepsilon_y \sim N(0,\sigma^2) \quad (6)$$

W_a is the average body weight at age a.

The fishing gear efficiency (q) is obtained using formula (7), where the number of years of the survey used for tuning is T years.

$$q = exp\left(\frac{\sum_y ln(u_y) - b\sum_y ln(\sum_a (N_{a,y} W_a))}{T}\right) \quad (7)$$

Parameters that minimize formula (8) to create the greatest consistency in trends between the observed values for CPUE and the theoretical values of CPUE obtained from biomass estimated through a tuning cohort analysis were estimated.

$$SS = \sum_y \left(\ln(u_y) - \ln\left(q \sum_a (N_{a,y} W_a)\right)\right)^2 \quad (8)$$

However, recruitment in recent years is often underestimated or overestimated in cohort analysis, and this analysis also calculated a significantly larger stock abundance of fish age 1 in 2021 estimated using the method above. Since this may lead to overly optimistic values when used for future projects, the assessment this year estimated the F for age 1 in 2021 using formula (2), with the stock abundance of age 1 in 2021 as 18.01 million fish, which is the average from 2018 to 2020.

SB was obtained by multiplying the age 1 and older stock abundance by the average body weight and maturation rate (fra, Supplementary Table 2-1).

$$SB_y = \sum_{a=1}^{7+} N_{a,y} W_a fr_a \quad (9)$$

(3) Contribution rates and estimated recruitment from wild fish and hatchery-released fish

The recruitment from hatchery-released fish in year y (Ra_y) was calculated by the following equation.

$$Ra_y = N_{1,y} \times \text{Contribution rate of hatchery} - \text{released fish}$$

Survival rate to recruitment is the ratio of all hatchery-released fish to that survived and added to the stock, which is calculated using the equation below.

$$\text{Survival to recruitment} = \frac{Ra_y}{Number\ of\ hatchery\ released\ fish\ \text{in year y}-1}$$

The recruitment from wild fish (Rn_y) was obtained by subtracting Ra_y from $N_{1,y}$.

$$Rn_y = N_{1,y} - Ra_y$$

(4) Analysis of YPR and SPR

The yield per recruitment (YPR) and spawning per recruitment (SPR) were calculated using the following equations.

$$YPR = \sum_{a=1}^{\infty} S_a W_a \exp(-M_a/2)\left(1 - \exp(-F_a)\right)$$
$$SPR = \sum_{a=0}^{\infty} fr_a S_a W_a$$
$$S_{a+1} = S_a \exp(-F_a - M_a) \qquad \text{(Provided that S\_0=1)}$$

In these equations, S_a is the survival rate at age a, and fr_a is the ratio of mature females at age a.

(5) Model diagnostics results

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).

The differences in VPA results with and without tuning are shown in Supplementary Fig. 2-1, the results of model diagnostics in tuning in Supplementary Fig. 2-2, and the stock analysis and resulting catch in number by age, fishing mortality at age, stock abundance at age, and biomass at age are shown in Supplementary Tables 2-2 to 2-5.

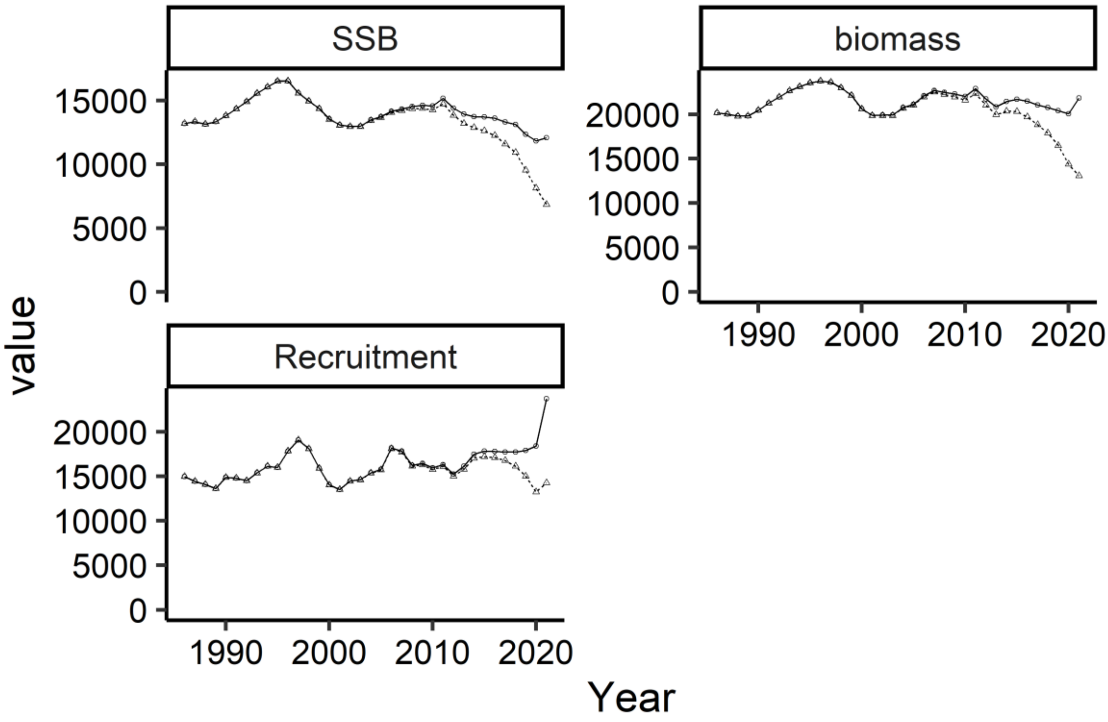
The results of the retrospective analysis for biomass, SB and recruitment are shown in Supplementary Fig. 2-3. Biomass analysis was revised slightly upward from the estimated values for 2017 to 2021. No major revisions were observed in the SB analysis. Upward revisions were observed for each year in the recruitment analysis, with step rises and falls in the most recent year.

References

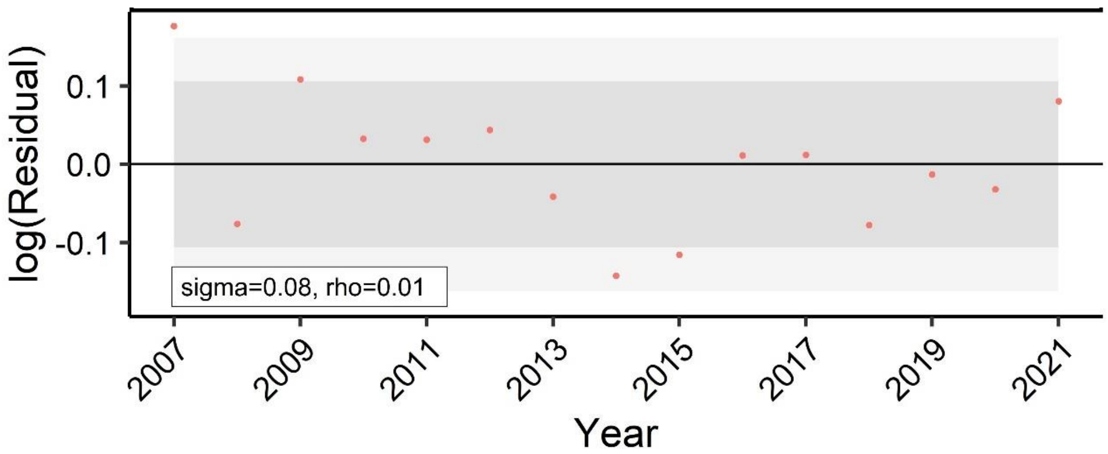
Hiramatsu, K. (2001) VPA (Virtual Population Analysis). The 2000 Report on the Establishment and Promotion of Stock Assessment Systems: Stock Analysis Methodology Textbook, Japan Fisheries Resource Conservation Association, 104-128. (in Japanese)

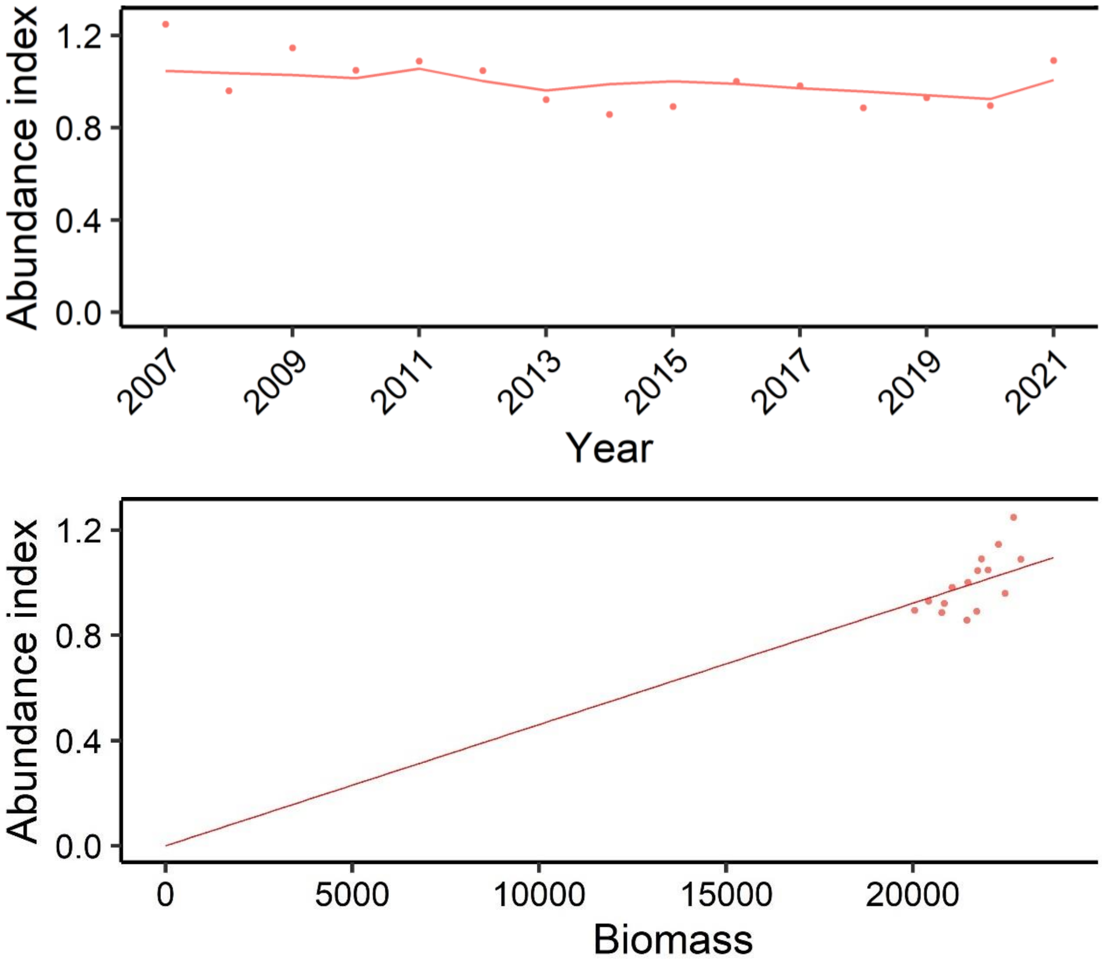
Stock Assessment Working Group (2022) Procedures for Model Diagnostics in Stock Assessment and Guidelines for Providing Diagnostics Results (Fiscal Year 2022). FRA-SA2022-ABCWG02-03.

Shimamoto, N. (1999) Study on population dynamics and stock enhancement of red sea bream, *Pagrus major*, in eastern waters of the Inland Sea of Japan. Hyogo Suishi Kenpo, 35, 43-112.

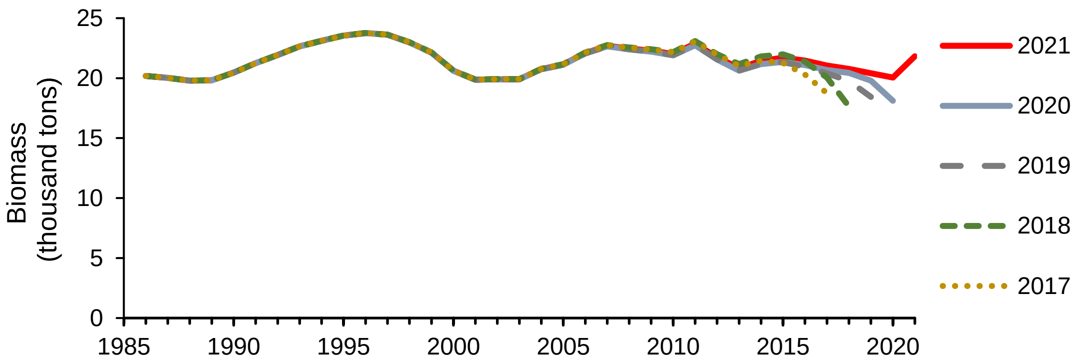


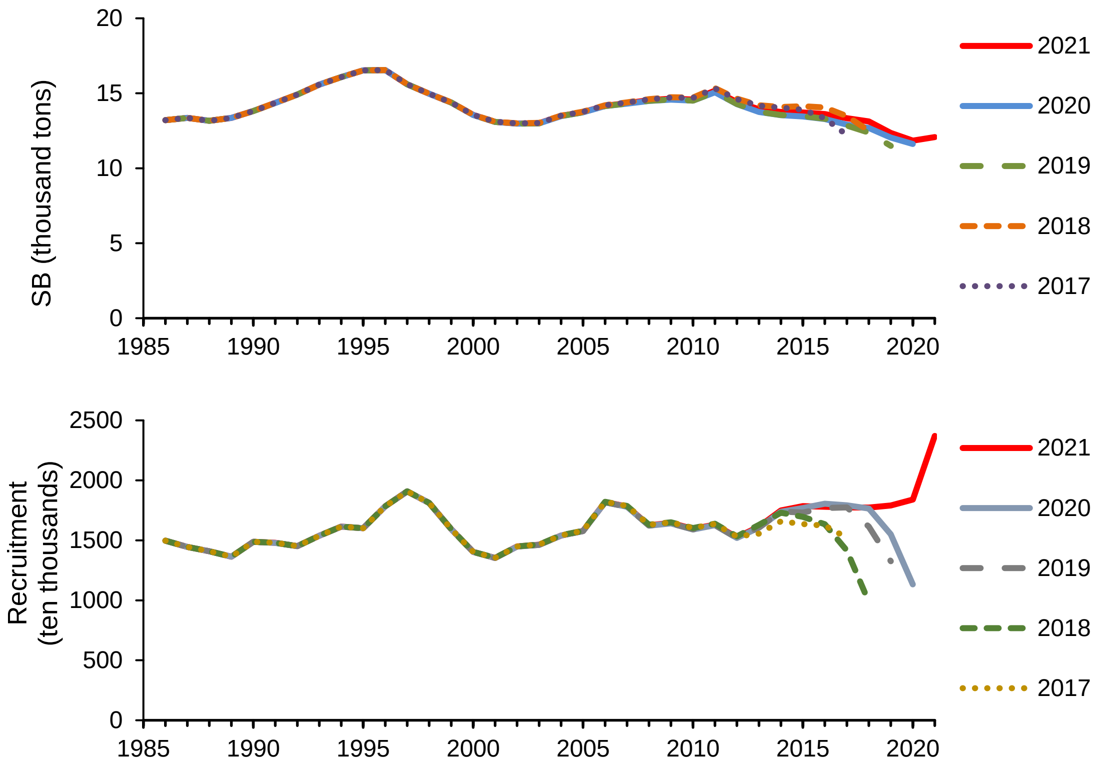
Supplementary Fig. 2-1. Results of VPA with (〇) and without (△) tuning





Supplementary Fig. 2-2. Model diagnostic results for VPA with tuning





Supplementary Fig. 2-3. Results of retrospective analysis on biomass, SB, and recruitment at age 1. The figures in the legend represent the final year of the cohort analysis.

Supplementary Table 2-1. Average body weight, maturation rate, and natural mortality (M) by age used in cohort calculations

Age	Average weight (kg)	Maturation rate	Natural mortality coefficient (M)	Age	Average weight (kg)	Maturation rate	Natural mortality coefficient (M)
1	0.136	0.0	0.24	5	1.694	1.0	0.17
2	0.382	0.0	0.17	6	2.230	1.0	0.17
3	0.742	0.5	0.17	7+	3.531	1.0	0.17
4	1.189	1.0	0.17				

Supplementary Table 2-2. Stock analysis results. Catch in number at age (thousands)

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+	Total
1986	4290	2680	1853	525	277	225	352	10201
1987	3902	2364	1716	577	314	274	380	9527
1988	3913	2286	1806	525	273	247	325	9375
1989	3297	2174	1708	481	259	235	303	8459
1990	3670	2308	1452	479	259	214	331	8712
1991	3542	2485	1417	504	275	229	359	8812
1992	3494	2516	1457	543	291	245	366	8912
1993	4252	2789	1566	575	274	241	358	10055
1994	4827	2874	1553	535	259	222	338	10608
1995	4817	3013	1726	560	268	246	345	10975
1996	4452	3025	1652	518	323	297	493	10761
1997	5265	4567	1727	587	283	181	395	13004
1998	4723	4395	1646	609	302	181	421	12276
1999	3715	4479	1946	666	325	176	406	11714
2000	2938	3449	1817	612	296	147	380	9639
2001	2152	2997	1837	562	322	159	323	8353
2002	3328	3070	1684	720	316	149	273	9539
2003	3169	2347	1422	616	344	151	308	8358
2004	3447	2754	1664	725	376	158	318	9442
2005	3377	2878	1676	730	389	148	285	9483
2006	3961	3375	1883	691	411	202	303	10826
2007	4242	4650	1745	657	408	214	315	12232
2008	3824	4077	1664	606	402	218	370	11161
2009	4011	3735	1621	699	392	224	369	11050
2010	3220	3391	1475	643	349	186	286	9551
2011	4097	3848	1854	737	465	247	410	11657
2012	4008	4098	1878	645	378	211	336	11554
2013	3211	3220	1523	535	329	165	325	9308
2014	4119	4070	1785	556	315	153	280	11278
2015	4605	4527	1933	561	313	143	280	12361
2016	4723	4590	1773	505	286	133	341	12351
2017	4761	4576	1615	506	293	133	340	12223
2018	3884	4226	1690	549	394	219	390	11352

2019	3946	4796	2028	557	303	174	337	12142
2020	2863	3955	1857	513	329	174	299	9990
2021	3422	3852	1769	434	222	111	235	10045

Supplementary Table 2-3. Stock analysis results. Fishing mortality at age (F)

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+	%SPR
1986	0.39	0.44	0.54	0.29	0.25	0.35	0.35	8.5
1987	0.36	0.39	0.54	0.31	0.27	0.40	0.40	8.6
1988	0.38	0.38	0.57	0.30	0.23	0.34	0.34	9.1
1989	0.32	0.37	0.52	0.27	0.23	0.30	0.30	10.6
1990	0.33	0.39	0.44	0.26	0.22	0.29	0.29	11.4
1991	0.31	0.39	0.42	0.26	0.22	0.31	0.31	11.5
1992	0.32	0.39	0.40	0.27	0.23	0.31	0.31	11.6
1993	0.37	0.45	0.43	0.26	0.21	0.29	0.29	10.4
1994	0.41	0.47	0.48	0.25	0.17	0.25	0.25	10.2
1995	0.41	0.49	0.56	0.30	0.18	0.24	0.24	9.0
1996	0.33	0.50	0.54	0.31	0.28	0.31	0.31	8.6
1997	0.37	0.68	0.59	0.35	0.27	0.24	0.24	7.0
1998	0.35	0.62	0.54	0.40	0.30	0.26	0.26	7.3
1999	0.31	0.66	0.60	0.42	0.38	0.28	0.28	6.5
2000	0.27	0.52	0.60	0.37	0.32	0.28	0.28	8.2
2001	0.20	0.49	0.57	0.36	0.32	0.27	0.27	9.5
2002	0.30	0.48	0.55	0.44	0.34	0.24	0.24	8.6
2003	0.28	0.36	0.42	0.38	0.37	0.26	0.26	11.1
2004	0.29	0.42	0.45	0.37	0.40	0.28	0.28	9.6
2005	0.28	0.42	0.48	0.35	0.34	0.26	0.26	10.2
2006	0.28	0.49	0.53	0.35	0.33	0.29	0.29	8.8
2007	0.31	0.63	0.50	0.34	0.35	0.28	0.28	7.7
2008	0.31	0.57	0.47	0.31	0.35	0.31	0.31	8.4
2009	0.32	0.57	0.45	0.35	0.32	0.32	0.32	8.3
2010	0.26	0.50	0.44	0.31	0.29	0.24	0.24	10.8
2011	0.33	0.57	0.55	0.40	0.37	0.33	0.33	7.0
2012	0.35	0.66	0.58	0.36	0.35	0.27	0.27	6.7
2013	0.25	0.54	0.54	0.31	0.30	0.25	0.25	9.5
2014	0.31	0.60	0.63	0.37	0.29	0.21	0.21	7.8
2015	0.34	0.67	0.62	0.39	0.35	0.20	0.20	6.9
2016	0.36	0.70	0.58	0.31	0.35	0.24	0.24	6.9
2017	0.36	0.71	0.55	0.31	0.28	0.26	0.26	7.1
2018	0.28	0.64	0.60	0.35	0.41	0.34	0.34	6.6
2019	0.29	0.69	0.71	0.39	0.31	0.31	0.31	6.0
2020	0.19	0.52	0.60	0.37	0.40	0.29	0.29	8.3
2021	0.24	0.43	0.45	0.26	0.27	0.22	0.22	13.3

Supplementary Table 2-4. Stock analysis results. Stock abundance at age (thousands)

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+	Total
1986	14971	8223	4833	2277	1371	825	1286	33786
1987	14456	7972	4475	2376	1439	903	1251	32872
1988	14084	7911	4554	2200	1474	925	1216	32365
1989	13633	7609	4575	2184	1374	993	1281	31648
1990	14882	7800	4423	2290	1400	921	1423	33140
1991	14790	8452	4461	2397	1493	944	1477	34014
1992	14521	8493	4848	2462	1560	1007	1502	34392
1993	15390	8324	4854	2751	1578	1048	1556	35501
1994	16141	8334	4461	2657	1793	1080	1647	36113
1995	16009	8416	4391	2337	1750	1275	1787	35965
1996	17841	8321	4333	2119	1457	1231	2041	37341
1997	19082	10086	4241	2138	1312	932	2033	39825
1998	18123	10341	4314	1992	1265	847	1974	38855
1999	15928	10067	4688	2128	1121	790	1827	36549
2000	14035	9235	4379	2167	1183	647	1674	33320
2001	13532	8435	4623	2025	1266	727	1474	32082
2002	14484	8736	4363	2213	1192	772	1413	33174
2003	14634	8442	4551	2134	1205	716	1456	33139
2004	15403	8701	4966	2533	1234	701	1411	34950
2005	15781	9060	4811	2661	1471	696	1345	35824
2006	18185	9418	5000	2519	1575	884	1325	38905
2007	17827	10792	4846	2488	1490	951	1399	39794
2008	16257	10261	4833	2485	1496	883	1497	37712
2009	16449	9397	4912	2549	1540	893	1468	37207
2010	15955	9381	4497	2655	1509	939	1447	36384
2011	16309	9694	4800	2439	1650	952	1579	37424
2012	15248	9196	4645	2347	1381	965	1532	35313
2013	16151	8439	3994	2193	1388	817	1604	34587
2014	17494	9857	4162	1971	1359	868	1593	37304
2015	17847	10108	4578	1872	1152	857	1679	38093
2016	17797	9955	4369	2087	1064	685	1751	37709
2017	17742	9811	4183	2058	1296	636	1620	37345
2018	17734	9733	4074	2045	1272	825	1468	37151
2019	17910	10505	4330	1885	1221	711	1375	37937
2020	18395	10588	4458	1790	1078	753	1290	38352
2021	18013	11932	5300	2055	1039	608	1289	40234

Supplementary Table 2-5. Stock analysis results. Biomass at age (tons)

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+	Total
1986	2,038	3,139	3,586	2,708	2,323	1,839	4,542	20,176
1987	1,968	3,043	3,321	2,826	2,437	2,013	4,418	20,026
1988	1,918	3,020	3,379	2,617	2,497	2,063	4,294	19,789
1989	1,856	2,905	3,394	2,597	2,328	2,214	4,523	19,817
1990	2,026	2,978	3,282	2,724	2,373	2,053	5,026	20,462
1991	2,014	3,226	3,310	2,851	2,529	2,105	5,216	21,252
1992	1,977	3,242	3,597	2,929	2,642	2,245	5,304	21,936
1993	2,095	3,178	3,602	3,272	2,674	2,338	5,493	22,652
1994	2,198	3,182	3,310	3,160	3,038	2,409	5,815	23,111
1995	2,180	3,213	3,258	2,779	2,965	2,844	6,308	23,548
1996	2,429	3,177	3,215	2,521	2,468	2,744	7,205	23,758
1997	2,598	3,850	3,147	2,543	2,223	2,079	7,180	23,620
1998	2,468	3,948	3,201	2,369	2,143	1,888	6,969	22,986
1999	2,169	3,843	3,478	2,531	1,899	1,762	6,452	22,134
2000	1,911	3,526	3,249	2,578	2,004	1,443	5,909	20,620
2001	1,843	3,220	3,430	2,409	2,145	1,620	5,204	19,871
2002	1,972	3,335	3,237	2,632	2,021	1,722	4,989	19,908
2003	1,993	3,223	3,377	2,538	2,042	1,597	5,143	19,912
2004	2,097	3,322	3,685	3,013	2,091	1,563	4,983	20,754
2005	2,149	3,459	3,569	3,165	2,492	1,553	4,749	21,136
2006	2,476	3,595	3,710	2,996	2,669	1,970	4,678	22,095
2007	2,427	4,120	3,596	2,960	2,525	2,120	4,941	22,689
2008	2,214	3,917	3,586	2,956	2,534	1,969	5,285	22,461
2009	2,240	3,587	3,644	3,032	2,609	1,990	5,184	22,287
2010	2,172	3,581	3,337	3,158	2,557	2,094	5,108	22,009
2011	2,221	3,701	3,562	2,901	2,795	2,124	5,575	22,879
2012	2,076	3,511	3,446	2,792	2,340	2,151	5,410	21,726
2013	2,199	3,222	2,964	2,609	2,351	1,823	5,664	20,832
2014	2,382	3,763	3,088	2,344	2,303	1,936	5,624	21,441
2015	2,430	3,859	3,396	2,227	1,952	1,911	5,927	21,703
2016	2,423	3,800	3,242	2,482	1,804	1,527	6,184	21,463
2017	2,416	3,745	3,103	2,448	2,197	1,418	5,719	21,046
2018	2,415	3,716	3,023	2,433	2,155	1,839	5,185	20,764
2019	2,439	4,010	3,213	2,242	2,070	1,585	4,855	20,414
2020	2,505	4,042	3,307	2,129	1,827	1,678	4,555	20,043
2021	2,453	4,555	3,933	2,444	1,760	1,355	4,550	21,049

Appendix 3 Proposed reference points and proposed fishing ban level

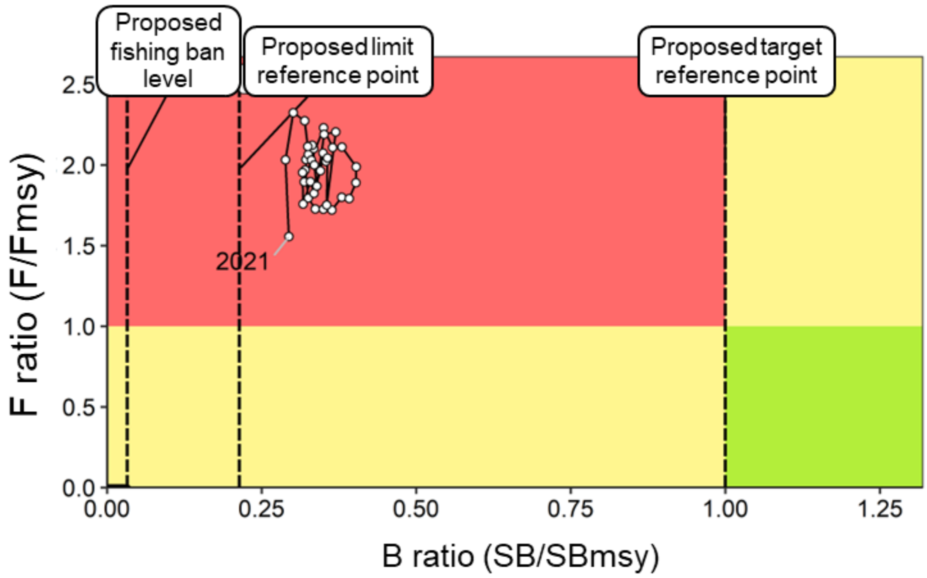
The Research Institute Meeting held in November 2021 proposed adoption of the followings: SB required for MSY (SBmsy: 39,300 tons) as a target reference point (SBtarget), SB required for 60% MSY (SB0.6msy: 9000 tons) as a limit reference point (SBlimit), and SB required for 10% MSY (SB0.1msy: 1,400 tons) as a fishing ban level (SBban) (Shimose et al. 2021, Supplementary Table 6-2). The parameters used for these estimates are shown in Supplementary Table 3-1.

The proposed target reference points and fishing mortality (F) required for MSY are shown in the Kobe plot in Supplementary Fig. 3-1. The SB for 2021 (SB2021: 12,100 tons) obtained from the cohort analysis is above the proposed limit reference point and the proposed fish ban level but below the proposed target reference point. Fishing mortality of this stock from 1986 to 2021 was judged to be above the fishing mortality required for MSY (Supplementary Fig. 3-1).

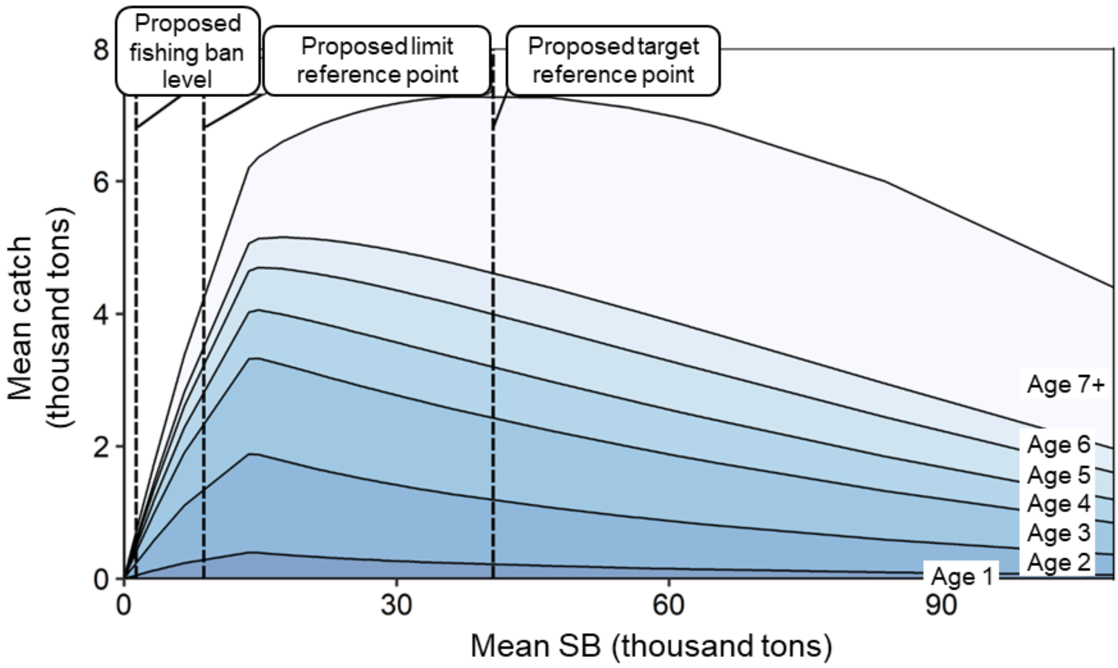
The relationship of average SB and average catch in weight at age at equilibrium is shown in Supplementary Fig. 3-2. While the majority of the fish caught were age 2 to age 3 when SB was below SBlimit, the proportion of older fish tended to increase as the SB increased, suggesting that the catch would be dominated by fish age 7+ at the point that SBmsy is achieved.

References

Shimose, T., Masubuchi, T., and Nakagawa, M. (2021) Materials for the Research Institute Meeting on Reference Points of Western Sea of Japan and East China Sea Stock of Japanese Seabream (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-39. FRA-SA2021-BRP05-001 https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20211124/FRA-SA2021-BRP05-001.pdf (last accessed 6 September 2022)



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



Supplementary Fig. 3-2. The relationship between SB and mean catch by age with the three reference points

Supplementary Table 3-1. Parameters used to estimate levels required for maximum sustainable yield (MSY)

Age	Selectivity	Fmsy	Current fishing mortality (F2022)	Average weight (kg)	Natural mortality (M)	Maturation rate
1	0.97	0.14	0.33	0.136	0.24	0.0
2	2.02	0.28	0.68	0.382	0.17	0.0
3	1.85	0.26	0.62	0.742	0.17	0.5
4	1.07	0.15	0.36	1.189	0.17	1.0
5	1.10	0.16	0.37	1.694	0.17	1.0
6	1.00	0.14	0.34	2.230	0.17	1.0
7+	1.00	0.14	0.34	3.531	0.17	1.0

Appendix 4. Future projections based on proposed HCRs

(1) Setting future projections

Future projection calculations were performed for the 2023 to 2053 fishing seasons using a progression method for cohort analysis applied to estimates for stock abundance in 2021 (Appendix 5). Recruitment in future projections was predicted based on values for SB in each year using the stock-recruitment relationship model. Calculations were replicated 1,000 times assuming errors which follow log-normal distribution to account for uncertainty in recruitment. Since the release of hatchery-reared fish is ongoing in this stock, projections were also made under the assumption that this current release would continue, the recruitment was also estimated by adding the average recruitment of age 1 hatchery-released fish from 2017 to 2021 to the recruitment for each year.

Catch in weight in the 2022 was assumed based on forecasted stock abundance and current fishing mortality (F2020-2021). Fishing mortality from 2020 onward was deemed to be at a lower level than 2019 and earlier due to the effects of the COVID-19 pandemic, a situation deemed ongoing in 2022 as well. For this reason, the current fishing mortality is the F value that gives the %SPR corresponding to average fishing mortality of 2020 and 2021 in this assessment, under the same selectivity and biological parameters (average body weight, etc.) as the calculations for proposed reference points. Fishing mortality in 2023 and onwards was set as the fishing mortality established in the following proposed HCRs, which are based on SB 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 SB, which set fishing mortality (F) and other factors that correspond to SB. The Basic Guidelines for Harvest Control Rules and ABC Calculation describes linear reduction of fishing mortality down to the proposed fishing ban level when SB falls below the proposed limit reference point, and an upper limit for fishing mortality equal to Fmsy multiplied by adjustment coefficient β when SB is above the limit reference point. Supplementary Fig. 4-1 shows the 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, “In 2032, ten years after fishing commences under the proposed HCRs, there is a 50% or higher probability that values will exceed proposed target reference points if β is less than 0.9.”

(3) Projected Values for 2023

The average catch in 2023 calculated based on HCRs with recruitment by stock-recruitment relationship only was 3,050 tons when β is 0.8 and 3,740 tons when β is 1.0 (Supplementary Table 6-4a). When current hatchling release was assumed, the average catch for 2023 was 3,070 tons when β is 0.8 and 3,770 tons when β is 1.0 (Supplementary Table 6-4b). The projected SB in 2023 fell below the target reference point in calculations for both cases and was also expected to average 15,500 tons in both cases.

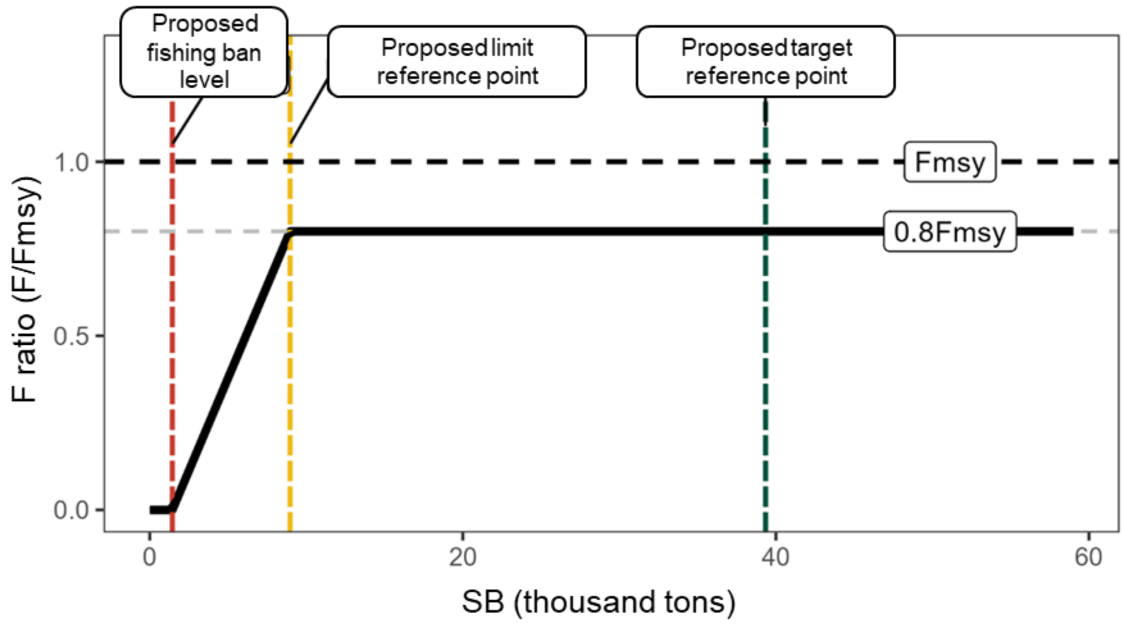
(4) Projections for 2024 and onwards

Results of future projections, including 2024 and onwards, are shown in Supplementary Fig. 4-2 and Supplementary Tables 4-1 to 4-4.

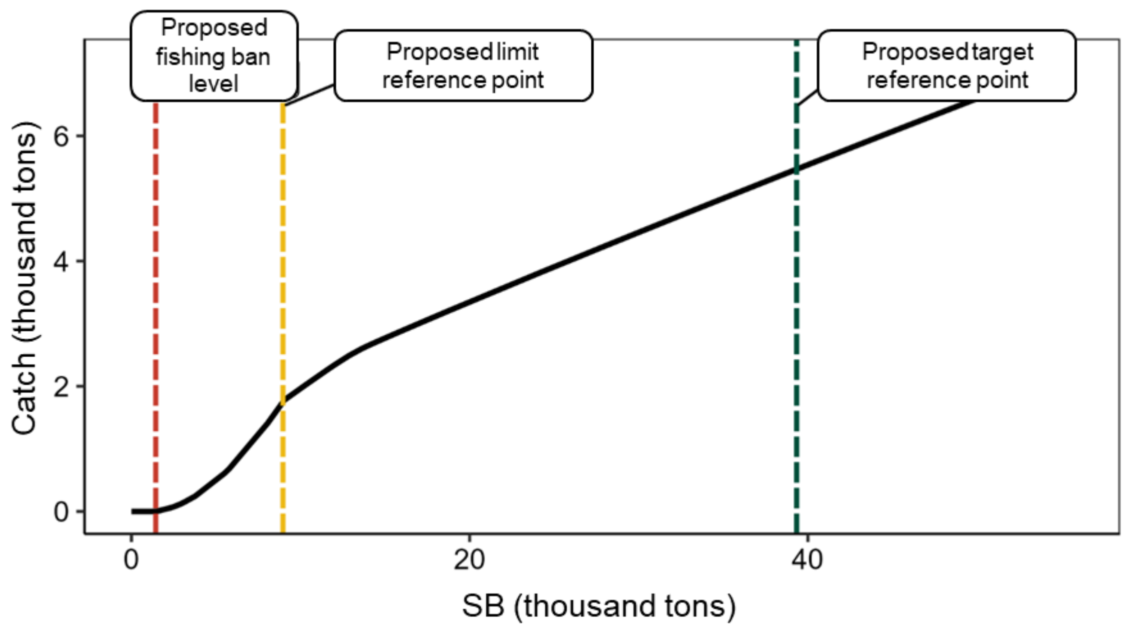
If management based on these proposed HCRs is continued for 10 years, the projected value of SB in 2033 when considering recruitment by stock-recruitment relationship only (Supplementary Fig. 4-2, Supplementary Tables 4-1a, 4-2a, 4-3a, and 4-4a) is 49,100 tons (90% prediction interval is 44,500 to 53,800 tons) when β is 0.8 and 39,400 tons (90% prediction interval is 35,500 to 43,100 tons) when β is 1.0 (Supplementary Table 6-5a). The probability that the projected value will exceed the proposed target reference points in 2033 exceeds 50% for both β values. The probability of exceeding the proposed limit reference point exceeds 50% for any β. If the current fishing mortality (F2022) is continued, then projected values for SB in 2033 will be 16,200 tons (90% prediction interval of 14,600 to 17,800 tons), with a 0% probability that the value will exceed the proposed target reference point, and a 100% probability that it will exceed the proposed limit reference point.

Similarly, the projected value for SB in 2033 when released fish in stock abundance was assumed (Supplementary Fig. 4-3, Supplementary Tables 4-1b, 4-2b, 403b, 4-4b) is 50,200 tons (90% prediction interval is 45,600 to 54,900 tons) when β is 0.8 and 40,200 tons (90% prediction interval is 36,400 to 44,000 tons) when β is 1.0 (Supplementary Table 6-5b). The probability that the projected value will exceed the proposed target reference points and the proposed limit reference point exceeds 50% for both β values. If the current fishing mortality (F2022) is continued, then projected values for SB in 2033 will be 16,500 tons (90% prediction interval of 15,000 to 18,200 tons), with a 0% probability that the value will exceed the proposed target reference point, and a 100% probability that it will exceed the proposed limit reference point.

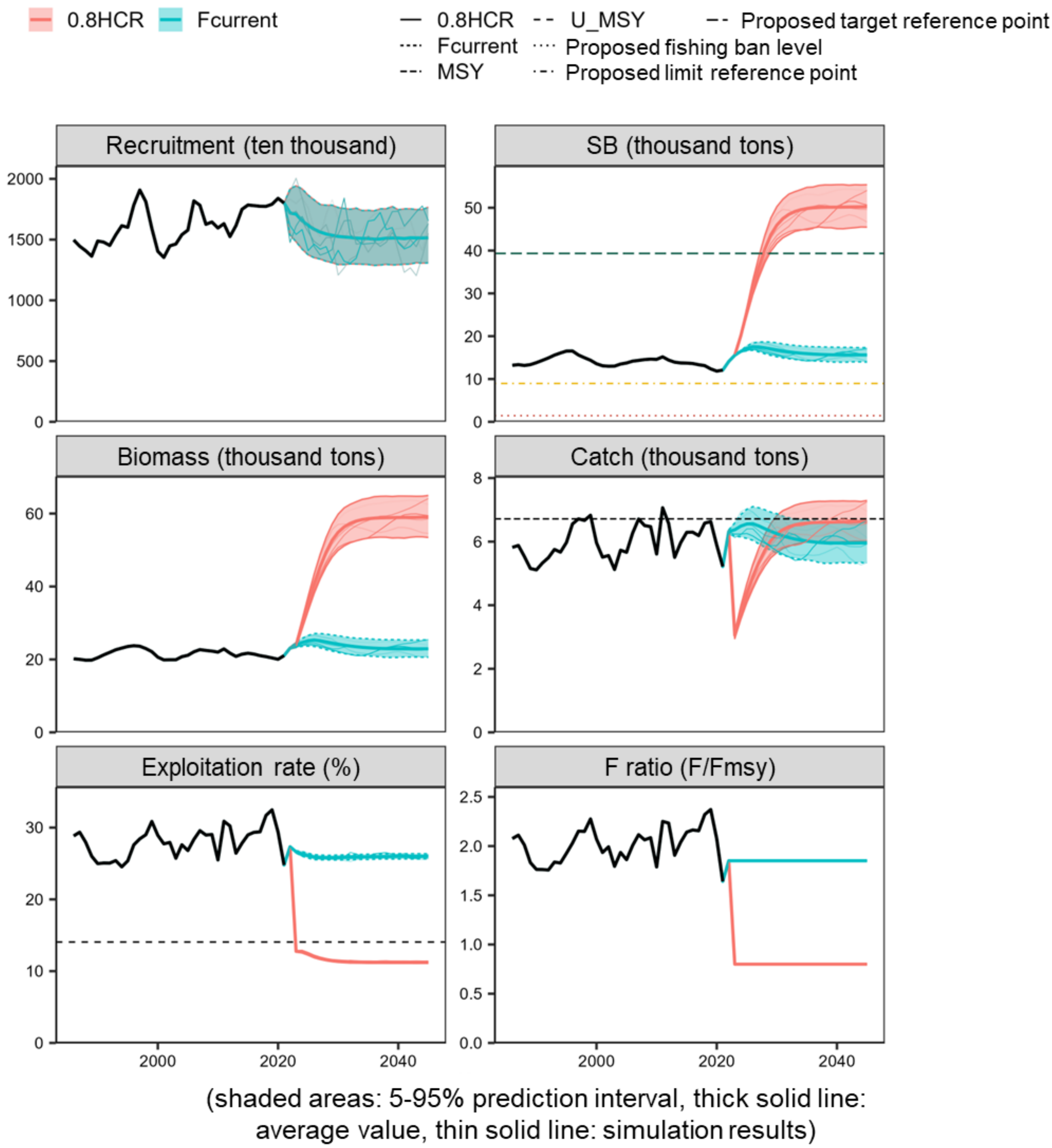
a)　When the vertical axis is fishing mortality



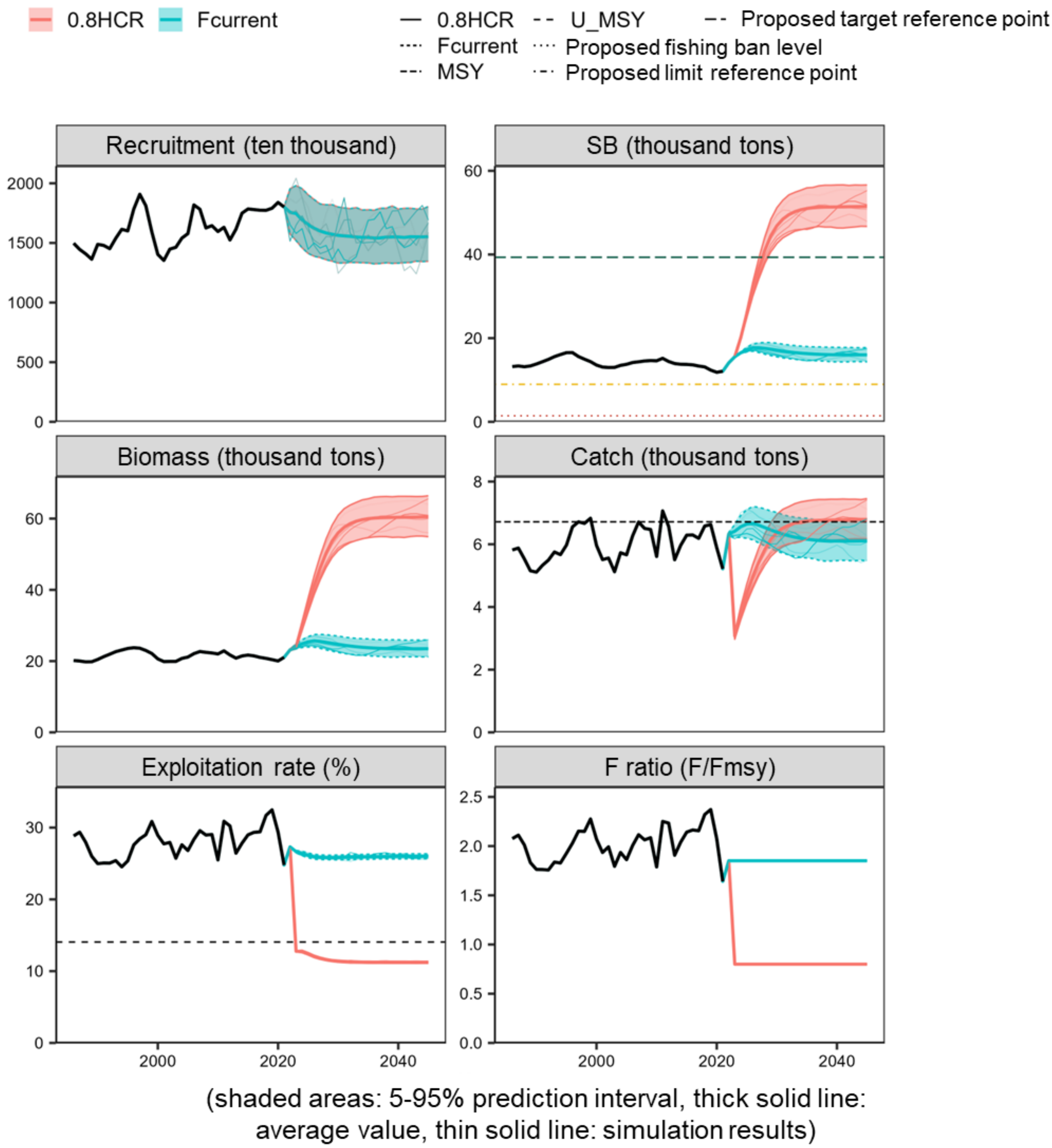
b)　When the vertical axis is catch in weight



Supplemental Fig. 4-1. The proposed HCRs and target reference points (SBtarget) are the SBmsy values calculated based on a hockey-stick stock-recruitment model. Standard values are used for the proposed limit reference point (SBlimit) and the proposed fish ban level (SBban), respectively. An adjustment coefficient of β = 0.8, the standard value, was used. The black dashed line represents Fmsy, the gray dashed line represents 0.8 Fmsy, the thick black line represents HCR, the red dashed line represents the proposed fish ban level, the yellow dashed line represents the proposed limit reference point, and the green dashed line represents the proposed target reference point. Graph (a) is the scenario when the vertical axis shows fishing mortality, and graph (b) is the scenario when the vertical axis shows catch in weight. In (b), while catch in weight varies slightly depending on the age composition in the year of catch, the catch in weight for the average age composition at equilibrium is shown here.



Supplementary Fig. 4-2. The thick solid lines for future recruitment when using proposed HCRs assuming recruitment by stock-recruitment relationship only (red) and future projections at the current fishing mortality (green) are the average values, while the shaded areas are the 90% prediction interval, which contain 90% of the simulation results, and the thin lines are examples of three future projections. In the SB graph, the green dashed line is the proposed target reference point, the yellow dotted line is the proposed limit reference point, and the red line is the proposed fishing ban level. In the exploitation rate graph, the dashed line indicates Umsy. The 2022 catch is based on predicted biomass and current fishing mortality (F2022), while catches in 2023 onward follow the proposed HCRs (Supplementary Fig. 4-1). An adjustment coefficient of β = 0.8 was used.



Supplementary Fig. 4-3. The thick solid lines for future projections when using proposed HCRs assuming the current release (red) and the current fishing mortality (green) are the average values, while the shaded areas are the 90% prediction interval, which contain 90% of the simulation results, and the thin lines are examples of three future projections. In the SB graph, the green dashed line is the proposed target reference point, the yellow dotted line is the proposed limit reference point, and the red line is the proposed fishing ban level. In the exploitation rate graph, the dashed line indicates Umsy. The 2022 catch is based on predicted biomass and current fishing mortality (F2022), while catches in 2023 onward follow the proposed HCRs (Supplementary Fig. 4-1). An adjustment coefficient of $\beta = 0.8$ was used. The average for 2017 to 2021 was used as the recruitment of hatchery-released fish in current abundance (374,000 ind.).

Supplementary Table 4-1. Probability that future SB will exceed proposed target reference points (%)

a) Assuming recruitment only from stock-recruitment relationships

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	0	0	0	0	0	0	0	0	7	23	37	45	**50**	**51**	**50**
0.9	0	0	0	0	0	0	0	11	59	81	90	94	**96**	**97**	**98**
0.8	0	0	0	0	0	0	2	69	96	100	100	100	**100**	**100**	**100**
0.7	0	0	0	0	0	0	36	98	100	100	100	100	**100**	**100**	**100**
0.6	0	0	0	0	0	0	91	100	100	100	100	100	**100**	**100**	**100**
0.5	0	0	0	0	0	3	100	100	100	100	100	100	**100**	**100**	**100**
0.4	0	0	0	0	0	45	100	100	100	100	100	100	**100**	**100**	**100**
0.3	0	0	0	0	0	94	100	100	100	100	100	100	**100**	**100**	**100**
0.2	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
0.1	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
0.0	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
F2022	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**

b) Assuming current level of hatchery-released fish recruit continue

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	0	0	0	0	0	0	0	1	12	35	52	61	**65**	**67**	**65**
0.9	0	0	0	0	0	0	0	19	72	90	96	98	**98**	**99**	**100**
0.8	0	0	0	0	0	0	4	80	99	100	100	100	**100**	**100**	**100**
0.7	0	0	0	0	0	0	49	99	100	100	100	100	**100**	**100**	**100**
0.6	0	0	0	0	0	0	95	100	100	100	100	100	**100**	**100**	**100**
0.5	0	0	0	0	0	6	100	100	100	100	100	100	**100**	**100**	**100**
0.4	0	0	0	0	0	57	100	100	100	100	100	100	**100**	**100**	**100**
0.3	0	0	0	0	0	97	100	100	100	100	100	100	**100**	**100**	**100**
0.2	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
0.1	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
0.0	0	0	0	0	0	100	100	100	100	100	100	100	**100**	**100**	**100**
F2022	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

Supplementary Table 4-2. Probability that future SB will exceed proposed limit reference points (%)

a) Assuming recruitment only from stock-recruitment relationships

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	100	100	100	100	**100**	**100**	**100**
0.9	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.8	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.7	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.6	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.5	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.4	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.3	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.2	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.1	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.0	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
F2022	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**

b) Assuming current level of hatchery-released fish recruit continue

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	100	100	100	100	**100**	**100**	**100**
0.9	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.8	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.7	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.6	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.5	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.4	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.3	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.2	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.1	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
0.0	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**
F2022	100	100	100	100	100	100	100	100	100	100	100	100	**100**	**100**	**100**

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

Supplementary Table 4-3. Trends in future average SB (tons)

a) Assuming recruitment only from stock-recruitment relationships

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	12,100	14,100	15,500	19,300	23,700	28,000	31,400	34,300	36,400	37,700	38,600	39,100	**39,400**	**39,400**	**39,500**
0.9	12,100	14,100	15,500	19,700	24,600	29,600	33,700	37,200	39,900	41,600	42,800	43,500	**43,900**	**44,400**	**44,500**
0.8	12,100	14,100	15,500	20,100	25,600	31,300	36,100	40,300	43,700	45,900	47,500	48,500	**49,100**	**50,200**	**50,300**
0.7	12,100	14,100	15,500	20,500	26,600	33,100	38,800	43,800	47,900	50,700	52,700	54,100	**55,000**	**56,900**	**57,000**
0.6	12,100	14,100	15,500	20,900	27,700	35,000	41,600	47,600	52,500	56,100	58,600	60,400	**61,600**	**64,600**	**64,800**
0.5	12,100	14,100	15,500	21,300	28,800	37,000	44,600	51,700	57,600	62,000	65,100	67,500	**69,100**	**73,600**	**74,000**
0.4	12,100	14,100	15,500	21,700	29,900	39,200	47,900	56,100	63,200	68,500	72,500	75,500	**77,700**	**84,100**	**84,800**
0.3	12,100	14,100	15,500	22,100	31,100	41,400	51,400	61,000	69,400	75,900	80,800	84,500	**87,400**	**96,500**	**97,600**
0.2	12,100	14,100	15,500	22,500	32,400	43,800	55,200	66,300	76,300	84,000	90,000	94,700	**98,400**	**111,000**	**113,000**
0.1	12,100	14,100	15,500	23,000	33,700	46,400	59,200	72,100	83,800	93,100	100,000	106,000	**111,000**	**128,000**	**131,000**
0.0	12,100	14,100	15,500	23,400	35,100	49,100	63,600	78,400	92,100	103,000	112,000	119,000	**125,000**	**149,000**	**153,000**
F2022	12,100	14,100	15,500	16,500	17,100	17,500	17,500	17,300	17,000	16,800	16,600	16,300	**16,200**	**15,600**	**15,600**

b) Assuming current level of hatchery-released fish recruit continue

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	12,100	14,100	15,500	19,400	23,900	28,300	31,900	34,800	37,100	38,500	39,400	39,900	**40,200**	**40,400**	**40,400**
0.9	12,100	14,100	15,500	19,800	24,800	29,900	34,200	37,800	40,600	42,500	43,700	44,400	**44,900**	**45,500**	**45,600**
0.8	12,100	14,100	15,500	20,100	25,800	31,600	36,600	41,000	44,500	46,900	48,500	49,500	**50,200**	**51,400**	**51,500**
0.7	12,100	14,100	15,500	20,500	26,800	33,500	39,300	44,500	48,800	51,700	53,800	55,200	**56,200**	**58,200**	**58,400**
0.6	12,100	14,100	15,500	20,900	27,900	35,400	42,200	48,300	53,500	57,200	59,800	61,700	**63,000**	**66,200**	**66,400**
0.5	12,100	14,100	15,500	21,300	29,000	37,400	45,200	52,500	58,700	63,200	66,500	68,900	**70,700**	**75,400**	**75,800**
0.4	12,100	14,100	15,500	21,700	30,200	39,600	48,500	57,100	64,400	69,900	74,000	77,100	**79,400**	**86,200**	**86,900**
0.3	12,100	14,100	15,500	22,200	31,400	41,900	52,100	62,000	70,700	77,400	82,400	86,300	**89,300**	**98,800**	**100,000**
0.2	12,100	14,100	15,500	22,600	32,700	44,300	55,900	67,400	77,700	85,700	91,900	96,700	**101,000**	**114,000**	**116,000**
0.1	12,100	14,100	15,500	23,000	34,000	46,900	60,000	73,300	85,400	94,900	102,000	109,000	**113,000**	**131,000**	**134,000**
0.0	12,100	14,100	15,500	23,500	35,300	49,700	64,500	79,700	93,800	105,000	114,000	122,000	**128,000**	**152,000**	**157,000**
F2022	12,100	14,100	15,500	16,500	17,200	17,700	17,700	17,600	17,400	17,100	16,900	16,700	**16,500**	**16,000**	**16,000**

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

Supplementary Table 4-4. Trends in future average catch in weight (tons)

a) Assuming recruitment only from stock-recruitment relationships

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	5,217	6,320	3,740	4,430	5,020	5,500	5,880	6,190	6,420	6,560	6,650	6,700	**6,730**	**6,730**	**6,730**
0.9	5,217	6,320	3,400	4,110	4,720	5,220	5,640	5,990	6,260	6,430	6,550	6,620	**6,660**	**6,710**	**6,710**
0.8	5,217	6,320	3,050	3,750	4,370	4,900	5,350	5,730	6,030	6,240	6,380	6,470	**6,530**	**6,620**	**6,630**
0.7	5,217	6,320	2,700	3,380	3,990	4,530	4,990	5,400	5,730	5,960	6,120	6,230	**6,310**	**6,460**	**6,470**
0.6	5,217	6,320	2,340	2,980	3,570	4,100	4,570	4,990	5,340	5,590	5,770	5,900	**5,980**	**6,200**	**6,210**
0.5	5,217	6,320	1,970	2,560	3,110	3,610	4,070	4,480	4,840	5,100	5,290	5,430	**5,530**	**5,800**	**5,830**
0.4	5,217	6,320	1,590	2,100	2,600	3,050	3,480	3,870	4,220	4,480	4,670	4,810	**4,920**	**5,240**	**5,270**
0.3	5,217	6,320	1,200	1,620	2,040	2,420	2,790	3,140	3,450	3,690	3,870	4,010	**4,110**	**4,460**	**4,500**
0.2	5,217	6,320	810	1,120	1,420	1,710	1,990	2,260	2,510	2,700	2,850	2,970	**3,060**	**3,400**	**3,400**
0.1	5,217	6,320	410	570	740	900	1,070	1,230	1,370	1,490	1,600	1,700	**1,700**	**1,900**	**2,000**
0.0	5,217	6,320	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
F2022	5,217	6,320	6,370	6,490	6,550	6,560	6,490	6,410	6,320	6,250	6,180	6,130	**6,080**	**5,950**	**5,950**

b) Assuming current level of hatchery-released fish recruit continue

β	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**2033**	**2043**	**2053**
1.0	5,217	6,330	3,770	4,480	5,090	5,590	5,980	6,300	6,550	6,700	6,800	6,860	**6,890**	**6,900**	**6,900**
0.9	5,217	6,330	3,420	4,150	4,780	5,300	5,740	6,100	6,380	6,570	6,690	6,770	**6,820**	**6,870**	**6,870**
0.8	5,217	6,330	3,070	3,800	4,430	4,980	5,440	5,830	6,150	6,370	6,520	6,610	**6,680**	**6,790**	**6,790**
0.7	5,217	6,330	2,720	3,420	4,050	4,600	5,080	5,500	5,850	6,090	6,260	6,370	**6,450**	**6,620**	**6,630**
0.6	5,217	6,330	2,350	3,020	3,620	4,160	4,640	5,080	5,450	5,710	5,890	6,030	**6,120**	**6,350**	**6,370**
0.5	5,217	6,330	1,980	2,590	3,150	3,660	4,130	4,570	4,940	5,210	5,410	5,550	**5,660**	**5,950**	**5,970**
0.4	5,217	6,330	1,600	2,130	2,630	3,100	3,540	3,950	4,300	4,570	4,770	4,920	**5,030**	**5,370**	**5,400**
0.3	5,217	6,330	1,210	1,640	2,060	2,460	2,840	3,200	3,520	3,760	3,950	4,100	**4,210**	**4,560**	**4,600**
0.2	5,217	6,330	820	1,130	1,440	1,730	2,020	2,310	2,560	2,760	2,910	3,040	**3,100**	**3,500**	**3,500**
0.1	5,217	6,330	410	580	750	920	1,080	1,250	1,400	1,520	1,600	1,700	**1,800**	**2,000**	**2,000**
0.0	5,217	6,330	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
F2022	5,217	6,330	6,420	6,560	6,640	6,670	6,610	6,530	6,460	6,390	6,320	6,270	**6,230**	**6,100**	**6,100**

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

Appendix 5 Future projection methods

Future projections were performed using the stock-recruitment relationship used to estimate the F value that would achieve maximum sustainable yield (Fmsy) at the Research Institute Meeting held in September 2021 (Shimose et al. 2021) as well as the various settings shown in Supplementary Table 5-1 (natural mortality, maturation rate, average weight by age, and current fishing mortality) according to the HCRs for Stock Group 1 in the Basic Guidelines for Harvest Control Rules and ABC Calculation at FY 2022 (FRA-SA2022-ABCWG02-01). The statistical software R (version 4.2.0) and the calculation package frasyr (version 2.2.0.2) were used to calculate projections for stock abundance and catch in weight based on the Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations (FRA-SA2022-ABCWG02-04).

This stock is a target of stock enhancement, and hatchery-reared fish have been released continuously (Table 4-3). When taking hatchling release into account in future projects, the average recruitment for fish age 1 from 2017 to 2021 (374,000 fish) was added as the future recruitment of hatchery-released fish.

The stock abundance of fish age 1 to 6 in future projections was obtained using the following equation.

$$N_{a,y} = N_{a-1,y-1}\exp\left(-M_{a-1} - F_{a-1,y-1}\right) \qquad (a = 1,\ldots,6)$$

The stock abundance of the plus group of fish age 7+ was obtained using the following equation.

$$N_{7+,y} = N_{6,y-1}\exp\left(-M_{6,y-1} - F_{6,y-1}\right) + N_{7+,y-1}\exp\left(-M_{7+,y-1} - F_{7+,y-1}\right)$$

Fishing mortality (F) in future projections was determined using the following equation based on the HCRs for Stock Group 1.

$$\mathrm{F_{a,y}} = \begin{cases} 0 & \text{if } \mathrm{SB_t} < \mathrm{SB_{ban}} \\ \beta\gamma(\mathrm{SB_t})\mathrm{F_{msy}} & \text{if } \mathrm{SB_{ban}} \le \mathrm{SB_t} < \mathrm{SB_{limit}} \\ \beta\mathrm{F_{msy}} & \text{if } \mathrm{SB_t} \ge \mathrm{SB_{limit}} \end{cases}$$

$$\gamma(SB_y) = \frac{SB_y - SB_{ban}}{SB_{limit} - SB_{ban}}$$

In these equations, SB_y is the SB in year y, while Fmsy and SBtarget, SBlimit, and SBban are the SB reference values shown as proposed in Supplementary Table 6-2.

The catch in number at age was also obtained using the following equation.

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

The biomass and catch in weight in future projections were obtained by multiplying the stock abundance or catch in number obtained here by the average body weight in Supplementary Table 5-1, and SB was calculated by multiplying this biomass by the maturation rate.

References

Fisheries Resources Institute, Japan Fisheries Research and Education Agency (2022) Basic Guidelines for Harvest Control Rules and ABC Calculation at FY 2022. FRA-SA2022-ABCWG02-01.

Stock Assessment Working Group (2022) Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations.FRA-SA2022-ABCWG02-04.

Shimose, T., Masubuchi, T., and Nakagawa, M. (2021) Materials for the Research Institute Meeting on Reference Points of Western Sea of Japan and East China Sea Stock of Japanese Seabream (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-39. FRA-SA2021-BRP05-001 https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20211124/FRA-SA2021-BRP05-001.pdf (last accessed 6 September 2022)

Supplementary Table 5-1. Set values used to calculate future projections

Age	Selectivity (Note 1)	Fmsy (Note 2)	F2022 (Note 3)	Average weight (kg)	Natural mortality (M)	Maturation rate
1	0.97	0.14	0.25	0.136	0.24	0.0
2	2.02	0.28	0.52	0.382	0.17	0.0
3	1.85	0.26	0.48	0.742	0.17	0.5
4	1.07	0.15	0.28	1.189	0.17	1.0
5	1.10	0.16	0.29	1.694	0.17	1.0
6	1.00	0.14	0.26	2.230	0.17	1.0
7+	1.00	0.14	0.26	3.531	0.17	1.0

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 FY2021 stock assessment).

Note 2: Fmsy estimated at the FY 2021 Research Institute Meeting (i.e., Fmsy/Fcurrent multiplied by Fcurrent in the FY2021 stock assessment).

Note 3: Under the selectivity above, an F value that gives the same fishing mortality as the average F value by age in 2020 and 2021 estimated in this stock assessment was calculated by conversion to %SPR. This F value was used as the assumed catch in weight for 2022.

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	1.20	12,579	0.063	0.733

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

Supplementary Table 6-2. Proposed reference points and MSY

Item	Value	Description
SBtarget (proposed)	39,300 tons	A proposed target reference point. SB required for MSY (SBmsy)
SBlimit (proposed)	8,960 tons	A proposed limit reference point. SB required for catch of 60% of MSY (SB0.6msy)
SBban (proposed)	1,440 tons	Proposed fishing ban level. SB required for catch of 10% of MSY (SB0.1msy)
Fmsy	Fishing mortality (F) required for MSY (Age 1, Age 2, Age 3, Age 4, Age 5, Age 6, Age 7 and older) = (0.14, 0.28, 0.26, 0.15, 0.16, 0.14, 0.14)	
%SPR (Fmsy)	26%	%SPR corresponding to Fmsy
MSY	6,720 tons	Maximum Sustainable Yield

Supplementary Table 6-3. SB and fishing mortality in most recent year

Item	Value	Description
SB2021	12,075 tons	SB in 2021
F2021	Fishing mortality (F) in 2021 (Age 1, Age 2, Age 3, Age 4, Age 5, Age 6, Age 7+) = (0.24, 0.43, 0.45, 0.26, 0.27, 0.22, 0.22)	
U2021	24.8%	Exploitation rate in 2021
%SPR (F2021)	13%	%SPR in 2021
Compared against proposed reference points		
SB2021 / SBmsy (SBtarget)	0.31	SB ratio required for MSY (proposed target reference point) to SB in 2021 fishing season
F2021 / Fmsy	1.64	F ratio required for MSY to fishing mortality in 2021*
Level of SB	Under the level required for MSY	
Level of fishing mortality	Over the level required for MSY	
Changes in SB	Decrease 要約の文と書き方が違う	

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

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

a) Assuming recruitment only from stock-recruitment relationships

SB in 2023 (average projected value): 15,500 tons			
Item	Catch (tons) in 2023	Ratio to current fishing mortality (F/F2022)	Exploitation rate in 2023 (%)
β = 1.0	3,740	0.54	15.6
β = 0.9	3,400	0.49	14.2
β = 0.8	3,050	0.43	12.7
β = 0.7	2,700	0.38	11.3
β = 0.6	2,340	0.32	9.8
β = 0.5	1,970	0.27	8.2
β = 0.4	1,590	0.22	6.6
β = 0.3	1,200	0.16	5.0
β = 0.2	810	0.11	3.4
β = 0.1	410	0.05	1.7
β = 0	0	0.00	0.0
F2020-2021	6,370	1.00	26.6

b) Assuming current level of hatchery-released fish recruit continue

SB in 2023 (average projected value): 15,500 tons			
Item	Catch (tons) in 2023	Ratio to current fishing mortality (F/F2022)	Exploitation rate in 2023 (%)
β = 1.0	3,770	0.54	15.6
β = 0.9	3,420	0.49	14.2
β = 0.8	3,070	0.43	12.8
β = 0.7	2,720	0.38	11.3
β = 0.6	2,350	0.32	9.8
β = 0.5	1,980	0.27	8.2
β = 0.4	1,600	0.22	6.6
β = 0.3	1,210	0.16	5.0
β = 0.2	820	0.11	3.4
β = 0.1	410	0.05	1.7
β = 0	0	0.00	0.0
F2020-2021	6,420	1.00	26.6

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

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

a) Assuming recruitment only from stock-recruitment relationships

Uncertainty under consideration: recruitment					
β	SB in 2033 (hundred tons)	90% prediction interval (hundred tons)	Probability (%) that SB will exceed the following proposed reference points in 2033		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
β = 1.0	394	355 – 431	50	100	100
β = 0.9	439	398 – 481	96	100	100
β = 0.8	491	445 – 538	100	100	100
β = 0.7	550	498 – 602	100	100	100
β = 0.6	616	558 – 675	100	100	100
β = 0.5	691	626 – 758	100	100	100
β = 0.4	777	703 – 852	100	100	100
β = 0.3	874	791 – 959	100	100	100
β = 0.2	984	891 – 1079	100	100	100
β = 0.1	1110	1004 – 1215	100	100	100
β = 0	1252	1134 – 1370	100	100	100
F2020-2021	162	146 – 178	0	100	100

b) Assuming current level of hatchery-released fish recruit continue

Uncertainty under consideration: recruitment					
β	SB in 2033 (hundred tons)	90% prediction interval (hundred tons)	Probability (%) that SB will exceed the following proposed reference points in 2033		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
β = 1.0	402	364 – 440	65	100	100
β = 0.9	449	408 – 491	98	100	100
β = 0.8	502	456 – 549	100	100	100
β = 0.7	562	510 – 614	100	100	100
β = 0.6	630	571 – 689	100	100	100
β = 0.5	707	641 – 773	100	100	100
β = 0.4	794	720 – 869	100	100	100
β = 0.3	893	810 – 978	100	100	100
β = 0.2	1006	913 – 1101	100	100	100
β = 0.1	1136	1028 – 1239	100	100	100
β = 0	1279	1161 – 1398	100	100	100
F2020-2021	165	150 – 182	0	100	100

The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.).

Supplementary Table 6-6. Summary of predicted SB/catch in weight when recruitment of hatchery-released fish is changed and the probability of SB exceeding the proposed reference points

Hypothesized future recruitment	β	Probability of exceeding the target in 10 years (%)	Projected average SB (tons)		Projected average catch in weight (tons)		
		Probability of SB exceeding the proposed target reference points	In 5 years	In 10 years	In 0 years	In 5 years	In 10 years
			2028	2033	2023	2028	2033
Recruitment according to stock-recruitment relationship only	1	50	34,300	39,400	3,740	6,190	6,730
	0.9	96	37,200	43,900	3,400	5,990	6,660
	0.8	100	40,300	49,100	3,050	5,730	6,530
	0.7	100	43,800	55,000	2,700	5,400	6,310
	0.6	100	47,600	61,600	2,340	4,990	5,980
	0.5	100	51,700	69,100	1,970	4,480	5,530
	F2020-2021	0	17,300	16,200	6,370	6,410	6,080
Hatchling release taken into account (374,000 ind.)*	1	65	34,800	40,200	3,770	6,300	6,890
	0.9	98	37,800	44,900	3,420	6,100	6,820
	0.8	100	41,000	50,200	3,070	5,830	6,680
	0.7	100	44,500	56,200	2,720	5,500	6,450
	0.6	100	48,300	63,000	2,350	5,080	6,120
	0.5	100	52,500	70,700	1,980	4,570	5,660
	F2020-2021	0	17,800	16,800	6,390	6,530	6,250

The results of changing the adjustment coefficient β in the proposed HCRs from 0.5 to 1.0 in increments of 0.1 are compiled here.

Values for 2023, the first year (year 0) of management under the proposed HCRs, are shown here along with values after 5 years and 10 years of management (2028 and 2033).

*The average for 2017 to 2021 was used as the recruitment of hatchery-released fish (374,000 ind.)