

Stock Assessment for the Southwestern Sea of Japan Stock of Shotted Halibut (Fiscal Year 2024)

Japan Fisheries Research and Education Agency

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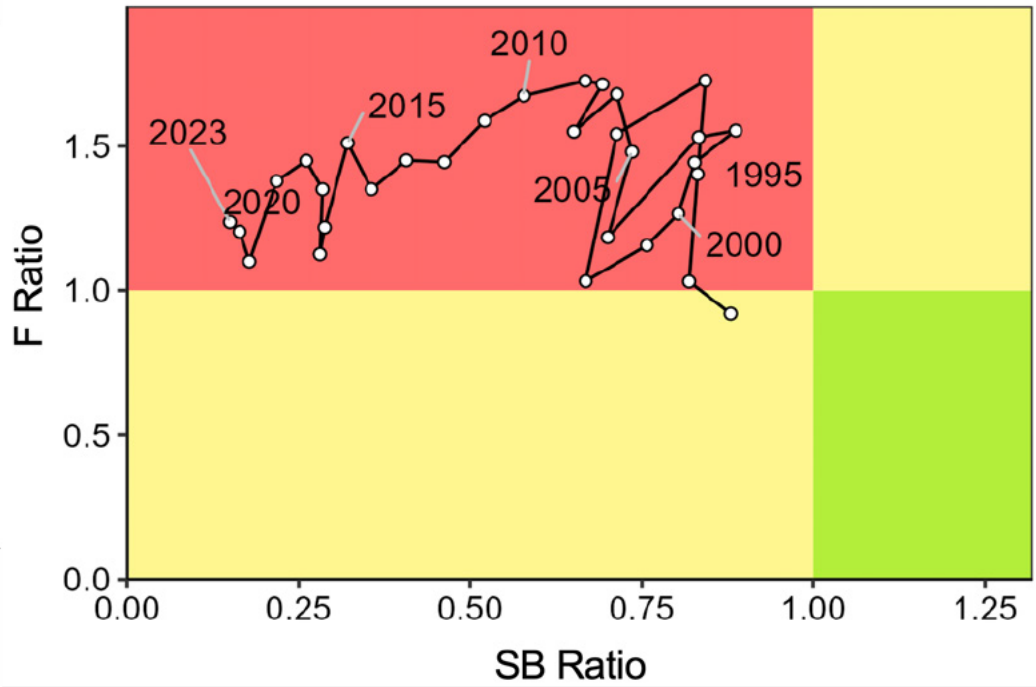
Summary

The biomass of this stock was estimated using a form of cohort analysis known as Virtual Population Analysis (VPA). The catch of this stock peaked at approximately 5,000 tons in the late 1970s, then fluctuated before declining to around 1,000 tons by the late 1990s. Since 2009, the catch has continued to decrease, reaching 275 tons in 2023. The biomass remained between 4,000 and 5,500 tons until 2009, but then declined below 2,000 tons in 2015. From 2016 to 2018, it fluctuated around 1,600 tons, before resuming a downward trend, reaching 819 tons in 2023. The spawning stock biomass (SSB) followed a similar pattern, with an estimated 600 tons in 2023.

At the Research Institute Meeting on Reference Points and Other Criteria held in October 2021, a hockey-stick model was applied to the stock-recruitment relationship of this stock. Based on this model, the spawning stock biomass to achieve the MSY (maximum sustainable yield) (SB_{msy}) was estimated at 4,000 tons. According to this criterion, the SSB in 2023 was significantly below the level for achieving MSY. Additionally, the fishing pressure on this stock in 2023 exceeded the fishing coefficient to maintain SB_{msy} (F_{msy}). Based on trends observed over the last five years (2019–2023), the SSB is determined to be in a "declining" trend.

For this stock, provisional reference points and projections proposed at the Research Institute Meeting on Reference Points and Other Criteria were used tentatively. These values will be finalized through discussions in the Stock Management Policy Commission.

Summary Figure and Tables



Metric	Value
SBmsy (Spawning Stock Biomass to achieve MSY)	4,000 tons
2023 SSB Level	Below SBmsy
2023 Fishing Pressure Level	Above Fmsy
2023 SSB Trend	Declining
Maximum Sustainable Yield (MSY)	1,500 tons
2025 Allowable Biological Catch (ABC)	-
Comments: <ul style="list-style-type: none"> • ABC will be determined after the Fishery Policy Council finalizes Harvest Control Rules (HCR) which is discussed in Stock Management Policy Commission. • Recent fishing pressure has been high, and the SSB has been declining. 	

Recent Biomass, SSB, Catch, and Fishing Pressure Trends					
Year	Biomass (tons)	SSB (tons)	Catch (tons)	F/Fmsy	Exploitation Rate (%)
2019	1,450	1,050	530	1.45	37
2020	1,190	870	440	1.38	37
2021	980	710	310	1.10	31
2022	910	660	290	1.20	32
2023	820	600	280	1.24	34
2024	710	520	240	1.22	34
2025	660	460	-	-	-

Notes: Values for 2024 and 2025 are averages based on future projections.

1. Data Sets

The following data sets were used in this stock assessment:

Data Sets	Basic Information and Related Surveys
Catch in weight	Offshore bottom trawl fishery catch performance reports (Fisheries Agency)
Catch in number at-age by year	Major port landings data (Yamaguchi, Shimane, and Tottori Prefectures) Market measurements (Shimane Prefecture)
Fishing effort and abundance indices	Offshore bottom trawl fishery catch performance reports (Fisheries Agency) Small-scale bottom trawl fishery catch performance reports (Shimane Prefecture)
Natural mortality coefficient (M)	Assumed at $M = 0.35$ per year (Tanaka 1960)

2. Ecology

(1) Distribution and Migration

Shotted halibut are distributed in warm continental shelf waters around Japan. In the Sea of Japan, they range widely from Aomori Prefecture to Tsushima Islands, mainly in the southwestern Sea of Japan, west of 135°E, off the shelf of Yamaguchi and Shimane Prefectures (Fig. 2-1, Imaoka and Misu 1969). They are also caught in Korean waters, but due to lack of data, this assessment focuses only on the stock caught by Japanese fisheries. In areas east of Tsushima, they concentrate in northeastern Tsushima and northwestern Mishima waters in autumn, dispersing during other seasons. West of Tsushima, they remain in western Tsushima waters in spring and summer, then migrate southwest for overwintering in autumn. Young fish inhabit shallow coastal areas, migrating offshore as they grow.

(2) Age and Growth

Total length of males and females are 10.9 cm and 11.4 cm at age 1, 16.5 cm and 17.2 cm at age 2, 21.2 cm and 21.4 cm at age 3, and 25.2 cm and 24.5 cm at age 4, respectively. After age 5, the difference between males and females increases: 28.6 cm and 26.9 cm at age 5, 31.6 cm and 28.6 cm at age 6, and 34.1 cm and 29.8 cm at age 7, respectively (Fig. 2-2, Imai and Miyazaki 2005). Lifespan is estimated to be about 7 years.

(3) Maturation and Spawning

The age at which maturity begins is age 2 for males and age 3 for females. The peak spawning season is from late January to late February west of Tsushima, and from early February to early March east of Tsushima (Imaoka 1971). For the calculation of SSB, the maturity rate at age 2 was set at 0.4 and the maturity rate at age 3 and older was set at 1.

(4) Predator-Prey Relationships

Individuals up to 12 cm in total length mainly feed on small crustaceans, while individuals of 12 cm in total length or longer feed on crabs, squids, etc. Individuals of 18 cm in total length and longer feed on fish (Imaoka 1972). Precise measurements and observation of stomach contents of Shimane prefecture catches show a high frequency of chainmailed poachers and crangonid shrimp (Shimane Prefecture Fisheries Technology Center, unpublished). The extent of predation is unknown.

3. Fishery Status

(1) Overview

Most shotted halibut catches in the southwestern Sea of Japan are made using offshore bottom trawling, including both one and two-boat offshore bottom trawls, as well as small bottom trawls. The fishing grounds extend from the southwestern waters of Tsushima to the area around the Oki Islands. Other fishing methods include gillnets, rod fishing, and longlines. Among bottom trawls, two-boat offshore bottom trawling based out of Hamada and Shimonoseki ports (west of Hamada), accounts for the most of catches, comprising 47–78% of total landings since 1986 (Fig. 3-1, Table 3-1).

(2) Trends in Catch

The catch volume of two-boat offshore bottom trawling (west of Hamada) peaked at approximately 5,000 tons in the late 1970s. It then declined to about 2,500 tons in the early 1980s and further to around 1,000 tons in the late 1980s. Since 2009, the catch has continued to decrease, with the catch in 2023 recorded at 137 tons (Fig. 3-1, Table 3-1). The catch from small bottom trawlers ranged from 300 to 600 tons since 1986, except in 2004 (197 tons), but has been declining since 2011, reaching 91 tons in 2023. The total catch for the stock in 2023 was 275 tons, 14 tons lower than the previous year. The share of each fishing method in the 2023 total catch was: two-boat offshore bottom trawling 50%, one-boat offshore bottom trawling 17%, and small bottom trawling 33%. The proportion of small bottom trawling is increasing (Appendix 10).

Fig. 3-2 shows trends in catch in number at age by year from 1993 to 2023, and Fig. 3-3 shows trends in catch at age and by year. Three peaks can be seen in the fluctuation of catch in number from 1993 to 2023 (Fig. 3-2, Supplementary Table 2-1). In recent years, the catch in number has been in a decreasing trend since 2009, reaching a record low of 2.67 million in 2023. Although age 1 and 2 fish have dominated the catch in most years, their combined share of the total catch in number has been declined from 80% in 2007 to 49% in 2021 and 53% in 2023. The number of young fish caught has remained few, and the proportion of age 3 and age 4 fish in the catch is gradually increasing (Fig. 3-3, Supplementary Table 2-1)

(3) Fishing Effort

The effective fishing effort for two-boat offshore bottom trawling (west of Hamada) peaked at about

80,000 hauls in the late 1970s, then steadily declined to 21,102 hauls in 2010 (Fig. 3-4, Table 3-2). Thereafter, though the number of nets remained stable at approximately 20,000, effort levels have continued to decrease again since 2014, reaching 9,608 hauls in 2023.

4. Stock Status

(1) Stock Assessment Methods

Catch data since 1966 has been collected for one-boat and two-boat offshore bottom trawls operating in the southwestern Sea of Japan, as well as small bottom trawls in Yamaguchi, Shimane, and Tottori prefectures. For two-boat offshore bottom trawls west of Hamada, for which statistical data are available, standardized CPUE calculations were performed from 1993 onwards, when detailed daily and vessel-based fishery data became available (Appendix 9). Using the data from two-boat offshore bottom trawls, overall annual age-specific catch numbers since 1993 were estimated. Based on this data, stock number, stock biomass, and spawning stock biomass (SSB) by year were estimated using Virtual Population Analysis (VPA). A tuning using standardized CPUE for the two-boat offshore bottom trawls in the VPA was not performed because retrospective bias was observed that overestimated stock biomass and SSB and underestimated the fishing coefficient (For details, see Appendix 12).

(2) Trend in Stock Abundance Indices

The standardized CPUE (kg/net) for two-boat offshore bottom trawls increased from 10.3 in 1998 to 29.2 in 2008 (Fig. 4-1, Table 3-2). After 2009, CPUE began declining, reaching 9.8 in 2016. It then showed a slight increase until 2020, but started declining again, hitting a historical low of 6.9 in 2023.

For long-term trends in stock abundance index observed in data from two-boat offshore bottom trawls since 1966 is shown in Fig. 4-2. Stock abundance index exceeded 50,000 in some years during the late 1960s and 1970s. However, they declined in the 1980s and have ranged between 9,000 and 25,000 since 1990 (Fig. 4-2, Table 3-2). Between 2011 and 2015, the stock abundance index remained around 16,000 but started decreasing further after 2016, reaching 5,528 in 2023.

(3) Trend in Stock Biomass and Fishing Pressure

Estimates for biomass at age from VPA analysis are shown in Fig. 4-3 and Supplementary Table 2-1. Stock biomass peaked in 2001 at 5,463 tons, then declined to 3,000 ton range in 2010, 2,000 ton range in 2012, and 1,000 ton range in 2015. It fell below 1,000 tons in 2021, and in 2023, the biomass was estimated to be 819 tons (Table 4-1).

The number of age 1 recruits and their trends, along with the SSB, are shown in Fig. 4-4 and Table 4-1. Recruitment remained above 30 million individuals until 2008 but has been declining since 2009 (2008 year class), reaching an estimated record low of 4.4 million individuals in 2023 (2022 year class). The SSB was relatively stable at around 3,000 tons until 2003 but started declining in 2009

(2,774 tons), dropping below 1,000 tons by 2020, and was estimated at 600 tons in 2023.

To assess the effect of the natural mortality coefficient (M) used in the cohort analysis on biomass estimation, Fig. 4-5 shows the impact of changing M by ± 0.1 from its base value of 0.35 on the estimated stock biomass, SSB, and recruitment for 2023. Increasing or decreasing M by 0.1 from 0.35 resulted in stock biomass and SSB variations of less than 30%, while recruitment exhibited a greater sensitivity, increasing by 33% at $M = 0.45$ compared to $M = 0.35$.

Transition in fishing mortality (F) by age are shown in Fig. 4-6 and Supplementary Table 2-1. The simple average of F across ages has fluctuated between approximately 0.3 and 0.6 over the long term. In recent years, F peaked at 0.59 in 2009, then declined to 0.50 in 2014, increased slightly to 0.53 in 2015, and decreased again to 0.45 in 2023. The current F value was set as the average of F from 2020 to 2022 (0.43).

The exploitation rate decreased from 39% in 2009 to 34% in 2014, temporarily increased to 36% in 2015, and then declined to 29% in 2017. In recent years, the exploitation rate has fluctuated between 31% and 37% (Fig. 4-7 and Table 4-1).

(4) Yield Per Recruit (YPR), Spawning Biomass 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. 4-8 shows the annual trends in %SPR, which represents the ratio of SPR under actual fishing pressure to SPR under no fishing pressure. A higher %SPR indicates lower fishing pressure. The %SPR has generally been on an upward trend, from 17% in 2008 to 28% in 2017, and has since remained in the 20% range, reaching 26% in 2023.

Fig. 4-9 illustrates the relationship between current fishing pressure, yield per recruit (YPR), and %SPR. The selectivity of F was defined based on values used to estimate the fishing mortality achieving MSY (F_{msy}) at the Research Institute Meeting held in October 2021. The same values were used for age-specific average body weight and maturity rate when calculating F_{msy} . When converted to %SPR, F_{msy} corresponds to 31%, which is lower than the current fishing pressure ($F_{2020-2022}$).

(5) Stock-Recruitment Relationship

The relationship between SSB (in weight) and recruitment (in number of individuals) is shown in Fig. 4-10. The Research Institute Meeting mentioned above applied the hockey-stick model to the stock-recruitment relationship for this stock (Yagi et al. 2021b). Data used for parameter estimation of stock-recruitment relationship were the SSB from 1993 to 2018 and recruitment at age 1 in the following years (1994–2019) obtained by the FY 2020 stock assessment (Yagi et al. 2021a). The least squares method was used for optimization, considering autocorrelation in recruitment residuals. Parameter estimates for the stock-recruitment relationship model are provided in Supplementary Table 6-1.

(6) Levels Achieving MSY Under Current Environmental Conditions

The SSB achieving maximum sustainable yield (SBmsy) and the catch to maintain MSY under current environmental conditions were estimated at the Research Institute Meeting held in October 2021 (Yagi et al. 2021b). The estimated values are summarized in Supplementary Table 6-2.

(7) Stock Levels/Trends and Fishing Pressure Levels

Fig. 4-11 shows the Kobe plot based on the spawning stock biomass that achieves MSY and the fishing pressure that maintains SBmsy. A summary of stock levels and fishing pressure is provided in Supplementary Table 6-3. In 2023, the SSB of this stock was 0.15 times the estimated SBmsy, indicating that it remains below SBmsy required to achieve MSY. Additionally, the fishing pressure in 2023 was 1.24 times Fmsy, showing that the fishing pressure exceeded the level maintains SBmsy. The ratio of fishing mortality (F/Fmsy) shown in Kobe plot are calculated by comparing the annual F values to the Fmsy converted from %SPR under current selectivity conditions.

Based on trends observed over the past five years (2019–2023), the trend of SSB is classified as "decreasing".

5. Summary of Stock Assessment

SSB has been declining since 2009 and remains below the level achieving MSY (SBmsy). Although it is on a downward trend in recent years, the fishing pressure on this stock was above the level maintains SBmsy (Fmsy). The stock biomass is judged to be on a downward trend.

6. Other

The proportion of 1-2 ages fish is high in the catch by age (Fig. 3-2), and many small fish with low unit price are caught. In addition, it is possible that small fish smaller than marketable size are being discarded (Ishikawa Prefectural Fisheries Center et al. 1994), so resource management measures aimed at protecting small fish will need to be considered in the future.

For this stock, past stock assessments were performed every year based on tuning VPA, with the standardized CPUE of the two-boat offshore bottom trawls west of Hamada as the stock abundance index. However, it has been pointed out that the stock biomass and spawning stock biomass were overestimated, and the fishing coefficient was underestimated due to retrospective bias, and it has been pointed out that the evaluation may be optimistic and not in accordance with the actual resource status (see detail in Appendix 12). Several issues are being considered to improve retrospective bias. First, we need to reconsider the age-length key for this stock. The age-length key used to calculate the age-specific catch of this stock is based on the measurements in the 1990s. These measurements lack the large individuals measurements. Second, we also need to reconsider the age composition. In VPA, it is ideal to set up a plus group at the age whose fishing coefficient becomes constant, and this stock is

decomposed into four age groups from 1 to 4+ years. However, the lifespan of this species is about 7 years, and the proportion of 3 and 4+ ages in the catch is high, so the fishing coefficient may change even after 4+ years. In addition, it is important to note that the proportion of small bottom trawls in the catch from the stock is increasing (Appendix 10). The assessment of this stock is largely based on information from the two-boat offshore bottom trawls (west of Hamada), and all age-specific catch calculations and standardized CPUE are based on the catch information and biological measurement results of the two-boat offshore bottom trawls (west of Hamada) (Appendix 2). Until the 2010s, the proportion of the two-boat offshore bottom trawls (west of Hamada) in the catch of this stock were high at 70-80%, but since 2021 it has decreased to 50-60%. On the other hand, the proportion of small bottom trawls in Shimane Prefecture has increased to 20-30%, and it is also important to prepare information on the actual fishing situation and operation status, such as the size and age composition of the catch, for small bottom trawls and incorporate it into resource calculations. These issues cannot be addressed by a single year of survey and analysis, and considering the current age decomposition of this stock, it is necessary to collect and accumulate information for multiple years over 5 years or more.

We also tried to improve retrospective bias by applying Ridge VPA (Okamura et al. 2017), but the expected results were not obtained (Appendix 12), and if we followed the conventional evaluation method, we had no choice but to continue with an optimistic evaluation that was thought to be inconsistent with the resource status. Therefore, from this year, we presented the evaluation results based on estimates from a simple VPA without tuning, so as not to rely on optimistic evaluations. The results based on the simple VPA do not match the increase in the fishing coefficient in recent years (Fig. 4-6) with the reality of the decline in fishing operations targeting this stock, and it cannot be denied that this may have resulted in a pessimistic assessment. However, in order to assess this stock, which is suspected to be declining in abundance, it is necessary to continue to improve the evaluation methodology, regardless of whether we are bound by conventional methods.

7. References

- Imai, C. and Miyazaki, Y. (2005) Reexamination of the Growth Model for the Western Japan Sea Group of shotted halibut using Otolith analysis. *Journal of National Fisheries University*, **53**, 21-34.
- Imaoka, Y. (1971) Biological Study II of shotted halibut fisheries from the southwestern Sea of Japan and surrounding waters. Maturation and spawning. *Bull. Seikai Natl. Fish. Res. Inst.*, **39**, 51-63.
- Imaoka, Y. (1972) Biological Study III of shotted halibut fisheries from the southwestern Sea of Japan and surrounding waters. Food habits. *Bull. Seikai Natl. Fish. Res. Inst.*, **42**, 77-89.
- Imaoka, Y. (1977) Biological Study (1972) of shotted halibut fisheries from the southwestern Sea of Japan and surrounding waters. Habitat of shotted halibut juveniles. *Shimane Fisheries*

Experimental Station Journal, FY 1972-1948, 297-299.

Imaoka, Y. and Misu, H. (1969) Biological study 1 of shotted halibut fisheries from the southwestern Sea of Japan and surrounding waters. Age and growth. Bull. Seikai Natl. Fish. Res. Inst., **37**, 51-70.

Ishikawa Prefecture Fisheries Research Center, Fukui Prefectural Fisheries Experiment Station, Hyogo Prefecture Tajima Fisheries Office, Tottori Prefectural Fisheries Experiment Station, and Shimane Prefectural Fisheries Experimental Station (1994) Comprehensive Report of the Project for Promotion of Development of New Technology of Regional Importance Related to Fisheries for Fiscal Years 1991 to 1993 (Research on Ecology and Resource Management of Important Flatfish Species), 118 pp.

Misu, H., Imaoka, Y., Suejima, T., Hanabuchi, N., Kojima, K., and Hanabuchi, Y. (1973) Biological study IV of shotted halibut fisheries from the southwestern Sea of Japan and surrounding waters - IV. Distribution and Migration of Insect Flounder in the Southwestern Sea of Japan and Surrounding Waters. Bull. Seikai Natl. Fish. Res. Inst., **43**, 23-36.

Yagi, Y., Fujiwara, K., Iida, M., Sakuma, K., Yoshikawa, A., and Shirakawa, H. (2021a) Stock Assessment for Southwestern Sea of Japan Stock of Shotted Halibut (Fiscal Year 2020). Japan Fisheries Research and Education Agency, 1-27. FRA-SA2020-RC05-6.

<https://abchan.fra.go.jp/digests2020/details/202065.pdf> (last accessed 13 August 2022)

Yagi, Y., Fujiwara, K., Iida, M., Sakuma, K., Yoshikawa, A., and Shirakawa, H. (2021b) Materials for the Research Institute Meeting on Reference Points of Southwestern Sea of Japan Stock of Shotted Halibut (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-22. FRA-SA2021-BRP12-2.

http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20211026/doc_mushigarei_japanese-a-sw_RIM.pdf (last accessed 13 August 2022)

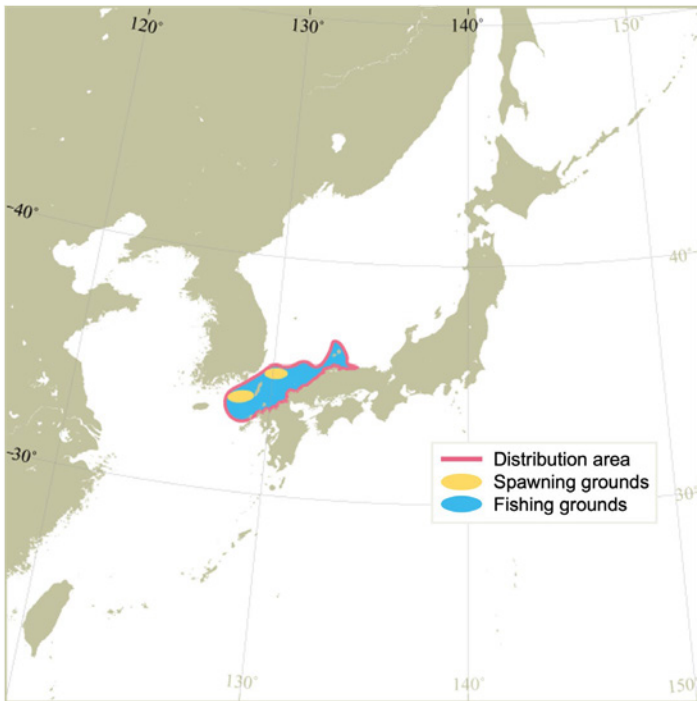


Fig. 2-1. Shotted halibut stock distribution in the southwestern part of the Sea of Japan

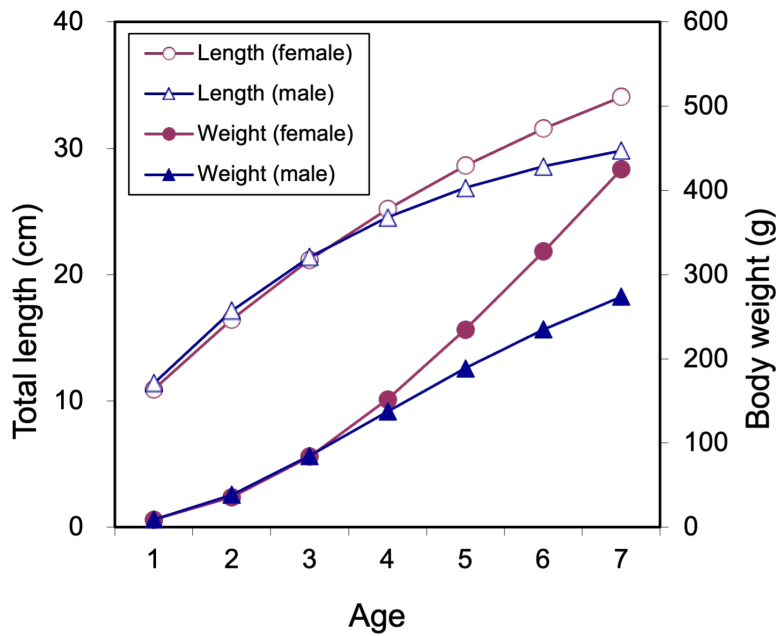


Fig. 2-2. Age and growth

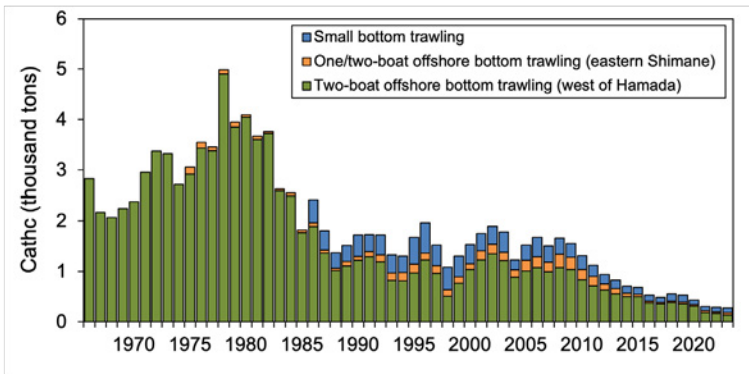


Fig. 3-1. Trend in catch by fishery type (no data for small bottom trawlers prior to 1985)

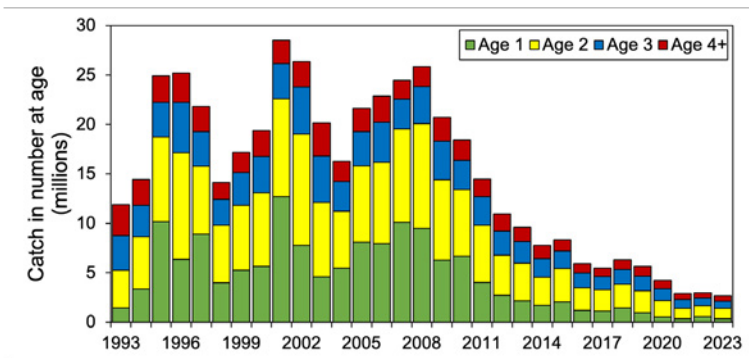


Fig. 3-2. Trend in catch in number at age

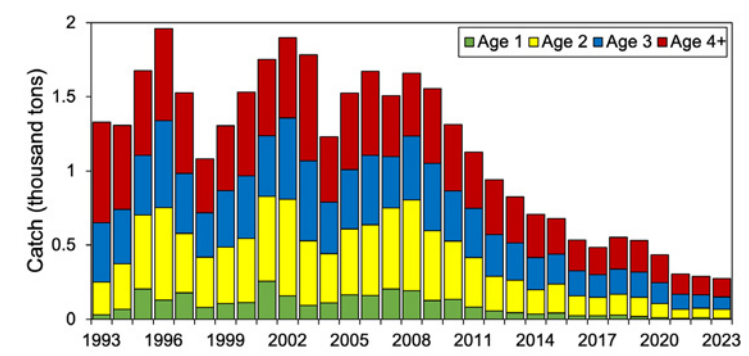


Fig. 3-3. Trend in catch in weight at age

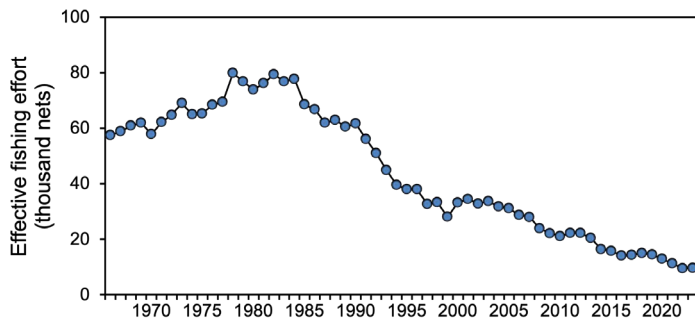


Fig. 3-4. Effective fishing effort (two-boat offshore bottom trawling, west of Hamada)

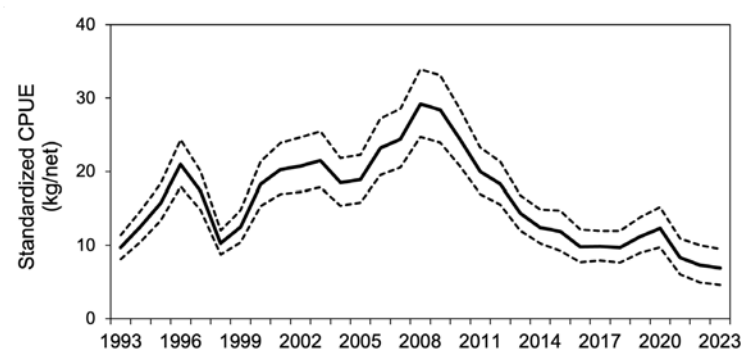


Fig. 4-1. Standardized CPUE (two-boat offshore bottom trawling, west of Hamada)
Dashed lines are 95% confidence intervals.

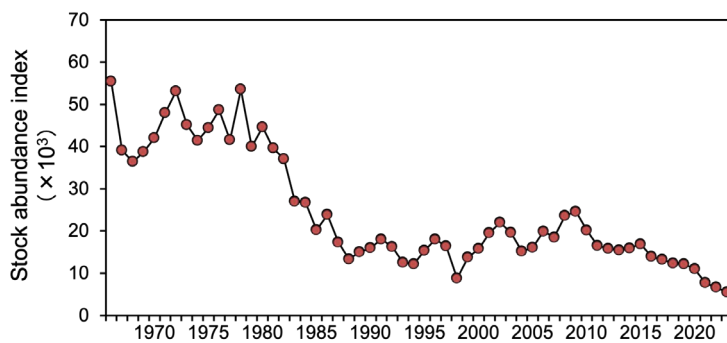


Fig. 4-2. Trend in stock abundance index (two-boat offshore bottom trawling, west of Hamada)

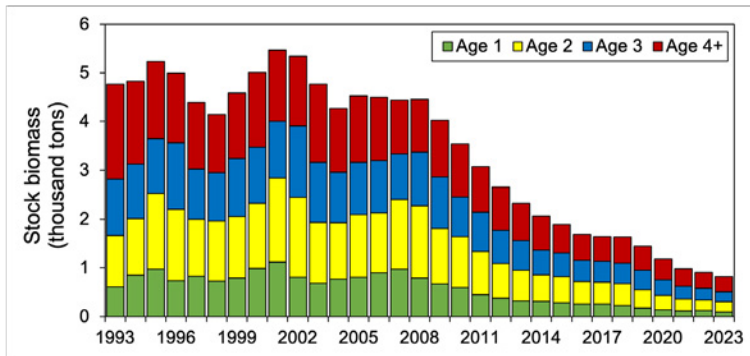


Fig. 4-3. Trend in stock biomass at age

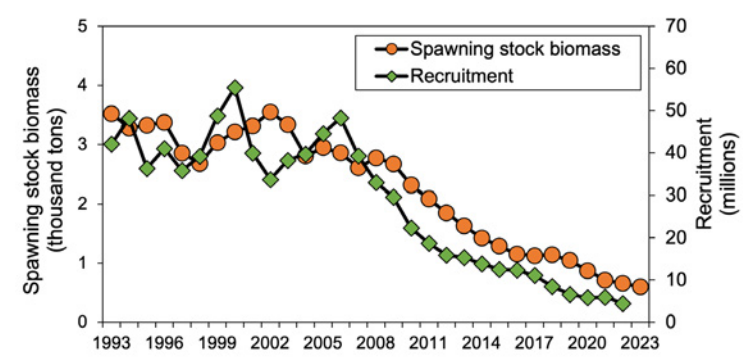


Fig. 4-4. Trends in SSB and recruitment (age 1)

Horizontal axis indicates spawning year.

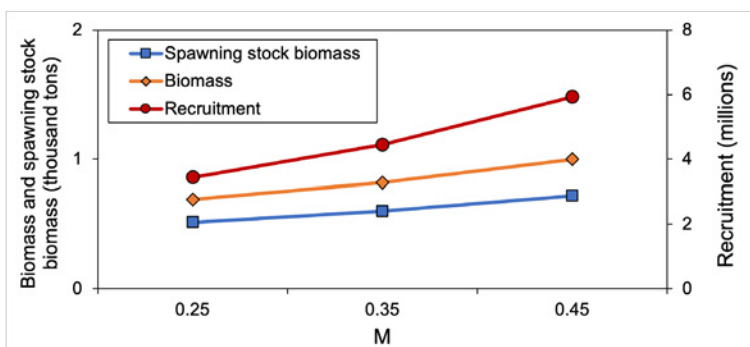


Fig. 4-5. Relationship between natural mortality (M) and biomass, SSB, and recruitment in 2023

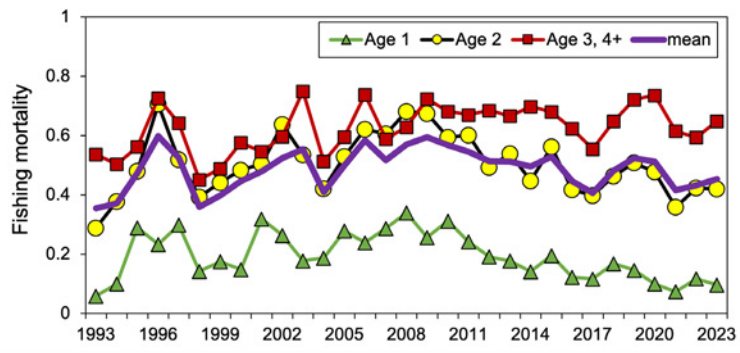


Fig. 4-6. Trends in fishing mortality F at age

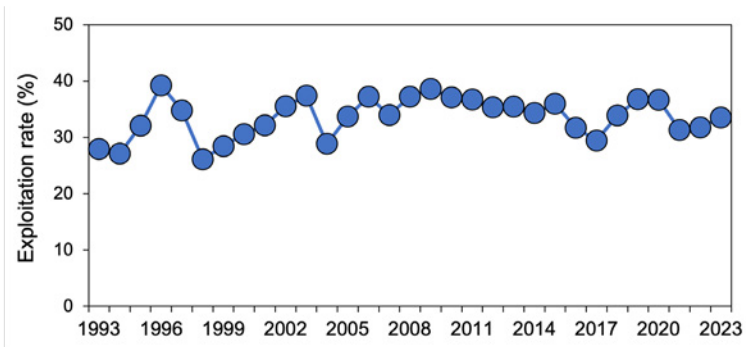


Fig. 4-7. Trend in exploitation rate

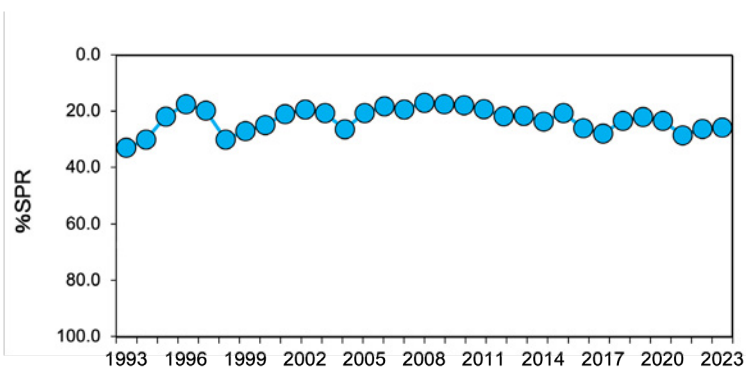


Fig. 4-8. Trend in %SPR

%SPR is the ratio of SSB with fishing and SSB without fishing, when F is high (low) then %SPR is smaller (larger).

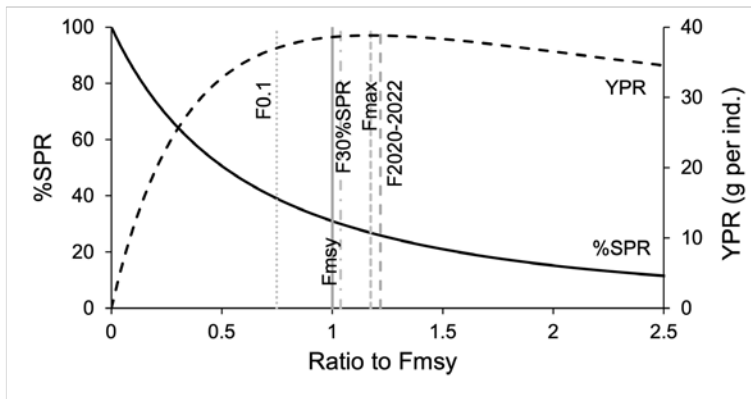


Fig. 4-9. Relationship between Fmsy and YPR, %SPR

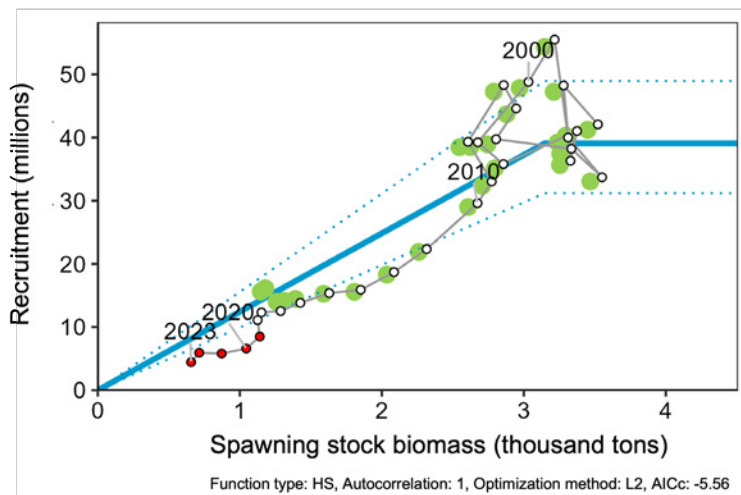


Fig. 4-10. Relationship between SSB and recruitment

For the stock-recruitment relationship, we used a hockey stick (HS) type reproduction relationship that takes into account autocorrelation, and parameter estimation was performed using the least squares method. Green circles indicate the SSB from 1993 to 2018 and recruitment of the following year (from 1994 to 2019) estimated in the analysis at the time of the 2020 stock assessment. The numbers in the figure indicate the year of cohort (birth year). The dotted lines above and below the stock-recruitment relationship (the solid blue line) is the interval estimated to contain 90% of observed data in the assumed stock-recruitment relationship. White circles indicate SSB from 2013 to 2018 and recruitment estimated in the FY 2022 stock assessment, and red circles indicate SSB and recruitment over the past five years (2019-2023).

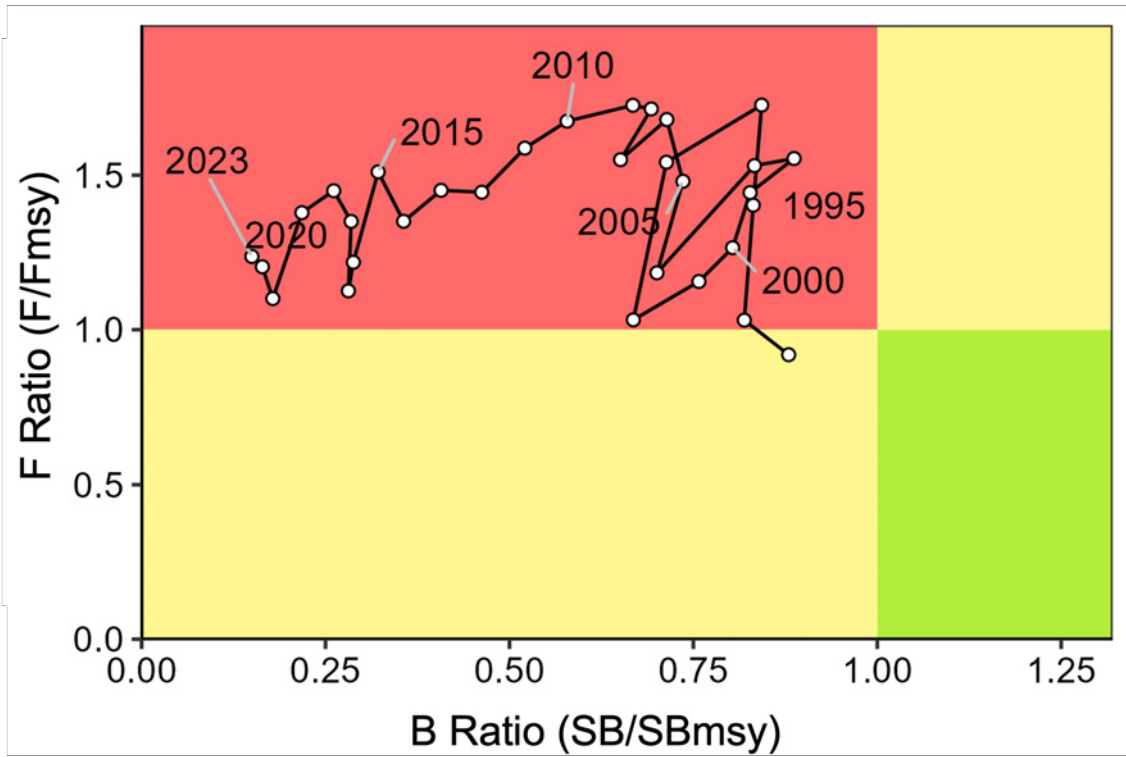


Fig. 4-11. Relationship between SBmsy that achieving maximum sustainable yield (MSY) and fishing pressure (Fmsy) that maintains SBmsy, and past SSB and fishing pressure (Kobe plot)

Table 3-1. Catch (tons) by fishery type for the southwestern Sea of Japan stock of shotted halibut

Year	Two-boat offshore bottom trawling		One-boat offshore bottom trawling	Small bottom trawling	Total
	West of Hamada	Eastern Shimane	Western Sea of Japan		
1966	2,829				2,829
1967	2,169				2,169
1968	2,069				2,069
1969	2,247				2,247
1970	2,384				2,384
1971	2,954				2,954
1972	3,371				3,371
1973	3,322				3,322
1974	2,711				2,711
1975	2,920	137			3,057
1976	3,436	109			3,545
1977	3,384	75			3,460
1978	4,906	86			4,991
1979	3,848	100			3,948
1980	4,048	46			4,094
1981	3,604	64			3,668
1982	3,721	38	2		3,761
1983	2,588	27	11		2,625
1984	2,490	50	6		2,546
1985	1,764	49	4		1,817
1986	1,887	72	2	456	2,417
1987	1,364	61	4	379	1,808
1988	1,017	40	1	314	1,373
1989	1,107	89	1	317	1,514
1990	1,221	68	5	428	1,722
1991	1,292	101	3	331	1,726
1992	1,187	139	2	393	1,722
1993	821	141	6	362	1,330
1994	814	157	5	333	1,308
1995	970	175	2	531	1,678
1996	1,225	140	2	593	1,960
1997	960	126	31	408	1,526
1998	507	115	17	444	1,083
1999	763	110	22	411	1,305
2000	1,037	107	10	377	1,531
2001	1,228	161	18	347	1,754
2002	1,346	179	12	362	1,899
2003	1,210	151	16	406	1,783
2004	887	110	37	197	1,231
2005	1,007	199	15	303	1,524
2006	1,076	191	22	385	1,674
2007	990	164	29	326	1,509
2008	1,074	243	24	318	1,659
2009	1,037	236	11	270	1,554
2010	833	172	32	276	1,313
2011	710	174	22	220	1,126
2012	630	96	28	187	940
2013	551	68	37	169	826
2014	502	23	40	143	708
2015	502	8	34	137	681
2016	369	3	34	128	534
2017	356	2	30	97	485
2018	377	2	32	142	553
2019	357	1	38	137	532
2020	313	1	27	93	435
2021	179	0	41	86	306
2022	170	0	30	89	289
2023*	137	0	47	91	275

*Provisional values

Table 3-2. Catch trends for shotted halibut by two-boat offshore bottom trawlers (west of Hamada)

Year	Catch (tons)	Effective fishing effort *1	Number of fishing areas with non-zero catches *1	Stock abundance index *1	Standardized CPUE *2
1966	2,829	57,426	1,125	55,430	
1967	2,169	58,805	1,059	39,069	
1968	2,069	60,832	1,070	36,385	
1969	2,247	61,894	1,066	38,703	
1970	2,384	57,777	1,018	42,010	
1971	2,954	62,139	1,008	47,926	
1972	3,371	64,747	1,020	53,104	
1973	3,322	69,069	939	45,160	
1974	2,711	64,965	993	41,436	
1975	2,920	65,281	992	44,372	
1976	3,436	68,379	968	48,643	
1977	3,384	69,365	852	41,571	
1978	4,906	79,841	872	53,580	
1979	3,848	76,802	798	39,979	
1980	4,048	73,844	814	44,621	
1981	3,604	76,131	837	39,622	
1982	3,721	79,403	791	37,071	
1983	2,588	76,750	802	27,040	
1984	2,490	77,753	835	26,745	
1985	1,764	68,513	786	20,236	
1986	1,887	66,718	844	23,867	
1987	1,364	61,896	787	17,348	
1988	1,017	62,958	827	13,360	
1989	1,107	60,453	819	14,997	
1990	1,221	61,599	806	15,973	
1991	1,292	56,045	784	18,069	
1992	1,187	50,931	696	16,227	
1993	821	44,873	682	12,480	9.7
1994	814	39,444	589	12,151	12.6
1995	970	37,970	600	15,322	15.8
1996	1,225	37,928	558	18,019	21.0
1997	960	32,672	558	16,402	17.3
1998	507	33,267	577	8,793	10.3
1999	763	27,996	504	13,728	12.5
2000	1,037	33,189	506	15,806	18.3
2001	1,228	34,420	547	19,510	20.2
2002	1,346	32,815	536	21,985	20.7
2003	1,210	33,635	546	19,640	21.5
2004	887	31,692	543	15,194	18.5
2005	1,007	31,130	498	16,114	18.9
2006	1,076	28,621	530	19,926	23.2
2007	990	27,949	522	18,494	24.4
2008	1,074	23,852	524	23,593	29.2
2009	1,037	22,102	525	24,633	28.4
2010	833	21,102	511	20,182	24.4
2011	710	22,173	515	16,488	20.0
2012	630	22,204	559	15,849	18.3
2013	551	20,393	573	15,490	14.4
2014	502	16,373	519	15,921	12.4
2015	502	15,747	530	16,892	11.9
2016	369	14,021	528	13,904	9.8
2017	356	14,316	530	13,186	9.8
2018	377	14,968	490	12,325	9.7
2019	357	14,400	492	12,202	11.2
2020	313	12,878	492	10,988	12.3
2021	179	11,191	379	7,707	8.3
2022	170	9,466	370	6,632	7.3
2023 ^{*3}	137	9,608	387	5,528	6.9

* 1 See detail in appendix 8

* 2 See detail in appendix 9

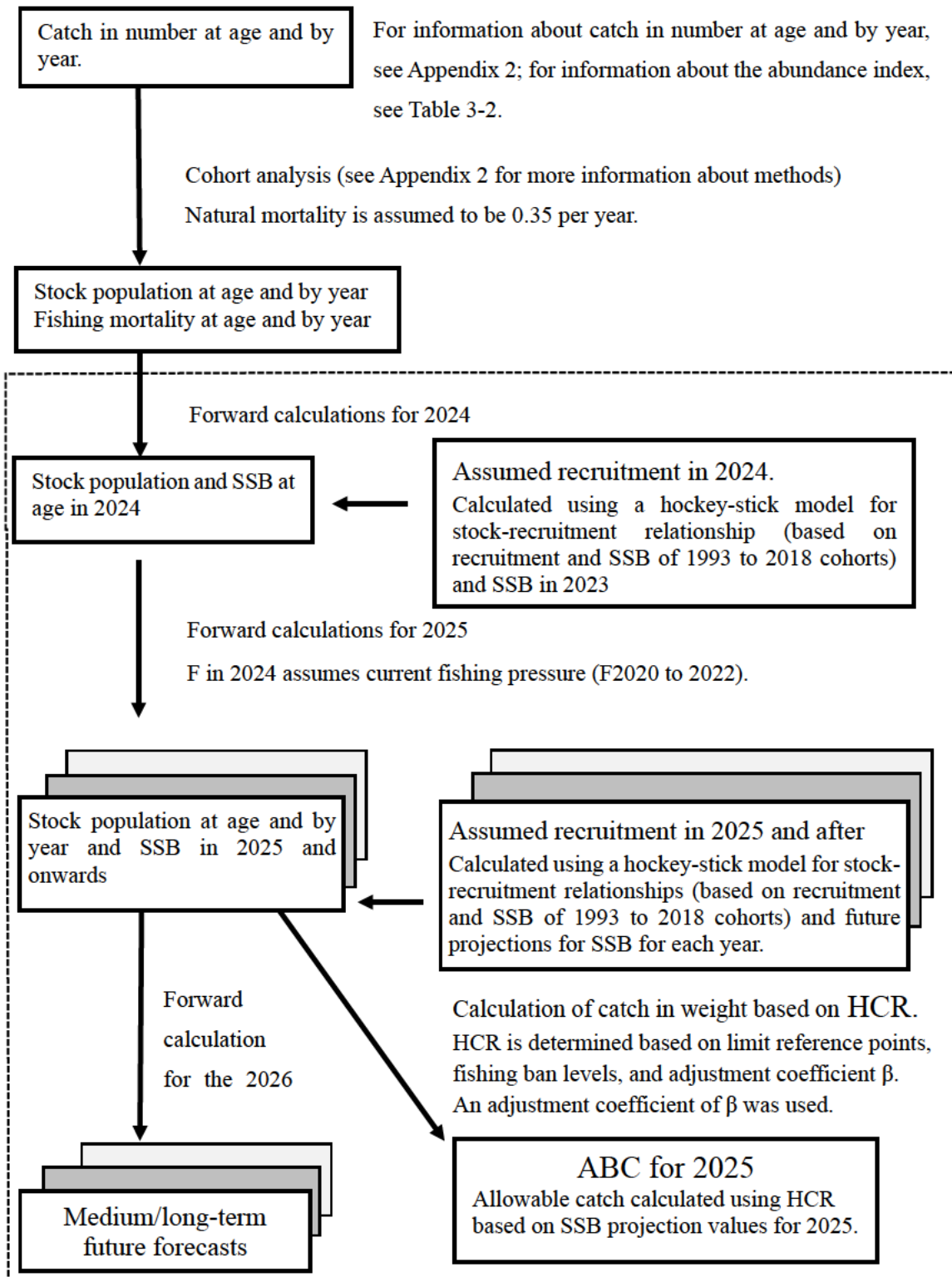
* 3 Provisional values

Table 4-1. Results of stock assessment of the southwestern Sea of Japan stock of shotted halibut

Year	Catch (tons)	Biomass (tons)	Spawning stock biomass (tons)	Recruitment in number (thousands)	Exploitation rate (%)	%SPR	F/Fmsy
1993	1,330	4,763	3,521	42,079	27	33	0.92
1994	1,308	4,827	3,279	48,237	27	30	1.03
1995	1,678	5,235	3,328	36,312	32	21	1.40
1996	1,960	4,992	3,374	41,027	39	17	1.73
1997	1,526	4,388	2,856	35,790	34	19	1.54
1998	1,083	4,144	2,676	39,237	26	30	1.03
1999	1,305	4,585	3,032	48,810	28	27	1.16
2000	1,531	5,009	3,216	55,502	30	24	1.27
2001	1,754	5,463	3,311	39,992	32	21	1.44
2002	1,899	5,346	3,550	33,713	35	19	1.55
2003	1,783	4,768	3,334	38,214	37	20	1.53
2004	1,231	4,267	2,804	39,732	28	26	1.18
2005	1,524	4,524	2,946	44,607	33	20	1.48
2006	1,674	4,495	2,858	48,307	37	18	1.68
2007	1,509	4,442	2,606	39,319	33	19	1.55
2008	1,659	4,455	2,773	33,033	37	17	1.71
2009	1,554	4,026	2,673	29,600	38	17	1.73
2010	1,313	3,539	2,315	22,342	37	17	1.67
2011	1,126	3,067	2,085	18,696	36	19	1.59
2012	940	2,658	1,851	15,900	35	21	1.44
2013	826	2,328	1,629	15,365	35	21	1.45
2014	708	2,062	1,425	13,829	34	23	1.35
2015	681	1,893	1,287	12,528	35	20	1.51
2016	534	1,684	1,152	12,320	31	26	1.22
2017	485	1,645	1,125	11,094	29	27	1.13
2018	553	1,633	1,140	8,496	33	23	1.35
2019	532	1,446	1,045	6,596	36	22	1.45
2020	435	1,185	872	5,802	36	23	1.38
2021	306	977	714	5,925	31	28	1.10
2022	289	908	656	4,445	31	26	1.20
2023	275	819	600	—	34	26	1.24

Recruitment: Number of individuals which emerge in the target year at age 1

Appendix 1 Stock Assessment Flow



※ Information inside the dotted line box is based on discussion of reference points, HCR, etc., by the Stock Management Policy Commission.

Appendix 2 Calculation Methods

(1) Catch at age

Based on the number of shotted halibut by age landed at Hamada Fishing Port, Shimane prefecture, by two-boat offshore bottom trawlers from 1993 to 2021, we determined the catch by age for the entire stock under assessment.

1. Total Length Composition for Hamada Fishing Port

Landings of two-boat offshore bottom trawls at Hamada fishing port in Shimane prefecture include categories such as number-per-box (size-dependent), weight-per-box, and others. For the number-per-box category, a total length composition (number in one box) conversion table including males and females was produced based on market survey data from March 2002 to December 2023. For weight-per-box category, a total length composition (number in one box) conversion table including males and females was produced based on market survey data for periods from March 2002 to May 2016 and September 2016 to December 2023, respectively. The total length composition (catch in number) of shotted halibut landed at Hamada fishing port in Shimane prefecture by two-boat offshore trawls in each month from 1993 to 2023 was calculated.

2. Age analysis

Based on the results of age assessments (held by the Yamaguchi Prefectural Fisheries Research Center, Shimane Prefectural Fisheries Experiment Station (Current Shimane Prefectural Fisheries Technology Center), and Seikai National Fisheries Research Institute (Current Fisheries Research and Education Agency, Nagasaki Office)), of otolith specimens from 1,708 shotted halibut collected in experimental operations and market purchases in the southwestern Sea of Japan between 1989 and 2003, the following age-length correlation tables for March to May, June to August, September to November, and December to February of the following year (Ueda 2006) were used to determine the catch in number at age for each month of shotted halibut landed at Hamada fishing port by two-boat offshore bottom trawls in number-per-box and weight-per-box categories. In the age-length correlation table used, the age starting date was March 1st, so each age group in January and February was treated as a +1 age group.

3. Extending to the Whole

The catch in number at age for shotted halibut caught in each month in number-per-box and weight-per-box categories was expanded to the catch in number at age for each month of the Hamada fishing port two-boat offshore bottom trawls. Next, the catch in number at age for each month were added up for the March to May, June to August, September to November, December, and January to February periods, and the total catch in number for each period was used to expand to the total catch in number

by age for this entire stock. The sum of these was used for cohort analysis as the catch in number at age in each year (calendar year).

(2) Stock calculation method (cohort analysis)

As age 0 fish are not caught, the oldest group of catch targets age 1 and older was defined as age 4 and older (hereafter denoted as 4+). Body weights and maturity ratios for each age group used are shown in the table below. Body weights for age 4+ from 1993 to 2023 were averages weighted by the proportion of age 4 and 5 and older in each year. The natural mortality coefficient, M , was obtained using the Tauchi/Tanaka formula (Tanaka 1960), assuming lifespan to be 7 years ($M = 2.5 \div 7$ years ≈ 0.35).

Age	1	2	3	4	5+
Weight (g)	20	58	115	188	331
Maturity Ratio (%)	0	40	100	100	100

Pope's equation was used to estimate the stock number at age, and fishing mortality F was assumed to be equal for each year for maximum age 4+ and age 3.

The numbers of 1- and 2-year-old were calculated using the following formula (1).

$$N_{a,y} = N_{a+1,y+1} \exp(M) + C_{a,y} \exp\left(\frac{M}{2}\right) \quad (\text{Stock population at age 1 to age 2}) \quad (1)$$

In this equation, N is stock number, C is the catch in number, a is age, and y is year. For age 3 fish were calculated using equation (2) and 4+ using equation (3).

$$N_{3,y} = \frac{C_{3,y}}{C_{4+,y} + C_{3,y}} N_{4+,y+1} \exp(M) + C_{3,y} \exp\left(\frac{M}{2}\right) \quad (\text{Stock population at age 3}) \quad (2)$$

$$N_{4+,y} = \frac{C_{4+,y}}{C_{3,y}} N_{3,y} = \frac{C_{4+,y}}{C_{4+,y} + C_{3,y}} N_{4+,y+1} \exp(M) + C_{4+,y} \exp\left(\frac{M}{2}\right) \quad (\text{Stock population aged 4+}) \quad (3)$$

For the most recent year, stock population for all ages and fishing mortality were calculated using formula (4) and (5), respectively.

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

$$F_{a,y} = \frac{1}{3} \sum_{y=2020}^{2022} F_{a,y} \quad (5)$$

Finally, $F_{4+,y}$ was exploratory-determined so that $F_{4+,y}=F_{3,y}$, and the number of fish by age was estimated.

(3) Model Diagnosis Results

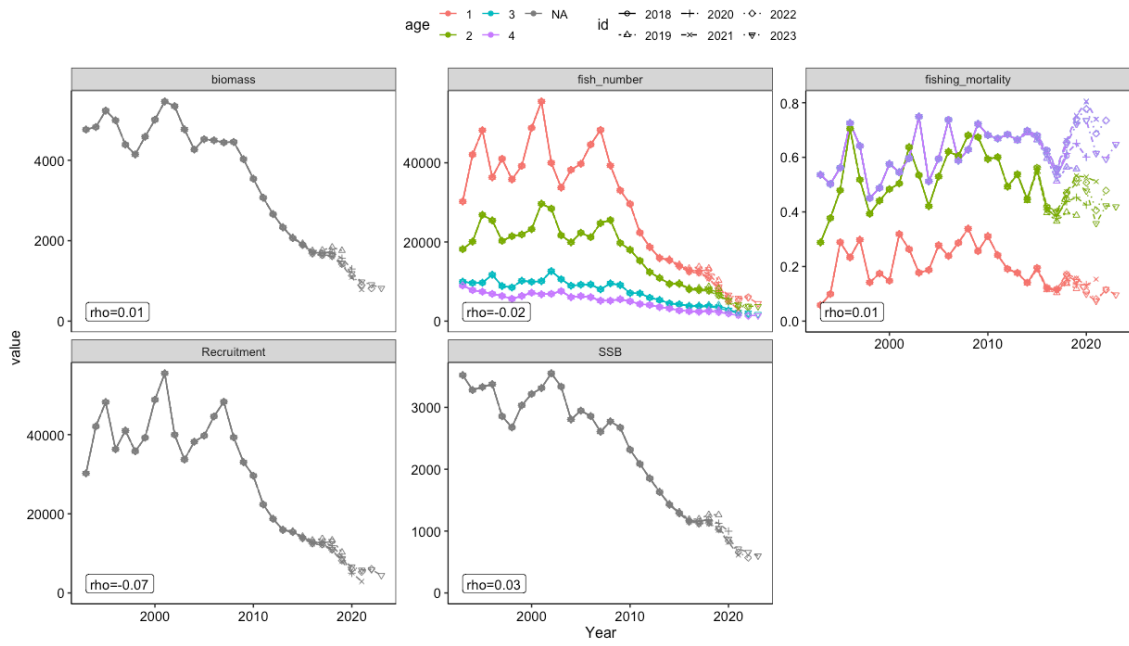
The robustness of the statistical validity of the VPA and assumptions used for this stock assessment were diagnosed according to the Stock Assessment Model Diagnostic Procedures and Data Provision Guidelines (FY 2024) (FRA-SA2024-ABCWG02-03).

In the retrospective analysis, no significant changes were found in the stock biomass, number of stock, number of 1-year-old fish (recruitment), and SSB due to the addition and updating of data, but there were slight changes in the fishing mortality (Supplementary Fig. 2-1).

The relationship between indices and projected values was negative residuals until 2014, except in 2009, and positive residuals in 2015 and 2016, but no constant bias was observed thereafter (Supplementary Figs. 2-1 and 2-2). The relationship between the indices and projected values was considered acceptable when assumed to be linear (Supplementary Fig. 2-3). In the retrospective analysis, the addition and updating of data has not caused significant changes in recruitment (age 1 stock population), but a tendency to slightly overestimate biomass and SSB was observed (Supplementary Fig. 2-4), and further investigation is needed to improve the methods for calculating stock population by age and CPUE standardization.

References

- Fisheries Research and Education Agency (2024) Stock Assessment Model Diagnostic Procedures and Data Provision Guidelines (FY 2024) (FRA-SA2024-ABCWG02-03).
- Tanaka, S (1960) Population Dynamics of fishery organisms and fishery resource management. Bull. Tokai Reg. Fish. Re. Lab., **28**, 1-200.
- Ueta, Y. (2006) Stock Assessment for Sea of Japan Stock of Shotted Halibut (Fiscal Year 2005). Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2005), Vol 3, Fisheries Research Agency, Fisheries Agency, 1232-1249.
- 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.



Supplementary Fig. 2-1. Results of retrospective analysis of stock biomass (biomass), stock number (fish number), fishing mortality (fishing mortality), 1-year-old fish stock number (Recruitment), and SSB (SSB)

Supplementary Table 2-1. Stock analysis results (1993 to 2003)

Catch at age (thousand)											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	1,446	3,341	10,169	6,339	8,882	3,974	5,272	5,632	12,723	7,773	4,596
Age 2	3,825	5,300	8,583	10,811	6,881	5,853	6,555	7,474	9,864	11,250	7,528
Age 3	3,476	3,188	3,501	5,074	3,523	2,590	3,309	3,646	3,561	4,762	4,689
Age 4+	3,137	2,596	2,682	2,983	2,522	1,718	2,060	2,633	2,388	2,597	3,353
Total	11,884	14,424	24,935	25,208	21,808	14,135	17,195	19,384	28,536	26,382	20,165
Catch (tons)											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	29	67	205	128	179	80	106	114	257	157	93
Age 2	221	307	497	626	398	339	380	433	571	651	436
Age 3	400	367	403	585	406	298	381	420	410	549	540
Age 4+	679	566	573	622	543	365	438	564	516	542	714
Total	1,331	1,308	1,679	1,960	1,527	1,083	1,305	1,531	1,754	1,899	1,783
Fishing mortality											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	0.06	0.10	0.29	0.23	0.30	0.14	0.17	0.15	0.32	0.26	0.18
Age 2	0.29	0.38	0.48	0.71	0.52	0.39	0.44	0.48	0.50	0.64	0.53
Age 3	0.54	0.50	0.56	0.73	0.64	0.45	0.49	0.58	0.55	0.60	0.75
Age 4+	0.54	0.50	0.56	0.73	0.64	0.45	0.49	0.58	0.55	0.60	0.75
Mean	0.35	0.37	0.47	0.60	0.52	0.36	0.40	0.45	0.48	0.52	0.55
Stock biomass in number (thousand)											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	30,224	42,080	48,237	36,313	41,028	35,791	39,238	48,811	55,502	39,992	33,713
Age 2	18,196	20,085	26,848	25,456	20,267	21,456	21,885	23,225	29,668	28,431	21,657
Age 3	9,980	9,612	9,705	11,715	8,863	8,506	10,206	9,919	10,093	12,627	10,591
Age 4+	9,005	7,827	7,434	6,887	6,344	5,642	6,353	7,163	6,767	6,887	7,574
Total	67,405	79,603	92,224	80,370	76,503	71,394	77,683	89,118	102,031	87,938	73,535
Stock biomass (tons)											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	611	850	974	734	829	723	793	986	1,121	808	681
Age 2	1,054	1,163	1,555	1,474	1,173	1,242	1,267	1,345	1,718	1,646	1,254
Age 3	1,150	1,107	1,118	1,350	1,021	980	1,176	1,143	1,163	1,455	1,220
Age 4+	1,950	1,707	1,589	1,435	1,366	1,199	1,350	1,536	1,462	1,438	1,613
Total	4,764	4,827	5,236	4,992	4,389	4,144	4,586	5,009	5,463	5,346	4,768
Spawning stock biomass (tons)											
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 1	0	0	0	0	0	0	0	0	0	0	0
Age 2	421	465	622	590	469	497	507	538	687	658	502
Age 3	1,150	1,107	1,118	1,350	1,021	980	1,176	1,143	1,163	1,455	1,220
Age 4+	1,950	1,707	1,589	1,435	1,366	1,199	1,350	1,536	1,462	1,438	1,613
Total	3,521	3,280	3,328	3,374	2,856	2,676	3,033	3,216	3,312	3,551	3,335

Supplementary Table 2-1. (Continued) Stock analysis results (2004 to 2013)

Catch at age (thousand)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	5,477	8,095	7,945	10,108	9,494	6,268	6,654	4,029	2,732	2,167
Age 2	5,739	7,708	8,235	9,438	10,597	8,126	6,771	5,793	4,039	3,805
Age 3	3,008	3,466	4,058	2,996	3,731	3,937	2,939	2,872	2,454	2,170
Age 4+	2,036	2,383	2,644	1,925	2,021	2,387	2,076	1,766	1,700	1,448
Total	16,259	21,652	22,882	24,466	25,842	20,717	18,441	14,459	10,926	9,589
Catch (tons)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	111	164	160	204	192	127	134	81	55	44
Age 2	332	446	477	546	614	470	392	335	234	220
Age 3	347	399	467	345	430	454	339	331	283	250
Age 4+	442	515	569	413	424	504	449	378	368	312
Total	1,231	1,524	1,674	1,509	1,659	1,555	1,314	1,126	940	826
Fishing mortality										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	0.19	0.28	0.24	0.29	0.34	0.26	0.31	0.24	0.19	0.18
Age 2	0.42	0.53	0.62	0.61	0.68	0.67	0.59	0.60	0.49	0.54
Age 3	0.51	0.60	0.74	0.59	0.63	0.72	0.68	0.67	0.68	0.67
Age 4+	0.51	0.60	0.74	0.59	0.63	0.72	0.68	0.67	0.68	0.67
Mean	0.41	0.50	0.58	0.52	0.57	0.59	0.57	0.55	0.51	0.51
Stock biomass in number (thousand)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	38,215	39,732	44,608	48,307	39,319	33,034	29,600	22,342	18,696	15,900
Age 2	19,899	22,332	21,204	24,765	25,557	19,739	18,017	15,273	12,362	10,882
Age 3	8,942	9,205	9,266	8,029	9,529	9,114	7,088	7,012	5,900	5,321
Age 4+	6,050	6,331	6,038	5,159	5,163	5,525	5,007	4,313	4,087	3,550
Total	73,106	77,600	81,116	86,260	79,568	67,411	59,712	48,941	41,046	35,653
Stock biomass (tons)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	772	803	901	976	794	667	598	451	378	321
Age 2	1,152	1,293	1,228	1,434	1,480	1,143	1,043	884	716	630
Age 3	1,030	1,060	1,067	925	1,098	1,050	817	808	680	613
Age 4+	1,313	1,369	1,300	1,108	1,084	1,166	1,082	924	885	765
Total	4,268	4,525	4,496	4,443	4,456	4,027	3,539	3,067	2,658	2,329
Spawning stock biomass (tons)										
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Age 1	0	0	0	0	0	0	0	0	0	0
Age 2	461	517	491	574	592	457	417	354	286	252
Age 3	1,030	1,060	1,067	925	1,098	1,050	817	808	680	613
Age 4+	1,313	1,369	1,300	1,108	1,084	1,166	1,082	924	885	765
Total	2,804	2,946	2,858	2,606	2,774	2,674	2,316	2,086	1,851	1,630

Supplementary Table 2-1. (Continued) Stock analysis results (2014 to 2023)

Catch at age (thousand)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	1,699	2,059	1,211	1,136	1,440	966	524	345	549	344
Age 2	2,841	3,391	2,294	2,152	2,407	2,208	1,648	1,063	1,100	1,068
Age 3	1,886	1,750	1,471	1,329	1,480	1,478	1,225	873	779	702
Age 4+	1,355	1,116	963	844	987	980	853	619	554	553
Total	7,782	8,316	5,939	5,462	6,313	5,632	4,250	2,901	2,982	2,667

Catch (tons)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	34	42	24	23	29	20	11	7	11	7
Age 2	164	196	133	125	139	128	95	62	64	62
Age 3	217	202	169	153	170	170	141	101	90	81
Age 4+	292	241	207	184	214	215	188	137	124	125
Total	708	681	534	485	553	532	435	306	289	275

Fishing mortality										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	0.14	0.20	0.12	0.12	0.17	0.15	0.10	0.07	0.12	0.10
Age 2	0.45	0.56	0.42	0.40	0.46	0.51	0.48	0.36	0.42	0.42
Age 3	0.70	0.68	0.62	0.55	0.65	0.72	0.74	0.61	0.59	0.65
Age 4+	0.70	0.68	0.62	0.55	0.65	0.72	0.74	0.61	0.59	0.65
Mean	0.50	0.53	0.45	0.41	0.48	0.52	0.51	0.42	0.43	0.45

Stock biomass in number (thousand)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	15,365	13,829	12,528	12,321	11,094	8,496	6,597	5,802	5,926	4,446
Age 2	9,386	9,402	8,017	7,812	7,729	6,610	5,176	4,209	3,799	3,715
Age 3	4,475	4,229	3,779	3,724	3,698	3,426	2,804	2,264	2,074	1,754
Age 4+	3,215	2,697	2,474	2,363	2,465	2,273	1,952	1,607	1,475	1,381
Total	32,440	30,157	26,798	26,220	24,986	20,805	16,530	13,882	13,273	11,296

Stock biomass (tons)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	310	279	253	249	224	172	133	117	120	90
Age 2	543	544	464	452	447	383	300	244	220	215
Age 3	515	487	435	429	426	395	323	261	239	202
Age 4+	693	582	531	515	535	498	429	356	330	312
Total	2,062	1,893	1,684	1,645	1,633	1,447	1,185	978	909	819

Spawning stock biomass (tons)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Age 1	0	0	0	0	0	0	0	0	0	0
Age 2	217	218	186	181	179	153	120	97	88	86
Age 3	515	487	435	429	426	395	323	261	239	202
Age 4+	693	582	531	515	535	498	429	356	330	312
Total	1,426	1,287	1,152	1,125	1,140	1,045	872	714	657	600

Appendix 3 Proposed Reference Points and Proposed Fishing Ban Level

The Research Institute Meeting held in October 2021 proposed adoption of the following: SSB achieving MSY (SB_{msy}: 4,000 tons) as a target reference point (SB_{target}), SSB required for 60% MSY (SB_{0.6msy}: 1,900 tons) as a limit reference point (SB_{limit}), and SSB required for 10% MSY (SB_{0.1msy}: 300 tons) as a fishing ban level (SB_{ban}) (Yagi et al. 2021, Supplementary Table 6-2).

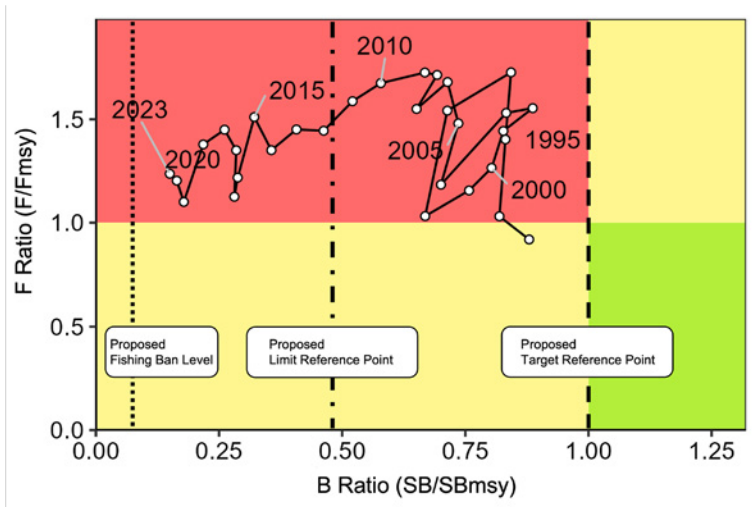
Kobe plot based on proposed target reference point and fishing pressure (F) to maintain MSY are shown in Supplementary Fig. 3-1. The SSB for 2023 (SB₂₀₂₃: 600 tons) obtained from the cohort analysis is below the proposed target reference point and the proposed limit reference point. Fishing pressure in 2023 is over the fishing pressure to maintain MSY (Supplementary Fig. 3-1, Supplementary Table 6-3).

The relationship of average SSB 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 1 to age 3, when SSB was below the SB_{limit}, the proportion of older fish tended to increase as the SSB increased, suggesting that the catch would be dominated by age 3 and older at the point the SB_{msy} is achieved.

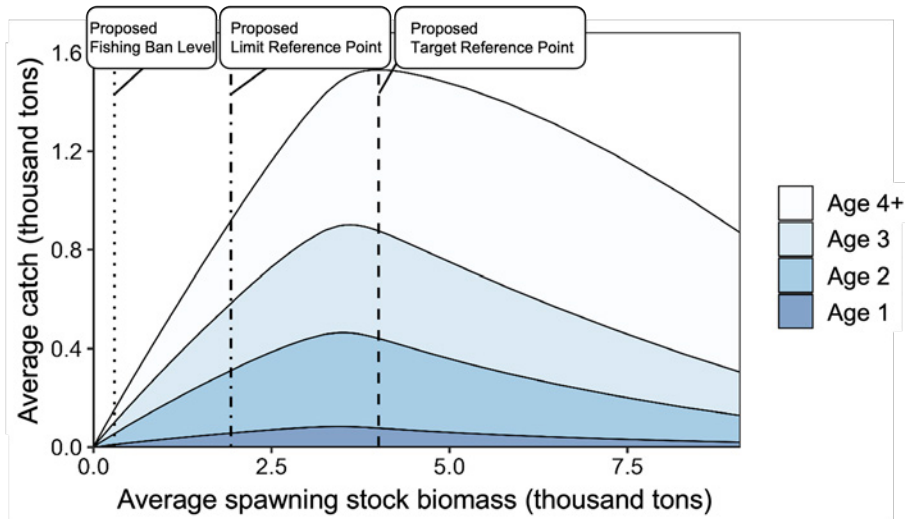
References

Yagi, Y., Fujiwara, K., Iida, M., Sakuma, K., Yoshikawa, A., and Shirakawa, H. (2021) Materials for the Research Institute Meeting on Reference Points of Southwestern Sea of Japan Stock of Shotted Halibut (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-22. FRA-SA2021-BRP12-2.

http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20211026/doc_mushigarei_japanese-a-sw_RIM.pdf (last accessed 13 August 2022)



Supplementary Fig. 3-1. Relationship between proposed reference points, and SSB and 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 HCR

(1) Setting Future Projections

Future projection calculations were performed for 2024 to 2055 using a progression method for cohort analysis applied to estimates for stock abundance in 2023 (Appendix 5). Recruitment in future projections were predicted based on values for SSB 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. The catch in 2024 was assumed according to the projected stock biomass and current fishing pressure (F2021 to 2023), and the biological parameters (e.g. average weight) were set according to the same conditions used for calculation of the proposed reference points. Fishing pressure in 2025 and onwards was set as the fishing pressure established in the following proposed HCR, which are based on SSB projections for each year.

(2) Proposed HCR

Proposed HCR guidelines which aim for better results than proposed target reference point 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 HCR and Basic Guidelines for 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 F_{msy} multiplied by adjustment coefficient β when SSB is above the limit reference point. Supplementary Fig. 4-1 shows the HCR from the Research Institute Meeting for this stock. This figure includes an example showing when the adjustment coefficient β is set to 0.8. In the proposal of the Research Institution Meeting, it is stated that “Although the risk of SSB falling below the limit reference point is low, β should be kept below the standard value of 0.8 because the stock has been subject to stock assessment for a short period of time and there are concerns about uncertainty in the stock-recruitment relationship and other aspects of the stock.

(3) Projected Values for 2025

The average catch in 2025, as calculated based on proposed HCR, will be 17 tons if β is set to 0.8, and 21 tons if β is set to 1.0 (Supplementary Table 6-4). Projected SSB in 2025, below the limit reference point in all repeated calculations, and is projected to be an average of 460 tons (Supplementary Table 4-2a). Because SSB is below the limit reference point, the catch pressure in 2025 was determined as $\gamma(SB_t) \times \beta F_{msy}$, multiplied by a coefficient corresponding to the SSB. In this step, $\gamma(SB_t)$ in 2025 was calculated to be 0.10 based on HCR for Stock Group 1 in the Basic Guidelines for Harvest Control Rules and Basic Guidelines for ABC Calculation using the following equation.

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

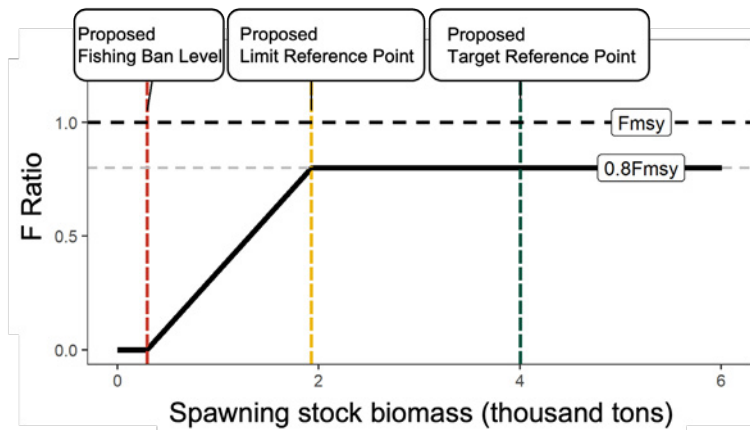
(4) Projections for 2026 and Onwards

Results of future projections, including 2026 and onwards, are shown in Supplementary Fig. 4-2 and Supplementary Tables 4-1, 4-2.

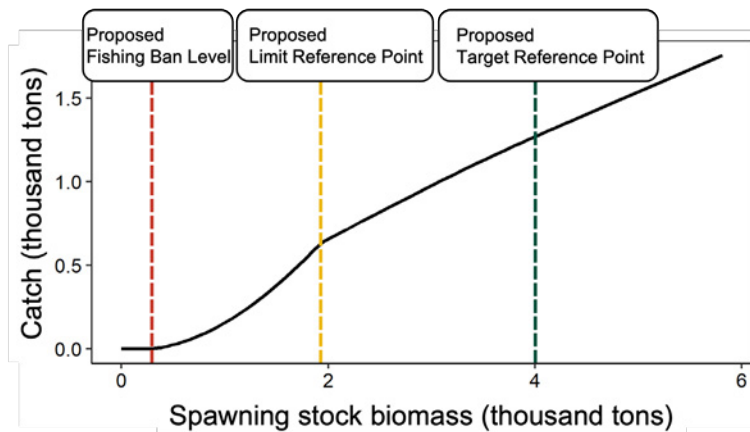
If management based on these proposed HCR is continued for 10 years, then projected values for average SSB in 2035 will be 2,600 tons if β is set to 0.8 (90% prediction interval: 1,800 to 3,600 tons), and 2,100 tons if β is set to 1.0 (90% prediction interval: 1,600 to 2,800 tons) (Supplementary Table 6-5). If β is 0.4 or lower, then there is a 50% or higher probability that the projected value will exceed the proposed target reference point. The probability of exceeding the proposed limit reference point exceeds 50% for any β . If the current fishing pressure (F2021 to 2023) is continued, then projected values for SSB in 2035 will be 500 tons (90% prediction interval of 200 to 800 tons), with a 0% probability that the value will exceed both proposed target and limit reference points.

If management under the proposed HCR continues, the year in which SSB would have a greater than 50% probability of exceeding the proposed target reference point is projected to be after 2045 and onwards if β is set at 0.8 (Supplementary Table 6-5). The year with a greater than 50% probability of exceeding the limit reference point was projected to be 2033. Even if catch pressure were reduced to zero ($\beta = 0$), it was projected that SSB would not exceed the proposed target reference points more than 50% of the time until 2033.

a) When the vertical axis is the fishing pressure

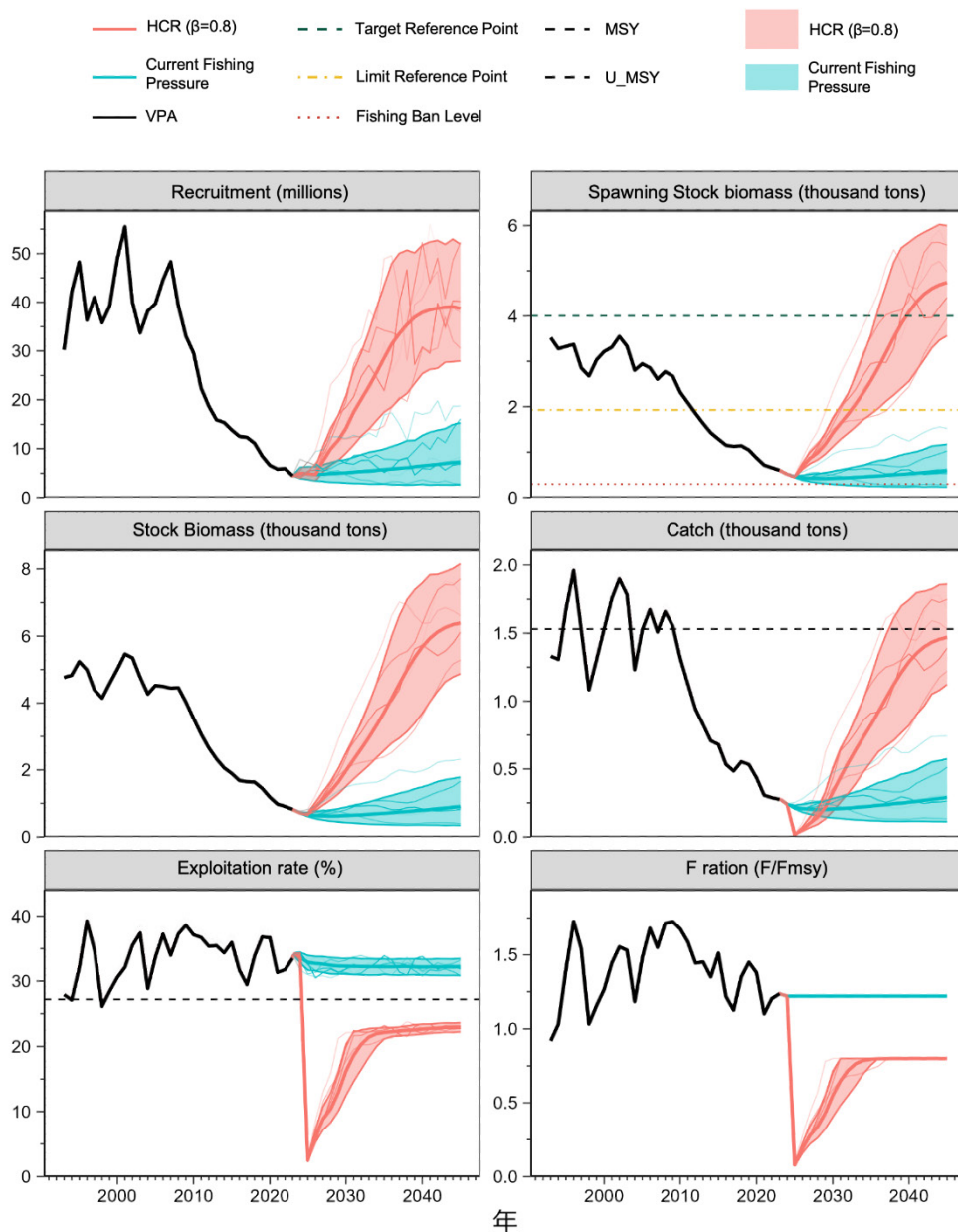


b) When the vertical axis is the catch



Supplementary Fig. 4-1. The proposed HCR

The target reference points (SB_{target}) is the SB_{msy} calculated based on a hockey-stick stock-recruitment model. Standard values are used for the proposed limit reference point (SB_{limit}) and the proposed fish ban level (SB_{ban}), respectively. An adjustment coefficient of $\beta = 0.8$, the standard value, was used. The black dashed line represents F_{msy} , the gray dashed line represents $0.8 F_{msy}$, 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 case when the vertical axis shows fishing pressure, and graph (b) is the case when the vertical axis shows catch in weight. In (b), while catch varies slightly depending on the age composition in the year, the catch for the average age composition at equilibrium is shown here.



Supplementary Fig. 4-2. Future projections when using proposed HCR (red) and the current fishing pressure (F₂₀₂₁₋₂₀₂₃; blue)

The thick solid lines 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 SSB graph, the blue 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. The dashed line in the graph of catch and exploitation rate indicates MSY and the level maintains target reference point (U_{msy}), respectively. An adjustment coefficient of $\beta = 0.8$ was used. Catch in 2025 and onwards were assumed to follow the proposed HCR (Supplementary Fig. 4-1).

Supplemental Table 4-1. Probability that future SSB will exceed proposed target or limit reference points

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

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.9			0	0	0	0	0	0	0	0	0	0	0	1
0.8			0	0	0	0	0	0	0	0	0	0	0	2
0.7			0	0	0	0	0	0	0	0	0	0	2	6
0.6			0	0	0	0	0	0	0	0	0	1	6	20
0.5			0	0	0	0	0	0	0	0	0	3	17	40
0.4			0	0	0	0	0	0	0	0	1	9	33	65
0.3			0	0	0	0	0	0	0	0	2	22	56	83
0.2			0	0	0	0	0	0	0	0	7	40	77	94
0.1			0	0	0	0	0	0	0	2	18	60	90	99
0.0			0	0	0	0	0	0	0	3	36	80	97	100
Current Fishing Pressure			0	0	0	0	0	0	0	0	0	0	0	0

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

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
1.0	0	0	0	0	0	0	0	0	2	10	29	47	63	
0.9			0	0	0	0	0	0	1	4	19	43	67	80
0.8			0	0	0	0	0	0	1	10	33	62	81	91
0.7			0	0	0	0	0	0	3	18	49	77	91	97
0.6			0	0	0	0	0	0	5	31	66	89	97	99
0.5			0	0	0	0	0	0	9	46	80	95	99	100
0.4			0	0	0	0	0	0	17	61	90	98	100	100
0.3			0	0	0	0	0	0	28	75	96	100	100	100
0.2			0	0	0	0	0	2	38	86	99	100	100	100
0.1			0	0	0	0	0	3	50	92	100	100	100	100
0.0			0	0	0	0	0	6	64	97	100	100	100	100
Current Fishing Pressure			0	0	0	0	0	0	0	0	0	0	0	0

The results of future projections are shown when β is changed from 0 to 1.0. The catch in 2024 is set at 240 tons, predicted from the current fishing pressure (F2020-2022), and fishing will be based on the proposed harvest control rule from 2025. For comparison, the results of continuing fishing at the current fishing pressure (F2020-2022) are also shown.

Supplementary Table 4-2. Trends in future average SSB and catch

a) Trends in average SSB (tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	600	516	456	674	843	947	1,111	1,323	1,489	1,639	1,798	1,947	2,088
0.9			456	676	853	966	1,140	1,369	1,557	1,728	1,917	2,108	2,302
0.8			456	679	863	986	1,172	1,420	1,632	1,832	2,060	2,309	2,576
0.7			456	682	873	1,007	1,206	1,476	1,717	1,954	2,237	2,561	2,921
0.6			456	684	884	1,029	1,243	1,538	1,815	2,099	2,453	2,874	3,349
0.5			456	687	895	1,052	1,283	1,606	1,926	2,273	2,717	3,258	3,872
0.4			456	689	906	1,076	1,326	1,683	2,055	2,481	3,037	3,723	4,499
0.3			456	692	917	1,102	1,373	1,768	2,206	2,730	3,420	4,280	5,237
0.2			456	695	929	1,129	1,424	1,865	2,382	3,024	3,877	4,942	6,096
0.1			456	697	941	1,158	1,480	1,975	2,588	3,370	4,418	5,721	7,087
0.0			456	700	953	1,189	1,542	2,101	2,828	3,777	5,057	6,630	8,224
Current Fishing Pressure			456	431	424	417	417	422	429	436	446	455	466

b) Trends in average catch (tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	275	240	21	67	118	162	237	345	445	544	642	725	796
0.9			19	61	110	154	228	338	444	546	645	733	812
0.8			17	55	101	144	217	329	439	542	641	734	825
0.7			15	49	92	134	205	316	427	530	628	727	831
0.6			13	43	81	121	189	298	408	506	604	711	827
0.5			10	36	70	107	171	275	378	470	568	680	804
0.4			8	29	58	91	149	244	335	420	516	629	753
0.3			6	22	46	73	122	203	279	353	442	548	661
0.2			4	15	32	52	89	149	206	265	338	426	516
0.1			2	8	16	28	49	83	114	150	195	248	302
0.0			0	0	0	0	0	0	0	0	0	0	0
Current Fishing Pressure			218	207	204	201	202	205	208	212	216	221	226

The results of future projections are shown when β is changed from 0 to 1.0. The catch in 2024 is set at 240 tons, predicted from the current fishing pressure (F2020-2022), and fishing will be based on the proposed harvest control rule from 2025. For comparison, the results of continuing fishing at the current fishing pressure (F2020-2022) are also shown.

Appendix 5 Future Projection Methods

Future projections were performed using the stock-recruitment relationship used to estimate the F that would maintain maximum sustainable yield (Fmsy) at the Research Institute Meeting held in October 2021 (Yagi et al. 2021) as well as the various settings shown in Supplementary Table 5-1 (natural mortality, maturity rate, average weight by age and current fishing pressure) according to the HCR for Stock Group 1 in the Basic Guidelines for Harvest Control Rules and Basic Guidelines for ABC Calculation (FRA-SA2024-ABCWG02-02) (Fisheries Research and Education Agency 2024a). The statistical software R (version 4.3.1) and the calculation package frasyr (version 2.4.0.0) were used to calculate projections for stock number and catch based on the Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations (FRA-SA2024-ABCWG02-04) (Fisheries Research and Education Agency 2024b).

The stock number of age 2 to 3 fish in future projections was obtained using the following equations.

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

The stock number of the plus group of fish age 4+ was obtained using the following equation.

$$N_{4+,y} = N_{3,y-1} \exp(-M_{3,y-1} - F_{3,y-1}) + N_{4+,y-1} \exp(-M_{4+,y-1} - M_{4+,y-1}) \quad (8)$$

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

$$C_{a,y} = N_{a,y} \left(1 - \exp(-F_{a,y})\right) \exp\left(-\frac{M_a}{2}\right) \quad (9)$$

The stock biomass and catch in future projections were obtained by multiplying the stock number or catch in number obtained here by the average weight in Supplementary Table 5-1, and SSB was calculated by multiplying this stock biomass by the maturity ratio.

References

- Fisheries Research and Education Agency (2024a) Harvest Control Rule and Basic Guidelines for ABC Calculation in FY 2024 (FRA-SA2024-ABCWG02-02).
- Fisheries Research and Education Agency (2024b) Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations (FRA-SA2024-ABCWG02-04), 15 pp.
- https://abchan.fra.go.jp/references_list/FRA-SA2024-ABCWG02-04.pdf (last accessed 9th August 2024)
- Yagi, Y., Fujiwara, K., Iida, M., Sakuma, K., Yoshikawa, A., and Shirakawa, H. (2021) Materials for the Research Institute Meeting on Reference Points of Southwestern Sea of Japan Stock of

Shotted Halibut (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-22. FRA-SA2021-BRP12-2.

http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20211026/doc_mushigarei_japanese-sw_RIM.pdf (last accessed 9th August 2024)

Supplementary Table 5-1. Parameters used to calculate future projections

	Selectivity (Note 1)	Fmsy (Note 2)	F2020-2022 (Note 3)	Average weight (g)	Natural mortality coefficient	Maturity ratio
Age 1	0.27	0.12	0.10	20	0.35	0
Age 2	0.79	0.36	0.42	58	0.35	0.4
Age 3	1.00	0.46	0.65	115	0.35	1.0
Age 4+	1.00	0.46	0.65	226	0.35	1.0

Note 1: Selectivity used to estimate the level to maintain MSY at the FY 2021 Research Institute Meeting (i.e., selectivity of $F_{current}$ in the FY2020 stock assessment).

Note 2: Fmsy estimated at the FY 2021 Research Institute Meeting (i.e., $F_{msy}/F_{current}$ multiplied by $F_{current}$ in the FY2020 stock assessment).

Note 3: The average F value for 2020 to 2022 was used as the current fishing pressure of this stock. This F value was used as the assumption for the catch in 2023.

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	12.419	3,147	0.137	0.675

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)	4,000 tons	A proposed target reference point. SSB to achieve MSY (SBmsy).
SBlimit (proposed)	1,900 tons	A proposed limit reference point. SSB required for catch of 60% of MSY (SB0.6msy).
SBban (proposed)	300 tons	Proposed fishing ban level. SSB required for catch of 10% of MSY (SB0.1msy).
Fmsy	Fishing pressure to maintain MSY (Age 1, Age 2, Age 3, Age 4 and older)=(0.12, 0.36, 0.46, 0.46)	
%SPR (Fmsy)	31%	%SPR corresponding to Fmsy
MSY	1,500 tons	Maximum Sustainable Yield

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

Item	Value	Description
SB2023	600 tons	SSB in 2023
F2023	Fishing pressure in 2023 (fishing mortality F) (Age 1, Age 2, Age 3, Age 4 and older)= (0.10, 0.42, 0.65, 0.65)	
U2023	34%	Exploitation rate in 2023
%SPR (F2023)	26%	%SPR in 2023
%SPR (F2021 to 2023)	26%	%SPR corresponding to current fishing pressure (2021 to 2023)*
Compared against proposed reference points		
SB2023 / SB _{msy} (SB _{target})	0.15	SSB ratio achieving MSY (proposed target reference point) to SSB in 2023
F2023 / F _{msy}	1.24	F ratio maintaining MSY to fishing pressure in 2023*
Level of SSB	Under the level achieving MSY	
Level of fishing pressure	Over the level maintaining MSY	
Trend in SSB	Decrease	

*The average value of F from 2020 to 2022 was used to assume the 2024 catch.

Supplementary Table 6-4. Projected catch and projected SSB

SSB in 2025 (average projected value): 456 tons			
Item	Average catch (hundred tons) in 2025	Ratio to current fishing pressure (F/F2020 to 2022)	Exploitation rate in 2025 (%)
β (standard value) proposed in the Research Institute Meeting			
$\beta=0.8$	17	0.08	3
If a different β is used			
$\beta=1.0$	21	0.10	3
$\beta=0.6$	13	0.06	2
$\beta=0.4$	8	0.04	1
$\beta=0.2$	4	0.02	1
$\beta=0.0$	0	0.00	0
F2020-2022	218	1.00	33

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

Uncertainty under consideration: Recruitment					
Item	SSB in 2035 (hundred tons)	90% prediction interval (hundred tons)	Probability (%) that SSB will exceed the following proposed reference points in 2035		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
β (standard value) proposed in the Research Institute Meeting					
$\beta=0.8$	26	18 – 36	2	91	100
If a different β is used					
$\beta=1.0$	21	16 – 28	0	63	100
$\beta=0.6$	33	22 – 48	20	99	100
$\beta=0.4$	45	28 – 64	65	100	100
$\beta=0.2$	61	39 – 85	94	100	100
$\beta=0.0$	82	55 – 111	100	100	100
F2020-2022	5	2 – 8	0	0	88

Supplementary Table 6-5. (continued).

Uncertainty under consideration: Recruitment			
	Year in which SSB exceeds the proposed reference points by more than 50%		
	SBtarget (proposed)	SBLimit (proposed)	SBban (proposed)
β (highest value) proposed in the Research Institute Meeting			
$\beta=0.8$	2045	2033	2023
If a different β is used			
$\beta=1.0$	After 2056	2035	2023
$\beta=0.6$	2045	2032	2023
$\beta=0.4$	2035	2031	2023
$\beta=0.2$	2034	2031	2023
$\beta=0.0$	2033	2030	2023
F2020-2022	After 2055	After 2055	2023

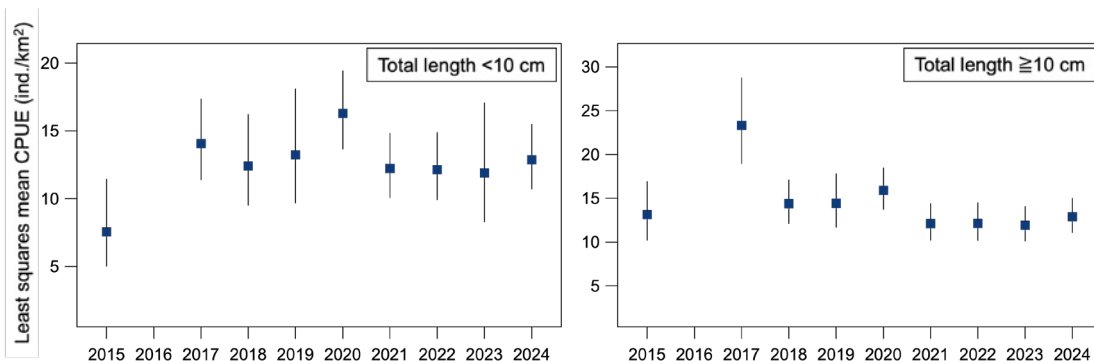
Appendix 7 Summary of Survey Results

The Yamaguchi Prefectural Fisheries Research Center has been conducting a survey of new recruitment in the waters east of Tsushima using a 4.5 m beam net, operated by the fisheries research vessel Kaisei. To examine the relationship between the occurrence of shotted halibut (classified as less than 10 cm and greater than 10 cm in total length) in the study area and the survey year, a CPUE-Lognormal model (Shono 2004) was constructed based on the results of surveys conducted from June to August. The number of shotted halibut collected (added a small value (0.1) to avoid zero catches) was divided by the tow distance, and the resulting natural logarithm was used as the objective variable. A full model was constructed using the survey year, survey month, water depth, and water temperature as explanatory variables, including interactions among those four variables. As a result of a best subset approach based on Akaike's Information Criterion with/without explanatory variables, a model including the survey year, survey month, and depth was selected as the best model for fish less than 10 cm in total length, and a model including the survey year, depth, and water temperature was selected for fish of 10 cm in total length or longer. To extract the annual trend in CPUE, the least squares mean of the survey yearly effects in the best model (Grafen and Hails 2002) was calculated. The CPUE least squares mean of fish less than 10 cm in total length, which are considered as the yearling fish, continues to increase and decrease during the survey period (Supplementary Fig. 7-1), and since 2021, it has remained roughly flat. The CPUE least squares mean for 10 cm in total length or longer was high in 2017, remained stable from 2018 to 2020, decreased in 2021, and then remained roughly stable until the latest year.

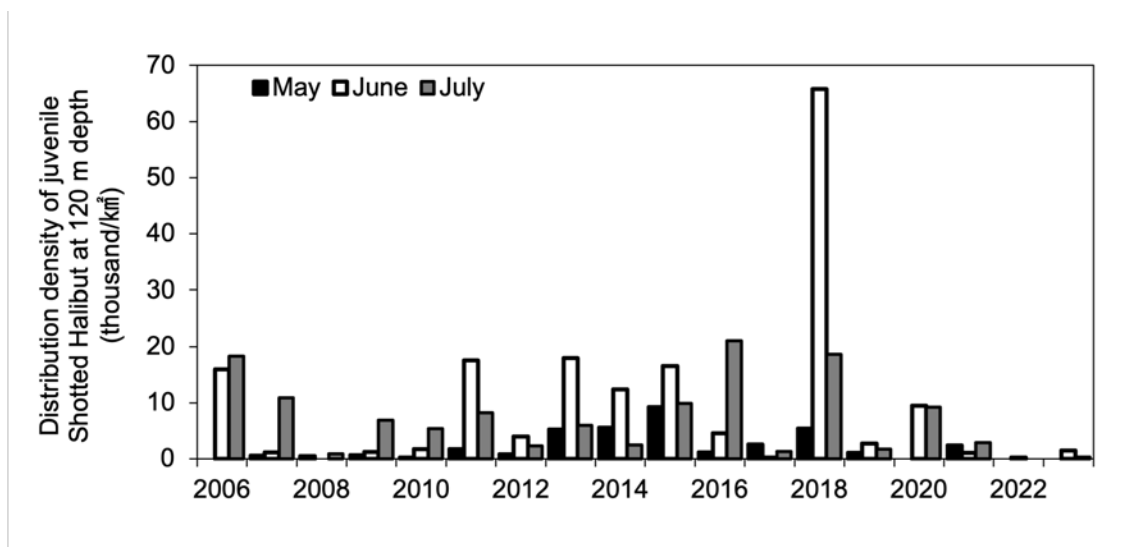
The Tottori Prefectural Fish Farming Center conducts a survey from April to September every year using a beam trawler with a beam length of 5 m for the purpose of understanding the abundance of coastal yearling flounder and flatfishes. Supplementary Fig. 7-2 shows the distribution density at 120 m depth from May to July, which is the main depth zone and timing of appearance of yearling shotted halibut in this survey. The distribution density (thousands/km²) of yearling fish has been relatively high in June or July since 2013, but was low in both months in 2017. The distribution density in June 2018 was particularly high at 66. In 2020, no samples were collected in May, and for June and July, values were similar to historical averages. For 2021, the distribution density was low for all months. In 2022, none were collected in May and the values in June were extremely low, while in 2023, samples were collected in June and July, albeit at low distribution densities.

References

- Grafen, A. and Hails, R. (2002) *Modern statistics for the life sciences*. Oxford University Press, Oxford, 345 pp.
- Shono, H. (2004) Some Statistical Approaches Used for CPUE Standardization. *Bull. Jpn. Soc. Fish. Oceanogr.*, **68**, 106-120.



Supplementary Fig. 7-1. Trends in least squares mean CPUE for the CPUE-Lognormal model for shotted halibut in the waters east of Tsushima, Yamaguchi prefecture. See text for details on model structure. The black line indicates the 95% confidence interval. In 2016, surveys were conducted in October and December and were not included in the analysis data.



Supplementary Fig. 7-2. Monthly trends in Distribution Density of juvenile Shotted Halibut Off Central Tottori Prefecture. No survey was conducted in July 2022.

Appendix 8 Method for Calculating Stock Abundance Indices Using Two-boat Offshore Trawls Catch Performance Reports

Two-boat offshore trawls catch performance reports aggregate catch in weight and number of nets by month and by fishing-zone (10-minute grid). Based on these, CPUE (U) in month (i), fishing-zone (j) is expressed in the following equation:

$$U_{i,j} = \frac{C_{i,j}}{X_{i,j}}$$

In the equation above, C is catch in weight, and X is effort (number of nets).

The abundance index (P) in the aggregation unit (month or small area) is expressed as the total CPUE in the following equation:

$$P = \sum_{i=1}^I \sum_{j=1}^J U_{i,j}$$

The relationship between the effective fishing effort (X'), catch in weight (C), and abundance index (P) in the aggregation unit is expressed in the following equation:

$$P = \frac{CJ}{X'} \text{ therefore } X' = \frac{CJ}{P}$$

In the above equation, J is the actual number of fishing areas with catch.

Within an expanse of fishing grounds, there are usually shades of fish density, and when vessels operate in areas with high fish density, CPUE, which is total catch in weight divided by total number of hauls, will be skewed toward the higher end of the scale. Therefore, the fishing grounds were subdivided into fishing zones of 10-minute boxes, and the density within the fishing zone was assumed to be uniform. Correcting for bias in fish stocks and effort, the abundance index was used to stock abundance index.

When the number of fishing zones is reduced, as in the case of two-boat offshore bottom trawl, the selectivity of fishing zones for vessels affects the abundance index. Since bottom trawl target multiple species of fish, with different species having different distribution densities in different areas, the decrease in the number of fishing zones may be due to the concentration of operations in fishing zones with high distribution densities of the main target species of fish being caught. In such cases, the abundance index will be underestimated because there is no data for fishing zones with low density.

Appendix 9 Standardized CPUE Calculation Method

We used data on number of hauls and catch by fishing vessel by day, divided in a latitude-longitude grid of 10 minutes, based on catch performance reports of two-boat offshore bottom trawlers from 1993 to 2023. Depth data was extracted from the ETOPO1 global relief model (<https://www.ngdc.noaa.gov/mgg/global/global.html>) and was used as the marine environmental data. Because the data used in this study are continuous values that include zero catches (i.e., the fishery is operating but the catch is zero), the delta-GLM (Lo et al. 1992) was used as the standardized model. The model was analyzed separately for two models, one to predict the probability of catch (catch probability model) and the other to predict the CPUE (natural logarithm) with catch (non-zero catch CPUE model), with binomial and normal distributions for the error distribution of each model. In each model, the explanatory variables for the most complex candidate model (full model) were the fixed effects of year, season, sea area, depth, and fishing vessel ID (all categorical variables) and the interaction between year and sea area. The area was divided into two east-west sections at 130°E, taking into account the transition of the fishing grounds for two-boat offshore bottom trawlers, and the distribution of CPUE for shotted halibut. The following full model was selected as the best model as a result of the total model selection by AIC with and without explanatory variables in each model. Because it was confirmed that there were no problems in the best models with scale or equal variance in residuals of non-zero CPUE, and that determination of zero/non-zero was sufficient, these models were used to calculate standardized CPUE (Supplementary Fig. 9-1).

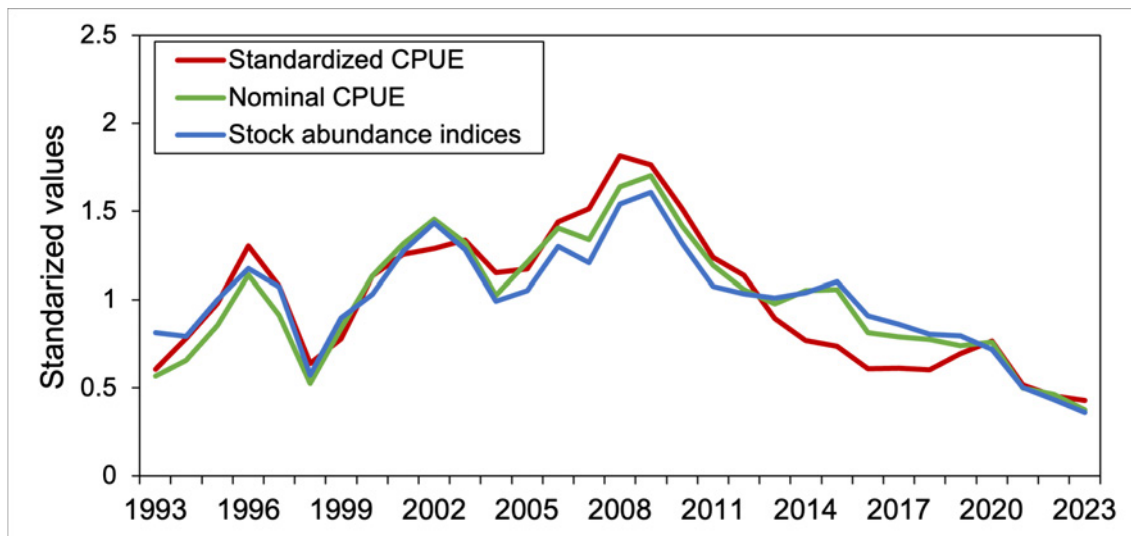
Catch probability model: catch probability \sim intercept + year + season + sea area + depth + fishing vessel ID + year:sea area

Non-zero catch CPUE model: $\ln(\text{CPUE}) \sim$ intercept + year + season + sea area + depth + fishing vessel ID + year:sea area

Details of model construction, standardized CPUE projection and model diagnostics are provided in a separate explanatory document (FRA-SA2024-SC03-0901).

References

Lo, N. C. H., Jacobson, L. D., and Squire, J. L. (1992) Indices of relative abundance from fish spotter data based on Delta-lognominal models. *Can. J. Fish. Aquat. Sci.*, **49**, 2515-2526.



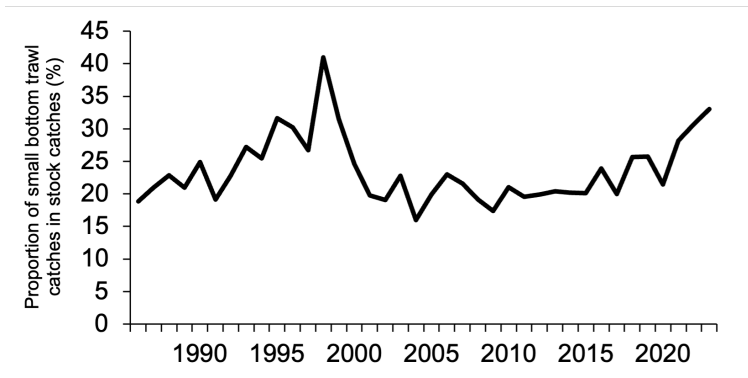
Supplementary Fig. 9-1. Transition in Standardized CPUE, Nominal CPUE, and Abundance Indices

Appendix 10 The current status of small bottom trawling in Shimane Prefecture

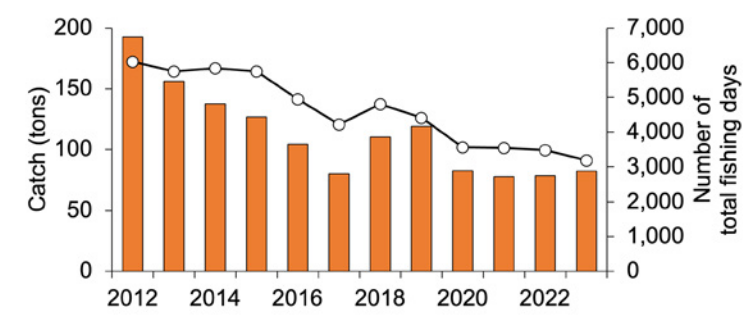
The stock assessment of this stock is based largely on the catch information from two-boat offshore bottom trawls (west of Hamada) (Appendix 2). Although the shotted Halibut is also an important target resource for small bottom trawls, there is little information on the operation status and actual fishing conditions of small bottom trawls. The proportion of small bottom trawls in the total catch of the stock increased from 19% in 1991 to 41% in 1998, but after 1999 it decreased to 16% in 2004. Since then, the proportion has increased with fluctuations, and was 33% in 2023 (Supplementary Fig. 10-1). In order to examine the resource status of this stock from a variety of perspectives, we decided to organize the catch status of small bottom trawls in Shimane Prefecture since 2012, when it was available.

Most of the records for small bottom trawls did not include the fishing area or number of nets. Therefore, the fishing effort was defined as the total number of fishing vessels (vessels*days) per year, and the annual catch of the fishing record was divided by this to calculate the CPUE (kg/vessel/day) for each year.

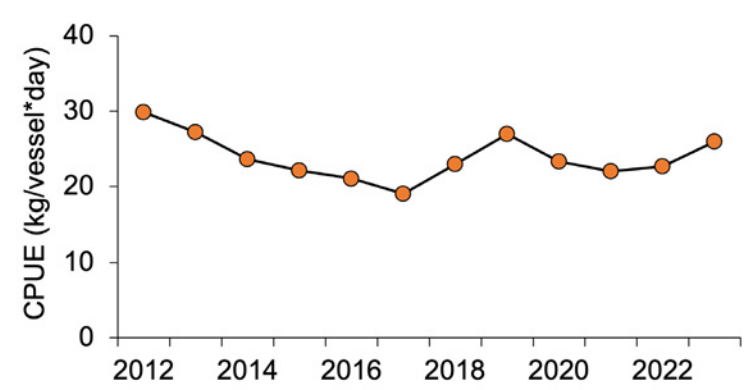
The number of vessels listed in the Shimane Prefecture small bottom trawl record decreased almost consistently from 52 in 2012 to 35 in 2022. The total number of fishing days decreased from 6,031 in 2012 to 4,220 in 2017, then increased to 4,803 in 2018, but then decreased to 3,180 in 2023 (Supplementary Fig. 10-2). The catch decreased from 193 tons in 2012 to 80 tons in 2017, then increased for two consecutive years, but decreased again in 2020 and has since shown a flat trend. Small bottom trawl CPUE (kg/vessel/day) decreased from 30 in 2012 to 19 in 2017, then increased to 27 in 2019. Since then, it has fluctuated around 23, with no significant increase or decrease observed throughout the available period (Supplementary Fig. 10-3). Comparing the annual trends in standardized CPUE for small bottom trawls and two-boat offshore bottom trawls (west of Hamada) (Fig. 4-1), there was a consistent trend of a decrease from 2012 to 2017, followed by an increase over the next 2 to 3 years. However, the trends from 2021 onwards are different for small bottom trawls and offshore bottom trawls, with small bottom trawls increasing and offshore bottom trawls decreasing. In the future, it is considered important to improve the accuracy of stock assessment by collating information on actual fishing conditions and operation status, such as size and age composition of catches, even for small bottom trawls, and incorporating this information into stock assessment.



Supplementary Fig. 10-1. Trend in the proportion of small bottom trawl catches in stock catches



Supplementary Fig. 10-2. Trends in small bottom trawling catches (bars) and total number of fishing days (line) in Shimane Prefecture



Supplementary Fig. 10-3. Trend in small bottom trawls CPUE in Shimane Prefecture

Appendix 11 Consideration on alternative harvest control rule (upper and lower limit rules)

In the proposed harvest control rule targeting MSY based on the stock assessment in FY2024, when $\beta=0.8$, the average catch in 2025 is 17 tons, a significant decrease of 7% of the previous year (2024, 240 tons). Therefore, for the stock assessment results in FY2024, we considered alternative harvest control rule (upper and lower limit rules) that set limits on the fluctuation range of the previous year's catch. Guidelines for alternative harvest control rule is summarized in FRA-SA2024-ABCWG02-06.

C_t is the catch in year t , L is the lower limit coefficient, and U is the upper limit coefficient. The limit on C_t is expressed as follows, multiplying the previous year's catch C_{t-1} by the limit coefficient.

$$C_{t-1} \times L \leq C_t \leq C_{t-1} \times U$$

The limit period for C_t was set at 10 years (10y) from 2025, and management following the normal harvest control rule was considered after that. Three variations in catch were considered: within $\pm 10\%$ of the previous year (CV10: $U=1.1$, $L=0.9$), within $\pm 20\%$ (CV20: $U=1.2$, $L=0.8$), and within $\pm 30\%$ (CV30: $U=1.3$, $L=0.7$). At the same time, future predictions were simulated by varying β in the range from 0.4 to 0.8, and compared with the results of the basic harvest control rule.

The guidelines for alternative harvest control rules recommend proposing management rules that have a 50% or higher probability of exceeding the target reference point about SSB in 10 years later. When $\beta = 0.8$, the probabilities that the SSB in 10 years later would exceed the proposed target reference point were less than 50% (4-36%) for any fluctuation range of catch within ± 10 -30%. When $\beta = 0.5$ and the fluctuation range was within $\pm 30\%$, the probability that the SSB in 10 years later would exceed the proposed target reference point was more than 50%. Therefore, the results of three future projections for the proposed harvest control rule (basic rule) and upper and lower limit rules with a fluctuation range of $\pm 30\%$ and, for reference, a fluctuation range of $\pm 20\%$ at $\beta = 0.5$ are shown in Supplementary Fig. 11-1. In addition, the average catch in the initial (2025), middle (2026-2029), and final (2030-2034) management periods was compared under the basic harvest control rule with $\beta = 0.5$, and the alternative fish management rule with a fluctuation range of $\pm 30\%$ (10y_CV30) and $\pm 20\%$ (10y_CV20) (Supplementary Table 11-1). The results of the future projections for the next 10 years are shown in Supplementary Tables 11-2 to 11-5. When the fluctuation range was within $\pm 30\%$, the average catch in the first year of management was higher than when the harvest control rule with $\beta = 0.5$ was applied, but was lower from the middle of the management period onwards. As an indicator of the sustainability of the stock, the average SSB in 5 years (2030) and 10 years (2035) after the start of management was compared (Supplementary Table 11-1). When $\beta=0.5$ and the fluctuation range was within $\pm 30\%$, the average SSB exceeded the value of the basic harvest control rule with $\beta=0.5$ from 2034.

When the basic harvest control rule was applied, the probability that the SSB would exceed the proposed target reference point 10 years from now was 40% when $\beta=0.5$, but when the fluctuation range was limited to $\pm 30\%$, it was 50% (Supplementary Table 11-1). This is because the upper limit

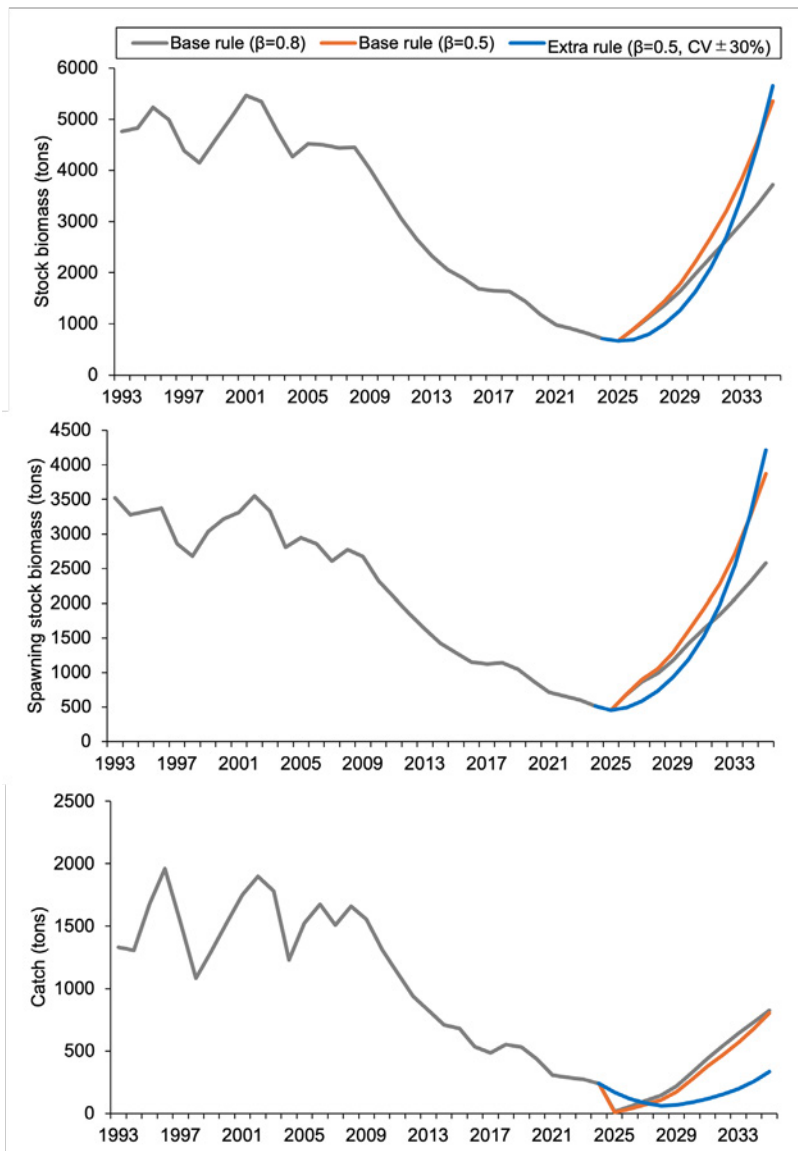
had the effect of suppressing fishing pressure after SSB and stock biomass had begun to recover. In addition, as an indicator of the risk of the stock falling into an undesirable state, the probability of falling below the proposed limit reference point and the proposed prohibition level even once in the 10 years since the harvest control rule was introduced was compared. The result was that although the SSB is already below the limit reference point at present, the probability of falling below the prohibition level was 0% for both.

A comparison of the average annual variation (AAV), average depletion ratio (ADR), maximum depletion ratio (MDR), and minimum catch (MinC) between the two harvest control rules as indicators of predicted changes in catch volume over the 10-year management period showed that the AAV was 0.68 under the basic harvest control rule, while it was 0.29 under 10y_CV30. The ADR was -0.29 under the alternative harvest control rule. The MDR was 0.00 under the basic harvest control rule, while it was -0.20 to -0.30 under the alternative harvest control rule. Furthermore, the MinC was 10 tons under the basic harvest control rule, while it was 57 tons under the alternative harvest control rule for 10y_CV30, which was higher. The future projections showed that even if alternative harvest control rules are applied, stock biomass and SSB 10 years from now will be higher than they are now (Supplementary Fig. 11-1).

Based on these results, alternative harvest control rules were categorized based on the guidelines for alternative harvest control rules (FRA-SA2024-ABCWG02-06). In the case of rule that have a $\beta=0.5$ and is within $\pm 30\%$ of the previous year for 10 years (10y_CV30), it was determined to be in Category 2 (probability of achieving the target is 50% or more and risk is less than or equal to the 1_Base50% value).

Reference

Fisheries Research and Education Agency (2024) Guidelines for proposing alternative harvest control rules (alternative rules) for FY2024. Japan Fisheries Research and Education Agency, 4 pp. FRA-SA2024-ABCWG02-06.



Supplementary Fig. 11-1. Future prediction results when CV is fixed for 10 years (10y)

Transitions were compared under three different patterns: basic harvest control rule (basic rule) with $\beta = 0.8$ and 0.5 , and alternative harvest control rule (upper and lower limit rule, fluctuation range within $\pm 30\%$) with $\beta = 0.5$.

Supplementary Table 11-1. Evaluating the performance of alternative harvest control rules (upper and lower limit rule)

Proposed HCR	β	Estimated mean catch (tons)			Estimated mean SSB (tons) Management objective			Risk	Variation of estimated catch during 10 years (from 2025 to 2034)					
		First year	Middle	End	5 years later	Probability of SSB will reach more than proposed target reference point in 2035	SSB decrease less than proposed limit reference point		SSB decrease less than proposed fishing ban level	Catch halved	AAV	ADR	MDR	MinC
Basic rule	0.8	17	130	537	1,420	2,576	2%	100%	0%	0%	0.61	-0.02	0.00	17
Basic rule	0.5	10	96	474	1,606	3,872	40%	100%	0%	0%	0.68	-	0.00	10
Alternative rule (CV \pm 30%)	0.5	168	83	163	1,193	4,215	50%	100%	0%	0%	0.29	-0.29	-0.30	57

AAV: Annual average variation of catches

ADR: Average depletion ratio

MDR: Maximum depletion ratio

MinC: Minimum catch during 10 years

Supplementary Table 11-2. The probability that future SSB will exceed the proposed target reference point when applying the proposed basic harvest control rules (basic rules) and upper and lower limit rule ($\beta=0.5 \pm 30\%$)

Proposed HCR	β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
Basic rule	0.8	0	0	0	0	0	0	0	0	0	0	0	0	2	
Basic rule	0.5			0	0	0	0	0	0	0	0	0	3	17	40
Alternative rule CV \pm 30%	0.5			0	0	0	0	0	0	0	0	0	3	22	50

Supplementary Table 11-3. The probability that future SSB will exceed the proposed limit reference point when applying the proposed basic harvest control rules (basic rules) and upper and lower limit rule ($\beta=0.5 \pm 30\%$)

Proposed HCR	β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Basic rule	0.8	0	0	0	0	0	0	0	1	10	33	62	81	91
Basic rule	0.5			0	0	0	0	0	9	46	80	95	99	100
Alternative rule CV \pm 30%	0.5			0	0	0	0	0	1	14	47	79	94	99

Supplementary Table 11-4. The average SSB in future when applying the proposed basic harvest control rules (basic rules) and upper and lower limit rule ($\beta=0.5 \pm 30\%$)

Proposed HCR	β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Basic rule	0.8	600	516	456	679	863	986	1,172	1,420	1,632	1,832	2,060	2,309	2,576
Basic rule	0.5			456	687	895	1,052	1,283	1,606	1,926	2,273	2,717	3,258	3,872
Alternative rule CV \pm 30%	0.5			456	490	587	729	930	1,193	1,532	1,972	2,546	3,285	4,215

Supplementary Table 11-5. The average catch in future when applying the proposed basic harvest control rules (basic rules) and upper and lower limit rule ($\beta=0.5 \pm 30\%$)

Proposed HCR	β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Basic rule	0.8	275	240	17	55	101	144	217	329	439	542	641	734	825
Basic rule	0.5			10	36	70	107	171	275	378	470	568	680	804
Alternative rule CV \pm 30%	0.5			168	118	82	62	70	90	117	153	198	258	335

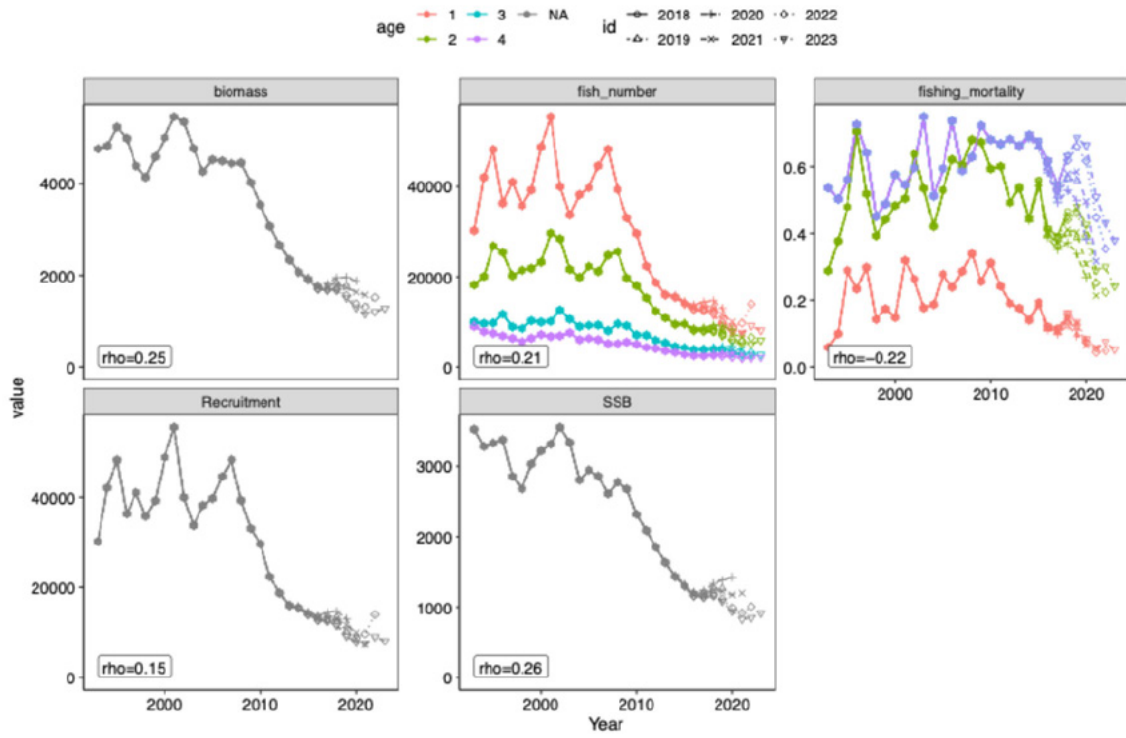
Appendix 12 Retrospective bias when tuning with VPA

In the assessment of this stock up until FY2023, the stock biomass and other values were estimated using VPA, which used standardized CPUE of the main fishery, two-boat offshore bottom trawls, for tuning. The results of a five-year retrospective analysis conducted as a diagnostic for the stock calculation model showed a tendency to overestimate the stock biomass and SSB, and underestimate the fishing mortality when data was added and updated (Supplementary Table 12-1). A similar retrospective bias was observed in the stock assessment in FY2024, when data from the latest year were added and updated (Supplementary Fig. 12-1). In previous years, future predictions have tended to show optimistic results due to retrospective bias, and in the Kobe plot, the past plot positions were revised from the yellow zone to the red zone as data was added and updated (Supplementary Fig. 12-2). Therefore, in order to stabilize the estimated fishing mortality, we applied ridge VPA (Okamura et al. 2017), which imposes penalties according to the size of the F value, in an attempt to improve the retrospective bias.

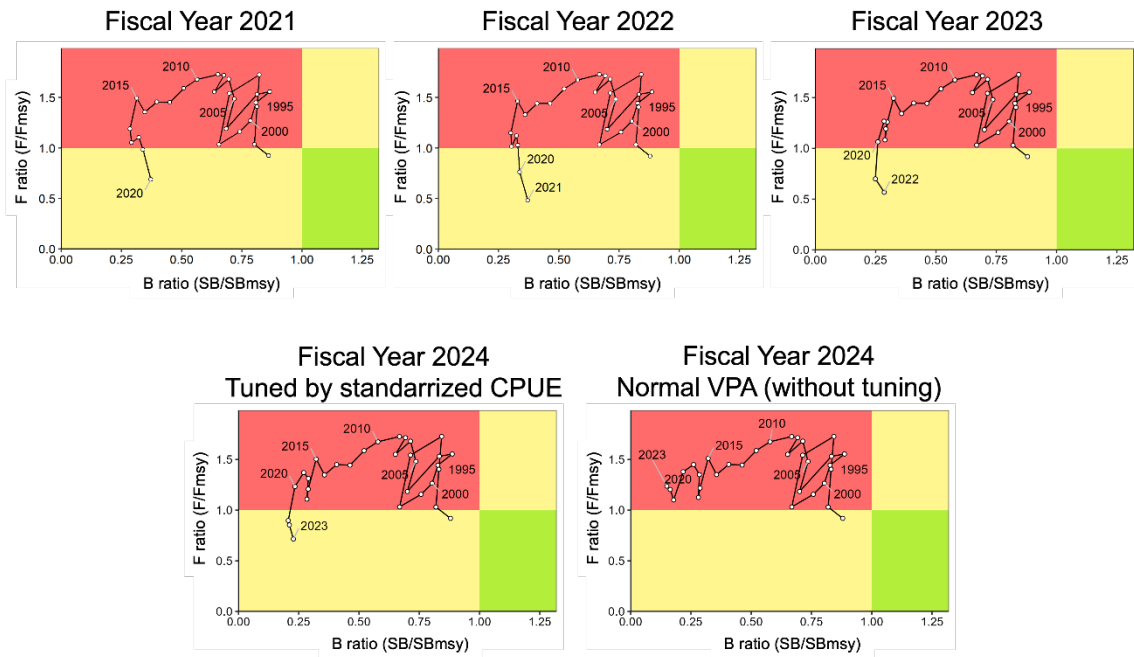
When the weight of the penalty λ was varied from 0 to 1, and the behavior of each VPA estimate and Mohn's ρ was examined, the fishing mortality decreased with increasing λ , and Mohn's ρ increased in the negative direction (i.e., the fishing mortality became more underestimated). The stock biomass and SSB increased with increasing λ , and Mohn's ρ increased in the positive direction (i.e., the fishing mortality became more overestimated) (Supplementary Fig. 12-3 and 12-4). Ridge VPA has the effect of eliminating retrospective bias by suppressing the fishing mortality of the most recent year by using a penalty, but in the case of this stock, the fishing mortality was underestimated, so imposing a penalty actually strengthened the retrospective bias. From next fiscal year onwards, we will continue to work on reviewing the values used in stock assessment, such as updating the aforementioned age-length keys, revising age-specific catch calculations in response to the increase in the catch proportion of small bottom trawls, and reexamining age decomposition. We will also need to continue to improve the retrospective bias and optimistic assessment of this stock, for example by considering VPAs that impose penalties on resource estimates other than the fishing mortality.

Reference

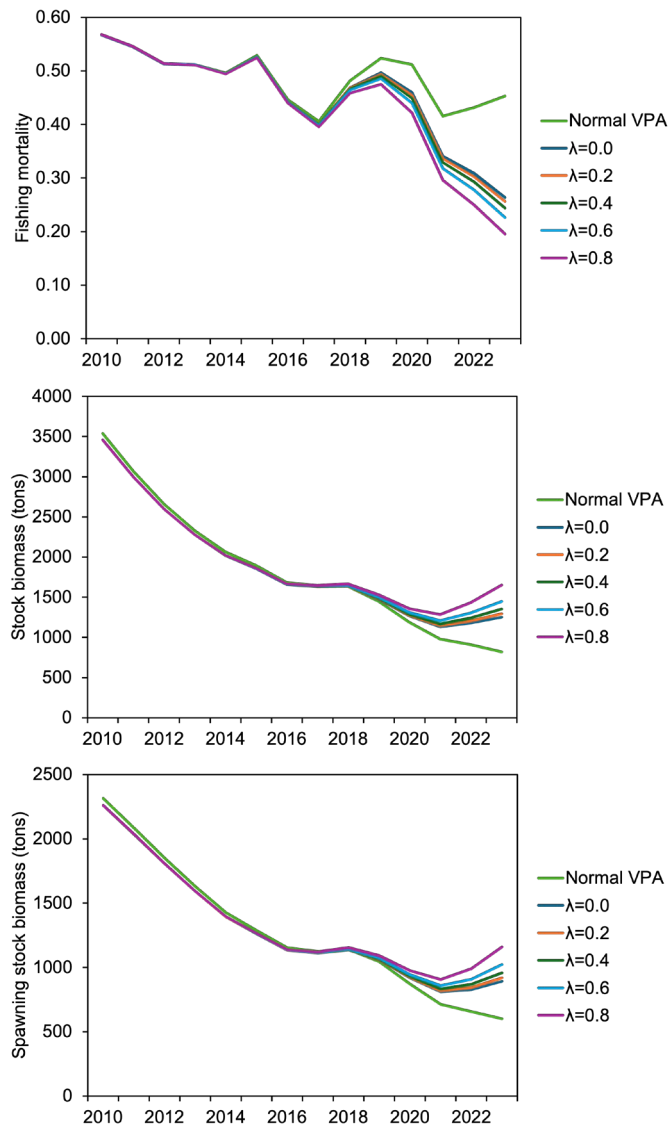
Okamura, H., Yamashita, Y., and Ichinokawa, M. (2017) Ridge virtual population analysis to reduce the instability of fishing mortalities in the terminal year. *ICES J. Mar. Sci.*, **74**, 2427-2436.



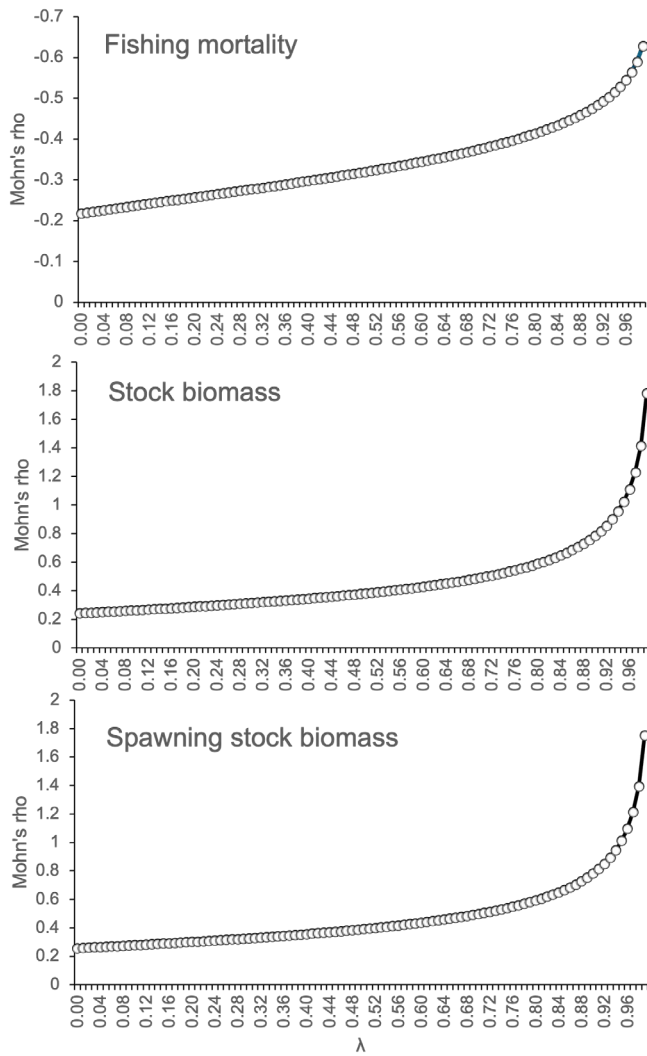
Supplementary Fig. 12-1. Retrospective analysis results of stock biomass, stock number (fish_number), fishing mortality, recruitment, and spawning stock biomass (SSB) when standardized CPUE is used for tuning.



Supplementary Fig. 12-2. Kobe plots from the stock assessments of this stock over the past three years (2021-2023) and Kobe plots for this year with and without tuning using standardized CPUE.



Supplementary Fig. 12-3. Behavior of estimated fishing mortalities, stock biomass, and SSB when applying Ridge VPA



Supplementary Fig. 12-4. Behavior of Mohn's ρ for penalty λ on fishing mortality, stock biomass and SSB.

Supplementary Table 12-1. Comparison of estimates for stock biomass, SSB and fishing mortality by simple VPA and tuning VPA.

Stock biomass (tons)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
NormalVPA_2024	2,062	1,893	1,684	1,645	1,633	1,447	1,185	978	909	819
TVPA_2024	2,066	1,900	1,696	1,666	1,669	1,509	1,292	1,155	1,205	1,282
TVPA_2023	2,071	1,910	1,713	1,697	1,723	1,603	1,453	1,439	1,739	-
TVPA_2022	2,088	1,940	1,767	1,794	1,893	1,896	1,902	1,968	-	-
TVPA_2021	2,015	1,870	1,713	1,780	1,919	2,024	2,335	-	-	-
TVPA_2020	2,018	1,876	1,724	1,800	1,971	2,046	-	-	-	-

Spawning stock biomass (tons)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
NormalVPA_2024	1,426	1,287	1,152	1,125	1,140	1,045	872	714	657	600
TVPA_2024	1,428	1,291	1,159	1,138	1,162	1,084	938	827	846	913
TVPA_2023	1,431	1,297	1,170	1,156	1,195	1,141	1,038	997	1,143	-
TVPA_2022	1,441	1,315	1,202	1,214	1,298	1,321	1,349	1,485	-	-
TVPA_2021	1,389	1,256	1,141	1,167	1,291	1,361	1,488	-	-	-
TVPA_2020	1,391	1,259	1,147	1,179	1,312	1,412	-	-	-	-

Fishing mortality (mean value of Age 1, 2, 3 abd 4+)										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
NormalVPA_2024	0.5	0.53	0.45	0.41	0.48	0.52	0.51	0.42	0.43	0.45
TVPA_2024	0.49	0.53	0.44	0.4	0.47	0.5	0.46	0.34	0.31	0.26
TVPA_2023	0.49	0.52	0.44	0.39	0.45	0.46	0.4	0.27	0.21	-
TVPA_2022	0.49	0.51	0.42	0.37	0.4	0.38	0.29	0.18	-	-
TVPA_2021	0.5	0.53	0.43	0.37	0.39	0.35	0.24	-	-	-
TVPA_2020	0.5	0.52	0.43	0.37	0.38	0.34	-	-	-	-

The tuning VPA is estimated back to the past five years. Each year represents the year in which the assessment was performed. This shows the figures for the last 10 years, where estimates change dramatically.