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Stock Assessment for Tsushima Warm Current Stock of Round Herring (Fiscal Year 2024)

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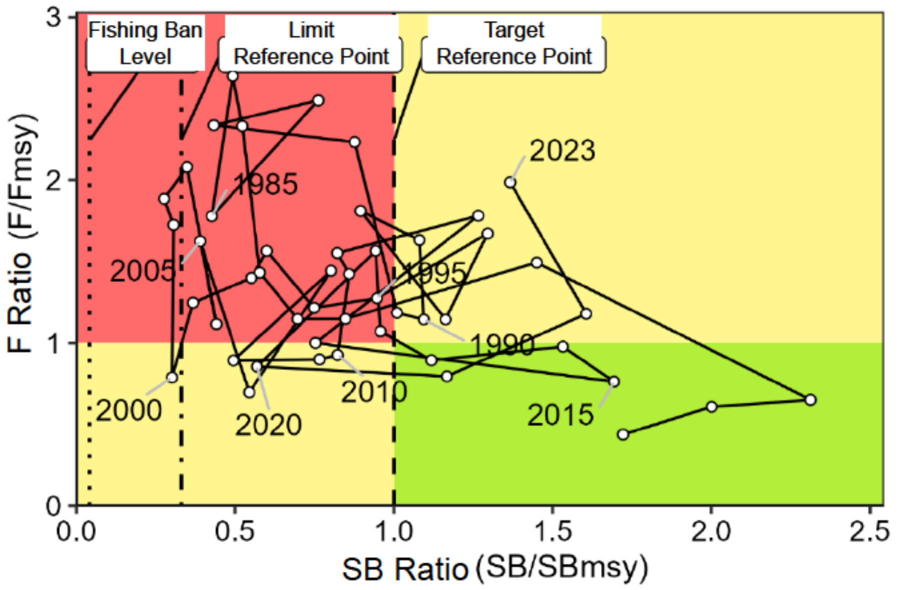
Summary

The biomass of this stock was estimated by cohort analysis using egg production data from egg and larvae surveys and abundance indices of large- to medium-scale purse seine fisheries as tuning indices. The biomass showed an increasing trend after 2004, peaking at 140,000 tons in 2015, but then declined to 62,000 tons by 2020. It began increasing again in 2021, reaching 116,000 tons in 2023. Recruitment in 2023 was the second highest since 1976.

The “Stock Management Policy Review Meeting” and the “Fishery Policy Council” were held in February 2023 and November 2023, respectively. After these meetings, the catch strategy, including the target reference points, limit reference points, and fishing ban levels for this stock was established. The target reference point is the spawning stock biomass (SBmsy: 54,000 tons) required for the realization of MSY. The spawning stock biomass (74,000 tons) of 2023 was over the level required for the realization of MSY. In addition, the fishing pressure on this stock in the 2023 fishing season was over than the fishing pressure level (Fmsy) required for the realization of MSY. Based on trends seen in the previous 5 years (2019 to 2023), SSB is judged to be in an “increasing” trend. Based on the catch strategy, the ABC for 2025, calculated from the spawning stock biomass and stock biomass for 2025, is 46,000 tons.

Summary Figures and Tables



Maximum Sustainable Yield (MSY), Spawning Stock Biomass (SSB) Levels and Trends, and Allowable (or Acceptable) Biological Catch (ABC)	
SSB required for MSY (SBmsy)	54,000 tons
Level of SSB in 2023	Over the level required for MSY
Level of fishing pressure in 2023	Over the level required for SBmsy
Changes in SSB in 2023	Increase
Maximum Sustainable Yield (MSY)	35,000 tons
ABC for 2025	46,000 tons
Comment: - The ABC was calculated using harvest control rules based on the catch strategy for this stock, which was compiled during the “Stock Management Policy Review Meeting” and established through the “Fishery Policy Council”. - Adjustment coefficient β = 0.80 was used.	

Stock Biomass, Spawning Stock Biomass, Catch, Fishing Pressure (F/Fmsy), and Exploitation Rate for the Most Recent 5 Years and the Next 2 Years					
Year	Stock biomass (Thousand tons)	Spawning stock biomass (Thousand tons)	Catch (Thousand tons)	F/Fmsy	Exploitation rate (%)
2019	67	51	35	1.56	53
2020	62	31	19	0.86	32
2021	96	63	34	0.80	35
2022	103	87	42	1.18	41
2023	116	74	62	1.99	53
2024	128	76	60	1.39	47
2025	123	80	46	0.80	37

- The values for 2024 and 2025 are estimates based on future projections.
- Fishing mortality (F) assumed for 2024 is the average of the F values for the most recent three years (2021-2023). ABC value was used for the 2025 catch.

1. Data Sets

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

Data Sets	Basic Information & Related Surveys
Catch in number at age and by year	Annual Statistics of Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landings at major ports (Niigata - Kagoshima (14) Prefectures) Catch Performance Report for Large and Medium-Sized Purse Seine Fisheries (Fisheries Agency) Monthly length composition surveys (Japan Fisheries Research and Education Agency, Kyoto - Kagoshima (8 prefectures))
Stock abundance index - Spawning stock biomass	Egg and larvae survey (annual, Fisheries Resources Institute, Aomori - Kagoshima (17 prefectures)) - NORPAC nets* Fish distribution survey “Pelagic Fish Abundance Survey Using Quantitative Echo Sounders” (August to September, Japan Fisheries Research and Education Agency) - Quantitative echo sounder, midwater trawl
- Stock biomass	Catch Performance Report for Large and Medium-Sized Purse Seine Fisheries (Fisheries Agency)*
Natural mortality (M)	Assuming M = 0.7 per year (Ohshimo 2003, 2009)
Fishing effort	Catch Performance Report for Large and Medium-Sized Purse Seine Fisheries (Fisheries Agency)

* Indicates the tuning index for cohort analysis

2. Ecology

(1) Distribution and Migration

This species is distributed mainly along the coast of Japan and is particularly common in the central part of Honshu and southwards (Ochiai and Tanaka 1986). The fishing grounds for the Tsushima Warm Current stock of round herring are primarily formed in a band along the coast from western Kyushu to the San’in region. It is considered that some migrate to the Sea of Japan during the summer and to the western coast of Kyushu during the winter (Fig. 2-1).

(2) Age and Growth

The growth function of round herring in the Tsushima Warm Current is as follows (Ohshimo et al. 2011, Fig. 2-2).

$$BL_m = 244.77(1 - exp(-0.10(m - 0.55)))$$

Here, BL_m represents the scaled body length (mm) at month (m) post-hatching. The lifespan is approximately three years.

(3) Maturation and Spawning

Based on the occurrence of eggs and juvenile fish, this stock is believed to spawn almost throughout the year in the waters around Kyushu. The spawning period is shorter in northern waters, and in the northern part of the Sea of Japan south of Aomori Prefecture, spawning occurs from spring to summer (Uchida and Dohtsu 1958). Round herring matures at age 1 (Fig. 2-3, Ohshimo et al. 2011)

(4) Predator-prey Relationships

Round herring prey on copepods, decapod larvae, amphipods, etc. (Tanaka et al. 2006) and are preyed upon by large fish, mammals, seabirds, and cephalopods.

3. Fishery Status

(1) Fishery Overview

These fishes are mainly caught using purse seine nets, set nets, and pole-hold nets.

(2) Trends in Catch in Weight

In this assessment, the catch in weight is obtained by adding the total catch from Aomori Prefecture through Kagoshima Prefecture from the Annual Statistics of Fishery and Aquaculture Production to the catch by fishing vessels belonging to areas other than the Sea of Japan area and the East China Sea area in the relevant area (East China Sea area), from the Catch Performance Report (Fig. 3-1, Table 3-1). The catch in weight by these fishing vessels was recorded going back to 1994. For the year 2023, the catch in weight at major ports of Ishikawa Prefecture was added, as the data of Ishikawa Prefecture for that year was not listed in the Annual Statistics of Fishery and Aquaculture Production.

From 1976 through 1998, the catch exceeded 20,000 tons each year. Especially from the late 1980s through the early 1990s, there were many years when the catch exceeded 40,000 tons. However, from the late 1990s through 2000, the catch declined to 10,000 tons. There has been an increasing trend since 2001, with the catch in weight reaching over 50,000 tons in 2013 and 2016. Thereafter, the catch in weight declined, fluctuating between 31,000 tons and 39,000 since 2017, but there was a significant decline to 19,000 tons in 2020. After 2021, the catch in weight increased again, reaching 62,000 tons in 2023, the highest since 1976. The catch is high in the East China Sea area and the West Sea of Japan area.

In addition to Japan, South Korea also catches round herring in the Tsushima Warm Current region. South Korea’s catch in weight was recorded at 14,000 tons from 1976 through 1986 but has not been reported since 1990 (Fisheries Statistics (Ministry of Oceans and Fisheries, Republic of Korea), https://www.fips.go.kr/p/S020304/, (June 2024)). The catch of round herring in China is unknown.

Trends in catch in number at age are shown in Fig. 3-2. The catch is dominated by age-0 and age-1 fishes (Fig. 3-2, Appendix 9).

(3) Fishing Effort

Purse seine fishing is primarily used, with large- and medium-sized purse seines often operating in the offshore area and medium- and small-sized purse seines in the coastal area accounting for the majority of the catch. Fig. 3-3 shows the number of large- and medium-sized purse seines operating in the East China Sea and the West Sea of Japan area. The number of nets reached a record high in the late 1980s but has continued to decline since 1990. The number of nets in 2023 was low at about 4,000 nets.

4. Stock Status

(1) Stock Assessment Methods

Cohort analysis was performed for the period 1976 - 2023 using catch in number at age estimated based on the catch in weight by month and body length measurement data since 1976. In the cohort analysis, the fishing mortality F for 2023 was adjusted using abundance indices (1997-2023) obtained by standardizing egg density data from egg and larvae surveys and abundance indices for large- and medium-sized purse seines (catch in weight per vessel based on extracted data; hereinafter referred to as “CPUE of the Large- and Medium-Sized Purse Seines”, 2007-2023) (Appendix 5 and 6). Since the distribution of round herring is limited mainly to coastal areas and the catch data from South Korea and China was not available, the stock assessment was performed based on the catch data of Japan.

(2) Trends in Abundance Indices

Fig. 4-1 and Supplementary Table 2-4 show the abundance indices used to adjust the fishing mortality F (values normalized by the average of each index). The abundance indices for this stock based on egg and larvae surveys conducted from the west coast of Kyushu to the Sea of Japan were stable at low levels from 1997 to the early 2000s but increased from the late 2000s, reaching a high level in 2016. However, there was a sharp decline toward 2018, with abundance indices falling to the same level as in the early 2000s, but an increasing trend has continued since 2019. The CPUE of the Large- and Medium-Sized Purse Seines has been relatively stable since 2007 despite some fluctuations. After 2021, a gradually increasing trend is observed. Appendix 4 presents an overview of the results of the egg and larvae survey and the quantitative echosounder survey.

(3) Trends in Stock Biomass and Fishing Pressure

The biomass determined by the cohort analysis declined from the late 1970s to the mid-

1980s and increased from the late 1980s to the early 1990s. Again, a decline was observed until the early 2000s, followed by an increase after 2004, exceeding 140,000 tons in 2015. A decline was observed thereafter, with an estimated value of 62,000 tons in 2020, which was followed again by an increase from 2021 onwards, with an estimated value of 116,000 tons in 2023 (Fig. 4-2). The spawning stock biomass (SSB) showed a similar trend to that of the biomass, reaching a high level of 92,000 tons in 2015 but declined toward 2020 and was estimated to be 31,000 tons. It began increasing again in 2021, and the spawning stock biomass in 2023 was estimated to be 74,000 tons (Fig. 4-2). An overview of the stock analysis results is shown in Table 4-1.

The recruitment volume (stock population of age 0 fish) exceeded 5 billion fish in 1992 but remained below 1 billion fish for a number of years in the late 1990s (Fig. 4-5). After the mid-2000s, the recruitment volume remained between 1.2 billion and 3.5 billion fish but was estimated to be 4.8 billion in 2023. In terms of stock population at age, age 0 fish accounted for a large proportion in terms of the catch in number at age, and in terms of the catch in weight at age, age 0 and age 1 fish accounted for a large proportion (Fig. 4-3 and Fig. 4-4).

Fig. 4-5 shows recruitment volume and recruitment per spawning (RPS) (ratio of recruitment volume to SSB). There were significant fluctuations in the RPS, with relatively high values in 2023.

Results of sensitivity analysis of the natural mortality (M) used in the cohort analysis are shown in Fig. 4-6, where M is varied to 0.5 times, 1.5 times, and 2 times assumed value (0.7). There was a tendency for biomass and SSB to increase as the natural mortality increased.

Fishing mortality F at age was relatively high for fish aged 1 and 2, with F exceeding 3 in some years. Since the mid-2000s, F has generally fluctuated between 1 and 1.5 (Fig. 4-7). The F of age 0 fish has been stable at a low level in recent years, falling below 1 in many years. The exploitation rate has been highly variable, exceeding 50% in some years, indicating a high level (Fig. 4-8). For the most recent five-year period (2019-2023), the exploitation rate varied between 32-53%.

Compared to the assessment of the previous fiscal year, the estimated values before 2021 were not significantly different but were revised upward after 2025. This is considered to be due to the high recruitment in 2023 (Appendix 7).

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

To compare fishing pressures while considering selectivity, we compared spawning per recruitment (SPR) based on scenarios with and without fishing. Fig. 4-9 shows the trends in the SPR ratio (%SPR), which compares SPR in a scenario without fishing pressure to SPR in a scenario with fishing for each year. The lower the fishing pressure, the larger the SPR. If we consider the most recent five years (2019–2023), the values fluctuated between 24% and 51%, showing a flat trend, with 2023 at 24%. Calculations showed that %SPR was 36% using the average F value of the previous 3 years (2021 to 2023) for the current fishing pressure.

The relationship between YPR and %SPR with respect to current fishing pressure (Fmsy) is shown in Fig. 4-10. The selectivity of F was defined as the value used to estimate the level of F (Fmsy) required for maximum sustainable yield (MSY) (Yoda et al. 2021b) at the Research Institute Meeting on Reference Points held in September 2021. In addition, the values used to calculate Fmsy were also used for average body weight at age and maturity rate. Fmsy is equivalent to 44.7% when converted to %SPR. The current fishing pressure (F2021 to 2023) is above Fmsy and F40%SPR and below F30%SPR.

(5) Stock-recruitment Relationship

The relationship between spawning stock biomass (weight) and recruitment (individuals) (stock-recruitment relationship) is shown in Fig. 4-11. At the above-mentioned “Research Institute Meeting”, a hockey stick stock-recruitment model was proposed for the stock-recruitment relationship of this stock (Yoda et al., 2021b). The data used for parameter estimation of the stock-recruitment relationship equation comprised spawning stock biomass and stock-recruitment relationship data from 1976 to 2018, based on the Stock Assessment for the Tsushima Warm Current Stock of Round Herring (Fiscal Year 2020) (Yoda et al., 2021a). The least squares method was used as the optimization method, taking into account autocorrelation regarding residuals in recruitment. The parameters of the stock-recruitment relationship model are shown in Supplementary Table 3-1.

(6) Levels Required for MSY Under Current Environmental Conditions and Reference Points

The F required for MSY under current environmental conditions (1976 onward), as estimated in the “Research Institute Meeting” published in September 2022 (Yoda et al. 2021b), is shown in Supplementary Table 3-2. Following the “Stock Management Policy Review Meeting” and the “Fishery Policy Council” held in February 2023, SBmsy (54,000 tons) was set as the target reference point in the harvest control scenarios under the resource management policy (https://www.jfa.maff.go.jp/j/suisin/#link1). The relationship between average SSB and average catch in weight at age at equilibrium (Yoda et al. 2021b) is shown in Fig. 4-12. The majority of the fish caught were age 0 and age 1 when the average SSB was below the limit reference point. The proportion of older fish tended to increase as the SSB increased.

(7) Stock Levels, Trends and Fishing Pressure Levels

Reference values for SSB required for MSY (SBmsy) and fishing pressure required to maintain SBmsy (Fmsy) are shown in a Kobe plot in Fig. 4-13. In addition, a summary of SSB and fishing pressure in 2023, and the comparison between these values and the reference points are shown in Supplementary Table 3-3. The spawning stock biomass of

2023 for this stock was over SBmsy (in other words, target reference points). The SSB of 2023 was 1.37 times SBmsy. In addition, the fishing pressure of 2023 was 1.99 times Fmsy. The F ratios (F/Fmsy) shown in the Kobe plot are the ratio between F values in each year and the value of F that gives the fishing pressure of Fmsy under the selectivity of F in each year, converted to %SPR. Based on trends seen in the previous 5 years (2019 to 2023), SSB is judged to be in an “increasing” trend. The SSB of this stock in the 2000s exceeded SBmsy in 2013 and 2015-2017 and was considerably below SBmsy in 2020; however, since the fishing pressure was below Fmsy in 2020-2021, the SSB again exceeded SBmsy after 2021.

5. Future Projections

(1) Setting Future Projections

Future projection calculations were performed from 2024 to 2054 using a forward method for cohort analysis applied to stock abundance estimates of 2023 from the stock assessment (Appendix 2). Recruitment in these future projections was predicted based on values for SSB in each year using the stock-recruitment relationship model. Calculations were replicated 10,000 times, assuming errors that follow log-normal distribution to account for uncertainty in recruitment. The catch in 2024 was assumed based on the projected stock abundance and the current fishing pressure (F2021-2023). The current fishing pressure is set to the F value that gives the %SPR corresponding to fishing pressure from 2021 to 2023 in this assessment, using the same selectivity and biological parameters (average body weight, etc.) as those used in the calculation of reference points. Fishing pressure after 2025 was calculated based on SSB projections for each year, according to the catch strategy compiled by the “Stock Management Policy Review Meeting” and set through the “Fishery Policy Council”. Catch in weight after 2025 was calculated based on the fishing pressure calculated using this catch strategy and biomass projections for each year.

(2) Harvest Control Rules

Fig. 5-1 shows the Harvest Control Rules (HCRs) for this stock according to the catch strategy set in the Basic Policy on Resource Management. These HCRs set fishing pressure equal to Fmsy multiplied by adjustment coefficient β when SSB is above the limit reference point and adopt linear reduction of fishing pressure down to the fishing ban level when SSB falls below the limit reference point, using an adjustment coefficient β of 0.8.

(3) Projected Values for 2025 and ABC calculation

The average projected catch in weight for 2025, calculated based on HCRs according to the catch strategy, is presented as ABC at 46,000 tons (Supplementary Table 3-4). The projected SSB in 2025 is forecast to be an average of 80,000 tons, which exceeds the limit reference points in all replicated calculations.

(4) Projections for 2026 onwards

Results of future projections, including 2026 and onwards, are shown in Fig. 5-2 and Tables 5-1, 5-2 and 5-3. If management based on the HCRs, which are according to catch strategy, is continued for 10 years, the average projected value for SSB in 2034 will be 63,000 tons (90% prediction interval of 29,000 to 116,000 tons), with a 55% probability that the projected value will exceed the target reference point, and a 100% probability that it will exceed the limit reference point.

As reference material, results of future projections when various β are used and when the current fishing pressure (F2021-2023) is continued are also shown. The average projected value for SSB in 2034 will be 59,000 tons (90% prediction interval of 27,000 to 109,000 tons) if β is set to 0.9 and 68,000 tons (90% prediction interval of 31,000 to 124,000 tons) if β is set to 0.7, with a 100% probability of exceeding the limit reference point in both cases. On the other hand, if the current fishing pressure is continued, the projected average SSB will be 45,000 tons (with a 90% prediction interval of 19,000 to 84,000 tons), with a 96% probability that it will exceed the limit reference points, and a 25% probability that it will exceed the target reference points.

6. Summary of Stock Assessment

The resource biomass in 2023 saw a significant increase compared to the previous year, with spawning stock biomass (SSB) exceeding the level required to achieve MSY (SBmsy) and the trend is judged to be “increasing” based on the trend over the previous five years (2019 to 2023). The fishing pressure was over the fishing pressure level (Fmsy) required to maintain SBmsy.

7. Others

This species has a short life span, and the majority of the catch consists of fish age 0 to 1. In order to ensure stable utilization of this stock, we believe that it will be effective to maintain SSB above a certain level. Therefore, when recruitment is deemed to be low, measures such as refraining from catching age 0 fish are believed to be effective.

One of the factors that may cause significant uncertainty in the stock assessment results and future projections for this stock is the recent increase in the stock population of Tsushima Warm Current Stock of Japanese sardines. In 2023, in particular, the catch in weight of Japanese sardines in the East China Sea increased dramatically, and the fishing pattern targeting sardines may be changing. In the future, it will be necessary to enhance the collection of catch data further and carefully assess the catch status while accounting for possible uncertainties (Appendix 9).

8. Cited literature

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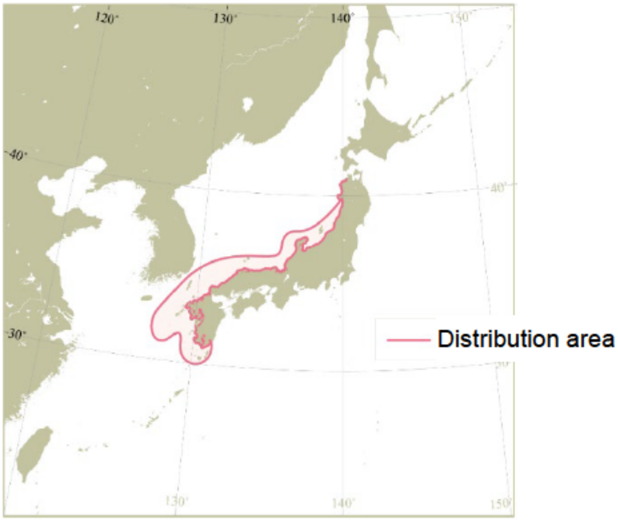


Fig. 2-1. Distribution area

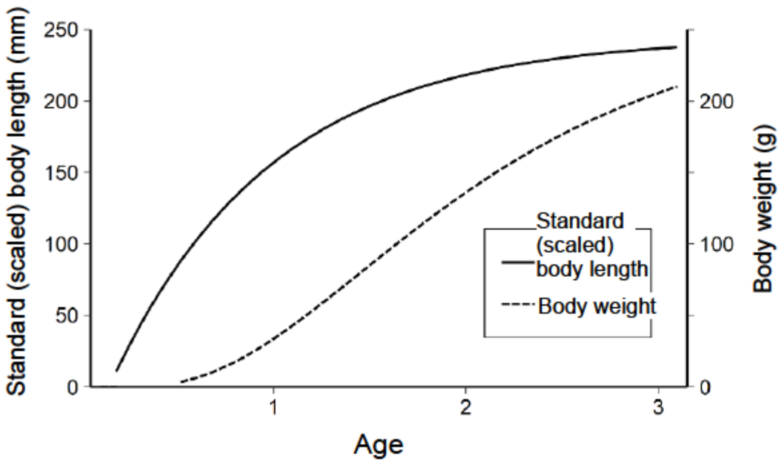


Fig. 2-2. Age and growth

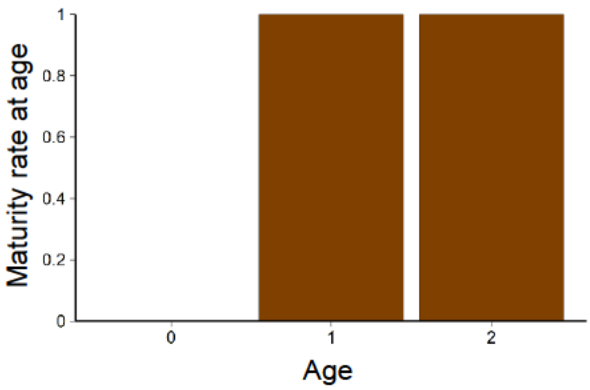


Fig. 2-3. Maturity rate at age

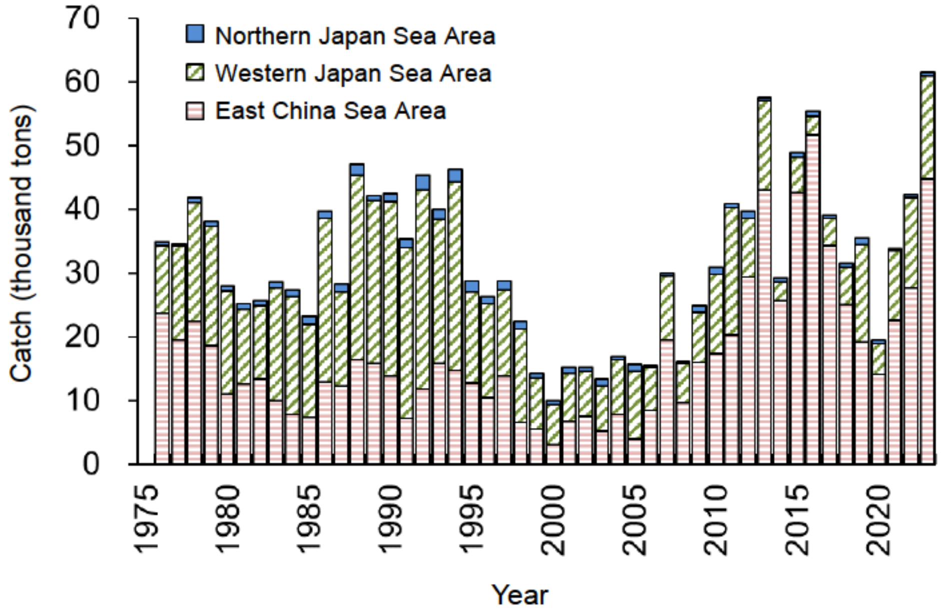


Fig. 3-1. Trends in catch in weight

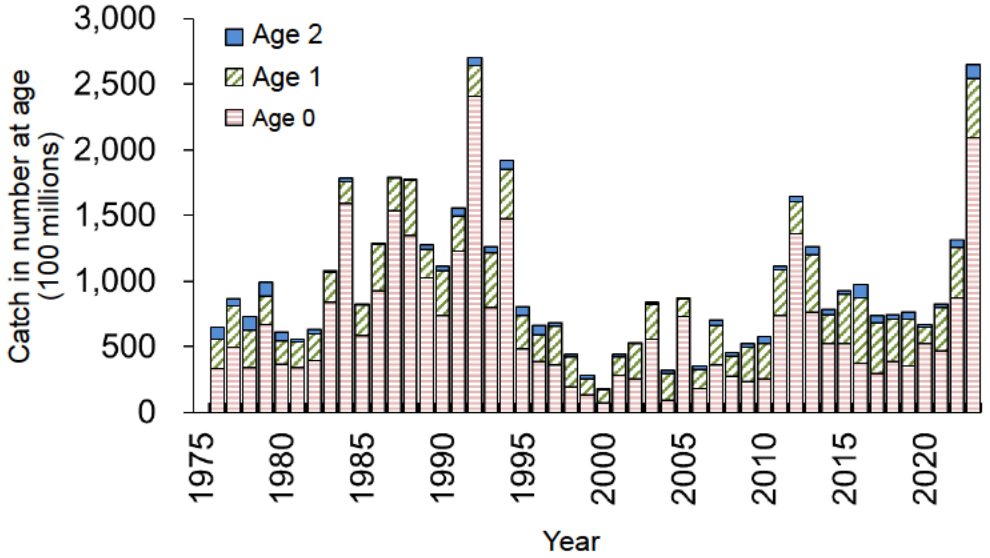


Fig. 3-2. Trends in catch in number at age

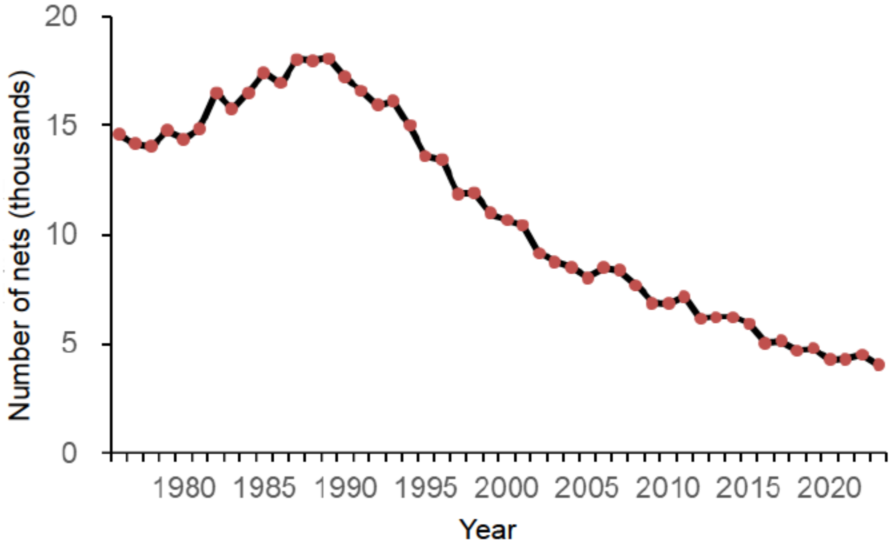


Fig 3-3. Trends in the number of large- and medium-sized purse seines operating in the East China Sea and the Western Sea of Japan

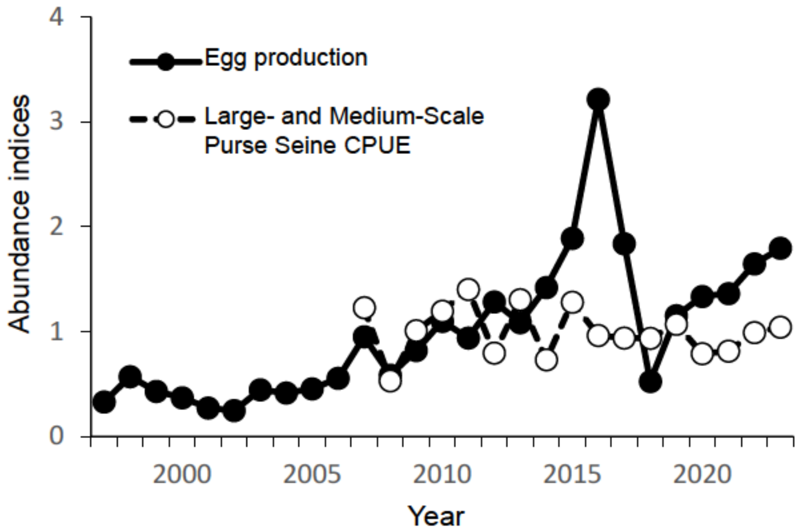


Fig. 4-1. Trends in abundance indices (Standardized and presented as an average value)

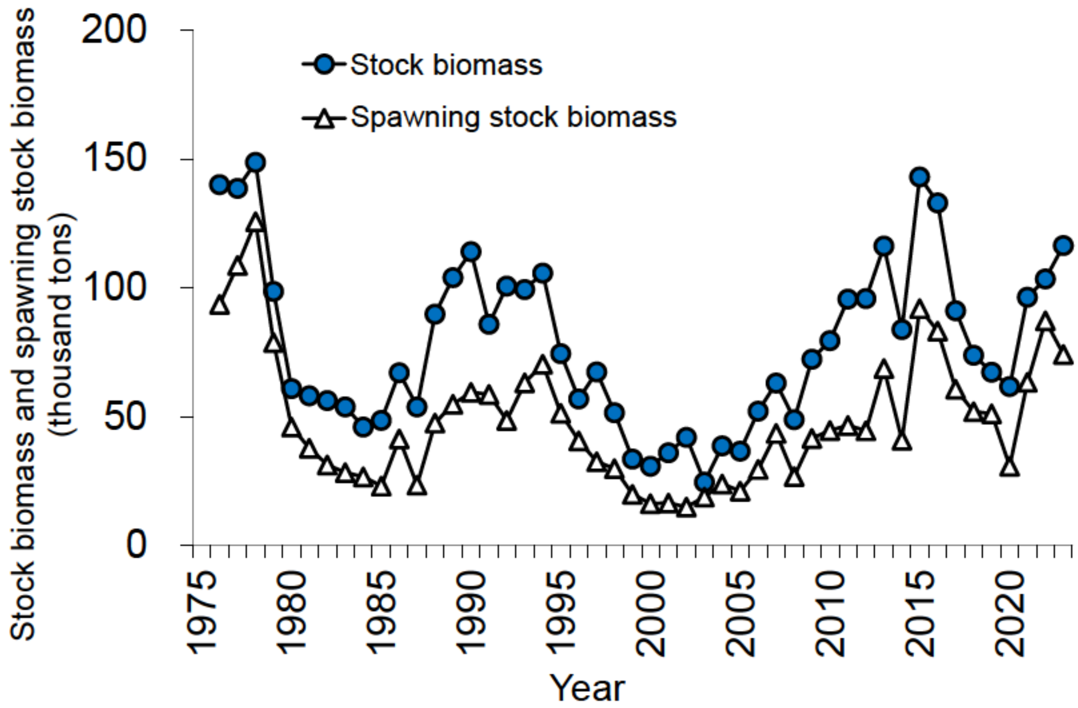


Fig. 4-2. Trends in stock biomass and spawning stock biomass

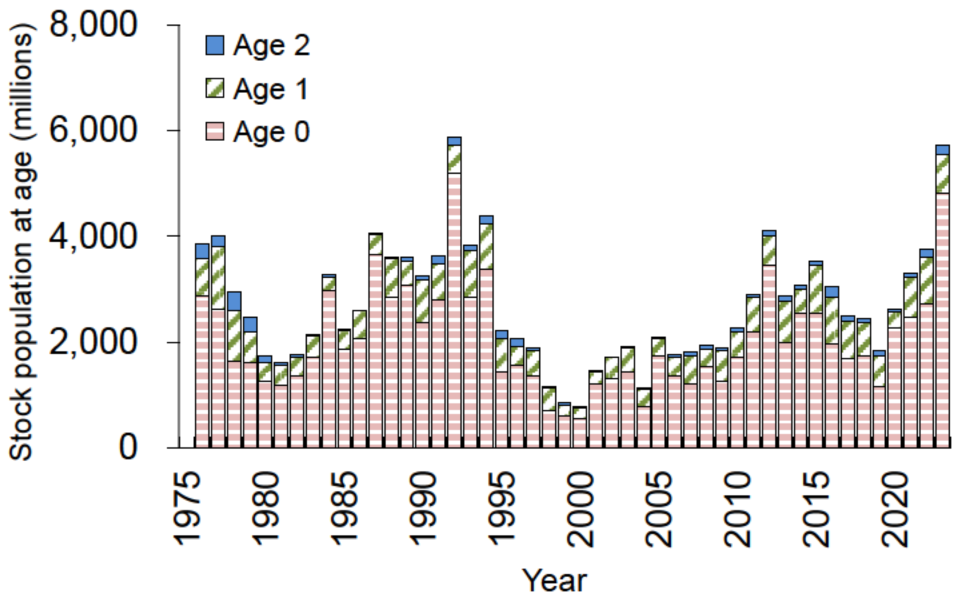


Fig. 4-3. Trends in stock population at age

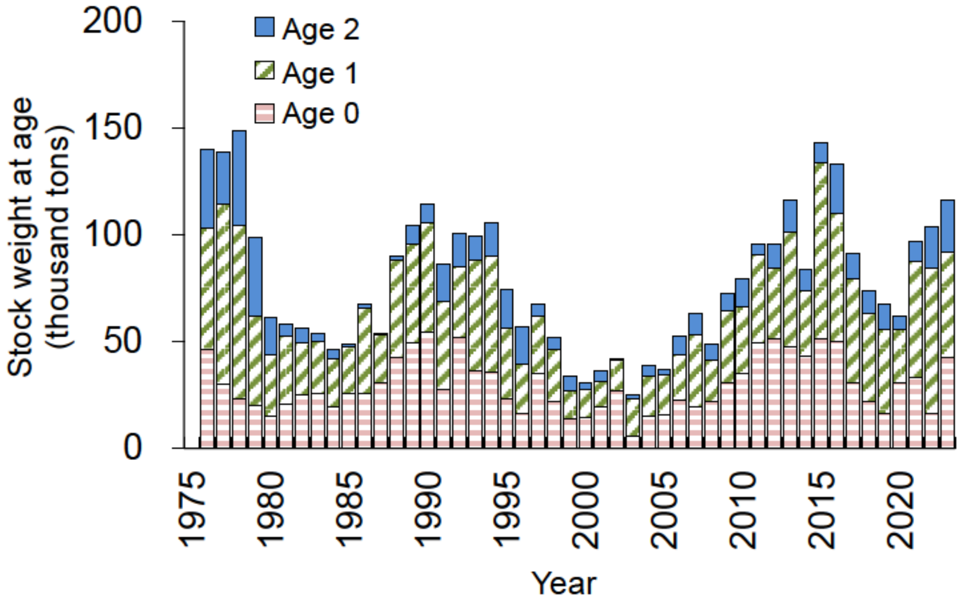


Fig. 4-4. Trends in stock weight at age

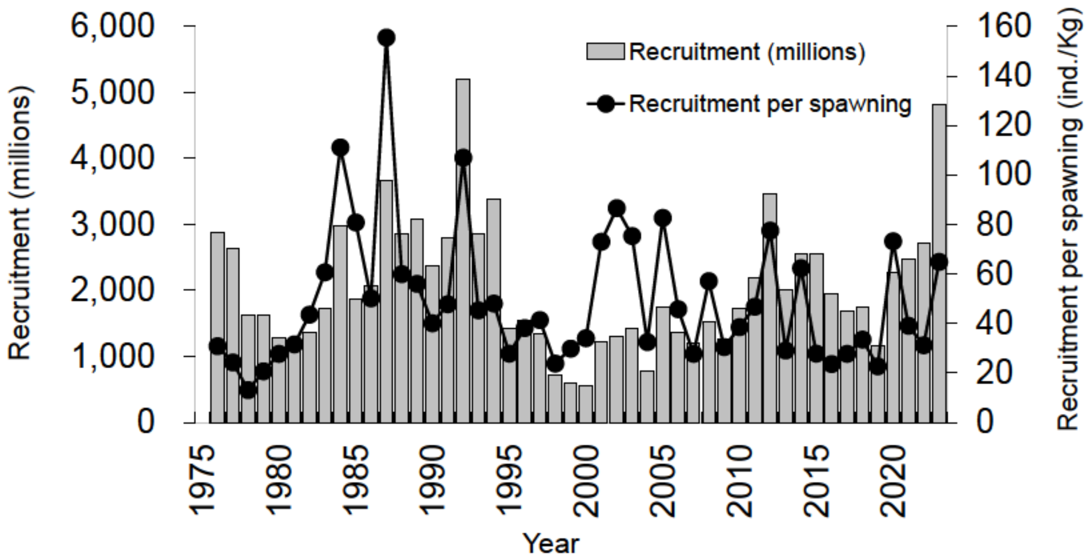


Fig. 4-5. Trends in recruitment and recruitment per spawning (RPS)

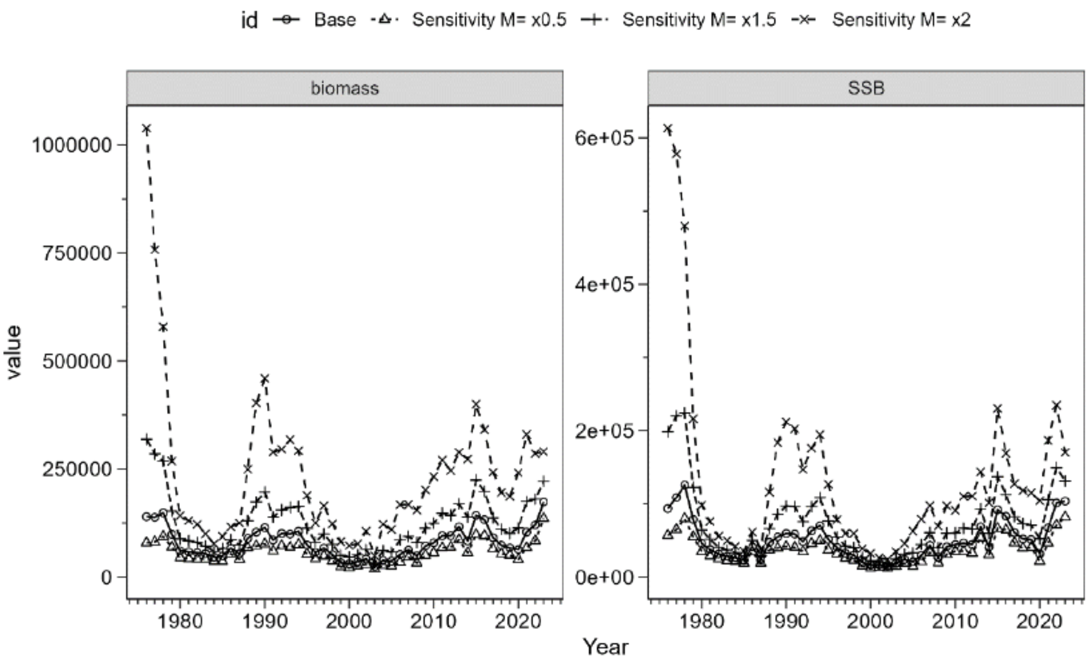


Fig. 4-6. Impact of natural mortality M on the estimation of stock biomass and spawning stock biomass

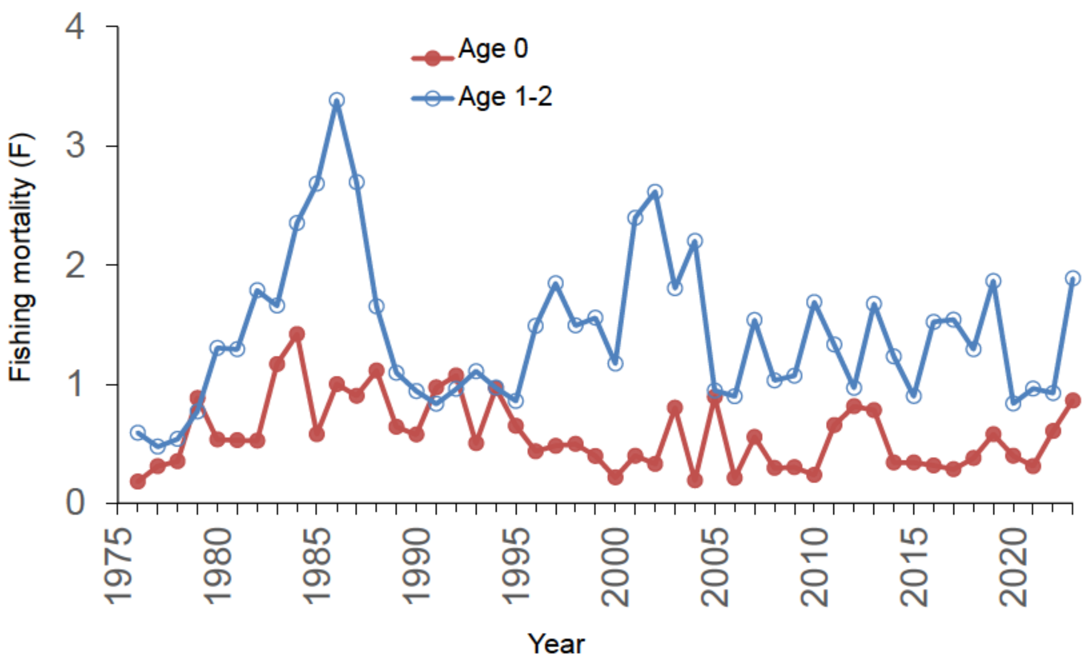


Fig. 4-7. Trends in fishing mortality Fat age

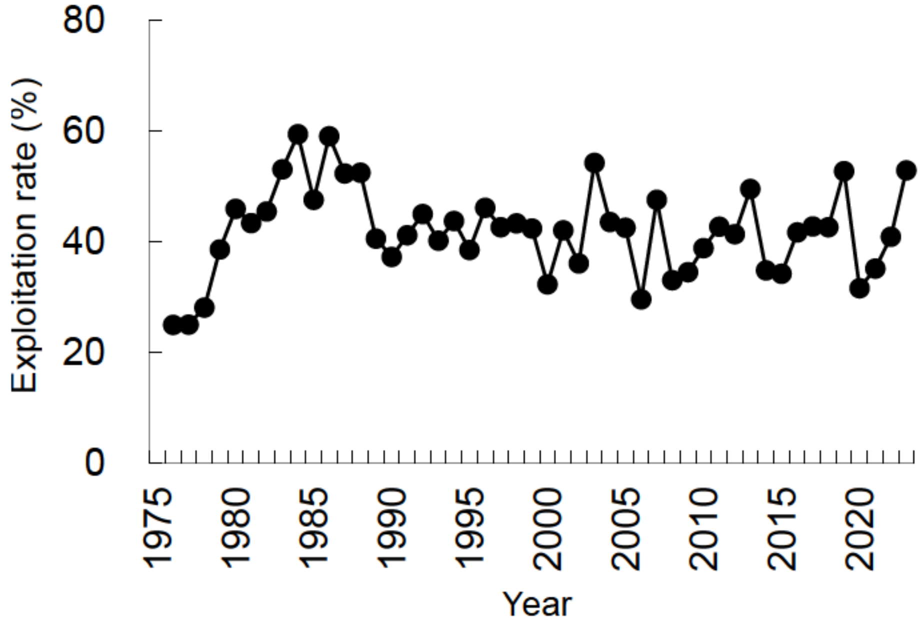


Fig. 4-8. Trends in exploitation rate

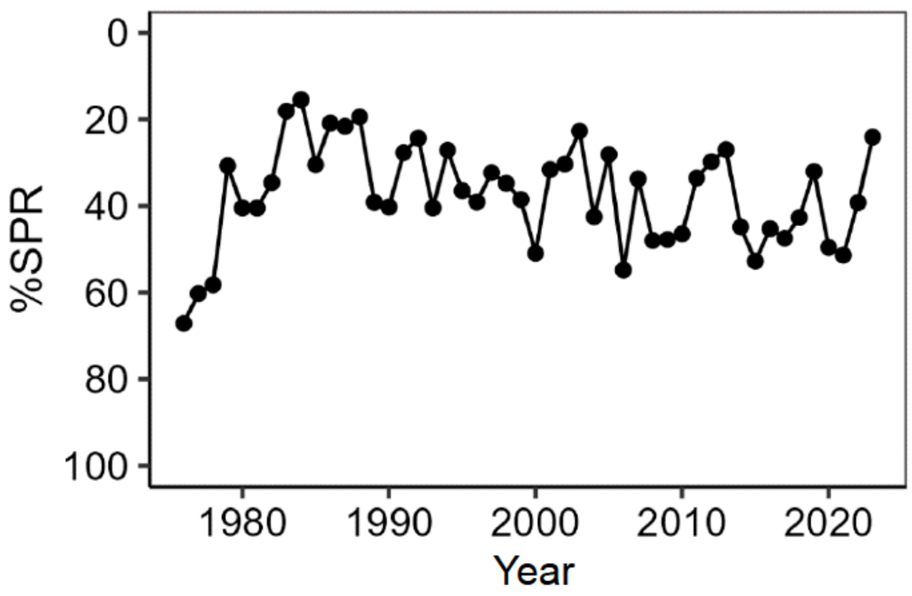


Fig. 4-9. Trends in %SPR

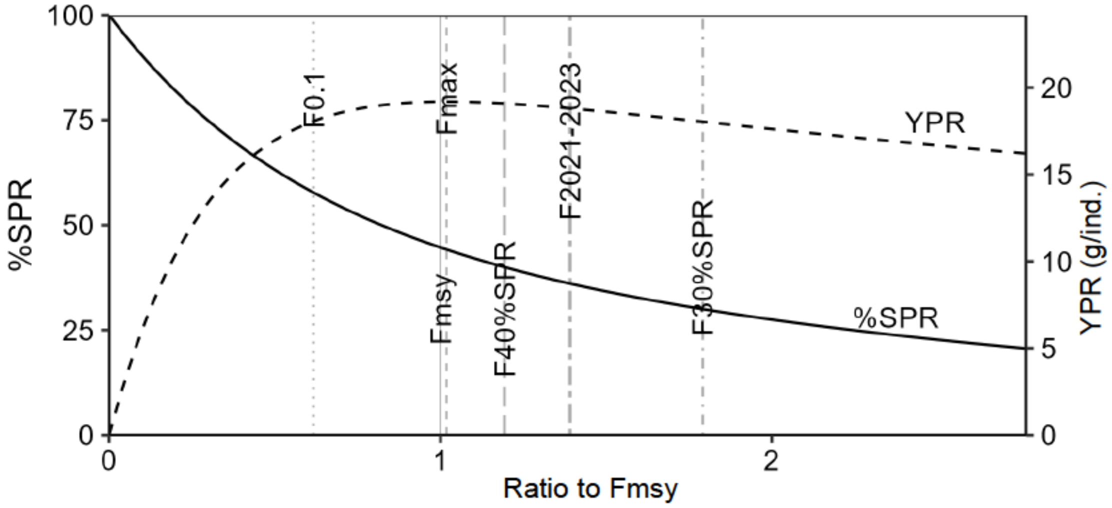


Fig. 4-10. Relationship between YPR and %SPR with respect to Fmsy

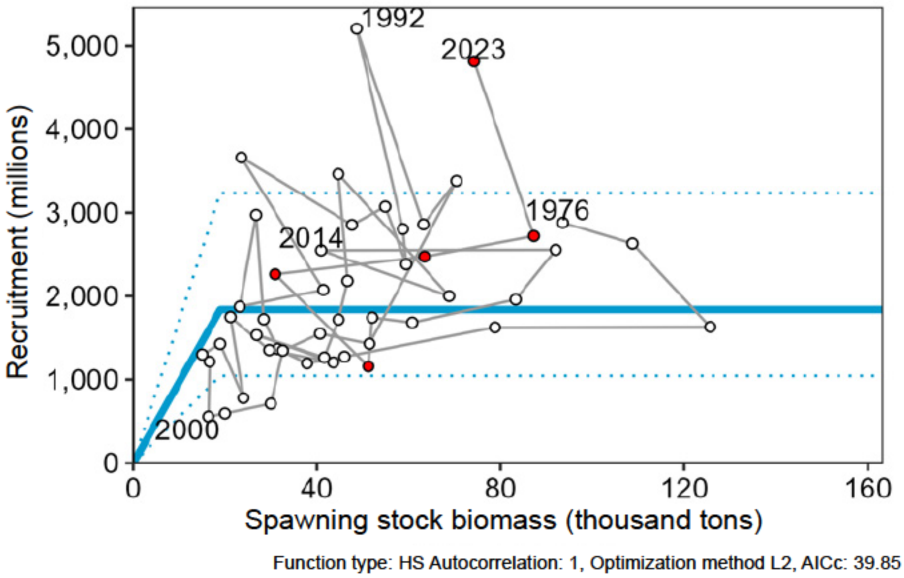


Fig. 4-11. Relationship between spawning stock biomass and recruitment (stock-recruitment relationship)

The proposed stock-recruitment relationship equation and the plot of the recruitment relationship at the “Research Institute Meeting” held in September 2021 (Yoda et al., 2021b). The dotted lines above and below the stock-recruitment relationship model (solid blue line) in the figure represent the interval estimated to contain 90% of observed data in the assumed stock-recruitment relationship. The white circles indicate SSB and recruitment from 1976 to 2023 for this fiscal year’s assessment (with red circles indicating data for 2019 to 2023). The numbers in the figure indicate the cohort (birth year) of the recruited stock.

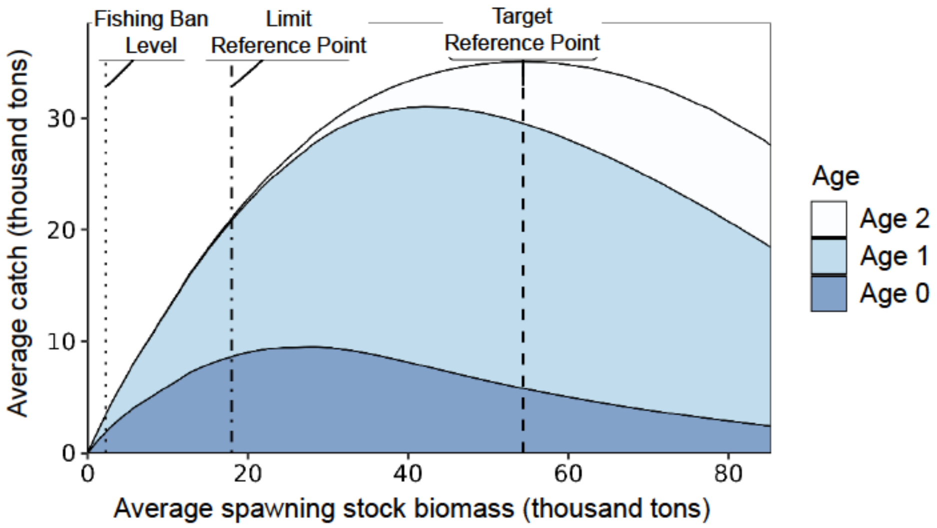


Fig. 4-12. Relationship of average SSB and average catch in weight at age at equilibrium (catch in weight curve)

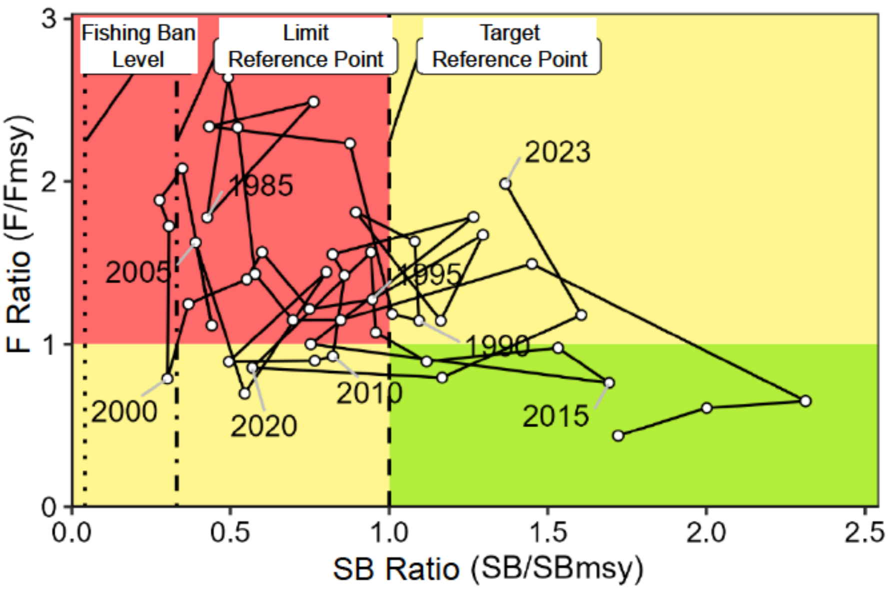
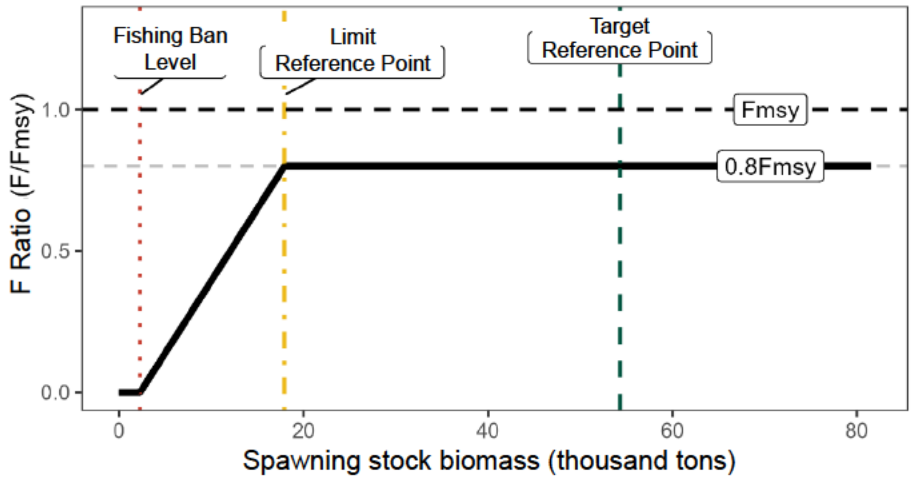


Fig. 4-13. Relationship of SSB required for MSY (SBmsy) and fishing pressure required to maintain SBmsy (Fmsy) against past levels of SSB and fishing pressure (Kobe plot)

a) When the vertical axis is fishing pressure



b) When the vertical axis is catch

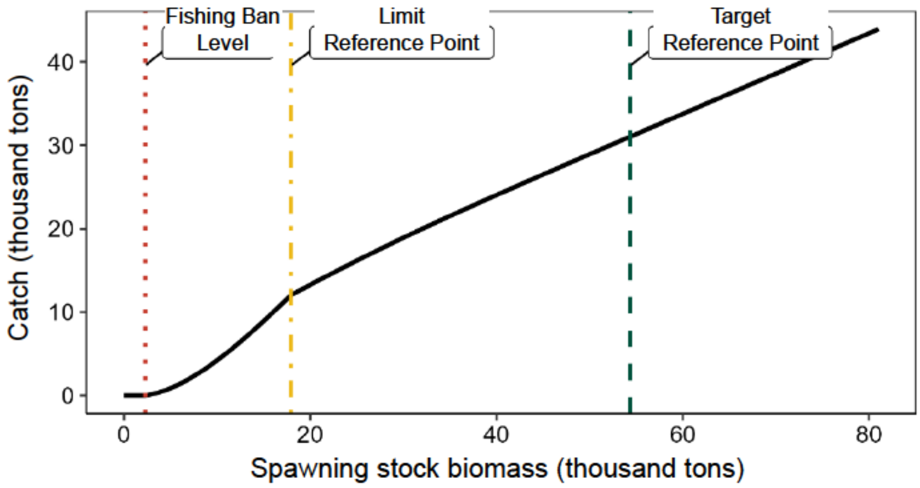


Fig. 5-1. Harvest control rules according to catch strategy

The target reference point is the spawning stock biomass required for the realization of MSY calculated based on the hockey stick (HS) type stock-recruitment relationship. The SSB required for a catch of 60% of the MSY is set as a limit reference point, and the SSB required for a catch of 10% of the MSY is set as a fishing ban level. Adjustment coefficient β = 0.8 was used. The line type and color indicate the following: The black dashed line indicates Fmsy, the gray dashed line indicates 0.8 Fmsy, the black thick line indicates the HCRs according to catch strategy, the red dotted line indicates the fishing ban level, the yellow dotted line indicates the limit reference point, and the green dashed line indicates the target reference point. a) When the vertical axis represents fishing pressure, b) When the vertical axis represents catch. For b), the catch in weight for the average age composition at equilibrium is shown.

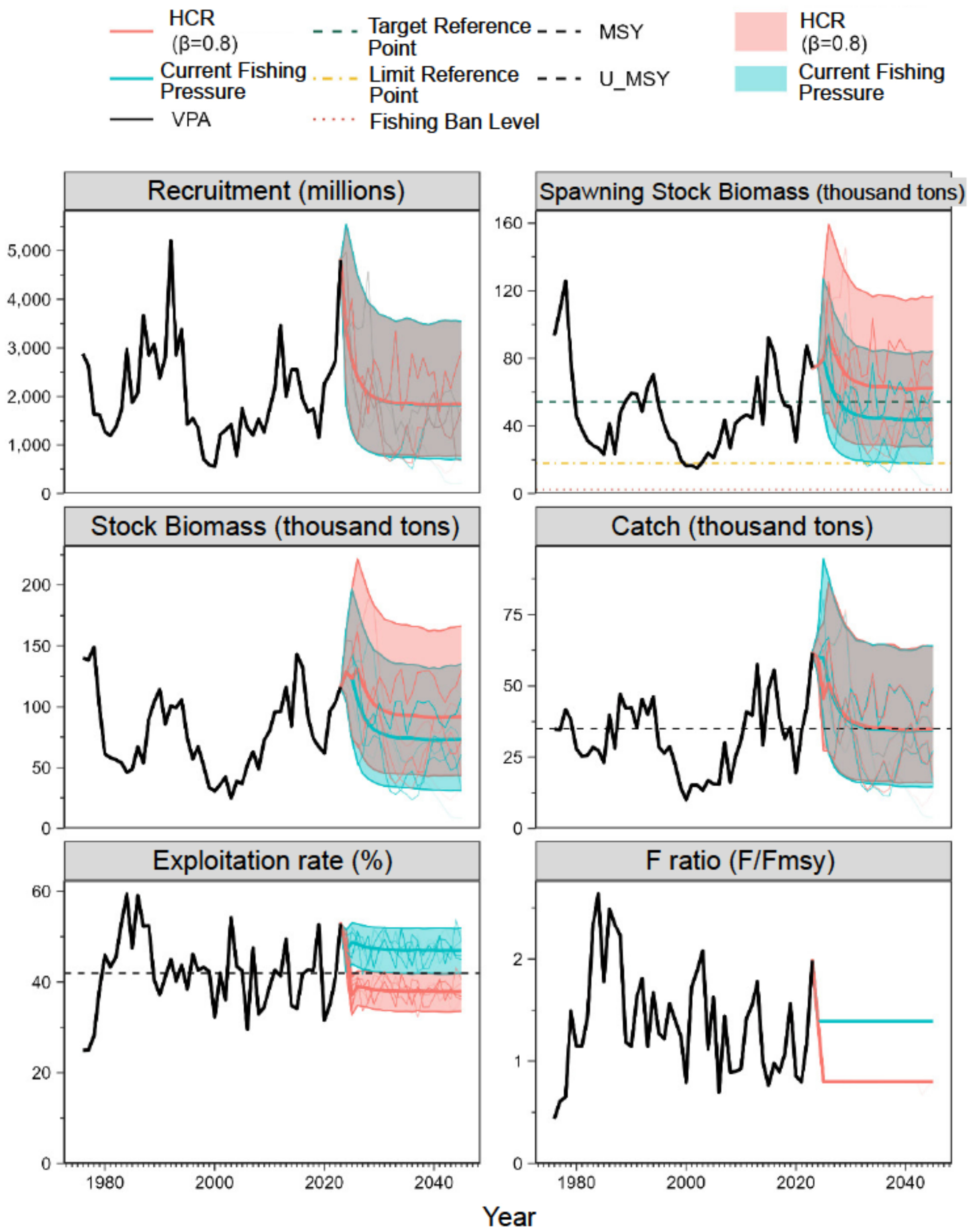


Fig. 5-2. Future projections based on the HCRs (red line) and future projections if the current fishing pressure (F2021-2023) is continued (blue line), as outlined in the catch strategy

The solid line indicates average values, the shaded area indicates the prediction interval, which contains 90% of simulation results, and the thin lines indicate 5 future projections. In the SSB graph, the green dashed line indicates the target reference point, the yellow dotted line indicates the limit reference point, and the red dotted line indicates the fishing ban level. In the catch graph, the dashed line indicates the maximum sustainable yield MSY. In the exploitation rate graph, the dashed line indicates the level of exploitation rate (Umsy) that maintains target reference points. In the catch strategy for this stock, an adjustment coefficient β = 0.8 was used. The catch in 2024 was assumed based on the projected stock abundance and the current fishing pressure (F2021-2023).

Table 3-1. Catch of round herring Tsushima warm current stock (tons)

Year	East China Sea Area	Western Japan Sea Area	Northern Japan Sea Area	Total	South Korea
1976	23,586	10,614	718	34,918	2,869
1977	19,516	14,671	428	34,615	6,227
1978	22,369	18,693	675	41,737	9,607
1979	18,586	18,671	828	38,085	4,212
1980	10,975	16,235	782	27,992	5,102
1981	12,585	11,698	949	25,232	4,244
1982	13,268	11,535	802	25,605	5,625
1983	9,949	17,699	910	28,558	10,606
1984	7,745	18,551	1,088	27,384	10,829
1985	7,244	14,684	1,186	23,114	8,994
1986	12,897	25,713	1,042	39,652	14,033
1987	12,244	14,826	1,115	28,185	10,300
1988	16,421	28,863	1,794	47,078	10,693
1989	15,789	25,488	854	42,131	7,280
1990	13,798	27,431	1,211	42,440	4,205
1991	7,152	26,755	1,420	35,327	4,463
1992	11,816	31,200	2,266	45,282	3,597
1993	15,709	22,671	1,548	39,928	24,383
1994	14,640	29,546	2,045	46,231	23,974
1995	12,770	14,222	1,668	28,660	18,345
1996	10,401	14,803	1,052	26,256	10,663
1997	13,799	13,518	1,421	28,738	5,593
1998	6,505	14,710	1,125	22,340	1,974
1999	5,416	8,068	780	14,264	6,674
2000	3,006	6,244	700	9,950	4,603
2001	6,769	7,520	863	15,152	766
2002	7,535	7,063	580	15,178	788
2003	5,232	7,064	1,101	13,397	885
2004	7,740	8,621	487	16,848	755
2005	3,876	10,638	1,083	15,597	-
2006	8,453	6,739	229	15,421	–
2007	19,544	9,952	499	29,995	–
2008	9,685	6,036	441	16,162	–
2009	15,980	7,813	1,146	24,939	–
2010	17,278	12,486	1,114	30,878	–

Table 3-1. (Continued)

Year	East China Sea Area	Western Japan Sea Area	Northern Japan Sea Area	Total	South Korea
2011	20,290	19,914	631	40,835	0
2012	29,401	9,174	1,030	39,605	–
2013	42,973	14,007	540	57,520	–
2014	25,641	2,887	670	29,198	–
2015	42,558	5,551	774	48,883	–
2016	51,631	2,865	917	55,413	–
2017	34,254	4,339	367	38,960	–
2018	25,082	5,782	615	31,479	–
2019	19,151	15,320	1028	35,499	–
2020	14,129	4,745	623	19,497	–
2021	22,524	10,961	371	33,857	–
2022	27,678	14,151	457	42,298	–
2023	44,728	16,110	685	61,574	–

Japan’s catch for 2023 is a provisional value.

Table 4-1. Stock analysis results for the Tsushima Warm Current Stock of round herring

Year	Stock biomass (Ton)	Spawning stock biomass (Ton)	Recruitment (10,000 fish)	Exploitation rate (%)	Recruitment per spawning (RPS) (fishes/kg)	%SPR	F/Fmsy
1976	139,996	93,572	287,970	25	31	67.1	0.44
1977	138,573	108,728	263,044	25	24	60.2	0.61
1978	148,711	125,671	163,148	28	13	58.2	0.65
1979	98,666	78,781	162,538	39	21	30.7	1.49
1980	60,941	46,031	127,399	46	28	40.5	1.15
1981	58,188	37,851	119,384	43	32	40.5	1.15
1982	56,352	31,402	136,787	45	44	34.6	1.43
1983	53,834	28,400	172,352	53	61	18.1	2.33
1984	46,073	26,767	297,385	59	111	15.5	2.64
1985	48,628	23,194	187,439	48	81	30.5	1.78
1986	67,136	41,395	207,426	59	50	20.9	2.49
1987	53,893	23,543	366,208	52	156	21.6	2.34
1988	89,763	47,635	285,387	52	60	19.4	2.23
1989	103,970	54,878	307,303	41	56	39.1	1.19
1990	114,078	59,465	238,126	37	40	40.3	1.14
1991	85,892	58,734	280,458	41	48	27.7	1.63
1992	100,723	48,647	520,556	45	107	24.4	1.81
1993	99,355	63,183	285,954	40	45	40.5	1.14
1994	105,718	70,386	338,137	44	48	27.1	1.67
1995	74,504	51,443	142,875	38	28	36.5	1.27
1996	56,969	40,690	155,033	46	38	39.1	1.22
1997	67,452	32,578	134,751	43	41	32.3	1.56
1998	51,600	29,942	71,039	43	24	34.8	1.40
1999	33,661	19,967	59,428	42	30	38.5	1.25
2000	30,830	16,361	55,615	32	34	51.0	0.79
2001	36,063	16,625	121,392	42	73	31.6	1.72
2002	42,097	15,017	130,066	36	87	30.4	1.88
2003	24,713	18,942	142,696	54	75	22.7	2.08
2004	38,719	23,983	77,851	44	32	42.5	1.12
2005	36,699	21,182	175,077	42	83	28.1	1.62
2006	52,180	29,599	135,422	30	46	54.8	0.70
2007	63,107	43,588	120,506	48	28	33.8	1.44
2008	48,946	26,868	153,382	33	57	48.0	0.89
2009	72,404	41,597	126,479	34	30	47.8	0.90
2010	79,585	44,705	171,935	39	38	46.5	0.93

Table 4-1. (Continued)

Year	Stock biomass (Ton)	Spawning stock biomass (Ton)	Recruitment (10,000 fish)	Exploitation rate (%)	RPS (fishes/kg)	%SPR	F/Fmsy
2011	95,695	46,677	218,210	43	47	33.6	1.42
2012	95,823	44,663	346,346	41	78	29.8	1.55
2013	116,228	68,801	200,057	49	29	27.0	1.78
2014	83,887	40,920	254,923	35	62	44.9	1.00
2015	143,010	92,019	255,507	34	28	52.8	0.76
2016	132,946	83,273	195,829	42	24	45.3	0.98
2017	91,123	60,771	168,355	43	28	47.5	0.89
2018	73,898	52,051	174,328	43	33	42.7	1.07
2019	67,340	51,216	115,740	53	23	32.0	1.56
2020	61,754	30,906	226,140	32	73	49.6	0.86
2021	96,416	63,422	247,343	35	39	51.4	0.80
2022	103,445	87,274	271,996	41	31	39.2	1.18
2023	116,411	74,235	481,320	53	65	24.1	1.99

Table 5-1. Probability of future spawning stock biomass exceeding the limit reference point

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

β	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	100	87	83	70	61	54	50	48	46	44	44	43
0.9			87	76	67	60	56	54	52	50	50	49
0.8			90	81	72	66	62	60	58	56	55	55
0.7			93	86	78	72	68	66	64	62	62	62
0.6			95	90	83	78	74	72	71	69	68	68
0.5			97	93	87	83	80	78	77	75	75	74
0.4			98	96	91	88	85	84	83	81	81	80
0.3			99	98	94	91	90	88	87	86	86	86
0.2			100	99	97	95	93	92	91	91	90	90
0.1			100	100	98	97	96	95	94	94	94	94
0.0			100	100	99	98	98	97	97	97	97	96
Current fishing pressure			64	49	40	34	31	29	27	27	25	26

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

β	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	100	100	100	100	100	100	99	99	99	99	99	99
0.9			100	100	100	100	100	99	99	99	100	100
0.8			100	100	100	100	100	100	100	100	100	100
0.7			100	100	100	100	100	100	100	100	100	100
0.6			100	100	100	100	100	100	100	100	100	100
0.5			100	100	100	100	100	100	100	100	100	100
0.4			100	100	100	100	100	100	100	100	100	100
0.3			100	100	100	100	100	100	100	100	100	100
0.2			100	100	100	100	100	100	100	100	100	100
0.1			100	100	100	100	100	100	100	100	100	100
0.0			100	100	100	100	100	100	100	100	100	100
Current fishing pressure			100	100	99	98	97	96	96	96	96	96

The results of future projections when β is varied from 0.0 to 1.0 are shown. The catch for 2024 has been set at 59,900 tons, predicted based on the current fishing pressure (F2021-2023), and from 2025 onward, the catch is determined according to the catch strategy. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2021-2023, corresponding to β = 1.39).

Table 5-2. Future average spawning stock biomass (thousand tons)

β	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	76	80	83	73	67	62	60	58	57	56	56	56
0.9			88	78	71	66	64	62	61	60	59	59
0.8			93	84	76	71	68	66	65	64	63	63
0.7			99	90	82	76	73	71	70	68	68	68
0.6			105	98	88	82	78	76	75	74	73	73
0.5			112	106	95	89	85	82	81	80	79	79
0.4			120	115	104	96	92	90	88	86	86	85
0.3			129	126	114	105	101	98	96	94	93	93
0.2			138	139	125	116	110	107	105	103	102	102
0.1			149	154	138	128	122	118	116	114	113	113
0.0			162	172	153	142	135	131	128	126	125	125
Current fishing pressure			68	59	54	50	48	47	46	45	45	45

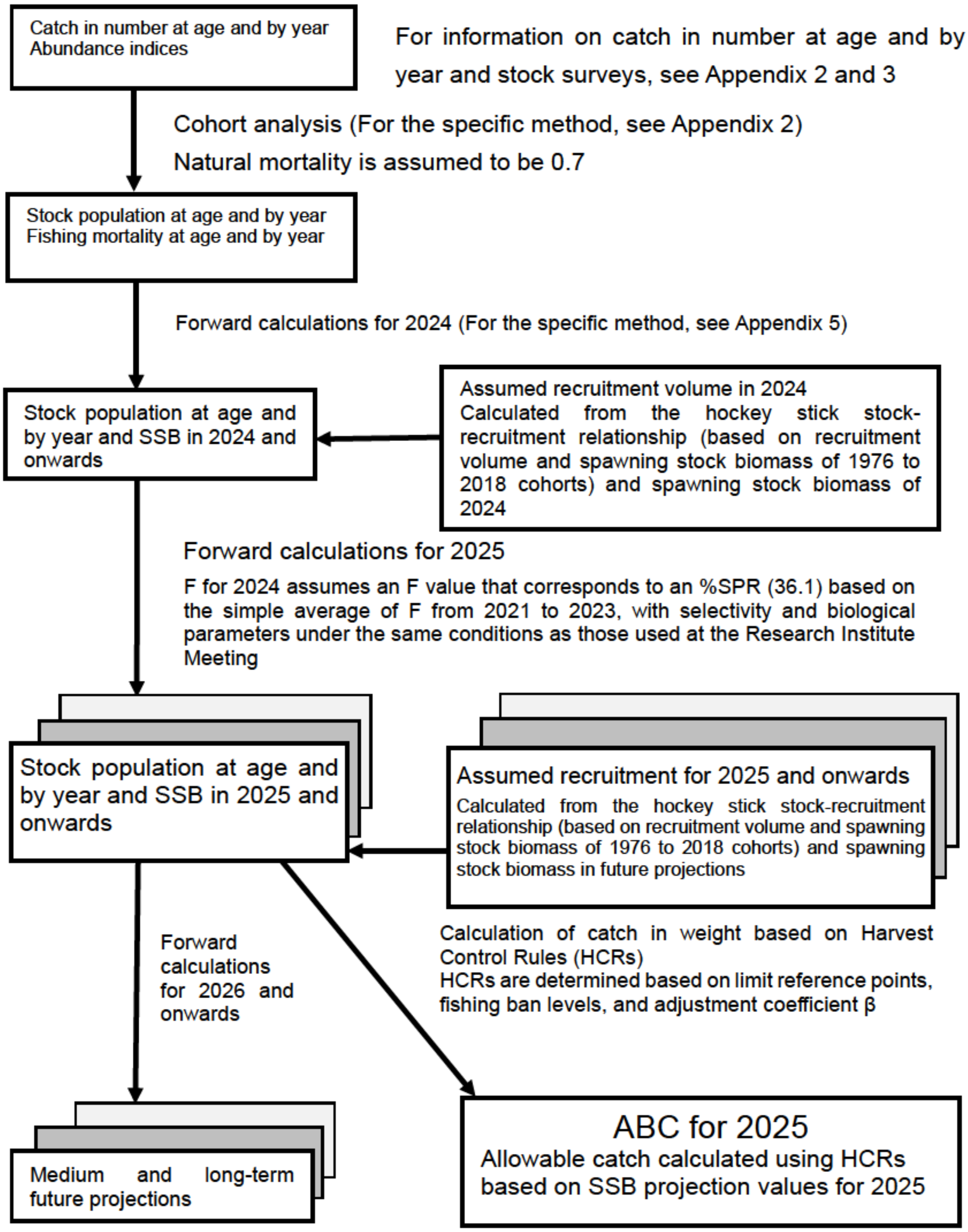
The results of future projections when β is varied from 0.0 to 1.0 are shown. The catch for 2024 has been set at 59,900 tons, predicted based on the current fishing pressure (F2021-2023), and from 2025 onward, the catch is determined according to the catch strategy. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2021-2023, corresponding to β = 1.39).

Table 5-3. Future average catch (thousand tons)

β	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	59.9	51.5	52.2	46.5	42.4	39.7	38.2	37.3	36.6	36.1	35.9	35.9
0.9		48.7	51.8	46.5	42.4	39.6	38.2	37.2	36.5	36.0	35.8	35.7
0.8		45.6	51.1	46.3	42.1	39.3	37.8	36.9	36.2	35.7	35.4	35.4
0.7		42.0	49.8	45.6	41.4	38.6	37.1	36.2	35.5	35.0	34.7	34.7
0.6		38.0	47.7	44.3	40.1	37.4	35.9	35.0	34.4	33.8	33.6	33.5
0.5		33.5	44.7	42.1	38.1	35.5	34.0	33.2	32.5	32.0	31.8	31.7
0.4		28.4	40.4	38.8	35.0	32.6	31.2	30.4	29.8	29.3	29.1	29.0
0.3		22.6	34.4	33.7	30.3	28.2	27.0	26.3	25.8	25.4	25.1	25.1
0.2		16.0	26.2	26.2	23.6	21.9	20.9	20.3	19.9	19.6	19.4	19.4
0.1		8.5	15.0	15.4	13.8	12.8	12.2	11.9	11.7	11.5	11.4	11.4
0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Current fishing pressure		59.9	51.2	44.9	41.1	38.6	37.3	36.4	35.7	35.2	34.9	34.9

The results of future projections when β is varied from 0.0 to 1.0 are shown. The catch for 2024 has been set at 59,900 tons, predicted based on the current fishing pressure (F2021-2023), and from 2025 onward, the catch is determined according to the catch strategy. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2021-2023, corresponding to β = 1.39).

Appendix 1 Stock Assessment Flow



Appendix 2 Calculation Methods

(1) Stock Calculation Methods

Using the catch in number at age and by year and the abundance indices from 1976 to 2023, the stock population at age and by year was estimated using tuned VPA (cohort analysis). For catch in number at age, data on landings and body length composition from major ports in the Sea of Japan to the East China Sea area for each month were used to aggregate monthly catch in weight and body length composition separately for the Sea of Japan and East China Sea areas. The body length composition was stretched to match the total value of the catch. Regarding body length composition from March to April 2023, when the number of samples was particularly high, the number of fish measured at one time was capped at 100 fish in order to reduce bias due to sampling. From the body length composition stretched by ocean area and month, the catch in number at age was calculated using a length-age key created by month and ocean area based on Ohshimo et al. (2011). The average weight of the catch by age for 2023 is shown in Supplementary Table 2-1, the natural mortality M used in stock calculations is shown in Supplementary Table 2-2, and the maturity rate is shown in Supplementary Table 2-3. Calculations were performed using the R package frasyr (version 2.4.0.0).

The starting month for the VPA was set to January, and the Pope approximation formula was used to calculate the stock population by age and year (Pope 1972). In addition, the lifespan of round herring was presumed to be 3 years (death at the end of age 2). Stock calculation methods are shown below.

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

The following equation (1) was used to calculate the stock population at age and by year of fish age 0 and 1 up to 2022, excluding the most recent year (2023).

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

In this equation, $N_{a,y}$ is the stock population of fish age a in year y, $C_{a,y}$ is the catch in number of fish age a in year y, and M is natural mortality (0.7). In addition, the following equation (2) was used to calculate the stock population of the oldest fish (age 2) and each age group in the most recent year (2023).

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

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

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

F was assumed to be equal for age 2 and age 1 fish. In the cohort analysis, F (terminal F) of fish age 0 and 1 in the most recent year (2023) was first set equal to the average value for fish of each age group in the previous 3-year period (2020 to 2022). F of fish age 2 was set equal to F of fish age 1. Next, we further adjusted F in the most recent year following the method in Step 2.

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

We obtained terminal F in an exploratory manner using tuning based on abundance indices. In Step 2, the selectivity that was calculated based on F in the most recent year (2023) obtained in Step 1 was assumed to be the selectivity of terminal F, and the value of F, which is multiplied by selectivity, was estimated using tuning.

The abundance indices used for tuning F were egg production obtained from egg and larvae surveys and the catch per net of large and medium-sized purse seine fishing boats (hereinafter referred to as large and medium-sized purse seine CPUE). Egg production is the total quantity of round herring eggs collected using NORPAC nets from Kagoshima to Aomori Prefectures in western Kyushu to the Sea of Japan coast (January to June) and standardized to average egg density (Appendix 5). We calculated large and medium-sized purse seine CPUE using directed CPUE, which was calculated by selecting operations that accounted for 90% of the total round herring catch for the year, starting with operations having the highest catch proportion of round herring per net (Appendix 6) (Biseau 1998).

Terminal F, which is the value that is the best fit of SSB obtained from cohort analysis for egg production, and the best fit of biomass, including fish of all ages for the large and medium-sized purse seine CPUE, was estimated using the maximum likelihood method. Based on each abundance index, the negative log-likelihood function to be minimized was defined as shown below (Hashimoto et al. 2018).

$$-lnL = \sum_k \sum_y \left[\frac{\left[lnI_{k,y} - \left(b_k lnB_{k,y} + lnq_k\right)\right]^2}{2\sigma_k^2} - \ln\left(\frac{1}{\sqrt{2\pi}\sigma_k}\right) \right] \quad (4)$$

In this equation, $I_{k,y}$ is the observed value of index k in year y (1: egg production, 2: large and medium-sized purse seine CPUE), $B_{k,y}$ is the biomass that fits index k in year y (1. SSB, 2. biomass), and q_k, b_k and σ_k are estimated parameters (estimated at the same time as terminal F).

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

$$I_{k,y} = q_k B_{k,y}^{b_k} \quad (5)$$

In this stock assessment, b_k was fixed at 1 because the egg production showed a roughly proportional relationship with the SSB, and large and medium-sized purse seine CPUE (k = 2) was assumed to be nonlinear ($b_2 \neq 1$).

The periods that were fitted to index values were 1997 and onwards, when the number of survey points for egg production was relatively stable, and 1994 and onwards for large and medium-sized purse seine CPUE. Estimates for F were $F_{0,2023}$ = 0.86 and $F_{1,2023}$ = $F_{2,2023}$ = 1.89, while estimates for other parameters are shown at the bottom of Supplementary Table 2-4.

The statistical validity of the VPA used in this stock assessment and the robustness of its assumptions were evaluated according to the “Procedures for Model Diagnostics in Stock Assessment and Guidelines for Providing Diagnostics Results (FY 2024), FRA-SA2024-ABCWG02-03, Japan Fisheries Research and Education Agency (2024a)”. Residual plots showed outliers for egg production, while large and medium-sized purse seine CPUE showed relatively smaller variance (Supplementary Fig. 2-1). Retrospective analysis showed a trend of large outliers in 2019 for stock population, fishing mortality, and recruitment volume. However, we determined that there were no problems with the estimates of the most recent year. Retrospective bias (Mohn’s ρ, Mohn 1999) was not very large, with 0.18 for biomass, 0.32 for stock population, 0.36 for fishing mortality, 0.39 for recruitment, and 0.05 for SSB (Supplementary Fig. 2-2).

(2) Future Projection Methods

The values in Supplementary Table 2-5 were used for the various settings in the future projections. The calculation package frasyr (ver. 2.4.0.0) for the statistical software R (version 4.4.1) was used to calculate projections for stock population and catch. Recruitment in future projections was estimated using a hockey stick model (with parameters a = 0.0971, b = 1.89e+04, ρ = 0.67, SD = 0.34) for the stock-recruitment relationship, agreed upon at the Stock Management Policy Review Meeting held in fiscal year 2021 and estimated annual spawning stock biomass (SSB). The data used for parameter estimation of the stock-recruitment relationship comprised spawning stock biomass and recruitment based on the stock assessment of fiscal year 2020, with the least squares method used as the optimization method. Recruitment residual autocorrelation was considered. For details, please refer to the “Report for the Research Institute Meeting for the Tsushima Warm Current Stock of Round Herring” for fiscal year 2021 (Yoda et al., 2021).

The fishing mortality F used in the future projections were values estimated based on harvest control rules for Stock Group 1A according to “The Basic Guidelines for Harvest Control Rules and ABC Calculation in FY 2024 (FRA-SA2024-ABCWG02-01)” (Japan

Fisheries Research and Education Agency 2024b). For selectivity and the average body weight of the catch in the future projections, we continued to use the same values as were used to estimate the various proposed reference points in the “Materials for the Research Institute Meeting” described above (Yoda et al. 2021). Similar to the stock-recruitment relationship, these values are based on the FY 2020 stock assessment, with selectivity being the average values for the period from 2016 to 2018 and the average body weight in catches being the average values for 2017 to 2019. The fishing pressure in 2024 (F2024) was set to the F value that gives the %SPR corresponding to the age-specific fishing pressure from 2021 to 2023 in this year’s assessment under the same selectivity and biological parameters (average body weight, etc.) as those used when calculating the reference points.

Projections for the stock population were made using the forward method for cohort analysis (equations (6) to (8)).

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

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

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

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Biseau, A. (1998) Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquat. Living. Resour., **11**, 119-136.

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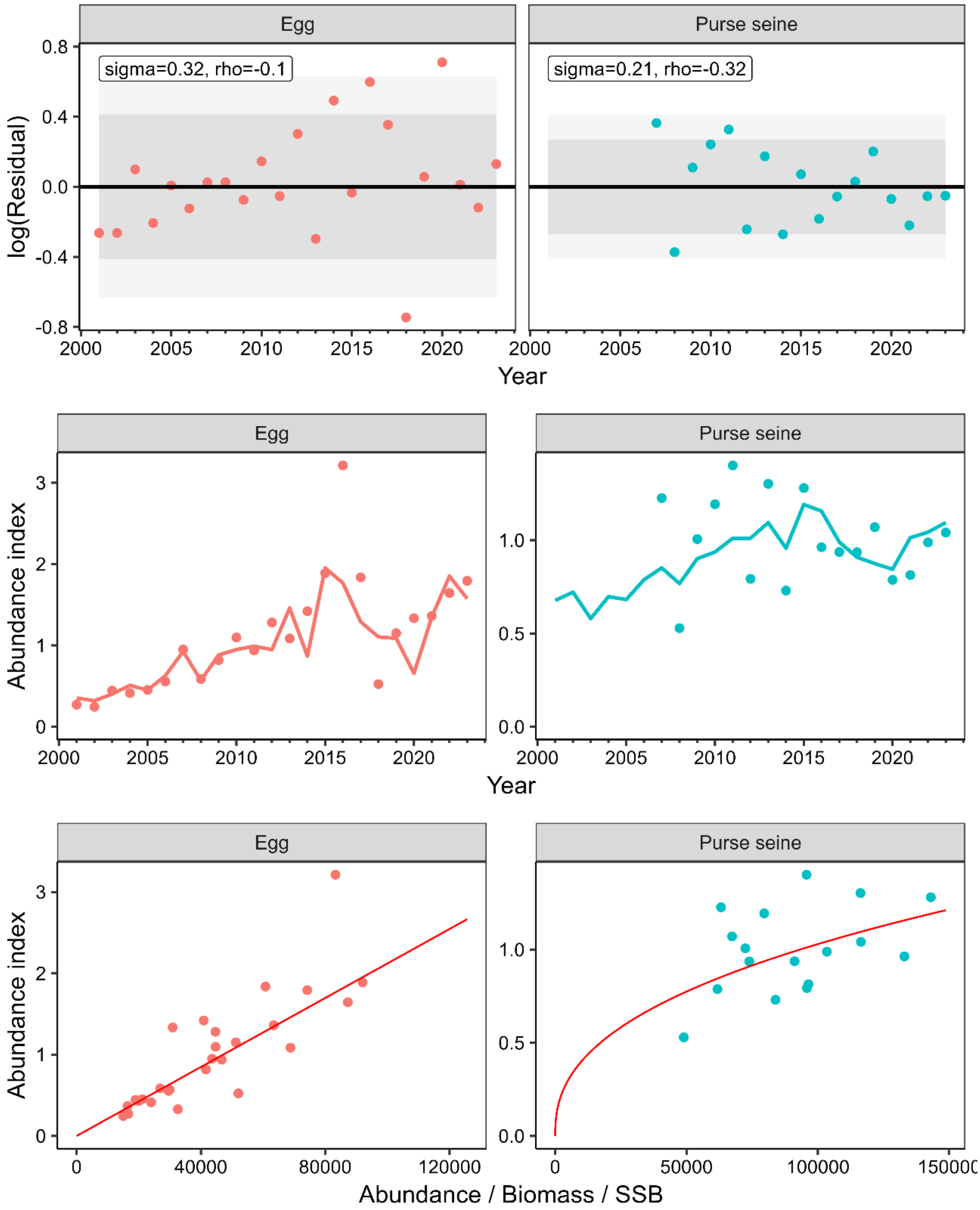
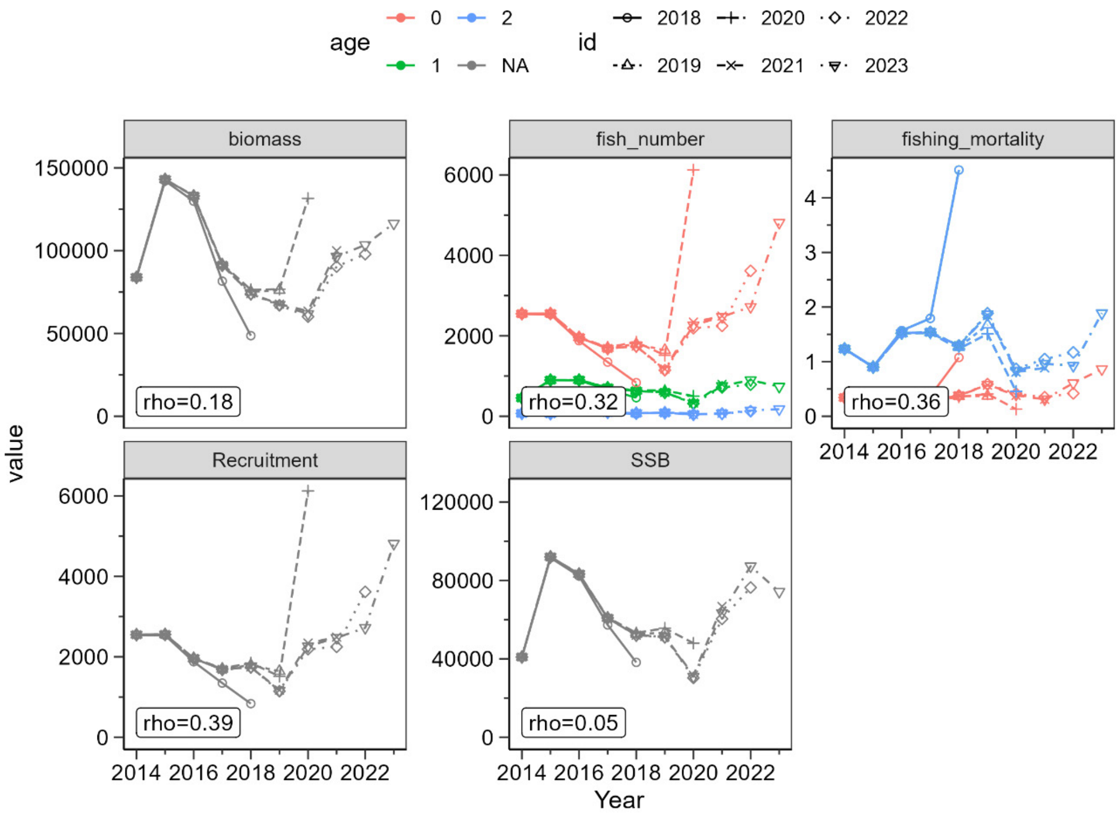
Meeting for the Tsushima Warm Current Stock of Round Herring for fiscal year 2021. FRA-SA2021-BRP03-4.



Supplementary Fig. 2-1. (Top) Residuals of observed values of indices and projected values in the model (egg production (left) and large and medium-sized purse seine CPUE (right)), (Middle) time series plots of observed values of indices (circles) and projected values in the model (solid lines), (Bottom) and regression of observed values and projected values (bottom row)



Supplementary Fig. 2-2. Results of retrospective analysis

Supplementary Table 2-1. Average body weight at age (2023)

Age	0	1	2
Weight (g)	8.8	67.4	138.8

Supplementary Table 2-2. Natural mortality M

Age	0	1	2
Mortality rate	0.7	0.7	0.7

Supplementary Table 2-3. Maturity rate at age

Age	0	1	2
Maturity rate	0	1	1

Supplementary Table 2-4. Tuning indices (standardized by average value)

Index value	Egg production	Large- and Medium Purse Seine CPUE
k	1	2
Target	SSB	B
1997	0.33	
1998	0.57	
1999	0.43	
2000	0.37	
2001	0.27	
2002	0.24	
2003	0.44	
2004	0.41	
2005	0.45	
2006	0.56	
2007	0.95	1.23
2008	0.59	0.53
2009	0.82	1.01
2010	1.10	1.19
2011	0.94	1.40
2012	1.28	0.79
2013	1.08	1.30
2014	1.42	0.73
2015	1.89	1.28
2016	3.21	0.96
2017	1.84	0.94
2018	0.52	0.94
2019	1.15	1.07
2020	1.33	0.79
2021	1.36	0.81
2022	1.64	0.99
2023	1.79	1.04
b_k	1.00E+00	4.10E-01
q_k	2.12E-05	9.16E-03
σ_k	3.22E-01	2.11E-01

Supplementary Table 2-5. Parameters for future projections

Age	Selectivity (Note 1)	Fmsy (Note 2)	F2021-2023 (Note 3)	Average body weight (g)	Natural mortality coefficient	Maturity rate
Age 0	0.23	0.33	0.46	15.9	0.7	0
Age 1	1.00	1.45	2.01	67.7	0.7	1.0
Age 2	1.00	1.45	2.01	134	0.7	1.0

Note 1: Selectivity used to estimate the level required for MSY at the FY 2021 Research Institute Meeting (i.e., selectivity of Fcurrent in the FY 2020 stock assessment).

Note 2: Fmsy estimated at the FY 2021 Research Institute Meeting (i.e., Fcurrent in the FY 2020 stock assessment multiplied by Fmsy/Fcurrent).

Note 3: F was assumed to be the value that gives the same fishing pressure as the average F by age in 2021 to 2023, estimated in this stock assessment calculated in terms of %SPR under the selectivity described above.

Appendix 3 Summary of Various Parameters and Assessment Results

Supplementary Table 3-1. Parameters for stock-recruitment relationship model

Stock-recruitment relationship model	Optimization method	Autocorrelation	a	b	S.D.	ρ
Hockey stick type	Least squares method	Yes	0.0971	1.89e+04	0.34	0.67

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

Supplementary Table 3-2. Reference points and MSY

Item	Value	Explanation
SBtarget	54,000 tons	Target reference points Spawning stock biomass required for the realization of Maximum Sustainable Yield MSY (SBmsy)
SBlimit	18,000 tons	Limit reference point SSB required for a catch of 60% of MSY (SB0.6msy)
SBban	2,000 tons	Fishing ban level SSB required for a catch of 10% of MSY (SB0.1msy)
Fmsy	Fishing Pressure (Fishing mortality F) required for the realization of Maximum Sustainable Yield (MSY) (Age 0, Age 1 and Age 2) = (0.33, 1.45, 1.45)	
%SPR (Fmsy)	44.7%	%SPR corresponding to Fmsy
Maximum Sustainable Yield (MSY)	35,000 tons	Maximum Sustainable Yield (MSY)

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

Item	Value	Explanation
SB2023	74,000 tons	SSB in 2023
F2023	Fishing pressure in 2023 (fishing mortality F) (Age 0, Age 1 and Age 2) = (0.86, 1.89, 1.89)	
U2023	53%	Exploitation rate of 2023
%SPR (F2023)	24.1%	%SPR of 2023
%SPR (F2021-2023)	36.1%	%SPR corresponding to current fishing pressure (2021 to 2023)
Comparison with the reference points		
SB2023/ SBtarget	1.37	B ratio required for MSY to SSB in the 2023 fishing season
F2023/ Fmsy	1.99	F ratio in 2023 to F required to maintain SBmsy*
Level of SSB	Over the level required for MSY	
Level of fishing pressure	Over the level required for SBmsy	
Trends of spawning stock biomass	Increase	

* Ratio calculated by converting the F that gives fishing pressure for Fmsy under 2023 selectivity into %SPR.

Supplementary Table 3-4. ABC and projected spawning stock biomass (SSB)

ABC of 2025 (Thousand tons)	SSB in 2025 Average projected value (Thousand tons)	F relative to current fishing pressure (F/F2021-2023)	Exploitation rate in 2025 (%)
46	80	0.58	37
Comment: - The ABC was calculated using harvest control rules based on the catch strategy for this stock, which was compiled during the “Stock Management Policy Review Meeting” and established through the “Fishery Policy Council”.			

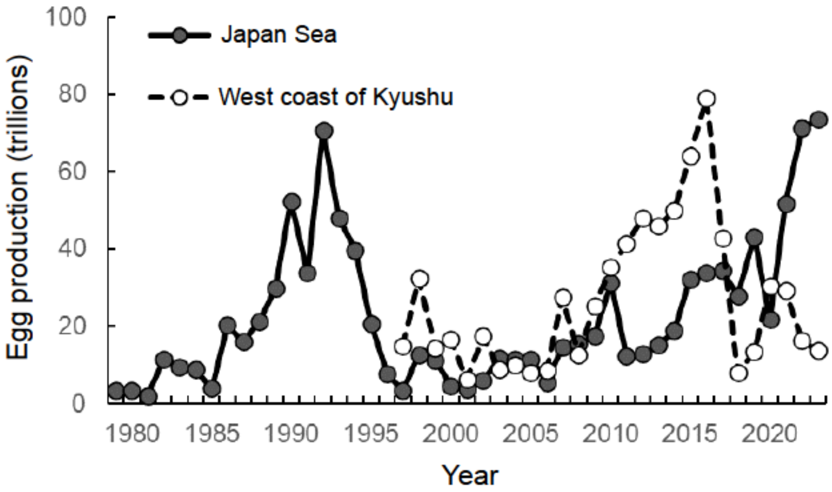
Supplementary Table 3-5. Results of future projections using various β

Uncertainty under consideration: Recruitment					
Item	Average SSB in 2034 (Thousand tons)	90% Prediction interval (Thousand tons)	Probability (%) that SSB will exceed the following proposed reference points in 2034		
			SBtarget	SBlimit	SBban
β used in catch strategy					
β = 0.8	63	29 – 116	55	100	100
If a β different from the above is used					
β = 1.0	56	25 – 103	44	99	100
β = 0.9	59	27 – 109	50	100	100
β = 0.7	68	31 – 124	62	100	100
β = 0.0	125	58 – 227	97	100	100
F2021-2023	45	19 – 84	25	96	100

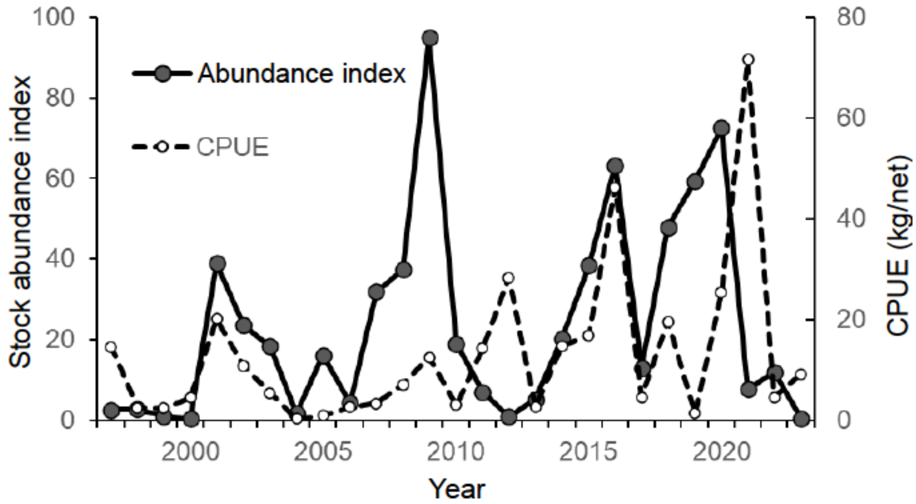
Appendix 4 Summary of Survey Results

We calculated egg production (spawning volume) based on the results of egg and larvae surveys conducted in the Sea of Japan (1979 and onwards) and the western coast of Kyushu (1997 and onwards) (Supplementary Fig. 4-1). Egg production in the Japan Sea once showed a large peak from the late 1980s to the early 1990s but then declined, reaching a low level in the late 1990s. Since then, it has shown an increasing trend with some fluctuations. Egg production on the western coast of Kyushu also increased from 2007 to 2016 but declined significantly until 2017. Although it showed a slight recovery from 2020 to 2021, it has been on the decline since 2022.

Supplementary Fig. 4-2 shows the stock abundance index of round herring (*Etrumeus micropus*) obtained from pelagic fish abundance surveys conducted along the western coast of Kyushu in summer using quantitative echo sounders (Ohshimo 2004, but recalculated from 2012 onwards) and the CPUE (kg/net) obtained from the results of surveys based on midwater trawls conducted at the same time. The CPUE of round herring for midwater trawls in 2023 (9.1 kg/net) increased slightly from 2022 (4.5 kg/net). The calculated standing stock index was 0.41, the lowest on record.



Supplementary Fig. 4-1. Changes in egg production over time



Supplementary Fig. 4-2. Results of the surveys using quantitative echo sounders and midwater trawls

Cited literature

Ohshimo, S. (2004) Spatial distribution and biomass of pelagic fish in the East China Sea in summer, based on acoustic surveys from 1997 to 2001. Fish. Sci., **70**, 389-400.

Appendix 5 Standardized CPUE of egg production

Since the areas where round herring actively spawn are believed to be changing, egg production was standardized using the Vector Autoregressive Spatio-Temporal (VAST) model (Thorson and Barnett, 2017). VAST is a (CPUE) standardization method that allows flexible handling of spatiotemporal variations in relative density by considering spatial autocorrelation. Standardization of egg production using this method was implemented for the Pacific stock of round herring, etc., to obtain abundance indices that take into account the survey area and a number of survey points, which are not constant by either year or month (Watanabe et al. 2021).

We used the average egg density of round herring per 15-minute grid in the Sea of Japan to the East China Sea from 1997 to 2023 (January to June) obtained from egg and larvae surveys.

The VAST model divides egg density into the encounter probability (linear predictor) of sample i (p1(i)) and the egg density (linear predictor) of sample i if the eggs are collected (p2(i)), and is expressed by the following equations.

$$p_1(i) = \beta_1(\mathrm{y_i}) + \omega_1(s_i) + \varepsilon_1(s_i, y_i) + \eta_1(y_i, m_i)$$

$$p_2(i) = \beta_2(\mathrm{y_i}) + \omega_2(s_i) + \varepsilon_2(s_i, y_i) + \eta_2(y_i, m_i)$$

$\beta(y_i)$ of the first term on the right is the fixed effect for survey year y, and the survey year effect is assumed to be independent for each survey year. $\omega(s_i)$ of the second term represents the spatial random effect, and $\epsilon(s_i, y_i)$ of the third represents the spatiotemporal random effect in survey year y and location s. $\eta(y_i, m_i)$ of the fourth term represents the random effect where the factor causes overdispersion in the egg collection rate (egg collectability). To account for changes in egg collectability by year and month, interaction between survey year y and survey month m was used. First, we used spatial information to determine the knots that approximate spatial distribution using k-means clustering. Then, we modeled the spatiotemporal changes in relative density at the knots. The number of knots was set at 100 since previous research has recommended the number of knots be 100 or more (Thorson 2019). The probability density function of the spatial effect uses multivariate normal distribution (MVN), expressed as ω1(・,f)~MVN(0, R1), ω2(・,f)~MVN(0, R2).

$$\omega_1(\cdot, f) \sim MVN(0, \mathbf{R_1}), \qquad \omega_2(\cdot, f) \sim MVN(0, \mathbf{R_2})$$

Here, R1 and R2 are Matérn correlation functions expressed by the following equations.

$$\boldsymbol{R_1}(s_n, s_m) = \frac{1}{2^{\phi-1}\Gamma(\phi)} \times (\kappa_1|\boldsymbol{d}(s_n, s_m)\boldsymbol{H}|)^{\phi} \times \mathrm{K}_v(\kappa_1|\boldsymbol{d}(s_n, s_m)\boldsymbol{H}|)$$

$$\boldsymbol{R_2}(s_n, s_m) = \frac{1}{2^{\phi-1}\Gamma(\phi)} \times (\kappa_2|\boldsymbol{d}(s_n, s_m)\boldsymbol{H}|)^{\phi} \times \mathrm{K}_v \kappa_2|\boldsymbol{d}(s_n, s_m)\boldsymbol{H}|)$$

Here, ϕ is not estimated. Γ is a gamma function, Kv is a modified Bessel function of the second kind, κ_1 and κ_2 are uncorrelated rates, $\boldsymbol{d}(s_n, s_m)$ is the distance between knots, and H is a matrix of geographic anisotropy (different degrees of correlation depending on the direction). Similarly, the probability density function of the spatiotemporal effect is given by,

$$\varepsilon_1(\cdot, f, y) \sim \begin{cases} MVN(0, \boldsymbol{R_1}) & if\ y = 1 \\ MVN(\rho_{\varepsilon 1}\varepsilon_1(\cdot, f, y-1), \boldsymbol{R_1}) & if\ y > 1 \end{cases}$$

$$\varepsilon_2(\cdot, f, y) \sim \begin{cases} MVN(0, \boldsymbol{R_2}) & if\ y = 1 \\ MVN(\rho_{\varepsilon 2}\varepsilon_2(\cdot, f, y-1), \boldsymbol{R_2}) & if\ y > 1 \end{cases}$$

which in this analysis was assumed to be independent of the survey year ($\rho_{\varepsilon 1} = \rho_{\varepsilon 2} = 0$). The parameters of the above model were estimated using the maximum likelihood method, which involves many random effects and requires high-speed computation. Therefore, we used a high-speed optimization software called Template Model Builder (Kristensen et al. 2016).

The analysis using this data used a delta-type model with binomial and gamma distributions, with projected encounter rate (r_1(i)) and projected egg density (r_2(i)) expressed by the following formulas (Thorson 2017).

$$r_1(i) = \mathrm{logit}^{-1} p_1(i)$$
$$r_2(i) = a_i \times \log^{-1} p_2(i)$$

a_i is the offset term, which in this case was set to 1 because the average egg density was used as the objective variable. The probability that egg density B is observed is expressed below, and the parameter with the maximum marginal likelihood was estimated.

$$\Pr(b_i = B) = \begin{cases} 1 - r_1(i) & \text{if}\, B = 0 \\ r_1(i) \times g\{B|r_2(i), \sigma_m^2(c)\} & \text{if}\, B > 0 \end{cases}$$

From the estimated parameters, the relative egg density at each location in each year was calculated as

$$d^*(s, y) = r_1^*(s, y) \times r_2^*(s, y)$$

and the sum of the area of each knot multiplied by the relative egg density was calculated as the egg production index.

$$I(y) = \sum_{s=1}^{n_s}(a(s) \times d(s,y))$$

We then performed average correction for random effects (Thorson and Kristensen 2016). For more information on the VAST model structure, refer to Thorson (2019) or GitHub (https://github.com/James-Thorson-NOAA/VAST). In this report, the relative value obtained by dividing I(y) of each year by the average value from 1997 to 2023 was used as the abundance index.

While standardized egg production showed a similar trend to nominal egg production, the standardized index in 2016 was higher than the nominal index, and standardization has made the trends in indices clearer (Supplementary Fig. 5-1).

From 2021 onwards, the standardized index has remained lower than the nominal index.

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Thorson, J. T. (2017) Three problems with the conventional delta-model for biomass sampling data, and a computationally efficient alternative. Can. J. Fish. Aquat. Sci., **75**, 1369-1382.

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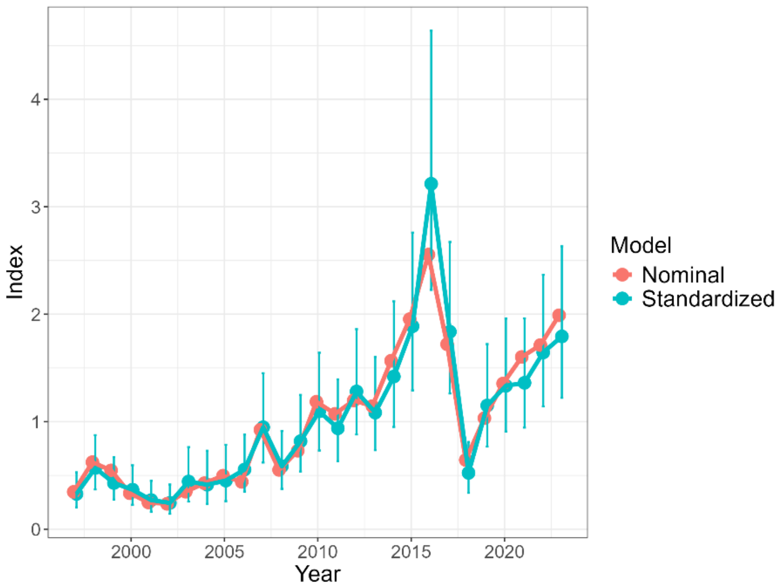


Supplementary Fig. 5-1. Trends in abundance indices with (Standardized) and without (Nominal) standardization (error bars representing the 95% confidence interval)

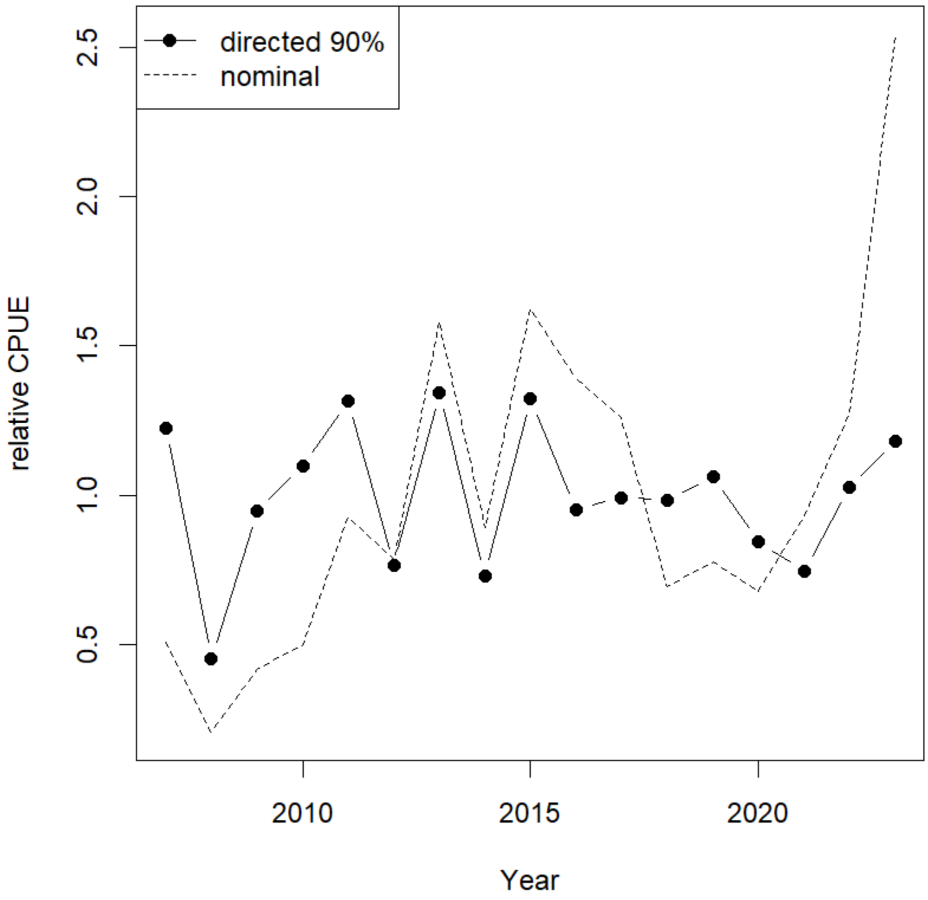
Appendix 6 Standardized CPUE of large and medium-sized purse seine

The main target species for large and medium-sized purse seine fisheries are Japanese jack mackerel, chub mackerel, spotted mackerel, and sardines. CPUE was calculated using catch per net (tons/net), and the directed CPUE method was used to calculate CPUE from a data set that extracted operations targeting round herring (Biseau 1998). This method extracts data in descending order of operations with the highest catch proportion of round herring per net (round herring catch/total catch) until the cumulative round herring catch for each year reaches 90% of the round herring catch for that year. The annual average value of CPUE in the extracted data set is called directed CPUE and is considered to be CPUE that takes into account targeted operations (Biseau 1998). Since the fishing effort of large and medium-sized purse seine has been on a declining trend, we referred to CPUE calculated from 2003 onwards, when detailed data such as fishing boat numbers were available. Data from 2007 onwards, when the retrospective bias became relatively small, was used as abundance indices.

Nominal CPUE (annual average value of round herring catch per net, including data with no round herring catch) showed larger fluctuations than directed CPUE and increased significantly in 2023 (Supplementary Fig. 6-1). Annual trends of directed CPUE have remained relatively stable despite some fluctuations and have been on an increasing trend since 2022.

Cited literature

Biseau, A. (1998) Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquat. Living. Resour., **11**, 119-136.

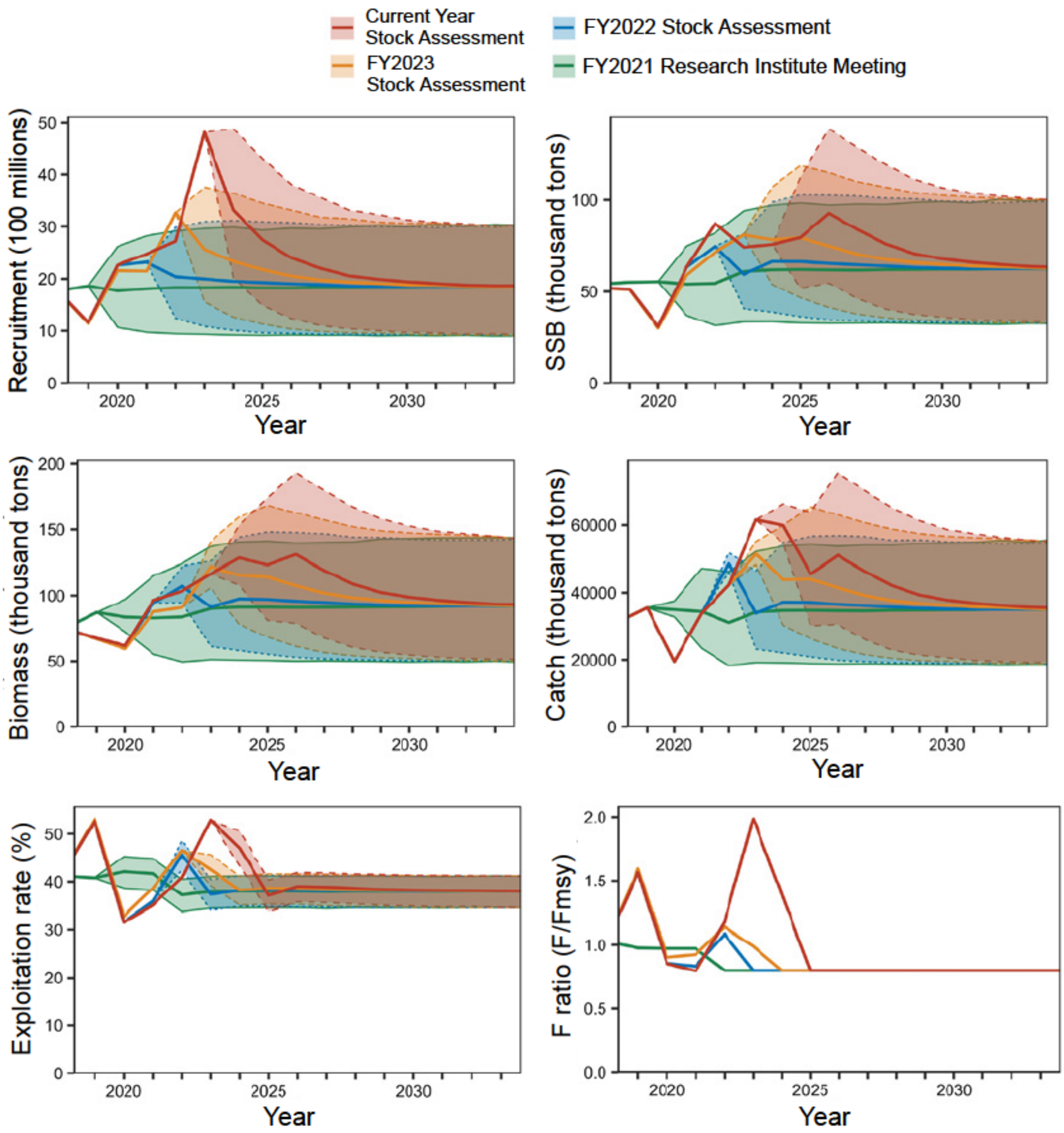


Supplementary Fig. 6-1. Trends in abundance indices with (directed 90%) and without (nominal) standardization of the large and medium-sized purse seine CPUE.

Appendix 7 Comparison with previous years' assessment results

The results of the stock assessment of the previous fiscal year were compared with the results of the stock assessment of the current fiscal year, and the 2022 recruitment was revised downward while spawning stock biomass and stock abundance were revised slightly upward. Recruitment for 2023 is estimated to be significantly higher than the previous fiscal year's projected value based on the stock-recruitment relationship. There were no significant differences in the estimated stock abundance and spawning stock biomass prior to 2021 (Supplementary Fig 7-1.). Although stock abundance and SSB from 2025 onwards have been revised upward, the results reflect that high recruitment will continue from 2024 onwards because recruitment is estimated based on the stock-recruitment relationship that assumes autocorrelation.

The probability that the projected SSB values would exceed the target reference points 10 years after the start of management under the agreed-upon HCRs was greater than 50%.



(Shaded areas: 10 to 90% prediction interval, thick solid lines: average value)

Supplementary Fig 7-1. Comparison of trends in estimated spawning stock biomass, stock abundance, recruitment, and catch by assessment year

Supplementary Table 7-1. Estimated recruitment, spawning stock biomass, total stock biomass, and F ratio by assessment year

(1) Recruitment (millions)

Evaluation Fiscal Year / Year	2019	2020	2021	2022	2023
FY 2022	1,157	2,260	2,319		
FY 2023	1,138	2,157	2,146	3,264	
FY 2024	1,157	2,261	2,473	2,720	4,813

(2) Biomass (thousand tons)

Evaluation Fiscal Year / Year	2019	2020	2021	2022	2023
FY 2022	51	31	63		
FY 2023	51	30	59	72	
FY 2024	51	31	63	87	74

(3) Stock biomass (thousand tons)

Evaluation Fiscal Year / Year	2019	2020	2021	2022	2023
FY 2022	67	62	94		
FY 2023	67	59	88	91	
FY 2024	67	62	96	103	116

(4) Fishing pressure (F/Fmsy)

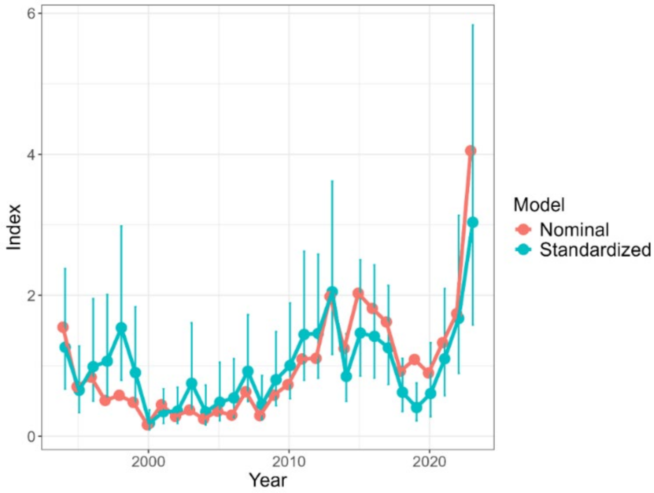
Evaluation Fiscal Year / Year	2019	2020	2021	2022	2023
FY 2022	1.57	0.86	0.83		
FY 2023	1.59	0.90	0.92	1.14	
FY 2024	1.56	0.86	0.80	1.18	1.99

Appendix 8 Stock assessment and future projections considering various uncertainties

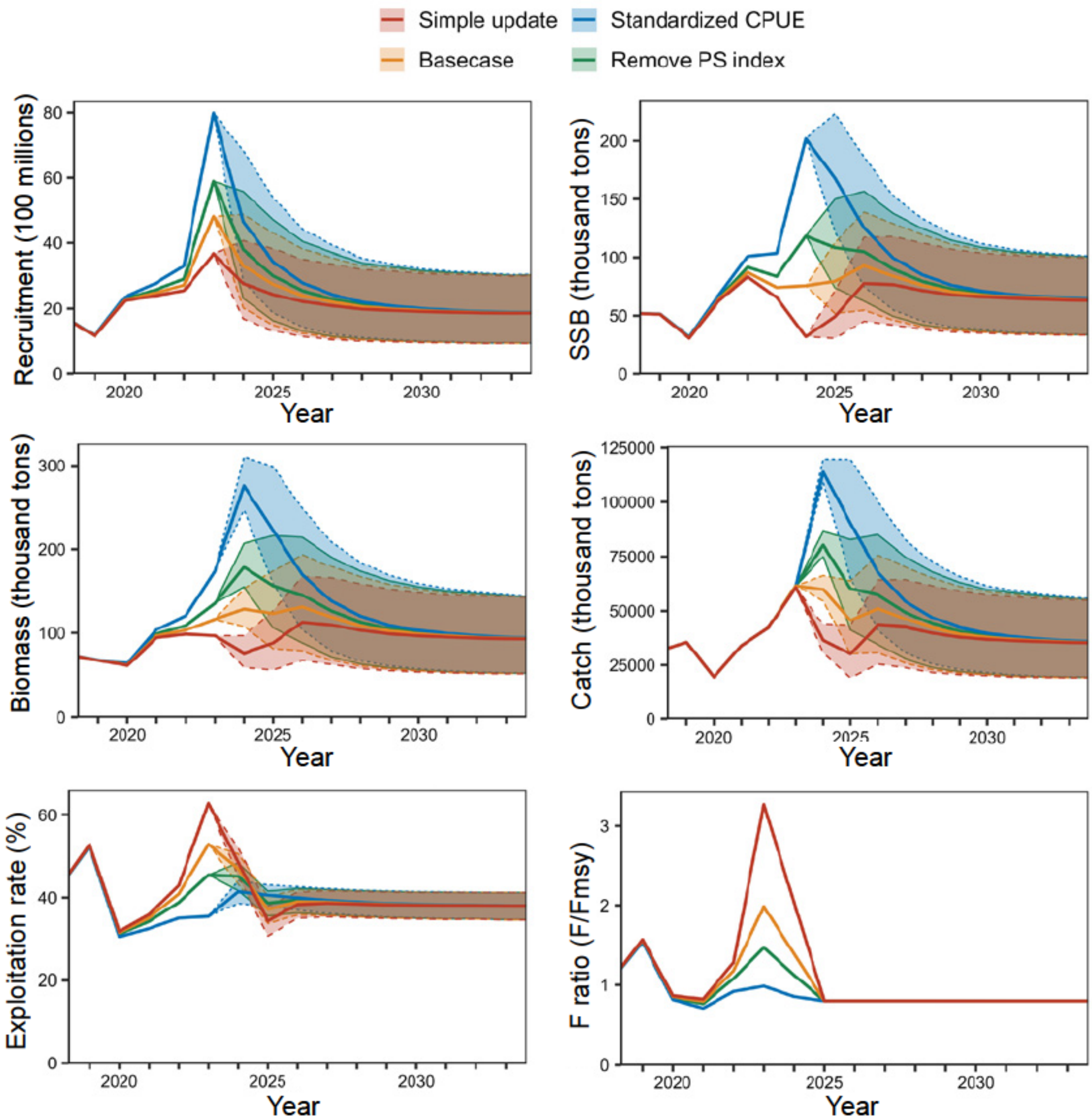
In the stock assessment of the current fiscal year, directed CPUE continued to be used as the abundance indices of large- to medium-scale purse seine fisheries, but in 2023, the percentage of fish caught as by-catch increased, and a deviation from the nominal CPUE was observed. Therefore, as a sensitivity analysis, we standardized CPUE (Supplementary Fig 8-1) using the Vector Autoregressive Spatio-Temporal (VAST) model (Thorson and Barnett 2017) in the same manner as we did for egg production and used this as the stock abundance indices instead of directed CPUE when carrying out stock assessment and future projections (Standardized CPUE). In addition, when directed CPUE was used as the indices like in the previous year (Simple update), a problem arose that F in 2023 was very high (Supplementary Fig. 8-2). Hence, we changed to a tuning method that assumes a nonlinear relationship between stock abundance and the indices, which is the base case for the current fiscal year (Basecase). In addition to these, as a sensitivity analysis, future projections were made without considering the indices of large and medium-sized purse seine fisheries (Remove PS index). In summary, the points are as follows.

- Current year stock assessment (Basecase)
- Stock abundance indices changed to standardized CPUE (Standardized CPUE)
- Same method as last year (assuming a linear relationship between the indices and stock abundance) (Simple update)
- Excluding the stock abundance indices (large and medium-sized purse seine) (Remove PS index)

Using standardized CPUE (Standardized CPUE) resulted in a huge estimate for recruitment in 2023 (8 billion fish), resulting in high levels of SSB and abundance. On the other hand, simple update (Simple update) gives the most pessimistic results, with a particularly high F ratio relative to Fmsy in 2023, estimated to be higher than 3. Therefore, it was estimated that abundance and SSB would decline from 2023 to 2024. When the indices of large and medium-sized purse seine fisheries are not considered (Remove PS index), the intermediate recruitment, SSB, abundance, and catch are shown to be between when standardized CPUE and when Directed CPUE were used, indicating that the two CPUEs have opposite tuning effects. The projected catch for 2025 was estimated to be 46,000 tons, 80,000 tons, 30,000 tons, and 60,000 tons for the Basecase, Standardized CPUE, Simple update, and Remove PS index scenarios, respectively.



Supplementary Fig. 8-1. Trends in abundance indices with (Standardized) and without (Nominal) standardization using the VAST model (error bars representing the 95% confidence interval)



(Shaded areas: 10 to 90% prediction interval, thick solid lines: average value)

Supplementary Fig. 8-2. Future projections considering various uncertainties

Appendix 9 Details of the Stock Analysis Results

Year	Catch in number (10,000 fish)			Catch in weight (tons)			Average body weight (g)		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1976	33,754	21,925	9,296	5,442	17,771	11,706	16	81	126
1977	49,638	31,779	5,095	5,632	22,557	6,427	11	71	126
1978	34,113	28,098	10,813	4,818	23,872	13,047	14	85	121
1979	67,230	21,596	10,497	8,225	15,796	14,063	12	73	134
1980	37,217	17,119	6,714	4,356	14,950	8,687	12	87	129
1981	34,541	18,933	2,296	5,884	16,320	3,028	17	86	132
1982	39,356	20,505	2,964	7,179	14,294	4,133	18	70	139
1983	83,715	22,932	1,656	12,354	14,034	2,170	15	61	131
1984	158,879	16,960	2,422	10,315	14,343	2,727	6	85	113
1985	58,123	23,448	824	7,887	14,260	967	14	61	117
1986	92,433	35,483	826	11,471	27,153	1,028	12	77	124
1987	153,413	24,884	577	12,715	14,779	691	8	59	120
1988	135,083	42,012	723	19,941	26,209	928	15	62	128
1989	102,529	21,833	3,292	16,379	21,635	4,117	16	99	125
1990	73,529	34,560	3,320	16,864	21,904	3,672	23	63	111
1991	122,892	26,498	6,201	11,900	16,475	6,951	10	62	112
1992	241,214	22,901	6,225	24,131	14,282	6,868	10	62	110
1993	79,828	41,792	4,730	10,098	24,426	5,404	13	58	114
1994	147,730	37,516	6,347	15,436	23,845	6,950	10	64	109
1995	48,137	25,912	6,556	7,770	13,425	7,466	16	52	114
1996	38,649	20,200	7,325	4,058	12,605	9,593	11	62	131
1997	36,339	29,525	2,465	9,405	15,858	3,475	26	54	141
1998	19,628	22,565	2,130	5,984	13,249	3,107	30	59	146
1999	13,711	11,927	2,565	3,159	7,349	3,755	23	62	146
2000	7,645	9,658	1,092	1,989	6,326	1,635	26	66	150
2001	28,124	14,239	1,954	4,503	7,688	2,961	16	54	152
2002	25,794	26,429	656	5,370	9,059	749	21	34	114
2003	55,461	27,331	865	2,243	10,213	942	4	37	109
2004	9,592	19,919	2,374	1,816	11,676	3,357	19	59	141
2005	72,944	13,753	752	6,465	8,193	939	9	60	125
2006	18,316	14,848	2,569	3,054	8,746	3,621	17	59	141
2007	36,278	30,068	3,975	5,876	18,673	5,445	16	62	137
2008	27,655	15,541	2,628	3,981	8,583	3,599	14	55	137

Appendix 9 (Continued)

Year	Catch in number (10,000 fish)			Catch in weight (tons)			Average body weight (g)		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
2009	23,268	26,259	2,812	5,667	15,405	3,866	24	59	137
2010	25,618	26,661	5,539	5,197	18,019	7,662	20	68	138
2011	73,980	34,930	2,210	16,619	21,671	2,545	22	62	115
2012	135,899	24,588	3,857	20,074	14,432	5,099	15	59	132
2013	76,479	43,639	6,066	18,131	30,670	8,720	24	70	144
2014	52,013	22,693	3,545	8,767	15,232	5,199	17	67	147
2015	52,159	37,604	2,751	10,409	34,576	3,898	20	92	142
2016	37,563	49,660	10,008	9,528	33,263	12,622	25	67	126
2017	29,434	39,194	5,405	5,306	27,023	6,631	18	69	123
2018	38,796	32,145	3,849	4,862	21,135	5,482	13	66	142
2019	35,834	35,280	5,101	4,992	23,469	7,037	14	67	138
2020	52,308	12,889	1,820	7,135	9,936	2,425	14	77	133
2021	46,714	32,859	3,014	6,231	23,569	4,056	13	72	135
2022	87,098	38,240	6,085	5,178	29,017	8,103	6	76	133
2023	196,120	44,064	10,584	17,185	29,701	14,688	9	67	139

Appendix 9 (Continued)

Year	Fishing mortality F			Stock population (10,000 fish)			Stock biomass (tons)		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1976	0.18	0.59	0.59	287,970	69,601	29,509	46,424	56,413	37,159
1977	0.31	0.48	0.48	263,044	119,215	19,112	29,844	84,619	24,109
1978	0.35	0.54	0.54	163,148	95,645	36,806	23,040	81,259	44,412
1979	0.88	0.77	0.77	162,538	56,978	27,695	19,885	41,677	37,104
1980	0.54	1.30	1.30	127,399	33,338	13,076	14,910	29,114	16,917
1981	0.53	1.29	1.29	119,384	37,038	4,492	20,337	31,928	5,923
1982	0.52	1.79	1.79	136,787	34,944	5,051	24,950	24,359	7,043
1983	1.17	1.66	1.66	172,352	40,192	2,903	25,434	24,597	3,804
1984	1.42	2.35	2.35	297,385	26,595	3,799	19,307	22,491	4,276
1985	0.58	2.68	2.68	187,439	35,717	1,255	25,434	21,721	1,473
1986	1.00	3.38	3.38	207,426	52,120	1,213	25,741	39,885	1,510
1987	0.90	2.70	2.70	366,208	37,868	878	30,350	22,491	1,052
1988	1.11	1.65	1.65	285,387	73,745	1,269	42,129	46,005	1,630
1989	0.64	1.10	1.10	307,303	46,528	7,015	49,093	46,105	8,773
1990	0.58	0.94	0.94	238,126	80,351	7,719	54,613	50,927	8,538
1991	0.97	0.83	0.83	280,458	66,435	15,547	27,158	41,306	17,428
1992	1.07	0.96	0.96	520,556	52,671	14,318	52,076	32,849	15,797
1993	0.50	1.11	1.11	285,954	88,519	10,018	36,171	51,736	11,447
1994	0.97	0.97	0.97	338,137	85,747	14,507	35,332	54,501	15,885
1995	0.65	0.86	0.86	142,875	63,810	16,144	23,061	33,058	18,385
1996	0.44	1.49	1.49	155,033	37,028	13,427	16,278	23,106	17,584
1997	0.48	1.85	1.85	134,751	49,751	4,153	34,874	26,721	5,856
1998	0.50	1.49	1.49	71,039	41,308	3,900	21,658	24,253	5,688
1999	0.40	1.56	1.56	59,428	21,446	4,612	13,694	13,215	6,753
2000	0.22	1.17	1.17	55,615	19,849	2,245	14,469	13,002	3,360
2001	0.40	2.40	2.40	121,392	22,230	3,051	19,438	12,003	4,623
2002	0.33	2.62	2.62	130,066	40,463	1,005	27,080	13,869	1,147
2003	0.80	1.81	1.81	142,696	46,412	1,469	5,770	17,343	1,599
2004	0.19	2.20	2.20	77,851	31,778	3,788	14,736	18,627	5,356
2005	0.89	0.95	0.95	175,077	31,900	1,744	15,517	19,005	2,177
2006	0.21	0.90	0.90	135,422	35,538	6,150	22,580	20,934	8,666
2007	0.56	1.54	1.54	120,506	54,342	7,184	19,519	33,748	9,840
2008	0.30	1.03	1.03	153,382	34,277	5,796	22,078	18,931	7,937

Appendix 9 (Continued)

Year	Fishing mortality F			Stock population (10,000 fish)			Stock biomass (tons)		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
2009	0.30	1.07	1.07	126,479	56,679	6,070	30,807	33,252	8,345
2010	0.24	1.69	1.69	171,935	46,411	9,642	34,880	31,368	13,337
2011	0.66	1.33	1.33	218,210	67,328	4,260	49,018	41,772	4,905
2012	0.81	0.97	0.97	346,346	56,227	8,820	51,160	33,003	11,660
2013	0.78	1.67	1.67	200,057	76,224	10,595	47,426	53,570	15,231
2014	0.34	1.23	1.23	254,923	45,451	7,100	42,967	30,508	10,412
2015	0.34	0.90	0.90	255,507	89,938	6,579	50,990	82,695	9,324
2016	0.32	1.52	1.52	195,829	90,125	18,163	49,672	60,367	22,906
2017	0.29	1.54	1.54	168,355	70,775	9,760	30,352	48,797	11,974
2018	0.38	1.29	1.29	174,328	62,861	7,526	21,847	41,330	10,721
2019	0.58	1.87	1.87	115,740	59,230	8,564	16,124	39,402	11,814
2020	0.40	0.84	0.84	226,140	32,223	4,551	30,848	24,842	6,064
2021	0.31	0.96	0.96	247,343	75,437	6,919	32,994	54,110	9,312
2022	0.61	0.93	0.93	271,996	89,908	14,306	16,171	68,223	19,051
2023	0.86	1.89	1.89	481,320	73,692	17,700	42,176	49,671	24,564