

## Stock Assessment for Japanese Anchovy – Seto Inland Sea (Fiscal Year 2024)

Japan Fisheries Research and Education Agency

Fisheries Stock Assessment Center, Fisheries Resources Institute

(Naoaki Kono, Masanori Takahashi, Tohya Yasuda, Mikio Watai, Junichi Imoto,  
Haruhiko Hino, Junji Kinoshita, Shota Nishijima)

Participating Organizations: Wakayama Prefectural Fisheries Research Institute; Fisheries Technology Center, Research Institute of Environment, Agriculture and Fisheries, Osaka Prefecture; Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries; Okayama Prefectural Technology Center for Agriculture, Forestry, and Fisheries Research Institute for Fisheries Science; Fisheries & Marine Technology Center, Hiroshima Prefectural Technology Research Institute; Inland Sea Research Division, Yamaguchi Prefectural Fisheries Research Center, Buzen Sea Laboratory, Fukuoka Fisheries and Marine Technology Research Center; Oita Prefectural Agriculture, Forestry and Fisheries Research Center; Research Institute of Cultivation Resources, Fisheries Research Center, Ehime Research Institute of Agriculture, Forestry and Fisheries; Kagawa Prefectural Fisheries Experimental Station; Fisheries Research Institute, Tokushima Prefectural Agricultural, Forestry and Fisheries Research Center

### Summary

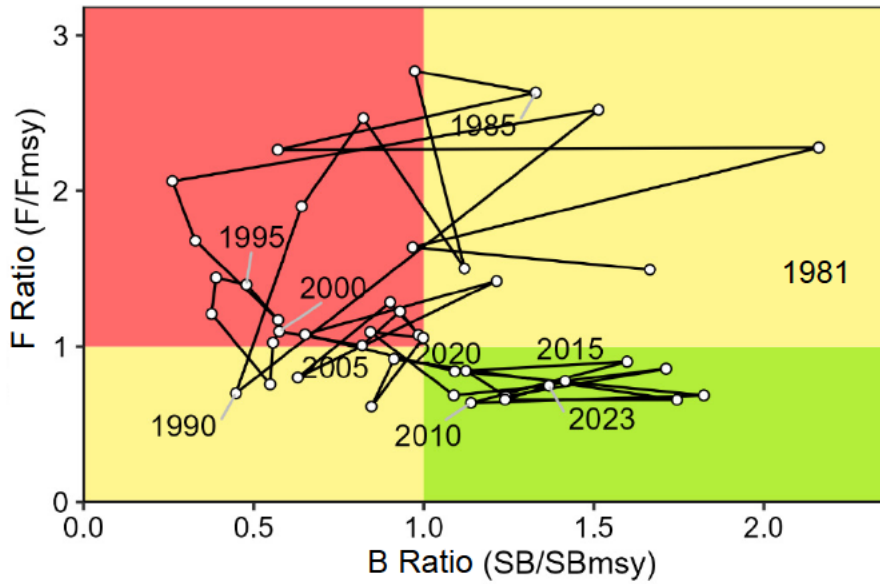
The biomass of this stock (Individuals aged 3 months or older) was estimated using cohort analysis, with egg production as the tuning index. The biomass decreased sharply in 1987 and continued to decline until 1997. Subsequently, the biomass showed an increasing trend, and in 2023, it was 366,000 tons. The spawning stock biomass (SSB) showed a downward trend from 93,000 tons in 1983 to 11,000 tons in 1992. Subsequently, the SSB showed an increasing trend, and in 2023 it was 59,000 tons. Recruitment was high in the early 1980s, showed a decreasing trend in the late 1980s, and was at a low level in the 1990s, but has generally been on the increase since then. The exploitation rate was high in the 1980s and early 1990s, but since then it has shown a decreasing trend.

In the “Materials for the Research Institute Meeting on Reference Points” published in September 2022, a hockey stick model was applied to the stock-recruitment relationship of this stock. Based on this, the Maximum Sustainable Yield (MSY) was estimated, and the SSB required to achieve MSY (SB<sub>msy</sub>) was calculated to be 43,000 tons. Following these criteria, the SSB of this stock in 2023 exceeds the level required to achieve MSY. In addition, the fishing pressure on this stock in the 2023 fishing season was lower than the fishing

pressure ( $F_{msy}$ ) required to maintain  $SB_{msy}$ . Based on trends seen in the previous 5 years (2019 to 2023), SSB is judged to be in an “increasing” trend.

For this stock, provisional values for reference points, future projections, and other related items are indicated based on the values discussed at the Research Institute Meeting on Reference Points and the Stock Management Policy Review Meeting.

Summary Figures and Tables



Maximum Sustainable Yield (MSY), Spawning Stock Biomass (SSB) Levels and Trends, and Allowable (or Acceptable) Biological Catch (ABC)	
SSB to achieve MSY (SBmsy)	43,000 tons
Level of SSB in 2023	Over the level to achieve MSY
Level of fishing pressure in 2023	Under the level to achieve SBmsy
Changes in SSB in 2023	Increase
Maximum Sustainable Yield (MSY)	39,000 tons
ABC for 2025	-
Comment: • ABC is calculated after the catch scenario for this stock is compiled by the “Stock Management Policy Review Meeting” and established through the “Fisheries Policy Council”.	

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	204	36	26	0.61	13
2020	259	43	39	1.06	15
2021	259	36	33	1.09	13
2022	345	47	42	0.69	12
2023	366	59	42	0.75	12
2024	319	105	37	0.26	11
2025	287	73	-	-	-

- The values for 2024 and 2025 are estimates based on future projections.  
- The average catch for the last 5 years (2019-2023) of 37,000 tons was used as the catch for 2024.

## 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	<p>Fishery in the Seto Inland Sea area (Statistics Department, Chugoku-Shikoku Regional Agricultural Administration Office)</p> <p>Fishery Trends in the Seto Inland Sea area (Statistics Department, Chugoku-Shikoku Regional Agricultural Administration Office)</p> <p>Fishery Trends in the Seto Inland Sea and the Southern Pacific area (Statistics Department, Chugoku-Shikoku Regional Agricultural Administration Office)</p> <p>Statistics of Fishery and Aquaculture Production (Statistics Department, Ministry of Agriculture, Forestry and Fisheries)</p> <p>Biological Data Collection Survey - Landings of major fishery cooperatives, sample vessels, and landings estimated based on joint sales (Wakayama to Oita (11 prefectures))</p> <p>Biological Data Collection Survey - Body length composition, precision measurements, by-catch ratio for Whitebait (Japan Fisheries Research and Education Agency, Wakayama to Oita (11 Prefectures))</p>
Stock abundance index - Egg production	<p>Egg and larvae survey (Wakayama to Oita (11 Prefectures))*</p> <p>- Remodeled NORPAC Nets and Marutoku B Nets</p>
Natural mortality (M)	Assume 2.1 for fish age 0 to 1 and 2.0 for fish age 2 and older
Fishing effort	Not captured

\* Indicates the tuning index for cohort analysis

In this report, individuals in post juvenile stage (aged 3 months or older) are referred to as Japanese anchovy, while individuals younger than that (aged 1 to 2 months) are referred to as whitebait. In the Seto Inland Sea, both Whitebait and Japanese anchovy are catch targets; however, as mentioned below, only Japanese anchovy was used for biomass estimation in this assessment.

## 2. Ecology

### (1) Distribution and migration

In addition to individuals born in the Seto Inland Sea, this stock includes some individuals born in the Pacific Ocean (Takao 1990). As for the latter, some of the individuals born

between Satsunan and the outer Kii Strait from March to May are carried by the Kuroshio, etc., and migrate to the Seto Inland Sea (Fig. 2-1). Most of the individuals that grow in the Seto Inland Sea migrate out to the open sea to winter but return to the Seto Inland Sea the following spring to spawn.

#### (2) Age and growth

After hatching, this species grows to 8 cm (scaled body length) in six months and 11 cm in one year (Yokota and Furukawa 1952, Doi et al. 1978, Fig. 2-2). The lifespan is considered to be approximately two years.

#### (3) Maturation and spawning

Spawning occurs almost year-round, but the main spawning season is from May to October (Kono and Zenitani 2008). The spawning grounds of this stock are throughout the Seto Inland Sea. However, individuals originating from the Pacific Ocean, which are part of this stock, have spawned in the waters from the Satsunan area to outside the Kii Channel (Fig. 2-1, Hattori 1982, Ochiai and Tanaka 1986, Takao 1990).

Based on the relationship between standard body length and maturity rate (Funamoto et al. 2004), it is believed that approximately 55% of individuals mature at 5 months of age, approximately 80% at 6 months, approximately 95% at 7 months, and 100% at 8 months or older. Although such premature groups are believed to be found immediately adjacent to the coast, inside of bays, or within inland seas (Funakoshi 1990), individuals born in May during the early main spawning season do not begin spawning until October at the earliest. The proportion of age 0 fish that contribute to the total egg production of spawning stock is considered to be very small. Therefore, the stock assessment for this stock was conducted, assuming that the fish spawn from the age of 1 (Fig. 2-3).

#### (4) Predator-prey Relationships

This species feeds primarily on small crustaceans such as copepods. It is preyed upon by piscivorous fish such as Japanese Spanish mackerel, Japanese sea bass, chub mackerel and spotted mackerel, and largehead hairtail (Kishida 1986, Ochiai and Tanaka 1986).

### 3. Fishery Status

#### (1) Fishery Overview

This stock is mainly caught by boat seine fishing and small to medium-scale purse seine fisheries. Fishing grounds are formed in various waters, from the Kii Strait to the eastern part of Suo-nada (Fig. 2-1). Fishing operations take place nearly year-round in the waters near the open sea and in the central Seto Inland Sea from spring through autumn. In some waters, fishing may be closed due to the appearance of fatty anchovy unsuitable for processing (Yamamoto & Honda 2008) or due to poor catches. This stock may be caught

in the open sea during the winter, but the catch is small and is considered to have little impact on the assessment results; therefore, this catch is not included in the analyses in this report.

## (2) Trends in Catch in Weight

The catch in weight of Japanese anchovy (the catch in weight of fish presumed to be “Japanese anchovy” according to commercial size category in the Statistics of Fishery and Aquaculture Production, without the inclusion of Whitebait (fish that are 1 to 2 months old)) are shown in Fig. 3-1 and Table 3-1. The catch peaked at 93,000 tons in 1985, then showed a downward trend, decreasing to 15,000 tons in 1998. Subsequently, the catch showed a gradual increasing trend, and in 2023 (provisional value), the catch was 42,000 tons. The catch in weight of fish presumed to be “Japanese anchovy” according to commercial size category by prefecture and fishery type is shown in Table 3-2, and the catch in weight at age and catch in number at age are shown in Fig. 3-2 and Fig. 3-3, respectively. For both catch in weight at age and catch in number at age, the percentage of fish age 1 and older has increased since the late 2000s.

## (3) Fishing Effort

The fishing effort for Japanese anchovy as the catch target cannot be determined.

## 4. Stock Status

### (1) Stock Assessment Methods

In the Seto Inland Sea, Whitebait, along with Japanese anchovy, is important as a fishing target stock. Therefore, in the stock assessment of this stock up to FY 2021, Whitebait was included when estimating the biomass at monthly age and by month. However, at this point, it is difficult to establish the stock-recruitment relationship necessary to estimate Maximum Sustainable Yield (MSY) in a manner that includes Whitebait since Whitebait is considered to face high mortality at the early stages of its growth when the natural mortality rates fluctuate greatly due to environmental effects, etc. In addition, if future projections are made on monthly age/month basis, uncertainty is likely to increase due to the complexity of monthly stock-recruitment relationship models, which are necessary to calculate the fishing pressure for MSY and the SSB to achieve MSY (SB<sub>msy</sub>). For these reasons, we decided to carry out biomass estimation on an annual basis and not include Whitebait in the MSY-based stock assessment for this stock.

Using catch in number at age and by year data from 1981 to 2023, the fishing mortality at age and by year, stock number, and biomass, etc., of Japanese anchovy were estimated by cohort analysis (i.e., tuned VPA) using egg production as an index value for SSB (Table 4-1, Appendix 1, Appendix 2). The catch in number at age and by year is based on the catch in weight of fish presumed to be “Japanese anchovy” according to commercial size category

in the Statistics of Fishery and Aquaculture Production, without inclusion of Whitebait (fish that are 1 to 2 months old) (Table 3-1).

## (2) Trends in Abundance Indices

The egg production in the Seto Inland Sea from 1980 to 2023 has fluctuated between 185 trillion to 1,686 trillion eggs (with an average of 757 trillion eggs) (Fig. 4-1, Table 4-1, Appendix 7). Although there is a large fluctuation from year to year, egg production has been on an increasing trend since the late 1990s, reaching a record high of 1,686 trillion eggs in 2022 and 1,065 trillion eggs in 2023.

## (3) Trends in Stock Biomass and Fishing Pressure

Tuned VPA was used to estimate the biomass of Japanese anchovy from 1981 to 2023 (Fig. 4-2, Table 4-1, and Appendix 2). The biomass decreased sharply in 1987 and further declined to 91,000 tons by 1997. Subsequently, the spawning stock biomass (SSB) showed an increasing trend, and in 2023, it was 366,600 tons. The SSB showed a general downward trend, decreasing from 93,000 tons in 1983 to 11,000 tons in 1992. Subsequently, the SSB showed an increasing trend, reaching 59,000 tons in 2023 (Fig. 4-2, Table 4-1). The stock number at age is composed mainly of age 0 fish (recruitment) (Fig. 4-3, Table 4-1, Appendix 2). Recruitment (stock number of age 0 fish) decreased sharply in 1987 and remained at a low level during the 1990s. Since the 2000s, the trend has generally been increasing, with recruitment of 125.3 billion fish in 2023. The exploitation rate (catch/biomass) fluctuated between 10% and 28% and was at a high level from the 1980s to the early 1990s. Since then, a decreasing trend was observed, and the exploitation rate in 2023 was 12% (Fig. 4-4, Table 4-1).

Fishing mortality  $F$  of age 0 fish was high from the 1980s to the early 1990s and then showed a decreasing trend (Fig. 4-5, Appendix 2). The  $F$  of fish age 1 and fish age 2 and older was also high from the 1980s to the early 1990s, then showed a decreasing trend, and remained at a low level from the late 1990s to the 2000s. After reaching high values of 9 or higher in 2012 and 2013, it started decreasing again, and the value of  $F$  of fish age 1 and fish age 2 and older was as small as 0.83 in 2023. The high  $F$  for fish age 1 and fish age 2 and older in 1987, 2012, and 2013 is due to small values assumed for the catch in number of fish age 2 and older in the years following these years for the sake of convenience, based on the judgement that "individuals aged 2 years or older were also caught in the years following these years, but were not observed in the samples" (Appendix 2, Kono et al. 2023).

Sensitivity analysis was performed for the assumed  $M$  when multiplied by 0.8 and by 1.2 (Fig. 4-6). When  $M$  was set low, the estimated values of biomass, SSB, and recruitment were all small; conversely, when  $M$  was set large, they were all larger.

Compared to the results of the stock assessment of the previous fiscal year, there were no major differences in the estimated values prior to 2020. However, the estimated values

changed after 2021. For example, the recruitment of the 2021 cohort (2021 age 0 fish, 2022 age 1 fish, 2023 age 2 fish) and the 2022 cohort (2022 age 0 fish, 2023 age 1 fish) was revised downward (Appendix 8).

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

To compare fishing pressures while considering selectivity, we compared the findings for spawning per recruitment (SPR) based on scenarios with and without fishing pressure. Fig. 4-7 and Table 4-1 show the trends in the SPR ratio (%SPR), which compares SPR in a scenario without fishing pressure against SPR in a scenario with fishing for each year. The lower the fishing pressure, the larger the SPR. After remaining low in the 1980s, %SPR showed an increasing trend from the 1990s, reaching 57.5% in 2023. Calculations showed that %SPR was 52.4% using the average F value of the previous 5 years, excluding the most recent year (2018 to 2022) for the current fishing pressure (Supplementary Table 6-3).

The relationship between YPR and %SPR with respect to  $F_{msy}$  is shown in Fig. 4-8. The values (Kono et al. 2022) used in the “Materials for the Research Institute Meeting on Reference Points” (published in September 2022) to estimate the fishing pressure ( $F_{msy}$ ) required to maintain  $SB_{msy}$  were used as the selectivity of F. In addition, the values used to calculate  $F_{msy}$  were also used for average body weight at age and maturity rate.  $F_{msy}$  is equivalent to 49.2% when converted to %SPR (Supplementary Table 6-2). Current fishing pressure ( $F_{2018-2022}$ ) is over  $F_{0.1}$  and below  $F_{msy}$  or  $F_{30\% SPR}$ .

#### (5) Stock-recruitment Relationship

The relationship (stock-recruitment relationship) between SSB (weight) and recruitment (individuals) is presented in Fig. 4-9. At the above-mentioned Research Institute Meeting on Reference Points, a hockey stick stock-recruitment model was applied for the stock-recruitment relationship of this stock (Kono et al., 2022). The data used for parameter estimation of the stock-recruitment relationship comprised SSB and recruitment based on the stock assessment of fiscal year 2022 (Kono et al. 2023s), with the least squares method used as the optimization method. Recruitment residual autocorrelation was not accounted for in the analysis. The parameters of the stock-recruitment relationship model are shown in Supplementary Table 6-1.

#### (6) Levels to Achieve MSY Under Current Environmental Conditions

The maximum sustainable yield (MSY), the SSB to achieve MSY ( $SB_{msy}$ ), and the F to achieve  $SB_{msy}$  ( $F_{msy}$ ) under current environmental conditions (1981 onward), as shown in the Materials for the Research Institute Meeting on Reference Points published in September 2022 (Kono et al. 2022), are shown in Supplementary Table 6-2.

#### (7) Stock Levels, Trends and Fishing Pressure Levels

Reference values for SSB to achieve MSY (SBmsy) and fishing pressure required to maintain SBmsy (Fmsy) are shown in a Kobe plot in Fig. 4-10. In addition, a summary of SSB and fishing pressure in 2023, and the comparison between these values and the proposed reference points are shown in Supplementary Table 6-3. SSB of this stock in the 2023 fishing season was higher than SBmsy, at 1.37 times the value of SBmsy. In addition, the fishing pressure of 2023 was under Fmsy and was 0.75 times of Fmsy. The F ratios (F/Fmsy) shown in the Kobe plot are the ratio between F values in each year and the value of F that gives the fishing pressure of Fmsy under the selectivity of F in each year, converted to %SPR. Based on trends seen in the previous 5 years (2019 to 2023), SSB is judged to be in an “increasing” trend. SSB of this stock was lower than SBmsy from 1988 to 2007 (except in 1991 and 2006), but it has generally been maintained higher than SBmsy in 2008 and onwards (except from 2020 to 2021), while the fishing pressure of this stock has been lower than Fmsy (Fig. 4-10, Table 4-1).

#### 5. Summary of Stock Assessment

Stock abundance (biomass) of Japanese anchovy was high in the early 1980s, then showed a decreasing trend, but has been increasing since the 2000s. The SSB in 2023 exceeded the value 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 below the fishing pressure level (Fmsy) required to maintain SBmsy.

#### 6. Others

It should be noted that the stock assessment (biomass estimation) of this stock is based on the catch in weight of fish presumed to be “Japanese anchovy” according to the commercial size category in the Statistics of Fishery and Aquaculture Production, without the inclusion of Whitebait (fish that are 1 to 2 months old) (see Appendix 9 for information on Whitebait).

In Hiuchi-nada, located in the central Seto Inland Sea, this species was designated as a target species for the Stock Recovery Plan in FY 2005, and through the Fisheries Adjustment Regulations and voluntary efforts among fishermen, the fishing season for boat seine fisheries was shortened, regular closed fishing days were established, and net size limits were imposed. Although the Stock Recovery Plan ended in FY 2011, measures implemented under the Plan have continued to be implemented since FY 2012 under the new framework of the resource management guidelines and plan, for example, measures to delay the opening of fishing for large fish (adult fish) (Gema 1995). This measure is expected to raise egg production, which forms the basis for recruitment, as much as possible, and also to produce better quality dried fish products by catching the fish after spawning rather than before spawning. In addition, delaying the opening date for fishing of Whitebait is expected to increase the catch in weight by waiting for the body weight of the

fish to increase before fishing. Furthermore, at least one regular closed fishing day per week shall be set during the fishing period in order to reduce effort, and closed fishing days shall be considered in line with trends in the stock. In the Seto Inland Sea, the catch target size differs depending on the sea area, and it is important to continue promoting measures that suit the actual conditions of each area.

#### 7. Cited literature

- Doi, N., Takao, K., Ishioka, K., Hayashi, G., and Yoshida, S. (1978) 6. Analysis Survey of Pelagic Fish Stock. Report on the Environmental Impact Study of Fisheries at Kansai International Airport in 1977, Part III. Fishery Organisms, Japan Fisheries Resource Conservation Association, 176-198.
- Funakoshi, S. (1990) Studies on the reproduction mechanisms of Japanese anchovy in the Enshu-nada Sea, Ise/Mikawa Bay, and surrounding waters. Aichi Fisheries Research Institute Performance Report Volume B, 10, 1-208.
- Funamoto, T., Aoki, I., and Wada, Y. (2004) Reproductive characteristics of Japanese anchovy, *Engraulis japonicus*, in two bays of Japan. *Fish. Res.*, **70**, 71-81.
- Gema, G. (1995) Anchovy Fisheries in the Seto Inland Sea and Boat and Boat Seine Management. *Japanese journal of fisheries economics*, **36**, 31-44.
- Hattori, S. (1982) 3. Distribution of eggs of Japanese anchovy, *Engraulis japonicus*, in the Seto Inland Sea, Japan. *Japanese Society of Fisheries Oceanography*, **41**, 39-44.
- Kishida, T. (1986) Feeding habits of Japanese Spanish mackerel in the central and western waters of the Seto Inland Sea. *Bull. Nansei Reg. Fish.*, 73-89.
- Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., and Kinoshita, J. (2022) Materials for the Research Institute Meeting of Seto Inland Sea stock of Japanese anchovy (FY 2022). FRA-SA2022-BRP05-01, Japan Fisheries Research and Education Agency, Yokohama, 55 pp.  
[https://www.fra.affrc.go.jp/shigen\\_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf](https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf)
- Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., Kinoshita, J., and Nishijima, S. (2023) Stock Assessment for Japanese Anchovy – Seto Inland Sea (Fiscal Year 2022). FRA-SA2022-AC-25, Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2022), Japan Fisheries Research and Education Agency, Fisheries Agency, Tokyo, 51 pp.  
[https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details\\_2022\\_25.pdf](https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details_2022_25.pdf)
- Kono, N. and Zenitani, H. (2008) Distribution of egg production of Japanese anchovy in the Seto Inland Sea from 1980 to 2005. *Fish. Sci.*, **74**, 636-644.
- Ochiai, A. and Tanaka, K. (1986) *Ichthyology, New Edition (Vol. 2)*. Kouseisha Kouseikaku, Tokyo, 1140 pp.
- Takao, K. (1990) Migration and spawning of Japanese anchovy in the Seto Inland Sea. *Fisheries Technology and Management*, **3**, 9-17.

Yamamoto, M. and Honda, K. (2008) Crude fat content and fatty acid composition of adult Japanese anchovy in eastern Hiuchi-nada, Seto Inland Sea. Kagawa Prefectural Water Research Institute Report, **9**, 5-9.

Yokota, T. and Furukawa, I. (1952) Studies on anchovy stock in Hyuga-nada, Japan Part III: Variation and growth of the vertebrae of Japanese anchovy. Fish. Sci., **17**, 60-64.

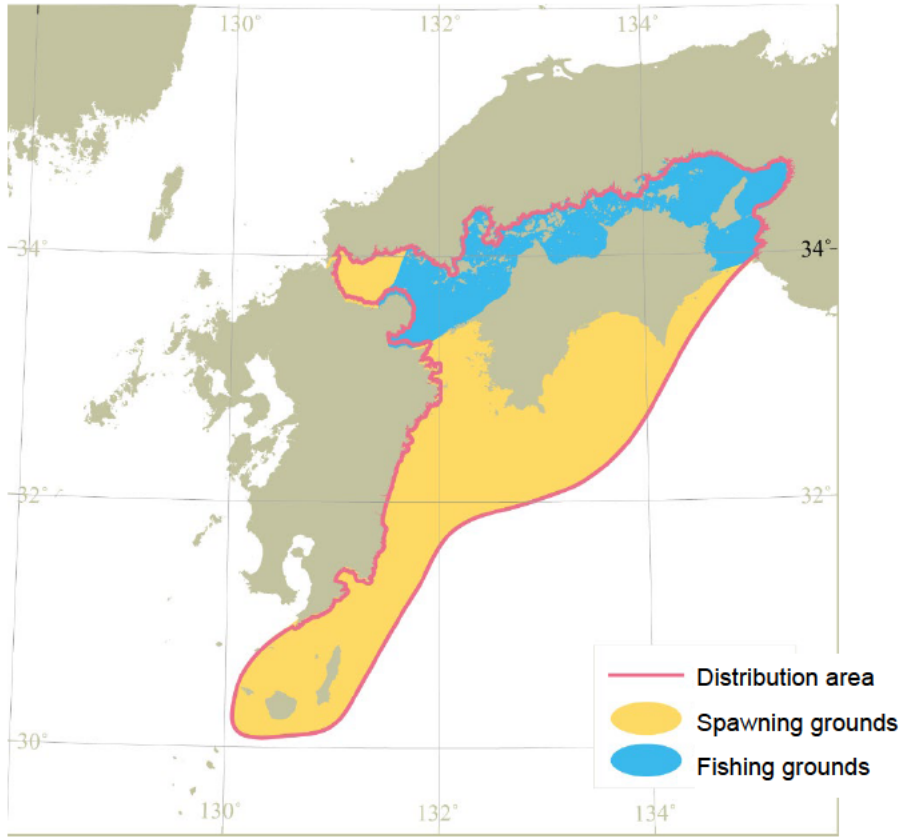


Fig. 2-1. Distribution area, spawning grounds, and fishing grounds of the Seto inland sea stock of Japanese anchovy

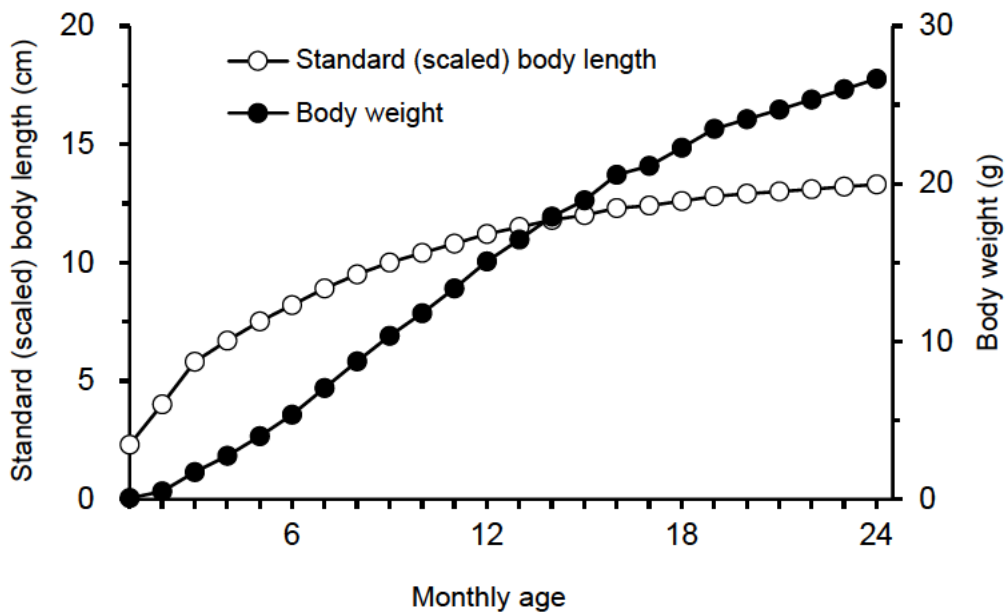


Fig. 2-2. Monthly age and growth



Fig. 2-3. Maturity rate at age

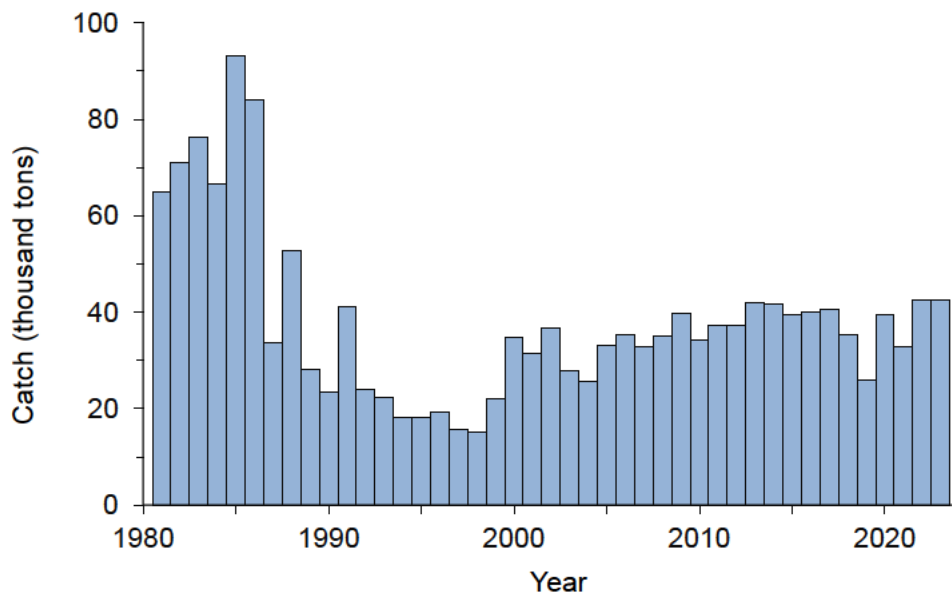


Fig. 3-1. Trends in catch in weight

This is the catch in weight of “Japanese anchovy” from the Fisheries and Aquaculture Production Statistics, excluding the portion of Whitebait (1-2 month old fish).

The values for 2023 are provisional.

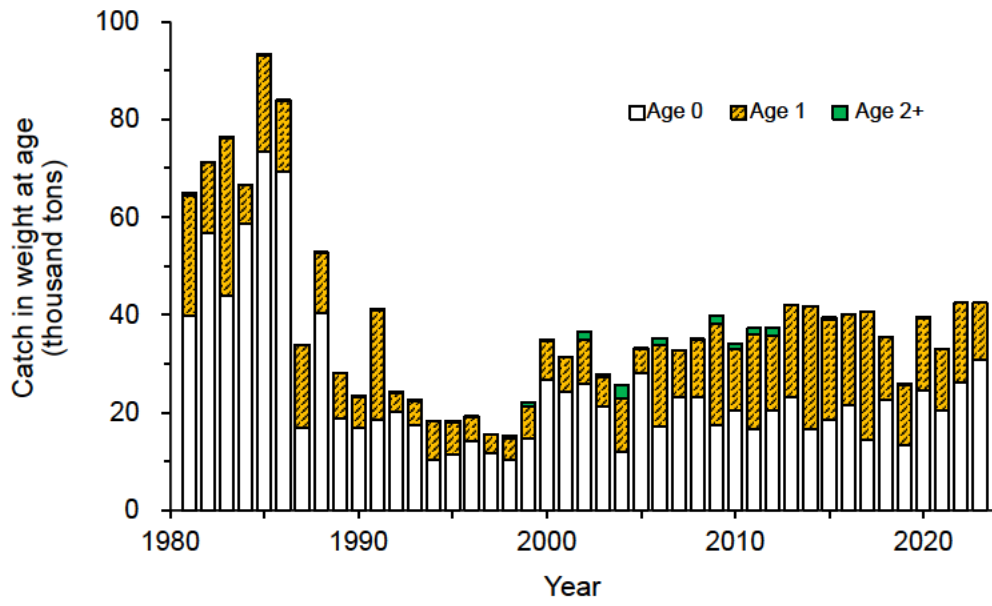


Fig. 3-2. Trends in catch in weight at age

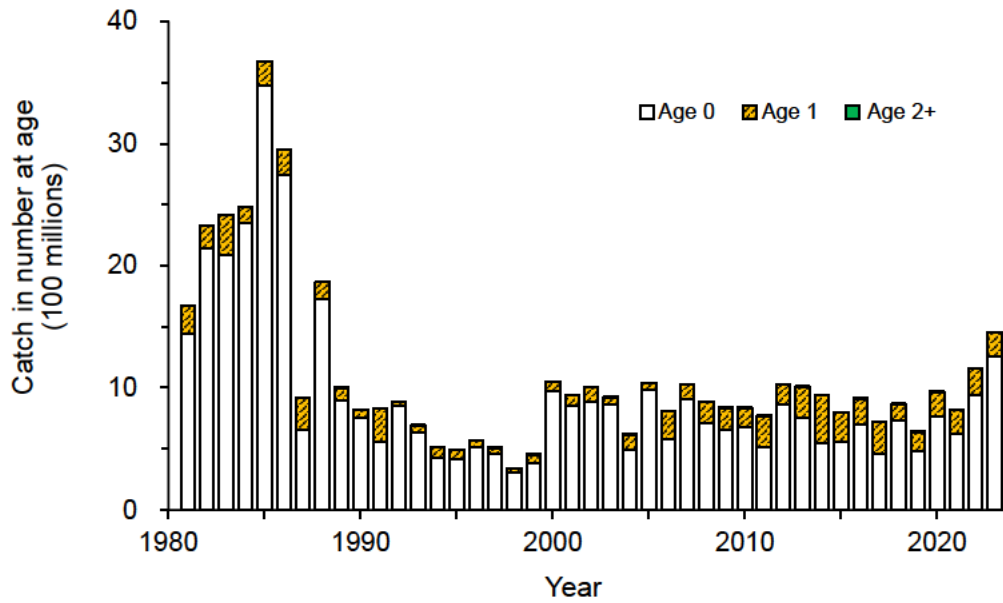


Fig. 3-3. Trends in catch in number at age

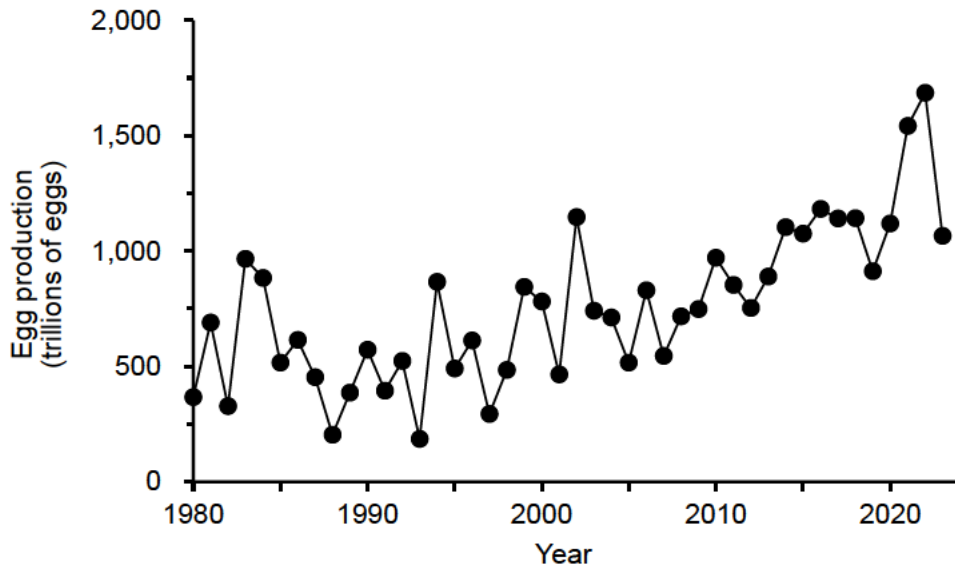


Fig. 4-1. Trends in egg production

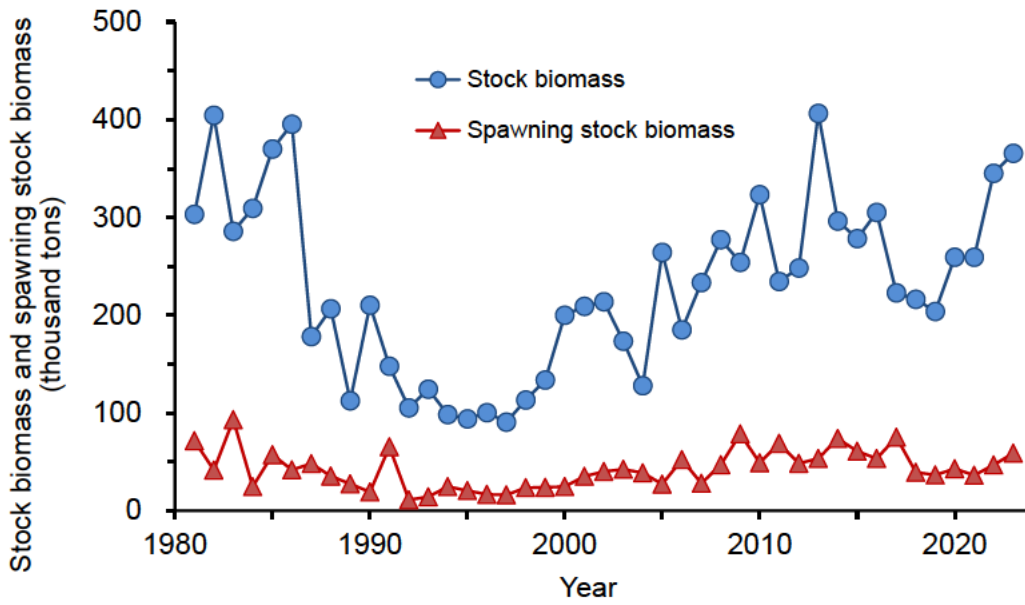


Fig. 4-2. Trends in stock biomass and spawning stock biomass

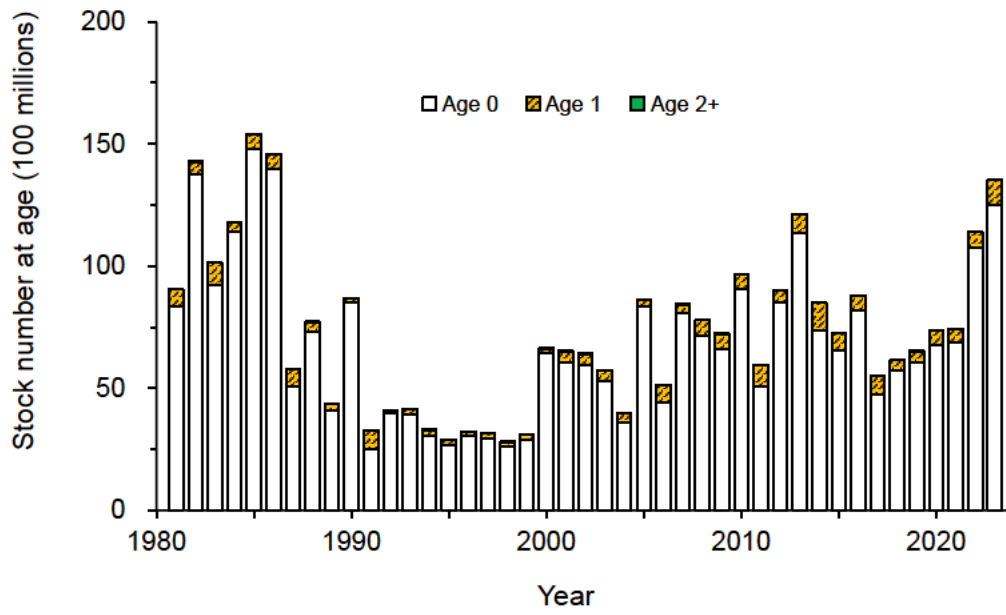


Fig. 4-3. Trends in stock number at age

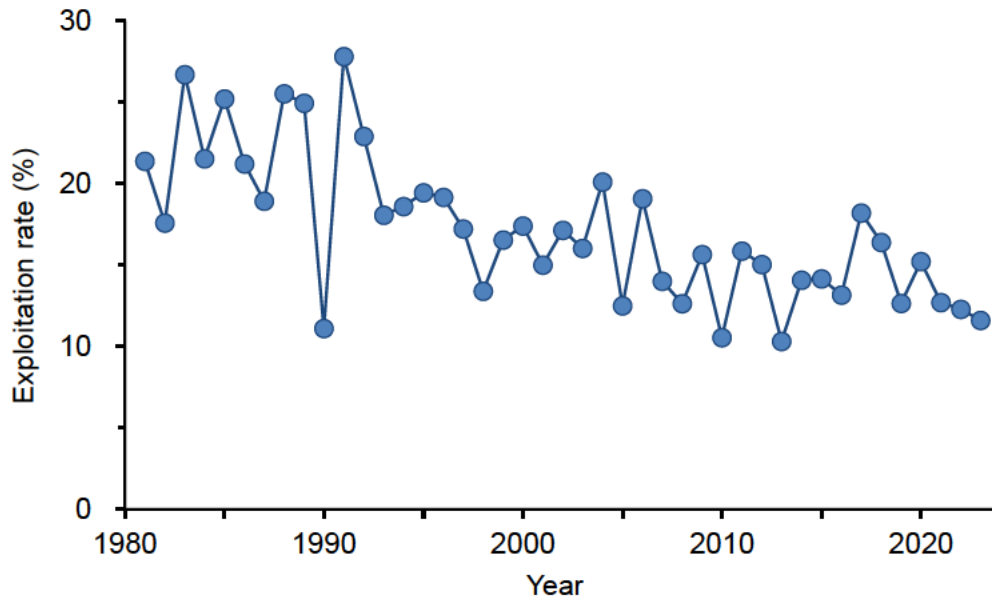


Fig. 4-4. Trends in exploitation rate

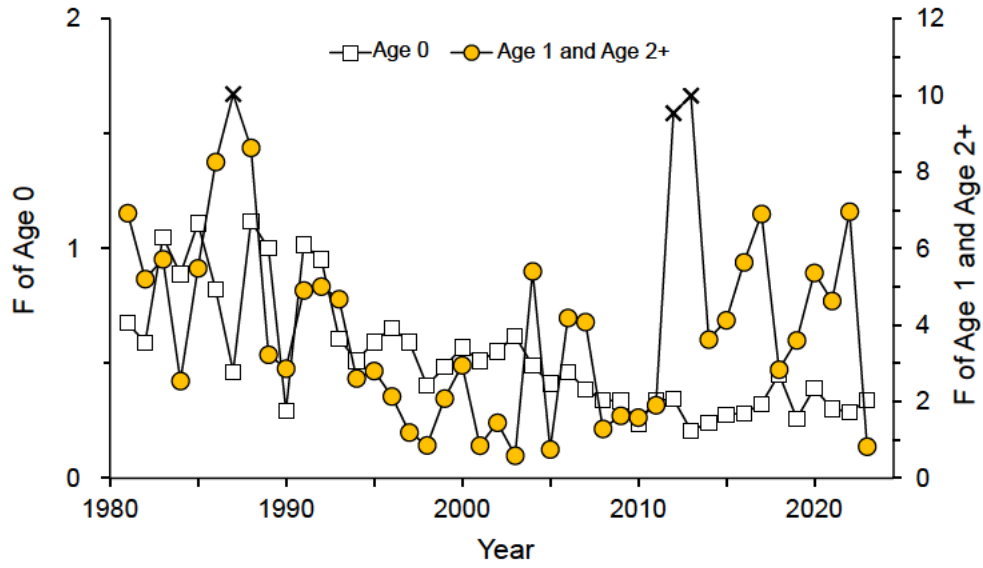


Fig. 4-5. Trends in F

×: The catch in number of fish age 2 and older in 1988 and from 2012 to 2013, which was regarded as zero individuals, is believed to be higher due largely to the use of values that, for the sake of convenience, is 50% (15,000 fish) of the lowest catch in number of fish age 2 and older in the past (Appendix 2).

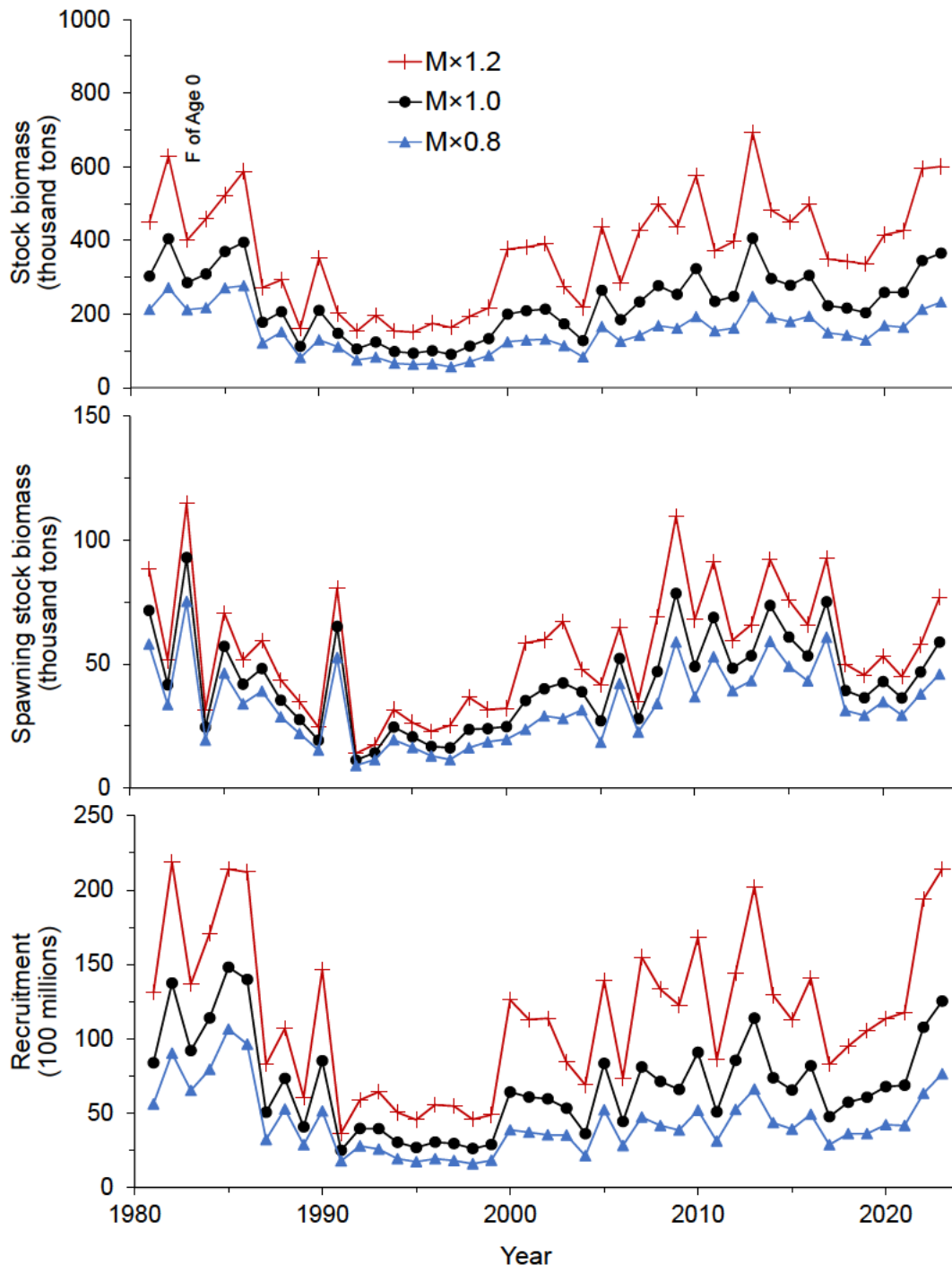


Fig. 4-6. Sensitivity analysis results of M

Upper is stock biomass, middle is spawning stock biomass and lower is recruitment.

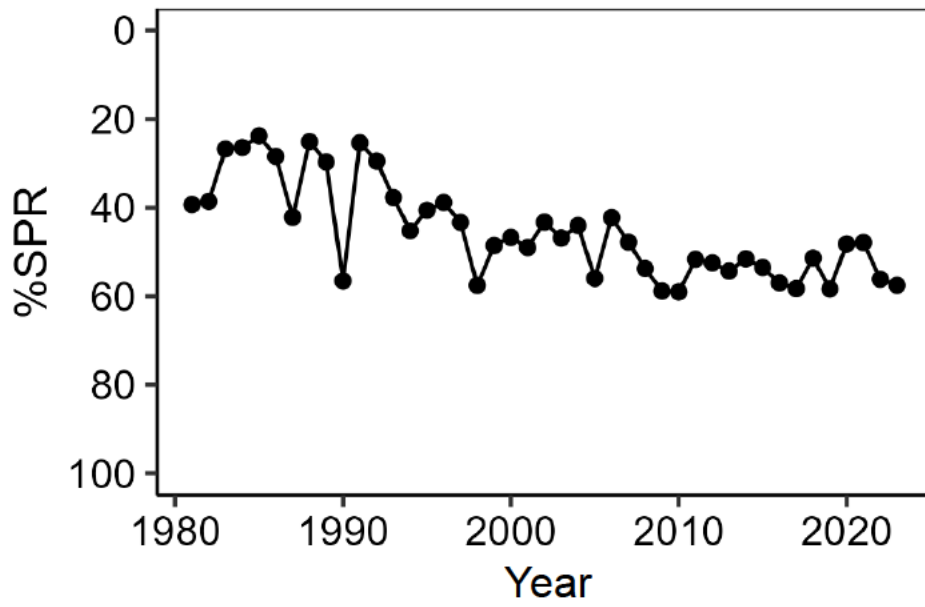


Fig. 4-7. Trends in %SPR

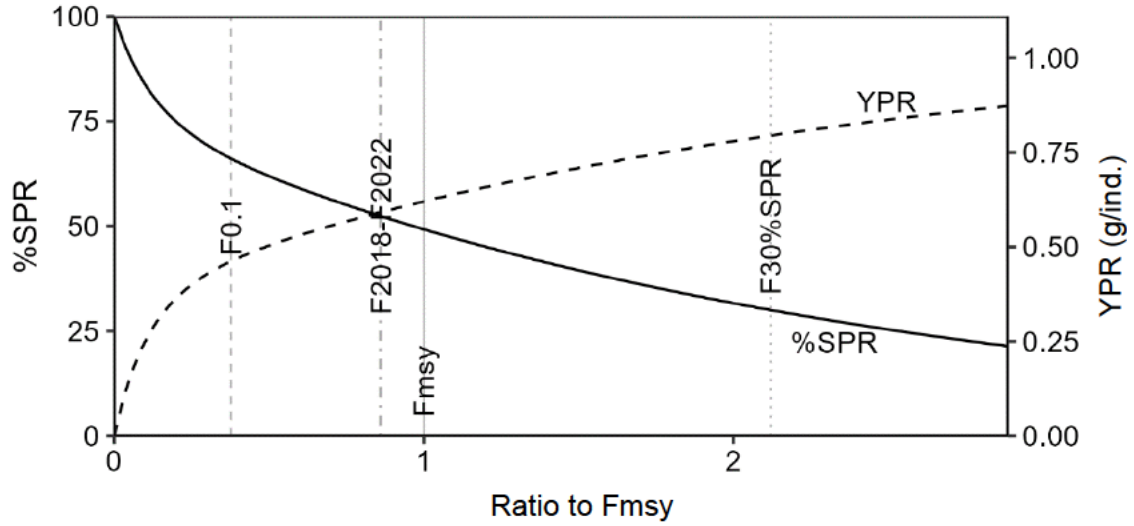


Fig. 4-8. Relationship between YPR and %SPR with respect to Fmsy

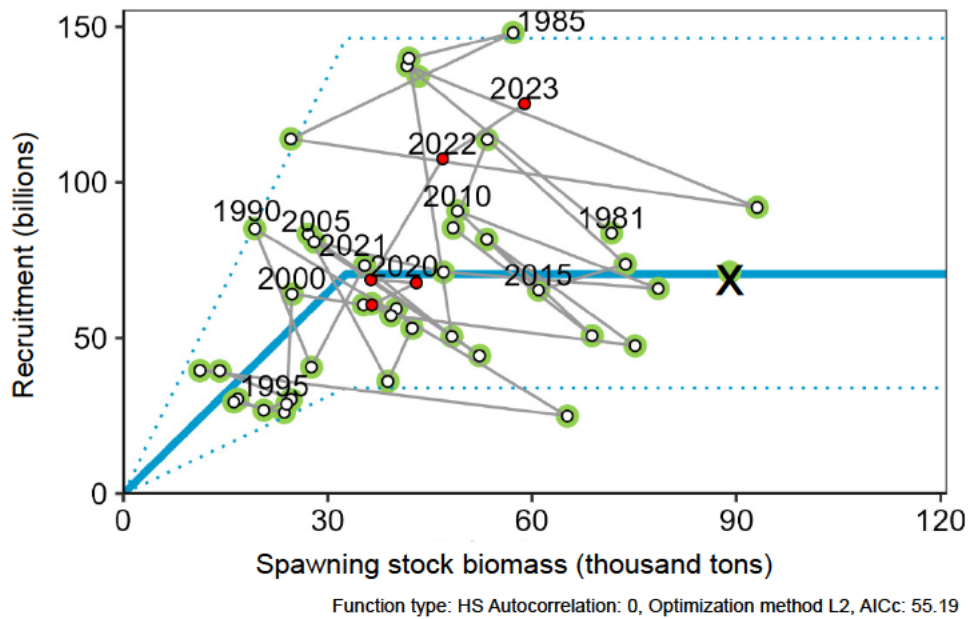


Fig. 4-9. Relationship between spawning stock biomass and recruitment (stock-recruitment relationship)

A hockey stick (HS) type stock-recruitment relationship that does not account for autocorrelation was used, and parameters were estimated using the least squares method. The green circles indicate SSB and recruitment from 1981 to 2020 at the time of the FY 2022 assessment, which was used for the analysis of the stock-recruitment relationship (except for 2021, the most recent year at the time of the FY 2022 assessment, which is marked with an  $\times$ ). The numbers in the figure indicate the cohort (birth year) of the recruited stock. The line plot with circular markers indicates SSB and recruitment from 1981 to 2023 for this fiscal year's assessment. The most recent five years (2019-2023) are circled in red.

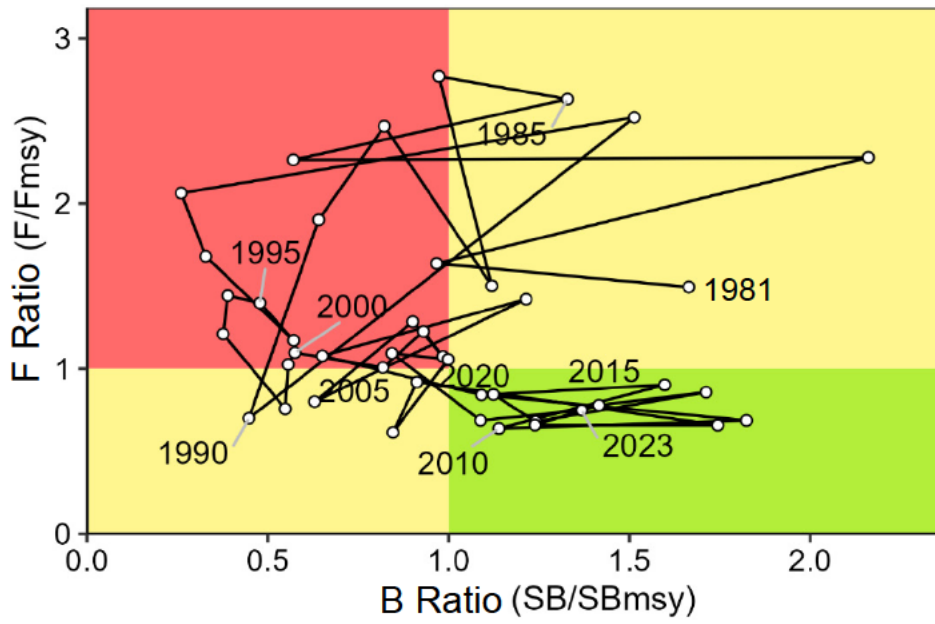


Fig. 4-10. Relationship of past levels of SSB and fishing pressure against SSB to achieve MSY (SBmsy) and fishing pressure required to maintain SBmsy (Fmsy) (Kobe plot)

Table 3-1. Trends in catch in weight (tons) of Japanese Anchovy

Year	Catch of "Japanese anchovy" according to commercial size category in the Statistics of Fishery and Aquaculture Production	Catch considered in this stock assessment*
1981	67,532	64,815
1982	76,088	71,150
1983	80,945	76,297
1984	75,012	66,617
1985	99,729	93,295
1986	92,887	83,932
1987	36,004	33,762
1988	57,595	52,729
1989	40,279	28,085
1990	31,548	23,400
1991	42,281	41,084
1992	27,287	24,125
1993	24,929	22,474
1994	20,511	18,331
1995	22,648	18,283
1996	19,802	19,246
1997	20,042	15,625
1998	16,480	15,176
1999	22,696	22,139
2000	36,523	34,831
2001	35,790	31,388
2002	43,066	36,634
2003	33,827	27,823
2004	32,917	25,705
2005	35,895	33,099
2006	41,883	35,298
2007	36,555	32,707
2008	39,316	35,059
2009	44,667	39,749
2010	36,678	34,116
2011	37,993	37,221
2012	39,956	37,336
2013	43,564	41,974
2014	43,740	41,736
2015	41,217	39,450
2016	42,727	40,162
2017	41,210	40,557
2018	37,963	35,476
2019	31,501	25,821
2020	40,760	39,491
2021	35,955	32,937
2022	45,100	42,469
2023	44,806	42,423

\* The catch in weight of fish presumed to be "Japanese anchovy" according to commercial size category in the Statistics of Fishery and Aquaculture Production, without inclusion of Whitebait (fish that are 1 to 2 months old). The values for 2023 are provisional.

Table 3-2. Trends in catch in weight (tons) of Japanese Anchovy according to commercial size category by prefecture and fishery type

Prefecture name	Fishery type	Year						
		2013	2014	2015	2016	2017	2018	2019
Wakayama Prefecture	Boat seine	5	3	19	2	7	2	2
	Purse seine	0	0	0	0	0	0	0
	Others	0	3	4	1	6	4	0
Osaka Prefecture	Boat seine	0	0	0	0	0	0	0
	Purse seine	8,208	10,410	5,958	8,054	9,520	549	1,410
	Others	2	4	3	4	1	1	1
Hyogo Prefecture	Boat seine	1	0	0	0	0	0	0
	Purse seine	2,754	4,216	3,942	4,199	1,603	4,101	1,389
	Others	0	0	0	0	0	0	0
Okayama Prefecture	Boat seine	0	0	0	0	0	0	0
	Purse seine	0	0	0	0	0	0	0
	Others	0	2	1	0	0	0	0
Hiroshima Prefecture	Boat seine	10,120	11,093	10,488	9,715	9,527	10,402	8,604
	Purse seine	2	0	59	0	0	0	0
	Others	0	0	1	0	1	0	0
Yamaguchi Prefecture	Boat seine	2,869	3,030	2,956	2,555	2,767	2,104	2,273
	Purse seine	0	0	0	0	0	0	0
	Others	132	123	183	57	73	51	61
Fukuoka Prefecture	Boat seine	0	0	0	0	0	0	0
	Purse seine	0	0	0	0	0	0	0
	Others	0	0	0	0	0	0	0
Oita Prefecture	Boat seine	1,279	1,772	1,483	1,747	1,109	913	1,240
	Purse seine	0	0	0	0	0	0	0
	Others	0	0	0	0	0	0	0
Tokushima Prefecture	Boat seine	2,005	1,379	1,014	437	0	834	802
	Purse seine	0	0	0	0	0	0	0
	Others	0	0	0	0	1	0	0
Kagawa Prefecture	Boat seine	8,902	5,214	8,324	9,368	8,848	11,333	8,533
	Purse seine	0	0	0	0	0	0	0
	Others	168	78	64	32	95	130	2
Ehime Prefecture	Boat seine	7,107	6,355	6,540	6,474	6,916	7,433	7,113
	Purse seine	0	0	0	0	0	0	0
	Others	1	11	5	4	4	4	5
Total		43,555	43,693	41,044	42,649	40,478	37,861	31,435

The totals may not necessarily match the values in Table 3-1 for reasons such as the confidentiality of statistical information. In addition, the table does not exclude Whitebait (fish that are 1 to 2 months old) from the catch in weight of fish presumed to be “Japanese anchovy” according to the commercial size category. The values for 2023 are provisional.

Table 3-2. (Continued)

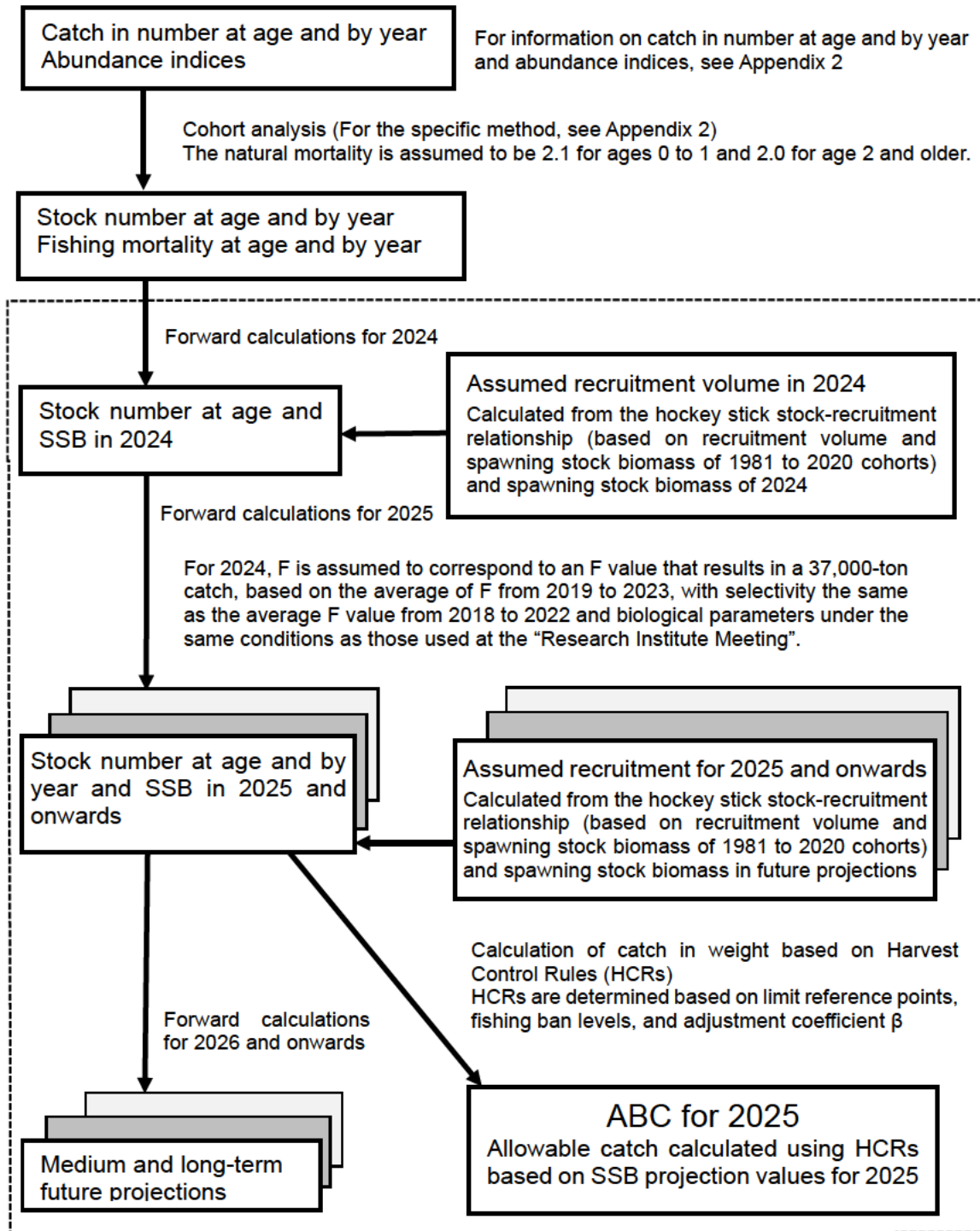
Prefecture name	Fishery type	Year			
		2020	2021	2022	2023
Wakayama Prefecture	Boat seine	4	9	0	0
	Purse seine	0	0	0	0
	Others	3	2	2	1
Osaka Prefecture	Boat seine	0	0	0	0
	Purse seine	5,597	6,069	11,835	6,664
	Others	3	1	1	0
Hyogo Prefecture	Boat seine	0	0	0	0
	Purse seine	2,614	2,826	4,331	4,331
	Others	0	0	0	0
Okayama Prefecture	Boat seine	0	0	0	0
	Purse seine	0	0	0	0
	Others	0	0	0	1
Hiroshima Prefecture	Boat seine	14,134	12,477	11,586	14,718
	Purse seine	0	65	82	91
	Others	24	0	0	1
Yamaguchi Prefecture	Boat seine	3,730	2,571	2,711	4,126
	Purse seine	0	0	0	0
	Others	45	27	12	4
Fukuoka Prefecture	Boat seine	0	0	0	0
	Purse seine	0	0	0	0
	Others	0	0	0	0
Oita Prefecture	Boat seine	700	947	1,494	924
	Purse seine	0	0	0	0
	Others	0	0	0	0
Tokushima Prefecture	Boat seine	1,316	1,492	526	385
	Purse seine	0	0	0	0
	Others	0	0	0	0
Kagawa Prefecture	Boat seine	5,597	4,702	8,216	8,554
	Purse seine	0	0	0	0
	Others	10	14	15	26
Ehime Prefecture	Boat seine	6,980	4,750	4,285	4,977
	Purse seine	0	0	0	0
	Others	3	3	3	3
Total		40,760	35,955	45,099	44,806

The totals may not necessarily match the values in Table 3-1 for reasons such as the confidentiality of statistical information. In addition, the table does not exclude Whitebait (fish that are 1 to 2 months old) from the catch in weight of fish presumed to be “Japanese anchovy” according to the commercial size category. The values for 2023 are provisional.

Table 4-1. Analysis results of Seto Inland Sea stock of Japanese Anchovy

Year	Catch (Thousand tons)	Stock biomass (Thousand tons)	Spawning stock biomass (Thousand tons)	Recruitment volume (billion fishes)	Exploitation rate (%)	Reproductive success rate (thousands of individuals/kg)	%SPR	F/Fmsy	Egg production (trillions of eggs)
1980	-	-	-	-	-	-	-	-	367
1981	65	303	72	837	21	1.2	39.3	1.49	690
1982	71	404	42	1,374	18	3.3	38.6	1.64	328
1983	76	286	93	920	27	1.0	26.8	2.28	966
1984	67	309	25	1,140	22	4.6	26.4	2.26	883
1985	93	370	57	1,481	25	2.6	23.8	2.63	516
1986	84	395	42	1,398	21	3.3	28.5	2.77	614
1987	34	178	48	505	19	1.0	42.2	1.50	453
1988	53	207	35	733	26	2.1	25.1	2.47	203
1989	28	113	28	406	25	1.5	29.7	1.90	386
1990	23	210	19	851	11	4.4	56.5	0.70	572
1991	41	148	65	249	28	0.4	25.4	2.52	394
1992	24	105	11	395	23	3.5	29.5	2.06	523
1993	22	124	14	395	18	2.8	37.7	1.68	185
1994	18	99	25	303	19	1.2	45.2	1.17	866
1995	18	94	21	268	19	1.3	40.6	1.40	491
1996	19	100	17	304	19	1.8	38.8	1.44	612
1997	16	91	16	294	17	1.8	43.3	1.21	294
1998	15	113	24	261	13	1.1	57.5	0.76	485
1999	22	134	24	288	17	1.2	48.6	1.03	845
2000	35	200	25	641	17	2.6	46.7	1.10	780
2001	31	209	35	607	15	1.7	49.0	1.01	465
2002	37	214	40	595	17	1.5	43.3	1.23	1,146
2003	28	173	42	532	16	1.3	46.8	1.07	741
2004	26	128	39	361	20	0.9	44.0	1.28	711
2005	33	264	27	833	13	3.1	56.0	0.80	516
2006	35	185	52	443	19	0.8	42.3	1.42	829
2007	33	233	28	809	14	2.9	47.8	1.08	546
2008	35	277	47	712	13	1.5	53.8	0.84	717
2009	40	254	79	659	16	0.8	58.8	0.69	748
2010	34	323	49	908	11	1.9	59.0	0.64	970
2011	37	235	69	507	16	0.7	51.6	0.90	853
2012	37	248	48	854	15	1.8	52.5	0.84	753
2013	42	407	53	1,138	10	2.1	54.3	0.68	889
2014	42	296	74	737	14	1.0	51.5	0.86	1,103
2015	39	278	61	654	14	1.1	53.5	0.78	1,075
2016	40	305	53	817	13	1.5	57.0	0.66	1,182
2017	41	223	75	475	18	0.6	58.3	0.66	1,140
2018	35	216	39	572	16	1.5	51.4	0.92	1,142
2019	26	204	36	607	13	1.7	58.4	0.61	913
2020	39	259	43	678	15	1.6	48.2	1.06	1,119
2021	33	259	36	687	13	1.9	47.9	1.09	1,542
2022	42	345	47	1,076	12	2.3	56.2	0.69	1,686
2023	42	366	59	1,253	12	2.1	57.5	0.75	1,065

Appendix 1 Stock Assessment Flow



\* The information inside the dotted line box is based on discussion of reference points, HCRs, etc., at the Stock Management Policy Review Meeting. ABC is calculated after the catch scenario for this stock is established through the Fisheries Policy Council.

## Appendix 2 Calculation Methods

### (1) Stock Calculation Methods

#### 1. Cohort analysis (Tuning VPA)

Catch in number at age and by year was calculated assuming an age composition of age 0, age 1, and age 2 and older (plus group), and the stock number at age and by year was estimated using VPA with tuning (Supplementary Table 2-1). Maturity rates and M at age used for stock calculations are shown in Supplementary Table 2-2. M at age was calculated based on M at monthly age (Supplementary Table 2-3) used in the stock assessment of this stock up to FY 2021, starting from January 1, for an age composition of age 0, age 1, and age 2 and older. Note that monthly M at age was calculated using the method of Chen and Watanabe (1989), and the matrix of M at monthly age and by month is shown in Supplementary Table 2-4. In each month, the M for each age was obtained by estimating the average of the values for each age and summing these values for January through December. As a result, the M for fish age 0 and fish age 1 was set at 2.1, while for fish age 2 and older, it was set at 2.0. The reason for using January 1 as the starting date for age is that, although spawning, recruitment, and fishing take place nearly year-round, they are at a much lower level during winter, making it easy to consider it as a break in the annual cycle, and also because fishery catch statistics are aggregated from January to December, which is convenient for calculations.

The catch in number at age and by year for Japanese anchovy was determined by excluding Whitebait (fish that are 1 to 2 months old) from the estimated catch in number at monthly age and by month and then aggregating the numbers at age and by year. January 1 was used as the starting date for age in the aggregation of catch in number at age and by year as well, assuming an age composition of age 0, age 1, and age 2 and older (Supplementary Table 2-5). Catch in weight at age and by year was obtained by multiplying the catch in number at monthly age and by month by the average weight by monthly age (Supplementary Table 2-3) and then aggregating the catch in weight at monthly age and by month thus obtained with value at age and by year using the same method used for the catch in number at age and by year. Body weight at age and by year was determined by dividing the catch in weight at age and by year by the catch in number at age and by year (Supplementary Table 2-1).

Catch in number at age and by year showed zero catches of fish age 2 and in 1988, 2013, and 2014. For the purpose of calculating the VPA, we considered that the “fish were actually present and caught, but not measured as a sample,” and, for the sake of convenience, used a value of 50% (15,000 fish) of the lowest catch in number of fish age 2 and older in the past (30,000 fish in 1989) as the catch in number of fish age 2 and older in these years (Kono et al. 2023).

The catch in number at monthly age and by month followed the calculation method used in the stock assessments of this stock until FY 2021 (Kono and Takahashi 2022). In addition

to the catch of “Japanese anchovy” according to commercial size category in the Statistics of Fishery and Aquaculture Production and the catch in weight by sea area in the Seto Inland Sea, the catch in weight by month, the body length composition by month, and body length-weight equations of the major fisheries cooperatives in each sea area were used in the calculation. The catch in number at monthly age and by month in each area was aggregated to obtain the total catch in number at monthly age and by month for this species in the entire Seto Inland Sea. The sea area was divided into five areas: eastern Seto Inland Sea, Hiuchi-nada, Aki-nada, Iyo-nada, and Suo-nada.

The following equation (Doi et al. 1978) was used for the growth function when estimating the catch in number at monthly age and by month. However, for the body length of fish age less than 2 months, the values were taken from Fukuhara and Takao (1988).

$$La = 140.1 - 117.8e^{-0.1189a} \quad (1)$$

Here,  $a$  is the age in months, and  $La$  is the body length (mm) of age  $a$  fish. The following equations were used to calculate the average length-weight equation.

$$BW = 5.811 \times 10^{-7} TL^{3.523} \quad (TL < 40 \text{ mm}; R^2 = 0.908, N = 496) \quad (2)$$

$$BW = 1.013 \times 10^{-6} TL^{3.396} \quad (TL \geq 40 \text{ mm}; R^2 = 0.977, N = 31,902) \quad (3)$$

Here,  $BW$  is body weight (g), and  $TL$  is total length (mm). Equation (3), expressed in terms of body length  $L$  (mm), is as follows.

$$BW = 2.379 \times 10^{-6} L^{3.319} \quad (R^2 = 0.977, N = 31,902) \quad (4)$$

The body length ranges for each monthly age determined from the growth equation, and readings are shown in Supplementary Table 2-3. The conversion from body length composition to monthly age composition was based on the thin section method (Tanaka 1985).

The catch in number at monthly age and by month does not include the catch in weight of “Whitebait” provided in the Statistics of Fishery and Aquaculture Production. However, after being recruited as Whitebait, this species in the Seto Inland Sea is continuously caught as it grows; therefore, the catch composition may range from “Whitebait” to “Japanese anchovy”. Therefore, samples assigned to “Japanese anchovy” according to commercial size category in the Statistics of Fishery and Aquaculture Production also included individuals of similar body size to Whitebait (fish that are 1 to 2 months old). These individuals were thus treated the same as “Whitebait” and were not included in the stock assessment of this stock (biomass estimation, etc.). For reference, the percentage of 1 to 2 months old fish in “Japanese anchovy” fish according to commercial size category in the Statistics of Fishery and Aquaculture Production that used in the stock assessment are

shown in Supplementary Fig. 2-1 and Supplementary Table 2-6. The percentage by weight of fish that are 1 to 2 months old is, on average, 10%.

The following Pope (1972) approximation formula was used to calculate the stock number at age and by year.

$$N_{a,y} = N_{a+1,y+1}e^{M_a} + C_{a,y}e^{\frac{M_a}{2}} \quad (5)$$

Here,  $N_{a,y}$  is the stock number of age  $a$  fish ( $a = 0$  years) in year  $y$ ,  $C_{a,y}$  is the catch in number of age  $a$  fish ( $a = 0$  years) in year  $y$ , and  $M_a$  is the natural mortality of age  $a$  fish ( $a = 0$  years). For the calculation of the stock number of the oldest group, the Hiramatsu (1999) method was used, assuming that the fishing mortality of fish age 1 and fish age 2 and older was the same. The stock number  $N_{1,y}$  for age 1 fish in year  $y$  and  $N_{2+,y}$  for fish age 2 months and older in year  $y$  were calculated using the following equations (Hiramatsu 2000).

$$N_{1,y} = \frac{C_{1,y}}{C_{2+,y} + C_{1,y}} N_{2+,y+1}e^{M_1} + C_{1,y}e^{\frac{M_1}{2}} \quad (6)$$

$$N_{2+,y} = \frac{C_{2+,y}}{C_{2+,y} + C_{1,y}} N_{2+,y+1}e^{M_{2+}} + C_{2+,y}e^{\frac{M_{2+}}{2}} \quad (7)$$

$F_{a,y}$ , which is the fishing mortality of age  $a$  fish (age 0 to 2+ years) in year  $y$ , was calculated using the following equation.

$$F_{a,y} = -\ln \left\{ 1 - \frac{C_{a,y}e^{\frac{M_a}{2}}}{N_{a,y}} \right\} \quad (8)$$

The stock number  $N_{a,t}$  of age  $a$  fish (age 0 to 2+ years) in the most recent year (year  $t$ ) was calculated using the following equation.

$$N_{a,t} = C_{a,t}e^{\frac{M_a}{2}} \frac{1}{1 - e^{-F_{a,t}}} \quad (9)$$

Here,  $C_{a,t}$  is the catch in number of age  $a$  fish (age 0 to 2+ years) in the most recent year.  $F_{a,t}$  is the fishing mortality of age  $a$  fish (age 0 to 2+ years) in the most recent year, and estimating  $F_{a,t}$  makes it possible to calculate the stock number at age and by year retroactively.

## 2. Estimated $F_{a,t}$ Using Tuned VPA

Tuned VPA was used to estimate  $F_{a,t}$ . Annual egg production (Fig. 4-1, Table 4-1) throughout the Seto Inland Sea was used as an index value for SSB, and the residual sum of squares (RSS) was calculated using the following equation.

$$\sum \{ \ln S - \ln(q \times B) \}^2 \quad (10)$$

Here,  $S$  is the egg production (trillion eggs),  $q$  is the proportionality constant, and  $B$  is the SSB (tons).  $q$  was calculated using the following equation, where  $n$  is the number of years of data.

$$q = \exp \left\{ \frac{\sum (\ln S - \ln B)}{n} \right\} \quad (11)$$

For egg production, data from the most recent available year for the past 43 years (1981 to 2023) was used (Appendix 7). Since it is assumed that fish age 1 and older mature in this stock, the  $F_{0,t}$  of age 0 fish was not included in the tuning by egg production, and the average value of  $F_{0,y}$  for the most recent five years (2018 to 2022) excluding the most recent year was used (Kono et al. 2023).

Additionally, ridge VPA (Okamura et al. 2017) was used to stabilize the  $F$  value in the most recent year. Ridge VPA is a method that is used to find terminal  $F$  by minimizing the function that adds penalties to the RSS. For tuning in this stock assessment,  $F_{1,t}$  ( $= F_{2+,t}$ ), which is the  $F$  value of fish age 1 in the most recent year that minimizes equation (12) for each  $\lambda$  while arbitrarily varying  $\lambda$  ( $0 \leq \lambda \leq 1$ ), was found exploratorily. It is assumed that  $F$  is equal for fish age 1 and fish age 2 and older since there is no difference in their distribution in the habitat or the fishing pattern of the fisheries.

$$(1 - \lambda) \times RSS + \lambda \times (F_{1,t})^2 \quad (12)$$

In this equation,  $\lambda$  indicates the size of the ridge regression penalty. The value of  $\lambda$  was selected to minimize the retrospective bias  $\rho$  (Mohn's rho, Mohn 1999) of fishing mortality in the retrospective analysis (see "3. Model Diagnostics" below). Furthermore,  $\lambda$  was calculated as a value in increments of 0.05 from 0 to 1; however, even when  $\lambda$  was 0.05, it was determined that the absolute value of  $\rho$  for fishing mortality did not reach the minimum value (the rightmost symbol for the panel of  $F$  in Supplementary Fig. 2-2). Therefore, recalculation was performed by setting an even smaller value for  $\lambda$  (39 values from the 2nd to the 14th decimal place, with the last digit being 1, 2, or 5).  $\rho$  is the average of the relative values for estimates from calculations that use the full data up to the most recent year of the latest stock assessment  $t$  (2023) and estimates from calculations that use data from the

most recent year with data for a certain number of years  $i$  excluded ( $t-i$ ). Based on 10 years of retrospective data,  $\lambda$  was estimated to be  $2 \times 10^{-13}$ , and  $q$  was estimated to be 0.0181 (Supplementary Fig. 2-2). Because of the extremely small value of  $\lambda$ , the change in stock assessment results due to the use of ridge VPA was small, and the value of  $p$  for fishing mortality also did not change compared to when ridge VPA was not used (Supplementary Fig. 2-3). Therefore, while the effect of ridge VPA cannot be obtained in the stock assessment of this fiscal year, we nevertheless decided to apply the ridge VPA to the stock assessment of this fiscal year in consideration of the possibility that  $F$  may become an unstable value depending on the year as data is accumulated in the future.

### 3. Model Diagnostics

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, Stock Assessment Working Group (2024)”.

In the retrospective analysis, a trend toward overestimation of SSB was observed in recent years (Supplementary Fig. 2-3).

The relationship between observed and projected abundance indices (egg production) is shown in Supplementary Figs. 2-4 through 2-6. The trends in log residuals showed that the residuals were large from the 1980s to the early 1990s but tended to become smaller from the 2000s onwards (Supplementary Fig. 2-6). Values outside the 95% confidence interval ( $1.96\sigma$ ) of the observed residuals were observed in 1988 and 1991, and a negative trend of residuals in the 1980s and a positive trend of residuals in the 1990s and from 2021 to 2023. However, the first-order autocorrelation coefficient  $\rho$  was small and insignificant. Therefore, we determined that the individual residuals were independent to some extent and that the assumption of independence of residuals was satisfied.

#### Cited literature

- Chen, S. and Watanabe, S. (1989) Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakkaishi*, **55**, 205-208.
- Doi, N., Takao, K., Ishioka, K., Hayashi, G., and Yoshida, S. (1978) 6. Analysis Survey of Pelagic Fish Stock. Report on the Environmental Impact Study of Fisheries at Kansai International Airport in 1977, Part III. Fishery Organisms, Japan Fisheries Resource Conservation Association, 176-198.
- Fukuhara, O. and K. Takao (1988) Growth and larval behaviour of *Engraulis japonica* in captivity. *J. Appl. Ichthyol.*, **4**, 158-167.
- Hiramatsu, K. (1999) VPA: Introduction and Practice. *Journal of the study meeting on fishery resource management*, **20**, 9-28.
- Hiramatsu, K. (2000) VPA (Virtual Population Analysis). The 2000 Report on the Establishment and Promotion of Stock Assessment Systems: Stock Analysis

Methodology Textbook, 104-127.

Kono, N. and Takahashi, M. (2022) Stock Assessment for Japanese Anchovy – Seto Inland Sea of (Fiscal Year 2021). FRA-SA2021-RC03-4, Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2021), Japan Fisheries Research and Education Agency, Fisheries Agency, Tokyo, 127 pp.

[https://abchan.fra.go.jp/wpt/wp-content/uploads/2021/details\\_2021\\_25.pdf](https://abchan.fra.go.jp/wpt/wp-content/uploads/2021/details_2021_25.pdf)

Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., Kinoshita, J., and Nishijima, S. (2023) Stock Assessment for Japanese Anchovy – Seto Inland Sea (Fiscal Year 2022). FRA-SA2022-AC-25, Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2022), Japan Fisheries Research and Education Agency, Fisheries Agency, Tokyo, 50 pp.

[https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details\\_2022\\_25.pdf](https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details_2022_25.pdf)

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

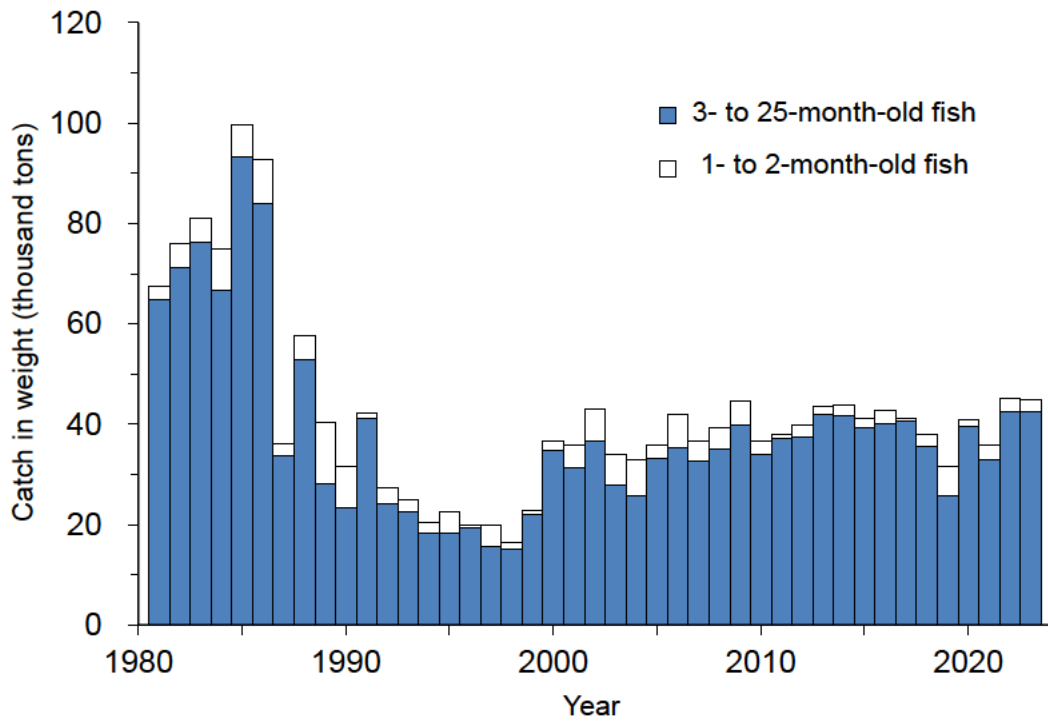
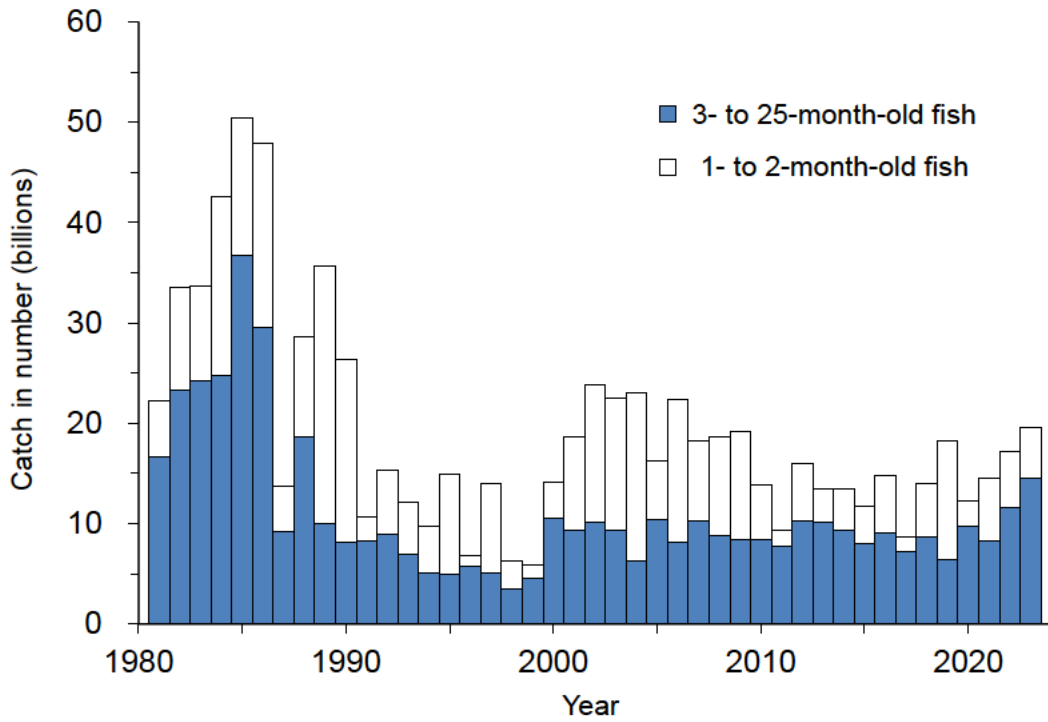
Okamura, H., Yamashita, Y., and Ichinokawa, M. (2017) Ridge virtual population analysis to reduce the instability of fishing mortalities in the terminal year. *ICES J. Mar. Sci.*, **74**, 2427-2436.

Pope, J. G. (1972) An investigation of the accuracy of virtual population analysis using cohort analysis. *Int. Comm. Alt. Fish. Res. Bull.*, **9**, 65-74.

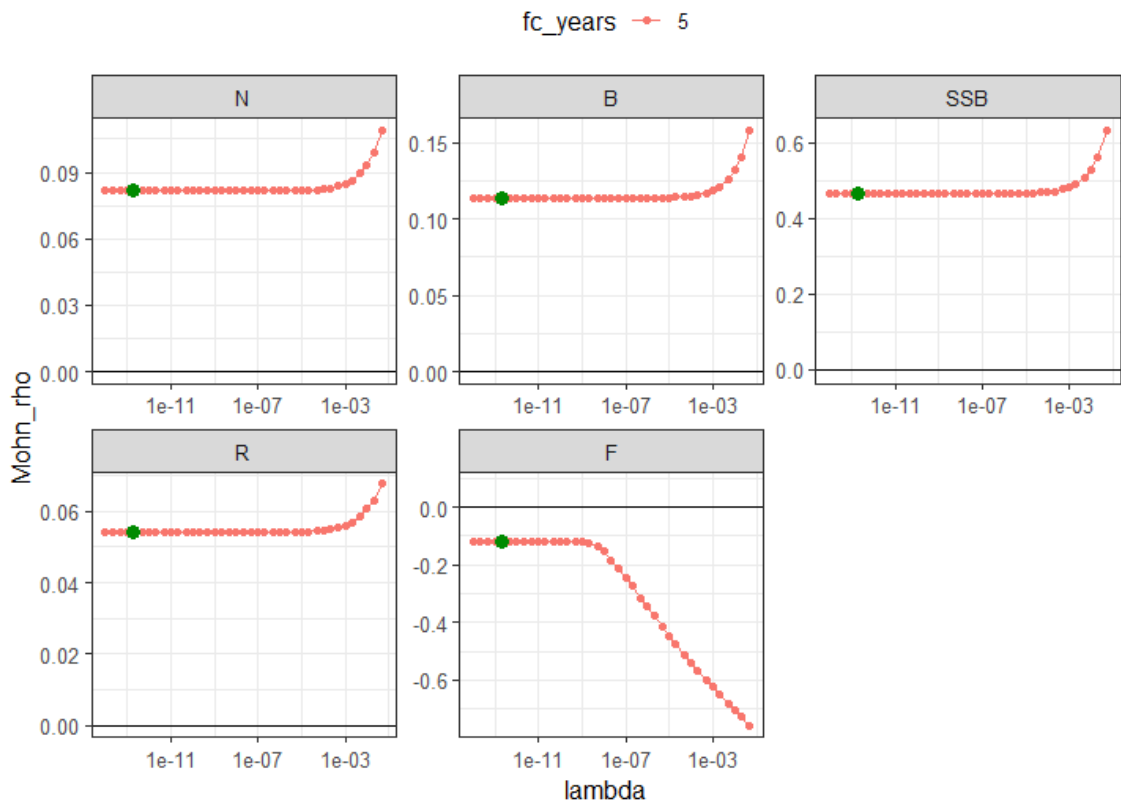
Stock Assessment Working Group (2024) (FY 2024) Procedures for Model Diagnostics in Stock Assessment and Guidelines for Providing Diagnostics Results. FRA-SA2024-ABCWG02-03, Japan Fisheries Research and Education Agency, Yokohama, 13 pp.

[https://abchan.fra.go.jp/references\\_list/FRA-SA2024-ABCWG02-03.pdf](https://abchan.fra.go.jp/references_list/FRA-SA2024-ABCWG02-03.pdf)

Tanaka, S. (1985) General Theory of Fisheries Resources. Kouseisha Kouseikaku, Tokyo, 381 pp.

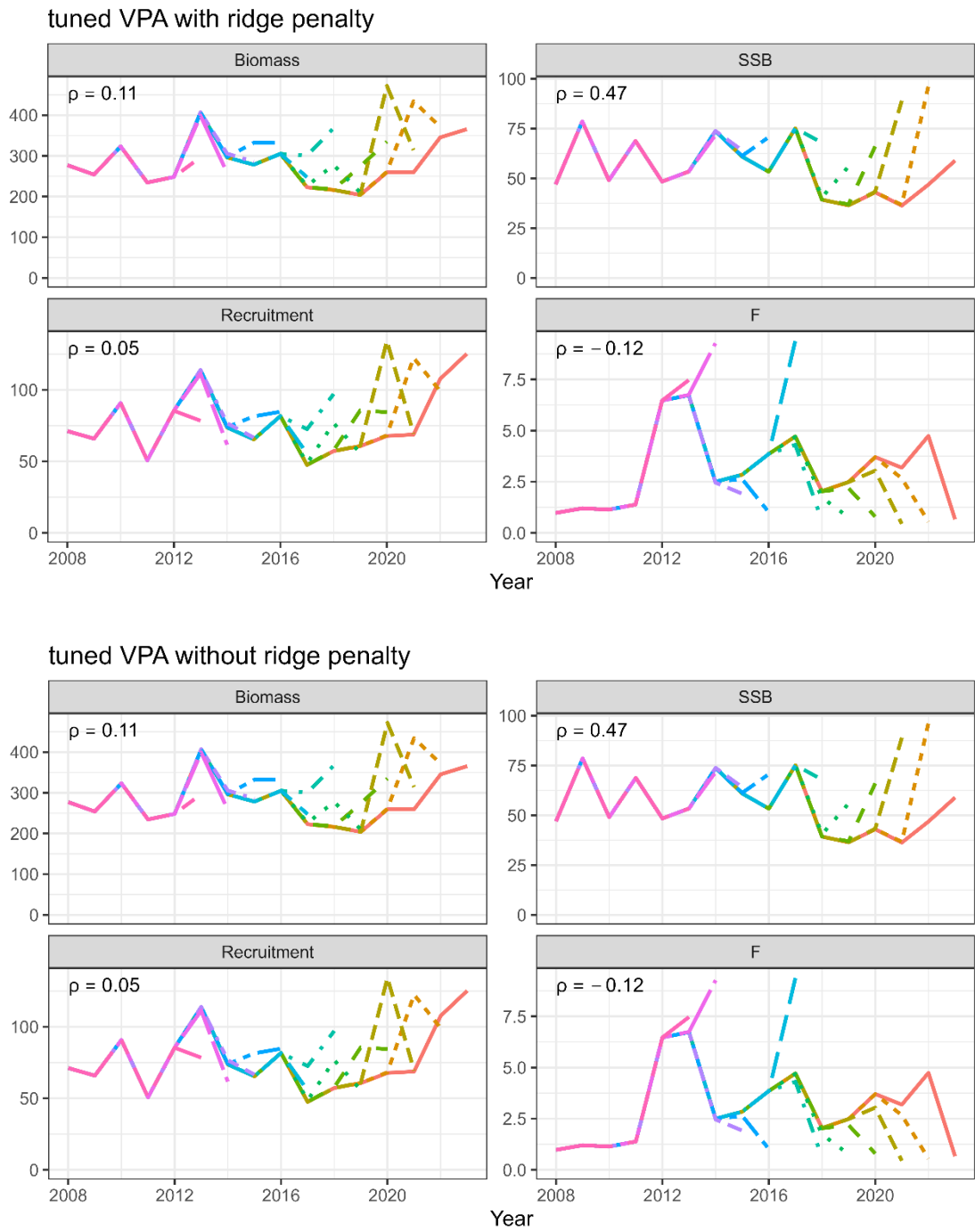


Supplementary Fig. 2-1. Monthly age composition of “Japanese anchovy” according to commercial size category in the Statistics of Fishery and Aquaculture Production  
Upper is the catch in number, and lower is the catch in weight.



Supplementary Fig. 2-2. Relationship between  $\lambda$  in the ridge VPA and  $\rho$  in the retrospective analysis

N is stock number, B is abundance (biomass), SSB is spawning stock biomass, R is recruitment, and F is fishing mortality.

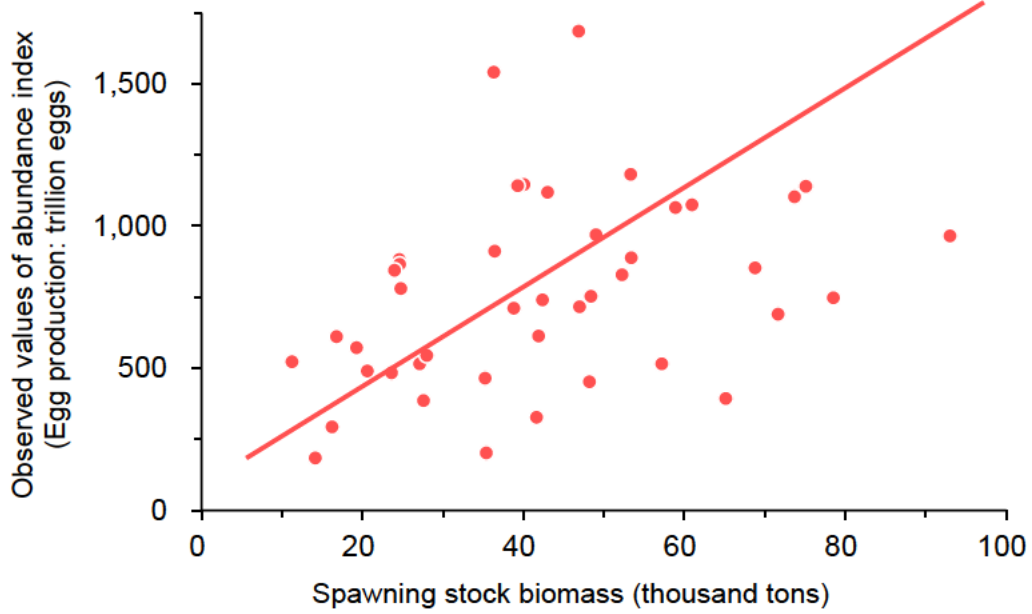


Supplementary Fig. 2-3. Results of retrospective analysis

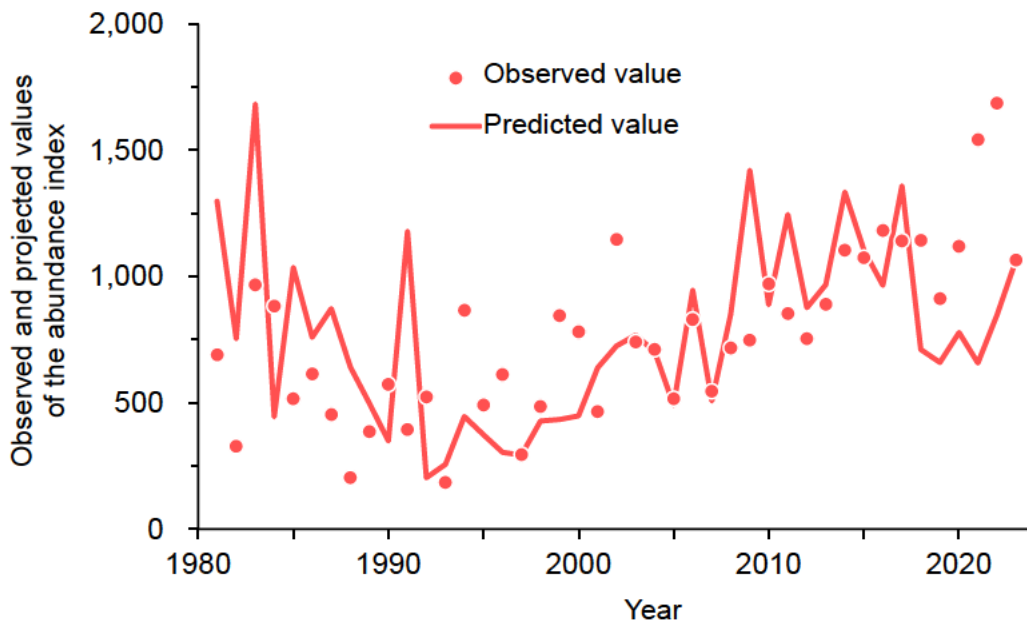
Upper: With ridge VPA ( $\lambda = 2 \times 10^{-13}$ , the average period of  $F_{0,t}$  is 5 years).

Lower: Without ridge VPA (average period of  $F_{0,t}$  is 5 years).

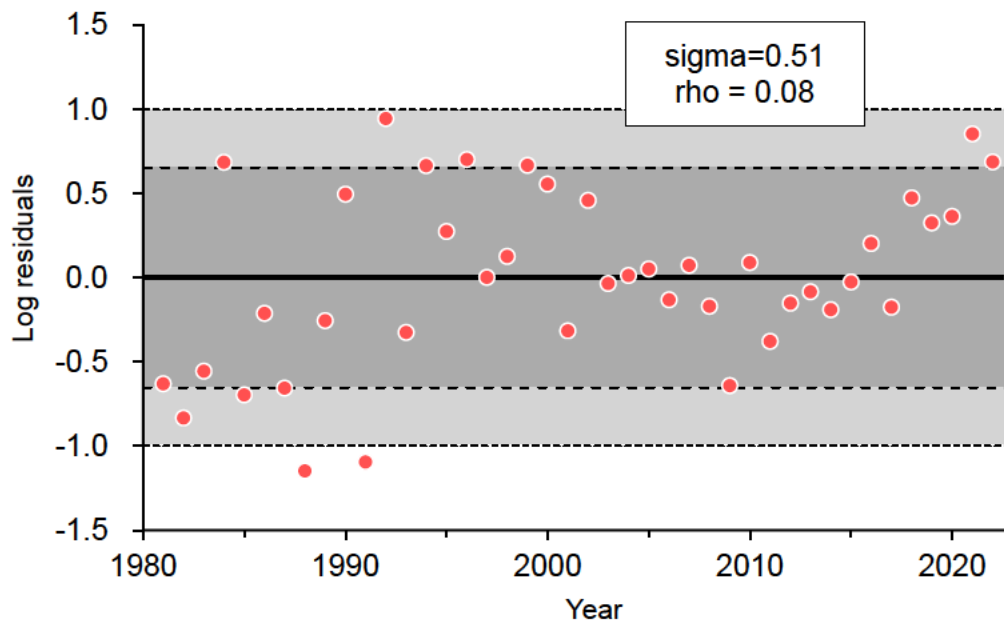
Biomass is abundance (thousand tons), SSB is spawning stock biomass (thousand tons), Recruitment is recruitment (billion fish), and F is fishing mortality.



Supplementary Fig. 2-4. Relationship between SSB and observed abundance indices



Supplementary Fig. 2-5. Trends in observed (egg production: trillion eggs) and projected (qB) abundance indices



Supplementary Fig. 2-6. Trends in log residuals of abundance indice and projected values  $\sigma$  is the standard deviation of log residuals ( $\ln S - \ln(qB)$ ),  $\rho$  is the first-order autocorrelation coefficient of residuals, the dark gray area indicates 80% of the range of observed values ( $1.28\sigma$ ), and the light gray area indicates 95% of the range ( $1.96\sigma$ ).

Supplementary Table 2-1. Details of Cohort Analysis Results

Catch (Tons)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	39,743	56,656	43,845	58,695	73,338	69,268	16,892	40,342
	Age 1	24,712	14,486	32,424	7,887	19,582	14,636	16,869	12,387
	Age 2+	361	7	28	35	375	29	2	0
	Total	64,815	71,150	76,297	66,617	93,295	83,932	33,762	52,729
Catch in number (millions)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	14,374	21,459	20,920	23,485	34,728	27,404	6,560	17,273
	Age 1	2,295	1,818	3,250	1,270	1,999	2,093	2,637	1,361
	Age 2+	16	0	1	1	14	1	0	0
	Total	16,685	23,277	24,172	24,756	36,741	29,497	9,197	18,634
Stock number (millions)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	83,726	137,415	91,964	113,954	148,085	139,841	50,501	73,301
	Age 1	6,564	5,223	9,318	3,941	5,736	5,981	7,535	3,889
	Age 2+	44	1	4	4	38	3	0	0
	Total	90,334	142,638	101,285	117,899	153,859	145,825	58,036	77,190
Fishing mortality	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	0.67	0.59	1.05	0.89	1.11	0.82	0.46	1.12
	Age 1	6.93	5.20	5.72	2.54	5.49	8.26	10.03	8.64
	Age 2+	6.93	5.20	5.72	2.54	5.49	8.26	10.03	8.64
Average body weight (g)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	2.8	2.6	2.1	2.5	2.1	2.5	2.6	2.3
	Age 1	10.8	8.0	10.0	6.2	9.8	7.0	6.4	9.1
	Age 2+	22.5	24.6	21.8	27.3	26.9	27.0	22.2	19.3
Stock biomass (Tons)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	231,490	362,799	192,741	284,805	312,726	353,472	130,043	171,200
	Age 1	70,687	41,625	92,961	24,465	56,191	41,834	48,207	35,403
	Age 2+	981	20	77	102	1,025	79	4	1
	Total	303,157	404,444	285,778	309,373	369,942	395,385	178,254	206,603
Spawning stock biomass (Tons)	Year	1981	1982	1983	1984	1985	1986	1987	1988
	Age 0	0	0	0	0	0	0	0	0
	Age 1	70,687	41,625	92,961	24,465	56,191	41,834	48,207	35,403
	Age 2+	981	20	77	102	1,025	79	4	1
	Total	71,668	41,645	93,038	24,568	57,216	41,913	48,211	35,404

Supplementary Table 2-1. (Continued)

Catch (Tons)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	18,814	17,031	18,443	20,221	17,570	10,355	11,498	14,061
	Age 1	9,270	6,245	22,522	3,848	4,896	7,959	6,581	5,049
	Age 2+	0	123	120	57	8	17	205	136
	Total	28,085	23,400	41,084	24,125	22,474	18,331	18,283	19,246
Catch in number (millions)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	8,999	7,588	5,569	8,500	6,292	4,239	4,192	5,112
	Age 1	985	603	2,698	384	648	852	731	559
	Age 2+	0	5	5	3	0	1	8	5
	Total	9,984	8,196	8,272	8,887	6,940	5,092	4,930	5,677
Stock number (millions)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	40,646	85,123	24,938	39,549	39,460	30,261	26,772	30,410
	Age 1	2,932	1,828	7,769	1,105	1,868	2,630	2,222	1,812
	Age 2+	0	14	13	7	1	2	24	17
	Total	43,578	86,966	32,719	40,661	41,330	32,893	29,018	32,238
Fishing mortality	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	1.00	0.29	1.02	0.95	0.61	0.51	0.59	0.65
	Age 1	3.23	2.86	4.91	5.01	4.68	2.61	2.81	2.14
	Age 2+	3.23	2.86	4.91	5.01	4.68	2.61	2.81	2.14
Average body weight (g)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	2.1	2.2	3.3	2.4	2.8	2.4	2.7	2.8
	Age 1	9.4	10.4	8.3	10.0	7.6	9.3	9.0	9.0
	Age 2+	16.4	24.9	25.4	22.0	23.9	23.5	24.8	25.0
Stock biomass (Tons)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	84,981	191,054	82,585	94,080	110,197	73,918	73,434	83,647
	Age 1	27,588	18,929	64,839	11,070	14,123	24,559	20,016	16,358
	Age 2+	1	355	328	155	22	50	590	416
	Total	112,570	210,338	147,751	105,304	124,341	98,528	94,041	100,421
Spawning stock biomass (Tons)	Year	1989	1990	1991	1992	1993	1994	1995	1996
	Age 0	0	0	0	0	0	0	0	0
	Age 1	27,588	18,929	64,839	11,070	14,123	24,559	20,016	16,358
	Age 2+	1	355	328	155	22	50	590	416
	Total	27,589	19,285	65,166	11,225	14,144	24,609	20,607	16,774

Supplementary Table 2-1. (Continued)

Catch (Tons)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	11,652	10,383	14,752	26,612	24,322	25,797	21,180	12,055
	Age 1	3,807	4,432	6,614	8,008	6,994	9,188	6,092	10,952
	Age 2+	166	361	773	211	73	1,649	552	2,698
	Total	15,625	15,176	22,139	34,831	31,388	36,634	27,823	25,705
Catch in number (millions)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	4,606	3,021	3,870	9,740	8,492	8,832	8,588	4,888
	Age 1	473	403	654	720	891	1,196	653	1,221
	Age 2+	7	16	35	12	3	67	23	108
	Total	5,086	3,439	4,559	10,472	9,386	10,094	9,263	6,216
Stock number (millions)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	29,449	26,067	28,793	64,131	60,691	59,456	53,155	36,098
	Age 1	1,935	1,994	2,135	2,172	4,445	4,460	4,190	3,504
	Age 2+	26	72	107	34	14	233	135	295
	Total	31,410	28,133	31,035	66,337	65,150	64,150	57,480	39,896
Fishing mortality	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	0.59	0.40	0.48	0.57	0.51	0.55	0.62	0.49
	Age 1	1.20	0.86	2.08	2.95	0.85	1.45	0.59	5.41
	Age 2+	1.20	0.86	2.08	2.95	0.85	1.45	0.59	5.41
Average body weight (g)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	2.5	3.4	3.8	2.7	2.9	2.9	2.5	2.5
	Age 1	8.0	11.0	10.1	11.1	7.9	7.7	9.3	9.0
	Age 2+	24.0	23.0	22.2	17.6	23.9	24.8	24.3	25.0
Stock biomass (Tons)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	74,500	89,588	109,762	175,231	173,818	173,660	131,093	89,038
	Age 1	15,574	21,951	21,583	24,146	34,909	34,271	39,102	31,438
	Age 2+	635	1,666	2,386	604	338	5,786	3,281	7,365
	Total	90,708	113,205	133,731	199,980	209,065	213,716	173,477	127,841
Spawning stock biomass (Tons)	Year	1997	1998	1999	2000	2001	2002	2003	2004
	Age 0	0	0	0	0	0	0	0	0
	Age 1	15,574	21,951	21,583	24,146	34,909	34,271	39,102	31,438
	Age 2+	635	1,666	2,386	604	338	5,786	3,281	7,365
	Total	16,208	23,617	23,969	24,749	35,247	40,056	42,384	38,803

Supplementary Table 2-1. (Continued)

Catch (Tons)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	28,082	17,211	23,064	23,128	17,554	20,393	16,660	20,331
	Age 1	5,006	16,655	9,528	11,886	20,669	12,605	19,421	15,520
	Age 2+	11	1,432	114	46	1,526	1,118	1,140	1,485
	Total	33,099	35,298	32,707	35,059	39,749	34,116	37,221	37,336
Catch in number (millions)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	9,862	5,749	9,089	7,153	6,591	6,752	5,101	8,689
	Age 1	501	2,328	1,176	1,708	1,750	1,605	2,609	1,550
	Age 2+	0	57	5	2	68	46	47	60
	Total	10,364	8,134	10,269	8,863	8,409	8,402	7,757	10,298
Stock number (millions)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	83,348	44,343	80,898	71,194	65,886	90,803	50,741	85,396
	Age 1	2,710	6,756	3,418	6,726	6,215	5,762	8,757	4,428
	Age 2+	2	157	13	7	226	155	148	162
	Total	86,060	51,255	84,329	77,927	72,327	96,719	59,646	89,986
Fishing mortality	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	0.41	0.46	0.39	0.34	0.34	0.24	0.34	0.34
	Age 1	0.75	4.19	4.08	1.29	1.63	1.59	1.91	9.53
	Age 2+	0.75	4.19	4.08	1.29	1.63	1.59	1.91	9.53
Average body weight (g)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	2.8	3.0	2.5	3.2	2.7	3.0	3.3	2.3
	Age 1	10.0	7.2	8.1	7.0	11.8	7.9	7.4	10.0
	Age 2+	26.5	25.2	24.6	23.8	22.6	24.5	24.4	24.9
Stock biomass (Tons)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	237,339	132,753	205,293	230,195	175,474	274,248	165,714	199,824
	Age 1	27,057	48,327	27,696	46,806	73,414	45,263	65,186	44,353
	Age 2+	56	3,950	316	169	5,107	3,781	3,613	4,037
	Total	264,451	185,030	233,305	277,170	253,995	323,292	234,513	248,214
Spawning stock biomass (Tons)	Year	2005	2006	2007	2008	2009	2010	2011	2012
	Age 0	0	0	0	0	0	0	0	0
	Age 1	27,057	48,327	27,696	46,806	73,414	45,263	65,186	44,353
	Age 2+	56	3,950	316	169	5,107	3,781	3,613	4,037
	Total	27,112	52,277	28,012	46,974	78,521	49,044	68,799	48,391

Supplementary Table 2-1. (Continued)

Catch (Tons)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	23,281	16,627	18,449	21,556	14,297	22,535	13,406	24,510
	Age 1	18,693	25,108	20,663	18,502	26,244	12,936	12,210	14,864
	Age 2+	0	0	338	104	16	5	204	117
	Total	41,974	41,736	39,450	40,162	40,557	35,476	25,821	39,491
Catch in number (millions)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	7,503	5,504	5,548	6,998	4,600	7,289	4,854	7,678
	Age 1	2,595	3,852	2,444	2,116	2,642	1,386	1,517	1,995
	Age 2+	0	0	13	5	1	0	11	5
	Total	10,098	9,356	8,005	9,119	7,243	8,676	6,382	9,679
Stock number (millions)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	113,794	73,697	65,397	81,717	47,516	57,226	60,656	67,780
	Age 1	7,417	11,309	7,099	6,067	7,558	4,209	4,457	5,729
	Age 2+	0	0	37	14	3	1	30	15
	Total	121,211	85,006	72,533	87,798	55,077	61,436	65,144	73,524
Fishing mortality	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	0.21	0.24	0.28	0.28	0.32	0.45	0.26	0.39
	Age 1	9.99	3.63	4.13	5.64	6.91	2.84	3.60	5.36
	Age 2+	9.99	3.63	4.13	5.64	6.91	2.84	3.60	5.36
Average body weight (g)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	3.1	3.0	3.3	3.1	3.1	3.1	2.8	3.2
	Age 1	7.2	6.5	8.5	8.7	9.9	9.3	8.0	7.4
	Age 2+	25.1	25.1	25.3	20.2	16.9	16.7	18.9	21.3
Stock biomass (Tons)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	353,100	222,626	217,491	251,712	147,680	176,925	167,518	216,369
	Age 1	53,422	73,711	60,015	53,061	75,071	39,271	35,870	42,676
	Age 2+	1	1	933	284	45	15	571	319
	Total	406,523	296,339	278,439	305,057	222,796	216,211	203,959	259,365
Spawning stock biomass (Tons)	Year	2013	2014	2015	2016	2017	2018	2019	2020
	Age 0	0	0	0	0	0	0	0	0
	Age 1	53,422	73,711	60,015	53,061	75,071	39,271	35,870	42,676
	Age 2+	1	1	933	284	45	15	571	319
	Total	53,423	73,712	60,948	53,345	75,116	39,286	36,441	42,995

Supplementary Table 2-1. (Continued)

	Year	2021	2022	2023
Catch (Tons)	Age 0	20,353	26,085	30,817
	Age 1	12,554	16,339	11,603
	Age 2+	30	44	3
	Total	32,937	42,469	42,423
Catch in number (millions)	Age 0	6,272	9,408	12,590
	Age 1	1,945	2,175	1,948
	Age 2+	1	2	0
	Total	8,219	11,585	14,539
Stock number (millions)	Age 0	68,737	107,643	125,271
	Age 1	5,613	6,222	9,890
	Age 2+	3	7	1
	Total	74,353	113,872	135,162
Fishing mortality	Age 0	0.30	0.29	0.34
	Age 1	4.63	6.97	0.83
	Age 2+	4.63	6.97	0.83
Average body weight (g)	Age 0	3.2	2.8	2.4
	Age 1	6.5	7.5	6.0
	Age 2+	25.1	17.8	20.0
Stock biomass (Tons)	Age 0	223,047	298,472	306,627
	Age 1	36,227	46,736	58,897
	Age 2+	83	120	14
	Total	259,357	345,328	365,539
Spawning stock biomass (Tons)	Age 0	0	0	0
	Age 1	36,227	46,736	58,897
	Age 2+	83	120	14
	Total	36,310	46,856	58,912

Supplementary Table 2-2. Maturity rates and M at age used for stock calculations

Age	Maturity rate	M
Age 0	0.0	2.1
Age 1	1.0	2.1
Age 2+	1.0	2.0

Supplementary Table 2-3. Standard (scaled) body length, average body weight, maturity rate and M for each monthly age.

Age in months	Standard or scaled body length (cm)	Average body weight (g)	Maturity rate	M
1	1.3 - 2.9	0.064	0.00	0.469
2	3.0 - 4.4	0.494	0.00	0.353
3	4.5 - 6.1	1.696	0.00	0.289
4	6.2 - 7.0	2.737	0.00	0.249
5	7.1 - 7.8	3.979	0.55	0.222
6	7.9 - 8.5	5.351	0.80	0.202
7	8.6 - 9.1	7.023	0.95	0.187
8	9.2 - 9.6	8.721	1.00	0.176
9	9.7 - 10.1	10.339	1.00	0.167
10	10.2 - 10.5	11.776	1.00	0.167
11	10.6 - 10.9	13.348	1.00	0.167
12	11.0 - 11.2	15.060	1.00	0.167
13	11.3 - 11.5	16.441	1.00	0.167
14	11.6 - 11.8	17.908	1.00	0.167
15	11.9 - 12.0	18.936	1.00	0.167
16	12.1 - 12.3	20.553	1.00	0.167
17	12.4 - 12.4	21.113	1.00	0.167
18	12.5 - 12.6	22.264	1.00	0.167
19	12.7 - 12.8	23.459	1.00	0.167
20	12.9 - 12.9	24.073	1.00	0.167
21	13.0 - 13.0	24.698	1.00	0.167
22	13.1 - 13.1	25.334	1.00	0.167
23	13.2 - 13.2	25.982	1.00	0.167
24	13.3 - 13.3	26.641	1.00	0.167
25	13.4 -	27.311	1.00	0.167

Supplementary Table 2-4. Matrix of M by monthly age and by month and calculation method of M by age

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1-mo-old												
2-mo-old												
3-mo-old	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289
4-mo-old	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249
5-mo-old	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222	0.222
6-mo-old	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
7-mo-old	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187
8-mo-old	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176
9-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
10-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
11-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
12-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
13-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
14-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
15-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
16-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
17-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
18-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
19-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
20-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
21-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
22-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
23-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
24-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167
25-mo-old	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan to Dec Total
Age 0				0.289	0.269	0.253	0.241	0.230	0.221	0.213	0.207	0.203	2.1
Age 1	0.199	0.196	0.194	0.184	0.177	0.172	0.169	0.168	0.167	0.167	0.167	0.167	2.1
Age 2+	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	2.0

In each month, the M for each age was obtained by estimating the average of the values for each age and summing these values for January through December.

Supplementary Table 2-5. Matrix of catch by age (in months) and by calendar month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1-mo-old												
2-mo-old												
3-mo-old	1	1	1	0	0	0	0	0	0	0	0	0
4-mo-old	1	1	1	1	0	0	0	0	0	0	0	0
5-mo-old	1	1	1	1	1	0	0	0	0	0	0	0
6-mo-old	1	1	1	1	1	1	0	0	0	0	0	0
7-mo-old	1	1	1	1	1	1	1	0	0	0	0	0
8-mo-old	1	1	1	1	1	1	1	1	0	0	0	0
9-mo-old	1	1	1	1	1	1	1	1	1	0	0	0
10-mo-old	1	1	1	1	1	1	1	1	1	1	0	0
11-mo-old	1	1	1	1	1	1	1	1	1	1	1	0
12-mo-old	1	1	1	1	1	1	1	1	1	1	1	1
13-mo-old	2	1	1	1	1	1	1	1	1	1	1	1
14-mo-old	2	2	1	1	1	1	1	1	1	1	1	1
15-mo-old	2	2	2	1	1	1	1	1	1	1	1	1
16-mo-old	2	2	2	2	1	1	1	1	1	1	1	1
17-mo-old	2	2	2	2	2	1	1	1	1	1	1	1
18-mo-old	2	2	2	2	2	2	1	1	1	1	1	1
19-mo-old	2	2	2	2	2	2	2	1	1	1	1	1
20-mo-old	2	2	2	2	2	2	2	2	1	1	1	1
21-mo-old	2	2	2	2	2	2	2	2	2	1	1	1
22-mo-old	2	2	2	2	2	2	2	2	2	2	1	1
23-mo-old	2	2	2	2	2	2	2	2	2	2	2	1
24-mo-old	2	2	2	2	2	2	2	2	2	2	2	2
25-mo-old	3	2	2	2	2	2	2	2	2	2	2	2

Numerical values represent age.

Supplementary Table 2-6. Percentage of "Japanese anchovy" fish according to commercial size category in the Statistics of Fishery and Aquaculture Production that are 1 to 2 months old

Year	Percentage of catch in number	Percentage of catch in weight
1981	0.25	0.04
1982	0.31	0.06
1983	0.28	0.06
1984	0.42	0.11
1985	0.27	0.06
1986	0.38	0.10
1987	0.33	0.06
1988	0.35	0.08
1989	0.72	0.30
1990	0.69	0.26
1991	0.23	0.03
1992	0.42	0.12
1993	0.43	0.10
1994	0.48	0.11
1995	0.67	0.19
1996	0.17	0.03
1997	0.64	0.22
1998	0.45	0.08
1999	0.22	0.02
2000	0.26	0.05
2001	0.50	0.12
2002	0.58	0.15
2003	0.59	0.18
2004	0.73	0.22
2005	0.36	0.08
2006	0.64	0.16
2007	0.44	0.11
2008	0.52	0.11
2009	0.56	0.11
2010	0.40	0.07
2011	0.17	0.02
2012	0.36	0.07
2013	0.25	0.04
2014	0.31	0.05
2015	0.32	0.04
2016	0.38	0.06
2017	0.16	0.02
2018	0.38	0.07
2019	0.65	0.18
2020	0.21	0.03
2021	0.43	0.08
2022	0.33	0.06
2023	0.26	0.05
Average	0.41	0.10
Minimum	0.16	0.02
Maximum	0.73	0.30

### Appendix 3 Proposed Reference Points and Proposed Fishing Ban Level

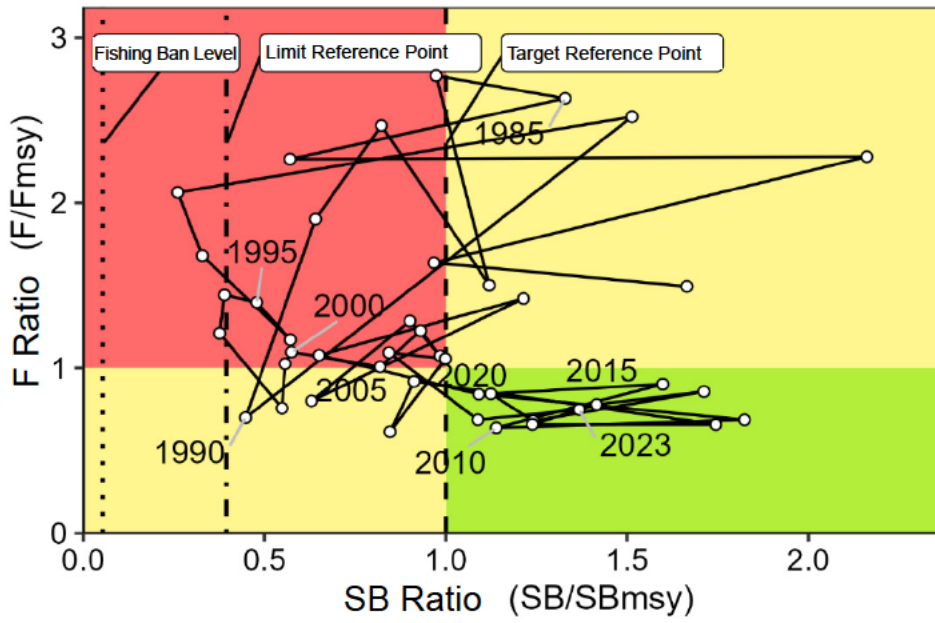
“Materials for the Research Institute Meeting on Reference Points” published in September 2022 proposed the adoption of the following: SSB to achieve MSY (SB<sub>msy</sub>: 43,000 tons) as a target reference point (SB<sub>target</sub>), SSB to achieve 60% MSY (SB<sub>0.6msy</sub>: 17,000 tons) as a limit reference point (SB<sub>limit</sub>), and SSB to achieve 10% MSY (SB<sub>0.1msy</sub>: 2,000 tons) as a fishing ban level (SB<sub>ban</sub>) (Kono et al. 2022, Supplementary Table 6-2).

Supplementary Fig. 3-1 shows a Kobe plot based on SB<sub>msy</sub> and the fishing pressure (F<sub>msy</sub>) to maintain it. The SSB for 2023 (SB<sub>2023</sub>: 59,000 tons) obtained from the cohort analysis is above the SB<sub>msy</sub> (Supplementary Tables 6-2 and 6-3). The fishing pressure of this stock since 2008 was judged to be below the fishing pressure to achieve SB<sub>msy</sub>, except in 2020 and 2021.

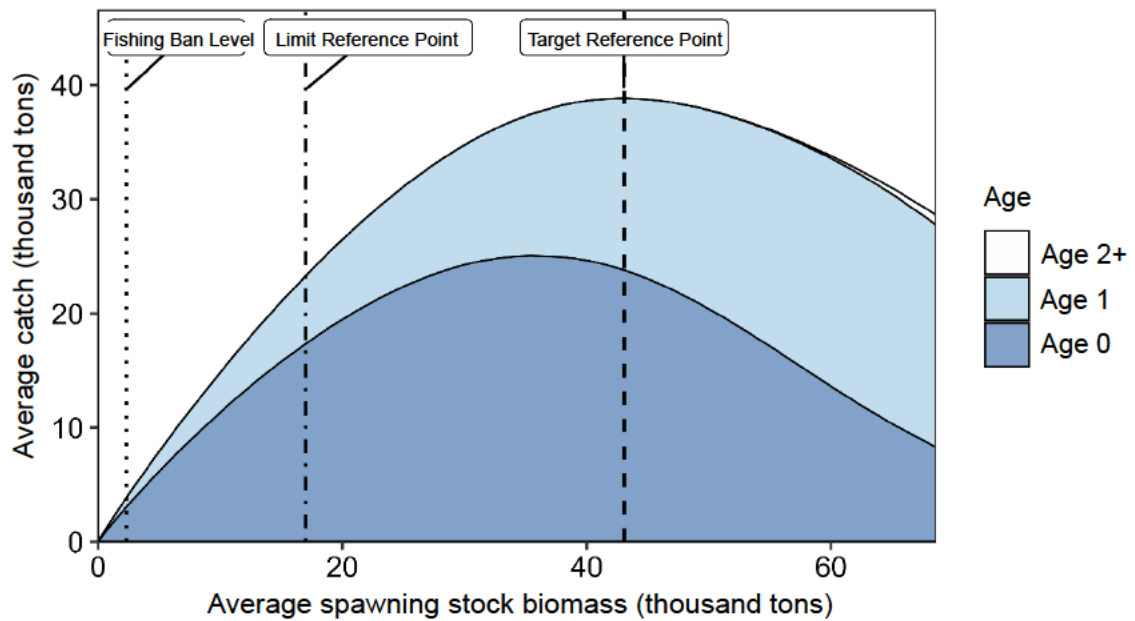
The relationship between average SSB and average catch in weight at age at equilibrium is shown in Supplementary Fig. 3-2. While the majority of the fish caught were age 0 and age 1 when the average SSB was below the proposed limit reference point, the proportion of older fish tended to increase as the SSB increased.

#### Cited literature

Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., and Kinoshita, J. (2022) Materials for the Research Institute Meeting of Seto Inland Sea stock of Japanese anchovy (FY 2022). FRA-SA2022-BRP05-01, Japan Fisheries Research and Education Agency, Yokohama, 55 pp.  
[https://www.fra.affrc.go.jp/shigen\\_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf](https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf)



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



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

## Appendix 4 Future Projections Based on Proposed HCRs

### (1) Setting Future Projections

Future projection calculations were performed for 2024 to 2055 using a forward method for cohort analysis applied to stock abundance estimates from the 2023 stock assessment. The future projections take into account the uncertainty of recruitment volume. Recruitment in future projections was predicted based on values for SSB in each year using the stock-recruitment relationship model, and uncertainty in recruitment was accounted for by introducing errors, which follow a log-normal distribution, to the predicted value. The degree of uncertainty was indicated through calculations replicated 10,000 times, introducing randomly selected errors from log-normal distribution to the projected value and determining their average value and 90% prediction interval.

Fishing pressure in 2024 was assumed to be the fishing pressure (F<sub>2024</sub>) such that the catch in 2024 would match the average of the most recent five years (2019 to 2023, 37,000 tons) under the same biological parameters (average body weight, etc.) as the calculations for proposed reference points. The selectivity was assumed to be the same as the average value of fishing mortality by year for the previous five years, excluding the most recent year (2018 to 2022). Catch in 2024 was assumed to be the most recent year under recent fishing conditions. Fishing pressure in 2025 was calculated based on SSB projections for each year in accordance with the following proposed HCRs. The calculation method of future projections is shown in Appendix 5.

### (2) Proposed Harvest Control Rules

Proposed HCRs guidelines, which aim for better results than proposed target reference points in consideration of the probability of success for both maintenance and recovery of SSB, set fishing pressure (F) and other factors that correspond to SSB. The “Basic Guidelines for Harvest Control Rules and ABC Calculation” (FY 2024). FRA-SA2024-ABCWG02-01. Japan Fisheries Research and Education Agency (2024)” proposes a linear reduction of fishing pressure down to the proposed fishing ban level when spawning stock biomass (SSB) falls below the proposed limit reference points, and upper limit for F multiplied by adjustment coefficient  $\beta$  is used as the fishing pressure for ABC calculation when SSB is above the proposed limit reference points. The proposed HCRs for this stock are shown in Supplementary Fig. 4-1. The fishing pressure when SSB is less than the proposed limit reference point is determined as  $\gamma(\text{SB}_t) \times \beta F_{\text{msy}}$ , multiplied by a factor ( $\gamma(\text{SB}_t)$ ) according to the SSB.  $\gamma(\text{SB}_t)$  is calculated using the following equation according to the control rules for Stock Group 1 in the Japan Fisheries Research and Education Agency (2024).

$$\gamma(\text{SB}_t) = \frac{\text{SB}_t - \text{SB}_{\text{ban}}}{\text{SB}_{\text{limit}} - \text{SB}_{\text{ban}}}$$

Supplementary Fig. 4-1 includes an example showing when the upper limit of  $F$  is set to the  $F_{msy}$ , and the adjustment coefficient  $\beta$  is set to 0.8. The proposals in the Materials for Research Institute Meeting on Reference Points state that “in the HCRs, which set the upper limit of  $F$  to the  $F_{msy}$ , when  $\beta$  is lower than 0.8, there is a 50% or higher probability that values will exceed the  $SB_{msy}$  (proposed target reference points) in 10 years”.

### (3) Projected Values for 2025

The projected SSB in 2025 is forecast to be an average of 73,000 tons, which exceeds the limit reference point in almost all the replicated calculations. The average catch in 2025, as calculated based on proposed HCRs, will be 48,000 tons if  $\beta$  is set to 0.8 and 52,000 tons if  $\beta$  is set to 1.0 (Supplementary Tables 4-3 and 6-4).

### (4) Projections for 2026 onwards

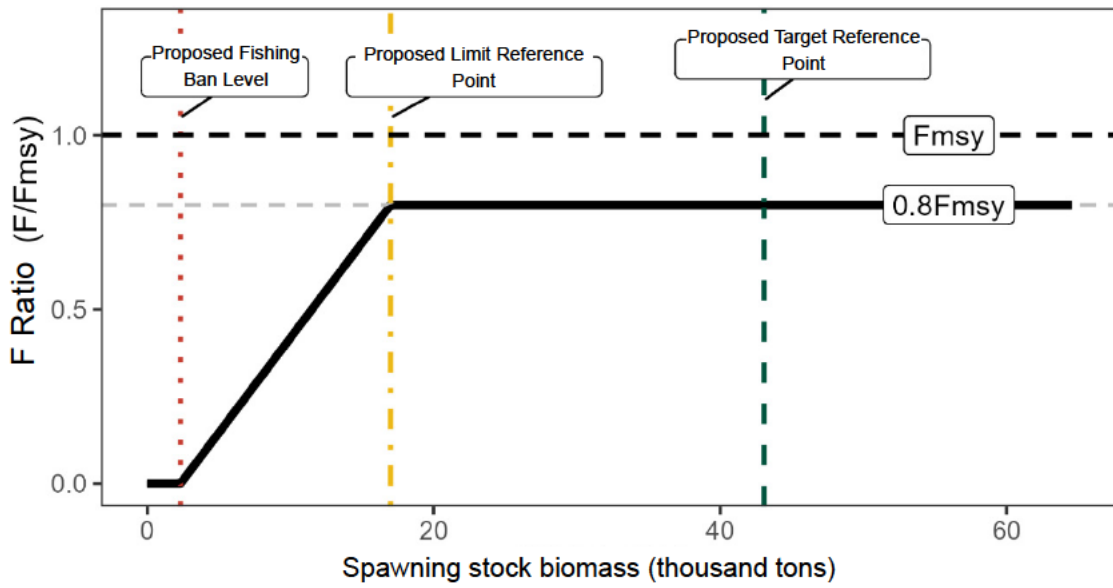
Results of future projections, including 2026 and onwards, are shown in Supplementary Fig. 4-2 and Supplementary Tables 4-1 to 4-3.

If management based on these proposed HCRs is continued for 10 years, then projected values for SSB in 2035 will average 50,000 tons if  $\beta$  is set to 0.8 (90% prediction interval: 20,000 to 96,000 tons) and average 44,000 tons if  $\beta$  is set to 1.0 (90% prediction interval: 17,000 to 86,000 tons) (Supplementary Table 6-5). If  $\beta$  is 0.8 or lower, there is a 50% or higher probability that the projected value of SSB will exceed the proposed target reference points in 2035. Meanwhile, even if  $\beta$  is 1.0, there is a 95% probability that the value will exceed the proposed limit reference point. If the current fishing pressure ( $F_{2018}$  to  $F_{2022}$ ) is continued, then projected values for average SSB in 2035 will average 51,000 tons (90% prediction interval of 21,000 to 98,000 tons), with a 56% probability that the value will exceed the  $SB_{msy}$ , and a 98% probability that it will exceed  $SB_{0.6msy}$ .

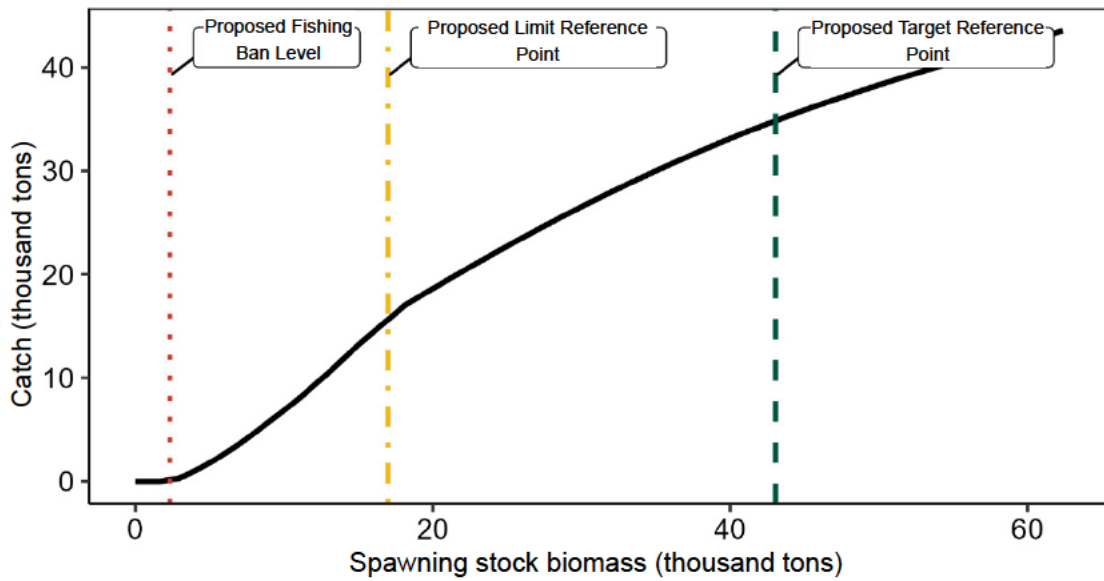
### Cited literature

Japan Fisheries Research and Education Agency (2024) The Basic Guidelines for Harvest Control Rules and ABC Calculation (FY 2024). FRA-SA2024-ABCWG02-01, Japan Fisheries Research and Education Agency, Yokohama, 23 pp.  
[https://abchan.fra.go.jp/references\\_list/FRA-SA2024-ABCWG02-01.pdf](https://abchan.fra.go.jp/references_list/FRA-SA2024-ABCWG02-01.pdf)

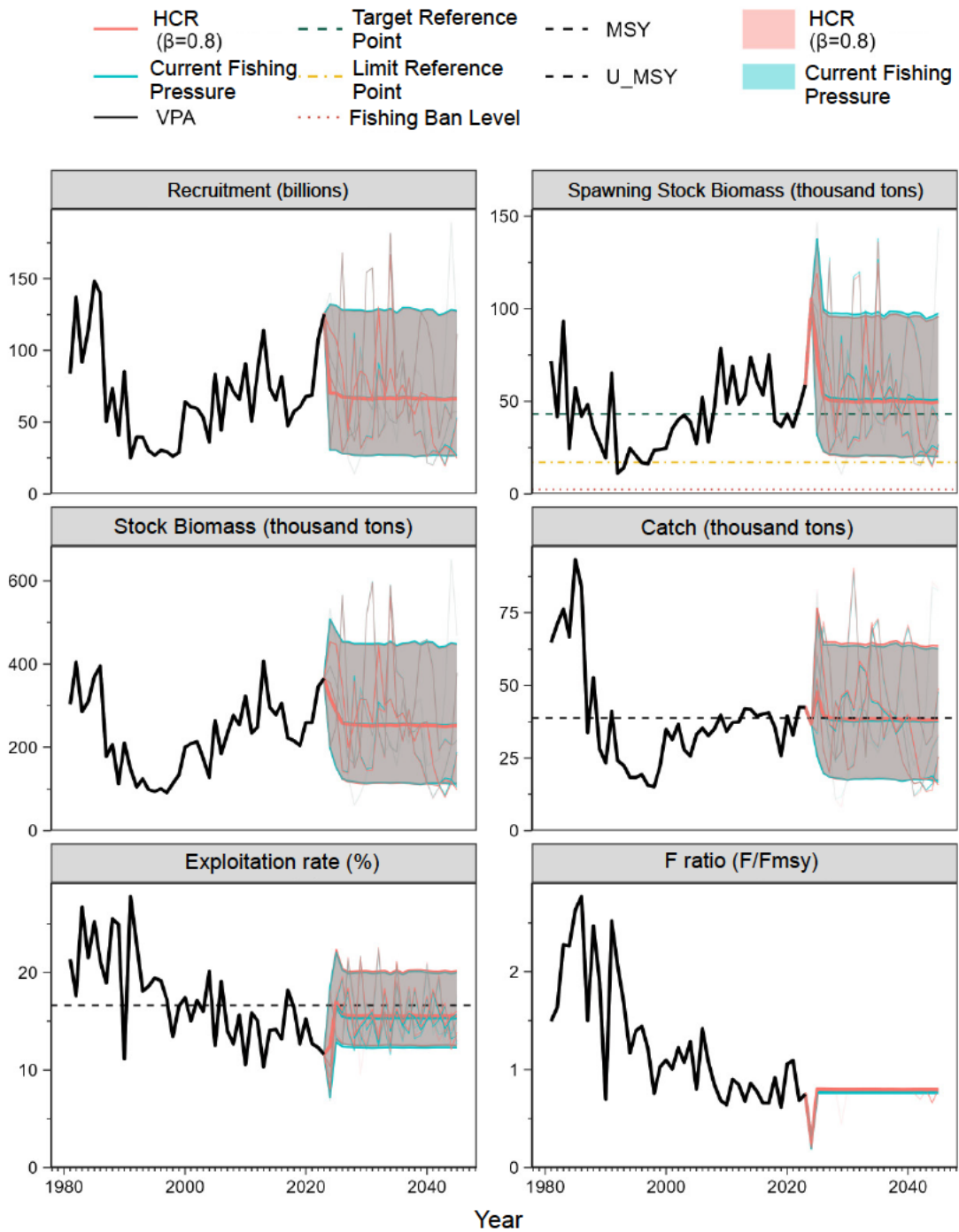
a) When the vertical axis is fishing pressure



b) When the vertical axis is catch



Supplementary Fig. 4-1. Harvest Control Rules draft



Supplementary Fig. 4-2. Future projections based on proposed HCRs (red line) and future projections if the current fishing pressure (F<sub>2018-2022</sub>) is continued (blue line). The solid line indicates average values, the shaded area indicates the prediction interval, which contains 90% of simulation results, and the thin lines indicate 5 future projections. In the SSB graph, the green dashed line indicates SB<sub>msy</sub>, the yellow dotted line indicates SB<sub>0.6msy</sub>, and the red dotted line indicates SB<sub>0.1msy</sub>. 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 (U<sub>msy</sub>) that maintains

SBmsy.  $\beta = 0.8$  was used as the adjustment coefficient in the proposed HCRs. The F for 2024 was set to the F that gives the average catch for the most recent 5-year period (2019 to 2023, 37,000 tons).

Supplementary Table 4-1. Probability of future spawning stock biomass exceeding the proposed target and limit reference point (%)

a) Probability of exceeding the proposed target reference point (%) with  $F_{msy}$  set as the upper limit of fishing pressure

$\beta$	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035		
1.0	100	83	52	46	45	44	44	43	42	43	43	44		
0.9			55	51	50	49	49	48	48	49	49	49	49	
0.8			59	55	55	54	54	53	53	54	54	54	54	
0.7			63	60	59	59	59	58	58	59	59	59	59	
0.6			67	64	64	64	64	63	63	64	64	64	64	
0.5			71	69	69	69	69	68	68	69	69	69	69	
0.4			75	74	74	74	74	73	74	74	74	74	74	
0.3			80	79	79	80	80	79	79	79	79	80	79	
0.2			86	86	86	86	86	85	86	86	86	86	86	
0.1			92	93	93	93	93	93	93	93	94	93	94	
0.0			97	99	99	99	99	99	99	99	99	99	99	
Current fishing pressure					61	57	56	56	56	55	55	55	56	56

b) Probability of exceeding the proposed limit reference point (%) with  $F_{msy}$  set as the upper limit of fishing pressure

$\beta$	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035		
1.0	100	100	98	96	96	95	95	95	95	95	95	95		
0.9			99	98	97	96	96	96	96	97	97	96		
0.8			99	98	98	97	97	98	98	98	98	98		
0.7			99	99	98	98	98	98	98	99	99	98		
0.6			100	99	99	99	99	99	99	99	99	99		
0.5			100	99	99	99	99	99	99	100	99	99		
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					99	98	98	98	97	98	98	98	98	98

The results of future projections when  $\beta$  is varied from 0 to 1.0 are shown. The catch for 2024 has been set at 37,000 tons, which is the average of the most recent five years (2019 to 2023), and for 2025 onward, the catch has been set in accordance with the proposed HCRs. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2018-2022, corresponding to  $\beta = 0.86$ ).

Supplementary Table 4-2. Future average spawning stock biomass (thousand tons)

a) Future average SSB using the proposed HCRs with  $F_{msy}$  set as the upper limit of fishing pressure

$\beta$	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
1.0	105	73	48	45	45	44	44	44	44	44	44	44	
0.9			50	48	48	47	47	47	47	47	47	47	
0.8			53	51	50	50	50	50	50	50	50	50	
0.7			55	53	53	53	53	53	53	53	53	53	
0.6			58	56	56	56	56	56	56	56	56	56	
0.5			60	59	59	59	59	59	59	59	59	59	
0.4			64	63	63	63	63	63	63	63	63	63	
0.3			68	67	68	67	67	67	67	67	68	67	68
0.2			73	73	73	73	73	73	73	73	74	73	73
0.1			81	82	82	82	82	82	82	82	82	82	82
0.0			93	97	98	98	98	98	98	98	99	98	99
Current fishing pressure			53	52	51	51	51	51	51	51	51	51	51

The results of future projections when  $\beta$  is varied from 0 to 1.0 are shown. The catch for 2024 has been set at 37,000 tons, which is the average of the most recent five years (2019 to 2023), and for 2025 onward, the catch has been set in accordance with the proposed HCRs. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2018-2022, corresponding to  $\beta = 0.86$ ).

Supplementary Table 4-3. Future average catch (thousand tons)

a) Future average catch using the proposed HCRs with Fmsy set as the upper limit of fishing pressure

$\beta$	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.0	37	52	42	41	40	40	40	40	40	40	40	40
0.9		50	41	40	40	39	39	39	39	39	39	39
0.8		48	40	39	39	39	38	38	38	39	39	38
0.7		45	38	38	38	38	37	37	37	38	38	37
0.6		43	37	36	36	36	36	36	36	36	36	36
0.5		40	35	35	35	35	35	34	35	35	35	35
0.4		36	33	33	33	33	33	32	33	33	33	33
0.3		32	30	30	30	30	30	30	30	30	30	30
0.2		26	26	26	26	26	26	26	26	26	26	26
0.1		16	17	18	18	18	18	18	18	18	18	18
0.0		0	0	0	0	0	0	0	0	0	0	0
Current fishing pressure		47	39	39	38	38	38	38	38	38	38	38

The results of future projections when  $\beta$  is varied from 0 to 1.0 are shown. The catch for 2024 has been set at 37,000 tons, which is the average of the most recent five years (2019 to 2023), and for 2025 onward, the catch has been set in accordance with the proposed HCRs. For comparison, results are also shown for the case where fishing continues at the current fishing pressure (F2018-2022, corresponding to  $\beta = 0.86$ ).

## Appendix 5 Future Projection Methods

The values in Supplementary Table 5-1 were used for the various settings in the future projections. The calculation package *frasyr* (ver. 2.4.0.0) for statistical software R (version 4.4.1) was used to calculate projections for stock number and catch in weight based on the Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations for FY 2024 (FRA-SA-2024-ABCWG02-04). Stock Assessment Working Group (2024). Recruitment in future projections was obtained using a hockey stick model for the stock-recruitment relationship proposed in the Materials for the Research Institute Meeting on Reference Points published in September 2022 (Kono et al. 2022) and estimated annual spawning stock biomass (SSB).

The fishing mortality  $F$  used in the future projections were values estimated based on control rules for Stock Group 1 according to The Basic Guidelines for Harvest Control Rules and ABC Calculation (FY 2024). FRA-SA2024-ABCWG02-01. Japan Fisheries Research and Education Agency (2024). For selectivity and the average body weight of the catch in the future projections, we continued to use the same values as those used to estimate the various proposed reference points in the “Materials for the Research Institute Meeting on Reference Points” described above (Kono et al. 2022, Supplementary Table 5-1). Similar to the stock-recruitment relationship, these values are based on the FY 2022 stock assessment (Kono et al. 2023), and the average body weight in catches is the average value for the period 2016 to 2020 in this calculation.

Fishing pressure in 2024 ( $F_{2024}$ ) was assumed to be 37,000 tons, which was the average catch of the most recent 5-year period (2019 to 2023). This means that if current fishing pressure ( $F_{2018}$  to 2022) is assumed for  $F$  in 2024, then the catch in 2024 would be 58,000 tons, but the range of catch for 2019 to 2023 is 26,000 to 42,000 tons. Thus, this value was considered likely to be an overestimate in light of fishing patterns and spawning status during the first half of 2024.

In the assessment of the previous fiscal year, the selectivity of  $F$  for the start year of future projections (2023) was set the same as  $F_{msy}$ . This selectivity is the average selectivity of  $F$  by age for a 5-year period (2016 to 2020), excluding the most recent year (2021) in the FY 2022 stock assessment, and was 0.06 for age 0 fish, and 1.00 for both fish age 1 and fish age 2 and older. For the assessment of this fiscal year, the average selectivity of  $F$  by age (0.07 for age 0 fish, and 1.00 for both fish age 1 and fish age 2 and older) for a five-year period (2018 to 2022) excluding 2023, the final year of biomass estimation, was used as the selectivity of  $F$  for the start year of future projections (2024) to reflect the current fishing status more closely.

Projections for the stock number were made using the forward method for cohort analysis (equations (13) to (15)).

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M) \quad (13)$$

$$N_{2+,y+1} = N_{2+,y} \exp(-F_{2+,y} - M) + N_{1,y} \exp(-F_{1,y} - M) \quad (14)$$

$$C_{a,y} = N_{a,y} \{1 - \exp(-F_{a,y})\} \exp\left(-\frac{M}{2}\right) \quad (15)$$

#### Cited literature

Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., and Kinoshita, J. (2022) Materials for the Research Institute Meeting of Seto Inland Sea stock of Japanese anchovy (FY 2022). FRA-SA2022-BRP05-01, Japan Fisheries Research and Education Agency, Yokohama, 55 pp.

[https://www.fra.affrc.go.jp/shigen\\_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf](https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/20220818/FRA-SA2022-BRP05-01.pdf)

Kono, N., Takahashi, M., Yasuda, T., Watanabe, C., Watai, M., Imoto, J., Kinoshita, J., and Nishijima, S. (2023) Stock Assessment for Japanese Anchovy – Seto Inland Sea (Fiscal Year 2022). FRA-SA2022-AC-25, Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2022), Japan Fisheries Research and Education Agency, Fisheries Agency, Tokyo, 51 pp.

[https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details\\_2022\\_25.pdf](https://abchan.fra.go.jp/wpt/wp-content/uploads/2023/07/details_2022_25.pdf)

Stock Assessment Working Group (2024) Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations for FY 2024. FRA-SA-2024-ABCWG02-04, Japan Fisheries Research and Education Agency, Yokohama, 15 pp.

[https://abchan.fra.go.jp/references\\_list/FRA-SA2024-ABCWG02-04.pdf](https://abchan.fra.go.jp/references_list/FRA-SA2024-ABCWG02-04.pdf)

Japan Fisheries Research and Education Agency (2024) The Basic Guidelines for Harvest Control Rules and ABC Calculation (FY 2024). FRA-SA2024-ABCWG02-01, Japan Fisheries Research and Education Agency, Yokohama, 23 pp.

[https://abchan.fra.go.jp/references\\_list/FRA-SA2024-ABCWG02-01.pdf](https://abchan.fra.go.jp/references_list/FRA-SA2024-ABCWG02-01.pdf)

Supplementary Table 5-1. Parameters for future projections

Age	Selectivity (Note 1)	Fmsy (Note 2)	F2024 (Note 3)	Average body weight (g)	Natural mortality coefficient	Maturity rate
Age 0	0.06	0.44	0.11	3.0	2.1	0.0
Age 1	1.00	6.93	1.58	8.7	2.1	1.0
2 years or more	1.00	6.93	1.58	18.8	2.0	1.0

Note 1: Selectivity used to estimate the level to achieve MSY at the FY 2022 Research Institute Meeting (i.e., selectivity of  $F_{current}$  in the FY 2022 stock assessment).

Note 2: Fmsy estimated at the FY 2022 Research Institute Meeting (i.e.,  $F_{current}$  in the FY 2022 stock assessment multiplied by  $F_{msy}/F_{current}$ ).

Note 3: F assuming that the catch in 2024 will be the average of the most recent 5-year period (2019 to 2023, 37,000 tons). Selectivity was set the same as the average F by age (0.07 for age 0 fish and 1.00 for both fish age 1 and fish age 2 and older) for the 5-year period (2018 to 2022), excluding the most recent year estimated in the stock assessment of this fiscal year.

## 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.	P
Hockey stick type	Least squares method	No	2.158	32,678	0.444	-

Supplementary Table 6-2. Proposed reference points and MSY

Item	Value	Explanation
SBmsy	43,000 tons	Proposed target reference points. Spawning stock biomass to achieve the realization of MSY.
SB0.6msy	17,000 tons	Proposed limit reference point. SSB to achieve catch of 60% of MSY.
SB0.1msy	2,000 tons	Proposed fishing ban level. SSB to achieve catch of 10% of MSY.
Fmsy	Fishing pressure to maintain SBmsy (Age 0, 1, 2+) = (0.44, 6.93, 6.93)	
%SPR (Fmsy)	49%	%SPR corresponding to Fmsy
Maximum Sustainable Yield (MSY)	39,000 tons	Maximum Sustainable Yield

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

Item	Value	Explanation
SB2023	59,000 tons	SSB in 2023
F2023	Fishing pressure in 2023 (fishing mortality F) (Age 0, Age 1, Age 2 and older) = (0.34, 0.83, 0.83)	
U2023	12%	Exploitation rate of 2023
%SPR (F2023)	57.5%	%SPR of 2023
%SPR (F2018-2022)	52.4%	%SPR corresponding to current fishing pressure (2018 to 2022)
Comparison with proposed reference point		
SB2023/ SBmsy	1.37	B ratio to achieve MSY to SSB (Sbmsy) in the 2023 fishing season
F2023/ Fmsy	0.75	F ratio to achieve MSY to fishing pressure in 2023*
Level of SSB	Over the level to achieve MSY	
Level of fishing pressure	Under the level to achieve SBmsy	
Trends of spawning stock biomass	Increase	

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

Supplementary Table 6-4. Projected catch in weight and projected spawning stock biomass (SSB)

SSB in 2025 (average projected value): 73,000 tons			
Item	ABC of 2025 Average catch (Thousand tons)	Relationship between current fishing pressure (F/F2018-2022)	ABC of 2025 Exploitation rate (%)
$\beta$ proposed in the Materials for the Research Institute Meeting (Maximum value)			
$\beta = 0.8$	48	1.04	17
If a $\beta$ different from the above is used			
$\beta = 1.0$	52	1.31	18
$\beta = 0.9$	50	1.18	17
$\beta = 0.6$	43	0.78	15
$\beta = 0.4$	36	0.52	13
$\beta = 0.2$	26	0.26	9
$\beta = 0.0$	0	0	0
F2018-2022	47	1.00	16

Supplementary Table 6-5. Results of future projections using various  $\beta$ 

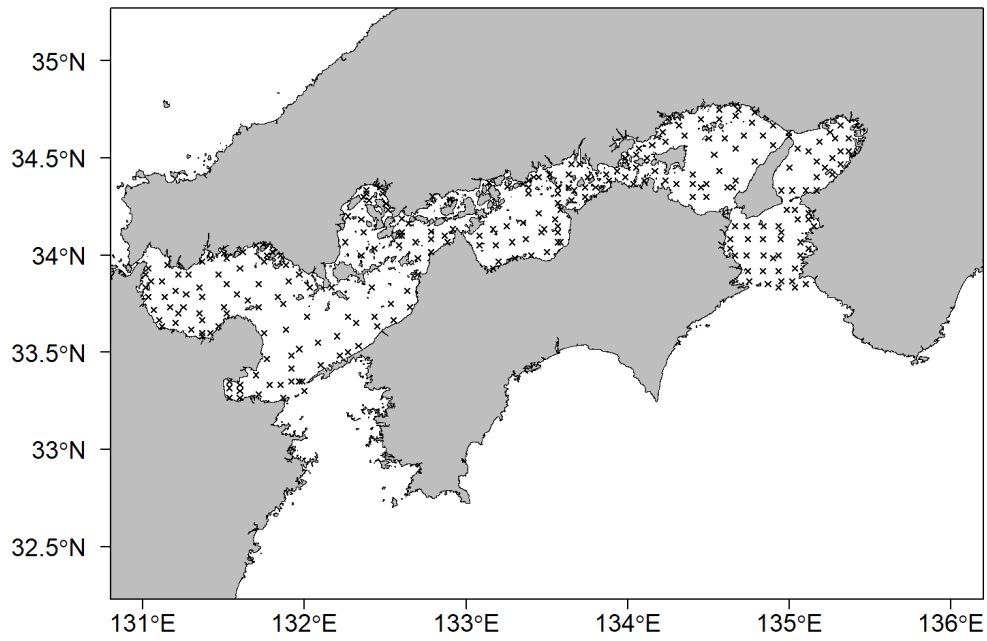
Uncertainty under consideration: Recruitment					
Item	Average SSB in 2035 (Thousand tons)	90% Prediction interval (Thousand tons)	Probability (%) that SSB will exceed the following proposed reference points in 2035		
			SBmsy	SB0.6msy	SB0.1msy
$\beta$ proposed in the Materials for the Research Institute Meeting (Maximum value)					
$\beta = 0.8$	50	20 – 96	54	98	100
If a $\beta$ different from the above is used					
$\beta = 1.0$	44	17 – 86	44	95	100
$\beta = 0.9$	47	19 – 91	49	96	100
$\beta = 0.6$	56	24 – 107	64	99	100
$\beta = 0.4$	63	28 – 119	74	100	100
$\beta = 0.2$	73	35 – 134	86	100	100
$\beta = 0.0$	99	53 – 167	99	100	100
F2018-2022	51	21 – 98	56	98	100

## Appendix 7 Summary of Survey Results

Egg and larvae survey using vertically hauled Marutoku B nets and remodeled NORPAC nets have been planned by fisheries research institutes in various prefectures (Wakayama to Oita (11 prefectures)) to cover most of the spawning season. Using the results of these surveys that have been conducted from the Kii Channel to Suo-nada since 1980, monthly egg production was calculated based on Kono and Zenitani (2008), and the values from January to December of each year were aggregated to estimate the egg production for each year. Hattori's (1983) equation was followed to obtain the average number of hatching days. For average survival during spawning, we used Watanabe's (unpublished) value of 0.6, as shown by Zenitani et al. (1995). A diagram showing the layout of the survey points is given below (Supplementary Fig. 7-1). The average number of hauls during the period was 2,466 per year, ranging from 1,940 to 2,909 hauls per year.

### Cited literature

- Hattori, S. (1983) Relationship between growth rate of Japanese anchovy eggs and temperature. Report of the 15th Nansei Sea Block Inland Sea Fisheries Research Meeting, 59-64.
- Kono, N. and Zenitani, H. (2008) Distribution of egg production of Japanese anchovy in the Seto Inland Sea from 1980 to 2005. *Fish. Sci.*, **74**, 636-644.
- Zenitani, H., Ishida, M., Konishi, Y., Goto, T., Watanabe, Y., and Kimura, R. (1995) Distribution status by month of eggs and juveniles of Japanese pilchard, Japanese anchovy, chub mackerel and spotted mackerel, red-eyed round herring, and Japanese jack mackerel, and larva of Japanese common squid, in ocean regions surrounding Japan: January 1991 to December 1993. Fisheries Agency Laboratory Resource Management Research Report Series, 368 pp.



Supplementary Fig. 7-1. Survey points (x) for egg and larvae surveys in the Seto Inland Sea

## Appendix 8 Comparison with previous years' assessment results

When comparing the stock assessment results for the previous fiscal year (FY 2023) (Kono et al. 2024) with the results of this fiscal year, there were no major differences in the estimated values for the years prior to 2020 or 2026 onwards. However, the estimated values for 2021 to 2025 changed (Supplementary Fig. 8-1 through 8-3 and Supplementary Table 8-1). For example, the recruitment (stock number of age 0 fish) of the 2021 cohort (2021 age 0 fish, 2022 age 1 fish, 2023 age 2 and older fish) and the 2022 cohort (2022 age 0 fish, 2023 age 1 fish) was revised downward (Supplementary Fig. 8-1).

For the 2021 cohort, because the stock number of fish age 1 was estimated to be high in the stock assessment of the previous year due to the low value of  $F$  estimated for fish age 1 targeted for tuning, the recruitment calculated retrospectively using a regression method of cohort analysis was also estimated to be a high value (blue triangle in Supplementary Fig. 8-1). In the assessment of this fiscal year, the  $F$  of fish age 2 and older, which were the target of tuning, was estimated to be a low value. However, because the catch in number of fish age 2 and older was small, the effect of increasing the stock number of younger fish in the same cohort was small. Therefore, the SSB for 2022 (red circle in Supplementary Fig. 8-2), when the 2021 cohort was the main adult fish, as well as the recruitment for 2021 (red triangle in Supplementary Fig. 8-1) were revised downward from the assessment of the previous year (Supplementary Table 8-1).

The 2022 cohort was not subject to tuning in the assessment of the previous fiscal year because they were age 0 fish, but in the assessment of this fiscal year, they were age 1 fish, and their  $F$  was a target for tuning. As a result, the  $F$  of age 1 fish was estimated to be a lower value, while the stock number of age 1 fish was estimated to be a higher value. The retroactive upward revision of recruitment was also estimated to be a higher value than before the 2021 cohort (red square in Supplementary Fig. 8-1).

Because the catch in number of age 0 fish in 2022 was large in the assessment of the previous fiscal year (Kono et al. 2024, Supplementary Table 2-1), recruitment for the 2022 cohort and forward calculated future projections based on it estimated the SSB in 2023 to be a high value. However, the 2022 catch of 53,000 tons (provisional) in the assessment of the previous fiscal year was revised downward to 42,000 tons as the finalized value in the assessment of this fiscal year (Supplementary Table 8-1). This downward revision of catch resulted in a downward revision of the recruitment for the 2022 cohort in the assessment of this fiscal year from the estimated value in the assessment of the previous fiscal year. However, as noted above, the recruitment was revised upward due to the effects of tuning (Supplementary Fig. 8-1). Similarly, although tuning resulted in a higher estimated value of SSB for 2023 in the assessment of this fiscal year, it was revised downward from the value estimated in the assessment of the previous fiscal year (Supplementary Fig. 8-2).

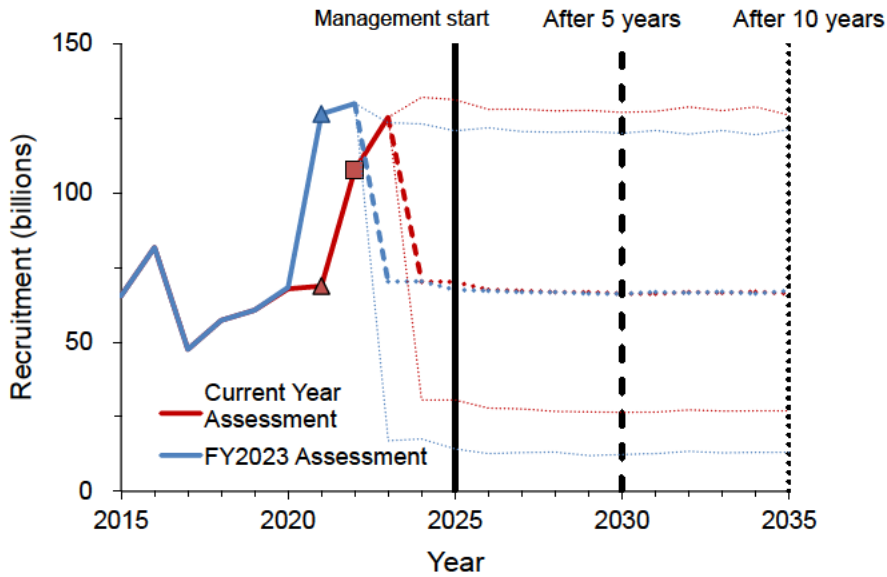
Since the main stock in this stock is age 0 fish, stock biomass showed similar changes to recruitment (Supplementary Fig. 8-3). As described above, there was a large difference in

estimated values for 2021 to 2022 between the assessment of the previous fiscal year and the assessment of this fiscal year. However, the difference became smaller from 2023 to 2025, and the projected values from 2026 onwards were nearly the same (Supplementary Figs. 8-1 to 8-3).

Trends in catch in the assessment of the previous fiscal year and the assessment of this fiscal year are shown in Supplementary Fig. 8-4. Projected catch for 2025 was larger this fiscal year than in the assessment of the previous fiscal year. The main reason for this is that the stock biomass for 2025 in the assessment of this fiscal year is larger than that in the assessment of the previous fiscal year. The catch for 2023 (average of 37,000 tons) in the assessment of the previous fiscal year and the catch for 2024 (37,000 tons) in the assessment of this fiscal year are assumed values (Appendix 5).

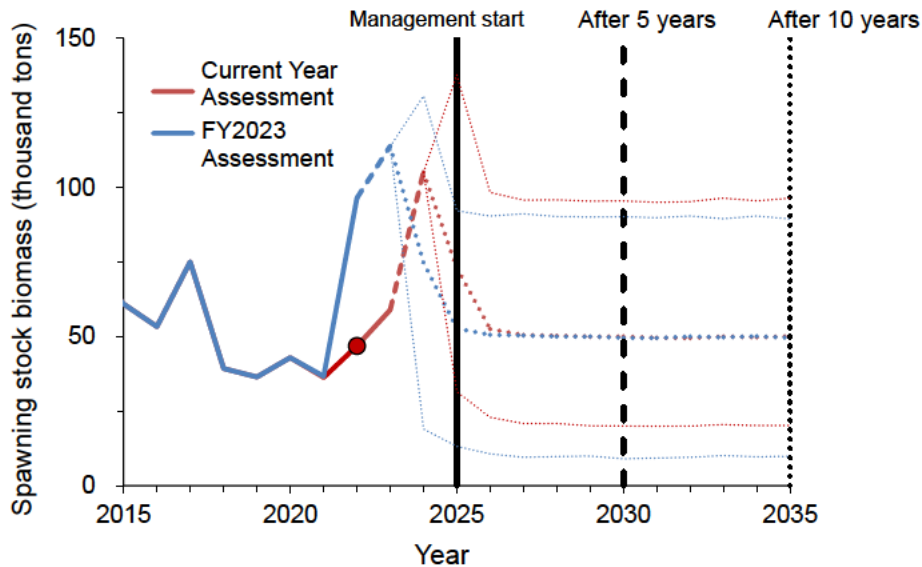
#### Cited literature

Kono, N., Takahashi, M., Yasuda, T., Watai, M., Imoto, J., Hino, H., Kinoshita, J., and Nishijima, S. (2024) Stock assessment for Japanese anchovy – Seto Inland Sea (Fiscal Year 2023). FRA-SA2024-AC025, Marine fisheries stock assessment and evaluation for Japanese waters (Fiscal Year 2023), Japan Fisheries Research and Education Agency, Fisheries Agency, Tokyo, 65 pp.  
[https://abchan.fra.go.jp/wpt/wp-content/uploads/2024/03/details\\_2023\\_25.pdf](https://abchan.fra.go.jp/wpt/wp-content/uploads/2024/03/details_2023_25.pdf)



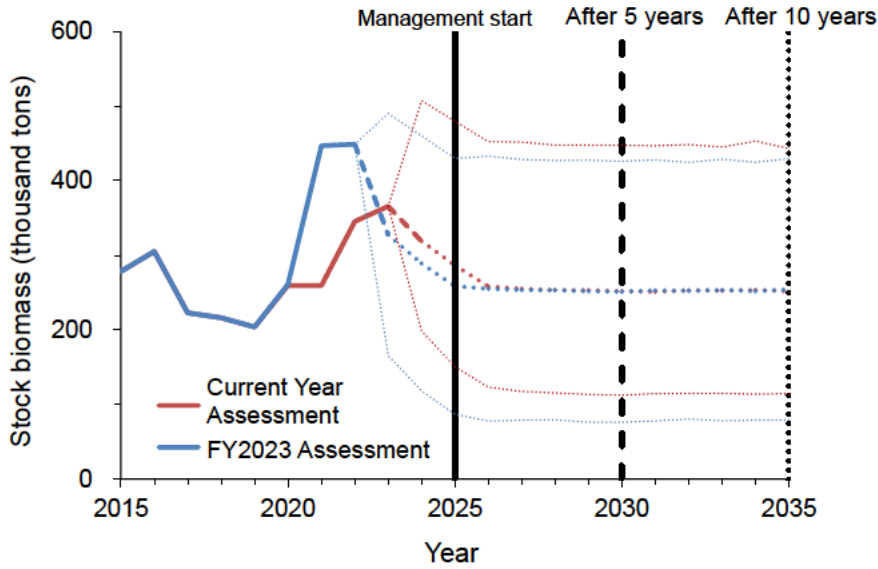
Supplementary Fig. 8-1. Comparison of stock assessment results (recruitment) between the previous fiscal year (FY 2023) and this fiscal year

The estimated recruitment and future projections based on the proposed harvest control rules with  $\beta$  set to 0.8 are presented. The solid line represents the VPA estimation results, the dashed line represents the future projection results, the thick line indicates the average values and the thin line shows the range predicted to be included with a 90% probability.



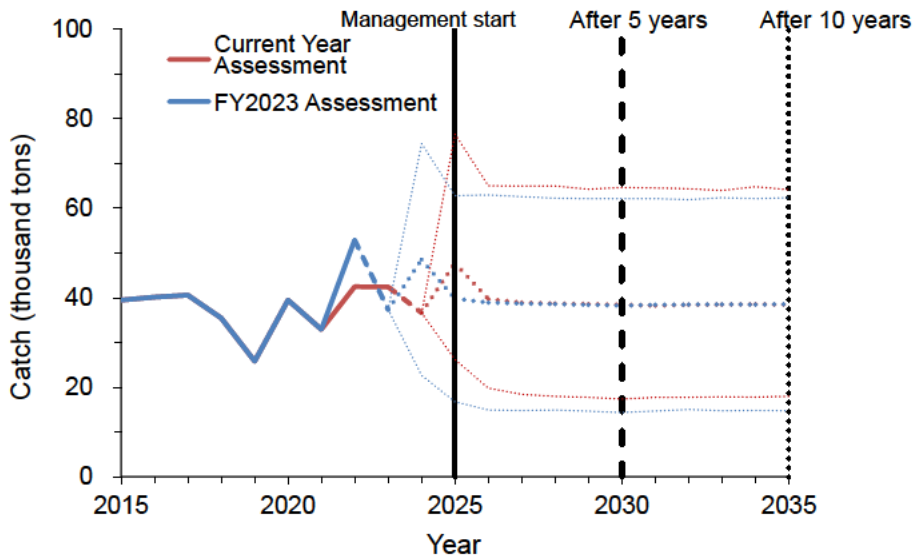
Supplementary Fig. 8-2. Comparison of stock assessment results (spawning stock biomass) between the previous fiscal year (FY 2023) and this fiscal year

The estimated spawning stock biomass and future projections based on the proposed harvest control rules with  $\beta$  set to 0.8 are presented. The solid line represents the VPA estimation results, the dashed line represents the future projection results, the thick line indicates the average values and the thin line shows the range predicted to be included with a 90% probability.



Supplementary Fig. 8-3. Comparison of stock assessment results (abundance) between the previous fiscal year (FY 2023) and this fiscal year

The estimated stock biomass and future projections based on the proposed harvest control rules with  $\beta$  set to 0.8 are presented. The solid line represents the VPA estimation results, the dashed line represents the future projection results, the thick line indicates the average values, and the thin line shows the range predicted to be included with a 90% probability.



Supplementary Fig. 8-4. Comparison of stock assessment results (catch in weight) between the previous fiscal year (FY 2023) and this fiscal year

The estimated catch and future projections based on the proposed harvest control rules with  $\beta$  set to 0.8 are presented. The solid line represents the VPA estimation results, the dashed line represents the future projection results, the thick line indicates the average values and the thin line shows the range predicted to be included with a 90% probability. The catch for 2023 in the stock assessment of the previous fiscal year and the catch for 2024 in the stock assessment of this fiscal year are assumed values.

Supplementary Table 8-1. Spawning Stock Biomass (SSB), Recruitment, and Catch for Each Year by Assessment Year

## (a) Spawning stock biomass (Thousand tons)

Assessment	2021	2022	2023	2024	2025
FY 2022	89	75	56		
FY 2023	37	96	114	75	
FY 2024	36	47	59	105	73

## (b) Recruitment volume (billion fishes)

Assessment	2021	2022	2023	2024	2025
FY 2022	712	712	685		
FY 2023	1,264	1,299	702	703	
FY 2024	687	1,076	1,253	702	701

## (c) Catch in Weight (Thousand tons)

Assessment	2021	2022	2023	2024	2025
FY 2022	34	46	41		
FY 2023	33	53	37	49	
FY 2024	33	42	42	37	48

Starting with the FY 2022 stock assessment, cohort analysis has been conducted using the catch in number at age and by year. Numbers in black for SSB and recruitment represent estimated values based on cohort analysis. Numbers in green for catch in weight represent actual (provisional) values, numbers in black represent actual (finalized) values, and numbers in blue represent assumed values for future projections. Numbers in red represent the average projected value if the proposed harvest control rules with  $\beta$  set to 0.8 are used. The assessment of the previous fiscal year was compared with this fiscal year's, and the SSB in 2022 was revised downward, as a result of which, the recruitment in 2021 was also revised downward. The provisional value of catch for 2022 was reported as 53,000 tons in the previous fiscal year but was revised downward to 42,000 tons in the finalized value this fiscal year.

## Appendix 9 Information on Whitebait

In the Seto Inland Sea, fishery targeting shirasu (Whitebait) is also well developed. Biological and fishery information regarding Whitebait is presented below.

### 1. Distribution and migration

In addition to individuals born in various areas of the Seto Inland Sea from spring to autumn, some individuals born in the southern Pacific area in spring also migrate to the Seto Inland Sea and become part of the stock that is caught. Therefore, the abundance level of individuals born in the southern Pacific area and the onshore-offshore movements of the Kuroshio affect the spring catch of Whitebait in the eastern Seto Inland Sea (Horiki 1971).

### 2. Trends in catch in weight

Shirasu (Whitebait) is mostly caught using boat seine fishery. The catch in weight of Whitebait (catch in weight of Whitebait according to commercial size category in the Statistics of Fishery and Aquaculture Production) from 1981 to 2023 are shown in Supplementary Fig. 9-1 and Supplementary Table 9-1. The catch in weight of Whitebait peaked at 53,000 tons in 1986, then showed a downward trend, decreasing to 21,000 tons in 1998. Since then, the catch in weight has fluctuated between 18,000 and 39,000 tons, with a provisional value of 30,000 tons for 2023.

### 3. Fishing Effort

The average value of the number of fishing trips made annually by representative fishery cooperatives (2 fishery cooperatives in Wakayama Prefecture, 1 in Osaka Prefecture, 2 in Hyogo Prefecture, and 1 in Ehime Prefecture) in boat seine fishing targeting Whitebait are shown below (Supplementary Fig. 9-2, Supplementary Table 9-2). Since the representative fisheries cooperatives of this fishery use one fishing gear between two vessels during operations, fishing effort is expressed in terms of the number of fishing trips. The number of fishing trips showed a downward trend from the 1990s but has remained generally steady since the late 2000s. The total catch in weight of Whitebait by the above representative fisheries cooperatives during each year accounts for 11 to 19% (average of 16%) of the total catch in weight of Whitebait in the entire Seto Inland Sea.

The average value of the number of operations conducted per year by sample vessels (1 vessel each in Tokushima Prefecture and Hiroshima Prefecture) in boat seine fishery targeting Whitebait are shown below (Supplementary Fig. 9-2 and Supplementary Table 9-2). The number of operations has been on a downward trend since the 1990s, with a particularly marked decline between 2017 and 2021. As per interviews with relevant persons, some sample vessels appear to have increased the duration of their operations in recent years, but we have not been able to obtain a detailed understanding of the actual situation. Therefore, information on sample vessels is presented for reference only.

#### 4. Trends in Abundance Indices

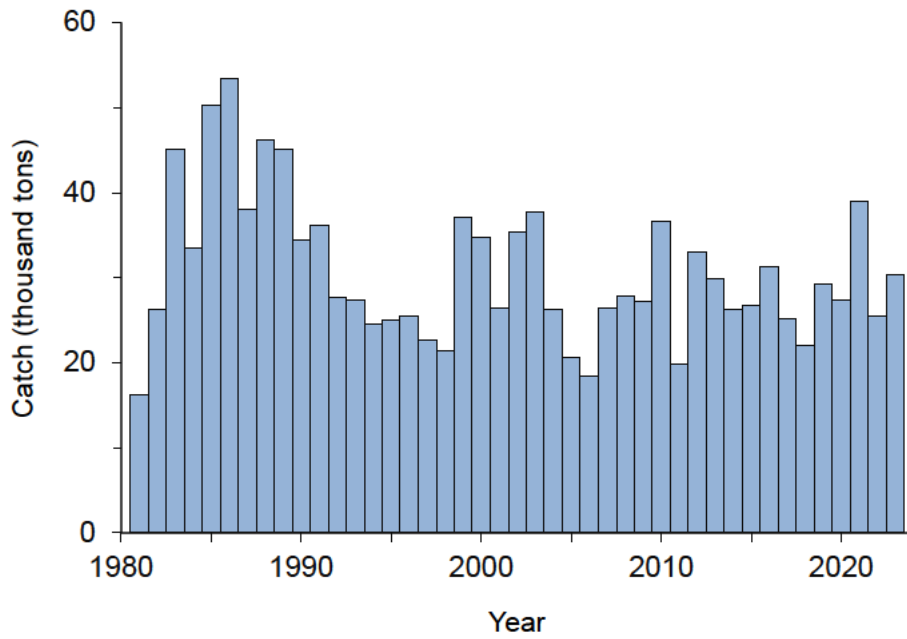
The average value of catch per unit effort (hereinafter referred to as “CPUE”) (tons/number of fishing trips) per year for the six representative fisheries cooperatives in boat seine fishery targeting Whitebait are shown below (Supplementary Fig. 9-3 and Supplementary Table 9-2). Also shown are the average values of CPUE (tons/net) per year for the two sample vessels. Both the CPUE have shown an increasing trend since the late 2000s, although there have been sharp increases and decreases.

#### 5. Others

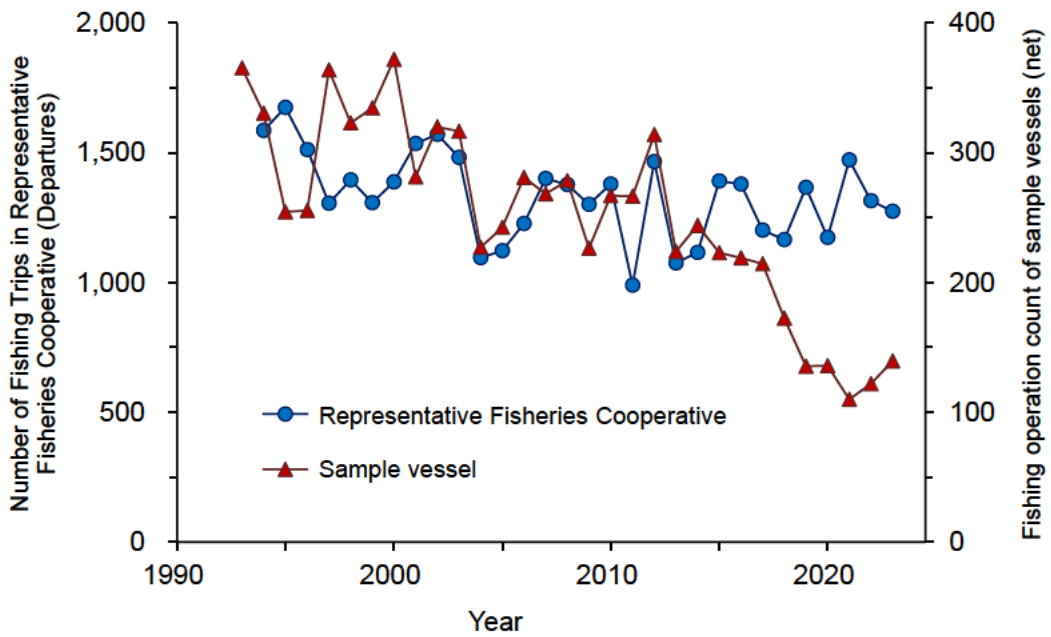
In Hiuchi-nada, located in the central Seto Inland Sea, the egg production is high but catches of Whitebait continue to be poor, and factors such as changes in the feeding environment during the larvae and adult stages have been identified as the causes for this (Fujita et al. 2021, Yoneda et al. 2022).

#### Cited literature

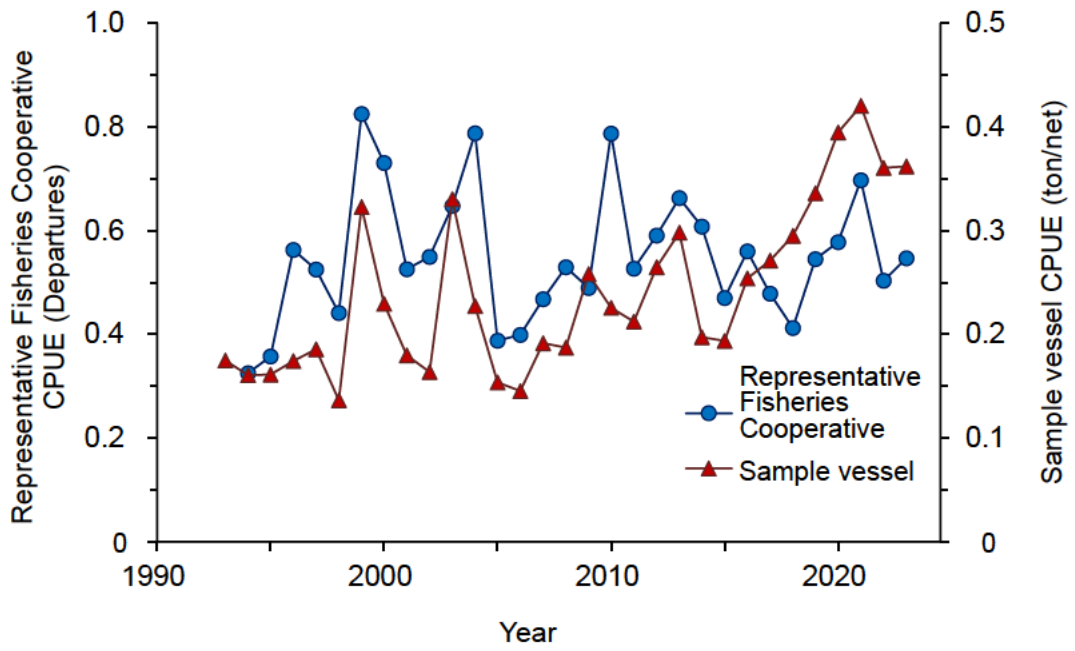
- Fujita, T., Yamamoto, M., Kono, N., Tomiyama, T., Sugimatsu, K., and Yoneda, M. (2021) Temporal variations in hatch date and early survival of Japanese anchovy (*Engraulis japonicus*) in response to environmental factors in the central Seto Inland Sea, Japan. *Fish. Oceanogr.*, **30**, 527-541.
- Horiki, N. (1971) The relationship between shirasu (Whitebait (spring Whitebait)) fishing conditions and sea conditions. FY 1970 report by Wakayama Pref. Fish. Exp. Stn., 159-163.
- Yoneda, M., Fujita, T., Yamamoto, M., Tadokoro, K., Okazaki, Y., Nakamura, M., Takahashi, M., Kono, N., Matsubara, T., Abo, K., Guo, X., and Yoshie, N. (2022) Bottom-up processes drive reproductive success of Japanese anchovy in an oligotrophic sea: A case study in the central Seto Inland Sea, Japan. *Progress in Oceanogr.*, **206**, 102860.



Supplementary Fig. 9-1. Trends in the catch in weight of Whitebait



Supplementary Fig. 9-2. Trends in fishing effort in the Whitebait fishery



Supplementary Fig. 9-3. Trends in CPUE in the Whitebait fishery

Supplementary Table 9-1. Trends in catch in weight (tons) of Whitebait+

Year	Agricultural and Forestry Statistics
1981	16,319
1982	26,264
1983	45,012
1984	33,443
1985	50,224
1986	53,385
1987	38,042
1988	46,157
1989	45,071
1990	34,426
1991	36,223
1992	27,700
1993	27,327
1994	24,577
1995	24,983
1996	25,557
1997	22,615
1998	21,446
1999	37,123
2000	34,780
2001	26,413
2002	35,299
2003	37,813
2004	26,239
2005	20,598
2006	18,410
2007	26,340
2008	27,861
2009	27,186
2010	36,555
2011	19,782
2012	33,048
2013	29,932
2014	26,291
2015	26,715
2016	31,324
2017	25,222
2018	21,975
2019	29,224
2020	27,459
2021	39,005
2022	25,453
2023	30,388

The values for 2023 are provisional.

Supplementary Table 9-2. CPUE of Representative Fisheries Cooperatives and Sample Vessels in the Whitebait Boat Seine Fishery of the Seto Inland Sea

Year	Representative Fisheries Cooperatives		Sample vessels	
	CPUE (Tons/Number of fishing trips)	Average number of fishing trips (Trips)	CPUE (Tons/Number of operations)	Average number of operations (times)
1993	-	-	0.17	366
1994	0.32	1,586	0.16	331
1995	0.36	1,675	0.16	255
1996	0.56	1,513	0.17	256
1997	0.53	1,306	0.19	364
1998	0.44	1,396	0.14	323
1999	0.82	1,308	0.32	335
2000	0.73	1,388	0.23	372
2001	0.53	1,536	0.18	282
2002	0.55	1,571	0.16	320
2003	0.65	1,483	0.33	317
2004	0.79	1,096	0.23	227
2005	0.39	1,123	0.15	243
2006	0.40	1,228	0.15	281
2007	0.47	1,401	0.19	269
2008	0.53	1,377	0.19	279
2009	0.49	1,301	0.26	227
2010	0.79	1,380	0.23	267
2011	0.53	990	0.21	267
2012	0.59	1,467	0.26	314
2013	0.66	1,075	0.30	224
2014	0.61	1,117	0.20	244
2015	0.47	1,392	0.19	223
2016	0.56	1,380	0.25	219
2017	0.48	1,202	0.27	215
2018	0.41	1,166	0.29	173
2019	0.54	1,367	0.34	136
2020	0.58	1,174	0.39	136
2021	0.70	1,473	0.42	110
2022	0.50	1,315	0.36	122
2023	0.55	1,275	0.36	140

The average number of fishing trips is the average of the number of fishing trips made annually by the six representative fishery cooperatives.

The average number of fishing operations is the average of the number of fishing operations conducted annually by the two sample vessels.