2023 Stock Assessment of the Honshu Northern Sea of Japan Stock of Pacific Cod

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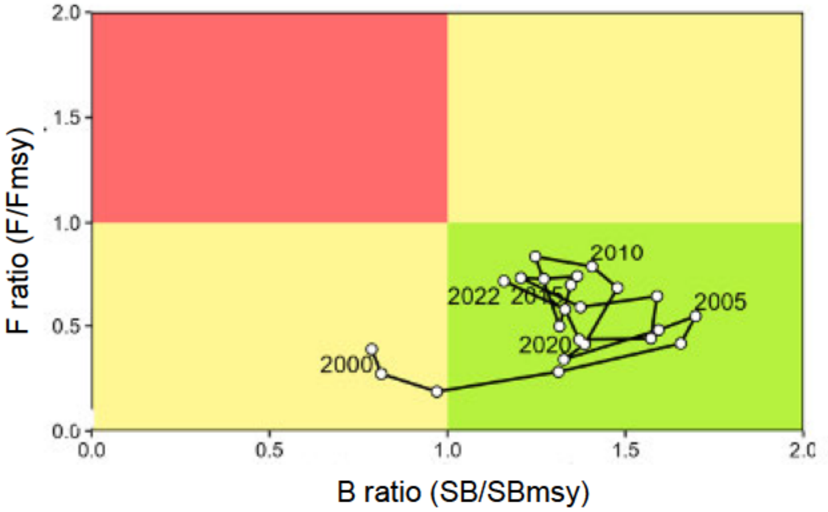
Summary

The status of this stock was assessed using cohort analysis with tuning based on the abundance index (standardized CPUE (catch per unit effort) of offshore bottom trawl fishing). Biomass surged from a record low in 2001 to a record high in 2005, then gradually decreased while fluctuation. In 2022, it was 11,000 tons. SSB (spawning stock biomass) also reached a record high in 2005 before gradually decreasing until 2016. SSB was 6,035 tons in 2022.

In the Research Institute Meeting held in October 2021, a hockey-stick model was applied to the spawner-recruitment relationship of this stock, the maximum sustainable yield (MSY) was estimated based on the model, and the level of SSB required for MSY (SBmsy) was calculated to be 5,200 tons. The SSB for this stock in 2022 exceeded the level required for maintaining MSY and, the fishing pressure for this stock in the 2022 fishing season was lower than the level required for maintaining MSY (Fmsy). The SSB in the previous 5 years (2018 to 2022) is judged to be in a “decreasing” trend. Low abundance of the year-class 2018 (recruited in 2021 as age 3 fish) and onwards suggested by recruitment surveys is potentially not reflected to the present stock calculations due to uncertainty stems from low exploitation rate of juveniles, because main target of the fisheries is mature individuals in the stock.

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

Summary Figures and Tables



MSY, SSB Levels and Trends, and ABC	
SSB required for MSY	5,200 tons
Level of SSB in 2022	Over the level required for MSY
Level of fishing pressure in 2022	Under the level required for MSY
Trends in SSB in 2022	Flat
Maximum Sustainable Yield (MSY)	2,900 tons
ABC for 2024	-

Comments:

・ABC is estimated after Harvest Control Rules (HCRs) for this stock are compiled by the Stock Management Policy Commission, and set through the Fishery Policy Council.

・ The recruitment level indicated in the recruitment survey was extremely low for the 2018 cohort and onwards, but this survey does not take into account worsening recruitment over the past few years. It is possible that future recruitment will fall below the averages expected from the spawner-recruitment relationship and that the state of the stock will deteriorate.

・ The values for SSB of this stock are from after the fishing season.

Recent Biomass, Catch, Fishing Pressure, and Exploitation Rate					
Year	Biomass (thousand tons)	SSB (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2018	12.1	8.3	2.7	0.64	22
2019	11.6	8.2	2.6	0.44	23
2020	11.5	7.1	2.9	0.43	27
2021	10.5	6.9	2.7	0.58	26
2022	10.5	6.0	3.2	0.71	31
2023	10.1	6.0	2.8	0.71	28
2024	10.2	-	-	-	-

・The values for 2023 and 2024 are estimates based on future projections.
・ The F value for 2023 was assumed to be the F value for 2022.
・ The values for SSB are from after the fishing season.

1. Data Sets

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

Data Sets	Basic Information & Related Surveys
Catch at age	Annual Statistics of Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landings (Aomori to Ishikawa (6 prefectures)) Length composition surveys (Aomori, Yamagata, and Ishikawa prefectures)Precision measurement surveys (Fisheries Resources Institute, Aomori, Akita, Yamagata, Niigata, and Ishikawa prefectures)
Abundance indices	Standardized CPUE for offshore bottom trawling (Aomori, Akita, Yamagata, Niigata, and Ishikawa prefectures)* CPUE of Gillnetting (Aomori, Akita, and Ishikawa prefectures) CPUE of Bottom Trawling (Akita, Yamagata, Niigata, and Ishikawa prefectures)
Natural mortality (M)	Assuming M = 0.28 per year (Tanaka 1960)
Fishing effort	Survey on Catch Status by Fishing Ground Catch Performance Report for Bottom-Trawl Fishing in Offshore Waters (Fisheries Agency)
Occurrence of juveniles	Recruitment Survey (Aomori: April to September, Akita: September to December, Yamagata: June to July, Niigata: April to May) Northern Sea of Japan Demersal Fish Stock Survey (Fisheries Resources Institute: July to August) Stock Survey on Chionoecetes Opilio and Other Demersal Fish in the Northern Sea of Japan (Fisheries Resources Institute: May to June)

* Indicates the tuning index for cohort analysis.

2. Biological characteristics

(1) Distribution / Migration

Pacific cod is widely found around the northern Pacific coast and is distributed around Japan from the Sea of Japan to the northern East China Sea, the Pacific Ocean off northern Japan, and the Sea of Okhotsk (Bakkala et al. 1984). This stock is distributed in the northern Sea of Japan along the continental margin (at depths of 200 to 400 meters) and migrates to shallow seas in winter to spawn (Mishima 1989, Fisheries Agency 1989). While Pacific cod are believed to be highly sedentary (Bakkala et al. 1984), large-scale migration is also suggested (Kanno et al. 2001). The Pacific cod in the western Sea of Japan is genetically distinct from those found north of Ishikawa prefecture (Suda et al. 2017, Sakuma et al. 2019), and catch trends also differ between the northern and western Sea of Japan. The biology of Pacific cod and the fishing industry west of Fukui prefecture is detailed in Appendix 9.

(2) Age / Growth

Pacific cod grow fast, reaching 30 cm at age 2, 43 cm at age 3, and more than 70 cm at age 7 (Fig. 2-2). Significant weight gain occurs during the juvenile stage, growing roughly 7 times in body weight from age 1 to 2, then 2.7 times from age 2 to 3. For the ages of Pacific cod used in this assessment, age 0 was considered to be the year when the fish was hatched up to December 31st, with subsequent ages added according to the calendar year. The lifespan of this species was deemed to be nine years based on the results of age estimation of catches (Goto and Fujiwara 2015).

(3) Maturation / Spawning

Pacific cod in the Sea of Japan mature at 40 cm long for males and 50 cm long for females (Nakata et al. 1995), and the age of maturity is believed to be age 3 to 4. Stock calculation assumes a maturity rate of 50% for fish age 3 and 100% for fish age 4 and older (Fig. 2-3). Spawning season is from January to March, and spawning grounds are locally distributed. The seafloor of spawning grounds is mud beds, sandy mud beds, and sandy gravel beds based on egg collection (Yoseda et al. 1992). Eggs are released in a single batch, completing annual spawning (Sakurai and Yoshida 1990).

(4) Predator-Prey Relationships

Immature and mature fish feed on fish, cephalopods, and crustaceans (shrimp) (Fisheries Agency 1989, Shibata 1994, Nakata et al. 1995). The primary predator of this species is unknown.

3. Fishery Status

(1) Fishery Overview

The fishing industry for this stock includes offshore bottom trawling (hereafter, offshore trawlers), coastal small bottom trawling (hereafter small trawlers), gillnetting, set net fishing, longline fishing, and angler fishing. The fishing season for bottom trawl fishing, including offshore trawlers and small trawlers, is from September to June of the following year. Gillnetting and set net fishing are done throughout the year, but both industries target spawning groups, meaning the primary fishing season is from January to March. Looking at this stock as a whole, the catch in weight from January to March occupies 50% of the annual catch in weight. In the Sea of Japan west of Fukui prefecture, bottom trawl fishing including both offshore and small trawlers accounts for more than 90% of the catch (Appendix 8).

(2) Trends in Catch in Weight

Catch in weight fluctuated in cycles between 1,700 and 4,200 tons until the mid-1980s, then, after reaching a record high in 1989 (5,200 tons), it again fluctuated in cycles between 1,000 to 2,100 tons from 1992 to 2004 (Fig. 3-1, Table 3-1). Since 2005, catch in weight has generally remained around 3,000 tons, with total catch by prefecture in 2022 at 3,153 based on Ministry of Agriculture, Forestry, and Fishery statistics. From around 1990 to 2005, when catch was low, Aomori and Akita prefectures accounted for 50% of the overall catch, but in recent years, Niigata and Ishikawa prefectures account for roughly 50% of the overall catch. Moreover, catches of the northern portion of this stock have surged in recent years, with Aomori and Akita prefectures accounting for 50% of the total catch in 2023. By fishery type, bottom trawl fishing including both offshore and small trawlers, has accounted for 50% of the overall catch for this stock, while gillnetting and set net fishing have accounted for 40% since the 1980s (Fig. 3-2, Table 3-2). In 2021 and 2022, bottom trawl fishing, gillnetting and set net fishing have accounted for 40, 30 and 20%

of the overall catch, respectively, with an increase of set net catch.

(3) Fishing Effort

Number of hauls by offshore trawlers with Pacific cod catch (hereafter non-zero catch) increased from 1972 to 1982, and then declined significantly in 1986 before reaching a record high of 39,000 in 1989 (Fig. 3-3, Table 3-3). The number of non-zero catches declined rapidly thereafter to 14,000 in 1993, then it has fluctuated in cycles between roughly 10,000 and 20,000. The figure was at a record low of 11,000 in 2022.

4. Stock Status

(1) Stock Assessment Methods

Number at age (NAA) and biomass at age (BAA) from 2000 to 20221 was estimated through VPA with tuning (cohort analysis) (Appendix 1, 2, and 3). Fishery catch statistics by fishery type (Table 3-2), catch length composition (for bottom trawling and gillnetting), and the age-length relationship and length-body weight relationship (Fig 2-2) were used for stock calculations. Natural mortality (M) was set to 0.28 based on the Tauchi-Tanaka formula (Tanaka 1960) and the lifespan of this species (9 years).

(2) Trends in Abundance Indices

The standardized CPUE for offshore trawlers, which was normalized by diving by the average, increased from 2003 (0.69) to 2009 (1.26), remaining flat with some fluctuation. In recent years, this value decreased from 2018 (1.06) to 2020 (0.95) before increasing slightly to 1.04 in 2022 (Fig. 4-1, Table 4-1, Appendix 9).

(3) Trends in Biomass and Fishing Pressure

Catch at age (CAA) is shown in Figure 4-2 and Table 2-1 in Appendix 2. Since 2000, the primary catch has consistently been mature fish age 4 and older, with fish age 4 to 6 accounting for 70% of the catch in number in recent years. Meanwhile, catch at age 3 has fluctuated greatly between 1% to 27% and was at 0.3% in 2022. In 2022, the ratio of fish age 5 was higher than a typical year at 45%. This is due to catches of the relatively strong 2017 cohort (Appendix 7).

Biomass increased from a record low in 2001 (6,000 tons) until 2005 (13,000 tons), then the figure fluctuated but gradually decreased, and subsequently increased again in 2016 and onwards (10,000 tons) (Fig. 4-3, Table 4-2, Appendix 3). Recently, biomass peaked in 2018 (12,000 tons) then decreased again, and was 11,000 tons in 2022. SSB followed a similar pattern to biomass, increasing from 2000 to 2005 before gradually decreasing. SSB was 6,035 tons in 2022. The exploitation rate reached a record low in 2003, and then increased to 2007 and 2011 (Fig. 4-3, Table 4-2). Exploitation rate was 31% in 2022, hit the highest value after 2012.

F values at age (FAA) are shown in Fig. 4-4 and Table 2-4 in Appendix 2. Fluctuations in F-values differed by age, with particularly high values for fish age 7 and older in 2007. F values for fish age 6 and older have also risen in 2022. Meanwhile, the F values for fish age 3 have been extremely low since 2000, with an average value of 0.04 up to 2021. The F value for fish age 4 peaked in 2016 and has been on a downward trend since.

(4) Trends in number of recruitments

Number of recruitment (number at age 3) reached a record high in 2003 (2.64 million) then remained around 2 million, with 2.53 million in 2009, 2.99 million in 2017, and 2.15 million in 2020. This is due to recruitment of age 3 fish from the strong 2006, 2014 and 2017 year-classes (Appendix 5). The value was 1.41 million in 2021. As mentioned earlier, the age 3 F value of this stock is extremely low, and recruitment for recent years has a high degree of uncertainty due to the nature of VPA based on backward stock calculation. The number of recruitments in the most recent year have therefore been estimated based on the spawner-recruitment relationship of this spawner-recruitment for 2022 was deemed to be 2.04 million according to projected values based on the hockey-stick model for spawner-recruitment relationships applied to this stock. Although recruitment surveys of the stock have suggested that abundance of the year-classes after 2018 has been at extremely low level, such a most recent stock status is not reflected to the results from the VPA because of the uncertainty of recruitments in the most recent years. We note that recruitment strength can be continuously at low level until at least 2022 year-class (recruitments as age 3 fish in 2025), regardless of the projected values based on the hockey-stick model

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

We compared the fishing pressures with consideration for selectivity at age, based on spawning per recruit (SPR) against a scenario without fishing pressure (Fig. 4-6). Lower fishing pressure means higher %SPR levels. The %SPR reached a record high in 2002 (39%), then decreased to a record low in 2011 (24%). %SPR has been kept around 30% and was 26% in 2022.

The current fishing pressure was shown on the basis of YPR and %SPR in Fig. 4-7. The current fishing pressure (F2022) and Fmsy are equivalent to 26% and 21% in SPR, respectively. The current fishing pressure is lower than the Fmsy or Fmax and close to the empirical reference point F30%SPR.

(5) Stock-Recruitment Relationship

The spawner-recruitment relationship, a relationship between SSB and number of recruitments is shown in Figure 4-8. Here, SSB is the values after the 2000 to 2017 fishing seasons, and recruitment is number at age 3 stock population at the start of the third year (2003 to 2020). The Research Institute Meeting mentioned previously has applied the hockey-stick model to the spawner-recruitment model for this stock (Sakuma et al. 2021). The data used to estimate the model parameters was based on SSB and number of recruitments reported in the FY 2020 stock assessment (Sakuma et al. 2021), and the optimization was done by the least squares method. In addition, autocorrelation in residuals of the recruitment was not considered. The parameters are shown in Supplementary Table 6-1.

(6) Levels Required for MSY Under Current Environmental Conditions

The Research Institute Meeting estimated the maximum sustainable yield (MSY) under the current environmental condition (since 2000) to be 2,900 tons and the SSB required for maintaining MSY (SBmsy) to be 5,200 tons (Supplementary Table 6-2).

(7) Stock Levels/Trends and Fishing Pressure Levels

Reference points for SSB and fishing pressure required for MSY are shown in a Kobe plot in Fig. 4-9. SSB in the 2021 fishing season was higher than the SSB required for maintaining MSY (SBmsy), specifically, SSB in the 2022 fishing season was 1.16 times higher than the value of SBmsy. In addition, the fishing pressure in the 2021 fishing season was 0.71 times lower than the fishing pressure required for MSY (Fmsy). The F ratio (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 (2018 to 2022), the SSB is judged to be in a “decreasing” trend. The SSB has been above SBmsy since 2003 and fishing pressure has been below FBmsy since 2000.

5. Summary of Stock Assessment

Biomass based on cohort analysis surged after record low in 2001 to reach a record high in 2005, then gradually decreased up to 2016. Afterwards, biomass temporarily increased, then decreased again in 2019, and was 11,000 tons in 2022. SSB followed a similar pattern to biomass, and reached a record high in 2005, and then gradually decreased until 2016. SSB was 6,035 tons in 2022. Biomass is high compared to the early 2000s, but as will be discussed later, the strength of the 2018 year-class and onwards has been at low level based on recruitment surveys (Appendix 7), and careful monitoring of stock status is recommended.

6. Additional Comments

Fishing of this stock primarily targets spawning individuals, and the catch of immature fish is fairly limited. The current fishing that targets mature fish should be maintained and the by-catch of immature fish should continue to be limited for sustainable fishery in future.

Catch is primary comprised of spawning fish in the stock and, estimating the year-class strength prior to recruitment (age 2 and less) hopefully improves precision of the future projection. Currently, local recruitment surveys are conducted by research vessels in each prefecture for this stock (Appendix 7), while a quantitative estimation of recruitment has not been achieved. Catch of the stock has as experienced drastic changes as well as the other cod stocks with significant population fluctuations (Fig. 3-1), but factors that lead to the fluctuations in the stock is still unclear. Continuing the current monitoring surveys and building models integrating environmental variables including water temperature and primary production will provide a recruitment index and a key to understand causes of the stock fluctuation.

Strength of the year-class 2012, 2014, and 2017 was high and, good recruitments have maintained high levels of biomass until recent years (Fig. 4-3 and 4-5). Meanwhile, the strength of the year-class 2018 and onwards was extremely low (Appendix 7) and, was to be recruited at age 3 in 2021, it is still not main target of the fishery. Recruitment of the year-class from 2019 onwards are also suggested to be at a low level based on the surveys, while it is not reflected to the future projections due to lack of integration of the results from various surveys. Therefore, there is concern about the future stock status regardless of the future projections based on the deterministic hockey-stick spawner-recruitment relationship, .

7. References

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State of Maturity Among Mature Pacific Cod and Distribution of Their Eggs and Larvae in the Area of Noto Island, Ishikawa Prefecture. Technical Reports of Japanese Sea Ranching Program, **21**, 21-30

Fig. 2-1. Distribution of the Honshu Northern Sea of Japan stock of Pacific cod

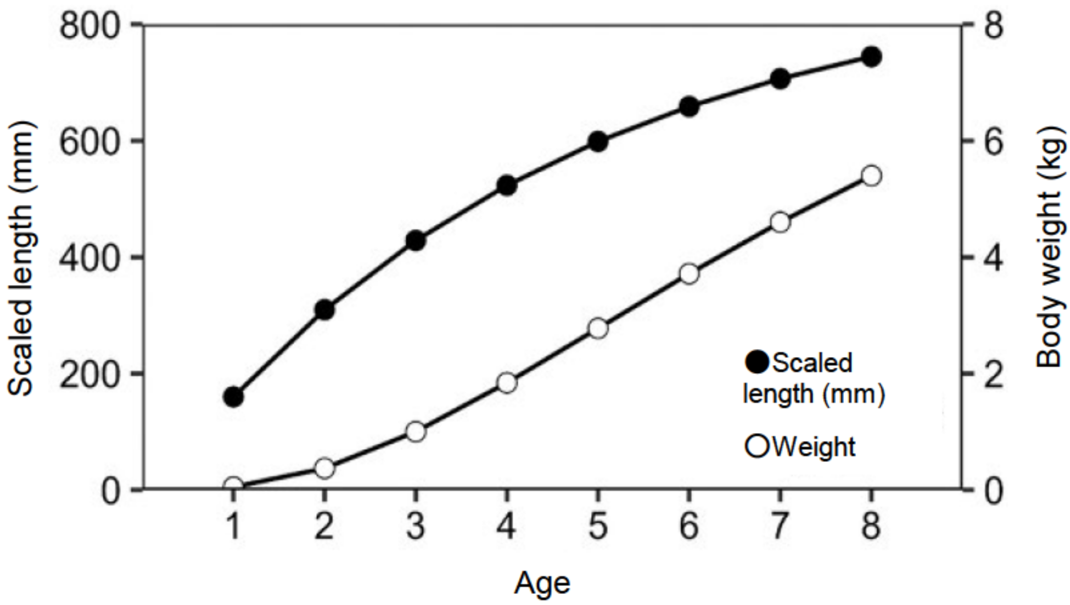


Fig. 2-2. Growth of Pacific cod in the Sea of Japan

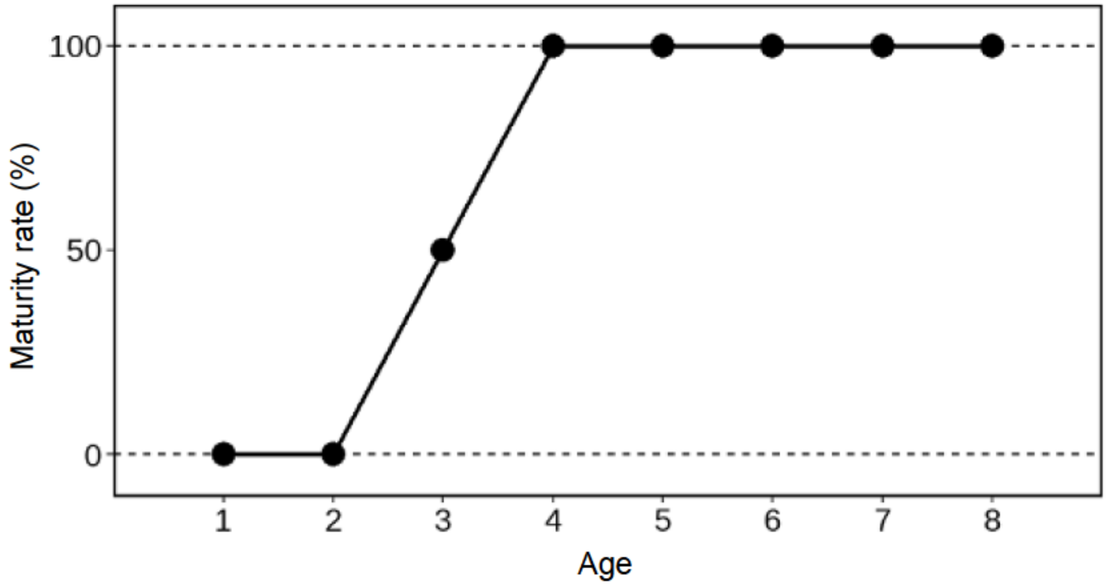


Fig. 2-3. Maturity at age in the Sea of Japan

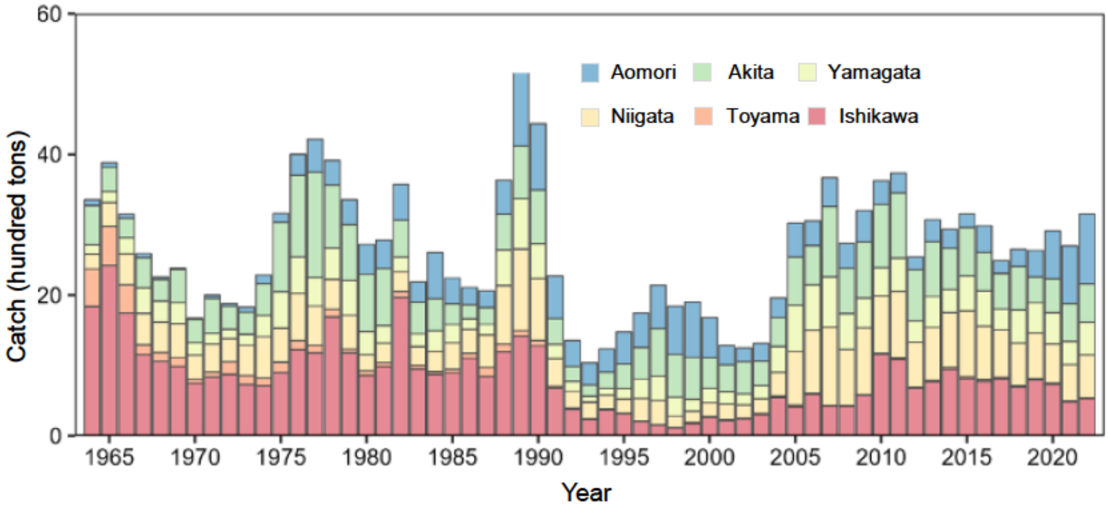


Fig. 3-1. Catch in weight by prefecture based on Annual Statistics of Fishery and Aquaculture Production (MAFF statistics) and prefectural statistics (by calendar year)

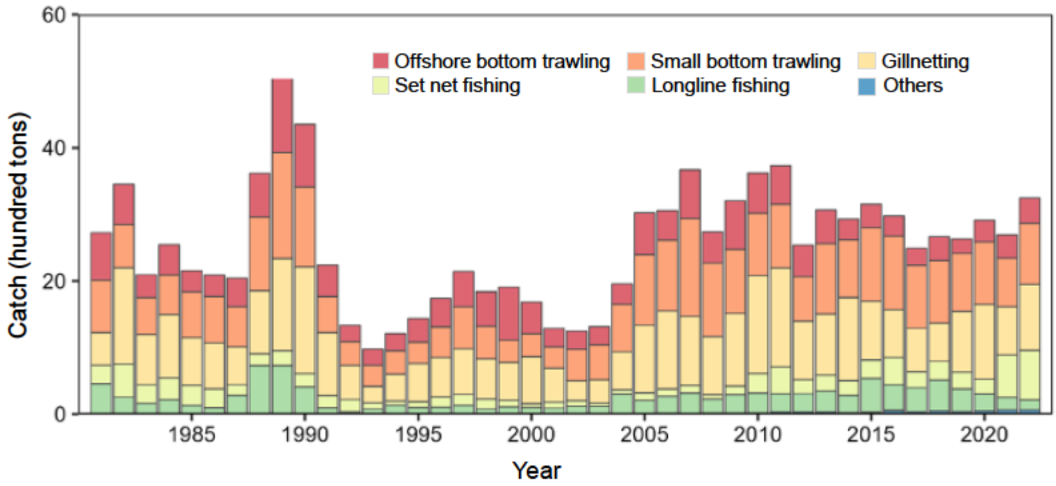


Fig. 3-2. Catch in weight by fishery type based on Annual Statistics of Fishery and Aquaculture Production and prefectural statistics (by calendar year)

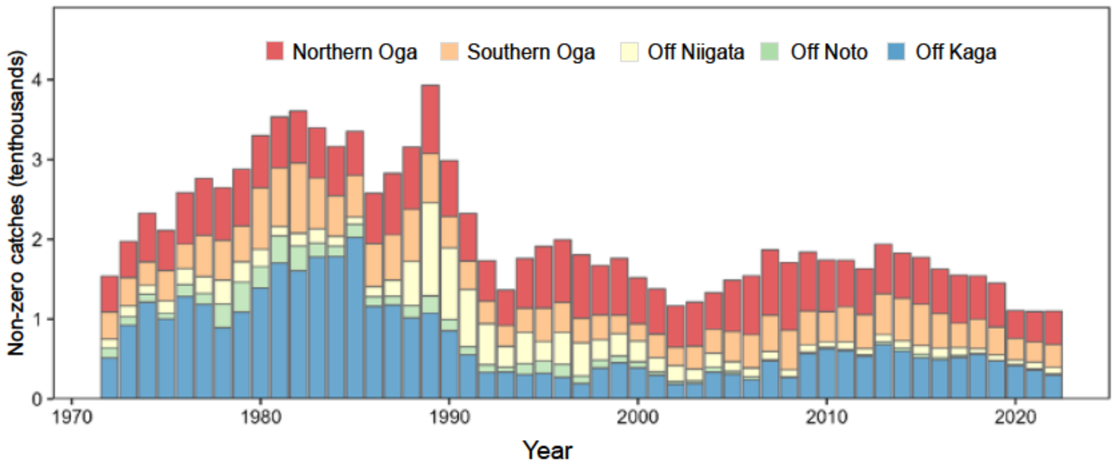


Fig. 3-3. Number of hauls by offshore trawlers with Pacific cod catch (Non-zero catches) by official fishing area based on official logbooks (ten thousands hauls)

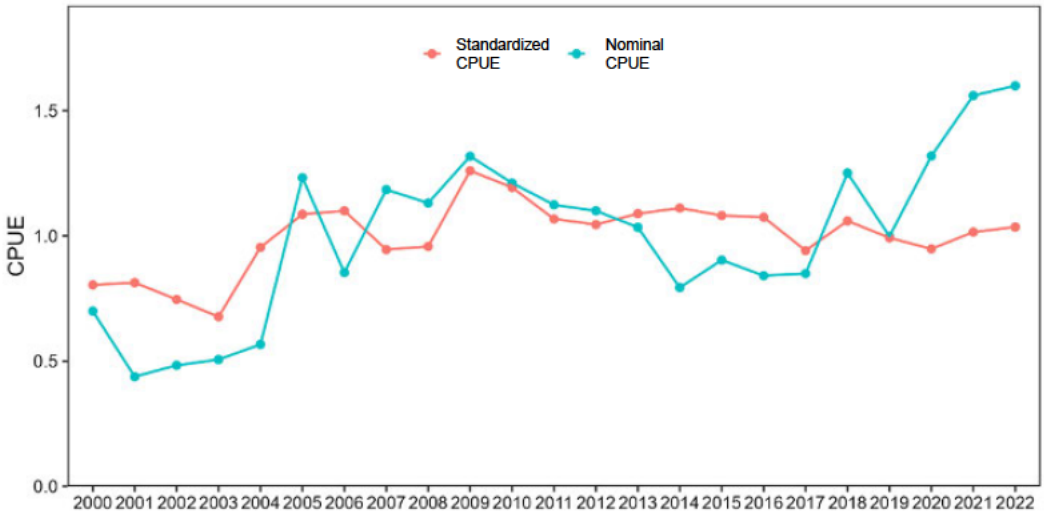


Fig. 4-1. Nominal CPUE (solid blue line), and standardized CPUE (solid red line) based on official logbooks for offshore trawl fisheries

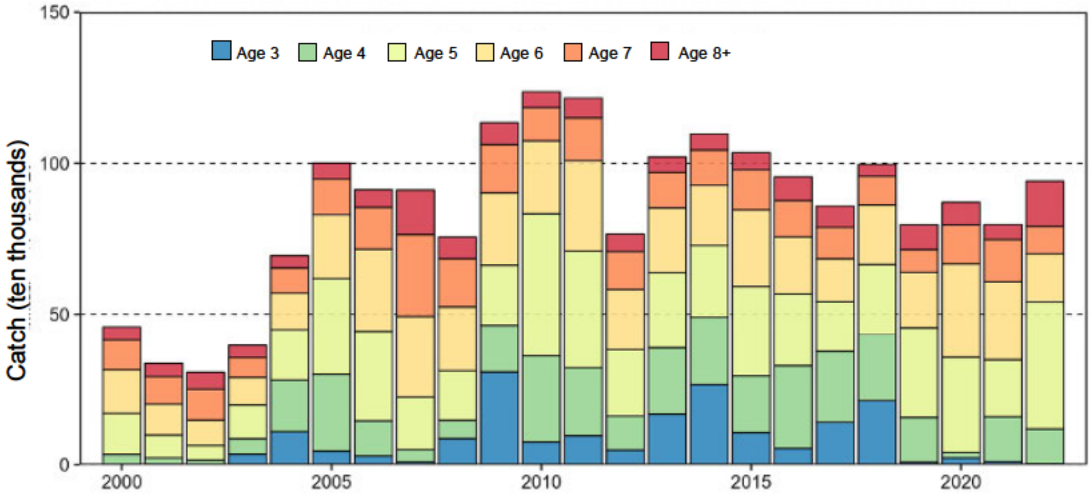


Fig. 4-2. Catch at age of the stock

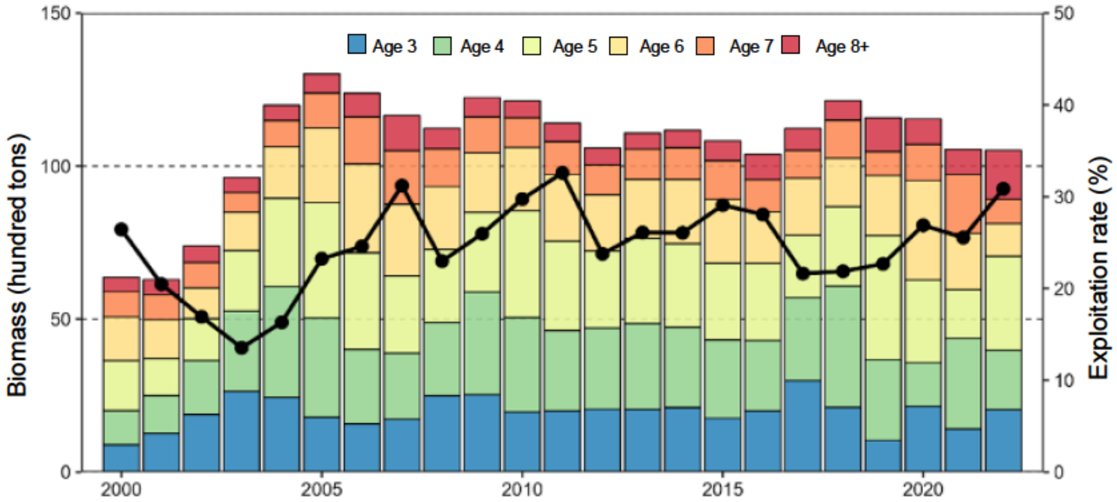


Fig. 4-3. Biomass at age (bar graph) and exploitation rate (line graph)

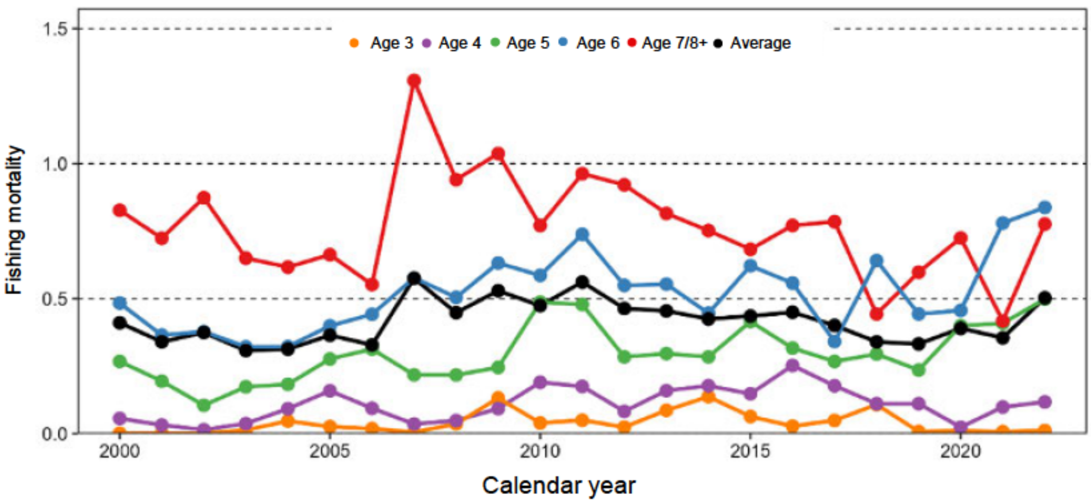


Fig. 4-4. Fishing mortality at age (F value)

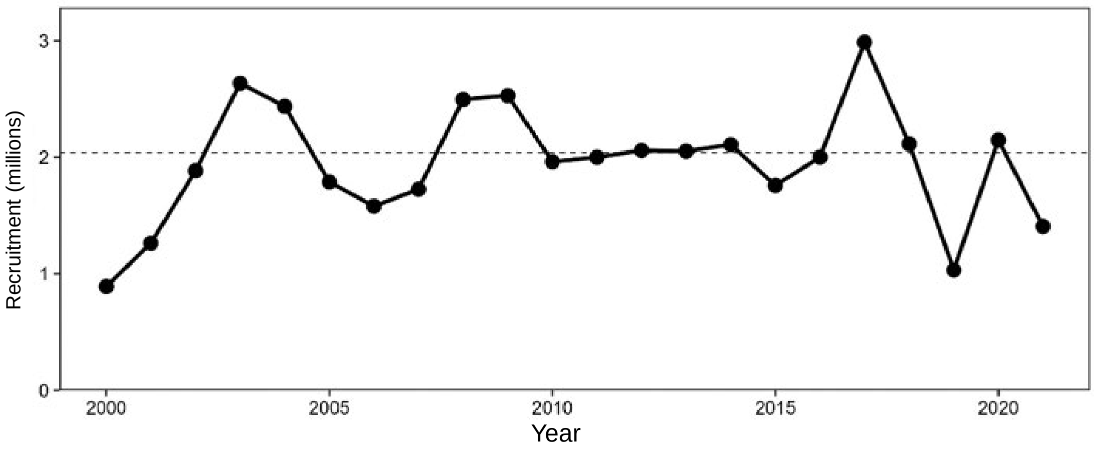


Fig. 4-5. Number of age 3 recruitment. The dashed line shows the mean values from the hockey-stick model for the spawner-recruitment relationship adopted at the Research Institute Meeting held in October 2021.

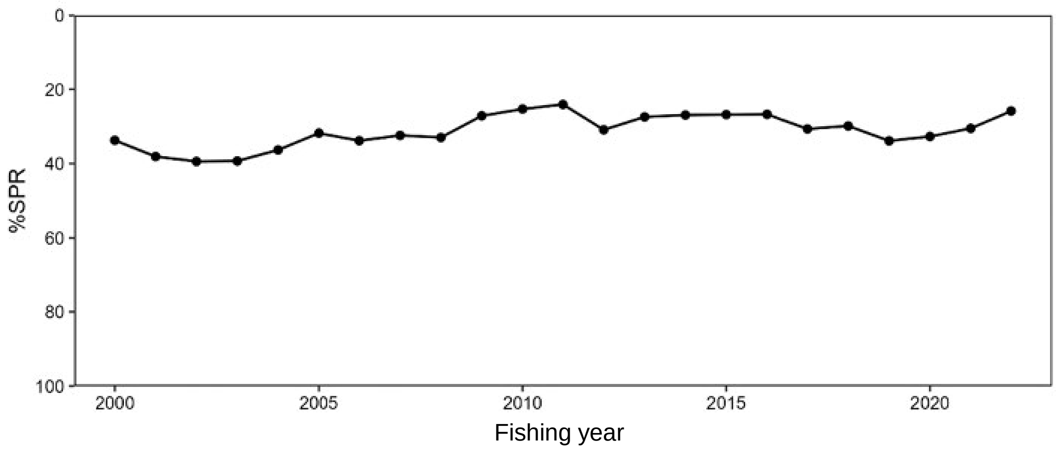


Fig. 4-6. Changes in %SPR, a ratio of SPR without fishing against SPR under fishing pressure for each year

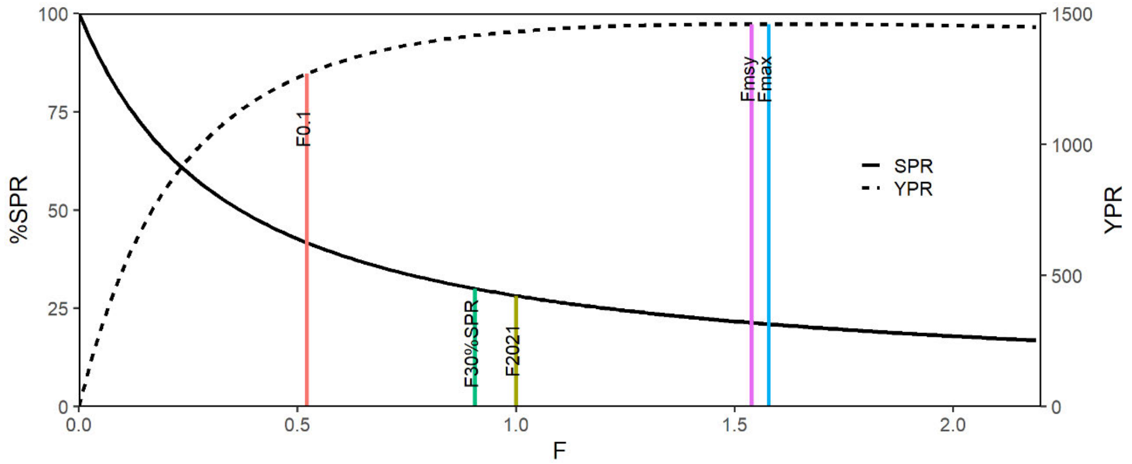


Fig. 4-7. Relationship between YPR and %SPR under various scenarios including current fishing pressure (F2022).

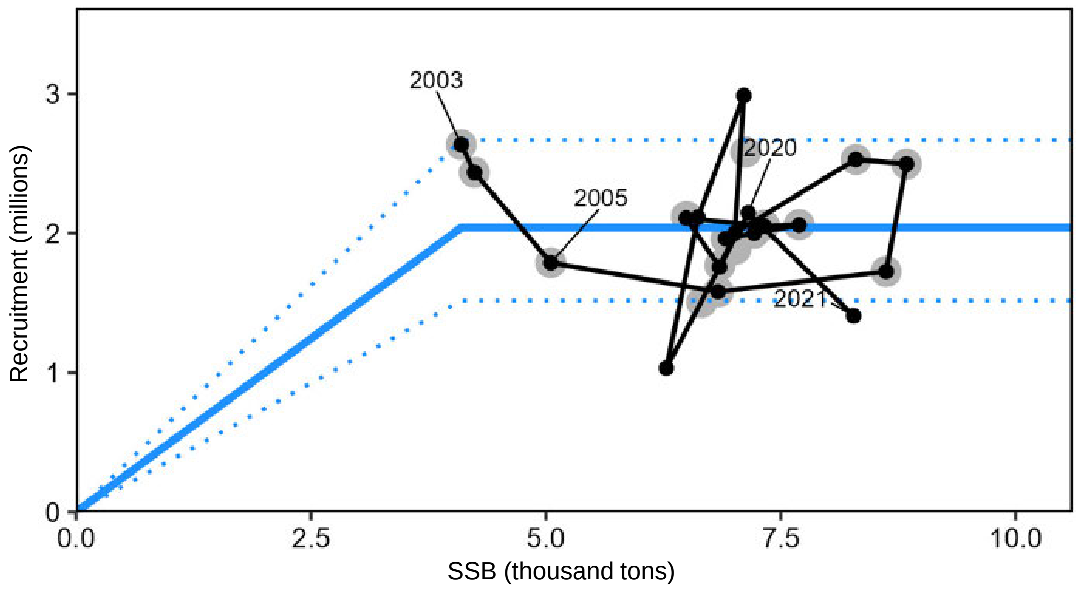


Fig. 4-8. Relationship between SSB and recruitment (spawner-recruitment relationship). The stock-recruitment relationship model was proposed at the Research Institute Meeting held in October 2020 (Sakuma et al. 2021). The blue solid and dashed lines indicate the median values of the approved hockey-stick model for spawner-recruitment, and the range of 90% prediction interval. The black and grey circles indicate SSB from 2000 to 2017 and corresponding recruitment from 2003 to 2020, based on this year's assessment and the dataset that used for estimating the model parameters. The numbers within the figure indicate years of recruitment at age 3.

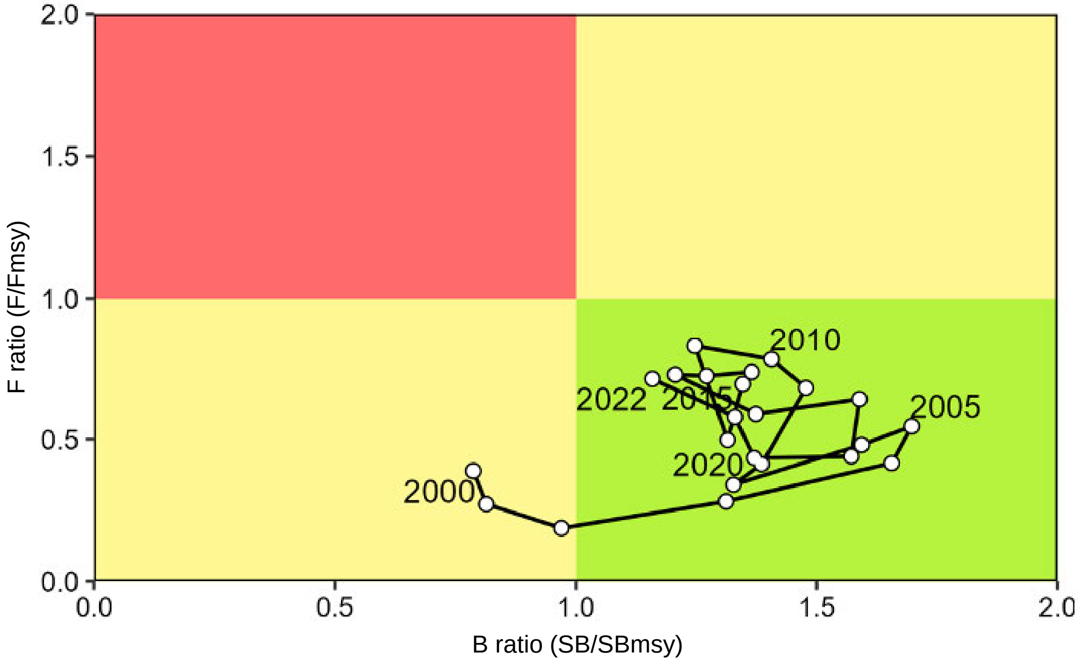


Fig. 4-9. Relationship of SSB required for maintaining MSY (SBmsy) and fishing pressure required for MSY (Fmsy) against previous levels of SSB and fishing pressure (Kobe plot)

Table 3-1. Catch by prefecture (tons)

Year	Sea of Japan stock							Western Sea of Japan *2	Total	South Korea
	Aomori*1	Akita	Yamagata	Niigata	Toyama	Ishikawa	Total			
1964	85	555	134	210	536	1,837	3,357	1,118	4,475	-
1965	63	347	158	337	557	2,421	3,883	619	4,502	2,252
1966	57	277	231	438	402	1,745	3,150	418	3,568	2,211
1967	58	428	364	444	141	1,154	2,589	274	2,863	2,286
1968	37	306	300	431	127	1,057	2,258	530	2,788	2,218
1969	19	471	301	479	126	988	2,384	1,132	3,516	3,279
1970	19	332	178	341	59	746	1,675	81	1,756	2,753
1971	45	497	154	398	70	835	1,999	38	2,037	2,571
1972	37	329	130	331	181	872	1,880	18	1,898	757
1973	73	313	155	432	126	730	1,829	119	1,948	717
1974	123	453	301	588	110	711	2,286	420	2,706	1,365
1975	128	989	515	483	148	900	3,163	273	3,436	1,653
1976	299	1,161	519	671	127	1,225	4,002	216	4,218	435
1977	468	1,498	407	558	108	1,178	4,217	229	4,446	1,456
1978	351	895	445	425	107	1,691	3,914	139	4,053	1,841
1979	355	790	500	482	50	1,180	3,357	251	3,608	1,883
1980	421	818	330	229	66	858	2,722	277	2,999	844
1981	407	811	250	276	55	985	2,784	468	3,252	3,646
1982	508	528	209	280	83	1,967	3,575	369	3,944	4,462
1983	289	451	182	266	51	950	2,189	185	2,374	3,784
1984	658	457	293	287	39	874	2,608	158	2,766	902
1985	368	291	261	377	50	895	2,242	113	2,355	2,996
1986	245	201	148	340	72	1,101	2,107	118	2,225	919
1987	240	238	150	464	127	843	2,062	207	2,269	839
1988	484	508	507	832	110	1,192	3,633	168	3,801	1,200
1989	1,055	750	715	1,159	80	1,415	5,174	183	5,357	3,020
1990	945	762	493	883	77	1,277	4,437	136	4,573	487
1991	603	368	202	397	29	672	2,271	57	2,328	665
1992	368	214	140	240	17	376	1,355	39	1,394	439
1993	314	161	85	235	9	234	1,038	27	1,065	481
1994	331	230	98	193	19	365	1,236	25	1,261	473
1995	456	350	149	198	12	312	1,477	29	1,506	273

Table 3-1. Catch by prefecture (tons) (continued)

Year	Sea of Japan stock							Western Sea of Japan *2	Total	South Korea
	Aomori*1	Akita	Yamagata	Niigata	Toyama	Ishikawa	Total			
1996	490	448	277	320	7	203	1,745	39	1,784	472
1997	617	674	344	347	4	154	2,140	29	2,169	481
1998	685	608	265	166	5	113	1,842	33	1,875	476
1999	790	596	171	156	19	174	1,906	31	1,937	894
2000	569	436	204	198	11	263	1,681	30	1,711	1,766
2001	275	384	174	222	12	217	1,284	34	1,318	2,458
2002	199	457	157	187	13	239	1,252	68	1,320	1,968
2003	252	348	188	203	24	299	1,314	101	1,415	1,826
2004	277	412	367	339	22	542	1,959	121	2,080	2,641
2005	484	684	655	766	27	408	3,024	156	3,180	4,272
2006	352	559	644	896	14	590	3,055	327	3,382	6,810
2007	410	998	717	1,112	8	424	3,669	381	4,050	7,533
2008	352	649	509	796	9	422	2,737	502	3,239	5,396
2009	447	799	422	949	8	578	3,203	491	3,694	6,870
2010	335	900	399	820	11	1,160	3,625	705	4,330	7,289
2011	285	926	473	944	22	1,086	3,736	1,076	4,812	8,585
2012	181	729	300	641	14	678	2,543	1,011	3,554	8,682
2013	312	779	441	755	15	769	3,071	844	3,915	9,134
2014	274	582	329	781	28	943	2,937	1,034	3,971	13,401
2015	195	686	498	935	28	813	3,155	1,289	4,444	7,821
2016	375	549	501	758	28	773	2,984	925	3,909	4,994
2017	184	504	293	679	25	805	2,490	670	3,160	6,475
2018	246	618	471	604	17	696	2,652	646	3,298	7,511
2019	380	364	432	650	17	794	2,637	594	3,231	9,520
2020	682	481	445	555	17	732	2,912	778	3,690	10,323
2021	822	539	328	515	14	483	2,701	595	3,296	9,095
2022*3	995	546	462	610	11	529	3,153	481	3,634	-

*1 South of Kodomari.

*2 Fukui–Shimane.

*3 Provisional values.

Table 3-2. Catch by fishery type (tons)

Year	Offshore bottom trawling	Small bottom trawling	Gillnetting	Set net fishing	Angler and longline fishing	Additional Comments	Total	Values from MAFF Statistics[*1]
1981	716	785	490	279	453	2	2,725	2,784
1982	607	647	1,448	500	250	1	3,453	3,575
1983	345	555	749	283	157	4	2,093	2,189
1984	456	594	950	328	217	0	2,545	2,608
1985	319	686	716	302	126	5	2,154	2,242
1986	324	696	691	282	95	2	2,090	2,107
1987	430	603	565	162	281	2	2,043	2,062
1988	658	1,106	948	175	729	1	3,617	3,633
1989	1,249	1,592	1,385	222	725	5	5,178	5,174
1990	943	1,200	1,603	198	409	0	4,353	4,437
1991	476	540	945	186	91	2	2,240	2,271
1992	245	356	510	184	37	1	1,333	1,355
1993	245	316	245	95	75	2	978	1,038
1994	260	351	402	63	133	2	1,211	1,236
1995	359	318	574	88	98	1	1,438	1,477
1996	429	457	593	157	100	2	1,738	1,745
1997	531	630	684	165	132	1	2,143	2,140
1998	519	490	604	149	76	1	1,839	1,842
1999	795	335	570	99	107	1	1,907	1,906
2000	474	346	705	56	100	1	1,682	1,681
2001	279	318	511	89	87	3	1,287	1,284
2002	278	472	299	84	115	2	1,250	1,252
2003	275	524	347	49	116	3	1,314	1,314
2004	309	709	574	64	296	5	1,957	1,959
2005	631	1,056	1,018	112	201	6	3,024	3,024
2006	445	1,062	1,172	109	256	12	3,056	3,055
2007	731	1,471	1,036	115	311	4	3,668	3,669
2008	470	1,103	874	64	210	16	2,737	2,737
2009	731	961	1,091	129	278	14	3,204	3,203
2010	606	936	1,472	293	298	17	3,622	3,625

Table 3-2. Catch by fishery type (tons) (continued)

Year	Offshore bottom trawling	Small bottom trawling	Gillnetting	Set net fishing	Angler and longline fishing	Additional Comments	Total	Values from MAFF Statistics[*1]
2011	578	957	1,486	401	273	35	3,730	3,736
2012	473	670	879	206	275	36	2,539	2,543
2013	505	1,059	916	239	313	34	3,066	3,071
2014	314	865	1,246	221	264	19	2,929	2,937
2015	355	1,103	883	276	505	31	3,153	3,155
2016	304	1,102	718	410	388	55	2,977	2,984
2017	259	944	654	236	362	37	2,492	2,490
2018	360	939	572	283	463	48	2,665	2,652
2019	217	872	911	253	340	38	2,631	2,637
2020	326	939	1,120	222	257	48	2,912	2,912
2021	352	728	722	642	186	63	2,693	2,701
2022[*2]	379	915	994	742	152	63	3,245	3,153

Based on the Annual Statistics of Agriculture, Forestry and Fisheries and the Annual Statistics of Fishery and Aquaculture Production for each prefecture.

*1 The difference between the total value and MAFF statistics is due to the difference between the hidden values in MAFF statistics and the values of prefectural statistics and MAFF statistics. Stock calculations used catch by fishery type.

*2 Provisional values.

Table 3-3. Number of hauls by offshore trawlers with Pacific cod catch (Non-zero catches) by official fishing area based on official logbooks (ten thousands hauls)

Year	Northern Oga	Southern Oga	Off Niigata	Off Noto	Off Kaga	Total
1972	4,494	3,376	1,088	1,279	5,139	15,376
1973	4,540	3,534	1,380	1,030	9,247	19,731
1974	6,109	2,914	1,098	1,033	12,119	23,273
1975	5,060	3,791	1,497	759	10,031	21,138
1976	6,440	3,058	2,008	1,496	12,844	25,846
1977	7,151	5,152	2,128	1,345	11,862	27,638
1978	6,610	4,973	2,997	2,954	8,932	26,466
1979	7,122	4,481	2,570	3,723	10,888	28,784
1980	6,559	7,698	2,186	2,646	13,920	33,009
1981	6,385	7,376	1,172	3,388	17,019	35,340
1982	6,555	8,792	1,570	3,119	16,058	36,094
1983	6,291	6,372	1,783	1,751	17,778	33,975
1984	6,157	5,092	1,211	1,321	17,842	31,623
1985	5,515	5,236	880	1,648	20,250	33,529
1986	6,323	5,405	1,244	1,206	11,609	25,787
1987	7,685	5,714	2,007	1,094	11,770	28,270
1988	7,806	6,541	5,538	1,525	10,159	31,569
1989	8,579	6,168	11,662	2,113	10,789	39,311
1990	7,011	3,925	8,998	1,403	8,535	29,872
1991	5,991	3,531	7,170	1,020	5,530	23,242
1992	5,079	2,830	5,134	963	3,309	17,315
1993	4,448	2,637	2,576	617	3,381	13,659
1994	6,247	3,009	3,931	1,355	3,062	17,604
1995	7,758	4,164	2,484	1,504	3,213	19,123
1996	7,860	3,776	3,998	1,611	2,709	19,954
1997	7,963	3,078	4,167	935	1,927	18,070
1998	6,198	3,107	2,555	1,004	3,855	16,719
1999	7,132	2,312	2,799	856	4,520	17,619
2000	5,800	2,149	2,591	764	3,889	15,193

Table 3-3. Number of hauls by offshore trawlers with Pacific cod catch (Non-zero catches) by official fishing area based on official logbooks (ten thousands hauls) (continued)

Year	Northern Oga	Southern Oga	Off Niigata	Off Noto	Off Kaga	Total
2001	5,681	2,950	1,770	409	2,984	13,794
2002	5,208	2,298	1,984	331	1,852	11,673
2003	5,524	2,877	1,462	346	1,926	12,135
2004	4,580	3,005	1,773	587	3,363	13,308
2005	6,440	3,781	1,189	387	3,085	14,882
2006	7,355	4,189	1,134	352	2,392	15,422
2007	8,220	4,545	1,032	161	4,742	18,700
2008	8,499	4,940	900	87	2,686	17,112
2009	7,398	4,221	969	140	5,674	18,402
2010	6,480	3,751	726	198	6,252	17,407
2011	5,813	4,408	968	188	6,001	17,378
2012	5,778	4,253	776	195	5,340	16,342
2013	6,220	5,100	966	311	6,795	19,392
2014	5,682	5,314	929	372	5,986	18,283
2015	5,852	5,211	1,063	461	5,151	17,738
2016	5,580	4,319	1,138	323	4,917	16,277
2017	6,019	3,053	999	271	5,167	15,509
2018	5,405	3,700	614	117	5,577	15,413
2019	5,514	3,503	679	77	4,749	14,522
2020	3,488	2,700	606	125	4,160	11,079
2021	3,819	2,546	853	172	3,577	10,967
2022	4,162	2,893	812	149	2,983	10,999

Table 4-1. Standardized CPUE based on official logbooks for offshore trawl fisheries

Year	Standardized CPUE
2000	0.80
2001	0.81
2002	0.75
2003	0.68
2004	0.95
2005	1.09
2006	1.10
2007	0.95
2008	0.96
2009	1.26
2010	1.19
2011	1.07
2012	1.05
2013	1.09
2014	1.11
2015	1.08
2016	1.07
2017	0.94
2018	1.06
2019	0.99
2020	0.95
2021	1.02
2022	1.04

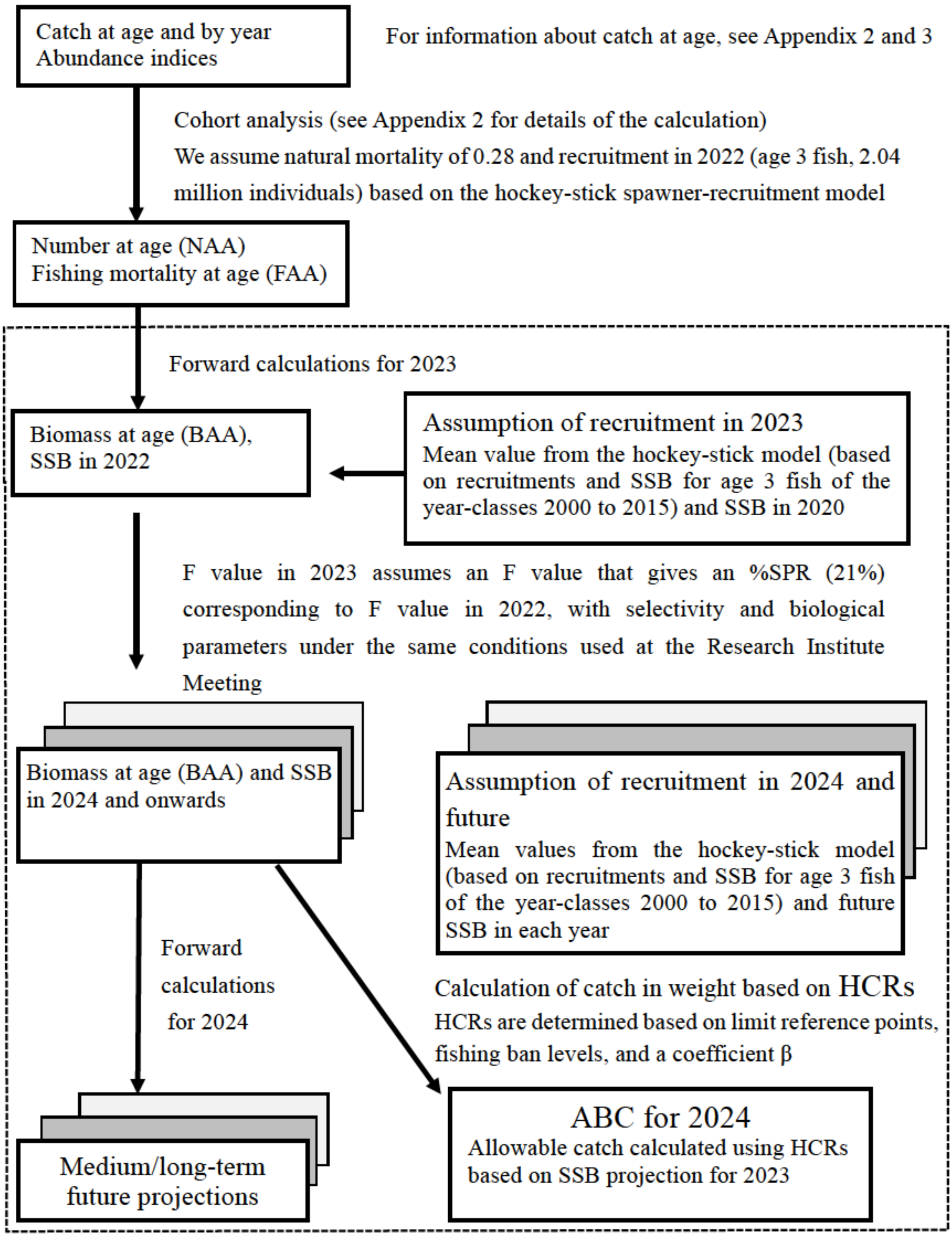
Table 4-2. Results of the stock calculation

Year	Catch*1 (tons)	Biomass (tons)	SSB*2 (tons)	Recruitment (age 3, ten thousands)	Exploitation rate (%)	F/Fmsy	%SPR
2000	1,682	6,362	4,100	89	26	0.39	34
2001	1,287	6,288	4,241	126	20	0.27	38
2002	1,250	7,392	5,053	188	17	0.19	39
2003	1,314	9,626	6,832	264	14	0.28	39
2004	1,957	11,989	8,622	244	16	0.42	36
2005	3,024	13,012	8,839	179	23	0.55	32
2006	3,056	12,383	8,298	158	25	0.48	34
2007	3,668	11,655	6,913	173	31	0.34	32
2008	2,737	11,231	7,217	250	23	0.41	33
2009	3,204	12,235	7,696	253	26	0.68	27
2010	3,622	12,129	7,324	196	30	0.78	25
2011	3,730	11,401	6,495	200	33	0.83	24
2012	2,539	10,590	6,848	206	24	0.50	31
2013	3,066	11,078	7,013	205	26	0.69	27
2014	2,929	11,174	7,108	211	26	0.74	27
2015	3,153	10,823	6,621	176	29	0.72	27
2016	2,977	10,384	6,282	200	28	0.73	27
2017	2,492	11,230	7,155	299	22	0.59	31
2018	2,665	12,135	8,275	211	22	0.64	30
2019	2,631	11,576	8,185	103	23	0.44	34
2020	2,912	11,540	7,135	215	27	0.43	33
2021	2,693	10,546	6,929	141	26	0.58	31
2022	3,245	10,516	6,035	204	31	0.71	26

*1 Total catch by fishery type.

*2 The value of SSB of this stock is for after the fishing season.

Appendix 1 Flow of Stock Assessment



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

Appendix 2 Stock Calculation Methods

1) Catch at age

The catch at age for the Sea of Japan stock of Pacific cod was obtained from catch statistics by fishery type (by calendar year) and body length composition of catches. The catch at age for bottom trawling and gillnetting from Aomori to Toyama prefectures and for all fishery types in Ishikawa prefecture were calculated by obtaining the body length composition of catches based on length measurement data from each fishery type (gillnetting: Aomori Prefectural Industrial Technology Research Center Fisheries Institute; Bottom trawling: Yamagata prefecture Fisheries Experiment Station; all fisheries in Ishikawa prefecture: Ishikawa Prefecture Fisheries Research Center). We then obtained the age composition and average body weight using the age-body weight and length-body weight relationships. Subsequently, we calculated catch at age for each fishery type based on the proportions of age composition and catch in number dividing the catch in weight by the average body weight . For other fisheries from Aomori to Toyama prefectures (set net fishing, longline fishing, angler fishing, etc.), the catch in weight was allocated evenly to bottom trawling and gillnetting, which was added to the catch in number at age. No measurement data was available for gillnetting from 2000 to 2004, so this figure was obtained by multiplying the length composition ratio from bottom trawling and gillnetting (average from 2005 to 2014) by bottom trawl composition.

2) Stock calculation

Number at age (NAA), biomass at age (BAA), exploitation rate, and F at age (FAA) were obtained using VPA with tuning (cohort analysis). Age composition was age 3 to 7, with age 8 and older as the plus group (8+), using January 1 as the starting point of the analysis. Pope’s approximation formula (1972) was used and the date of age and catch was set to February 1 based on the life history of the Pacific cod and the characteristics of the fishing industry. The Hiramatsu method (1999) was used to calculate NAA (thus other statistics) of the plus group. The catch at age and average body weight at age were used for calculation, and natural mortality (M) was set to 0.28 using the method of Takeuchi and Tanaka (Tanaka 1960) and the life span of this species (9 years).

NAA for each year ($N_{a,y}$) was calculated using equation (1).

$$N_{a,y} = N_{a+1,y+1}\exp(M) + C_{a,y}\exp\left(\frac{M}{12}\right) \quad (1)$$

In these equations, $N_{a,y}$ is the number of fish age *a* in year *y*, and $C_{a,y}$ is the catch of fish age *a* in year *y*, and M is natural mortality. The number at age 7 ($N_{7,y}$) and age 8 and older ($N_{8+,y}$) were obtained using the equations (2) and (3) below.

$$N_{7,y} = \frac{C_{7,y}}{C_{7,y}+C_{8+,y}} N_{8+,y+1}\exp(M) + C_{7,y}\exp\left(\frac{M}{12}\right) \quad (2)$$

$$N_{8+,y} = \frac{C_{8+,y}}{C_{7,y}+C_{8+,y}} N_{8+,y+1} \exp(M) + C_{8+,y} \exp\left(\frac{M}{12}\right) \tag{3}$$

The number at age 4 ($N_{a,y}$) in the most recent year was obtained through equation (4) using the FAA in the most recent year, while the number at age 3 was set to 2.04 million, which is the projected value based on the hockey-stick model adopted as the spawner-recruitment relationship for this stock at the Research Institute Meeting, in consideration of the uncertainty due to the nature of VPA using regression methods.

$$N_{a,y} = \frac{C_{a,y} \exp\left(\frac{M}{12}\right)}{1-\exp\left(-F_{a,y}\right)} \tag{4}$$

The FAA for each year excluding the most recent year ($F_{a,y}$,) was obtained using equation (5). The F at age 7 and 8+ were assumed to be equal.

$$F_{a,y} = -\ln\left(1 - \frac{C_{a,y} \exp\left(\frac{M}{12}\right)}{N_{a,y}} \right) \tag{5}$$

The SSB in each year (SSB_y,) was obtained using equation (6) as the value as of February 1 after the fishing season (Supplementary Table 2-5, Appendix 2).

$$SSB_y = \sum_{a=3}^{8+} \left(N_{a,y} \exp\left(-\frac{M}{12}\right) - C_{a,y} \right) m_a w_a \tag{6}$$

In this equation, m_a is the maturity rate at age a and w_a is the weight at age a.

In tuning, the sum of square residuals (SS) for biomass and the abundance index was obtained using equations (7) and (8), and we searched for the F at age 8+ in the most recent year that would minimize SS. The standardized CPUE for offshore bottom trawling was used as the abundance index (details listed in Supplementary Fig. 2-1, Appendix 7, and the attached explanatory document (FRA-SA2022-RC04-102)). The tuning period was set from 2004 to 2022 based on the assessment of the previous fiscal year.

$$SS = \left(I_y - q_i B_y \right)^2 \tag{7}$$

$$\widehat{q_i} = \frac{\sum_y I_y B_y}{\sum_y {B_y}^2} \tag{8}$$

In this equation, B_y is the biomass as of January 1 of year y, and I_y is the abundance index for year y. The F values for age 3 to 6 were obtained using equation (9) based on average selectivity for the past three years.

$$F_{a,y} = \frac{1}{3} \left(\frac{F_{a,y-1}}{F_{8+,y-1}} + \frac{F_{a,y-2}}{F_{8+,y-2}} + \frac{F_{a,y-3}}{F_{8+,y-3}} \right) F_{8+,y} \tag{9}$$

Standardized CPUE for offshore trawling in the Sea of Japan (FRA-SA2023-RC04-102) was used for the tuning index. In this stock, the CPUE of gillnetting in Aomori, Akita, and Ishikawa prefectures was also used as tuning indices until 2019; however, significant retrospective bias was observed when using these non-standardized CPUEs as indices, and we ceased using these indices in 2020. The results of the retrospective analysis for this year are shown in Supplementary Fig. 2-2.

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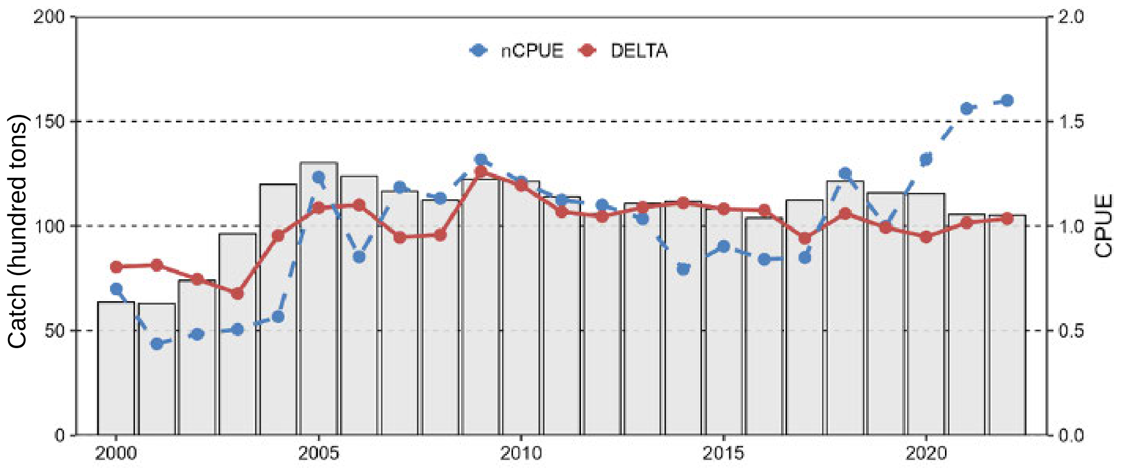
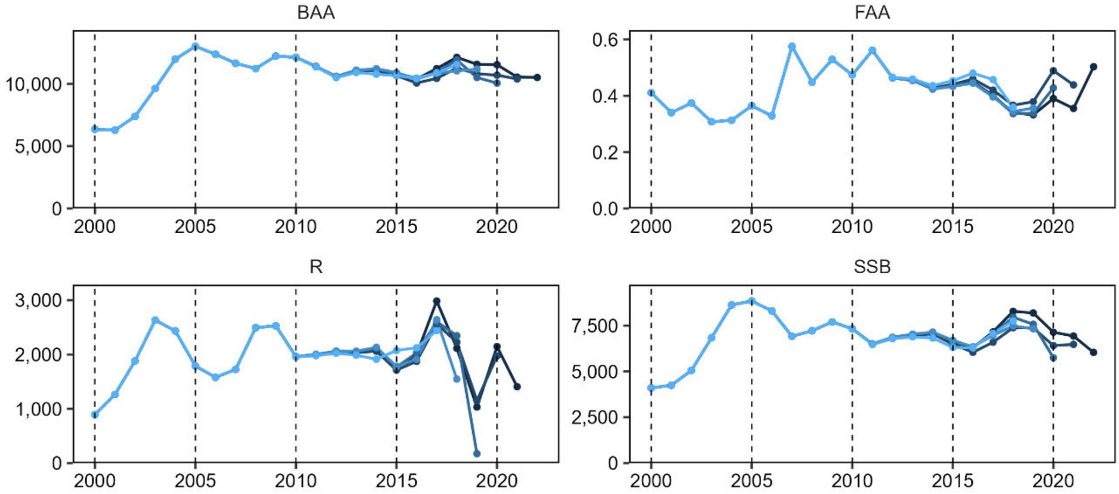
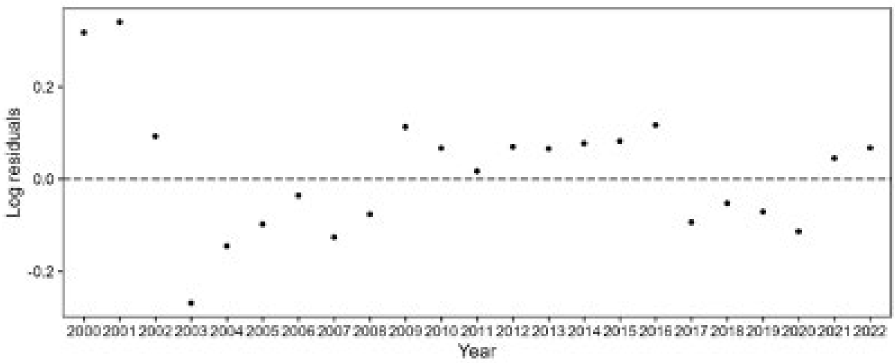


Supplementary Fig. 2-1. Trends in the total biomass (bar graph), standardized CPUE (red solid line), and nominal CPUE (blue dashed line) in offshore bottom trawl fishing. CPUEs were normalized by dividing them by the average of all years.



Supplementary Fig. 2-2. Trends in biomass (BAA), average F value for all ages (FAA), recruitment at age 3 (R), and spawning stock biomass (SSB) obtained from a retrospective analysis. The years prior to the most recent year is shown for R because the projected value (2.04 million) based on the hockey stick model was used for recruitment at age 3 in the most recent year.



Supplementary Fig. 2-3.Log residuals for the tuning VPA, between the model and empirical biomass.

Supplementary Table 2-1. Catch at age (CAA, thousand individuals)

Age	Year 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3	1	2	2	35	109	45	28	9	86	305	75	95	48	166	264
4	32	21	14	51	170	253	116	40	60	158	284	224	112	219	226
5	135	75	48	111	170	321	299	174	164	199	474	391	220	252	238
6	144	102	83	91	122	211	273	270	215	239	241	299	204	215	199
7	98	91	102	66	83	118	138	271	160	160	111	142	125	118	116
8+	46	44	56	41	41	53	59	148	72	72	52	66	58	51	54

Age	Year 2015	2016	2017	2018	2019	2020	2021	2022
3	106	54	140	211	8	22	10	3
4	187	272	234	221	147	18	148	115
5	300	241	169	233	300	314	188	423
6	254	189	142	197	184	313	262	160
7	133	120	104	95	75	129	140	91
8+	57	79	70	40	82	75	50	149

Supplementary Table 2-2. Number at age (NAA, thousand individuals)

Age	Year 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3	891	1,263	1,883	2,635	2,436	1,788	1,580	1,725	2,495	2,528	1,961	1,999	2,059	2,052	2,108
4	607	674	955	1,425	1,969	1,761	1,319	1,175	1,300	1,824	1,678	1,428	1,441	1,522	1,425
5	588	434	495	713	1,040	1,360	1,138	910	858	938	1,259	1,051	908	1,005	983
6	385	341	271	337	454	656	781	630	554	523	556	586	493	518	566
7	179	180	179	141	185	249	333	380	268	253	211	234	212	216	225
8+	85	87	98	88	90	113	141	207	120	115	99	108	99	94	104

Age	Year 2015	2016	2017	2018	2019	2020	2021	2022
3	1,757	2,000	2,987	2,115	1,032	2,147	1,407	2,040
4	1,392	1,249	1,473	2,154	1,438	775	1,609	1,058
5	904	910	735	935	1,460	975	574	1,104
6	560	452	502	426	527	874	495	289
7	274	228	196	270	170	256	419	172
8+	118	150	132	113	187	149	149	283

Supplementary Table 2-3. Biomass at age (BAA, tons)

Age	Year 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3	892	1,264	1,885	2,636	2,437	1,789	1,581	1,726	2,497	2,530	1,963	2,001	2,060	2,053	2,109
4	1,116	1,240	1,758	2,624	3,624	3,240	2,428	2,162	2,392	3,356	3,089	2,628	2,651	2,802	2,624
5	1,631	1,205	1,373	1,979	2,887	3,774	3,158	2,525	2,383	2,603	3,494	2,918	2,520	2,789	2,729
6	1,430	1,266	1,006	1,253	1,686	2,438	2,901	2,341	2,059	1,944	2,065	2,176	1,833	1,923	2,102
7	823	827	824	647	852	1,146	1,534	1,749	1,233	1,166	970	1,078	975	993	1,037
8+	469	485	547	488	502	625	781	1,152	667	636	549	601	550	519	575
Total	6,362	6,288	7,392	9,626	11,989	13,012	12,383	11,655	11,231	12,235	12,129	11,401	10,590	11,078	11,174

Age	Year 2015	2016	2017	2018	2019	2020	2021	2022
3	1,759	2,002	2,988	2,116	1,033	2,148	1,408	2,041
4	2,562	2,300	2,712	3,964	2,647	1,427	2,961	1,947
5	2,510	2,525	2,041	2,595	4,053	2,706	1,592	3,064
6	2,082	1,680	1,865	1,583	1,959	3,246	1,840	1,072
7	1,262	1,049	902	1,243	782	1,180	1,929	791
8+	649	830	722	634	1,102	833	817	1,600
Total	10,823	10,384	11,230	12,135	11,576	11,540	10,546	10,516

Supplementary Table 2-4. F value at age (FAA)

Age	Year 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3	0.002	0.002	0.001	0.014	0.047	0.026	0.019	0.005	0.036	0.132	0.040	0.050	0.024	0.087	0.137
4	0.056	0.032	0.015	0.037	0.092	0.159	0.094	0.036	0.049	0.093	0.190	0.175	0.083	0.159	0.177
5	0.268	0.195	0.105	0.174	0.183	0.277	0.313	0.218	0.217	0.245	0.487	0.478	0.284	0.297	0.284
6	0.483	0.365	0.378	0.321	0.322	0.399	0.442	0.577	0.505	0.632	0.586	0.738	0.549	0.554	0.446
7	0.827	0.724	0.874	0.650	0.617	0.663	0.552	1.308	0.941	1.037	0.771	0.963	0.921	0.816	0.752
8+	0.827	0.724	0.874	0.650	0.617	0.663	0.552	1.308	0.941	1.037	0.771	0.963	0.921	0.816	0.752
Average	0.411	0.340	0.375	0.308	0.313	0.365	0.329	0.575	0.448	0.529	0.474	0.561	0.464	0.455	0.425

Age	Year 2015	2016	2017	2018	2019	2020	2021	2022
3	0.063	0.028	0.049	0.108	0.008	0.011	0.007	0.012
4	0.148	0.252	0.177	0.111	0.111	0.024	0.099	0.118
5	0.415	0.317	0.268	0.295	0.236	0.400	0.409	0.498
6	0.622	0.558	0.341	0.641	0.443	0.456	0.780	0.838
7	0.683	0.771	0.785	0.443	0.598	0.725	0.418	0.776
8+	0.683	0.771	0.785	0.443	0.598	0.725	0.418	0.776
Average	0.436	0.450	0.401	0.340	0.332	0.390	0.355	0.503

Supplementary Table 2-5. Spawning stock biomass (SSB, tons)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SSB	4,100	4,241	5,053	6,832	8,622	8,839	8,298	6,913	7,217	7,696	7,324	6,495	6,848	7,013	7,108

2015	2016	2017	2018	2019	2020	2021	2022
6,621	6,282	7,155	8,275	8,185	7,135	6,929	6,035

Appendix 3 Proposed Reference Points and Proposed Fishing Ban Level

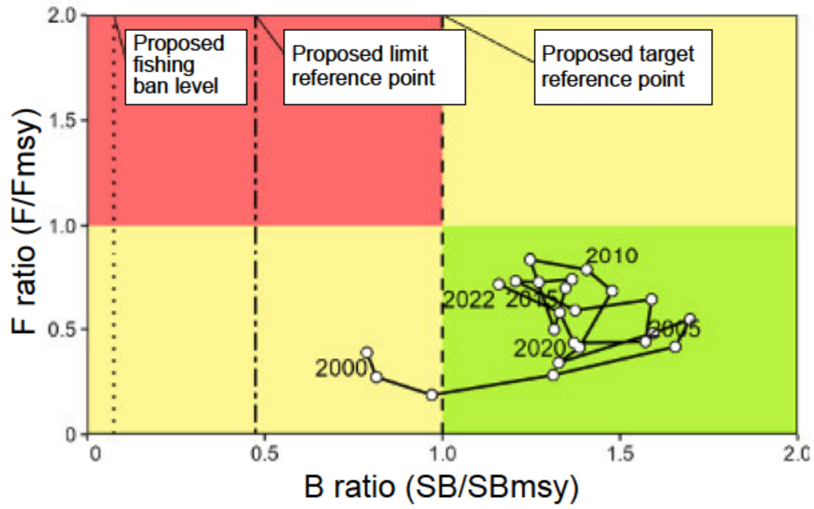
The Research Institute Meeting held in October 2021 proposed adoption of the following: SSB required for MSY (SBmsy: 5,200 tons) as a target reference point (SBtarget), SSB required for 60% MSY (SB0.6msy: 2,500 tons) as a limit reference point (SBlimit), and SSB required for 10% MSY (SB0.1msy: 400 tons) as a fishing ban level (SBban) (Sakuma et al. 2021, Supplementary Table 6-2). The parameters used to estimate these proposed reference points are shown in Supplementary Table 4-1.

The proposed target reference points and fishing pressure (F) required for MSY are shown in the Kobe plot in Supplementary Figure 3-1. SSB in 2022 (SB2022: 6,000 tons) obtained from cohort analysis is above the proposed target reference points, the proposed limit reference points, and the proposed fishing ban level. Fishing pressure of this stock since 2003 was judged to be well below the fishing pressure required for MSY.

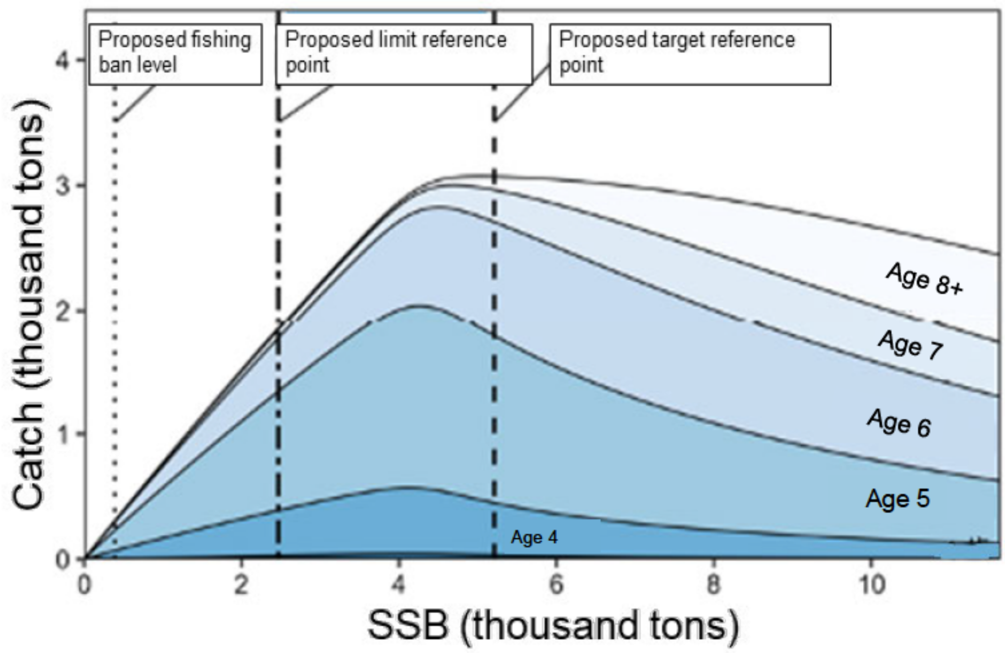
The relationship of average SSB and average CAA at equilibrium is shown in Supplementary Fig. 3-2. In case where SSB is above the target reference point, proportion of fish age 8+ tend to increase and fish age 4 to decrease.

References

Sakuma, K., Fujiwara, K., Yagi, Y., Yoshikawa, A., Iida, M., Shirakawa, H. (2021) Materials for the Research Institute Meeting on Reference Points of Honshu Northern Sea of Japan Stock of Pacific Cod (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-27. FRA-SA2021-BRP-12-1.



Supplementary Fig. 3-1. Relationship of SSB required for MSY (SBmsy) and fishing pressure required for MSY (Fmsy) against previous levels of SSB and fishing pressure (Kobe plot)



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

Appendix 4 Future Projections Based on Proposed HCRs

(1) Assumptions in Future Projections

Future projection was performed for the 2023 to 2033 fishing seasons using a progression method applied to BAA in 2022 (Appendix 5). We assumed recruitment in future by using the SSB with a lag of three years and the spawner-recruitment relationship. Calculations were iterated 10,000 times assuming errors following log-normal distribution to account for uncertainty in recruitment.

Catch in weight in the 2023 was estimated based on forecasted BAA and current fishing pressure (F2022). Here, the current fishing pressure is the F value in 2022 in this assessment, under the same selectivity and biological parameters (average body weight, etc.) in 2022. Fishing pressure in 2023 and onwards was set as the fishing pressure established in the following proposed HCRs, which are based on SSB projections for each year. For details about future projections including calculation and formulation are available in Appendix 5.

(2) Proposed HCRs

Proposed HCRs guidelines set fishing pressure (F) and other factors that correspond to SSB in consideration of the probability of both maintaining and recovering SSB higher than proposed target reference points. The Harvest Control Rules and Basic Guidelines for ABC Calculation proposed linear reduction of fishing pressure down to the proposed fishing ban level in case where SSB depletes below the proposed limit reference point. Otherwise, an upper limit for fishing pressure equal to Fmsy multiplied by a coefficient β is proposed when SSB is above the limit reference point. The SSB in this stock is the value after the end of the fishing season, and thus the SSB referred to in the HCRs is the value from the previous year. Supplementary Figure 4-1 shows the proposed HCRs from the Research Institute Meeting for this stock. This figure includes an example showing when the coefficient β is set to 0.8.

(3) Projected Values for 2024

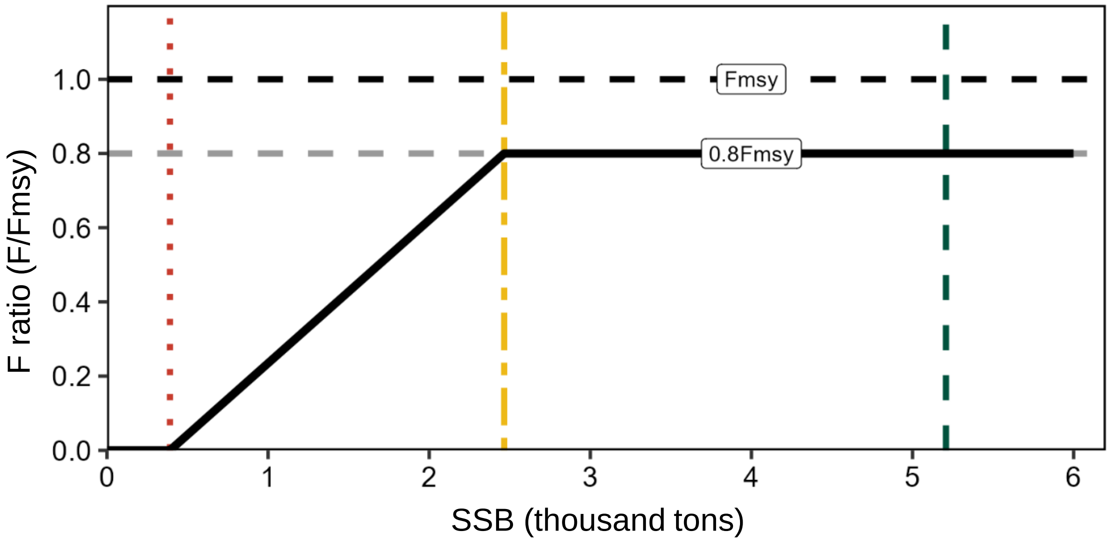
The average catch in weight for 2024 estimated based on the HCRs was 3,000 tons when β was set to 0.8 (Supplementary Table 4-3 and 6-4). The SSB projected for 2023 was 6,000 tons and well above the limit reference point, thus fishing pressure for 2024 was obtained by multiplying β by Fmsy.

(4) Projections for 2026 and Onwards

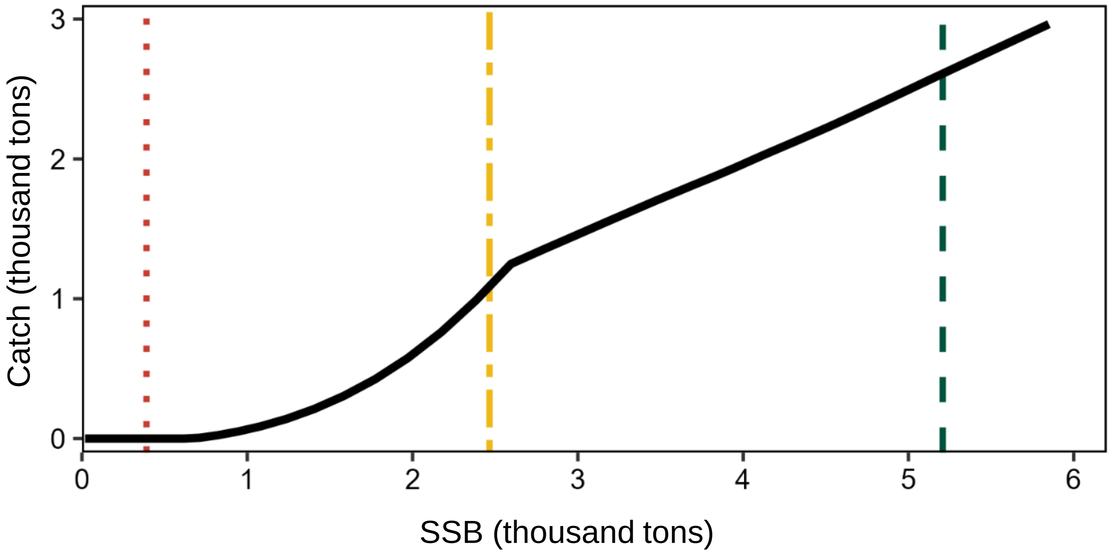
The results of future projections, including those for 2025 and after, are shown in Supplementary Fig. 4-2, Supplementary Table 4-1, 4-2 and 4-3. In this stock, the HCRs refer to the SSB after the end of the fishing season in the previous year, meaning that the SSB to be referenced in 2024, the first year of the start of harvest control, is the value for 2023 (year 0). If management based on these proposed HCRs is continued for 10 years, then projected values for average SSB in 2033 will be 6,000 tons if β is set to 0.95 or less (90% prediction interval: 5,100 to 6,900 tons), and there is a 50% probability that it will exceed the target reference point. Moreover, if current fishing pressure (F2022) continues, the average SSB for 2033 will be 6,400 tons (90% prediction interval: 5,500 to

7,400 tons), which has a 100% probability of exceeding the target reference point. The strength of the year-class 2018 and onwards was suggested to be extremely low based on the recruitment surveys (Appendix 7). The situation is, however, not reflected due to uncertainty in the number of juvenile fish that stems from low exploitation rate, because main target of the fisheries is mature individuals in the stock. There is concern about the future stock status regardless of the future projections based on the deterministic hockey-stick model.

a) When the vertical axis is ratio of fishing pressure.

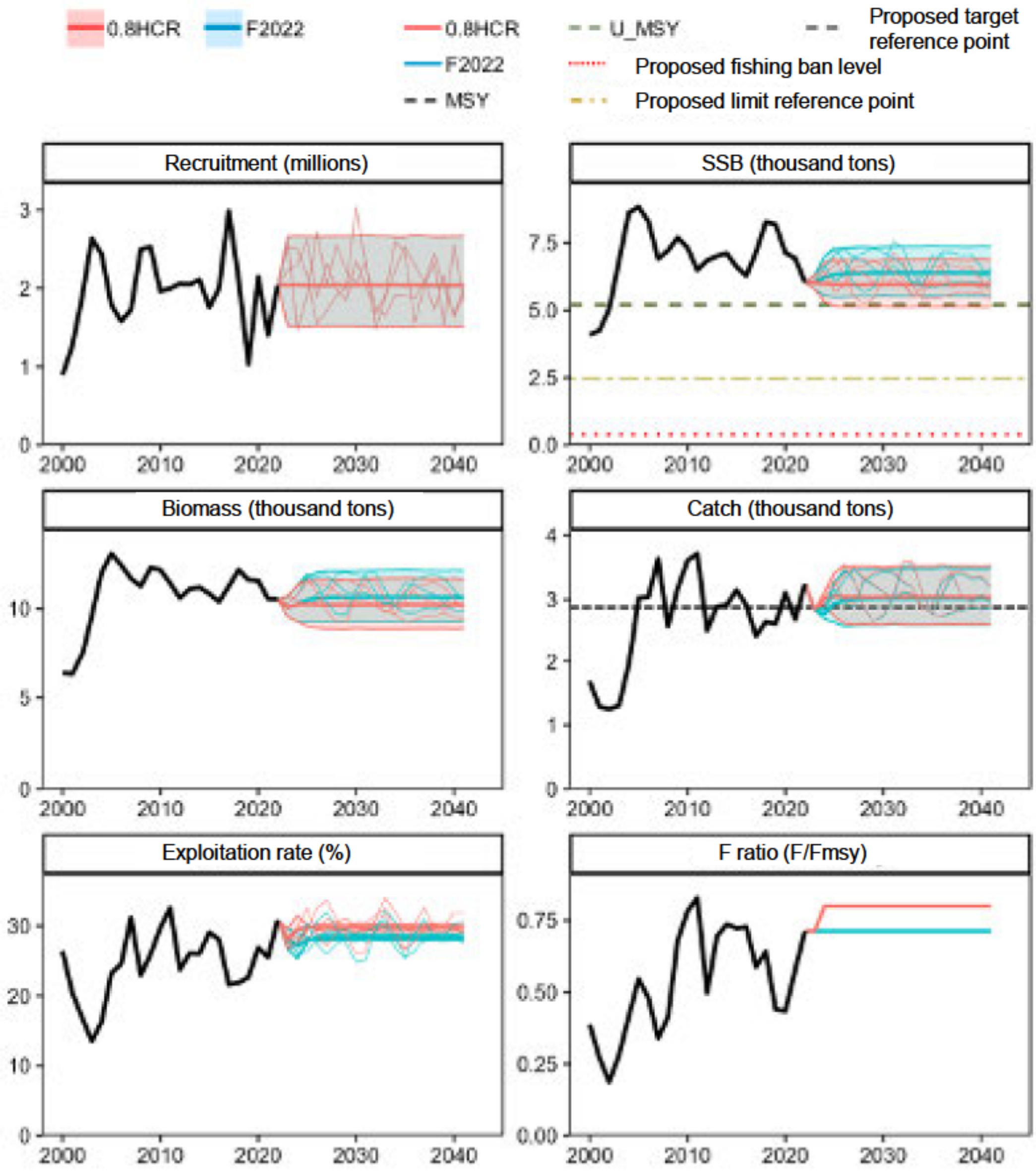


b) When the vertical axis is catch in weight.



Supplementary Fig. 4-1. Proposed HCRs

Target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) were proposed to be SBmsy, SB0.6msy, SB0.1msy, respectively, on the basis of SSB of the stock. The standard value of 0.8 was used for the coefficient β. The black dashed line (Fmsy); the gray dashed line (0.8 Fmsy), the thick black line (HCR), the red dashed line (SBban), the yellow dashed line (SB0.6msy), and the green dashed line (SBmsy). Graph a) shows the F ratio on the vertical axis, and graph b) shows the catch on the vertical axis.



Supplementary Fig. 4-2. Future projections using proposed HCRs and current fishing pressure

The solid line and shaded area indicate average values and 90% prediction interval, respectively. The thin lines indicate three examples of future projections. The black, red and blue lines show values based on the stock assessment, future projections using the proposed HCRs, and that based on the current fishing pressure, respectively. In the SSB graph, the green dashed line, yellow dot-dashed line and red dotted line denote the proposed target reference point (SBmsy), limit reference point (SB0.6msy), and fishing ban level (SB0.1msy), respectively. In the catch in weight graph, the black dashed line shows maximum sustainable yield (MSY). Catch in weight for 2023 was estimated by using biomass and fishing pressure (F2022) in 2022. The proposed HCRs (2024 and onwards) are based on the reference points in this report (Fig. 4-1). A coefficient of $\beta = 0.8$ was used.

Supplemental Table 4-1. Probability that future SSB will exceed the proposed target reference point and the limit reference point

a) Probability of SSB exceeding the target reference point

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.00	100	73	54	50	48	48	48	48	47	47	48	47
0.95	100	82	66	62	62	60	61	61	60	60	61	61
0.90	100	89	78	74	74	74	74	74	73	73	74	74
0.85	100	94	87	85	85	85	85	85	85	85	85	85
0.80	100	97	93	92	93	93	93	93	93	93	93	93
0.75	100	99	97	97	97	98	97	98	97	97	97	98
0.70	100	100	99	99	99	99	99	99	99	99	99	99
0.65	100	100	100	100	100	100	100	100	100	100	100	100
0.60	100	100	100	100	100	100	100	100	100	100	100	100
0.55	100	100	100	100	100	100	100	100	100	100	100	100
0.50	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	99	99	99	99	99	99	99	99	99

b) Probability of SSB exceeding the limit reference point

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.00	100	100	100	100	100	100	100	100	100	100	100	100
0.95	100	100	100	100	100	100	100	100	100	100	100	100
0.90	100	100	100	100	100	100	100	100	100	100	100	100
0.85	100	100	100	100	100	100	100	100	100	100	100	100
0.80	100	100	100	100	100	100	100	100	100	100	100	100
0.75	100	100	100	100	100	100	100	100	100	100	100	100
0.70	100	100	100	100	100	100	100	100	100	100	100	100
0.65	100	100	100	100	100	100	100	100	100	100	100	100
0.60	100	100	100	100	100	100	100	100	100	100	100	100
0.55	100	100	100	100	100	100	100	100	100	100	100	100
0.50	100	100	100	100	100	100	100	100	100	100	100	100
F2022	100	100	100	100	100	100	100	100	100	100	100	100

Results from the future projections with various coefficient β from 0.5 to 1.0 are shown. Fishing pressure in 2023 was assumed to be the current F (F2022), then scenarios under the harvest control rule was applied from 2024 and onwards. Results under the assumption of current (corresponding to β=0.71) was also shown.

Supplementary Table 4-2. Average SSB projected in future (thousand tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.00	6.0	5.5	5.3	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
0.95	6.0	5.6	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
0.90	6.0	5.7	5.6	5.6	5.6	5.5	5.5	5.6	5.5	5.5	5.5	5.5
0.85	6.0	5.9	5.8	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
0.80	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
0.75	6.0	6.1	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
0.70	6.0	6.3	6.4	6.4	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
0.65	6.0	6.4	6.6	6.7	6.7	6.8	6.8	6.8	6.8	6.8	6.8	6.8
0.60	6.0	6.6	6.8	7.0	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
0.55	6.0	6.7	7.1	7.3	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5
0.50	6.0	6.9	7.4	7.7	7.8	7.9	7.9	7.9	7.9	7.9	7.9	7.9
F2022	6.0	6.2	6.3	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4

Results from the future projections with various coefficient β from 0.5 to 1.0 are shown. Fishing pressure in 2023 was assumed to be the current F (F2022), then scenarios under the harvest control rule was applied from 2024 and onwards. Results under the assumption of current (corresponding to β=0.71) was also shown.

Supplementary Table 4-3. Average catch projected in future (thousand tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.00	2.8	3.5	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
0.95	2.8	3.4	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
0.90	2.8	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
0.85	2.8	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.0	3.0
0.80	2.8	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.75	2.8	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.70	2.8	2.7	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.65	2.8	2.6	2.8	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.60	2.8	2.4	2.7	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.55	2.8	2.3	2.6	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
0.50	2.8	2.1	2.5	2.7	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.9
F2022	2.8	2.8	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Results from the future projections with various coefficient β from 0.5 to 1.0 are shown. Fishing pressure in 2023 was assumed to be the current F (F2022), then scenarios under the harvest control rule was applied from 2024 and onwards. Results under the assumption of current (corresponding to β=0.71) was also shown.

Appendix 5 Calculations and formulations in Future Projection

Future projections were performed using the spawner-recruitment relationship which was used to estimate the F required for maintaining maximum sustainable yield (Fmsy) and approved in the Research Institute Meeting held in October 2021 (Sakuma et al. 2021). The calculation was done in accordance with the HCRs for Stock Group 1 in the 2022 Harvest Control Rules and Basic Guidelines for ABC Calculation (FRA-SA2022-ABCWG02-01). The software R (version 4.0.2) was used for stock calculations and projections.

Future projections were done through forward calculations based on equation (10).

$$N_{a+1,y+1} = N_{a,y} \exp\left(-F_{a,y} - M\right) \quad (10)$$

Number at age 8+ was obtained by forward calculation of the sum of fish age 7 and fish age 8+.

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

$$F_{a,y} = \begin{cases} 0 & \text{if } \mathrm{SB_t} < \mathrm{SB_{ban}} \\ \beta\gamma(\mathrm{SB_t})\mathrm{F_{msy}} & \text{if } \mathrm{SB_{ban}} \le \mathrm{SB_t} \le \mathrm{SB_{limit}} \\ \beta \mathrm{F_{msy}} & \text{if } \mathrm{SB_t} \ge \mathrm{SB_{limit}} \end{cases} \quad (11)$$

$$\gamma(\mathrm{SB_y}) = \frac{\mathrm{SB_y} - \mathrm{SB_{ban}}}{\mathrm{SB_{limit}} - \mathrm{SB_{ban}}} \quad (12)$$

In these equations, SBy is the SBB in year y, while Fmsy and SBtarget, SBlimit, and SBban are the SSB reference values shown as proposed in Supplementary Table 7-2.

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

$$\gamma(\mathrm{SB_\gamma}) = \frac{\mathrm{SB_y} - \mathrm{SB_{ban}}}{\mathrm{SB_{limit}} - \mathrm{SB_{ban}}} \quad (12)$$

The biomass and catch in weight in the future projections were obtained by multiplying the stock population or catch in number obtained here by the average body weights in Supplementary Table 5-1, and SSB was obtained using the values after the end of the fishing season according to equation (6) in Appendix 2.

References

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

Sakuma, K., Fujiwara, K., Yagi, Y., Yoshikawa, A., Iida, M., Shirakawa, H. (2021) Materials for the Research Institute Meeting on Reference Points of Honshu Northern Sea of Japan Stock of Pacific Cod (Fiscal Year 2021). Japan Fisheries Research and Education Agency, 1-27. FRA-SA2021-BRP-12-1

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

Supplementary Table 5-1. Parameters used for future projections

Age	Natural mortality	Maturity Ratio	Average weight (g)[*1]	Selectivity [*2]	Fmsy[*3]	Current fishing pressure[*4] (F2022)
3	0.28	0.5	1,001	0.15	0.017	0.012
4	0.28	1.0	1,841	0.15	0.165	0.118
5	0.28	1.0	2,776	0.64	0.699	0.498
6	0.28	1.0	3,715	1.08	1.176	0.838
7	0.28	1.0	4,600	1.00	1.089	0.776
8+	0.28	1.0	5,649	1.00	1.089	0.776

[*1] Body weight in 2022

[*2] Selectivity calculated based on the F values in 2022

[*3] F values estimated under assumption of selectivity in 2022 to obtain the same fishing pressure as Fmsy approved in the Research Institute Meeting held in October 2021. The value was converted via %SPR.

[*4] F values in 2022

Appendix 6 Summary of Various Parameters and Assessment Results

Supplementary Table 6-1. Parameters for spawner-recruitment model

Spawner-recruitment model	Optimization method	Autocorrelation	a	b	S.D.	ρ
Hockey-stick model	Least squares method	None	0.498	4,100	0.172	-

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

Supplementary Table 6-2. Proposed reference points and MSY

Item	Value	Description
SBtarget (proposed)	5,200 tons	A proposed target reference point. SSB required for maintaining MSY (SBmsy).
SBlimit (proposed)	2,500 tons	A proposed limit reference point. SSB required for maintaining catch of 60% of MSY (SB0.6msy).
SBban (proposed)	400 tons	Proposed fishing ban level. SSB required for maintaining catch of 10% of MSY (SB0.1msy).
Fmsy	Fishing pressure required for MSY (fishing mortality F) (Age 3, Age 4, Age 5, Age 6, Age 7, Age 8 and older) = (0.173 0.32, 0.55, 0.96, 1.11, 1.11)	
%SPR (Fmsy)	21%	%SPR corresponding to Fmsy
MSY	2,900 tons	Maximum Sustainable Yield

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

<table>
<tr><th>Item</th><th>Value</th><th>Description</th></tr>
<tr><td>SB2022</td><td>6,000 tons</td><td>SSB in 2022</td></tr>
<tr><td>F2022</td><td colspan="2">Fishing pressure in 2022 (fishing mortality F)
(Age 3, Age 4, Age 5, Age 6, Age 7, Age 8 and older)
= (0.01 0.12, 0.50, 0.84, 0.78, 0.78)</td></tr>
<tr><td>U2022</td><td>28%</td><td>Exploitation rate in 2022</td></tr>
<tr><td>%SPR (F2022)</td><td>26%</td><td>%SPR in 2022</td></tr>
<tr><td colspan="3">Compared against proposed reference points</td></tr>
<tr><td>SB2022 / SBmsy (SBtarget)</td><td>1.16</td><td>Ratio of SSB required for maintaining MSY (proposed target reference point) to that in 2022</td></tr>
<tr><td>F2022 / Fmsy</td><td>0.71</td><td>Ratio of fishing pressure (F) required for maintaining MSY (proposed target reference point) to that in 2022*</td></tr>
<tr><td>Level of SSB</td><td colspan="2">Above SSB required for maintaining MSY</td></tr>
<tr><td>Level of fishing pressure</td><td colspan="2">Below fishing pressure required for maintaining MSY</td></tr>
<tr><td>Trends in SSB</td><td colspan="2">Decreasing</td></tr>
</table>

*Ratio is calculated with converting F to %SPR under the assumption of selectivity in 2023 to give the fishing pressure of Fmsy.

Supplementary Table 6-4. Projected catch in weight

SSB in 2024 (average projected value): 6,000 thousand tons			
Item	Catch (thousand tons) in 2024	Ratio to current fishing pressure (F/F2022)	Exploitation rate in 2024 (%)
β=1.00	3.5	1.41	36
β=0.95	3.4	1.34	30
β=0.90	3.3	1.27	24
β=0.80	3.0	1.13	18
β=0.70	2.7	0.99	9
F2022	2.8	1.00	26

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

Uncertainty under consideration: Recruitment					
β	Average SSB in 2032 (thousand tons)	90% Prediction interval (thousand tons)	Probability (%) of SSB in 2033 exceeding the proposed reference points		
			SBtarget (proposed)	SBlimit (proposed)	SBban (proposed)
β=1.00	5.2	4.4 – 6.1	48	100	100
β=0.95	5.4	4.6 – 6.3	61	100	100
β=0.90	5.5	4.8 – 6.5	74	100	100
β=0.80	6.0	5.1 – 6.9	93	100	100
β=0.70	6.5	5.6 – 7.4	99	100	100
F2022	6.4	5.5 – 7.4	99	100	100

Appendix 7 Recruitment surveys of the stock.

The recruitment of Pacific cod at age 0 and age 1 was investigated based on results from research vessel surveys conducted by the Fisheries Stock Assessment Center as well as prefectural fisheries research institutes of Aomori, Akita, Yamagata, and Niigata (Supplementary Fig. 7-1).

Bottom-trawl surveys were conducted off Ishikawa prefecture (at a depth of 190 to 550 m) from May to June in 2012–2021 (T/S Tanshu-Maru, Hyogo prefecture), and biomass of the age 1 (body length of 250 mm or shorter) was estimated using the swept-area method (Ishikawa, Supplementary Fig. 7-1). While the gear-efficiency of Pacific cod in bottom-trawl surveys is known to vary by age (Ueda et al. 2006), there have been no reports about age selectivity in the Sea of Japan. We assume no variation in gear efficiency by age, and a value of 0.24, the average gear efficiency of fish age 1 to 9 in the Pacific Ocean off Tohoku (Ueda et al. 2006), was used. The age 1 stock was abundant in 2011, 2014, and 2017 year-classes, and scant in 2013, 2015, 2016, and 2018 year classes and onwards.

Bottom trawl surveys has also been conducted by the Aomori Prefectural Industrial Technology Research Center Fisheries Institute, at depths between 100 to 350 m from April to September from 2007 to 2021 (R/V Seiho-Maru, Aomori, Supplementary Fig. 7-1). The age 0 and age 1 stock sizes were estimated using the swept-area method (Aomori Prefectural Technology Research Center), supporting high levels of recruitment in the 2010, 2012, and 2017 year-classes, while low levels in the 2007, 2011, 2013, 2015, 2018, 2019, 2020, and 2021 year-classes. For the 2014 year-class, the standing stock population was low for age 0 but high for age 1.

From 2007 to 2021, the Akita Prefecture Fishery Research Center has conducted surveys by using Danish seine, 20 to 30 operations annually to obtain the CPUE (individuals/haul, R/V Senshu-Maru, Akita, Supplementary Fig. 7-1). The average CPUE was high for the 2009 and 2011, and low for the 2007, 2013, 2015, 2019, 2020, and 2021 year-classes.

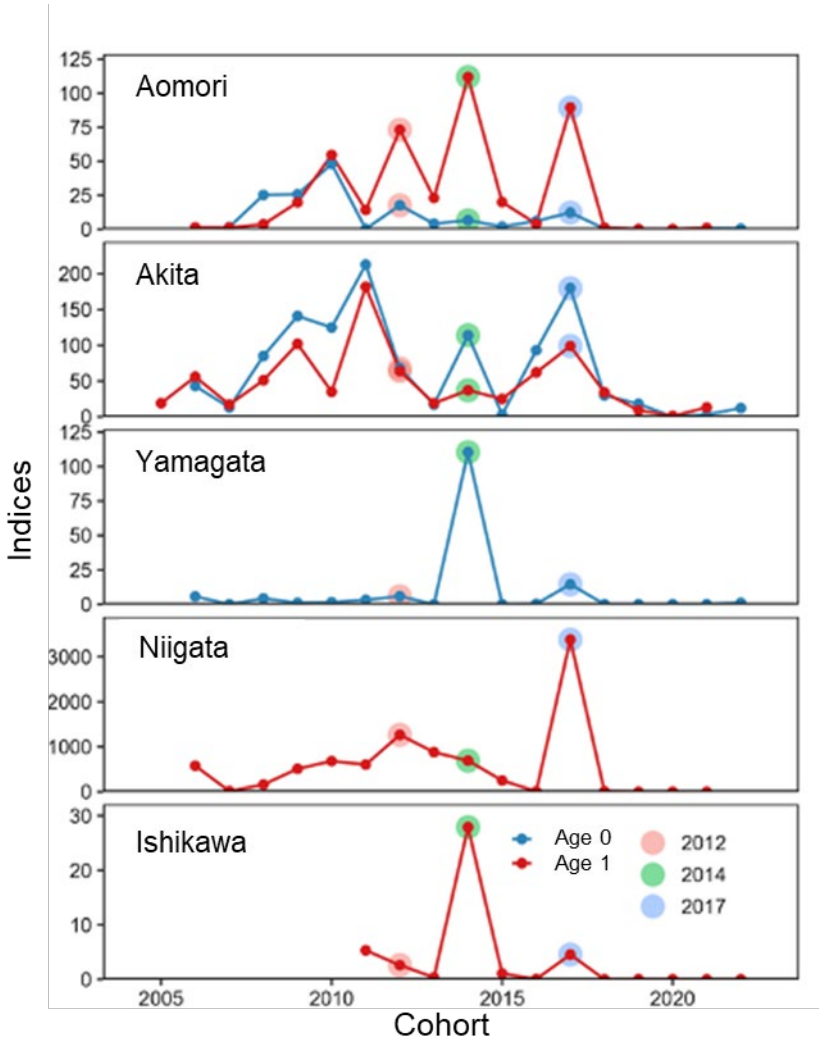
The CPUE (individuals/haul) was also obtained for small bottom trawl off the coast of Yamagata prefecture (June to July, R/V Mogami-Maru, Yamagata Prefecture Fisheries Research Station), indicating remarkably high levels of recruitment for the 2014 and 2017 year-classes (Yamagata, Supplementary Fig. 7-1).

Off the coast of Niigata prefecture, surveys were conducted by commercial small bottom trawler (Danish seiners) in April to May from 2005 to 2022 by the Fisheries Stock Assessment Center and the Niigata Prefectural Fisheries and Marine Research Institute. The CPUE (individuals/haul) was high for the 2012 and 2017 and low for the 2007, 2015, 2018, 2019, 2020, and 2021 year-classes (Niigata, Supplementary Fig. 7-1).

Overall, recruitment of the 2014 and 2017 year-classes were at high levels, while the 2015, 2016, 2018, 2019, 2020, and 2021 year-classes were not abundant. Among the year-classes with low abondance, the year-classes 2019 and onwards are not yet included in the stock calculations (Appendix 2). Moreover, the abundance of the year-class 2018 recruited in 2021 as age 3 fish in the present stock calculations is potentially not reflected due to uncertainty in the number of juvenile fish that stems from low exploitation rate, because main target of the fisheries is mature individuals in the stock. Based on poor recruitment in the most recent year, it is possible that the stock will decline in the future.

References

Ueda, Y., Narimatsu, Y., Hattori, T., Ito, M., Kitagawa, D., Tomikawa, N. and Matsuishi, T. (2006) Fishing efficiency estimated based on the abundance from virtual population analysis and bottom-trawl surveys of Pacific cod Gadus macrocephalus in the waters off the Pacific coast of northern Honshu, Japan. Fish. Sci., **72**, 201-209.



Supplementary Fig. 7-1. Results for Pacific cod at age 0 and 1 in prefectural recruitment surveys. As the chart shows, the 2012, 2014, and 2017 year-classes were typically strong. See the text for units used in index values.

Appendix 8 Stock status of Pacific cod in the western Sea of Japan

The distribution, related fisheries, and stock status of Pacific cod in the western Sea of Japan (east of Shimane prefecture and west of Fukui prefecture) are summarized below.

8-1. Distribution

Pacific cod in the western Sea of Japan is distributed along the coast of Honshu from the eastern coast of South Korea to the Noto Peninsula. The results of bottom-trawl surveys show higher density of fish west of the Oki Islands and lower density off the coast of Hyogo and Fukui prefectures (Supplementary Fig. 8-1). Trawl surveys ("stock assessment surveys on snow crabs and other demersal fish in the Sea of Japan") showed that mainly 400 mm or larger individuals (thought to be age 2 and older) are found in the western Sea of Japan, excluding years with strong recruitment such as 2017 and 2018 (Supplementary Fig. 8-1 and 8-2, with a gear efficiency of 0.24 by Ueda et al., 2006). The stock in the western Sea of Japan, especially west of Wakasa Bay is genetically distinct from the stock north of Ishikawa prefecture, and are thought to be a migratory group with spawning grounds in the South Korean coast (off Busan) (Suda et al. 2017, Sakuma et al. 2019).

8-2. Fisheries

The main fishery is bottom trawling (Danish seiners) including offshore trawlers and coastal small trawlers which comprise 86% and 12% of the catch in weight for 2022, respectively (Supplementary Fig. 8-3, Supplementary Table 8-1). Historically, catch in weight fluctuated and peaked at about 1,100 tons in the 1960s and 500 tons in the 1970s to 1980s. It dropped to below 100 tons in the 1990s before a surge in the 2000s and, recovered to 1,000 tons in the 2010s. In 2022, the catch was 481 tons (provisional value). The fluctuation patterns of catch in weight in the western Sea of Japan were similar to those in South Korea (Supplementary Fig. 8-4, Supplementary Table 8-2). Prefectures that accounted for more than 50% of the catch in weight were Hyogo and Tottori in the 1960s, Fukui in the 1970s and 1980s, Hyogo in the 1990s, and Tottori and Shimane in the 2000s and 2010s. In recent years, the majority of the catch has been from Tottori prefecture.

References

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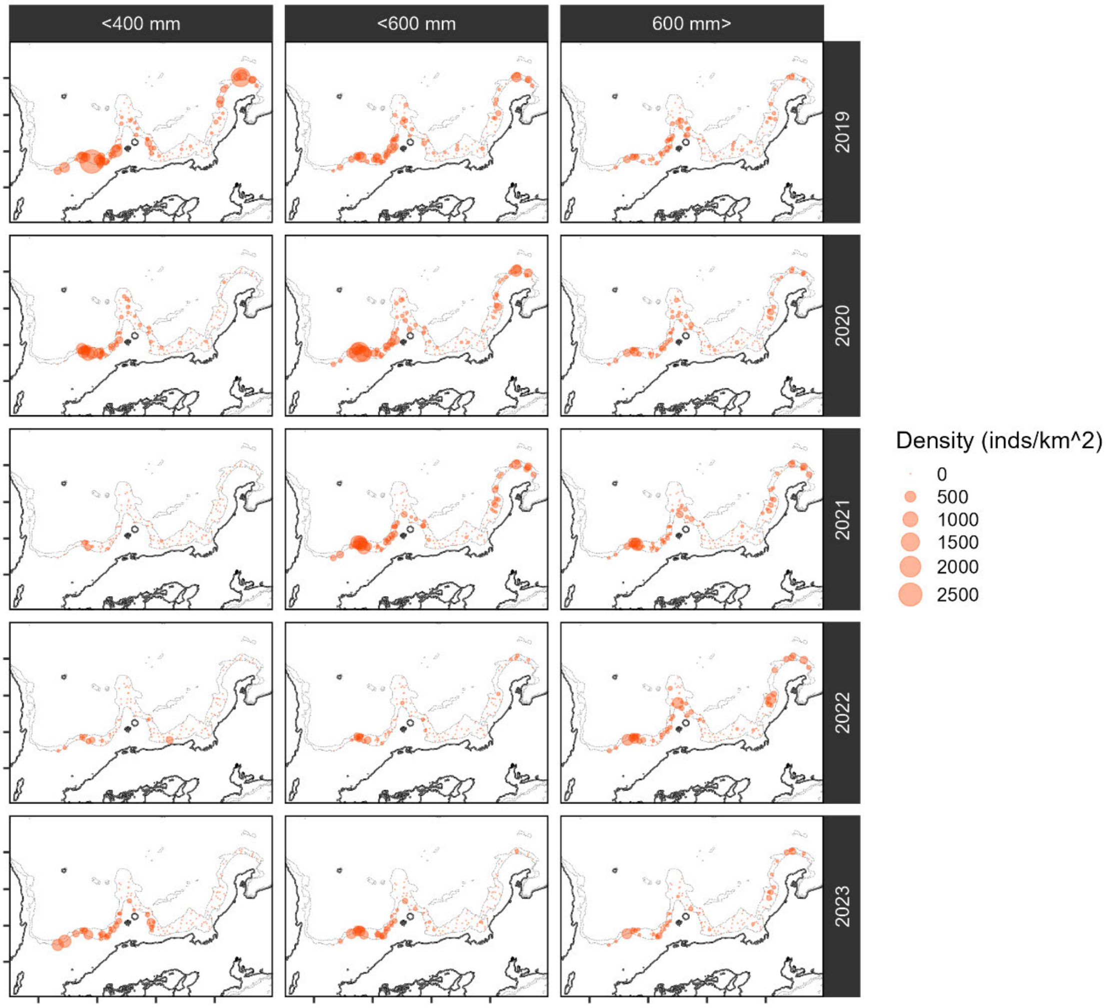
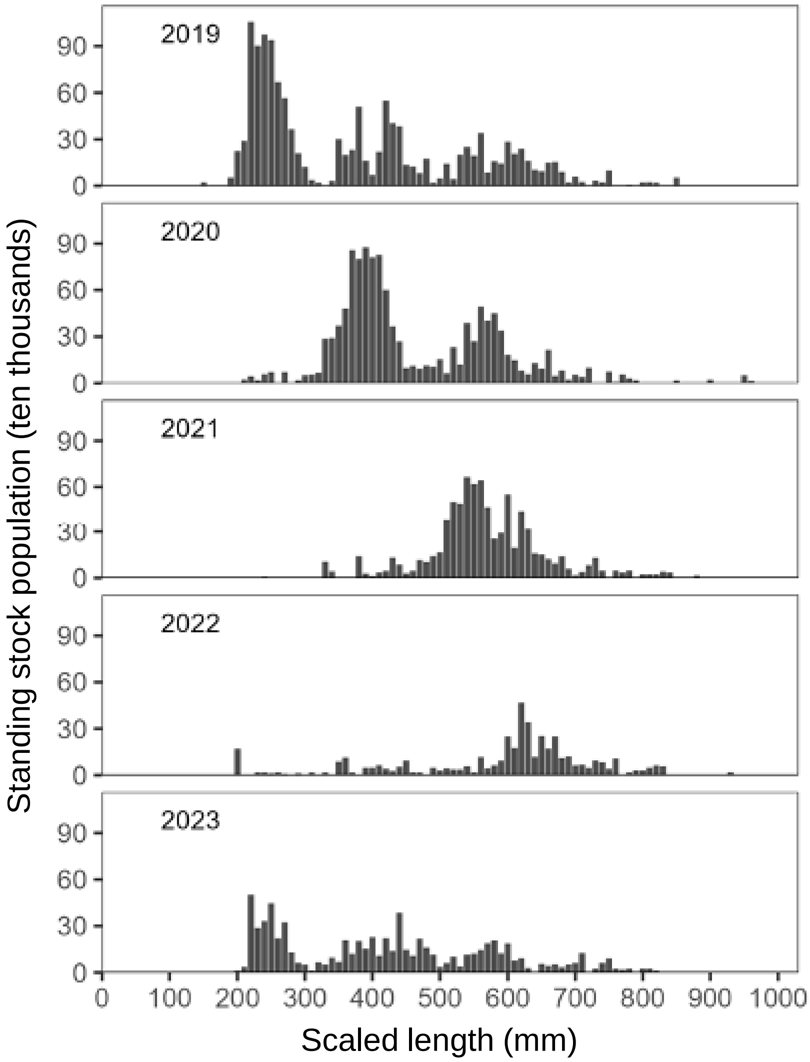
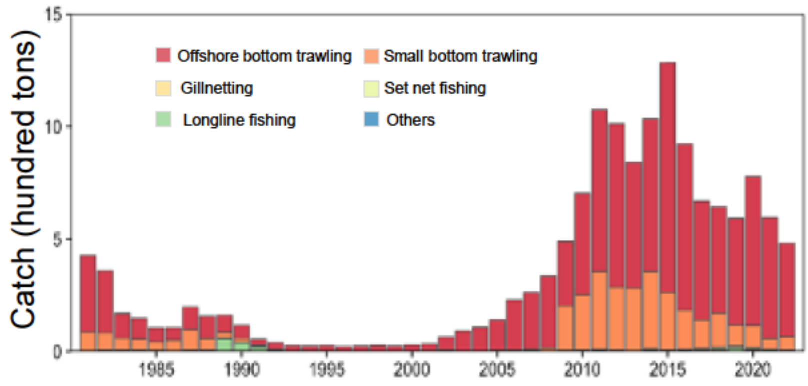


Supplementary Fig. 8-1. Distribution of Pacific cod by age and size group in trawl surveys (“stock assessment surveys on snow crabs and other demersal fish in the Sea of Japan”)

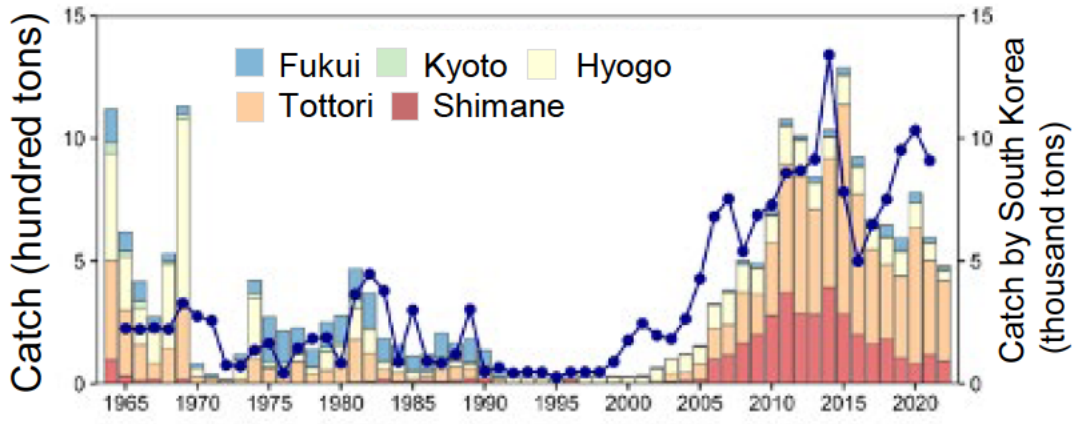


Supplementary Fig. 8-2. Body length composition of Pacific cod in the western Sea of Japan (2019 to 2023)

The stock size by standard body length (increments of 10 mm) in the area spanning from off the coast of Shimane to Hyogo prefectures is shown.



Supplementary Fig. 9-3. Catch in weight by fishery type



Supplementary Fig. 9-4. Catch in weight by prefecture (bar graph) and that in South Korea (line graph)

Supplementary Table 9-1. Catch by fishery type in the western Sea of Japan (tons)

Year	Offshore bottom trawling	Small bottom trawling	Gillnetting	Set net fishing	Longline fishing	Additional Comments	Total	Values from MAFF Statistics*1
1981	340	83	2	2	0	0	427	468
1982	275	78	1	4	1	0	359	369
1983	110	52	1	5	1	0	169	185
1984	94	48	2	3	1	0	148	158
1985	62	38	2	2	1	0	105	113
1986	56	46	1	2	1	0	106	118
1987	101	90	1	3	2	0	197	207
1988	99	50	2	1	4	0	156	168
1989	75	26	1	3	56	0	161	183
1990	57	17	2	1	39	0	116	136
1991	26	6	2	1	19	0	54	57
1992	30	1	1	1	6	0	39	39
1993	23	2	1	0	1	0	27	27
1994	21	3	1	0	0	0	25	25
1995	23	1	2	0	1	0	27	29
1996	21	0	1	0	0	0	22	39
1997	24	1	0	0	0	0	25	29
1998	27	1	0	0	0	0	28	33
1999	23	1	0	0	1	0	25	31
2000	27	1	0	1	1	0	30	30
2001	29	1	0	3	0	0	33	34
2002	58	0	1	6	0	0	65	68
2003	90	1	0	0	0	0	91	101
2004	105	2	1	0	0	0	108	121
2005	135	3	1	1	0	0	140	156
2006	223	4	1	1	0	0	229	327
2007	254	6	1	1	1	0	263	381
2008	319	12	1	1	2	0	335	502
2009	287	198	1	0	4	0	490	491
2010	453	245	1	2	3	0	704	705

Supplementary Table 9-1. Catch by fishery type in the western Sea of Japan (tons) (continued)

Year	Offshore bottom trawling	Small bottom trawling	Gillnetting	Set net fishing	Longline fishing	Additional Comments	Total	Values from MAFF Statistics[*1]
2011	721	344	2	5	3	0	1,075	1,076
2012	726	279	2	3	2	0	1,012	1,011
2013	559	278	1	3	0	0	841	844
2014	679	344	5	6	0	0	1,034	1,034
2015	1,022	256	3	4	0	0	1,285	1,289
2016	739	175	2	3	4	0	923	925
2017	529	127	4	6	3	0	669	670
2018	473	151	3	8	8	0	643	646
2019	475	92	1	9	15	0	592	594
2020	664	97	1	7	9	0	778	778
2021	538	48	0	6	3	0	595	595
2022[*2]	415	60	0	5	1	0	481	481

Based on the Annual Statistics of Agriculture, Forestry and Fisheries and the Annual Statistics of Fishery and Aquaculture Production for each prefecture.

[*1] The difference between the total value and MAFF statistics is due to the the hidden values in MAFF statistics.

[*2] Provisional values.

Supplementary Table 9-2. Catch by prefectures in the western Sea of Japan (tons)

Year	Fukui	Kyoto	Hyogo	Tottori	Shimane	Total	South Korea
1964	136	46	436	404	96	1,118	-
1965	78	24	218	267	32	619	2,252
1966	79	37	145	143	14	418	2,211
1967	46	17	127	66	18	274	2,286
1968	31	13	341	144	1	530	2,218
1969	35	20	751	308	18	1,132	3,279
1970	17	2	32	27	3	81	2,753
1971	10	1	9	17	1	38	2,571
1972	5	2	8	3	0	18	757
1973	20	5	78	16	0	119	717
1974	52	22	249	93	4	420	1,365
1975	182	22	9	57	3	273	1,653
1976	130	19	15	52	0	216	435
1977	98	13	29	89	0	229	1,456
1978	67	6	26	39	1	139	1,841
1979	102	19	77	52	1	251	1,883
1980	111	12	83	70	1	277	844
1981	127	34	129	172	6	468	3,646
1982	141	9	95	114	10	369	4,462
1983	91	7	31	40	16	185	3,784
1984	78	5	29	36	10	158	902
1985	57	8	26	14	8	113	2,996
1986	64	5	17	20	12	118	919
1987	97	28	26	46	10	207	839
1988	72	8	19	57	12	168	1,200
1989	94	10	16	41	22	183	3,020
1990	63	6	13	34	20	136	487
1991	29	2	10	13	3	57	665
1992	10	0	25	4	0	39	439
1993	4	0	20	3	0	27	481
1994	4	0	19	2	0	25	473
1995	4	1	21	2	1	29	273

Supplementary Table 9-2. Catch by prefectures in the western Sea of Japan (tons) (continued)

Year	Fukui	Kyoto	Hyogo	Tottori	Shimane	Total	South Korea
1996	2	0	21	1	15	39	472
1997	2	1	24	0	2	29	481
1998	2	0	27	0	4	33	476
1999	3	0	23	0	5	31	894
2000	3	0	26	1	0	30	1,766
2001	6	0	27	1	0	34	2,458
2002	8	0	49	10	1	68	1,968
2003	2	0	56	34	9	101	1,826
2004	5	0	70	33	13	121	2,641
2005	5	1	71	63	16	156	4,272
2006	5	2	94	128	98	327	6,810
2007	8	2	132	122	117	381	7,533
2008	14	4	111	207	166	502	5,396
2009	16	5	107	164	199	491	6,870
2010	17	4	112	294	278	705	7,289
2011	22	5	155	522	372	1,076	8,585
2012	16	5	144	561	285	1,011	8,682
2013	20	9	105	429	281	844	9,134
2014	24	5	88	524	393	1,034	13,401
2015	27	9	116	855	282	1,289	7,821
2016	36	9	108	573	199	925	4,994
2017	33	6	85	385	161	670	6,475
2018	47	8	106	304	181	646	7,511
2019	50	8	98	332	106	594	9,520
2020	37	6	100	554	81	778	10,323
2021	20	3	70	385	117	595	9,095
2022*1	17	3	43	326	92	481	-

Based on the Annual Statistics of Agriculture, Forestry and Fisheries and the Annual Statistics of Fishery and Aquaculture Production for each prefecture.

*1 Provisional values.

Appendix 9 CPUE Standardization

To obtain yearly trends in biomass based on fishery-dependent CPUE, we believe that it is appropriate to standardize CPUE using statistical methods to remove biases stem from trends in distribution by month, usage of fishing grounds, and other spatiotemporal effects. We therefore performed standardized CPUE from offshore trawl fisheries as a biomass index for bottom trawl fisheries accounting for around 50% of the catch of the Sea of Japan stock of Pacific cod. The CPUE of offshore trawlers possibly reflect trends for overall bottom trawling because in the northern Sea of Japan (corresponding to the offshore bottom trawling fishing areas of northern Oga, southern Oga, off Niigata, off Noto, and off Kaga), the difference in vessel size of small coastal trawlers and offshore trawlers has been small, and the fishing grounds for the two fisheries largely overlap. Small bottom trawling was not included in standardization because the records are sometimes incomplete and require further careful scrutiny.

Official logbooks for offshore trawlers contain information regarding catch (catch in weight per vessel) and fishing effort (number of hauls per vessel). Records since 2000 from offshore trawlers in the northern Sea of Japan area described above, namely, in prefectures from Aomori to Ishikawa, was used for CPUE standardization. The records in logbooks include “zero catch” data without Pacific cod catch and, we divided data into “zero catch” and “non-zero catch” to apply delta models (Lo et al. 1992). The delta models separately standardize CPUE with a catch probability model that estimates the ratio of zero catches, and CPUE model that estimates the CPUE of non-zero catch data. We introduced a Directed residual mixture model (DRM) (Okamura et al. 2018) as a method to estimate types of fishing strategy for each record and is applicable to the catch probability models. For the CPUE standardization, latitude, longitude, and depth are used as splines in the framework of the generalized additive model (GAM) in consideration of the spatiotemporal variation of fishing grounds. The catch probability model assuming binomial distribution was optimized in the first step, then the CPUE model assuming log-normal distribution was built in the second step.

The response variables were the presence/absence of Pacific cod catch in individual records in the catch probability model, and logarithm of CPUE (catch of Pacific cod/number of hauls) in the CPUE model. The explanatory variables were year (Year), month (Month), prefecture (Prefecture), target (Target), year × month (Year : Month, all categories, fixed), latitude and longitude (s(Latitude, Longitude)), year × latitude and longitude (Year : s(Latitude, Longitude)), and month × latitude and longitude (Month : s(Latitude, Longitude) all splines) for both models. In this model, the targets are types of fishing strategy estimated using DRM (refer to the standardization document for details).

The full models were selected for both of the catch probability model and the non-zero catch CPUE model through model selection using a best subset approach based on the Akaike Information Criterion (AIC).

Catch probability model

logit(P) ~ Year + Month+ s(Longitude, Latitude) + Prefecture + Target + Year:Month + Year:s(Longitude, Latitude) + Month:s(Longitude, Latitude)

P is catch probability.

Non-zero catch probability CPUE model

log(CPUE) ~ Year + Month+ s(Longitude, Latitude) + Prefecture + Target + Year:Month + Year:s(Longitude, Latitude) + Month:s(Longitude, Latitude)

Model diagnostic results showed no major problems with either model, so CPUE standardization was performed following these full models, and yearly trends were identified (Supplementary Fig. 9-1). Details of model construction, standardized CPUE and model diagnostics are provided in a separate explanatory document (FRA-SA2023-SC07-0401).

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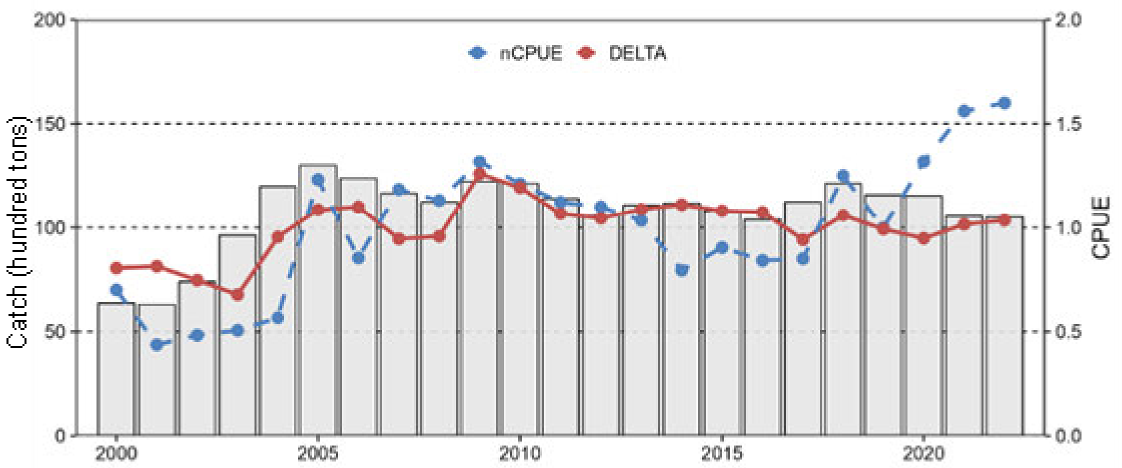


Supplementary Fig. 9-1. Catch based on official logbooks for offshore bottom trawlers (bar graph), standardized CPUE (red solid line), and nominal CPUE (blue dashed line). Both CPUE values have been normalized by dividing by the average.

Appendix 10 Projected catch in weight by month

Catch in weight of this stock is based on the Annual Statistics of Agriculture, Forestry and Fisheries aggregated by calendar year (January to December), and catch in weight in future projections is also calculated by calendar year. However, considering that Pacific cod is mainly caught in winter to spring in this stock, and that this species spawns in winter, it is appropriate to apply the bottom trawl fishing year (September to August of the following year) and/or the fiscal year (April to March of the following year) as the fishing year for stock assessments and the management year for total allowable catch (TAC). Therefore, in order to compare projected catch in weight under these different aggregation periods, we performed calculations for 2024 (the ABC calculation year) and for 2025, to find the average catch in weight by month under different β values, based on the average catch in weight ratio by month for the previous 3 year period according to prefectural statistical data (Supplementary Table 10-1).

Catch in weight by month for the most recent 3 year and 5 year periods, according to prefectural statistical data, and the corresponding catch in weight ratio by month, are shown in Supplementary Table 10-1. The catch in weight ratio by month is high in January and February, and comprises 50% of the annual catch. Likewise, the 5 month period from November to March of the following year comprises 80% of the annual catch. Average catch in weight by month using different β values is shown in Supplementary Table 10-2. The projected catch in weight for 2024 (β = 0.8) was 3,000 tons for the calendar year, 3,100 tons for the fiscal year (April to March of the following year), and 3,100 tons for the bottom trawl fishing year (September to August of the following year), and these values were consistent whether the ratio by month was under the previous 3 year period or the previous 5 year period.

Supplementary Table 10-1. Catch in weight by month (kg) for the previous 5 year period (2020 to 2022) based on prefectural statistical data

Month	Catch					Average catch in weight in the most recent year		Catch in weight ratio	
	2018	2019	2020	2021	2022	Average of 3 years	Average of 5 years	Average of 3 years	Average of 5 years
1	371,330	425,416	658,641	537,676	979,366	725,228	594,486	26.5%	22.1%
2	810,507	989,569	837,353	652,082	731,986	740,473	804,299	27.0%	29.9%
3	422,922	187,778	267,697	402,282	506,207	392,062	357,377	14.3%	13.3%
4	99,914	96,366	69,240	99,251	196,917	121,803	112,338	4.4%	4.2%
5	98,278	79,710	105,325	67,729	126,697	99,917	95,548	3.6%	3.6%
6	109,552	70,467	109,006	69,284	44,459	74,250	80,554	2.7%	3.0%
7	6,993	6,313	5,486	4,055	3,156	4,232	5,201	0.2%	0.2%
8	5,681	9,101	5,027	3,067	1,510	3,202	4,877	0.1%	0.2%
9	49,073	80,643	33,157	43,944	38,714	38,605	49,106	1.4%	1.8%
10	134,342	110,461	58,112	92,805	68,391	73,103	92,822	2.7%	3.5%
11	249,111	282,797	212,343	181,730	139,358	177,810	213,068	6.5%	7.9%
12	256,186	260,292	184,628	499,223	185,757	289,869	277,217	10.6%	10.3%
Total	2,613,889	2,598,912	2,546,014	2,653,127	3,022,520	2,740,553	2,686,892	100.0%	100.0%

Supplementary Table 10-2. Average catch in weight by month using different β values

(a) Catch in weight ratio by month under the most recent 3 year period

Item	Average catch Annual total (thousand tons)	Average catch by month (2024) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
β = 1.00	3.5	0.77	1.05	0.47	0.15	0.12	0.10	0.01	0.01	0.06	0.12	0.28	0.36
β = 0.95	3.4	0.75	1.02	0.45	0.14	0.12	0.10	0.01	0.01	0.06	0.12	0.27	0.35
β = 0.90	3.3	0.73	0.99	0.44	0.14	0.12	0.10	0.01	0.01	0.06	0.11	0.26	0.34
β = 0.80	3	0.66	0.90	0.40	0.13	0.11	0.09	0.01	0.01	0.05	0.10	0.24	0.31
β = 0.70	2.7	0.60	0.81	0.36	0.11	0.10	0.08	0.01	0.00	0.05	0.09	0.21	0.28
F2022	2.8	0.62	0.84	0.37	0.12	0.10	0.08	0.01	0.01	0.05	0.10	0.22	0.29
Catch in weight ratio by month		0.22	0.30	0.13	0.04	0.04	0.03	0.00	0.00	0.02	0.03	0.08	0.10

Item	Average catch Annual total (thousand tons)	Average catch by month (2025) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
β = 1.00	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.95	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.90	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.80	3.1	0.69	0.93	0.41	0.13	0.11	0.09	0.01	0.01	0.06	0.11	0.25	0.32
β = 0.70	2.9	0.64	0.87	0.39	0.12	0.10	0.09	0.01	0.01	0.05	0.10	0.23	0.30
F2022	2.9	0.64	0.87	0.39	0.12	0.10	0.09	0.01	0.01	0.05	0.10	0.23	0.30
Catch in weight ratio by month		0.22	0.30	0.13	0.04	0.04	0.03	0.00	0.00	0.02	0.03	0.08	0.10

(b) Catch in weight ratio by month under the most recent 5 year period

Item	Average catch Annual total (thousand tons)	Average catch by month (2024) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
β = 1.00	3.5	0.77	1.05	0.47	0.15	0.12	0.10	0.01	0.01	0.06	0.12	0.28	0.36
β = 0.95	3.4	0.75	1.02	0.45	0.14	0.12	0.10	0.01	0.01	0.06	0.12	0.27	0.35
β = 0.90	3.3	0.73	0.99	0.44	0.14	0.12	0.10	0.01	0.01	0.06	0.11	0.26	0.34
β = 0.80	3	0.66	0.90	0.40	0.13	0.11	0.09	0.01	0.01	0.05	0.10	0.24	0.31
β = 0.70	2.7	0.60	0.81	0.36	0.11	0.10	0.08	0.01	0.00	0.05	0.09	0.21	0.28
F2022	2.8	0.62	0.84	0.37	0.12	0.10	0.08	0.01	0.01	0.05	0.10	0.22	0.29
Catch in weight ratio by month		0.22	0.30	0.13	0.04	0.04	0.03	0.00	0.00	0.02	0.03	0.08	0.10

Item	Average catch Annual total (thousand tons)	Average catch by month (2025) Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
β = 1.00	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.95	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.90	3.2	0.71	0.96	0.43	0.13	0.11	0.10	0.01	0.01	0.06	0.11	0.25	0.33
β = 0.80	3.1	0.69	0.93	0.41	0.13	0.11	0.09	0.01	0.01	0.06	0.11	0.25	0.32
β = 0.70	2.9	0.64	0.87	0.39	0.12	0.10	0.09	0.01	0.01	0.05	0.10	0.23	0.30
F2022	2.9	0.64	0.87	0.39	0.12	0.10	0.09	0.01	0.01	0.05	0.10	0.23	0.30
Catch in weight ratio by month		0.22	0.30	0.13	0.04	0.04	0.03	0.00	0.00	0.02	0.03	0.08	0.10

Appendix 11 Stock calculations assuming population migration from other stocks

This stock includes the waters of Aomori adjacent to the Hokkaido Sea of Japan area, and the Hokkaido Pacific Ocean area (Mutsu Bay), so migration between these adjacent ocean areas is possible. Catch in weight in Aomori has been increasing since 2019. In particular, catch in weight by gill net fishery and set net fishery (including bottom set nets) has increased significantly. The Hokkaido Sea of Japan stock of Pacific cod adjacent to Aomori has shown a big increase in catch since 2018, indicating higher recruitment strength of the 2014 and subsequent year-classes. If it is assumed that the increase in catch by gill net fishery and set net fishery in Aomori is due to migration from other stocks, this can lead to overestimation of biomass and uncertainty in stock assessments. Meanwhile, offshore bottom trawl fishery in Aomori operates in different fishing grounds from near -shore gill net and set net fishing grounds. No sudden increase in catch has been seen in offshore bottom trawl fishery in recent years, indicating that the impact of migration is minimal. Accordingly, we assumed that 50% of catch by gill net fishery and set net fishery in Aomori since 2019 is due to migration ("transfer catch"), and subtracted transfer catch to recalculate annual catch by fishery type, and performed cohort analysis.

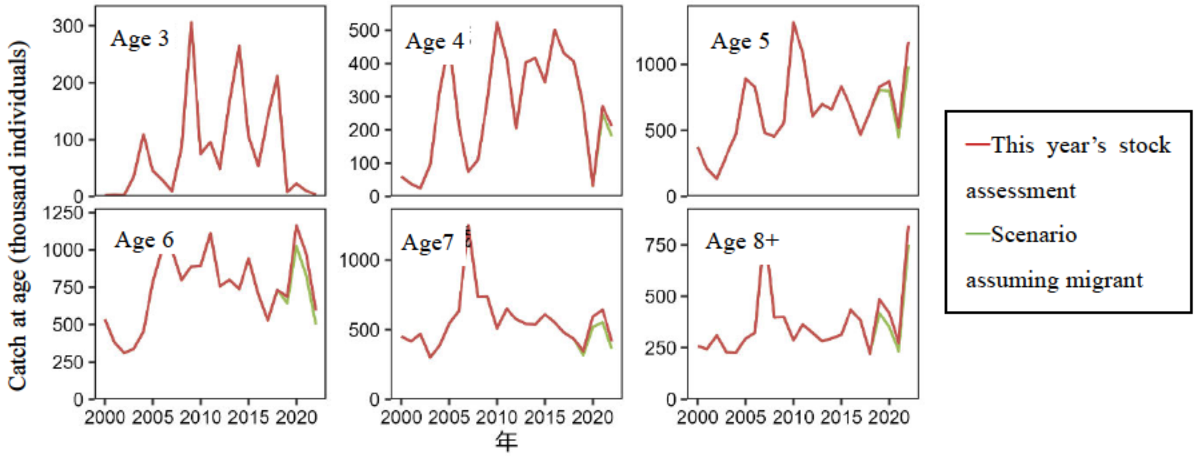
Estimates for transfer catch are shown in Supplementary Table 11-1. From 2019 to 2022, transfer catch increased steadily from 174 tons to 466 tons. Estimated catch at age tends to be lower since 2019, compared to this year's assessment, except for fish age 3, under the assumption of migration in Aomori. However, number at age (NAA) does not change much even after migration is assumed. Meanwhile, F values tend to be lower, especially for fish age 5+, when migration is assumed (Supplementary Fig. 11-1). In this year's assessment, SSB was clearly in a decreasing trend, but the decrease is less severe when migration in Aomori is assumed (Supplementary Fig. 11-2).

These results indicate that in this assessment, catch increased due to population migration from other stocks, suggesting the possibility that fishing pressure was overestimated. However, it remains difficult to accurately estimate the exact proportion of migration in annual catch. Estimated SSB is more optimistic when migration is assumed. Because there are concerns about a decrease in the future stock size (Appendix 7), for this year's stock assessment, we do not consider migration, in order to avoid the uncertainty associated with overestimation of abundance. Further investigation is required to develop methods to identify migration.

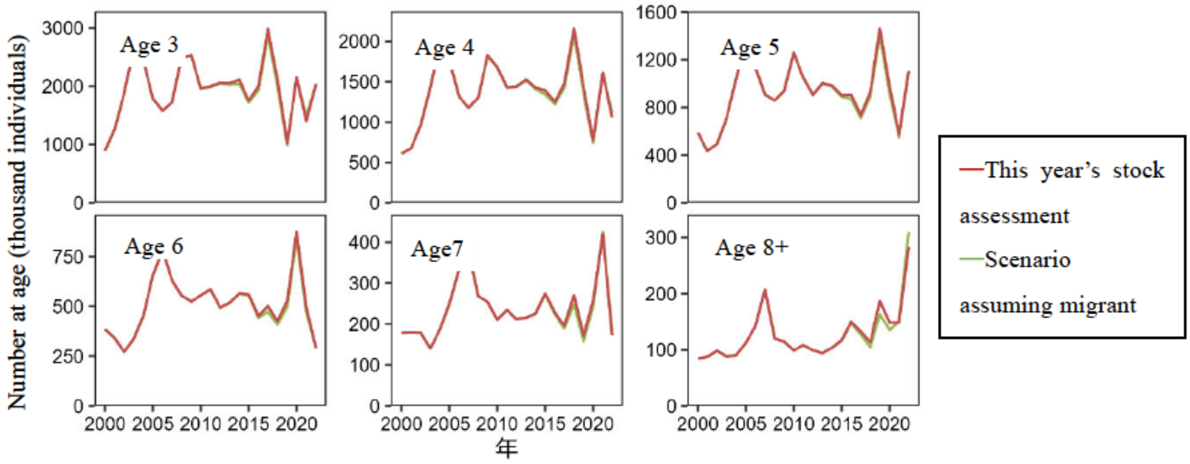
References

Sakai, O., Chimura, M., Chiba, S., and Hamatsu, T. (2023) Stock Assessment for Hokkaido Sea of Japan Stock of Pacific Cod (Fiscal Year 2022). Japan Fisheries Research and Education Agency, 1-23. FRA-SA-2022-AC-31

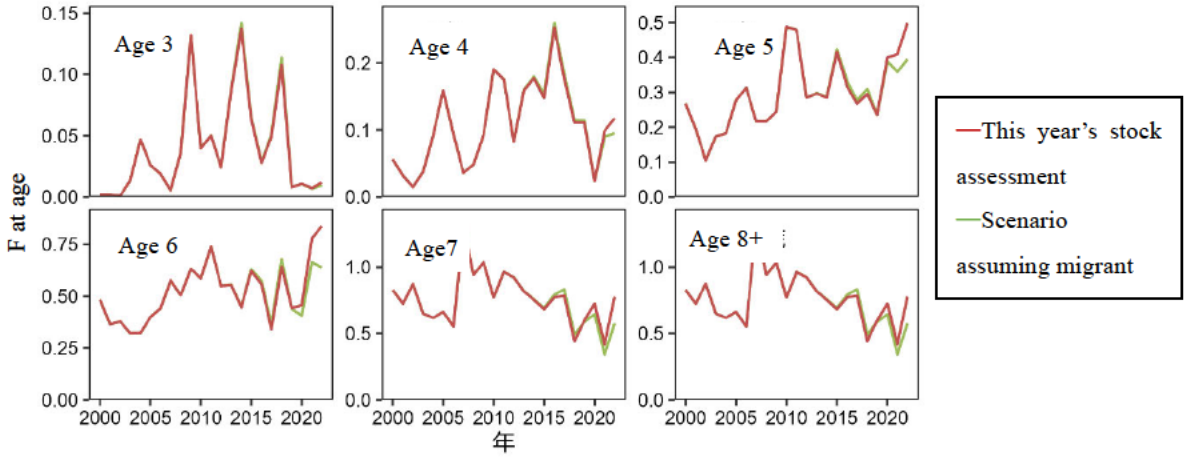
Catch at age



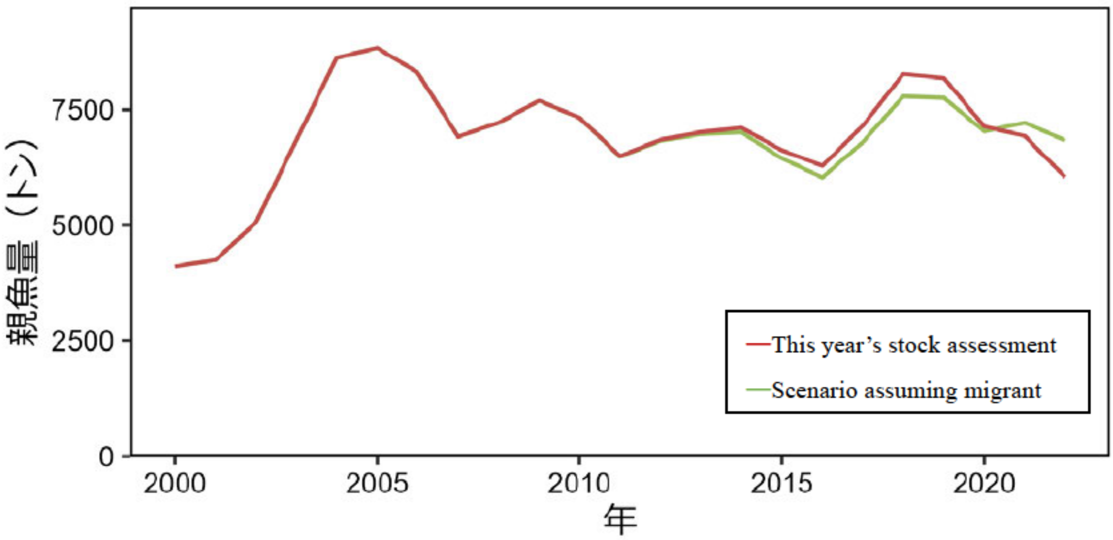
Number at age



F at age



Supplementary Fig. 11-1. Catch at age, number at age, and F value by age, based on this year's stock assessment, and under the assumption that migration is occurring in gill net fishery and set net fishery catches in Aomori since 2019



Supplementary Fig. 11-2. Estimated SSB based on this year's stock assessment, and under the assumption that migration is occurring in gill net fishery and set net fishery catches in Aomori since 2019

Supplementary Table 11-1. Projected catch and population transfer catch (tons) under the assumption that migration comprises 50% of catch by gill net fishery and set net fishery since 2019

Year	Catch			Projected catch		Transfer catch
	Offshore bottom trawl	Gillnet	Set net	Gillnet	Set net	
2019	31	192	155	96	78	174
2020	25	523	134	262	67	328
2021	81	333	406	166	203	370
2022	61	379	552	190	276	466