Stock Assessment for Northern Hokkaido Stock of Pointhead Flounder (Fiscal Year 2023)

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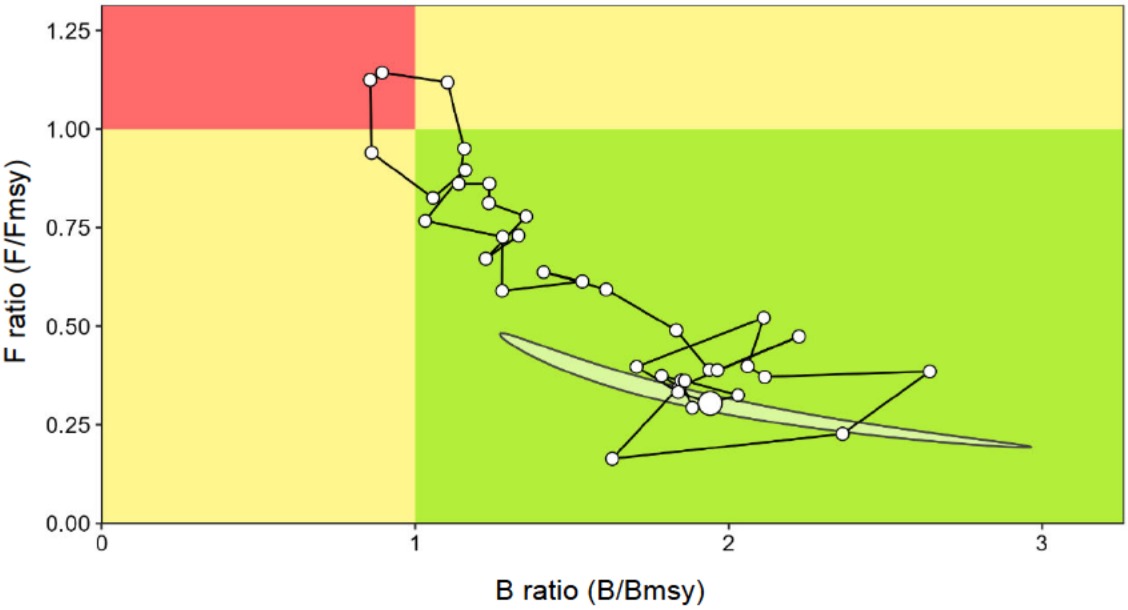
Summary

The status of this stock was assessed using a state-space surplus production model. Results from two base case models, which had different prior information input methods, were merged to judge stock status. Similar trends were estimated in both of the base case models for biomass and fishing pressure. According to the merged results from these two base case models, biomass since the 1985 fishing year (FY: from August to July of the following year) decreased to 2,600 tons in the 1994 FY (90% confidence interval of 1,800 to 3,500 tons, other values in parentheses below indicate the intervals for each typical value), followed by a steady increasing trend, and reached 7,800 tons (5,900 to 10,400 tons) in the 2016 FY. It then decreased to an estimated 5,700 tons (4,200 to 7,800 tons) in the 2022 FY. Fishing pressure has been in a long-term decreasing trend that is opposite to trends in biomass, reaching an estimated 0.28 (0.21 to 0.38) in the 2022 FY.

In the 2022 FY, biomass exceeded the biomass required for MSY (Bmsy). In addition, the fishing pressure in the 2022 FY was lower than the fishing pressure level required for MSY (Fmsy). Based on trends seen in the previous 5 years (2018 to 2022), the biomass is judged to be in a “stable” trend.

In this stock, the reference points, HCRs, and other items are provisional values as proposed at the Research Institute Meeting, which will be finalized based on discussions of the stakeholder meeting.

Summary Figures and Tables



MSY, Biomass Levels and Trends, and ABC	
Biomass required for MSY	3,000 tons (90% confidence interval: 1,800 to 4,400 tons)
Level of biomass for the 2022 FY	Above Bmsy
Level of fishing pressure for the 2022 FY	Below Fmsy
Trends in biomass in 2022	Stable
Maximum Sustainable Yield (MSY)	2,700 tons (90% confidence interval: 2,600 to 2,900 tons)
ABC for the 2024 FY	—
Comments: ・ ABC is estimated after Harvest Control Rules (HCRs) for this stock are compiled by the stakeholder meeting, and set through the Fisheries Policy Council. ・ The values shown outside of parentheses are typical values (the median values calculated by regenerating the parameter sets for the number of iterations according to estimated results from the two base models), and values inside parentheses indicate the 90% confidence interval derived from the 5th percentile and the 95th percentile. Moving forward, results from these two models will be summarized when they were calculated using the method described above.	

Biomass, Catch, Fishing Pressure, and F/Fmsy for the previous 5 years and the next 2 years

Fishing year	Biomass (thousand tons) (90% confidence interval)	Catch (tons)	Fishing pressure (F) (90% confidence interval)	F/Fmsy (90% confidence interval)
2018	6.1 (4.4 to 8.5)	2,241	0.37 (0.26 to 0.51)	0.40 (0.26 to 0.55)
2019	6.3 (4.6 to 8.7)	3,000	0.48 (0.34 to 0.66)	0.52 (0.34 to 0.71)
2020	5.1 (3.6 to 7.2)	1,848	0.37 (0.26 to 0.52)	0.40 (0.26 to 0.54)
2021	5.4 (4.0 to 7.5)	1,668	0.31 (0.22 to 0.42)	0.33 (0.23 to 0.45)
2022	5.7 (4.2 to 7.8)	1,612	0.28 (0.21 to 0.38)	0.31 (0.21 to 0.41)
2023	6.2 (4.5 to 8.6)	1,700	0.28 (0.21 to 0.38)	0.30 (0.20 to 0.41)
2024	6.3 (4.5 to 8.8)	—	—	—

- The values for 2023 and 2024 are estimates based on future projections.
- Biomass for each year shows the stock abundance of catch targets.
- Fishing year is from August to July of the following year.
- Catch is observed values, while biomass, fishing pressure, and F/Fmsy are estimated values.

1. Data Sets

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

Data Sets	Basic Information & Related Surveys
Catch*	Landings at major ports by fishery type (Hokkaido) Catch Performance Report for offshore bottom trawl fishery in Hokkaido (Fisheries Agency)
Fishing effort	Catch Performance Report for offshore bottom trawl fishery in Hokkaido (Fisheries Agency)
Abundance indices*	Standardized CPUE for offshore bottom trawl fishery and stock assessment results using VPA (Hokkaido Research Organization)

*Asterisks indicate data used for biomass estimates based on surplus production model(s).

2. Ecology

(1) Distribution / Migration

Pointhead flounder is distributed along the western coast of the Kamchatka Peninsula, along the Pacific coast from the North Kuril Islands to off the coast of Joban, along the Hokkaido coast of the Sea of Okhotsk and throughout most of the Sea of Japan, and are also found in the Yellow Sea (Watanabe 1956, Hokkaido District Demersal Fish Research Group 1960). The distribution of the Northern Hokkaido stock of pointhead flounder is shown in Fig. 2-1. This stock is thought to be composed of two groups, one which is spawned in the Sea of Japan and lives in the northern area of Sea of Japan, and another which is transported to the Sea of Okhotsk as eggs and larvae, which migrates to the northern area of Sea of Japan for spawning as mature fish (Fujioka 2003).

(2) Age / Growth

Total length and body weight by sex for each age group (age in years assuming a “birthday” of August 1) is shown in Fig. 2-2 (Itaya and Fujioka 2006a). Individuals age 7+ of both sexes are collected in surveys, so lifespan is thought to be 7 years or older.

(3) Maturation / Spawning

The total length at 50% maturity is 217 mm for females and 170 mm for males, and the age at which more than half of individuals are considered to be mature is age 3 for females and age 2 for males (Itaya and Fujioka 2006b). The main spawning grounds are thought to be the offshore waters between Bikuni and Furubira (depth of 60 to 80 m), between Mashike and Rumoi (depth of 50 to 60 m), and around the Musashi Bank (Tanaka and Hinata 1964, Nagasawa 1990, Fishing Management Division, Bureau of Fisheries, Department of Fisheries and Forestry, Hokkaido Government and Hokkaido Research Organization, Fisheries Research Department 2019). Spawning season is from May to September, and peaks in July (Nagasawa 1990, Tominaga et al. 1993, Tominaga et al. 2000).

(4) Predator-Prey Relationships

Mature fish prey on western sand lances, juveniles of cods, and other small fishes, krill, brittle stars, polychaetes, squids, shrimps, and bivalves (Hokkaido District Demersal Fish Research Group 1960, Tanaka and Hinata 1964, Research Department, Fisheries Agency 1989). Predators of this species include marine mammals (Goto et al. 2017).

3. Fishery Status

(1) Fishery Overview

The majority of this stock is caught by offshore bottom trawl fisheries (offshore bottom trawl) and coastal gill net fisheries, with equal catch volume by offshore bottom trawl and coastal fisheries up through the 2000s. Then, catch by coastal fisheries started to decrease in the 2010s, while offshore bottom trawl catches started to increase in the 2016 FY and after. In recent years, the proportion caught by offshore bottom trawl increased to exceed 70% of catches in the 2022 FY. Offshore bottom trawl mainly catches foraging groups from September to April of the following year, and coastal gill net fishery mainly catches spawning groups from April to July. In addition, catches in the Sea of Okhotsk are extremely small compared to catches in the Sea of Japan.

(2) Trends in Catch in Weight

Catch of this stock is shown in Fig. 3-1 and Table 3-1. Offshore bottom trawl catch reached 2,302 tons in the 1980 FY, then fell to 997 tons in the 1982 FY, and has fluctuated in cycles since then. The catch was a record low of 504 tons in the 2014 FY, followed by a sharp increase to reach a record high of 2,622 tons in the 2019 FY. It then declined to 1,195 tons in the 2022 FY. Whether operations target pointhead flounder or not depends on the trends in catch of other major species (Alaska pollock, Okhotsk atka mackerel, Pacific cod, etc.), the demands of the market, and the unit price. In particular, interviews with fishery stakeholders revealed that operations in Otaru intensively targeted pointhead flounder in the 2016 to 2019 FYs due to a spike in demand from international sales channels. In addition, landings for small individuals of total length of 23 cm or less were previously flat due to voluntary regulations, but the introduction of a new commercial size category (“bara”: unsorted) led to a higher catch (Central and Wakkanai Fisheries Research Institutes, 2023). Then, the COVID-19 pandemic caused a drop in demand from international sales channels and the unit price has declined since the latter half of the 2019 FY. Currently, there are no operations intensively targeting this stock. Based on these results, it is inferred that a relatively large fluctuation in catch has occurred since 2015.

Catch by coastal fisheries (including gill net fishery) increased from the late 1980s and reached 1,860 tons in the 1991 FY. It fluctuated in cycles while showing a long-term decreasing trend, then started to decline dramatically around 2010, and fell to 205 tons in the 2016 FY. Catch was 417 tons in the 2022 FY.

(3) Fishing effort

In this report, fishing effort for this stock was based on the total number of hauls by all operations of offshore bottom trawl fishery with Danish seine, which is the primary method of catch, and data for the number of non-zero catches of pointhead flounder by month, by vessel, and by fishing area (excluding experimental operations) (Fig. 3-2). The total number of hauls by all operations was over 80,000 hauls in some years during the 1980s, but has declined significantly, and was less than 30,000 hauls in the 2000 FY. It has continued to decline and was 10,137 hauls in the 2022 FY. The number of non-zero catches remained around 30,000 hauls in the early 1980s, then fluctuated in cycles while declining since the late 1980s, and was 3,627 hauls in the 2022 FY. Details about the fishing effort of coastal operations are not known.

(4) Age Composition of Catches

Catch in number at age by sex as estimated by the Hokkaido Research Organization (HRO) is shown in Fig. 3-3. Up to the early 1990s, catch in number of males was equal to females, but few males have been caught since the late 1990s. Meanwhile, data for females shows that up to the 1991 FY, females age 2 comprised the majority of catches, but few females age 2 have been caught since the 1992 FY, and since then the majority of catches have been females age 3 to 4. The primary cause of this is thought to be avoidance of landing small fish with a low unit price, and catch restrictions based on stock management agreements between fishery stakeholders which aim to conserve immature fish (Central and Wakkanai Fisheries Research Institutes, 2023). However, the catch of males increased in the 2016 to 2017 FYs, and the catch in number of males was equal to females. During this period, the proportion of females age 2 also increased temporarily. The cause of this is thought to be a higher catch by offshore bottom trawl of small individuals of total length of 23 cm or less following the introduction of a new commercial size category (“bara”: unsorted), which were previously not landed due to voluntary regulations (Central and Wakkanai Fisheries Research Institutes, 2023). Catch in number of males, and the proportion of females age 2, decreased again since the 2017 FY, and current levels have dropped to the same levels as seen before the 2014 FY.

4. Stock Status

(1) Stock Assessment Methods

This stock assessment used SPiCT, which is a Pella-Tomlinson state-space surplus production model (a stochastic state-space surplus production model in continuous time: Pedersen and Berg 2017) (Appendix 1 and 2). The surplus production models used catch aggregated by FY from 1985 to 2022, the CPUE of offshore bottom trawl in the 1985 to 2022 FYs, and the total surviving biomass for both sexes calculated from the biomass of females in the 1994 to 2014 FYs as estimated using VPA by the HRO (Central and Wakkanai Fisheries Research Institutes, 2023). The CPUE of offshore bottom trawl used for abundance indices was standardized before use (Appendix 3). Details about standardized CPUE are described in un-published report “CPUE standardization for the northern Hokkaido stock of pointhead flounder in offshore danish seine fishery in 2023” (FRA-SA-2023-SC16-101) (Chiba et al. 2023).

Results from two base case models, which were surplus production models with different prior information input methods, were used to judge stock status. Results from these models were merged, and parameter sets for iterative calculations were randomly regenerated based on a multivariate normal distribution, and the median values were used as typical values. Specifically, the variance of the multivariate normal distribution was a variance-covariance matrix (inverse precision matrix) which shows the precision of estimated parameters in each model. In addition, the 90% confidence interval derived from the 5th percentile and the 95th percentile was calculated. In this stock assessment, calculations for reference values related to biomass, fishing pressure, and MSY were performed with 15,000 iterations (number of parameter sets) for each model, for a total of 30,000 iterations. Details about the surplus production models used and estimated parameters are described in Appendix 2.

(2) Trends in Abundance Indices

Abundance indices used in the surplus production models are shown in Fig. 4-1 and Table 4-1. The standardized CPUE of offshore bottom trawl declined throughout the 1990s, then increased in the 2000s, followed by a dramatic decrease during the 2008 to 2014 FYs. In the 2015 FY it increased again and reached a record high in the 2016 FY. It has decreased since then, and was 75.4 kg/net in the 2022 FY. The total surviving biomass of both sexes, as estimated based on the biomass of female pointhead flounder which was estimated by the HRO using VPA, increased during the 2008 FY, followed by a decrease, then increased again from the 2010 FY. It decreased in the 2013 and 2014 FYs, then increased dramatically in the 2015 FY.

(3) Levels Required for MSY Under Current Environmental Conditions

Estimated parameters for the surplus production models are shown for both of the two base case models in Appendix 2 (Supplementary Table 2-1). The estimated intrinsic growth rate (r) was 0.66 (90% confidence interval of 0.33 to 1.31, other values in parentheses below indicate the intervals for each typical value) in Model 1, and 0.72 (0.44 to 1.19) in Model 2. The carrying capacity (K) was 9,300 tons (6,900 to 12,600 tons) in Model 1 and 9,500 tons (7,300 to 12,500 tons) in Model 2. The shape parameter (n) that determines the shape of the surplus production curve was 0.65 (0.26 to 1.61) in Model 1 and 0.86 (0.49 to 1.50) in Model 2.

Under current conditions, the biomass required for MSY (Bmsy) corresponds to the biomass at maximum surplus production, and it was estimated to be 2,700 tons (1,700 to 4,300 tons) in Model 1 and 3,200 tons (2,300 to 4,600 tons) in Model 2 (Fig. 4-2). Based on the estimated results calculated from these base case models, the typical value (and 90% confidence interval) was 3,000 tons (1,800 to 4,400 tons) (Table 4-2).

Meanwhile, the fishing pressure required for Bmsy (Fmsy) was estimated to be 1.00 (0.62 to 1.63) in Model 1 and 0.84 (0.58 to 1.21) in Model 2 (Supplementary Table 2-1), and the typical value was calculated to be 0.92 (0.62 to 1.52).

(4) Trends in Stock Abundance and Fishing Pressure

In the typical values based on the merged results from two base case models (surplus production models), biomass showed a long-term increase since 1995, and was 5,700 tons (4,200 to 7,800 tons) in the most recent year (2022 FY) (Fig. 4-3, Table 4-3). Fishing pressure increased up to the 1992 FY, then fell into a decreasing trend, with a slight increase in the 2015 to 2019 FYs, and has declined since the 2020 FY. Fishing pressure was 0.28 (0.21 to 0.38) in the 2022 FY (Fig. 4-4, Table 4-3). According to the results of stock assessment using both models, biomass in the most recent year was 5,500 tons (4,100 to 7,400 tons) in Model 1 and 6,000 tons (4,400 to 8,100 tons) in Model 2 (Appendix 2). Similarly, fishing pressure in the most recent year was 0.29 (0.22 to 0.39) in Model 1 and 0.27 (0.20 to 0.37) in Model 2. The increase in stock since the 1995 FY is thought to be due to a decrease in fishing pressure since the 1994 FY. It is inferred that the reason for this is the introduction of stock management agreements in March 1994, which include catch regulations for smaller fish. In addition, one reason for the increase in fishing pressure in the 2015 to 2019 FYs is thought to be that operations in Otaru intensively targeted pointhead flounder due to a spike in demand from international sales channels, as previously mentioned. In last year’s stock assessment (FRA-SA2022-SC08-01), estimates for the 2021 FY using two base case models showed that biomass was 5,400 tons (3,900 to 7,400 tons) in Model 1 and 5,700 tons (4,100 to 7,900 tons) in Model 2, and fishing pressure was 0.31 (0.22 to 0.43) in Model 1 and 0.29 (0.21 to 0.40) in Model 2. In this year’s stock assessment, estimates for the 2021 FY showed that biomass was 5,200 tons (3,800 to 7,100 tons) in Model 1 and 5,700 tons (4,100 to 7,800 tons) in Model 2, and fishing pressure was 0.32 (0.23 to 0.44) in Model 1 and 0.29 (0.21 to 0.40) in Model 2, which suggests the addition of one year of data had a slight impact on estimated values.

(5) Stock Levels/Trends and Fishing Pressure Levels

Stock status based on the biomass required for MSY (Bmsy) and the fishing pressure required for MSY (Fmsy) are shown in a Kobe plot in Fig. 4-5. According to the merged results from these two base case models, it is judged that the current biomass (biomass in the 2022 FY) exceeds Bmsy, including the 90% confidence interval, and the current fishing pressure (fishing pressure in the 2022 FY) is lower than Fmsy, including the 90% confidence interval. For the previous 5 years (2018 to 2022 FYs), the biomass is judged to be in a “stable” trend.

The ratio of the current biomass to Bmsy is 1.92 (1.48 to 2.79), and the ratio of the current fishing pressure to Fmsy is 0.31 (0.21 to 0.41) (Table 4-4). The results of both base case models are shown in a Kobe plot in Appendix 2.

5. Summary of Stock Assessment

Based on estimated biomass from the surplus production models, the biomass of pointhead flounder was in a long-term increasing trend since the 1995 FY, and peaked in the 2016 FY. Then the stock was in a decreasing trend, however, biomass in the most recent year (2022 FY) exceeded Bmsy.

6. Additional Comments

According to catch restrictions based on stock management agreements between fishery stakeholders which aim to conserve immature fish of this stock, catch limits are in place for individuals with a total length of 18 cm (body length of 15 cm) or less, but juveniles were caught in the 2016 and 2017 FYs, despite having been avoided in the past. Catches in the 2018 FY and after avoided juveniles again, and it is important to ensure that fishing pressure of juveniles remains at the current low level.

7. References

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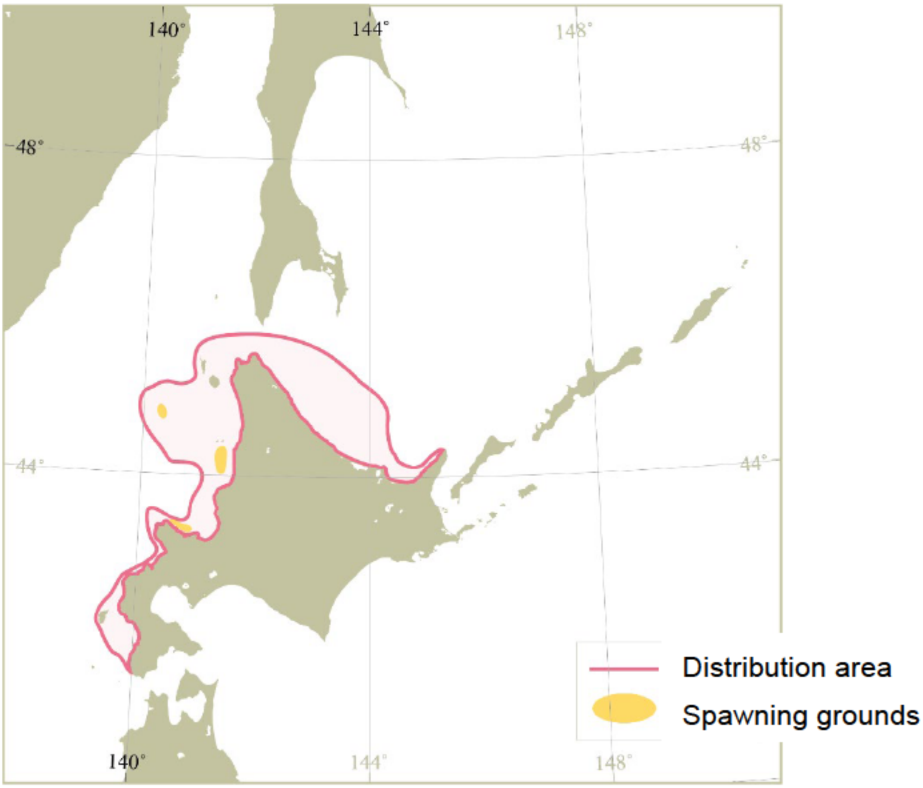


Fig. 2-1. Distribution of the northern Hokkaido stock of pointhead flounder

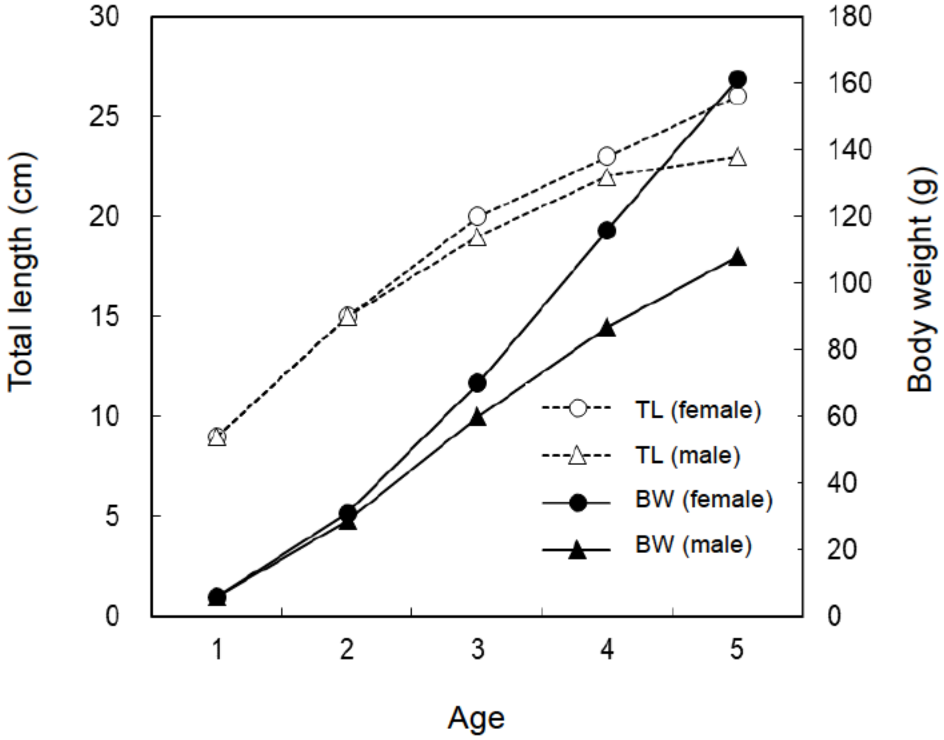


Fig. 2-2. Relationship between age and growth (values from Itaya and Fujioka (2006a))

TL: total length, BW: body weight.

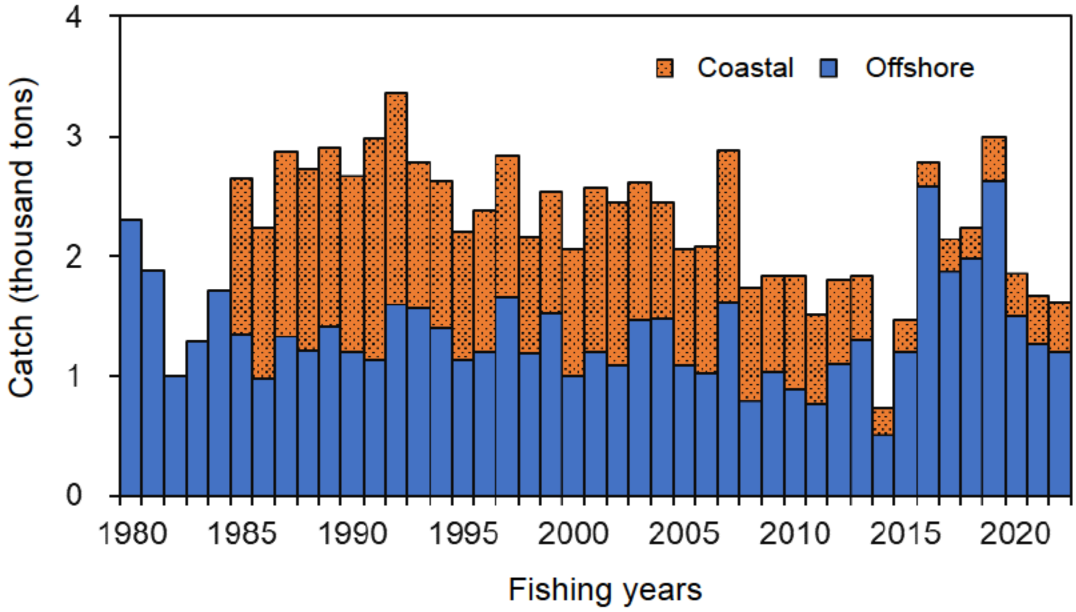


Fig. 3-1. Trends in catch (no coastal fishery catch data prior to the 1984 fishing year)
Fishing year is from August to July of the following year.

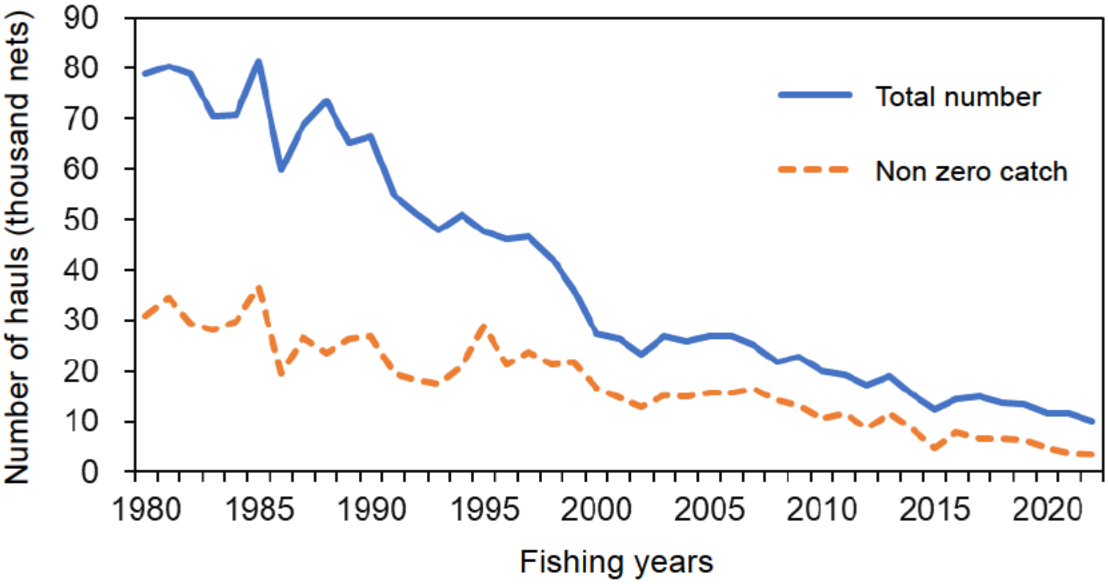
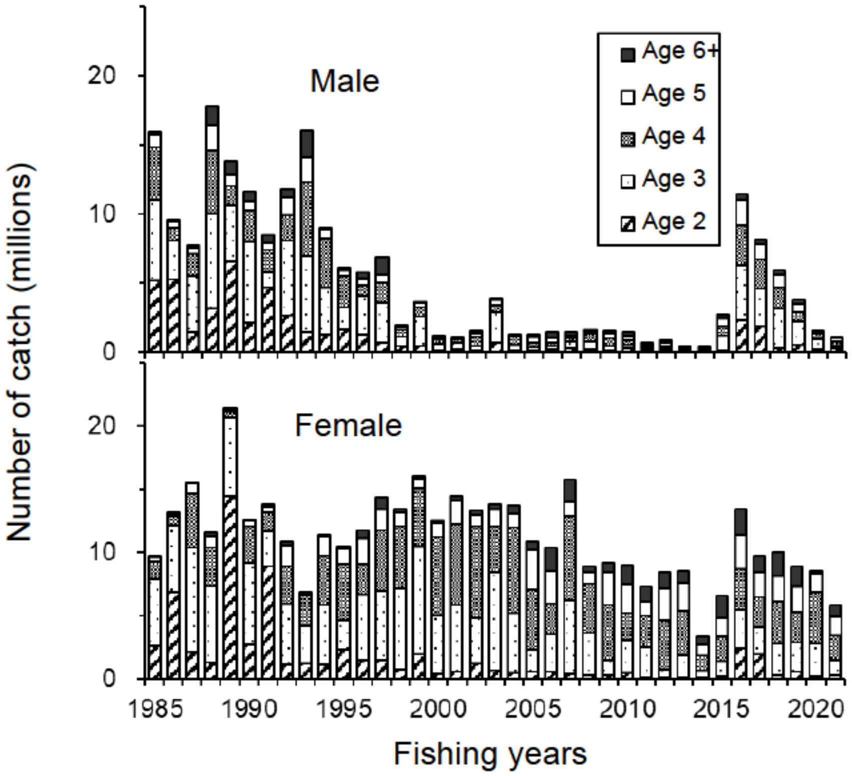


Fig. 3-2. Trends in fishing effort



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293 Fig. 3-3. Catch in number at age and by sex

294 Source: Central Fisheries Research Institute, Wakkanai Fisheries Research Institute (2023)

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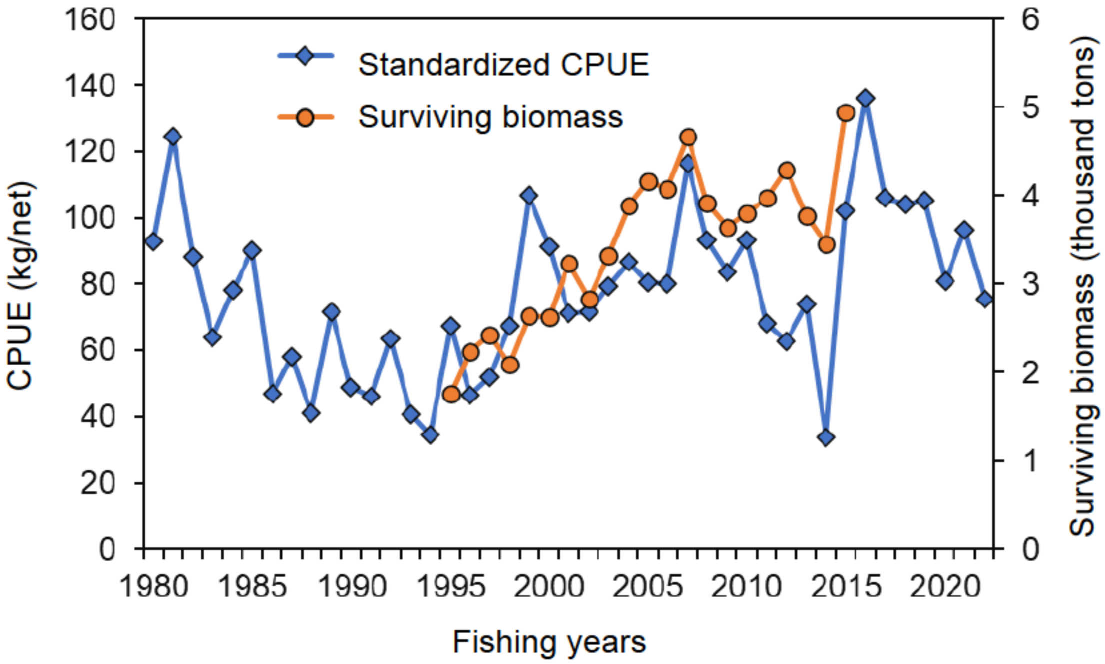

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298 Fig. 4-1. Standardized CPUE of offshore bottom trawl and surviving biomass of both sexes

299 calculated from the biomass of females as estimated using VPA

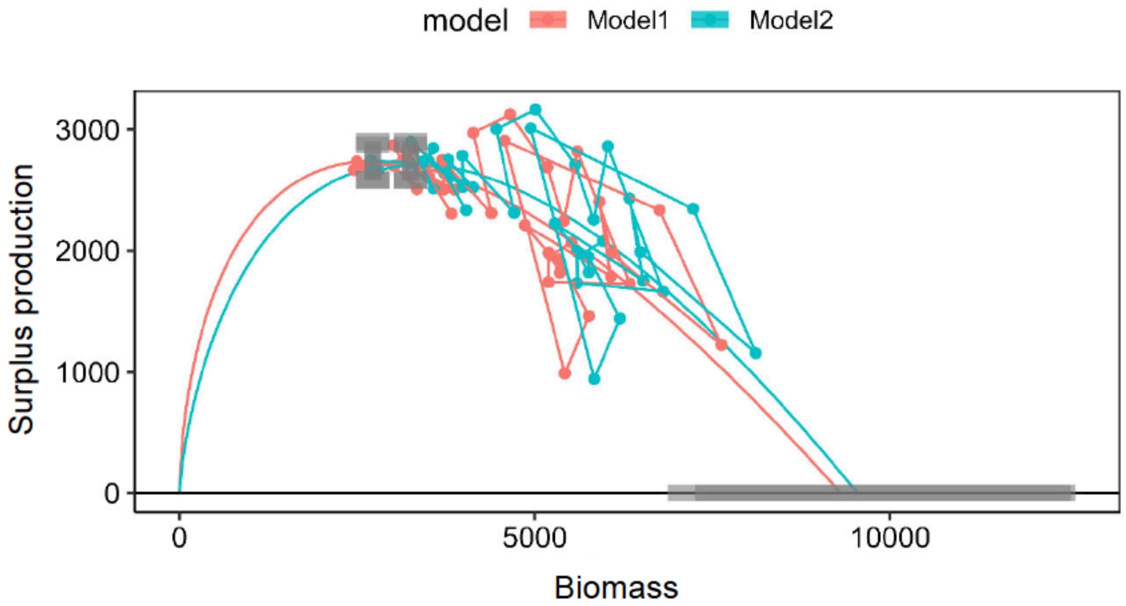


Fig. 4-2. Relationship of biomass and surplus production (surplus production curve), and trends in estimated surplus production in each fishing year

Grey shading indicates the 90% confidence interval.

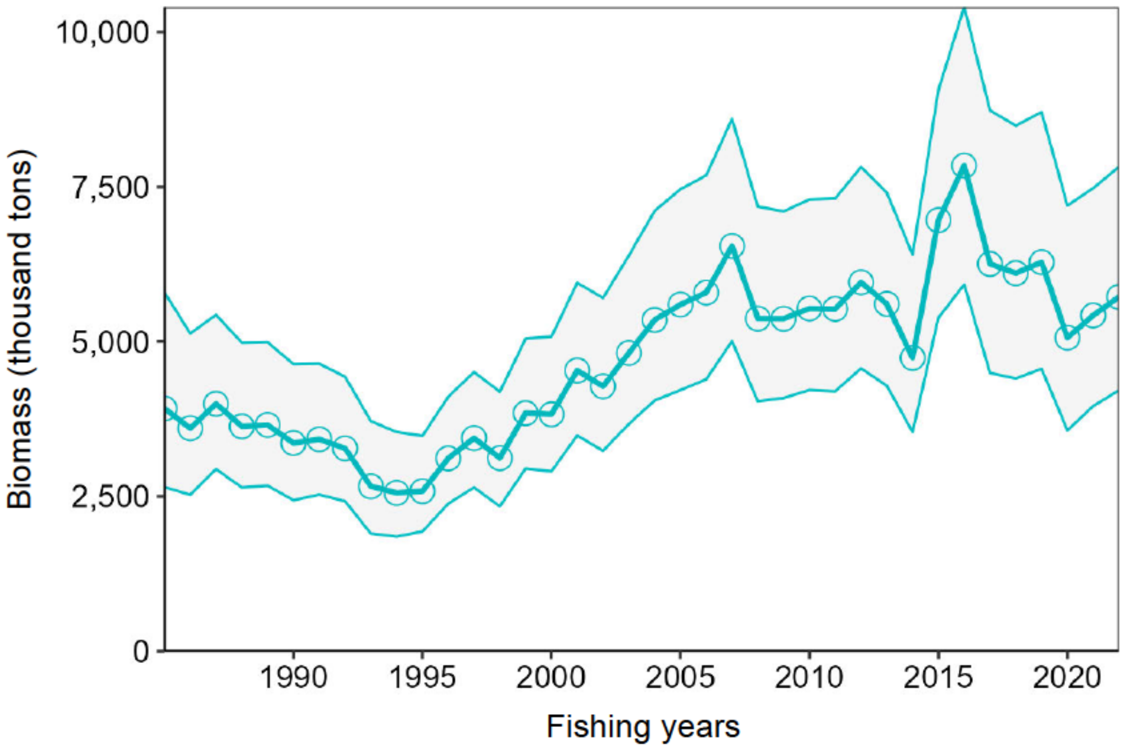


Fig. 4-3. Trends in biomass (thick solid line) and the 90% confidence interval (grey shading)

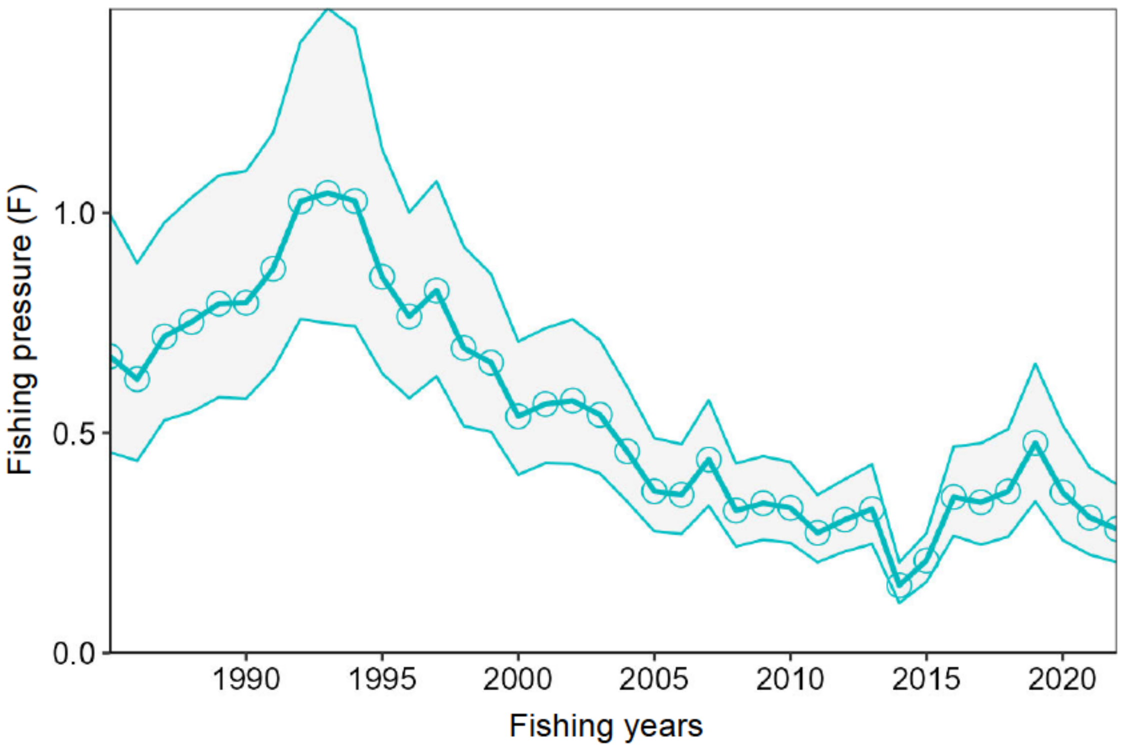


Fig. 4-4. Trends in fishing pressure (F) (thick solid line) and the 90% confidence interval (grey shading)

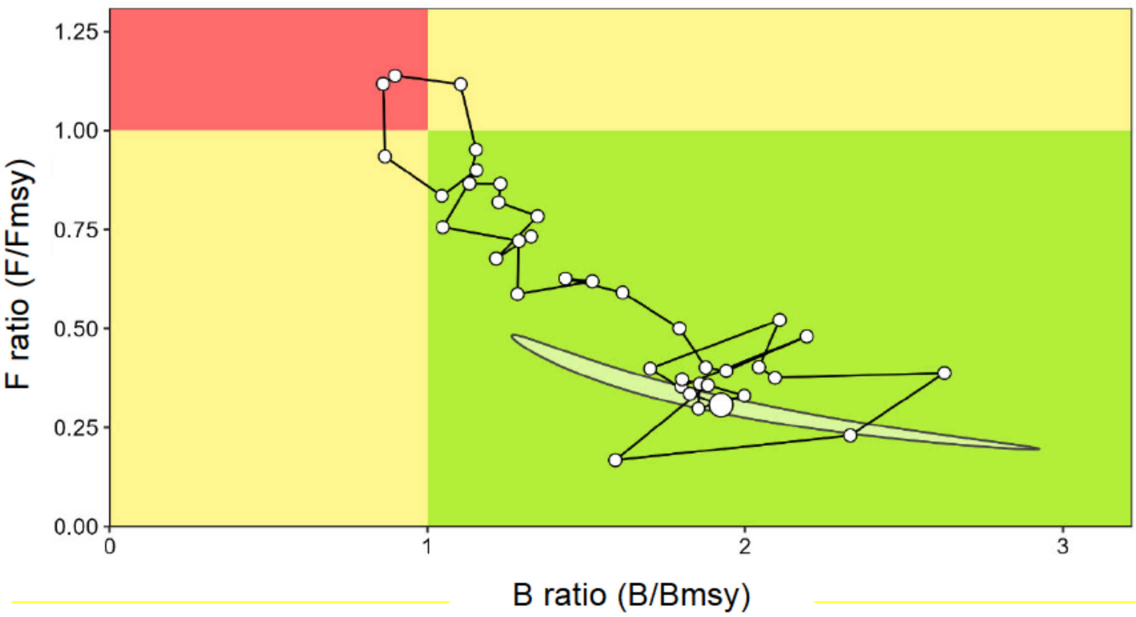


Fig. 4-5. Kobe plot

The large white circle indicates the relationship of biomass and fishing pressure in the 2022 fishing year. The shaded elliptical shape indicates the 90% confidence interval.

Table 3-1. Trends in catch (tons)

Fishing year	Offshore bottom trawl			Coast			Total
	Okhotsk	Sea of Japan	Subtotal	Okhotsk	Sea of Japan	Subtotal	
1980	196	2,106	2,302				
1981	102	1,781	1,883				
1982	137	860	997				
1983	112	1,176	1,288				
1984	296	1,417	1,713				
1985	122	1,231	1,353	17	1,271	1,287	2,640
1986	44	930	974	21	1,243	1,264	2,238
1987	36	1,293	1,329	21	1,523	1,544	2,873
1988	21	1,192	1,213	13	1,506	1,519	2,732
1989	199	1,219	1,419	35	1,446	1,481	2,900
1990	153	1,044	1,197	26	1,448	1,475	2,671
1991	74	1,057	1,130	36	1,824	1,860	2,990
1992	197	1,398	1,595	38	1,727	1,766	3,361
1993	39	1,522	1,561	40	1,185	1,224	2,785
1994	51	1,348	1,398	48	1,179	1,227	2,626
1995	119	1,021	1,140	115	954	1,069	2,209
1996	121	1,083	1,204	122	1,054	1,176	2,380
1997	105	1,556	1,661	66	1,109	1,175	2,836
1998	96	1,090	1,185	51	923	975	2,160
1999	174	1,344	1,518	69	949	1,018	2,536
2000	95	903	998	72	985	1,056	2,055
2001	87	1,111	1,198	69	1,299	1,367	2,566
2002	75	1,021	1,096	59	1,298	1,358	2,454
2003	108	1,362	1,470	91	1,048	1,139	2,609
2004	185	1,294	1,479	65	907	972	2,451
2005	143	952	1,095	45	917	962	2,058
2006	84	930	1,014	62	1,006	1,068	2,082
2007	134	1,487	1,621	81	1,175	1,256	2,877
2008	107	684	791	58	888	945	1,736
2009	45	985	1,030	45	752	797	1,827
2010	49	844	893	73	860	933	1,826
2011	47	708	756	57	694	751	1,506
2012	40	1,068	1,108	53	641	694	1,803
2013	40	1,251	1,291	43	502	545	1,836
2014	35	469	504	35	188	222	726
2015	69	1,133	1,202	49	212	261	1,463
2016	42	2,534	2,575	42	163	205	2,780
2017	17	1,853	1,871	78	195	273	2,144
2018	21	1,963	1,984	29	228	257	2,241
2019	18	2,605	2,622	58	320	378	3,001
2020	5	1,493	1,498	40	310	350	1,848

Table 3-1. Trends in catch (tons) (continued)

Fishing year	Offshore bottom trawl			Coast			Total
	Okhotsk	Sea of Japan	Subtotal	Okhotsk	Sea of Japan	Subtotal	
2021	3	1,257	1,260	50	357	408	1,668
2022	3	1,192	1,195	34	383	417	1,612

Fishing year is from August to July of the following year.

The aggregated range of offshore bottom trawl fisheries is the central ocean area of the Sea of Japan around Hokkaido, and the coast of the Sea of Okhotsk (excluding Russian waters).

The aggregated range of coastal fisheries is from Okushiri to Utoro.

Values for the 2021 and 2022 fishing years are provisional values.

No coastal fishery catch data prior to the 1984 fishing year.

Table 3-2. Trends in fishing effort of offshore bottom trawl fishery with Danish seine

Fishing year	Total number of hauls of all operations	Non-zero catches
1980	78,969	30,954
1981	80,436	34,367
1982	78,797	29,316
1983	70,562	28,173
1984	70,700	29,848
1985	81,513	36,748
1986	59,854	19,466
1987	68,669	26,526
1988	73,431	23,673
1989	65,273	26,468
1990	66,372	26,943
1991	54,789	19,565
1992	51,242	18,311
1993	48,004	17,590
1994	51,004	21,000
1995	47,703	28,776
1996	46,148	21,213
1997	46,631	23,758
1998	42,238	21,298
1999	36,246	21,863
2000	27,298	16,592
2001	26,268	14,716
2002	23,409	12,886
2003	26,888	15,311
2004	25,871	14,897
2005	26,818	15,690
2006	26,977	15,585
2007	25,206	16,472
2008	21,866	14,070
2009	22,693	13,123
2010	20,081	10,682
2011	19,310	11,614
2012	17,169	8,527
2013	19,018	11,525
2014	15,432	8,668
2015	12,334	4,757
2016	14,492	7,830
2017	14,961	6,600
2018	13,740	6,481
2019	13,388	6,243
2020	11,756	4,836
2021	11,584	3,874
2022	10,137	3,627

Values are for normal operations by month, by ocean area, and by vessel, excluding experimental operations. However, since the 2015 FY, some experimental operations have been included in normal operations.

Table 4-1. Trends in Abundance Indices

Fishing year	Standardized CPUE of offshore bottom trawl fishery (kg/net)	Surviving biomass D (tons)
1980	92.9	
1981	124.7	
1982	88.1	
1983	64.0	
1984	78.1	
1985	90.1	
1986	47.0	
1987	58.0	
1988	41.1	
1989	71.6	
1990	48.8	
1991	46.1	
1992	63.7	
1993	40.7	
1994	34.4	
1995	67.3	1,760
1996	46.5	2,233
1997	51.9	2,428
1998	67.2	2,096
1999	106.7	2,640
2000	91.2	2,626
2001	71.1	3,242
2002	71.7	2,835
2003	79.2	3,322
2004	86.6	3,890
2005	80.5	4,162
2006	80.1	4,081
2007	116.5	4,669
2008	93.3	3,919
2009	83.8	3,645
2010	93.1	3,807
2011	68.0	3,972
2012	62.7	4,294
2013	74.0	3,767
2014	33.7	3,453
2015	102.0	4,944
2016	136.3	
2017	105.9	
2018	104.3	
2019	105.1	
2020	80.9	
2021	96.5	
2022	75.4	

Table 4-2. Biomass and fishing pressure required for MSY (typical values and the 90% confidence interval)

Item	Biomass (thousand tons)	Ratio to carrying capacity	Fishing pressure	Anticipated catch (thousand tons)	Ratio to current fishing pressure
Biomass required for MSY (Bmsy)	3.0 (1.8 to 4.4）	0.32 (0.19 to 0.45)	0.92 (0.62 to 1.52)	2.7 (2.6 to 2.9)	3.26 (2.44 to 4.85)

Table 4-3. Estimated biomass and fishing pressure (typical values and the 90% confidence interval)

Fishing year	Biomass (thousand tons)			Fishing pressure		
	Lower Limit	Typical values	Upper Limit	Lower Limit	Typical values	Upper Limit
1985	2.6	3.9	5.8	0.46	0.67	1.00
1986	2.5	3.6	5.1	0.44	0.62	0.89
1987	2.9	4.0	5.4	0.53	0.72	0.98
1988	2.6	3.6	5.0	0.55	0.75	1.03
1989	2.7	3.7	5.0	0.58	0.79	1.09
1990	2.4	3.4	4.6	0.58	0.80	1.09
1991	2.5	3.4	4.6	0.64	0.87	1.18
1992	2.4	3.3	4.4	0.76	1.03	1.39
1993	1.9	2.7	3.7	0.75	1.05	1.47
1994	1.8	2.6	3.5	0.74	1.03	1.42
1995	1.9	2.6	3.5	0.64	0.85	1.15
1996	2.4	3.1	4.1	0.58	0.76	1.00
1997	2.6	3.4	4.5	0.63	0.82	1.07
1998	2.3	3.1	4.2	0.52	0.69	0.92
1999	2.9	3.8	5.0	0.50	0.66	0.86
2000	2.9	3.8	5.1	0.41	0.54	0.71
2001	3.5	4.5	5.9	0.43	0.57	0.74
2002	3.2	4.3	5.7	0.43	0.57	0.76
2003	3.7	4.8	6.4	0.41	0.54	0.71
2004	4.0	5.3	7.1	0.34	0.46	0.61
2005	4.2	5.6	7.5	0.28	0.37	0.49
2006	4.4	5.8	7.7	0.27	0.36	0.47
2007	5.0	6.5	8.6	0.33	0.44	0.57
2008	4.0	5.4	7.2	0.24	0.32	0.43
2009	4.1	5.4	7.1	0.26	0.34	0.45
2010	4.2	5.5	7.3	0.25	0.33	0.43
2011	4.2	5.5	7.3	0.21	0.27	0.36
2012	4.6	6.0	7.8	0.23	0.30	0.39
2013	4.3	5.6	7.4	0.25	0.33	0.43
2014	3.5	4.7	6.4	0.11	0.15	0.21
2015	5.4	7.0	9.1	0.16	0.21	0.27
2016	5.9	7.8	10.4	0.27	0.35	0.47
2017	4.5	6.3	8.7	0.25	0.34	0.48
2018	4.4	6.1	8.5	0.26	0.37	0.51
2019	4.6	6.3	8.7	0.34	0.48	0.66
2020	3.6	5.1	7.2	0.26	0.37	0.52
2021	4.0	5.4	7.5	0.22	0.31	0.42
2022	4.2	5.7	7.8	0.21	0.28	0.38

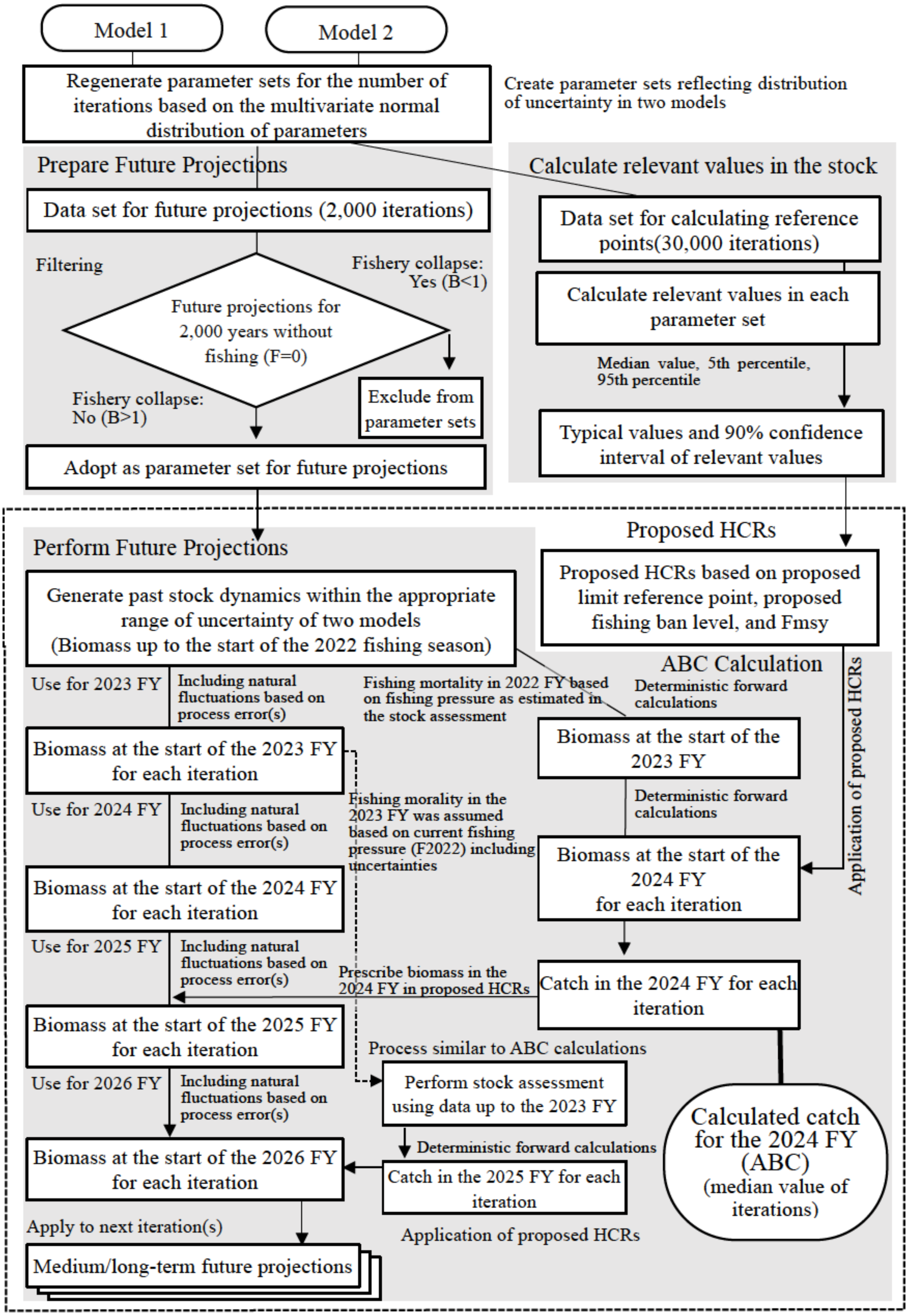
Table 4-4. Ratio of biomass to Bmsy, and ratio of fishing pressure to Fmsy (typical values and the 90% confidence interval)

Fishing year	B/Bmsy			F/Fmsy		
	Lower Limit	Typical values	Upper Limit	Lower Limit	Typical values	Upper Limit
1985	0.87	1.33	2.20	0.43	0.73	1.13
1986	0.85	1.22	1.90	0.42	0.68	0.98
1987	0.98	1.35	2.03	0.51	0.78	1.10
1988	0.92	1.22	1.80	0.54	0.82	1.12
1989	0.93	1.23	1.80	0.58	0.87	1.17
1990	0.87	1.13	1.63	0.59	0.87	1.15
1991	0.89	1.15	1.64	0.65	0.95	1.26
1992	0.87	1.10	1.56	0.77	1.12	1.46
1993	0.71	0.90	1.24	0.80	1.14	1.47
1994	0.68	0.86	1.21	0.77	1.12	1.45
1995	0.69	0.87	1.25	0.63	0.93	1.22
1996	0.82	1.05	1.53	0.55	0.83	1.10
1997	0.91	1.15	1.69	0.60	0.90	1.19
1998	0.83	1.05	1.51	0.51	0.76	0.99
1999	1.01	1.29	1.88	0.48	0.72	0.95
2000	1.02	1.28	1.86	0.39	0.59	0.77
2001	1.20	1.52	2.20	0.42	0.62	0.81
2002	1.14	1.43	2.07	0.42	0.63	0.82
2003	1.28	1.61	2.33	0.40	0.59	0.77
2004	1.42	1.79	2.59	0.34	0.50	0.65
2005	1.48	1.88	2.72	0.27	0.40	0.53
2006	1.54	1.94	2.80	0.27	0.39	0.51
2007	1.74	2.19	3.17	0.32	0.48	0.63
2008	1.43	1.80	2.61	0.24	0.35	0.46
2009	1.43	1.80	2.60	0.25	0.37	0.49
2010	1.47	1.86	2.68	0.24	0.36	0.47
2011	1.47	1.85	2.68	0.20	0.30	0.39
2012	1.59	2.00	2.88	0.22	0.33	0.43
2013	1.50	1.88	2.71	0.24	0.36	0.47
2014	1.25	1.59	2.30	0.11	0.17	0.22
2015	1.84	2.33	3.40	0.15	0.23	0.30
2016	1.99	2.63	3.96	0.25	0.39	0.52
2017	1.56	2.09	3.22	0.24	0.38	0.51
2018	1.54	2.04	3.11	0.26	0.40	0.55
2019	1.60	2.11	3.17	0.34	0.52	0.71
2020	1.29	1.70	2.53	0.26	0.40	0.54
2021	1.41	1.83	2.66	0.23	0.33	0.45
2022	1.48	1.92	2.79	0.21	0.31	0.41

Table 4-5. Stock analysis results (typical value)

FY	Catch (thousand tons)	Biomass (thousand tons)	Fishing pressure (F)	B/Bmsy	F/Fmsy
1985	2.6	3.9	0.68	1.33	0.73
1986	2.2	3.6	0.62	1.22	0.68
1987	2.9	4.0	0.72	1.35	0.78
1988	2.7	3.6	0.75	1.22	0.82
1989	2.9	3.7	0.80	1.23	0.87
1990	2.7	3.4	0.80	1.13	0.87
1991	3.0	3.4	0.88	1.15	0.95
1992	3.4	3.3	1.03	1.10	1.12
1993	2.8	2.7	1.05	0.90	1.14
1994	2.6	2.6	1.04	0.86	1.12
1995	2.2	2.6	0.86	0.87	0.93
1996	2.4	3.1	0.76	1.05	0.83
1997	2.8	3.4	0.82	1.15	0.90
1998	2.2	3.1	0.70	1.05	0.76
1999	2.5	3.8	0.67	1.29	0.72
2000	2.1	3.8	0.54	1.28	0.59
2001	2.6	4.5	0.56	1.52	0.62
2002	2.5	4.3	0.59	1.43	0.63
2003	2.6	4.8	0.54	1.61	0.59
2004	2.4	5.3	0.45	1.79	0.50
2005	2.1	5.6	0.36	1.88	0.40
2006	2.1	5.8	0.36	1.94	0.39
2007	2.9	6.5	0.44	2.19	0.48
2008	1.7	5.4	0.32	1.80	0.35
2009	1.8	5.4	0.34	1.80	0.37
2010	1.8	5.5	0.33	1.86	0.36
2011	1.5	5.5	0.27	1.85	0.30
2012	1.8	6.0	0.30	2.00	0.33
2013	1.8	5.6	0.33	1.88	0.36
2014	0.7	4.7	0.15	1.59	0.17
2015	1.5	7.0	0.21	2.33	0.23
2016	2.8	7.8	0.35	2.63	0.39
2017	2.1	6.3	0.34	2.09	0.38
2018	2.2	6.1	0.37	2.04	0.40
2019	3.0	6.3	0.48	2.11	0.52
2020	1.8	5.1	0.37	1.70	0.40
2021	1.7	5.4	0.31	1.83	0.33
2022	1.6	5.7	0.28	1.92	0.31

Appendix 1 Flow of Analysis



*Steps inside the dotted line box are developed based on discussion by the stakeholder meeting.

Appendix 2 Calculation Methods

The status of this stock was assessed by stock analysis using SPiCT, which is a Pella-Tomlinson state-space surplus production model (a stochastic state-space surplus production model in continuous time: Pedersen and Berg 2017). Generally, estimated values from SPiCT were the basis for proposed target reference points such as the biomass required for MSY (Bmsy) and the upper limit of fishing pressure in HCRs (Fmsy). The basic equations and parameters used in SPiCT are shown below.

(1) State-space surplus production model

State model

In SPiCT, changes over time in biomass (state model), which cannot be observed directly, are described as follows.

$$dB_t = \frac{r}{n-1} B_t \left(1 - \left[\frac{B_t}{K}\right]^{n-1}\right) dt - F_t B_t dt + \sigma_B B_t dW_t \tag{1}$$

In this equation, B_t is biomass at time t, F_t is fishing mortality at time t, r is the intrinsic growth rate, and K is the carrying capacity. In addition, $\sigma_B B_t dW_t$ is the process error, σ_B is the standard deviation of the process error, and W_t is the Brownian motion. Then, n is the shape parameter that determines the shape of the surplus production curve, and a larger parameter indicates a greater relative position of Bmsy (biomass required for MSY) compared to carrying capacity. Generally, there is a strong relationship between r and K, and Fletcher's (1978) adjustments to Equation (2) allow for more stable estimates.

$$dB_t = \left(\gamma m \frac{B_t}{K} - \gamma m \left[\frac{B_t}{K}\right]^n - F_t B_t\right) dt + \sigma_B B_t dW_t \tag{2}$$

In this equation, γ is defined in Equation (3), and m is defined in Equation (4).

$$\gamma = n^{n/(n-1)}/(n-1) \tag{3}$$

$$m = \frac{rK}{n^{n/(n-1)}} \tag{4}$$

For a parameter relating to biomass in the first year of the stock assessment period, *bkfrac*, which is the ratio of biomass in the first FY to the carrying capacity, can be found indirectly. Deterministic ($\sigma_B = 0$) population dynamics presume that m corresponds to MSY as described in Equation (5). In addition, deterministic Bmsy and Fmsy are described in Equation (6) and (7), respectively.

$$MSY^d = m \tag{5}$$

$$B_{msy}^d = n^{1/(1-n)} K \tag{6}$$

$$F_{msy}^d = m/B_{msy} \tag{7}$$

Meanwhile, stochastic MSY, Bmsy, and Fmsy are described in Equation (8), (9), and (10), respectively.

$$MSY^s = MSY^d \left(1 - \frac{n/2}{1-\left(1-F_{msy}^d\right)^2} \sigma_B^2\right) \tag{8}$$

$$B_{msy}^s = B_{msy}^d \left(1 - \frac{1+F_{msy}^d (n-2)/2}{F_{msy}^d - \left(2-F_{msy}^d\right)^2} \sigma_B^2\right) \tag{9}$$

$$F_{msy}^{s} = F_{msy}^{d} - \frac{(n-1)(1-F_{msy}^{d})}{\left(2-F_{msy}^{d}\right)^{2}}\sigma_B^2 \tag{10}$$

When the shape parameter n is less than 1, then stochastic MSY, Bmsy, and Fmsy estimates become unstable. Following the recommendation of Pedersen and Berg (2017), stochastic values were used when n>1, and deterministic values were used when 0<n≤1.

SPiCT allows for development of models for the process of seasonal fishing, as described in Equation (11) and (12), which makes it possible to divide a 1 year period into shorter increments to perform calculations.

$$F_t = S_t G_t \tag{11}$$

$$d\log G_t = \sigma_F dV_t \tag{12}$$

This equation shows the composition of fishing mortality F_t, when S_t is seasonal changes in catch, and G_t is a random effect. In addition, σ_F is the standard deviation relating to noise in fishing mortality, and V_t is the Brownian motion. When developing models for seasonal changes in catch, other methods are available, such as assuming that S_t follows a periodic B-spline curve.

Observation model

Index values used to estimate parameters in SPiCT can be processed using the following observation model.

$$\log\left(I_{t,i}\right) = \log(q_i B_t) + e_{t,i} \tag{13}$$

$$e_{t,i} \sim N\left(0, \sigma_{I,i}^2\right) \tag{14}$$

SPiCT allows for the use of multiple index values. In this equation, $I_{t,i}$ is the value of the number i index value at time t, and q_i is the catchability parameter for the number i index value. Next, $e_{t,i}$ is the observational error of the number i index value, and $\sigma_{I,i}$ is the standard deviation.

SPiCT can also handle errors in aggregated catch by estimating catch as a value which cannot be observed directly using Equation (15) and (16).

$$\log(C_t) = \log\left(\int_t^{t+\Delta} F_s B_s ds\right) + \epsilon_t \tag{15}$$

$$\epsilon_t \sim N(0, \sigma_C^2) \tag{16}$$

In this equation, ϵ_t is the observational error of catch, and σ_C is the standard deviation. However, in the model for this stock, it was assumed that the observed error of catch was quite small (fixed at σ_C = 0.01).

Estimated stock assessment parameters

SPiCT can also estimate surplus production model parameters using the penalized maximum likelihood method, which is a type of Bayesian estimation. For this stock, *n*, *m*, *K*, q_i, B_t, F_t, σ_B, $\sigma_{I,i}$, σ_F, and *bkfrac* are estimated values. The estimated intrinsic growth rate (*r*) can be found using estimates for *n*, *m*, and *K* in Equation (17).

$$r = m\left(\frac{K}{n^{(n/(n-1))}}\right)^{-1} \tag{17}$$

Prior distribution can be used as prior information before estimating each parameter, or it can be used as a prior known parameter.

(2) Available data and model settings in this stock assessment

Data Sets

Catch values used in the surplus production model were based on aggregated catch data from the 1985 to 2022 FYs. As previously mentioned, SPiCT estimates can assume that catch also includes errors, but in the model for this stock, it was assumed that the observed error of catch was quite small. The surviving biomass in the 1995 to 2015 FYs *(D)* was used as the index value I_1, specifically, the biomass of females as estimated by the HRO using VPA (Central and Wakkanai Fisheries Research Institutes, 2023) was converted for use in surplus production models. This is because biomass as estimated by the VPA follows a different definition than biomass as estimated by the surplus production model. Biomass based on the VPA represents the population size based on the population growth (maturity and recruitment) in a certain year, before the impact of fishing in that year. Meanwhile, biomass based on the surplus production model represents the population size in a certain year before the addition of surplus production, and before the impact of fishing in that year. In the VPA, this is equivalent to the surviving biomass after decrease due to the impact of fishing and natural mortality in the previous year (Supplementary Fig. 2-1). In this study, the surviving biomass$D$ for each year was calculated using the following equation in order to compare the VPA results with the surplus production model.

$$D_y = (B_{y-1} \cdot e^{\left(-\frac{M}{2}\right)} - C_{y-1})e^{\left(-\frac{M}{2}\right)} \tag{18}$$

In this equation, B_y is biomass in year y as estimated based on the VPA, C_y is catch in year y, M is the natural mortality (0.25) assumption for analysis using the VPA, and D corresponds to biomass as estimated in the surplus production model. Because the biomass of females in this stock is estimated using the VPA, it is necessary to add the biomass of males to By. This analysis assumed that the population ratio of males to females is 1:1, and the body weight ratio is 1:0.8, so the combined biomass of males and females is the female biomass multiplied by 1.8. In addition, because the catch status of males in this stock varies greatly from year to year, we anticipate that the assumptions above will mean a large discrepancy in data for some years. Accordingly, the biomass was estimated by VPA using data from the 1994 to 2014 FYs, when the catch status of males was relatively low and stable, and the result was used in the equation above to calculate D in the 1995 to 2015 FYs. Then, it was used for the index value I_1 in analysis. As described above, the combined biomass of males and females was found using the estimated biomass of females with an assumption for the sex ratio, and was then used as an index value, so it is important to stay aware that uncertainty in the assumption for sex ratio might lead to uncertainty in estimated results. The standardized CPUE for offshore bottom trawl fishery with Danish seine was reviewed, and the values were scaled so the mean value in the 1985 to 2022 FYs (same FYs as aggregated catch) was equal to 1, and the result was used for the index value I_2. Details about standardized CPUE are described in "CPUE standardization for the northern Hokkaido stock of pointhead flounder in offshore danish seine fishery in 2023" (FRA-SA2023-SC16-101) (Chiba et al. 2023).

SPiCT makes it possible to divide a year period into shorter increments to include seasonal data in the model, but for this stock, only one data set is used for the full year of catch and index values, so seasonal data is not included in the model. Therefore, the time increments in the model are set to match the 12 month increments of population dynamics, which is the same as a typical discrete surplus production model ($S_t = 1$ in Equation 11).

Prior distribution of parameters

SPiCT uses the penalized maximum likelihood method, which is a type of Bayesian estimation, so it can assign prior distribution when estimating parameters. In general, the shape parameter (n) is often difficult to estimate, so this analysis was attempted using the prior mean (n = 2.00). Likewise, the prior mean for the intrinsic growth rate (r) was based on FishLife (Thorson 2020) (r = 0.32). In addition, in each model, the mean value was used as the catchability parameter for the index valueI_1 ($q_1 = 1$), and another mean value was used as prior information for the magnitude of the observation error ($\sigma_{I1} = 0.15$). Details about sensitivity analysis when the catchability parameter (q_1) and the magnitude of observation error (σ_{I1}) are assigned as prior information are described in the previous fiscal year's report, "Stock analysis for the northern Hokkaido stock of pointhead flounder using state-space surplus production model in 2022" (FRA-SA2022-SC08-201) (Chiba et al. 2022). The values q_2, σ_B, $\sigma_{I,2}$, σ_F, *and bkfrac* were estimated without assigning prior distribution.

(3) Model diagnostics results

Judging validity of estimated values

Following the "Guideline for application of state-space surplus production models to Japanese resources" (FRA-SA2023-ABCWG02-07) (Japan Fisheries Research and Education Agency 2023), no major problems were identified in the model convergence conditions or the stability/validity of estimated parameters in the following two models taken from stock calculation results using SPiCT, so these models were judged to obtain appropriate estimated values, and they were adopted as the base case models for this stock assessment. Model 1 uses a wide prior distribution which assumes a log-normal distribution with a standard deviation of 1, while Model 2 uses a narrow prior distribution with a standard deviation of 0.50, and these models were used to estimate parameters. Each model used the standard deviation of 0.30 for the catchability parameter q_1, and the standard deviation of 0.50 for the magnitude of the observation error σ_{I1}. Results for estimated parameters are shown in Supplementary Table 2-1. In addition, estimated values for biomass and fishing pressure in each model are shown in Supplementary Table 2-2.

Model Diagnostics

The results of retrospective analysis showed that estimated values could be obtained for every year in both of the base case models, and that there was no significant retrospective bias in the biomass to Bmsy ratio (Mohn's ρ = −0.02 to −0.01) (Supplementary Fig. 2-2). Likewise, there was no significant retrospective bias in the fishing pressure to Fmsy ratio (Mohn's ρ = 0.01 to 0.02). There was no significant difference in the retrospective bias between the models.

Residual analysis was performed to check the fit of index values, and in both models, the residuals fit well with the assumption of normal distribution, and there were no significant autocorrelation patterns (Supplementary Fig. 2-3). The relationship of index values and biomass (estimated based on the merged results from the two base case models, as discussed below) was reviewed, and it was observed that index value 1 (surviving biomass) and estimated biomass followed the same trends (Supplementary Fig. 2-4). It is believed that there are no specific problems in model estimates using these index values.

Factor analysis was performed to examine whether estimated fluctuations in biomass are impacted by surplus production, catch, and/or process error(s). Although many points concerning fluctuations in biomass can be explained by surplus production and catch, there were very few fluctuations that could be explained by process error(s) (Supplementary Fig. 2-5).

(4) Merger of base case model results

Due to the framework of the surplus production models, values for biomass and fishing pressure relating to MSY (including Bmsy and Fmsy) are updated in every stock assessment. Values related to these reference points were found by merging the results from the two base case models. Next, relevant values in the stock assessment were found by merging the results from the two base case models. Calculations for merged results were performed, and a variance-covariance matrix was created for estimated parameters in each model. Then, the parameter sets were regenerated with consideration for relationships between parameters. Specifically, the fixed effect parameters were n, m, K, σ_B, σ_C, σ_F, $\sigma_{I,1}$, $\sigma_{I,2}$, q_1, and q_2, and the random effect parameters were logarithmic values for B and F in the 1985 to 2022 FYs. The parameter sets containing these values were randomly generated for the number of iterative calculations based on a multivariate normal distribution, and these were used to obtain the stock dynamics, and the parameter sets, included in the range of uncertainty in estimates from both models. The variance used for multivariate normal distribution was the variance-covariance matrix (inverse precision matrix) estimated in each model. This study used the median values, the 5th percentile, and the 95th percentile of the parameter sets for the number of iterations which were generated from the two base case models to find the typical values and the 90% confidence interval. The number of iterations for calculating relevant values in the stock assessment was 30,000. The Kobe plot in Fig. 4-5 shows the combined results for both of the two base case models used in the stock assessment. There is also a color-coded Kobe plot for each base case model in Supplementary Fig. 2-6. Similar results were obtained from both of the two base case models used in the stock assessment, and it was estimated that the biomass to Bmsy ratio (B/Bmsy) in the most recent year exceeds 1, including the 90% confidence interval, and that the fishing pressure to Fmsy ratio (F/Fmsy) in the most recent year is less than 1, including the 90% confidence interval. Although stock statuses in previous years did not include a confidence interval in the Kobe plots, it should be kept in mind that the confidence interval(s) are available, just like the most recent year, as shown in Supplementary Fig. 2-7.

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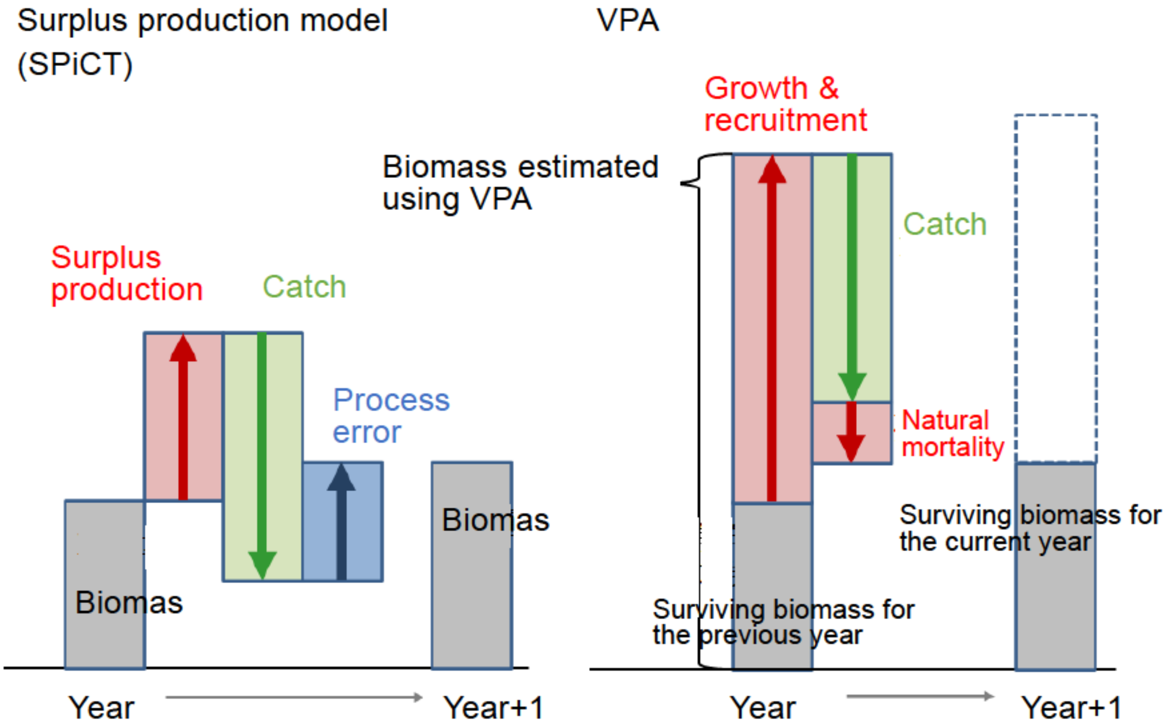
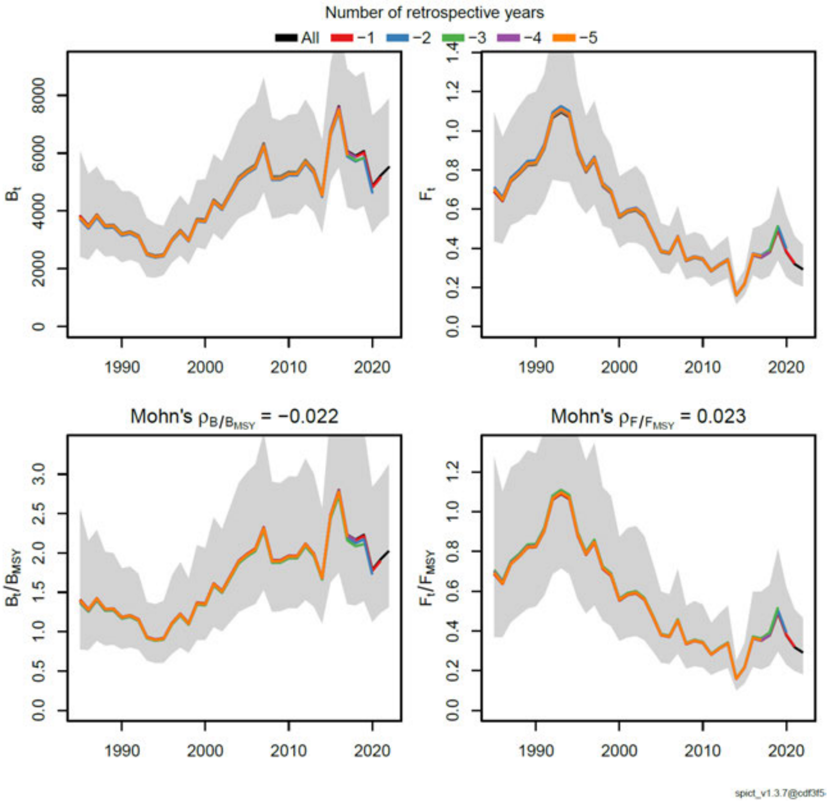
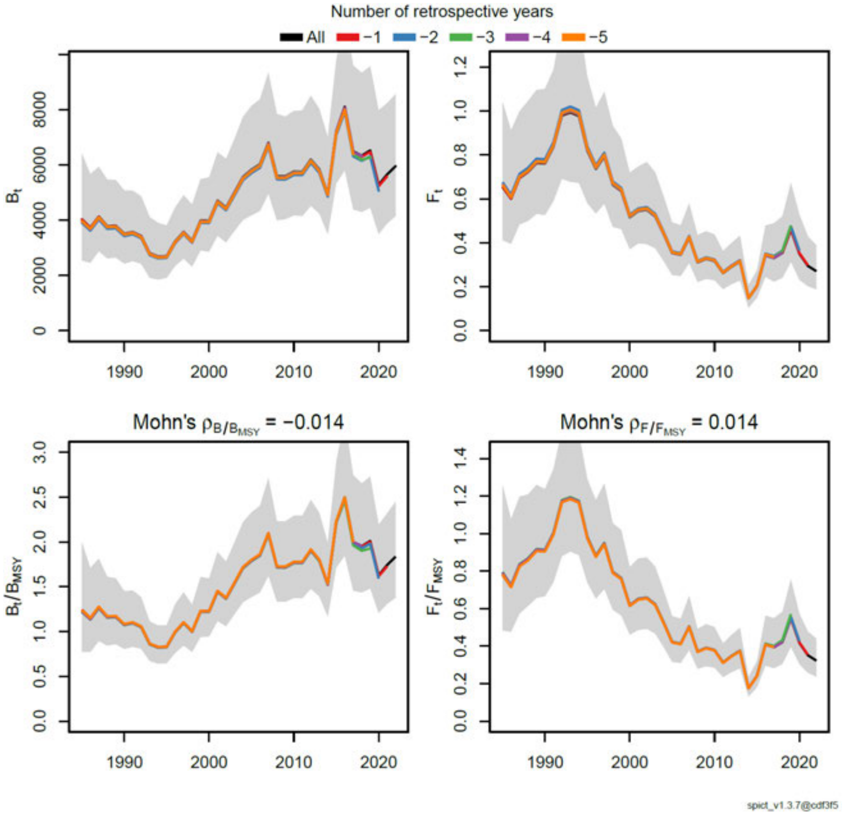


Supplementary Fig. 2-1. Concept diagram of biomass estimated using a surplus production model (SPiCT) and VPA

A) Model 1

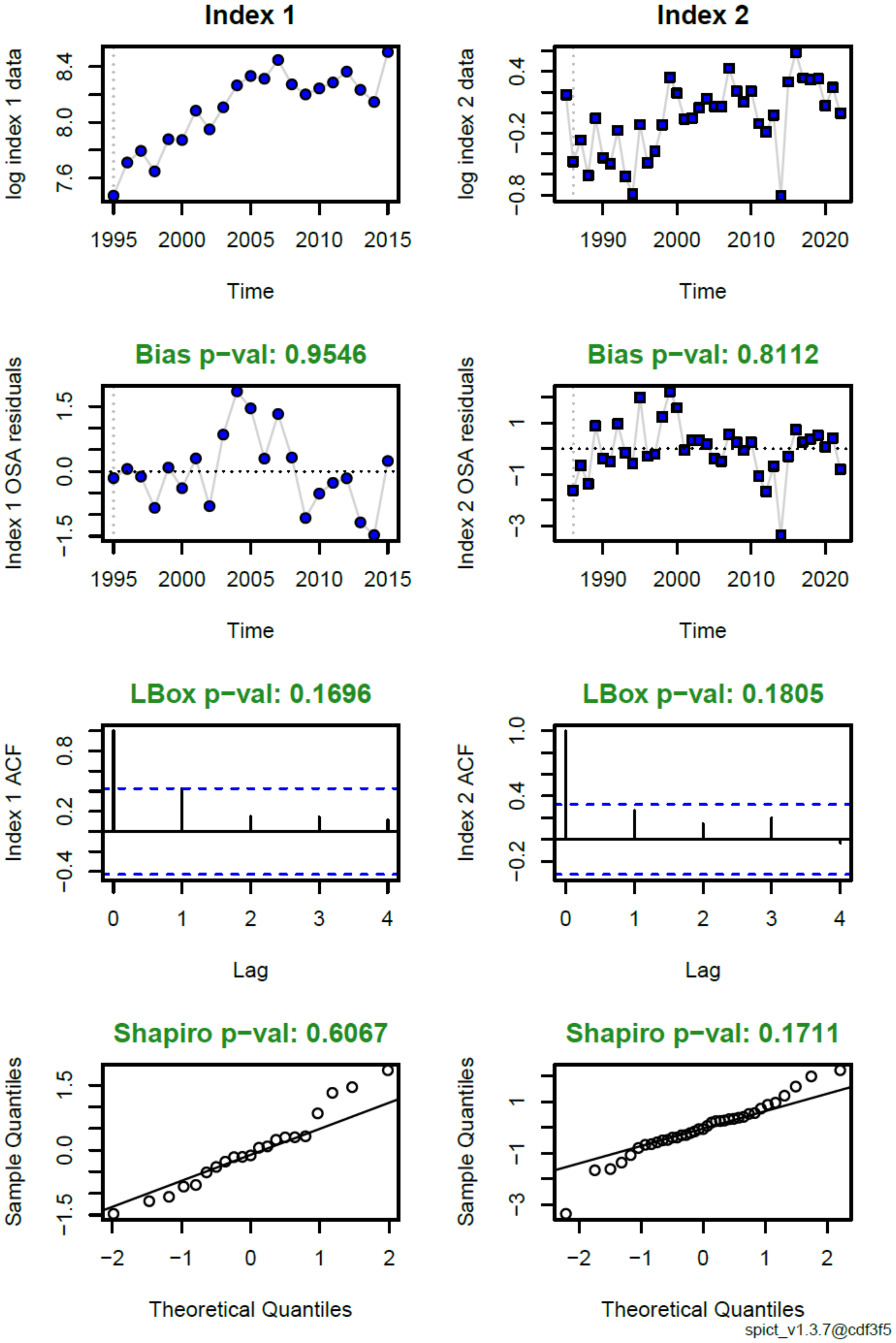


B) Model 2



Supplementary Fig. 2-2. Results of retrospective analysis

604 A) Model 1



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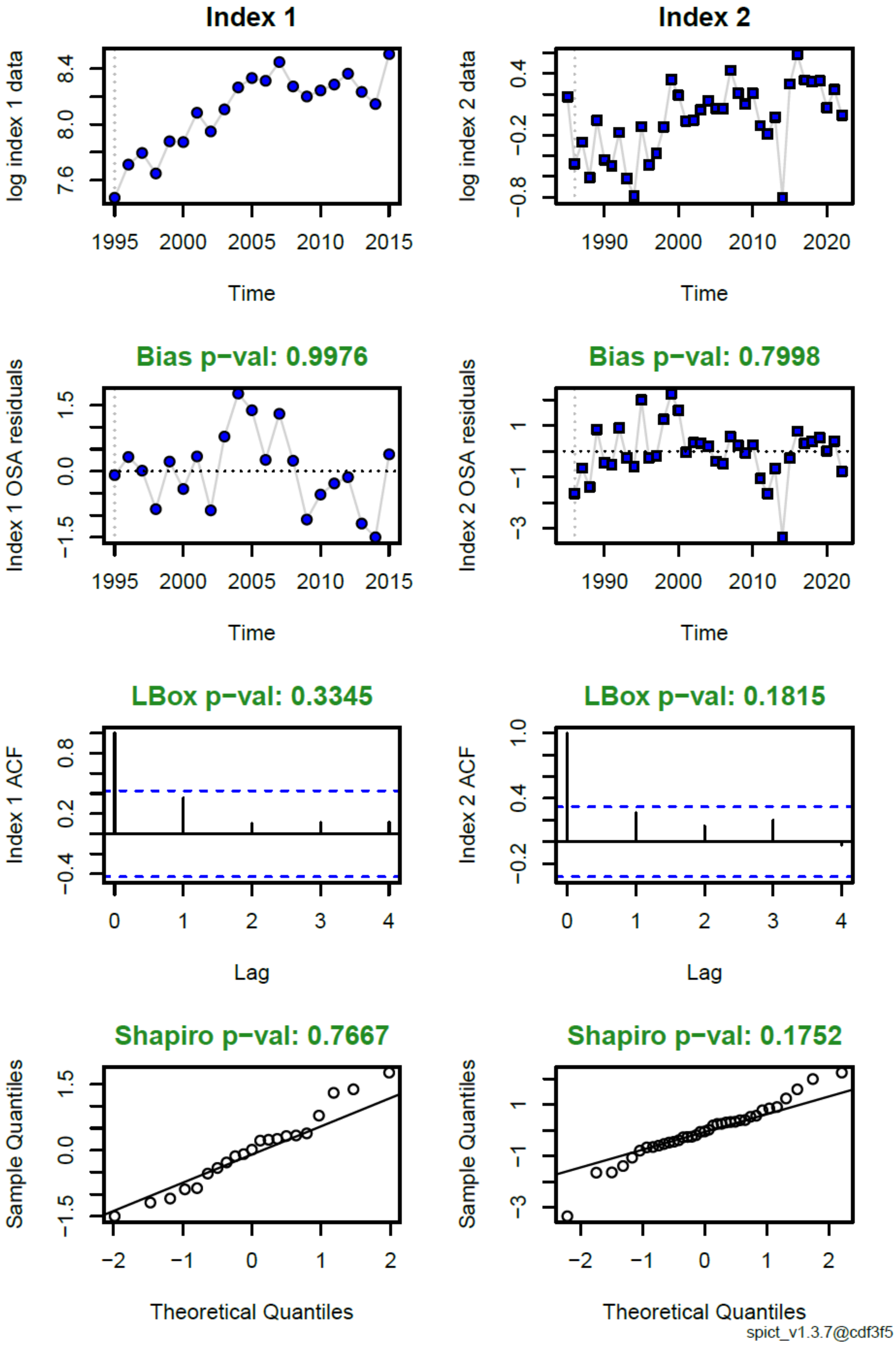
606 Supplementary Fig. 2-3. Residual analysis of index values

607 B) Model 2



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609 Supplementary Fig. 2-3. Residual analysis of index values (continued)

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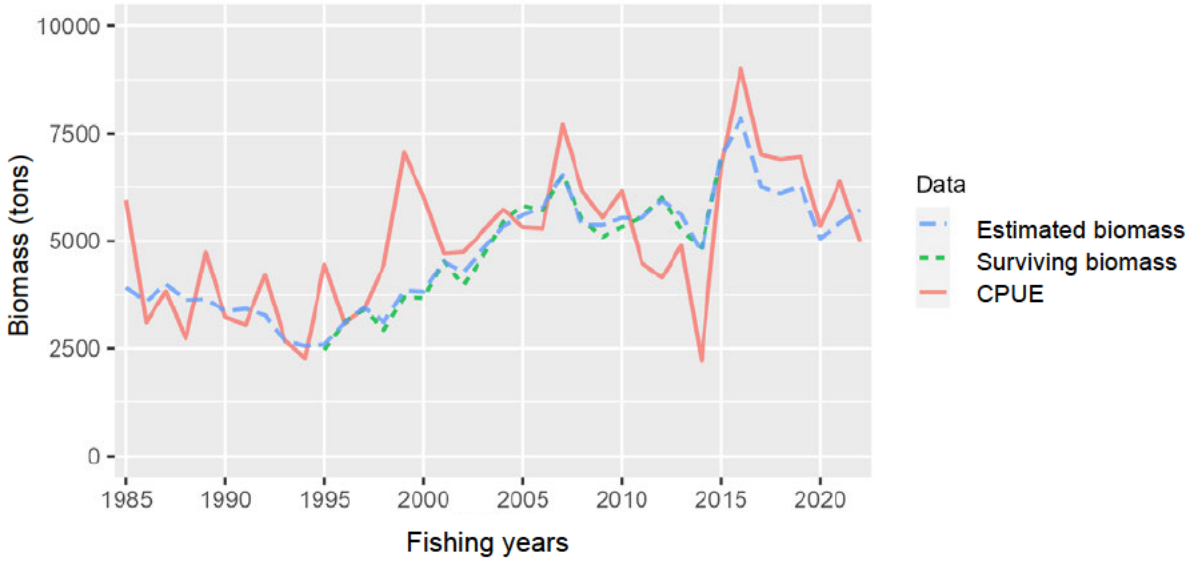
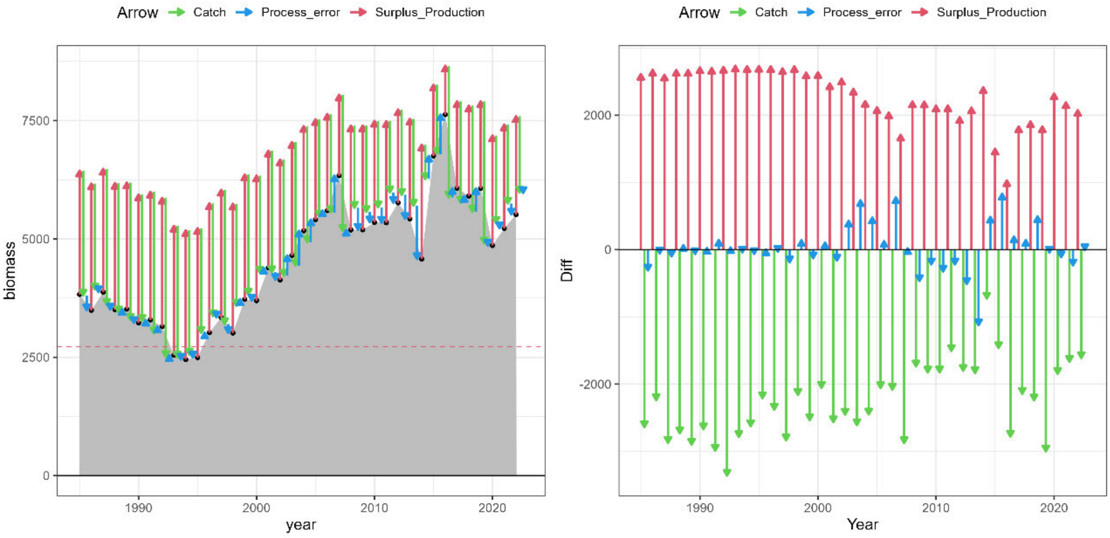


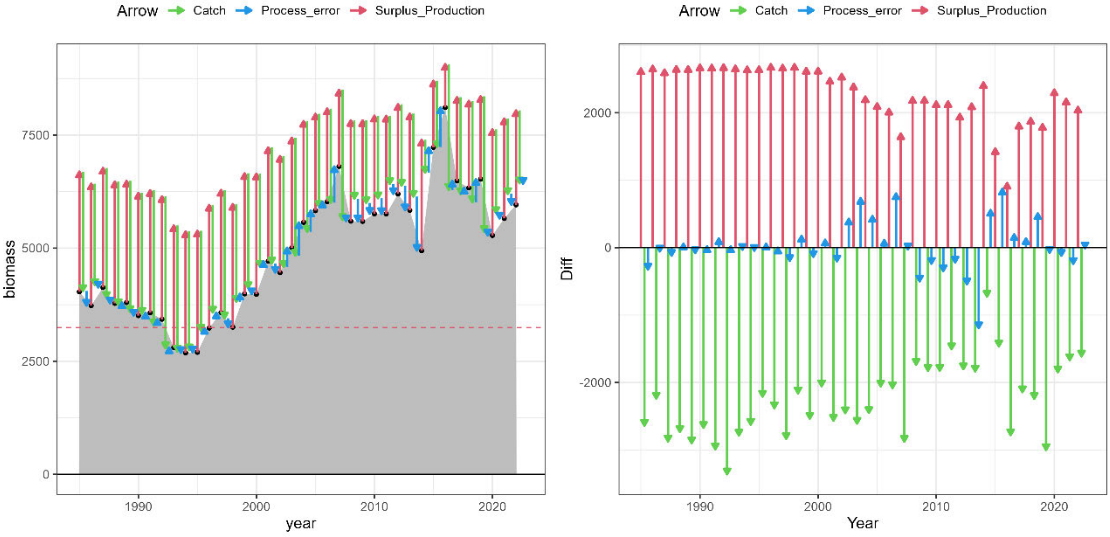
Supplementary Fig. 2-4. Relationship between index value(s) and estimated biomass

The index value(s) have been scaled to match estimated biomass

A) Model 1

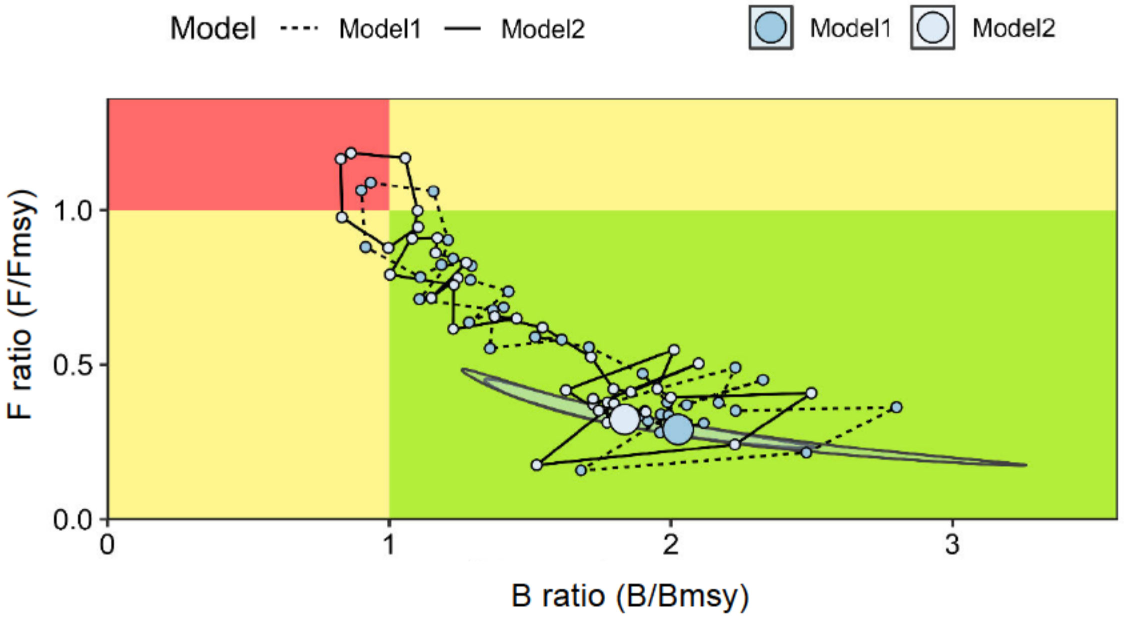


B) Model 2



Supplementary Fig. 2-5. Factor stratification plots for each base case model

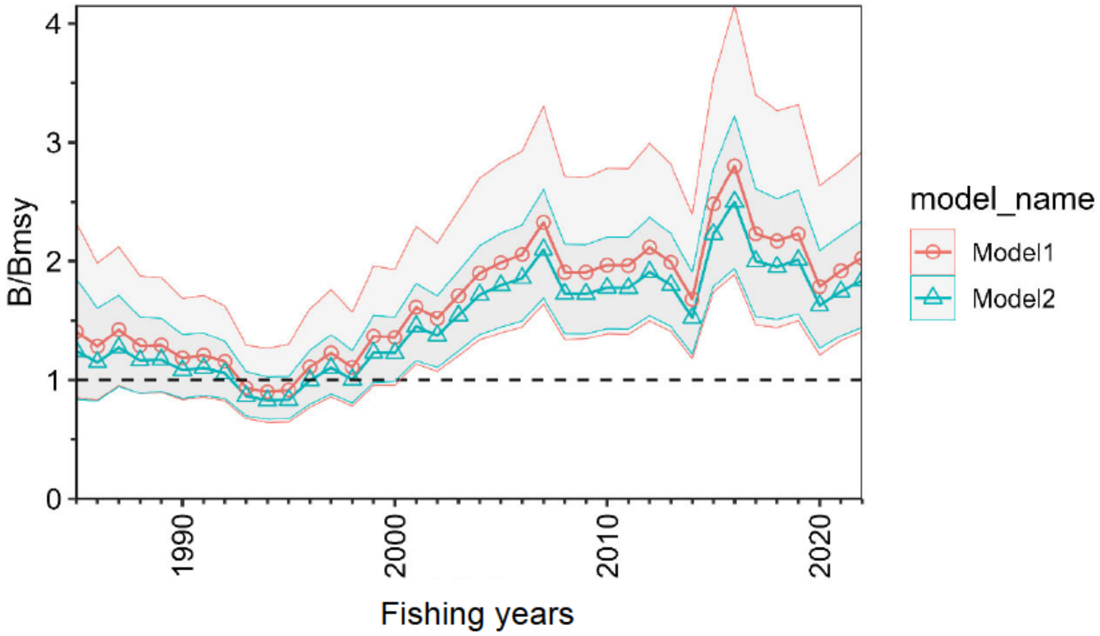
Left: the grey shaded area represents estimated biomass, and the red, green, and blue arrows represent the magnitude of impact of surplus production, catch, and process error(s) in relation to fluctuations in biomass. Right: the magnitude of impact of surplus production, catch, and process error(s) with a baseline of 0.



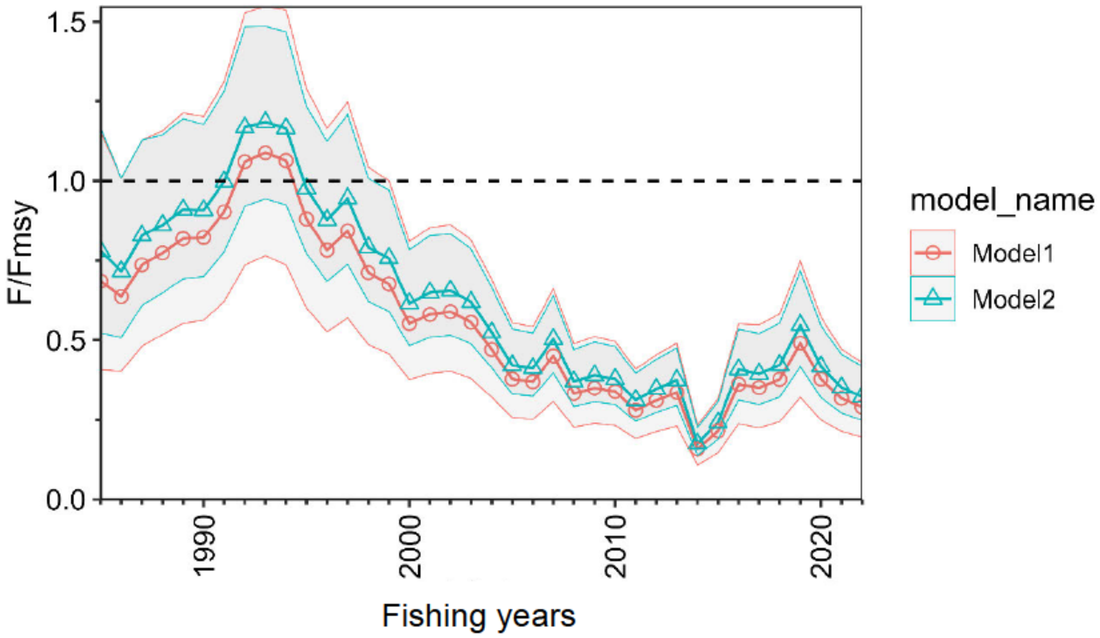
Supplementary Fig. 2-6. Kobe plot for each base case model

Large circles indicate the relationship of biomass and fishing pressure in the 2022 FY. The shaded elliptical shape indicates the 90% confidence interval.

A) B/Bmsy



B) F/Fmsy



Supplementary Fig. 2-7. Trends in B/Bmsy and F/Fmsy in each base case model
Grey shading indicates the 90% confidence interval.

Supplementary Table 2-1. Estimated parameters in the base case models

	Model 1			Model 2		
Prior distribution settings	Assumptions: mean shape parameter n = 2.00, mean intrinsic natural growth rate r = 0.32, wide prior distribution SD = 1			Assumptions: mean shape parameter n = 2.00, mean intrinsic natural growth rate r = 0.32, narrow prior distribution SD = 0.5		
	5% lower limit	Estimated values	5% upper limit	5% lower limit	Estimated values	5% upper limit
r	0.33	0.66	1.31	0.44	0.72	1.19
K	6,900	9,300	12,600	7,300	9,500	12,500
$ln\ (q_1)$	−0.57	−0.32	−0.07	−0.66	−0.39	−0.13
$ln\ (q_2)$	−8.70	−8.44	−8.17	−8.79	−8.51	−8.24
n	0.26	0.65	1.61	0.49	0.86	1.50
σ_B	0.07	0.10	0.13	0.07	0.09	0.13
σ_F	0.17	0.22	0.28	0.18	0.22	0.28
$\sigma_{I,1}$	0.04	0.06	0.11	0.04	0.06	0.11
$\sigma_{I,2}$	0.21	0.26	0.32	0.21	0.26	0.32
MSY	2,600	2,700	2,900	2,600	2,700	2,900
$Bmsy$	1,700	2,700	4,300	2,300	3,200	4,600
$B2022$	4,100	5,500	7,500	4,400	6,000	8,100
$B2022/B_{msy}$	1.41	2.03	2.92	1.44	1.84	2.34
$Fmsy$	0.62	1.00	1.63	0.58	0.84	1.21
$F2022$	0.22	0.29	0.39	0.20	0.27	0.37
$F2022/F_{msy}$	0.20	0.29	0.43	0.25	0.32	0.42

Each model used the same settings for σ_{I1} (mean = 0.15, prior distribution of standard deviation = 0.50) and q_1 (mean = 1.00, prior distribution of standard deviation = 0.30).

Because n was less than 1 in both base case models for this stock, Bmsy, Fmsy, and MSY were calculated using a deterministic method.

Each value was rounded to units of hundreds, or up to two decimal places.

Supplementary Table 2-2. Estimated biomass, fishing pressure, and the 90% confidence interval for each base case model

A) Model 1

Fishing year	Biomass (thousand tons)			Fishing pressure		
	Lower Limit	Estimated values	Upper Limit	Lower Limit	Estimated values	Upper Limit
1985	2.6	3.8	5.6	0.47	0.69	1.02
1986	2.5	3.5	4.9	0.45	0.64	0.91
1987	2.9	3.9	5.2	0.55	0.74	1.00
1988	2.6	3.5	4.8	0.57	0.78	1.06
1989	2.6	3.5	4.8	0.61	0.82	1.12
1990	2.4	3.2	4.4	0.61	0.83	1.13
1991	2.4	3.3	4.4	0.68	0.91	1.22
1992	2.3	3.1	4.2	0.79	1.07	1.43
1993	1.8	2.5	3.5	0.79	1.10	1.52
1994	1.8	2.5	3.4	0.78	1.07	1.46
1995	1.9	2.5	3.3	0.67	0.89	1.17
1996	2.3	3.0	3.9	0.61	0.79	1.02
1997	2.6	3.3	4.3	0.66	0.85	1.10
1998	2.3	3.0	4.0	0.54	0.72	0.95
1999	2.9	3.7	4.8	0.53	0.68	0.88
2000	2.8	3.7	4.8	0.42	0.56	0.73
2001	3.4	4.4	5.7	0.45	0.58	0.76
2002	3.1	4.1	5.4	0.45	0.59	0.78
2003	3.6	4.7	6.1	0.43	0.56	0.73
2004	4.0	5.2	6.8	0.36	0.47	0.62
2005	4.1	5.4	7.1	0.29	0.38	0.50
2006	4.3	5.6	7.3	0.28	0.37	0.49
2007	4.9	6.3	8.2	0.35	0.45	0.59
2008	3.9	5.2	6.8	0.25	0.33	0.44
2009	4.0	5.2	6.8	0.27	0.35	0.46
2010	4.1	5.4	7.0	0.26	0.34	0.44
2011	4.1	5.3	7.0	0.22	0.28	0.37
2012	4.4	5.8	7.5	0.24	0.31	0.41
2013	4.2	5.4	7.0	0.26	0.34	0.44
2014	3.4	4.6	6.1	0.12	0.16	0.21
2015	5.3	6.8	8.7	0.17	0.22	0.28
2016	5.8	7.6	10.0	0.28	0.36	0.48
2017	4.4	6.1	8.4	0.26	0.35	0.49
2018	4.3	5.9	8.1	0.28	0.38	0.52
2019	4.4	6.1	8.3	0.36	0.49	0.68
2020	3.5	4.9	6.8	0.27	0.38	0.54
2021	3.8	5.2	7.1	0.23	0.32	0.44
2022	4.1	5.5	7.4	0.22	0.29	0.39

Supplementary Table 2-2. Estimated biomass, fishing pressure, and the 90% confidence interval for each base case model (continued)

B) Model 2

Fishing year	Biomass (thousand tons)			Fishing pressure		
	Lower Limit	Estimated values	Upper Limit	Lower Limit	Estimated values	Upper Limit
1985	2.7	4.0	6.0	0.44	0.65	0.97
1986	2.6	3.7	5.3	0.42	0.60	0.85
1987	3.0	4.1	5.6	0.51	0.70	0.94
1988	2.8	3.8	5.2	0.53	0.72	0.99
1989	2.8	3.8	5.1	0.56	0.76	1.03
1990	2.6	3.5	4.8	0.56	0.76	1.04
1991	2.7	3.6	4.8	0.62	0.84	1.12
1992	2.6	3.4	4.6	0.73	0.98	1.31
1993	2.0	2.8	3.9	0.72	0.99	1.37
1994	2.0	2.7	3.7	0.71	0.98	1.34
1995	2.0	2.7	3.6	0.61	0.82	1.09
1996	2.5	3.2	4.2	0.56	0.74	0.96
1997	2.7	3.6	4.7	0.61	0.79	1.03
1998	2.4	3.3	4.3	0.50	0.66	0.88
1999	3.1	4.0	5.2	0.49	0.64	0.83
2000	3.0	4.0	5.3	0.39	0.52	0.68
2001	3.6	4.7	6.1	0.42	0.54	0.71
2002	3.4	4.5	5.9	0.42	0.55	0.73
2003	3.8	5.0	6.6	0.40	0.52	0.68
2004	4.2	5.6	7.3	0.33	0.44	0.58
2005	4.4	5.8	7.7	0.27	0.35	0.47
2006	4.6	6.0	7.9	0.26	0.35	0.46
2007	5.2	6.8	8.9	0.32	0.42	0.55
2008	4.2	5.6	7.4	0.23	0.31	0.41
2009	4.3	5.6	7.4	0.25	0.33	0.43
2010	4.4	5.8	7.6	0.24	0.32	0.42
2011	4.4	5.8	7.6	0.20	0.26	0.34
2012	4.8	6.2	8.1	0.22	0.29	0.38
2013	4.5	5.8	7.6	0.24	0.31	0.41
2014	3.7	4.9	6.6	0.11	0.15	0.20
2015	5.6	7.2	9.3	0.16	0.20	0.26
2016	6.1	8.1	10.8	0.26	0.34	0.45
2017	4.7	6.5	9.0	0.24	0.33	0.46
2018	4.6	6.3	8.8	0.26	0.35	0.49
2019	4.7	6.5	9.0	0.33	0.46	0.63
2020	3.7	5.3	7.5	0.25	0.35	0.50
2021	4.1	5.7	7.8	0.21	0.29	0.40
2022	4.4	6.0	8.1	0.20	0.27	0.37

Appendix 3 Standardized CPUE for offshore bottom trawl fishery (Danish seine)

The CPUE (catch of pointhead flounder per haul (kg/net)) was standardized based on aggregated catch reports by month and by vessel for offshore bottom trawl fishery (Danish seine) in Northern Hokkaido, and it was used as an index value in the surplus production model. Data was filtered down to 818,751 operations according to what is considered to be relevant for trends in pointhead flounder stock in this area. Specifically, the base of operations was limited to Wakkanai, Esashi, and Otaru, and non-zero catch data from operations in the lowest 5% of water depth distribution (equivalent to 340 m or deeper) was excluded. In order to consider the effect of targeted operations, the filtered data was processed using a Direct Principal Component model (DPC) (Winker et al. 2013) to model the effect of targeting. The DPC model used the continuous principal component score obtained from principal component analysis of catch composition data as the nonlinear factor within a generalized additive model (GAM) framework. In general, this stock is categorized by-catch species, which has a high volume of zero catch data, so a Tweedie distribution model was also used for error distribution because it can add zero catch data to the model by using continuous variables for CPUE in the objective variables. The explanatory variables selected by Type-III ANOVA, AIC, and 5-fold cross-validation were FY (1980 to 2022 FYs), quarter (August to October, November to January of the following year, February to April, and May to July), horsepower class (11 categories), vessel class (2 categories), base location (Wakkanai, Esashi, and Otaru), 1st principal component score, 2nd principal component score, latitude and longitude, water depth, and the Pacific Decadal Oscillation as primary effects and the interactions between FY and base location, and quarter and base location. No major deviation was seen between estimates for distribution of projected values or distribution of observed values from the selected model (Supplementary Fig. 3-1), so this model was selected as the final model. Annual trends in standardized CPUE as estimated by combination calculations matched to the final model are shown in Supplementary Fig. 3-2. Details about standardized CPUE are described in “CPUE standardization for the northern Hokkaido stock of pointhead flounder in offshore danish seine fishery in 2023” (FRA-SA-2023-SC16-101) (Chiba et al. 2023).

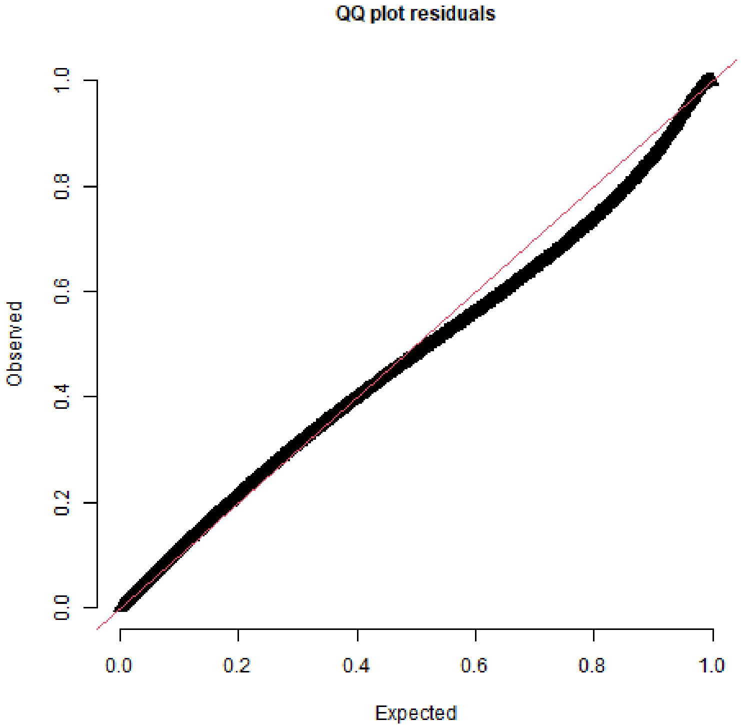
Final model

Statistical Model: Generalized additive model
Response variable(s): CPUE
Explanatory variable(s): FY, Quarter, HP_class, Vessel_class, Base, PC1*, PC2*, Lat: Lon*, Dep*, PDO*, Base: FY, Base: Quarter (*smoothing spline)
Error distribution: Tweedie
Link function: log
Power parameter (p): 1.591

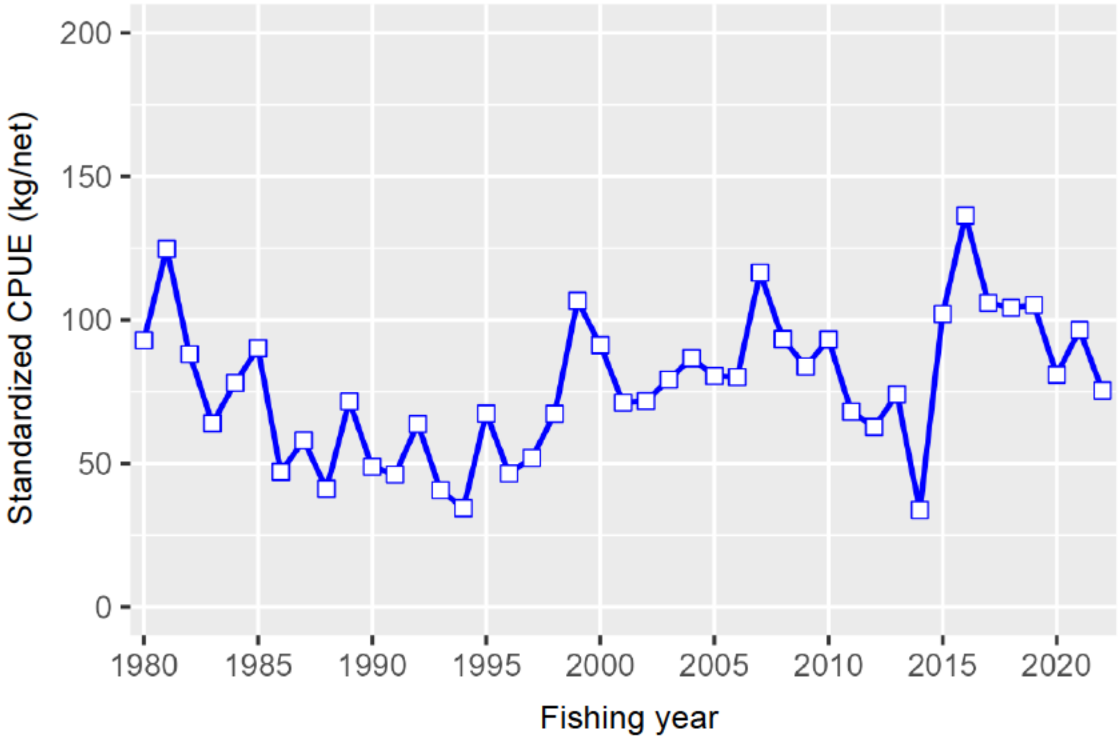
References

Chiba, S., Sato, R., Morita, M., Sakai, O., and Hamatsu, T. (2023) CPUE standardization for the northern Hokkaido stock of pointhead flounder in offshore danish seine fishery in 2023. FRA-SA-2023-SC16-101. (in Japanese)

Winker, H., Kerwath, SE., and Attwood, CG. (2013) Comparison of two approaches to standardize catch-per-unit-effort for targeting behavior in a multispecies hand-line fishery. Fish. Res., 139, 118-131.



Supplementary Fig. 3-1. QQ plot of the final model



Supplementary Fig. 3-2. Annual trends in standardized CPUE of offshore bottom trawl fishery (Danish seine)

Appendix 4. Proposed Reference Points and Fishing Ban Level

The “Scientific meeting on reference points for northern Hokkaido pointhead flounder in fiscal year 2023” (FRA-SA2023-BRP03-01) (Chiba et al. 2023) held in May 2023 proposed adoption of the following: the biomass required for MSY (Bmsy) as the target reference point, the lowest record of biomass before 2021 FY as estimated in stock assessments (Bmin) as the limit reference point, and 0 tons as the fishing ban level (Supplementary Table 4-1).

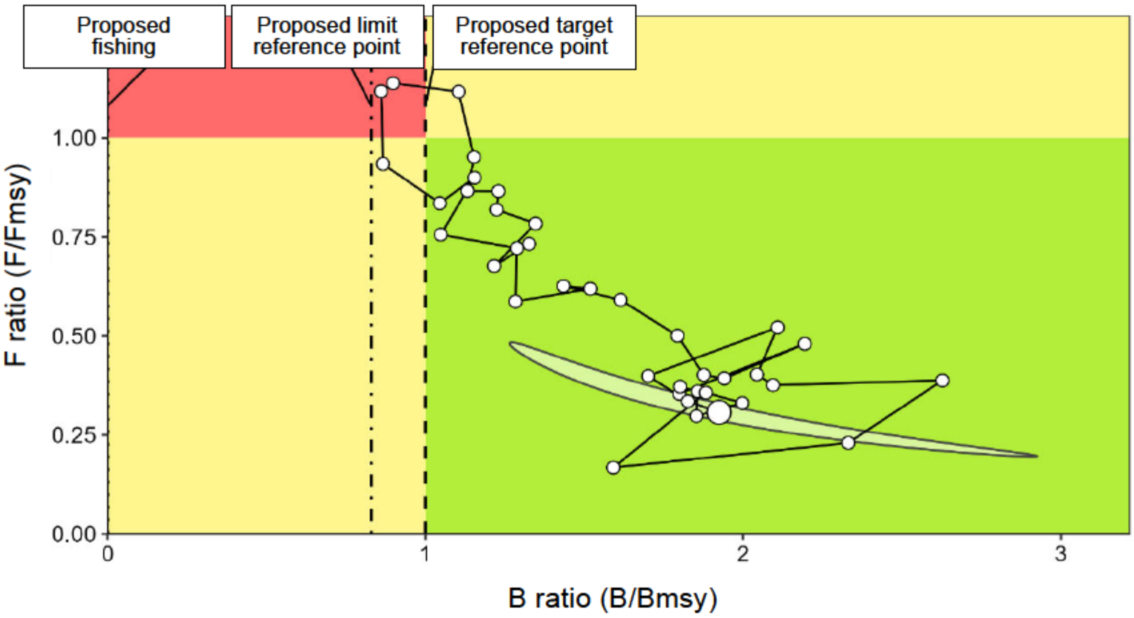
In this year’s stock assessment, the biomass that corresponds to the proposed target reference point (Bmsy) was estimated to be 2,700 tons (1,700 to 4,300 tons) in Model 1 and 3,200 tons (2,300 to 4,600 tons) in Model 2 (Supplementary Table 2-1). Based on the estimated results calculated from these base case models, the typical value (and 90% confidence interval) was 3,000 tons (1,800 to 4,400 tons) (Supplementary Table 4-1). The biomass that corresponds to the proposed limit reference point (Bmin) was estimated to be 2,500 tons (1,800 to 3,400 tons) in Model 1 and 2,700 tons (2,000 to 3,700 tons) in Model 2, and the typical value was calculated to be 2,500 tons (1,800 to 3,400 tons) (Supplementary Table 4-1).

Kobe plots with lines representing the proposed target reference point, the proposed limit reference point, and the proposed fishing ban level are shown in Supplementary Fig. 4-1. The ratio of the current biomass (biomass in the most recent year (2022 FY)) to the proposed reference points was examined. The ratio to the proposed target reference point Bmsy was 0.52 (0.36 to 0.67), and the ratio to the proposed limit reference point Bmin was 0.43 (0.35 to 0.53), and the typical value for current biomass exceeds both of these proposed reference points.

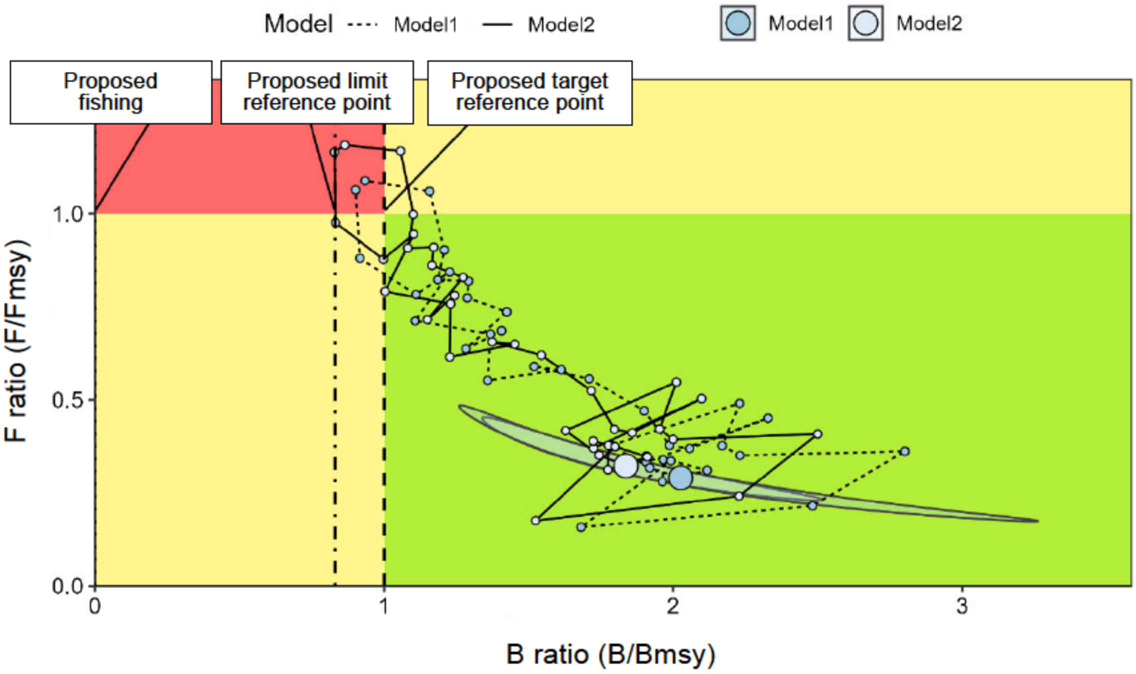
References

Chiba, S., Sato, R., Morita, M., Sakai, O., Ichinokawa, M., and Hamatsu, T. (2023) Scientific meeting on reference points for northern Hokkaido pointhead flounder in fiscal year 2023. FRA-SA2023-BRP03-01. https://www.fra.go.jp/shigen/fisheries_resources/meeting/stok_assesment_meeting/2023/files/2023-03/fra-sa2023-brp03-01.pdf (in Japanese)

a) Kobe plot based on typical values



b) Kobe plot for each base case model



Supplementary Figure 4-1. Relationship of proposed reference points and biomass/fishing pressure (Kobe plot)

Supplemental Table 4-1. Proposed target reference points, proposed limit reference points, and proposed fishing ban level

Proposed reference points	Biomass (thousand tons)	Ratio to carrying capacity	Fishing pressure	Anticipated Catch (thousand tons)	Ratio to current fishing pressure
Proposed target reference points (Bmsy)	3.0 (1.8 to 4.4)	0.32 (0.19 to 0.45)	0.92 (0.62 to 1.52)	2.7 (2.6 to 2.9)	3.26 (2.44 to 4.85)
Proposed limit reference points (Bmin)	2.5 (1.8 to 3.4)	0.26 (0.20 to 0.33)	1.08 (0.78 to 1.49)	2.7 (2.4 to 2.9)	3.83 (3.07 to 4.79)
Proposed fishing ban level (0 tons)	0	0	–	0	–

This table shows values for each proposed reference point based on the results of the surplus production model: the corresponding biomass (Bmsy), the ratio to carrying capacity (K), the corresponding fishing pressure (Fmsy), anticipated biomass under the corresponding fishing pressure (MSY), and the ratio of the corresponding fishing pressure to the current fishing pressure (Fmsy/F2022). The typical values, which are the median values calculated by regenerating the parameter sets for the number of iterations according to estimated results from the two base case models (30,000 iterations), and the 90% confidence interval derived from the 5th percentile and the 95th percentile, are shown.

Appendix 5 Future Projections Based on Proposed HCRs

(1) Setting Future Projections

In order to calculate relevant values for the stock assessment, we merged the results of two base case models. Future projections were calculated in a similar way by performing different stock dynamics simulations using each parameter set, which were regenerated for 2,000 iterative calculations, in order to consider previous estimates for stock dynamics and the uncertainty of parameters (Appendix 1 and 2). In the future projection, in order to replicate the process of updating the stock assessment by fitting the surplus production model to the annual data, prospective catch was calculated by executing a process that the ABC-like calculations for each year and each iteration which were based on the proposed HCRs, as described below. Accordingly, future projections are handled in a similar way to stock assessments, and stock calculations and two years of forward calculations are performed following a surplus production model (SPiCT) using catch and abundance indices obtained from up to two years prior as data. In this process, which is ABC-like calculations, the proposed limit reference point and the fishing pressure required for MSY (Fmsy), which are used in proposed HCRs, are also updated based on stock calculation results. When performing two years of forward calculations, no error is assigned to natural fluctuations in biomass, and catch is assumed according to the fishing pressure corresponding to the ABC value. Projection results calculated using this process, with catch for each year and each iteration, were used as future projections under the condition that catch is performed following proposed HCRs. Future projections were performed for a 15-year period, but fishing pressure in the first year using this method, which is the 2022 FY, was based on actual catch statistics. The catch in the 2023 FY was assumed based on the fishing pressure in the 2022 FY as estimated by each iteration, and management following the proposed HCRs was set to begin in the 2024 FY. However, biomass in future projections is different than the forward calculations using the ABC-like calculations, so natural fluctuations were assigned based on the process error for each iteration. For purposes of comparison, results under the condition that catch continues under the current fishing pressure (2022 FY) are also shown. This fishing pressure was not subject to iterations using SPiCT as described above.

(2) Proposed HCRs

Proposed HCRs are guidelines which aim for better results than proposed target reference points in consideration of the probability of success for both maintenance and recovery of biomass, which set fishing pressure (F) and other factors that correspond to biomass. These rules set an upper limit for fishing pressure equal to Fmsy multiplied by adjustment coefficient β when biomass is above the proposed limit reference point, and reduce fishing pressure linearly to the proposed fish ban level when biomass is below the proposed limit reference point. The Research Institute Meeting for this stock recommends that the adjustment coefficient β is set to 0.8.

(3) Projected Values for the 2024 FY

The catch in the 2024 FY, calculated by applying proposed HCRs to projections for biomass in the 2024 FY, will be 4,600 tons if β is set to 0.8, and 5,800 tons if β is set to 1.0. Projections for biomass in the 2024 FY were calculated using deterministic forward calculations without consideration for uncertainty in natural fluctuations in biomass, and 2,000 iterations were performed for two models. It was assumed that the catch in the year before the projection year was under the current fishing pressure (F2022). The values used for current fishing pressure were different values within the range of uncertainty for each iteration. For each set of iterations, the relative position between the projection for biomass in the 2024 FY and the proposed limit reference point (Bmin) or the fishing ban level (biomass = 0 tons), were used to set the fishing pressure (βFmsy) to be used in ABC calculations in each model. These results were used together with projections for biomass in the 2024 FY to calculate catch in the 2024 FY. Specifically, the mean value of the two models was obtained for each iteration, and the typical value (median value) of these results was set as the calculated catch for the stock management year.

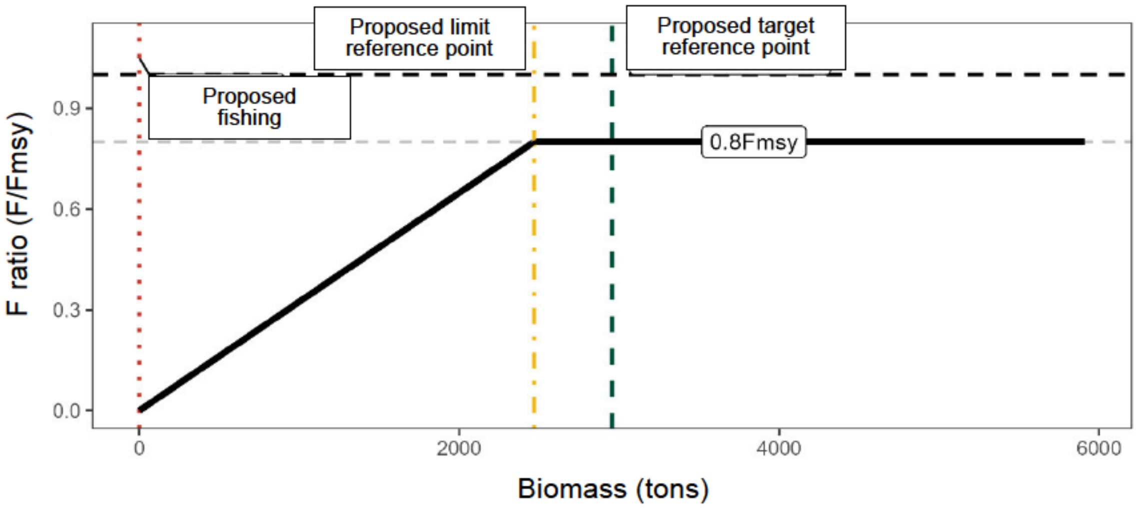
Projections for biomass in the 2024 exceeded the proposed limit reference point in all iterations (median value of 6,300 tons, 90% prediction interval of 4,500 to 8,800 tons).

(4) Projections for the 2025 FY and After

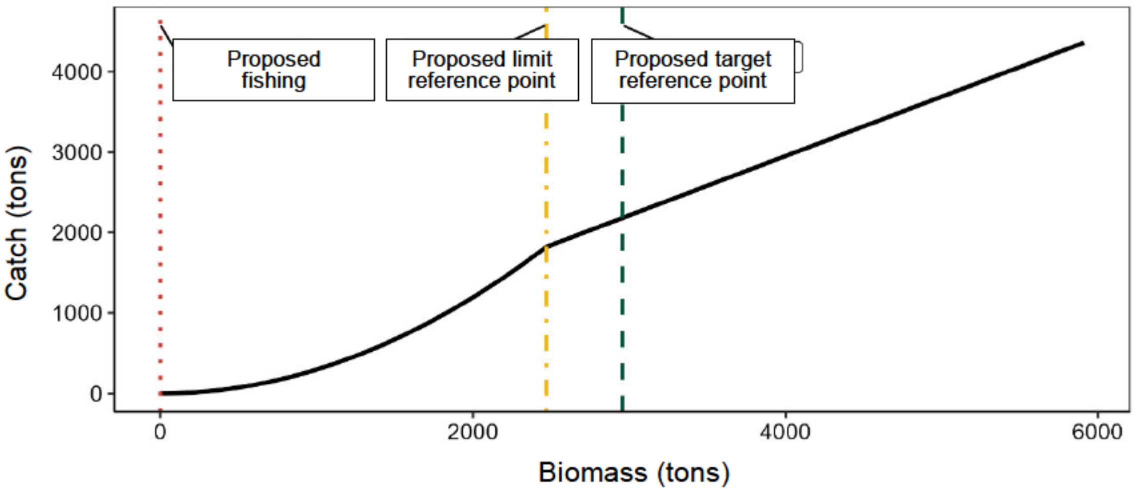
Results of future projections, including 2025 and onwards, are shown in Supplementary Figure 5-2 and Supplementary Tables 5-1 and 5-2. If β (the adjustment coefficient used in HCRs) is set to 0.8, then the projected biomass in the 2034 FY is 3,600 tons (90% prediction interval of 2,000 to 5,700 tons, other values in parentheses below indicate the intervals for each typical value), while the probability that the projected value will exceed the proposed target reference point is 81%, and the probability that it will exceed the proposed limit reference point is 92%. If β is set to 1.0, then the projected biomass in the 2034 FY is 3,000 tons (1,400 to 5,400 tons), while the probability that the projected value will exceed the proposed target reference point is 58%, and the probability that it will exceed the proposed limit reference point is 73%. If the current fishing pressure (F2022) is continued, then the projected biomass in the 2034 FY is 6,400 tons (4,500 to 8,900 tons), while the probability that the projected value will exceed both the proposed target reference point and the proposed limit reference point is 100%.

The “Scientific meeting on reference points for northern Hokkaido pointhead flounder in fiscal year 2023” (FRA-SA2023-BRP03-01) supplemented the preexisting criteria, which is that the probability that biomass will exceed the proposed target reference point is 50% or higher, with additional threshold values aimed to suppress the risk that biomass will fall below the proposed limit reference point (Bmin). Specifically, a criteria was adopted to recommend the following as HCRs: the probability that biomass will exceed the proposed target reference point in the 10 year period after management starts is 90% or higher, and the probability that biomass will fall below the proposed limit reference point 1+ time(s) in the 10 year period after management starts is 30% or less. Based on these criteria, “Scientific meeting on reference points for northern Hokkaido pointhead flounder in fiscal year 2023” (FRA-SA2023-BRP03-01) recommended that the adjustment coefficient β is set to 0.8. Based on this year's stock assessment, if the same criteria is applied to both the probability that biomass in the 2034 FY will exceed the proposed limit reference point, and the probability that it will fall below the proposed limit reference point 1+ time(s) in this 10 year period, the same coefficient value would still be selected (β = 0.8) (Table 5-3 and 5-4).

a) When the vertical axis is fishing pressure

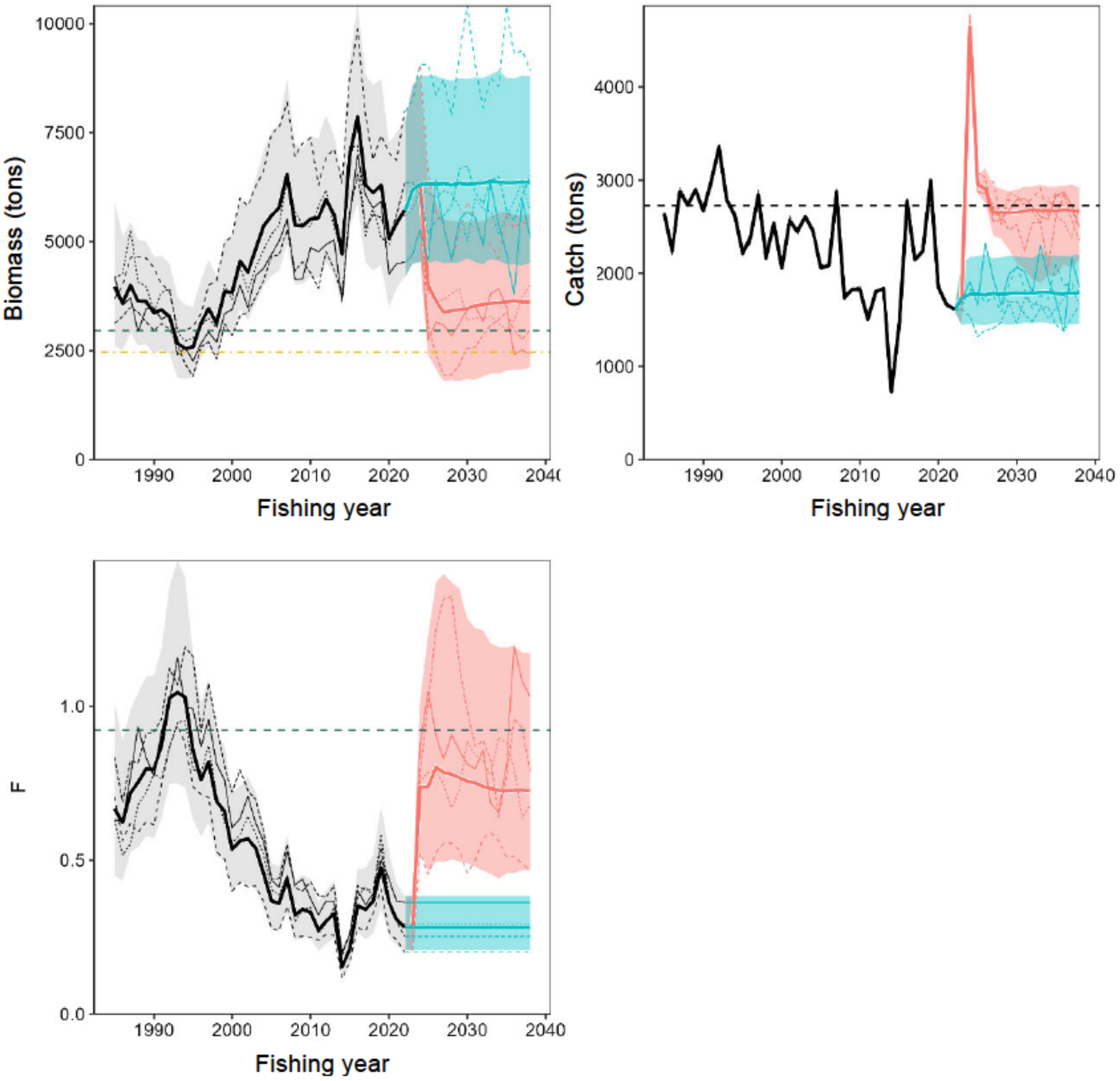


b) When the vertical axis is catch in weight



Supplementary Fig. 5-1. Proposed HCRs

The proposed target reference point is Bmsy as calculated based on the surplus production models. The proposed limit reference point is Bmin and the fishing ban level is 0 tons. These charts use an adjustment coefficient of β = 0.8. The black dashed line represents Fmsy, the gray dashed line represents 0.8 Fmsy, the thick black line represents HCRs, the red dashed line represents the proposed fishing ban level, the yellow dashed line represents the proposed limit reference point, and the green dashed line represents the proposed target reference point.



Supplementary Fig. 5-2. Projected biomass, fishing pressure (F), and catch

The thick blue lines and shaded areas represent the median value and 90% prediction interval of catch under the current fishing pressure (F2022), the thick red lines and shaded areas represent the median value and 90% prediction interval of catch following proposed HCRs with β = 0.8, the thick black lines and grey shaded areas represent the median value and 90% confidence interval of catch estimates for the 1985 to 2022 FYs, and the thin lines in various colors represent the results of iterative calculations. In the biomass graph, the green dashed line represents the level required for the proposed target reference point, and the yellow dash-dot line represents the proposed limit reference point. In the catch graph, the black dashed line represents MSY, and in the fishing pressure (F) graph, the green dashed line represents Fmsy.

Supplementary Table 5-1. Probability that biomass will exceed proposed target/limit reference points

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

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.0	100	100	68	51	35	40	42	48	51	55	56	**58**
0.9	100	100	82	67	52	54	56	59	62	65	66	**67**
0.8	100	100	92	82	73	74	74	76	76	78	79	**81**
0.7	100	100	97	93	89	89	89	90	89	89	91	**91**
0.6	100	100	99	98	97	97	97	97	97	97	97	**98**
0.5	100	100	100	100	100	100	100	100	100	100	100	**100**
Current F	100	100	100	100	100	100	100	100	100	100	100	**100**

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

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.0	100	100	91	75	58	60	60	65	67	70	72	**73**
0.9	100	100	96	88	74	75	75	77	78	80	82	**84**
0.8	100	100	98	95	90	91	90	90	90	90	92	**92**
0.7	100	100	100	99	97	98	97	97	97	97	97	**97**
0.6	100	100	100	100	100	100	100	100	100	100	100	**100**
0.5	100	100	100	100	100	100	100	100	100	100	100	**100**
Current F	100	100	100	100	100	100	100	100	100	100	100	**100**

Future projection results are shown for scenarios when β changes from 1.0 to 0.5. Catch in the 2023 FY assumes that current fishing pressure (F2022) applies, and catch in the 2024 FY follows proposed HCRs. For purposes of comparison, results under the condition that catch continues under the current fishing pressure (F2022, β = 0.31) are also shown. Values in bold indicate values in the target year, which is 10 years after starting management based on proposed HCRs.

Supplementary Table 5-2. Trends in projected typical values of biomass and catch

a) Median value of biomass (thousand tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.0	6.2	6.3	3.3	3.0	2.6	2.7	2.7	2.9	2.9	3.0	3.0	**3.0**
0.9	6.2	6.3	3.6	3.3	3.0	3.0	3.0	3.1	3.2	3.2	3.3	**3.3**
0.8	6.2	6.3	4.0	3.6	3.4	3.4	3.4	3.5	3.5	3.6	3.6	**3.6**
0.7	6.2	6.3	4.4	4.1	3.8	3.9	3.9	3.9	3.9	4.0	4.0	**4.0**
0.6	6.2	6.3	4.8	4.5	4.4	4.4	4.4	4.4	4.4	4.5	4.5	**4.5**
0.5	6.2	6.3	5.3	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	**5.0**
Current F	6.2	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.4	**6.4**

b) Median value of catch (thousand tons)

β	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
1.0	1.7	5.8	3.1	3.1	2.6	2.7	2.6	2.7	2.7	2.8	2.7	**2.7**
0.9	1.7	5.2	3.0	3.0	2.7	2.7	2.7	2.7	2.7	2.7	2.7	**2.7**
0.8	1.7	4.6	3.0	2.9	2.7	2.7	2.6	2.7	2.7	2.7	2.7	**2.7**
0.7	1.7	4.1	2.8	2.8	2.6	2.6	2.6	2.6	2.6	2.6	2.6	**2.6**
0.6	1.7	3.5	2.7	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	**2.5**
0.5	1.7	2.9	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	**2.3**
Current F	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	**1.8**

Future projection results are shown for scenarios when β changes from 1.0 to 0.5. Catch in the 2023 FY assumes that current fishing pressure (F2022) applies, and catch in the 2024 FY follows proposed HCRs. For purposes of comparison, results under the condition that catch continues under the current fishing pressure (F2022, β = 0.31) are also shown. Values in bold indicate values in the target year, which is 10 years after starting management based on proposed HCRs.

Supplementary Table 5-3. Projected biomass and catch, and probability that biomass will exceed the proposed reference point

β	Probability of exceeding the target in 10 years		Median value of projected biomass (thousand tons)		Median value of projected catch (thousand tons)		
	Probability that biomass will exceed the proposed target reference point	Probability that biomass will exceed the proposed limit reference point	In 5 years	In 10 years	Year 1	Avg. in Year 2 to 5	Avg. in Year 6 to 10
			2029 Fishing year	2034 Fishing year	2024 Fishing year	2025 to 2028 Fishing years	2029 to 2033 Fishing years
1.0	58%	73%	2.7	3.0	5.8	2.9	2.7
0.9	67%	84%	3.0	3.3	5.2	2.8	2.7
0.8	81%	92%	3.4	3.6	4.6	2.8	2.7
0.7	91%	97%	3.9	4.0	4.1	2.7	2.6
0.6	98%	100%	4.4	4.5	3.5	2.6	2.5
0.5	100%	100%	5.0	5.0	2.9	2.4	2.3

Supplementary Table 5-4. Probability that biomass will fall below the proposed limit reference point 1+ time(s) in the 10-year period

β	Risk that biomass will fall below the limit reference point (probability for 1+ time(s) in the 10-year period)						
	B0.1msy	B0.2msy	B0.6msy	B0.7msy	B0.8msy	B0.9msy	Bmin
1.0	0%	0%	6%	11%	19%	31%	72%
0.9	0%	0%	4%	7%	11%	18%	48%
0.8	0%	0%	2%	4%	5%	8%	25%
0.7	0%	0%	1%	2%	2%	3%	7%
0.6	0%	0%	0%	0%	0%	0%	1%
0.5	0%	0%	0%	0%	0%	0%	0%

Appendix 6 Calculation methods for proposed reference points and future projections

(1) Proposed reference points

As described in Appendix 2, values for biomass and fishing pressure relating to MSY (Bmsy and Fmsy) were found by merging the results from the two base case models. Therefore, values for n, m, and K from regenerated parameter sets, and for their derivatives r which are calculated using Equation (17), and σ_B were found with iterations using Equations (5) to (10), and the values corresponding to the proposed target reference point were updated. Likewise, biomass relating to the proposed limit reference point (Bmin) was found and updated for each iteration. Because these biomass values at equilibrium ($E(B_\infty|F_t)$) can be approximated using fixed values for F_t and B_t in Equation (23) below (Pedersen and Berg 2017), and because of the typical relationship between catch, biomass, and fishing pressure in Equation (24), it was also possible to do exploratory calculations to find the fishing pressure F_t under the condition that catch C_t is expressed as a certain percentage of MSY, and to find the biomass at equilibrium ($E(B_\infty|F_t)$).

$$E(B_\infty|F_t) = K\left(1-\frac{(n-1)}{n}\left(\frac{F_t}{F_{msy}^d}\right)\right)^{1/(n-1)} \cdot \left(1-\frac{n/2}{1-\left(1-n\cdot F_{msy}^d+(n-1)F_t\right)^2}\sigma_B^2\right) \tag{23}$$

$$C_t = B_t \cdot F_t \tag{24}$$

However, the equation for $\sigma_B = 0$ was used when n<1. These typical values, which are the median values from iterative calculations, and the 90% confidence interval derived from the 5th percentile and the 95th percentile, are shown in Appendix 5.

(2) Future Projection

Future projections were calculated for each iteration according to stock dynamics using parameter sets which were regenerated based on a multivariate normal distribution. The forward calculations used for future projections use surplus production and catch mortality following Pedersen and Berg (2017) with a Lamperti transformation, as described in Equation (25).

$$dZ_t = \left(\gamma\frac{m}{K}-\gamma\frac{m}{K}\left[\frac{\exp(Z_t)}{K}\right]^{n-1}-F_t\right)dt \tag{25}$$

In this equation, $Z_t = \ln(B_t)$. Next, F_t was found based on catch as prescribed in proposed HCRs for future projections (C_t) and the biomass in the same time period (B_t). Because forward calculations use a process error (σ_B) to assign natural fluctuations in biomass, Equation (26) was used to describe biomass in the following FY (B_{t+1}).

$$B_{t+1} = \exp(Z_t + dZ_t)\exp(\varepsilon_t) \tag{26}$$

In this equation, $\varepsilon_t \sim N(-0.5\sigma_B^2, \sigma_B^2)$. The stock dynamics described above are defined by r, K, n, and σ_B as regenerated in each iteration, which are then used to calculate γ and m using Equation (3) and (4).

In order to consider the uncertainty of the stock assessment in future projections, the values used to describe the stock status (biomass and fishing pressure) at the start of the future projection period were also regenerated in each iteration. Some parameter sets which were regenerated based on a multivariate normal distribution demonstrated extreme stock dynamics. Therefore, future projections were made for each iteration under the condition of no fishing (F = 0) for the next 2,000 years, and then parameter combinations that revealed stock dynamics in which the stock collapsed (B<1) despite zero fishing pressure were excluded from the collection of parameter sets to be used in iterative calculations for future projections. The distribution of parameter sets which were regenerated for future projections is shown in Supplementary Fig. 6-1, and the excluded parameter sets are shown in Supplementary Fig. 6-2. However, for this stock, no parameter sets were excluded through this process.

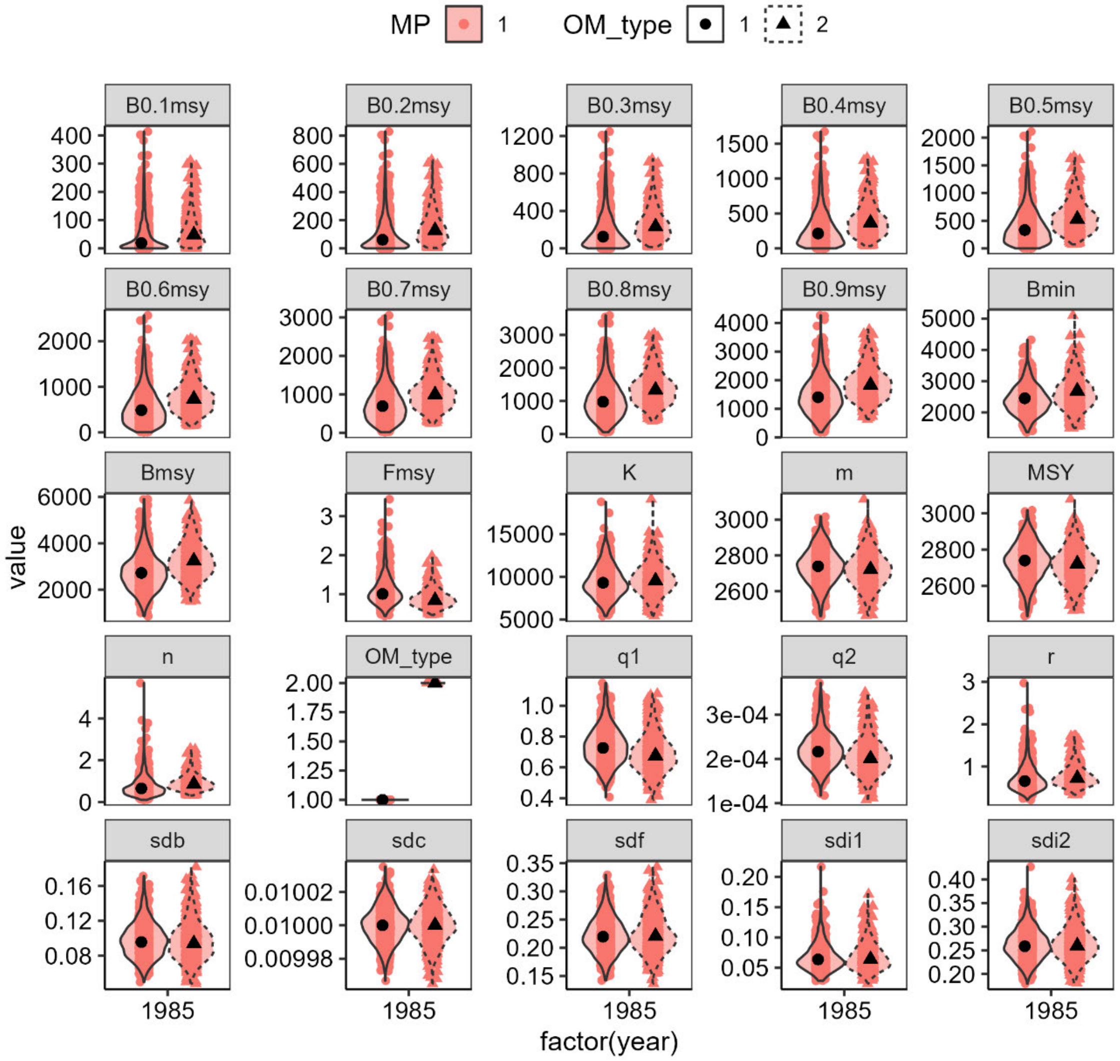
ABC calculations, which are based on HCRs, calculate the catch to be used as the ABC by performing stock assessments using catch and the abundance index for up to 2 years before the ABC target year (ABC year), and by fitting biomass in the ABC year, as obtained from forward calculations for 2 years, to the HCRs. In this study, future projections were performed using a process which is similar to ABC calculations in order to consider uncertainty in future stock assessments. Therefore, biomass was estimated for each iteration using SPiCT with the catch and the abundance index for up to 2 years before each year in future projections (using Equation (1) to (14)), and forward calculations for 2 years were performed (using Equation (25) and (26), with no assumption for process error), and the biomass obtained from these calculations was fitted to the HCRs to determine the catch in future projections. Catch used in the stock assessment period (1985 to 2022 FYs) considered a slight observational error for each iteration. The abundance indices used in the stock assessment period were observed values. Catch and abundance indices in the future projection period all used different projected values for each iteration. Catch was results from the process which is similar to ABC calculations, and abundance indices were found using biomass in each projection year (B_t), catchability (q_i), and random observational error ($e_{t,i}$) (standard deviation = $\sigma_{I,i}$) using Equation (13) and (14). When the process which is similar to ABC calculations is used for future projections, forward calculations do not assign natural fluctuations in biomass based on process error ($\sigma_B = 0$). In addition, except for the first time that catch was calculated for proposed HCRs, catch mortality as assigned during forward calculations was the catch in each year as calculated in each iteration for proposed HCRs. During the first time that catch was calculated for proposed HCRs, catch mortality in the 2022 FY was based on observed catch without consideration for observational errors. Fishing morality in the 2023 FY was assumed based on fishing pressure in the 2022 FY (F2022). As mentioned previously, the value of F2022 was regenerated for each iteration.

Biomass for each year of future projections was calculated for each iteration using catch estimates from the process which is similar to ABC calculations, as described above, and Equation (25) and (26). During this step, the maximum fishing pressure (F) in each year was restricted to twice the value of Fmsy in order to prevent it from becoming unrealistically large. In the future projection, when making estimates by repeatedly checking the fit to state-space models, if ABC calculations cannot be performed due to a lack of convergence in the models, then it is decided to reuse the ABC value from the previous year. The typical values for biomass and catch shown in future projections in this study are median values obtained from these iterations. Likewise, the 90% prediction interval for relevant values in future projections is derived from the 5th percentile and the 95th percentile of these iterative calculations. These results were merged into two types of OM generated based on the parameters estimated by the two base case models used in the stock assessment. Results of future projections are shown by OM type with color coding in Supplementary Fig. 6-3. In these two OM types, there are only small differences in the process errors and in the absolute values of biomass, fishing pressure, and catch, while the confidence intervals of B/Bmsy and F/Fmsy tend to be wider in OM 1. Details about calculation methods for future projections are shown in "Application of management strategy evaluation and future projection using state-space surplus production model to northern Hokkaido stocks of pointhead flounder and yellow striped flounder." (FRA-SA2023-BRP03-101) (Ichinokawa et al. 2023).

References

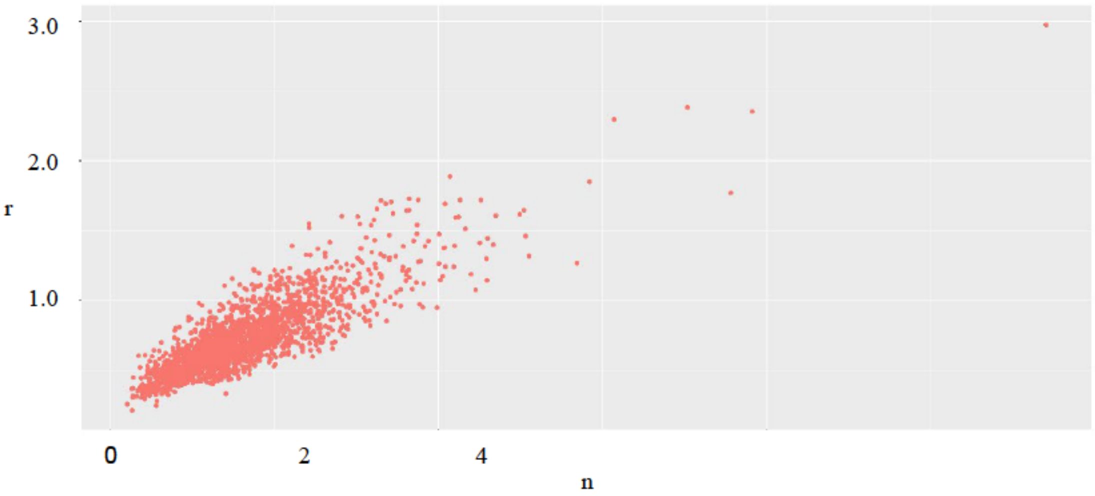
Ichinokawa, M., Chiba, S., and Sakai, O. (2023) Application of management strategy evaluation and future projection using state-space surplus production model to northern Hokkaido stocks of pointhead flounder and yellow striped flounder. FRA-SA2023-BRP03-101. (in Japanese)

Pedersen, M. W., & Berg, C. W. (2017) A stochastic surplus production model in continuous time. Fish and Fisheries, 18, 226-243.



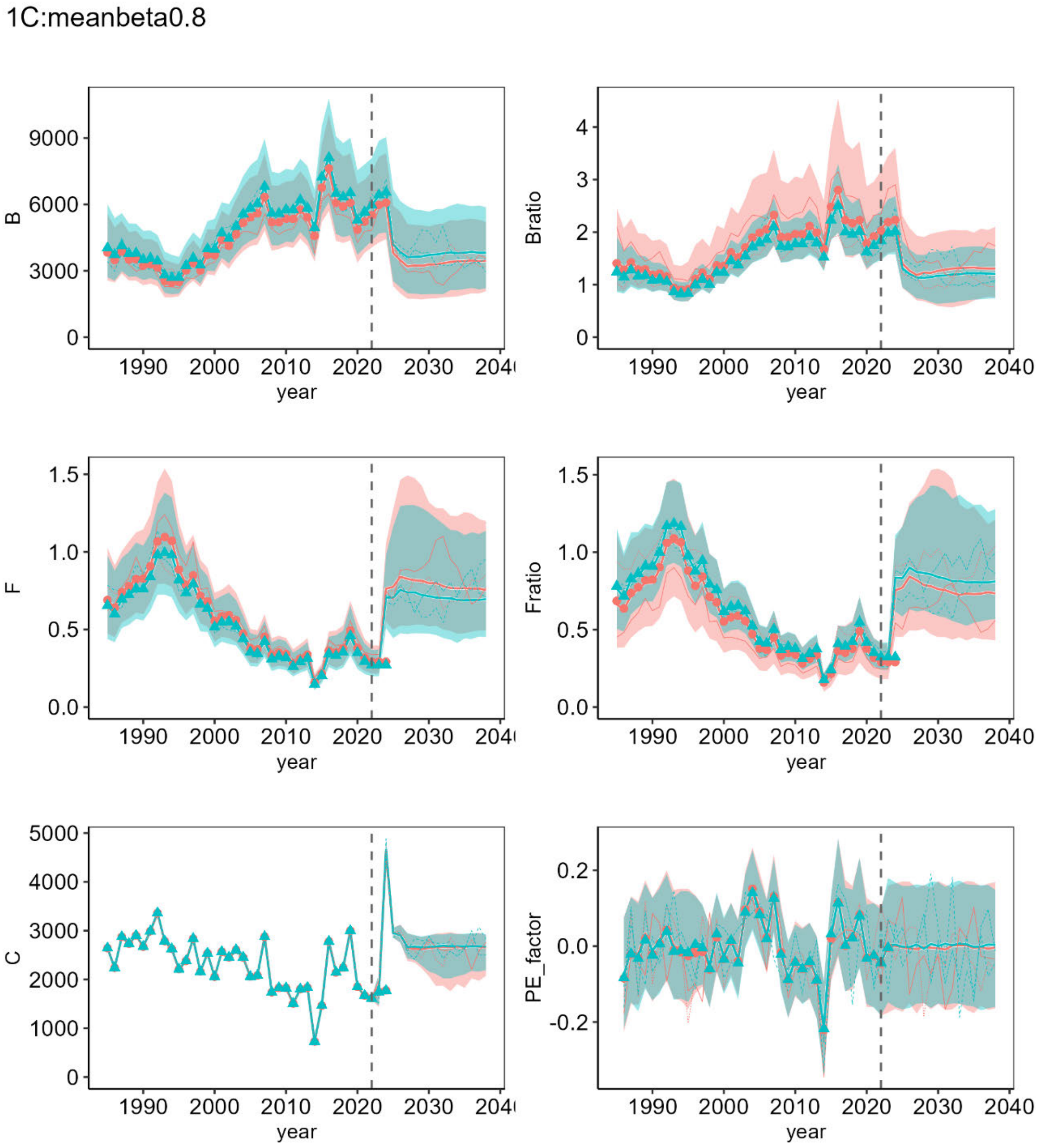
Supplementary Figure 6-1. Distribution of parameter sets regenerated for future projections

The two base case models correspond to the two types of OM.



Supplementary Fig. 6-2. Results of filtering parameter sets regenerated for future projections

The relationship between the shape parameter (n) and the intrinsic growth rate (r) of parameter sets used for future projections (red) and parameter sets excluded after filtering (blue). However, for this stock, there were no parameter sets which demonstrated stock collapse.



Supplementary Fig. 6-3. The future biomass, ratio of biomass to Bmsy, fishing pressure, ratio of fishing pressure to Fmsy, catch, and the process error of each base case model

The median values (thick lines) and 90% interval (shaded areas) of projected values under the condition that catch follows proposed HCRs (β = 0.8). Red represents OM 1, which was regenerated from parameter sets as estimated by stock assessment Model 1, and blue represents OM 2, which was regenerated from parameter sets as estimated by stock assessment Model 2. The thin colored lines represent the results of iterative calculations.

Appendix 7 Summary of Various Parameters and Assessment Results

Supplementary Table 7-1. Proposed reference points and MSY

Item	Description	Values based on this year's stock assessment (90% confidence interval)
Proposed target reference points Btarget (proposed)	Biomass required for MSY (Bmsy)	Typical value: 3,000 tons (1,800 to 4,400 tons) Model 1: 2,700 tons (1,700 to 4,300 tons) Model 2: 3,200 tons (2,300 to 4,600 tons)
Proposed limit reference points Blimit (proposed)	Historic minimum biomass (Bmin) during the stock assessment period	Typical value: 2,500 tons (1,800 to 3,400 tons) Model 1: 2,500 tons (1,800 to 3,400 tons) Model 2: 2,700 tons (2,000 to 3,700 tons)
Proposed fishing ban level Bban (proposed)	Biomass = 0 tons	–
Fmsy	Fishing pressure corresponding to Fmsy	Typical value: 0.92 (0.62 to 1.52) Model 1: 1.00 (0.62 to 1.63) Model 2: 0.84 (0.58 to 1.21)
MSY	Maximum Sustainable Yield	Typical value: 2,700 tons (2,600 to 2,900 tons) Model 1: 2,700 tons (2,600 to 2,900 tons) Model 2: 2,700 tons (2,600 to 2,900 tons)

Supplementary Table 7-2. Biomass and fishing pressure in most recent year

Item	Value (90% confidence interval)	Description
B2022	5,700 tons (4,200 to 7,800 tons)	Biomass in the 2022 FY
F2022	0.28 (0.21 to 0.38)	Fishing pressure in the 2022 FY
Compared against reference points		
B2022/Bmsy Btarget (proposed)	1.92 (1.48 to 2.79)	Ratio of biomass required for MSY (proposed target reference point) to biomass in the 2022 FY
F2022/Fmsy	0.31 (0.21 to 0.41)	F ratio required for MSY to fishing pressure in 2022
Level of biomass	Above Bmsy	
Level of fishing pressure	Below Fmsy	
Trends in biomass	Stable	

Supplementary Table 7-3. Projections for calculated catch

Median value (and 90% interval) of projections for biomass in the 2024 FY:6,300 tons (4,500 to 8,800 tons)			
Item	Catch in 2024 (thousand tons)	Ratio to current fishing pressure (F/F2022)	Fishing pressure (F) in 2024
Using β as proposed by the Research Institute Meeting (max)			
β=0.8	4.6	2.61	0.74
Using other β values			
β=1.0	5.8	3.26	0.92
β=0.9	5.2	2.94	0.83
β=0.7	4.1	2.28	0.64
β=0.6	3.5	1.96	0.55
β=0.5	2.9	1.63	0.46
F2022	1.8	1.00	0.28

Supplementary Table 7-4. Results of future projections using various β

Uncertainties considered: natural fluctuations in biomass (process errors), stock assessment and ABC calculation processes					
Item	Biomass in 2034 (thousand tons)	90% Prediction interval (thousand tons)	Probability (%) that biomass will exceed the following proposed reference points in 2034		
			Btarget (proposed)	Blimit (proposed)	Bban (proposed)
Using β as proposed by the Research Institute Meeting (max)					
β=0.8	3.6	2.0 to 5.7	81	92	100
Using other β values					
β=1.0	3.0	1.4 to 5.4	58	73	100
β=0.9	3.3	1.6 to 5.5	67	84	100
β=0.7	4.0	2.4 to 6.0	91	97	100
β=0.6	4.5	3.0 to 6.6	98	100	100
β=0.5	5.0	3.5 to 7.3	100	100	100
F2022	6.4	4.5 to 8.9	100	100	100