Stock Assessment of Walleye Pollock Northern Sea of Japan Stock in 2020

Fisheries Stock Assessment Center, Fisheries Resources Institute, Japan Fisheries Research and Education Agency

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Summary

The biomass of this stock was estimated by a cohort analysis using the abundance indices, estimated by research vessel surveys, as the tuning index. The biomass (total weight of fish of age 2 and above) and the spawning biomass were 868 thousand tons and 342 thousand tons, respectively, in the fishing season of 1990 (from April 1990 to March of 1991). However, the biomass and the spawning biomass decreased for a long time until the early 2000s and remained at a low level in the late 2000s. The biomass started to increase after the 2014 fishing season and the spawning biomass after the 2015 fishing season. In the 2019 fishing season, the biomass was 154 thousand tons and the spawning biomass was 56 thousand tons. Due to the recruitment of the 2015, 2016, 2018 and 2019 year classes with high abundance, the biomass and spawning biomass are expected to increase in the future. In order to recover this stock, it is important to keep these year classes with high abundance and to increase the spawning biomass.

At the “Research Institute Meeting on Reference Points” held in April 2019, the hockey stick (HS) model was applied to the stock-recruitment (S-R) relationship of this stock. SBmsy, which is the level of spawning biomass that produces the maximum sustainable yield (MSY) was estimated to be 382 thousand tons based on the applied S-R relationship. According to this basis, the spawning biomass of this stock in the 2019 fishing season would be lower than the level that produces MSY. Also, the fishing mortality would be lower than the level that produces MSY (Fmsy). The trend of the spawning biomass is determined to be “increasing” in light of the transition over the past five years (2015-2019 fishing season).

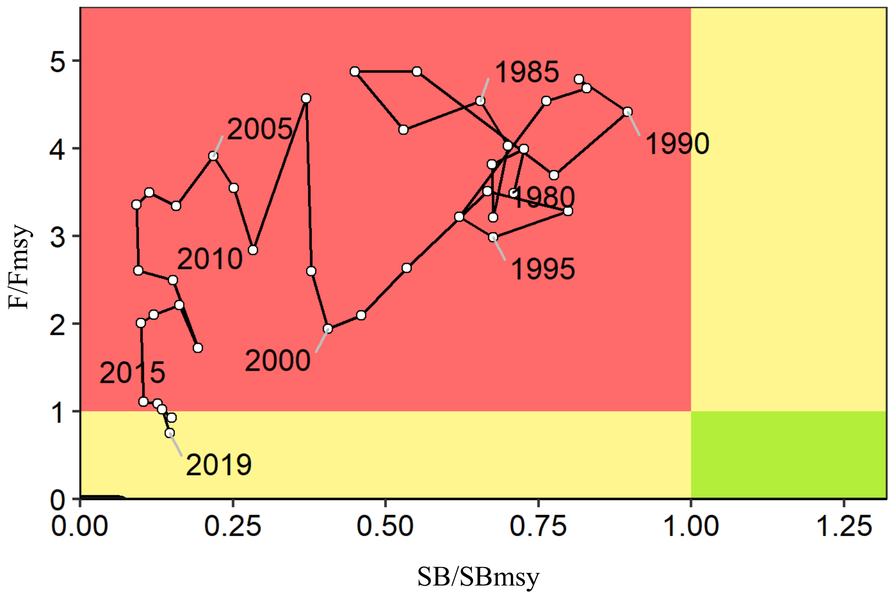
With regard to the items that are to be finalized based on discussions at the Committee of Stock Management Policy, such as reference points and future projections, we tentatively indicated the values proposed at the Research Institute Meeting on Reference Points.

Item	Value	Explanation
Level that produces MSY under the current environment		
SBmsy	382 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and above) = (0.02, 0.04, 0.07, 0.09, 0.13, 0.14, 0.15, 0.12, 0.12)	
%SPR (Fmsy)	60%	%SPR corresponding to Fmsy
MSY	43 thousand tons	Maximum Sustainable Yield
Spawning biomass and fishing mortality in the 2019 fishing season		
SB2019	56 thousand tons	Spawning biomass in the 2019 fishing season
F2019	Fishing mortality in the 2019 fishing season (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and above) = (0.01, 0.01, 0.03, 0.12, 0.12, 0.12, 0.12, 0.12, 0.12)	
%SPR (F2019)	66%	%SPR in the 2019 fishing season
%SPR (F2015-2019)	60%	%SPR corresponding to the current fishing mortality (2015-2019 fishing seasons)
Ratio to MSY		
SB2019/SBmsy	0.15	Ratio of the spawning biomass in the 2019 fishing season to the spawning biomass that produces MSY
F2019/Fmsy	0.76	Ratio of the fishing mortality in the 2019 fishing season to the fishing mortality that produces MSY*

* Ratio between F in the 2019 fishing season and F under the selectivity in the 2019 fishing season that gives Fmsy which has been converted into %SPR.

S-R relationship: HS model (no autocorrelation)

Level of fishing mortality	Below SBmsy
Level of fishing mortality	Below Fmsy
Trend in fishing mortality	Increasing



Fishing year	Biomass (thousand tons)	Spawning biomass (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2016	81	48	6.0	1.09	7
2017	102	57	5.3	0.93	5
2018	145	51	5.6	1.02	4
2019	154	56	5.2	0.76	3
2020	175	92	6.7	0.63	4
2021	204	121	-	-	-

The catch in the 2019 fishing season here is TAC. Values of Biomass and spawning biomass in the 2020 and 2021 fishing seasons are estimates based on future projections.

1. Data set

The data set used for the stock assessment is as follows.

Data set	Data source and research
Catch in number at age	Landing at major ports by fishery (Hokkaido-Ishikawa [7] prefectures) Report on catch in offshore trawl fishery in Hokkaido area (Fisheries Agency of JapanFisheries Agency of Japan) Report on catch in offshore trawl fishery in the Sea of Japan area (Fisheries Agency of JapanFisheries Agency of Japan) Length-age measurement survey (Hokkaido, National Research Institute of Fisheries Science [NRIFS])
Abundance index - Spawning biomass	 Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults) (October, Hokkaido) ・Quantitative echo sounder, trawl* Survey of the recruitment of walleye pollock in the Sea of Japan (survey during the fishing season in the Hiyama sea area) (December, Hokkaido) ・Quantitative echo sounder
- Abundance in number of 0 year old and 1 year old	Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of larvae and juveniles) (April, Hokkaido) ・Quantitative echo sounder, frame trawl* Survey of walleye pollock using quantitative echo sounders (May, NRIFS) ・Quantitative echo sounder, trawl Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of juveniles) (August-September, Hokkaido) ・Quantitative echo sounder, trawl*
Natural mortality (M)	Assuming M = 0.25 (0.3 is applied to age 2 fish) per year
Fishing effort	・Report on catch in offshore trawl fishery in Hokkaido area (Fisheries Agency of JapanFisheries Agency of Japan) Questionnaire/hearing survey of offshore trawl fishermen (NRIFS) Effort of longline fishery on Hiyama coast (Hokkaido) Hearing survey of coastal fishermen (Hokkaido, NRIFS)

Asterisk (*) denotes data used as the tuning index for the cohort analysis.

As for each survey of the recruitment of walleye pollock in the Sea of Japan, only the name of the survey in brackets is mentioned in the main text. The fishing season of this stock is from April to March of the following year, and the age is counted from April 1.

2. Ecology of the stock

(1) Distribution and migration

This stock are distributed from Noto Peninsula to the west coast of Sakhalin. However, it is mainly distributed along the coast of Hokkaido in recent years (Figure 2-1). The sea areas from off the coast of Ofuyu to Rishiri and Rebun Islands and Musashi Bank seemed to be nursery grounds for juvenile fish, and young fish of ages 0 to 2 used to be distributed around Musashi Bank densely (Sasaki and Natsume 1990). Afterward, it is thought that the distribution quantity largely decreased around Musashi Bank (Miyake 2008), but many young individuals are said to be distributed around Musashi Bank in recent years (Misaka 2016). In the current situation of biomass, it is thought that there are few biomass exchanges between the sea areas of Japan and Russia. So it is supposed that Japan and Russia use fish that are distributed in each sea area.

(2) Age and growth

The relationship between the age and fork length and weight of this stock that are calculated from the materials on measurements of catch in gill net fishery in Matsumae and trawl fishery during the seasons from March to May of 1995-2002 are shown in Figure 2-2. The body length of walleye pollock of this stock of age 4 and above, when starting to mature, is slightly smaller than that of three other stocks subject to the stock assessment (Chimura et al. 2020, Ishino et al. 2020, Sakai et al. 2020). Although its lifespan is unknown, individuals of age 10 and above have also been caught. It is estimated that the oldest one in the Bering Sea is age 28 (Beamish and McFarlane 1995).

(3) Maturity and spawning

The relationship between the age and maturity of female individuals is shown in Figure 2-3 and Appendix Table 2-1. The maturity rate is calculated from the measurement of catch in offshore trawl and shrimp beam trawl fisheries from November to January of the 2007-2013 fishing seasons (from April to March of next year, the same hereafter). The fish of this stock start to mature at the age of 3 (about 30%) and almost all of them become fully matured at the age of 5. Their main spawning grounds are Iwanai Bay and off the coast of Otobe in the Hiyama sea area (Miyake 2008). It is said that there used to be spawning areas around the coast of Hiyama, Iwanai Bay, Ishikari Bay, coast of Ofuyu, Musashi Bank, and Rishiri and Rebun Islands (Tanaka 1970, Tsuji 1978), but those in Ofuyu and northward have not been confirmed recently (Miyake et al. 2008). The spawning season is from December to March and the peak period is from January to February (Tanaka and Oikawa 1968, Tsuji 1990, Maeda et al. 1998).

(4) Prey-predator relationships

The feeding period of adult walleye pollock in the Sea of Japan is mainly from the early summer to autumn. Their main feed creatures are amphipods and euphausiacea (Kooka et al. 1997, Kooka et al. 2001). They prey on various creatures such as squids, annelid, small fish, and benthonic crustaceans. Although there is no information about being preyed on by other fish, it is thought that they are important feed for sea animals (Ohizumi et al. 2000), and it is known that they are preyed on by northern fur seals and steller sea lions.

2. Status of fisheries

(1) Outline of fisheries

This stock is caught in fisheries such as offshore trawl, longline, and gill net, and the main fishing ground is the Sea of Japan area along the west coast of Hokkaido (hereafter, "Sea of Japan westward of Hokkaido"). In the coast of Hiyama-Shiriberi area, adult fish that visit spawning grounds are caught by coastal fishery, and in Ishikari Bay and northward (around north of Shakotan Cape - Musashi Bank), they are caught in offshore trawl fishery all year around except during the closed season from June to September. Fishing by South Korean vessels operated in the 1987-1998 fishing seasons in the Sea of Japan westward of Hokkaido, but it has not been carried out since the 1999 fishing season.

(2) Changes in catch

The changes in catch of this stock since the 1970 fishing season by fishing ground and by fishery (only limited to Hokkaido sea area) are shown in Figure 3-1 and in Table 3-1. The catch increased and decreased repeatedly from 83.7 thousand to 168.9 thousand tons from the 1970 fishing season to the 1992 fishing season, but it has been decreasing since the 1993 fishing season. The catch after the 2008 fishing season remains at a lower level than TAC (20.0 thousand tons in the 2008 fishing season, 16.0 thousand tons in the 2009 and 2010 fishing seasons, 13.0 thousand tons in the 2011-2014 fishing seasons, 7.4 thousand tons in the 2015 fishing season, 8.3 thousand tons in the 2016 fishing season, and 6.3 thousand tons in the 2017-2019 fishing seasons). The catch in the 2019 fishing season was 5.2 thousand tons, which was the least since the 1970 fishing season. Since the 2015 fishing season, fishing operations have been controlled remarkably as TAC was set at a lower level, which seems to be the main reason for low catches. The catch in the northern Sea of Japan area along Japan's mainland has gradually been decreasing since the latter half of the 1970s and it was lower than 0.1 thousand tons after the 2016 fishing season, and that in the 2019 fishing season was 0.04 thousand tons.

Catch in number at age of this stock is shown in Figure 3-2 and Appendix 5. In the fishing seasons around 1990, when the catch was higher, most of the catch were ages 3 to 5 fish. However, the ratio of ages 3 to 5 decreased after the 1997 fishing season. In the fishing seasons of 2001 and 2002, when the catch increased, fish of the 1998 year class were caught at age 3 or 4, but the catch after the 2003 fishing seasons did not contain many of the 1998 year class. In the 2008 fishing season, many age 2 fish of the 2006 year class were caught, and after the 2009 fishing season, most of the catch were the 2006 year class. Since the 2014 fishing season, the ratio of the 2012 year class has been increasing, and most of the catch in the 2015-2018 fishing seasons are the 2012 year class. In the 2019 fishing season, the ratios of age 4 fish (2015 year class) in addition to age 7 fish (2012 year class) were high in both number and weight (Appendix 5).

(3) Fishing effort

The fishing effort for this stock tends to decrease for a long time and it has been very low recently (Appendix 3). The number of licensed fishing vessels for offshore trawl fishery in the Sea of Japan westward of Hokkaido (vessels which belong to Hokkaido and are based in ports from Otaru to Wakkanai) was 79 in the 1980s, but it decreased largely afterward and there were only ten vessels after

November 2014: nine Danish seine vessels of more than 100 tons and one otter trawl. Assuming that the target of the fishing operation in which more than 50% of the catch was walleye pollock in the daily operation data by vessel and by fishing area was walleye pollock, most of the catch of walleye pollock by Danish seine vessels of more than 100 tons was achieved by operations targeting walleye pollock (Appendix Table 3-2). The number of trawls targeting walleye pollock has tended to decrease since the latter half of the 1990s. It was 6.6 thousand times in the 1996 fishing season, but it has been less than one thousand times since the 2008 fishing season, reaching 0.3 thousand times in the 2019 fishing season (Appendix Table 3-2). Moreover, the total number of trawls, including those without catches of walleye pollock by Danish seine vessel of more than 100 tons, was more than 20 thousand times until the 1999 fishing season, more than 10 thousand times until the 2007 fishing season, and between 7.0 to 9.8 thousand times in the 2008-2014 fishing seasons. However, it decreased rapidly to 4.4 thousand times in the 2015 fishing season. The total number of trawls in the 2019 fishing season was 4.6 thousand times, which means that the size of offshore trawl fishery remains shrunk.

In coastal fisheries, fishing effort is also decreasing in each area due to operation control. Among coastal fisheries, the catch in and fishing effort (the number of vessels sailing out for fishing) of longline fishery in the four areas along Hiyama coast, on which we obtained detailed information, are shown in Appendix Figures 3-2 and 3-3 and Appendix Table 3-4. After correcting the ratio of the number of vessels sailing out for fishing to the number of lines used per vessel, the number of vessels sailing out for fishing in the 2019 fishing season (212 vessels) was slightly more than twice that in the 2018 fishing season, but it was 4% of that in the 1998 fishing season (5,373 vessels).

4. Stock status

(1) Stock assessment method

We estimated the numbers and biomass at age of age 2 and above fish by tuned VPA using the equation in Pope (1972) (Appendices 1 and 2). In the calculation, we use total catch in number at age and average body weight at age of each fishing year after the 1980 fishing season. As for the spawning biomass index, the estimated value of standing stock as of October by the survey of the distribution of spawning adults (Figure 4-1, Appendix 4-(1)) was used. As for the recruitment index, the estimated abundance of age 0 fish by the survey of the distribution of larvae and juveniles and that of age 1 fish by the survey of the distribution of juveniles were used (Figure 4-2, Appendices 4-(3) and 4-(4)). The fishing mortality in the most recent year was explored to fit the surveyed standing stock. Here, in order to stabilize the estimated value of F at age, we applied the estimation method of applying a penalty according to the magnitude of F value (Ridge VPA; Okamura et al. 2017), assuming that the selectivity in the most recent year is constant for age 5 and above fish. Natural mortality (M) was set as 0.3 for age 2 fish and as 0.25 for age 3 and above fish. As for the year that South Korea achieved some catches, the catches by South Korean fishing vessels were added to the catch in number at age. The age composition of the catch by South Korean fishing vessels was assumed to be the same as that by Japanese offshore trawl vessels.

(2) Changes in abundance index value

As for the abundance index of this stock, the estimated value of standing stock is obtained by the survey using quantitative echo sounders (Figures 4-1 and 4-2 and Appendix 4). The spawning biomass as of October estimated from the survey of the distribution of spawning adults tended to decrease until 2008. However, it turned to an increase in 2009 and 2010 because the 2006 year class had matured (Figure 4-1, Appendix 4-(1)). After 2013, it remained at around 59 thousand to 65 thousand tons, and after 2018, it increased to 90 thousand tons in 2019, which was the same level as that in 2010. It is supposed that the increase in the spawning biomass after 2018 occurred as the 2015 year class had matured. From the results of the surveys on the distributions of larvae and juveniles (ages 0 to 2), it is thought that the abundance of the 2006, 2012, 2015, and 2016 year classes are high, but on the other hand, that those of 2007-2009, 2011, 2013, 2014 and 2017 year classes are low (Figure 4-2, Appendices 4-(3) and 4-(4)). As for the recruitment of year classes after the 2020 fishing season, the abundance of the 2018 year class is expected to be high (Appendices 4-(3), 4-(4)). Although only information at age 0 is available, the abundance of the 2019 year class is very large and that of the 2020 year class is relatively large (Appendix 4-(3)).

(3) Trends in biomass and fishing mortality

Figures 4-3, 4-4 and Table 4-1 show the changes in the number of age 2 and above fish that would be a target of fishing estimated by the tuned VPA, biomass and spawning biomass (for details, see Appendix 5).

The biomass remained at a high level of 712 thousand to 868 thousand tons in the fishing seasons during 1987-1992, but it decreased to 88 thousand tons in the 2007 fishing season, which was 10% of the peak. In the 2008 fishing season, it increased to 125 thousand tons due to recruitment of the 2006 year class. Then, it kept decreasing until the 2013 fishing season because the recruitment of the 2007-2009 year classes was small. After the 2014 fishing season, it increased due to the recruitment of the 2012, 2015 and 2016 year classes, and the biomass of the 2019 fishing season was 154 thousand tons.

Spawning biomass remained at a high level of 237 thousand to 342 thousand tons during the fishing seasons of 1989-1996, but it decreased to 35 thousand tons in the 2008 fishing season, which was 10% of the peak. Then, it kept increasing until the 2011 fishing season due to recruitment of the 2006 year class. Although it decreased again since the 2012 fishing season, it tended to increase again since the 2015 fishing season and it was 56 thousand tons in the 2019 fishing season.

Figure 4-5 shows the changes in recruitment per spawning (RPS: ratio of recruitment to spawning biomass) for each year class since 1980. Here, the number of fish at the age of 2 is deemed to be recruitment as the targets of fishing are individuals of age 2 and above for this stock. Although the RPS remained at a low level since the 1989 year class, the RPS of the 2006, 2015, and 2016 year classes was as high as seen in the 1980s. But the recruitment of these year classes is between 240 million to 400 million individuals because the spawning biomass is at a low level in recent years. It is rather lower than the year classes with high recruitment in the 1980s. Moreover, the recruitment of the 2007, 2008, 2009, 2013, 2014 and 2017 year classes was very low and below 50 million. In order to recover this stock by avoiding such low level recruitment and obtaining good recruitment in years with suitable circumstances for reproduction, it is important to increase the spawning biomass sufficiently.

When both M of age 2 (0.3) and M of age 3 and above (0.25) are changed in the range from -0.05 to +0.05, the biomass, the spawning biomass, and the recruitment in the 2019 fishing season increase as the value of M becomes larger, and decreases as it becomes smaller (Figure 4-6).

As for the changes in fishing mortality (F) at age, although the profiles of change in F value are different depending on age (Figure 4-7), they remained at a low level since the 2015 fishing season for all ages. The exploitation rate (Figure 4-8) was high, at 18 to 24% in the 2002-2007 fishing seasons, but it decreased and remained at less than 10% since the 2014 fishing season. It was 3% in the 2019 fishing season, which was the lowest since the 1980 fishing season.

In the assessment of this year, the values of biomass in the 2018 and 2019 fishing seasons were revised downward from those in the previous assessment by 34 thousand tons and 48 thousand tons, respectively, along with the addition and revision of data of catch in number at age and abundance index obtained after the previous assessment. The spawning biomass in the 2019 fishing season was revised downward from the projection of the previous assessment by 8 thousand tons. Moreover, the recruitment in the 2015-2019 fishing seasons was revised downward by 14 million from the previous assessment to 133 million individuals. Here, the calculation method of biomass used this year is the same as that used last year.

Item	Value	Explanation
SB2019	56 thousand tons	Spawning biomass in the 2019 fishing season
F2019	Fishing mortality in the 2019 fishing season (ages 2, 3, 4, 5, 6, 7, 8, 9, 10 and above) = (0.01, 0.01, 0.03, 0.12, 0.12, 0.12, 0.12, 0.12, 0.12)	
U2019	3%	Exploitation rate in the 2019 fishing season

(4) Yield per recruitment (YPR), spawning per recruitment (SPR) and current fishing mortality

In order to compare the fishing mortality considering the influence of selectivity, we made a comparison with the case with no fishing mortality, based on SPR. Figure 4-9 shows the ratio of SPR with catch to SPR assuming no catch (%SPR) for each year. The lower the fishing mortality, the higher the %SPR. It was roughly between 20 to 40% before the 2014 fishing year, but since the 2015 fishing year, it remained above the level of 57%. It was 66% in the 2019 fishing season. The value of %SPR was calculated as 60% from the average F value for the most recent five years (2015-2019 fishing seasons) as for the current fishing mortality.

Figure 4-10 shows the relationship between YPR and %SPR for the current fishing mortality. As for the selectivity in F, we used the selectivity value which was used to estimate F that produces the maximum sustainable yield (MSY) (Fmsy) (Yamashita et al. 2020a) at the "Research Institute Meeting on Reference Points" held in April 2019. For the average body weight at age and the maturity rate, we also used the values which were used to calculate Fmsy. The value of Fmsy is equivalent to 60% when converted to %SPR. The current fishing mortality (F2015-2019) is F0.1, which is much lower than F30%SPR and slightly lower than Fmsy.

Item	Value	Explanation
%SPR (F2019)	66%	%SPR in the 2019 fishing season
%SPR(F2015-2019)	60%	%SPR corresponding to the current fishing mortality (2015-2019 fishing seasons)

(5) Stock-recruitment relationship

Figure 4-11 shows the relationship between spawning biomass (in weight) and recruitment (in the number of 2 years old) (stock-recruitment (S-R) relationship). The "Research Institute Meeting on Reference Points" mentioned above applied the hockey stick (HS) model to the S-R relationship of this stock (Yamashita et al. 2019). Here, data used for parameter estimation of the S-R relationship is the spawning biomass and recruitment based on the stock assessment in 2018 and the least squares method is used for optimization. The model does not consider autocorrelation between the residuals of the recruitment. The parameters for the S-R relationship are shown in the table below.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey stick	Least squares method	None	1.806	341,742	0.812

Here, parameter a is the steepness (thousand individuals/kg) of the HS S-R curve from the origin to the break point, and b is the spawning biomass (tons) at the break point.

(6) Level that produces MSY under the current environment

The table below show the estimated values proposed at the "Research Institute Meeting on Reference Points" mentioned above (Yamashita et al. 2019) as the spawning biomass (SBmsy) that produces MSY and the fishing mortality (Fmsy) that produces MSY under the current circumstances (since the 1980 fishing season).

Item	Value	Explanation
SBmsy	382 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 2, 3, 4. 5. 6. 7. 8. 9. 10 and above) = (0.02, 0.04, 0.07, 0.09, 0.13, 0.14, 0.15, 0.12, 0.12)	
%SPR (Fmsy)	60%	%SPR corresponding to Fmsy
MSY	43 thousand tons	Maximum Sustainable Yield

(7) Stock status, stock trend and level of fishing mortality

Figure 4-12 and Appendix 7 show a Kobe plot (Kobe chart) based on the spawning biomass that produces MSY (SBmsy) and fishing mortality that produces MSY (Fmsy or Umsy). The ratio of the fishing mortality (F) (F/Fmsy) shows the yearly ratio between F and F under the current selectivity that produces Fmsy, which was converted to %SPR. The value of F of this stock was below Fmsy in the 2017 and 2019 fishing seasons, and the value of F in the 2019 fishing season was 0.76 times Fmsy. The spawning biomass of this stock was below SBmsy for the whole period, and the spawning biomass in the 2019 fishing season was 0.15 times SBmsy. The trend of the spawning biomass is determined to be "increasing" in light of the transition over the past five years (2015-2019 fishing seasons).

Item	Value	Explanation
SB2019/SBmsy	0.15	Ratio of the spawning biomass in the 2019 fishing season to the spawning biomass that produces MSY
F2019/Fmsy	0.76	Ratio of the fishing mortality in the 2019 fishing season to the fishing mortality that produces MSY*

* Ratio between F in 2019 and F under the selectivity in the 2019 fishing season that gives Fmsy which has been converted into %SPR.

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Below Fmsy
Trend in spawning biomass	Increasing

5. Stock assessment summary

The biomass of this stock was at a high level of 712 thousand to 868 thousand tons during the 1987-1992 fishing seasons. Then, it decreased to 88 thousand tons in the 2007 fishing season, which was about 10% of the peak. Afterward, it turned to an increase due to continual generation of high-abundance year classes, and it was 154 thousand tons in the 2019 fishing season. In addition, the spawning biomass was at a high level of 237 to 342 thousand tons during the 1989-1996 fishing seasons. However, it decreased to 35 thousand tons in the 2008 fishing season, which was about 10% of the peak. It turned to an increase since the 2016 fishing season, and it was 56 thousand tons in the 2019 fishing season.

Although the spawning biomass in the 2019 fishing season was lower than the level that produces MSY, the trend is determined to be "increasing" in light of the transition over the past five years (2015-2019 fishing seasons). The fishing mortality has tended to decrease in recent years, and it was lower than the level that produces MSY in the 2017 and 2019 fishing seasons.

6. Others

According to the agreement on stock management between the fishermen of offshore trawl and coastal fisheries, in order to protect juveniles, they take measures to move to another fishing ground when the percentage of smaller fish than the lower limit of body length (body length of 30 cm or total length of 34 cm) exceeds 20% of the catch of walleye pollock. In addition, in offshore trawl fishery, as measures to recover biomass, the following measures are taken voluntarily in 2008-2009: (1) the reduction rate of the number of operation days by vessels targeting walleye pollock is extended to 20%, (2) the area of fishing ground that fishing vessels move to due to the limit of body length is clarified as “another fishing ground,” (3) the operation targeting walleye pollock is self-restrained for the rest of the voyage when the percentage of smaller fish exceeds 20% even after moving to another fishing ground, and (4) the operation targeting walleye pollock is self-restrained on the following operation day when the total landing of walleye pollock in a day exceeds 800 tons. These measures have continued to be taken in and after 2010. In offshore trawl fishery, areas closed to fishing are set in spawning grounds. In the Hiyama sea area, in order to protect spawning biomass and foster egg laying, fishing is stopped early in response to the condition of emergence of transparent eggs that are seen just before egg laying and during the spawning season. As for the recent situation, it is expected that the spawning biomass will increase in the future due to recruitment of the 2015 and 2016 year classes. In order to recover this stock, it is important to secure an increase of spawning biomass by keeping these high-abundance year classes remaining.

7. References

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shino, Satoru Chiba, Tomonori Hamatsu)

(Authors: Masayuki Chimura, Yuuho Yamashita, Osamu Sakai, Mitsuhiro I

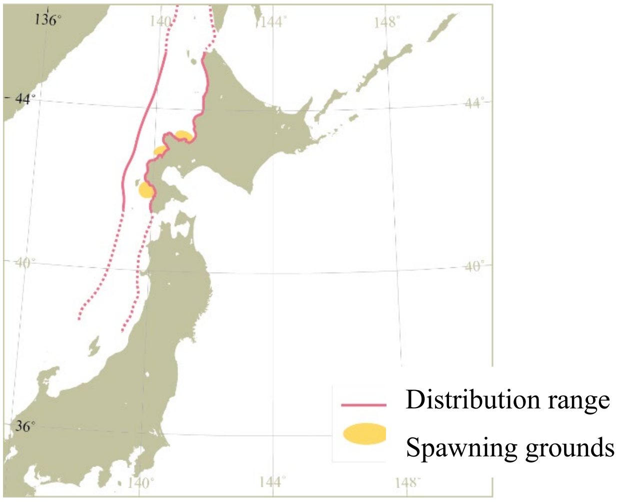


Figure 2-1. Distribution range of walleye pollock Northern Sea of Japan stock and their spawning grounds

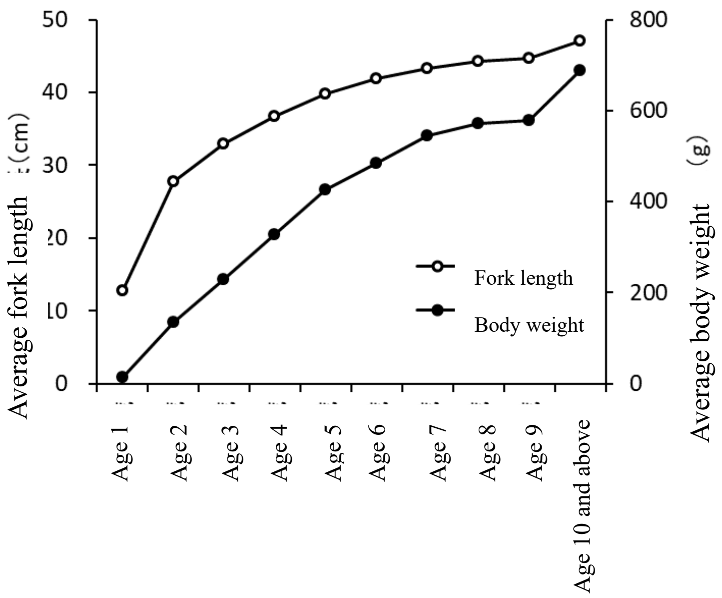


Figure 2-2. Age and growth (Average value is shown for age 10 and above)

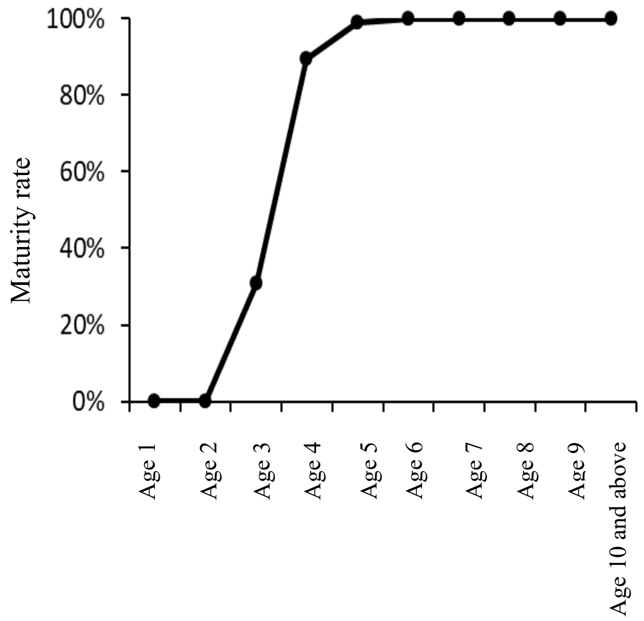


Figure 2-3. Maturity rate for females in spawning season at age

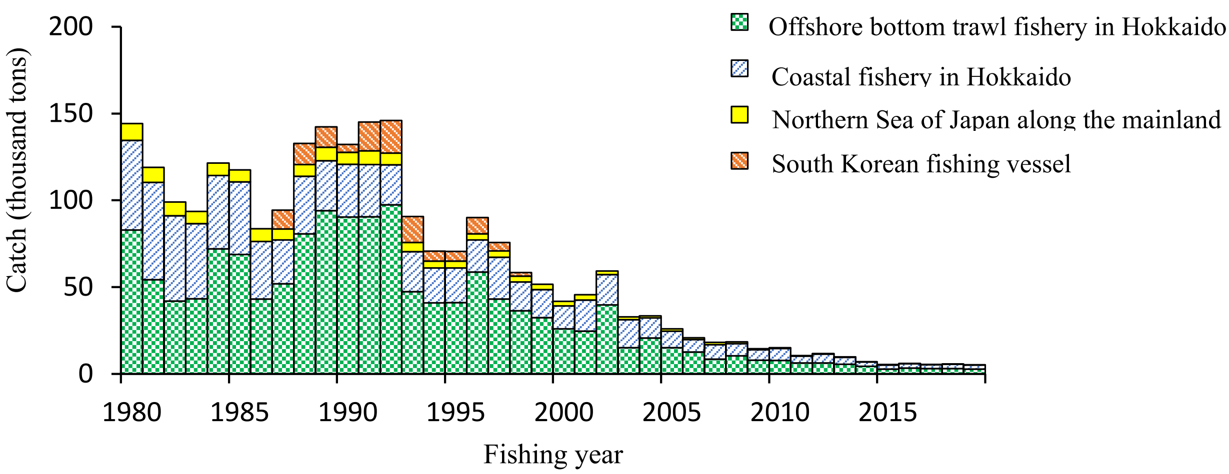


Figure 3-1. Changes in catch

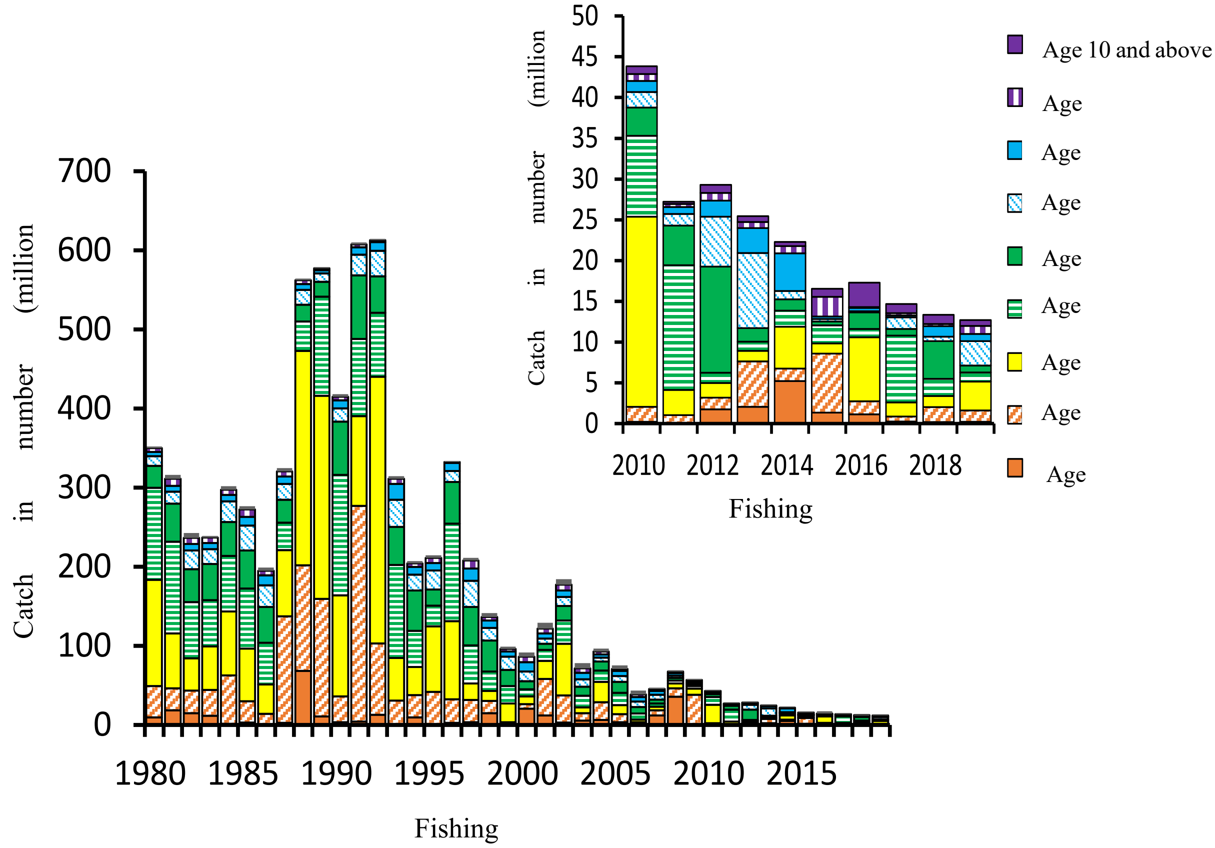


Figure 3-2. Changes in catch in number at age

The upper right enlarged figure shows details of the 2010 fishing season onward.

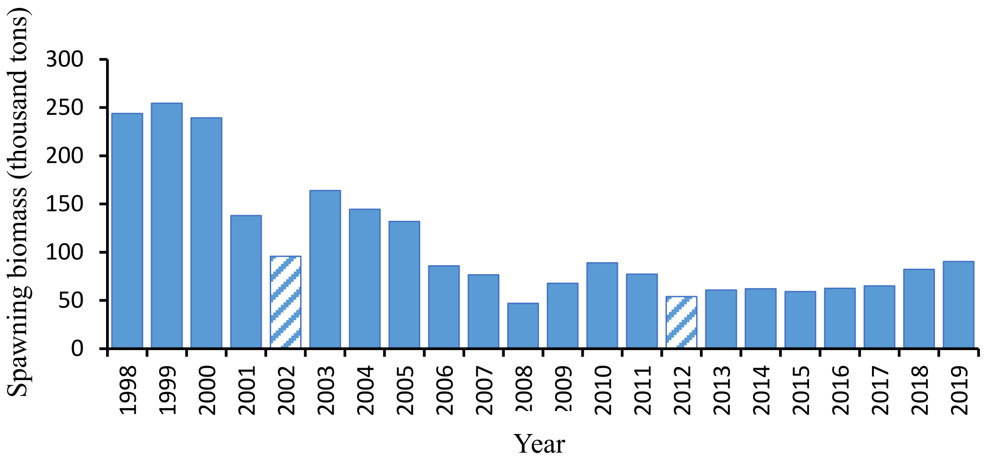


Figure 4-1. Changes in spawning biomass index

Estimated spawning biomass from the survey of recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults). The values for 2002 and 2012 are shown just for reference because a sufficient area for survey could not be secured in those years due to bad weather (prepared based on a figure in a report from Wakkanai, Chuo and Hakodate Fishery Research Institutes (printing underway)).

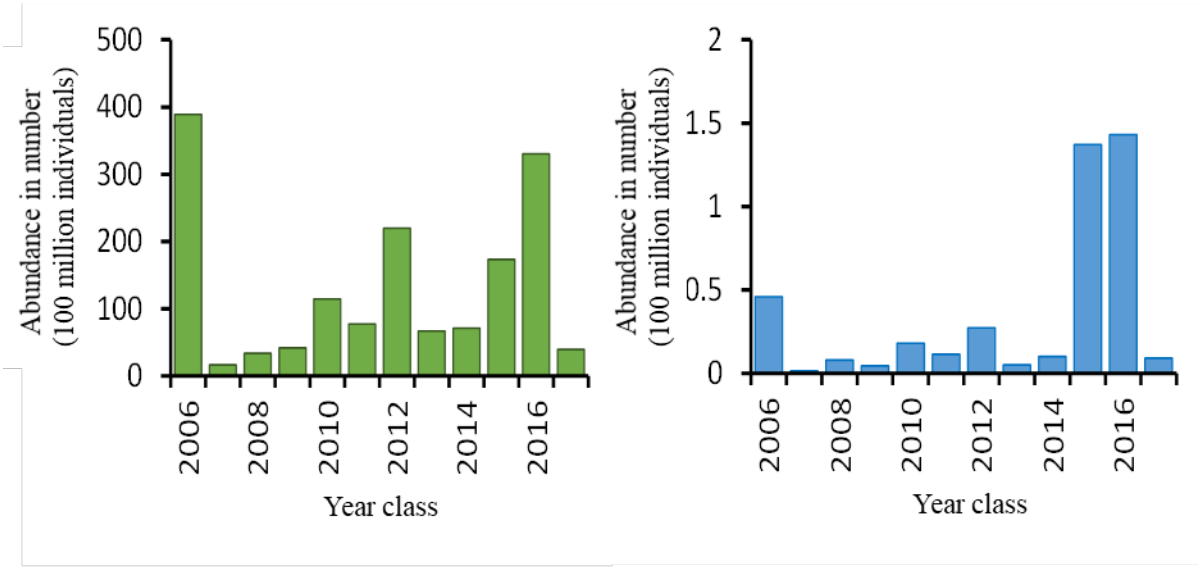


Figure 4-2. Changes in recruitment index

Estimated number of 0 year old (left) and 1 year old (right) from the survey of the recruitment of walleye pollock in the Sea of Japan (Survey of the distribution of larvae and juveniles (left) and Survey of the distribution of juveniles (right)) (prepared from figures in a report from Wakkanai, Chuo and Hakodate Fishery Research Institutes (printing underway)).

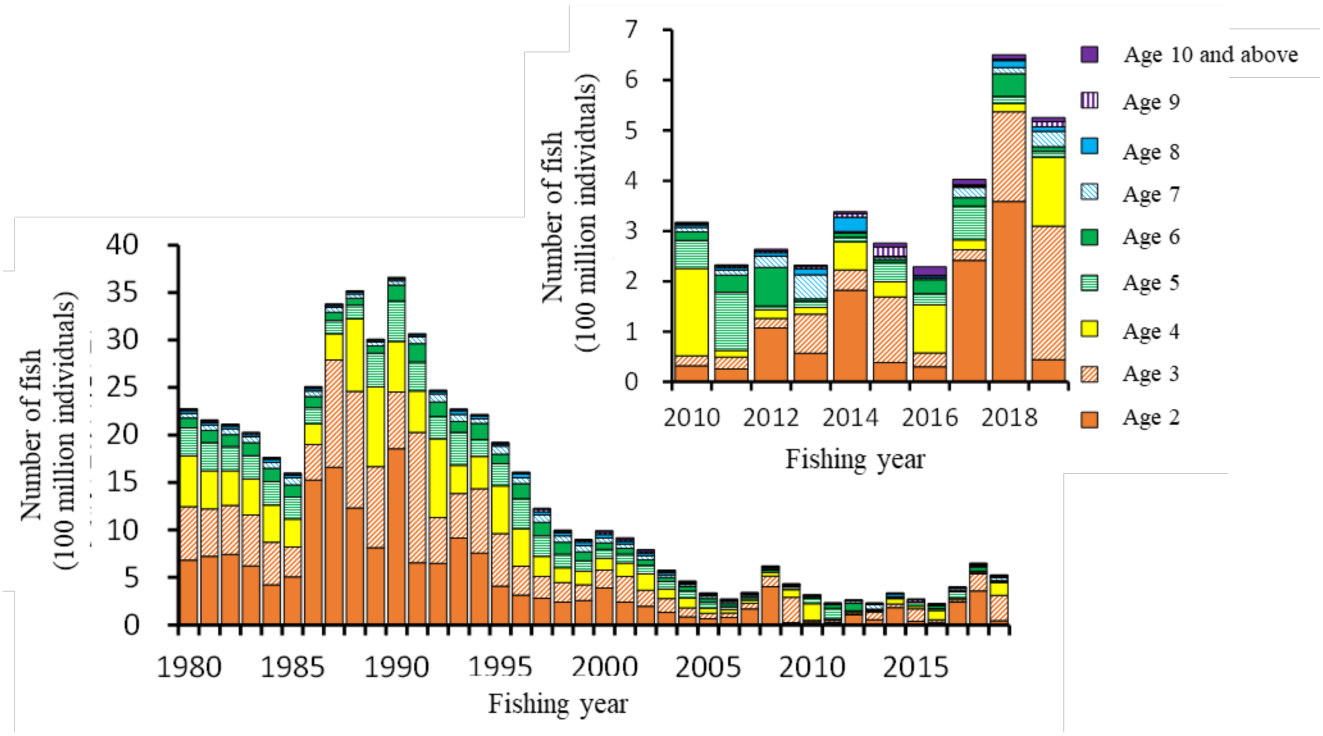


Figure 4-3. Changes in the number of fish at age

The upper right enlarged figure shows details of the 2010 fishing season onward.

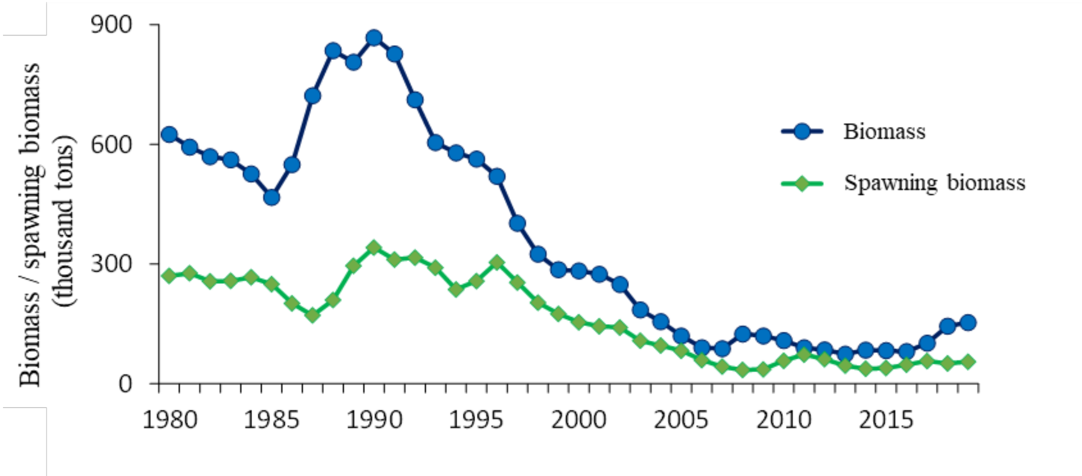


Figure 4-4. Changes in biomass and spawning biomass

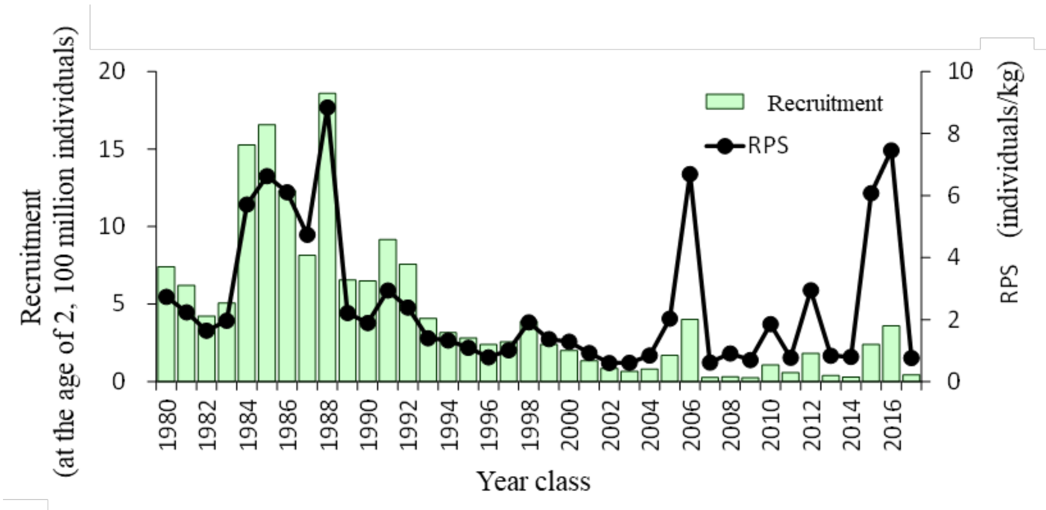


Figure 4-5. Changes in recruitment and recruitment per spawning (RPS)

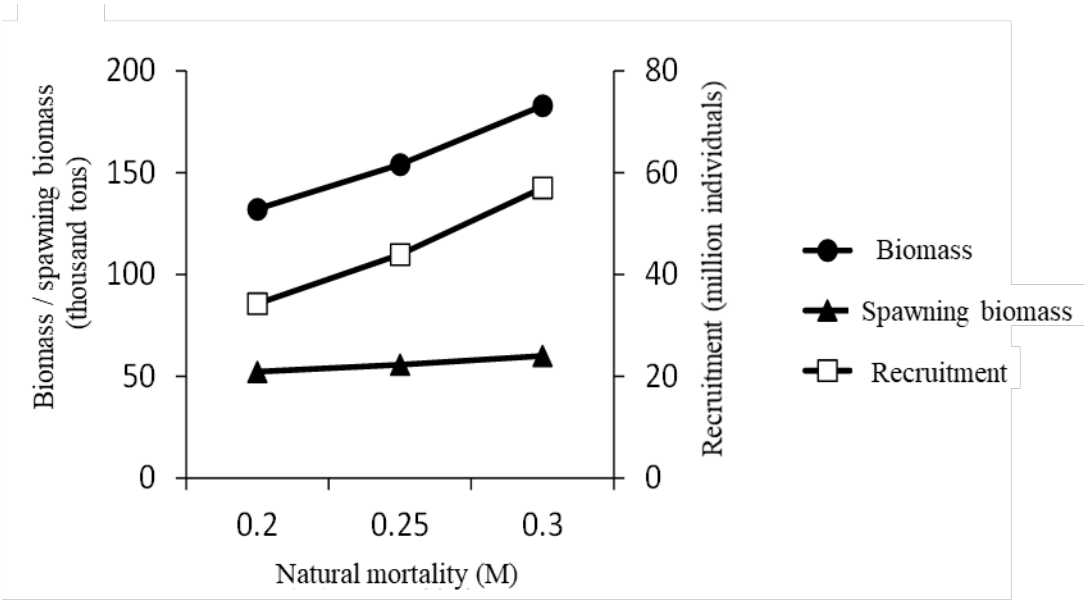


Figure 4-6. Changes in biomass, spawning biomass, and recruitment in the 2019 fishing season when M is changed

M is the value for age 3 and above. The value of M for age 2 can be obtained by adding 0.05 to the M for age 3 and above.

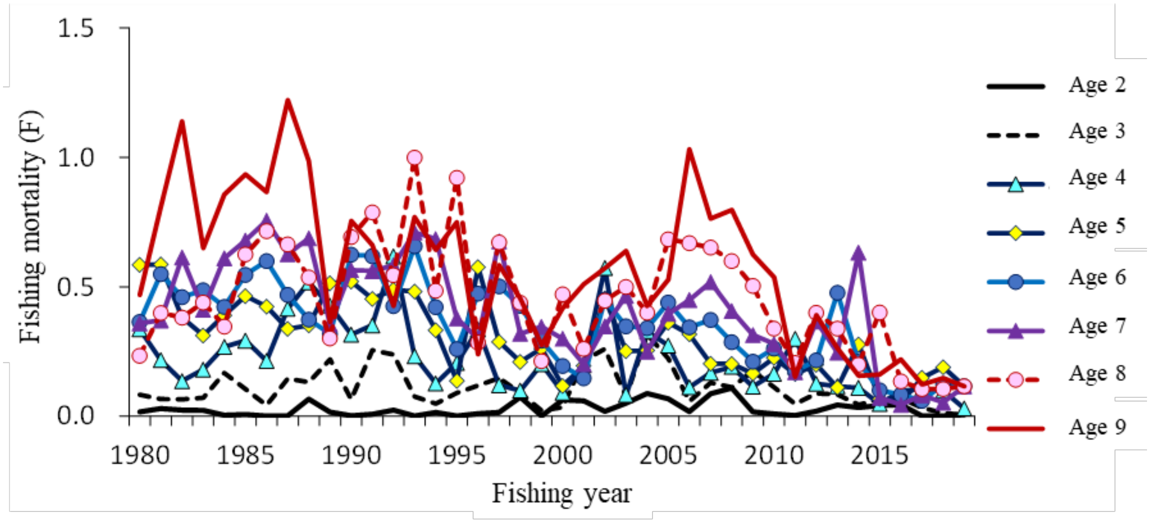


Figure 4-7. Changes in F at age

The F of age 10 and above fish is the same as the F of age 9 fish

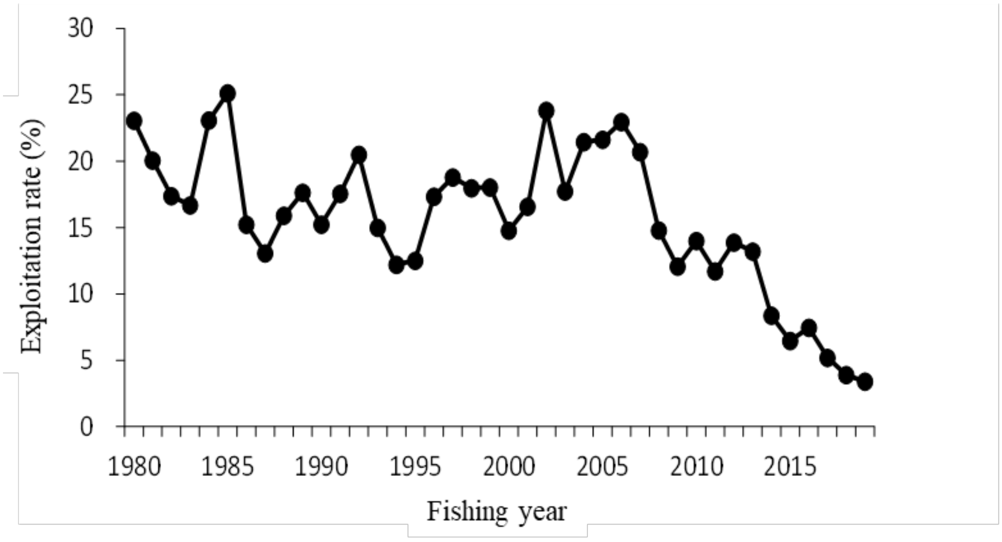


Figure 4-8. Changes in exploitation rate

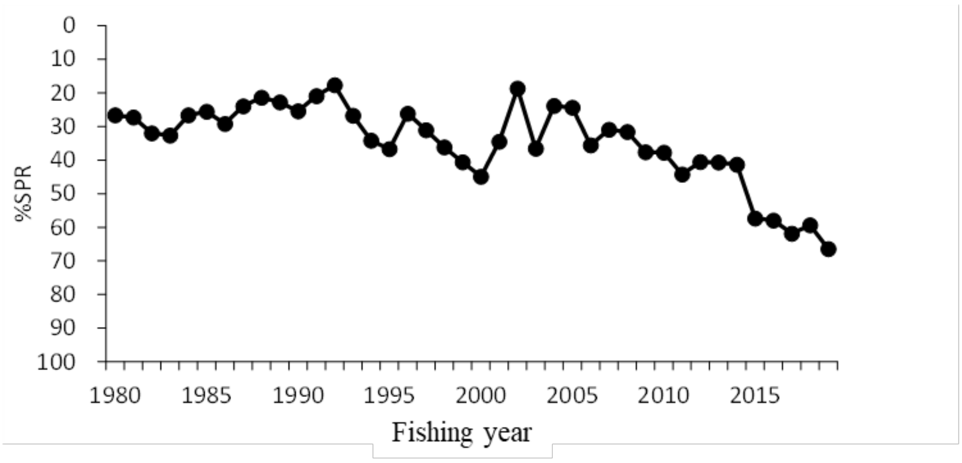


Figure 4-9. Changes in %SPR value

The %SPR indicates the ratio of spawning biomass with catch to spawning biomass assuming no catch. The higher (lower) the fishing mortality (F), the lower (higher) the %SPR.

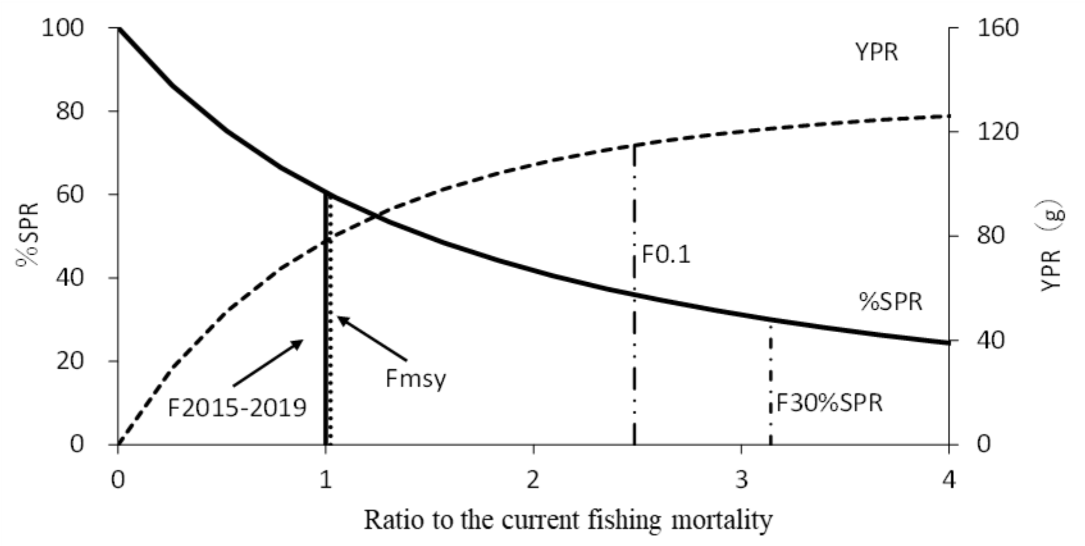


Figure 4-10. Relationship between YPR and %SPR to the current fishing mortality (F2015-2019)

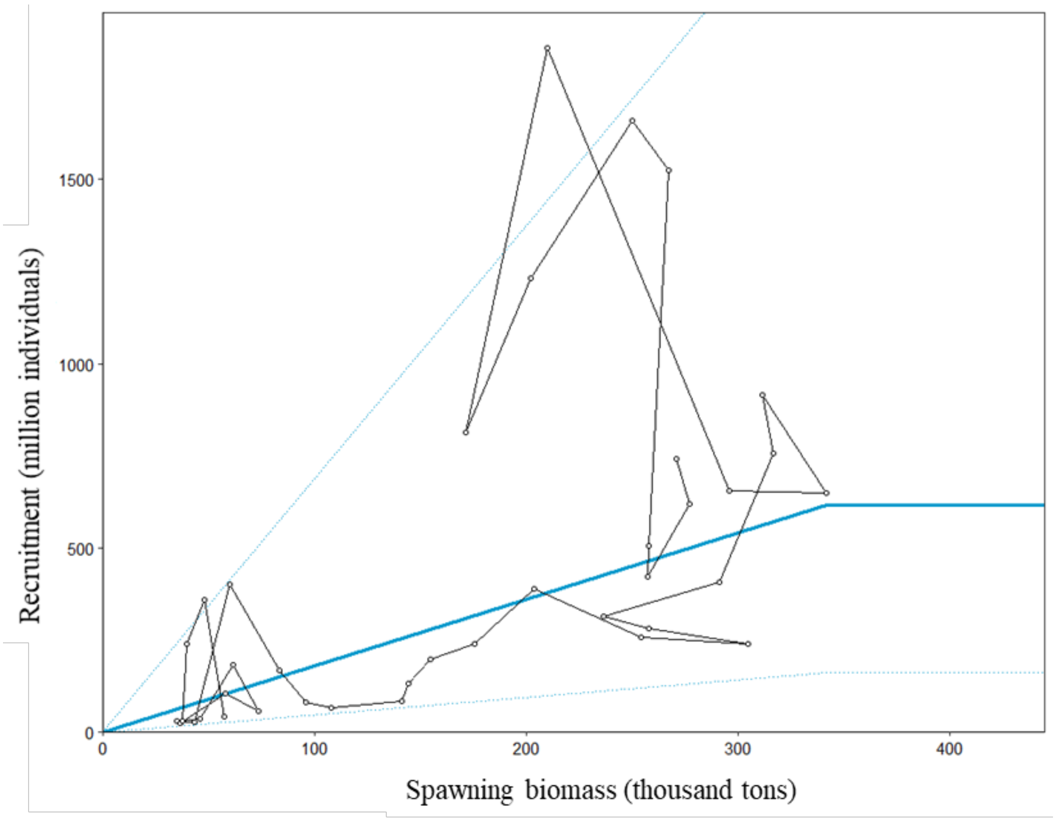


Figure4-11. Relationship between spawning biomass and recruitment (S-R relationship)

The blue line indicates the S-R relationship applied at the "Research Institute Meeting on Reference Points" held in April 2019 (Yamashita et al. 2019). The dotted lines show the range that is estimated to cover 90% of the observation data.

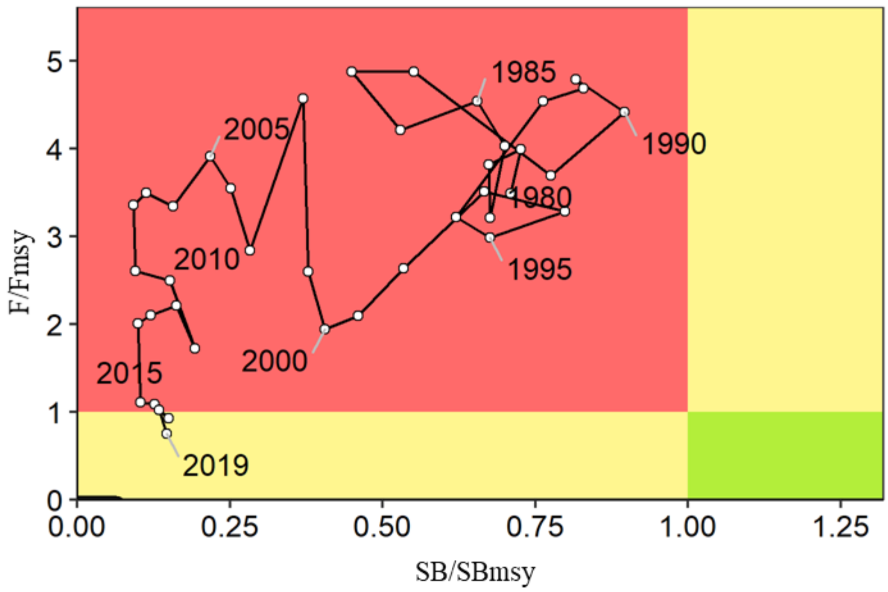


Figure 4-12. Relationship of the spawning biomass and fishing mortality to the spawning biomass that produces MSY (SBmsy) and fishing mortality that produces MSY (Fmsy) (Kobe plot)

Table 3-1. Catch of walleye pollock Northern Sea of Japan stock (tons)

Fishing year	Total of northern Sea of Japan stock	Sea of Japan along Hokkaido				Northern Sea of Japan along the mainland
		Subtotal	Offshore bottom trawl fishery	Coastal fishery	South Korean vessel	
1970	111,254	92,482	58,803	33,679	-	18,772
1971	102,946	90,275	57,018	33,257	-	12,671
1972	154,926	137,935	107,074	30,861	-	16,991
1973	136,332	108,327	80,518	27,809	-	28,005
1974	112,174	86,188	63,248	22,940	-	25,986
1975	143,159	121,748	100,056	21,692	-	21,411
1976	112,584	94,373	69,914	24,458	-	18,211
1977	119,961	102,077	51,789	50,288	-	17,884
1978	158,045	148,936	93,058	55,878	-	9,109
1979	168,909	159,827	102,903	56,924	-	9,082
1980	144,205	134,560	82,928	51,632	-	9,645
1981	119,043	110,266	54,341	55,925	-	8,777
1982	99,036	91,092	41,969	49,123	-	7,944
1983	93,666	86,614	43,278	43,335	-	7,052
1984	121,527	114,229	71,997	42,232	-	7,298
1985	117,468	110,676	68,874	41,802	-	6,792
1986	83,665	76,363	43,140	33,224	-	7,302
1987	94,351	77,254	51,936	25,318	10,804	6,293
1988	132,809	113,846	80,777	33,069	12,186	6,777
1989	142,245	122,858	94,019	28,838	11,635	7,752
1990	132,251	120,762	90,429	30,333	4,677	6,812
1991	145,042	120,605	90,502	30,103	16,451	7,986
1992	146,028	120,443	97,459	22,984	18,786	6,799
1993	90,678	70,487	47,386	23,102	15,011	5,180
1994	70,734	61,045	41,018	20,027	5,774	3,915
1995	70,557	61,033	41,116	19,917	5,540	3,984
1996	90,154	77,175	58,693	18,482	9,384	3,595
1997	75,712	67,265	43,158	24,107	4,857	3,590
1998	58,447	52,957	36,430	16,527	2,119	3,371
1999	51,627	48,535	32,482	16,053	-	3,092
2000	41,847	39,157	25,952	13,204	-	2,690
2001	45,616	42,603	24,646	17,957	-	3,013
2002	59,359	57,309	39,733	17,576	-	2,050
2003	32,896	31,267	15,209	16,058	-	1,629
2004	33,492	32,291	20,717	11,574	-	1,201
2005	26,022	24,646	15,134	9,511	-	1,376
2006	20,873	19,883	12,605	7,278	-	991
2007	18,244	16,870	8,506	8,364	-	1,374
2008	18,516	17,550	10,383	7,168	-	965
2009	14,533	13,970	7,894	6,075	-	564
2010	15,187	14,662	7,768	6,894	-	525
2011	10,637	10,248	6,395	3,853	-	389
2012	11,813	11,524	6,375	5,150	-	289
2013	9,888	9,553	5,595	3,957	-	335
2014	7,085	6,858	4,484	2,374	-	227
2015	5,389	5,233	2,814	2,420	-	156
2016	6,041	5,966	3,387	2,579	-	74
2017	5,315	5,281	3,093	2,187	-	34
2018	5,640	5,616	3,095	2,521	-	24
2019	5,241	5,197	2,768	2,428	-	44

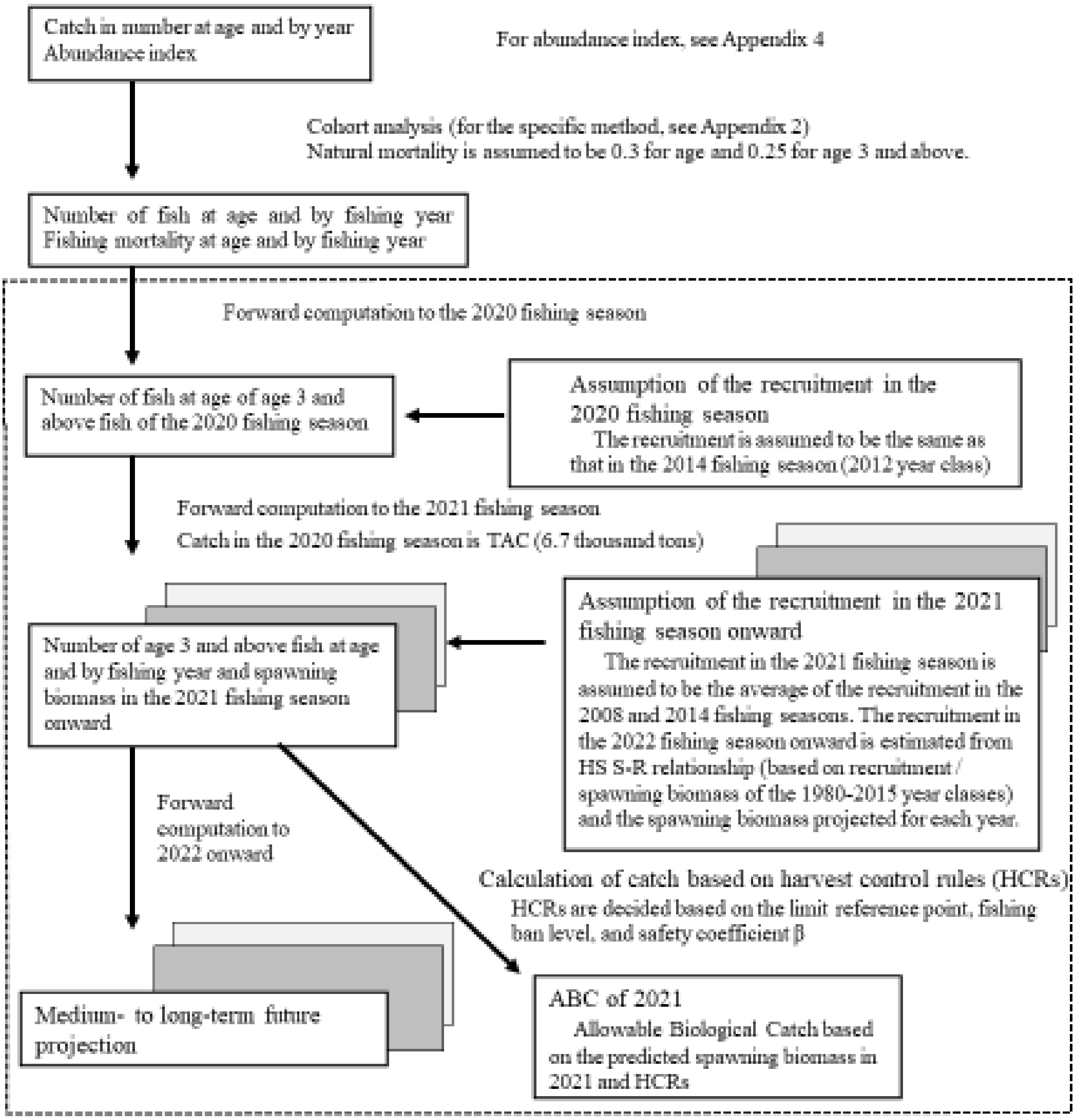
The area subject to aggregation of catch in coastal fishery in Hokkaido is from Wakkanai City to Fukushima Town. The values of the Northern Japan Sea along the mainland before the 2002 fishing season are annual totals. *Values for 2018 and 2019 fishing seasons are preliminary values.

Table 4-1. Result of the cohort analysis of walleye pollock Northern Sea of Japan stock

Fishing year	Catch (tons)	Biomass (tons)	Spawning biomass (tons)	Age 2 recruitment (million individuals)	Exploitation rate (%)	Recruitment per spawning (individuals/kg)
1980	144,205	625,355	270,570	741	23	2.74
1981	119,043	593,173	277,112	621	20	2.24
1982	99,036	569,662	257,149	422	17	1.64
1983	93,666	561,521	257,924	507	17	1.97
1984	121,527	526,554	267,099	1,526	23	5.71
1985	117,468	467,476	249,990	1,658	25	6.63
1986	83,665	549,703	201,830	1,233	15	6.11
1987	94,351	722,398	171,594	814	13	4.74
1988	132,809	835,017	210,110	1,858	16	8.84
1989	142,245	806,215	295,857	655	18	2.21
1990	132,251	867,859	341,743	648	15	1.90
1991	145,042	826,580	311,391	916	18	2.94
1992	146,028	712,371	316,383	757	20	2.39
1993	90,678	604,658	291,215	409	15	1.40
1994	70,734	578,948	236,624	315	12	1.33
1995	70,557	563,737	257,806	281	13	1.09
1996	90,154	520,130	304,515	240	17	0.79
1997	75,712	402,812	254,223	257	19	1.01
1998	58,447	325,178	203,690	390	18	1.91
1999	51,627	286,228	175,562	241	18	1.37
2000	41,847	283,222	154,532	199	15	1.29
2001	45,616	275,224	144,239	133	17	0.92
2002	59,359	249,320	141,211	85	24	0.60
2003	32,896	185,548	108,023	66	18	0.61
2004	33,492	156,144	96,054	81	21	0.84
2005	26,022	120,264	83,276	169	22	2.03
2006	20,873	90,884	59,861	401	23	6.70
2007	18,244	88,149	43,190	27	21	0.62
2008	18,516	125,189	34,896	32	15	0.91
2009	14,533	120,434	36,478	26	12	0.70
2010	15,187	108,545	57,863	107	14	1.85
2011	10,637	90,754	73,490	57	12	0.77
2012	11,813	85,110	61,763	182	14	2.95
2013	9,888	74,854	45,770	38	13	0.84
2014	7,085	84,654	37,907	30	8	0.80
2015	5,389	83,302	39,666	241	6	6.08
2016	6,041	81,068	48,099	359	7	7.46
2017	5,315	102,170	57,271	44	5	0.77
2018	5,640	144,681	51,149	—	4	—
2019	5,241	154,001	55,688	—	3	—

Although the fishing year of catch, stock biomass, spawning biomass and exploitation rate correspond to the fishing year of the catch statistics in Table 3-1 or the results of the cohort analysis, the recruitment of age 2 and its recruitment per spawning (recruitment of age 2 ÷ spawning biomass) are indicated in the fishing year when the fish were born. As those generated in the 2018 and 2019 fishing seasons were not recruited into biomass of the fishing target as of the end of 2019 fishing year, the cells are indicated as "-.

Appendix 1. The workflow of stock assessment



* Workflows in the dashed box are prepared based on discussions on reference points and HCRs at the Committee of Stock Management Policy. (http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/index.html)

20

Appendix 2. Calculation method of abundance

The catch in number at age and the average body weight of catch at age of walleye pollock Northern Sea of Japan stock were estimated from the values calculated by each responsible Fisheries Research Institute under Fisheries Research Department of the Hokkaido Research Organization based on the catch by fishing year and age composition of the catch in each month, reflecting the catch in the Sea of Japan off Japan's mainland and that by South Korea (the catch by South Korea was considered only for the 1987-1998 fishing seasons). The fish of age 10 and above for which age estimation was difficult are grouped into the plus group (indicated as 10+).

The number of fish at age, biomass in weight and fishing mortality are estimated by cohort analyses. In cohort analysis, we calculated the values at age from age 2 to 10+ starting from April based on the life cycle of walleye pollock. We used Pope' s approximation (1972) for calculation of the number of fish at age (N), while using the method of Hiramatsu (1999) for the number of fish of plus group. The natural mortality (M) was assumed to be 0.3 for age 2 and 0.25 for age 3 and above. Spawning biomass index and recruitment index were used for tuning.

As for spawning biomass index, the results of the survey of the distribution of spawning adults were used (Figure4-1, Appendix 4-(1)). Here, the estimated values of standing stock in 2002 and 2012, when a sufficient area for survey could not be secured due to bad weather, were excluded from tuning. As for the recruitment index, the abundance in number of age 1 fish by the survey of the distribution of juveniles in 2007-2017 (2006-2016 year classes) (Figure 4-2, Appendix 4-(4)) and the abundance in number of age 0 fish by the survey of the distribution of larvae and juveniles in 2006-2016 (Figure 4-2, Appendix 4-(3)) were used. As for the fishing mortality (F) for recent years, the F value at age was explored by applying a penalty according to the method of Ridge VPA (Okamura et al. 2017) so that the changes in the spawning biomass and the recruitment fit best to the changes in the standing stock obtained from the surveys. Here, it is concerned that the error of the explored F value would be large especially for ages with small abundance, and the validity of this change of value was low considering the actual fishing operations. Therefore, we assumed that the F value is constant for fish of age 5 and above in the most recent year (selectivity = 1) (Yamashita et al. 2019).

Specific equation for biomass estimation is as follows:

The number of fish at age of each year ($N_{a,y}$) is calculated using equation (1) based on the catch in number at age and natural mortality of each age:

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

Here, $N_{a,y}$ is the number of age a fish in year y, $C_{a,y}$ is catch in number of age a fish in year y, and M_a is natural mortality of age a fish.

The number of ages 9 and 10+ fish were obtained from the following equations (2) and (3), respectively.

$$N_{9,y} = \frac{C_{9,y}}{C_{9,y} + C_{10+,y}} N_{10+,y+1} \exp(M_9) + C_{9,y} \exp(\frac{M_9}{2}) \qquad (2)$$

$$N_{10+,y} = \frac{C_{10+,y}}{C_{9,y} + C_{10+,y}} N_{10+,y+1} \exp(M_{10+}) + C_{10+,y} \exp(\frac{M_{10+}}{2}) \qquad (3)$$

The number at age in the most recent year Y, $N_{a,Y}$, was obtained from the equation (4) using the fishing mortality at age, $F_{a,Y}$, and catch in number at age, $C_{a,Y}$, in the recent year.

$$N_{a,Y} = \frac{C_{a,Y} \exp\left(\frac{M_a}{2}\right)}{\left(1 - \exp(-F_{a,Y})\right)} \qquad (4)$$

The spawning biomass, SSB_y, in each year was obtained from the equation (5).

$$SSB_y = \sum_{a=2}^{10+} N_{a,y} \times m_{fa-1} \times w_a \qquad (5)$$

Here, m_{fa} is the maturity rate for a female individuals of age a, w_a is body weight of age a. The abundance estimated by the stock assessment is the initial biomass as of April 1 when the new fishing year starts. However, as April is just after the end of the spawning season, we calculated the spawning biomass by multiplying the initial biomass in each fishing year by the maturity rate for the one-year-older female individuals in Appendix Table 2-1 (for example, the maturity rate for age 3 fish is applied to age 4 fish).

The fishing mortality (F) is calculated from equation (6), excluding for the oldest fish (10+) and in the most recent year.

$$F_{a,y} = -\ln\left(1 - \frac{C_{a,y} \exp(\frac{M_a}{2})}{N_{a,y}}\right) \qquad (6)$$

We assumed that F of age 10+ fish is equal to that of age 9 fish.

The selectivity by fishing year and at age (the value obtained by dividing the F value at age in a certain year by the F value for the plus group in the year) is calculated based on the F by fishing year and at age obtained here.

As for the fishing mortality in the most recent year (2019 fishing season), we estimated the value applying the Ridge VPA (Okamura et al. 2017) method. Here, it is a concern that the error of the explored F value would be large, so we assumed that the F value is constant for fish of age 5 and above in the most recent year (Yamashita et al. 2019a). By using the spawning biomass obtained from the survey of the distribution of spawning adults (Appendix 4-(1)), abundance in number of age 0 fish obtained from the survey of the distribution of larvae and juveniles (Appendix 4-(3)), and abundance in number of age 1 fish obtained from the survey of the distribution of juveniles (Appendix 4-(4)), we searched F value at age that minimizes the target function (equation (7)) which is weighted with the compatibility with these abundance indices and with the square of F as penalty.

$$(1-\lambda)\times\sum_{k}\sum_{v}\left[W_k\times\left[\ln(I_{k,y})-\ln(q_kN_y)\right]^2\right]+\lambda\times\sum_{a=2}^{9}\left(F_{a,Y}\right)^2 \qquad (7)$$

Here, λ is the weight of the penalty (0≦λ<1, details are described below), W_k is a weight of the abundance index k, $I_{k,y}$ is the value of the abundance index k in the year y, q_k is the proportionality coefficient between the abundance index k and abundance, N_y is the value of abundance calculated from VPA corresponding to the abundance index k in year y, and $F_{a,y}$ is the value of F for age a in the most recent year (2019 fishing season). As for the weight of abundance index W_k, the spawning biomass index was set to be 10, and the recruitment index was set to be 1.

The proportional coefficient q_k is obtained from equation (8). Here, T is the number of years of the survey used for the tuning.

$$q_k=exp\left(\frac{\sum ln\left(\frac{I_k}{N_y}\right)}{T}\right) \qquad (8)$$

As the spawning biomass index is the standing stock in October, the spawning stock biomass corresponding to this was obtained from equation (9).

$$SSB_{octy}=\sum_{a=2}^{10+} N_{a,y}\exp\left(-\frac{M_a}{2}\right)\times m_a\times w_a \qquad (9)$$

Here, m_a is the maturity rate for both male and female fish of age a (Appendix Table 2-2).

The changes in the standing stock by each survey and the estimated biomass and residuals are shown in Appendix Figure 2-1.

The value of λ was set so that the retrospective bias (ρ) of the spawning biomass obtained from equation (10) would be the closest to 0.

$$\rho=\sum_{i=1}^{P}\left(\frac{SSB_{Y-i}^{R_i}-SSB_{Y-i}}{SSB_{Y-i}}\right) \qquad (10)$$

Here, P is the number of years for the retrospective calculation. We used the data of the most recent 5 years. The value of $SSB^{Ri}_{Y\text{-}I}$ is the spawning biomass in the terminal year of the retrospective calculation for i years, $SSB_{Y\text{-}I}$ is the spawning biomass of 2019－i years in calculation using the data until the most recent year (2019 fishing season).

Here in estimation, the maximum value of F was limited to 1.5 base on the highest value in the past. The outline of the relationship between ρ and λ is shown in Appendix Table 2-3. The value of ρ for other than spawning biomass was calculated according to the equation (10).

The value of λ that makes the value of ρ of spawning biomass closest to 0 was 0.878. The changes in spawning biomass for this value of λ is shown in Appendix Figure 2-2.

For details of the application of the S-R relationship and estimation of the level that produces MSY, see the report of the “Research Institute Meeting on Reference Points” held in April 2019 (Yamashita et al. 2019b). Here, the S-R relationship applied and the settings used for future projection in the Marine fisheries stock assessment and evaluation for Japanese waters in 2018 (Yamashita et al. 2019a) are used for the estimation of the level that produces MSY. Namely, the S-R relationship is the HS model based on the recruitment and spawning biomass of the 1980-2015 year classes as estimated by the stock assessments, while natural mortality, maturity rate, average body weight at age and selectivity of fishing are used as conditions of simulation. Selectivity was based on the average fishing coefficient (F) of each age during the 2013-2017 fishing seasons, and the value that makes the simple average F value of each age equal to the average value of the 2015-2017 fishing seasons under the selectivity above is used as Fcurrent. As average body weight of catch, the average value of the 2013-2017 fishing seasons is used (Appendix Table 2-4). Through simulations with the conditions and S-R relationship above, fishery coefficient that maximizes catch at equilibrium was estimated as Fmsy, spawning biomass with the Fmsy was as SBmsy and the average of the maximized catch at equilibrium was estimated as MSY.

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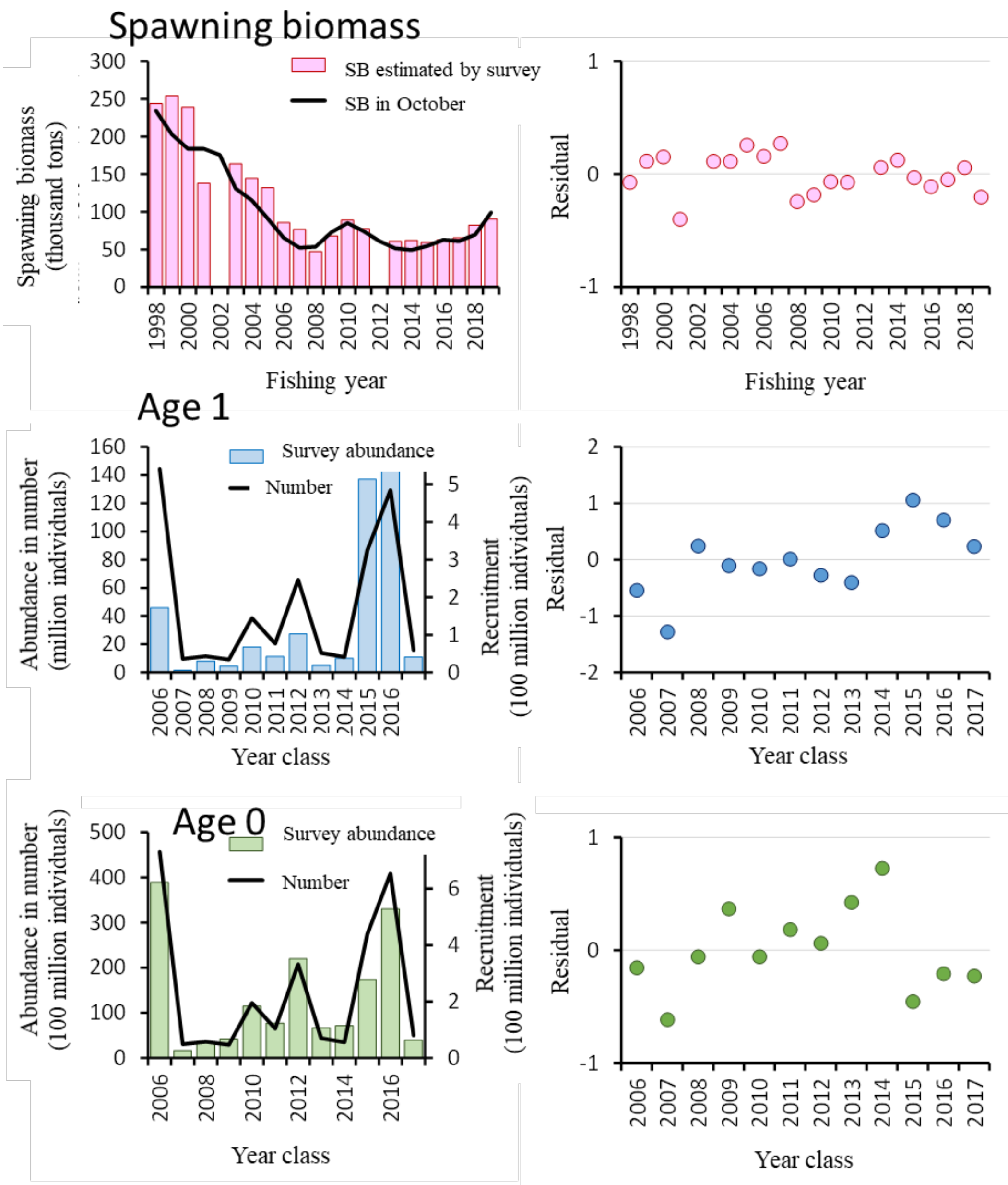
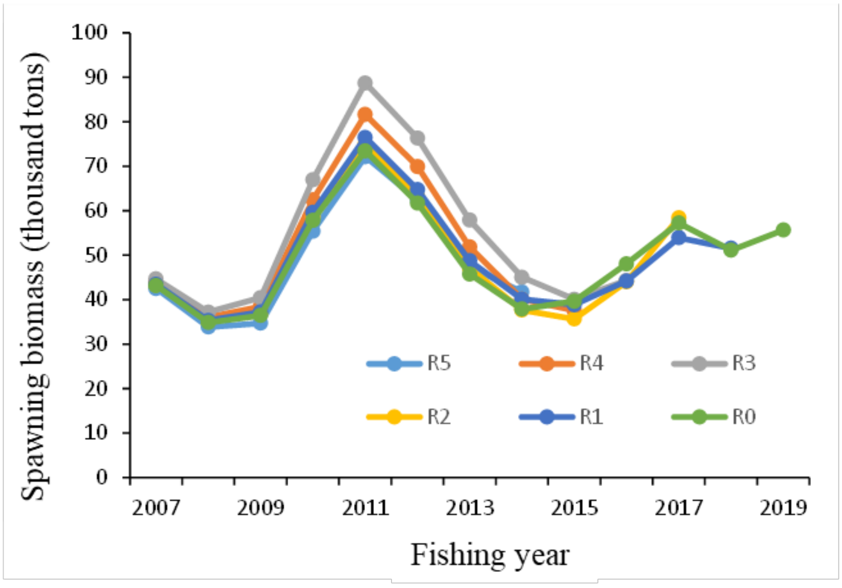


Appendix Figure 2-1. Changes in estimated standing stock from each survey and the biomass corresponding to the estimation (left) and the residuals (right)

The upper figures show the spawning biomass from the survey of recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults) and the spawning biomass in October. The middle figures show the number of age 1 fish from the survey of recruitment of walleye pollock in the Sea of Japan (survey of the distribution of juveniles) and the number of age 1 in April. The bottom figures show the abundance in number of age 0 fish from the survey of recruitment of walleye pollock in the Sea of Japan (survey of the distribution of larvae and juveniles) and the number of age 0 fish in April. The number of ages 0 and 1 fish was calculated by assuming that: the catch in number of ages 0 and 1 fish is 0; and the value of the natural mortality (M) is the same as that of age 2 fish.



Appendix Figure 2-2. Changes in spawning biomass calculated by retrospective analysis (λ = 0.878) R0 indicates the changes in spawning biomass in the calculation using the data until the most recent year (2019 fishing season). R1 to R5 show the changes in spawning biomass in the retrospective calculation for 1 to 5 years.

Appendix Table 2-1. Maturity rate of female at age (%)

Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10 and above
0	0	31	89	99	100	100	100	100	100

Appendix Table 2-2. Maturity rate for both male and female at age (%)

Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10 and above
0	9	48	90	99	100	100	100	100	100

Appendix Table 2-3. Value of ρ calculated for each value of λ (0.0 to 0.9)

λ	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Spawning biomass	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	-0.01	0.01
Biomass	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.15
Recruitment	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.43	0.44
%SPR	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06
F at age										
Age 2	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.29	-0.29
Age 3	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24	-0.24
Age 4	-0.23	-0.23	-0.23	-0.23	-0.22	-0.22	-0.22	-0.22	-0.21	-0.20
Age 5	0.35	0.34	0.34	0.34	0.34	0.33	0.33	0.32	0.31	0.28
Age 6	0.39	0.39	0.39	0.39	0.38	0.38	0.38	0.37	0.35	0.33
Age 7	0.81	0.80	0.80	0.80	0.80	0.80	0.79	0.79	0.77	0.75
Age 8	-0.04	-0.04	-0.04	-0.05	-0.05	-0.05	-0.06	-0.06	-0.08	-0.10
Age 9	-0.05	-0.05	-0.06	-0.06	-0.06	-0.07	-0.07	-0.08	-0.10	-0.13

Appendix Table 2-4. Parameters used for estimation of the level that produces MSY (Yamashita et al. 2019b)

Age	Natural mortality	Maturity rare	Average body weight of stock (g)	Average body weight of catch (g)	Selectivety (Note 1)	Fcurrent (Note 2)
2	0.30	0.00	134	98	0.18	0.02
3	0.25	0.00	229	202	0.36	0.04
4	0.25	0.31	326	287	0.60	0.08
5	0.25	0.89	425	370	0.81	0.10
6	0.25	0.99	485	442	1.15	0.14
7	0.25	1.00	545	489	1.24	0.16
8	0.25	1.00	570	548	1.31	0.16
9	0.25	1.00	578	607	1.00	0.13
10 and above	0.25	1.00	688	680	1.00	0.13

Note 1: Selectivity used for estimation of the level that produces MSY is the selectivity of Fcurrent of the stock assessment in 2018 (selectivity of average F of the 2013-2017 fishing seasons)
Note 2: Fcurrent of the stock assessment in 2018 (The value that makes the simple average F value of each age equal to the average value of the 2015-2017 fishing seasons under the selectivity of the average F value of the 2013-2017 fishing seasons)

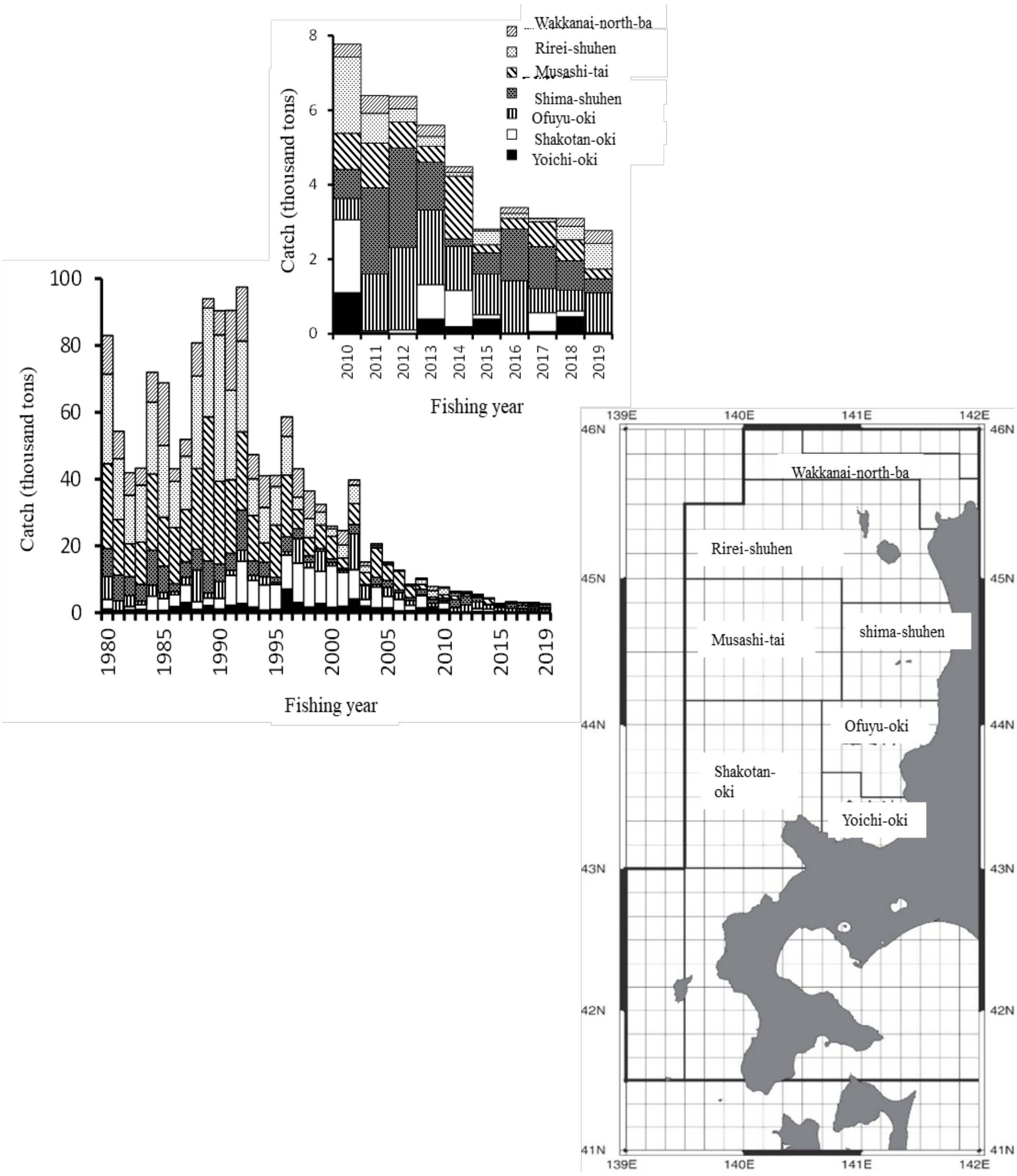
Appendix 3. Details of fishery

(1) Catch by local fishing zone / area

Appendix Figure 3-1 shows the changes in catch in offshore trawl fishery by local fishing zone. The main fishing areas were Musashi-tai, Rirei-shuhen, and Wakkanai-north-ba before the 1992 fishing season. Since the 1993 fishing season, the catch in these northern sea areas largely decreased. On the other hand, since the 1991 fishing season, the catch at Shakotan-oki, which is located in the southern area, increased and the portion was relatively high until the 2008 fishing season. In many years after the 2011 fishing season, fishing was conducted mainly at Ofuyu-oki and Shima-shuhen. In the 2019 fishing season, catch at Ofuyu-oki and Rirei-shuhen was large.

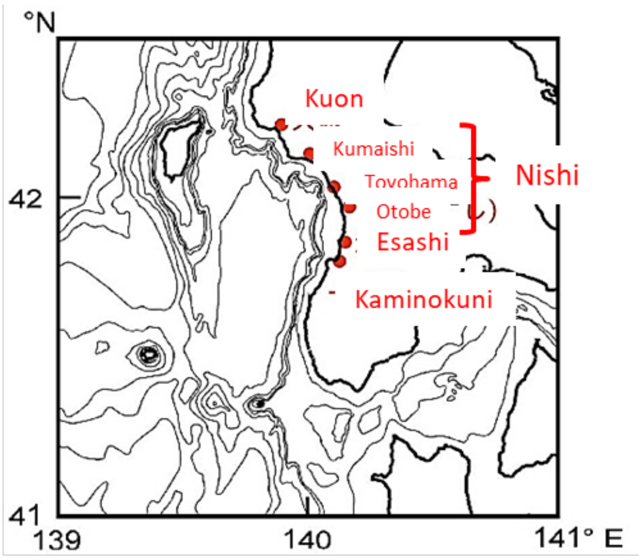
The catch in offshore trawl fishery was almost equal to TAC since the 2008 fishing season, but the catch in the 2014 and 2015 fishing seasons was much lower than TAC, and since the 2016 fishing season, as TAC was set at lower level, the catch remained at a similar level.

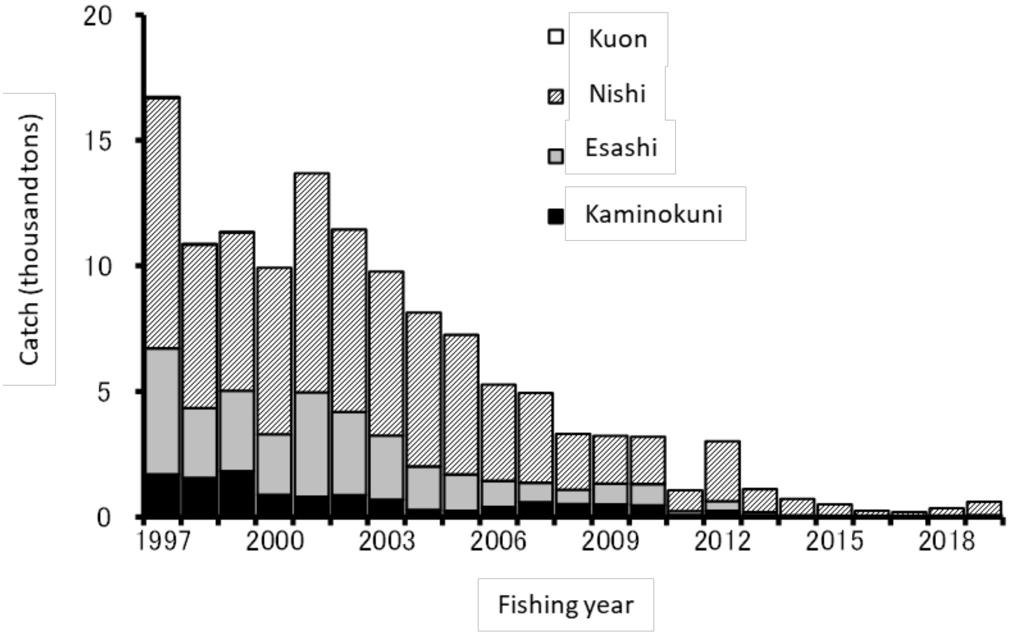
As for offshore fisheries, the changes in catch by sea area since the 1997 fishing season in Hiyama coast is shown in Appendix Figure 3-2. This sea area is the main fishing ground of longline fishery targeting spawning biomass that wander to the coastal area in winter (November to February). The total catch in Hiyama coast has been decreasing since the 2002 fishing season, and the fishing area also shrank to only the Nishi area since the 2014 fishing season. The catch in the 2019 fishing season was 0.6 thousand tons, which was much smaller than the past, even though it increased twice as much as that in the previous fishing season. The ratio of the catch in Hiyama coast to the total catch in offshore fishery was 60 to 70% during the period of the 1992-2006 fishing seasons, but it decreased to 10 to 20% since the 2016 fishing season.



Appendix Figure 3-1. Changes in catch of walleye pollock in offshore trawl fishery by local fishing zone in the Sea of Japan along Hokkaido

The upper right enlarged figure shows details of the 2010 fishing season onward, and the right map shows the location of each local fishing zone.





Appendix Figure 3-2. Changes in catch by longline fishery targeting spawning adults (November to February) in four areas in Hiyama District (Hakodate Fisheries Research Institute (unpublished))

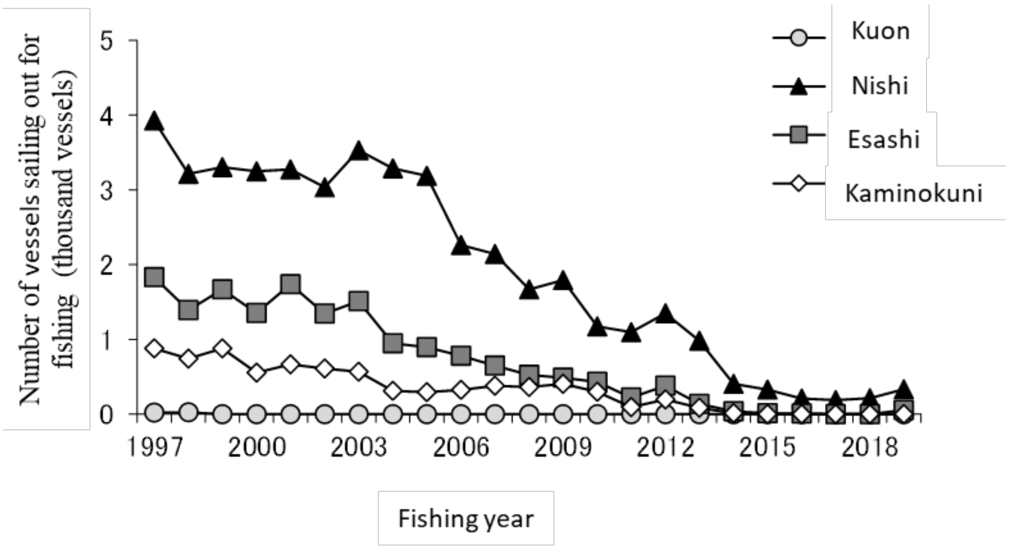
(2) Catch and fishing effort

The catch and fishing effort (number of trawls with catch of walleye pollock) of offshore fishery aggregated by month and by operation type are shown in Appendix Table 3-1. Here, although all the offshore trawlers were licensed for test operations in the 2015-2016 fishing seasons, those fishing vessels in normal operation in the 2014 fishing season were considered to be the same after the 2015 fishing season because there was no change in equipment of vessels. Both the catch and the number of trawls have been decreasing since the 1990s. The number of trawls of Danish seine vessels of less than 100 tons remained around 11 thousand to 14 thousand times in the first half of the 1980s, but since the 1986 fishing season, it decreased to less than one thousand times in the 1998 fishing season. The number of trawls of Danish seine vessels of less than 100 tons rapidly decreased to 8 thousand times in the 2000 fishing season due to the measure to reduce fishing vessels. It kept decreasing, and since the 2009 fishing season, it remained at around 1 thousand to 2 thousand times. The number of trawls of otter trawl vessels is small in recent years and it is less than 1 thousand times since the 2004 fishing season.

Appendix 3-2 shows the aggregated daily operation data on Danish seine vessels of less than 100 tons by vessel and by fishing area. Assuming that the operation where more than 50% of the catch is walleye pollock is the one targeting walleye pollock, more than 80% of the catch is caught in the operation targeting walleye pollock. The catch in the operation targeting walleye pollock tends to decrease since the 1996 fishing season and it remained at around 2 thousand to 5 thousand tons, which is less than 10% of that of the 1996 fishing season. The number of trawls also tends to decrease, and it remained at around 0.4 thousand to 0.6 thousand times since the 2013 fishing season, which is less than 10% of that in the 1996 fishing season. Moreover, when focusing on the operation where walleye pollock account for more than 80% of the total catch (operation targeting walleye pollock only), the same trends can be seen in catch and the number of trawls.

As for coastal fishery, the fishing effort of longline (the number of fishing vessels sailing out for fishing before correction of the number of lines) in four zones in the coast of Hiyama is shown in Appendix Figure 3-3. The number of vessels sailing out for fishing tends to decrease since latter half of the 1990s. Such trend is confirmed in all areas and in Nishi fishing zone, which is the main area for the fishery, the number was more than 3 thousand before the 2005 fishing season, but it began to decrease largely since the 2006 fishing season to less than 0.5 thousand vessels since the 2014 fishing season. In Kaminokuni, the number of vessels sailing out for fishing has been zero since the 2015 fishing season. The number of lines used per vessel in the Toyohama area of the Nishi fishing area was around 6.7 thousand to 7.5 thousand nets during the period from the 1998 fishing season until the 2004 fishing season, but it decreased afterward to 2 thousand to 4 thousand nets since the 2008 fishing season, which was 20 to 60% of that in the 1998 fishing season (Appendix Table 3-3). In addition, the number of vessels was three after the 2016 fishing season and was only two in the 2019 fishing season.

Appendix Table 3-4 shows the number of vessels sailing out for fishing after correcting the number of lines, which is obtained by multiplying the number of vessels sailing out for fishing before correction of the number of lines in the four areas along Hiyama coast by the ratio of nets used when the number of lines used per vessel in the 1998 fishing season in the Otobe/Toyohama area is normalized to be 1. The number of vessels sailing out for fishing in the 2019 fishing season was 212, which was much larger than that in the previous fishing season, but it was about 4% of that in the 1998 fishing season.



Appendix Figure 3-3. Fishing efforts of longline fishery by area in the four areas in Hiyama District (Number of vessels sailing out for fishing before correction of the number of lines; Hakodate Fisheries Research Institute (unpublished))

Appendix Table 3-1. Catch and fishing effort of offshore bottom trawl fishery based in Hokkaido (from Monthly data)

	Catch (tons)			Fishing effort (thousand tows)		
Fishing year	Danish seine fishery (Less than 100 tons)	Danish seine fishery (100 tons and above)	Otter trawl fishery	Danish seine fishery (Less than 100 tons)	Danish seine fishery (100 tons and above)	Otter trawl fishery
1980	17,260	29,169	36,499	12.0	11.1	7.2
1981	12,362	19,988	21,990	13.0	12.1	5.4
1982	12,675	13,421	15,872	14.4	13.3	3.2
1983	10,198	14,022	19,058	11.4	13.5	2.6
1984	14,540	16,987	40,471	13.7	15.9	4.6
1985	14,335	22,267	32,272	13.9	16.9	3.8
1986	8,121	16,554	18,464	8.1	15.7	3.2
1987	8,963	25,309	17,664	6.9	17.1	2.0
1988	17,761	58,620	4,396	7.5	17.9	0.7
1989	23,160	66,319	4,539	7.2	16.5	0.8
1990	13,105	48,195	29,128	6.9	19.7	2.2
1991	15,418	51,968	23,115	6.5	20.0	2.2
1992	17,260	63,906	16,293	4.9	17.0	1.2
1993	8,558	35,991	2,837	3.6	15.7	0.5
1994	3,395	33,604	4,018	1.8	14.3	0.5
1995	1,474	37,666	1,976	1.6	16.3	0.6
1996	2,066	52,402	4,215	1.1	15.3	0.7
1997	1,620	37,153	4,385	1.0	15.7	0.4
1998	736	33,017	2,677	0.7	13.5	0.1
1999	805	31,104	573	0.5	13.9	0.1
2000	297	23,621	2,035	0.2	8.0	1.1
2001	-	21,896	2,750	-	9.7	1.4
2002	-	38,205	1,288	-	8.0	0.9
2003	-	13,823	1,074	-	8.6	1.0
2004	-	19,262	659	-	6.9	0.8
2005	-	13,448	892	-	6.3	0.7
2006	-	12,175	47	-	5.0	0.6
2007	-	8,233	117	-	6.4	0.8
2008	-	10,178	205	-	5.6	0.6
2009	-	7,203	692	-	2.4	0.5
2010	-	6,500	621	-	2.3	0.4
2011	-	5,407	455	-	1.5	0.2
2012	-	5,428	412	-	2.1	0.3
2013	-	5,526	34	-	2.3	0.2
2014	-	3,930	285	-	1.9	0.2
2015	-	2,394	217	-	1.9	0.2
2016	-	3,033	72	-	1.3	0.3
2017	-	2,828	265	-	1.6	0.2
2018	-	2,854	241	-	1.7	0.2
2019	-	2,768	0.2	-	1.0	0.05

Normal operation only. The values of test operations deemed to be normal operations are included in the 2015 and 2016 fishing seasons. The values in the 2018 and 2019 fishing seasons are provisional. The fishing effort is the number of tows with catch of walleye pollock. *Gross tonnage of vessel

Appendix Table 3-2. Catch and fishing effort of offshore bottom trawl fishery (by Danish seine vessels which gross tonnage is 100 tons and above) based in Hokkaido

Fishing year	Catch (tons)			Fishing effort (number of tows)			
	Operation targeting walleye pollock only	Operation targeting walleye pollock	Total of Operations	Operation targeting walleye pollock only	Operation targeting walleye pollock	Operation with catch of walleye pollock	Total of Operations
1996	41,803	48,360	52,402	5,220	6,592	12,095	20,907
1997	26,846	31,649	37,153	3,120	4,151	11,862	21,990
1998	21,553	27,770	33,017	2,691	3,926	10,372	20,330
1999	22,828	27,125	31,104	2,601	3,559	10,442	22,241
2000	17,742	20,294	23,621	2,065	2,653	6,273	14,854
2001	14,058	18,272	21,896	1,563	2,178	7,436	13,662
2002	25,979	33,472	38,205	2,398	3,591	6,976	10,660
2003	8,481	11,069	13,823	1,065	1,589	6,684	12,341
2004	9,140	14,677	19,262	1,186	2,024	5,504	11,812
2005	10,245	12,412	13,448	1,612	2,160	4,822	12,224
2006	11,212	11,655	12,175	2,053	2,188	3,999	12,863
2007	5,250	6,744	8,233	930	1,352	4,852	12,359
2008	6,284	8,217	10,178	633	977	4,083	9,823
2009	3,975	6,030	7,203	451	811	1,780	8,708
2010	4,924	5,828	6,500	518	781	1,474	7,885
2011	4,549	5,146	5,407	435	607	1,109	7,405
2012	4,452	4,835	5,428	652	796	1,692	7,048
2013	3,548	4,720	5,526	415	634	1,573	7,462
2014	2,420	3,521	3,930	320	490	1,254	7,389
2015	2,157	2,271	2,394	368	424	1,302	4,366
2016	2,235	2,888	3,033	290	456	1,017	4,616
2017	2,703	2,780	2,828	448	481	1,229	4,608
2018	1,900	2,568	2,854	231	366	1,200	5,657
2019	1,575	2,273	2,768	185	327	881	4,611

Normal operation only. The values of test operations deemed to be normal operations are included in the 2015 and 2016 fishing seasons. The values in the 2018 and 2019 fishing seasons are provisional. Based on the daily operation data by vessel and by fishing ground, the operation where the catch of walleye pollock accounted for more than 50% of the total catch was assumed to be the operation targeting walleye pollock, and the operation where the catch of walleye pollock accounted for more than 80% of the total catch was assumed to be the operation targeting walleye pollock only.

Appendix Table 3-3. Data on fishing effort of longline fishery in the Otobe/Toyohama area (Hakodate Fisheries Research Institute (unpublished))

Fishing year	Vessel type	Number of lines used/vessel	Number of vessels	Subtotal of the number of lines by vessel type	Total number of lines	Number of days sailing out for fishing	Number of lines used per vessel	Ratio of the number of lines used (referencing 1998)
1998	Large	7,375	17	125,375	130,695	56	7,261	1.00
	Small	5,320	1	5,320				
1999	Large	7,125	17	121,125	125,925	58	6,996	0.96
	Small	4,800	1	4,800				
2000	Large	6,775	15	101,625	106,545	60	6,659	0.92
	Small	4,920	1	4,920				
2001	Large	7,450	14	104,300	109,760	62	7,317	1.01
	Small	5,460	1	5,460				
2002	Large	6,900	14	96,600	101,680	58	6,779	0.93
	Small	5,080	1	5,080				
2003	Large	7,650	14	107,100	112,700	71	7,513	1.03
	Small	5,600	1	5,600				
2004	Large	7,100	14	99,400	104,600	69	6,973	0.96
	Small	5,200	1	5,200				
2005	Large	5,750	14	80,500	85,020	66	5,668	0.78
	Small	4,520	1	4,520				
2006	Large	4,425	14	61,950	64,750	50	4,317	0.59
	Small	2,800	1	2,800				
2007	Large	4,565	13	59,345	59,345	49	4,565	0.63
2008	Large	2,775	13	36,075	36,075	43	2,775	0.38
2009	Large	3,040	13	39,520	39,520	44	3,040	0.42
2010	Large	2,680	12	32,160	32,160	32	2,680	0.37
2011	Large	1,930	12	23,160	23,160	30	1,930	0.27
2012	Large	3,580	12	42,960	42,960	45	3,580	0.49
2013	Large	2,390	11	26,290	26,290	33	2,390	0.33
2014	Large	1,630	11	17,930	17,930	17	1,630	0.22
2015	Large	2,200	5	11,000	11,000	26	2,200	0.30
2016	Large	1,710	3	5,130	5,130	21	1,710	0.24
2017	Large	1,300	3	3,900	3,900	19	1,300	0.18
2018	Large	3,255	3	5,805	5,805	41	3,255	0.45
2019	Large	3,965	2	7,930	7,930	50	3,965	0.55

The ratio of the number of lines used is indicated as the ratio when the number of lines used per vessel in the 1998 fishing season is normalized as 1. The number of lines used per vessel is different depending on the type of vessel, and it can be obtained by dividing the total annual number of lines by the number of vessels sailing out for fishing. We calculated the total annual number of lines by aggregating the subtotals of the number of lines, which were obtained by multiplying the lines used by the number of vessels according to the type of vessel.

Appendix Table 3-4. Data on catch and fishing effort of longline fishery in four areas in Hiyama District (Hakodate Fisheries Research Institute (unpublished))

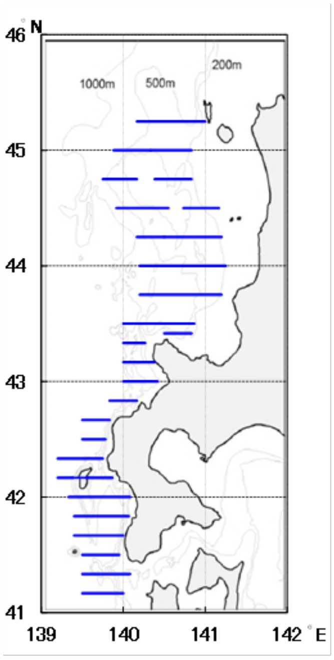
		Before correction of the number of lines	After correction of the number of lines
Fishing year	Catch (tons)	Fishing effort (vessels)	Fishing effort (vessels)
1998	10,883	5,373	5,373
1999	11,334	5,854	5,640
2000	9,922	5,154	4,727
2001	13,686	5,675	5,719
2002	11,451	4,987	4,656
2003	9,768	5,606	5,801
2004	8,147	4,547	4,367
2005	7,252	4,381	3,420
2006	5,273	3,371	2,004
2007	4,932	3,173	1,995
2008	3,308	2,557	977
2009	3,233	2,686	1,125
2010	3,189	1,902	702
2011	1,057	1,416	376
2012	3,020	1,927	950
2013	1,114	1,205	397
2014	715	458	103
2015	495	344	104
2016	249	219	52
2017	186	189	34
2018	349	214	96
2019	595	389	212

Fishing effort after correction of the number of lines (the number of vessels sailing out for fishing) was calculated by multiplying the fishing effort before correction by the ratio of the number of lines used when the number of lines used per vessel in the 1998 fishing season in the Otobe/Toyohama area indicated in Appendix Table 3-3 was normalized as 1.

Appendix 4. Results of research ship survey and peripheral information

(1) Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults): Wakkanai, Central and Hakodate Fisheries Research Institutes, Hokkaido Research Organization

Every October, surveys on spawning biomass of walleye pollock using quantitative echo sounders are conducted by Wakkanai, Central and Hakodate Fisheries Research Institutes of the Hokkaido Research Organization. The surveyed fishing area and the estimated standing stock are shown in Appendix Figure 4-1, and Appendix Table 4-1 and Figure 4-1 of the main text, respectively. We used the spawning biomass estimated by this survey for tuning of VPA (Appendix 2). Here, because a sufficient area for survey could not be secured in 2002 and 2012 due to bad weather, we use the values of the surveyed areas for 2002, and the correlation between the values of the areas surveyed in 2012 and those of all the surveyed areas (2007-2011) for 2012. Therefore, the values for these two years were excluded from the tuning of VPA.



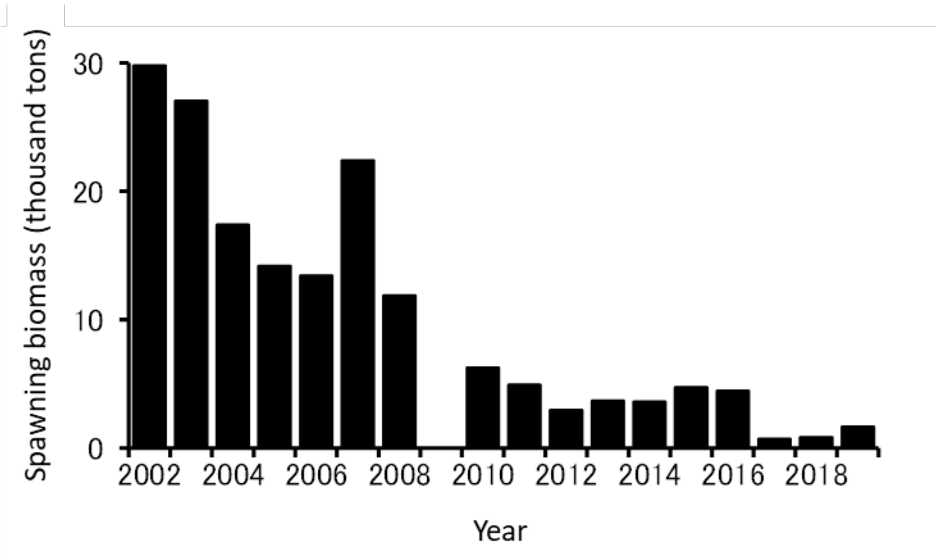
Appendix Figure 4-1. Fixed survey lines in the survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults)

Appendix Table 4-1. Estimated spawning biomass by the survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of spawning adults) (Wakkanai, Central and Hakodate Fisheries Research Institutes (unpublished))

Year	Spawning biomass (tons)	Year	Spawning biomass (tons)	Year	Spawning biomass (tons)
1998	243,745	2006	85,818	2014	62,091
1999	254,470	2007	76,630	2015	59,183
2000	239,238	2008	47,037	2016	62,566
2001	137,923	2009	67,840	2017	64,975
2002	95,823	2010	88,916	2018	82,183
2003	163,874	2011	77,264	2019	90,418
2004	144,515	2012	53,971		
2005	131,948	2013	60,748		

(2) Survey of the recruitment of walleye pollock in the Sea of Japan (survey during fishing season in Hiyama fishing area): Hakodate Fisheries Research Institute, Hokkaido Research Organization

Appendix Figure 4-2 shows the results of survey of biomass using quantitative echo sounders, which targets spawning biomass visiting spawning grounds in the fishing areas of longline fishery along Hiyama coast. This survey has been conducted by the Hakodate Fisheries Research Institute of the Hokkaido Research Organization every December. In 2009, they couldn’t conduct the survey due to bad weather. The standing stock of spawning biomass visiting the sea area along Hiyama coast tended to decline since 2002 until 2012. Although the standing stock remained at around 3.6 thousand to 4.7 thousand tons during the period of 2013-2016, it decreased to around 0.7 thousand to 0.8 thousand tons during 2017-2018. Although it increased to 1.7 thousand tons in 2019, which was about twice the level in the previous year, it still remained at low level.



Appendix Figure 4-2. Estimated spawning biomass in the Hiyama fishing area by the survey of the recruitment of walleye pollock in the Sea of Japan (survey during fishing season in Hiyama fishing area) (prepared based on a figure in a report from Wakkanai, Central and Hakodate Fisheries Research Institutes (printing underway))

(3) Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of larvae and juveniles): Wakkanai and Central Fisheries Research Institutes, Hokkaido Research Organization

In order to investigate the distribution of walleye pollock of age 0 that has not been recruited into fishery resource and its quantitative change, Wakkanai and Central Fisheries Research Institutes of the Hokkaido Research Organization has been conducting the survey of the distribution of larvae and juveniles using quantitative echo sounders and frame trawls in the Sea of Japan of Ishikari Bay and northward in every April. The results of the survey are shown in Appendix Table 4-2 and Figure 4-2 of the main text. Here, the abundance in number of the 2005 year class is for reference because the method of the survey in 2005 was different from that conducted afterward.

Here, we define the year classes whose abundance in number is less than 10 billion individuals as low abundance, those with between 10 billion to 20 billion individuals as medium abundance, and those with more than 20 billion individuals as high abundance. As for the year classes recruited by the 2019 fishing season, the abundance of the 2007, 2008, 2009, 2011, 2013, 2014 and 2017 year classes were low, those of the 2010 and 2015 year classes were medium, and those of the 2006, 2012 and 2016 year classes were high. As for the standing stock in number of the year classes expected to be recruited after 2020, the abundance of the 2018 year class was as high as that of the 2012 year class, that of the 2019 year class was the highest since the 2006 year class, and that of the 2020 year class was as medium as that of the 2015 year class. On the other hand, because the distribution of the 2018 and 2019 year classes is localized to the areas northward from Teuri and Yagishiri Islands and the body length was small, there is a possibility that a large part of these year classes flowed out to the Okhotsk Sea and the degree of depletion might be high (Wakkanai, Central and Hakodate Fisheries Research

Institutes (printing underway)).

During 2005-2007, a sampling of larvae and juveniles using frame trawl was conducted in the main spawning grounds in the Sea of Japan westward of Hokkaido, which is southward from Ishikari Bay including Iwanai Bay and the Hiyama fishing area. However, no larvae and juveniles were collected in the Sea of Japan westward of Hokkaido, which is southward from Ishikari Bay (Itaya et al. 2009). Miyake et al. (2008) presume that this is because most of the eggs spawned in Iwanai Bay and the Hiyama fishing area had been transported to the sea area around Ishikari Bay due to the Tsushima Warm Current based on the results of this survey and the distribution of eggs and their developmental stage.

Appendix Table 4-2. Abundance in number of walleye pollock of age 0 estimated from the survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of larvae and juveniles) (Wakkanai, Central and Hakodate Fisheries Research Institutes (unpublished))

Year class	Abundance in number (100million individuals)	Year class	Abundance in number (100million individuals)
2005	61	2013	67
2006	389	2014	71
2007	16	2015	173
2008	34	2016	330
2009	42	2017	40
2010	115	2018	232
2011	77	2019	1,010
2012	220	2020	148

The value for 2005 is for reference, and the value for 2020 is preliminary value.

(4) Survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of juveniles): Wakkanai and Central Fisheries Research Institutes, Hokkaido Research Organization

The results of survey using quantitative echo sounders targeting walleye pollock of ages 0 to 2 in fishing area around Musashi Bank are shown in Appendix Table 4-3 and Figure 4-2 of the main text. This survey has been conducted every August to September by Wakkanai and Central Fisheries Research Institutes of the Hokkaido Research Organization.

As the survey on continental shelf (shallower than the depth of 200 m) where a large amount of walleye pollock of age 0 live has only been conducted since 2007, the abundance of age 0 fish before the 2006 year classes and after the 2007 classes cannot be compared directly. In addition, in some years age 2 fish are distributed outside of the survey area or are localized. On the other hand, it is deemed appropriate to use the estimated abundance in number of age 1 as the index of abundance, treating that of ages 0 and 2 merely as reference, because it is considered that the main areas of distribution were surveyed thoroughly in this survey and that age 1 is near to the timing of recruitment.

Considering the abundance in number as of age 1, while it is relatively large, 46 million individuals, for the 2006 year class with good recruitment, that of the 2015 and 2016 year classes was about three times larger than that of the 2006 year class. The abundance in number of the 2010 and 2012 year classes was also relatively large and around the same level as the 2005 year class. On the other hand, the abundance in number of the 2007, 2008, 2009, 2011, 2013, 2014 and 2017 year classes was small and lower than 11 million individuals. The standing stock in number of the 2018 year class which will be recruited in the 2020 fishing season was 56 million individuals and was lower than that of the 2015 and 2016 year classes, but it was higher than that of the 2012 year class and slightly higher than that of the 2006 year class. On the other hand, the range of distribution was small (Wakkanai and Central Fisheries Research Institutes (private communication))

Appendix Table 4-3. Abundance in number of walleye pollock of ages 0 to 2 in fishing areas around Musashi Bank estimated from the survey of the recruitment of walleye pollock in the Sea of Japan (survey of the distribution of juveniles) (million individuals; Wakkanai Fisheries Research Institutes (unpublished))

Year class	Age 0	Age 1	Age 2
2005	—	20.0	23.6
2006	74.5	45.9	89.0
2007	0.0	1.5	1.2
2008	12.6	8.0	2.6
2009	12.9	4.5	1.8
2010	30.8	18.0	16.5
2011	23.8	11.3	2.3
2012	163.0	27.3	23.2
2013	10.4	5.1	18.7
2014	7.9	10.0	6.6
2015	168.0	137.2	150.1
2016	169.2	143.1	49.1
2017	31.0	11.0	21.4
2018	38.8	56.0	—
2019	200.3	—	—

(5) Survey of walleye pollock using quantitative echo sounders: Hokkaido Fisheries Research Institute

Appendix Table 4-4 shows the results of the survey of juvenile walleye pollock using quantitative echo sounders, which was conducted by the Hokkaido District Fishery Research Institute in May of 2005-2019 in the Sea of Japan northward from Ishikari Bay.

The amount of standing stock of each year class estimated in this survey almost corresponds to the results of the survey of the distribution of larvae and juveniles (Appendix 4-(3)) and the survey of the distribution of juveniles (Appendix 4-(4)). However, the amplitude of changes in the abundance in number estimated from this survey is larger than that from other surveys. As a reason, it is presumed that juveniles of age 0 in pelagic stage would form a school as they grow up, which results in localized distribution. The distribution of ages 1 and 2 fish which live at the sea bottom is also thought to be localized. It is deemed appropriate to treat the values of age 3 merely as reference, because the range of the surveyed area did not cover the whole area of distribution. Here, the value for the 2005 year class is for reference, because the method of the survey in 2005 was different from that conducted afterward.

As for age 0 fish, the abundance is high in the 2006, 2012, 2015, 2016, and 2019 year classes, and that of the 2015 year class was relatively high. The abundance of the 2006, 2012 and 2015 year classes as of age 1 and above was high. As for the 2016 year class, the abundance of age 1 fish was not so high, but that of ages 2 fish was relatively high. On the other hand, the abundance of the 2007, 2008, 2009 and 2011 year classes as of ages 0 to 2 were low.

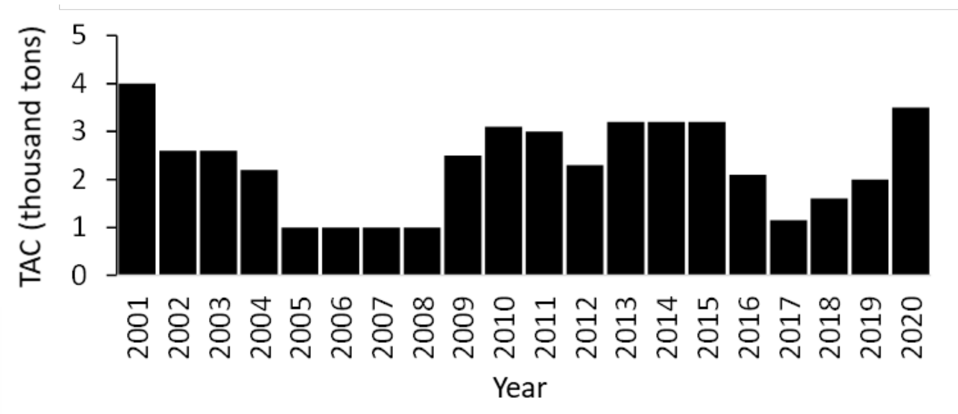
Appendix Table 4-4. Abundance in number of walleye pollock (million individuals) in the area northward from Ishikari Bay estimated from the survey of walleye pollock using quantitative echo sounders

Year class	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10 and above
2005	0.0	0.4	3.4	2.1	1.9	1.6	1.8	3.7	1.8	0.4	0.5
2006	10,182.4	105.7	39.6	27.7	34.0	22.1	7.2	8.8	4.9	4.9	3.1
2007	16.1	0.0	0.5	0.6	4.8	2.7	3.0	2.7	0.9	2.3	2.0
2008	60.2	0.7	0.4	1.0	1.1	1.5	1.6	0.6	1.2	0.9	—
2009	142.2	0.1	0.0	0.1	0.8	1.1	1.9	0.8	0.4	—	—
2010	881.6	1.8	1.0	1.4	4.2	4.9	2.1	1.2	—	—	—
2011	184.7	0.2	0.1	2.0	6.4	2.0	3.3	—	—	—	—
2012	17,340.7	13.7	29.3	17.6	8.9	9.1	—	—	—	—	—
2013	779.5	3.4	2.8	3.7	3.9	—	—	—	—	—	—
2014	796.2	3.7	0.3	0.9	15.4 *	—	—	—	—	—	—
2015	3,107.3	19.0	29.8	6.9	—	—	—	—	—	—	—
2016	11,495.8	2.2	13.9	21.3 **	—	—	—	—	—	—	—
2017	1,008.1	1.8	4.2	—	—	—	—	—	—	—	—
2018	976.3	0.9	—	—	—	—	—	—	—	—	—
2019	11,888.0	—	—	—	—	—	—	—	—	—	—

*The value for age 4 in the survey in 2018 is the sum of the values for age 4 and above.
**The value for age 3 in the survey in 2019 is the sum of the values for age 3 and above.

(6) TAC in the west fishing area of Sakhalin island in Russia

Although there is little detailed information on catch and properties of the catch in the Sea of Japan outside the territorial waters of Japan, Russia also sets the TAC and conducts fishing operations there. The distribution of this stock and the TAC set for the neighboring fishing area are shown in Appendix Figure 4-3 (in Russian name of fishing area: West Sakhalin). The TAC of this fishing area remained at around 2.1 thousand to 3.2 thousand tons during the period of 2009-2016, but it decreased to 1.2 thousand tons in 2017. Since 2018, it increased and the TAC in 2020 was set at 3.5 thousand tons.



Appendix Figure 4-3. TAC of walleye pollock for West Sakhalin (name of fishing area) set by the Russian Federation

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Miyake H., K. Itaya, H. Asami, H. Shimada, M. Watanobe, T. Mutoh and T. Nakatani (2008) Present condition of walleye pollock spawning ground formation in the Sea of Japan off western Hokkaido, viewed from the recent condition of the egg distributions. Bulletin of the Japanese Society of Fisheries Oceanography, 72, 265-272.

Wakkanai, Central and Wakkanai Fisheries Research Institutes (printing underway). walleye pollock (Sea of Japan). 2020 nendo suisan shigen kanri kaigi hyoukasho (Assessment report of council of stock management in 2020). Fisheries Research Department, Hokkaido Research Organization.

Appendix 5. Details of cohort analysis results (1980-1992 fishing seasons)

Catch in number at age (thousand individuals)

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	9,626	18,373	14,808	11,727	1,537	2,916	511	2,746	68,223	10,623	3,297	4,466	12,996
Age 3	39,478	28,005	28,701	32,501	61,194	27,218	13,671	134,737	133,592	148,582	32,814	272,577	90,025
Age 4	134,394	69,145	40,873	55,192	80,766	66,308	37,132	83,611	270,938	256,779	127,577	113,400	337,004
Age 5	116,416	116,094	70,698	58,493	70,265	75,911	52,579	34,761	37,395	125,341	152,276	97,680	80,962
Age 6	27,773	48,192	41,825	45,613	42,862	48,255	45,146	29,014	21,011	18,835	67,479	80,136	46,018
Age 7	12,161	15,239	23,505	18,815	25,909	31,244	27,424	19,915	18,788	10,828	16,913	26,057	32,187
Age 8	5,423	7,228	8,386	7,690	8,429	11,149	12,792	9,178	7,390	3,851	9,867	9,466	11,320
Age 9	4,516	8,901	7,799	6,725	6,238	9,611	5,794	6,729	4,752	2,472	4,514	3,722	2,135
Age 10 and above	2,248	4,876	5,873	2,397	4,469	3,739	3,901	3,863	2,163	978	3,245	2,599	1,822
Total	352,037	316,053	242,466	239,152	301,669	276,351	198,951	324,553	564,250	578,290	417,981	610,104	614,470

Catch at age (tons)

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	1,291	2,465	1,987	1,573	206	391	69	368	9,153	1,425	442	599	1,744
Age 3	9,043	6,415	6,574	7,445	14,017	6,234	3,131	30,862	30,600	34,033	7,516	62,435	20,620
Age 4	43,851	22,561	13,336	18,008	26,353	21,635	12,116	27,281	88,403	83,784	41,627	37,001	109,960
Age 5	49,517	49,380	30,071	24,880	29,887	32,289	22,365	14,785	15,906	53,314	64,770	41,548	34,437
Age 6	13,473	23,378	20,290	22,127	20,793	23,409	21,901	14,075	10,193	9,137	32,735	38,875	22,324
Age 7	6,624	8,300	12,802	10,247	14,111	17,017	14,936	10,847	10,233	5,898	9,212	14,192	17,531
Age 8	3,093	4,123	4,783	4,386	4,808	6,359	7,297	5,235	4,215	2,196	5,628	5,399	6,457
Age 9	2,609	5,143	4,506	3,886	3,604	5,553	3,348	3,888	2,746	1,429	2,608	2,151	1,234
Age 10 and above	1,548	3,357	4,043	1,650	3,076	2,574	2,686	2,660	1,489	673	2,234	1,790	1,254
Total	131,050	125,122	98,392	94,202	116,855	115,462	87,848	110,001	172,936	191,889	166,772	203,989	215,561

Fishing mortality at age

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	0.02	0.03	0.02	0.02	0.00	0.01	0.00	0.00	0.07	0.02	0.00	0.01	0.02
Age 3	0.08	0.07	0.06	0.07	0.17	0.10	0.04	0.15	0.13	0.22	0.06	0.25	0.24
Age 4	0.34	0.22	0.14	0.18	0.27	0.29	0.21	0.42	0.52	0.43	0.32	0.35	0.62
Age 5	0.59	0.59	0.38	0.31	0.39	0.46	0.42	0.34	0.35	0.51	0.52	0.45	0.49
Age 6	0.36	0.55	0.46	0.49	0.42	0.55	0.60	0.47	0.37	0.32	0.62	0.62	0.43
Age 7	0.36	0.37	0.61	0.41	0.61	0.68	0.76	0.63	0.69	0.36	0.56	0.56	0.58
Age 8	0.23	0.40	0.38	0.44	0.35	0.63	0.71	0.66	0.54	0.30	0.69	0.79	0.54
Age 9	0.47	0.81	1.14	0.65	0.86	0.93	0.87	1.22	0.99	0.36	0.75	0.66	0.43
Age 10 and above	0.47	0.81	1.14	0.65	0.86	0.93	0.87	1.22	0.99	0.36	0.75	0.66	0.43
%SPR	26.7	27.3	32.0	32.7	26.7	25.6	29.2	24.0	21.4	22.8	25.5	20.9	17.7

Number of fish at age (thousand individuals)

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	684,227	722,105	741,035	621,134	422,469	506,829	1,525,663	1,658,494	1,233,070	813,716	1,858,237	655,268	648,357
Age 3	561,518	498,602	519,135	536,227	450,054	311,650	372,958	1,129,799	1,226,279	854,761	593,673	1,373,779	481,591
Age 4	533,063	402,471	363,598	378,974	388,932	296,499	218,694	278,395	760,984	837,133	534,565	433,395	829,352
Age 5	297,803	296,547	252,425	247,100	246,439	231,625	172,397	137,550	143,028	353,553	425,352	303,734	237,453
Age 6	103,089	129,193	128,499	134,198	140,822	129,918	113,398	87,862	76,448	78,389	164,734	196,882	150,345
Age 7	45,734	55,775	58,086	63,165	64,260	71,847	58,595	48,473	42,822	40,995	44,428	68,745	82,611
Age 8	29,526	24,886	29,989	24,495	32,589	27,181	28,382	21,433	20,176	16,770	22,371	19,675	30,544
Age 9	13,669	18,209	13,003	15,955	12,290	17,942	11,330	10,815	8,592	9,192	9,662	8,715	6,969
Age 10 and above	6,804	9,975	9,791	5,686	8,805	6,981	7,628	6,209	3,910	3,635	6,945	6,086	5,948
Total	2,275,433	2,157,764	2,115,560	2,026,935	1,766,660	1,600,471	2,509,044	3,379,029	3,515,309	3,008,144	3,659,968	3,066,278	2,473,171

Biomass at age (tons)

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	91,794	96,876	99,415	83,330	56,677	67,995	204,679	222,499	165,425	109,166	249,296	87,909	86,982
Age 3	128,617	114,206	118,910	122,825	103,086	71,384	85,427	258,784	280,883	195,786	135,983	314,668	110,310
Age 4	173,931	131,321	118,637	123,654	126,903	96,744	71,357	90,837	248,299	273,145	174,421	141,411	270,606
Age 5	126,670	126,136	107,368	105,104	104,822	98,521	73,329	58,507	60,837	150,383	180,923	129,193	101,000
Age 6	50,009	62,672	62,336	65,101	68,314	63,024	55,010	42,622	37,085	38,027	79,914	95,509	72,934
Age 7	24,909	30,378	31,637	34,403	34,999	39,132	31,914	26,401	23,323	22,328	24,198	37,442	44,994
Age 8	16,842	14,195	17,106	13,972	18,589	15,504	16,189	12,225	11,509	9,565	12,761	11,223	17,422
Age 9	7,898	10,521	7,513	9,219	7,101	10,367	6,546	6,249	4,964	5,311	5,582	5,036	4,027
Age 10 and above	4,684	6,867	6,741	3,915	6,062	4,806	5,252	4,274	2,692	2,503	4,781	4,190	4,095
Total	625,355	593,173	569,662	561,521	526,554	467,476	549,703	722,398	835,017	806,215	867,859	826,580	712,371

Spawning biomass at age (tons)

Fishing year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Age 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 3	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 4	53,660	40,514	36,601	38,149	39,151	29,846	22,014	28,024	76,603	84,268	53,811	43,627	83,485
Age 5	113,068	112,591	95,839	93,817	93,566	87,942	65,454	52,224	54,304	134,235	161,495	115,320	90,155
Age 6	49,509	62,046	61,712	64,450	67,631	62,394	54,460	42,196	36,715	37,647	79,115	94,554	72,205
Age 7	24,909	30,378	31,637	34,403	34,999	39,132	31,914	26,401	23,323	22,328	24,198	37,442	44,994
Age 8	16,842	14,195	17,106	13,972	18,589	15,504	16,189	12,225	11,509	9,565	12,761	11,223	17,422
Age 9	7,898	10,521	7,513	9,219	7,101	10,367	6,546	6,249	4,964	5,311	5,582	5,036	4,027
Age 10 and above	4,684	6,867	6,741	3,915	6,062	4,806	5,252	4,274	2,692	2,503	4,781	4,190	4,095
Total	270,570	277,112	257,149	257,924	267,099	249,990	201,830	171,594	210,110	295,857	341,743	311,391	316,383

The catch at age until the 2007 fishing season was obtained by multiplying the number of catch at age by the body weight at age of the stock, which is different from the actual catch.

Appendix 5. Details of cohort analysis results (1993-2005 fishing seasons)

Catch in number at age (thousand individuals)

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	367	9,582	179	2,640	3,436	14,741	276	20,593	11,887	3,197	5,668	6,205	3,641
Age 3	30,345	28,116	41,788	29,808	27,998	15,561	3,132	5,760	46,350	33,982	9,404	22,429	10,173
Age 4	54,011	35,616	82,655	98,949	20,910	12,920	23,565	9,688	22,589	65,402	7,048	25,841	11,231
Age 5	117,511	45,571	26,127	123,270	48,222	24,210	22,268	9,082	13,970	29,489	14,640	14,369	15,710
Age 6	48,203	50,944	20,566	52,540	48,617	39,212	20,374	10,239	7,774	18,308	11,681	11,533	13,727
Age 7	34,309	20,058	23,786	13,962	33,191	15,837	16,782	12,130	6,762	11,231	9,329	4,832	7,224
Age 8	20,028	9,927	9,556	10,009	15,280	9,506	6,320	11,881	6,200	8,526	8,292	4,044	6,583
Age 9	6,535	4,315	6,538	1,049	10,445	4,540	3,226	7,051	6,144	7,056	5,570	3,452	2,625
Age 10 and above	3,111	3,076	3,365	1,471	3,208	4,903	3,066	5,285	7,425	6,915	6,665	3,695	4,300
Total	314,419	207,205	214,560	333,697	211,308	141,429	99,008	91,708	129,099	184,106	78,298	96,400	75,214

Catch at age (tons)

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	49	1,286	24	354	461	1,978	37	2,763	1,595	429	760	832	488
Age 3	6,951	6,440	9,572	6,828	6,413	3,564	717	1,319	10,617	7,784	2,154	5,137	2,330
Age 4	17,623	11,621	26,969	32,286	6,823	4,216	7,689	3,161	7,370	21,340	2,300	8,432	3,665
Age 5	49,983	19,383	11,113	52,433	20,511	10,298	9,472	3,863	5,942	12,543	6,227	6,112	6,682
Age 6	23,384	24,713	9,977	25,487	23,585	19,022	9,884	4,967	3,771	8,882	5,667	5,595	6,659
Age 7	18,687	10,925	12,955	7,604	18,077	8,626	9,140	6,606	3,683	6,117	5,081	2,632	3,935
Age 8	11,424	5,662	5,451	5,709	8,716	5,422	3,605	6,777	3,536	4,863	4,730	2,307	3,755
Age 9	3,776	2,493	3,777	606	6,035	2,623	1,864	4,074	3,550	4,077	3,219	1,995	1,516
Age 10 and above	2,142	2,118	2,317	1,013	2,209	3,375	2,111	3,639	5,112	4,760	4,589	2,544	2,960
Total	134,017	84,641	82,155	132,320	92,830	59,123	44,518	37,168	45,175	70,794	34,726	35,585	31,991

Fishing mortality at age

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	0.00	0.01	0.00	0.01	0.01	0.07	0.00	0.06	0.06	0.02	0.05	0.09	0.07
Age 3	0.08	0.05	0.09	0.12	0.15	0.09	0.02	0.03	0.22	0.26	0.08	0.32	0.22
Age 4	0.23	0.13	0.21	0.34	0.12	0.10	0.20	0.09	0.20	0.57	0.08	0.33	0.27
Age 5	0.48	0.33	0.14	0.58	0.29	0.21	0.26	0.12	0.20	0.46	0.25	0.25	0.36
Age 6	0.66	0.42	0.26	0.47	0.50	0.43	0.29	0.19	0.15	0.45	0.35	0.34	0.44
Age 7	0.71	0.68	0.38	0.30	0.68	0.32	0.35	0.30	0.20	0.35	0.47	0.25	0.40
Age 8	1.00	0.48	0.92	0.29	0.67	0.44	0.21	0.47	0.26	0.45	0.50	0.40	0.68
Age 9	0.77	0.64	0.75	0.24	0.58	0.45	0.27	0.42	0.51	0.57	0.64	0.43	0.53
Age 10 and above	0.77	0.64	0.75	0.24	0.58	0.45	0.27	0.42	0.51	0.57	0.64	0.43	0.53
%SPR	26.8	34.2	36.7	26.2	31.1	36.2	40.6	44.9	34.5	18.7	36.6	23.9	24.4

Number of fish at age (thousand individuals)

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	915,500	756,606	408,558	315,089	281,354	239,703	256,751	389,501	240,951	199,449	133,279	85,389	65,615
Age 3	469,129	677,904	552,260	302,513	231,151	205,475	164,889	189,968	270,824	168,269	145,003	93,856	57,917
Age 4	295,617	338,579	503,140	393,223	209,292	155,312	146,291	125,651	142,864	170,015	101,059	104,630	53,302
Age 5	348,495	182,562	232,255	318,903	218,921	144,544	109,555	93,136	89,307	91,329	74,691	72,485	58,681
Age 6	113,479	167,705	101,963	157,823	139,577	127,940	91,205	65,671	64,520	57,224	45,103	45,250	43,770
Age 7	76,478	45,839	85,651	61,260	76,547	65,798	65,035	53,051	42,109	43,388	28,409	24,817	25,063
Age 8	35,933	29,284	17,998	45,713	35,388	30,324	37,267	35,840	30,612	26,827	23,879	13,892	15,063
Age 9	13,798	10,310	14,046	5,584	26,769	14,076	15,228	23,446	17,427	18,369	13,369	11,279	7,251
Age 10 and above	6,568	7,349	7,230	7,830	8,223	15,202	14,469	17,575	21,061	18,001	15,996	12,072	11,879
Total	2,274,997	2,216,137	1,923,101	1,607,938	1,227,221	998,373	900,690	993,838	919,675	792,870	580,788	463,671	338,541

Biomass at age (tons)

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	122,821	101,504	54,811	42,271	37,746	32,158	34,445	52,254	32,325	26,757	17,880	11,456	8,803
Age 3	107,455	155,276	126,497	69,292	52,946	47,065	37,768	43,513	62,033	38,543	33,213	21,498	13,266
Age 4	96,456	110,474	164,168	128,303	68,289	50,676	47,733	40,998	46,615	55,474	32,974	34,139	17,392
Age 5	148,232	77,652	98,789	135,645	93,118	61,481	46,599	39,615	37,987	38,846	31,770	30,831	24,960
Age 6	55,050	81,355	49,463	76,561	67,710	62,065	44,244	31,857	31,299	27,760	21,880	21,951	21,233
Age 7	41,654	24,966	46,650	33,365	41,691	35,837	35,422	28,894	22,934	23,631	15,473	13,517	13,650
Age 8	20,496	16,703	10,266	26,075	20,185	17,297	21,257	20,443	17,461	15,302	13,621	7,924	8,592
Age 9	7,972	5,957	8,116	3,226	15,467	8,133	8,798	13,547	10,069	10,614	7,724	6,517	4,189
Age 10 and above	4,522	5,060	4,978	5,391	5,661	10,466	9,961	12,100	14,500	12,393	11,013	8,311	8,178
Total	604,658	578,948	563,737	520,130	402,812	325,178	286,228	283,222	275,224	249,320	185,548	156,144	120,264

Spawning biomass at age (tons)

Fishing year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Age 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 3	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 4	29,758	34,082	50,648	39,583	21,068	15,634	14,726	12,648	14,381	17,114	10,173	10,532	5,366
Age 5	132,314	69,314	88,181	121,079	83,118	54,879	41,595	35,361	33,908	34,675	28,358	27,521	22,280
Age 6	54,499	80,541	48,969	75,796	67,033	61,444	43,802	31,539	30,986	27,482	21,661	21,731	21,021
Age 7	41,654	24,966	46,650	33,365	41,691	35,837	35,422	28,894	22,934	23,631	15,473	13,517	13,650
Age 8	20,496	16,703	10,266	26,075	20,185	17,297	21,257	20,443	17,461	15,302	13,621	7,924	8,592
Age 9	7,972	5,957	8,116	3,226	15,467	8,133	8,798	13,547	10,069	10,614	7,724	6,517	4,189
Age 10 and above	4,522	5,060	4,978	5,391	5,661	10,466	9,961	12,100	14,500	12,393	11,013	8,311	8,178
Total	291,215	236,624	257,806	304,515	254,223	203,690	175,562	154,532	144,239	141,211	108,023	96,054	83,276

The catch at age until the 2007 fishing season was obtained by multiplying the number of catch at age by the body weight at age of the stock, which is different from the actual catch.

Appendix 5. Details of cohort analysis results (2006-2019 fishing seasons)

Catch in number at age (thousand individuals)

Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	1,254	12,078	35,501	391	240	70	1,761	2,076	5,216	1,350	1,128	259	203	231
Age 3	2,215	6,320	10,720	37,725	1,815	956	1,407	5,566	1,543	7,246	1,603	599	1,824	1,377
Age 4	3,368	4,556	6,174	7,636	23,342	3,099	1,810	1,299	5,118	1,234	7,866	1,738	1,346	3,552
Age 5	7,563	4,085	3,561	3,486	9,911	15,301	1,251	1,102	1,992	2,225	1,031	8,191	2,120	1,104
Age 6	8,168	4,915	3,513	2,355	3,477	4,877	13,044	1,676	1,384	462	2,012	842	4,634	864
Age 7	7,012	6,277	2,841	2,224	1,901	1,416	6,117	9,192	1,002	320	148	1,399	549	2,997
Age 8	5,655	4,616	3,247	1,743	1,350	856	1,962	3,090	4,642	292	423	255	1,290	861
Age 9	3,362	2,471	2,150	1,430	862	369	942	719	865	2,437	91	263	244	985
Age 10 and above	4,990	1,924	1,642	1,126	953	281	994	730	542	962	2,987	1,126	1,137	742
Total	43,587	47,242	69,348	58,116	43,850	27,224	29,287	25,451	22,304	16,528	17,289	14,671	13,348	12,713

Catch at age (tons)

Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	168	1,620	4,342	35	34	13	216	268	396	108	141	20	26	18
Age 3	507	1,448	2,748	6,370	432	220	351	1,245	337	1,238	324	116	343	246
Age 4	1,099	1,486	2,460	1,896	6,510	917	499	410	1,459	397	2,094	428	422	974
Age 5	3,217	1,737	1,581	1,271	3,669	5,488	390	396	686	987	383	2,717	827	401
Age 6	3,962	2,384	1,662	1,053	1,556	2,274	4,896	679	580	236	980	327	2,104	375
Age 7	3,819	3,419	1,493	1,189	1,008	780	2,985	4,164	458	164	80	673	271	1,490
Age 8	3,226	2,633	1,766	997	811	511	1,147	1,706	2,277	176	233	139	744	513
Age 9	1,943	1,428	1,295	919	476	227	572	467	519	1,391	54	163	144	647
Age 10 and above	3,435	1,325	1,168	804	691	206	757	552	373	693	1,753	731	759	576
Total	21,376	17,480	18,516	14,533	15,187	10,637	11,813	9,888	7,085	5,389	6,041	5,315	5,640	5,241

Fishing mortality at age

Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	0.02	0.09	0.11	0.02	0.01	0.00	0.02	0.04	0.03	0.04	0.04	0.00	0.00	0.01
Age 3	0.06	0.13	0.11	0.17	0.11	0.05	0.09	0.08	0.04	0.06	0.07	0.03	0.01	0.01
Age 4	0.11	0.17	0.19	0.11	0.16	0.30	0.13	0.12	0.11	0.05	0.10	0.10	0.10	0.03
Age 5	0.32	0.20	0.20	0.17	0.23	0.16	0.20	0.11	0.28	0.07	0.05	0.15	0.19	0.12
Age 6	0.34	0.37	0.29	0.21	0.26	0.17	0.22	0.48	0.21	0.10	0.08	0.06	0.12	0.12
Age 7	0.45	0.52	0.41	0.31	0.28	0.17	0.37	0.25	0.63	0.07	0.04	0.08	0.05	0.12
Age 8	0.67	0.65	0.60	0.50	0.34	0.21	0.40	0.34	0.20	0.40	0.13	0.11	0.11	0.12
Age 9	1.03	0.76	0.80	0.62	0.54	0.15	0.39	0.26	0.16	0.16	0.22	0.12	0.15	0.12
Age 10 and above	1.03	0.76	0.80	0.62	0.54	0.15	0.39	0.26	0.16	0.16	0.22	0.12	0.15	0.12
%SPR	35.6	31.0	31.6	37.6	37.8	44.3	40.6	40.7	41.3	57.4	58.0	61.9	66.5	0.0

Number of fish at age (thousand individuals)

Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	80,933	169,108	401,074	26,790	31,781	25,532	107,255	56,878	182,257	38,383	30,349	241,116	358,943	43,934
Age 3	45,475	58,877	114,882	266,568	19,510	23,337	18,854	77,941	40,350	130,530	27,273	21,512	178,400	265,737
Age 4	36,128	33,461	40,276	80,010	174,311	13,592	17,331	13,442	55,789	30,063	95,262	19,826	16,225	137,328
Age 5	31,600	25,165	22,039	25,919	55,573	115,154	7,851	11,900	9,322	38,931	22,324	67,249	13,907	11,449
Age 6	31,837	17,936	15,994	14,021	17,109	34,534	76,179	5,010	8,295	5,502	28,356	16,476	45,145	8,959
Age 7	21,974	17,587	9,631	9,355	8,841	10,256	22,591	47,817	2,423	5,239	3,877	20,308	12,088	31,070
Age 8	13,144	10,926	8,157	4,993	5,323	5,208	6,738	12,196	29,128	1,003	3,798	2,889	14,581	8,930
Age 9	5,921	5,246	4,435	3,487	2,351	2,954	3,301	3,517	6,771	18,588	523	2,584	2,026	10,217
Age 10 and above	8,788	4,085	3,388	2,747	2,600	2,254	3,482	3,575	4,244	7,337	17,191	11,080	9,416	7,692
Total	275,800	342,389	619,876	433,890	317,398	232,822	263,583	232,276	338,579	275,576	228,954	403,039	650,730	525,315

Biomass at age (tons)

Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	10,858	22,687	53,807	3,594	4,264	3,425	14,389	7,631	24,451	5,149	4,072	32,347	48,155	5,894
Age 3	10,416	13,486	26,314	61,058	4,469	5,345	4,319	17,853	9,242	29,898	6,247	4,928	40,863	60,868
Age 4	11,788	10,918	13,142	26,106	56,875	4,435	5,655	4,386	18,203	9,809	31,083	6,469	5,294	44,808
Age 5	13,441	10,704	9,374	11,024	23,638	48,981	3,339	5,062	3,965	16,559	9,495	28,604	5,915	4,870
Age 6	15,444	8,701	7,759	6,802	8,300	16,753	36,955	2,430	4,024	2,669	13,756	7,993	21,900	4,346
Age 7	11,968	9,579	5,245	5,095	4,815	5,586	12,304	26,044	1,319	2,853	2,112	11,061	6,584	16,922
Age 8	7,497	6,232	4,653	2,848	3,036	2,971	3,844	6,956	16,615	572	2,166	1,648	8,317	5,094
Age 9	3,421	3,031	2,563	2,015	1,358	1,707	1,907	2,032	3,912	10,740	302	1,493	1,170	5,903
Age 10 and above	6,050	2,812	2,333	1,891	1,790	1,552	2,398	2,461	2,922	5,051	11,836	7,628	6,483	5,296
Total	90,884	88,149	125,189	120,434	108,545	90,754	85,110	74,854	84,654	83,302	81,068	102,170	144,681	154,001

Spawning biomass at age (tons)

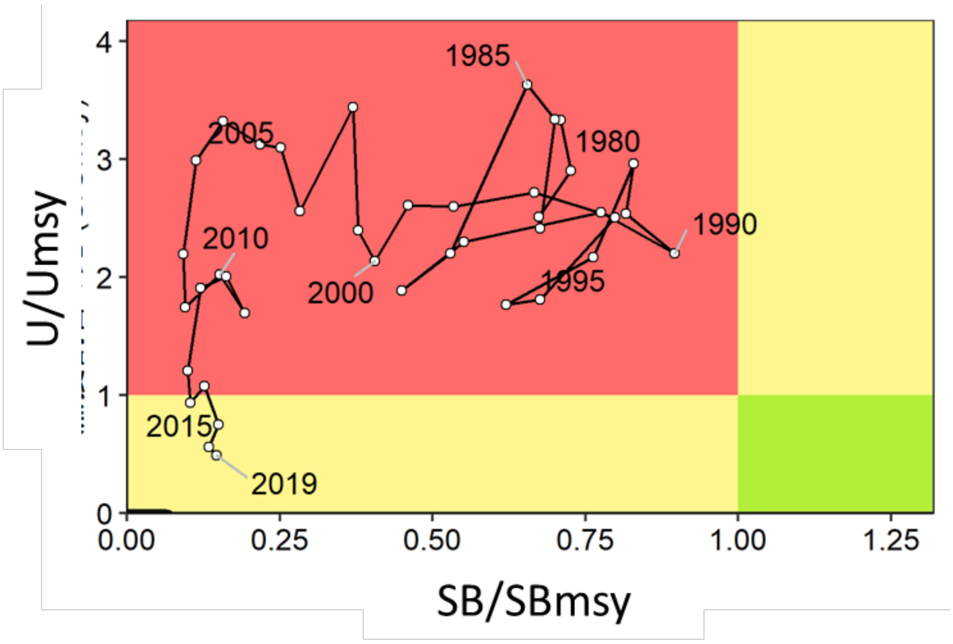
Fishing year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 4	3,637	3,368	4,054	8,054	17,547	1,368	1,745	1,353	5,616	3,026	9,589	1,996	1,633	13,824
Age 5	11,998	9,554	8,368	9,841	21,099	43,721	2,981	4,518	3,539	14,781	8,476	25,533	5,280	4,347
Age 6	15,290	8,614	7,681	6,734	8,217	16,585	36,586	2,406	3,984	2,642	13,618	7,913	21,681	4,303
Age 7	11,968	9,579	5,245	5,095	4,815	5,586	12,304	26,044	1,319	2,853	2,112	11,061	6,584	16,922
Age 8	7,497	6,232	4,653	2,848	3,036	2,971	3,844	6,956	16,615	572	2,166	1,648	8,317	5,094
Age 9	3,421	3,031	2,563	2,015	1,358	1,707	1,907	2,032	3,912	10,740	302	1,493	1,170	5,903
Age 10 and above	6,050	2,812	2,333	1,891	1,790	1,552	2,398	2,461	2,922	5,051	11,836	7,628	6,483	5,296
Total	59,861	43,190	34,896	36,478	57,863	73,490	61,763	45,770	37,907	39,666	48,099	57,271	51,149	55,688

The catch at age until the 2007 fishing season was obtained by multiplying the number of catch at age by the body weight at age of the stock, which is different from the actual catch.

Appendix 6. Kobe plot based on exploitation rate

The Appendix Figure 6-1 shows a Kobe plot based on the spawning biomass that produces MSY (SBmsy) and exploitation rate that produces MSY (Umsy). Although the spawning biomass of this stock is lower than SBmsy over the whole period, the exploitation rates (U) in the 2015 fishing season and since the 2017 fishing season were lower than Umsy.

Item	Value	Explanation
SBmsy	382 thousand tons	Spawning biomass that produces MSY
Umsy	6.9%	Exploitation rate that produces MSY
U2019	3.4%	Exploitation rate in the 2019 fishing season
U2019/Umsy	0.49	Ratio of the exploitation rate in the 2019 fishing season to the exploitation rate that produces MSY



Appendix Figure 6-1. Relationship of the past spawning biomass and exploitation rate to the spawning biomass that produces MSY (SBmsy) and exploitation rate that produces MSY (Umsy) (Kobe plot)

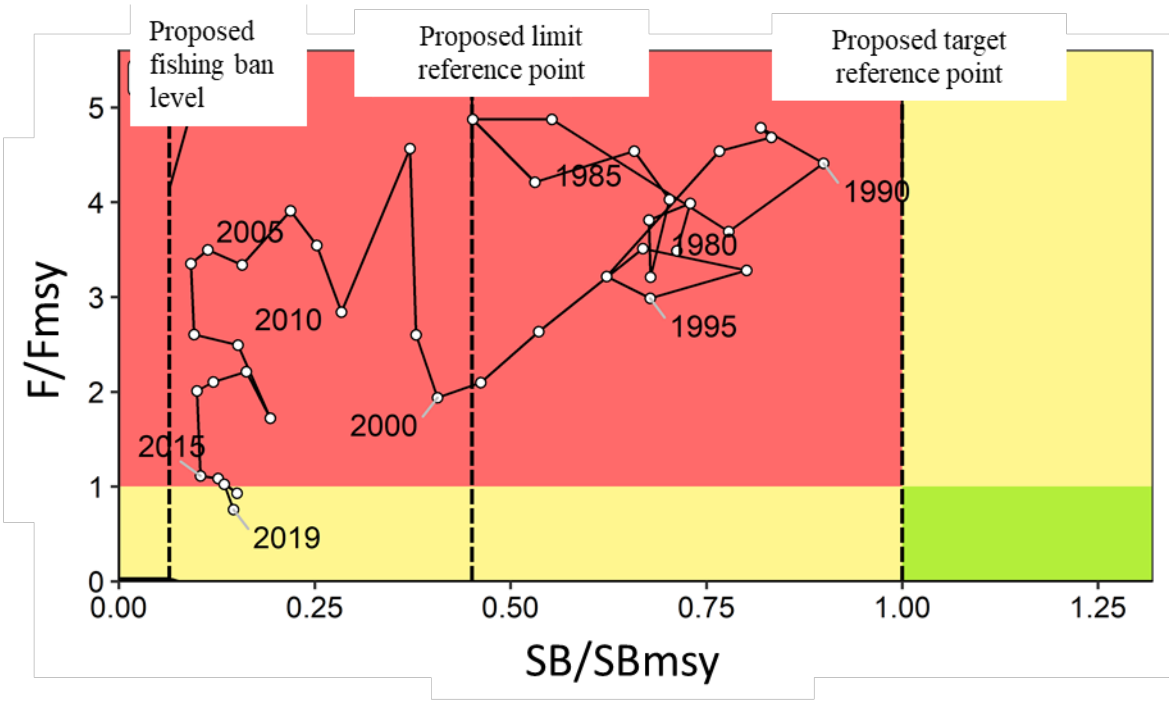
Appendix 7. Proposed reference points and fishing ban level, etc.

The reference points and fishing ban level proposed for this stock are as shown below.

Item	Value	Explanation
Proposed SBtarget	382 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	171 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	25 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

It was proposed at the "Research Institute Meeting on Reference Points" held in April 2019 that the spawning biomass that produces MSY (SBmsy: 382 thousand tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 171 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 25 thousand tons) be used for the fishing ban level (SBban).

Appendix Figure 7-1 shows a Kobe plot based on the proposed SBtarget and fishing mortality (F) that produces MSY. Although the spawning biomass in the 2019 fishing year obtained from cohort analysis (SB2019: 56 thousand tons) was lower than the proposed SBtarget and SBlimit, it was higher than the proposed SBban. The fishing mortality in the 2017 and 2019 fishing seasons of this stock is judged to have been lower than Fmsy.



Appendix Figure 7-1. Relationship between the proposed reference points and spawning biomass / fishing mortality (Kobe plot)

Appendix 8. Future projection compliant with the proposed HCRs

(1) Setting of future projection

We calculated the future projection for the 2020-2051 fishing seasons using forward calculation of cohort analysis based on the biomass in the 2019 fishing season estimated in stock assessment (Appendix 9). For recruitment in the future projection, we used the value predicted from the spawning biomass in each year based on the S-R relationship. We assumed error following a lognormal distribution as uncertainty in recruitment, and made 10,000 iterations. However, the recruitments of the 2020 fishing season (2018 year class) and 2021 fishing season (2019 year class) have high recruitment index values, and the abundance of ages 0 (Appendix 4-(3)) and 1 (Appendix 4-(4)), respectively. The recruitment is considered to be greatly larger than the recruitment estimated based on the spawning biomass using the S-R relationship. For this reason, we assumed the recruitment in the 2020 and 2021 fishing seasons using the recruitment of the two high-abundance year classes, namely the 2008 fishing season (2006 year class) and the 2014 fishing season (2012 year class), which are thought not to change largely even when the data is added in the future. The standing stock of the 2018 year class as of the age 0 was almost the same as that of the 2012 year class, and as of age 1, it was larger than the standing stock of the 2012 year class and also slightly larger than that of the 2006 year class. On the other hand, as the range of the distribution was small (Appendices 4-(3) and 4-(4)), the recruitment in the 2020 fishing season (2018 year class) was assumed to be the same as that in the 2014 fishing season (2012 year class). The recruitment in the 2021 fishing season (2019 year class) was assumed to be the average of the 2008 fishing season (2006 year class) and the 2014 fishing season (2012 year class), because the distribution of the 2019 year class localized to north and the body length was small, and there is a possibility that a large part of them flowed out to the Okhotsk Sea and the degree of depletion might be high (Appendix 4-(3)), though the abundance at age 0 was the largest since the 2006 year class. The catch in 2020 was assumed to be the amount of TAC, 6.7 thousand tons. For the current fishing mortality, we used the F value that gives %SPR corresponding to the fishing mortality in the 2015-2019 fishing seasons as estimated in this year's assessment, under the same conditions of selectivity and biological parameters (average body weight, etc.) as those for calculating the proposed reference points. For the fishing mortality in the 2021 fishing season onward, we used the fishing mortality specified in the proposed HCRs below based on the spawning biomass projected for each fishing year.

(2) Proposed HCRs

Proposed HCRs represent a proposed fishing scenario that specifies the fishing mortality (F), etc. corresponding to spawning biomass, taking into consideration the probability of maintaining/recovering spawning biomass to a level above the proposed target reference point. The "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)" provide that, if spawning biomass is below the proposed limit reference point, the fishing mortality is to be reduced in a linear manner to the proposed fishing ban level, and if it is above the target reference point, the value obtained by multiplying Fmsy by safety coefficient β should be the upper limit of fishing mortality. Appendix Figure 8-1 shows the HCRs proposed at the "Research

Institute Meeting on Reference Points" for this stock. Here, we present a case where safety coefficient β is 0.8, as an example.

(3) Projected values for 2021

The average catch in the 2021 fishing season estimated from the proposed HCRs was 8.4 thousand tons when β is 1.0, and 6.8 thousand tons when β is 0.8. The projected spawning biomass in the 2021 fishing season was estimated at 121 thousand tons on average, and the estimation was below the limit reference point in all iterations. For this reason and because the spawning biomass is below the fishing mortality of the limit reference point, the fishing mortality of the 2021 fishing season is calculated by multiplying by the coefficient corresponding to the spawning biomass: γ(SBt) × βFmsy. Here, γ(SBt) of the 2021 fishing season was calculated as 0.66 with the equation below based on the HCRs set for the first group of stocks of the “Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)”

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

Spawning biomass in the 2021 fishing season (average projection value): 121 thousand tons			
Item	Catch in the 2021 fishing season (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019)	Exploitation rate in the 2021 fishing season (%)
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	8.4	0.67	4
β = 0.8	6.8	0.53	3
β = 0.6	5.1	0.40	3
β = 0.4	3.4	0.27	2
β = 0.2	1.7	0.13	1
β = 0	0	0	0
F2015-2019	12.4	1.00	6

(4) Projection for 2022 onward

Appendix Figures 8-3 and Appendix Tables 8-1 and 8-2 show the future projection results including after 2022. If management based on the proposed HCRs is continued for 10 years, the projected spawning biomass in the 2031 fishing season is 182 thousand tons where β is 1.0 (the 80% confidence interval is 117 thousand to 266 thousand tons), and 199 thousand tons where β is 0.8 (the 80% confidence interval is 127 thousand to 293 thousand tons). However, even when β is set to 0, spawning biomass is 308 thousand tons on average (80% confidence interval: 194 thousand to 451 thousand tons) and the probability that the prediction value will exceed the proposed target reference point is 20%. The probability of exceeding the proposed limit reference point is 46% with β set to 1.0 and 57% with β set to 0.8. The probability of exceeding the proposed fishing ban level is 100% for all proposed

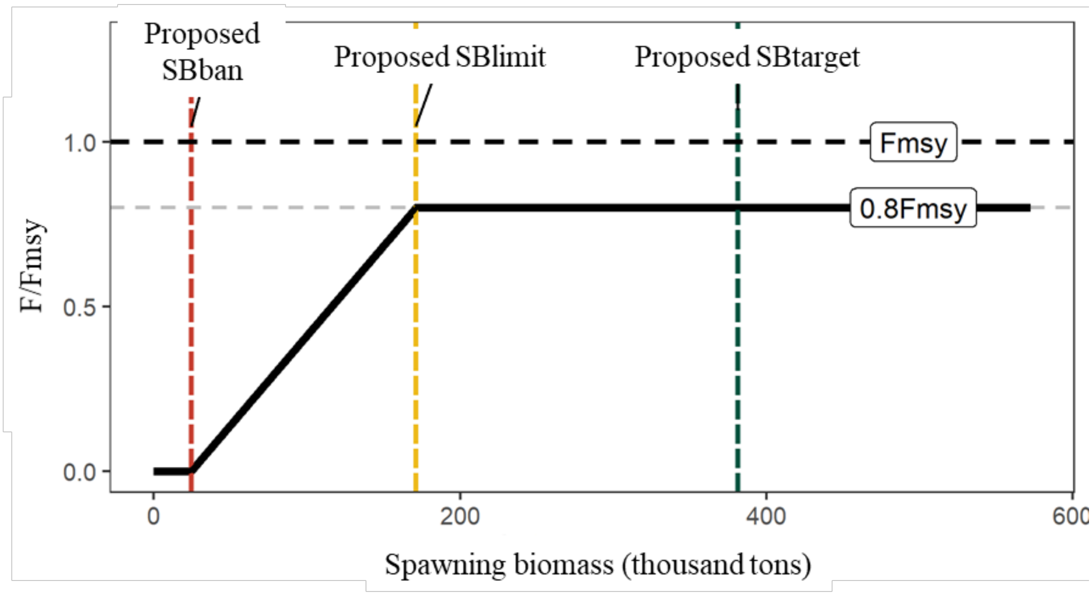
HCRs.

When control based on the proposed HCRs is continued, the spawning biomass will exceed the proposed target reference point with the probability of 50% or higher after 2051 fishing season with β set to 1.0 or 0.8 and if fishing is continued with F2015-2019. The fishing year of exceeding the limit reference point with the probability of 50% or higher is predicted to be before the 2030 fishing season if β is set to 0 to 0.8. Even when fishing mortality is zero (β = 0), it is predicted that spawning biomass will exceed the proposed target reference point with the probability of 50% or higher in the 2035 fishing season.

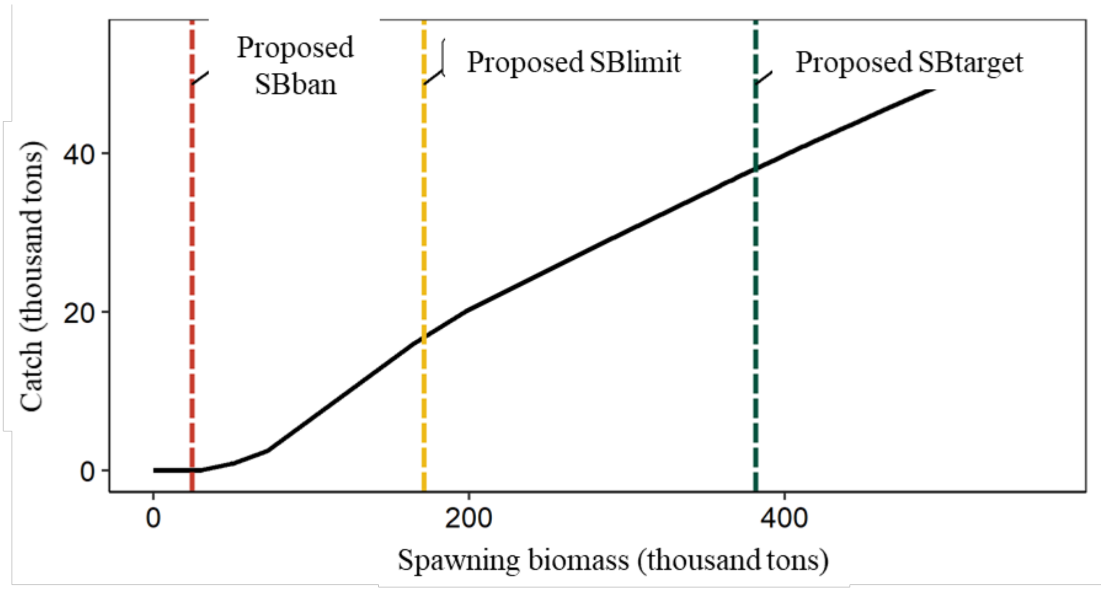
Uncertainty considered: recruitment					
Item	Spawning biomass in the 2031 fishing season (thousand tons)	80% confidence interval (thousand tons)	Probability for spawning biomass in the 2031 fishing season to exceed the reference points (%)		
			Proposed target reference point	Proposed limit reference point	Proposed fishing ban level
Other strategy (when using different β in the proposed HCRs)					
β = 1.0	182	117-266	2	46	100
β = 0.8	199	127-293	3	57	100
β = 0.6	219	138-324	5	69	100
β = 0.4	244	152-360	8	80	100
β = 0.2	273	171-402	12	90	100
β = 0	308	194-451	20	96	100
F2015-2019	163	97-246	1	35	100

Uncertainty considered: recruitment			
	Fishing year for spawning biomass to exceed the reference points with the probability of 50% or higher		
	Proposed target reference point	Proposed limit reference point	Proposed fishing ban
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	After 2051 fishing season	2033 fishing season	2019 fishing season
β = 0.8	After 2051 fishing season	2030 fishing season	2019 fishing season
β = 0.6	2047 fishing season	2029 fishing season	2019 fishing season
β = 0.4	2041 fishing season	2027 fishing season	2019 fishing season
β = 0.2	2037 fishing season	2026 fishing season	2019 fishing season
β = 0	2035 fishing season	2025 fishing season	2019 fishing season
F2015-2019	After 2051 fishing season	2037 fishing season	2019 fishing season

(a)

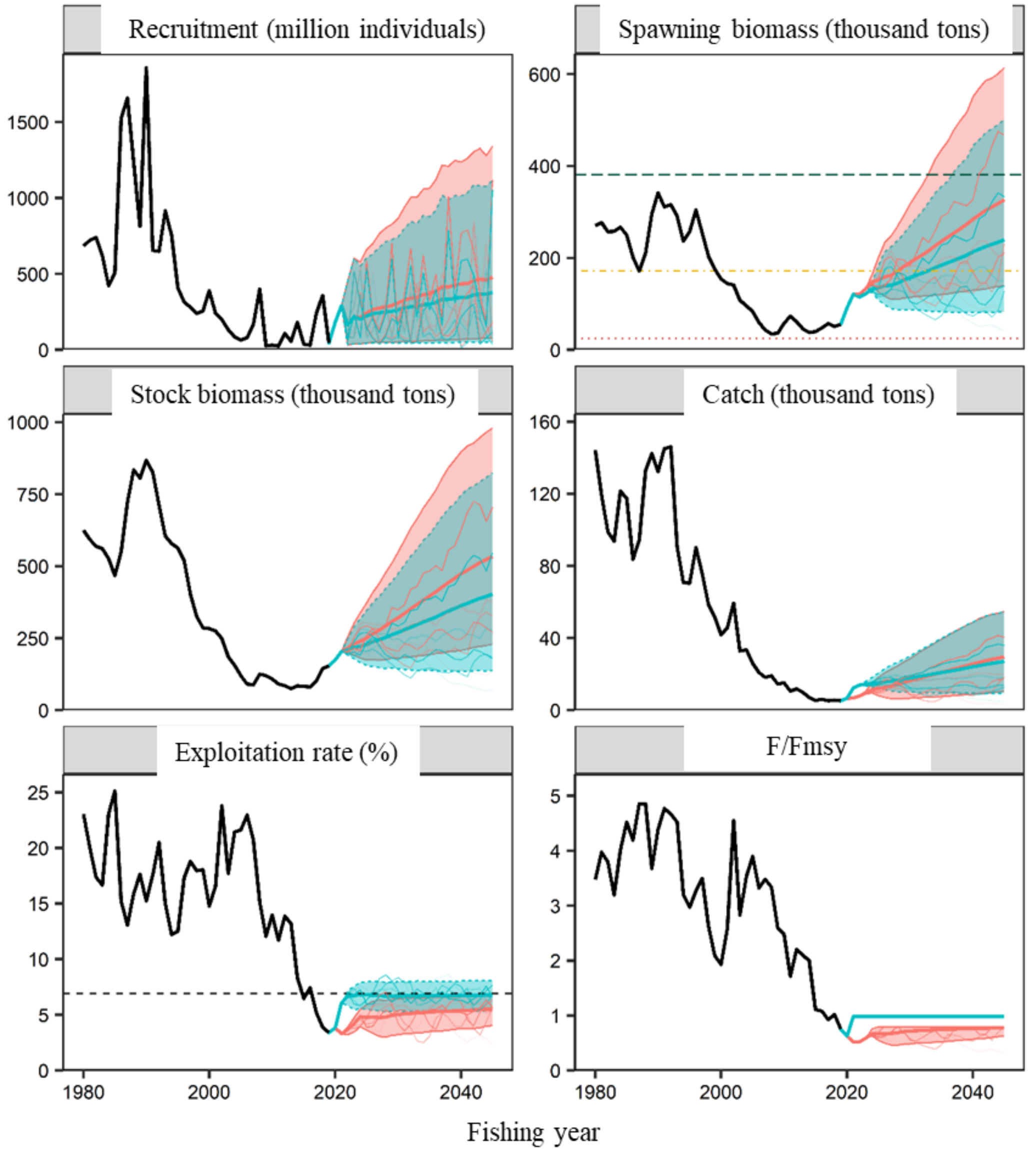


(b)



Appendix Figure 8-1. Proposed HCRs

The figure shows when β is 0.8. The black dashed line represents Fmsy; the grey dashed line represents 0.8Fmsy; the black thick line represents the proposed HCRs; the red dashed line represents the proposed fishing ban level (SBban); the yellow dashed line represents the proposed limit reference point (SBlimit); and the green dashed line represents the proposed target reference point (SBtarget). The upper chart (a) expresses a schematic diagram of the proposed HCRs where fishing mortality is put to the vertical axis. The lower chart (b) where the catch is put to the vertical axis shows the catch that is expected based on the proposed HCRs under the respective spawning biomass.



Appendix Figure 8-2. Future projection based on the proposed HCRs (in red) and the future projection that assumes continued fishing at the current fishing mortality level (F2015-2019) (in blue)

The thick solid line, shaded area and thin lines represent average value, the 90% prediction interval that includes 90% of the simulation results, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed limit reference point and the red line shows the proposed fishing ban level. The dashed line in the figure of exploitation rate shows Umsy. The figure shows the results of the proposed HCRs with β set to 0.8. The recruitment of the 2020 fishing season is set to the value of the recruitment of the 2014 fishing season. The recruitment of the 2021 fishing season is set to the average of the recruitments of the 2008 fishing season and the 2014 fishing season. The catch of the 2020 fishing season is set to TAC (6.7 thousand tons).

Appendix Table 8-1. Probability for future spawning biomass to exceed the proposed target reference point and limit reference point

The catch in the 2020 fishing season is TAC (6.7 thousand tons) while the catch in the 2021 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	1	1	1	2	13	24
0.9	0	0	0	0	0	0	0	0	0	1	1	1	2	17	31
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	22	39
0.7	0	0	0	0	0	0	0	0	0	1	1	2	4	27	50
0.6	0	0	0	0	0	0	0	0	0	1	2	3	5	35	59
0.5	0	0	0	0	0	0	0	0	1	1	2	4	6	42	70
0.4	0	0	0	0	0	0	0	0	1	2	3	5	8	51	79
0.3	0	0	0	0	0	0	0	0	1	2	4	6	10	61	86
0.2	0	0	0	0	0	0	0	0	1	2	4	8	12	70	92
0.1	0	0	0	0	0	0	0	1	1	3	6	10	16	78	96
0.0	0	0	0	0	0	0	0	1	2	4	7	13	20	85	98

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	2	12	21	25	31	38	43	46	70	82
0.9	0	0	0	0	0	2	14	24	28	35	43	48	51	76	88
0.8	0	0	0	0	0	2	16	27	32	39	48	53	57	82	92
0.7	0	0	0	0	0	3	18	30	36	44	53	59	63	87	95
0.6	0	0	0	0	0	4	21	34	41	49	59	65	69	91	97
0.5	0	0	0	0	0	5	25	39	46	55	65	70	75	94	99
0.4	0	0	0	0	0	8	29	45	51	60	71	76	80	97	99
0.3	0	0	0	0	0	10	35	51	57	67	77	81	85	98	100
0.2	0	0	0	0	0	14	41	57	63	73	82	86	90	99	100
0.1	0	0	0	0	0	20	49	64	70	79	87	91	94	100	100
0.0	0	0	0	0	0	32	59	72	76	85	91	94	96	100	100

Appendix Table 8-2. Changes in future average spawning biomass and future average catch

The catch in the 2020 fishing season is TAC (6.7 thousand tons) while the catch in the 2021 fishing season and after is based on the proposed HCRs.

(a) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	119	130	144	146	152	154	160	169	176	182	249	301
0.9	56	92	121	120	132	146	149	155	158	165	175	183	190	270	332
0.8	56	92	121	121	134	148	152	159	162	171	181	190	199	294	366
0.7	56	92	121	121	135	151	155	163	167	176	189	199	209	321	403
0.6	56	92	121	122	137	153	158	167	172	183	196	208	219	351	442
0.5	56	92	121	123	139	156	162	172	178	189	204	218	231	383	482
0.4	56	92	121	124	140	158	166	177	184	197	213	228	244	419	524
0.3	56	92	121	125	142	161	170	182	190	205	223	240	258	458	566
0.2	56	92	121	126	144	164	174	188	197	213	234	253	273	500	609
0.1	56	92	121	126	146	167	179	193	204	222	245	267	290	544	654
0	56	92	121	127	148	171	183	200	212	232	258	282	308	592	700

b) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	8.4	9.6	11.3	13.3	13.7	14.6	15.2	16.0	17.3	18.2	19.1	27.5	33.8
0.9	5.2	6.7	7.6	8.8	10.5	12.4	12.9	13.7	14.3	15.2	16.4	17.4	18.3	27.2	33.8
0.8	5.2	6.7	6.8	7.9	9.6	11.4	11.9	12.8	13.4	14.2	15.5	16.4	17.3	26.6	33.3
0.7	5.2	6.7	5.9	7.1	8.6	10.4	10.9	11.7	12.3	13.1	14.3	15.2	16.2	25.6	32.2
0.6	5.2	6.7	5.1	6.2	7.6	9.3	9.8	10.5	11.1	11.9	13.0	13.9	14.8	24.1	30.3
0.5	5.2	6.7	4.3	5.2	6.6	8.0	8.5	9.2	9.8	10.5	11.5	12.3	13.2	22.1	27.6
0.4	5.2	6.7	3.4	4.3	5.4	6.7	7.1	7.7	8.2	8.8	9.7	10.5	11.3	19.4	24.0
0.3	5.2	6.7	2.6	3.3	4.2	5.2	5.6	6.1	6.5	7.0	7.7	8.3	9.0	15.9	19.4
0.2	5.2	6.7	1.7	2.2	2.9	3.6	3.9	4.3	4.6	4.9	5.4	5.9	6.4	11.6	14.0
0.1	5.2	6.7	0.9	1.1	1.5	1.9	2.0	2.2	2.4	2.6	2.9	3.1	3.4	6.3	7.5
0	5.2	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 9. Method of future projection

The recruitment of each year in the future projection is estimated by the HS model (a = 1.81, b = 341,742, SD = 0.81), which was applied at the “Research Institute Meeting on Reference Points” held in April 2019. The data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment based on the stock assessment conducted in 2018, and as for the optimization method, the least squares method is used. The model does not consider autocorrelation between the residuals of the recruitment. For details, see “Report on Research Institute Meeting on Reference Points for walleye pollock Northern Sea of Japan stock in 2019.” However, we adopted the value of the recruitment of the 2014 fishing season (2012 year class) as the recruitment of the 2020 fishing season (2018 year class), and the average of the recruitments of the 2008 fishing season (2006 year class) and the 2014 fishing season (2012 year class) as the recruitment of the 2021 fishing season (2019 year class), based on the recruitment index values and data on distribution and body length surveyed by research vessels (for details, see Appendix 8-(1)).

For fishing mortality (F) in future projection, we used the value calculated based on the HCRs set for the first group of stocks detailed in the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)." The parameters used for the future projection are shown in Appendix Table 9-1. As for the selectivity, average body weight of the catch, etc., we again used the values used for estimation of the level that produces MSY at the "Research Institute Meeting on Reference Points” held in April 2019. These values are based on the 2018 stock assessment as with the case of the S-R relationship. The selectivity and average body weight of the catch are the average calculation result for the 2013-2017 fishing seasons. As the current fishing mortality (F2015-2019), we use the value where the %SPR presumed at this selectivity is equal to the %SPR presumed from the average F value of the 2015-2019 fishing seasons. The F value that gives TAC in the 2020 fishing season (6.7 thousand tons) was explored based on the parameters used for the future projection.

We conducted forward calculation of cohort analysis (equation (1)) to predict the number of fish.

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M_a) \qquad (1)$$

As for the calculation for the plus group of age 10 and above, the value was calculated forward from the sum of ages 9 and 10 and above of the previous year.

The catch in number was obtained from equation (2), based on the F value assumed from the number of fish calculated above and each fishing scenario.

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

Appendix Table 9-1. Parameters used for calculating the future projection

	Selectivity (Note 1)	Fmsy (Note 2)	F2015-2019 (Note 3)	Average body weight of stock (g)	Average body weight of catch (g)	Natural mortality	Maturity rate
Age 2	0.18	0.02	0.02	134	98	0.30	0.00
Age 3	0.36	0.04	0.04	229	202	0.25	0.00
Age 4	0.60	0.07	0.07	326	287	0.25	0.31
Age 5	0.81	0.09	0.09	425	370	0.25	0.89
Age 6	1.15	0.13	0.13	485	442	0.25	0.99
Age 7	1.24	0.14	0.14	545	489	0.25	1.00
Age 8	1.31	0.15	0.15	570	548	0.25	1.00
Age 9	1.00	0.12	0.11	578	607	0.25	1.00
Age 10 and above	1.00	0.12	0.11	688	680	0.25	1.00

Note 1: Selectivity used for estimating the level that produces MSY at the 2019 Research Institute Meeting (i.e., selectivity of Fcurrent in the 2018 stock assessment).

Note 2: Fmsy estimated at the 2019 Research Institute Meeting (i.e., the Fcurrent in the 2018 stock assessment multiplied by Fmsy/Fcurrent).

Noe 3: F value under the selectivity above that gives the same fishing mortality as the average F at age for the 2015-2019 fishing seasons estimated in this stock assessment, which has been converted to %SPR.

Appendix 10. Updating of the S-R relationship, proposed reference points and future projection

Introduction

The first Committee of Stock Management Policy on this stock (held on August 20 and 21, 2020) made a request to simply update the proposed reference points, proposed fishing ban level, the proposed HCRs and future projection results to the values based on the latest stock assessment. In addition, it was requested to do trial calculations of the probability of exceeding the proposed reference points for each of the five years from the 2021 fishing season, where catch is fixed at 7,000 tons, 8,000 tons, 9,000 tons or 10,000 tons, with varying β in 0.1 intervals within the range of 0 to 1.0.

In this material, we first updated the values of the S-R relationship based on the stock assessment of this year, and next, we presented the results of recalculation of the proposed reference points, proposed level and proposed HCRs based on the updated S-R relationship by using the method that was used by the Research Institute Meeting. We also presented the results of future projection based on the updated values. In the future projection, we did trial calculations for each year of the five years from the 2021 fishing season, where catch is fixed at 7,000 tons, 8,000 tons, 9,000 tons or 10,000 tons.

The proposal at the Research Institute Meeting held in April 2019 is based on the latest stock assessment results at the time (results of the stock assessment in 2018). The stock assessment results used in this material are based on the stock assessment in 2020. The latest stock assessment includes two more assessment years of abundance, etc. compared with the stock assessment in 2018.

S-R relationship

As the S-R relationship of this stock, the Research Institute Meeting proposed the HS S-R relationship. The least squares method is used for parameter estimation of the relationship. A model that considers autocorrelation in residuals of observation values of recruitment against the predicted values is not used. Parameters of this S-R relationship are updated using the recruitment and spawning biomass of the 1980-2017 year class based on the latest stock assessment. The result is shown in the table below and Appendix Figure 10-1. Inclination of the HS model (parameter a in the table below) and break point (parameter b in the table below) of the updated relationship are almost the same as before the update. Recruitment that can be obtained on average with the spawning biomass above the break point of the HS model is 614 million individuals (617 million with the S-R relationship before the update).

Proposal	S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Proposal by the Research Institute Meeting (2019)	Hockey stick	Least squares method	No	1.805	341,742	0.812
Updated value	Hockey stick	Least squares method	No	1.797	341,743	0.799

Here, parameter a is the steepness of the HS S-R curve from the origin to the break point, and b is the spawning biomass (tons) at the break point.

Because the S-R relationship of this stock shows a strong linear relationship between the spawning biomass and recruitment, and no density effect is found in Ricker (RI) and Beverton-Holt (BH) S-R curves, almost the same values are estimated in the HS, RI and BH models (Appendix Figure 10-2, Appendix Table 10-1). However, when the inflection point is not within the observation range of the HS model, it can be set at the maximum value of spawning biomass. For this reason, it is judged that the HS model is suitable for the S-R relationship of this stock. Regarding the optimization method, the small-sample-size-corrected version of Akaike information criterion (AICc) is smaller with the least squares method compared with the least absolute value method (Appendix Table 10-1). The trend of residuals over time and autocorrelation plot of the HS model (Appendix Figure 10-2) are the same as those before the update (Yamashita et al. 2019). Yamashita et al (2019) found significant autocorrelation in residuals, but concluded that the significance of the autocorrelation coefficient greatly depended on the estimates of recruitment and spawning biomass before the 1988 year class and that autocorrelation was not found in residuals of the 1989 year class and after. For this reason, we did not consider the autocorrelation of residuals in this updating of the S-R relationship either.

Proposed reference points and proposed fishing ban

At the Research Institute Meeting on Reference Points in 2019, we proposed for this stock: SBmsy, which is the spawning biomass that produces MSY for the target reference point (SBtarget); SB0.6msy, which is the spawning biomass that produces 60% of MSY for the limit reference point (SBlimit); and SB0.1msy, which produces 10% of MSY for the fishing ban level (SBban). The results of updating these values using the 2020 stock assessment result are shown in the table below and Appendix Table 10-2.

Proposal	Item	Value	Remarks
Proposal by the Research Institute Meeting (2019)	Proposed SBtarget	382 thousand tons	Spawning biomass that produces MSY (SBmsy)
	Proposed SBlimit	171 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
	Proposed SBban	25 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)
Updated value	Proposed SBtarget	380 thousand tons	Spawning biomass that produces MSY (SBmsy)
	Proposed SBlimit	171 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
	Proposed SBban	25 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

We calculated SBmsy to be proposed as the target reference point with assumption of the proposal by the 2019 Research Institute Meeting: namely assuming equilibrium after the simulation period that is 50 times the average generation time (8.19 years) and setting as Fmsy the F value at which the average catch at equilibrium is maximized and setting as SBmsy the average spawning biomass at equilibrium when fishing is conducted at the Fmsy. For the simulation, we used the S-R relationship updated based on the results of the 2020 stock assessment (as mentioned above). The selectivity we used is based on the average F value at age in the 2013-2019 fishing seasons. The selectivity used in the Research Institute Meeting proposal in 2019 was based on the average F value at age of the latest five years at the time, namely the 2013-2017 fishing seasons. The latest five years of this update are the 2015-2019 fishing seasons. The selectivity based on the average F value at age of the 2015-2019 fishing seasons (Appendix Table 10-3) is particularly low for fish of age 7. However, considering the fishing condition of this stock, it is difficult to imagine that the big difference in F depending on age would continue in the future. In addition, the selectivity varies greatly from the selectivity used in the Research Institute Meeting proposal in 2019 (Appendix Table 10-3). For these reasons, for this update, we decided to use the selectivity based on the average F value at age in the 2013-2019 fishing seasons by adding the data of the succeeding two years to the data used for the proposal by the 2019 Research Institute Meeting. As current fishing mortality (F2015-2019*), we used the %SPR-converted F value that puts the same fishing mortality as that of the average F value at age in the 2015-2019 fishing seasons under this selectivity. For the average body weight of the catch, we used the average of the 2015-2019 fishing seasons. The settings of other biological parameters used for the simulation are shown in Appendix Table 10-4.

Average spawning biomass at equilibrium when F is changed variously and the corresponding average catch at age are shown in Appendix Figure 10-4.

The updated value of SBmsy that maximizes the average catch is 380 thousand tons, which is almost the same value as that of the proposal by the 2019 Research Institute Meeting. The updated proposed limit reference point (SB0.6msy) and fishing ban level (SB0.1msy) are spawning biomass of 171 thousand tons and 25 thousand tons, respectively, which are almost the same as those of the 2019 Research Institute Meeting proposal.

Kobe plot

The updated proposed target reference point (SBmsy) and Kobe plot based on the corresponding fishing mortality (Fmsy) or exploitation rate (Umsy) are shown in Appendix Figure 10-5. Fishing mortality (F) of this stock is judged to have been below the fishing mortality that produces MSY in the 2017 and 2019 fishing seasons. Exploitation rate (U) is judged to have been under the level that produces MSY in the 2017 and 2019 fishing seasons and after. Spawning biomass has been below the proposed target reference point (SBmsy) for the whole period.

Proposed HCRs

The HCRs are rules to set the fishing mortality (F) corresponding to the spawning biomass, etc. considering the probability of maintaining or recovering the spawning biomass above the proposed target reference point. The HCRs set for the first group of stocks of the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)" presents a rule to lower the fishing mortality directly to the proposed fishing ban level when the spawning biomass has fallen below the proposed limit reference point, while multiplying the Fmsy that is the upper limit of fishing mortality by safety coefficient β. Appendix Figure 10-6 shows an example where safety coefficient β is set to 0.8.

Future projection

(1) Setting of future projection

We updated the future projection results by using the updated S-R relationship and the proposed HCRs. For future projection, we have done forward calculation of cohort analysis from the number at age of the 2019 fishing season estimated by the 2020 stock assessment to the 2020-2051 fishing seasons. Recruitment for the future projection is given from the S-R relationship where values projected based on the spawning biomass of the respective year are updated. We assumed errors in logarithmic normal distribution as the uncertainty of recruitment, and repeated calculation 10,000 times. However, the recruitments of the 2020 fishing season (2018 year class) and 2021 fishing season (2019 year class) have high recruitment index values surveyed by research vessels and estimated values of standing stock of fish of ages 0 and 1, respectively. The recruitment is considered to be greatly larger than the recruitment estimated based on the spawning biomass using the S-R relationship. For this reason, we adopted the value of the recruitment of the 2014 fishing season (2012 year class) as the recruitment of the 2020 fishing season (2018 year class), and the average of the recruitments of the 2008 fishing season (2006 year class) and the 2014 fishing season (2012 year class) as the recruitment of the 2021 fishing season (2019 year class). For details, see Appendix 8. We set the catch of the 2020 fishing season to 6.7 thousand tons, which is the TAC quantity. As current fishing mortality (F2015-2019*), we used the value for the calculation of the proposed reference points. As fishing mortality in the 2021 fishing season and after, we used the fishing mortality provided by the proposed HCRs based on the spawning biomass projected for the respective fishing year. For mathematical equations used for the calculation, see Appendix 9.

(2) Predicted values of the 2021 fishing season

Spawning biomass predicted in the 2021 fishing season is below the limit reference point in all repeat calculations and projected to be 121 thousand tons on average. For this reason and because the spawning biomass is below the fishing mortality of the limit reference point, the fishing mortality of the 2021 fishing season is calculated by multiplying by the coefficient corresponding to the spawning biomass: γ(SBt) × βFmsy. Here, γ(SBt) of the 2021 fishing season was calculated as 0.66 with the equation below based on the HCRs set for the first group of stocks of the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)"

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

Average catch of the 2021 fishing season as calculated based on the updated proposed HCRs is 8.8 thousand tons when β is set to 1.0, while it is 7.1 thousand tons when β is set to 0.8.

Spawning biomass in the 2021 fishing season (average projection value): 121 thousand tons			
Item	Catch in the 2021 fishing season (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019)	Exploitation rate in the 2021 fishing season (%)
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	8.8	0.67	4
β = 0.8	7.1	0.53	3
β = 0.6	5.3	0.40	3
β = 0.4	3.6	0.27	2
β = 0.2	1.8	0.13	1
β = 0	0	0	0
F2015-2019*	12.9	1.00	6

Selectivity of F2015-2019* is different from the selectivity in the 2020 stock assessment report (F2015-2019). F2015-2019 is obtained by %SPR-conversion of the F value that gives the fishing mortality of the average F value at age of the 2015-2019 fishing seasons under the selectivity used for the calculation of MSY reference points at the 2019 Research Institute Meeting. F2015-2019* is obtained by %SPR-conversion of the F value that gives the fishing mortality of the average F value at age of the 2015-2019 fishing seasons under the selectivity used for this update of MSY reference points.

(3) Estimated values for the 2022 fishing season and after

Results of the medium- to long-term future projection based on the updated HCR proposal are shown in Appendix Figure 10-7 and Appendix Table 10-5. When control based on the proposed HCRs is continued for 10 years, predicted spawning biomass of the 2031 fishing season is 182 thousand tons (80% confidence interval: 117 thousand to 265 thousand tons) with β set to 1.0, and 199 thousand tons (80% confidence interval: 127 thousand to 292 thousand tons) with β set to 0.8. However, even when β is set to 0, spawning biomass is 309 thousand tons on average (80% confidence interval: 195 thousand to 449 thousand tons) and the probability that the prediction value will exceed the proposed target reference point (SBtarget) is 20%. The probability of exceeding the proposed limit reference point (SBlimit) is 46% with β set to 1.0 and 57% with β set to 0.8. The probability of exceeding the proposed fishing ban level (SBban) is 100% for all proposed HCRs.

When control based on the proposed HCRs is continued, the spawning biomass will exceed the proposed target reference point with the probability of 50% or higher after 2051 fishing season with β set to 1.0 or 0.8 and if fishing is continued with the current fishing mortality (F2015-2019*). The fishing year of exceeding the limit reference point with the probability of 50% or higher is predicted to be before the 2030 fishing season if β is set to 0 to 0.8. Even when fishing mortality is zero (β = 0), it is predicted that spawning biomass will exceed the proposed target reference point with the probability of 50% or higher in the 2035 fishing season.

Uncertainty considered: recruitment					
Item	Spawning biomass in the 2031 fishing season (thousand tons)	80% confidence interval (thousand tons)	Probability for spawning biomass to exceed the reference points in the 2031 fishing season		
			Proposed SBtarget	Proposed SBlimit	Proposed SBban
Other strategy (when using different β in the proposed HCRs)					
β = 1.0	182	117 – 265	2	46	100
β = 0.8	199	127 – 292	3	57	100
β = 0.6	219	138 – 322	4	69	100
β = 0.4	244	153 – 358	7	81	100
β = 0.2	273	171 – 400	12	90	100
β = 0	309	195 – 449	20	96	100
F2015-2019*	163	97 – 246	1	35	100

Uncertainty considered: recruitment			
	Year for spawning biomass to exceed the reference points with the probability of 50% or higher		
	Proposed SBtarget	Proposed SBlimit	Proposed SBban
Other strategy (when using different β in the proposed HCRs)			
β = 1.0	After 2051 fishing season	2033 fishing season	2019 fishing season
β = 0.8	After 2051 fishing season	2030 fishing season	2019 fishing season
β = 0.6	2047 fishing season	2029 fishing season	2019 fishing season
β = 0.4	2041 fishing season	2027 fishing season	2019 fishing season
β = 0.2	2038 fishing season	2026 fishing season	2019 fishing season
β = 0	2035 fishing season	2025 fishing season	2019 fishing season
F2015-2019*	After 2051 fishing season	2037 fishing season	2019 fishing season

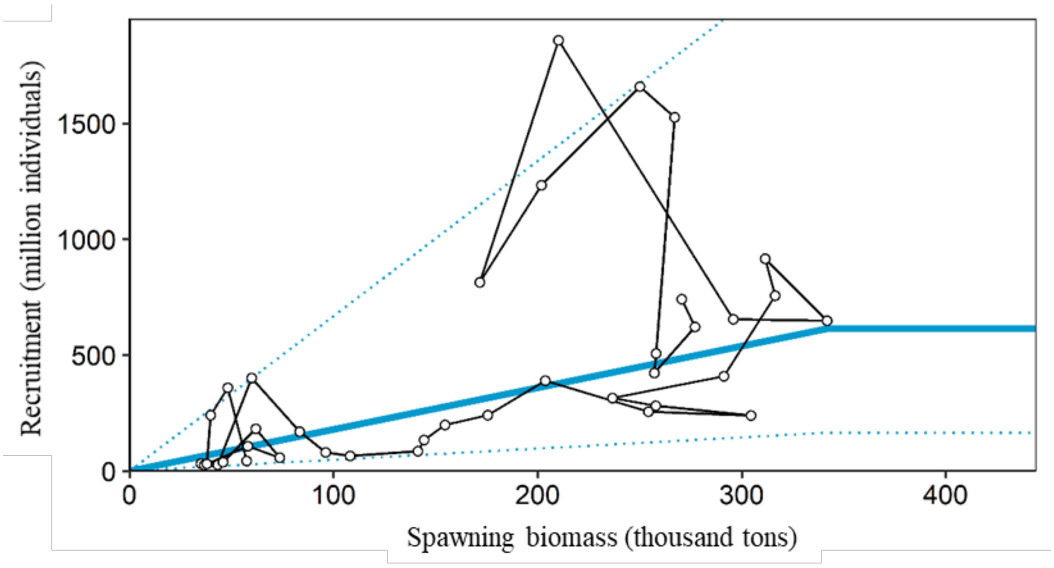
(4) Trial calculations where catch for each of the five years from the 2021 fishing season is fixed at 7,000 tons, 8,000 tons, 9,000 tons or 10,000 tons

Results of the trial calculation are shown in Appendix Tables 10-6 to 10-9. When the amount of catch that is fixed for the five years from the 2021 fishing season is increased, the probability that the spawning biomass will exceed the proposed target reference point and limit reference point decrease.

The probability that the estimated spawning biomass of the 2031 fishing season will exceed the proposed target reference point is 9 to 12% when β is set to 0. The probability of exceeding the proposed limit reference point is 48 to 55% when β is set to 1.0, and 56 to 62% when β is set to 0.8. The probability of exceeding the fishing ban level is 100% for all values of catch fixed for the five years and all proposed HCRs.

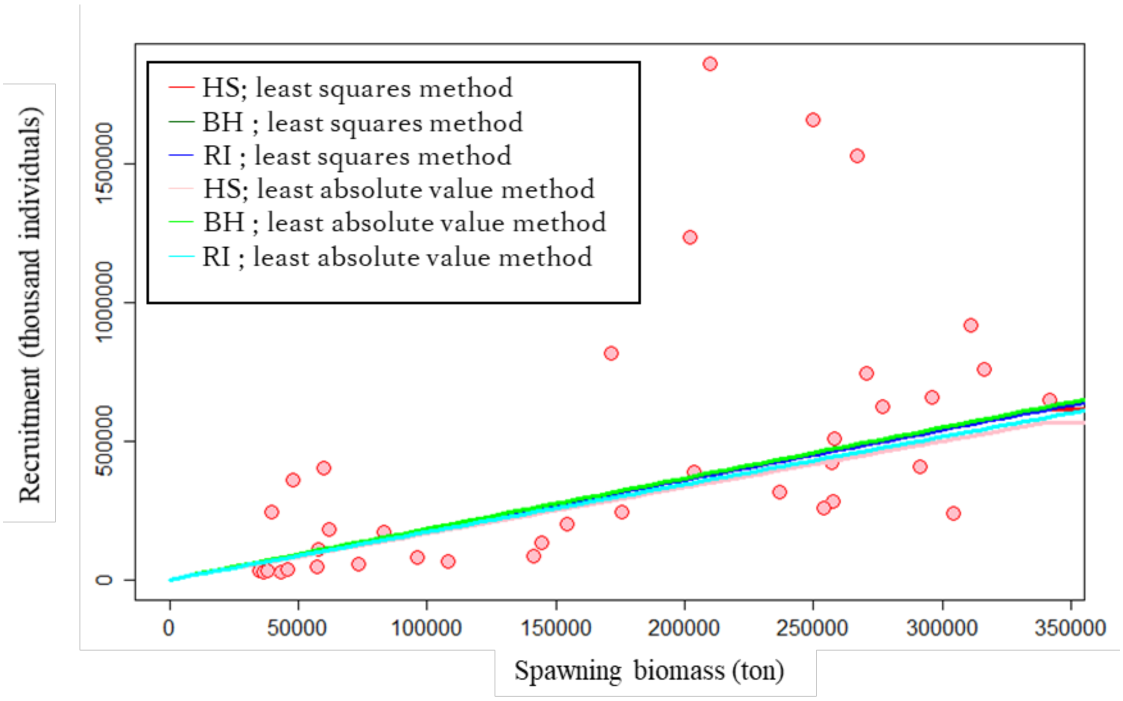
References

Yamashita Y., O. Sakai, M. Chimura and M. Ishino (2019) Report of the Research Institute Meeting on Reference Points for walleye pollock Northern Sea of Japan Stock in 2019. http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_suketou_n.pdf



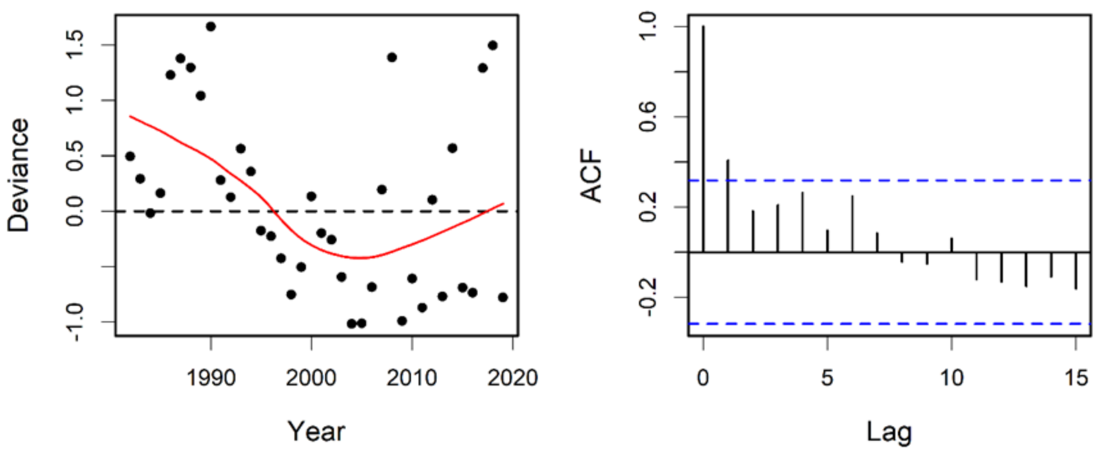
Appendix Figure 10-1. Updated S-R relationships (relationship between spawning biomass and recruitment)

The blue line expresses the HS S-R relationship as estimated based on the recruitment and spawning biomass of the 1980-2017 year class, which are estimated in the 2020 stock assessment. The dotted lines show the range supposed to include 90% of spawning biomass and recruitment.



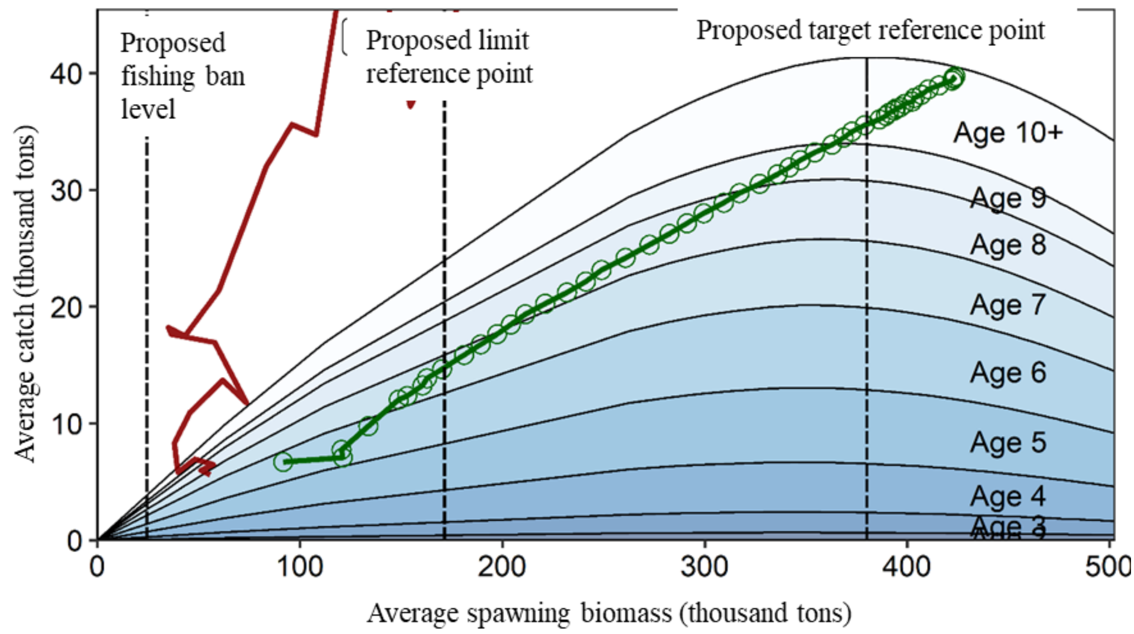
Appendix Figure 10-2. Comparison of the S-R relationships

HS, Ricker RI and BH S-R relationships are applied using the least squares method and the least absolute value method. For the parameters of the relationships, see Appendix Table 10-1.



Appendix Figure 10-3. Residual trend in the HS S-R relationship and autocorrelation plot

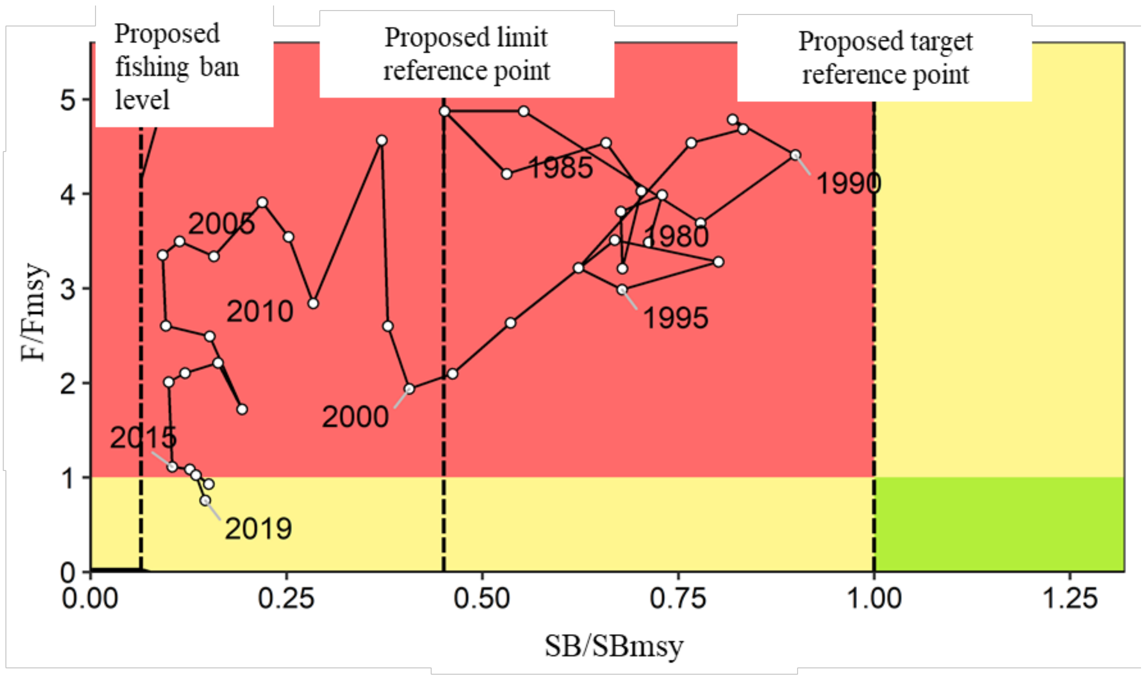
Based on the results when the HS S-R relationship is applied using the least squares method. The blue dashed lines in the right figure of autocorrelation plot express the 95% confidence interval.



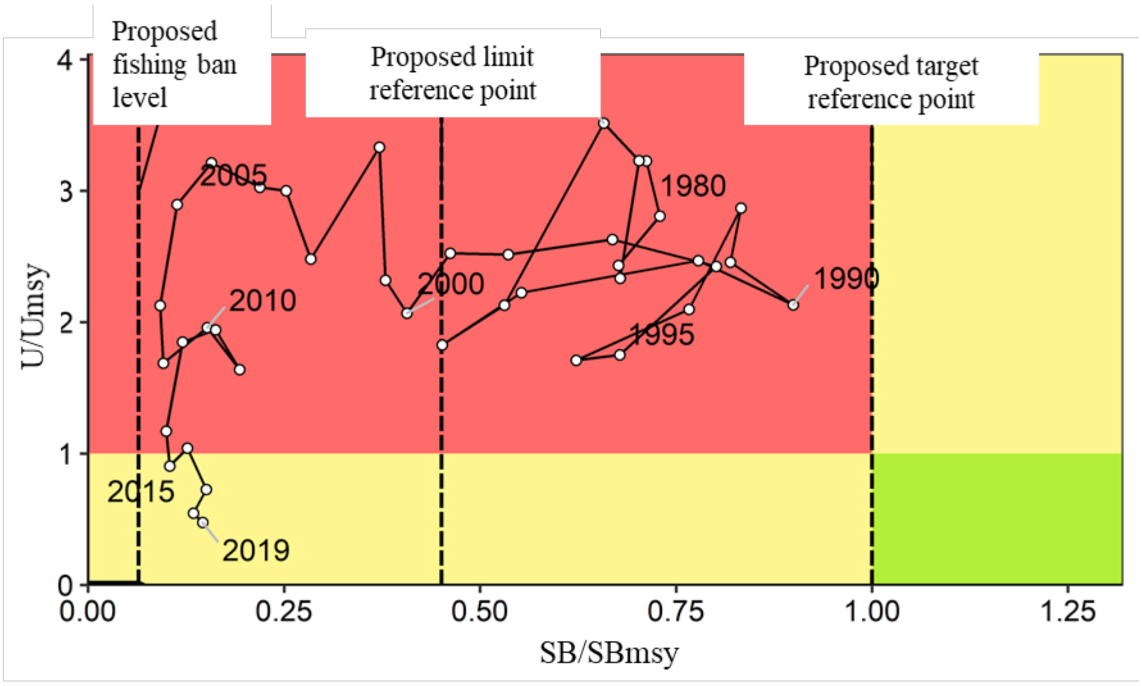
Appendix Figure 10-4. Relationship between the proposed reference points and curves of catch at age

The figure shows the average catch at age corresponding to the spawning biomass, and the relationship between each of the proposed reference points at equilibrium in the future projection simulation. The red line represents the relationship between the spawning biomass and catch, which are estimated by the stock assessment, while the green line represents changes in the average spawning biomass and average catch in the future projection when fishing is conducted based on the proposed HCRs (β = 0.8) under the proposed reference points.

a) When the vertical axis is the ratio of Fmsy to the fishing mortality of each year



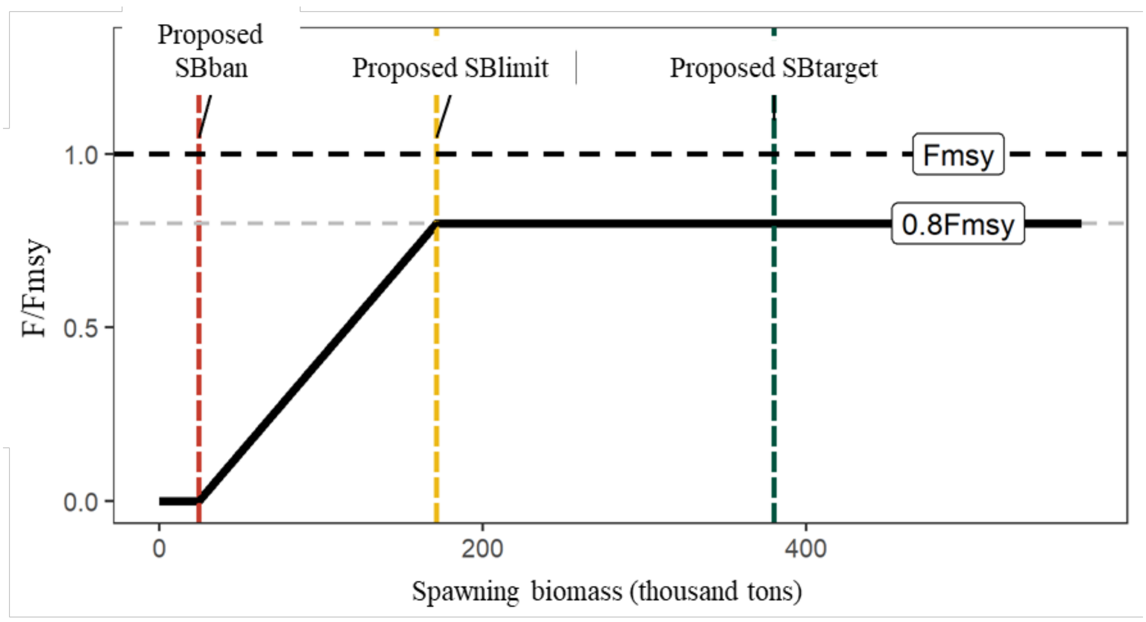
b) When the vertical axis is the ratio of Umsy to the exploitation rate of each year



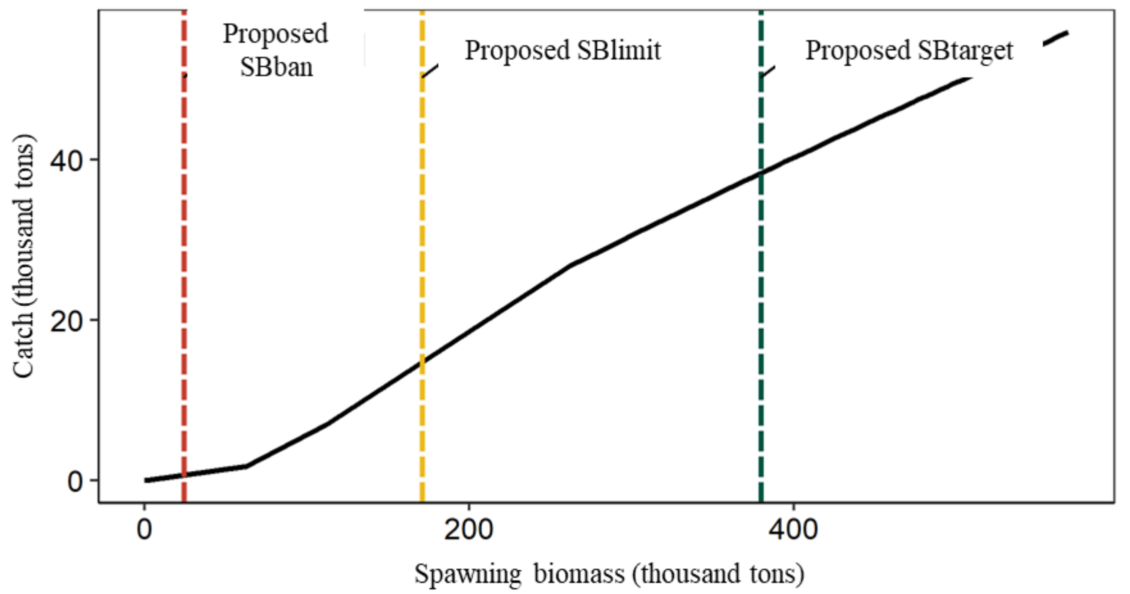
Appendix Figure 10-5. Kobe plot based on the reference points concerning the updated MSY

The upper chart (Figure 4a) shows the relationship of spawning biomass and fishing mortality (F) with the spawning biomass that produces MSY (SBmsy) and the fishing mortality that produces MSY (Fmsy). The lower chart (Figure 4b) shows the relationship when exploitation rate (U) is used instead of F value.

a)

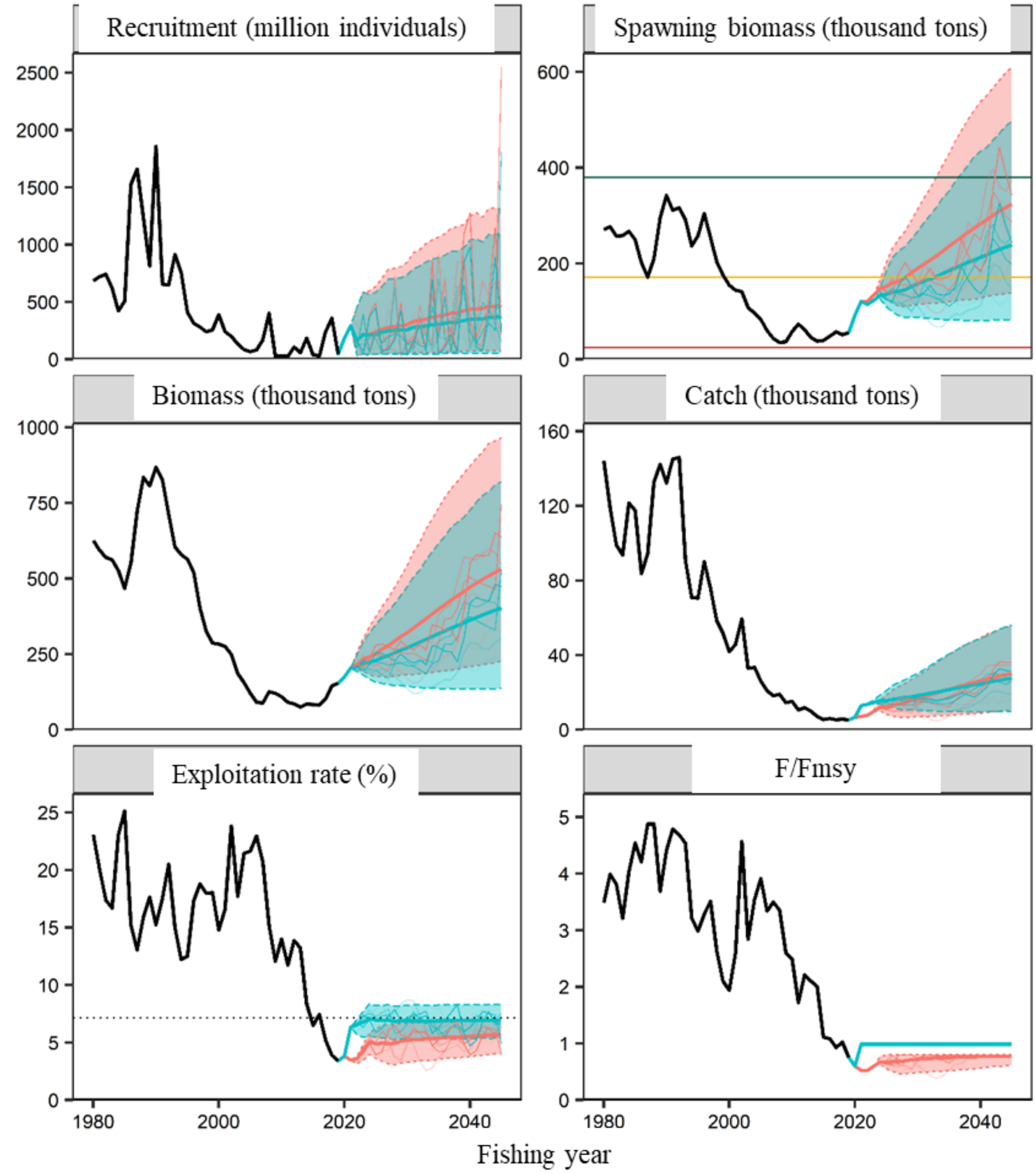


b)



Appendix Figure Proposed HCRs (when β is 0.8)

The black dashed line represents Fmsy; the grey dashed line represents 0.8Fmsy; the black thick line represents the proposed HCRs; the red dashed line represents the proposed fishing ban level (SBban); the yellow dashed line represents the proposed limit reference point (SBlimit); and the green dashed line represents the proposed target reference point (SBtarget). The upper chart (a) expresses a schematic diagram of the proposed HCRs where fishing mortality is put to the vertical axis. The lower chart (b) where the catch is put to the vertical axis shows the catch that is expected based on the proposed HCRs under the respective spawning biomass.



Appendix Figure 10-7. Future projection based on the proposed HCRs (in red) and the future projection that assumes continued fishing at the current fishing mortality level (F2015-2019*) (in blue)

The thick solid line, shaded area and thin lines represent average value, the 90% prediction interval that includes 90% of the simulation results, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed limit reference point and the red line shows the proposed fishing ban level. The dashed line in the figure of exploitation rate shows Umsy. The figure shows the results of the proposed HCRs with β set to 0.8. The recruitment of the 2020 fishing season is set to the value of the recruitment of the 2014 fishing season. The recruitment of the 2021 fishing season is set to the average of the recruitments of the 2008 fishing season and the 2014 fishing season. The catch of the 2020 fishing season is set to TAC (6.7 thousand tons).

Appendix Table 10-1. Examination results of S-R relationships

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.	AICc	Data quantity
Hockey stick	**Least squares method**	**None**	**1.797**	**341,743**	**0.799**	**97.5**	**38**
Ricker	Least squares method	None	1.797	1.58×10^{-13}	0.799	97.5	38
Beverton-Holt	Least squares method	None	1.797	2.77×10^{-13}	0.799	97.5	38
Hockey stick	Least absolute value method	None	1.661	341,743	0.803	104.7	38
Ricker	Least absolute value method	None	1.715	5.90×10^{-23}	0.801	104.7	38
Beverton-Holt	Least absolute value method	None	1.826	1.09×10^{-22}	0.799	104.7	38

The recommended S-R relationship is indicated in bold face. S.D. is an index expressing magnitude of dispersion of recruitment, which is the standard deviation of log residuals (square root of mean square error).

Appendix Table 10-2. Average spawning biomass at equilibrium of the respective proposed reference points; ratio to the initial spawning biomass assuming no catch (SB0); average catch; %SPR-converted fishing mortality; exploitation rate; proportional connection of fishing effort to F2015-2019* (Note 1); and fishing mortality at age at the fishing mortality that produces MSY (Fmsy)

Item	Explanation	Spawning biomass (thousand tons)	Ratio to SB0	Catch (thousand tons)	Fishing mortality (%SPR)	Exploitation rate	Ratio of the fishing effort
Proposed target reference point	Spawning biomass that produces MSY (SBmsy)	380	0.53	44	60	0.07	1.01
Proposed limit reference point	Spawning biomass that produces 60% of MSY (SB0.6msy)	171	0.24	27	52	0.09	1.36
Proposed fishing ban level	Spawning biomass that produces 10% of MSY (SB0.1msy)	25	0.03	4	48	0.10	1.58
Fishing mortality that produces MSY (Fmsy)	(Ages 2, 3, 4, 5, 6, 7, 8, 9 and 10+) = (0.02, 0.03, 0.07, 0.11, 0.13, 0.14, 0.15, 0.13, 0.13)						

Note 1: Value obtained by %SPR-conversion of the F value that gives the same fishing mortality as

the average F value at age of the 2015-2019 fishing seasons under the selectivity of the average F of the 2013-2019 fishing seasons based on the stock assessment in 2020

Appendix Table 10-3. Selectivity

Age	Average of the 2013-2019 fishing seasons (Note 1)	Average of the 2015-2019 fishing seasons	Average of the 2013-2017 fishing seasons (Note 2)
2	0.14	0.12	0.18
3	0.26	0.24	0.36
4	0.51	0.50	0.60
5	0.81	0.75	0.81
6	0.99	0.63	1.15
7	1.05	0.48	1.24
8	1.18	1.13	1.31
9	1.00	1.00	1.00
10	1.00	1.00	1.00

Note 1: Selectivity used for this update of MSY reference points and future projection

Note 2: Selectivity used for calculation of MSY reference points in the proposal by the Research Institute Meeting in 2019

Appendix Table 10-4. Parameters used for MSY reference point calculation and future projection

Age	Natural mortality	Maturity rate	Average weight of stock (g)	Average weight of catch (g) (Note 1)	Selectivity (Note 2)	F2015-2019* (Note 3)
2	0.30	0.00	134	98	0.14	0.02
3	0.25	0.00	229	187	0.26	0.03
4	0.25	0.31	326	284	0.51	0.07
5	0.25	0.89	425	380	0.81	0.10
6	0.25	0.99	485	455	0.99	0.13
7	0.25	1.00	545	505	1.05	0.14
8	0.25	1.00	570	574	1.18	0.15
9	0.25	1.00	578	605	1.00	0.13
10+	0.25	1.00	688	680	1.00	0.13

Note 1: Average body weight of catch of the 2015-2019 fishing seasons
Note 2: Selectivity of the average F of the 2013-2019 fishing seasons based on the 2020 stock assessment in 2020
Note 3: Value obtained by %SPR-conversion of the F value that gives the same fishing mortality as the average F value at age of the 2015-2019 fishing seasons under the selectivity of Note 2

Appendix Table 10-5. Probability for spawning biomass to exceed the proposed target reference point (a) and the proposed limit reference point (b)

The catch in the 2020 fishing season is TAC (6.7 thousand tons) while the catch in the 2021 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	0	1	1	2	12	24
0.9	0	0	0	0	0	0	0	0	0	0	1	1	2	16	31
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	21	39
0.7	0	0	0	0	0	0	0	0	0	1	1	2	3	27	49
0.6	0	0	0	0	0	0	0	0	0	1	2	3	4	35	59
0.5	0	0	0	0	0	0	0	0	1	1	2	4	6	43	69
0.4	0	0	0	0	0	0	0	0	1	1	3	5	7	53	78
0.3	0	0	0	0	0	0	0	0	1	2	3	6	10	61	86
0.2	0	0	0	0	0	0	0	0	1	2	4	8	12	70	91
0.1	0	0	0	0	0	0	0	1	1	3	6	10	16	78	96
0	0	0	0	0	0	0	0	1	2	3	7	13	20	86	98

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	2	12	22	25	31	37	43	46	70	82
0.9	0	0	0	0	0	2	14	24	28	35	42	48	51	76	87
0.8	0	0	0	0	0	3	16	28	32	39	48	53	57	82	92
0.7	0	0	0	0	0	3	18	31	36	44	53	59	63	87	95
0.6	0	0	0	0	0	4	21	35	41	49	59	65	69	91	97
0.5	0	0	0	0	0	6	25	39	46	55	65	71	75	94	99
0.4	0	0	0	0	0	7	29	45	52	61	71	76	81	97	99
0.3	0	0	0	0	0	10	35	50	57	67	77	82	86	98	100
0.2	0	0	0	0	0	14	42	58	64	73	82	87	90	99	100
0.1	0	0	0	0	0	21	50	66	70	79	87	91	93	100	100
0	0	0	0	0	0	32	60	73	78	85	91	94	96	100	100

Appendix Table 10-5(continued). Changes in future average spawning biomass (c) and future average catch (d)

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2021 fishing season and after is based on the proposed HCRs.

(c) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	119	131	144	146	152	154	160	168	175	182	246	299
0.9	56	92	121	120	132	146	149	156	158	165	174	182	190	267	330
0.8	56	92	121	120	134	149	152	159	163	170	181	190	199	291	364
0.7	56	92	121	121	135	151	155	163	168	176	188	198	209	318	399
0.6	56	92	121	122	137	154	159	168	173	182	196	208	219	347	437
0.5	56	92	121	123	139	156	162	172	178	189	204	217	231	380	477
0.4	56	92	121	124	140	159	166	177	184	197	213	228	244	415	518
0.3	56	92	121	125	142	162	170	182	191	204	223	240	258	454	560
0.2	56	92	121	126	144	165	174	188	198	213	233	253	273	496	603
0.1	56	92	121	127	146	168	179	194	205	222	245	267	290	541	648
0	56	92	121	127	148	171	184	200	213	232	257	282	309	589	695

(d) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	8.8	9.3	11.5	13.9	14.1	15.0	15.6	16.4	17.7	18.6	19.5	28.0	34.4
0.9	5.2	6.7	7.9	8.5	10.7	13.0	13.2	14.2	14.8	15.6	16.9	17.8	18.7	27.7	34.5
0.8	5.2	6.7	7.1	7.7	9.8	12.0	12.2	13.2	13.8	14.6	15.9	16.8	17.8	27.1	34.0
0.7	5.2	6.7	6.2	6.9	8.8	10.9	11.2	12.1	12.7	13.5	14.7	15.7	16.6	26.1	32.9
0.6	5.2	6.7	5.3	6.0	7.8	9.7	10.0	10.9	11.5	12.2	13.4	14.3	15.2	24.7	31.0
0.5	5.2	6.7	4.5	5.1	6.7	8.4	8.7	9.5	10.1	10.8	11.8	12.7	13.5	22.6	28.3
0.4	5.2	6.7	3.6	4.2	5.5	7.0	7.3	8.0	8.5	9.1	10.0	10.8	11.6	19.9	24.7
0.3	5.2	6.7	2.7	3.2	4.3	5.5	5.7	6.3	6.7	7.2	7.9	8.6	9.3	16.4	20.1
0.2	5.2	6.7	1.8	2.2	2.9	3.8	4.0	4.4	4.7	5.1	5.6	6.1	6.6	12.0	14.5
0.1	5.2	6.7	0.9	1.1	1.5	2.0	2.1	2.3	2.5	2.7	3.0	3.2	3.5	6.5	7.8
0	5.2	6.7	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 10-6. Probability for spawning biomass to exceed the proposed reference points when the catch of the five years from the 2021 fishing season is fixed at 7,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	1	1	2	3	15	26
0.9	0	0	0	0	0	0	0	0	0	1	1	2	3	19	33
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	23	41
0.7	0	0	0	0	0	0	0	0	1	1	1	3	4	29	50
0.6	0	0	0	0	0	0	0	0	1	1	2	3	5	36	59
0.5	0	0	0	0	0	0	0	0	1	1	2	4	6	43	69
0.4	0	0	0	0	0	0	0	0	1	1	2	4	6	50	77
0.3	0	0	0	0	0	0	0	0	1	1	2	5	8	57	84
0.2	0	0	0	0	0	0	0	0	1	1	3	5	9	65	90
0.1	0	0	0	0	0	0	0	0	1	2	3	6	11	72	94
0	0	0	0	0	0	0	0	0	1	2	4	7	12	78	97

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	4	23	39	38	40	47	51	55	74	84
0.9	0	0	0	0	0	4	23	39	39	43	50	55	59	79	89
0.8	0	0	0	0	0	4	23	39	40	45	53	59	62	84	92
0.7	0	0	0	0	0	4	23	39	42	48	56	62	66	88	95
0.6	0	0	0	0	0	4	23	39	44	50	60	65	70	91	97
0.5	0	0	0	0	0	4	23	39	45	53	63	69	73	94	99
0.4	0	0	0	0	0	4	23	39	47	56	67	72	77	96	99
0.3	0	0	0	0	0	4	23	39	48	59	70	76	81	98	100
0.2	0	0	0	0	0	4	23	39	50	62	73	79	84	99	100
0.1	0	0	0	0	0	4	23	39	52	64	76	82	86	99	100
0	0	0	0	0	0	4	23	39	53	67	79	85	89	100	100

Appendix Table 10-6 (continued). Changes in the average of future spawning biomass (c) and catch (d) when the catch of the five years from the 2021 fishing season is fixed at 7,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(c) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	121	135	152	160	172	169	172	179	188	197	260	310
0.9	56	92	121	121	135	152	160	172	171	175	183	193	202	280	339
0.8	56	92	121	121	135	152	160	172	172	178	188	198	208	301	370
0.7	56	92	121	121	135	152	160	172	174	181	192	203	215	324	403
0.6	56	92	121	121	135	152	160	172	176	184	196	209	222	349	438
0.5	56	92	121	121	135	152	160	172	178	187	201	215	229	377	475
0.4	56	92	121	121	135	152	160	172	179	191	206	221	236	406	513
0.3	56	92	121	121	135	152	160	172	181	194	211	227	244	438	553
0.2	56	92	121	121	135	152	160	172	183	198	216	234	253	473	595
0.1	56	92	121	121	135	152	160	172	185	201	222	241	262	510	639
0	56	92	121	121	135	152	160	172	187	205	227	249	271	550	685

(d) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	7.0	7.0	7.0	7.0	7.0	18.3	18.1	18.4	19.5	20.5	21.6	29.7	35.7
0.9	5.2	6.7	7.0	7.0	7.0	7.0	7.0	16.6	16.6	17.0	18.2	19.2	20.3	29.1	35.4
0.8	5.2	6.7	7.0	7.0	7.0	7.0	7.0	14.8	15.0	15.6	16.8	17.8	18.8	28.1	34.6
0.7	5.2	6.7	7.0	7.0	7.0	7.0	7.0	13.0	13.4	14.0	15.2	16.1	17.2	26.7	33.2
0.6	5.2	6.7	7.0	7.0	7.0	7.0	7.0	11.2	11.7	12.4	13.5	14.4	15.4	24.8	31.1
0.5	5.2	6.7	7.0	7.0	7.0	7.0	7.0	9.4	10.0	10.6	11.6	12.5	13.4	22.4	28.2
0.4	5.2	6.7	7.0	7.0	7.0	7.0	7.0	7.6	8.1	8.7	9.6	10.4	11.2	19.5	24.4
0.3	5.2	6.7	7.0	7.0	7.0	7.0	7.0	5.7	6.2	6.7	7.5	8.1	8.7	15.8	19.8
0.2	5.2	6.7	7.0	7.0	7.0	7.0	7.0	3.8	4.2	4.6	5.1	5.6	6.1	11.4	14.3
0.1	5.2	6.7	7.0	7.0	7.0	7.0	7.0	1.9	2.2	2.4	2.7	2.9	3.2	6.2	7.7
0	5.2	6.7	7.0	7.0	7.0	7.0	7.0	0	0	0	0	0	0	0	0

Appendix Table 10-7. Probability for spawning biomass to exceed the proposed reference points when the catch of the five years from the 2021 fishing season is fixed at 8,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	1	1	2	3	14	26
0.9	0	0	0	0	0	0	0	0	0	1	1	2	3	18	33
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	23	40
0.7	0	0	0	0	0	0	0	0	0	1	1	2	4	28	49
0.6	0	0	0	0	0	0	0	0	0	1	1	3	4	34	58
0.5	0	0	0	0	0	0	0	0	1	1	2	3	5	41	68
0.4	0	0	0	0	0	0	0	0	1	1	2	4	6	49	77
0.3	0	0	0	0	0	0	0	0	1	1	2	4	7	56	84
0.2	0	0	0	0	0	0	0	0	1	1	3	5	8	63	90
0.1	0	0	0	0	0	0	0	0	1	1	3	6	10	71	94
0	0	0	0	0	0	0	0	0	1	2	4	7	11	77	97

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	3	20	35	35	38	44	49	53	73	84
0.9	0	0	0	0	0	3	20	35	36	40	48	52	57	78	88
0.8	0	0	0	0	0	3	20	35	38	43	51	56	60	83	92
0.7	0	0	0	0	0	3	20	35	39	45	54	60	64	87	95
0.6	0	0	0	0	0	3	20	35	40	48	57	63	68	91	97
0.5	0	0	0	0	0	3	20	35	42	50	61	67	71	93	98
0.4	0	0	0	0	0	3	20	35	44	53	64	70	75	96	99
0.3	0	0	0	0	0	3	20	35	45	56	67	74	79	97	100
0.2	0	0	0	0	0	3	20	35	47	59	71	77	82	98	100
0.1	0	0	0	0	0	3	20	35	48	62	74	80	85	99	100
0	0	0	0	0	0	3	20	35	50	64	77	83	87	100	100

Appendix Table 10-7 (continued). Changes in the average of future spawning biomass (c) and catch (d) when the catch of the five years from the 2021 fishing season is fixed at 8,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(c) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	120	133	149	157	168	166	169	177	185	193	257	307
0.9	56	92	121	120	133	149	157	168	167	172	180	190	199	276	336
0.8	56	92	121	120	133	149	157	168	169	175	184	194	205	297	367
0.7	56	92	121	120	133	149	157	168	171	178	189	200	211	320	400
0.6	56	92	121	120	133	149	157	168	172	181	193	205	217	344	435
0.5	56	92	121	120	133	149	157	168	174	184	198	211	224	371	472
0.4	56	92	121	120	133	149	157	168	176	187	202	217	232	401	511
0.3	56	92	121	120	133	149	157	168	177	191	207	223	240	433	551
0.2	56	92	121	120	133	149	157	168	179	194	212	230	248	467	593
0.1	56	92	121	120	133	149	157	168	181	198	218	237	257	504	636
0	56	92	121	120	133	149	157	168	183	201	223	244	266	543	683

(d) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	8.0	8.0	8.0	8.0	8.0	17.6	17.5	17.9	19.1	20.1	21.1	29.3	35.4
0.9	5.2	6.7	8.0	8.0	8.0	8.0	8.0	15.9	16.1	16.6	17.8	18.8	19.8	28.7	35.2
0.8	5.2	6.7	8.0	8.0	8.0	8.0	8.0	14.2	14.6	15.2	16.4	17.4	18.4	27.7	34.4
0.7	5.2	6.7	8.0	8.0	8.0	8.0	8.0	12.5	13.0	13.7	14.8	15.8	16.8	26.3	33.0
0.6	5.2	6.7	8.0	8.0	8.0	8.0	8.0	10.8	11.4	12.1	13.2	14.1	15.0	24.5	30.9
0.5	5.2	6.7	8.0	8.0	8.0	8.0	8.0	9.0	9.7	10.4	11.3	12.2	13.1	22.1	28.0
0.4	5.2	6.7	8.0	8.0	8.0	8.0	8.0	7.3	7.9	8.5	9.4	10.1	10.9	19.2	24.3
0.3	5.2	6.7	8.0	8.0	8.0	8.0	8.0	5.5	6.0	6.6	7.3	7.9	8.6	15.6	19.7
0.2	5.2	6.7	8.0	8.0	8.0	8.0	8.0	3.7	4.1	4.5	5.0	5.5	6.0	11.3	14.2
0.1	5.2	6.7	8.0	8.0	8.0	8.0	8.0	1.8	2.1	2.3	2.6	2.8	3.1	6.1	7.7
0	5.2	6.7	8.0	8.0	8.0	8.0	8.0	0	0	0	0	0	0	0	0

Appendix Table 10-8. Probability for spawning biomass to exceed the proposed reference points when the catch of the five years from the 2021 fishing season is fixed at 9,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	0	1	1	2	13	25
0.9	0	0	0	0	0	0	0	0	0	1	1	2	3	17	32
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	22	39
0.7	0	0	0	0	0	0	0	0	0	1	1	2	3	27	48
0.6	0	0	0	0	0	0	0	0	0	1	1	2	4	33	57
0.5	0	0	0	0	0	0	0	0	0	1	2	3	5	40	67
0.4	0	0	0	0	0	0	0	0	1	1	2	3	5	47	76
0.3	0	0	0	0	0	0	0	0	1	1	2	4	6	55	83
0.2	0	0	0	0	0	0	0	0	1	1	2	4	7	62	89
0.1	0	0	0	0	0	0	0	0	1	1	3	5	9	69	94
0	0	0	0	0	0	0	0	0	1	1	3	6	10	76	97

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	3	18	32	32	36	42	47	51	72	83
0.9	0	0	0	0	0	3	18	32	33	38	45	50	54	77	88
0.8	0	0	0	0	0	3	18	32	35	41	48	54	58	82	92
0.7	0	0	0	0	0	3	18	32	36	43	51	57	62	86	95
0.6	0	0	0	0	0	3	18	32	38	45	55	61	66	90	97
0.5	0	0	0	0	0	3	18	32	39	48	58	65	69	93	98
0.4	0	0	0	0	0	3	18	32	40	50	61	68	73	95	99
0.3	0	0	0	0	0	3	18	32	42	53	64	71	76	97	100
0.2	0	0	0	0	0	3	18	32	44	56	68	75	80	98	100
0.1	0	0	0	0	0	3	18	32	45	58	71	78	83	99	100
0	0	0	0	0	0	3	18	32	46	61	74	81	86	99	100

Appendix Table 10-8 (continued). Changes in the average of future spawning biomass (c) and catch (d) when the catch of the five years from the 2021 fishing season is fixed at 9,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(c) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	119	131	147	153	164	163	166	174	182	190	254	305
0.9	56	92	121	119	131	147	153	164	164	169	177	186	195	272	333
0.8	56	92	121	119	131	147	153	164	166	172	181	191	201	293	364
0.7	56	92	121	119	131	147	153	164	167	175	185	196	207	315	398
0.6	56	92	121	119	131	147	153	164	169	178	190	201	213	340	433
0.5	56	92	121	119	131	147	153	164	171	181	194	207	220	366	469
0.4	56	92	121	119	131	147	153	164	172	184	199	213	227	395	508
0.3	56	92	121	119	131	147	153	164	174	187	203	219	235	427	548
0.2	56	92	121	119	131	147	153	164	175	190	208	225	243	461	590
0.1	56	92	121	119	131	147	153	164	177	194	214	232	252	497	634
0	56	92	121	119	131	147	153	164	179	197	219	239	261	536	681

(d) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	9.0	9.0	9.0	9.0	9.0	16.9	17.0	17.4	18.6	19.6	20.6	28.9	35.1
0.9	5.2	6.7	9.0	9.0	9.0	9.0	9.0	15.3	15.6	16.2	17.4	18.3	19.3	28.2	34.9
0.8	5.2	6.7	9.0	9.0	9.0	9.0	9.0	13.6	14.1	14.8	16.0	16.9	17.9	27.3	34.1
0.7	5.2	6.7	9.0	9.0	9.0	9.0	9.0	12.0	12.6	13.3	14.5	15.4	16.4	25.9	32.8
0.6	5.2	6.7	9.0	9.0	9.0	9.0	9.0	10.3	11.0	11.8	12.8	13.7	14.7	24.1	30.7
0.5	5.2	6.7	9.0	9.0	9.0	9.0	9.0	8.7	9.3	10.1	11.1	11.9	12.8	21.8	27.9
0.4	5.2	6.7	9.0	9.0	9.0	9.0	9.0	7.0	7.6	8.3	9.2	9.9	10.7	18.9	24.2
0.3	5.2	6.7	9.0	9.0	9.0	9.0	9.0	5.3	5.8	6.4	7.1	7.7	8.4	15.4	19.6
0.2	5.2	6.7	9.0	9.0	9.0	9.0	9.0	3.5	4.0	4.4	4.9	5.4	5.8	11.1	14.1
0.1	5.2	6.7	9.0	9.0	9.0	9.0	9.0	1.8	2.0	2.3	2.5	2.8	3.0	6.0	7.6
0	5.2	6.7	9.0	9.0	9.0	9.0	9.0	0	0	0	0	0	0	0	0

Appendix Table 10-9. Probability for spawning biomass to exceed the proposed reference points when the catch of the five years from the 2021 fishing season is fixed at 10,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(a) Probability for spawning biomass to exceed the proposed target reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	0	0	0	0	0	1	1	2	13	25
0.9	0	0	0	0	0	0	0	0	0	1	1	2	2	16	31
0.8	0	0	0	0	0	0	0	0	0	1	1	2	3	21	39
0.7	0	0	0	0	0	0	0	0	0	1	1	2	3	26	48
0.6	0	0	0	0	0	0	0	0	0	1	1	2	4	32	56
0.5	0	0	0	0	0	0	0	0	0	1	1	3	4	38	66
0.4	0	0	0	0	0	0	0	0	0	1	2	3	5	46	75
0.3	0	0	0	0	0	0	0	0	1	1	2	4	6	53	83
0.2	0	0	0	0	0	0	0	0	1	1	2	4	7	61	89
0.1	0	0	0	0	0	0	0	0	1	1	2	5	8	68	93
0	0	0	0	0	0	0	0	0	1	1	3	5	9	75	96

(b) Probability for spawning biomass to exceed the proposed limit reference point

(%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	0	2	16	29	30	34	39	45	48	71	83
0.9	0	0	0	0	0	2	16	29	31	36	43	48	52	76	87
0.8	0	0	0	0	0	2	16	29	32	38	46	51	56	81	91
0.7	0	0	0	0	0	2	16	29	34	40	49	55	59	85	94
0.6	0	0	0	0	0	2	16	29	35	43	52	59	63	89	97
0.5	0	0	0	0	0	2	16	29	36	45	55	62	67	92	98
0.4	0	0	0	0	0	2	16	29	37	48	59	66	70	95	99
0.3	0	0	0	0	0	2	16	29	39	50	62	69	74	97	100
0.2	0	0	0	0	0	2	16	29	40	52	65	72	78	98	100
0.1	0	0	0	0	0	2	16	29	42	55	68	75	81	99	100
0	0	0	0	0	0	2	16	29	43	58	72	78	84	99	100

Appendix Table 10-9 (continued). Changes in the average of future spawning biomass (c) and catch (d) when the catch of the five years from the 2021 fishing season is fixed at 10,000 tons and β is changed in 0.1 intervals within the range of 0 to 1.0

The catch of the 2020 fishing season is TAC (6.7 thousand tons) while the catch of the 2026 fishing season and after is based on the proposed HCRs.

(c) Average spawning biomass

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	56	92	121	118	129	144	150	160	159	163	171	179	186	250	302
0.9	56	92	121	118	129	144	150	160	161	166	175	183	191	269	331
0.8	56	92	121	118	129	144	150	160	162	169	178	188	197	289	362
0.7	56	92	121	118	129	144	150	160	164	171	182	193	203	311	395
0.6	56	92	121	118	129	144	150	160	165	174	186	198	209	335	430
0.5	56	92	121	118	129	144	150	160	167	177	191	203	216	361	466
0.4	56	92	121	118	129	144	150	160	169	180	195	209	223	390	505
0.3	56	92	121	118	129	144	150	160	170	183	200	215	230	421	545
0.2	56	92	121	118	129	144	150	160	172	187	204	221	238	454	588
0.1	56	92	121	118	129	144	150	160	173	190	209	228	246	491	632
0	56	92	121	118	129	144	150	160	175	193	215	235	255	529	679

(d) Average catch

(Thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	5.2	6.7	10.0	10.0	10.0	10.0	10.0	16.2	16.4	17.0	18.2	19.1	20.1	28.4	34.8
0.9	5.2	6.7	10.0	10.0	10.0	10.0	10.0	14.6	15.1	15.7	16.9	17.9	18.9	27.8	34.6
0.8	5.2	6.7	10.0	10.0	10.0	10.0	10.0	13.1	13.6	14.4	15.6	16.5	17.5	26.9	33.8
0.7	5.2	6.7	10.0	10.0	10.0	10.0	10.0	11.5	12.2	12.9	14.1	15.0	16.0	25.5	32.5
0.6	5.2	6.7	10.0	10.0	10.0	10.0	10.0	9.9	10.6	11.4	12.5	13.4	14.3	23.8	30.5
0.5	5.2	6.7	10.0	10.0	10.0	10.0	10.0	8.3	9.0	9.8	10.8	11.6	12.5	21.5	27.7
0.4	5.2	6.7	10.0	10.0	10.0	10.0	10.0	6.7	7.4	8.1	8.9	9.7	10.4	18.7	24.1
0.3	5.2	6.7	10.0	10.0	10.0	10.0	10.0	5.0	5.6	6.2	6.9	7.5	8.2	15.2	19.6
0.2	5.2	6.7	10.0	10.0	10.0	10.0	10.0	3.4	3.8	4.3	4.8	5.2	5.7	11.0	14.1
0.1	5.2	6.7	10.0	10.0	10.0	10.0	10.0	1.7	2.0	2.2	2.5	2.7	3.0	5.9	7.6
0	5.2	6.7	10.0	10.0	10.0	10.0	10.0	0	0	0	0	0	0	0	0