

Stock Assessment of the Walleye Pollock for Japanese Pacific Stock in 2020

Fisheries Stock Assessment Center, Fisheries Resources Institute (FRI), Japan Fisheries Research and Education Agency (FRA)

Marine Fisheries Research and Development Center (JAMARC), Japan Fisheries Research and Education Agency (FRA)

Participating organizations:

Kushiro Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization (HRO); Mariculture Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization (HRO); Hakodate Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization (HRO); Fisheries Institute, Aomori Prefectural Industrial Technology Research Center; Iwate Fisheries Technology Center; Miyagi Prefecture Fisheries Technology Institute; Fukushima Prefectural Fisheries and Marine Science Research Centre; Fukushima Prefectural Research Institute of Fisheries Resources; Ibaraki Prefectural Fisheries Experimental Station, and Marine Ecology Research Institute

Summary

We estimated biomass of this stock by cohort analysis that was tuned by the abundance indices (CPUE for offshore trawl and coastal fisheries). It was estimated that the total biomass (total weight of fish of age 0 and above) had been stable in the range of 909 thousand to 1.4 million tons from the 1981 to 2011 fishing year (FY: from April to March of the next year), but it has tended to decrease since the 2012 FY. Total biomass of the 2019 FY was estimated at 866 thousand tons. Spawning stock biomass (SSB) was estimated in the range of 151 thousand to 322 thousand tons from the 1981 to 2009 FY, and suddenly increased in the 2010 FY. After peaking at 562 thousand tons in 2012 FY, SSB began to decrease, and recent SSB was estimated at 266 thousand tons in the 2018 FY and 302 thousand tons in the 2019 FY. Recruitment (number of age 0 fish) fluctuation within the range from 0.4 to 5.4 billion was estimated. The recruitment exceeded 3.0 billion was defined as “dominant year classes”, which was observed in the 1981, 1991, 1994, 1995, 2005 and 2007 year-classes. After 2007 FY, recruitment of the 2009 year-class was relatively abundant at 2.6 billion, whereas recruitment of the 2010 and 2015 year-classes was below 0.5 billion, which was the lowest level throughout all assessment periods. In recent years, recruitment of the 2014 and 2016 year-classes, which were ages 5 and 3, respectively in the 2019 FY, was relatively high. In addition, the recruitment of the 2017 year-class was estimated to be high based on the acoustic survey. Thus, it is considered that recent decreasing trend in total biomass and SSB will stop in the short term.

The “Scientific Meeting for Reference Points” which was held in April 2019 concluded to apply the Hockey stick (HS) model as the stock-recruitment (S-R) relationship to estimate MSY reference points of this stock. Here, SSB corresponding to the maximum sustainable yield (MSY) (SB_{msy}) was

estimated to be 220 thousand tons. Based on this reference point, current “stock status” was determined as follows; the SSB in the 2019 FY is above SBmsy, while the fishing mortality was below the level that can produce MSY (Fmsy). The “stock trend” is judged to be “stable” based on the SSB trend in past five years (2015-2019 FY).

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

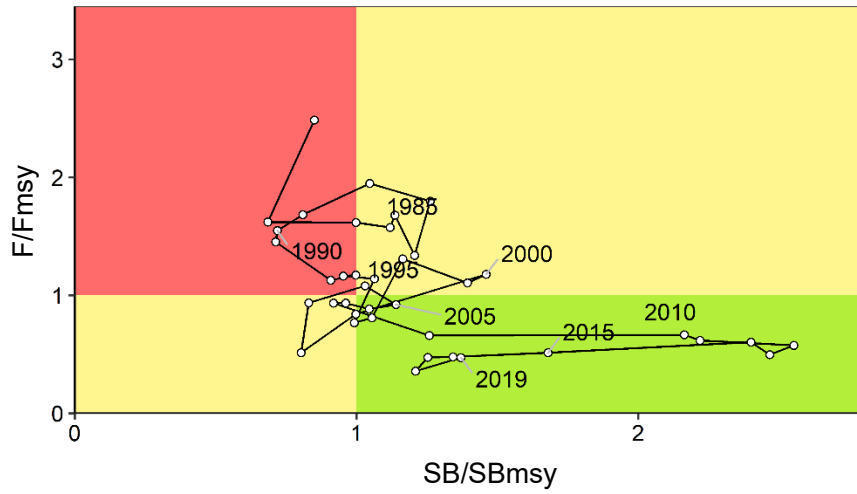
Item	Value	Explanation
Level that can produce MSY under the current environment		
SBmsy	220 thousand tons	Spawning stock biomass (SSB) corresponding MSY
Fmsy	Fishing mortality (F) that can produce MSY (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+) = (0.02, 0.02, 0.08, 0.14, 0.37, 0.61, 0.68, 0.68, 0.68, 0.68, 0.68)	
%SPR (Fmsy)	19%	%SPR equivalent to Fmsy
MSY	176 thousand tons	Maximum Sustainable Yield
SSB and F in the 2019 fishing year (FY)		
SB2019	302 thousand tons	SSB in the 2019 FY
F2019	F in the 2019 FY (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+) = (0.00, 0.00, 0.02, 0.08, 0.19, 0.17, 0.51, 0.21, 0.21, 0.38, 0.38)	
%SPR (F2019)	36.2%	%SPR equivalent to F in the 2019 FY
%SPR (F2015-2019)	36.1%	%SPR equivalent to the current F (2015-2019 FY)
Ratio to MSY		
SB2019/SBmsy	1.37	Ratio of the SSB in the 2019 FY to the SSB corresponding to MSY
F2019/Fmsy	0.47	Ratio of F in the 2019 FY to F that can produce MSY*

* Ratio between F in the 2019 FY (F2019) and Fmsy (%SPR-converted F value that gives the fishing mortality of Fmsy under the current selectivity).

S-R relationship: HS model (no autocorrelation)

Stock status and trend:

Level of SSB	Above SBmsy
Level of F	Below Fmsy
Trend in SSB	Stable



Fishing Year (FY)	Total Biomass (thousand tons)	Spawning Stock Biomass (SSB) (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation rate (%)
2016	815	296	100	0.48	12
2017	872	276	93	0.48	11
2018	1,035	266	76	0.36	7
2019	866	302	90	0.47	10
2020	995	270	110	0.47	11
2021	1,011	340	—	—	—

Values for 2020 and 2021 FY are based on future projections.

1. Data set

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

Data set	Data source and research
Catch in number at age (CAA) and annual catch	Landing at major ports by fishery (Hokkaido-Ibaraki [6] prefectures) Catch statistics of offshore trawl fisheries in Hokkaido (Logbook) (Fisheries Agency of Japan) Catch statistics of offshore trawl fisheries in the Northern Pacific (Logbook) (Fisheries Agency of Japan) Biological data collection survey (FRA, and Hokkaido-Ibaraki [6] prefectures)
Abundance index • Index for SSB • Recruitment index • Index for SSB	Walleye pollock egg and larva distribution survey (Dec.-Mar., FRA) • Ring net Spring quantitative survey of larval and juvenile of walleye pollock (Apr., FRA) • Quantitative echosounder • Frame trawl Walleye pollock acoustic and trawl survey (Jun.-Jul., FRA)* • Quantitative echosounder • Trawl Survey of walleye pollock in the Eastern Hokkaido Pacific (Nov., HRO) • Quantitative echo sounder • Trawl Survey of new recruitment of Pacific cod and walleye pollock and distribution of snow crab (Apr., FRA); Survey of new recruitment of Pacific cod and walleye pollock (Apr.-Dec., Iwate-Fukushima [3] prefectures) • Quantitative echosounder • Trawl Standardized CPUE at age for Hokkaido offshore trawl fishery: (FRA)** • Catch statistics of offshore trawl fisheries in Hokkaido (Logbook) • Biological data collection survey Survey of migration of Spawners of walleye pollock (August-September, HRO) • Quantitative echosounder • Trawl CPUE for anchored gillnet fishery of walleye pollock in Hokkaido (Hokkaido) • Abundance index ** based on the catch statistics (Logbook) • Standardized CPUE based on skipper's note**
Natural mortality (M)	0.25 per year is assumed for age 3 and older (Widrig (1954) method) 0.3, 0.35 and 0.4 are assumed for age 2, age 1 and age 0, respectively.
Fishing effort	Catch statistics of offshore trawl fisheries in Hokkaido (Logbook) (Fisheries Agency of Japan) Catch statistics of anchored gillnet fisheries of walleye pollock in Hokkaido (Hokkaido)

* denotes the recruitment index used for estimation of recruitment in the last three years

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

Catch in number at age (CAA) was calculated based on the age composition data which was estimated from biological sampling. The sampling was conducted by fishery and by period at major landing ports. For the CAA in the eastern Hokkaido offshore trawl fisheries (“offshore trawl”), we have obtained their samples from the operations by both two-type fishing gear since the 2016 FY; the otter trawl operation (“otter trawl”) and Danish sein operation (“Danish sein”). Before that, the sample only from “otter trawl” was used to estimate the CAA of offshore trawl (up to the 2015FY). Because the fishing year of this stock starts on the 1st of April and ends 31st of March of the following year, the 1st of April is assumed to be the date of birth (recruitment) for this stock in the assessment model.

2. Ecology of the stock

(1) Distribution and migration

This stock is distributed along the Japan’s Pacific coast from Joban to the four islands of the Northern Territories (Figure 2-1). The major spawning ground has been observed at/aroundn Funka Bay (Nishimura et al. 2002), and it has been thought that there are the other spawning grounds around Kinkazan, eastern Hokkaido, and Etorofu Island (Kodama et al.1988, Tsuji 1989, Hamatsu and Yabuki 1995, Velikanov 2013). Eggs that are spawned in the water aroundn Funka Bay are transported into the Funka bay, and survive during their larval and juvenile stages. Then, most of them migrate to the nursery area of eastern Hokkaido and the four islands of the Northern Territories (Nakatani 1988, Honda et al. 2003, Honda et al. 2004). Many of fish distributed in these areas during immature age migrate to the water aroundn Funka Bay after maturity for spawning. After spawning, they migrate back to the water of eastern Hokkaido and the four islands of the Northern Territories. Then, they repeat this spawning migration. Many of fish distributed on the Tohoku Pacific coast are also originated from the water aroundn Funka Bay (Kobayashi 1985, Kanamaru 1989). It is suggested that, during the 1980s, when the Oyashio current was strong, recruitment was relatively stable because the Tohoku water had fulfilled a function as good nursery ground for this stock (Shida et al. 2007).

(2) Age and growth

Fork length (as of April 1) and body weight (average of the fishing seasons) of each age are shown in Figure 2-2. This stock reaches 40 cm at the age 4 and 50 cm at age 7. Their lifespan is still not clear, but the catch in the eastern Hokkaido area infrequently contains individual fish over age 20. The oldest fish in the Bering Sea is estimated to be age 28 (Beamish and McFarlane 1995).

(3) Maturity and spawning

Individual fish of this stock start to mature at the age 3, and most of them are mature at the age 4 (Figure 2-3). 50%-mature body length is 36 to 41 cm for female fish and 33 to 38 cm for male fish. It was suggested that the length at maturity affects annual density and growth status (Hamatsu and Yabuki 2007). Spawning season in the water aroundn Funka Bay that is the major spawning ground

is from December to March with the main spawning season in January and February (Maeda et al. 1981, Yoon 1981).

Factors of recruitment fluctuation of this stock are currently under research by the commissioned project from Fisheries Agency of Japan. It is suggested that a decadal-scale change in the ocean environment in the 1980s and 1990s influenced the stock-recruitment (S-R) structure of this stock (Hamatsu et al. 2004). It is also suggested that higher water temperature during winter (Funamoto 2007, Funamoto et al. 2013, 2014) and largert body length of larval fish (Funamoto et al. 2013) are important for the stronger year classes strength. Actually, in the year when water temperature arrownd Funka Bay was high during winter (in 1991, 1995 and 2000) and larva fish were large (in 2005 and 2007), strong year classes were observed. Conversely, in 2010 and 2011, when water temperature was low and larval fish were small, year class strength was week. However, there were some exceptions; the some year classes were week or not so strong even when high water temperature (e.g. 1997 year class) and large larval fish (e.g. 2008 year class) was observed. Further study is necessary to clarify the recruitment mechanisms related to water temperature and body length.

(4) Prey-predator relationships

Major prey items are crustaceans including euphausiid and copepod. Small fish, cuttlefish, sea-bottom crustaceans and annelida are also fed (Maeda et al. 1983, Yamamura et al. 2002). Pacific cod, Kamchatka flounder and threadfin hakeling are reported to be predators in the eastern Hokkaido area. There is also cannibalism by larger fish (Yamamura 2004, Yamamura and Nobetsu 2011). It is also important as prey item of marine animals (Tamura and Fujise 2002). Because of the predation pressure through cannibalism and other species as described above, it is suggested that the larva size is possibly important for survive and produce higher recruitment abundance (Funamoto et al. 2013).

3. Status of fisheries

(1) Outline of fisheries

This stock is caught by not only offshore trawl fishery, but also coastal fishery including anchored gillnet fishery for walleye pollock (“gillnet”) and set net fishery. Offshore trawl fishery includes two-types operation; otter trawl and Danish seine. Catch in the waters around the four islands of the Northern Territories and Tohoku Pacific coast was also large in the 1980s but major fishing grounds in recent years are Oshima-Iburi and Tokachi-Kushiro of Hokkaido. In Oshima-Iburi, there are mainly coastal fishery, and the main fishing season is from October to January of the following year. In Tokachi-Kushiro, there are mainly offshore trawl fishery, and the main fishing season is from September to November. Large Russian trawlers are operating in the southeastern area of the Kurile Islands but the detail information are not obtained.

The fisheries which use this stock are managed under the TAC system. From 2010 FY, an additional rule was introduced to the TAC system, which is an advance use of the following year’s TAC whenever large population migrate into fishing grownd unpredicted in ABC calculation. In 2013, 2014, and 2015

FY, TAC was revised and expanded during the fishing seasons. In the water around Funka Bay, the regulation of input control of gillnet fishery (i.e. fishing season, catch and fishing effort) have been getting stronger through administrative guidance since the 2007 FY. Operation of offshore trawl fishery is also regulated with consideration of TAC.

Regarding catch in the Nemuro Peninsula, the catch in bottom set net and small set net fisheries in Nemuro excluding Ochiishi area is added to the catch of walleye pollock Nemuro Channel stock, while the rest is added to the catch of Japanese Pacific stock since the 2011 FY. All the catch in Nemuro before the 2010 FY was added to the catch of the Japanese Pacific stock.

(2) Changes in catch volume

Yearly changes of catch of this stock are shown in Figure 3-1 and Table 3-1. During the period of 2000-2004, the total catch rapidly decreased from over 200 thousand tons to 109 thousand tons in the 2002 FY, but later changed to increase and was stable in the range from 143 thousand to 175 thousand tons in the 2005-2014, through the effective regulation of TAC. During the recent years, total catch was on the decrease in the 2015-2018 and fell to 77 thousand tons in the 2018 FY. In the 2019 FY, total catch turned to increase and was reaching 90 thousand tons. Regarding the catch amount share rate by area, the share of southwestern Hokkaido (westward from Erimo) was larger than that of eastern Hokkaido in the 2004-2013 FY, but since the 2014 FY the share of eastern Hokkaido has been increase, overtaing that of southwestern Hokkaido. In the waters of the four islands of the Northern Territories, offshore trawl fishery had been conducted based on the Japan-Russia (Soviet Union) Offshore Fisheries Agreement. Quota of walleye pollock in these waters was greatly reduced by the Japan-Russia Fisheries Committee in 2015, then there has been no catch after the 2015 FY. South Korean vessels started operation in the 1987 FY with catch reaching 75 thousand tons in 1998, but the operation ended in the 1999 FY based on the new Japan-Republic of Korea fisheires agreement (Table 3-1).

Catch in number at age (CAA) is shown in Figure 3-2 and Appendix 4. In the 1980s, a large part of catch was ages 0 and 1 fish, which were mainly caught along Tohoku Pacific Coast. With decrease of catch in this area, catch of this age group has been small since the 1990s. While ages 2 to 3 fish accounted for a large part of the catch in the 1990s, age 4 and above fish account for the largest part of the catch since the period of 2005-2009 and the majority (62%) of the catch in the 2019 FY. The ratio of age 5 fish (2014-year class) and age 3 fish (2016-year class) was especially high (22% and 25%, respectively).

(3) Fishing effort

Offshore trawl fishery based in Hokkaido and gillnet fishery in the southwestern Hokkaido have a big share in the total catch. In the 2019 FY, offshore trawl fishery based in Hokkaido accounted for 62% of the total catch, while gillnet fishery in the southwestern Hokkaido accounted for 29%. Fishing efforts of these fisheries are shown in Figures 3-3, 3-4 and 3-5 and Table 3-2.

Yearly changes in the number of operations with positive catch of walleye pollock are shown in Figure 3-3 as representing the fishing effort of offshore trawl fishery based in Hokkaido. Regarding Danish seine operations in the southwestern Hokkaido, the number of operations has been around 4 thousand in the 2000-2012 FY, decreased with the scrapping of vessels in the 2013-2014 and has been around 2.5 thousand since the 2015 FY. Efforts of Danish seine in the eastern Hokkaido and the four islands of the Northern Territories was on the decrease since the 1980s but has been generally stable since the 2003 FY. Effort of Otter trawl in these areas was on the decrease in the 1980s and after, turned to be stable in the 2000-2006 FY and decreased again in the 2007-2016 FY. The number of operations has been 1.1 thousand to 1.3 thousand since the 2016 FY. The fishing effort targeting walleye pollock, which is defined as the number of operations where walleye pollock account for over 50% of the total catch a day, are shown in Figure 3-4. This yearly change of targeting fishing effort has been slightly decreasing since the 1996 FY for Danish seine in the southwestern Hokkaido, whereas slightly increasing through increases and decreases in the 1996-2004 FY for Danish seine in the eastern Hokkaido. Otter trawl in the eastern Hokkaido was slightly increasing after the 2000 FY, but it has been decreasing since the 2007 FY.

As fishing effort of gillnet fishery in the southwestern Hokkaido, Figure 3-5 shows monthly accumulated total numbers of the nets used by Minami Kayabe, Shikabe and Iburi central fishery cooperatives, based on the catch statistics of anchored gillnet fisheries of walleye pollock. Because specification of gillnet gear varies depending on the fishery cooperative, the number of nets is corrected with their length. The compilation covers only the 179th, the 182nd to 194th and the 197th the fishing grounds that are used almost every year. The cumulated period is from October to January because there was no operation from February and after in some fishing years due to restriction based on TAC. During the period since the 2003 FY, for which operation records are available, the total number of nets used slightly increased up to the 2007 FY, then rapidly decreased in the 2008-2010 FY and has been slightly decreasing afterwards.

4. Stock status

(1) Stock assessment method

We estimated total biomass from 1981 to 2019 FY by cohort analysis using Pope's approximation (1972). For calculation, we used the CAA and average weight at age, which were compiled for the fishing years since the 1981 FY, and estimated fishing mortality (F) at age, where the standardized CPUE at age for offshore trawl fishery based in Hokkaido (Age 3 to 7) and CPUE for coastal fishery (abundance index obtained from the catch statistics of anchored gillnet fisheries and the standardized CPUE obtained from skipper's note of cooperative gillnet fishermen) were used for tuning indices. For stabilization of estimation of F value at age, we used an estimation method to give a ridge penalty according to the F value (Ridge VPA; Okamura et al. 2017). (For details, see Appendix 2). Because ages 0 to 2 fish of this stock are not the main target of fishing, the reliability of estimated recruitments of the last three year-classes are low through cohort analysis. For this reason, up to the last year's

assessment, last three years recruitment was assumed by the average recruitment of 5 year before that. In this assessment, we estimated the abundance of last three year-classes (2017-2019 year classes) based on the results of age 1 survey abundance which was obtained by a walleye pollock acoustic trawl survey (Appendix 2).

(2) Changes in abundance indices

Abundance indices from gillnet fishery in the southwestern Hokkaido since the 2003 FY are shown in Figure 4-1. The abundance indices from gillnet fishery are calculated based on the catch and effort of gillnet fishery by month and fishing area, and aggregated these results by month. Because the abundance index of each month is thought to represent the fish stock passing the fishing ground during the month, we considered that the aggregated value by month (from October to January) indicates the spawning stock biomass (SSB) of the entire fishing season. This abundance index was on the decrease from the peak in the 2010 FY up to the 2016 FY. Then, the index remained almost stable but slightly increased from the 2018 FY to the 2019 FY.

For the 2010 FY and after, we collected skipper's note from 18 representing vessels of gillnet fleet of Oshima-Iburi fishery cooperatives and calculated standardized CPUE. For the standardization, operating position (longitude and latitude) of each operation day, number of nets used, catch and other data were used. The standardized CPUE is used as index of SSB, which tended to decrease up to the 2016 FY but recovered to the level of the 2015 FY in the 2017 and 2018 FYs. From the 2018 FY to 2019 FY, the index was increased slightly (Figure 4-2).

Standardized CPUE at age for offshore trawl fishery based in Hokkaido is shown in Figure 4-3. Here, the standardized CPUE at age (age 3 to 7) regarding catch in number per operation since 1999 was calculated by using delta-type two-step model, based on the daily catch report from fishing vessel (logbook), where we used operation data targeting walleye pollock (which is defined as the operations where walleye pollock account for over 50% of total catch of the day), and the age composition data of biological sampling from this fishery (for details, see Appendix 2 and the document on the standardized CPUE: FRA-SA2020-SC03-101). The CPUE of age 3 fish was high in the 2003 and 2008 FYs, which correspond to the 2000 and 2005 year-classes, respectively. The CPUE of age 4 fish was high in the 1999 and 2009 FYs, which correspond to the 1995 and 2005 year-classes, respectively. The CPUE of the 1995 and 2005 year-classes were high also at other ages: in the 2000 and 2010 FYs when they are at age 5; in the 2001 and 2011 FYs when they are at age 6; and in the 2002 and 2012 FYs when they are at age 7. Some year classes showed higher CPUE compared with others at older ages (g.g. the 2007 and 2009 year-classes). The 2010 year-class that had shown a low CPUE at age 3 in the 2012 FY has showed low CPUE later at every age. Regarding the recruited groups in the latest five years, the 2014 year-class that was caught as age 4 fish in the 2018 FY and as age 5 fish in the 2019 FY showed slightly higher CPUE compared with other year classes. The 2016 year-class showed the highest CPUE of age 3 fish among the year-classes in the latest five years, though the data is limited up to the time when they are at age 3.

(3) Trends in biomass and fishing mortality

Recruitment (number of age 0 fish), total biomass and SSB estimated by cohort analysis are shown in Figures 4-4, 4-5, 4-6 and 4-7 and Table 4-1 (for details, see Appendix 4).

Recruitment was estimated to have fluctuated between 0.4 billion and 5.4 billion fish since the 1981 FY (Figure 4-4, Table 4-1). If “dominant year class” is defined as the year class with recruitment exceeding 3.0 billion fish, the 1981, 1991, 1994, 1995, 2005 and 2007 year-classes are considered to be dominant year classes. The 1982, 1988, 1989 and 2000 year-classes also showed high recruitment between 2.7 billion and 2.9 billion fish and are considered to be strong year classes following the dominant year class. In recent years, abundance of the 2009 year-class was estimated relatively high, at 2.6 billion fish, whereas the recruitment of the 2010 and 2015 year-classes are below 0.5 billion, which is the lowest among all assessment periods. A dominant year class has not been observed since 2008. In recent years, the 2014 year-class that was age 5 fish in the 2019 FY and the 2016 year-class that was age 3 in the same season have relatively strong, that are estimated as 1.7 billion and 1.9 billion, respectively. Because of the reliability of last three year-classes abundance from cohort analysis (2017-2019 year classes), we estimated them through linear extrapolation based on the relationship between age 1 survey index obtained by the acoustic trawl survey and the abundance of age 1 fish estimated through cohort analysis. The 2017 year-class has a very high survey index, thus its recruitment is estimated to be 2.4 billion individuals. On the other hand, the 2018 and 2019 year-classes have low survey index, thus are estimated to be 1.0 billion and 0.9 billion individuals, respectively. The ratio of recruitment to SSB (recruitment per spawning: RPS) showed roughly similar fluctuation to that of recruitment (Figure 4-4).

Total biomass (total weight of fish aged 0 and above) and abundance (total number of fish aged 0 and above) were within the range of 909 thousand to 1.4 million tons and 4.1 billion to 9.3 billion individuals, respectively in the 1981-2011 FYs. The abundance tended to be high in the fishing seasons when dominant year class or strong year class appeared, while total biomass tended to increase one or two years later (Figures 4-5 and 4-6, Table 4-1). Total biomass turned to decrease in the 2012 FY and has been between 800 thousand and 900 thousand tons since the 2014 FY, except for the 2018 FY. Total biomass in the 2019 FY was estimated to be 866 thousand tons.

SSB corresponds to the matured part of the initial biomass in the fishing season. Therefore this SSB can be defined that the matured population spawned in winter of the previous year and produced the year class of the fishing season. Estimated SSB was stable within the range of 151 thousand to 322 thousand tons in the 1981-2009 FYs but rapidly increased in the 2010 FY and after, reaching 562 thousand tons in the 2012 FY (Figure 4-7, Table 4-1). Then, it turned to decrease and dropped to 266 thousand tons in the 2018 FY. In the 2019 FY, it was estimated to have increased to 302 thousand tons. Rapid increase in SSB from the 2010 FY to 2012 FY is attributed to the first spawning of the 2005 and 2007 year-classes, they are considered as dominant year classes. These dominant year classes are already aging; the 2005 and 2007 year-classes became age 10+ in the 2015 and 2017 FYs, respectively.

The 2009 year-class that is relatively abundant also became age 10+ in the 2019 FY. Decline in abundance and SSB in recent years is attributed to the decrease in these strong year classes, absence of dominant year class since 2008, and low abundance of the 2010, 2011 and 2015 year-classes, in particular.

In order to examine the influence of the value of natural mortality (M) used for the cohort analysis, we estimated total biomass and SSB in the 2019 FY when the M of age 3 and above (0.25) is changed by ± 0.05 (linked with the M of age 2 and below) as sensitivity analysis. Both total biomass and SSB in the 2019 FY increased with a larger value of M and decreased with a smaller value of M (Figure 4-8).

The yearly changes of fishing mortality (F) varies also depending on age, but the F value of every age fell since the 2010 FY. F of older fish at age 6 and above, in particular, has been stable at low values (Figure 4-9). The exploitation rate was around 20% up to 2000-2004 when the catch was over 200 thousand tons, but was stable within the range from 11 to 13% in the 2006-2012 FYs (Figure 4-10, Table 4-1). From the 2013 FY, when total biomass turned to decrease, the exploitation rate rose for two consecutive years, reaching 18% in the 2014 FY, but turned to decline with the decrease of catch since the 2015 FY and fell to 7% in the 2018 FY. For the 2019 FY, the exploitation rate is estimated to be 10%.

As described above, the latest three years' recruitment in previous assessment was average values of 5 year before that. In the assessment of last year, we assumed the recruitment in the 2016-2018 FYs to be 1.0 billion in number, which is the average of the recruitments in the 2011-2015 FYs. In the assessment of this year, by contrast, the recruitment in the 2016 FY is estimated by cohort analysis, and is revised upward to 1.94 billion fish. The recruitment in the 2017 FY is also revised upward greatly to 2.39 billion but the recruitment in the 2018 FY does not show significant change, which are estimated based on the acoustic survey in this year's assessment. Estimated total biomass in the 2016 to 2018 FYs were also revised upward in this year, as a result of the upward revision of the recruitments of the 2016 and 2017 year classes. Because these revisions are limited to fish of ages 0 to 3, the estimation of the SSB in the 2016 to 2018 FY is not influenced. Stock assessment of this year revised the SSB in the 2017 and 2018 FYs downward by 5 thousand tons from the assessment result of the previous year, but this is considered to be caused by addition of the data of the 2019 FY.

Item	Value	Remarks
SB2019	302 thousand tons	SSB in the 2019 FY
F2019	Fishing mortality (F) in the 2019 FY (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+) = (0.00, 0.00, 0.02, 0.08, 0.19, 0.17, 0.51, 0.21, 0.21, 0.38, 0.38)	
U2019	10%	Exploitation rate in the 2019 FY

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

In order to compare the fishing mortality (F) considering the influence of selectivity, we made a comparison with the case with no fishing mortality, based on the spawning per recruitment (SPR). Figure 4-11 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. Since the 1981 FY, %SPR showed an overall increase although there were some fluctuations. %SPR has been over 30% since the 2011 FY and increased to 42% in the 2018 FY. %SPR of 2019 FY is estimated to be 36%. The current fishing mortality, which is the %SPR calculated from the average F value of the latest 5 years (from the 2015 to 2019 FYs), was 36.1%.

Figure 4-12 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 can produce the maximum sustainable yield (MSY) (F_{msy}) (Sakai et al. 2019) at the "Scientific Meeting on Reference Points" held in April 2019. F_{msy} described below corresponds to 19% when converted to %SPR. Selectivity of F_{msy} is based on the F value at age of the 2013-2017 FYs as estimated in the stock assessment in 2018. Because the plus group is expanded from age 8+ to age 10+ in the stock assessment in 2018, we set the selectivity for ages 8, 9 and 10+ to the value of the previous selectivity for age 8+. For the average weight at age, we also used the value of F_{msy} calculation and set the average weight at age for ages 8, 9 and 10+ to the value for age 8+ which was used for the calculation of F_{msy}. The current fishing mortality (F₂₀₁₅₋₂₀₁₉) is below F_{msy}, F_{30%SPR} and F_{0.1}.

Item	Value	Remarks
%SPR (F2019)	36.2%	%SPR in the 2019 FY
%SPR (F2015-2019)	36.1%	%SPR equivalent to the current fishing mortality (from 2015 to 2019 FY)

(5) S-R relationship

Figure 4-13 shows the relationship between SSB (in weight) and recruitment (in the number of individuals) (S-R relationship). The “Scientific Meeting on Reference Points” mentioned above concluded to apply the Hockey-stick (HS) model for the S-R relationship of this stock (Sakai et al. 2019). Here, parameters of HS model were estimated based on the SSB and recruitment from 2018 stock assessment, using the least squares method for optimization. The model did not consider residual autocorrelation of the recruitment. The parameters for the model are shown in the table below. The break point of the HS model is at SSB of 151 thousand tons (parameter b of the table below). With SSB above this level, recruitment of around 1.9 billion individuals is expected on average.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey stick (HS)	Least squares method	No	12.455	150,944	0.532

Here, parameter “a” is the slope of the HS model of S-R curve from the origin to the break point, and “b” is the SSB (tons) at the break point.

(6) Level that can produce MSY under the current environment

The table below shows the estimates of the SSB corresponding to MSY (SBmsy) and fishing mortality that can produce MSY (Fmsy) under the current environment (since the 1981 FY), which are presented at the “Scientific Meeting on Reference Points” mentioned above (Sakai et al. 2019).

Item	Value	Remarks
SBmsy	220 thousand tons	SSB corresponding to MSY
Fmsy	Fishing mortality (F) that can produce MSY (Fmsy) (ages 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+) = (0.02, 0.02, 0.08, 0.14, 0.37, 0.61, 0.68, 0.68, 0.68, 0.68, 0.68)	
%SPR (Fmsy)	19%	%SPR equivalent to Fmsy
MSY	176 thousand tons	Maximum Sustainable Yield

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

A Kobe plot (Kobe chart) based on SSB corresponding to MSY (SBmsy) and fishing pressure that can produce MSY (Fmsy or Umsy) is shown in Figure 4-14 and Appendix 6. The ratio (F/Fmsy) of fishing mortality (F) is the ratio of the %SPR-converted F value that gives the fishing mortality of Fmsy under the selectivity of the year to the F value of each year. Historically, the F has been below Fmsy since the 2001 FY, except for the 2004 FY. The F in the 2019 FY is about half (0.47 times) of Fmsy. SSB has been above SBmsy since the 2009 FY. SSB in the 2019 FY was 1.37 times of SBmsy. The trend of SSB is judged to be “stable” based on the SSB trend in past five years (2015-2019 FYs).

Item	Value	Remarks
SB2019/SBmsy	1.37	Ratio of the SSB in the 2019 FY to the SSB corresponding to MSY
F2019/Fmsy	0.47	Ratio of F in the 2019 FY to F that can produce MSY*

* Ratio between F in 2019 FY (F2019) and Fmsy (%SPR-converted F value that gives the fishing mortality of Fmsy under the current selectivity).

Level of SSB	Above SBmsy
Level of F	Below Fmsy
Trend in SSB	Stable

5. Stock assessment summary

Biomass of this stock has been stable without a big drop since the 1981 FY and the SSB in the 2019 FY is above the level corresponding to MSY. Because biomass of this stock tends to increase after the appearance of a dominant/strong year class, it is necessary to ensure sustainable use by continuing to maintain the SSB at an appropriate level which can produce dominant/strong year classes. The fishing mortality on this stock is below the level that can produce MSY, and there is no concern of the stock status.

In the most recent 10 years, dominant year class has not observed, while some year classes, including the 2010, 2011 and 2015 year-classes, had particularly low recruitment, which caused a continued decrease in both total biomass and SSB. However, because the recruitment of the 2016 year-class is estimated to be relatively high, and recruitment of the 2017 year-class is also considered to be high based on the survey, it is considered that recent decreasing trend in total biomass and SSB will stop in the short term. It is expected that the use of these year classes with appropriate fishing mortality will maintain and recover the biomass (Appendix 8).

6. Others

As a management measure other than TAC, body length restriction (body length 30 cm or full length 34 cm) based on a fisheries management agreement is implemented for protection of juveniles in Hokkaido. Under this agreement, when the fish smaller than the length limit were caught over 20% of total catch, evacuate from the fishing ground was required for the fishing vessel. As a consequence, the catch of fish aged 0 to 2 tends to be very small in Hokkaido. The protection of juveniles fish is considered to be effective for ensuring SSB, thus this fisheries management agreement is desirable to continue. Biomass of this stock tends to increase after the appearance of dominant/strong year class. It is important to maintain the SSB which can produce such year classes in the future.

7. References

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(Authors: Osamu Sakai, Masayuki Chimura, Mitsuhiro Ishino, Mami Kawamura, Yoji Narimatsu, Kazuhiro Sadayasu)

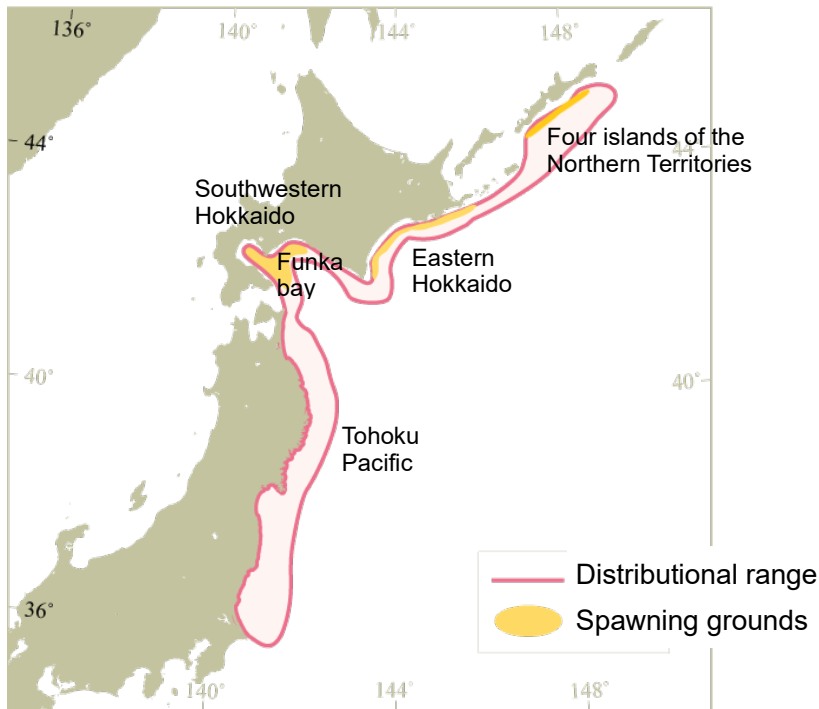


Figure 2-1. Distributional range and spawning grounds of Walleye Pollock Japanese Pacific stock
 Reprinted from Honda et al. (2004)

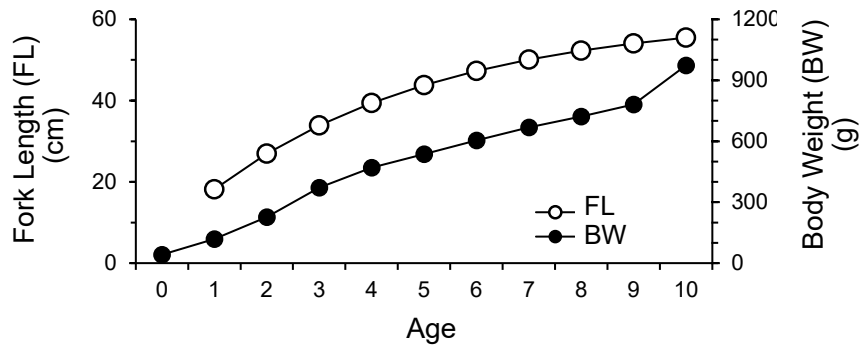


Figure 2-2. Age and Growth (Body weight of age 10 is the average of age 10+)

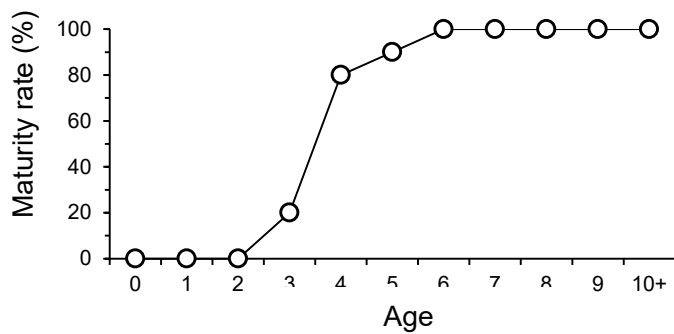


Figure 2-3. Maturity rate at age

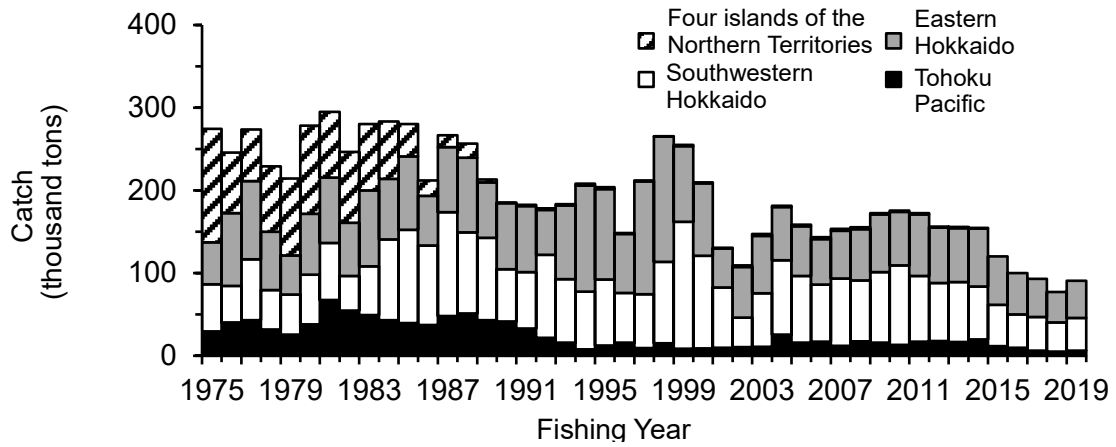


Figure 3-1. Catch by area

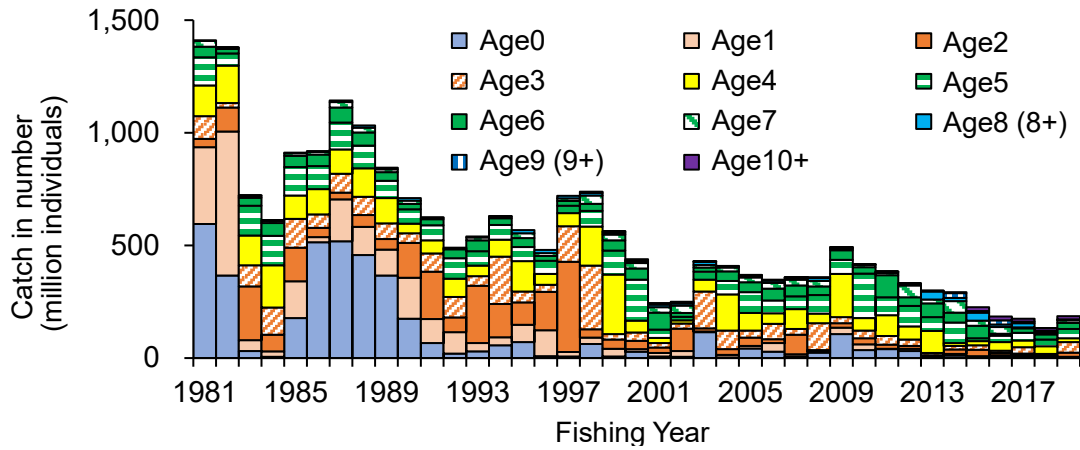


Figure 3-2. Catch in number at age (CAA)

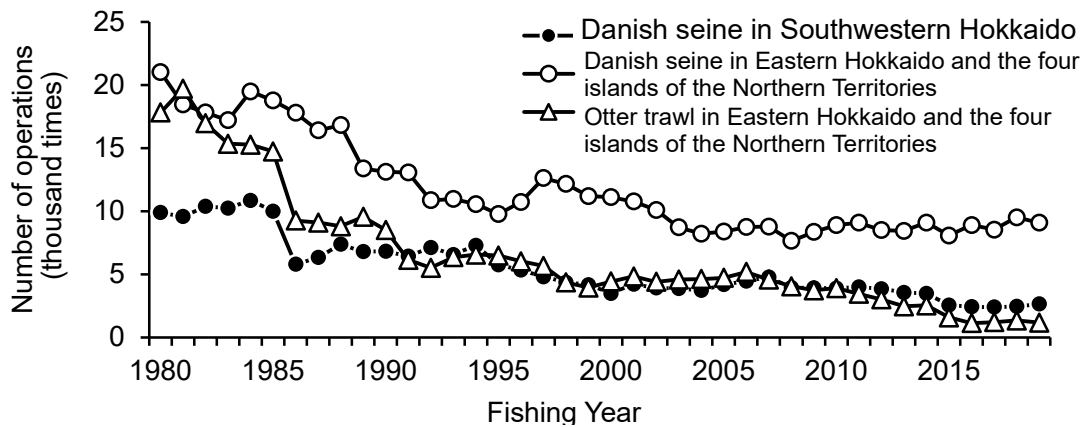


Figure 3-3. Number of operations with positive catch of Walleye Pollock in offshore trawl fishery based in Hokkaido

Based on the catch statistics aggregated value by month, by vessel, and by fishing ground

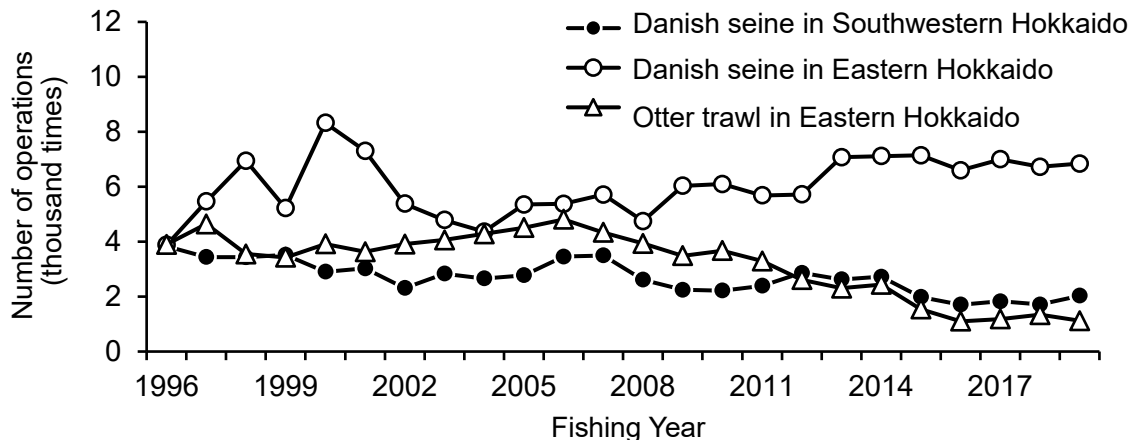


Figure 3-4. Number of operations in offshore trawl fishery based in Hokkaido, where walleye pollock account for over 50% of the total catch of the day (defined as “targeting”) Based on the catch statistics aggregated value by day, by vessel and by fishing ground

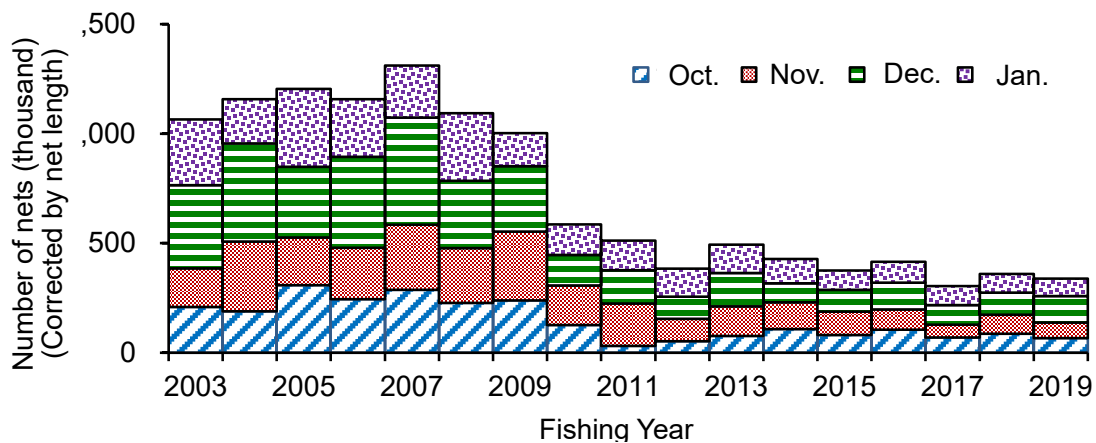


Figure 3-5. Effort of anchored gillnets for walleye pollock in the southwestern Hokkaido

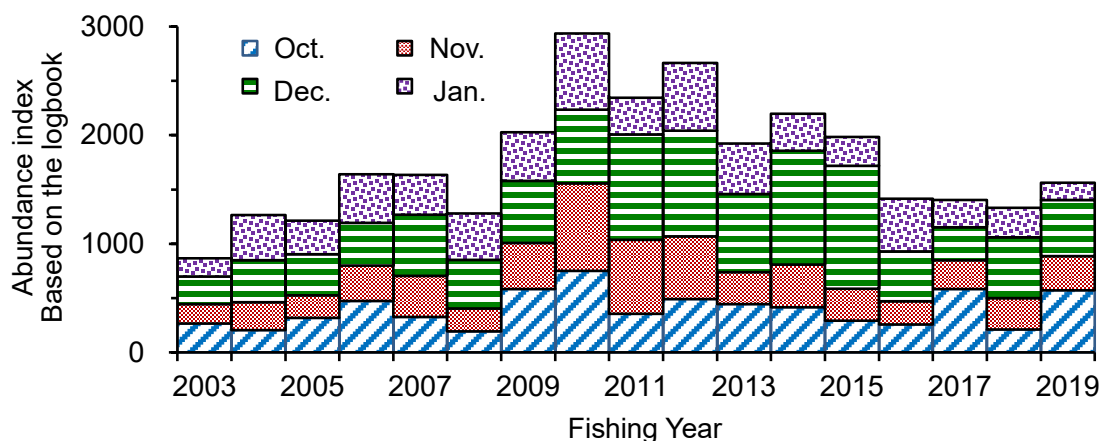


Figure 4-1. Abundance index of anchored gillnet fishery for walleye pollock in the southwestern Hokkaido calculated based on catch statistics (logbook)

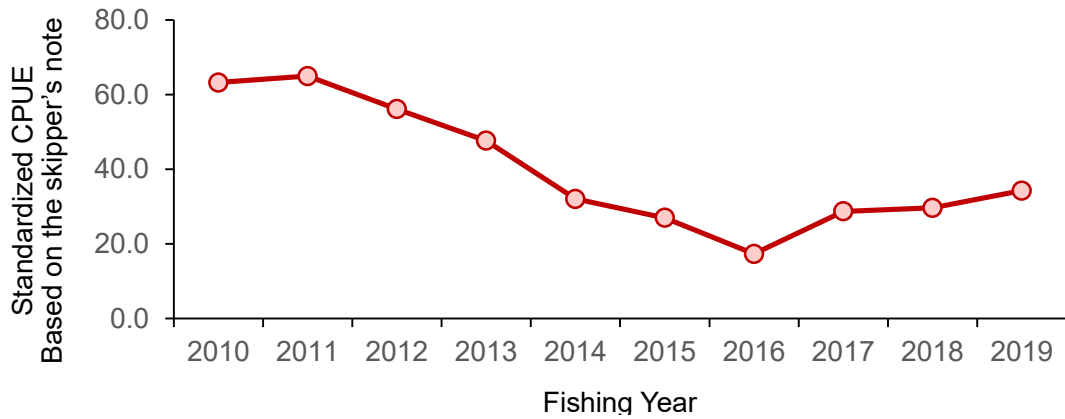


Figure 4-2. Standardized CPUE for anchored gillnet fishery for walleye pollock in the southwestern Hokkaido based on the skipper's note

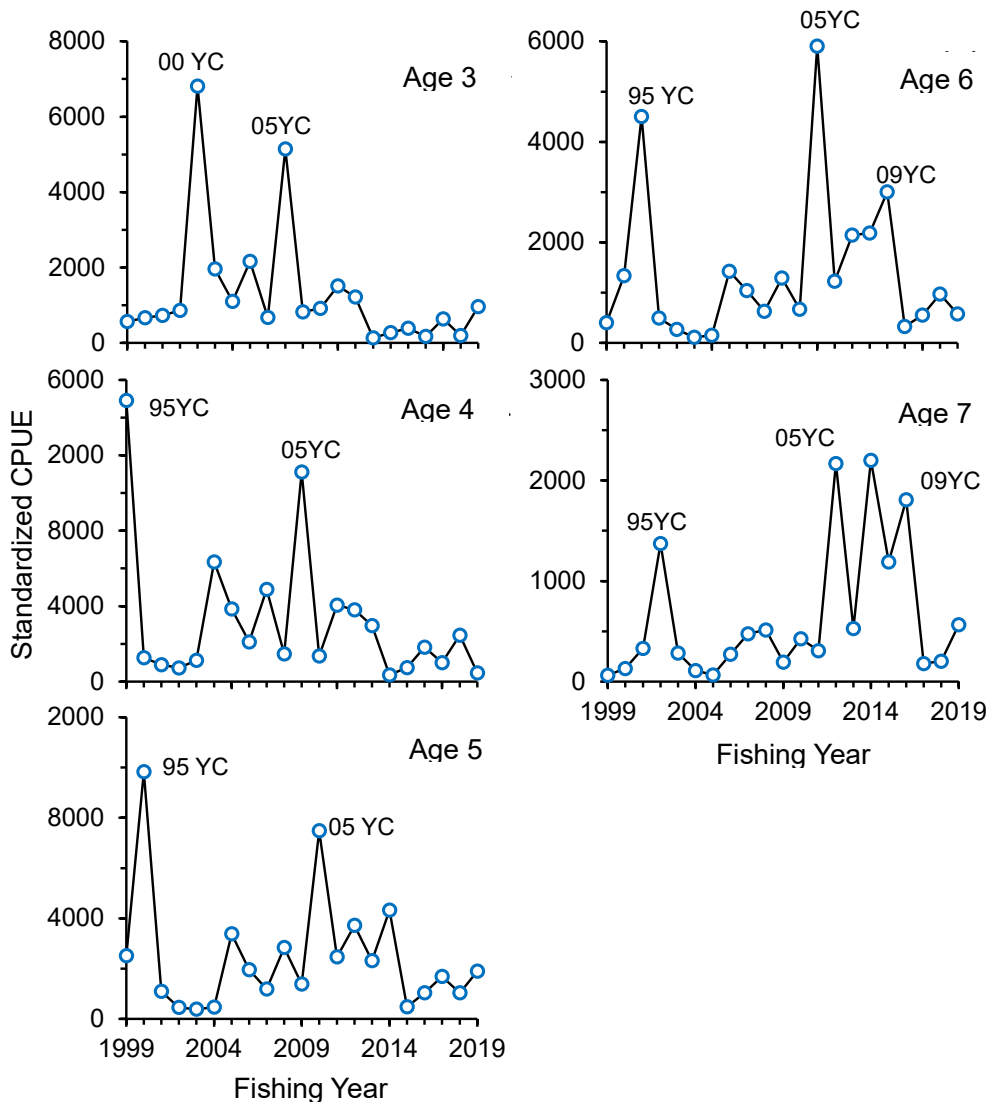


Figure 4-3. Standardized CPUE at age for offshore trawl fishery based in Hokkaido

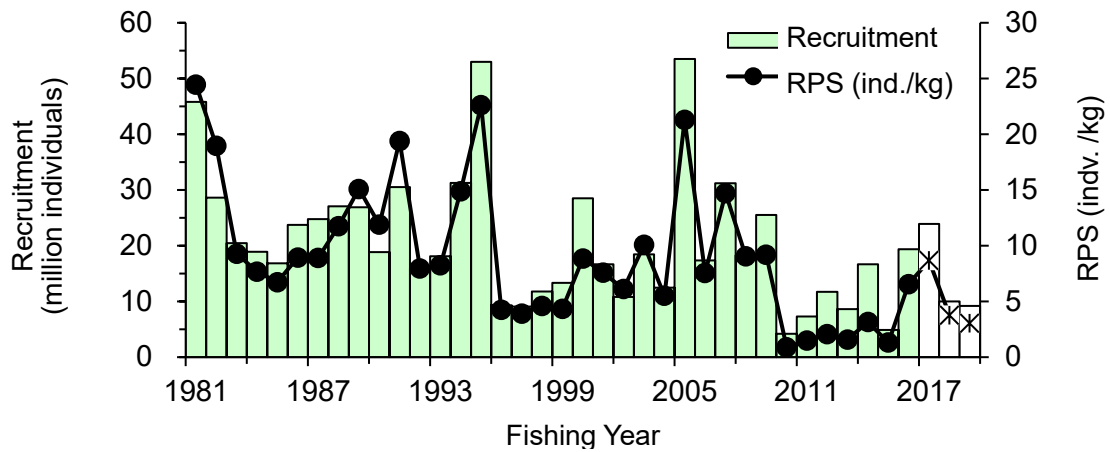


Figure 4-4. Yearly changes in recruitments (number of age 0 fish) and RPS

RPSs corresponding to the recruitment that is estimated based on the survey (white spaces) are indicated by a * mark.

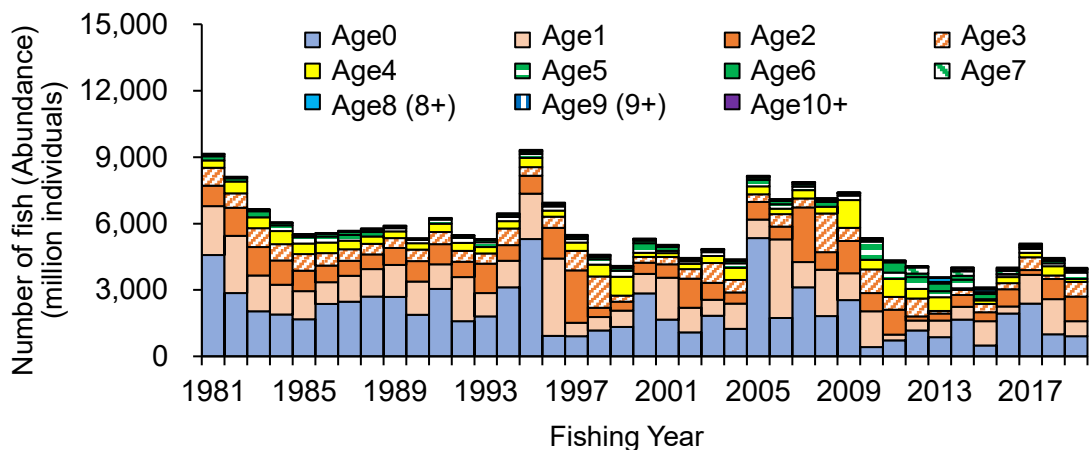


Figure 4-5. Yearly changes in the number of fish (abundance) at age

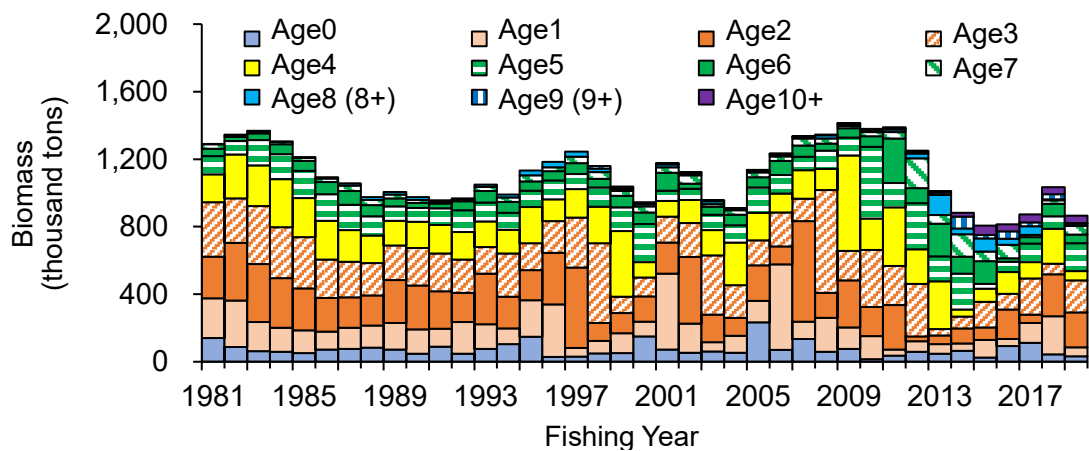


Figure 4-6. Yearly changes in Biomass (stock in weight) at age

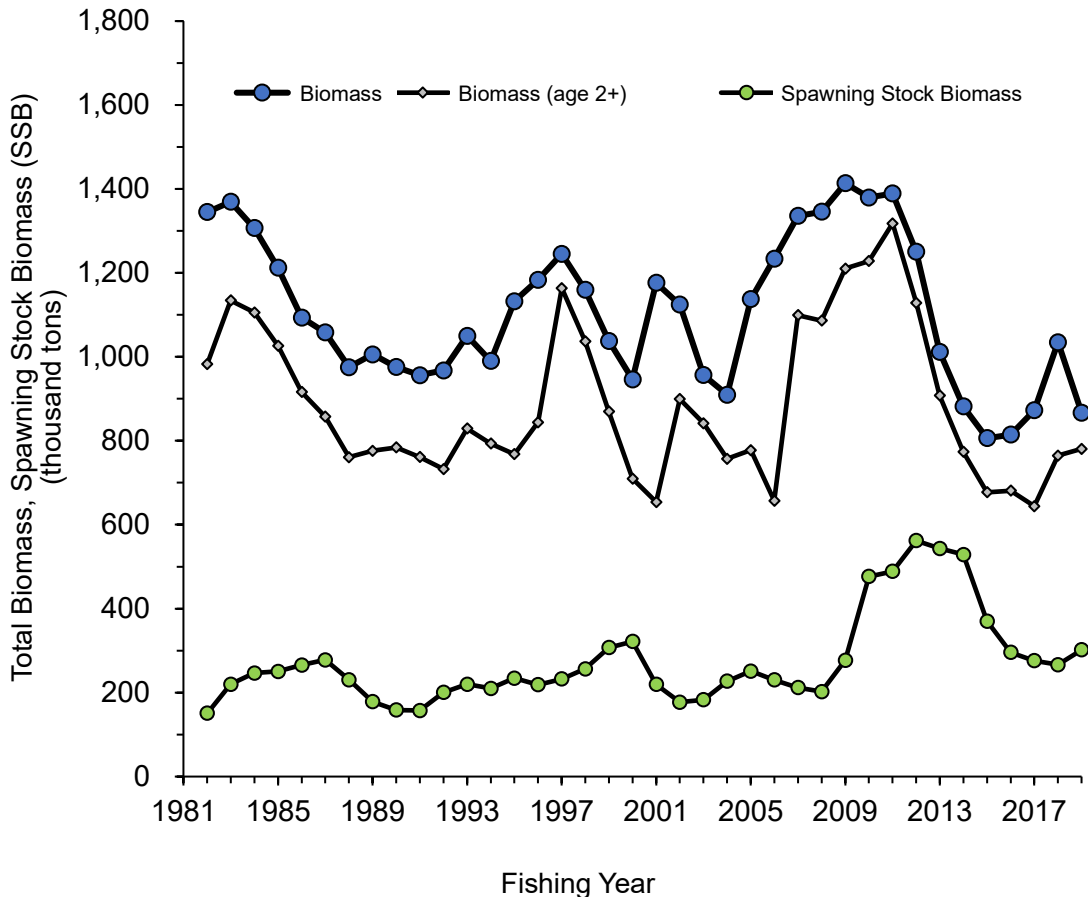


Figure 4-7. Yearly changes in total biomass (total weight of age 0+), biomass of age 2+, and Spawning Stock Biomass (SSB)

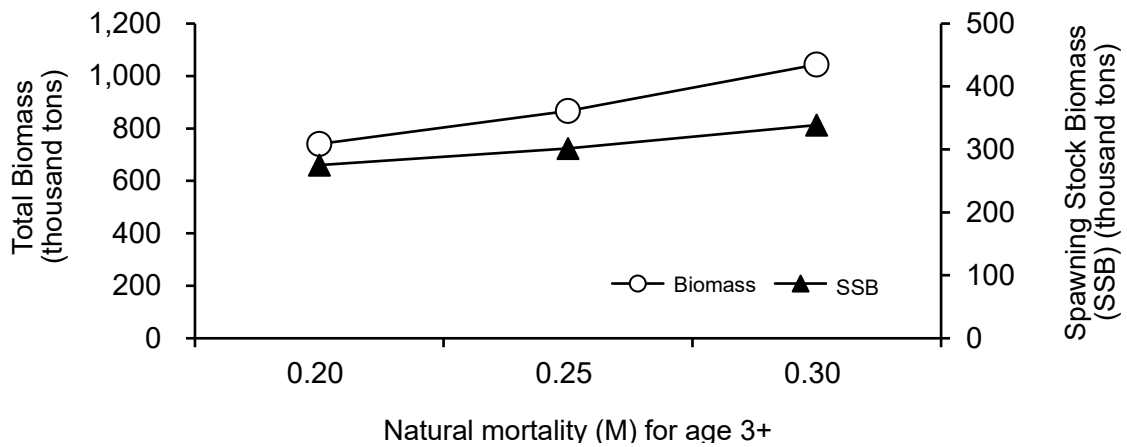


Figure 4-8. Influence of natural mortality (M) on total biomass and SSB (total biomass and SSB in the 2019 FY)

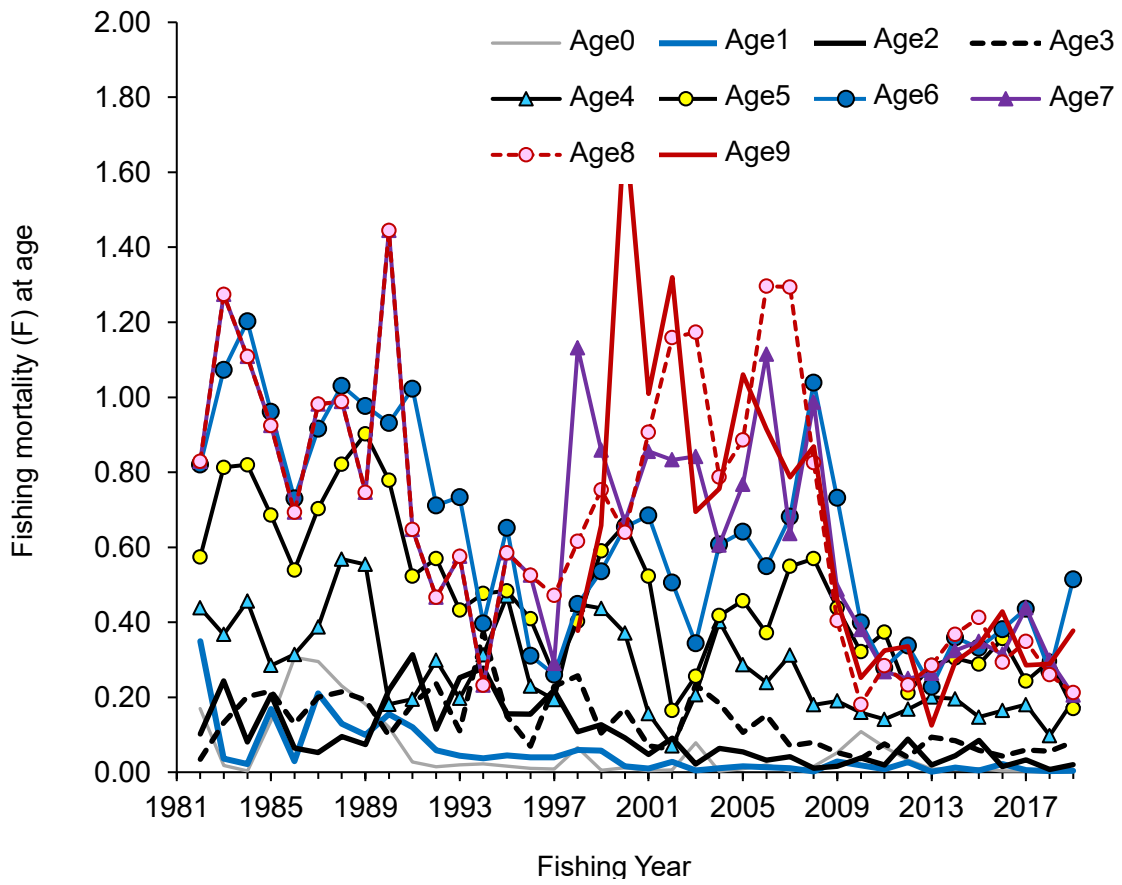


Figure 4-9. Yearly changes in Fishing mortality (F) at age
 The F of age 10+ is the same as the F of age 9

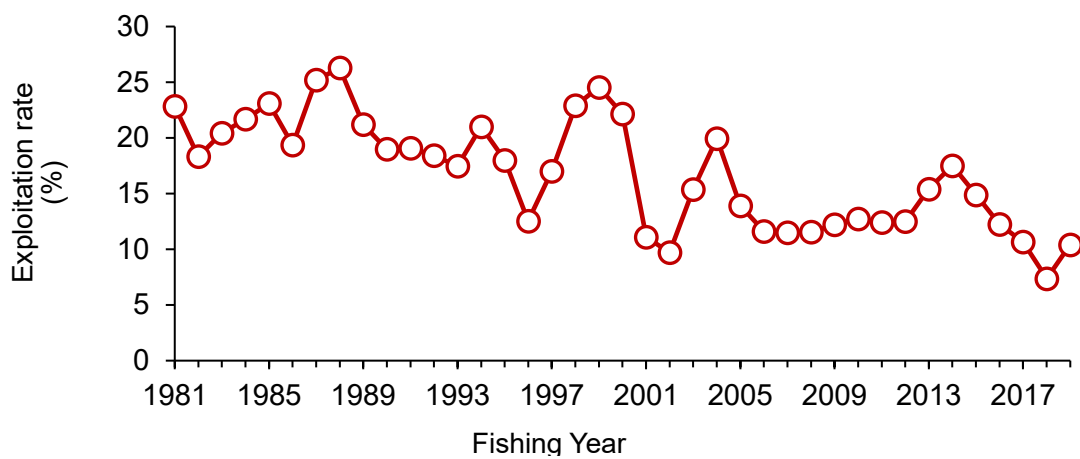


Figure 4-10. Yearly changes in exploitation rate

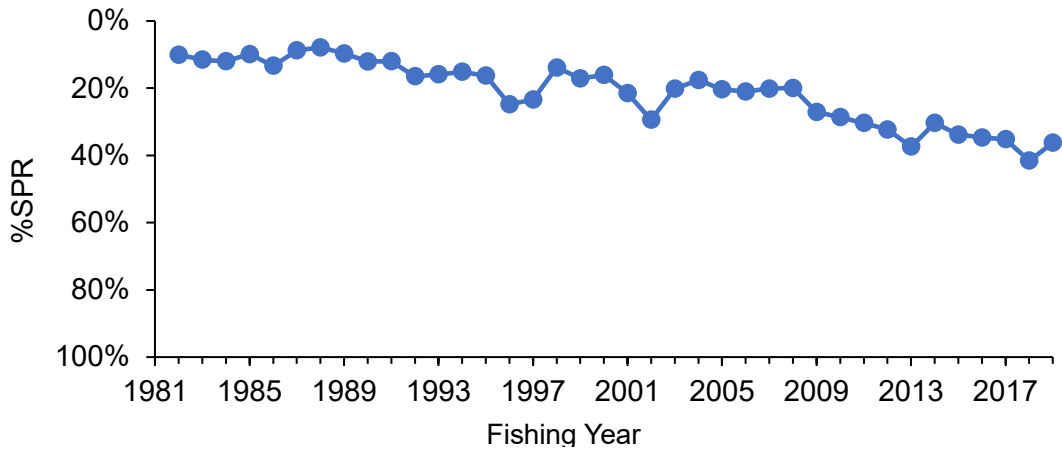


Figure 4-11. Yearly changes in %SPR at the F value in each fishing year

The %SPR indicates the ratio of the SPR (Spawning per average recruitment) in the absence of fishing mortality to the SPR assuming no catch. The higher (lower) the fishing mortality (F), the lower (higher) the %SPR.

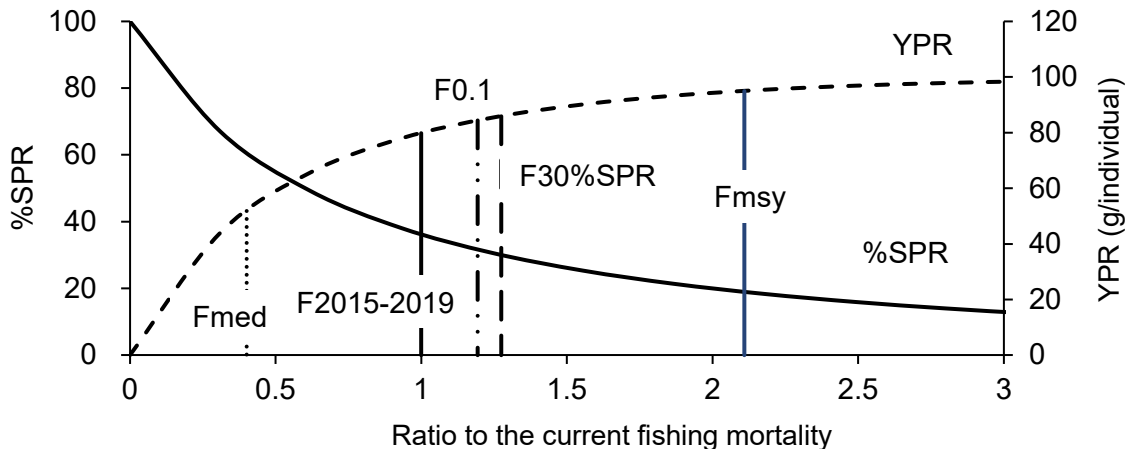


Figure 4-12. Relationship between YPR and %SPR for the current fishing mortality

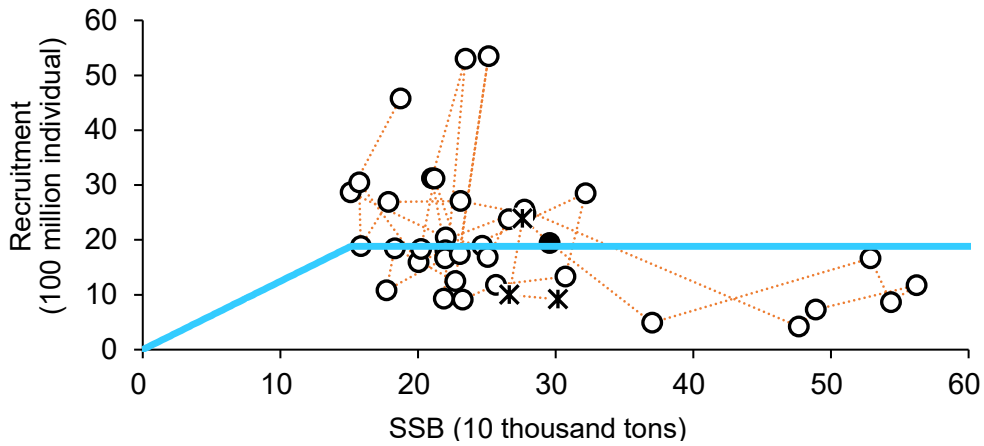


Figure 4-13. Relationship between SSB and recruitment (HS model of S-R relationship)

The blue line indicates the HS model of S-R relationship applied at the "Scientific Meeting on Reference Points" held in April 2019 (Sakai et al. 2019). Recruitment marked with asterisk (*) are estimates from survey. Filled circle (●) indicates the 2016 year-class, which was newly estimated in the cohort analysis from this stock assessment.

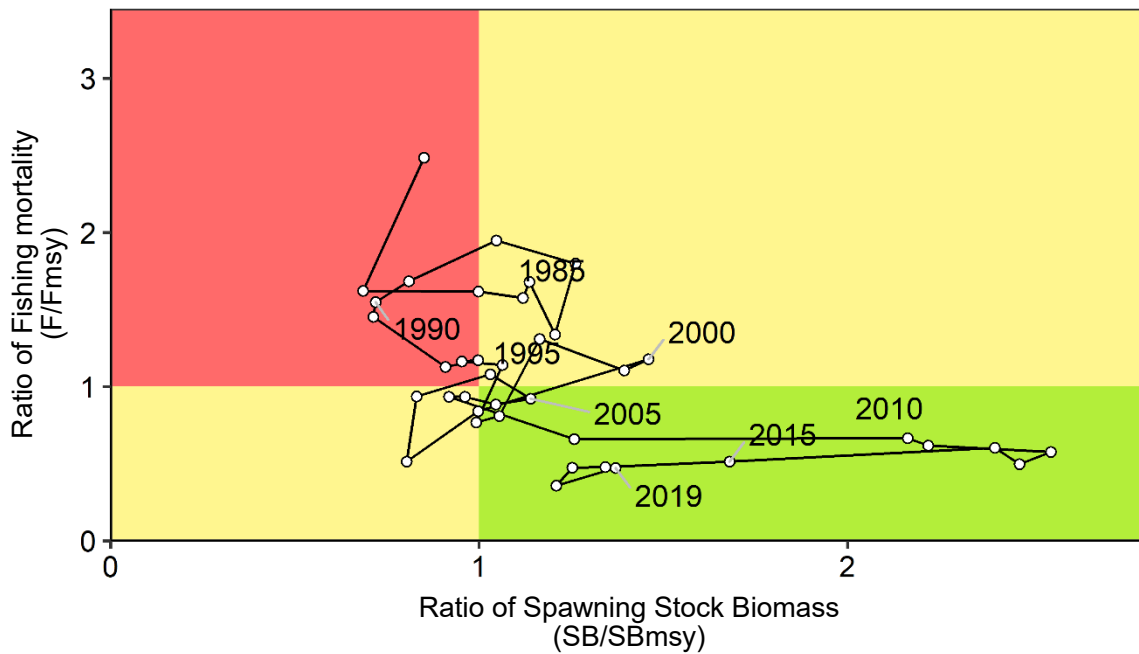


Figure 4-14. Relationship of the Spawning Stock Biomass (SSB) ratio to SBmsy and fishing mortality (F) ratio to Fmsy (Kobe plot)

Table 3-1. Catch of walleye pollock by area (aggregated by fishing year: tons)

Fishing Year	Tohoku Pacific			Southwestern Hokkaido			South Korean
	Total	Offshore trawl	Coastal	Total	Offshore trawl	Coastal	
1975	29,157			57,186			
1976	40,065			44,458			
1977	42,829			73,709			
1978	31,796			47,458			
1979	25,400			48,616			
1980	37,769			60,093			
1981	67,423	53,327	14,096	68,803	8,311	60,492	0
1982	54,378	41,886	12,492	42,075	7,955	34,120	0
1983	49,258	38,304	10,954	58,815	8,205	50,610	0
1984	42,763	27,482	15,281	97,802	9,582	88,220	0
1985	39,477	29,388	10,089	112,697	13,233	99,464	0
1986	37,052	24,099	12,953	96,051	11,831	84,220	0
1987	47,845	36,053	11,792	125,863	14,215	97,395	14,253
1988	51,047	41,971	9,076	98,087	7,803	77,649	12,634
1989	43,007	35,475	7,532	99,528	9,987	81,837	7,704
1990	41,375	35,913	5,462	63,088	11,204	49,041	2,842
1991	32,788	28,361	4,427	68,169	14,745	53,424	0
1992	21,403	19,447	1,956	100,428	18,559	81,869	0
1993	15,734	14,347	1,387	76,792	14,312	62,480	0
1994	7,689	6,939	750	69,814	23,115	46,699	0
1995	12,222	11,526	696	79,766	24,725	55,041	0
1996	15,734	14,914	820	60,219	13,473	46,746	0
1997	9,078	8,662	416	65,201	13,339	51,861	0
1998	14,911	14,303	607	98,684	17,417	81,267	0
1999	8,293	7,591	702	153,609	29,195	124,414	0
2000	8,901	8,280	621	111,787	21,799	89,988	0
2001	9,403	9,048	355	72,872	19,947	52,925	0
2002	10,175	9,179	996	36,006	15,405	20,601	0
2003	10,813	8,736	2,077	64,749	19,866	44,883	0
2004	25,432	23,844	1,588	90,095	20,261	69,833	0
2005	15,839	14,045	1,793	80,401	19,885	60,516	0
2006	16,817	14,567	2,250	69,043	19,846	49,197	0
2007	11,716	10,791	925	81,395	27,072	54,323	0
2008	17,440	14,738	2,702	73,552	21,741	51,812	0
2009	15,847	14,070	1,777	85,251	19,305	65,945	0
2010	12,998	12,175	822	96,103	19,086	77,017	0
2011	16,781	16,304	477	79,577	19,846	59,731	0
2012	17,687	17,215	472	70,114	20,109	50,004	0
2013	16,400	15,293	1,108	72,467	20,244	52,223	0
2014	19,752	18,220	1,532	63,929	21,541	42,388	0
2015	11,428	10,778	650	49,908	16,024	33,885	0
2016	9,697	9,303	394	40,308	14,756	25,552	0
2017	6,134	5,681	453	40,615	9,234	31,381	0
2018*	4,911	4,537	374	35,155	10,554	24,601	0
2019*	6,221	5,472	750	39,385	12,362	27,023	0

Fishing Year is from April to March. The geographical range of coastal fishery in Tohoku Pacific is Ibaraki prefecture (Hashikami town)-Aomori prefecture (Oma town); before 2001 FY, the catch amount is aggregated by calendar year. The geographical range of coastal fishery in Southwestern Hokkaido is Shiriuchi Town – Erimo Town. The catch amounts of 2018 and 2019 FYs are preliminary values (*).

Table 3-1 (continued). Catch of walleye pollock by area (aggregated by fishing year: tons)

Fishing Year	Eastern Hokkaido			Four islands of Northern Territory		All area		Total
	Total	Offshore trawl	Coastal	South Korean	Offshore trawl	Japanese	South Korean	
1975	50,893				137,145	274,381		274,381
1976	87,657				73,591	245,771		245,771
1977	94,744				62,291	273,573		273,573
1978	70,766				78,939	228,959		228,959
1979	47,027				93,002	214,045		214,045
1980	73,666				106,621	278,149		278,149
1981	78,986	75,326	3,660	0	79,553	294,765	0	294,765
1982	64,197	60,012	4,185	0	85,856	246,506	0	246,506
1983	91,975	83,470	8,505	0	79,868	279,916	0	279,916
1984	73,093	67,031	6,062	0	69,696	283,354	0	283,354
1985	88,621	79,431	9,190	0	39,124	279,919	0	279,919
1986	60,113	53,349	6,764	0	18,517	211,733	0	211,733
1987	78,658	58,540	4,700	15,418	14,106	236,801	29,671	266,472
1988	90,147	64,198	3,400	22,549	17,089	221,187	35,183	256,370
1989	66,955	55,894	2,369	8,692	3,647	196,741	16,396	213,137
1990	79,786	61,399	3,011	15,376	1,011	167,041	18,218	185,259
1991	79,748	61,724	2,621	15,403	1,603	166,906	15,403	182,309
1992	54,515	32,396	3,133	18,986	1,851	159,211	18,986	178,197
1993	89,097	54,609	1,768	32,721	1,751	150,653	32,721	183,374
1994	128,104	68,152	2,937	57,015	2,433	151,026	57,015	208,041
1995	109,375	44,689	7,841	56,845	2,350	146,869	56,845	203,714
1996	71,292	31,803	4,080	35,409	1,037	112,874	35,409	148,283
1997	136,633	86,156	3,711	46,766	1,007	165,153	46,766	211,919
1998	151,551	71,301	5,725	74,525	313	190,934	74,525	265,459
1999	91,398	77,005	5,316	9,076	1,425	245,649	9,076	254,725
2000	87,840	81,155	6,685	0	1,041	209,568	0	209,568
2001	47,346	42,487	4,859	0	805	130,426	0	130,426
2002	61,130	59,606	1,524	0	1,757	109,069	0	109,069
2003	69,406	67,457	1,949	0	2,146	147,114	0	147,114
2004	64,149	58,487	5,662	0	1,759	181,435	0	181,435
2005	60,145	53,442	6,703	0	1,883	158,268	0	158,268
2006	54,954	50,467	4,487	0	2,432	143,246	0	143,246
2007	58,009	53,384	4,625	0	2,430	153,549	0	153,549
2008	61,852	57,297	4,554	0	2,409	155,254	0	155,254
2009	69,574	63,756	5,818	0	1,828	172,499	0	172,499
2010	64,889	60,283	4,606	0	1,485	175,474	0	175,474
2011	74,303	70,549	3,754	0	1,579	172,239	0	172,239
2012	67,127	61,911	5,216	0	1,244	156,172	0	156,172
2013	65,437	60,959	4,478	0	1,519	155,823	0	155,823
2014	70,256	65,424	4,832	0	400	154,337	0	154,337
2015	58,667	55,812	2,855	0	0	120,003	0	120,003
2016	49,742	46,601	3,141	0	0	99,748	0	99,748
2017	46,170	42,563	3,607	0	0	92,919	0	92,919
2018*	36,884	34,965	1,919	0	0	76,950	0	76,950
2019*	44,786	43,300	1,485	0	0	90,392	0	90,392

Fishing Year is from April to March. The geographical range of coastal fishery in Eastern Hokkaido is Syoya Erimo town – Nemuro city; bottom set net and small fixed net fisheries in Nemuro city excluding the Ochishi area has been removed since 2011 FY. The catch amounts of 2018 and 2019 FYs are preliminary values (*).

Table 3-2. Catch and efforts of offshore bottom trawl fishery based in Hokkaido

Fishing Year	Fishing operations which have positive catch of walleye pollock					
	Southwestern Hokkaido		Eastern Hokkaido and Four islands of Northern Territory			
	Danish seine		Danish seine		Otter trawl	
	Catch (thousand tons)	Effort (thousand op.)	Catch (thousand tons)	Effort (thousand op.)	Catch (thousand tons)	Effort (thousand op.)
1980	13.3	9.9	57.7	21.0	96.2	17.8
1981	7.9	9.6	35.4	18.5	121.2	19.7
1982	7.7	10.4	25.0	17.8	115.8	17.0
1983	7.8	10.3	25.4	17.2	114.8	15.4
1984	9.2	10.9	26.1	19.5	123.0	15.3
1985	12.5	10.0	21.8	18.8	96.4	14.7
1986	14.1	5.8	21.9	17.8	50.6	9.3
1987	13.2	6.3	20.6	16.4	50.4	9.1
1988	7.5	7.4	17.9	16.8	61.7	8.8
1989	9.4	6.8	9.5	13.4	48.9	9.6
1990	10.0	6.8	9.9	13.1	51.4	8.5
1991	13.3	6.4	19.8	13.1	42.5	6.1
1992	16.7	7.1	11.2	10.9	22.5	5.5
1993	13.3	6.6	17.0	11.0	38.9	6.4
1994	21.9	7.3	22.2	10.6	47.4	6.6
1995	24.2	5.8	15.3	9.8	30.3	6.5
1996	13.0	5.3	8.1	10.7	24.4	6.0
1997	13.1	4.8	21.9	12.6	65.0	5.7
1998	16.5	4.4	27.7	12.2	43.6	4.4
1999	28.3	4.2	28.4	11.2	49.8	4.0
2000	21.6	3.5	39.4	11.1	42.5	4.4
2001	19.8	4.2	23.2	10.8	20.0	4.8
2002	15.2	3.9	26.3	10.1	35.0	4.4
2003	19.7	3.9	25.4	8.7	44.0	4.6
2004	19.9	3.7	21.3	8.2	38.7	4.6
2005	19.8	4.2	24.1	8.4	31.0	4.7
2006	19.7	4.5	23.4	8.8	29.3	5.2
2007	26.7	4.8	21.6	8.8	34.0	4.6
2008	21.7	4.0	26.4	7.7	32.9	4.1
2009	19.0	3.9	31.0	8.4	34.3	3.7
2010	19.0	3.9	31.2	8.9	30.3	3.9
2011	19.8	4.0	37.9	9.1	34.1	3.5
2012	20.1	3.9	38.0	8.5	24.8	3.0
2013	20.2	3.6	44.3	8.4	18.1	2.5
2014	21.5	3.5	45.4	9.1	20.3	2.5
2015	15.8	2.6	44.0	8.1	11.8	1.6
2016	14.7	2.4	36.7	8.9	9.9	1.1
2017	9.2	2.4	33.0	8.5	9.5	1.2
2018	10.5	2.5	26.7	9.5	8.3	1.3
2019*	12.4	2.7	33.6	9.1	9.7	1.2

Fishing Year is from April to March.

The catch and efforts of 2019 FY are preliminary values (*).

Table 3-2 (continued). Catch in, fishing efforts of, and CPUE for offshore bottom trawl fishery based in Hokkaido

Fishing Year	Fishing operations where walleye pollock account for over 50% of total catch of the day								
	Southwestern Hokkaido			Eastern Hokkaido					
	Danish seine			Danish seine			Otter trawl		
	Catch (thousand tons)	Effort (thousand op.)	CPUE (ton/op.)	Catch (thousand tons)	Effort (thousand op.)	CPUE (ton/op.)	Catch (thousand tons)	Effort (thousand op.)	CPUE (ton/op.)
1996	12.4	3.8	3.3	6.7	3.9	1.7	22.5	3.9	5.8
1997	12.4	3.4	3.6	19.5	5.5	3.6	64.4	4.6	13.9
1998	16.4	3.4	4.8	25.8	6.9	3.7	41.7	3.5	11.8
1999	28.2	3.5	8.0	26.8	5.2	5.1	48.8	3.4	14.3
2000	21.4	2.9	7.4	38.0	8.3	4.6	41.6	3.9	10.6
2001	19.5	3.0	6.5	21.3	7.3	2.9	19.4	3.6	5.3
2002	15.0	2.3	6.5	23.4	5.4	4.4	34.6	3.9	8.9
2003	19.3	2.8	6.8	22.7	4.8	4.7	43.7	4.1	10.8
2004	19.7	2.7	7.4	18.9	4.4	4.3	38.7	4.3	9.0
2005	19.3	2.8	6.9	22.0	5.3	4.1	31.0	4.5	6.9
2006	19.6	3.5	5.7	20.2	5.4	3.8	29.2	4.8	6.1
2007	26.4	3.5	7.5	18.2	5.7	3.2	33.9	4.3	7.8
2008	19.4	2.6	7.4	23.3	4.7	4.9	32.8	3.9	8.3
2009	16.6	2.2	7.4	28.6	6.0	4.7	34.2	3.5	9.8
2010	16.9	2.2	7.6	26.2	6.1	4.3	30.3	3.7	8.2
2011	17.6	2.4	7.3	31.5	5.7	5.5	34.1	3.3	10.4
2012	19.8	2.9	6.9	31.9	5.7	5.6	24.7	2.6	9.5
2013	20.1	2.6	7.7	41.3	7.1	5.8	18.0	2.3	7.8
2014	21.4	2.7	7.9	43.9	7.1	6.2	20.3	2.4	8.3
2015	15.2	2.0	7.7	42.5	7.1	6.0	11.8	1.5	7.6
2016	14.5	1.7	8.5	34.2	6.6	5.2	9.9	1.1	9.0
2017	9.0	1.8	4.9	31.5	7.0	4.5	9.5	1.2	8.1
2018	10.3	1.7	6.0	24.8	6.7	3.7	8.3	1.3	6.2
2019*	12.1	2.0	6.0	31.9	6.8	4.7	9.6	1.1	8.6

Fishing Year is from April to March.

The catch and efforts of 2019 FY are preliminary values (*).

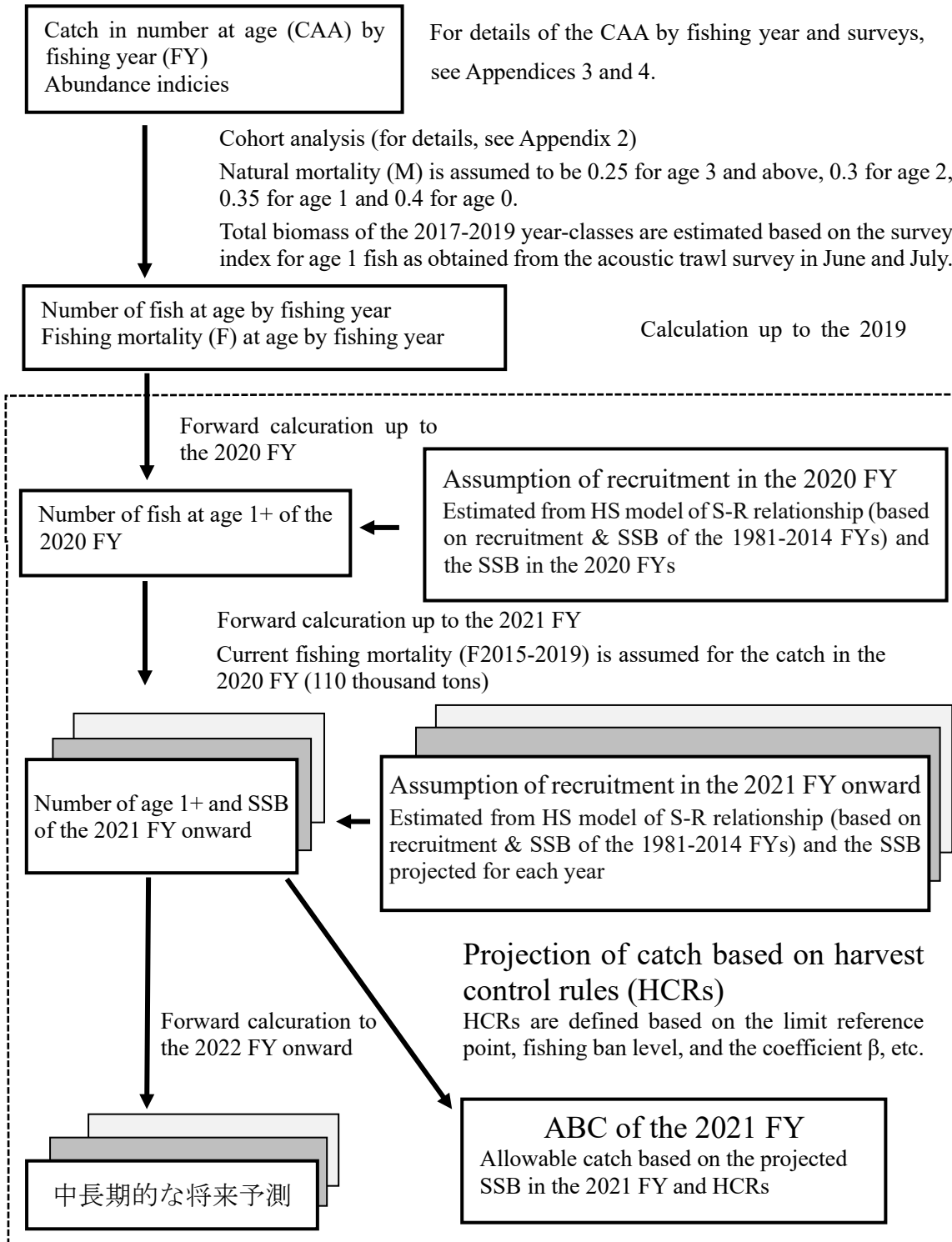
Table 4-1. Result of stock analysis

Fishing Year	Catch (thousand tons)	Biomass (thousand tons)	Biomass of age2+ (thousand tons)	SSB (thousand tons)	Recruitment Number of age0 (100 million indiv.)	Exploitation rate (%)	%SPR	Recruitment per spawning (indv./kg)
1981	295	1,291	915	187	45.8	23	7	24.4
1982	247	1,345	983	151	28.6	18	10	19.0
1983	280	1,369	1,134	220	20.4	20	11	9.3
1984	283	1,307	1,106	246	18.9	22	12	7.7
1985	280	1,212	1,026	250	16.9	23	10	6.7
1986	212	1,093	916	266	23.7	19	13	8.9
1987	266	1,058	857	278	24.8	25	9	8.9
1988	256	975	761	231	27.1	26	8	11.7
1989	213	1,006	776	178	26.9	21	10	15.1
1990	185	976	784	158	18.8	19	12	11.9
1991	182	956	761	157	30.5	19	12	19.4
1992	178	967	732	200	15.9	18	16	8.0
1993	183	1,050	829	220	18.1	17	16	8.2
1994	208	990	793	210	31.3	21	15	14.9
1995	204	1,132	768	234	53.0	18	16	22.6
1996	148	1,183	844	219	9.3	13	25	4.2
1997	212	1,245	1,164	232	9.1	17	23	3.9
1998	265	1,159	1,037	256	11.8	23	14	4.6
1999	255	1,038	869	307	13.3	25	17	4.3
2000	210	946	709	322	28.5	22	16	8.9
2001	130	1,176	654	220	16.6	11	21	7.6
2002	109	1,124	899	177	10.8	10	29	6.1
2003	147	956	842	183	18.4	15	20	10.1
2004	181	909	757	227	12.5	20	18	5.5
2005	158	1,137	778	251	53.5	14	20	21.3
2006	143	1,234	657	230	17.4	12	21	7.5
2007	154	1,336	1,099	212	31.2	11	20	14.7
2008	155	1,346	1,086	202	18.3	12	20	9.1
2009	172	1,413	1,210	277	25.5	12	27	9.2
2010	175	1,379	1,228	477	4.2	13	29	0.9
2011	172	1,389	1,318	489	7.3	12	30	1.5
2012	156	1,250	1,129	562	11.7	12	32	2.1
2013	156	1,012	908	543	8.6	15	37	1.6
2014	154	882	773	529	16.6	18	30	3.1
2015	120	806	677	370	4.9	15	34	1.3
2016	100	815	681	296	19.4	12	35	6.6
2017	93	872	644	276	23.9	11	35	8.7
2018	76	1,035	765	266	10.0	7	42	3.7
2019	90	866	781	302	9.2	10	36	3.0

Fishing Year is from April to March.

Recruitment of age 0 fish in the 2017-2019 FYs were assumed based on the survey data. Total biomass, exploitation rate, %SPR and RPS in the 2017-2019 FYs affected by these assumed values.

Appendix 1. The workflow of stock assessment



Note: Process in the above dashed box is going to be involved according to the discussions on reference points and HCRs at the Conference of Stock Management Policy (Stakeholder meeting) (https://www.jfa.maff.go.jp/j/press/sigen/200529_29.html).

Appendix 2. Stock calculation method

(1) Cohort analysis

The catch in number at age (CAA) and the average weight at age were derived based on the age composition and weight of the catch in each area (Appendix 4). While we do not have detailed information on the age composition of the catch by South Korean fishing vessels, we assumed it to be the same as that for Japanese offshore trawlers, because their fishing grounds overlapped with those of Japanese offshore trawlers. The body weight at age, which is used in estimating the total biomass and SSB, is available annually after the 1989 FY. Before that, the average value for the 1989-1993 FYs was used (Appendix Table 2-1). Older fish were grouped together as a plus-group. The ages attributed to the plus-group are age 8 and above (age 8+) for those in 1997 and earlier, age 9 and above (age 9+) for those in 1998, and age 10 and above (age 10+) for those in and after 1999.

The number of fish at age, biomass in weight and fishing mortality (F) are estimated by cohort analyses based on the data above. In cohort analysis, we calculated the values at age from age 0 to 10+ starting from April based on the life cycle of walleye pollock. We used Pope's approximation for calculation of the number of fish at age (N), while using the method of Hiramatsu (1999) for the number of fish of the plus group. Natural mortality (M) of age 3 and above is estimated based on the CPUE and fishing efforts of offshore trawl fishery in the eastern Hokkaido according to Widrig (1954) (Appendix Table 2-2). M of under age 3 is assumed considering that M of young fish is generally higher than M of older fish. Biomass is defined as the initial biomass on 1st of April when the fishing year starts, but April is just after the end of spawning. For this reason, we determined that the mature part of the initial biomass in a fishing year is the SSB that generated the year class in the fishing year. For example, SSB in the 2019 FY is the SSB that spawned at the end of the 2018 FY and generated the 2019 year-class. Therefore, we used the maturity rate shown in Appendix Table 2-3 (the rates of Figure 2-3 are moved by one year to the older side) for calculation of SSB, and calculated SSB by multiplying the initial biomass by this maturity rate in each fishing year.

Because ages 0 to 2 fish of this stock are not the main target of fishing in recent years, the catch number for these ages is not likely to correspond to the abundance. Moreover, because only the data of ages 0 to 2 fish are available for the latest three year-classes, estimation reliability of the recruitment by cohort analysis is considered to be low. For these reasons, we decided to estimate the abundance of the 2017-2019 year-classes that compose ages 0 to 2 fish in the most recent years based on the result of the walleye pollock acoustic trawl survey that is conducted from June to July (described later).

For tuning, we used the standardized CPUE at age for the offshore trawl fishery based in Hokkaido (Ages 3 to 7: Appendix Table 2-4), abundance index from the logbook of gillnet fishery, and the standardized CPUE obtained from skipper's note (Appendix Table 2-5). We tuned the F value of ages 3 to 10+ fish in the most recent year so that the CPUE for offshore trawl would match the catch in number of each age at the middle of the fishing season, while the abundance index and standardized CPUE for gillnet fishery would match the SSB at the middle of the fishing season. We calculated the F values for age 0 to age 2 in the most recent year from the catch in number and abundance which

were estimated based on the survey results as described above. Specific equation for estimation is as follows:

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

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

Here, $N_{a,y}$ is the number of age a fish in fishing year y , $C_{a,y}$ is catch in number of age a fish in fishing year y , and M_a is M of age a fish. $F_{a,y}$ below is F of age a fish in fishing year y , m_a is maturity rate at age a , and $w_{a,y}$ is body weight of age a fish in fishing year y .

Because the age of the plus group is extended for the period from 1997 to 1999, we calculated the number of fish of age 7 and age 8+ before 1996 by using equations (2) and (3), respectively, while the number of fish of age 9 and age 10+ after 1999 is calculated by using equations (4) and (5), respectively. Equation (1) also applies to the plus groups of 1997 and 1998 because the plus group of their respective following year is extended to these years.

$$N_{7,y} = \frac{C_{7,y}}{C_{7,y}+C_{8+,y}} N_{8+,y+1} \exp(M_7) + C_{7,y} \exp\left(\frac{M_7}{2}\right) \quad (2)$$

$$N_{8+,y} = \frac{C_{8+,y}}{C_{7,y}+C_{8+,y}} N_{8+,y+1} \exp(M_{8+}) + C_{8+,y} \exp\left(\frac{M_{8+}}{2}\right) \quad (3)$$

$$N_{9,y} = \frac{C_{9,y}}{C_{9,y}+C_{10+,y}} N_{10+,y+1} \exp(M_9) + C_{9,y} \exp\left(\frac{M_9}{2}\right) \quad (4)$$

$$N_{10+,y} = \frac{C_{10+,y}}{C_{9,y}+C_{10+,y}} N_{10+,y+1} \exp(M_{10+}) + C_{10+,y} \exp\left(\frac{M_{10+}}{2}\right) \quad (5)$$

The number of fish at age of ages 3 to 10+ fish in the terminal year Y of the latest stock assessment ($N_{a,Y}$) is calculated by equation (6) using fishing mortality ($F_{a,Y}$) and CAA ($C_{a,Y}$) of the most recent year.

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

The fishing mortality F was derived from equation (7) for the years except the most recent year for which F was estimated by tuning. Here, we premised that F for the plus-group is equal to F for the population that is one year younger than the plus-group, except F for 1997 and 1998 for which the number of fish was derived from equation (1).

$$F_{a,y} = -\ln\left(1 - \frac{C_{a,y} \exp\left(\frac{M_a}{2}\right)}{N_{a,y}}\right) \quad (7)$$

We estimated F for ages 3-9 for the most recent year according to the method of ridge VPA (Okamura et al. 2017). F for ages 0-2 was calculated using the number of fish at age (to be mentioned later) that was derived by the forward calculation of cohort analysis and the CAA, because estimated values from surveys have been added to the recruitment for the latest three years. F for age 10+ was assumed to be equal to that of age 9. Ridge VPA is a method to reduce instability in estimation by introducing penalty according to the value of F. The objective function, which consists of likelihood L that indicates fitness with a tuning index value (defined as negative log-likelihood $-\ln L$) and of the penalty-weighted square of F, is defined as equation (8). We estimated F to minimize the objective function. In estimating F, we searched appropriate penalty coefficients λ and η to find the best ridge penalty weighting. To apply separate weighting for age 3 and the other ages (ages 4 to 9), the coefficient η is used for age 3 penalty, because the retrospective bias is particularly large for age 3 compared to the other ages (ages 4 to 9). As the appropriate penalty weighting, we searched values of λ and η that minimize the differences between estimated values of the SSB and F for each age (ages 3 to 9) that were derived from retrospective analysis. Here, α is a weighting factor that was given for convenience to the penalty term to make the search of λ and η easy. In this analysis, we set $\alpha = 20$. We used the RMSPE (Root Mean Square Percentage Error) shown in equations (9) and (10) as the index of differences between the estimated values derived from retrospective analysis.

$$-(1 - \lambda)\ln L + \alpha\lambda \left[(1 - \eta) \sum_{a=4}^9 F_{a,Y}^2 + \eta F_{3,Y}^2 \right] \quad (8)$$

$$RMSPE_{SSB'} = \sqrt{\frac{1}{n} \sum_{k=Y-i}^n \left(\frac{SSB_k^{Ri} - SSB_k'}{SSB_k'} \right)^2} \quad (9)$$

$$RMSPE_{F_{a'}} = \sqrt{\frac{1}{n} \sum_{k=Y-i}^n \left(\frac{F_{a,k}^{Ri} - F_{a,k}'}{F_{a,k}'} \right)^2} \quad (10)$$

$$SSB'_y = \sum_{a=0}^{10+} N_{a,y} \times m_a \times w_{a,y} \quad (11)$$

Here, Ri indicates that this is the value of retrospective calculation of year i . n is the range of comparison of difference in estimates. In this analysis, n is set to 11 to compare the number of cohort-ages. SSB is defined by equation (11). The RMSPE indicates the ratio that expresses the difference of the estimated values (for last n years) between the estimation from all data-set and the estimation using the data-set removing the latest data for i years. Data used for retrospective calculation go back five years. We obtained the combination of λ ($0 \leq \lambda < 1$) and η ($0 \leq \eta \leq 1$) by grid searching for the value at which the average RMSPE of SSB and F value of each age for the retrospective years is smallest in intervals of 0.05, then further searching in intervals of 0.005 around the resulting combination with the smallest value. Negative log likelihood $-\ln L$ for minimization is defined by

equation (12) below (Hashimoto et al. 2018). Power relation is assumed between the index and the number of fish or SSB.

$$\begin{aligned}
-\ln L = & \sum_a \sum_y \left[\frac{[\ln I_{a,y} - (b_a \ln D_{a,y} + \ln q_a)]^2}{2\sigma_a^2} - \ln \left(\frac{1}{\sqrt{2\pi}\sigma_a} \right) \right] \\
& + \sum_y \left[\frac{[\ln J_y - (b' \ln S_y + \ln q')]^2}{2\sigma'^2} - \ln \left(\frac{1}{\sqrt{2\pi}\sigma'} \right) \right] \\
& + \sum_y \left[\frac{[\ln K_y - (b'' \ln S_y + \ln q'')]^2}{2\sigma''^2} - \ln \left(\frac{1}{\sqrt{2\pi}\sigma''} \right) \right] \tag{12}
\end{aligned}$$

Here, $I_{a,y}$ is CPUE of age a in the fishing year y (Appendix Note 1), $D_{a,y}$ is the number of fish of age a at the middle of fishing season in the fishing year y , J_y is abundance index for gillnet fishery, K_y is the standardized CPUE for gillnet fishery (Appendix Note 2), and S_y is the SSB during the fishing season. $D_{a,y}$ and S_y are calculated by equations (13) and (14), respectively. The maturity rate during the fishing season shown in Appendix Table 2-6 (maturity rate in Figure 2-3) is used for calculation of SSB during the fishing season.

$$D_{a,y} = N_{a,y} \exp \left(-\frac{M_a + F_{a,y}}{2} \right) \tag{13}$$

$$S_y = \sum_{a=0}^{10+} D_{a,y} \times m'_a \times w_{a,y} \tag{14}$$

Here, m'_a is the maturity rate during the fishing season at age a . Coefficient b_a and q_a are concerning age a . Coefficients b' , b'' , q' and q'' are corresponding to the respective index and calculated by equations (15) to (20) below. Parameters σ_a , σ' and σ'' are simultaneously estimated with the F value of each age in the most recent year.

$$q_a = \exp \left(\frac{1}{n} \sum_y \ln(I_{a,y}) - \frac{b_a}{n} \sum_y \ln(D_{a,y}) \right) \tag{15}$$

$$b_a = \frac{\sum_y (\ln(I_{a,y}) - \frac{1}{n} \sum_y \ln(I_{a,y})) (\ln(D_{a,y}) - \frac{1}{n} \sum_y \ln(D_{a,y}))}{\sum_y (\ln(D_{a,y}) - \frac{1}{n} \sum_y \ln(D_{a,y}))^2} \tag{16}$$

$$q' = \exp \left(\frac{1}{n} \sum_y \ln(J_y) - \frac{b'}{n} \sum_y \ln(S_y) \right) \tag{17}$$

$$b' = \frac{\sum_y (\ln(J_y) - \frac{1}{n} \sum_y \ln(J_y)) (\ln(S_y) - \frac{1}{n} \sum_y \ln(S_y))}{\sum_y (\ln(S_y) - \frac{1}{n} \sum_y \ln(S_y))^2} \tag{18}$$

$$q'' = \exp \left(\frac{1}{n} \sum_y \ln(K_y) - \frac{b''}{n} \sum_y \ln(S_y) \right) \tag{19}$$

$$b'' = \frac{\sum_y (\ln(K_y) - \frac{1}{n} \sum_y \ln(K_y)) (\ln(S_y) - \frac{1}{n} \sum_y \ln(S_y))}{\sum_y (\ln(S_y) - \frac{1}{n} \sum_y \ln(S_y))^2} \quad (20)$$

Here, n is the number of years of data of each tuning index. The period of tuning index is: since the 1999 FY for standardized CPUE at age for offshore trawl fishery; since the 2003 FY for the abundance index for gillnet fishery, and; since the 2010 FY for the standardized CPUE for gillnet fishery. The residual plot of each tuning index and projection value is shown in Appendix Figure 2-1. The estimation results of b_a , q_a , b' , b'' , q' , q'' , σ_a , σ' and σ'' are shown in Appendix Table 2-7. Details of the results of cohort analysis after the tuning are shown in Appendix 4. Based on the search result, we used 0.540 for λ and 0.945 for η (Appendix 5).

(2) Recruitment of the latest three years

Recruitment of the 2017-2019 year-classes is estimated using the results of walleye pollock acoustic trawl survey from June to July as mentioned above. The survey data we used is the index of abundance of age 1 fish (excluding 2005 and 2007 year-classes) after the survey in 2006. We determined the linear relational equation through logarithmic conversion of the survey index and the number of age 1 fish estimated by cohort calculation up to the 2017 data. Then, by applying the survey index for the abundance of age 1 fish of the latest three years (2018-2020 FY) to this equation, we calculated the number of age 1 fish of the 2017-2019 year-classes through linear extrapolation. Based on this, we calculated the number of age 0 fish in the 2017-2019 FYs and the number of age 2 fish in the 2019 FY by backward calculation (equation (1)) and forward calculation (equation (22)) of cohort analysis, respectively. F value of each age is calculated by equation (7).

$$N_{a+1,y+1} = (N_{a,y} \exp\left(-\frac{M_a}{2}\right) - C_{a,y}) \exp\left(-\frac{M_a}{2}\right) \quad (21)$$

The relationship between the survey index and the number of fish estimated by cohort analysis, and the linear relational equation are shown in Appendix Figure 2-2. As a result of the linear extrapolation, the number of fish of the 2017-2019 year-classes at age 1 is 1,597 million, 668 million and 613 million individuals, respectively. Here, the number of fish (recruitment) at age 0 as estimated by backward computation is 2,390 million, 997 million and 918 million individuals, respectively.

(3) S-R relationship and estimation of MSY

For details of the applied model of the S-R relationship and estimated SSB and F level that can produce MSY, see the report of the “Scientific Meeting on Reference Points” held in April 2019 (Sakai, et al. 2019). Here, the model of S-R relationship based on the 2018 stock assessment were used for the estimation of the level that can produce MSY: The HS model based on the recruitment and SSB of the 1981-2014 year-classes as estimated by the 2018 stock assessments, while natural mortality, maturity rate, average body weight at age and selectivity of fishing were used as conditions of simulation. Selectivity was based on the average fishing coefficient (F value) of each age during the

2013-2017 FYs (i.e. $F_{current}$ used in the stock assessment in 2018). As the average body weight of catch, the average value of the 2013-2017 FYs was used (Appendix Table 2-8). Through simulations with the conditions and S-R relationship above, the fishing mortality that maximizes catch at equilibrium condition was estimated as F_{msy} . SSB corresponding the F_{msy} was estimated as SB_{msy} and the average of the maximized catch at equilibrium condition was estimated as MSY.

Appendix Note 1: Standardized CPUE at age for offshore trawl fishery

The standardized CPUE at age for offshore trawl fishery was calculated in the following steps:

- 1) As area factor of fishing ground, Eastern Hokkaido is divided into east and west based on Kushiro (offshore trawl small fishing zones 31-35 and 30, 36, 37, respectively), Southwestern Hokkaido is divided into off Urakawa-Shizunai (zones 28 and 29) and off Mukawa-Noboribetsu-Usujiri-Esan (zones 24-27). The year and month where measurement samples for estimation of age composition corresponding to the offshore trawl catch of these four sea areas are identified for each fishery (otter trawl and Danish seine fisheries).
- 2) For the identified years, months and fishing gear, the catch and effort data targeting walleye pollock (over 50% of the total catch of the day are walleye pollock) are extracted from the catch statistics of offshore trawl fishery (logbook) of each vessel.
- 3) Assuming that the age composition data from measurement samples (by year, by month, by fishing gear and by area) reflect the age composition of the catch targeting walleye pollock of the same period, area, and fishing gear, we obtained catch and efforts at age data for the standardization.
- 4) Because even the data of catch targeting walleye pollock can include zero catch for some ages, a Delta type two-step model (Lo et al. 1992) is used for standardization. In this model, firstly, the ratio of zero-catch data is estimated by generalized linear model (GLM) using binominal distribution; secondly, GLM assuming logarithmic normal distribution in non-zero-catch data (positive catch data) is applied; and lastly, standardized CPUE is calculated by multiplying the ratio of non-zero-catch data by the response variable of the positive catch part (CPUE). As the full model, Fishing year, month, age, fishing gear and area are used as explanatory variables in the first step, while fishing year, month, age, fishing gear, vessel ID and horsepower are used in the second step. The final model is obtained by variable selection using BIC for main effect and interaction. Following a preceding study (Rodríguez-Marín et al. 2003), the least mean square (lsmean) of the interaction of fishing year and age is calculated in the final model in order to obtain the yearly trend of CPUE at age.
- 5) The final model was the same as the model for last year. The model formula is as follows:

[1st step] : $positive\ rate \sim Intercept + Year + Age + Area + Year \times Age + error\ term,$

[2nd step] : $\log(CPUE) \sim Intercept + Year + Age + Area + Month + VesselID + Year \times Age + Age \times Month + Age \times Area + error\ term$

Here, Year stands for fishing year, Age for age, Month for month, Vessel ID for vessel ID and Area for sea area. For details of standardization, see the document on CPUE (FRA-SA2020-SC03-101).

Appendix Note 2: Standardized CPUE for gillnet fishery (operation logbook)

The standardized CPUE for gillnet fishery (based on the skipper's note) is calculated as follows (Hakodate Mariculture Fisheries Research Institute (printing underway))

- 1) Skipper's note that are used as data record the operation location (latitude/longitude) of each operation day, number of nets used and catch (kg) of the 18 representing vessels of anchored gillnet fleet for walleye pollock of Oshima-Iburi district.
- 2) We used a generalized linear model assuming normal distribution for standardization of CPUE; logarithmically transformed CPUE by vessel and day for response variable; and year, month, water depth at the center of fishing gear, immersion days of fishing gear, base port, and operation area as explanatory variables. Because CPUE showed different yearly fluctuation patterns by operation area, by month and by water depth, these explanatory variables are modeled as interaction with the year. Because the operation data included data with no catch, a constant term was added into CPUE before logarithmically conversion, and used as a response variable. This constant term is set to 10% of the average CPUE (constant).

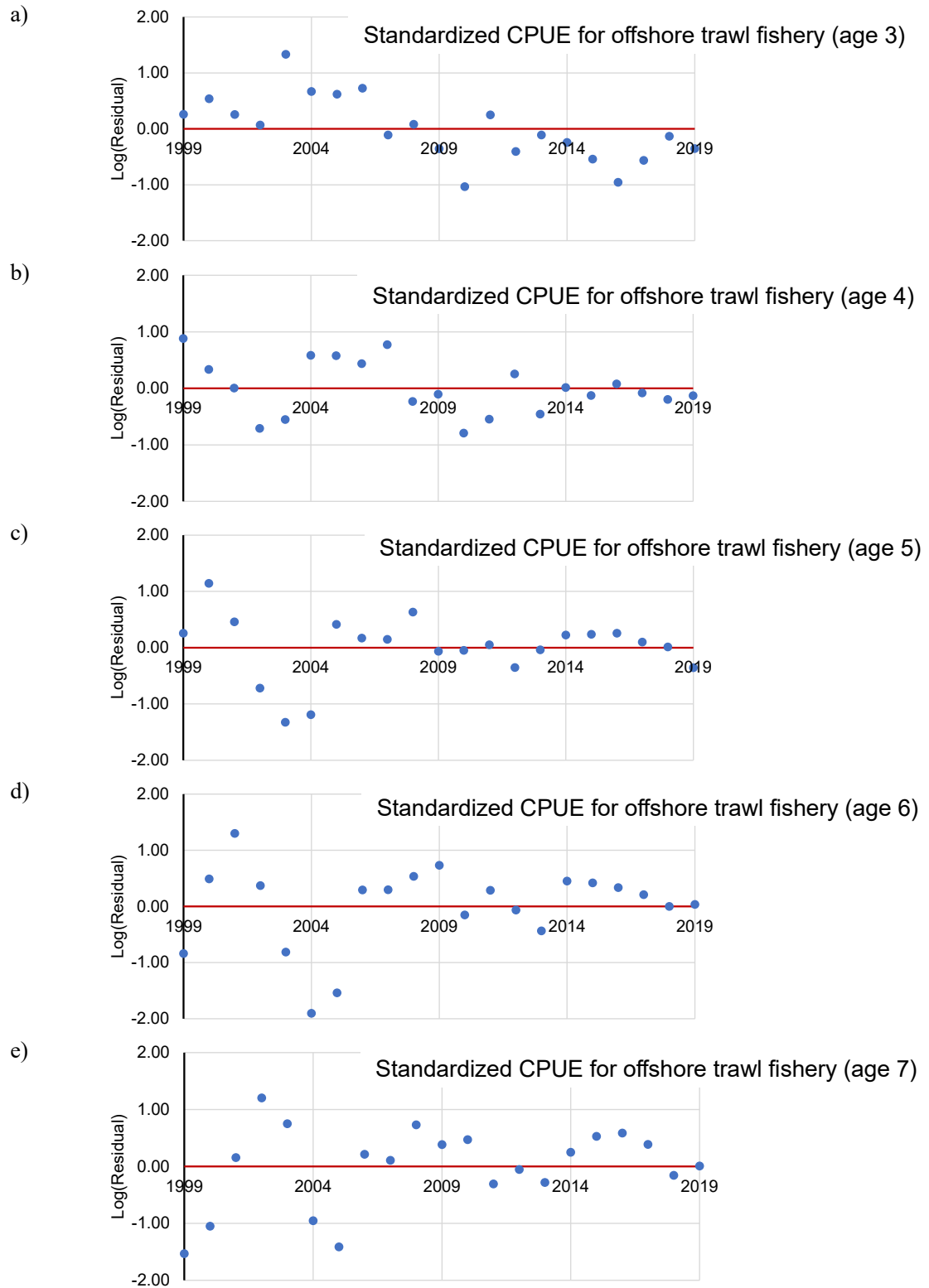
$$\log(\text{CPUE} + \text{constant}) \sim \text{Intercept} + \text{Year} + \text{Month} + \text{Area} + \text{Depth} + \text{Duration} + \text{Port} + \text{Year} \times \text{Month} \\ + \text{Year} \times \text{Area} + \text{Year} \times \text{Depth} + \text{error term}$$

Here, CPUE is the value obtained by dividing catch (kg) by vessels/days by efforts (net length); Year is the 2010-2019 FYs where the skipper's note were recorded; Month is from October to February of the following year (operation ended before February in some years); Area is the operation area, and its classification is same as that of offshore trawl net fishery; Depth is water depth at the center of fishing gear (7 categories: up to 100 m, up to 150 m, up to 200 m, up to 250 m, up to 300 m, up to 350 m and up to 400 m); Duration is immersion days of fishing gear (one to 3 days); and Port is base port. All explanatory variables were used as categorical variables.

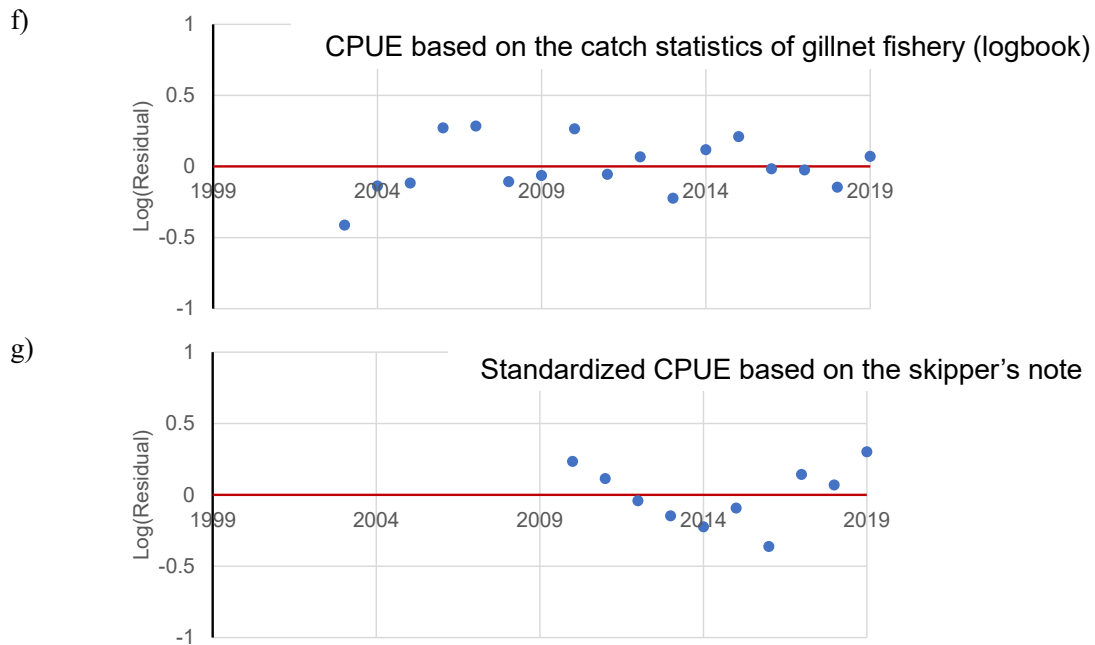
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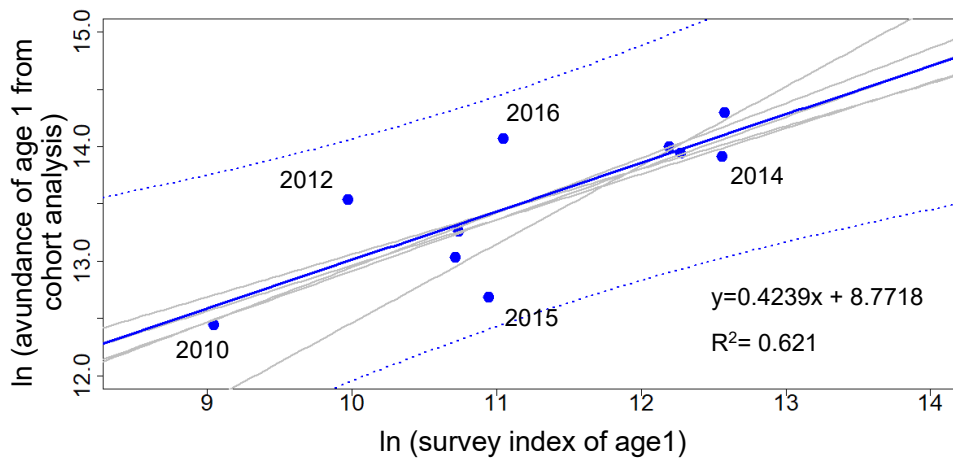
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Appendix Figure 2-1. Residual plot of each tuning index



Appendix Figure 2-1 (continued). Residual plot of each tuning index



Appendix Figure 2-2. The relationship between the survey index and the abundance from cohort analysis: linear relational equation (thick solid line) and the 95% prediction interval (dotted line)

Linear relationship of logarithmically transformed survey index and the abundance of age 1 from cohort analysis were examined for 2006, 2008-2016 year-classes. The data for 2005 and 2007 year-classes were removed from the analysis because the survey did not detect these dominant year class then. The year number attached to the plot is the year class corresponding to the plot. The total biomass of the latest three year-classes (2017-2019 year-classes) was calculated with the obtained relational equation. The thin gray lines represent the relational equations estimated by retrospective analysis for five years. All those relationships were within the 95% prediction interval.

Appendix Table 2-1. Average body weight at age (g)

Fishing Year	Before 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Age 0	31	27	25	29	30	42	33	28	29	32	41	39	53	44	49	32
Age 1	106	109	96	95	94	138	79	106	89	85	121	158	97	238	155	76
Age 2	267	332	284	246	248	227	264	222	221	201	258	300	304	297	301	216
Age 3	405	453	419	409	400	343	338	397	368	338	335	347	432	467	461	395
Age 4	489	492	539	452	464	500	435	525	485	452	400	459	473	530	565	470
Age 5	564	585	618	529	538	547	526	536	557	541	476	520	526	583	586	517
Age 6	639	682	662	594	612	643	607	591	632	639	522	549	591	626	639	625
Age 7	788	819	820	806	718	777	686	641	583	738	639	605	651	680	705	682
Age 8 (Age 8+)	999	879	1,030	1,024	841	1,222	881	782	814	869	740	658	758	727	783	738
Age 9 (Age 9+)											828	689	843	717	831	840
Age 10+												751	902	1,302	1,037	1,198

Fishing Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	42	44	40	43	32	30	37	48	50	54	38	48	48	46	43	35
Age 1	88	152	143	89	96	105	84	141	139	76	77	95	124	91	142	80
Age 2	213	265	184	242	188	189	208	236	160	164	165	183	227	224	274	185
Age 3	349	422	359	316	347	300	318	393	381	308	313	402	341	379	391	284
Age 4	463	460	453	455	417	449	431	433	480	464	479	477	461	479	497	462
Age 5	510	525	530	527	512	542	524	502	505	530	548	539	559	598	556	564
Age 6	579	575	594	595	615	590	636	576	579	565	611	603	634	646	660	668
Age 7	646	625	642	665	682	700	696	749	655	614	632	638	650	721	720	762
Age 8 (Age 8+)	695	675	686	661	692	687	770	761	909	719	653	654	713	739	739	784
Age 9 (Age 9+)	787	711	755	796	749	684	837	1,020	853	785	742	712	727	788	761	791
Age 10+	997	968	994	982	1,110	713	1,152	1,085	1,062	884	1,063	819	797	807	832	840

Appendix Table 2-2. Natural mortality (M)

Age	0	1	2	3	4	5	6	7	8 (8+)	9 (9+)	10+
M	0.4	0.35	0.3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Plus group is age 8+ before 1997, age 9+ in 1998, and age 10+ after 1999.

Natural mortality (M) of those plus group is 0.25 for all years.

Appendix Table 2-3. Maturity rate at age used for calculation of SSB (%)

Age	0	1	2	3	4	5	6	7	8 (8+)	9 (9+)	10+
Maturity Rate (%)	0	0	0	0	20	80	90	100	100	100	100

Plus group is age 8+ before 1997, age 9+ in 1998, and age 10+ after 1999.

Maturity rate of those plus group is 100% for all years.

Appendix Table 2-4. Standardized CPUE at age for offshore trawl fishery (tuning index value)

Standardized CPUE (based on catch in number per operation)											
Fishing Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Age 3	569	672	733	860	6,811	1,966	1,104	2,161	675	5,147	824
Age 4	14,908	1,274	899	731	1,129	6,350	3,854	2,108	4,891	1,473	11,124
Age 5	2,513	9,826	1,088	457	382	468	3,377	1,947	1,192	2,830	1,380
Age 6	405	1,338	4,506	494	270	113	156	1,427	1,045	632	1,293
Age 7	64	131	330	1,373	285	109	68	274	475	513	194

Fishing Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 3	918	1,510	1,218	136	272	393	171	642	197	966
Age 4	1,366	4,047	3,814	2,963	348	741	1,820	1,010	2,462	465
Age 5	7,485	2,464	3,721	2,318	4,322	478	1,037	1,689	1,032	1,896
Age 6	673	5,904	1,230	2,146	2,187	3,006	327	553	970	580
Age 7	427	307	2,170	527	2,202	1,190	1,810	181	203	566

Appendix Table 2-5. CPUE for gillnet fishery (tuning indices)

Abundance indices											
Fishing Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Catch/net (kg)	867	1,265	1,215	1,641	1,635	1,279	2,028	2,937	2,344	2,666	
Standardized CPUE								63	65	56	

Fishing Year	2013	2014	2015	2016	2017	2018	2019
Catch/net (kg)	1,922	2,199	1,984	1,415	1,404	1,332	1,563
Standardized CPUE	48	32	27	17	29	30	34

Appendix Table 2-6. Maturity rate at age used for calculation of SSB at the middle of the year in the tuning

Age	0	1	2	3	4	5	6	7	8 (8+)	9 (9+)	10+
Maturity Rate (%)	0	0	0	20	80	90	100	100	100	100	100

Plus group is age 8+ before 1997, age 9+ in 1998, and age 10+ after 1999.

Maturity rate of these plus group is 100% for all years.

Appendix Table 2-7. Estimation results of coefficients b, q and σ

Age a	b_a	q_a	σ_a	b'	q'	σ'
3	1.281	8.449×10^{-09}	0.566	0.771	8.513×10^{-02}	0.186
4	1.329	1.340×10^{-08}	0.463			
5	1.132	8.888×10^{-07}	0.550			
6	1.084	2.428×10^{-06}	0.732	b''	q''	σ''
7	1.022	7.203×10^{-06}	0.704	1.198	6.672×10^{-06}	0.199

Appendix Table 2-8. Parameters used for estimation of MSY reference point (Sakai et al. 2019)

Age	Natural mortality	Maturity rate	Average body weight (g)	Selectivity (Note 1)	Fcurrent (Note 2)
0	0.40	0.0	47	0.026	0.007
1	0.35	0.0	96	0.025	0.007
2	0.30	0.0	195	0.111	0.032
3	0.25	0.0	348	0.200	0.059
4	0.25	0.2	472	0.548	0.160
5	0.25	0.8	555	0.906	0.265
6	0.25	0.9	612	0.996	0.291
7	0.25	1.0	651	1.000	0.292
8+	0.25	1.0	696	1.000	0.292

Note 1: the selectivity of Fcurrent of the stock assessment in 2018 (selectivity of average F of the 2013-2017 FYs) was used for estimation of MSY reference point.

Note 2: Fcurrent of the stock assessment in 2018 is average F value of the 2013-2017 FYs.

Appendix 3. Result of research ship survey and peripheral information

(1) Walleye pollock acoustic trawl survey

(Marin Fisheries Research and Development Center / Fisheries Resources Institute, FRA: June-July)

In order to assess the abundance of ages 1 and 2 fish in Hokkaido Pacific Coast, a survey has been conducted using quantitative echo sounders and trawl nets. The survey started in 1996 and its scope has been expanded to the current survey area after 2001. Since 2018, we have been reviewing the allocation of echo sounder response in the past survey data. This paper describes the results of the data of the 2006 survey and after, reanalysis of which has been completed (Appendix Figure 3-1). The standing stock in number of age 1 fish as estimated in this survey is average or low for the 2005 and 2007 year-classes, which are dominant year classes, but similar to the year class abundance based on the stock assessment for other year-classes. Among the year classes to which stock assessment provided recruitment estimates from this survey, the 2017 year-class had the highest abundance in number of age 1 fish for the period of the data review. Because this year class also had a large abundance in number of age 2 fish in the 2019 survey, the year-class is expected to be utilized as the major part of fishing resource in the future. However, we need to pay attention to the uncertainty of the survey result. For example, the survey failed to detect the abundance of the 2005 and 2007 year-classes, which are dominant year classes, in particular, as described above. This uncertainty may be attributed to the possibility that the waters around the four islands of the Northern Territories have become the nursery ground for ages 1 and 2 fish in recent years.

(2) Survey of walleye pollock in the eastern Hokkaido Pacific

(Kushiro Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization: November)

In order to assess the abundance of age 0 fish in the eastern Hokkaido in November, a catch survey has been conducted using trawl nets. The trawl net results of CPUE for age 0 fish of the dominant year classes are various: value for the 1995 year-class is high, the value for the 2005 year-class is highest but the value for the 2007 is low (Appendix Figure 3-2). In recent years, the 2015 year-class has high value, but the stock assessment of this year estimated the abundance of 2015 year-class as low as that of the 2010 year-class. We need to carefully interpret the results. The 2017 year-class has a high value also in this survey as with the case of the walleye pollock acoustic survey described above.

(3) Walleye pollock egg and larva distribution survey

(Fisheries Resources Institute, FRA: December-March)

In order to assess the abundance of eggs and larvae of walleye pollock in Hokkaido Pacific Coast (from the southwestern Hokkaido to eastern Hokkaido), a survey has been conducted using ring nets (80 cm in diameter). Eggs and larvae of walleye pollock are collected in the wide area from the water around Funka Bay to eastern Hokkaido, but the collection amount in the eastern Hokkaido is small. The average number of eggs per net, which were collected in the water around Funka Bay, is shown

in Appendix Figure 3-3. The number of eggs rapidly increased during the first decade of the 2000s and reached the peak in the 2010 FY, but rapidly decreased thereafter. The number of eggs of the 2015-2019 FYs has been at the lowest level since the first decade of the 2000s. Given that the number of eggs reflects the migration of SSB, the migration to the water around Funka Bay is considered to have passed the peak around the 2010 FY. Since the first decade of the 2000s, the ratio of the Ihuri coast has been relatively high.

(4) Spring quantitative survey of larval and juvenile of walleye pollock

(Fisheries Resources Institute, FRA: April)

In order to assess the abundance of larvae in the water around Funka Bay, a survey has been conducted using quantitative echo sounders and frame trawl nets. In this survey, the total backscattering volume of larvae by echo sounders was high for the 2009 year-class that had relatively high abundance, while the same of the 2010 year-class that had the lowest ever recruitment was low. However, the total backscattering volume of larvae was small or average for the 2005 and 2007 year-classes that were dominant year classes. The total backscattering volumes of larvae does not always correspond with the recruitment trend (Appendix Figure 3-4). The survey in 2020 was cancelled because of COVID-19.

(5) Survey of migration of SSB of walleye pollock (Hakodate Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization: August-September)

In order to assess the migrating SSB in the water around Funka Bay, which is the major spawning ground, a survey has been conducted using quantitative echo sounders and trawl nets. The total backscattering volume of mature fish detected by echo sounders marked high values in the 2009-2011 FYs and greatly fell in the 2012 and 2013 FYs. A high value was observed again in the 2014 FY, however, there is a possibility of migration of parent fish earlier than usual is considered then. After decline in the 2015 FY, total backscattering volume of echo sounders has been mostly level, excluding a temporary drop in the 2018 FY (Appendix Figure 3-5).

(6) Survey of new recruitment of Pacific cod and walleye pollock and distribution of snow crab (Fisheries Resources Institute, FRA: April)、Survey of new recruitment of Pacific cod and walleye pollock (Iwate Fisheries Technology Center, Miyagi Prefecture Fisheries Technology Institute: May-July, Fukushima Prefectural Fisheries and Marine Science Research Centre and Fukushima Prefectural Research Institute of Fisheries Resources: July-December)

In order to assess the abundance of ages 0 and 1 fish in the Tohoku area, a survey has been conducted mainly using bottom trawls. The Tohoku area had been an important nursery ground in the 1980s, but the eastern Hokkaido and eastward has been the major nursery ground since the 1990s. For this reason, it is considered difficult to presume recruitments of this stock based on the survey in the Tohoku area. As an example, the abundance of age 0 fish in the Tohoku area in October is shown in Appendix Figure

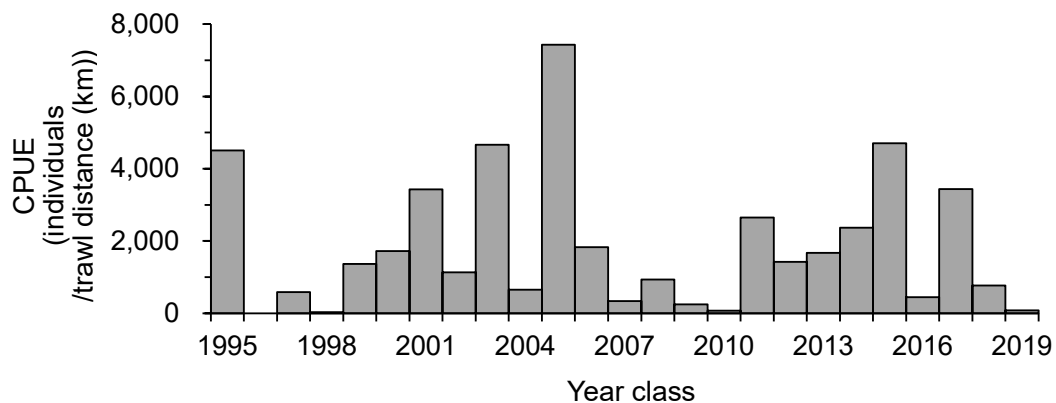
3-6. Survey abundance of age 0 fish was average or low for the 2005 and 2007 year-classes, which were dominant year classes. Survey abundance of the 2015-2018 year-classes was below average, while that of the 2019 year-class was above average.

(7) Russian TAC of the southwest sea area of the Chishima Islands

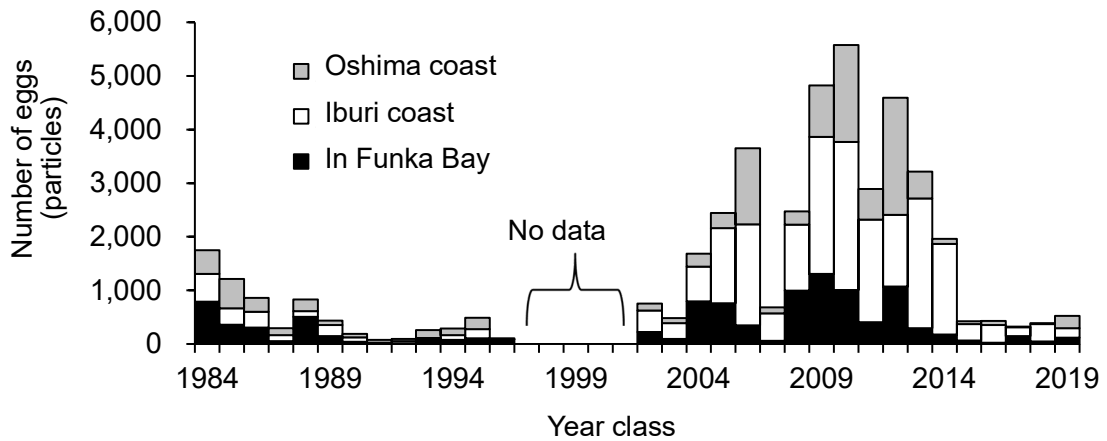
Large Russian trawlers operate in the water southwest of the Kuril Islands (Chishima Islands) but detailed information has not been obtained; concerning their catch, characteristics of catch or other details. Appendix Figure 3-7 shows Russian TAC for the fishing zone (named Southern Kuril zone) in Russia that includes this water. TAC of this fishing zone rapidly increased in 2009 and after and has been in the range of 89 thousand to 115 thousand tons since 2011. Given that the TAC reflects the biomass of this water, the stock status is considered to be in a good condition in 2020 as well.



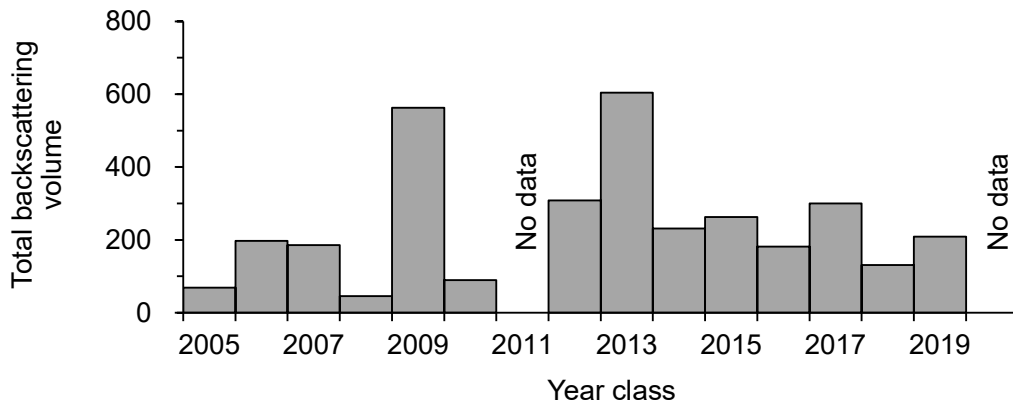
Appendix Figure 3-1. Abundance of ages 1 and 2 in Hokkaido Pacific Coast as estimated by walleye pollock acoustic trawl survey (June-July)



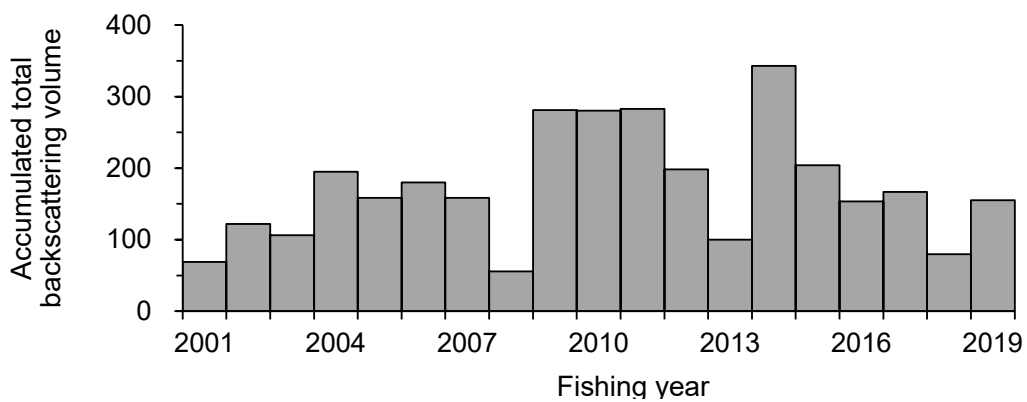
Appendix Figure 3-2. CPUE for trawl survey for age 0 in the eastern Hokkaido (November)



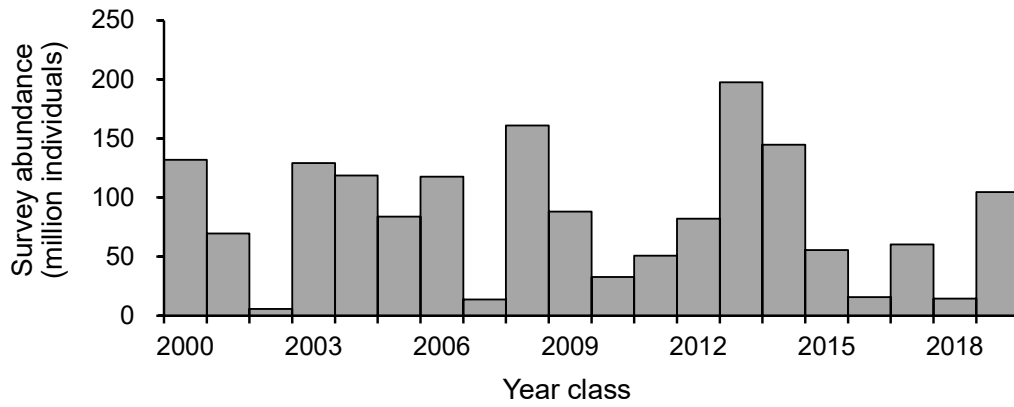
Appendix Figure 3-3. Number of eggs collected in the water around Funka Bay under the survey of eggs and larvae of walleye pollock (December-March)



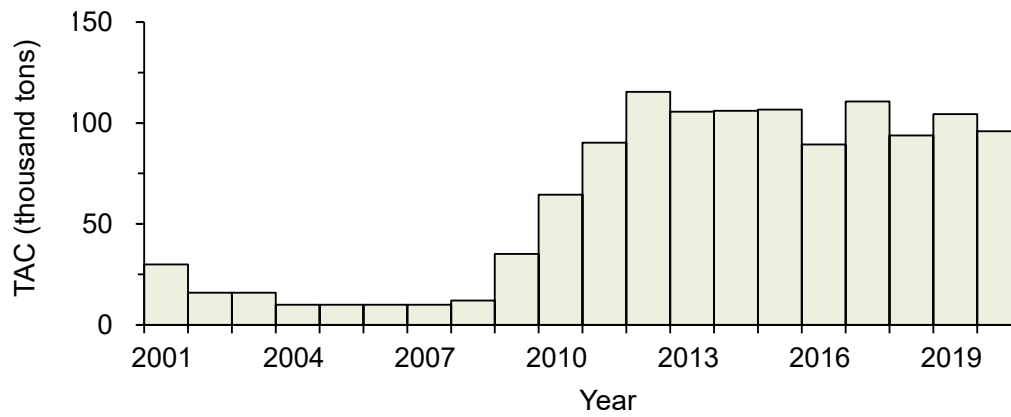
Appendix Figure 3-4. Total backscattering volume of larvae by echo sounders in the water around Funka Bay in the spring quantitative survey of larvae of walleye pollock (April)



Appendix Figure 3-5. Accumulated total backscattering volume of matured fish in the water around Funka Bay in the survey of migration of SSB of walleye pollock (August-September)



Appendix Figure 3-6. Survey abundance of age 0 in the Tohoku area in the survey of new recruitment of Pacific cod and walleye pollock



Appendix Figure 3-7. TAC amount of walleye pollock in the Russian fishing zone “South Krill” set by the Russian Federation

Appendix 4. Details of the stock analysis results (1981-1993 FYs)

Catch in number at age (CAA) (thousand individuals)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	594,529	366,429	30,115	5,007	176,725	513,309	518,240	457,112	366,705	174,167	66,851	19,430	28,650
Age 1	341,925	639,149	49,009	24,655	164,059	24,071	186,800	125,630	114,936	181,518	106,516	95,215	37,837
Age 2	37,002	106,635	238,807	73,472	148,636	40,474	29,863	52,302	46,816	155,443	210,041	65,450	253,570
Age 3	101,209	19,775	93,260	120,398	129,027	59,792	83,425	80,606	69,665	43,217	80,385	91,002	42,652
Age 4	135,940	166,383	133,364	188,057	103,686	112,225	108,326	127,396	111,782	42,289	58,173	80,832	47,709
Age 5	124,604	54,898	131,058	130,792	125,754	102,104	119,575	99,969	77,036	63,600	67,524	91,496	63,610
Age 6	46,630	19,352	36,268	56,894	49,512	51,509	66,731	58,726	38,124	24,802	26,906	38,974	48,231
Age 7	26,641	5,801	8,542	9,838	11,485	11,949	23,329	21,777	13,346	13,702	5,987	4,388	12,808
Age 8 (Age 8+)	1,829	1,508	3,175	2,374	2,827	3,665	7,600	9,066	7,484	11,176	2,850	2,820	4,130
Age 9 (Age 9+)													
Age 10+													
Total	410,309	1,379,930	723,598	611,487	911,711	919,098	1,143,889	1,032,584	845,894	709,914	625,233	489,607	539,197

Catch in weight at age (tons)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	18,199	11,217	922	153	5,410	15,713	15,864	13,993	9,882	4,392	1,944	580	1,203
Age 1	36,358	67,962	5,211	2,622	17,445	2,559	19,863	13,359	12,536	17,379	10,104	8,977	5,210
Age 2	9,892	28,508	63,843	19,642	39,737	10,820	7,984	13,983	15,549	44,105	51,627	16,205	57,680
Age 3	40,957	8,003	37,740	48,723	52,215	24,197	33,761	32,620	31,584	18,093	32,852	36,374	14,629
Age 4	66,542	81,444	65,282	92,054	50,754	54,934	53,026	62,360	54,971	22,810	26,314	37,471	23,876
Age 5	70,216	30,936	73,853	73,704	70,865	57,537	67,383	56,334	45,103	39,321	35,749	49,196	34,779
Age 6	29,778	12,359	23,161	36,333	31,619	32,894	42,615	37,503	26,002	16,417	15,975	23,872	31,005
Age 7	20,995	4,571	6,732	7,753	9,051	9,416	18,385	17,162	10,935	11,233	4,825	3,153	9,947
Age 8 (Age 8+)	1,827	1,506	3,172	2,371	2,824	3,662	7,593	9,057	6,576	11,509	2,918	2,371	5,046
Age 9 (Age 9+)													
Age 10+													
Total	294,765	246,506	279,916	283,354	279,919	211,733	266,472	256,370	213,137	185,259	182,309	178,197	183,374

Fishing mortality (F)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	0.173	0.170	0.018	0.003	0.137	0.307	0.295	0.231	0.182	0.120	0.027	0.015	0.020
Age 1	0.203	0.349	0.037	0.022	0.168	0.030	0.211	0.129	0.100	0.155	0.120	0.059	0.044
Age 2	0.048	0.102	0.244	0.081	0.206	0.065	0.053	0.095	0.074	0.219	0.313	0.115	0.252
Age 3	0.155	0.035	0.132	0.202	0.216	0.129	0.200	0.214	0.193	0.098	0.182	0.236	0.111
Age 4	0.611	0.438	0.368	0.456	0.285	0.314	0.387	0.568	0.554	0.181	0.195	0.298	0.197
Age 5	1.337	0.574	0.813	0.820	0.686	0.539	0.703	0.821	0.902	0.779	0.523	0.570	0.433
Age 6	1.510	0.820	1.073	1.202	0.961	0.730	0.916	1.030	0.977	0.931	1.023	0.712	0.734
Age 7	2.229	0.829	1.274	1.108	0.925	0.693	0.981	0.989	0.746	1.444	0.647	0.467	0.576
Age 8 (Age 8+)	2.229	0.829	1.274	1.108	0.925	0.693	0.981	0.989	0.746	1.444	0.647	0.467	0.576
Age 9 (Age 9+)													
Age 10+													
Total	7%	10%	11%	12%	10%	13%	9%	8%	10%	12%	12%	16%	16%

Number of fish at age (thousand individuals)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	4,578,178	2,864,137	2,043,096	1,888,943	1,685,414	2,374,249	2,477,575	2,708,200	2,691,020	1,882,832	3,048,396	1,593,250	1,811,021
Age 1	2,216,568	2,582,086	1,619,882	1,344,873	1,262,097	985,077	1,171,245	1,236,469	1,441,109	1,503,612	1,119,504	1,988,668	1,052,080
Age 2	924,684	1,274,958	1,283,027	1,100,371	927,019	751,664	673,965	668,551	765,864	919,409	907,201	699,466	1,321,461
Age 3	796,741	653,174	852,730	744,947	751,937	558,821	522,010	473,583	450,258	527,071	547,057	491,287	461,858
Age 4	336,899	511,186	491,241	581,806	473,914	471,743	382,444	332,920	297,692	289,182	372,344	355,108	302,305
Age 5	191,508	142,411	266,856	264,886	287,151	277,582	268,356	202,250	146,852	133,195	187,895	238,645	205,224
Age 6	67,814	39,184	62,463	92,169	90,869	112,656	126,075	103,471	69,290	46,384	47,606	86,743	105,111
Age 7	33,831	11,663	13,438	16,640	21,573	27,075	42,280	39,297	28,757	20,319	14,237	13,331	33,161
Age 8 (Age 8+)	2,323	3,032	4,994	4,015	5,309	8,306	13,775	16,360	16,126	16,573	6,777	8,567	10,693
Age 9 (Age 9+)													
Age 10+													
Total	148,546	810,831	6,637,727	6,038,650	5,505,283	5,567,173	5,677,725	5,781,101	5,906,968	5,338,217	6,251,017	5,475,085	5,302,914

Total Biomass (tons)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	140,143	87,674	62,541	57,823	51,592	72,678	75,841	82,901	72,515	47,479	88,625	47,539	76,029
Age 1	235,692	274,558	172,245	143,003	134,201	104,745	124,541	131,476	157,178	143,957	106,194	187,503	144,880
Age 2	247,207	340,851	343,008	294,176	247,832	200,952	180,180	178,732	254,358	260,768	222,987	173,185	300,595
Age 3	322,425	264,326	345,082	301,465	304,293	226,143	211,247	191,649	204,135	220,663	223,574	196,369	158,406
Age 4	164,912	260,015	240,462	284,793	231,981	230,918	187,206	162,964	146,396	155,977	168,431	164,614	151,287
Age 5	107,918	80,251	150,378	149,267	161,814	156,422	151,223	113,971	85,979	82,348	99,475	128,314	112,206
Age 6	43,307	25,023	39,889	58,860	58,030	71,943	80,513	66,078	47,259	30,704	28,265	53,130	67,571
Age 7	26,661	9,191	10,590	13,113	17,001	21,336	33,319	30,968	23,563	16,658	11,475	9,578	25,753
Age 8 (Age 8+)	2,320	3,029	4,989	4,011	5,304	8,297	13,760	16,343	14,170	17,067	6,940	7,203	13,063
Age 9 (Age 9+)													
Age 10+													
Total	290,585	1,344,919	1,369,185	1,306,511	1,212,048	1,093,435	1,057,829	975,083	1,005,552	975,621	955,965	967,435	1,049,788

Spawning Stock Biomass (tons)													
Fishing Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Age 0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 1	0	0	0	0	0	0	0	0	0	0	0	0	0
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	32,982	52,003	48,092	56,959	46,396	46,184	37,441	32,593	29,279	31,195	33,686	32,923	30,257
Age 5	86,334	64,201	120,302	119,414	129,451	125,138	120,978	91,177	68,784	65,879	79,580	102,651	89,765
Age 6	38,976	22,521	35,900	52,974	52,227	64,749	72,462	59,470	42,533	27,634	25,438	47,817	60,814
Age 7	26,661	9,191	10,590	13,113	17,001	21,336	33,319	30,968	23,563	16,658	11,475	9,578	25,753
Age 8 (Age 8+)	2,320	3,029	4,989	4,011	5,304	8,297	13,760	16,343	14,170	17,067	6,940	7,203	13,063
Age 9 (Age 9+)													
Age 10+													
Total	187,274	150,944	219,874	246,471	250,379	265,703	277,960	230,551	178,328	158,433	157,119	200,172	219,651

Appendix 4 (continued). Details of the stock analysis results (1994-2006 FYs)

Catch in number at age (CAA) (thousand individuals)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	55,572	70,418	7,993	6,569	61,599	5,958	27,594	6,056	5,744	114,337	2,780	42,282	28,337
Age 1	36,319	76,250	115,758	20,345	29,459	34,815	12,005	16,029	25,435	2,874	10,256	11,400	38,510
Age 2	148,305	100,255	170,534	399,891	36,850	41,164	37,096	24,826	98,938	14,412	26,745	36,457	15,736
Age 3	209,139	48,542	30,280	157,997	282,344	24,353	36,070	20,019	22,838	163,587	81,749	31,267	69,567
Age 4	76,429	134,986	48,312	57,979	172,858	264,805	53,201	21,992	14,399	52,560	160,240	78,735	46,107
Age 5	64,709	62,083	58,855	33,454	69,918	106,187	181,795	37,473	15,359	34,983	60,826	92,555	57,224
Age 6	29,972	39,503	20,748	20,780	31,671	45,545	49,360	75,129	16,893	19,479	42,433	43,241	52,472
Age 7	7,177	21,240	13,680	11,173	36,853	25,119	24,351	23,950	33,630	11,363	16,781	21,206	25,145
Age 8 (Age 8+)	3,508	14,132	14,146	11,787	11,873	7,222	6,798	11,916	9,457	13,908	3,648	9,222	10,382
Age 9 (Age 9+)					4,791	5,238	4,126	3,756	4,608	1,687	2,573	1,551	3,021
Age 10+						3,921	6,314	1,106	1,592	882	1,057	1,636	789
Total	631,130	567,409	480,306	719,975	738,216	564,327	438,710	242,252	248,893	430,072	409,088	369,552	347,290

Catch in weight at age (tons)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	1,836	1,957	236	213	2,556	230	1,454	264	279	3,714	117	1,841	1,136
Age 1	2,858	8,073	10,340	1,721	3,576	5,494	1,168	3,823	3,949	219	899	1,732	5,504
Age 2	39,158	22,208	37,734	80,519	9,503	12,343	11,274	7,374	29,801	3,117	5,709	9,661	2,891
Age 3	70,731	19,284	11,136	53,408	94,524	8,443	15,567	9,346	10,520	64,595	28,494	13,191	24,988
Age 4	33,212	70,884	23,431	26,201	69,156	121,511	25,146	11,656	8,137	24,727	74,163	36,200	20,905
Age 5	34,038	33,299	32,806	18,087	33,307	55,167	95,628	21,829	9,002	18,090	31,019	48,630	30,343
Age 6	18,195	23,336	13,112	13,288	16,533	25,023	29,162	47,063	10,800	12,171	24,576	24,846	31,157
Age 7	4,921	13,624	7,970	8,241	23,554	15,209	15,848	16,282	23,694	7,748	10,843	13,255	16,140
Age 8 (Age 8+)	3,092	11,050	11,519	10,240	8,786	4,751	5,150	8,658	7,408	10,258	2,536	6,225	7,119
Age 9 (Age 9+)					3,965	3,611	3,476	2,693	3,827	1,418	2,025	1,103	2,279
Age 10+						2,944	5,695	1,440	1,651	1,057	1,054	1,584	784
Total	208,041	203,714	148,283	211,919	265,460	254,725	209,568	130,426	109,069	147,114	181,435	158,268	143,246

Fishing mortality (F)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	0.022	0.016	0.011	0.009	0.066	0.005	0.012	0.004	0.007	0.079	0.003	0.010	0.020
Age 1	0.037	0.045	0.040	0.040	0.060	0.058	0.016	0.010	0.028	0.005	0.011	0.016	0.013
Age 2	0.278	0.156	0.155	0.219	0.108	0.127	0.092	0.048	0.091	0.022	0.064	0.055	0.032
Age 3	0.373	0.149	0.069	0.229	0.258	0.105	0.170	0.071	0.061	0.234	0.184	0.106	0.152
Age 4	0.313	0.470	0.229	0.194	0.448	0.437	0.372	0.156	0.070	0.207	0.402	0.287	0.239
Age 5	0.477	0.484	0.409	0.260	0.403	0.590	0.660	0.523	0.165	0.256	0.418	0.458	0.372
Age 6	0.397	0.652	0.311	0.260	0.448	0.536	0.654	0.685	0.506	0.344	0.607	0.642	0.549
Age 7	0.232	0.586	0.525	0.290	1.132	0.859	0.667	0.856	0.833	0.842	0.606	0.768	1.115
Age 8 (Age 8+)	0.232	0.586	0.525	0.472	0.616	0.753	0.640	0.906	1.159	1.173	0.787	0.886	1.296
Age 9 (Age 9+)					0.378	0.658	1.735	1.009	1.319	0.695	0.756	1.060	0.916
Age 10+						0.658	1.735	1.009	1.319	0.695	0.756	1.060	0.916
Total	15%	16%	25%	23%	14%	17%	16%	21%	29%	20%	18%	20%	21%

Number of fish at age (thousand individuals)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	3,125,007	5,299,766	928,176	910,425	1,178,882	1,332,670	2,847,100	1,664,331	1,080,945	1,844,423	1,249,573	5,347,196	1,736,302
Age 1	1,190,507	2,049,257	3,494,886	615,631	604,898	739,796	888,437	1,885,876	1,110,677	719,876	1,142,742	835,338	3,549,715
Age 2	709,626	808,448	1,380,078	2,365,631	416,749	401,535	492,099	615,994	1,315,499	761,329	504,876	796,668	579,083
Age 3	760,713	398,057	512,623	875,607	1,408,313	277,018	262,034	332,628	434,971	889,389	551,601	351,001	558,807
Age 4	322,055	407,880	267,169	372,509	542,492	847,628	194,251	172,240	241,384	318,602	548,292	357,445	245,767
Age 5	193,333	183,368	198,532	165,436	238,944	269,947	426,444	104,333	114,733	175,283	201,743	285,599	208,895
Age 6	103,693	93,462	88,020	102,677	99,318	124,388	116,525	171,681	48,185	75,800	105,638	103,439	140,746
Age 7	39,297	54,306	37,927	50,239	61,626	49,399	56,680	47,190	67,404	22,618	41,843	44,823	42,398
Age 8 (Age 8+)	19,205	36,132	39,219	35,524	29,266	15,472	16,304	22,652	15,615	22,816	7,587	17,778	16,194
Age 9 (Age 9+)					17,264	12,315	5,676	6,698	7,126	3,816	5,496	2,689	5,707
Age 10+						9,217	8,687	1,972	2,462	1,996	2,259	2,836	1,490
Total	463,436	9,330,676	6,946,630	5,493,679	4,597,752	4,079,385	5,314,237	5,025,595	4,439,001	4,835,948	4,361,650	8,144,812	7,085,104

Total Biomass (tons)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	103,240	147,261	27,356	29,497	48,914	51,364	150,049	72,545	52,583	59,918	52,495	232,806	69,597
Age 1	93,670	216,972	312,183	52,089	73,435	116,742	86,440	449,772	172,462	54,798	100,129	126,921	507,298
Age 2	187,369	179,083	305,366	476,324	107,470	120,402	149,557	182,953	396,240	164,642	107,780	211,108	106,379
Age 3	257,274	158,131	188,522	295,985	471,483	96,042	113,085	155,290	200,366	351,193	192,264	148,084	200,718
Age 4	139,948	214,184	129,574	168,341	217,036	388,951	91,814	91,288	136,402	149,886	253,763	164,340	111,432
Age 5	101,695	98,352	110,661	89,443	113,826	140,245	224,320	60,775	67,245	90,638	102,881	150,060	110,766
Age 6	62,948	55,212	55,623	65,659	51,846	68,341	68,844	107,545	30,805	47,362	61,182	59,436	83,572
Age 7	26,947	34,834	22,095	37,054	39,387	29,909	36,887	32,080	47,490	15,422	27,036	28,018	27,215
Age 8 (Age 8+)	16,929	28,252	31,936	30,863	21,658	10,177	12,351	16,459	12,233	16,829	5,273	11,999	11,105
Age 9 (Age 9+)					14,289	8,489	4,782	4,803	5,918	3,207	4,325	1,912	4,306
Age 10+						6,921	7,835	2,569	2,553	2,390	2,252	2,746	1,482
Total	990,021	1,132,281	1,183,315	1,245,255	1,159,343	1,037,582	945,964	1,176,078	1,124,297	956,285	909,380	1,137,431	1,233,870

Spawning Stock Biomass (tons)													
Fishing Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Age 0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 1	0	0	0	0	0	0	0	0	0	0	0	0	0
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	27,990	42,837	25,915	33,668	43,407	77,790	18,363	18,258	27,280	29,977	50,753	32,868	22,286
Age 5	81,356	78,681	88,529	71,555	91,061	112,196	179,456	48,620	53,796	72,511	82,305	120,048	88,613
Age 6	56,653	49,691	50,060	59,093	46,661	61,507	61,960	96,791	27,725	42,626	55,064	53,492	75,215
Age 7	26,947	34,834	22,095	37,054	39,387	29,909	36,887	32,080	47,490	15,422	27,036	28,018	27,215
Age 8 (Age 8+)	16,929	28,252	31,936	30,863	21,658	10,177	12,351	16,459	12,233	16,829	5,273	11,999	11,105
Age 9 (Age 9+)					14,289	8,489	4,782	4,803	5,918	3,207	4,325	1,912	4,306
Age 10+						6,921	7,835	2,569	2,553	2,390	2,252	2,746	1,482
Total	209,875	234,295	218,536	232,232	256,463	306,989	321,634	219,580	176,995	182,962	227,009	251,084	230,222

Appendix 4 (continued). Details of the stock analysis results (2007-2019 FYs)

Catch in number at age (CAA) (thousand individuals)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	6,045	23,733	106,104	35,453	39,169	30,360	5,983	11,325	3,979	6,177	7,012	164	2,170
Age 1	10,602	4,092	28,654	24,789	1,810	10,115	1,198	6,114	4,664	5,988	5,897	3,938	2,370
Age 2	86,920	7,312	19,908	26,866	18,367	12,865	5,172	19,759	28,019	10,295	6,242	5,618	19,591
Age 3	25,017	118,764	26,208	34,131	37,725	28,163	9,471	16,239	18,946	10,099	28,681	7,651	45,781
Age 4	88,392	43,795	192,822	55,943	93,150	58,028	97,712	13,366	19,752	37,272	29,555	34,129	18,114
Age 5	56,202	81,685	61,453	197,168	78,636	91,388	61,399	90,110	12,066	29,090	34,999	29,864	40,482
Age 6	48,918	38,650	43,000	28,608	98,311	38,778	61,438	43,699	55,641	8,916	18,703	23,342	27,087
Age 7	26,290	24,471	6,367	9,816	10,681	52,755	17,421	51,820	23,217	29,736	5,308	6,880	10,967
Age 8 (Age 8+)	6,937	12,951	3,763	1,305	4,085	5,628	35,931	13,845	35,626	11,006	18,461	1,721	2,946
Age 9 (Age 9+)	1,658	1,185	2,899	1,310	1,421	2,766	1,964	21,618	6,997	18,942	6,237	8,624	1,419
Age 10+	1,078	1,035	461	995	1,741	1,830	1,054	4,497	17,138	16,171	12,679	11,172	14,479
Total	358,059	357,673	491,639	416,384	385,096	332,676	298,743	292,392	226,045	183,692	173,774	133,103	185,406

Catch in weight at age (tons)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	262	763	3,177	1,326	1,891	1,507	323	436	191	298	326	7	75
Age 1	944	394	3,015	2,076	255	1,406	91	472	444	743	535	560	191
Age 2	21,023	1,372	3,773	5,596	4,335	2,065	848	3,257	5,134	2,333	1,397	1,539	3,621
Age 3	7,911	41,159	7,868	10,838	14,822	10,738	2,913	5,075	7,621	3,445	10,864	2,994	13,015
Age 4	40,250	18,279	86,654	24,122	40,307	27,850	45,373	6,398	9,425	17,174	14,158	16,960	8,572
Age 5	29,608	41,833	33,285	103,238	39,513	46,188	32,560	49,387	6,501	16,260	20,940	16,596	22,844
Age 6	29,104	23,764	25,376	18,201	56,668	22,435	34,700	26,703	33,536	5,656	12,088	15,403	18,105
Age 7	17,486	16,690	4,456	6,830	7,999	34,565	10,691	32,749	14,820	19,314	3,827	4,956	8,362
Age 8 (Age 8+)	4,583	8,964	2,584	1,005	3,110	5,114	25,851	9,038	23,312	7,851	13,636	1,272	2,309
Age 9 (Age 9+)	1,320	887	1,982	1,096	1,449	2,361	1,542	16,042	4,982	13,779	4,913	6,562	1,123
Age 10+	1,059	1,148	329	1,147	1,888	1,944	932	4,780	14,038	12,896	10,233	9,298	12,164
Total	153,549	155,254	172,499	175,474	172,239	156,172	155,823	154,337	120,003	99,748	92,917	76,146	90,182

Fishing mortality (F)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	0.002	0.016	0.052	0.108	0.068	0.032	0.008	0.008	0.010	0.004	0.004	0.000	0.003
Age 1	0.011	0.002	0.029	0.018	0.009	0.027	0.002	0.013	0.005	0.022	0.005	0.003	0.004
Age 2	0.042	0.011	0.016	0.038	0.019	0.088	0.019	0.044	0.085	0.016	0.033	0.007	0.020
Age 3	0.071	0.080	0.052	0.037	0.075	0.040	0.094	0.084	0.058	0.043	0.059	0.056	0.081
Age 4	0.312	0.180	0.190	0.159	0.141	0.168	0.200	0.196	0.147	0.165	0.180	0.098	0.191
Age 5	0.549	0.570	0.439	0.322	0.373	0.212	0.285	0.305	0.288	0.356	0.243	0.297	0.170
Age 6	0.681	1.039	0.732	0.399	0.278	0.338	0.228	0.359	0.332	0.381	0.436	0.269	0.514
Age 7	0.636	0.987	0.488	0.380	0.268	0.250	0.264	0.324	0.349	0.315	0.438	0.299	0.206
Age 8 (Age 8+)	1.294	0.826	0.404	0.181	0.284	0.233	0.285	0.368	0.413	0.294	0.349	0.260	0.212
Age 9 (Age 9+)	0.787	0.869	0.461	0.252	0.325	0.336	0.125	0.294	0.340	0.429	0.286	0.289	0.377
Age 10+	0.787	0.869	0.461	0.252	0.325	0.336	0.125	0.294	0.340	0.429	0.286	0.289	0.377
Total	20%	20%	27%	29%	30%	32%	37%	30%	34%	35%	35%	42%	36%

Number of fish at age (thousand individuals)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	3,117,204	1,829,850	2,548,444	421,663	731,290	1,170,057	864,033	1,664,236	488,476	1,938,417	2,390,638	997,362	917,815
Age 1	1,140,678	2,084,576	1,207,154	1,621,402	253,623	458,130	759,456	574,281	1,106,298	324,177	1,294,302	1,596,752	668,418
Age 2	2,469,115	794,922	1,465,541	826,613	1,121,773	177,206	314,347	534,174	399,556	775,680	223,417	907,129	1,121,907
Age 3	415,451	1,754,352	582,600	1,068,564	589,246	815,221	120,204	228,422	378,719	271,882	565,777	160,139	667,183
Age 4	373,806	301,476	1,261,482	430,601	802,078	425,613	610,041	85,257	163,564	278,227	202,830	415,316	117,965
Age 5	150,714	213,115	196,141	812,279	285,983	542,454	280,258	388,870	54,602	109,953	183,791	131,882	293,330
Age 6	112,187	67,778	93,887	98,523	458,603	153,328	341,814	164,081	223,331	31,876	59,959	112,250	76,355
Age 7	63,306	44,201	18,677	35,172	51,483	270,401	85,190	211,986	89,223	124,827	16,956	30,191	66,822
Age 8 (Age 8+)	10,829	26,102	12,829	8,927	18,729	30,669	164,033	50,972	119,364	48,998	70,974	8,521	17,441
Age 9 (Age 9+)	3,450	2,312	8,899	6,670	5,801	10,982	18,918	96,400	27,479	61,521	28,447	38,983	5,117
Age 10+	2,243	2,019	1,415	5,067	7,107	7,263	10,153	19,977	67,308	52,521	57,829	50,499	52,218
Total	8,589,983	7,120,703	7,397,069	5,335,481	4,325,716	4,061,324	3,568,447	4,018,296	3,117,920	4,018,079	5,094,920	4,449,024	4,004,571

Total Biomass (tons)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	135,023	58,812	76,311	15,771	35,303	58,071	46,652	63,997	23,447	93,439	111,030	43,192	31,833
Age 1	101,582	200,677	127,016	135,802	35,797	63,679	57,416	44,334	105,273	40,229	117,507	226,918	53,755
Age 2	597,192	149,190	277,719	172,165	264,788	28,439	51,520	88,052	73,206	175,744	50,001	248,505	207,361
Age 3	131,370	607,991	174,912	339,306	231,508	310,841	36,973	71,392	152,336	92,745	214,313	62,675	189,679
Age 4	170,216	125,830	566,907	185,669	347,066	204,268	283,274	40,808	78,043	128,205	97,166	206,384	54,523
Age 5	79,398	109,141	106,238	425,313	143,703	274,159	148,623	213,131	29,419	61,460	109,962	73,287	165,525
Age 6	66,746	41,674	55,408	62,681	264,347	88,708	193,052	100,266	134,604	20,220	38,751	74,071	51,037
Age 7	42,107	30,147	13,071	24,472	38,556	177,166	52,280	133,970	56,951	81,076	12,226	21,746	50,948
Age 8 (Age 8+)	7,155	18,066	8,812	6,876	14,261	27,867	118,016	33,273	78,107	34,953	52,425	6,299	13,669
Age 9 (Age 9+)	2,746	1,731	6,085	5,581	5,918	9,371	14,851	71,265	19,568	44,752	22,409	29,660	4,050
Age 10+	2,203	2,241	1,009	5,840	7,711	7,717	8,973	21,237	55,134	41,884	46,671	42,027	43,871
Total	3,357,736	3,445,501	3,413,488	3,379,476	3,388,958	3,250,286	3,011,631	3,117,920	2,806,088	3,117,920	4,018,079	4,449,024	4,004,571

Spawning Stock Biomass (tons)													
Fishing Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age 1	0	0	0	0	0	0	0	0	0	0	0	0	0
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	34,043	25,166	113,381	37,134	69,413	40,854	56,655	8,162	15,609	25,641	19,433	41,277	10,905
Age 5	63,518	87,313	84,991	340,250	114,962	219,327	118,898	170,505	23,535	49,168	87,970	58,630	132,420
Age 6	60,071	37,506	49,867	56,413	237,912	79,837	173,747	90,240	121,144	18,198	34,875	66,664	45,933
Age 7	42,107	30,147	13,071	24,472	38,556	177,166	52,280	133,970	56,951	81,076	12,226	21,746	50,948
Age 8 (Age 8+)	7,155	18,066	8,812	6,876	14,261	27,867	118,016	33,273	78,107	34,953	52,425	6,299	13,669
Age 9 (Age 9+)	2,746	1,731	6,085	5,581	5,918	9,371	14,851	71,265	19,568	44,752	22,409	29,660	4,050
Age 10+	2,203	2,241	1,009	5,840	7,711	7,717	8,973	21,237	55,134	41,884	46,671	42,027	43,871
Total	211,843	202,171	277,215	476,566	488,733	562,138	543,420	528,651	370,047	295,672	276,010	266,303	301,796

Appendix 5. Search for the weight of penalty term of Ridge VPA

For tuning of cohort analysis of this stock, F value of the terminal year is estimated by age since the assessment of the last year. The Ridge VPA method (Okamura et al. 2017) has been introduced to mitigate the instability of estimation. For maximum likelihood estimation of F value at age of the terminal year, Ridge VPA mitigates the instability of estimation by using likelihood L , which indicates fitness with the tuning index (defined as negative log likelihood $-\ln L$), and an objective function where penalty is weighted to the square value of F. Usually, penalty λ is given uniformly to the square value of F as shown in equation (1). However, because the retrospective bias of F value of age 3 of this stock is particularly strong, equation (2) is used to change the weight of penalty between the F value of age 3, which has an especially strong bias, and the F value of other ages (ages 4 to 9). Penalty weight λ and η take a value between 0 and 1. α is added in this assessment and is a weight conveniently given to search for λ and η easily. The value of α is set to 20.

$$-(1 - \lambda)\ln L + \lambda \sum_{a=3}^9 F_{a,2019}^2 \quad (1)$$

$$-(1 - \lambda)\ln L + \alpha \lambda [(1 - \eta) \sum_{a=4}^9 F_{a,2019}^2 + \eta F_{3,2019}^2] \quad (2)$$

* Repost of equation (8) of Appendix 2

We eventually chose λ and η by searching for the values where the retrospective difference of estimated SSB and F value at age (ages 3 to 9) is smallest. The index for retrospective difference we used is RMSPE (Root Mean Square Percentage Error), which is expressed by equations (3) and (4) below.

$$RMSPE_{SSB'} = \sqrt{\frac{1}{n} \sum_{k=Y-i}^n \left(\frac{SSB'_k{}^{R_i} - SSB'_k}{SSB'_k} \right)^2} \quad (3)$$

$$RMSPE_{F'_a} = \sqrt{\frac{1}{n} \sum_{k=Y-i}^n \left(\frac{F'_{a,k}{}^{R_i} - F'_{a,k}}{F'_{a,k}} \right)^2} \quad (4)$$

* Repost of equations (9) and (10) of Appendix 2

Here, R_i indicates that this is the value of retrospective calculation of year i . n is the range of comparison of difference in estimates. In this analysis, n is set to 11 corresponding to the number of cohort-ages. Data used for the retrospective calculation go back five years. Last year, retrospective bias ρ (Mohn 1999) defined in equation (5) below was used, and the index for %SPR was focused in addition to SSB and F value at age. However, though ρ is effective for detection of unidirectional bias, it is insufficient for an equation to calculate degree of variation of estimation.

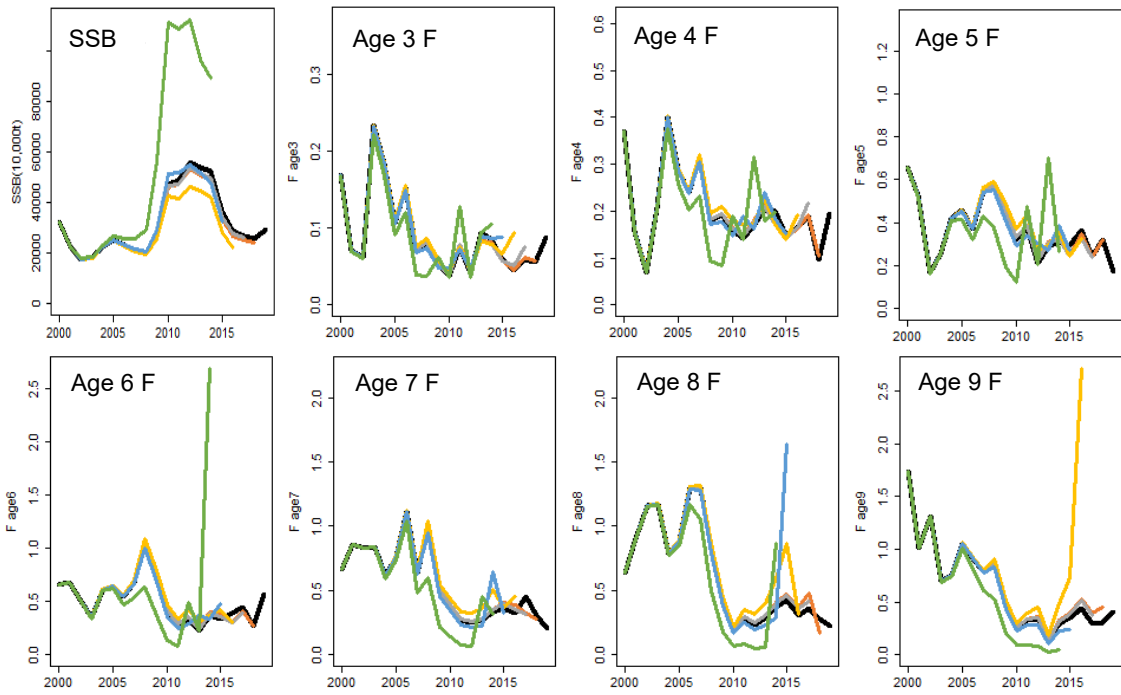
$$\rho_{SSB'} = \frac{1}{P} \sum_{i=1}^P \frac{SSB'_{Y-i}{}^{R_i} - SSB'_{Y-i}}{SSB'_{Y-i}} \quad (5)$$

* Example of calculation of retrospective bias ρ of SSB

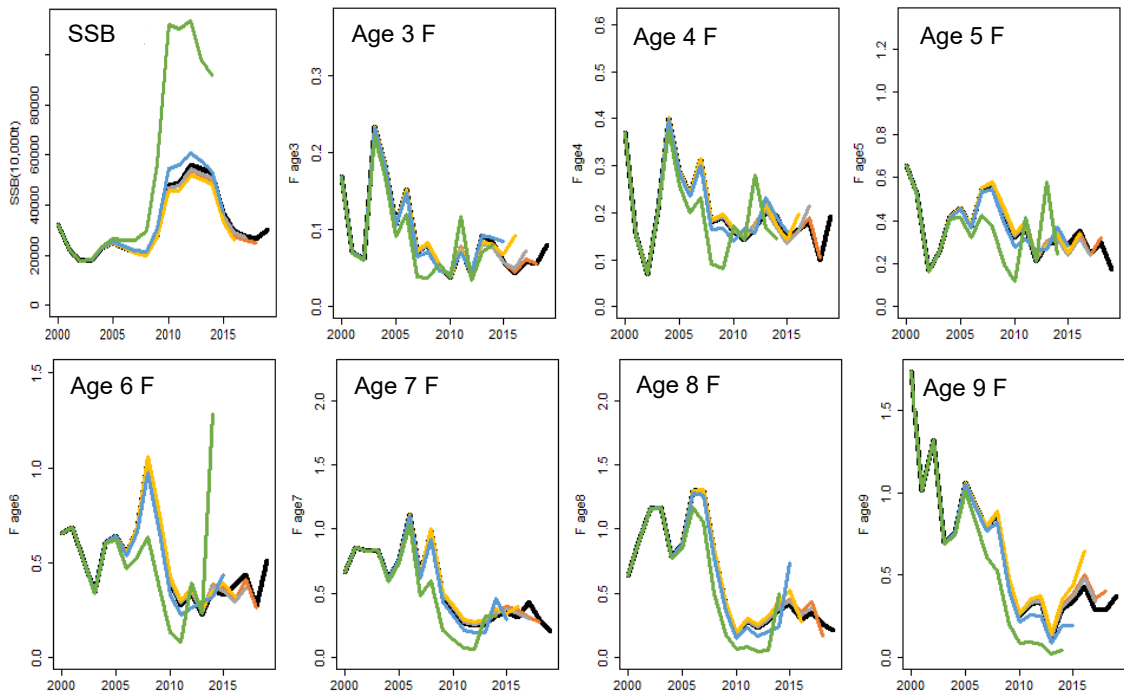
We obtained the combination of λ ($0 \leq \lambda < 1$) and η ($0 \leq \eta \leq 1$) by grid searching for the value at which the average RMSPE of SSB and F value of each age is smallest first with intervals of 0.05, then with intervals of 0.005 around the combination with the smallest value of the first search. Search results with 0.05 intervals and 0.005 intervals are shown in Appendix tables 5-1 and 5-2, respectively. As a result of search, when λ was 0.540 and η was 0.945, the average RMSPE of SSB and F value of each age was smallest (0.199). When penalty was not given, the average RMSPE of SSB and F value at age was 0.309. Giving a penalty was able to reduce the variation of estimates of retrospective analysis, but could not prevent deviation of estimates of SSB and F value of age 6 fish when the data of the five years were removed (Appendix Figures 5-1 and 5-2). RMSPE of SSB and F values at age of the combinations where average RMSPE was smallest, second and third smallest, as well as the values without penalty, together with the estimated SSB of the terminal year, are shown in Appendix Table 5-3. When the penalty where the average of RMSPE was smallest (λ is 0.540 and η is 0.945), second smallest (λ is 0.505 and η is 0.930) and third smallest (λ is 0.555 and η is 0.950), every RMSPE of SSB and F values at age had a smaller variation of estimates compared with the values without penalty, which may indicate stable estimation. The difference among the SSB of the terminal year (2019 FY) with varied penalties was less than 1 thousand tons.

References

- Mohn, R. (1999) The retrospective problem in sequential population analysis: an investigation using cod fishery and simulated data. *ICES J. Mar. Sci.*, 56, 473-488.
- Okamura, H., Y. Yamashita and M. Ichinokawa (2017) Ridge virtual population analysis to reduce the instability of fishing mortalities in the terminal year. *ICES J. Mar. Sci.*, 74(9), 2427-2436.



Appendix Figure 5-1. Result of retrospective analysis (without penalty)



Appendix Figure 5-2. Result of retrospective analysis of Ridge VPA when λ is 0.540 and η is 0.945.

Appendix Table 5-1. Average RMSPE (Root Mean Squared Percentage Error) of SSB and F value at age when penalties λ and η are changed with intervals of 0.05

RMSPE	Eta	Lambda																			
		0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95
	0	0.309	0.227	0.213	0.228	0.236	0.252	0.270	0.258	0.296	0.300	0.337	0.329	0.374	0.442	0.672	0.960	1.120	1.244	6.363	10.123
	0.05	0.309	0.225	0.219	0.226	0.237	0.257	0.251	0.267	0.277	0.282	0.308	0.331	0.392	0.385	0.631	0.889	1.179	1.442	3.456	1.2E+08
	0.1	0.309	0.226	0.218	0.234	0.236	0.268	0.250	0.285	0.283	0.333	0.301	0.347	0.367	0.418	0.415	0.876	0.996	1.531	3.356	1.1E+08
	0.15	0.309	0.228	0.220	0.229	0.231	0.244	0.236	0.270	0.268	0.307	0.302	0.380	0.442	0.392	0.402	0.752	0.947	1.255	3.233	5E+08
	0.2	0.309	0.227	0.225	0.225	0.228	0.241	0.257	0.289	0.302	0.277	0.306	0.302	0.342	0.379	0.467	0.658	0.847	1.109	1.437	1.9E+09
	0.25	0.309	0.228	0.220	0.220	0.252	0.243	0.256	0.260	0.283	0.266	0.304	0.292	0.339	0.352	0.377	0.624	0.797	1.264	1.362	2.3E+08
	0.3	0.309	0.220	0.228	0.233	0.223	0.235	0.247	0.279	0.257	0.263	0.297	0.289	0.365	0.337	0.403	0.589	0.779	1.035	1.288	Inf
	0.35	0.309	0.222	0.222	0.229	0.233	0.225	0.249	0.245	0.273	0.257	0.284	0.282	0.331	0.394	0.344	0.459	0.723	0.955	1.213	8.216
	0.4	0.309	0.224	0.229	0.220	0.235	0.246	0.256	0.257	0.255	0.268	0.267	0.303	0.294	0.320	0.326	0.522	0.719	0.970	1.136	7.699
	0.45	0.309	0.226	0.229	0.224	0.238	0.225	0.257	0.276	0.257	0.253	0.284	0.279	0.294	0.331	0.333	0.417	0.606	0.846	1.354	7.190
	0.5	0.309	0.225	0.224	0.216	0.227	0.228	0.236	0.233	0.245	0.273	0.269	0.272	0.287	0.309	0.364	0.389	0.403	0.753	1.123	6.676
	0.55	0.309	0.306	0.224	0.221	0.237	0.226	0.230	0.239	0.254	0.248	0.275	0.260	0.283	0.286	0.317	0.325	0.424	0.706	1.042	6.145
	0.6	0.309	0.293	0.227	0.217	0.222	0.230	0.233	0.228	0.233	0.241	0.263	0.256	0.270	0.281	0.310	0.333	0.411	0.639	0.949	3.521
	0.65	0.309	0.307	0.228	0.223	0.211	0.221	0.226	0.229	0.240	0.241	0.240	0.250	0.282	0.291	0.300	0.322	0.432	0.574	0.826	1.355
	0.7	0.309	0.321	0.232	0.218	0.217	0.218	0.234	0.225	0.219	0.225	0.236	0.256	0.283	0.263	0.288	0.305	0.348	0.384	0.821	1.183
	0.75	0.309	0.309	0.222	0.218	0.226	0.220	0.226	0.225	0.225	0.234	0.229	0.223	0.253	0.242	0.267	0.311	0.312	0.468	2.591	3.893
	0.8	0.309	0.304	0.231	0.221	0.224	0.228	0.214	0.221	0.222	0.230	0.232	0.231	0.240	0.238	0.244	0.308	0.281	0.314	2.339	3.417
	0.85	0.309	0.323	0.234	0.223	0.230	0.225	0.215	0.221	0.216	0.221	0.234	0.229	0.234	0.230	0.239	0.258	0.268	0.381	0.354	3.050
	0.9	0.309	0.315	0.240	0.231	0.230	0.237	0.225	0.227	0.220	0.215	0.219	0.218	0.224	0.227	0.229	0.238	0.239	0.248	0.306	2.379
	0.95	0.309	0.335	0.250	0.232	0.228	0.235	0.233	0.230	0.219	0.223	0.229	0.207	0.211	0.209	0.218	0.213	0.210	0.223	0.254	0.302
	1	0.309	0.370	0.292	0.287	0.294	0.288	0.291	0.282	0.281	0.281	0.296	0.290	0.279	0.285	0.293	0.275	0.282	0.274	0.270	0.273

Appendix Table 5-2. Average RMSPE (Root Mean Squared Percentage Error) of SSB and F value at age when penalties λ and η are changed with intervals of 0.005

Further search around the combination at which the value was smallest in the search with intervals of 0.05 (see Appendix Table 5-1)

RMSPE	Eta	Lambda																				
		0.500	0.505	0.510	0.515	0.520	0.525	0.530	0.535	0.540	0.545	0.550	0.555	0.560	0.565	0.570	0.575	0.580	0.585	0.590	0.595	0.600
	0.905	0.214	0.213	0.212	0.215	0.213	0.214	0.213	0.219	0.214	0.214	0.216	0.221	0.224	0.218	0.227	0.228	0.219	0.238	0.225	0.224	0.221
	0.910	0.211	0.211	0.213	0.213	0.217	0.216	0.216	0.220	0.217	0.215	0.215	0.215	0.216	0.219	0.217	0.217	0.221	0.217	0.228	0.233	0.221
	0.915	0.210	0.217	0.223	0.217	0.218	0.219	0.224	0.216	0.225	0.218	0.217	0.219	0.220	0.219	0.218	0.217	0.220	0.219	0.225	0.225	0.213
	0.920	0.211	0.216	0.208	0.208	0.216	0.217	0.219	0.220	0.220	0.220	0.219	0.219	0.220	0.220	0.221	0.216	0.218	0.218	0.216	0.220	0.232
	0.925	0.212	0.209	0.218	0.219	0.215	0.218	0.217	0.211	0.224	0.223	0.222	0.222	0.222	0.220	0.218	0.222	0.218	0.218	0.221	0.216	0.220
	0.930	0.208	0.202	0.209	0.215	0.209	0.211	0.215	0.213	0.214	0.214	0.215	0.224	0.224	0.224	0.223	0.219	0.219	0.222	0.222	0.226	0.217
	0.935	0.207	0.207	0.211	0.207	0.209	0.207	0.216	0.216	0.215	0.221	0.217	0.214	0.214	0.218	0.224	0.224	0.223	0.216	0.225	0.220	0.227
	0.940	0.207	0.208	0.210	0.208	0.208	0.209	0.206	0.211	0.212	0.213	0.213	0.213	0.213	0.213	0.213	0.214	0.217	0.213	0.209	0.211	0.213
	0.945	0.227	0.218	0.209	0.209	0.209	0.208	0.210	0.209	0.199	0.210	0.210	0.212	0.213	0.215	0.215	0.215	0.215	0.215	0.211	0.207	0.211
	0.950	0.229	0.220	0.221	0.211	0.209	0.209	0.207	0.210	0.213	0.210	0.207	0.202	0.212	0.211	0.214	0.215	0.209	0.214	0.208	0.205	0.211
	0.955	0.222	0.229	0.225	0.220	0.216	0.213	0.209	0.208	0.210	0.208	0.211	0.211	0.212	0.213	0.214	0.215	0.213	0.214	0.214	0.206	0.204
	0.960	0.223	0.226	0.224	0.231	0.229	0.216	0.218	0.210	0.209	0.208	0.219	0.214	0.210	0.211	0.213	0.214	0.214	0.214	0.213	0.215	0.205
	0.965	0.231	0.226	0.226	0.226	0.225	0.223	0.221	0.219	0.215	0.211	0.209	0.209	0.214	0.207	0.207	0.210	0.213	0.214	0.214	0.214	0.214
	0.970	0.228	0.231	0.232	0.229	0.225	0.223	0.234	0.226	0.221	0.218	0.214	0.211	0.212	0.210	0.208	0.208	0.208	0.207	0.207	0.214	0.216
	0.975	0.239	0.228	0.232	0.233	0.226	0.226	0.225	0.230	0.233	0.224	0.220	0.215	0.215	0.212	0.220	0.209	0.209	0.209	0.209	0.209	0.209
	0.980	0.238	0.242	0.234	0.232	0.235	0.234	0.230	0.228	0.226	0.238	0.223	0.231	0.221	0.217	0.218	0.213	0.212	0.212	0.211	0.211	0.211
	0.985	0.233	0.232	0.234	0.241	0.235	0.248	0.230	0.232	0.231	0.228	0.229	0.229	0.227	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229
	0.990	0.238	0.238	0.248	0.238	0.247	0.247	0.243	0.242	0.237	0.238	0.234	0.233	0.233	0.233	0.227	0.219	0.224	0.223	0.221	0.217	0.215
	0.995	0.242	0.259	0.253	0.259	0.260	0.255	0.260	0.250	0.252	0.246	0.247	0.244	0.241	0.243	0.240	0.233	0.241	0.233	0.231	0.230	0.229

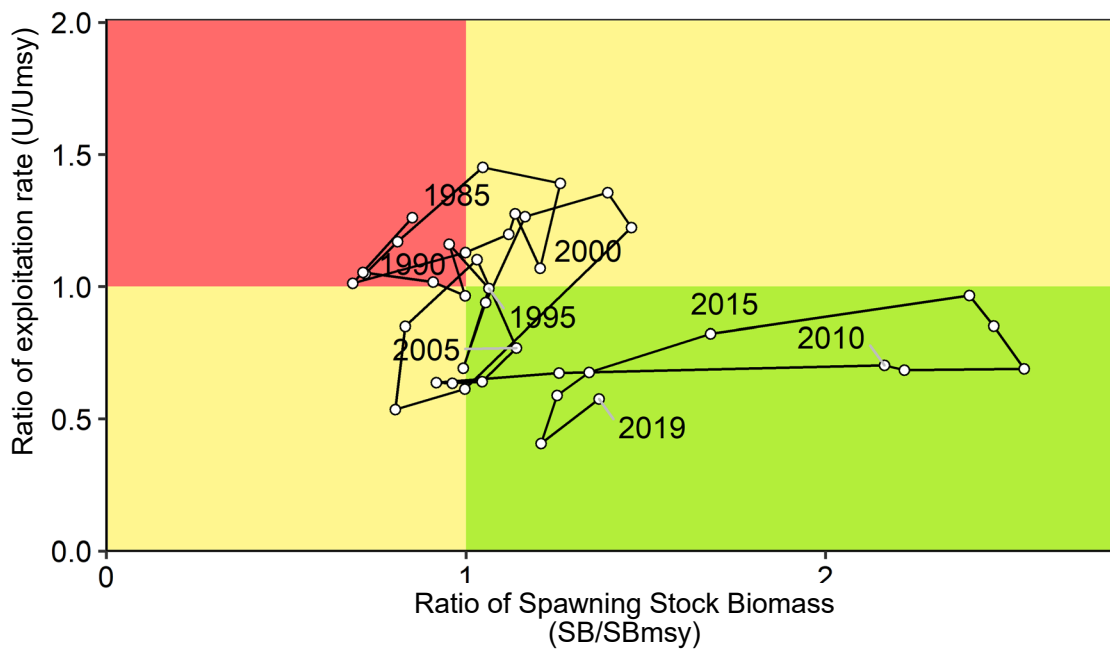
Appendix Table 5-3. Penalties λ and η , with which Root Mean Squared Percentage Error (RMSPE) of SSB and F value at age is smallest, second and third smallest in the retrospective analysis, RMSPE with the combinations, and the estimated SSB of the terminal year (2019 FY)

λ	η	RMSPE										Estimated SSB2019 (1000 t)
		Average	SSB	F age3	F age4	F age5	F age6	F age7	F age8	F age9		
0	0	0.309	0.215	0.200	0.144	0.190	0.509	0.256	0.434	0.522	293.9	
0.540	0.945	0.199	0.203	0.192	0.129	0.151	0.258	0.193	0.227	0.242	301.8	
0.505	0.930	0.202	0.245	0.198	0.131	0.148	0.222	0.197	0.229	0.245	302.4	
0.555	0.950	0.202	0.258	0.192	0.130	0.151	0.249	0.197	0.233	0.246	301.6	

Appendix 6. Kobe plot based on exploitation rate

The figure below shows a Kobe plot based on the SSB corresponding to MSY (SBmsy) and exploitation rate (U) that can produce MSY (Umsy). The SSB of the present stock has been above SBmsy since the 2009 FY, and U has been below Umsy since the 2005 FY. (Appendix Figure 6-1).

Item	Value	Remarks
SBmsy	220 thousand tons	SSB corresponding to MSY
Umsy	18%	Exploitation rate that can produce MSY
U2019	10%	Exploitation rate in the 2019 FY
U2019/Umsy	0.575	Ratio of U2019 to Umsy



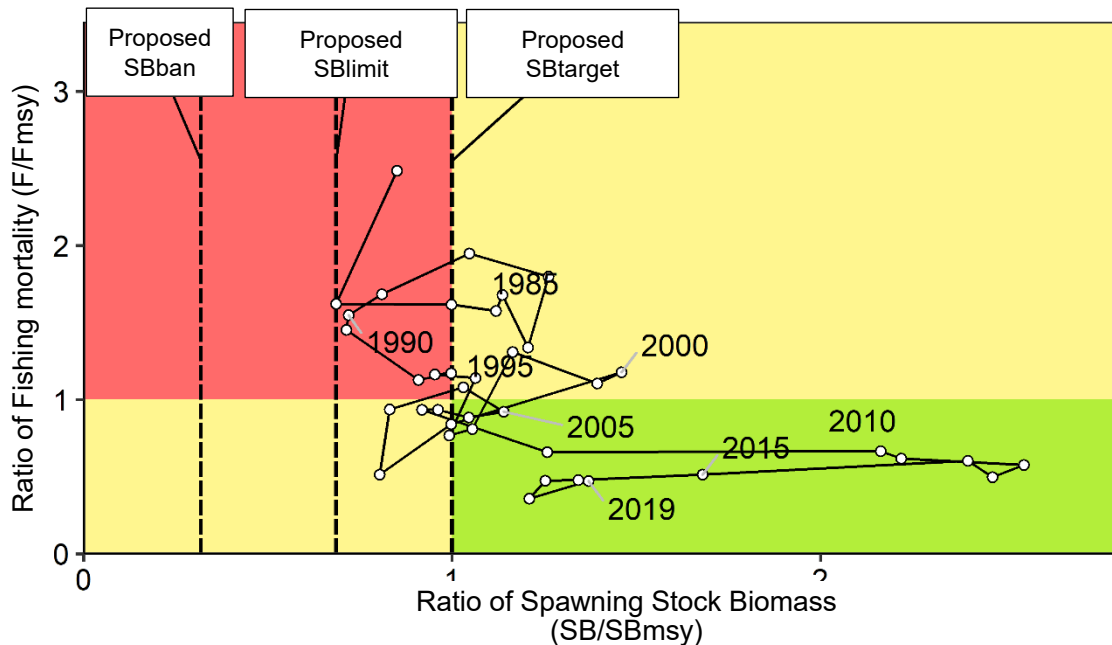
Appendix Figure 6-1. Relationship of Spawning Stock Biomass (SSB) ratio to SBmsy and exploitation rate (U) ratio to Umsy (Kobe plot)

Appendix 7. Proposed reference points and fishing ban level

The reference points and fishing ban level, etc. proposed for the present stock are as shown below.

Item	Value	Remarks
Propose SBtarget	220 thousand tons	SSB corresponding to MSY (SBmsy)
Proposed SBlimit	151 thousand tons	The smallest SSB ever observed (SBmin)
Proposed SBban	70 thousand tons	The threshold of for SSB to recover to the proposed target reference point with a probability of 50% under fishing based on the proposed HCRs ($\beta = 0.8$) for 10 years

The Research Institute Meeting held in April 2019 proposed the following: SSB corresponding to MSY (SBmsy: 220 thousand tons) as the proposed target reference point (SBtarget); the lowest SSB that has ever been observed in history (SBmin: 151 thousand tons) as the proposed limit reference point (SBlimit); and the threshold value at which the SSB will recover to the target reference point in 10 years with a probability of 50% under fishing based on the proposed HCRs (Appendix 8) with safety coefficient β set to 0.8 (70 thousand tons) as the proposed fishing ban level (SBban). This proposed limit reference point has the same value as “the lowest SSB with which generation of a high abundance year class is expected (151 thousand tons where the 1982 year-class was generated),” which had been used as Blimit. For details, see the “Report of the Research Institute Meeting on Reference Points of walleye pollock Pacific stock in 2019.”



Appendix Figure 7-1. Relationship between the proposed reference points and kobe plot based on SB/SBmsy vs F/Fmsy

Appendix 8. Future projection compliant with the proposed HCRs

(1) Setting of future projection

We conducted the future projection from 2020 to 2051 FYs using forward calculation of cohort analysis started from the stock condition in the 2019 FY, which was estimated in this stock assessment (Appendix 9). For recruitment in the future projection, we used the value given from the HS model and projected SSB of the respective year. We assumed errors in logarithmic normal distribution as uncertainty in recruitment in 10,000 stochastic simulations. The catch in the 2020 FY was assumed from the projected biomass and the current fishing mortality (F2015-2019). For the F2015-2019, we obtained this by %SPR-conversion of the average F value of the 2015-2019 FYs, which was 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 MSY reference points (e.g. Fmsy). For the F in the 2021 FY onward, we used the F specified in the proposed HCRs below based on the SSB projected for each year.

(2) Proposed HCRs

The HCRs are rules to specify the F corresponding to the SSB, considering the probability of maintaining SSB above the proposed SBtarget. The HCRs are described in the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)" as the Type-I rule. In this rule, the F is controlled to directly reduced according to the SSB level, when the SSB falls below the SBlimit. The SBban is the SSBlevel which catches should be prohibited. Upper limit of F is determined to multiplying the Fmsy by the β value which works as the safety coefficient. Appendix Figure 8-1 shows the HCRs proposed at the Scientific Meeting held in April 2019. Here, we present a case where the coefficient β is 0.8, which is the value recommended by the Scientific Meeting, as an example.

(3) Projection for the 2021 FY

We projected the SSB and catch in 2021 FY according to the future projection using the proposed HCRs. The average catch in 2021 FY was 195 thousand tons where β was 0.8. The projected SSB in 2021 FY was 340 thousand tons on average, which was above SBlimit in all simulations. For this reason, the fishing mortality of the 2021 FY, which was provided by the proposed HCRs, is Fmsy multiplied by the coefficient β .

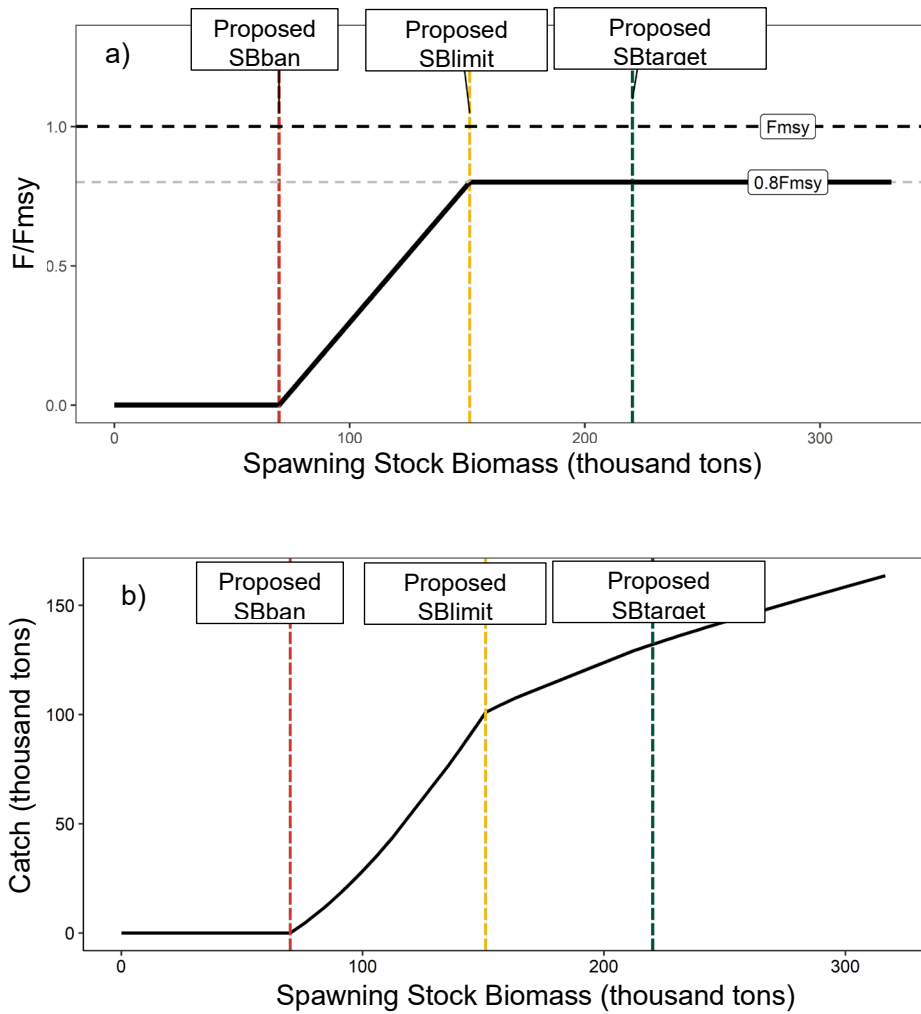
SSB in the 2021 FY (average projection value): 340 thousand tons			
Item	Catch in the 2021 FY (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019)	Exploitation rate in the 2021FY (%)
When using β recommended by the Scientific Meeting in the proposed HCRs			
$\beta=0.8$	195	1.69	19
The Other haevest strategy (when using different β in the proposed HCRs, etc.).			

$\beta=1.0$	233	2.11	23
$\beta=0.9$	214	1.90	21
$\beta=0.7$	175	1.48	17
$\beta=0.6$	153	1.27	15
$\beta=0.5$	131	1.05	13
$\beta=0$	0	0	0
F2015-2019	125	1.00	12

(4) Projection for the 2022 FY onward

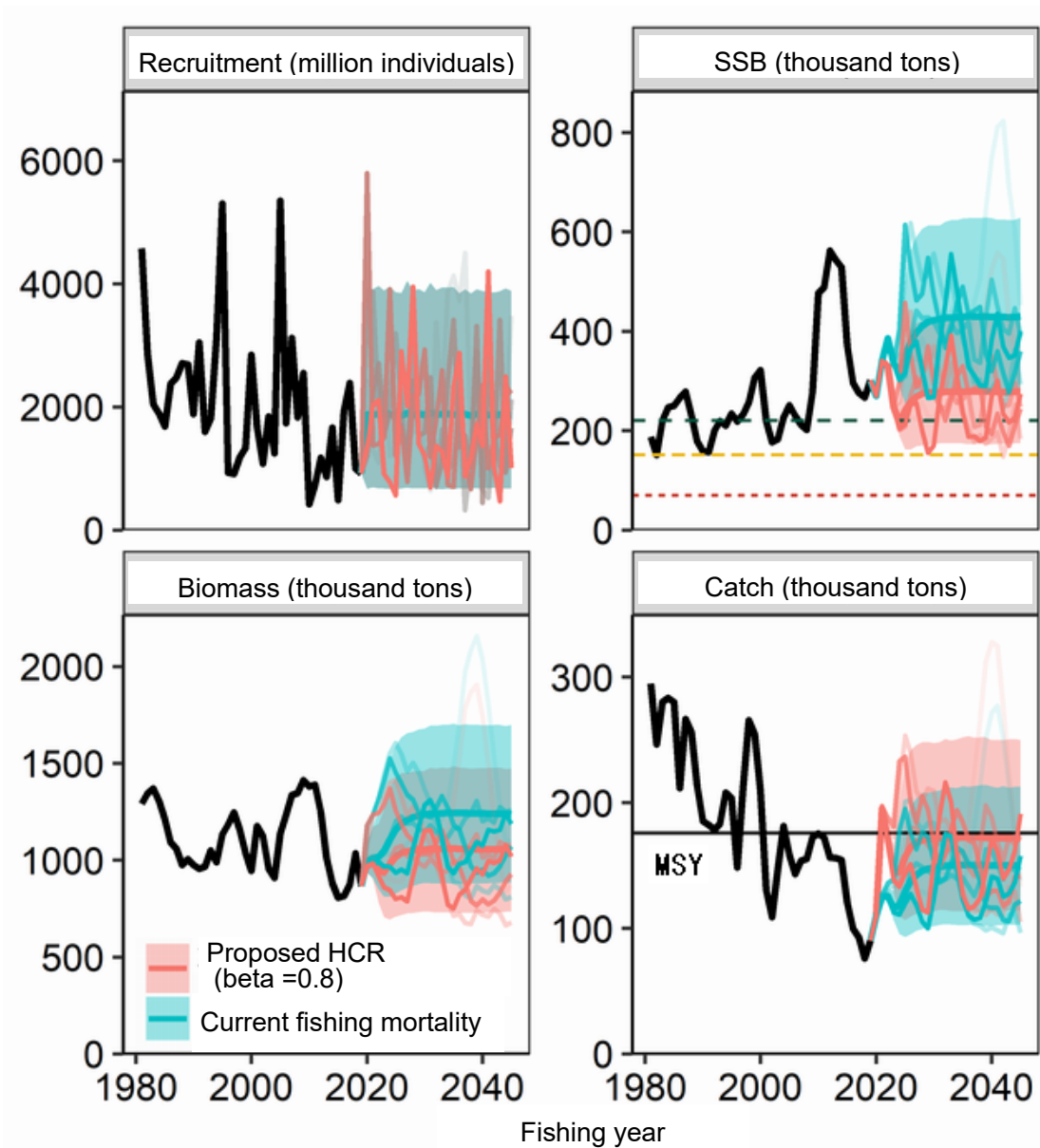
Appendix Figures 8-2 and Appendix Tables 8-1 and 8-2 show the medium- to long-term future projection results based on the proposed HCRs (Appendix Figures 8-1). When catch control based on the proposed HCRs is continued for 10 years, the projected SSB in the 2031 FY will be 277 thousand tons on average with β set to 0.8 (80% confidence interval: 192 thousand to 376 thousand tons). The probability of the projected SSB being above the proposed target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) in the 2031 FY is 77%, 99% and 100%, respectively. Most recently, the 2016 year-class is estimated to be relatively abundant and the abundance of the 2017 year-class is also estimated to be high. For this reason, it is projected that the SSB and abundance will stop declining in the short-term but we need to pay attention to the information that strength of the 2018-2019 year-classes seems to be weak. If we have the average recruitment that is projected from the HS model, it is expected that the SSB will be maintained above the proposed SBtarget with a high probability in the medium- to long- term.

Uncertainty considered: recruitment					
Item	SSB in the 2031 FY (thousand tons)	80% Confidence interval (thousand tons)	Probability of the SSB in the 2031 FY being above the following reference points (%)		
			Proposed SBtarget	Proposed SBlimit	Proposed SBban
When using β recommended by the Scientific Meeting in the proposed HCRs					
$\beta=0.8$	277	192-376	77	99	100
The Other harvest strategy (when using different β in the proposed HCRs, etc.).					
$\beta=1.0$ (Fmsy)	220	149-304	43	89	100
$\beta=0.9$	247	169-338	60	95	100
$\beta=0.7$	312	220-420	90	100	100
$\beta=0.6$	355	252-475	97	100	100
$\beta=0.5$	408	293-542	99	100	100
$\beta=0$	1,064	826-1336	100	100	100
F2015-2019	424	306-562	100	100	100



Appendix Figure 8-1. Proposed HCR (when β is 0.8)

The proposed target reference point (SB_{target}) is SB_{msy} , which is calculated based on the HS model of S-R relationship. As the proposed limit reference point (SB_{limit}), we used the lowest SSB that has ever been observed in assessment periods. As the proposed fishing ban level (SB_{ban}), we used the threshold value for SSB to recover to the SB_{target} in 10 years with a probability of 50% under fishing based on the proposed HCRs with the coefficient β set to 0.8. The black dashed line represents F_{msy} ; the grey dashed line represents $0.8F_{msy}$; the black thick line represents the proposed HCR; the red dashed line represents the proposed SB_{ban} ; the yellow dashed line represents the proposed SB_{limit} ; and the green dashed line represents the proposed SB_{target} . The upper chart a) expresses a schematic diagram of the proposed HCR where the vertical axis is fishing mortality. The lower chart b) where the vertical axis is the expected catch based on the proposed HCR under the respective SSB. Whereas the actual catch volume slightly different depending on the age composition, b) shows the catch volume in the case of average age composition in an equilibrium state.



Appendix Figure 8-2. Comparison of the future projection based on the proposed HCR ($\beta = 0.8$) with the future projection that assumes continued fishing at the current fishing mortality (F2015-2019)

The thick solid line, shaded area and thin lines represent average value, the 80% prediction interval and three future projection examples, respectively. In the figure of SSB, 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 catch in the 2020 FY was assumed based on the projected total biomass and the current fishing mortality (F2015-2019). The coefficient β in the proposed HCR used as an example is set to 0.8.

Appendix Table 8-1. Probability for SSB to exceed the proposed target reference point (SBtarget) (a) and the proposed limit reference point (SBlimit) (b)

The following tables show the results of the future projection when β is changed between 0 and 1.0 under the catch control by HCRs, or when the current fishing mortality is continued, after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass and the current fishing mortality (F2015-2019).

(a) Probability for SSB 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	100	100	100	100	0	4	28	37	42	44	45	43	43	44	44
0.9	100	100	100	100	100	11	39	50	56	59	60	60	60	61	61
0.8	100	100	100	100	100	31	55	65	71	74	75	76	77	76	77
0.7	100	100	100	100	100	85	75	80	85	87	89	89	90	89	90
0.6	100	100	100	100	100	100	92	93	95	95	96	96	97	97	97
0.5	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2015-2019	100	100	100	100	100	100	100	99	99	100	100	100	100	100	100

(b) Probability for SSB 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	100	100	100	100	100	93	80	84	88	89	89	89	89	89	89
0.9	100	100	100	100	100	100	91	93	95	95	95	95	95	95	96
0.8	100	100	100	100	100	100	98	98	98	99	98	98	99	99	99
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2015-2019	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 8-2. Projected average values of future SSB (a) and catch (b)

The following tables show the results of the future projection when β is changed between 0 and 1.0 under the catch control by HCRs, or when the current fishing mortality is continued, after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass and the current fishing mortality (F2015-2019).

(a) Future average SSB (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	302	270	340	299	207	174	198	212	219	222	222	220	220	221	222
0.9	302	270	340	314	226	193	218	233	242	246	247	247	247	248	249
0.8	302	270	340	329	248	215	241	258	268	274	276	276	277	278	279
0.7	302	270	340	345	271	241	268	287	300	307	311	311	312	314	315
0.6	302	270	340	363	298	270	301	322	338	347	352	354	355	357	358
0.5	302	270	340	381	327	305	339	365	384	396	403	406	408	412	413
0.4	302	270	340	400	360	345	386	416	440	457	468	473	476	483	483
0.3	302	270	340	420	397	392	441	479	511	534	549	558	564	576	576
0.2	302	270	340	442	438	448	509	558	600	633	656	670	680	704	704
0.1	302	270	340	465	484	513	592	656	714	762	797	821	839	890	890
0.0	302	270	340	488	535	590	694	781	862	933	989	1031	1064	1176	1183
F2015-2019	302	270	340	386	336	315	350	377	397	411	419	422	424	429	429

*Yellow shading expresses that the value is below the proposed target reference point.

(b) Average catch (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	90	110	233	189	152	153	166	173	176	177	176	175	176	176	177
0.9	90	110	214	181	148	149	162	169	173	174	174	174	175	175	175
0.8	90	110	195	171	144	145	157	165	168	170	171	171	172	172	172
0.7	90	110	175	160	138	139	151	159	163	165	166	166	167	167	168
0.6	90	110	153	146	130	132	143	151	155	158	159	160	161	161	161
0.5	90	110	131	130	119	122	133	141	145	149	150	151	152	153	153
0.4	90	110	107	112	105	109	120	127	132	136	138	139	140	141	141
0.3	90	110	83	90	87	92	102	109	114	118	120	122	123	125	125
0.2	90	110	56	64	65	70	78	84	89	92	95	97	98	100	100
0.1	90	110	29	34	36	40	45	49	53	55	57	59	60	63	63
0.0	90	110	0	0	0	0	0	0	0	0	0	0	0	0	0
F2015-2019	90	110	125	126	116	119	130	138	142	146	147	148	149	150	150

Appendix 9. Method of future projection of the stock

The HS model, which was applied at the “Scientific Meeting on Reference Points” held in April 2019, and the values calculated from the SSB for each year were used for estimating the future recruitment. The data used for estimating the parameters for the HS model are the SSB and recruitment based on the 2018 stock assessment, in which the optimization method to use the parameter estimation for HS model was the least squares method. The residual autocorrelation of recruitment was not considered in the model. For details, see the “Report of the Scientific Meeting on Reference Points of walleye pollock, Japanese Pacific stock in 2019.”

For fishing mortality (F) in future projection, we used the value calculated based on the HCRs according to 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. For the future projection, we used the selectivity that was used for simulation to estimate the level that can produce MSY at the meeting above (i.e. the selectivity based on the average F at age in the 2013-2017 Fys, which was used for future projection in the stock assessment in 2018). However, because the plus group was extended from age 8+ to age 10+ from the 2019 stock assessment, selectivity for ages 8, 9 and 10+ was set to the value of the previous selectivity for age 8+. Average body weight at age was also set to the value for the Fmsy calculation in order to maintain the consistency with the assumption of the calculation of Fmsy that was estimated by the 2019 Scientific Meeting. For this reason, average body weight of ages 8, 9 and 10+ is set to the value of the average body weight of age 8+ in the Fmsy calculation.

Future number of fish was estimated by forward calculation of cohort analysis as shown in equation (1). The plus group of age 10+ is calculated from ages 9 and 10+ of the previous year.

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

Future CAA was projected by equation (2) based on the number of fish obtained above and the F value assumed from the respective catch scenario since 2021 FY (i.e. HCRs). As F value in the 2020 FY, we gave the current fishing mortality (F2015-2019). We obtained F2015-2019 by %SPR-conversion of the average F value of the 2015-2019 Fys under the selectivity above.

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

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

Age	Selectivity (Note 1)	Fmsy (Note 2)	F2015-2019 (Note 3)	Average Body weight (g) (Note 4)	Natural Mortality	Maturity rate
0	0.026	0.017	0.008	47	0.40	0.0
1	0.025	0.017	0.008	95	0.35	0.0
2	0.111	0.075	0.036	194	0.30	0.0
3	0.200	0.136	0.064	349	0.25	0.0
4	0.548	0.371	0.176	473	0.25	0.2
5	0.906	0.614	0.291	555	0.25	0.8
6	0.996	0.675	0.320	612	0.25	0.9
7	1.000	0.678	0.322	651	0.25	1.0
8	1.000	0.678	0.322	740	0.25	1.0
9	1.000	0.678	0.322	740	0.25	1.0
10+	1.000	0.678	0.322	740	0.25	1.0

Note 1: Selectivity used for estimating the level that can produce MSY at the 2019 Scientific Meeting (i.e. the selectivity of $F_{current}$ in the 2018 stock assessment). However, the values for ages 8, 9 and 10+ are set to the value for age 8+ of this selectivity.

Note 2: Fmsy estimated at the 2019 Scientific Meeting (i.e. $F_{current}$ in the stock assessment in 2018 multiplied by $F_{msy}/F_{current}$). However, the values for ages 8, 9 and 10+ are set to the value for age 8+ of this selectivity.

Note 3: Calculated by %SPR-conversion of the average F value of the 2015-2019 Fys estimated in this stock assessment under the selectivity above. This F value was used for assumption of catch in the 2020 FY.

Note 4: Average body weight at age is set to the value for the Fmsy calculation in order to maintain consistency with the assumption of the calculation of Fmsy that was estimated by the 2019 Scientific Meeting. Average body weight of ages 8, 9 and 10 and above is set to the average body weight of age 8 and above in the Fmsy calculation.

Appendix 10. Revised S-R relationship, reference points and future projection

1. Introduction

The first Conference of Stock Management Policy (Stakeholder meeting) on this stock (held on August 20 and 21, 2020) requested to simply update the proposed target and limit reference points, fishing ban level, HCRs and future projection results based on the latest stock assessment. The meeting also requested to present the specific value of the coefficient β , with which the probability that the SSB will exceed the target reference point in the 2031 FY is exactly 50%.

In response, firstly we showed revised results for the parameter estimation of the HS model of S-R relationship based on the SSB and recruitment, which are estimated by the stock assessment of this year; secondly, we presented the revised proposal for the reference points, fishing ban level, and HCRs based on the revised HS model by using the same method as presented at the previous Scientific Meeting (held on April 19, 2019). Finally, we presented the results of future projection based on the updated conditions. In the future projection, we examined β , with which the probability that the SSB will exceed the target reference point is 50%, within the range of 0.9 to 1.0 in intervals of 0.01.

The proposal at the Scientific Meeting held in April 2019 was based on the 2018 stock assessment results (i.e. results of the latest stock assessment at that time). The revised proposal in this section is based on the 2020 stock assessment, which is the latest assessment result now. The latest stock assessment includes two more assessment years of abundance, etc. compared with the 2018 stock assessment. The plus group of cohort analysis has been expanded from age 8+ to age 10+ since the stock assessment of the last year (the stock assessment in 2019).

2. S-R relationship

As the S-R relationship of this stock, the Scientific Meeting has proposed the HS model for the S-R relationship. The least squares method was used for parameter estimation of the relationship. A model that considers autocorrelation in residuals of observation values of recruitment against the predicted values was not used. We updated the parameters of this HS model using the recruitment and SSB of the 1981-2016 FYs based on the latest stock assessment results. Compared to the previous model, we found a slight change in the slope of the updated HS model (parameter a in the table below and Appendix Figure 10-1). The breakpoint of the HS model is at 151 thousand tons of SSB also in the updated relationship (parameter b in the table below). The expected recruitment on average with the SSB at this level or higher is about 1.8 billion in number (previous value was about 1.9 billion). As is the case with the proposal at the Scientific Meeting in 2019, we did not use the data of the recent three years (2017-2019 FYs) for the estimation of the parameters of HS model, because the recruitment was not directly estimated from cohort analysis for these years.

Proposal	S-R relationship	Optimization method	Autocorrelation	<i>a</i>	<i>b</i>	S.D.
Proposal by the Scientific Meeting (2019)	Hockey stick (HS)	Least squares method	No	12.455	150,944	0.532
Updated value	Hockey stick (HS)	Least squares method	No	11.795	150,944	0.580

Here, *a* represents the slope of the S-R curve to the break point, while *b* represents the SSB (tons) at the break point.

Regarding this stock, we have no historical information of decrease in recruitment associated with the depletion of SSB. Compared with the HS model, Beverton-Holt (BH) and Ricker (RI) models have a milder decrease of the projected recruitment associated with a decrease of SSB (Appendix Figure 10-2). The 2019 Scientific Meeting concluded that, if SSB fell below the recorded low level, a non-conservative extrapolation number as recruitment would pose a risk, in the context of the fisheries management based on future projection result. Therefore, the HS model which can produce more conservative recruitment was approved to apply the S-R relationship. The updated data of recruitment and SSB has not changed this conclusion. We compared the least squares method and the least absolute value method for optimization of parameter estimation using the updated data, then the difference of the small-sample-size-corrected version of Akaike information criterion (AICc) between the two methods was very small, at 0.16. Therefore, there is no need to change the optimization method in this revision (Appendix Table 10-1). There is also no need to consider autocorrelation for the HS model because a diagnostic did not show any autocorrelation in the residuals between the predicted value and observed value (Appendix Figure 10-3). For these reasons, in this revision based on the 2020 stock assessment, we did not change the model of the S-R relationship, optimization method, and treatment of autocorrelation from those of the 2019 Scientific Meeting (Appendix Figure 10-4).

3. Proposed target reference point / limit reference point / fishing ban

The 2019 Scientific Meeting proposed as following: SB_{msy}, which is the SSB corresponding to MSY, as the target reference point (SB_{target}); SB_{min}, which is the lowest SSB that has ever been observed in history, as the limit reference point (SB_{limit}); and the SSB level at which the SSB will recover to the SB_{target} in 10 years with a probability of 50% or higher under fishing based on the proposed HCRs, as the fishing ban level (SB_{ban}). The revised results using the 2020 stock assessment are shown in the table below and Appendix Table 10-2.

Proposal	Item	Value	Remarks
Proposal by the Scientific Meeting (2019)	SB _{target}	220 thousand tons	SSB corresponding to MSY (SB _{msy})
	SB _{limit}	151 thousand tons	The smallest SSB ever observed (SB _{min})
	SB _{ban}	70 thousand tons	The threshold for SSB to recover to the proposed SB _{target} with a probability of 50%

			under fishing based on the proposed HCRs ($\beta = 0.8$) for 10 years
Updated value	SBtarget	228 thousand tons	SSB corresponding to MSY (SBmsy)
	SBlimit	151 thousand tons	The smallest SSB ever observed (SBmin)
	SBban	60 thousand tons	The threshold of for SSB to recover to the updated SBtarget with a probability of 50% under fishing based on the proposed HCRs ($\beta = 0.8$) for 10 years

We updated SBmsy as the SBtarget in the same way as used for the 2019 Scientific Meeting: i.e. the equilibrium situation is defined as after the simulation period that is 20 times the average generation time (8.46 years); Fmsy is defined as the F value which can maximize the average catch at equilibrium situation; SBmsy is defined as the average SSB at equilibrium situation under fishing by Fmsy. For the simulation, we used the updated HS model 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 2015-2019 FYs. The settings of other biological parameters used for the simulation are shown in Appendix Table 10-3. Average SSB at equilibrium situation when we used various F and the corresponding average catch at age are shown in Appendix Figure 10-5. Here, the ratio of older fish in expected catch were increase on average with higher SSB level. Updated SBmsy that maximizes the average catch was increased by 8 thousand to 228 thousand tons compared to the proposal at the 2019 Scientific Meeting.

SBmin, which is the proposed SBlimit, was 151 thousand tons based on the 2020 stock assessment as well. This is the same level as “the minimal SSB that may produce strong year class (SSB of 151 thousand tons that produced 1982 year class)” which was empirically used as Blimit in the past.

We searched candidate values of SBban in the range of 5 thousand to 150 thousand tons. From these candidate values, the minimal value for recovery to the SBtarget after 10 years with a probability of 50% was chosen based on the simulation assuming the catch control by the HCRs which was also depended on the candidates of SBban. The starting condition of simulation (e.g. age composition, average body weight at age, and selectivity) were randomly chosen from the observed value of the 1981-2019 FYs, while the fishing mortality during the recovery period was given from the HCRs according to the SSB of each year. Simulation was made 10,000 times for each SSB candidate values at the starting point. As is the case with the proposal at the 2019 Scientific Meeting, the coefficient β is set to 0.8. As a result, we updated the proposed SBban to 60 thousand tons (Appendix Tables 10-2 and 10-4). The threshold for SSB to recover to the SBlimit in 10 years with a probability of 50% or higher when β is set to 0.8 was 30 thousand tons (Appendix Tables 10-2 and 10-5).

4. Kobe plot

The revised Kobe plot based on the updated SBmsy and corresponding exploitation rate (Umsy) or fishing mortality (Fmsy) are shown in Appendix Figure 10-6. Fishing mortality (F) of this stock was

judged to have been below the F_{msy} since the 2001 FY, excluding the 2004 and 2008 FYs. Exploitation rate (U) was judged to have been below the U_{msy} since the 2001 FY, excluding the 2004 and 2008 FYs. SSB has been over the SB_{msy} (proposed SB_{target}) since the 2009 FY.

5. Proposed HCRs

The HCRs are rules to set the fishing mortality (F) corresponding to the SSB, considering the probability of maintaining or recovering the SSB above the proposed SB_{target} . The HCRs are described in the “Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)” as the Type-I rule. In this rule, the F is controlled to directly reduced according to the SSB level, when SSB falls below the SB_{limit} . The SB_{ban} is the SSB level which catches should be prohibited. Multiplying the F_{msy} by the coefficient β is the upper limit of F . Based on the updated SB_{limit} and SB_{ban} , because the SB_{ban} is updated to 60 thousand tons from 70 thousand tons, the slope to reduce F when SSB falls below the SB_{limit} is slightly gentler. The proposed HCR that used 0.8 for the coefficient β is shown in Appendix Figure 10-7.

6. Future projection

(1) Setting of future projection

We updated the future projection based on the updated S-R relationship and HCRs. For future projection, we made forward cohort calculation from the abundance of the 2019 FY estimated by the 2020 stock assessment to the 2051 FYs. Recruitment for the future projection was given from the HS model and projected SSB of the respective year. We assumed errors in logarithmic normal distribution as the uncertainty of recruitment in 10,000 stochastic simulations. The catch in the 2020 FY was assumed from the projected biomass and the current F ($F_{2015-2019^*}$). The current F is average F value at age of the 2015-2019 FYs and the same selectivity is used for update of SB_{msy} . Settings of other biological parameters that are used for the future projection are shown in Appendix Table 10-2. As fishing mortality in the 2021 FY and after, we used the F provided by the updated HCRs according to the SSB projected for the respective fishing year. For mathematical equations used for the calculation, see Appendix 9.

(2) Prediction for the 2021 FY

Based on the future projection that uses the updated HCRs, we projected the SSB and catch of the 2021 FY. The projected SSB in the 2021 FY was 350 thousand tons on average, which was above the SB_{limit} in all simulations. For this reason, the fishing mortality of the 2021 FY, which was provided by the updated HCRs, is F_{msy} multiplied by the coefficient β . The average catch of the 2021 FY was 189 thousand tons when β is set to 0.8.

SSB in the 2021 FY (average projection value): 350 thousand tons			
Item	Catch in the 2021 FY (thousand tons)	Ratio to the current fishing mortality (F/F2015-2019*)	Exploitation rate in the 2021 FY (%)
$\beta=1.0$	226	2.08	22
$\beta=0.9$	208	1.88	20
$\beta=0.8$	189	1.67	18
$\beta=0.7$	169	1.46	16
$\beta=0.6$	148	1.25	14
$\beta=0.5$	127	1.04	12
$\beta=0$	0	0	0
F2015-2019*	122	1.00	12

Selectivity of F2015-2019* is different from the selectivity in the report of the 2020 Stock Assessment (i.e. F2015-2019). Selectivity of F2015-2019 is the same as that used for the calculation of MSY reference points at the 2019 Scientific Meeting. F2015-2019 is obtained by %SPR-conversion of the average F value of the 2015-2019 FYs under this selectivity. F2015-2019* is simply averaged value of F at age for the 2015-2019 FYs. Both have the same %SPR.

(3) Projection for the 2022 FY onward

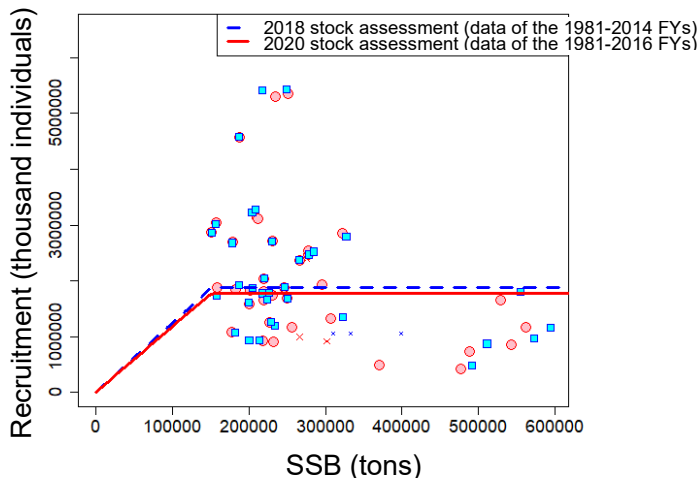
Results of the medium- to long-term future projection based on the updated HCRs are shown in Appendix Figure 10-8, Appendix Tables 10-6 and 10-7. When catch control based on the updated HCRs is continued for 10 years, projected SSB in the 2031 FY will be 284 thousand tons on average with β set to 0.8 (80% confidence interval: 190 thousand to 398 thousand tons). The probability of the projected SSB being above the updated SBtarget, SBlimit, and SBban in the 2031 FY is 72%, 98%, and 100%, respectively. As presented in the report of the 2020 stock assessment, most recently, the 2016 year-class of this stock is estimated to be relatively abundant and the abundance of the 2017 year-class is also estimated to be high. For this reason, it is projected that the SSB and abundance will stop declining in the short-term but we need to pay attention to the information that strength of the 2018-2019 year-classes seems to be weak. If we have the average recruitment that is projected from the HS model, it is expected that the SSB will be maintained above the updated SBtarget with a high probability in the medium- to long-term, but there is also a possibility that the SSB will fall below the updated SBtarget in the short-term. As presented previously, in order to prevent the SSB falling below the updated SBtarget with a probability of over 50% in the short term, it should be considered to set β to 0.7 and under. In order to avoid the risk that the SSB will fall below the SBlimit, it is not recommended to set β to 0.9 or higher.

Uncertainty considered: recruitment					
Item	SSB in the 2031 FY (thousand tons)	80% Confidence interval (thousand tons)	Probability of the SSB in the 2031 FY being above the following reference points (%)		
			Proposed SBtarget	Proposed SBlimit	Proposed SBban
$\beta=1.0$ (Fmsy)	232	153-327	44	91	100
$\beta=0.9$	256	170-359	58	96	100
$\beta=0.8$	284	190-398	72	98	100
$\beta=0.7$	318	215-441	85	99	100
$\beta=0.6$	359	246-494	94	100	100
$\beta=0.5$	411	286-559	98	100	100
$\beta=0$	1,063	808-1355	100	100	100
F2015-2019*	423	295-573	99	100	100

7. β with which the probability that the SSB will exceed the target reference point after 10 years is 50%

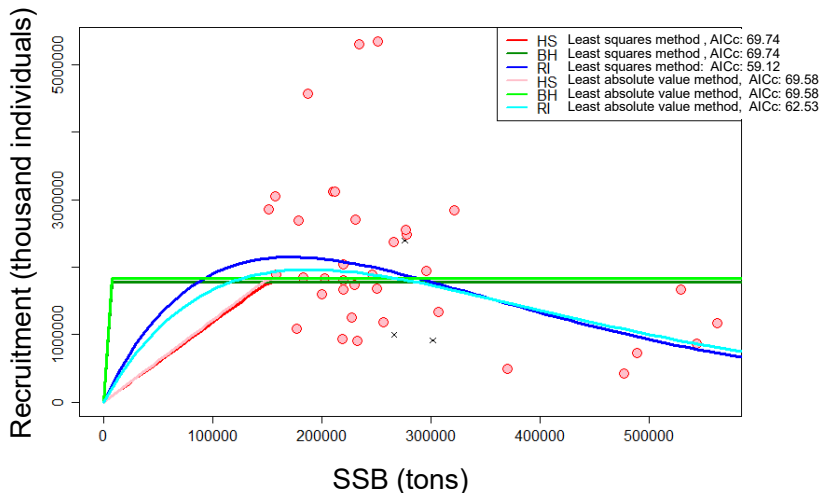
In the future projection, we conducted additional scenarios using the coefficient β within the range of 0.9 to 1.0 with intervals of 0.01, to find the scenario showing exactly 50% probability that the SSB in the 2031 FY will exceed the proposed SBtarget. As the result, when β was set to 0.95, the probability was nearly 50% (Tables 10-8 and 10-9). When we searched β more finely around 0.95, the probability that the SSB in the 2031 FY will exceed the SBtarget was exactly 50% when β was set in the range of 0.952 to 0.948, and 51% when β was set in the range of 0.945 to 0.951. In these ranges of β (0.945 to 0.958), the difference between the maximum and the minimum value of the average catch was from 1 thousand to 2.3 thousand tons for the 2021-2022 FYs, while it was several hundred tons after the 2023 FY.

As mentioned in the report of the 2019 Scientific Meeting, it has not been recommended to use a high β value such as over 0.9. The updated result of future projection doesn't change this conclusion; the probability that the SSB will fall below the updated SBtarget and SBlimit in the short-term became higher, when higher β value was used. For example, when β was set to 0.95, it was projected that SSB will decrease in the short term and will fall below the updated SBtarget in the 2024 FY with a high probability. The probability of falling below the proposed SBlimit in the 2025 and 2026 FYs was projected to be 10% or higher (Appendix Table 10-8). If higher fishing mortality was applied for the catch control using the high β value, we would have to be faced the higher risk of biomass depletion. It is considered that we need to avoid such a risk whenever possible.



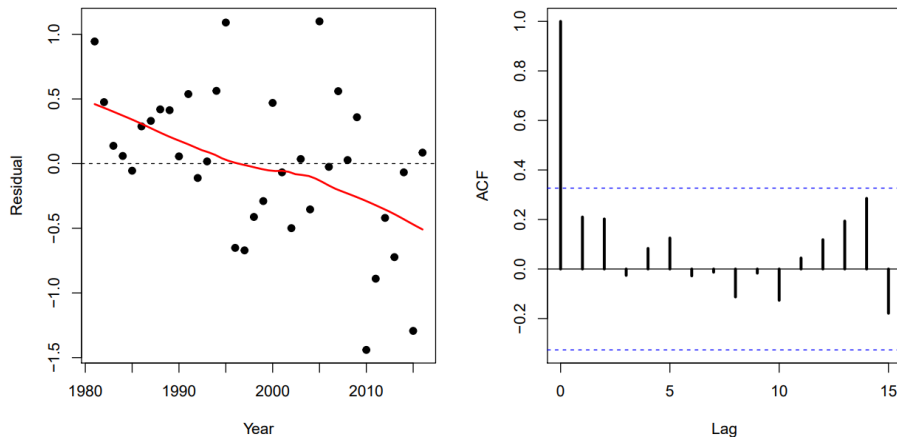
Appendix Figure 10-1. Comparison of estimation results of HS model of S-R relationship

The blue squares represent the SSB and recruitments of the 2019 stock assessment, while the red circles represent the SSB and recruitments based on the 2020 stock assessment. For the estimation of HS model parameter, we didn't use the latest three years' data (cross marks) which were not based on the direct estimation from cohort analysis. The blue dashed line is the HS model proposed at the 2019 Scientific Meeting, while the red solid line is updated one based on the 2020 stock assessment.

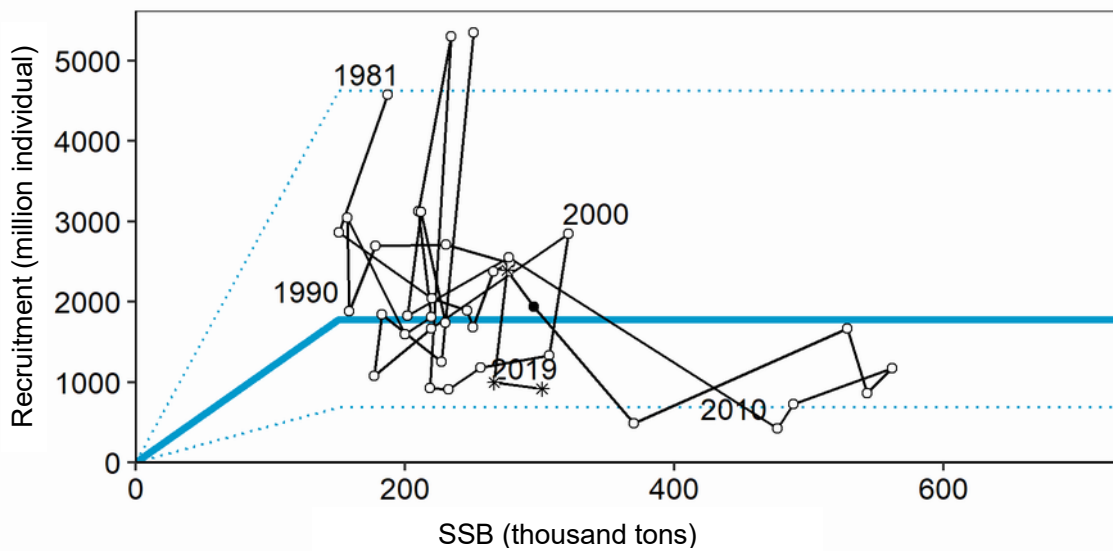


Appendix Figure 10-2. Comparison of the models of S-R relationships

HS, RI and BH models are applied for S-R relationships using the least squares method and the least absolute value method. The upper-right numbers in the figure are values of the small-sample-size-corrected version of AIC (AICc). The red circles represent the SSB and recruitments (1981-2016 FYs) used for the analysis. The data for latest three years (2017-2019 FYs) are not used for analysis because these are not based on the direct estimation from cohort analysis (cross marks).

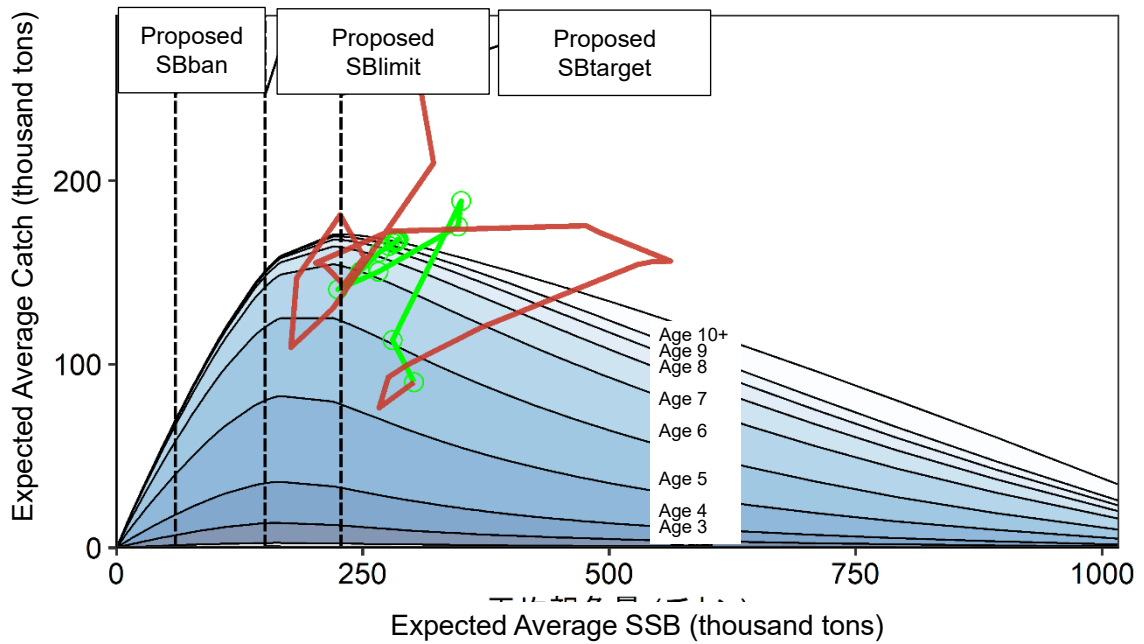


Appendix Figure 10-3. Residual trend in the HS model of S-R relationship and autocorrelation plot
 Based on the results when the HS model is applied for S-R relationship using the least squares method. The blue dashed lines in the right figure of autocorrelation plot express the 95% confidence interval.



Appendix Figure 10-4. Updated HS model of S-R relationships (relationship between SSB and recruitment)

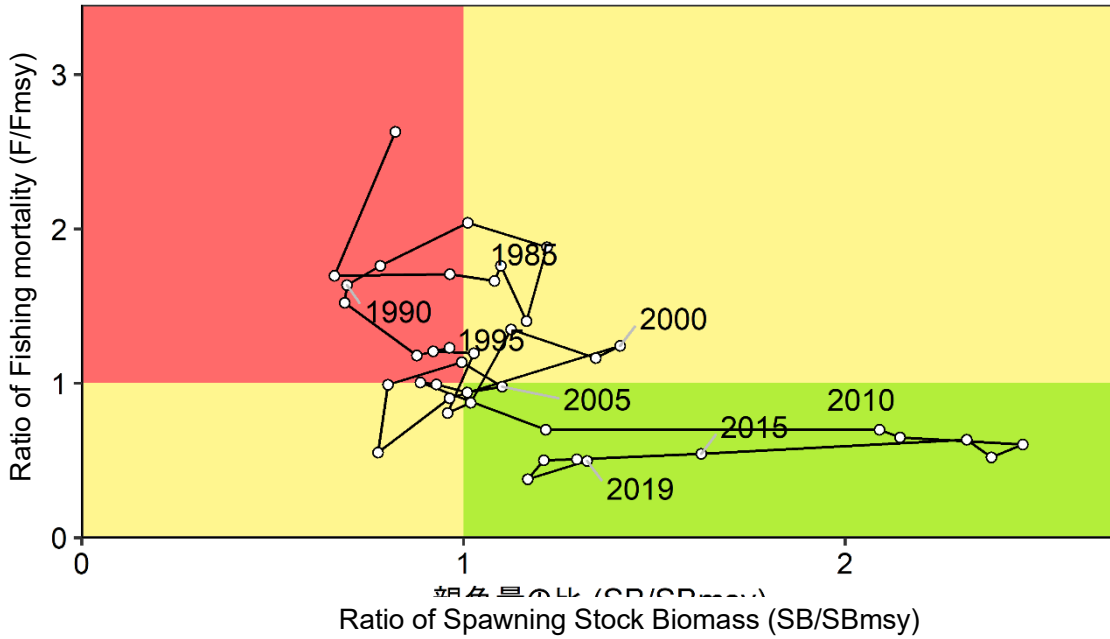
The blue line indicates the HS model of S-R relationship based on the recruitment and SSB of the 1981-2016 FYs, which are estimated in the stock assessment in 2020. We didn't use the data of the 2017-2019 FYs (with asterisk (*) mark) for the estimation of the HS model parameters, because the recruitment values of these data were estimates from the survey data. Filled circle (●) indicates the 2016 year-class, which was newly estimated in the cohort analysis from this stock assessment. The dotted lines show the 90% interval of SSB and recruitment.



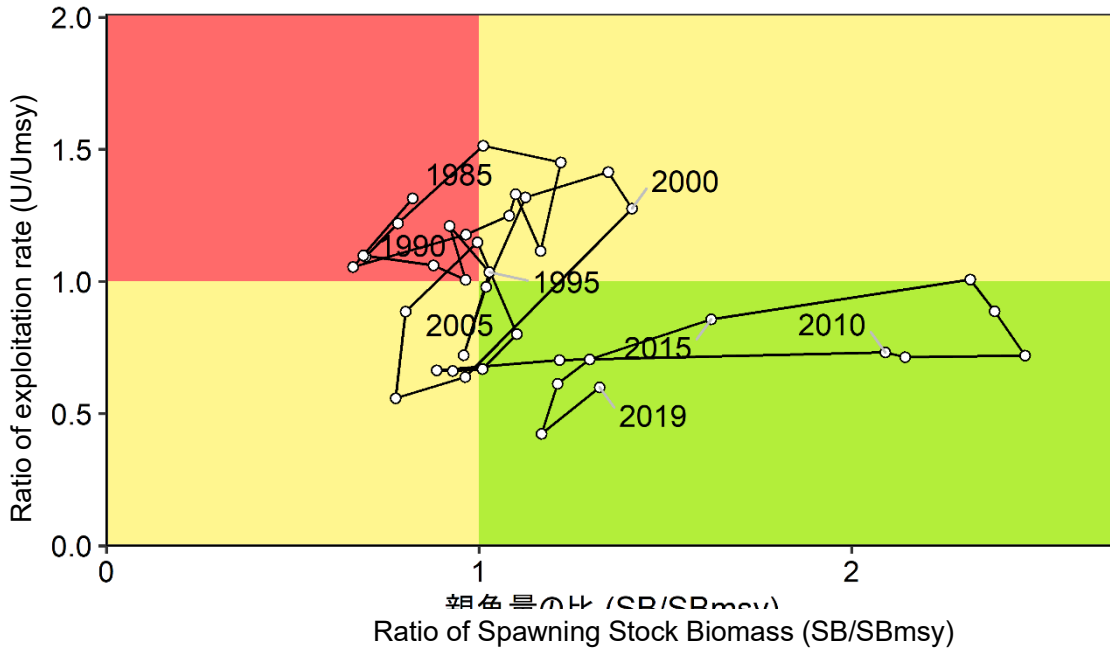
Appendix Figure 10-5. Relationship between the proposed reference points and yield curves at age

The figure shows the average catch weight at age corresponding to the SSB, and the relationship between each of the proposed reference points at equilibrium situation based on the future projection simulation. The red line represents the relationship between the SSB and catch, which were estimated by the 2020 stock assessment, while the green line represents yearly changes in the average SSB and average catch in the future projection when fishing is conducted based on the proposed HCR ($\beta = 0.8$) under the proposed reference points. The unfished SSB (SB0) is estimated to be 1.179 million tons.

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

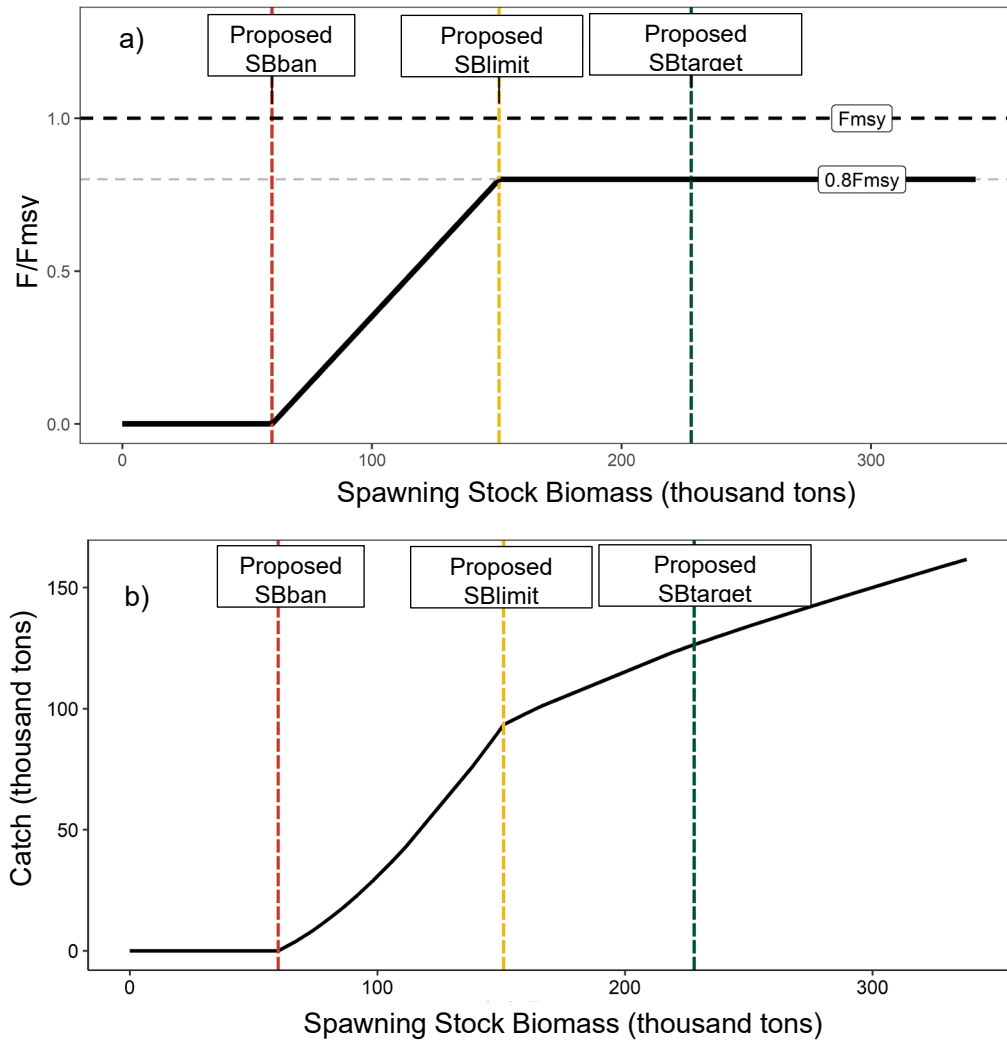


b) When the vertical axis is the ratio of Umsy to the exploitation rate of each year



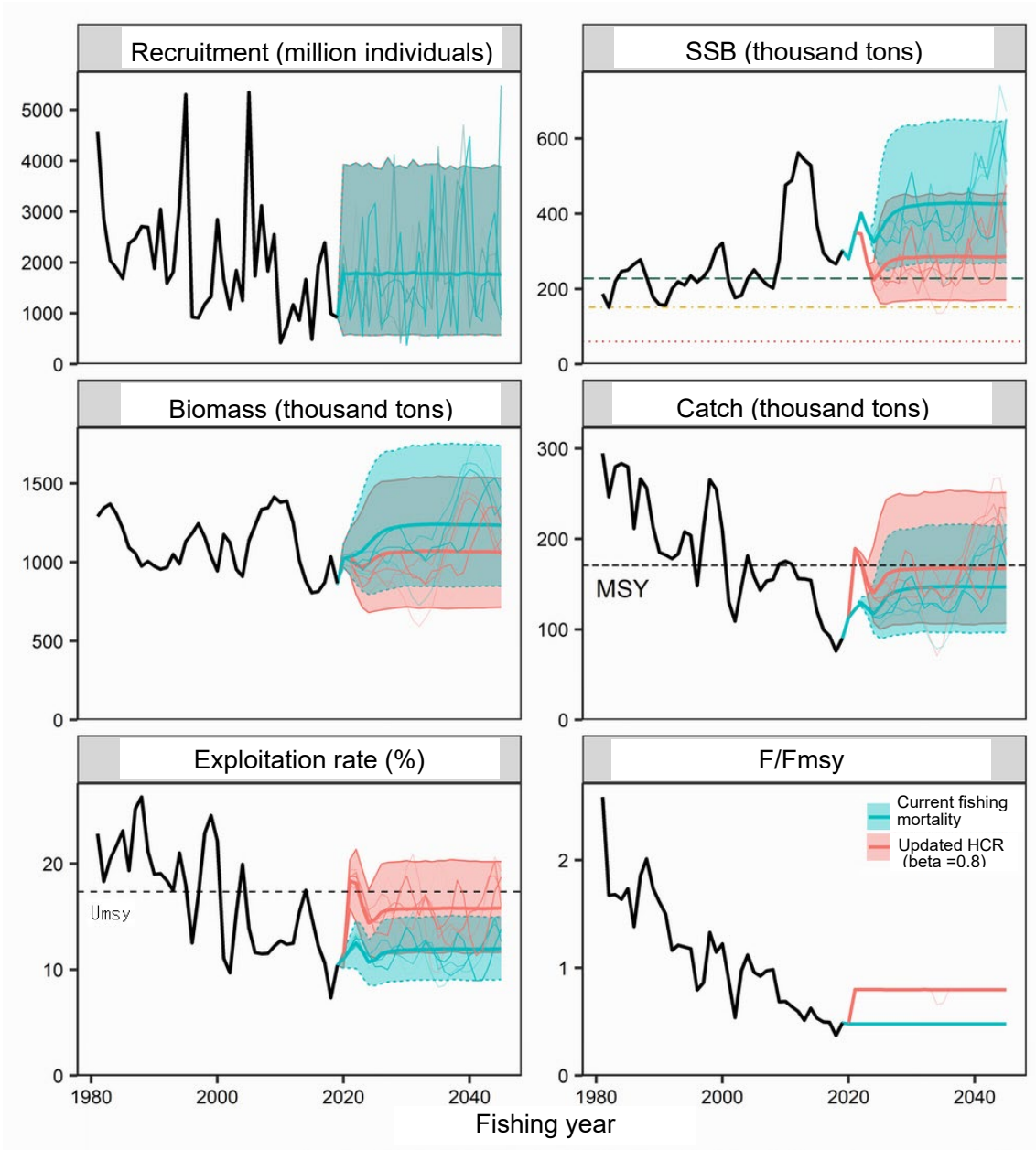
Appendix Figure 10-6. Kobe plot based on the updated MSY reference points

The upper chart (a) shows the relationship of Spawning Stock Biomass (SSB) ratio to SBmsy and fishing mortality (F) ratio to Fmsy. The lower chart (b) shows the relationship of SSB ratio to SBmsy and exploitation rate (U) ratio to Umsy.



Appendix Figure 10-7. Updated HCR (when β is 0.8)

The proposed target reference point (SB_{target}) is SB_{msy} , which is calculated based on the updated HS model. As the proposed limit reference point (SB_{limit}), we used the lowest SSB that has ever been observed in assessment periods. As the proposed fishing ban level (SB_{ban}), we updated the threshold value for SSB to recover to the SB_{target} in 10 years with a probability of 50% under fishing based on the updated HCRs with the coefficient β set to 0.8. The black dashed line represents F_{msy} ; the grey dashed line represents $0.8F_{msy}$; the black thick line represents the updated HCR; the red dashed line represents the updated SB_{ban} ; the yellow dashed line represents the proposed SB_{limit} ; and the green dashed line represents the updated SB_{target} . The upper chart a) expresses a schematic diagram of the updated HCR where the vertical axis is fishing mortality. The lower chart b) where the vertical axis is the expected catch based on the updated HCR under the respective SSB. Whereas the actual catch volume slightly different depending on the age composition, b) shows the catch volume in the case of average age composition in an equilibrium state.



(Shaded: 5-95% prediction interval; thick solid line: average value; thin solid line: simulation example)

Appendix Figure 10-8. Comparison of the future projection based on the updated HCR ($\beta=0.8$) with the future projection that assumes continued fishing at the current fishing mortality (F2015-2019*)

The thick solid line, shaded area and thin lines represent average value, the 90% prediction interval, and three future projection examples, respectively. In the figure of SSB, 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 catch of the 2020 FY was assumed based on the projected total biomass and the current fishing mortality (F2015-2019*: average F value at age of the 2015-2019 FYs). The coefficient β in the HCR used as an example is set to 0.8.

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

Model of S-R relationship	Optimization method	Autocorrelation	a	b	S.D.	AICc	n
Hockey stick	Least squares method	No	11.795	150,944	0.580	69.74	36
Ricker	Least squares method	No	33.988	5.82x10 ⁻⁶	0.501	59.12	36
Beverton-Holt	Least squares method	No	1.18x10 ⁷	6.636	0.580	69.74	36
Hockey stick	Least absolute value method	No	12.172	150,944	0.581	69.58	36
Ricker	Least absolute value method	No	28.275	5.30x10 ⁻⁶	0.506	62.53	36
Beverton-Holt	Least absolute value method	No	4.44x10 ¹⁹	2.42x10 ¹³	0.581	69.58	36

The recommended model of 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 SSB at equilibrium of the respective proposed reference points; ratio to the unfished SSB (SB0); average catch; %SPR-converted fishing mortality; exploitation rate; proportional connection of fishing effort to the current fishing mortality (F2015-2019*); and fishing mortality at age that can produce MSY (Fmsy)

Proposed reference points etc.	Explanation	SSB (thousand tons)	Depletion ratio (Ratio to SB0)	Catch (thousand tons)	Fishing pressure (%SPR)	Exploitation rate	Ratio of the fishing effort
SBtarget	SSB corresponding to MSY (SBmsy)	228	0.193	171	19.7	0.17	2.08
SBlimit	Smallest SSB ever observed (SBmin)	151	0.128	151	15.2	0.19	2.71
SBban	The threshold of SSB at which it can recover to the SBtarget in 10 years with 50% probability under fishing based on the HCRs (β set to 0.8)	60	0.051	70	13.2	0.20	3.10
--	The threshold of SSB at which it can recover to the SBlimit in 10 years with 50% probability under fishing based on the HCRs (β set to 0.8)	30	0.025	36	12.6	0.21	3.22
Fmsy	Fishing mortality that can produce MSY (Age 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10+) = (0.009, 0.017, 0.067, 0.124, 0.326, 0.565, 0.805, 0.670, 0.637, 0.717, 0.717)						

F2015-2019* is the average F value at age of the 2015-2019 FYs.

Appendix Table 10-3. Parameters used for MSY reference point calculation and future projection

Age	Natural mortality	Maturity rate	Average body weight (g)	Selectivity	Current fishing mortality (F2015-2019*)
0	0.40	0.0	44	0.010	0.004
1	0.35	0.0	107	0.020	0.008
2	0.30	0.0	218	0.083	0.032
3	0.25	0.0	360	0.154	0.059
4	0.25	0.2	475	0.404	0.156
5	0.25	0.8	563	0.701	0.271
6	0.25	0.9	642	1.000	0.386
7	0.25	1.0	698	0.832	0.321
8	0.25	1.0	726	0.791	0.306
9	0.25	1.0	756	0.891	0.344
10+	0.25	1.0	819	0.891	0.344

F2015-2019* is the average F value at age of the 2015-2019 FYs.

Appendix Table 10-4. Probability for SSB to exceed the target reference point (SBtarget) after 10 years – by candidate value for the fishing ban level (SBban)

If the SBban is low, it is necessary to lower the fishing mortality of the recovery period (by setting β lower). β value is changed in the range between 0.1 and 1 in 0.1 intervals.

(%)

SSB at the start of recovery (candidate value for the fishing ban level: 1 thousand tons)																														
β	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
1.0	0	0	1	2	5	8	11	15	20	23	27	30	34	36	38	41	42	44	46	47	49	50	51	52	53	55	55	56	57	57
0.9	0	0	1	3	7	11	17	22	27	32	36	40	44	47	49	51	54	56	58	60	61	63	64	65	66	67	67	69	69	70
0.8	0	0	2	5	10	17	24	30	36	42	47	51	55	58	61	64	66	69	71	72	74	75	77	77	78	79	80	81	81	81
0.7	0	0	3	7	15	23	32	40	47	53	58	63	66	70	73	76	78	80	82	84	85	86	87	88	89	89	89	90	90	91
0.6	0	1	4	11	21	32	42	50	58	64	69	74	77	81	83	86	88	90	91	92	93	94	94	95	95	96	96	96	96	96
0.5	0	1	6	16	30	42	52	61	69	74	79	83	86	89	91	93	95	96	96	97	97	98	98	98	98	99	99	99	99	99
0.4	0	2	9	24	39	52	63	71	78	83	87	90	93	95	96	97	98	98	99	99	99	99	99	100	100	100	100	100	100	100
0.3	0	3	14	33	49	63	73	80	86	90	93	95	97	98	99	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	0	4	20	42	60	73	81	87	92	95	97	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	0	6	30	54	70	81	88	93	96	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	0	10	40	64	79	87	93	96	98	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 10-5. Probability of SSB to exceed the limit reference point (SBlimit) after 10 years – by candidate value for the fishing ban level (SBban)

If the SBban is low, it is necessary to lower the fishing mortality of the recovery period (by setting β lower). β value is changed in the range between 0.1 and 1 in 0.1 intervals.

(%)

SSB at the start of recovery (candidate value for the fishing ban level: 1 thousand tons)																														
β	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
1.0	0	2	10	20	31	41	49	56	62	67	72	76	79	82	84	87	88	89	91	92	93	94	94	95	95	96	96	96	97	97
0.9	0	3	13	26	38	49	57	64	70	76	80	83	86	88	90	92	93	94	95	96	96	97	97	97	97	98	98	98	98	99
0.8	0	4	17	32	46	57	65	73	78	83	86	89	91	93	95	96	96	97	98	98	98	99	99	99	99	99	99	99	99	99
0.7	0	6	22	39	54	65	74	80	85	88	91	94	95	96	97	98	98	99	99	99	99	100	100	100	100	100	100	100	100	100
0.6	0	8	28	47	62	73	80	86	90	93	95	97	98	98	99	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	0	11	35	55	70	79	86	91	94	96	98	99	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	1	15	43	63	77	85	91	95	97	98	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	1	20	50	71	83	90	95	97	99	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	1	26	59	77	88	94	97	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	2	33	66	83	92	97	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	2	40	73	88	95	98	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 10-6. Probability for SSB to exceed the proposed target reference point (SBtarget) (a) and the proposed limit reference point (SBlimit) (b)

The following tables show the results of the future projection when β is changed between 0 and 1.0 under the catch control by HCRs, or when the current fishing mortality is continued, after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass of the 2020 FY and the current fishing mortality (F2015-2019*). F2015-2019* is the average F value at age of the 2015-2019 FYs.

(a) Probability for SSB 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	100	100	100	100	0	5	28	38	43	45	45	44	44	45	45
0.9	100	100	100	100	100	13	38	50	55	57	58	58	58	59	58
0.8	100	100	100	100	100	33	52	63	68	70	71	72	72	72	73
0.7	100	100	100	100	100	88	70	76	80	83	84	84	85	85	86
0.6	100	100	100	100	100	100	88	89	91	92	93	94	94	94	95
0.5	100	100	100	100	100	100	99	97	98	98	98	98	98	98	99
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2015-2019*	100	100	100	100	100	100	100	98	98	99	99	99	99	99	99

(b) Probability for SSB 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	100	100	100	100	100	100	81	88	90	91	90	91	91	91	91
0.9	100	100	100	100	100	100	91	93	95	95	95	95	96	96	96
0.8	100	100	100	100	100	100	98	97	98	98	98	98	98	98	98
0.7	100	100	100	100	100	100	100	99	99	100	99	99	99	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
F2015-2019*	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 10-7. Projected average values of future SSB (a) and catch (b)

The following tables show the results of the future projection when β is changed between 0 and 1.0 under the catch control by HCRs, or when the current fishing mortality is continued, after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass and the current fishing mortality (F2015-2019*). F2015-2019* is the average F value at age of the 2015-2019 FYs.

(a) Future average SSB (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	302	280	350	317	224	183	205	223	231	233	234	232	232	233	234
0.9	302	280	350	331	244	202	224	243	252	255	256	255	256	257	258
0.8	302	280	350	346	266	225	247	267	277	281	284	284	284	285	286
0.7	302	280	350	362	290	251	274	296	308	313	316	317	318	319	320
0.6	302	280	350	379	317	281	306	330	345	352	357	358	359	362	362
0.5	302	280	350	397	348	317	345	372	390	400	406	409	411	414	415
0.4	302	280	350	416	381	358	391	423	447	460	469	473	476	483	483
0.3	302	280	350	436	419	407	446	486	517	536	549	556	562	573	573
0.2	302	280	350	457	461	464	515	565	607	634	654	667	677	699	699
0.1	302	280	350	479	508	532	598	665	723	763	795	818	835	884	884
0.0	302	280	350	502	560	613	702	792	876	938	989	1030	1063	1174	1180
F2015-2019*	302	280	350	401	354	324	353	382	401	411	418	421	423	427	427

*Yellow shading expresses that the value is below the proposed target reference point.

(b) Future average catch (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	90	113	226	193	158	148	156	168	172	172	172	171	172	172	173
0.9	90	113	208	185	155	145	154	165	168	170	170	170	170	170	171
0.8	90	113	189	175	151	141	150	161	164	166	166	167	167	167	168
0.7	90	113	169	163	145	136	145	155	159	161	162	162	163	163	163
0.6	90	113	148	150	136	129	137	148	152	154	155	156	156	157	157
0.5	90	113	127	133	126	120	128	139	143	145	147	147	148	149	149
0.4	90	113	104	114	111	108	115	126	130	133	135	136	137	138	138
0.3	90	113	80	92	93	91	98	108	113	116	118	119	120	122	122
0.2	90	113	54	66	69	69	75	84	88	91	93	95	96	99	99
0.1	90	113	28	35	39	40	44	49	53	55	57	58	59	62	62
0.0	90	113	0	0	0	0	0	0	0	0	0	0	0	0	0
F2015-2019*	90	113	122	130	123	117	125	136	141	143	144	145	146	147	147

Appendix Table 10-8. Probability for SSB to exceed the proposed target reference point (SBtarget) (a) and the proposed limit reference point (SBlimit) (b)

The following tables show the results of the future projection when β is changed in the range of 0.91 to 0.99 with intervals of 0.01 under the catch control by HCRs, after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass of the 2020 FY and the current fishing mortality (F2015-2019*). F2015-2019* is the average F value at age of the 2015-2019 FYs.

(a) Probability for SSB to exceed the proposed target reference point (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
0.99	100	100	100	100	0	5	29	39	44	46	47	46	46	47	47
0.98	100	100	100	100	0	6	30	40	45	47	48	47	47	48	48
0.97	100	100	100	100	100	6	31	41	47	48	49	49	48	49	49
0.96	100	100	100	100	100	7	32	43	48	49	50	50	49	50	50
0.95	100	100	100	100	100	8	33	44	49	50	51	51	51	51	52
0.94	100	100	100	100	100	9	34	45	50	51	52	52	52	53	53
0.93	100	100	100	100	100	9	35	46	51	53	54	54	54	54	55
0.92	100	100	100	100	100	10	36	47	52	54	55	55	55	55	56
0.91	100	100	100	100	100	11	37	48	53	55	56	57	57	57	57

(b) Probability for SSB to exceed the proposed limit reference point (%)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
0.99	100	100	100	100	100	100	82	88	91	91	91	91	92	91	92
0.98	100	100	100	100	100	100	83	89	91	92	92	92	92	92	92
0.97	100	100	100	100	100	100	84	89	92	92	92	92	93	92	93
0.96	100	100	100	100	100	100	85	90	92	92	93	93	93	93	93
0.95	100	100	100	100	100	100	86	90	93	93	93	93	94	93	94
0.94	100	100	100	100	100	100	87	91	93	93	93	94	94	94	94
0.93	100	100	100	100	100	100	88	92	94	94	94	94	95	94	95
0.92	100	100	100	100	100	100	89	92	94	94	94	95	95	95	95
0.91	100	100	100	100	100	100	90	93	95	95	95	95	95	95	96

Appendix Table 10-9. Projected average values of future SSB (a) and catch (b)

The following tables show the results of the future projection when β is changed between 0 and 1.0 under the catch control by HCRs after the 2021 FY. The catch of the 2020 FY is assumed based on the projected biomass and the current fishing mortality (F2015-2019*).

F2015-2019* is the average F value at age of the 2015-2019 FYs.

(a) Future average SSB (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
0.99	302	280	350	318	226	185	207	225	233	235	236	234	234	235	236
0.98	302	280	350	319	228	187	209	227	235	237	238	236	236	237	238
0.97	302	280	350	321	230	189	210	229	237	239	240	238	238	240	241
0.96	302	280	350	322	232	190	212	231	239	241	242	241	241	242	243
0.95	302	280	350	324	234	192	214	233	241	244	245	243	243	244	245
0.94	302	280	350	325	236	194	216	234	243	246	247	245	245	247	248
0.93	302	280	350	327	238	196	218	236	245	248	249	248	248	249	250
0.92	302	280	350	328	240	198	220	239	247	250	251	250	250	252	253
0.91	302	280	350	330	242	200	222	241	249	253	254	253	253	254	255

*Yellow shading expresses that the value is below the proposed target reference point.

(b) Future average catch (thousand tons)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
0.99	90	113	224	192	158	148	156	168	171	172	172	171	172	172	173
0.98	90	113	222	192	157	147	155	168	171	172	171	171	171	172	172
0.97	90	113	220	191	157	147	155	168	171	172	171	171	171	172	172
0.96	90	113	219	190	157	147	155	167	170	171	171	171	171	171	172
0.95	90	113	217	189	156	146	155	167	170	171	171	171	171	171	172
0.94	90	113	215	188	156	146	155	167	170	171	171	170	171	171	172
0.93	90	113	213	188	156	146	155	166	169	170	170	170	171	171	172
0.92	90	113	211	187	156	145	155	166	169	170	170	170	170	171	171
0.91	90	113	210	186	155	145	154	165	169	170	170	170	170	170	171