Stock Assessment of Northern Hokkaido Stock of the Arabesque Greenling in 2020

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

Participating organizations: Wakkanai, Central, and Abashiri Fisheries Research Institutes, Fisheries Research Department, Hokkaido Research Organization

Summary

The stock biomass was estimated by a tuned VPA using the abundance index. The biomass of this stock increased from 94 thousand to 466 thousand tons in 1985-1995, and then it remained at around 255 thousand to 451 thousand tons until 2008. Afterward, it tended to decrease to less than 130 thousand tons since 2010 and decreased to 37 thousand tons in 2016. However, it turned to increase to 79 thousand tons in 2018 and 107 thousand tons in 2019. The spawning biomass remained at around 100 thousand tons in 1998-2005, but it decreased to 12 thousand tons in 2016. The spawning biomass increased slightly in 2017, but it decreased to the lowest-ever level, 11 thousand tons in 2018. The spawning biomass increased to 24 thousand ton in 2019.

It is suggested that the stock biomass may have decreased since the very low recruitment and recruitment per spawning occurred in 2010. Although a slight increase trend can be seen since 2016, the spawning biomass remained at a low level. It is necessary to continue to observe carefully the stock status. The catch has been increasing due to recruitment of the strong 2017 year class, and the following recruitment of the 2019 year class. It is important to include these year classes of high abundance in recruitment to restore biomass.

At the "Research Institute Meeting on Reference Points" held in April 2019, the Hockey Stick (HS) model was used for the stock-recruitment (S-R) relationship of the present stock. SBmsy, which is the level of spawning biomass that produces the maximum sustainable yield (MSY), estimated based on this model is 112 thousand tons. According to this basis, the spawning biomass of the present stock in 2019 is below the level that produces MSY. In addition, the fishing mortality on the stock in 2019 is approximately the same as the level of fishing pressure that produces MSY. The trend of spawning biomass is determined to be "flat" in light of the transition between 2015 to 2019 (past five years).

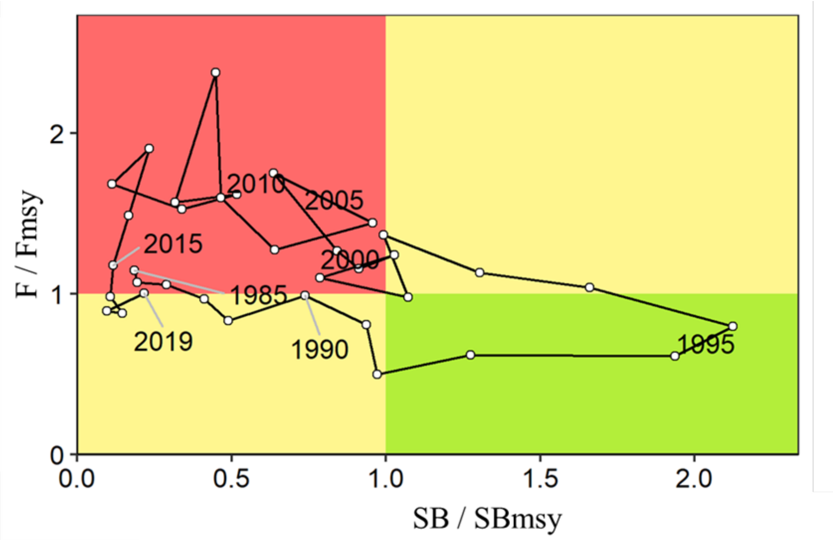
The reference points, etc. applied in this material are those proposed temporarily by the Research Institute Meeting on Reference Points as subjects to be discussed by the Committee of Stock Management Policy (meeting of stakeholders). These values will be finalized by the meeting of stakeholders.

Item	Value	Remarks
Level that produces MSY under the current environment		
SBmsy	112 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3, 4 and above) = (0.11, 0.77, 0.57, 0.92, 0.92)	
%SPR (Fmsy)	13.7%	%SPR corresponding to Fmsy
MSY	120 thousand tons	Maximum Sustainable Yield
Spawning biomass and fishing mortality in 2019		
SB2019	24 thousand tons	Spawning biomass in 2019
F2019	Fishing mortality in 2019 (ages 0, 1, 2, 3, 4 and above) = (0.16, 0.57, 0.88, 0.95, 0.95)	
%SPR (F2019)	13.9%	%SPR in 2019
%SPR (F2017-2019)	15.4%	%SPR corresponding to the current fishing mortality (2017 to 2019)
Ratio to MSY		
SB2019/SBmsy	0.22	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.0	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

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

・S-R relationship: HS model (no autocorrelation)
・Summary of stock status

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Approx. the same as Fmsy
Trend in spawning biomass	Flat



Year	Stock biomass (thousand tons)	Spawning biomass (thousand tons)	Catch (thousand tons)	F/Fmsy	Exploitation date (%)
2016	37	12	16	0.98	43
2017	61	16	17	0.88	27
2018	79	11	27	0.89	34
2019	107	24	29	1.00	27

1. Data set

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

Data set	Data source and research
Catch in number at age	Length composition by month (National Research Institute of Fisheries Science [NRIFS], Hokkaido) Catch in number at age and by year (Hokkaido)
Catch	Annual Statistics on Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landing at major ports by fishery (Hokkaido) Report on catch in offshore bottom trawl fishery in Hokkaido area (Fisheries Agency of Japan)
Abundance index	Report on catch in offshore bottom trawl fishery in Hokkaido area (Fisheries Agency of Japan)
Natural mortality (M)	Assuming 0.295 per year (Irie 1983)

Fishing effort	Report on catch in offshore bottom trawl in Hokkaido area (Fisheries Agency of Japan) Annual Statistics on Fishery and Aquaculture Production (Ministry of Agriculture, Forestry and Fisheries) Landing at major ports by fishery (Hokkaido)

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

2. Ecology of the stock

(1) Distribution and migration

Main distribution areas of Northern stock of Arabesque greenling are the Sea of Japan (from Shakotan peninsula in Hokkaido to the north), the Okhotsk Sea, and southwest coast of Sakhalin (Figure 2-1, Arabesque greenling research group 1983). The juveniles live in the surface layer from the central area of the Sea of Japan to the coast of Sakhalin or of the Okhotsk Sea, then they move to the bottom of the ocean in autumn when they become age 1. Most population move to the Sea of Japan after settlement, but some of them remain in the Okhotsk Sea and live there for another one or two years. After passing winter, they migrate to surface in group including some after spawning population and search food actively as "spring Arabesque greenling".

(2) Age and growth

The relationships between age and body length, and between body length and weight are shown below, sampled from the catch and research vessels of this stock in 2007 and 2008 (Takashima et al. 2013).

Male:

$$L_t = 292.2/\{1+1.086\times\exp(-0.955\times t)\}$$
$$W = 0.469\times L^{3.612}\times 10^{-6}$$

Female:

$$L_t = 307.0/\{1+1.191\times\exp(-0.876\times t)\}$$
$$W = 0.884\times L^{3.493}\times 10^{-6}$$

Here, L is standard length (mm), W is body weight (g) and t is age. The body length and weight by age estimated from the equations above (Figure 2-2). The hatching day is set to January 1 after the spawning for convenience, and then the age is incremented annually on January1. The longevity was estimated 8 to 9 years. It matures relatively early, but the growth stops in post-maturity (after age 3). So it is difficult to distinguish the difference of body length caused by age.

(3) Maturity and spawning

As mature fish stay around their spawning ground. They dose not move or migrate over a large area. Some individuals mature around the end of age 1, but almost all mature at the end of age 2 (Takashima and Mitsuhashi2009). The spawning season is from the middle of September to the early November, and the spawning season for the higher latitude is earlier than that for the lower latitude. The spawning grounds are the coastal areas of Rishisi and Rebun Islands and the shallowest area of Musashi bank. The number of spawning times is 2 to 4 in one spawning season, and the number of eggs per spawning is 2,800 to 4,500.

(4) Prey-predator relationships

The larvae feed mainly on copepods, and juveniles feed on amphipods. Once they inhabit around a reef, they feed on various kinds of animals, such as fish, fish eggs, squids, shrimps, amphipods and krills (Natsume 2003).

3. Status of fisheries

(1) Outline of fisheries

Northern Hokkaido stock of Arabesque greenling are caught in both offshore bottom trawl and coastal fisheries (gill net, bottom set net, set net, etc.). The main fishing season, fishing ground, and main age of fishing target are different depending on the fishery and they are summarized in the below table. The catch in offshore bottom trawl fishery is operated by Danish seine vessel ("Danish seine") and otter-trawl vessel ("otter-trawl"). Until 2014, the catch in offshore bottom trawl fishery in the Sea of Japan accounted for about 60% of the total catch. The ratio of coastal fishery in the Sea of Japan to the total catch was 10 to 30%,and that of offshore bottom trawl fishery in the Okhotsk Sea was 10%. The ratio of the catch in coastal fishery in the Okhotsk sea was less than 10%. On the other hand, since 2015, the ratio of coastal fishery increased until it reached 70% of the total catch in 2017. Though it decreased to about 50% in 2018, the catch by coastal fishery increased again in 2019 to about 70% of the total catch. The voluntary restraints on fishing, which aim to reduce 30% of the catch or fishing effort compared with those in 2008-2010, had been continued since the latter half of 2012, for the purpose of restoring biomass of Arabesque greenling of this stock (Central, Wakkanai and Abashiri Fisheries Research Institutes, printing underway).

Fishery	Sea area	Fishing ground	Main fishing ground	Main fishing season	Fishing target
Offshore bottom trawl	Sea of Japan	Sea of Japan from Ishikari Bay northward	Wakkanai north area, around Rirei, Offshore of Yoichi, Offshore of Oumu	Almost a year around	Age 0 and above
	Okhotsk Sea	Wakkanai east	Monbetsu,		

		area, Anbashiri Bay, around Kitami Yamato bank	Wakkanai east area		
Gill net	Sea of Japan	Rirei - Shimamaki	Around Rirei, around Musashi bank	June to October	Age 1 and above
	Okhotsk Sea	Oumu - Shari	Abashiri - Shari		
Bottom set net	Sea of Japan	Rirei - Shimamaki	Suttsu - Shimamaki	March to May	Age 1 and above
	Okhotsk Sea	Oumu - Shari	Monbetsu -Yubetsu	October to November	Age 0 and above
Set net for salmon	Sea of Japan	Rirei - Shimamaki	Kamoenai - Shimamaki	September to November	Age 0 and above
	Okhotsk Sea	Oumu - Shari	Abashiri - Shari		

(2) History of catch

The changes in catch of this stock are shown in Figure 3-1 and Table 3-1. The total catch decreased from about 100 thousand tons to about 30 thousand tons in the first half of the 1980s, but it recovered to more than 100 thousand tons in the first half of the 1990s. It continued to increase and exceeded 200 thousand tons in 1998. It remained at around 96 thousand to 151 thousand tons during the period of 2000-2009, but it drastically decreased since 2010. In 2015-2017, the catch was around 16 thousand to 17 thousand tons, which was the least since 1985. However, it turned to increase to 27 thousand tons in 2018 and 29 thousand tons in 2019.

The catch in offshore bottom trawl fishery was 17 thousand to 56 thousand tons in the 1980s, but it began to increase in the 1990s and reached 168 thousand tons in 1998 (Figure 3-1, Table 3-1). It remained at around 100 thousand tons during the period of 2000-2007, then it decreased since 2008 to 5 thousand tons in 2017. Then it increased to 13 thousand tons in 2018 and was 8 thousand tons in 2019. Comparing the catches in 2018 and 2019 by fishing area, the catch in the Sea of Japan decreased from 10 thousand to 7 thousand tons and that in the Okhotsk Sea decreased from 2 thousand to 0.7 thousand tons.

The catch in coastal fishery increased since 1985 and it remained around 17 thousand to 43 thousand tons from the 1990s until about 2005. Then, it decreased to 17 thousand tons in 2011 (Figure 3-1, Table 3-1). It increased to 25 thousand tons in 2012, but decreased again. Then, it increased from 14 thousand tons in 2018 to 22 thousand tons in 2019. Comparing the catches in 2018 and 2019 by fishing area, the catch in the Sea of Japan increased from 11 thousand to 14 thousand tons and that in the Okhotsk Sea increased from 4 thousand to 7 thousand tons.

The catch in number at age of Northern Hokkaido stock of Arabesque greenling calculated by the Hokkaido Research Organization indicates that ages 0 and 1 fish were dominant until the latter half of the 1980s (Figure 3-2, Central, Wakkanai and Abashiri Fisheries Research Institutes; printing underway). The proportion of age 2 fish increased in the 1990s. The catch in number of age 0 fish was around 200 million to 600 million individuals between 1997 to 2009, but it decreased rapidly to 20 million individuals in 2010. Afterward, the catch in number of age 0 fish decreased and it was the smallest-ever, 1 million individuals, in 2016. Although it increased to 60 million individuals in 2017, it decreased to lower than 3 million individuals in 2018. It increased again to 70 million individuals in 2019, which was higher than that in 2017.

(3) Fishing effort

The fishing effort of offshore bottom trawl fishery for this stock tends to decrease for the long term. In order to show the long-term tendency of the fishing effort, we used monthly statistics of the number of trawls with catch targeting Arabesque greenling by Danish seine or otter trawl since 1985 (Appendix Table 3-3). As fishing efforts of coastal fishery, we used the number of fishing units described in the Annual report of fishery statistics in Hokkaido for small set net fishery, the number of fishing units and the number of licenses for set net fishery for salmon described in the Annual report of fishery statistics in Hokkaido for set net fishery for salmon, and the number of fishermen who use bottom set net for flatfish, flounder and arabesque greenling included in class 2 common fishery right for bottom set net (Appendix Table3-4).

The fishing effort (number of trawls) of Danish seines in the Sea of Japan remained at around 13 thousand to 22 thousand trawls between the latter half of the 1980s and the latter half of the 1990s, around 10 thousand trawls in 2001-2009, around 7 thousand trawls since 2010, and 4 thousand to 5 thousand trawls since 2015 (Appendix Figure 3-2, Appendix Table 3-3). The fishing effort of otter trawls remained around one thousand until 2008, then it decreased to 0.3 thousand trawls in 2019. The fishing effort of Danish seines in the Okhotsk Sea decreased to less than 10 thousand since 2000, compared with the latter half of the 1980s. It remained at around 7 thousand since 2017.

As for the number of fishing units of set net fishery, that of small set net fishery was large in the first half of the 1980s and decreased in the latter half of 1980. From 1990 until 2006, the data were aggregated by each General Subprefectural Bureau and there was no remarkable change in this period (Appendix Table 3-4). The number of fishing units of set net fishery for salmon increased from the first half of the 1980s until the middle of the 1990s, but it has not changed largely since the first decade of the 2000s (Appendix Table 3-4). The number of those who use bottom set net varied by Development Bureau, and it decreased in most of the bureaus in the first decade of the 2000s compared with that in the latter half of the 1990s.

4. Stock status

(1) Stock assessment method

We estimated the number of fish, biomass and fishing mortality (F), at age, in the period of 1985-2019 by cohort analysis (tuning-VPA) based on the data of catch in number at age provided by the Hokkaido Research Organization (Figure 3-2) (Appendices 1 and 2). In the cohort analysis, we tuned the data by using standardized CPUE (catch per unit effort) of offshore bottom Danish seine vessels of more than 100 tons in 2005-2019 (Appendix 5). We applied the ridge VPA method (Okamura et al. 2017) to reduce the uncertainty of F for older population (Appendices 2 and 8) in the tuning-VPA method. In recent years, fishing operation changed so much, especially offshore fishery and coastal fishery, that they have been unable to catch age 0 fish and now refrain from attempting to catch those fish according to voluntary restraints. Therefore, it is still necessary to improve methods of assuming selectivity of the F value of the terminal year of the cohort analysis and of assuming the number of age 0 fish in the tuning (Appendix 8).

(2) Changes in abundance indices

CPUE for Danish seine fishery in the Sea of Japan was 7.6 tons/net in 2008, but it decreased to 3.4 tons/net in 2011 (Appendix Figure 3-3 and Appendix Table 3-3). It further decreased since 2015 to 0.7 tons/net in 2017. Then, it increased to 2.1 tons/net in 2018 and it was 1.5 tons/net in 2019. The value of the CPUE for otter trawl fishery in the Sea of Japan was high, at 5.2 tons/net, then it decreased to 0.8 tons/net in 2017, and 0.9 tons/net in 2018. However, it increased to 1.6 tons/net in 2019. In recent years, CPUE for Danish seine fishery tends to be higher than that for otter trawl fishery in the Okhotsk Sea. CPUE for Danish seine in the Okhotsk Sea exceeded 3 tons/net in 2004. However, it decreased afterward and was less than 1 ton/trawl since 2009. In 2015, the value was the lowest in the past of 0.02 tons/net in 2015. Then, it increased to 0.3 tons/net in 2018 and decreased again in 2019 to 0.09 tons/net. On the other hand, CPUE for otter trawl fishery in the Okhotsk Sea remained less than 1 ton/trawl except for 1998, and it was especially low in and after 2013, at almost 0 ton/trawl.

The area-weighted standardized CPUE index for bottom trawl fishery using for the tuning index (Appendix Figure 3-3, Appendix Table 3-3; for details, see Appendix 5) increased to 2.15 in 2008, but it decreased rapidly to 0.09 in 2017. Though it increased to 0.37 in 2018, it decreased to 0.18 in 2019.

(3) Trends in biomass and fishing mortality

The total biomass increased since 1985 to 466 thousand tons in 1995. Since 1996, it decreased to 308 thousand tons in 2001. It increased to 382 thousand tons in 2003 but decreased again and remained at around 255 thousand to 290 thousand tons in 2004-2008. Since 2009, it decreased to less than 200 thousand tons and continued to decrease to 37 thousand tons in 2016, which was the lowest in the past. Then, it turned to increase to 107 thousand tons in 2019 (Table 4-1, Figures 4-2 and 4-3, Appendix 4). In recent years, both the number and weight of biomass of age 0 fish declined but the recruitments of the 2017 year class and 2019 year class were assumed to be relatively high since 2012 (Figures 4-1 and 4-2).

The spawning biomass had increased since 1985 to 239 thousand tons in 1995. Then, it turned to decrease and remained at around 100 thousand tons in 1998-2005. Afterward, it decreased to 36 thousand tons in 2009. In 2010, it increased to 58 thousand tons but turned to decrease to less than 20 thousand tons in 2014-2018. It slightly increased in 2019 to 24 thousand tons (Table 4-1, Figure 4-3, Appendix 4).

The changes of recruitment and the ratio of recruitment to spawning biomass (Recruitment Per Spawning (RPS)) for each year class since the 1980s are shown in Table 4-1, Figure 4-4 and Appendix 4. The recruitment increased from 500 million individuals in 1985 and changed with increase and decrease between 600 million to 1.3 billion individuals until 1996. It recorded 2.1 billion individuals as the highest value in 1997, and afterward, it changed largely between 700 million and 1.9 billion individuals until 2007. Since 2008, it rapidly decreased to less than 100 million individuals in 2010. In 2011, it increased again to 800 million individuals, but turned to decrease and was at the lowest level of 20 million individuals in 2016. In 2017 and 2018, it was 340 million and 130 million individuals, respectively, then it was assumed to be 590 million individuals in 2019, which was the highest since 2012. As for the most recent five years, the value for the 2016 year class is very small. On the other hand, those for 2017 and 2019 year classes are relatively high since 2012. However, it is necessary to attention that the estimated value of recruitment in 2019 might be updated depending on the catch in the future, because there is large uncertainty in assuming the biomass of age 0 fish in recent years in the calculation of biomass. The spawning biomass in 2010 was 58 thousand tons. Though it was not so small compared with the spawning biomass in 2007-2009 (36 thousand to 52 thousand tons), the recruitment in 2010 was so small that it may be one of the causes of further decrease in biomass afterward.

The RPS decreased from 29.6 individuals/kg in 1986 to 3.7 individuals/kg in 1996, then it changed between 9.2 to 20.1 individuals/kg with increase and decrease in 1997-2006. In 2007, it increased to 31.6 individuals/kg and then decreased to 1.6 individuals/kg in 2010, which was the lowest in the past. It increased in 2011-2012 to above 20 individuals/kg, and remained at around 5.7 to 10.4 individuals/kg since 2013. It was the second lowest of 1.7 individuals/kg in 2016 to that in 2010. In 2017, the value of recruitment largely increased although the spawning biomass was small, so the value of RPS also increased to 20.6 individuals/kg. Though it decreased again in 2018 to 11.5 individuals/kg, it increased in 2019 to 24.3 individuals/kg (Figure 4-4, Appendix 4).

The changes in fishing mortality (fishing mortality (F)) and exploitation rate are shown in Figures 4-5 and 4-6 and Appendix 4. As for the fishing mortality at age, the F of age 1 fish that was dominant in catch increased with increase and decrease, and it remained at a high level in the first decade of the 2000s. But it decreased since 2012 and was the lowest in 2017 since 2000. The F for age 0 fish was high in 2004-2005, but it remained at a lower level below 0.5. It further decreased since 2014 and remained at a low value. The F for age 0 fish in 2019 decreased to about half of the reference year (2008-2010) (Figure 4-5). The simple average of fishing mortality (F) at age remained at around 0.30 to 1.62 in 1985-2015 (Appendix 4). The value of F tended to increase since 1992, when F was the lowest, and marked a high value in 2008. Afterward, it decreased in 2009 but then increased until 2013. Since the latter half of 2012, voluntary restraints on fishing, which aim to reduce 30% of catch or fishing effort compared with those in 2008-2010 have continued (Central, Wakkanai and Abashiri Fisheries Research Institutes; printing underway). The simple average of F at age decreased since 2013 and it have been less than the average of the reference years (1.16) in recent years.

The exploitation rate decreased from 39% in 1987 to 19% in 1992, and changed below 40% until 1996 (Figure 4-6, Table4-1). Afterwards, it increase as high as 55% in 2010. Then, it tended to decrease and remained at around a level above 35% since 2000, and decreased to 27% in 2017. In 2018, it increased to 34% and it decreased again to 27% in 2019.

In the assessment conducted last year, the value of the 2018 year class was estimated to be 20 million, but it was revised upward as 130 million in the assessment conducted this year. The reasons for this upward revision are that it was difficult to estimate the the number of fish properly at the time of the assessment last year due to the impact of voluntary restraints on fishing of age 0 fish. And then, the estimated value of abundance was replaced by the one which reflects the actual catch based on the the information that the year class became the target of fishing as age 1 fish in 2019. As for classes of other years, there was no remarkable change from the estimated values in the assessment of the last year. The biomass in 2018 was revised upward from 63 thousand tons in the assessment conducted last year to 79 thousand tons, mainly due to the upward revision of the number of fish of the 2018 year class. As this upward revision is limited to age 0 fish, it has no influence on the estimation of the spawning biomass in 2018. The spawning biomass in 2018 is 11 thousand tons, which is almost the same value as that assessment conducted last year. It is difficult to tune (estimation of CPUE for bottom trawl fishery or the selectivity of the final year) in cohort analysis based on only fishery information, especially due to voluntary restraints on fishing of age 0 fish conducted in recent years. It is necessary to improve the analysis method in order to assure robustness of analysis against the yearly change of fishing operation and the impact of the degree of the amount of recruitment.

<table>
<tr><th>Item</th><th>Value</th><th>Remarks</th></tr>
<tr><td>SB2019</td><td>24 thousand tons</td><td>Spawning biomass in 2019</td></tr>
<tr><td>F2019</td><td colspan="2">Fishing mortality in 2019
(ages 0, 1, 2, 3, 4 and above) = (0.16, 0.57, 0.88, 0.95, 0.95)</td></tr>
<tr><td>U2019</td><td>27%</td><td>Exploitation rate in 2019</td></tr>
</table>

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

In order to compare fishing mortality considering the influence of selectivity, the %SPR-converted F values for each year (the ratio of SPR with catch to SPR assuming no catch (%SPR) for each year) are shown in Figure 4-7. The lower the fishing mortality shows the higher the %SPR. It remained above 15% during 1991-1995, but it remained under 10% from 2004 until 2014. Since 2015, it increased again to 16.0% in 2018, but it was 13.9% in 2019.

Figure 4-8 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 gives MSY (Fmsy) (Morita et al. 2019) at the "Research Institute Meeting on Reference Points" held in April 2019. For the average body weight at age and the maturity rate, we also used the values which were used to calculate Fmsy. Fmsy corresponds to 13.7% in %SPR. Current fishing mortality (F2017-F2019) is lower than Fmsy, and higher than F0.1 and F30%SPR.

Item	Value	Remarks
%SPR (F2019)	14%	%SPR in 2019
%SPR (F2017-2019)	15%	%SPR corresponding to the current fishing mortality (2017 to 2019)

(5) Stock-recruitment relationship

Figure 4-9 shows the relationship between spawning biomass (in weight) and recruitment (in the number of individuals) (S-R relationship). According to "Research Institute Meeting on Reference Points" mentioned above, it is suggested to use the Hockey Stick (HS) model for the stock-recruitment (S-R) relationship of this stock (Morita et al. 2019). Parameters for the S-R relationship is estimated based on SSB and recruitment which are estimated by the stock assessment conducted in 2018, and as for the optimization method, the least absolute value method is used. The model does not consider autocorrelation between the residuals of the recruitment. The parameters for the S-R relationship are shown in the table below.

S-R relationship	Optimization method	Autocorrelation	a	b	S.D.
Hockey Stick	Least absolute value method	No	0.022	51,051	0.620

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

(6) Level that produces MSY under the current environment

The table below shows the spawning biomass and F that produces MSY (SBmsy, Fmsy) under the current (in and after 1985) environment, which was suggested at the "Research Institute Meeting on Reference Points" (Morita et al. 2019).

Item	Value	Remarks
SBmsy	112 thousand tons	Spawning biomass that produces MSY
Fmsy	Fishing mortality that produces MSY (ages 0, 1, 2, 3, 4, and above) = (0.11, 0.77, 0.57, 0.92, 0.92)	
%SPR (Fmsy)	13.7%	%SPR corresponding to Fmsy
MSY	120 thousand tons	Maximum Sustainable Yield

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

Figure 4-10 and Appendix 7 shows a Kobe plot based on the spawning biomass that produces MSY (SBmsy) and fishing pressure that produces MSY (Fmsy or Umsy). The ratio of F (F/Fmsy) shows the yearly ratio between F and F under the current selectivity that produces Fmsy, which was converted to %SPR. The value F in this stock exceeded Fmsy since 2000 until 2015 (except for 2001). Since 2016, it was smaller than Fmsy, and the F value in 2018 was 0.89 times Fmsy and 1.00 times Fmsy in 2019. The spawning biomass of this stock was smaller than SBmsy since 2000 (except for 2001), and the spawning biomass in 2019 was 0.22 times SBmsy. The trend of spawning biomass is judged as flat from the change in these recent five years (2015-2019).

Item	Value	Remarks
SB2019/SBmsy	0.22	Ratio of the spawning biomass in 2019 to the spawning biomass that produces MSY
F2019/Fmsy	1.00	Ratio of the fishing mortality in 2019 to the fishing mortality that produces MSY*

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

Level of spawning biomass	Below SBmsy
Level of fishing mortality	Approx. the same as Fmsy
Trend in spawning biomass	Flat

5. Stock assessment summary

The biomass of this stock tended to increase from 94 thousand to 466 thousand tons during 1985-1995, then it decreased to 37 thousand tons in 2016. Afterwards, it increased to 107 thousand tons in 2019 because of contribution of recruitment of the 2017 year class, the abundance of which is relatively high. The spawning biomass decreased after it reached 239 thousand tons in the middle of the 1990s and remained at around 11 thousand to 16 thousand tons during 2015-2018. It increased in 2019 to 24 thousand tons. Although the values of stock biomass and spawning biomass increased slightly since 2016, it still remained at the lowest level in the long term.

The spawning biomass in 2019 was lower than the SBmsy and the trend was judged to be flat in light of the transition over the past five years (2015-2019). The fishing mortality for this stock continued to be at a high level since 2000. It was lower than the Fmsy from 2016 until 2018, and it was almost the same level in 2019.

6. Others

In response to the present situation in which the stock status remains at the lowest level ever, the voluntary restraints on fishing which aim to reduce 30% of catch or fishing effort have continued since the latter half of 2012 among the fishermen of coastal fishery and offshore bottom trawl fishery for the purpose of restoring the biomass (Central, Wakkanai and Abashiri Fisheries Research Institutes; printing underway). From the results of questionnaire given to the fishermen of offshore bottom trawl fishery (Appendix 6), the catch of fish presumed to be in the 2019 year class is large, but information on the catch of the 2018 year class is little, so it is supposed that the stock biomass has not recovered yet as a whole. It is necessary to continue to maintain control in the future.

It is necessary to monitor environmental factors, because the possibility of delay the migration period of spawning ground or localization of fish groups to the sea areas of relatively low water temperature might occur due to water temperature increase in the southern sea area of Hokkaido (Hoshino et al. 2009). And there is also the possibility of influence by water temperature on recruitment (Morita et al. 2015, Morita 2017). It is necessary to continue discussion on the influences of the environmental factors on the spawning and recruitment of this stock.

7. References

Arabesque greenling research group (1983), Hokkaido syuhen kaiiki no hokke no bunpu, kaiyu, saikin no hokke no chosa kenkyu (Distribution and migration of Arabesque greenling in the sea area around Hokkaido, Research and study on the present Arabesque greenling), Central Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization, Yoichi, 44-59.

Takashima, T., and M. Mitsuhashi (2009) 1.1.2 Hokke:, Heisei 19 nendo Chuo suisan sikenjo jigyo hokokusho (Annual Report of Central Fisheries Research Institute in 2007), Central Fisheries Research Institute, Fisheries Research Department, Hokkaido Research Organization, Yoichi, 21-27.

Takashima, T., N. Hoshino, K. Itaya, K. Maeda and K. Miyashita (2013) Jiseki danmen kansatsu niyoru hokke dohokukeigun no nenrei sateiho to nenrei – saizu kankei (Method of estimation of age by observation of section of otolith and correlation of age and body length of Northern Hokkaido stock of the Arabesque greenling), FISHERIES SCIENCE, 79: 383-393.

Natsume, M. (2003) Arabesque greenling: Fisheries and Aquatic Life in Hokkaido (Mizushima, T., and M. Torisawa (editors)), The Hokkaido Shimbun Press, 196-201.

Hoshino, N., T. Takashima, M. Watanobe and T. Fujioka (2009) Age-structures and catch fluctuations of Arabesque greenling (Pleurogrammus azonus) in the coastal area of southern Hokkaido, Japan, SCIENTIFIC REPORT OF HOKKAIDO FISHERIES RESEARCH INSTITUTES, 76: 1-11.

Central, Wakkanai and Abashiri Fisheries Research Institutes, (printing underway), Arabesque greenling (Sea of Japan of Middle Hokkaido - Okhotsk Sea area), 2020 nendo suisan shigen kanri kaigi hyokasyo (Assessment report of council of stock management in 2020), Fisheries Research Department, Hokkaido Research Organization, http://www.fishexp.hro.or.jp/exp/central/kanri/SigenHyoka/Kokai/ (last accessed

Morita, S., H. Kuroda, K. Sakaguchi and Y. Suzuki (2015) Kinnen no hokke gyokaku doukou to kaiyouo kankyou tono kakawari (Relationship between the recent trends in catch of Arabesque greenling and the marine environment), Bulletin of the Japanese Society of Fisheries Oceanography, 79: 333-351.

Morita, S.(2017) Hokkaido syuhen no hokke no shigen no genjo (Current status of Arabesque greenling stock around Hokkaido), Kaiyo monthly, 49: 481-485.

Morita, S., Y. Yamashita, O. Sakai, T. Isono, K. Hattori and M. Ichinokawa (2019), Report of the Research Institute Meeting on Reference Points for Northern Hokkaido stock of the Arabesque greenling in 2019 https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_hokke_h.pdf (last accessed on October 15, 2019)

Okamura, H., Yamashita, Y., and Ichinokawa, M. (2017). Ridge virtual population analysis to reduce the instability of fishing mortalities in the terminal year. ICES Journal of Marine Science 74 (9): 2427–2436.

(Authors: Syoko Morita, Osamu Sakai, Mitsuhiro Ishino, Satoru Chiba, Tomonori Hamatsu)

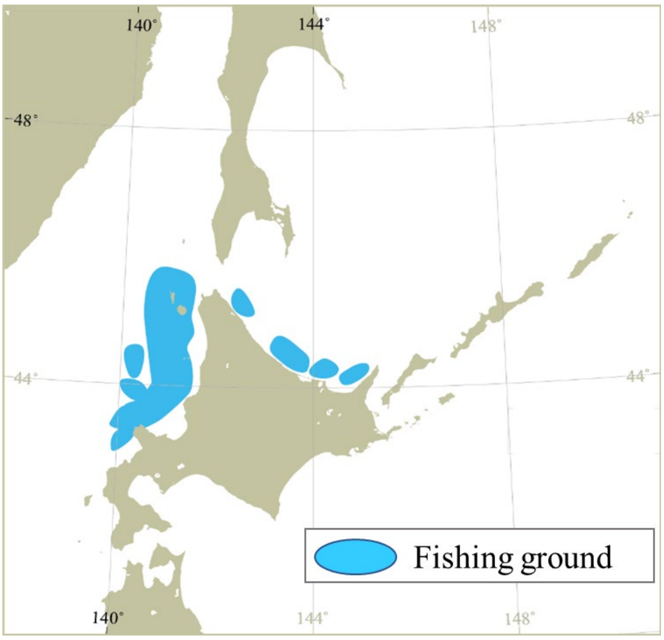


Figure2-1. Fishing ground of Northern Hokkaido stock of the Arabesque greenling (modified from Arabesque greenling research group (1983))

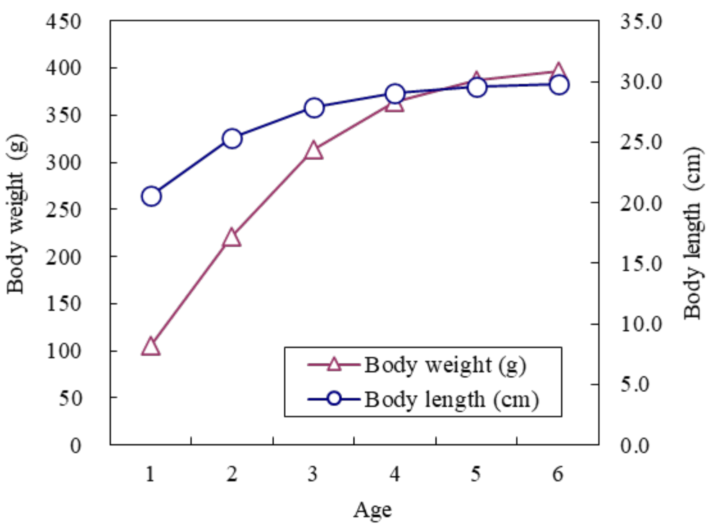


Figure 2-2. Relationship between age and average body length/weight of Northern Hokkaido stock of the Arabesque greenling (averaged for male and female) (Takashima et al. 2013)

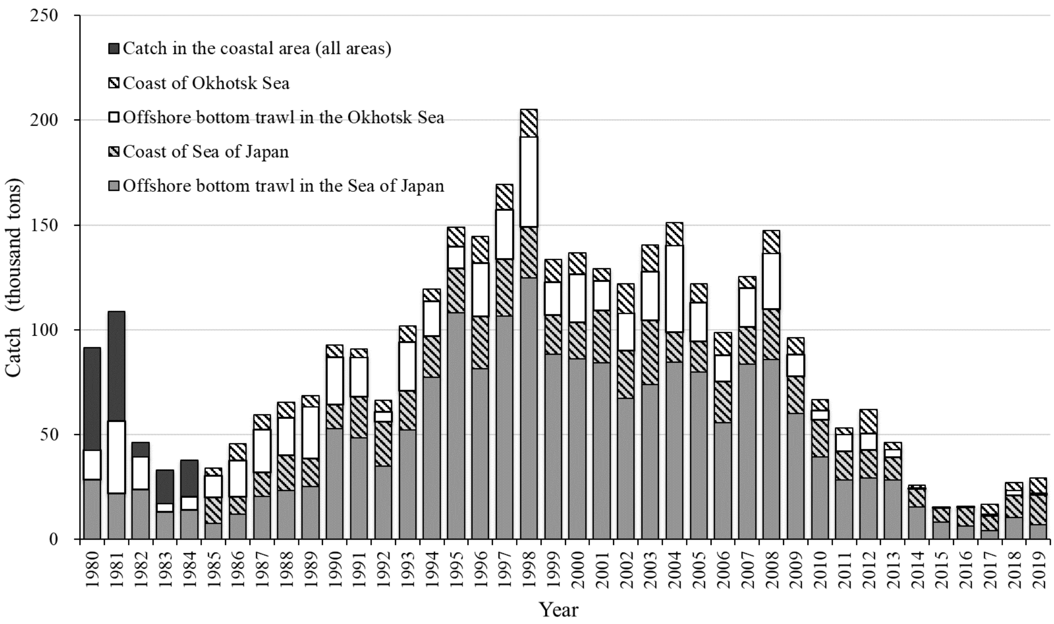


Figure3-1. Changes in catch of Northern Hokkaido stock of the Arabesque greenling

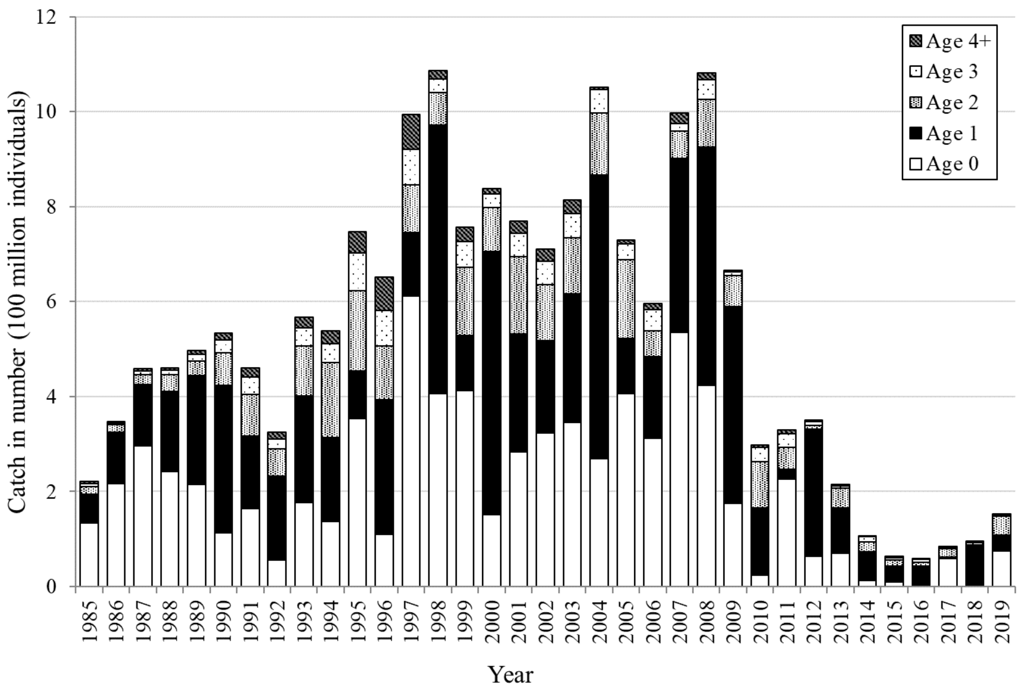


Figure 3-2. Changes in catch in number at age of Northern Hokkaido stock of the Arabesque greenling (Central, Wakkanai and Abashiri Fisheries Research Institutes; printing underway)

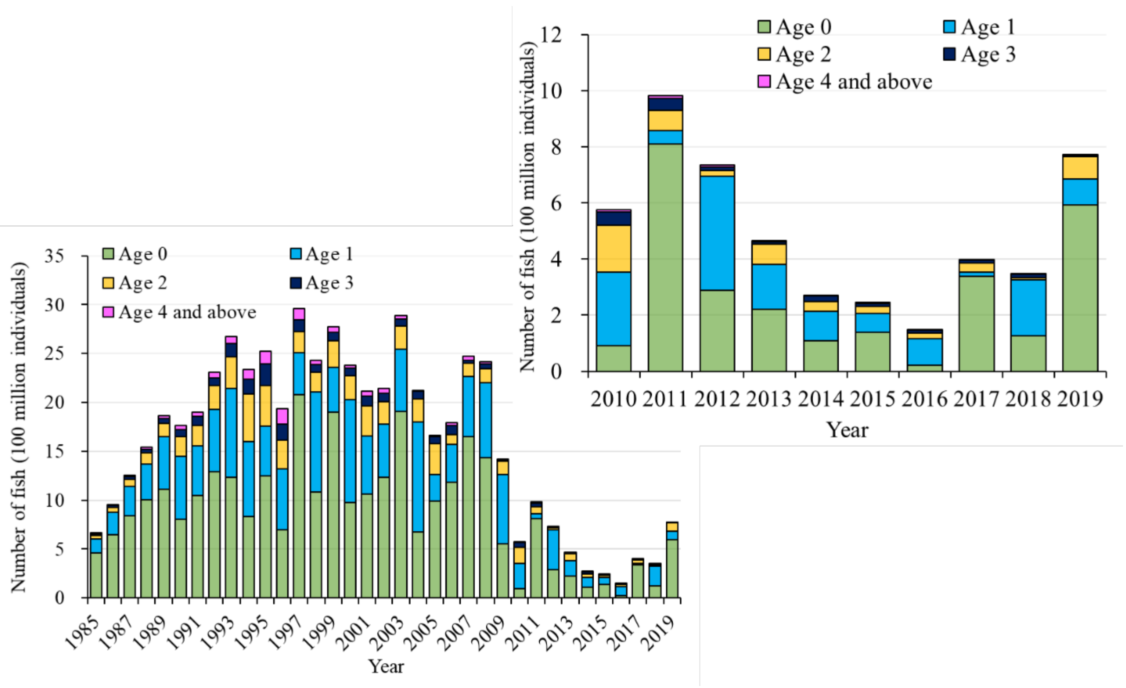


Figure 4-1. Changes in the number of fish at age
The upper right figure shows details of 2010 onward.

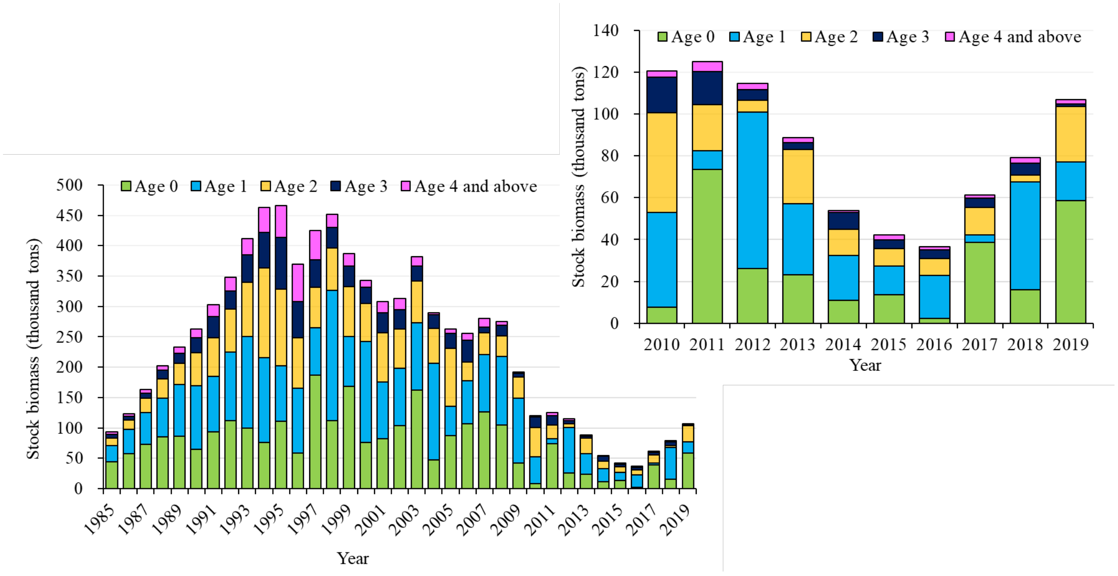


Figure 4-2. Changes in weight of biomass at age
The upper right figure shows details of 2010 onward.

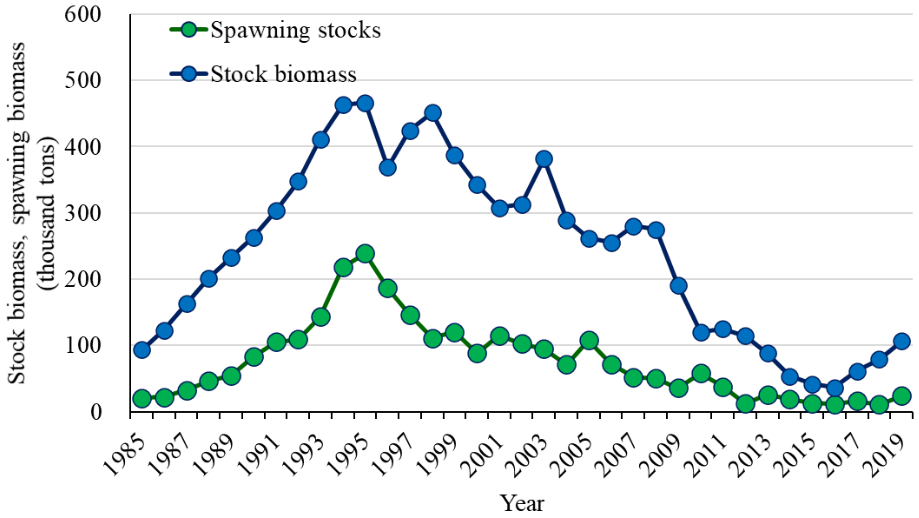


Figure 4-3. Changes in stock biomass and spawning biomass

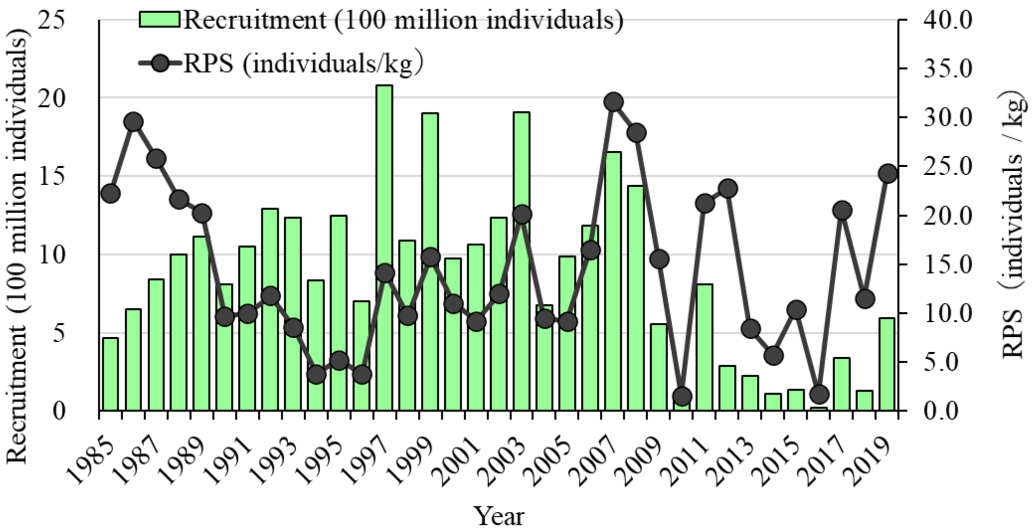


Figure 4-4. Changes in recruitment and RPS

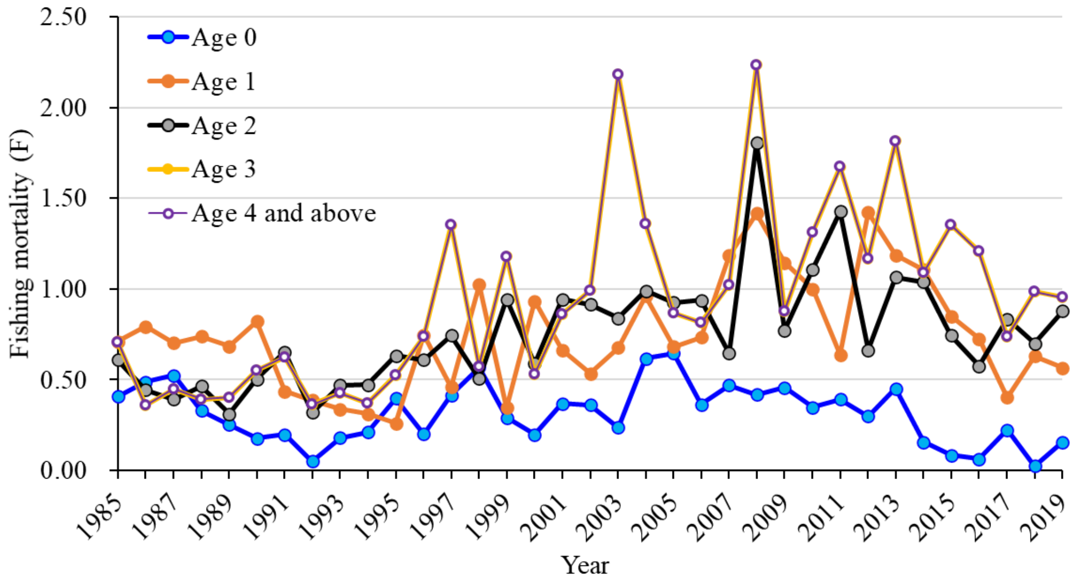


Figure 4-5. Changes in fishing mortality (F) at age

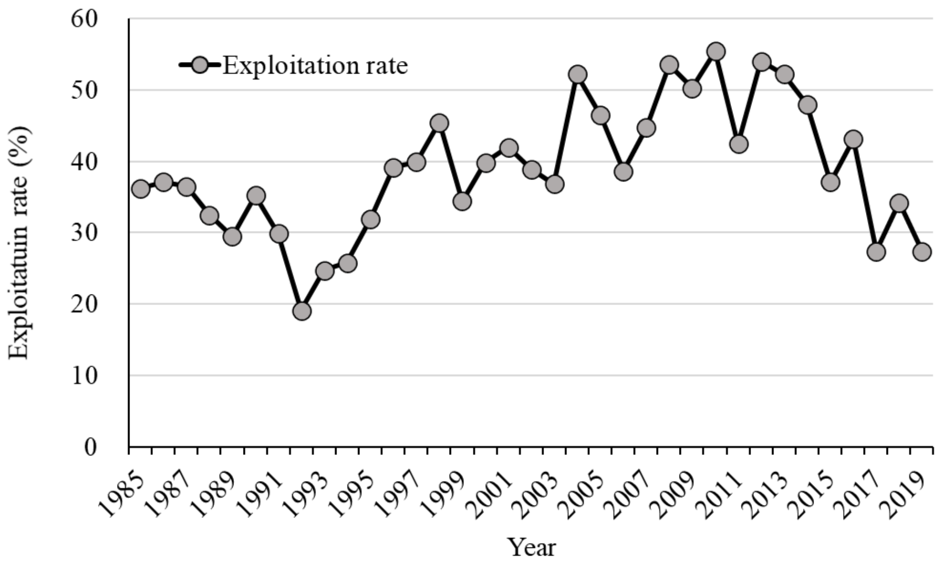


Figure 4-6. Changes in exploitation rate

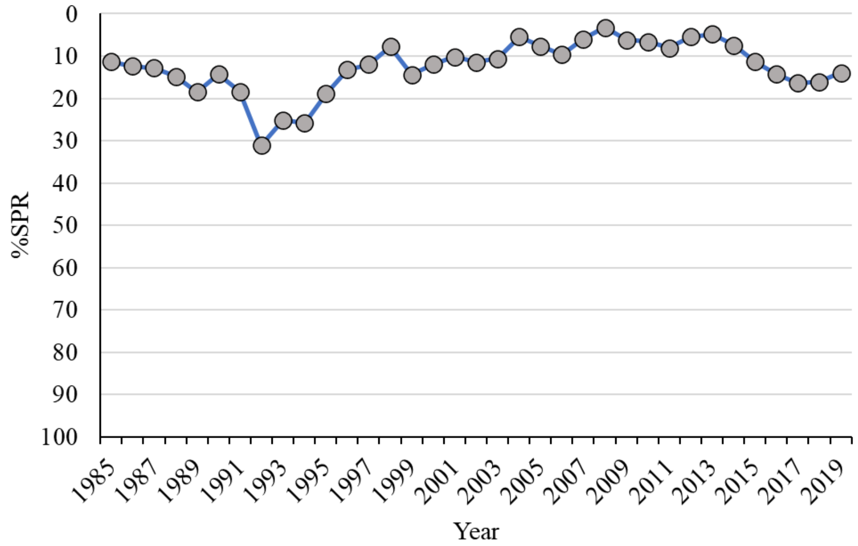


Figure 4-7. Changes in %SPR values

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

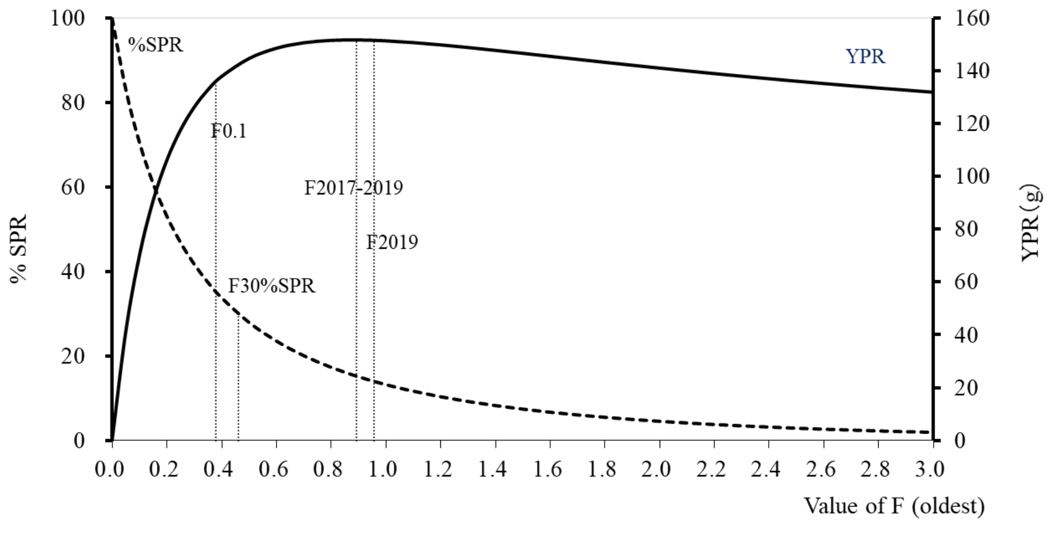


Figure 4-8. Relationship between YPR and %SPR for the current fishing mortality (F2017-F2019)

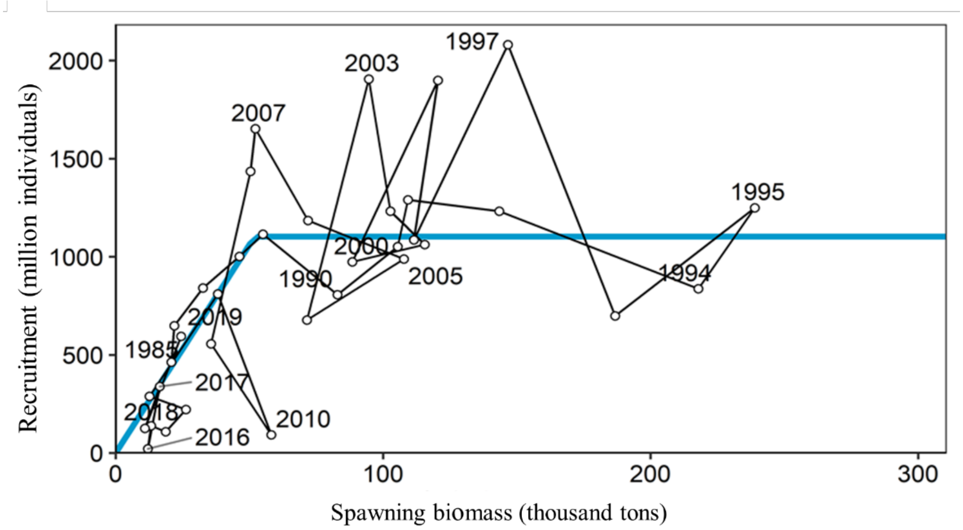


Figure 4-9. Relationship between spawning biomass and recruitment (S-R relationship)

The blue line shows the S-R relationship applied at the "Research Institute Meeting on Reference Points" held in April 2019. ● and ● respectively represent the 2018 and 2019 year classes.

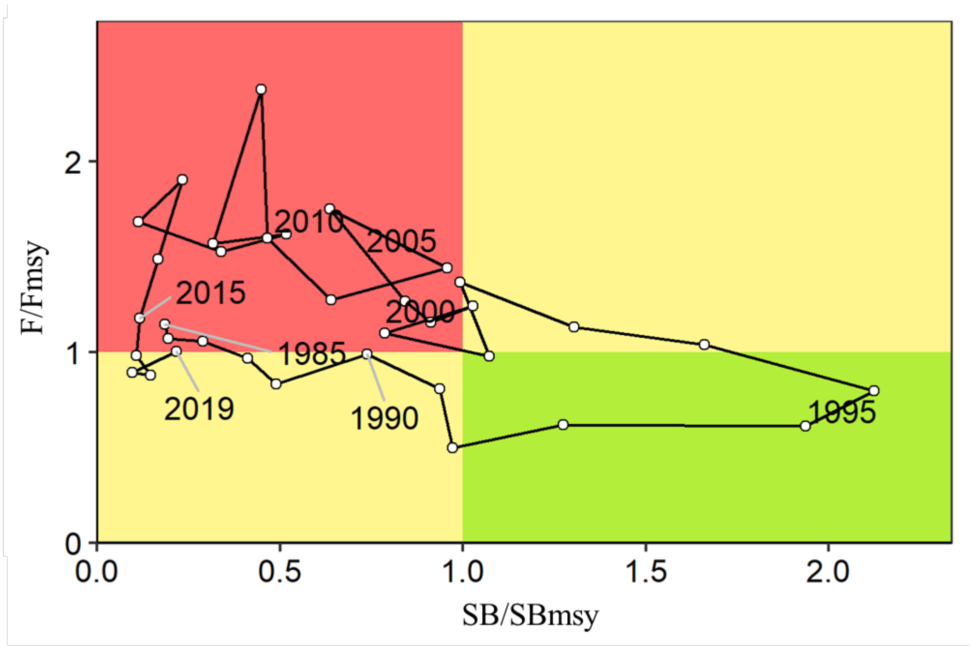


Figure 4-10. Relationship of the spawning biomass and fishing mortality to the spawning biomass that produces MSY (SBmsy) and fishing mortality that produces MSY (Fmsy) (Kobe plot)

Table 3-1. Catch of Northern Hokkaido stock of the Arabesque greenling (tons)

Year	Sea of Japan		Okhotsk Sea		Catch in offshore bottom trawl fishery (total)	Catch in the coastal fishery (total)	Totals of sea areas
	Catch in offshore bottom trawl fishery	Catch in coastal fishery	Catch in offshore bottom trawl fishery	Catch in coastal fishery			
1980	28,567		14,033		42,600	48,826	91,426
1981	22,043		34,453		56,496	52,271	108,767
1982	23,673		15,703		39,376	6,995	46,371
1983	12,969		4,212		17,181	15,897	33,078
1984	14,166		6,280		20,447	17,471	37,918
1985	7,545	12,322	10,640	3,454	18,185	15,777	33,962
1986	12,054	8,270	17,434	7,813	29,488	16,083	45,571
1987	20,397	11,571	20,457	7,041	40,854	18,612	59,466
1988	23,185	17,031	17,908	7,424	41,092	24,455	65,548
1989	25,105	13,326	24,869	5,344	49,974	18,670	68,644
1990	52,699	11,586	22,734	5,646	75,434	17,232	92,665
1991	48,445	19,523	18,846	3,885	67,290	23,408	90,698
1992	35,041	21,206	4,749	5,476	39,790	26,682	66,472
1993	52,199	18,546	23,389	7,693	75,588	26,239	101,827
1994	77,369	19,439	16,862	5,810	94,232	25,249	119,481
1995	108,187	21,141	10,478	9,176	118,665	30,318	148,983
1996	81,310	25,191	25,391	12,571	106,701	37,763	144,464
1997	106,621	26,984	23,657	12,201	130,277	39,185	169,462
1998	124,626	24,450	42,930	13,079	167,556	37,530	205,086
1999	88,431	18,624	15,788	10,546	104,219	29,170	133,389
2000	86,252	17,251	22,985	10,123	109,237	27,374	136,611
2001	84,316	24,788	14,249	5,704	98,565	30,492	129,057
2002	67,324	22,839	17,771	13,941	85,096	36,780	121,876
2003	73,981	30,401	23,492	12,616	97,473	43,017	140,491
2004	84,405	14,566	41,179	11,049	125,584	25,615	151,199
2005	79,775	14,586	18,688	8,745	98,463	23,331	121,794
2006	55,560	19,744	12,557	10,758	68,117	30,502	98,619
2007	83,530	17,811	18,657	5,252	102,187	23,063	125,250
2008	85,689	23,999	26,803	10,755	112,492	34,754	147,246
2009	60,094	17,607	10,532	8,083	70,626	25,690	96,316
2010	39,439	17,533	4,515	5,311	43,954	22,844	66,798
2011	28,281	13,592	8,171	3,038	36,452	16,630	53,082
2012	29,391	13,266	7,859	11,452	37,250	24,718	61,968
2013	28,413	10,861	3,664	3,357	32,077	14,218	46,295
2014	15,317	8,705	504	1,263	15,821	9,968	25,789
2015	8,252	6,769	160	437	8,411	7,207	15,618
2016	6,364	9,004	149	235	6,513	9,239	15,752
2017	4,047	7,264	760	4,705	4,806	11,969	16,775
2018	10,467	10,596	2,292	3,720	12,758	14,316	27,074
2019	7,043	14,256	661	7,363	7,704	21,619	29,323

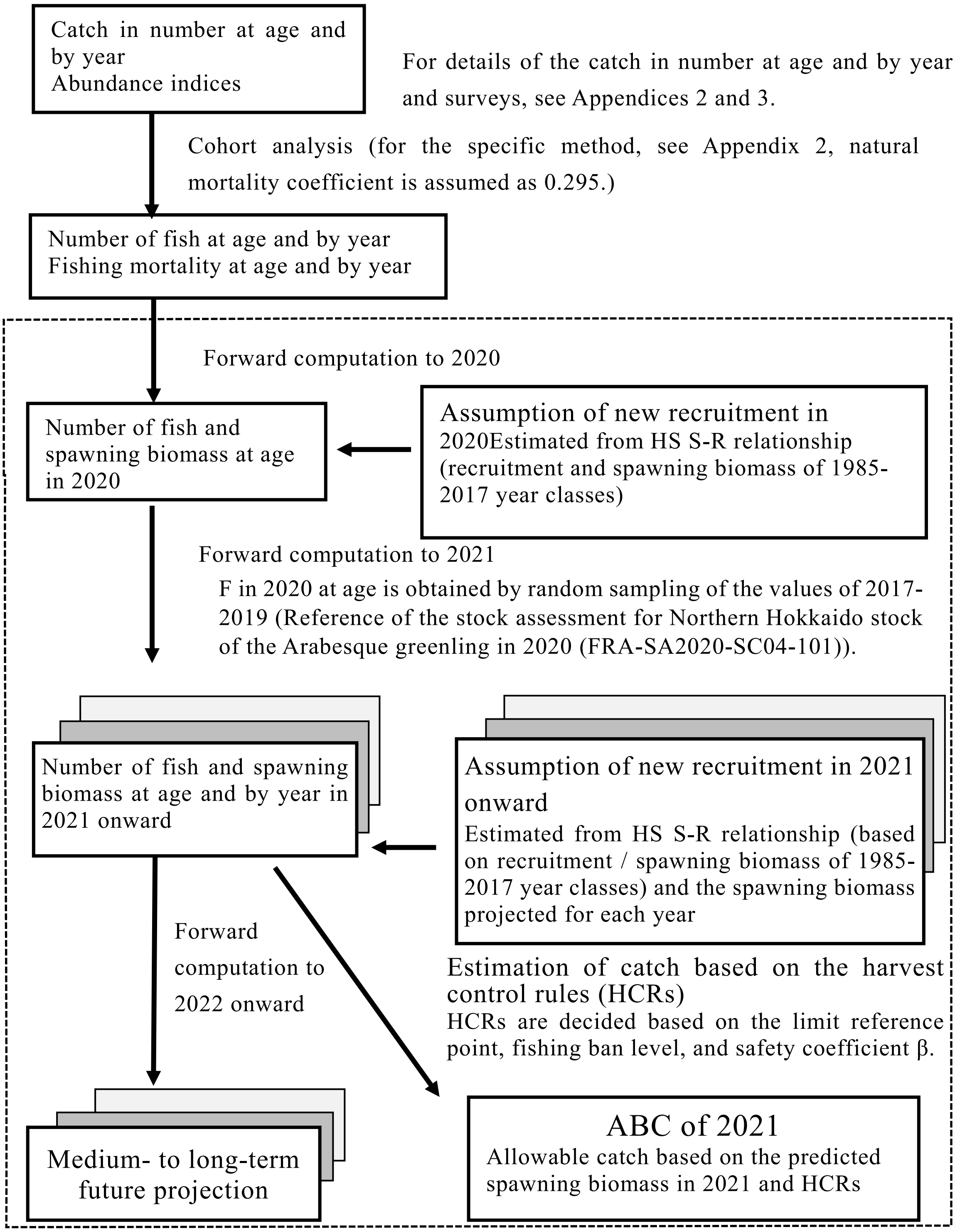
The catch (unit: tons) includes those in test operations.
Sea of Japan (offshore trawl fishery): Statistical data of catch in offshore bottom trawl fishery in Hokkaido (middle sea zone: west of Hokkaido, since 2004 Sea of Japan off Hokkaido)
Sea of Japan (coastal fishery): Report on fishery yield (Hokkaido Department of Fishery and

Forestry) (Sea of Japan except for Hiyama and Oshima)
Okhotsk Sea (offshore bottom trawl fishery): Statistical data of catch in offshore bottom trawl fishery in Hokkaido (middle sea zone: Okhotsk, since 2004 coastal Okhotsk (Sea of Japan))
Okhotsk Sea (coastal fishery): Report on fishery yield (Hokkaido Department of Fishery and Forestry) (excluding the catch in offshore bottom trawl fishery in the Okhotsk Sea except for in Nemuro Strait)
Catch in coastal fishery (total of sea areas): Report on fishery yield (Hokkaido Department of Fishery and Forestry) (excluding the catch in offshore bottom trawl fishery from each of the General Subprefectural Bureaus of Shiribeshi, Ishikari, Rumoi, Souya and Okhotsk)
The figure for the catch in coastal fishery in 2019 is a preliminary value aggregated by the Hokkaido Fishery Research Institute, and that for the catch in offshore bottom trawl fishery is a definitive value.

Table 4-1. Results of the stock assessment of Northern Hokkaido stock of the Arabesque greenling

年	Catch (thousand tons)	Stock biomass (thousand tons)	Spawning stocks (thousand tons)	Recruitment (100 million indiviauals)	Exploitation rate (%)	RPS (individuals /kg)
1985	34	94	21	463	36	22.3
1986	46	123	22	649	37	29.6
1987	59	163	33	841	37	25.8
1988	66	202	46	1,001	32	21.6
1989	69	233	55	1,115	29	20.3
1990	93	263	83	806	35	9.7
1991	91	303	105	1,051	30	10.0
1992	66	348	109	1,289	19	11.8
1993	102	412	143	1,232	25	8.6
1994	119	463	218	836	26	3.8
1995	149	466	239	1,249	32	5.2
1996	144	369	187	699	39	3.7
1997	169	425	147	2,080	40	14.2
1998	205	451	112	1,086	45	9.7
1999	133	387	121	1,899	34	15.8
2000	137	343	88	974	40	11.0
2001	129	308	116	1,062	42	9.2
2002	122	313	103	1,232	39	12.0
2003	140	382	95	1,906	37	20.1
2004	151	290	72	677	52	9.5
2005	122	262	108	989	46	9.2
2006	99	255	72	1,184	39	16.5
2007	125	280	52	1,652	45	31.6
2008	147	275	50	1,436	54	28.5
2009	96	192	36	556	50	15.6
2010	67	121	58	92	55	1.6
2011	53	125	38	810	42	21.2
2012	62	115	13	288	54	22.8
2013	46	89	26	222	52	8.4
2014	26	54	19	108	48	5.7
2015	16	42	13	138	37	10.4
2016	16	37	12	21	43	1.7
2017	17	61	16	338	27	20.6
2018	27	79	11	126	34	11.5
2019	29	107	24	594	27	24.3

Appendix 1. The workflow of stock assessment



※ Workflows in the dashed box are prepared based on discussions on reference points and HCRs at the Committee of Stock Management Policy. (https://www.jfa.maff.go.jp/j/press/sigen/200529_29.html))

Appendix 2. Calculation method

(1) Stock calculation method

We estimated the number of fish, fishing mortality and biomass of age 0 to 4+ fish (fish of age 4 and above are indicated as 4+ (plus group)) in 1985-2019 by cohort analysis. In the cohort analysis, we used catch in number at age calculated by the Hokkaido Research Organization. We assumed that about 80% fish spawn at the end of age 1, and that the maturity rate at the age of 2 is 80% in the calculation (Appendix Table 2-1). The maturity rate is constant among years irrespective of stock status. We applied the average body weight at age of the catch (Appendix Table 2-2) as body weight at age of the population. The natural mortality (M) is assumed as 0.295 (Irie 1983). In the calculation of the number of fish at age, we applied approximation of Pope (1972), and applied the method of Hiramatsu (1999) for the number of fish of the plus group. The area weighted standardized CPUE index for bottom trawl fishery (Appendix Table 3-3 and Appendix 5) was used as the tuning index. In order to reduce instability in the estimation of the F value of recent years in tuning, we used a penalty based on the method of ridge VPA (Okamura et al. 2017).

The number of fish at age a in year y was calculated from the following equation.

$$N_{a,y} = N_{a+1,y+1} \times \exp(M) + C_{a,y} \times \exp\left(\frac{M}{2}\right) \qquad (1)$$

where, N is the number of fish, C is catch in number and M is natural mortality per year.

Abundance for the age of the oldest-1 (suffix $p-1$) and the oldest (plus group, suffix p) of the most recent year were calculated from equations (2) to (4).

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

$$N_{p-1,y} = \frac{C_{p-1,y}}{C_{p,y} + C_{p-1,y}} N_{p,y+1} \times \exp(M) + C_{p-1,y} \times \exp\left(\frac{M}{2}\right) \qquad (3)$$

$$N_{p,y} = \frac{C_{p,y}}{C_{p-1,y}} N_{p-1,y} = \frac{C_{p,y}}{C_{p,y} + C_{p-1,y}} N_{p,y+1} \times \exp(M) + C_{p,y} \times \exp\left(\frac{M}{2}\right) \qquad (4)$$

The fishing mortality ($F_{a,y}$) at age a in year y was obtained from the equations (5) and (6), except for the most recent year (terminal F).

$$F_{a,y} = -\ln\left\{1 - \frac{C_{a,y} \times \exp\left(\frac{M}{2}\right)}{N_{a,y}}\right\} \quad (5)$$

$$F_{3,y}=F_{4+,y} \quad (6)$$

From the F at age obtained, the selectivity at age was calculated using equation (7).

$$S_{a,y} = F_{a,y}/\max\,(F_{4+,y}) \quad (7)$$

The weight of biomass at age and spawning biomass in each year were calculated from equations (8) and (9).

$$B_{a,y} = N_{a,y} \times w_{a,y} \quad (8)$$

$$SSB_y = \sum_{a=0}^{4+} N_{a,y} \times m_a \times w_{a,y} \quad (9)$$

Here, $w_{a,y}$ is the average body weight of age a in year y (Appendix Table 2-2), and m_a is maturity rate at age a (Appendix Table 2-1).

Since the latter half of 2012, voluntary restraints have been conducted, which might influence the catch in recent years. As for the voluntary restraints in offshore bottom trawl fishery, the tendency to not catch age 0 fish is becoming stronger. In recent years, urgent countermeasures to protect the 2017 year class, the abundance of which is presumed to be high (Suzuki 2017) is put into operation (Central, Wakkanai and Abashiri Fisheries Research Institutes; printing underway). In order to take its influences into consideration, the F was calculated so that the tendency of variation of area weighted CPUE corresponds to that of biomass of age 0 to 4 fish, using the exploitation rate of bottom trawl fishery (Central, Wakkanai and Abashiri Fisheries Research Institutes; unpublished data).

The F was decided so that the absolute average of ρ, which is the retrospective bias of F value for older fish (4+, the same value is applied to age 3 fish) expressed in equation (10), becomes the smallest when the weighting factor of penalty λ (0≦λ<1) varies by 0.01.

$$\rho_{F'_{4+}} = \frac{1}{P}\sum_{i=1}^{P} \frac{{F'_{4+Y-i}}^{Ri} - F'_{4+Y-i}}{F'_{4+Y-i}} \quad (10)$$

where, P is the number of years to be removed in the retrospective calculation, and we used 5 years as the recent time range. Ri indicates the value of retrospective calculation for i years. The value of ρ is the average of relative deviation between the estimate value for terminal year (Y-i year) where data for i years are lacking from the latest data and the estimate value for year Y-I based on full data up to terminal year Y (Mohn 1999).

The value of $F_{4+,2019}$ that gives the least value of equation (11) was searched by tuning for the period of 2005-2019 for which the fishing efficiency is similar to the current status such as the number of fishing vessels.

The objective function was set as follows.

$$Obj = (1-\lambda)\times\sum_y \left[\log(CPUE_y) - \log\left(q\left\{\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}B_{a,y} \,/\, \sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}\right\}^b\right)\right]^2 + \lambda\times\sum_{a=1}^{4+}(F_{a,Y})^2 \quad (11)$$

where, λ is the weight of penalty (0≦λ< 1, see Appendix 8 for details), $\Omega_{a,y}$ is the exploitation rate of offshore bottom trawl fishery to the total catch of age a in year y, $S_{a,y}$ is selectivity of the total catch of age a in year y, $B_{a,y}$ is weight of stock biomass of age a in year y. The value q is the coefficient that expresses the relationship between CPUE and biomass, b is a parameter that indicates the degree of non-linearity of CPUE and biomass (Okamura et al. 2017, Hashimoto et al. 2018), which are calculated as follows, respectively.

$$b = \frac{\mathrm{cov}\left(\log(CPUE_y), \log(\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}B_{a,y}/\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y})\right)}{\mathrm{var}(\log(\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}B_{a,y}/\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}))}, \quad (11)$$

$$q = \exp\left(\frac{1}{n}\sum_y\log(CPUE_y) - \frac{b}{n}\sum_y\log(\sum_{a=0}^{4+}\Omega_{a,y}S_{a,y}B_{a,y} \,/\, \sum_{a=0}^{4+}\Omega_{a,y}S_{a,y})\right) \quad (12)$$

Here, λ was set as the value that the retrospective bias (ρ) of the F of aged fish derived from equation (10) would be closest to 0 (0.09).

The fishing mortality at age of fish of age 2 and below for the latest year (2019) was estimated from the equation (13) based on the assumption that it is equal to the average of selectivity of the past two years, and that of age 4 was estimated from equation (14).

Age 0 to 2:

$$F_{a,2019} = \frac{1}{2}\sum_{y=2017}^{2018}\frac{F_{a,y}}{F_{4+,y}}\times F_{4+,2019} \quad (13)$$

Age 3:

$$F_{3,2019} = F_{4+,2019} \quad (14)$$

We used MS-Excel and the RVPA package of statistical language R (Ichinokawa and Okamura 2014) for all calculations.

Presently, we use the area weighted standardized CPUE obtained from the offshore bottom trawl fishery as the tuning index. In recent years, fishing operation in offshore fishery changed greatly as they do not catch age 0 fish. So, it is difficult to use the CPUE obtained from offshore bottom trawl fishery as the tuning index for age 0 to 4+ fish. Also, as the annual variation of recruitment is large year by year, and voluntary restraints may have an influence not only on offshore bottom trawl fishery but also on coastal fishery, it is presumed that the strategy for fishing operation would be unstable. Therefore, the fishing mortality at age (that is, F at age) in each year may largely change in the near future, and the most recent actual fishing operation might not be considered sufficiently in the assumption of selectivity in tuning in cohort analysis. One of the candidates to solve this problem is to estimate each F at age, instead of assuming the average of selectivity of recent several years, in estimating the F value of the terminal year. In this case, however, effective information for tuning by age is necessary. Presently, the Hokkaido Research Organization provides information to establish the method of CPUE at age, and we will establish such tuning method that does not depend on the assumption of selectivity by considering the introduction of the standardized method to the information.

For details of the application of the S-R relationship and the estimation of the level that produces MSY, see the report of the "Research Institute Meeting on Reference Points" held in April 2019 (Morita et al. 2019). Here, in estimating the level that produces MSY, we used the applied S-R relationship and each parameter and settings used for future predictions in the 2018 marine fisheries stock assessment and evaluation for Japanese waters. That is, we applied as a S-R relationship the HS model based on the recruitment and spawning biomass of the 1985-2017 year classes estimated in the stock assessment, and the natural mortality, maturity rate, average body weight at age and selectivity of catch were used as parameters in the simulation. The selectivity was based on the average of the fishing mortalitys (F) at age in 2015-2017 (that was, Fcurrent in the stock assessment in 2020) (Appendix Table 2-3). As negative correlation is confirmed between the number of fish and body weight in this stock, we used as the body weight at age in the future the value derived by adding stochastic variation to the predicted value derived from the regression equation when the parameter of body weight recurred in the number of fish. In the simulation under the conditions mentioned above with the S-R relationship applied, the fishing mortality that maximizes the catch at equilibrium, the spawning biomass at that time, and the average of the catch that is maximized at equilibrium were estimated as Fmsy, SBmsy, and MSY, respectively.

References

Irie, T., (1983) "Suisan shigen no kaiseki to hyoka sono syuho to tekiyorei (Series of Fisheries Science 46: Analysis and assessment of fishery stock, the Method and Applications)", edited by Ishii.,T, Tokyo, KOUSEISHA KOUSEIKAKU, 91-103.

Hashimoto, M., Okamura, H., Ichinokawa, M., Hiramatsu, K., and Yamakawa, T. (2018). Impacts of the nonlinear relationship between abundance and its index in a tuned virtual population analysis. Fisheries Science 84:335–347.

Ichinokawa, M.,and H. Okamura (2014) Review of stock evaluation methods using VPA for fishery stocks in Japan: implementation with R, Bulletin of the Japanese Society of

Fisheries Oceanography, 78, 1-10.
Suzuki, Y. (2017) 2017 nen ni Hokkaido okiai de saisyu sareta hokke shichigyo ni tsuite: Shiken-kenkyu ha Ima (Juvenile of Arabesque greenling caught offshore Hokkaido in 2017: Current Statue of Experimental Research), 833. (online), downloadable from: http://www.hro.or.jp/list/fisheries/marine/att/ima833.pdf
Central, Wakkanai and Abashiri Fisheries Research Institutes, (printing underway), Hokke (Arabesque greenling) (Sea of Japan of Middle Hokkaido-Okhotsk Sea area), 2020 nendo suisan shigen kanri kaigi hyokasyo (Assessment report of council of stock management in 2020), Fisheries Research Department, Hokkaido Research Organization. http://www.fishexp.hro.or.jp/exp/central/kanri/SigenHyoka/Kokai/ (last accessed XX)
Hiramatsu, K. (1999) Introduction and practice of VPA. Suisan shigen kanri danwa kaiho (Journal of the study meeting on fishery resource management), 20, 9-28.
Morita, S., Y. Yamashita, O. Sakai, T. Isono, K. Hattori and M. Ichinokawa (2019) Report of the Research Institute Meeting on Reference Points for Northern Hokkaido stock of the Arabesque Greenling in 2019. https://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_hokke_h.pdf (last accessed on October 15, 2019).
Okamura, H., Yamashita, Y., and Ichinokawa, M. (2017). Ridge virtual population analysis to reduce the instability of fishing mortalities in the terminal year. ICES Journal of Marine Science 74 (9): 2427–2436.
Pope, J.G. (1972) An investigation of the accuracy of virtual population using cohort analysis. Res. Bull. inst. Comm. Northw. Atlant. Fish., 9, 65-74.

Appendix Table 2-1. Maturity rate of Northern Hokkaido stock of the Arabesque greenling (%)

Age	0	1	2	3	4+
Maturity rate (%)	0	0	80	100	100

Appendix Table 2-2. Body weight of catch at age (g)

Year	Body weight at age (g)				
	Age 0	Age 1	Age 2	Age 3	Age 4 and above
1985	95	192	320	402	443
1986	88	178	297	374	412
1987	87	177	295	370	408
1988	85	173	288	362	398
1989	78	158	263	330	364
1990	80	162	271	340	375
1991	89	181	302	380	418
1992	87	176	293	369	406
1993	81	165	275	345	380
1994	90	183	305	384	423
1995	89	181	301	378	417
1996	84	171	285	358	395
1997	90	182	304	382	421
1998	103	209	349	438	483
1999	89	180	300	376	415
2000	78	157	262	330	363
2001	78	157	262	330	363
2002	84	171	286	359	395
2003	85	173	289	363	400
2004	70	142	237	298	328
2005	88	178	298	374	412
2006	90	183	304	383	421
2007	76	155	258	324	357
2008	73	147	246	309	340
2009	75	152	254	319	351
2010	85	172	286	360	396
2011	91	184	307	386	426
2012	90	184	306	385	424
2013	105	213	355	446	491
2014	101	206	343	431	475
2015	98	199	332	418	460
2016	108	219	366	460	506
2017	115	233	388	488	537
2018	127	257	428	538	593
2019	99	201	335	420	463

Appendix Table 2-3. Values of parameters used for estimation of the level that produces MSY (Morita et al. 2019)

Age	Natural mortality rate	Maturity rate (%)	Average body weight(biomass,g)	Selectivity (note1)	Fcurrent (note2)
0	0.295	0	81	0.125	0.15
1	0.295	0	164	0.84	0.99
2	0.295	0.8	273	0.628	0.74
3	0.295	1	343	1	1.18
Age 4 and above	0.295	1	378	1	1.18

Note 1: The selectivity used for estimating the level that produces MSY is the selectivity of Fcurrent in the 2019 stock assessment (the selectivity of the average F for the 2015-2017 fishing seasons).
Note 2: Fcurrent in the 2018 stock assessment (average F for the 2015-2017 fishing seasons)

Appendix 3. Outline of surveys conducted for stock assessment

(1) Changes in catch in the long period around Hokkaido

The catch of this stock decreased since 1998 and fell down to the lowest level since 1980. The catch of Arabesque greenling in Japan and Hokkaido since 1956 is shown as reference as an indicator of the status of catch before 1980 (Appendix Table 3-1). Total catch in Japan changed around 80 thousand to 200 thousand tons in the 1960s and exceeded 200 thousand tons in the latter half of the 1970s. However, it decreased to the level of 50 thousand tons in Japan and 40 thousand tons in Hokkaido in the first half of the 1980s. Afterwards, it increased again to above 200 thousand tons respectively in 1998 but decreased since then. It remained at around 17 thousand tons during the period of 2015-2017, then it increased in 2018 and 2019 to 34 thousand tons in Japan. The catch remains at a very low level for a long term.

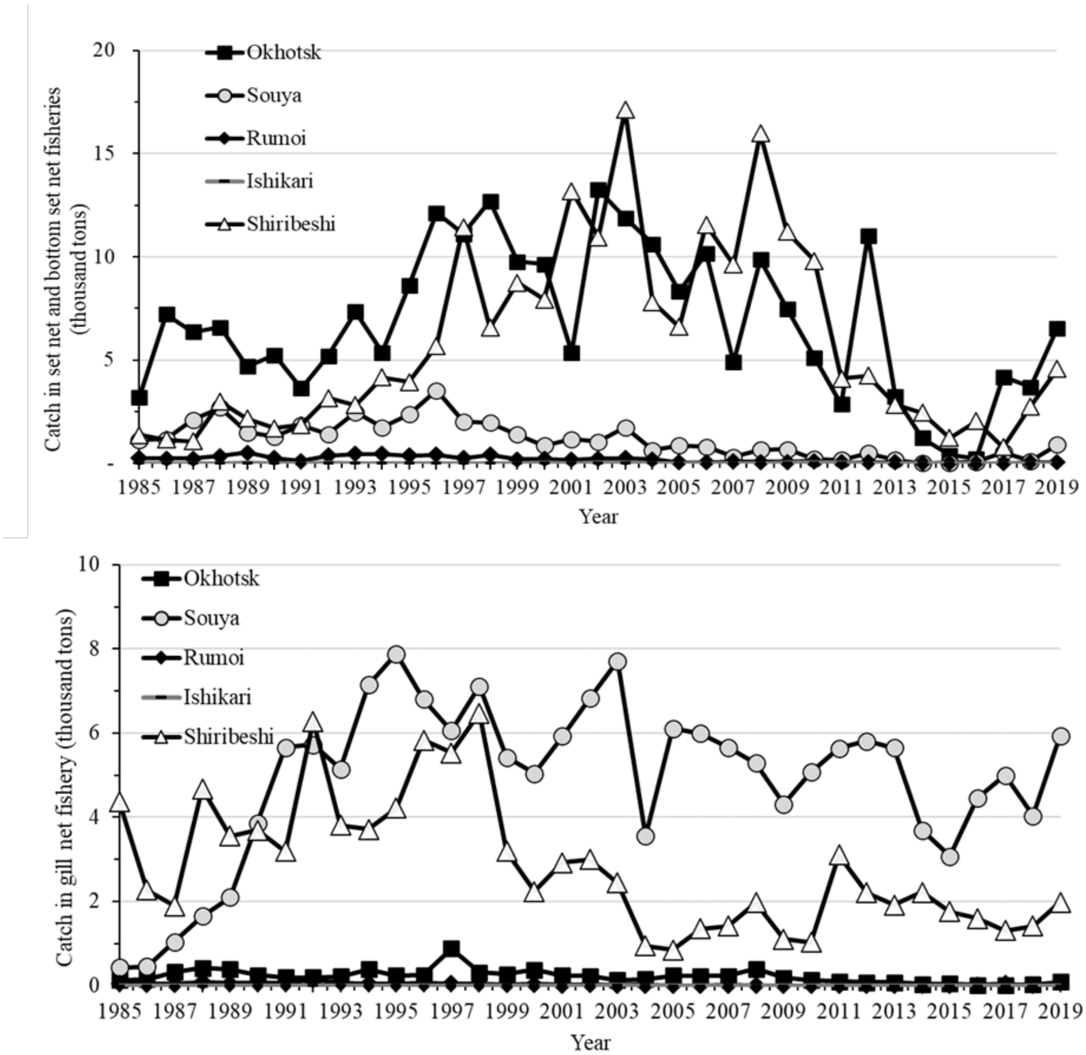
(2) Catch in set net, bottom set net and gill net fisheries by General Subprefectural Bureau

Appendix Figure 3-1 and Appendix Table 3-2 show the catch by General Subprefectural Bureau, obtained by set net, bottom set net and gill net that account for 50 to 60% of the catch by coastal fishery. The catch in set net and bottom set net fisheries is large in the areas governed by Okhotsk General Subprefectural Bureau (Okhotsk) and Shiribeshi General Subprefectural Bureau (Shiribeshi). The catches in Okhotsk and Shiribeshi increased in the 1990s and remained at a high level around 10 thousand to 17 thousand tons until about 2005. Since 2008, it tended to decrease and it was 0.8 thousand tons in 2017 in Shiribeshi, and it increased to 3 thousand tons in 2018. In Okhotsk, it increased rapidly from 0.2 thousand tons in 2016 to 4 thousand tons in 2017, then it remained at around 4 thousand tons in 2018 and increased to near 7 thousand tons in 2019. The catch in gill net fishery was the largest in Souya. It exceeded 7 thousand tons in some years from the 1990s to the about 2005, although it remained at around 5 thousand tons until 2013. It decreased to 3 thousand tons in 2014-2015, but it increased to 5 thousand tons in 2016-2017. In 2018, it decreased to 4 thousand tons and increased again in 2019 to 6 thousand tons. In Shiribeshi, it remained at around 2 thousand to 6 thousand tons until 1998 and then it decreased to less than 1 thousand tons in 2004. It exceeded 3 thousand tons in 2011, and remained at around 1 thousand ton in 2017-2018, then it increased to 2 thousand tons in 2019.

(3) Catch and fishing effort

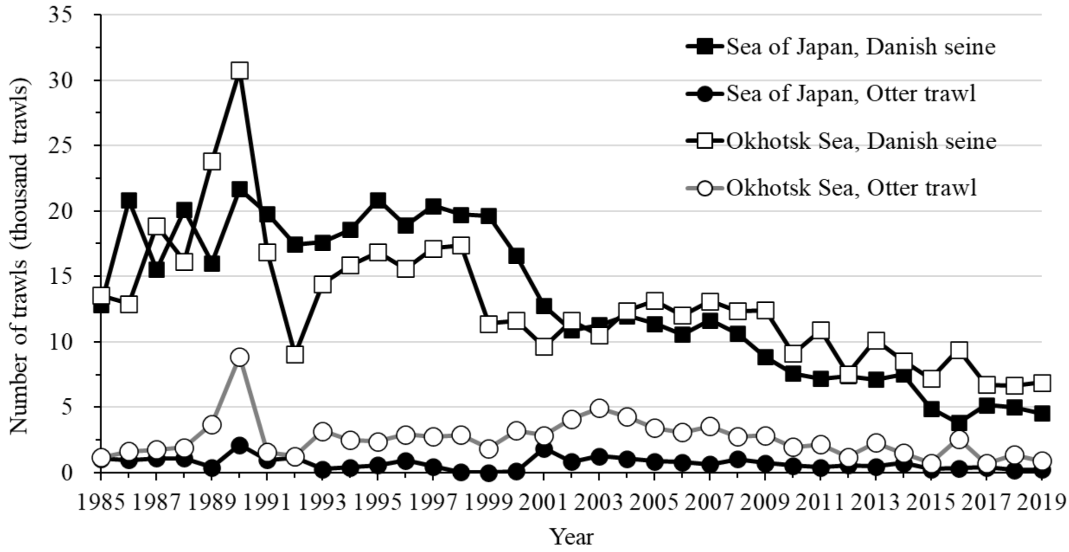
The effort (the number of trawls of Arabesque greenling with catch) of offshore bottom trawl fishery (Danish seine and otter trawl) is shown in Appendix Figure 3-2 and Appendix Table 3-3. Although the number of trawls with catch by Danish seine in the Sea of Japan remained at around 20 thousand trawls in the latter half of the 1980s, it tends to decrease in the first decade of the 2000s. Since 2008, the number fell down to below 10 thousand trawls, and it has remained at around 4 thousand to 5 thousand trawls since 2015. (Appendix Figure 3-2 and Appendix Table 3-3). The number of trawls with catch by otter trawl remained at around one thousand trawls, but it decreased to 0.2 thousand trawls in 2018. The number of trawls with catch by Danish trawl in the Okhotsk Sea remained at around 9 thousand to 31 thousand trawls since the latter half of the 1980s until the latter half of the 1990s, and it remained at around 10 thousand since 2000, which was the same tendency as in the Sea of Japan. It decreased to 8 thousand trawls in 2012, but it increased to 10 thousand in 2013 due to increase of fishing of Japanese common squid, etc. other than Arabesque greenling. In 2017, it decreased from 9 thousand trawls in the previous year to 7 thousand trawls, and it remained at around the same level until 2019. The number of trawls with catch by otter trawl remained at around 2 thousand to 5 thousand trawls, but it decreased from 2.6 thousand in the previous year to 0.7 thousand in 2017. In 2018, it increased to 1.4 thousand trawls, but it decreased to 0.9 thousand trawls in 2019.

As fishing efforts of coastal fishery, we used the number of fishing units described in the Annual report of fishery statistics in Hokkaido for small set net fishery, the number of fishing units and the number of licenses for set net fishery for salmon described in the Annual report of fishery statistics in Hokkaido for set net fishery for salmon, and the number of fishermen who use bottom set net for flatfish, flounder and Arabesque greenling included in class 2 common fishery right for bottom set net (Appendix Table 3-4).As for the number of fishing units of set net fishery, that of the fishing unit of small set net fishery was large in the first half of the 1980s. It decreased in the latter half of the 1980s, and no remarkable change has been confirmed since the 1990s until 2006, during which period the aggregation by the General Subprefectural Bureau was conducted. The number of trawls for set net fishery for salmon increased from the first half of the 1980s until the middle of the 1990s, but it has not shown any remarkable change since the first decade of the 2000s. As for the number of fishermen who use bottom set net roughly decreased in that decade, compared with in the latter half of the 1990s, with some differences between General Subprefectural Bureaus.

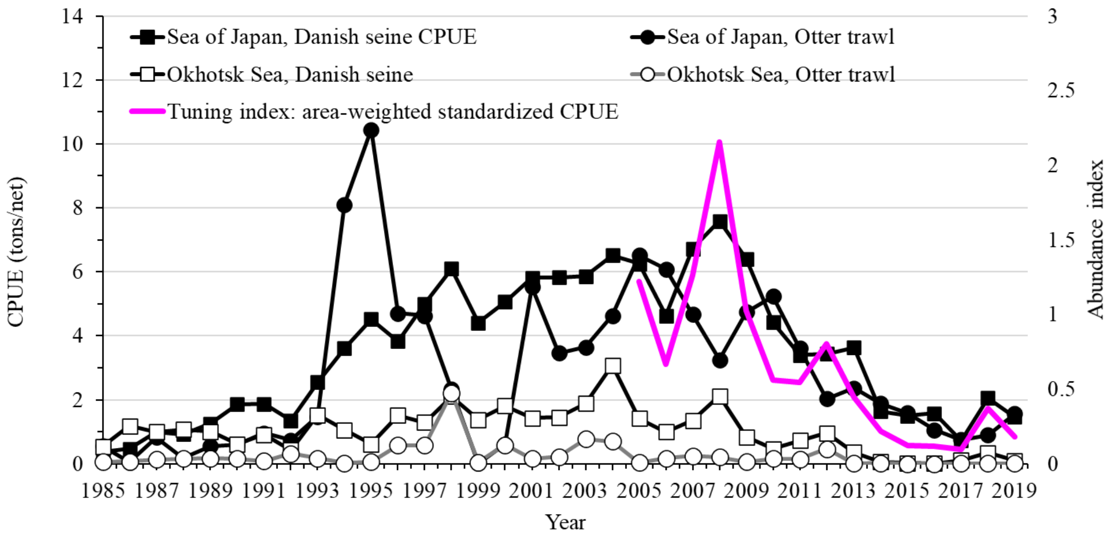


Appendix Figure 3-1. Changes in catch by General Subprefectural Bureau

Catch in set net and bottom set net fisheries (upper figure) and gill net fishery (bottom figure) are shown.



Appendix Figure 3-2. Changes in the number of trawls with catch in offshore bottom trawl fishery for Northern Hokkaido stock of the Arabesque greenling



Appendix Figure 3-3. CPUE for offshore bottom trawl of Northern Hokkaido stock of the Arabesque greenling by sea area and by fishery

Appendix Table 3-1. Catch of Arabesque greenling in Japan and Hokkaido (Unit: tons)

Year	Hokkaido	Japan	Year	Hokkaido	Japan
1956	120,349	121,162	1988	93,751	104,160
1957	104,944	105,562	1989	103,325	114,945
1958	47,642	47,933	1990	121,482	133,605
1959	100,185	100,300	1991	112,104	130,385
1960	115,798	115,978	1992	88,405	97,564
1961	184,898	185,248	1993	126,509	135,529
1962	120,425	122,218	1994	145,581	152,503
1963	150,089	150,393	1995	168,276	176,603
1964	202,900	204,888	1996	173,834	181,513
1965	106,031	107,288	1997	199,777	206,763
1966	105,026	106,016	1998	233,231	240,971
1967	81,395	81,912	1999	163,011	169,481
1968	84,641	86,855	2000	160,085	165,118
1969	98,096	102,581	2001	157,453	161,160
1970	142,643	146,516	2002	147,328	154,736
1971	145,693	147,209	2003	160,137	167,989
1972	178,219	180,552	2004	167,010	175,544
1973	112,928	114,986	2005	135,457	140,450
1974	138,534	143,500	2006	112,658	116,391
1975	110,635	114,706	2007	134,830	139,154
1976	223,074	229,194	2008	164,646	169,807
1977	219,492	234,812	2009	116,341	119,325
1978	123,889	134,763	2010	82,362	84,497
1979	107,422	118,888	2011	61,180	62,583
1980	102,864	117,351	2012	67,935	68,762
1981	104,483	122,839	2013	52,009	52,690
1982	85,791	102,884	2014	28,194	28,438
1983	43,660	55,531	2015	17,026	17,195
1984	55,468	65,650	2016	17,199	17,393
1985	52,767	66,384	2017	17,695	17,776
1986	74,718	89,039	2018	32,577	33,667
1987	88,001	99,377	2019	32,799	34,107

Statistical Survey on Marine Fishery Production (catch by fishery type and by fish type) (Ministry of Agriculture, Forestry and Fishery); Values for 2019 are preliminary.

Appendix Table 3-2. Catch in set net, bottom set net and gill net fisheries in General Subprefectural Bureaus of Okhotsk, Souya, Rumoi, Ishikari and Shiribeshi (tons)

Set net and bottom set net fisheries							Gill net fisheries						
Year/ General Subprefectual Bureau	Okhotsk	Souya	Rumoi	Ishikari	Shiribeshi	Total	Year/ General Subprefectual Bureau	Okhotsk	Souya	Rumoi	Ishikari	Shiribeshi	Total
1985	3,210	1,119	240	2	1,362	5,933	1985	138	437	51	0	4,378	5,004
1986	7,222	1,159	232	0	1,142	9,756	1986	153	454	35	0	2,267	2,909
1987	6,372	2,112	233	5	1,062	9,783	1987	324	1,038	36	0	1,902	3,299
1988	6,592	2,705	360	8	2,988	12,653	1988	423	1,657	96	0	4,680	6,856
1989	4,687	1,491	511	17	2,166	8,872	1989	390	2,103	61	1	3,551	6,106
1990	5,251	1,299	247	4	1,688	8,489	1990	247	3,868	61	5	3,698	7,878
1991	3,635	1,840	99	5	1,863	7,442	1991	200	5,665	62	1	3,187	9,115
1992	5,199	1,408	376	34	3,154	10,172	1992	194	5,720	148	6	6,283	12,352
1993	7,350	2,465	448	13	2,811	13,087	1993	224	5,149	75	4	3,806	9,258
1994	5,363	1,736	456	3	4,171	11,730	1994	388	7,143	50	1	3,715	11,298
1995	8,598	2,361	375	1	3,945	15,280	1995	236	7,888	45	1	4,222	12,392
1996	12,132	3,531	418	10	5,689	21,781	1996	247	6,809	55	0	5,835	12,946
1997	11,122	2,024	252	4	11,444	24,846	1997	884	6,054	51	1	5,534	12,524
1998	12,703	1,958	415	0	6,568	21,644	1998	317	7,118	48	2	6,469	13,954
1999	9,758	1,390	187	5	8,747	20,088	1999	275	5,430	25	2	3,188	8,919
2000	9,653	858	213	22	7,932	18,678	2000	378	5,038	40	3	2,243	7,702
2001	5,357	1,163	176	7	13,193	19,895	2001	243	5,930	16	10	2,922	9,123
2002	13,254	1,048	219	21	10,948	25,489	2002	225	6,822	24	7	3,002	10,081
2003	11,891	1,731	259	18	17,135	31,034	2003	139	7,707	17	12	2,448	10,323
2004	10,625	637	179	14	7,808	19,264	2004	160	3,557	15	3	944	4,678
2005	8,323	856	43	8	6,614	15,845	2005	240	6,105	11	1	853	7,210
2006	10,173	792	47	6	11,556	22,574	2006	233	5,992	11	0	1,357	7,593
2007	4,896	319	82	3	9,630	14,930	2007	229	5,660	15	1	1,420	7,326
2008	9,869	651	57	5	15,982	26,564	2008	403	5,291	7	1	1,977	7,678
2009	7,480	674	72	22	11,207	19,454	2009	188	4,309	6	0	1,105	5,608
2010	5,117	211	107	26	9,818	15,278	2010	131	5,075	6	0	1,037	6,249
2011	2,863	171	55	19	4,109	7,217	2011	100	5,643	11	0	3,102	8,856
2012	11,024	492	52	3	4,242	15,813	2012	80	5,815	18	0	2,212	8,125
2013	3,216	168	40	2	2,847	6,272	2013	79	5,647	7	0	1,919	7,653
2014	1,226	9	8	1	2,450	3,694	2014	33	3,693	6	0	2,219	5,951
2015	387	29	5	0	1,220	1,640	2015	49	3,076	20	0	1,762	4,908
2016	223	70	9	0	2,047	2,349	2016	19	4,456	20	0	1,602	6,097
2017	4,190	536	6	0	785	5,517	2017	13	4,993	49	0	1,311	6,366
2018	3,686	111	38	0	2,750	6,586	2018	27	4,034	10	0	1,419	5,490
2019	6,554	898	51	1	4,565	12,070	2019	92	5,934	8	0	1,988	8,022

Unit: tons

Appendix Table 3-3. Catch in and fishing effort of offshore bottom trawl fishery based in Hokkaido (monthly statistics)
The figures for Okhotsk Sea and of the area-weighted standardized CPUE of both sea areas used for tuning are shown in the next page.

Year	Sea of Japan							
	Number of trawl with catch*1 (monthly)			Catch (tons)			CPUE (tons / net)	
	Danish seine*2	Otter trawl	Test operation	Danish seine*2	Otter trawl	Test operation	Danish seine*2	Otter trawl
1985	12,835	1,083	0	4,852	601	0	0.38	0.55
1986	20,834	985	0	9,807	52	0	0.47	0.05
1987	15,517	1,115	0	15,361	920	0	0.99	0.83
1988	20,078	1,095	0	18,612	181	0	0.93	0.17
1989	16,028	399	0	20,108	221	0	1.25	0.55
1990	21,686	2,133	0	40,211	1,248	0	1.85	0.59
1991	19,790	968	0	36,957	931	0	1.87	0.96
1992	17,451	1,155	0	23,709	846	0	1.36	0.73
1993	17,610	259	0	44,971	383	0	2.55	1.48
1994	18,581	403	0	66,999	3,265	0	3.61	8.10
1995	20,861	577	0	94,196	6,027	0	4.52	10.45
1996	18,913	932	0	72,427	4,381	0	3.83	4.70
1997	20,387	482	0	101,852	2,232	0	5.00	4.63
1998	19,735	50	0	120,274	117	0	6.09	2.33
1999	19,618	3	0	86,471	0	0	4.41	0.01
2000	16,574	107	0	83,969	65	0	5.07	0.61
2001	12,756	1,846	0	74,102	10,214	0	5.81	5.53
2002	10,887	829	132	63,397	2,869	1,058	5.82	3.46
2003	11,292	1,254	787	66,152	4,574	3,255	5.86	3.65
2004	11,990	1,067	320	78,183	4,947	1,275	6.52	4.64
2005	11,402	865	787	71,396	5,640	2,740	6.26	6.52
2006	10,552	806	812	48,865	4,908	1,788	4.63	6.09
2007	11,668	624	827	78,455	2,917	2,158	6.72	4.67
2008	10,645	1,025	531	80,773	3,330	1,586	7.59	3.25
2009	8,833	725	13	56,549	3,439	107	6.40	4.74
2010	7,578	523	756	33,492	2,736	3,211	4.42	5.23
2011	7,184	395	957	24,450	1,427	2,404	3.40	3.61
2012	7,379	556	982	25,353	1,130	2,908	3.44	2.03
2013	7,124	488	271	25,888	1,152	1,373	3.63	2.36
2014	7,530	734	943	12,288	1,385	1,643	1.63	1.89
2015	4,910	267	445	7,350	423	478	1.50	1.58
2016	3,803	343	315	6,001	363	543	1.58	1.06
2017	5,172	393	0	3,752	295	0	0.73	0.75
2018	4,997	206	0	10,281	186	0	2.06	0.90
2019	4,532	257	0	6,642	402	0	1.47	1.56

Sea of Japan (offshore trawl fishery): Statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido (middle sea zone: west of Hokkaido, since 2004 Sea of Japan off Hokkaido)
Okhotsk Sea (offshore trawl fishery): Statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido (middle sea zone: Okhotsk, since 2004 coastal Okhotsk (Sea of Japan))
*1 Aggregated figures of the statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido since 1985, by month, by vessel, and by fishing area
*2 Danish seine vessels of more than 100 tons
Appendix Table 3-3 (continued). Catch in and fishing effort of offshore bottom trawl fishery

based in Hokkaido (monthly statistics; Okhotsk Sea)

Year	Sea of Okhotsk								Both sea areas
	Number of trawl with catch*1 (monthly)			Catch (tons)			CPUE (tons / net)		Area-weighted standardized CPUE*3
	Danish seine*2	Otter trawl	Test operation	Danish seine*2	Otter trawl	Test operation	Danish seine*2	Otter trawl	
1985	13,546	1,164	0	7,250	74	0	0.54	0.06	
1986	12,906	1,617	0	15,246	113	0	1.18	0.07	
1987	18,865	1,757	0	18,709	244	0	0.99	0.14	
1988	16,158	1,927	0	17,202	317	0	1.06	0.16	
1989	23,787	3,712	0	23,918	634	0	1.01	0.17	
1990	30,754	8,890	0	18,802	1,445	0	0.61	0.16	
1991	16,852	1,558	0	15,446	127	0	0.92	0.08	
1992	9,057	1,263	0	3,932	398	0	0.43	0.32	
1993	14,435	3,177	0	21,966	547	0	1.52	0.17	
1994	15,843	2,480	0	16,783	68	0	1.06	0.03	
1995	16,851	2,384	0	10,344	134	0	0.61	0.06	
1996	15,599	2,930	0	23,702	1,689	0	1.52	0.58	
1997	17,137	2,752	0	22,052	1,605	0	1.29	0.58	
1998	17,374	2,881	0	36,527	6,403	0	2.10	2.22	
1999	11,399	1,859	0	15,700	88	0	1.38	0.05	
2000	11,621	3,214	0	21,103	1,883	0	1.82	0.59	
2001	9,648	2,863	0	13,804	445	0	1.43	0.16	
2002	11,633	4,115	0	16,869	903	0	1.45	0.22	
2003	10,492	4,927	0	19,702	3,790	0	1.88	0.77	
2004	12,390	4,288	0	38,198	2,981	0	3.08	0.70	
2005	13,131	3,412	0	18,559	129	0	1.41	0.04	1.22
2006	12,012	3,098	0	12,020	537	0	1.00	0.17	0.66
2007	13,098	3,545	0	17,807	850	0	1.36	0.24	1.26
2008	12,346	2,772	0	26,218	585	0	2.12	0.21	2.15
2009	12,400	2,869	0	10,361	170	0	0.84	0.06	1.02
2010	9,099	1,971	0	4,211	304	0	0.46	0.15	0.56
2011	10,900	2,155	0	7,862	309	0	0.72	0.14	0.54
2012	7,560	1,207	0	7,290	569	0	0.96	0.47	0.80
2013	10,128	2,290	0	3,633	31	0	0.36	0.01	0.44
2014	8,560	1,494	107	472	31	12	0.06	0.02	0.22
2015	7,196	737	207	157	2	23	0.02	0.00	0.12
2016	9,393	2,574	109	147	2	0	0.02	0.00	0.12
2017	6,717	693	0	754	6	0	0.11	0.01	0.09
2018	6,654	1,365	0	2,279	12	0	0.34	0.01	0.37
2019	6,877	892	0	653	7	0	0.09	0.01	0.18

Sea of Japan (offshore bottom trawl fishery): Statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido (middle sea zone: west of Hokkaido, since 2004 Sea of Japan off Hokkaido)

Okhotsk Sea (offshore trawl fishery): Statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido (middle sea zone: Okhotsk, since 2004 coastal Okhotsk (Sea of Japan))

*1 Aggregated figures of the statistical data of catch by fishing ground in offshore bottom trawl fishery in Hokkaido since 1985, by month, by vessel, and by fishing area

*2 Danish seine vessels of more than 100 tons

*3 Abundance index used as the tuned VPA, which is the area-weighted standardized CPUE index for the period of January-December

Appendix Table 3-4. Fishing effort of bottom set net, set net and small set net fisheries in General Subprefectural Bureaus of Okhotsk, Souya, Rumoi, Ishikari and Shiribeshi (figures for small set net fishery are shown in the next page).

Bottom set net fishery*1 (number of users)							Set net fishery for salmon*2 (total)						
Year / General Subprefectural Bureau	Okhotsk	Souya	Rumoi	Ishikari	Shiribeshi	Total	Year / General Subprefectural Bureau	Okhotsk	Souya	Rumoi	Ishikari	Shiribeshi	Total
1973							1973	105	26	8	8	4	151
1974							1974	104	30	9	9	6	158
1975							1975	104	26	9	10	4	153
1976							1976	104	61	12	8	5	190
1977							1977	106	61	10	10	5	192
1978							1978	106	64	9	12	5	196
1979							1979	102	73	15	17	5	212
1980							1980	102	74	15	16	5	212
1981							1981	102	92	19	17	5	235
1982							1982	102	88	16	17	5	228
1983							1983	102	88	11	17	5	223
1984							1984	89	79	23	18	4	213
1985							1985	90	80	23	18	4	215
1986							1986	89	80	23	18	4	214
1987							1987	84	79	23	18	5	209
1988							1988	84	80	22	18	5	209
1989					291		1989	77	67	25	18	116	303
1990					307		1990	77	67	25	18	113	300
1991					349		1991	73	67	27	18	115	300
1992					531		1992	76	67	25	18	111	297
1993					369		1993	79	67	25	18	116	305
1994					362		1994	67	65	23	19	226	400
1995					369		1995	147	64	22	18	237	488
1996	451	238	55		369		1996	74	63	21	16	227	401
1997	231	200	50		311		1997	74	59	19	16	215	383
1998	479	153	75		315		1998	71	60	19	16	213	379
1999	471	185	71		290		1999	71	56	18	18	228	391
2000	491	187	56		333		2000	71	56	-	17	224	368
2001	584	179	66	23	293	1,145	2001	71	56	-	16	216	359
2002	396	174	40	24	295	929	2002	72	53	19	16	212	372
2003	206	103	48	16	295	668	2003	72	50	19	16	201	358
2004	357	150	43	18	91	659	2004	75	52	18	15	209	369
2005	370	150	45	16	111	692	2005	73	52	18	16	209	368
2006	361	152	41	16	302	872	2006	74	51	21	16	205	367
2007	349	138	28	16	298	829	2007	74	51	21	(16)	234	396
2008	120	137	28	16	303	604	2008	78	51	21	(16)	224	389
2009	119	135	36	12	76	378	2009	78	52	20	(16)	224	390
2010	119	128	37	13	86	383	2010	78	52	20	(16)	224	390
2011	179	127	35	12	75	428	2011	78	52	20	(16)	224	390
2012	125	125	39	12	83	384	2012	78	52	20	(16)	224	390
2013	142	125	33	12	76	388	2013	82	52	19	(16)	209	389
2014	123	131	36	12	73	375	2014	82	51	18	(16)	(209)	377
2015	124	138	35	12	62	371	2015	(82)	(51)	(18)	(16)	(209)	376
2016	124	131	41	12	63	371	2016	(82)	(51)	(18)	(16)	(209)	376
2017	119	131	25	12	63	350	2017	(82)	(51)	(18)	(16)	(209)	376
2018	119	131	23	12	63	348	2018	(82)	(51)	(18)	(16)	(209)	376
2019	119	131	23	12	63	348	2019	(82)	(51)	(18)	(16)	(209)	376

*1 The number of fishing units of bottom set net fishery is the number of those who use bottom set net for flat fish, flounder, and Arabesque greenling included in class 2 common fishery rights (published by each General Subprefectural Bureau).
The data of 2014 is the latest for Okhotsk, Souya, Shiribeshi and Rumoi, while 2011 for Ishikari.

*2 The number of fishing units of set net fishery for salmon and small set net fishery was extracted from the annual statistical report of agriculture, forestry and fishery in Hokkaido (set net for salmon and small set net fisheries), and the number of fishing units of small set net fishery was assumed to be the same as that in 2007-2016 because the figures since 2007 were not obtained.
The number of set net fisheries for salmon since 2007 is the licensed number for set net fishery for salmon (each General Subprefectural Bureau except for Ishikari General Subprefectural Bureau).
The figures in parentheses are those of the previous year in case the figures are not updated.

Appendix Table 3-4 (continued). Fishing effort of small set net fishery in General Subprefectural Bureaus of Okhotsk, Souya, Rumoi, Ishikari and Shiribeshi.

Small set net fishery[*2]						
Year / General Subprefectural Bureau	Okhotsk	Souya	Rumoi	Ishikari	Shiribeshi	Total
1973	466	533	57	63	435	1,554
1974	523	600	97	60	498	1,778
1975	521	632	146	67	535	1,901
1976	508	559	115	70	411	1,663
1977	526	584	172	73	486	1,841
1978	573	546	158	29	500	1,806
1979	540	517	220	58	692	2,027
1980	555	443	175	43	703	1,919
1981	595	428	153	82	765	2,023
1982	648	447	126	116	916	2,253
1983	586	344	114	132	894	2,070
1984	518	380	83	55	815	1,851
1985	525	418	86	69	708	1,806
1986	514	398	126	96	699	1,833
1987	526	386	136	58	729	1,835
1988	569	400	107	47	605	1,728
1989	426	454	91	55	642	1,668
1990	536	429	112	53	674	1,804
1991	567	416	145	34	615	1,777
1992	496	385	101	38	606	1,626
1993	590	389	103	32	615	1,729
1994	480	293	120	33	567	1,493
1995	683	337	154	22	590	1,786
1996	718	414	98	21	546	1,797
1997	658	409	60	20	498	1,645
1998	746	380	100	25	536	1,787
1999	713	345	88	31	539	1,716
2000	673	338	144	40	546	1,741
2001	646	294	125	36	565	1,666
2002	647	284	103	31	532	1,597
2003	611	283	98	33	493	1,518
2004	688	291	97	44	512	1,632
2005	714	291	93	35	506	1,639
2006	658	277	95	37	464	1,531
2007	(658)	(277)	(95)	(37)	(464)	1,531
2008	(658)	(277)	(95)	(37)	(464)	1,531
2009	(658)	(277)	(95)	(37)	(464)	1,531
2010	(658)	(277)	(95)	(37)	(464)	1,531
2011	(658)	(277)	(95)	(37)	(464)	1,531
2012	(658)	(277)	(95)	(37)	(464)	1,531
2013	(658)	(277)	(95)	(37)	(464)	1,531
2014	(658)	(277)	(95)	(37)	(464)	1,531
2015	(658)	(277)	(95)	(37)	(464)	1,531
2016	(658)	(277)	(95)	(37)	(464)	1,531
2017	(658)	(277)	(95)	(37)	(464)	1,531
2018	(658)	(277)	(95)	(37)	(464)	1,531
2019	(658)	(277)	(95)	(37)	(464)	1,531

*1 The number of fishing units of bottom set net fishery is the number of those who use bottom set net for flat fish, flounder, and Arabesque greenling included in class 2 common fishery rights (published by each General Subprefectural Bureau).

The data of 2014 is the latest for Okhotsk, Souya, Shiribeshi and Rumoi, while 2011 for Ishikari.
*2 The number of fishing units of set net fishery for salmon and small set net fishery was extracted from the annual statistical report of agriculture, forestry and fishery in Hokkaido (set net for salmon and small set net fisheries), and the number of fishing units of small set net fishery was assumed to be the same as that in 2007-2016 because the figures since 2007 were not obtained.
The number of set net fisheries for salmon since 2007 is the licensed number for set net fishery for salmon (each General Subprefectural Bureau except for Ishikari General Subprefectural Bureau).
The figures in parentheses are those of the previous year in case the figures are not updated.

Appendix 4. Results of stock analysis for Northern Hokkaido stock of the Arabesque greenling (1985-1995)

Catch at age (tons)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	12.6	19.0	25.8	20.7	16.7	9.0	14.6	4.8	14.3	12.3	31.5
Age 1	11.7	19.3	22.8	28.9	36.2	50.6	27.8	31.2	37.1	32.3	18.0
Age 2	4.9	4.7	6.4	10.1	8.0	18.6	26.4	16.7	28.8	48.2	50.8
Age 3	2.9	1.5	2.8	3.9	4.8	9.0	13.8	7.9	13.5	15.5	29.9
Age 4 and above	1.8	1.0	1.7	2.0	3.0	5.4	8.0	5.9	8.1	11.1	18.7
Total	34.0	45.6	59.5	65.5	68.6	92.7	90.7	66.5	101.8	119.5	149.0

Number of fish at age (million individuals)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	463	649	841	1001	1115	806	1051	1289	1232	836	1249
Age 1	139	229	297	371	536	644	503	641	913	766	505
Age 2	39	51	77	109	132	201	211	242	324	485	418
Age 3	16	16	24	39	51	72	90	82	131	151	225
Age 4 and above	10	9	13	18	28	40	48	55	71	98	128
Total	667	954	1252	1539	1862	1763	1903	2309	2671	2336	2524

Fishing mortality at age

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	0.41	0.49	0.52	0.33	0.25	0.18	0.20	0.05	0.18	0.21	0.40
Age 1	0.71	0.79	0.70	0.74	0.68	0.82	0.44	0.39	0.34	0.31	0.26
Age 2	0.61	0.44	0.39	0.46	0.31	0.50	0.65	0.32	0.47	0.47	0.63
Age 3	0.71	0.36	0.45	0.39	0.40	0.55	0.62	0.36	0.43	0.37	0.52
Age 4 and above	0.71	0.36	0.45	0.39	0.40	0.55	0.62	0.36	0.43	0.37	0.52
Average	0.63	0.49	0.50	0.46	0.41	0.52	0.51	0.30	0.37	0.35	0.47
%SPR	11.3	12.4	12.8	14.8	18.5	14.2	18.3	31.1	25.1	25.8	18.9

Stock biomass at age and spawning biomass (thousand tons) and RPS (number of age 0 fish / spawning biomass, individuals / kg)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	43.8	57.1	73.3	85.2	86.6	64.6	93.9	111.9	100.1	75.5	111.2
Age 1	26.7	40.9	52.4	64.1	84.5	104.7	91.1	112.8	150.3	140.2	91.1
Age 2	12.5	15.1	22.8	31.5	34.7	54.5	63.8	70.9	89.1	148.1	125.7
Age 3	6.5	5.9	9.0	14.0	16.9	24.5	34.4	30.1	45.2	57.9	85.1
Age 4 and above	4.2	3.9	5.4	7.1	10.4	14.9	20.0	22.4	26.9	41.4	53.2
Stock biomass	93.7	122.9	162.9	201.8	233.1	263.1	303.2	348.1	411.6	463.1	466.3
Spawning biomass	20.8	21.9	32.6	46.3	55.0	82.9	105.4	109.2	143.4	217.8	238.9
RPS	22.3	29.6	25.8	21.6	20.3	9.7	10.0	11.8	8.6	3.8	5.2

Appendix 4 (continued). Details of the results of cohort analysis (1996-2007)

Catch at age (tons)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	12.6	19.0	25.8	20.7	16.7	9.0	14.6	4.8	14.3	12.3	31.5
Age 1	11.7	19.3	22.8	28.9	36.2	50.6	27.8	31.2	37.1	32.3	18.0
Age 2	4.9	4.7	6.4	10.1	8.0	18.6	26.4	16.7	28.8	48.2	50.8
Age 3	2.9	1.5	2.8	3.9	4.8	9.0	13.8	7.9	13.5	15.5	29.9
Age 4 and above	1.8	1.0	1.7	2.0	3.0	5.4	8.0	5.9	8.1	11.1	18.7
Total	34.0	45.6	59.5	65.5	68.6	92.7	90.7	66.5	101.8	119.5	149.0

Number of fish at age (million individuals)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	463	649	841	1001	1115	806	1051	1289	1232	836	1249
Age 1	139	229	297	371	536	644	503	641	913	766	505
Age 2	39	51	77	109	132	201	211	242	324	485	418
Age 3	16	16	24	39	51	72	90	82	131	151	225
Age 4 and above	10	9	13	18	28	40	48	55	71	98	128
Total	667	954	1252	1539	1862	1763	1903	2309	2671	2336	2524

Fishing mortality at age

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	0.41	0.49	0.52	0.33	0.25	0.18	0.20	0.05	0.18	0.21	0.40
Age 1	0.71	0.79	0.70	0.74	0.68	0.82	0.44	0.39	0.34	0.31	0.26
Age 2	0.61	0.44	0.39	0.46	0.31	0.50	0.65	0.32	0.47	0.47	0.63
Age 3	0.71	0.36	0.45	0.39	0.40	0.55	0.62	0.36	0.43	0.37	0.52
Age 4 and above	0.71	0.36	0.45	0.39	0.40	0.55	0.62	0.36	0.43	0.37	0.52
Average	0.63	0.49	0.50	0.46	0.41	0.52	0.51	0.30	0.37	0.35	0.47
%SPR	11.3	12.4	12.8	14.8	18.5	14.2	18.3	31.1	25.1	25.8	18.9

Stock biomass at age and spawning biomass (thousand tons) and RPS (number of age 0 fish / spawning biomass, individuals/kg)

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Age 0	43.8	57.1	73.3	85.2	86.6	64.6	93.9	111.9	100.1	75.5	111.2
Age 1	26.7	40.9	52.4	64.1	84.5	104.7	91.1	112.8	150.3	140.2	91.1
Age 2	12.5	15.1	22.8	31.5	34.7	54.5	63.8	70.9	89.1	148.1	125.7
Age 3	6.5	5.9	9.0	14.0	16.9	24.5	34.4	30.1	45.2	57.9	85.1
Age 4 and above	4.2	3.9	5.4	7.1	10.4	14.9	20.0	22.4	26.9	41.4	53.2
Stock biomass	93.7	122.9	162.9	201.8	233.1	263.1	303.2	348.1	411.6	463.1	466.3
Spawning biomass	20.8	21.9	32.6	46.3	55.0	82.9	105.4	109.2	143.4	217.8	238.9
RPS	22.3	29.6	25.8	21.6	20.3	9.7	10.0	11.8	8.6	3.8	5.2

Appendix 4 (continued). Details of the results of cohort analysis (2008-2019)

Catch at age (tons)

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	30.8	13.2	2.0	20.6	5.8	7.3	1.4	0.9	0.1	6.7	0.3	7.4
Age 1	74.1	63.0	24.6	3.6	49.0	20.3	12.5	6.8	9.2	1.0	20.8	6.8
Age 2	24.7	16.4	27.6	14.5	2.4	14.7	6.9	3.9	3.0	6.4	1.4	13.5
Age 3	12.8	2.7	10.9	11.1	2.9	2.3	4.6	2.6	2.5	2.0	3.2	0.6
Age 4 and above	4.9	1.0	1.8	3.3	1.8	1.7	0.4	1.5	0.9	0.6	1.3	1.0
Total	147.2	96.3	66.8	53.1	62.0	46.3	25.8	15.6	15.8	16.8	27.1	29.3

Number of fish at age (million individuals)

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	1436	556	92	810	288	222	108	138	21	338	126	594
Age 1	769	704	262	48	408	159	105	68	94	15	201	91
Age 2	139	139	167	72	19	73	36	26	22	34	7	80
Age 3	54	17	48	41	13	7	19	10	9	9	11	3
Age 4 and above	19	6	7	11	7	5	1	5	3	3	4	4
Total	2416	1422	576	982	735	466	269	247	149	399	349	772

Fishing mortality at age

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	0.42	0.46	0.35	0.39	0.30	0.45	0.16	0.08	0.06	0.22	0.02	0.16
Age 1	1.42	1.14	1.00	0.64	1.42	1.19	1.11	0.85	0.73	0.40	0.63	0.57
Age 2	1.81	0.77	1.11	1.43	0.66	1.07	1.04	0.75	0.58	0.83	0.70	0.88
Age 3	2.24	0.88	1.31	1.67	1.17	1.82	1.09	1.35	1.21	0.74	0.98	0.95
Age 4 and above	2.24	0.88	1.31	1.67	1.17	1.82	1.09	1.35	1.21	0.74	0.98	0.95
Average	1.62	0.83	1.02	1.16	0.94	1.27	0.90	0.88	0.76	0.59	0.66	0.70
%SPR	3.3	6.2	6.5	8.0	5.4	4.8	7.5	11.3	14.3	16.4	16.0	13.9

Stock biomass at age and spawning biomass (thousand tons) and RPS (number of age 0 fish / spawning biomass, individuals/kg)

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Age 0	104.3	41.8	7.8	73.7	26.1	23.2	10.9	13.5	2.3	38.8	15.9	58.7
Age 1	113.3	107.1	45.1	8.9	74.8	33.9	21.6	13.7	20.7	3.4	51.7	18.3
Age 2	34.3	35.2	47.8	22.1	5.8	26.0	12.4	8.6	8.0	13.2	3.1	26.7
Age 3	16.6	5.4	17.2	15.8	4.9	3.2	8.1	4.0	4.2	4.4	5.9	1.1
Age 4 and above	6.3	2.0	2.8	4.7	3.1	2.3	0.7	2.3	1.4	1.4	2.5	2.0
Stock biomass	274.9	191.6	120.6	125.1	114.7	88.6	53.7	42.1	36.6	61.2	79.1	106.9
Spawning biomass	50.4	35.7	58.2	38.2	12.6	26.3	18.7	13.2	12.0	16.4	10.9	24.4
RPS	28.5	15.6	1.6	21.2	22.8	8.4	5.7	10.4	1.7	20.6	11.5	24.3

Appendix 4 (continued)

Because the catch in number at age in the period of 1985-2018 contains information obtained by a budget other than the commissioned project to promote marine fisheries stock assessment and evaluation for Japanese waters, the tables with figures are not published here according to the request from the Hokkaido Research Organization, which prepared and provided the data.

Catch in number at age in 2019 (million individuals)

Age 0	Age 1	Age 2	Age 3	Age 4 and above	Total
75	34	40	1	2	153

Appendix 5. About standardization of CPUE for offshore bottom trawl

1. Method of standardization

The CPUE for offshore bottom trawl fishery is standardized using a generalized linear model, setting the CPUE for Danish seine vessel of more than 100 tons as response function, and year (Y), month (M) and small sea area (SA) as descriptions (categorical variables), based on the detailed daily data of statistics of offshore bottom trawl fishery. In the procedure, as there is a year without fishing operation in some small sea areas, the figures of SA2, 3, 16 and 17 are integrated for calculation. Assuming that the logarithmic value of CPUE distribution is Gaussian, the standardized CPUE is estimated by the following model.

$$\log(\mathrm{CPUE}) = Y + M + SA + Y \times M + Y \times SA$$

If the size of each sea area is different and interaction between the year and area is observed, the correction considering area size is necessary. In this case, the value of the abundance index multiplied by estimated area size is presumed to correspond to relative abundance (Nose et al. 1998, Yamada and Tanaka 1999, Shono 2004). Therefore, in order to extract standardized abundance index from the estimated CPUE, the area-weighted standardized CPUE is calculated using the following equation, considering the difference in size of small sea areas.

$$\log(\mathrm{CPUE}) = Y + E(Y \times M) + E_w(Y \times SA)$$

Where $E(Y \times M)$ is the average of interaction between Y and M, $E_w(Y \times SA)$ is the area-weighted average of Y and SA. The size is the number of fishing zones used in the operations in the small sea area, and the index is calculated by normalizing the value after index transformation of the averaged logarithmic value of CPUE.

2. CPUE used this year

In the process of calculation of stock, the exploitation rate of offshore bottom trawl fishery of all age fish (age 0 to 4) were used to take the influence into consideration (Appendix 2), and the area-weighted standardized CPUE for January to December was used as the tuning index (Appendix Figure 5-1). In recent years, fishing operation in offshore bottom trawl fishery changed so much that they no longer catch age 0 fish. Therefore, the F value and number of age 0 fish in recent years estimated by tuning might not properly indicate the actual stock status. In order to solve this problem, it is desirable to establish the abundance index for age 0 fish independently, but there is no information available for it.

References

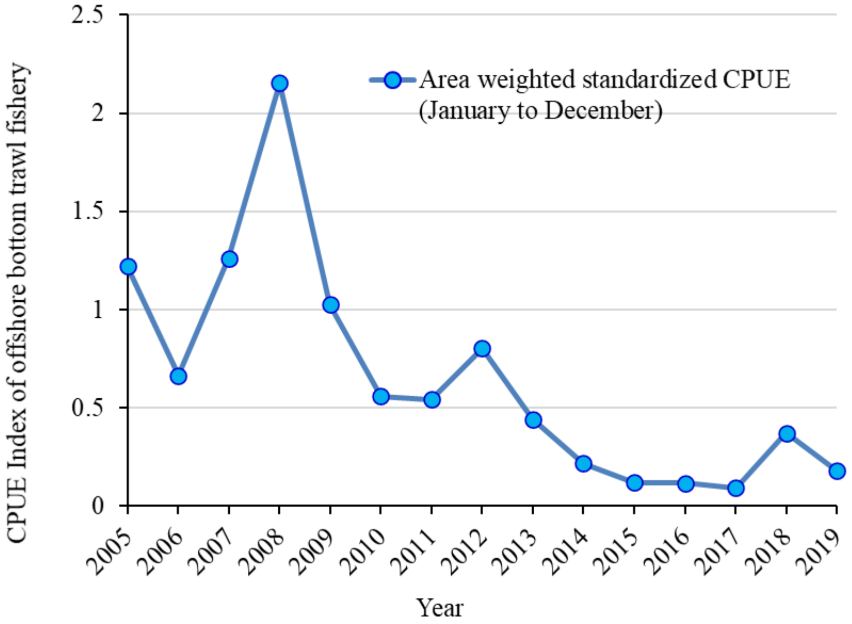
Yamada, S. and E. Tanaka (1999) Suisan shigen kaiseki gaku (Fish Population Analysis), Tokyo, SEIZANDO-SHOTEN PUBLISHING, pp151.

Nose, Y., T. Ishii and M. Shimizu (1988) Suisan shigen gaku (Fisheries Resource Science), Tokyo, University of Tokyo Press, pp217.

Shono, H. (2004) A Review of Some Statistical Approaches Used for CPUE Standardization, Bulletin of the Japanese Society of Fisheries Oceanography, 68, 106-120.

Suzuki, Y. (2017) 2017 nen ni Hokkaido okiai de saisyu sareta hokke shichigyo ni tsuite: Shiken-kenkyu ha Ima (Juvenile of Arabesque greenling caught offshore Hokkaido in 2017: Current Statue of Experimental Research), 833. (online), downloadable from: http://www.hro.or.jp/list/fisheries/marine/att/ima833.pdf.

Central, Wakkanai and Abashiri Fisheries Research Institutes, (printing underway), Hokke (Arabesque greenling) (Sea of Japan of Middle Hokkaido-Okhotsk Sea area), 2020 nendo suisan shigen kanri kaigi hyokasyo (Assessment report of council of stock management in 2020), Fisheries Research Department, Hokkaido Research Organization. http://www.fishexp.hro.or.jp/exp/central/kanri/SigenHyoka/Kokai/ (last accessed XX)



Appendix Figure 5-1. Changes in area-weighted standardized CPUE used for tuning (January-December CPUE) (2005-2019)

Appendix 6. Questionnaire on the catch of Arabesque greenling for fishermen of offshore bottom trawls fishery (conducted in June 2020)

We ask fishermen engaged in offshore bottom trawl fishery (Danish seine, trawl) some questions about fishing status for the purpose of collecting the latest information on the catch of Arabesque greenling and including it in the report on the stock assessment. This year, we asked the Otaru fishermen's cooperative society, Wakkanai Trawl Fisheries Cooperative Association, Monbetsu fishermen's cooperative society, and Abashiri fishermen's cooperative society for cooperation with this questionnaire, and received responses for it. The questions and answers are as follows.

Q. What have you noticed about the fishery condition of Arabesque greenling last year and this year?
A. Compared with recent years, the biomass is large. The fishery condition is bad, normal, good, etc., depending on the area.

Q. What size are most of the Arabesque greenling you caught?
A. Middle to small, most are small. The body length is mainly 20 to 25 cm, around 30 cm.

Q. Have you noticed any tendencies, for example, does the size of Arabesque greenling change depending on fishing area or fishing season?
A. The size of Arabesque greenling in fishing area change by season.

Q. How about changes in fishing effort, fishing mortality, and time of search?
A. We restrain the catch in order to reduce it by 30% compared with the catch in the last several years; we still continue to limit the catch per day and the days of fishing; we make efforts to raise the prices of fish; we don't target Arabesque greenling; etc.

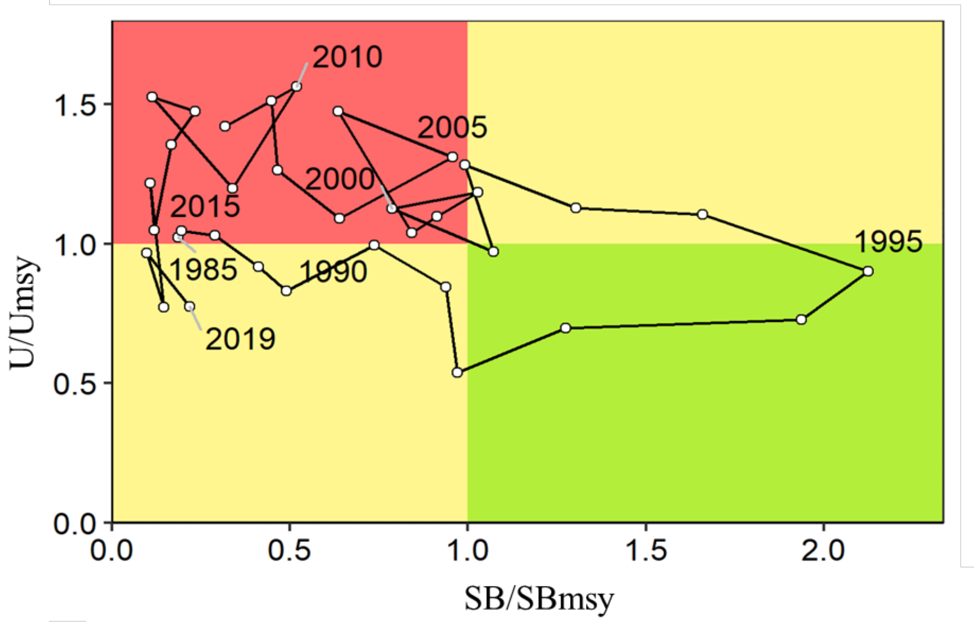
Q. If you have something that you realized concerning the catch of Arabesque greenling, please let us know.
A. There is a recruitment mainly of the 2019 year class, which is a remarkable effect of the limitation of fishing days.

From the answers to this questionnaire on the fishery condition of this year, we obtained the following information: many juveniles that are supposed to be in the 2019 year class were caught in some fishing areas; the fishermen limit the catch (including the number of boxes) per day to protect juveniles as voluntary restraint; and they shorten the fishing time. On the other hand, we obtained information that the fishery condition was bad in some fishing areas. It is indicated that the abundance of the 2019 year class was as high as that of the 2017 year class. However, considering an opinion that the abundance of middle- to large-size fish was small, it is presumed that the abundance of the 2018 year class was small. It is important to continue to limit the catch of the 2019 year class, the abundance of which is relatively high, to promote the generation of the following year classes.

Appendix 7. Kobe plot based on exploitation rate

The figure below shows a Kobe plot based on the spawning biomass that produces MSY (SBmsy) and exploitation rate that produces MSY (Umsy). The spawning biomass of this stock has been below SBmsy since 2000 (except for 2001), and the exploitation rate (U) has been below Umsy since 2017. The U in 2019 decreased from that in 2018 (Appendix Figure 7-1).

Item	Value	Remarks
SBmsy	112 thousand tons	Spawning biomass that produces MSY
Umsy	35%	Exploitation rate that produces MSY
U2019	27%	Exploitation rate in 2019
U2019/Umsy	0.77	Ratio of the exploitation rate in 2019 to the exploitation rate that produces MSY



Appendix Figure 7-1. Relationship of the spawning biomass and exploitation rate to the spawning biomass that produces MSY (SBmsy) and exploitation rate that produces MSY (Umsy) (Kobe plot)

Appendix 8. Changes in tuning method for cohort analysis

In tuning the cohort analysis of this stock, the fishing mortality at age in the latest year was estimated assuming that the selectivity equals the average of the past two years. However, the condition of offshore trawl and coastal fisheries changed so much, due to restraint in the catch of juvenile by voluntary restraint and recruitment of the 2017 and 2019 year classes with relatively high abundance, that the F for the older population tends to be unstable. In order to reduce the instability of F for the older population, we introduced the ridge VPA Okamura et al. 2017) into the cohort analysis of stock assessment in 2020. The CPUE for offshore bottom trawl fishery used in tuning may be affected by the restriction of catch of age 0 fish, so it is necessary to note that the uncertainties in estimated F value of terminal year in cohort analysis and the number of age 0 fish.

[Method]

In estimating the F value at age in terminal year using ridge VPA, we averaged and weighted the objective function (define as the least squares SSQ) that indicates conformity to the tuning index and an objective function that weights the penalty to squared value of F The instability of estimation is reduced by minimizing the weighted objective function.

Normally, penalty λ is given to squared F value for each age evenly, as indicated in equation (1), where 0<λ<1. In this stock, as the retrospective bias of the F value of aged fish tends to be strong (Appendix Figure 8-1), the value of λ finally selected was searched so that the retrospective bias ρ of the F value of age 4+ fish (the same for age 3 fish) is minimum when the value is changed by 0.01. Here, ρ is the average of relative value to the estimated value of terminal year by lacking data (5 years for this stock) for each single year from the latest data (Mohn 1999).

$$(1-\lambda)SSQ + \lambda \sum_{a=1}^{4+} F_{a,2019}^2 \qquad (1)$$

[Results]

The results of the searched weight of penalty of ridge VPA, λ, are shown in Appendix Table 8-1. The value of λ was explored within the range of 0 to 1. The value of λ that leads minimum value of retrospective bias ρ of the F value of age 3 fish was 0.09. (Appendix Table 8-1 and Appendix Figure 8-2). In this case, the retrospective bias of spawning biomass increased from 1 to 8.9% compared to the case without penalty, although the bias of the F value of each age was reduced. In particular, the bias of the F value of age 3 fish improved from 18.4 to -0.6%.We presume that the results of the stock assessment with overall low retrospective bias was obtained by using the value of 0.09 as the weight of penalty λ in tuning. On the other hand, the average of absolute value of retrospective bias ρ for the spawning biomass and F value by age became minimum when λ was 0.13 (Appendix Table 8-1 and Appendix Figure 8-3). In this case, the value of retrospective bias of age 1 fish became smaller compared with that when λ is 0.09 (from 9.7% to 1.0%), spawning biomass (from 8.9% to 14.7%), the F value of age 2 fish (from -7.5% to -14.4%), and the F value of age 3 fish (from -0.6% to -7.7%) became larger.

[Problems to be solved in the future]

As mentioned above, although we use the CPUE for offshore bottom trawl fishery to tune cohort analysis, operation forms changed greatly in recent years, as exemplified by the limitation of catch of age 0 fish in offshore bottom trawl fishery. Therefore, the F value and number of age 0 fish of the latest year estimated by tuning might not reflect the actual conditions of the biomass sufficiently. In order to solve this problem, it is desirable to establish the abundance index for age 0 fish independently, but there is no information available for it.

In recent years, not only in offshore bottom trawl fishery but also coastal fishery, have been affected by the voluntary restraints. Considering the large variation in recruitment in addition to the voluntary restraints, the operation strategy for fishing would be unstable. Therefore, the fishing mortality at age (that is, F at age) in each year may largely change in recent year, it might not be considered sufficiently for the most recent actual fishing operation in the selectivity assumption of tuning cohort analysis. One of the candidates to solve this problem is to estimate each F at age, instead of assuming the average of selectivity of recent several years, in estimating the F value of the terminal year. In this case, however, effective information for tuning by age is necessary. Although, we are provided information for establish of CPUE at age by Hokkaido Research Organization presently, we need to consider introducing the method of standardized these information and establish the tuning cohort analysis which does not depend on the assumption of selectivity.

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.

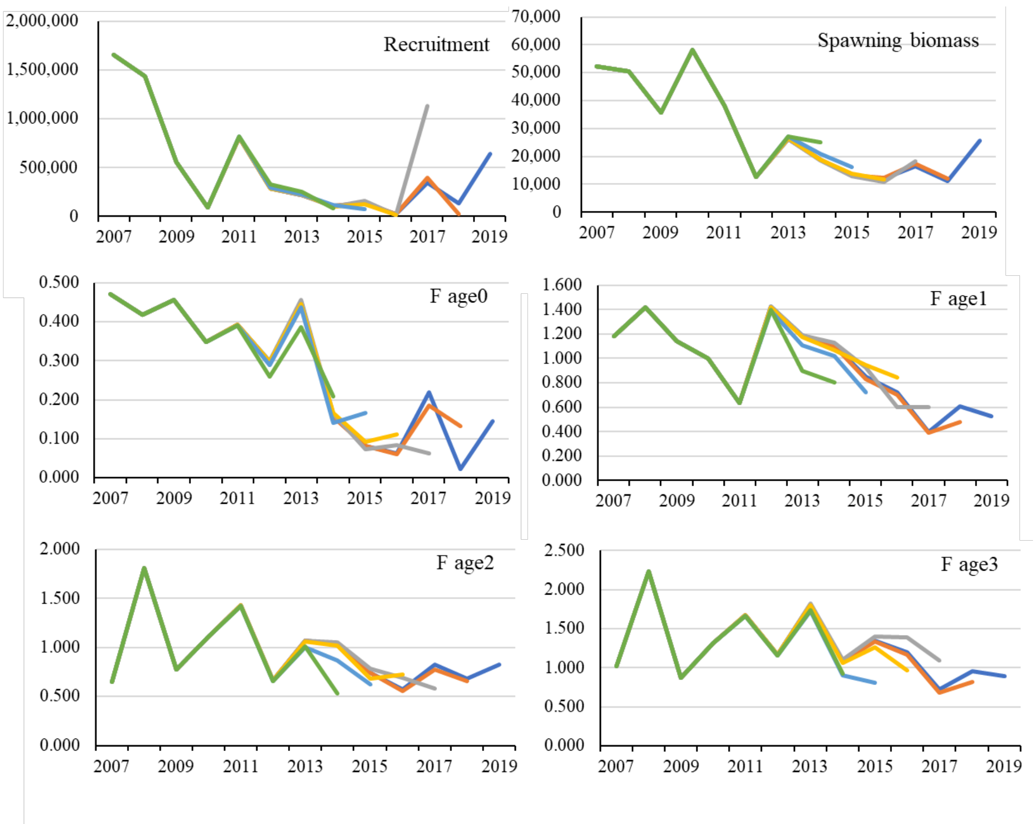
Pope, J. G. (1972) An investigation of accuracy of virtual population analysis using Cohort Analysis. Res. Bull. int. comm. Northw. Atlant. Fish., 9, 65-74.

Appendix Figure 8-1. Comparison of the results of retrospective analysis with penalty by ridge VPA (in the case without penalty)

The solid lines of different colors show results of retrospective analysis when data of all years were used (until 2019) and when data of 1 to 5 years were lacking.

Appendix Figure 8-2. Comparison of the results of retrospective analysis with penalty by ridge VPA (when λ = 0.09, which gives the minimum value of ρ of the F value of age 3 fish)

The solid lines of different colors show results of retrospective analysis when data of all years were used (until 2019) and when data of 1 to 5 years were lacking.



Appendix Figure 8-3. Comparison of the results of retrospective analysis with penalty by ridge VPA (when λ = 0.13, which gives the minimum average of spawning biomass and absolute value of retrospective bias of the F value at age)

The solid lines of different colors show results of retrospective analysis when data of all years were used (until 2019) and when data of 1 to 5 years were lacking.

Appendix Table 8-1. Spawning biomass and retrospective bias ρ of the F value at age when the weight of penalty λ is changed by ridge VPA

If ρ of spawning biomass becomes smaller (λ = 0, λ = 0.04), the retrospective bias of the F value of age 3 fish cannot be solved.

λ	Recruitment	Spawning biomass	F age0	F age1	F age2	F age3	Average of absolute values exclusing recruitement
0	-17.2%	-1.0%	168.5%	34.9%	14.8%	18.4%	59.4%
0.01	-32.8%	-11.8%	228.1%	65.7%	38.0%	43.4%	96.8%
0.02	-26.5%	-7.2%	195.6%	47.1%	22.6%	29.0%	75.4%
0.03	-21.7%	-3.8%	178.2%	36.6%	14.1%	20.8%	63.4%
0.04	-17.7%	-1.0%	166.6%	29.4%	8.2%	15.1%	55.1%
0.05	-14.1%	1.3%	157.8%	23.9%	3.8%	10.8%	49.4%
0.06	-11.0%	3.5%	150.8%	19.4%	0.3%	7.2%	45.3%
0.07	-8.0%	5.4%	145.0%	15.7%	-2.7%	4.2%	43.3%
0.08	-5.3%	7.2%	140.1%	12.5%	-5.3%	1.7%	41.7%
0.09	-2.7%	8.9%	135.7%	9.7%	-7.5%	**-0.6%**	40.6%
0.1	-0.3%	10.4%	131.8%	7.2%	-9.5%	-2.6%	40.4%
0.11	2.1%	11.9%	128.4%	4.9%	-11.3%	-4.4%	40.2%
0.12	4.3%	13.4%	125.2%	2.9%	-12.9%	-6.1%	40.1%
0.13	6.5%	14.7%	122.3%	1.0%	-14.4%	-7.7%	**40.0%**
0.14	8.6%	16.1%	119.6%	-0.7%	-15.8%	-9.1%	40.3%
0.15	10.6%	17.4%	117.0%	-2.4%	-17.1%	-10.4%	41.1%
0.16	12.6%	18.6%	114.7%	-3.9%	-18.3%	-11.7%	41.8%
0.17	14.5%	19.8%	112.4%	-5.3%	-19.4%	-12.8%	42.5%
0.18	16.4%	21.0%	110.3%	-6.7%	-20.5%	-13.9%	43.1%
0.19	18.3%	22.2%	108.4%	-7.9%	-21.5%	-15.0%	43.7%
0.2	20.1%	23.3%	106.5%	-9.1%	-22.4%	-16.0%	44.3%