Reference for the 2020 Stock Assessment of Northern Hokkaido Stock of the Arabesque Greenling
(proposal for consideration of stock management targets, etc.)

The reference points, fishing ban level, future projection and harvest control rules (HCRs) 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.

Summary

We used the Hockey Stick (HS) S-R relationship for Northern Hokkaido Stock of Arabesque greenling. As the target reference point (SBtarget), we used SBmsy (112 thousand tons), which is the spawning biomass that produces the maximum sustainable yield (MSY). As the limit reference point (SBlimit), we used SB0.6msy (34 thousand tons), which is the spawning biomass that produces 60% of MSY. As fishing ban level (SBban), we used SB0.1msy (5 thousand tons), which produces 10% of MSY. We calculated the catch in 2021 based on the proposed harvest control rules (HCRs) obtained from the proposed reference points.

Item	Value	Remarks
Proposed reference points / fishing ban, β		
Proposed SBtarget	112 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	34 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	5 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)
β	-	Safety coefficient by which to multiply Fmsy for setting of the upper limit of fishing mortality of the HCRs. The Research Institute Meeting recommends using β not exceeding 0.7 in order to avoid the risk that the spawning biomass will fall below the proposed limit reference point.

Spawning biomass in 2021 (average projection value): 47 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2017-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β=1.0	55	1.01	28
β=0.9	51	0.91	26
β=0.8	46	0.81	24
β=0.7	42	0.71	22
β=0.6	37	0.61	19
β=0.5	32	0.51	16
β=0	0	0	0
F2017-2019	55	0.93	28

Uncertainty considered: recruitment, fishing mortality in 2020					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points and fishing ban below (%)		
			Proposed target reference point (SB target)	Proposed limit reference point (SB limit)	Proposed fishing ban level (SB ban)
When using β proposed by the Research Institute Meeting in the proposed HCR					
β=1.0（Fmsy）	110	64-164	39	100	100
β=0.9	125	74-186	55	100	100
β=0.8	144	86-213	70	100	100
β=0.7	166	102-243	84	100	100
β=0.6	194	120-279	93	100	100
β=0.5	228	144-325	98	100	100
β=0	666	469-891	100	100	100
F2017-2019	122	69-186	51	100	100

1. Stock status

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

Figure 1 shows YPR and %SPR (ratio of SPR which assumes no fishing divided by the SPR with current catch) based on F that uses the selectivity assumed for future fishing. As for the selectivity in F, we used the selectivity value which was used to estimate F that produces MSY (Fmsy) at the "Research Institute Meeting on Reference Points" held in April 2019 (Appendix 1, Appendix Table 1). As current fishing mortality (F2017-2019), we use the value where the %SPR presumed at this selectivity is equal to the %SPR presumed from the average F value of 2017-2019. F2017-F2019 is higher than F0.1 and F30%SPR, and lower than Fmsy.

(2) Stock-recruitment relationship

Figure 2 shows the relationship between spawning biomass (in weight) and recruitment (in the number of individuals) (S-R relationship). According to the "Research Institute Meeting on Reference Points" mentioned above, it is suggested to use the Hockey Stick (HS) model for the S-R relationship of the present stock. Here, the data used for estimating the parameters for the S-R relationship are the spawning biomass and recruitment based on the stock assessment conducted in 2018, and as for the optimization method, the least absolute value method is used. The model does not consider autocorrelation between the residuals of the recruitment. For details, see “Report of the Research Institute Meeting on Reference Points for the Northern Hokkaido stock of the Arabesque greenling in 2019.”

In the future projection of this stock, we calculated future recruitments according to this HS S-R relationship and assumed errors that follow logarithmic normal distribution as uncertainty of recruitments.

(3) Proposed reference points and fishing ban level

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

Item	Value	Remarks
Proposed reference points and fishing ban		
Proposed SBtarget	112 thousand tons	Spawning biomass that produces MSY (SBmsy)
Proposed SBlimit	34 thousand tons	Spawning biomass that produces 60% of MSY (SB0.6msy)
Proposed SBban	5 thousand tons	Spawning biomass that produces 10% of MSY (SB0.1msy)

It was proposed at the Research Institute Meeting held in April 2019 that the spawning biomass that produces MSY (SBmsy: 112 thousand tons) be used for the target reference point (SBtarget), the spawning biomass that produces 60% of MSY (SB0.6msy: 34 thousand tons) be used for the limit reference point (SBlimit), and the spawning biomass that produces 10% of MSY (SB0.1msy: 5 thousand tons) be used for the fishing ban level (SBban) (Morita et al 2019).

Figure 3 shows a Kobe plot based on the proposed SBtarget (SBmsy) and fishing mortality that produces MSY (Fmsy). The fishing mortality (F) of this stock was above Fmsy for the period from 2000 to 2015, excluding in 2001, but was below Fmsy after 2016 and almost the same as Fmsy in

2019 (2019F/Fmsy: 1.00). The exploitation rate of 2019 (U2019: 27%) is below the exploitation rate that produces MSY (Umsy: 35%). Spawning biomass was over the proposed target reference point for the period from 1993 to 1997, in 1999 and 2001 but has been below the point since 2002. Spawning biomass in 2019 (SBcurrent: 24 thousand tons) was below the proposed target and limit reference points (SBlimit) but above the proposed fishing ban level (SBban).

2. Future projection

(1) Setting of future projection

We calculated the catch in 2021 according to the future projection that uses the proposed HCRs above. For future projection, we provided recruitments presumed from the spawning biomass based on the S-R relationship in addition to the forward calculation of cohort analysis. We assumed error following a lognormal distribution as uncertainty in recruitment and made 10,000 iterations. Because selectivity of this stock greatly varies due to voluntary management, including refraining from fishing of age 0 fish in recent years, it is difficult to set the fishing mortality for future projection. Under this condition, in order to incorporate the uncertainty of fishing mortality in future projection, we set F at age in 2020 based on the random resampling from the values of 2017-2019 (Appendix 3), we used fishing mortality for calculation of the catch in 2021 as the fishing mortality by the proposed HCRs based on the spawning biomass of 2021 projected by future projection.

(2) Proposed HCRs

Proposed HCRs is fishing scenarios which determine Fishing mortality to taking into the probability of maintaining / recovering spawning biomass above the proposed target reference point (SBtarget). The "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)" provide that, if spawning biomass decreased below the proposed limit reference point (SBlimit), the fishing mortality has to be reduced until the proposed fishing ban level (SBban) along straight line. Fmsy, which will be the upper limit of fishing mortality, is multiplied by tuning parameter β, which will be the safety coefficient. Figure 4 shows the HCRs proposed at the Research Institute Meeting held in April 2019 where safety coefficient β is 0.8, as an example. The proposal of the Research Institute Meeting states: “with β not exceeding 0.8, it is presumed that the spawning biomass will exceed the proposed target reference point after 10 years with a probability of 50% or higher.”

(3) Projected values for 2021

The average catch in 2021 estimated based on the proposed HCRs was 46 thousand tons where β was 0.8, and 55 thousand tons where β was 1.0. The projected spawning biomass in 2021 was estimated at 47 thousand tons on average, and the estimation was above the proposed limit reference point (34 thousand tons) in all iterations (Table 2a).

Spawning biomass in 2021 (average projection value): 47 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2017-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β=1.0	55	1.01	28
β=0.9	51	0.91	26
β=0.8	46	0.81	24
β=0.7	42	0.71	22
β=0.6	37	0.61	19
β=0.5	32	0.51	16
β=0	0	0	0
F2017-2019	55	0.93	28

* F2017-2019 assumes the current fishing mortality (F2017-2019) as the fishing mortality in 2021 and after.

(4) Projection for 2022 onward

Results of the future projection based on the proposed HCRs are shown in Figure 5 and Tables 1 and 2. The projected spawning biomass in 2031 is 110 thousand tons on average where β is 1.0 (the 80% confidence interval is 64 thousand to 164 thousand tons), and 144 thousand tons on average where β is 0.8 (the 80% confidence interval is 86 thousand to 213 thousand tons). The probability of the projected spawning biomass being above proposed SBtarget is 70%. The projected spawning biomass is 666 thousand tons on average where β is 0 (the 80% confidence interval is 469 thousand to 891 thousand tons), and the probability of its being above the proposed SBtarget is 100%. The probabilities of exceeding the proposed SBlimit and the proposed SBban are 100% with all values of β. The Research Institute Meeting recommended to use β not exceeding 0.7 in order to avoid the risk that the spawning biomass will fall below the proposed SBlimit. It was also presented that, with β set to 0.5, the probability of recovering to the proposed SBtarget in around 10 years is 50% or higher even when low recruitment continues in the future (backward resampling scenario). When we updated the backward resampling scenario based on the new stock assessment result, the β value necessary for recovery to the proposed SBtarget with the probability of 50% or higher when low recruitment continues was 0.6 and under (Appendix 2).

Because recruitment of this stock abruptly decreased in 2010, the spawning biomass stayed at a low level since 2011 and high abundance recruitment was not observed during 2012 to 2016. However, the 2017 year class and the 2019 year class are considered to be of high abundance in recent years. If there are the average recruitments projected based on the S-R relationship, the biomass will be maintained over the proposed SBtarget with a high probability in the medium- to long-term.

Uncertainty considered: recruitment, fishing mortality in 2020					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points and fishing ban below (%)		
			Proposed target reference point (SB target)	Proposed limit reference point (SB limit)	Proposed fishing ban level (SB ban)
When using β proposed by the Research Institute Meeting in the proposed HCR					
β=1.0（Fmsy）	110	64-164	39	100	100
β=0.9	125	74-186	55	100	100
β=0.8	144	86-213	70	100	100
β=0.7	166	102-243	84	100	100
β=0.6	194	120-279	93	100	100
β=0.5	228	144-325	98	100	100
β=0	666	469-891	100	100	100
F2017-2019	122	69-186	51	100	100

Uncertainty considered: recruitment, fishing mortality in 2020			
	Year for spawning biomass to exceed the limit reference point with the probability of 50% or higher		
	Proposed target reference point (SB target)	Proposed limit reference point (SB limit)	Proposed fishing ban level (SB ban)
Other strategy (when using different β in the proposed HCRs)			
β=1.0	2051 and after	2021	2020
β=0.8	2025	2021	2020
β=0.6	2024	2021	2020
β=0.4	2023	2021	2020
β=0.2	2023	2021	2020
β=0	2023	2021	2020
F2017-2019	2030	2021	2020

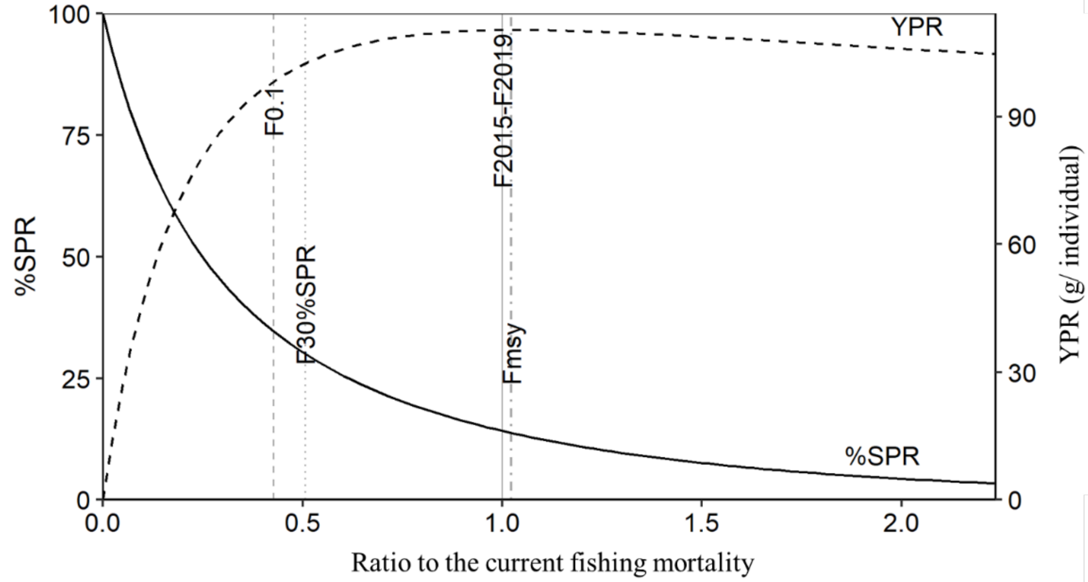


Figure 1. Relationship between YPR and %SPR for the current fishing mortality (F2017-2019)

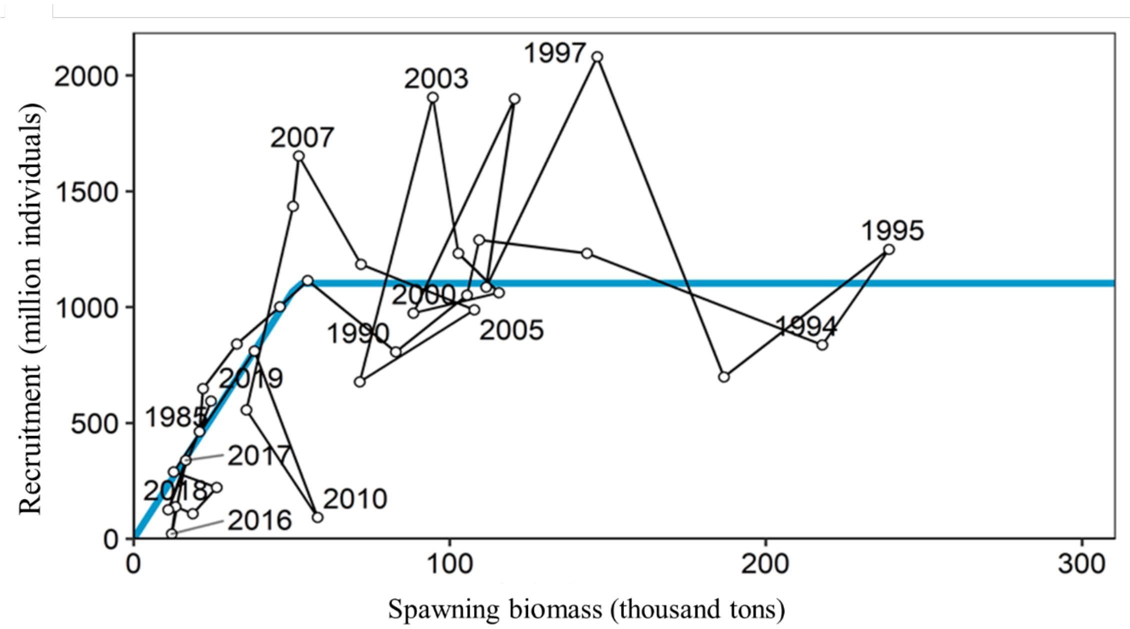


Figure 2. Relationship between spawning biomass and recruitment (S-R relationship)

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 that are projected in this stock assessment (2020).

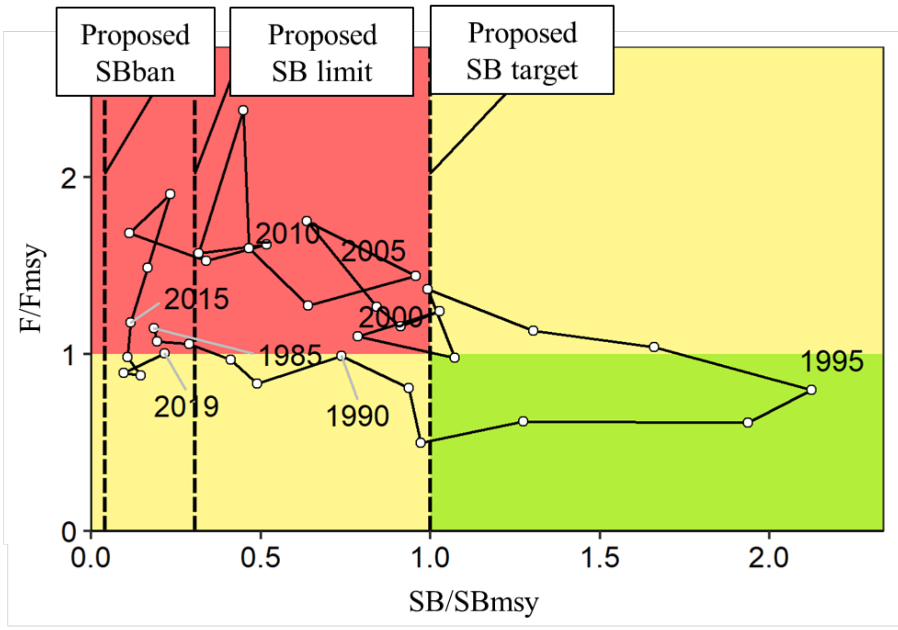
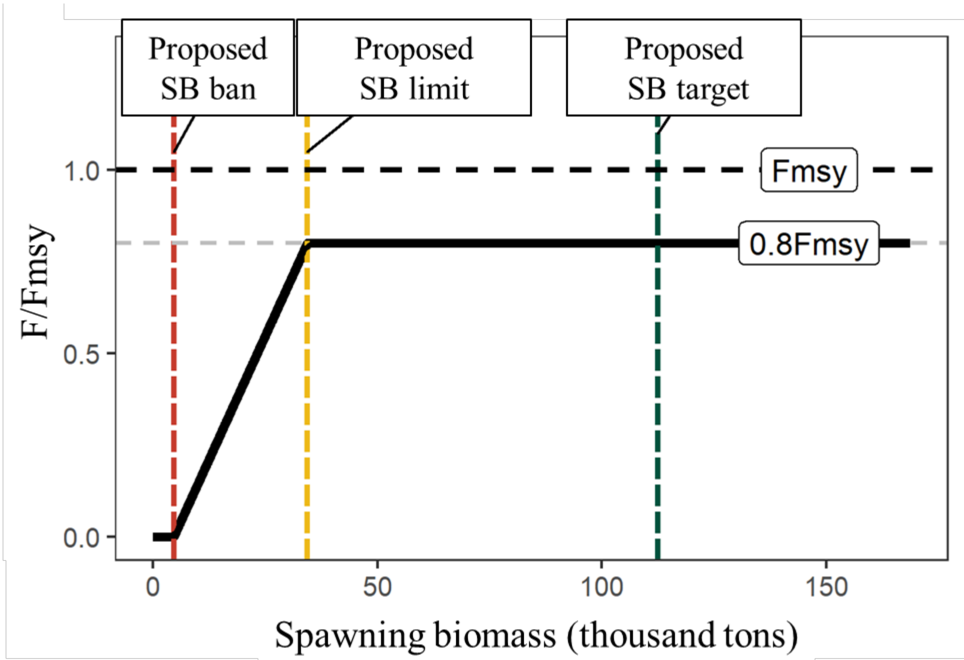


Figure 3. Relationship between proposed reference points and spawning biomass / fishing mortality (Kobe plot)

a) When the vertical axis is fishing mortality



b) When the vertical axis is catch

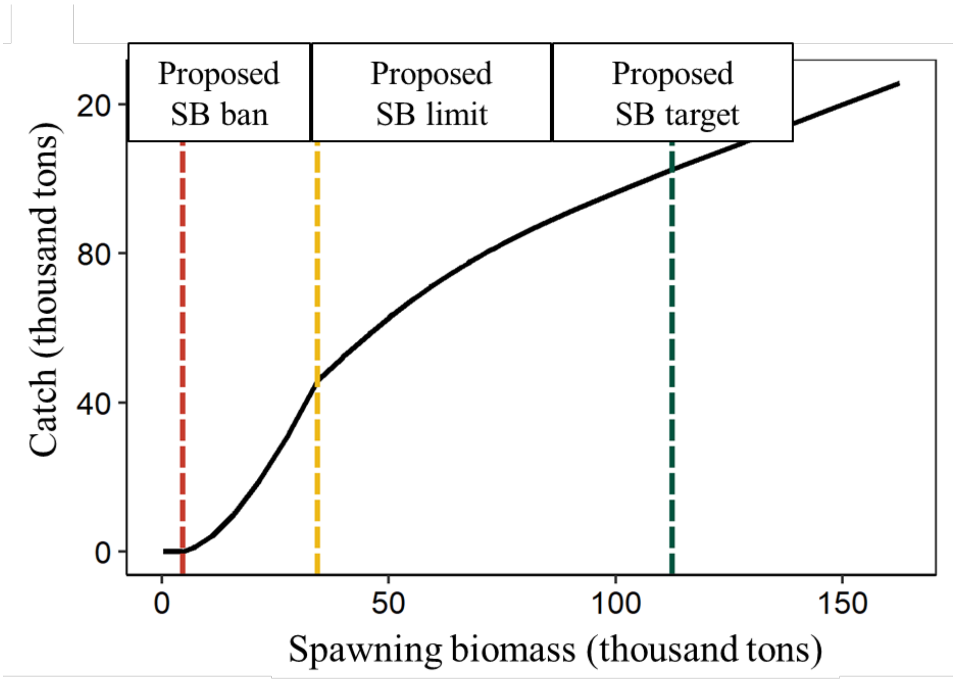


Figure 4. Proposed HCRs (where β is 0.8)

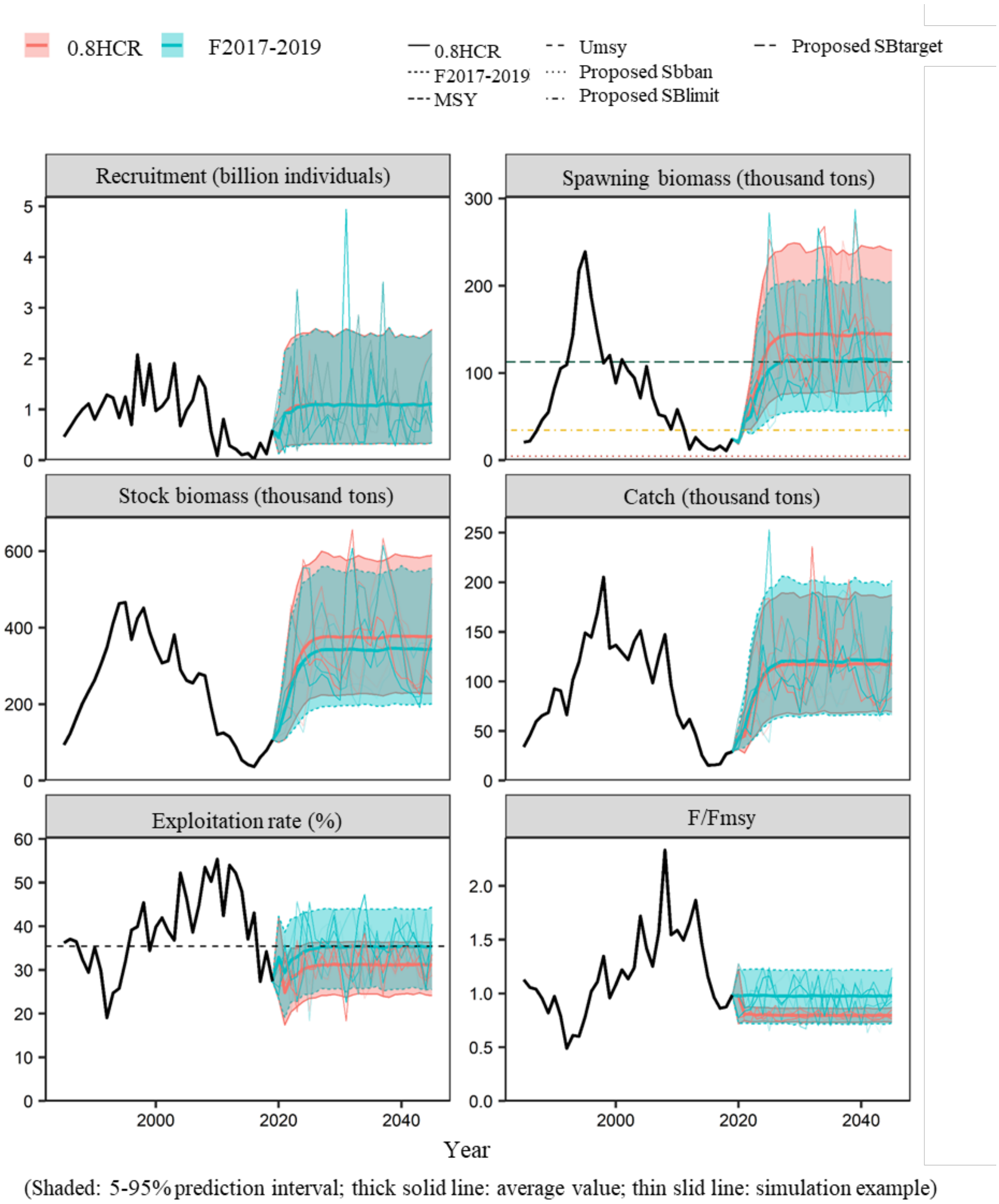


Figure 5. Comparison of the future projection between based on the proposed HCRs and the case of continuing fishing at the current fishing mortality level (F2017-2019)

The thick solid line, shaded area and thin lines indicate average value, the 80% prediction interval, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed SBtarget, the yellow dotted line represents the proposed SBlimit and the red line shows the proposed SBban. The catch in 2020 is assumed using the value of random resampling from the fishing mortality of 2017-2019. The figure shows the results of the proposed HCRs with β set to 0.8.

Table 1. Probability for future spawning biomass to exceed the proposed SBtarget (a) and the proposed SBlimitt (b)

The table shows the results of future projection under β values from 0 to 1.0. The catch in 2020 is assumed based on the projected biomass and the value of random resampling from the fishing mortality of 2017-2019. The catch in 2021 and after is based on the proposed HCRs.

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

(%)

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	0	0	1	12	24	32	35	39	38	39	40	39	40	40
0.9	0	0	1	18	35	46	50	53	53	54	56	55	55	55
0.8	0	0	2	23	48	60	65	68	70	69	70	70	72	70
0.7	0	0	3	31	61	75	80	82	83	83	83	84	85	84
0.6	0	0	4	41	73	86	90	92	93	94	93	93	94	94
0.5	0	0	6	51	83	93	96	98	98	98	98	98	99	99
0.4	0	0	8	62	91	98	99	100	100	100	100	100	100	100
0.3	0	0	10	73	96	100	100	100	100	100	100	100	100	100
0.2	0	0	13	82	99	100	100	100	100	100	100	100	100	100
0.1	0	0	17	90	100	100	100	100	100	100	100	100	100	100
0	0	0	23	95	100	100	100	100	100	100	100	100	100	100

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

(%)

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	0	100	95	97	99	100	100	100	100	100	100	100	100	100
0.9	0	100	98	99	100	100	100	100	100	100	100	100	100	100
0.8	0	100	99	99	100	100	100	100	100	100	100	100	100	100
0.7	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	0	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 2. Change in future average spawning biomass (a) and future average catch (b)

The table shows the results of future projection under β values from 0 to 1.0. The catch in 2020 is assumed based on the projected biomass and the value of random resampling from the fishing mortality of 2017-2019. The catch in 2021 and after is based on the proposed HCRs.

(a) Average spawning biomass

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	21	47	52	76	93	101	105	108	110	110	111	110	111	110
0.9	21	47	55	84	105	116	121	124	126	126	127	125	127	126
0.8	21	47	59	92	120	134	139	143	144	145	145	144	145	144
0.7	21	47	63	102	136	153	161	165	166	167	168	166	168	166
0.6	21	47	67	113	154	176	186	191	193	194	195	194	195	194
0.5	21	47	71	125	174	203	215	223	226	228	229	228	230	228
0.4	21	47	76	138	197	234	251	262	268	270	273	271	274	272
0.3	21	47	81	153	224	271	296	311	320	325	329	328	332	330
0.2	21	47	86	170	254	314	350	373	388	397	404	404	412	410
0.1	21	47	92	188	290	367	418	454	478	494	507	511	528	527
0	21	47	98	209	331	431	503	558	599	628	653	666	713	715

(Thousand tons)

(b) Average catch

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	39	55	84	96	108	113	116	118	118	119	118	119	119	119
0.9	39	51	81	95	107	113	116	118	118	119	117	118	118	119
0.8	39	46	76	92	105	112	115	117	117	118	116	117	117	118
0.7	39	42	71	88	102	109	113	115	115	116	115	115	116	116
0.6	39	37	65	83	97	105	109	111	112	113	112	112	113	113
0.5	39	32	57	75	90	99	104	106	107	108	107	108	108	108
0.4	39	26	49	66	81	91	96	98	100	101	100	101	101	101
0.3	39	20	39	54	68	78	83	87	88	90	90	90	91	91
0.2	39	14	28	40	52	60	66	69	71	72	73	73	74	74
0.1	39	7	15	22	29	35	39	42	44	45	46	46	47	48
0	39	0	0	0	0	0	0	0	0	0	0	0	0	0

(Thousand tons)

Appendix 1. Method of future projection

We conducted future projection from the stock biomass projected in the 2020 stock assessment, based on the proposed HCRs. For projection of future recruitment, we used values estimated based on the HS S-R relationship (a = 0.022, b = 51051, SD = 0.62) applied at the "Research Institute Meeting on Reference Points" held in April 2019. The parameters for the S-R relationship are estimated from the spawning biomass based on 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 (Morita et al 2019).

For at age fishing mortality (F) in future projection, we used the value calculated based on the HCRs set for the first group of stocks (group of data rich species) detailed in the "Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC)." The parameters used for the future projections are shown in Appendix Table 1-1. As for the selectivity, average body weight of the catch, we used the values that was suggested at "Research Institute Meeting on Reference Points" held in April 2019 which based on the 2018 stock assessment as with the case of the S-R relationship. The selectivity is the average calculation result for 2015-2017. As the current fishing mortality (F2017-2019), we use the value where the %SPR presumed at this selectivity is equal to the %SPR presumed from the average F value of 2017-2019. F in 2020 is obtained by random resampling from the fishing mortality (F) of 2017-2019 (Appendix 3).

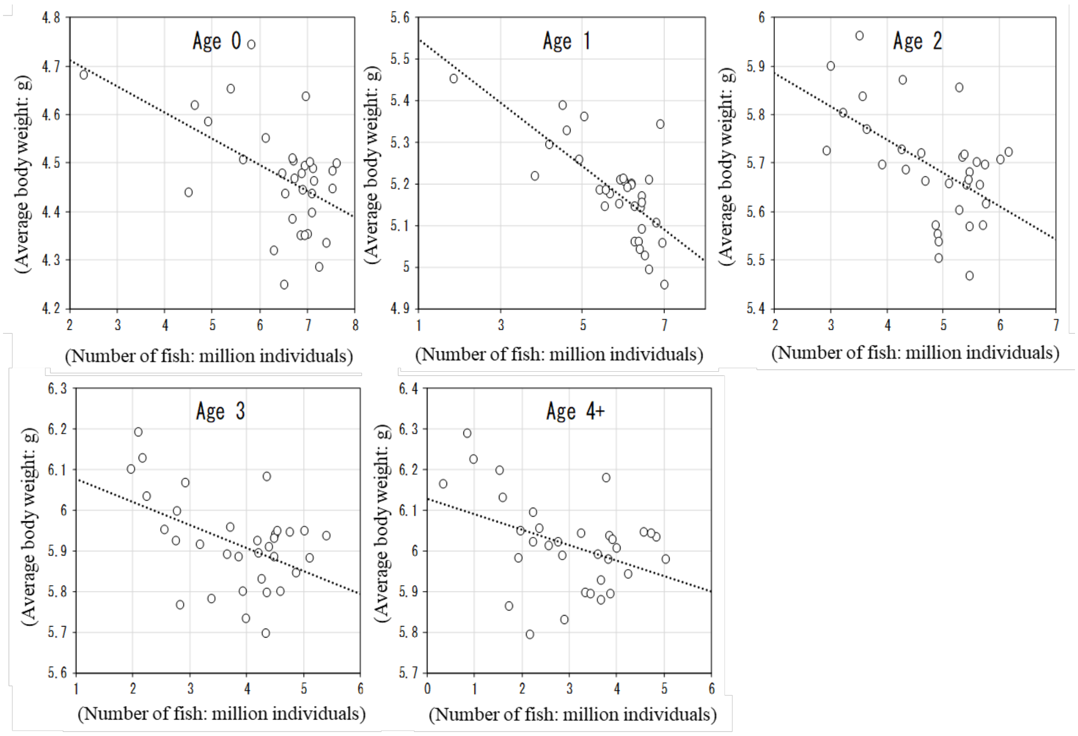
For projection of the number of fish, we used forward calculation of cohort analysis (equation (1)).

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

The plus group of fish of age 4 and above is forwarded from the sum of the fish of age 3 and age 4 and above of the previous year.

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

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



Appendix Figure 1-1. Relationship between then number of fish and body weight at age

As for the number of fish and average body weight of the catch, we used the values used for estimation of the level that produces MSY (Morita et al., 2019). These values are based on the 2018 stock assessment as with the case of the S-R relationship.

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

	Selectivity	Fmsy	F2017	F2018	F2019	Average body weight at SBmsy (g)	Natural mortality	Maturity rate (at beginning of the year)
Age 0	0.15	0.11	0.22	0.02	0.16	86	0.295	0
Age1	0.6	0.77	0.4	0.63	0.57	172	0.295	0
Age 2	0.9	0.57	0.83	0.7	0.88	287	0.295	0.8
Age 3	1	0.92	0.74	0.98	0.95	358	0.295	1
Age 4 and above	1	0.92	0.74	0.98	0.95	400	0.295	1

A negative correlation is found between the number of fish and body weight at age of this stock (Appendix Figure 1-1). Therefore, in estimation of the level that produces MSY and future projection, we used the regression formula of body weight at age corresponding to the number of fish shown below and the projected average body weight at age of 1985-2017 added observed error. Parameters of the regression formula of the number of fish and body weight of each age, and the average number of fish of 1985-2017 are shown in Appendix Table 1-2. The number of fish and body weight at age we used are values based on the 2018 stock assessment as is the case with the S-R relationship.

[Regression formula of body weight at age against the number of fish]

$$\log(Bw_x) = \mathrm{a} \times \log(N_x) + b + e, \quad e \sim \mathrm{N}(0, \sigma^2)$$

Here, Bw_x and N_x represent the body weight and number of fish at age x, respectively, while *e* represents error.

Appendix Table 1-2. Parameters of the regression formula of the number of fish and body weight at age

	a	b	SD	Average number of fish of 1985-2017 (minimum value and maximum value are in parentheses) (million individuals)		Body weight projected from the regression formula at each number of fish to the left (g)	
Age 0	-0.054	4.82	1.272	908	(10-2080)	86	(82-109)
Age1	-0.076	5.624	0.826	482	(7-1121)	173	(162-240)
Age 2	-0.068	6.022	0.763	176	(19-485)	290	(271-338)
Age 3	-0.057	6.135	1.256	66	(7-225)	364	(339-412)
Age 4 and above	-0.038	6.123	1.739	37	(1-156)	398	(377-450)

Appendix 2. Future projection that considers a low-recruitment scenario

We examined various low-recruitment scenarios considering the possibility of negative residuals in succession, because the residuals of the recruitment observation values against the predicted values lean to the negative side in recent years (Morita et al 2019).

In recent years, stock biomass and spawning biomass have been increasing since 2016 due to the recruitment of the 2017 year class and the 2019 year class. However, the stock is not yet recovered to the situation before 2008, where over one billion fish were recruited every several years. When the HS S-R relationship is assumed, residuals of the recruitment observation values against the projected values lean to the negative side in the most recent 10 years (Appendix Figure 2-1). If there is a year class with extremely low-recruitment such as 2010 and 2016, stock status can deteriorate again. Therefore, we conducted future projection with a backward resampling method assuming low-recruitment based on the stock calculation results up to 2019 (Appendix Figure 2-2, Appendix Tables 2-1 and 2-2). The average catch in 2021 calculated based on the proposed HCRs is 32 thousand tons with β set to 0.8, and 38 thousand tons with β set to 1.0. The spawning biomass in 2021 was estimated at 47 thousand tons at average, and the estimation was above the proposed limit reference point in all iterations (Appendix Table 2-2).

Spawning biomass in 2021 (average projection value): 47 thousand tons			
Item	Catch in 2021 (thousand tons)	Ratio to the current fishing mortality (F/F2017-2019)	Exploitation rate in 2021 (%)
When using β proposed by the Research Institute Meeting in the proposed HCRs			
β=1.0	38	1.01	31
β=0.9	35	0.91	29
β=0.8	32	0.81	26
β=0.7	29	0.71	24
β=0.6	26	0.61	21
β=0.5	22	0.51	18
β=0	0	0	0
F2017-2019	41	0.93	33

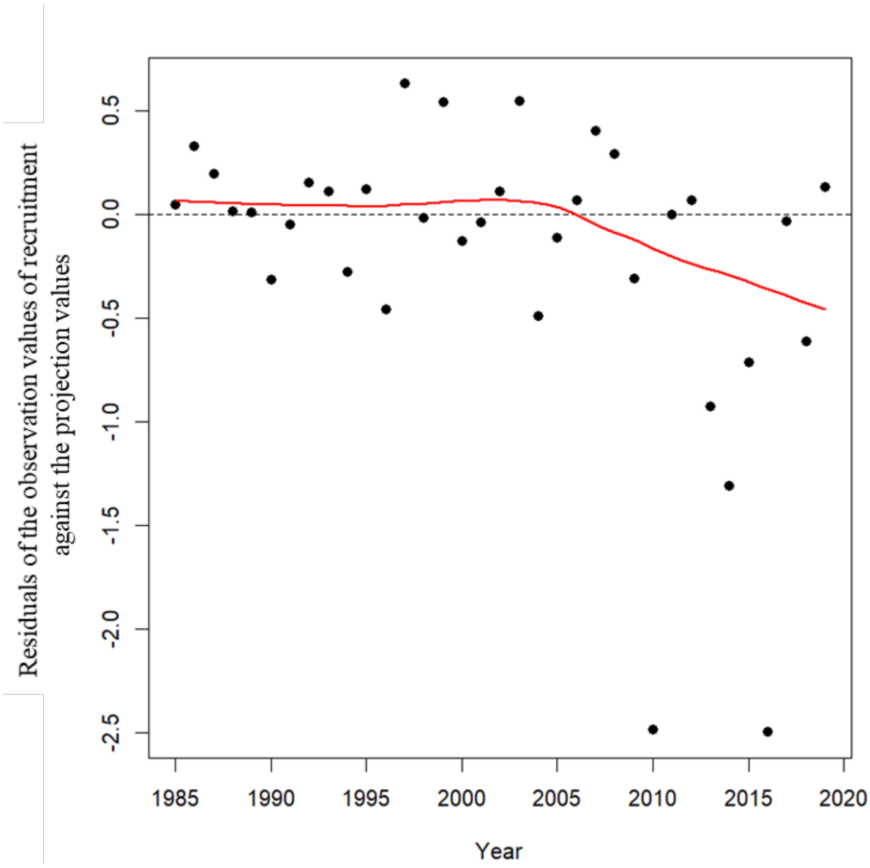
When management based on the proposed HCRs is continued for 10 years, the projected average spawning biomass in 2031 is 70 thousand tons (80% confidence interval: 29 thousand to 121 thousand tons) with β set to 1.0; 95 thousand tons (80% confidence interval: 41 thousand to 157 thousand tons) with β set to 0.8. The probability that the projected value will exceed the proposed SBtarget is 35%. With β set to 0, the average spawning biomass is 428 thousand tons (80%

confidence interval: 246 thousand to 634 thousand tons) and the probability that the projected value will exceed the proposed SBtarget is 100%.

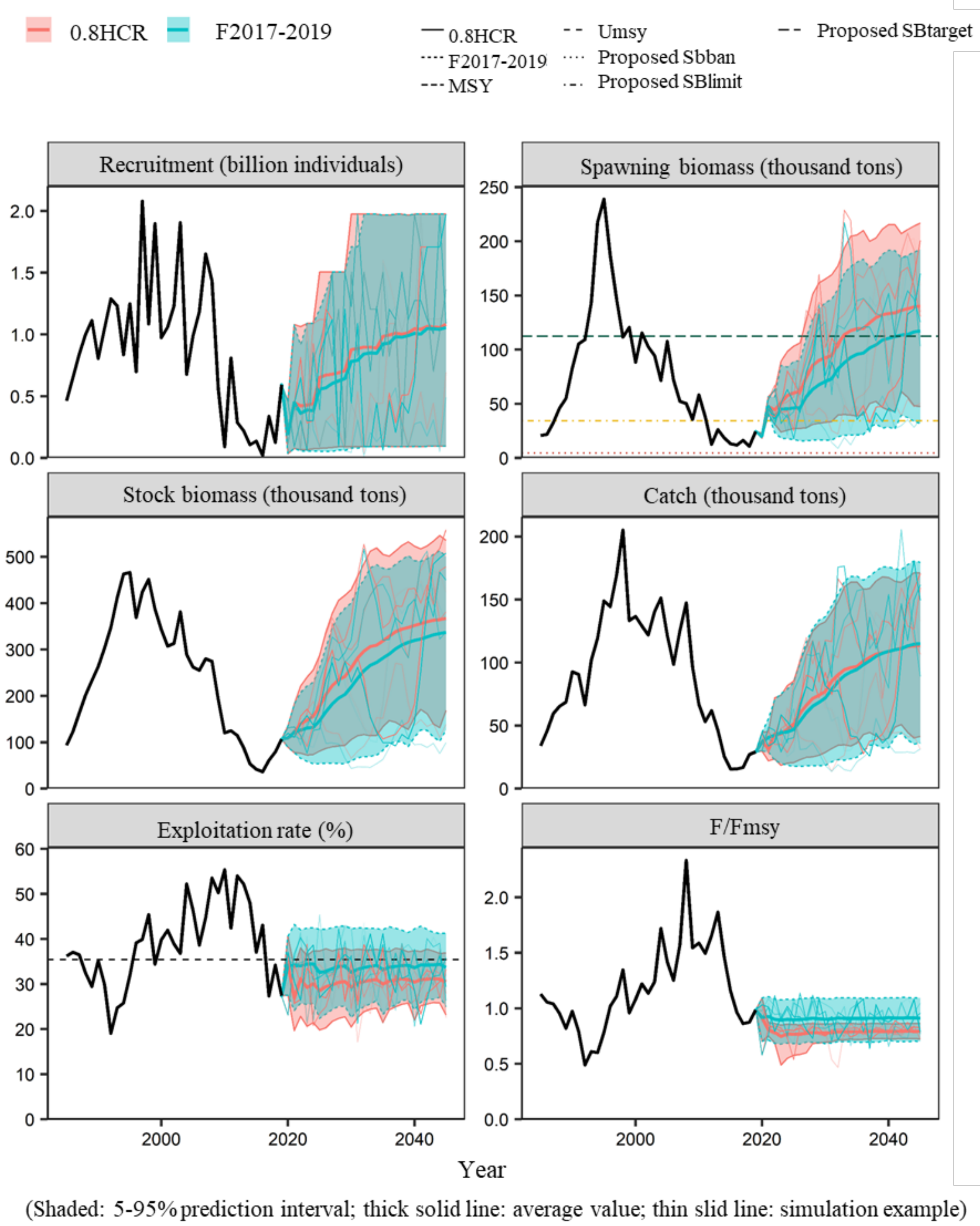
Because this stock had two year classes with extremely low recruitment in the last ten years, we need to pay due consideration to the possibility of similar low recruitment in the future. When examining HCR proposal, it is desirable to choose a preventive value for safety coefficient β based on a future projection that considers the possibility that low recruitment will continue in the future.

Uncertainty considered: recruitment, fishing mortality in 2020					
Item	Spawning biomass in 2031 (thousand tons)	80% confidence interval (thousand tons)	Probability of the spawning biomass in 2031 being above the proposed reference points and fishing ban below (%)		
			Proposed target reference point (SB target)	Proposed limit reference point (SB limit)	Proposed fishing ban level (SB ban)
When using β proposed by the Research Institute Meeting in the proposed HCR					
β=1.0（Fmsy）	70	29-121	15	83	100
β=0.9	81	34-138	25	90	100
β=0.8	95	41-157	35	95	100
β=0.7	111	50-181	45	97	100
β=0.6	130	61-209	57	99	100
β=0.5	153	74-244	68	100	100
β=0	428	246-634	100	100	100
F2017-2019	73	23-135	22	100	100

Uncertainty considered: recruitment, fishing mortality in 2020			
	Year for spawning biomass to exceed the limit reference point with the probability of 50% or higher		
	Proposed target reference point (SB target)	Proposed limit reference point (SB limit)	Proposed fishing ban level (SB ban)
Other strategy (when using different β in the proposed HCRs)			
β=1.0	2051 and after	2021	2020
β=0.8	2041	2021	2020
β=0.6	2029	2021	2020
β=0.4	2026	2021	2020
β=0.2	2024	2021	2020
β=0	2023	2021	2020
F2017-2019	2041	2021	2020



Appendix Figure 2-1. Residuals
of the observation values of recruitment against the projection values (1985-2019) based on HS S-R relationship proposed by the "Research Institute Meeting on Reference Points" held in April 2019



Appendix Figure 2-2. Comparison of the future projection based on the proposed HCRs and the future projection that assumes continued fishing at the current fishing mortality level (F2017-2019)

The thick solid line, shaded area and thin lines represent average value, the 80% prediction interval, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed SBlimit and the red line shows the proposed fishing ban level. The catch in 2020 is assumed using the value of random resampling from the fishing mortality of 2017-2019. The figure shows the results of the proposed HCRs with β set to 0.8.

Appendix Table 2-1. Probability for future spawning biomass to exceed the proposed target reference point (a) and the proposed limit reference point (b)

The table shows the results of future projection when β is changed within the range from 0 to 1.0. The catch in 2020 is assumed based on the projected biomass and the value of random resampling from the fishing mortality of 2017-2019. The catch in 2021 and after is based on the proposed HCRs.

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

(%)

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	0	0	0	0	0	0	0	1	4	10	13	15	46	56
0.9	0	0	0	0	0	1	1	4	14	20	23	25	59	73
0.8	0	0	0	0	1	3	3	12	25	31	32	35	67	80
0.7	0	0	0	1	4	8	9	26	38	41	43	45	73	84
0.6	0	0	0	3	12	18	20	42	50	54	55	57	79	88
0.5	0	0	0	8	22	31	35	55	64	66	67	68	85	91
0.4	0	0	0	14	33	47	53	70	77	78	79	79	92	94
0.3	0	0	0	20	46	62	72	83	89	89	90	90	96	98
0.2	0	0	0	26	60	77	86	92	95	96	97	97	99	100
0.1	0	0	0	36	74	89	95	97	98	99	99	99	100	100
0	0	0	1	51	86	96	98	100	100	100	100	100	100	100
Fcurrent	0	0	0	0	0	1	1	4	11	16	19	22	55	69

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

(%)

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	0	100	71	66	71	68	69	76	82	82	82	83	93	95
0.9	0	100	80	74	80	78	80	84	89	89	89	90	96	97
0.8	0	100	88	81	87	87	88	90	93	93	94	95	98	99
0.7	0	100	92	85	92	94	94	95	96	97	97	97	99	99
0.6	0	100	97	91	95	97	97	98	98	99	99	99	100	100
0.5	0	100	99	95	97	98	99	99	99	100	100	100	100	100
0.4	0	100	100	98	99	99	100	100	100	100	100	100	100	100
0.3	0	100	100	100	99	100	100	100	100	100	100	100	100	100
0.2	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	0	100	100	100	100	100	100	100	100	100	100	100	100	100
0	0	100	100	100	100	100	100	100	100	100	100	100	100	100
Fcurrent	0	100	58	68	66	66	65	72	77	77	77	78	92	95

Appendix Table 2-2. Change in future average spawning biomass (a) and future average catch (b)

The table shows the results of future projection when β is changed within the range from 0 to 1.0. The catch in 2020 is assumed based on the projected biomass and the value of random resampling from the fishing mortality of 2017-2019. The catch in 2021 and after is based on the proposed HCRs.

(a) Average spawning biomass

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	21	47	39	42	45	45	45	55	62	65	68	70	102	111
0.9	21	47	42	46	51	52	53	64	73	76	79	81	116	127
0.8	21	47	45	51	58	60	62	75	86	90	92	95	134	146
0.7	21	47	47	56	66	70	73	88	101	106	108	111	155	168
0.6	21	47	50	63	75	82	86	103	118	125	127	130	181	196
0.5	21	47	54	70	86	96	101	121	139	147	150	153	213	231
0.4	21	47	57	78	99	113	120	142	163	174	178	182	253	275
0.3	21	47	61	86	113	132	143	168	193	207	213	219	306	333
0.2	21	47	64	96	130	155	170	201	231	249	259	268	378	413
0.1	21	47	69	108	150	183	205	243	280	305	321	334	481	528
0	21	47	73	120	173	217	248	297	346	381	406	428	639	711
Fcurrent	21	47	37	45	45	46	46	57	63	68	71	73	112	123

(Thousand tons)

(b) Average catch

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1	37	38	47	43	45	47	55	61	68	70	74	82	109	117
0.9	37	35	45	43	47	49	58	64	70	73	76	84	110	118
0.8	37	32	43	43	47	50	60	66	72	74	77	85	110	117
0.7	37	29	41	43	47	51	60	67	72	74	77	85	109	116
0.6	37	26	38	41	46	50	59	66	71	73	76	83	106	113
0.5	37	22	34	38	44	48	57	63	68	70	73	79	102	109
0.4	37	18	29	34	40	44	52	58	63	65	68	73	95	102
0.3	37	14	23	29	34	39	45	50	55	58	60	65	85	91
0.2	37	10	17	21	26	30	35	39	44	46	48	52	69	75
0.1	37	5	9	12	15	18	21	24	26	28	30	32	44	47
0	37	0	0	0	0	0	0	0	0	0	0	0	0	0
Fcurrent	37	41	42	44	45	47	54	60	65	69	72	79	110	119

(Thousand tons)

Appendix 3. Assumption of the fishing mortality in 2020

Background

In the stock assessment and management of Japan, the biomass is estimated up to the year before the stock assessment year (2020 in this case) through VPA, while the number of fish in 2020 and after is calculated through simulation of forward calculation of the cohort that assumes random recruitment (numbers) in the future. In 2021 and after, fishing is conducted based on the fishing mortality at age that is decided according to the ABC calculation rule and the HCR guidelines. An especially important for management is the catch (2021) in the year after the stock assessment year, which corresponds to ABC. For stocks subject to TAC, this value is treated as the ground for TAC. The value is treated as target catch for management for stocks not subject to TAC as well.

However, because the catch in 2021 is the value projected based on the future projection for one year after 2020, the value is greatly influenced by the assumption of the catch and recruitment in 2020. Moreover, the new ABC calculation guideline proposes HCRs where the fishing mortality can be lowered according to the ratio of the projected spawning biomass in 2021 to the proposed SBlimit, when the spawning biomass is below the proposed SBlimit. When this control rule is applied, the uncertainty of the spawning biomass in 2021 will influence the catch in 2021 through fishing mortality.

According to the 2020 stock assessment of Northern Hokkaido stock of Arabesque greenling (FRA-SA2020-SC04-1) relatively abundant recruitment is projected for 2019, while the fishing mortality of fish of age 1 and above in 2019 is high. For this reason, it is projected that number of age 1 fish will be relatively high but stock of age 2 and above will decrease. In this age composition, the prediction value of catch and spawning biomass for 2021 will heavily depend on the assumption of the fishing mortality of age 1 fish in 2020. The greater the remainder of age 1 fish in 2020, the greater catch of age 2 fish is expected in 2021. Conversely, if the fishing mortality of age 1 fish is high in 2020, it is expected that the residual stock of age 2 fish, catch and spawning biomass will decrease in 2021.

Uncertainty of the assumption of the fishing mortality (F) in the first year of future prediction is a problem for other fish stocks as well. However, because it is expected that age 1 fish will account for the most part of the abundance of the Northern Hokkaido stock of the Arabesque greenling in 2020, in particular, the impact is considered to become significant.

Here, we propose a method to resample F values of the most recent years rather than setting F in 2020 to a single value, and check the extent of the change in the spawning biomass and catch in 2021 depending on the assumption of F in 2020. This method will eliminate the need to decide one value of F at age in 2020 and enable incorporation of the uncertainty of F in 2020 in the future projection.

Method

We assumed F in 2020 in the following three ways and examined its influence on the spawning biomass and catch in 2021.

1. Use the F at age in 2020 as the average F value at age of 2017-2019 (“average_2017_2019”).
2. Convert the fishing mortality of F at age of 2017-2019 with %SPR and make it adapted to the selectivity of Fmsy (“convert_2017_2019”).
3. Randomly sample F at age of 2017-2019 as F in 2020 (“random F”). Here, we randomly sampled F of three years from 2017 to 2019, but in actual, an appropriate sampling period that is considered to reflect the intensity of fishing in recent years can be used.

Here, we used the VPA result of the “2020 stock assessment of Northern Hokkaido stock of the Arabesque greenling” (FRA-SA2020-SC04-1). The number of simulations for this appendix is 300 for the purpose of saving calculation time.

Result

The averages, medians and ranges of distribution of catch and spawning biomass in 2021 varied among the three methods (Appendix Figure 3-1). F by random sampling (random_F) has almost the same average and median of catch and spawning biomass as those of average_2017_2019, but its distribution range is wider, which is considered to be reflection of the uncertainty of F in 2020. When the selectivity of MSY calculation is used (convert_2017_2019), the catch in 2020 is large, which makes the catch in 2021 relatively small because the selectivity is particularly high for age 1 fish (Appendix Figure 3-2).

In order to explore the cause of the uncertainty of future spawning biomass and catch, we examined the relationship of the 2021 catch with the F on age 1 fish in 2020 and the recruitment of 2020/2021 in the simulation results (Appendix Figure 3-3a and b). Most of the uncertainty of the catch in 2021 is explained by the recruitment in 2020/2021 (upper charts of Appendix Figures 3-3a and b) but the distribution of catch varies depending on the assumption of F on age 1 fish in 2021. When backward resampling is assumed in recruitment, and F on age 1 fish in 2020 is assumed to be around a relatively large value of 0.6, the catch is about 40 thousand tons in 2020 but about 31 thousand tons in 2021. On the other hand, if F on age 1 fish is assumed to be a relatively small 0.4, the catch in 2020 is reduced to about 32 thousand tons while the catch in 2021 will slightly increase to 34 thousand tons.

The spawning biomass in 2021 is also greatly influenced by F on age 1 fish in 2020 (Appendix Figure 3-4). Because the spawning biomass in 2021 is above the proposed SBlimit for this stock (34 thousand tons) both in the backward resampling and the logarithmic normal distribution, difference in the spawning biomass is not reflected in catch through γ. However, if it is projected that the spawning biomass in 2021 will fall below the SBlimit, the catch in 2020 will influence the catch in 2021 through γ, which will increase the importance of the assumption of F in 2020.

Summary

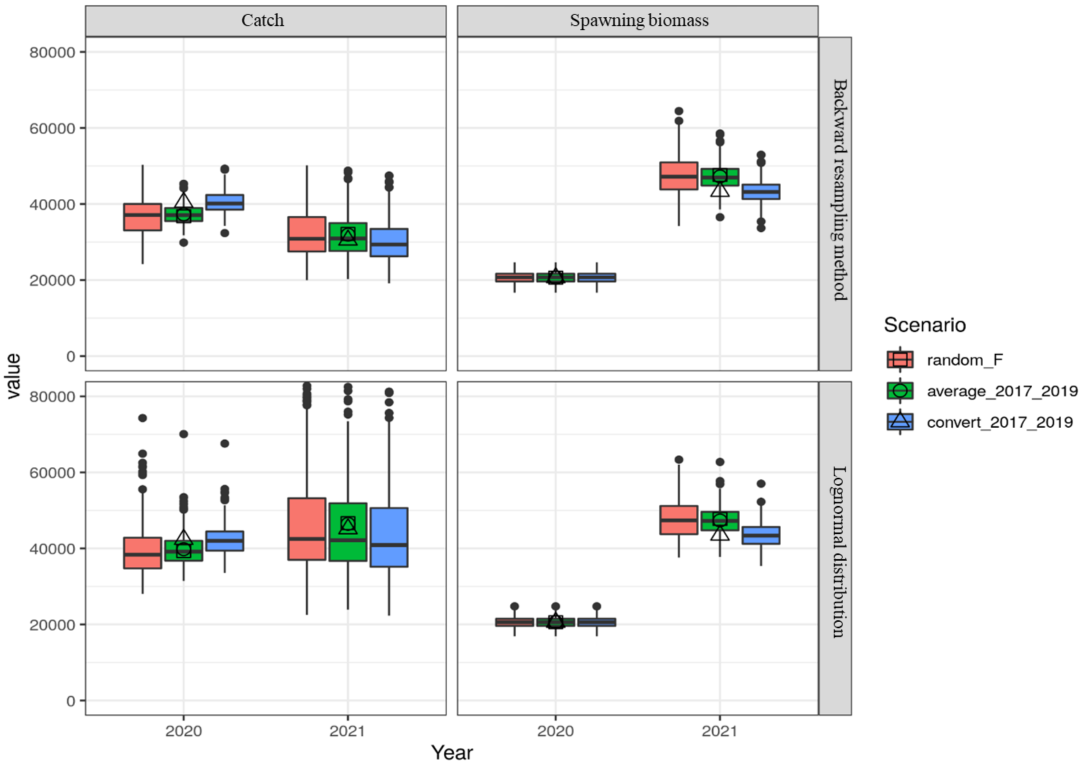
・Because the tendency for the single year class to account for most of the catch in terms of number is projected to become stronger for this stock, the assumption of the catch in 2020 will greatly influence the catch in 2021. For this reason, it is necessary to carefully consider the assumption of the 2020 catch.

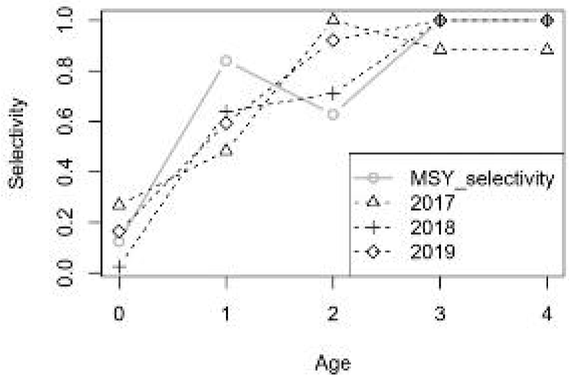
・When it is difficult to select of F, there is an approach of random sampling of F during a period that is considered to reflect the fishing conditions in recent years. In this way, the range of uncertainty in the future can be considered more appropriately (with almost the same average value).

・It is considered that the future projection of this stock, which has a strong tendency to depend on the the single year class, is particularly susceptible to the assumed values of the catch and recruitment in 2020. In order to reduce the uncertainty of ABC, it is important for stock management to stably preserve older fish and ensure diversity in the age composition of the remainder of the stock.

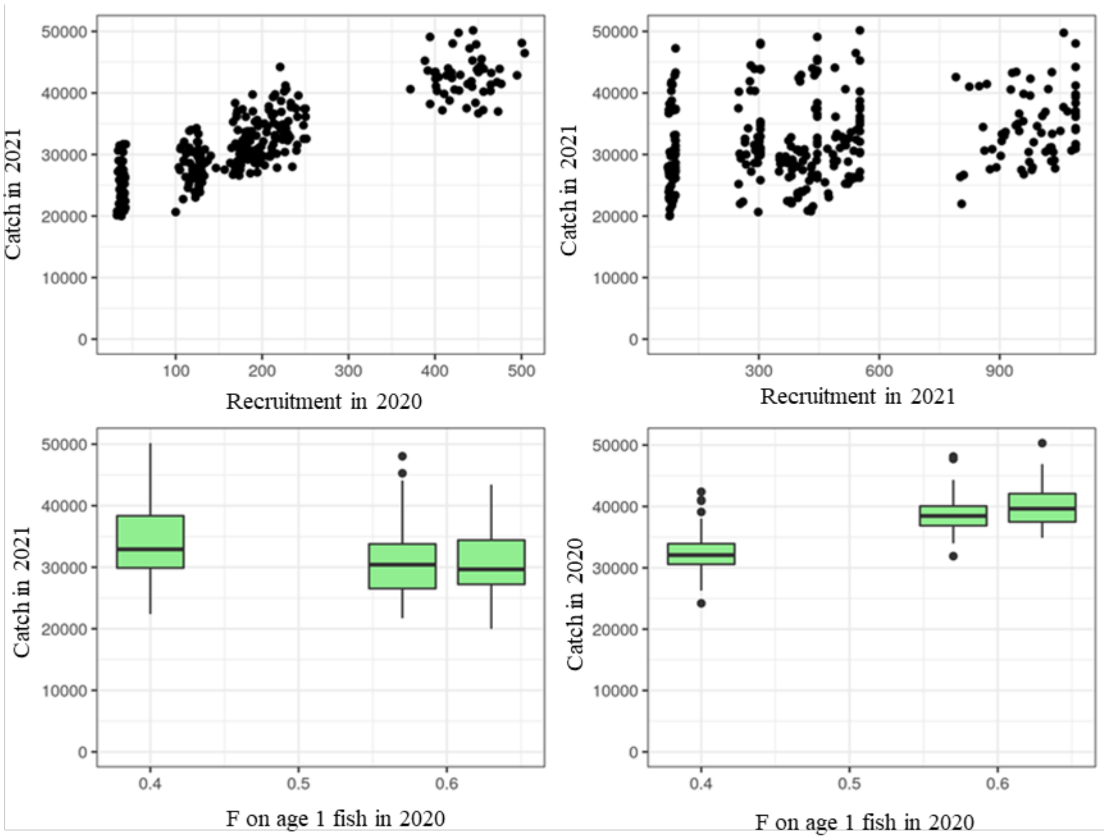
Appendix Figure 3-1. Difference in projected values of the catch (tons; left) and spawning biomass (tons; right) in 2020 and 2021 between the three methods (simulation is made 300 times)

The upper charts assume the recruitment of backward resampling method, while the lower charts assume usual logarithmic normal distribution. The outlined symbols at the center are averages of the respective legend.



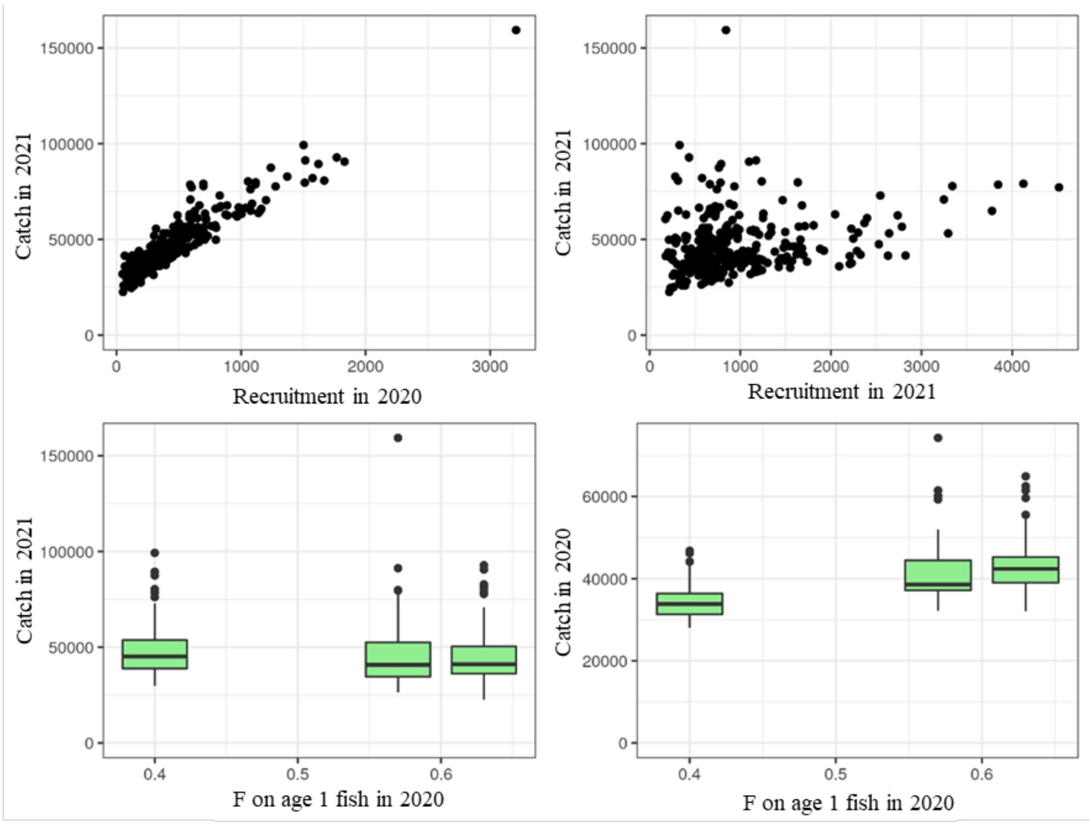


Appendix Figure 3-2. Estimated selectivity of 2017-2019 and the selectivity used for MSY calculation

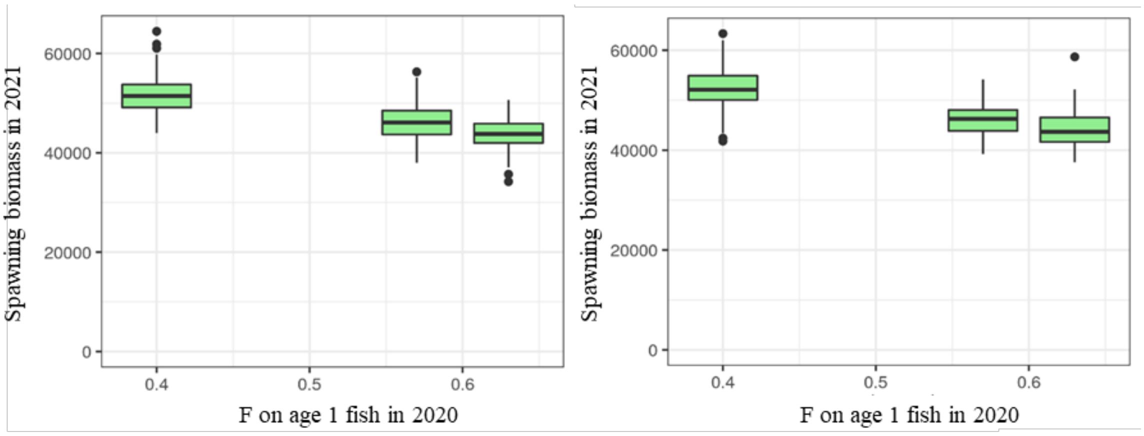


Appendix Figure 3-3a. Relationship of the catch in 2021 (tons) with the recruitment in 2021 (million individuals; upper left), the recruitment in 2020 (million individuals; upper right) and F on age 1 fish in 2020 (lower left)

The lower right chart shows its relationship with F on age 1 fish in 2020 when the catch in 2020 (tons) is put to the vertical axis. Recruitment with backward resampling is assumed.



Appendix Figure 3-3b. The same as Figure 2 but recruitment of logarithmic normal distribution is assumed.



Appendix Figure 3-4. Relationship between the spawning biomass in 2021 (tons) and F on age 1 fish in 2020

Left: backward resampling method; right: lognormal distribution