Report of the Research Institute Meeting on Reference Points for the Tsushima Warm Current Stock of Japanese Sardine in 2020

Responsible institute: Saikai National Fisheries Research Institute

Summary

We examined the stock-recruitment (S-R) relationship and the proposed reference points by using the stock assessment data of this stock of 2019. Because the S-R relationship of this stock greatly varies from decade to decade, we exclude the high recruitment period (1976-1987), choose as candidate the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) that are considered to reflect the recent recruitment status, and apply the hockey stick (HS) S-R relationship that does not consider autocorrelation of residuals to the spawning biomass and recruitment data estimated in the stock assessment. We use the least squares method for estimation of parameters of the HS S-R relationship. As a target reference point, we propose SBmsy (990 thousand tons), which is the spawning biomass that produces the maximum sustainable yield (MSY) calculated based on the S-R relationship. As the limit reference point, we propose SB0.6msy (454 thousand tons), which is the spawning biomass that produces 60% of MSY. As the fishing ban level, we propose SB0.1msy (63 thousand tons), which produces 10% of MSY. Fishing mortality that produces MSY (Fmsy) is 1.01 times the current fishing mortality (average fishing mortality during the period from 2014 to 2018).

Spawning biomass (thousand tons)	Ratio to the current spawning biomass (2018)	Ratio to the initial spawning biomass (2.553 million tons)	Average catch expected under the conditions of a normal recruitment period (thousand tons)	Ratio to the current fishing mortality (2014-2018)*	Explanation
Proposed target reference point					
990	3.95	0.39	316	1.01	Spawning biomass that produces MSY (SBmsy)
Proposed limit reference point					
454	1.81	0.18	190	1.34	Spawning biomass that produces 60% of MSY (SB0.6msy)

Proposed fishing ban level					
63	0.25	0.02	32	1.59	Spawning biomass that produces 10% of MSY (SB0.1msy)
2018					
251	1.00	0.10	71**		Value of 2018

* Coefficient to multiply the current fishing mortality of each age when calculating the proposed reference points and proposed fishing ban level based on the selectivity at age under the current fishing mortality

**Actual catch in 2018

1. Stock-recruitment relationship

1-1) Data set to be used

In accordance with the "2020 Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC) (FRA-SA2020-ABCWG01-01)," we used the following data set for settings of stock-recruitment (S-R) relationships of this stock. We used R package frasyr (v2.01) for analysis. For detail of the equations used in frasyr, see "Technical Note on Estimation of stock-recruitment relationship, reference point calculation and future prediction simulation (2020 Research Institute Meeting Version) (FRA2020-ABCWG01-02)."

Data set	Data source and research
Stock biomass / spawning biomass	Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2019/2020) (Fisheries Agency of Japan; Japan Fisheries Research and Education Agency [FRA])

1-2) Examination of S-R relationship

As the S-R relationship to be used for calculation of the spawning biomass that produces the maximum sustainable yield (MSY) and of the future forecast, we considered hockey stick (HS), Ricker (RI) and Beverton-Holt (BH) S-R relationships based on the "Technical Note on Estimation of stock-recruitment relationship, reference point calculation and future prediction simulation (2020 Research Institute Meeting Version) (FRA2020-ABCWG01-02)" (Appendix 1). We chose the least squares method and the least absolute value method as candidates for optimization.

We used the data of recruitment and spawning biomass for the period of 1969 to 2017 as estimated in the stock assessment. We excluded the latest 2018 data that is considered to be highly uncertain in terms of recruitment. Based on the "Evaluation of estimation bias of simultaneous estimation of autocorrelation coefficient using simulation (FRA-SA2020-

BRP01-6)," we considered autocorrelation by using the method to simultaneously estimate the parameters of the S-R relationship and autocorrelation in the case of the least squares method, and by using the two-stage estimation method that considers autocorrelation in residuals in the case of the least absolute value method (Appendix 1). Regardless of the S-R relationship or optimization method, the small-sample-size-corrected version of Akaike information criterion (AICc) is lower in the model that considers autocorrelation in residuals compared with the models that do not consider autocorrelation in residuals (Appendix Table 1-1). Candidates for examination of the S-R relationship are shown in Table 1.

This stock exhibited biomass changes in a several-decade cycle, and the changes have been recognized as response to regime shifts in the marine ecosystem (Ohshimo et al. 2009). Biomass of this stock was small from the 1960s to the early 1970s, showed a sharp increasing tendency since the mid-1970s, reached a peak in the latter half of the 1980s, and dropped steeply in the 1990s. These biomass changes are considered to be influenced by the changes in the marine environment, which are attributed to the monsoon indicators during winter (Ohshimo et al. 2009). Changes in biomass and marine environment influence individual growth and maturity as well as recruitment success, which can in turn change the S-R relationship. For this reason, assuming that the period from 1960 to 2017 can be divided into two or three periods based on recruitments, we examined combinations of applicable recruitment modes and switching time. Believing that consideration of changes in recruitment mode is a way of handling autocorrelation, we considered models in which autocorrelation is not considered (Appendix 1). When we selected combinations of period and recruitment mode, which have the lowest small-sample-size-corrected version of AICc, the model that assumes two recruitment modes was chosen for every S-R relationship (Appendix 1). Excluding the BH model with the least absolute value method, the period is divided into the normal recruitment period (1960-1975 and 1988-2017) and high recruitment period (1976-1987). Examination candidates of the S-R relationship with a divided recruitment mode and period are shown in Table 1.

1-3) Stock-recruitment relationship

The small-sample-size-corrected version of AICc was lower when the S-R relationship is divided into a normal recruitment period and a high recruitment period compared with the scenario where the relationship was applied to the data of the whole period. AICc was lowest when the BH model was adopted with optimization by the least absolute value method. The difference between AICc of the HS model and AICc of the BH model was 2.07. Following 2.b (Recommendation of HS model) and 3.a (Predictive capacity) of the "Guidelines for Estimation of Stock-recruitment Relationship (FRA-SA2020-ABCWG01-03)," we apply the HS S-R relationship where the S-R relationship is divided into a normal recruitment period and a high recruitment period as a candidate for the S-R relationship of this stock. As the optimization method, we adopted the least squares method that showed high reliability of parameters as a result of model diagnosis based on the "Model Diagnostic Method for Estimation of Stock-recruitment Relationship (FRA-SA2020-BRP01-5)" (Appendix 1). We determined that the normal recruitment periods (1960-1975 and 1988-2017) including 2017 reflected the current state and used the parameters that were estimated accordingly. For reference, we also show the results of the HS model with the least squares method and simultaneous estimation of autocorrelation, which uses the data of the whole period (1960-2017) (Appendix 2).

Estimates of the parameters of the S-R relationship are shown in Appendix 1 (Appendix Table 1-2) and the relationship between the spawning biomass and the observed value of recruitment is shown in Figure 1. We assumed a lognormal distribution for error distribution of recruitment and used the standard deviation of log residuals (S.D.; Table 1) between the predictive value and observed value of the S-R relationship. (Technical Note on estimation of the S-R relationship, reference point calculation and future prediction simulation: FRA2020-ABCWG01-02).

When the true S-R relationship is not clearly divided into a normal recruitment period and a high recruitment period, estimation based on the S-R relationship of the normal recruitment period results in an excessive catch, which poses a risk of biomass depletion. This is because the spawning biomass that produces MSY (SBmsy) is lower for the normal recruitment period. For this reason, we used a simplified Management Strategy Evaluation (MSE) to assess the impacts of application of the S-R relationship of the normal recruitment period when the true S-R relationship is a relationship that covers the whole period (Appendix 3). For details of MSE in this material, see "Comparison of robustness of multiple reference points and examination of HCRs using simplified MSE (FRA-SA2020-BRP01-7)." As a result of the simplified MSE, when safety coefficient β is set to 0.8, the probability that the average spawning biomass projected after 10 years will exceed the true limit reference point is 72%, which indicates that use of the S-R relationship of the normal recruitment period has a considerable risk that the biomass would not recover. On the other hand, if the S-R relationship for the whole period is applied when the true S-R relationship is that of the normal recruitment period, the average catch of 2021 is projected to decrease compared with the case correctly applying the S-R relationship, to 53%, which suggests a risk of losing fishing opportunity in a short term.

When stock status changes considerably, biological parameters and age composition can also change considerably. It is necessary to carefully examine the handling of data in estimation of the S-R relationship. During the period from 1988 to 1990, the spawning biomass of this stock hit a peak and its recruitment started to decline. This can be a transitional period from a high recruitment period to a normal recruitment period. Therefore, removing this transitional period from the normal recruitment period and adding it to the high recruitment period, namely, assuming that there was a switch from a high recruitment period to a normal recruitment period in 1991, we made an examination using the HS S-R relationship with the least squares method (Appendix 4). When switching to a normal recruitment period in 1991 is assumed, AICc is higher by 4.27 compared with AICc when switching in 1988 is assumed. Because the control points proposed based on the normal recruitment periods (1960-1975 and 1991-2017) excluding the transitional period are lower than the value of the proposed normal recruitment periods (1960-1975 and 1988-2017), there is a risk of delay in biomass recovery due to overestimation of catch. Review of risk by MSE shows that, if we use the S-R relationship of the normal recruitment periods excluding the transitional period when the S-R relationship of the normal recruitment period is true and when β is set to 0.8, the probability that the projected average spawning biomass will exceed the true limit reference point after 10 years is 91%, which is 8% lower than the probability when the S-R relationship of the normal recruitment period is applied. There is a risk that the biomass would not recover. Based on the AICc and MSE results, we judged that we can propose more robust control points when the transitional period is not excluded from the S-R relationship.

2. Reference points

2-1) Data sets and calculation method

We made calculation of spawning biomass that produces MSY and future prediction according to the rules for one-stock biomass of the "2020 Basic Guidelines for the Harvest Control Rules and the Estimation of the Allowable Biological Catch (ABC) (FRA-SA2020-ABCWG01-01)" and using the S-R relationship presented in 1-3) above and the settings (natural mortality; maturity rate; average body weight at age, and; selectivity of fishing) used for the future projection calculation in the Marine fisheries stock assessment and evaluation for Japanese waters (fiscal year 2019/2020) (Fisheries Agency of Japan and FRA). Here, current fishing mortality (Fcurrent; Figure 2) is the average of fishing mortality (F) during the period from 2014 to 2018 (Table 2). For this stock, assuming equilibrium after the simulation years (76 years) that are 20 times as long as the average generation time (approx. 3.8 years), we set an F value that maximizes the average catch to Fmsy and the average spawning biomass at the equilibrium when fishing is conducted at Fmsy to SBmsy.

2-2) Proposed reference points and fishing ban level

We propose: SBmsy (990 thousand tons), which is the spawning biomass that produces the MSY under the normal recruitment period for the target reference point (SBtarget); SB0.6msy (454 thousand tons), which is the spawning biomass that produces 60% of MSY for the limit reference point (SBlimit); and SB0.1msy (63 thousand tons), which produces 10% of MSY for the fishing ban level (SBban). The ratios of the proposed reference points and fishing ban level to the initial spawning biomass assuming no catch (SB0), the average catch at equilibrium under the corresponding fishing mortality and the ratio of the corresponding fishing mortality to the current fishing mortality are shown in Table 3. SBmsy, which is proposed as the target reference point is equivalent to 39% of SB0 and the average catch expected with this spawning biomass (MSY) is 316 thousand tons. The ratio of the fishing mortality corresponding to the proposed target reference point (fishing mortality that produces MSY: Fmsy) to the current (2014-2018) fishing mortality (Fmsy/Fcurrent) is 1.01 and the exploitation rate (Umsy) in this case is 20%. SB0.6msy, which is proposed as the limit reference point corresponds to 18% of

SB0 and the average catch expected at this spawning biomass is 190 thousand tons. The ratio of the fishing mortality corresponding to SB0.6msy to the current fishing mortality is 1.34 and the exploitation rate is 24% in this case. SB0.1msy proposed as the fishing ban level corresponds to 2% of SB0 and the average catch expected with this spawning biomass is 32 thousand tons. Ratio of the fishing mortality corresponding to SB0.1msy to the current fishing mortality is 1.59 and the exploitation rate is 28% in this case.

Average spawning biomass at equilibrium when F is changed variously and the corresponding average catch at age are shown in Figure 3. There is a tendency that the higher the stock status of the spawning biomass, the higher the ratio of older fish in the average catch is.

2-3) Proposed target reference point and exploitation rate

The proposed target reference point (SBmsy) and Kobe plot that is based on the fishing mortality (Fmsy) or exploitation rate (Umsy) corresponding to the proposal are shown in Figure 4. Fishing mortality of this stock was greatly over the MSY level in almost all years in the early 1960s and during the period from the 1990s to the 2000s. After 2010, excluding 2013, fishing mortality has been at the level of MSY. A similar tendency is found also in the exploitation rate. Current spawning biomass (251 thousand tons in 2018) is below the proposed limit reference point. The ratios of the proposed target reference point, the proposed limit reference point and the proposed fishing ban level to the current spawning biomass is 3.95, 1.81 and 0.25, respectively.

2-4) Proposed harvest control rules

The proposed harvest control rules (HCRs) are rules to change fishing mortality (F), which is the basis of harvest control at the threshold of spawning biomass, for which the proposed limit reference point and the proposed fishing ban level are to be used. In this rule, when spawning biomass falls below the proposed limit reference point, fishing mortality is lowered directly to the proposed fishing ban level. The upper limit of F is obtained by multiplying Fmsy by β that is proposed by the HCRs. Figure 5a shows the relationship between spawning biomass and fishing mortality in the proposed HCRs when standard values are used for the proposed limit reference point and proposed fishing ban level (proposed SBlimit set to SB0.6msy; proposed SBban set to SB0.1msy), while Figure 5b shows the relationship between spawning biomass and the average prospective catch under the same condition. β is set to the standard value 0.8 in the proposed HCRs illustrated in the figures.

2-5) Future projection based on the proposed harvest control rule

(1) When safety coefficient β is set to the standard value

Percentage changes of biomass, spawning biomass, catch, recruitment and fishing effort when future projection is made based on the proposed HCRs that use standard values for the proposed limit reference point and proposed fishing ban level, and set β to 0.8 (Figure 5a) are shown in Figure 6. This future projection assumes that fishing based on the proposed HCRs starts in 2021 and catch of 2019 and 2020 are assumed based on the predicted biomass and Fcurrent.

Because predicted spawning biomass in 2021 is below the proposed limit reference point, based on the proposed HCRs and with β set to 0.8, the fishing mortality at 0.8Fmsy corresponds to the fishing mortality that decreases the current fishing effort by 54%. For this reason, it is predicted that the catch of the first year after introducing the proposed HCRs would decrease. In medium- to long-term, it is projected that continued fishing at 0.8 Fmsy will keep catch and spawning biomass at the MSY level.

(2) When safety coefficient β is changed

In the future projection based on the proposed HCRs that use standard values for the proposed limit reference point and proposed fishing ban level, the probability that spawning biomass will exceed the proposed target reference point, probability of its exceeding the proposed limit reference point, probability of its exceeding the proposed fishing ban level, and changes in the average spawning biomass and average catch when β is changed between 0.0 and 1.0 are shown in Tables 4 to 8. The lower β is, the higher the probability for spawning biomass to exceed the proposed target reference point is (Table 4). It is projected that, if β is set to 0.8 or lower, the stock would be able to maintain the spawning biomass above the proposed target reference point with a probability of over 50% in 2031, 10 years after starting fishing based on the proposed HCRs. When β is set to 1, the probability that spawning biomass will exceed the proposed target reference point in 2031 is below 50%, but the probability of its exceeding the proposed limit control point is 94% (Table 5). With either value of β, the probability that spawning biomass will fall below the proposed fishing ban level is considered to be low (Table 6). In 2022 and after, the lower β is, the larger the spawning biomass will be (Table 7). With either value of β, the catch in 2021 that is the first year after introduction of the proposed HCRs can be controlled below the current level (71 tons in 2018) (Table 8).

3. Summary

As a model of the S-R relationship of this stock, we apply the HS S-R relationship that is recommended by the "Guidelines for Estimation of Stock-recruitment Relationship (FRA-SA2020-ABCWG01-03)." The biomass of this stock is believed to change under the influence of the marine environment, and AICc is lower when the period is divided into normal and high recruitment periods. For this reason, we applied the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) including 2017. We apply the model where parameters are optimized by the least squares method, and autocorrelation is not considered.

Results of MSE indicated a risk that future biomass would not recover if fishing is conducted based on the proposed reference points and the assumption regarding recruitment mode is wrong. On the other hand, if fishing is conducted based on the whole-period (1960-2017) scenario and the assumption regarding recruitment mode is wrong, there would be a great loss of fishing opportunity in a short term.

As a target control point, we propose SBmsy (990 thousand tons), which is estimated based on the S-R relationship of the normal recruitment periods. We propose SB0.6msy (SBlimit: 454 thousand tons) for the limit control point and SB0.1msy (SBban: 63 thousand tons), which is the standard value for fishing ban level.

Current spawning biomass of this stock is considered to be under the proposed limit control point, but with β set to 0.8 or lower, it is projected that the medium- to long-term spawning biomass will be maintained above the proposed target control point with a probability over 50%.

4. Future considerations

We divided the S-R relationship of this stock and applied the normal recruitment periods that include 2017 based on AICc. In the future, it is possible that recruitment will increase with the increase of biomass and the S-R relationship of a high recruitment period will be established. With review of the S-R relationship, it is necessary to examine how to review and change the HCRs.

5. References

Ohshimo S., H. Tanka, and Y. Hiyama (2009) Long-term stock assessment and growth changes of the Japanese sardine (*Sardinops melanostictus*) in the Sea of Japan and East China Sea from 1953 to 2006. Fish. Oceanogr.18: 346–358.

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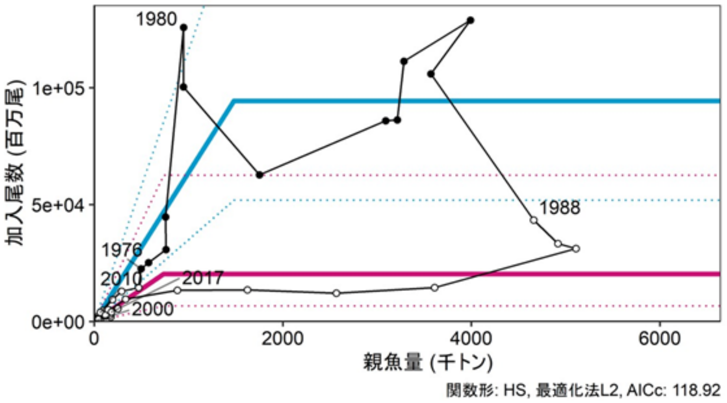
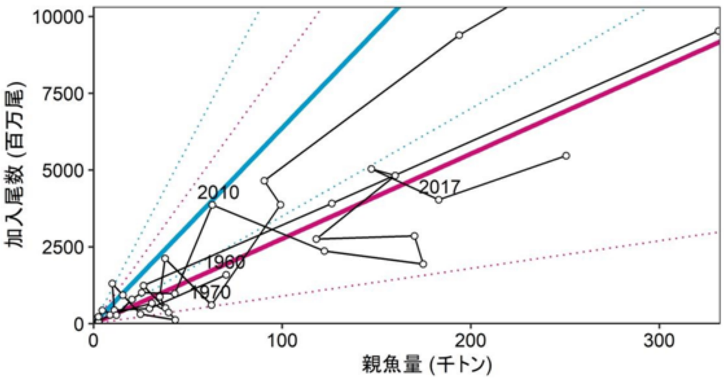
a)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)
関数形：HS，最適化法 L2，AICc: 118.92	Model: HS; optimization method: L2; AICc: 118.92

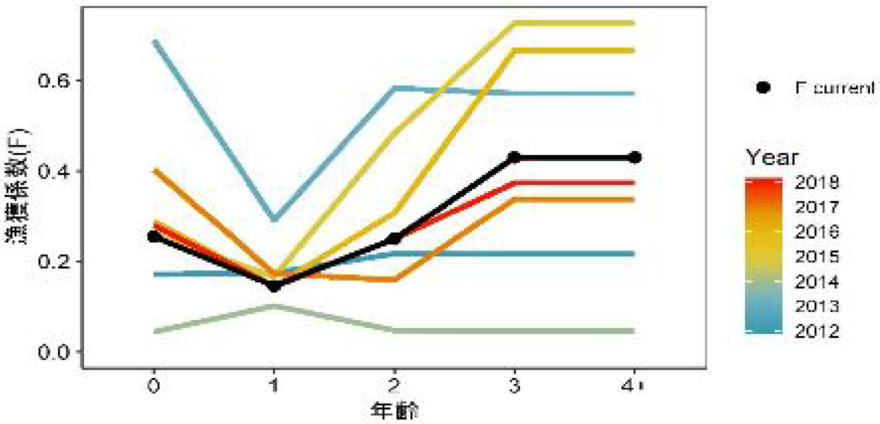
b)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

Figure 1. S-R relationship

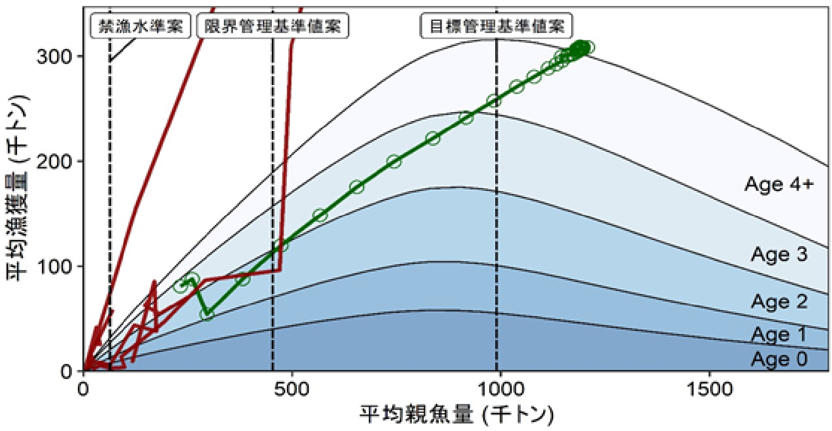
(a) Spawning biomass and recruitment of the normal recruitment periods (1960-1975 and 1988-2017; white circles and red solid line) and the high recruitment period (1976-1987; black circles and blue solid line) when the recruitment period is divided, and (b) its enlarged view. Numbers in the figure indicate the class of recruited group (birth year). For the S-R relationship, we used the HS S-R relationship where autocorrelation is not considered and estimated parameters using the least squares method. Dotted-lines over and below the S-R relationship (solid line) show the range supposed to include 90% of the observed data of the respective S-R relationship.



漁獲係数	Fishing mortality
年齢	Age

Figure 2. Fishing mortality (F) at age

F at age of each year from 2012 is shown in different colors. The black line represents Fcurrent that is the average F of the period from 2014 to 2018.



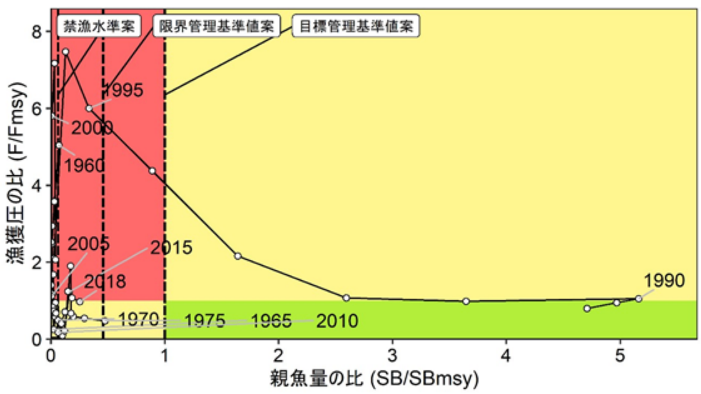
平均漁獲量（千トン）	Average catch (thousand tons)
平均親魚量（千トン）	Average spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level
限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

Figure 3. Relationship between the proposed reference points / fishing ban level and curves of catch at age

The figure shows the relationship of average catch at age corresponding to the average spawning biomass, with the proposed reference points and fishing ban level at equilibrium in the future projection simulation when the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) is applied. The red line represents changes in the spawning biomass and catch, which are estimated by the stock assessment, while the green line represents the average spawning biomass and average catch in the future projection assuming fishing conducted based on the proposed HCRs. Part of the past spawning biomass and catch are outside the scope (maximum values: spawning biomass: 5.111 million tons; catch: 1.605 million tons).

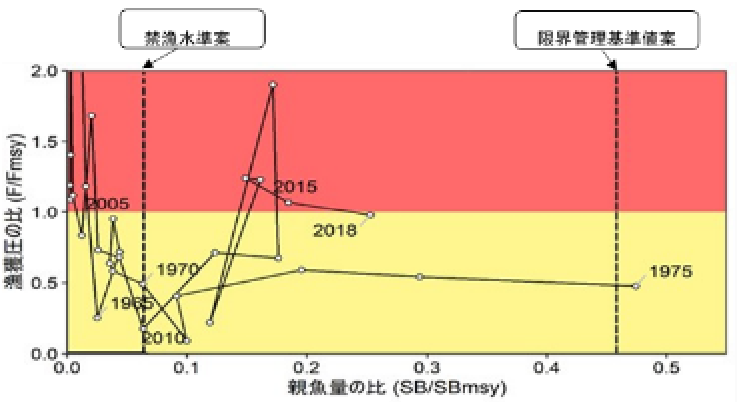
Safety coefficient β used in the proposed HCRs is 0.8. The initial spawning biomass assuming no catch (SB0) is 2.553 million tons.

a-1) When the vertical axis is the ratio of the fishing mortality (F/Fmsy)



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

a-2) Enlarged view



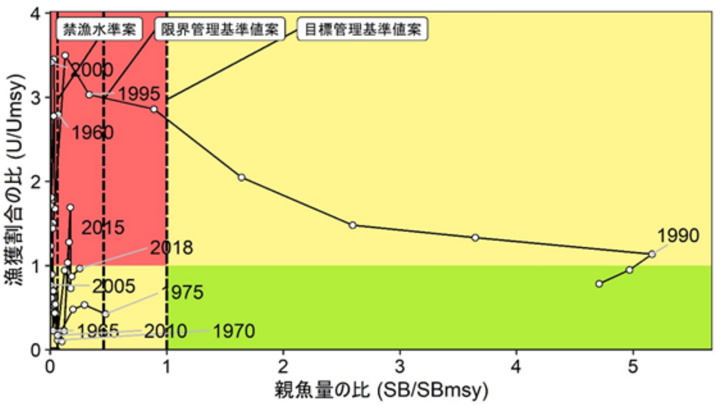
漁獲圧の比	F/Fmsy

親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Figure 4. Kobe plot (four sections)

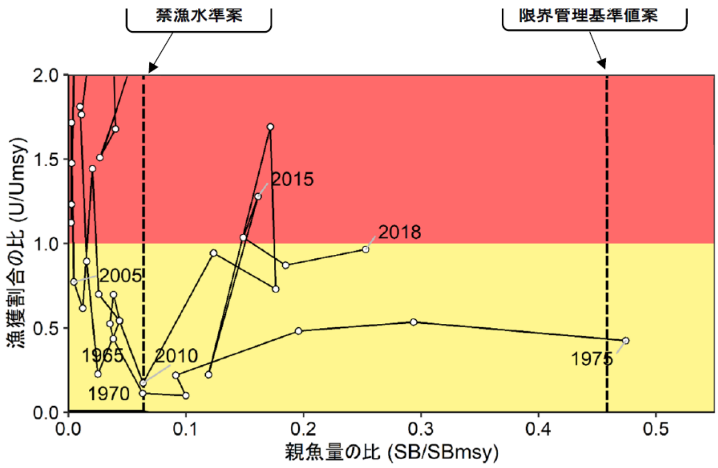
When the ratio of fishing mortality is put on the vertical axis (a-1) and its enlarged view (a-2). As the proposed target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) in the figures, we used SBmsy, SB0.6msy and SB0.1msy, respectively, which assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017).

b-1) When the vertical axis is the ratio of the exploitation rate (U/Umsy)



漁獲割合の比	U/Umsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

b-2) Enlarged view

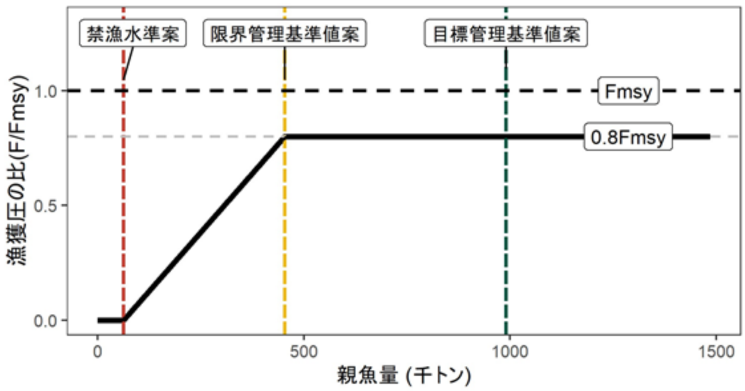


漁獲割合の比	U/Umsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Figure 4 (continued). Kobe plot (four sections)

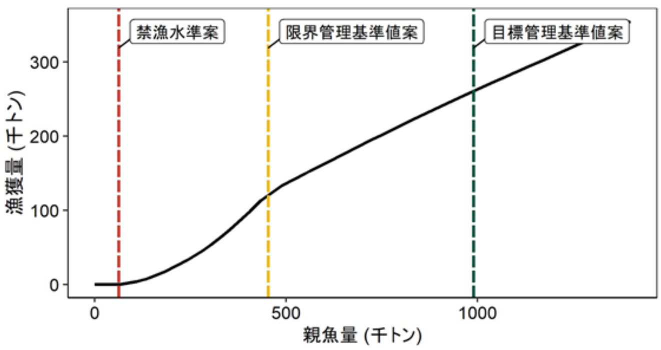
When the ratio of fishing mortality is used (b-1) and its enlarged view (b-2). As the proposed target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) in the figures, we used SBmsy, SB0.6msy and SB0.1msy, respectively, which assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017).

a) When the vertical axis is fishing mortality



漁獲圧の比	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

b) When the vertical axis is catch

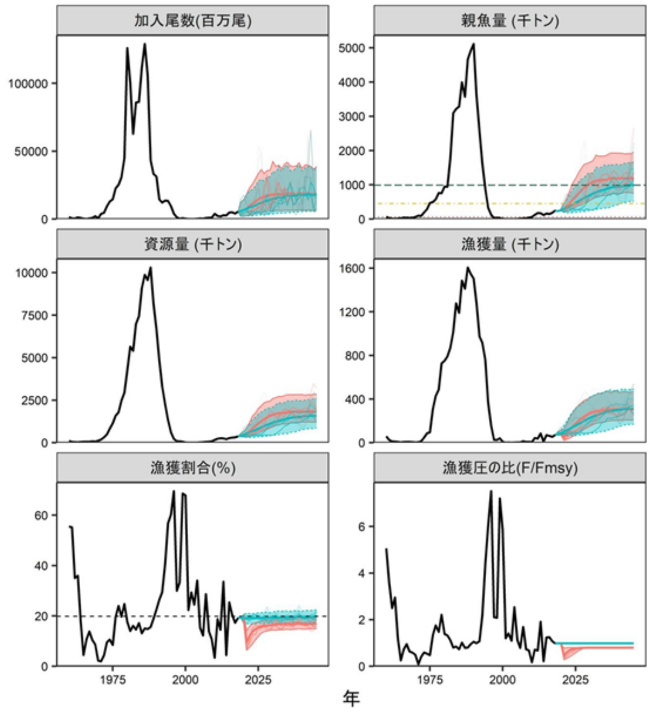


漁獲量（千トン）	Catch (thousand tons)

親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

Figure 5. Proposed HCRs

The proposed target reference point (SBtarget) is SBmsy calculated based on the HS S-R relationship that assumes the conditions of the normal recruitment periods (1960-1975 and 1988-2017). Standard values are used for the proposed limit reference point (SBlimit) and the proposed fishing ban level (SBban). Safety coefficient β is set to 0.8, which is the standard value. The black dashed line represents Fmsy; the grey dashed line represents 0.8Fmsy; the black thick line represents the proposed HCRs; the red dashed line represents the proposed fishing ban level; the yellow dashed line represents the proposed limit reference point; and the green dashed line represents the proposed target reference point. In a) the ratio of fishing mortality is put on the vertical axis, while in b) the catch is put on the vertical axis. Regarding b), the catch varies a little depending on the age composition of the fishing year but here we show the catch of average age composition at equilibrium.



加入尾数（百万尾）	Recruitment (million individuals)
資源量（千トン）	Stock biomass (thousand tons)
漁獲割合	Exploitation rate (%)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)

漁獲圧の比	Ratio of the fishing mortality to MSY
年	Year

Figure 6. Comparison of the future projection based on the proposed HCRs (in red) with the future projection that assumes continued fishing at the current fishing mortality level (in green) when the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) is applied.

The thick solid line, shaded area and thin lines represent average value, 90% prediction interval that includes 90% of the simulation results and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed limit reference point and the red line shows the proposed fishing ban level. The dashed line in the chart of catch expresses MSY. The dashed line in the chart of exploitation rate expresses Umsy. The catch in 2019 and 2020 are assumed based on the projected stock biomass and Fcurrent, while the catch in 2021 and after is based on the proposed HCRs (Figure 5). Safety coefficient β is set to 0.8.

Table 1. Candidates for S-R relationship: the S-R relationship to be applied is indicated in bold face

When applied to the whole period

再生産関係式	最適化法	自己相関	推定法	期間	AICc	ΔAICc	順位	S.D.
ホッケー・スティック型	最小二乗法	有	同時	1960~2017	124	0	1	0.651
リッカー型	最小二乗法	有	同時	1960~2017	124	0.380	2	0.653
ベバートン・ホルト型	最小二乗法	有	同時	1960~2017	124	0.599	3	0.654
ホッケー・スティック型	最小絶対値法	有	二段階	1960~2017	144	19.9	4	0.660
リッカー型	最小絶対値法	有	二段階	1960~2017	146	22.7	5	0.649
ベバートン・ホルト型	最小絶対値法	有	二段階	1960~2017	147	23.0	6	0.665

再生産関係式	S-R relationship
最適化法	Optimization method
自己相関	Autocorrelation
推定法	Estimation method
期間	Period
順位	Rank
ホッケー・スティック型	Hockey stick
リッカー型	Ricker

ベバートン・ホルト型	Beverton-Holt
最小二乗法	Least squares method
最小絶対値法	Least absolute value method
有	Yes
同時	Simultaneous
二段階	Two-stage

When divided into two periods

再生産関係式	最適化法	自己相関	加入期	期間	AICc	ΔAICc	順位	S.D.
ホッケー・スティック型	**最小二乗法**	**無**	**通常**	**1960~1975 1988~2017**	**119**	**2.07**	**3**	**0.683**
			高	**1976~1987**				**0.364**
リッカー型	最小二乗法	無	通常	1960~1975 1988~2017	121	3.70	6	0.690
			高	1976~1987				0.374
ベバートン・ホルト型	最小二乗法	無	通常	1960~1975 1988~2017	119	1.97	2	0.676
			高	1976~1987				0.378
ホッケー・スティック型	最小絶対値法	無	通常	1960~1975 1988~2017	119	2.09	4	0.697
			高	1976~1987				0.423
リッカー型	最小絶対値法	無	通常	1960~1975 1988~2017	119	2.18	5	0.699
			高	1976~1987				0.437
ベバートン・ホルト型	最小絶対値法	無	通常	1960~1974 1988~2017	117	0	1	0.692
			高	1975~1987				0.444

再生産関係式	S-R relationship
最適化法	Optimization method
自己相関	Autocorrelation
加入期	Recruitment period
期間	Period
順位	Rank
ホッケー・スティック型	Hockey stick
リッカー型	Ricker
ベバートン・ホルト型	Beverton-Holt
最小二乗法	Least squares method
最小絶対値法	Least absolute value method
無	No
通常	Normal
高	High

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

Table 2. Settings used for calculation of the spawning biomass that produces MSY and future projection

年齢	自然死亡係数	成熟率	平均重量 (g)	選択率	現状の漁獲圧 (Fcurrent)
0	0.40	0.0	16	0.592	0.254
1	0.40	0.25	43	0.340	0.146
2	0.40	1.0	71	0.580	0.249
3	0.40	1.0	90	1.000	0.430
4 歳以上	0.40	1.0	114	1.000	0.430

年齢	Age
自然死亡係数	Natural mortality
成熟率	Maturity rate
平均重量	Average weight
選択率	Selectivity
現状の漁獲圧	Fcurrent
4 歳以上	Age 4 and above

Table 3. Catch, fishing mortality, etc. corresponding to the proposed reference points and fishing ban level

管理基準値案または禁漁水準案	説明	親魚量 (千トン)	SB0 に対する比※	漁獲量※※ (千トン)	漁獲圧※※※ (%SPR)	漁獲割合※※※※	現状の漁獲圧に対する比※※※※※
目標管理基準値案（通常加入期）	SBmsy	990	0.39	316	40.1	0.20	1.01
限界管理基準値案（通常加入期）	SB0.6msy	454	0.18	190	32.3	0.24	1.34
禁漁水準案（通常加入期）	SB0.1msy	63	0.02	32	27.6	0.28	1.59
MSY を実現する漁獲圧	Fmsy	（0 歳, 1 歳, 2 歳, 3 歳, 4+歳）＝（0.257, 0.148, 0.252, 0.435, 0.435）					

管理基準値案または禁漁水準案	Proposed reference points or fishing ban level
説明	Explanation
親魚量（千トン）	Spawning biomass (thousand tons)
SB0 に対する比	Ratio to SB0
漁獲量（千トン）	Catch (thousand tons)
漁獲圧	Fishing mortality
漁獲割合	Exploitation rate
現状の漁獲圧に対する比	Ratio to the current fishing mortality
目標管理基準値案（通常加入期）	Proposed target reference point (Normal recruitment period)
限界管理基準値案（通常加入期）	Proposed limit reference point (Normal recruitment period)
禁漁水準案（通常加入期）	Proposed fishing ban level (Normal recruitment period)

MSY を実現する漁獲圧	Fishing mortality that produces MSY
（0 歳, 1 歳, 2 歳, 3 歳, 4+歳） = （0.257, 0.148, 0.252, 0.435, 0.435）	(Ages 0, 1, 2, 3, 4+) = (0.257, 0.148, 0.252, 0.435, 0.435)

* Ratios of the proposed reference points and fishing ban level to the initial spawning biomass assuming zero catch (SB0)

** Average catch at equilibrium under the fishing mortality corresponding to the proposed reference points and fishing ban level

*** %SPR-converted value of fishing mortality corresponding to the proposed reference points and fishing ban level

**** Exploitation rate corresponding to the proposed reference points and fishing ban level

***** Ratios of the fishing mortality corresponding to the proposed reference points and fishing ban level to the current fishing mortality

Table 4. Probability for future spawning biomass to exceed the proposed target reference point (%)

Result of the future projection based on the proposed HCRs (Figure 5) that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and a catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	1	3	4	6	10	13	18	20	24	28	42	43
0.9	0	0	0	1	3	5	8	12	18	25	30	37	41	56	57
0.8	0	0	0	1	3	6	10	17	27	35	43	51	58	70	71
0.7	0	0	0	1	3	7	13	22	35	45	58	66	72	83	81
0.6	0	0	0	1	4	9	17	31	46	60	71	79	84	91	91
0.5	0	0	0	1	4	11	22	40	58	74	82	89	92	96	96
0.4	0	0	0	1	5	14	28	52	69	83	90	94	96	98	98
0.3	0	0	0	1	6	16	36	61	79	90	95	98	98	100	99
0.2	0	0	0	1	6	19	44	70	86	94	98	99	99	100	100
0.1	0	0	0	2	7	24	53	78	92	97	99	100	100	100	100
0.0	0	0	0	2	8	30	61	84	95	99	99	100	100	100	100

Table 5. Probability for the future spawning biomass to exceed the proposed limit reference point (%)

Result of the future projection based on the proposed HCRs (Figure 5) that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	5	16	34	51	66	75	83	87	90	93	94	99	99
0.9	0	0	5	17	39	58	73	82	88	92	94	96	98	100	100
0.8	0	0	5	18	44	64	78	87	92	95	97	98	99	100	100
0.7	0	0	5	19	48	69	83	91	95	98	99	99	99	100	100
0.6	0	0	5	21	52	75	87	94	98	99	99	99	100	100	100
0.5	0	0	5	23	56	78	91	97	98	99	100	100	100	100	100
0.4	0	0	5	24	60	82	93	98	99	99	100	100	100	100	100
0.3	0	0	5	26	64	86	96	99	99	100	100	100	100	100	100
0.2	0	0	5	27	68	89	97	99	100	100	100	100	100	100	100
0.1	0	0	5	29	71	91	98	99	100	100	100	100	100	100	100
0.0	0	0	5	31	75	93	98	99	100	100	100	100	100	100	100

Table 6. Probability that future spawning biomass will exceed the proposed fishing ban level (%)

Result of the future projection based on the proposed HCRs (Figure 5) that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 7. Changes in average spawning biomass in the future (thousand tons)

Result of the future projection based on the proposed HCRs (Figure 5) that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	261	296	370	444	514	572	630	691	743	791	833	867	1,001	1,010
0.9	232	261	296	376	458	540	611	684	759	825	883	931	970	1,097	1,103
0.8	232	261	296	382	473	568	655	744	837	917	984	1,038	1,079	1,193	1,198
0.7	232	261	296	388	489	598	703	812	922	1,016	1,093	1,150	1,191	1,295	1,300
0.6	232	261	296	394	506	631	756	887	1,017	1,125	1,209	1,269	1,311	1,408	1,413
0.5	232	261	296	400	524	667	814	969	1,120	1,242	1,335	1,398	1,440	1,536	1,540
0.4	232	261	296	406	543	705	878	1,059	1,233	1,371	1,472	1,539	1,582	1,682	1,686
0.3	232	261	296	413	562	746	948	1,157	1,355	1,509	1,621	1,694	1,740	1,851	1,855
0.2	232	261	296	419	583	791	1,024	1,265	1,489	1,662	1,786	1,868	1,920	2,051	2,055
0.1	232	261	296	426	605	839	1,106	1,383	1,636	1,831	1,971	2,066	2,128	2,289	2,294
0	232	261	296	432	628	891	1,197	1,512	1,798	2,020	2,183	2,295	2,371	2,578	2,586

Table 8. Changes in average catch in the future (thousand tons)

Result of the future projection based on the proposed HCRs (Figure 5) that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	81	88	66	102	133	160	184	205	224	241	256	269	279	318	322
0.9	81	88	60	95	127	155	181	203	224	243	259	272	282	315	317
0.8	81	88	54	88	120	148	175	199	221	242	257	271	280	307	308
0.7	81	88	48	80	111	140	167	192	215	235	251	264	272	293	295
0.6	81	88	41	71	101	129	156	181	205	224	240	251	258	276	277
0.5	81	88	35	62	89	116	142	166	189	208	222	232	239	253	254
0.4	81	88	28	51	76	99	124	146	167	185	197	206	212	224	225
0.3	81	88	21	40	60	80	101	121	139	154	165	172	177	187	188
0.2	81	88	14	28	42	57	73	89	103	114	122	128	132	140	140
0.1	81	88	7	14	22	31	40	49	57	64	68	72	74	79	80
0	81	88	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 9. Summary of the projected spawning biomass, catch and the probability for spawning biomass to exceed the proposed reference points

Result when the proposed HCRs based on the proposed reference points that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) are used and when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1.

β	10 年後（2031 年）の平均親魚量（千トン）	10 年後（2031 年）に親魚量が目標管理基準値案を上回る確率	0 年後（2021 年）の予測漁獲量（千トン）	5 年後（2026 年）の予測漁獲量（千トン）	10 年後（2031 年）の予測漁獲量（千トン）	10 年後（2031 年）に親魚量が限界管理基準値案を上回る確率
1	867	28%	66	205	279	94%
0.9	970	41%	60	203	282	98%
0.8	1,079	58%	54	199	280	99%
0.7	1,191	72%	48	192	272	99%
0.6	1,311	84%	41	181	258	100%
0.5	1,440	92%	35	166	239	100%
0.4	1,582	96%	28	146	212	100%
0.3	1,740	98%	21	121	177	100%
0.2	1,920	99%	14	89	132	100%
0.1	2,128	100%	7	49	74	100%
0	2,371	100%	0	0	0	100%

10 年後（2031 年）の平均親魚量（千トン）	Average spawning biomass (thousand tons) after 10 years (2031)
10 年後（2031 年）に親魚量が目標管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed target reference point after 10 years (2031)
0 年後（2021 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 0 years (2021)
5 年後（2026 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 5 years (2026)
10 年後（2031 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 10 years (2031)

10 年後（2031 年）に親魚量が限界管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed limit reference point after 10 years (2031)

Appendix 1. Division of S-R relationship and results of model diagnosis

As the S-R relationship to be used for calculation of the spawning biomass that produces MSY and future projection, we considered HS (Clark et al 1985), BH (1957) and RI (1954) S-R recruitment relationships following the "Technical Note on Estimation of stock-recruitment relationship, reference point calculation and future prediction simulation (2020 Research Institute Meeting Version) (FRA2020-ABCWG01-02)." Mathematical equations of the respective S-R relationship are as follows:

$$R_y = \begin{cases} \begin{cases} ab & \text{if } B_y \geq b \\ aB_y & \text{if } B_y < b \end{cases} & \text{(Hockey stick, HS)} \\ \dfrac{aB_y}{(1 + bB_y)} & \text{(Beverton Holt, BH)} \\ aB_y \exp(-bB_y) & \text{(Ricker, RI)} \end{cases}$$

Here, R_y represents recruitment in year y and B_y represents the spawning biomass of year y. In all S-R relationships, two parameters - a and b - are estimated. In the case of the HS model, parameter a represents the steepness (individual/g) of the S-R curve from the origin to the break point, while b represents the spawning biomass (tons) at the break point. When examining the S-R relationship, we also calculated the residual standard deviation (s.d.) of the recruitment from the estimated S-R curve.

When using the whole-period (1960-2017) data, we applied HS, RI and BH S-R relationships using the least squares method and the least absolute value method. Regardless of the S-R relationship and optimization method, the two-stage estimation models that consider autocorrelation in residuals have lower small-sample-size-corrected version of AICc compared with the models that do not consider the same. Because the estimated autocorrelation coefficient is high, based on the "Evaluation of estimation bias of method for simultaneous estimation of autocorrelation coefficient using simulation (FRA-SA2020-BRP01-6)," we used the method to simultaneously estimate parameters of S-R relationship and autocorrelation for the least squares method (Appendix Figure 1-1-1). The HS model with the least squares method that simultaneously estimates autocorrelation has the lowest AICc, but there is no significant difference with the other two S-R relationships under similar conditions (Appendix Table 1-1).

Appendix Table 1-1. Estimated values of the parameters in the S-R relationships based on the data of the whole period

再生産関係式	最適化法	自己相関	推定法	a	b	S.D.	Rho	AICc
ホッケー・スティック型	最小二乗法	有	同時	0.0314	1,198,983	0.651	0.517	124
リッカー型	最小二乗法	有	同時	0.0312	2.29e-07	0.653	0.519	124
ベバートン・ホルト型	最小二乗法	有	同時	0.0316	3.57e-07	0.654	0.531	124

ホッケー・スティック型	最小絶対値法	有	二段階	0.0309	2,775,634	0.660	0.534	144
リッカー型	最小絶対値法	有	二段階	0.0322	2.66e-07	0.648	0.527	146
ベバートン・ホルト型	最小絶対値法	有	二段階	0.0312	5.00e-08	0.665	0.561	147

再生産関係式	S-R relationship
最適化法	Optimization method
自己相関	Autocorrelation
推定法	Estimation method
ホッケー・スティック型	Hockey stick
リッカー型	Ricker
ベバートン・ホルト型	Beverton-Holt
最小二乗法	Least squares method
最小絶対値法	Least absolute value method
有	Yes
同時	Simultaneous
二段階	Two-stage

S.D. is an index expressing magnitude of dispersion of recruitment, which is the standard deviation of log residuals (square root of mean square error).

Next, we examined the divided periods and the models of the S-R relationship. It is thought that the changes in biomass of this stock from the 1970s to the 1990s were influenced also by changes in the natural environment in 1976/1977 and 1988/1989 (Ohshimo et al. 2009). There can be a time lag between changes in biological properties including individual growth and maturity on one hand and changes in the natural environment and population density, on the other. For this reason, we assumed a change of the S-R relationship during 1975-1979 and during 1987-1990. We also considered two scenarios of the S-R relationship for each recruitment period: (1) scenario with two modes of S-R relationship (normal recruitment period → high recruitment period → normal recruitment period) and (2) scenario with three modes (normal recruitment period 1 → high recruitment period → normal recruitment period 2). For combinations of all years and scenarios, we estimated parameters a, b, and s.d. of the S-R relationship. Assuming that consideration of change in recruitment mode is a way to handle autocorrelation, we used models that do not consider autocorrelation.

We selected the combination with the lowest AICc for each S-R relationship and estimation method as a candidate for examination of the S-R relationship with divided recruitment period (Appendix Figure 1-1-2). In all cases, a model with two modes of S-R relationship was selected. For division of the period, the combination of 1976 and 1988 was selected, but the combination of 1975 and 1988 was chosen for the BH model with the least absolute value method (Appendix Table 1-2).

Appendix Table 1-2. Estimates of parameters of S-R relationship based on the data where the period is divided

再生産関係式	最適化法	期間	加入期	a	b	S.D.	Rho	AICc
ホッケー・スティック型	**最小二乗法**	**1960~1975 1988~2017**	**通常**	**0.0276**	**736,128**	**0.683**	**0**	**119**
		1976~1987	**高**	**0.0637**	**1,481,346**	**0.364**	**0**	
リッカー型	最小二乗法	1960~1975 1988~2017	通常	0.0276	3.52e-07	0.690	0	121
		1976~1987	高	0.0717	2.46e-07	0.374	0	
ベバートン・ホルト型	最小二乗法	1960~1975 1988~2017	通常	0.0294	9.56e-07	0.676	0	119
		1976~1987	高	0.0785	4.39e-07	0.378	0	
ホッケー・スティック型	最小絶対値法	1960~1975 1988~2017	通常	0.0287	503,542	0.697	0	119

再生産関係式	S-R relationship
最適化法	Optimization method
期間	Period
加入期	Recruitment period
ホッケー・スティック型	Hockey stick
リッカー型	Ricker
ベバートン・ホルト型	Beverton-Holt
最小二乗法	Least squares method
最小絶対値法	Least absolute value method
通常	Normal
高	High

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

We conducted diagnosis of the HS model based on the "Model Diagnosis Method for Estimation of S-R Relationship (FRA-SA2020-BRP01-5)." The recruitment of the whole period since the latter half of the 1990s tends to be lower than the expected value of the model, but when the period is divided, the trend of residuals is eliminated with the least squares method (Appendix Figure 1-2). We examined the normality of residuals to the S-R relationship models by using the Shapiro-Wilk test and Kolmogorov-Smirnov test and found no significant deviation in either of the cases (Appendix Figure 1-3). When we examined the influence of individual data (year) on parameter estimation by using Jack Knife analysis, we found that parameters of the high-recruitment period tended to be subject to the influence (Appendix Figures 1-4 and 1-5). When we conducted nonparametric bootstrapping of residuals 1,000 times, the least squares method showed smaller bias in parameter estimation (Appendix

Figures 1-6 and 1-7). It is confirmed that profile likelihood when parameters a and b are changed is maximum at the estimated value (Appendix Figure 1-8). From the results above, it is considered that estimation by the least squares method estimates parameters as the optimum solution for every period.

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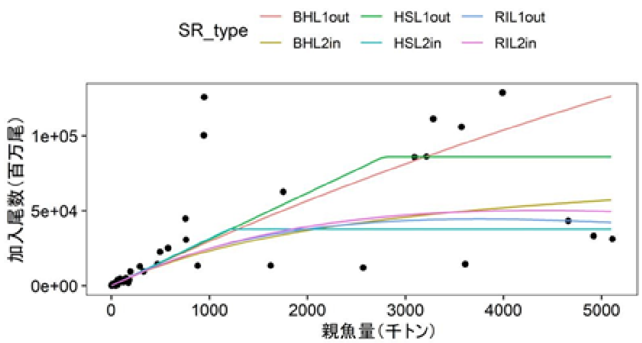
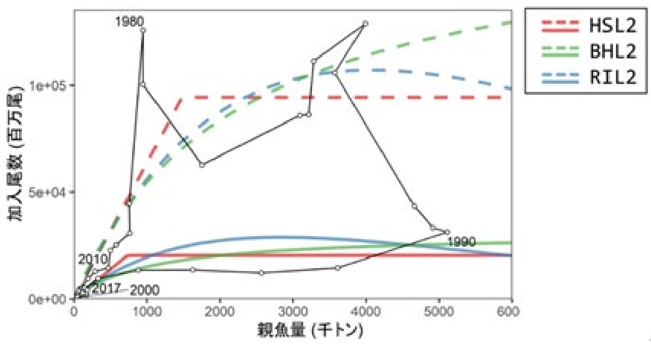
Ricker W. E. (1954) Stock and recruitment. Journal of the Fisheries Research Board of Canada, 11: 559–623.

(1)



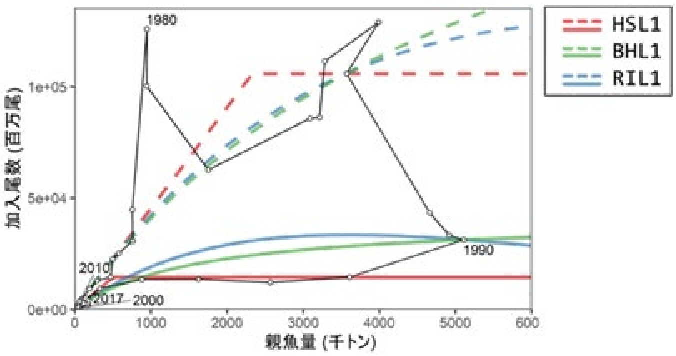
加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

(2)-(a)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

(2)-(b)

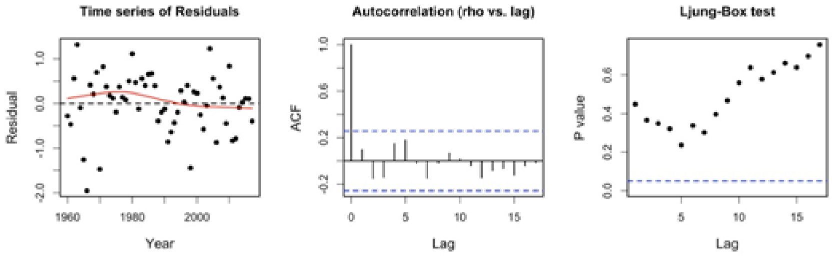


加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

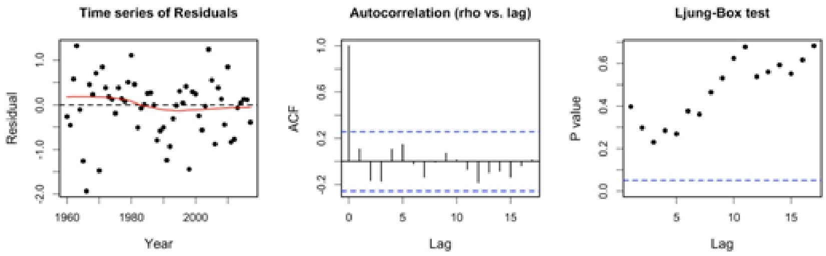
Appendix Figure 1-1. S-R relationship of each model

(1) Based on the data of the whole period; (2) when the period is divided (normal recruitment period: solid line; high recruitment period: dotted line). HS (Clark et al 1985), BH (1957) and RI (1954) S-R relationships are applied using (a) the least squares method (L2) and (b) the least absolute value method (L1). We used a method to simultaneously estimate autocorrelation coefficient and other parameters (in) for (1) without regime and L2, and a method to estimate autocorrelation coefficient in two stages (out) for L1. Numbers in the figures represent the class (birth year) of the recruited group.

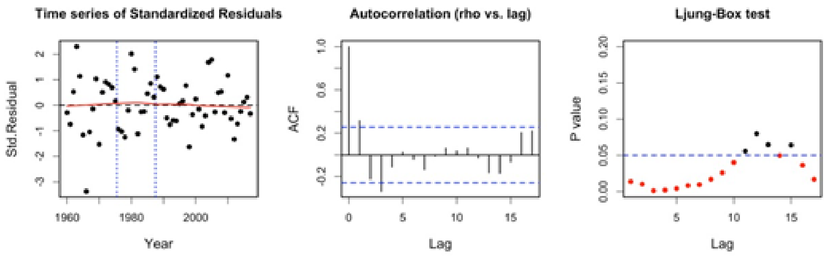
Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method



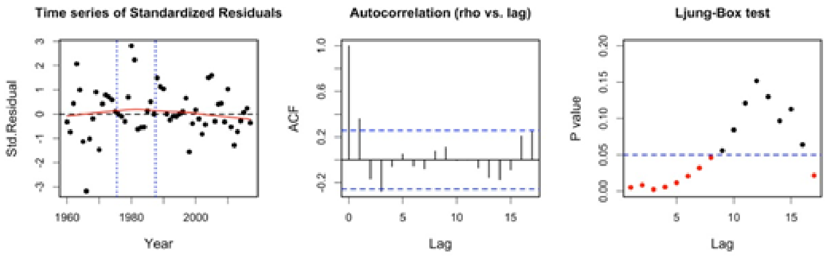
Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method



Scenario to divide the period of S-R relationship: HS model: least squares method



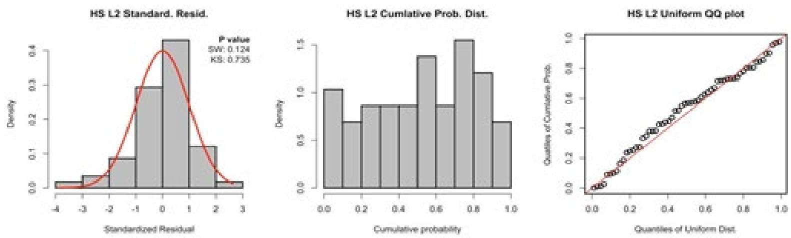
Scenario to divide the period of S-R relationship: HS model: least absolute value method



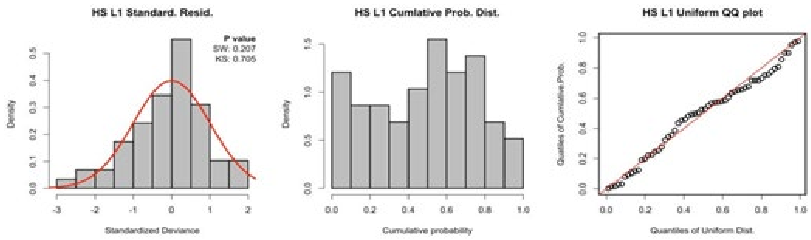
Appendix Figure 1-2. Residual trend in HS model

In the figure of time series of standardized residuals, the red line expresses a smoothed curve and the vertical blue dotted line represents the switching points of the S-R relationship. The blue dotted lines in the correlogram express the 95% confidence interval. The blue dotted line in the figure of P value of Ljung-Box test expresses the 5% level.

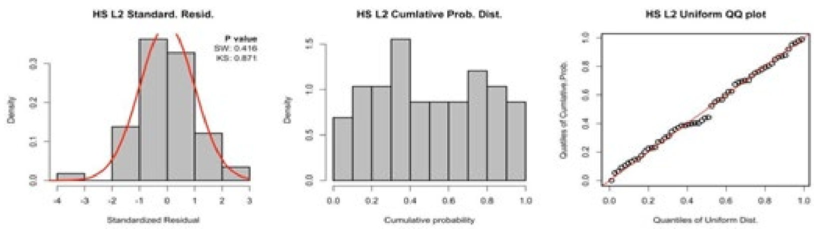
Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method



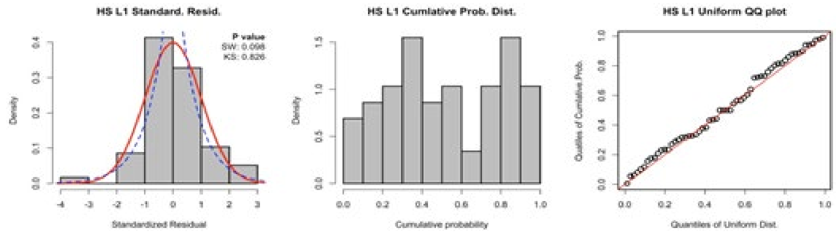
Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method



Scenario to divide the period of S-R relationship: HS model: least squares method



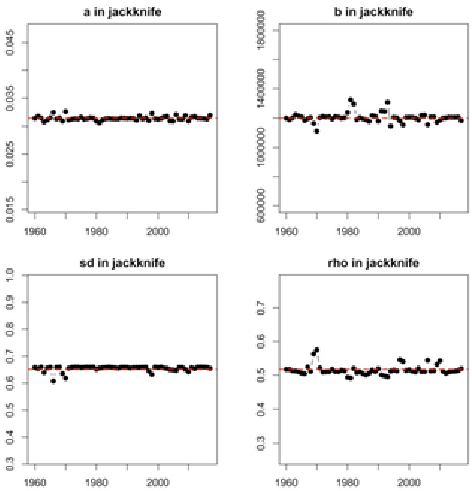
Scenario to divide the period of S-R relationship: HS model: the least absolute value method



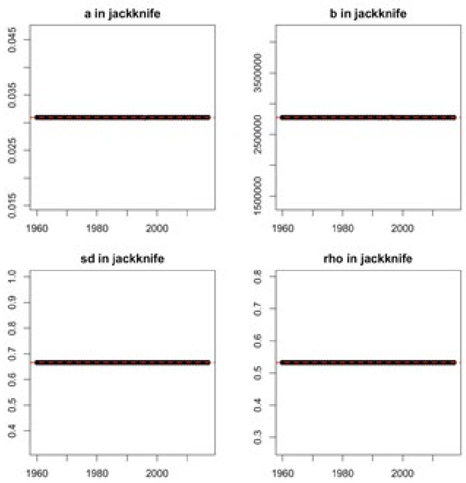
Appendix Figure 1-3. Histogram of standardized residual and normality test result (left), histogram of residual cumulative probability density (center) and QQ plot assuming uniform distribution (right) in the model where the HS model is assumed and the S-R relationship is divided by period

The upper-right numbers in the residual distribution histogram represent results of the Shapiro-Wilk test (SW) and Kolmogorov-Smirnov test (KS). The red line of the QQ plot represents theoretical value.

Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method

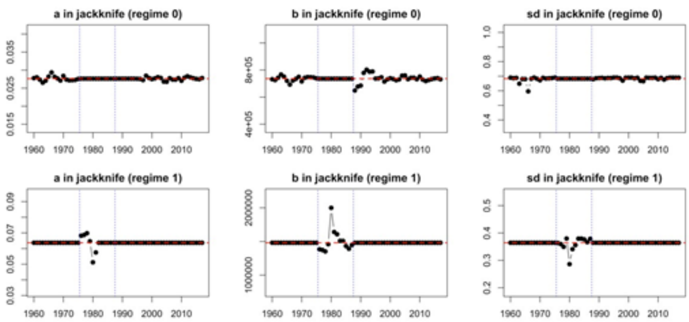


Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method

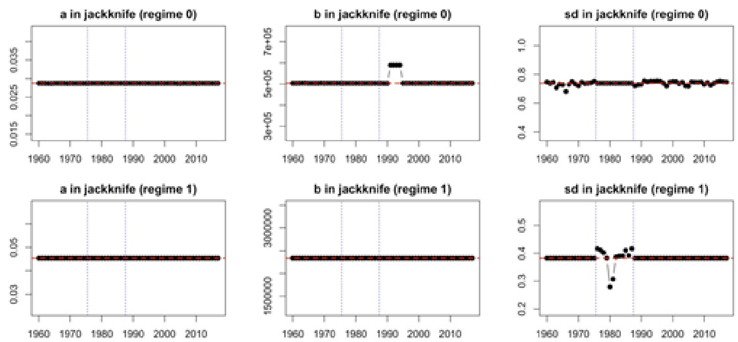


Appendix Figure 1-4. Influence by parameter in HS Jack Knife analysis

Scenario to divide the period of S-R relationship: HS model: least squares method

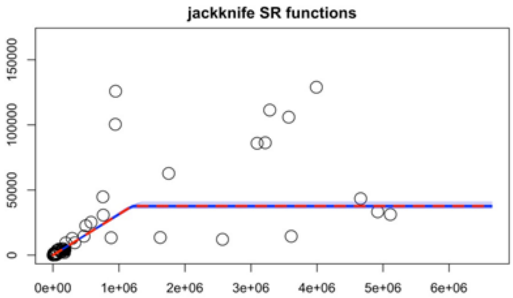


Scenario to divide the period of S-R relationship: HS model: least absolute value method

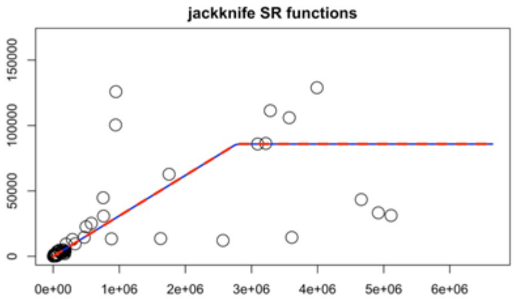


Appendix Figure 1-4 (continued). Influence by parameter in HS Jack Knife analysis

Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method

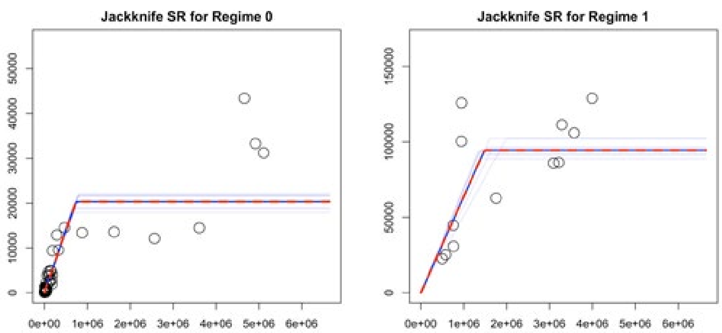


Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method

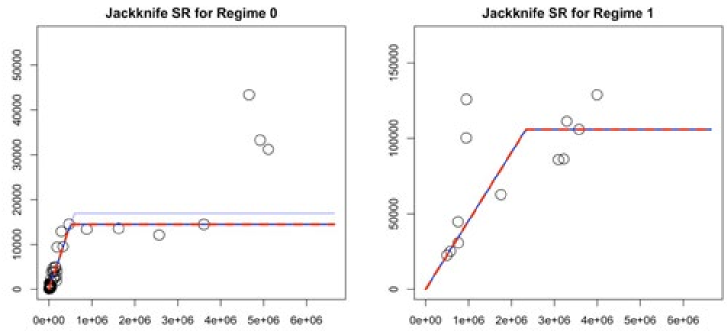


Appendix Figure 1-5. Estimation results of Jack Knife analysis with HS S-R relationship
The red line expresses the estimates of all data, while the blue line expresses the estimates when the data of the respective year is removed. Circles show the spawning biomass and recruitment, which are used for the analysis. The black circle represents the terminal year (2017) of the data period used.

Scenario to divide the period of S-R relationship: HS model: least squares method



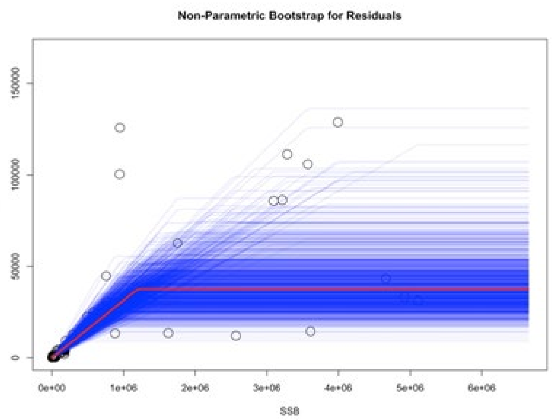
Scenario to divide the period of S-R relationship: HS model: least absolute value method



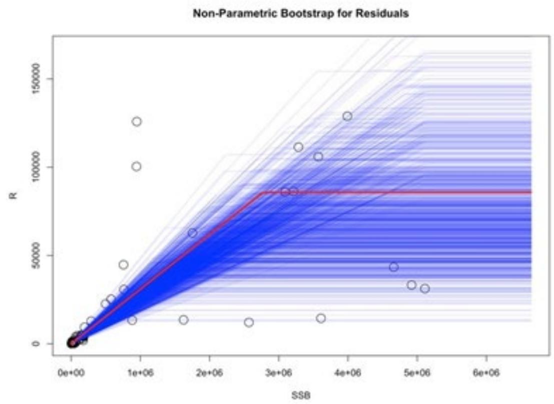
Appendix Figure 1-5 (continued). Estimation results of Jack Knife analysis with HS S-R relationship

The red line expresses the estimates of all data, while the blue line expresses the estimates when data of the respective year is removed. Circles show the spawning biomass and recruitment, which are used for the analysis. The black circle represents the terminal year (2017) of the data period used.

Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method



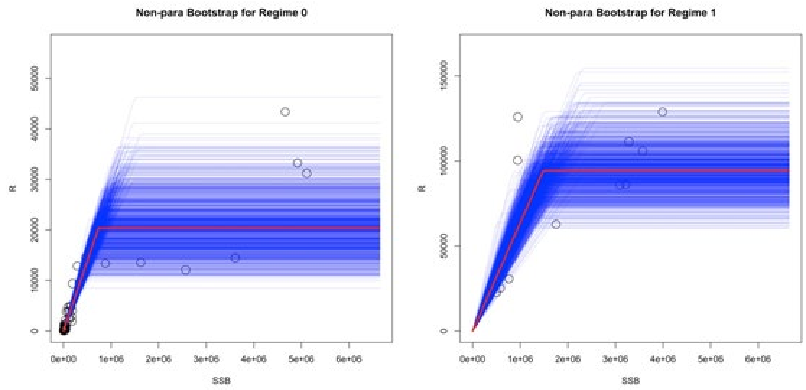
Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method



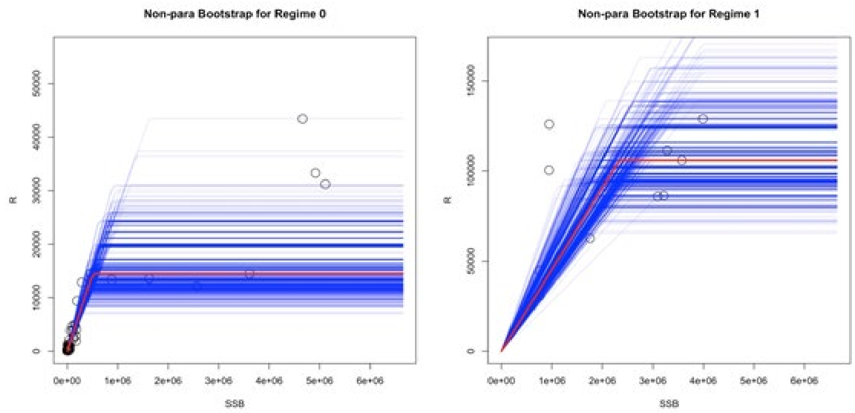
Appendix Figure 1-6. Results of residual bootstrap analysis with the HS S-R relationship

The red line represents the estimated value of the original data. The blue lines represent estimated values of nonparametric bootstrapping. Circles show the spawning biomass and recruitment, which are used for the analysis. The black circle represents the terminal year (2017) of the data period used.

Scenario to divide the period of S-R relationship: HS model: least squares method



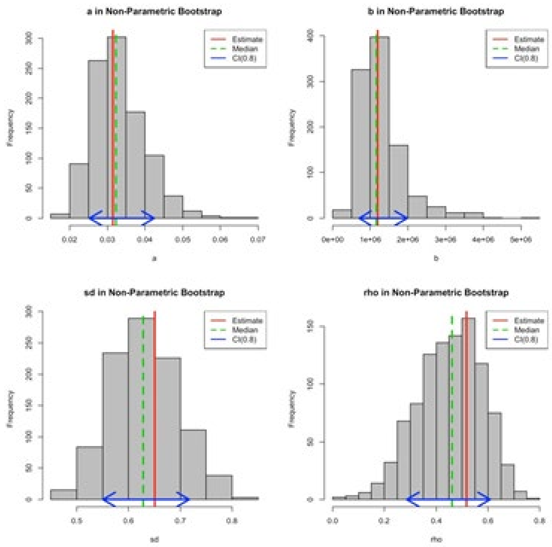
Scenario to divide the period of S-R relationship: HS model: least absolute value method



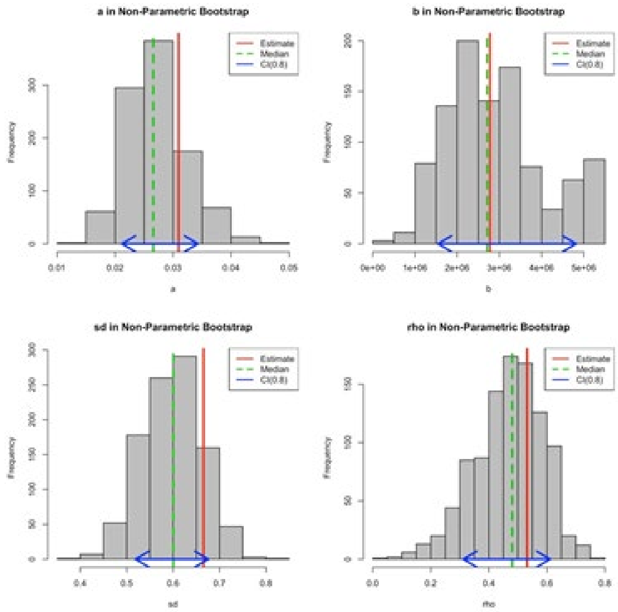
Appendix Figure 1-6 (continued). Result of residual bootstrap analysis with the HS S-R relationship

The red line represents the estimated value of the original data. The blue lines represent estimated values of nonparametric bootstrapping. Circles show the spawning biomass and recruitment, which are used for the analysis. The black circle represents the terminal year (2017) of the data period used.

Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method



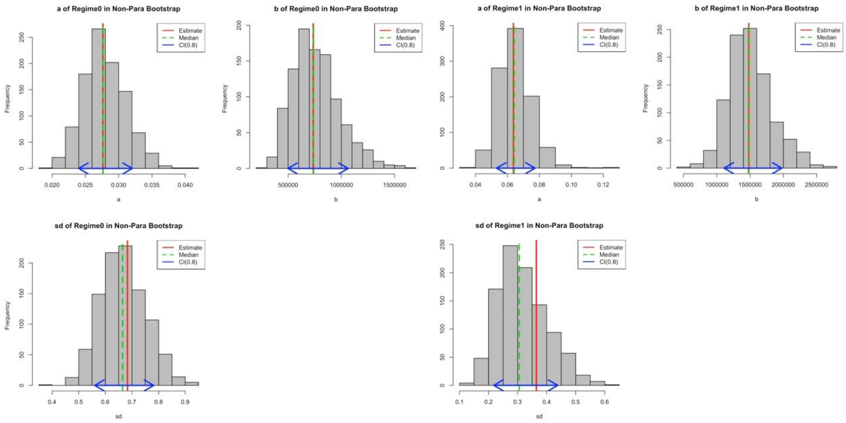
Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method



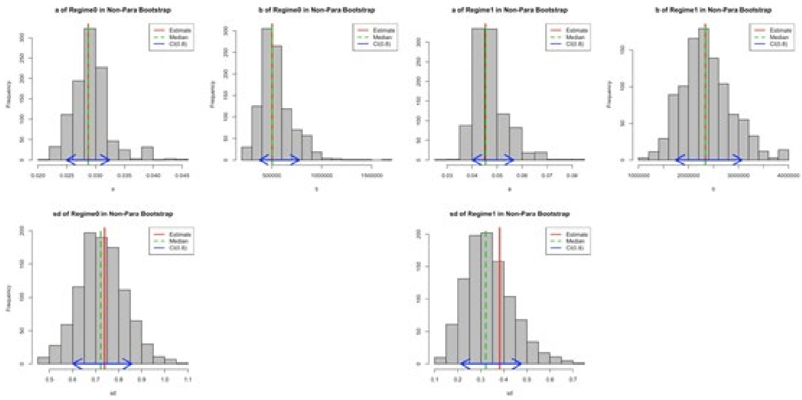
Appendix Figure 1-7. Median (green dotted line) and 80% confidence interval (blue line) of residual bootstrap analysis

Red line represents point estimation of parameters.

Scenario to divide the period of S-R relationship: HS model: least squares method



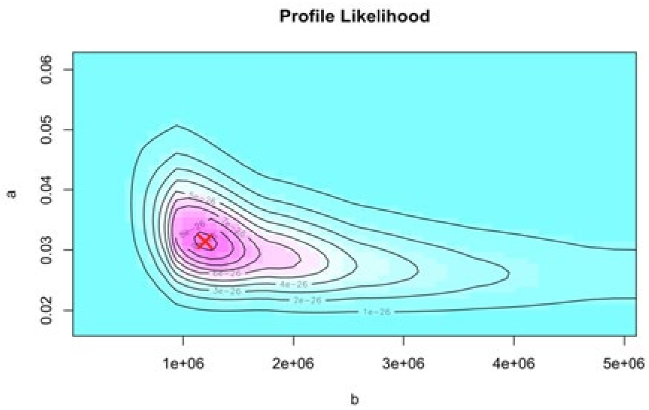
Scenario to divide the period of S-R relationship: HS model: least absolute value method



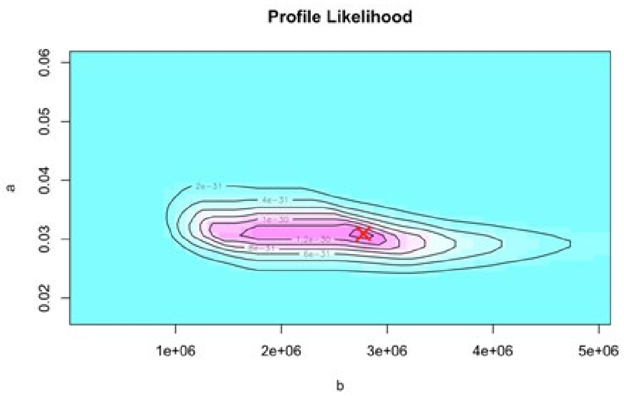
Appendix Figure 1-7 (continued). Median (green dotted line) and 80% confidence interval (blue line) of residual bootstrap analysis

Red line represents point estimation of parameters.

Whole period scenario: HS model: least squares method and simultaneous autocorrelation estimation method

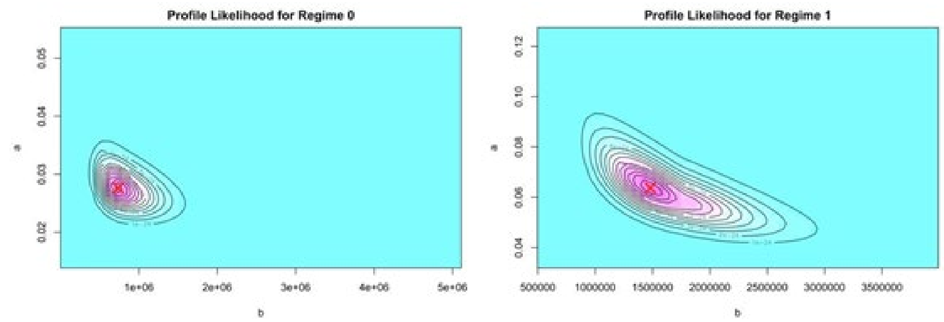


Whole period scenario: HS model: least absolute value method and two-stage autocorrelation estimation method

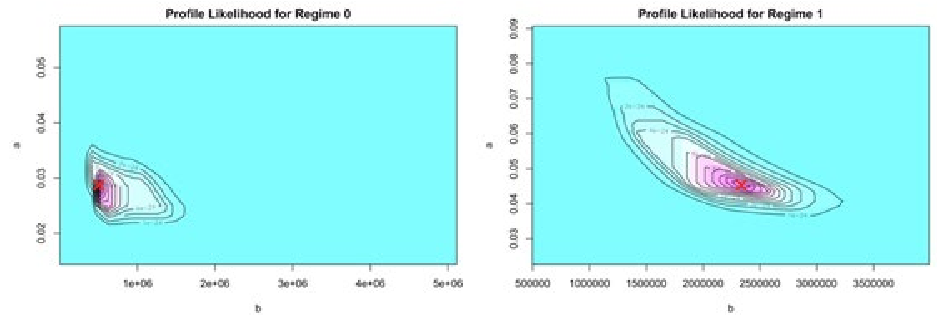


Appendix Figure 1-8. Profile likelihood of estimated parameters of HS S-R relationship
The × marks correspond to the likelihood at the estimated parameter values.

Scenario to divide the period of S-R relationship: HS model: least squares method



Scenario to divide the period of S-R relationship: HS model: least absolute value method

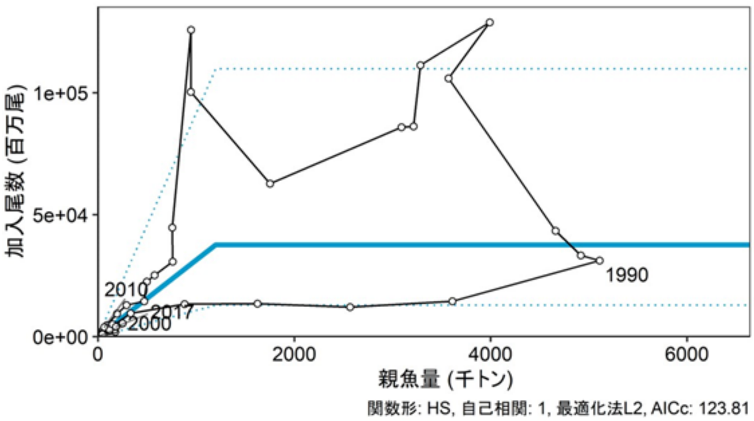


Appendix Figure 1-8 (continued). Profile likelihood of estimated parameters of HS S-R relationship

The × marks correspond to the likelihood at the estimated parameter values.

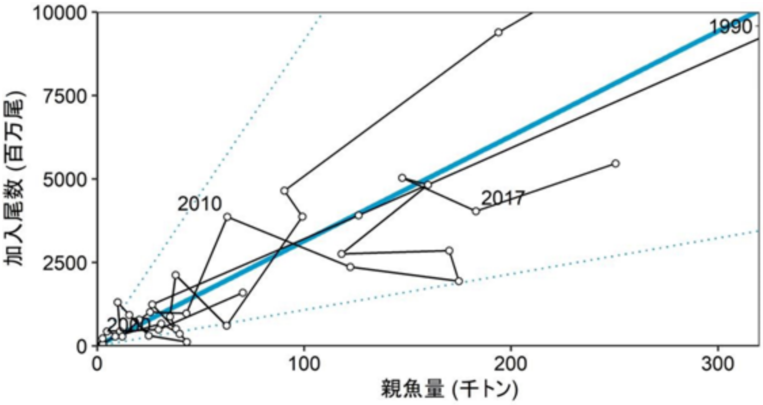
Appendix 2. Results of S-R relationship when the data of the whole period (1960-2017) are used

a)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)
関数形：HS，最適化法 L2，AICc:123.81	Model: HS; autocorrelation: 1; optimization method: L2; AICc:123.81

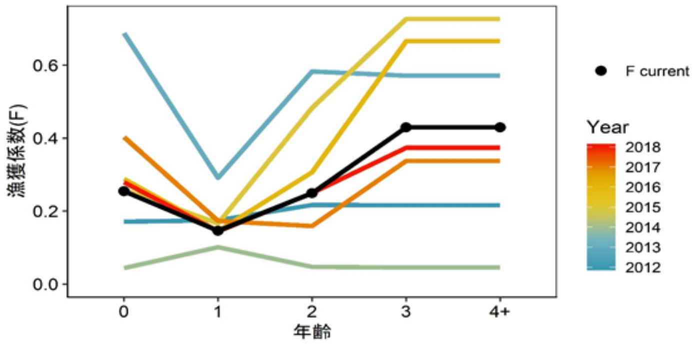
b)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

Appendix Figure 2-1.

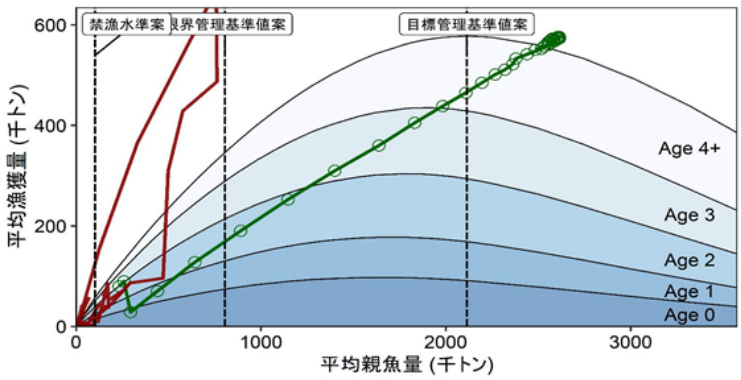
(a) Spawning biomass and recruitment when the whole-period data (1960-2017) are used and (b) its enlarged view. Numbers in the figures represent the class (birth year) of the recruited group. We used the HS S-R relationship for the S-R relationship and estimated parameters by using the least squares method and simultaneous estimation of the autocorrelation method. The dotted lines over and below the S-R relationship (blue solid line) show the range that is estimated to contain 90% of observation data under the assumed S-R relationship.



漁獲係数	Fishing mortality
年齢	Age

Appendix Figure 2-2. Fishing mortality (F) at age

F at age of each year from 2012 is shown in different colors. The black line represents Fcurrent that is the average F of the period from 2014 to 2018.



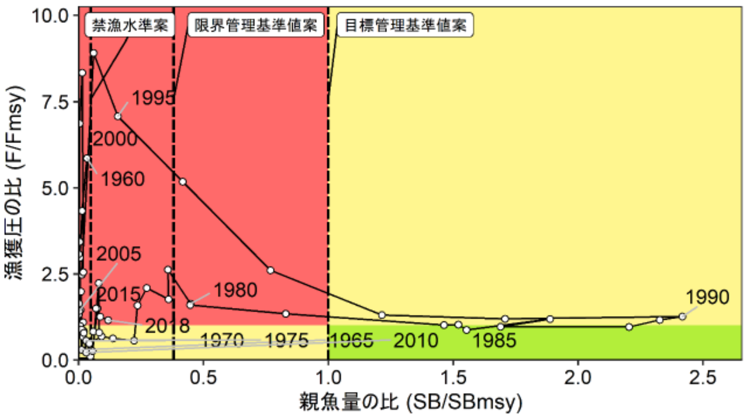
平均漁獲量（千トン）	Average catch (thousand tons)
平均親魚量（千トン）	Average spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

Appendix Figure 2-3. Relationship between the proposed reference points / fishing ban level and curves of catch at age

The figure shows the average catch at age corresponding to the average spawning biomass, and relationship of the proposed reference points and fishing ban level at equilibrium in the future projection simulation assuming the conditions of the whole period (1960-2017). The red line represents changes in the spawning biomass and catch, which are estimated by the stock assessment, while the green line represents changes in the average spawning biomass and average catch in the future projection when fishing is conducted based on the proposed

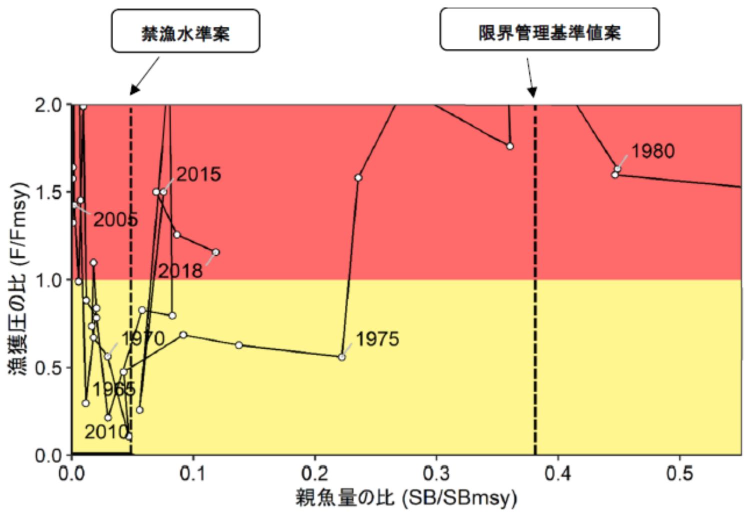
HCRs. Part of the past spawning biomass and catch are outside of the scope (maximum value: spawning biomass: 5.111 million tons; catch: 1.605 million tons). Safety coefficient β used in the proposed HCRs is 0.8. The initial spawning biomass assuming no catch (SB0) is 5.109 million tons.

a-1) When the vertical axis is the ratio of the fishing mortality (F/Fmsy)



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

a-2) Enlarged view

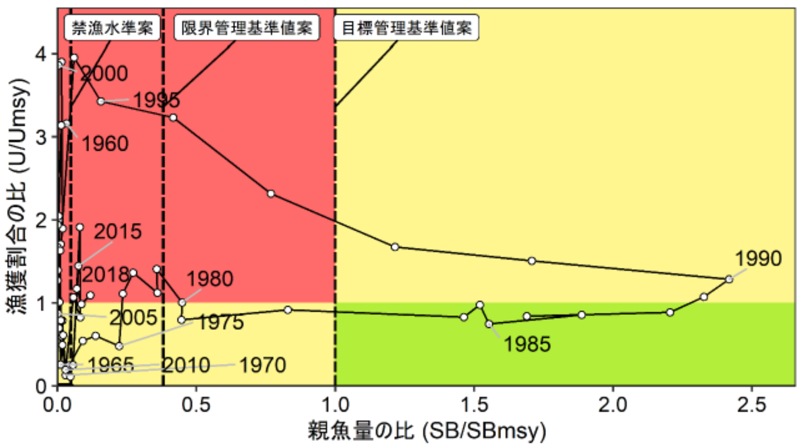


漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Appendix Figure 2-4. Kobe plot (four sections)

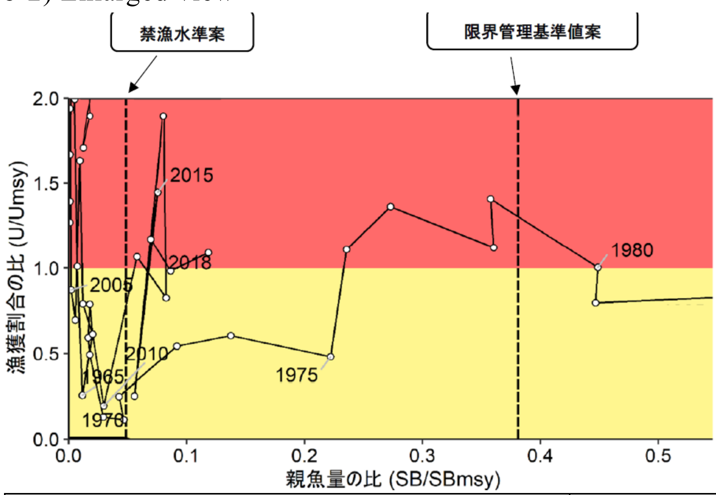
When the ratio of fishing mortality is put on the vertical axis (a-1) and its enlarged view (a-2). As the proposed target reference point (SBtarget), proposed limit reference point (SBlimit), and proposed fishing ban level (SBban) in the figure, we used SBmsy, SB0.6msy, and SB0.1msy respectively assuming the conditions of the whole period (1960-2017).

b-1) When the vertical axis is the ratio of the exploitation rate (U/Umsy)



漁獲割合の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

b-2) Enlarged view



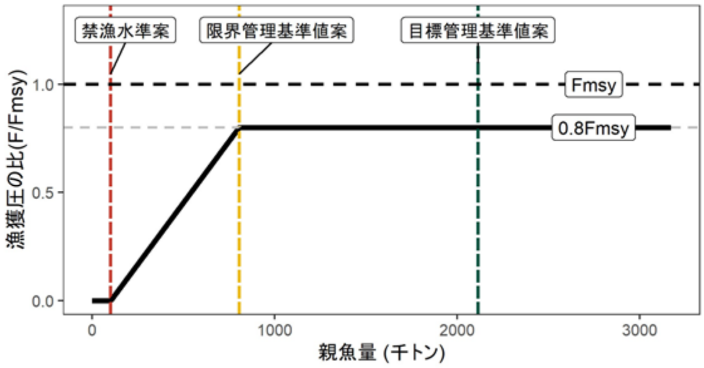
漁獲割合の比	F/Fmsy
親魚量の比	SB/SBmsy

禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Appendix Figure 2-4 (continued). Kobe plot (four sections)

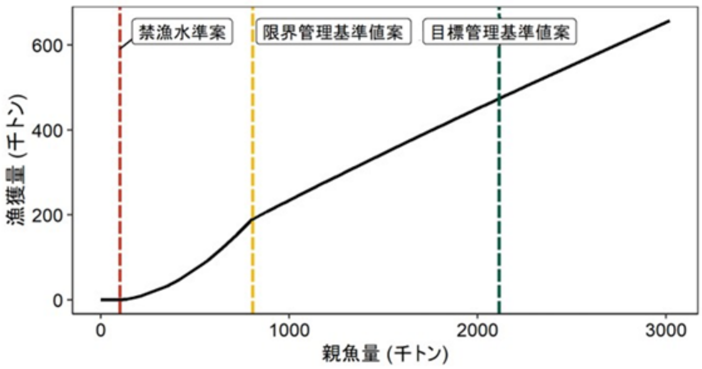
When the ratio of fishing mortality is put on the vertical axis (a-1) and its enlarged view (a-2). As the proposed target reference point (SBtarget), proposed limit reference point (SBlimit), and proposed fishing ban level (SBban) in the figure, we used SBmsy, SB0.6msy, and SB0.1msy respectively assuming the conditions of the whole period (1960-2017).

a) When the vertical axis is fishing mortality



漁獲圧の比	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

b) When the vertical axis is catch

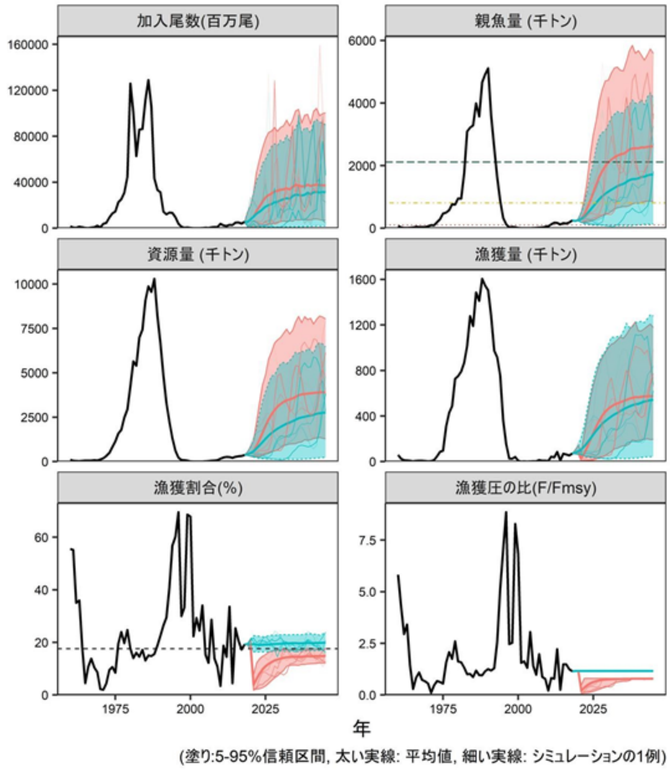


漁獲量（千トン）	Catch (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

目標管理基準値案	Proposed SBtarget

Appendix Figure 2-5. Proposed HCRs

The proposed target reference point (SBtarget) is SBmsy calculated based on the HS S-R relationship that assumes the conditions of the whole period (1960-3017). The proposed limit reference point (SBlimit) and proposed fishing ban level (SBban) in the figure are set to SB0.6msy and SB0.1msy, respectively. Safety coefficient β is set to 0.8, which is the standard value. The black dashed line represents Fmsy; the grey dashed line represents 0.8Fmsy; the black thick line represents the proposed HCRs; the red dashed line represents the proposed fishing ban level; the yellow dashed line represents the proposed limit reference point; and the green dashed line represents the proposed target reference point. In a) fishing mortality is put on the vertical axis. In b) the catch is put on the vertical axis. Regarding b), the catch varies a little depending on the age composition of the fishing year but here we show the catch of average age composition at equilibrium.



加入尾数（百万尾）	Recruitment (million individuals)
資源量（千トン）	Stock biomass (thousand tons)
漁獲割合	Exploitation rate (%)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲圧の比	Ratio of the fishing mortality to MSY

年	Year
（塗り：5-95％信頼区間，太い実線：平均値，細い実線：シミュレーションの 1 例）	(Shaded: 5-95% confidence interval; thick solid line: average value; thin slid line: simulation example)

Appendix Figure 2-6. Comparison of the future projection using the proposed HCRs that assume the conditions of the whole period (1960-2017) (in red) with the future projection that assumes continued fishing at the current fishing mortality (in green)

The thick solid line, shaded area and thin lines represent average value, the 90% prediction interval that includes 90% of the simulation results, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed limit reference point and the red line shows the proposed fishing ban level. The dashed line in the chart of exploitation rate expresses Umsy. The catch in 2019 and 2020 are assumed based on the projected biomass and Fcurrent, while the catch in 2021 and after is based on the proposed HCRs (Appendix Figure 2-5). Safety coefficient β is set to 0.8.

Appendix Table 2-1. Catch, fishing mortality, etc. corresponding to the proposed reference points and fishing ban level

管理基準値案または禁漁水準案	説明	親魚量（千トン）	SB0に対する比※	漁獲量※※（千トン）	漁獲圧※※※（%SPR）	漁獲割合※※※※	現状の漁獲圧に対する比※※※※
目標管理基準値案（全期間）	SBmsy	2114	0.41	577	44.8	0.18	0.86
限界管理基準値案（全期間）	SB0.6msy	806	0.16	346	31.5	0.25	1.38
禁漁水準案（全期間）	SB0.1msy	103	0.02	58	24.1	0.30	1.82
MSYを実現する漁獲圧	Fmsy	（0歳, 1歳, 2歳, 3歳, 4+歳）=（0.219, 0.125, 0.214, 0.370, 0.370）					

管理基準値案または禁漁水準案	Proposed reference points or fishing ban level
説明	Explanation
親魚量（千トン）	Spawning biomass (thousand tons)
SB0 に対する比	Ratio to SB0
漁獲量（千トン）	Catch (thousand tons)
漁獲圧	Fishing mortality
漁獲割合	Exploitation rate
現状の漁獲圧に対する比	Ratio to the current fishing mortality
目標管理基準値案（全期間）	Proposed target reference point(whole period)
限界管理基準値案（全期間）	Proposed limit reference point (whole period)
禁漁水準案（全期間）	Proposed fishing ban level (whole period)

MSY を実現する漁獲圧	Fishing mortality that produces MSY
（0 歳，1 歳，2 歳，3 歳，4+歳）＝（0.219, 0.125, 0.214, 0.370, 0.370）	(Ages 0, 1, 2, 3, 4 and above) = (0.219, 0.125, 0.214, 0.370, 0.370)

* Ratios of the proposed reference points and fishing ban level to the initial spawning biomass assuming zero catch (SB0)

** Average catch at equilibrium under the fishing mortality corresponding to the proposed reference points and fishing ban level

*** %SPR-converted value of fishing mortality corresponding to the proposed reference points and fishing ban level

**** Exploitation rate corresponding to the proposed reference points and fishing ban level

***** Ratios of the fishing mortality corresponding to the proposed reference points and fishing ban level to the current fishing mortality

Appendix Table 2-2. Probability for future spawning biomass to exceed the proposed target reference point (%)

The table shows the result of future prediction based on the proposed HCRs that assume the conditions of the whole period (1960-2017) (Appendix Figure 2-5) when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	2	6	10	15	22	25	28	32	33	42	43
0.9	0	0	0	0	2	6	11	18	24	28	32	36	38	49	48
0.8	0	0	0	0	2	7	13	20	27	32	37	41	44	54	55
0.7	0	0	0	0	2	7	14	21	29	36	42	46	50	62	60
0.6	0	0	0	0	3	8	15	24	32	41	46	52	55	68	66
0.5	0	0	0	0	3	8	17	27	36	44	51	56	61	74	72
0.4	0	0	0	0	3	9	19	31	40	48	56	60	66	78	78
0.3	0	0	0	1	3	10	20	33	44	53	60	66	71	83	84
0.2	0	0	0	1	4	10	22	36	48	57	65	70	75	89	88
0.1	0	0	0	1	4	11	24	39	52	62	70	75	80	93	93
0.0	0	0	0	1	4	12	26	42	55	66	73	80	84	96	96

Appendix Table 2-3. Probability for the future spawning biomass to exceed the proposed limit reference point (%)

The table shows the result of future prediction based on the proposed HCRs that assume the conditions of the whole period (1960-2017) (Appendix Figure 2-5) when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	1	6	20	37	48	58	65	72	76	80	82	91	91
0.9	0	0	1	6	20	39	50	61	67	74	79	83	84	93	94

0.8	0	0	1	7	21	41	52	62	70	76	81	86	88	95	96
0.7	0	0	1	7	22	42	54	65	72	79	83	87	89	96	98
0.6	0	0	1	7	23	43	56	66	74	81	85	89	92	98	99
0.5	0	0	1	8	25	44	57	69	76	83	87	90	93	99	99
0.4	0	0	1	8	25	46	59	70	77	84	89	92	94	99	99
0.3	0	0	1	8	27	47	60	72	78	85	90	93	95	100	100
0.2	0	0	1	9	28	48	62	74	81	87	91	94	96	100	100
0.1	0	0	1	9	29	50	64	75	82	88	93	95	96	100	100
0.0	0	0	1	9	30	52	66	77	84	90	93	96	97	100	100

Appendix Table 2-4. Probability that future spawning biomass will exceed the proposed fishing ban level (%)

The table shows the result of future prediction based on the proposed HCRs that assume the conditions of the whole period (1960-2017) (Appendix Figure 2-5) when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 2-5. Changes in the average spawning biomass in the future (thousand tons)

The table shows the result of future prediction based on the proposed HCRs that assume the conditions of the whole period (1960-2017) (Appendix Figure 2-5) when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	259	294	433	619	836	1,049	1,255	1,448	1,601	1,720	1,818	1,886	2,216	2,200
0.9	232	259	294	436	630	862	1,096	1,324	1,538	1,711	1,845	1,956	2,033	2,393	2,376
0.8	232	259	294	439	642	890	1,145	1,398	1,637	1,830	1,982	2,106	2,193	2,583	2,570
0.7	232	259	294	443	654	919	1,198	1,478	1,743	1,959	2,131	2,270	2,368	2,791	2,781
0.6	232	259	294	446	666	949	1,254	1,564	1,858	2,100	2,294	2,450	2,559	3,019	3,013
0.5	232	259	294	449	679	982	1,315	1,656	1,983	2,254	2,473	2,648	2,770	3,271	3,269
0.4	232	259	294	452	693	1,016	1,379	1,756	2,118	2,422	2,669	2,867	3,005	3,553	3,553
0.3	232	259	294	456	707	1,051	1,447	1,863	2,265	2,607	2,886	3,108	3,265	3,873	3,874
0.2	232	259	294	459	721	1,089	1,520	1,979	2,425	2,808	3,124	3,376	3,556	4,238	4,242
0.1	232	259	294	462	736	1,128	1,598	2,104	2,599	3,030	3,389	3,676	3,884	4,661	4,670
0	232	259	294	466	751	1,169	1,681	2,239	2,789	3,275	3,684	4,014	4,255	5,158	5,177

Appendix Table 2-6. Changes in the average catch in the future (thousand tons)

The table shows the result of future prediction based on the proposed HCRs that assume the conditions of the whole period (1960-2017) (Appendix Figure 2-5) when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	80	90	35	84	148	217	282	340	389	434	467	493	512	600	601
0.9	80	90	32	78	139	204	268	326	376	422	455	481	501	588	588
0.8	80	90	29	71	128	190	252	310	360	405	438	465	484	568	570
0.7	80	90	25	63	116	175	234	289	339	383	416	442	462	542	544
0.6	80	90	22	55	103	157	213	265	313	355	387	412	432	506	509
0.5	80	90	18	47	89	137	188	237	281	321	351	375	393	462	464
0.4	80	90	15	39	74	115	159	203	243	278	306	328	344	405	407
0.3	80	90	11	30	57	91	127	163	197	227	251	269	284	335	337
0.2	80	90	7	20	40	64	90	117	142	165	183	197	208	247	249
0.1	80	90	4	10	21	33	48	63	77	90	100	109	115	138	139
0	80	90	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 2-7. Summary of the projected spawning biomass, catch and the probability for spawning biomass to exceed the proposed reference points

The table shows the result when the proposed HCRs estimated based on the whole period data are used and when safety coefficient β is changed from 0.0 to 1.0 by interval of 0.1.

β	10年後（2031年）の平均親魚量（千トン）	10年後（2031年）に親魚量が目標管理基準値案を上回る確率	0年後（2021年）の予測漁獲量（千トン）	5年後（2026年）の予測漁獲量（千トン）	10年後（2031年）の予測漁獲量（千トン）	10年後（2031年）に親魚量が限界管理基準値案を上回る確率
1	1,886	33%	35	340	512	82%
0.9	2,033	38%	32	326	501	84%
0.8	2,193	44%	29	310	484	88%
0.7	2,368	50%	25	289	462	89%
0.6	2,559	55%	22	265	432	92%
0.5	2,770	61%	18	237	393	93%
0.4	3,005	66%	15	203	344	94%
0.3	3,265	71%	11	163	284	95%
0.2	3,556	75%	7	117	208	96%
0.1	3,884	80%	4	63	115	96%
0	4,255	84%	0	0	0	97%

10年後（2031年）の平均親魚量（千トン）	Average spawning biomass (thousand tons) after 10 years (2031)
10年後（2031年）に親魚量が目標管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed target reference point after 10 years (2031)
0年後（2021年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 0 years (2021)
5年後（2026年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 5 years (2026)
10年後（2031年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 10 years (2031)
10年後（2031年）に親魚量が限界管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed limit reference point after 10 years (2031)

Appendix 3. Management Strategy Evaluation (MSE) of division of the recruitment period

When the S-R relationship chosen for calculation of the catch is not the true S-R relationship, there is a risk of decrease in the spawning biomass or a risk of unnecessary loss of fishing opportunity. The proposed reference points based on the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) are lower than the proposed reference points based on the S-R relationship of the whole period (1960-2017), and fishing mortality is higher when spawning biomass is small (Table 3 and Appendix Table 2-3). If the proposed reference points based on the S-R relationship of the normal recruitment periods are used for calculation of the catch when the true S-R relationship is for the whole period, there is a risk that the catch is set too high and the stock biomass would not recover. Conversely, if the proposed reference points based on the whole period are used for catch calculation when the true S-R relationship is for the normal recruitment periods, there is a risk to set catch too low and lose fishing opportunity.

For this reason, we used simplified MSE to assess the impact when the S-R relationship chosen for catch calculation is not the true S-R relationship. Based on the "Comparison of robustness of multiple reference points and examination of HCRs using simplified MSE (FRA-SA2020-BRP01-7)," the fishing scenario of MSE is set as follows. Simulation is conducted 300 times.

(1) Stock biomass is estimated every year based on the catch.

(2) Future projection is made based on the S-R relationship chosen for catch calculation to estimate the average catch after two years.

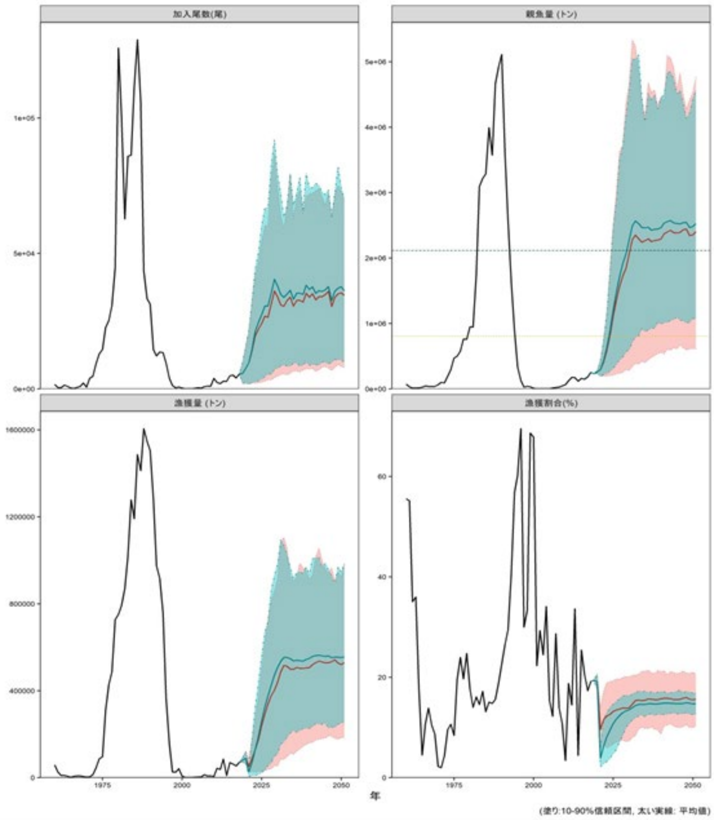
(3) Fishing is conducted with the catch estimated in (2).

[1] Risk of biomass depletion

HS model with the least squares method and the simultaneous autocorrelation estimation method, which is applied to the data of the whole period (1960-2017) is used for the true S-R relationship, while the HS model with the least squares method, which is applied to the data of the normal recruitment periods (1960-1975 and 1988-2017) is used for the S-R relationship that is applied to the catch calculation. The results are shown in Appendix Figure 3-1 and Appendix Tables 3-1 to 3-4. The probability that the projected average spawning biomass will exceed the true limit reference point (806 thousand tons when applied to the data of the whole period) was 72% when β is set to 0.8. To make the probability of its exceeding the true limit reference point 90% or higher, it is necessary to set β to 0.3 for after 10 years, to 0.6 for after 20 years and 0.7 or lower for after 30 years (Appendix Table 3-2). It is necessary to set β to a low value in order to control the risk that biomass would not recover when the assumption of the recruitment mode was wrong.

[2] Risk of losing fishing opportunity

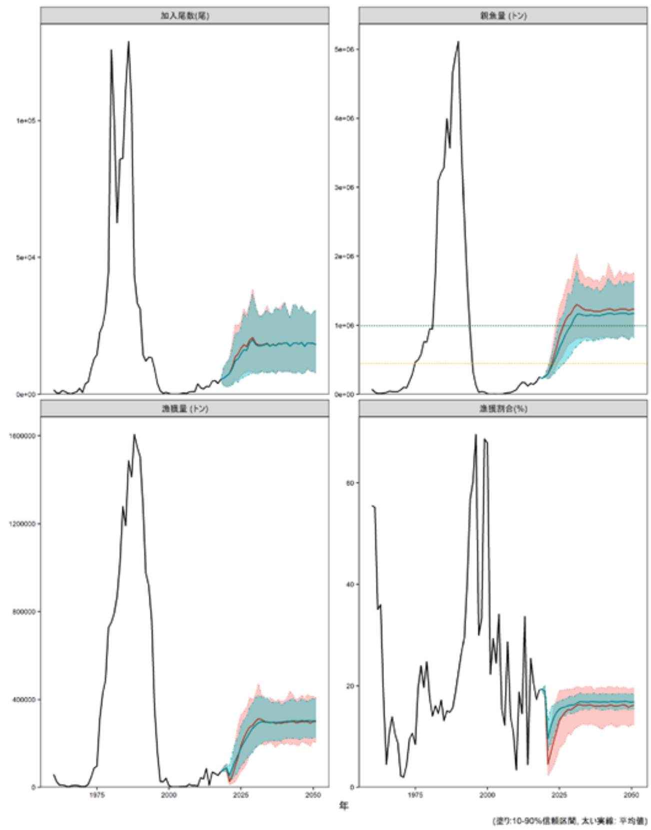
The HS model with the least squares method, which is applied to the data of the normal recruitment periods (1960-1975 and 1988-2017) is used for the true S-R relationship, while the HS model with the least squares method and the simultaneous autocorrelation estimation method, which is applied to the data of the whole period (1960-2017) is used for the S-R relationship that is applied to the catch calculation. The result is shown in Appendix Figure 3-2 and Appendix Tables 3-5 to 3-9. When β is set to 0.8, the average catch projected for 2021 was 25 thousand tons, 53% decrease from the catch calculated based on the S-R relationship of the normal recruitment periods. However, the catch increased 11% to 312 thousand tons after 10 years. The result indicates a risk of a short-term loss of fishing opportunity.



加入尾数（尾）	Recruitment (individuals)
漁獲量（トン）	Catch (tons)
親魚量（トン）	Spawning biomass (tons)
漁獲割合	Exploitation rate (%)
年	Year
（塗り：10-90%信頼区間，太い実線：平均値）	(Shaded: 10-90% confidence interval; thick solid line: average value)

Appendix Figure 3-1. MSE future projection using the proposed HCRs based on the normal recruitment periods (1960-1975 and 1988-2017) HS model (red line) and the future projection using the proposed HCRs based on the whole period HS model (green line) when it is assumed that the true S-R relationship is the whole period (1960-2017) HS model

The thick solid line represents average values. The shaded area shows the 80% prediction interval. The dashed lines in the spawning biomass chart represent the proposed reference points of the whole period HS model (green: proposed target reference point; yellow: proposed limit reference point). The catch in 2019 and 2020 is assumed based on the projected biomass and Fcurrent, while catch in 2021 and after is based on the proposed HCRs (Figure 5). Safety coefficient β is set to 0.8.



加入尾数（尾）	Recruitment (individuals)
漁獲量（トン）	Catch (tons)
親魚量（トン）	Spawning biomass (tons)
漁獲割合	Exploitation rate (%)
年	Year
（塗り：10-90%信頼区間，太い実線：平均値）	(Shaded: 10-90% confidence interval; thick solid line: average value)

Appendix Figure 3-2. MSE future projection using the proposed HCRs based on the whole period (1960-2017) HS model (red line) and the future projection using the proposed HCRs based on the normal recruitment period HS model (green line) when it is assumed that the true S-R relationship is the normal recruitment periods (1960-1975 and 1988-2017) HS model

The thick solid line and shaded area represent the average value and the 80% prediction examples, respectively. The dashed lines in the spawning biomass chart represent the proposed reference points of the normal recruitment period HS model (green: proposed target reference point; yellow: proposed limit reference point). Catch in 2019 and 2020 is assumed based on the projected biomass and Fcurrent. The proposed HCRs (for 2021 and after) are based on the standard proposed reference points. (Appendix Figure 2-5). Safety coefficient β is set to 0.8.

Appendix Table 3-1. Probability that the future spawning biomass will exceed the proposed target reference point of the true S-R relationship (%)

When the true S-R relationship is for the whole period, while the catch is calculated based on the S-R relationship of the normal recruitment period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	3	6	11	14	17	21	24	27	31	33	34
0.9	0	0	0	0	3	7	11	15	20	25	27	30	35	37	40
0.8	0	0	0	0	3	8	12	17	23	29	29	35	41	44	44
0.7	0	0	0	0	3	8	13	18	25	32	32	41	46	48	50
0.6	0	0	0	0	3	9	15	21	27	34	37	45	50	55	57
0.5	0	0	0	0	3	10	16	22	31	38	45	50	56	63	66
0.4	0	0	0	0	3	10	18	25	35	43	51	55	60	71	75
0.3	0	0	0	0	3	11	20	28	38	46	56	62	64	79	80
0.2	0	0	0	0	4	13	22	33	43	53	62	69	73	87	85
0.1	0	0	0	0	4	14	23	37	47	57	67	73	78	89	92
0.0	0	0	0	0	4	14	25	40	52	63	72	79	84	95	97

Appendix Table 3-2. Probability that the future spawning biomass will exceed the proposed limit reference point of the true S-R relationship (%)

When the true S-R relationship is for the whole period, while the catch is calculated based on the S-R relationship of the normal recruitment period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	6	19	26	35	42	47	53	57	63	62	73	74
0.9	0	0	0	7	20	28	37	44	51	57	62	67	68	77	79
0.8	0	0	0	7	21	30	39	48	54	61	66	70	72	82	86
0.7	0	0	0	8	22	31	44	51	57	63	70	73	78	89	90
0.6	0	0	0	8	23	33	45	54	60	65	72	77	80	92	96
0.5	0	0	0	9	24	35	46	58	63	69	75	80	83	97	98
0.4	0	0	0	9	24	37	48	61	67	75	78	82	87	99	99
0.3	0	0	0	9	25	38	52	64	71	77	83	86	91	100	99
0.2	0	0	0	9	26	42	55	67	76	82	88	91	94	100	100
0.1	0	0	0	10	29	43	60	72	81	87	91	94	95	100	100
0.0	0	0	0	11	30	46	65	76	84	89	93	95	96	100	100

Appendix Table 3-3. Changes in the average spawning biomass in the future (thousand tons)

When the true S-R relationship is for the whole period, while the catch is calculated based on the S-R relationship of the normal recruitment period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	259	293	401	550	759	1,006	1,208	1,358	1,477	1,563	1,743	1,945	1,978	2,005
0.9	232	259	293	406	565	788	1,056	1,279	1,452	1,594	1,696	1,891	2,106	2,161	2,198
0.8	232	259	293	412	580	820	1,110	1,357	1,556	1,722	1,842	2,054	2,283	2,370	2,403
0.7	232	259	293	417	597	854	1,168	1,442	1,671	1,862	2,004	2,235	2,480	2,601	2,631
0.6	232	259	293	423	614	891	1,232	1,536	1,797	2,018	2,184	2,433	2,698	2,853	2,881
0.5	232	259	293	429	632	930	1,301	1,639	1,935	2,188	2,382	2,652	2,937	3,124	3,143
0.4	232	259	293	435	650	971	1,375	1,752	2,089	2,381	2,605	2,901	3,208	3,417	3,428
0.3	232	259	293	441	670	1,016	1,457	1,877	2,261	2,597	2,856	3,183	3,513	3,746	3,750
0.2	232	259	293	447	691	1,063	1,545	2,014	2,452	2,838	3,139	3,500	3,861	4,121	4,111
0.1	232	259	293	453	712	1,114	1,641	2,166	2,665	3,109	3,460	3,862	4,261	4,560	4,541
0	232	259	293	460	735	1,169	1,745	2,332	2,901	3,413	3,824	4,276	4,715	5,081	5,062

Appendix Table 3-4. Changes in the average catch in the future (thousand tons)

When the true S-R relationship is for the whole period, while the catch is calculated based on the S-R relationship of the normal recruitment period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	80	89	63	104	146	195	258	314	355	390	413	448	500	520	531
0.9	80	89	57	97	138	186	249	305	348	385	410	445	496	523	534
0.8	80	89	52	89	129	176	237	293	338	377	403	438	488	519	529
0.7	80	89	46	81	119	164	223	278	324	363	390	425	472	508	516
0.6	80	89	39	72	107	150	206	259	304	343	372	405	449	486	492
0.5	80	89	33	62	94	133	185	235	278	317	345	375	416	452	456
0.4	80	89	27	51	79	114	160	205	245	281	307	336	371	404	406
0.3	80	89	20	40	63	91	129	168	203	234	258	282	312	339	341
0.2	80	89	14	28	44	65	93	122	150	174	193	212	234	255	255
0.1	80	89	7	14	23	35	50	67	83	97	109	119	132	144	144
0	80	89	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 3-5. Probability that the future spawning biomass will exceed the proposed target reference point of the true S-R relationship (%)

When the true S-R relationship is for the normal recruitment periods, while the catch is calculated based on the S-R relationship of the whole period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	1	4	11	18	20	31	37	43	49	53	49	49
0.9	0	0	0	1	4	12	20	27	38	43	52	58	62	54	59
0.8	0	0	0	1	4	13	22	35	47	52	61	68	71	65	71
0.7	0	0	0	1	5	13	25	43	54	61	73	79	78	79	82
0.6	0	0	0	1	5	16	28	50	62	74	83	85	87	91	90
0.5	0	0	0	1	5	18	32	55	72	83	88	92	93	96	98
0.4	0	0	0	1	5	20	37	62	80	89	91	96	96	99	99
0.3	0	0	0	1	6	22	43	68	85	92	96	98	98	100	100
0.2	0	0	0	1	7	24	48	73	88	93	97	99	99	100	100
0.1	0	0	0	1	8	26	55	79	91	97	99	99	100	100	100
0.0	0	0	0	1	9	29	59	84	92	98	99	100	100	100	100

Appendix Table 3-6. Probability that the future spawning biomass will exceed the proposed limit reference point of the true S-R relationship (%)

When the true S-R relationship is for the normal recruitment periods, while the catch is calculated based on the S-R relationship of the whole period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	5	25	51	79	91	93	96	97	98	99	99	100	100
0.9	0	0	5	26	53	80	93	94	97	97	99	99	100	100	100
0.8	0	0	5	26	55	83	93	95	97	98	99	99	100	100	100
0.7	0	0	5	27	57	85	94	96	97	99	100	100	100	100	100
0.6	0	0	5	27	60	86	95	98	98	99	100	100	100	100	100
0.5	0	0	5	28	63	88	96	98	98	100	100	100	100	100	100
0.4	0	0	5	29	65	89	96	98	99	100	100	100	100	100	100
0.3	0	0	5	30	67	90	96	98	99	100	100	100	100	100	100
0.2	0	0	5	30	70	91	97	98	99	100	100	100	100	100	100
0.1	0	0	5	31	71	91	97	98	99	100	100	100	100	100	100
0.0	0	0	5	32	73	94	97	99	100	100	100	100	100	100	100

Appendix Table 3-7. Changes in the average spawning biomass in the future (thousand tons)

When the true S-R relationship is for the normal recruitment periods, while the catch is calculated based on the S-R relationship of the whole period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	261	295	401	519	644	778	864	946	1,003	1,031	1,102	1,142	1,066	1,075
0.9	232	261	295	404	527	663	809	908	1,001	1,065	1,099	1,173	1,217	1,140	1,150
0.8	232	261	295	406	537	682	842	956	1,061	1,135	1,174	1,252	1,301	1,223	1,235
0.7	232	261	295	409	546	703	878	1,008	1,128	1,212	1,258	1,342	1,396	1,318	1,331
0.6	232	261	295	412	556	725	916	1,064	1,201	1,298	1,353	1,443	1,503	1,427	1,441
0.5	232	261	295	415	566	748	957	1,127	1,282	1,394	1,459	1,557	1,624	1,549	1,565
0.4	232	261	295	418	576	772	1,001	1,195	1,371	1,501	1,578	1,685	1,760	1,689	1,707
0.3	232	261	295	421	587	798	1,049	1,270	1,470	1,620	1,711	1,829	1,913	1,851	1,870
0.2	232	261	295	424	598	825	1,101	1,351	1,579	1,751	1,861	1,992	2,087	2,038	2,058
0.1	232	261	295	427	610	854	1,156	1,440	1,699	1,897	2,028	2,175	2,283	2,256	2,278
0	232	261	295	430	621	884	1,216	1,536	1,830	2,060	2,215	2,383	2,508	2,514	2,539

Appendix Table 3-8. Changes in the average catch in the future (thousand tons)

When the true S-R relationship is for the normal recruitment periods, while the catch is calculated based on the S-R relationship of the whole period.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	81	88	32	65	109	154	208	240	268	290	299	319	333	311	317
0.9	81	88	29	60	102	147	200	233	261	283	292	311	324	305	310
0.8	81	88	25	54	95	138	190	223	252	273	282	299	312	295	300
0.7	81	88	22	49	86	128	178	210	238	260	268	283	296	281	286
0.6	81	88	19	43	77	116	163	194	221	241	249	263	275	263	267
0.5	81	88	16	36	67	102	145	175	199	218	226	238	249	239	243
0.4	81	88	13	30	56	87	124	151	172	189	197	208	217	210	212
0.3	81	88	10	23	44	69	99	122	140	154	161	170	178	173	175
0.2	81	88	7	16	30	49	71	88	101	112	117	124	130	128	129
0.1	81	88	3	8	16	26	38	47	55	61	64	68	72	71	72
0	81	88	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4. Result of the S-R relationship using the data of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period

It is considered that the decrease in recruitments of this stock since 1988 suggests the lower survival rate at the early stage of growth due to changes in the marine environment (Ohshimo et al. 2009). We assumed switching from a high recruitment period to a normal recruitment period in 1988 based on the small-sample-size-corrected version of AICc. However, because the spawning biomass hit the peak during the period from 1988 to 1990, we can also assume that this was the transitional period from a high recruitment period to a normal recruitment period. During a transitional period that involves rapid changes in the stock status, biological parameters and age composition of the biomass can greatly change, which can cause gross errors in the estimated results of the number of fish at age. For this reason, careful consideration is necessary for the handling of data of a transitional period when estimating the S-R relationship. Therefore, we removed the period from 1988 to 1990 from the normal recruitment period and assumed switching from a high recruitment period to a normal recruitment period in 1991. The S-R relationship and results based on this assumption are shown here.

再生産関係式	最適化法	期間	加入期	a	b	S.D.	Rho	AICc
ホッケー・スティック型	最小二乗法	1960~1975 1991~2017	移行期を除く通常	0.0276	483,613	0.678	0	123
		1976~1990	移行期を含む高	0.0637	1,070,395	0.487	0	

再生産関係式	S-R relationship
最適化法	Optimization method
期間	Period
加入期	Recruitment period
ホッケー・スティック型	Hockey stick
最小二乗法	Least squares method
移行期を除く通常	Normal period excluding the transitional period
移行期を含む高	High period including the transitional period

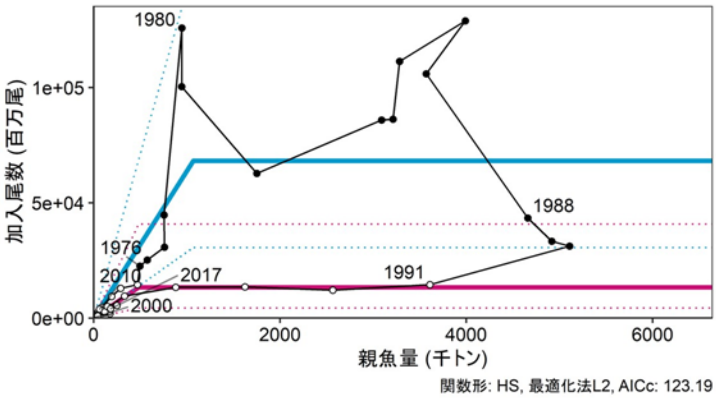
* a represents the steepness (individual/g) of the S-R curve to the break point, while b represents the spawning biomass (tons) at the break point.

We applied the HS model that does not consider autocorrelation for the S-R relationship and estimated parameters by the least squares method. Calculation results are: proposed target reference point (SBtarget) is the spawning biomass at the MSY level under the condition of the normal recruitment period excluding the transitional period (SBmsy: 674 thousand tons); proposed limit reference point (SBlimit) is the spawning biomass that produces 60% of MSY

(SB0.6msy: 296 thousand tons); and proposed fishing ban level (SBban) is the spawning biomass that produces 10% of MSY (SB0.1msy: 42 thousand tons) (Appendix Table 4-1). The expected MSY is estimated to be 217 thousand tons. The fishing mortality (Fmsy) that achieves the proposed target reference point (SBmsy) is 1.00 times of the current level (average fishing coefficient of 2014-2018).

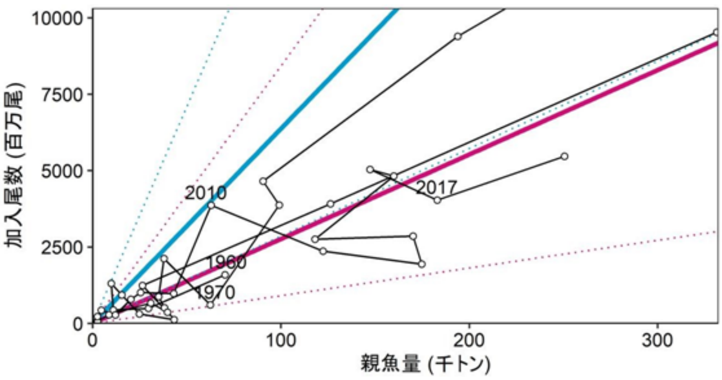
Compared with the scenario that assumes the conditions of the normal recruitment period (Table 3), AICc is higher by 4.27. SBmsy decreases by 32%, SB0.6msy decreases by 35%, MSY decreases by 31% and Fmsy decreases by 1%.

a)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)
関数形：HS，最適化法 L2，AICc:123.19	Model: HS; optimization method:L2; AICc:123.19

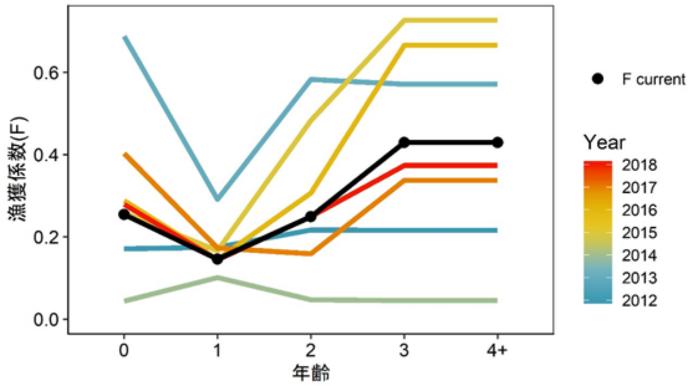
b)



加入尾数（百万尾）	Recruitment (million individuals)
親魚量（千トン）	Spawning biomass (thousand tons)

Appendix Figure 4-1.

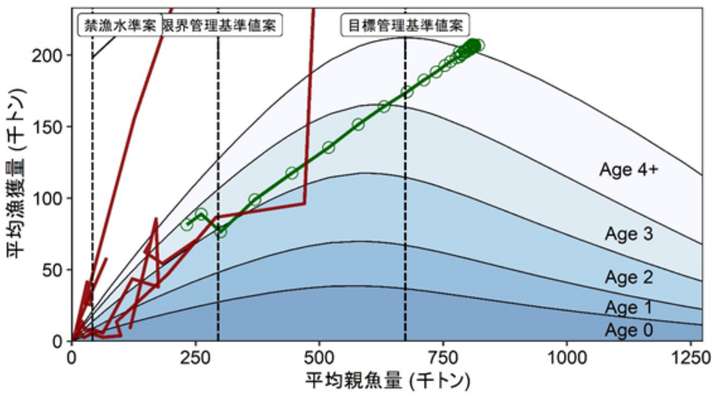
(a)The spawning biomass and recruitments when the recruitment period is divided: the normal recruitment periods (1960-1975 and 1988-2017; white circles and red solid line) where the transitional period is removed; and the high recruitment period (1976-1990; black circles and blue solid line) including the transitional period, and (b) its enlarged view. Numbers in the figure indicate the class of recruited group (birth year). For the S-R relationship, we used the HS S-R relationship where autocorrelation is not considered and estimated parameters using the least squares method. Dotted-lines over and below the S-R relationship in the figure show the range supposed to include 90% of the observed data of the assumed S-R relationship.



漁獲係数	Fishing mortality
年齢	Age in years

Appendix Figure 4-2. Fishing mortality (F) at age

F at age of each year from 2012 is shown in different colors. The black line represents Fcurrent that is the average F of the period from 2014 to 2018.



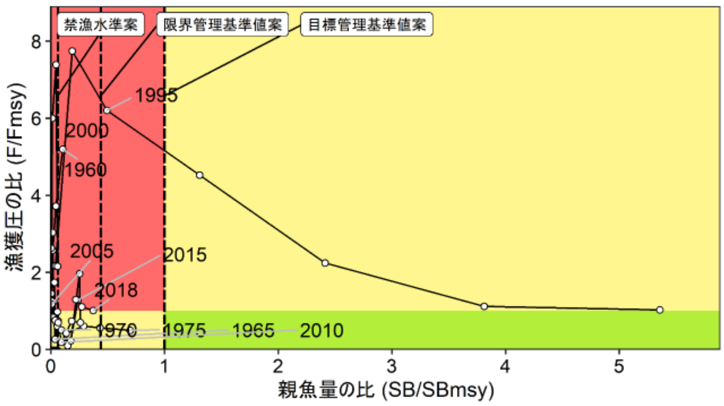
平均漁獲量（千トン）	Average catch (thousand tons)
平均親魚量（千トン）	Average spawning biomass (thousand tons)
禁漁水準案	Proposed fishing ban level

限界管理基準値案	Proposed limit reference point
目標管理基準値案	Proposed target reference point

Appendix Figure 4-3. Relationship between the proposed reference points / fishing ban level and curves of catch at age

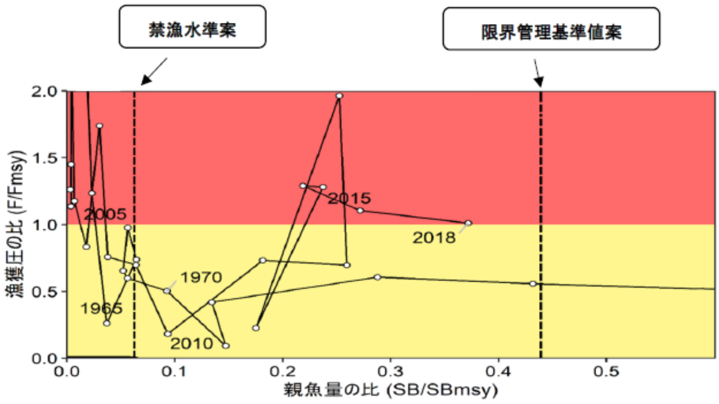
The figure shows the average catch at age corresponding to the average spawning biomass, and the relationship of the proposed reference points and fishing ban level at equilibrium in the future projection simulation when the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period is applied. The red line represents changes in the spawning biomass and catch, which are estimated by the stock assessment, while the green line represents the average spawning biomass and average catch in the future projection assuming fishing conducted based on the proposed HCRs. Part of the past spawning biomass and catch are outside the scope (maximum values: spawning biomass: 5.111 million tons; catch: 1.605 million tons). Safety coefficient β used in the proposed HCRs is 0.8. The initial spawning biomass assuming no catch (SB0) is 1.722 million tons.

a-1) When the vertical axis is the ratio of the fishing mortality (F/Fmsy)



漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

a-2)Enlarged view

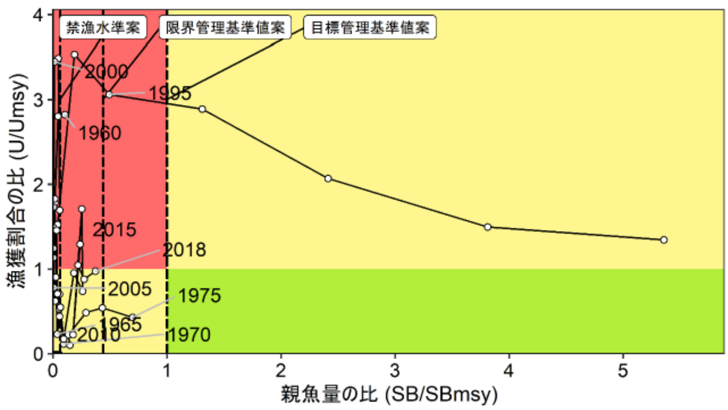


漁獲圧の比	F/Fmsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Appendix Figure 4-4. Kobe plot (four sections)

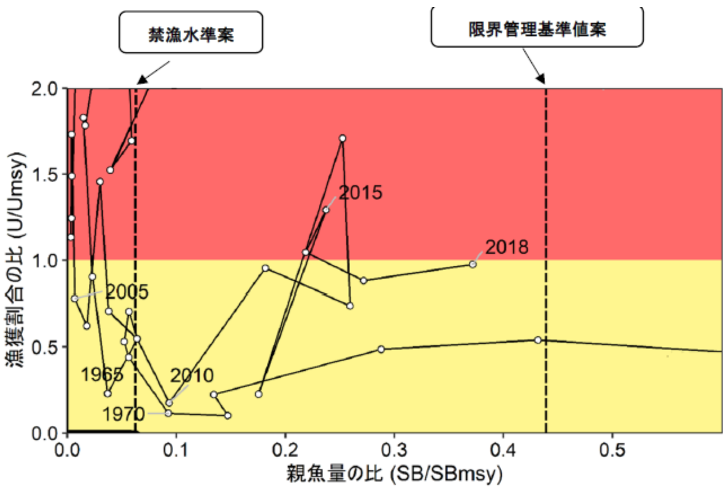
When the ratio of fishing mortality is put on the vertical axis (a-1) and its enlarged view (a-2). For the proposed target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) in the figure, we used SBmsy, SB0.6msy and SB0.1msy, respectively, which assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period.

b-1) When the vertical axis is the ratio of the exploitation rate (U/Umsy)



漁獲割合の比	U/Umsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

b-2)Enlarged view

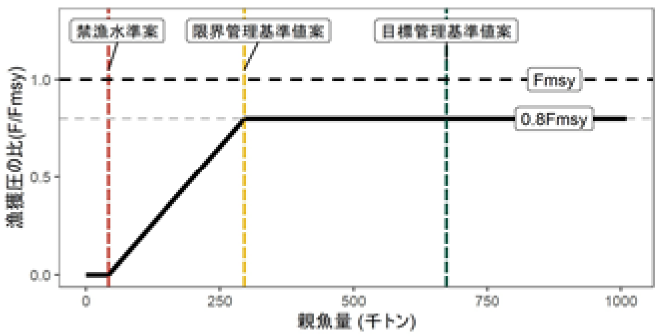


漁獲割合の比	U/Umsy
親魚量の比	SB/SBmsy
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit

Appendix Figure 4-4 (continued). Kobe plot (four sections)

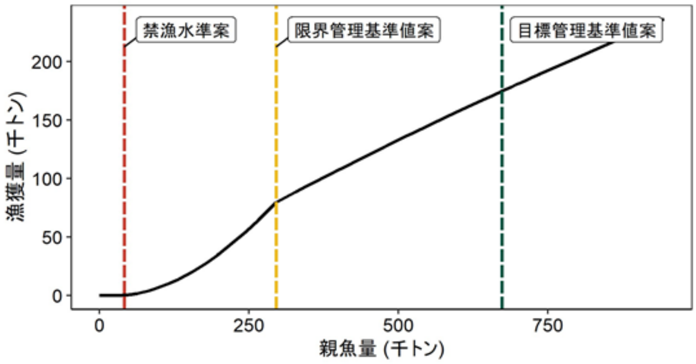
When the ratio of fishing mortality is used (b-1) and its enlarged view (b-2). As the proposed target reference point (SBtarget), limit reference point (SBlimit) and fishing ban level (SBban) in the figures, we used SBmsy, SB0.6msy and SB0.1msy, respectively, which assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period.

a) When the vertical axis is fishing mortality



漁獲圧の比	F/Fmsy
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

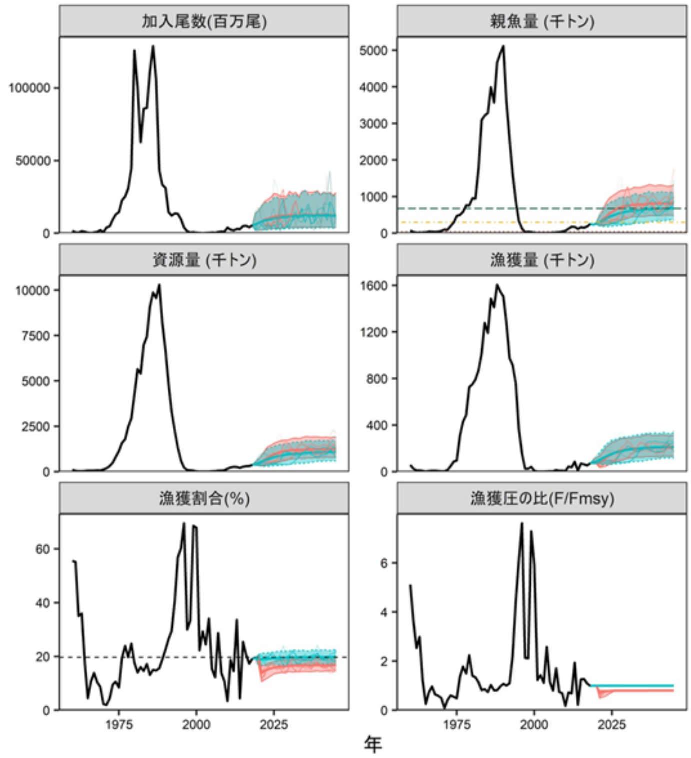
b) When the vertical axis is catch



漁獲量（千トン）	Catch (thousand tons)
親魚量（千トン）	Spawning biomass (thousand tons)
禁漁水準案	Proposed SBban
限界管理基準値案	Proposed SBlimit
目標管理基準値案	Proposed SBtarget

Appendix Figure 4-5. Proposed HCRs

The proposed target reference point (SBtarget) is SBmsy, which is calculated based on the HS S-R relationship assuming the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period. Standard values are used for the proposed limit reference point (SBlimit) and the proposed fishing ban level (SBban). Safety coefficient β is set to 0.8, which is the standard value. The black dashed line represents Fmsy; the grey dashed line represents 0.8Fmsy; the black thick line represents the HCRs; the red dashed line represents the proposed fishing ban level; the yellow dashed line represents the proposed limit reference point; and the green dashed line represents the proposed target reference point. In a) the ratio of fishing mortality is put on the vertical axis, while in b) the catch is put on the vertical axis. Regarding b), the catch varies a little depending on the age composition of the fishing year but here we show the catch of average age composition at equilibrium.



加入尾数（百万尾）	Recruitment (million individuals)
資源量（千トン）	Stock biomass (thousand tons)
漁獲割合	Exploitation rate (%)
親魚量（千トン）	Spawning biomass (thousand tons)
漁獲量（千トン）	Catch (thousand tons)
漁獲圧の比	Ratio of the fishing mortality to MSY
年	Year

Appendix Figure 4-6. Comparison of the future projection based on the proposed HCRs (in red) with the future projection that assumes continued fishing at the current fishing mortality level (in green) when the S-R relationship of the normal recruitment period (1960-1975 and 1991-2017) excluding the transitional period is applied.

The thick solid line, shaded area and thin lines represent average value, the 90% prediction interval that includes 90% of the simulation results, and three future projection examples, respectively. In the figure of spawning biomass, the green dashed line represents the proposed target reference point, the yellow dotted line represents the proposed limit reference point and the red line shows the proposed fishing ban level. The dashed line in the chart of exploitation rate shows Umsy. The dashed line in the chart of exploitation rate expresses Umsy. The catch in 2019 and 2020 are assumed based on the projected stock biomass and Fcurrent, while the catch in 2021 and after is based on the proposed HCRs (Appendix Figure 2-5). Safety coefficient β is set to 0.8.

Appendix Table 4-1. Catch, fishing mortality, etc. corresponding to the proposed reference points and fishing ban level

管理基準値案	説明	親魚量（千トン）	SB0に対する比※	漁獲量（千トン）※※	漁獲圧（%SPR）※※※	漁獲割合※※※※	現状の漁獲圧に対する比※※※※※
目標管理基準値案（移行期を除く通常加入期）	SBmsy	674	0.39	217	40.5	0.20	1.00
限界管理基準値案（移行期を除く通常加入期）	SB0.6msy	296	0.17	127	31.5	0.25	1.38
禁漁水準案（移行期を除く通常加入期）	SB0.1msy	42	0.02	21	27.1	0.28	1.63
MSYを実現する漁獲圧	Fmsy	（0歳, 1歳, 2歳, 3歳, 4+歳）=（0.254, 0.146, 0.249, 0.429, 0.429）					

管理基準値案	Proposed reference points
説明	Explanation
親魚量（千トン）	Spawning biomass (thousand tons)
SB0 に対する比	Ratio to SB0
漁獲量（千トン）	Catch (thousand tons)
漁獲圧	Fishing mortality
漁獲割合	Exploitation rate
現状の漁獲圧に対する比※	Ratio to the current fishing mortality*
目標管理基準値案（移行期を除く通常加入期）	Proposed target reference point (normal recruitment periods excluding the transitional period)
限界管理基準値案（移行期を除く通常加入期）	Proposed limit reference point (normal recruitment periods excluding the transitional period)
禁漁水準案（移行期を除く通常加入期）	Proposed fishing ban level (normal recruitment periods excluding the transitional period)
MSY を実現する漁獲圧	Fishing mortality that produces MSY
（0 歳, 1 歳, 2 歳, 3 歳, 4+歳）＝（0.254, 0.146, 0.249, 0.429, 0.429）	(Ages 0, 1, 2, 3, 4 and above) = (0.254, 0.146, 0.249, 0.429, 0.429)

* Ratios of the proposed reference points and fishing ban level to the initial spawning biomass assuming zero catch (SB0)

** Average catch at equilibrium under the fishing mortality corresponding to the proposed reference points and fishing ban level

*** %SPR-converted value of fishing mortality corresponding to the proposed reference points

and fishing ban level
**** Exploitation rate corresponding to the proposed reference points and fishing ban level
***** Ratios of the fishing mortality corresponding to the proposed reference points and fishing ban level to the current fishing mortality

Appendix Table 4-2. Probability for future spawning biomass to exceed the proposed target reference point (%)

The table shows the result of the future projection based on the HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period (Appendix Figure 4-5), when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	1	3	7	13	16	22	28	30	32	35	36	45	44
0.9	0	0	1	3	8	16	22	30	37	40	44	47	49	55	56
0.8	0	0	1	3	10	21	29	37	45	50	56	60	64	67	69
0.7	0	0	1	4	12	25	36	49	56	64	68	72	74	80	78
0.6	0	0	1	4	14	31	45	57	66	75	78	82	84	88	87
0.5	0	0	1	4	16	36	52	67	76	83	86	89	92	94	94
0.4	0	0	1	5	19	42	61	75	84	89	93	95	96	97	98
0.3	0	0	1	6	22	49	68	82	91	94	97	98	98	99	99
0.2	0	0	1	6	27	54	76	89	95	97	99	99	99	100	100
0.1	0	0	1	7	31	61	82	93	97	99	100	100	100	100	100
0.0	0	0	1	7	37	68	87	96	98	99	100	100	100	100	100

Appendix Table 4-3. Probability for the future spawning biomass to exceed the proposed limit reference point (%)

The table shows the result of the future projection based on the HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period (Appendix Figure 4-5), when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	8	41	61	72	79	84	89	91	92	94	96	96	99	99
0.9	0	8	41	63	77	82	89	92	94	96	97	98	98	100	100
0.8	0	8	41	66	80	87	92	96	97	98	98	99	99	100	100
0.7	0	8	41	69	82	90	95	98	98	99	99	100	100	100	100
0.6	0	8	41	72	86	93	97	99	99	99	100	100	100	100	100
0.5	0	8	41	75	88	94	98	99	100	100	100	100	100	100	100
0.4	0	8	41	77	91	96	99	99	100	100	100	100	100	100	100
0.3	0	8	41	79	92	97	99	100	100	100	100	100	100	100	100
0.2	0	8	41	81	93	98	99	100	100	100	100	100	100	100	100
0.1	0	8	41	84	95	99	100	100	100	100	100	100	100	100	100
0.0	0	8	41	85	96	99	100	100	100	100	100	100	100	100	100

Appendix Table 4-4. Probability that future spawning biomass will exceed the proposed fishing ban level (%)

The table shows the result of the future projection based on the HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period (Appendix Figure 4-5), when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix Table 4-5. Changes in average spawning biomass in the future (thousand tons)

The table shows the result of the future projection based on the HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period (Appendix Figure 4-5), when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	262	300	354	408	458	495	529	562	586	605	620	631	685	686
0.9	232	262	300	362	426	487	535	577	617	646	668	685	696	748	749
0.8	232	262	300	370	444	519	578	630	677	711	735	753	764	813	814
0.7	232	262	300	378	464	553	625	687	742	781	808	826	837	882	883
0.6	232	262	300	386	485	589	676	750	812	856	885	904	915	958	959
0.5	232	262	300	395	508	628	731	817	889	938	969	989	1,000	1,044	1,044
0.4	232	262	300	404	531	670	791	891	972	1,026	1,062	1,084	1,095	1,142	1,142
0.3	232	262	300	413	556	715	855	971	1,063	1,125	1,165	1,189	1,203	1,255	1,256
0.2	232	262	300	422	582	764	925	1,059	1,165	1,235	1,282	1,310	1,327	1,389	1,389
0.1	232	262	300	432	609	815	1,002	1,156	1,277	1,359	1,415	1,450	1,471	1,548	1,549
0	232	262	300	442	638	871	1,084	1,263	1,403	1,500	1,568	1,613	1,641	1,741	1,743

Appendix Table 4-6. Changes in average catch in the future (thousand tons)

The table shows the result of the future projection based on the HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period (Appendix Figure 4-5), when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals. The projection assumes Fcurrent catch for 2019 and 2020 and catch corresponding to the proposed HCRs for 2021 and after.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	81	89	93	114	130	145	159	169	178	186	191	196	200	215	216
0.9	81	89	85	107	125	141	156	168	177	186	191	196	199	212	213
0.8	81	89	77	99	118	135	152	164	174	183	188	193	195	206	207
0.7	81	89	68	90	109	128	145	158	168	176	182	186	188	197	198
0.6	81	89	59	81	99	118	135	148	159	167	172	176	178	185	186
0.5	81	89	50	70	88	106	123	136	146	154	158	162	163	170	170
0.4	81	89	40	58	74	91	107	119	129	136	140	143	145	150	150
0.3	81	89	31	45	59	74	87	98	107	113	117	119	121	125	125
0.2	81	89	21	31	42	53	64	72	79	84	87	89	90	94	94
0.1	81	89	11	16	22	28	35	40	44	47	48	50	50	53	53
0	81	89	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix Table 4-7. Summary of the expected spawning biomass / catch and the probability that the spawning biomass will exceed the proposed reference points

Results when safety coefficient β is changed from 0.0 to 1.0 in 0.1 intervals for the scenario of using the proposed HCRs that assume the conditions of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period.

β	10 年後（2031 年）の平均親魚量（千トン）	10 年後（2031 年）に親魚量が目標管理基準値案を上回る確率	0 年後（2021 年）の予測漁獲量（千トン）	5 年後（2026 年）の予測漁獲量（千トン）	10 年後（2031 年）の予測漁獲量（千トン）	10 年後（2031 年）に親魚量が限界管理基準値案を上回る確率
1	631	36%	93	169	200	96%
0.9	696	49%	85	168	199	98%
0.8	764	64%	77	164	195	99%
0.7	837	74%	68	158	188	100%
0.6	915	84%	59	148	178	100%
0.5	1,000	92%	50	136	163	100%
0.4	1,095	96%	40	119	145	100%
0.3	1,203	98%	31	98	121	100%
0.2	1,327	99%	21	72	90	100%
0.1	1,471	100%	11	40	50	100%
0	1,641	100%	0	0	0	100%

10 年後（2031 年）の平均親魚量（千トン）	Average spawning biomass (thousand tons) after 10 years (2031)
10 年後（2031 年）に親魚量が目標管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed target reference point after 10 years (2031)
0 年後（2021 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 0 years (2021)
5 年後（2026 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 5 years (2026)
10 年後（2031 年）の予測漁獲量（千トン）	Projected catch (thousand tons) after 10 years (2031)
10 年後（2031 年）に親魚量が限界管理基準値案を上回る確率	Probability for spawning biomass to exceed the proposed limit reference point after 10 years (2031)

MSE of handling of transitional periods

This proposal assumes that the normal recruitment periods are 1960-1975 and 1988-2017. However, based on the proposed HCRs that remove the period from 1988 to 1990 as the transitional period from the normal recruitment periods, fishing mortality is high when the spawning biomass is small (Table 3 and Appendix Table 4-3). If the normal recruitment periods excluding the transitional period are applied to catch calculation when the true S-R period is that of the normal recruitment period, there is a risk to set the catch too high and the biomass would not recover.

If the assumption of the recruitment mode is wrong, namely the normal recruitment period excluding the transitional period is applied to catch calculation even though the true S-R relationship is that for the whole period, the risk that the biomass would not recover might increase.

For this reason, we used simplified MSE to assess the impact when the S-R relationship chosen for catch calculation is not the true S-R relationship. Based on the "Comparison of robustness of multiple reference points and examination of HCRs using simplified MSE (FRA-SA2020-BRP01-7)," we conducted simulation 300 times.

[1] Risk of delay in biomass recovery involved in handling of transitional period

As the true S-R relationship, we assumed the HS model applied to the data of the normal recruitment periods (1960-1975 and 1988-2017) by using the least squares method, and used for catch calculation the HS S-R relationship applied to the data of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period by using the least squares method (Appendix Tables 4-9 to 4-11). We compared the result with the result when catch calculation is also based on the normal recruitment periods (Tables 4 to 8) to examine the risk of delay in biomass recovery when handling of the transitional period is wrong.

When the normal recruitment periods excluding the transitional period is applied to catch calculation and β is set to 0.8, the probability that the average spawning biomass estimated in 2031 that is 10 years after starting the control will exceed the true reference points (990 thousand tons for normal recruitment period) is 54% (Appendix Table 4-8); and the probability to exceed the true limit reference point (454 thousand tons) is 91%. (Appendix Table 4-9). The average catch projected in 2021 is 76 thousand tons (Appendix Table 4-11).

When the normal recruitment periods are applied also to catch calculation and β is set to 0.8, the probability of exceeding the proposed target reference point in 2031 is 58% (Table 4); the probability of exceeding the proposed limit reference point is 99% (Table 5) and; the average catch projected in 2021 is 54 thousand tons (Table 8).

If the handling of the transitional period is wrong, the catch in 2021 will increase but there is a risk of delay in biomass recovery.

[2] Risk of delay in biomass recovery involved in selection of recruitment mode assumption

We used the HS model applied to the data of the whole period (1960-2017) using the least squares and simultaneous autocorrelation estimation methods for the true S-R relationship, while the HS S-R relationship applied to the data of the normal recruitment periods (1960-1975 and 1988-2017) excluding the transitional period with the least squares method is used for the catch calculation (Appendix Tables 4-12 to 4-15). By comparing the results with the results when the catch is calculated based on the S-R relationship of the normal recruitment periods (1960-1975 and 1988-2017) (Appendix Tables 3-1 to 3-4), we examined the risk of delay in biomass recovery when selection of the assumption of the recruitment mode is wrong.

When the proposed reference points based on the normal recruitment period excluding the transitional period are applied to catch calculation and when β is set to 0.8, the probability that the average spawning biomass estimated in 2031 that is 10 years after starting the control will exceed the true proposed target reference point (2.114 million tons for whole period) is 41% (Appendix Table 4-12), and the probability of its exceeding the true proposed limit reference point (806 thousand tons) is 71% (Appendix Table 4-9).

When the proposed reference points based on the normal recruitment periods is applied to catch calculation and when β is set to 0.8, the probability of exceeding the proposed target reference point in 2031 is 41% (Appendix Table 3-1) and the probability of exceeding the proposed limit reference point is 72% (Appendix Table 3-2).

If the handling of transitional period is wrong, there are some risks that biomass will not exceed the limit reference point and a risk of delay in biomass recovery involved in selection of recruitment mode.

Appendix Table 4-8. Probability that the future spawning biomass will exceed the proposed target reference point of the true S-R relationship (%)

When the true S-R relationship is that of the normal recruitment period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	3	5	10	12	12	18	22	27	34	41	50
0.9	0	0	0	1	3	7	11	15	16	23	29	36	42	53	61
0.8	0	0	0	1	3	8	12	19	23	30	35	48	54	68	74
0.7	0	0	0	1	3	10	16	23	31	38	49	61	65	79	83
0.6	0	0	0	1	4	11	20	29	40	50	64	70	77	92	91
0.5	0	0	0	1	5	12	24	33	49	63	77	83	88	96	97
0.4	0	0	0	1	5	16	27	44	61	75	86	91	94	99	99
0.3	0	0	0	1	5	20	32	56	73	86	91	95	97	100	100
0.2	0	0	0	1	7	22	40	65	82	91	95	98	98	100	100
0.1	0	0	0	1	7	24	49	75	89	93	98	99	99	100	100

Appendix Table 4-9. Probability that the future spawning biomass will exceed the proposed limit reference point of the true S-R relationship (%)

When the true S-R relationship is that of the normal recruitment period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	5	17	26	34	42	51	54	61	66	69	74	92	95
0.9	0	0	5	17	27	36	48	57	65	71	77	81	85	97	99
0.8	0	0	5	18	29	38	55	65	73	78	84	88	91	99	100
0.7	0	0	5	20	33	48	63	73	82	88	91	94	95	100	100
0.6	0	0	5	21	37	54	71	81	88	92	94	97	98	100	100
0.5	0	0	5	22	40	61	80	89	92	94	97	98	98	100	100
0.4	0	0	5	23	46	72	86	91	94	98	99	99	99	100	100
0.3	0	0	5	26	51	82	91	95	98	98	99	100	100	100	100
0.2	0	0	5	27	59	85	95	97	98	99	100	100	100	100	100
0.1	0	0	5	29	66	90	96	98	99	100	100	100	100	100	100

Appendix Table 4-10. Changes in the average spawning biomass in the future (thousand tons)

When the true S-R relationship is that of the normal recruitment period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	261	295	343	397	458	533	587	646	692	726	809	880	989	1,058
0.9	232	261	295	351	414	487	576	643	716	777	825	920	1,002	1,117	1,165
0.8	232	261	295	359	432	519	624	706	796	875	936	1,045	1,136	1,229	1,261
0.7	232	261	295	367	451	553	677	778	888	986	1,060	1,179	1,275	1,335	1,358
0.6	232	261	295	375	472	590	735	857	989	1,106	1,194	1,319	1,417	1,445	1,463
0.5	232	261	295	384	493	630	798	945	1,101	1,237	1,335	1,464	1,562	1,565	1,580
0.4	232	261	295	393	516	674	868	1,043	1,225	1,378	1,484	1,616	1,715	1,698	1,715
0.3	232	261	295	402	540	720	944	1,150	1,358	1,529	1,643	1,780	1,881	1,851	1,870
0.2	232	261	295	411	566	771	1,027	1,269	1,504	1,692	1,816	1,960	2,065	2,033	2,052
0.1	232	261	295	420	593	825	1,118	1,398	1,662	1,868	2,005	2,158	2,270	2,250	2,272

Appendix Table 4-11. Changes in the average catch in the future (thousand tons)

When the true S-R relationship is that of the normal recruitment period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	81	88	92	109	124	140	160	175	190	205	213	229	250	282	299
0.9	81	88	84	102	119	136	158	175	192	208	219	236	257	288	299
0.8	81	88	76	95	113	131	155	173	191	209	221	240	261	284	291
0.7	81	88	67	87	105	124	148	168	188	207	220	239	259	273	278
0.6	81	88	58	78	96	115	139	160	180	200	214	231	249	257	260
0.5	81	88	49	68	85	104	127	148	168	188	202	217	232	236	238
0.4	81	88	40	56	72	90	111	131	151	169	182	194	207	208	210
0.3	81	88	30	44	58	73	91	109	127	142	153	163	174	173	175
0.2	81	88	21	31	41	52	67	81	95	107	115	122	129	129	130
0.1	81	88	10	16	22	28	37	45	53	60	65	69	73	73	74

Appendix Table 4-12. Probability that the future spawning biomass will exceed the proposed target reference point of the true S-R relationship (%)

When the true S-R relationship is that of the whole period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	0	3	6	11	14	19	21	24	28	30	35	38
0.9	0	0	0	0	3	7	12	14	20	23	27	30	35	40	43
0.8	0	0	0	0	3	8	12	17	21	27	28	34	41	45	48
0.7	0	0	0	0	3	8	13	18	25	29	32	39	45	50	53
0.6	0	0	0	0	3	9	14	20	27	34	37	44	49	58	61
0.5	0	0	0	0	3	10	15	22	29	38	44	50	55	64	70
0.4	0	0	0	0	3	10	18	24	35	42	49	55	60	73	77
0.3	0	0	0	0	3	11	20	27	38	45	56	61	63	81	81
0.2	0	0	0	0	4	12	22	32	41	52	62	69	72	86	87
0.1	0	0	0	0	4	14	23	37	47	57	67	73	77	90	92

Appendix Table 4-13. Probability that the future spawning biomass will exceed the proposed limit reference point of the true S-R relationship (%)

When the true S-R relationship is that of the whole period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	0	0	0	6	17	25	33	39	44	50	55	59	61	73	78
0.9	0	0	0	6	18	27	35	42	45	54	59	62	65	77	83
0.8	0	0	0	6	20	28	37	45	50	58	61	66	71	82	88
0.7	0	0	0	7	21	30	40	47	54	60	64	71	74	89	94
0.6	0	0	0	7	21	32	43	50	58	63	70	74	77	94	97
0.5	0	0	0	8	23	33	45	54	62	68	74	78	81	96	99
0.4	0	0	0	9	24	36	48	59	65	73	77	81	85	99	99
0.3	0	0	0	9	25	38	49	61	69	75	81	85	89	100	99
0.2	0	0	0	9	26	41	54	67	75	81	87	91	93	100	100
0.1	0	0	0	10	28	43	59	71	81	87	90	94	95	100	100

Appendix Table 4-14. Changes in the average spawning biomass in the future (thousand tons)

When the true S-R relationship is that of the whole period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	232	259	293	377	512	711	949	1,146	1,292	1,411	1,497	1,687	1,900	2,038	2,108
0.9	232	259	293	385	529	744	1,002	1,220	1,389	1,532	1,633	1,838	2,063	2,231	2,312
0.8	232	259	293	392	548	778	1,059	1,301	1,496	1,662	1,781	2,001	2,239	2,436	2,512
0.7	232	259	293	400	567	816	1,122	1,390	1,616	1,807	1,948	2,185	2,436	2,664	2,735
0.6	232	259	293	408	587	856	1,190	1,490	1,748	1,969	2,137	2,393	2,661	2,913	2,971
0.5	232	259	293	416	609	899	1,264	1,598	1,893	2,148	2,345	2,623	2,911	3,180	3,219
0.4	232	259	293	424	631	946	1,345	1,718	2,054	2,346	2,576	2,878	3,191	3,467	3,498
0.3	232	259	293	433	655	996	1,432	1,849	2,233	2,570	2,835	3,168	3,505	3,788	3,800
0.2	232	259	293	441	680	1,049	1,528	1,995	2,433	2,821	3,125	3,491	3,858	4,153	4,148
0.1	232	259	293	450	707	1,107	1,632	2,156	2,656	3,101	3,454	3,858	4,260	4,579	4,561

Appendix Table 4-15. Changes in the average catch in the future (thousand tons)

When the true S-R relationship is that of the whole period but the catch is calculated based on the S-R relationship of the normal recruitment period excluding the transitional period

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2041	2051
1.0	80	89	88	108	136	177	233	284	322	354	374	409	462	507	525
0.9	80	89	80	102	129	170	226	277	317	351	374	409	460	509	528
0.8	80	89	72	94	122	162	216	268	309	345	369	403	453	504	521
0.7	80	89	64	86	113	152	205	255	297	335	360	394	440	492	505
0.6	80	89	56	77	102	139	190	239	281	318	345	378	421	470	480
0.5	80	89	47	67	90	124	171	218	259	295	322	353	393	437	443
0.4	80	89	38	56	76	106	148	191	229	263	289	317	352	390	395
0.3	80	89	29	43	61	86	120	157	190	220	243	267	297	327	330
0.2	80	89	20	30	43	61	87	115	141	164	183	201	223	246	246
0.1	80	89	10	16	23	33	47	63	78	92	103	114	126	139	139