Basic Guidelines for Harvest Control Rules and ABC Calculation (Fiscal Year 2022)

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I. Preface

United Nations Convention on the Law of the Sea and Fishery Stock Resources Management in Japan

In association with maritime law, Article 61 of the United Nations Convention on the Law of the Sea (UNCLOS) stipulates with regard to the conservation of biological stock within the country's own exclusive economic zone (EEZ) that: 1) The coastal State shall determine the allowable catch of the living resources in its exclusive economic zone [1], 2) The coastal State, taking into account the best scientific evidence available to it, shall ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation. (As appropriate, the coastal State and competent international organizations, whether subregional, regional or global, shall cooperate to this end.) [2], and 3) Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global.[3] Japan, as a ratified member of UNCLOS, must strive to manage and conserve its own marine living resources in accordance with this convention. The Fishery Act (Revised Fishery Act), which entered into effect in December 2020, also determines target reference point(s) required for MSY (target levels for

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[2] The coastal State, taking into account the best scientific evidence available to it, shall ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation. (As appropriate, the coastal State and competent international organizations, whether subregional, regional or global, shall cooperate to this end.)

[3] Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global.

sustainability and recovery), and a total allowable catch (TAC) to ensure that stock levels exceed the target reference point(s) in a sustainable way. Additionally, the Basic Policy on Resource Control (Fisheries Agency 2020), which is formulated based on the Revised Fishery Act, prescribes targets for resource management including the target reference point(s) and limit reference point(s) from Article 12.1.1 and 12.1.2 of the revised Fishery Act, and also prescribes the stock levels from Article 12.2 as target values to achieve sustainability and/or recovery. Based on these regulations, for fisheries resources which are not considered to be international, catch strategies for each fisheries resource are drafted based on more specific target values and term limits decided by the stakeholder meeting and the Fisheries Policy Council. These catch strategies are published in order of completion as appendices to the Basic Policy on Resource Control to set specific stock management policies for individual fisheries resources. The catch calculated from these individual catch strategies makes up the allowable biological catch (ABC), and in principle becomes the upper limit of the TAC.

Harvest Control Rules (HCR), which are used to prescribe reference points and catch strategies, are prescribed according to policies described in these guidelines, in the same way that catch strategies are prescribed according to the Revised Fishery Act and the Basic Policy on Resource Control when the Japan Fisheries Research and Education Agency is commissioned by the Minister of Agriculture, Forestry and Fisheries to conduct business relating to stock assessments. The preface defines MSY and introduces the concepts of risk management and adaptive management, and HCR based on these concepts are prescribed from Section II onward.

MSY (maximum sustainable yield)

MSY is generally defined as the maximum catch that allows for continuous and sustainable fishing. The classic definition of MSY was based on the surplus production model (Tanaka 1998), which states that if a fishery maintains an exploitation rate of half the natural growth rate, then stock size will be sustained at half of the initial stock size, and the maximum catch will continue forever. However, classic MSY was criticized for ignoring the impact of uncertainty, failing to account for the fact that some species of fish cannot be fished at a fixed rate due to the vulnerability of their environment, lacking adequate consideration for economic perspectives, and difficulty in performing estimates (Larkin 1977). In response to such criticisms, interpretations of MSY and methodologies for applying MSY to actual management have developed significantly. Now, it possible to leverage the concept of MSY in actual management practices while considering various uncertainties and factors affecting MSY (Tanaka 1991, Mace 2001, Punt and Smith 2001).

Under the Revised Fishery Act, MSY is defined as the maximum amount of a fisheries resource that is possible to catch sustainably under natural conditions in the present, and in the logically projected future. Furthermore, these guidelines consider MSY to be the maximum catch that can be obtained when fishing pressure is kept constant under conditions as projected by currently available data, while considering uncertainties in stock assessment and MSY estimates in addition to fluctuations in natural conditions.

Acceptable Biological Catch (ABC) Calculation Based on Risk and Adaptive Management

The gathering of fisheries resource data, and performing stock assessments based on that data, generally involves a large degree of uncertainty. For this reason, dependence on point estimates based on deterministic models invites the risk of mismanaging stocks and failing to achieve the desired results (Punt et al. 2016). Accordingly, these guidelines place importance on risk assessment based on probabilistic future projection models for stock size. Using statistical methods and simulation tools, we propose management rules that allow for sustainable fishing in a future projection simulation that takes into account the uncertainties associated with data sampling, parameter estimation, and implementing management, as well as the impact of environmental fluctuations.

Likewise, there is also uncertainty in estimated reference values (reference points), which set targets and limits for stock management, due to factors such as the lack of biological and time-series data, and errors in stock assessment. Consequently, the reference points for stock management in Japan are fundamentally reviewed and updated every five years (because they are reviewed every five years, flexible revisions can be made according to information found in the data). Despite this short management period, if new findings arise which pose a significant risk for the implementation of management policies, or if it is judged that changes in the reference points or catch strategies are recommended due to circumstances outside of initial expectations, then these will be updated as appropriate (see Appendix: Guidelines for Revising Reference Points and HCR Within the Management Period).

Consideration of the Characteristics of Individual Stocks

Fisheries resources in Japan are characterized by the fact that many stocks experience significant fluctuations in stock size due to changes in the atmospheric and marine environment (Watanabe et al. 1995, 1996), and that autonomous management systems established by fisheries cooperatives already exist because the fishing industry has a long history (Makino 2011). Meanwhile, there are also some stocks for which it is difficult to estimate MSY with high reliability due to a lack of data and rough stock assessment. These guidelines describe basic recommendations for proposing reference points and HCRs, but if there exists a more appropriate method which considers the characteristics of individual stocks as described above, then that method can be used according to scientific explanation and a mutual understanding among participating research institutions. Appropriate scientific explanation demands the consideration of objectivity (the calculation method used to find numerical evidence is objective), reproducibility (anyone can reproduce the results), and transparency (the reasoning for choosing rules can be explained).

II. Stocks Subject to Assessment in Japan

Overview of Stock Assessment

In order to provide maximum consideration for the biological characteristics of each target species, stock assessments for each stock should involve estimation of stock size and reference points using a population dynamics model which includes as much age composition data as possible, and the stock-recruitment relationship. Population dynamics models used to estimate stock size preferentially employs cohort analysis (Virtual Population Analysis, or VPA) and Statistical Catch At Age (SCAA), which consider age composition. When using a technique such as VPA, in which parameters related to the stock-recruitment relationship are not estimated within the stock assessment model, the stock-recruitment relationship estimates are performed outside the population dynamics model using estimates for recruitment and spawning stock biomass (SSB) obtained from the model.

At the same time, even when catch in number at age is unavailable, it is recommended to use a stock assessment model which is appropriate for the data and biological characteristics obtained for each stock in order to evaluate estimated stock size and its uncertainty. Stock assessment techniques which can be used in the absence of data on catch in number at age include Statistical Catch at Size (when age data is not available, but body size data such as length is available) and production models (when data on catch and the abundance index can be obtained, but age composition data is not available) (e.g., Quinn and Deriso 1999, Chapter 2 and 5).

In order to make practical use of information on relative trends in stock fluctuations, it is also recommended that information on fishing effort be utilized in addition to catch when estimating stock size. However, when catch per unit effort (CPUE), which is the catch obtained from fisheries or surveys divided by the units of effort, is used as an abundance index, then it is necessary to use standardization (CPUE standardization), which eliminates factors that bias the abundance index, in order to make results closer to the true trend of the stock size (Maunder and Punt 2004). If the abundance index is available, but estimates cannot be obtained from the stock assessment model, or are not considered to be reliable, then the stock status should be judged based on changes over time in the abundance index. When the abundance index is invalid, catch size or changes over time in biological data of catches can be used as resources to judge changes in the stock size, but this is only a short-term stopgap measure, so efforts should be made to promptly obtain a valid abundance index.

If there is insufficient information to estimate absolute or relative values for stock size, or if a reliable abundance index cannot be obtained, then information on catch size and fishing effort, and survey data, should be collected to continuously monitor trends in stock.

Stock assessments should be conducted periodically (making estimates on an annual basis is recommended, especially for basic information such as stock size and exploitation rate). In addition, expedited publication by way of peer-reviewed scientific journals is encouraged when new and previously unknown findings or techniques are applied to stock assessments.

Classification of Japanese Fisheries Resources (Group 1 and Group 2)

Japan's fisheries resources are classified into the following two groups according to differences in available information and methods for estimating stock size, while basic HCRs are prescribed for each classification group.

Group 1:Cases when population dynamics models are used to estimate stock size based on catch size and fishing effort information by inserting estimates into the stock-recruitment relationship to obtain results for reference points calculated based on MSY (MSY reference points) or similar reference points, future absolute abundance, and the exploitation rate, while future projections can also be used. However, this group is broadly divided into the following three categories based on the methods used to calculate the reference point(s).

1A: Cases when estimated stock size has been obtained from age-structured population dynamics models, and robust MSY reference points can be calculated based on the stock-recruitment relationship. In these cases, the MSY reference point based on the stock-recruitment relationship is proposed as the target reference point.

1B: Cases when estimated stock size has been obtained from age-structured population dynamics models, but MSY reference points based on the stock-recruitment relationship are considered to be imprecise or not robust due to significant uncertainties in the stock-recruitment relationship, etc., even though other alternative biological reference points can be calculated. In these cases, a biological reference point based on fishing pressure (F-based biological reference point) can be used to propose target reference points. For example, F that corresponds to the %SPR (the ratio of spawning per recruit when fishing at a certain intensity, to when there is no fishing) (specifically, $F_{\%SPR}$), can be used as an alternative to Fmsy (fishing pressure required for MSY).

1C: Cases when estimated stock size and MSY reference points can be obtained from population dynamics models based on stock biomass, but cannot be obtained from age-structured population dynamics models. In these cases, the MSY reference points estimated from the population dynamics models based on stock biomass are proposed as the target reference points.

Group 2:Cases when information on catch size and fishing effort is valid, but cannot be easily fitted into population dynamics models, and either absolute abundance, exploitation rate, or estimated reference points are unavailable. In these cases, we recommend the application of empirical HCR, and propose that the levels established in management rules be used as the reference points.

III. Reference Points and Harvest Control Rules (Group 1A)

Establish reference points in order to fulfill Japan's stock management goals. The target reference point for the total stock size or SSB shall be set as B_{target} or SB_{target}, the limit reference point as B_{limit} or SB_{limit}, and the fishing ban level as B_{ban} or SB_{ban}, and the values estimated in accordance with the following guidelines shall be proposed by the participating research institutions. If multiple candidate reference values/levels are proposed, the advantages and disadvantages of said candidates, and the reasons for their proposal, shall be included. This section describes cases when SSB is used as the reference value for management. However, the same approach also applies when total stock size is used as the reference point. Additionally, details relating to the calculation of reference points and future projections for Stock Group 1 are described in Technical Notes on Stock-Recruitment Relationship Estimates, Reference Point Calculations, and Future Projection Simulations (FY 2022) (FRA-SA2022-ABCWG02-04), and the approach for selecting a stock-recruitment relationship is described in Guidelines for Determining Stock-Recruitment Relationships (FY2022) (FRA-SA2022-ABCWG02-03).

<u>Stock-Recruitment Relationships</u>

In order to project mid/long-term [4] catch size and SSB, it is necessary to choose a stock-recruitment relationship that assumes a density effect, which demonstrates the relationship between recruitment in number and the spawning population size, and to choose a population dynamics model that describes how recruited individuals mature and die. Although Beverton-Holt and Ricker stock-recruitment curve models are widely employed for stock-recruitment relationships when age composition models are used, because SB_{msy} (SSB required for MSY) may appear in a range extremely far from the observed range of SSB, the use of a Hockey-Stick (HS) stock-recruitment curve is standard, taking into consideration the advantage that the growth rate can be estimated in a stable manner while avoiding extreme extrapolations (Ichinokawa et al. 2017). Beverton-Holt, Ricker, or an average of these two models, may also be used if appropriate.

[4] In these guidelines, short-term is considered to be approximately 1 to 5 years, the short/medium-term is approximately 1 to 10 years, medium-term is approximately 10 to 30 years, mid/long-term is approximately 10 to 100 years, and long-term is approximately 30 to 100 years.

When estimating MSY which supports the target reference points, or MSY reference points such as SB_{msy} and F_{msy}, use the stock-recruitment relationship projected based on SSB and recruitment values which fall within the range that may possibly occur from the present to the future, and estimate the reference points while considering the uncertainty of those factors. In cases when the projections based on a single stock-recruitment relationship are considered to be unreliable due to the impact of mid/long-term environmental changes such as regime shifts, it is possible to use multiple stock-recruitment relationships to calculate the reference points. Also, if multiple stock-recruitment relationships are being considered, and their respective reference points differ significantly, the most logical stock-recruitment relationship (including use of multiple stock-recruitment relationships and/or their model averages) should be selected according to mutual understanding among scientists based on criteria such as robustness with regard to uncertainty.

Reference Points

Target reference point (SB_{target})

SB_{target} is proposed according to the SSB level required for maximum average catch when fishing continues at a fixed rate of fishing mortality (SB_{msy}) in mid/long-term projections which consider essential uncertainties including fluctuations in recruitment. In these cases, the maximum average catch is MSY, and the corresponding fishing mortality is F_{msy}.

Limit reference point (SB_{limit})

When SSB is maintained at a level below SB_{limit}, significantly low sustainable yield is obtained due to recruitment overfishing. SB_{limit} is the threshold to avoid levels which would suppress the reproduction capacity of existing stock. In mid/long-term future projections which consider essential uncertainties including fluctuations in recruitment, we propose the standard SB_{limit} to be the value which can produce a catch of 60% of MSY when fishing continues at a fixed rate of fishing mortality that is higher than F_{msy}.

Fishing ban level (SB_{ban})

SB_{ban} is the spawning stock level when fishing should be stopped (catch of 0) because it is thought that if the level gets any lower, then the stock will be extremely slow to recover, or will never recover. In mid/long-term future projections which consider essential uncertainties including fluctuations in recruitment, we propose the standard SB_{ban} to be the value which corresponds to a catch of 10% of MSY when fishing continues at a fixed rate of fishing mortality.

Under the premise that the reference points fulfill the basic definitions described above, alternative values for MSY reference points may be proposed according to a logical scientific explanation and a mutual understanding among participating research institutions, depending on the characteristics of the individual stock. For example, it is feasible that there may be insufficient time series data to estimate the stock-recruitment relationship, the reference point may be a significantly extrapolated value, the stock-recruitment relationship may be affected by long-term environmental changes, or the residuals of the stock-recruitment relationship may be found to have an obvious autocorrelation.

Reference points and HCR shall be consistent within short-term management units (standard of five years) unless there are drastic revisions or changes to the stock-recruitment curve or population dynamics models. At the end of five years, the stock-recruitment relationship shall be re-examined in accordance with updated information, and then a decision should be made whether or not to propose new reference points. As a standard, this process shall be repeated every five years to accommodate major environmental changes and updated information.

Harvest Control Rules

Among the HCR proposed by the research institutions, the HCRs mutually agreed upon through stakeholder meetings and the Fisheries Policy Council shall comprise the catch strategy for calculating ABC. These guidelines recommend to use the following Basic HCR based on Okamura et al (2020) to use as candidate HCRs. However, if the stakeholder meetings or the Management Approach Study Group (of the Resource Management Subcommittee, Fisheries Policy Council) request a proposal for alternative management rules (alternative rules), the results of the performance evaluation under the alternative rules shall be presented after considering the impact of the above management on resources and consulting the participating research institutions. In principle, catch strategies should be consistent within a short-term management unit (standard of five years), just as with reference points. However, this is not applicable in situations where there are sufficient grounds to assess that the status of stock will deviate significantly from the future projections used to determine the catch strategy. The Appendix describes when to propose revisions to catch strategies (Guidelines for Revising Reference Points and HCR Within the Management Period).

Basic Harvest Control Rules (Basic HCRs)

Fishing mortality in Basic HCR is determined according to stock levels as follows (Fig. 1):

$$\mathrm{F_t} = \begin{cases} 0 & \text{if } \mathrm{SB_t} < \mathrm{SB_{ban}} \\ \beta\gamma(\mathrm{SB_t})\mathrm{F_{msy}} & \text{if } \mathrm{SB_{ban}} \le \mathrm{SB_t} < \mathrm{SB_{limit}} \\ \beta\mathrm{F_{msy}} & \text{if } \mathrm{SB_t} \ge \mathrm{SB_{limit}} \end{cases}$$

In this equation, β is an adjustment coefficient that considers the impact of uncertainty (usually

$0 < \beta \leq 1$), and SB_t is SSB in the year t ($SB_t = \sum_a m_{t,a} w_{t,a} N_{t,a}$: $m_{t,a}$ is the maturity rate at age a in year t, while $w_{t,a}$ is the mean weight at age a in year t, and $N_{t,a}$ is the number at age a in year t). In addition, $\gamma(SB_t)$ is a coefficient that changes in response to SSB in order to expedite recovery when the SSB is below the limit, and is defined as follows:

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

Because the first year of management is accompanied by a time delay from the last year of valid data, a probabilistic future projection simulation is performed which considers factors such as fluctuations in recruitment, and the projected values are used as the values corresponding to ABC.

The robustness of these Basic HCR has been confirmed by simulations based on information such as biological parameters typical of Japan's Stock Group 1 (Okamura et al 2020). The same simulations also show that if $\beta = 0.8$, then the 40-10 management rule employed in the U.S. (HCR with $SB_{limit} = 0.4SB_0$ and $SB_{ban} = 0.1SB_0$ as described above (SB_0 is the average SSB when fishing is stopped for a long period of time), Thorson et al. 2015) has a similar long-term performance. There are also advantages over the 40-10 rule in short-term performance, and $\beta = 0.8$ is recommended for stock recovery within 10 years on average when uncertainty is high, and stock levels are low (0.2 B_{msy}).

Furthermore, probabilistic future projections are made based on the stock assessment results for each stock in order to incorporate the characteristics of each stock, and to find the short/medium-term impact on resources. When β is adjusted between 0 and 1 after the year ABC is calculated, the probability (%) of the SSB exceeding the target reference points and limit reference points, and the fishing ban level, after a set number of years (e.g., 10 years) is indicated along with the catch at that point. In particular, the appropriate β (or range of β) is determined based on information such as how much difference there is between the performance/risk of the management method compared to when using a value that is recommended according to general simulation results ($\beta = 0.8$), then suggestions are proposed to managers. Additionally, if future projections are obtained that indicate significant fluctuations in the catch during the management period, it is possible to simultaneously present the trial calculation results based on the upper and lower limits rule [5] (Ichinokawa et al. 2022), which restricts the lower and upper limits of fluctuations in the catch during the management period.

If the characteristics of the stock and fisheries are considered to be different from the typical pattern produced by the simulation, such as significantly poor stock status or insufficient stock-recruitment relationship data, it is recommended to run a new simulation to consider a more appropriate β. For short/medium-term future projections, it is recommended, when there is proper

[5] Fundamentally speaking, catches adhere to the Basic HCR, but the lower limit of the catch in year t (C_t) shall be x_{lower} C_t of the catch in year $t-1$ (C_{t-1}) and the upper limit shall be x_{upper} C_t.

evidence to do so, to perform simulations using future projections which include assumptions weighted by trends in recruitment in previous years (e.g. 5 to 10 years) up to the most recent year of stock assessment, and biological information from the most recent year, while considering uncertainty in the short/medium-term recruitment status and biological information. In this manner, if assumptions used in the short/medium-term future projections differ from those in the future projections used for calculating the reference points, then the rationality and robustness of using such assumptions should be discussed, and efforts should be made to reach a mutual understanding among scientists.

Alternative Harvest Control Rules (Alternative HCR)

When research institutions receive requests to consider alternative rules from the stakeholder meetings or the Management Approach Study Group, simulations are performed using Alternative HCR which meet the requests, and the performance is observed. Then the participating research institutions reach a mutual agreement on which rules can be recommended as catch strategies for ABC, and this information is shared with managers together with various performance indices. The scientifically recommended Alternative HCR must meet the management objectives of the stock management policy (e.g., a 50% or greater probability of exceeding the target reference point after 10 years). In addition, risks related to stock sustainability must not be significantly damaging. For this reason, Alternative HCR are divided into two categories for evaluation regarding 1) whether they meet the management objectives, and 2) how their performance ranks against Basic HCR in terms of risks related to stock sustainability. The procedure for categorizing HCR based on performance indices, and the guidelines for recommending Alternative HCR, are described in detail in Guidelines for Proposing Alternative Harvest Control Rules (Alternative HCR) (FY 2022) (FRA-SA2022-ABCWG02-06).

IV. Reference Points and Harvest Control Rules (Group 1B)

Scope of Application of 1B Rules

Estimated stock size can be obtained from age-structured population dynamics models, but it is difficult to obtain robust MSY reference points from the stock-recruitment relationship due to significant uncertainties in the stock-recruitment relationship, or other reasons. However, if other reference points (e.g., $F_{\%SPR}$) can be calculated with relatively high precision, it is possible to propose alternative values corresponding to the MSY reference points based on those biological reference points (HCR based on such alternative reference points are referred to as 1B rules). Cases in which these rules would apply include, for example, those where there is insufficient SSB and recruitment data to estimate the parameters of the stock-recruitment relationship, or where robust MSY reference points cannot be obtained due to instability in estimating the parameters of the stock-recruitment relationship, or where assumptions are made on the parameters of the stock-recruitment relationship in the model. For more details, please refer to the Guidelines for Determining Stock-Recruitment Relationships (FY 2022, FRA-SA2022-ABCWG02-05).

At the same time, however, calculating alternative biological reference points requires knowledge of life history parameters and other factors. Bear in mind, as the calculation of ABC also requires stock size estimates, the data applied for 1B rules requires relatively reliable estimates for alternative target reference points and estimated stock size. Therefore, it is necessary to evaluate uncertainty in estimated stock size and life history parameters, as well as its impact on alternative target reference points.

Reference Points

In 1B rules, the reference points are determined in the following order: the alternative limit reference point, the alternative F_{msy}, and the alternative SB_{msy} (or B_{msy}). The approach behind each respective reference point is summarized below.

Alternative Limit Reference Point (SB_{limit})

In 1A rules, the limit reference point is threshold to avoid levels which would suppress the reproduction capacity of existing stock due to recruitment overfishing, but for Group 1B stocks with a high degree of uncertainty in the stock-recruitment relationship, it is difficult to determine the threshold for recruitment overfishing based on the observed stock-recruitment relationship. Accordingly, the 1B rules use the historical minimum SSB (SB_{min}, or equivalent value) as an alternative limit reference point to prevent SSB from falling below previously unseen low levels. The minimum SSB from the period prior to the initial year of stock management under the Revised Fishery Act is used as the historical minimum SSB, and SB_{limit} is not updated even if the minimum SSB is updated during the management period. Or else, if SB_{min} is deemed to be too small compared to SB_0, such as 10-20%, etc. [6] of the SSB in the absence of fishing (SB_0 or equivalent value), the criterion for SB_0 is considered. It is feasible that a value equivalent to SB_{min} could be a value reached by multiplying SB_{min} by a fixed coefficient when it is deemed to be too large or too small, or a 95% confidence interval of the estimated value of SB_{min} when the uncertainty of the estimated value of SB_{min} is evaluated, etc.

Alternative F_{msy}

The fishing pressure $F_{x\%SPR}$ should be a value for which the spawning per recruit (SPR) is x% of

[6] If the limit reference point is set to SB_{min}, there is a concern that management may become too lenient. A criterion considered appropriate for the situation should be used.

the value when there is no fishing. In principle, *x*% should be the largest value from the following criteria.

① YPR criteria: The %SPR corresponding to F_{max} (F required for maximum YPR), or $F_{0.1}$ if F_{max} is too large (F which gives a slope of 10% at the origin of the YPR curve)

② SPR criteria: The %SPR that is considered robust within the range of stock-recruitment relationship parameters as set based on information from prior meta-analysis, etc., with considerations for each species (e.g., Miyagawa and Ichinokawa, FRA-SA2021-ABCWG02-05).

③ Precautionary criteria: The %SPR corresponding to the largest F which keeps the probability of falling below the limit reference point sufficiently low if fishing continues at $F_{x\%SPR}$ (ICES WKMSYREF3 REPORT 2014)

In principle, the value of $F_{x\%SPR}$ should be consistent during the management period (five years).

Alternative Target Reference Point

Using the alternative F_{msy} as determined above, the alternative target reference point shall be the average SSB, etc., at equilibrium when probabilistic simulations are performed for future projections. For assumptions of recruitment in future projections, appropriate values are selected that are considered representative of future recruitment patterns. (e.g., mean value + logarithmic distribution errors or resampling of past recruitment). In particular, when making future projections for ABC calculation, if more precautionary management can be achieved using a backward resampling method which reflects trends in recruitment in recent years, then that method can also be used. (This method involves the resampling of residuals when a fixed rate of recruitment is assumed, but a spawning relationship is not assumed. However, if this is below the historical minimum SSB, then it is possible to use assumptions of a linear decrease in average recruitment) (FRA-SA2022-ABCWG01-01).

Harvest Control Rules

The Basic HCR and Alternative HCR for Group 1A stocks can be used as HCR for Group 1B. However, based on simulation results which consider uncertainty of averaging error (however, without bias) in F_{msy} (FRA-SA2022-ABCWG01-01), when the true value of $F_{\%SPR}$ which corresponds to F_{msy} is unknown, and using $F_{\%SPR}$ as an alternative for F_{msy}, it has been shown that when $\beta = 0.7$ the performance is equivalent to using $\beta = 0.8$ for Group 1A stocks.

V. Reference Points and Harvest Control Rules (Group 1C)

<u>Stock Assessment and Stock-Recruitment Relationships</u>

When a stock assessment model (production model) without age composition is used (1C rules), the shape of the surplus production curve includes the stock-recruitment relationship, which significantly affects MSY reference points. However, the shape parameters used to determine the shape of the surplus production curve are often difficult to estimate in the model.

Reference Points

In basic terms, reference points such as those defined for Group 1A are used. However, due to the significant uncertainty of estimated values in the production model, the confidence interval should also be indicated for reference points, and it should be updated at the same time the data is updated.

Harvest Control Rules

Similar to Group 1A, start by proposing HCR with robustness proven according to management strategy evaluation (MSE), then implement future projections as necessary. However, reliable estimates for stock size are required for management policies that calculate ABC by multiplying the current estimated stock size by a specific fishing pressure, such as F_{msy}. In cases when there is high uncertainty in absolute stock size, and only the relative trend in stock size is described in the stock assessment, information on absolute stock size cannot be used. In these situations, it is possible to use the relative trend in stock size as an abundance index, and to apply HCR for Stock Group 2 as described below.

VI. Reference Points and Harvest Control Rules (Stock Group 2)

When stock size estimates cannot be obtained from population dynamics models, or when MSY reference points cannot be obtained due to uncertainty in the stock-recruitment relationship, it is not possible to use methods such as those defined for Stock Group 1 which calculate ABC by multiplying the estimated stock size by the appropriate fishing pressure. Therefore, for Stock Group 2 for which only time series data on catch and abundance index (catch per unit effort, or CPUE) is available, empirical HCRs are used to determine the ABC after two years by looking at the amount of change in the abundance index when the catch has been altered. The abundance index to be used here should be estimated as an index that is considered to adequately represent changes in the relative abundance of the stock, based on available data, ecological and fishery knowledge of the target stock, and through examination using statistical techniques such as standardization, and then used only after providing an appropriate scientific explanation. Note that relative trends in stock derived from the production model can also be used.

The target level (B_T) and limit level (B_L) for the abundance index can be defined according to the empirical management rules discussed here, but these exist for the purpose of convenience, and they do not directly correspond to the target reference points and limit reference points of

Stock Group 1. These levels should be treated as thresholds to make the catch higher than the recent catch when the abundance index exceeds the target, or to sharply reduce catch when it falls below the limit.

ABC for Stock Group 2 HCR is obtained using the following equation:

$$\mathrm{ABC} = \alpha_t \beta \bar{C}_t = \exp[k_t(D_t - B_T)] \times \beta \times \bar{C}_t$$

β is a coefficient that adjusts the overall value, and its default value is 1. The coefficient k_t in the exponential function is exactly as follows (Fig. 2):

$$k_t = \begin{cases} \delta_1 & D_t > B_L \\ \delta_1 + \delta_2 \exp\left[\delta_3 \log\left(AAV_t^2 + 1\right)\right] \dfrac{B_L - D_t}{D_t - B_B} & B_B < D_t \leq B_L \\ \infty & D_t \leq B_B \end{cases}$$

In this equation, $\bar{C}_t$ represents the average catch in the past five years, and D_t is the current stock level (year t), which is calculated as a value between 0 and 1 by applying the following cumulative normal distribution to the past CPUE:

$$D_t = \int_{-\infty}^{CPUE_t} \phi\left[\frac{x - E(CPUE)}{SD(CPUE)}\right] dx$$

In this equation, ϕ represents the standard normal distribution, $E(CPUE)$ is the CPUE mean, and $SD(CPUE)$ is the standard deviation of the CPUE. Next, AAV_t is an index of yearly fluctuations in the abundance index calculated from the CPUE up to year t, and when the number of valid CPUE used in the calculation is N (N = length of the time series - 1 - number of missing values), it is defined as follows:

$$AAV_t = \frac{1}{N} \sum_{u=1}^{t} \frac{2|CPUE_u - CPUE_{u-1}|}{CPUE_u + CPUE_{u-1}}$$

In this equation, B_T is a probability value from 0 to 1 obtained by converting CPUE with a normally distributed cumulative curve at the target level of the abundance index (this is a type of smoothing to reduce the impact of calculation errors in CPUE). Next, B_L is the limit level and B_B is the fishing ban level, which shall be 100 × P_L percent of the target level ($B_L = P_L \times B_T$), and 100 × P_B percent of the target level ($B_B = P_B \times B_T$), respectively. Set the ABC so that stock size gently approaches the target level when it is near B_T, and if it falls to a low level that is less than B_L, then lower ABC so CPUE rapidly approaches the target level (Fig. 2).

The coefficient δ_2 is an adjustment coefficient to induce stock recovery when stock levels are low. Additionally, it is recommended to induce stock recovery as quickly as possible when there are significant uncertainties in the CPUE, so the coefficient δ_3 increases the stock recovery rate when the AAV of the CPUE is large.

The performance of this rule was evaluated by a simulation utilizing the surplus production output type of population dynamics model as used by Ichinokawa et al. (2015), which demonstrated a significant improvement over the existing rules in stock conservation and ABC stabilization (FRA-SA2020-ABCWG01-01). When evaluating performance according to the balance of management objectives (stock conservation, increasing average catch, and minimizing fluctuations in catch), the reference values for the selected parameters became B_T = 0.8, P_L = 0.7 (B_L = 0.56), P_B = 0.0 (B_B = 0.0), (δ_1, δ_2, and δ_3) = (0.5, 0.4, 0.4) (FRA-SA2020-ABCWG01-01). Therefore, the HCR using these reference values shall be the Basic HCR for Stock Group 2. Since the population dynamics of the target stock are unknown, this Basic HCR can be interpreted as a robust HCR that does its best to curb the probability of extreme reductions in the target stock in cases when stock trends and the parameters related to population dynamics set within a reasonable range are considered equally plausible for the stock.

In addition to the basic simulation outcomes, when robustness tests were performed for cases with significant observation errors in CPUE, including hyperstability (the CPUE declines slower than the stock), and hyperdepletion (the CPUE declines faster than the stock) (Hashimoto et al. 2018), then HCR for Stock Group 2 were considered to be more robust against various uncertainties. Nevertheless, in order to ensure that the stock conservation performance is equivalent to the basic simulation outcome even when the uncertainty is greater than in the basic simulation outcome, β in the equation for ABC should be set to 0.9.

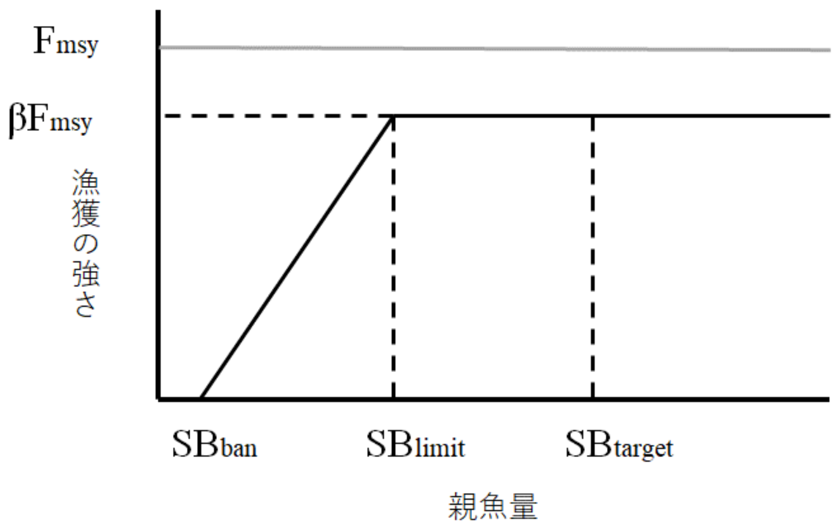

Fig. 1. Schematic Figure of HCR for Stock Group 1

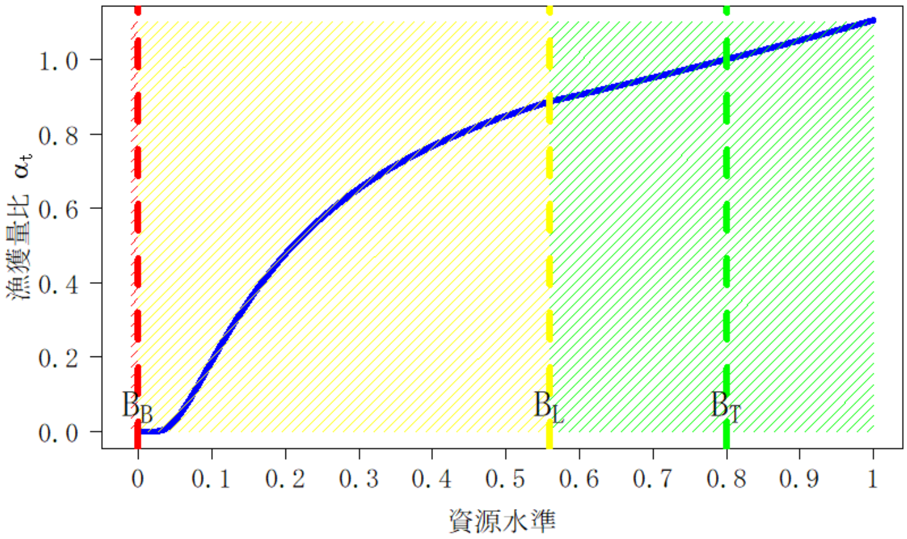

Fig. 2. Schematic Figure of HCR for Stock Group 2

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