

Basic Guidelines for Harvest Control Rules and ABC Calculation (Fiscal Year 2024)

July 3, 2024¹Fisheries Stock Assessment Center, Fisheries Resources Institute,
Japan Fisheries Research and Education Agency

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 ², 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, 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.⁴ Japan, as a ratified member of UNCLOS, must strive to manage and conserve its own marine living resources in

¹ Changes from the 2023 edition: 1) addition of the concept of target and limit reference point for Group 2 resources, 2) added description of a one-year lag to reduce catch fluctuations in Group 2 resources (section VI), and 3) other editorial changes.

² The coastal State shall determine the allowable catch of the living resources in its exclusive economic zone.

³ 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.)

⁴ 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.

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 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 is 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.

Evaluation of Harvest Control Rule 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. The framework for the evaluation of harvest control rules using simulations that fully incorporate the uncertainties that can particularly affect management policies is called Management Strategy Evaluation (MSE) (Punt et al. 2016). When proposing management rules, it is advisable to actively use the MSE framework in addition to the usual future projections.

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 used 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, reproducibility, and transparency.

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 employ 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, there are cases where catch size or changes over time in biological data of catches are 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 (F-based biological reference point) based on F that corresponds to a particular %SPR (specifically, $F_{\%SPR}$) can be used as an alternative to F_{msy} (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 2024) (FRA-SA2024-ABCWG02-04), and the approach for selecting a stock-recruitment relationship is described in Guidelines for Determining Stock-Recruitment Relationships (FY2024) (FRA-SA2024-ABCWG02-05).

Stock-Recruitment Relationships

In order to project mid/long-term⁵ catch size and SSB for group 1A resources, 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

⁵ 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.

extrapolations (Ichinokawa et al. 2017). Beverton-Holt, Ricker, or an average of these two models, may also be used if appropriate. When estimating MSY which supports the target reference points, or 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 continue to use consistent values and definitions⁶ 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, after consultation with the Fisheries Policy Council, HCR corresponding to the catch scenarios described in the Basic Policy on Resource Control will be used to calculate the 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).

⁶ For example, 1A and 1B use a consistent value (abundance) as the target reference point, while the target reference point in 1C and the target level in Group 2 use a consistent definition (calculation method) (but the corresponding value differs every year).

Basic Harvest Control Rules (Basic HCRs)

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

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

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:

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

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 $SB_{\text{limit}} = 0.4SB_0$ and $SB_{\text{ban}} = 0.1SB_0$ 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 ($0.2 B_{\text{msy}}$).

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 ⁷ (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 after catch scenarios have been determined, it is recommended, when there is proper 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 2024) (FRA-SA2024-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

⁷ 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 $x_{upper} C_t$.

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 2024, FRA-SA2024-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 (Miyagawa et al. 2022). Or else, if SB_{min}

is deemed to be too small compared to SB_0 , such as 10-20%, etc.⁸ 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 the value when there is no fishing, and this value is used as an alternative value for F_{msy} . 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 2024).
- 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 %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).

⁸ 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.

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)

Stock Assessment

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. Therefore, in production models, the uncertainty of various estimated parameters, including shape parameters, must be fully evaluated. If the confidence intervals for the estimated parameters, such as biomass, are too wide, the stock assessment results should indicate that these statistics are highly uncertain, along with the estimated confidence intervals. In cases where the model can not be narrowed down to a single model, such as when the prior distribution assumptions are arbitrary, it is also possible to present stock assessment results based on multiple stock assessment results obtained from different prior distribution settings. In addition, even when reliable biomass estimates are not available, if robust results (e.g., biomass is above B_{msy} etc.) are available for the estimated relative trends in biomass or stock status relative to management reference points such as B_{msy} and F_{msy} , these results should also be described in the Appendix. For more information and application examples, please refer to “Guidelines for the application of state space production models to Japanese resources (FY2024) (FRA-SA2024-ABCWG02-07)”.

Reference Points

In basic terms, reference points such as those defined for Group 1A are used, but total biomass estimated from the production model will be used instead of spawning biomass as the unit for reference points. Therefore, target reference point for Group 1C is denoted as B_{target} and is basically estimated from B_{msy} . Limit reference point and band reference point are denoted by B_{limit} and B_{ban} . In addition, 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. For example, Chiba et al. (2023), based on the results of a production model, proposed an MSE framework to propose a harvest control rule that is considered robust to the uncertainty estimated in the stock assessment based on simulations that consider stochastic variation due to process errors, uncertainty in estimating past abundances and parameters, uncertainty among models with different prior distributions, and uncertainty in future ABC calculations. Such an MSE framework can be used. 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} . When absolute abundance information is not available due to high uncertainty in stock assessment, and only relative trends in abundance are shown, the relative trends in abundance, etc. are considered as abundance indices, and the harvest control rules used for stocks of Group2, described below, are applied. In this case, it is possible to conduct MSE for each stock using the results of the production model used to estimate the stock indices to confirm that there is little concern about increased risk of stock depletion due to management failure, and then propose Group 2 harvest control rule with coefficients adjusted to take into account the characteristics of individual stocks (e.g., Sakai et al. (2022)).

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 empirical management rules presented here define target level (BT) and a limit level (BL) for the abundance indices, which are thresholds in the management rules that allow an increase in catch from the most recent catch when the abundance indices exceeds the target level and require a sharp reduction in catch when it falls below the limit level. Therefore, it should be noted

that these thresholds do not correspond directly to the target or limit reference point for group 1 stocks, and are not criteria that allow stock levels to be evaluated independently of the Group2 harvest control rule. However, since it is expected that the application of this harvest control rule will result in as large catch as possible while ensuring sustainability even under uncertainty, the target and limit levels are proposed as substitute values for the target and limit reference points, respectively, on the assumption that management is conducted based on this harvest control rule.

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

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

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):

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

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 ($N = \text{length of the time series} - 1 - \text{number of missing values}$), 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 $100 \times P_L$ percent of the target level ($B_L = P_L \times B_T$), and $100 \times P_B$ 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 $B_T = 0.8$, $P_L = 0.7$ ($B_L = 0.56$), $P_B = 0.0$ ($B_B = 0.0$), $(\delta_1, \delta_2, \text{ and } \delta_3) = (0.5, 0.4, 0.4)$ (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 can be set to 0.9. However, $\beta=0.9$ is a harvest control rule that does not allow an increase in catch even if the abundance index increases, so it is expected to be used only when there is a high degree of uncertainty and serious concern about the stock status and an urgent need to reduce catches.

There are other possible harvest control rules that could be considered so that the performance of stock conservation⁹ is equivalent to the basic harvest control rules. For example, 1) $B_T = 0.6$, $P_L = 0.7$, $P_B = 0.0$, $(\delta_1, \delta_2, \delta_3) = (0.4, 0.7, 1)$ ¹⁰, if the time delay in management is improved to 1 year instead of 2 years, or $B_T = 0.65$, $P_L = 0.7$, $P_B = 0.0$, $(\delta_1, \delta_2, \delta_3) = (0.5, 0.7, 1)$ ¹¹, 2) It was found that $B_T = 0.8$, $P_L = 0.7$, $P_B = 0.0$, and $(\delta_1, \delta_2, \delta_3) = (0.3, 0.6, 0.3)$ showed the same stock conservation performance as the basic harvest control rule when the catch variability was to be kept within $\pm 40\%$ of the previous year's catch (Fukui and Ichinokawa 2022). Furthermore, 3) if

⁹ Defined as high stock conservation performance when the risk of extreme stock depletion in the last 10 years of stock management is small.

¹⁰ In cases where information on both abundance indices and catches is available up to the previous year of the management year.

¹¹ If information on abundance indices is available up to the year before the management year, and if information on catches is available up to the year before the management year.

the catch variability is to be kept within $\pm 40\%$ of the previous year's catch in situations where the time lag in management is improved in a year, $B_T = 0.65$, $P_L = 0.7$, $P_B = 0.0$ (0.5, 0.7, 1.0)¹⁰ or $B_T = 0.75$, $P_L = 0.7$, $P_B = 0$ (0.5, 0.7, 1.0)¹¹ performed as well as the basic harvest control rules (Fukui and Ichinokawa 2024). In (1), even if the target level is lowered by reducing the time delay of feedback management, it still performs better than the basic harvest control rule, which has a two-year delay in management in terms of both stock conservation and catch. 2) shows slightly poorer performance in terms of long-term average catches, because it limits rapid reductions in catches while maintaining stock conservation performance. 3) is a management strategy that performs intermediate between the two.

Even when the target level of the abundance index is reduced from $B_T = 0.8$ to $B_T = 0.7$ ($P_L = 0.7$, $P_B = 0.0$), the results show that the rule performs better than existing rules¹² in terms of both stock conservation and catch by setting $(\delta_1, \delta_2, \delta_3) = (0.4, 0.7, 1)$ etc. (Fukui and Ichinokawa 2022). However, when compared to the basic harvest control rules, the performance of the fishery catch exceeded that of the basic harvest control rules, while the performance of stock conservation was slightly lower. Furthermore, when $B_T = 0.65$, $P_L = 0.7$, $P_B = 0.0$, $(\delta_1, \delta_2, \delta_3) = (0.4, 0.7, 1)$ etc., more catch can be expected than the existing rule of the basic harvest control rule with $B_T = 0.8$, but the stock conservation performance drops to the level of the existing rule. Note that the reduction in the risk of stock conservation performance is particularly pronounced when the most recent stock condition is poor and the stock is highly variable. Setting $B_T = 0.6$ is generally not recommended because it results in a much lower resource protection performance than the existing rule. In the case of such an HCR, it is necessary to demonstrate that there is little concern about an increased risk of resource depletion due to management failure in the resource in question, based on information other than the trend of the abundance index value.

¹² Fishery harvest control rules for Group 2 stock in the absence of proposed target reference point, etc. as presented in FRA-2023-ABCWG02-02.

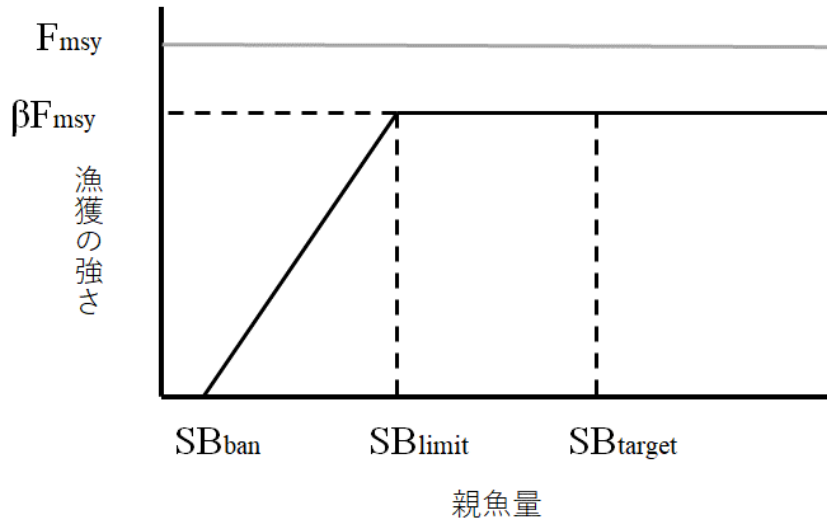


Fig. 1. Schematic Figure of HCR for Stock Group 1

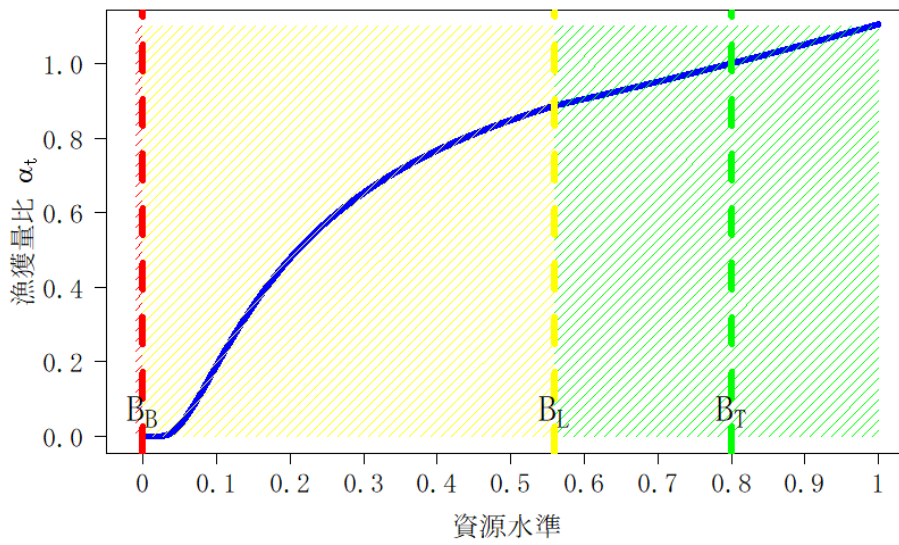


Fig. 2. Schematic Figure of HCR for Stock Group 2

References

- Chiba, S., Sato, R., Morita, S., Sakai, O., Ichinokawa, M., Hamatsu, T. (2021) Document of the meeting of research Institutes concerning management reference points, etc., for the northern Hokkaido Stock of Souhachi (Japanese only) FRA-SA2023-BRP03-01, Japan Fisheries Research and Education Agency, Yokohama
https://abchan.fra.go.jp/references_list/FRA-SA2023-BRP03-01.pdf
- Fukui, S. and Ichinokawa, M. (2024) Catch fluctuation mitigation options for group 2 stocks when catch information is available with a one-year lag. FRA-SA2024-ABCWG01-01, Japan Fisheries Research and Education Agency, Yokohama
- Hashimoto, M., Okamura, H., Ichinokawa, M., Hiramatsu, K., and Yamakawa, T. (2018) Impacts of the nonlinear relationship between abundance and its index in a tuned virtual population analysis. *Fisheries Science* 84:335–347.
- Ichinokawa, M., Okamura, H., and Kurota, H. (2017) The status of Japanese fisheries relative to fisheries around the world. *ICES Journal of Marine Science* 74: 1277–1287.
- Ichinokawa, M., Okamura, H., Kurota, H., Yukami, R., Tanaka, H., Shibata, Y., and Ohshimo, S. (2015) Searching for optimum management procedures by quantifying management objectives for Japanese domestic fishery stocks without stock biomass estimation. *Fish. Sci.*, 81, 206–218.
- Ichinokawa, M., Nishijima, Muko, S., Kurota, H., Ohshimo, S. (2022) Alternative harvest control rules for achieving sustainable fisheries under the revised Fisheries Act in Japan: case studies in two Japanese sardine stocks *Fish. Sci.*, DOI: 10.2331/suisan.21-00041
- Larkin, P. (1977) An epitaph for the concept of maximum sustained yield. *Transactions of the American Fisheries Society* 106: 1–11.
- Mace, P. M. (2001) A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries* 2: 2–32.
- Makino, M. (2011) *Fisheries Management in Japan*. Springer.
- Maunder, M. N. and Punt, A. E. (2004) Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141–159.
- Miyagawa, M., Ichinokawa, M., Okamura, H. (2022) Investigation of the effectiveness of applying management measures using F%SPR to Japanese fishery resources. FRA-SA2022-ABCWG01-01, Japan Fisheries Research and Education Agency, Yokohama
- Miyagawa, M., Ichinokawa, M. (2024) What stock-per recruit target can be applied to Japanese fisheries resources under large uncertainties in the stock-recruitment relationship? *Fisheries Science*, <https://doi.org/10.1007/s12562-024-01786-x>
- Okamura H., Ichinokawa M., Hilborn, R (2020) Evaluating a harvest control rule to improve the sustainability of Japanese fisheries. *bioRxiv* doi: <https://doi.org/10.1101/2020.07.16.207282>

- Okamura, H., Ichinokawa, M., Ueda, Y., Watari, S., Sakai, O. (2020) New Group 2 and Group 3 Rules. FRA-SA2020-ABCWG01-01
- Punt, A. E. and Smith, A. D. M. (2001) The gospel of maximum sustainable yield in fisheries management: birth, crucifixion and reincarnation. In: Reynolds JD, Mace GM, Redford KH, Robinson JG, editors. Conservation of exploited species. Cambridge, UK: Cambridge University Press. p. 41–66.
- Punt, A.E., Butterworth, D.S., de Moor, C. L., De Oliveira, J. A. A. and Haddon, M. (2016) Management strategy evaluation: best practices. *Fish and Fisheries* 17: 303–334.
- Quinn and Deriso (1999) *Quantitative Fish Dynamics*. Oxford University Press.
- Fisheries Agency (2020) <https://www.jfa.maff.go.jp/j/council/seisaku/kanri/attach/pdf/200918-1.pdf>
- Tanaka, S (1991) Proposal for a Model Independent Cetacean Resource Management Method. “Research and Management of Cetacean Resources,” edited by Sakuramoto Kazumi, Hidehiro Kato, and Tanaka Syoiti (Kouseisha Kouseikaku): 184–197.
- Tanaka, S (1998) *A General Introduction to Learning Fisheries Resources*. Kouseisha Kouseikaku.
- Thorson, J. T., Jensen, O. P., and Hilborn, R. (2015) Probability of stochastic depletion: an easily interpreted diagnostic for stock assessment modelling and fisheries management. *ICES Journal of Marine Science* 72: 428–435.
- Watanabe, Y., Zenitani, H., and Kimura, R. (1995) Population decline off the Japanese sardine *Sardinops melanostictus* owing to recruitment failures. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 1609–1616.
- Watanabe, Y., Zenitani, H., and Kimura, R. (1996) Offshore expansion of spawning of the Japanese sardine, *Sardinops melanostictus*, and its implication for egg and larval survival. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 55–61.

Appendix. Guidelines for changing reference points and harvest control rules within the management period.

Basically, the reference point and harvest control rules are the same for five years after the catch scenario is agreed upon and applied. If, after five years, the data have been updated and evaluated, it is considered necessary to revise the data, changes will be proposed through consultation at the research institute. This is to avoid excessive fluctuations in ABC due to frequent changes in reference points. However, if, after the start of management, circumstances arise that were not anticipated at the time the reference points and catch scenarios were developed, and it is considered that the ABC calculated from the previously agreed catch scenarios has a significant potential to jeopardize the sustainability of the biological resources and fisheries, the fishery is then allowed to re-examine the new information and re-propose reference points and harvest control rules without waiting for a five year period. This process consists of (1) determining whether or not an unforeseen situation has occurred and (2) taking countermeasures in the event of an unforeseen situation.

(1) Determining whether an unforeseen event has occurred

- When it is confirmed that future projections “differ from initial assumptions” due to a series of years in which the number of recruitment or the magnitude of their variation is larger (smaller) than expected, or due to major changes in data updates or stock assessment methods.
- For the case where the future projections “differs from the original assumption,” we pay particular attention to the probability of the following:
 - ① Risk of stock abundance falling below the limit or ban level in the short term (e.g., an unexpectedly high probability that the predicted spawning biomass will fall below SB_{limit} or SB_{ban} during the five-year management period),
 - ② Probability of maintaining the resource above the target reference point in the medium to long term (e.g., the probability of reaching SB_{target} in 10 years is significantly lower or higher than originally projected). It should be noted, however, that the probability of maintaining the resources above the target referent point is often set at 50%, which means that in such cases there is a half chance that the resource will be below the target reference point.
- When major information updates are made and there is a need to take immediate action (e.g., natural disasters, international negotiations, etc.)

(2) Measures to be taken in the event of unexpected situations

- Consider whether recalculation of reference points is necessary

- Consider whether the problem can be addressed by changes to the β
- If the new reference point or modified β are deemed safe enough to fish under the uncertainty of considering new and unforeseen circumstances, changes to the harvest control rule may be proposed even within the five-year management period. Proactive recommendations should be made, especially when there is a high probability of resource depletion and a high probability that some measures are needed.
- Even if changes are proposed and made to the harvest control rule and β within the five-year management period, the five-year review shall be conducted as usual.