16.4.11 ICES technical guidance for harvest control rules and stock assessments for stocks in categories 2 and 3

Introduction

ICES provides advice for more than 250 stocks of fish and shellfish. More than 60% of these stocks are "data-limited" in that they do not have full analytical assessments, reference points, or short-term forecasts. Since 2010 ICES has worked to develop and test methods and advice rules for data-limited stocks in order to bring the best available science and information to managers for fisheries and biodiversity goals. To date, ICES data-limited advisory framework and methods were captured in several resources, all based on ICES Guidance for Data-Limited Stocks (ICES, 2012a). Since this initial application, ICES has worked to continuously advance and test the methods and to develop the advisory framework from the precautionary approach towards the MSY approach for data-limited stocks.

This document provides the latest guidance on harvest control rules (HCRs) for use with stocks using a surplus production model in continuous time (SPiCT) assessment and forecast (category 2 MSY advice) and stocks using the empirical methods from WKLIFE X (category 3 MSY advice [Annex 3 in ICES, 2020a]) as illustrated by the orange boxes in Figure 1. The HCRs described here should be applied to relevant stocks, and proxy reference points should be estimated using ICES (2018a) to provide catch advice and stock status for stocks in categories 2 and 3. Further specifications are provided for both short-lived and elasmobranch species using these methods.

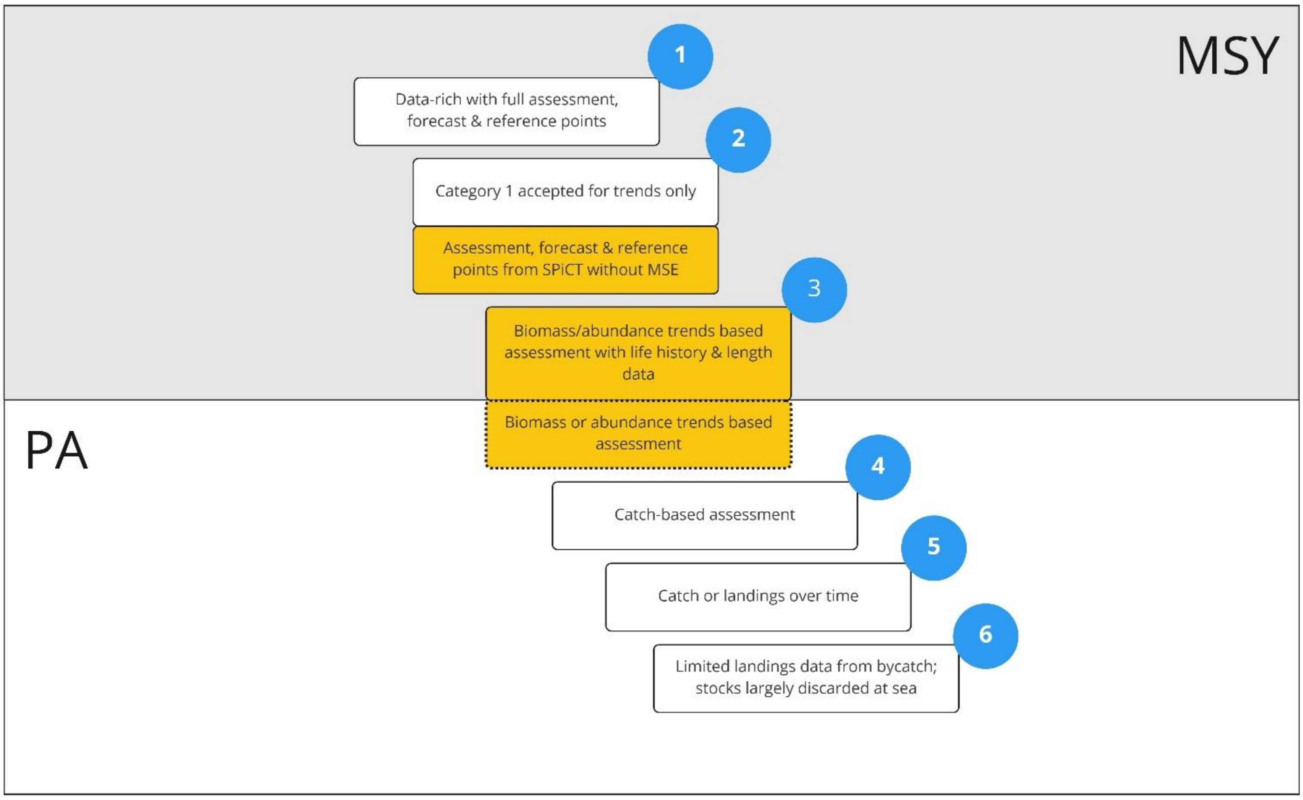


Figure 1 ICES stocks are categorized 1 to 6 by the types of data available and methods used in the provision of advice. These technical guidelines refer only to the orange boxes, categories 2 and 3. The suggested method for category 2 (SPiCT assessment without a management strategy evaluation [MSE] of the HCR) follows ICES MSY approach. The suggested approach for category 3 (empirical methods) includes methods following the MSY approach and, if this is not possible, alternative methods following ICES precautionary approach (PA).

Setting the stage

The advice rules presented here have been tested through management strategy evaluation (MSE). Operating models used for the testing were conditioned on life history parameters for a range of stocks, reflecting different life history characteristics and a range of exploitation histories. Such generic testing was necessary given that the rules tested were to be applied to data-limited stocks, where stock-specific parameterization is not feasible (as it is for category 1).

The methods presented are based on either empirical rules or production models. For the latter case, it remains important to check fits to the data and the plausibility of model estimates and predicted dynamics. The criteria for accepting an assessment (see method 1 below) are therefore important and will require sufficient peer review before use in advice.

Background

ICES stocks are categorized by the types of data available and are used in the provision of advice (Figure 1). Multiple assessment methods are available for each category (ICES, 2012a, 2021a). These technical guidelines are explicitly for stocks in category 2 (using method 1) and category 3 (using methods 2 and 3).

This document provides a description of advice rules developed by the Workshop on the Development of the ICES Approach to Providing MSY Advice for Category 3 and 4 stocks (WKMSYCat34; ICES, 2017), the eighth, ninth, and tenth workshops on the development of quantitative assessment methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data limited stocks (WKLIFE VIII [ICES, 2018b]; WKLIFE IX [ICES, 2019a]; WKLIFE X [ICES, 2020a]), and the first, second, and third workshops on data-limited stocks of short-lived species (WKDLSSLS [ICES, 2019b]; WKDLSSLS2 [ICES, 2020b]; ICES WKDLSSLS3 [ICES, 2021a]). These are HCRs used by ICES for data-limited stocks in category 3 (using Methods 2 and 3) and Category 2 (using Method 1). The objective of these seven workshops was to investigate the performance of HCRs across life history types through simulation using MSEs. This was done to identify the potential approaches that best meet the goals of management, i.e. maximizing long-term yield while minimizing the probability of stocks falling below biologically sustainable limits.

Applying the advice rules – how to get started

The stock assessment approaches explained in these guidelines include:

- **Method 1:** advice rules for short-term forecasts utilizing a surplus production model (e.g. SPiCT)
- **Method 2:** advice rules for empirical approaches based on life-history traits: the "rfb", "chr" and "rb" rules
- **Method 3:** harvest control rules (HCRs) for short-lived species: 1-over-2 for short-lived species
  These also include an indicative SPiCT, and a "chr" method based on an MSE.

Application of these methods are referenced in the relevant sections throughout this document.

Choice of the appropriate method for a stock is dependent on the availability of data, its ability to fit an acceptable SPiCT model, and the value of the growth coefficient "***k***" in a von Bertalanffy growth function appropriate to the stock (Equation 1).

The hierarchy of method selection and basic details and data requirements of each method are given in the decision tree in Figure 2 and in Table 1. Each approach, along with its constituent components and calculations, is explained in subsequent sections.

In the first instance a SPiCT model should be investigated. If a suitable SPiCT model cannot be developed, then available biomass/abundance time-series data and "***k***" should be explored, with the estimated value of "***k***" indicating choice from method 2: rfb, chr and rb rules, and the appropriate value of the multiplier (***m***) to apply.

If available data do not allow for choice from these methods, further direction to lower category assessment is outlined.

$$L(a) = L_\infty(1 - \exp(-k(a - t_0)))$$ (1) von Bertalanffy function

L = length
a = age
k = growth coefficient
t_0 = theoretical age when size is zero,
$L\infty$ = asymptotic length

The decision tree flow diagram in Figure 2 shows how to choose the appropriate method for a stock.

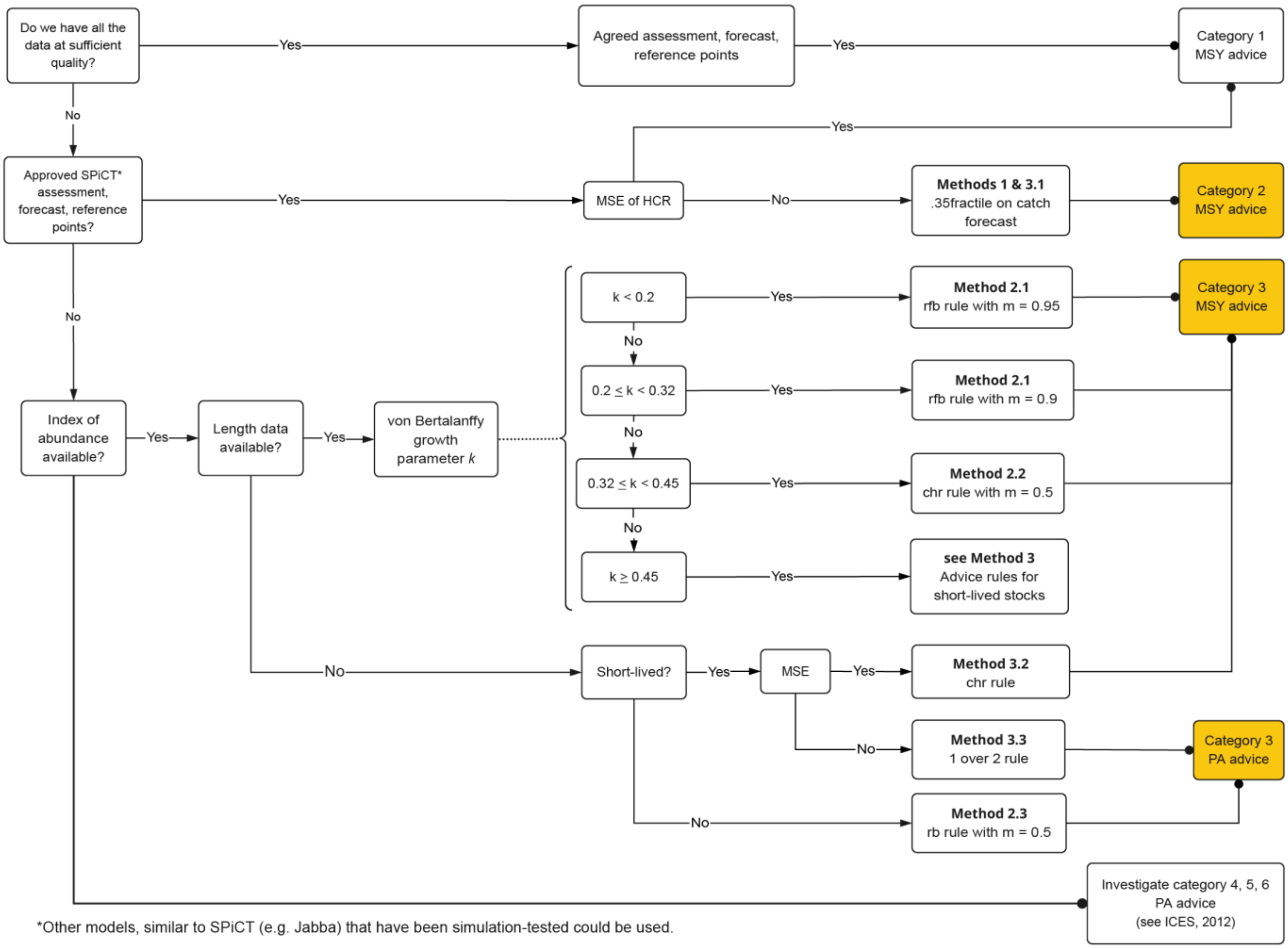


Figure 2 The decision tree for applying ICES advice rules, focusing on the methods covered in this technical guidance and developed by ICES (2021a) and methods for category 3 (category 2 if the technical criteria for accepting a SPiCT assessment are met) stocks with life history information, catch data, and a biomass or abundance index. The boxes on the left side of the diagram refer to the reliable data and information to be used in the provision of advice; "*k*" refers to the von Bertalanffy growth parameter *k* (unit: yr^{-1}). Note that other models, similar to SPiCT (e.g. Jabba) that have been simulation-tested could be used.

Table 1 Methods, names, brief details, base equations and data requirements.

Method	Short name	Details	Base equation	Data requirements
1	Advice rules for short-term forecasts utilizing a surplus production model (SPiCT)			
	SPiCT	Surplus Production model in Continuous Time		Biomass time series Catch time series
2	Advice rules for empirical approaches based on life history traits			
2.1	rfb	r: biomass ratio (survey trend) f: fishing proxy (length data, target) b: biomass safeguard m: multiplier; tuning parameter	$A_{y+1} = A_y \times r \times f \times b \times m$ −30%: +20% cap	*k,* L_∞; von Bertalanffy growth coefficients Biomass time-series Previous year's catch/advice Catch length data
2.2	chr	Constant harvest rate rule	$A_{y+1} = I_{y-1} \times F_{proxy,MSY} \times b \times m$ −30%: +20% cap	*k,* L_∞; von Bertalanffy growth coefficients Biomass time-series Catch time-series Catch length data
2.3	rb not for short-lived stocks	r: biomass ratio (survey trend) b: biomass safeguard m: multiplier; tuning parameter	$A_{y+1} = A_y \times r \times b \times m$ −30%: +20% cap	Biomass time-series Previous year's catch/advice
3	Advice rules for short-lived species			
3.1	SPiCT	Surplus Production model in Continuous Time		
3.2	chr – MSE	Constant harvest rate rule	$A_{y+1} = I_{current} \times HR_{MSYproxy}$	Current biomass estimate MSY harvest rate proxy from MSE
3.3	1-over-2 for short-lived stocks	1-over-2 rule for short-lived stocks	$A_{y+1} = A_y * (I_y / \text{mean } I_{y-1}:I_{y-2})$ ±80% cap	Biomass time series Previous year's catch/advice
Other	Catch and landings based			
	Landings only	Other approaches based on only catch or landings data. ICES assessment categories 4, 5, and 6		

Method 1: advice rules for short-term forecasts utilizing a surplus production model (SPiCT)

The first method to explore is SPiCT; the stochastic surplus production model in continuous time (SPiCT; Pedersen and Berg, 2017). SPiCT is a state-space re-parameterized version of the Pella-Tomlinson surplus production model (Pella and Tomlinson, 1969); i.e. it quantifies observation and process errors and estimates stock status and reference levels with associated confidence intervals.

Note that other similar models (e.g. Jabba) that have been simulation-tested could be used.

- SPiCT provides fishery and biomass reference points and a short-term forecast for stocks with a biomass index and a catch time-series.
- The technical criteria to accept a SPiCT assessment are given below; more detailed information and example code is included in the SPiCT technical guidelines (Mildenberger *et al*., 2021), which is a living document maintained by the developers of SPiCT.
- A fractile rule is used for the catch advice. Without a stock-specific MSE of the HCR, the default rule agreed by ACOM, on the basis of recommendations from WKLIFE, is the 35th percentile, and this should result in a category 2 stock assessment and advice. A stock-specific MSE of the HCR for a stock with a SPiCT assessment is able to provide the best HCR (limit and target biomass reference points and fractiles) that meets predefined management objectives.

Technical criteria for accepting a SPiCT assessment

When determining harvest limits using output from SPiCT, appropriate application first depends on model performance. An accepted assessment using SPiCT has to fulfil all of the following criteria:

1. The optimization has converged.
2. All variance parameters of the model parameters are finite.
3. There should be no serious violation of model assumptions based on one-step-ahead residuals (bias, autocorrelation, normality). This means that p-values of the relevant statistical tests, implemented in SPiCT, are insignificant ($p > 0.05$). Slight violations of these assumptions do not necessarily invalidate model results. For example, autocorrelation and normality issues should be examined. Autocorrelation in the residuals can occur when indices with conflicting signals are used. Normality issues can occur when there are outliers in the input time series, especially observations close to zero.
4. There are consistent patterns in the retrospective analysis. This means that there is no tendency of consistent under- or overestimation of the relative fishing mortality (F/F_{MSY}) and relative biomass (B/B_{MSY}) in successive assessment. The retrospective trajectories of those two quantities should be mostly inside the confidence intervals of the base run; most importantly in the end of the time series. Mohn's rho for both quantities is reported by SPiCT. Mohn's rho values should be inside ICES acceptable ranges, and the number or peels should follow standard ICES practice (ICES, 2020c).
5. There is a realistic production curve. The shape of the production curve should not be too skewed (B_{MSY}/K, where K is the carrying capacity estimate, should be between 0.1 and 0.9). Low values of B_{MSY}/K allow for an infinite population growth rate.
6. The main variance parameters (i.e. of the biomass and fishing mortality processes, and the catch and index observations) should not be unrealistically high. Confidence intervals for B/B_{MSY} and F/F_{MSY} should not span more than one order of magnitude. Note that this does not hold for short-lived, fast-growing species, where the confidence intervals are expected to be larger. High assessment uncertainty can indicate a lack of contrast in the input data or violation of the ecological model assumptions.
7. Initial values do not influence the parameter estimates. The optimization should converge to the same estimates when starting from different initial parameter values.

Caveats

Different options can be explored to stabilize SPiCT for data with low contrast or high observation errors. SPiCT allows the use of prior distributions, for example on the shape of the production curve or the initial depletion level, which can help stabilize the optimization procedure. However, using priors with lower standard deviations affects the results (confidence intervals and parameter estimates). Several options to stabilize SPiCT assessments have been explored and tested within WKLIFE VIII and IX and are described in detail in the SPiCT technical guidelines (ICES, 2018b, 2019a; Mildenberger *et al*., 2021).

Fractile rules and biomass reference points for catch advice

ICES developed an MSY HCR ("median rule") for assessments using SPiCT (Section 3.1 in ICES, 2017). Based on the median rule, WKLIFE VII-X developed and evaluated the "fractile rules" that account for uncertainty and demonstrated that the fractile rules are more effective and precautionary than the median rule and the "2-over-3" rule (ICES DLS method 3.2; ICES, 2012a; 2018b; 2018c; 2019a; 2021a). Furthermore, the standard category 1 HCR that is based on two biomass reference points, a trigger reference point (MSY $B_{trigger}$), and a limit reference point (B_{lim}) is used. The two biomass reference points should depend on each other, e.g. be fractions or multiples of a common reference point like B_{MSY} (Mildenberger *et al*., 2022).

For stocks that have an accepted SPiCT assessment, ICES uses the fractile rule with the 35th percentile of the predicted catch distribution ($f^{\mathrm{C}}_{0.35}$) for the catch advice. In theory, with increasing time-series lengths and decreasing observation error, the estimated catch with the $f^{\mathrm{C}}_{0.35}$ rule approximates the median rule suggested by ICES (2017) while being more precautionary.

The $f^{\mathrm{C}}_{0.35}$ rule recommends the TAC based on the 35th percentile of the predicted catch distribution given the target fishing mortality F^{τ}_{pred} during the prediction year.

$$\mathrm{TAC} = \Phi^{-1}_{(C_{\mathrm{pred}}|F^{\tau}_{\mathrm{pred}})}(0.35), \tag{2}$$

where Φ^{-1} is the inverse distribution function, thus $\Phi^{-1}_{(C_{pred}|F^{\tau}_{pred})}(0.35)$, is the catch that corresponds to the 35th percentile of the estimated catch distribution. The target fishing mortality, F^{τ}_{pred}, during the prediction period depends on the median expected relative biomass at the start of the prediction period ($\frac{B_y}{MSY\ B_{trigger}}$) and the median relative fishing mortality at the start of the prediction period ($\frac{F_y}{F_{MSY}}$). Thus, the target fishing mortality corresponds to the median rule proposed by WKMSYCat34 (ICES, 2017), i.e.

$$F^{\tau}_{pred} = F_{MSY} \min\left(1, \max\left(0, \frac{B_y - B_{lim}}{MSY\ B_{trigger} - B_{lim}}\right)\right) \tag{3}$$

This advice rule is one of the default management scenarios included in the "manage()" function in the spict R package.

A more precautionary alternative is based on the fractiles lower than the median for the estimated relative fishing mortality, relative biomass, and predicted catch distributions:

$$F^{\tau}_{pred} = F_y \frac{\min\left(1, \max\left(0, \Phi^{-1}_{\frac{B_y - B_{lim}}{MSY\ B_{trigger} - B_{lim}}}(f^B)\right)\right)}{\Phi^{-1}_{\frac{F_y}{F_{MSY}}}(1 - f^F)} \tag{4}$$

where f^B and f^F are the fractiles lower than 0.5. When all 3 fractiles are used, Mildenberger et al. (2022) suggest to use values in the range 0.25—0.45.

Application of the rule

This HCR is intended to be applied annually.

If a SPiCT model is not acceptable, method 2 advice rules based on life history traits and length frequency data should be explored.

Method 2: advice rules for empirical approaches based on life-history traits

It is recommended that SPiCT be attempted first. If SPiCT is found not to be appropriate for the stock, an empirical approach (i.e. a model-free, length-based method) should be explored. This section (method 2) describes three empirical control rules (the rfb rule, the chr rule, and the rb rule). These methods have been developed and tested with MSEs and have been designed to explicitly follow ICES precautionary approach, i.e. the long-term risk of stocks falling below the limit reference point B_{lim} below which recruitment is thought to be impaired does not exceed 5%.

The process may require estimation of ***k*** (the von Bertalanffy growth parameter) and length data.

The simulation work on the rfb rule presented in ICES (2018b, 2018c, 2019a, 2021a) is peer-reviewed and published in three articles in ICES Journal of Marine Science (Fischer *et al*., 2020, 2021a, 2021b). Fischer *et al*. (2020) also provides extensive robustness tests and a detailed description of the setup of the operating models.

The MSE simulations were conducted using FLR (Kell *et al*., 2007) and FLR's MSE package. The source code for the simulation in this section is available on GitHub[1]

Generic application

The advice rules presented here were tested for the types of data that are typically available. The testing was done generically to ensure wider application of the rules. Generic simulations included a diversity of stocks (fast/slow-growing, short/long-lived, roundfish, flatfish, and elasmobranchs; 29 stocks total), two alternative fishing histories, and MSY and explicit precautionary considerations. Any change from the generic parameters of the control rules should be justified with case-specific simulations.

Stock-specific application

Case-specific simulation testing and optimization of the parameters of the control rules may be conducted to better tune the assessment to a particular stock while still following ICES precautionary approach (e.g. if time-lags are reduced so that more recent information is used or individual components of the rule are weighted differentially based upon improved knowledge). In the absence of such additional simulation testing, it is recommended that the rules presented below, with associated generic multipliers, be applied.

The applicability of the methods presented here depends on the individual growth rate of the harvested species, expressed through the von Bertalanffy growth parameter ***k*** (unit: year^{-1}), see the flowchart in Figure 2. Applying these methods beyond their recommended *k*-range might be possible if case-specific simulations support this.

Multiplier (m)

All empirical control rules of method 2 include a multiplier (***m***). The multiplier values were selected so that the risk of falling below B_{lim} does not fall below 5% in the long term. Incorporating a multiplier less than one will decrease risk (i.e. a reduced probability of the stock falling below B_{lim}) by sufficiently buffering against the uncertainty associated with each component of the HCR and thus leading to the appropriate management action, given these uncertainties. The risk of the stock falling below B_{lim} is related to the life history dynamics of the stock. It is recommended that the application of the HCR includes a life history-based multiplier to reduce risk. Section 3.6 in WKLIFE X (ICES, 2020a) provides the justification for the multipliers associated with each method below.

[1] https://git.io/JTF9q (There are several branches of this repository for different analyses.)

Stability clause

An asymmetric stability clause (uncertainty cap) of +20% and −30% is recommended where the advised catch would be limited to increase by a maximum of 20% or decrease by a maximum of 30% relative to the most recent advised catch in all applications of the empirical rules. The application of the cap is conditional on the biomass safeguard (***b***) of the empirical rules and should be ceased as soon as $\boldsymbol{b} < \mathbf{1}$, i.e. when the most recent index value falls below I_{trigger} (see details below for the empirical rules). This is meant to ensure greater flexibility in catches (both for reduction and increases) when the stock is estimated to be below its trigger value. The values for the uncertainty cap are based on the considerations of Fischer *et al.* (2020, 2021b).

Advice interval

The recommendation is to apply the rfb rule (method 2.1) and the rb rule (method 2.3) with biennial advice (i.e. the catch advice is set for two years), and the chr rule (method 2.2) with annual advice (i.e. the catch advice is set every year). These recommendations are based on the outcomes of simulations, which have shown that, particularly for trend-based rules (rfb and rb), setting the advice more frequently does not necessarily lead to better management performance and can increase the risks for stocks falling below B_{lim}. Consequently, the rfb and rb rules should be applied with biennial advice and the chr rule with annual advice (unless stated otherwise below).

Biomass safeguard

All empirical control rules of method 2 include a biomass safeguard. This biomass safeguard reduces the catch advice when the stock falls below a threshold, and this is measured by comparing the level of a biomass index to a trigger value ($I_{trigger}$). This trigger value should be set to the level below at which the stock's productivity is impaired (e.g. $0.5B_{\text{MSY}}$). Care should be taken when determining this value based on the stock productivity as well as its susceptibility to effects from fishery-specific activities. The following sections for method 2 describe how the trigger value can be set if no other information exists.

Method 2.1: rfb rule

This HCR provides MSY advice for category 3 stocks based on the stock trend from a biomass index (similar to the previous "2-over-3 rule"), the mean length in the catch relative to an MSY proxy length and a biomass safeguard to ensure compliance with ICES precautionary approach (ICES, 2017; Fischer *et al*., 2020, 2021a, 2021b). The three name-giving elements of the rfb rule are:

r : biomass ratio (survey trend)
f : fishing proxy (length data, target)
b : biomass safeguard

This HCR improves on the "2-over-3" rule (ICES, 2012a) with the addition of multipliers based on a stock's life history characteristics, its status in terms of relative biomass, and its status relative to a target reference length (ICES, 2018c, 2019a).

The rfb catch rule is defined as:

$$A_{y+1} = A_y \times r \times f \times b \times m \qquad (5)$$

where the advised catch (*A*) for next year *y*+1 (set on a biennial basis) is based on the most recent year's advised catch A_y adjusted by the components in Table 3.

Table 2 Data requirements of the rfb rule.

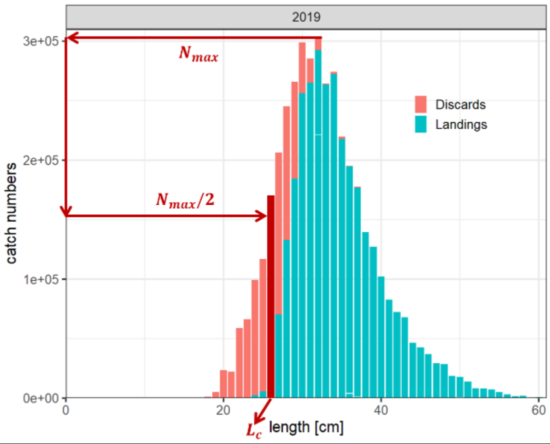
Component	Details
Previous catch advice	• If no previous catch advice (A_y) exists, use the most recent catch (C_{y-1}), or the average of the last three years of catch • If C_y is very different from A_y, consider replacing A_y as the **rfb** rule is meant to adjust realised catches influencing the stock
Biomass index	• At least five years of data needed • Without age structure • Should be representative of the stock • It is possible to combine indices for better coverage of the stock unit (e.g. VAST [Thorson *et al.*, 2019) was used for ple.27.7h-k in 2021 [ICES, 2021b]).
Length data	• At least one year of data needed • Should be representative of the fishery (ideally covering all fleets or gears; if not possible, ensure that mean length in the catch and length reference points are comparable) • Use total catch (if available) • Calculate mean length in the catch (consider lengths greater than length at first capture L_c) • If the distribution is noisy, consider increasing the bin width or applying a smoother • Length at first capture L_c should be determined following ICES (Section 3.4.1 in 2012b) 1. Find the mode of length distribution (length class with highest catch numbers N_{max}) 2. Find first length class where catch is at or above $N_{max}/2$. This is the length at first capture L_c 3. For estimating the mean catch length, consider only length classes above L_c 
Life history parameters	• von Bertalanffy growth parameters: k, L_∞

Table 3 Components of the rfb rule.

Component	Definition	Description and use
A_{y+1}	$A_y \times r \times f \times b \times m$	The advised catch for next year *y*+1 (set on a biennial basis).
A_y		The most recent year's advised catch.
r	$\frac{\sum_{i=y-2}^{y-1}(I_i/2)}{\sum_{i=y-5}^{y-3}(I_i/3)}$	The rate of change in the biomass index (I), based on the average of the two most recent years of data (*y*–2 to *y*–1) relative to the average of the three years prior to the most recent two (*y*–3 to *y*–5), and termed the "2-over-3" rule; *y* = assessment (intermediate) year.
f	$\frac{\bar{L}_{\mathrm{y}-1}}{L_{F=M}}$	The fishing proxy is the mean length in the observed catch ($\bar{L}_{\mathrm{y}-1}$) relative to an MSY proxy length ($L_{F=M}$) and is meant to move the stock towards MSY. Only lengths above the length of first capture (L_c) are considered for $\bar{L}_{\mathrm{y}-1}$. The target reference length is $L_{F=M} = 0.75L_c + 0.25L_\infty$, where L_c is defined as length at 50% of modal abundance (ICES, 2012b, 2018a). The reference length follows Beverton and Holt (1957), derived by Jardim et al. (2015), and assumes *M*/*k* = 1.5.
b	$\min\left\{1, \frac{I_{y-1}}{I_{\mathrm{trigger}}}\right\}$	Biomass safeguard. Adjustment to reduce catch when the most recent index data I_{y-1} is less than $I_{\mathrm{trigger}} = 1.4I_{\mathrm{loss}}$ such that b is set equal to $I_{y-1}/I_{\mathrm{trigger}}$. When the most recent index data I_{y-1} is greater than I_{trigger}, ***b*** is set equal to 1. I_{loss} is generally defined as the lowest observed index value for that stock. I_{trigger} may need to be adapted if the stock has been exploited only heavily or lightly in the past.
m	$[0,1]$	A tuning parameter to ensure that the rfb rule is precautionary (that risk does not exceed 5%). It does not decrease advice continuously but can be considered as adjusting the target in component *f*. ***m*** is linked to von Bertalanffy ***k*** and based on generic MSE simulations. May range from 0 to 1.0.
Stability clause	$min\{max(0.7A_y, A_{y+1}), 1.2A_y\}$	Asymmetric conditional uncertainty cap. Limits the amount the advised catch (A_{y+1}) can change upwards or downwards relative to the previous catch advice (A_y). The recommended values are +20% and −30%; i.e. the catch would be limited to a maximum 20% increase or a maximum 30% decrease relative to the previous year's advised catch. The stability clause does not apply when **b** < 1.

Each component of the HCR is combined (multiplied together), in order to determine next year's catch advice by adjusting this year's catch advice upwards or downwards. This is based on the trend in the index (i.e. whether the stock is going up or down; ***r***), the observed mean length in the catch relative to the target mean length (***f***), and a factor to adjust catch downwards if the current stock falls below a threshold index value (***b***). The multiplier (***m***) is then applied as a precautionary measure to ensure that the probability of the stock falling below B_{lim} is less than or equal to 5%.

The performance of the catch rule is driven largely by three factors:

- The life history of the species
- The trend in the index being a good measure of the current status of the stock based on the life history
- The I_{trigger} value being defined at or near the true threshold level (e.g. $0.5B_{\mathrm{MSY}}$).

Choosing the multiplier

For the harvest estimate for longer-lived stocks with low natural mortality and slow individual growth (von Bertalanffy ***k*** < 0.2 yr^{-1}; e.g. redfish or ling), a multiplier of **m** = 0.95 should be applied to the control rule ($A_{y+1} = A_y \times r \times f \times b \times 0.95$), i.e. by setting the estimated catch for the following year to 95% of the estimated yield, based on the control rule. Medium-lived stocks with 0.2 ≤ *k* < 0.32 yr^{-1} (e.g. plaice, red mullet) should apply a multiplier of **m** = 0.90 to next year's estimated catch. If there is no reliable information about *k* – but *k* is considered to be less than 0.32 yr^{-1} – then the more precautionary multiplier of **m** = 0.90 should be used.

von Bertalanffy growth parameter k

The von Bertalanffy growth parameter *k* is an individual growth rate. For these advice rules, only a rough estimate of *k* is needed: $\boldsymbol{k} < 0.2\text{yr}^{-1}$ or $0.2 \leq \boldsymbol{k} < 0.32\text{yr}^{-1}$. Ideally, stock-specific values (e.g. using age–length keys) should be used, but an alternative *k* might be borrowed from another adjacent stock of the same species or from the literature using expert judgement. Survey data or catch data can be used as the data source, and data sources can be combined to ensure that sufficient young and old individuals are included.

Elasmobranch stocks

The rfb rule can be used for elasmobranch stocks, which are generally slow-growing stocks. ICES (2021a) evaluated the performance of this rule. The rfb rule was shown to result in more stable risks, irrespective of the fishing history of the stock. See Section 3.6 in ICES (2021a) for further details.

In the past, other ratios were used for category 3 elasmobranch stocks (e.g. 2-over-5). This practice is no longer supported as ICES (2021a) showed that ratios like 3-over-5 versus 2-over-3 result in higher risk, slower recovery, and higher uncertainty that can be detrimental to the stock. The 2-over-5 I_{hist}) in much higher risks for elasmobranch stocks when over-exploitation has occurred.

Deep-water stocks

It is likely that $\boldsymbol{k} < 0.2\text{yr}^{-1}$ (slow growing).

Advice interval

Method tested with advice every two years (biennial).

Considerations

- Use the most recent data available (e.g. I_y instead of I_{y-1})
- Do not change the interval (or any other parameter of the rfb rule) without simulations that support it

Method 2.2: constant harvest rate (chr) rule

The constant harvest rate (chr) rule, also called the F_{proxy} rule (ICES, 2017), or the "Icelandic" rule, was originally proposed again by ICES (2017). It applies a constant harvest rate ($F_{\text{proxy,MSY}}$) that is considered a proxy for an MSY harvest rate and applies this to the index.

The chr rule was developed to address cases where $\boldsymbol{k} \geq 0.32$ yr^{-1}, and the rfb rule should not be applied. See Section 3.6.1 in ICES (2021a) for a justification of the multipliers to ensure that the long-term risk of falling below B_{lim} does not exceed 5% in compliance with ICES precautionary approach

ICES (2017) proposed that historical data be used to define $F_{\text{proxy,MSY}}$, so the approach used here is to extract the ratio C_y/I_y from those historical years for which the quantity $f > 1$, where f is the ratio of mean length above L_c relative to $L_{F=M}$, and to calculate the mean of this C_y/I_y ratio.

Simulation testing of this rule found it was suitable for stocks where $0.32 \leq \boldsymbol{k} < 0.45$ yr^{-1} (where k is the von Bertalanffy growth parameter, see Section 3.4 in ICES [2021a])

$$A_{y+1} = I_{y-1} \times F_{proxy,MSY} \times b \times m \qquad (6)$$

where the advised catch (A) for next year y+1 (set on an annual basis). The components of the chr rule are presented in Table 4.

Table 4 Components of the chr rule.

Component	Definition	Description and use
A_{y+1}	$I_{y-1} \times F_{proxy,MSY} \times b \times m$	The advised catch for next year *y*+1 (set on an annual basis)
I_{y-1}		The most recent index value, usually from year *y*−1. A more recent index value (e.g. I_y) can be used if available
$F_{proxy,MSY}$	$\frac{1}{u}\sum_{y \in U} C_y/I_y$	Target harvest rate. Is the mean of the ratio C_y/I_y for the set of historical years U for which the quantity *f* >1, and u is the number of years in the set U. C_y are observed catches and I_y index values for corresponding historical years. The quantity *f* is the ratio of the mean length in the observed catch that is above the length of first capture relative to the target reference length (mean length/target reference length). The target reference length is $L_{F=M} = 0.75L_c + 0.25L_\infty$, where L_c is defined as length at 50% of modal abundance (ICES, 2012b, 2018a). See the rfb rule (method 2.1) above for details.
b	$\min\left\{1, \frac{I_{y-1}}{I_{\text{trigger}}}\right\}$	Biomass safeguard. Adjustment to reduce catch when the most recent index data I_{y-1} is less than $I_{trigger} = 1.4I_{loss}$ such that b is set equal to $I_{y-1}/I_{\text{trigger}}$. When the most recent index data I_{y-1} is greater than I_{trigger}, ***b*** is set equal to 1. I_{loss} is generally defined as the lowest observed index value for that stock. I_{trigger} may need to be adapted if the stock has been exploited only heavily or lightly in the past.
m	[0,1]	Multiplier applied to the HCR to maintain the probability of the biomass declining below B_{lim} to no more than 5%. It does not decrease advice continuously but can be considered as adjusting the target ($F_{proxy,MSY}$). The ***m*** component may range from 0 to 1.0.
Stability clause	$min\{max(0.7A_y, A_{y+1}), 1.2A_y\}$	Asymmetric conditional uncertainty cap. Limits the amount the advised catch (A_{y+1}) can change upwards or downwards relative to the previous catch advice (A_y). The recommended values are +20% and −30%; i.e. the catch would be limited to a maximum 20% increase or a maximum 30% decrease relative to the previous year's advised catch. The stability clause does not apply when ***b*** < 1.

Choosing a multiplier (m)

For medium to faster-growing stocks with 0.32 ≤ ***k*** < 0.45 yr^{-1} (e.g. brill, whiting), a multiplier of m = 0.5 should be applied to next year's estimated catch. See Section 3.6.3 in ICES (2021a) for a justification of the multiplier.

For slower-growing stocks with ***k*** ≤ 0.32 year^{-1}, the chr rule might be applicable; however, this will likely require case-specific simulations to determine an appropriate target harvest rate.

For stocks for which ***k*** ≥ 0.45 year^{-1}, it is proposed that the method for short-lived stocks be used (method 3).

Advice interval

Method tested with advice every year (annual).

Considerations

- Use the most recent data available (e.g. I_y instead of I_{y-1}), and
- Do not change the interval (or any other parameter of the chr rule) without simulations that support it.

Method 2.3: rb rule

The rb rule is a simpler version of the rfb rule and is meant to cover those cases where length data (***f***) are not available. This is method is a last resort and should be avoided if possible, as it reduces catch advice over time unless the stock is increasing strongly with ***r*** ≥ 2. The rb rule adjusts the catch advice by the trend from a biomass index but does not include a target (the *f* target from the rfb is not included) and has a tendency to increase risk over time. Therefore, to ensure the advice follows ICES precautionary approach, catches need to be reduced over time.

The rule is decoupled from the life history parameter k, and is tuned to ensure that the 5% risk threshold is met across a broad range of **K** values. It is intended as a replacement for the widely-used "2-over-3" rule, for the cases where the rfb and chr rules cannot be used.

The "2-over-3" rule (coupled with an uncertainty cap and precautionary buffer) has consistently been shown to deliver poor performance when compared to alternative rules (such as the rfb rule).

$$A_{y+1} = A_y \times r \times b \times m \qquad (7)$$

The components of the **rb** rule are presented in Table 5.

Table 5 Components of the rb rule.

Component	Definition	Description and use
A_{y+1}	$A_y \times r \times b \times m$	The advised catch for next year y+1 (set on a biennial basis)
A_y		The most recent year's advised catch
r	$\frac{\sum_{i=y-2}^{y-1}(I_i/2)}{\sum_{i=y-5}^{y-3}(I_i/3)}$	The rate of change in the biomass index (I), based on the average of the two most recent years of data (*y*−2 to *y*−1) relative to the average of the three years prior to the most recent two (*y*−3 to *y*−5), and termed the "2-over-3" rule.
b	$\min\left\{1, \frac{I_{y-1}}{I_{\mathrm{trigger}}}\right\}$	Biomass safeguard. Adjustment to reduce catch when the most recent index data I_{y-1} is less than $I_{trigger} = 1.4 I_{loss}$ such that b is set equal to $I_{y-1}/I_{\mathrm{trigger}}$. When the most recent index data I_{y-1} is greater than I_{trigger}, b is set equal to 1. I_{loss} is generally defined as the lowest observed index value for that stock. I_{trigger} may need to be adapted if the stock has been exploited only heavily or lightly in the past.
m	$[0,1]$	Multiplier applied to the harvest control rule to maintain the probability of the biomass declining below B_{lim} to no more than 5%. May range from 0 to 1.0.
Stability clause	$min\{max(0.7A_y, A_{y+1}), 1.2A_y\}$	Asymmetric conditional uncertainty cap. Limits the amount the advised catch (A_{y+1}) can change upwards or downwards relative to the previous catch advice (A_y). The recommended values are +20% and −30%; i.e. the catch would be limited to a maximum 20% increase or a maximum 30% decrease relative to the previous year's advised catch. The stability clause does not apply when *b* < 1.

The use of the rb rule should be accompanied by a multiplier of m = 0.5, applied to the next year's estimated catch. See Section 3.6.2 in ICES (2021a) for a justification of the multiplier.

Advice interval

Method tested with advice every two years (biennial).

Considerations

- Use the most recent data available (e.g. I_y instead of I_{y-1})
- Do not change the interval (or any other parameter of the rb rule) without simulations that support it

Method 3: advice rules for harvest control rules for short-lived species

Given their dynamics, the risk of harvesting short-lived stocks with high interannual biomass variability is inherently greater than for longer-lived species. As such, the HCRs applied to short-lived stocks are designed in a manner that incorporates the dynamics of these specific stocks.

There is no specific definition of a "short-lived" stock. The simulations used $\boldsymbol{k} \geq 0.45\text{yr}^{-1}$ (the fastest growing species such as John Dory, pilchard, herring, and sandeel).

Method 3.1: SPICT for short-lived stocks

For short-lived, data-limited stocks with sufficiently long data series and contrast in biomass and production, surplus production models can be fitted and the advice can be formulated on the basis of F_{MSY} (rather than on constant catch at MSY). Advice could also possibly be formulated on less than F_{MSY} to account for the strong fluctuations of these short-lived species (i. e., following method 1 with the generic 35th fractile or determine a better fractile through MSE for the stock-specific case study).

Such an F_{MSY} rule would be most successful if applied to an assessment that included an indicator of the biomass population just prior to the management calendar while including most of the harvestable population age classes.

A year lag between the assessment and management years worsens the performance of the management for short-lived species, and this should be evaluated in comparison with other potential HCRs. Refer to ICES (2021a) for further details on this method and its caveats.

Method 3.2: constant harvest rate (chr) rule for short-lived stocks

If a SPiCT model cannot be fitted to a short-lived, data-limited stock, and the stock has an accepted survey, the best way to adjust catches to the highly fluctuating nature of these stocks may be by removing a constant fraction of the stock every year, corresponding with a sustainable harvest rate ($HR_{\text{MSY.proxy}}$), applicable to the abundance indicator of the stock (I_{current}), so that risk of falling below B_{lim} is kept < 0.05.

$$A_{y+1} = I_{\text{current}} \cdot HR_{\text{MSY.proxy}} \qquad (8)$$

The constant harvest rate HCR can be complemented with a biomass safeguard factor (**b factor**) based on a trigger index value, below which the advice should be corrected downwards in proportion to the drop of the most recent abundance index over the I_{trigger} value.

Application of the method

A stock-specific MSE process should be conducted when implementing this method. The MSE should: (1) determine the constant harvest rate that is most robust to the operating model and observation system uncertainties, (2) consider the time-lag between the index availability and management implementation, and (3) determine the I_{trigger} value, aiming at assuring allowable risk levels.

Caveats

This constant harvest rate HCR is dependent on the actual life history of the stock and is conditioned on the survey catchability and observation error. Therefore, the degree of prior knowledge on the range of potential catchabilities and the likely magnitude of observation errors should be taken into account when considering this as a risk-averse HCR.

The application of a constant harvest rate can only be achieved for a management calendar triggered immediately after the abundance index becomes available (either from the survey or from the fishery). The longer the lag in time between the availability of the abundance index and the implementation of the management decision the lower would be the sustainable harvest rate.

Method 3.3: One-over-two rule for short-lived stocks

When knowledge of catchability and observation errors of the abundance index are so poor as to preclude the selection of a robust constant harvest rate, a HCR that determines next year's advised catch based on the last advised catch can be used.

The HCR is defined as:

$$A_{y+1} = \left\{ \begin{Bmatrix} 0.2\,A_y & \dfrac{I_y}{\sum_{y-1}^{y-2} I_y/2} < 0.2 \\ A_y \dfrac{I_y}{\sum_{y-1}^{y-2} I_y/2} & 0.2 \le \dfrac{I_y}{\sum_{y-1}^{y-2} I_y/2} < 1.8 \\ 1.8\,A_y & \dfrac{I_y}{\sum_{y-1}^{y-2} I_y/2} \ge 1.8 \end{Bmatrix} \cdot \left[min\left(1, \frac{I_{current}}{I_{trig}}\right)\right] \right. \qquad (9)$$

where A_y and I_y represent the advised catch and the biomass indicator for year *y*, respectively.

The first and third cases of the formula correspond to the application of an 80% symmetrical uncertainty cap.

The last term in the equation refers to the biomass safeguard based on a trigger index value, below which the advice would be corrected downwards in proportion to the drop of the most recent abundance index over the I_{trigger} value. This is a term which has been shown to further reduce the risks associated to this management system. A recommendation is made to take I_{trigger} as I_{stat} = *geometric mean* (I_{hist}) exp(−1.645 *sd*(log (I_{hist})), where I_{hist} is the available historical series of the abundance index.

- The notation of these rules is for in-year advice where the advised catch for the current year is based on last year's advised catch adjusted by the trend in the most recent abundance index, I_y, relative to the average of the index value in the previous two years.
- An uncertainty cap is applied to limit the change in the index trend, the I_y component of the HCR, to ±80%, which allows the current years advised catch to increase or decrease up to 80% relative to the previous years advised catch.
- Note that $\frac{I_y}{\sum_{y-1}^{y-2} I_y/2}$ should be replaced by $\frac{I_{y+1}}{\sum_{y}^{y-1} I_y/2}$ in the formula above if the index is available at the beginning of the management year *y+1*, instead of being available at the end of the interim (management) year *y*.

Application of the HCR

For some short-lived species, assessments are so sensitive to incoming recruitment that information on the incoming year class is essential to assessment and management. Therefore, for these species, the management quota year should be coupled as closely as possible to the availability of the abundance index. For most of the stocks concerned, such data are obtained just before the fishery starts (or during the fishing year). Therefore, the advice on fishing possibilities is often given just prior to the start of the fishing season or after the fisheries have started, which corresponds with the two formulations provided above.

In the case where the survey is at the beginning of the management year, the fishery could start with a provisional catch to be updated when the abundance index is available.

The HCR for short-lived stocks is composed of three components: the advised catch in the previous year, the trend in the index, and the uncertainty cap. The trend in the index performs best for short-lived stocks when the most recent years, including data from the current year, are applied. It is recommended to use the most recent year of data divided by the average of the index over the preceding two years (termed 1-over-2). The rule has greatest performance when a large fraction of the harvested population in the management year is covered by the index.

The first time this rule is applied to a stock, the initial catch should be taken from the mean of the catch from the previous two years (ICES, 2019b).

Short-lived stocks with high interannual variability of biomass can show large biomass fluctuations from one year to the next. A symmetrical 80% uncertainty cap allows appropriate adjustment of the HCR accordingly from year to year. Large reductions in catch may be necessary between years to respond accordingly to reductions in the underlying stock biomass.

The precautionary buffer will certainly reduce the initial risks associated with a historic substantial exploitation of the stock (above F_{MSY}), though is probably unnecessary for lightly exploited stocks. The performance of the rule has been tested without any precautionary buffer. Therefore, the convenience of applying such a precautionary buffer would depend on an early assessment of the exploitation levels and depletion of the resource.

Caveats

This is a blind HCR as it does not necessarily lead to MSY exploitation, but it implies a decreasing trend of catch options in time after repeated applications, particularly when coupled to the 80% symmetrical uncertainty cap constraint, whereby for stocks substantially exploited (around or above F_{MSY}) it will decrease risks of falling below 20%B_0 below 0.2 in about ten years, and to levels around 0.05 or below after 20–30 years of applications (ICES, 2021a; Sanchez-Maroño *et al*. 2021). Therefore, this trend-based rule should be considered a provisional HCR with the aim of achieving a better management approach within ten years. Long-term application of this HCR may lead to major losses of yield.

For stocks that were heavily exploited in the past, the rule does not necessary lead to precautionary levels of risk in the short term, but rather it gradually leads to sustainable exploitation in the long term.

Application of the uncertainty cap can lead to major reduction of catches in the long term. It is recommended that this HCR rule be periodically re-evaluated (Sanchez-Maroño *et al*., 2021).

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