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HCR design considerations for South Pacific albacore

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Executive Summary

To support development of a Roadmap for South Pacific albacore management, SC14 endorsed an initial focus on empirical based MPs when developing harvest strategies for South Pacific albacore. Preliminary work on the management strategy evaluation (MSE) framework based on the empirical management procedure (MP) approach was also presented to SC15.

In this paper, we present initial harvest control rule (HCR) design considerations for South Pacific albacore. The HCRs are based on the empirical data (observed CPUE or mean length). The performances of the HCRs demonstrated that such designs may have potential to achieve the targeted CPUE or target reference point (TRP). Meanwhile, a clear trade-off in achieving different management objectives is also observed. Noting that the evaluations presented in this paper are preliminary, future designs and evaluations can be done, based on the comments from SC16.

In particular, we seek advice from SC16 on:

- Input into candidate HCR designs;
- Feedback on presentational approaches to enhance decision making;
- Support the continued development of empirical management procedures for South Pacific albacore;
- Note different empirical management procedures could result in different performances;
- Note empirical data from alternative fisheries could also be used in the management procedures.

1 Introduction

WCPFC12 agreed to a workplan for the adoption of harvest strategies for WCPO skipjack, bigeye, yellowfin and South Pacific albacore tuna. A key component of a harvest strategy is the management procedure (MP), which is a pre-specified combination of data collection, estimation method (to monitor stock status and provide the signal for management action), and a decision rule, known as a harvest control rule (HCR), that sets fishing opportunities based on the estimates of stock status (Butterworth et al., 1997; Punt et al., 2014). All three components of an MP are agreed together as a single package.

An MP can be categorised as either empirical or model based. An empirical MP may determine stock status from direct observation of fishery data, such as an index of catch per unit of effort (CPUE), whereas a model based MP will employ more analytic approaches, such as a stock assessment model. SC14 has endorsed an initial focus on developing empirical MPs that use CPUE as the primary indicator of stock status, noting that model based approaches may also be considered.

Preliminary analyses presented to SC15 included a small number of "proof of concept" HCRs (Scott et al., 2019b). These represented preliminary investigations of the form and function of empirical MPs that were implemented primarily to test the MSE modeling framework. This paper describes further developments in the design of empirical MPs for South Pacific albacore. CPUE is used as the primary index of stock status and a biological metric. The mean length of fish in the catch is also considered as a potential indicator of stock status.

An MP is adopted on the basis that it is likely to achieve the agreed management objectives. WCPFC15 adopted an interim target reference point (TRP) for South Pacific albacore of 56% $SB_{F=0}$, with the objective of achieving an 8% increase in CPUE for the southern longline fishery from 2013 levels (WCPFC15; para 207). The MPs described here attempt to achieve these objectives.

To illustrate the design and functioning of the framework, we present results from an initial set of HCRs but stress that these results are preliminary and are shown to provide an indication of the type and form of HCR that may be considered. The results of these preliminary evaluations have also been used for the calculation of illustrative performance indicators for the southern longline fishery, which are presented in a version of PIMPLE (i.e. SPAMPLE; https://ofp-sam.shinyapps.io/spample/) similar to that previously presented for WCPO skipjack (Scott et al., 2019a; Yao et al., 2019).

2 The MSE Framework

Before an MP is adopted, the relative performance of candidate MPs, including the robustness to uncertainty, can be tested using management strategy evaluation (MSE) (Punt et al., 2014; Scott et al., 2019b). In MSE modelling frameworks, the biological dynamics of the stock and the fishery interactions are simulated by an operating model (OM).

An initial set of OMs for South Pacific albacore which covered a range of plausible scenarios, known as an uncertainty grid, was presented to SC15 (Scott et al., 2019b). The grid comprised model uncertainty (steepness, natural mortality, growth and CPUE input, consistent with the stock assessment assumptions), process uncertainty in the form of future recruitment variability, and observation uncertainty applied to future catch estimates (Table 1). The OMs have the same fishery and regional structure as the most recent stock assessment (Tremblay-Boyer et al., 2018).

Axis	**Levels**		**Options**	
	Reference	**0**	**1**	**2**
Process Error				
Recruitment Variability	**1**	**1982-2014**		
Observation Error				
Catch and effort	**1**	**30%**		
Model Error				
Steepness ‡	**3**	**0.8**	**0.65**	**0.95**
Natural Mortality ‡	**2**	**0.3**	**0.4**	
Growth ‡	**2**	**estimated**	**fixed, Chen-Wells**	
Size freq wtg ‡	**1**	**50**		
CPUE ‡	**2**	**geo-statistics**	**traditional**	
Implementation Error				
Scenarios to be developed				

Table 1: South Pacific albacore reference case operating model (OM) uncertainty grid. ‡ denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required.

The South Pacific albacore MSE framework used here to evaluate the candidate MPs is similar to that presented to SC15 (Scott et al., 2019b). As well as the uncertainty covered by the range of scenarios and assumptions in the OM grid, further uncertainty is included in the MSE simulations through the inclusion of observation error and future recruitment variability. Observation error (30% CV) was applied only to catch and not effort to generate the simulated observed data used by the MP.

3 Candidate HCR design

A harvest control rule (HCR) is a key component of an MP. HCR returns a catch scaler that determines catches for the next management period, based on the monitoring data and estimation method (e.g. CPUE),. In this paper, two categories of empirical HCR design were used:

- CPUE-based HCR, where future fishing activity is based on the observed CPUE;
- Length-based HCR, where future fishing activity is based on the observed mean length in catch.

3.1 CPUE-based HCR

Two types of HCRs based on CPUE are used here: i) a very simple one-phase HCR that relates recent CPUE directly to fishing opportunity, and ii) a two-phase HCR that additionally takes into account the recent trend in CPUE. Both HCRs are based on the CPUE time series of the combined Pacific Island Countries and Territories (PICT) longline fisheries in Region 2 (Fishery 4) of the stock assessment (Figure. 1) (Tremblay-Boyer et al., 2018).

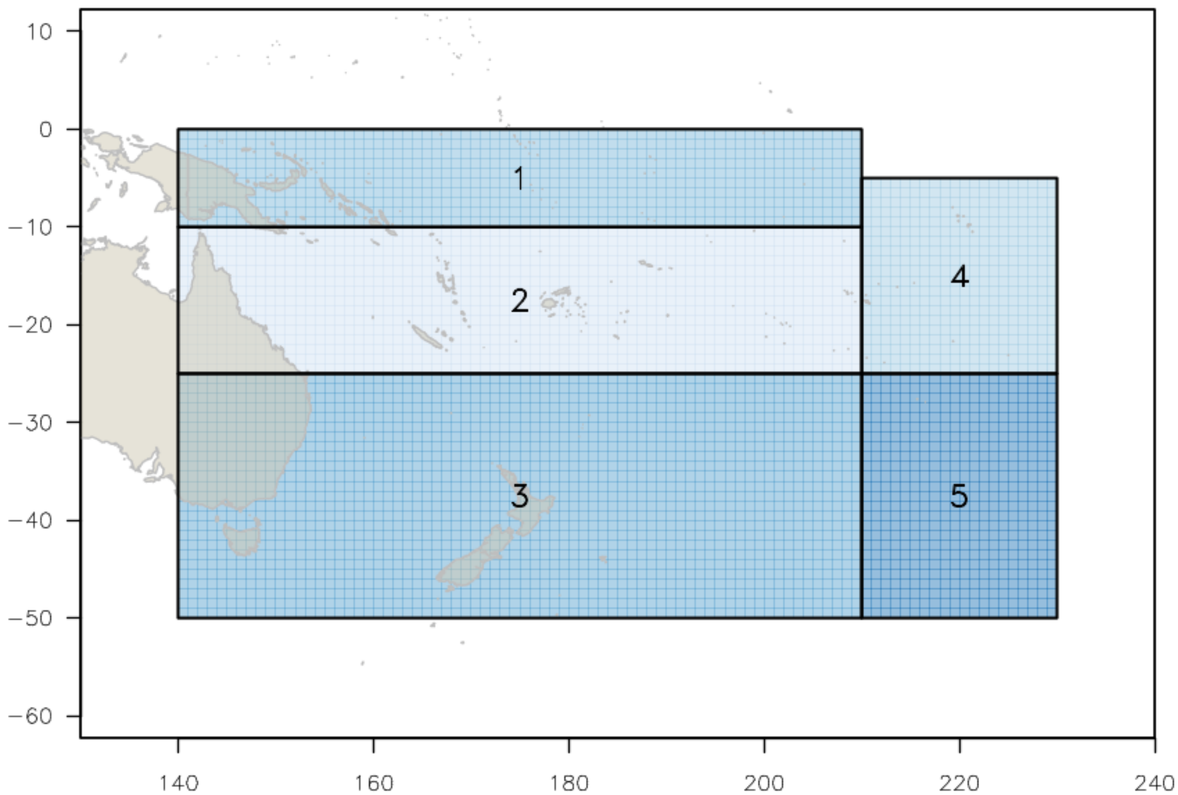


Figure 1: The geographical area covered by the stock assessment and the boundaries for the 5 regions under the updated "2018 regional structure".

Following the initial work on the MSE framework, the HCRs determine the catch for all fisheries in the model for the next management period by returning a catch scalar that is applied to a reference catch level (the average catch in the years 2014 to 2016) (Scott et al., 2019b).

3.1.1 One-phase HCR

The one-phase HCR is based on a simple linear relationship between relative CPUE and the resulting catch scaler. The catch scaler for each management cycle is based on the recent observed CPUE averaged over a specified period (Y_{ave}), relative to a reference CPUE:

$$scaler = g1 * \frac{\overline{CPUE}}{CPUE_{ref}} + (1 - g1) \quad (1)$$

where $\overline{CPUE}$ is the average CPUE of the last Y_{ave} years, $CPUE_{ref}$ is the reference CPUE, and $g1$ is a gain parameter that controls how reactive the HCR is to the average CPUE levels (Table 2).

If the average CPUE is lower than the reference CPUE level, the catch scalar is set to be less than 1, i.e. catches are reduced compared to the reference catch level, and vice versa (Figure 2). The gain parameter, $g1$, controls the amount of the catches will be reduced (or increased) when the average CPUE is away from the reference CPUE. There is also an optional parameter ΔC_{max} that limits the amount that the catch scalar can change compared to its previous value.

Parameter	**Name**	**Description**
g1	Gain	Determines how reactive the HCR is
Y_{ave}	Average years	Years to average CPUE over
$\overline{CPUE}$	Average CPUE	Average CPUE of the last Y_{ave} years
$CPUE_{ref}$	CPUE reference	The reference CPUE level against which the average CPUE is compared
ΔC_{max}	Maximum change in catch	The catch scaler can only increase or decrease by ΔC_{max} of the previous catch.

Table 2: Description of parameters used in the one-phase HCR.

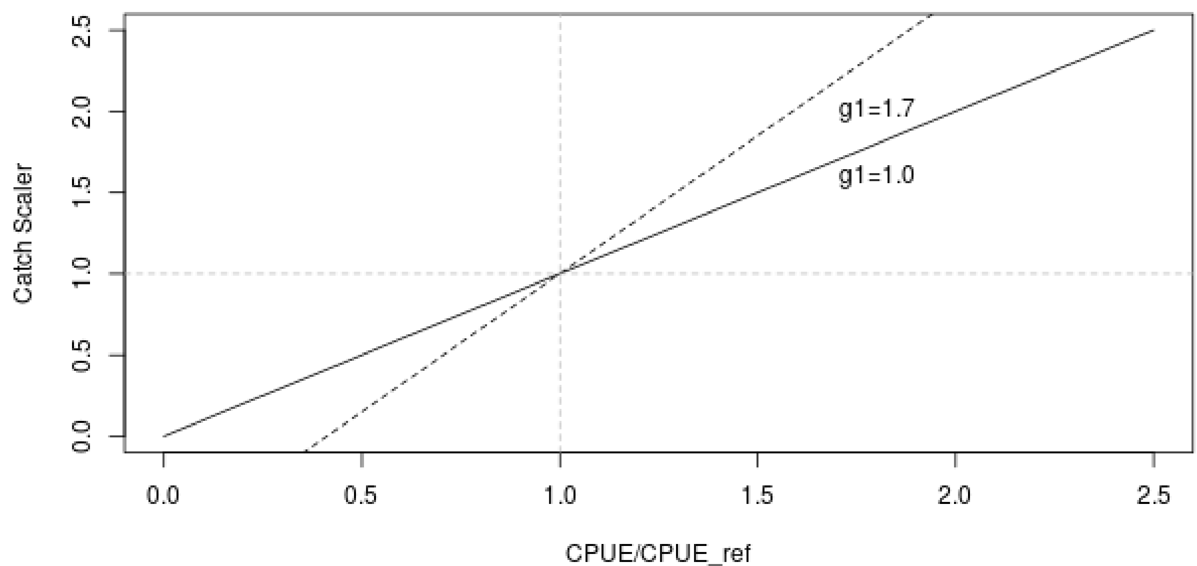


Figure 2: One-phase harvest control rule that relates fishing opportunity (catch scaler) to relative CPUE ($\overline{CPUE}$ / $CPUE_{ref}$). The slope of the line can be modified by $g1$ to make the scaler more or less reactive to changes in CPUE.

3.1.2 Two-phase HCR

The two-phase HCR has two components, each returning an independent scaler for catch which are combined to return a single catch scaler.

Similar to the one-phase HCR, the scaler from the first component is determined from the ratio of $\overline{CPUE}$ to $CPUE_{ref}$. The ratio is compared to two levels, $Trig_{up}$ and $Trig_{down}$, that determine whether the resulting scalar will have a value of 1, S_{lower} or S_{higher} (Table **??**).

This first part of the rule has three outcomes: if $\overline{CPUE}$ is close to the $CPUE_{ref}$, catches are unchanged, otherwise they are scaled up or down accordingly (Figure 3a):

$$scaler.1 = \begin{cases} Trig_{up} < \frac{\overline{CPUE}}{CPUE_{ref}}, & S_{upper} \\ Trig_{down} < \frac{\overline{CPUE}}{CPUE_{ref}} < Trigup, & 1.0 \\ \frac{\overline{CPUE}}{CPUE_{ref}} < Trig_{down}, & S_{lower} \end{cases} \quad (2)$$

The second component calculates the gradient of a straight line fitted to the time series of CPUE for the last Y_{ave} years (Figure 3b). If CPUE is increasing the gradient of the line will be positive and the scaler will be greater than 1. Conversely, if CPUE is decreasing the gradient will be negative and the scaler will be less than 1. The scalar from the second component is calculated from the gradient and a gain parameter ($g2$) (Figure 3c):

$$scaler.2 = 1 + g2 * gradient + (1 - g2) \quad (3)$$

The resulting overall catch scaler from the HCR is calculated as the product of scaler 1 and scaler 2 (i.e. the two scalers multipled together).

$$scaler = scaler.1 * scaler.2 \quad (4)$$

The description of each parameter is given in Table **??**. For the examples presented in this paper, an equal weighting was applied to each component of the HCR. A different weighting system can be discussed in the future.

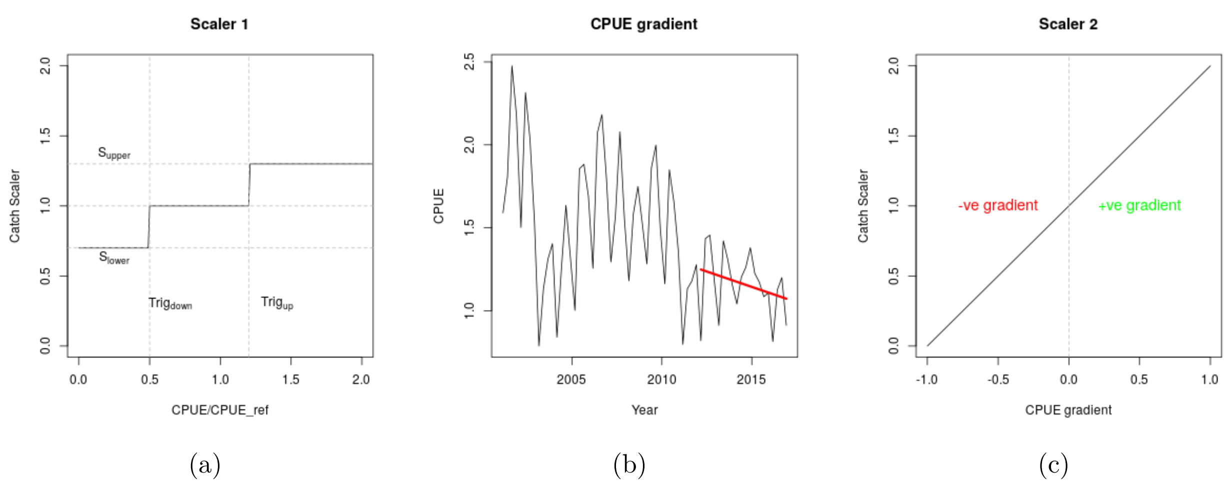


Figure 3: Two-phase harvest control rule: Phase 1 produces a simple scaler dependent on the relative CPUE ($\overline{CPUE}$ to $CPUE_{ref}$). Phase 2 produces a scaler dependent on the gradient of the recent trajectory of CPUE (greater than 1 for +ve gradients and less than 1 for -ve gradients). The resulting scaler for management of the fishery is the product of scaler 1 and scaler 2.

Parameter	Name	Description
Y_{ave}	Average years	Years to average CPUE over and take the CPUE gradient over
$\overline{CPUE}$	Average CPUE	Average CPUE of the last Y_{ave} years
$CPUE_{ref}$	CPUE reference	The reference CPUE level against which the average CPUE is compared
$Trig_{up}$	Upper trigger point for catch scaler increase	The trigger point that controls the upper range of the $\frac{\overline{CPUE}}{CPUE_{ref}}$
$Trig_{down}$	Lower trigger point for catch scaler reduction	The trigger point that controls the lower range of the $\frac{\overline{CPUE}}{CPUE_{ref}}$
S_{upper}	Maximum catch scaler	If the $\frac{\overline{CPUE}}{CPUE_{ref}}$ is bigger than the $Trig_{up}$, the maximum scaler will apply
S_{lower}	Minimum catch scaler	If the $\frac{\overline{CPUE}}{CPUE_{ref}}$ is smaller than the $Trig_{down}$, the minimum scaler will apply
g2	Gain	Determines how reactive the HCR is to the gradient of the average CPUE.

Table 3: Description of parameters used in the two-phase HCR.

3.2 Length-based HCR

Changes in the mean length in the catch can be an indicator of changes in stock status and can potentially be used as input for an HCR. The length-based HCR described here attempts to set an appropriate catch level based on the mean length in catch of the combined PICT longline fisheries in Region 2 (Fishery 4) of the stock assessment (Figure. 1) (Tremblay-Boyer et al., 2018).

Two reference length levels are defined: a target (L_{tar}=96.37mm) and limit (L_{lim}=92.79mm) that represent the mean length in catch of the combined PICT longline fisheries in Region 2 (Fishery 4) when stock depletion ($SB/SB_{F=0}$) reaches the interim TRP and the limit reference point (LRP), as determined from deterministic projections, respectively.

The catch scaler for the target-based mean length HCR is based on the recent observed mean length in the catch ($\overline{L_{obs}}$) averaged over Y_{ave} years (Figure. 4). r is an additional reactivity parameter.

$$Scaler = \begin{cases} [\frac{(1+(\overline{L_{obs}}-L_{lim})/(L_{tar}-L_{lim}))}{2}]^r & \text{if} \quad \overline{L_{obs}} >= L_{lim} \\ 1/(2*(\frac{\overline{L_{obs}}}{L_{lim}})^{2r}) & \text{if} \quad \overline{L_{obs}} < L_{lim} \end{cases} \tag{5}$$

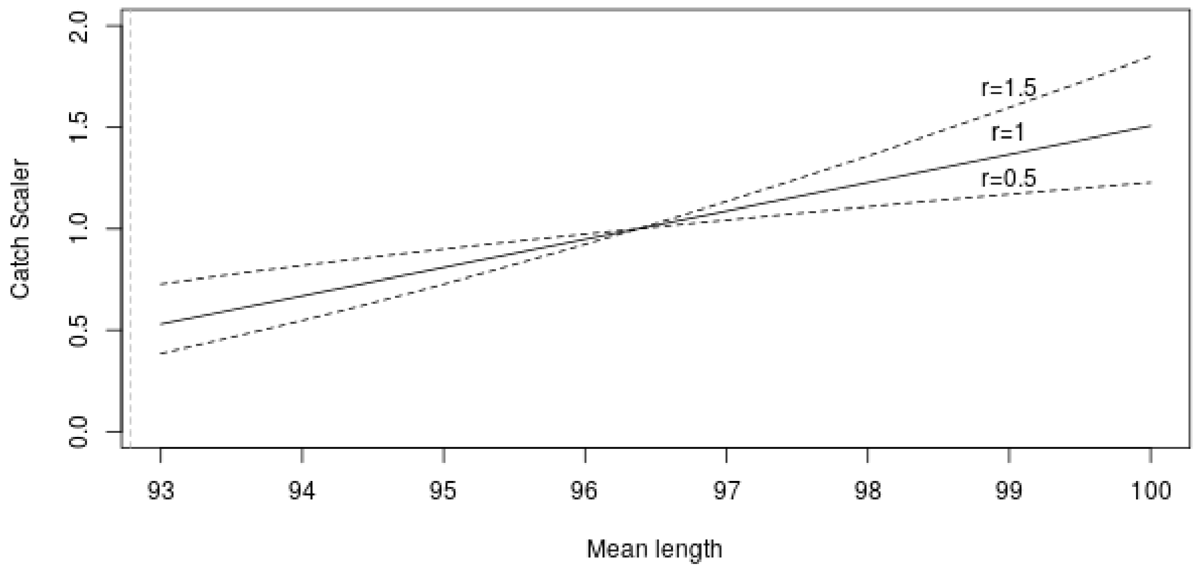


Figure 4: The length-based HCR is driven by the ratio of $\overline{L_{obs}}$ to the target length (L_{tar}=96.37mm) and the limit length (L_{lim}=92.79mm) in the catch.

3.3 General settings for the evaluations

Preliminary evaluations were conducted across the grid of 24 operating models (OMs) described in Section 2 and for the three categories of HCRs described in Section 3. Ten replicates (or iterations) were run for each OM resulting in 240 replicates for each HCR, where each replicate had a different realisation of observation error on the simulated catches and recruitment variability.

Both CPUE-based HCRs rely on a relative CPUE ($\overline{CPUE}/CPUE_{ref}$) which has been calculated here as the average CPUE over the last Y_{ave} years (which varies with HCR) divided by the reference CPUE level (i.e. the CPUE in 2013 plus 8%, as used as the basis for the interim TRP). The year range used to calculate the $\overline{CPUE}$ is applied as a moving window and will therefore change for each management cycle. The resulting catch scaler was used to set catch limits for all fisheries (longline and troll) by applying the scaler to the reference catch level (the average catch in the years 2014 to 2016). A 3-year management cycle was assumed in this instance but shorter (or longer) periods can be considered.

The settings for the evaluations have been selected based on the settings in previous analyses (Scott et al., 2019b) (Table 4). Further consideration of these settings is recommended for future evaluations.

Axis	Setting
Management Period	3 years
Projection period	30 years
Baseline years for catch scaling	2014-2016
Reference CPUE	the CPUE level of 2013 plus 8%
Management quantity	catch
Managed fisheries	all fisheries

Table 4: Settings for testing the South Pacific albacore HCRs.

4 Results

The results presented here are preliminary and are shown to provide an indication of the type and form of HCR that may be considered. Summary diagnostics ($\overline{CPUE}/CPUE_{ref}$ of the PICT longline fleet, depletion ($SB/SB_{F=0}$) and catch) are calculated to illustrate the general characteristics of each HCR. The median and the 80th percentile range across the replicates are calculated over time, where the wider the precentile range, the greater the uncertainty in the result. The variability of catches is also considered.

The results from the simulations form the basis of the performance indicators that are presented in a South Pacific albacore version of PIMPLE (i.e. SPAMPLE; https://ofp-sam.shinyapps.io/spample/) (Scott et al., 2019a; Yao et al., 2019).

4.1 CPUE-based HCR

4.1.1 One-phase HCR

Three different parameterisations of the one-phase HCR (HCR 1, HCR 2 and HCR 3) were tested (Table 5). The performance of these three HCRs are presented below (Figure 5).

HCR 1 was reasonably good at achieving the reference CPUE, with the median value of $\overline{CPUE}/CPUE_{ref}$ being close to 1 during the simulation period (Figure 5a). The median CPUE values from HCRs 2 and 3 were slightly below the reference CPUE. The range of uncertainty in the CPUE is approximately the same for the three HCRs.

The median stock depletion under HCR 3 reaches the interim TRP after about 12 years (Figure 5b). Under HCRs 1 and 2 the median depletion reaches the interim TRP in a similar timescale, but then remains above the interim TRP, suggesting that the stock is potentially underexploited under these HCRs. All HCRs avoid levels of depletion falling below the LRP with high probability.

It should be noted that the CPUE presented here is calculated for the PICT longline fleet (Fishery 4 in assessment Region 2), and not the combined CPUE of the whole longline fleet. For this reason achieving the interim TRP in terms of depletion does not necessarily result in the CPUE achieving the reference CPUE (as is the case with HCR 3).

HCR 3 yields the highest overall median catch but there is high variability in catches, particularly in the short-term (Figure. 5c). The median catches from HCR 2 are lower than from HCR 3 but are much more stable, particularly in the medium to long-term, because the ΔC_{max} parameter prevents large changes in catch from one management period to the next. This is an important trade-off that should be considered by stakeholders: high, variable catches versus lower, stable catches. The stepped nature of the catch plot is a result of the HCRs setting the catch limits for all fisheries and the management period being 3 years. Both HCR1 and HCR2 require reductions in the short-term, while HCR 3 allows initial increases in catch on average. The catch transitions in the different time periods should also be noted.

HCR	$\boldsymbol{Y_{ave}}$	$\boldsymbol{g1}$	$\boldsymbol{CPUE_{ref}}$	$\boldsymbol{\Delta C_{max}}$
HCR 1	5	1.7	1.49	0
HCR 2	5	1.0	1.49	1.15
HCR 3	3	1.0	1.29	0

Table 5: Parameters for one-phase CPUE-based HCR.

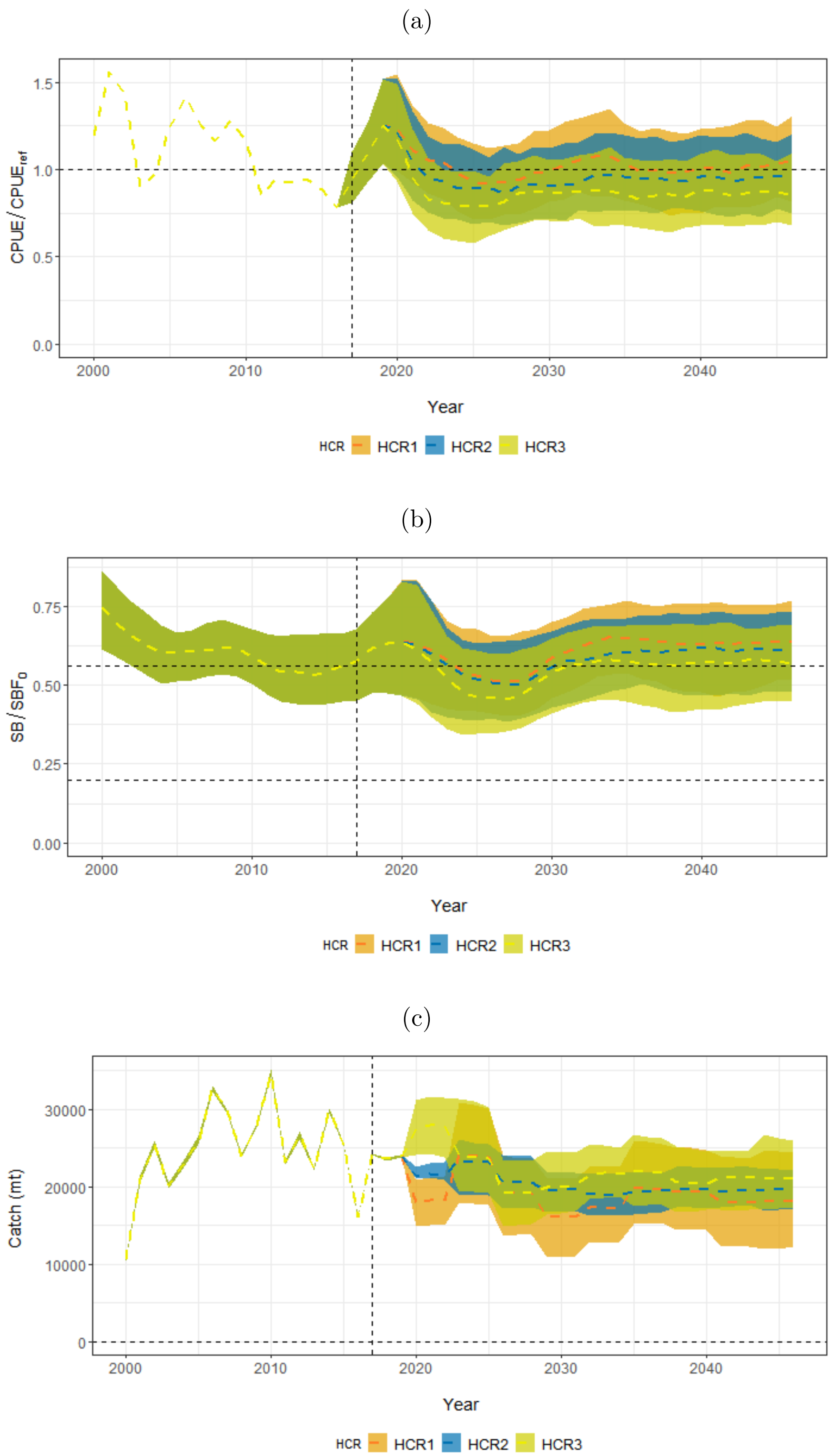


Figure 5: Performance of the CPUE-based one-phase HCR. Shaded area shows the 80th percentile range for each summary diagnostic. The dashed line shows the median value across the replicates.

4.1.2 Two-phase HCR

Three two-phase CPUE-based HCRs (HCRs 4, 5 and 6) were tested (Table 6). The performance of these three HCRs are presented below (Figure. 6).

HCR	$\boldsymbol{Y_{ave}}$	$\boldsymbol{Trig_{up}}$	$\boldsymbol{Trig_{down}}$	$\boldsymbol{S_{upper}}$	$\boldsymbol{S_{lower}}$	$\boldsymbol{g2}$
HCR 4	5	1.5	0.8	1.3	0.7	1.4
HCR 5	5	1.2	0.8	1.3	0.7	1.0
HCR 6	3	1.6	0.2	1.8	0.2	1.0

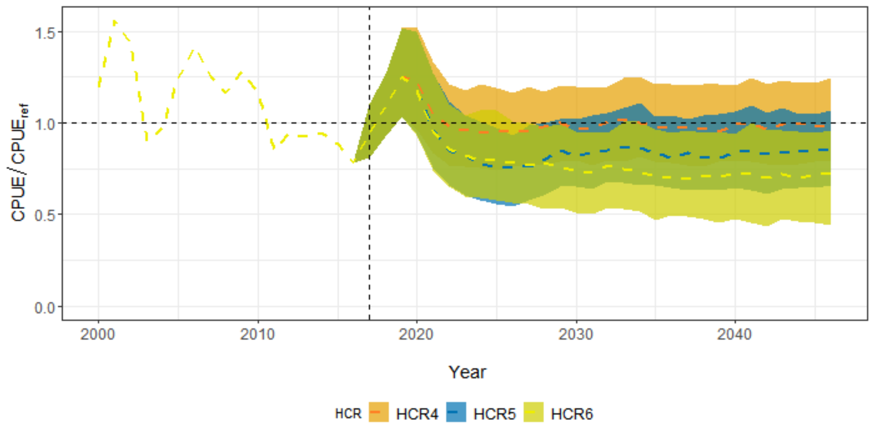
Table 6: Parameters for two-phase CPUE-based HCR.

The median value of CPUE from HCR 4 achieved the target CPUE, while the median values of CPUE under HCRs 5 and 6 were both slightly below the target (Figure. 6a).

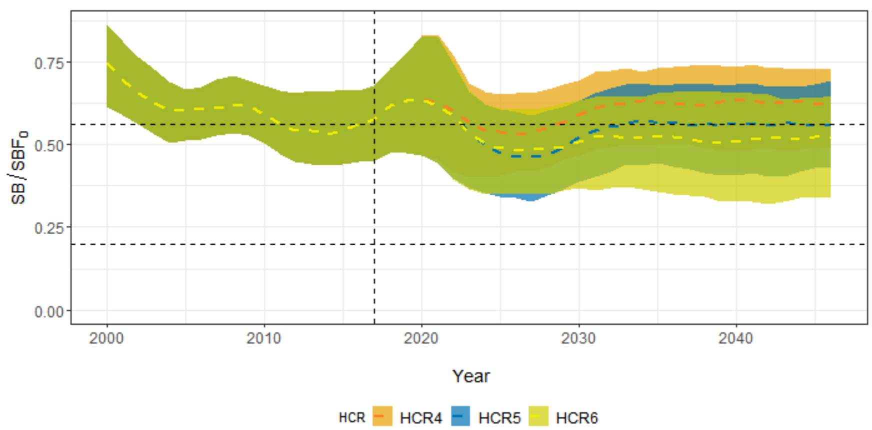
The median depletion from HCR 5 reached the interim TRP, while the median depletion from HCRs 4 and 6 had higher and lower values than the interim TRP respectively (Figure. 6b). As mentioned above, the CPUE presented here is from the PICT longline fleet (Fishery 4 in Region 2), not the combined CPUE of the whole longline fleet which is why achieving the interim TRP in terms of depletion does not necessarily result in the CPUE achieving the reference CPUE.

The median catches from HCRs 4 and 6 were stable over time and with a low level of uncertainty (the ribbons in the plot are narrow) with catches from HCR 6 being higher. Median level of catches from HCR 5 were similar to HCR 6 in the medium to long-term, but with higher level of uncertainty (the ribbons in the plot are wide) (Figure. 6c).

(a)



(b)



(c)

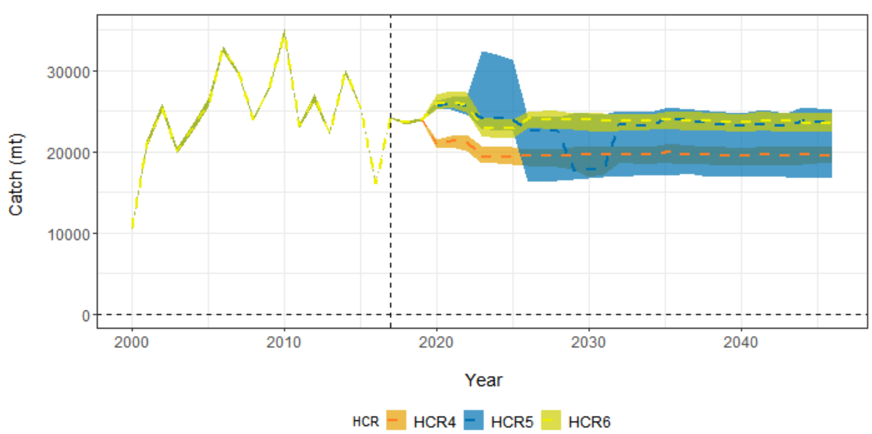


Figure 6: Performance of CPUE-based two-phase HCR. Shaded area shows the 80th percentile for the summary diagnostics.

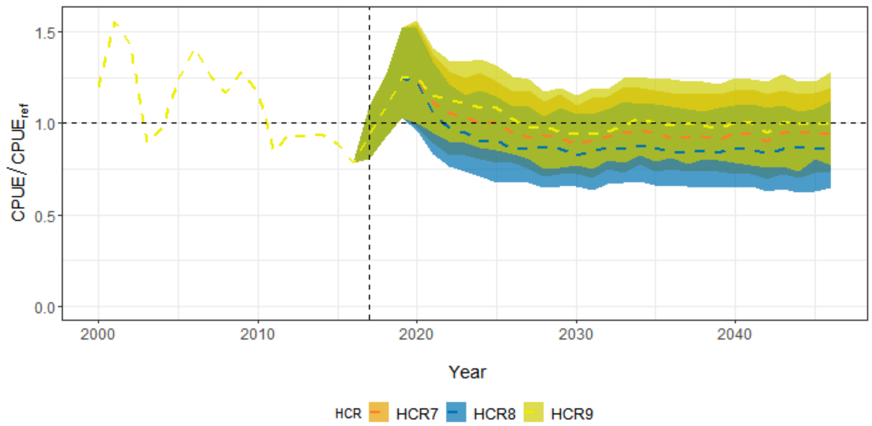
4.2 Length-based HCR

Three length-based HCRs (HCR 7, 8 and 9) were tested. The observed mean length is averaged over the most recent five years. The value of r for was set to 1, 0.5 and 1.5 respectively.

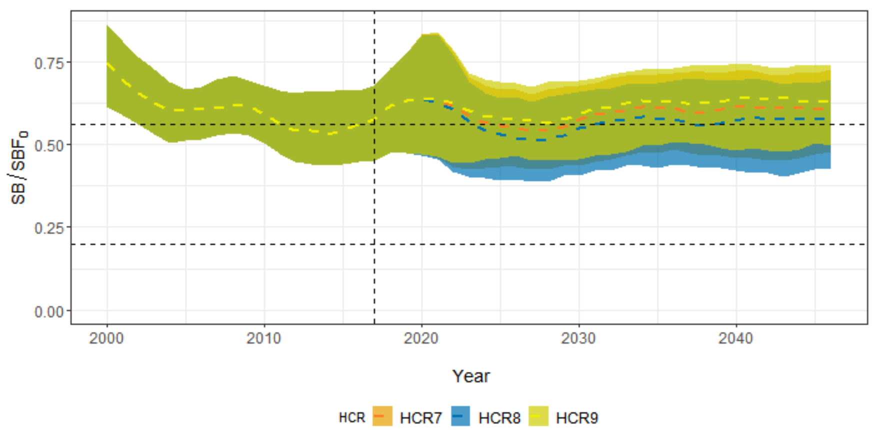
Of the three HCRs, the median value of CPUE from HCR 9 achieved the reference CPUE, while the median CPUEs from HCR 7 and HCR 8 were lower. The median depletion from HCR 8 reached the interim TRP, while the median depletion from HCRs 7 and 9 were higher. The uncertainty in the catches (the width of the ribbon) is low, and the catches relatively stable, for all three HCRs with HCR 8 giving higher median catches.

On the basis of these results, the length-based HCRs appear to perform well. We note, however, that the methods for simulating length frequency data within the evaluation framework re-samples lengths from a multinomial distribution using a user defined effective sample size. This approach produces length composition data with much less modal variability than might be seen in real observations. Consequently the length information used in the evaluations to 'drive' the HCR may not fully represent the true variability that might be expected in reality. This feature of the length composition data is also noted in investigations of the skipjack evaluation framework (SC16-MI-IP10) and it is intended that this issue will be addressed in future developments of the MULTIFAN-CL assessment software. HCRs that rely solely on length composition data will be more adversely affected by this than HCRs that rely on a combination of data types. Until this issue is resolved, the results of evaluations of HCRs that rely solely on length frequency information should be treated with caution.

(a)



(b)



(c)

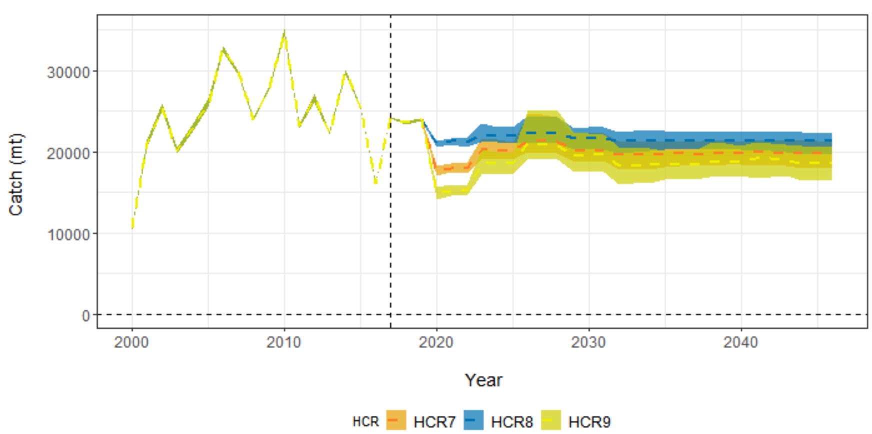


Figure 7: Performance of target rule mean length HCR. Shaded area shows the approximate 80% confidence interval for each summary diagnostics.

5 Discussion

In this paper, we presented the designs and outcomes of nine MPs based on two types of empirical data (observed CPUE and mean length) and three types of HCRs. The results suggest that such MP designs may potentially achieve the targeted CPUE or interim TRP. As such, they can continue to be developed as candidate MPs for South Pacific albacore.

The results show a clear trade-off in achieving different management objectives (e.g. catch variability versus catch level). The relatively small number of HCRs of each type tested here means it is not possible to draw detailed conclusions about the interactions of the HCR parameters but it is possible to make some general observations. In particular, the parameters affect the speed of the response to perceived changes in stock status and the magnitude of that response.

The gain parameters $g1$ and $g2$ and reactive parameter r control the extent to which the output catch scaler reacts to changes in the empirical data. Higher values for these parameters means that HCRs respond strongly to changes in the empirical data meaning that catches can quickly increase to take advantage of perceived increases in stock status, or reduce quickly if the stock status is thought to be declining. However, there is a trade-off with the resulting catch stability, with higher values for these parameters leading to higher variability of catches.

Catch stability can be increased through the use of the ΔC_{max} parameter which limits how much the catch can change with respect to the previous catch level. This can help protect industry from large fluctuations in the catch and can subsequently assist longer-term economic planning. Additionally, for the two-phase CPUE-based HCR, $Trig_{up}$ and $Trig_{down}$ control the two CPUE levels at which the catch scaler would change. Therefore, increasing distances between $Trig_{up}$ and $Trig_{down}$ could also result in a more stable catch.

Y_{ave} controls the number of years over which the average CPUE is calculated and can also affect how quickly the HCR reacts to changes in the empirical time series (but not the magnitude of the response). Low values for this parameter mean that the catch scaler will respond more rapidly to recent changes in the empirical data. Although this will allow the catches to closely track the perceived stock status, the empirical data may be subject to high levels of observation error. There is the risk that the catch scaler will track this error, rather than the real signal. Conversely, high values for Y_{ave} mean that the catch scaler will respond to longer-term changes in empirical data. Catch changes will likely be more gradual, meaning that fishers will be slower to take advantage of improvements in stock status, or potentially not reactive enough if the stock declines.

The MPs that use a HCR based on mean-length in the catch appear to be perform well. However, the results should be treated with caution. The performance of the MPs that use the mean-length in the catch depend on the assumption that a declining mean-length is an indicator of a decline in a stock status. However, this may not always the case. Changes in the catch size composition can also be driven by changes in the selectivity patterns, which are not considered in these simulations. Strong recruitment events can also affect the catch size composition by reducing the mean-length in the catch, even though the stock status is actually improving.

The length-based HCR also relies on high quality biological sampling from the longline fishery, in the real world. Additionally, as mentioned above, there are currently limitations with the generation of psuedo size composition data with MULTIFAN-CL meaning that the results may be overly-optimistic. Consequently, from the results presented here, we cannot say with confidence that an MP that only uses the catch mean-length as the input signal to the HCR is sufficiently robust to uncertainty. However, changes in mean-length in the catch may contain useful information about the stock status and so it may be worthwhile exploring the utility of MPs that use CPUE as well as mean-length in the catch (e.g. combine HCRs by weighting).

The selection of an appropriate empirical time series to "drive" the HCR is one of the biggest challenges faced when developing empirical MPs. The use of raw (nominal) CPUE in the MP is the simplest and most transparent approach although the MP may perform better if the CPUE is subject to some level of pre-analysis before being passed to the HCR. The raw CPUE can be influenced by many factors such as vessel targetting behavior, vessel performance and environmental factors that can all vary over time or space. For this reason, CPUE time series inputs for stock assessments are often standardised to try to remove these influences and better reflect the underlying stock biomass. The better the selected CPUE series reflects overall biomass, the better the MP is likely to perform. For the preliminary evaluations in this paper, the raw CPUE data from the PICTs longline fleet in Region 2 is selected to "drive" the HCR. It is noted that it's also possible to use other CPUE time series as well as apply standardization process to the raw CPUE before using it as the estimation model in the future.

WCPFC15 tasked the scientific services provider to identify a range of alternative catch pathways and time frames that achieve the interim TRP, no later than 20 years. In response, multiple fixed catch trajectories were proposed to achieve the interim TRP by reducing catch by constant proportions over time until the TRP is reached (SC16-MI-IP01). A comparison of the performances of one of the two-phase HCRs (HCR 4) and the "achieve the TRP in 20 years" catch reduction scenario can be seen Figure. 8. The results suggest that both catch reduction and the HCR are able to achieve the target CPUE in 20 years. The catch reduction scenario cuts catch continuously during the simulation period, while HCR 4 cuts catch in the short-term, and then stays relatively stable in the medium and long-term (Figure. 8c). An alternative catch reduction trajectory that was developed to achieve the interim TRP was "reduce catch for 10 years then maintain catch at that level for the remaining 10 years". This is compared to reduce catch for 10 years then apply HCR 4 in Figure 9. Although this demonstrates that using fixed catch reduction trajectories may achieve the interim TRP, this style of management is very limited. The catch trajectories are fixed in time and do not dynamically respond to changes in the stock status. For example, the fixed catch trajectories would not be able to take advantage of periods of high recruitment by potentially increasing catches, or be more conservative during periods of low stock productivity, without getting consensus from all WCPFC members. One of the clear advantages of the harvest strategy approach is that after the selection of the preferred MP by stakeholders, discussions can be focused on other important management issues, instead of catch and effort limits.

The SC14 endorsed the initial focus on the empirical MPs approach and the SC15 reviewed the initial framework that was developed accordingly for the South Pacific albacore. The MPs described in this paper are all based on the use of empirical data. However, model-based MPs may also been considered in the future. Given the relationship between CPUE and the noted economic management objectives, a simple biomass dynamics model that uses CPUE may be sufficient as the estimation model in a model-based MP. This approach may be developed in the future.

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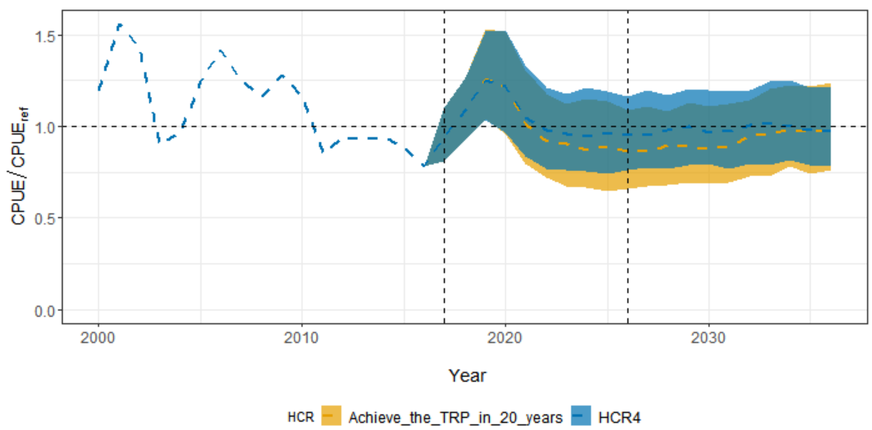
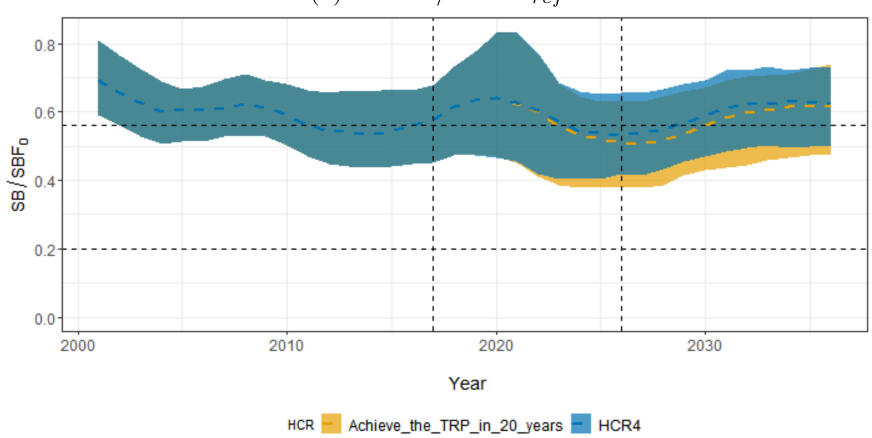
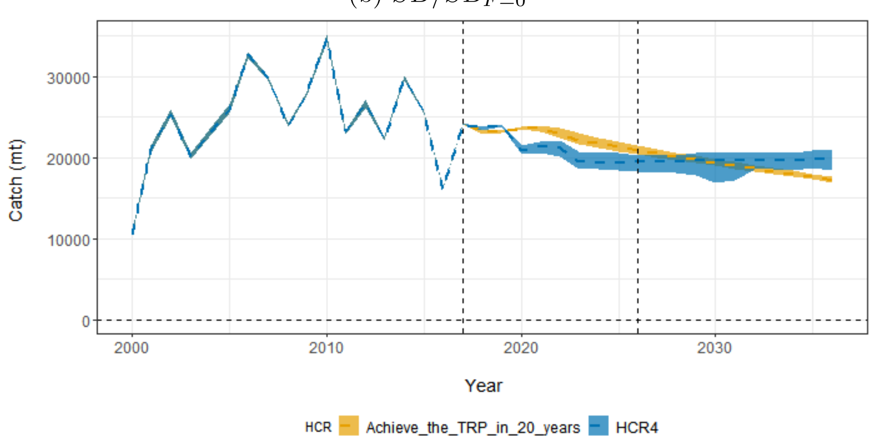


(a) $CPUE/CPUE_{ref}$

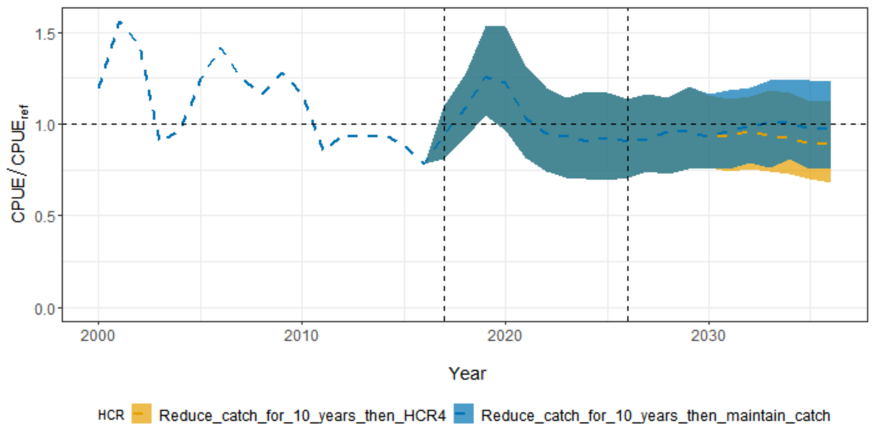


(b) $SB/SB_{F=0}$

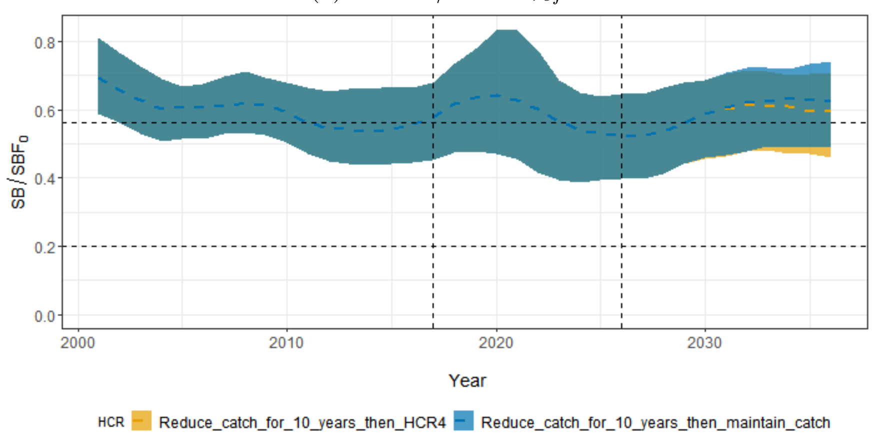


(c) $Catch$

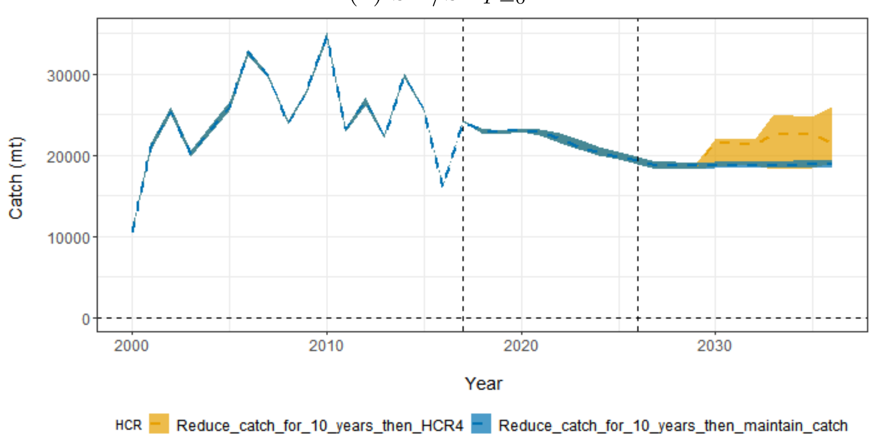
Figure 8: Comparison of the performances between the HCR 4 and "achieve the TRP in 20 years" scenario. Shaded area shows the approximate 80% confidence interval for each summary diagnostics.



(a) $CPUE/CPUE_{ref}$



(b) $SB/SB_{F=0}$



(c) $Catch$

Figure 9: Comparison of the performances between the "reduce catch for 10 years then maintain catch at that level for the remaining 10 years" and "reduce catch for 10 years then apply HCR 4 for 10 years". Shaded area shows the approximate 80% confidence interval for each summary diagnostics.