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Evaluation of candidate management procedures for South Pacific albacore

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- Updated catches in the transient period. This has slightly modified the performance of the candidate management procedures, particularly in the short term.

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Executive Summary

The WCPFC harvest strategy workplan schedules the adoption of the South Pacific albacore management procedure (MP) for the end of 2024. This report describes the evaluation of six different candidate MPs for South Pacific albacore, and presents various indicators to evaluate their performance.

The candidate MPs are evaluated using management strategy evaluation (MSE). The operating models (OMs) are based on the 2021 stock assessment for South Pacific albacore and include an additional factor for effort creep in the longline fisheries. The OM grid will continue to evolve during the harvest strategy development process.

In the evaluations the model fisheries are managed through the application of catch limits. The MP only manages the fisheries in the WCPFC-CA regions in the model. The future catches of the fisheries in the Eastern Pacific Ocean are held constant at the average 2017-2019 level. The output of the candidate MPs is a catch scalar, applied to the average 2017-2019 catch level, i.e. an output of 1 sets the catches to the 2017-2019 average catch level. Each model fishery is treated equally, i.e. the catch limits of each fishery increase or decrease by the same proportion.

The MP first operates in 2025 and sets the catch levels for the next management period starting in 2026. The management period is three years, i.e. the catch levels set by the MP are held constant for three years. There is a two year lag in data collection, e.g. calling the MP in 2025 uses data up to and including 2023. The last historical year in the OMs is 2019. The catches in the period 2020-2022 are set to the recorded values. The catches in the period 2023-2025 are set to the average of the 2020-2022 period.

The candidate MPs all have the same data collection and estimation method (an age structured production model (ASPM), implemented in Multifan-CL), and differ only in their harvest control rules (HCRs). Three of the MPs have the same HCR shape, but different levels of catch constraint, i.e. the maximum allowable amount of change in HCR output between management periods.

The candidate MPs have been selected to explore a range of possible behaviours. The results are presented to elicit feedback from members about possible MP design and to allow further refinement. In particular, the level of catch constraint should be carefully considered. At this stage, the results in this report are presented without any recommendation.

We invite WCPFC-SC to:

- Note progress in development of the MSE framework for South Pacific albacore;
- Provide feedback on the use of the ASPM as the estimation method (see Scott et al., 2023b);
- Provide feedback on performance of candidate management procedures and suggest alternative designs, meta-rules and/or preferred behaviour;
- Provide feedback on the suite of performance indicators.

1 Introduction

According to the WCPFC harvest strategy workplan, the MP for South Pacific albacore is scheduled for adoption at the end of 2024 (WCPFC, 2022). During the harvest strategy development process, candidate management procedures (MPs) are evaluated using management strategy evaluation (MSE) (Punt et al., 2014). Performance indicators are used to evaluate the relative performance of each candidate MP and to enable the selection of a preferred option (Scott et al., 2018).

This report describes the evaluation of six different candidate MPs for South Pacific albacore, and presents various indicators to evaluate their performance. The candidate MPs have been selected to explore a range of possible behaviours, including the impact of different levels of catch constraint, i.e. the level that catches may change between management periods. The results are presented to elicit feedback from members about possible MP design and to allow further refinement.

2 The management strategy evaluation framework

The evaluations are conducted using the 2021 stock assessment grid of 72 models as the basis for the operating models (OMs) (Table 1) (Castillo Jordan et al., 2021) and implemented using Multifan-CL. Each OM has the same regional structure, with four model regions: three in the WCPFC convention area (WCPFC-CA) and one representing the Eastern Pacific Ocean (EPO).

For these evaluations, an additional grid factor of effort creep is included. This is applied to the longline fisheries only. Combining all these grid factors gives a total of 144 OMs. Each OM is weighted equally.

Estimating effort creep levels in the longline fisheries is challenging. Here, levels of 0 and 2% per annum are used. We note that the intention of the OMs is to provide a plausible range of uncertainty rather than 'best estimates'. In turn we note recent discussions on the need to assess available information to better understand patterns of effort creep in the region's longline fishery, which would help inform the plausible range evaluated here.

Table 1: Grid of operating models used in the evaluations. The grid is based on the 2021 stock assessment with an additional factor of effort creep applied to the longline fisheries.

Axis	1	2	3
Steepness	0.65	0.80	0.90
Movement	Estimated	SEAPODYM	
Size data weight	Low (50)	Medium (25)	High (10)
Recruitment distribution	SEAPODYM	Regions 3 and 4	
Growth / Nat. mortality	Fixed otolith	Estimated	
Effort creep	0	2% per annum	

It is noted that the final grid of OMs to be used in the evaluations is yet to be agreed and the OMs used here are subject to change (Scott et al., 2023c).

The last historical value in the OMs is 2019. For the projection years 2020-2022 the catches of each model fishery are set to the recorded catches. The MP is first evaluated in 2025, setting fishing levels in 2026 (see section below). For the years 2023-2025 the catches of each model fishery are set to the average of the 2020-2022 level. The period 2020-2025 is considered to be the 'transient period' in the projections, i.e. before the MP sets fishing levels.

Stochastic projections are run until 2052, with variability included in the stock-recruitment process through resampling of the historical recruitment residuals across the period 1960 to 2019.

Observation error is included on the fishery-specific quarterly catch and effort through the application of log-normal error based on a user defined coefficient of variation (c.v.) (Davies et al., 2018). Separate coefficients can be applied for either catch or effort but cannot currently be applied to individual fisheries. In other words the catch c.v. applies to all catch projected fisheries and the effort c.v. to all effort projected fisheries. Here a c.v. of 0.25 is used to generate observed catch and effort used by the estimation method in the MP (Scott et al., 2023b). This level gives uncertainty consistent with that seen in 'real' data. Functionality exists within Multifan-CL to generate pseudo data for the historical time period, however, for the purposes of these current evaluations the historical data remain unchanged and pseudo data are generated only for the future time period. As such variability in the historical period arises solely from the different grid settings outlined in Table 1.

For each candidate MP, each of the 144 OMs is projected four times, giving 576 iterations per MP.

3 Candidate MPs

Following investigations into candidate estimation methods, the candidate MPs explored here all use the Age-Structured Production Model implemented in Multfan-CL to provide an estimate of stock status for the HCR (Scott et al., 2023b). This estimation method provides an estimate of the $SB/SB_{F=0}$ in the WCPFC-CA, averaged over the the last three years. Data collection is assumed to be the same for each MP. The candidate MPs therefore only differ in terms of the HCR shape.

The MPs only apply to fisheries in the WCPFC-CA. Future catches of fisheries in the Eastern Pacific Ocean (model region 4) from 2026 onward are fixed at the average of 2017-2019 levels. All fisheries are managed through annual catch limits and it is assumed the catch limit is always fully taken. The output of each HCR is a scalar that is applied to the average catches in the period 2017-2019 for each model fishery, i.e. an output of 1 sets the catches for each fishery at the 2017-2019 level. Each model fishery in the WCPFC-CA is treated equally, i.e. the catches of all fisheries increase or decrease by the same relative level.

It is noted that under the mixed fishery harvest-strategy approach, longline fisheries operating north of 10 degrees South would be managed through the bigeye MP (Scott et al., 2023a). For these evaluations, all model longline fisheries, including those north of 10 degrees South, are managed through the South Pacific albacore MP.

There are four different candidate HCRs (Figure 1; Table 2). The HCRs have an additional catch constraint as a meta-rule where the output cannot change by more than 5 or 10% from the previous HCR output. HCR 1 has three versions based on the level of catch constraint: The first has no catch constraint, meaning that any change in catch levels is unconstrained; the remaining two have catch constraints of 5 and 10%. These provide the opportunity to explore the possible impacts of different catch constraint levels on the performance of this HCR.

When the MP is first called in 2025 there is no previous HCR output to which the current HCR output can be compared. To allow the catch constraint to be applied in 2025, it is assumed that the 'previous' output is 1, the baseline value of the HCR. For example, the lowest output from an HCR that has a catch constraint of 10% is 0.9 when it is first called in 2025. Note that the evaluations are run by setting catch numbers, whereas the catch based plots below are based on catch weight.

HCRs 1, 3 and 4 have a typical 'hockey-stick' shape. HCR 2 has a shape that is similar to the one adopted for the interim skipjack MP, with a slope and a rising portion for higher estimated levels of $SB/SB_{F=0}$. HCRs 2, 3 and 4 all have a 10% catch constraint.

The plateaus of HCRs 1 and 2 are at a scalar of 0.86. This is taken from the South Pacific albacore TRP evaluations which suggest that this level of catch scalar will achieve 2017-2019 levels of $SB/SB_{F=0}$ in the long term (SPC-OFP, 2023). HCR 2 allows higher levels of fishing should the estimated $SB/SB_{F=0}$ exceed 0.55. HCRs 3 and 4 provide a conservative and less conservative HCR respectively, as constrast to HCRs 1 and 2.

Table 2: Parameters of the candidate harvest control rules (HCRs).

HCR		Limit	Threshold	Step end	Maximum	Constraint
HCR 1	SB/SBF=0	0.2	0.45			none; 5%; 10%
	HCR output	0.2	0.86			
HCR 2	SB/SBF=0	0.2	0.45	0.55	0.8	10%
	HCR output	0.2	0.86	0.86	1.1	
HCR 3	SB/SBF=0	0.25	0.6			10%
	HCR output	0.2	0.7			
HCR 4	SB/SBF=0	0.2	0.40			10%
	HCR output	0.2	1.0			

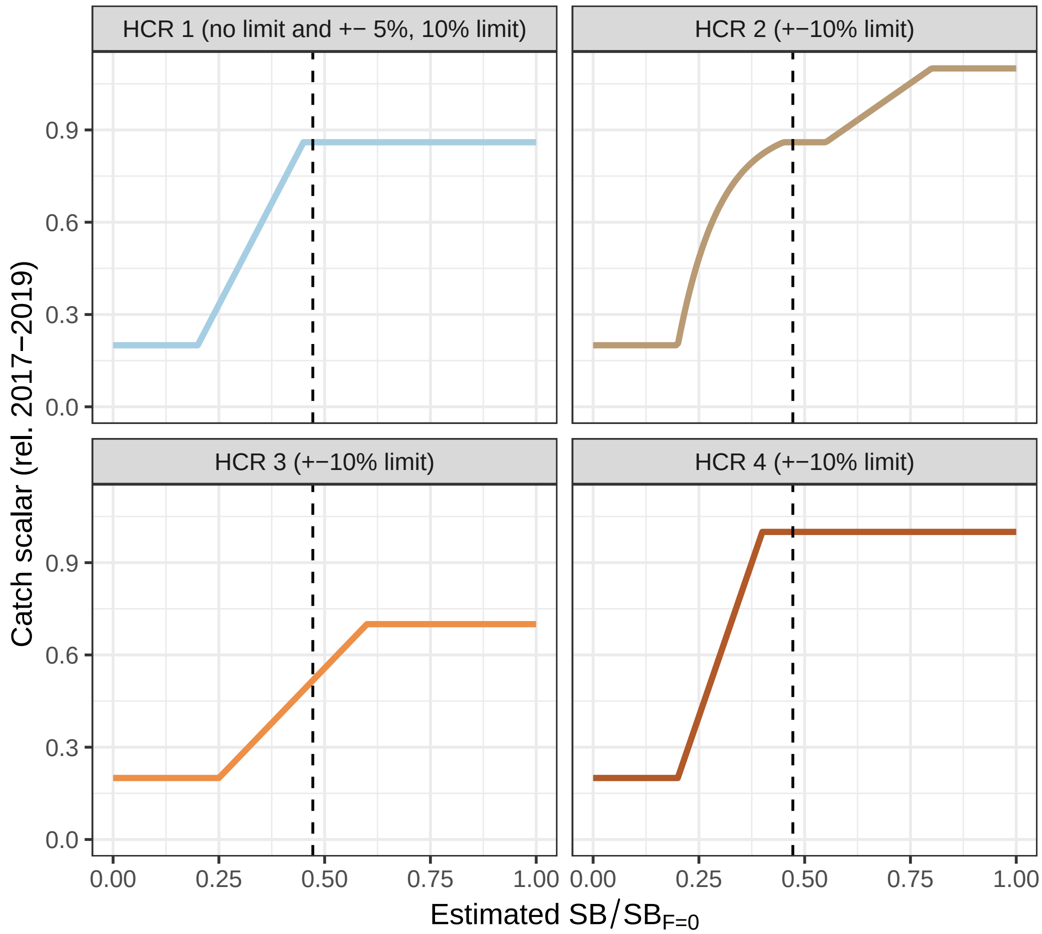

Figure 1: Shapes of the harvest control rules (HCRs) in the candidate management procedures. Note that there are three versions of HCR 1 with differing levels of catch constraint (no limit, 5 and 10%).

The management period is three years, i.e. the MP is called every three years and resulting catch levels are fixed for the next three years. The MP is first called in 2025, and is used to set the fishing opportunities in 2026-2028; the MP is next called in 2028 and is used to the fishing opportunities in 2029-2031 and so on. The MPs are run using data with a two year lag, e.g. when the MP is called in 2025 it uses data only up to and including 2023. This is consistent with the current SC approach for assessments incorporating longline data. In the simulations, the MP is called nine times, the last time being 2049.

4 Performance indicators

WCPFC-SC15-2019/MI-WP-10 discussed potential performance indicators for South Pacific albacore, based on outcomes from the Management Objectives Workshops (Yao et al., 2019; WCPFC, 2017). It is noted that not all desired performance indicators in Table 1 of Yao et al. (2019) can be calculated from the MSE framework, including the indicator relating to Article 30 of the WCPFC convention. For example, it is not possible to report the expected catches for fisheries from individual members, as only aggregated fisheries are used in the model. Similarly, detailed economic indicators are not reported by the model. Instead, proxy indicators may be used. For example, total catches can be used as a proxy for revenue etc. Additionally, many of the proposed indicators can be included in the monitoring strategy to evaluate the performance of the adopted MP when it is operational. The suite of performance indicators to evaluate the South Pacific albacore MPs will continue to develop as work progresses.

In these evaluations, six indicators are calculated to evaluate performance (Table 3).

Table 3: Calculated performance indicators.

No.	Objective type	Objective description	Performance indicator
	Biological	Stock status	$SB/SB_{F=0}$
1	Biological	Maintain ALB (and SWO, YFT and BET) biomass at or above levels that provide fishery sustainability throughout their range	Probability of $SB/SB_{F=0} > 0.2$
3	Economic	Maximise economic yield from the fishery	Average expected catch.
4	Economic	Maintain acceptable CPUE	Average deviation of predicted CPUE from reference period levels
6	Economic	Catch stability	Average annual variation in catch
8	Economic	Stability and continuity of market supply	Probability of being at, and deviation from, the TRP

Average expected catch (PI 3) and CPUE (PI 4) are presented as relative to the average catch levels in 2017-2019. CPUE (PI 4) can be calculated from the different model fisheries (see Castillo Jordan et al., 2021). Here only the CPUE of the PICT fishery in model region 2 is presented as an example. Catch stability (PI 6) is scaled between 0 and 1, where 1 implies maximum stability (no variability) and 0 implies a high degree of variability. Probability of being at, and deviation from, the TRP (PI 8) is calculated as a proximity to the TRP, where a value of 1 means that the stock status is at the TRP all of the time, and a value of 0 means that the stock status is as far from the TRP as possible (either above, or below the TRP). To provide examples of this indicator, a target level of the average $SB/SB_{F=0}$ in the period 2017-2019 is used in place of a TRP.

The indicators are calculated over three time periods: short- (2026-2034), medium- (2035-43) and long-term (2044-2052). Each time period corresponds to three management periods of three years each.

5 Results

This section presents time-series plots, box-plots of the indicators, analysis of the HCR performance and a comparison of the impact of different levels of catch constraint. The results are presented without any recommendation.

The results from future evaluations will be presented using an online app, similar to PIMPLE for the skipjack MP results (SPC-OFP, 2022).

Several of the stochastic projections lead to the stock crashing, particularly in the early years. This is due to a combination of lower than average levels of recruitment in those iterations and higher levels of fishing than can be sustained. Instead of excluding these iterations from the results, the biomass, catch and effort are set to 0 for the remaining years. This results in the ribbon of the time-series plots, and the tails of the box-plots (containing the 80th percentile range) being wide, with the lower limit close to 0 for some HCRs (most notably HCR 1 with the +-5% limit). The number of iterations leading to a stock crash depends on the HCR (Table 4). The majority of crashes happened the first few times the MP is called. For example, when the MP is called in 2028, 13 iterations of HCR 1 (+- 5% limit) crash on the subsequent projection using the MP output. Only 3 iterations of HCR 1 (no constraint) crash, illustrating that the crashes are generally caused by the catch constraint being unable to reduce catches sufficiently.

Table 4: Number of iterations in which the stock crashed after projecting the management period using the HCR output set in that year. 576 iterations were run for each candidate MP.

HCR	2025	2028	2031	2034	2037	2040	2043	2046	2049	Total	Total %
HCR 1	0	1	1	0	0	0	0	0	0	2	0.3
HCR 1 (+-10% limit)	4	13	17	5	9	7	2	1	0	58	10.1
HCR 1 (+-5% limit)	7	13	16	12	14	7	3	3	1	76	13.2
HCR 2 (+-10% limit)	4	13	17	5	9	7	2	1	0	58	10.1
HCR 3 (+-10% limit)	4	13	17	5	9	7	2	1	0	58	10.1
HCR 4 (+-10% limit)	4	13	17	5	9	7	2	1	0	58	10.1

5.1 Time series plots

Time series plots of $SB/SB_{F=0}$, catches relative to average catch in 2017-2019 and the CPUE are presented here.

As expected, the most conservative HCR (HCR 3 (+- 10% limit)) results in the highest median levels of $SB/SB_{F=0}$ (Figure 2). However, for this HCR there is still a probability of falling below the LRP (see Section 5.2 below) as the result of the stock crashing in several iterations in the early part of the time series. This is because the 10% catch constraint prevents the HCR from setting low enough catches for these iterations (see Section 5.4 below).

HCR 1 (no constraint) is quicker at reaching a steady median level than the same HCRs with catch constraints. Again, this is due to the impact of the catch constraint. Where the catch constraint on HCR 1 is 5%, median recovery to the 2017-2019 $SB/SB_{F=0}$ average takes close to the 30 year projection period. This is discussed further in Section 5.4.

The depletion trajectory outcomes for the four alternative HCR options (comparing all with a 10% catch constraint) are influenced by the shape of those HCRs. HCR 4, which permist a higher catch scalar at lower estimated stock status levels, correspondingly results in a more depleted stock over time. HCR 3, the more 'precautionary' HCR that sets a lower catch scalar when stock status is good, leads to a less depleted stock overall. Comparing the performance of HCRs 1 and 2 shows quite comparable performance over time, with HCR 1 stabilising closer to 2017-2019 $SB/SB_{F=0}$ average levels than HCR 2.

The total catch from the WCPFC-CA, relative to the average in 2017-2019, is presented in Figure 3. It is possible to possible to present the catches by model fishery, fishery groupings and region.

Multifan-CL requires that the projections are based on catch numbers, not catch weight. Here, the relative catch is reported by weight. As the stock structure changes in time, the catch weight is not held completely constant for each three year management period.

Evaluating the performance of HCR 1 with different catch constraints in terms of resulting catch, the version without a catch constraint shows potentially large reductions in catch the first time the MP is called, but in the medium- to long-term are generally higher than those seen where a catch constraint is placed on this HCR, and without the lower 'tail' of relative catches that increases with the constrained HCR versions over time. Where a 10% constraint is placed on catch change, catches are reduced more slowly over time, then are increased. Where a tighter 5% constraint is set, catches decline slowly, while a growing 'tail' of zero catches in the medium- to long-term are seen as some iterations 'crash' the stock.

Comparing the different HCR designs, all with the 10% constraint, all show a lower 'tail' of lower relative catches over time. HCR 4, which allows higher catches at lower estimated stock status, results in generally higher catches, and the more conservative HCR 3 allows lower catches. Catches resulting from HCR 2 and HCR 1 are slightly lower than those from HCR 4.

When examining the impact of constraints on HCR 1, a pattern comparable to that seen for depletion is identifiable. Where there is no constraint on catch change, CPUE recovers more rapidly compared to where a constraint is applied.

In terms of the different HCR designs, as expected, the most conservative HCR, HCR 3 (+- 10% limit), results in the highest relative CPUE in the medium- to long-term with a median level equal to that seen in the 2017-2019 period (Figure 4). CPUE recovery is not as fast as that seen under HCR 1 with no constraint, however. HCR 4, which allows higher catches, implies lower relative CPUE over time. HCRs 1 and 2 behave comparably, with HCR 2 leading to a slightly lower median CPUE.

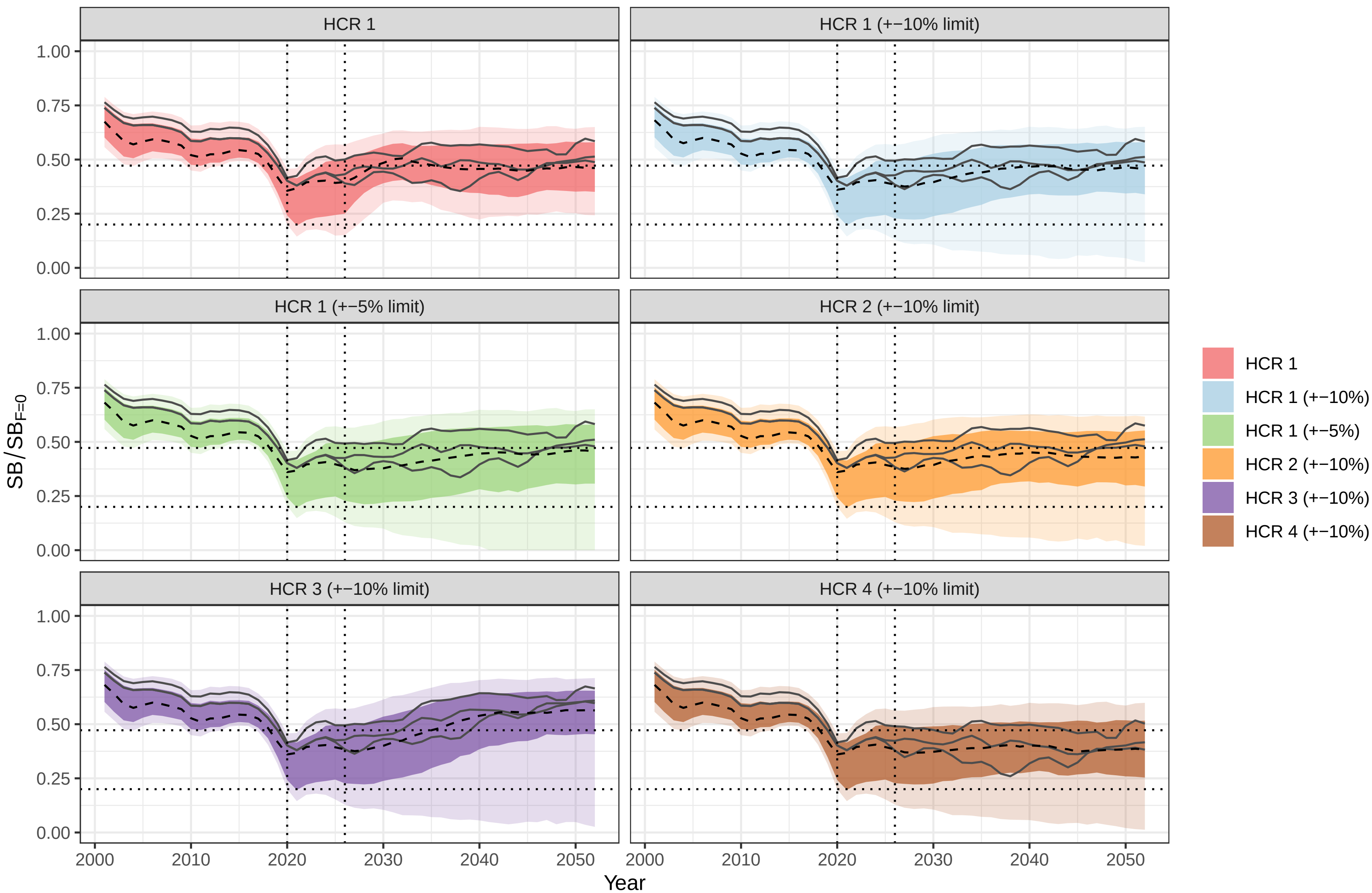

Figure 2: Time series of expected SB/SB$_{F=0}$ in the WCPFC_CA for each HCR. The outer ribbon shows the 80th percentile range, the inner ribbon shows the 50th percentile range. The median is shown as a dashed line. The vertical lines show the start of the projection period (2020) and the first year the management procedure is called (2026). Horizontal dashed lines show the Limit Reference Point (0.2) and the median of the 2017-2019 SB/SB$_{F=0}$ average. Several individual trajectories are shown for illustration. Only values from 2000 onwards are shown.

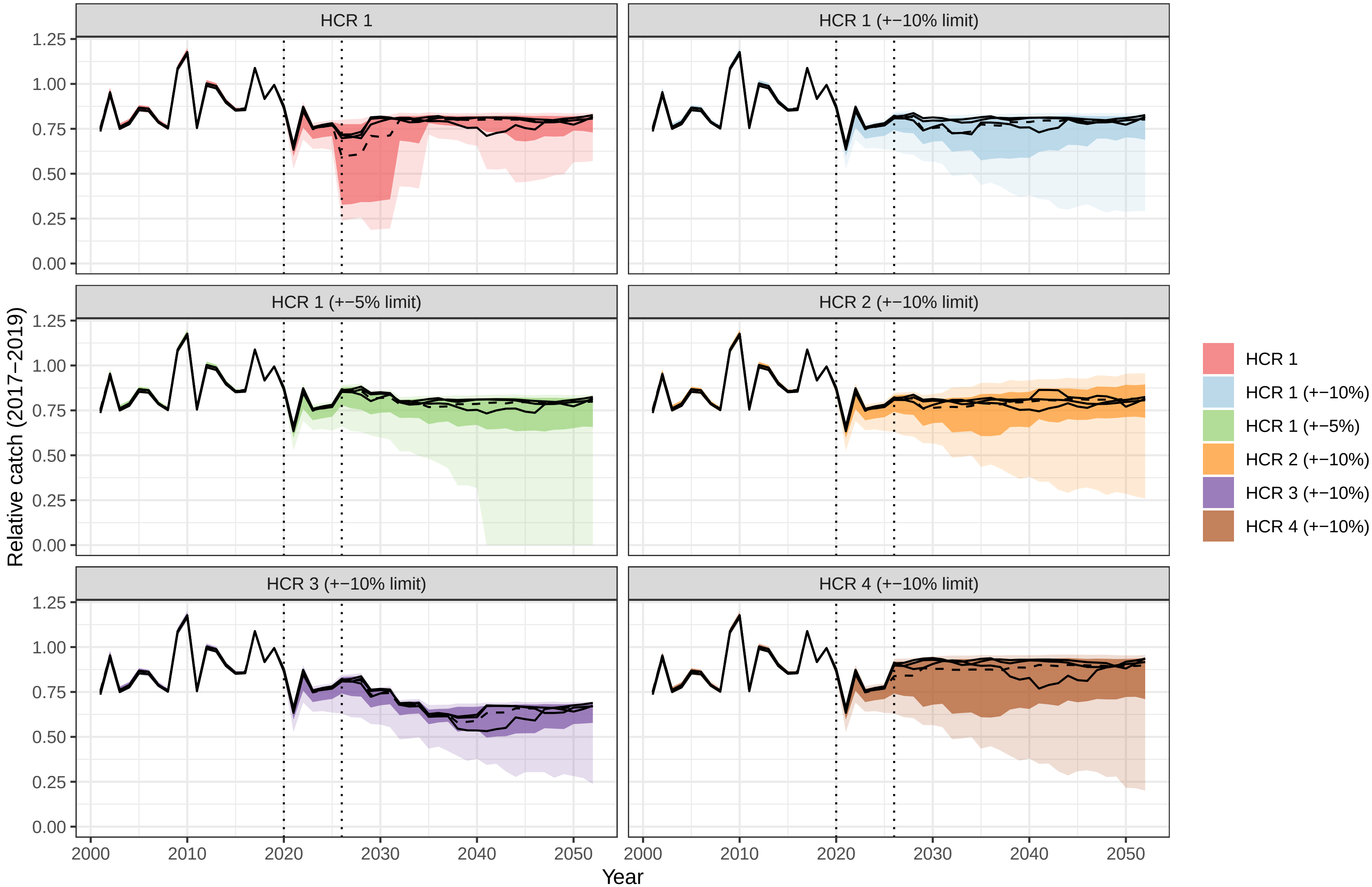

Figure 3: Time series of expected total catch in the WCPFC_CA relative to the average catch in 2017-2019 for each HCR. The outer ribbon shows the 80th percentile range, the inner ribbon shows the 50th percentile range. The median is shown as a dashed line. The vertical lines show the start of the projection period (2020) and the first year the management procedure is called (2026). Several individual trajectories are shown for illustration.

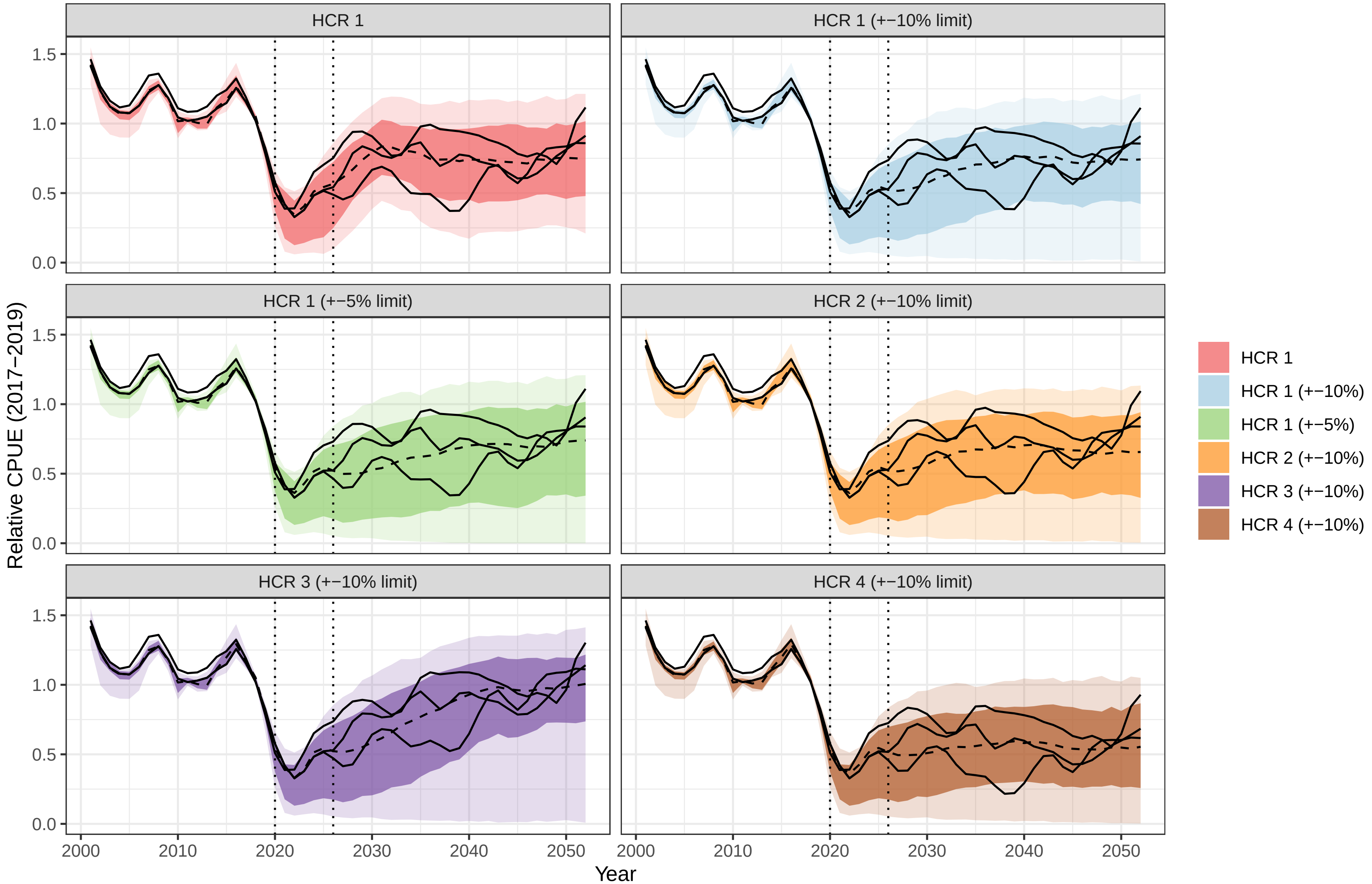

Figure 4: Time series of expected CPUE of the PICT fishery in model region2 relative to the average CPUE in 2017-2019. The outer ribbon shows the 80th percentile range, the inner ribbon shows the 50th percentile range. The median is shown as a dashed line. The vertical lines show the start of the projection period (2020) and the first year the management procedure is called (2026). Several individual trajectories are shown for illustration.

5.2 Box plots of indicators

Box plots of the performance indicators for each MP in the three different time-periods are shown in Figure 5. Catches are for the whole of the WCPFC-CA. It is possible to present the catches by model fishery, fishery groupings and region. Only the CPUE for the PICT longline fishery in model region 2 is presented here. The CPUE of other fisheries can be available in future results.

In the short-term, only HCR 1 (with no constraint) results in a probability of at least 0.8 of being above the LRP, with the others being just below 0.8. This is because only this HCR is able to reduce catches sufficiently to achieve this - all other HCRs have a catch constraint that prevents the required change. This initial reduction in catches in the short-term is visible in the catch plot. However, this HCR also has the lowest catch stability as a result of this flexibility.

HCR 1 (+- 5% limit) has the tightest constraint on the catches. The result is the lowest probability of being above the LRP out of the candidate HCRs (78-81% probability) and greatest depletion across the time series of the three HCR 1 variants. The trade off is that this HCR setting has the highest catches out of the three HCR 1 options, particularly in the short-term. This HCR also has the highest catch stability, simply because catches are unable to change much between management periods.

Comparing HCR designs, performance is comparable in terms of the probability of being above the LRP, with HCR 3 (the conservative HCR that limits catches when the stock is abundant) performing slightly better. As noted, that HCR performs less well in terms of catch, as a result of its design, and better in terms of CPUE, and results in a less depleted stock overall. HCR 4, which allows greater catch at lower estimated stock depletions, shows the opposite performance. Comparing HCRs 1 and 2, HCR 2 results in a slightly higher catch and lower CPUE in the longer term, slightly lower catch stability (since catches are allowed to increase at higher stock sizes), and comparable performance in terms of proximity to 2017-2019 $SB/SB_{F=0}$ average levels and slightly lower median $SB/SB_{F=0recent}$ levels.

This suggests that there are potential trade-offs between HCRs - an HCR that reduces catches in the short-term but with lower catch stability, or an HCR with higher risk of falling below the LRP but stability in catches.

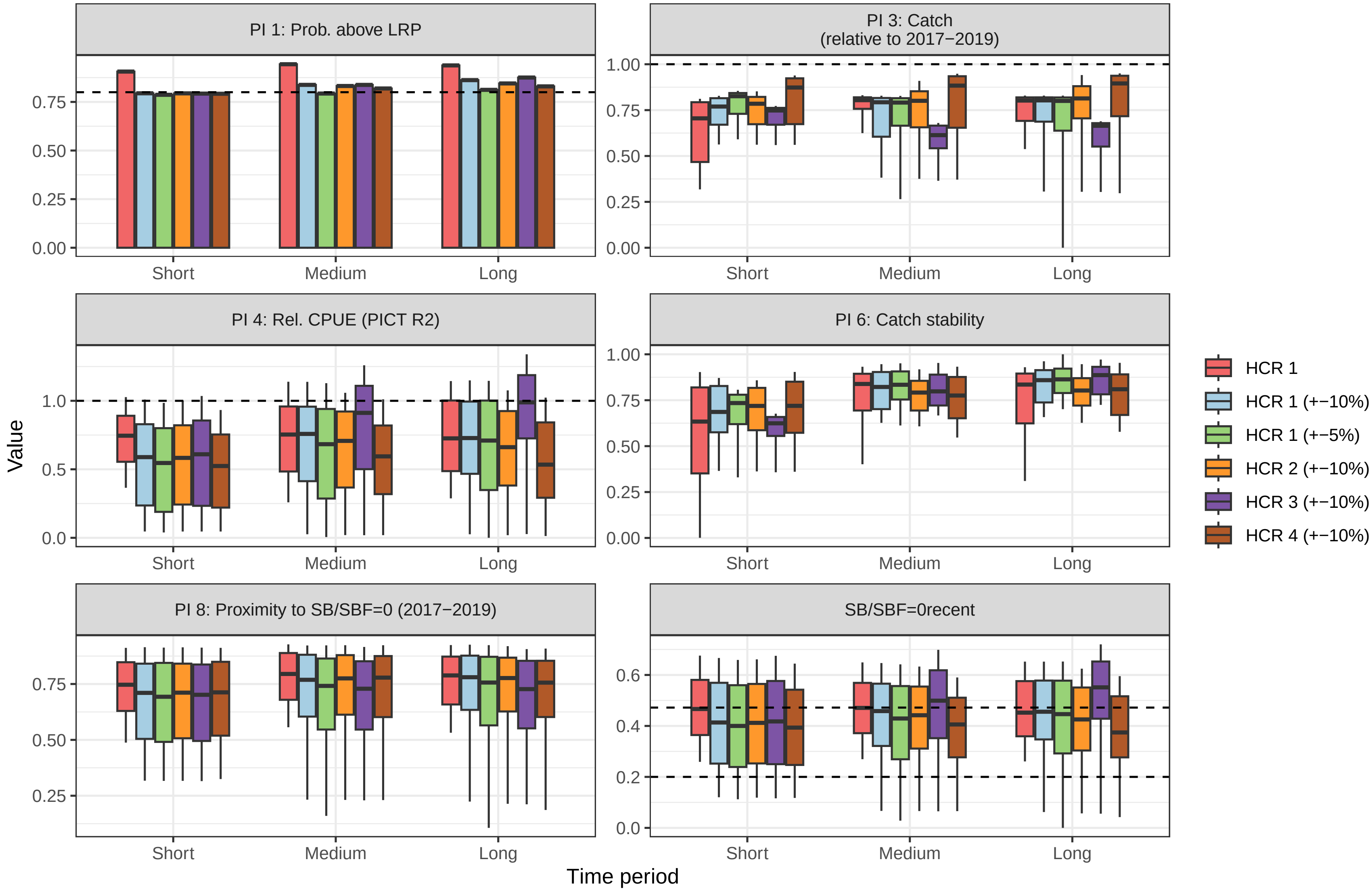

Figure 5: Performance indicators for each HCR. The indicators are calculated over three time periods: short-(2026-34), medium- (2035-43) and long-term (2044-52). Horizontal dashed lines have been added to illustrate the 0.8 probability of being above the LRP, the LRP and median $SB/SB_{F=0}$ (2017-19) on the $SB/SB_{F=0}$ plot, and at 1.0 for the relative catch and CPUE plots. The boxes show the 50th percentile range and the whiskers the 80th percentile range. The solid black line is the median value.

5.3 HCR analysis

As well as looking at the indicator values, when considering HCR designs it can be useful to visualise which parts of the HCR were 'active' during the evaluations (Figure 6). The marginal histograms show that the lowest estimates of $SB/SB_{F=0}$ tended to occur in the short-term (2026-2034), reflecting the initial 'recovery' of the stock to levels defined by the particular HCR.

The horizontal lines of points are a result of the catch constraints, i.e. the HCR is attempting to set lower or higher catches than is allowed by the constraint, noting that the first time the MP is called in 2025, to allow the constraint to be applied, the 'previous' HCR output is assumed to be 1. The horizontal lines for HCR 1 (+- 5%) are closest together as a result. When there is no catch constraint (HCR 1), all of the points lie on the HCR shape.

HCR 2 (+- 10% limit) has the largest range of output scalars, driven by the higher catches allowed at higher estimates of $SB/SB_{F=0}$.

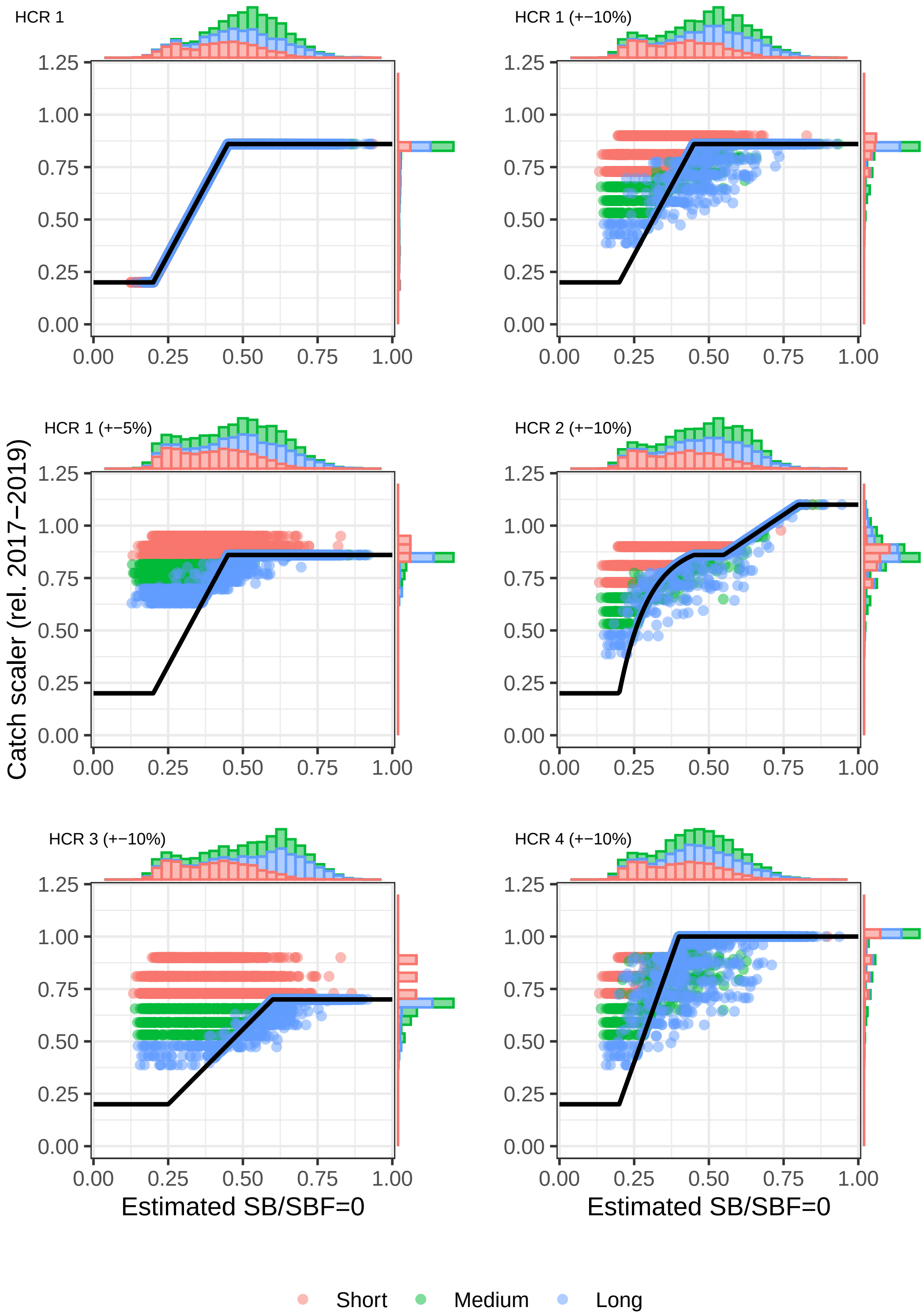

Figure 6: Candidate harvest control rules overlayed with the estimated $SB/SB_{F=0}$ and resulting output scaler through the simulations. The point colours are defined by the time period in which they occurred: short-(2026-34), medium- (2035-43) and long-term (2044-52). Marginal histograms are also shown.

Figure 7 shows the range of the catch scalar that is output by the HCR in each management period. The change in the scalar, equivalent to the variability in HCR output, is shown in Figure 8. The unconstrained HCR (HCR 1) has the largest range of catch scalar and also shows the highest variability in the first three management periods. The tighter the constraint, the lower the variability in HCR output (e.g. HCR 1 (+-5% limit)). However, a tight constraint may mean that the HCR is not able to react quickly enough to changes in the stock status, leading to an increased risk of falling below the LRP (see section below).

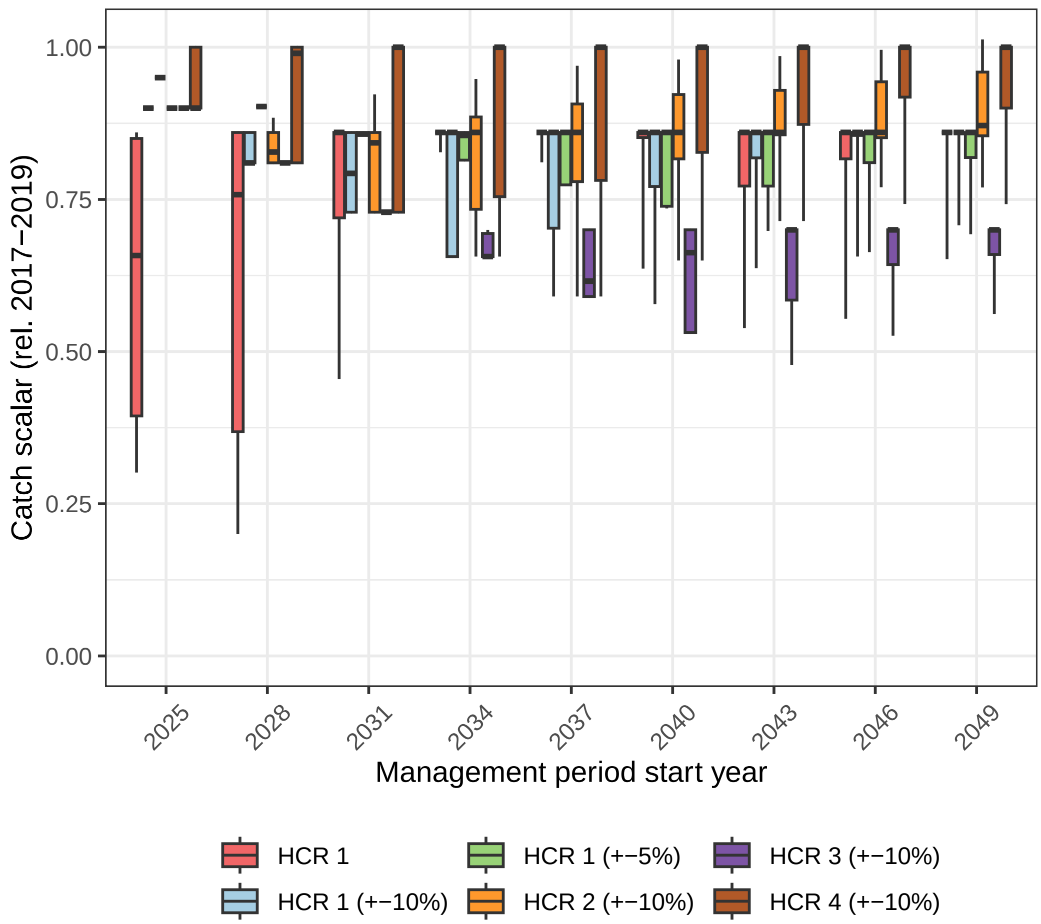

Figure 7: The range of the catch scalar that is output by each candidate HCR every time the management procedure is called, i.e. the variability in the HCR output. The boxes show the 50th percentile, and the tails the 80th percentile. The median is the solid black line.

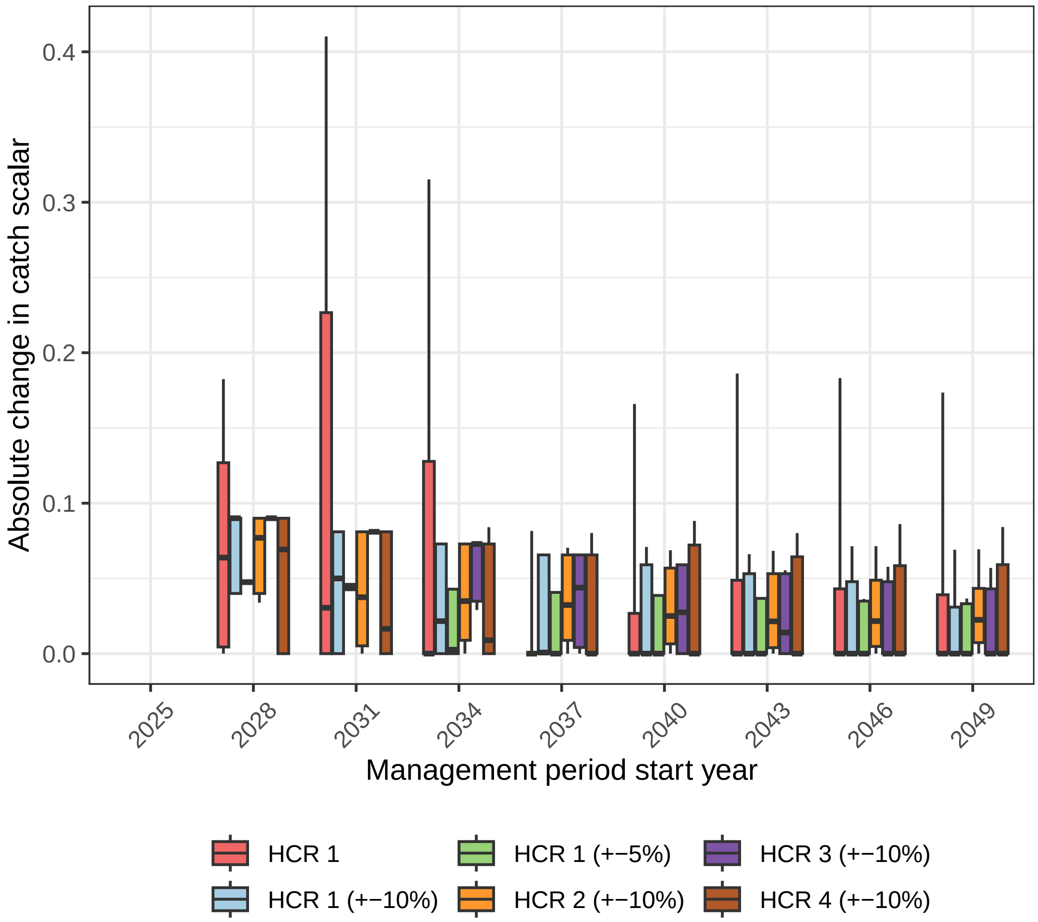

Figure 8: The range of the absolute change in the catch scalar that is output by each candidate HCR every time the management procedure is called. The boxes show the 50th percentile, and the tails the 80th percentile. The median is the solid black line.

5.4 Impact of the catch constraint

The impact of different levels of catch constraint can be seen in Figure 9. This figure shows the catches in the WCPCA-CA, relative to the average in 2017-2019, and $SB/SB_{F=0recent}$ for three individual iterations of the three variants of HCR 1 (iterations 5, 41 and 433) as an illustration. Each iteration comes from a different operating model so the initial stock statuses in 2020 are different. The observation error and recruitment variability are the same within each iteration meaning the results are directly comparable between HCRs.

When there is no constraint (HCR 1), catches are initially set lower, leading to higher levels of stock status in the short-term. When a constraint is present, the catches tend to be more stable but the stock status tends to be lower in the short-term. For example, the stock status of iteration 433 starts off below the LRP. When there is no constraint, the HCR cuts catches to below 0.3 times the 2017-2019 average, relieving fishing pressure so that the stock status can quickly recover. With a constraint in place, the reduction in catches is gradual, meaning it takes longer for the stock status to recover. These are the kind of trade-offs that will need to be considered when further developing candidate MPs.

In this preliminary analysis, we have applied equal (symmetrical) constraints to both increases and decreases in catches between management periods. Asymmetrical constraints where, for example, greater levels of catch decreases can be permissible compared to increases can also be evaluated.

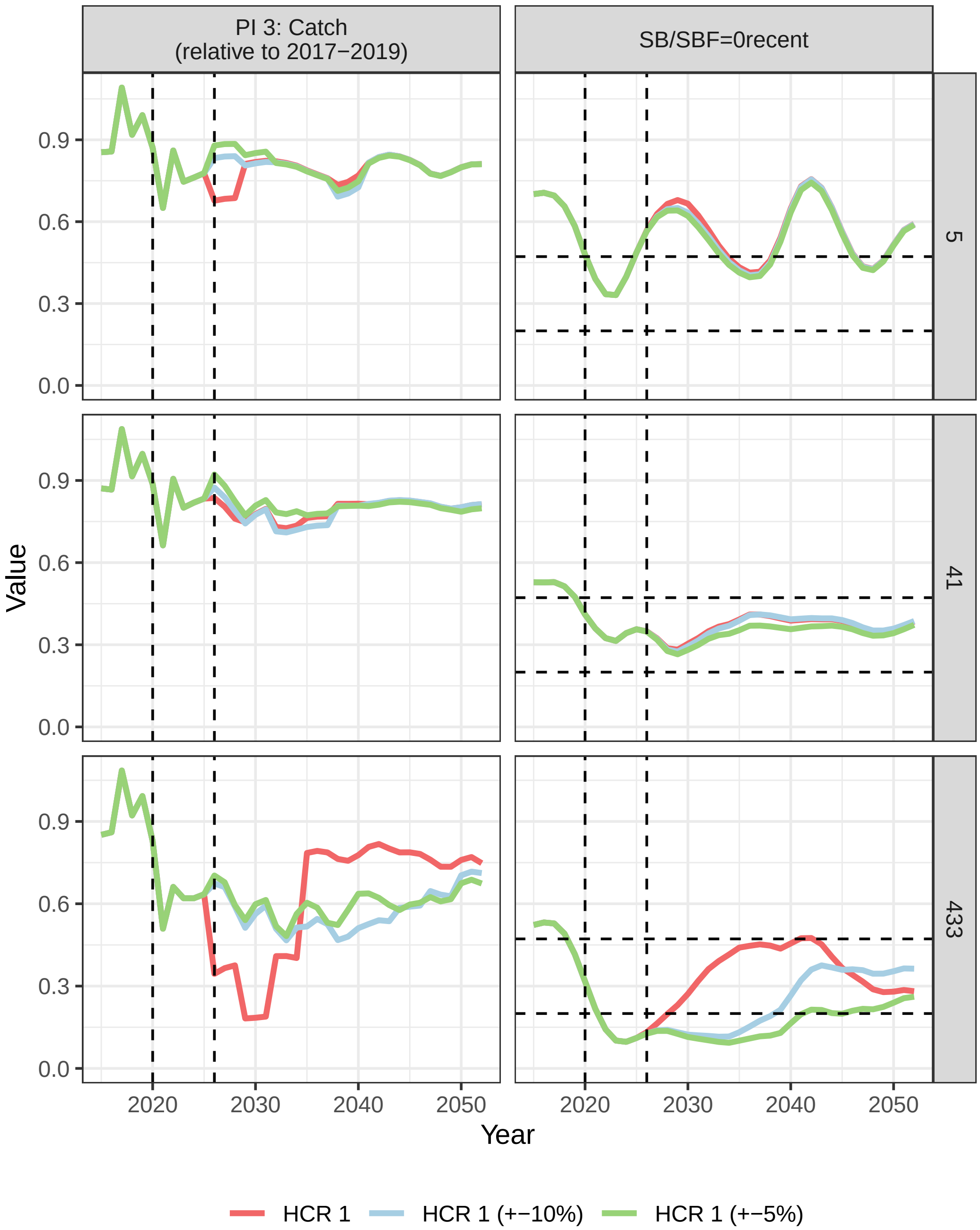

Figure 9: Catches in the WCPCA-CA, relative to the average in 2017-2019, and $SB/SB_{F=0recent}$ for three individual iterations of the three variants of HCR 1. The HCR variants differ only in the catch constraint. The observation error and recruitment variability are the same within each iteration meaning the results are directly comparable between HCRs. The two vertical dashed lines show the first year of the projection and the first year the output MP is applied. The horizontal dashed line are the LRP and the median $SB/SB_{F=0}$ in the years 2017-2019.

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