Testing management advice procedures for short-lived data limited stocks in Category 3

by

A. Uriarte[1], S. Sánchez[1], L. Ibaibarriaga[2], A. Silva[3], F. Ramos[4] and M. Rincón[5]

[1] AZTI, Herrera Kaia - Portualdea z/g. E-20110 Pasaia – GIPUZKOA (Spain) | Mail: auriarte@azti.es

[2] AZTI; [3] IPMA; [4] IEO.

Working Document for the ICES Workshop on Data-limited Stocks of Short-lived Species (WKDLSSLS). 16–20 September 2019. AZTI, San Sebastian, Spain.

1. Introduction

In order to provide advice on fishing opportunities and stock status, ICES classifies the stocks into six categories depending on the available information. The highest category is Category 1 that comprises stocks with full analytical assessments, whereas the lowest category is Category 6 that includes stocks with negligible landings and stocks caught in minor amounts as bycatch. Depending on the stock category, ICES follows a different advice rule (ICES, 2018a). For category 1 and 2 stocks the advice is based on the ICES MSY approach, whereas for category 3-6 stocks, the available knowledge is limited and the advice rule is based on the precautionary approach. Several workshops have aimed at testing and developing tools for stocks that are in Categories 3-6. However, most of the methods have been developed for long-lived species and are considered not valid for short-lived stocks due to their special life-history traits and their high interannual variability. In WKLIFE 8 (ICES, 2018b), Uriarte et al. (2018) evaluated the performance of in-year advice harvest control rules for short-lived species in Category 3 (stocks for which survey or other indices are available and provide reliable indications of trends about stock status). The results depended on the ratio of observation error and interannual variability. However, in general, 1-over-2 and 1-over-3 rules outperformed 2-over-3 rules and 80% uncertainty cap or no uncertainty cap performed better than 20% cap. The results were considered interesting, but it was suggested that the simulation framework should be generalised to confirm the results.

In this document we continue that work and try to generalise the main outcomes. Using management strategy evaluation, we evaluate the performance of the current ICES advice rule for Category 3 stocks for two types of short-lived stocks (anchovy and Norway pout-like and sardine and sprat-like). Their performance is compared to various alternative harvest control rules that include variants such as changing the timing of the advice and management calendar, using various levels of uncertainty caps, using or not a precautionary buffer and options for setting the reference catch in the first year of rule application. Moreover, we evaluate the sensitivity of the performance to the operating model (stock type and historical exploitation level) and to the observation error of the survey index. The results could be used to revise the ICES guidelines for the advice of short-lived stocks in Category 3.

2. Material and methods

2.1. Type of stocks

The list of short-lived stocks that are classified in Categories 3-6 includes species such as anchovies, sardines, sprats, sandeels and Norway pout. These species can be classified in two main groups according to their life-history characteristics (Table 2.1):

(1) Anchovy, Norway pout and sandeels-like stocks: stocks with high natural mortality (with mean across ages 1-3 above 0.8), various levels of maturity at age 1 and high interannual variability. In this case, we will use anchovy like stocks which is a subset of the first group characterized by full maturity at age 1, while sandeels and Norway pout have a very reduced maturity at age 1 (below 0.3).

(2) Sprat and sardine-like stocks: stocks with medium natural mortality, fully mature at age 2 and intermediate interannual variability.

Table 2.1. Life history characteristics for the two main groups defined. STK1, anchovy and Norway pout-like; and STK2, sardine and sprat-like.

	STK1 (anchovies)	**STK2 (sprats and sardines)**
Natural mortality (ages 1-3) (mean survivorship)	high M (~30%)	medium M (~57%)
Natural mortality pattern	decreasing	decreasing
Growth pattern & length-weight relationship	species specific	species specific
Maturity ogive	Full at age 1 (1)	Half at age 1 (0.5)
Stock-recruitment relationships	Beverton & Holt	Beverton & Holt
Steepness	Medium (0.75)	Medium (0.75)
Virgin biomass (B0)	100,000	100,000
Recruitment residuals (standard deviation around SR)	low & medium (i.e. 0.5 & 0.75)	low & medium (i.e. 0.5 & 0.75)
Autocorrelation in residuals	0	0
Expected interannual variability	0.36-0.8	0.16-0.39
Fishery selectivity at age	neutral (=maturity)	neutral (=maturity)

2.2. Management Strategy Evaluation (MSE)

The evaluation of advice rules for Category 3 stocks was performed using a management Strategy Approach (MSE) simulation framework (Punt *et al.*, 2016). The simulations were carried out using FLBEIA software (García *et al.*, 2017), which is a tool to perform bio-economic impact assessment of fisheries management strategies based on FLR tools (Kell *et al.*, 2007).

The simulation framework has two main components: the operating model (OM), which represents the *real world* (i.e. the fish stocks and the fleets targeting them); and the management procedure (MP), representing the advice process (i.e. assessment and advice rule). Both components are connected through the observation model that feeds the MP with information on the OM (e.g. observation of catches, biological parameters and/or abundance indices) and the implementation model, that alters the OM given the advice from the MP.

2.2.1. Operating model based on life-history parameters

The biological OM was an age-structured (ages 0-6$^+$) model by semester. Spawning was assumed to occur at the beginning of the second semester (1st July), so that recruits (age 0 individuals) entered into the population on 1st July. The operating model for each type of stock was based on the life-history parameters given in Table 2.2. Length-at-age at the beginning of each semester was calculated according to the Von Bertalanffy growth model (Table 2.2). Then, weight-at-age of the stock in each of the semesters was derived according to the weight-length model (Table 2.2). Catch weights-at-age were based on length-at-age at the middle of each semester. Natural mortality was estimated according to Gislason *et al*. (2010), with some corrections for age 0, as estimated mortalities for this age class were unrealistically high. Natural mortality for ages 1-6+ was assumed to be equal by semester (Table 2.3), whereas total annual natural mortality for age 0 occurred in the 2nd semester. Regarding maturity ogive, for STK1 (anchovy and Norway-pout like stocks) all individuals were mature at age 1 (i.e. knife-age), while for STK2 (sardine and sprat-like stocks) 50% of individuals were mature at age 1 and 100% at age 2. The selection pattern was assumed to be equal to the maturity, so that individuals at age 1 in STK1 and age 2 in STK2 were fully selected. The vectors of weight-at-age in the stock and in the catch, natural mortality, maturity and selectivity for the two type of stocks are given in Table 2.3.

Annual recruitments were generated according to the Beverton and Holt stock-recruitment model with steepness equal to 0.75 and virgin biomass equal to 10000 tonnes without autocorrelation in residuals (Table 2.2). Three different values of standard deviation (σ_{REC}) were tested: 0.5, 0.75 and 1 (Table 2.2).

Based on the above dynamics and assuming that 50% of the catches occurred in each semester, we calculated the reference points for each of the stocks. The limit biomass (B_{lim}) was set as 20% of the virgin biomass B0, the biomass at which the stock had collapsed ($B_{collapse}$) was set as 10% of the virgin biomass B0 and a proxy for F_{MSY} ($F_{MSYproxy}$) was based on $F_{40\%B0}$, i.e. the fishing mortality rate associated with a biomass of 40% B0 at equilibrium. All the values are given in Table 2.4.

Table 2.2. Life history parameters for STK1 (anchovy and Norway pout -like stocks) and STK2 (sardine and sprat-like stocks).

Stock type	Type	Model	Parameters	Reference
STK1	Growth equation	Von Bertalanffy	$L\infty = 18.69$ $k = 0.89$ $t0 = -0.02$	Bellido et al. (2000)
	Length-weight relationship	$L = aw^b$	$a = 0.004799048$ $b = 3.134380952$	From "teleost" object in the R library FLife () for the "Engraulis encrasicolus"
	Stock-recruitment	Beverton-Holt (no autocorrelation in residuals) $R = \frac{a \cdot SSB}{b+SSB} \cdot e^{\varepsilon}$, $\varepsilon \sim N(0, \sigma_{REC})$	Steepness=0.75 (medium) Virgin biomass (B0=10000) $a = 29988835.109$ $b = 9090.909$ $\sigma_{REC} \in \{0.5, 0.75, 1\}$	
STK2	Growth equation	Von Bertalanffy	$L\infty = 22.83$ $k = 0.56$ $t0 = 0.80$	Fitting to mean size at age in annual sardine catches from 8.abd in the Basque Country - 2002 to 2018
	Length-weight relationship	$L = aw^b$	$a = 0.005793333$ $b = 3.059766667$	From "teleost" object in the R library FLife () for the "Sardina pilchardus"
	Stock-recruitment	Beverton-Holt (no autocorrelation in residuals) $R = \frac{a \cdot SSB}{b+SSB} \cdot e^{\varepsilon}$, $\varepsilon \sim N(0, \sigma_{REC})$	Steepness=0.75 (medium) Virgin biomass (B0=10000) $a = 2376695.112$ $b = 9090.909$ $\sigma_{REC} \in \{0.5, 0.75, 1\}$	

Table 2.3. Biological parameters' estimates for STK1 and STK2.

Stock type	Age	Mean weight-at-age in the stock (kg)		Mean weight-at-age in the population (kg)		Natural mortality	Maturity = selectivity
		1st sem.	2nd sem.	1st sem.	2nd sem.	(year^{-1})	
STK1	0	0.000	0.002	0.000	0.005	1.4495	0
	1	0.009	0.018	0.014	0.022	1.518	1
	2	0.026	0.033	0.030	0.035	1.123	1
	3	0.037	0.040	0.039	0.042	1.008	1
	4	0.042	0.044	0.043	0.044	0.965	1
	5	0.045	0.045	0.045	0.046	0.949	1
	6+	0.046	0.046	0.046	0.046	0.942	1
STK2	0	0.004	0.011	0.007	0.016	0.494	0
	1	0.021	0.031	0.026	0.036	0.692	0.5
	2	0.041	0.049	0.045	0.053	0.543	1
	3	0.057	0.062	0.060	0.065	0.480	1
	4	0.067	0.071	0.069	0.072	0.449	1
	5	0.074	0.076	0.075	0.077	0.433	1
	6+	0.078	0.079	0.078	0.080	0.424	1

Table 2.4. Reference points for STK1 and STK2.

Stock type	Reference point	Value	Technical basis
STK1	F_{MSY}	1.2	F_{MSY} proxy: $F_{40\%B0}$ estimated by simulation
	B_{lim}	20000	$B_{lim} = 0.20\ B0$
	$B_{collapse}$	10000	$B_{collapse} = 0.10\ B0$
STK2	F_{MSY}	0.45	F_{MSY} proxy: $F_{40\%B0}$ estimated by simulation
	B_{lim}	20000	$B_{lim} = 0.20\ B0$
	$B_{collapse}$	10000	$B_{collapse} = 0.10\ B0$

The historical trajectory of each stock was simulated for 30 years. Each stock started from a virgin population and during the first 10 years exploitation increased linearly up to a constant level of fishing mortality (F_{target}) that was kept constant for the next 20 years. Variability in the historical F was included through a log-normal distribution with a coefficient of variation (CV_F) of 10% (i.e. $F = g(F_{target}) \cdot e^{\varepsilon}$, with $\varepsilon \sim N\left(0, \sqrt{\log(1 + CV_F^2)}\right)$). The percentage of fishing mortality in each semester was kept constant at the value that leaded to 50% of the catches in each semester (0.3 for STK1 and 0.4 for STK2). Three levels of fishing mortality in the historical period were tested:

- low fishing mortality, $F_{target} = 0.5 \cdot F_{MSYproxy}$,
- optimum fishing mortality, $F_{target} = F_{MSYproxy}$,
- high fishing mortality, $F_{target} = 2 \cdot F_{MSYproxy}$,

where $F_{MSYproxy} = F_{40\%B0}$.

The dynamics of the fleet was based on the Cobb-Douglas model:

$$C_{y,s,a} = q_{y,s,a} \, E_{y,s,f}^{\alpha_{y,s,f}} \left(N_{y,s,a} \, w_{y,s,a}\right)^{\beta_{y,s,a}}$$

where C denotes the total catch, E the fleet effort, N the numbers-at-age, w the mean weights-at-age , α and β are the elasticity parameters and y, s and a are the subindices for year, season and age, respectively . Elasticity parameters (α and β) were set to 1. Effort was set to one in the historical period, and the catchability parameter by age for the projection period was estimated as the average of the ratio between catch at age and biomass at age over the last five years of the historical period.

For each stock, we calculated the interannual variation (IAV) in the historical period as the average of the interannual variation of each iteration:

$$IAV_{iter} = \frac{\sum_{y=1}^{n-1} \left(\ln(B_{y+1,iter}) - \ln(B_{y,iter})\right)^2}{n-1}$$

where $B_{y,iter}$ is the total abundance in mass in year *y* and iteration *iter* and n is the number of historical years (30 in this case).

2.2.2. Observation Model

In each year *y*, we considered an index of biomass at age 1+ at the beginning of the second semester ($B_{y,2,1+}$) that followed a Log-normal distribution as follows:

$$I_y = q \cdot B_{y,2,1+} \cdot e^{\varepsilon}, \text{ with } \varepsilon \sim N\left(0, \sqrt{\log(1 + CV_I^2)}\right),$$

where I_y is the abundance index at age 1 or older in year *y* and q is the catchability of the survey which was set equal to 1. The following CVs were tested:

- Low: $CV = 0.25$
- High: $CV = 0.5$
- IAV: $CV = IAV$
- 2IAV: $CV = 2 \cdot IAV$

Observations from the survey are assumed and simulated to start 10 years prior to the start of the management period (i.e., for the last 10 years of the historical trajectory of the stocks).

2.2.3. Management procedure

The management procedure was based on a harvest control rule of type n-over-m. This means that the TAC in year *y+1* is based on the previous year TAC adjusted to the change in the stock size index for the values in the most recent n years relative to the values in the preceding m years. We tested the 2-over-3 rule that is the default ICES harvest control rule, and we compared it with respect to other rules that could potentially react faster to the high interannual variation of the short-lived stock dynamics, namely, 1-over-2, 1-over-3 and 1-over-5. We considered the following variants of these rules:

- Precautionary buffer (recommended to be applied when it is likely that F> F_{MSY} or when the stock status relative to candidate reference points for stock size or exploitation is unknown):
    - no precautionary buffer
    - 20% precautionary buffer in the first projection year
- Symmetric uncertainty caps (i.e. a change limit applied to the advice to avoid susceptibility to noise):
    - no uncertainty cap
    - 20%
    - 50%
    - 80%
- Initialization of the Rule. The rule depends on the reference TAC value, refTAC, in the first year of application of the rule:
    - Previous year catch (pyc):

$$\mathrm{refTAC} = C_{y-1}$$

    - Recent average (nin):

$$\mathrm{refTAC} = \frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{C}_i}{\mathrm{m}}$$, where y is the last historical year, and m are the number of preceding years in the denominator of the HCR

    - Perfect knowledge (pob):

$$\mathrm{refTAC} = \frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{C}_i}{\mathrm{m}} \cdot \frac{\frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{F}_i}{\mathrm{m}}}{\mathrm{F}_{MSY}}$$, where y and m have the same meaning as above

- Biomass safeguard. For the 1-over-2 rule the application of a biomass safeguard was tested. The advised TAC was multiplied by a factor $\mathrm{b} = \min(1, I_y/I_{trig})$, where I_{trig} corresponded to the lowest historic index value.

The usual management calendar goes from January to December. Index on 1st July in year y is used to set the TAC from January to December in year (y+1) (Figure 2.1a). This means that there is no indication of age 1 in the TAC year, which for short-lived species might be the bulk of the population.

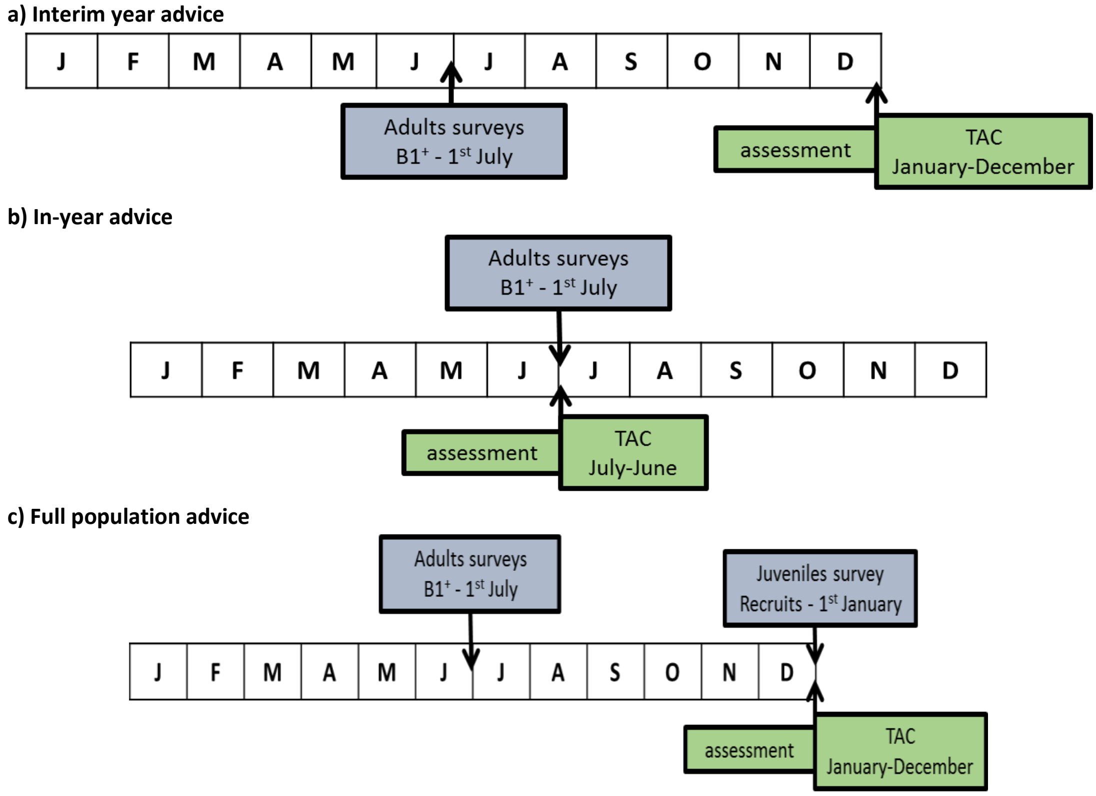

Figure 2.1. TAC calendars.

We evaluated two alternative management calendars. The first one, where the index on 1st July in year y was used to set the TAC from July year y to June in year (y+1). This means that during the second semester in year y age 1 is known, but not during the first semester of year (y+1). The later management calendar sets the TAC from January to December in year (y+1) based on the B1plus index on 1st January of year (y+1). This is the usual case when a recruitment index is available. In this case, the index provides information on all the age classes that are going to be exploited. Therefore, according to the interim year management calendar, the n-over-m rule would be:

$$\mathrm{TAC}_{y+1} = \mathrm{TAC}_y \frac{\frac{\sum_{i=y-\mathrm{n}}^{y-1} I_i}{\mathrm{n}}}{\frac{\sum_{i=y-(\mathrm{n}+\mathrm{m})}^{y-\mathrm{m}} I_i}{\mathrm{m}}}.$$

And for the in-year advice and the full population management calendars the n-over-m rule would be as follows:

$$\mathrm{TAC}_{y+1} = \mathrm{TAC}_y \frac{\frac{\sum_{i=y-\mathrm{n}+1}^{y} I_i}{\mathrm{n}}}{\frac{\sum_{i=y-(\mathrm{n}+\mathrm{m})+1}^{y-\mathrm{m}+1} I_i}{\mathrm{m}}}.$$

2.2.4. Implementation Model

No implementation error was simulated. All the TAC was taken as far as the population supported it. The expected catches were not allowed to be larger than 90% of the numbers at age in the population. The percentage of the TAC taken in each semester was set to 50%. When the seasonal quota was not taken, it was transferred to the next season within the same management calendar.

2.3. Scenarios

Simulated scenarios are the combination of the alternatives for the different components listed in Table 2.5.

Table 2.5. List of alternative scenarios simulated for the different components.

Variable	Description	scenario	Scenario description
STKN	Stock type	STK1	anchovy like
		STK2	sprat/sardine like
LHSC	Life-history scenario	bc	see Table 2.2
SIGR	Standard deviation for the recruitment log-normal error	0.5, 0.75, 1	
FHIST	F target in the historical period	fopt	$F_{target} = F_{40\%B0}$
		flow	$F_{target} = 0.5 \cdot F_{40\%B0}$
		fhigh	$F_{target} = 2 \cdot F_{40\%B0}$
CVFH	CV for the FHIST error	0.10	
IDXT	Index type	b1p	Biomass index on individuals age 1 or older
CVID	Coefficient of variation of the error term for the B1plus index	low	$CV = 0.25$
		high	$CV = 0.50$
		iav	$CV = IAV$
		2iav	$CV = 2 \cdot IAV$
ADVT	Advice type	Int	Interim-year advice
		Iny	In-year advice
		Fpa	full population advice
HCRT	HCR type	2o3, 1o2, 1o3, 1o5	n-over-m type rules (see Section 2.2.3)
PBUF	Precautionary buffer in the 1st projection year	0	no buffer applied
		0.2	20% reduction of TAC
UCPL	Uncertainty cap (lower bound)	0	no uncertainty cap
		0.2, 0.5, 0.8	minimum increase in TAC of 20, 50 and 80% from previous year
UCPU	Uncertainty cap (upper bound)	0	no uncertainty cap
		0.2, 0.5, 0.8	maximum increase in TAC of 20, 50 and 80% from previous year
HCRI	HCR initialization (i.e. reference TAC in the 1st simulation year)	pyc	$refTAC = C_{y-1}$
		nin	$\mathrm{refTAC} = \frac{\sum_{i=y-m}^{y-1} \mathrm{C}_i}{\mathrm{m}}$ (for n-over-m rule)
		pob	$\mathrm{refTAC} = \frac{\sum_{i=y-m}^{y-1} \mathrm{C}_i}{\mathrm{m}} \cdot \frac{\frac{\sum_{i=y-m}^{y-1} \mathrm{F}_i}{\mathrm{m}}}{\mathrm{F}_{MSY}}$ (for n-over-m rule) where y is the last historical year

2.4. Simulations

Dynamics were simulated for 30 years and run for 1000 iterations for each scenario. Uncertainty in the projection period was introduced through: (i) recruitment predictions derived from a Beverton and Holt stock-recruitment relationship; and (ii) the lognormal observation error on the $B1^+$ index used to establish the TAC.

2.5. Performance statistics

The following performance statistics were calculated for each scenario:

- catch : median catch;
- f : median fishing mortality (F);
- hr : median harvest rate (i.e. catch/biomass);
- ssb : median spawning stock biomass (SSB);
- catch.iyv : interannual variability of catches;
- catch.var : variance in catches;
- ssb.B0 : ratio between SSB and virgin biomass (B0);
- f.F40B0 : ratio between F and $F_{40\%B0}$;
- quotaUpt : quota uptake;
- Risk1.Collapse : ICES type 1 risk of falling below $B_{collapse} = 10\%$ B0;
- Risk1.Blim : ICES type 1 risk of falling below B_{lim}= 20% B0;
- Risk2.Collapse : ICES type 2 risk of falling below $B_{collapse} = 10\%$ B0;
- Risk2.Blim : ICES type 2 risk of falling below B_{lim}= 20% B0;
- Risk3.Collapse : ICES type 3 risk of falling below $B_{collapse} = 10\%$ B0;
- Risk3.Blim : ICES type 3 risk of falling below B_{lim}= 20% B0;
- Risk.hrmax : probability of F being above the maximum F in the 10 last historical years.

All of them were calculated in three different timeframes:

(i) short-term (first five projection years; i.e. years 31-35);
(ii) medium-term (next five projection years; i.e. years 36-40)
(iii) long-term (last ten projection years; years 51-60).

3. Results

3.1. Results focusing on one OM

In present section, we will focus on the results for the anchovy-type stock (STK1), with a standard deviation for the recruitment at 0.5 (sigR=0.5), F historical at F optimum (Fhist=Fopt) and low CV for the B1plus index (CVID=0.25). Figure 3.1 and Figure 3.2 show the simulated historical trajectories for catches and SSB for different precautionary buffers and uncertainty caps for rules 1-over-2 and 2-over-3, respectively.

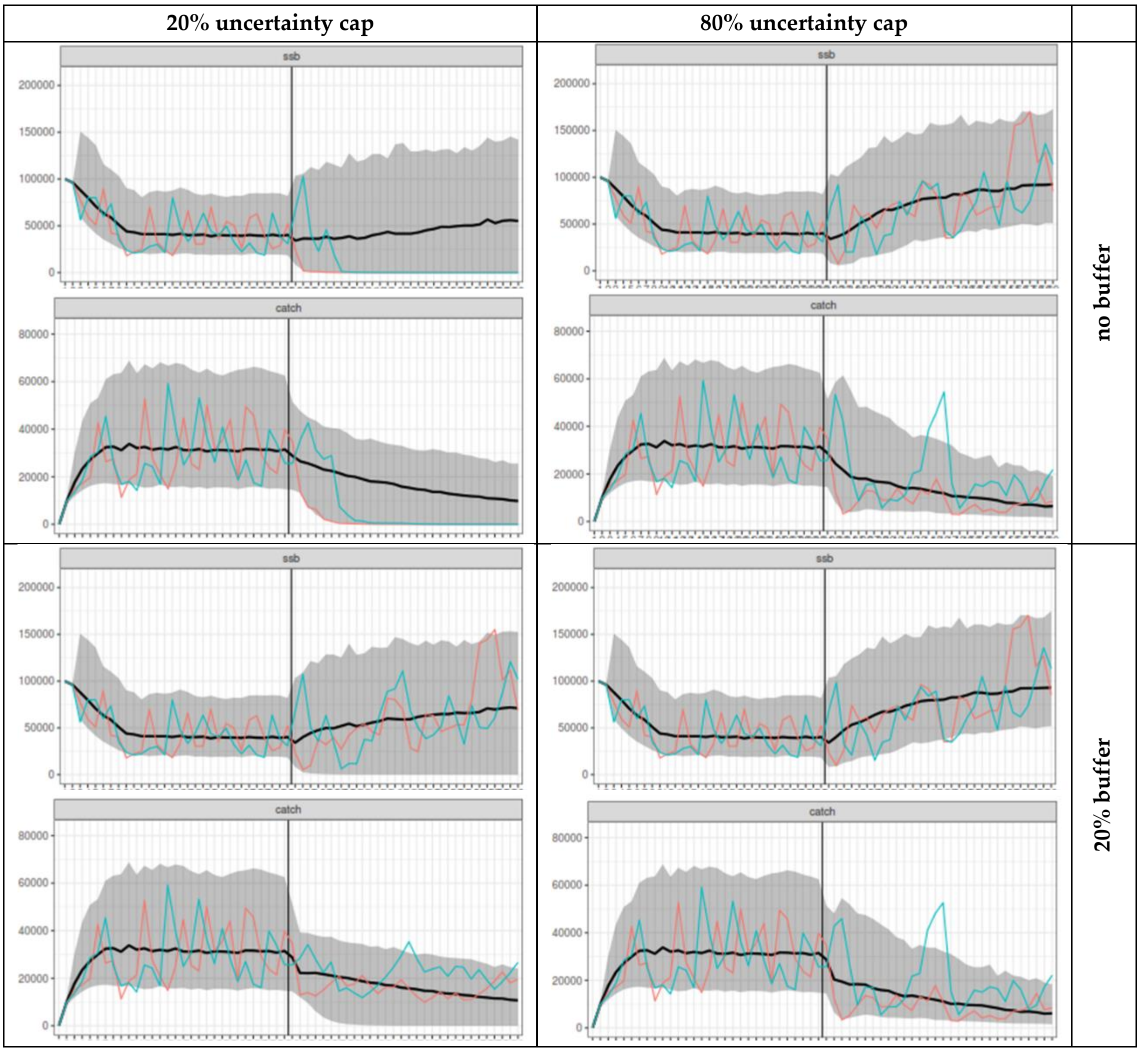

Figure 3.1. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, HCR=1-over-2, HCRI=nin). From top to bottom: SSB and catch by year, for different uncertainty caps (columns) and precautionary buffers (rows). The solid line represents the median and the shaded area the 90 % confidence intervals computed from the 5th and 95th percentiles. The dashed vertical line is located before year 31, which is the first year of the projection period. Colour lines corresponds to randomly selected iterations.

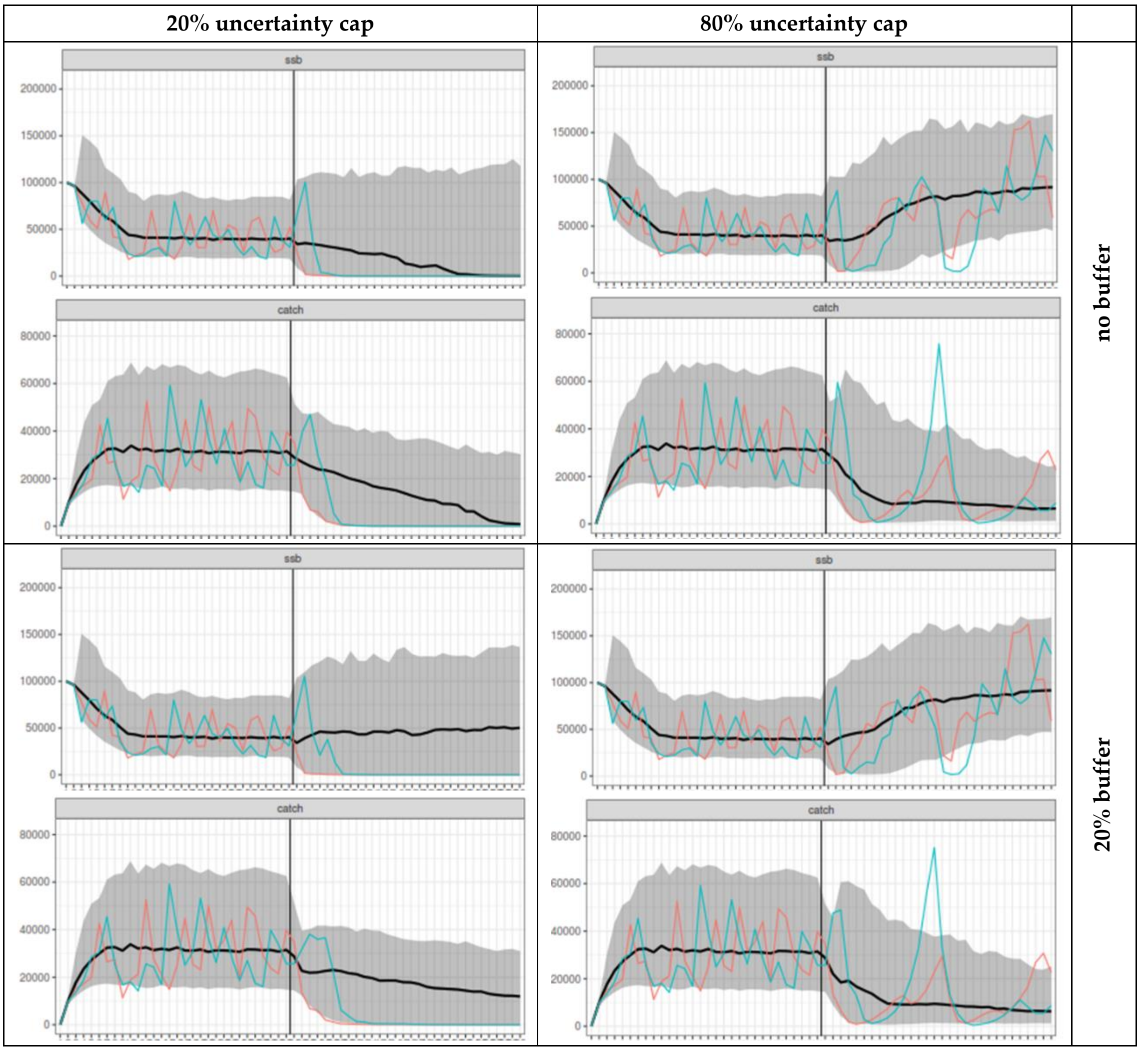

Figure 3.2. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, HCR=2-over-3, HCRI=nin). From top to bottom: SSB and catch by year, for different uncertainty caps (columns) and precautionary buffers (rows). The solid line represents the median and the shaded area the 90 % confidence intervals computed from the 5^{th} and 95^{th} percentiles. The dashed vertical line is located before year 31, which is the first year of the projection period. Colour lines corresponds to randomly selected iterations.

In general, the shorter the lag between observation and management (int>iny>fpa), the bigger catches and smaller risks (Figure 3.3). In-year advice (iny) performs always better than interim year advice (int), and generally full population advice (fpa) performs better than the two others as well, except in a few cases (e.g. the 2-over-3 rule, with 80% or without uncertainty cap as it occasionally increases risks).

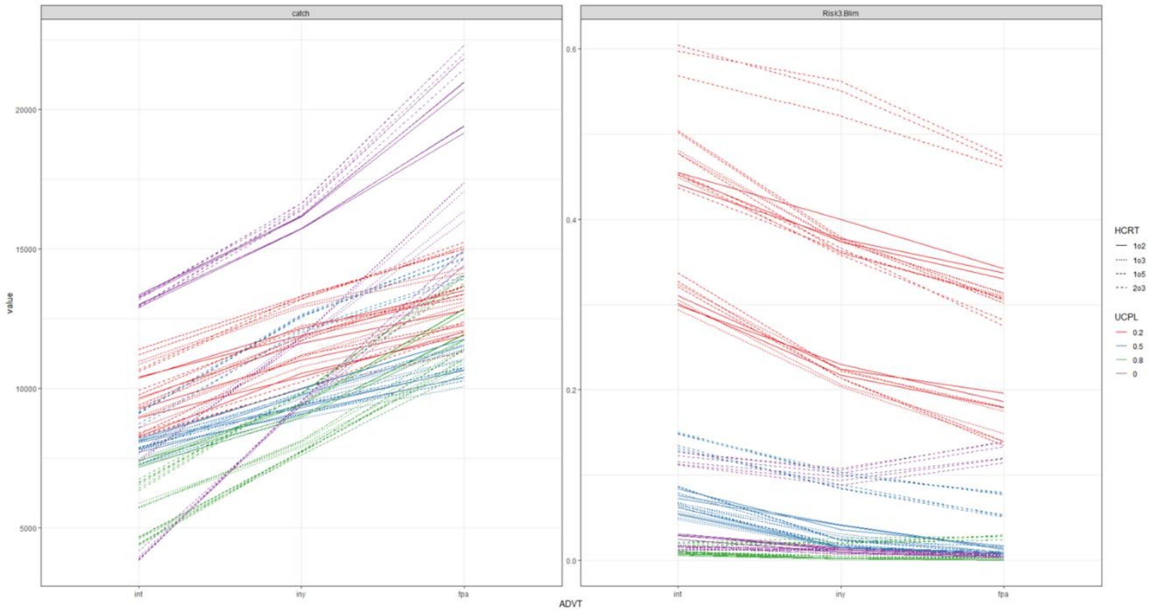

Figure 3.3. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each calendar (int: interim year calendar; iny: in-year calendar; and fpa: full population advice), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3; dashed line – 1o5: 1-over-5; and dot-dashed line – 2o3: 2-over-3) and uncertainty cap (red - 0.2: 20%; blue - 0.5: 50%; green - 0.8: 80%; and purple - 0: no uncertainty cap).

In the short term, with in-year advice, the precautionary buffer reduces catches and risks (Figure 3.4). Whereas in the long-term, with in-year advice, the precautionary buffer reduces risks but not so much catches (Figure 3.5). Actually, catches increase for the 20% uncertainty cap and decrease or kept constant for the rest.

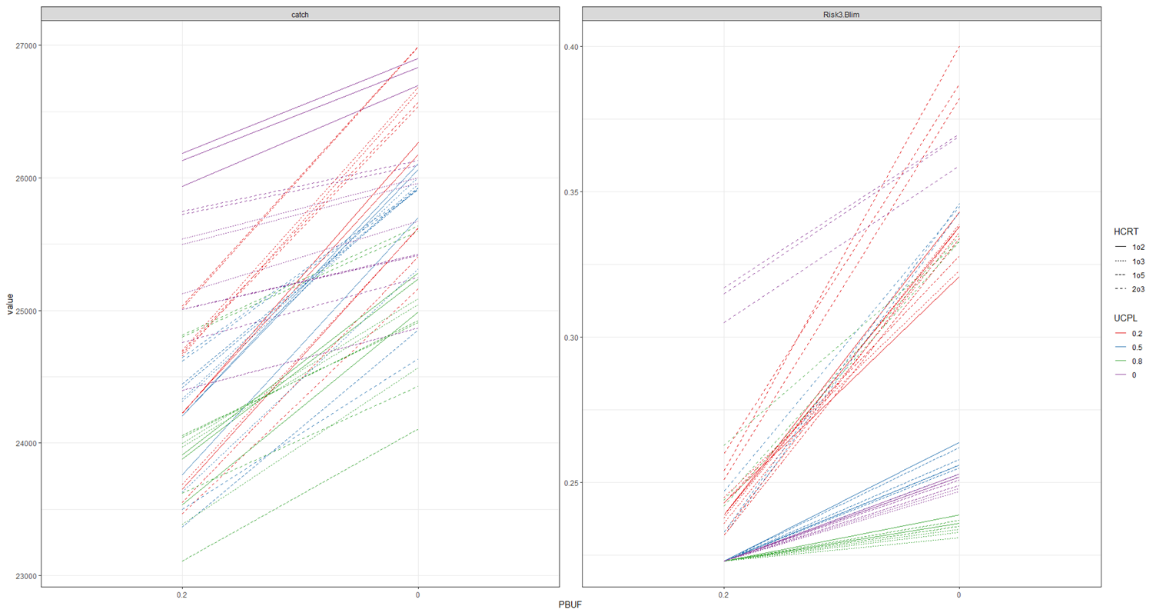

Figure 3.4. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the short-term (years 31-35), for each precautionary buffer (0.2: 20% buffer; and 0: no buffer), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3; dashed line – 1o5: 1-over-5; and dot-dashed line – 2o3: 2-over-3) and uncertainty cap (red - 0.2: 20%; blue - 0.5: 50%; green - 0.8: 80%; and purple - 0: no uncertainty cap).

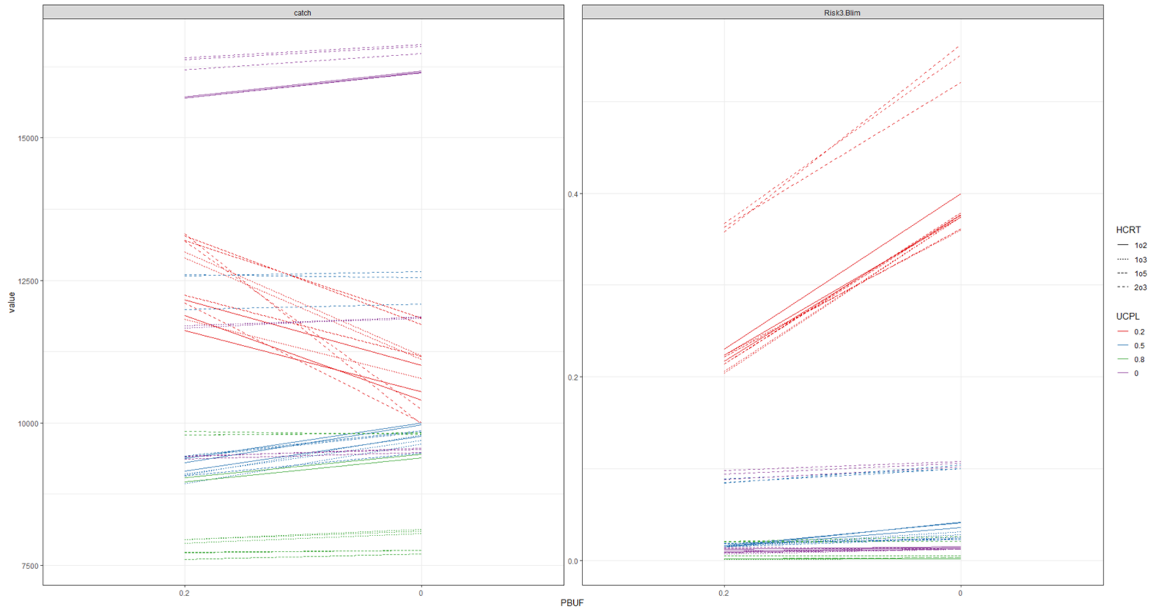

Figure 3.5. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: catch median and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each precautionary buffer (0.2: 20% buffer; and 0: no buffer), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3; dashed line – 1o5: 1-over-5; and dot-dashed line – 2o3: 2-over-3) and uncertainty cap (red - 0.2: 20%; blue - 0.5: 50%; green - 0.8: 80%; and purple - 0: no uncertainty cap).

Applying a 20% buffer without any uncertainty cap has no impact in the long-term performance of the 1-over-2 rule, but risks are reduced when the 20% uncertainty cap is applied. (Figure 3.6).

In the long-term, the initial catch to start HCR has a negligible impact (Figure 3.7). Therefore, recent mean catch (nin) might be preferred, as it would smooth the potential noise of the latest catch before management.

The rule 2-over-3 has larger risks than any of the others (Figure 3.8 top). Regarding the uncertainty caps, the 20% one has much larger risks than the rest (included having no uncertainty cap), being non-precautionary regardless the type of HCR (Figure 3.8 bottom).

Radar plots allow to compare the type of HCRs based on several performance statistics (Figure 3.9). The rule 2-over-3 besides having larger risks for Blim and Bcollapse, has also larger probability of exceeding the historical exploitation level. For all the uncertainty caps except for the 20%, catches according to the 2-over-3 are larger than for the other rules (at the expenses of higher risks).

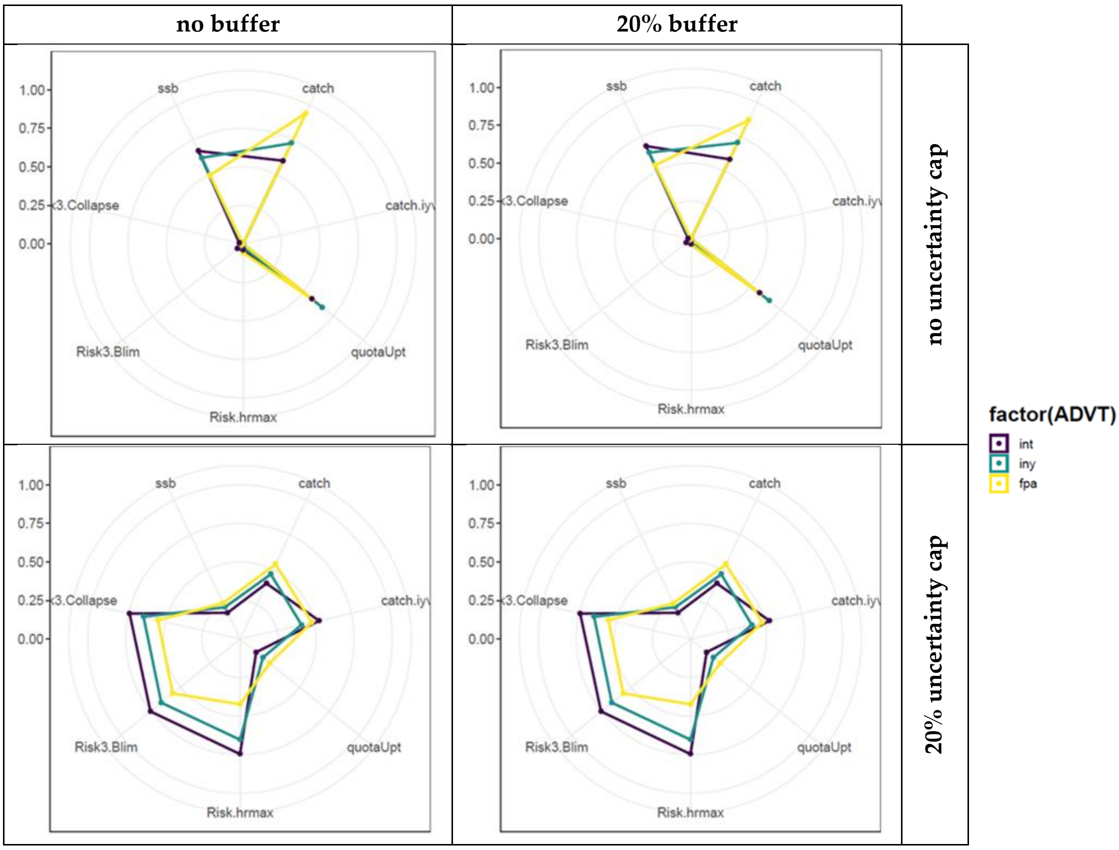

Figure 3.6. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low, HCR 1-over-2). Median SSB (ssb), median catch (catch), interannual variation of catches (catch.iyv), quota uptake (quotaUpt), probability of harvest rate being higher than the maximum hr in the last 10 historic years (Risk.hrmax), Risk3 of falling below B_{lim} = 20% B0 (Risk3.Blim), Risk3 of falling below 10% B0 (Risk3.Collapse), in the long-term (years 51-60), for different uncertainty caps and precautionary buffers by calendar (int: interim year calendar; iny: in-year calendar; and fpa: full population advice). Values rescaled relative to maximum and minimum values.

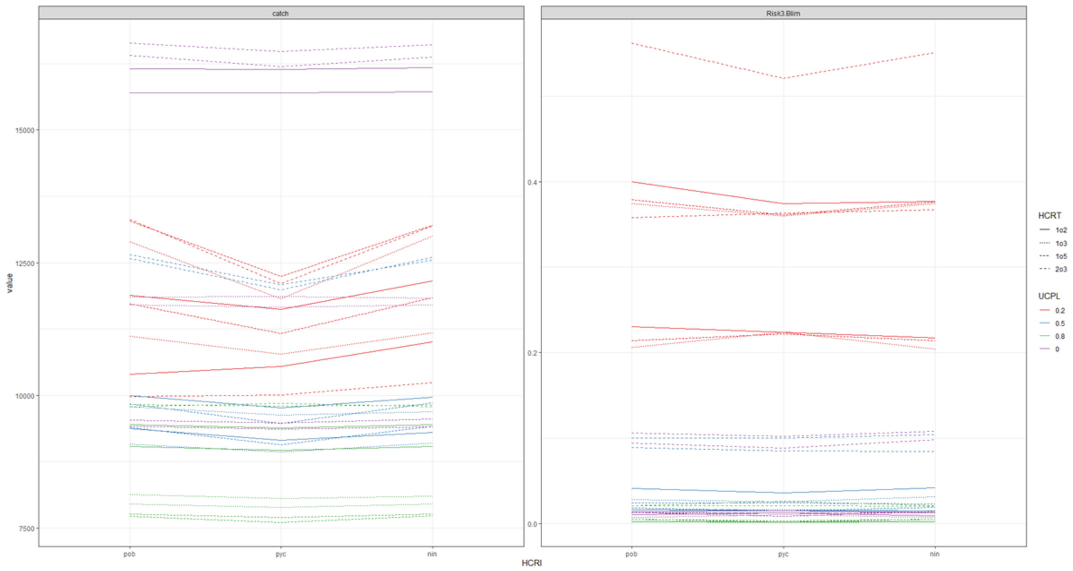

Figure 3.7. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each rule initialisation (pyc: previous year catch; nin: recent mean catch; and pob: perfect Initialization), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3; dashed line – 1o5: 1-over-5; and dot-dashed line – 2o3: 2-over-3) and uncertainty cap (red - 0.2: 20%; blue - 0.5: 50%; green - 0.8: 80%; and purple - 0: no uncertainty cap).

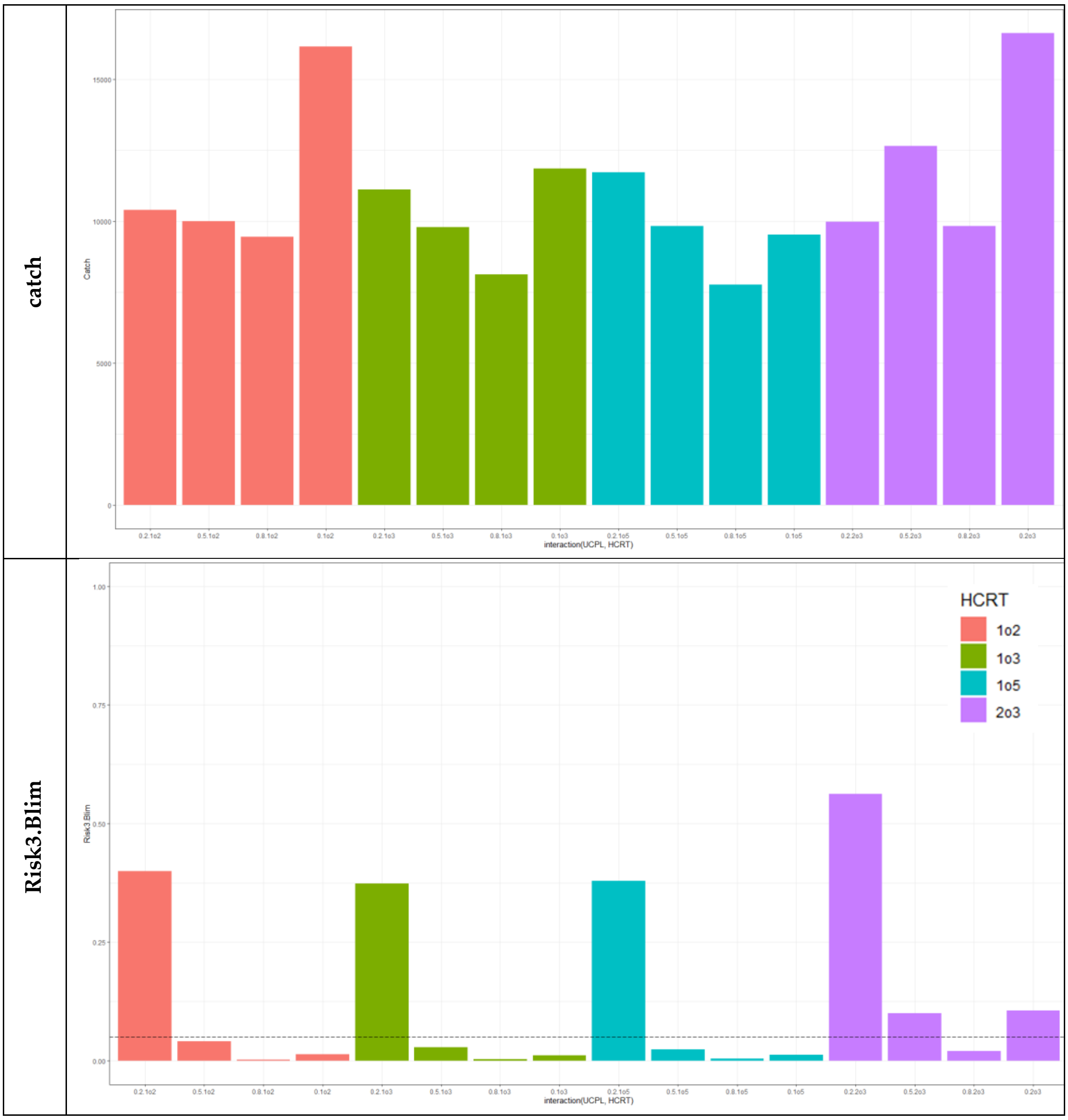

Figure 3.8. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, PBUF= 0, HCRI=pob). From top to bottom: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60) for each HCR type and buffer (0.2 1o2: 1-over-2 with 20% uncertainty cap; 0.5 1o2: 1-over-2 with 50% uncertainty cap; 0.8 1o2: 1-over-2 with 80% uncertainty cap; 0 1o2: 1-over-2 without uncertainty cap; 0.2 1o3: 1-over-3 with 20% uncertainty cap; 0.5 1o3: 1-over-3 with 50% uncertainty cap; 0.8 1o3: 1-over-3 with 80% uncertainty cap; 0 1o3: 1-over-3 without uncertainty cap; 0.2 1o5: 1-over-5 with 20% uncertainty cap; 0.5 1o5: 1-over-5 with 50% uncertainty cap; 0.8 1o5: 1-over-5 with 80% uncertainty cap; 0 1o5: 1-over-5 without uncertainty cap; 0.2 2o3: 2-over-3 with 20% uncertainty cap; 0.5 2o3: 2-over-3 with 50% uncertainty cap; 0.8 2o3: 2-over-3 with 80% uncertainty cap; and 0 2o3: 2-over-3 without uncertainty cap).

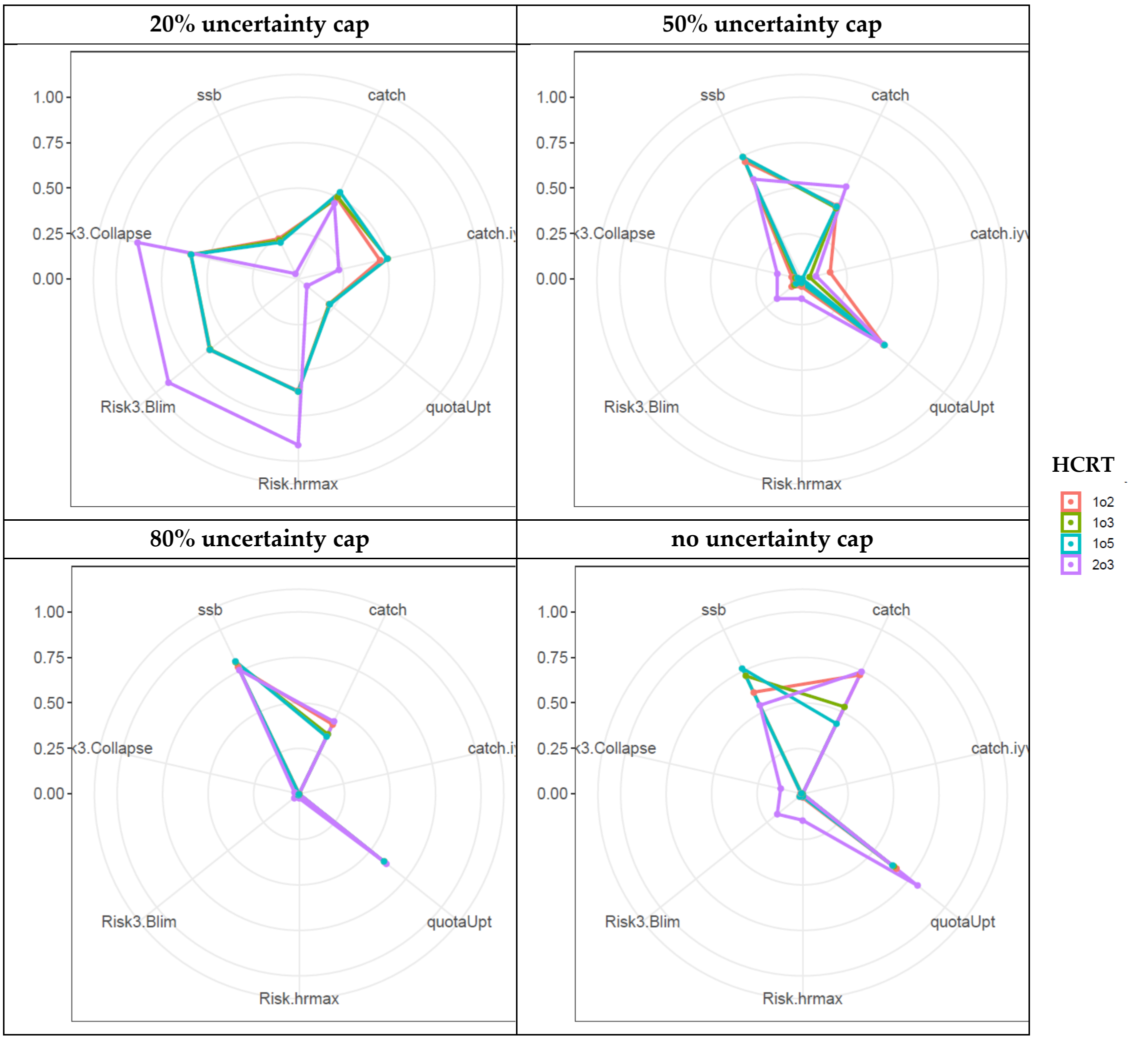

Figure 3.9. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, PBUF= 0, HCRI=pob). Median SSB (ssb), median catch (catch), interannual variation of catches (catch.iyv), quota uptake (quotaUpt), probability of harvest rate being higher than the maximum hr in the last 10 historic years (Risk.hrmax), Risk3 of falling below B_{lim} = 20% B0 (Risk3.Blim), Risk3 of falling below 10% B0 (Risk3.Collapse), in the long-term (years 51-60), for different uncertainty caps and HCR type (red – 1o2: 1-over-2; green – 1o3: 1-over-3; blue – 1o5: 1-over-5; and purple – 2o3: 2-over-3). Values rescaled relative to maximum and minimum values.

3.2. Sensitivity to alternative OMs

We will compare by stocks the performance of the main harvest control rules 2-over-3 rule and 1-over-2 rule at different historical exploitation levels (Fhist) for the different Uncertainty cap in the short and long-term across different operating models defined by the combinations of the CV of the survey index (CVID) and the standard deviation of the recruitment (sigR) by stocks (Figure 3.10 to Figure 3.12 and Figure 3.13 to Figure 3.15).

Some generalities emerge for the two stocks:

- Differences between HCRs performance increase with time, so that the greatest differences appear in the long term
- The absolute levels of risk depend mostly directly of the historical harvest trajectory so that the more intense the historical exploitation the higher the absolute levels of risks both in the short and in the long term.

- For both rules, maximum risks are achieved in the long term with the 20% uncertainty cap.

Anchovy-like stocks (STK1)

For anchovy-like stocks (STK1), there are not major differences in the performance of the two rules in terms of catches in the short-term across the different CVID, uncertainty caps and OMs (Figure 3.10, Figure 3.11 and Figure 3.12). But differences are greater in the long term, where catches are higher for the 2-over-3 rule but at the expenses of larger risks than 1-over-2. In terms of risks, rule 1-over-2 implies always less risks than 2-over-3 rule (both in the short and long-term). These risks are minimal in the long term for the 1-over-2 rule with 80% uncertainty cap and without any uncertainty cap (although the later slightly higher). Maximum risks are reached, in the long term, for rule 2-over-3 with 20% uncertainty cap.

Regarding the uncertainty caps, usually highest catches are seen for the 20% uncertainty cap and by the case without uncertainty cap, being the differences minor in the short term but larger in the long term. These differences increase when the CV of the index equals to $2\ IAV$ and for large sigR (=0.75), so that at the greatest values usually the catches of the 20% uncertainty cap are greater than those without uncertainty cap, while the rules without uncertainty cap overcome the catches of the rules with 20% uncertainty cap for the smaller values of these parameters. Those differences are amplified in the long term. In any case, in terms of risks, generally for both rules (and always for rule 1-over-2) the 20% uncertainty cap results in far higher risks than any other uncertainty cap. Absolute minimum risks are obtained always for the 80% uncertainty cap.

Therefore, for anchovy-like stocks (STK1), in the short-term 1-over-2 rule overcomes 2-over-3 one, as for quite similar level of catches it leads to lower risks, although above 0.05 and the higher the historical fishing mortality the higher the absolute levels of risks in the short term. Moreover, the greater the CV for the index, slightly greater the risk. Minimum risks are achieved with the 80% uncertainty cap. In the long-term, 2-over-3 rule generates great catches for moderate risk (up to about 0.20 at historical Fhigh) at weak uncertainty caps, while the 1-over-2 rule reduces strongly the catches and risks to 0.01. For both rules, in the long-term, the 20% uncertainty cap results in the highest risk levels.

If we focus in the different timeframes:

- In the short-term:
  - For any level of historical fishing mortality, 1-over-2 rule overcomes 2-over-3 rule, as for quite similar level of catches it leads to a bit smaller risks, although above 0.05. The greater the CV of the index, slightly greater the risk. Minimum risks are achieved with the 80% uncertainty cap or without any cap.
  - The greater the historical exploitation, the greater the risks in the short term. For 1-over-2 rule, the risk in the short term increases from less than 0.25 (mean 0.14 across uncertainty caps at Fhist=Flow) to a mean about 0.31 (at Fhist=Fopt) and reaching to a mean around 0.56 at Fhist=Fhigh (about 2*F_{MSY} proxy).
  - Initial diagnostic of the degree of past exploitation of the stock in relation to F_{MSY} proxy would be very helpful to decide the adoption of an initial cutting buffer or not, as its application should imply a reduction in the expected risks (typically higher) at the beginning of the management period of application of the HCRs.

- In the long term:
    - For any level of historical fishing mortality, 2-over-3 rule generates greatest catches for moderate risk (0.20 or less) at weak uncertainty caps, while 1-over-2 rule reduces strongly the catches and risks to 0.01. The 20% uncertainty cap results in highest risk levels for the two HCRs.
    - The greater the historical exploitation, the greater the risks, but for weak uncertainty caps the differences in risks are minimized, staying usually below 0.01 for rule 1-over-2 and below 0.2 for rule 2-over-3, for the three historical exploitation levels.

As the short term (and medium terms) prevails over the long term, 1-over-2 rule overcomes 2-over-3 rule to start the management with in-year Advice for anchovy-like stocks.

Figure 3.10. Scenario (OM: Stock=STK1, Fhist=Flow; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

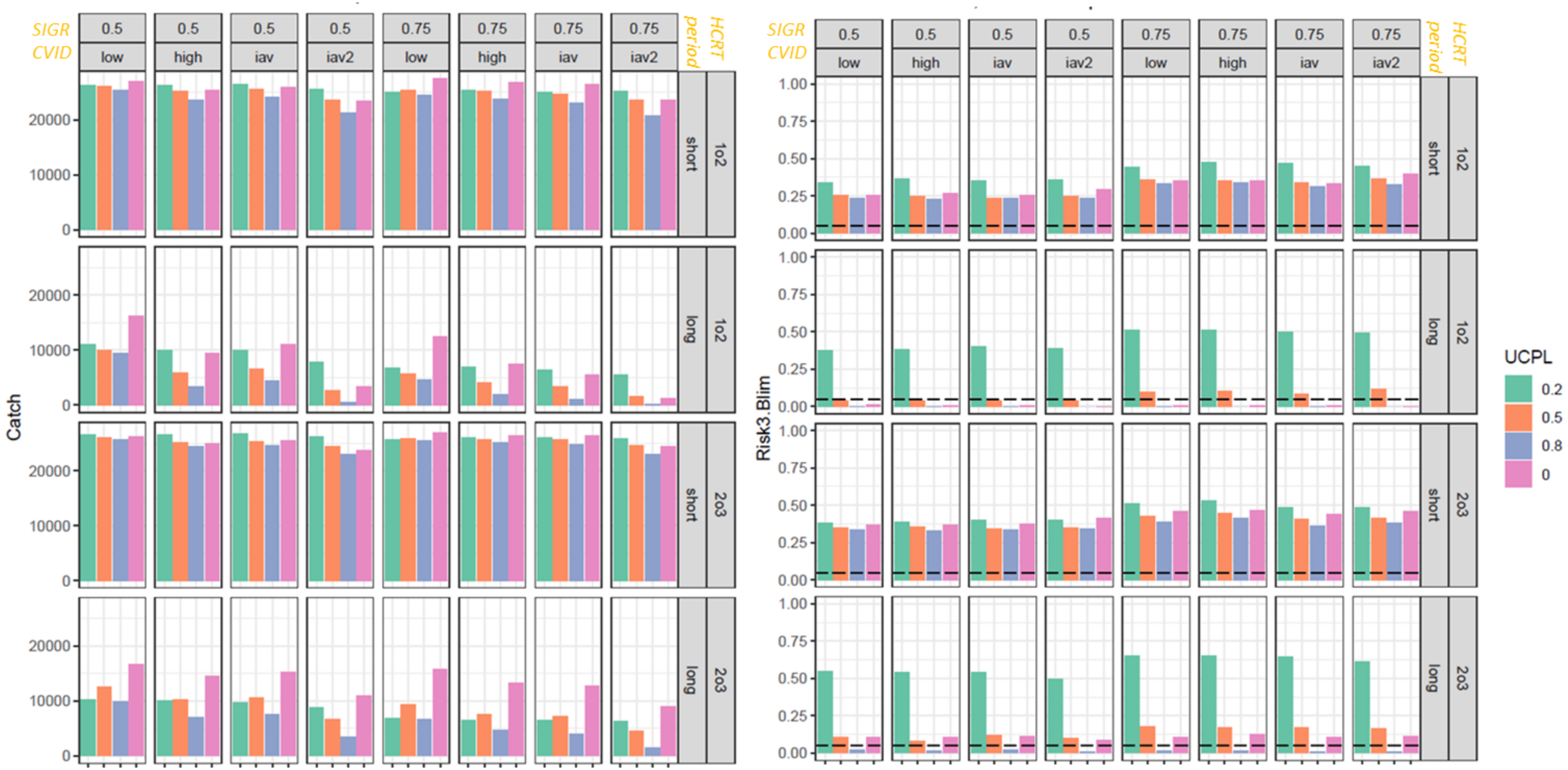

Figure 3.11. Scenario (OM: Stock=STK1, Fhist=Fopt; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

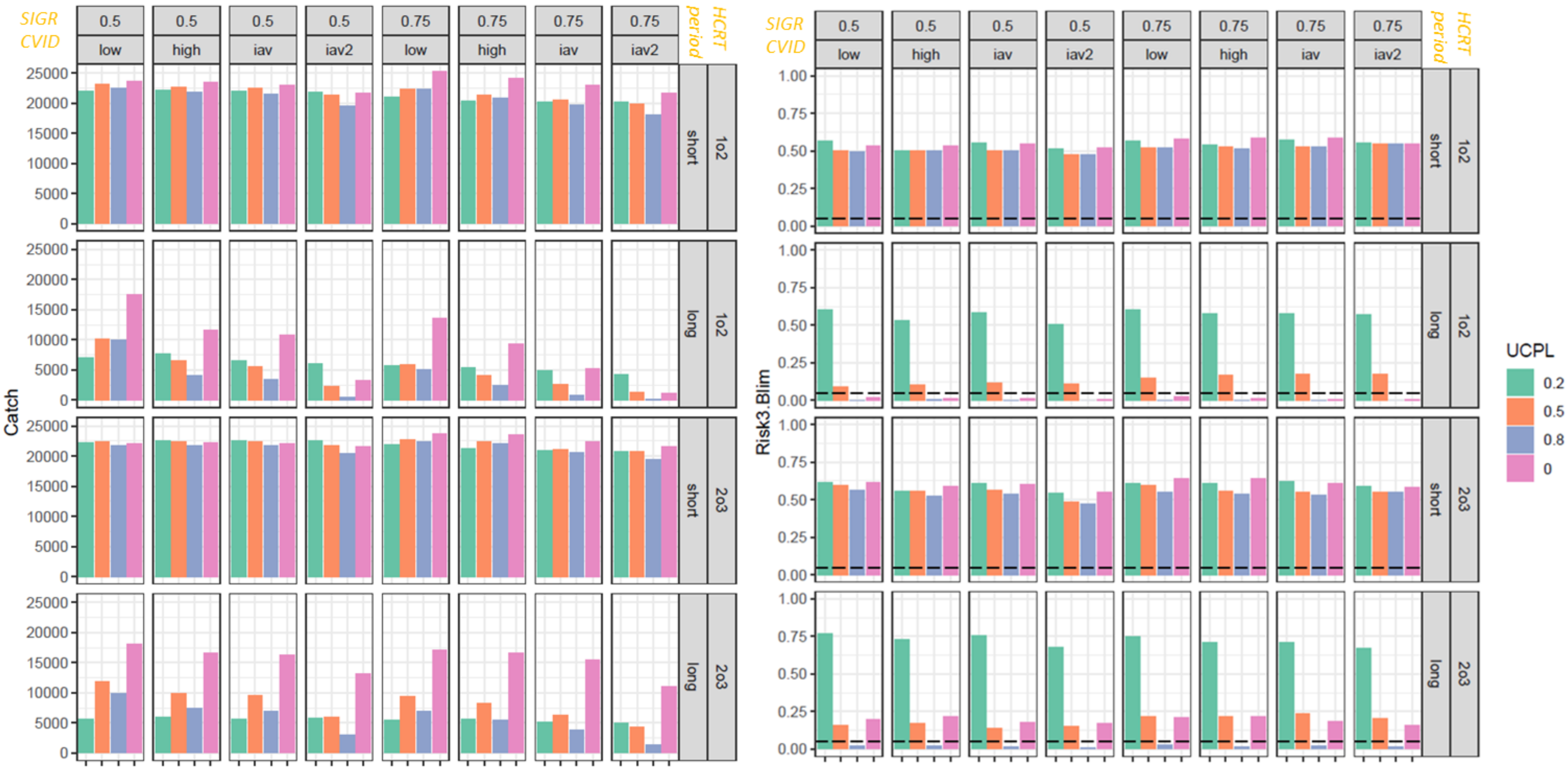

Figure 3.12. Scenario (OM: Stock=STK1, Fhist=Fhigh; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

Sardine/sprat-like stocks (STK2)

From Figure 3.13 to Figure 3.15 the performance for sardine/sprat-like stocks of previous rules under alternative operating models are presented, for alternative historical F values: low F (Figure 3.13), at 0.5 $F_{MSYproxy}$; optimum F (Figure 3.14), at $F_{MSYproxy}$; and high F (Figure 3.15), at 2 $F_{MSYproxy}$.

For sardine-like stocks (STK1), there are not major differences in the performance of the two rules in terms of catches in the short-term across the different CVID, uncertainty caps and OMs, but differences are greater in the long term, where catches are higher for the 2-over-3 rule but at the expenses of larger risks than 1-over-2. In the short term, generally catches increase a bit while the recruitment error (sigR) increases. In terms of risks, rule 1-over-2 implies always less risks than 2-over-3 rule (both in the short and long-term). These risks are minimal in the long term for the 1-over-2 rule with 80% uncertainty cap followed by very similar levels at 50% uncertainty cap and slightly higher values without any uncertainty cap. Maximum risks are reached, in the long term, for rule 2-over-3 with 20% uncertainty cap (with historical trajectories at Fopt and at Fhigh.

Regarding the uncertainty caps, usually highest catches are seen for the rule without uncertainty cap, being the differences minor in the short term but larger in the long term. These differences decrease when the CV of the index equals to 2 IAV. Those differences are amplified in the long term. In any case, in terms of risks, in the short-term risks are maxima without uncertainty cap and minima with 80% uncertainty cap, while in the long-term risks are maxima for the 20% uncertainty cap and minima again for the 80% uncertainty cap. So absolute minimum risks are obtained always for the 80% uncertainty cap.

Therefore, for sardine-like stocks (STK2), in the short-term 1-over-2 rule overcomes 2-over-3 one, as for quite similar level of catches it leads to lower risks, although above 0.05 if historically exploited at Fopt or higher. For the rule 1-over-2 minimum risks are achieved with the 80% uncertainty cap both in the short as in the long term. For both rules, in the long-term, the 20% uncertainty cap results in the highest risk levels.

Aiming at generalizing the results across the historical F values, if we focus in the different timeframes:

- In the short-term:
  - For any level of historical fishing mortality, 1-over-2 rule without uncertainty cap overcomes 2-over-3 rule without uncertainty cap, as both produce very similar and highest catches but the former results in lower risks.
  - At historical F at Fopt and Fhigh, application of a 80% uncertainty cap to the 1-over-2 rule, instead of not having uncertainty cap, is beneficial as reduces 20-30% the risks keeping catches at 90% of the ones expected for the same rule without uncertainty cap (such reduction increases in the medium term).
  - The greater the historical exploitation, the greater the risks in the short term and the smaller the reduction of risks of 1-over-2 versus 2-over-3. For 1-over-2 rule, the risk in the short term increases from less than 0.05 (mean 0.02 across uncertainty caps at Fhist=Flow) to a mean about 0.14 (at Fhist=Fopt) and reaching to a mean around 0.48 at Fhist=Fhigh (about 2*F_{MSY} proxy).
  - Initial diagnostic of the degree of past exploitation of the stock in relation to F_{MSY} proxy would be very helpful to decide the adoption of an initial cutting

buffer or not, as its application should imply a reduction in the expected risks (typically higher) at the beginning of the management period of application of the HCRs.

- In the long term:
    - For any level of historical fishing mortality, 1-over-2 rule without any uncertainty cap generates greatest catches for generally precautionary levels of risks. Except for Fhist=Fhigh, where it may reach 0.10 for low CVID).
    - The 20% uncertainty cap results in highest risk levels for the two HCRs.
    - The greater the CV in the index, the greater the risks and the contrasts in the performance of both HCRs at different uncertainty caps.
    - The greater the historical exploitation, the greater the risks, but for weak uncertainty caps the differences in risks are minimized, staying usually below 0.1 for rule 1-over-2 and below 0.4 for rule 2-over-3, at any historical exploitation level.

As the short term (and medium terms) prevails over the long term, 1-over-2 rule overcomes 2-over-3 rule to start the management with in-year Advice for sardine/sprat-like stocks and its performance is enhanced at Fopt and Fhigh with the 80% uncertainty cap.

Joint discussion for both stocks

For the two stocks it has been found that rules 1-over-2 overcomes 2-over-3 in terms of catches and risks as for similar levels of catches result in smaller levels of risks. Figure 3.16 shows the relative changes in risks (X axis) and catches (Y axis) when moving from harvest control rules 2-over-3 to 1-over-2 both without any uncertainty cap. In all cases in the short and medium term moving from 2-over-3 to 1-over-2 rule implies relevant reduction of risks for minimum reductions of catches (in some cases even gains, i.e. improving catches). In the long-term, the reduction of risks is counterbalanced by some reduction of catches (but of less relative magnitude than the reductions of risks (as all points lay above the line 1:1)

For the two stocks it has been found that rules 1-over-2 with 80% uncertainty cap overcomes the same rule without any uncertainty cap, as for moderate reduction of catches imply a more relevant reductions of risks. Figure 3.17 shows the relative changes in risks (X axis) and catches (Y axis) when moving from harvest control rules 1-over-2 with 80% uncertainty cap vs no uncertainty cap. For the two stocks, in the short, medium and long-term moving from 1-over-2 rule without uncertainty cap to 80% uncertainty cap implies relevant relative reductions of risks, but in the case of the STK1 (anchovy-like stock) such relative reduction is encompassed by a rather similar relative reduction of catches, while for STK2 (sardine/sprat-like) the relative reduction of catches is smaller than that achieved in risks. This suggests that the benefits in terms of the balance between relative reduction of catches versus reduction of risks is better in the case of STK2 (sardine/sprat-like stocks) than in the case of stock1 (anchovy like stocks). For STK2 in the medium and long term there are some cases where risks are not reduced but increased even with a strong reduction of catches which correspond with very high CVID/IAV ratios and general at high sigR (=0.75)

Globally, for these short living species as the short term (and medium terms) should prevail over the long term performance, 1-over-2 rule overcomes 2-over-3 rule to start the management with in-year advice for these short lived stocks and its performance is enhanced in terms of risks if applied with the 80% uncertainty cap.

Figure 3.13. Scenario (OM: Stock=STK2, Fhist=Flow; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

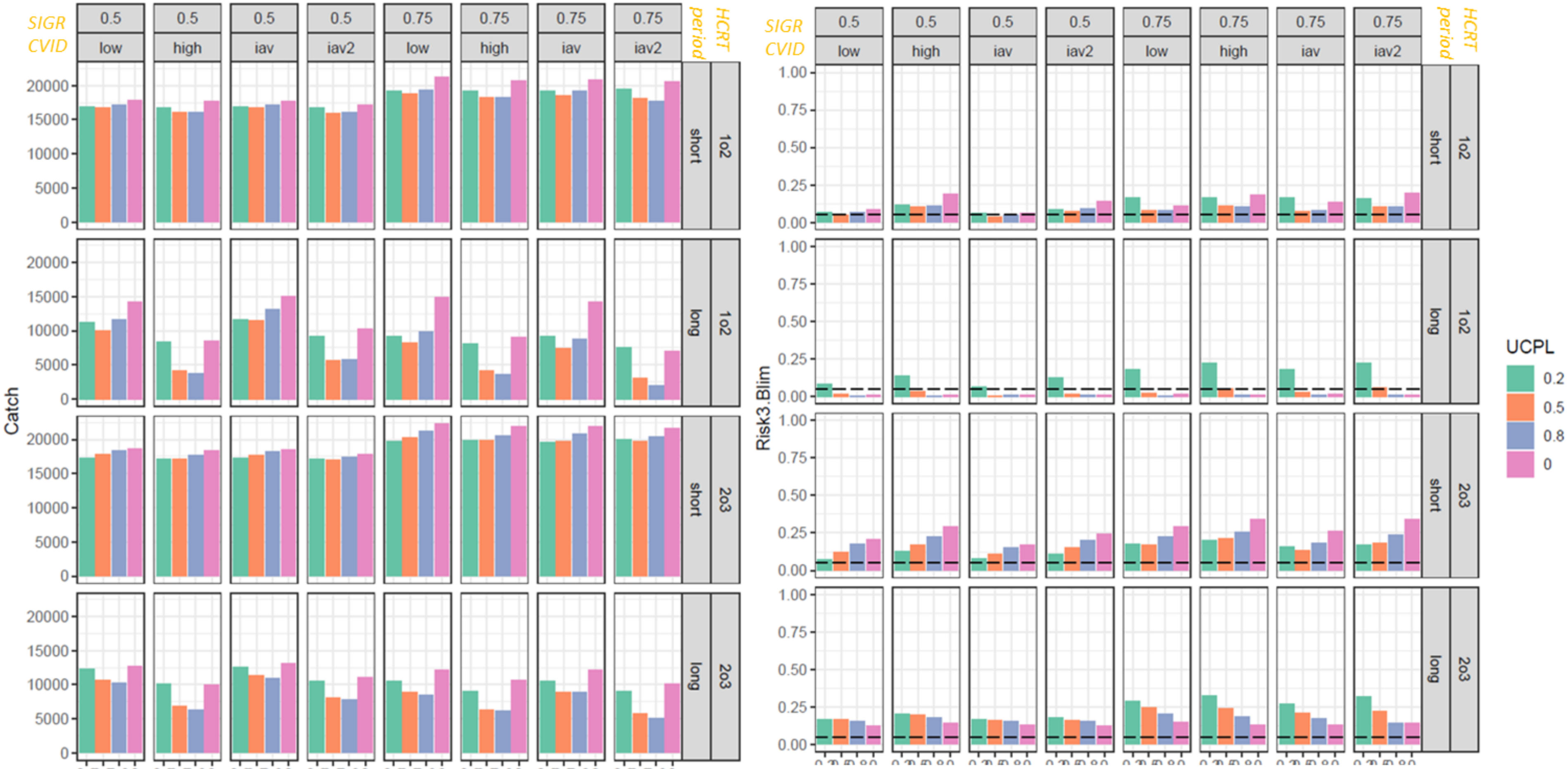

Figure 3.14. Scenario (OM: Stock=STK2, Fhist=Fopt; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

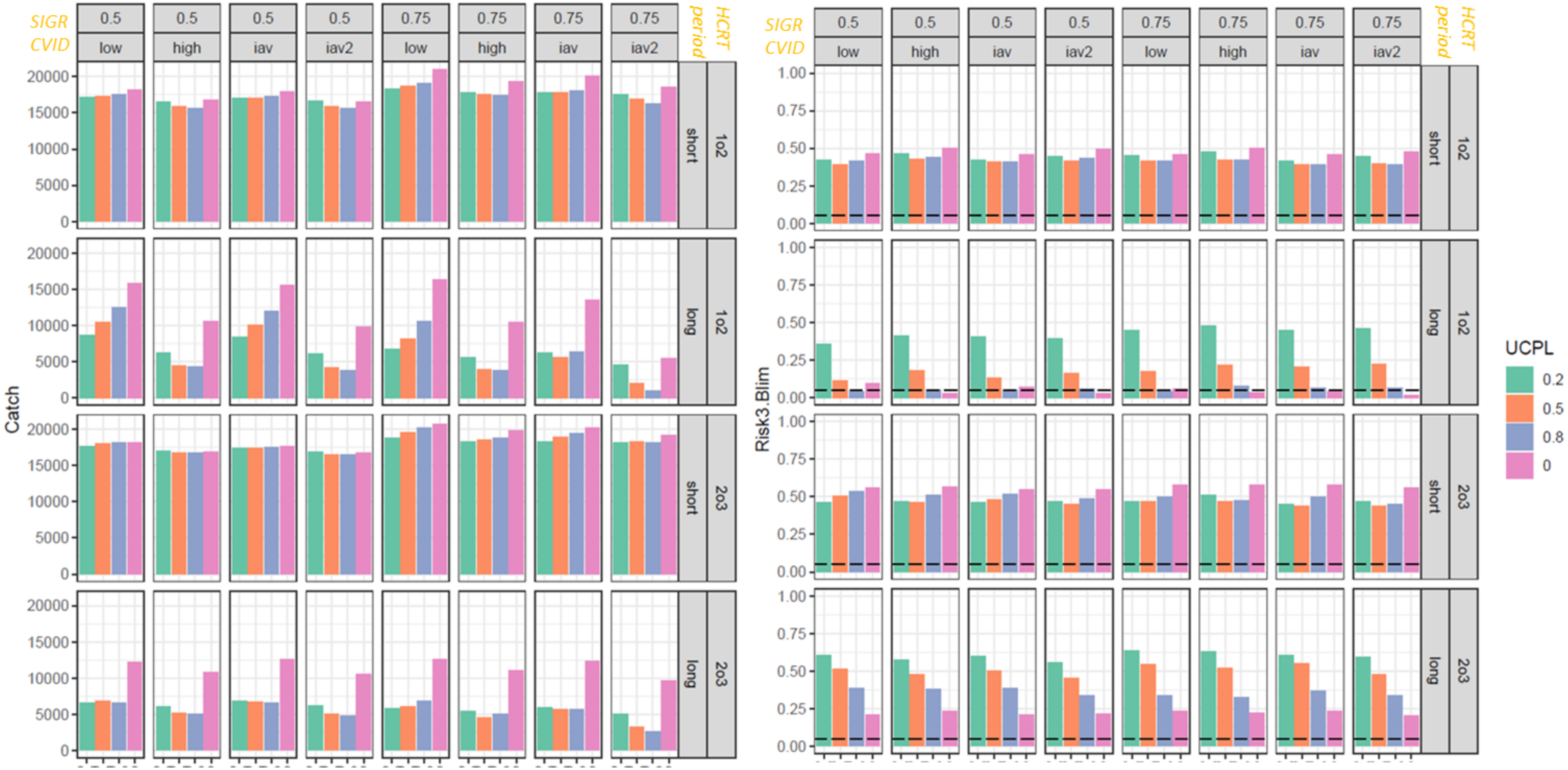

Figure 3.15. Scenario (OM: Stock=STK2, Fhist=Fhigh; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; iav: equal to interannual variation; and 2iav: 2-times IAV), HCR type (1o2: 1-over-2; and 2o3: 2-over-3), projection period (short: years 31-35; long:: year 51-60) and uncertainty caps (green - 0.2: 20%; orange - 0.5: 50%; blue - 0.8: 80%; and pink - 0: no uncertainty cap).

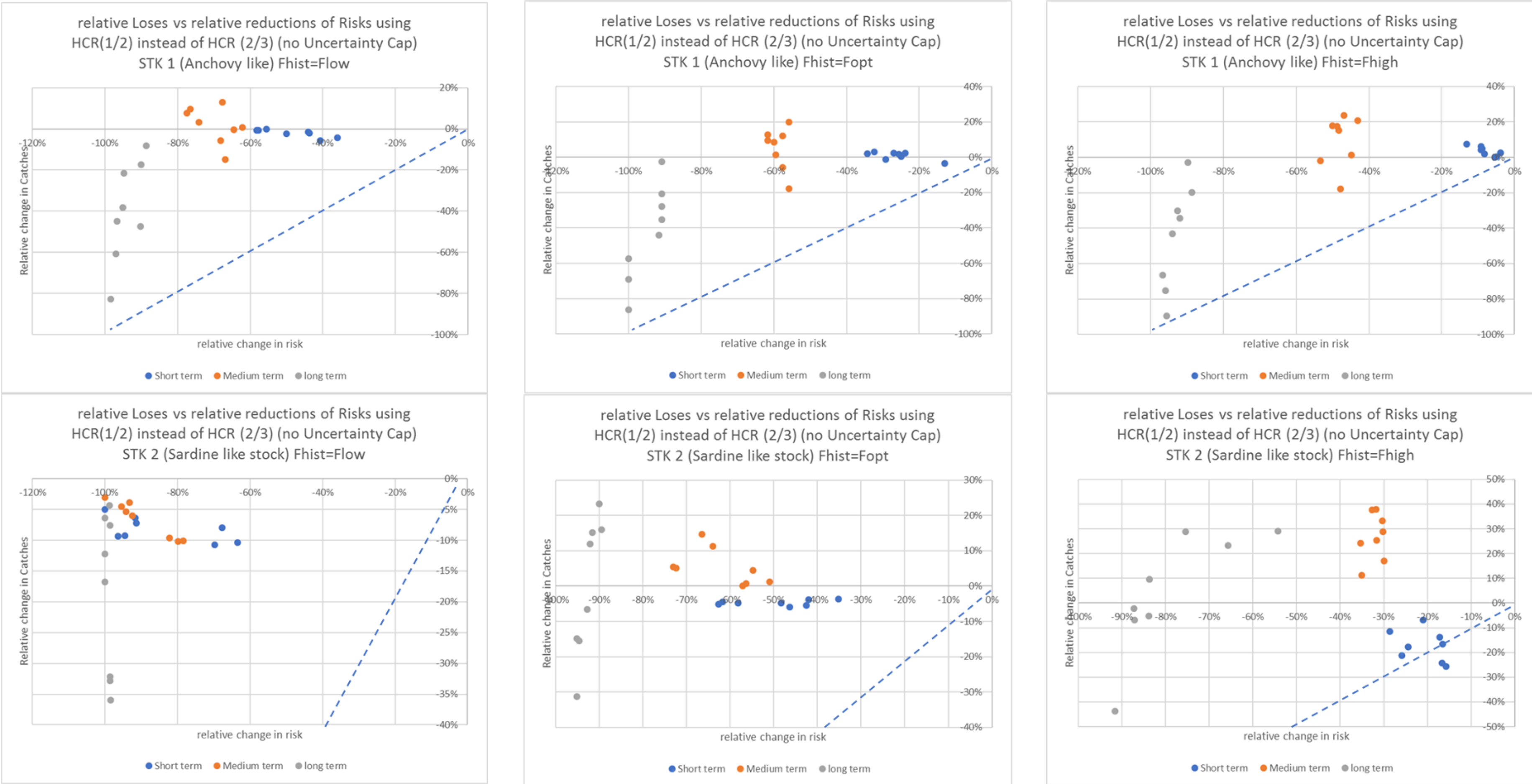

Figure 3.16. Relative changes in risks (X axis) and catches (Y axis) when moving from a harvest control rules 2-over-3 to 1-over-2 both without any uncertainty cap, for an anchovy like stock (upper row of figures) and sardine/sprat-like stock (bottom row), for Flow, Fopt and Fhigh historical exploitations (columns from left to right) and different time frames (blue -short (1-5 y), orange- medium (6-10y) and grey-long-term (20-30 y)).

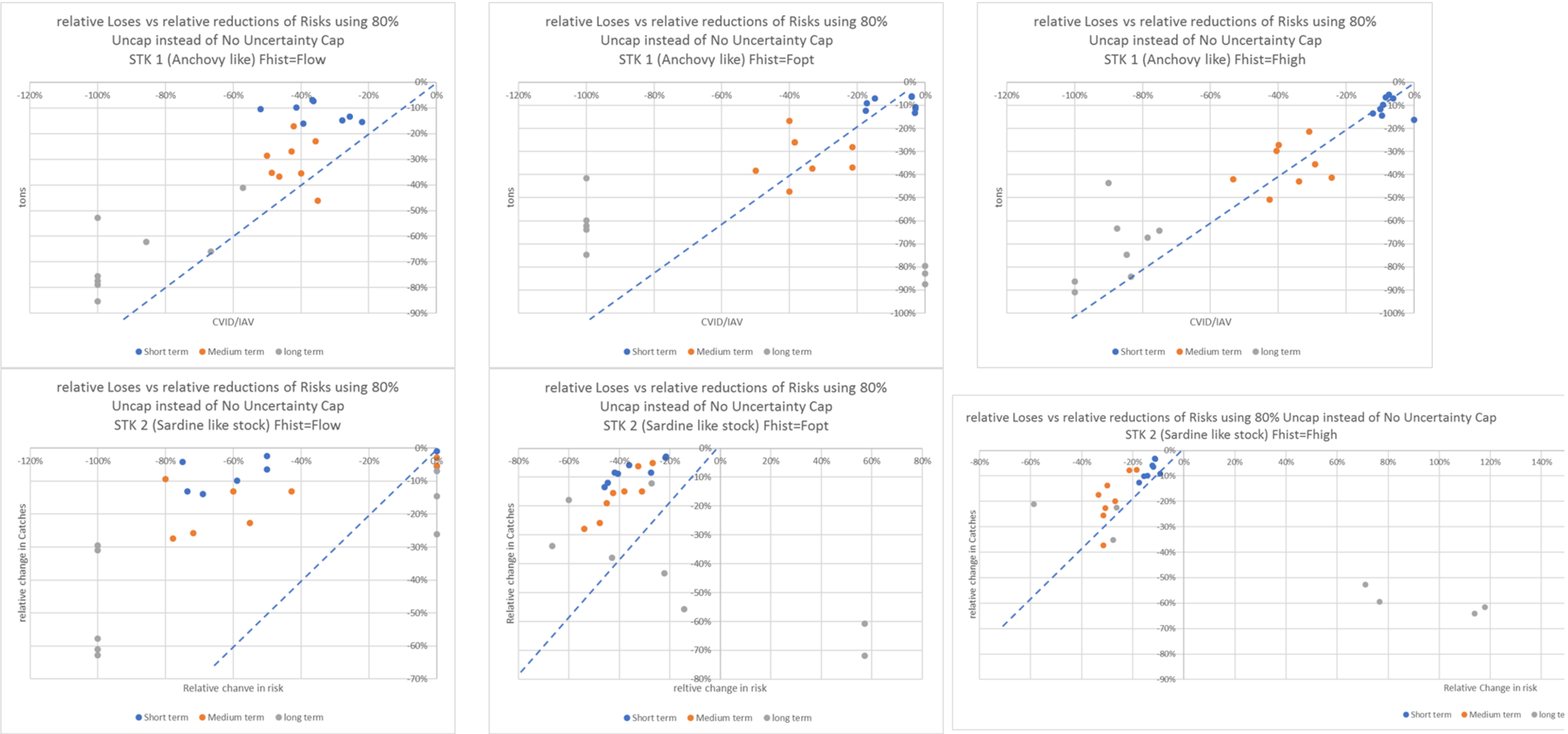

Figure 3.17. Relative changes in risks (X axis) and catches (Y axis) when moving from a harvest control rules 1-over-2 without any uncertainty cap to 1-over-2 with 80% uncertainty cap, for an anchovy like stock (upper row of figures) and sardine/sprat-like stock (bottom row), for Flow, Fopt and Figh historical exploitations (columns from left to right) and different time frames (blue - short (1-5 y), orange- medium (6-10y) and grey-long-term (20-30 y)).

General conclusions for the two stocks:

- Risks are largely driven by order of relevance by the historical fishing mortality applied to the stock before management (the starting depletion level), and the Harvest control with the selected uncertainty cap level. Secondarily, risks also are also increased by the increases in Survey CV (CVID) and with the ratio of CVID/IAV
    - The greater the historical exploitation the greater the risks in the short term and the smaller the reduction of risks of 1-over-2 vs 2-over-3 rule: This may be due to the fact that higher F increases IAV and in addition that the Biomass at the beginning of the management period is lower, show the risk is itself already higher since the beginning.
    - For any level of historical fishing mortality, in the short-term 1-over-2 rule without uncertainty cap overcomes 2-over-3 rule without uncertainty cap, as they both produce very similar and highest catches but the former results in lower risks.
    - Exceptionally, a*t low IAV and CVID not larger than 0.5 (as it is STK2 with Flow), performance of 2-over-3 rule with the 80% uncertainty cap is rather similar to 1-over-2 rule without uncertainty cap) leading to risks around 0.05. Because, in general, such rule imply lesser reduction of catches for that case of starting low risks levels.*
- At Fhist=Fopt and Fhigh application of the 80% uncertainty cap to 1-over-2 instead of no uncertainty cap is beneficial. Such benefit is larger for the sardine/sprat-like stocks (moderate IAV) as it reduces 20-30% risks keeping catches at 90% of the catch without uncertainty cap. In the case of the STK1 (anchovy-like stock) such relative reduction is encompassed by a similar relative reduction of catches.
- Initial diagnostic of the degree of past exploitation of the stock in relation to F_{MSY} proxy would be very helpful to decide the adoption of an initial cutting buffer or not, as its application should imply a reduction in the expected risks (typically higher) at the beginning of the management period of application of the HCRs
- Globally, for these short living species as the short term (and medium terms) should prevail over the long term performance, 1-over-2 rule overcomes 2-over-3 rule to start the management with in-year Advice and its performance is enhanced in terms of risks if applied with the 80% uncertainty cap.

3.3. Alternative HCR with biomass safeguard

For sardine-like stocks (STK2), when the biomass safeguard is applied to the 1-over-2 rule, risks are below 5% in the short term only for the stocks historically exploited at low F values (Figure 3.18). The 1-over-2 rule without any precautionary buffer or uncertainty caps, performs very similar to the one with the biomass safeguard both in terms of catches and risks in the short-term(Figure 3.18). Implying this last one, slightly lower catches and risks. However, in the long term these differences are higher (Figure 3.19 and Figure 3.20). Risks for the 1-over-2 rule with biomass safeguard are always lower than 5% for all the alternative assumptions on the historical F levels in the long-term(Figure 3.19 and Figure 3.20).

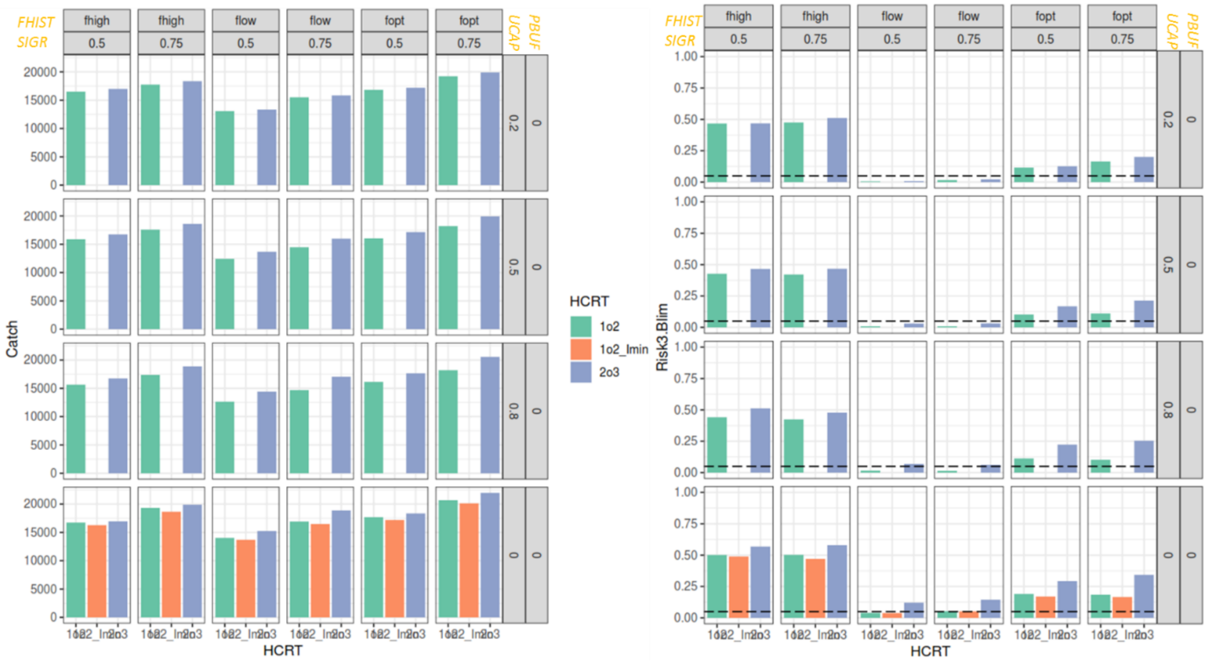

Figure 3.18. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, in the short-term (years 31-35), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 2o3: 2-over-3), by historical F (Fhigh: $2*F_{MSY}$; Flow: $0.5*F_{MSY}$; and Fopt: F_{MSY}),standard deviations for the recruitment - SIGR (0.5; and 0.75), precautionary buffers (0: no buffer) and uncertainty caps (0.2: 20%; 0.5: 50%; 0.8: 80%; and 0: no uncertainty cap).

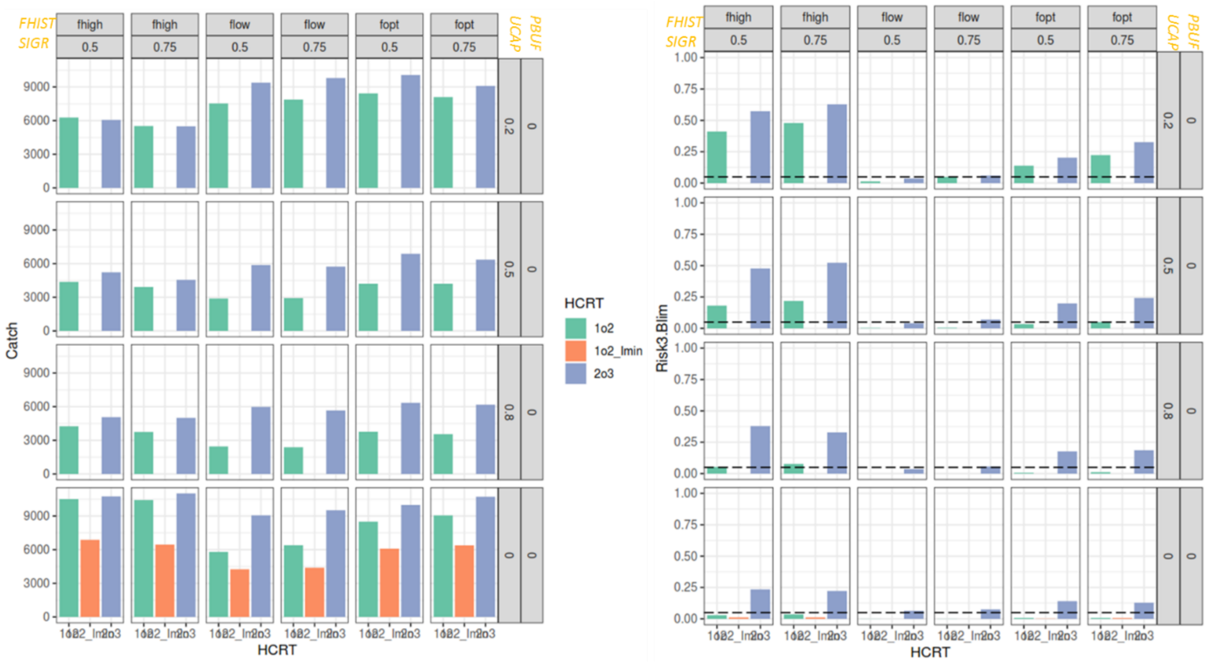

Figure 3.19. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 2o3: 2-over-3), by historical F (Fhigh: $2*F_{MSY}$; Flow: $0.5*F_{MSY}$; and Fopt: F_{MSY}),standard deviations for the recruitment - SIGR (0.5; and 0.75), precautionary buffers (0: no buffer) and uncertainty caps (0.2: 20%; 0.5: 50%; 0.8: 80%; and 0: no uncertainty cap).

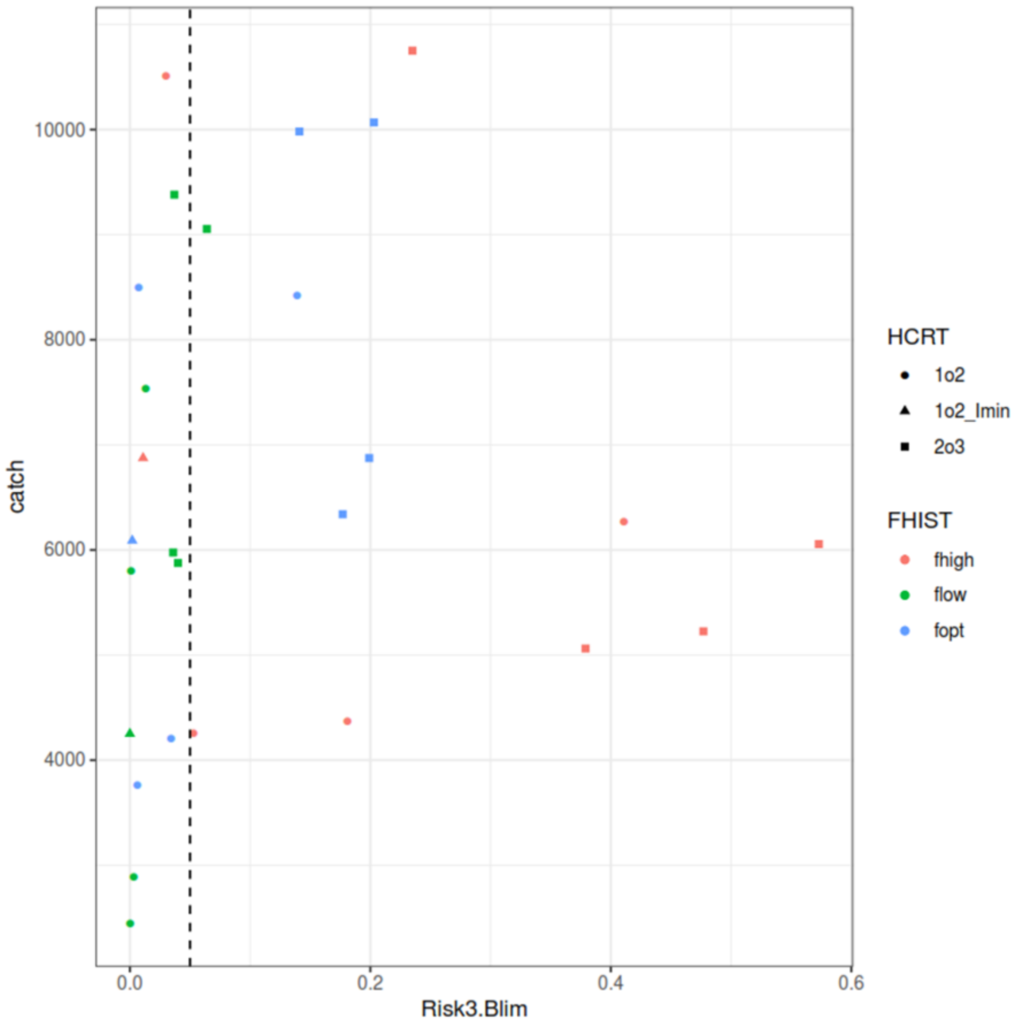

Figure 3.20. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). Median catch versus Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 2o3: 2-over-3) and historical F (Fhigh: 2*F_{MSY}; Flow: 0.5*F_{MSY}; and Fopt: F_{MSY}). Values with same form and colour correspond to alternative standard deviations for the recruitment (0.5 or 0.75) and uncertainty caps (20%, 50%, 80% or no uncertainty cap).

Results for anchovy-like stocks (STK1) are consistent with the previous ones for sardine-like stocks. But in this case, absolute risk levels are higher. Consequently, these are always above 5% in the short-term.

Figure 3.21 shows the relation between risks and catches for all the scenarios simulated for rule 1-over-2 without any cap, with an 80% uncertainty cap and with a biomass safeguard. Given these results, we see that:

- The higher the catches, the higher the risks.
- Catches and risks have a decreasing trend as time goes on.
- Risks are always lower than 5% in the long-term (except in rule 1-over-2 with 80% uncertainty cap for STK2 at historical Fhigh). However, in the short-medium term it is only for STK2 at the historical low F values.
- The most precautionary rule is the 1-over-2 rule with an 80% uncertainty cap.

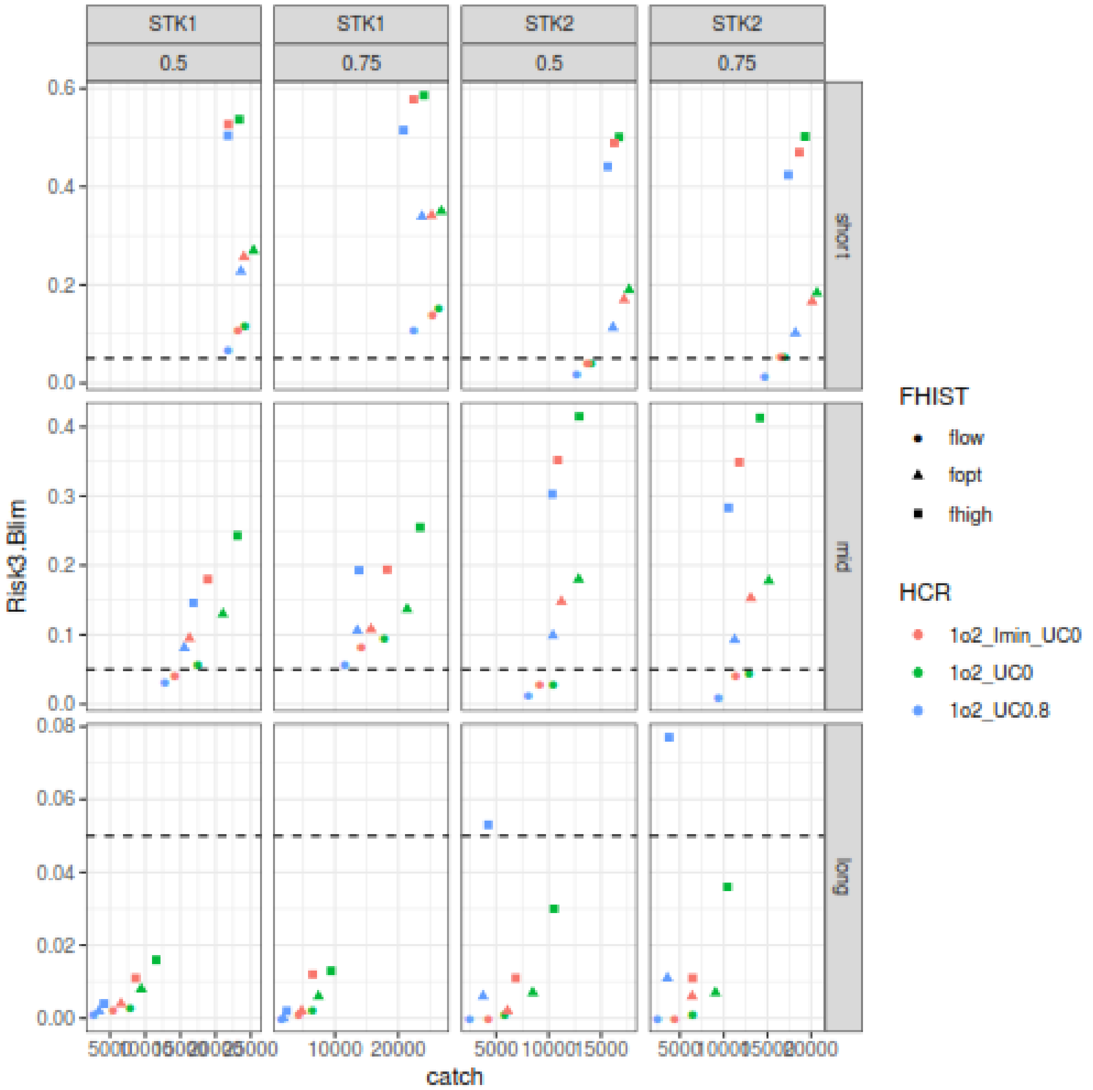

Figure 3.21. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Risk3 of falling below B_{lim} versus median catch for alternative historical F levels (circle - Flow: 0.5*F_{MSY}; triangle - Fopt: F_{MSY}; and square - Fhigh: 2*F_{MSY}), HCRs (red – 1o2_Imin_UC0: 1-over-2 with biomass safeguard; green – 1o2_ UC0: 1-over-2 without uncertainty cap; blue – 1o2_ UC0.8: 1-over-2 with an 80% uncertainty cap), stock types (STK1: anchovy-like; STK2: sardine-like), standard deviation for the recruitment (0.25 or 0.75) and timeframes (short: years 31-35; medium: years 36-40; and long-term: years 51-60).

Figure 3.22 shows the comparison between the relative increase in risks and catches, where below the line implies fewer reduction in risks than in catches. In the medium-term, moving from 1-over-2 rule with 80% uncertainty cap to 1-over-2 rule with biomass safeguard does not compensate, as a small reduction in catches implies a similar or greater increase in risks. ON the contrary, in the long-term, the catch levels can be increased with a much smaller increase in risk.

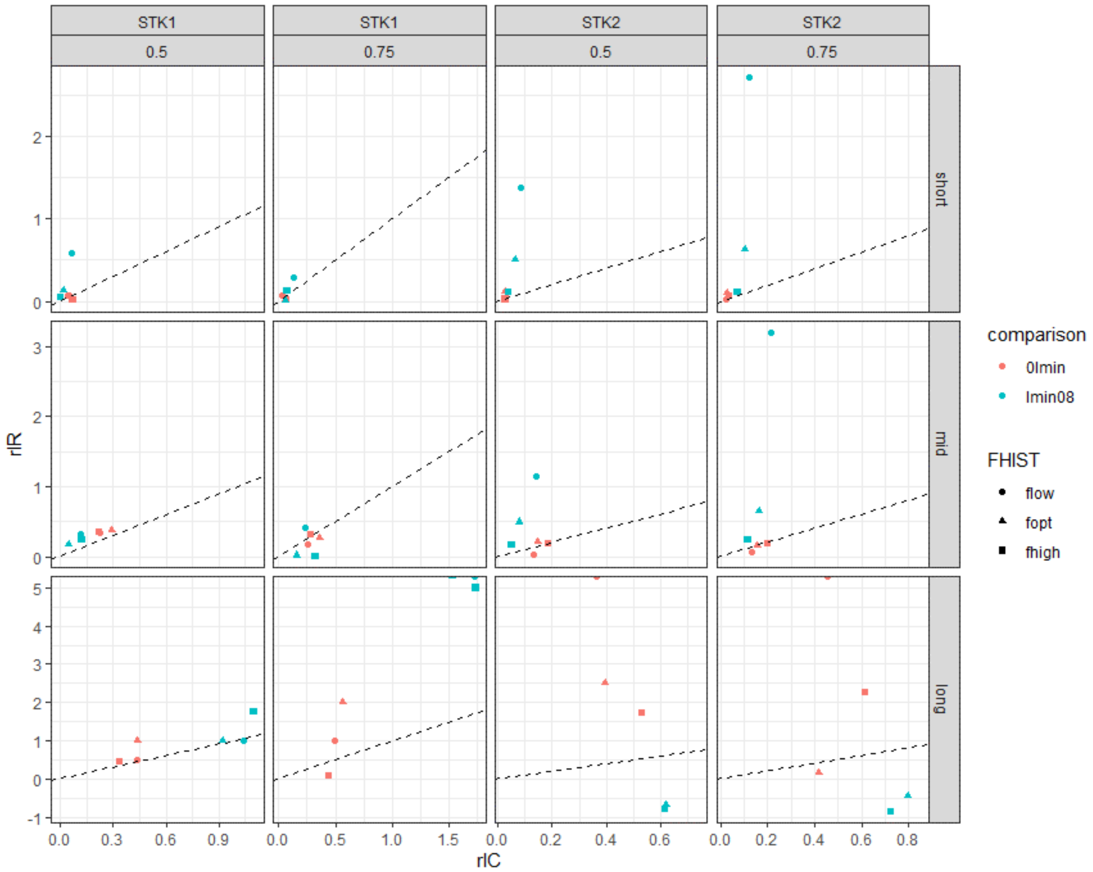

Figure 3.22. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Relative changes in Risk3 of falling below B_{lim} (rlR) versus relative changes in median catch (rlC) for alternative HCR ratios (red – 0lmin: 1-over-2 without uncertainty cap/1-over-2 with biomass safeguard-1; green – lmin08: 1-over-2 with biomass safeguard/1-over-2 with an 80% uncertainty cap-1), historical F levels (circle - Flow: 0.5*F_{MSY}; triangle - Fopt: F_{MSY}; and square - Fhigh: 2*F_{MSY}), stock types (STK1: anchovy-like; STK2: sardine-like), standard deviation for the recruitment (0.25 or 0.75) and timeframes (short: years 31-35; medium: years 36-40; and long-term: years 51-60). Dotted line corresponds to the 1:1 ratio (below the line implies fewer reduction in risks than in catches).

4. Conclusions

- Regarding the timing for advice and management, the shorter the lag between observation and management (int>iny>fpa), the bigger catches and smaller risks. Therefore, in-year advice system is always better than usual year advice (i.e. with an interim year in the middle).

- The 2-over-3 rule has larger risks than any of the others tested.

- In the short-term, 1-over-2 rule overcomes 2-over-3 rule, as for quite similar level of catches have a bit smaller risks, although often above 0.05 (particularly for fully or highly harvesting levels before the start of management). Moving from 1-over-2 rule without uncertainty cap to an 80% uncertainty cap, reduces further the risks with a small reduction in catches. But the greater the IAV, the greater the reduction of catches with the 80% uncertainty cap (in the medium and long-term). Therefore, benefits are clearer for sardine/sprat-like stocks than for anchovy like stocks.

- Historical F determines initial risks on the application of any HCR. The larger the historical F, the larger the risks in the short-term and the smaller the reduction of risks of 1-over-2 versus 2-over-3 rule.

- The precautionary buffer reduces the initial risks at the start of the management period, but not so much the long-term risks.

- The 20% uncertainty cap has much larger risks, being non-precautionary regardless the type of HCR.

- Rule 1-over-2, with 80% uncertainty cap can be recommend for short lived species as produce moderate lower catches but lower risks than the 1-over-2 rule with biomass safeguard. Although in the short-term differences are smaller in terms of catches and risks.

5. References

Bellido et al. (2000). Use of frequency analysis methods to estimate growth of anchovy (Engraulis encrasicolus L. 1758) in the Gulf of Cadiz (SW, Spain). Fisheries Research 48: 107-115.

García, D., Sánchez, S., Prellezo, R., Urtizberea, A., and Andrés, M. 2017. FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies. SoftwareX, 6: 141-147.

Gislason, H., Daan, N., Rice, J. C., and Pope, J. G. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries, 11: 149-158.

ICES. 2018a. ICES Advice basis. https://doi.org/ 10.17895/ices.pub.4503

ICES. 2018b. Report of the Eighth Workshop on the development of quantitative assessment methodologies based on life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE VIII), 8-12 October 2018, Lisbon, Portugal. ICES CM 2018/ACOM:40. 172 pp.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., et al. 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science, 64: 640-646.

Punt, A. E., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A., and Haddon, M. 2016. Management strategy evaluation: best practices. Fish and Fisheries, 17: 303-334.

Uriarte, A., Rincón, M., Garrido, S., Ramos, F., Silva, A., Ibaibarriaga, L. and Sanchez, S. 2018. Testing the performance of different catch rules based on survey trends for the management of short-lived category 3 stocks. Working document to WKLIFE VIII.