WORKSHOP ON DATA-LIMITED STOCKS OF SHORT-LIVED SPECIES (WKDLSSLS)

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Contents

i Executive summary

The Workshop on Data Limited Stocks of Short-Lived Species aimed to provide guidelines on the estimation of MSY proxy reference points for category 3–4 short-lived species and to evaluate the management procedures currently in use and their appropriateness for short-lived species by means of Long-Term Management Strategy Evaluations (LT-MSE).

In relation to assessment methods for short-lived data-limited stocks and estimation of biological and MSY proxy reference points, the WK focused on the application of SPICT (Pedersen and Berg, 2017). The WK was updated on recent improvements of SPiCT and the harvest control rules (HCRs) used to manage stocks after WKLIFE VII and VIII by including either the MSY-fractile or MSY-PA rules. For the optimal SPiCT advice rule, users should refer to the update ICES guidelines. Work on fitting SPICT to case studies was made before and during the workshop: Assessments to Anchovy in 9.a South resulted in a satisfactory fitting of SPICT, whilst fits to Anchovy in 9.a West and to Sprat 7.de were still unsatisfactory. In addition, there were some presentations on applications of SPiCT to several Cephalopod populations. Length-based indicators of stock status were discarded as generally they are not suitable for short-lived species where recruitment induces major interannual changes in the length distribution of catches. A provisional application of a two-stage assessment was presented for Sprat in 7de, but results were still provisional.

In relation to the evaluation of management procedures for these stocks, MSE testing of harvest control rules based on trends of biomass indices were analysed for anchovy-, sprat-, and sardine-like stocks including several operating models. All simulations showed that the shorter the lag between observations, advice and management, the bigger the catches and the smaller the risk. This implies that In-year advice should always be preferred over the normal calendar (with an interim) year advice for these stocks. Major drivers of risks are by order of relevance: historical exploitation level (and trajectory), and the harvest control rule (HCR) with its selected Uncertainty Cap (UCap). This emphasizes the relevance of trying an initial assessment of the relative status of the stock regarding optimal exploitation to judge if a precautionary buffer is required to start management. Further work on the assessment of past exploitation level is required.

Regarding the trend-based harvest control rules (HCRs): In general, 1-over-2 outperforms 2-over-3 rule (ICES default rule) because for quite similar catches the former implies lower risks. For symmetrical application of the interannual uncertainty cap, best performance (least risks for minimum reduction of catches) occurs using the 1-over-2 rule with a symmetrical 80% uncertainty cap. The riskiest performance results were from applying a 20% uncertainty cap, both for 1-over-2 and 2-over-3, and the performance worsens with time. For asymmetrical Uncertainty Caps, tested for rules with a maximum interannual upward revision of 20%, results showed optimal performance when allowing reductions of 60% or greater percentages from the previous advices for in-year advice, and of 70% or greater for normal (calendar) advice. While the 1-over-2 rule with asymmetric uncertainty cap is the most precautionary, it implies a continued large reduction of catches. The 1-over-2 rule with no uncertainty cap gives the highest catches at all times. Intermediate rules in terms of balance between catches and risks are: 1-over-2 (with symmetrical 80%Ucap) and 1-over-2 with biomass safeguard (using either Imin, the minimum past observed abundance index, or Itrigger, 1.4*Imin). Rule 1-over-2 with symmetrical 80% Uncertainty cap might be preferred as a good compromise between moderate risks and catches though it can lead to major reduction of catches in the long term

Given the trade-off between competing rules, it seems that selection of a rule should better be made in consultancy with managers and stake holders according to their objectives for each fishery.

Further research will be needed on the definition of proxies for BRPs and of the optimal harvest control rules (including the SPiCT advice rules) for the management of these SLDLS, covering further testing of biomass safeguards and of asymmetric uncertainty caps or the use of constant or variant harvest rate strategies instead of the trend-based rules.

ii Expert group information

Expert group name	Workshop on Data-Limited Stocks of Short-Lived Species (WKDLSSLS)
Expert group cycle	NA
Year cycle started	2019
Reporting year in cycle	1/1
Chairs	Andrés Uriarte, Spain
	Mollie Brooks, Denmark
Meeting venue and dates	16–20 September 2019, San Sebastian, Spain, 20 participants

1 Introduction

1.1 Terms of Reference

The **Workshop on Data-limited Stocks of Short-Lived Species (WKDLSSLS)**, chaired by Andrés Uriarte, Spain, and Mollie Brooks, Denmark, met in San Sebastian, Spain, 16–20 September 2019.

The life-history characteristics of short-lived species, including large fluctuations in annual recruitment, pose specific challenges for management. Alternatives to the current advice rules for data-limited stocks (category 3 and 4) used within ICES should be evaluated for use on these short-lived species. On the basis of the outcome of WKLIFE VII, WKLIFE VIII, WKSPRAT 2018 and WKSPRAT-MSE 2018, the following issues should be addressed:

a) Test different assessment methods for data-limited short-lived species (seasonal SPiCT, two-stage Biomass model, others).
b) Provide guidelines on the estimation of MSY proxy reference points for category 3–4 short-lived species.
c) Evaluate the management procedures currently in use and their appropriateness for short-lived species by means of Long-Term Management Strategy Evaluations (LT-MSE). This will imply the revision of the advice rules used, the time lag between assessment and enforcement, the suitability and magnitude of the uncertainty caps.

WKDLSSLS will report by the 14 October 2019 for the attention of ACOM.

1.2 Background

Short-lived species such as anchovy and sardine pose challenges for management, because their life-history characteristics including large fluctuations in annual recruitment make them highly variable and raise questions about the successful application of commonly used management approaches in particular for data-limited stocks. During WKLIFE VIII (ICES, 2018), WKMSYCat34 catch rule 3.2.1 (ICES, 2017) was tested for its performance towards achieving MSY exploitation, across a series of stocks covering an ample set of life-history categories. Such analysis proved that using Gislason mortality and sigmaR=0.3, and with the usual lags (2-over-3 rule and a year lag between assessment and advice), the 3.2.1 catch rule without further tuning resulted in collapses for stocks with k>0.32. Performance was improved by reducing time lags (*i.e.*, using more recent data), even for some of the k>0.32 stocks. Similar conclusions were found to apply for the 3.2.2 catch rule (the "Icelandic" rule) in terms of the clusters based on k, and the improvement in performance by reducing time lags. Direct simulations during WKLIFE on an anchovy-like stock showed that for short-lived species in category 3 stocks with a survey index (or accepted CPUE index) monitoring system, moving from classical DLS methods with one-year lag in between advice and management to in-year advice will be beneficial as it will be using the most recent index to manage the resource. In addition, it was pointed out that 1-over-2 or 1-over-3 rules, informing on the most recent changes of these populations, seems to outperform rules 2-over-3 and 3-over-5 for In-Year advice. In addition, low (highly restrictive) uncertainty caps (e.g. 20%) worsen the performance of the HCRs for this short-lived species with high interannual variability. It was considered that further verification of these results for In-year management of other short-lived category 3 stocks and expansion of the analysis to account for some potential modifications of the harvest control rules would be needed.

Overall WKLIFE 2018 concluded that the highly fluctuating nature of short-lived species conditioned the performance of these harvest control rules and require the evaluation of *ad hoc* options for short-lived data-limited stocks (category 3 and 4). These considerations lead to the conclusion that a workshop on assessment, harvest control rules and MSE for data-limited short-lived species was needed. For this reason, a specific workshop was recommended to take place during 2019 to address, on the basis of the outcome of WKLIFE VII, VKLIFE VIII, WKSPRAT 2018 and WKSPRAT-MSE 2018, the evaluation of different assessment and management methods for short-lived data-limited stocks.

As many cephalopods are also short-lived species, and therefore share the problems of assessment and management of short-lived fish populations, during 2019 inclusion of experiences on cephalopod case studies were considered of interest to generalize the scope of the workshop.

1.3 Conduct of the meeting

The agenda for the workshop is presented in Annex 1 and attendees are listed in Annex 2. An online meeting took place in advance of the WKDLSSLS meeting by WebEx in May 2019 with some of the participants of the workshop (minutes in Annex 3).

External participation was encouraged and there were two attendees coming from the SWFPO Crew (South Western Fish Producer Organisation), mainly concerned with the fishery on sprat in divisions 7.de (see their contribution in Annex 5). Four participants worked by correspondence during the meeting (Annex 2) and the facilities of Skype were relied upon for their full contribution to the workshop's subgroups and plenary discussions, particularly during the first two days and at the end of the meeting. This worked well, and lively discussions resulted from this interaction.

During the meeting, the presentations were used to define the work programme for the remainder of the workshop and the identification of virtual subgroups, two of which were identified:

- Subgroup 1 – focused on ToRs 1 & 2 Assessments and definition of BRPs, with work pivoting mostly on case studies;
- Subgroup 2 – focused on ToR 3: Testing MSE of HCRs based on indicators trends, with work pivoting mostly on simulations of harvest control rules either on particular case studies or general short-lived populations.

The structure of the report followed the presentations and work carried out in these two groups.

After the presentations during the first two days of the meeting, much of the time was spent on improving the fits of SPiCT to specific stocks and further evaluation of several ad hoc harvest control rules, in addition to writing text for the main report. During the last two days of the meeting, several presentations updating the progress achieved by subgroups were presented. As a result of the many runs and MSE work carried out during the meeting some work needed to be finished after the meeting and such work was planned during the last day of the meeting.

Proposing guidelines for management of short-lived data-limited species and most of the writing of the report (including closing the conclusions) took place after the meeting, via exchange of emails and by a WebEx meeting on Friday 4 October 2019.

1.4 Structure of the report

The structure of the report follows the presentations and work carried out during the meeting in the two groups.

After the introductory texts of Section 1, Section 2 presents the results of Subgroup 1 – focused on ToRs 1 & 2 assessments and definition of BRPs, where the different work pivoting mostly on case studies is presented. First progress (Section 2.1) in SPiCT assessment method and harvest control rules are presented in Section 2.1, according to the work after WKLIFE VII and VIII. Next a general overview of the progress of FarFish project (www.farfish.eu) (a Research & Innovation project that started in 2017) is made (Section 2.2). This project aims at providing knowledge, tools and methods to support responsible, sustainable and profitable EU fisheries outside European waters. The rest of Section 2 are subsections on case studies, first on the initial assessments of the Sprat in the English Channel (Section 2.3), next on the trials of SPiCT fitting to the anchovy in 9.a West (Section 2.4) and South (Section 2.5) and on a MSE scenario evaluation of trend based procedures (2.6). And finally, assessment and management of Cephalopods (Section 2.7) is presented followed by some conclusions and future directions of research regarding this Section 2 (Sections 2.8 and 2.9).

In Section 3 the report for Subgroup 2 – focused on ToR 3 is made, where the MSE testing of HCRs based on indicator trends is presented for particular or generic case studies. First (Section 3.1) the MSEs for a simulated stock of sprat in 7.de is made. Next (Section 3.2) MSE testing of SPiCT and trend-based HCRs to North Sea Sprat is made. Finally (Section 3.3) Testing management advice procedures for rather generic short-lived data-limited stocks in Category 3 are presented. This is followed by some conclusions and future directions of research regarding this Section 3 (Sections 3.4 and 2.5).

The report ends with a compilation of general conclusions (Section 4) and future directions (Section 5).

1.5 Consideration of Timing for advice

The time-lag between monitoring, assessment-advice and management affects the performance of any harvest control rule. Therefore, the workshop tried to quantify how the three typical time frames affect the performance. These are:

The usual management calendar goes from January to December. Index available during the interim year y (in Figure 1.5.1 it is made available on 1st July) is used to set the TAC from January to December of year (y+1) (Figure 1.5.1.a). 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.

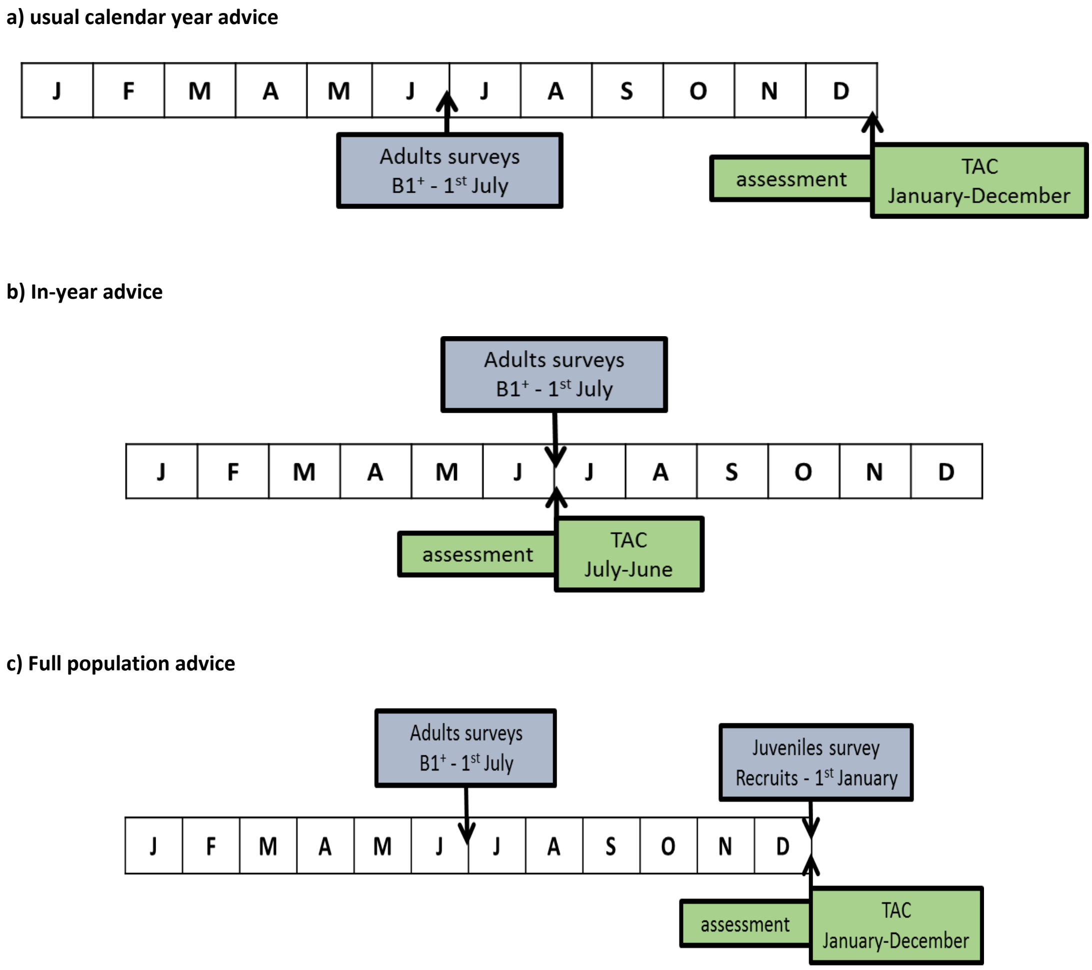

Figure 1.5.1. TAC calendars.

Two alternative management calendars are: The first one, the in-year advice correspond with the case where the index is available during the first half of the interim year y (in the figure on 1st July) and it is used to set the TAC from July year y to June in year (y+1) (to generalize this starting in the same year when the index is made available). This means that during the second semester in year y age 1 is known, but not during the first semester of year (y+1). A second alternative case of management calendar sets the TAC from January to December in year (y+1) but based on the B1plus index on 1st January of year (y+1). This is the usual case when one or two surveys provide information during the interim year of both the biomass of ages 1 and older (B1+) and of the recruits at age 0. In this case, the index(es) provides information on all the age classes that are going to be exploited in year y+1. This was called here full population advice it was only tested in a few cases. Most of the MSE presented in this workshop cover the usual calendar year advice and the In-Year advice, whilst the full population advice was just tested in a subset of cases (in Uriarte *et al.*, WD 2019). In the latter case, as the entire management population is informed by the abundance index the capacity of achieving a good management is enhanced.

1.6 Follow-up process within ICES

The workshop was also required to review the current ICES technical guidance on advice rules for stocks in categories 3 and 4. Draft technical guidance on advice rules for short-lived stocks in categories 3 and 4 were produced and passed to WKLIFE IX which was tasked to review the draft and, in addition, the report of WKDLSSLS.

ICES WKLIFE IX met from 30 September to 4 October 2019, Lisbon, and a summary of the work carried out in WKDLSSLS was presented to the group on the first day. The report of WKDLSSLS was not available at the time WKLIFE met, but an extensive summary of the work is included in a section of the WKLIFE report. The draft guidance on advice rules for short-lived stocks in categories 3 and 4 proposed by WKDLSSLS were reviewed by WKLIFE IX on Friday 4 October.

The WKLIFE revised drafted technical guidance on advice rules for stocks in categories 3 and 4 (including the section on short-lived stocks) and the report of WKLDLSLS will be reviewed by ACOM in autumn 2019.

1.7 References

ICES. 2017. Report of the Workshop on the Development of the ICES approach to providing MSY advice for category 3 and 4 stocks (WKMSYCat34), 6–10 March 2017, Copenhagen, Denmark. ICES CM 2017/ ACOM:47. 53 pp.

ICES. 2018. 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.

2 Subgroup 1 ToRs 1 & 2 Assessments and definition of BRPs

2.1 The stochastic production model in continuous time (SPiCT) (TK Mildenberger and A. Kokkalis)

2.1.1 Time variant productivity in surplus production models

The productivity of fish populations varies naturally over time, dependent on integrated effects of abundance, ecological factors, and environmental conditions. These changes can be expressed as gradual or abrupt shifts in productivity as well as fluctuations on any time-scale from seasonal oscillations to long-term changes (Vert-pre *et al*., 2013; Britten *et al*., 2017). In particular, short-lived fast-growing fish species exhibit wide fluctuations in stock productivity (Essington *et al*., 2015). Mildenberger *et al*. (2019a) introduce three model extensions to the stochastic surplus production model in continuous time (SPiCT, Pedersen and Berg, 2017), that allow to model time-variant productivity in fish populations as long-term stepwise shifts between productivity regimes, long-term gradual changes, or seasonal oscillating productivity. With simulation testing and a case study, the authors show that estimated reference levels and stock status are biased when time-variant processes are not accounted for. The novel models has higher data requirements (seasonal catches and biannual survey indices), however, it is a promising approach to incorporate environmental conditions into stock assessments without the need of complex and data-demanding (ecosystem) models.

2.1.2 Guidelines for the use of SPiCT

ICES category 3 stocks can be managed using the official advice rules based on SPiCT (3.1.1 and 3.1.2 in ICES, 2018). These advice rules require the acceptance of a SPiCT assessment. A condensed summary with specific guidelines for the use of SPiCT has been developed within the frame of WKDLSSLS. In particular, the document contains: (i) the main assumptions and data requirements of SPiCT, (ii) a checklist for the acceptance of a SPiCT assessment, and (iii) other helpful tips. Target audience of this document are stock assessors and members of assessment groups who apply SPiCT and are responsible for deciding on accepting or rejecting a SPiCT assessment. The document is a living document and part of the SPiCT package and can be accessed and downloaded here (https://github.com/DTUAqua/SPiCT/blob/master/SPiCT/vignettes/SPiCT_guidelines.pdf; Mildenberger *et al*., 2019b).

2.2 General: Farfish data-limited methods tool (Margarita Rincon)

The FarFish project (www.farfish.eu) is a four-year Research & Innovation project that started in 2017 and will finish in 2021. It is funded by the European framework programme HORIZON 2020 under the topic H2020-SFS-21-2016: Advancing basic biological knowledge and improving management tools for commercially important fish and other seafood species. The focus of the project is on providing knowledge, tools and methods to support responsible, sustainable and profitable EU fisheries outside European waters.

In this project framework the need of tools for stock assessment in some of the case studies has emerged (Figure 2.2.1), but also the amount of data available has become a limitation. Thus, this has led to the development of a tool intending to be understandable by everyone and giving some outputs of different stock assessment estimations according to the data available.

The tool is available and ready to use by anyone at https://ffdb.farfish.eu/shiny/dlmgui/. The link shows a page with several tabs in the top. The first one "Edit data" is a template for data input followed by four tabs designed for data input visualization. Then, a tab for "Diagnostics" where a list of management procedures that can be applied and not applied for the fishery according to data availability is presented, and finally in the last tab, a quota estimation with its corresponding uncertainty for each of the plausible management procedures, is displayed. The management procedures available are the 111 provided by the DLMtool (Carruthers and Hordyk, 2016).

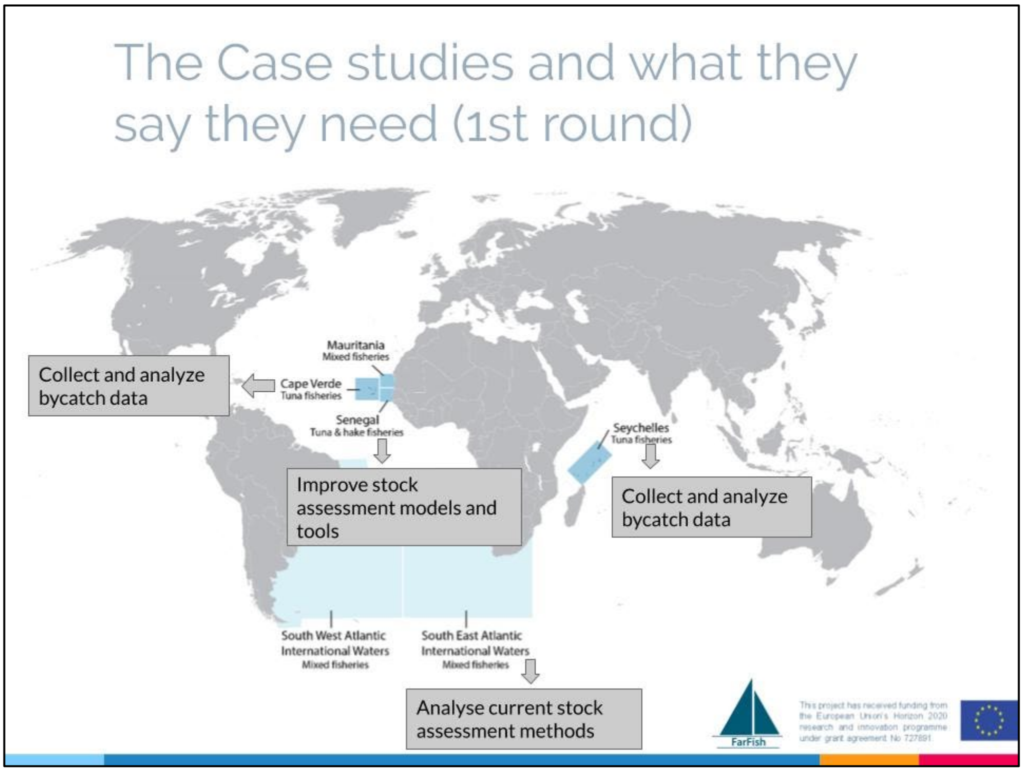

Figure 2.2.1. Farfish data-limited methods tool. Map showing the Farfish case studies and their needs related to stock assessment compiled during the first stakeholders meetings.

This tool has been designed to be used by everyone without needing a deep knowledge to run it, but it is important to remark that some stock assessment background is needed to interpret the results obtained. As a decision support tool, this tool is not automating decision-making and it is in no way intended to replace skilled decision-makers.

At this stage the tool is suitable for comparison and training purposes but further developments for the tool includes the definition of a risk measure associated to each management procedure and also the insertion of new harvest control rules based on SPiCT implementation.

2.3 Case Study Sprat in 7de: Two Stage biomas / Seasonal SPiCT/ LBI application (Marta Quinzan and Rosana Ourens)

Sprat (*Sprattus sprattus*) is the only small pelagic species in the English Channel with quota (ICES divisions 7.d and e). It is a small fishery where currently three UK vessels under 15 m are responsible for the majority of the landings. The fishery starts in August and runs into the following February and sometimes March. Most of the catch is taken in 7.e, in particular in the Lyme Bay area. Discards are considered negligible.

The information available to assess this stock is as follows:

Time-series of international sprat landings (1950–2018)

Time-series of sprat biomass and number-at-age in Division 7.e, estimated during the PELTIC acoustic survey conducted annually by Cefas (2013–2018).

Time-series of Landing per Unit of Effort (LPUE), based on days at sea (1989–2018). It has been estimated from the 3-4 English vessels targeting sprat in Lyme Bay, and accounting for, on average, 95% of total landings in divisions 7.d and e.

Size composition of the landings and mean weight-at-length for the fishing season 2018/2019. The data have been collected by the fishing industry (fishers and producers) as part of a pilot self-sampling programme recently started in the southwest of the UK.

Two attempts for an analytical assessment was carried out for sprat in the English Channel (ICES, 2014; 2018) but they were considered preliminary and still not suitable to be used as a basis for advice. Therefore, the quota advice for sprat in Division 7.de is based on the ICES framework for category 3 stocks, using the 2 over 3 rule: i.e. ratio between the mean biomass estimated in the two latest PELTIC acoustic surveys and the mean of the three preceding values multiplied by the recent ICES advised catch.

With the current survey and advice timing, the survey data are not very informative of the fishing opportunities for the advice period (Figure 2.3.1): The current advice is produced in March of the interim year ***y*** for the following management calendar year (January to December of year ***y+1***), based on the abundance index from an acoustic survey carried out in October of the previous year ***y-1***. The main fishing season takes place from August to February, and therefore there is a gap of almost two years between the survey and the main fishing season managed by the advice from that survey. By then, much of the population assessed by the survey of year ***y-1*** would be of ages 2 and older and may either be caught or died by natural causes, remaining little in the fishery (Figure 2.3.1). This should be expected for a short-lived species like the sprat, with little survivorship at age 3+. In order to reduce as much as possible the lag between survey index, assessment and advice, and finally management, a seasonal in-year advice for a management period going from July of the interim year ***y*** to June ***y+1*** has been suggested. In this way, a larger fraction of the harvestable population would be actually taken into account by the advice in March of year ***y***.

On top of this, the rule 2-over-3 currently in-use degrades the most recent information on stock size, as a large fraction of the population assessed in year ***y-2*** is probably gone three years later. This rule enhances the problem of the lag in time between direct assessment, advice and management, and therefore the 1-over-2 rule has been explored as an alternative method to manage this fishery in Section 3.1 of this report.

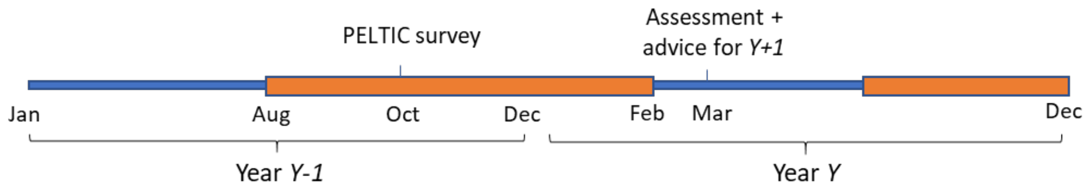

Figure 2.3.1. Time frame including the events related to the sprat fishery in 7.de. Orange lines represent the fishing season.

The aim of this work was to test analytical assessments for sprat in Division 7.de, using both calendar and seasonal year as time-step. Two-stage biomass model, Surplus Production in Continuous Time (SPiCT, Pedersen and Berg, 2017) and Length Based Indicators (LBI. see ICES, 2015) trials were performed (see Quinzán and Ouréns, 2019 WD for more details).

Neither of the methods tested here were appropriate to assess sprat in Division 7.de. The outputs of the two-stage biomass and SPiCT were not realistic because of the lack of contrast in the data and the short time-series of the PELTIC. Length-based approaches are not recommended for short-lived species as the assumption of constant recruitment is violated. In addition, the method is sensitive to the input data, and there is a large uncertainty associated with all the life-history parameters of sprat in Division 7.de.

In the absence of any other appropriate or applicable methods to assess sprat in Division 7.de, it is suggested to continue using a descriptive analysis of the temporal trends of LPUE, landings and biomass. It is also recommended that the two-stage biomass and SPiCT are re-run to estimate reference points and assess the stock when a longer time-series of the PELTIC survey becomes available.

Two observers from the SWFPO Crew (South Western Fish Producer Organisation) mainly concerned with the fishery on sprat in Divisions 7de attended the meeting and their input is appended in Annex 5.

2.4 Case study Anchovy: SPiCT Anchovy 9.a West (Alexandra Silva, Susana Garrido)

The assessment of anchovy 9.a started in 2018 as category 3, providing separate assessment for the western (9.a N, CN and CS) and the south (9.a S-alg and 9.a cad) components. The southern component is assessed with a Gadget model and the western component with a survey trend using the biomass estimated during the spring acoustic surveys (PELACUS+PELAGO). Assessment years are from July year y to June year y+1. The first year when assessment was provided the biomass of this stock component increased significantly and the 1 over 2 rule with 20% uncertainty cap was applied. The following year, the biomass of the western component decreased by more than 90% and, since the 20% cap would lead to a very high harvest rate, the 80% cap was applied. During this workshop, several trials of application of the seasonal SPiCT to the anchovy in 9.a were tested. Input data included quarterly catches in 1989–2019, total biomass from spring acoustic surveys PELACUS+PELAGO 1996–2019, biomass index (kg/hour) from the autumn Portuguese IBTS survey 1989–2017. The models had four seasons/quarters and started at the middle of the year (1st July). The performance with respect to the estimation model was tested using different data sets (survey inputs, acoustic and BTsurvey) and various model (fixing parameters n, alfa, beta, q). Models allowing seasonal fishing mortality and seasonal and long-term trends in productivity were also tested. Seasonal F and long-term changes in productivity were considered reasonable assumptions but there was no basis for seasonal productivity. Globally results were very uncertain, a possible cause being that the survey indices were not sampling the exploitable biomass.

The analysis of survey consistency indicated a significant correlation between the IBTS in year y and the acoustic survey in year y+1. However, the IBTS survey appeared to catch mostly juveniles in years of good recruitment. Assuming anchovy juveniles = 12 cm the IBTS index was split into one index of juveniles and index of adult abundance. The IBTS index of juveniles was used in the model, shifted one year back in time. However, due to the low contrast in the time-series (most years with very low abundance, just the last ones with a high peak), SPICT still produced uncertain results for this stock.

2.5 Case study Anchovy: SPiCT Anchovy 9.a South (Margarita Rincon)

A SPiCT model has been fitted to anchovy 9.a South data and different scenarios were defined assuming seasonal productivity and time varying growth. The implementation results showed that these assumptions do not have a remarkable influence when compared with the standard implementation that assumes constant productivity and constant growth. In addition, a comparison of biomass estimates between the standard implementation of SPiCT and a Gadget model (which is the current model used as basis for the assessment) was performed and it results in very similar trends suggesting that the properties of the only datasets used for the SPiCT implementation, the catches and two survey index, are good enough to provide a good estimation for population dynamics parameters. Details on the scenarios definition and results are presented in Rincon *et al*., WD (2019).

2.6 Case study Anchovy: MSE like procedure for scenario evaluation under the trend-based procedure used for anchovy assessment (Margarita Rincon)

The effect of the environment on anchovy (*Engraulis encrasicolus*) recruitment in area 9.a South has been extensively documented. Spawning process occurs when sea surface temperature is high (usually between May and September) then larvae and juveniles are affected by strong winds and also by the discharges of the Guadalquivir River, and finally recruits and adults mortality (individuals older than six months age) is mainly driven by the fishery (Ruiz *et al*., 2006; Prieto *et al*., 2009).

Current scientific advice for this fishery is based on a recommended catch that is defined as the product of last year recommended catches with a ratio (a trend ratio) that uses the last three years of a biomass indicator time-series (see 1 over 2 rule (ICES, 2018)). The biomass indicator is provided by a Gadget model that estimates an annual stock–spawning biomass time-series at the time of the advice which corresponds to the middle of the year (usually the second week of June).

This Gadget model includes the latest survey available (the PELAGO survey), but the time of the advice coincides with the spawning time. Therefore, if there are strong winds or a lack of discharges from the river during the next six months after spawning, then their influence on population dynamics cannot be accounted in the assessment which is in June.

In addition, the trend ratio used to calculate the recommended catch is not allowed to change more than a 20% from one year to another (20% uncertainty cap (ICES, 2017). Nevertheless, several simulations (WKLIFE 2018, Uriarte WD) provide evidence to support that a higher variability is needed for short-lived species.

The exercise presented in the meeting simulates the effect of the 20 and 80% uncertainty caps, and also their performance when the natural mortality is higher for larvae and juveniles. To this aim, we tested the population size growth when there are two consecutive years with a trend ratio with more than a 20% variability under a 20% uncertainty cap and analogously under an 80% uncertainty cap. Finally these two scenarios were also explored assuming a higher natural mortality rate for individuals before recruitment. The test followed a MSE like methodology following a modified version of the operating model with monthly resolution used in Rincon *et al.*, 2016.

The operating model starts with a fixed initial population in the spawning months (May to September) that grows with a constant survival rate (e(-1)) and no exploitation during three years. After that period the recruitment is defined as the product of the spawning biomass available six months before and a different constant survival rate. At that time also, the exploitation by the fishery starts with catches assumed as equal to the recommended catch in the first year of the analytical assessment for this stock (4476 t). This fixed catches value and a constant natural mortality (M1) determine the survival rate (e-(M1+F)) and also the amount for the individuals available to the fishery at the end of the year (older than six months age).

Running this operating model for the two following consecutive years (year 5 and 6) assuming a 20% uncertainty cap and that the trend ratio change more than a 20% in those years i.e. catches are supposed to be 4476*1.2 in the fifth year and 4476*1.2*1.2 in the sixth, the population showed a mean increase of a 20%. Analogously with the 80% uncertainty cap, the population decreased by 4%. The same scenarios with a higher mortality rate before recruitment result in a 4% decrease under the 20% uncertainty cap and a 40% under the 80% uncertainty cap.

These results suggest that a 20% uncertainty cap would be better than an 80% uncertainty cap in these particular scenarios, but this is not conclusive because it is just an example of the possible situations. Further analysis should include the major source of variability for population size that is the one associated to the recruitment and a different exploitation pattern at the beginning of the simulations. Actually, some work has been done in that direction but it is still very preliminary.

2.7 Case study Cephalopods: Assessment and Management of Cephalopods (Jean-Paul Robin, Angela Larivain and Ane Iriondo)

Nowadays the majority of the commercially exploited stocks lack a scientific assessment and therefore they are exploited while their abundance, productivity and sustainability are undetermined or highly uncertain. Such is the case of the cephalopods in different ICES divisions, which support large- and small-scale fisheries. However, they remain essentially outside the scope of the European Community's Common Fisheries Policy and understanding of their stock dynamics, particularly in European coastal waters, remains variable (ICES, 2013).

In the last years, there has been an increasing effort to compile all the information available (regarding biology, landings) on cephalopods in the Northeast Atlantic that would allow ICES to provide management advice. With this aim, preliminary diagnoses of Northeastern Atlantic cephalopod stocks using the generalized global model were deployed and European Atlantic

Cephalopod stocks have already been the subject of ad hoc assessments using a wide range of tools. But the available information (an abundance index and total landings) and the population biology (short-lived species with high and variable natural mortality) restrict the variety of methods that can be applied to assess the state of cephalopod stocks (Pierce and Boyle, 2003). For example, depletion methods of stock assessment, as DCAC (MacCall, 2009), based solely on catches information, are considered inadequate for this population due to its high natural mortality. Similarly, two-stage biomass dynamic models applied to similar species (Roel and Butterworth, 2000; Gras *et al*., 2013) cannot be applied due to the lack of data disaggregated by age.

Therefore, an attempt to fit surplus production model (SPiCT) to evaluate a series of cephalopod stocks was conducted using R SPiCT package framework. Results were presented in ICES ASC 2019 as "Do non-quota species tend to be overexploited? Preliminary diagnostics in Northeast Atlantic Cephalopod Stocks using surplus production models" Authors: Angela Larivain, Ane Iriondo, Leire Ibaibarriaga, Marina Santurtún, Anne Marie Power, Ana Moreno, Graham Pierce, Ignacio Sobrino, Christopher Barret, Jean-Paul Robin', ASC 2019 CM Code: H:531.

The main conclusion from the analysis are:

- Despite effort being done to improve the knowledge on cephalopod biology and fisheries, there are many data issues not fully resolved yet like species and stock identification.
- Additional information on the stock, like a recruitment index would allow considering alternative models, more suitable for short-lived stocks.
- Additional assumptions are needed to get model convergence. Most of the results are highly uncertain.
- SPiCT can provide valid results (satisfactory diagnoses $B > B_{MSY}$ and $F < F_{MSY}$) but additional assumptions are needed to get model convergence.
- Further analyses taking into account "in season management" or "early stage indices of abundance" should better fit than "long-term averages of optimal exploitation".

In relation to the general conclusions of the WKDLSSLS, the accomplishment of "Guidelines for the use of SPiCT" will be a very useful tool to do some new trials and assumptions for cephalopod stocks.

2.8 Future directions

- Explore methods to assess initial stock status either from Catch only trend or from the survey trends.
- Testing further the SPiCT advice rules for management for these short-lived species.
- Borrowing parameters between SPiCT assessments (incl. prior sensitivity testing).
- Include the SPiCT in some interactive tool like the one developed in FarFish project, or develop a new one.

2.9 Conclusions

- Short-lived ICES category 3 stocks can be managed using the official advice rules based on the stochastic production model in continuous time (SPiCT; Pedersen and Berg, 2017) conditioned upon a successful SPiCT fitting (whenever possible apply SPiCT with dt_{Euler} of 1/16) according to the specific guidelines for the use of SPiCT developed within the frame of WKDLSSLS and WKLIFE. The guidelines are part of a living document attached to the R package as a vignette and can be downloaded here (https://github.com/DTUAqua/SPiCT/blob/master/SPiCT/vignettes/SPiCT_guidelines.pdf).

- During the workshop SPiCT assessments to Anchovy in 9.a South, Anchovy 9.a West and to Sprat in 7.de were performed, resulting in a satisfactory application to Anchovy in 9.a South, with estimates very similar to those provided by a Gadget model (a data-rich model used as basis of the current assessment). Results for Sprat 7.de and Anchovy 9.aWest were still unacceptable, even after SPiCT experts made improvements. In addition, there were presentations on applications of SPiCT to several Cephalopods population and to *Loligo vulgaris*.
- No alternative reference points definition for management were produced by WKDLSSLS, apart from those already available from SPICT assessment. Length-based indicators of stock status are known to be generally not suitable for short-lived species because recruitment interannually induces major changes in the length distribution of catches (ICES reference points for stocks in categories 3 and 4). Exploring the values of Length-Based Indicators (LBI screening methods) across the mean of a series of catch-at-length distribution (presuming the mean approaches stationarity) may be worth exploring to have a rough idea of the selectivity of the fleet, particularly in relation to length-at-maturity and optimal exploitation.
- The two-stage approaches need further work: A provisional application was presented for Sprat in 7.de, but results were still preliminary.

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3 Subgroup 2 Testing MSE of HCRs based on indicators trends

3.1 Management strategy evaluations for a simulated stock of sprat in 7.de (Nicola Walker WD)

In the absence of an accepted assessment (see Section 2.3), advice for sprat in 7.de follows the ICES framework for category 3 stocks which adjusts the recent ICES advised catch by the ratio of the average of the last two PELTIC biomass estimates and the average of the three preceding estimates (2-over-3 rule) and is subject to a 20% uncertainty cap. Advice is provided on an annual basis where the latest estimates from the October PELTIC survey feed into an assessment in February/March to give advice starting the following January.

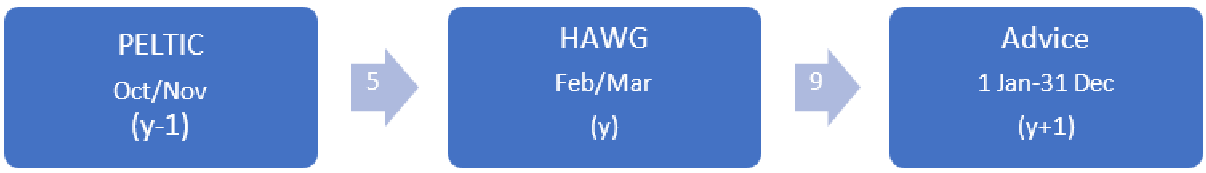

Figure 3.1.1. Current schedule for providing advice on fishing opportunities for Channel sprat. y relates to a model year which in this case is the same as a calendar year. The numbers in the arrows represent the number of months between each of the processes.

However, to reduce the lag between observation and implementation of advice and better match timing of the fishery, it has been suggested to provide advice on an in-year basis, running from July–June.

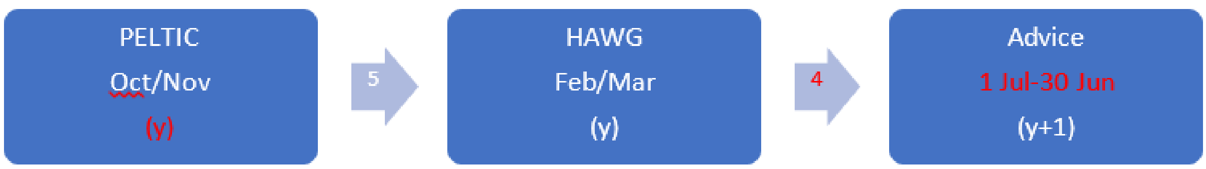

Figure 3.1.2. Suggested schedule for providing advice on fishing opportunities for Channel sprat. y relates to a model year which in this case runs from 1st July–30th June. Quantities in red signify changes from the annual schedule.

Furthermore, it has been suggested that the 2-over-3 rule is not dynamic enough for short-lived and highly productive species (ICES WKSPRAT, 2018; ICES WKSpratMSE, 2019).

Management strategy evaluation (MSE) was used to evaluate two types of harvest control rule (HCR) both on an annual and in-year advice basis: (1) catch rules where advice is based on the most recent advised catch multiplied by the ratio of the most recent biomass index value and the average of the two preceding values (1-over-2 rule) or the average of the two most recent biomass index values and the three preceding values (2-over-3 rule) (ICES WKMSYCat34, 2017), and (2) harvest rates where advised catch corresponds to a fixed proportion of the biomass index. Both HCRs were tested with additional mechanisms for stability and safeguarding biomass at perceived low stock levels: (1) uncertainty caps constrain the amount advice can vary from one year to the next. Asymmetric caps have different upper and lower bounds while symmetric uncertainty caps have the same bounds. (2) Biomass safeguards act to reduce advice if a new biomass index value falls below some reference point. Reference points tested were I_{lim}, the lowest historic biomass index value, and $I_{trigger} = 1.4I_{lim}$.

Each HCR was tested on six operating models representing a simulated stock of sprat in 7.de. These operating models were based on two levels of recruitment variability (either sigmaR at 0.3 or 0.5) and three different fishing histories (see Walker, 2019 WD for more details). All simulations were run in FLR package FLash (www. flr-project.org) with each operating model projected forward 25 years with 500 iterations for each HCR. HCRs were evaluated in terms of maximising yield whilst maintaining precautionary levels of biomass.

The main conclusions of this work are given below while details of the results are presented in Walker WD (2019).

No catch rule was precautionary without the addition of stability or safeguarding mechanisms (risk >5%). Short-term risk was largely influenced by initial conditions while medium- to long-term the 1-over-2 rule was more precautionary than the 2-over-3 rule and the in-year advice schedule more precautionary than the annual schedule (Figure 3.1.3). The annual 2-over-3 rule with 20% uncertainty cap (current procedure for providing advice) was the least precautionary of the key HCRs tested and resulted in high levels of risk and collapse.

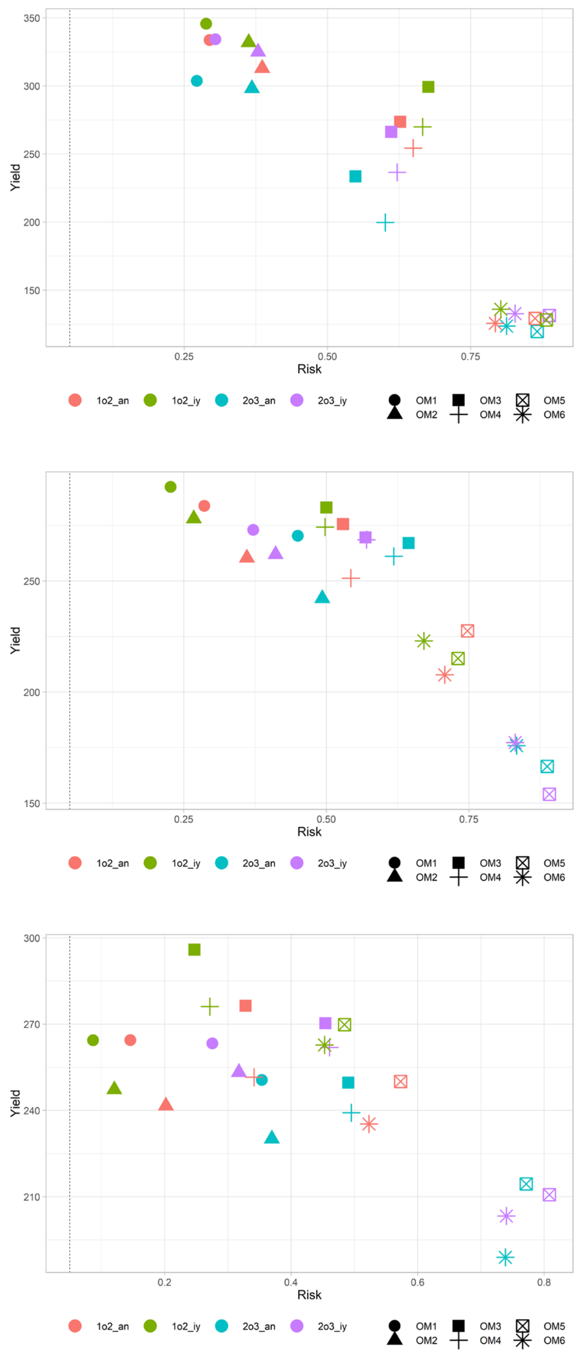

Figure 3.1.3. Short-, medium- and long-term plots of yield against risk for the 1-over-2 (1o2) and 2-over-3 (2o3) rules following annual (an) and in-year (iy) advice schedules.

Additional mechanisms were needed to make the 1-over-2 rule precautionary, both on an annual and in-year advice schedule. Of the key mechanisms tested (see Figure 3.1.4) an asymmetric uncertainty cap with 20% upper bound and 80% lower bound was the most precautionary option but resulted in the largest loss of long-term yield (Figure 3.1.4). The upper bound was fixed at 20% and likely too constraining. Based on these simulations and evaluation of long-term risk, the lower bound of the uncertainty cap should be at least 60% although future work should consider different combinations of upper and lower bound on the uncertainty cap. Symmetric uncertainty caps were tested only for the in-year advice schedule and offered an intermediate trade-off between maximising long-term yield and reducing risk (Figure 3.1.4).

Biomass safeguards provided another intermediate trade-off between minimising risk and maximising long-term yield (Figure 3.1.4). However, care should be taken as the relationship between PELTIC index biomass and stock status is unknown. Further testing should consider robustness of the reference points to new data and inclusion of reference point updates (i.e. through benchmarks) when evaluating performance of the HCRs.

Harvest rates were tested assuming an in-year advice schedule only, with rates of up to 17% of the estimated biomass index shown precautionary in the long-term across OMs. Of the key HCRs presented in Figure 3.1.4, a 17% harvest rate resulted in the highest yield and lowest risk across OMs. The robustness of long-term risk and yield statistics to OM suggests that a harvest rate strategy may be suitable when stock status is unknown. However, harvest rates applied to these simulated stocks may not translate directly to sprat in 7.de. Future work should test the sensitivity of harvest rates to model assumptions including catchability, model uncertainties, stock recruitment, operating model and modelling platform. Additional mechanisms were shown to be ineffective when employing a fixed harvest rate.

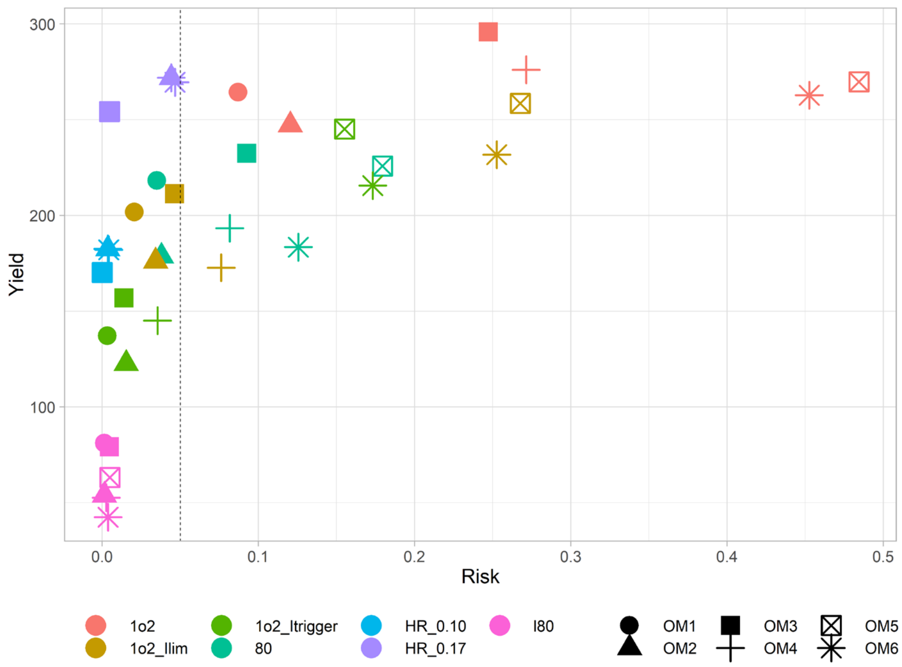

Figure 3.1.4. Long-term yield against risk for select HCRs following an in-year advice schedule. 1-over-2 rule (1o2), 1-over-2 rule with biomass safeguards (Ilim = Ilim safeguard; Itrigger = Itrigger safeguard) 1-over-2 rule with 80% symmetric (80) and asymmetric uncertainty cap (I80), 10% harvest rate (HR_0.10) and 17% harvest rate (HR_0.17).

3.2 North Sea Sprat SPiCT MSE and HCRs (Mollie Brooks WD)

The purpose of this study was to compare harvest control rules (HCRs) for category 3 stocks including SPiCT, 1-over-2, 2-over-3, and modifications of those rules. Although North Sea sprat is not a category 3 stock, enough data are available on this stock to parameterize a simulation model. The stock was used simply because a simulation model was needed to evaluate the HCRs and one was available for the North Sea sprat. The SMS assessment model used to estimate the parameters used in the simulation model is not the same as the SMS assessment model used in the 2018 sprat benchmark; the version used here, has catches in all quarters because SPiCT developers recommend that all observed catches should be non-zero.

Age and quarterly structured operating model

The MSE projects the age-structured population forward in the operating model, TAC year by TAC year, accounting for management advice (i.e. setting the TAC based on estimates from the assessment), fishing mortality, natural mortality, and recruitment. The operating and observation models used in this MSE are structured by quarters and by age as done in the SMS assessment model. Age groups are 0, 1, 2, and 3+. The TAC year is shifted by 2 quarters from the calendar year, the quarters of the TAC year are quarters 3, 4, 1, and 2 of the calendar year (abbreviated s1, s2, s3, s4 henceforth). The escaped SSB is calculated in s1 after the TAC year. The state variables N (stock numbers) and E (exploitation or selectivity pattern), are both structured according to season and age. E refers to the exploitation pattern before it is multiplied by an F multiplier to get fishing mortality. For details of conditioning including initial population, biological parameters, implementation error, and observations, see the working document distributed with this report.

Observation simulator

The MSE previously done for North Sea sprat included an observation simulator that produces age and quarterly-structured catch and survey data (see working document for details). However, age-structured data aren't available for category 3 stocks and therefore, we needed to aggregate the data to make them relevant to this exercise. The age-structured surveys and catches were converted to biomass indices and catch by multiplying by the true weight-at-age and summing across ages. This produced three surveys in different quarters and catches in each quarter. See working document for details on how the three surveys were combined to make one for input to the 1-over-2 and 2-over-3 rules.

North Sea sprat MSE results

This operating model produced a higher risk than the operating model for sprat in 7.e; it could be because more sources of variation were included, or it may be that recruitment was lower (see working document for details of simulated stock–recruitment). This simulated stock started out in a relatively good state, so short-term risk is lower than long-term risk. The HCRs show more differences in the long term. In the long term, the (0.2, 0.2) uncertainty cap was the riskiest and (0.8, 0.2) was the least risky. Among biomass safeguards, Ilim defined as the 5 percentile of past observed indices was the least risky, followed by the minimum index, and the riskiest was to have no biomass safeguard. In the short term, the 2-over-3 rule is slightly riskier than the 1-over-2, but the difference is small. In the long term, the 1-over-2 rule was riskier than the 2-over-3 rule. With no uncertainty cap and no biomass safeguard, in the long term, SPiCT was less risky than either the 1-over-2 or 2-over-3. In the short term, SPiCT fell between the two in terms of risk. In general, patterns of the median TACs were the same as patterns of risk, i.e. higher risk HCRs produced higher TACs.

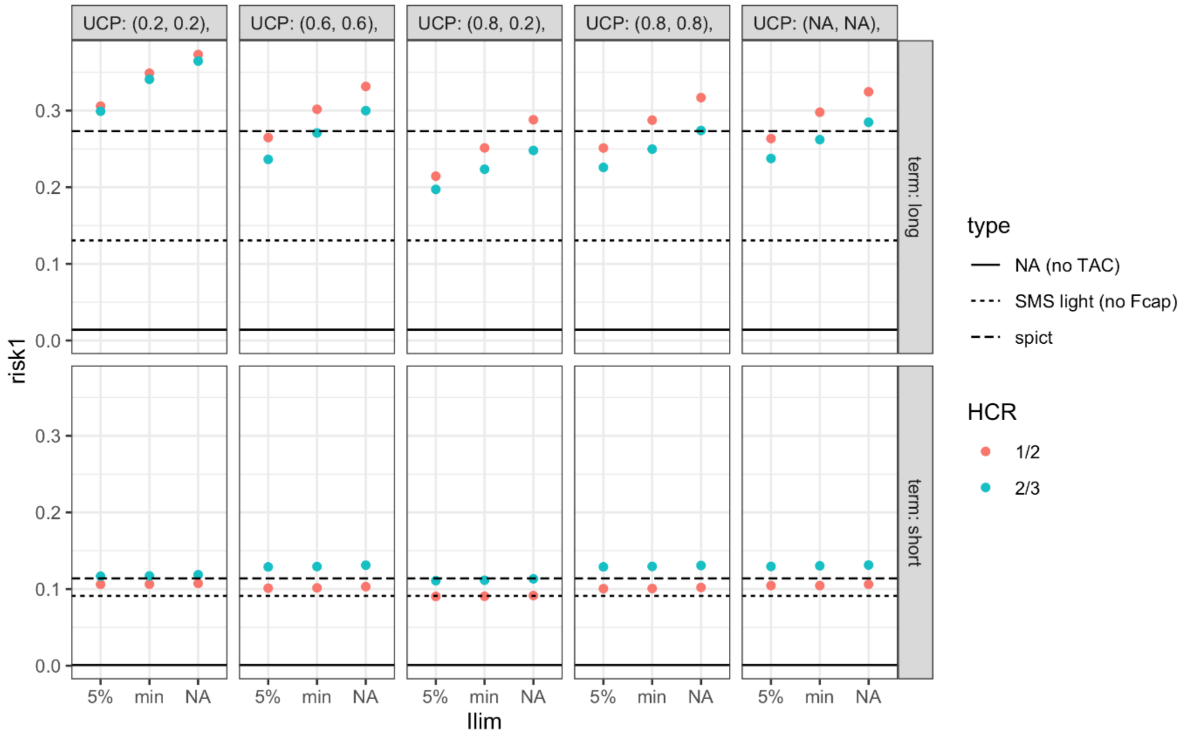

Figure 3.2.1. Type 1 Risk. Each point is a different HCR with a combination of uncertainty caps and biomass safeguards (or marked NA for no extra modifications). Each column of panels has a different uncertainty cap (UCP). The top row of panels is for the last ten years of the simulation and the bottom row of panels is for the first five years. The x-axis of each panel describes the biomass safeguard that was implemented; we did not directly use Ilim, but rather advised TAC was reduced by the distance between the current biomass index and Itrigger = 1.4 Ilim. Horizontal lines represent HCRs of no catch, SMS light, or SPiCT; no uncertainty caps or biomass safeguards were combined with these.

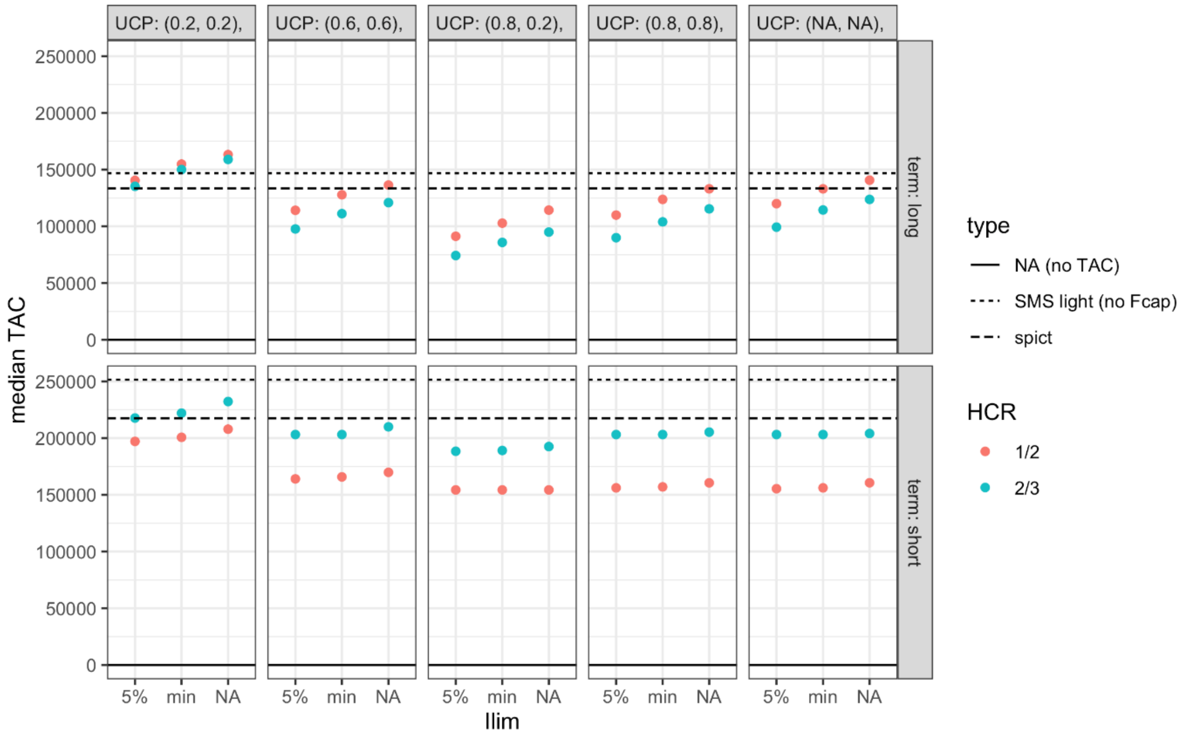

Figure 3.2.2. Median TAC. Each point is a different HCR with a combination of uncertainty caps and biomass safeguards (or marked NA for no extra modifications). Each column of panels has a different uncertainty cap. The top row of panels is for the last ten years of the simulation and the bottom row of panels is for the first five years. The x-axis of each panel describes the biomass safeguard that was implemented; we did not directly use Ilim, but rather advised TAC was reduced by the distance between the current biomass index and Itrigger = 1.4 Ilim. Horizontal lines represent HCRs of no catch, SMS light, or SPiCT; no uncertainty caps or biomass safeguards were combined with these.

3.3 Testing management advice procedures for short-lived category 3 data-limited stocks (Uriarte *et al*. WD)

ICES classifies the stocks depending on their data availability and accordingly different advice rules are used to provide advice on stock status and fishing opportunities (ICES, 2018a). However, most of the used 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 2018, within ICES WKLIFE8 (ICES, 2018b), Uriarte *et al.* (2018) evaluated the performance of in-year advice harvest control rules for some 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 highlighted the dependence of results on the ratio of the observation error and the interannual variability.

In present work, we evaluate the performance of the current ICES advice rule for Category 3 stocks for two types of short-lived stocks (anchovy-like and sardine and sprat-like stocks). The first ones, anchovy-like, are characterised by high natural mortality (with mean across ages 1–3 above 0.8), fully mature at age 1 and with high interannual variability. Whereas the second ones, sardine-like, are stocks with medium natural mortality, fully mature at age 2 and with intermediate interannual variability. We used management strategy evaluation approach (Punt *et al.*, 2016) with FLBEIA software (García *et al.*, 2017). The performance of various alternative harvest control rules were compared across a range of different settings 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 biological operating model (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 was conditioned based on the life-history parameters of the stock type and annual recruitments were generated according to a Beverton and Holt stock–recruitment model with steepness equal to 0.75 and virgin biomass equal to 10 000 tonnes without autocorrelation in residuals, while different values of standard deviation (σ_{REC}) were tested. The operating model worked in half-yearly steps and it was assumed that 50% of the catches were occurring in each semester. The historical trajectory of each stock was simulated for 30 years. Each stock started from a virgin population and during the first ten years exploitation increased linearly up to a constant level of fishing mortality (F_{target}) that was kept constant for the next 20 years. Three levels of fishing mortality in the historical period were tested: (i) low fishing mortality, $F_{target} = 0.5 \cdot F_{MSYproxy}$; optimum fishing mortality, $F_{target} = F_{MSYproxy}$; or high fishing mortality, $F_{target} = 2 \cdot F_{MSYproxy}$. Variability in the historical F was included through a log-normal distribution with a coefficient of variation (CV_F) of 10%.

Regarding the reference points, the limit biomass (B_{lim}) was set as 20% of the virgin biomass B_0, the biomass at which the stock had collapsed ($B_{collapse}$) was set as 10% of the virgin biomass B_0 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% B_0 at equilibrium.

Each year, an index of biomass at age 1+ (with catchability equal to 1) was observed, which followed a log-normal distribution with alternative coefficients of variation. Observations from the survey are assumed and simulated to start ten years prior to the start of the management period (i.e., for the last ten years of the historical trajectory of the stocks).

Within the management procedure, three alternative calendars were tested:

- Interim-year calendar. The usual management calendar goes from January to December. Index on 1st July informing on B1+ (biomass index of age 1 and older) in year y is used to set the TAC from January to December in year (y+1). 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.
- In-year calendar. Where the index on 1st July in year y on B1+ 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).
- Full population knowledge. 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 the autumn of age 0 or in January itself of age 1). In this case, the index provides information on all the age classes that are going to be exploited.

Model free harvest control rules were tested, where the TAC is set based on the changes in the stock status based on the observed index. Rules of type n-over-m type were tested, where the TAC is calculated as:

$$TAC_{y+1} = TAC_y \frac{\frac{\sum_{i=l-n+1}^{y} I_i}{n}}{\frac{\sum_{i=l-(n+m)+1}^{l-m+1} I_i}{m}}$$

where I_l is the last available index. For the in-year calendar $l = y$, for the interim year $l = y - 1$ and for the case where some indication of recruitment is available $l = y + 1$. Additionally, the use of a precautionary buffer in the first simulation year and the application of uncertainty caps were tested. In the first simulation year, the reference TAC value was set using: (i) the previous year catch; (ii) a mean of last historical years; or (iii) a mean of the last historical years corrected by the ratio of the last historical F values relative to F_{MSY}.

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.

Dynamics were simulated for 30 years and run for 1000 iterations for each scenario (Table 3.3.1). 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.

Table 3.3.1. 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 0.2	no buffer applied 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	$refTAC = \frac{\sum_{i=y-m}^{y-1} C_i}{m}$ (for n-over-m rule)
		pob	$refTAC = \frac{\sum_{i=y-m}^{y-1} C_i}{m} \cdot \frac{\frac{\sum_{i=y-m}^{y-1} F_i}{m}}{F_{MSY}}$ (for n-over-m rule) where y is the last historical year

In addition following the discussions during WKDLSSLS two additional harvest control rules were tested:

- 1-over-2 with a Biomass safeguard, which reduced the advice by a multiplier equal to Ii/Imin (where Ii is the most recent abundance survey index and Imin is the minimum index value observed in the available historical series before management) if Ii<Imin.
- 1-over-2 with asymmetrical Uncertainty cap of 80%/20% (1o2 Ucap(0.8,0.2)) allowing for a maximum interannual relative change in the advice of an 80% reduction and of 20% increase.

Main results follow

Regarding the **coupling in time between assessment, advice and management**: The shorter the lag between observations, advice and management, the bigger the catches and the smaller are the risks. This means that in-year advice should always be preferred over the normal calendar (with an interim) year advice. Results are very consistent across the different OM essayed (Figure 3.3.1).

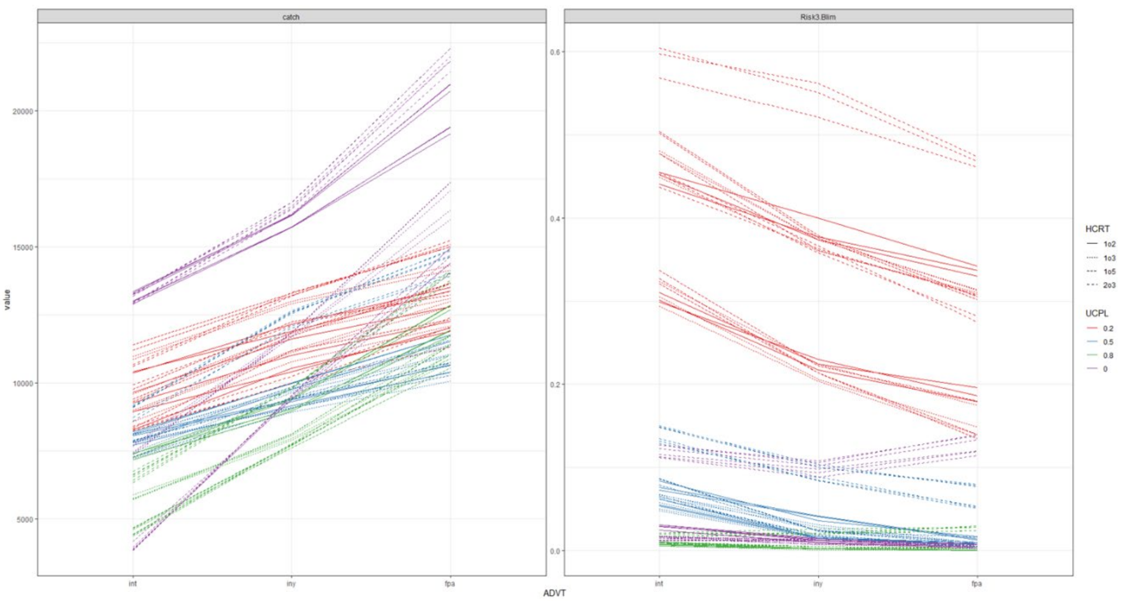

Figure 3.3.1. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51–60), for each calendar (int: interim year calendar; iny: in-year calendar; and fpa: full population advice), by HCR type (solid line – 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).

Initialization of the advice in the first year of the management period either with the last year catch or with the mean of the last year catches corresponding with those in the denominator of the HCR) did no produce relevant differences in the performance of the HCRs. We suggest using the latter option to start with some mean harvest rate over a recent set of years to filter out some of the inherent noise coming from fluctuations in the interannual catchability before the starting of management.

Regarding the application of a **precautionary buffer reduction of 20%** of the initial advice at the start of the management period: In the short term, with in-year advice, the precautionary buffer reduces catches and risks for all harvest control rules and uncertainty cap levels (Figure 3.3.1). Whereas in the long term, with in-year advice, the precautionary buffer induces little reductions of risks and catches for all rules and uncertainty cap levels except at the 20% uncertainty cap level where the effect of reducing risks is more pronounced allowing at the same time bigger catches.

Regarding **the trend based harvest control rules**: For the two stocks and for the different operating models, it was found that in the short term and medium term, 1-over-2 rule overcomes 2-over-3 rule at the same uncertainty cap level 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). In the long term, the reduction of risks is counterbalanced by some stronger reduction of catches. Figure **3.3.2** allows comparing rules 1-over-2 with the 2-over-3 in terms of catches and risks for the same uncertainty cap levels (compare the empty symbols -1o2- with the same coloured symbols -2o3- in Figure **3.3.2** by periods and stocks), showing that for rather similar levels of catches (or slightly smaller) at a given uncertainty cap level, the former rule results in smaller levels of risks.

Regarding the **level of uncertainty cap** applied to the rule, for the two stocks and for the different operating models it was found that lowest risks are obtained for the 80% uncertainty cap levels in the short and medium term associated to a moderate reduction of catches compared to the other uncertainty caps and in particular with 1-over-2 without any Uncertainty cap (which produced the biggest catches among all rules usually). The former statement is also valid in the long term with the only exception occurred for sardine–sprat like stock (stock 2) at highest historical exploitation and high standard deviation for the recruitment (i.e. highest IAV) where the lowest risks and highest catches corresponded to the 1-over-2 without any uncertainty cap. Figure **3.3.2** allows verifying the previous comparisons between the various uncertainty cap levels for the 1-over-2 rule (by comparing for the 1o2 the empty circles -1o2 with 80% uncertainty cap -with the other empty symbols of the same colours- i.e. same historical exploitation levels, in Figure **3.3.2** by periods and stocks). And the same for 2-over-3 rule (by comparing the filled circles -2o3 with 80% uncertainty cap with the other filled symbols of the same colours, with minor exceptions for this rule).

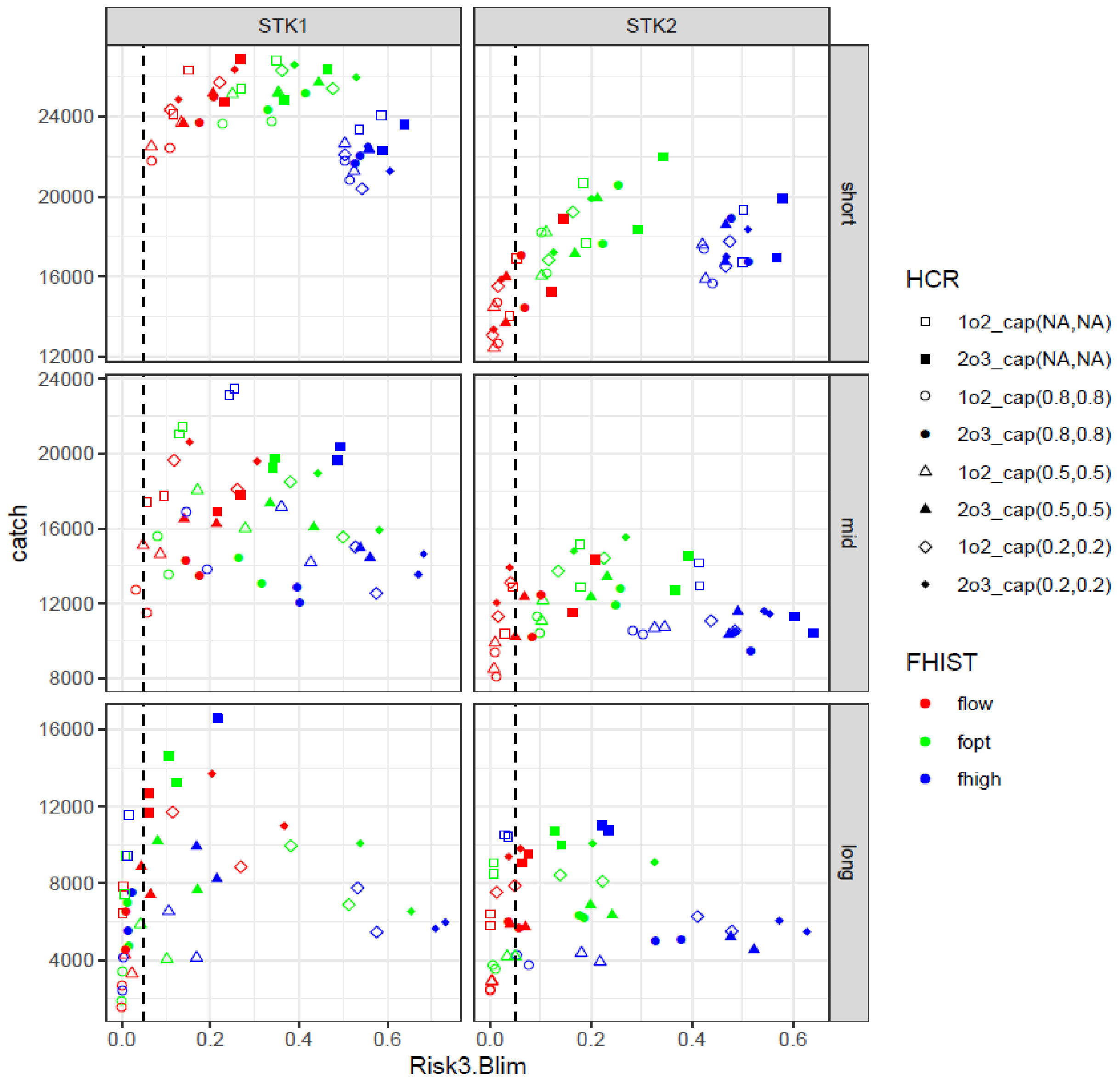

Figure 3.3.2. Median catch versus Risk3 of falling below B_{lim}, in the short (upper graphs), medium (middle graphs) and long term (bottom graphs), by stocks (anchovy like -right panels- and sardine/sprat like -left panels) for each HCR combined with various uncertainty cap levels (see right upper legend) and for historical fishing mortality F levels (Fhigh: 2*F_{MSY} -blue-; F_{low}: 0.5*F_{MSY} -red-; and F_{opt}: F_{MSY} -green-). There are two repeated values with the same form and colour which correspond to alternative standard deviations for the recruitment (0.5 or 0.75). Case Scenario: OM: Stock=STKs 1 & 2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin).

Figure **3.3.3** shows an example of the benefit of applying the 80% Ucap for the case of assessing the relative changes in risks (X axis) and catches (Y axis) when moving from harvest control rules 1-over-2 with no uncertainty cap to 1-over-2 with 80% 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). In other words, the greater the population interannual variability (IAV) (as in anchovy like stocks), the greater the reduction of catches with the 80% uncertainty cap (in the medium and long-term) relative to the reduction achieved on risks. Therefore, benefits are clearer for sardine/sprat-like stocks than for anchovy like stocks.

Finally, Figure **3.3.2** also shows for both stocks that the greater the historical exploitation (colours in the figure), the greater the risks in the short term.

As a result of the former analysis, it is concluded that when comparing the performance of the harvest control rules 1-over-2 and 2-over-3 for different levels of symmetrical uncertainty caps, across the different operating models, the best performance is achieved for 1-over-2 rule with 80% uncertainty cap, as it reduces risks in the short and medium term compared with the other rules at the expense of a moderate reduction of catches. The 1-over-2 without any Uncertainty cap results higher catches but also risks in the short and medium term. In the long term both 1-over-2 rules, either with 80% uncertainty cap or without uncertainty cap lead to precautionary levels of risks.

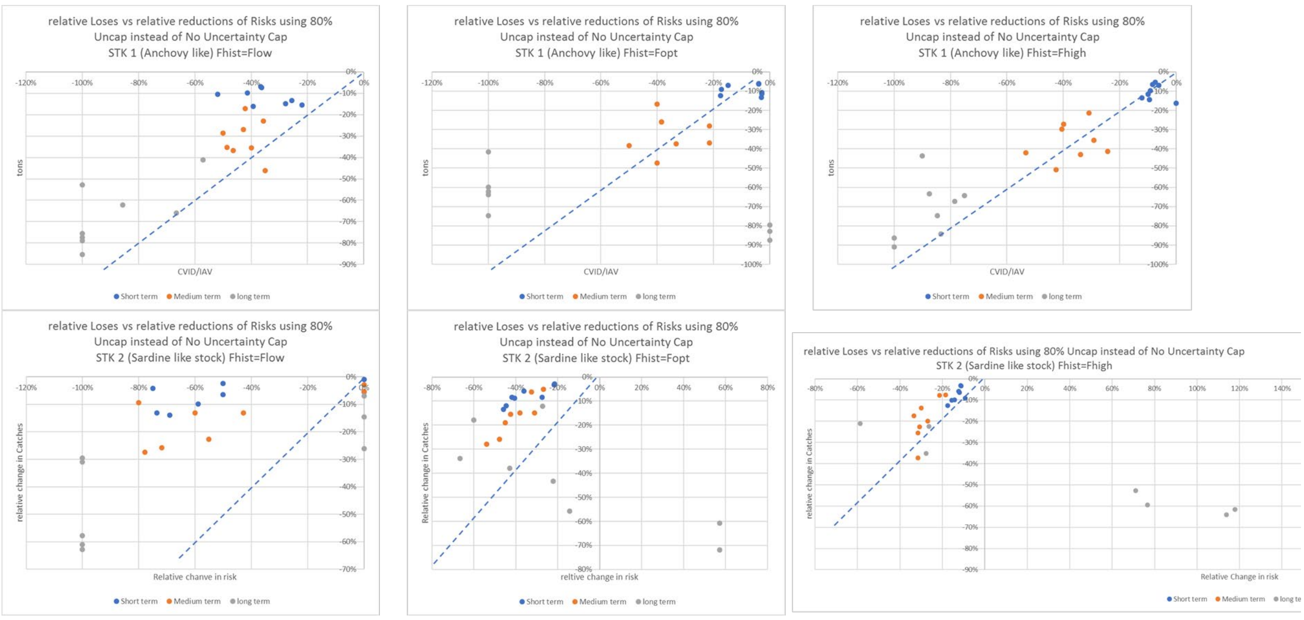

Figure 3.3.3. Relative changes in risks (X axis) and catches (Y axis) when moving from a harvest control rules 1-over-2 without any uncertainty cap to 1-over-2 with 80% uncertainty cap, for an anchovy like stock (upper row of figures) and sardine/sprat-like stock (bottom row), for F_{low}, F_{opt} and F_{igh} 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)).

Two rules were in addition compared to the 1-over-2 with symmetrical 80% or without any Uncertainty cap: the 1-over-2 with a Biomass safeguard (without any uncertainty cap) and the 1-over-2 with asymmetrical uncertainty cap of 80%/20% (1o2_cap(0.8,0.2)). Figure 3.3.4 shows again for all these harvest control rules that the bigger the historical exploitation, the greater the catches and risks at any time frame, but particularly in the short and medium term, as catches and risks have a decreasing trend with time, and are minima in the long term.

In general terms, we can order the rules from less to highest risky rules as follows:

- 1o2_cap(0.8,0.2) < 1o2_cap(0.8,0.8) < 1o2_Imin < 1o2

Where:

- 1o2_cap(0.8,0.2) :1-over-2 with asymmetrical uncertainty cap (0.8,0.2);
- 1o2_cap(0.8,0.8) :1-over-2 with 80% symmetric uncertainty cap;
- 1o2_Imin :1-over-2 with biomass safeguard; and
- 1o2 :1o2 without any uncertainty caps.

Therefore, at all times 1-over-2 with asymmetrical uncertainty cap (0.8,0.2) leads to smallest risks, but also at the expense of allowing the smallest catches. It is worth noting that in the long term, all rules are precautionary, but catches of the 1-over-2 rule with asymmetric uncertainty caps (0.8,0.2) become very small, almost equal to 0 t (i.e. fishery is almost closed). Therefore some rule showing an intermediate behaviour might be put forward for management consideration. Intermediate rules in terms of balance between catches and risks are: 1-over-2 with symmetrical 80% uncertainty cap (1o2_cap(0.8,0.8)) and 1-over-2 with biomass safeguard (1o2_Imin). Rule with the 80% uncertainty cap (1o2_cap(0.8,0.8)) results to be a bit more precautionary in the short and medium term, without major loses of catches compared to the other rule, though the drop in catches in the long term is a bit more pronounced. The 1-over-2 rule with symmetrical 80% uncertainty cap might be preferred over the asymmetrical with 80% lower and 20% upper uncertainty caps for a better compromise in terms of catches versus risks in the short and medium term. Although given the trade-off between risks and catches (for the short, medium and long term) this discussion should be partly passed to managers and stakeholders.

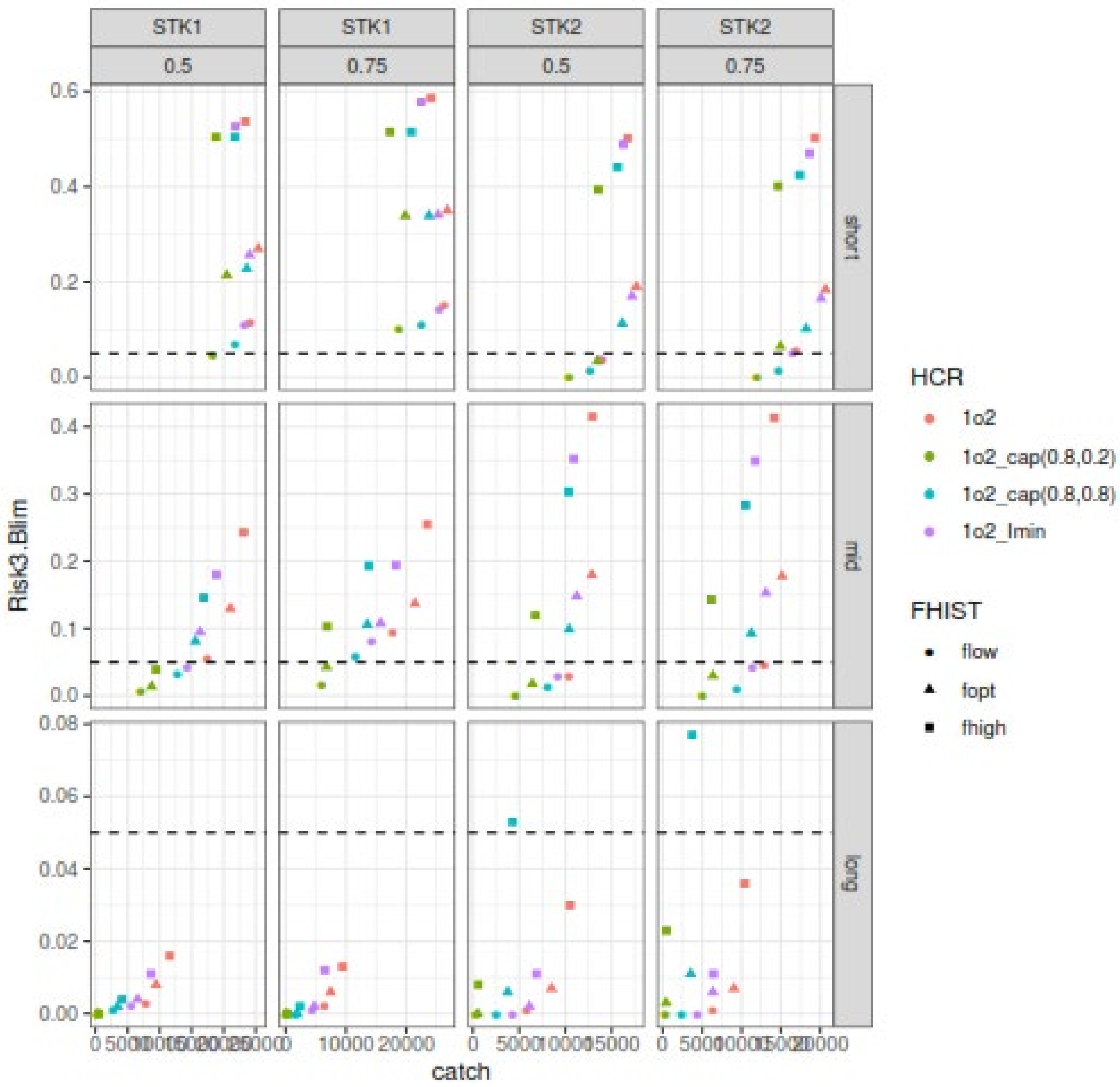

Figure 3.3.4. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Risk3 of falling below B_{lim} versus median catch for alternative historical F levels (circle - F_{low}: 0.5*F_{MSY}; triangle - F_{opt}: F_{MSY}; and square - F_{high}: 2*F_{MSY}), HCRs (red – 1o2: 1-over-2 without uncertainty cap; green – 1o2_cap(0.8,0.2): 1-over-2 with lower and upper uncertainty caps of 80% and 20%, respectively; blue – 1o2_cap(0.8,0.8): 1-over-2 with symmetric uncertainty cap of 80%; and purple – 1o2_Imin: 1-over-2 with biomass safeguard), 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).

The main conclusions of this work are:

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).

Initialization of the advice in the first year of the management period either with the last year catch or with the mean of the last year catches corresponding with those in the denominator of the HCR) did no produce relevant differences in the performance of the HCRs. We suggest using the latter option to start with some mean harvest rate over a recent set of years to filter out some of the inherent noise coming from fluctuations in the interannual catchability of the fishery before the starting of management.

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 (as in anchovy-like stocks), the greater the reduction of catches with the 80% uncertainty cap (in the medium and long term) relative to the reduction achieved on risks. 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.

Comparison of performance between 1-over-2 versus 2-over-3 rule with different symmetrical uncertainty cap levels for the two kind of stocks simulated here and for the different operating models explored, leads to recommend 1-over-2 rule, with 80% uncertainty cap for short-lived species as the one which produces moderate lower catches but lower risks than the 1-over-2 rule at any other uncertainty caps or with biomass safeguard. Although in the short term, differences are smaller in terms of catches and risks.

- Expansion of the comparisons to include asymmetrical uncertainty cap leads to rank the best rules as follows (from least to highest risk):

1o2_cap(0.8,0.2) < 1o2_cap(0.8,0.8) < 1o2_Imin < 1o2

- Rule 1-over-2 with asymmetric uncertainty cap (0.8,0.2) results in the most precautionary approach to management, but at the expense of major reduction of catches (being almost 0 t in the long term). Opposite to this, the 1-over-2 without uncertainty cap results in the highest catches and risks, particularly in the short and medium term, while the risk would be reduced to precautionary levels in the long term.
- Intermediate rules in terms of balance between catches and risks are: 1-over-2 with symmetrical 80% uncertainty cap (1o2_cap(0.8,0.8)) and 1-over-2 with biomass safeguard (1o2_Imin). Rule with 80% uncertainty cap results to be a bit more precautionary in the short and medium term without major loses of catches compared to the other rule, though the drop in catches in the long term is a bit more pronounced.
- None of the (model free) trend rules tested can assure in the short and medium terms that risks to B_{lim} will be lower than 5%, as this would basically depend upon the historical exploitation of the population before management starts. Even though in the long term almost all rules become precautionary. Therefore, the selection of any rule is more based on relative performance between the rules (particularly in the short and medium term) and on the speed of reducing risks to precautionary levels along with the final catches which would be allowed in the long term.

The 1-over-2 rule with symmetrical 80% uncertainty cap might be preferred over the asymmetrical with 80% lower and 20% upper uncertainty caps for a better compromise in terms of catches versus risks in the short and medium term. Although given the trade-off between risks and catches (for the short, medium and long term) this discussion should be partly passed to managers and stakeholders.

3.4 Future directions

Several points for improvement were put forward during discussion in WKDLSSLS:

- Assessing initial stock status relative to MSY with simpler analysis of historical catches, the abundance indexes or from expert knowledge would be of relevance to assess on the convenience of applying a precautionary buffer. Testing the goodness of some available methods in literature or developing new ones is encouraged.
- Testing properly the precautionary buffer role in terms of mitigating short-term risks but keeping long-term benefits (for instance on 1-over-2 rule without any uncertainty cap vs 1-over-2 rule with an 80% uncertainty cap).
- Further exploring the benefits of adding a biomass safeguard of minimum observed index or at a fractile of available index series to the rules either alone or in combination to uncertainty cap levels.
- Further testing of asymmetric uncertainty caps with variable upper and lower bounds.
- Testing the effect of shifting the uncertainty cap from 80% to no uncertainty cap in time (for instance after 8–10 years of application of the 80% uncertainty cap).
- Constant or variant harvest rate strategies instead of the trend-based rules (aligned with HCR 3.2.2 Catch rule based on applying an F_{proxy} (WKMSYCat34). Harvest rates and how they vary with assumed catchability. Further testing of harvest rates under a range of catchability, uncertainty and life-history assumptions and across modelling platforms.

3.5 Main conclusions on harvest control rules

- The lag between abundance index, advice and management should be minimized, this leads to select in-year advice, implying that the management year (i.e. TAC year) generally differs from the calendar year.
- Major drivers of risks are (in order of relevance): historical exploitation level (and trajectory), and the harvest control rule (HCR) with uncertainty cap (UCap). This emphasizes the relevance of trying an initial assessment of the relative status of the stock regarding optimal exploitation to judge if a precautionary buffer is required to start management.
- Regarding the trend-based HCRs: For all simulations except the North Sea sprat, in the short, medium and long term 1-over-2 outperformed 2-over-3 (ICES default rule). For quite similar level of catches, 1-over-2 has a bit lower risk than 2-over-3. This is valid for all uncertainty caps tested (including no uncertainty cap).
- Application of some uncertainty caps to constrain interannual variability in the advice led to a reduction of catches and risks, only up to an intermediate uncertainty cap beyond which risks start to increase again:
  - For symmetrical uncertainty caps: Best performance (least risks for minimum reduction of catches) was from 1-over-2 with symmetric 80% Ucap. The most risky performance was from a symmetric 20% uncertainty cap, both for 1-over-2 and 2-over-3, and the performance worsens with time.
  - For asymmetrical uncertainty caps, tested for rules with a maximum interannual upward revision of 20%, optimal performance was achieved when allowing reductions of 60% or more from the previous advice for in-year advice, and of 70% or more for calendar-year advice.

- Biomass safeguards (based on the minimum historical abundance index -Ilim- or on the 5th percentile of the historical index) show a rather good performance, generally reducing risk without too much reduction in catch, when applied to any HCR, possibly in combination with uncertainty caps.
- The constant rate HCRs can be appropriate but require a good knowledge of the catchability/error/properties of the index. This should be studied in a case-by-case basis and deserves further simulations.
- There is a strong trade-off between risks and catches. The 1-over-2 rule with asymmetric Ucap (0.8,0.2) has the lowest risks through a progressive strong reduction of catches (maximum reduction in the long term). The 1-over-2 rule with no Ucap produce the highest catches with long-term risk being at precautionary levels for some operating models tested. Intermediate rules in terms of balancing catches and risks are: 1-over-2 with UCap (0.8,0.8) and 1-over-2 with biomass safeguard (Imin)
- While 1-over-2 with Ucap (0.8,0.2) is the lowest risk rule, in order to avoid excessive reductions of catches, 1-over-2 with Ucap (0.8,0.8) might be preferred as a good compromise between risk and catches. Application of the symmetric 80% Ucap can lead to major reduction of catches in the long term. So, its implementation should be temporary while aiming at achieving a better management of the stock in 8–10 years.
- Given the trade-off between competing rules, it seems that selection of a rule should be made in consultancy with managers and stakeholders.
- The work of WKDLSSLS is considered unfinished. Further research on the definition of optimal harvest control rules for data-limited short-lived stocks is ongoing. Therefore, the suggested rule (1-over-2 with symmetrical 80% Ucap) should be taken as an interim (provisional) proposal while guidelines are refined in 2020.

3.6 References

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4 General conclusions

4.1 On Assessments and BRPs

- Short-lived ICES category 3 stocks can be managed using the official advice rules based on the stochastic production model in continuous time (SPiCT; Pedersen and Berg, 2017) conditioned upon a successful SPiCT fitting, according to the specific guidelines for the use of SPiCT developed within the frame of WKDLSSLS and WKLIFE. The guidelines are part of a living document attached to the R package as a vignette and can be downloaded here (https://github.com/DTUAqua/SPiCT/blob/master/SPiCT/vignettes/SPiCT_guidelines.pdf).
- During the workshop SPiCT assessments to Anchovy in 9.a South, Anchovy 9.a West and to Sprat in 7.de were performed, resulting in a satisfactory application to Anchovy in 9.a South, with estimates very similar to those provided by a Gadget model (a data-rich model used as basis of the current assessment). Results for Sprat 7.de and Anchovy 9.aWest were still unacceptable, even after SPiCT experts made improvements. In addition, there were presentations on applications of SPiCT to several Cephalopods populations.
- No alternative reference points definition for management were produced by WKDLSSLS, apart from those already available from SPICT assessment. Length-based indicators of stock status are known to be generally not suitable for short-lived species because recruitment interannually induces major changes in the length distribution of catches (ICES reference points for stocks in categories 3 and 4). Exploring the values of Length-Based Indicators (LBI screening methods) across the mean of a series of catch-at-length distribution (presuming the mean approaches stationarity) may be worth exploring to have a rough idea of the selectivity of the fleet, particularly in relation to length-at-maturity and optimal exploitation.
- The two-stage approaches need further work: A provisional application was presented for Sprat in 7.de, but results were still preliminary.

4.2 On HCRs

- The time-lag between abundance index, advice and management should be minimized, this leads to select in-year advice, implying that the management year (i.e. TAC year) generally differs from the calendar year.
- Major drivers of risks are (in order of relevance): historical exploitation level (and trajectory), and the harvest control rule (HCR) with uncertainty cap (UCap). This emphasizes the relevance of trying an initial assessment of the relative status of the stock regarding optimal exploitation to judge if a precautionary buffer is required to start management.
- Regarding the trend-based HCRs: For all simulations except the North Sea sprat, in the short, medium and long term 1-over-2 outperformed 2-over-3 (ICES default rule). For quite similar level of catches, 1-over-2 has a bit lower risk than 2-over-3. This is valid for all uncertainty caps tested (including no uncertainty cap).
- Application of some uncertainty caps to constrain interannual variability in the advice led to a reduction of catches and risks, only up to an intermediate uncertainty cap beyond which risks start to increase again:

    - For symmetrical uncertainty caps: Best performance (least risks for minimum reduction of catches) was from 1-over-2 with symmetric 80% Ucap. The most risky performance was from a symmetric 20% uncertainty cap, both for 1-over-2 and 2-over-3, and the performance worsens with time.
    - For asymmetrical uncertainty caps tested for rules with a maximum interannual upward revision of 20%, optimal performance was achieved when allowing reductions of 60% or more from the previous advice for in-year advice, and of 70% or more for calendar-year advice.
- Biomass safeguards (based on the minimum historical abundance index -Ilim- or on the 5th percentile of the historical index) show a rather good performance, generally reducing risk without too much reduction in catch, when applied to any HCR, possibly in combination with uncertainty caps.
- The constant rate HCRs can be appropriate but require a good knowledge of the catchability/error/properties of the index. This should be studied in a case-by-case basis and deserves further simulations.
- There is a strong trade-off between risks and catches. The 1-over-2 rule with asymmetric Ucap (0.8,0.2) has the lowest risks through a progressive strong reduction of catches (maximum reduction in the long-term). The 1-over-2 rule with no Ucap produce the highest catches with long-term risk being at precautionary levels for some operating models tested. Intermediate rules in terms of balancing catches and risks are: 1-over-2 with UCap (0.8,0.8) and 1-over-2 with biomass safeguard (Imin)
- While 1-over-2 with Ucap (0.8,0.2) is the lowest risk rule, in order to avoid excessive reductions of catches, 1-over-2 with Ucap (0.8,0.8) might be preferred as a good compromise between risk and catches. Application of the symmetric 80% Ucap can lead to major reduction of catches in the long term. So, its implementation should be temporary while aiming at achieving a better management of the stock in 8–10 years.
- Given the trade-off between competing rules, it seems that selection of a rule should be made in consultancy with managers and stakeholders.
- The work of WKDLSSLS is considered unfinished. Further research on the definition of optimal harvest control rules for data-limited short-lived stocks is ongoing. Therefore, the suggested rule (1-over-2 with symmetrical 80% Ucap) should be taken as an interim (provisional) proposal while guidelines are refined in 2020.

5 Future directions of work for DLS SLS stock

The work of WKDLSSLS is considered unfinished and a recommendation for a new workshop in 2020 is proposed. Several points of further research are put forward below:

- Further work on assessment methods of initial stock status relative to MSY with simpler analysis of historical catches, the abundance indices or from expert knowledge is of relevance.
- Further research/suggestions on SPICT:
    - Borrowing parameters between SPiCT assessments (incl. prior sensitivity testing);
    - Testing further the SPiCT advice rules for management for these short-lived species;
    - Include the SPiCT in some interactive tool like the one developed in FarFish project, or develop a new one.
- Testing properly the precautionary buffer role in terms of mitigating short-term risks but keeping long-term benefits for the different harvest control rules and historical exploitation trajectories.
- Further exploring the benefits of adding a biomass safeguard of minimum observed index or at a fractile of available index series to the rules either alone or in combination to uncertainty cap levels.
- Further testing of asymmetric uncertainty caps with variable upper and lower bounds.
- Testing the effect of shifting the uncertainty cap from 80% to no uncertainty cap in time (for instance after 8-10 years of application of the 80% uncertainty cap).
- Constant or variant harvest rate strategies instead of the trend-based rules (aligned with HCR 3.2.2 Catch rule based on applying an F_{proxy} (WKMSYCat34). Harvest rates and how they vary with assumed catchability. Further testing of harvest rates under a range of catchability, uncertainty and life history assumptions and across modelling platforms.

Annex 1: WKDLSSLS agenda

PASAIA, San Sebastiá (Gipuzkoa), 16–20 September 2019

Day	Time	Items	Who?	Cotribution content
Monday	**Time**	**Items**	**Who?**	**Cotribution content**
16	10:00	Introduction	Andrés & Mollie	Wellcome and presentation and meeting organization
			Andrés & Mollie	Introduction to WKDLSSLS TORs
	11:00	Coffe break		
16	11:20	Block: Anchovy contributions		
	11:20	Presentation	Margarita Rincón	Farfish data limited methods tool
	12:45	Presentation	Margarita Rincón	MSE like procedure for scenario evaluation under the trend-based procedure used for anchovy assessment
	13:30	Lunch time		
16	14:30	Block: General Very short & medium living species		
	14:30	Presentation	Leire Ibaibarriaga & Sonia & Andrés	Testing different catch rules based on survey trends for in-year management of short lived category 3 stocks
16	16:00	Coffe break		
16	16:30	General Discussion	All	Main achievements regarding TORs of today session // Unsolved issues // Pending simulations for this meeting and for future work
16	17:30	Closing and summarizing the day		
	17:45	Leaving		

Tuesday	**Time**	**Items**	**Who?**	**Cotribution content**
17	9:00	Introduction		Wellcome and overview of the day
17	9:15	Block Spratt contributions		
	9:15	Presentation	Mollie Brooks & Tobias	SPiCT assessment and provision of advice for Sprat like stock (adapted from North sea to Cat 3-4 stocks)
	10:15	Presentation	Tobias Mildenberger & Alex Kokkalis	Improvement on SPiCT HCR for data-limited stocks accounting for high assessment uncertainties
17	11:00	Coffe break		
17	11:20	Block Spratt contributions II		
	11:20	Presentation	Marta Quinzan (and Rosana Ourens)	Annual and seasonal SPiCT, two-stage biomass model and length-based indicators for Sprat in 7de
	12:20	Presentation	Nicola Walker	Testing the 1-over-2 rule and fixed harvest rates with asymmetric uncertainty caps and breakpoints related to the lowest survey values and annual vs seasonal advice for Spratt in 7de
17	13:30	Lunch time		
17	14:30	Inputs from SWFPO Crew (South Western Fish Producer Organisation)		
		Presentation	All	Inputs and views on management from fishermen SWFPO
17	16:00	Coffe break		
	17:00	General Discussion	All	Main achievements regarding TORs// Unsolved issues // Pending simulations for this meeting and for future work
17	17:30	Closing and summarizing the day		
	17:45	Leaving		

Wednesday	Time	Items	Who?	Cotribution content
18	9:00	Introduction		Wellcome and overview of the day
	9:15	Introduction		Structure and Index of contents of the report
18	9:30	Presentation	Alexandra (Webex)	Application of seasonal-SPICT to 9.a.west anchovy
18	10:15	Cephalops Contribution		
	10:15	Presentation	Angela Larivain & Jean-Paul Robin	SPICT Generalized Surplus Production on Cephalopods
18	11:00	Coffe break		
18	11:20	Working by Subgroups & Drafting		
18	13:30	Lunch time		
18	14:30	Working by Subgroups & Drafting		
18	16:00	Coffe break		
18	16:15	Working by Subgroups & Drafting		
18	17:30	Closing and summarizing the day		
	17:45	Leaving		

Thursday	Time	Items	Who?	Cotribution content
19	9:00	Introduction		Wellcome and overview of the day
19	9:15	Presentations of previous day advances		
19	11:00	Coffe break		
19	11:20	Working by Subgroups & Drafting		Groups by TORs
19	13:30	Lunch time		
19	14:30	Working by Subgroups & Drafting		Groups by TORs
19	16:00	Coffe break		
19	16:15	Plenary	All	Presenting draft main conclusions of the work by sugbgroups
19	17:30	Closing and summarizing the day		
	17:45	Leaving		

Friday	Time	Items	Who?	Cotribution content
20	9:00	Introduction		Wellcome and overview of the day
20	9:15	Presentations on advances	Margarita Rincón	Fitting Spict to Anchovy Ixa South
		Presentations on advances	Alex Kokkalis and Alexandra Silva and Marta Quinzan	Fitting Spict to Anchovy Ixa west and Sprat in 7de
20	11:00	Coffe break		
20	11:20	Presentations on advances	Mollie Brooks & Tobias	SPiCT assessment and provision of advice for Sprat like stock (adapted from North sea to Cat 3-4 stocks)
		Presentations on advances	Nicola Walker	Testing the 1-over-2 rule and fixed harvest rates with asymmetric uncertainty caps and breakpoints related to the lowest survey values and annual vs seasonal advice for Spratt in 7de
			Sonia Sanchez & Andrés	Testing different catch rules based on survey trends for in-year management of short lived category 3 stocks
20	13:00	Closing the meeting		Pending issues and future works


azti
tecnalia

Annex 2: WKDLSSLS List of participants

Attendees to WKDLDSLS	Attending?	COUNTRY	INSTITUTE
Sarah Louise Millar sarah-louise.millar@ices.dk	Yes	Denmark	International Council for the Exploration of the Seas (ICES)
Mollie Elisabeth Brooks molbr@aqua.dtu.dk	Yes	Denmark	National Institute of Aquatic Resources Technical University of Denmark DTU AQUA
Tobias Mildenberger tobm@aqua.dtu.dk	Yes	Denmark	National Institute of Aquatic Resources Technical University of Denmark DTU AQUA
Alex Kokkalis (DTU) alko@aqua.dtu.dk	Yes	Denmark	National Institute of Aquatic Resources Technical University of Denmark DTU AQUA
Alexandra (Xana) Silva asilva@ipma.pt	Webex	Portugal	Instituto Português do Mar e da Atmosfera (IPMA)
Susana Garrido susana.garrido@ipma.pt	Yes	Portugal	Instituto Português do Mar e da Atmosfera (IPMA)
Margarita Rincón Hidalgo margarita.rincon@csic.es	Yes	SPAIN	Instituto de Ciencias del Mar (Cadiz)
Fernando Ramos fernando.ramos@ieo.es	Yes	SPAIN	Instituto Español de Oceanografía (IEO)
Sonia Sanchez ssanchez@azti.es	Yes	SPAIN	FUNDACION AZTI (Pasaia)
Leire Ibaibarriaga libaibarriaga@azti.es	Yes	SPAIN	FUNDACION AZTI (Sukarrieta)
Andrés Uriarte auriarte@azti.es	Yes	SPAIN	FUNDACION AZTI (Pasaia)
Miren Altuna maltuna@azti.es	Yes	SPAIN	FUNDACION AZTI (Pasaia)
Ane Iriondo airiondo@azti.es	Yes	SPAIN	FUNDACION AZTI (Sukarrieta)
Nicola Walker (Cefas) nicola.walker@cefas.co.uk	Yes	U.K.	Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Marta Quinzan (Cefas) marta.quinzan@cefas.co.uk	Yes	U.K.	Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Rosana Ourens (Cefas) rosana.ourens@cefas.co.uk	Webex	U.K.	Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Jean-Paul Robin jean-paul.robin@unicaen.fr	Webex	France	University of Caen

Attendees to WKDLDSLS	Attending?	COUNTRY	INSTITUTE
Angela Larivain angela.larivain@unicaen.fr	Webex	France	University of Caen
Richard Caslake richard.caslake@seafish.co.uk	Yes	U.K.	SWFPO Crew (South Western Fish Producer Organisation)
Will Burton willburton1974@aol.co.uk	Yes	U.K.	SWFPO Crew (South Western Fish Producer Organisation)

Annex 3: Minutes of the WebEx meeting held May 2019

Short Minutes of the WebEx meeting on May 3 2019.

Attendees: Andrés Uriarte (chair); Mollie Brooks (chair); Helle Gjeding (ICES); Jean-Paul Robin; Leire Ibaibarriaga; Margarita Rincón; Nicola Walker; Robyn Forrest; Sonia Sánchez; Tobias Mildenberger; Alexandra Silva.

Agenda is attached:

A brief introduction to the ToRs of WKDLSSLS was made by A. Uriarte and M. Brooks. The ToRs are:

1. Test different assessment methods for data-limited short-lived species (seasonal SPiCT, two-stage Biomass model, others).
2. Provide guidelines on the estimation of MSY proxy reference points for category 3–4 short-lived species.
3. Evaluate the management procedures currently in use and their appropriateness for short-lived species by means of Long-Term Management Strategy Evaluations (LT-MSE). This will imply the revision of the advice rules used, the time lag between assessment and enforcement, the suitability and magnitude of the uncertainty caps.

which was followed by a summary outline of the work foreseen to present in the next WKDLSSLS meeting in September:

DTU-Aqua: Mollie: Reported on the simulations they are preparing, with a sprat-like of stock (simulating the one in the North Sea, actually not a DLS), for which they will simulate survey observations and catches according to fishing exploitation applicable to other stocks. Then they will apply SPiCT for assessment and provision of advice for management.

Tobias mentioned that the DTU-AQUA team is currently developing harvest control rules for SPiCT in data-limited situations and harvest control rules accounting for high assessment uncertainties. They are working on ways to make robust SPiCT assessments and account for time-variant parameters. These advancements are specifically useful for assessments of short-lived species, which often show high assessment uncertainties.

Mark Taylor and Tobias are currently developing an individual based operating model, which allows to simulate seasonal processes and monthly data.

Thus, DTU-Aqua will contribute to all ToRs (1–3).”

IPMA (Portugal): Alexandra Silva. She presented the advances on the application of seasonal SPiCT to the anchovy in 9.a, whereby assessment starts at the middle of the year (1st July). The performance using different datasets (survey inputs, acoustic and BTsurvey) and various model configurations (fixing parameters n, alfa, beta, q) with respect to the estimation model were tested. Globally results were very uncertain. She will contact W. Casper or Tobias directly to improve fitting and change starting month/season of the year. Application of the SPiCT modelling allowing changes in productivity, may be of interest to this case study. Main contribution is for ToR A (assessment) and B (reference points).

CSIC and IEO (Spain): Margarita Rincón presented the *ad hoc* MSE modelling for anchovy in 9.a South, with a monthly age-structured model for scenario evaluation under the trend-based procedure used for anchovy assessment. The model assumes spawning dependent on population in the last month, sex ratio, weight-at-age and estimated number of eggs per gramme of female during the summer months, happening once, twice, thrice or four times per month and that individuals become recruits after six months and die when they are two years old. Natural mortality is assumed as equal to the determined by the current assessment model used and the F value is calculated to be consistent with the recommended quota in the 2018–2019 period (3760 tons). This simulated population allows to see what would be the population the next year if the trend indicator is below 0.8, or if it is between 0.8 and 1.2 and if it is higher than 1.2, and two years later considering all the possible outcomes of trend indicator combinations, for example, first year below 0.8 and second year above 1.2. All possible outcomes for two years make a summary of nine possible scenarios. Another possible experiment would be to explore the same scenarios but assuming recruitment influenced by environmental covariates, which are known for this stock. This operative model is flexible enough to be applied in other cases just changing accordingly the parameter values and the time of spawning, recruitment and death.

AZTI (Spain): S. Sanchez, A. Uriarte and L. Ibaibarriaga presented an expansion of the work provided to WKLIFE8 to cover a rider range of life histories: "Testing different catch rules based on survey trends for in-year management of short-lived category 3 stocks". Basically we plan to study the performance of different harvest control rules to Short-lived category_3 stocks for which an indicator of global abundance or of recruitment is available as (ToR 3) a function of:

- Their life-history characteristics (K and M) and recruitment variability + Interannual Variability IAV;So far covering Anchovies; Sandeels; Spratt; Sardines…
- Content and quality of the Indicator regarding the population for which management is required and the Observation Error of the Indicator
- Initial stock status according historical trajectories of Catches and Stock indicator & initial assessment of such stock status according to a few selected methods (ToR 1).

According to these different ranges of situations (scenarios) we will assess the performance of Different HCRs (basically T(1/2) ; T(1/3) ; T(2/3) or others…???) coupled to Different interannual Uncertainty Cap levels: of 20%, 50%, 80% or No Uncertainty Cap, and potential application of an initial or periodic Buffer cutdowns as a function of the perception on the initial stock status Major contribution expected for ToR C.

MI (Ireland): Yves Reecht, explained by email (in advance) that he has moved from MI (Ireland) to IMR (Bergen) and he can no longer attend this meeting due to his new job. Therefore, the follow up of MI with this WK is uncertain.

Cefas (UK): Nicola Walker, explained she had to organize and coordinate their contribution to the WKDLSSLS with Lisa Readdy, and then they will update us on their intentions.

Dr Robyn Forrest, from the Department of Fisheries and Oceans Canada, explained that there are proposed changes to Canada's legislation, which will make definition of limit reference points (LRPs) mandatory for all major fish stocks, and require that fish stocks be managed so that they remain above the LRP or be rebuilt if they are below the LRP. The proposed legislation will make Canada's current Sustainable Fisheries Framework policy a legal requirement. Therefore, they are very much interested in understanding methods for defining BRPs for short-lived species being developed in Europe and ICES. Dr Forrest will be working in collaboration with Dr Tom Carruthers from the University of British Columbia, developing and applying the DLMtool kit, to simulation test alternative management procedures for sustainable management of SLS, and therefore also hopes to provide inputs on the three ToRs.

Jean-Paul Robin University of Caen Normandy described the New stock assessment exercises in European Cephalopod Stocks (using generalized surplus production models, applied with SPiCT) which will be presented in the ICES ASC 2019 on several stocks of squids and octopus. Hence main contributions on ToRs 1 and 2

The meeting was closed letting the possibility of having a second WebEx before the September meeting open according to future suggestions or demands of the participants.

Annex 4: Recommendations

Recommendation	For follow up by:
It is recommended by WKDLSSLS that a new workshop on this subject (WKDLSSLS II) takes place in Copenhagen DENMARK tbc. 14–18 September 2020, the ToRs of which should be discussed by ACOM at their November 2019 consultation meeting.	ACOM

Annex 5: Views from the South West Sprat Association (SWSA)

The SW Sprat Association was set up in July 2019 to maximize, by good management practices, the present value and the economic benefits from the SW Sprat Fishery to its members on an ecologically sound basis. The Association is made up of representatives from the three active pelagic trawl vessels, the three key Sprat processors, the Southwest Fish Producers organisation and SeaFish.

Name of the Fishery

SWFPO Channel Sprat Mid-water Trawler Fishery

1. Species Common Name

Sprat

2. Species Latin Name

Sprattus sprattus

3. Method of Catch

Mid-water trawl, 20 mm - minimum 16 mm mesh.

4. Location of Fishery

The 'Channel Sprat' fishery is managed as "Celtic Seas / North Sea Sprat in divisions 7.d and 7.e. This is the unit for which management advice is produced by ICES, and quotas are set by the EU.

SWFPO members land almost the entirety of the catch in the management unit, fished exclusively in Division 7.e. Division 7.e covers the western end of the English Channel.

The majority of the fish are taken within Greater Lyme Bay.

The FAO statistical area is 27, Northeast Atlantic.

5. Fishing Season

The start and finish dates of the fishing season vary from year to year. The season usually runs from August until February.

Vessel currently in the fishery (September 2019).

Name	PLN	Length	Tonnage	Gear
Constant Friend	BM484	14.99 m	28.85 t	Trawl
Girl Rona	TH117	14.83 m	38.98 t	Trawl
Mary Anne	BM482	11.98 m	15.9 t	Trawl

6. Catch Data

The SWFPO group represents the vast majority of sprat quota and landings from the stock designated 7.d and e. This operates as a "fish for the market" fishery, where sales are first secured, and then fishermen catch the amount demanded. In recent years, the fishery has been managed by applying the "use it or lose it" policy and quotas have been cut simply because catches have been 'low' or data has been "poor".

Table 2. Quotas, official total landings, and client group landings for Sprat in divisions 7.d and 7.e

Year	TAC (tonnes)	Official UK landings (tonnes)	SWFPO Quotas (tonnes)	SWFPO SWAPS TONNES	£ PER TONNE RENT	£ COST OF RENT	SWFPO landings (tonnes)	£ PER TONNE SALES	GROSS INCOME £	INCOME AFTER LEASE £	SWFPO VOYAGE DAYS	£ PER TONNE NETT	£ PER DAY NETT
2007	6100	2706	3102				2685	200	537000	537000	356	200	1508
2008	6100	3367	3534				3198	200	639600	639600	481	200	1330
2009	6100	2773	3202	298	25	7450	2712	200	542400	534950	336	197	1592
2010	5500	4408	2882	1423	25	35575	4360	218	950480	914905	364	210	2514
2011	5400	3138	2765	329	25	8225	3094	229	708526	700301	272	226	2575
2012	5100	4458	2682	1005	25	25125	4418	220	971960	946835	236	214	4012
2013	5150	3793	2584	1405	35	49175	3790	197	746630	697455	312	184	2235
2014	5150	3338	2592	1390	35	48650	3288	212	697056	648406	299	197	2169
2015	5150	2659	2680	0	0	0	2614	164	428696	428696	245	164	1750
2016	5150	2867	2490	230	40	9200	2720	191	519520	510320	309	188	1652
2017	4120	2498	1744	1352	40	54080	2417	226	546242	492162	219	204	2247
2018	3296	1776	1674	675	40	27000	1765	222	391830	364830	229	207	1593
2019	2637		1368	600?	40	24000	1968?						

The fishery was "free for all" from introduction of the TAC in the 1980s. The TAC has always been "Precautionary" rather than "Analytical".

The catches in the fishery have mostly been in the region of 2000 to 4000 tonnes, with exceptions being in the late 1970s and early 1980s when up to 18 000 tonnes were harvested (1980), mostly then by Danish industrial fishing. Low points were 2004 (842tonnes) 2002 (1196) and 1986 (1178). The three UK vessels currently catch over 90% of the Sprat caught in this fishery. Due to the limited size of the fishery it is of little interest to the large pelagic fleets operated by the Danes and Dutch.

7. Science

The first Biomass estimate was not until 2013 carried out as part of the Cefas Peltic survey. From 2013 to 2016 the Peltic survey only covered the English part of area 7.d and e. This was extended in 2017 to include the French waters of 7.e and further extended in 2018 into area 7.d. Also in 2018, an acoustic survey was also carried out in the inshore areas of Lyme Bay on a commercial vessel in line with the Peltic survey. The fishery is currently managed using the 2-over-3 rule though very few fish (8% of biomass) live beyond three years. The use of the 2-over-3 rule has resulted in ICES advice of a precautionary 20% reduction in catch in 2017, a further 36% reduction in 2018, and advice of further cuts of 20% for both 2019 and 2020. This has related to a cut in quotas during the period from 5150 tonnes to a TAC set at 2637 for 2019.

The ICES advice for 2020 is a further 20% cut to 1506 tonnes. This would be the lowest catch figure for the UK since 2004.

If the current ICES advice for 2020 resulted in a further 20% cut in quota this would set the TAC 2110 tonnes. At this level of quota the three member vessels of the SWSA as well as having their quota allocation cut this would put additional pressure on the need to lease in quota from the other nations in order to maintain an economically viable fishery.

The industry has for the past two seasons been working with Cefas as part of a Fisheries Science Partnership (FSP) to improve the information and data within the fishery, and to assist ICES assessment.

8. Economics of the fishery

Since 2009 and virtually every year, the UK SWFPO fishermen had to "swap in" North Sea Sprats with Denmark to obtain quotas of 7.de Sprats. This has been a costly exercise, with a lease fee required of around £40 for every tonne swapped, though income is only derived from every tonne landed. The current quota year for Channel Sprat runs from the 1st January to 31st December so any quota not caught by the 31st December is lost.

Although the prime period for catches of sprat, in terms of quality, is between August and December, large quantities of Sprat are still available to be caught in January and February. Due to the size of the vessels and the nature of the fishery, weather plays a vital role in when the fish can be targeted and caught. In periods of poor weather, which can be frequent and sustained during the winter months, vessels are unable to go to sea. Also during periods of very poor weather, shoals can disperse and may take several days before they can successfully be targeted by the fishermen. As quota arrangements, "swaps" need to be made well in advance; it is somewhat of a gamble for the fishermen to judge how much fish they require prior to the end of the calendar year, as there is no guarantee as to whether the fish will be present or the weather conditions will be such that it allows them to successfully target them. A prime example of this was seen in the fishery in 2018 where the SWFPO swapped in 675 tonnes of Channel sprat on behalf of the fishermen at the cost of £40 per tonne. Due to poor weather during December, 584 tonnes remained uncaught. During the same period the InterFish PO undershot their quota by a further

425 tonnes due to the same issues with weather. The cost of the unused quota for 2018 was just over £40 000.

The calendar year assessment does not allow the fishermen the flexibility to roll their quota over to the following year. A seasonal quota, aligned with North Sea Sprat, would ease the pressure on quota negotiations and be economically beneficial, allowing the fishermen the opportunity to utilise any remaining quota during January and February. **The industry would support a move from to a seasonal quota allocation.**

The current 2-over-3 assessment of channel sprat has led to a 20% cut in quota, year on year, for the last four years. This has resulted in a reduction of quota from 5150 tonnes in 2016 to 2637 tonnes in 2019. The UK allocation of quota is approximately 50% of the total allocation with the Danish and the Dutch making up the majority of the other 50%. The three UK, SWSA member vessels catch over 90% of the sprat caught in 7.d/e. Although catches have remained fairly constant since 2010, recent cuts in quota have increased the pressure on the requirement to lease in additional quota from the other nations, reducing the economic viability of the fishery. A maximum 1968 tonnes is available to SWFPO members in 2019. The intention for 2019 is to swap-in 600 tonnes from Denmark.

Further cuts in quota are likely to render the fishery unviable, resulting in vessels leaving the fishery. Fisheries generated data will then be unavailable and current markets for UK sprat lost due to no supply. Once these markets and fisheries expertise have been lost, they will be extremely difficult to re-establish. Alongside adding additional economic pressure to both the fishermen and processors engaged in the fishery.

The industry request that current cuts in quota be put on hold and an economically viable TAC set allowing SWSA members to continue their partnership with Cefas to improve the information and data on 7.de sprat.

This would also allow the time required for ICES to review the current method of assessment for Channel Sprat.

Members of the SW Sprat association recently attended an ICES Workshop on Data-limited Stocks of Short-Lived Species (WKDLSSLS) in Pasaia, Spain. SWSA members engaged in discussions with stock scientists on channel sprat and possible alternatives to the current 2-over-3 method of assessment. SWSA members also discussed issues in the fishery which have been highlighted in this report.

Key points from the WKDLSSLS included:

- General consensus from the group was that the 2-over-3 rule does not provide a precautionary approach to management and the 1-over-2 rule is a better fit and gives a smaller risk in both the short and long term;
- Both the 1-over-2 rule and the Harvest rate methods offer a precautionary approach for management especially when combined with uncertainty caps;
- Work will continue to further investigate alternative methods for short-lived species though this could take time to be adopted by ICES;
- Length–frequency data collection is very useful in stock assessment and the building of a longer dataset would be very useful;
- The current Peltic survey generally produces a poor quality of data for smaller fish below one year of age (not many about when the survey is carried out in October/November);
- Further surveys would be useful to improve data, particularly on the smaller, younger fish;
- Only 8% of fish live to over three years of age though current models take into account five years;

- We made it clear that the industry supports both a seasonal assessment (July–June) and revision to the current 2-over-3 method of assessment.

Annex 6: Working documents

In the following pages the working documents presented to WKDLSSLS are inserted in full:

WD1: SPiCt model for anchovy 9a South. By Margarita Rincón.

WD2: Stock assessment models applied to sprat (*Sprattus sprattus*) in the English Chanel (division 7.de). By Marta Quinzán and Rosana Ouréns.

WD3: Management strategy evaluations for a simulated stock of sprat (*Sprattus sprattus*) in the English Channel. By Nicola Walker.

WD4: North Sea Sprat SPiCT MSE. By Mollie Brooks.

WD5: Testing management advice procedures for short-lived data-limited stocks in Category 3. By Uriarte, A. Sánchez, S., Ibaibarriaga, L., Silva, A., Ramos, F., and. M. Rincón.

SPiCt model for anchovy 9a South

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Abstract

An SPiCt model has been fitted to anchovy 9a South data using catches biomass time series and PELAGO and ECOCADIZ survey indexes testing different model features. Results of different scenarios will be presented and also a comparison with the current model used as basis for the assessment which is a Gadget model.

1. Model Description

SPiCt model fits an stochastic surplus production model in continuous time incorporating dynamics in both biomass and fisheries and observation error of both catches and biomass indices. The model has a general state-space form that can contain process and observation-error as well as state-space models that assume error-free catches (Pedersen and Berg, 2017).

The general SPiCT model description and all the options available can be found in Pedersen and Berg (2017), as well as a user guide available at `https://github.com/mawp/spict/raw/master/spict/vignettes/vignette.pdf`.

2. Data and priors

Quarterly catches time series from 1989 to the second quarter of 2019. For the first two quarters of year 2019, provisional catches estimations of Spanish (until May 27th) purse-seine fleet were used and catches for June were estimated as the 37% of January to May catches based on historical records from 2009 to 2018. There were not any catches for Portuguese purse-seine in these two quarters. ECOCADIZ and PELAGO acoustic survey biomass indexes were provided at the exact time of the year when the surveys were carried out.For ECOCADIZ that corresponds to March of 2004 and 2006, April of 2007, 2009, 2010, 2014-2018, and May of 2013, and for PELAGO to February of 1998, 2000-2002 and April of 2005-2010, 2013-2019. Data summary is presented in Figure 1.

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Priors for parameters were set to default.

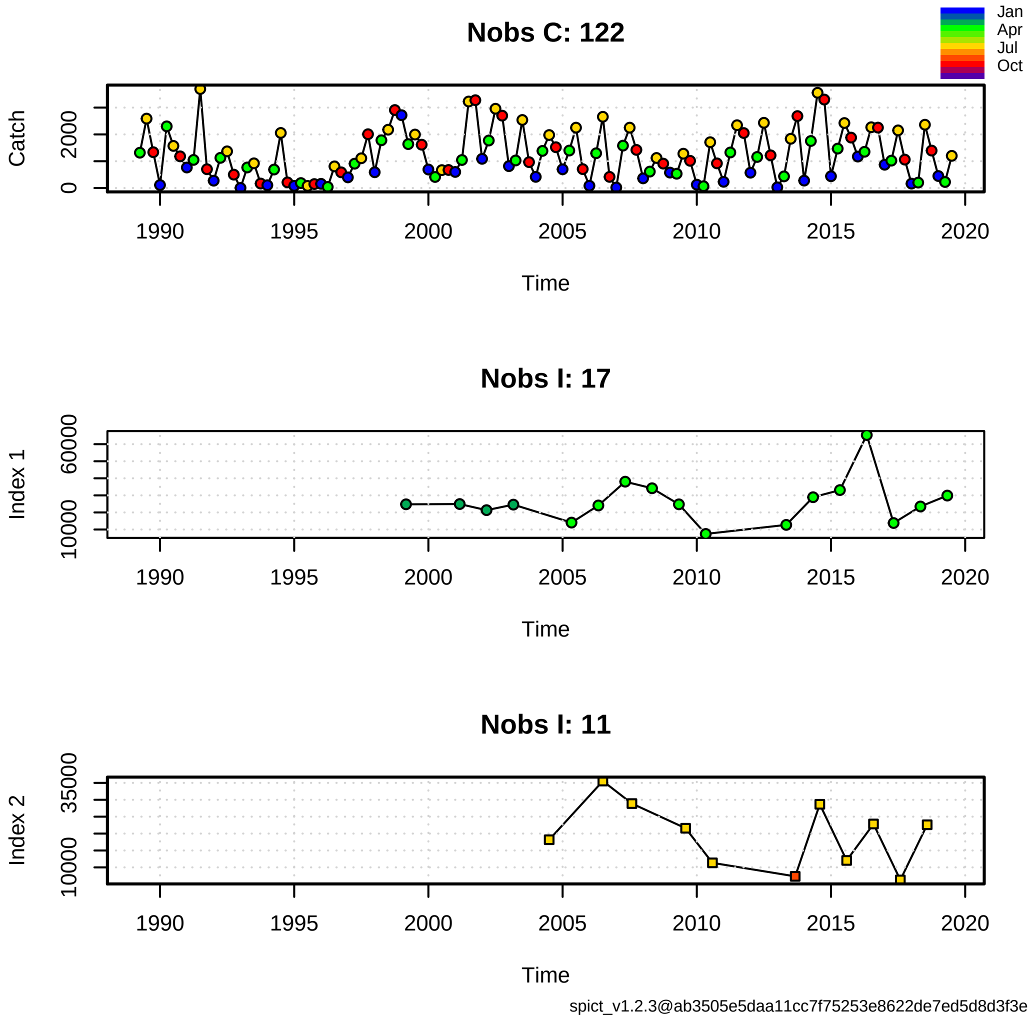

Figure 1: Summary of data used for the SPiCt model

3. Scenarios

Four different scenarios were tested, the first one with no seasonal productivity, the second one assuming seasonal productivity, the third one with no seasonal productivity and with time-varying growth and the last one with no seasonal productivity, no time-varying growth and with the data restricted to the 1999-2019 period where there is a more stable length distribution pattern.

4. Results

4.1. Scenario 1

Most important outputs for scenario 1 are displayed in figure 2. This scenario assumes no seasonal productivity, no time-varying growth and uses the whole data set available. Diagnostics are displayed in figure 3 and the following is the results summary:

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 186.4590926
Euler time step (years):  1/16 or 0.0625
Nobs C: 122,  Nobs I1: 17,  Nobs I2: 11

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1686837    0.0316033 9.003538e-01 -1.7797300
 alpha2    0.2308633    0.0521441 1.022127e+00 -1.4659295
 beta      1.9479512    0.8512938 4.457349e+00  0.6667782
 r         7.0869111    1.3361591 3.758857e+01  1.9582496
 rc        7.4977432    3.0255245 1.858063e+01  2.0146021
 rold      7.9591389    3.5343402 1.792354e+01  2.0743208
 m      8165.4118106 4524.3133270 1.473681e+04  9.0076624
 K      4453.1914241 1839.9603643 1.077790e+04  8.4013763
 q1        7.6780998    3.6259220 1.625882e+01  2.0383721
 q2        5.8617460    2.4843999 1.383033e+01  1.7684475
 n         1.8904118    0.7501732 4.763776e+00  0.6367947
 sdb       1.2482709    0.6798603 2.291913e+00  0.2217593
 sdf       0.3244957    0.1490765 7.063318e-01 -1.1254830
 sdi1      0.2105629    0.0436652 1.015380e+00 -1.5579707
 sdi2      0.2881800    0.0728714 1.139647e+00 -1.2441702
 sdc       0.6321018    0.4971600 8.036702e-01 -0.4587049
 phi1      0.0792707    0.0359859 1.746197e-01 -2.5348866
 phi2      0.3921424    0.1945560 7.903929e-01 -0.9361302
 phi3      1.1306343    0.4808124 2.658696e+00  0.1227788

Deterministic reference points (Drp)
          estimate       cilow        ciupp  log.est
 Bmsyd 2178.098541 1047.671284  4528.245952 7.686208
```

```
 Fmsyd    3.748872    1.512762     9.290315 1.321455
 MSYd  8165.411811 4524.313327 14736.810919 9.007662
Stochastic reference points (Srp)
          estimate       cilow        ciupp  log.est rel.diff.Drp
 Bmsys 1942.908686 1147.149128  3290.674307 7.571942   -0.1210504
 Fmsys    4.995816    2.536235     9.840643 1.608601    0.2495978
 MSYs  9999.683755 5522.445108 18106.775759 9.210309    0.1834330

States w 95% CI (inp$msytype: s)
                    estimate       cilow        ciupp    log.est
 B_2019.50      3080.4797171 988.3353615 9601.3515827  8.0328406
 F_2019.50         1.1379704   0.3449539    3.7540572  0.1292464
 B_2019.50/Bmsy    1.5854990   0.6465166    3.8882327  0.4608992
 F_2019.50/Fmsy    0.2277847   0.0737322    0.7037067 -1.4793545

Predictions w 95% CI (inp$msytype: s)
                  prediction       cilow        ciupp    log.est
 B_2019.75      2807.0645578 812.2521973 9700.9419709  7.9398946
 F_2019.75         1.1345796   0.3318796    3.8787285  0.1262622
 B_2019.75/Bmsy    1.4447743   0.5273923    3.9579132  0.3679531
 F_2019.75/Fmsy    0.2271059   0.0707523    0.7289817 -1.4823387
 Catch_2019.75  1162.4449555 475.6135383 2841.1265993  7.0582808
 E(B_inf)       3339.8562663          NA           NA  8.1136831
```

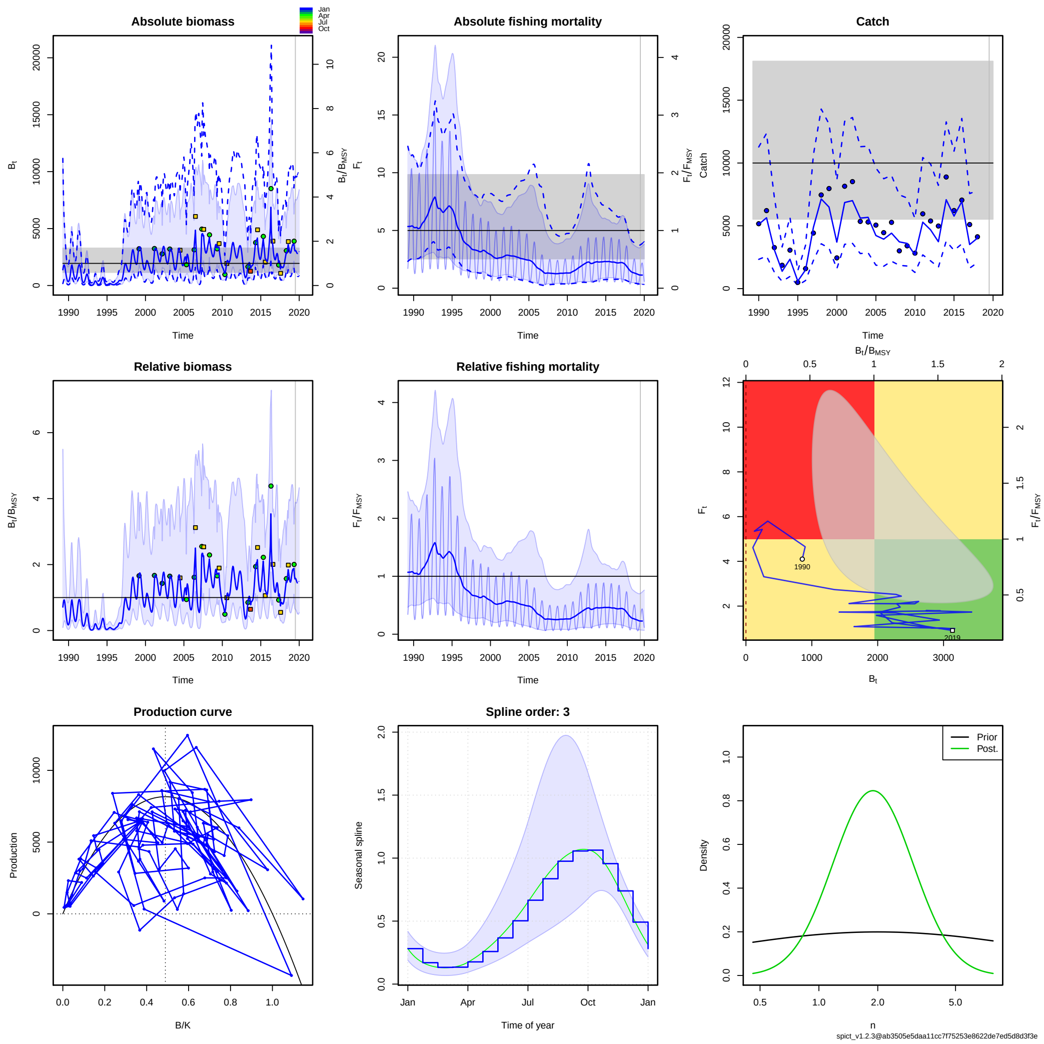

Figure 2: Summary of SPiCt results for scenario 1

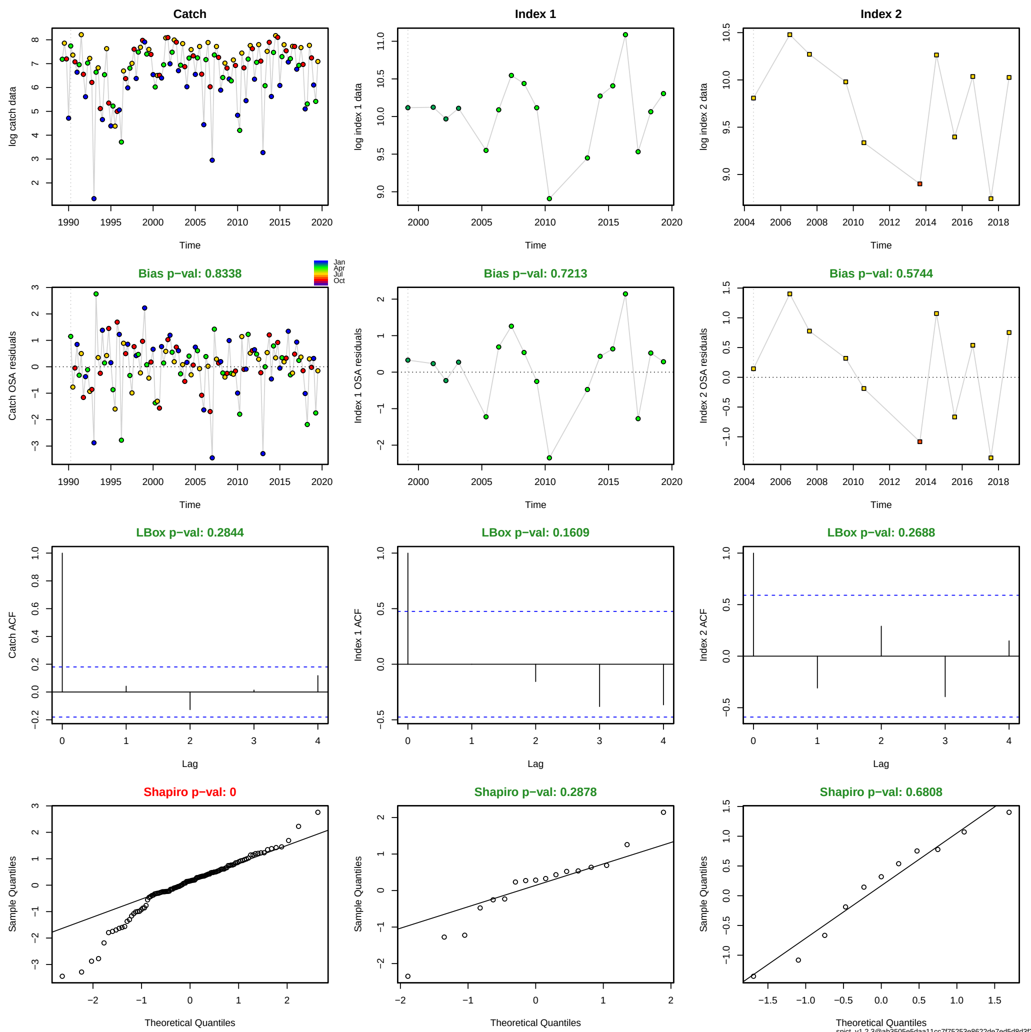

Figure 3: Summary of SPiCt diagnostics for scenario 1

4.2. Scenario 2

Most important outputs for scenario 2 are displayed in figure 4. This scenario assumes a seasonal productivity, no time-varying growth and uses the whole data set available. Diagnostics are displayed in figure 5 and a plot on how the model estimates the seasonal productivity pattern is presented in figure 6. The following is the results summary:

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 186.4595744
Euler time step (years):  1/16 or 0.0625
Nobs C: 122,  Nobs I1: 17,  Nobs I2: 11


Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]


Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1686874    0.0316168 9.000100e-01 -1.7797078
 alpha2    0.2308533    0.0521504 1.021913e+00 -1.4659730
 beta      1.9478428    0.8512866 4.456891e+00  0.6667225
 r         7.0847339    1.3379740 3.751452e+01  1.9579423
 rc        7.4959731    3.0269441 1.856315e+01  2.0143660
 rold      7.9578958    3.5343004 1.791814e+01  2.0741646
 m      8165.6045341 4525.0670122 1.473505e+04  9.0076860
 K      4454.4734360 1841.5590187 1.077475e+04  8.4016641
 q1        7.6763773    3.6269349 1.624699e+01  2.0381477
 q2        5.8598336    2.4837934 1.382468e+01  1.7681212
 n         1.8902773    0.7507828 4.759230e+00  0.6367235
 sdb       1.2482505    0.6799812 2.291430e+00  0.2217429
 sdf       0.3245047    0.1490906 7.063041e-01 -1.1254553
 sdi1      0.2105642    0.0436923 1.014761e+00 -1.5579649
 sdi2      0.2881627    0.0729190 1.138767e+00 -1.2442301
 sdc       0.6320841    0.4971382 8.036606e-01 -0.4587328
 phi1      0.0792892    0.0360136 1.745667e-01 -2.5346538
 phi2      0.3921144    0.1945981 7.901088e-01 -0.9362017
 phi3      1.1304671    0.4807266 2.658384e+00  0.1226309
```

```
 amp       0.0003355    0.0000000 1.580936e+35 -8.0000000
 phase    -0.0003169          NaN          NaN -0.0003169

Deterministic reference points (Drp)
         estimate       cilow        ciupp  log.est
 Bmsyd 2178.664304 1048.121834  4528.651151 7.686467
 Fmsyd    3.747987    1.513472     9.281574 1.321219
 MSYd  8165.604534 4525.067012 14735.051929 9.007686
Stochastic reference points (Srp)
          estimate       cilow        ciupp  log.est rel.diff.Drp
 Bmsys  1943.187523 1147.927492  3289.386984 7.572085   -0.1211807
 Fmsys     4.995563    2.538085     9.832474 1.608550    0.2497369
 MSYs  10001.091156 5522.378816 18112.090393 9.210449    0.1835286

States w 95% CI (inp$msytype: s)
                 estimate       cilow        ciupp    log.est
 B_2019.50      3081.386589 988.6586962 9603.8636464  8.0331350
 F_2019.50         1.137644   0.3448468    3.7530722  0.1289599
 B_2019.50/Bmsy    1.585738   0.6464497    3.8898085  0.4610500
 F_2019.50/Fmsy    0.227731   0.0736890    0.7037877 -1.4795902

Predictions w 95% CI (inp$msytype: s)
                prediction       cilow        ciupp    log.est
 B_2019.75      2807.6760947 812.3270478 9704.2749883  7.9401124
 F_2019.75         1.1342563   0.3317775    3.8777115  0.1259772
 B_2019.75/Bmsy    1.4448817   0.5272476    3.9595876  0.3680275
 F_2019.75/Fmsy    0.2270527   0.0707119    0.7290565 -1.4825729
 Catch_2019.75  1162.3462245 475.5104342 2841.2599356  7.0581958
 E(B_inf)       3340.8645443          NA           NA  8.1139849
```

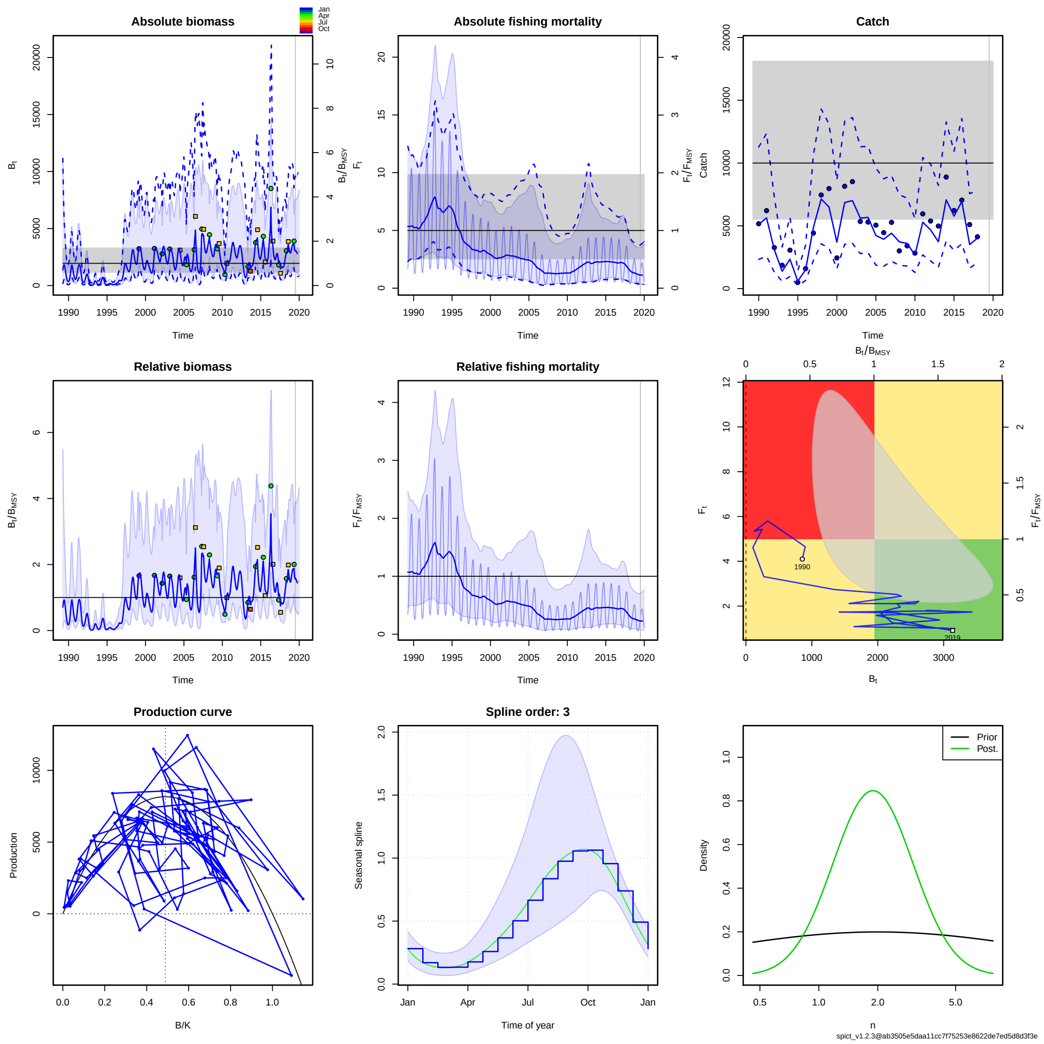

Figure 4: Summary of SPiCt results for scenario 2

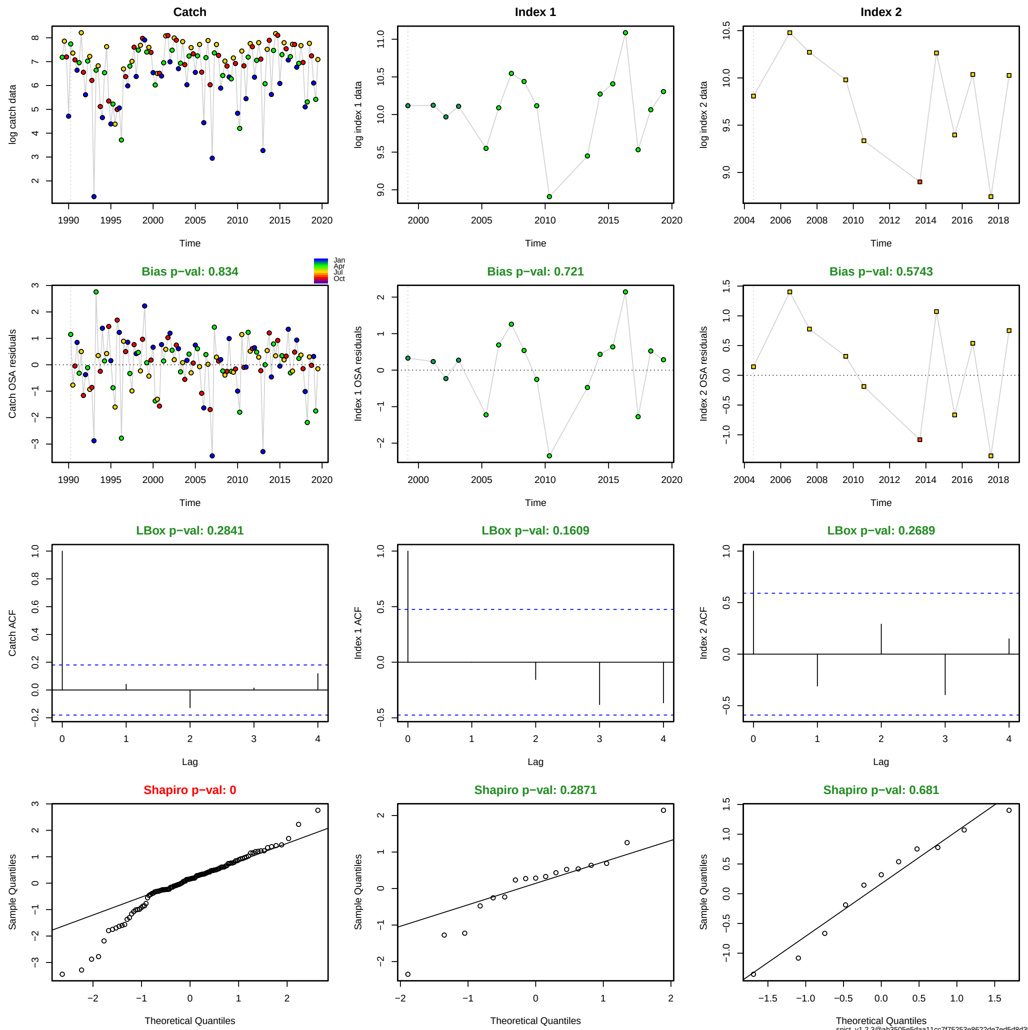

Figure 5: Summary of SPiCt diagnostics for scenario 2

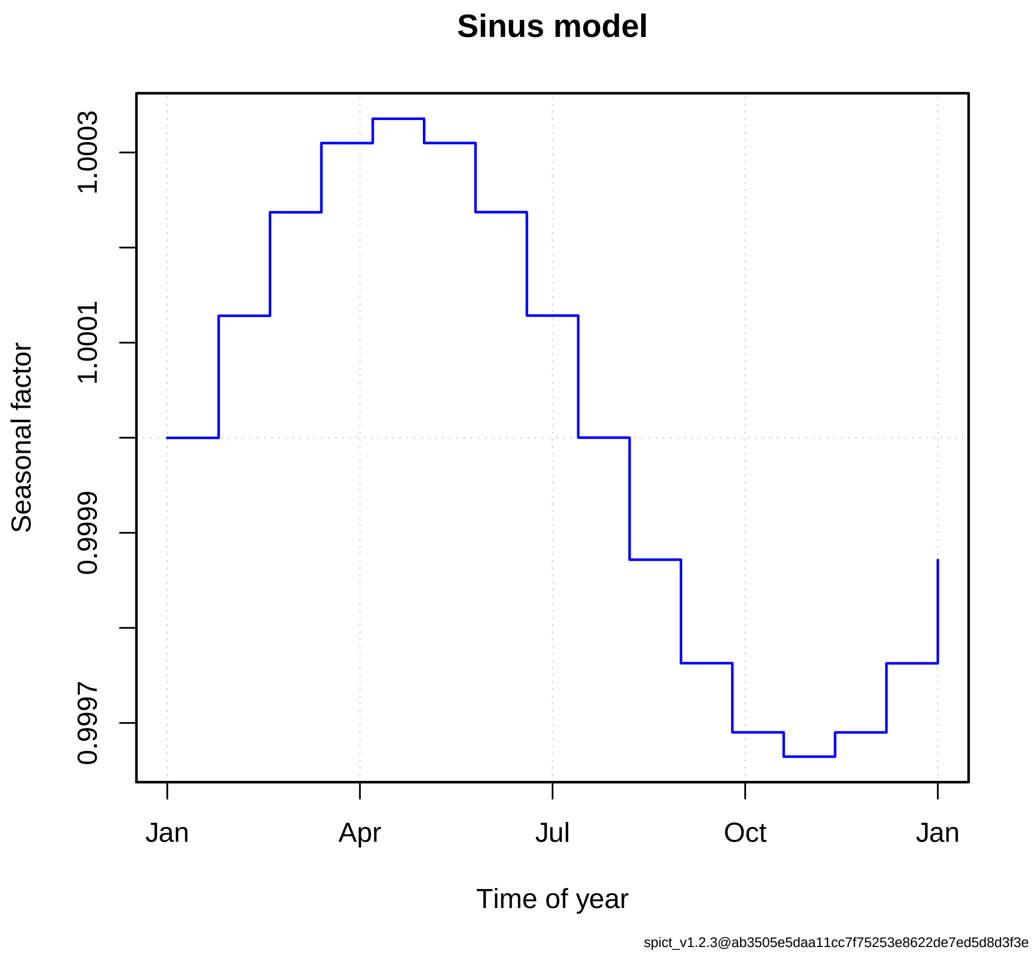

Figure 6: Estimation of the seasonal productivity pattern in scenario 2

4.3. Scenario 3

Most important outputs for scenario 3 are displayed in figure 7. This scenario assumes no seasonal productivity, time-varying growth and uses the whole data set available. Diagnostics are displayed in figure 8 and the following is the results summary:

```
Convergence: 0  MSG: relative convergence (4)
Objective function at optimum: 191.2945767
Euler time step (years):  1/16 or 0.0625
Nobs C: 122,  Nobs I1: 17,  Nobs I2: 11

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]
   logsdm  ~  dnorm[log(0.2), 2^2]
   logpsi  ~  dnorm[log(0.01), 2^2]

Model parameter estimates w 95% CI
            estimate        cilow        ciupp    log.est
 alpha1    0.1747161    0.0327516 9.320373e-01 -1.7445930
 alpha2    0.2464850    0.0558037 1.088724e+00 -1.4004542
 beta      1.9115679    0.8646641 4.226024e+00  0.6479238
 r         5.0245410    1.4378351 1.755835e+01  1.6143341
 rc        6.0818922    2.6404915 1.400853e+01  1.8053159
 rold      7.7028622    3.1976010 1.855581e+01  2.0415920
 m      7827.0471484 4902.7752965 1.249551e+04  8.9653406
 K      5425.1479192 1972.9627446 1.491778e+04  8.5988004
 q1        6.5446201    2.3616037 1.813685e+01  1.8786434
 q2        4.8626939    1.6062899 1.472075e+01  1.5815926
 n         1.6522953    0.9045477 3.018171e+00  0.5021654
 sdb       1.1232171    0.6197546 2.035671e+00  0.1161970
 sdf       0.3378626    0.1594611 7.158557e-01 -1.0851161
 sdi1      0.1962441    0.0451987 8.520548e-01 -1.6283960
 sdi2      0.2768561    0.0796199 9.626901e-01 -1.2842572
 sdc       0.6458472    0.5202440 8.017750e-01 -0.4371923
 sdm       0.0144663    0.0011247 1.860730e-01 -4.2359361
 psi       0.0449757    0.0008308 2.434887e+00 -3.1016331
```

```
 phi1      0.0828584    0.0374137 1.835026e-01 -2.4906226
 phi2      0.4199858    0.1984411 8.888686e-01 -0.8675344
 phi3      1.1660226    0.4900278 2.774554e+00  0.1535985

Deterministic reference points (Drp)
          estimate       cilow        ciupp  log.est
 Bmsyd 2512.307100 1009.046073  6255.102849 7.828957
 Fmsyd    3.040946    1.320246     7.004266 1.112169
 MSYd  7639.790467 4777.219251 12217.651173 8.941126
Stochastic reference points (Srp)
        estimate       cilow        ciupp  log.est rel.diff.Drp
 Bmsys  2058.935 1140.343215  3717.488723 7.629944   -0.2201974
 Fmsys     4.591    2.862361     7.363598 1.524098    0.3376288
 MSYs  10155.321 4852.027531 21255.143497 9.225753    0.2477057

States w 95% CI (inp$msytype: s)
                    estimate       cilow        ciupp    log.est
 B_2019.50      3678.0851610 989.8982042 13666.365283  8.2101476
 F_2019.50         0.9330044   0.2195515     3.964888 -0.0693454
 B_2019.50/Bmsy    1.7864018   0.4465503     7.146409  0.5802035
 F_2019.50/Fmsy    0.2029033   0.0404334     1.018211 -1.5950258

Predictions w 95% CI (inp$msytype: s)
                  prediction       cilow        ciupp    log.est
 B_2019.75      3338.9384853 780.0941065 14291.237577  8.1134082
 F_2019.75         0.9305503   0.2121979     4.080738 -0.0719791
 B_2019.75/Bmsy    1.6216824   0.3611831     7.281220  0.4834641
 F_2019.75/Fmsy    0.2024185   0.0392562     1.043739 -1.5974182
 Catch_2019.75  1109.3222870 442.6164180  2780.276299  7.0115046
 E(B_inf)       4178.2951651          NA           NA  8.3376586
```

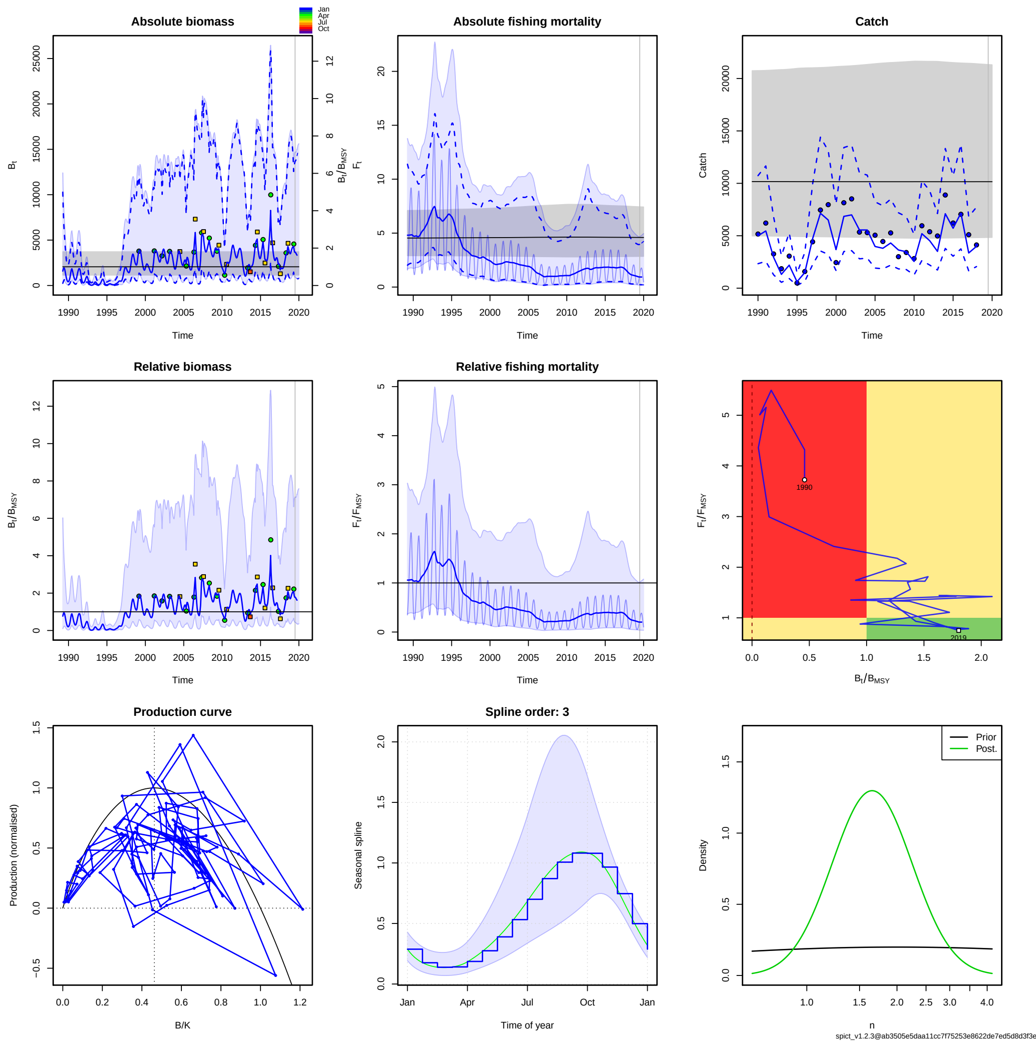

Figure 7: Summary of SPiCt results for scenario 3

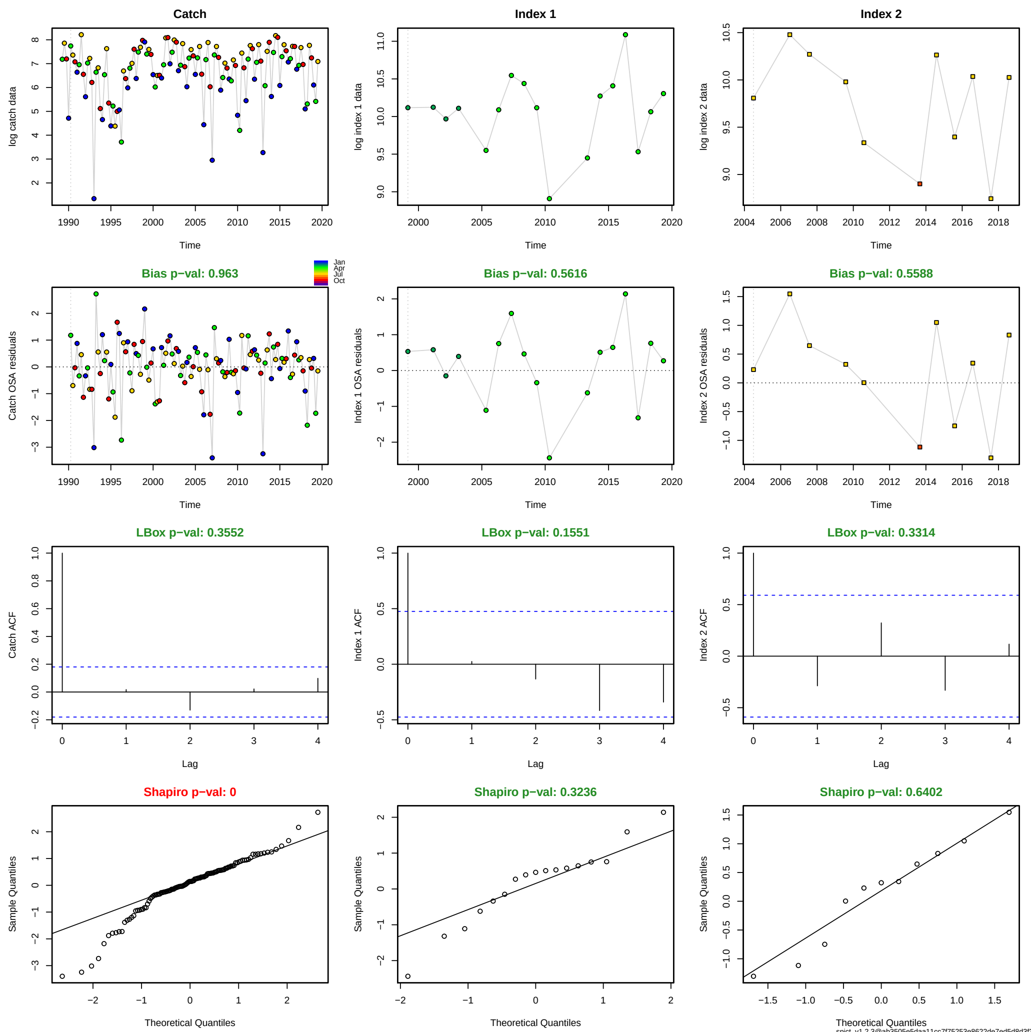

Figure 8: Summary of SPiCt diagnostics for scenario 3

4.4. Scenario 4

Most important outputs for scenario 4 are displayed in figure 9. This scenario assumes no seasonal productivity, no time-varying growth and uses a restricted dataset, with data only for the 1999-2019 period where there is a more stable length distribution pattern. Diagnostics are displayed in figure 10 and the following is the results summary:

```
Convergence: 1  MSG: false convergence (8)
WARNING: Model did not obtain proper convergence! Estimates and uncertainties are most likely invalid and
Gradient at current parameter vector
        logm         logK         logq         logq         logn       logsdb
 -229402447.0  169948388.7   41643949.8   30459097.0  174610954.4   45861469.9
      logsdf       logsdi       logsdi       logsdc       logphi       logphi
   28358501.1   -1609455.3  -21143364.2   -1723031.6    -138697.5  -73257366.8
      logphi
  -11024319.3

Objective function: 111.765618
Euler time step (years):  1/16 or 0.0625
Nobs C: 83,  Nobs I1: 17,  Nobs I2: 11

Priors
     logn  ~  dnorm[log(2), 2^2]
 logalpha  ~  dnorm[log(1), 2^2]
  logbeta  ~  dnorm[log(1), 2^2]

Model parameter estimates w 95% CI
           estimate        cilow        ciupp    log.est
 alpha1 8.191790e-02    0.0730463 9.186690e-02 -2.5020383
 alpha2 2.136928e-01          NaN          NaN -1.5432156
 beta   3.179735e-01    0.3071098 3.292215e-01 -1.1457871
 r      1.871786e+01   16.0294065 2.185721e+01  2.9294779
 rc     2.132445e+01   20.4816439 2.220194e+01  3.0598543
 rold   2.477447e+01          NaN          NaN  3.2098138
 m      1.001575e+04 8916.1950082 1.125090e+04  9.2119139
 K      1.978463e+03 1686.4483161 2.321042e+03  7.5900757
 q1     1.763961e+01   13.9938815 2.223514e+01  2.8701471
 q2     1.366832e+01          NaN          NaN  2.6150804
```

```
 n      1.755530e+00          NaN          NaN  0.5627708
 sdb    2.000006e+00    1.7688369 2.261386e+00  0.6931501
 sdf    7.312129e-01    0.6474514 8.258108e-01 -0.3130506
 sdi1   1.638362e-01          NaN          NaN -1.8088882
 sdi2   4.273869e-01          NaN          NaN -0.8500655
 sdc    2.325064e-01          NaN          NaN -1.4588377
 phi1   3.759640e-02          NaN          NaN -3.2808458
 phi2   1.290048e-01    0.0981358 1.695839e-01 -2.0479056
 phi3   4.843067e-01          NaN          NaN -0.7250370

Deterministic reference points (Drp)
          estimate      cilow       ciupp  log.est
 Bmsyd   939.36747  881.20498  1001.36889 6.845207
 Fmsyd    10.66222   10.24082    11.10097 2.366707
 MSYd  10015.74737 8916.19501 11250.89743 9.211914
Stochastic reference points (Srp)
          estimate      cilow       ciupp  log.est rel.diff.Drp
 Bmsys   940.79196  867.20560  1020.62247 6.846722  0.001514142
 Fmsys    11.05139   10.35991    11.78902 2.402556  0.035214015
 MSYs  10396.50344 9261.45504 11670.65902 9.249225  0.036623473

States w 95% CI (inp$msytype: s)
                   estimate       cilow        ciupp    log.est
 B_2019.50      1687.1868010 516.0911333 5515.6911592  7.4308178
 F_2019.50         2.0089208   0.4253312    9.4885190  0.6975977
 B_2019.50/Bmsy    1.7933686   0.5515466    5.8311869  0.5840958
 F_2019.50/Fmsy    0.1817799   0.0384496    0.8594097 -1.7049584

Predictions w 95% CI (inp$msytype: s)
                 prediction       cilow        ciupp    log.est
 B_2019.75      1387.4876749 495.2834499 3886.9097049  7.2352500
 F_2019.75         2.1345676   0.6119577    7.4455784  0.7582641
 B_2019.75/Bmsy    1.4748082   0.5298689    4.1049008  0.3885279
 F_2019.75/Fmsy    0.1931493   0.0553197    0.6743828 -1.6442920
 Catch_2019.75  1393.8285650 481.5539614 4034.3517536  7.2398096
 E(B_inf)       1470.3526704          NA           NA  7.2932576
```

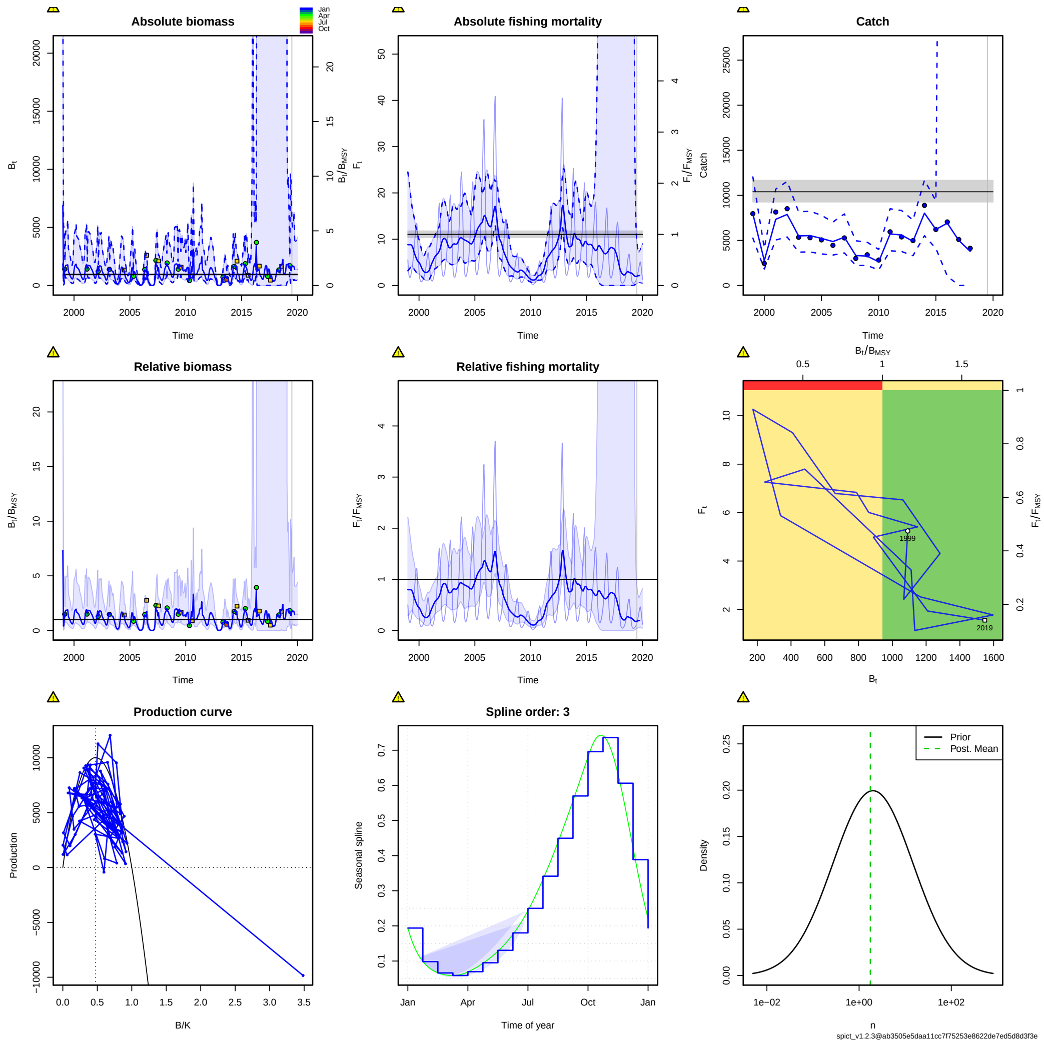

Figure 9: Summary of SPiCt results for scenario 4

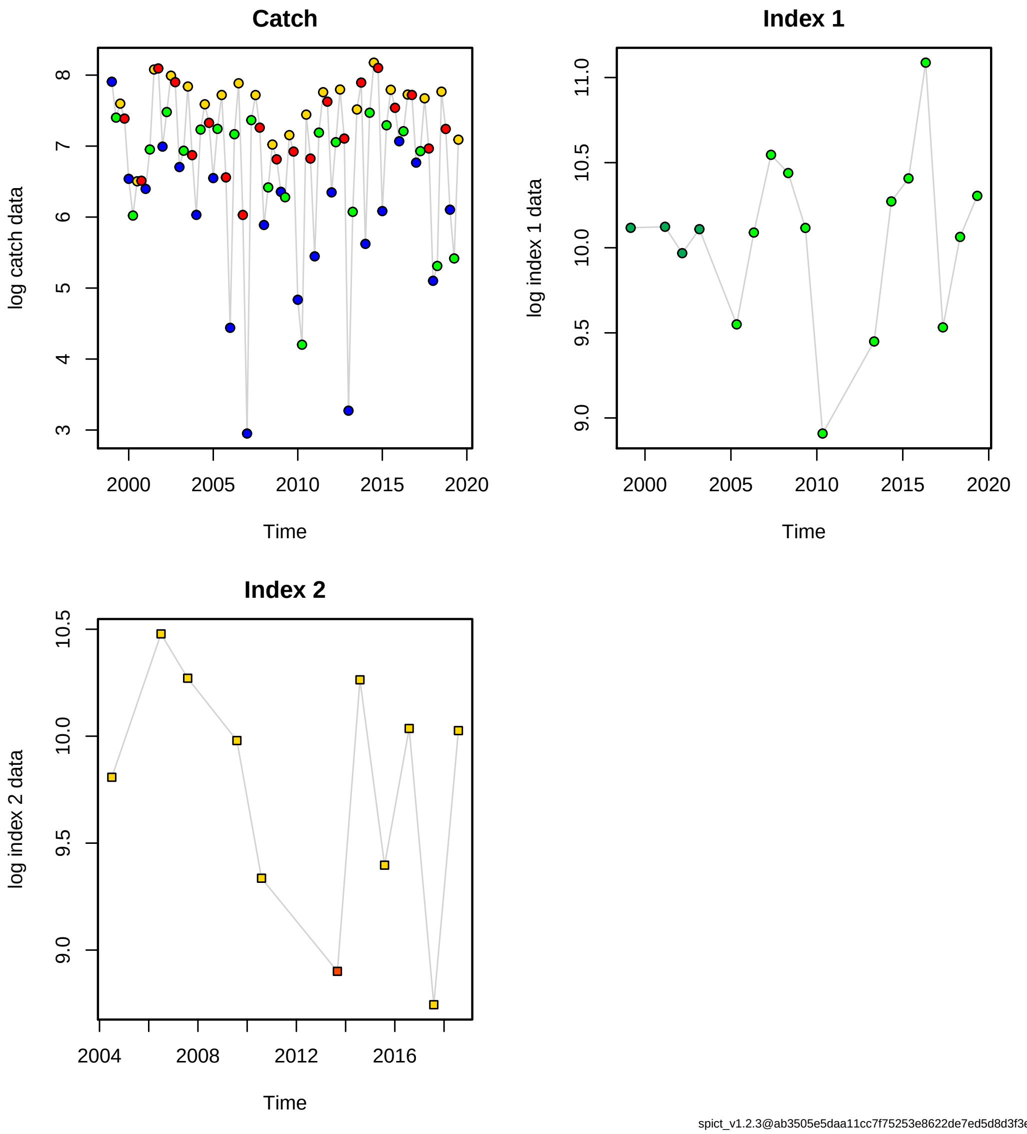

Figure 10: Summary of SPiCt diagnostics for scenario 4

5. Comparison of harvestable biomass estimation obtained in scenario 1 with harvestable biomass estimated by Gadget

Figures 11 and 12 show a model comparison estimates of absolute (in tonnes) and relative harvestable biomass at the end of the second quarter, respectively. The SPiCt scenario 1 output was compared with the Gadget model output used in the latest anchovy 9a South assessment (Rincón et al., 2019). The data used for the SPiCt scenario was also the same used in this assessment.

Figure 11: Comparison of absolute harvestable biomass estimates at the end of the second quarter of each year by Spict (scenario 1) and Gadget, pink and blue lines, respectively.

Figure 12: Comparison of relative harvestable biomass estimates at the end of the second quarter of each year by Spict (scenario 1) and Gadget, pink and blue lines, respectively.

6. References

Pedersen, M.W., Berg, C.W., 2017. A stochastic surplus production model in continuous time. Fish and Fisheries 18, 226–243. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/faf.12174, doi:10.1111/faf.12174, arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/faf.12174.

Rincón, M.M., Ramos, F., Uriarte, A., Ibaibarriaga, L., Garrido, S., Silva, A., 2019. Updated Gadget for anchovy 9a South: Model description and results to provide catch advice and reference points (WGHANSA 2019). Technical Report. Working Document presented to ICES WGHANSA 2018. Lisbon 26–30 June. Lisbon; Portugal. URL: https://www.researchgate.net/publication/334896165_Updated_Gadget_for_anchovy_9a_South_Model_description_and_results_to_provide_catch_advice_and_reference_points_Presented_for_ICES_WGHANSA-1_2019.

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

Stock assessment models applied to sprat (*Sprattus sprattus*) in the English Channel (division 7.de)

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1. Introduction

Sprat (*Sprattus sprattus)* is the only small pelagic species in the English Channel with quota (ICES Divisions 7.de). It is a small fishery where three UK vessels under 15 m are responsible for the majority of the landings (on average they have taken 96% of the total landings since 2003). The primary gear is midwater trawls, although sprat can be also caught with driftnets, fixed nets, lines or pots. Most of the landings are taken in 7.e, mainly in the Lyme Bay area, and they are sold for human consumption. Discards are considered negligible in this fishery.

The stock structure is not clear, and it has been long debated whether the sprat in the North Sea, Skagerrak-Kattegat and the English Channel are the same or different stocks. The last WKSPRAT benchmark (ICES, 2018) supported the merging of the North Sea and Skagerrak-Kattegat stocks into one single stock. Not enough evidence was presented to support the inclusion of the English Channel stock as well, and therefore this separation has been maintained. In addition, it is unclear as to the relationship between the English Channel stock and stocks to the west e.g. the Celtic Seas Region (Bristol Cannel, Celtic Sea and Irish Sea). Further investigations and work are required to resolve all of these uncertainties.

Sprat is a short-lived species with large inter-annual fluctuations in stock biomass. The natural inter-annual variability in stock abundance, mainly driven by recruitment variability, is high and does not appear to be strongly influenced by the observed levels of fishing effort (ICES, 2019).

The quota advice for sprat in division 7.de is based on the ICES framework for category 3 stocks, using the 2 over 3 rule: i.e. ratio between the mean biomass estimated in the two latest PELTIC acoustic surveys (see section 2.1.) and the mean of the three preceding values multiplied by the recent ICES advised catch. The current advice is annual (i.e. January to December), but it has been suggested to provide a seasonal advice instead (July to June). The logical behind this suggestion is the fishing season takes place from August to February, and at the time of the advice (March) a large part of the biomass observed in the previous year acoustic survey (October) has been already caught or naturally died, and therefore is not available to the fishery for the year advice (Fig.1.1). Essentially, with the current survey and advice timing, the survey data are not very informative of the fishing opportunities for the advice period.

The aim of this work is to test analytical assessments for sprat in division 7.de, using both calendar and seasonal year as time step. Two-stage biomass model, Surplus Production in Continuous Time (SPiCT, Pedersen and Berg, 2017) and Length Based Indicators (LBI. See ICES, 2015) trials were performed.

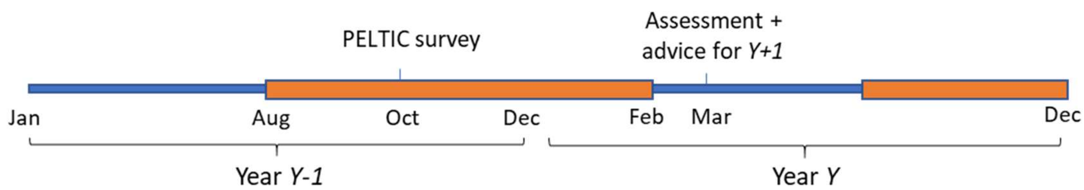

Figure 1.1. Time frame including the events related to the sprat fishery in 7.de. Orange lines represent the fishing season.

2. Data available

2.1. PELTIC survey

A pelagic survey has been undertaken since 2013 in the western English Channel and Eastern Celtic Sea to acoustically assess the biomass of the small pelagic fish community within this area (divisions 7.e–g). This survey, conducted from the RV *Cefas Endeavour*, is divided into three geographically separated regions: the western English Channel, the Isles of Scilly and the Bristol Channel. The survey was expanded in 2017 to cover the French part of division 7.e; and in 2018 to cover the eastern English Channel, division 7.d (Figure 2.1.1A). Few sprat were observed, at this time, either in the southern part of Division 7.e or in Division 7.d, which suggests that the majority of the stock is within the area surveyed every year.

The acoustic data is processed using StoX software (Johnsen et al. 2019) to estimate biomass and number at age. The biomass estimated with the survey in the western English Channel (Figure 2.1.1B) has been used since 2016 to provide advice for sprat in 7.de.

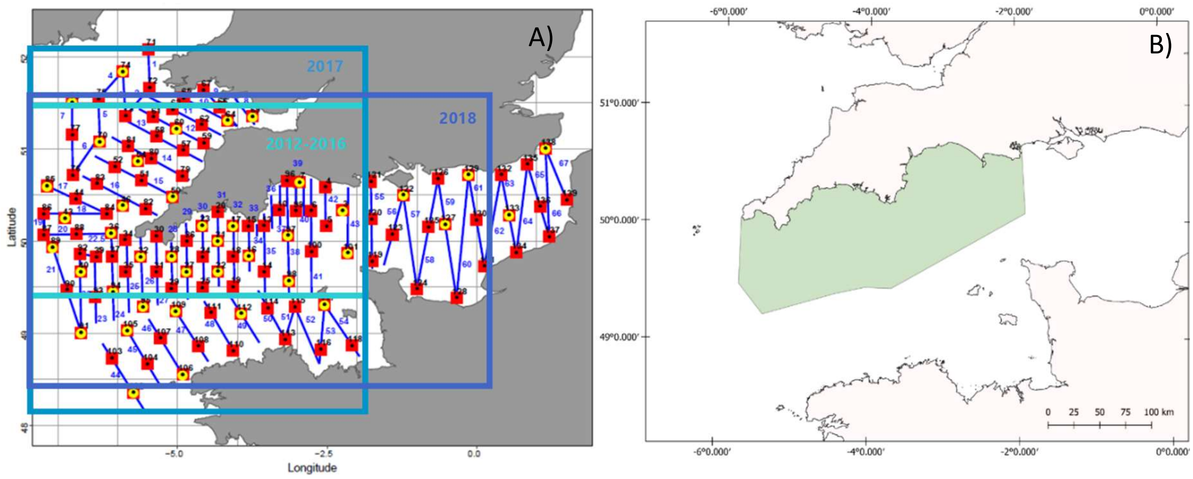

Figure 2.1.1. A) Survey area for each year, with the acoustic transect (blue lines), plankton stations (red squares) and hydrographic stations (yellow circles). B) Survey area in the western English Channel, used to estimate sprat biomass in 7.de

The sprat biomass (age 1+) in the western English Channel has been around 74000 tonnes in the period 2013-2015, but it has drastically decreased since 2016 (Figure 2.1.2). The biomass estimated in 2018 was 17000 tonnes.

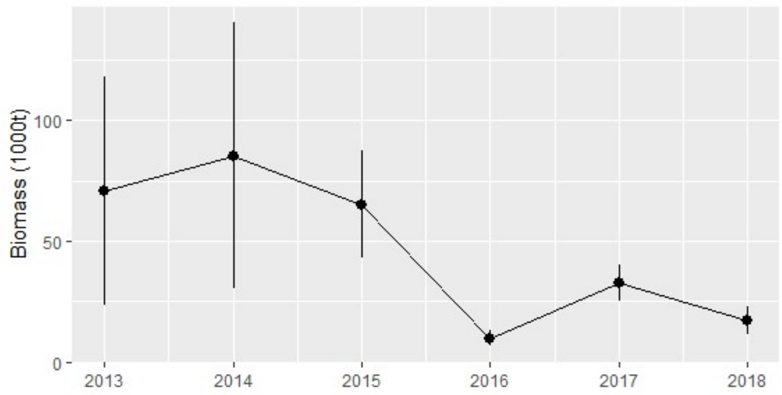

Figure 2.1.2. Time series of the sprat biomass in division 7.de estimated from the PELTIC survey. Error bars represent standard deviation estimated from bootstrap

2.2. Landings

Total landings from the international sprat fishery are available since 1950 (Figure 2.2.1). According to official catch statistics, large catches were taken by Danish trawlers in the late 1970s and 1980s from the English Channel. However, the identity of the catches was not confirmed by the Danish data managers raising the question of whether those reported catches (during the period of the herring fishery closure in the North Sea) were the result of species misreporting (i.e. herring misreported as sprat). Therefore, ICES cannot verify the quality of catch data prior to 1988. For the last 20 years, most of the catches have been caught by UK.

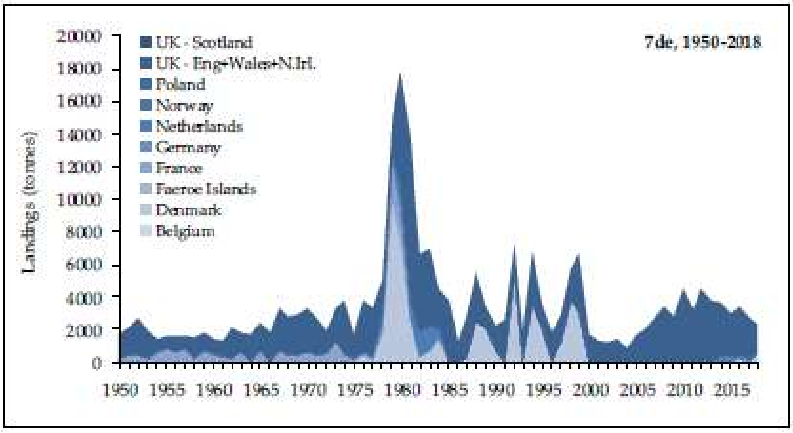

Figure 2.2.1. Sprat landings 1950-2018 in 7.de

More than 80% of the catches occur in quarter 3 and 4, and given the seasonal nature of the fishery, it was suggested to provide advice on a seasonal basis (July–June). A comparison between seasonal catches and calendar year catches is provided in Figure 2.2.2. Seasonal catches were quantified using the quarter landings available in Intercatch since 2010 and the rebuilt quarter landings for the period 1989-2009. The percentage landed by the UK fleet by quarter and year has been used to estimate the quarter landings during 1989-2009. On average, the UK contributed 91% to the total landings in division 7.de during the corresponding time period.

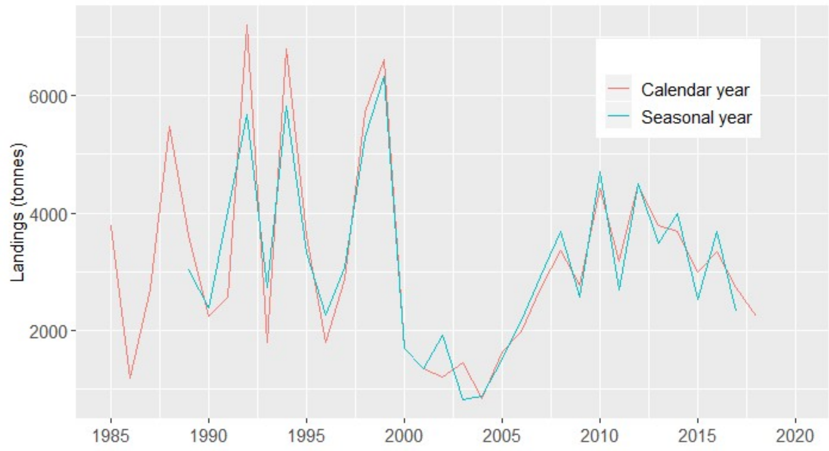

Figure 2.2.2. Seasonal (July–June) vs Calendar year (January–December) landings from 1985 to 2018 for sprat in 7.de

2.3. Landings per unit effort (LPUE)

The LPUE, estimated as daily landings per vessel, is based on data from the four UK vessels that targeted sprat in division 7.de during the period 1989-2018. Vessels considered for LPUE calculations have been making use of standard sonar technology to locate the fish throughout the period of analysis and therefore no other major technical advances need to be factored out. Also, these vessels account for, on average, 95% of total landings for the area. The LPUE was computed by calendar year and seasonal year (Figure 2.3.1). The index has fluctuated over the time, and it shows a decreasing trend in the last 4 years.

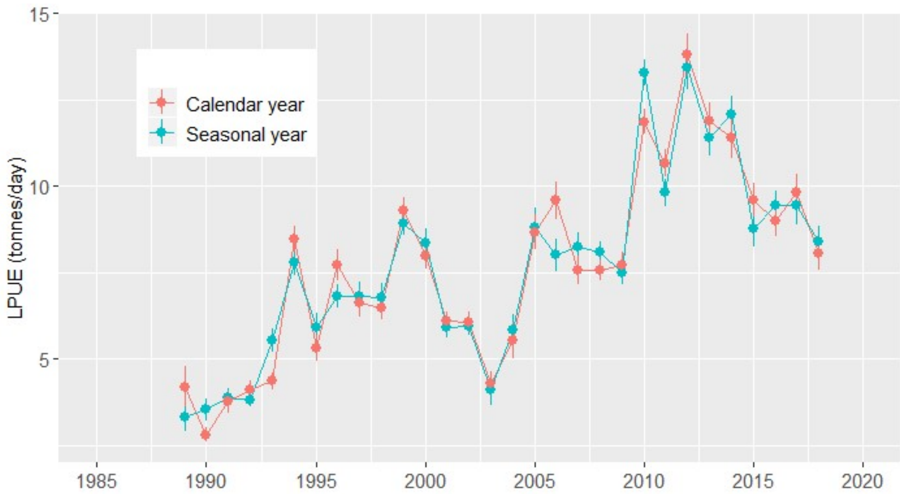

Figure 2.3.1. LPUE (mean ± standard error) for sprat in 7.de

2.4. Self-sampling program

A pilot self-sampling programme (FSP) started in the South West of UK in 2018/2019 fishing season for sprat. Fishermen from Lyme bay have been asked to collect length data for length frequency distributions of the catches and record information on fishing trips, such as position, fishing time, depth, and weather condition. The main processors for the fishery have been engaged as well and asked to provide length-weight data from random selected catch subsamples.

One out of the three current UK vessels targeting sprat in the English Channel and one producer provided biological information on the catches. The fishing vessel participating in the programme measured 900 sprats (13 samples) during the period August-October 2018, whereas the producer provided 971 length-weight measurements (9 samples from a different vessel as providing the 'at sea' data) during the period November 2018-January 2019. Differences in the size structure obtained from both data sources might be caused by the different time periods covered with the samples (Figure 2.4.1).

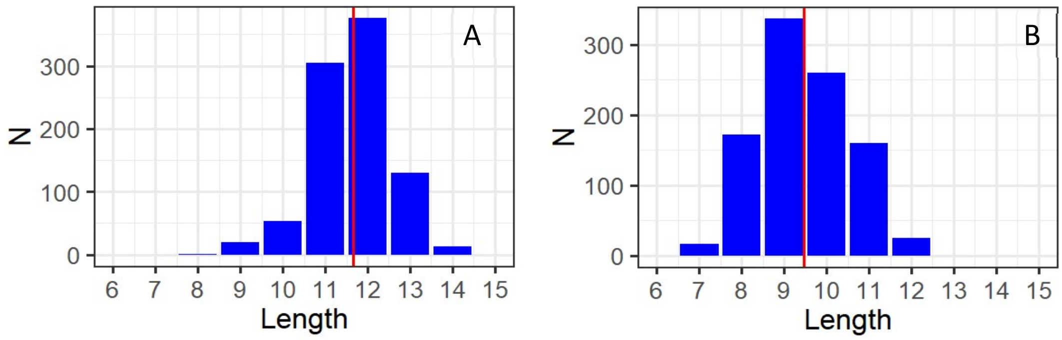

Figure 2.4.1. Size composition of the sprat samples provided by the skipper (A) and the producer (B). The red line represents the mean size of the samples

The length-weight relationship for sprat in the English Channel was estimated with the data provided by the producer (Figure 2.4.2).

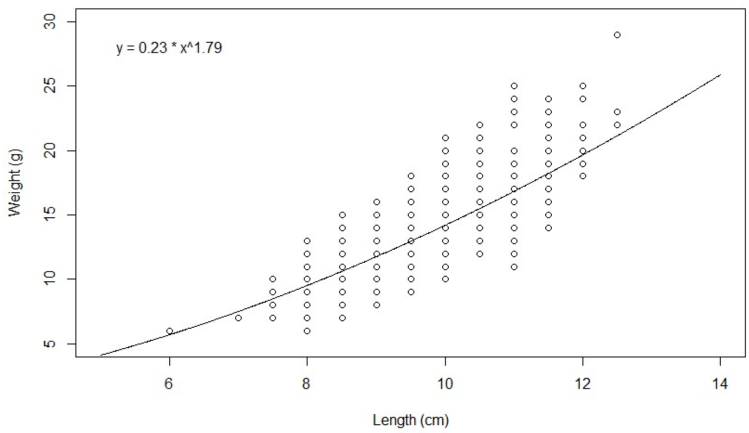

Figure 2.4.2. Length-weight relationship for sprat in the English Channel

3. Methods tested to assess the stock

3.1. Two-stage biomass

The two-stage biomass model describes the population dynamics in terms of biomass with two distinct age groups, fish aged 1 year and fish that are 2 or more years old (i.e. age group 2+). Modelling the recruits of the population separately captures the major changes in the population of this short-lived species, which is mainly dominated by the incoming recruitment. Biomass decreases continuously in time according to an instantaneous rate of biomass decrease g.

Two implementations of the model were tested. Firstly, a method as developed for chokka squid (*Loligo vulgaris*) by Roel and Butterworth (2000) and for cuttlefish (*Sepia officinalis*) in the English Channel by Gras *et al*. (2014). These previous implementations were developed to capture the life cycles of cephalopods, many of which have short life spans lasting between 1 and 2 years, with recruitment to the fishery occurring at the end of the first year. The implementation tested here includes an optional plus group for longer-lived species.

The input data were catch time series and index of abundance for both stages (age classes) from the PELTIC survey from 2013 to 2018. Two scenarios were considered in order to evaluate the effects of using calendar (January-December) and seasonal (July-June) year. Total catch in year *y* is assumed to be taken instantaneously as a pulse. Other input parameters were the parameter *g*, which was fixed externally, and initial values for the estimable parameters: the biomass of the fully recruited stage in the first year of the analysis ($B_{A,1}$), the biomass of recruits in all years ($B_{R,ybeg}$,...,$B_{R,yend}$) and the survey catchabilities (k_1,...,k_S).

The parameter *g* is a composite population growth parameter accounting for natural mortality and population growth, such that:

$$g = M - G$$

where M is natural mortality and G represents annual population growth.

The parameter M was estimated from Gislason *et al*. (2010). The parameter G was derived from the mean weight at age using data collected by PELTIC survey according to Gras *et al*. (2014).

$$G = \sum_{age=1\ year}^{age\_end} ln\left(\frac{wt_{age+1}}{wt_{age}}\right)$$

The data used are not necessarily representative of the cohorts studied, but were the only information available to provide some indication of growth rate (G) and ultimately of *g*.

In this first implementation, the uncertainty was accounted for by using a bootstrap procedure to estimate confidence intervals of the estimated model parameters. Resampling with replacement of the best fit residuals was carried out 100 times and each new generated residual data set is combined with the optimum predicted abundance indices to obtain 100 new bootstrap samples of index data. The model is refitted to each of these bootstrap samples and the bootstrap estimates of each parameter stored. The central 95% of these bootstrap estimates (the 0.025 and 0.975 percentile values of the sorted estimates) are taken as the confidence interval.

Secondly, a state-space version of the model as has been implemented for finfish species anchovy and herring (Ibaibarriaga *et al.,* 2008; Roel *et al.,* 2009) was tested. For modelling the dynamics of the sprat two periods were considered within each year. The first begins on 1st January, when it is assumed that age incrementation occurs and age 1 recruits enter the exploitable population and runs to the date when the acoustic research survey takes place. The timing of the survey varies slightly from year to year, but for the purposes of this model, it is assumed to occur on 15th October. The second period covers the rest of the year. The total biomass at survey time in any year *y* can be expressed as a function of the initial biomass, defined as the total biomass at the beginning of the second period of year 0, and all previous recruitment and catch values.

In this implementation, recruitment is considered as a stochastic process whereas biomass of recruits and adults are interpreted as deterministic state equations, expressing age 1 and total biomass at survey time each year as a function of the unknown total initial biomass, B_0, annual recruitments, R_y, and the rate of biomass decrease, *g*. Biomass of each age group *a* decreases continuously in time according to g_a, where $g_a = M_a - G_a$ for ages a = 1, 2+.

3.2. SPiCT

A Surplus Production Model in Continuous Time (SPiCT, Pedersen and Berg, 2017) was applied to estimate MSY proxy reference points for sprat in division 7.de. The input data of the model were a fisheries-independent survey time series (PELTIC, 2013-2018), a LPUE time series from the UK fleet (1989-2018), and a landing time series (1985-2018).

Two exploratory SPiCT assessments were performed in order to evaluate the effects of using calendar (January-December) and seasonal (July-June) year. Each assessment was run twice, using annual and quarter data.

3.3. Length based indicators

Length based indicators (LBI) are one of the methods used by ICES to estimate MSY proxy reference points for data-limited stocks. The method assumes stocks are in equilibrium and therefore recruitment is constant over time. This assumption is not met for short-lived species such as sprat, where recruitment induces interannual major changes in the length distribution of catches. However, the approach might be valid for providing an overall perception of stock status, and therefore the LBIs proposed by WKLIFE V (ICES, 2015) were applied to sprat in division 7.de.

This method requires the catch at length and some life-history parameters: size at 50% maturity (Lmat), von Bertalanffy length infinity (Linf), the ratio between natural mortality and von Bertalanffy k constant (M/k), and length-weight relationship parameters.

The catch at length was estimated from the size composition of the landings provided by the fishing industry (section 2.4), assuming zero discards (Figure 3.3.1). The raising procedure was as follows: the size composition of the samples was raised to fishing trip, then landing port, and finally total landings in division 7.de. As the samples covered the period August 2018-January 2019, LBI were only estimated for the fishing season 2018/2019. Because total landings for this period are currently not available, they have been assumed to be UK landings from July 2018 to June 2019 + 12.9% (average contribution of other countries to total landings in the last 5 years).

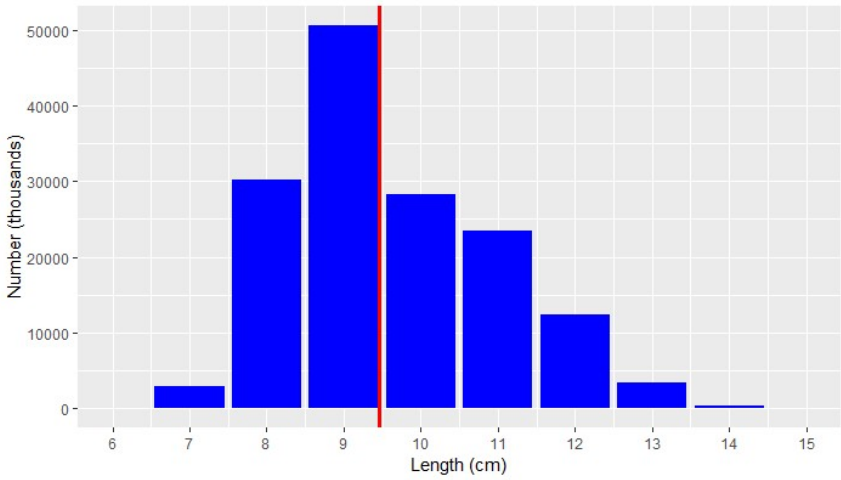

Figure 3.3.1. Length distribution of the sprat catch in 7.de for the fishing season 2018/2019. The red line represents the mean length (9.5 cm)

Little is known about the life-history parameters of sprat in the English Channel, and therefore LBI were calculated using a range of parameter values taken from the literature (Table 3.3.1), and the length-weight relationship estimated from the data provided by the producers (section 2.4).

Table 3.3.1. Life-history parameters used to estimate LBIs

Parameter	Value	Region	Reference
Linf	13	North Sea	Beverton & Holt (1959)
Linf	16.4	Western England	Iles & Johnson (1962)
Lmat	8.5	North Sea	Froese & Sampang (2013)
Lmat	10	North Sea	Beverton & Holt (1959), Johnson (1970)
M	0.7	Western Baltic	Pauly (1980)
k	0.53	Western England North Sea	Iles & Johnson (1962) Johnson (1970)
k	0.7	North Sea	Beverton & Holt (1959)

Table 3.3.2 shows the LBI, reference points, indicator ratios and their expected values. These are grouped in terms of i) conservation/sustainability; ii) optimal yield; and iii) MSY considerations. A traffic light approach was used to compare LBI estimates to reference points.

Table 3.3.2. LBIs and reference points suggested by WKLIFE V (ICES, 2015)

Indicator	Calculation	Reference point	Indicator ratio	Expected value	Property
Lmax5%	Mean length of largest 5%	Linf	Lmax5%/Linf	>0.8	Conservation (large individuals)
L95%	95th percentile		L95%/Linf		
Pmega	Proportion of individuals above Lopt+10%	0.3–0.4	Pmega	>0.3	
L25%	25th percentile of length distribution	Lmat	L25%/Lmat	>1	Conservation (immatures)
Lc	Length at first catch (length at 50% of mode)	Lmat	Lc/Lmat	>1	
Lmean	Mean length of individuals larger Lc	Lopt = 2/3 Linf	Lmean/Lopt	≈1	Optimal yield
Lmaxy	Length class with maximum biomass in catch	Lopt = 2/3 Linf	Lmaxy/Lopt	≈1	
Lmean	Mean length of individuals larger Lc	LF=M = (0.75Lc+0.25Linf)	Lmean/LF=M	≥1	MSY

4. Results

4.1. Two-stage biomass

Several attempts were performed considering different initial values of parameters and age groups along with calendar and seasonal landings respectively. For the deterministic implementation of the model, M was taken as 0.7, G calculated as 1.4, and estimation of *g* resulted in -0.7, which was used in the model to reflect biomass decrease rate.

The state-space implementation requires input data to be split by age group. Length frequency distributions of landings collected within the FSP in 2018 were used to estimate the contribution of each age group to the landings of 2018 and were applied to obtain annual landings by age group for the time series. Values of natural mortality were taken for age 1 as M_R= 1.0 and for age 2+ group as average of remaining ages, M_A=0.7. Values of G_R and G_A were estimated as 0.4 and 0.3 respectively, resulting in estimates for g_R =0.6 and g_A =0.4.

Model estimates from both implementations were not acceptable as negative biomasses were obtained due to the lack of contrast in the input data and the short length of time series.

4.2. SPiCT

Several attempts were made to fit a surplus production model to the data available. These consisted of, testing different starting values, use of the PELTIC and LPUE indices separately vs. together in the model, adding uncertainty for the years with rebuilt quarter landings, or using the two methods available to describe the seasonality of the data (i.e. B-splines, and stochastic differential equations). However, because of the lack of contrast in the data and the short time series of the PELTIC survey, the models either did not converge, or the confidence intervals were too large to consider the outputs reliable.

4.3. Length based indicators

The LBIs estimated for sprat in division 7.de are shown in Table 4.3.1. The analysis is highly sensitive to the input life-history parameters, specially Linf. The results show the stock is exploited at MSY level if Linf is 13 cm, but above MSY if Linf is 16.4 cm. Considering a threshold of ±0.10 for the Optimizing Yield indicator ratio, the stock is not being fished close to optimum yield for any of the parameter combinations tested and reported in this document. Because of the uncertainty in the life-history parameters for sprat in division 7.de, LBI is not an appropriate method to assess this stock.

Table 4.3.1. LBIs for sprat in division 7.de during the fishing season 2018/2019. The life-history parameters used for the calculations are indicated

Parameters			Conservation				Optimizing yield	MSY
Linf	**Lmat**	**M/k**	**Lc_Lmat**	**L25_Lmat**	**Lmax5_Linf**	**Pmega**	**Lmean_Lopt**	**Lmean_LFeM**
			>1	**>1**	**>0.8**	**>30%**	**~1**	**>=1**
16.4	10	1	0.80	0.90	0.76	0	0.88	0.89
16.4	8.5	1	0.94	1.06	0.76	0	0.88	0.89
13	10	1	0.80	0.90	0.96	26	1.11	1.00
13	8.5	1	0.94	1.06	0.96	26	1.11	1.00
16.4	10	1.3	0.80	0.90	0.76	2	0.88	0.93
16.4	8.5	1.3	0.94	1.06	0.76	2	0.88	0.93
13	10	1.3	0.80	0.90	0.96	45	1.11	1.03
13	8.5	1.3	0.94	1.06	0.96	45	1.11	1.03

5. Conclusions

Neither of the methods tested here were appropriate to assess sprat in division 7.de. The outputs of the two-stage biomass and SPiCT are not realistic because of the lack of contrast in the data and the short time series of the PELTIC. Length based approaches are not recommended for short-lived species as the assumption of constant recruitment is violated. In addition, the method is sensitive to the input data, and there is a large uncertainty associated with all the life-history parameters of sprat in division 7.de.

In the absence of any other appropriate or applicable methods to assess sprat in division 7.de, it is suggested to continue using a descriptive analysis of the temporal trends of LPUE, landings and biomass. It is also recommended that the two-stage biomass and SPiCT are re-run to estimate reference points and assess the stock when a longer time series of the PELTIC survey becomes available.

6. Acknowledgements

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

Management strategy evaluations for a simulated stock of sprat (*Sprattus sprattus*) in the English Channel

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INTRODUCTION

Sprat in the Channel area, specifically in the vicinity of Lyme Bay (south-west England), is currently subject to a fishery. ICES consider the population which occurs and is exploited in the area as a stock and as such provides advice on catch levels (ICES WKSPRAT, 2014, 2018). The current advice is based on ICES divisions 7.de which is a much larger area than simply Lyme Bay. In addition, there are additional sprat in other parts of the area and their occurrence and abundance varies seasonally. Currently there is no information on the stock boundaries for this area nor the relatedness with populations which occur to the east (North Sea and Skagerrak) or west (Celtic Seas). Currently there are genetic studies underway which may shed light on the population structure of sprat across the southern portion of the Greater North Sea and Celtic Seas Ecoregions.

Sprat is considered a short-lived species with a high inter annual variability in recruitment. In addition, it is prey for many larger piscivores which results in a relatively high natural mortality.

Data available for sprat in 7.de include landings with no disaggregation to age and estimates of biomass, with some information on age and length, from an acoustic survey (PELTIC) that has been operating in the area since 2013. Advice for this stock follows the ICES framework for category 3 stocks which adjusts the recent ICES advised catch by the ratio of the average of the last two PELTIC biomass estimates and the average of the three preceding estimates (termed the 2-over-3 rule) and is subject to a 20% uncertainty cap. Advice is provided on an annual basis where the latest estimates from the October PELTIC survey feed into an assessment in February/March to give advice starting the following January. However, it has been suggested to provide in-year advice, running from July–June, to reduce the lag between observation and implementation and to better match the timing of the fishery.

The last benchmark (ICES WKSPRAT, 2018) suggested that the 2-over-3 rule is not dynamic enough for short-lived and highly productive species. This was confirmed with management strategy evaluation (MSE) by the recent sprat MSE workshop (ICES WKSpratMSE, 2019) which also tested a 1-over-2 rule and found this not to be precautionary. The workshop suggested that a 20% harvest rate was appropriate to maintain the stock at safe biomass levels and produce relatively high yield.

Here management strategy evaluation (MSE) is used to evaluate two types of harvest control rule (HCR) both on an annual and in-year advice basis: (1) 1-over-2 rule and (2) harvest rates. Both HCRs are tested with additional mechanisms for stability and safeguarding biomass at perceived low stock levels. The rules are evaluated in terms of maximising yield whilst maintaining safe levels of biomass.

OPERATING MODELS

Stocks

Age-structured stocks were constructed using FLR packages FLife and FLBRP (www. flr-project.org) based on the life history parameters in Table 1, which were considered by ICES WKSpratMSE (2019) to be representative of the sprat stock in the English Channel. Two values of standard deviation were considered when simulating recruitment (σ_R=0.3; 0.5), giving two stock life histories. The creation of stocks followed WKSpratMSE (see ICES WKSpratMSE 2019 for further details) and the resulting life-history is summarised in Figure 1.

Table 1: Life-history parameters assumed in the construction of biological stocks.

	L_∞	k	T_0	a	b	s	B_{virgin}	σ_R
LH1	16	0.6	-0.8	0.0000048	3.19	0.5	1000	**0.3**
LH2	16	0.6	-0.8	0.0000048	3.19	0.5	1000	**0.5**

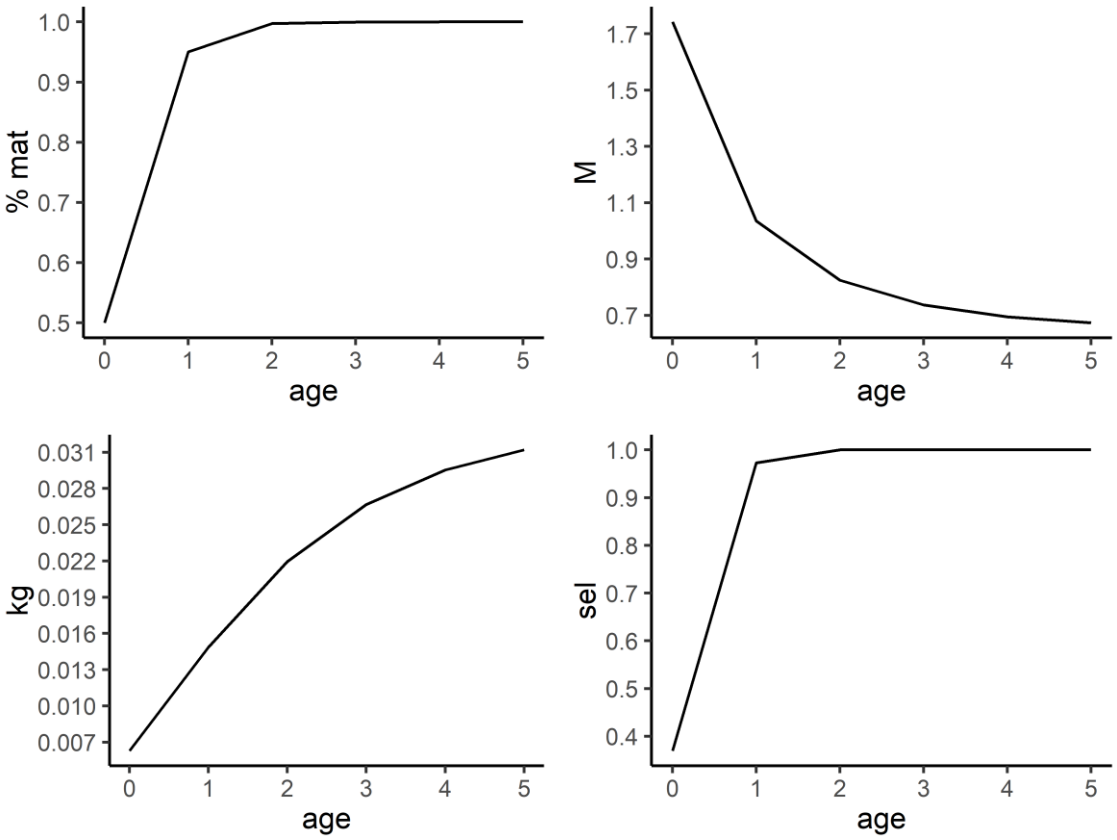

Figure 1: Life-history relationships simulated from the parameters in Table 1: (a) maturity ogive, (b) natural mortality, (c) weight-at-age and (d) selectivity-at-age.

Fishing history

Starting from virgin conditions (B_{virgin}=1000), three different fishing histories were applied to both stocks for 25 years prior to the start of the projection period (Patterson, 1992; ICES WKLIFE 7, 2018):

FH1 (Patterson): Fishing mortality increased exponentially from 0 to F_P corresponding to Patterson's exploitation rate (E=0.4=F/Z). F_P is considered to represent an appropriate level of exploitation and leads to median depletion levels of 68–69% of virgin biomass at the end of the historical period. There are no visual signs of recruitment impairment.

FH2 (One-way trip): Fishing mortality increased exponentially from 0 to 1.5F_P. This leads to a stronger depletion of the two stocks (median = 45–48% of virgin biomass) and visual signs of recruitment impairment towards the end of the historic period.

FH3 (Roller-coaster): Fishing mortality increased exponentially from 0 to 1.5F_P, stayed at this level for five years and then decreased exponentially to F_P by the end of the 25-year historic period. This leads to strong depletion and recruitment impairment for both stocks. The stock with lower recruitment variability is driven to its lowest level in year 23 (median = 17% virgin biomass) and is beginning to recover while the stock with high recruitment variability declines to 18% virgin biomass by the end of the historic period.

The combination of two life histories with three fishing histories gives six operating models in total. The historical development of the operating models is shown in Figure 2.

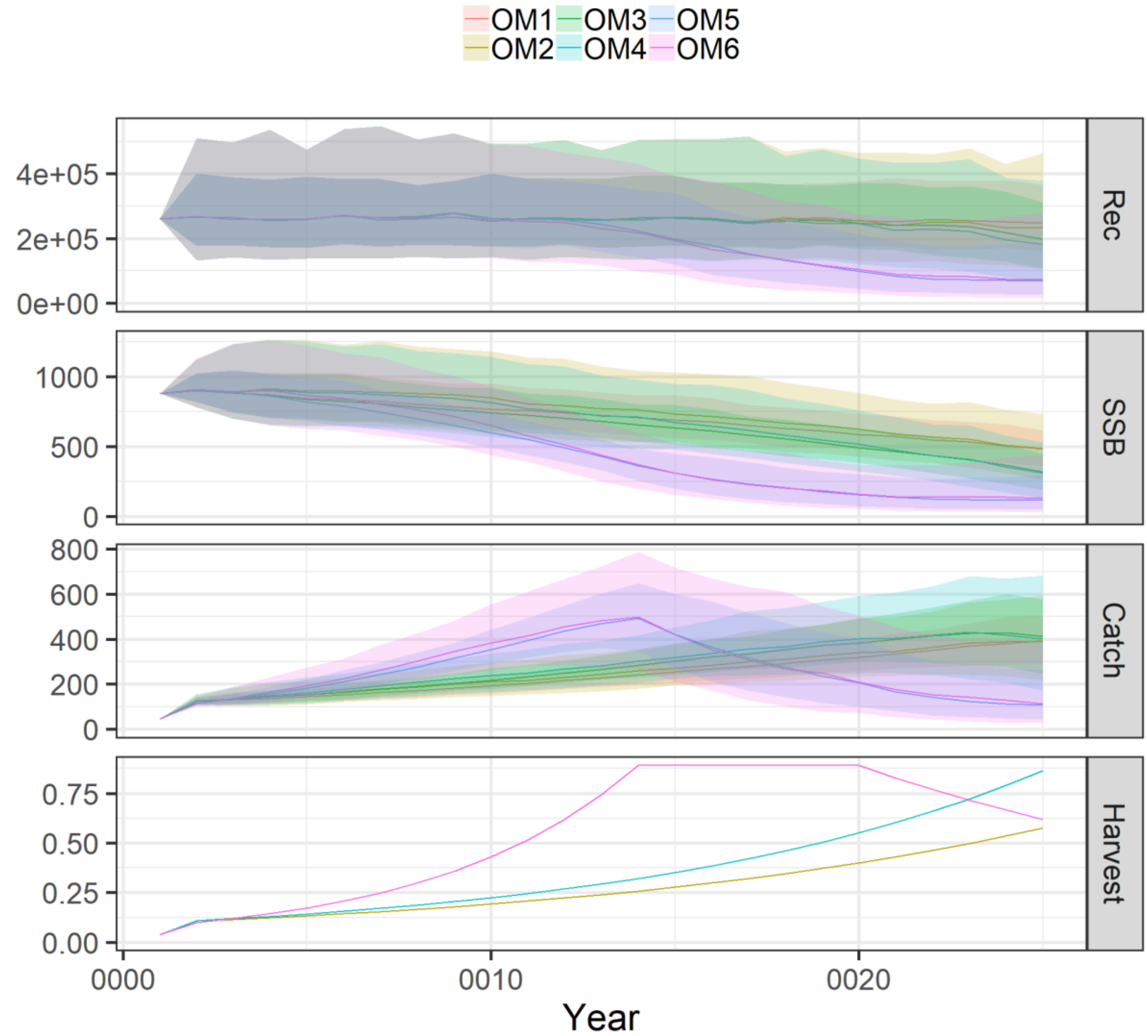

Figure 2: Historical development of the operating models. OMs 1, 2 and 5 assume σ_R=0.3 while OMs 2, 4 and 6 assume σ_R=0.5. OMs 1–2 assume the Patterson fishing history, OMs 3–4 one-way and OMs 5–6 roller-coaster.

Observation

Survey observations were generated from the operating model as follows:

$$I_{a,y} = q_a N_{a,y} e^{-t_s(F_a+M_a)} e^{\varepsilon_{a,y}}$$

Where q_a is survey catchability-at-age, $N_{a,y}$ are stock numbers-at-age and year from the operating model, t_s is the timing of the survey in relation to the modelled year and F_a and M_a are fishing and natural mortalities-at-age respectively. Survey catchability-at-age is modelled as a logistic curve with overestimation of ages 2+ (see ICES WKSpratMSE 2019) and with observation error applied such that $\varepsilon_{a,y} \sim N(0, 0.5)$.

MANAGEMENT PROCEDURE

Advice schedule

Currently advice is provided on an annual basis where the latest biomass estimates from the October PELTIC survey feed into the Herring Assessment Working Group (HAWG) estimations February/March to provide advice for the following year (1st January–31st December; Figure 3).

Figure 3: Current schedule for providing advice on fishing opportunities for Channel sprat. y relates to a model year which in this case is the same as a calendar year. The numbers in the arrows represent the number of months between each of the processes.

Given the high natural mortality rate and consequent short life span of sprat, many of the fish observed in the provision of advice will die before that advice is implemented. To reduce this lag between observation and advice, it has been suggested to provide in-year advice from 1st July–30th June (see ICES HAWG 2019 for how this has been implemented for North Sea sprat). This would result in the PELTIC survey and HAWG working group occurring in the same model year and reduce the lag between calculation and implementation of advice.

Figure 4: Suggested schedule for providing advice on fishing opportunities for Channel sprat. y relates to a model year which in this case runs from 1st July–30th June. Quantities in red signify changes from the annual schedule.

To implement these processes in the MSE, timing of the PELTIC survey (t_s) was set to 5/12 or 11/12 to relate the time of the survey (October/November) to the beginning of the model year.

Estimation model

Survey observations by age were multiplied by stock weights-at-age to emulate the process of obtaining a survey biomass index for provision of advice:

$$B_y^S = \sum_a w_a I_{a,y}$$

Where w_a are stock weights-at-age.

Decision model

Two types of harvest control rule (HCR) were tested (note that the equations are based on the provision of in-year advice; for annual advice change *y* to *y-1*):

Catch rule: Advised catch (*A*) is based on the most recent advised catch multiplied by the ratio (*r*) of the most recent biomass index value and the average of the two preceding values (1-over-2 rule), or the average of the two most recent biomass index values and the three preceding values (2-over-3 rule) (ICES WKMSYCat34, 2017).

$$A_{y+1} = rA_y; r = \frac{\sum_{i=y-x+1}^{y} B_i^s / x}{\sum_{i=y-x-z+1}^{y-x} B_i^s / z}$$

Where *x* is the numerator of the catch rule and *z* the denominator (e.g. *x*=1 and *z*=2 corresponds to the 1-over-2 rule).

Harvest rate: Advised catch corresponds to a fixed proportion (α) of the biomass index.

$$A_{y+1} = \alpha B_y^s$$

In addition, two stability and safeguarding mechanisms were tested with each of the harvest control rules:

Uncertainty cap: A change limit is imposed such that the advised catch must stay within a fixed percentage of the previous advised catch. For asymmetric caps, an upper bound of 20% change was imposed and variable lower bounds (*x*) tested.

$$A_{y+1} = \min\left(\max\left((1-x)A_y, A_{y+1}\right), 1.2A_y\right); x \geq 0.2$$

For symmetric caps both the upper and lower bounds varied together.

$$A_{y+1} = \min\left(\max\left((1-x)A_y, A_{y+1}\right), (1+x)A_y\right); x \geq 0.2$$

Biomass safeguard: The advised catch is reduced if the new biomass index value falls below reference points derived from the historic biomass index. Two reference points were considered: I_{lim}, the lowest historic index value observed at the start of the projection period, and $I_{trigger} = 1.4I_{lim}$. The reduction in advice corresponds to the distance between B_y^s and the specified reference point *I*:

$$A_{y+1} = bA_{y+1}; b = \min\left(1, \frac{B_y^s}{I}\right)$$

Performance statistics

Each operating model was projected forward for 25 years with 500 iterations for each HCR tested.

For the calculation of risk, a value of B_{lim} must be defined. The definition of B_{lim} adopted by WKSpratMSE was used here, i.e. B_{lim} was taken as 40%B_{virgin}, corresponding to the breakpoint of the segmented regression modelling recruitment in the OMs (see ICES WKSpratMSE 2019 for further details). It should be noted that this quite high value of B_{lim} will affect the classification of results as precautionary or not (see definition of risk below).

The following performance statistics were calculated for the short (first 5 projection years; 26–30), medium (next 10 years; 31–40) and long term (last 10 years; 41–50):

Risk: The average probability of SSB being below B_{lim} where the average is taken across iterations and the specified years of the projection period. Values < 0.05 are considered acceptable.

Mean yield: Median of the mean catch over the specified years of the projection period across iterations.

Mean SSB: Median of the mean SSB over the specified years of the projection period across iterations.

Mean F: Median of the mean $\bar{F}$ (ages 1–3) over the specified years of the projection period across iterations.

Mean interannual catch variability (ICV): Median of the mean ICV over the specified years of the projection period across iterations.

$$ICV = \left|\frac{C_{y+1}}{C_y} - 1\right|$$

The following statistic was calculated for the whole projection period:

Collapse: The proportion of iterations where the stock collapsed at any point during the projection period. A collapse is defined as a state where SSB < 1.

Harvest control rules are primarily evaluated in terms of maximising yield whilst maintaining safe levels of risk.

RESULTS

Catch rule

No catch rule was precautionary without the addition of stability or safeguarding mechanisms (risk > 5%). Short term risk was largely influenced by initial conditions while medium to long term the 1-over-2 rule was more precautionary than the 2-over-3 rule and the in-year advice schedule more precautionary than the annual schedule (with the exception of the roller-coaster OMs where the annual 2-over-3 rule was more precautionary than the in-year 2-over-3 rule medium term for OM 5 and long term for OMs 5–6; Figure 5). Time-series plots show the 2-over-3 rule to be more variable and uncertain that the 1-over-2 rule (Figure 6).

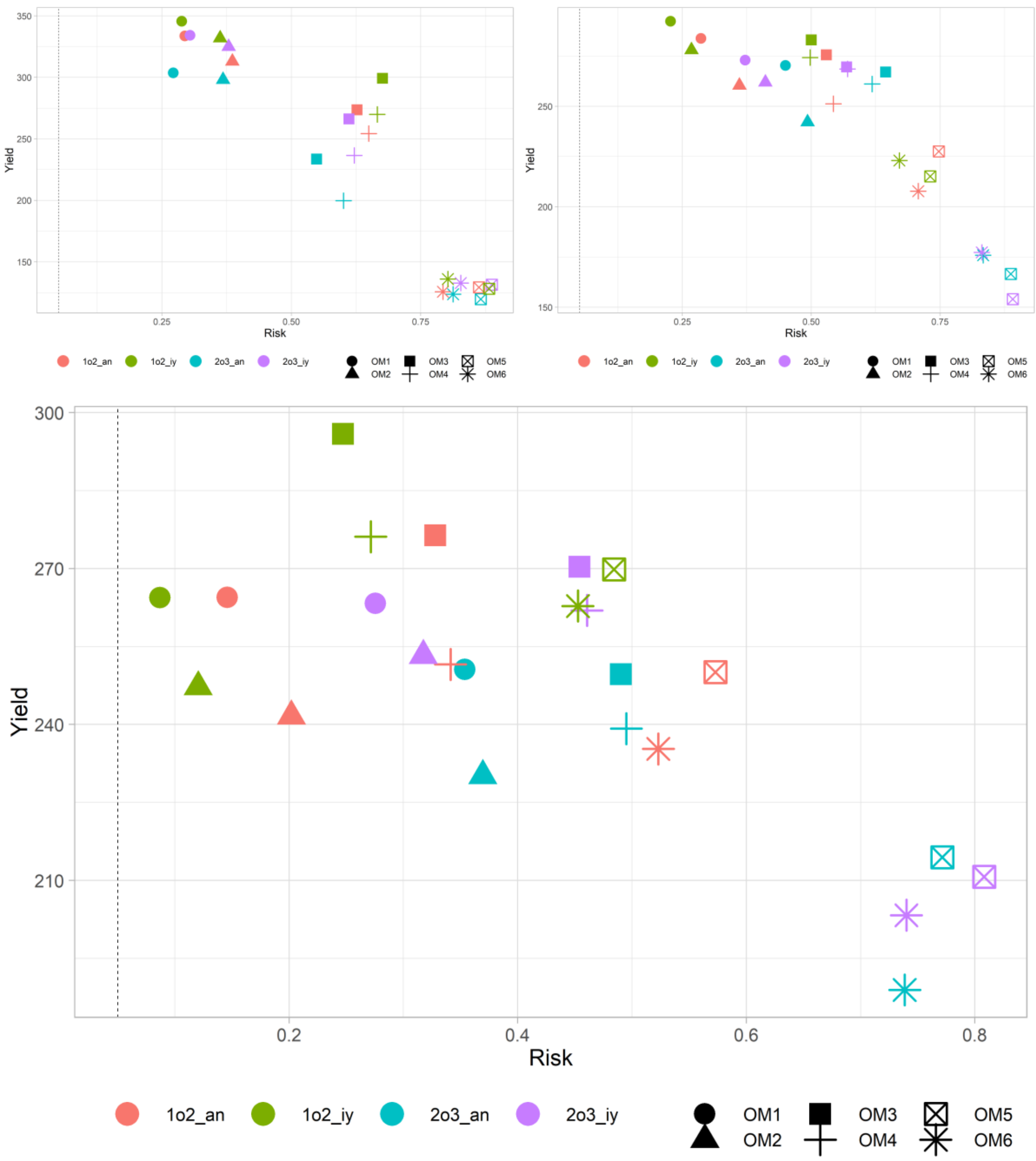

Figure 5: Short-, medium- and long-term plots of yield against risk for the 1-over-2 (1o2) and 2-over-3 (2o3) rules following annual (an) and in-year (iy) advice schedules.

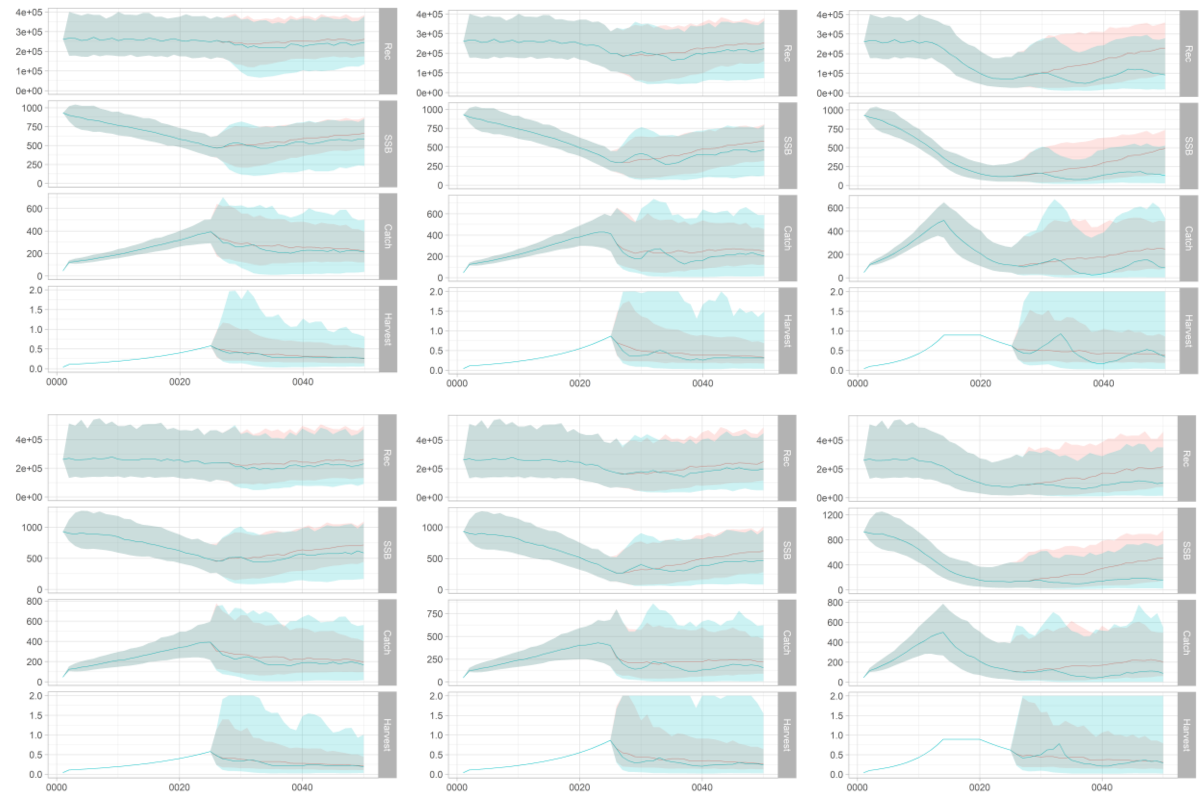

Figure 6: Time-series plots for recruitment, spawning stock biomass (SSB), catch and harvest for the 1-over-2 (red) and 2-over-3 (blue) rules following an in-year advice schedule. Top row: OMs 1, 3 and 5 with low recruitment variability. Bottom row: OMs 2, 4, and 6 with higher recruitment variability. Left: Patterson fishing history. Middle: One-way fishing history. Right: Roller-coaster fishing history.

__In-year 1-over-2 rule with mechanisms__

Adding an uncertainty cap with asymmetric bounds makes the in-year 1-over-2 rule precautionary in the long term for all OMs tested provided the lower bound of the uncertainty cap is larger than 60% (Figure 7). It was not precautionary for any OMs in the short term or when the lower bound of the uncertainty cap was set to 20%. The probability of collapse was >1% when the lower bound of the uncertainty cap was 50% or less and was as high as 56% for the 20% uncertainty cap (OM4). There was little difference in mean long term yield (< 2 tonnes across OMs) when applying asymmetric uncertainty caps with lower bounds larger than 80% (Figure 7). Symmetric uncertainty caps were shown not to be precautionary in the short to medium term and were only sometimes precautionary in the long term for OMs with Patterson fishing history (OMs 1–2) if the bounds of the uncertainty cap were greater than 60% (Figure 7). In this case the probability of collapse was greater than 1% when bounds of the uncertainty cap were 60% or less.

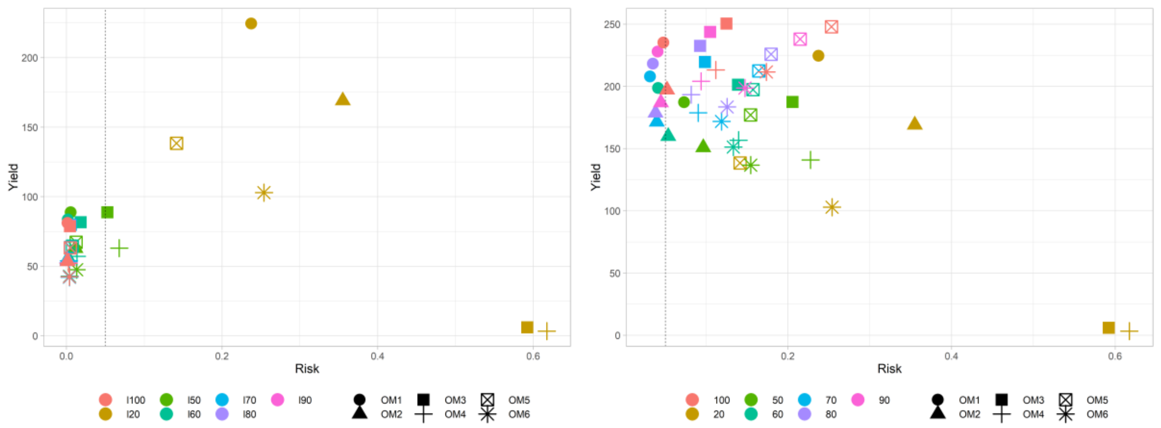

Figure 7: Long-term yield against risk for the 1-over-2 rule on an in-year advice basis with asymmetric (left) and symmetric (right) uncertainty caps.

Adding a biomass safeguard, employing either I_{lim} or $I_{trigger}$, makes the in-year 1-over-2 rule more precautionary medium to long term (Figures Figure 8Figure 9). Long term risk is less than 5% for OMs 1–3 when employing I_{lim} as a reference point and for all OMs with Patterson or one-way fishing history (OMs 1–4) when employing $I_{trigger}$ as a reference point (Figure 9).

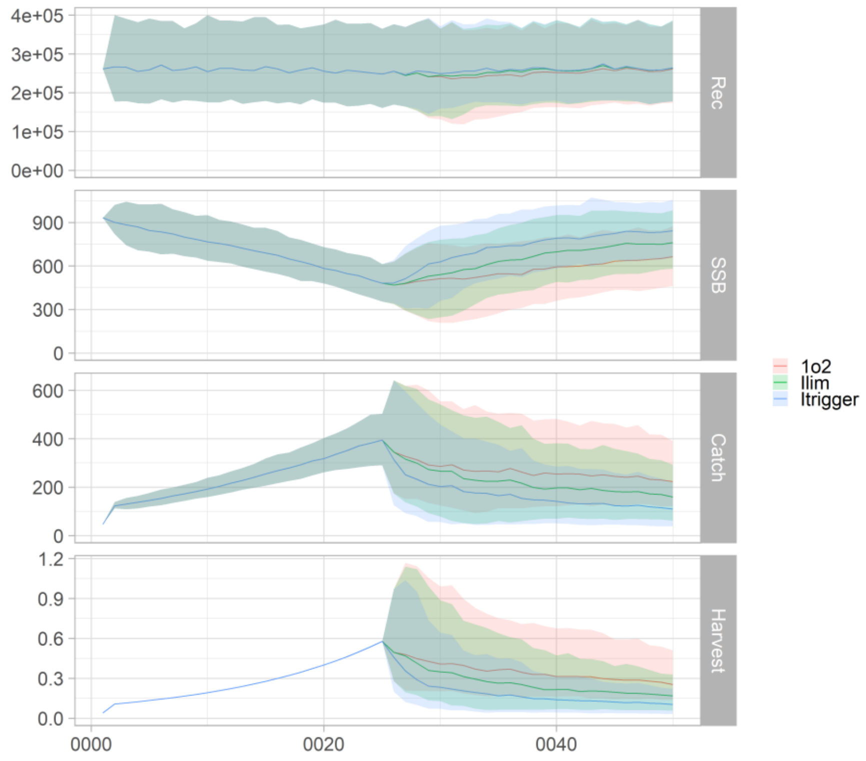

Figure 8: Time-series plots for recruitment, spawning stock biomass (SSB), catch and harvest for the 1-over-2 rule and 1-over-2 rule with biomass safeguards following an in-year advice schedule. Results are plotted for OM1 but trends are similar across OMs.

Short term risk and catch statistics are primarily driven by historical exploitation while the trade-offs between HCRs are better seen in the medium- to long-term (Figure 9). Of the key mechanisms presented in Figure 9 an asymmetric uncertainty cap with 20% upper bound and 80% lower bound is the most precautionary but results in the largest loss of long-term yield. The biomass safeguards and symmetric 80% uncertainty cap provide an intermediate trade-off between minimising risk and maximising long-term yield.

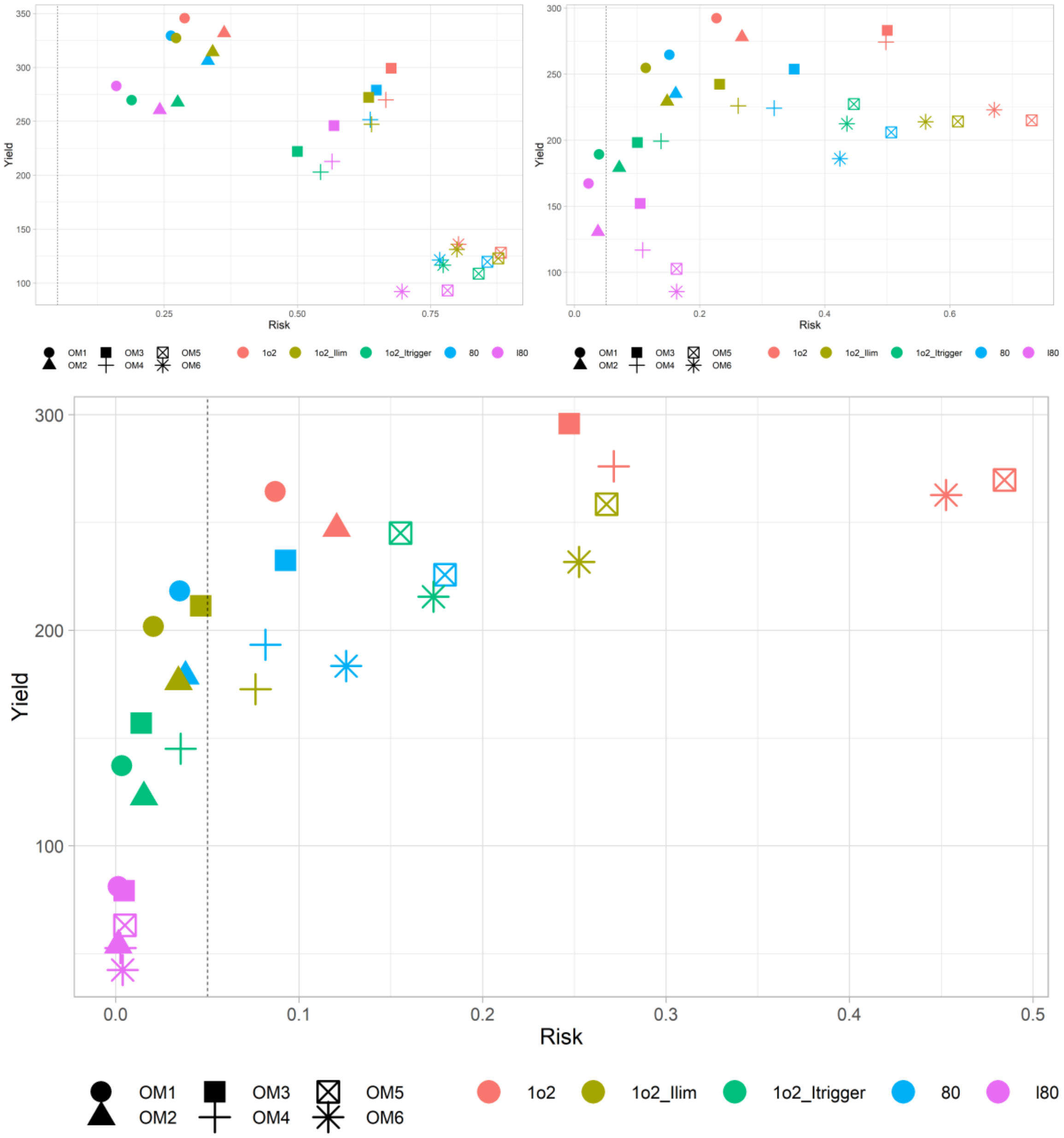

Figure 9: Short-, medium- and long-term plots of yield against risk for the 1-over-2 rule (1o2) and 1-over-2 rule with select mechanisms (Ilim = Ilim safeguard; Itrigger = Itrigger safeguard; 80 = 80% symmetric uncertainty cap; I80 = asymmetric uncertainty cap with 20% upper bound and 80% lower bound) following an in-year advice schedule.

Annual catch rules with mechanisms

Adding an uncertainty cap with asymmetric bounds makes the annual 1-over-2 rule precautionary in the long term for all OMs tested provided the lower bound of the uncertainty cap is larger than 60% (Figure 10). As for the in-year advice schedule, it was not precautionary for any OMs in the short term or when the lower bound of the uncertainty cap was set to 20%. The probability of collapse was >1% when the lower bound of the uncertainty cap was 50% or less and was as high as 56% for the 20% uncertainty cap (OM4).

An asymmetric uncertainty cap makes the annual 2-over-3 rule precautionary in the long term for all OMs only when the lower bound of the uncertainty cap is larger than 80%. It is not precautionary for any OMs in the short to medium term. The 20% uncertainty cap is the least precautionary option and results in collapse probabilities as high as 53% (Figure 10).

Symmetric uncertainty caps (aside from 20%) were not tested under an annual advice schedule.

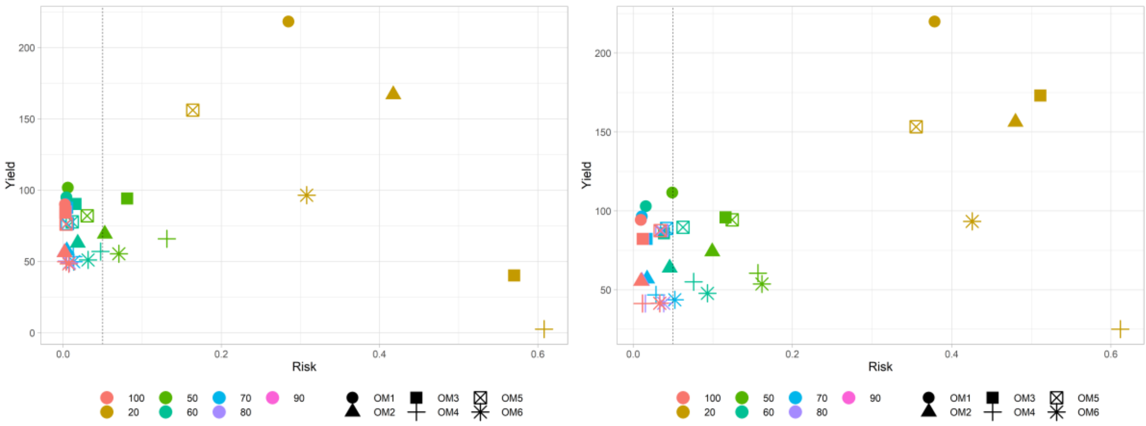

Figure 10: Long-term yield against risk for the 1-over-2 (left) and 2-over-3 (right) rules on an annual advice basis with asymmetric uncertainty caps.

Adding a biomass safeguard, employing either I_{lim} or $I_{trigger}$, makes the annual 1-over-2 rule more precautionary medium to long term (Figure 11). Long term risk is less than 5% for OMs 1–2 when employing I_{lim} as a reference point and, as for the in-year advice schedule, for all OMs with Patterson or one-way fishing history (OMs 1–4) when employing $I_{trigger}$ as a reference point (Figure 12).

As for the in-year one-over-2 rule, an asymmetric uncertainty cap with 20% upper bound and 80% lower bound is the most precautionary of the key mechanisms tested but results in the largest loss of long-term yield (Figure 12). Biomass safeguards provide an intermediate trade-off between minimising risk and maximising long-term yield.

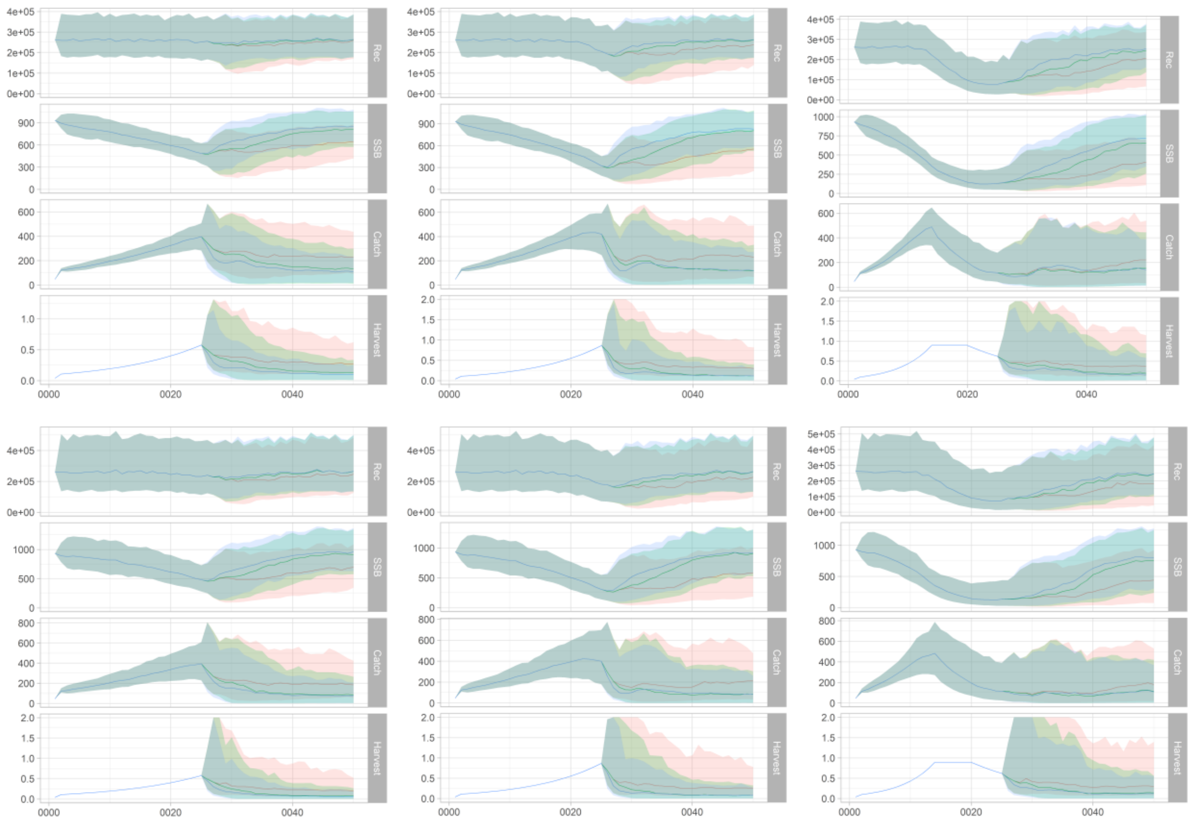

Figure 11: Time-series plots for recruitment, spawning stock biomass (SSB), catch and harvest for the 1-over-2 rule (red) and 1-over-2 rule with biomass safeguards based on I_{lim} (green) and $I_{trigger}$ (blue) following an annual advice schedule. Top row: OMs 1, 3 and 5 with low recruitment variability. Bottom row: OMs 2, 4, and 6 with higher recruitment variability. Left: Patterson fishing history. Middle: One-way fishing history. Right: Roller-coaster fishing history.

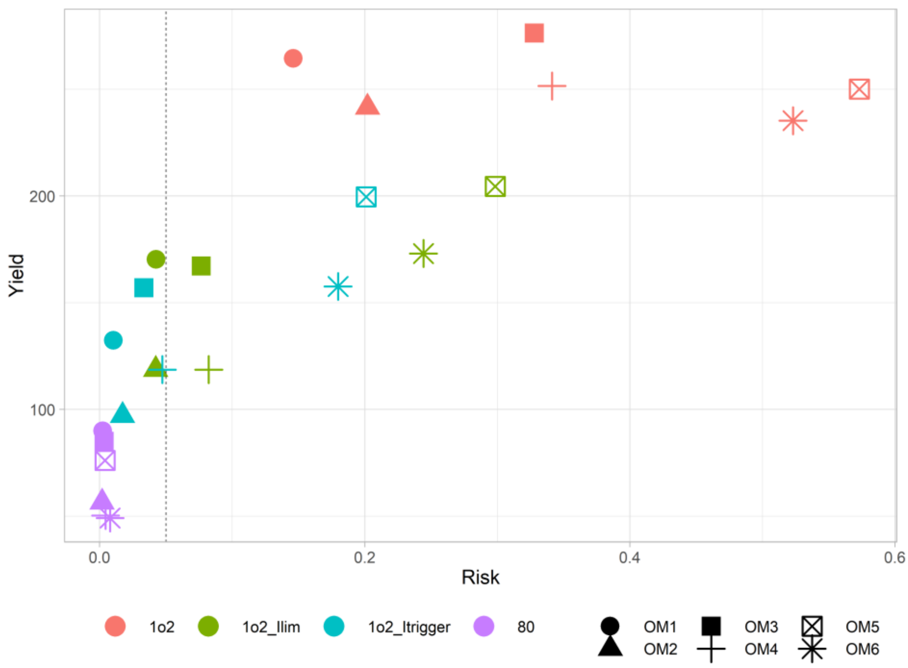

Figure 12: Long-term yield against risk for the 1-over-2 rule (1o2) and 1-over-2 rule with select mechanisms (Ilim = Ilim safeguard; Itrigger = Itrigger safeguard; 80 = asymmetric uncertainty cap with 20% upper bound and 80% lower bound) following an annual advice schedule.

Harvest rate

Harvest rates were tested assuming an in-year advice schedule. Time-series plots of constant harvest rates between 10–40% of the biomass index show spawning stock biomass to decrease with increasing harvest rate and catches to increase initially but decline when the harvest rate becomes too high (Figure 13).

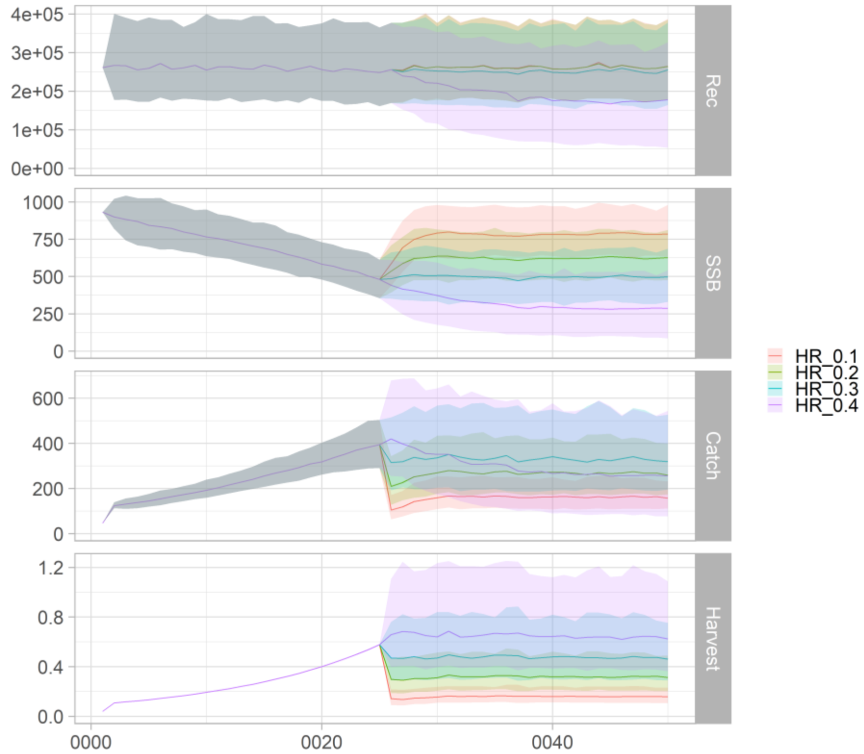

Figure 13: Time-series plots for recruitment, spawning stock biomass (SSB), catch and harvest for a fixed harvest rate HCR following an in-year advice schedule. Results are plotted for OM1 but trends are similar across OMs.

Harvest rates of up to 17% of the estimated biomass index were shown to be precautionary in the long-term for all OMs while harvest rates of up to 22% were precautionary for the OMs with lower recruitment variability (Table 2).

Including an asymmetric uncertainty cap with maximum change limits of 20% upwards and 80% downwards resulted in higher harvest rates becoming precautionary in the long-term (19% for all OMs and 26% for the OMs with lower recruitment variability; Table 2) but with some loss of yield.

Biomass safeguards did not alter the 17% harvest rate for all OMs to be precautionary and the 22% rate for OMs with lower recruitment variability, but did result in higher harvest rates becoming precautionary for some OMs (23% for OM1 when considering I_{lim} as a reference point; 25% and 23% for OMs 1 and 3 with lower recruitment variability and 19% and 18% for OMs 2 and 4 with higher recruitment variability when considering $I_{trigger}$ as a reference point; Table 2).

Table 2: Short-, medium- and long-term risk statistics for harvest rates between 17–27% with and without stability and safeguarding mechanisms.

Short term

	No mechanisms						Asymmetric uncertainty cap (20/80)						Biomass safeguard (Ilim)						Biomass safeguard (Itrigger)					
	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6
17%	3%	10%	21%	29%	66%	59%	3%	9%	20%	27%	63%	55%	3%	9%	19%	27%	66%	58%	2%	7%	15%	22%	63%	56%
18%	3%	11%	22%	30%	68%	59%	3%	9%	21%	28%	64%	56%	3%	10%	20%	28%	67%	59%	2%	7%	15%	23%	64%	57%
19%	4%	12%	23%	32%	69%	61%	3%	10%	21%	29%	65%	57%	4%	11%	21%	30%	68%	60%	2%	8%	16%	24%	65%	58%
20%	4%	14%	25%	34%	70%	62%	4%	11%	22%	30%	66%	58%	4%	12%	22%	32%	70%	61%	2%	9%	16%	25%	66%	59%
21%	5%	15%	26%	35%	71%	63%	4%	12%	23%	31%	66%	59%	5%	13%	24%	33%	71%	62%	3%	10%	17%	26%	67%	60%
22%							5%	14%	24%	32%	68%	60%	6%	14%	25%	34%	72%	63%	3%	11%	18%	27%	68%	61%
23%							5%	15%	26%	33%	68%	60%							4%	12%	19%	28%	68%	61%
24%																			4%	12%	20%	29%	70%	62%
25%																			5%	13%	21%	30%	71%	63%

Medium term

	No mechanisms						Asymmetric uncertainty cap (20/80)						Biomass safeguard (Ilim)						Biomass safeguard (Itrigger)					
	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6
17%	1%	4%	1%	5%	8%	14%	0%	2%	0%	2%	4%	7%	1%	3%	1%	5%	8%	13%	0%	2%	1%	4%	6%	12%
18%	1%	5%	1%	7%	9%	16%	0%	3%	0%	3%	4%	8%	1%	5%	1%	6%	9%	15%	1%	3%	1%	5%	7%	14%
19%	1%	7%	2%	8%	10%	18%	0%	4%	0%	4%	5%	9%	1%	6%	1%	8%	10%	18%	1%	4%	1%	6%	8%	16%
20%	2%	9%	2%	10%	12%	20%	0%	4%	0%	5%	5%	10%	2%	7%	2%	9%	12%	20%	1%	5%	2%	7%	9%	17%
21%	3%	11%	3%	12%	14%	23%	1%	6%	1%	6%	6%	11%	3%	9%	3%	11%	13%	22%	2%	6%	2%	9%	11%	20%
22%	4%	13%	4%	15%	16%	26%	1%	7%	1%	7%	6%	12%	3%	10%	4%	13%	16%	25%	2%	8%	3%	10%	13%	22%
23%	5%	16%	6%	17%	19%	29%	2%	8%	1%	8%	7%	13%	5%	12%	5%	15%	18%	28%	3%	9%	4%	12%	15%	25%
24%							3%	10%	2%	9%	8%	14%	6%	14%	7%	18%	21%	31%	4%	10%	6%	14%	18%	28%
25%							3%	11%	3%	11%	9%	15%							5%	12%	7%	16%	21%	30%
26%							5%	13%	4%	12%	10%	16%												
27%							6%	14%	5%	14%	12%	18%												

Long term

	No mechanisms						Asymmetric uncertainty cap (20/80)						Biomass safeguard (Ilim)						Biomass safeguard (Itrigger)					
	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6	OM1	OM2	OM3	OM4	OM5	OM6
17%	0%	4%	0%	4%	0%	5%							0%	4%	0%	4%	0%	5%	0%	3%	0%	3%	0%	4%
18%	1%	6%	1%	6%	1%	6%							1%	5%	1%	5%	1%	6%	0%	4%	1%	5%	1%	6%
19%	1%	7%	1%	7%	1%	8%	1%	4%	1%	4%	1%	4%	1%	6%	1%	7%	1%	8%	1%	4%	1%	6%	1%	7%
20%	2%	9%	2%	9%	2%	9%	1%	5%	1%	6%	1%	5%	2%	7%	2%	8%	2%	9%	1%	5%	2%	7%	2%	9%
21%	3%	10%	3%	10%	3%	11%	1%	6%	1%	6%	1%	6%	3%	8%	3%	10%	3%	11%	2%	6%	3%	8%	3%	10%
22%	4%	12%	4%	12%	4%	13%	2%	7%	2%	7%	2%	6%	3%	10%	4%	11%	4%	13%	2%	7%	3%	10%	4%	12%
23%	6%	14%	6%	14%	6%	15%	2%	8%	2%	8%	2%	7%	5%	11%	5%	13%	6%	15%	3%	9%	4%	11%	6%	14%
24%							3%	10%	3%	9%	3%	9%	6%	13%	7%	15%	8%	17%	4%	10%	5%	13%	7%	17%
25%							4%	11%	4%	11%	4%	10%							5%	12%	7%	15%	9%	19%
26%							5%	12%	5%	12%	5%	11%							6%	13%	8%	17%	11%	22%
27%							6%	14%	6%	14%	5%	13%												

Comparison of select HCRs

Tables Table 3Table 5 show all performance statistics for select HCRs across all OMs and ranks the HCRs according to long-term risk. The annual 2-over-3 rule with 20% uncertainty cap (currently used to provide advice) is the least precautionary HCR and carries the largest probability of collapse (note the ranking for OMs 5–6 is due to the numeric precision of the software allowing the stocks to recover after collapse). The catch rules without stability or safeguarding mechanisms rank the lowest across all OMs with the 2-over-3 rule performing worse than the 1-over-2 rule.

The asymmetric uncertainty cap with 20% upper and 80% lower bounds and 10% and 17% harvest rates were precautionary across all OMs but with the asymmetric uncertainty cap resulting in the lowest yield (except for OM4 where the annual 2-over-3 rule with 20% uncertainty cap had the lowest yield). A 17% harvest rate results in some of the highest yields whilst remaining precautionary across all OMs (Figure 14).

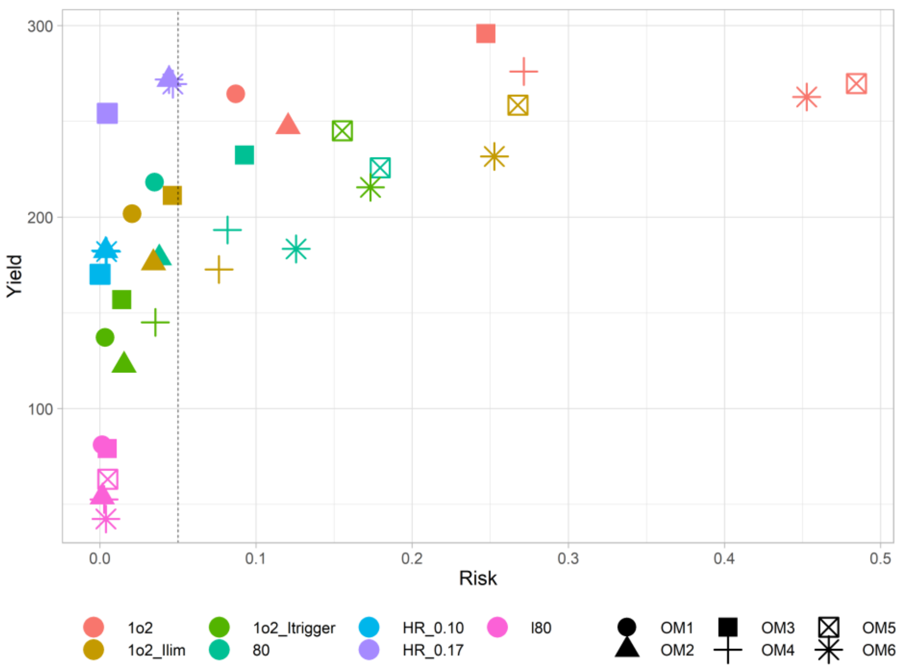

Figure 14: Long-term yield against risk for select HCRs following an in-year advice schedule. 1-over-2 rule (1o2), 1-over-2 rule with biomass safeguards (Ilim = Ilim safeguard; Itrigger = Itrigger safeguard) 1-over-2 rule with 80% symmetric (80) and asymmetric uncertainty cap (I80), 10% harvest rate (HR_0.10) and 17% harvest rate (HR_0.17).

Table 3: Performance statistics for select HCRs applied to OMs 1 and 2 with Patterson fishing history. HRCs are ranked according to long-term risk. Risks >5% are highlighted in red and yields are coloured according to magnitude.

	risk			collapse	yield			mean SSB			mean F			mean ICV		
	short	medium	long		short	meduim	long	short	medium	long	short	medium	long	short	medium	long
OM1																
HR_0.1	1%	0%	0%	0%	143	172	170	725	790	792	0.15	0.17	0.17	45%	33%	33%
1o2_UCl_80	16%	2%	0%	0%	283	167	81	556	755	902	0.39	0.18	0.07	22%	21%	19%
1o2_Itrigger	19%	4%	0%	0%	270	189	137	566	734	817	0.37	0.21	0.13	43%	38%	30%
HR_0.17	3%	1%	0%	0%	227	257	254	645	671	673	0.27	0.29	0.29	41%	36%	36%
1o2_Ilim	27%	11%	2%	0%	327	255	202	513	629	728	0.48	0.33	0.22	37%	41%	32%
1o2_UC_80	26%	15%	4%	0%	329	265	218	512	604	704	0.49	0.35	0.24	33%	35%	31%
1o2_noUC	29%	23%	9%	0%	346	292	264	502	548	631	0.50	0.42	0.33	35%	41%	36%
1o2_an_noUC	29%	29%	15%	0%	334	284	264	517	535	615	0.50	0.44	0.35	36%	47%	43%
2o3_noUC	30%	37%	28%	0%	334	273	263	516	473	557	0.49	0.48	0.41	30%	47%	47%
2o3_an_noUC	27%	45%	35%	0%	304	270	251	541	443	536	0.43	0.54	0.44	30%	62%	76%
2o3_UCl_20_an	27%	35%	38%	28%	319	276	220	518	554	588	0.45	0.46	0.41	17%	18%	18%
OM2																
1o2_UCl_80	24%	4%	0%	0%	261	131	54	590	859	1010	0.34	0.13	0.04	24%	21%	20%
HR_0.1	6%	0%	0%	0%	148	185	183	742	847	848	0.15	0.17	0.17	49%	38%	36%
1o2_Itrigger	28%	7%	2%	0%	268	179	123	571	791	909	0.35	0.18	0.11	49%	45%	35%
1o2_Ilim	34%	15%	3%	0%	314	229	176	522	683	830	0.46	0.28	0.17	45%	49%	37%
1o2_UC_80	33%	16%	4%	0%	306	235	179	527	672	825	0.45	0.28	0.17	39%	38%	34%
HR_0.17	10%	4%	4%	0%	234	276	272	657	716	719	0.27	0.30	0.29	46%	42%	40%
1o2_noUC	36%	27%	12%	0%	332	278	247	510	572	699	0.49	0.39	0.29	42%	49%	41%
1o2_an_noUC	39%	36%	20%	0%	313	260	242	526	552	685	0.49	0.41	0.30	43%	58%	50%
2o3_noUC	38%	41%	32%	0%	325	262	253	521	490	603	0.50	0.47	0.39	38%	62%	60%
2o3_an_noUC	37%	49%	37%	0%	298	242	230	533	465	583	0.43	0.55	0.44	38%	74%	88%
2o3_UCl_20_an	37%	42%	48%	39%	313	231	156	516	582	588	0.46	0.44	0.45	18%	19%	19%

Table 4: Performance statistics for select HCRs applied to OMs 3 and 4 with one-way fishing history. HRCs are ranked according to long-term risk. Risks >5% are highlighted in red and yields are coloured according to magnitude.

	risk			collapse	yield			mean SSB			mean F			mean ICV		
	short	medium	long		short	meduim	long	short	medium	long	short	medium	long	short	medium	long
OM3																
HR_0.1	15%	0%	0%	0%	120	171	170	645	789	792	0.14	0.17	0.17	54%	34%	33%
1o2_UCI_80	57%	11%	0%	0%	246	152	79	393	711	898	0.53	0.18	0.07	25%	20%	19%
HR_0.17	21%	1%	0%	0%	190	256	254	571	671	673	0.25	0.29	0.29	51%	37%	36%
1o2_Itrigger	50%	10%	1%	0%	222	198	157	432	691	787	0.42	0.23	0.16	52%	41%	31%
1o2_Ilim	63%	23%	5%	0%	272	242	211	350	578	720	0.59	0.34	0.23	45%	47%	33%
1o2_UC_80	65%	35%	9%	0%	279	254	232	338	503	662	0.63	0.40	0.28	37%	38%	33%
1o2_noUC	68%	50%	25%	0%	299	283	296	329	408	540	0.67	0.52	0.43	40%	47%	40%
1o2_an_noUC	63%	53%	33%	0%	274	276	276	351	397	502	0.61	0.55	0.45	41%	54%	50%
2o3_noUC	61%	57%	45%	0%	266	270	270	382	341	441	0.54	0.62	0.53	39%	64%	67%
2o3_an_noUC	55%	64%	49%	0%	234	267	250	415	322	439	0.45	0.75	0.56	37%	76%	95%
2o3_UCI_20_an	68%	49%	51%	42%	281	234	173	312	459	438	0.62	0.55	0.59	18%	19%	19%
OM4																
1o2_UCI_80	57%	11%	0%	0%	213	117	53	398	814	1010	0.44	0.13	0.04	27%	21%	20%
HR_0.1	22%	1%	0%	0%	119	183	183	653	842	848	0.14	0.17	0.17	58%	39%	36%
1o2_Itrigger	54%	14%	4%	0%	203	199	145	414	720	877	0.38	0.22	0.13	56%	49%	35%
HR_0.17	29%	5%	4%	0%	189	274	272	576	713	719	0.26	0.29	0.29	55%	42%	40%
1o2_Ilim	64%	26%	8%	0%	247	226	173	348	613	808	0.54	0.31	0.18	50%	55%	38%
1o2_UC_80	64%	32%	8%	0%	252	224	193	342	580	780	0.54	0.32	0.20	41%	41%	35%
1o2_noUC	67%	50%	27%	0%	270	274	276	323	435	591	0.64	0.48	0.39	46%	55%	47%
1o2_an_noUC	65%	54%	34%	0%	254	251	252	327	419	578	0.62	0.52	0.40	47%	62%	59%
2o3_noUC	62%	57%	46%	0%	237	269	262	356	377	486	0.54	0.61	0.52	46%	73%	75%
2o3_an_noUC	60%	62%	50%	0%	200	261	239	389	361	472	0.45	0.70	0.58	44%	85%	99%
2o3_UCI_20_an	70%	58%	61%	53%	262	161	25	267	344	6	0.71	0.99	2.00	20%	24%	33%

*Table 5: Performance statistics for select HCRs applied to OMs 5 and 6 with roller-coaster fishing history. HRCs are ranked according to long-term risk. Risks >5% are highlighted in red and yields are coloured according to magnitude. *A large proportion of these stocks were driven to low levels/collapse short- to medium term but were able to recover due to the numeric precision of the software and restrictive 20% cap, hence the more optimistic long-term risk ranking.*

	risk			**collapse**	**yield**			**mean SSB**			**mean F**			**mean ICV**		
	short	medium	long		short	meduim	long	short	medium	long	short	medium	long	short	medium	long
OM5																
HR_0.1	59%	3%	0%	0%	57	162	170	359	763	792	0.13	0.16	0.17	60%	39%	33%
HR_0.17	66%	8%	0%	0%	87	240	254	301	643	673	0.23	0.28	0.29	54%	42%	36%
1o2_UCl_80	78%	16%	1%	0%	93	103	63	216	709	926	0.38	0.13	0.06	21%	19%	19%
1o2_Itrigger	84%	45%	16%	0%	109	227	245	183	455	630	0.45	0.41	0.32	51%	51%	37%
1o2_UC_80	86%	51%	18%	0%	120	206	226	165	411	630	0.53	0.42	0.30	37%	41%	35%
1o2_Ilim	88%	61%	27%	0%	123	214	259	159	348	549	0.57	0.50	0.39	46%	52%	41%
2o3_UCl_20_an*	84%	42%	36%	28%	111	157	153	187	529	642	0.40	0.35	0.33	17%	19%	17%
1o2_noUC	88%	73%	48%	0%	128	215	270	156	262	416	0.60	0.58	0.50	44%	50%	45%
1o2_an_noUC	86%	75%	57%	0%	129	228	250	162	241	368	0.54	0.64	0.52	42%	55%	56%
2o3_an_noUC	87%	89%	77%	0%	120	167	214	170	133	238	0.50	0.89	0.75	40%	77%	105%
2o3_noUC	89%	89%	81%	0%	131	154	211	156	139	208	0.58	0.81	0.76	43%	73%	85%
OM6																
1o2_UCl_80	70%	16%	0%	0%	92	86	42	255	815	1023	0.35	0.10	0.03	22%	20%	20%
HR_0.1	53%	6%	0%	0%	64	171	182	392	807	848	0.13	0.17	0.17	62%	43%	36%
HR_0.17	59%	14%	5%	0%	97	252	270	335	676	717	0.23	0.28	0.29	57%	47%	40%
1o2_UC_80	77%	42%	13%	0%	122	186	183	202	512	756	0.46	0.33	0.21	42%	43%	35%
1o2_Itrigger	77%	44%	17%	0%	117	213	216	206	496	711	0.43	0.38	0.25	57%	59%	43%
1o2_Ilim	80%	56%	25%	0%	131	214	232	185	388	641	0.55	0.44	0.32	52%	60%	46%
2o3_UCl_20_an*	76%	47%	43%	37%	112	107	93	196	532	692	0.41	0.33	0.31	19%	20%	18%
1o2_noUC	80%	67%	45%	0%	136	223	263	175	303	474	0.58	0.54	0.44	49%	58%	52%
1o2_an_noUC	79%	71%	52%	0%	126	208	235	169	265	424	0.60	0.59	0.49	50%	65%	63%
2o3_an_noUC	81%	83%	74%	1%	124	176	189	161	169	259	0.57	0.85	0.70	46%	86%	112%
2o3_noUC	83%	83%	74%	0%	133	177	203	163	175	241	0.59	0.75	0.71	51%	78%	89%

CONCLUSIONS

- The current procedure for providing advice (2-over-3 rule with 20% uncertainty cap on an annual advice schedule) is not precautionary and resulted in high levels of risk and collapse.
- In general, the 1-over-2 rule is more precautionary than the 2-over-3 rule and the in-year advice schedule more precautionary than the annual advice schedule.
- Additional mechanisms are needed for the 1-over-2 rule (both on an annual and in-year advice schedule) to be precautionary.
- Of the key mechanisms tested an asymmetric uncertainty cap with 20% upper bound and 80% lower bound is the most precautionary but resulted in the largest loss of long-term yield. The 20% upper bound may be too constraining and future work should consider variable upper and lower bounds of the uncertainty cap.
- Biomass safeguards and the 80% symmetric uncertainty cap provide an intermediate trade-off between minimising risk and maximising long-term yield. However, care should be taken as the relationship between PELTIC index biomass and stock status is unknown. Further testing should consider the robustness of the reference points and inclusion of reference point updates (i.e. through benchmarks) when evaluating performance of the HCRs.
- Additional mechanisms were shown to be ineffective when employing a fixed harvest rate.
- A 17% harvest rate lead to the highest yields whilst being precautionary across all OMs and may therefore be a suitable option when initial stock status is unknown. However, harvest rates applied to these simulated stocks may not translate directly to sprat in 7.de. Future work should test the sensitivity of harvest rates to model assumptions including catchability, model uncertainties, stock recruitment, operating model and modelling platform.

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North Sea Sprat SPiCT MSE

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7 October 2019

Introduction

The purpose of this study was to compare harvest control rules (HCRs) for category 3 stocks including SPiCT, 1-over-2, 2-over-3, and modifications of those rules Although North Sea sprat is not a category 3 stock, enough data is available on this stock to parameterize a simulation model. The stock was used simply because a simulation model was needed to evaluate the HCRs and one was available for the North Sea sprat. The assessment model used to estimate the parameters used in the simulation model is not the same as the assessment model used in the 2018 sprat benchmark; the version used here has catches in all quarters because SPiCT developers reccommend that all observed catches should be non-zero.

Methods

Management Strategy Evaluation conceptual overview

The MSE projects the age structured population forward in the operating model, TAC year by TAC year, accounting for management advice (i.e. setting the TAC based on estimates from the assessment), fishing mortality, natural mortality, and recruitment. The true stock numbers on the log scale (logN) and the true exploitation pattern on the log scale (logE) in a given year of a given simulation trial represent the state of the system at that time and are referred to as the "true state". The true state has one value of logN and one value of logE per age per quarter of every year and simulation trial (later we assume that the true logE is constant across TAC years). "Estimated state" also refers to the state of the system in a given year and simulation trial; it has a median logN and logE for each age and quarter, but with uncertainty around those estimates, represented by a multivariate normal distribution.

Seasonal and age structured operating model

The operating and observation models used in this MSE are structured by quarters and by age as done in the SMS assessment model. Age groups are 0, 1, 2, and 3+. The TAC year is shifted by 2 quarters from the calendar year, the quarters of the TAC year are quarters 3, 4, 1, and 2 of the calendar year (abbreviated s1, s2, s3, s4 henceforth). The escaped SSB is calculated in s1 after the TAC year. The state variables N (stock numbers) and E (exploitation or selectivity pattern), are both structured according to season and age. E refers to the exploitation pattern before it is multiplied by an F multiplier to get the actual fishing mortality in an individual year.

Starting state

This MSE begins in the 2018 TAC year. Each simulation trial of the MSE randomly draws a true state of the system (logN and logE) from the joint distribution estimated by the last stock assessment. For each simulation trial, the random draw of the true state of logN gives us the stock numbers in s1 of the 2018 TAC year. The random draw of E is scaled so that any F multiplier will be equivalent to the mean fishing mortality for ages 1 and 2 (Fbar). We assume that this true E is constant across years within a simulation trial of the MSE, but varies among simulation trials.

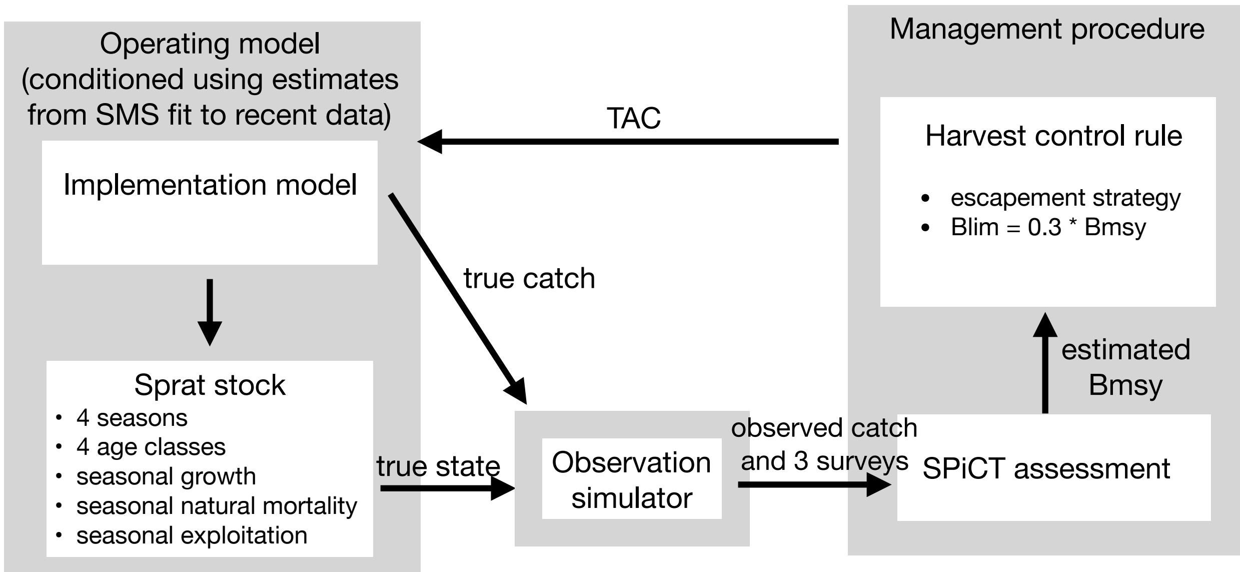


Figure 1: Conceptual overview of SPiCT MSE. In this MSE, SPiCT is used to estimate B_{msy}, and an escpement strategy is used as the HCR. In MSEs of the 1-over-2 and 2-over-3 rules, the 3 surveys are combined into one survey that goes into the management procedure and the management procedure is much simpler without any estimation, only direct calculation from the input catch and survey.

Operating model

Biological and fishery model

Given a TAC estimated from the management strategy, the operating model simulates the fishery and the biological dynamics affecting the population. The TAC is taken from the true population. As the TAC is taken, the dynamics of the true population are simultaneously simulated season by season. Given, N(a,t), the number of fish of age a in season t, mortality is implemented as N(a,t+1)=N(a,t) * exp(-(F(a,t) + M(a))). Survivors from s4 increase in age as they move to s1. Recruitment occurs in s1 based on the SSB in the same season. Survivors from seasons 1 through 4 by applying age-specific fishing and natural mortality each season.

Conditioning (input variables)

The distribution of initial N and E is estimated by the most recent assessment. Past recruitment is also estimated by the most recent assessment. The biological parameters (natural mortality, weight at age, and maturity) are chosen from past inputs to SMS in unison from a single year in the past to account for possible correlations. Each simulation trial is conditioned with different initial N, E, and biological parameters. All simulation trials are conditioned with the same estimates of past recruitment.

Initial population

The number of individuals at the beginning of the 2018 TAC year (s1) as estimated by the SMS assessment are in the table below (CV represents variability among replicates).

age	median	CV
0	133402140.1	0.43
1	110952687.1	0.50

age	median	CV
2	9731832.6	0.28
3	375589.4	0.37

Natural mortality

The MSE assumes that natural mortality is constant within a simulation trial but varies across simulation trials. For each simulation trial, natural mortality is drawn from a year from 1983 to 2017, the same year as the other biological parameters are taken from for a given simulation trial. See the 2018 benchmark report for values.

Mean weights at age

The MSE assumes that stock and catch weights are constant within a simulation trial but vary across simulation trials. For each simulation trial, stock and catch weights are drawn from a year from 1983 to 2017, the same year as the other biological parameters are taken from for a given simulation trial. See the 2018 benchmark report for values.

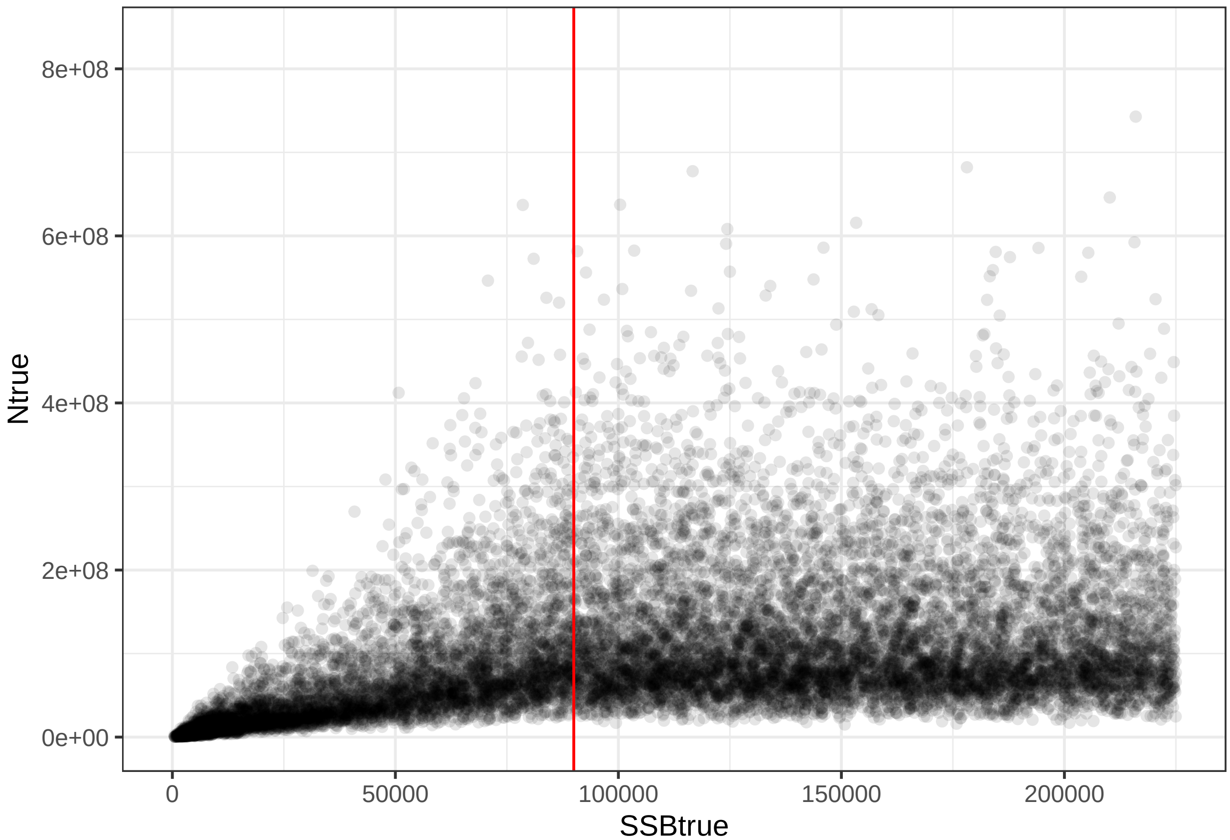
Proportion mature

The MSE assumes that the proportion of fish mature is constant at the same value from the 2018 benchmark.

Recruitment

If SSB in s1 is above 9×10^4 tonnes (the estimated break point in a hockey-stick model from the benchmark, not the recent assessment), then recruitment is a single random sample from a smoothed distribution of the estimated recruitment from previous years when SSB was above Blim. From the recent SMS assessment, the median estimates of past recruitment in years when SSB was above Blim are 7.92896×10^7, 1.33086×10^8, 2.51512×10^8, 3.33165×10^7, 7.1576×10^7, 4.85886×10^7, 1.11651×10^8, 7.18083×10^7, 7.75671×10^7, 7.19685×10^7, 2.08573×10^8, 6.50995×10^7, 8.10144×10^7, 5.91218×10^7, 1.57971×10^8, 1.21795×10^8, 1.39125×10^8, 8.45745×10^7, 7.35898×10^7, 2.14314×10^8, 2.28747×10^8, 9.28593×10^7, 1.46831×10^8, 3.51383×10^8.

If SSB in s1 is below Blim, then recruitment is impaired and it is simulated from the same smoothed distribution, but with a mean that is tapering towards the origin (fig below). The smoothed distribution was written with specialized R code and designed to have shorter upper tails than a log-normal distribution. The new recruits are log transformed and stored into the true logN structure in age 0, in the same season in which SSB is calculated, s1.



Implementation model

The TAC is taken from the true population, but only up to an Fbar equal to 2.213, i.e. F_{hist}, which is the maximum of the past estimates of Fbar and occurred in 2016. This is a form of implementation error conveying the maximum effort that the fleet has historically implemented.

Observation simulator

The observation simulator takes the true state as input and then simulates observations of the catch and surveys. All 3 surveys use linear catchability, rather than estimates from the most recent benchmark because power-law catchability was giving unreasonably large indecies in some simulations. Surveys are simulated such that the expected survey number is Ntrue∗survey_effort∗catchability as this was the form assumed in the assessment model. The term "survey_effort" is a multiplier that improves the numerical stability in the assessment model. The mode observed catch is the true catch. To generate the observed catch and surveys, observation error with a multivariate normal distribution is added to the log of the expected values. This is equivalent to multiplying by log-normally distributed observation errors. The multivariate normal distribution of the observation errors is estimated from the residuals (e.g. log(Catch true)-log(Catch estimated) and log(Survey true) - log(Survey estimated)) coming from the SMS assessment. This allows for errors to be correlated across ages, seasons, surveys, and catch within one year of one trial.

Finally, if any of the quarterly observed catches were below 500 tonnes, we increased the observed catch to this value. This is recommended when running SPiCT.

The procedure described above produced age structured surveys and catches. They were converted to biomass indecies and catch by multiplying by the true weight at age and summing across ages. This produced 3 surveys in different quarters and catches

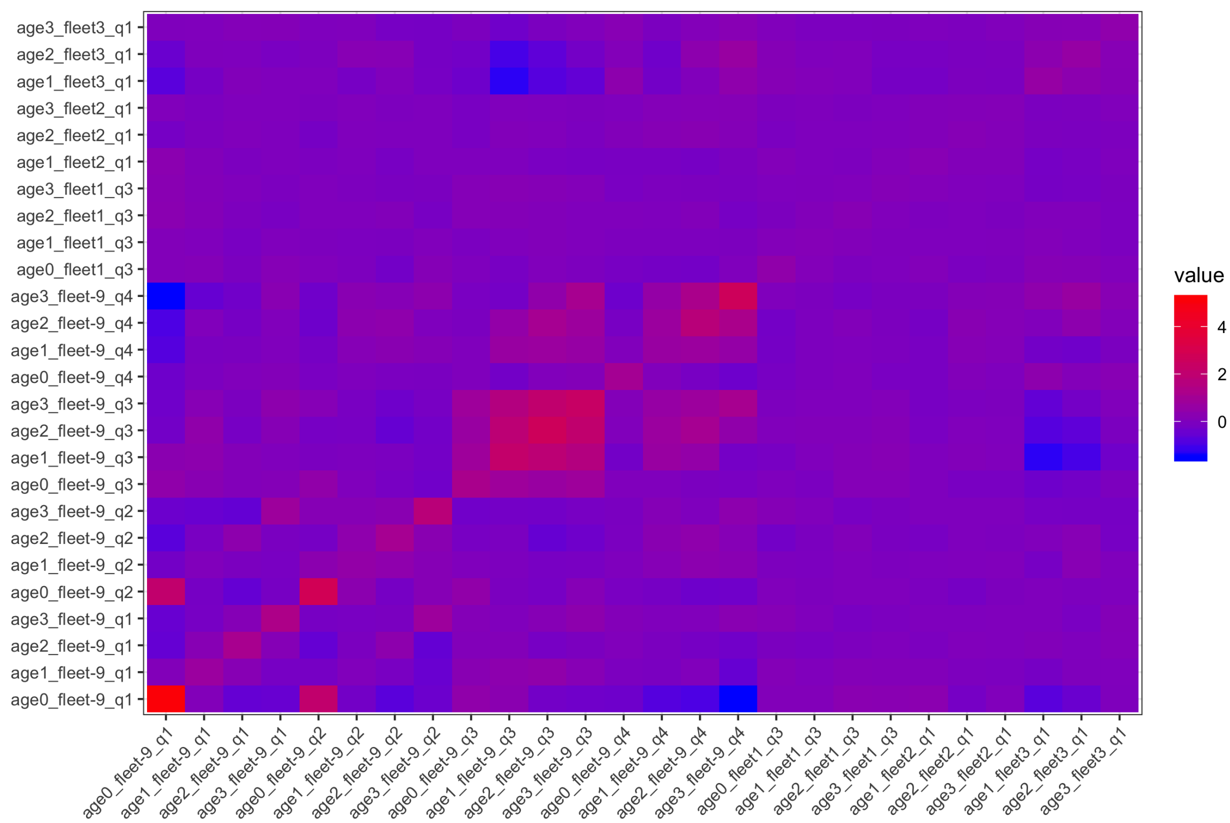


Figure 2: Covariance of age structured survey and catch observation errors. The 3 surveys are labeled fleet1, fleet2, and fleet3. The catch is labeled fleet-9. Labels q1 to q4 refer to quarters (i.e. seasons) of the TAC year, not the calendar year (e.g. q1 is season1).

Replication in simulations

For each HCR tested, we ran 1000 simulation trials forward for 25 years. Random numbers drawn for initial conditions (N and E) are unique across simulation trials.

Harvest Control Rules

SPiCT

In each year of the MSE, observed catches and surveys were input to a SPiCT assessment with the following settings in the first year:

```
seasontype=1
timepredc= 2018.5## forecast year start
dtpredc=1## one year ahead
timepredi=2019.5## forecast year end
manstart=2018.5## forecast year start
```

Each following year, `timepredc`, `timepredi`, and `manstart` were incremented by 1. These values represent the bounds of the TAC year which is offset from the calendar year by 0.5. A deterministic forecast was performed to set the TAC according to an escapement strategy with Blim=Bmsy $*$ 0.3 as described in ICES guidelines. The details of this method are documented in the main text of this report.

There were convergence issues with 0.6 % of the replicates. Years after a convergenence issue occcured (including the year with a problem) in a replicate were ommitted from performance statistic calculations.

1-Over-2 and 2-Over-3

We tested the 1-over-2 and 2-over-3 rules. Since they require a single biomass index, in each year of the MSE, we combined our 3 biomass indecies as follows. (1) We removed years before 2006 because all 3 were only available after 2006. (2) We divided each index by its mean. (3) For each year, we took the average of the 3 indecies. The details of the 1-over-2 and 2-over-3 methods are documented in the main text of this report.

Uncertainty Caps

We tested several uncertainty caps that were symmetric (0.2, 0.2), (0.6, 0.6), and (0.8, 0.8). We also tested one that was assymetric (0.8, 0.2). Future work could test more comminations. The details of this method are documented in the main text of this report.

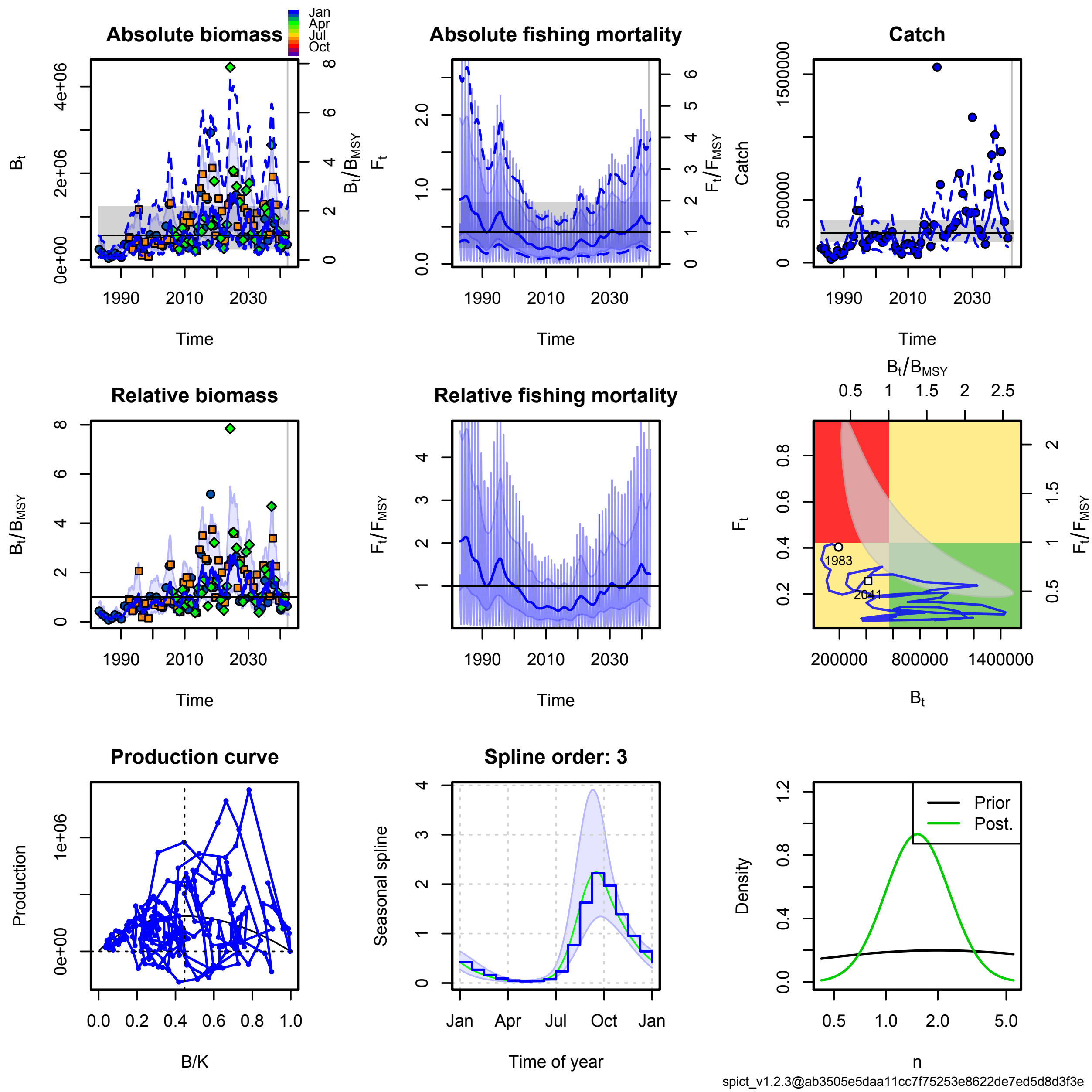
Biomass safeguards

We considered biomass safeguards where Ilim is equal to either the minimum observed biomass index (changing through time within each simulation trial) or the 5 percentile of observed biomass index (also changing through time within each simulation trial). The reason for testing the 5 percentile is that the minimum is not a robust statistic. In this study, we did not directly use Ilim as a reference point, but rather used Itrigger = 1.4Ilim. Advised TAC was reduced by the distance between the current biomass index and Itrigger. As was done for sprat in other parts of the WKDLSSLS report, future work could use Ilim as a threshold instead of Itrigger.

HCRs for comparison

For the purpose of comparison, we also conducted MSEs with either no catch, or using an emulated SMS assessment (SMS light) with no Fcap.

Results


Absolute biomass
Jan
Apr
Jul
Oct
Bt
Bt/BMSY
Ft
Time
Absolute fishing mortality
Ft/FMSY
Catch
Relative biomass
Relative fishing mortality
1983
2041
Production curve
Production
B/K
Spline order: 3
Seasonal spline
Time of year
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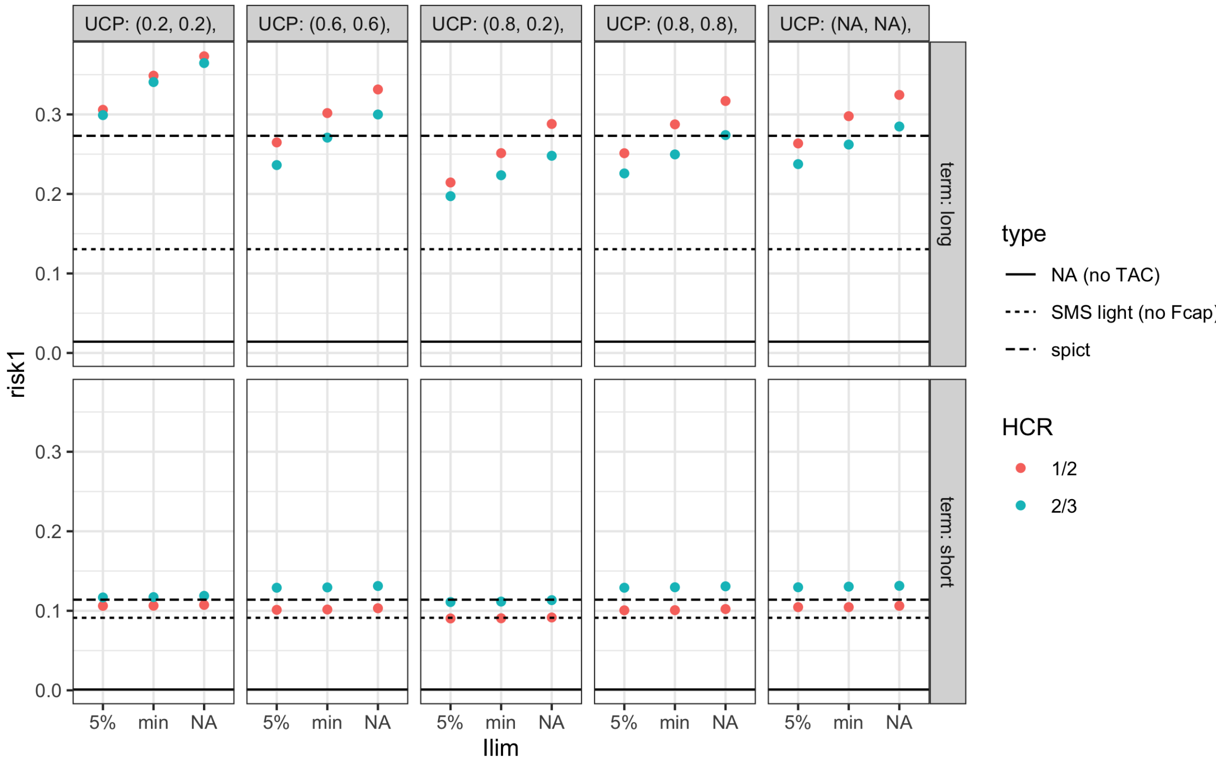
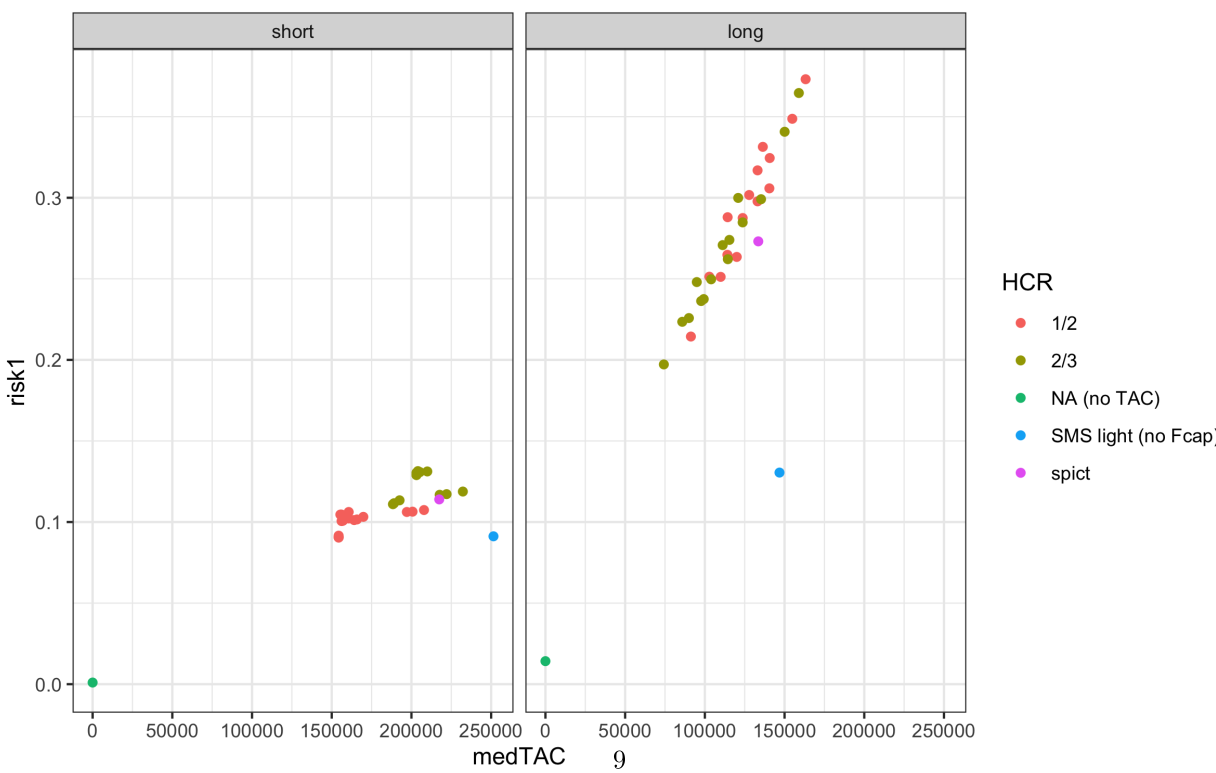


Figure 3: Type 1 Risk. Each point is a different HCR with a combination of uncertainty caps and biomass safeguards (or marked NA for no extra modifications). Each column of panels has a different uncertainty cap. The top row of panels is for the last 10 years of the simulation and the bottom row of panels is for the first 5 years. The x-axis of each panel describes the biomass safeguard that was implemented. Horizontal lines represent HCRs of no catch, SMS light, or SPiCT; no uncertainty caps or biomass safeguards were combined with these.



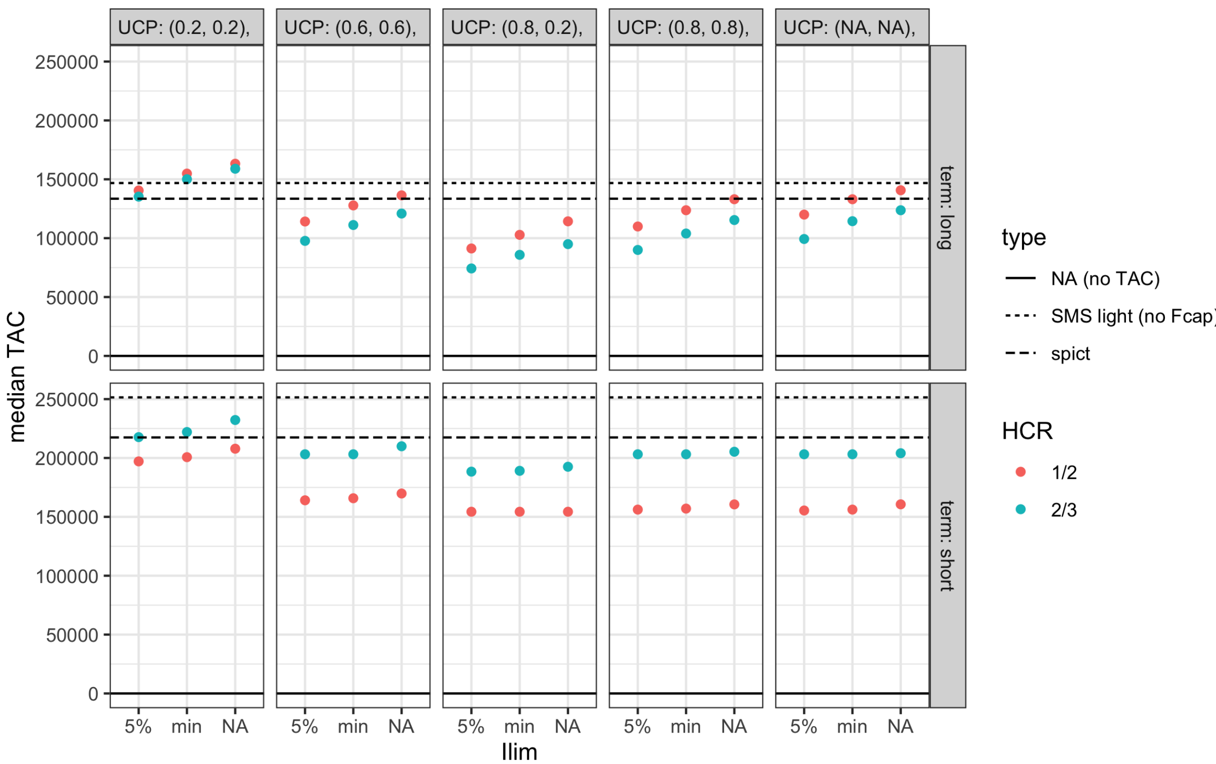


Figure 4: Median TAC. Each point is a different HCR with a combination of uncertainty caps and biomass safeguards (or marked NA for no extra modifications). Each column of panels has a different uncertainty cap. The top row of panels is for the last 10 years of the simulation and the bottom row of panels is for the first 5 years. The x-axis of each panel describes the biomass safeguard that was implemented. Horizontal lines represent HCRs of no catch, SMS light, or SPiCT; no uncertainty caps or biomass safeguards were combined with these.

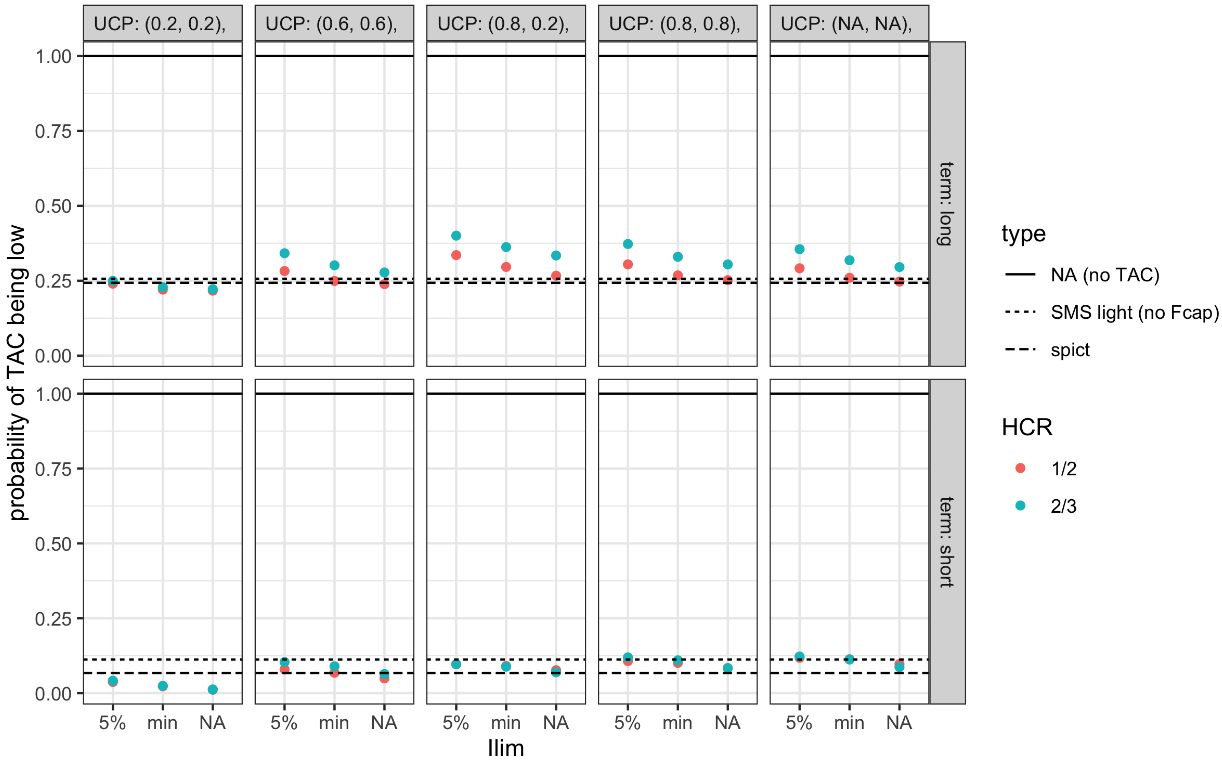


Figure 5: Low TAC. Each point is a different HCR with a combination of uncertainty caps and biomass safeguards (or marked NA for no extra modifications). Each column of panels has a different uncertainty cap. The top row of panels is for the last 10 years of the simulation and the bottom row of panels is for the first 5 years. The x-axis of each panel describes the biomass safeguard that was implemented. Horizontal lines represent HCRs of no catch, SMS light, or SPiCT; no uncertainty caps or biomass safeguards were combined with these.

This simulated stock started out in a relatively good state, so short-term risk is lower than long-term risk. The HCRs show more differences in the long-term. In the long-term the (0.2, 0.2) uncertainty cap was the riskiest and (0.8, 0.2) was the least risky. Among biomass safeguards, Ilim defined as the 5 percentile of past observed indecies was the least risky, followed by the minimum inex, and the riskiest was to have no biomass safeguard. In the short-term, the 2-over-3 rule is slightly riskier than the 1-over-2, but the difference is small. In the long-term, the 1-over-2 rule was riskier than the 2-over-3 rule. With no uncertainty cap and no biomass safebuard, in the long-term, SPiCT was less risky than either the 1-over-2 or 2-over-3. In the short term, SPiCT fell between the two in terms of risk. In general patterns of the medain TACs were the same as patterns of risk, i.e. higher risk HCRs produced higher TACs.

Acknowledgements

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

by

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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-like and sardine and sprat-like stocks). 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 (IAV). 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 (IAV)	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. Birthdate is assumed at first January, this implies that age 0 group only last for 6 months in the population, becoming afterwards age 1 group. 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 was entirely applied in the 2nd semester when age 0 appears. Regarding maturity ogive, for STK1 (anchovy-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) $R_{July} = \frac{a \cdot SSB}{b+SSB} \cdot e^{\varepsilon}$, $\varepsilon \sim N(0, \sigma_{REC})$	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) $R_{July} = \frac{a \cdot SSB}{b+SSB} \cdot e^{\varepsilon}$, $\varepsilon \sim N(0, \sigma_{REC})$	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

* Only applied to the second half of the year when age 0 appears to the stock

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:

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

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):

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

  - Recent average (nin):

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

  - Perfect knowledge (pob):

    $$\text{refTAC} = \frac{\sum_{i=y-\text{m}}^{y-1} \text{C}_i}{\text{m}} \cdot \frac{\frac{\sum_{i=y-\text{m}}^{y-1} \text{F}_i}{\text{m}}}{\text{F}_{MSY}}$$, 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 $\text{b} = \min(1, I_y/I_{trig})$, 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.

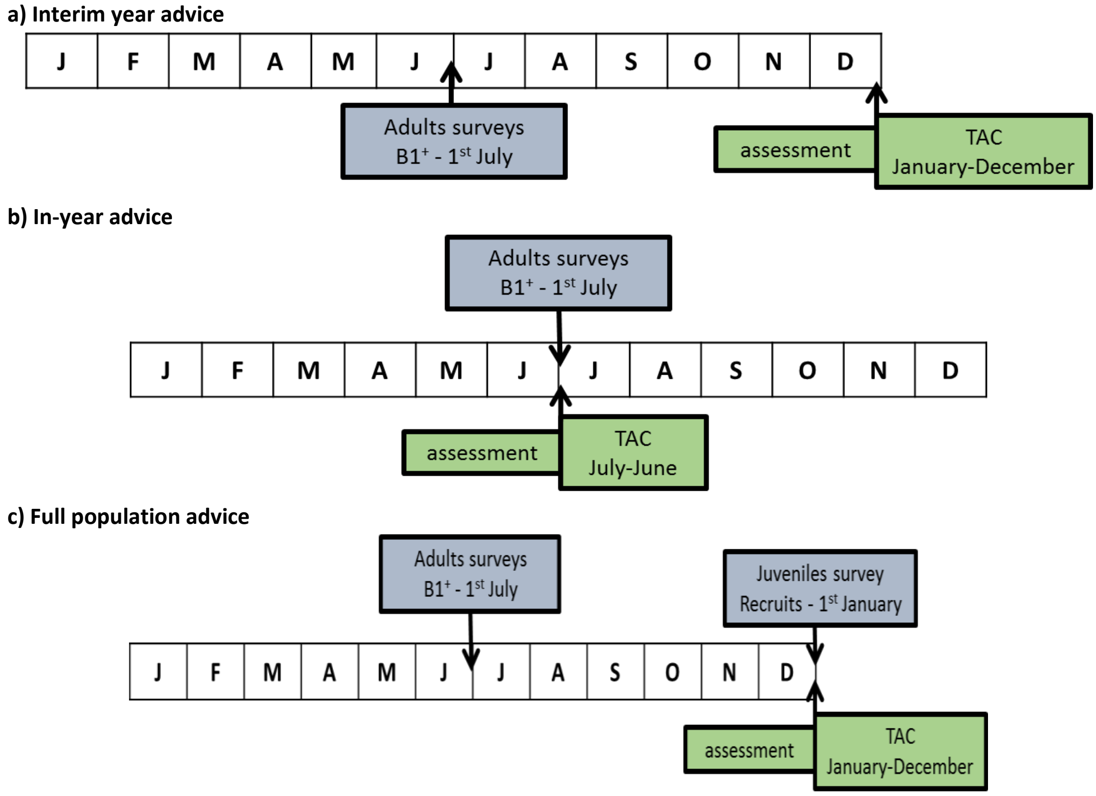

Figure 2.1. TAC calendars.

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:

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

where i is the index referring to year, y in the interim year (just before management) and n and m are the number of preceding years in the numerator and denominator of the HCR.

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	$\mathrm{refTAC} = \frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{C}_i}{\mathrm{m}}$ (for n-over-m rule)
		pob	$\mathrm{refTAC} = \frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{C}_i}{\mathrm{m}} \cdot \frac{\frac{\sum_{i=y-\mathrm{m}}^{y-1} \mathrm{F}_i}{\mathrm{m}}}{\mathrm{F}_{MSY}}$ (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 $B_{collapse} = 10\%\ \mathrm{B0}$;
- Risk1.Blim : ICES type 1 risk of falling below B_{lim}= 20% B0;
- Risk2.Collapse : ICES type 2 risk of falling below $B_{collapse} = 10\%\ \mathrm{B0}$;
- Risk2.Blim : ICES type 2 risk of falling below B_{lim}= 20% B0;
- Risk3.Collapse : ICES type 3 risk of falling below $B_{collapse} = 10\%\ \mathrm{B0}$;
- 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. It is remarkable that, when a 20% uncertainty cap is applied without any precautionary buffer in the 1-over-2 rule, the two randomly selected cases corresponded with examples of population and fishery collapse, while those which applied a 20% precautionary buffer did not show these collapses. Whereas the examples of the 1-over-2 with an 80% uncertainty cap did not coincide with stock or fishery collapses. For the cases of the 2-over-3 rule, all randomly selected examples with a 20% uncertainty cap collapsed.

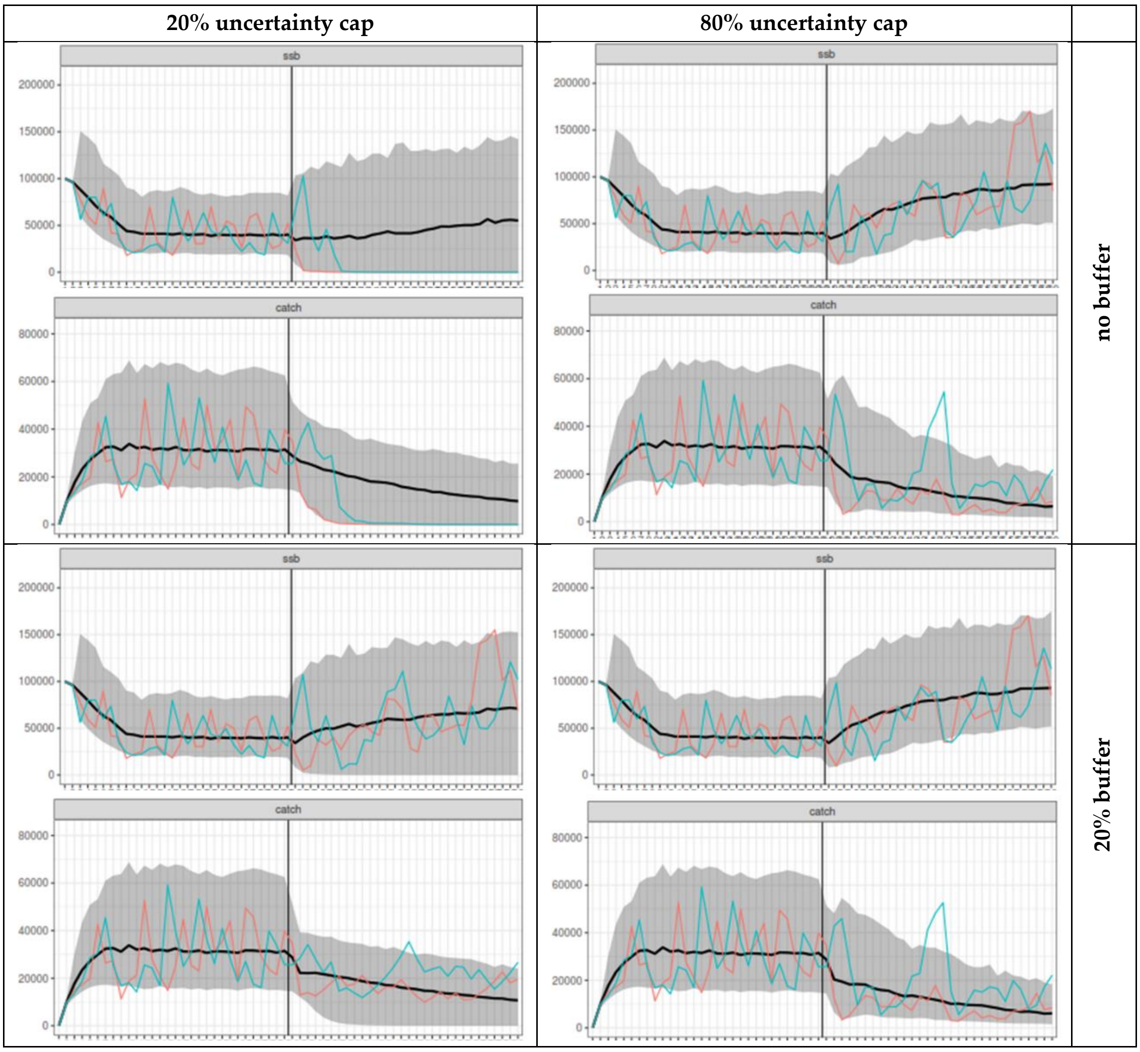

Figure 3.1. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, HCR=1-over-2, HCRI=nin). From top to bottom: SSB and catch by year, for different uncertainty caps (columns) and precautionary buffers (rows). The solid line represents the median and the shaded area the 90 % confidence 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.

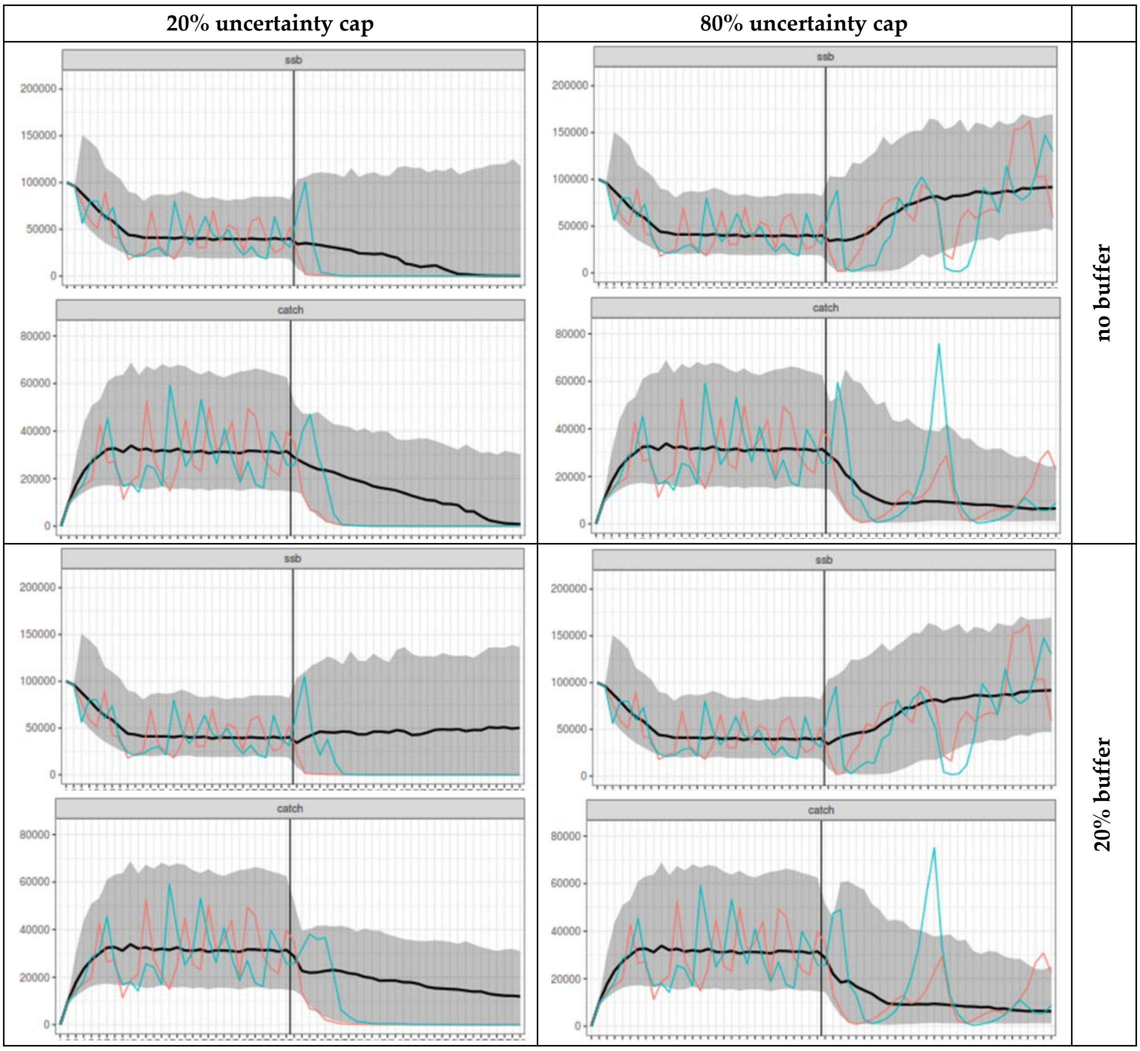

Figure 3.2. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, HCR=2-over-3, HCRI=nin). From top to bottom: SSB and catch by year, for different uncertainty caps (columns) and precautionary buffers (rows). The solid line represents the median and the shaded area the 90 % confidence intervals computed from the 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.

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).

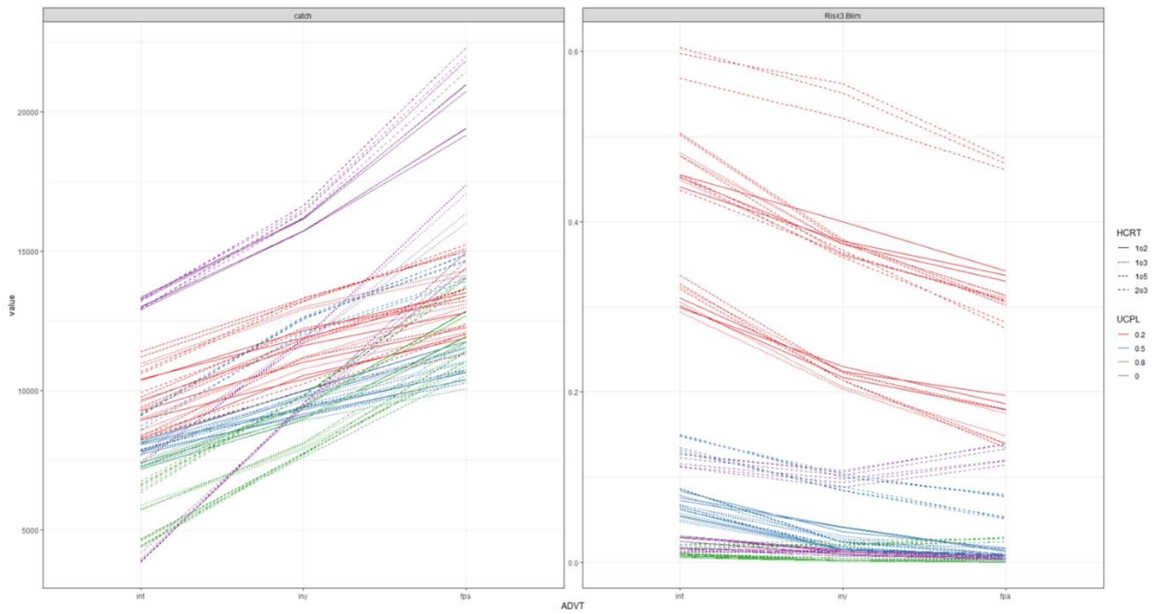

Figure 3.3. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each calendar (int: interim year calendar; iny: in-year calendar; and fpa: full population advice), by HCR type (solid line – 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 for all the harvest control rules and uncertainty cap levels (Figure 3.4). Whereas in the long-term, with in-year advice, the precautionary buffer induces little reductions of risks and catches for all rules and uncertainty cap levels (Figure 3.5), except for the 20% uncertainty cap where the effect of reducing risks is more pronounced allowing at the same time bigger catches.

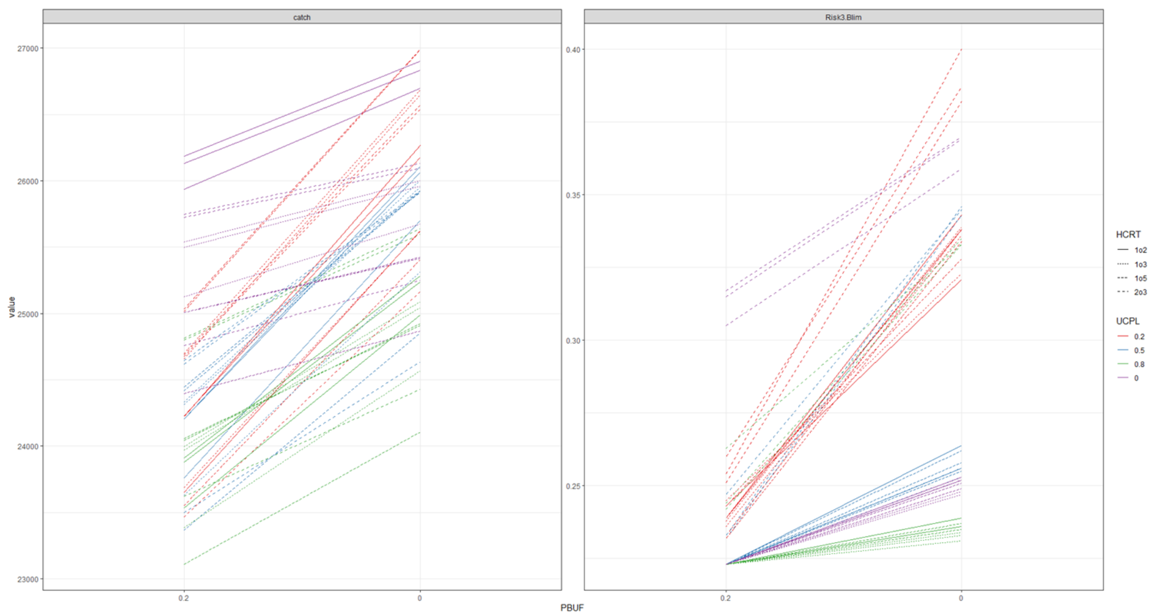

Figure 3.4. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the short-term (years 31-35), for each precautionary buffer (0.2: 20% buffer; and 0: no buffer), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3;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

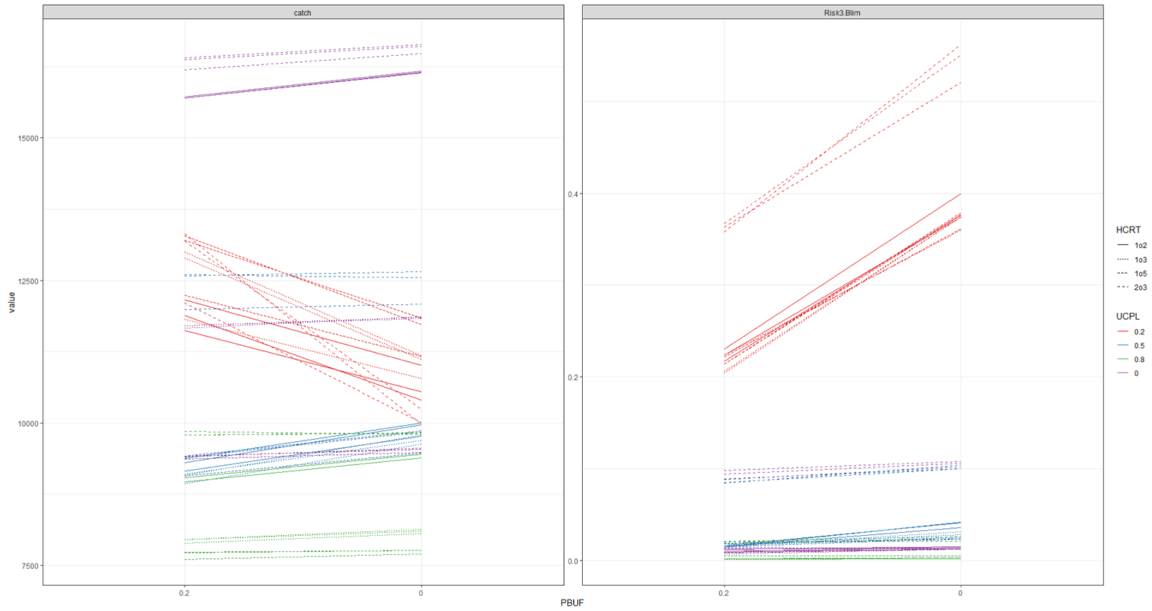

Figure 3.5. Scenario (OM: stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: catch median and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each precautionary buffer (0.2: 20% buffer; and 0: no buffer), by HCR type (solid line – 1o2: 1-over-2; dotted line – 1o3: 1-over-3; 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 -mean of the years in the denominator of the HCR) might be preferred, as it would smooth the potential noise of the latest catch before management, in other words this can filter out some of the inherent noise coming from fluctuations in the interannual catchability of the fishery before the starting of management. In this way, the initial catch to start the advice in the first year would be that corresponding with the mean harvest rate over the recent set of years.

At any uncertainty cap level, the comparison of the rules show that rule 2-over-3 has equal or larger catches and always higher risks than any of the other rules (Figure 3.8) while differences between the other rules (rules 1-over-N with N equal either to 2, 3 or 5) are minor in terms of catches and risks. 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 and some concrete realizations in Figure 3.1 and Figure 3.2). Uncertainty caps equal or higher than 50% (i.e. 50%, 80% or free when no uncertainty cap is applied) result in the long term in precautionary levels of risk for harvest control rules of the type 1-over-N, with minimum risks obtained at the 80% uncertainty cap (Figure 3.8).

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 B_{lim} and $B_{collapse}$, 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).

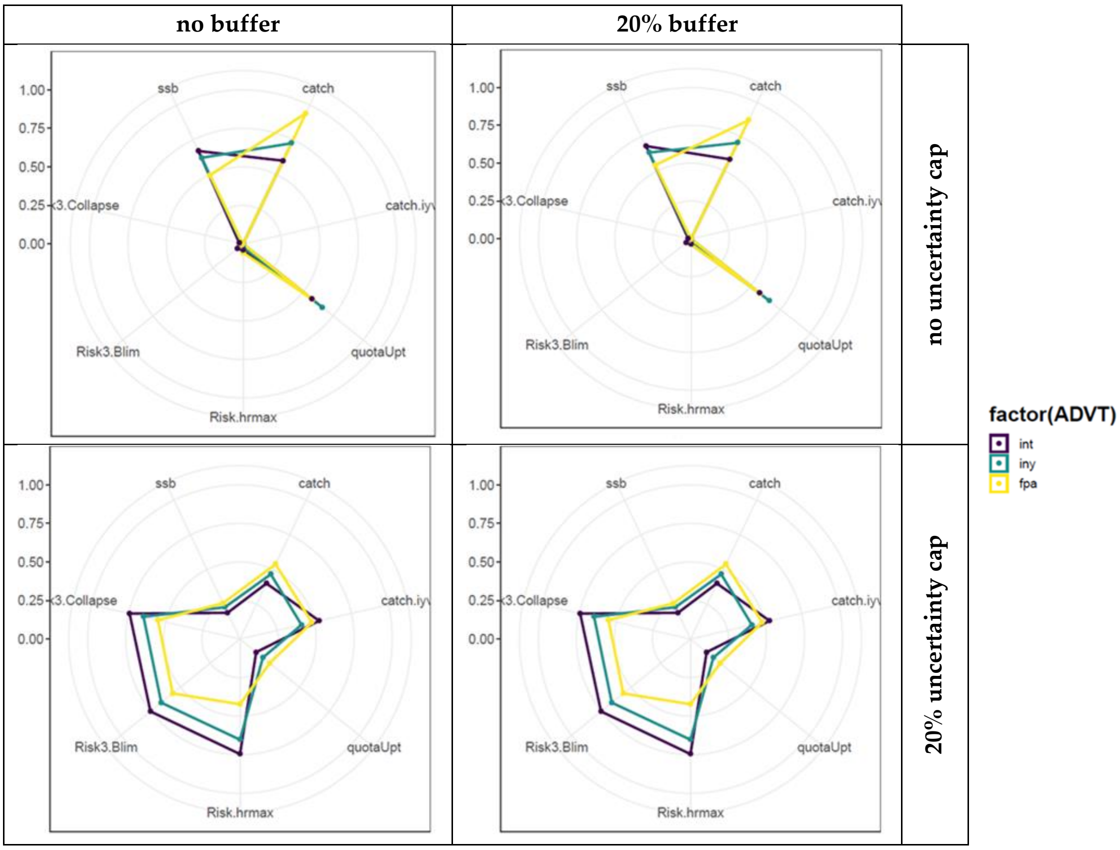

Figure 3.6. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low, HCR 1-over-2). Median SSB (ssb), median catch (catch), interannual variation of catches (catch.iyv), quota uptake (quotaUpt), probability of harvest rate being higher than the maximum hr in the last 10 historic years (Risk.hrmax), 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.

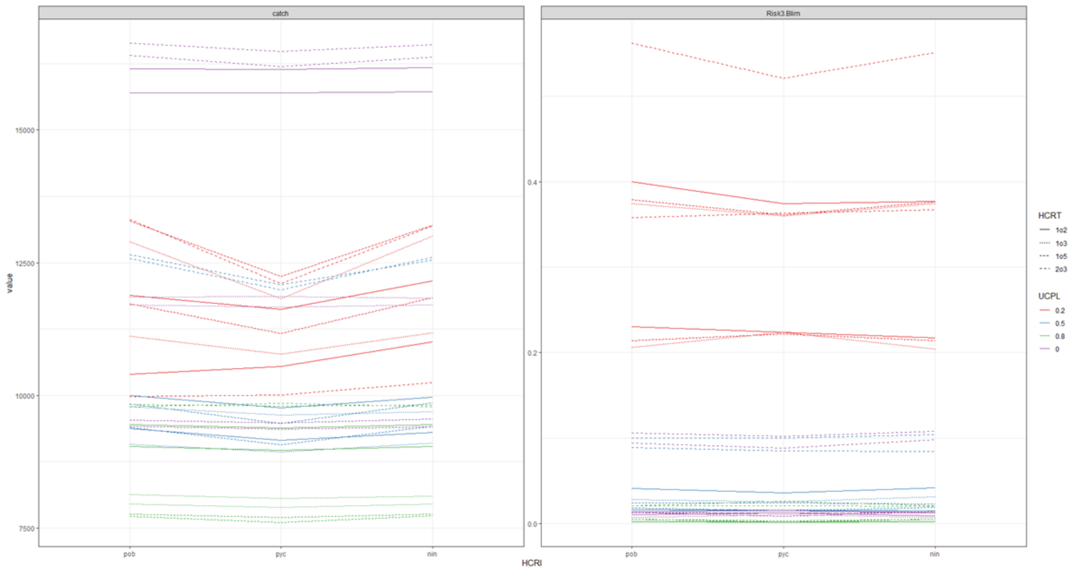

Figure 3.7. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low). From left to right: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each rule initialisation (pyc: previous year catch; nin: recent mean catch; and pob: perfect Initialization), by HCR type (solid 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).

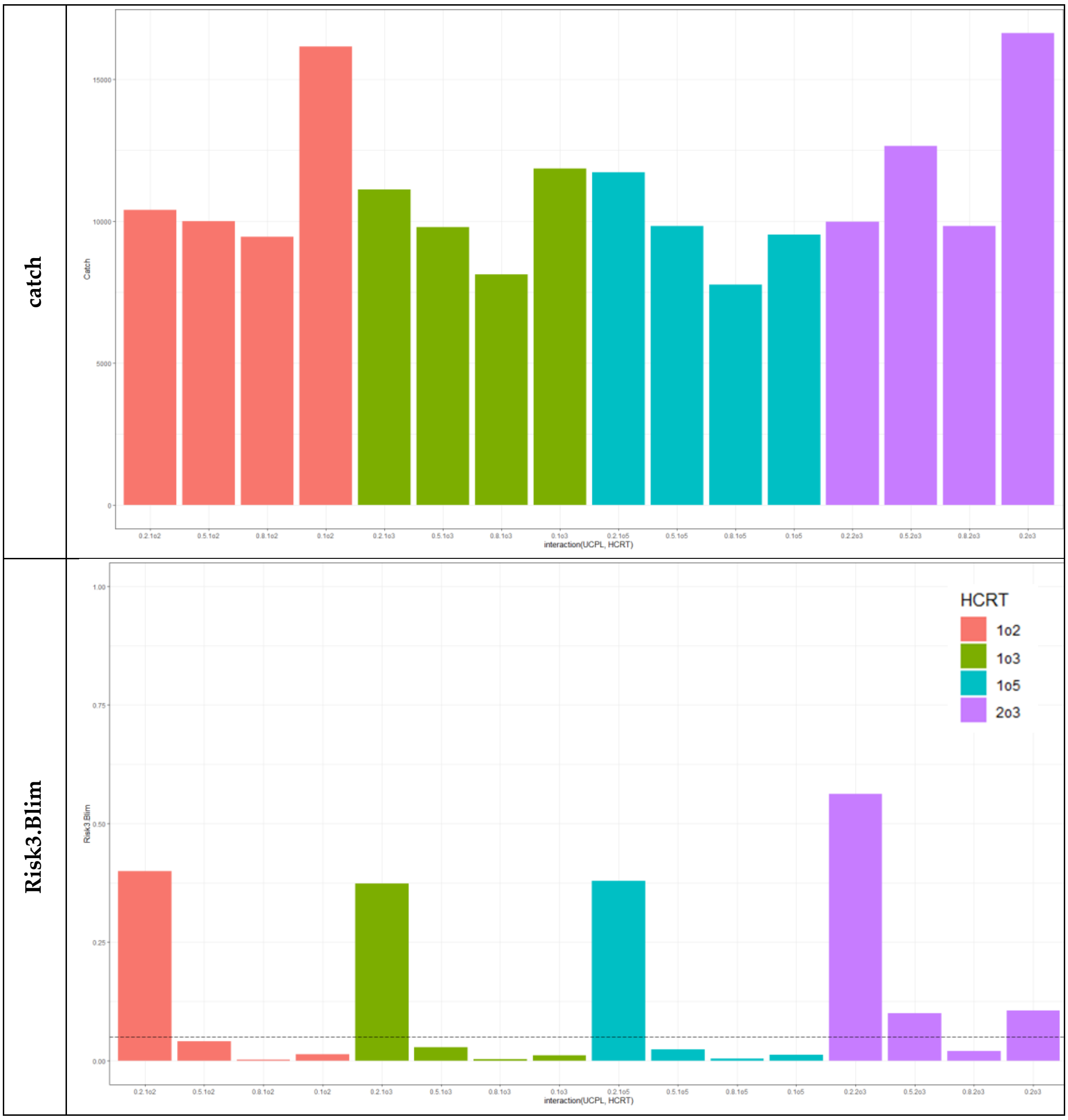

Figure 3.8. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, PBUF= 0, HCRI=pob). From top to bottom: median catch and Risk3 of falling below B_{lim}, in the long-term (years 51-60) for each HCR type and buffer (0.2 1o2: 1-over-2 with 20% uncertainty cap; 0.5 1o2: 1-over-2 with 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).

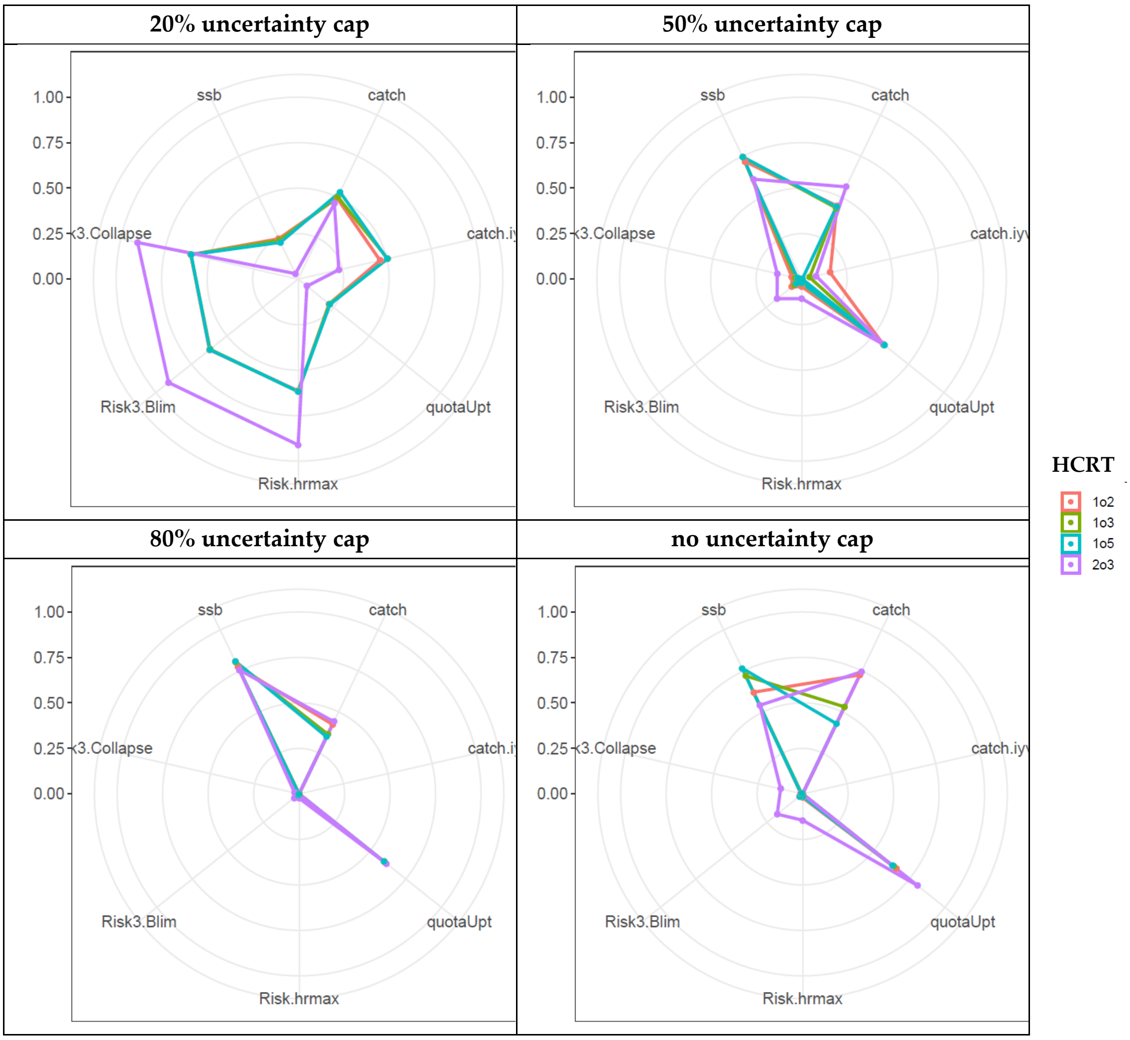

Figure 3.9. Scenario (OM: Stock=STK1, sigR=0.5, Fhist=Fopt, CVID=low; MP: ADVT=iny, PBUF= 0, HCRI=pob). Median SSB (ssb), median catch (catch), interannual variation of catches (catch.iyv), quota uptake (quotaUpt), probability of harvest rate being higher than the maximum hr in the last 10 historic years (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). Rules 1-over-3 and 1-over-5 were left aside at this stage of the analysis for simplicity, as the former section showed that these rules have very similar performance to rule 1-over-2.

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 with the 20% uncertainty cap, well evidenced in the long term.

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.

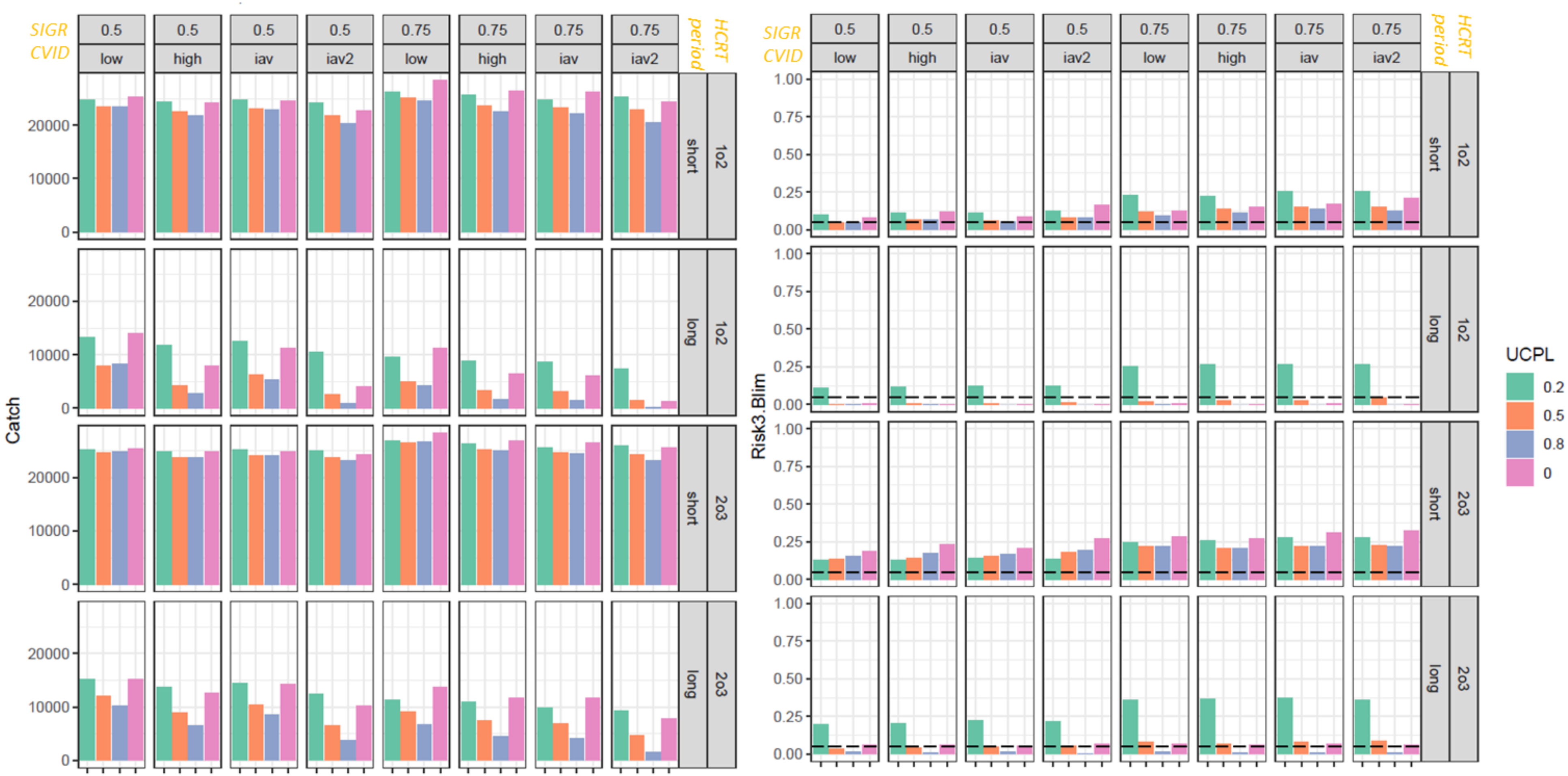

Figure 3.10. Scenario (OM: Stock=STK1, Fhist=Flow; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; 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).

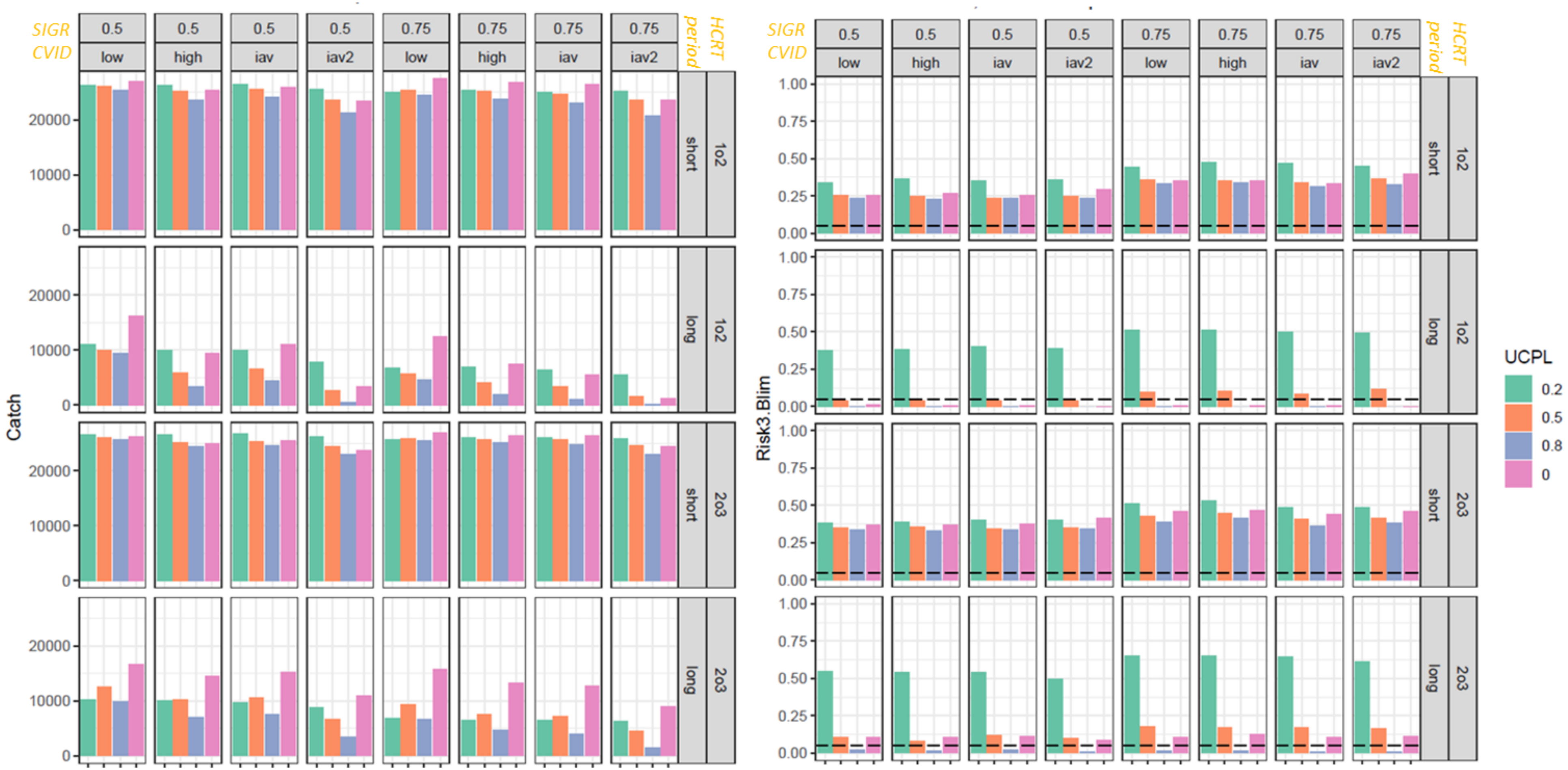

Figure 3.11. Scenario (OM: Stock=STK1, Fhist=Fopt; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; 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).

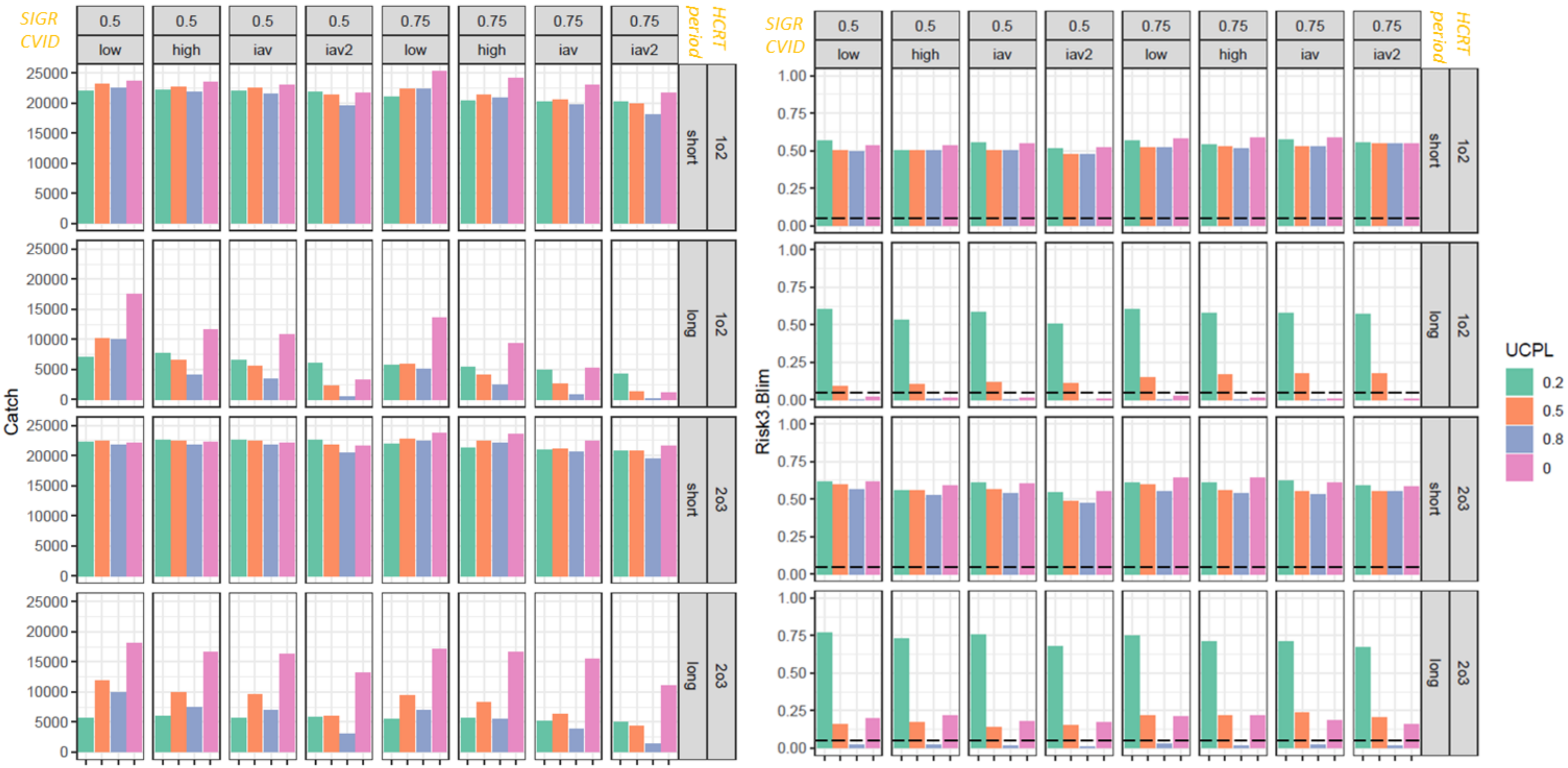

Figure 3.12. Scenario (OM: Stock=STK1, Fhist=Fhigh; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; 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 (STK2), 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 rather similar levels of catches (or slightly smaller) the former results in smaller levels of risks (see Figure 3.10 to Figure 3.15 and compare the empty symbols -1o2- with the same coloured symbols-2o3-in Figure 3.18 by periods and stocks). For example, 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 with any other uncertainty cap, as for moderate reduction of catches imply a more relevant reductions of risks, placing it at the lowest levels of risks (see Figure 3.10 to Figure 3.15 and compare the empty circles -1o2 with 80% uncertainty cap- with the other empty symbols of the same colours in Figure 3.18 by periods and stocks). This is particularly true for the short and medium-term, whilst in the long term the 80% uncertainty cap implies stronger (more remarkable) reduction of catches compared to other rules. For example, 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 no uncertainty cap to 1-over-2 with 80% 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 when passing from no uncertainty cap to the 80% uncertainty cap, which correspond with very high CVID/IAV ratios (corresponding to F hist=Fhigh and high sigR at 0.75). In that particular case, the most precautionary rule is the 1-over-2 without any uncertainty cap, but in both cases, either with 80% or without uncertainty cap, the 1-over-2 rule is precautionary (with risk around or below 5%).

Globally, for these short-lived 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 implying a moderate reductions of catches.

Figure 3.18 allows verifying that for both stocks the greater the historical exploitation (colours in the figure), the greater the risks in the short term.

As a result of the former analysis, it is concluded that when comparing the performance of the harvest control rules 1-over-2 and 2-over-3 for different levels of symmetrical uncertainty caps, across the different operating models, the best performance is achieved for 1-over-2 rule with 80% uncertainty cap, as it reduces risks in the short and medium-term compared with the other rules at the expense of a moderate reduction of catches. The 1-over-2 without any uncertainty cap results in higher catches but also risks in the short and medium-term. In the long term, both 1-over-2 rules, either with 80% uncertainty cap or without uncertainty cap lead to precautionary levels of risks.

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).

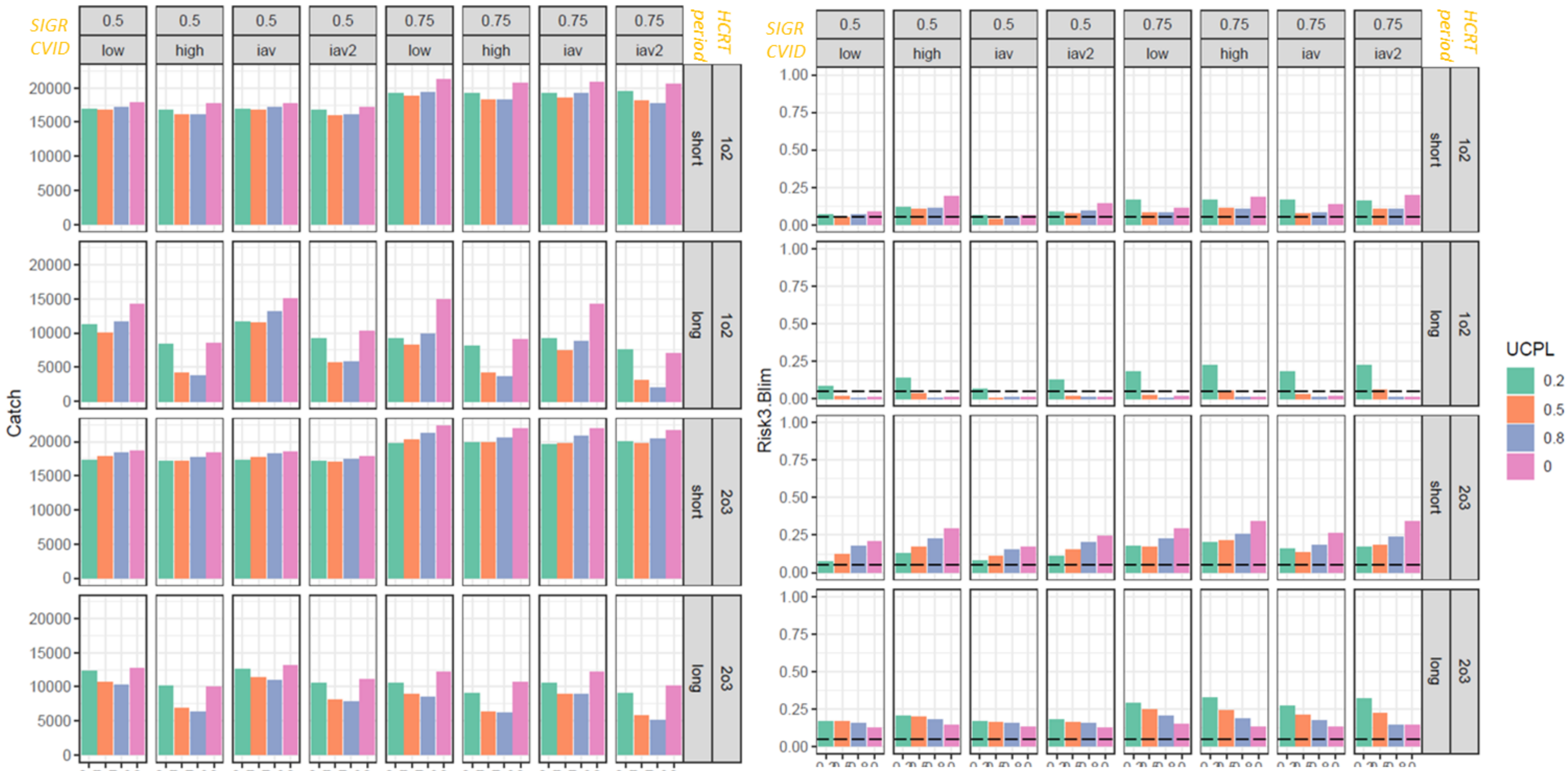

Figure 3.14. Scenario (OM: Stock=STK2, Fhist=Fopt; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; 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).

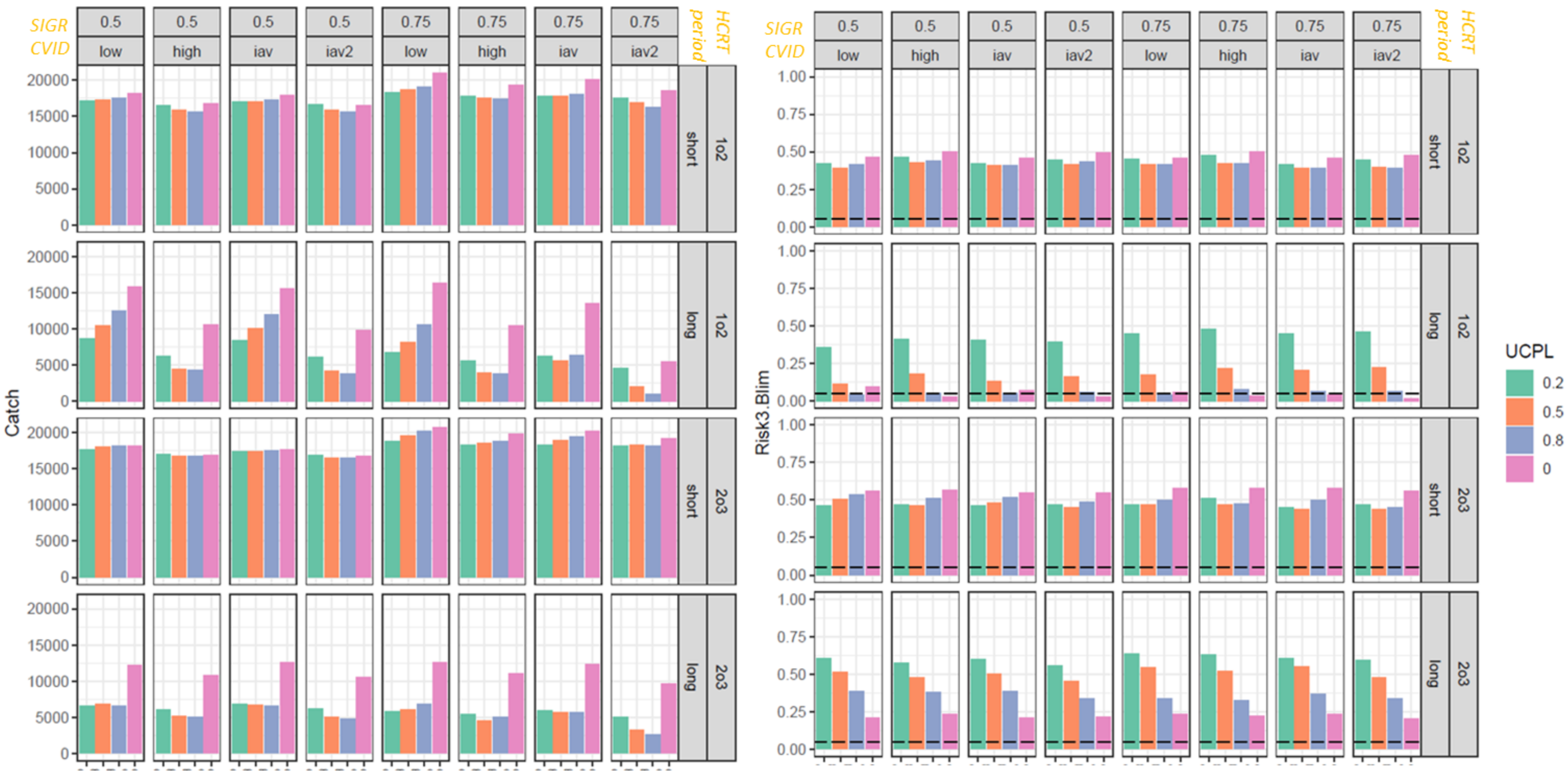

Figure 3.15. Scenario (OM: Stock=STK2, Fhist=Fhigh; MP: ADVT=iny, PBUF= 0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, for different standard deviations for the recruitment - SIGR (0.5; and 0.75), coefficients of variation of the index – CVID (low: 0.25; high: 0.5; 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).

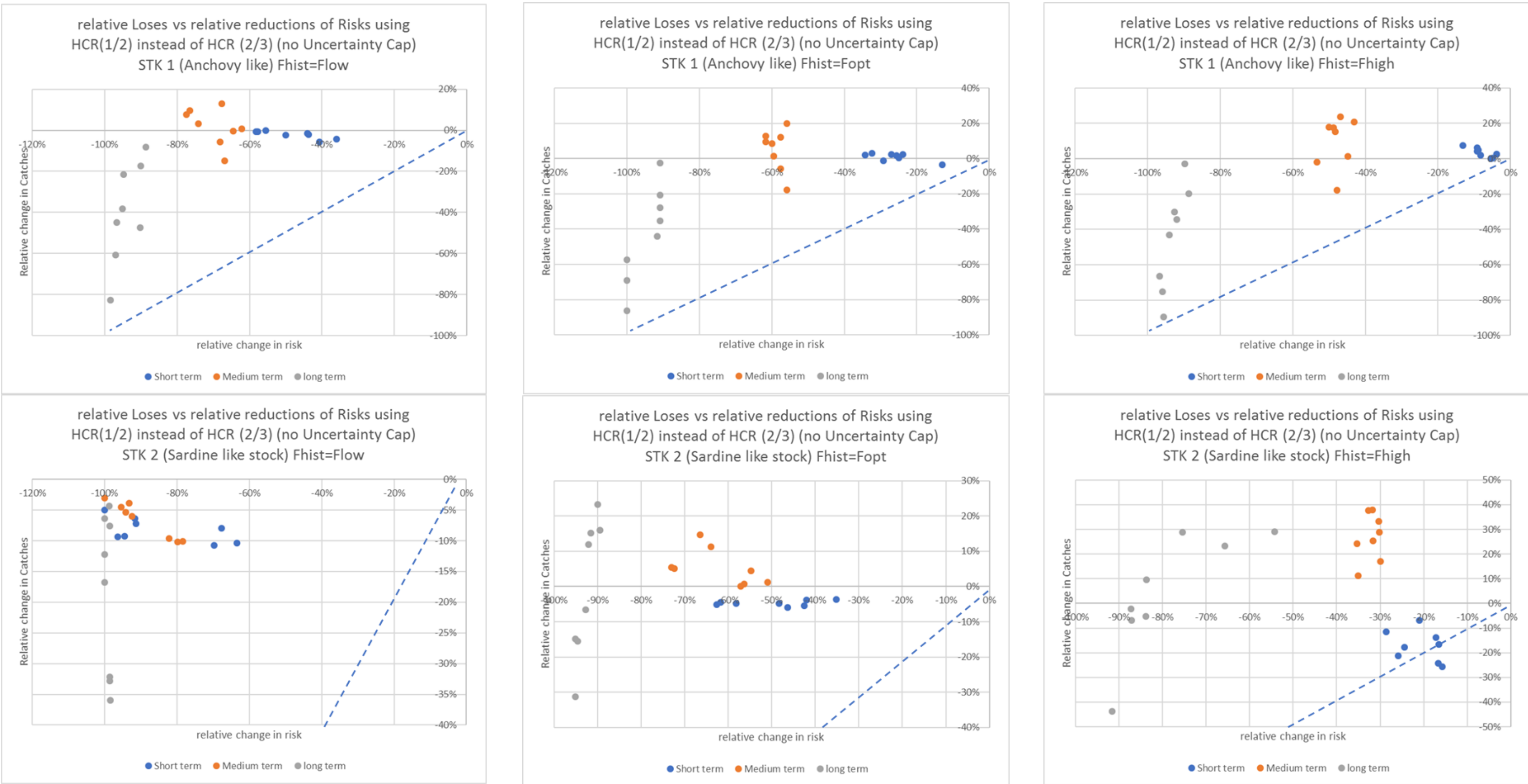

Figure 3.16. Relative changes in risks (X axis) and catches (Y axis) when moving from a harvest control rules 2-over-3 to 1-over-2 both without any uncertainty cap, for an anchovy like stock (upper row of figures) and sardine/sprat-like stock (bottom row), for Flow, Fopt and Fhigh historical exploitations (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)).

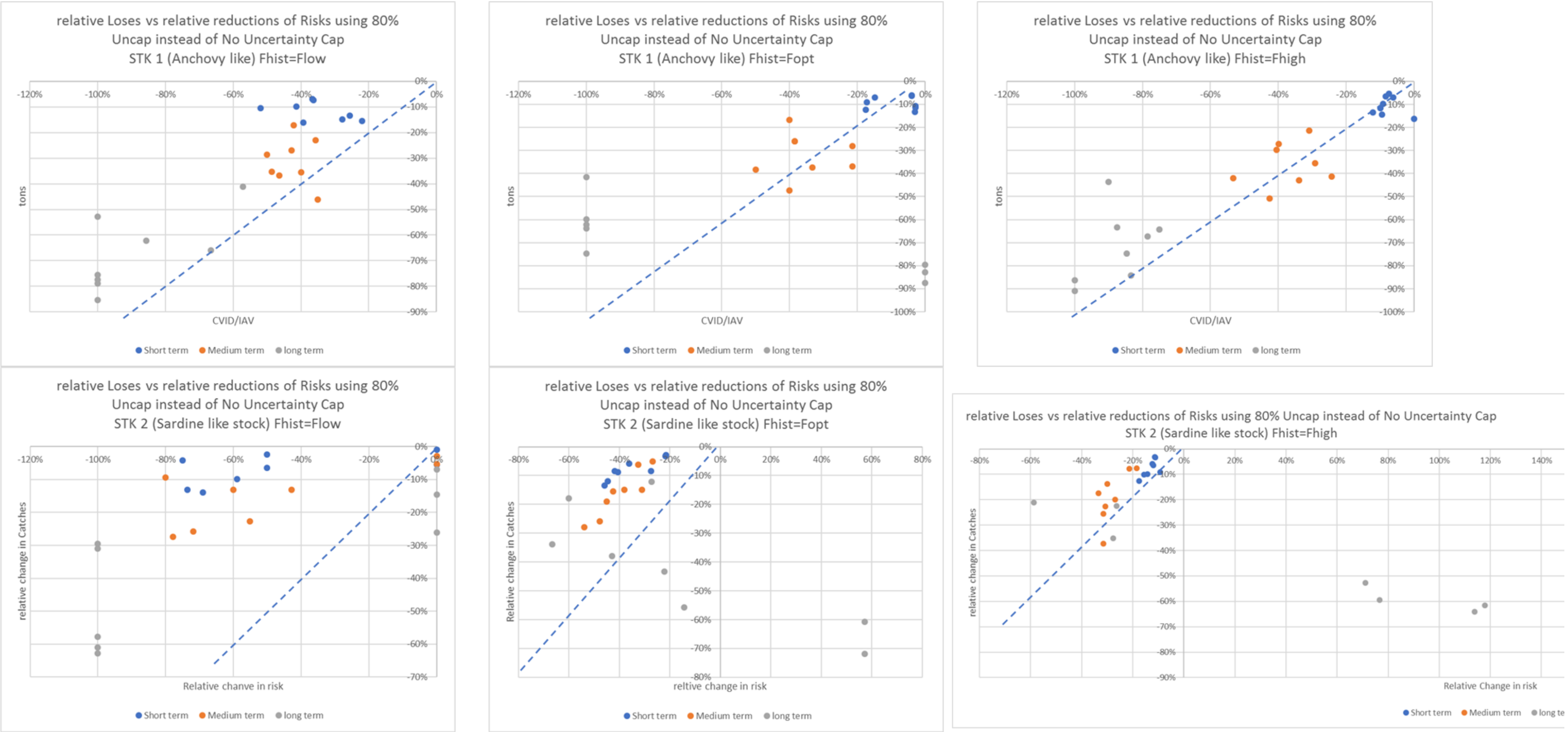

Figure 3.17. Relative changes in risks (X axis) and catches (Y axis) when moving from a harvest control rules 1-over-2 without any uncertainty cap to 1-over-2 with 80% uncertainty cap, for an anchovy like stock (upper row of figures) and sardine/sprat-like stock (bottom row), for Flow, Fopt and Figh 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)).

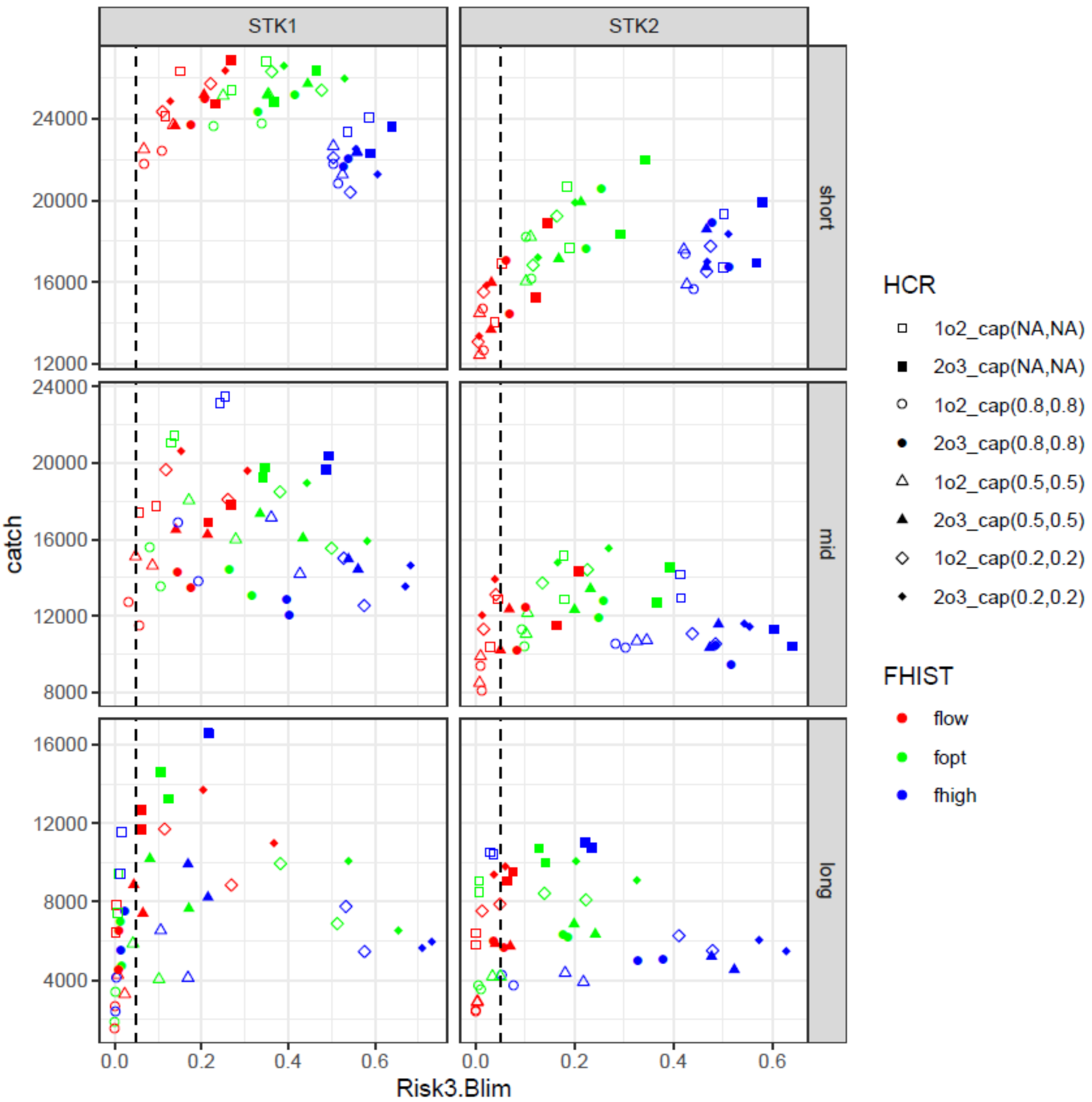

Figure 3.18. Median catch versus Risk3 of falling below B_{lim}, in the short (upper graphs), medium (middle graphs) and long-term (bottom graphs), by stocks (anchovy like -right panels- and sardine/sprat like -left panels) for each HCR combined with various uncertainty cap levels (see right upper legend) and for historical fishing mortality F (Fhigh: 2*FMSY -blue-; Flow: 0.5*FMSY -red-; and Fopt: FMSY -green-). There are two repeated values with the same form and colour which correspond to alternative standard deviations for the recruitment (0.5 or 0.75). Case Scenario: OM: Stock=STKs 1 & 2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin).

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-lived 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), the inclusion of the biomass safeguard to the 1-over-2 rule implies risks below 5% in the short term only for the stocks historically exploited at low F values (Figure 3.19), while at higher historical exploitation levels risks are higher. 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 3.19). Implying the biomass safeguard, slightly lower catches and risks. However, in the long term these differences are higher (Figure 3.20 and Figure 3.21). 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 3.20 and Figure 3.21), similar in risks but with poorer catches that the results for the 1-over-2 rule without biomass safe guard.

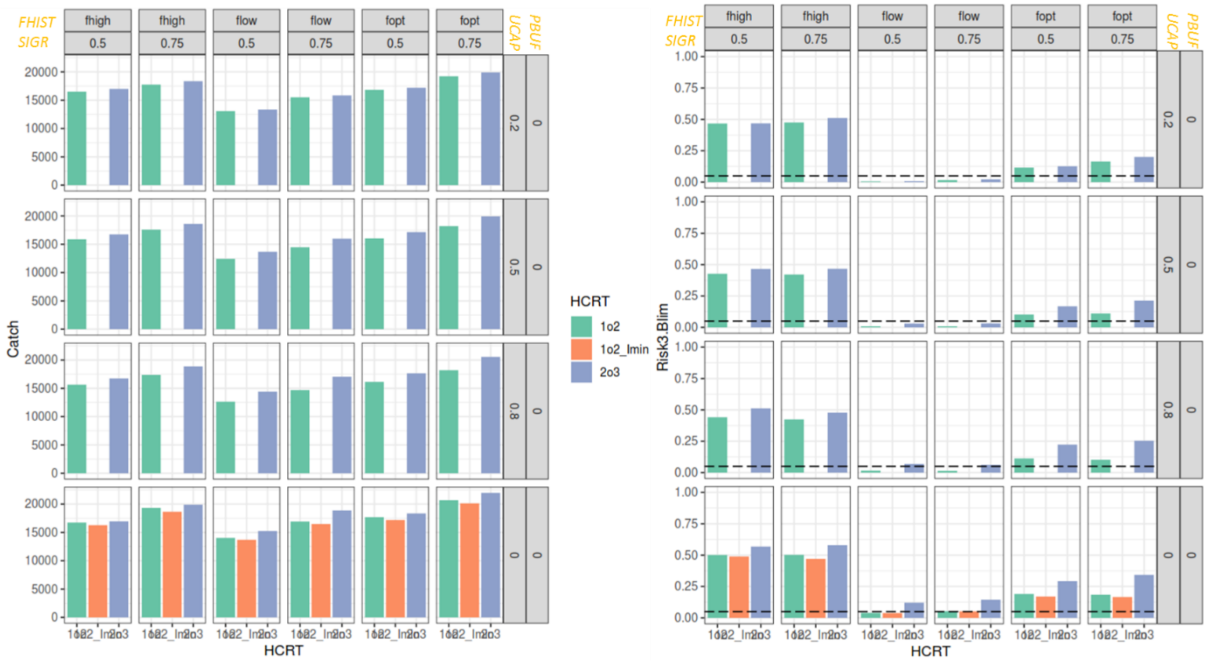

Figure 3.19. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, in the **short-term** (years 31-35), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 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).

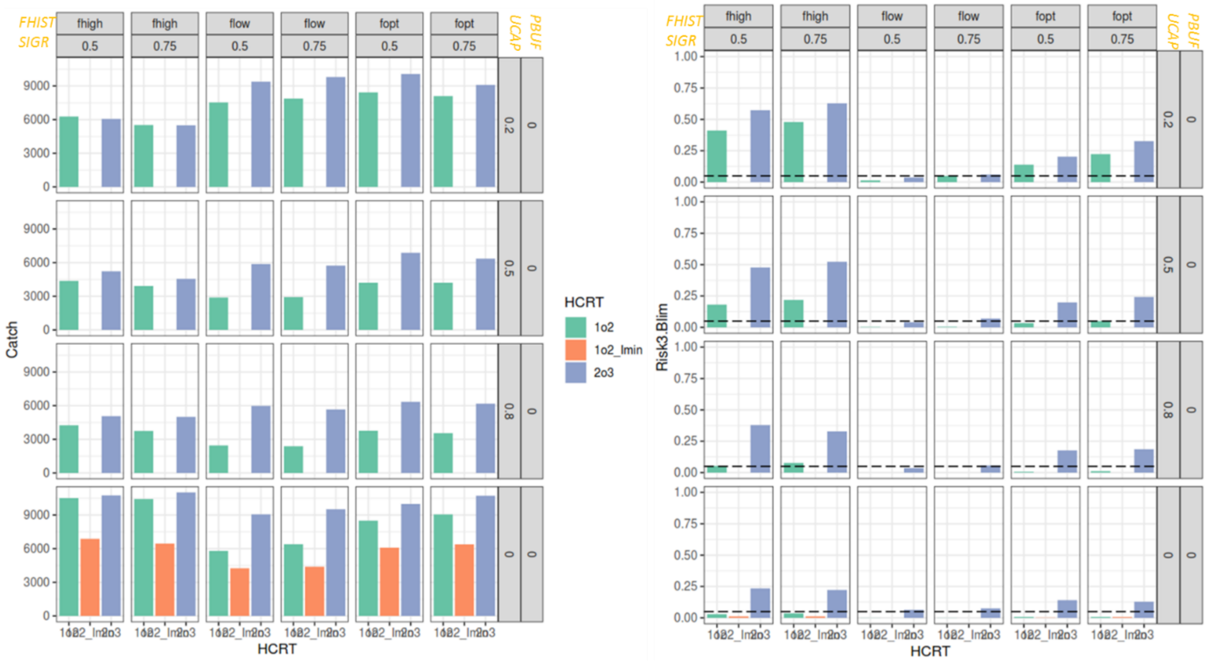

Figure 3.20. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). From left to right: median catch and Risk3 of falling below B_{lim}, in the **long-term** (years 51-60), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 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).

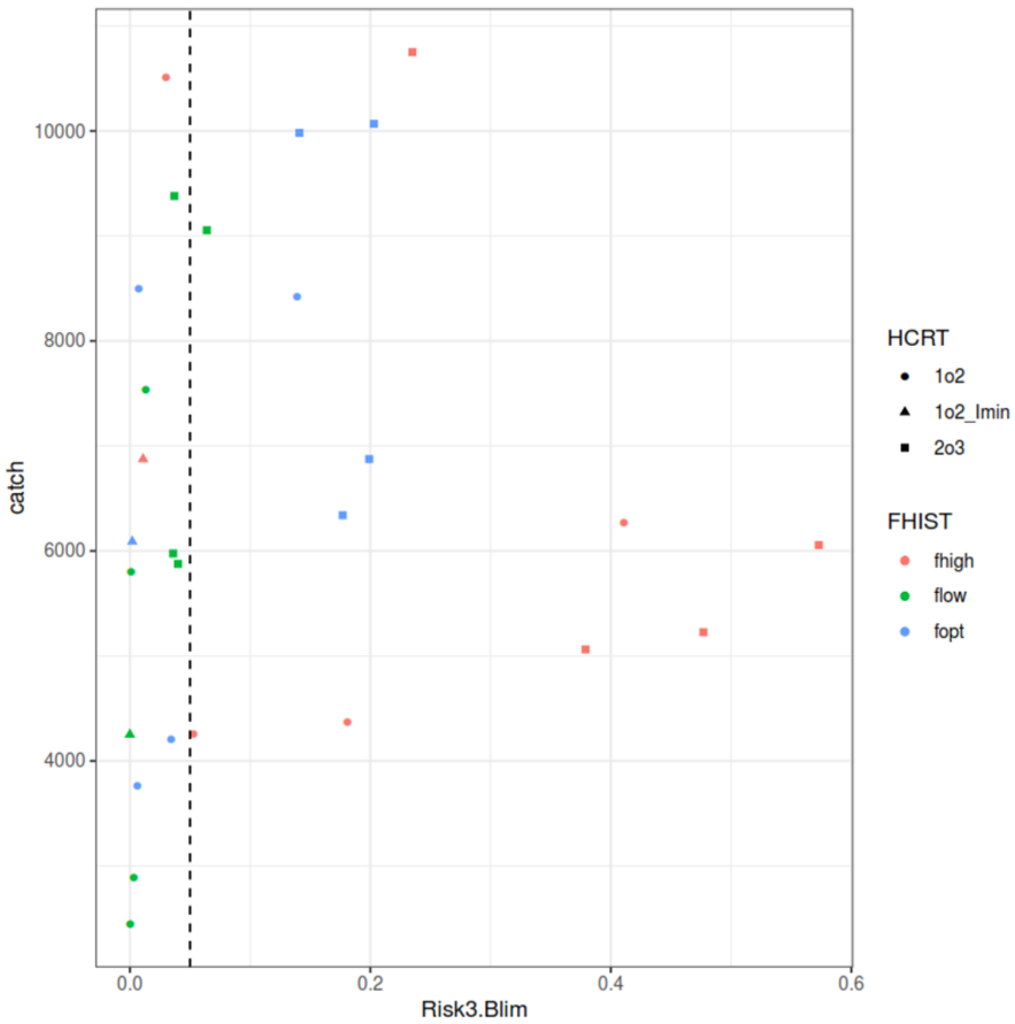

Figure 3.21. Scenario (OM: Stock=STK2, CVID=high; MP: ADVT=iny, PBUF=UCPL=UPCU=0, HCRI=nin). Median catch versus Risk3 of falling below B_{lim}, in the long-term (years 51-60), for each HCR type (green – 1o2: 1-over-2; orange – 1o2_Imin: 1-over-2 with biomass safeguard; and blue – 2o3: 2-over-3) and 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 3.22 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.
- The bigger the historical exploitation, the greater the catches and risks at any time frame, but particularly in the short and medium term.
- 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 one resulting in risks below 5%.

- The most precautionary rule is the 1-over-2 rule with an 80% uncertainty cap, while the 1-over-2 rule with biomass safeguard shown an intermediate behaviour between the former 1-over-2 rule with an 80% uncertainty cap and the same rule without uncertainty cap.

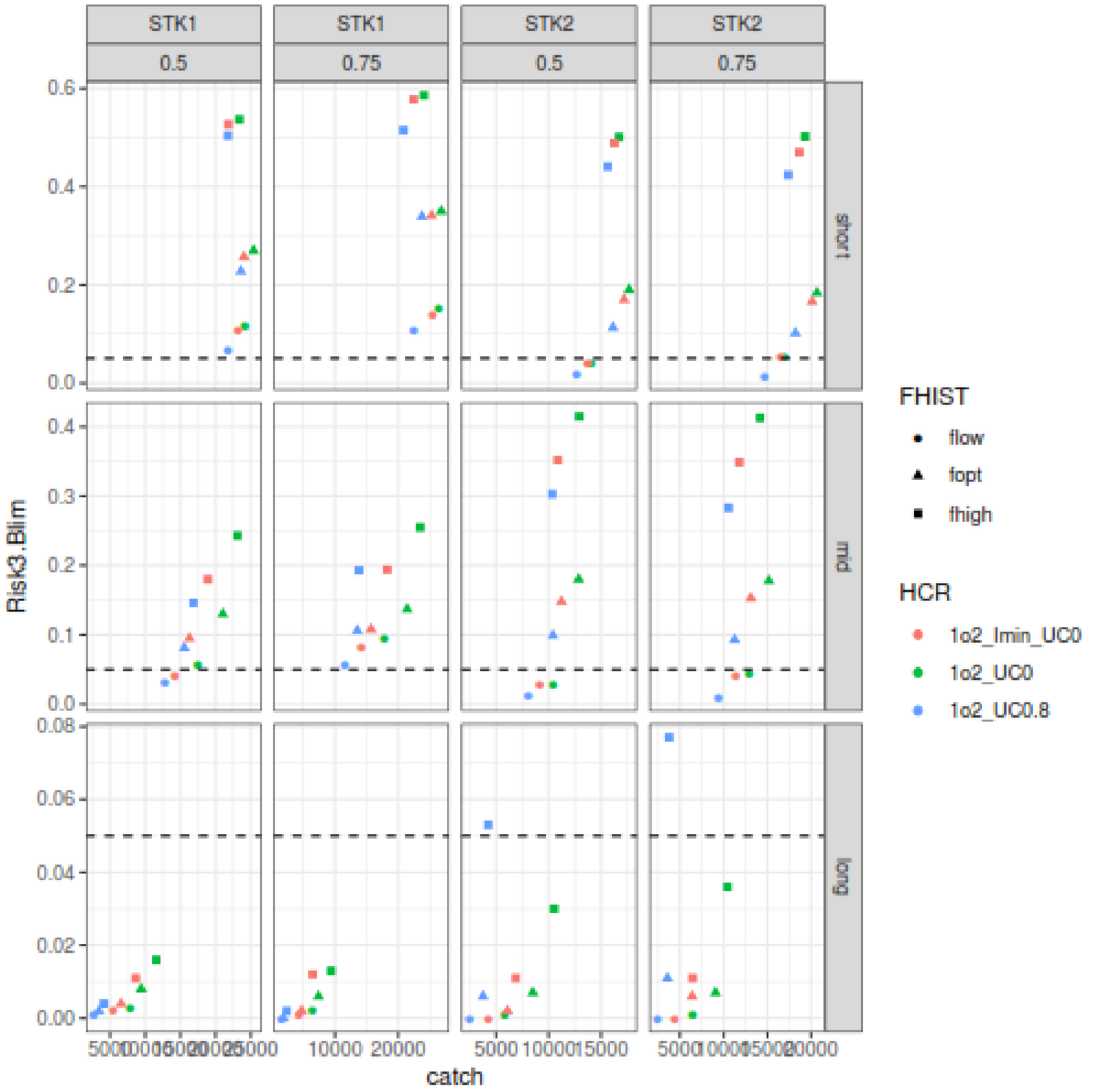

Figure 3.22. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Risk3 of falling below B_{lim} versus median catch for alternative historical F levels (circle - Flow: 0.5*F_{MSY}; triangle - Fopt: F_{MSY}; and square - Fhigh: 2*F_{MSY}), HCRs (red – 1o2_Imin_UC0: 1-over-2 with biomass safeguard; 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 3.23 shows the comparison between the relative increase in risks and catches, where below the line implies bigger relative increase in catches than in risks. 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 increase 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.

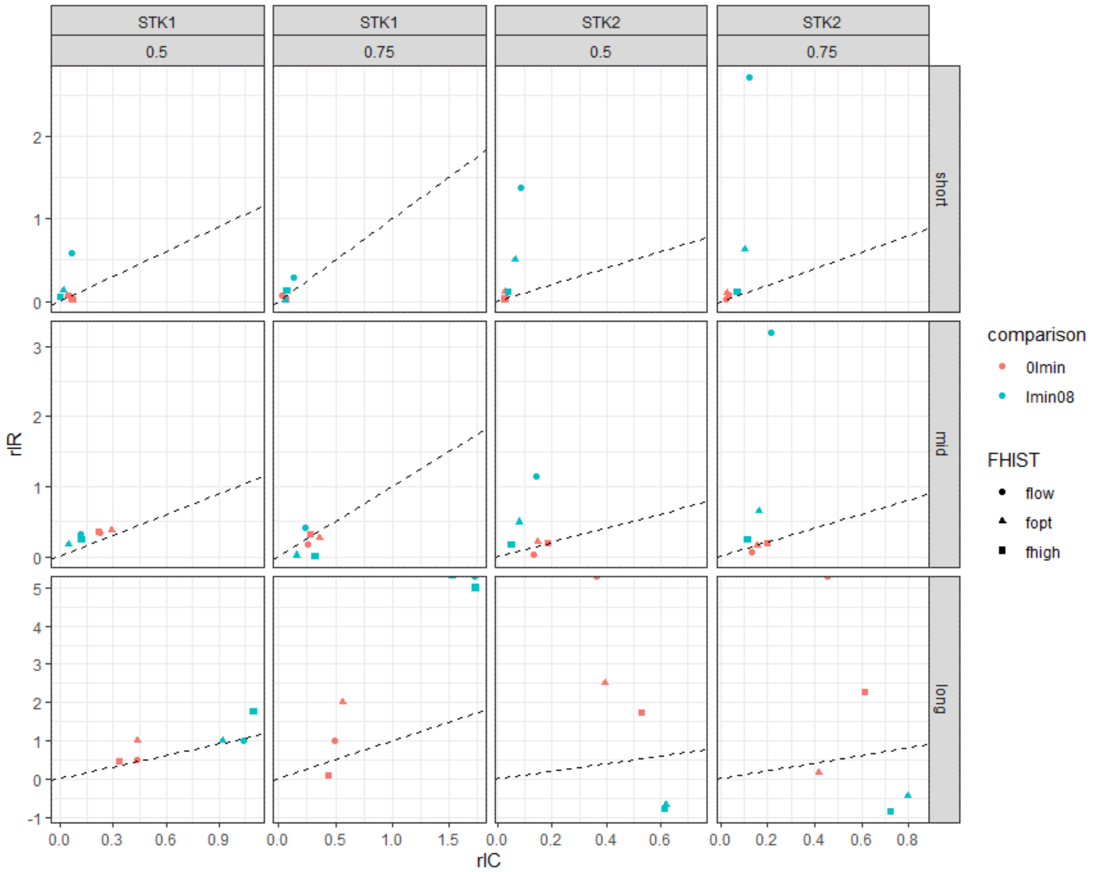

Figure 3.23. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Relative changes in Risk3 of falling below B_{lim} (rIR) versus relative changes in median catch (rIC) for alternative HCR ratios (red – 0Imin: 1-over-2 without uncertainty cap/1-over-2 with biomass safeguard-1; green – Imin08: 1-over-2 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).

3.4. Potential HCRs for short-lived stocks

In addition to the rules mentioned up to now, the 1-over-2 rule with asymmetrical uncertainty cap was also tested for comparison with the alternative MSE works carried out within the ICES WKDLSSLS workshop.

Figure 3.24 compares the performance of the potentially best rules in terms of catches and risks in different periods (short, medium and long-term). As in former sections, it is evidenced that historical exploitation drives risk and this is reduced with time.

In general terms, we can order the rules from less to highest risky rules as follows:

1o2_cap(0.8,0.2) < 1o2_cap(0.8,0.8) < 1o2_Imin < 1o2

Where:

- 1o2_cap(0.8,0.2) : 1-over-2 with asymmetrical uncertainty cap (0.8,0.2);
- 1o2_cap(0.8,0.8): 1-over-2 with 80% symmetric uncertainty cap;
- 1o2_Imin : 1-over-2 with biomass safeguard; and
- 1o2 : 1o2 without any uncertainty caps.

Therefore, at all times 1-over-2 with asymmetrical uncertainty cap (0.8,0.2) leads to smallest risks, but also to smallest catches. It is worth noting that in the long term, all rules are precautionary, but catches of the 1-over-2 rule with asymmetric uncertainty caps (0.8,0.2) become very small, almost equal to 0 t (i.e., fishery is almost closed).

For STK1 (anchovy-like stocks), when comparing rules 1o2_cap(0.8,0.8) and 1o2_Imin, 1o2_Imin might be preferred due to similar performance of catches and risks in the short and medium terms but highest catches in the long-term. However, for STK2 (sardine/sprat-like stocks), even though 1o2_Imin could be selected again for the rather similar reasons as for STK1, the 1o2_cap(0.8,0.8) might be preferred as it leads to a bit less risks and catches mainly in the short and medium terms. In the latter preference for rule 1o2_cap(0.8,0.8) we are applying the principle of prioritizing the performance in the short and medium term (first 10 years of management) versus the long term.

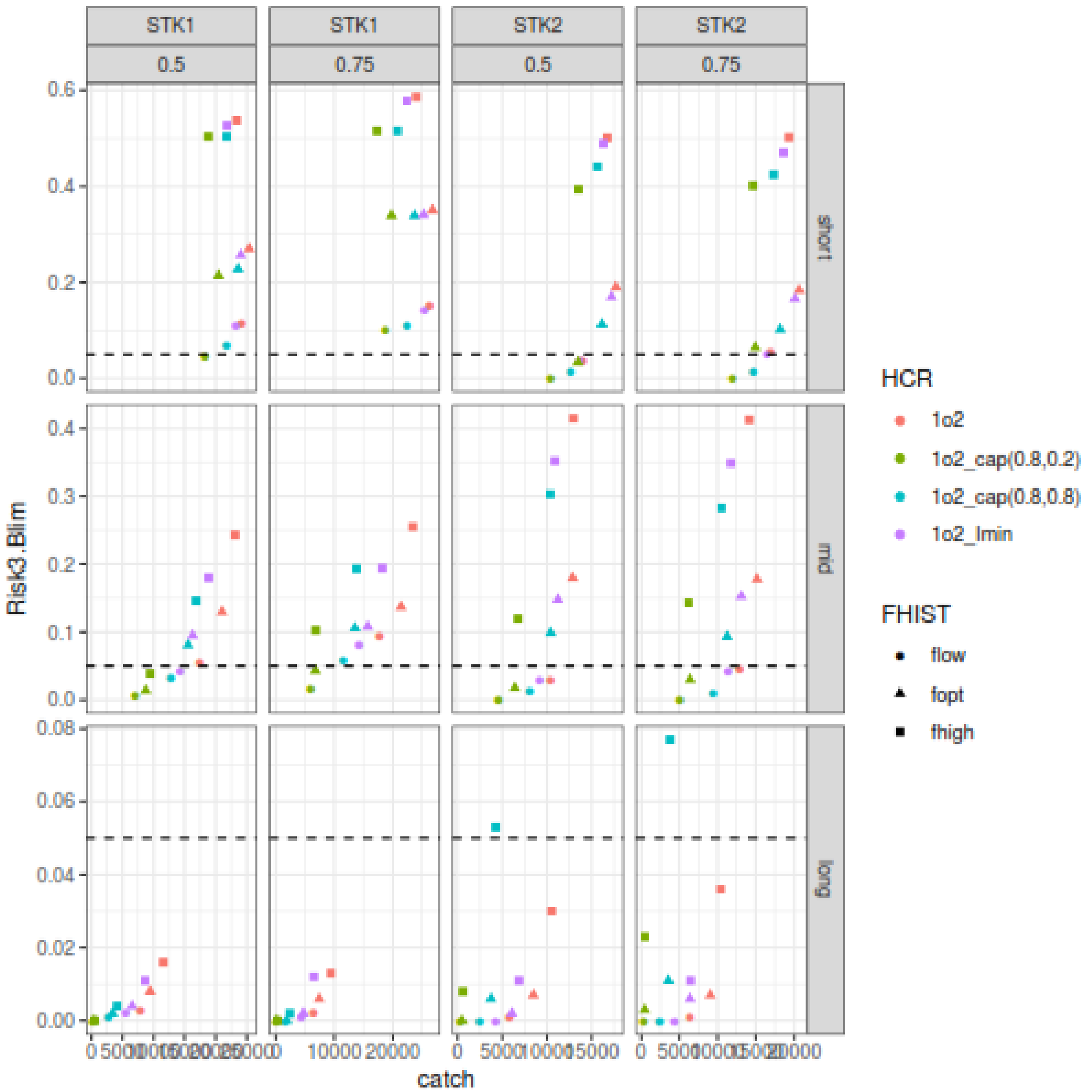

Figure 3.24. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Risk3 of falling below B_{lim} versus median catch for alternative historical F levels (circle - Flow: 0.5*F_{MSY}; triangle - Fopt: F_{MSY}; and square - Fhigh: 2*F_{MSY}), HCRs (red – 1o2: 1-over-2 without uncertainty cap; green – 1o2_cap(0.8,0.2): 1-over-2 with lower and upper uncertainty caps of 80% and 20%, respectively; blue – 1o2_cap(0.8,0.8): 1-over-2 with symmetric uncertainty cap of 80%; and purple – 1o2_Imin: 1-over-2 with biomass safeguard), 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 3.25 compares the relative changes in risks (X-axis) versus the relative changes in catches (Y-axis). For the cases where risks are below 5% (i.e. all rules in the long term, see bottom line's plots in Figure 3.24 and Figure 3.25 and when Fhist=Flow, see circles in Figure 3.25), the rule resulting in higher catches can be preferred as it does not affect much risks, neither the relative changes. Attention should be paid for the rest of cases, i.e. for the short and medium-term performance and for the historical F at Fopt and Fhigh, which induce risks above 5%. Those points above the line would indicate changes worth considering, as in this case the relative increase in catches is higher than the relative change in risks. Generally, points do not deviate much from 1:1 line, so relative changes in catches are similar to those in risks when moving from one rule to the other. This implies that globally relative changes in risks associated to the different rules will be proportional to the relative changes in catches. Exceptions to this occur for medium term at sigR=0.5 at Fhist=Fopt for STK2 (sardine-like) and at Fhist=Fhigh for SKT1 (anchovy-like), when moving from 1-over-2 with asymmetrical uncertainty cap (i.e. 1o2_cap(0.8,0.2)) to the one with symmetrical uncertainty cap (i.e. 1o2_cap (0.8,0.8)) which leads to proportionally far larger relative increase in risks than the relative increase of catches (Figure 3.25, but see also Figure 3.24 to better judge pros and cons on this).

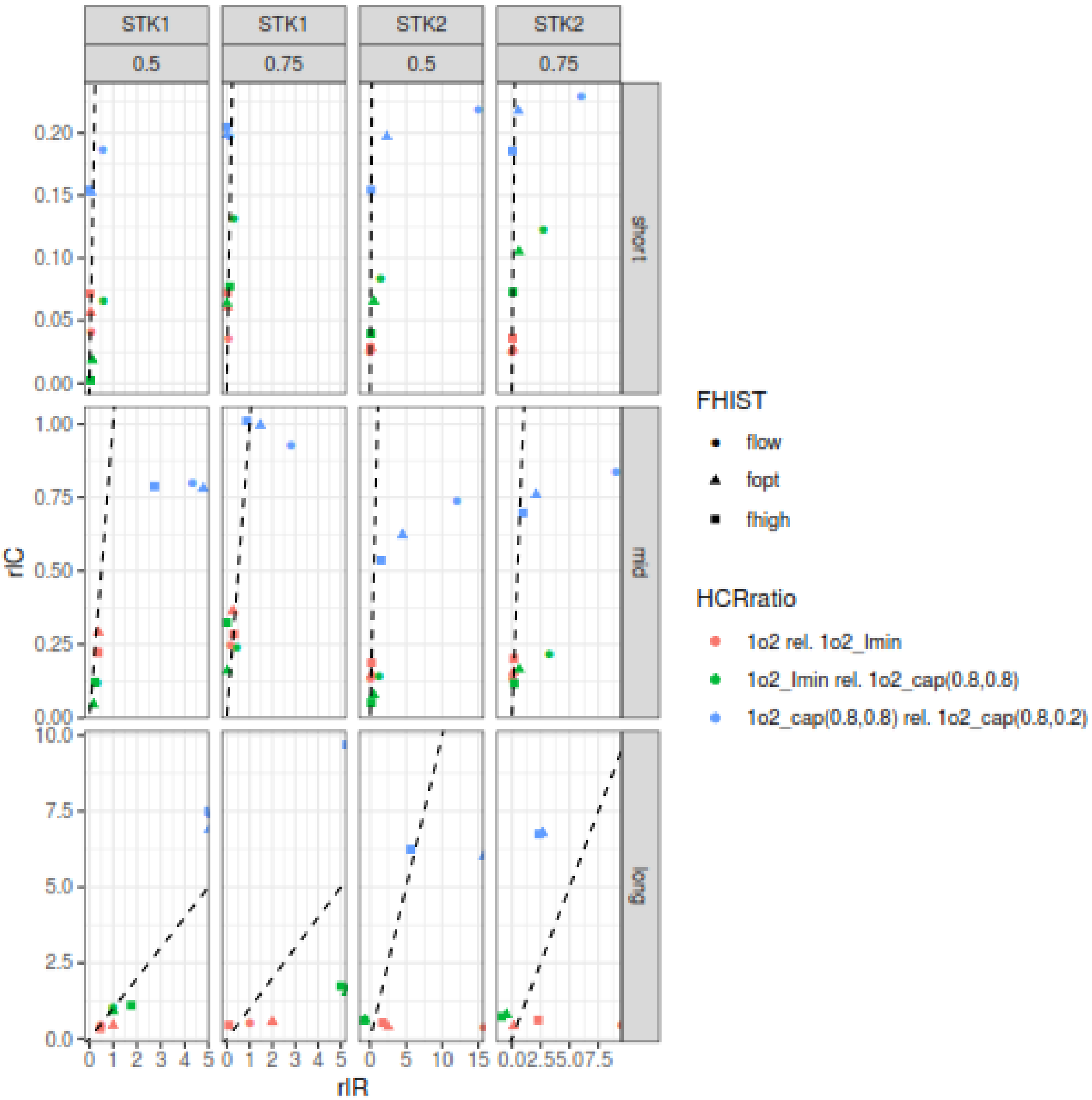

Figure 3.25. Scenario (OM: CVID=high; MP: ADVT=iny, PBUF=0, HCRI=nin). Relative changes in median catch (rIC) versus relative changes in Risk3 of falling below B_{lim} (rIR) for alternative HCR ratios (red – 1o2 rel. 1o2_Imin: 1-over-2 without uncertainty cap/1-over-2 with biomass safeguard-1; green – 1o2_Imin rel. 1o2_cap(0.8,0.8): 1-over-2 with biomass safeguard/1-over-2 with a symmetric 80% uncertainty cap-1; and blue – 1o2_cap(0.8,0.8) rel. 1o2_cap(0.8,0.2): 1-over-2 with a symmetric 80% uncertainty cap /1-over-2 with a lower and upper uncertainty caps of 80% and 20% resp. -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). In this case, m relative to m, means relative changes when moving from n to m rule.

Some conclusive remarks from this final crossed analysis of the best performant rules follow:

- There is strong trade-off between the rules for the short, medium and long term between risks and catches.
- The rules ordered by risk (from least to highest risk) are:

  1o2_cap(0.8,0.2) < 1o2_cap(0.8,0.8) < 1o2_Imin < 1o2
- Obviously, the smaller the catches the smaller the risks and for this reason the 1-over-2 rule with asymmetric uncertainty cap (0.8,0.2) results in the most precautionary approach to management, but at the expense of major reduction of catches (being almost 0 t in the long-term). Opposite to this, the 1-over-2 without uncertainty cap results in the highest catches and risks, particularly in the short and medium term, while the risk would be reduced to precautionary levels in the long-term.
- Intermediate rules in terms of balance between catches and risks are: 1-over-2 with symmetrical 80% uncertainty cap (1o2_cap(0.8,0.8)) and 1-over-2 with biomass safeguard (1o2_Imin). Rule with the 80% uncertainty cap (1o2_cap(0.8,0.8)) results to be a bit more precautionary in the short and medium term, without major loses of catches compared to the other rule, though the drop in catches in the long term is a bit more pronounced.
- None of the trend rules we have tested can assure in the short and medium terms that risks to B_{lim} will be lower than 5%, as this would basically depend upon the historical exploitation of the population before management starts. Even though in the long term almost all rules become precautionary. Therefore, the selection of any rule is more based on relative performance between the rules (particularly in the short and medium-term) and on the speed of reducing risks to precautionary levels along with the final catches which would be allowed.
- The 1-over-2 rule with symmetrical 80% uncertainty cap might be preferred over the asymmetrical with 80% lower and 20% upper uncertainty caps for a better compromise in terms of catches versus risks in the short and medium-term. Although given the trade-off between risks and catches (for the short, medium and long term) this discussion should be partly passed to managers and stakeholders.
- 1-over-2 rule with biomass safeguard at minimum observed index (1o2_Ilim) is a promising rule which deserves further testing as it performance may depend upon the series of historical indexes available before management.

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.

- Comparison of performance between 1-over-2 versus 2-over-3 rule with different symmetrical uncertainty cap levels for the two kind of stocks simulated here and for the different operating models explored, leads to recommend 1-over-2 rule with 80% uncertainty cap for short lived species as the one which produces moderate lower catches but lower risks than the 1-over-2 rule at any other uncertainty caps or with biomass safeguard. Although in the short-term differences are smaller in terms of catches and risks.

- Expansion of the comparisons to include asymmetrical uncertainty cap leads to rank the best rules as follows (from least to highest risk):

  1o2_cap(0.8,0.2) < 1o2_cap(0.8,0.8) < 1o2_Imin < 1o2

- Rule 1-over-2 with asymmetric uncertainty cap (0.8,0.2) results in the most precautionary approach to management, but at the expense of major reduction of catches (being almost 0 t in the long-term). Opposite to this, the 1-over-2 without uncertainty cap results in the highest catches and risks, particularly in the short and medium term, while the risk would be reduced to precautionary levels in the long-term.

- Intermediate rules in terms of balance between catches and risks are: 1-over-2 with symmetrical 80% uncertainty cap (1o2_cap(0.8,0.8)) and 1-over-2 with biomass safeguard (1o2_Imin). Rule with 80% uncertainty cap results to be a bit more precautionary in the short and medium term without major loses of catches compared to the other rule, though the drop in catches in the long term is a bit more pronounced.

- None of the trend rules we have tested can assure in the short and medium terms that risks to B_{lim} will be lower than 5%, as this would basically depend upon the historical exploitation of the population before management starts. Even though in the long term almost all rules become precautionary. Therefore, the selection of any rule is more based on relative performance between the rules (particularly in the short and medium-term) and on the speed of reducing risks to precautionary levels along with the final catches which would be allowed.

- The 1-over-2 rule with symmetrical 80% uncertainty cap might be preferred over the asymmetrical with 80% lower and 20% upper uncertainty caps for a better compromise in terms of catches versus risks in the short and medium-term. Although given the trade-off between risks and catches (for the short, medium and long term) this discussion should be partly passed to managers and stakeholders.

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