Workshop on the management strategy evaluation of the reference point, F_{cap}, for Sprat in Division 3.a and Subarea 4. (WKspratMSE)

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Workshop on the management strategy evaluation of the reference point, F_{cap}, for Sprat in Division 3.a and Subarea 4 (WKspratMSE)

11-12 December 2018

ICES HQ, Copenhagen, Denmark

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Executive summary

The Workshop on the management strategy evaluation of the reference point, F_{cap}, for Sprat in Division 3.a and Subarea 4 (WKSpratMSE) was held in ICES headquarters in Copenhagen 11-12 December 2018, and continued to work by correspondence through February 2019. The aim of the workshop was to estimate an appropriate F_{cap} for sprat in Division 3.a and Subarea 4 (Skagerrak, Kattegat, and North Sea) and sprat in divisions 7.d and 7.e (English Channel). This was done in response to the outcomes of the Benchmark Workshop on Sprat (WKSPRAT 2018). Two external reviewers participated and reviewed the analytical work and conclusions of the workshop. See full participant list in Annex 1.

Sprat in the English Channel (Divisions 7de) is a category 3 stock and is assessed based on the acoustic survey carried out in area 7.e. Previously, the "2-over-3" rule had been used to provide catch advice, but evaluations during the last WKSPRAT benchmark suggested that such rule is not appropriate for short, highly productive species. The workshop therefore compared through simulations the performances of a "1-over-2" rule (with and without an uncertainty cap) and of different fixed harvest rates. The simulations suggested that a 1-over-2 rule for short-lived highly productive species might cause the stock to fall below safe levels and eventually to collapse because the rule is not reactive enough to limit the catches when there is a recruitment failure. When removing the uncertainty cap, performances improve, but the risk still remains above safe limits. The use of a fixed harvest rate seems to prevent risk and maximize catch, depending on the proportion used. Simulations suggest that a 20% harvest rate is considered appropriate to maintain the stock at safe biomass levels and to produce relatively high yield. One external reviewer suggested that these rules continue to be explored at the relevant upcoming Workshop for Data-limited Short-lived Stocks (WKDLSSLS).

Sprat in Skagerrak, Kattegat, and the North Sea (Division 3a, Subarea 4) is a category 1 stock and follows the ICES MSY approach where the advised yearly catches correspond to the estimated stock biomass in excess of the MSY $B_{escapement}$, but constrained so that the fishing mortality is no higher than a limit F (F_{cap}). A "full" closed loop management strategy evaluation (MSE) was carried out to test for a range of F's and find an appropriate F_{cap} value that showed a less than 5% probability of SSB < $B_{escapement}$. The value of F_{cap} was conditioned on using B_{pa} as MSY $B_{escapement}$. A "short-cut" MSE featuring an assessment emulator was implemented to compare the two approaches. The stock and fleet dynamics were conditioned on the most recent assessment from WKSPRAT2018. Performance statistics between the "full" and "short-cut" MSEs were similar, suggesting that short-cut MSEs should continue to be explored, as they have the advantage of being unaffected by assessment numeric convergence. According to these analyses, F_{cap} of 0.69 is precautionary.

1 Introduction

The Workshop on the Management Strategy Evaluation (MSE) of the reference point F_{cap} for Sprat (*Sprattus sprattus*) in Division 3.a and Subarea 4 (Skagerrak, Kattegat and North Sea) (WKspratMSE), chaired by Piera Carpi (UK) and reviewed by Sigurður Þór Jónsson (Iceland), and Leire Ibaibarriaga (Spain) met in Copenhagen, Denmark, 11–12 December 2018. The workshop assessed which value of F_{cap} should be applied to the escapement strategy used for sprat in the North Sea and evaluated which harvest strategy would be more appropriate to manage the sprat stock in the English Channel.

Specifically, the workshop was asked to

a) On the basis of the outcome of WKSPRAT 2018 (ICES, 2018a) (assessments, PA reference points) and guidance provided by WKMSYRef2 (ICES, 2014), estimate an appropriate F_{cap} for each stock. Review the final model configuration following model optimisation to minimise retrospective bias.

1.1 Background

North Sea/Skagerrak-Kattegat Sprat stock is managed through an escapement strategy. Escapement strategy, where the stock is fished down to B_{pa}, has been proved not to be precautionary for such stock, unless an F limit control rule is applied (ICES, 2014). F_{cap} for this stock was set at 0.7 until the last assessment in March 2018. However, since the assessment has been revised during the 2018 WKSPRAT benchmark (ICES, 2018a), and given the inclusion of the Skagerrak-Kattegat stock within the larger North Sea component, a revision of the F_{cap} was also required. A full closed loop management strategy evaluation was carried out to test for different F_{cap} values: the F_{cap} chosen corresponded to the F providing a probability of Spawning Stock Biomass (SSB) falling below B_{lim} lower than 5%.

English Channel sprat stock is a category 3 data poor stock and is assessed based on the acoustic survey carried out in area 7.e. The "2-over-3" rule has been used till the last assessment to provide catch advice. During the last WKSPRAT benchmark (ICES, 2018a), and in line with the preliminary results reported at WKLIFE (ICES, 2018b; ICES, 2018c) it was agreed that such rule is not appropriate for short, highly productive species. The workshop therefore compared through simulations the performances of a "1-over-2" rule and of different fixed harvest rates.

2 Sprat in 7.de

2.1 Methodology

The MSE for the sprat stock in the English Channel was carried out using the FLR libraries. The code used is available on https://github.com/PieraC/MSE_Sprat.

Very little information is available for sprat in 7.de. Hence, the WKLIFE framework to simulate stock types was used.

2.2 Operating models

The MSE was carried out on simulated short-lived life history types. In particular, six Operating Models (OM) were initially tested, combining different options for the growth parameters and the fluctuations in recruitment.

Each operating model simulates the fishery and the biological dynamics affecting the population, given a TAC estimated from the selected management strategies. The TAC is taken from the true population, and as the TAC is taken, the stock is simulated accordingly. The operating models (Table 1.1) attempted to incorporate all the uncertainties relative to this specific stock, its fishery and more in general to short-lived species, i.e.:

- Large fluctuations in recruitment occurring from one year to the next; the highest value of 0.5 used for the standard deviation when simulating recruitment variability was chosen because a similar value was observed for North Sea sprat.
- A fast growth: two different values for k and L_{inf} were tested, and consequently different natural mortality values.
- Potential tendency of acoustic survey to overestimate the mature component.

The age-structured operating models were constructed using FLR packages FLife and FLBRP (www. flr-project.org), based on the life-history parameters (Table 1.1). Virgin biomass was set at 1000, the maximum age was defined as the age at 95% L_∞. Ages were converted to lengths using the growth parameters (Table 1.1).

Spawning time takes place between February and May, and since the advice is provided seasonally (1 June–31 of May), the SSB is calculated towards the end of the assessment year.

For the final evaluation, 2 operating models, that were considered to be a better representation of the sprat stock in the English Channel, were chosen (Table 1.1).

Table 1.1: Sprat 7de - Operating Models used for simulations. (*) The asterisks highlight the two models considered for final scrutiny.

	L_{inf}	k	Sd Rec	T0	a	b	B_{virgin}
OM1*	16	0.6	0.3	-0.8	0.0000048	3.19	1000
OM2*	16	0.6	0.5	-0.8	0.0000048	3.19	1000
OM3	16	0.4	0.3	-0.8	0.0000048	3.19	1000
OM4	16	0.4	0.5	-0.8	0.0000048	3.19	1000
OM5	13	0.6	0.3	-0.8	0.0000048	3.19	1000
OM6	13	0.6	0.5	-0.8	0.0000048	3.19	1000

Maturity is modelled as a logistic, with 50% mature at age 0 and fully mature from age 1 onward for OMs 1-2-5-6; on the other hand, in OM3-4 maturity is almost zero for age 0 and A50 is equal to age 1 (Figure 1.1a).

Values a and b for the length-weight relationship are derived from the biological data collected in the PELTIC survey (Figure 1.1b).

Natural mortality at age was derived from the Von Bertalannffy growth parameters using the Gislason's equation (Gislason *et al.*, 2010) (Figure 1.1c).

Selectivity at age from the fishery was modelled as a logistic curve according to information from the pelagic trawlers targeting sprat in Lyme Bay: age 2 was considered the fully selected age; a quite high selectivity was however attributed to age 1 as well for the faster growing OMs, while a lower value was used in the slow growth OM (Figure 1.1d).

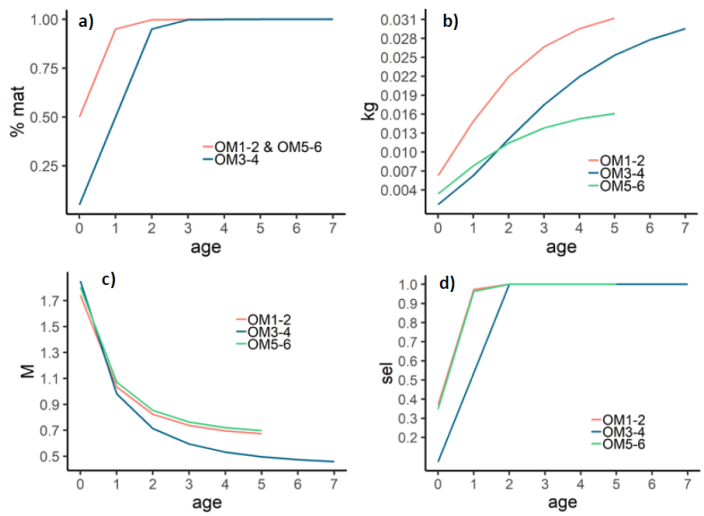

Figure 1.1. Sprat 7.de – Life history and fishery characteristics of the 6 Operating models tested: a) maturity at age; b) weight at age; c) Natural mortality at age; d) Selectivity at age.

Catchability at age from the survey was modelled as a logistic curve (Figure 1.2): the catchability for ages 2 onward was modelled to be higher than 1, to account for the potential of the acoustic survey to overestimate the total biomass for older ages. Survey time was set equal to 5/12, to emulate the current situation for sprat in 7.de where the advice is provided seasonally (1 June to 31 May of the following year) (ICES, 2018a) and the survey takes place between October and November.

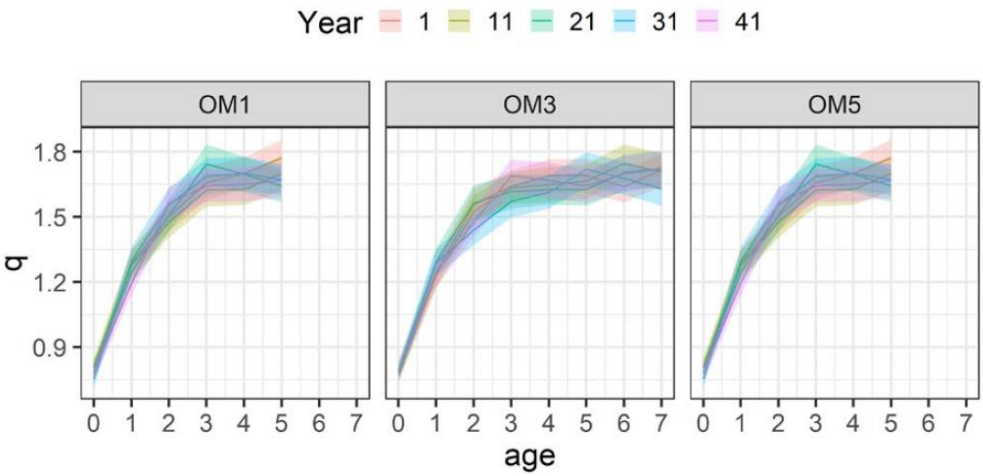

Figure 1.2. Sprat 7.de – Catchability at age for the fishery independent index of biomass for the 6 OMs tested. 6 years from the historical and simulated period are shown.

Stock recruitment relationship was modelled using a segmented regression, with breakpoint equal to 40% B_{virgin}. This quite high value (40% B_{virgin} is often used as a proxy for B_{MSY}) was used as B_{lim} to add an extra precautionary buffer to the simulations. Autocorrelation in recruitment was not tested because no autocorrelation is observed for North Sea sprat.

An F reference point based on the Patterson's exploitation rate (E) of 0.4 (E=F/Z) was chosen as target of the historical fisheries development (25 years), i.e. at the beginning of the time series the F increased gradually from 0 to the F corresponding to E=0.4. The stock develops accordingly. At the start of the long term forecast the simulated stock is then experiencing an average exploitation level, with an average value of SSB and recruitment (Figure 1.3).

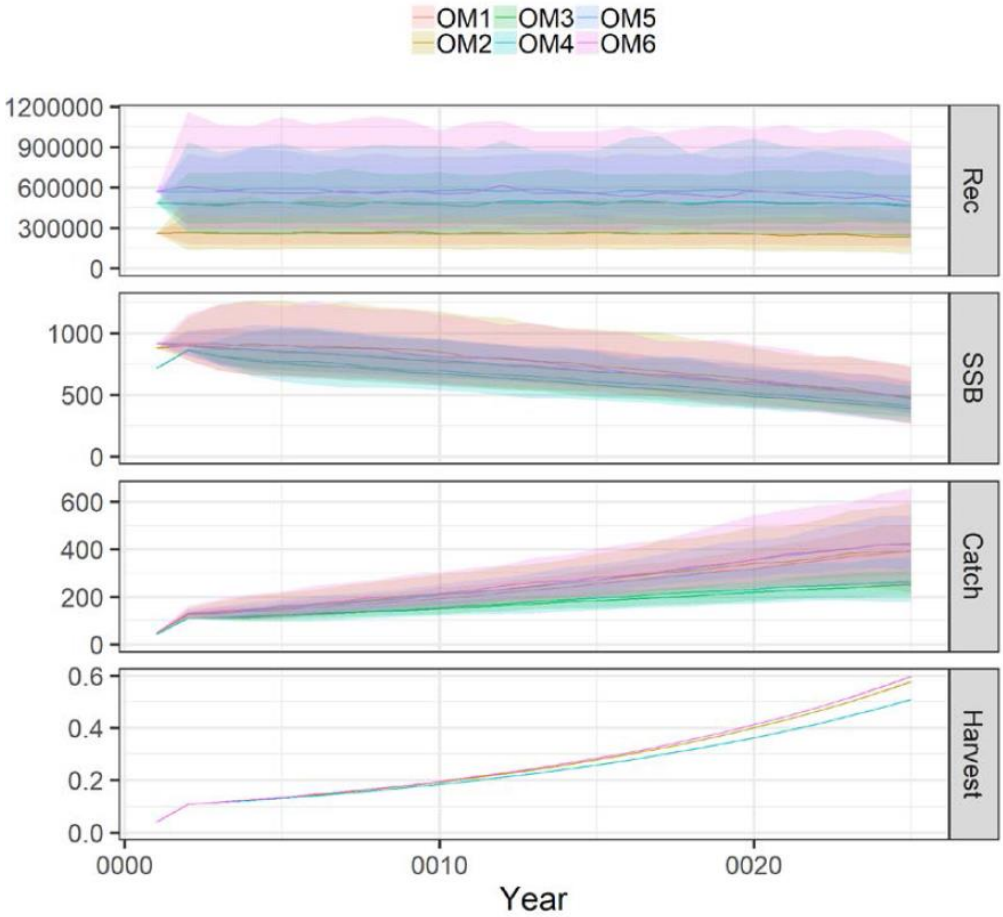

Figure 1.3. Sprat 7.de – Historical stock development for each of the simulated OMs.

A series of features of OMs was cross-checked with North Sea sprat characteristics. In particular, it was ensured that the correlation between numbers-at-age in the stock and numbers-at-age as observed by the index of abundance was relatively low; that the internal consistency between subsequent ages in the survey was poor; that the overall CV of the acoustic index at the beginning of the forecast period was close to 0.5 (which is the average CV of the acoustic survey estimated by the assessment model for the North Sea sprat).

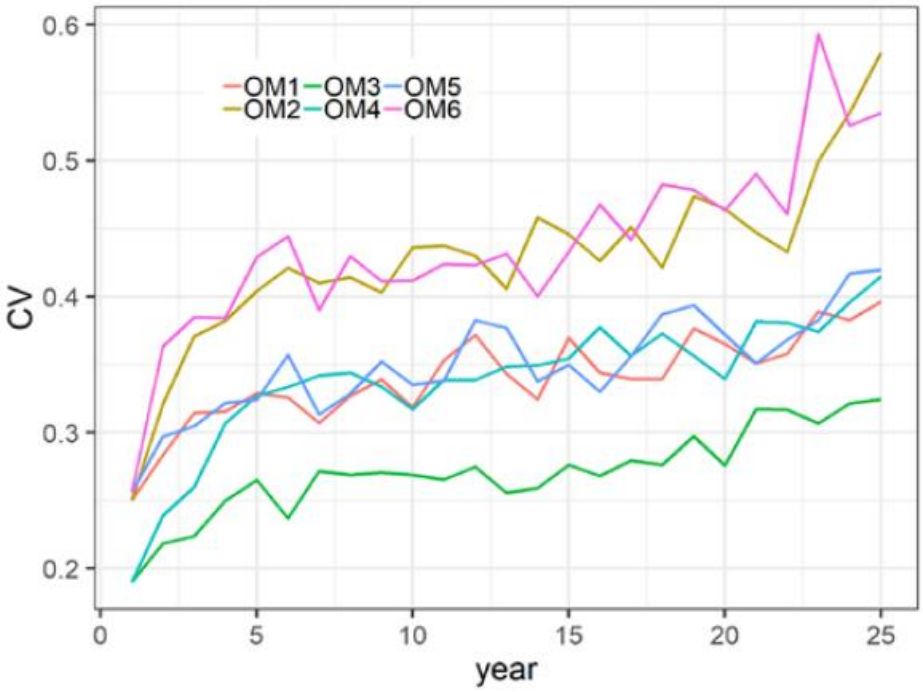

Figure 1.4. Sprat 7.de – CV of the fishery independent index of biomass for the historical time period.

Recruitment development for the 6 operating models for one iteration is shown in Figure 1.4.

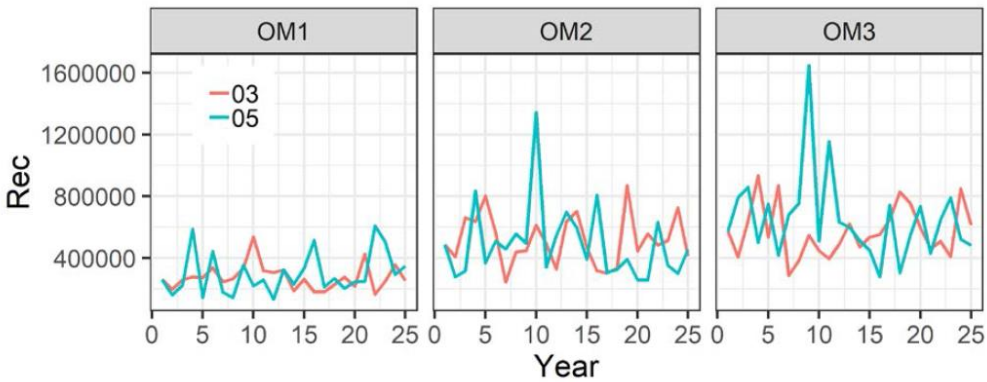

Figure 1.5. Sprat 7.de – Example of recruitment development for 1 random iteration for each operating model in the historical period.

2.3 Management strategy

2.3.1 Assessment emulator

For each replicate, in each year of the MSE, a stock assessment is emulated to produce an estimated state. In this specific case, the assessment is based on empirical estimates from the acoustic survey carried out in the region. Hence, the assessment emulator draws an estimated state (numbers at age) from the catchability and the numbers at age in the true population. This index of abundance is converted into a biomass estimate using the stock weight at age and the timing of the survey.

2.3.2 Harvest control rules

The Harvest Control Rules (HCR) tested are applied directly to the simulated biomass index. The HCR tested are i) the "1-over-2" rule, i.e. the ration of the last biomass estimates and the average of the two previous years of the fisheries independent index; two different options were tested, that is the application or not of the 20% uncertainty cap; ii) a fixed harvest rate, i.e. a fixed proportion of the biomass estimates; values from 10% to 40% were tested.

No implementation error was included in the forecast, because the catches are believed to be a correct representation of the overall removal.

2.3.3 Simulations

The FLR MSE simulations carried out to analyze the performance of the HCRs are based on 500 populations, each projected for 25 years.

Simulations were carried out using the FLR packages FLCore and FLash.

2.3.4 Performance statistics

During each simulation a series of metrics were recorded for the evaluation of the HCRs. They include the median average and 5th–95th percentiles in total catch (short as well as long term), fishing mortality ('true' and 'perceived') and SSB. The probability of SSB falling below B_{lim} was also computed throughout the entire time-series.

2.4 Results

The trajectories of the key parameters recruitment, SSB, Yield and fishing mortality for the different operating models are shown in figures 2.1–2.4. Performance statistics were shown for the two operating models that were considered more representative of the sprat stock in the Channel, i.e. OM1 and OM2.

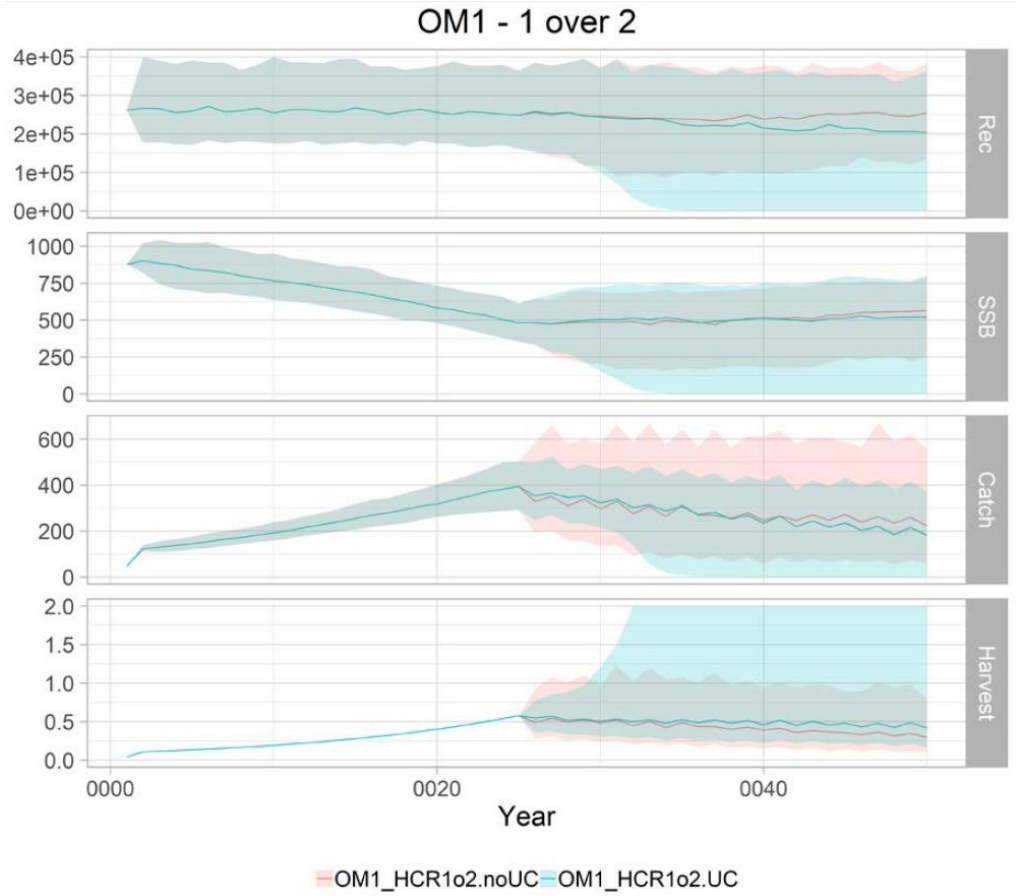

Figure 2.1. Sprat 7.de – Simulation results for OM1 for the 1over2 harvest control rule with (UC) and without (noUC) uncertainty cap.

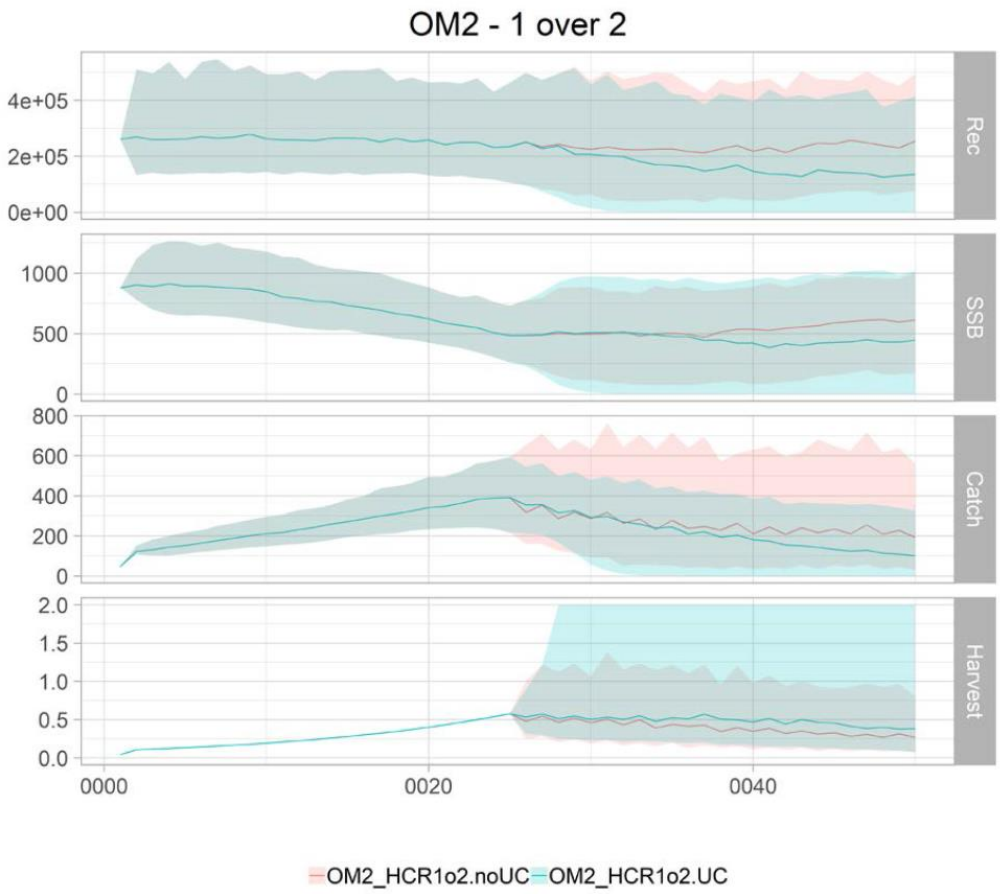

Figure 2.2. Sprat 7.de – Simulation results for OM2 for the 1over2 harvest control rule with (UC) and without (noUC) uncertainty cap.

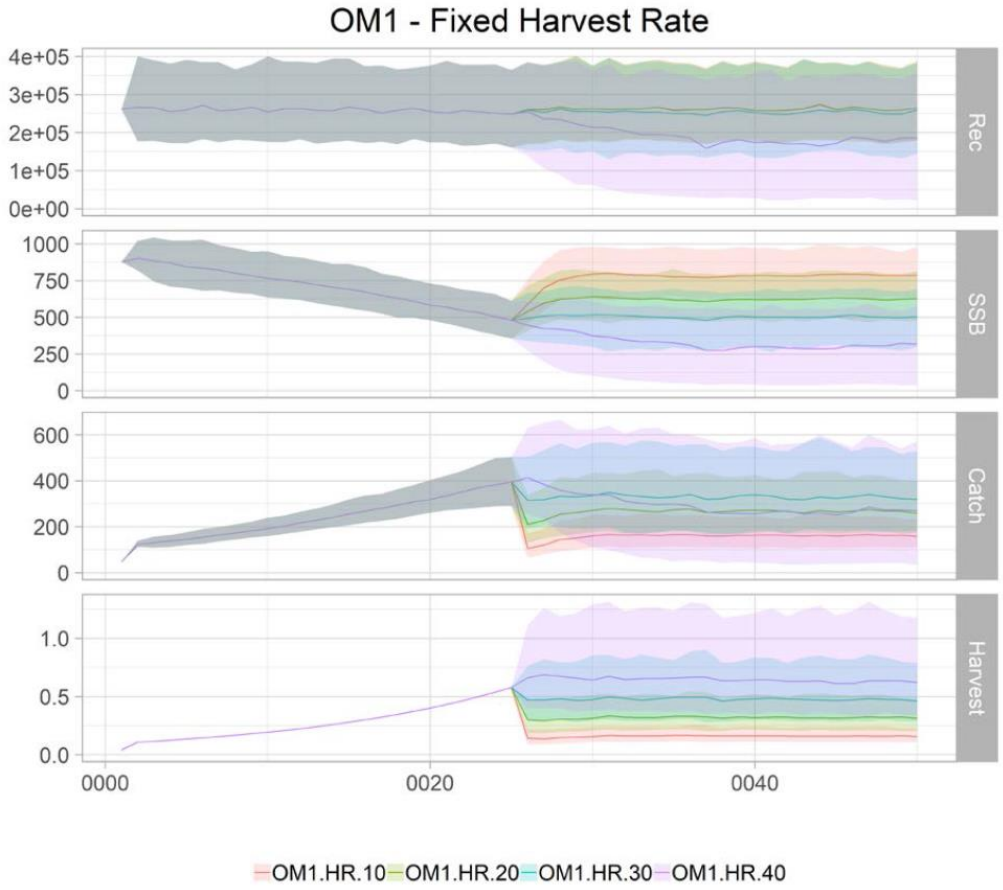

Figure 2.3. Sprat 7.de – Simulation results for OM1 for the fixed harvest rate, testing levels from 10% (OM1.HR.10) to 40% (OM1.HR.40).

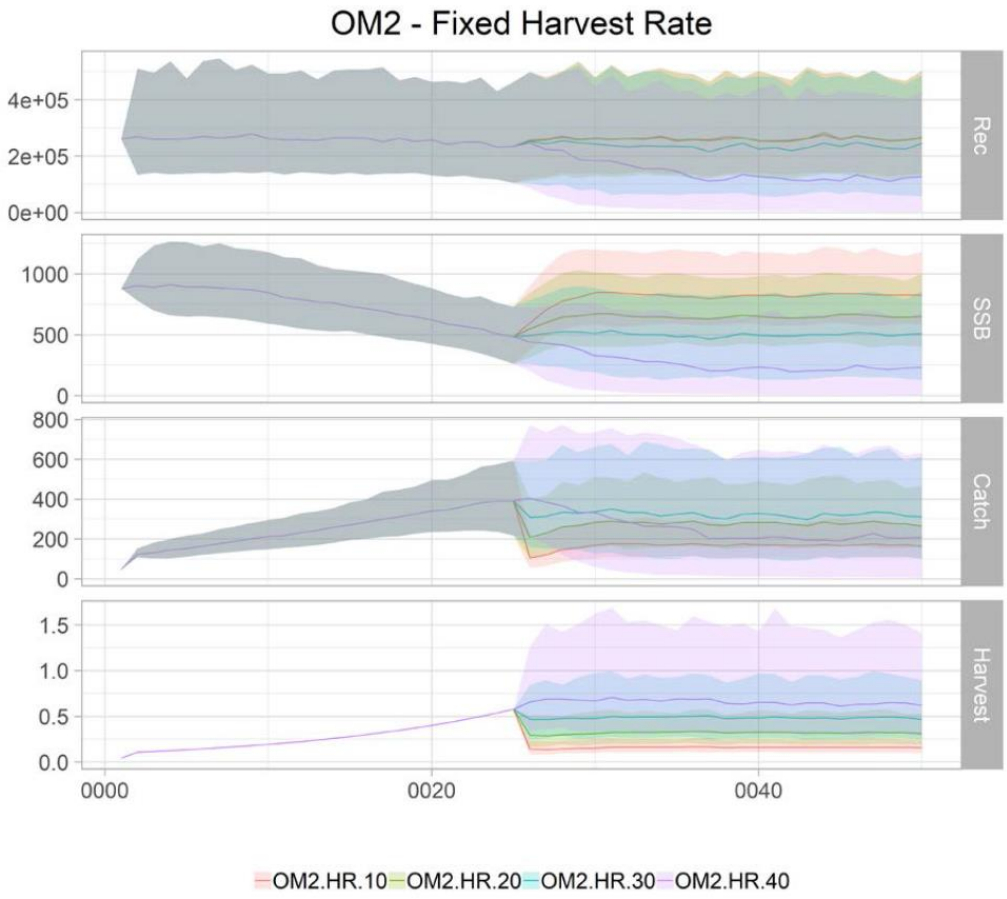

Figure 2.4. Sprat 7.de – Simulation results for OM2 for the fixed harvest rate, testing levels from 10% (OM1.HR.10) to 40% (OM1.HR.40).

Because we are running a full-feedback MSE with an independent assessment for each population in each simulation loop, there is an added variability generated from the assessment, based on the differences between the 'true' and 'perceived' stock. In this case this difference is driven by the catchability-at-age model with lognormally distributed error to include observation error. The stock perceived by the fishery independent survey has been built so to overestimate the true biomass: the comparison between the two is shown in Figure 2.5. For the least precautionary harvest rates (i.e. 30% and 40%) the drop in SSB are such that, despite the higher catchability for the mature component, the perceived biomass is at the same level or lower than the true biomass.

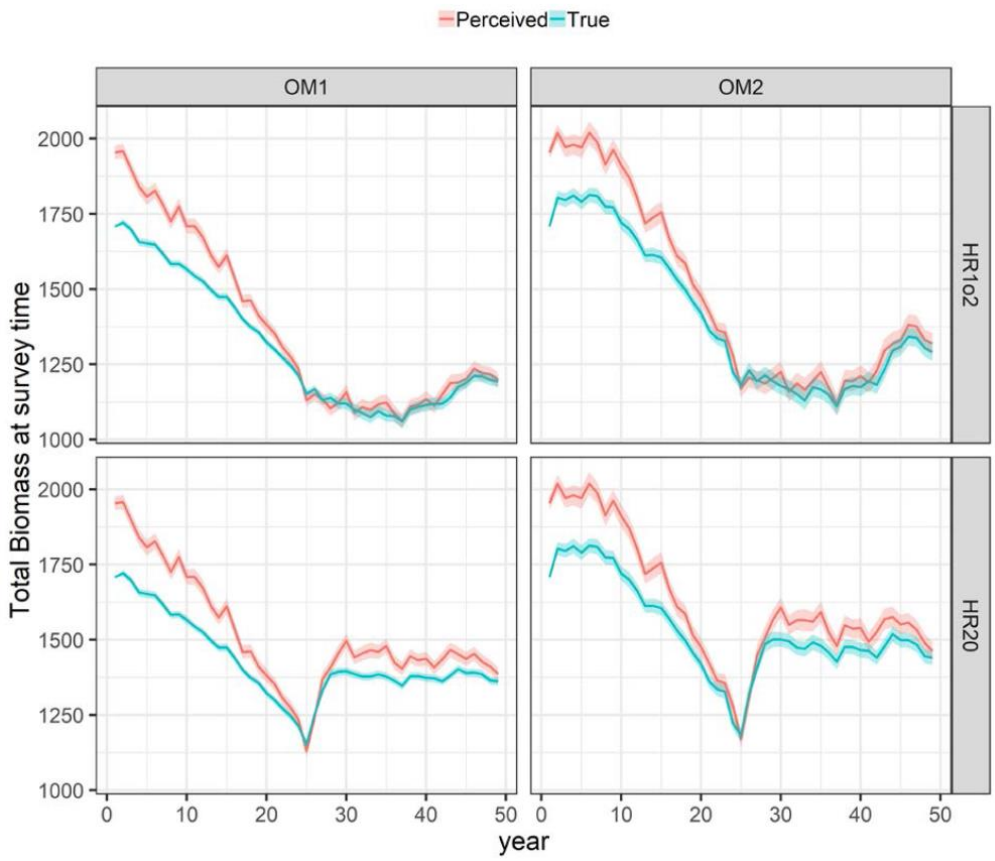

Figure 2.5. Sprat 7.de – Comparison between the true stock (stock biomass at survey time) and the perceived stock (survey biomass at survey time) for the two main operating models and the 1 over 2 rule vs the 20% fixed harvest rate.

Table 2.1 summarizes risk type 1 probabilities for the stock to fall below B_{lim}, to collapse and to hit F_{max}. The years included in the calculation are those after the simulations stabilized. The average yield is shown as well.

Table 2.1. Performance statistics for the main scenarios tested.

Scenarios	SSB below B_{lim} probability	Collapse probability	F_{max} probability	Yield
OM1.1o2.noUC	0.276	0.000	0.012	311
OM1.1o2.UC	0.363	0.129	0.194	232
OM2.1o2.noUC	0.306	0.007	0.020	305
OM2.1o2.UC	0.473	0.188	0.243	179
OM1.HR.01.noUC	0.000	0.000	0.000	173
OM1.HR.02.noUC	0.021	0.000	0.000	289
OM1.HR.03.noUC	0.231	0.000	0.001	353
OM1.HR.04.noUC	0.636	0.003	0.013	298
OM2.HR.01.noUC	0.004	0.000	0.000	187
OM2.HR.02.noUC	0.086	0.000	0.000	309
OM2.HR.03.noUC	0.347	0.000	0.004	356
OM2.HR.04.noUC	0.657	0.018	0.035	289

The probability of falling below B_{lim} remain lower than 5% only for OM1 with 10 and 20% HR and for OM2 with 10% harvest rate. OM2 has a slightly higher probability for the stock to fall below B_{lim} with a 20% HR due to the higher variability in recruitment. Apart from the 1 over 2 rule with UC, all others seem to avoid the risk of collapse with more than 95% probability. F_{max} is hit with high probability only when applying a 1 over 2 with uncertainty cap. Highest yield is reached for both operating models with a 30% HR.

The SSB distribution across OMs for each simulated year for the stable period is presented in Figure 2.6. For both OMs, the best strategies seem to be the fixed harvest rate of 10% and 20%. Higher harvest rate have a strong impact on the stock and cause the SSB to fall below B_{lim} with high probabilities. The 1 over 2 rule with the uncertainty cap show the worst performance across all operating models, while a slight improvement is observed when removing the UC.

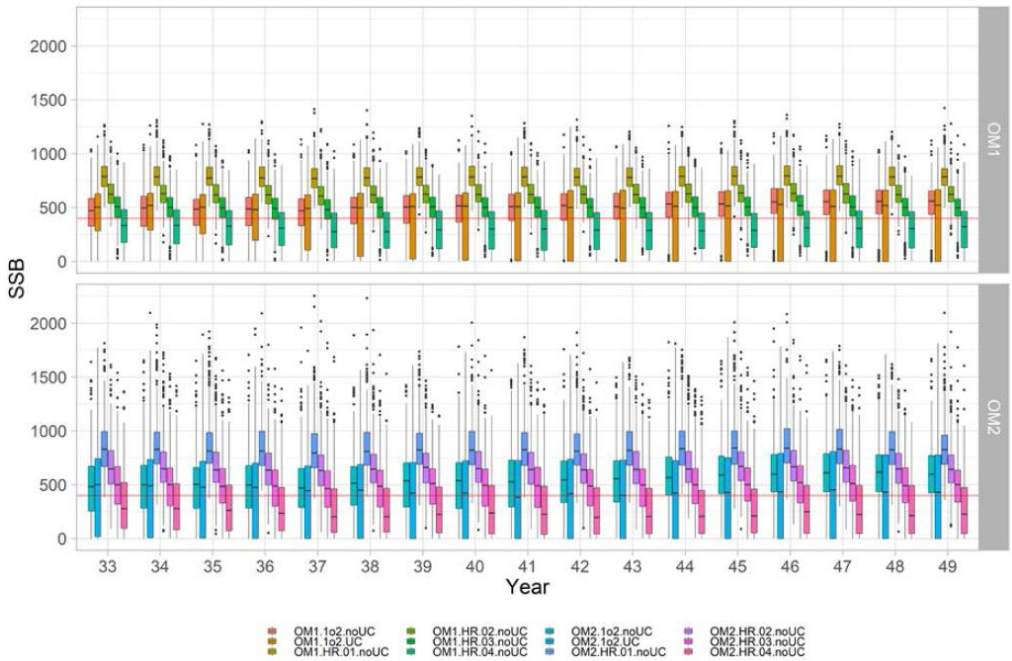

Figure 2.6. Sprat 7.de - SSB distribution across OMs for each simulated year.

The best performance for catches is when using a 30% harvest rate, while worst performance is given again by the 1 over 2 rule with the inclusion of the UC (Figure 2.7).

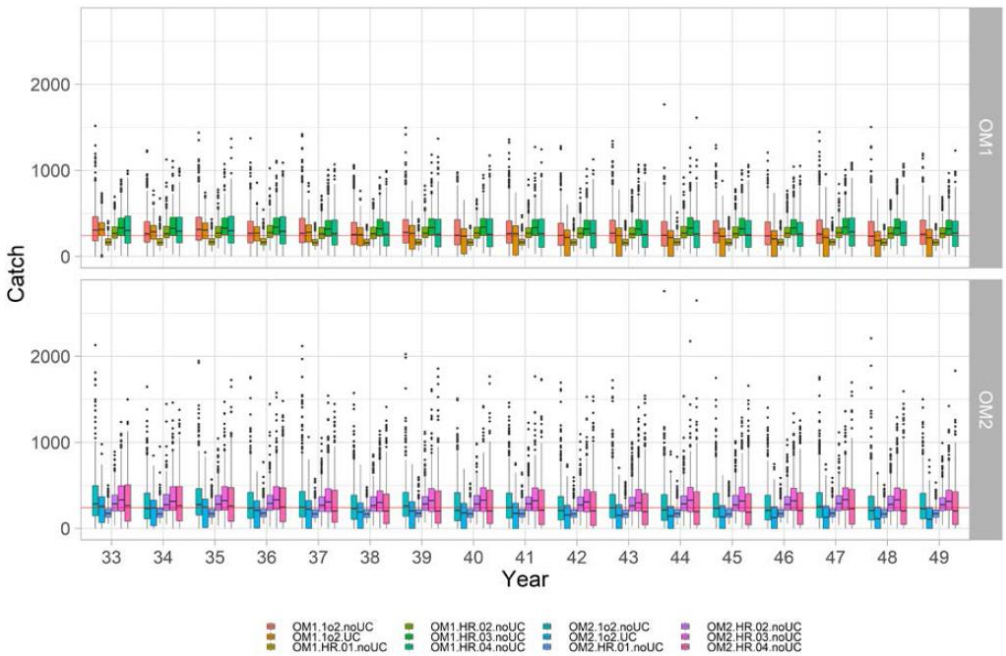

Figure 2.7. Sprat 7.de - Catch distribution across OMs for each simulated year.

These results are summarized in the risk vs yield plot (Figure 2.8): best performances for both operating models are given by the fixed 20% harvest rate, even though in the case of OM2 the risk is equal to 8.6%.

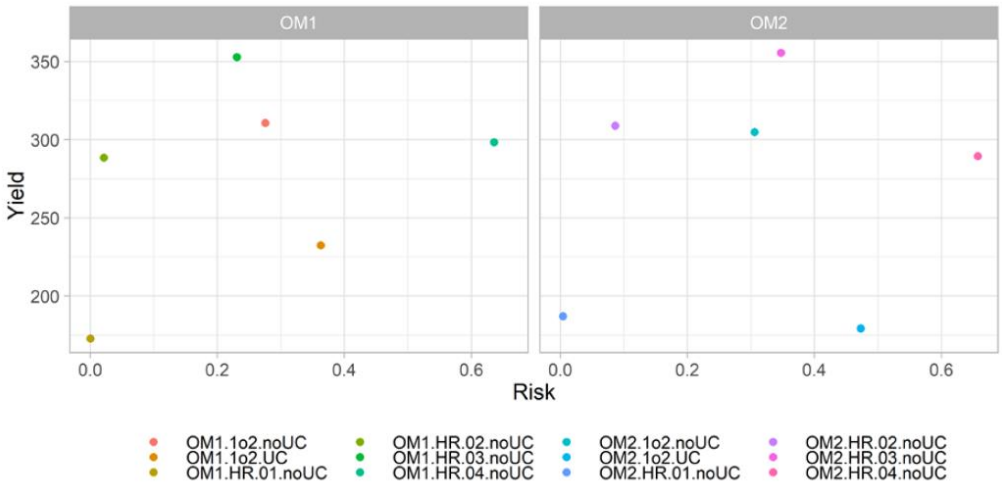

Figure 2.8. Sprat 7.de - Yield vs Risk for the 6 OMs tested.

According to the sensitivity analysis, in the case of operating model 2 a harvest rate of 18% would guarantee a risk of ~5% (Table 2.2).

Table 2.2. Harvest rates and corresponding risk metrics for simulations of sprat 7.de.

OM	HR (%)	SSB below B_{lim} probability	Collapse probability	F_{max} probability	Yield
1	15	0.001	0.0000	0.0000	236
1	16	0.004	0.0000	0.0000	247
1	17	0.006	0.0000	0.0000	258
1	18	0.009	0.0000	0.0000	269
1	19	0.014	0.0000	0.0000	279
2	15	0.026	0.0000	0.0000	255
2	16	0.034	0.0000	0.0000	267
2	17	0.045	0.0000	0.0000	278
2	18	0.057	0.0000	0.0001	289
2	19	0.073	0.0000	0.0000	299

2.5 Conclusions

The simulations carried out attempted to test the performances of different management strategies on short lived species. One of the harvest rules tested, the "1-over-2" rule with uncertainty cap, is commonly used in ICES for data poor category 3 stocks. The simulations suggested that this rule for short lived, highly productive species, might cause the stock to fall below safe levels and eventually to collapse. The reason is the rule not being reactive enough to limit the catches when there is a recruitment failure. When removing the uncertainty cap, performances improve, but the risk still remain above the safe limit used by ICES. On the other hand, the use of a fixed harvest rate seems to prevent risk and maximize catch, depending on the proportion used. A 20% harvest rate is considered appropriate to maintain the stock at safe biomass levels and to produce relatively high yield. In the scenario with OM2 the risk using a 20% HR is higher than 5%: however, it should be considered that several additional precautionary considerations have been included in the simulations:

- For the current simulations, we used the best knowledge we have on the species and the stock, and we emulated as much as possible the current situation of the fishery and the management strategy in place.
- Historically (2013–2017), the harvest rate of this stock has oscillated between 5% and 30%: despite that, the stock biomass has recovered from low levels, suggesting a strong dependence to the environment and little influence from the fishery, whose catches has remained stable.
- The F_{cap} used for the sprat in the North Sea corresponds to a 13% HR which gives a risk just below 5%. While this harvest rate refers to a different stock and therefore has limited applicability, the value lends a credence to the 20% HR value suggested for Channel sprat.
- The risk, the way it has been defined in the simulations, is the probability of the stock to fall below B_{lim}: B_{lim} corresponds to 40% B_{virgin}, which is a quite high level for B_{lim}.
- The underlying assumption is that the acoustic biomass provides an absolute level of the stock size. To account for the potential of the acoustic survey to overestimate the actual level, the catchability has been modelled so the stock size is never underestimated, and hence a less precautionary advice is given.

In light of what shown and discussed above, the current "1-over-2" rule is inadequate for highly dynamic short-lived species. It is suggested to use a 20% fixed harvest rate instead, which would have resulted in the advices shown in Table 2.3:

Table 2.3. Sprat 7.de – PELTIC acoustic survey biomass estimates for Sprat in 7.de. The survey covers the English waters of the Western English Channel. The advice that would have been provided using the 20% fixed harvest rate is shown as well.

Year	Biomass (t)	Next season advice (t)
2013	70007	14001
2014	82728	16546
2015	64665	12933
2016	9795	1959
2017	32830	6566
2018	17561	3512

3 Sprat in Division 3.a and Subarea 4

3.1 Overview

3.1.1 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.

We implemented two versions of an MSE: one with the SMS assessment model as part of the yearly loop (i.e. a "full MSE", Figure 3.1A) and one where an assessment emulator is substituted for an SMS assessment (i.e. a "short-cut MSE", Figure 3.1B).

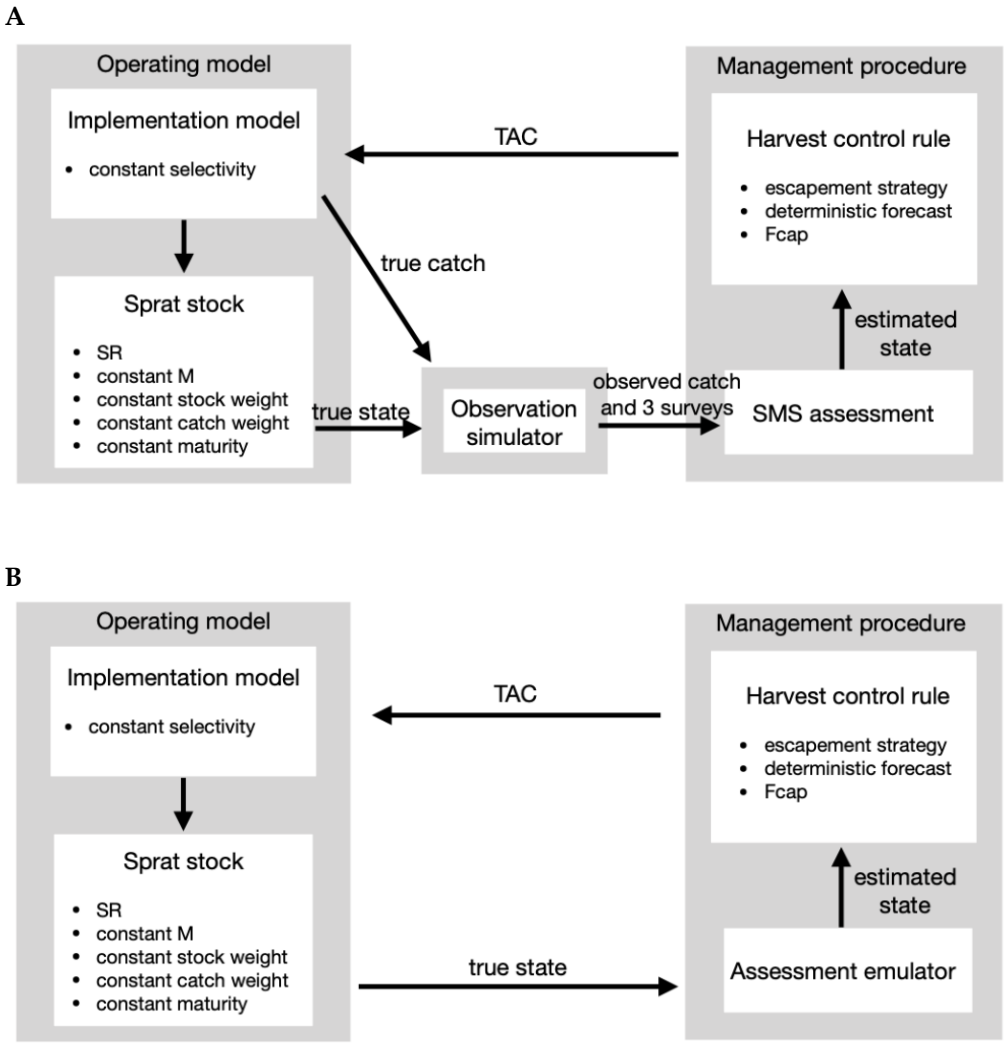

Figure 3.1. Conceptual overview of the management strategy evaluation modelling process in a full (A) and short-cut (B) MSE (adapted from Punt *et al.*, 2016).

3.1.2 Seasonal and age structured model

The 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.

3.1.3 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 (F_{bar}). We assume that this true E is constant across years within a simulation trial of the MSE, but varies among simulation trials.

3.2 Operating model

3.2.1 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.

3.2.2 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 to avoid adding error twice when a distribution is assumed around a hockey-stick model as described below.

3.2.2.1 Initial population

The number of individuals at the beginning of the 2018 TAC year (s1) as estimated by the SMS assessment are in Table 3.1.

Table 3.1. Median numbers of individuals (millions) and CV in each age class at the beginning of the 2018 TAC year.

	s1
Age 0	126531266 (0.404)
Age 1	93830451 (0.522)
Age 2	8727592 (0.272)
Age 3+	305285 (0.394)

3.2.3 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 in the past (Figure 3.2), the same year as the other biological parameters are taken from for a given simulation trial.

3.2.3.1 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 in the past (Figure 3.2), the same year as the other biological parameters are taken from for a given simulation trial.

3.2.3.2 Proportion mature

The MSE and the stock assessment assume that the proportion of fish mature is constant.

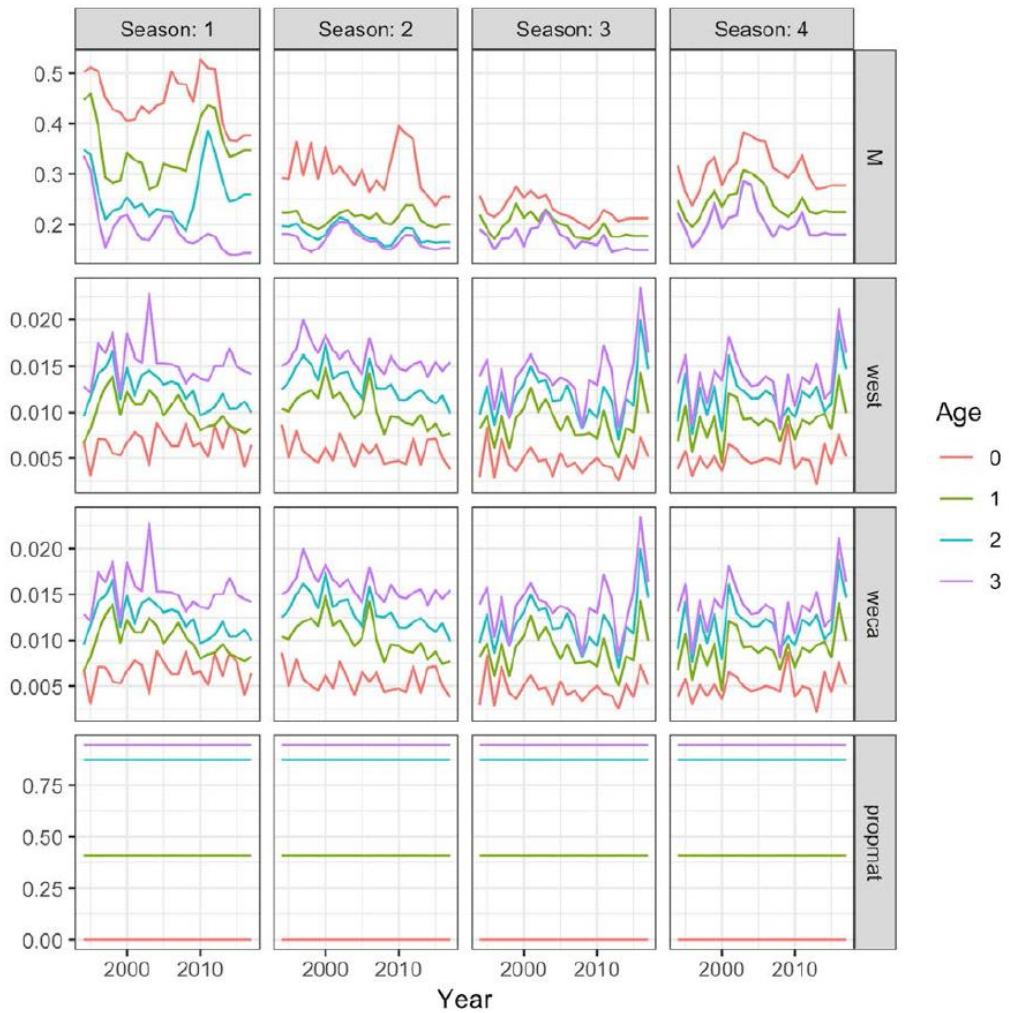

Figure 3.2. Past biological parameters by year. Each row of panels depicts a different parameter on the y-axis: natural mortality (M), weight at age in the stock (west), weight at age in the catch (weca), and proportion mature at age (propmat). Each column of panels represents a season of the TAC year, equivalent to q3, q4, q1, and q2 of the calendar year. Colours depict the separate age classes. Each simulation trial drew its parameters from a single year.

3.2.3.3 Fishing mortality

The exploitation pattern for each simulation trial of the MSE is drawn from a multivariate lognormal distribution with medians in Table 3.2. After a true exploitation pattern is drawn for a simulation trial it stays constant across all years of that simulation trial.

Table 3.2. Median exploitation pattern (and CV) estimated from the new assessment, corresponding to annual $F_{bar(1–2)}$ of 1.

	s1	s2	s3	s4
Age 0	0.001 (0.329)	0.008 (0.320)	0.017 (0.288)	0.000 (0.000)
Age 1	0.232 (0.253)	0.248 (0.246)	0.101 (0.306)	0.000 (0.000)
Age 2	0.398 (0.283)	0.799 (0.273)	0.222 (0.319)	0.000 (0.000)
Age 3+	0.335 (0.293)	0.732 (0.317)	0.452 (0.508)	0.000 (0.000)

3.2.3.4 Recruitment

If SSB in s1 is above 92 000 tonnes (the estimated break point in a hockey-stick model), then recruitment is a single random sample from a smoothed distribution of the estimated recruitment from previous years when SSB was above B_{lim}. From the SMS assessment, the median estimates of past recruitment in years when SSB was above B_{lim} are 145 588 000, 32 558 400, 60 803 300, 44 928 100, 99 344 000, 7 175 2400, 67 716 600, 59 499 000, 77 295 000, 101 513 000, 194 032 000, 65 257 300, 81 799 800, 57 662 900, 147 049 000, 119 218 000, 133 144 000, 85 115 000, 71 950 800, 194 046 000, 206 761 000, 104 322 000, 148 702 000, 297 702 000.

If SSB in s1 is below B_{lim}, then recruitment is impaired and it is simulated from the same smoothed distribution, but with a mean that is tapering towards the origin (Figure 3.3). 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.

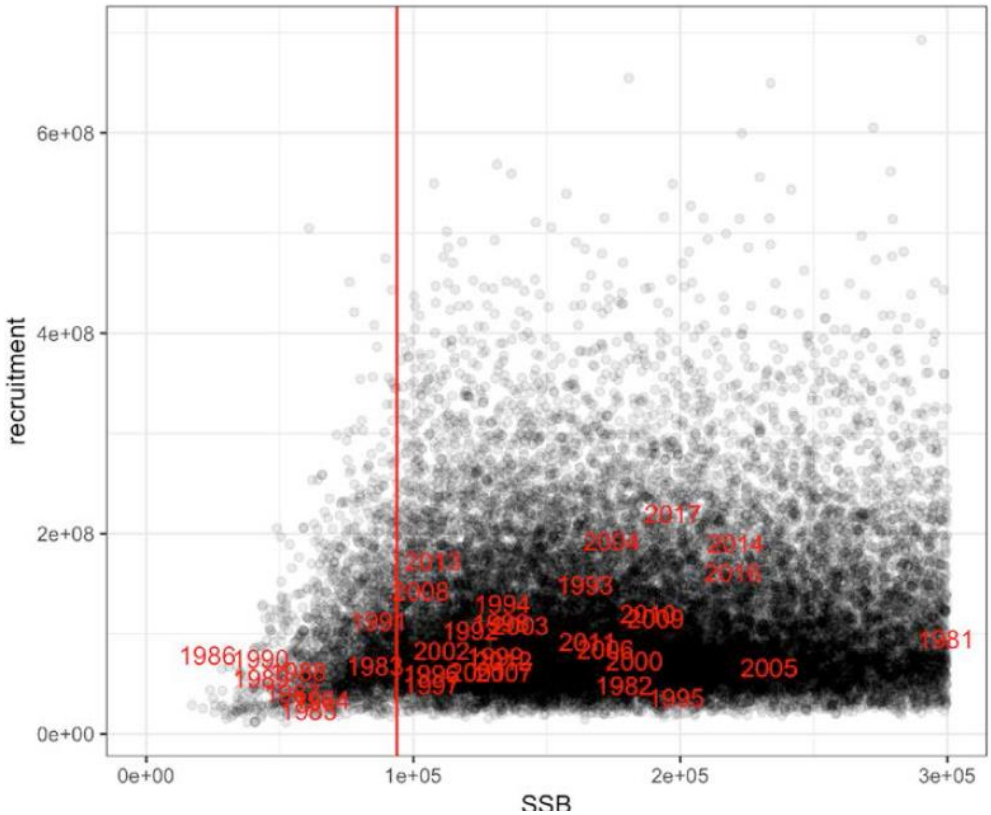

Figure 3.3. Simulated recruitment. Red numbers represent the estimated recruitment from the recent benchmark. The red vertical line is B_{lim} estimated at the recent benchmark. Points are simulated recruitment at a given SSB in s1 in the biological model.

3.2.4 Implementation model

The TAC is taken from the true population, but only up to an F_{bar} equal to 2.35, i.e. F_{hist}, which is the maximum of the past estimates of F_{bar} and occurred in 2016. This is a form of implementation error conveying the maximum effort that the fleet has historically implemented.

3.3 Management strategy

3.3.1 Observation simulator

The full version of the MSE uses a real SMS assessment to estimate the state (N in s1 and E for all seasons) in each year of each simulation trial. The observation simulator takes the true state as input and then simulates observations of the catch and surveys. All 3 surveys use the catchability estimates from the most recent benchmark. Surveys 2 and 3 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. For survey 1, the assessment and thus the simulator assumes that the expected survey number is density dependent as in (Ntrue^p)*survey_effort*catchability. The expected 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 obser-

vation 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 recent benchmark assessment. This allows for errors to be correlated across ages, seasons, surveys, and catch within one year of one trial.

3.3.2 Assessment emulator

In the short-cut version of the MSE, an assessment emulator is used in place of an SMS assessment. The main advantages of the short-cut version is that all simulation trials ran through the full simulation without any numerical errors that cause the code to stop. Another advantage is that the short-cut version can all be run in parallel through a single R program.

For each simulation trial, in each year of the MSE, a stock assessment is emulated to produce an estimated state. The assessment emulator adds observation error to the true state to get an estimated state. In this MSE, the assessment emulator randomly draws an estimated state (log N and log E) from a multivariate normal distribution which has the true state as the mean and a variance-covariance matrix as estimated by SMS. Moving from the log scale to the natural scale, this implies that estimated N and E are log-normally distributed with the true N and E as the median. Then, the estimated E is scaled so that any F multiplier is the estimated F_{bar}.

3.3.3 Deterministic forecast

A deterministic forecast is performed on the estimated state to suggest a TAC. The goal of a deterministic forecast in an escapement strategy is to find the TAC that gives exactly escaped SSB (i.e. the surviving SSB after the TAC is taken) equal to B_{pa}. In this stock, B_{pa} is 125 000, as described in the stock annex and the benchmark report. Biological parameters (Figure 3.2) input to the forecast are identical to those used in the biological model (i.e. with zero observation error). As described in the stock annex, recruitment (i.e. stock numbers of age 0 fish in s1) input to the forecast is the geometric mean of estimated recruitment in the period from 11 years before the assessment year to 2 years before the assessment year.

3.4 Replication in simulations

For each HCR tested, we ran 1000 simulation trials forward for 35 years. Random numbers drawn for initial conditions (N and E) are unique across simulation trials.

3.5 Performance statistics

Table 3.3. Performance statistics were calculated from 1000 simulation trials.

performance statistic	meaning
risk1	probability of SSB < B_{lim} across years 2032–2052
lowTAC	probability of TAC < 50 000 across years 2032–2052
meanTAC	mean TAC in tonnes across years 2032–2052
medianTAC	median TAC in tonnes across years 2032–2052
atFhist	probability that TAC is not taken across years 2032–2052 (see implementation model)
conv	proportion of simulation trials that produced answers

3.6 Results

Visual comparison of the “full” and "short-cut” MSE results look similar, including worm plots (Figure 3.4), yearly risk estimates (Figure 3.5), time series with confidence intervals (Figure 3.6), the relationship between the true and the estimated stock numbers (Figure 3.7), the relationship between the true and the estimated exploitation pattern (Figure 3.8), and the relationship between the true and the estimated F_{bar} (Figure 3.9). Performance statistics are quite similar including Risk1 estimates which differed by less than 0.01 (Table 3.4).

Table 3.4. Performance statistics for full and short-cut MSEs with different F_{cap} values. See table above for definitions and units of each performance statistic.

F_{cap}	MSE type	risk1	lowTAC	meanTAC	medTAC	conv	atFhist
0.68	full	0.048	0.073	144936.1	124508.2	0.965	0.021
0.68	short-cut	0.049	0.083	144062.3	123308.8	1.000	0.021
0.69	full	0.050	0.073	146016.8	125486.0	0.960	0.023
0.69	short-cut	0.050	0.083	144976.9	124042.8	1.000	0.023
0.70	full	0.051	0.074	146973.4	126137.7	0.959	0.025
0.70	short-cut	0.051	0.084	145879.1	124751.4	1.000	0.024

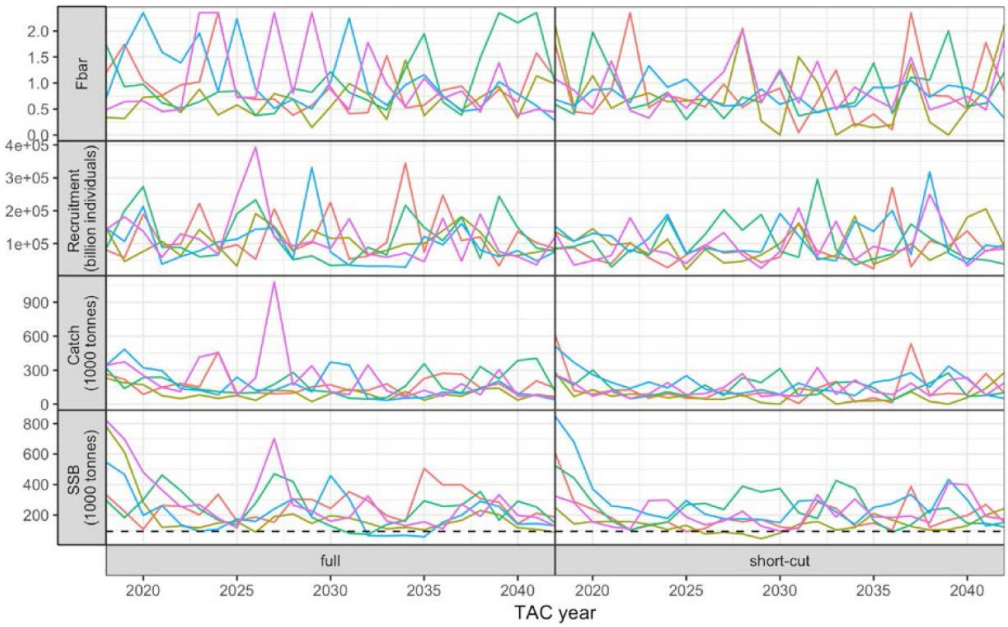

Figure 3.4. Worm plots. Each colour represents one of 5 simulation trials with F_{cap} = 0.69 run with full (left panel) and short-cut (right panel) MSEs. Later years of the time series (2043–2052) are omitted for visibility.

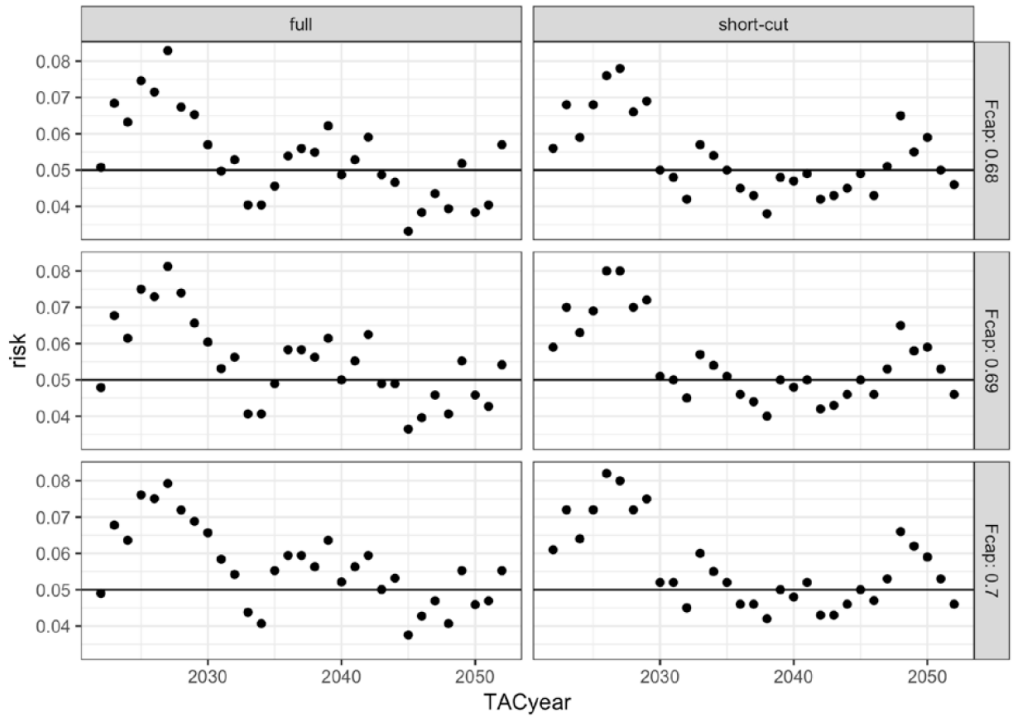

Figure 3.5. Risk across years. Each panel shows how risk of SSB dropping below B_{lim} (calculated across 1000 simulation trials) varies by TAC year. Each row of panels depicts a different F_{cap} value used in the management procedure. The left column is simulations from full MSEs and the right column is from short-cut MSEs.

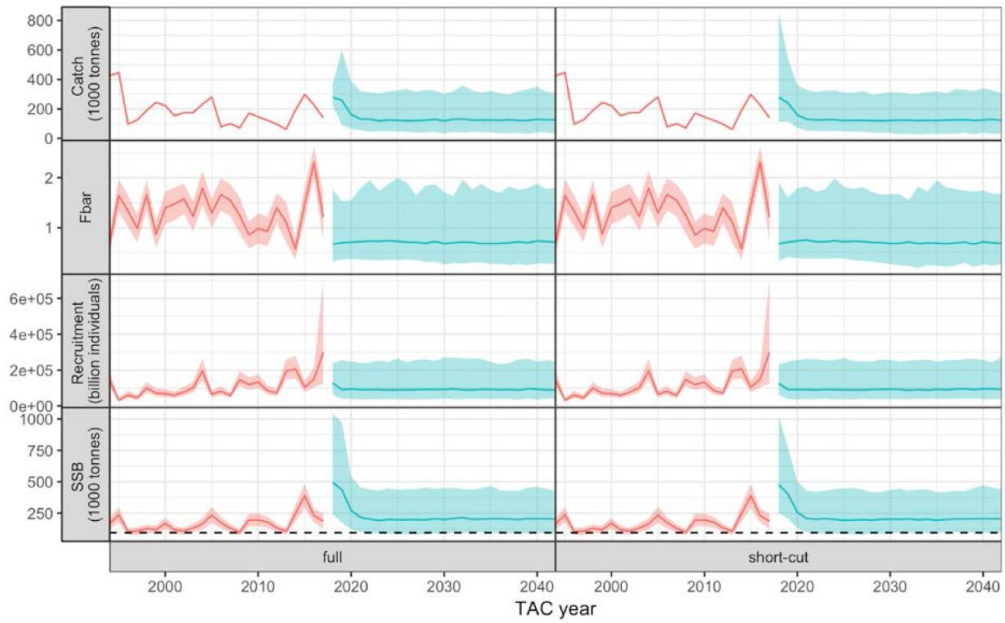

Figure 3.6. Time series with of past estimates and simulated projections for F_{cap} = 0.69. Red portions of the graphs are estimates and 95% CI from the most recent stock assessment. Green lines represent the median of 1000 simulation trials; green ribbons encompass the 0.05 to 0.95 ogives of the simulation trials. Left panels are results from the full MSE and right panels are the short-cut. Later years of the time series (2043–2052) are omitted for visibility.

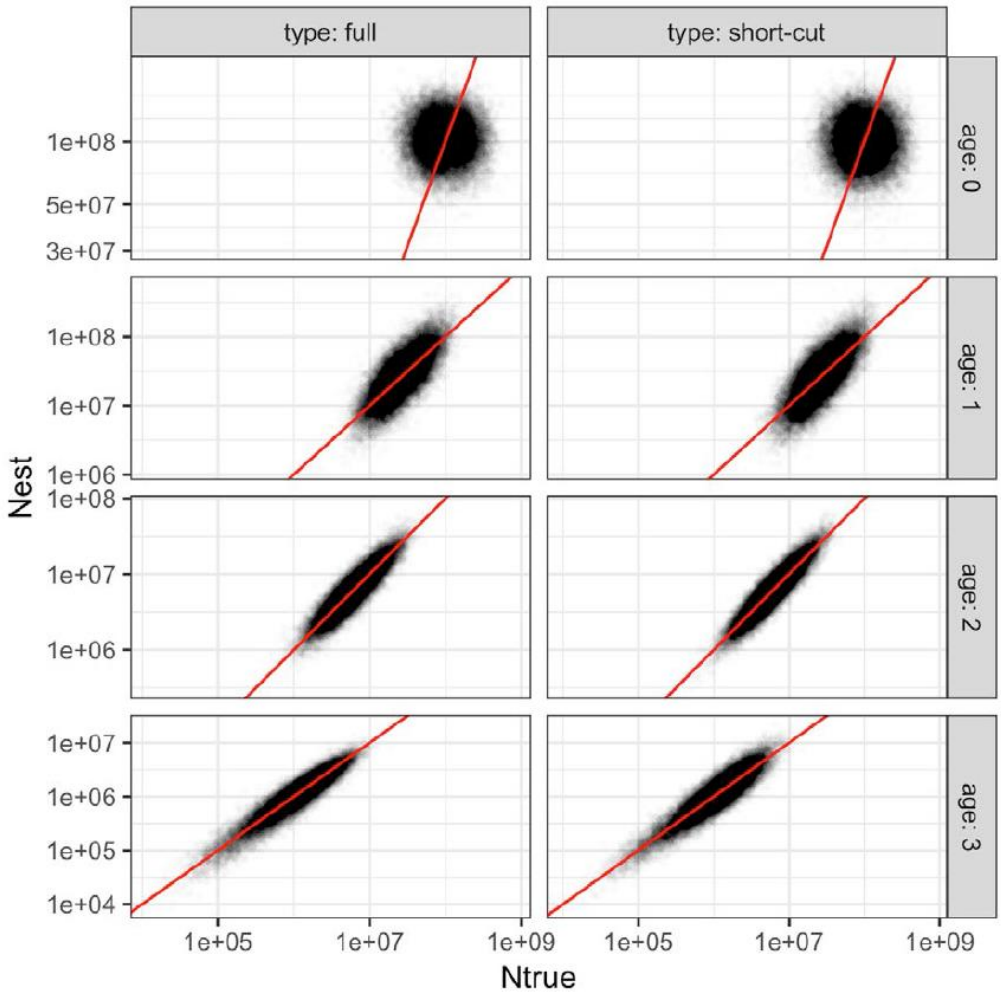

Figure 3.7. True verses estimated stock numbers for F_{cap} = 0.69. Each semi-transparent point represents the age-specific stock numbers in season 1 from one year of one simulation trial; years (2023–2052) and 1000 trails are plotted together. The red line represents equality.

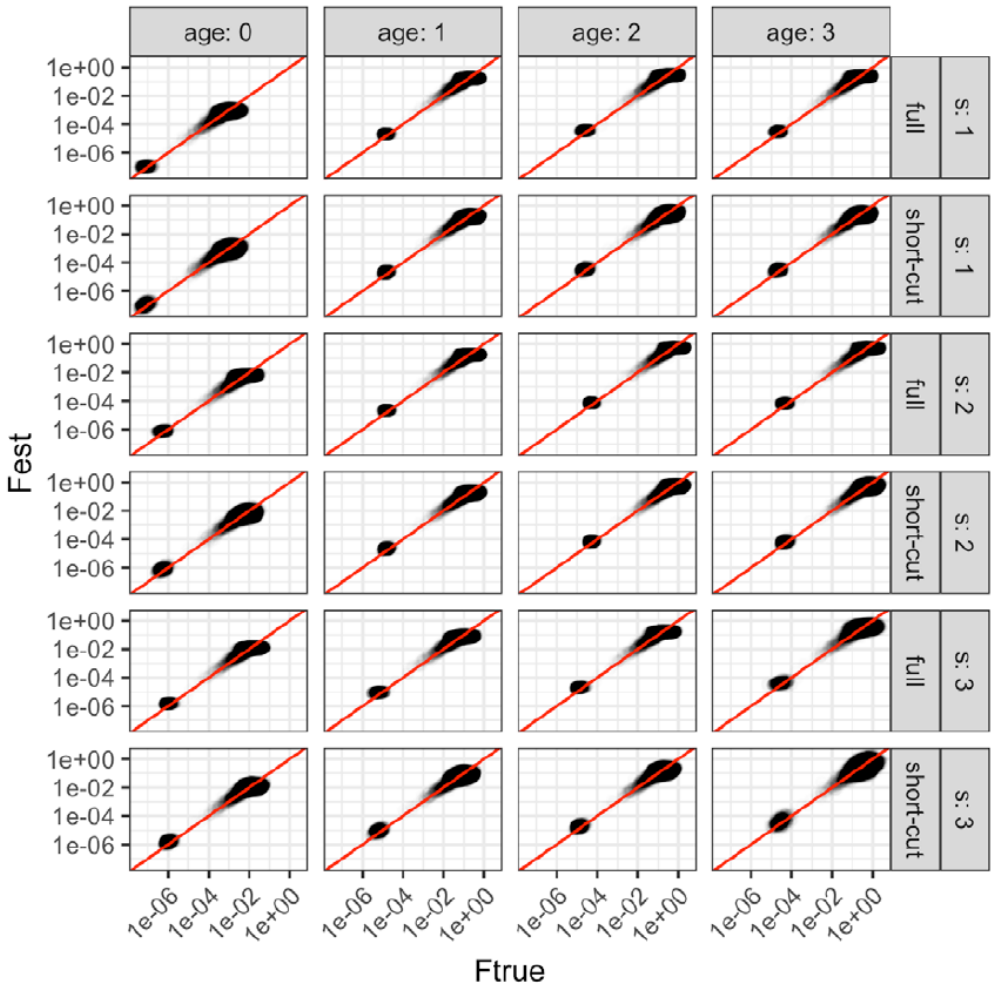

Figure 3.8. True verses estimated F values for F_{cap} = 0.69. Each semi-transparent point represents the age-and-season-specific F value from one year of one simulation trial; years (2023–2052) and 1000 trails are plotted together. Season 4 is not plotted because true and estimated F was forced to be 0. The red line represents equality.

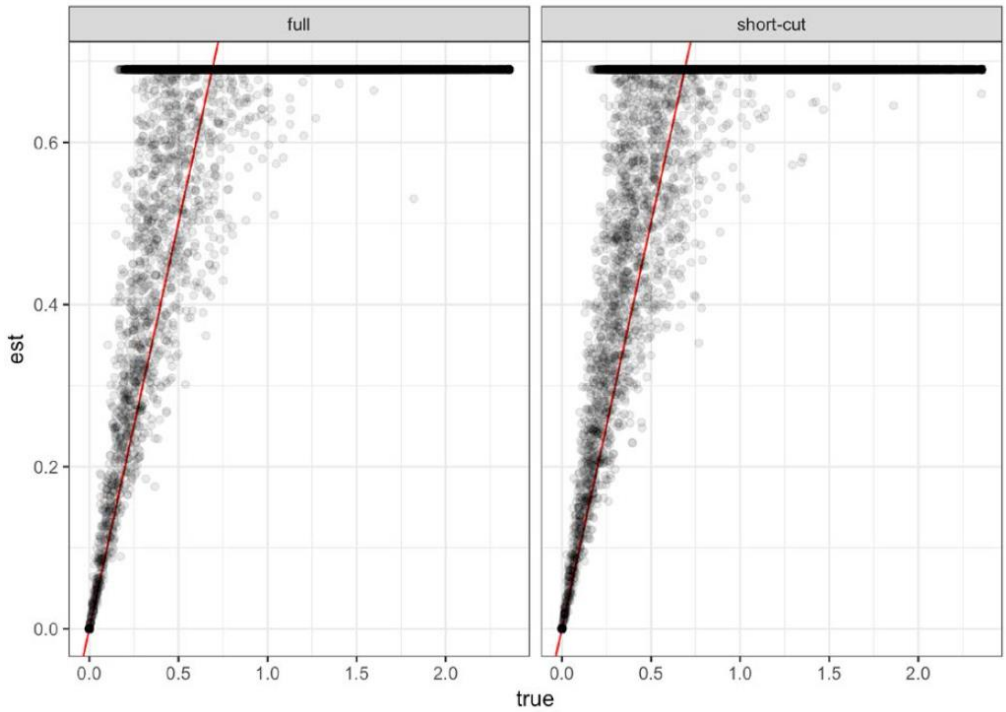

Figure 3.9. True verses estimated F_{bar} values for F_{cap} = 0.69. Each semi-transparent point represents F_{bar} value from one year of one simulation trial; years (2023–2052) and 1000 trails are plotted together. The red line represents equality.

3.7 Conclusion

Because estimated recruitment for 2017 was high (Figure 3.3), the stock started out the simulations with a high SSB (Figure 3.6). Thus, when calculating performance statistics, we omitted years 2018 to 2031 of the simulation results. Because risk varied across years (Figure 3.5), we averaged across years when calculating precautionary (i.e. we used risk 1).

According to these analyses, F_{cap} of 0.69 is precautionary. However, it should be noted that these analyses assumed that the management procedure had perfect knowledge of the biological parameters and the only errors were in the stock numbers and exploitation patterns.

4 References

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5 Reviewer's comments

The Workshop on the management strategy evaluation of the reference point F_{cap} for sprat (*Sprattus sprattus*) in Division 3.a and Subarea 4 (Skagerrak, Kattegat and North Sea) included two external reviewers. The external reviewers recognize the substantial work done and commend all the participants for their efforts and work during the workshop.

Although both external reviewers participated fully in the workshop, the review text was drafted by Reviewer 1.

In general, the external reviewer considers that the analyses and outcomes of the benchmark are appropriate to provide management advice. Following the terms of reference and the discussions during the workshop, the specific thoughts of the external reviewer were as follows:

Sprat in Divisions 7.d and 7.e (English Channel)

In the benchmark workshop WKSPRAT 2018, sprat in divisions 7.d and 7.e was classified as Category 3 and it was proposed to provide a seasonal advice based on either one of the following two rules: the "1-over-2" or a fixed harvest rate rule. In WKspratMSE, the performance of these two types of rules was compared through simulation using the Management Strategy Evaluation (MSE) framework developed in WKLIFE. Due to the little information available for this stock, several operating models were considered depending on life-history traits and recruitment variability. The results indicated that the "1-over-2" rule with uncertainty cap that is commonly used for category 3 stocks might be too restrictive and not reactive enough for short-lived species. Removing the uncertainty cap of 20% improved the performance of the rule, but the risk was still above the level of 0.05 set by ICES as precautionary. These results agreed with previous MSE results for other short-lived species (WKLIFE VIII). In contrast, the 20% harvest rate maintained the stock at safe biomass levels while producing relatively high yields. This value is within the range of historical harvest rates for this stock (5–30%). Even though there are uncertainties on the current simulations, the reviewers agreed that they are based on the best available knowledge on the dynamics of the stock and the fishery. Furthermore, the simulations included additional precautionary considerations. Therefore, the reviewer supports the suggestion of the group to provide management advice based on a 20% harvest rate rule. Meanwhile, she recommends that advice rules for short-lived category 3 stocks are further explored, for which the workshop on Data-limited Stocks of Short-lived Species (WKDLSSLS) might be relevant.

Sprat in Division 3.a and Subarea 4 (Skagerrak, Kattegat and North Sea)

The assessment settings and PA reference points for sprat in division 3.1 and Subarea 4 were set in WKSPRAT 2018. According to the ICES MSY approach for short-lived Category 1 stocks, the advised yearly catches correspond to the estimated stock biomass in excess of the MSY $B_{escapement}$ (a deterministic biomass limit below which a stock is considered to have reduced reproductive capacity), but constrained so that the fishing mortality is no higher than a limit F named F_{cap}. For this stock MSY $B_{escapement}$ was set equal to B_{pa}. The reviewer notes that sometimes MSY $B_{escapement}$ and B_{pa} are used interchangeably and recommend further care. In WKspratMSE a full closed loop management strategy evaluation (MSE) was carried out to test for a range of F's and find an appropriate F_{cap} value that showed a less than 5% probability of SSB < $B_{escapement}$. The stock dynamics were simulated in a seasonal basis and the time frame was selected to

match the actual assessment and management periods. The stock and fleet dynamics were conditioned on the most recent assessment from WKSPRAT2018. Natural mortality and weights at age in the stock and in the catch were drawn together from the past but were kept constant within each simulation trial. The exploitation pattern was drawn from a multivariate lognormal centered around the last assessment exploitation pattern and was kept constant within each simulation trial. Therefore, no interannual variability was included neither in the biological parameters nor in the exploitation pattern. In the management procedure, biological parameters were assumed to be known without any errors and a full loop approach incorporating explicitly the assessment was compared to a short-cut approach. In this case, the results from the full-loop and the shortcut approaches were basically the same. The short-cut approach presented less problems as it was not affected by numeric convergence issues of the assessment model. The deterministic forecast was included according to the procedure and assumptions agreed in WKSPRAT2018. As a result, the value of F_{cap} was conditioned on using B_{pa} as MSY $B_{escapement}$. The reviewer found the analyses conducted to define F_{cap} as adequate and support the use of F_{cap} equal to 0.69 for management advice.

Annex 1: Participants list

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