EU, Norway, and the Faroe Islands request on the long-term management strategies for Northeast Atlantic mackerel (full feedback approach)

Advice summary

ICES provides combinations of F_{target} and $B_{trigger}$ that maximize the median annual yield in the long term and simultaneously minimize the risk of the Northeast Atlantic mackerel stock falling below B_{lim}. F_{target} values are between 0.27 and 0.30, in combination with $B_{trigger}$ values between 3 000 000 tonnes and 4 500 000 tonnes. Higher F_{target} values are associated with higher $B_{trigger}$ values.

The maximum sustainable yield (MSY) was estimated to be 970 000 tonnes in the long term, which corresponded to an F_{target} = 0.29 and a long-term median spawning–stock biomass (SSB) = 4 500 000 tonnes when simulated with $B_{trigger}$ = 4 250 000 tonnes. The simulations suggest that long-term yields within 1% of MSY can be achieved with a lower F_{target}. This would result in higher SSB and less variation in the yield and SSB in the long term.

All management strategies considered precautionary in the long term were also precautionary in the short term. When additional management measures (limitation of TAC interannual variation and banking and borrowing) were applied in the harvest control rule (HCR), they had a limited influence on the median annual long-term yield or stock status.

Two sets of simulations were carried out, based on alternative estimates of recruitment from 1998 onwards. Only small differences were found between these simulations. Including recruitment from years prior to 1998 (when recruitment was lower) impacts the precautionarity of the HCR. If future recruitment is lower than that assumed in the base case scenario, simulations show that this will result in both reduced yield and increased risk of SSB < B_{lim}.

Request

The European Union, Norway, and the Faroe Islands jointly request ICES to advise on the long-term management strategies on Northeast Atlantic Mackerel. A request is provided below.

ICES is requested to identify appropriate precautionary combinations in the Tables given in its response to the EU, Norway and the Faroe Islands request to ICES to evaluate a multi-annual management strategy for mackerel in the North East Atlantic (ICES, 2017), using:

- *A range of $B_{trigger}$ from two to five million tonnes with an appropriate range of target Fs*
- *A harvest control rule with a fishing mortality equal to the target F when SSB is at or above $B_{trigger}$*
- *In the case that the SSB is forecast to be less than $B_{trigger}$ at spawning time in the year for which the TAC is to be set, the TAC shall be fixed consistently with a fishing mortality that is given by: $F = F_{target}*SSB/B^{trigger}$*

All alternatives should be evaluated with and without a constraint on the inter-annual variation of TAC. When the rules would lead to a TAC, which deviates by more than 20% below or 25% above the TAC of the preceding year, the Parties shall fix a TAC that is respectively no more than 20% less or 25% more than the TAC of the preceding year. The TAC constraint shall not apply if the SSB at spawning time in the year for which the TAC is to be set is less or equal to $B_{trigger}$.

The constraint mechanism shall be tested separately from and in combination with 10% banking and borrowing mechanism.

Evaluation and performance criteria

Each alternative shall be assessed in relation to how it performs in the short term (5 years), medium term (next 10 years) and long term (next 25 years) in relation to:

- *Average SSB*
- *Average yield*
- *Indicator for year to year variability in SSB and yield*
- *Risk of SSB falling below B_{lim}*

The approach should follow the same full feedback methodology that has been recently used to evaluate stocks in the North Sea (ICES, 2019a). The evaluation should be conducted to identify options that are robust to alternative operating models including but not limited to:

A. Investigating alternative plausible recruitment dynamics and scenarios,
B. Alternative natural mortality assumptions,
C. The potential impact of density dependent growth.

Following initial consideration of the request by ICES, the requesting parties confirmed that the strategy should also be evaluated with a banking and borrowing scheme representative of recent behaviour. The requesters furthermore confirmed that banking and borrowing should be suspended when SSB is below $B_{trigger}$, and that the implications of any future catch scenario that exceeds the advised catch should not be evaluated.

Elaboration on the advice

Harvest control rule and management strategies

ICES was requested to identify precautionary combinations of harvest control rule (HCR) parameters F_{target} and $B_{trigger}$ for a number of management strategies (Figure 1). This is termed the base HCR (*baseHCR*).

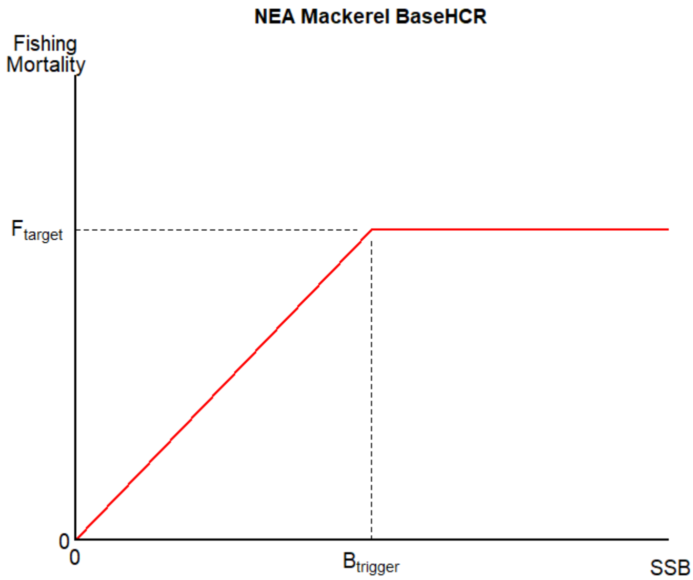


Figure 1 Schematic of the base harvest control rule (*baseHCR*) evaluated for Northeast Atlantic mackerel. The fishing mortality to be applied is set as F_{target} when the SSB at spawning time in the advice year is above $B_{trigger}$. When the SSB is below $B_{trigger}$, the F applied is reduced linearly towards zero fishing at zero biomass.

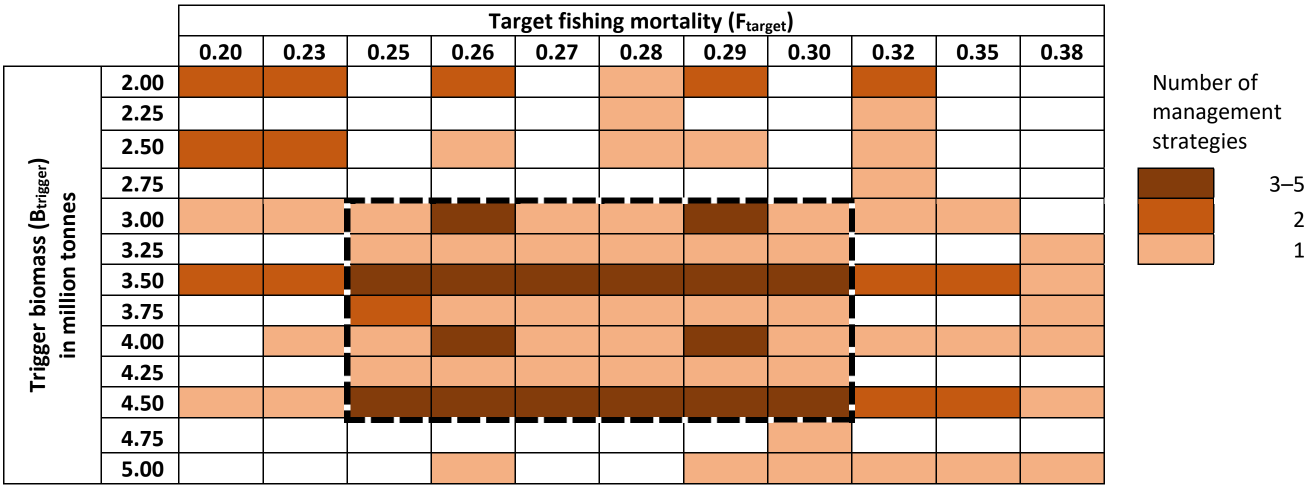
In addition to the *baseHCR*, additional management measures were evaluated:

Management strategy	Description	Number of scenarios run
baseHCR	The base harvest control rule (HCR). This is the HCR applied to derive target fishing mortality based on SSB at spawning time in the advice year (SSB_AY).	82
IAVcap	*baseHCR,* including limitations on the interannual variability (IAV) in TAC. Changes are limited to a maximum increase of 25% or decrease of 20% from the TAC from the previous year, suspended when the SSB_AY is below $B_{trigger}$.	31
B&B_5%	*baseHCR,* including constant annual banking of 5% of the TAC, suspended when observed SSB is below $B_{trigger}$.	8
Combo_5%	*IAVcap* and *B&B_5%*: A combination of *IAVcap* and *B&B_5%,* i.e. limited interannual change in TAC in combination with 5% constant banking, suspended when SSB_AY is below $B_{trigger}$.	17
Combo_10%	*IAVcap* and B&B_10%: A combination of *IAVcap* and 10% banking and 10% borrowing applied in alternate years, suspended when SSB_AY is below $B_{trigger}$.	4

Evaluation of management strategies

The request asks for an update of the tables presented in the 2017 mackerel management strategy evaluation (MSE) advice (ICES, 2017). It was not possible to simulate all of the combinations of F_{target} and $B_{trigger}$ carried out in 2017 under the context of the full feedback evaluations. Analyses were focused on identifying those combinations of F_{target} and $B_{trigger}$ that were both precautionary (no more than a 5% probability of SSB being below B_{lim}, where the probability is the maximum of the annual probabilities over the reporting period) and associated with the high long-term yield. The scenarios explored were sufficient to identify an appropriate range of harvest-rule parameters (F_{target} and $B_{trigger}$). The widest range of F_{target}–$B_{trigger}$ combinations explored was for the *baseHCR* management strategy, with a subset selected to test the effects of the limitation in TAC variation and banking and borrowing schemes.

The F_{target}–$B_{trigger}$ combinations run for each management strategy with the base case operating model (OM) are summarized in the table below. The parameter values within the dashed-line box are those that have been explored in more detail. The intensity of colour reflects the number of management strategies explored for that particular combination of F_{target} and $B_{trigger}$.



Robustness and alternative operating models

The process uncertainty (i.e. other plausible representations of reality in terms of stock dynamics and fisheries) that was examined in this evaluation was limited.

ICES explored alternative operating models with respect to recruitment:

Alternative recruitment assumption (*R_2*). To incorporate additional information from the catch data in the estimates of recruitment, an alternative recruitment time-series was constructed, based on abundance estimates of fully selected ages from the state–space assessment model (SAM) and observed catch-at-age of the younger age classes. The resulting time-series has a slightly higher variability in recruitment compared to the baseline OM, with similar trends. A subset of *baseHCR* management strategy scenarios (25) were evaluated.

Extended recruitment time-series (*R_3*). To compare results with the previous MSE of this stock (ICES, 2017), the recruitment time-series from 1990 onward was used (the base case OM is 1998 onward). The period from 1990 to 1997 has lower recruitment estimates than the period after 1997. A subset of *baseHCR* management strategy scenarios (3) were evaluated.

It was not possible to explore alternative operating models that incorporated varying levels of natural mortality or density-dependence in growth within the time frame of the request.

Performance indicators

The request defines three periods (5, 10, and 25 years) over which the performance of the management strategies tested should be evaluated in terms of average SSB, average yield, an indicator for year-to-year variability in SSB and yield, and the risk of SSB falling below B_{lim}.

The performance indicators considered were:

- Probability that SSB < B_{lim} (Risk Type 3–maximum annual probability that SSB < B_{lim})
- SSB
- Yield
- Realized F
- Variability in yield
- Variability in SSB
- Proportion of management decisions from the slope (i.e. SSB < $B_{trigger}$)

The ICES criterion to define a multiannual plan as precautionary (ICES, 2016) is that the maximum annual probability of SSB falling below B_{lim} is less than 5% for all years (i.e. short as well as long terms; Risk Type 3).

All three time periods were considered, but due to issues with assessment error in the short and medium terms, the advice is primarily based on the long-term performance.

Results

Base HCR

A range of F_{target} and $B_{trigger}$ parameter combinations were tested for the *baseHCR* management strategy, i.e. without stabilization measures. Tables 1–6 present the results for the long-term probability of SSB < B_{lim}, median SSB, realized F, yield, interannual variability in TAC, and the probability of F_{target} being reduced because SSB < $B_{trigger}$. A summary is provided in Table 7. Given the current high stock size, the risk is higher in the long term. A number of options lead to the highest long-term yields; these are all associated with relatively low long-term risks and are therefore precautionary, and they are also associated with a range of median SSB. The non-precautionary F_{target}–$B_{trigger}$ combinations are associated with lower long-term yields.

The maximum sustainable yield (MSY) was estimated to be 970 000 t in the long term, which corresponded to an F_{target} = 0.29, long-term median SSB = 4 500 000 tonnes, when simulating a $B_{trigger}$ = 4 250 000 tonnes. A broad range of the F_{target}–$B_{trigger}$ combinations produce long-term yields within 1% of the MSY. Many of these combinations have higher median SSB and lower interannual variation (yield and SSB). For example, the simulations suggest that long-term yields of

961 000 tonnes (i.e. 0.9% lower than MSY) can be achieved by fishing at F = 0.25 with a $B_{trigger}$ = 4 250 000 tonnes, resulting in a 10% larger SSB and 16% less IAV in yield in the long term.

The realized F is more likely to differ from F_{target} when $B_{trigger}$ is high (Table 3), as F_{target} is more likely to be reduced (Table 6).

Table 1 Base HCR (*BaseHCR*) – probability (SSB < B_{lim}), expressed as a percentage, for the long-term period (years 16–40). The shading corresponds to the risk. Those red cells that are delineated by the heavy line correspond to non-precautionary combinations of F_{target} and $B_{trigger}$.

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	0.005	0.011		0.017		0.030	0.035		0.059		
2250						0.027			0.055		
2500	0.004	0.010		0.015		0.023	0.030		0.046		
3000	0.003	0.007	0.011	0.012	0.014	0.017	0.020	0.024	0.034	0.051	
3250			0.010	0.009	0.012	0.013	0.018	0.021			0.066
3500	0.002	0.006	0.008	0.008	0.010	0.012	0.015	0.016	0.024	0.035	0.055
3750			0.005	0.007	0.009	0.010	0.012	0.015			0.043
4000		0.003	0.006	0.006	0.008	0.009	0.010	0.011	0.014	0.024	0.032
4250			0.004	0.005	0.005	0.007	0.008	0.009			
4500			0.003	0.004	0.004	0.005	0.007	0.007	0.009	0.013	0.021
4750								0.006			
5000				0.003			0.005	0.005	0.007	0.009	0.013

Table 2 Base HCR (*BaseHCR*) – median SSB (million tonnes), for the long-term period (years 16–40). Grey shaded cells correspond to non-precautionary combinations of F_{target} and $B_{trigger}$ (P [SSB < B_{lim}] > 5%).

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	5.604	5.066		4.617		4.340	4.186		3.821		
2250						4.332			3.825		
2500	5.588	5.084		4.606		4.328	4.210		3.833		
3000	5.589	5.068	4.782	4.628	4.477	4.334	4.220	4.095	3.882	3.592	
3250			4.769	4.631	4.486	4.359	4.234	4.119			3.416
3500	5.595	5.080	4.782	4.648	4.500	4.383	4.276	4.150	3.952	3.716	3.499
3750			4.813	4.678	4.544	4.414	4.319	4.202			3.597
4000		5.117	4.850	4.706	4.578	4.467	4.356	4.264	4.084	3.865	3.687
4250			4.883	4.766	4.634	4.535	4.437	4.341			
4500			4.937	4.808	4.700	4.599	4.501	4.422	4.259	4.040	3.878
4750								4.508			
5000				4.938			4.663	4.565	4.422	4.251	4.053

Table 3 Base HCR (*BaseHCR*) – realized fishing mortality (ages 4–8) in the long term (years 16–40). Grey shaded cells correspond to non-precautionary combinations of F_{target} and $B_{trigger}$ (P [SSB < B_{lim}] > 5%). For the remaining cells, the darker shades correspond to higher yields. Empty cells are scenarios that were not evaluated.

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	0.187	0.217		0.247		0.267	0.278		0.308		
2250						0.267			0.307		
2500	0.187	0.217		0.246		0.266	0.276		0.305		
3000	0.186	0.216	0.235	0.245	0.254	0.264	0.272	0.282	0.300	0.325	
3250			0.234	0.243	0.252	0.261	0.271	0.279			0.341
3500	0.186	0.214	0.232	0.241	0.250	0.259	0.267	0.276	0.291	0.314	0.332
3750			0.230	0.239	0.247	0.256	0.263	0.272			0.323
4000		0.210	0.228	0.236	0.244	0.252	0.260	0.267	0.281	0.300	0.316
4250			0.225	0.233	0.241	0.248	0.256	0.262			
4500			0.222	0.229	0.236	0.244	0.250	0.256	0.268	0.284	0.298
4750								0.251			
5000				0.223			0.238	0.245	0.255	0.270	0.283

Table 4 Base HCR (*BaseHCR*) – median yield (in thousand tonnes; kt) in the long-term period (years 16–40). Grey shaded cells correspond to non-precautionary combinations of F_{target} and $B_{trigger}$ (P [SSB < B_{lim}] > 5%). The maximum yield (970 kt) is associated with an F_{target} value of 0.29 and a $B_{trigger}$ of 4250 kt.

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	930	954		963		962	963		948		
2250						965			951		
2500	931	955		965		965	963		952		
3000	931	953	962	965	963	966	963	960	957	940	
3250			963	963	967	965	966	965			931
3500	932	953	964	963	969	967	967	967	962	953	936
3750			963	965	968	969	966	966			942
4000		952	960	967	969	968	964	968	964	956	947
4250			961	962	967	968	970	966			
4500			953	962	965	966	965	967	964	962	953
4750								965			
5000				953			961	964	963	963	957

Table 5 Base HCR (*BaseHCR*) – median interannual variability (IAV; the percentage change between two consecutive years) in yield in the long-term period (years 16–40). Grey shaded cells correspond to non-precautionary combinations of F_{target} and $B_{trigger}$ (P [SSB < B_{lim}] > 5%). $B_{trigger}$ is shown in thousand tonnes.

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	8.2	8.7		9.5		9.8	10.0		10.7		
2250						9.9			11.2		
2500	8.2	8.8		9.5		10.1	10.5		11.6		
3000	8.3	9.1	9.8	10.1	10.7	11.1	11.7	12.5	13.6	15.6	
3250			10.1	10.7	11.4	12.2	12.7	13.4			18.4
3500	8.6	9.8	10.8	11.6	12.3	13.1	13.9	14.4	16.3	17.8	18.9
3750			11.8	12.7	13.5	14.2	14.8	15.4			19.4
4000		11.0	12.6	13.5	14.3	15.1	15.7	16.6	17.8	18.8	19.7
4250			13.6	14.2	15.1	15.9	16.1	17.1			
4500			14.3	15.0	15.8	16.3	16.6	17.2	17.9	19.1	19.5
4750								17.7			
5000				16.5			18.0	18.2	18.6	19.4	19.5

Table 6 Base HCR (*BaseHCR*) – the probability of average annual proportion of TAC setting, involving a reduction in the target fishing mortality (as the observed SSB is below the associated $B_{trigger}$) in the long term (years 16–40). Values associated with non-precautionary combinations of F_{target} and $B_{trigger}$ are shaded grey. For the remaining cells, the darker shades correspond to higher proportions. $B_{trigger}$ is shown in thousand tonnes.

$B_{trigger}$	F_{target}										
	0.2	0.23	0.25	0.26	0.27	0.28	0.29	0.3	0.32	0.35	0.38
2000	0.001	0.005		0.012		0.022	0.028		0.053		
2250						0.038			0.090		
2500	0.007	0.020		0.042		0.067	0.083		0.139		
3000	0.028	0.062	0.096	0.116	0.139	0.162	0.188	0.216	0.275	0.364	
3250			0.144	0.170	0.197	0.226	0.257	0.286			0.534
3500	0.078	0.147	0.204	0.233	0.264	0.295	0.328	0.361	0.425	0.522	0.614
3750			0.269	0.302	0.336	0.371	0.407	0.437			0.680
4000		0.267	0.340	0.374	0.411	0.444	0.479	0.513	0.576	0.668	0.743
4250			0.410	0.447	0.484	0.517	0.550	0.584			
4500			0.481	0.519	0.552	0.586	0.619	0.649	0.709	0.780	0.838
4750								0.711			
5000				0.644			0.736	0.760	0.805	0.859	0.899

Table 7 Base HCR (*BaseHCR*) – long-term (LT) performance criteria of a selection of management options, no interannual TAC change limitation. Weights are in thousand tonnes (kt).

F_{target}	$B_{trigger}$ (kt)	Yield		SSB		Risk (%)
		Median (kt)	IAV (%)	Median (kt)	IAV (%)	
0.23	2500	955	8.8	5084	8.5	1.0
0.25	3000	962	9.8	4782	8.7	1.1
0.27	3250	967	11.4	4486	9.0	1.2
0.28	3750	969	14.2	4414	9.1	1.0
0.29	4250	970	16.1	4437	9.1	0.8
0.30	3250	965	13.4	4119	9.3	2.1
0.30	4500	967	17.2	4422	9.1	0.7
0.35	4500	962	19.1	4040	9.5	1.3

Evaluation of additional management measures

The subset of *baseHCR* scenarios evaluated with additional management measures (limitations of TAC IAV and of banking and borrowing [B&B]) were all precautionary in the long term. Median long-term yields are also little changed by the use of TAC IAV limitations or B&B (Table 8). Median yields and risk are unaffected by the inclusion of TAC IAV limitations, because the variation observed in the base HCR scenario (*BaseHCR*) of 10%–20% is generally below the change limits tested in *IAVcap* (max. increase 25%, max. decrease 20%).

Limiting the interannual change in TAC only marginally reduces median IAV, but it reduces the frequency of extreme changes (> 25%) in TAC, particularly for HCRs with low $B_{trigger}$ values.

Table 8 Effects of additional management measures on yield and variability in yield. IAV = Interannual variation. Weights are in thousand tonnes (kt).

F_{target}	$B_{trigger}$ (kt)	*BaseHCR*		*IAVcap*		*B&B_5%*		*Combo_5%*		*Combo_10%*	
		Median yield (kt)	IAV (%)	Median yield (kt)	IAV (%)	Median yield (kt)	IAV (%)	Median yield (kt)	IAV (%)	Median yield (kt)	IAV (%)
0.26	3500	963	11.6	966	10.8	967	10.9	966	10.3	968	12.3
0.26	4500	962	15.0	963	14.1	963	15.1	962	14.1	964	15.3
0.29	3500	967	13.9	966	12.6	963	13.6	964	12.4	969	14.0
0.29	4500	965	16.6	965	16.3	968	16.6	965	16.4	969	17.4

BaseHCR = base HCR; *IAVcap* = +25%, −20% TAC change limitation (only when above $B_{trigger}$); *B&B_5%* = 5% constant banking (only when above $B_{trigger}$); *Combo_5%* = combination of TAC change limits and 5% banking; *Combo_10%* = combination of TAC change limits and alternate banking and borrowing 10%.

To illustrate a range of individual possible future outcomes in relation to the median projections, an example of the simulation results for *Combo_5%* is shown in Figure 2.

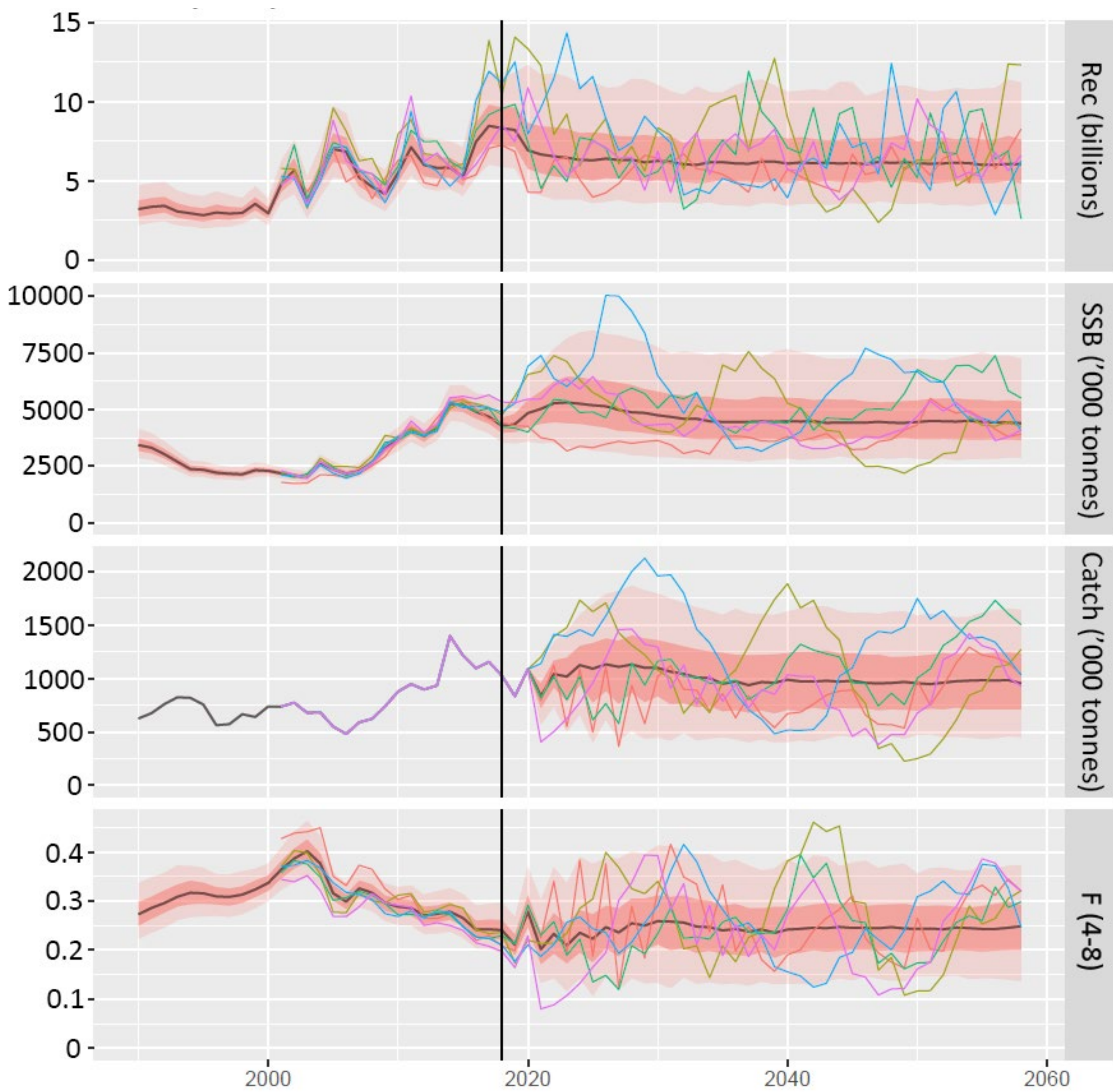


Figure 2 Management strategy of *Combo_5%*. Summary projection for F_{target} = 0.29 and $B_{trigger}$ = 4 500 000 tonnes, including stabilization measures on interannual variability in TAC (maximum 25% increase, maximum 20% decrease) and 5% constant banking (stabilization measures suspended below $B_{trigger}$). The top plot represents recruitment (age 0, billions), the second plot SSB (thousand tonnes), the third plot catch (thousand tonnes), and the bottom plot shows mean F (ages 4–8). The vertical black line separates the historical period from the projection period. The solid black line represents the median value with the darker shaded area, indicating the 25th and 75th percentiles, and the light shaded area the 5th and 95th percentiles. The results for five individual iterations are shown as solid coloured lines.

Robustness and alternative operating models

The current advice is based on the most recent stock information, such that recruitment estimates from 1998 onwards are believed representative for future recruitment. This represents the latest period and coincides with increased recruitment and an expansion of stock distribution. Assessment estimates prior to this period indicate lower and less variable recruitment, although they are based on fewer data (no recruitment index). Limited simulations were conducted with two alternative recruitment time-series: (i) derived from the abundance of a fully selected age class (*R_2*) and (ii) including recruitment estimates from 1990 onwards (*R_3*).

Using *R_2* had limited impact on results; however, there are indications that *R_3* is associated with both reduced yield and increased risk such that F_{target} values greater than 0.23 ($B_{trigger}$ = 2500 tonnes) are non-precautionary. This is in line with expectations of using a time-series with lower average recruitment. The risk criterion for assessing precautionarity is considered an overestimate due to the limited number of iterations (n = 100) run on the current operating model.

Conclusions

The simulations revealed combinations of F_{target} and $B_{trigger}$ that maximize the median annual yield in the long term while simultaneously minimizing the risk of the Northeast Atlantic mackerel stock falling below B_{lim}. For these combinations F_{target} values are between 0.27 and 0.30, and $B_{trigger}$ values are between 3 000 000 tonnes and 4 500 000 tonnes; higher F_{target} values are associated with higher $B_{trigger}$ values.

All management strategies considered precautionary in the long term (LT) were also precautionary in the short term (ST). When additional management measures (limitations of TAC interannual variation and of banking and borrowing, i.e. management strategies *IAVcap, B&B_5%, Combo_5%, Combo_10%*) were applied in the HCR, they had limited influence on median annual long-term yield or stock status compared to *BaseHCR* simulations.

Two sets of simulations were carried out, based on alternative estimates of recruitment from 1998 onwards (*BaseHCR* and *R_2*). Only small differences were found between these simulations. Inclusion of recruitment from years prior to 1998 (*R_3*), when recruitment was lower, impacts the precautionarity of the HCR. If future recruitment is lower than assumed in the base case scenario, simulations show that this will result in both reduced yield and increased risk of SSB < B_{lim}.

Interpretation of the evaluation

The results are contingent on the assumption that the benchmark SAM assessment provides a good representation of the stock dynamics, both present and future, as this is the scenario against which the harvest control rules are tested. This assumption is critical, as previous assessment updates have resulted in changes to stock perception due to the underlying nature of the input datasets (short time-series, high uncertainty, and contradicting signals). There is also evidence of assessment instability, including an overestimation of SSB and underestimation of F particularly during the short and medium time frames, and oscillations in yield and fishing mortality over the first decade of the simulations at high values of F_{target}. Although these oscillations were found to be linked to the interplay of the larger stock assessment error in the initial years of the projection and how the assessment uncertainty is propagated through the short-term forecast, the exact cause of these oscillations is not understood. It is therefore difficult to say if such oscillations should be expected in reality. Consequently, simulation results in the short and medium terms should be interpreted with caution. In the long term, SSB was overestimated and F underestimated by approximately 5%, which led to more precautionary management in the simulation.

While biological data on growth and spawning time have exhibited clear temporal trends since the mid-2000s, the cause of these trends is unknown. It was not possible to determine the direction of future changes in these characteristics, and biological information incorporated into the operating model reflected recent characteristics of the stock (2014 to 2018).

Uncertainty is incorporated into the operating model in several ways, and uncertainty in future recruitment was evaluated using two alternative operating models. However, a fuller representation of the uncertainties associated with the mackerel stock dynamics and fishery (such as environmental factors and climate change, density-dependence, natural mortality, changes in selectivity, and deviation from the HCR) was not possible within the scope of this framework.

In the last decade there has been an overshoot of advised catch and the implications of continuing an overshoot has not been considered in this evaluation as specified by the requesters. The HCR stabilization controls were evaluated, based on the assumption that the HCR advised catch is caught in full each year.

Suggestions

The development of this MSE tool provides a useful instrument to explore the SAM stock assessment for Northeast Atlantic mackerel. The quality of stock assessment would benefit from further development of the MSE tool as it allows a more thorough investigation of the diagnostics, weighting of input data, and performance of SAM. The performance and contribution to the assessment of survey and tagging data should be explored.

The MSE tool now offers further opportunities to explore a wider range of uncertainties associated with the dynamics and fisheries of Northeast Atlantic mackerel. Development of alternative operating models (such as incorporating density-dependent growth and changes in natural mortality) should be encouraged.

This advice is based on simulations that used a full feedback approach. The available experts had to develop the MSE tool to include new types of information (tagging data), and this information in the SAM model slowed down the processing time. Thus, availability of computing time, restrained the ability of ICES to answer the request in full. Future requests should include greater consideration of the resources required and the availability of high-powered computing.

Basis of the advice

Background

An updated stock assessment method (SAM) was adopted for mackerel at the inter-benchmark assessment in 2019 (ICES, 2019b). The inter-benchmark also evaluated and updated the reference points for the stock.

In June 2019, the European Union, Norway, and the Faroe Islands sent a joint request to ICES for an evaluation of a long-term management strategy for the stock using a full feedback approach. This request was dealt with by WKMSEMAC (ICES Workshop on Management Strategy Evaluation of Mackerel) which met in a physical meeting 7–9 January 2020 and subsequently by correspondence, following the travel restrictions imposed during the COVID emergency (ICES, 2020).

Methods

A full feedback stochastic simulation model was used for the evaluation of the long-term management strategy. The framework is an adaptation of the code developed for previous evaluations using Fisheries Libraries in R (FLR).

The current Northeast Atlantic mackerel SAM assessment is used to condition the operating model and also as the estimation model within the full feedback loop. This assessment provides population numbers with uncertainty up to 2019 and recruitment estimates up to 2017. Biology and fishery characteristics during the projection period are based on data from the most recent five years.

Uncertainty is included in the MSE through the operating model via parameter estimation error (based on estimates of parameter values and their variances and co-variances from the most recent stock assessment) , process error, observation error (when deriving monitoring data such as surveys, catch-at-age, and tagging), and banking and borrowing schemes. Alternative operating models are used to investigate the robustness of the base case operating model to alternative recruitment assumptions.

Simulations were run for 40 years with results summarized for the periods indicated in the request, i.e. short term (first five years), medium term (MT – the following ten years), and the long term (LT – the following 25 years). Simulations over a longer time-scale indicated that median SSB had largely stabilized during the long-term period, such that the impact of the initial conditions had dissipated. Following current guidelines, 1000 iterations were used. Analyses with 2000 iterations indicated that the risk type 3 measure, used to determine performance with respect to precautionarity, continues to decrease when the number of iterations exceeds 1000, albeit by a small proportion. Since risk 3 decreases with the number of iterations and computational runtime is significantly increased, 1000 iterations is considered to be both conservative and practical.

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