EU and Norway request concerning the long-term management strategy of cod, saithe, and whiting, and of North Sea autumn-spawning herring

Advice summary

ICES provides an answer to the request through combinations of F_{target} and $B_{trigger}$; these would maximize the yield while ensuring a less than 5% probability of the SSB falling below B_{lim}. The F_{target} and $B_{trigger}$ combinations vary, depending on the option for the management strategy. The main differences are the reduction of F when the stock is below B_{lim}, and the application of different stability elements (limits on interannual TAC variation and on "banking and borrowing" schemes).

The methods used to carry out this MSE differ from the standard ICES approach for estimating MSY reference points. This does not undermine the appropriateness of MSY reference points previously proposed by ICES.

Cod: Optimum values of F_{target} were found to be between 0.36 and 0.40 and $B_{trigger}$ between 130 000 and 190 000 t across management strategies, with a higher F_{target} requiring a higher $B_{trigger}$. All requested management scenarios are considered precautionary in the long term, but none of them in the short term. ICES advises, however, the use of the existing ICES MSY advice rule with an F_{MSY} of 0.31 and an MSY $B_{trigger}$ of 150 000 t, with added stability elements if desired. This is because the ICES MSY advice rule was the only management strategy that was precautionary across all robustness tests, with a minimal loss of yield and reduced interannual variation of the catch.

Whiting: Optimum values of F_{target} were found to be between 0.14 and 0.16 and $B_{trigger}$ between 200 000 and 250 000 t across management strategies. All requested management scenarios are considered precautionary in the long term, but none of them in the short term. The median long-term yield differs by up to 15% across the management strategies. The ICES MSY advice rule with current F_{MSY} and MSY $B_{trigger}$ was found not to be precautionary (probability of SSB< B_{lim} higher than 5%) under the assumptions of the present simulations.

Saithe: Optimum values of F_{target} were found to be between 0.35 and 0.36 and $B_{trigger}$ between 150 000 and 250 000 t across management strategies (including the ICES MSY advice rule with current F_{MSY} and MSY $B_{trigger}$). All requested management scenarios are considered precautionary in the long term, but not all in the short term. The median long-term yield differs by less than 5% across the management strategies.

North Sea autumn-spawning-herring: Optimum values of F_{target} were found to be between 0.22 and 0.23 and $B_{trigger}$ at 1 400 000 t across management strategies. Not all management strategies are considered precautionary in the long term. The median long-term yield differs by less than 2% across the management strategies. The ICES MSY advice rule with current F_{MSY} and MSY $B_{trigger}$ was found not to be precautionary (probability of SSB< B_{lim} higher than 5%) under the assumptions of the present simulations.

Request

The European Union and Norway jointly request ICES to advice on the long-term management strategies on joint stocks between Norway and the European Union. A summary is provided below.

*For **cod, haddock, saithe and whiting** ICES is asked to:*

1. *Tabulate the long-term yield, long term SSB, inter annual TAC variability and risk of SSB falling below B_{lim} for the range of combinations of $B_{trigger}$ and F_{target} values evaluated.*
2. *For each of the stocks requested, to estimate the combination of F_{target} and $B_{trigger}$ that maximises yield given the rules set out in six "sets" defined in the table attached. The six sets are A, B, C, A+D, B+E and C+E.*
3. *Evaluate the performance of the six sets of rules with corresponding pairs of F_{target} and $B_{trigger}$. Thereafter, ICES is requested to evaluate the additional fishing pressure scenarios of 0.9*F_{target}, F_{target}, 1.1*F_{target}, $F_{MSY\ lower}$ and $F_{MSY\ upper}$. (5 pairs, 6 sets = 30 scenarios per stock).*
4. *For **haddock**, two additional scenarios should be evaluated: F_{target} & 1.5*$B_{trigger}$ and F_{target} & 2*$B_{trigger}$ (2 pairs, rules sets A and A+D = 4 scenarios).*
5. *In addition, for **saithe**, another stability mechanism should be evaluated (for rule A+D): the maximum deviation of the TAC from that of the preceding year should be 15% (label A+D_1)*

For ***North Sea autumn-spawning herring*** *ICES is asked to:*

1. *Tabulate the long-term yield, long term SSB, inter annual TAC variability and risk of SSB falling below B_{lim} for the range of combinations of $B_{trigger}$ and F_{target} values evaluated.*
2. *Estimate the combination of F_{target} and $B_{trigger}$ that maximises yield given the rules set out in five "sets" defined in the table attached. The five sets are A, B, A+C, A+D and B+E*
3. *Evaluate the performance of the four sets of rules with corresponding pairs of F_{target} and $B_{trigger}$ and the additional fishing pressure scenarios of 0.9*F_{target}, F_{target}, 1.1*F_{target}, $F_{MSY\ lower}$ and $F_{MSY\ upper}$. (5 pairs, 5 sets = 25 scenarios).*

An additional request was received for autumn-spawning herring late in the process (email received 11 February 2019), asking for an additional scenario where F_{target} is set to zero for 0–1 ringers for management strategy A + C (both for A1 and A2, Table 5). Because of the lateness of the request, this was treated as a sensitivity test on the original A + C, rather than looking for the optimum combination of F_{target} and $B_{trigger}$ that maximize long-term yield and meets the precautionary criterion.

Elaboration on the advice

Haddock

The management strategy evaluation on haddock could not be finalized within the specified time-frame for this request; an answer will be provided at a later stage in a separate advice.

Cod, saithe, and whiting

ICES was tasked to find optimal combinations of harvest control rule parameters (F_{target} and $B_{trigger}$) for management strategies, with or without stability elements (see D and E in Table 1). Optimal combinations were defined as those combinations of F_{target} and $B_{trigger}$ that simultaneously maximized long-term yield while being precautionary (no more than 5% probability of SSB< B_{lim}*). Three different Harvest Control Rules (HCRs) were provided by the requesting parties, which differ only in the reduction of F if SSB is below B_{lim} (Table 1 and Figure 1).

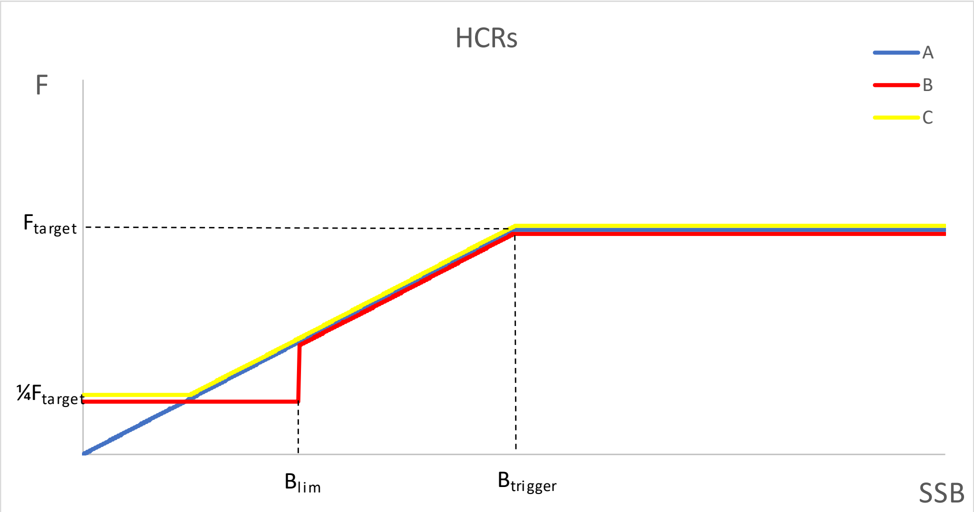

Figure 1 Graphic illustration of the requested harvest control rules (HCRs) for cod, whiting, and saithe.

For the purposes of this advice, short term refers to the first 5 years, medium term to years 6–10, and long term to years 11−20.

* Risk3 = maximum probability in any year of SSB< B_{lim}, measured over a pre-defined period.

The request also asked for sensitivity tests once the management strategies were optimized. These were performed with different Fs. In addition, robustness tests were carried out with alternate operating models.

The Management Strategy Evaluation (MSE) approach adopted for all stocks was to model the assessment and forecast, as implemented by ICES, to mimic the assessment and advice process as closely as possible.

Table 1 Definition of Harvest Control Rules (HCRs) for management strategies for the demersal stocks (cod, haddock, saithe, and whiting) tested in the request.

A	**Long-term yield**
1.	When the spawning stock (SSB) at the start of the TAC year is at or above $B_{trigger}$ the yearly TAC set shall correspond to a fishing pressure equal to F_{target}.
2.	If SSB at the start of the TAC year is below $B_{trigger}$, the TAC set shall correspond to a fishing mortality of F_{target} × SSB/$B_{trigger}$.
B	**Long-term yield**
1.	When the spawning stock (SSB) at the start of the TAC year is at or above $B_{trigger}$ the yearly TAC set shall correspond to a fishing pressure equal to F_{target}.
2.	If SSB at the start of the TAC year is below $B_{trigger}$ but above B_{lim}, the TAC set shall correspond to a fishing mortality of F_{target} × SSB/$B_{trigger}$.
3.	Where the SSB is estimated to be below B_{lim} at the start of the TAC year, the TAC shall be set at a level corresponding to a fishing mortality rate of 0.25 × F_{target}.
C	**Long-term yield**
1.	When the spawning stock (SSB) at the start of the TAC year is at or above $B_{trigger}$ the yearly TAC set shall correspond to a fishing pressure equal to F_{target}.
2.	If SSB at the start of the TAC year is below $B_{trigger}$ but above B_{lim}, the TAC set shall correspond to a fishing mortality of F_{target} × SSB/$B_{trigger}$.
3.	Where the SSB is estimated to be below B_{lim} at the start of the TAC year, the TAC shall be set at a level corresponding to a fishing mortality rate that is the greater of F_{target} × SSB/$B_{trigger}$ and 0.25 × F_{target}.
D	**Stability**
1.	Where the rule in paragraph A1 leads to a TAC that deviates more than 25% up or 20% down from the preceding year, the change is limited to 25% up or 20% down.
2.	The TAC given by paragraphs A1 and D1 can deviate with up to 10% according to the interannual quota flexibility provided for in paragraphs 1–3 of Annex VII of the “Agreed Record of fisheries consultations between Norway and European Union for 2018”, signed in Bergen on 1 December 2017 (the "banking and borrowing" scheme; see Annex attached to this advice).
E	**Stability**
1.	Where the rule in paragraphs B1 or C1 leads to a TAC that deviates more than 25% up or 20% down from the preceding year, the change is limited to 25% up or 20% down.
2.	The TAC given by paragraphs [B1, B2, B3, and E1] or [C1, C2, C3, and E1] can deviate with up to 10% according to the "banking and borrowing" scheme.

An additional HCR (A*) was also tested. This was the ICES MSY advice rule with present values for F_{MSY} and MSY $B_{trigger}$ (ICES, 2018a).

Cod

The baseline operating model (OM1) was the accepted benchmark assessment for cod, coupled with a period of low recruitment from 1998 onwards (ICES, 2018a). Alternative operating models were: an alternative recruitment period of 1988+ (OM2); year effects in the International Bottom Trawl Surveys (IBTS) (OM3); and density-dependent natural mortality to simulate cannibalism (OM4).

<u>Search grid for optimal combination of F_{target} and $B_{trigger}$</u>

The search for optimal combinations of F_{target} and $B_{trigger}$ (i.e. those that maximize long-term yield while fulfilling the ICES precautionary criterion), was only conducted for the baseline OM1 for each of the six management strategies (see Figure 2 for management strategy A). The optimal combinations for the six management strategies requested are shown in Table 2, along with three additional management strategies, including a version of management strategy A that sets $F_{target} = F_{MSY} = 0.31$ and $B_{trigger}$ = MSY $B_{trigger}$ = 150 000 t labelled as A* (i.e. the ICES MSY advice rule; see Figure 2), a version of A* that includes stability elements, is labelled as A* + D, and an F = 0 scenario.

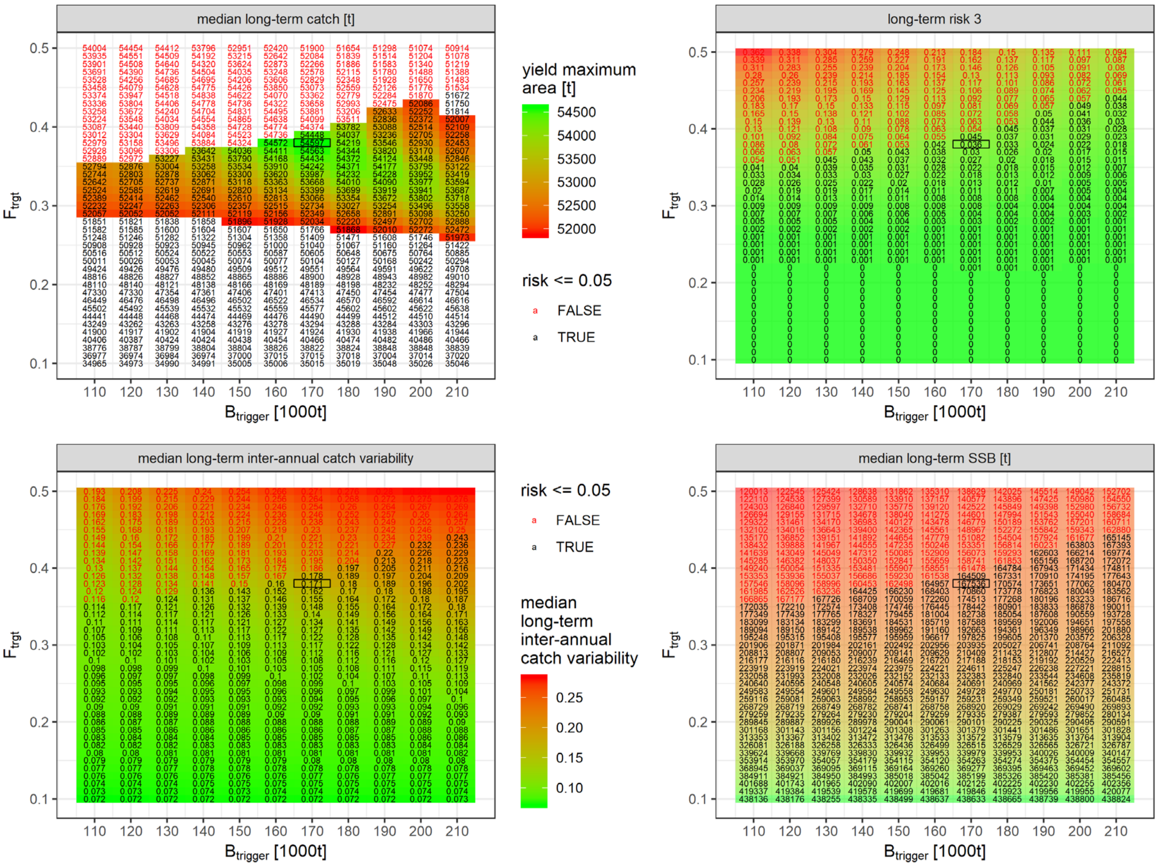

Figure 2 Cod in Subarea 4, Division 7.d and Subdivision 20: Grid search for optimal combination of F_{target} and $B_{trigger}$ for <u>management strategy A</u> for the long term (i.e. final 10 years of the 20-year projection). The top-left plot is median long-term catch, top-right is the long-term probability of SSB< B_{lim} (Risk3), bottom-left is the median long-term interannual catch variability, and bottom-right is the median long-term SSB. The optimal combination is surrounded by a black box. The combinations that meet the precautionary criterion are in black text, while those that do not are in red. For the catch plot, only those cells that are precautionary and within 5% of the maximum are coloured.

Table 2 Cod in Subarea 4, Division 7.d and Subdivision 20: optimal combinations for F_{target} and $B_{trigger}$ for the six management strategies defined in the request (1–6), and three additional management strategies (7–9). Also reported are the median long-term values for catch (in tonnes), SSB (in tonnes), realized mean F (ages 2–4), interannual catch variability (ICV)†, and probability (SSB< B_{lim}) over the final 10 years of the projection.

Scenario	Management strategy	F_{target}	$B_{trigger}$	Catch	SSB	Realized F(2–4)	ICV	P(SSB< B_{lim})
1	A	0.38	170000	54597	167536	0.362	0.171	0.036
2	B	0.38	160000	54790	165561	0.369	0.166	0.040
3	C	0.38	170000	54597	167536	0.362	0.171	0.036
4	A + D	0.40	190000	52532	167587	0.351	0.260	0.038
5	B + E	0.36	130000	52728	168381	0.356	0.329	0.046
6	C + E	0.36	140000	52440	168157	0.353	0.318	0.049
7	A* (ICES MSY advice rule)	0.31 = F_{MSY}	150000 = MSY $B_{trigger}$	52610	195959	0.311	0.113	0.011
8	A* + D	0.31 = F_{MSY}	150000 = MSY $B_{trigger}$	51880	195477	0.305	0.315	0.011
9	F = 0	0	0	0	701275	0	0	0

Management strategies A and C have identical optimized control parameters because SSBs do not drop low enough to result in a difference in target F (see Figure 1). Management strategy B results in a slightly higher median long-term catch, but also a lower SSB and higher risk. When the stock is at a very low SSB (e.g. as a result of recruitment failure), all rules react appropriately by reducing catch, and all can recover the stock once recruitment improves. Of the management strategies provided by the requesting parties, A leads to the most rapid recovery of the stock to above B_{lim}, followed by B, then C. In all three cases, the median long-term SSB is close to the $B_{trigger}$ value, implying that the rule will often operate "on the slope" of the HCRs (see Figure 1), resulting in ICVs of around 17% and a realized F that is lower than the target F.

When stability mechanisms are included, median long-term catch is slightly reduced, and ICV substantially increases in all cases. The increase in ICV is due to the extreme "banking and borrowing" scenario implemented (see section on "Caveats for all stocks" below). F_{target} and $B_{trigger}$ are increased for A + D, but reduced for strategies B + E and C + E. This is likely due to the differences in the application of the "banking and borrowing" scheme (only when SSB ≥$B_{trigger}$ for A, but throughout for B and C; additional safeguards [paragraph 5 in the Annex] are introduced for B and C compared to A).

The ICES MSY advice rule (A*) produces a long-term yield that is less than 5% lower than for any of the six management strategies, but with a much lower probability of SSB< B_{lim}, lower ICV, and a higher SSB. The addition of the stability elements (A* + D) does not increase the probability of SSB< B_{lim} and slightly reduces long-term yield, but substantially increases the ICV compared to A* due to the way the "banking and borrowing" is implemented in the MSE.

Short-term comparisons indicate that none of the management strategies (and not even closing the fishery; F = 0) has an associated probability of SSB< B_{lim} lower than 5%, which is an indication of current stock status (SSB close to B_{lim}). This implies that there are no management strategies that would be deemed precautionary in the short term for cod. Recovery is quick in the simulation, however, and all management strategies are precautionary in the medium and long term (recovery to above B_{pa} is 2–3 years in all cases, but with a slight delay for strategies B + E and C + E).

† Median absolute interannual rate of change in catch over the final 10 years.

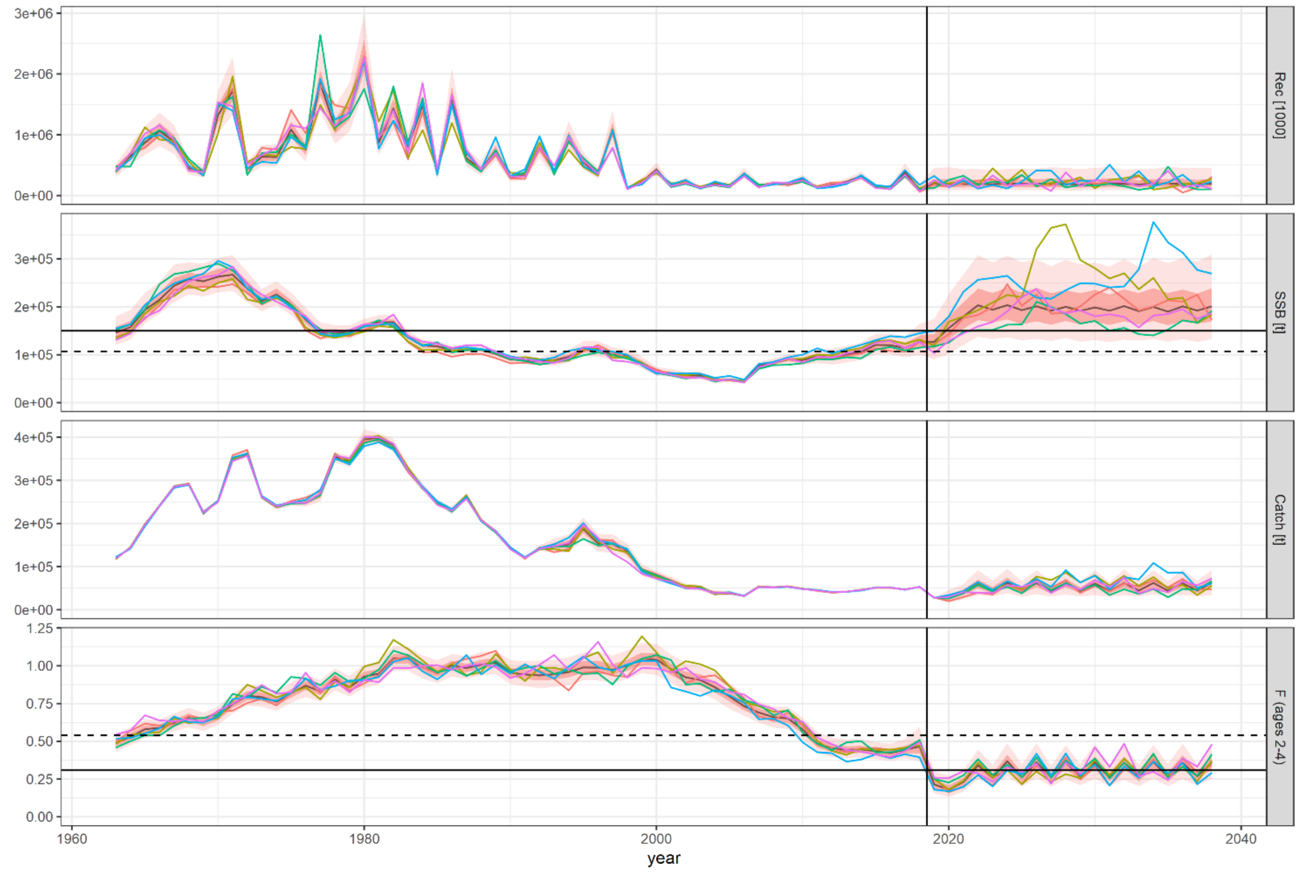

Figure 3 Cod in Subarea 4, Division 7.d and Subdivision 20: Summary projections for <u>management strategy A*+D</u> (i.e. the ICES MSY advice rule with F_{target} = F_{MSY} = 0.31 and $B_{trigger}$ = MSY $B_{trigger}$ = 150 000 t coupled with the stability elements and “banking and borrowing”). Top plot is recruitment (age 1), second plot is SSB, third plot is catch, and bottom plot is mean F (ages 2–4). The vertical black line separates the historical period from the projection period. The SSB plot includes B_{pa} = MSY $B_{trigger}$ (horizontal solid line) and B_{lim} (107 000 t; horizontal dashed line), while the mean F plot includes F_{MSY} (horizontal solid line) and F_{lim} (0.54; horizontal dashed line). The plots show medians (solid black line) with the darker shaded area indicating the 25th and 75th percentiles, and the light shaded area the 5th and 95th percentiles. For illustration purposes, the coloured lines show the values from five replicates.

<u>Sensitivity testing</u>

None of the management strategies are precautionary when F is increased to 1.1 F_{target} and $F_{MSY\text{-}upper}$ (long-term probability of SSB< B_{lim} is above 5%). Short-, medium-, and long-term catches are similar across the F ranges for the sensitivity tests, except for $F_{MSY\text{-}lower}$, which has a consistently lower value.

For $B_{trigger}$ = 150 000 t (MSY $B_{trigger}$), $F_{MSY\text{-}upper}$ would not be considered precautionary. This is inconsistent with previous ICES advice using a different framework.

<u>Robustness of management strategies across alternative operating models</u>

The alternative operating model 2 (OM2) considered an alternative period of recruitment, 1988+, to reflect a higher period of recruitment than recently observed. The management strategies all perform better under this operating model scenario.

The alternative operating model 3 (OM3) considered that year effects in the IBTS are present, but ignored by the management strategy. Year effects mean that indices for all ages are over- or under-estimated in a given year. This is considered a potential problem in recent North Sea cod assessments (ICES, 2018a). None of the optimized management strategies are precautionary in the long term under this operating model; however, management strategy A* (the current MSY approach for cod) remains precautionary in the medium and long term under this alternative operating model (Figure 4).

The alternative operating model 4 (OM4) considered a density-dependence increase in natural mortality due to cannibalism (ICES, 2018b). The simulation of cannibalism increases the probability of falling below B_{lim} compared to the baseline operating model (OM1). However, the probability of SSB< B_{lim} increased above 5% for management strategies B + E and C + E.

Management strategy A* is the only management strategy that remains precautionary in the medium and long term under all alternative operating models (Figure 4). This is also likely to be the case for management strategy A* + D as well, although it has not been fully tested.

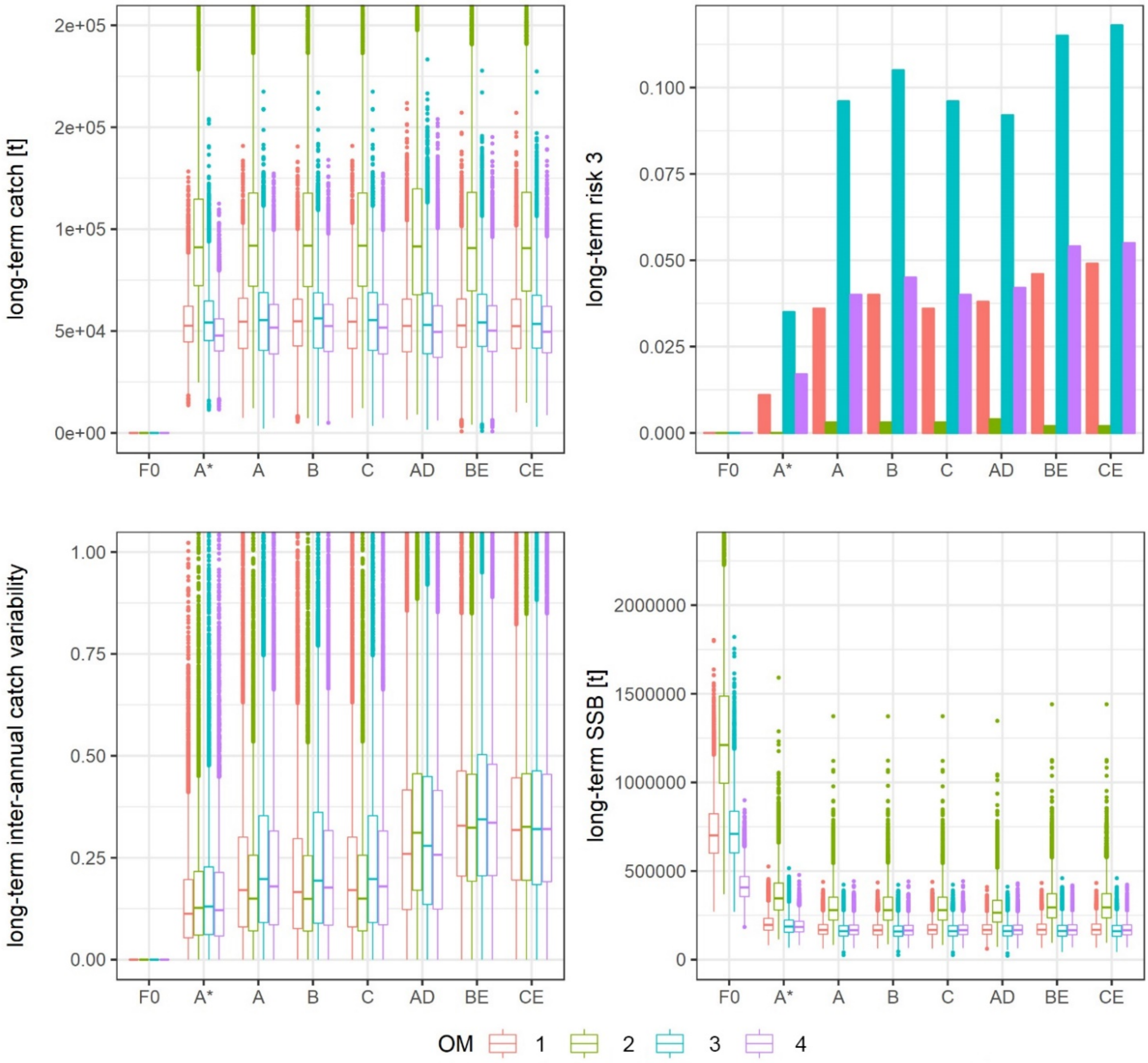

Figure 4 Cod in Subarea 4, Division 7.d, and Subdivision 20: Performance statistics for the various management strategies with alternate operating models <u>in the long term (final 10 years)</u>. Individual plots are labelled on the *y*-axis. Within each plot, the management strategies are F0 (i.e. F = 0), A* (i.e. management strategy A with F_{target} = F_{MSY} = 0.31 and $B_{trigger}$ = MSY $B_{trigger}$ = 150 000 t), and the six optimized management strategies (A, B, C, A + D, B + E, and C + E). The operating models are OM1 (the baseline), OM2 (higher recruitment), OM3 (year effects in the IBTS surveys) and OM4 (density-dependent M). In the box and whisker plots, the heavy horizontal line within the box indicates the median, the edges of the box indicate the 25th and 75th percentiles, and the whiskers extend to the largest and smallest values within 1.5 times the inter-quartile range (IQR) from the edges, and the remaining points indicated as dots outside the whiskers are the outliers to 1.5 × IQR from the edges.

Saithe

The baseline operating model (OM1) was conditioned on the most recent SAM assessment for North Sea saithe (ICES, 2019). The alternative operating model 2 (OM2) used a natural mortality of 0.1 instead of 0.2. The alternative operating model 3 (OM3) used a natural mortality of 0.3.

Search grid for optimal combination of F_{target} and $B_{trigger}$

The searches for optimal combinations of F_{target} and $B_{trigger}$ (i.e. those that maximize long-term yield while fulfilling the ICES precautionary criterion) were conducted only for the baseline OM for each of the seven management strategies (see Figure 5 for management strategy A). Note that for North Sea saithe, ICES was also asked to evaluate scenario A + D with a TAC constraint of −15% and +15% (labelled A + D_1 below).

Table 3 summarizes optimal combinations and diagnostics for each of the seven requested scenarios. Additionally, a version of management strategy A that sets F_{target} = F_{MSY} = 0.363 and $B_{trigger}$ = MSY $B_{trigger}$ = 149 098 t (A* – the ICES MSY advice rule), a version of A* that includes stability elements (A* + D), and a scenario with F = 0 are all presented in Table 3.

Projections are summarized for the optimal pairs for each management strategy, using the baseline operating model in terms of recruitment (age 0), SSB, catch, and mean F (age 4–7) (see Figure 6 for management strategy A).

Table 3 Saithe in Subareas 4 and 6 and Division 3.a: optimal combinations of F_{target} and $B_{trigger}$ for the baseline OM for the seven management strategies in the request (1–7; A + D_1 is the ±15% TAC constraint scenario requested for saithe), A* (F_{target} = F_{MSY} and $B_{trigger}$ = MSY $B_{trigger}$), A* + D, and F = 0.and three additional strategies (8-10). Also reported are the median values for catch, SSB, realized mean F (ages 4–7), interannual catch variability (ICV), and the probability of SSB< B_{lim} in the long term (final 10 years).

Scenario	Management strategy	F_{target}	$B_{trigger}$	Median catch	Median SSB	Realized mean F	ICV	P(SSB< B_{lim})
1	A	0.35	250000	116700	292067	0.34	0.177	0.015
2	B	0.39	200000	116835	254513	0.38	0.186	0.034
3	C	0.35	250000	116700	292013	0.34	0.177	0.015
4	A + D	0.41	210000	112250	249213	0.38	0.335	0.043
5	B + E	0.39	220000	112562	263268	0.36	0.364	0.032
6	C + E	0.36	230000	112351	285057	0.34	0.36	0.015
7	A + D_1	0.36	230000	112377	284997	0.34	0.36	0.015
8	A*	0.363	149098	115270	265531	0.36	0.151	0.019
9	A* + D	0.363	149098	111330	263568	0.35	0.345	0.019
10	F = 0	0	0	0	1493002	0	0	0

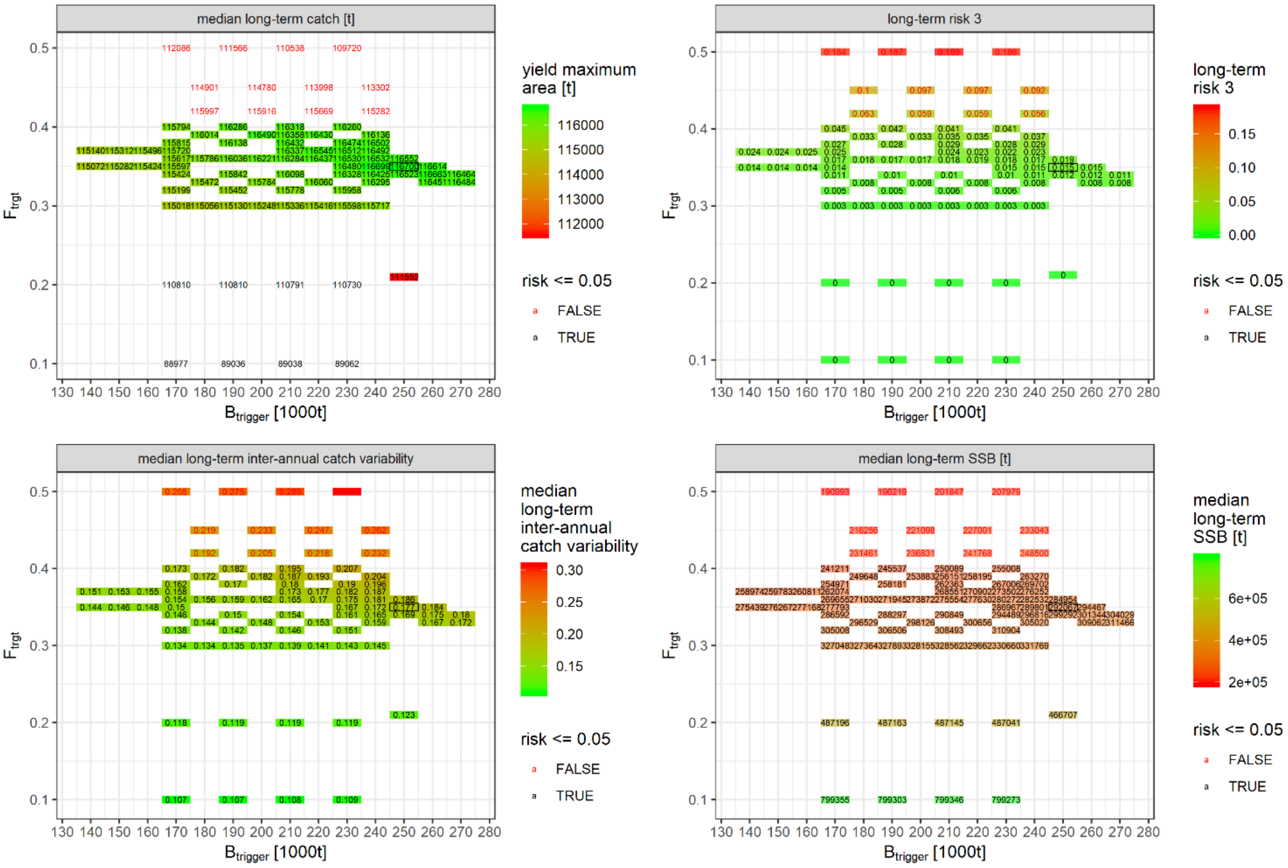

Figure 5 Saithe in subareas 4 and 6 and Division 3.a: Grid search for optimal combination of F_{target} and $B_{trigger}$ for management strategy A for the long term (i.e. final 10 years of the 20-year projection). The top-left plot is median long-term catch, top-right is the long-term probability of SSB< B_{lim} (Risk3), bottom-left the median long-term interannual catch variability, and bottom-right the median long-term SSB. The optimal combination is surrounded by a black box. The combinations that meet the precautionary criterion (Risk3 ≤ 5%) are in black text, while those that do not are in red. For the catch plot, only those cells within 5% of the maximum are coloured.

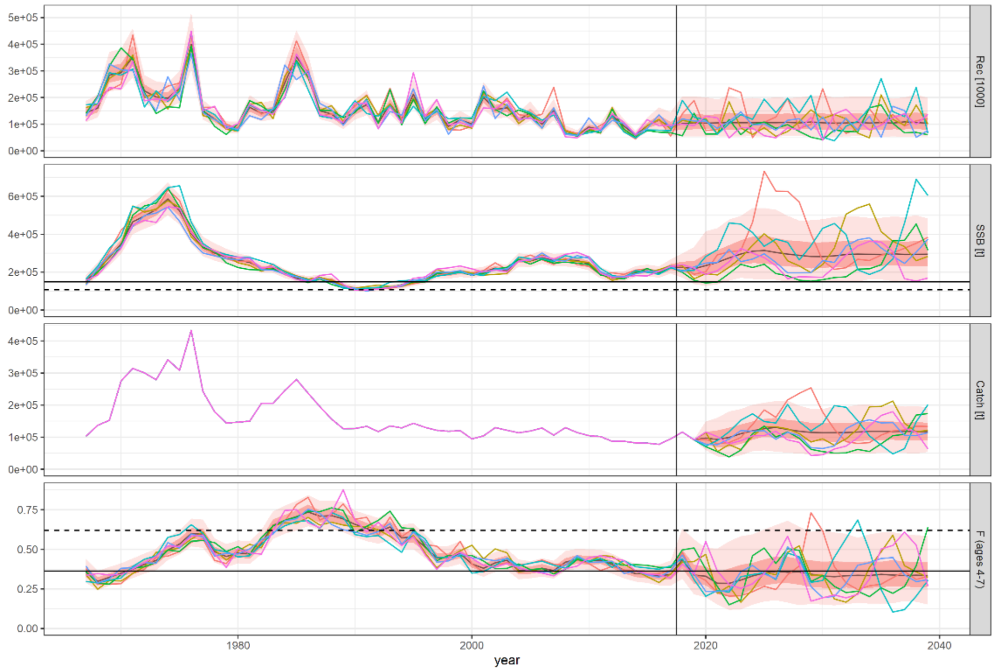

Figure 6 Saithe in subareas 4 and 6 and Division 3.a: Summary projections for management strategy A. Top plot is recruitment (age 3), second plot SSB, third plot catch, and bottom plot mean F (ages 4–7). The vertical black line separates the historical period from the projection period. The SSB plot includes B_{pa} = MSY $B_{trigger}$ (horizontal solid line) and B_{lim} (horizontal dashed line), while the mean F plot includes F_{MSY} (horizontal solid line) and F_{lim} (horizontal dashed line). The plots show medians (solid black line) with the darker shaded area indicating the 25th and 75th percentiles, and the light shaded area the 5th and 95th percentiles. The coloured lines represent the values from five replicates.

The median long-term SSB is above $B_{trigger}$ for all optimized management strategies without stability elements. The performance of A and C are very similar because SSB does not drop low enough in the majority of the replicates to trigger a change in F. For A and C, the short-term probability of SSB< B_{lim} remains under 5%, and the quoted $B_{trigger}$ and F_{target} levels are precautionary in both the short- and long-term. However, for B, the short-term probability of SSB< B_{lim} is higher than 5% despite the long-term probability of SSB< B_{lim} being lower than 5%. This is because of the higher F_{target} and lower $B_{trigger}$ that results from optimizing B in the long term.

Optimized management strategies including stability elements resulted in lower median catch and greater ICV for all options. The increase in the ICV resulted from the extreme "banking and borrowing" implementation used (see the section "Caveats for all stocks" below). SSB was lower for A + D, A + D_1, C + E, and A* + D than for the corresponding management strategies without stability elements. F_{target} was higher and $B_{trigger}$ was lower for all management strategies except B + E, when comparing to corresponding management strategies without stability elements. The ICES MSY advice rule (A*) produces a similar long-term yield as the seven management strategies, but with a lower ICV. The probability of SSB< B_{lim} is higher and long-term SSB lower for A* than for A, C, C + E, and A + D_1. For B, A + D, and B + E (i.e. those that are not precautionary in the short term),; compared to these management strategies, A* has a lower long-term probability of SSB< B_{lim} and a slightly higher long-term SSB. The short-term probability of SSB< B_{lim} is more than 5% for management strategies B, A + D, and B + E.

Sensitivity testing

Short- and long-term catches are broadly similar across the F ranges for the sensitivity tests; $F_{MSY\text{-}lower}$ and $F_{MSY\text{-}upper}$ have slightly lower catches. Medium-term catches show a gradient across the F ranges, from low with $F_{MSY\text{-}lower}$ to a high with $F_{MSY\text{-}upper}$.

The probability of SSB< B_{lim} is above 5% for $F_{MSY\text{-}upper}$ (all management strategies) and for 1.1 × F_{trgt} (B, A + D, and B + E). For B, A + D, and B + E, any fishing above the F_{target} calculated here is considered non-precautionary. Consequently, if management strategies B, A + D, or B + E are selected, the upper end of any F-range should be set to the F-target level presented here.

Robustness of management strategies across alternative operating models

Under the alternative operating model 2 (OM2; M = 0.1), all management strategies tested were precautionary in the long, medium, and short term.

Under the alternative operating model 3 (OM3; M = 0.3), management strategies B, A + D, and B + E were not precautionary in the long term. Furthermore, none of the management strategies were precautionary under this alternative operating model in the medium or short term. If the assumption that M = 0.2 is incorrect and natural mortality is 0.3 or higher in the population, the management strategies investigated here are not precautionary.

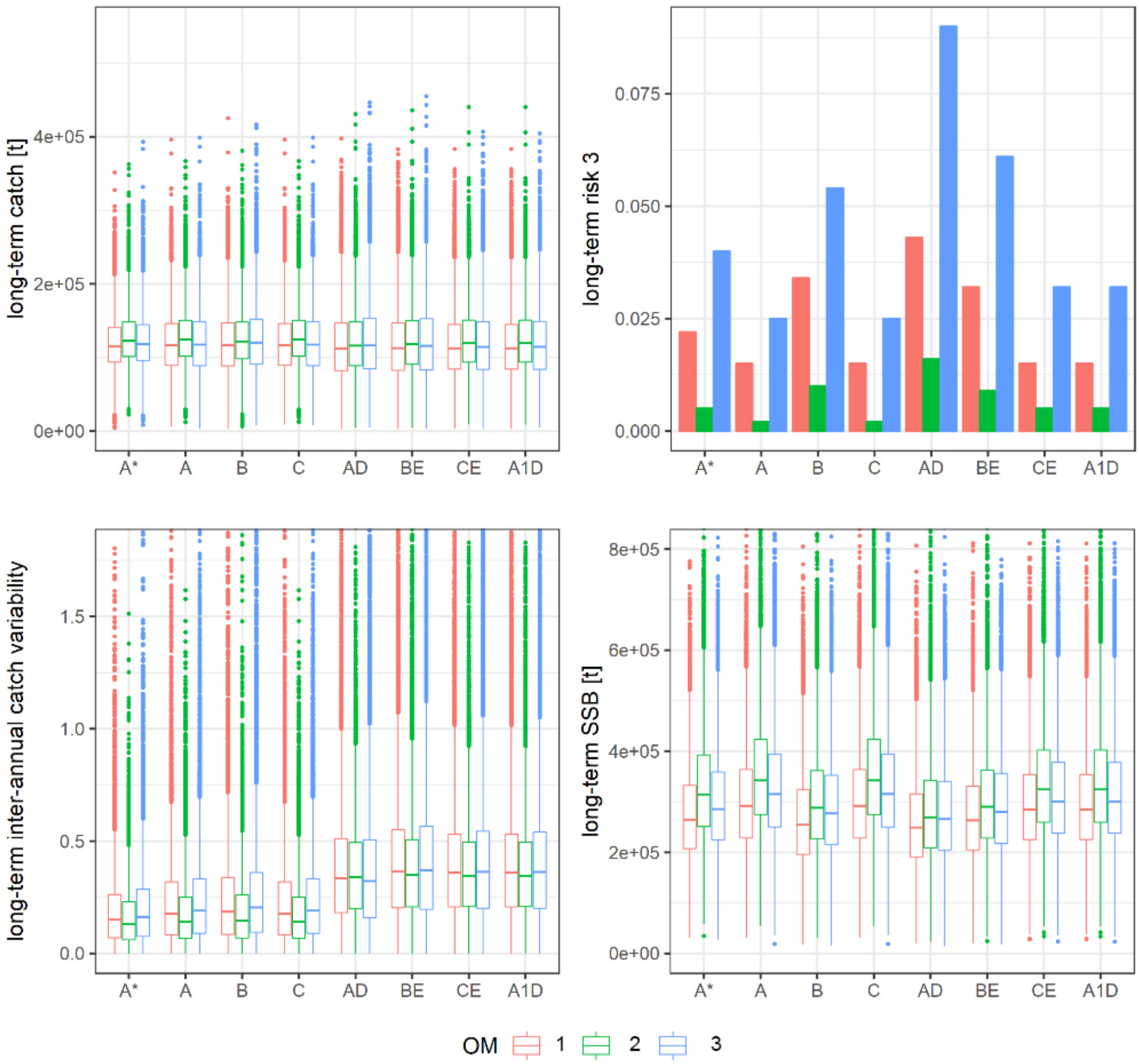

Figure 7 Saithe in subareas 4 and 6 and Division 3.a: Performance statistics for the various management strategies with alternate operating models in the long-term (final 10 years). Plots include median catch, probability of SSB< B_{lim} (Risk3), interannual catch variability, and SSB, Individual plots are as indicated by the label on the *y*-axis. Within each plot, the management strategies are A* (i.e. management strategy A with F_{target} = F_{MSY} = 0.363 and $B_{trigger}$ = MSY $B_{trigger}$ = 149 098 t), and the seven optimized management strategies (A, B, C, A + D, B + E, C + E, and A + D_1; the latter is labelled A1D in the figure). The operating models are OM1 (the baseline), OM2 (M = 0.1), and OM3 (M = 0.3). In the box and whisker plots, the heavy horizontal line within the box indicates the median, the edges of the box indicate the 25th and 75th percentiles, and the whiskers extend to the largest and smallest values within 1.5 times the inter-quartile range (IQR) from the edges, and the remaining points indicated as dots outside the whiskers are the outliers to 1.5 × IQR from the edges.

Whiting

The baseline operating model was conditioned on the latest SAM assessment for North Sea whiting fitted to total catches (ICES, 2018a). Alternative operating model 2 (OM2) tested lower recruitment than the baseline. Alternative operating model 3 (OM3) tested lower recruitment than the baseline in addition to variability in industrial bycatch.

Search grid for optimal combination of F_{target} and $B_{trigger}$

A grid search was performed to determine the optimal combination of F_{target} and $B_{trigger}$ for each of the six management strategies under the baseline operating model (see Figure 8 for management strategy A). The optimal pairs were selected to produce maximum yield with a probability of SSB< B_{lim} less than 5% in the long term (Table 4 and Figure 84).

Projections are summarized for the optimal pairs for each management strategy using the baseline operating model in terms of recruitment (age 0), SSB, catch, and mean F (age 2–6) (see Figure 8 for management strategy A).

Table 4 Whiting in Subarea 4 and Division 7.d: optimal combinations for F = 0, ICES MSY advice rule (A*), and for optimized pairs of F_{target} and $B_{trigger}$ for the probability of SSB< B_{lim} not falling below 5%, as well as maximized yield management strategies defined in the request (1–6) and two additional management strategies (7–8). Also shown are the median long-term values for catch (in tonnes), SSB (in tonnes), realized mean F (ages 2–4), interannual catch variability (ICV)‡, and probability (SSB< B_{lim}) over the long term for the final 10 years of the projection.

Scenario	Management strategy	F_{trgt}	$B_{trigger}$	Catch	SSB	ICV	P(SSB< B_{lim})	Realized F
1	A	0.14	220000	22832	202702	0.140	0.050	0.123
2	B	0.16	200000	26308	195791	0.131	0.049	0.146
3	C	0.14	220000	22844	202678	0.140	0.050	0.123
4	A + D	0.16	250000	22534	201011	0.205	0.050	0.124
5	B + E	0.16	210000	24846	196370	0.369	0.050	0.139
6	C + E	0.15	230000	22855	200634	0.363	0.050	0.124
7	A*	0.172	166708	27974	189125	0.118	0.084	0.163
8	F = 0	0	166708	0	259460	1	0.01	0

‡ Median absolute interannual rate of change in catch over the final 10 years.

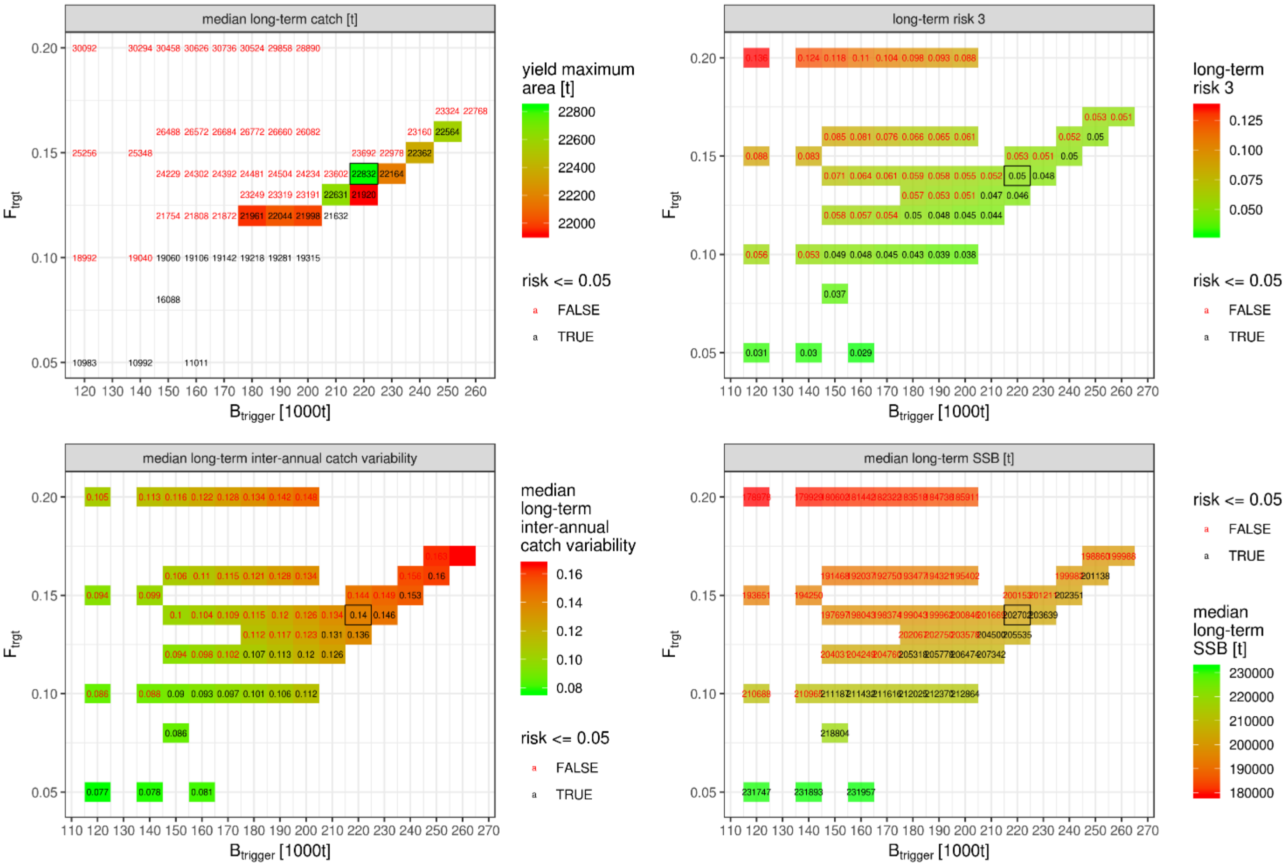

Figure 8 Whiting in Subarea 4 and Division 7.d. Grid search for optimal combination for management strategy A. Long-term results (final 10 years of the 20-year projection) median catch, probability of SSB< B_{lim} (Risk 3R), median interannual catch variability, and median SSB. The optimal combination delivers maximum long-term catch while meeting the precautionary criterion (probability of SSB< B_{lim} less than 5%), F_{target} = 0.14, $B_{trigger}$ = 220 000 t. The combinations with probability of SSB< B_{lim} less than 5% are in black, otherwise in red. For the catch plot, only those cells within 5% of the maximum are coloured.

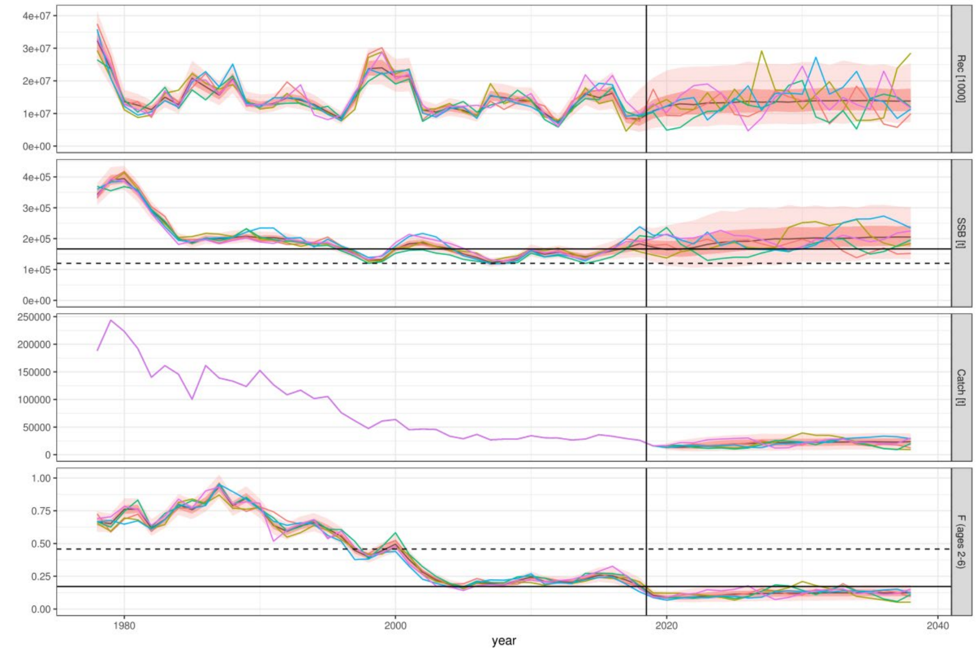

Figure 9 Whiting in Subarea 4 and Division 7.d. Summary projections for management strategy A. Top plot is recruitment (age 0), second plot SSB, third plot catch, and bottom plot mean F (ages 2–6). The vertical black line separates the historical period from the projection period. The SSB plot includes B_{pa} = MSY $B_{trigger}$ (horizontal solid line) and B_{lim} (horizontal dashed line), while the mean F plot includes F_{MSY} (horizontal solid line) and F_{lim} (horizontal dashed line). The plots show medians (solid black line) with the darker shaded area indicating the 25th and 75th percentiles, and the light shaded area the 5th and 95th percentiles. The coloured lines represent the values from five replicates.

Management strategies A and C perform similarly in terms of catch and SSB, because the optimal F_{target} and $B_{trigger}$ are the same and because these management strategies would result in the same catch target unless SSB is well below B_{lim}.

In comparison, the optimized pair for B results in a slightly higher long-term catch and slightly lower SSB. Long-term probability of SSB< B_{lim} is around 0.05 for all HCRs (optimized to the long term). All management strategies were found to be non-precautionary in the short term, apart from F = 0. In the short term, the probability of SSB< B_{lim} was lowest for A, C, and A + D. The ICES MSY advice rule, F_{target} = F_{msy} together with $B_{trigger}$ = MSY $B_{trigger}$ (A*), was found to be non-precautionary, even in the long term.

In all management strategies, median SSB in the long term is below the respective $B_{trigger}$ and realized F is below F_{target}, indicating the HCRs are operating "on the slope" (Figure 1).

When stability elements are included, median long-term catch is slightly reduced. Management strategies A + D, B + E, and C + E lead to higher interannual catch variability compared to the management strategies without stability elements due to the way the "banking and borrowing" is implemented in the MSE.

The MSY approach advice rule (A*) produces a slightly higher long-term catch than the six optimized management strategies, but with a much higher probability of SSB< B_{lim} (>5%) and ICV, and lower SSB.

Sensitivity testing

The sensitivity of performance statistics was tested for the six optimized HCRs (A, B, C, A + D, B + E, and C + E) to five fishing scenarios (0.9 × F_{target}, F_{target}, 1.1 × F_{target}, $F_{MSY\text{-}lower}$ = 0.158, and $F_{MSY\text{-}upper}$ = F_{MSY} = 0.172). Short-, medium-, and long-term catches are similar across the F ranges for the sensitivity tests, but lowest for 0.9 × F_{target}.

Long-term probability of SSB< B_{lim} is always above 5% for 1.1 × F_{target} and $F_{MSY\text{-}upper}$. For A, C, and C + E, F_{target} is lower than $F_{MSY\text{-}lower}$, and therefore $F_{MSY\text{-}lower}$ leads to long-term probability of SSB< B_{lim} above 5%.

Robustness of management strategies across alternative operating models

No optimized management strategy was precautionary under the alternative operating models that included recruitment level shifts (lower recruitment scenarios). In the alternative operating model 3 (OM3), including the catch variability due to industrial bycatch had only a marginal effect compared to lower recruitment alone (OM2; Figure 10). Given the significant effects of lower recruitment, if future recruitment remains at a relatively low level compared to the data series since 1983, more precautionary management strategies than those evaluated would be needed and a faster management response to recruitment changes is required.

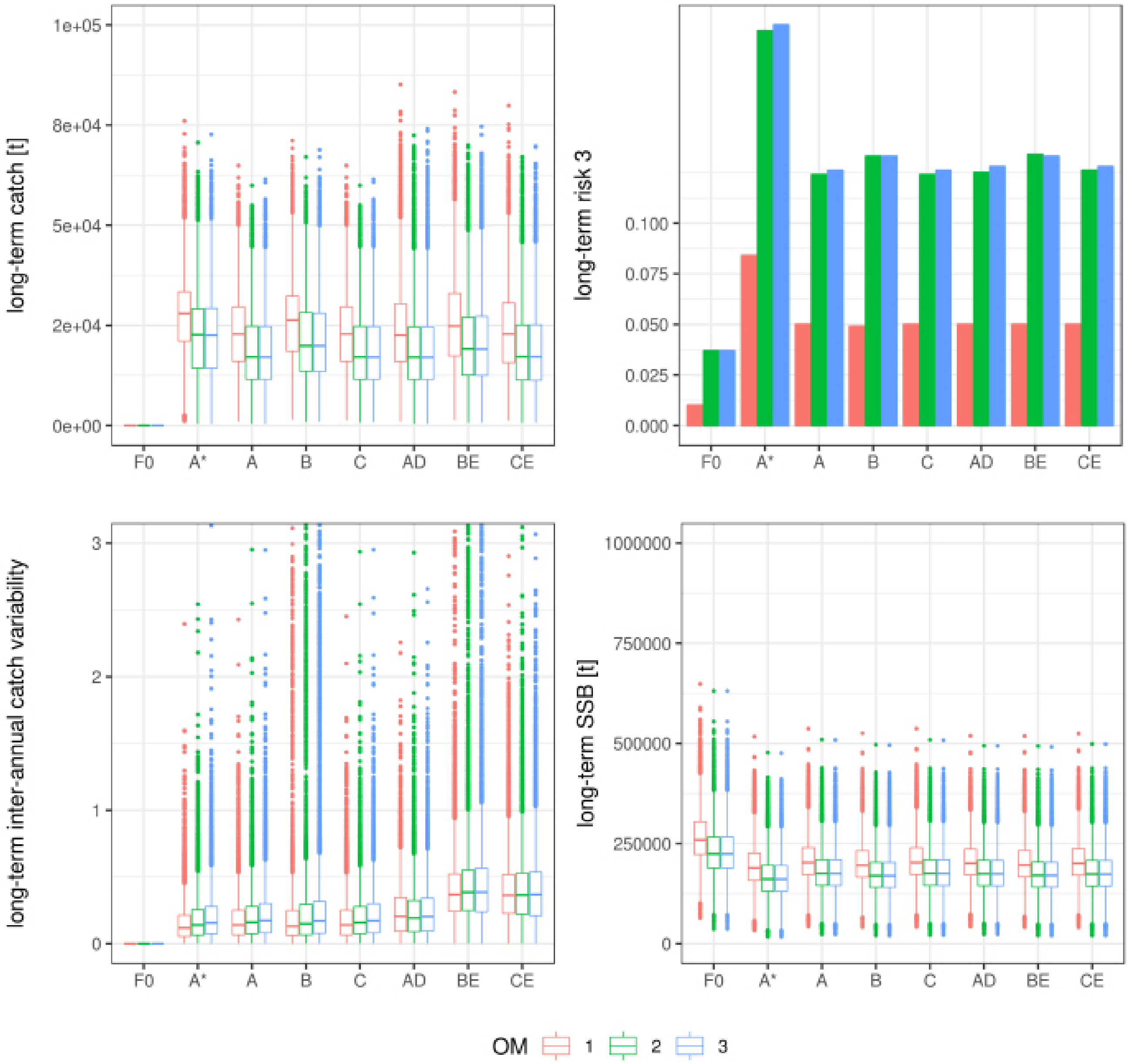

Figure 10 Whiting in Subarea 4 and Division 7.d: Performance statistics for the various management strategies with alternate operating models in the long-term (final 10 years). Individual plots are as indicated by the label on the *y*-axis. Within each plot, the management strategies are F0 (i.e. F = 0), A* (i.e. management strategy A with $F_{target} = F_{MSY} = 0.172$ and $B_{trigger}$ = MSY $B_{trigger}$ = 166 708 t), and the six optimized management strategies (A, B, C, A + D, B + E, and C + E). The operating models are OM1 (the baseline), OM2 (lower recruitment), and OM3 (lower recruitment and variable industrial bycatch). In the box and whisker plots, the heavy horizontal line within the box indicates the median, the edges of the box indicate the 25th and 75th percentiles, and the whiskers extend to the largest and smallest values within 1.5 times the inter-quartile range (IQR) from the edges. The remaining points, indicated as dots outside the whiskers, are the outliers to 1.5 × IQR from the edges.

North Sea autumn-spawning (NSAS) herring

The requested options for NSAS herring differed slightly from those tested on the demersal stocks (Table 5).

Table 5 Definition of Harvest Control Rules (HCRs) for management strategies for NSAS herring tested in the request.

A	**Long-term yield**
1.	When the SSB in the autumn (spawning time) of the TAC year is estimated to be above [$B_{trigger}$], yearly TAC will be set as to correspond to a fishing pressure at F_{target} for 2-ringers and older and at 0.05 for 0-1 ringers.
2.	Should the spawning stock (SSB) in the autumn of the TAC year be below [$B_{trigger}$] the TAC will be set to correspond to a fishing mortality at F_{target}*SSB/[$B_{trigger}$] for 2-ringers and older and at 0.05*SSB/[$B_{trigger}$] for 0 to 1 ringers.
B	**Long-term yield**
1.	When the SSB in the autumn (spawning time) of the TAC year is estimated to be above [$B_{trigger}$], yearly TAC will be set as to correspond to a fishing pressure at F target for 2-ringers and older and at 0.05 for 0-1 ringers.
2.	Should the spawning stock (SSB) in the autumn of the TAC year be below [$B_{trigger}$] but above B_{lim}, the TAC will be set to correspond to a fishing mortality at F_{target}*SSB/[$B_{trigger}$] for 2-ringers and older and at 0.05 for 0-1 ringers.
3.	Should the spawning stock (SSB) in the autumn of the TAC year be below B_{lim} the TAC will be set to correspond to a fishing mortality at 0.1 for 2 ringers and older and at 0.04 for 0-1 ringers.
C	**Stability**
1.	Where the rule in paragraph Al leads to a TAC in the directed fishery that deviates more than 25% up or 20% down from the preceding year, the change is limited to 25% up or 20% down.
2.	The TAC given in the directed fishery by paragraph Al and Cl can be deviated with up to 10% according to the inter-annual quota flexibility provided for in paragraphs 1-3 of Annex VII of the Agreed Record of fisheries consultations between Norway and European Union for 2018 signed in Bergen on 1 December 2017. (the "banking and borrowing" scheme)
D	**Stability**
1.	Where the rule in paragraph A 1 leads to a TAC that deviates more than 25% up or 20% down from the preceding year, the change is limited to 25% up or 20% down.
2.	The TAC given by paragraph Al and Dl can be deviated with up to 10% according to the inter-annual quota flexibility provided for in paragraphs 1-3 of Annex VII of the Agreed Record of fisheries consultations between Norway and European Union for 2018 signed in Bergen on 1 December 2017. (the "banking and borrowing" scheme)
E	**Stability**
1.	Where the rules in paragraphs B 1, B2 or B3 leads to a TAC that deviates more than 25% up or 20% down from the preceding year, the change is limited to 25% up or 20% down.
2.	The TAC given by paragraph B 1, B2, B3 and E 1 can be deviated with up to 10% according to the "banking and borrowing" scheme.

An additional HCR (A*) was also tested. This was the ICES MSY advice rule with present values for F_{MSY} and MSY $B_{trigger}$ (ICES, 2018c).

For this management strategy evaluation, the conditioning of the baseline operating model is based on the latest assessment (ICES, 2018c) but excluding the LAI index (spawning component index) to simplify implementation. This index has marginal influence on the results of the assessment.

The TAC setting procedures and allocation of catch to each of the fleets follows from the management strategy and potential transfers from one fleet to another (Table 6). In practice, optimization of the catches in the A-fleet according to the management strategy is also conditional on the B-fleet F_{target} given by the management strategy, and the catches simulated for the C- and D-fleets. Both the C-fleet and D-fleet catches are assumed to derive from fixed TACs of 48 427 t (Division 3.a TAC set in 2018) and 6659 t (fixed TAC), respectively, with the C-fleet transferring between 40% and 50% of its quota to the A-fleet based over the last 10 years. In the A-, C-, and D-fleets, however, the catches do not consist of one herring stock alone, but contains a mixture of both NSAS (North Sea autumn spawners) and WBSS (Western Baltic spring spawners). As the MSE evaluated how precautionary certain management strategies were for the stocks, the mixed nature of the catches has to be accounted for in the simulations. ICES advised zero catches for WBSS herring in 2019, so the *status quo* assumption about continued fishing at a fixed TAC in Division 3.a may be unrealistic. However, the assumption chosen here is more precautionary for the NSAS herring stock than the assumption of a closure of the herring fishery in Division 3.a.

Table 6 North Sea Autumn-spawning herring: The four fleets fishing NSAS herring.

Area where NSAS are caught	Fleet	Fishery
North Sea (Subarea 4, Division 7.d)	A	Directed herring fisheries
	B	Bycatches of herring
Division 3.a	C	Directed herring fisheries
	D	Bycatches of herring

Over the past 10 years, an average of 32% of the C-fleet's catch consists of NSAS and 68% of WBSS. On average, 64% of the D-fleet's catch consists of NSAS and 36% of WBSS. The proportion of WBSS in the A-fleet catch is negligible and is therefore ignored.. The impact of this level of mixing for the catches of NSAS is mimicked in the simulations. The observed utilization of the B- and D-fleet TACs over the last 10 years is taken into account and simulated. Analyses of the past 10 years showed a low contribution from the C-fleet to the NSAS F_{bar}, between 1% and 2% without trend.

Search grid for optimal combination of F_{target} and $B_{trigger}$

A grid search was performed to determine the optimal combination of F_{target} and $B_{trigger}$ for each of the five management strategies under the baseline operating model (Table 7 and, for illustrative purposes, Figure 11 for management strategy A). The optimal pairs were selected to produce maximum yield while maintaining the probability of SSB< B_{lim} at ≤ 5% in the long term. Additionally, a version of management strategy A that sets F_{target} = F_{MSY} = 0.26 and $B_{trigger}$ = MSY $B_{trigger}$ = 1 400 000 t (A* – the ICES MSY advice rule) as well as a version of A* that includes stability elements (A* + D) are both presented in Table 7.

No optimal combination could be found for HCR B + E within the projected time-frame (20 years). The design of the management strategy allows TAC constraints even if the stock is below B_{lim}. Given that the stock has been on a downward trend in the most recent years, the TAC requires a substantial decrease to counter the downward trend. Under scenario B + E this reduction in TAC is not possible and for some replicates this results in very high F in the short term, which require much longer time-frames to recover from..

Table 7 North Sea Autumn-spawning herring. Optimal combinations for F_{target} and $B_{trigger}$ for four of the five management strategies defined in the request (1–4), plus three additional management strategies (5–7). Also reported are the median long-term values for catch (tonnes), SSB (tonnes), realized mean F (ages 2–6), interannual catch variability (ICV), and probability (SSB< B_{lim}) over the final 10 years of the projection.

Scenario	Management strategy	F_{target}	$B_{trigger}$	Catch	SSB	Realized F(2–6)	ICV	P(SSB< B_{lim})
1	A	0.22	1400000	345646	1471026	0.219	0.151	0.046
2	B	0.22	1400000	344582	1467080	0.219	0.149	0.050
3	A + C	0.22	1400000	345095	1473686	0.219	0.157	0.048
4	A + D	0.23	1400000	349286	1446241	0.228	0.159	0.049
5	A*	0.26 = F_{MSY}	1400000 = MSY $B_{trigger}$	358346	1363961	0.248	0.168	0.072
6	A* + D	0.26 = F_{MSY}	1400000 = MSY $B_{trigger}$	358937	1368652	0.249	0.171	0.076
7	F = 0	0	0	0	2687033	0	0	0

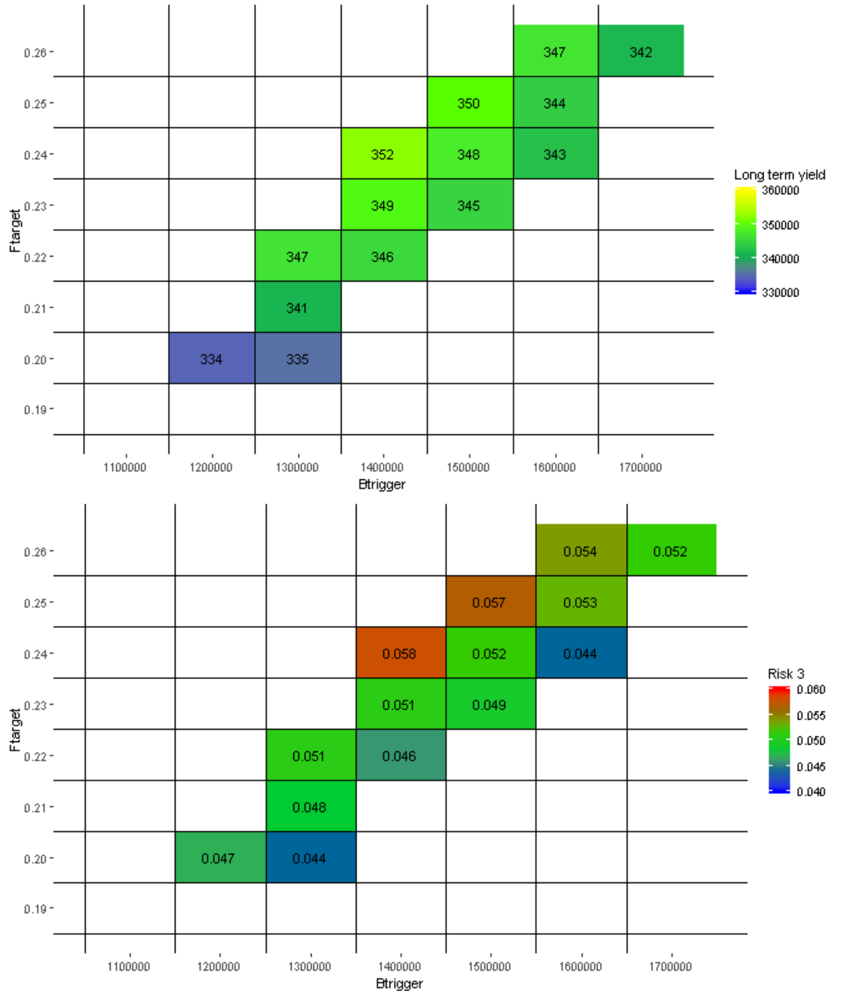

Figure 11 North Sea herring. Grid search for management strategy A (no stabilizers). Long-term yield (upper panel) and the probability of SSB< B_{lim} (Risk3, lower panel) calculated over the last 10 years of the projected period.

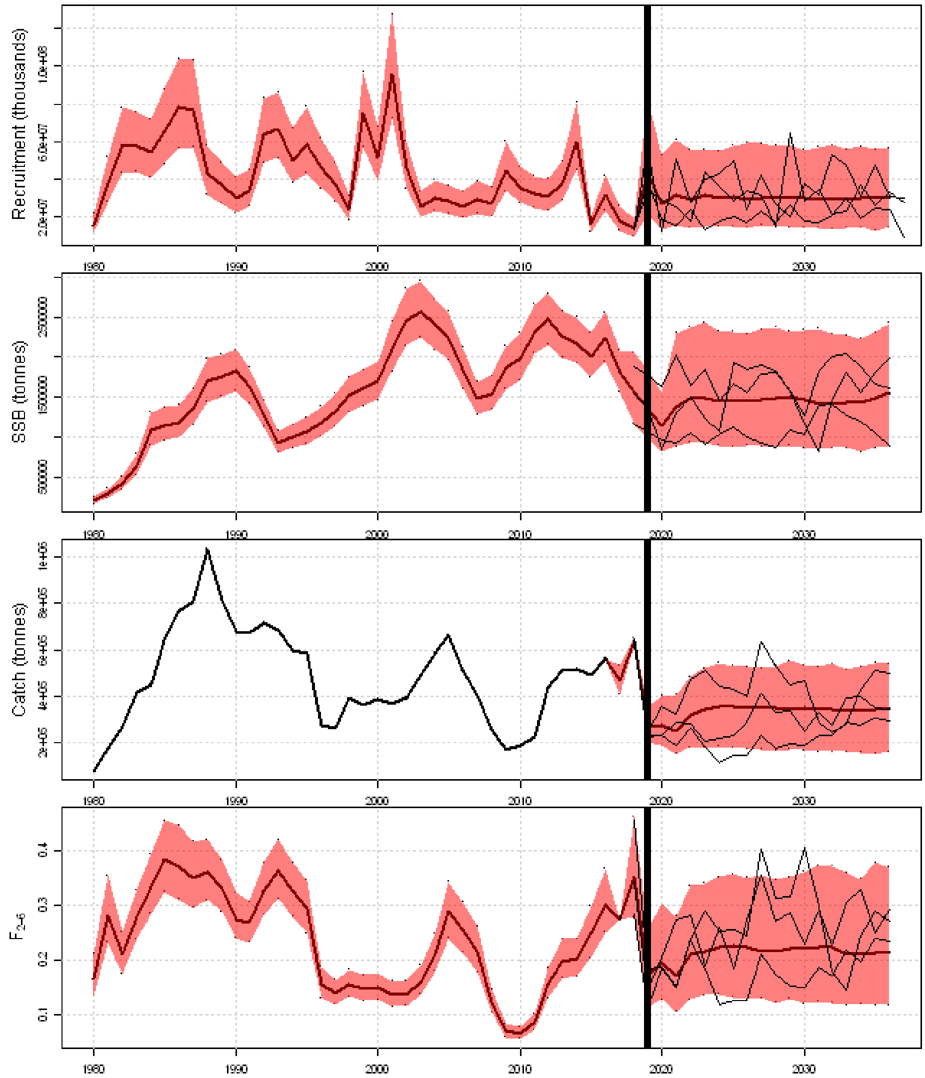

Figure 12 North Sea herring. Stock trends of the OM for the optimal management strategy A. Top panel shows recruitment, followed by SSB, catch, and finally the mean F on ages 2–6 (adult fishery). For illustration purposes, the individual lines show the values from three replicates.

All projections (excluding management strategy B + E) show that median SSB increases under optimal F_{target} levels to 1 400 000–1 500 000 t. In each of the management strategies evaluated, optimal $B_{trigger}$ is estimated around this level. This implies that in all cases, the applied F is often less than F_{target} since biomass is often below $B_{trigger}$.

The management strategy A + D (with TAC interannual variation cap on fleet A and B, and "banking and borrowing" applicable to fleets A and B), gave an optimal F_{target} value of 0.23 compared to F_{MSY} = 0.26. Both used the same SSB reference point (MSY $B_{trigger}$ and $B_{trigger}$) of 1 400 000 t. This option gave an average B-fleet TAC of 17 365 tonnes.

The optimal F_{target} values are somewhat smaller than the F_{MSY} reference points as estimated by ICES (2018c). One clear reason is that the realized catch from the stock is regularly higher than the TAC set for the North Sea, owing to several biological processes and managerial decisions in place. North Sea herring reside for part of their life in Division 3.a where they are caught by the C- and D-fleets. Furthermore, in the past decade, herring quota was transferred from Division 3.a to the North Sea, imposing additional mortality on North Sea herring. Both aspects are fully considered in the MSE, but were not so for the calculation of the present reference points.

In general, there is less than 0.2% difference in long-term yield between the requested scenarios, while all remain precautionary. HCR B + E gives markedly different outcomes: the variation in SSB is very high from the start and only slowly reduces towards the end of the simulations. The two scenarios using the present reference points (A* and A* + D) were not considered precautionary in the present evaluation (the probability of SSB< B_{lim} was greater than 5% in the long term).

Robustness of management strategies

Three sensitivity scenarios were undertaken.

A scenario for which F was set to zero was done to evaluate maximum stable biomass in the long term. This scenario is key to indicate how long it takes for the stock to stabilize in terms of SSB, and to investigate the long-term risk. Under a no-fishing regime, SSB increases rapidly after 2018 to around 2 700 000 t in the long term. At around 2024 it reaches this level and fluctuates around the dynamic equilibrium. The assumption made in this study that a 20-year projection period would suffice in the need to reach a dynamic equilibrium therefore seems valid.

Another scenario used an alternative implementation of how the C-fleet catches are calculated. In this scenario the C-fleet catch is calculated as 5.7% of the A-fleet TAC + 41% of the fixed WBSS catch, multiplied with the mixing rate of WBSS vs. NSAS to only account for the outtake of NSAS in Division 3.a. The results showed very little difference compared to the baseline approach. The benefit of the baseline is that it is no longer dependent on rules stipulated for Western Baltic spring-spawning herring and can therefore remain in place even if the advice procedure for WBSS changes.

The last scenario set the TAC of the bycatch fleets (B and D) at close to zero. When minimal catches in the B- and D-fleets are assumed to be taken under the optimized management strategy A + C (F_{target} of 0.22 and MSY $B_{trigger}$ of 1 400 000 t), the stock increases to above 1 500 000 t in the medium to long term. Substantially reducing catches from the B- and D-fleet (currently about 24 000 t) shows a reduction in the probability of SSB< B_{lim} and allows the A-fleet to catch more herring (about 15 000 t).

Caveats for all stocks

Mixed fisheries

Cod, haddock, whiting, and saithe are often caught together in mixed fisheries in the North Sea. The MSE has been conducted on a single species basis without considering any mixed fisheries interactions. Management strategies that are precautionary on a single species basis may only be precautionary if mixed fisheries are stopped as soon as the first species quota is exhausted (i.e. enforcement of the landing obligation), which would lead to a reduction in overall yield compared to that predicted in the MSE.

Multispecies effects and environmental considerations

Multispecies effects have only been indirectly taken into account for cod and saithe in robustness tests, through density-dependent cannibalism, and alternative natural mortality scenarios. Likewise, future environmental changes, e.g. due to possible climate change, have not been directly considered. Indirectly, environmental change has been taken into account by choosing appropriate historical periods of recruitment as the basis for future recruitment, and through robustness tests to alternative productivity/recruitment (whiting and cod). Any results are only valid under the assumptions about productivity made in the simulations.

Banking and borrowing

The optional possibility of banking quota to be used next year, or borrowing quota from next year to be used this year (known as “banking and borrowing”), has been implemented in a subset of the MSE runs. The approach taken for the demersal stocks has been to consider an extreme case of full banking in year *y* followed by full borrowing in year *y*+1, as this is likely to generate the maximum risk from “banking and borrowing” (see Figure 3 for the resulting zigzag pattern in F and catches). This is done to simulate a worst-case scenario for “banking and borrowing” (in terms of potential increase in the probability of SSB< B_{lim}), although this behaviour has not been observed historically. For herring, the maximum allowed banking was done in the first year, followed by borrowing from the second year onwards. An additional issue is that simulations with banking and borrowing also included the +25%/−20% limit on variation of TAC asked for in the request. The TAC variation limits are thought to increase stability in catches while the “banking and borrowing”, as implemented, should decrease stability. The request did not separate "banking and borrowing" from the TAC variation limits. ICES highlights that more active interaction/participation of the requester in the process would aid in deciding upon more realistic management assumptions to implement in the MSE.

ICES reference points and precautionary criteria

Using a target fishing mortality equal to the current value of $F_{MSY\text{-}upper}$ appeared to be non-precautionary (i.e. probability of SSB falling below B_{lim} > 5%) in all management strategies tested for this request (including the ICES MSY advice rule with the current MSY $B_{trigger}$ reference points). For whiting and herring, even the current reference point combination of F_{MSY} and MSY $B_{trigger}$ appears not to be precautionary under the assumptions of the new simulations. Full feedback management strategy evaluations were carried out to answer this request. This approach mimics the annual stock assessment and forecast procedures, while including realistic levels of uncertainty for each operating model, when testing the various management rules. In addition, some robustness testing was also carried out using alternative plausible operating models for each stock. This is a more complex modelling framework and makes different assumptions than the standard approach used by ICES to estimate MSY reference points (e.g. the equilibrium assumptions in EQSIM, ICES, 2015) and it is not surprising that there are some differences in the results between the two approaches. These differences do not undermine the appropriateness of existing MSY reference points which are appropriate to exploitation rates in the long term under equilibrium conditions to maximize yield, rather they highlight the differences to perception of risk when the stocks are not in equilibrium.

Implementation error

The recommendations for cod, whiting, and saithe do not consider additional uncertainty in annual catch beyond the "banking and borrowing" scheme (apart from the OM that considered an industrial bycatch variation for whiting). An example would be uncertainty in implementation of the landing obligation, phased in from 2015, which may result in annual catches being underestimated in the simulations.

Suggestions

Discontinuities in HCRs

Management strategy B has a discontinuity at B_{lim} (i.e. a sudden change in F) which is problematic when SSB is estimated to be very near B_{lim}. In simulations the rule is applied as specified, but in practice this could lead to arguments about to which side of the discontinuity the stock is, potentially leading to TACs that deviate from what was simulated. ICES therefore recommends that HCRs with discontinuities or sharp changes should be avoided.

Stability elements

The suspension of the application of stability elements below $B_{trigger}$ can have some unintended consequences. If the stock is recovering from below $B_{trigger}$, the 25% TAC change limit could lead to a loss in potential catch because of the restrictive 25% increase in TAC being applied to a low starting point. The increase in catch levels would lag behind the increase in stock size, particularly for stocks with large variation in recruitment. For stocks where this could be a problem, this might be accounted for in the HCR by adding a clause saying that the stability criterion should also be suspended in the first year after recovering above $B_{trigger}$. The consequences of this should be simulated to estimate the potential impact of such a rule given the assessment uncertainty. Such a clause is included in the HCRs for Northeast Arctic cod, haddock, and saithe.

Basis of the advice

Methods

The MSEs for cod, saithe, and whiting were conducted using the a4a MSE framework (https://github.com/flr/mse), as developed by the Joint Research Centre of the European Union (JRC). Although this framework has not been used for autumn-spawning herring, FLR (Kell *et al.* 2007), which forms the basis of the a4a MSE framework, has been used in this case.

Full feedback MSEs were conducted for all stocks (i.e. not using a "short-cut" approach to generate assessment error), as described in ICES (2013) and Punt *et al.* (2016). In this approach, the estimation model is exactly the same assessment model that ICES would use to conduct annual assessments (following the stock annex), having exactly the same model settings and the same type of data. It also incorporates the same assumptions used for conducting a short-term forecast through the intermediate year to the start of the TAC year. It was not possible to reproduce the forecast procedure exactly for whiting because the forecast is based on deterministic multi-fleet forecast software that was not possible to include in the management procedure, so the SAM stochastic forecast approach was used, taking the medians to represent the deterministic forecast.

The number of projection years and replicates to use in the MSE was explored for cod, and to a limited extent for autumn-spawning herring. A 20-year projection period was considered long enough that the effects of initial numbers had largely dissipated by the time the long-term phase had been reached (final 10 years) and median SSB had stabilized. This was adopted for all stocks considered. Current guidelines suggest 1000 replicates should be the default and that was considered adequate; this was adopted for all stocks considered. However, it appears that Risk3 (the appropriate measure for precaution following ICES guidelines) was both positively biased and relatively slow to converge. Given that bias in Risk3 is negatively correlated with the number of replicates, the use of Risk3 with 1000 replicates can be considered a conservative approach.

A key part of the MSE is the inclusion of uncertainty. This is introduced through the operating model (OM) by including parameter estimation error (using e.g. a variance–covariance matrix derived from fitting a model to data), process error (e.g. in recruitment and survival), observation error (when deriving monitoring data), and implementation error (e.g. introduced by the "banking and borrowing" scheme). Such uncertainty is included in a self-consistent manner within each iteration.

Uncertainty can also be introduced by defining alternative OMs, and from the fact that the estimation model in the MP does not have to be the same as the model on which the OM is conditioned. Base case OMs were defined for each stock as the primary focus of the evaluation. These were conditioned on the current ICES assessment. A number of alternative operating models were also used as robustness tests.

Recruitment was modelled by resampling residuals (with replacement) from a stock-recruit function (e.g. segmented regression), fitted to stock-recruit pairs from a selected period in the recent past. The presence of significant autocorrelation was investigated and, if significant, was included. A validation check was conducted in each case to ensure that recruitment generated in future is consistent with that estimated in the past.

More information can be found in the WKNSMSE report (ICES, 2019).

Sources and references

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Annex

Copied below is Annex VII of the "Agreed Record of fisheries consultations between Norway and European Union for 2018", signed in Bergen on 1 December 2017 (Anon., 2017).

ANNEX VII

INTER-ANNUAL QUOTA FLEXIBILITY

1. The Inter-annual quota flexibility scheme as described in this Annex is applicable for the quotas of herring, haddock, saithe, plaice and whiting established in this Agreed Record.

2. Each Party may transfer to the following year unutilised quantities of up to 10% of the quota allocated to it. The quantity transferred shall be in addition to the quota allocated to the Party concerned in the following year. This quantity cannot be transferred further to the quotas for subsequent years.

3. Each Party may authorise fishing by its vessels of up to 10% beyond the quota allocated. All quantities fished beyond the allocated quota for one year shall be deducted from the Party's quota allocated for the following year.

4. Complete catch statistics and quotas for the previous year should be made available to the other Party no later than 1 April in the format as set out below. The Delegations agreed that in order to ensure transparency in the operation of inter-annual quota flexibility, more detailed information on catch utilisation shall be exchanged.

5. The inter-annual quota flexibility scheme should be terminated if the stock is estimated to be under the precautionary biomass level (B_{pa}) and the fishing mortality is estimated to be above the precautionary mortality level (F_{pa}) the following year, or if the SSB is estimated to be below B_{pa} in two consecutive years.