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Report of the Ad hoc Group on Cod Recovery Management Plan (AGCREMP)

18–19 August 2008

Copenhagen, Denmark

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

EC (DG MARE) requested ICES to evaluate an EC proposal for cod recovery plans. The request was extended to include a proposed management plan by the Norwegian authorities. For practical reasons, the Ad hoc group could only address the North Sea cod stock.

We constructed models that applied the proposed EC and Norwegian Plans to simulated assessments of simulated stocks. This approach is widely applied to the evaluation of management plans, although technical details vary between applications.

Stock size trajectories, fishing mortality rates and yields were simulated for 2008–2025. The results for 2015 are considered most informative for evaluating the Plans because they are far enough into the future so that stock recovery is an achievable objective, but they are not so far into the future that simulated stock sizes are outside of the observed range. Several different scenarios were considered to address sources of uncertainty in assessments. In addition, the performance of the Plans was evaluated for a "standard" recruitment model that reflects the long-term relationship between spawning stock size and recruitment, and for a "low" recruitment model that reduces recruitment by 50%. The latter reflects the recent situation.

The simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models, are summarized as follows:

Recruitment Model	Prob(SSB>Blim) in 2015		Prob(SSB>Bpa) in 2015		Avg. Yield (tonnes) in 2015	
	EC	Norway	EC	Norway	EC	Norway
Standard	0.84	0.96	0.77	0.90	96.4	128.5
Low	0.61	0.81	0.54	0.66	76.1	88.9

The probabilities vary in both directions (i.e. both higher and lower) for the scenarios presented in Table 4.2.1. For the worst case scenarios, the probabilities of recovery above B_{lim} by 2015 are 0.42 and 0.56 for the EC and Norwegian Plans, respectively.

We also considered the performance of alternative versions of the EC and Norwegian Plans where constraints on the annual change in TAC were eliminated. The probabilities of recovery were almost unaffected, but the average yields in 2015 were much higher (see scenarios 13 and 26 of Table 4.2.1).

There is no advice on the suitability of the Plans in relation to the precautionary approach because generally agreed criteria are lacking for Recovery Plans. Future Plans should state their objective about the target date for recovery and the acceptable level of risk that recovery does not occur by that date.

1 Introduction

1.1 Participants

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1.2 ToR

The EC (DG MARE) requested ICES to evaluate an EC proposal for cod recovery plans. The request was extended to include the proposed management plan by the Norwegian authorities. In a discussion between DG MARE and ICES it was agreed that the answer to be delivered 12 September 2008 would deal with North Sea Cod only. The final Terms of Reference were agreed on 10th July 2008 as:

1) to evaluate objectives foreseen in the long-term management plan and to analyse if a fishing mortality rate of 0.4 will appear well defined for all cod stocks covered by such a plan.

   The objective of the cod plan is to exploit the stocks at MSY. ICES has previously advised that a fishing mortality in the range 0.2 to 0.4 is consistent with MSY for the North Sea cod stock. EC and Norway have agreed on F=0.4 as a target fishing mortality for the North Sea cod. The European Commission, in its proposal to Member States, has adopted this value also as a proxy for Fmsy for other cod stocks: in the Kattegat, the West of Scotland the Celtic Sea and the Irish Sea. The Commission would like ICES' advice as to whether alternative values would be better proxies for Fmsy for the stocks outside the North Sea, Skagerrak and VIId.

2) To analyse both the Commission proposal and the Norwegian lawful Authorities proposal in the light of objectives set out for such a long-term plan with the purpose to appreciate if they will be suitable for matching targets that will be suggested in therms of fishing mortality rates for all the cod stocks that will be covered by the Cod Recovery Plan.

   In particular, we would like to know the consequences of the plans in terms of:

   2.1) biological risks, in particular in relation to the ICES interpretation of the precautionary approach;

   2.2) yields, especially in the longer term;

   2.3) stability of catches.

3) To suggest any alternative proposal for methodologies which might appear more consistent in defining TACs in relation to cod stocks status.

This report will concentrate on ToR 2 and 3.

1.3 Approach

ICES evaluated the contents of the management plans by interpreting the texts (see Annex 2 and 3) and by simulating the potential results of the plans.

Management Strategy Evaluation (MSE) was done using the simulation tool FLR (Fisheries Library for R, http://www.flr-project.org, Kell *et al.*, 2007). This tool provides the required flexibility to address the specifics of the suggested alternative Harvest Control Rules (HCR) of the EC and Norway.

The MSE compares the behaviour of the EU-rule and Norway-rule under the default assumptions in the underlying model but also the robustness of the HCR to different types of misspecification of the underlying processes.

Thorough analysis of alternative HCRs was not feasible within the time frame that was available to conduct the evaluation. However, a few simulations were carried out with an HCR that has a perfect implementation (i.e. the calculated fishing mortality is directly applied to the underlying stock, without translating into a TAC) and with HCRs where the TAC constraint has been removed (see Annex 3 for a specification of the scenarios).

Simulations have been carried out for the period 2008–2025. However, the simulated trends beyond 2015 are highly uncertain because they depend on assumptions made for the stock-recruitment relationships which are very uncertain. Simulations with a low fishing mortality tend to generate large population sizes which are beyond the historical ranges that have been observed, which raises additional uncertainties, such as ecological constraints on stock size. Thus interpretation of the results is restricted to the period 2008–2015 for which the results are still in the observed domain. However, the results for 2025 are included in because they demonstrate interesting dynamics that may be induced by aspects of the Plans.

2 Interpreting the proposed management plans

Below, a summary of the two proposals is presented and the assumptions made for the evaluation are specified. Both proposals have been reviewed on the analysis for North Sea cod, other cod stocks as mentioned in the EU plan have not yet been taken into consideration.

For this evaluation, ICES defines F, SSB, etc. in the same fashion as these are used in the ICES assessment process. In comparing SSB to biomass reference points (Blim and Bpa), estimates of SSB refer to the beginning of the year.

2.1 EU recovery plan proposal

ART	TEXT	REMARKS/ASSUMPTIONS
6.1	Each year, the Council shall decide on the TAC for the following year for each of the depleted cod stocks. The TACs shall, based on the advice of STECF, satisfy all of the following conditions:	
a)	if the size of the stock in the year prior to the year of application of the TAC is below the minimum level established in Table 1, the fishing mortality rate shall be reduced by 25% in the year of application of the TAC as compared with the fishing mortality rate in the prior year	The minimum level in Table 1 is 70 000 t of SSB (which is equal to Blim)
b)	if the size of the stock in the year prior to the year of application of the TAC is below the precautionary level set out in Table 1 and above or equal to the minimum level established in Table 1, the fishing mortality rate shall be reduced by 15% in the year of application of the TAC as compared with the fishing mortality rate in the prior year; and	
c)	if the size of the stock in the year prior to the year of application of the TAC is above or equal to the precautionary level set out in Table 1, the fishing mortality rate shall be reduced by 10% in the year of application of the TAC as compared with the fishing mortality rate in the prior year.	The precautionary level in Table 1 is 150 000 t of SSB (which is equal to Bpa)
6.2	If the application of paragraph 1(b) and (c) would, based on the advice of STECF, result in a fishing mortality rate lower than 0,4 on age groups 2, 3 and 4, the Council shall set the TAC at a level resulting in a fishing mortality rate of 0,4 on those age groups.	ICES assumes that F on ages 2, 3 and 4 refers to the average F over ages 2–4.
6.3	When giving its advice in accordance with paragraphs 1 and 2, STECF shall assume that the stock is fished, in the year prior to the year of application of the TAC, with a reduction in fishing mortality equal to the reduction maximum allowable fishing effort that applies in that year.	In the first year, fishing mortality rate in the prior (intermediate) year is interpreted as F(prior year)*0.9. For the following years, ICES assumes that the intermediate year F equals the F for the preceding year times the reduction in F intended in setting the current TAC. This is consistent with 6.3 so long as effort is reduced proportionally to the intended total reduction in F.

Art	Text	Remarks/Assumptions
6.4	Notwithstanding paragraph 1(b) and (c) and paragraph 2, the Council shall not set the TAC at a level that is more than 15% below or above the TAC established in the previous year.	ICES interprets this clause as the overriding rule when the stock is above Blim.
6.5	The TAC shall be calculated by deducting the following quantities from the total removals of cod that are forecast by STECF as corresponding to the fishing mortality rates referred to in paragraphs 1 and 2	For this evaluation, ICES assumes the ratio between discards-at-age and landings-at-age to be constant. If the ratios of these mortalities change in future, for example as a consequence of significant reductions in discards, this will have to be re-evaluated.
a)	a quantity of fish equivalent to the expected discards of cod from the stock concerned,	For this evaluation, ICES assumes that discards will occur in future as in the recent past (average proportion by age over the last 3 years)
b)	as appropriate a quantity corresponding to other relevant sources of cod mortality to be fixed on the basis of a proposal from the Commission.	ICES assumes that other sources of cod mortality (e.g. misreporting, additional natural mortality) occur in future as in the recent past
6a	Procedure for setting TACs in data poor conditions.	ICES did not consider cases with data poor conditions

2.2 Norwegian management plan proposal

The Norwegian HCR (Harvest Control Rule) does not specify how to calculate the fishing mortality in the intermediate year. ICES has made the same assumption as in the evaluation of the EC plan: In the first year, fishing mortality rate in the intermediate year is interpreted as 0.64*0.9=0.58. For the following years, ICES assumes that the intermediate year F equals the F for the preceding year times the reduction in F intended in setting the current TAC.

Art	Text	Remarks/Assumptions
	The plan covers an initial recovery phase and a long-term management phase and shall consist of the following elements:	ICES assumes that the recovery phase is described by paragraphs 1–3, the long-term phase is under paragraph 4–8, although paragraph 9 and 10 apply to both phases
1	The fishing mortality (F2–4) will be reduced to a level no higher than 0.4 by reducing the F by 25% in 2009 and by 15% in consecutive years. The reduction is from the intended F and not the estimated realized value.	The paragraph is not quite clear because the intended F(2–4) for 2008 is not fully specified. ICES assumes that for the intermediate year 2008, the F(2–4) is 0.58, and the intended F's are as follows; F 2009 = 0.44 F 2010 = 0.37 F 2011 = 0.31 F 2012 = 0.27 F 2013 = 0.23, etc.

Art	Text	Remarks/Assumptions
2	The recovery phase does not take into account biomass reference points, and will be replaced by the long-term management plan on 1 January the first year the management plan implies a higher TAC than the recovery plan.	
3	Every effort shall be made to maintain a minimum level of Spawning Stock Biomass (SSB) greater than Blim, (70 000 t).	For ICES evaluation purposes, this para is covered by points 5–7.
4	Where the SSB at the beginning of the "intermediate" year, i.e. one year before the application of the rule, is estimated to be above Bpa (150 000 t), the parties agreed to restrict their fishing on the basis of a TAC consistent with a fishing mortality rate that maximizes long-term yield. The parties agreed to use F=0.4 on appropriate age groups.	By default for North Sea cod ICES uses ages 2–4 as the appropriate age groups. Choosing other age groups would require a revision of reference points.
5	Where the rule in paragraph 4 would lead to a TAC which deviates by more than 15% from the TAC for the preceding year, the Parties shall fix a TAC that is neither more than 15% greater nor 15% less than the TAC of the preceding year.	The 15% constraint only applies when the SSB is above Bpa.
6	Where the SSB referred to in paragraph 4 is estimated to be below Bpa but above Blim the TAC shall not exceed a level which will result in a fishing mortality rate equal to 0.4–0.3*(Bpa-SSB)/(Bpa-Blim). This consideration overrides paragraph 5.	
7	Where the SSB referred to in paragraph 4 is estimated to be below Blim the TAC shall be set at a level corresponding to a total fishing mortality rate of no more than 0.1. This consideration overrides paragraph 5.	
8	The Parties may where considered appropriate reduce the TAC by more than 15% compared to the TAC of the preceding year	ICES did not evaluate the possibility of TAC reductions larger than 15%
9	This plan shall be subject to triennial review, the first of which will take place before 1 January 2012, including appropriate adaptations to the target mortality rate specified in paragraph 2 and to any scientifically agreed revisions of Blim and Bpa.	
10	The TAC shall be calculated by deducting the following quantities from the total removals of cod that are forecast by ICES as corresponding to the fishing mortality rates consistent with the management plan:	
a)	a quantity of fish equivalent to the expected discards of cod from the stock concerned;	Same as EC text under 6.5 a
b)	a quantity corresponding to other relevant sources of cod mortality.	Same as EC text under 6.5 b

2.3 Comparison of the two proposals

ICES evaluated the contents of the management plans by interpreting the texts (Annexes 1 and 2) and by simulating the potential results of the plans. The main differences between the two management plans can be summarized as follows:

	NORWEGIAN PROPOSAL	EC PROPOSAL
15% TAC constraint	When the stock is above Bpa	When the stock is above Blim
Recovery phase	Target fishing mortality is the only constraint.	Only one phase
Long-term phase	This phase starts when the TAC following from the recovery phase is lower than the TAC following the long-term criteria. Once the long-term phase is applied, it continues to apply.	Starts immediately
F targets when the Plan is initiated	Pre-specified targets, defined as % reductions from the 2008 assessment outcomes	Specifies reductions relative to the most recent assessment
F targets if stock size declines while in the long-term phase	If stock size is below Bpa, the plan specifies reductions in F below 0.4	F is maintained at or above 0.4 during the long-term phase. If the stock falls below Flim it is considered in need of recovery again, but reductions in F below 0.4 are not specified.

2.4 A worked example for 2008

As a simple case study, the ICES advice for the 2009 quota year was regenerated assuming that the proposed management plan revisions had been in place.

The following are based on the forecasts produced by the WG in May 2008, which all assume a) a reduction in fishing mortality of 10% between 2007 and 2008, and b) that total removals = landings + discards (no unaccounted removals). The split between landings and discards in the forecasts is generated by applying the ratios of landings to discards at each age that were observed in 2007. Recruitment is resampled from the 1997–2006 year classes.

On this basis, SSB at the start of 2008 ("the year prior to the application of the TAC") was 49 941 tonnes, while the corresponding mean F(2–4) was 0.58.

EC plan

Estimated SSB in 2008 was less than Blim (70 000 tonnes), so paragraph 1a of article 6 applies: the mean fishing mortality over ages 2–4 in 2009 needs to be 25% less than the mean fishing mortality in 2008. Paragraph 2 does not apply.

Mean F(2–4) in 2008 was 0.58. Applying the 25% reduction gives an intended mean F(2–4) in 2009 of 0.435. Given the above assumptions, this results in forecast landings for 2009 of 36 409 tonnes (from Table 14.14d in the WGNSSK 2008 report).

Paragraph 4 says "notwithstanding paragraph 1(b) and 1(c) and paragraph 2", there should be a ±15% TAC constraint. However, SSB(2008) <Blim, so the advice should be based on paragraph 1(a). As a result, the TAC constraint does not apply in this case, and that the proposed TAC for 2009 is 36 409 tonnes: this represents an increase of 43.3% on the 2008 TAC (25 400 tonnes).

In addition to this, regarding effort: Article 8a, paragraph 3a implies a cut in 25% in effort (corresponding to the cut in fishing mortality).

Norwegian plan

The recovery phase (paragraph 1) states that F should be reduced by 25% in 2009. A 25% reduction gives a mean F(2–4) in 2009 of 0.435. Given the above assumptions, this results in forecast landings for 2009 of 36 409 tonnes (from Table 14.14d in the WGNSSK 2008 report). As this is the separate recovery phase, the TAC constraint (±15%) does not apply.

The management plan phase (paragraphs 3–8) states that the TAC should be set to correspond to a mean F(2–4) of 0.1 (total removals). There is no such option given in the ICES advice, but interpolating implies a TAC in 2009 of 8818 tonnes. This would override the TAC constraint because SSB(2008) <Blim.

Paragraph 2 states that the management plan phase will kick after in the first year that the management plan TAC is higher than the recovery-plan TAC. As this is clearly not yet the case, we must conclude that the recovery phase TAC is what would be used- i.e. 36 409 tonnes. This is the same figure that is generated when using the EC's proposed revised recovery plan.

3 Material and methods

3.1 Data and methods

The Management Strategy Evaluation (MSE) for North Sea cod uses the FLR open source software framework (Fisheries Library for R, http://www.flr-project.org, Kell *et al*., 2007). The MSE comprises three elements:

- the Operating Model (OM),
- the Observation-Error Model (OEM) and
- the Management Procedure (MP).

Software, inputs and outputs of the simulations are stored on the ICES SharePoint server at: http://groupnet.ices.dk/AGCREMP2008/FLR/Forms/AllItems.aspx

A key part of setting up an MSE is conditioning of the operating model (i.e. parameterizing it based on available data). The population estimates ($N_{y,a}$ and $F_{y,a}$), data (tuning indices $U_{s,y,a}$ for each survey *s*, catch-at-age $C_{y,a}$) and population parameters (mean weight-at-age $w_{y,a}$, natural mortality M_a, maturity-at-age m_a) are based upon the ICES estimates (ICES-WGNSSK 2008). With this information, it was possible to parameterize the operating models under a variety of hypotheses using FLR.

3.2 Simulation design

Operating model

- bias in M or bias in Catch
- stock recruitment: Ricker curve: Two options

Observation error model

- One of three
  - adjusted catches, constant M (Catch)
  - unadjusted catches, constant M (WG assumption)
  - unadjusted catches, annually varying M (M)

Management procedure

- Uses XSA as the assessment method
- One of four management rules
  - EC Rule
  - Norway rule
  - Norway rule with direct implementation of F (“perfect knowledge”)
  - EC rule or Norway rule without TAC constraint (not for all options)

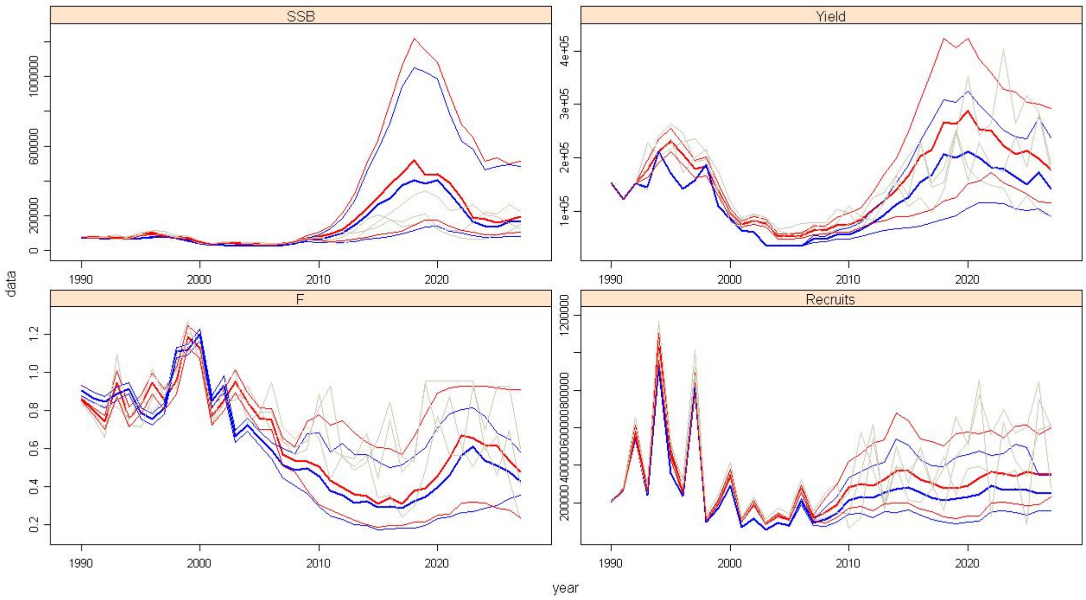
More details can be found in Annex 2.

4 Results

4.1 Display of results

Management Strategy Evaluations (MSE) are notoriously difficult to summarize and graphically display the results to different audiences. Traditionally, MSE involve multiple scenarios and each scenario takes a fixed number of iterations (in this evaluation: 250 iterations).

One often used way of summarizing information is to present a plot like below which have the median and interquartile ranges for the assessed stock and for the HCR for a number of variables of interest. In this case, we have also plotted a number of individual iterations.



One of the key challenges appears to be to balance the overall picture that results from the simulations as medians and interquartile ranges with the variability of the individual runs. In the real world, obviously there will only be one realization of the system, which is likely to be closer to the individual simulations than to the smoothed trends from the median plots.

A second issue is to assess the plausibility of the overall levels that are generated from the simulations. AGLTA (ICES 2005) already highlighted that some MSE tended to generate populations levels that have not been experienced over the period for which assessments have been carried out. For example, median SSB values in the forward simulations sometimes reach over 1 million tonnes of North Sea cod. From the known biology and exploitation of North Sea cod it is reasonably well known that a lower exploitation rate than observer for the last 40 years would give a high probability of increasing stock size. The recruitments that are generated in the simulations do appear to be within the range of previously observed values. So the combination of an appropriate recruitment level and a low fishing mortality could lead to the simulated increases in stock size. On the other hand, there are no checks and balances within the model with regards to density-dependent growth rates and available food resources. It is well known that high abundances could lead to cannibalism and possibly also to lower growth rates.

We presented result by plotting the F and SSB from individual simulations. These are the two variables that are used to determine the status of a stock. The plot can be divided into four quadrants according reference levels of F and SSB:

SSB below reference level F above reference level	SSB above reference level F above reference level
SSB below reference level F below reference level	SSB above reference level F below reference level

In general, the upper left quadrant represents a zone that should be avoided or where action corrective action is needed (i.e. a recovery plan). The lower left quadrant represents the desired situation which fisheries management generally aims to achieve. The other two quadrants represent transition zones. For the upper right quadrant, the fishing mortality is too high, and the SSB can be expected to transition to the left. For the lower left quadrant, fishing mortality is below the reference level and SSB can be expected to recover (transitioning to the right). The degree of caution reflected in the plot depends on the choice of reference levels. For example, it is more cautious to describe the lower right quadrant as a desirable zone if precautionary reference levels are used instead of limit reference levels.

Since a large number of simulation results (hundreds or thousands of points) can be displayed on a single quadrant plot, the plots provide a “rich” visualization of range of outcomes that might result from the management plan being evaluated. However, each quadrant plot is for a specific point in time. A series of plots over time can be used to display the temporal development of the fishery, or a trajectory of the median outcome from a management plan evaluation can also be plotted on a single phase plot.

The group used quadrant plots to display the distribution of simulated outcomes in 2015 for the management plans being evaluated and each operating model. The median trajectory during the simulation period is also plotted, and the number of outcomes in each quadrant is enumerated.

4.2 Interpretation of variables

- All values given in the output Table 4.2.1 are means (not medians) over 250 iterations. Although this makes sense for the P (probability) stats, it could be an issue for other stats (especially avg(Y)) because of the skewed distributions.
- avg(Y) is landings yield (i.e. catch minus discards). Total catch could be calculated but has not been done during the WG.
- avg(F) is actually not the traditional instantaneous fishing mortality. It is a harvest rate (HR): biomass caught divided by stock biomass. A comparison of HR and fishing mortality (Fbar) for case 14 (as an example) shows:

	mean		median	
	h.	fbar	h.	fbar
2008	0.33	0.58	0.33	0.58
2010	0.27	0.49	0.24	0.41
2012	0.19	0.32	0.16	0.24

2015 0.12 0.17 0.09 0.13

4.3 MSE results

Results of simulations are presented in Figures 4.2.1–4.2.2 and Table 4.2.1. Time trends and pseudo confidence intervals are presented in Annex 3.

Both the EC and the Norway rules resulted in a larger than 50% probability of rebuilding cod SSB above B_{pa} in 2015 under the assumption of historic recruitment levels (also referred to as the standard recruitment) with unreported catches taken into account in the assessment process (Table 4.2.1, scenarios 1 and 14, referred to as the base cases).

For the base case scenarios, the probabilities of SSB and F in 2015 to be in the target domain (F<0.4, SSB>B_{pa}) are 76% for the EC rule and 88% for the Norwegian rule (see Figure 4.2.1). Under the assumption that recruitment levels at each biomass level are reduced to 50% of the historic levels (also referred to as low recruitment, Table 4.2.1: scenarios 7 and 20), these probabilities are 52% and 62% respectively (see Figure 4.2.2). The differences between the EC and Norway rules in the simulations are small. The Norwegian rule is slightly more robust to biases in the catch and leads to higher probabilities to be above B_{lim} or B_{pa} in these scenarios. However, the EC rule leads to slightly higher probabilities when unknown changes in natural mortality are assumed. Therefore, the simulations do not provide a basis for selecting either of the rules.

The probability of a recovery depends on the assumed dynamics underlying the simulation and Table 4.2.1 presents some scenarios for the population dynamics. For both HCRs, 1/3 of scenarios resulted in a stock recovering above B_{lim} in 2015 with a 95% probability.

Changes in natural mortality generate different probabilities for recovery compared to a bias in catch. Under certain combinations of assumptions of bias in the catch data, natural mortality rates and assessment models, rebuilding has a low probability of occurrence by 2015. These are the scenarios with the assumption of low recruitment and an uncorrected bias in natural mortality (Table 4.2.1, scenarios 10, 12, 23, 25).

Constraints on interannual TAC changes could induce unintended consequences. Instead of stabilizing TACs, they could induce long-term fluctuations because the change in TAC does not match the change in stock abundance. The potential for growth of the North Sea cod stock at low fishing mortality rates is greater than 15%. The 15% constraint on TAC change during stock recovery therefore results in a strong reduction in fishing mortality to very low levels as rebuilding outstrips the increase in quota. Table 4.2.1 illustrates that the low mortality rates are maintained until at least 2015 with realized average fishing mortality well below the target of 0.4 throughout the simulation. The low fishing mortality rate could result in increased rates of discards unless effort is strongly reduced or cod avoidance measures are introduced. In addition, a TAC constraint could also promote a collapse of the stock towards B_{lim} if the decline in the stock is faster than 15% per year. Without TAC constraints the fluctuations in the cod SSB and fishing mortality rates are still induced by the management system, but to a lesser extent.

Exploration using a "perfect implementation" was carried out to check the performance of the HCRs when the intended fishing mortality could be directly implemented. These scenarios do not include the calculation of a short-term forecast or a TAC, but instead directly implement the intended fishing mortality. These types of simulations can more easily be compared with other HCR evaluations that have been carried out by ICES, where no feedback loop has been assumed. The results indicate a stabilized F and yield (results are presented in the *Ad-hoc* Group report (ICES, 2008a)). Therefore, it was concluded that the observed oscillations in stock dynamics that are characteristic of the full-feedback simulations are to an important extent driven by the time-lag that is inherent in the assessment, forecasting and implementation processes.

5 Discussion

The modelling approach used for this evaluation is based on state-of-the-are methodology for MSE worldwide. The model includes a dynamic feedback between the operating model, the observation-error model and the management procedure. The assessment process was dynamically included in the management procedure.

Several sources of uncertainty have been included in the modelling (e.g. bias in natural mortality or catch, different recruitment regimes, ...). The conclusions on the MSE are given for different assumptions on the operating model and observation-error model. This is similar to the ICCAT approaches to MSE.

A number of processes have not been included in the modelling:

- non-stationarity in biological parameters,
- density-dependent effects on growth and maturity.

Perceived catches can be influenced by two processes: bias and simple observation noise. The MSE implemented here considers the bias part in detail, as covered in the scenarios described in Section 3.3. The catch observation noise is neglected. Neglecting catch observation noise is consistent with the assessment procedure applied, and usually justified by the fact that the catch observation noise is often small compared to the observation noise on survey indices. For North Sea cod a large fraction (approximately 50% in 2007) of the total catch is estimated discards, where the observation noise is much larger than for the reported landings. The consequences of this is not investigated, but inclusion of realistic observation noise would presumably lead to more uncertainty in the simulated quantities (e.g. SSB, F(2–4)).

The evaluation used XSA as the assessment tool in the management procedure whereas the assessment that is used in the ICES WGNSSK is BAdapt. It is unclear what type of impact this would have on the results obtained from the MSE.

Multispecies effects

The MSE used for the evaluations is a strict singlespecies approach without estimating predation mortalities neither inside the assessment- nor in the operational model. Although bias in M was considered and M varies statistically in time, especially systematic changes in natural mortality over time are not taken into account. An increasing cannibalism with increasing cod SSB was not considered. This may be one reason why potentially unrealistic high cod SSBs (SSB values up to 1 million tones) were calculated by the MSE in long-term projections. Natural mortalities at high SSBs were most likely underestimated. Evaluations of the Study Group on Multi Species Assessment in the North Sea (SGMSNS; ICES 2003) on the EU recovery plan implemented in 2004 ((EC) No 423/2004) came to the result that the recovery rates are much lower when taking multi species effects into account (SSB of 250 thousand tones after eight years) compared to single species evaluations assuming constant natural mortalities (SSB of 800 thousand tones after eight years). Next to the already mentioned systematic increase in cannibalism rates predation from other predators also potentially prolongs a recovery. For instance, grey gurnard is discussed to exert high mortality rates on 0-group cod in the current North Sea foodweb (Floeter *et al.*, 2005).

In addition, multi species effects on other stocks (especially prey stocks for cod) can be expected. In the evaluations of the SGMSNS it became obvious that a recovery of cod will cost productivity in prey stocks. For instance, the whiting stock is currently in bad shape (ICES 2007) and increasing predation mortalities on this stock as a consequence of a recovering cod stock will increase the probability of a total collapse. Such considerations are important aspects of an ecosystem approach to fisheries management. However, multi species evaluations in the North Sea have to be based on stomach content data from 1991. Therefore, the value of multispecies evaluations of HCR can be questioned by dint of high structural uncertainties caused by such old data (Kempf *et al*., 2006). The current status of the North Sea foodweb has to be determined by new stomach samples, before such evaluations inside an ecosystem approach to fisheries management can be achieved.

Spatial aspects and fleet behaviour

One of the basic assumptions of the cod recovery plans discussed in this report (and of their evaluations) is that cod are evenly spread throughout the North Sea. This implies that they are equally available to the fisheries which are trying to catch them. A further assumption is that the behaviour of those fisheries, in terms of targeting or (potentially) discarding cod, remains constant through time.

Both of these assumptions are incorrect. Cod are not distributed evenly, but are to be found in patches concentrated on suitable habitat or spawning grounds. Vessels fishing in these areas are likely to experience higher catch rates than would be expected for the North Sea on average. If stock abundance in these cod concentrations rises faster than the quota for the vessels concerned, they will most probably start to discard. In this situation the assumption of constant discarding rates will be violated.

It could be argued that vessels encountering higher cod catch rates should simply move away and fish elsewhere and real time closure schemes such as those implemented in Scotland are an attempt to encourage this. However, to remain viable, fishing vessels need to catch something that is marketable and profitable. If cod are intermingled with other target species (haddock or monkfish, for example), it may become difficult to fish profitably without catching cod.

The key problem with management of a fishery like the North Sea is that it is very difficult to determine combinations of effort and quota allowances that are appropriate for every vessel, every area and every species. The current system does not try to do this, but rather sets effort and quota allowances that are suitable for the average vessel fishing in an average area. It is inevitable that certain vessels will find cod aggregations in the areas where they are fishing, and will find it difficult to avoid catching them. The management evaluations presented in this report do not incorporate this aspect of the system. This needs to be borne in mind when considering the impact of any particular management approach on the stock and on the fisheries.

6 Conclusions

Both the EU and the Norway rules resulted in a larger than 50% probability of rebuilding cod SSB above Bpa in 2015 under the assumption of historic recruitment levels (also referred to as the standard recruitment) with unreported catches taken into account in the assessment process (Table 4.2.1, scenarios 1 and 14, referred to as the base cases).

For the base case scenarios, the probabilities of SSB and F in 2015 to be in the target domain (F<0.4, SSB>Bpa) are 76% for the EU rule and 88% for the Norwegian rule (see Figure 4.2.1). Under the assumption that recruitment levels at each biomass level are reduced to 50% of the historic levels (also referred to as low recruitment, Table 4.2.1: scenarios 7 and 20), these probabilities are 52% and 62% respectively (see Figure 4.2.2). The differences between the EU and Norway rules in the simulations are small. The Norway rule is slightly more robust to biases in the catch and leads to higher probabilities to be above Blim or Bpa in these scenarios. However, the EU rule leads to slightly higher probabilities when unknown changes in natural mortality are assumed. Therefore, the simulations do not provide a basis for selecting either of the rules.

The probability of a recovery depends on the assumed dynamics underlying the simulation and Table 4.2.1 presents some scenarios for the population dynamics. For both HCRs, 1/3 of scenarios resulted in a stock recovering above Blim in 2015 with a 95% probability.

Changes in natural mortality generate different probabilities for recovery compared to a bias in catch. Under certain combinations of assumptions of bias in the catch data, natural mortality rates and assessment models, rebuilding has a low probability of occurrence by 2015. These are the scenarios with the assumption of low recruitment and an uncorrected bias in natural mortality (Table 4.2.1, scenarios 10, 12, 23, 25).

Constraints on interannual TAC changes could induce unintended consequences. Instead of stabilizing TACs, they could induce long-term fluctuations because the change in TAC does not match the change in stock abundance. The potential for growth of the North Sea cod stock at low fishing mortality rates is greater than 15%. The 15% constraint on TAC change during stock recovery therefore results in a strong reduction in fishing mortality to very low levels as rebuilding outstrips the increase in quota. Table 4.2.1 illustrates that the low mortality rates are maintained until at least 2015 with realized average fishing mortality well below the target of 0.4 throughout the simulation. The low fishing mortality rate could result in increased rates of discards unless effort is strongly reduced or cod avoidance measures are introduced. In addition, a TAC constraint could also promote a collapse of the stock towards Blim if the decline in the stock is faster than 15% per year. Without TAC constraints the fluctuations in the cod SSB and fishing mortality rates are still induced by the management system, but to a lesser extent.

Exploration using a "perfect implementation" was carried out to check the performance of the HCRs when the intended fishing mortality could be directly implemented. These scenarios do not include the calculation of a short-term forecast or a TAC, but instead directly implement the intended fishing mortality. These types of simulations can more easily be compared with other HCR evaluations that have been carried out by ICES, where no feedback loop has been assumed. The results indicate a stabilized F and yield (results are presented in the Ad hoc Group report). Therefore, we conclude that the observed oscillations in stock dynamics that are characteristic of the full-feedback simulations are to an important extent driven by the time-lag that is inherent in the assessment, forecasting and implementation processes.

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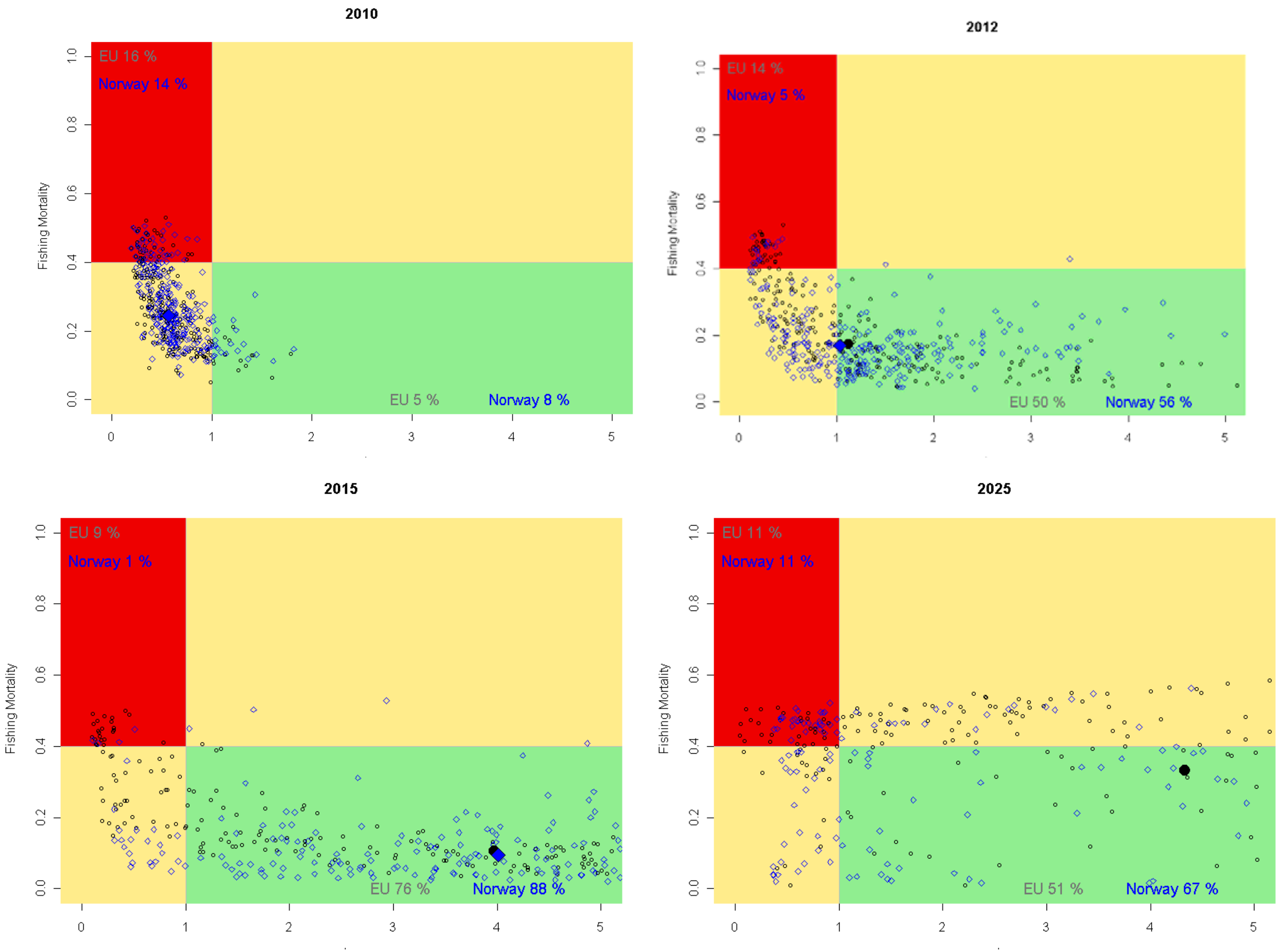

Figure 4.2.1 Phase-plot results for 2010, 2012, 2015 and 2025 of North Sea cod MSE assuming standard stock-recruitment relationship (scenarios 1 and 14). The small black circles indicate the individual iterations for the EC rule, the small blue diamonds the Norway rule. The big circle and diamond indicate the midpoints of the iterations for the EC rule and the Norway rule. The green square indicates SSB above B_{pa} and fishing mortality below target of 0.4; red square indicates SSB below B_{pa} and fishing mortality above target of 0.4. The percentages indicate the proportion of the iterations in the relevant square.

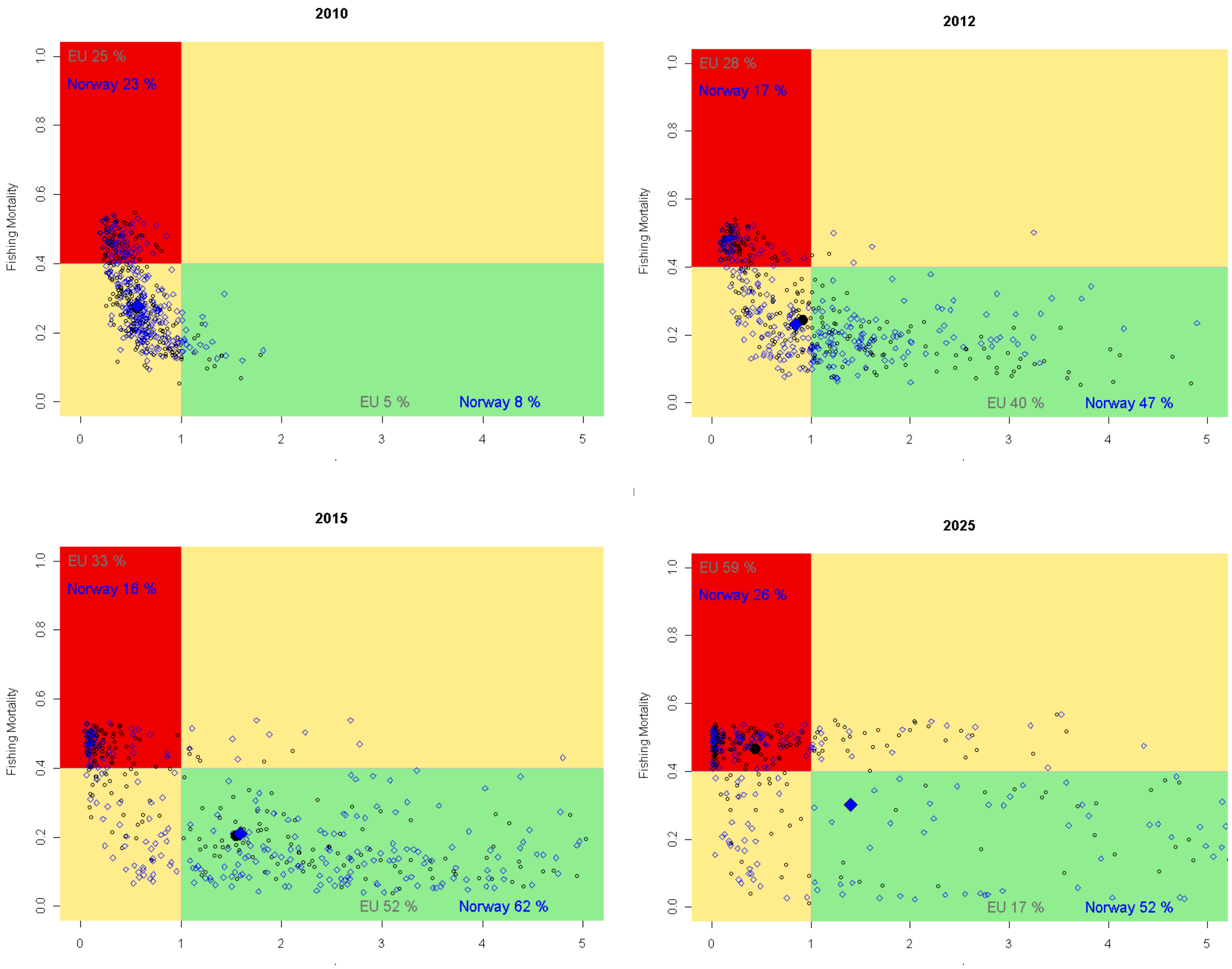

Figure 4.2.2 Phase-plot results for 2010, 2012, 2015 and 2025 of North Sea cod MSE assuming reduced stock-recruitment relationship (scenarios 7 and 20). The small black circles indicate the individual iterations for the EC rule, the small blue diamonds the Norway rule. The big circle and diamond indicate the midpoints of the iterations for the EC rule and the Norway rule. The green square indicates SSB above B_{pa} and fishing mortality below target of 0.4; red square indicates SSB below B_{pa} and fishing mortality above target of 0.4. The percentages indicate the proportion of the iterations in the relevant square.

Table 4.2.1 Summary results of North Sea cod MSE for 26 scenarios. The columns labelled HCR, SR, OM and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB above B_{lim} and B_{pa} in 2010, 2012 and 2015 and the average yield (Y, in '000 t.) and the average fishing mortality (F) in 2008, 2010, 2012 and 2015. The red scenarios indicate the base case where there is bias because of unreported catch but where the bias is taken into account in the assessment process.

Scen	HCR	SR	OM	OEM	TAC constr.	P(>Blim) 2010	P(>Blim) 2012	P(>Blim) 2015	P(>Bpa) 2010	P(>Bpa) 2012	P(>Bpa) 2015	Avg(Y) 2008	Avg(Y) 2010	Avg(Y) 2012	Avg(Y) 2015	Avg(F) 2008	Avg(F) 2010	Avg(F) 2012	Avg(F) 2015
1	EC	1.0	catch	catch	yes	0.63	0.73	0.84	0.05	0.50	0.77	50.3	53.8	68.2	96.4	0.33	0.27	0.22	0.15
2	EC	1.0	catch	m	yes	0.81	0.95	1.00	0.12	0.77	0.99	50.3	38.6	45.6	67.1	0.33	0.17	0.09	0.04
3	EC	1.0	catch	landing	yes	0.71	0.86	0.98	0.08	0.60	0.92	50.3	46.6	57.0	82.2	0.33	0.22	0.15	0.08
4	EC	1.0	m	catch	yes	0.48	0.62	0.71	0.04	0.28	0.56	37.2	40.3	49.9	66.3	0.24	0.23	0.21	0.20
5	EC	1.0	m	m	yes	0.66	0.83	0.96	0.05	0.46	0.88	37.2	28.7	32.8	47.2	0.24	0.14	0.10	0.06
6	EC	1.0	m	landing	yes	0.56	0.74	0.86	0.04	0.37	0.73	37.2	34.8	41.5	57.3	0.24	0.19	0.15	0.12
7	EC	0.5	catch	catch	yes	0.63	0.64	0.61	0.05	0.41	0.54	50.3	53.6	61.2	76.1	0.33	0.30	0.29	0.28
8	EC	0.5	catch	m	yes	0.80	0.92	0.97	0.12	0.68	0.92	50.3	38.6	44.0	62.6	0.33	0.19	0.13	0.09
9	EC	0.5	catch	landing	yes	0.71	0.78	0.82	0.08	0.52	0.74	50.3	46.5	53.4	71.9	0.33	0.25	0.21	0.17
10	EC	0.5	m	catch	yes	0.48	0.51	0.42	0.03	0.23	0.28	37.2	40.1	44.3	45.8	0.24	0.25	0.28	0.33
11	EC	0.5	m	m	yes	0.66	0.76	0.82	0.05	0.39	0.56	37.2	28.7	31.2	41.4	0.24	0.16	0.14	0.14
12	EC	0.5	m	landing	yes	0.56	0.65	0.60	0.04	0.29	0.42	37.2	34.8	38.3	45.6	0.24	0.21	0.21	0.23
13	EC	1.0	catch	catch	no	0.63	0.72	0.81	0.05	0.46	0.68	50.3	56.2	106.2	213.9	0.33	0.27	0.28	0.34
14	Norway	1.0	catch	catch	yes	0.74	0.83	0.96	0.08	0.57	0.90	50.3	58.8	81.7	128.5	0.33	0.27	0.19	0.12
15	Norway	1.0	catch	m	yes	0.74	0.87	0.98	0.08	0.64	0.96	50.3	49.0	58.6	92.9	0.33	0.23	0.13	0.07
16	Norway	1.0	catch	landing	yes	0.66	0.81	0.96	0.07	0.54	0.90	50.3	56.1	72.7	113.0	0.33	0.27	0.18	0.10
17	Norway	1.0	m	catch	yes	0.57	0.69	0.85	0.04	0.34	0.68	37.2	43.8	52.4	73.3	0.24	0.23	0.18	0.15
18	Norway	1.0	m	m	yes	0.58	0.73	0.90	0.04	0.40	0.79	37.2	36.7	39.4	55.6	0.24	0.20	0.13	0.09
19	Norway	1.0	m	landing	yes	0.52	0.68	0.86	0.04	0.35	0.68	37.2	41.9	46.9	63.6	0.24	0.23	0.17	0.13
20	Norway	0.5	catch	catch	yes	0.73	0.74	0.81	0.08	0.49	0.66	50.3	58.6	72.7	88.9	0.33	0.30	0.26	0.23
21	Norway	0.5	catch	m	yes	0.74	0.84	0.89	0.08	0.54	0.83	50.3	48.9	54.1	70.5	0.33	0.26	0.18	0.13
22	Norway	0.5	catch	landing	yes	0.66	0.71	0.80	0.07	0.48	0.67	50.3	55.8	65.7	80.6	0.33	0.30	0.25	0.21
23	Norway	0.5	m	catch	yes	0.57	0.60	0.56	0.04	0.26	0.33	37.2	43.7	46.4	45.8	0.24	0.25	0.25	0.26
24	Norway	0.5	m	m	yes	0.56	0.63	0.73	0.04	0.32	0.50	37.2	36.7	36.0	39.7	0.24	0.22	0.19	0.17
25	Norway	0.5	m	landing	yes	0.52	0.56	0.60	0.04	0.26	0.37	37.2	41.7	41.9	42.3	0.24	0.25	0.24	0.23
26	Norway	1.0	catch	catch	no	0.74	0.85	0.97	0.08	0.58	0.89	50.3	58.3	94.8	194.0	0.33	0.26	0.21	0.21

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule)

SR refers to the stock recruitment relationship (1.0=standard, 0.5=reduced).

OM refers to the assumption in the underlying operating model (catch=bias because of unreported catch, m=bias because of changes in natural mortality),

OEM refers to the Observation Error Model (landings=no correction for unreported catch, catch=correction for bias because of unreported catch, m=correction for bias because of change in m).

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Annex 2 Technical specification of North Sea Cod MSE

General

In this section we present the Management Strategy Evaluation (MSE) for North Sea cod as implemented in the FLR open source software framework (Fisheries Library for R, http://www.flr-project.org, Kell *et al*., 2007).

The three main elements of a MSE are the:

1) Operating Model (OM), that represents alternative plausible hypotheses about stock and fishery dynamics, allowing integration of a higher level of complexity and knowledge than is generally used within stock assessment models;

2) Observation-error Model (OEM) that describes how simulated fisheries data, or pseudo-data, are sampled from the Operating Model; and

3) the Management Procedure (MP) or management strategy which is the combination of the available pseudo-data, the stock assessment used to derive estimates of stock status and the management model or Harvest Control Rule (HCR) that generates the management outcomes, such as a target fishing mortality rate or Total Allowable Catch.

All terminology is based upon that of Rademeyer *et al*., 2007.

An important aspect of MSE is that the management outcomes from the HCR are fed back into the operating model so that their influence on the simulated stock and hence on the future simulated fisheries data are propagated through the stock dynamics (Figure 2.1).

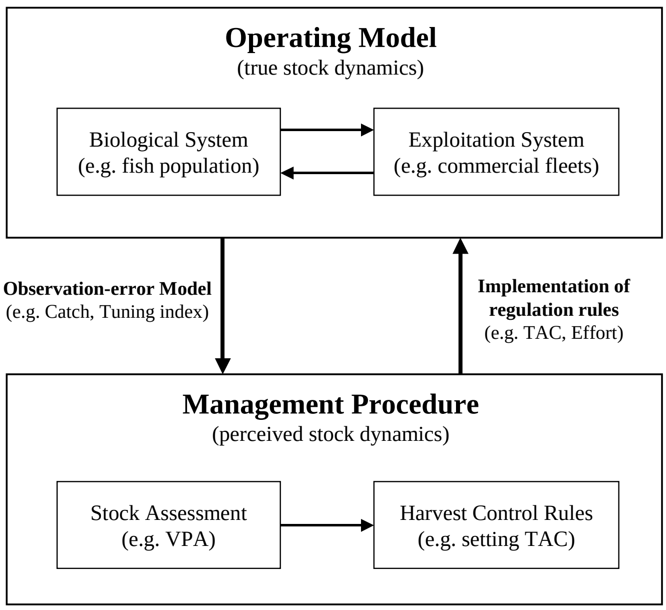


Figure 2.1 Conceptual framework for Management Strategy Evaluation.

The success of the MSE approach depends on the extent to which the true range of uncertainty can be identified and represented in operating models. Several authors (e.g. Rosenberg and Restrepo, 1994; Francis and Shotton, 1997; Kell *et al*., 2006) have attempted to identify and categorize the uncertainties that can hinder attempts to manage fisheries (and other natural resources) successfully. These uncertainties include the following:

- ***process error***–natural variation in dynamic processes such as recruitment, somatic growth, natural mortality, and the selectivity of the fishery;
- ***observation error***–related to collecting data from a system (e.g. age sampling, catches, surveys);
- ***estimation error***–related to estimating parameters, both in the operating model, and, if a model-based management procedure is used, in the assessment model within the management procedure that leads to the perception of current resource status;
- ***model error***–related to uncertainty about model structure (e.g. causal assumptions of the models), both in the operating model and in the management procedure; and
- ***implementation error***–because management actions are never implemented perfectly and may result in realized catches that differ from those intended.

The MSE for North Sea cod presented in this document attempts to account for each of these sources of error.

Operating model

Conditioning the Operating Model

A key part of setting up an MSE is conditioning of the operating model (i.e. parameterizing it based on available data). The population estimates ($N_{y,a}$ and $F_{y,a}$), data (tuning indices $U_{s,y,a}$ for each survey *s*, catch-at-age $C_{y,a}$) and population parameters (mean weight-at-age $w_{y,a}$, natural mortality M_a, maturity-at-age m_a) are based upon the ICES estimates (ICES-WGNSSK 2008). With this information, it was possible to parameterize the operating models under a variety of hypotheses using FLR.

The above approach bases the conditioning on the ICES estimates, where the operating model is not that dissimilar to the model used for the stock assessment. Whereas it is one of the simplest ways of constructing an operating model, it is a very useful initial approach because if management procedures do not perform well when reality is as simple as implied by the assessment model, then they are unlikely to do well under more realistic levels of uncertainty (De Oliveira *et al*., 2008). However, the construction of more complex and structurally different operating models (pursued here only to a limited extent, given time constraints) are important because they ensure that management procedures are able to deal with most hypotheses that have some credibility, either in the light of existing data for the resource, or from other sources of information.

A further justification for basing the operating model on the current ICES assessment is the importance of maintaining consistency between previous perceptions of stock status (and the advice that followed from those), and current perceptions (and hence advice that could flow). Such consistency helps maintain and enhance credibility with stakeholders (ICES-SGRAMA 2007). Furthermore, the objective of these evaluations is a limited reform of the present system (modifications to the harvest control rules), similar to the approach pursued by Kell *et al*., 2005, rather than a radical overhaul.

Bias scenarios

The North Sea cod assessment is based on B-adapt, a variation of ADAPT-VPA (Gavaris, 1988), developed specifically to handle the problem of misreported catch (ICES-WGNSSK 2008). B-Adapt corrects for retrospective bias by estimating the quantity of additional "unallocated removals" (through parameter b_y in Equation 3 below) that would be required to be added or removed from the catch-at-age data in order to remove any persistent trends in survey catchability.

Although such retrospective patterns are a common problem encountered by stock assessment working groups, determining what causes them, is not so easy. They can be caused by conflicting signals coming from commercial or survey indices, but also by changes in population characteristics that are assumed to be stable over time, such as selectivity, catchability, or natural mortality. Therefore "unallocated removals" could include components as a consequence of changes in natural mortality, discarding not included in the catch-at-age estimates, or misreported landings.

Because such bias is important in affecting the performance of a harvest control rule, particularly if it is also a function of trends in the data and if the stock assessment attempts to correct it, two alternative scenarios are considered in order to test the robustness of the harvest control rules.

Bias scenario 1: bias in $C_{y,a}$

The interpretation in bias scenario 1 is that the "unallocated removals" are either as a consequence of discarding not included in catch-at-age estimates, or to misreported landings, so that the catch-at-age data need to be adjusted. Model equations are given by:

$$N_{y,a} = \frac{C^*_{y,a}(F_{y,a} + M_a)}{F_{y,a}(1 - e^{-F_{y,a} - M_a})} \qquad 1$$

and

$$N_{y,a} = N_{y+1,a+1} e^{F_{y,a} + M_a} \qquad 2$$

where

$$C^*_{y,a} = b_y C_{y,a} \qquad 3$$

and

$$F_{y,A} = F_{y,A-1} = (F_{y,A-2} + F_{y,A-3} + F_{y,A-4})/3 \qquad 4$$

Equation 3 assumes that the "unallocated removals" has the same age composition as the combination of reported landings and estimated discards each year.

The estimable parameters for B-adapt are final year survivors $N_{Y+1,1},\dots,N_{Y+1,A-1}$ and bias parameters $b^{est}_{y_b},\dots,b^{est}_Y$, where

$$b_y = \begin{cases} 1 & , y < y_b \\ b^{est}_y & , y_b \le y \le Y \end{cases} \qquad 5$$

where Y is the final data year (2007; the first data year is 1963), y_b is the first year of the period when catch data are considered potentially subject to bias (1993), and A is the plus-group age (7 for North Sea cod; age-at-recruitment is 1). The objective function ($SSQ = SSQ_{sur} + SSQ_{b_y}$) has a component dealing with the fit to survey data:

$$SSQ_{sur} = \sum_s \sum_y \sum_a [\ln(U_{s,y,a}) - \ln(q_{s,a} N_{s,y,a})]^2 \qquad 6$$

where

$$N_{s,y,a} = \left[\frac{e^{-\alpha_s Z_{y,a}} - e^{-\beta_s Z_{y,a}}}{(\beta_s - \alpha_s) Z_{y,a}} \right] N_{y,a} \qquad 7$$

In Equation 7 (taken form Darby and Flatman 1994), $Z_{y,a} = F_{y,a} + M_a$ and α_s and β_s indicate the start and end of the period (expressed as fractions of the year) over which survey s operates. The objective function also has another component that constrains the b_y so that the bias-adjusted catch-at-age does not vary markedly from year to year (λ=0.5 is used):

$$SSQ_{b_y} = \lambda \sum_y [\ln(b_y \sum_a C_{y,a} w_{y,a}) - \ln(b_{y+1} \sum_a C_{y+1,a} w_{y+1,a})]^2 \qquad 8$$

The above B-adapt model fit thus provides $N_{y,a}$ and $F_{y,a}$ matrices, which together with mean weights-at-age $w_{y,a}$ (stock weights are assumed equal to catch weights), maturity-at-age m_a , and natural mortality-at-age M_a, describe the dynamics of North Sea cod for this scenario. These matrices and vectors are supplied to operating model and can be used to re-create $C^*_{y,a}$ (Equation 1) and to calculate SSB:

$$B^{ssb}_y = \sum_a w_{y,a} m_a N_{y,a} \qquad 9$$

and the data-pairs { B^{ssb}_{y-1}, $N_{y,1}$} used as a basis to construct a stock-recruit relationship for the operating model. The bias parameter b_y follows from Equation 3 (where $C_{y,a}$ is available from input files). [Note: the $N_{y,a}$ and $F_{y,a}$ matrices are actually 3-dimensional arrays, with the third dimension storing 1000 non-parametric bootstrap iterations (same as produced for ICES-WGNSSK 2008), reflecting estimation error.]

Bias scenario 2: change in M

The interpretation in bias scenario 2 is that the "unallocated removals" are as a consequence of changes in natural mortality, and that the catch-at-age data reflect true catches. Under this scenario,

$$N_{y,a} = \frac{C_{y,a}(F^*_{y,a} + M^*_{y,a})}{F^*_{y,a}(1 - e^{-F^*_{y,a} - M^*_{y,a}})} \qquad 10$$

where

$$F^*_{y,a} = F_{y,a} / b_y \qquad 11$$

and

$$M^*_{y,a} = M_a + F_{y,a}(1 - 1/b_y) \qquad 12$$

In Equations 10–12, $N_{y,a}$, $C_{y,a}$, $F_{y,a}$, M_a and b_y are all as for bias scenario 1. For this scenario, the matrices and vectors provided to the operating model are therefore $N_{y,a}$, $C_{y,a}$, $F^*_{y,a}$, $w_{y,a}$, m_a and $M^*_{y,a}$, from which B^{ssb}_y can be calculated (Equation 9), and a stock-recruit relationship constructed.

Stock-recruit scenarios

A Ricker stock-recruit relationship is fitted to the stock-recruit pairs {B^{ssb}_{y-1}, $N_{y,1}$}:

$$N_{y,1} = \alpha B^{ssb}_{y-1} e^{-\beta B^{ssb}_{y-1}} e^{\varepsilon^R_y} \qquad , \varepsilon^R_y \sim N[0; \sigma^2_R] \qquad 13$$

Properties of the deterministic part of this relationship is that it has a slope of α at the origin, and provides a maximum recruitment of $\alpha/(\beta e)$, which occurs when $B^{ssb}_{y-1} = 1/\beta$. One of the features of the B-adapt assessment of North Sea cod is that the geometric mean recruitment over the recent period (1998–2007) is less than half that of the full period (1963–2007), so that two future recruitment scenarios can be considered.

Stock-recruit scenario 1: Ricker full period

This scenario assumes that stock-recruit relationship over the full period is representative of the future, and therefore uses all available stock-recruit pairs to estimate the stock-recruit parameters α, β and σ_R in Equation 13. These parameters are estimated using the point estimates of the stock-recruit pairs from the B-adapt assessment (and not the stock-recruit pairs derived from the 1000 bootstrap simulations).

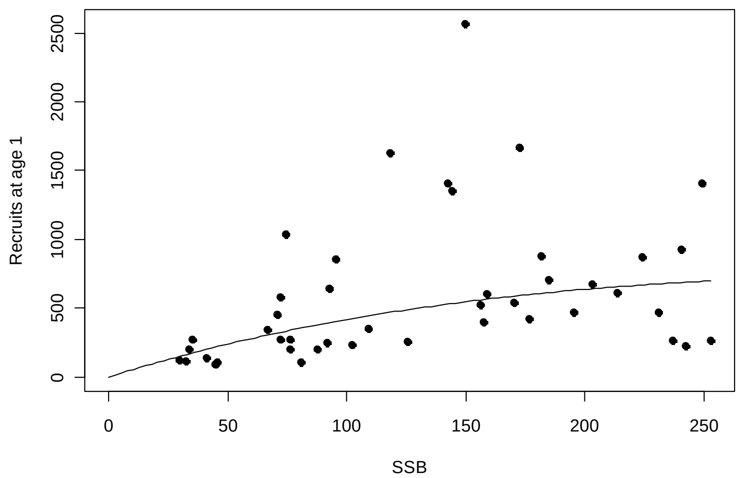


Figure 2.2 Stock recruit scenario 1: Ricker curve over the full period.

Stock-recruit scenario 2: Ricker recent period

This scenario assumes that there has been a shift in recruitment dynamics, and the recent recruitment level (1998–2007) is reflective of what can be expected in future. This scenario therefore replaces α with $\alpha^* = 0.5\alpha$, but keeps the same β and σ_R as for stock-recruit scenario 1.

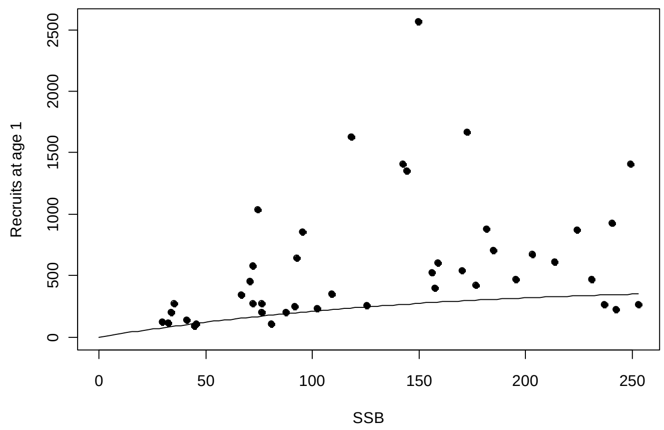


Figure 2.3 Stock recruit scenario 2: Ricker curve over the recent period (1998–2007).

Other quantities for operating model projections

For the operating model projection period, $w_{y,a}$ is replaced by w_a, the mean of $w_{y,a}$ for the last three data years (Y-2, Y-1, Y), and fishing mortality is modelled as the combination of a year and age (selectivity-at-age) effect, where selectivity-at-age is calculated as:

$$s_a = \frac{\frac{1}{3}\sum_{y=Y-2}^{Y} F_{y,a}}{\frac{1}{9}\sum_{a=2}^{4}\sum_{y=Y-2}^{Y} F_{y,a}} \qquad 14$$

so that for $y > Y$, fishing mortality-at-age is calculated as:

$$F_{y,a} = s_a \overline{F}_y \qquad 15$$

where $\overline{F}_y$ is effectively the mean fishing mortality over ages 2–4-this is the mean F that is of interest to management and forms the basis of the harvest control rules in the management procedure. Another quantity needed to allow the operating model to convert TACs supplied by the management procedure into catch (landings and discards) is a 3-year average of the ratio ϕ_a of landings to "allocated" catch (landings and discards), calculated as follows:

$$\phi_a = \frac{1}{3}\sum_{y=Y-2}^{Y} \frac{L_{y,a}}{L_{y,a} + D_{y,a}} \qquad 16$$

where $L_{y,a}$ and $D_{y,a}$ represent the landings and discards biomass-at-age respectively. More complicated models for w_a, s_a and ϕ_a are possible, but these were initially kept simple.

Apart from these, the operating model also requires the bias parameter b_y for bias scenario 1, reflecting "unallocated" removals, and annually varying natural mortality $M^*_{y,a}$, for bias scenario 2. These were generated for the projection period by randomly sampling (with replacement) years from the period y_b to Y and allocating the corresponding b_y and $M^*_{y,a}$ values from these years to the years in the projection period. This allows the b_y values relevant to bias scenario 1 to remain consistent with the $M^*_{y,a}$ values for bias scenario 2.

It is possible to include dynamic behaviour for the b_y parameter for the projection period, such as linking it to the mismatch between TAC and effort through an implementation error model, but initially this was not attempted.

Implementing the Operating Model

The operating model is the combination of the relevant bias and stock-recruit scenario. It can be categorized into a historic period where actual data are available, and a projection period.

Historic period (y ≤ Y)

For the historic period, the operating model takes the matrices and vectors supplied by the relevant bias scenario. [Note: estimation error is accounted for by including an additional dimension (not indicated in the notation that follows) storing bootstrap iterations.]

Projection period (y > Y)

Future dynamics of the North Sea cod stock use the historic period values as a starting point, and are subsequently governed by the following:

$$N_{y+1,a+1} = \begin{cases} N_{y,1} & , a = 1 \\ N_{y,a} e^{-F'_{y,a} - M'_{y,a}} & , 1 < a < A-1 \\ N_{y,A-1} e^{-F'_{y,A-1} - M'_{y,A-1}} + N_{y,A} e^{-F'_{y,A} - M'_{y,A}} & , a = A-1 \end{cases} \quad 17$$

where recruitment $N_{y,1}$ relies on the previous years' SSB, as given by the relevant recruitment scenario and Equations 9 and 13.

The calculation of quantities $F'_{y,a}$ and $M'_{y,a}$, and of the associated $C'_{y,a}$, rely on the relevant operating model bias scenario, and on the TAC output from the management procedure (for $y = Y+2$ onwards). Given the bias parameter b'_y and TAC_y forthcoming from the management procedure, it is possible to calculate $\bar{F}'_y$ by solving the following equation:

$$b'_y TAC_y = \sum_a \frac{s_a \bar{F}'_y}{s_a \bar{F}'_y + M'_{y,a}} \phi_a w_a N_{y,a} (1 - e^{-s_a \bar{F}'_y - M'_{y,a}}) \quad 18$$

where $F'_{y,a}$ follows from Equation 15, and where:

for bias scenario 1, $M'_{y,a} = M_a$ and $b'_y = b_y$; and

for bias scenario 2, $M'_{y,a} = M^*_{y,a}$ and $b'_y = 1$.

$C'_{y,a}$ can be derived from Equation 18 be replacing ϕ_a with 1 on the right-hand side, and $b'_y TAC_y$ with $C'_{y,a}$ on the left-hand side.

Because the management procedure does not supply a TAC in the first year of the projection ($y = Y+1$), a different approach is required for this year. Here, the same assumption is made as that adopted by the ICES Working Group that assesses North Sea cod (ICES-WGNSSK 2008) for their medium-term projections, namely that the fishing mortality in $Y+1$ is cut by 10% relative to Y, so that $\bar{F}'_{Y+1} = 0.9\bar{F}'_Y$, where $\bar{F}'_y$

is derived from $F_{Y,a}$ (bias scenario 1) or $F^*_{Y,a}$ (bias scenario 1). It is then possible to calculate $C'_{Y+1,a}$ using Equation 1, $M'_{Y+1,a}$, $\bar{F}'_{Y+1}$ and s_a (via Equation 15).

Observation error model

An observation error model is required for when pseudo-data are generated from the operating model for the purposes of the management procedure. The observation error model attempts to generate data that will have the same properties (in terms of error structure and bias) that actual data will have when the management procedure is implemented. It is also a useful device to allow investigation of the consequences of the violation of operating model assumptions (e.g. when natural mortality varies annually in the operating model, but the management procedure assumes it doesn't).

Survey observation-error scenarios

In the case of the tuning indices $U_{s,y,a}$, Equation 6 is used as the basis for the observation-error model by first calculating catchability-at-age $q_{s,a}$ and associated variability $\sigma_{s,a}$ for each survey s (with n_s number of years each):

$$q_{s,a} = \exp\left[\frac{1}{n_s}\sum_y (\ln U_{s,y,a} - \ln N_{s,y,a})\right] \qquad 19$$

and

$$\sigma^2_{s,a} = \frac{1}{n_s}\sum_y [\ln U_{s,y,a} - \ln(q_{s,a} N_{s,y,a})]^2 \qquad 20$$

Residuals are then calculated as follows:

$$\varepsilon_{s,y,a} = \frac{\ln U_{s,y,a} - \ln(q_{s,a} N_{s,y,a})}{\sigma_{s,a}} \qquad 21$$

These residuals are stored so as to be drawn a year at a time (after randomly selecting a year) when generating the pseudo-tuning index data. This procedure (randomly selecting a year then using all residuals for that year) ensures that within-year correlations among residuals are preserved. Because $\varepsilon_{s,y,a}$ accounts for scaling, it is no longer necessary to include $q_{s,a}$ when generating pseudo-tuning indices from the operating model.

All other data (as required by the management procedure) are taken from the operating model without error.

Survey observation-error scenario 1: no increase in variance

Pseudo-tuning indices are re-generated for the historic period by using the residuals appropriate to each year and survey, then generated for the projection period by sampling a year y^* at random (with replacement) from the n_s years of historic data available for survey s, and allocating residuals associated with that year (Equation 21) as follows (the *mp* subscript refers to pseudo-data for the management procedure):

$$U^{mp}_{y,s,a} = \begin{cases} N_{s,y,a} e^{\varepsilon_{s,y,a}\sigma_{s,a}} & , y \le Y \\ N_{s,y,a} e^{\varepsilon_{s,y^*,a}\sigma_{s,a}} & , y > Y \end{cases} \qquad 22$$

where Y is the final year of data.

Survey observation-error scenario 2: no trend in q, increase in variance

The same procedure is followed as for survey observation-error scenario 1, but an additional parameter is introduced for the projection period to account for an increase in variance:

$$U^{mp}_{y,s,a} = \begin{cases} N_{s,y,a} e^{\varepsilon_{s,y,a}\sigma_{s,a}} & , y \le Y \\ N_{s,y,a} e^{\varepsilon_{s,y*,a}\sqrt{1+\gamma}\,\sigma_{s,a}} & , y > Y \end{cases} \quad 23$$

where in addition γ is the factor by which variance has increased in the projection period (e.g. $\gamma = 0.25$ implies a 25% increase in variance).

Catch observation-error scenarios

The catch observation-error scenarios deal with which data on catch-at-age and M are available to the management procedure, regardless of what the underlying operating model scenarios are. Thus, it is possible that the true catch-at-age and M in the operating model are $C_{y,a}$ and $M^*_{y,a}$ (bias scenario 2), but the management procedure receives $C^{mp}_{y,a} = \hat{b}_y C_{y,a}$ and $M^{mp}_{y,a} = M_a$ (catch observation-error scenario 1), or alternatively the operating model quantities are $C^*_{y,a} = b_y C_{y,a}$ and M_a, but the management procedure receives $C^{mp}_{y,a} = C_{y,a}$ and $M^{mp}_{y,a} = \hat{M}^*_{y,a}$. The quantities $\hat{b}_y$ and $\hat{M}^*_{y,a}$ are the medians (over 1000 bootstrap iterations) of the corresponding operating model quantities b_y and $M^*_{y,a}$ respectively, which introduces error associated with estimating these quantities in the management procedure.

Catch observation-error scenario 1: adjusted catches, constant M

This scenario feeds catches adjusted for b_y to the management procedure, assuming M varies by age but is constant over time. This adjustment allows XSA to be used in the management procedure such that it effectively mimics the behaviour of B-adapt being fitted to unadjusted catches and estimating b_y. The data received by the management procedure is $C^{mp}_{y,a} = \hat{b}_y C_{y,a}$ and $M^{mp}_{y,a} = M_a$.

Catch observation-error scenario 2: unadjusted catches, constant M

This scenario ignores any adjustment to catches being fed to the management procedure, and assumes M varies by age, but is constant over time. This allows consideration of a management procedure that does not include an assessment model that adjusts for b_y. The data received by the management procedure is $C^{mp}_{y,a} = C_{y,a}$ and $M^{mp}_{y,a} = M_a$.

Catch observation-error scenario 3: unadjusted catches, annually varying M

This scenario also ignores any adjustment to catches fed to the management procedure, but assumes unaccounted for mortality is reflected in annually varying estimates of M. The data received by the management procedure is $C^{mp}_{y,a} = C_{y,a}$ and $M^{mp}_{y,a} = \hat{M}^*_{y,a}$.

Management procedure

The management procedure is model-based, and therefore consists of a stock assessment model being applied to pseudo-data from the observation-error model, a short-term forecast being carried out for two years after the final year of pseudo-data, and harvest control rules being applied to derive a TAC (Figure 2.1).

For the purposes of what follows, y is interpreted as the last year of pseudo-data, y+1 as the year during which the stock assessment is conducted (also called the intermediate year), and y+2 as the year for which a TAC is required (the TAC year). Furthermore, B_{lim} = 70 000 t and B_{pa} = 150 000 t.

The stock assessment

For the purposes of this work, XSA is used as the stock assessment model (see Table 1 for the settings used). However, catch observation-error scenario 1 mimics B-adapt behaviour by including catches that have been adjusted for the bias parameter b_y. The stock assessment provides a perception of stock status up to year y, which forms the basis for the application of harvest control rules.

Table 2.1 Settings used for the XSA assessment model in the management procedure. Settings remain unchanged throughout.

OPTION	VALUE
The convergence tolerance	1e-09
The maximum number of iterations allowed	30
The minimum value of SE permitted in estimate of N hat	0.3
The minimum value of SE permitted in estimate of N hat	0.5
set SE of F when shrinking to mean F	0
The oldest age for which the two parameter model is used for catchability-at-age	5
The age after which catchability is no longer estimated. q at older ages set to the value at this age	TRUE
shrinkage to mean N	TRUE
shrinkage to mean F	3
The number of years to be used for shrinkage to F for terminal year	3
The number of ages to be used for shrinkage to F for terminal age	100
The time window to consider in the model	100
The number of years to be used in the time-series	0
The power to be used in the time-series taper	FALSE
Assessment Method	Cohort Analysis

The short-term forecast

In order to set a TAC in year y+2, it is necessary to project population numbers provided by the stock assessment forward to years y+1 and y+2. This can be done by applying Equation 17 to the stock assessment outputs, but assumptions are required with regard to recruitments $N_{y+1,1}$ and $N_{y+2,1}$, selectivity-at-age s_a, mean fishing mortality in year y+1 $\overline{F}_{y+1}$ (with latter two combined as in Equation 15), and mean natural mortality-at-age $\overline{M}_a^{mp}$ (because it can vary annually depending on the catch observation-error scenario).

$N_{y+1,1}$ and $N_{y+2,1}$ are assumed to be the geometric mean of recruitment over the years 1998-y, while s_a is calculated using Equation 14, where $F_{y,a}$ is from the stock assessment, and the 3-year average is the final three years of the stock assessment (y-2, y-1 and y). Natural mortality $\overline{M}_a^{mp}$ is also taken as the average over the final three years of the stock assessment. For the intermediate year, $\overline{F}_{y+1} = \lambda_y \overline{F}_y$, where λ_y is a quantity that depends on the harvest control rule being used (reflecting the implied cut in effort, and therefore F, from year y to year y+1; see below), and $\overline{F}_y$ is from the final year of the stock assessment. In order to be consistent with the assumption made by ICES-WGNSSK (2008), a value of λ_Y = 0.9 is used to calculate $\overline{F}_{Y+1}$ in first year of the projection period (Y+1). All subsequent values of λ_y are calculated when the harvest control rule is applied each year.

The TAC calculation

For the purposes of calculating the TAC, management procedure equivalents of the quantities shown in Equation 18 are needed. This equation is now expressed as follows:

$$TAC_{y+2} = \frac{1}{\overline{b}^{mp}} \sum_a \frac{s_a \overline{F}_{y+2}}{s_a \overline{F}_{y+2} + \overline{M}_a^{mp}} \phi_a w_a N_{y+2,a} (1 - e^{-s_a \overline{F}_{y+2} - \overline{M}_a^{mp}}) \qquad 24$$

The quantities are supplied by the short-term forecast and associated assumptions ($N_{y+2,a}$, $\overline{M}_a^{mp}$ and s_a), or are taken from the operating model without error (ϕ_a, w_a). $\overline{F}_{y+2}$ is supplied by the harvest control rule. A value for the bias parameter $\overline{b}^{mp}$ is also required, but this depends on the catch observation-error scenario-for scenario 1 (mimicking B-adapt) it is set equal to the average (over y-2, y-1 and y) of $\hat{b}_y$, but for scenarios 2 and 3 it is set to 1.

The Harvest Control Rules

Two categories of harvest control rules are applied, one based on a proposal by the European Commission for amendments to the cod Recovery Plan (EC 2008; Appendix 1), and one based on a proposal by Norway (Appendix 2). These are interpreted below in the form of pseudo-code. [Note that the $\overline{F}$ values in the harvest control rules are relevant to a particular run of the stock assessment, and change each time the stock assessment is re-run (i.e. each year).]

The EC cod recovery proposal

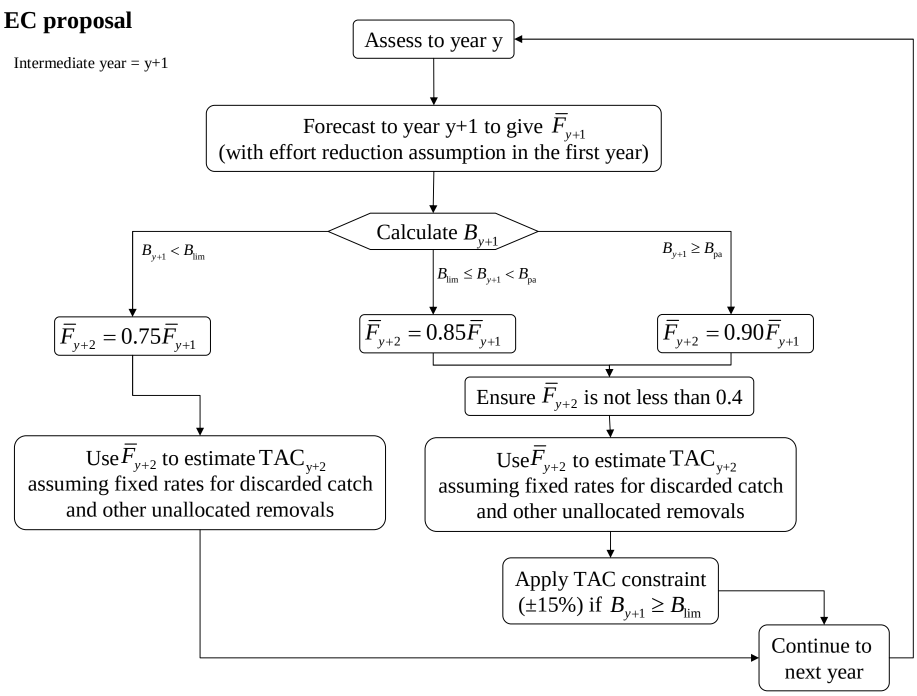


Figure 2.4 Diagram for the EU recovery proposal.

The pseudo-code for the EU proposed amendment (Article 6 of EC 2008; reproduced in Appendix 1) is as follows:

1) Calculate $\overline{F}_{y+1}$ and $\overline{F}_{y+2}$

$\overline{F}_{y+1} = \lambda_y \overline{F}_y$, where $\lambda_Y = 0.9$ the first time the harvest control rule is used (i.e. Y+1 for setting a TAC in Y+2), and is as calculated in step 3 for all subsequent years.

If $B^{ssb}_{y+1} < B_{lim}$

$\overline{F}_{y+2} = 0.75\overline{F}_{y+1}$

If $B_{lim} \leq B^{ssb}_{y+1} < B_{pa}$

$\overline{F}_{y+2} = \max\{0.85\overline{F}_{y+1}; 0.4\}$

If $B^{ssb}_{y+1} \geq B_{pa}$

$\overline{F}_{y+2} = \max\{0.9\overline{F}_{y+1}; 0.4\}$

2) Calculate TAC and apply TAC constraints only if $B^{ssb}_{y+1} \geq B_{lim}$

Calculate TAC_{y+2} using Equation 24 and $\overline{F}_{y+2}$ from step 1

If $B^{ssb}_{y+1} \geq B_{lim}$

If $TAC_{y+2} > 1.15 TAC_{y+1}$, set $TAC_{y+2} = 1.15 TAC_{y+1}$

If $TAC_{y+2} < 0.85 TAC_{y+1}$, set $TAC_{y+2} = 0.85 TAC_{y+1}$

3) Re-calculate $\overline{F}_{y+2}$, and calculate λ_{y+1}

Use TAC_{y+2} from step 2 and Equation 24 to re-calculate $\overline{F}_{y+2}$

Calculate λ_{y+1} as follows:

$$\lambda_{y+1} = \frac{\overline{F}_{y+2}}{\overline{F}_{y+1}}$$

In steps 1 and 3, $\overline{F}_y$ is the average $F_{y,a}$ over ages 2–4 from the final year of the stock assessment.

Steps 1 and 2 fulfil the requirements of Article 6, points 1, 2 and 4 of EC (2008). The quantity λ_{y+1} reflects the cut in effort from the intermediate year to the TAC year implied by the application of the harvest control rule steps 1 and 2, and once calculated (step 3) it is saved to be used the following year by the harvest control rule in order to fulfil the requirements of Article 6, point 3 of EC (2008). This assumes that effort is a constant multiple of fishing mortality. The inclusion of $\overline{b}^{mp}$ and ϕ_a in the calculation of TAC_y (Equation 24) fulfils the requirements of Article 6, point 5 of EC (2008).

The Norwegian cod recovery proposal

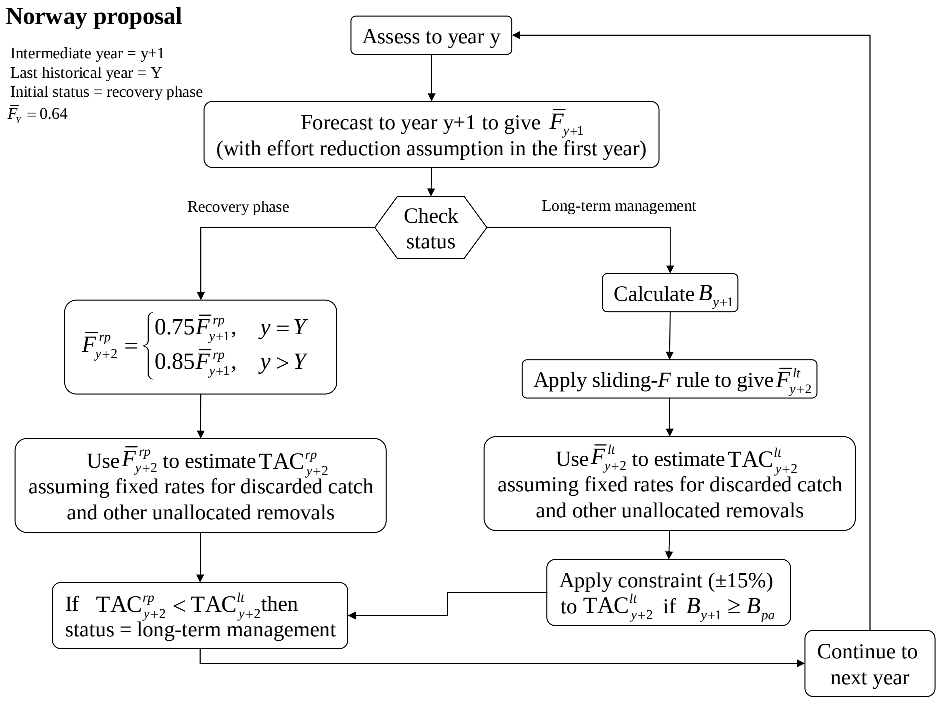


Figure 2.5 Diagram for the Norwegian recovery proposal.

The pseudo-code for the Norwegian proposal (reproduced in Appendix 2) is as follows:

a) Check Management Procedure Status

If MP^{status} = “recovery phase”, proceed to b

If MP^{status} = “long-term phase”, proceed to c

[For year Y+2 (the first year the harvest control rule is applied), MP^{status} = “recovery phase”.]

b) Recovery Phase (RP)

i) Calculate $\bar{F}^{RP}_{y+2}$

$$\bar{F}^{RP}_{y+2} = \rho_{y+2}\bar{F}^{RP}_{y+1}$$

$$\text{where } \rho_y = \begin{cases} 0.9 & , y = Y+1 \\ 0.75 & , y = Y+2 \\ 0.85 & , y > Y+2 \end{cases}$$

and $\bar{F}^{RP}_{Y+1} = \rho_{Y+1}\bar{F}^{RP}_{Y}$, $\bar{F}^{RP}_{Y} = \bar{F}^{WG}_{2007} = 0.64$ (ICES-WGNSSK 2008)

[Here, $\bar{F}^{RP}_{y+2}$ is the intended target F, initially based on ICES-WGNSSK (2008), and is not influenced by the subsequent stock assessment estimates of F, or by the short-term forecast assumptions regarding the intermediate year F. Once calculated, $\bar{F}^{RP}_{y+2}$ is saved to be used the following year by the harvest control rule.]

ii) Calculate RP TAC

Calculate TAC_{y+2}^{RP} using Equation 24, setting $\overline{F}_{y+2} = \overline{F}_{y+2}^{RP}$ from step b.1

iii) Proceed to c

c) Long-term Phase (LP)

Calculate $\overline{F}_{y+2}^{LP}$

If $B_{y+1}^{ssb} < B_{lim}$

$$\overline{F}_{y+2}^{LP} = 0.1$$

If $B_{lim} \leq B_{y+1}^{ssb} < B_{pa}$

$$\overline{F}_{y+2}^{LP} = 0.4 - 0.3\left(\frac{B_{pa} - B_{y+1}^{ssb}}{B_{pa} - B_{\text{lim}}}\right)$$

If $B_{y+1}^{ssb} \geq B_{pa}$

$$\overline{F}_{y+2}^{LP} = 0.4$$

Calculate LP TAC and apply TAC constraints only if $B_{y+1}^{ssb} \geq B_{pa}$

Calculate TAC_{y+2}^{LP} using Equation 24, setting $\overline{F}_{y+2} = \overline{F}_{y+2}^{LP}$ from step c.i

If $B_{y+1}^{ssb} \geq B_{pa}$

If $TAC_{y+2}^{LP} > 1.15TAC_{y+1}$, set $TAC_{y+2}^{LP} = 1.15TAC_{y+1}$

If $TAC_{y+2}^{LP} < 0.85TAC_{y+1}$, set $TAC_{y+2}^{LP} = 0.85TAC_{y+1}$

Calculate final TAC, re-calculate $\overline{F}_{y+2}$, and calculate λ_{y+2}

If MP^{status} = "recovery phase"

If $TAC_{y+2}^{LP} > TAC_{y+2}^{RP}$, set MP^{status} = long-term phase"

If $TAC_{y+2}^{LP} \leq TAC_{y+2}^{RP}$, set $TAC_{y+2} = TAC_{y+2}^{RP}$

If MP^{status} = "long-term phase"

Set $TAC_{y+2} = TAC_{y+2}^{LP}$

Use above TAC_{y+2} and Equation 24 to re-calculate $\overline{F}_{y+2}$

Calculate λ_{y+1} using

$$\lambda_{y+1} = \frac{\overline{F}_{y+2}}{\overline{F}_{y+1}}$$

[Here, $\overline{F}_{y+1} = \lambda_y \overline{F}_y$, where $\overline{F}_y$ is the average $F_{y,a}$ over ages 2–4 from the final year of the stock assessment. As for the EC proposal, $\lambda_Y = 0.9$ the first time the harvest control rule is used (i.e. Y+1 for setting a TAC in Y+2), and is as calculated in this step above for all subsequent years. Furthermore, MP^{status} and λ_{y+1} are saved to be used the following year by the harvest control rule.]

The rationale for calculating λ_{y+1} is to have a means to deal with the intermediate year F calculation, and is the same rationale as adopted for the EC proposal described above.

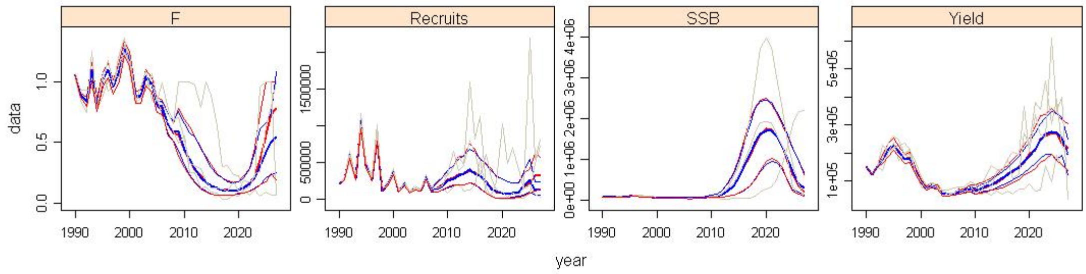
With regard to the text of the Norwegian proposal (Appendix 2), it is not possible to translate points 3 and 8 into pseudo-code without more concrete details being provided. Step b deals with point 1, whereas steps a and c.iii deal with point 2, the transition from the "recovery" phase to the "long-term" phase. Once this transition is made, then the harvest control rule remains in the "long-term" phase. Step c.i deals with points 4, 6 and 7, while step c.ii deals with point 5. Point 10 is treated in the same way as Article 6, point 5 of the EC proposal (inclusion of $\bar{b}^{mp}$ and ϕ_a in Equation 24). Point 9 deals with a triennial review, and is not within the scope of this study.

Annex 3 Detailed simulations outputs for North Sea cod MSE

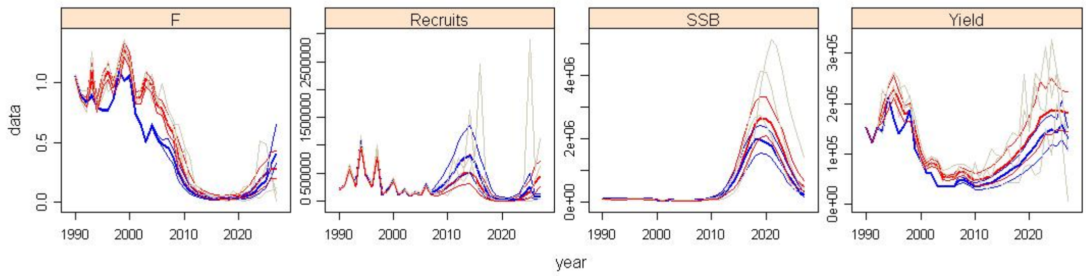
These figures were generated as the basis for the initial advice as released 12–09–2008.

NB: For all the figures, red lines indicate the true stock trends distributions and the blue lines indicate the perceived distributions.

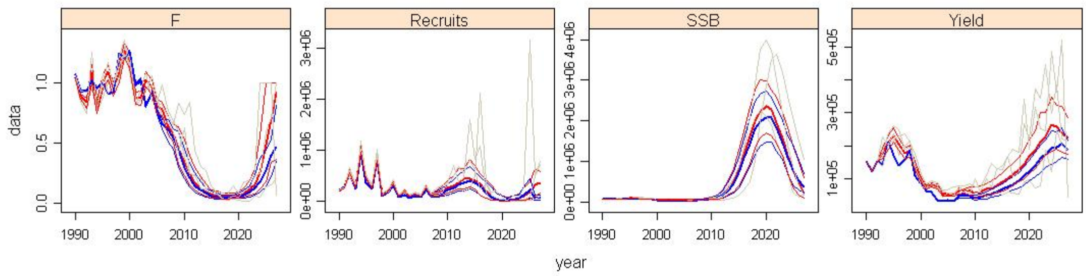
Scen=1, HCR=EU, SR=1.0, OM=catch, OEM=catch, TAC constraint=yes.



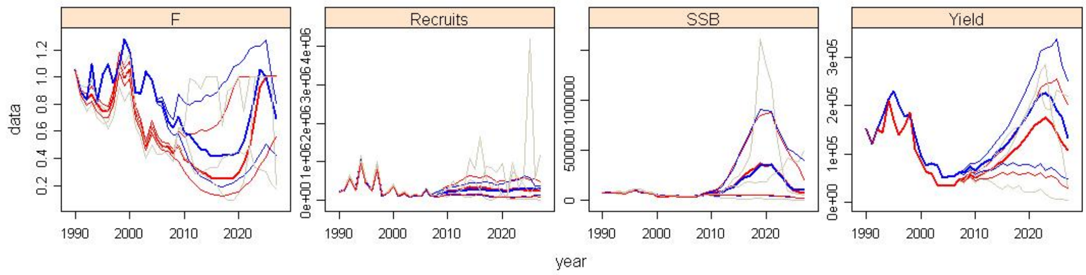
Scen=2, HCR=EU, SR=1.0, OM=catch, OEM=m, TAC constraint=yes.



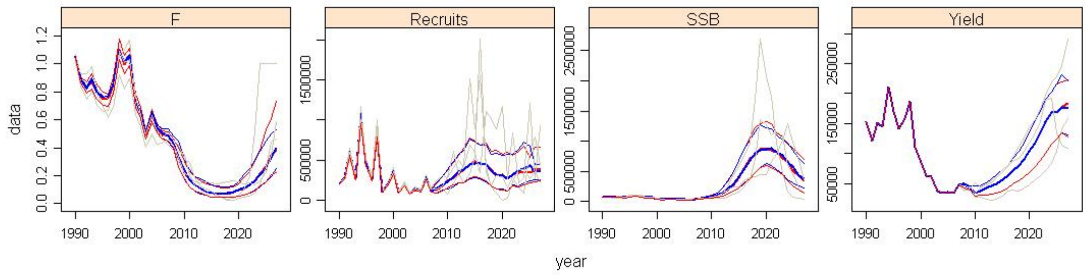
Scen=3, HCR=EU, SR=1.0, OM=catch, OEM=landing, TAC constraint=yes.



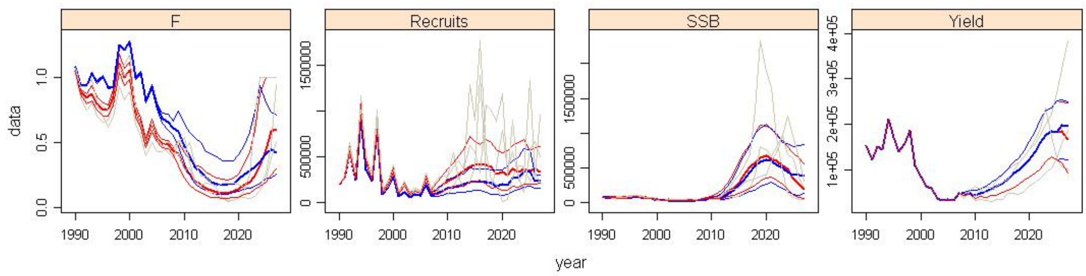
Scen=4, HCR=EU, SR=1.0, OM=m, OEM=catch, TAC constraint=yes.



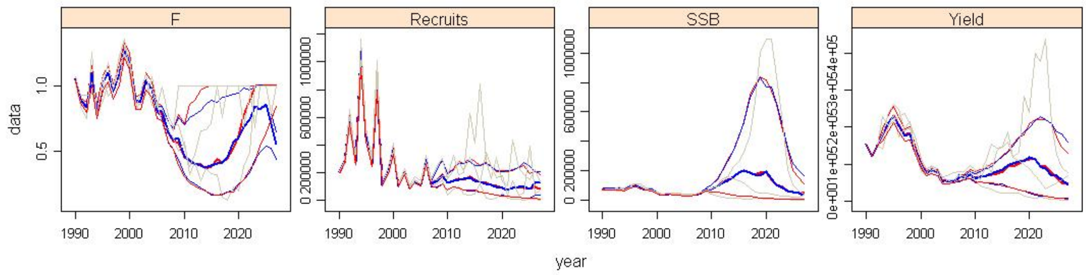
Scen=5, HCR=EU, SR=1.0, OM=m, OEM=m, TAC constraint=yes.



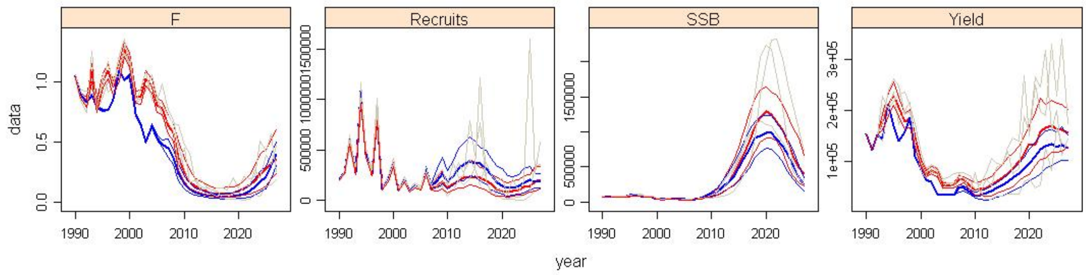
Scen=6, HCR=EU, SR=1.0, OM=m, OEM=landing, TAC constraint=yes.



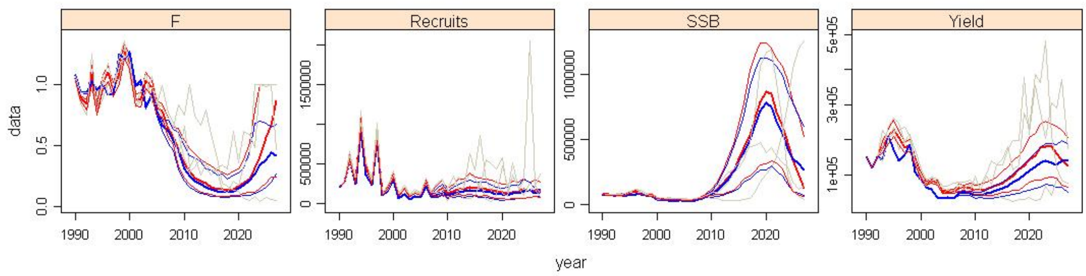
Scen=7, HCR=EU, SR=0.5, OM=catch, OEM=catch, TAC constraint=yes.



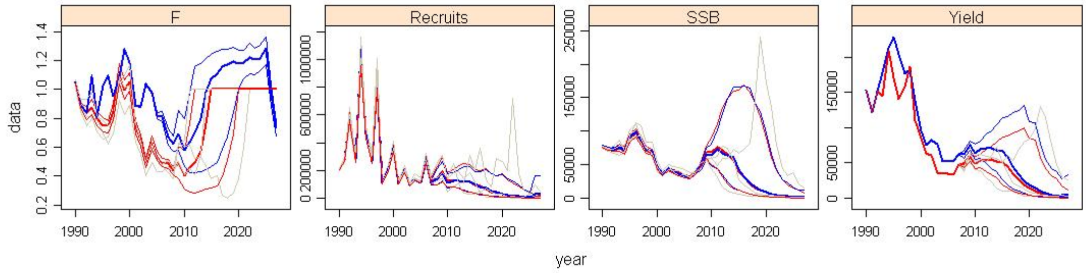
Scen=8, HCR=EU, SR=0.5, OM=catch, OEM=m, TAC constraint=yes.



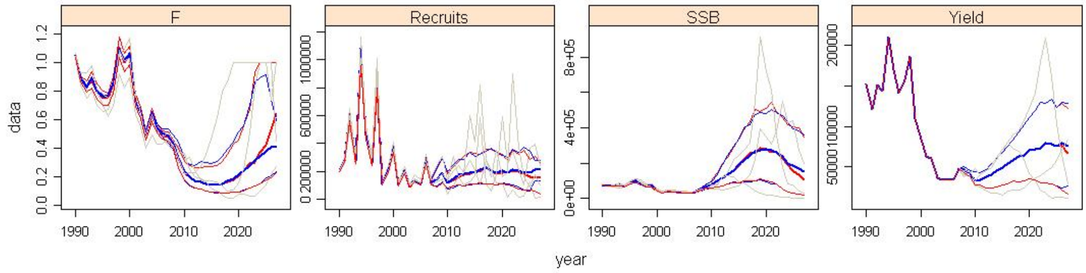
Scen=9, HCR=EU, SR=0.5, OM=catch, OEM=landing, TAC constraint=yes.



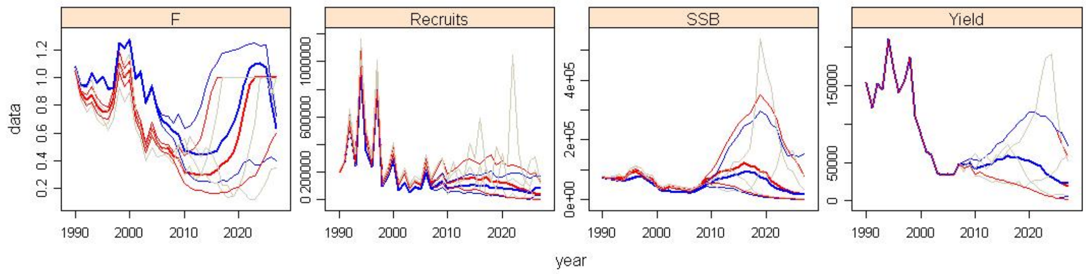
Scen=10, HCR=EU, SR=0.5, OM=m, OEM=catch, TAC constraint=yes.



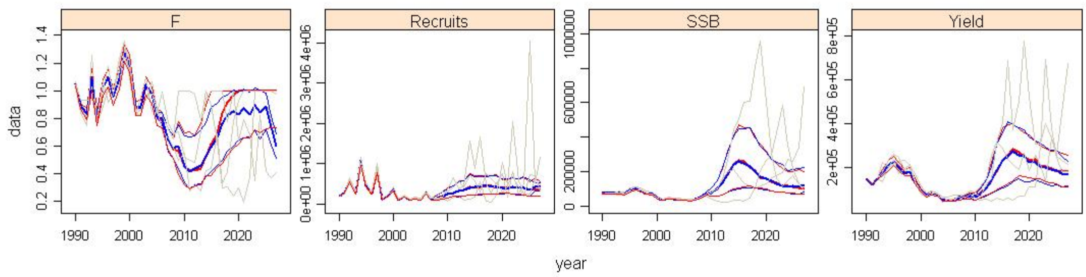
Scen=11, HCR=EU, SR=0.5, OM=m, OEM=m, TAC constraint=yes.



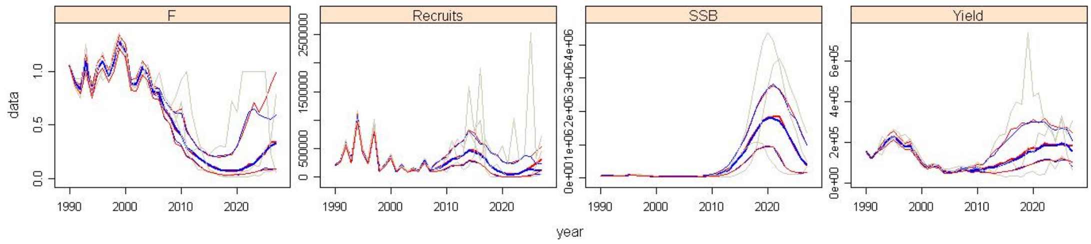
Scen=12, HCR=EU, SR=0.5, OM=m, OEM=landing, TAC constraint=yes.



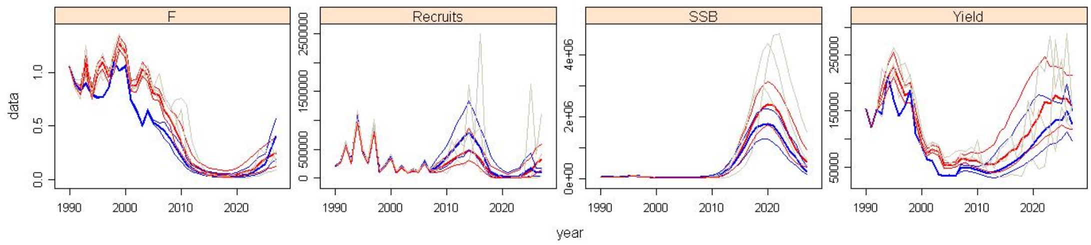
Scen=13, HCR=EU, SR=1.0, OM=catch, OEM=catch, TAC constraint=no.



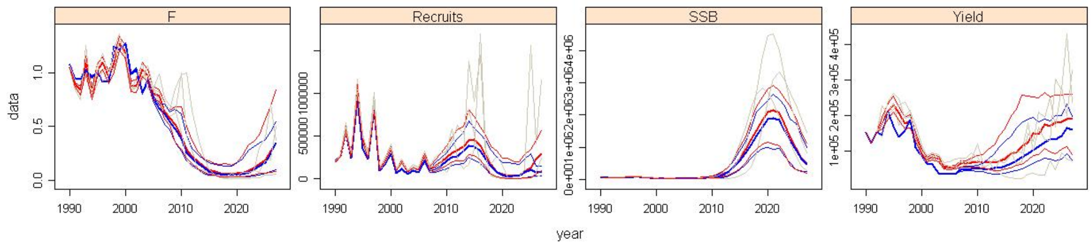
Scen=14, HCR=Norway, SR=1.0, OM=catch, OEM=catch, TAC constraint=yes.



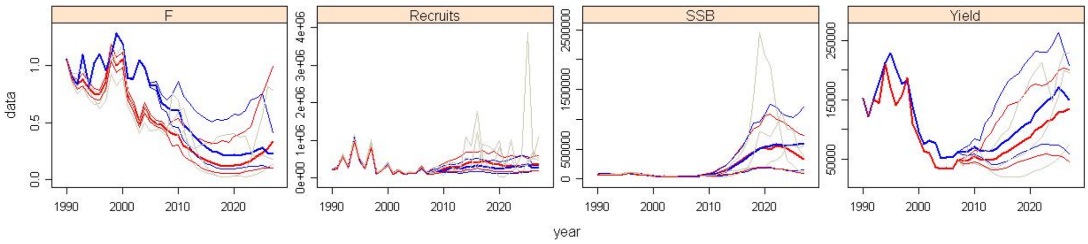
Scen=15, HCR=Norway, SR=1.0, OM=catch, OEM=m, TAC constraint=yes.



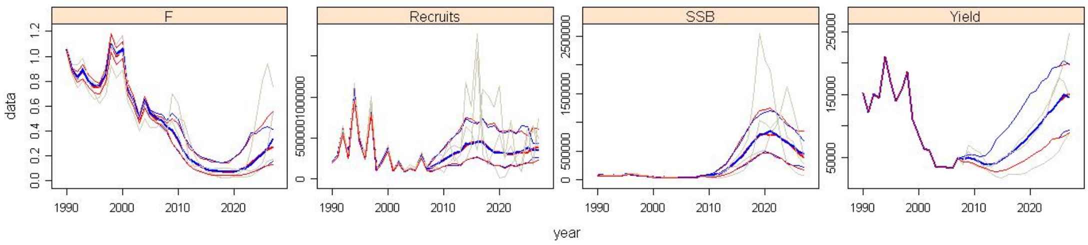
Scen=16, HCR=Norway, SR=1.0, OM=catch, OEM=landing, TAC constraint=yes.



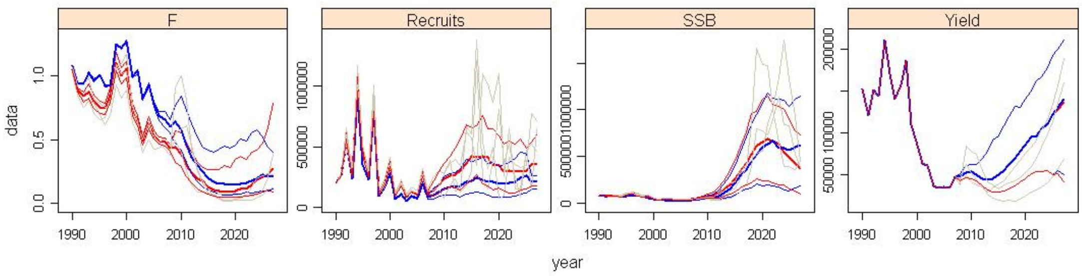
Scen=17, HCR=Norway, SR=1.0, OM=m, OEM=catch, TAC constraint=yes.



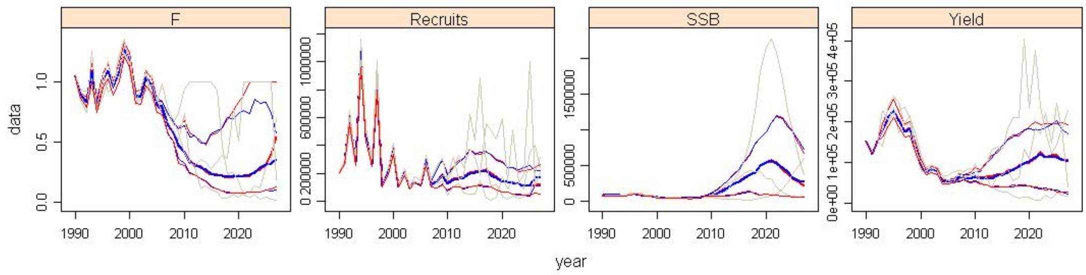
Scen=18, HCR=Norway, SR=1.0, OM=m, OEM=m, TAC constraint=yes.



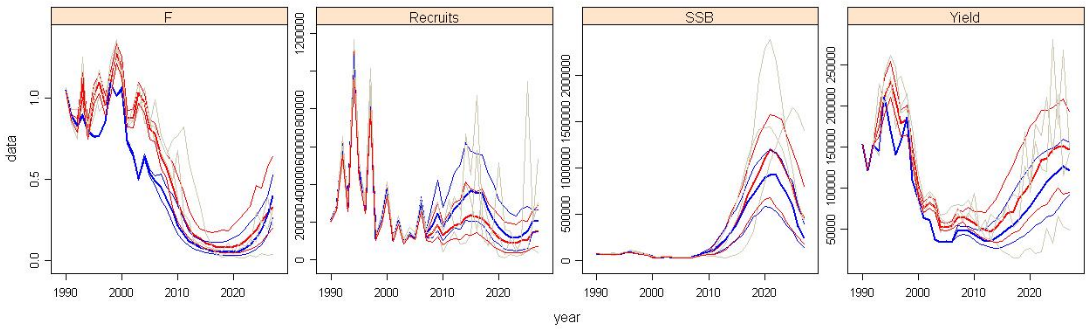
Scen=19, HCR=Norway, SR=1.0, OM=m, OEM=landing, TAC constraint=yes.



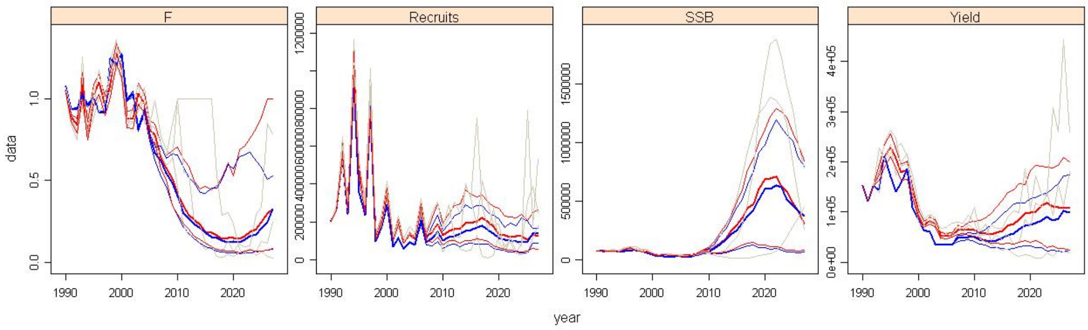
Scen=20, HCR=Norway, SR=0.5, OM=catch, OEM=catch, TAC constraint=yes.



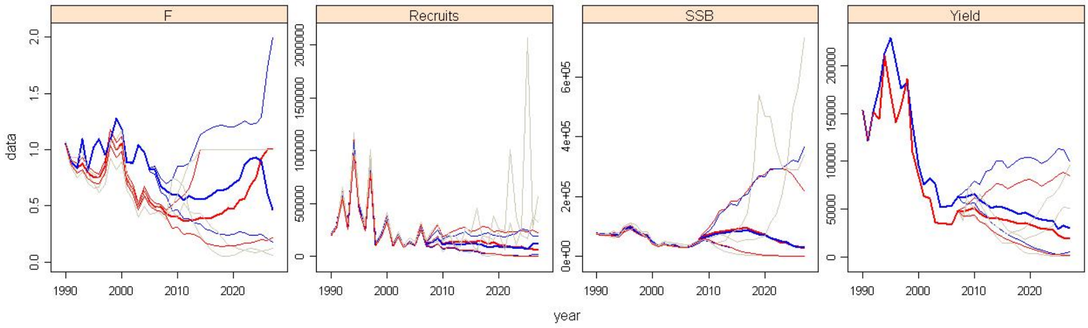
Scen=21, HCR=Norway, SR=0.5, OM=catch, OEM=m, TAC constraint=yes.



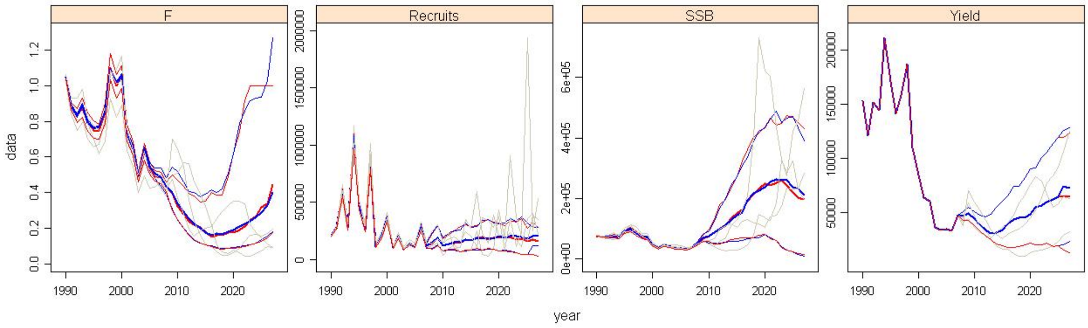
Scen=22, HCR=Norway, SR=0.5, OM=catch, OEM=landing, TAC constraint=yes.



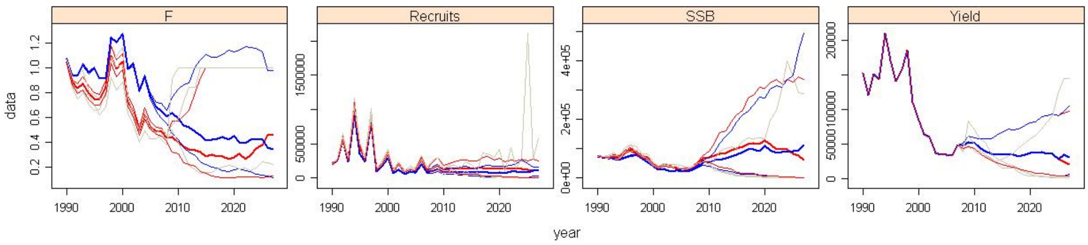
Scen=23, HCR=Norway, SR=0.5, OM=m, OEM=catch, TAC constraint=yes.



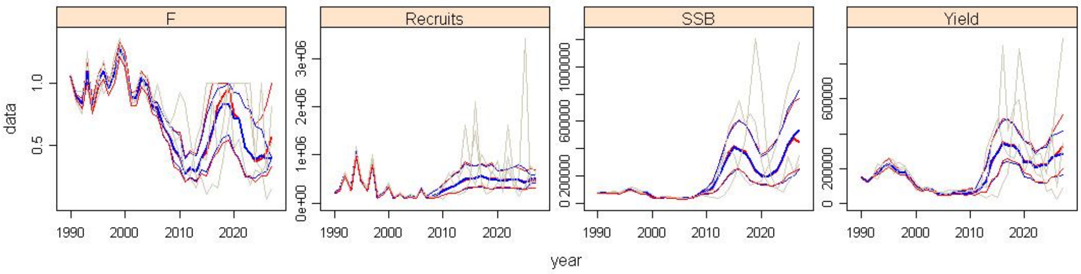
Scen=24, HCR=Norway, SR=0.5, OM=m, OEM=m, TAC constraint=yes.



Scen=25, HCR=Norway, SR=0.5, OM=m, OEM=landing, TAC constraint=yes.



Scen=26, HCR=Norway, SR=1.0, OM=catch, OEM=catch, TAC constraint=no.



Annex 4 Problems identified in the code for the evaluation of NS cod recovery plans

The work of AGCREMP resulted in initial advice that was released on 12 September 2008. When an additional request from the French government came in during October 2008, problems were discovered in the original code that was used to provide the initial advice. Sections 1–3 below (of this Annex), deal with these code problems. Following the release of the advice on the French request (14 November 2008), which included the changes described in Sections 1–3, a further problem was discovered and is detailed in Section 4. In addition, Section 5 clarifies the calculation of the *avg(F)* that appears in Chapter 4 of this report and in the Advice.

Both Advisory sections (ICES Advisory book 2008 Sections 6.3.3.7 and 6.3.3.8) have been updated on 18 December 2008 reflecting all corrections. These led to minor recalculations but did not alter the conclusions and Advice.

This report up until Annex 3 reflects the initial calculations. This Annex reflects all corrections made, while Annex 5 describes the results of the French request and takes on board the corrections as made in Sections 1–3 below.

1) Incorrect adjustment for misreporting

The relevant code is given below between the two broken lines, with the problematic statement highlighted in bold.

```
Code-1-----------------------------------------------------------------------------

##file NSCodMSE.R##############################################################

if (HCR=="EU") s.<-hcrEU( iYr,smryHCR,MPStk,Bpa,Blim,0.4,minTAC,maxTAC) else

if (HCR=="Norway") s.<-hcrNor(iYr,smryHCR,MPStk,Bpa,Blim,0.1,0.4,minTAC,maxTAC) else

if (HCR=="f") s.<-hcrF(  iYr,smryHCR,MPStk,Bpa,Blim,0.1,0.4,minTAC,maxTAC)

MPStk<-s.$m

smryHCR<-s.$s

if (OEM=="catch")

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]/c(catchMisrepMP[,ac(iYr+2),,,,nits])

if (OM=="catch")

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]*(catchMisrepOM[,ac(iYr+2),,,,nits]) else

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]

---------------------------------------------------------------------------------
```

In order to understand the problem, some background to the evaluation (performed using FLR) is needed. The operating model (OM) simulates the "real" world, while the management procedure (MP) simulates our perception based on three stages, namely: applying an assessment model to available data generated by the observation error model (OEM), conducting a short-term forecast, and applying a harvest control rule (HCR). The evaluation considered various combinations of OMs and OEMs.

When the "catch" option was used for both the OM and OEM (the so called "catch-catch" option), this implied that additional cod mortality was due to mortality in the fishery that had not been accounted for (e.g. misreporting), and that the assessment model estimates this additional mortality (effectively what the B-Adapt assessment model does for North Sea cod). Because B-Adapt is not yet available to use in the FLR framework, this was achieved by removing the OM misreporting factor (catchMisrepOM), and adding it back in (catchMisrepMP) before applying the assessment model in the MP (XSA was used)-the combination of adding it back in and then applying XSA effectively simulates what B-Adapt would do.

There is a difference between catchMisrepOM and catchMisrepMP (for each year the catchMisrepMP value is the median of the catchMisrepOM values across all iterations) that allows estimation error for the misreporting factor to be taken into account. Once the assessment model is applied, a short-term forecast is conducted and the HCR applied. The application of the HCR includes defining a target F and calculating the corresponding TAC (the latter based on landings only, and removing catchMisrepMP). When converting the TAC to resultant landings and discards in the OM, misreporting needs to be added back in (by applying catchMisrepOM).

The reason the above code in bold is incorrect is that for the "catch-catch" case, catchMisrepMP is removed from the TAC to get landings, but then this landings allocation is ignored when catchMisrepOM is added back into the TAC in the subsequent landings calculation. This code also does not change the TAC itself (by removing catchMisrepMP) – this TAC will be needed the following year to apply the TAC constraint. Changing the code in bold to the following solves this particular problem:

```
Code-2------------------------------------------------------------------------------------

if (OEM=="catch")

  smryHCR["TAC",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]/c(catchMisrepMP[,ac(iYr+2),,,,nits])

------------------------------------------------------------------------------------------
```

However, this code change introduces another problem (and is therefore not appropriate) because of the order in which the TAC constraint and the misreporting adjustments are made.

2) Order in which TAC constraint and misreporting adjustments are made.

The original specification document set out step-by-step the procedure for calculating the TAC for both HCRs considered (EU and Norway). This procedure was effectively as follows:

Step A1: Calculate the target F using the HCR rules

Step A2: Calculate the catch based on this target F and remove discards and, where appropriate (e.g. if OEM="catch"), misreporting (divide by catchMisrepMP) from this catch to derive the TAC.

Step A3: Apply the TAC constraints to derive a revised TAC

When converting this revised TAC to resultant landings and discards in the OM, misreporting is added back in (by applying catchMisrepOM).

The code with the modification given in Code-2 above has the order as follows:

Step B1: Calculate the target F using the HCR rules

Step B2: Calculate the catch based on this target F, remove discards and apply the TAC constraints to derive a TAC.

Step B3: Where appropriate, remove the misreporting (divide by catchMisrepMP) from this TAC to derive a revised TAC

When converting this revised TAC to resultant landings and discards in the OM, misreporting is added back in (by applying catchMisrepOM).

A simple example is given below to demonstrate why the order given in Steps B1–3 is problematic. In this example, discards are ignored for simplicity.

Example--

Let the TAC in 2008 be 100, and fishing mortalities in subsequent years leading to potential TACs of 130, 150 and 200 in 2009, 2010 and 2011, and assume the misreporting factor=1.3, and TAC constraints allow changes of no more than 15% from year to year. In the first case (adjust for misreporting, then apply TAC constraint), we get:

CASE 1 (Steps A1–3):

	F-based TAC	adj misrep	set TAC (TAC constr)
2008			100
2009	130	100	100
2010	150	115	115
2011	200	154	132

In the second case (apply TAC constraint, then adjust for misreporting), we get the following:

CASE 2 (Steps B1–3):

	F-based TAC	TAC constr	set TAC (adj misrep)
2008			100
2009	130	115	88
2010	150	101	78
2011	200	90	69

It is clear from this example that the order is important, and very different TACs result. The consequence of applying Steps B1–3 is that sequentially lower TACs result, even when the F-based calculation wants to set higher and higher TACs, which is clearly inappropriate.

In order to correct for the problems mentioned in this section and in Section 1, the following modifications have been made to the code (modified statements in bold, omitted statements crossed out, code not shown indicated with "…").

```
Code-3------------------------------------------------------------------------------

##file NSCodMSE.R#################################################################

if (HCR=="EU") s.<-hcrEU( iYr,smryHCR,MPStk,Bpa,Blim,0.4,catchMisrepMP,OEM,minTAC,maxTAC)
else

if (HCR=="Norway") s.<-
hcrNor(iYr,smryHCR,MPStk,Bpa,Blim,0.1,0.4,catchMisrepMP,OEM,minTAC,maxTAC) else

if (HCR=="f") s.<-hcrF( iYr,smryHCR,MPStk,Bpa,Blim,0.1,0.4,minTAC,maxTAC)

MPStk<-s.$m

smryHCR<-s.$s

if (OEM=="catch")

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]/c(catchMisrepMP[,ac(iYr+2),,,,nits])

if (OM=="catch")

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]*(catchMisrepOM[,ac(iYr+2),,,,nits]) else

  smryHCR["landings",ac(iYr+2),]<-smryHCR["TAC",ac(iYr+2),]

------------------------------------------------------------------------------------

Code-4------------------------------------------------------------------------------

##file HCRs.R, function hcrNor#################################################################

hcrNor<-

func-

tion(iYr,smryHCR,MPStk,Bpa,Blim,Fmin,Fmax,catchMisrepMP,OEM,minTAC=0.85,maxTAC=1.15,lambda

=TRUE)


#### Recovery mode

value<-array(smryHCR["f",ac(iYr+2),,drop=T],c(1,nits))

trgt<-fwdTarget(year=iYr+2,quantity="f",value=mean(value[1,]))

MPStkRecovery<-fwd(MPStk,trgt,value=value,sr.model="geomean",sr.params=mnRec)

if (OEM=="catch") {

  value[1,]<-c(computeLandings(MPStkRecovery)[,ac(iYr+2)])/c(catchMisrepMP[,ac(iYr+2),,,,1:nits])

  trgt<-fwdTarget(year=iYr+2,quantity="landings",value=mean(value[1,]))

  MPStkRecovery<-fwd(MPStk,trgt,value=value,sr.model="geomean",sr.params=mnRec)

}

#### Longterm mode
```

```
value<-array(NA,c(2,nits))

value[1,]<-pmax(Fmin,pmin(Fmax,Fmax-(Fmax-Fmin)*c((Bpa-ssb(MPStk)[,ac(iYr+1)]))/(Bpa-Blim)))

min<-array(NA,c(2,nits))

max<-array(NA,c(2,nits))

min[2,]<-c(smryHCR["TAC",ac(iYr+1),1:nits])*minTAC

max[2,]<-c(smryHCR["TAC",ac(iYr+1),1:nits])*maxTAC

if (OEM=="catch") {

  trgt<-fwdTarget(year=c(iYr+2),quantity=c("f"),value=c(mean(value[1,])))

  MPStkLongterm<-
fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)

  value[1,]<-c(computeLandings(MPStkLongterm)[,ac(iYr+2)])/c(catchMisrepMP[,ac(iYr+2),,,,1:nits])

      trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("landings","landings"),value=c(mean(value[1,]),NA),
    min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))

}     else     trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("f","landings"),value=c(mean(value[1,]),NA),

min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))

MPStkLongterm<-fwd(MPStk,trgt,value=value,min=min,max=max,sr.model="geomean",sr.params=mnRec)

--------------------------------------------------------------------------------------

Code-5------------------------------------------------------------------------------

##file HCRs.R, function hcrEU################################################################

hcrEU<-
func-
tion(iYr,smryHCR,MPStk,Bpa,Blim,FTarget,catchMisrepMP,OEM,minTAC=0.85,maxTAC=1.15,lambda=
TRUE)

## turns off TAC constraint if SSB<Blim

tacFlag<-c(ssb(MPStk)[,ac(iYr+1)])<=Blim

if (any(tacFlag)) {

  max[2,tacFlag]<-max[2,tacFlag]*1000

  min[2,tacFlag]<-min[2,tacFlag]*0.001

}

if (OEM=="catch") {

  trgt<-fwdTarget(year=c(iYr+2),quantity=c("f"),value=c(mean(value[1,])))

  MPStk<-fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)

  value[1,]<-c(computeLandings(MPStk)[,ac(iYr+2)])/c(catchMisrepMP[,ac(iYr+2),,,,1:nits])

      trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("landings","landings"),value=c(mean(value[1,]),NA),
    min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))
```

```
} else trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("f","landings"),value=c(mean(value[1,]),NA),
  min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))

MPStk <- fwd(MPStk,trgt,value=value,min=min,max=max,sr.model="geomean",sr.params=mnRec)
```

----

3) TAC constraint not switched off for Norway rule below Bpa.

Once the Norway HCR switches to the long-term phase, it requires the TAC constraints to be active only when SSB is above B_{pa}. However, the code does not appear to have the TAC constraints switched off when SSB is below Bpa. What is requires is something similar to what is included for the EU rule, shown in the lines of code not in bold in Code-5 above. Therefore, Code-6 below repeats what is shown in Code-4 above, but with the addition of code correcting for this problem.

Code-6--

```
##file HCRs.R, function hcrNor####################################################################
hcrNor<-
func-
tion(iYr,smryHCR,MPStk,Bpa,Blim,Fmin,Fmax,catchMisrepMP,OEM,minTAC=0.85,maxTAC=1.15,lambda
=TRUE)

#### Recovery mode
value<-array(smryHCR["f",ac(iYr+2),,drop=T],c(1,nits))
trgt<-fwdTarget(year=iYr+2,quantity="f",value=mean(value[1,]))
MPStkRecovery<-fwd(MPStk,trgt,value=value,sr.model="geomean",sr.params=mnRec)
if (OEM=="catch") {
  value[1,]<-c(computeLandings(MPStkRecovery)[,ac(iYr+2)])/c(catchMisrepMP[,ac(iYr+2),,,,1:nits])
  trgt<-fwdTarget(year=iYr+2,quantity="landings",value=mean(value[1,]))
  MPStkRecovery<-fwd(MPStk,trgt,value=value,sr.model="geomean",sr.params=mnRec)
}
#### Longterm mode
value<-array(NA,c(2,nits))
value[1,]<-pmax(Fmin,pmin(Fmax,Fmax-(Fmax-Fmin)*c((Bpa-ssb(MPStk)[,ac(iYr+1)]))/(Bpa-Blim)))
min<-array(NA,c(2,nits))
max<-array(NA,c(2,nits))
min[2,]<-c(smryHCR["TAC",ac(iYr+1),1:nits])*minTAC
max[2,]<-c(smryHCR["TAC",ac(iYr+1),1:nits])*maxTAC
tacFlag<-c(ssb(MPStk)[,ac(iYr+1)])<=Bpa
```

```
if (any(tacFlag)) {
  max[2,tacFlag]<-max[2,tacFlag]*1000
  min[2,tacFlag]<-min[2,tacFlag]*0.001
}
if (OEM=="catch") {
  trgt<-fwdTarget(year=c(iYr+2),quantity=c("f"),value=c(mean(value[1,])))

  MPStkLongterm<-
fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)
  value[1,]<-c(computeLandings(MPStkLongterm)[,ac(iYr+2)])/c(catchMisrepMP[,ac(iYr+2),,,,1:nits])
     trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("landings","landings"),value=c(mean(value[1,]),NA),
   min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))
}    else    trgt<-fwdTarget(year=rep(iYr+2,2),quantity=c("f","landings"),value=c(mean(value[1,]),NA),
min=c(NA,c(mean(min[2,]))),max=c(NA,c(mean(max[2,]))))

MPStkLongterm<-fwd(MPStk,trgt,value=value,min=min,max=max,sr.model="geomean",sr.params=mnRec)
-----------------------------------------------------------------------------------------------------------
```

4) Incorrect calculation of λ

The parameter λ reflects the change in effort between years as implied by the application of the harvest control rule. An error has been detected in the way the TAC calculation has been done. This occurred because the code was "hard-wired" for this particular calculation.

A function (*fwd*) was developed that can solve equations to meet more than one objective (e.g. solve for target F, but override this by solving for a TAC constraint). In using the *fwd* function, the Baranov catch equation needed to be "hard-wired". For the North Sea cod evaluation the Baranov catch equation was used with an additional factor adjusting for misreporting. Because the misreporting factor couldn't be placed inside the *fwd* function, it had to be done outside it, which caused the problem.

In the case where an adjustment to misreporting was needed, the sequence of calculations was first to work out the landings portion of the catch associated with the target F (set by the HCR), then to adjust this landings amount for misreporting and apply the TAC constraint to give the TAC. What was then needed (and wasn't done) for the purpose only of calculating the F intended by the HCR (to be stored and used for the intermediate year assumption next year, in the form of the λ factor, for both the EU and Norway rules) was to add the misreporting back in and calculate the associated F. The lack of this final part meant that the λ calculation (which was all it was needed for) was not correct. This has implications for future TAC calculations for both the EU and Norway rules. Code-7 and Code-8 below indicate in bold the additions required to the EU and Norway code respectively to correct this problem.

```
Code-7-----------------------------------------------------------------------------------------------------------
##file HCRs.R, function hcrEU###################################################################
```

```
hcrEU<-function(iYr,smryHCR,MPStk,Bpa,Blim,FTarget,catchMisrepMP,OEM,minTAC=0.85,
maxTAC=1.15,lambda=TRUE)

## set TAC

smryHCR["TAC",ac(iYr+2),]<-c(computeLandings(MPStk)[,ac(iYr+2)])

MPStklambda<-MPStk

if (OEM=="catch") {

  value[1,] <- c(computeLandings(MPStk)[,ac(iYr+2)])*c(catchMisrepMP[,ac(iYr+2),,,,1:nits])

  trgt <- fwdTarget(year=c(iYr+2),quantity=c("landings"),value=c(mean(value[1,])))

  MPStklambda                                                                    <-
fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)

}

smryHCR["f",ac(iYr+2),]<-c(fbar(MPStklambda)[,ac(iYr+2)])

## 3) Recalculate lambda

if (lambda)

  smryHCR["lambda",ac(iYr+1),]<-smryHCR["f",ac(iYr+2),]/FCurrent[1,] else

  smryHCR["lambda",ac(iYr+1),]<-1.0

---------------------------------------------------------------------------------------------------------------

Code-8-----------------------------------------------------------------------------------------------------------

##file HCRs.R, function hcrNor##############################################################

hcrNor<-function(iYr,smryHCR,MPStk,Bpa,Blim,Fmin,Fmax,catchMisrepMP,OEM,minTAC=0.85,

maxTAC=1.15,lambda=TRUE)

#### Choosing between Recovery and Longterm plans

## compares TAC under longterm and recovery mode; if TAC greater under LT than Rec, then you are
now in LT mode

## also if previously you were in LT mode then you are always in LT mode

flagLT<-c(flagLT                                                                                |
(c(computeLandings(MPStkLongterm)[,ac(iYr+2)])>c(computeLandings(MPStkRecovery)[,ac(iYr+2)])))

if (any(flagLT))

  smryHCR["rule",ac(iYr+2),flagLT]<-4

##set TACs based upon appropriate mode, selected by flagLT which is a boolean

if (any(!flagLT)) {                                         ## Recovery Mode

  iter(MPStk,!flagLT)<-iter(MPStkRecovery,!flagLT)

  smryHCR["TAC",ac(iYr+2),!flagLT]<-c(computeLandings(MPStkRecovery)[,ac(iYr+2),,,,!flagLT])

  if (OEM=="catch") {

    value[1,] <- c(computeLandings(MPStkRecovery)[,ac(iYr+2)])*c(catchMisrepMP[,ac(iYr+2),,,,1:nits])
```

```
    trgt <- fwdTarget(year=c(iYr+2),quantity=c("landings"),value=c(mean(value[1,])))
    MPStkRecovery <-
fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)
  }
  smryHCR["f",ac(iYr+2),!flagLT]<-c(fbar(MPStkRecovery)[,ac(iYr+2),,,,!flagLT])
}
if (any(flagLT)) {                                   ## Longterm Mode
  iter(MPStk,flagLT)<-iter(MPStkLongterm,flagLT)
  smryHCR["TAC",ac(iYr+2), flagLT]<-c(computeLandings(MPStkLongterm)[,ac(iYr+2),,,,flagLT])
  if (OEM=="catch") {
    value[1,] <- c(computeLandings(MPStkLongterm)[,ac(iYr+2)])*c(catchMisrepMP[,ac(iYr+2),,,,1:nits])
    trgt <- fwdTarget(year=c(iYr+2),quantity=c("landings"),value=c(mean(value[1,])))
    MPStkLongterm <-
fwd(MPStk,trgt,value=array(c(value[1,]),c(1,nits)),sr.model="geomean",sr.params=mnRec)
  }
  smryHCR["f",ac(iYr+2), flagLT]<-c(fbar(MPStkLongterm)[,ac(iYr+2),,,, flagLT])
}
## 3) Recalculate lambda
if (lambda)
  smryHCR["lambda",ac(iYr+1),]<-smryHCR["f",ac(iYr+2),]/FCurrent[1,] else
  smryHCR["lambda",ac(iYr+1),]<-1.0
---------------------------------------------------------------------------------------------------------------
```

The effects of the different changes in code on population trajectories are shown in Figures 1–2 for the EU HCR (with and without TAC constraint), and Figures 3–4 for the Norway HCR (with and without TAC constraint).

5) Calculation of *avg(F)* used by AGCREMP.

The *avg(F)* calculation that appears in tables produced by ICES-AGCREMP is not the usual instantaneous fishing mortality calculation, but rather based on a yield to biomass ratio, calculated as follows:

```
Code-9--------------------------------------------------------------------------------------------
c.<-apply(catch.n(fleet,1,1)*catch.wt(fleet,1,1),c(2,6),sum)
b.<-apply(biol@n*biol@wt,c(2,6),sum)
h.<-c./b.
----------------------------------------------------------------------------------------------------
```

The standard calculation of avg(F) would have been as follows:

```
Code-10-----------------------------------------------------------------------------------------------

f.<-landings.sel(fleet,1,1)+discards.sel(fleet,1,1)

f..<-sweep(f.,c(2,6),effort(fleet),"*")

fbar<-apply(f..[ac(2:4)],c(2,6),mean)

-----------------------------------------------------------------------------------------------------------
```

In the figure 1–4 below, the standard calculation of F (Code-10) has been presented.

Conclusions

Following modifications to the code the AGCREMP simulations were re-run to compare model output with the original results that formed the basis for the ICES advice, in order to establish whether the conclusions reached would have been different. The summary output tables, before and after modification of the code, are presented in Table 1 (below). The full table of output from the re-run HCR simulations for the EC and Norway rules are presented in Table 2 (below).

Including the estimated catch appropriately within the simulation model and applying the appropriate TAC constraints had two major effects on the model output. There is an improved probability that the stock will recover to Blim and Bpa by 2015 for both the high and low recruitment scenarios. The improvement is apparent for both rules. In contrast the difference in yield between the EU and Norway rules (presented in the last columns of Table 1) is significantly different following the code modification. The yield from the EU rule is forecast to be considerably lower, that from the Norway rule higher.

The levels of probability quoted in the September ICES advice have been recalculated and are considered to be low. However, ***the ICES conclusions presented in the September advice are still applicable-both plans will lead to stock recovery in similar time frames and with similar probabilities***.

Table 1 The original and revised AGCREMP and ACOM summary table of the North Sea cod simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models; based on the AGCREMP FLR code.

Original

Recruitment Model	Prob(SSB>Blim) in 2015		Prob(SSB>Bpa) in 2015		Avg. Yield (tonnes) in 2015	
	EC	Norway	EC	Norway	EC	Norway
Standard	0.84	0.96	0.77	0.90	96.4	128.5
Low	0.61	0.81	0.54	0.66	76.1	88.9

Revised

Recruitment Model	Prob(SSB>Blim) in 2015		Prob(SSB>Bpa) in 2015		Avg. Yield (tonnes) in 2015	
	EC	Norway	EC	Norway	EC	Norway
Standard	1.00	1.00	0.98	1.00	76.1	158.0
Low	0.94	1.00	0.87	0.95	70.5	110.1

Table 3.3 Summary results of North Sea cod MSE for 13 scenarios. The columns labelled HCR, SR, OM, and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB being above Blim and Bpa in 2010, 2012, and 2015 and the average yield (Y, in '000 t) and the average fishing mortality (F) in 2008, 2010, 2012, and 2015. The red scenarios indicate the base case where there is bias due to unreported catch but where the bias is taken into account in the assessment process.

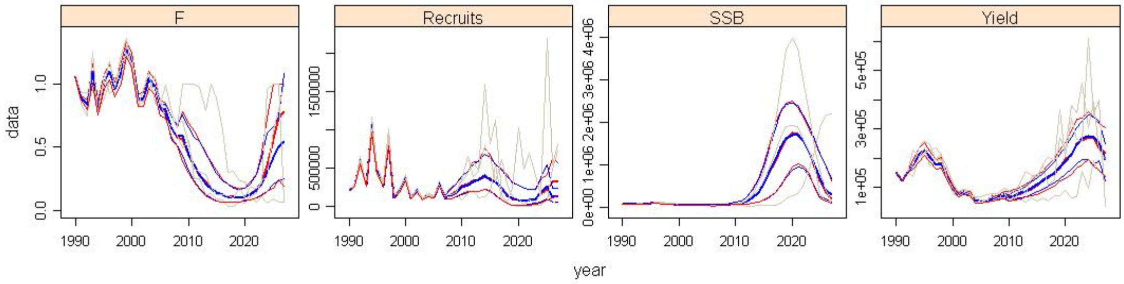
Scen	HCR	SR	OM	OEM	TAC	p(>Blim)	p(>Blim)	p(>Blim)	p(>Bpa)	p(>Bpa)	p(>Bpa)	avg(Y)	avg(Y)	avg(Y)	avg(Y)	avg(F)	avg(F)	avg(F)	avg(F)
					constr.	2010	2012	2015	2010	2012	2015	2008	2010	2012	2015	2008	2010	2012	2015
1	EU	1	catch	catch	yes	0.79	0.93	1.00	0.11	0.73	0.98	50.3	42.3	51.7	76.1	0.58	0.28	0.13	0.06
2	EU	1	catch	m	yes	0.81	0.95	1.00	0.12	0.77	0.99	50.3	38.6	45.6	67.1	0.58	0.24	0.11	0.04
3	EU	1	catch	wg	yes	0.71	0.86	0.98	0.08	0.60	0.92	50.3	46.6	57.0	82.2	0.58	0.35	0.17	0.07
4	EU	1	m	catch	yes	0.63	0.80	0.94	0.04	0.44	0.82	37.2	31.5	37.4	53.6	0.43	0.26	0.17	0.10
5	EU	1	m	m	yes	0.66	0.83	0.96	0.05	0.46	0.88	37.2	28.7	32.8	47.2	0.43	0.22	0.13	0.07
6	EU	1	m	wg	yes	0.56	0.74	0.86	0.04	0.37	0.73	37.2	34.8	41.5	57.3	0.43	0.30	0.21	0.13
7	EU	0.5	catch	catch	yes	0.79	0.89	0.94	0.11	0.63	0.87	50.3	42.3	49.7	70.5	0.58	0.29	0.18	0.11
8	EU	0.5	catch	m	yes	0.80	0.92	0.97	0.12	0.68	0.92	50.3	38.6	44.0	62.6	0.58	0.25	0.14	0.08
9	EU	0.5	catch	wg	yes	0.71	0.78	0.82	0.08	0.52	0.74	50.3	46.5	53.4	71.9	0.58	0.35	0.23	0.16
10	EU	0.5	m	catch	yes	0.62	0.71	0.75	0.04	0.36	0.50	37.2	31.5	35.5	46.0	0.43	0.26	0.23	0.21
11	EU	0.5	m	m	yes	0.66	0.76	0.82	0.05	0.39	0.56	37.2	28.7	31.2	41.4	0.43	0.23	0.17	0.15
12	EU	0.5	m	wg	yes	0.56	0.65	0.60	0.04	0.29	0.42	37.2	34.8	38.3	45.6	0.43	0.31	0.30	0.31
13	EU	1	catch	catch	no	0.79	0.93	1.00	0.11	0.71	0.98	50.3	44.3	89.4	288.9	0.58	0.28	0.22	0.34
14	Norway	1	catch	catch	yes	0.87	0.97	1.00	0.12	0.80	1.00	50.3	45.2	76.4	158.0	0.58	0.26	0.16	0.12
15	Norway	1	catch	m	yes	0.74	0.92	1.00	0.08	0.66	1.00	50.3	44.3	66.1	131.8	0.58	0.29	0.16	0.11
16	Norway	1	catch	wg	yes	0.66	0.86	1.00	0.07	0.57	0.96	50.3	53.1	80.4	147.7	0.58	0.38	0.24	0.14
17	Norway	1	m	catch	yes	0.70	0.84	0.98	0.05	0.46	0.86	37.2	33.4	49.0	89.6	0.43	0.26	0.19	0.16
18	Norway	1	m	m	yes	0.58	0.78	0.96	0.04	0.42	0.81	37.2	32.9	44.1	79.5	0.43	0.28	0.19	0.14

SCEN	HCR	SR	OM	OEM	TAC	P(>BLIM)	P(>BLIM)	P(>BLIM)	P(>BPA)	P(>BPA)	P(>BPA)	AVG(Y)	AVG(Y)	AVG(Y)	AVG(Y)	AVG(F)	AVG(F)	AVG(F)	AVG(F)
					constr.	2010	2012	2015	2010	2012	2015	2008	2010	2012	2015	2008	2010	2012	2015
19	Norway	1	m	wg	yes	0.52	0.70	0.91	0.04	0.34	0.69	37.2	39.3	52.1	82.1	0.43	0.35	0.26	0.17
20	Norway	0.5	catch	catch	yes	0.87	0.96	1.00	0.12	0.71	0.95	50.3	45.2	66.5	110.1	0.58	0.26	0.19	0.17
21	Norway	0.5	catch	m	yes	0.74	0.88	0.96	0.08	0.58	0.91	50.3	44.3	56.9	93.6	0.58	0.30	0.19	0.16
22	Norway	0.5	catch	wg	yes	0.66	0.74	0.88	0.07	0.50	0.74	50.3	53.0	68.8	96.2	0.58	0.39	0.29	0.20
23	Norway	0.5	m	catch	yes	0.70	0.77	0.83	0.05	0.39	0.50	37.2	33.4	42.5	58.5	0.43	0.26	0.22	0.22
24	Norway	0.5	m	m	yes	0.56	0.66	0.79	0.04	0.32	0.49	37.2	32.9	37.8	49.3	0.43	0.29	0.24	0.19
25	Norway	0.5	m	wg	yes	0.52	0.60	0.61	0.04	0.26	0.33	37.2	39.2	44.2	48.2	0.43	0.36	0.34	0.23
26	Norway	1	catch	catch	no	0.87	0.97	1.00	0.12	0.80	1.00	50.3	45.2	89.8	321.8	0.58	0.26	0.19	0.34

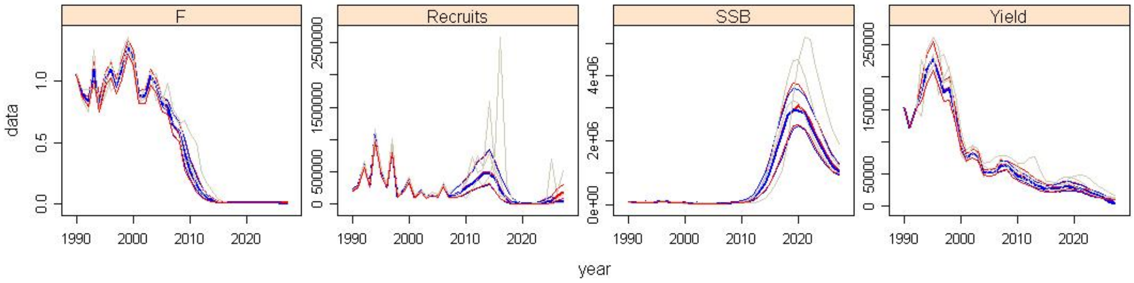
HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model (catch=bias due to unreported catch, m=bias due to changes in natural mortality). OEM refers to the Observation Error Model (landings=no correction for unreported catch, catch=correction for bias due to unreported catch, m=correction for bias due to change in m). Note in above, avg(F) is instantaneous total fishing mortality (landings +discards) - average over ages 2-4, as specified in the HCR (and not harvest ratio as used in the AGCREMP report).

Figure 1. EU rule (scenario 1, <u>with</u> TAC constraint) under baseline operating model.

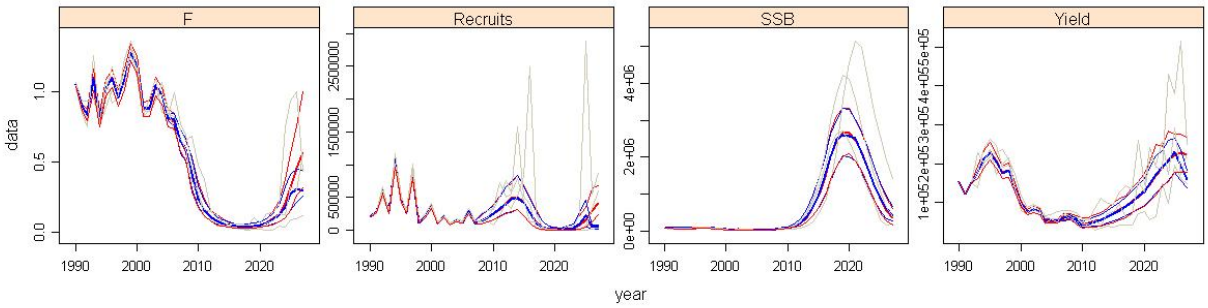
Code-1:



Code-2



Code-3 and Code-5



Code-3, Code-5 and Code-7

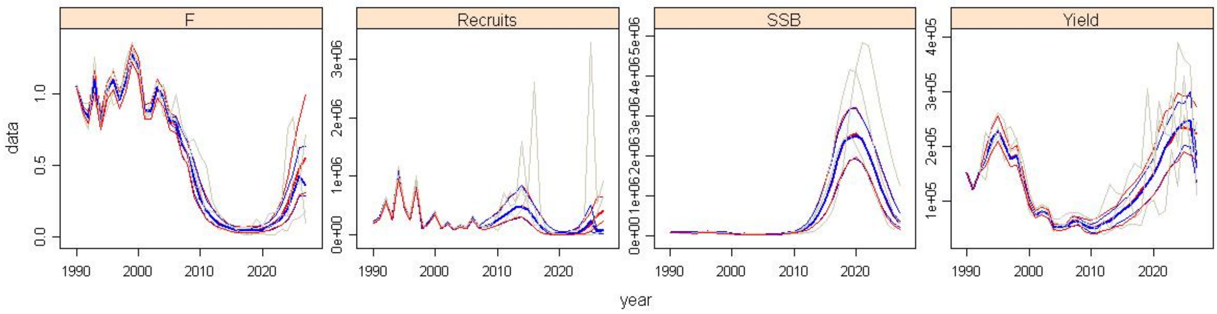
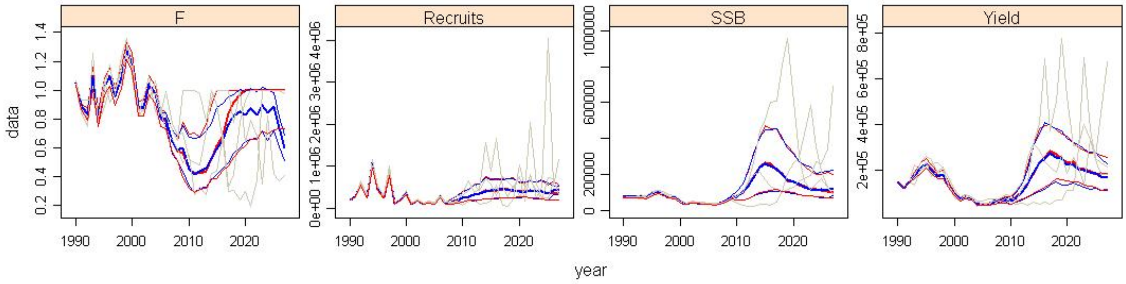
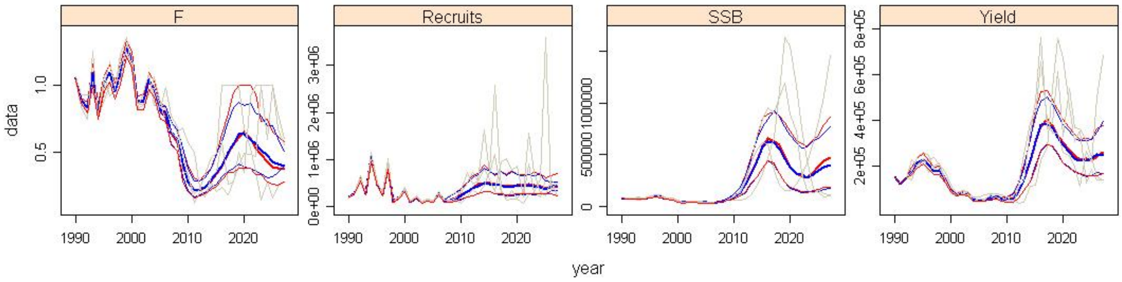


Figure 2. EU rule (Scenario 13, <u>without</u> TAC constraint) under baseline operating model.

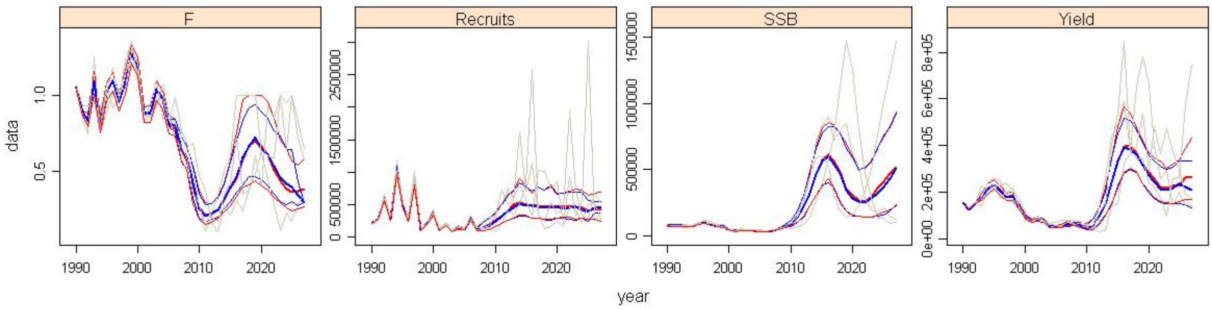
Code-1



Code-2



Code-3 & Code-5



Code-3, Code-5 & Code-7

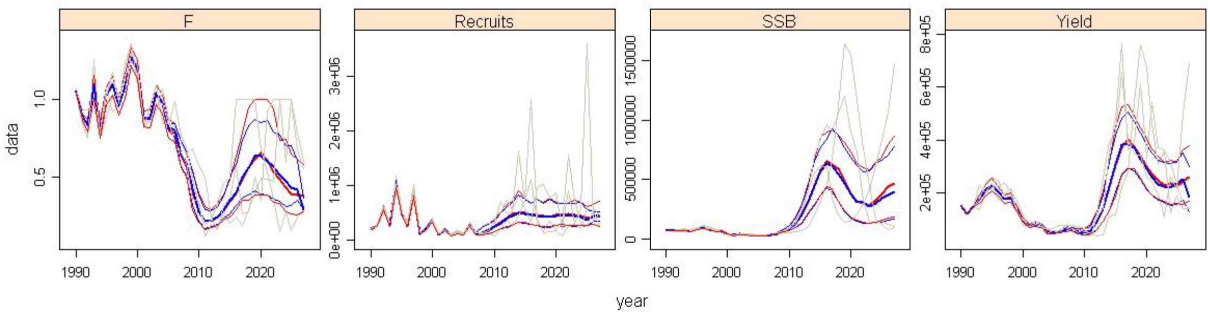
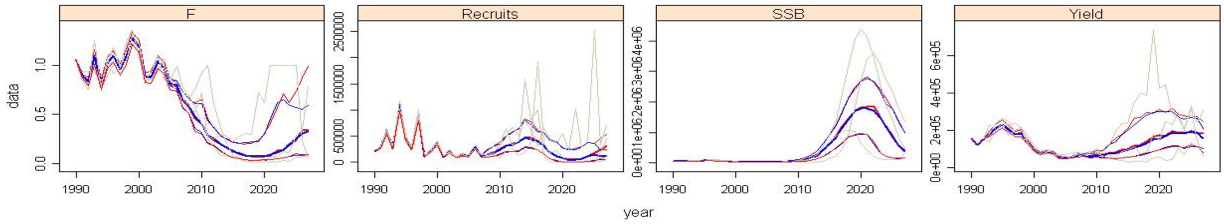
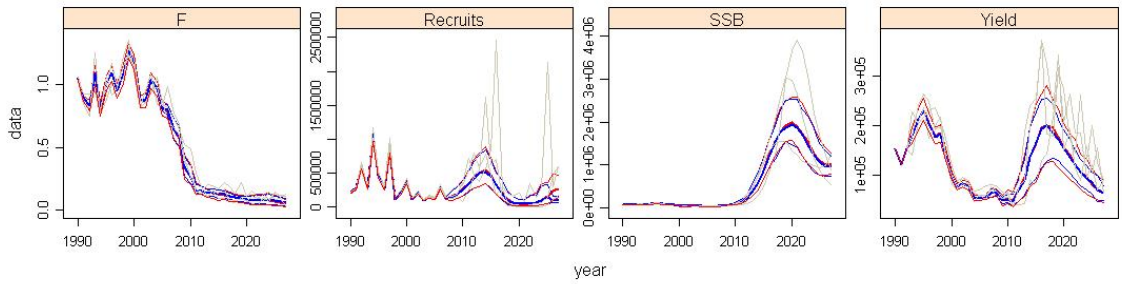


Figure 3. Norway rule (Scenario 14, with TAC constraint) under baseline operating model.

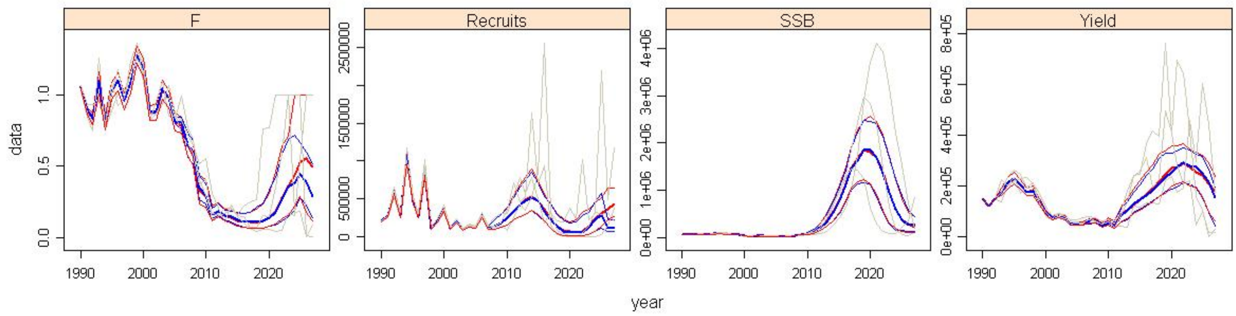
Code-1



Code-2



Code-3 & Code-6



Code-3, Code-6 & Code-8

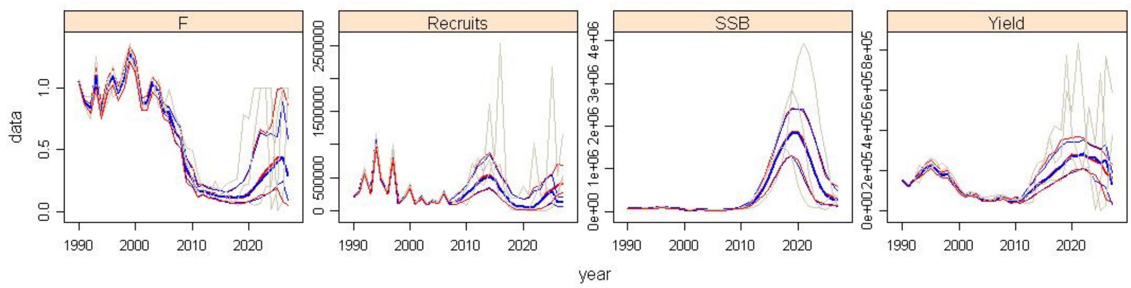
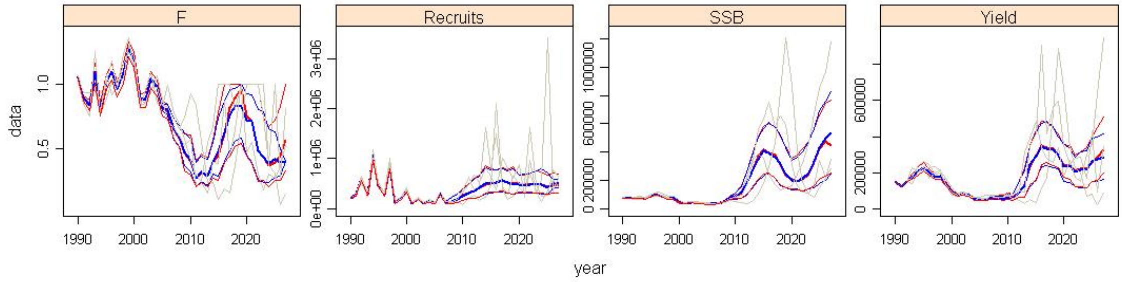
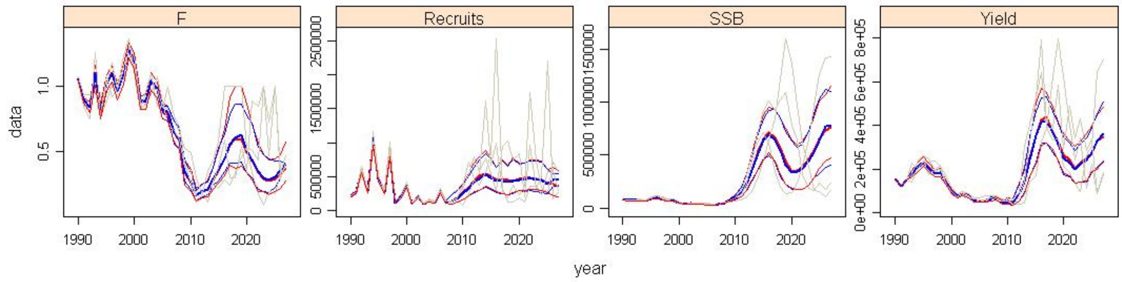


Figure 4. Norway rule (Scenario 26, <u>without</u> TAC constraint) under baseline operating model.

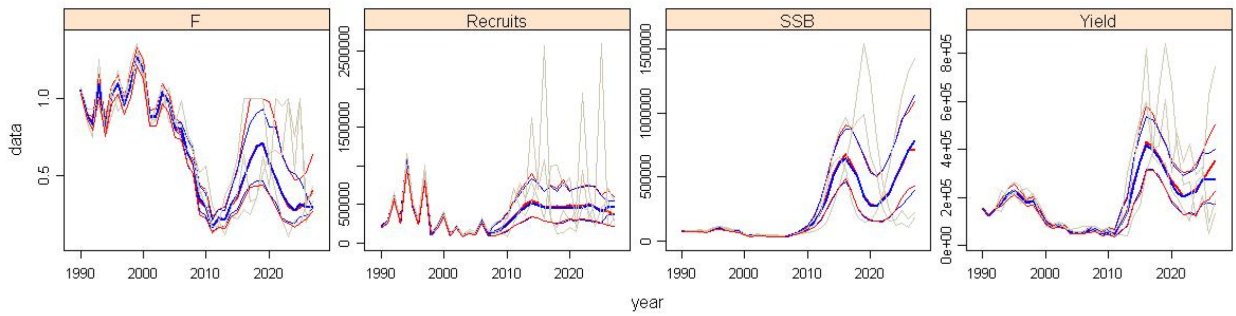
Code-1



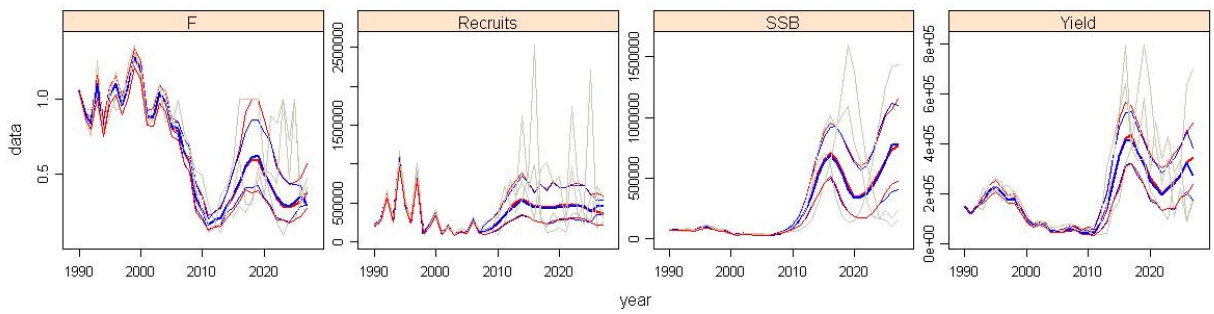
Code-2



Code-3 & Code-6



Code-3, Code-6 & Code-8



Annex 5 Further simulations of the North Sea Cod Harvest Control Rules proposal, in response to the French request

10/11/2008

By: Chris Darby and Jose d'Oliveira

1. Background

EC (DG MARE) requested ICES to evaluate an EC proposal for cod recovery plans. The request was extended to include a proposed management plan by the Norwegian authorities. It was agreed that the answer to be delivered 12 September 2008 would deal with North Sea Cod only. The final Terms of Reference were agreed on 10 July 2008 as:

1) to evaluate objectives foreseen in the long term management plan and to analyse if a fishing mortality rate of 0.4 will appear well defined for all cod stocks covered by such a plan.

   The objective of the cod plan is to exploit the stocks at MSY. ICES has previously advised that a fishing mortality in the range 0.2 to 0.4 is consistent with MSY for the North Sea cod stock. EC and Norway have agreed on F=0.4 as a target fishing mortality for the North Sea cod. The European Commission, in its proposal to Member States, has adopted this value also as a proxy for F_{MSY} for other cod stocks: in the Kattegat, the West of Scotland, the Celtic Sea and the Irish Sea. The Commission would like ICES' advice as to whether alternative values would be better proxies for F_{MSY} for the stocks outside the North Sea, Skagerrak and Division VIId.

2) To analyse both the Commission proposal and the Norwegian lawful Authorities proposal in the light of objectives set out for such a long-term plan with the purpose to appreciate if they will be suitable for matching targets that will be suggested in terms of fishing mortality rates for all the cod stocks that will be covered by the Cod Recovery Plan.

   In particular, we would like to know the consequences of the plans in terms of:

   - biological risks, in particular in relation to the ICES interpretation of the precautionary approach;
   - yields, especially in the longer term;
   - stability of catches

3) To suggest any alternative proposal for methodologies which might appear more consistent in defining TACs in relation to cod stocks status.

The Ad-hoc Group on Cod Recovery Management Plan Request (AGCREMP, 18–19 August 2008) carried out a series of evaluations of the proposed rules with ICES providing a response to the request in September 2008 (ICES ACOM 6.3.3.7 Request on Cod Recovery Management Plans).

In a follow up request, France has requested ICES to evaluate a further set of scenarios for the EC proposal and to provide some additional summary statistics that would aid decision making:

1) The consequences of the alternative scenarios of fishing mortality. The proposal of the European Commission considered a reduction of 25%

when B<Blim, of 15% when Blim<B<Bpa and 10% when B>Bpa (25/15/10). The request asks for an evaluation of 25/10/5 and 15/10/5.

2) With a comparison between scenarios proposed by the European Commission and the alternatives, of:

The year in which precautionary biomass Bpa would be reached.

The year in which the target fishing mortality would be reached

The year in which the equilibrium biomass corresponding to the target fishing.

mortality would be reached.

A subgroup of the WGNSSK reviewed and modified the AGCREMP code and ran the simulations required to respond to the additional request during the 3–7 November.

1.1 The original EU and Norway harvest control rules

Two harvest control rules were evaluated by AGCREMP, they differed in the approach to reducing fishing mortality during the first few years and the rates of mortality change at specified levels of spawning stock biomass. The rules are described in detail in the report of AGCREMP. In summary:

1.1.1 EU rule (25/15/10)

SSB < Blim

Annual 25% reduction in F-no minimum

Blim < SSB < Bpa

Annual 15% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

Bpa < SSB

Annual 10% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

1.1.2 Norway rules

Interim rule

- A 25% reduction in F in year 1, followed by an annual 15% reduction in subsequent years

Long-term rule

takes over permanently when Long-term catch > Interim catch

SSB < Blim

- F = 0.1

Blim < SSB < Bpa

- Sliding scale of increasing F from 0.1 at Blim to 0.4 at Bpa, conditional on the relative level of SSB between Blim and Bpa

Bpa < SSB

- F = 0.4, conditional on 15% TAC constraint

1.2 ICES September advice

The ICES advice on the two rules based on the AGCREMP simulations was that:

- ICES advises that both the EC and Norwegian proposed Recovery/Management Plans are likely (see probabilities below) to recover the North Sea cod stock.
- ICES constructed models that applied the proposed EC and Norwegian Plans to simulated assessments of simulated stocks. This approach is widely applied to the evaluation of management plans, although technical details vary between applications.
- Stock size trajectories, fishing mortality rates and yields were simulated for 2008–2025. The results for 2015 are considered most informative for evaluating the Plans because they are far enough into the future so that stock recovery is an achievable objective, but they are not so far into the future that simulated stock sizes are outside of the observed range. Several different scenarios were considered to address sources of uncertainty in assessments. In addition, the performance of the Plans was evaluated for a "standard" recruitment model that reflects the long term relationship between spawning stock size and recruitment, and for a "low" recruitment model that reduces recruitment by 50%. The latter reflects the recent situation.

The simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models, are summarized as follows:

Recruitment Model	Prob(SSB>Blim) in 2015		Prob(SSB>Bpa) in 2015		Avg. Yield (tonnes) in 2015	
	EC	Norway	EC	Norway	EC	Norway
Standard	0.84	0.96	0.77	0.90	96.4	128.5
Low	0.61	0.81	0.54	0.66	76.1	88.9

The probabilities vary in both directions (i.e., both higher and lower) for the scenarios presented in Table 6.3.3.7.1. For the worst case scenarios, the probabilities of recovery above B_{lim} by 2015 are 0.42 and 0.56 for the EC and Norwegian Plans, respectively.

ICES also considered the performance of alternative versions of the EC and Norwegian Plans where constraints on the annual change in TAC were eliminated. The probabilities of recovery were almost unaffected, but the average yields in 2015 were much higher (see scenarios 13 and 26 of Table 6.3.3.7.1).

ICES does not advise on the suitability of the Plans in relation to the precautionary approach because generally agreed criteria are lacking for Recovery Plans. ICES recommends that future Plans state their objective in terms of the target date for recovery and the acceptable level of risk that recovery does not occur by that date.

(ICES ACOM 2008 Section 6.3.3.7 Request on Cod Recovery Management Plans).

2 The additional request for ICES advice

In a follow up request, France has requested ICES to evaluate a further set of scenarios for the EC proposal and to provide some additional summary statistics that would aid decision making:

1) The consequences of the alternative scenarios of fishing mortality. The proposal of the European Commission considered a reduction of 25% when B<Blim, of 15% when Blim<B<Bpa and 10% when B>Bpa (25/15/10). The request asks for an evaluation of 25/10/5 and 15/10/5.

2) With a comparison between scenarios proposed by the European Commission and the alternatives, of:

The year in which precautionary biomass Bpa would be reached.

The year in which the target fishing mortality would be reached

The year in which the equilibrium biomass corresponding to the target fishing mortality would be reached

2.1 Modifications to the EU harvest control rule

The new rules defined by the request are specified as:

EU rule (25/10/5)

SSB < Blim

- Annual 25% reduction in F-no minimum

Blim < SSB < Bpa

- Annual 10% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

Bpa < SSB

- Annual 5% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

EU rule (15/10/5)

SSB < Blim

- Annual 15% reduction in F-no minimum

Blim < SSB < Bpa

- Annual 10% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

Bpa < SSB

- Annual 5% reduction in F with a minimum of 0.4; conditional on +/-15% change in the TAC constraint

2.2 Additional simulation results

The modified FLR code was run to simulate the dynamics of the North Sea cod stock under the HCR settings specified for the EU model in the new request to ICES and to calculate the additional management metrics for the EU and Norwegian rules.

The full table of output from the HCR simulations for the EC and Norwegian rules are listed in Tables 2.1–2.6. Table 2.1 provides a summary of the simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models. It is an extension of the table produced for the previous ICES advice adding the two new HCR specifications.

Table 2.3 presents a detailed comparison of the EU model runs with the 25/15/10 original specification (lines 1a,2a,3a,…13a), with those from the 25/10/5 rule (lines 1b,2b,3b,…13b) and 15/10/5 rule (lines 1c,2c,3c,…13c). Similarly for the Norway rule that only applies a 25% cut in fishing mortality in the first year followed by 15% in subsequent years for the recovery phase, the detailed results are presented in Table 2.5.

In addition to the base runs the request for further simulations asked for additional metrics to be presented–the year in which the stock recovers to Bpa and the year in which fishing mortality reaches 0.4. Table 2.2 provides a summary of the simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models. Table 2.4 presents the detailed statistics for each scenario of the EC harvest control rule. Table 2.6 presents the statistics for the Norwegian rule.

For scenarios corresponding to the way in which the stock is currently assessed-the simulations indicate that the stock would achieve Bpa by 2012 and F would be reduced to 0.4 by 2009/10 for all of the rules applied and independent of the level of recruitment.

Independence of the year in which recovery is achieved, and F reduced, is a consequence of the current cohort abundance and simulation of current management actions being implemented. Recruitment levels and the harvest control rule settings determine the dynamics during the years after Bpa has been achieved and F reduced to below 0.4, not the stock and fishery dynamics in the near future.

2.3 The effect of TAC constraints on achieving fishing mortality levels

It was noted in Section 2.2 that the corrected FLR code resulted in a reduction in the simulated yield from the EC plan and an increase in that from the Norwegian plan (c.f. Tables 2.1 and 2.2). The difference was such that for the base scenario-mimicking the estimation of unallocated mortality currently carried out at the WGNSSK-the yield in 2015 from the Norwegian plan was twice that resulting from the EC plan.

The reductions in fishing mortality imposed in the initial years of the two plans are similar, 25% in the first year with a series of 15% reductions in subsequent years. Therefore the simulated potential changes in target fishing mortality at specified biomass levels do not result in the large differences in yield between rules. The other major variation between the two rules is in the application of constraints on TAC change from year to year. The EC rule restricts TAC changes between years to 15% when the spawning stock is above Blim; at lower stock levels than the Norwegian rule, which applies the restrictions when the stock is above Bpa. Therefore, during application, the rules impose differing realised fishing mortality levels for comparable stock sizes when the stock is between Blim and Bpa.

The North Sea cod stock simulation models the current spawning stock dynamics as closely as possible-the stock is increasing in abundance from just below Blim towards Bpa. Therefore over the range of biomasses that the stock will exhibit during 2009–2011 (mostly between Blim and Bpa) the EC rule applies a 15% constraint on TAC increase in the majority of cases whereas the Norwegian rule is still in the recovery phase which is unconstrained and allows greater flexibility to manage changes in stock biomass.

The application of the 15% rule during the period of stock recovery to Bpa restricts the increase in TAC to levels that are considerably less than the rate at which the stock is increasing. Consequently the fraction of the stock that is removed is consistently lower than that required to achieve the target fishing mortality. Table 2.7 (scenarios 1a, b, c and 14a) illustrates the impact on yield and fishing mortality (landings and discards) of applying the TAC constraints within the EU and Norwegian Harvest Rules. Fishing mortality is continually reduced to extremely low levels well below those specified as targets in the HCR. Removing the constraints allows yield to increase as stock abundance increases and the transition to the target mortality is achieved without generating extremely low levels of fishing mortality (Table 2.7 scenarios 13a, b and c and 26a).

At the low levels of fishing mortality associated wit the 15% constraint, the methods used for the assessment of the stock become unstable and additional uncertainty is introduced to the management process. This is compounded by the reductions in fishing effort that would be required to achieve such low levels of mortality. The current assessment and management scenario of the EU HCR (scenario 1a) reduces total fishing mortality in 2015 to 0.05, one tenth of the current levels. If effort is not reduced to the same extent, the 15% restrictions on TAC change will result in a substantial increase in discarding that is not simulated within the scenarios explored in the ICES analysis.

2.4 Equilibrium biomass

In the long-term the level of future recruitment will determine the equilibrium biomass resulting from fishing at constant target fishing mortality levels. Recruitment scenarios are used in the simulations to explore the robustness of the rates and probabilities of recovery, level yield, etc. to future recruitment. ICES considers that the dynamics of future recruitment are too uncertain to make realistic predictions as to when a “stable” level of biomass would be achieved.

2.5 Summary of the results from the new ICES simulations

The application of each of the variations of the EU approach (25/15/10, 25/10/5 and 15/10/5) and the Norwegian harvest control rule in the management of the North Sea cod stock would lead to recovery of the stock with a high probability by 2015.

For scenarios corresponding to the way in which the stock is currently assessed-all of the variations of rules resulted in the stock recovering to Bpa by 2012 and F being reduced to 0.4 by 2009/10.

The current level of interannual TAC constraints (15%) within the harvest rules will result in total fishing mortalities from 2010 to at least 2015 that are predicted to be well below the target level of 0.4 from 2010 to at least 2015. The constraints are applied at lower levels of stock abundance within the EU rule leading to considerably lower total levels of fishing mortality, <0.1, by 2015. Removing the constraints allows yield to increase as stock abundance increases and the transition to the target mortality is achieved without generating extremely low levels of fishing mortality.

At such low levels of fishing mortality the behaviour of the assessment models, effort control and increases in the level of discarding will lead to a highly uncertain scientific advice on the consequences of management. Such changes in the stock and management have not been modelled in this analysis and would require further investigations.

In the long-term the level of future recruitment will determine the equilibrium biomass resulting from fishing at the target fishing mortality of 0.4. ICES considers that the dynamics of future recruitment are too uncertain to make realistic predictions as to when a "stable" level of biomass would be achieved.

Table 2.1 The summary table of the North Sea cod simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models, including the new runs requested by the EC.

Recruitment Model	Prob(SSB>Blim) in 2015		Prob(SSB>Bpa) in 2015		Avg. Yield (tonnes) in 2015	
	EC	Norway	EC	Norway	EC	Norway
Standard (a)	1.00	1.00	0.99	1.00	67.6	153.6
Standard (b)	1.00	-	0.99	-	67.7	-
Standard (c)	1.00	-	0.96	-	78.2	-
Low (a)	0.96	0.99	0.90	0.92	63.4	109.2
Low (b)	0.96	-	0.90	-	64.4	-
Low (c)	0.90	-	0.82	-	70.6	-

The scenarios in bold, labelled (a), refer to the level of cuts in F in the HCR, corresponding to 25% above Bpa, 15% between Bpa and Blim and 10% below Blim for the EU rule, and 25% in the first year followed by 15% in subsequent years for the recovery phase of the Norway rule. Corresponding values for the additional scenarios (EU only) are labelled (b) 25%, 10% and 5% and (c) 15%, 10% and 5%.

Table 2.2 Summary table of the North Sea cod simulation results for the scenarios that correspond to the way the stock is currently assessed, and for the two recruitment models, including the new runs requested by the EC. The results shown are the probability of SSB achieving Bpa in any year and the year in which F is first reduced to 0.4.

RECRUIT MODEL	HCR	PROBABILITY OF ACHIEVING BPA IN YEAR							PROBABILITY OF ACHIEVING F=0.4 IN YEAR						
		Median	2010	2011	2012	2013	2014	2015	Median	2008	2009	2010	2012	2013	2014
Standard	EU(a)	2012	0.11	0.34	0.31	0.14	0.07	0.02	2010	0.05	0.44	0.33	0.11	0.03	0.02
	EU(b)	2012	0.11	0.34	0.31	0.14	0.06	0.03	2010	0.05	0.44	0.33	0.11	0.04	0.02
	EU(c)	2012	0.09	0.30	0.27	0.18	0.08	0.05	2010	0.05	0.34	0.35	0.11	0.08	0.04
	Norway	2012	0.12	0.34	0.33	0.15	0.06	0.01	2009	0.05	0.61	0.13	0.18	0.02	0.01
Low	EU(a)	2012	0.11	0.32	0.25	0.12	0.08	0.03	2009	0.05	0.45	0.31	0.10	0.03	0.02
	EU(b)	2012	0.11	0.32	0.25	0.12	0.08	0.03	2009	0.05	0.45	0.31	0.10	0.03	0.02
	EU(c)	2012	0.09	0.28	0.21	0.11	0.10	0.06	2010	0.05	0.35	0.34	0.07	0.06	0.03
	Norway	2012	0.12	0.31	0.26	0.11	0.10	0.04	2009	0.05	0.61	0.12	0.16	0.02	0.02

The scenarios labelled (a), refer to the level of cuts in F in the HCR, corresponding to 25% above Bpa, 15% between Bpa and Blim and 10% below Blim for the EU rule, corresponding values for the additional scenarios (EU only) are labelled (b) 25%, 10% and 5% and (c) 15%, 10% and 5%. The Norwegian rule applies a 25% cut in fishing mortality in the first year followed by 15% in subsequent years for the recovery phase.

Table 2.3 Summary results of North Sea cod MSE for 13 scenarios. The columns labelled HCR, SR, OM, and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB being above Blim and Bpa in 2010, 2012, and 2015 and the average yield (Y, in '000 t) and the average fishing mortality (F) in 2008, 2010, 2012, and 2015. The red scenarios indicate the base case where there is bias due to unreported catch but where the bias is taken into account in the assessment process. The scenarios in bold, labelled a, refer to the level of cuts in F in the HCR, corresponding to 25% above Bpa, 15% between Bpa and Blim and 10% below Blim for the EU rule. Corresponding values for the new scenarios are labelled (b) 25%, 10% and 5% and (c) 15%, 10% and 5%.

Scen	HCR	SR	OM	OEM	TAC	p(>Blim)	p(>Blim)	p(>Blim)	p(>Bpa)	p(>Bpa)	p(>Bpa)	avg(Y)	avg(Y)	avg(Y)	avg(Y)	avg(F)	avg(F)	avg(F)	avg(F)
					constr.	2010	2012	2015	2010	2012	2015	2008	2010	2012	2015	2008	2010	2012	2015
1a	EU	1	catch	catch	yes	0.79	0.95	1.00	0.11	0.76	0.99	50.3	38.3	45.8	67.6	0.58	0.24	0.11	0.05
1b	EU	1	catch	catch	yes	0.79	0.95	1.00	0.11	0.76	0.99	50.3	38.3	45.9	67.7	0.58	0.24	0.11	0.05
1c	EU	1	catch	catch	yes	0.72	0.90	1.00	0.09	0.65	0.96	50.3	43.6	53.7	78.2	0.58	0.31	0.15	0.07
2a	EU	1	catch	m	yes	0.81	0.95	1.00	0.12	0.77	0.99	50.3	38.6	45.6	67.1	0.58	0.24	0.11	0.04
2b	EU	1	catch	m	yes	0.81	0.95	1.00	0.12	0.77	0.99	50.3	38.6	45.6	67.2	0.58	0.24	0.11	0.05
2c	EU	1	catch	m	yes	0.75	0.90	0.99	0.10	0.67	0.96	50.3	44.0	54.1	78.7	0.58	0.30	0.15	0.06
3a	EU	1	catch	wg	yes	0.71	0.86	0.98	0.08	0.60	0.92	50.3	46.6	57.0	82.2	0.58	0.35	0.17	0.07
3b	EU	1	catch	wg	yes	0.71	0.86	0.98	0.08	0.60	0.91	50.3	46.6	57.1	82.5	0.58	0.35	0.17	0.08
3c	EU	1	catch	wg	yes	0.65	0.76	0.87	0.07	0.52	0.80	50.3	52.1	64.9	91.5	0.58	0.42	0.25	0.13
4a	EU	1	m	catch	yes	0.63	0.83	0.96	0.04	0.45	0.87	37.2	28.6	33.0	47.4	0.43	0.22	0.13	0.08
4b	EU	1	m	catch	yes	0.63	0.83	0.96	0.04	0.45	0.87	37.2	28.6	33.0	47.5	0.43	0.22	0.13	0.08
4c	EU	1	m	catch	yes	0.58	0.78	0.92	0.04	0.40	0.78	37.2	32.4	39.0	55.4	0.43	0.27	0.19	0.11
5a	EU	1	m	m	yes	0.66	0.83	0.96	0.05	0.46	0.88	37.2	28.7	32.8	47.2	0.43	0.22	0.13	0.07
5b	EU	1	m	m	yes	0.66	0.83	0.96	0.05	0.46	0.88	37.2	28.7	32.9	47.2	0.43	0.22	0.13	0.07
5c	EU	1	m	m	yes	0.60	0.78	0.91	0.04	0.40	0.79	37.2	32.6	39.3	55.7	0.43	0.27	0.19	0.11
6a	EU	1	m	wg	yes	0.56	0.74	0.86	0.04	0.37	0.73	37.2	34.8	41.5	57.3	0.43	0.30	0.21	0.13
6b	EU	1	m	wg	yes	0.56	0.74	0.86	0.04	0.37	0.73	37.2	34.8	41.6	57.6	0.43	0.30	0.21	0.13
6c	EU	1	m	wg	yes	0.50	0.66	0.75	0.04	0.32	0.60	37.2	38.9	47.6	63.1	0.43	0.38	0.31	0.21

Scen	HCR	SR	OM	OEM	TAC	p(>Blim)	p(>Blim)	p(>Blim)	p(>Bpa)	p(>Bpa)	p(>Bpa)	avg(Y)	avg(Y)	avg(Y)	avg(Y)	avg(F)	avg(F)	avg(F)	avg(F)
					constr.	2010	2012	2015	2010	2012	2015	2008	2010	2012	2015	2008	2010	2012	2015
7a	EU	0.5	catch	catch	yes	0.79	0.92	0.96	0.11	0.68	0.90	50.3	38.3	44.5	63.4	0.58	0.25	0.14	0.08
7b	EU	0.5	catch	catch	yes	0.79	0.91	0.96	0.11	0.68	0.90	50.3	38.3	44.5	63.4	0.58	0.25	0.14	0.08
7c	EU	0.5	catch	catch	yes	0.71	0.85	0.90	0.08	0.56	0.82	50.3	43.6	51.0	70.6	0.58	0.31	0.19	0.13
8a	EU	0.5	catch	m	yes	0.80	0.92	0.97	0.12	0.68	0.92	50.3	38.6	44.0	62.6	0.58	0.25	0.14	0.08
8b	EU	0.5	catch	m	yes	0.80	0.92	0.97	0.12	0.68	0.92	50.3	38.6	44.1	62.6	0.58	0.25	0.14	0.08
8c	EU	0.5	catch	m	yes	0.74	0.85	0.90	0.10	0.58	0.82	50.3	43.9	51.0	69.9	0.58	0.31	0.20	0.13
9a	EU	0.5	catch	wg	yes	0.71	0.78	0.82	0.08	0.52	0.74	50.3	46.5	53.4	71.9	0.58	0.35	0.23	0.16
9b	EU	0.5	catch	wg	yes	0.71	0.78	0.82	0.08	0.52	0.74	50.3	46.5	53.5	72.0	0.58	0.35	0.24	0.16
9c	EU	0.5	catch	wg	yes	0.64	0.65	0.68	0.07	0.43	0.56	50.3	51.9	58.4	74.1	0.58	0.44	0.36	0.31
10a	EU	0.5	m	catch	yes	0.62	0.74	0.81	0.04	0.40	0.55	37.2	28.6	31.5	42.4	0.43	0.23	0.18	0.16
10b	EU	0.5	m	catch	yes	0.62	0.74	0.81	0.04	0.40	0.55	37.2	28.6	31.5	42.5	0.43	0.23	0.18	0.16
10c	EU	0.5	m	catch	yes	0.58	0.66	0.70	0.04	0.34	0.46	37.2	32.4	36.4	45.8	0.43	0.28	0.25	0.24
11a	EU	0.5	m	m	yes	0.66	0.76	0.82	0.05	0.39	0.56	37.2	28.7	31.2	41.4	0.43	0.23	0.17	0.15
11b	EU	0.5	m	m	yes	0.66	0.76	0.82	0.05	0.39	0.56	37.2	28.7	31.2	41.5	0.43	0.23	0.17	0.15
11c	EU	0.5	m	m	yes	0.60	0.66	0.69	0.04	0.33	0.46	37.2	32.6	36.5	45.3	0.43	0.28	0.25	0.23
12a	EU	0.5	m	wg	yes	0.56	0.65	0.60	0.04	0.29	0.42	37.2	34.8	38.3	45.6	0.43	0.31	0.30	0.31
12b	EU	0.5	m	wg	yes	0.56	0.65	0.60	0.04	0.29	0.42	37.2	34.8	38.3	45.6	0.43	0.31	0.30	0.31
12c	EU	0.5	m	wg	yes	0.49	0.54	0.46	0.04	0.24	0.31	37.2	38.8	42.5	45.1	0.43	0.39	0.47	0.66
13a	EU	1	catch	catch	no	0.79	0.94	1.00	0.11	0.74	0.98	50.3	41.2	91.7	307.3	0.58	0.26	0.22	0.39
13b	EU	1	catch	catch	no	0.79	0.94	1.00	0.11	0.74	0.98	50.3	41.2	91.6	307.3	0.58	0.26	0.22	0.39
13c	EU	1	catch	catch	no	0.72	0.90	1.00	0.09	0.64	0.94	50.3	45.4	90.5	275.7	0.58	0.31	0.24	0.36

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model (catch=bias due to unreported catch, m=bias due to changes in natural mortality). OEM refers to the Observation Error Model (landings=no correction for unre-

ported catch, catch=correction for bias due to unreported catch, m=correction for bias due to change in m). Note in above, avg(F) is instantaneous total fishing mortality (landings +discards) - average over ages 2-4, as specified in the HCR (and not harvest ratio as used in the previous report).

Table 2.4 Summary results of North Sea cod MSE for 13 scenarios. The columns labelled HCR, SR, OM, and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB achieving Bpa in any year and the year in which F is first reduced to 0.4. The red scenarios indicate the base case where there is bias due to unreported catch but where the bias is taken into account in the assessment process. The scenarios in bold, labelled a, refer to the level of cuts in F in the HCR, corresponding to 25% above Bpa, 15% between Bpa and Blim and 10% below Blim for the EU rule. Corresponding values for scenarios labelled (b) are 25%, 10% and 5% and (c) 15%, 10% and 5%.

Scen	HCR	SR	OM	OEM	TAC	Probability of achieving Bpa in year							Probability of achieving F=0.4 in year						
					constr.	Median	2010	2011	2012	2013	2014	2015	Median	2008	2009	2010	2012	2013	2014
1a	EU	1	catch	catch	yes	2012	0.11	0.34	0.31	0.14	0.07	0.02	2010	0.05	0.44	0.33	0.11	0.03	0.02
1b	EU	1	catch	catch	yes	2012	0.11	0.34	0.31	0.14	0.06	0.03	2010	0.05	0.44	0.33	0.11	0.04	0.02
1c	EU	1	catch	catch	yes	2012	0.09	0.30	0.27	0.18	0.08	0.05	2010	0.05	0.34	0.35	0.11	0.08	0.04
2a	EU	1	catch	m	yes	2012	0.12	0.36	0.30	0.14	0.06	0.02	2009	0.05	0.48	0.30	0.12	0.02	0.03
2b	EU	1	catch	m	yes	2012	0.12	0.36	0.30	0.14	0.06	0.02	2009	0.05	0.48	0.30	0.12	0.02	0.03
2c	EU	1	catch	m	yes	2012	0.10	0.29	0.28	0.16	0.10	0.04	2010	0.05	0.38	0.31	0.10	0.08	0.04
3a	EU	1	catch	wg	yes	2012	0.08	0.25	0.27	0.17	0.10	0.05	2010	0.05	0.33	0.27	0.13	0.08	0.05
3b	EU	1	catch	wg	yes	2012	0.08	0.25	0.27	0.17	0.10	0.05	2010	0.05	0.33	0.27	0.13	0.08	0.05
3c	EU	1	catch	wg	yes	2012	0.07	0.20	0.26	0.15	0.08	0.06	2010	0.05	0.28	0.18	0.14	0.08	0.07
4a	EU	1	m	catch	yes	2013	0.04	0.19	0.22	0.21	0.14	0.08	2009	0.21	0.51	0.18	0.04	0.02	0.02
4b	EU	1	m	catch	yes	2013	0.04	0.19	0.22	0.21	0.14	0.08	2009	0.21	0.51	0.18	0.04	0.02	0.02
4c	EU	1	m	catch	yes	2013	0.04	0.18	0.19	0.20	0.11	0.10	2009	0.21	0.38	0.25	0.06	0.03	0.02
5a	EU	1	m	m	yes	2013	0.05	0.20	0.21	0.22	0.13	0.08	2009	0.21	0.57	0.12	0.04	0.02	0.01
5b	EU	1	m	m	yes	2013	0.05	0.20	0.21	0.22	0.13	0.08	2009	0.21	0.57	0.12	0.04	0.02	0.01
5c	EU	1	m	m	yes	2013	0.05	0.19	0.19	0.18	0.12	0.10	2009	0.21	0.44	0.19	0.05	0.03	0.02
6a	EU	1	m	wg	yes	2013	0.05	0.17	0.18	0.16	0.15	0.08	2009	0.22	0.35	0.22	0.07	0.04	0.01

Scen	HCR	SR	OM	OEM	TAC	Probability of achieving Bpa in year							Probability of achieving F=0.4 in year						
					constr.	Median	2010	2011	2012	2013	2014	2015	Median	2008	2009	2010	2012	2013	2014
6b	EU	1	m	wg	yes	2013	0.05	0.17	0.17	0.17	0.15	0.09	2009	0.22	0.35	0.22	0.07	0.05	0.01
6c	EU	1	m	wg	yes	2013	0.05	0.16	0.17	0.15	0.13	0.09	2009	0.23	0.27	0.22	0.07	0.04	0.04
7a	EU	0.5	catch	catch	yes	2012	0.11	0.32	0.25	0.12	0.08	0.03	2009	0.05	0.45	0.31	0.10	0.03	0.02
7b	EU	0.5	catch	catch	yes	2012	0.11	0.32	0.25	0.12	0.08	0.03	2009	0.05	0.45	0.31	0.10	0.03	0.02
7c	EU	0.5	catch	catch	yes	2012	0.09	0.28	0.21	0.11	0.10	0.06	2010	0.05	0.35	0.34	0.07	0.06	0.03
8a	EU	0.5	catch	m	yes	2012	0.12	0.34	0.23	0.13	0.09	0.03	2009	0.05	0.49	0.29	0.08	0.03	0.02
8b	EU	0.5	catch	m	yes	2012	0.12	0.34	0.23	0.13	0.09	0.03	2009	0.05	0.49	0.29	0.08	0.03	0.02
8c	EU	0.5	catch	m	yes	2012	0.10	0.28	0.22	0.12	0.09	0.05	2010	0.05	0.39	0.31	0.07	0.05	0.02
9a	EU	0.5	catch	wg	yes	2012	0.09	0.26	0.21	0.10	0.07	0.09	2010	0.05	0.34	0.24	0.11	0.06	0.04
9b	EU	0.5	catch	wg	yes	2012	0.09	0.26	0.21	0.10	0.07	0.08	2010	0.05	0.34	0.24	0.11	0.06	0.03
9c	EU	0.5	catch	wg	yes	2012	0.09	0.25	0.25	0.09	0.10	0.01	2010	0.07	0.36	0.21	0.10	0.07	0.04
10a	EU	0.5	m	catch	yes	2013	0.05	0.22	0.20	0.06	0.09	0.08	2009	0.22	0.53	0.17	0.03	0.02	0.01
10b	EU	0.5	m	catch	yes	2013	0.05	0.22	0.20	0.06	0.09	0.09	2009	0.22	0.53	0.17	0.03	0.02	0.01
10c	EU	0.5	m	catch	yes	2013	0.05	0.22	0.19	0.06	0.12	0.06	2009	0.23	0.40	0.26	0.04	0.03	0.01
11a	EU	0.5	m	m	yes	2013	0.06	0.21	0.19	0.08	0.10	0.07	2009	0.22	0.59	0.11	0.03	0.02	0.01
11b	EU	0.5	m	m	yes	2013	0.06	0.21	0.19	0.08	0.10	0.07	2009	0.22	0.59	0.11	0.03	0.02	0.01
11c	EU	0.5	m	m	yes	2013	0.06	0.22	0.17	0.08	0.11	0.06	2009	0.23	0.48	0.20	0.03	0.02	0.01
12a	EU	0.5	m	wg	yes	2013	0.07	0.24	0.16	0.09	0.09	0.09	2009	0.24	0.39	0.23	0.03	0.03	0.02
12b	EU	0.5	m	wg	yes	2013	0.07	0.25	0.17	0.10	0.08	0.10	2009	0.24	0.39	0.23	0.03	0.03	0.02
12c	EU	0.5	m	wg	yes	2012	0.09	0.28	0.20	0.10	0.09	0.06	2009	0.29	0.34	0.25	0.04	0.02	0.02
13a	EU	1	catch	catch	no	2012	0.11	0.33	0.29	0.14	0.06	0.04	2010	0.05	0.44	0.33	0.11	0.03	0.02
13b	EU	1	catch	catch	no	2012	0.11	0.33	0.29	0.14	0.06	0.04	2010	0.05	0.44	0.33	0.11	0.03	0.02
13c	EU	1	catch	catch	no	2012	0.09	0.29	0.26	0.18	0.08	0.06	2010	0.05	0.33	0.35	0.10	0.06	0.05

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model (catch=bias due to unreported catch, m=bias due to changes in natural mortality). OEM refers to the Observation Error Model (landings=no correction for unreported catch, catch=correction for bias due to unreported catch, m=correction for bias due to change in m).

Table 2.5 Summary results of North Sea cod MSE for 13 scenarios to which the Norwegian rule is applied with a 25% in fishing mortality in the first year followed by 15% in subsequent years for the recovery phase. The columns labelled HCR, SR, OM, and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB being above Blim and Bpa in 2010, 2012, and 2015 and the average yield (Y, in '000 t) and the average fishing mortality (F) in 2008, 2010, 2012, and 2015. The red scenarios indicate the base case where there is bias due to unreported catch but where the bias is taken into account in the assessment process.

SCEN	HCR	SR	OM	OEM	TAC	P(>BLIM)	P(>BLIM)	P(>BLIM)	P(>BPA)	P(>BPA)	P(>BPA)	AVG(Y)	AVG(Y)	AVG(Y)	AVG(Y)	AVG(F)	AVG(F)	AVG(F)	AVG(F)
					constr.	2010	2012	2015	2010	2012	2015	2008	2010	2012	2015	2008	2010	2012	2015
14a	Norway	1	catch	catch	yes	0.87	0.97	1.00	0.12	0.78	1.00	50.3	49.8	81.6	153.6	0.58	0.29	0.18	0.12
15a	Norway	1	catch	m	yes	0.74	0.92	1.00	0.08	0.66	1.00	50.3	44.3	66.1	131.8	0.58	0.29	0.16	0.11
16a	Norway	1	catch	wg	yes	0.66	0.86	1.00	0.07	0.57	0.96	50.3	53.1	80.4	147.7	0.58	0.38	0.24	0.14
17a	Norway	1	m	catch	yes	0.70	0.83	0.98	0.05	0.46	0.84	37.2	36.8	52.6	89.0	0.43	0.29	0.21	0.16
18a	Norway	1	m	m	yes	0.58	0.78	0.96	0.04	0.42	0.81	37.2	32.9	44.1	79.5	0.43	0.28	0.19	0.14
19a	Norway	1	m	wg	yes	0.52	0.70	0.91	0.04	0.34	0.69	37.2	39.3	52.1	82.1	0.43	0.35	0.26	0.17
20a	Norway	0.5	catch	catch	yes	0.87	0.95	0.99	0.12	0.68	0.92	50.3	49.8	70.8	109.2	0.58	0.29	0.21	0.18
21a	Norway	0.5	catch	m	yes	0.74	0.88	0.96	0.08	0.58	0.91	50.3	44.3	56.9	93.6	0.58	0.30	0.19	0.16
22a	Norway	0.5	catch	wg	yes	0.66	0.74	0.88	0.07	0.50	0.74	50.3	53.0	68.8	96.2	0.58	0.39	0.29	0.20
23a	Norway	0.5	m	catch	yes	0.70	0.74	0.78	0.05	0.37	0.45	37.2	36.8	45.3	57.1	0.43	0.29	0.26	0.23
24a	Norway	0.5	m	m	yes	0.56	0.66	0.79	0.04	0.32	0.49	37.2	32.9	37.8	49.3	0.43	0.29	0.24	0.19
25a	Norway	0.5	m	wg	yes	0.52	0.60	0.61	0.04	0.26	0.33	37.2	39.2	44.2	48.2	0.43	0.36	0.34	0.23
26a	Norway	1	catch	catch	no	0.87	0.97	1.00	0.12	0.78	1.00	50.3	49.8	96.4	312.4	0.58	0.29	0.21	0.36

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model (catch=bias due to unreported catch, m=bias due to changes in natural mortality). OEM refers to the Observation Error Model (landings=no correction for unre-

ported catch, catch=correction for bias due to unreported catch, m=correction for bias due to change in m). Note in above, avg(F) is instantaneous total fishing mortality (landings +discards) - average over ages 2-4, as specified in the HCR (and not harvest ratio as used in the previous report).

Table 2.6 Summary results of North Sea cod MSE for 13 scenarios to which the Norwegian rule is applied with a 25% in fishing mortality in the first year followed by 15% in subsequent years for the recovery phase. The columns labelled HCR, SR, OM, and OEM refer to the different permutations of the assumptions underlying the simulations as explained at the bottom of the table. The results are shown as the probability of SSB achieving Bpa in any year and the year in which F is first reduced to 0.4. The red scenarios indicate the base case where there is bias due to unreported catch but where the bias is taken into account in the assessment process.

Scen	HCR	SR	OM	OEM	TAC	Yr to Bpa	Yr to Bpa	Yr to Bpa	Yr to Bpa	Yr to Bpa	Yr to Bpa	Yr to Bpa	Yr to F=0.4	Yr to F=0.4	Yr to F=0.4	Yr to F=0.4	Yr to F=0.4	Yr to F=0.4	Yr to F=0.4
					constr.	Median	2010	2011	2012	2013	2014	2015	Median	2008	2009	2010	2012	2013	2014
14a	Norway	1	catch	catch	yes	2012	0.12	0.34	0.33	0.15	0.06	0.01	2009	0.05	0.61	0.13	0.18	0.02	0.01
15a	Norway	1	catch	m	yes	2012	0.08	0.27	0.31	0.22	0.08	0.04	2010	0.05	0.34	0.33	0.16	0.09	0.03
16a	Norway	1	catch	wg	yes	2012	0.07	0.22	0.28	0.16	0.15	0.08	2010	0.05	0.30	0.22	0.20	0.09	0.11
17a	Norway	1	m	catch	yes	2013	0.05	0.19	0.22	0.17	0.14	0.08	2009	0.21	0.66	0.04	0.06	0.01	0.01
18a	Norway	1	m	m	yes	2013	0.04	0.17	0.20	0.19	0.12	0.11	2009	0.21	0.40	0.22	0.08	0.05	0.04
19a	Norway	1	m	wg	yes	2014	0.04	0.15	0.16	0.14	0.15	0.09	2009	0.21	0.30	0.19	0.12	0.08	0.06
20a	Norway	0.5	catch	catch	yes	2012	0.12	0.31	0.26	0.11	0.10	0.04	2009	0.05	0.61	0.12	0.16	0.02	0.02
21a	Norway	0.5	catch	m	yes	2012	0.08	0.26	0.25	0.14	0.12	0.08	2010	0.05	0.34	0.32	0.12	0.09	0.06
22a	Norway	0.5	catch	wg	yes	2013	0.07	0.21	0.22	0.09	0.10	0.08	2010	0.05	0.30	0.22	0.12	0.11	0.09
23a	Norway	0.5	m	catch	yes	2014	0.05	0.20	0.15	0.06	0.09	0.04	2009	0.21	0.66	0.04	0.04	0.00	0.04
24a	Norway	0.5	m	m	yes	2014	0.04	0.18	0.13	0.08	0.10	0.06	2009	0.21	0.40	0.22	0.04	0.04	0.03
25a	Norway	0.5	m	wg	yes	2015	0.04	0.16	0.11	0.07	0.05	0.07	2009	0.21	0.30	0.18	0.07	0.06	0.08
26a	Norway	1	catch	catch	no	2012	0.12	0.34	0.33	0.15	0.06	0.01	2009	0.05	0.61	0.13	0.18	0.02	0.01

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model (catch=bias due to unreported catch, m=bias due to changes in natural mortality). OEM refers to the Observation Error Model (landings=no correction for unreported catch, catch=correction for bias due to unreported catch, m=correction for bias due to change in m).

Table 2.7 Summary table of the North Sea cod simulation results with and without TAC constraints for the scenarios that correspond to the way the stock is currently assessed, and for the standard recruitment model. The results shown are the average yield and total fishing mortality (landings +discards) - average over ages 2-4 for the years 2008, 10, 12, and 15.

Scen	HCR	SR	OM	OEM	TAC	avg(Y)	avg(Y)	avg(Y)	avg(Y)	avg(F)	avg(F)	avg(F)	avg(F)
					constr.	2008	2010	2012	2015	2008	2010	2012	2015
1a	EU	1	catch	catch	yes	50.3	38.3	45.8	67.6	0.58	0.24	0.11	0.05
1b	EU	1	catch	catch	yes	50.3	38.3	45.9	67.7	0.58	0.24	0.11	0.05
1c	EU	1	catch	catch	yes	50.3	43.6	53.7	78.2	0.58	0.31	0.15	0.07
14a	Norway	1	catch	catch	yes	50.3	49.8	81.6	153.6	0.58	0.29	0.18	0.12
13a	EU	1	catch	catch	no	50.3	41.2	91.7	307.3	0.58	0.26	0.22	0.39
13b	EU	1	catch	catch	no	50.3	41.2	91.6	307.3	0.58	0.26	0.22	0.39
13c	EU	1	catch	catch	no	50.3	45.4	90.5	275.7	0.58	0.31	0.24	0.36
26a	Norway	1	catch	catch	no	50.3	49.8	96.4	312.4	0.58	0.29	0.21	0.36

HCR refers to the Harvest Control Rule that is applied (EC-rule or Norway rule). SR refers to the stock–recruitment relationship (1.0=standard, 0.5=reduced). OM refers to the assumption in the underlying operating model. The scenario labelled (a) refers to the level of cuts in F in the HCR, corresponding to 25% above Bpa, 15% between Bpa and Blim and 10% below Blim for the EU rule, corresponding values for the scenarios labelled (b) are 25%, 10% and 5% and (c) 15%, 10% and 5%.