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Evaluation of the proposed harvest control rule for Northeast Arctic saithe – background, population model, parameters, data and preliminary analyses

by

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1. INTRODUCTION

This working document addresses the first part of a request to ICES from the Norwegian Ministry of Fisheries and Coastal Affairs (MFCA) 4 December 2006:

"**Northeast Arctic saithe – management objectives**

Norwegian authorities are close to adopting a fishing strategy for saithe in the Norwegian waters north of 62^{nd} latitude (northeast arctic saithe). A draft prepared by the Norwegian Directorate of Fisheries was sent on a public hearing December 7. 2004.

As a member country Norway takes ICES' advice into account when deciding on the total allowable catch for saithe. The Ministry therefore asks ICES to evaluate and give advice on the long-term strategy. In order to facilitate for this, a translated version of the strategy is enclosed.

We will ask ICES to evaluate the potential excess value by setting the fishing mortality less than F_{pa}. Finally we would appreciate any advice from ICES on the effect of allowing live catch of saithe below minimum length for feeding.

Strategy for the harvesting of Northeast Arctic saithe
The yearly Total Allowable Catch (TAC) for Northeast Arctic saithe shall, within safe biological limits, be determined so that the highest potential economical yield is realized both

from the harvest of saithe and from the harvest of other species in interaction with saithe.

To achieve the abovementioned objective yearly Total Allowable Catch of north east arctic saithe shall, when circumstances does not order otherwise, be determined as follows:

1) The TAC for North East arctic saithe shall be set with basis in an average fishing mortality of 0,35 for the next three years within the year-classes 4-7.

2) Annual change in TAC shall not be more than 15 %.

3) Should the spawning stock level fall below B_{pa}, fishing mortality according to the above shall have a linear reduction from F_{pa} at B_{pa}, to zero when spawning stock is zero. At spawning stock below B_{pa}, there is no restriction on the maximum annual change of the TAC."

7 February 2007 ICES sent a letter to MFCA to clarify some points in the preliminary plan in order to be able to simulate the likely effects:

"In Paragraph 1, there is some uncertainty as to what is meant with the formulation average fishing mortality of 0,35 for 3 years', in particular what the term average refers to. With respect to the SSB referred to in Paragraph 3, it is unclear at which time the SSB should be considered. It could for example be the SSB in the last assessment year or the SSB after the TAC has been taken. Finally, it is also unclear what is meant with "the effect of allowing live catch of saithe below minimum length for feeding". Does that mean a directed fishery for juveniles in addition to the fishery for older fish, and if so, what magnitudes of such fishery would be relevant to consider?"

After consulting The Institute of Marine Research (IMR), MFCA 27 February confirmed that "Norway asks ICES to evaluate whether the following harvest control rule for setting the annual fishing quota (TAC) for Northeast Arctic saithe is consistent with the precautionary approach:

1) **estimate the average TAC level for the coming 3 years based on F_{pa}, TAC for the next year will be set to this level as a starting value for the 3-year period.**

2) **the year after, the TAC calculation for the next 3 years is repeated based on the updated information about the stock development, however the TAC should not be changed by more than +/- 15% compared with the previous year's TAC.**

3) **if the spawning stock biomass (SSB) in the beginning of the year for which the quota is set (first year of prediction), is below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at SSB=B_{pa} to 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC."**

MFCA withdrew the original request on advice from ICES on the effect of allowing live catch of saithe below minimum landing for feeding.

2. THE NORWEGIAN DIRECTORATE OF FISHERIE'S SUGGESTION TO A MANAGEMENT STRATEGY

ICES gives advice on annual TAC level based on the precautionary fishing mortality (F_{pa}). If the annual quotas are set according to this fishing mortality, the risk for stock collapse is low. Beyond that a TAC at this level does not imply any optimisation of neither biological nor economic yield from the stock. Evaluated as a natural resource, a fish stock should be managed to give the highest total economic yield for the society. This implies that one has to take into account a number of factors such as total yield for different stock sizes, stability, prices, costs and the stocks effect on other fish stocks.

During autumn 2004 the Norwegian Directorate of Fisheries (FDIR) suggested a management strategy for the stock of Northeast Arctic saithe (Anon 2004). Figure 1 shows the elements FDIR meant was important to take into account when choosing a management strategy:

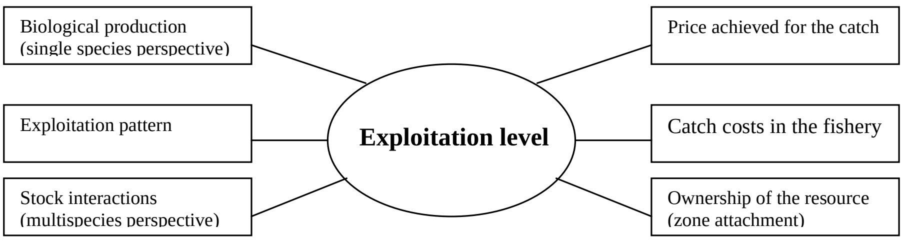

Figure 1 Some factors the exploitation level of NEA saithe may affect, and therefore should be taken into account when deciding the exploitation level.

Based on discussions and an over all evaluation of these factors FDIR suggested a management strategy similar to that for Northeast Arctic cod (Skagen et al. 2003; Bjordal *et a*l. 2004; Bogstad *et al*. 2004, 2005; ICES 2004/ACFM:28, ICES 2005/ACFM:20, Kovalev and Bogstad 2005), but with an exploitation level somewhat lower than what is biologically safe (F_{pa}). The strategy was based on a fishing mortality of F=0.20, and F_{pa} was at that time 0.26.

The complete suggestion for a management strategy were as follows:

1) The total quota for Northeast Arctic saithe shall be based on the average of the total quotas that a fishing mortality of 0.20 will produce the next three years.

2) The TAC shall not be changed from year to year by more than 10 %.

3) If the spawning stock falls below B_{pa}, the rule above shall be based on a fishing mortality that is changed linearly from 0.20 at B_{pa} to zero at spawning stock equal to zero. At such low spawning stock levels there is not set any limitation on variation in total quota from the year-to-year.

One reason for setting a lower fishing mortality than what is biologically safe was to aim at a somewhat larger saithe stock that may produce a higher long time yield. FDIR did not suggest an even lower fishing mortality (e.g. $F_{0.1}$) due to the role of saithe as a predator on economically important stocks in the ecosystem, or what is called ”Stock interactions” in Figure 1. A larger saithe stock is expected to consume more of other fish stocks that may be valuable for Norwegian fishermen.

3. PUBLIC HEARING AND FOLLOW UP

The management strategy drafted by FDIR was sent on a public hearing 7 December 2004. Most governmental organizations and some NGOs were positive to the suggestion. The Institute of Marine Research (IMR) also supported the strategy, but pointed out that the reference age groups used for calculating the reference F in the assessment were about to be evaluated in AFWG spring 2005 and might be changed from 3-6 years to 4-7 years, which would also effect PA reference points and the choice of F in the harvest rule. A few local community organizations and most stakeholder organizations were more critical. They found the strategy too rigid and wanted more room for quota adjustments (level out total quotas) when the quotas of NEA cod and haddock and North Sea saithe are low. If a management strategy has to be implemented it should be based on an exploitation at F_{pa}-level, similar to that for NEA cod and haddock. But first the PA reference points should be evaluated, and effects of stock interactions should be analysed. Having a large saithe stock, the costs in form of consumption of other fish species may be considerable. With the knowledge we have about this to day, they found it unwise to suggest such a low exploitation level as the Directorate of Fisheries did.

The Department of Marine Resources and Environment, MFCA, recommended further work with an aim of adopting a strategy for setting the annual TAC within the end of 2005. The Department suggested that ICES should evaluate the rule for different exploitation levels (0.20, 0.23 and 0.26) with different trigger points for reduction in F for the three alternatives, and with an alternative limit for annual change in TAC (25 %), as well as the effect of changing the reference age in the assessment from 3-6 years to 4-7 year. In a letter of 11 April 2005 MFCA asked FDIR and IMR to evaluate the usefulness of single species management strategies, the relation between cod, haddock and saithe, the suitability of multispecies models including the three species and the appropriateness of treating Northeast Arctic saithe as a “buffer stock” in relation to cod and haddock. MFCA further asked for an evaluation of the strategy applied in the setting of the TAC in later years and, if possible, what would the development of the saithe stock have been if the suggested management strategy had been applied in the setting of the TAC. Finally MFCA asked if it would be difficult to adjust the strategy to possible new reference points if ICES AFWG changed the reference age used in the assessment.

FDIR and IMR answered the different points in a joint letter. Regarding single species strategies, the few adopted have proven useful, giving predictability for the industry and preventing stock collapse. However, these strategies are built on simplified interactions both between stocks and fisheries. For predator stocks, where prey species also are commercially exploited, the usefulness of the management strategy would increase if the most important stock interactions were incorporated. For NEA saithe the economically most important interactions is with Norwegian spring spawning (NSS) herring. Quantification of this interaction is important, and FDIR and IMR already had planed to work on this autumn 2005. Beyond this there were no clear indications of strong biological linkage between saithe and cod/haddock, but the knowledge on this field is still scarce. Regarding the question about treating Northeast Arctic saithe as a "buffer stock" in relation to cod and haddock, FDIR and IMR answered that this could be possible, but would be a special kind of strategy in itself and no replacement for the suggested one. It could imply that in some years the fishing mortality would be well above F_{pa}, and this would have to be evaluated by ICES whether or not it is in accordance with the PA principle. It would also have to be evaluated against the different stakeholders and vessel groups.

ICES advice for NEA saithe has since 1999 been to reduce F below F_{pa} or keep F below F_{pa}. In the last years there has been a tendency to overestimate F and underestimate stock size in the assessment year. The exploitation pattern has improved over the last ten years with much lower catches of 2 and 3 year old fish, while the element of larger fish has been increasing. The estimation of F_{pa} performed in 1998 was based on the exploitation pattern in 1960-1996, and the F_{pa} of 0.26 was probably conservative compared to the exploitation pattern in later years. In later years the TAC has been set in accordance with the advice. These circumstances contributed to keep the exploitation well below F_{pa} and there was a rapid increase in stock size. The realized F has been closed to the suggested F of 0.2 in the management strategy. It would, however, mainly be speculations to evaluate what would the development of the saithe stock have been if the suggested management strategy had been applied in the setting of the TAC. Advised TAC would have been a little lower in the beginning of the period and the increase in stock size may be even more rapid. The realized F could have been even lower than 0.2, but this would probably have resulted in a demand of increasing F in the strategy towards F_{pa}.

The final question from the Ministry regarded adjustments to new reference points if ICES AFWG changed the reference age used in the assessment. At the AFWG spring 2005 (ICES CM 2005/ACFM:20) F_{bar} was changed from 3-6 to 4-7 and age at recruitment from 2 to 3, and the lim and pa reference points were re-estimated. The lim reference points were estimated according to the new methodology outlined in ICES CM 2003/ACFM:15, while the pa reference point estimation was based on the old procedure (ICES CM 1998/ACFM:10). The new F_{pa} of 0.35 estimated with reference age 4-7 years does not necessarily imply a higher yield than a F_{pa} of 0.26 estimated with reference age 3-6 years. However, the catches of 3-year olds have been low in the last ten years, and F_{3-6} have become lower than the F on the dominating age groups in the fishery since it is estimated as an arithmetic unweighted average over the actual age groups. Also the realized F_{bar} in the fishery will be higher with the new reference age. The F of 0.20 in the suggested management strategy was a compromise between high long term yield at $F_{0.1}$ = 0.12 and a higher F taking stock interactions into account, limited upwards against the F_{pa} of 0.26. With the new reference age, the exploitation level should probably be in the upper half of the interval between the corresponding re-estimated values of 0.15 ($F_{0.1}$) and 0.35 (F_{pa}), i.e. between 0.25 and 0.35. FDIR and IMR therefore recommended that ICES should evaluate the rule for exploitation levels 0.25, 0.30 and 0.35 and limits for annual change in TAC of 10 and 25 %. It was further recommended that the trigger point for reduction in F was set independent of exploitation level since all alternatives were at or below F_{pa} for stock sizes above $B_{pa.}$

4. ANALYSIS OF EFFECTS OF STOCK INTERACTIONS

Even if FDIR to some extent took predator interactions into account in the suggested management strategy, these costs could of course legitimize a higher exploitation level. To evaluate this it was necessary to quantify the saithe stock's predation and what economic loss this predation implies in form of lost catch in other fisheries. One of the most important prey items for NEA saithe is young age groups of NSS herring (Mehl WD 7 2005) and the costs of this predation was estimated (Mehl *et al*. 2006a and b; Mehl *et al*. WD 10 2006). Such predator costs will also depend on how one manages/exploits the herring, but only the management strategy adopted for Norwegian spring spawning herring by the coastal states in 2001 was applied. This implies that herring consumed by saithe alternatively could have materialized as catch through the adopted management strategy, of which Norway would have received a fixed amount.

First the saithe stock's annual consumption of different age groups of herring was estimated. Then it was projected what the consumed herring could have produced in form of yield in the herring fishery if it not had been eaten by saithe. The costs of the saithe's consumption were estimated as what economic yield this herring could have given Norwegian herring fishers. Figure 2 presents one of analyses made where the expected spawning stock, gross catch value in the saithe fishery, predator costs and total catch value (gross catch value in the saithe fishery minus predator costs) changes with increasing fishing mortality.

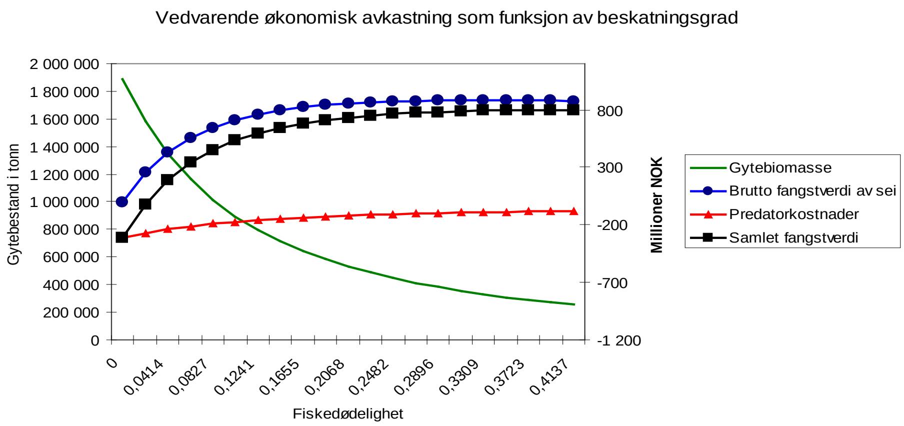

Figure 2 Spawning stock biomass, gross first hand value of saithe, predator costs and total catch value in relation to fishing mortality. First hand value of saithe is 6 NOK/kg., first hand value of herring is 2 NOK/kg.

Finally it was evaluated if these costs imply that the suggested management strategy should be changed. There are large uncertainties connected to all the factors that enter the estimations. The estimations was, however, carried out to get an indication of what the costs of the saithe's predation on herring could imply and how it could affect the choice of management strategy for saithe.

The following was concluded:

- The saithe's predation on herring reduces the economic yield in the herring fishery
- When the price of saithe increases relative to the price of herring, the costs of predation are of less importance for the total economic yield in the saithe and herring fisheries.
- If the predation on herring is reduced proportionally with a reduction in saithe stock size, the total economic yield will increase with increasing fishing mortality in the saithe fishery in the whole interval considered (0-0.41), but the increase is marginal for Fs above 0.30.

Depending on the assumptions made, these analyses indicate that the exploitation level of Northeast Arctic saithe should be in the interval 0.30 – 0.35. The total economic yield in the saithe and herring fisheries will, however, not increase significantly if the fishing mortality of saithe is increased from 0.30 to 0.35, while the expected spawning stock biomass of saithe is somewhat reduced. Considering the uncertainties in all data and stock assessment and the need for stability in quotas from year to year, one should consider carefully if such a marginal increase in expected economic yield is preferred.

5. GENERAL CONSIDERATIONS FOR EVALUATION OF HARVEST CONTROL RULES

Evaluation of HCRs is usually done using simulation models for the population(s) in question. The scope, nature and quality standards of simulation models that may be used in order to evaluate HCRs are discussed e.g. by Skagen *et al*. (2003) and described by SGMAS (ICES 2005/ ACFM:09, ICES 2006/ACFM:15, ICES 2007/ACFM:04). SGMAS also gives guidelines for evaluation of management strategies.

Important issues for evaluation of harvest control rules are:

- Choice of population model
- Inclusion of uncertainty in population model
- Use of long-term and/or medium-term simulations
- Choice of initial values for simulations
- Choice of harvest control rules for use in the evaluation (constant F rules, how to reduce F when $SSB<B_{pa}$, limit on year-to-year variation in catch etc.)
- Performance measures for harvest control rules (yield, stock size, F, probability of $SSB<B_{lim}$, annual variation in catches etc.)

These issues are addressed below.

6. POPULATION MODEL USED

Several variants of the population model were tried. In all cases, 2000 simulations for the period 2006-2126 were performed and the results for the last 100 years of this period were considered. This is done in order to exclude the effect of the initial values. The stock size for 2006 (initial data) was taken from the 2006 assessment.

The 'default' model was:

- A Beverton-Holt spawning stock-recruitment model with lognormal error distribution
- Assessment error and bias are estimated as age-dependent, normally distributed.
- Density-dependent weight at age in catch (average for 1981-2005 used for age groups where density-dependence was not found)
- Weight at age in stock is set equal to weight at age in catch
- Time series (1986-2005) average used for maturation at age without density-dependence
- No uncertainty in weight at age, maturity at age or natural mortality at age
- Exploitation pattern: 1997-2005 averages used for all age groups in all years
- Implementation of catch: First, the catch at age is calculated from the perceived stock using the fishing mortality derived from the harvest control rule and the given exploitation pattern. This catch at age is then applied to the actual stock.
- Implementation error and bias is estimated using the same percentage for all age groups

Recruitment

The recruitment dynamics shows some relatively clear changes over time. This is not to easily infer from the pattern of residuals over time, but are quite clear when visualizing the dynamics using 5 year running means for both SSB and recruitment.

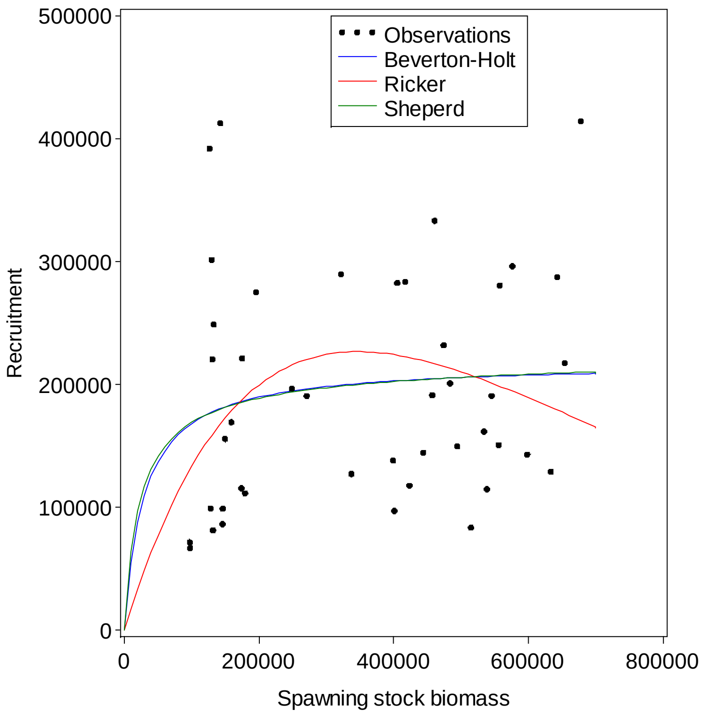

Figure 3. Spawning Stock - Recruitment (age 3) plot for North East Arctic Saithe**.**

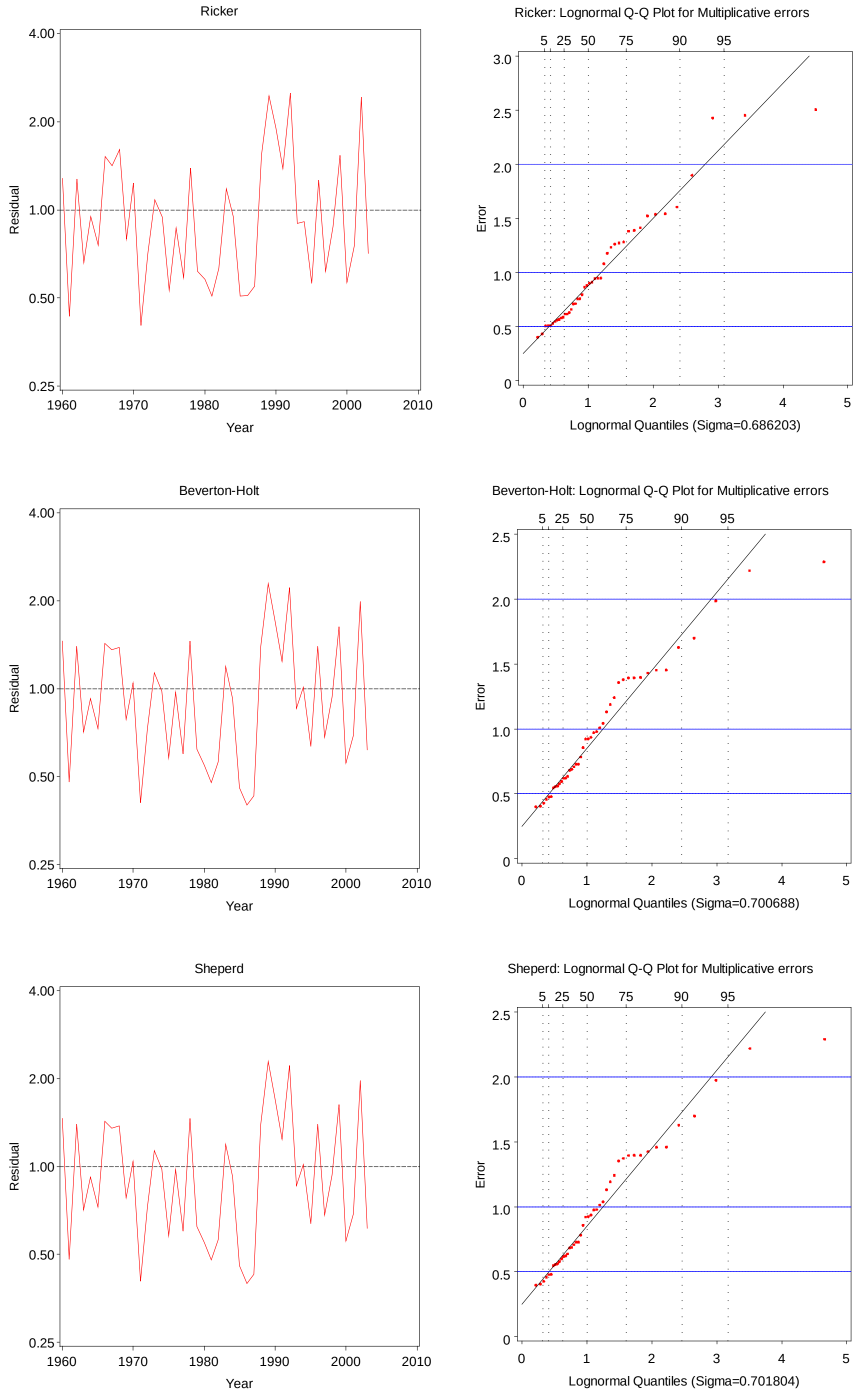

Figure 4. Multiplicative residuals (left) and their Lognormal Q-Q plot (right) for different SR model fits.

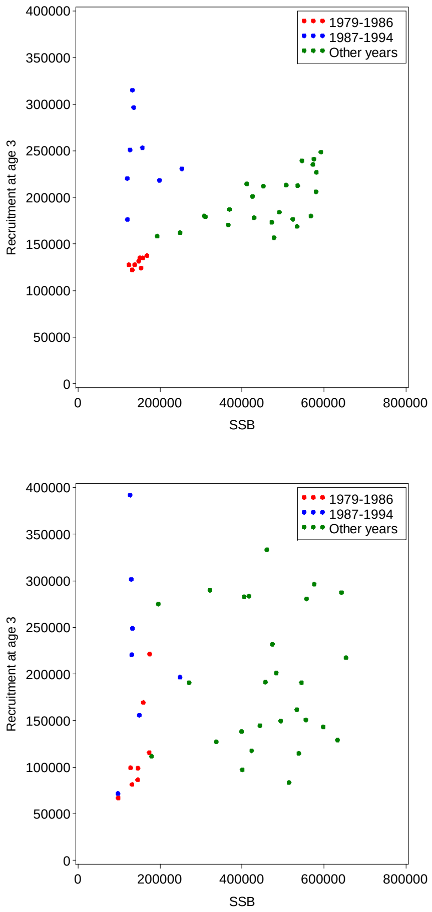

Figure 5. SSB vs R using 5 year running mean (upper left), SSB - R using a 3 year running mean (upper right) and the SSB-R plot (bottom left) with the points grouped into different time periods.

For modelling recruitment, we followed the approach outlined by Skagen and Aglen (2002). They suggested 3 quality criteria for stochastic stock-recruitment functions:

1. Independence between residuals and SSB
2. Probability coverage
3. The recruitment estimates should be unbiased.

We tried both a Beverton-Holt, Ricker and segmented regression stock-recruitment relationship as well as normal and log-normal error distributions, and found a Beverton-Holt relationship with a log-normal error distribution to give the best fit to the data. A constraint on the sum of the difference between modelled and observed recruitments being zero was applied.

The Beverton-Holt stock-recruitment function with a log-normal error distribution is given by

$$R = \frac{a * SSB}{b + SSB} e^{\varepsilon}$$

where the stochastic term ε is normally distributed N(0,σ).

The fit was done using Solver in Excel spreadsheets described by Skagen and Aglen (2002). The following values of a, b and σ were estimated (units: tonnes and thousand of fish)

a=207703, b=49415, σ = 0.478

Criterion 1) was been tested for by looking at the deterministic stock-recruitment function (Fig. 6). The residuals are not correlated with SSB, but the variability in recruitment seems to be higher at low SSBs, and this could be modelled by making the variance a function of SSB.

2) is a control that the distribution assumed for the residuals is adequate, while 3) may be used as an additional constraint when finding the parameters of the stock-recruitment function.

Assuming that each of the historic residuals is equally likely, the rank of each of them, divided by the number of observed residuals, gives the empirical cumulated probability of the historical residuals. On the other hand, according to the model that is assumed for the residuals in the prediction, there corresponds a cumulated probability for the value of each observed residual. Each of these model probabilities should be close to the empirical cumulated probability of the same historic residual. The Kolmogorov goodness of fit test is based on this reasoning, and the Kolmogorov test statistic can be derived directly from the pairs of modelled and observed values.

Fig. 7 and 8 show the probability coverage and observed vs. modelled recruitment for this distribution. The fit seems to be rather satisfactory.

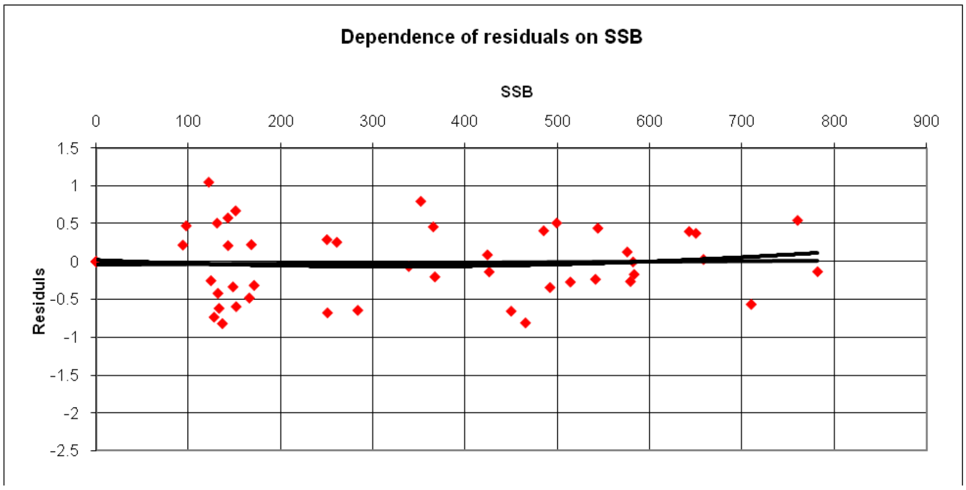

Figure 6. Residuals with linear and 2nd order trend lines relative to SSB.

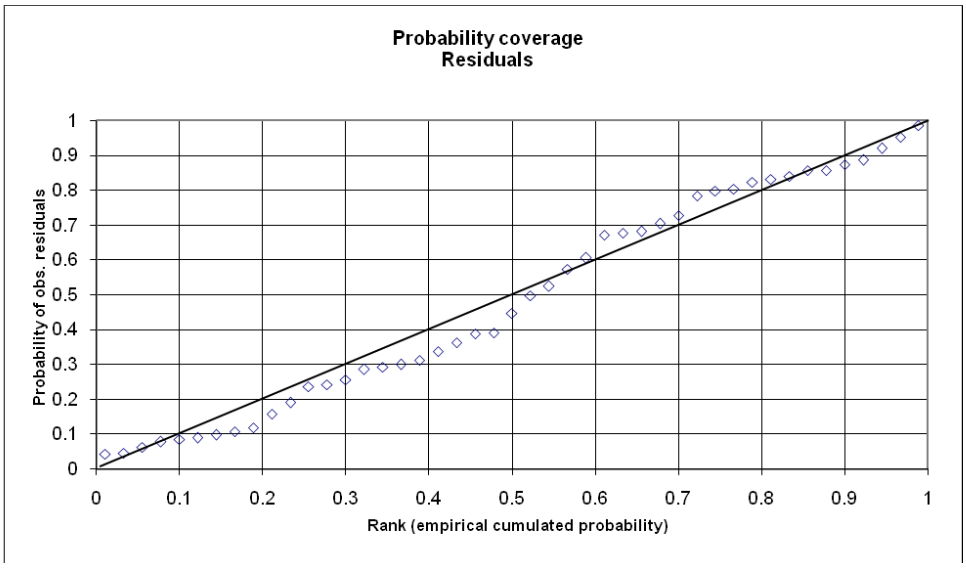

Figure 7. Probability coverage of residuals

Figure 8. Observed cumulative frequency of recruitment vs. modelled cumulative frequency of recruitment

Growth (weight at age)

Growth is modelled as density dependent. We have used the time series of catch weights in 1990-2005 vs. total stock biomass in 1989-2004 to fit a density-dependent model for weight at age (kg) in the stock $ws_{a,y}$ for ages 3-10. The model is of the form

$$ws_{a,y} = -\alpha_a TSB_{y-1} + \beta_a$$, where

TSB_y is the total stock biomass in year y, a is age and α_a and β_a are constants. Regressions are shown in Figure 9a-i and the parameters in the regressions are given in Table 1.

Age	α_a	β_a	R^2	p
3	-0.0489	0.70432	0.0257	> 0.05
4	-0.1487	1.12823	0.0903	> 0.05
5	-0.4365	1.89119	0.2803	> 0.05
6	-0.599	2.58340	0.3783	0.029
7	-0.931	3.51032	0.4217	0.024
8	-1.1976	4.38208	0.4562	0.030
9	-1.3471	5.20247	0.4244	0.046
10	-1.5778	6.15132	0.4258	0.002

Table 1. Parameters in regression for density-dependent weight at age in catch

The relationship for ages 3-5 is insignificant. For those ages TSB could not be used as predictor and we use average values for these age groups. For age 10+ we also use a historic average.

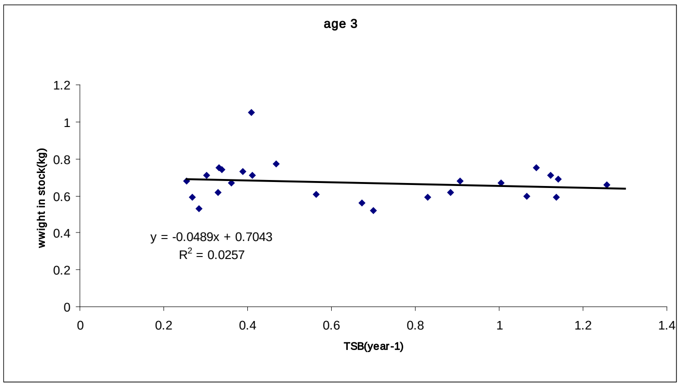

Figure 9a. Weight in catch vs. total stock biomass for age 3 saithe

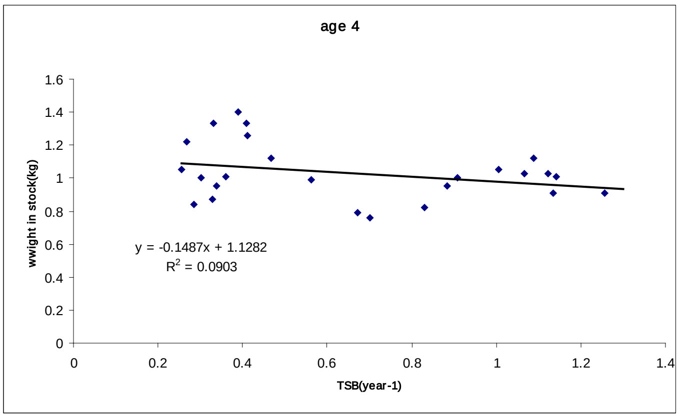

Figure 9b. Weight in catch vs. total stock biomass for age 4 saithe

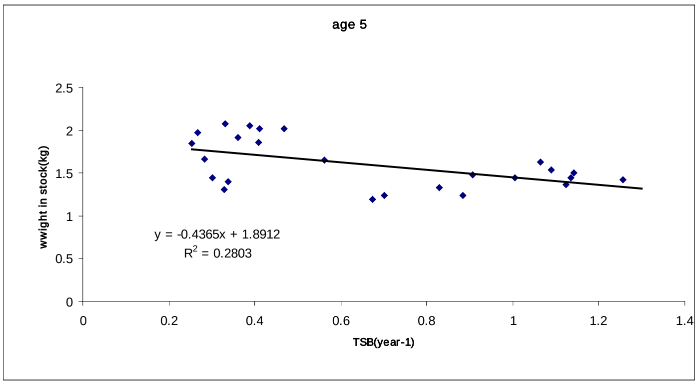

Figure 9c. Weight in catch vs. total stock biomass for age 5 saithe

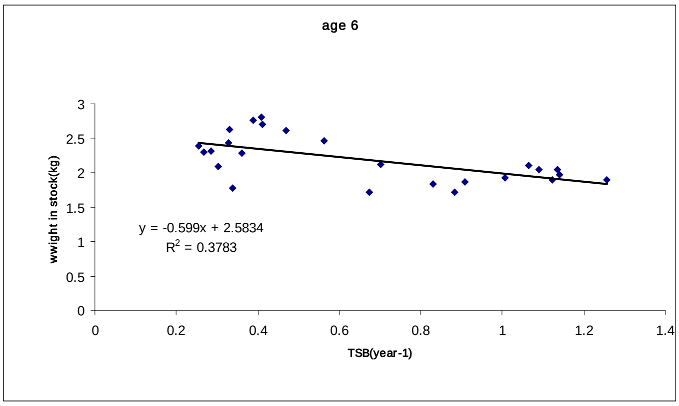

Figure 9d. Weight in catch vs. total stock biomass for age 6 saithe

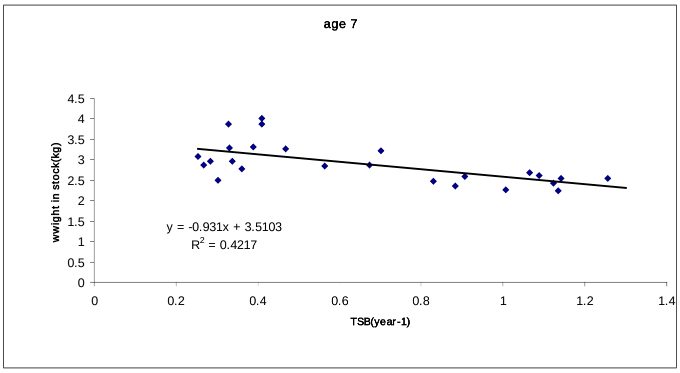

Figure 9e. Weight in catch vs. total stock biomass for age 7 saithe

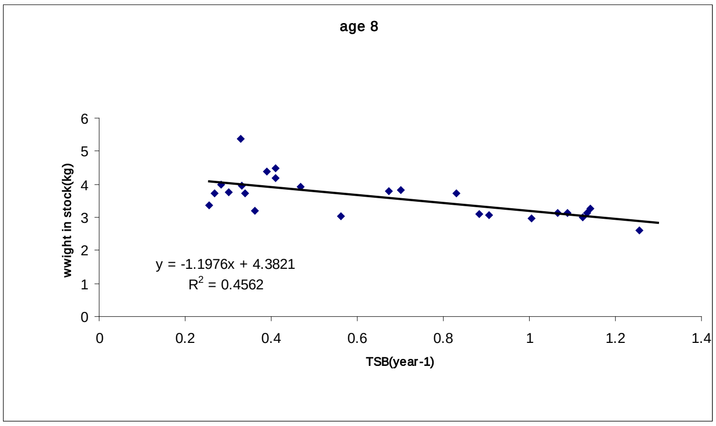

Figure 9f. Weight in catch vs. total stock biomass for age 8 saithe

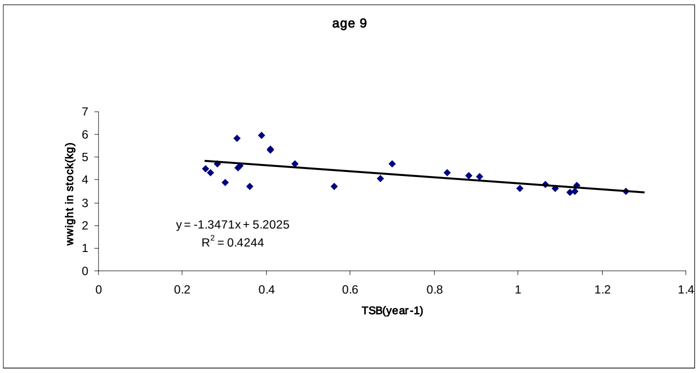

Figure 9g. Weight in catch vs. total stock biomass for age 9 saithe

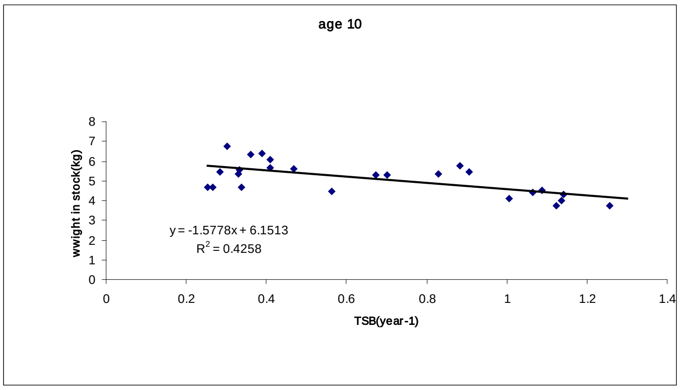

Figure 9h. Weight in catch vs. total stock biomass for age 10 saithe

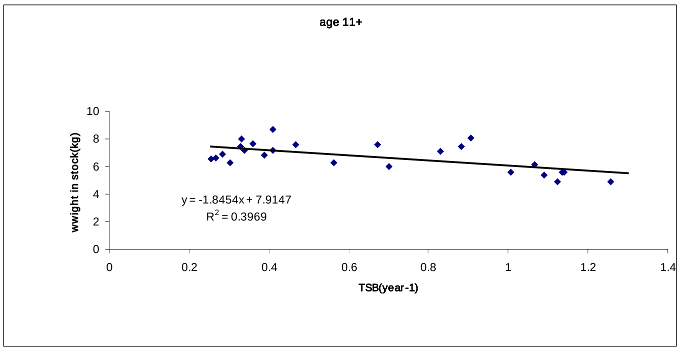

Figure 9i. Weight in catch vs. total stock biomass for age 11 saithe

Maturity

Maturity at age was analysed for density dependence, but no significant results were found. Therefore the time series (1986-2005) average was used for maturation at age.

Fishing mortality/fishing pattern

The exploitation pattern has improved over the last ten years with much lower catches of 2 and 3 year old fish, while the element of larger fish has been increasing. The minimum landing size was increased in 1999, but the improvement started even before this, partly due to regulations and partly due to better prices for larger saithe. There is no reason to include periods when the pattern was significantly different from what it can be expected to be in the future, due to different regulations. We have therefore used the 1997-2005 averages by age for all years (Table 2). Since the fishing patterns are calculated by a VPA, the computed Fs contain all the noise in the catch data. It may be necessary to smooth the fishing pattern in order not to include more noise than appropriate.

Table 2. Exploitation pattern 1997-2005 with average for the period

Age	1997	1998	1999	2000	Year 2001	2002	2003	2004	2005	1997 2005
3	0.0662	0.0258	0.0344	0.0713	0.0215	0.0220	0.0237	0.0064	0.0444	0.0351
4	0.1105	0.1221	0.1351	0.1064	0.0818	0.1299	0.2317	0.0796	0.1224	0.1244
5	0.2049	0.1576	0.2533	0.1186	0.178	0.1640	0.1382	0.2379	0.1644	0.1797
6	0.2655	0.2910	0.1991	0.1795	0.1921	0.2561	0.1410	0.1523	0.2447	0.2135
7	0.2927	0.2605	0.2816	0.1734	0.1753	0.1702	0.1408	0.2148	0.2202	0.2144
8	0.2278	0.1875	0.1583	0.1915	0.1270	0.1512	0.2617	0.1727	0.2461	0.1915
9	0.1435	0.1361	0.1650	0.1709	0.1579	0.1338	0.1776	0.2048	0.2113	0.1668
10	0.1720	0.1849	0.1530	0.1909	0.1921	0.1659	0.2013	0.2299	0.3186	0.2010
11+	0.1720	0.1849	0.1530	0.1909	0.1921	0.1659	0.2013	0.2299	0.3186	0.2010

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Assessment and implementation error

Assessment and implementation error and bias are estimated explicitly as percentages of stock over/under estimation and over/under fishing. The assessment bias and error are modelled as age-dependent, with no correlation between age groups. The pattern used is based on an historical analysis. Two approaches were used to estimate the pattern. First, the bias in the number at age in the period 1999-2005 was calculated by comparing the estimated number at age in the year when the assessment was carried out, to the number at age from the 2006 assessment (Year-by-year method). The mean and standard deviation of this ratio was calculated for each age group. Second, the retrospective VPA-runs were compared to the assessment in 2006, to estimate the bias (Retrospective method). Data from 1999 to 2005 were used to calculate the relative bias and corresponding standard deviations. It was decided to apply for all age groups normal distributed errors around the mean values for the age group with the largest σ, truncated at ± 2.5σ. The two approaches are compared in the text table below:

METHOD	AGE	3	4	5	6	7	8	9	10	11+
Year-by-year method	Bias	1.00	1.05	0.58	0.56	0.49	0.43	0.43	0.38	0.61
	St. dev	0.37	0.39	0.29	0.25	0.19	0.17	0.18	0.19	0.58
Retrospective method	Bias	1.00	1.05	0.62	0.60	0.50	0.47	0.46	0.42	0.71
	St. dev	0.39	0.47	0.26	0.21	0.17	0.15	0.18	0.20	0.65

The two methods gave quite similar results, and a year-by-year analysis for the period 1995-2001 also gave similar results, but with a slightly lower bias. For both methods the 11+ group showed an opposite trend in the last year (2005), i.e. an overestimation in the assessment year. This result was confirmed by preliminary analysis of 2006 data (2007 assessment), and it was decided not to smooth or average the 11+ group data. Because the assessment methodology and settings have varied considerably during the period, it was decided to base the analysis on the estimated bias and variance from the retrospective runs. In periods of stock decrease, the trend of the bias may change from positive to negative, as for NEA cod in the last half of the 1990s. It was therefore decided to also perform analyses with the opposite trend in assessment bias.

Implementation error and bias is modelled using the same percentage for all age groups. To explore the amount of bias and error to introduce, the relation between catch and quota for the period 1989-2006 was fitted to a normal distribution. The fit was considered acceptably good for the purpose and the estimated parameters were $\mu = 1.032$ and $\sigma = 0.09$. Thus, it was decided to include a bias of 3% with normally distributed error with a CV of 0.08 truncated at $\pm 2.5\sigma$ for all age groups.

Reality check

A reality check of the 'default' model was made with $F_{4\text{-}7} = 0.38$ for all SSB levels, 50% maximum year-to-year-change in TAC and three options for assessment error. $F_{4\text{-}7} = 0.38$ is equal to the average fishing mortality for the period 1960-2005. Three runs were performed, one with no assessment error (option 1), one with assessment error estimates based on the period 1999-2005 (option 2) and one with an opposite trend in assessment error (option 3). For option 1 the realised F is slightly higher than 0.38 due to the implementation error included in the simulations. Recruitment, TSB and SSB are all close to the VPA average. The stock sizes are much higher for option 2 with a positive retrospective trend in assessment error while with the opposite trend (option 3) the stock sizes are lower than the historic averages. The catches from all simulations are higher than the historic average due to a better fishing pattern in the simulations. The runs indicate that the model performs reasonably well at this level of fishing mortality. The small difference between the VPA average F and the average F in the simulation option 1 is due to the implementation bias.

	$F_{4\text{-}7}$	Recruitment (million)	TSB (1000 t)	SSB (1000 t)	Catch (1000 t)
VPA average 1960-2005	0.38	189	696	366	160
Simulation result opt. 1	0.395	200	771	378	193
Simulation result opt. 2	0.30	209	983	572	186
Simulation result opt. 3	0.53	195	673	292	192

7. SOFTWARE USED

The simulations were carried out using the PROST software for stochastic projections (Åsnes 2007). PROST was especially developed for this purpose because existing software for harvest control rule simulations such as WGMTERM, STPR and CS5 do not incorporate the 3-year averaging process (hereafter called the '3-year-average-rule') for setting TAC given by the agreed decision rule. However, PROST is intended as a general tool for stochastic projections.

8. MATHEMATICAL FORMULATION OF THE RULE

Let y denote the year for which the quota is to be set. Let the term "3-year rule (F1, x)" denote applying the 3-year average rule described above with $F_{4\text{-}7} = F1$ and an x % limit on year-to-year changes in TAC. The limit on increase of TAC from year to year could be set different from the limit on decrease from year to year, but such asymmetric rules were not tested. It is assumed that SSB(y) is not affected by F(y), which is in line with the current settings used by AFWG (the proportion of F and M before spawning is set to 0).

The rule can then be described in the following way:

If SSB(y) > B_{pa} then

if SSB(y-1) > B_{pa} and SSB(y+1) > B_{pa} and SSB(y+2) > B_{pa}

F(y) set by 3-year rule(0.35, 15)

else

F(y) set by 3-year rule(0.35, unconstrained)

else

F(y) set by 3-year rule($0.35\frac{SSB(y)}{B_{pa}}$,unconstrained)

SSB(y+1) and SSB(y+2) in this calculation is derived using F=0.35 in years y and y+1.

In addition, we will test the performance of the rule in a situation where stock rebuilding is needed.

9. LONG-TERM SIMULATIONS

The various settings used in long-term simulations are described in Table 3, and the results of the simulations are described in Table 4.

Table 3. Settings for each run

Run No.	F	3-year rule	Option for assessment error	Percent change TAC	F below Bpa
1	0.35	No	1	15	Flat
2	0.35	Yes	1	15	Linear
3	0.35	Yes	2	15	Linear
4	0.35	Yes	3	15	Linear
5	0.35	Yes	2	10	Linear
6	0.35	Yes	3	10	Linear
7	0.35	Yes	2	20	Linear
8	0.35	Yes	3	20	Linear
9	0.30	Yes	1	15	Linear
10	0.30	Yes	2	15	Linear
11	0.30	Yes	3	15	Linear
12	0.25	Yes	1	15	Linear
13	0.25	Yes	2	15	Linear
14	0.25	Yes	3	15	Linear

Most of the results of the simulations are quite similar. Catches range from 174 000 to 200 000 tonnes, recruits from 195 to 214 millions, while the variations in estimated biomasses are larger, SSB range from 317 000 to 850 000 tonnes. Only in one case, with an opposite retrospective trend and for the highest F alternative, there is a very small risk of falling below

Table 4 Results of long-term simulations. Catch, TSB and SSB in 1000 tonnes, recruits in millions.

Run No.	Error option	Input F	Realised F	Catch	TSB	SSB	Recr.	% years SSB< B_{lim}	% years SSB< B_{pa}	Average year-to-year change in TAC
1	1	0.35	0.36	194	823	421	202	0	0	5
2	1	0.35	0.37	194	813	413	202	0	0.001	3
3	2	0.35	0.29	185	1015	602	209	0	0	10
4	3	0.35	0.48	193	703	317	195	0	3	8
5	2	0.35	0.29	184	1016	602	209	0	0	8
6	3	0.35	0.48	193	704	318	195	0.005	3	7
7	2	0.35	0.29	185	1017	603	210	0	0	11
8	3	0.35	0.48	193	702	317	195	0	3	9
9	1	0.30	0.32	196	917	499	206	0	0	3
10	2	0.30	0.25	181	1140	713	212	0	0	10
11	3	0.30	0.41	198	790	384	201	0	0.049	8
12	1	0.25	0.26	194	1044	609	210	0	0	3
13	2	0.25	0.21	174	1291	850	214	0	0	9
14	3	0.25	0.33	200	897	473	205	0	0	8

$B_{lim.}$ However, the risk is so low that it is not considered not to be consistent with the precautionary approach. Catches are in general highest for option 3 and lowest for option 2, and the opposite for the biomass estimates, while option 1 (no assessment error) is intermediary. In a situation with underestimation of stock size in the assessment year (option 2), the highest exploitation rate (F=0.35) give the highest catches, for the opposite trend in assessment error F=0.25 gave the highest catch, while for no assessment error (option 1) the long-time yield is quite similar for all exploitation levels. For all three options the highest biomass estimates are found at the lowest exploitation level. And in a situation with an opposite trend in assessment error (option 3) the risk of falling below B_{lim} will increase for increasing exploitation level and/or for increasing assessment bias. The highest average year-to-year change in TAC of 11 % was found in run 7 where the limit was set to 20 %. The part of the HCR limiting the annual change in TAC to 15 % is therefore probably not too restrictive and it was large enough to maintain SSB above B_{lim} in practically all the simulated cases.

10. CONSEQUENCES OF THE RULE IN A PERIOD OF RECOVERY

To study the performance of the rule in a stock recovery situation we made runs starting in 1986 and ending in 1993. 1986 was chosen because it was a year with a fairly low stock size, the total stock size was 284 000 tonnes and the SSB was 98 000 t, i.e. below B_{lim}.

For 1986, the weight at age in the stock and in the catch, maturity-at-age, natural mortality at age, fishing pattern and F were set to the same values as used in the assessment made by the

ICES Arctic Fisheries Working Group in 2006. For 1986 and later years, the following values were used:
Recruitment at age 3: For the recruitment in 1987 and 1988 the same values as calculated in the 2006 assessment with a CV of 0.25 were used while for later years the stock-recruitment relationship from the long-term simulations of the HCR was used.
Weight, maturity and natural mortality at age: The same values as used in the 2006 assessment were used.
Fishing pattern: The average of the 1987-1990 pattern estimated by the 2006 WG was used.

Two runs were made, one with no bias in the assessment and on with an "opposite trend" in assessment bias compared to what is experienced in later years (option 3 in the long-term simulations). A CV of 0.25 was set for initial stock size in both runs and future stock assessments in the run with no bias (run 1), while for run 2 the same bias and bias and CV as in option 3 in the long-term simulations was used for future stock assessments. The implantation error was the same as in the long-term simulations of the HCR for both runs. 2000 simulations were performed in each case.

The results of the simulations are given in Tables 5-9. In run 1 the probability of SSB being below B_{lim} is 1 for the first year (1987), very low the next year and zero the following years. The probability for the SSB to be below B_{pa} is 1 during the first two years, but then decreases during the next three years. Also in run 2 the probability of SSB being below B_{lim} is 1 for the first year (1987), low the next year, very and zero the following two years and zero in the last year presented (1991). The probability for the SSB to be below B_{pa} is 1 during the first two years, close to 1 in the next two years but then decreases in the last year. The SSB reaches B_{pa} one year earlier in run 1 than in run 2, while realised F and catches are highest for run 2.

Table 5 Mean SSB (1000 tonnes) in 1986-1991 for different runs.

Run no.	Mean SSB 1986	Mean SSB 1987	Mean SSB 1988	Mean SSB 1989	Mean SSB 1990	Mean SSB 1991
1	98	87	181	203	227	279
2	98	87	164	182	191	231

Table 6 Probability of SSB <> B_{pa} in 1986-1991 for different runs.

Run no.	P(SSB < B_{pa}) 1986	P(SSB < B_{pa}) 1987	P(SSB < B_{pa}) 1988	P(SSB < B_{pa}) 1989	P(SSB < B_{pa}) 1990	P(SSB < B_{pa}) 1991
1	1	1	0.9785	0.7795	0.4085	0.0595
2	1	1	1	0.954	0.886	0.413

Table 7 Probability of SSB<> B_{lim} in 1986-1991 for different runs.

Run no.	P(SSB < B_{lim}) 1986	P(SSB < B_{lim}) 1987	P(SSB < B_{lim}) 1988	P(SSB < B_{lim}) 1989	P(SSB < B_{lim}) 1990	P(SSB < B_{lim}) 1991
1	1	1	0.0065	0	0	0
2	1	1	0.0745	0.0095	0.005	0

Table 8 Mean catches (1000 tonnes) in 1986-1991 for different runs

Run no.	Mean catch 1986	Mean catch 1987	Mean catch 1988	Mean catch 1989	Mean catch 1990	Mean catch 1991
1	71	43	95	114	128	136
2	71	57	100	126	138	138

Table 9 Mean F values in 1986-1991 for different runs

Run no.	Mean F 1986	Mean F 1987	Mean F 1988	Mean F 1989	Mean F 1990	Mean F 1991
1	0.54	0.21	0.36	0.41	0.41	0.39
2	0.54	0.33	0.49	0.57	0.54	0.51

These runs were made for a situation where the stock was low, but a strong year class was entering the fishable stock (the 1983 year class). Thus, this analysis does not cover all recovery situations.

11. CONCLUSIONS

The analyses presented indicate that the HCR proposed by The Norwegian Ministry of Fisheries and Coastal Affairs is in agreement with the precautionary approach, provided that the assessment uncertainty, assessment error and implementation error are not greater than those calculated from historic data and used in the evaluation.

According to the simulations made, the HCR will help rebuild the stock to above B_{lim} level within three years.

It should be noted that the conclusions drawn here is based on a risk level of 5 %. They will also hold for higher risk levels. The risk level to use should be decided by managers. If lower risk levels than 5 % is preferred, the harvest control rule should be evaluated against that level.

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