ICES WKNEAMP-2 REPORT 2016

ICES ADVISORY COMMITTEE

ICES CM 2016/ACOM:47

Report of the second workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-2)

25–28 January 2016

Kirkenes, Norway

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

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

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2016. Report of the second workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-2), 25–28 January 2016, Kirkenes, Norway. ICES CM 2016/ACOM:47. 104 pp.

Contents

Executive summary

WKNEAMP-2 met in Kirkenes, Norway 25–28 January 2016 to carry out an evaluation of harvest control rules (HCRs) for Northeast Arctic cod and haddock and Barents Sea capelin. The managing body (Joint Norwegian-Russian Fisheries Commission, JNRFC) has made a request for evaluation of a number of alternative harvest control rules for these three stocks (ten for cod, six for haddock and four for capelin, including the rules currently in use).

For cod and haddock, the evaluation was based on long-term stochastic simulations. Supplementary information was obtained from short-term predictions. The proposed rules differed in terms of target fishing level and stability criteria. For cod, there were also a number of 'two-step' rules (i. e. rules where the fishing mortality is increased at high SSB levels).

For cod, all rules were found to be precautionary, and the difference in long-term yield between the rules was small, while the difference in variability in catch between the rules was considerable. The current HCR seems a reasonable compromise with regard to average catch, and with regard to long and short term stability of catches. The target fishing mortality of 0.40 in the current HCR is high compared to what has been advised for other cod stocks in recent years.

For haddock, all proposed rules were found to be precautionary, although the rule with the highest target fishing mortality (0.43) is close to the limit for being precautionary. Also, a rule with a very strict stability criterion (max 10% annual variation in catches compared to 25% which is presently used), performed poorly in terms of long-term yield. For the other rules, as for cod, the difference in long-term yield between the rules was small while the difference in variability in catch between the rules was considerable.

For capelin, a simplified model described in Section 5 of this report was used to illustrate the general effects of changing the current HCR. A survey biomass (maturing capelin) result below around 1150 kt indicates that the fishery be closed. Each doubling of the risk from 5% to 10% and from 10% to 20% adds about 50 kt to the TAC and the minimum survey biomass that will allow a fishery is lowered by about 150 kt. The assessment model for capelin includes predation from cod, and the results apply to cod biomasses which are expected under current management and current productivity of the NEA cod stock. It is advised to keep the present HCR. The appropriateness of B_{lim} (=200 kt) was reviewed and it was concluded that there is no evidence suggesting that this value should be changed.

1 Introduction

1.1 Background

At its 45th session in October 2015, the Joint Norwegian-Russian Fisheries Commission (JNRFC) decided that a number of alternative harvest control rules (HCRs) for Northeast Arctic cod and haddock and Barents Sea capelin should be evaluated by ICES (Anon, 2015, Appendix 19). The rules are described in Annex 1 to this report. The first Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-1) was held 24–26 November 2015 in Murmansk, Russia (ICES, 2015a).

Following the request and WKNEAMP-1, ICES decided that:

The Second Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-2), chaired by Bjarte Bogstad, Norway, will be established and meet 25–28 January 2016 in Kirkenes, Norway to:

a) Taking into account the input from the reviewers, conclude the work required to respond to the joint Norwegian – Russian request, to evaluate possible harvest control rules for:

i. Cod (Gadus morhua) in Subareas I and II (Northeast Arctic);

ii. Haddock (Melanogrammus aeglefinus) in Subareas I and II (Northeast Arctic) and

iii. Capelin (Mallotus villosus) in Subareas I and II, excluding Division IIa west of 5°W (Barents Sea capelin);

To the largest extent possible, the evaluation should follow the guidelines provided by the "Workshop on Guidelines for Management Strategy Evaluations" (ICES, 2013a), including the guidelines for reporting provided in Section 6 of the WKGMSE report. The agreed ACOM criteria for considering management plans as precautionary should also be taken into account in the evaluation.

If reference points need to be reconsidered during the evaluation, the current ICES guidelines on reference points approved by ACOM in 2015 shall be considered.

WKNEAMP-2 will report by 12 February for the attention of the Advisory Committee.

1.2 Structure of this report

The report is organised with Section 2 describing the common issues to all stocks such as choice of software, simulation technicalities, and terminology. The evaluation methods and results are described in one section for each stock (Section 3: Cod, 4: Haddock, 5: Capelin). References are found in Section 6. The request is given in Annex 1, list of participants in Annex 2 and reviewers' conclusions in Annex 3.

2 Simulation issues

2.1 Software used

PROST (Åsnes, 2014) is a tool for making single-fleet, single-area long-term stochastic projections and was used for the simulations. It is available on the ICES website (http://ices.dk/marine-data/tools/Pages/Software.aspx). PROST has previously been used in the evaluation of harvest control rules for Northeast Arctic cod, haddock and saithe.

For cod, some of the proposed HCRs could not be realized in the present version of PROST, while all the proposed HCRs for haddock could be realized. Also, some of the biological models (e.g. autocorrelation in recruitment) could not be realized in PROST as it is now. Updating of the PROST code to include this option was not considered an option, as the PROST programmer is no longer employed by IMR.

In order to simulate new HCRs, special ad-hoc software was developed. The model is similar to the previously used software, PROST, and is called new Prost or NE_PROST[1]. It is realized in Excel. Excel sheets are used as source of input data and to print out results of calculations from simulation models. Program code is realized as macros written in Visual Basic. The program is open for reading and changing. Some Excel sheets are used to calculate all processes in a "traditional" way by Excel formulas to check if the program calculates things correctly. NE_PROST software is available on the WKNEAMP-2 SharePoint site.

Some runs with PROST for cod were made for comparison with NE_PROST for testing purposes and the discrepancies between the results from PROST and NE_PROST were very small (WD3 in ICES, 2015a).

For capelin, the CapTool model (Gjøsæter *et al.*, 2002 and 2015) was used.

2.2 Banking and borrowing – cod and haddock

In 2014, JNRFC introduced 10% annual quota flexibility (banking and borrowing) for national quotas (Norway and Russia) for cod and haddock. This feature is not included in the request for evaluation of HCRs. Evaluations made of banking and borrowing for other stocks (e. g. for NEA mackerel: ICES, 2014; North Sea herring: ICES, 2012; North Sea saithe: ICES, 2013b; North Sea plaice: ICES, 2013c; Blue whiting: ICES, 2013d) indicate that the effect of 10% banking and borrowing on the performance and risk levels for harvest control rules is fairly small, thus it was decided not to include this feature in the simulations.

2.3 Simulation periods and guidelines – cod and haddock

We used three years for short-term simulations and 80 years for long-term (running for 100 years but discarding the first 20 years).

In the short-term, consequences of various HCRs can be illustrated using deterministic prognoses as made by AFWG (Arctic Fisheries Working Group). For long-term, stochastic simulations should be used.

The guidelines from WKGMSE (ICES, 2013a) were considered and discussed. 5% probability of SSB < B_{lim} was defined as the precautionary criteria. For the stationary

[1] For further information, please contact the Chair of WKNEAMP, B. Bogstad.

period (years 21–100), Risk type 1 (average of annual probabilities) was considered relevant.

2.4 Terminology for harvest control rules with two steps

Some of the suggested rules for cod (no. 6–10) are of this kind.

Such a rule has been used e.g. for blue whiting (ICES, 2013d, see Fig 2.1), and we will use the terminology indicated in Figure 2.1 in this report.

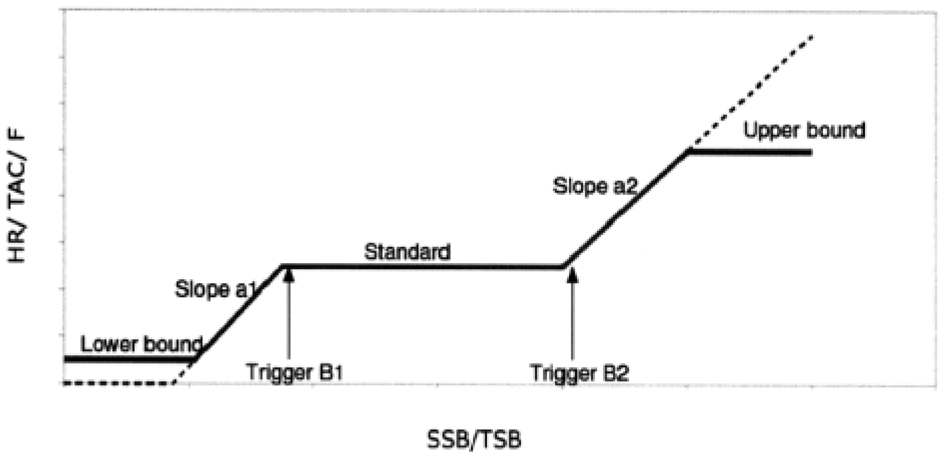


Figure 1. General outline of the new harvest rule examined, with different parameters indicated.

Figure 2.1. Suggested terminology for two-step harvest control rules.

3 Northeast Arctic cod

3.1 Data series used

The time series for weight (in catch and in stock), maturity, fishing mortality and natural mortality at age used in this document were taken from the 2015 report of the ICES Arctic Fisheries Working Group (ICES, 2015b).

3.2 Modelling of biological processes

A summary of the modelling of the biological processes is given in Table 3.1.

3.2.1 Recruitment

A comprehensive description of modelling of stock-recruitment relationship modelling for this stock is found in WD6 to WKARCT 2015 (ICES, 2015c). The segmented regression approach used to simulate stock-recruitment relationships for NEA cod during HCR evaluations. The model was extended by including a cyclic term as well as a stochastic term using equation 3.1:

$$R_3(year+3) = f(SSB(year))e^{A*Sin(\frac{2\pi(year-1946+\varphi)}{T})+\varepsilon} \tag{3.1}$$

where:

SSB(year) – spawning stock biomass in year;

R3(year+3) – recruitment at age 3 in year +3;

A – amplitude of the sinusoid function;

ϕ – phase, deviation against the starting year 1946;

T – period of oscillation;

ε – random error;

f(SSB) is a segmented regression:

$$f(SSB) = \min(\frac{\alpha}{\beta}SSB, \alpha) \tag{3.2}$$

The segmented regression function fitted to data series for the year classes 1946–2011 is shown in Figure 3.1.

Table 3.1. Models/processes and associated input data for NE_PROST for cod.

Models/processes	Relationship	Function	Limits (if any)	Period of data used	Reference/comment
Recruitment underlying function	$R_y=f(SSB_{y-3})+\varepsilon$	Segmented Regression + cyclic term $R_3(year+3)=f(SSB(year))e^{A*Sin(\frac{2\pi(year-1946+\varphi)}{T})+\varepsilon}$	R_{max} observed	1946–2014	WD1, WKNEAMP-1 (ICES, 2015a)
Random noise distribution for R	Log-normal	Residuals drawn from observations (nonparametric in simulations)	Max R = maximum observed	1946–2014	WD1, WKNEAMP-1 (ICES, 2015a)
Cannibalism(M2)	Included for ages 3-5 $M2_{age3}=f(R)+f(SB6+)$; $M2_{age 4/age5}=f(M2_{age 3})$	ln(M2) = ln(N3) * a + ln(SB6+) * b + c M2 (age 4/5) = a * M2 (age 3)	0–0.388	1946–2014	WD1, WKNEAMP-1 (ICES, 2015a)
WEST (Ws)	W for ages 3-5 – constant values; W_y for ages 6-13 = $f(TSB_{y-1})$	$ws_{a,y}=\alpha_a TSB_{y-1}+\beta_a$	Limits for all ages (min observed – max observed for 1946–2015)	1946–2015	WD1, WKNEAMP-1 (ICES, 2015a)
WECA (Wc)	Wc=f(Ws) for ages 3-8; WEST=WECA for ages 9-13+	$wc_{a,y}=\alpha_a ws_{a,y}+\beta_a$		1983–2014 (Survey and catch weights for regression available since 1983)	WD1, WKNEAMP-1 (ICES, 2015a)
Maturity ogives	P_{age}=f(generation)	$P_{age,y}=\frac{1}{1+e^{-a\ (age-b*TSB_y+c)}}$	Limits for all ages (min observed – max observed) for 1946-2015	1946–2015	WD1, WKNEAMP-1 (ICES, 2015a)
Selection pattern	Constant	Mean		1995–2014	AFWG 2015 (ICES, 2015b)
Capelin dynamics	Replication by n times		min observed – max observed	1973–2015	AFWG 2015 (ICES, 2015b)

Models/processes	Relationship	Function	Limits (if any)	Period of data used	Reference/comment
Implementation errors	Log normal distribution	real catch * EXP(normal (mean, sigma))	± 2 sigma	2004–2014 Without IUU catches	WD4, WKNEAMP-1 (ICES, 2015a)
Assessment errors	Normal distribution	real N * Normal (mean, sigma) * bias	± 2 sigma	2001–2014	WD4 , WKNEAMP-1 (ICES, 2015a)

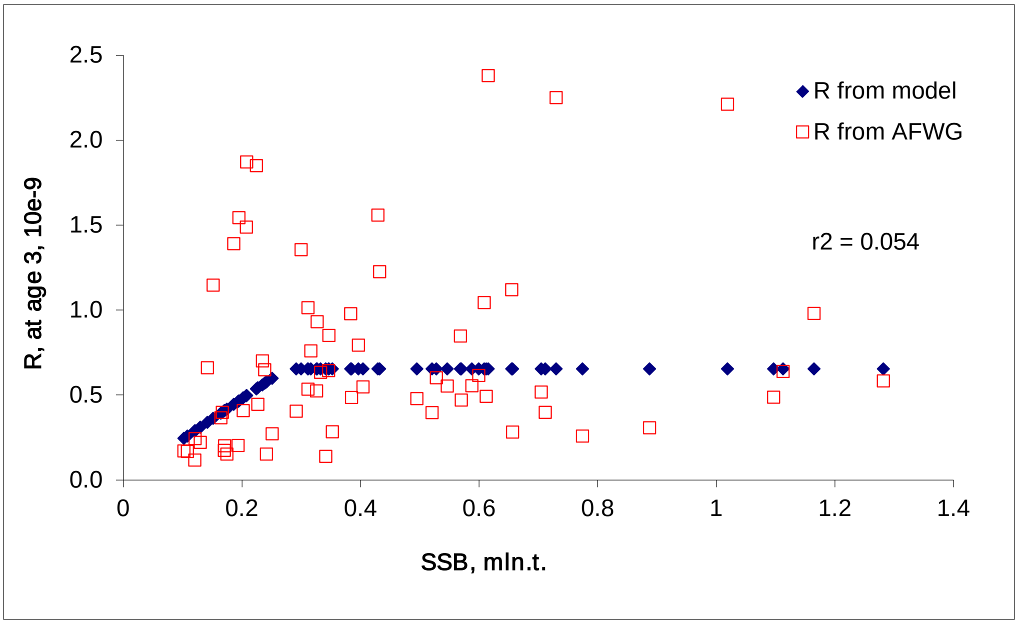


Figure 3.1. Segmented regression recruitment function fit to data for spawning stock biomass and recruitment at age 3 (R estimated with cannibalism since 1946).

The residuals obtained when fitting the segmented regression stock-recruitment relationship vary in a cyclic way with time. This cyclic term was included in the exponent in equation (3.1). The model fit (minimising log SSQ) using Solver in Excel. The models do not pick up the outstanding year classes, but significantly increased r^2 of models (Figure 3.2).

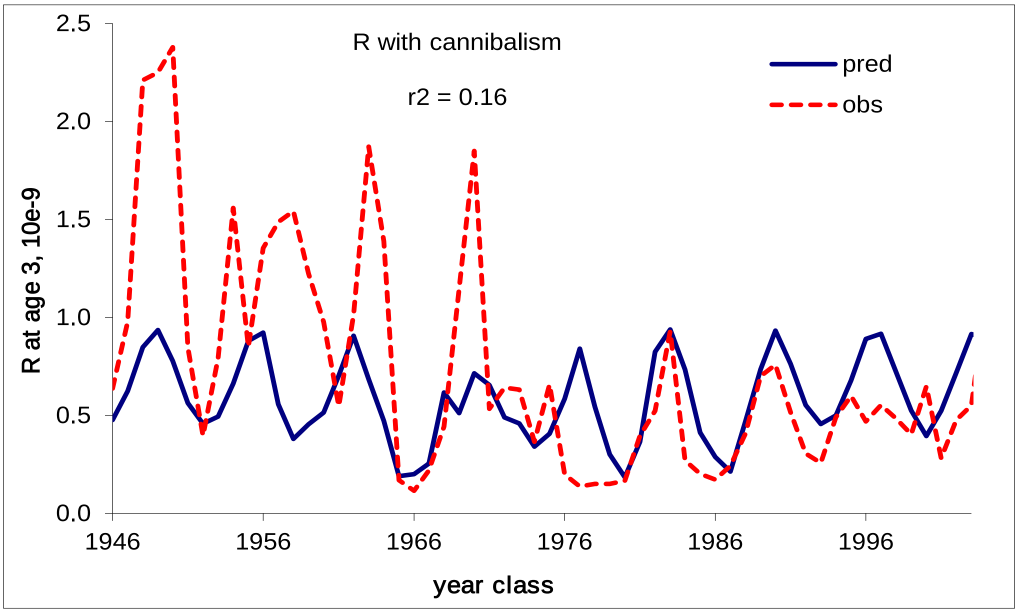


Figure 3.2. Observed vs. modelled recruitment when a cyclic term is included in the recruitment function.

Diagram of residuals for the segmented regression including cyclic term models are presented in Figure 3.3. The distribution is not symmetric and possibly the best way of simulating it in a population model is bootstrapping of observed residuals in order to obtain distributions and densities similar to those observed.

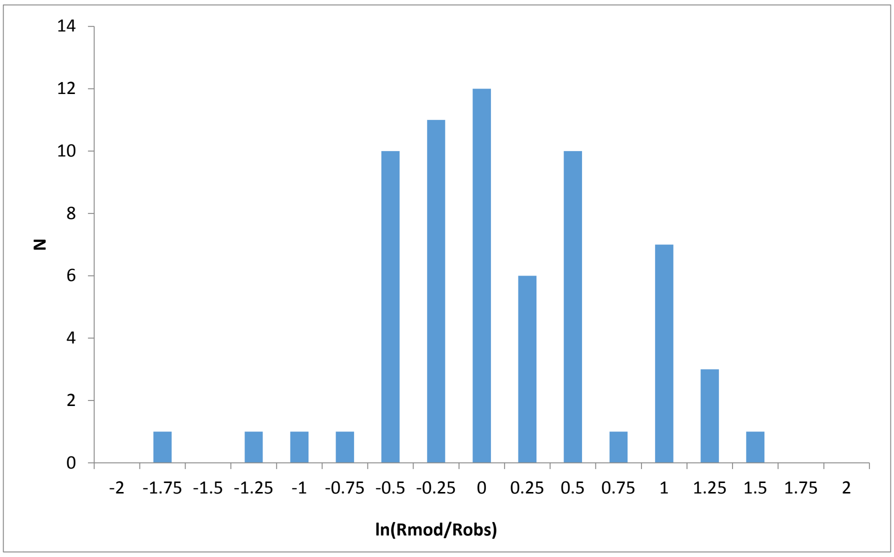


Figure 3.3. Distributions of segmented regression including cyclic term models residuals (ln(Rmod/Robs).

3.2.2 Cannibalism and natural mortality

In the last version of the population model two predictors were used for cannibalism mortality: SSB with -3 year lag and biomass of cod (SB) at ages 6–7 in the beginning of year. A new time series including of cannibalism mortality since 1946 is available now (ICES, 2015b). Both previously used predictors show worse power of relationship with this time series. The coefficients of determination were reduced from 0.74 to 0.2 for SSB and from 0.28–0.38 to 0.08 for SB 6–7.

A number of new candidates were explored and the most promising predictors were abundance of cod at age 3 (index of available preys) as well as biomass of cod at ages 6 and older (index of predators). Logarithmic functions perform better compared to linear ones. Residuals of linear functions were not normally distributed and have long tails. So, in order to normalize model residuals and get a better fit all data were log transformed (Figure 3.4):

$$\ln(M2) = \ln(N3) * a + \ln(SB6+) * b + c \qquad (3.3)$$

where M2 is the natural mortality of cod at age 3 due to cannibalism; N3 (unit: 10^9) is cod abundance at age 3 in the beginning of year; SB_{6+} (unit: million t) is biomass of cod at ages 6 and older; a, b, c – parameters.

Equation 3.3 was used only for age group 3.

M2 at ages 4 and 5 are well correlated with M2 at age 3. The constant terms of these linear regressions are assumed to be equal to 0.

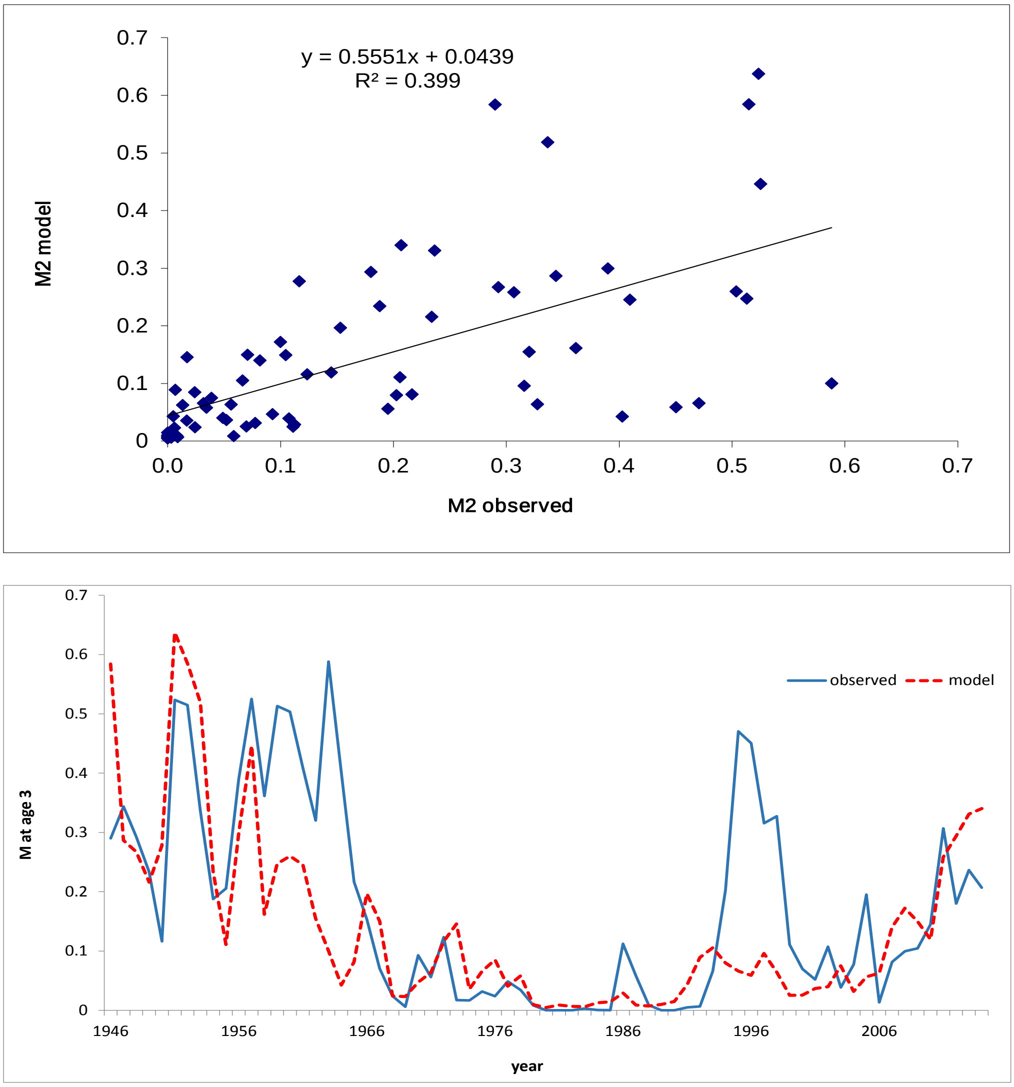


Figure 3.4. Modelled vs. observed cannibalism mortality of cod at age 3 in linear (upper figure) and time series dynamic (lower figure).

Model coefficients and correlation coefficients are presented in Table 3.2. It should be noted that in order to obtain a better fit, multispecies considerations, e.g. cannibalism inversely related to capelin abundance, could be included. The periods when observed cannibalism is much higher than observed values (early 1960s, mid-1980s, mid-1990s) are all periods with low capelin abundance. Although this relationship is not very strong (Figure 3.4) it could be concluded that in periods where capelin biomass exceeded 4 million tonnes NEA cod cannibalism on age 3 and older cod was negligible.

Table 3.2. Predictors and parameters in regressions for cannibalism mortality.

Age	predictors	a	b	c	R^2	p
M2 at age3	N at age3, SB_{6+}	1.124	1.223	-2.065	0.40	<0.01
M2 at age4	M2 at age3	0.366	-	-	0.93	<0.01
M2 at age5	M2 at age3	0.091	-	-	0.76	<0.01

3.2.3 Growth/weight at age

Both the entire time series (stock weights in 1947–2015 vs. total stock biomass in 1946–2014) and the time series for which survey weights are available (stock weights in 1983–2015 vs. total stock biomass in 1982–2014) were used to fit a density-dependent model for weight at age (kg) in the stock $ws_{a,y}$ for ages 3–9. The model is of the form

$$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a \tag{3.4}$$

where TSB_y is the total stock biomass in year y, a is age and α_a and β_a are constants. The parameters in the regressions are given in Table 3.3 (entire time series) and Table 3.4 (shortened time series).

The range of possible values of cod weight was truncated, in order to avoid unrealistic values due to extrapolations. The highest/lowest observed values of cod weight at each age were used as upper/lower bounds in the model.

Table 3.3. Parameters in regression for density-dependent weight at age in the stock, and minimum, maximum and average value for the period 1946–2015.

age	α_a	β_a	R^2	p	min. observed weight	max. observed weight	mean weight
3	0.001	0.323	0.00	>0.05	0.194	0.518	0.328
4	-0.034	0.757	0.04	<0.05	0.404	1.172	0.683
5	-0.059	1.374	0.07	<0.05	0.790	1.820	1.245
6	-0.109	2.284	0.13	<0.01	1.477	2.823	2.041
7	-0.191	3.507	0.21	<0.01	2.140	4.059	3.081
8	-0.317	5.119	0.26	<0.01	2.920	5.833	4.413
9	-0.574	7.310	0.38	<0.01	3.650	8.927	6.032
10	-0.920	10.080	0.38	<0.01	4.560	12.154	8.036
11	-1.157	12.151	0.37	<0.01	5.840	15.026	9.569
12	-0.981	13.359	0.32	<0.01	7.080	12.731	11.127
13	-1.187	15.764	0.43	<0.01	8.146	14.848	13.070

As previously seen the relationship for ages 3-5 is not significant (at significance level $\alpha = 0.01$), which is in line with other analyses based on a long time series of Russian survey data (Kovalev and Yaragina, 2009). For those ages, TSB is not used as predictor. The biology and food composition of those age groups is different from that of older ages. Average values for these age groups were used instead of linear models. For ages 10-12 average values were used in previous studies (Kovalev and Bogstad, 2005), but could certainly be included although the data set for these age groups is less reliable except for the most recent years when the abundance of these age groups has been high.

If we limit our analysis to the period 1983–2015, when survey weights are available, the results are quite different (Table 3.4). Most relationships become insignificant (at significance level $\alpha = 0.01$) although some coefficients of regressions are similar to those estimated for whole time series.

Table 3.4 Parameters in regression for density-dependent weight at age in the stock, and minimum, maximum and average value for the period 1983–2015.

age	α_a	β_a	R^2	p	min. observed weight	max. observed weight	mean weight
3	-0.043	0.351	0.20	<0.01	0.194	0.518	0.274
4	-0.068	0.785	0.08	>0.05	0.404	1.172	0.660
5	-0.082	1.421	0.07	>0.05	0.790	1.820	1.269
6	-0.106	2.332	0.08	>0.05	1.477	2.823	2.141
7	-0.149	3.535	0.09	<0.05	2.458	4.059	3.267
8	-0.197	5.057	0.09	<0.05	3.565	5.833	4.730
9	-0.247	6.993	0.07	>0.05	4.710	8.927	6.609
10	-0.501	9.780	0.10	<0.05	6.821	12.154	8.997
11	-0.441	11.481	0.05	>0.05	8.112	15.026	10.802
12	0.164	12.326	0.10	<0.05	10.850	12.731	12.670
13	0.113	14.031	0.10	<0.05	12.988	14.311	14.270

We now have some observations for high stock sizes, which were not available when the HCR was tested in 2005.

It was decided to use the density-dependence as estimated for the whole period 1946–2015 (Table 3.3) in the simulations.

For simplicity, uncertainty from the regression has not been included in simulations previously and we do not plan to do so this time either.

Weight at age in catch is modelled as a function of weight at age in stock, using equation (3.5):

$$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a \tag{3.5}$$

The values of α_a and β_a for ages 3–8 are given in Table 3.5. The regressions are based on data from 1983–2014, when observations of both stock weights at age from surveys and catch weights at age are available.

Table 3.5. Parameters in regression for weight at age in the catch vs. weight at age in the stock.

age	α_a	β_a	R^2	p
3	1.594	0.326	0.56	6.23
4	0.895	0.604	0.77	10.15
5	0.922	0.582	0.86	13.59
6	0.859	0.672	0.86	13.36
7	0.787	0.993	0.68	7.93
8	0.727	1.541	0.68	7.95

In the simulations weight at age in the catch is calculated directly from weight at age in the stock using equation (3.5). Uncertainties associated with the regression were not taken into account. For ages 9 and older weight at age in the catch is set equal to weight at age in the stock.

3.2.4 Maturation

Figure 3.5 shows the development of age at 50% maturity (calculated by linear interpolation between the proportion mature at age having values closest to 50% above/below), and Figure 3.6 shows the age at 50% maturity plotted vs. the total stock biomass in the preceding year, with different symbols for the periods 1946–1981 and 1982–present. There is a big shift in maturity ogives around 1982, some of which may be due to changes in methodology (ICES, 2003). Using only the values from the period 1982-present would give a different relationship, probably with the maturation being much less dependent on the weight at age. The outlying point in the 'after 1982' series in Figure 3.6 is 1987 when the condition factor of cod was very low during the first capelin collapse.

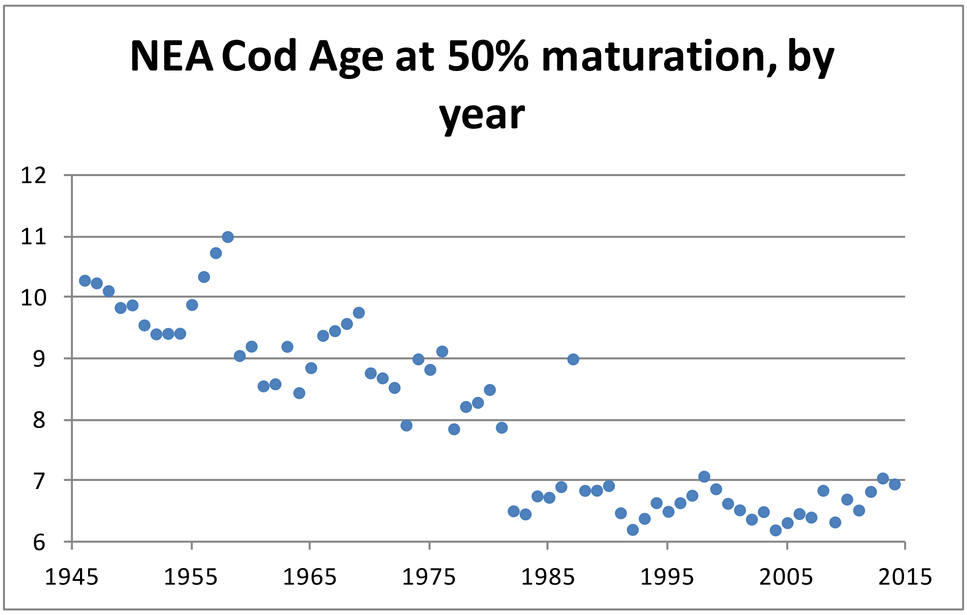


Figure 3.5. Cod age at 50% maturation, by year.

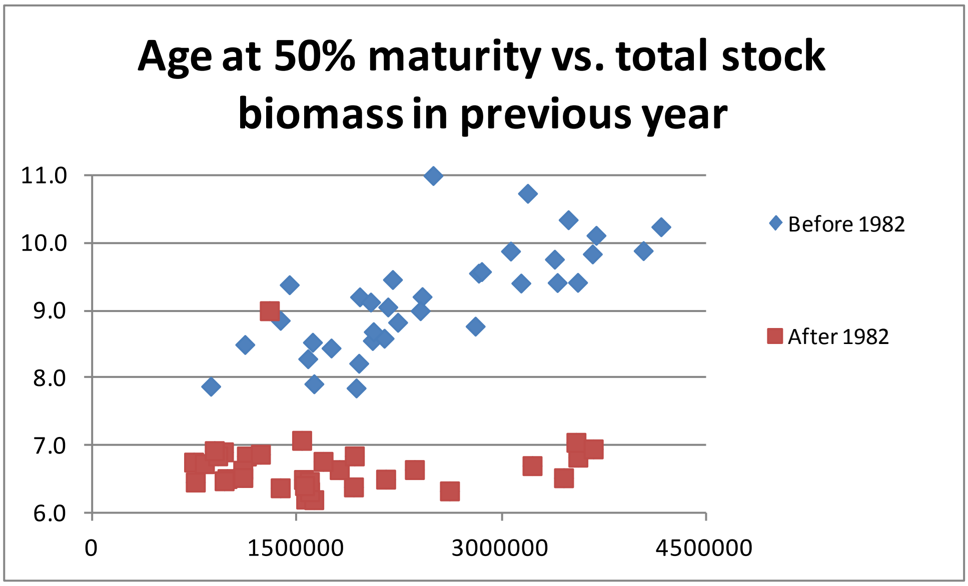


Figure 3.6. Age at 50% maturity vs. total stock biomass (TSB) in previous year.

In order to consider density dependence in maturation process it could be more logical to simulate maturity by cohorts. Maturation is more inertial process than growth and cod weight at age in the same year in such a situation may not be a reliable predictor. An alternative approach was investigated using equation 3.6:

$$P_{age,y} = \frac{1}{1 + e^{-a\ (age - age_{50\%})}} \qquad (3.6)$$

where $P_{age,y}$ – is portion of mature fish of certain generation at age in year y, a – parameter giving the slope of the sigmoid curve (taken as a constant over time), age 50% - is age where 50% of fish of this cohort is mature.

The age when 50% of fish becomes mature can be modelled as density dependent related to TSB:

$$age_{50\%} = b * TSB_{y-lag} + c \qquad (3.7)$$

where b, c - parameters, $TSB_{y\text{-}lag}$ – is total stock biomass in year y – the year where generation was at age 3, lag – is extra parameter to allow to find a time lag providing better relationship.

The model was fitted to observed data for generations 1946 to 2005. For lag > 0 the first generations was excluded from analysis as TSB estimates are available only since 1946. The best fit was reached using lag -4 years but such a long time lag is difficult to explain and the value was fixed at 0 in simulation model. R^2 for the model with lag 0 is 0.495 (generations 1946–2005). The fit to the observations is shown in Figure 3.7. It is seen that maturation is predicted to be slower than the values observed in recent years.

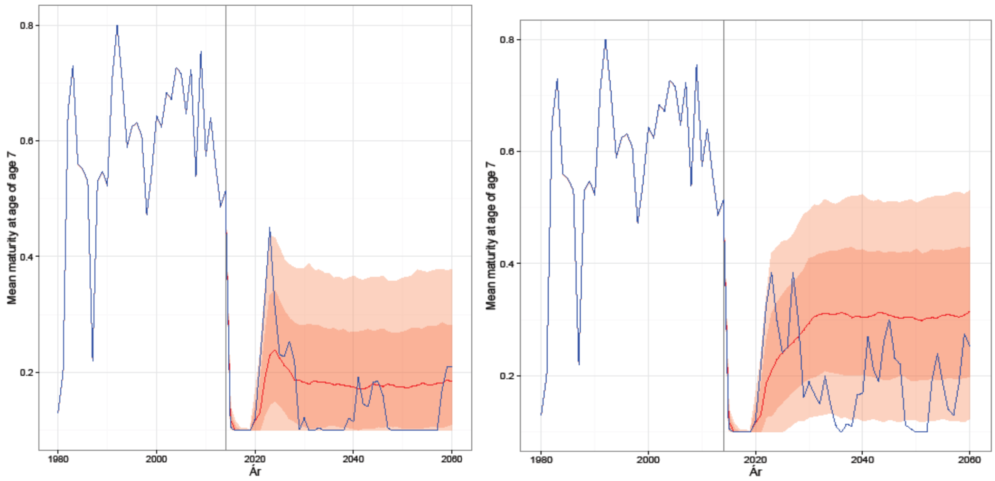


Figure 3.7. Modelled maturity at age 7 vs. observed maturity since 2000, for stock size corresponding to F = 0.4 (left) and 0.7 (right). Blue line until 2015 – observed, blue line after 2015 – one single trajectory (simulation), - red line (50% percentile) and 5–25–75–95 percentiles – modelled values.

3.2.5 Exploitation pattern

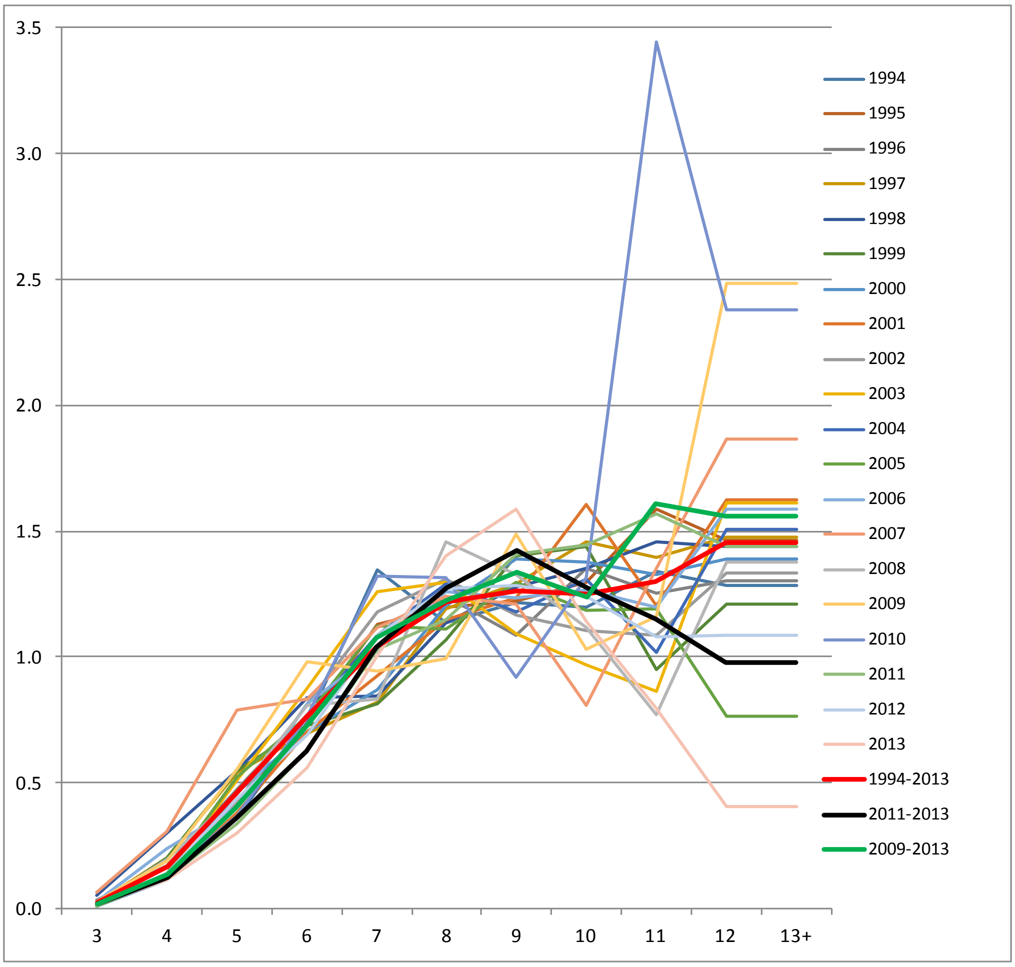


Figure 3.8. Recent exploitation pattern for NEA cod. Age on x-axis and pattern scaled so that average for ages 5–10 is equal to 1 on y-axis.

The average exploitation pattern for the period 1995–2014 was used in the simulations. The technical regulations, distribution of catch by gear and fishing strategy has been fairly stable over this period.

3.2.6 Modelling of capelin stock dynamics for use in harvest control rules 8 and 9

Replication of historical capelin stock dynamics (1973–2015) was used for cod HCR model simulations.

3.2.7 Supplementary analyses of population dynamics

Supplementary analysis of cod population dynamics were made by Björnsson (WD1, see Annex 4).

3.3 Assessment error

Assessment error is here considered to be the difference between the advice that is given and the advice that would have been given based on converged assessment 5+ years later. The assumption is of course that the converged assessment is correct.

The assessment is conducted in April each year based on catch data until the year before and survey data until February-March in the assessment year. Stock Weight and Maturity at age in the assessment year have already been obtained from the survey in the assessment year, catch in the assessment year can be predicted from the TAC set the year before plus some deviance due to banking and borrowing. The only thing missing for the assessment year are the catch weights and selection.

The final product of the assessment is the TAC for next year. For cod, predictions have to be made 3 years ahead, preferably using a TAC constraint in the assessment year but F_{target} after that. Also maturity at age, stock weight at age, selection at age and catch weight at age have to be predicted and the uncertainty in those variables adds to the uncertainty in stock in numbers.

The simulation model used for HCR evaluation assumes F status quo in the assessment year, an assumption that changes uncertainty less than catch constraint. With TAC constraint, uncertainty due to stock in numbers increases by approximately 1/(1-*r*) where *r* is the proportion of the stock biomass removed (approximately 0.3 for the Northeast Arctic cod). After the assessment year the predictions are with specified F leading to a TAC for the year following the assessment year that is the average of the catch in those 3 years.

Quantifying the increase of uncertainty in those simulations is difficult but the stabilizer makes the effect of assessment error on next year's advice relatively small.

Uncertainty in stock biomass in the assessment year can be obtained in 3 ways.

1. Look at standard deviations from assessment models.

2. Look at analytical retros.

3. Look at historical retros.

4. Running a combination of biological model, observation model and assessment model.

The first method is known to underestimate uncertainty both due to "wrong structure" of the model and neglected correlations. The time period of available survey data is usually rather short for the second and third type of analysis but they are the only ones that can give indication of the autocorrelation of the assessment. The fourth method can help in understanding behaviour of assessment model.

One of the main sources of uncertainty in the assessment is the prediction of SSB 3 years ahead but the stabilizer is not applied if predicted SSB in any of those years is below B_{pa}. Maturity in this stock can be quite variable, a recent example is 2015 but SSB is 15% lower than it would have been based on predicted maturity the year before, everything else being the same. Prediction of the SSB is therefore relatively uncertain, the CV might be higher than 0.3 in the final year. The effect of this uncertainty is though one-sided in most cases as overestimation of SSB due to incorrect maturity does not affect the TAC next year (except for high SSBs in rule 6–10) but underestimation can lead to lower TAC as the SSB can be predicted to be below B_{pa} in any prediction year. This effect starts becoming possible at SSB around 700 kt or even higher if recruitment is underestimated. Above F = 0.35 the probability of this one-sided action starts to increase leading to average F from the rule being lower than the intended F.

The HCR model uses the average of last 3 years for weights, maturation and mortality when projecting 3 years forward. This approach takes account of the estimation uncertainty in weights, maturity and mortality at age but the reliability of the final results do also depend on the biological model does representing those values reasonably well.

The value used for CV in the biomass in assessment year for cod was 0.2. The value of 0.2 is higher than indicated by the retrospective patterns that were shown and estimates from assessment models. The retrospective pattern converge slowly so the last 5 years can hardly been used and the usable period was therefore rather short.

Including autocorrelation (0.7) of assessment error increases the risk of spawning stock going below B_{lim}. For the NEA cod, B_{lim} is on the other hand so low that this probability is much less than 0.05 for all plausible alternatives. Taking into account amplification of assessment error with TAC in the assessment year that is ignored by using F constraint, the value of 0.2 could correspond to 0.2*(1–0.3) = 0.14 assuming that 30% of the biomass is removed. This value is still higher than indicated by the retrospective patterns and stock assessment. The autocorrelation used is high but realistic for a stock with low fishing mortality.

Modelling the assessment error as lognormal can lead to occasional unrealistic values. These values could be removed by truncating the distributions but they do not matter in the simulations as long as the program does not crash and the 0.000* or 0.999* quantiles are not presented or considered.

3.4 Implementation error

A comprehensive description of observed implementation errors is presented in WD4 to WKARCT 2015 (ICES, 2015c).

Data for estimation of implementation errors are taken from 2015 ICES advice for NEA cod (ICES, 2015d) (see Table 3.6). The most relevant period to use for estimation of implementation errors was chosen to be 2004–2014 after implementing by JRNFC the new strategy after which the HCR for calculating NEA cod TAC was used (the first advice given in 2003 for year 2004). IUU catches where observed for NEA cod in 2002–2008 but since this problem in regulation was resolved by increasing level of control and implementing port control, it will be more correct to account for implementation errors in the simulation model without IUU catches. So, observed errors are taken as:

Imp. Error = (ICES landings - unreported landings) / Predicted catch corresp. to advice).

This implementation errors gives lognormal type of distribution (mean = 0.074; Std.Dev. = 0.1189). These parameters are used to simulate implementation errors corresponding to current management practice.

Note that a long term difference in selection pattern compared to what is used in the HCR simulations can lead to the removal rate from the stock being different from the intended one.

3.5 Experience with current harvest control rule in the period it has been in place

The rule was suggested by the JRNFC in autumn 2002, and subsequently tested by ICES in 2005 and found to be precautionary. Although the JRNFC started using the rule from 2004 onwards, it did not really take effect until 2007, when IUU catches were eliminated. 2007 was the last year when IUU catches were added to the assessment, and the added catch that year was quite small. The transition phase from a high F in the pre-HCR period (around 0.6 in 2001–2006 and even higher in previous years) occurred in a period when two very strong year classes, 2004 and 2005, were entering the stock. During this transition period the geographical distribution of the stock also increased, and thereby led to incomplete survey coverage and underestimation of stock size. In combination, these factors led to a rapid increase of stock size and that the constraint of maximum 10% annual increase in catch was the limiting factor for the TAC. To circumvent this, the JNRFC in 2009 introduced an additional clause in the HCR, which overrides the limit on annual change in TAC: If the SSB is above B_{pa}, F should never fall below 0.30. As seen from Table 3.6, this clause has actually come into effect three times. The +10% constraint came into effect 2 times, and the -10% constraint came into effect 2 times. The cod HCR has never been tested in a rebuilding situation, although in its first year of existence, SSB was estimated to be slightly below B_{pa} so that part of the rule came into effect.

The agreed TAC was higher than the ICES advice for the years 2007 and 2008. The reason for this was the JNRFC and ICES used different numbers for IUU catches when calculating the TAC. For 2010 the Parties agreed to increase the TAC more than implied by the HCR used at that time, but in accordance with the new F > = 0.30 clause in the HCR. For 2009, 2013 and 2016 the TAC was set higher than the HCR indicated, without basing the decision on alternative calculations. It is also interesting to note that when the quota for 2016 was agreed, JNRFC did not follow the recommendation of a 10% quota reduction. The quota was maintained at the 2015 level, arguing that a higher cod catch could be beneficial in the case of low stock of capelin and other prey. This also led to the suggestion of capelin-dependent HCRs (rule 8 and 9).

Table 3.6. Quota advice, agreed TAC and actual catch for northeast Arctic cod.

Year	ICES advice	TAC	Catch	Catch-IUU	Part of rule deciding HCR advice
2004	398*	486	606	514	3-year average
2005	485	485	641	475	3-year average
2006	471	471	538	471	3-year average
2007	309**	424	487	446	3-year average, Tac above rule
2008	409	430	464	449	3-year average, Tac above rule
2009	473	525	523	523	+10%
2010	577.5***	607	610	610	F > = 0.30***
2011	703	703	720	720	F > = 0.30
2012	751	751	728	728	3-year average
2013	940	1000	966	966	F > = 0.30
2014	993	993	986	986	3-year average
2015	894	894			-10%
2016	805	894			-10%

***HCR not yet evaluated by ICES, advice according to F_{pa}**

****F_{pa}-advice due to IUU-problem**

*****+10% advised, F > = 0.30 introduced by managers that year**

3.6 Performance of harvest control rules in a short and medium term perspective

In order to investigate how the various rules would perform in the present situation, short-term (3-year) predictions were performed using the prediction input from AFWG 2015 (ICES, 2015b). For 2016 it was assumed that the TAC was constrained relative to the 2015 TAC of 894 000 tonnes. For the capelin-dependent rules (rule no. 8 and 9) it was for illustrative purposes assumed that the capelin stock is low in 2015 and 2016 but high in 2017 (i. e. the capelin-related clause of increasing F at high SSB comes into effect when deciding the 2016 and 2017 TAC but not the 2018 TAC). The results are shown in Figures 3.9 and 3.10. Except for the rules with different target Fs (1 and 3 with 0.30 and 0.50 respectively), the differences between the rules are rather small. We also see that in this case there is no difference between a 20% constraint on annual TAC variation and no constraint.

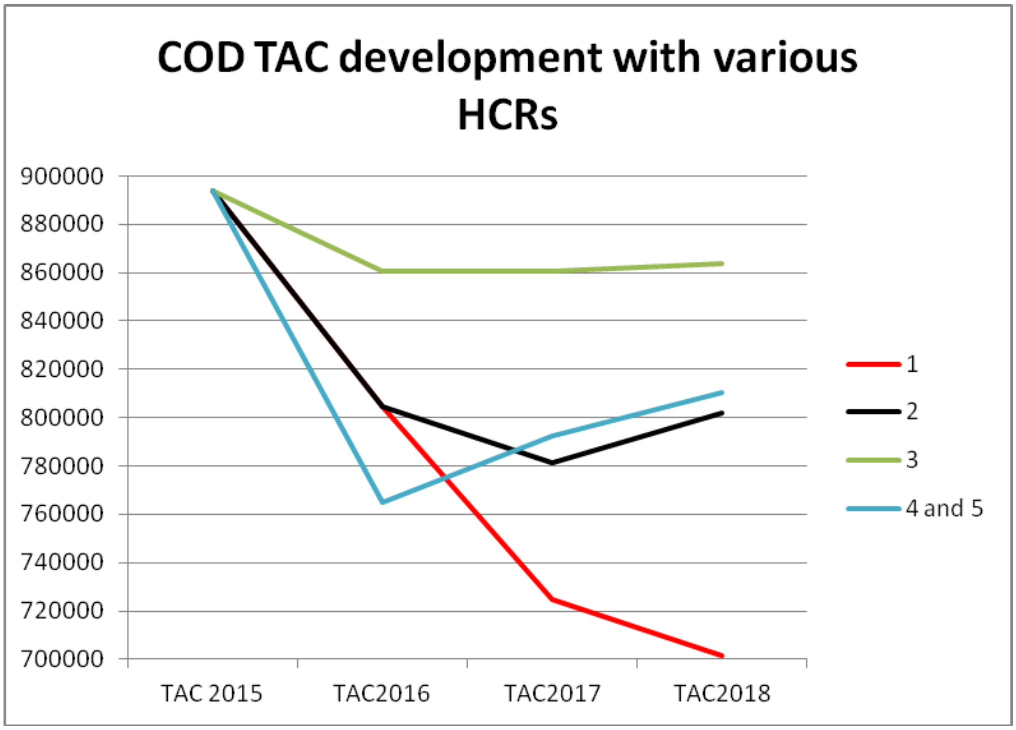


Figure 3.9. TAC development (tonnes) for cod in the period 2016–2018 for harvest control rules 1–5, based on the AFWG 2015 assessment (ICES, 2015b).

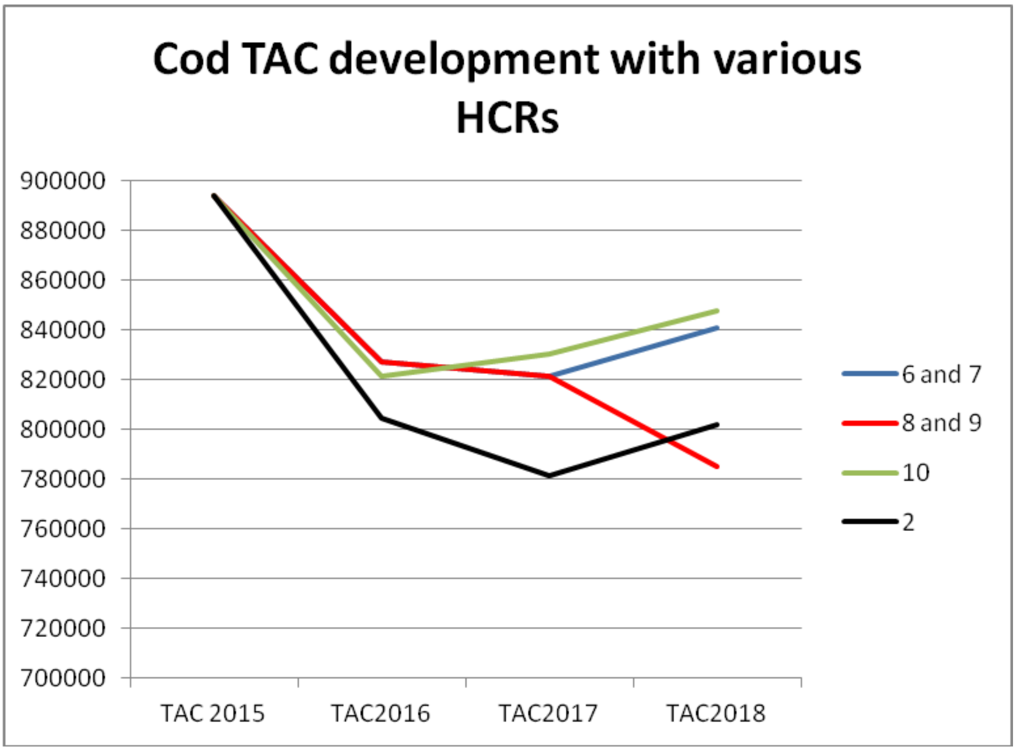


Figure 3.10. TAC development (tonnes) for cod in the period 2016–2018 for harvest control rules 6–10 and 2, based on the AFWG 2015 assessment (ICES, 2015b). (Rules 6–9 all give the same result except for 2018).

3.7 Comparison of rules based on simulations from 2009 onwards to compare behavior of rules at high SSB levels

The long-term simulations indicate that it is quite rare (< 5% of years) that SSB increases above 2*B_{pa} (trigger 2) so that the clause of increasing F at high SSB in rules 6–9 comes into effect. However, the SSB has recently been in the range between 2*B_{pa} and 4*B_{pa} (Figure 3.11). In order to illustrate how those rules function compared to other rules, we did some deterministic projections starting in 2009 based on the AFWG assessment 2015. When determining the catch for 2009, the constraint in maximum annual change of TAC was applied based on the 2008 catch. Recruitment, growth, maturation and natural mortality were the same for all runs. The results (total stock, spawning stock, catch, fishing mortality) are shown in Figure 3.12a-d.

The difference between rule 2 and the actual stock size development (2015 assessment) is mainly due to assessment errors during the period. Concerning rules 6 and 7, these both give a higher increase in catches in the beginning of the period, compared to rule 2, but then the catches level out. Rule 7 shows a huge increase in catches from 2008 to 2009 (when SSB passes 2*B_{pa} on the way up), but then they level off at a lower level than the other rules. Rule 6 implies a 20% annual decrease in catches towards the end of the period.

Total catches for the period 2009–2015 as well as stock size in the beginning of 2016 is shown in Table 3.7. The table shows that Rule 2 gives the lowest total catches during the period, but also that when catches and remaining stock at the end of the period is summed, rule 2 performs best.

This exercise should just be treated as one possible scenario of how the different rules would perform and conclusions of the general performance of rule should not be drawn from this.

Table 3.7. Catches (1000 tonnes) during the period 2009–2015 and remaining biomass at start of 2016, for the current assessment and three harvest control rules.

SUM 2009–2015	5427	5207	5543	5453
TSB 2016	2900	3146	2709	2696
SUM+TSB 2016	8327	8353	8252	8148

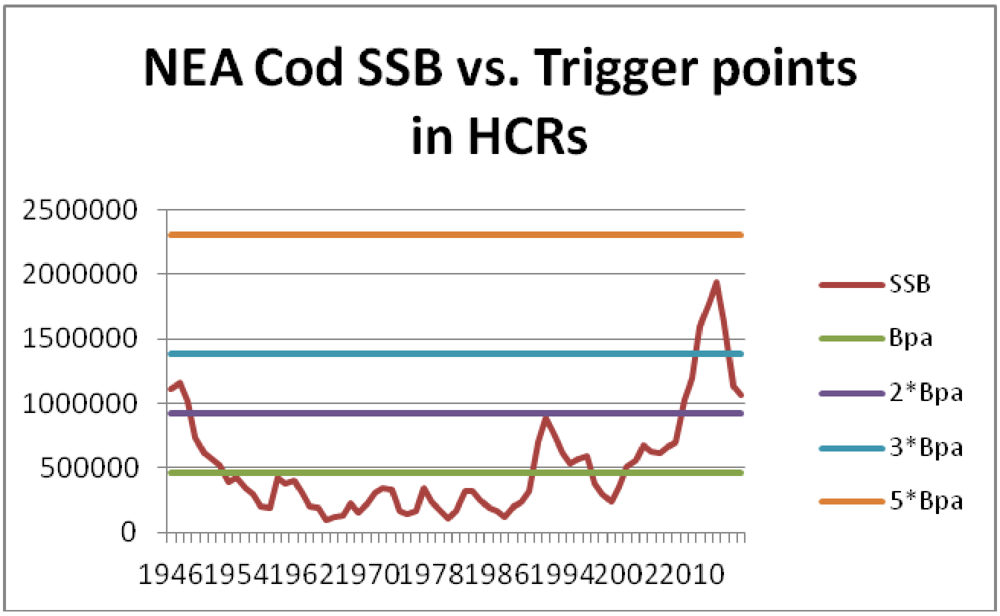


Figure 3.11 NEA cod SSB development (tones) vs. trigger points in HCRs.

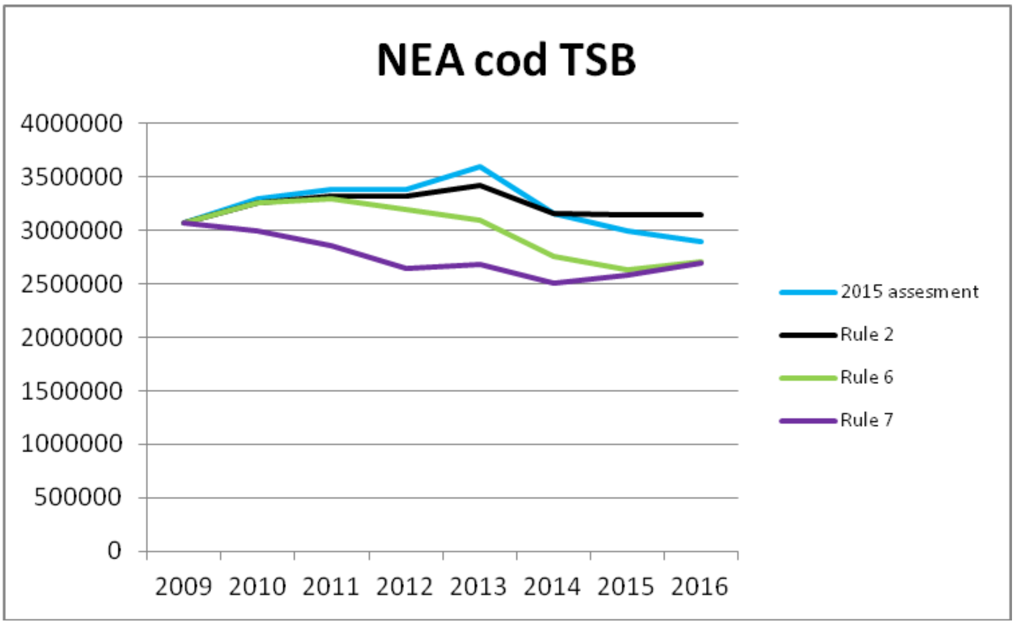


Figure 3.12a. NEA cod total stock biomass (tonnes) for different HCRs starting in 2009.

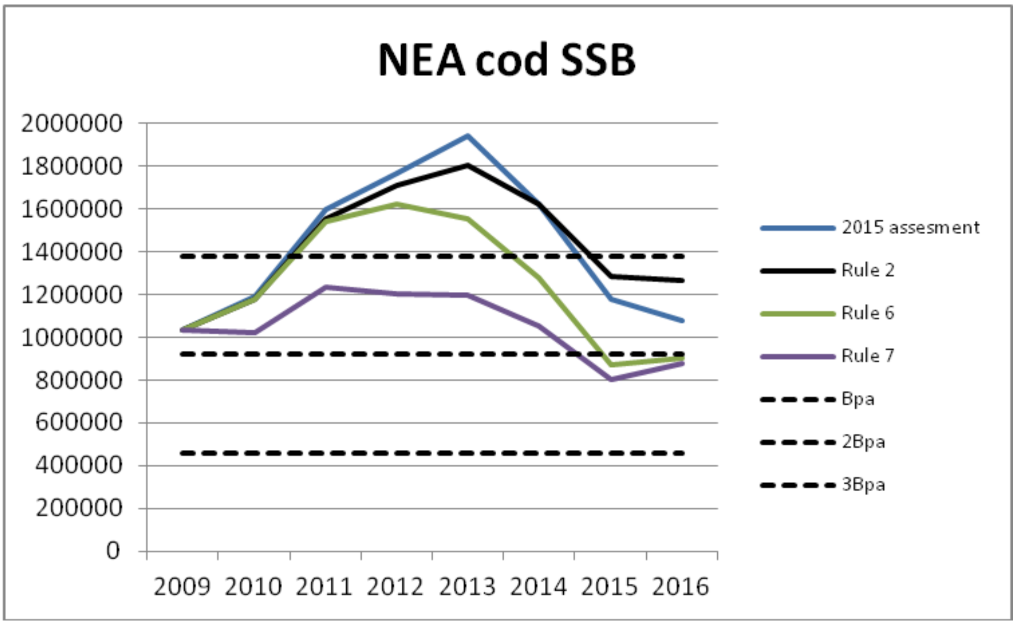


Figure 3.12b. NEA cod spawning stock biomass (tonnes) for different HCRs starting in 2009.

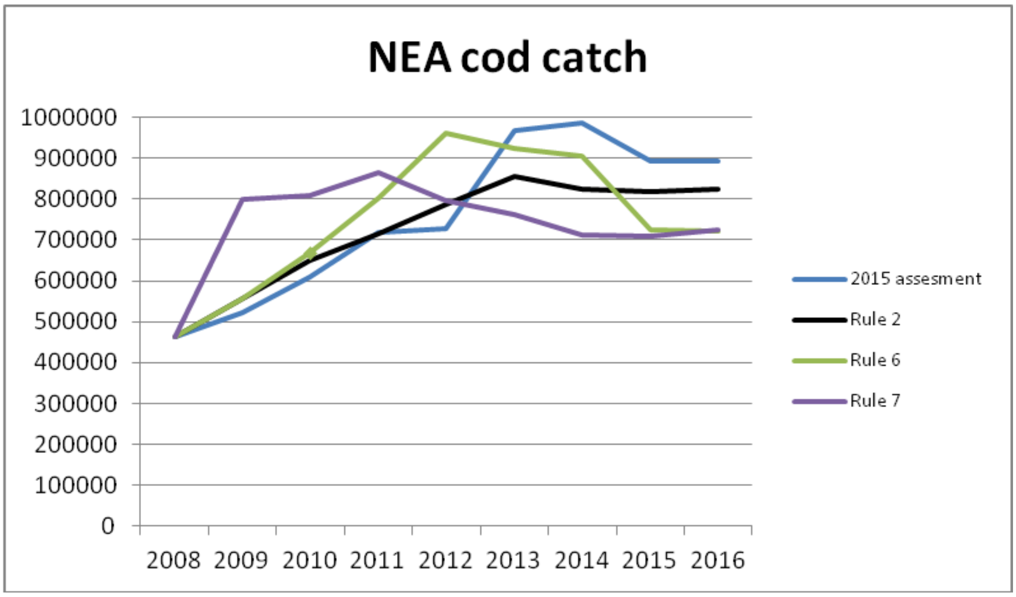


Figure 3.12c. NEA cod TAC (tonnes) for different HCRs starting in 2009.

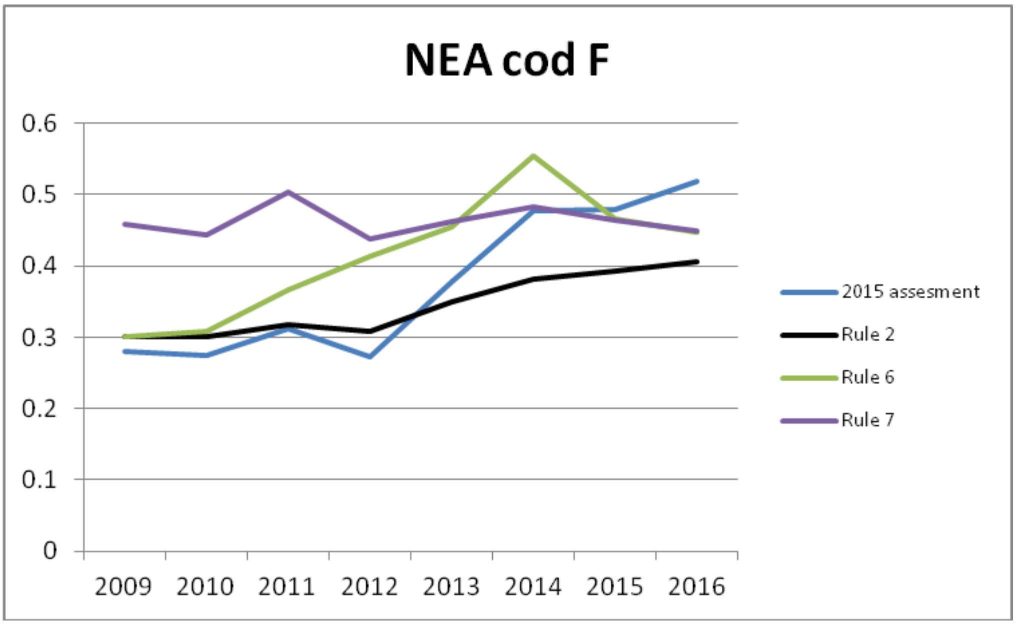


Figure 3.12d. NEA cod fishing mortality for different HCRs starting in 2009.

3.8 MSY and validation of long-term simulation results

Some runs were done to estimate possible MSY and corresponding F using simulation model with same settings as for HCR testing with a small exception (Figure 3.13, Table 3.8). Another run was done for same settings but using constant F at all SSB levels instead of a HCR where F is reduced linearly from F_{target} at B_{pa} as done in all proposed HCRs.

Both curves (upper and lower panel in Fig 3.13) have a rather flat maximum. The F_{msy} based on runs reducing F below B_{pa} is estimated around 0.7 while the yield at F = 0.4 is only 7% less than MSY. The probability of SSB to be below B_{lim} reaches 5% at F somewhat above 0.7. It should be mentioned that the mean realised F in the model becomes less than the target F because of the precautionary part of HCR reducing F when SSB < B_{pa}.

Table 3.8. Results of long-term stochastic simulations with different level of target F using 5000 iterations.

	target F										
parameter	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
mean realized F	0.00	0.10	0.20	0.31	0.41	0.50	0.57	0.64	0.70	0.75	0.79
mean SSB	2871	1718	1197	880	684	573	503	453	413	387	375
min SSB	1991	1148	738	508	344	197	85	51	53	48	51
mean TSB	6508	4699	3794	3259	2913	2707	2574	2464	2357	2267	2217
mean catch	0	420	614	718	778	813	831	838	836	831	832
% SSB < Bpa	0	0	0	0	1	20	42	56	65	70	72
2.5% SSB	2317	1408	969	671	477	361	279	202	151	128	128
97.5% SSB	3690	2099	1457	1119	933	878	827	799	760	736	723
% SSB < Blim	0	0	0	0	0	0.002	0.38	3.75	9.23	14.36	16.95
mean R	892	900	894	895	894	892	885	866	840	815	809
Mean M at age 3	0.72	0.63	0.54	0.48	0.43	0.40	0.38	0.35	0.33	0.32	0.31

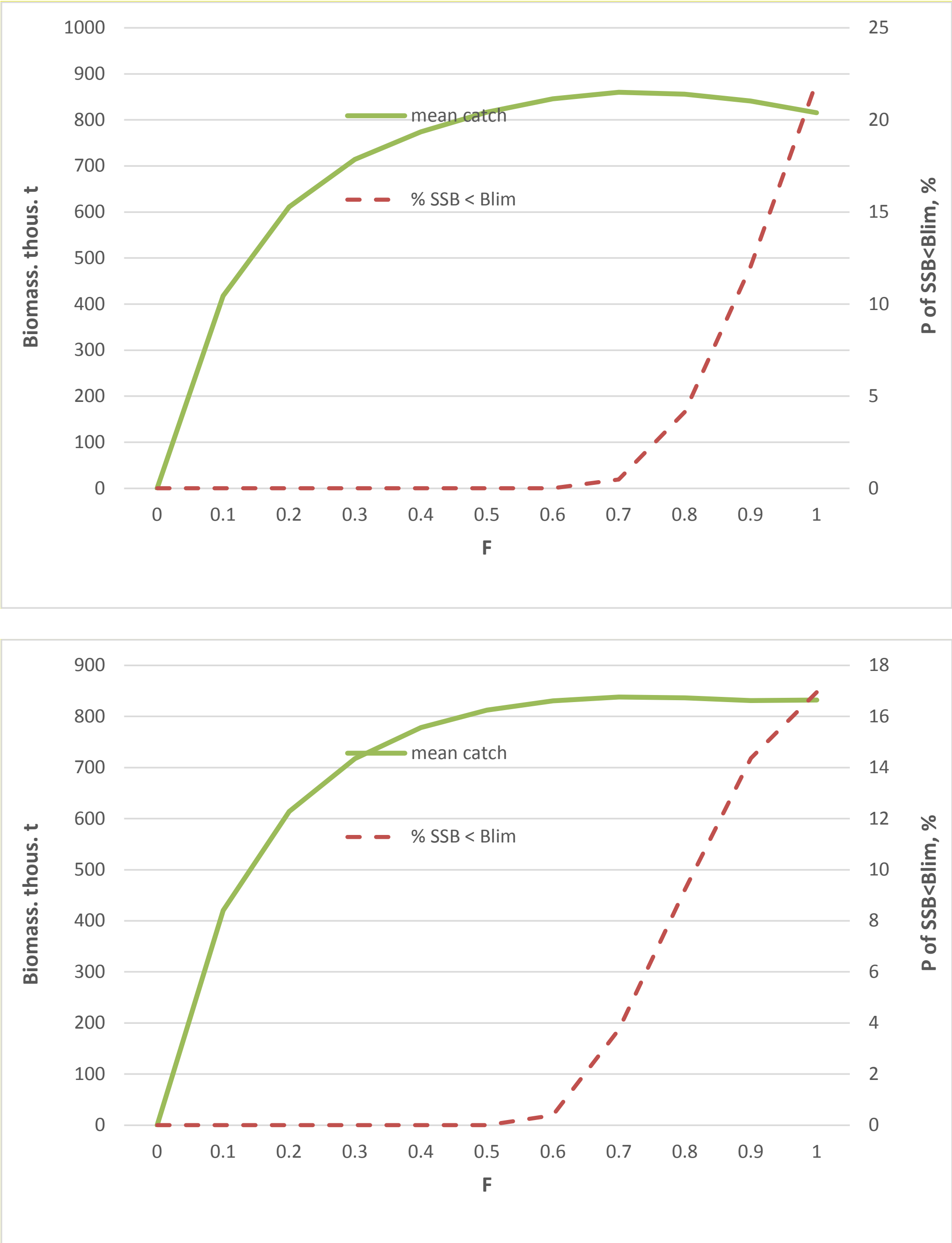


Figure 3.13. NEA cod mean catch and risk to fall below B_{lim} (Prob1) as a function of target F with a HCR where F is reduced when SSB < B_{pa} (upper panel) and in case where target F was constant for the whole range of SSB values (lower panel).

3.9 Evaluation of harvest control rules in a long-term perspective

The first ten runs done for all proposed HCRs and an additional run corresponding to rule 2 (currently used rule but with implementation error) were all made taking into account assessment errors.

The harvest control rules are given in Annex 1.

Simulation settings

For each run, 10 000 simulations for 100 years into the future were made. The average values for the last 80 years of the period were used, in order to avoid the influence of the initial values. In all simulations recruitment, natural mortality of young cod at ages 3–5, weight and maturity depend on population density.

Assessment error was included (CV = 0.2 for all age groups, uncorrelated). The influence of implementation errors on results was tested in an extra run corresponding to current harvest control rule.

The risk of SSB to be below B_{lim} was estimated in three different ways according to ICES guidelines (ICES, 2013a) corresponding to probability 1, 2 and 3. Quotation:

– ***Prob1*** = *average probability that SSB is below Blim, where the average (of the annual probabilities) is taken across ny years.*

– ***Prob2*** = *probability that SSB is below Blim at least once during ny years.*

– ***Prob3*** = *maximum probability that SSB is below Blim, where the maximum (of the annual probabilities) is taken over ny years.*

Probability 3 should be used in accordance to guide but it should be mentioned that this type of criteria is dependent on number of years used in the simulation model. The more years used the higher value of Prob 3 parameters we get. It is problematic to base the conclusion on this criterion. The more appropriate criterion is Prob 1.

The results of the runs are shown in Table 3.9.

Table 3.9. Results of long-term stochastic simulations (catches and biomasses in 1000 tonnes).

Run No.	1	2	3	4	5	6	7	8	9	10	11
HCR No.	1	2	3	4	5	6	7	8	9	10	2
Implementation error	No	No	No	No	No	No	No	No	No	No	Yes
Target F	0.30	0.40	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Realised F	0.29	0.36	0.42	0.38	0.41	0.39	0.43	0.38	0.42	0.44	0.39
Mean catch	704	744	773	758	777	761	783	759	779	788	758
Std catch	96	137	178	153	197	171	235	158	210	265	196
Median catch	704	754	787	758	768	761	764	759	767	770	763
5% of catch	550	490	455	501	468	473	429	493	457	378	421
Mean TSB	3329	3113	2944	3033	2926	3015	2897	3028	2917	2863	3030
Median TSB	3310	3082	2909	3010	2908	2995	2882	3006	2900	2848	2993
95% of TSB	3986	3897	3800	3712	3546	3728	3559	3718	3550	3568	3934
Mean SSB	930	810	717	756	689	745	669	753	683	649	767
Median SSB	900	754	654	727	678	716	658	724	672	637	696
Mean R	893	893	890	893	892	892	891	892	892	892	890
Median R	728	727	724	727	727	727	726	727	727	727	725
Prob 1 %	0.00	0.01	0.34	0.01	0.02	0.06	0.19	0.02	0.06	0.07	0.34
Prob 2 %	0.00	0.63	16.34	0.50	1.70	3.70	11.48	1.36	4.03	4.66	16.35
Prob 3 %	0.00	0.05	0.87	0.06	0.10	0.19	0.67	0.15	0.54	0.29	0.83
% years SSB<Bpa	0.15	6.12	18.10	5.55	7.91	7.95	11.08	6.25	8.82	11.17	14.69
Mean annual change in TAC % (absolute value)	9.03	12.40	17.20	17.79	26.94	19.59	31.77	18.30	28.38	36.64	17.02
Mean annual change in catch % (absolute value)	9.03	12.40	17.18	17.79	26.94	19.59	31.76	18.30	28.38	36.64	21.76
Mean weight in catch	3.39	3.19	3.03	3.13	3.03	3.11	2.99	3.12	3.02	2.96	3.11
Mean M at age 3	0.49	0.46	0.43	0.45	0.43	0.45	0.43	0.45	0.43	0.42	0.44
Prop years where + constraint % of TACapplied	38.20	21.84	26.71	18.26	0.00	19.87	0.00	18.80	0.00	0.00	19.18
Prop years where - constraint % of TAC applied	28.74	19.85	14.22	11.89	0.00	12.79	0.00	12.19	0.00	0.00	15.97
Prop years where "Min F=0.3" applied	0.00	21.61	14.74	11.49	0.00	11.80	0.00	11.61	0.00	0.00	23.58
For 3 steps rule Prop years SSB> trigger 2, %	n/a	n/a	n/a	n/a	n/a	20.99	15.46	6.92	5.16	79.89	n/a
SSB> trigger 3, %	n/a	n/a	n/a	n/a	n/a	3.16	0.88	0.96	0.28	0.00	n/a

All simulations have been shown to be precautionary and give similar average yield.

Simulations show that if the target F in the harvest control rule is increased above 0.35 the realized fishing mortality increases at much slower rate than the intended F. The reason for this is that the catch stabilizer in the HCR is not used if SSB in any of the prediction years is predicted to be below B_{pa}. When F is higher the stock is more often close to B_{pa}, and the stabiliser is less frequently in operation. The asymmetry occurs, because usually when the stock is predicted to be below B_{pa} in any of the 3 prediction years the stock and catches are going down. Due to assessment error there is an increasing probability that the stock is predicted to be below B_{pa} when the true spawning stock decreases below 600 thousand tonnes.

Rules where fishing mortality increases when estimated spawning stock exceeds certain triggers (2 step rules or rules with linearly increasing F) were tested (rules 6–10). The main result of the simulations was that compared to the existing rule (rule 2), the average catch increased only marginally (2%–6%). The variability in catch increased considerably (15%–93%). The 5th percentile of catch was low for all these rules (378 kt–473 kt) compared to 490 kt for the existing rule. Rule 10 with linearly increasing fishing mortality with size of the spawning stock has a little (6%) higher average catch than the existing rule but much higher standard deviation and interannual variability of catches, and has the lowest 5th percentile of catch. If the rules 6–10 should aim at protecting the ecosystem, they should be based on the total cod biomass rather than the spawning biomass.

Rules allowing for increased F at high SSB may motivate for increased fleet capacity. This could cause overcapacity problems when the stock after a few years is fished down to more normal levels and the F has to be reduced.

Specifying the selection pattern to be used in prediction is an important issue. If the selection of the fleet changes towards older fish, the catch as proportion of the total biomass will decrease and vice versa.

The current HCR was also tested with implementation error (run 11). Implementation is biased so it works like increasing F and changing the catch constraint in some years. The results are according to that slightly higher average catch, more variability, higher F and lower spawning stock. These results demonstrate the effect of the implementation error. The work shop concluded on the other hand that including implementation errors in HCR simulations was somewhat questionable.

Relaxing the constraint on the current HCR to 20% (Rule 4) leads to similar average catch and less standard deviation of catches but considerably higher interannual variability. Relaxing the constraints completely (Rule 5) leads to much higher interannual variability and also higher standard deviation in catches.

To summarize; the current HCR seems to be a reasonable compromise with regard to average catch, and with regard to long and short term stability of catches. The fishing mortality of 0.40 is relatively high compared to what had been advised for other cod stocks in recent years but things are of course not exactly comparable between areas.

4 Northeast Arctic haddock

4.1 Data series used

The time series for stock abundance and biomass, weight (in catch and in stock), maturity, fishing mortality and natural mortality at age used in the analyses were taken from the AFWG 2015 report (ICES, 2015b). The time series covers the period 1950–2014. However, in this series the stock weight at age and maturity at age is constant for the period 1950–1979, the catch weight at age is constant for 1950–1982 and the natural mortality is constant for the period 1950–1983. Thus only the period 1983(1984)–2014 were used for analyses depending on these data.

We used age range 3–13+ in the simulations, in order to be consistent with AFWG 2015. However, as real data on stock weight and catch weight for these oldest age groups are sparse and have low sample size, we have assumed that in catch and stock, maturity at age and selection pattern for ages 12 and 13 equal to the values for age 11.

The biological models used are summarized in Table 4.1.

Table 4.1. Models/processes and associated input data for haddock population model.

Models/processes	Relationship	Function	Limits (if any)	Period of data used	Reference/comment
Recruitment underlying function	$R_y=f(SSB_{y-3})+\varepsilon$	Segmented regression	R_{max} observed	1950–2014	WD 2, WKNEAMP-1 (ICES, 2015a)
Random noise distribution for R	Log-normal	Autocorrelation Residuals drawn from observations or parametric	+/- 2*sigma	1950–2014	WD 2, WKNEAMP-1 (ICES, 2015a)
Natural mortality(M2) 1	Constant	Average		1984–2014	WD 2, WKNEAMP-1 (ICES, 2015a)
WEST (Ws)	W for all ages 3–11 = $f(TSB_{y-1})$	$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a$	Limits for all ages (min observed – max observed for 1946-2015)	1983–2015 (Survey weights available since 1983)	WD2, AFWG 2015 (ICES, 2015b)
WECA (Wc)	Wc=f(Ws) for 3–8; WECA = f(WEST), age 9-11 = WEST	$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a$		1983–2014 (Survey and catch weights for regression available since 1983)	WD2, AFWG 2015 (ICES, 2015b)
Maturity ogives	$P_{age}=f(Ws)$	$P_{a,y} = P(ws_{a,y}) = \frac{1}{1+e^{-\lambda_a(ws_{a,y}-w_{50,a})}}$	Limits for all ages (min observed – max observed) for 1946–2015)	1980–2015	WD 2, WKNEAMP-1 (ICES, 2015a)
Selection pattern	Constant	Mean		1995–2014	AFWG 2015 (ICES, 2015b)
Implementation errors	Not used				WD 2, WKNEAMP-1 (ICES, 2015a)
Assessment errors	Mean of normal distribution	real N * EXP(normal (mean, sigma))	Sigma = 0.25	2004–2014	AFWG 2015 (ICES, 2015b)

4.2 Modelling of biological processes

4.2.1 Recruitment

The stock-recruitment relationship has been discussed at length in AFWG and in related fora. Figure 4.1 shows the plot for the period 1950–2014.

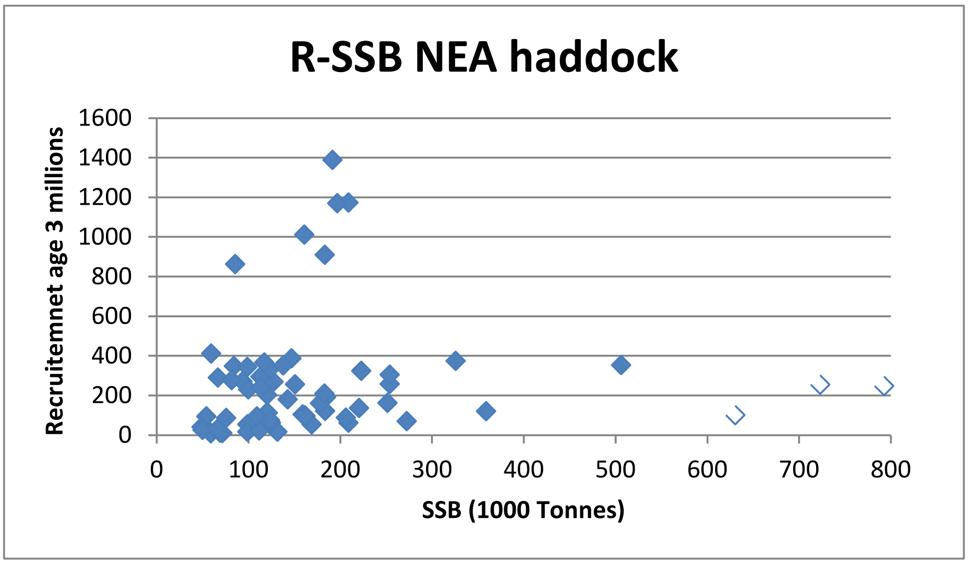


Figure 4.1. Stock – recruitment relationship of northeast arctic haddock 1950–2014, open diamonds are the three last year classes (2012–2014).

Various interpretations of this plot have been suggested but neither of the proposed models (hockey-stick, Ricker, or Beverton and Holt) presented a convincing fit. One proposal is to isolate the six strongest year classes as extreme events that are controlled by a different mechanism from what is controlling the recruitment formation in other years. However, the relationship does not really improve as is illustrated in the same plot below (Figure 4.2) but now in logarithmic terms.

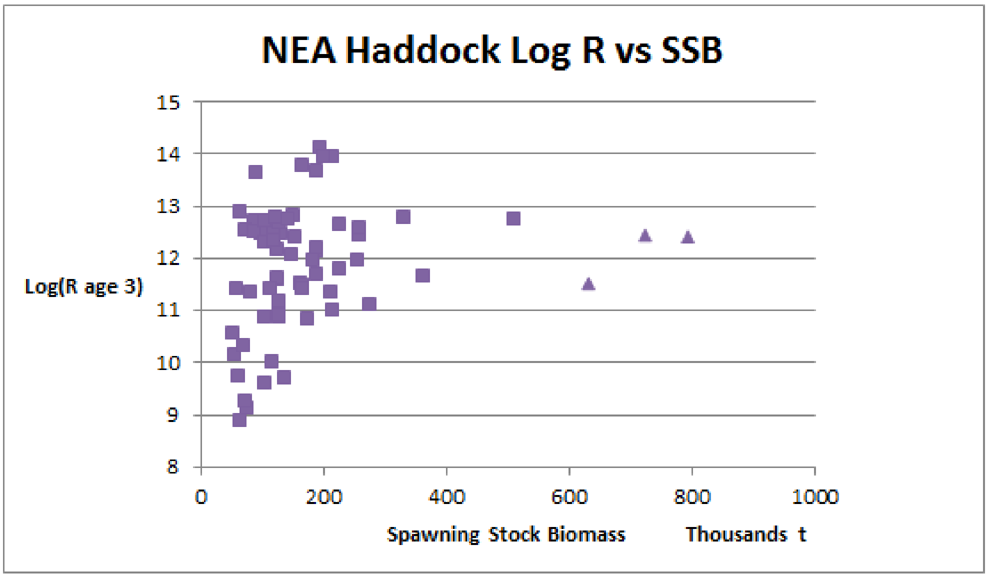


Figure 4.2. Stock – recruitment (log scale) relationship of northeast arctic haddock 1950–2014 (2012–2014 year classes shown as triangles).

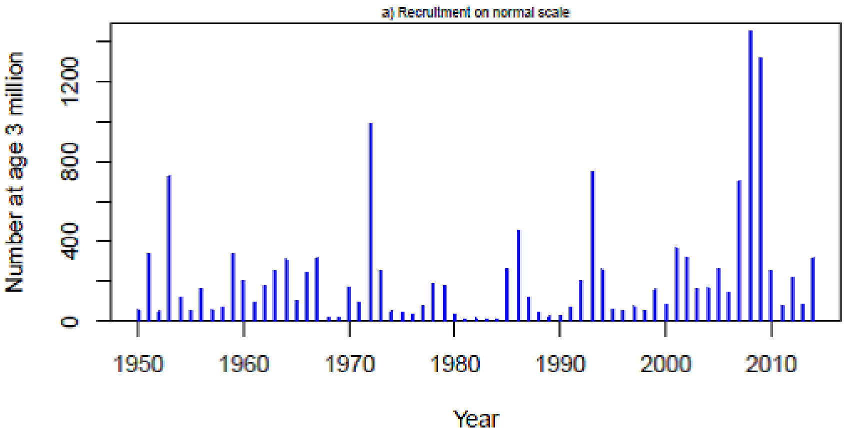
This graph might suggest a hockey stick relationship in logarithmic recruitment up to a SSB in the range of 100 000–200 000 tons. However, such a relationship is not easy to understand in biological terms as it implies an exponential increase with SSB, R ~ exp(α*SSB) with a positive α in contrast to standard theory (e.g. Ricker stock-recruitment R ~SSB* exp(α*SSB) with a negative α). The Group therefore concluded that there was no reasonable stock - recruitment model at hand and instead looked for an empirically based approach that would for the purpose of the simulation generate a realistic recruitment time series. It was decided to use a hockey stick recruitment function with break point of B_{loss} = 50 000 tonnes and a recruitment plateau of 136 million (geometric mean of historic recruitment) with log-normal error structure.

Recruitment of Northeast arctic haddock is extremely variable (Figure 4.3). The contrast in year class-size is 1:183 (7.6/1389 million at age 3). Looking at the plot on log scale (Figure 4.3) illustrates clearly how poor the year classes 1977–1981 were with an average of only 14 million recruits or 9800 tonnes assuming YPR = 700g/recruit. In addition, bad or good year-classes are shown to come consecutively, with a first order autocorrelation of log(R) around 0.5 (Figure 4.4). This value is rather poorly estimated as shown by the confidence intervals. The Workshop considered that this might best be simulated by introducing some form of autocorrelation between years, i.e. that a bad year-class is more likely than not to be followed by another bad year-class. On the other hand, the Workshop also realised that occasionally very strong year-classes occur something that traditionally is simulated by assuming that the process is generating log-normal residuals. Finally experimenting with such models it was realised that this process would occasionally generated unrealistic large year-classes and therefore some cap on the largest possible year-class would need to be introduced in the process. The cap was set to 1400 million, slightly above the highest observed.

A study of the autocorrelations of 1–3th order suggests that the 2nd and 3th order autocorrelations are very low and therefore the model investigated further is given in equation 4.1.

$$R(t) = (R(t-1)*\alpha + (1-\alpha)*R_{geom})*\exp(\varepsilon) \qquad (4.1)$$

where R_{geom} is geometric mean of historic recruitment and ε is normally distributed (0, σ^2). The σ was estimated from the time series to be around 1 and α around 0.5. It should be stressed that the time series is short and the estimates are not precise but rather impressions based on the available data.



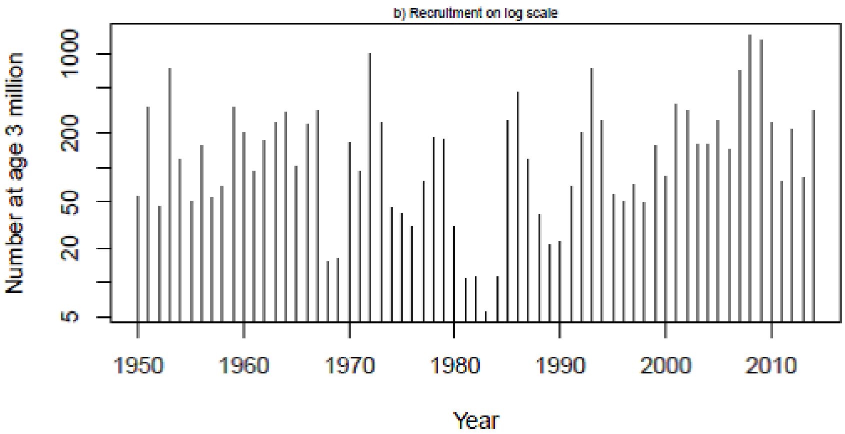


Figure 4.3. Northeast arctic haddock recruitment 1950–2014 on absolute scale (upper panel) and logarithmic scale (lower panel).

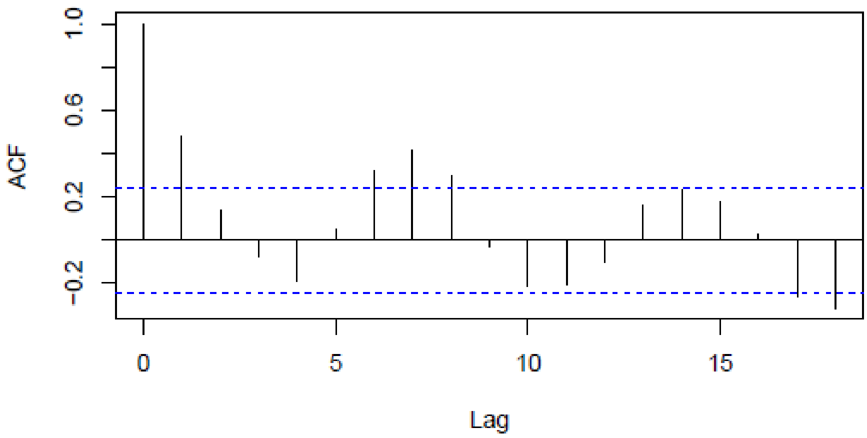


Figure 4.4. Northeast arctic haddock recruitment autocorrelation.

4.2.2 Natural mortality

The natural mortality (M) was set to 0.2 for age groups 7+. For age 3–6, two scenarios were run: Average M (1984–2014 average, Table 4.2) and high M (average of last 10 years or other high value). The M value is related to cod and capelin stock size (Figure 4.5). Low M values were assumed less relevant to use because the cod stock is less likely to be so small in the future after the introduction of HCR which reduced the fishing mortality on cod considerably.

Table 4.2. M values for various scenarios.

Scenario	M age 3	M age 4	M age 5	M age 6
Average (1984–2014 average)	0.301	0.247	0.231	0.212
High (2004–2014 average)	0.355	0.292	0.262	0.229

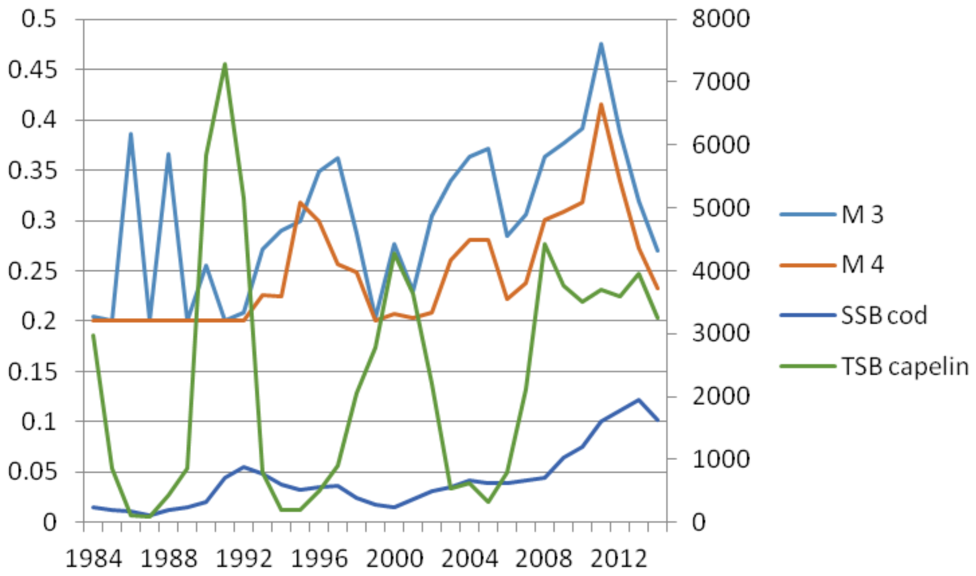


Figure 4.5. M at age 3 and 4 vs. cod SSB and capelin biomass in 1984–2014.

4.2.3 Growth/weight at age

The period of the time series when survey weights are available (stock weights in 1983–2015 vs. total stock biomass in 1982–2014) were used to fit a density-dependent model for weight at age (kg) in the stock $ws_{a,y}$ for ages 3–11+. The model is of the form

$$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a \qquad (4.2)$$

where TSB_y is the total stock biomass in year y, a is age, and α_a and β_a are constants. The parameters in the regressions are given in Table 4.3.

The range of possible values of haddock weight was truncated, in order to avoid unrealistic values due to extrapolations. The highest/lowest observed values of haddock weight at each age were used as upper/lower bounds in the model. For simplicity, uncertainty from the regression has not been included in simulations.

Table 4.3. Parameters in regression for density-dependent weight at age in the stock, and minimum, maximum and average value for the period 1982–2015.

Age	α	B	R^2	P	Min	Max	Mean
3	-0.0678	0.369	0.22	0.01453	0.262	0.524	0.335
4	-0.0175	0.711	0.3	< 0.01	0.482	1.098	0.619
5	-0.3244	1.141	0.38	< 0.01	0.747	1.632	0.972
6	-0.4230	1.581	0.37	< 0.01	1.048	2.195	1.356
7	-0.4994	2.033	0.33	< 0.01	1.371	2.761	1.776
8	-0.4925	2.450	0.25	< 0.01	1.704	3.307	2.197
9	-0.5415	2.895	0.25	< 0.01	2.038	3.822	2.622
10	-0.6525	3.370	0.32	< 0.01	2.411	4.297	3.043
11	-0.8026	3.859	0.43	< 0.01	2.845	4.73	3.453

Weight at age in catch is modelled as a function of weight at age in stock, using equation 4.3

$$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a \tag{4.3}$$

The values of α_a and β_a for ages 3–8 are given in Table 4.4. The regressions are based on data from 1983–2014, when observations of stock weights at age from surveys and catches are available.

Weight at age in the catch is calculated directly from weight at age in the stock using equation (4.3). Uncertainties associated with the regression were not taken into account. For ages 9 and older weight at age in the catch is set equal to weight at age in the stock.

Table 4.4. Parameters in regression for weight at age in the catch vs. weight at age in the stock.

Age	α_a	β_a	R^2	P	Min	Max
3	1.1027	0.3847	1.188	0.01328909	0.497	1.218
4	1.1428	0.3303	0.628	< 0,01	0.765	1.632
5	0.9775	0.3619	0.8141	< 0,01	0.998	2.038
6	1.0028	0.237	0.7701	< 0,01	1.176	2.852
7	0.6603	0.6712	0.5287	< 0,01	1.361	2.845
8	0.5509	0.8973	0.3657	< 0,01	1.704	3.218
9	1.0	0.0	0.2299		2.038	3.822
10	1.0	0.0	0.1265		2.411	4.297
11	1.0	0.0	0.2187		2.845	4.73

4.2.4 Maturation

Maturity at age was modeled as a function of weight at age in the stock in the same year:

$$P_{a,y} = P(ws_{a,y}) = \frac{1}{1+e^{-\lambda_a (ws_{a,y} - w_{50,a})}} \tag{4.4}$$

Fitting this model for ages 3–10 for the whole time series gave the results presented in Table 4.5.

Table 4.5. Parameters in regression for maturity at age vs. weight at age in the stock.

Age	λ_a	$W_{50,a}$	1980–2014 mean value
3	2.71526	1.63879	0.030
4	1.46324	2.09442	0.109
5	1.37998	1.55576	0.318
6	1.28825	1.05920	0.598
7	1.32132	0.64812	0.812
8	1.36813	0.26576	0.929
9	1.38587	0.00466	0.972
10	2.18397	0.69212	0.992

For age 3 P = 0.016 is used and for ages 10, 11, 12 and 13+ P = 1.

4.2.5 Exploitation pattern

The selection pattern used previously was last 3-year average. Such a short time period can give an unstable average. There have not been major changes in minimum sizes, gear types or division of quota on gear types in the last 20 years (1995–2014). Thus, as expected the selection pattern for ages 3–7 has not changed much during this period (Figure 4.6). We have used the last twenty years average as the default exploitation pattern S(a) (Table 4.5).

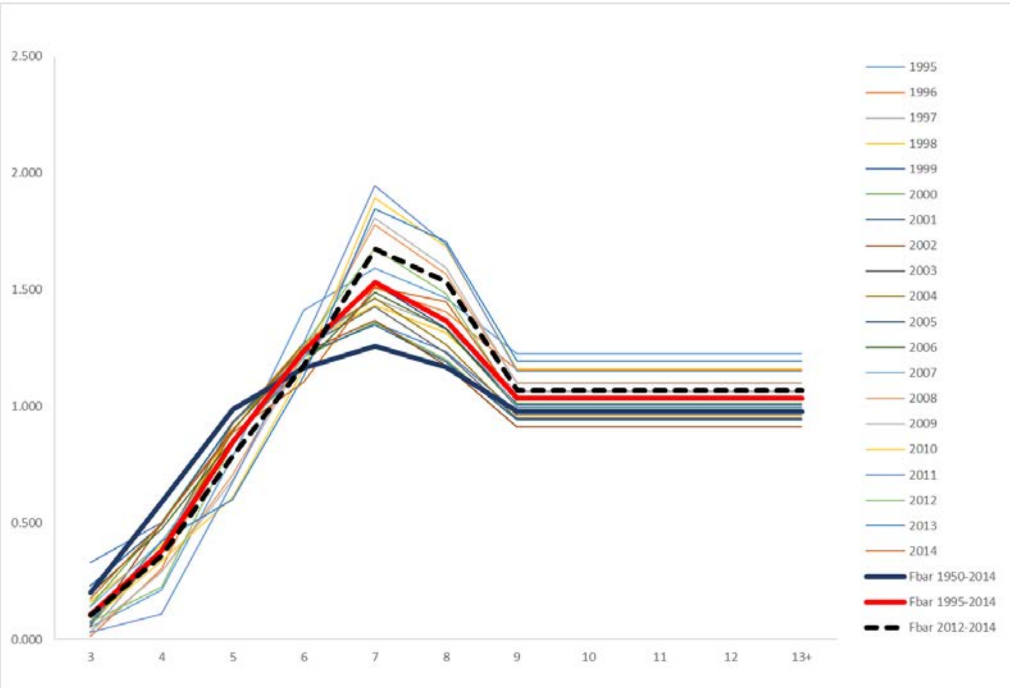


Figure 4.6 Selection pattern by age 1995–2014 (normalized to obtain F4–7 = 1.0).

Table 4.5. Default exploitation pattern (normalized to obtain F4–7 = 1.0).

Age	3	4	5	6	7	8	9	10	11+
Selection	0.1084	0.3760	0.8290	1.2293	1.5657	1.4016	1.0436	1.0436	1.0436

4.2.6 Supplementary analyses of population dynamics

Supplementary analysis of haddock population dynamics were made by Björnsson (WD1, see Annex 4).

4.3 Assessment error

Same approach as for NEA cod (section 3.3) but with CV = 0.25 for haddock compared to 0.2 for cod.

4.4 Implementation error

Not applied.

4.5 Reference points

The stock-recruitment relationship was investigated and as discussed in section 4.2.1, no model can represent this relationship adequately for northeast arctic haddock. Thus, The Group found no justification for changing the biological reference points. B_{lim} is based on B_{loss} = 50 000 t which gives B_{pa} = 80 000 t. B_{pa} is used as trigger B1 in the Harvest Control Rule. MSY reference points are investigated in section 4.8. Different target Fs were investigated in the evaluation and are discussed in section 4.9.

4.6 Experience with current harvest control rule in the period it has been in place

The harvest rule for NEA haddock proposed by JRNFC in 2003 was similar to the rule for NEA cod, including a TAC based on a 3-year forecast with target F (F_{pa} = 0.35), and constrained by a maximum 25% change compared to the TAC in the previous year. This was in operation for the advice years 2004–2006. For the years 2007–2008 the assessment was considered too uncertain, and the advice and TAC-setting were based on recent catches. Since the advice year 2009 a modified rule without 3 year ahead predictions has been applied. In 2015 the assessment model was changed and a considerable upward revision occurred. This also lead to a within year revision of the 2015 TAC. A summary is given in Table 4.6.

Table 4.6. Historic overview of previous HCRs for haddock. The 3 year ahead predictions were used for the advice years 2004–2006.

Year	ICES advice	TAC	Catch	Catch-IUU	Part of rule deciding HCR advice
2004	< 120	130	158	133	3-yr-rule, overruling 25%
2005	< 106*	117	158	128	3-yr-rule
2006	< 112*	120	153	141	3-yr-rule
2007	< 130**	150	162	150	2001–2004 average
2008	< 130**	155	156	150	2001–2004 average
2009	< 194	194	200	200	+25%
2010	< 243	243	249	249	+25%
2011	< 303	303	310	310	+25%
2012	< 318	318	316	316	Ftarget
2013	< 238	200	194	194	-25%
2014	< 150	178.5	178	178	-25%
2015	< 165	223***			Ftarget/+25% for revised adv.
2016	< 244	244			Ftarget

***one year F_{pa}-advice, HCR not evaluated**

****Uncertain assessment, HCR not evaluated**

*****within year revision with new assessment model**

4.7 Performance of harvest control rules in a short and medium term perspective

In order to investigate how the various rules would perform in the present situation, short-term (3-year) predictions were performed using the prediction input from AFWG 2015 (ICES, 2015b). For 2016 it was assumed that the TAC was constrained relative to the 2015 TAC of 223 000 tonnes. The results are shown in Figure 4.7. The 25% constraint is not applied in any years for rules 2 (current rule) and 6, thus rules 2 (25% both ways), 5 (no constraint) and 6 (only -25% constraint) all give the same results for these predictions.

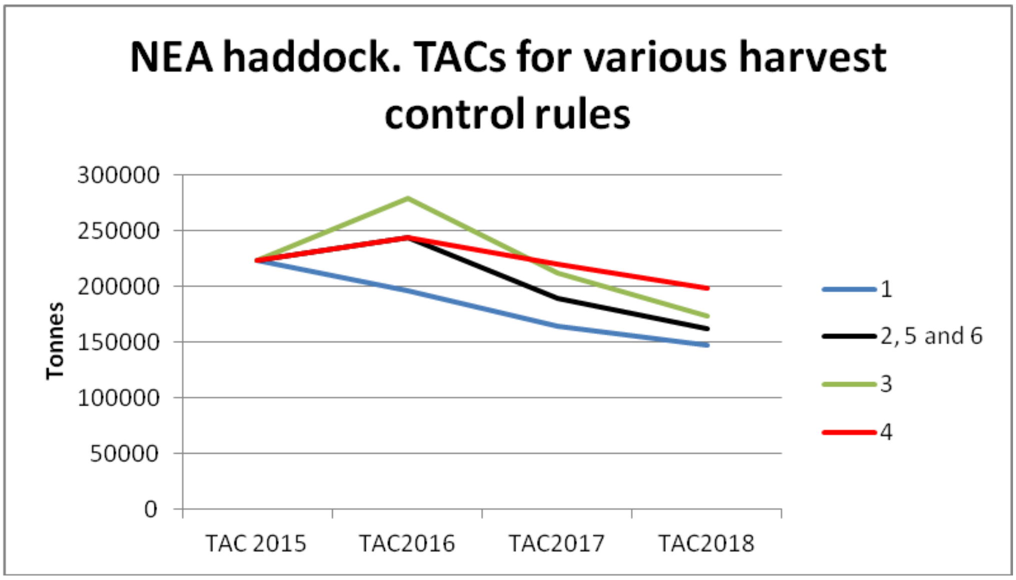


Fig 4.7. TACs for various harvest control rules for the period 2016–2018. When calculating the 2016 TAC, constraints on annual change in TAC were taken into account based on the 2015 TAC.

4.8 MSY and validation of long-term simulation results

Simulations of long-term variations of SSB and catch using same settings as applied for HCR investigations with different target Fs were done in NE_PROST program. Runs were made using constant F at all SSB levels instead of a HCR where F is reduced linearly from F_{target} at B_{pa} as done in all proposed HCRs. Assessment error was not included.

The results indicate that it is not likely to increase the yield by increasing the current target F = 0.35, and the simulations also indicate a reduced yield in tonnes at lower fishing mortalities (economic yield is another issue).

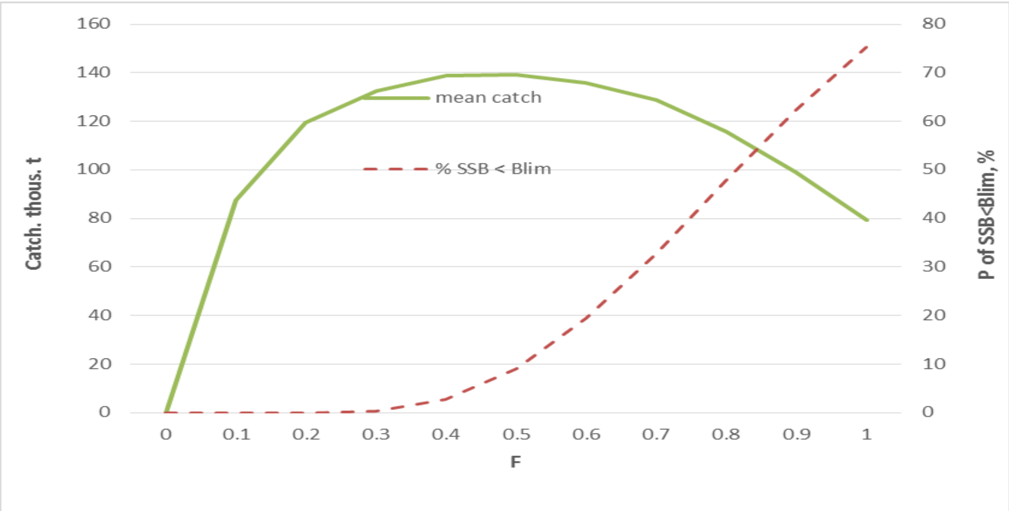


Figure 4.8. Mean catch with corresponding F target and probability of SSB < B_{lim} (5000 iterations).

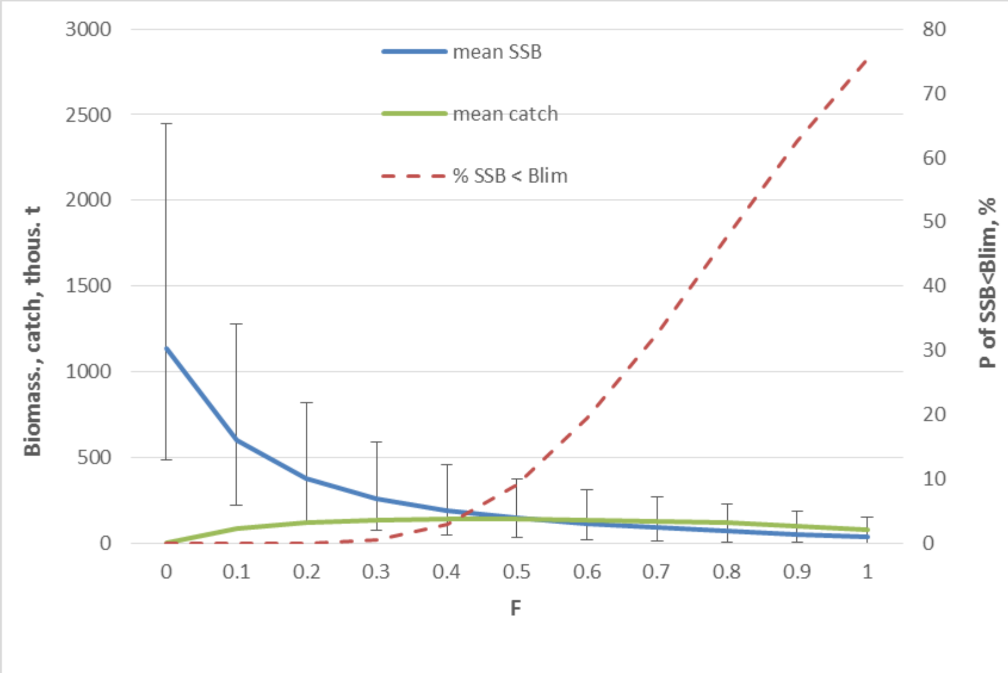


Figure 4.9. Biomass with 95% confidence intervals and mean catch with corresponding F target and probability of SSB < B_{lim} (5000 iterations).

Table 4.7 shows that the yield is fairly stable in the range F = 0.3 to F = 0.6, but F = 0.4 and F = 0.5 gives a higher yield than the other values. At the same time 95% probability of SSB > B_{pa} corresponds to the range F = 0.3 to F = 0.4.

Table 4.7 Values of SSB, TSB, catch (1000 tonnes) and probabilities of decreasing SSB below B_{pa} and B_{lim} with different target F. Results of 5000 iterations.

	target F										
parameter	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
mean F	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
mean SSB	113 5	600	376	258	191	146	114	90	69	51	36
min SSB	204	79	32	21	11	3	1	0	0	0	0
mean TSB	146 6	904	660	524	443	382	332	287	239	191	145
mean catch	0	88	120	132	139	139	136	129	116	99	79
% SSB < Bpa	0	0	0	3	12	26	41	55	69	80	88
2.5% SSB	487	223	121	74	48	33	21	12	6	2	1
97.5% SSB	245 0	1278	821	589	459	372	311	265	224	188	153
% SSB < Blim	0	0	0.0	0.4	2.8	9.1	19.4	32.6	47.8	62.4	75.2
mean R	228	228	229	228	228	224	215	203	181	154	122

4.9 Evaluation of harvest control rules in a long-term perspective

JNRFC has previously agreed to revise the existing harvest control rules for Northeast Arctic haddock by 2015. In order to provide background information for this revision, a list of harvest control rules to be explored was suggested by JNRFC in 2015 (Annex 1 of this report).

Simulation settings

For each run, 5000 simulations 100 years into the future were made. The average values for the last 80 years of the period were used, in order to avoid the influence of the initial values. In all simulations recruitment, weight and maturity depend on population density, natural mortality taken as average for period 1984–2014 (see above).

Assessment error was included (CV = 0.25 for all age groups, uncorrelated). Implementation error is not included.

Based on the prob 1 estimates (Table 4.8), all rules are within precautionary approach (prob 1 < 5%). However, only rule 1 is above B_{pa} in more than 95% of the cases (Figure 4.10). There are small differences in median catches between the rules, 103–113 thousand tonnes (Table 4.8). These values are a little lower than the median historic catch (130 kt), which may be related to the low target Fs and different selection patterns throughout the time series. It is also possible that the density dependent growth effect in our model is too weak at low stock sizes and too strong at high stock sizes, as indicated in Figure 4.11. Density dependent effects may also affect modelled yield.

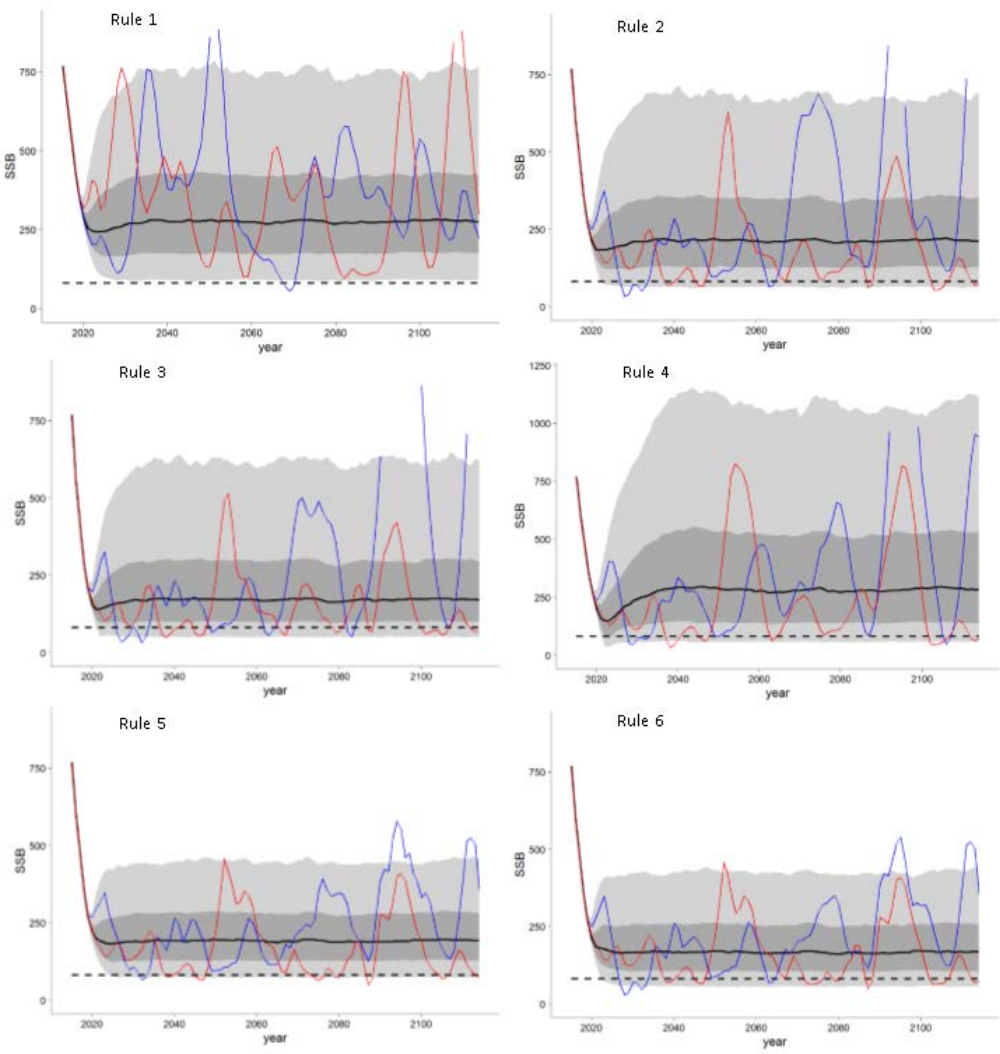


Figure 4.10. Northeast arctic haddock simulated SSB (1000 tonnes), rules 1–6. Median SSB (black line), B_{pa} (dashed line) 50% confidence limit (dark grey), 90% confidence limit (light grey), and two individual runs (red and blue). Note the different scaling on the y-axis in rule 4.

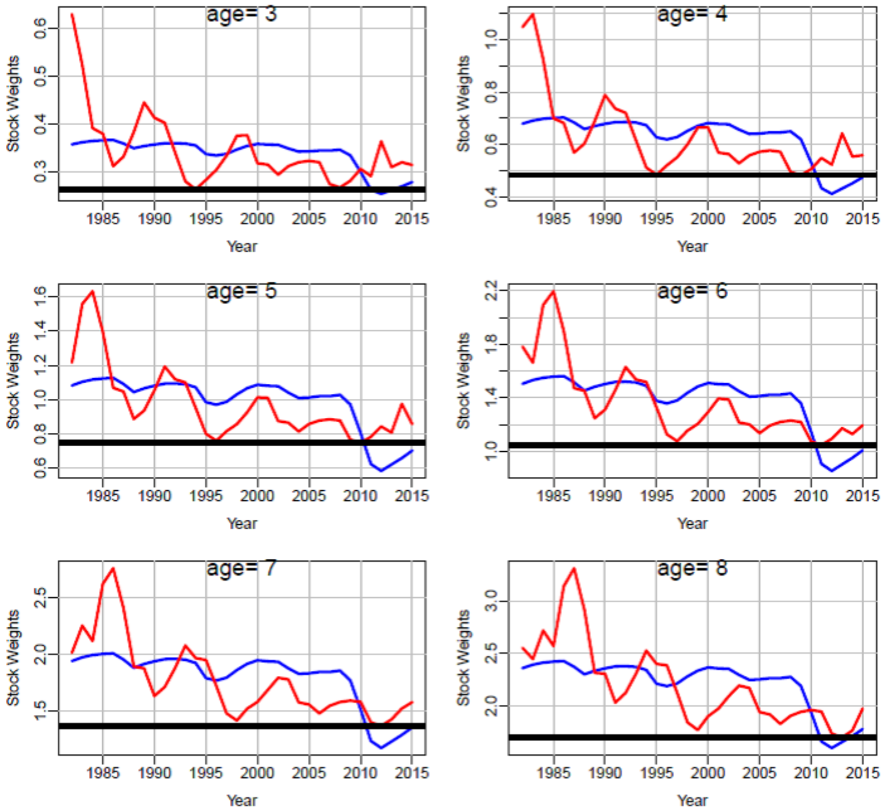


Figure 4.11. Predicted stock weights for age 3–8 (blue) vs observed (red). Minimum values shown as black horizontal lines.

F_{bar} levels are within reasonable levels. However, the 95th percentiles in rule 3 and 4 are above $F_{lim} = 0.77$ (Figure 4.12).

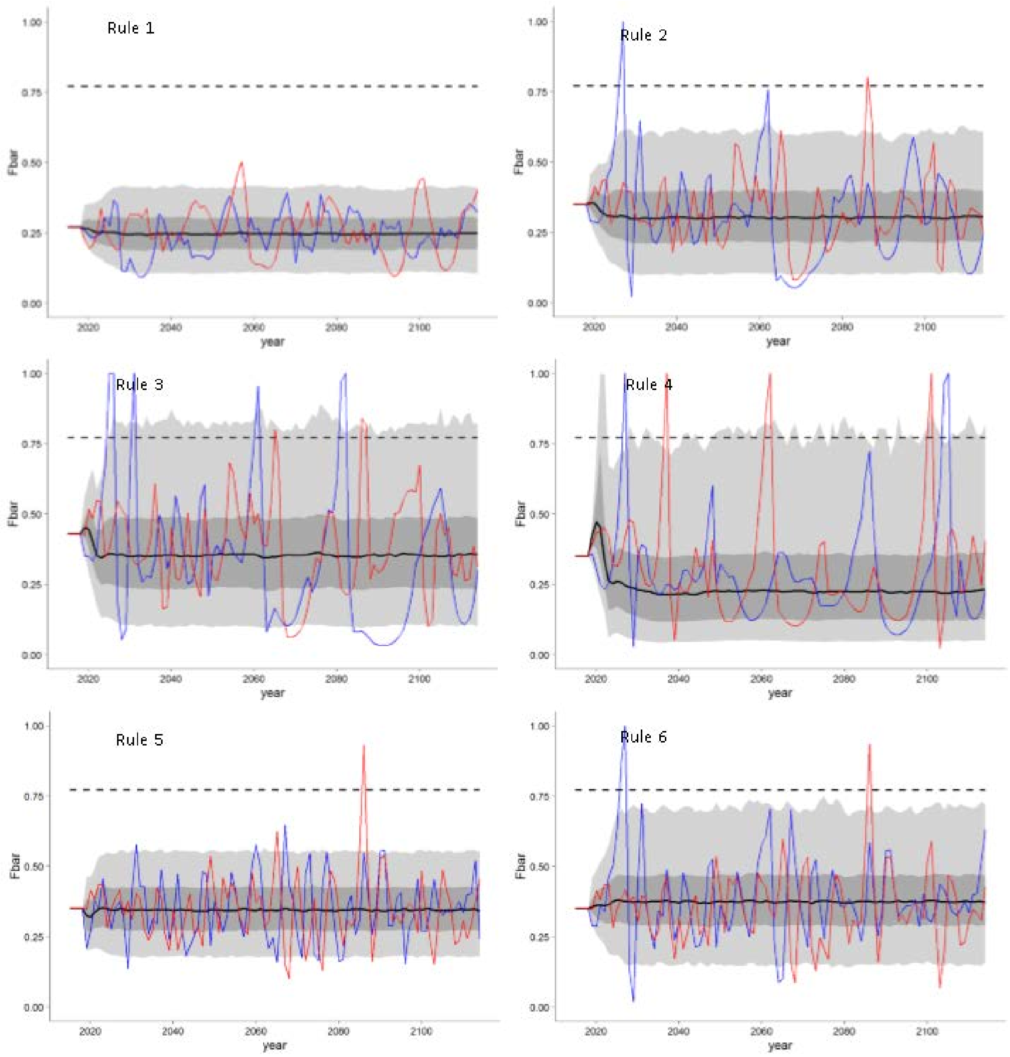


Figure 4.12. Northeast arctic haddock simulated F. Median F (black line) F_{lim} (dashed line) 50% confidence limit (dark grey), 90% confidence limit (light grey), and two individual runs (red and blue).

The rule with the highest probability of SSB < B_{lim} is rule 3 (F = 0.43, max 25% year-to year change in TAC), with prob 1 = 4.9%. This rule can also be used as a reality check. The average value of F for the period 1950–2014 is 0.46, and the average values of total biomass, SSB, landings are 464, 175 and 136 thousand tonnes, respectively. The average recruitment at age 3 is 255 million. The mean stock sizes and catches from rule 3 are close to these historical averages. This indicates that the model performs reasonably well at this level of fishing mortality. As expected, median SSB is above historic median due to lower target F in the later period. The selection pattern has also changed throughout the time series. In the beginning of the period there was higher fishing pressure at younger ages.

It is also seen that using a max 10% year-to year change in TAC increases (rule 4) the probability of SSB < B_{lim} and B_{pa} similar to increasing of F target. All rules give variable catches from year to year, caused by the high variability in recruitment. However, rules 3, 5, and 6 give the most variable catches (Figure 4.13, Table 4.8).

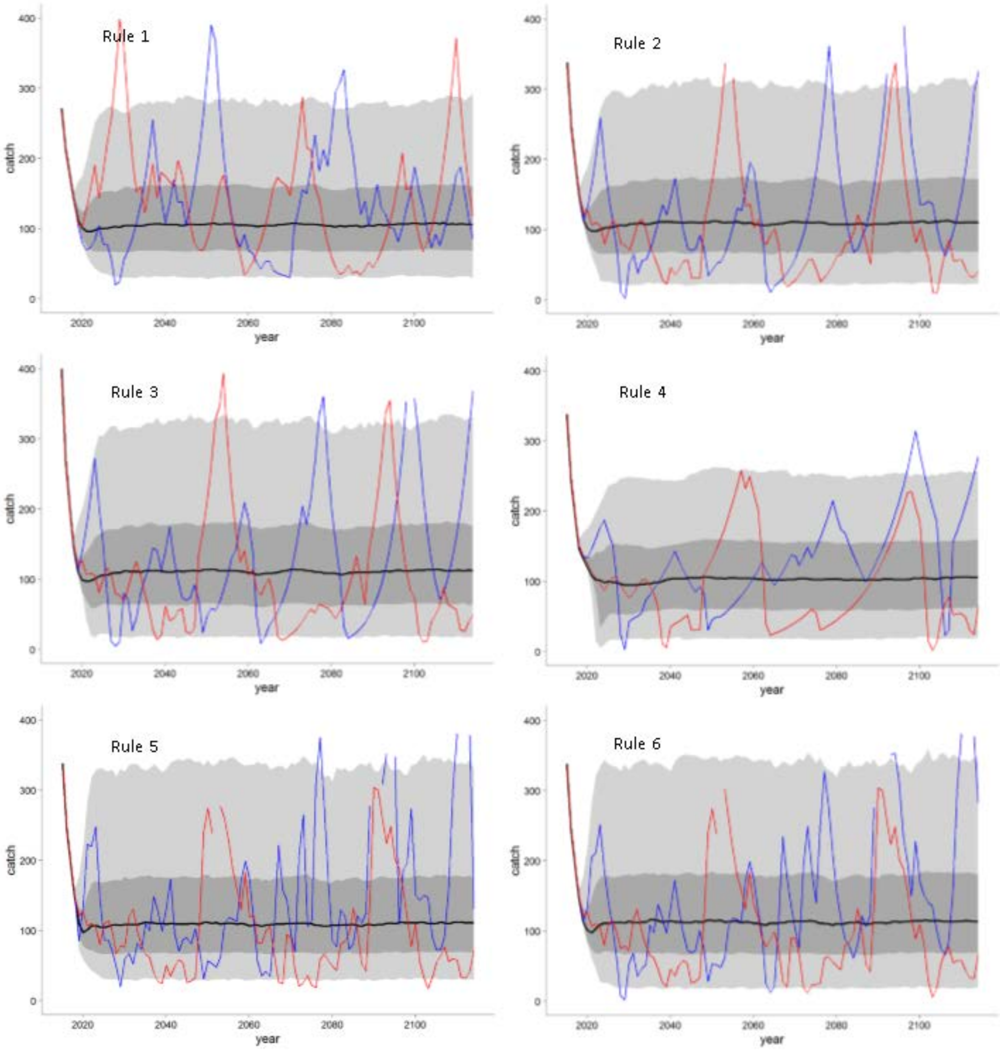


Figure 4.13. Northeast arctic haddock simulated catch. Median catch (black line), 50% confidence limit (dark grey), 90% confidence limit (light grey), and two individual runs (red and blue).

The runs with F = 0.27 with 25% TAC variation (rule 1) and F = 0.35, and no limit on maximum year-to-year-change in TAC (rule 5) gave the lowest probability of SSB < B_{lim} and B_{pa}.

Table 4.8. Results of long-term stochastic simulations – stock biomass, recruitment and yield. Values for the 5000 simulations with assessment error performed for each HCR.

HCR No.	Target F	% of TAC changing	Mean F realised	Catch, (1000 t)		annual change in catch % (absolute value)		TSB, (1000 t)		SSB, (1000 t)		Recruitmentage 3 (millions)	
				mean	median	mean	median	mean	median	mean	median	mean	median
1	0.27	±25	0.255	125	106	26.1	21.4	611	512	331	276	228	136
2	0.35	±25	0.323	130	109	36.1	24.4	543	440	273	214	228	135
3	0.43	±25	0.384	133	111	45.1	27.0	495	388	233	171	227	135
4	0.35	±10	0.277	115	103	32.5	11.4	673	539	391	282	227	135
5	0.35	±1000	0.353	136	109	40.9	31.0	476	403	218	192	228	136
6	0.35	+1000 -25	0.395	138	113	49.0	31.5	448	373	195	167	227	135

Table 4.9. Results of long-term stochastic simulations. Probabilities of SSB < B_{lim} and B_{pa} and overview of how often different parts of HCR are applied. Mean values for the 5000 simulations with assessment error performed for each HCR.

HCR No.	Target F	% of TAC changing	Mean F realised	Probabilities when SSB < Blim (%) (ICES, 2013a)			% of years SSB < Bpa	% of years where various parts of HCR decide TAC	
				prob 1	prob 2	prob 3		restricted by % increase	restricted by % decrease
1	0.27	±25	0.255	0.6	22.8	0.9	3.5	37.0	21.5
2	0.35	±25	0.323	2.3	65.7	2.9	9.8	38.3	17.9
3	0.43	±25	0.384	4.9	88.7	5.4	16.7	37.6	13.2
4	0.35	±10	0.277	3.3	82.9	4.1	10.7	58.2	16.8
5	0.35	±1000	0.353	0.8	27.8	1.1	6.9	0.0	0.0
6	0.35	+1000 -25	0.395	3.4	79.1	3.9	13.9	0.0	22.8

4.10 Conclusions

Simulations of long-term variations of SSB and catch using settings of current and proposed HCR show that all rules are within precautionary approach (prob 1 < 5%). Increasing target from F = 0.35 to 0.43 leads to increasing probability of SSB < B_{lim} (4.9%) and using a max 10% year-to year change in TAC increases the probability of SSB < B_{lim} and B_{pa} similar to increase of F target and decreasing mean catch.

The run with F = 0.35, and no upper limit or without any limit on year-to-year-change in TAC (rule 5 and 6) gave low probability of SSB < B_{lim} and B_{pa}, but give the most variable catches. Running MSY evaluations leads to maximum yield at range F = 0.4 to F = 0.5, but at the same time 95% probability of SSB > B_{pa} corresponds to the range F = 0.3 to F = 0.4.

The Workshop concluded:

1. Do not increase F_{target} (not precautionary)

2. The proposal of 10% limitation of annual TAC variability will decrease average yield.

Among the six HCRs tested, the current HCR (rule 2) performs best in terms of average yield, stability of yield and degree of precaution.

5 Barents Sea capelin

5.1 Background

For capelin, annual acoustic abundance estimates from September are available from 1973 onwards. In the assessment and management of this stock, these estimates are assumed to be absolute estimates. There is no VPA-type model for capelin.

In 2002, the JRNFC agreed to adopt a management strategy based on the rule that, with 95% probability, at least 200 000 t of capelin should be allowed to spawn. Consequently, 200 000 t has been used as a B_{lim} since then. The basis for this was as follows: The 1989 year class is the highest observed recruitment at age 1 in the time series. The SSB in that year was around 100 000 t. The B_{lim} is set to a value somewhat above this, i.e. 200 000 t. The B_{lim} (SSB_{lim}) management approach was suggested for this stock (Gjøsæter *et al.,* 2002) where further details can be found.

Fishery is recommended only during January-March and is assumed to target the maturing stock only. Historically, there was also a fishery in autumn catching both maturing and immature capelin, but since 1993 the fishery is closed in autumn.

5.2 The current harvest control rule – models and performance

The TAC advice is based on a 6–month prediction from survey to spawning (1 October–1 April) using a multispecies model (Gjøsæter *et al.,* 2002). The starting point of this prediction is the maturing biomass (capelin > 14 cm) as measured in the acoustic survey. The elements of the model are natural mortality in the autumn (October-December) and predation by immature cod in January-March the following year. In this model predation by cod on capelin is modelled explicitly in January-March while natural mortality in October-December is drawn from historically observed values.

Figure 5.1 shows the removal of maturing capelin biomass in autumn caused by various sources (natural mortality in October-December, consumption by cod in January-March, catch) together with the surviving spawning stock biomass, according to the assessment model. This figure shows that in years with high maturing biomass, fishery accounts for a minor part of the removal of biomass, and that in years with low biomass, there is no excess available for fishery.

The Barents Sea capelin assessment is based on the use of two different models. CapTool is an Excel spreadsheet from which the catch quota corresponding to the harvest control rule is calculated using stochastic simulations from the time of measurement (October 1) to the time of spawning (April 1 the following year). Bifrost is a model which is used to estimate parameters in the two main biological processes behind the CapTool simulations: maturation and predation by cod. Bifrost can be used for making long-term stochastic simulations of harvest control rules for capelin for given harvesting strategies for cod (see Tjelmeland, 2005), but the model was not available for use at the WKNEAMP-2 meeting. The results reported here are from CapTool.

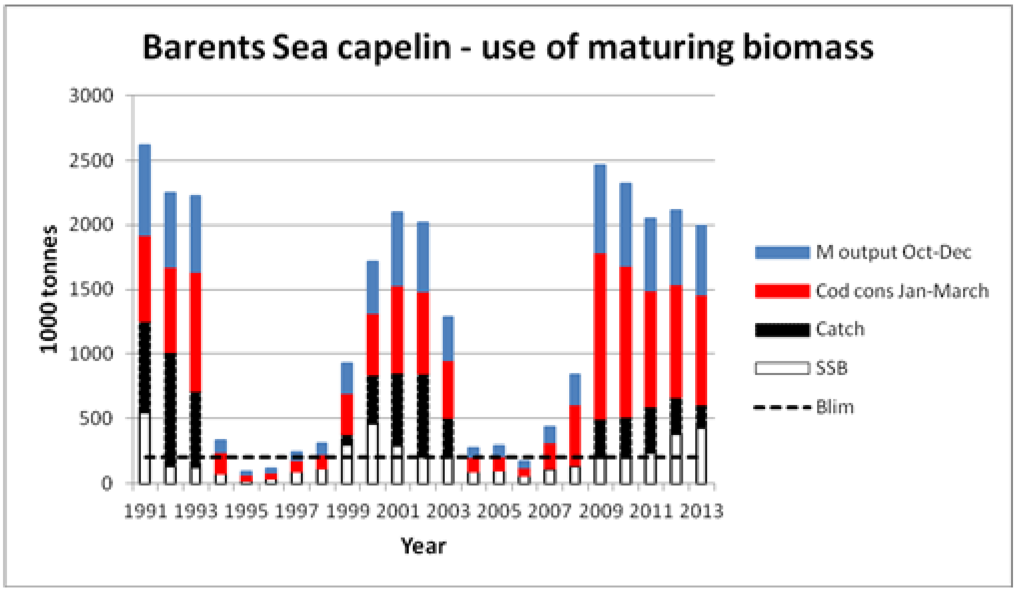


Figure 5.1. The removal of maturing capelin biomass in autumn due to natural mortality in the autumn (M output Oct – Dec), Cod consumption and Catch. The surviving biomass is spawning stock biomass (SSB) (data from Gjøsæter *et al.*, 2015).

Gjøsæter *et al.*, (2015) retrospectively investigated the performance of the capelin assessment using information from cod stock and catch data now available, for the period from 1990 onwards. They reran the simulations of capelin SSBs for the years 1991 to 2013 based on the cod assessment from 2013 (ICES, 2013e) and the actual catches of capelin in winter during that period.

The difference between the assumed immature cod stock biomass in the capelin quota year at the time when the capelin assessment was carried out and the corresponding biomass based on the 2013 cod assessment is considerable in some years. In the period 2009–2013, the immature stock abundance was underestimated mainly because the strong 2004 and 2005 cod year classes were underestimated when they were young. Also, the model for natural mortality of cod used in the early part of the period gives lower values for natural mortality than the model used at present.

In all cases where a quota larger than 0 was advised, the quota and the SSB would have been lower, given today's knowledge about the actual cod stock size (Figures 5.2 and 5.3). In addition, in two years (2009 and 2010) where a non-zero quota was advised, their results show that the advice would have been zero quotas.

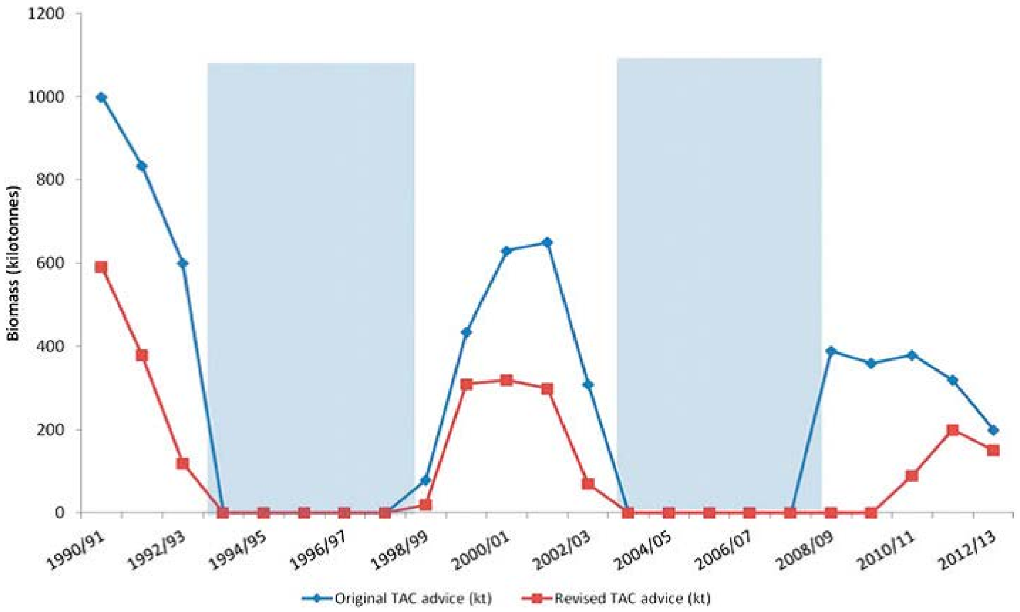


Figure 5.2. (Figure 2 in Gjøsæter *et al.*, 2015). Original and revised TAC advice originally given for capelin. Blocks denote the periods when no fishery took place because the capelin stock was in a collapsed state.

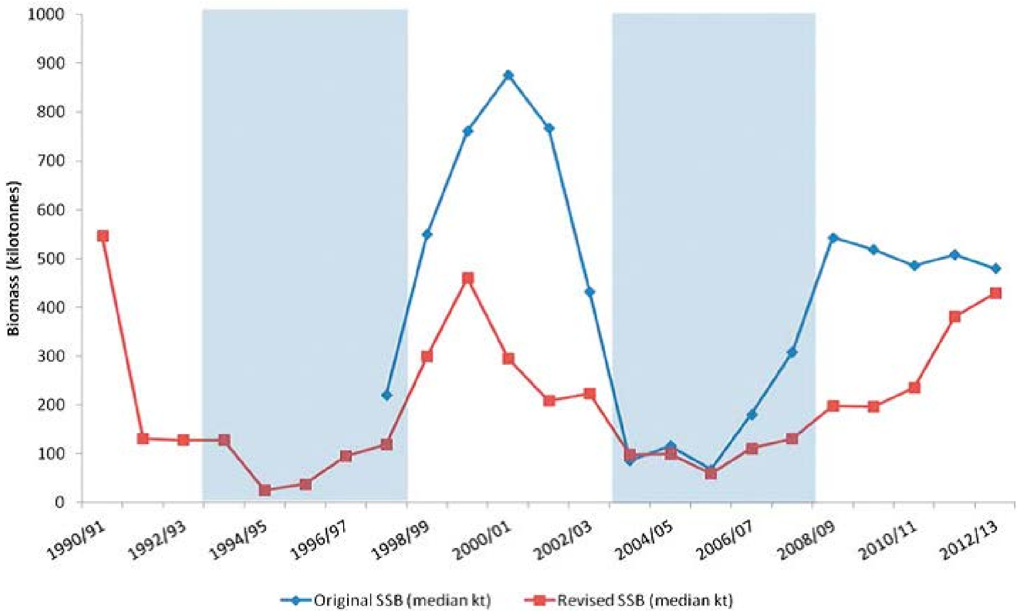


Figure 5.3. (Figure 3 in Gjøsæter *et al.*, 2015) Original and revised estimates of median capelin SSB. Blocks denote the periods when no fishery took place because the capelin stock was in a collapsed state.

There are, however, considerable uncertainties with the estimation of capelin spawning stock (illustrated by vanishing SSB in several years before 1987 using the present model approach). One of the reasons for vanishing historical SSB in some years is that the true capelin stock size may have been underestimated in the survey in the 1970s as acoustic estimates from that period are likely to be underestimates compared to newer ones (Gjøsæter *et al.*, 2015). Also, when using the model for periods when the proportion of the stock caught by the fishery is higher than after 1990, the results become more vulnerable to the assumption that acoustic estimates are on an absolute scale (i. e. same scale as catches) and thus catches can be subtracted directly from the acoustic estimates in calculations of SSB.

However, the spawning stock seems to have been sufficient to ensure adequate recruitment in years with good recruitment conditions, and this indicates that the current HCR is precautionary.

5.3 JRNFC Request

JRNFC asks ICES for Barents Sea capelin to investigate

> *The existing harvest control rule with varying probabilities for the spawning stock biomass to be above 200 thousand tonnes (i.e. 80, 85, 90 or 95%).*
>
> *This gives a total of 4 different rules to be explored, one of which corresponds to the existing harvest control rule.*
> *The effect of each of the harvest control rules for cod stated above on the capelin yield should be explored.*

The existing harvest control rule is to assure that 200 000 tons SSB are left for spawning with 95% probability or equivalent that there is at most a 5% risk that the SSB goes below B_{lim} (= 200 000 t) i.e. applying the ICES approach of using a 5% criterion that SSB drops below the B_{lim} for evaluating whether a HCR is precautionary or not. Clearly, changing the risk levels as indicated in the requests means that the resulting HCR is not precautionary in the ICES sense if the B_{lim} of 200 000 tonnes is maintained.

Changing the risk criterion is equivalent to change the B_{lim} and maintain the 5% probability criterion. The Group notes that the effect of changing the risk level and changing the B_{lim} is equivalent but conceptually different. Changing the risk and maintaining B_{lim} suggests that the reproduction dynamics of the capelin stock is unchanged while changing B_{lim} should be based on information on capelin reproduction dynamics. The most recent evaluation of the spawning stock and recruitment time series is Gjøsæter *et al.* (2016). As noted above, the basis for the present B_{lim} value is the highest observed recruitment at age 1 (1989 year class) which was produced by a SSB around 100 000 t. Year classes since 1989 have been smaller independent of the SSB. The Group concluded that there is no basis on which to revise the B_{lim} value. However, there are large uncertainties in the calculation of SSB, many historical SSB values are very low and further research on stock-recruitment relationships and reference points is required.

This stock is managed by a target escapement strategy and F-based reference points are not relevant. Also, with an assessment where uncertainty is included and the HCR prescribes a low probability for SSB < B_{lim}, B_{pa} is not needed either. Such rules will generate very high fishing mortalities when the stock is large.

5.4 Harvest control rules with different risk levels

The current catch rule can be approximated by the following equation:

$$TAC = \begin{cases} 0\ if\ S * b * u < Blim \\ S * b - \dfrac{B_{lim}}{u}\ otherwise \end{cases}$$

'S' is the biomass of the maturing component of the stock as measured by the survey around 1 Oct. The 'b' parameter accounts for cod predation, other capelin mortality and growth in the period 1 October–1 April and is accounted for through an assessment model (Gjøsæter *et al.*, 2002). The 'u' parameter accounts for the uncertainty in the estimate of the SSB (1 April) generated by survey results 'S' uncertainty as measured at around 1 October and projection of the survey biomass until the capelin spawns around 1 April and reflects the 5% percentile of the calculated SSB probability distribution. Note that u < 1 by definition and therefore 1/u > 1. The fishery is concentrated towards the end of the season and the formula is derived on the assumption that the fishery takes place at the end of the fishing season.

The CapTool model was used to calculate the SSB probability distribution for the years 2008–2016 (1 April) on the assumption that no fishing takes place and based on the actual survey results, Figure 5.4.

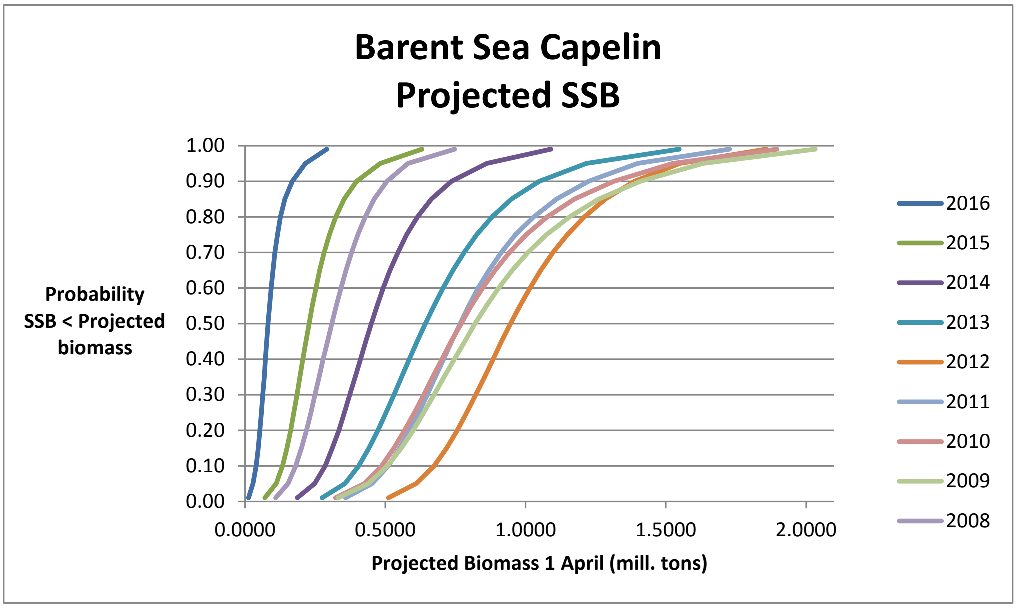


Figure 5.4. Cumulated distribution of projected SSB for 2008–2016, i.e. projection of survey biomass (maturing component) from the period 2007–2015. Based on CapTool simulations.

The simulations suggest that the resulting distribution is approximately lognormal, Figure 5.5.

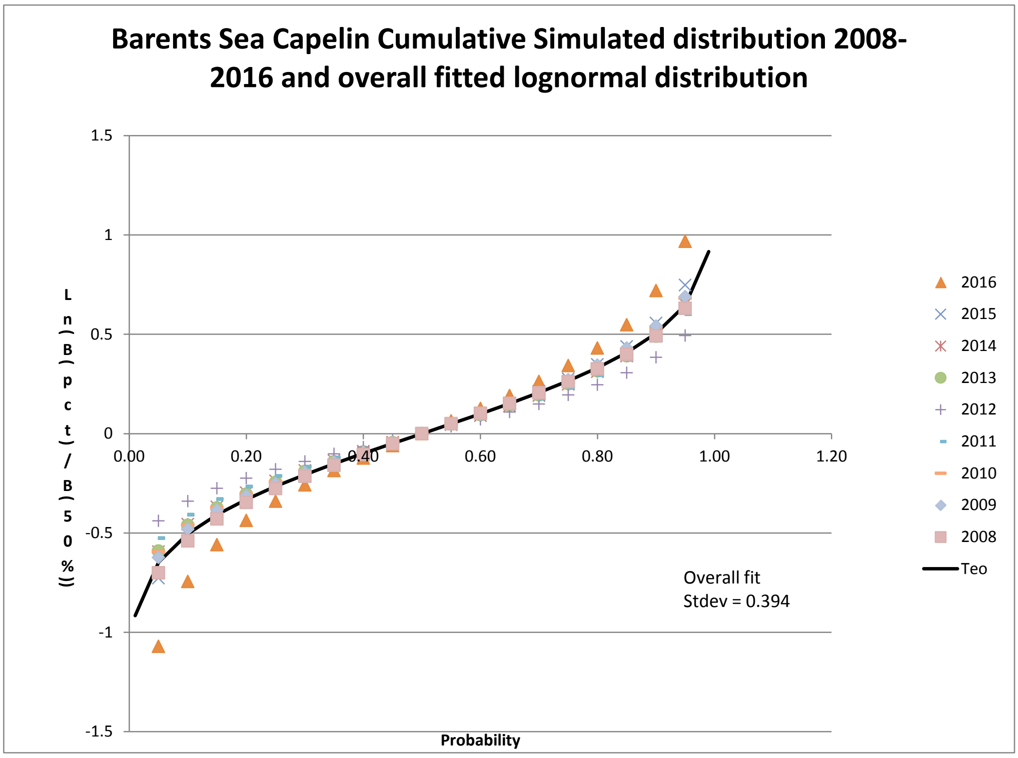


Figure 5.5. Survey results of maturing biomass (cumulative probability distribution) projected to 1 April the following year for the survey years 2007–2015. The 2016 projection is based on projected cod biomass. The 'Teo' line shows the overall fit to the annual distributions.

The ratio 'Predicted median Biomass (50%) at 1 April [B(1 Apr)/Survey result (1 Oct)] with no fishing' is found in Table 5.1.

Table 5.1. Summary of NEA cod biomass estimates, survey results and the b = Predicted/Survey parameters. TSB: Total biomass; SSB: Spawning stock biomass; imm: Immature biomass. Source AFWG 2015 (ICES, 2015b) Tables 3.24a and 3.26.

	2016	2015	2014	2013	2012	2011	2010	2009	2008	Average
Cod TSB	2893	2963	3152	3591	3389	3379	3289	3072	2512	
Cod SSB	1063	1139	1620	1943	1770	1599	1192	1036	701	
Cod imm	1830	1824	1532	1648	1619	1780	2097	2036	1811	
Survey results	375	873	1471	1997	2115	2051	2323	2468	844	
"b"	0.22	0.26	0.31	0.32	0.45	0.37	0.33	0.33	0.37	0.33

For illustration of the effect of the changing the risk level we base the following calculations on averages. For a specific year the calculations will be done using the full model however, the general behaviour of the HCR is captured by the results presented below. Taking averages we estimate the following parameters in the HCR based on B_{lim} = 200 000 t and 5% criterion.

b ~ 0.33 from the median ratio (Table 5.2)

u is found in Table 5.3 and is calculated as the 'Risk' standardised value in the lognormal distribution (0,stdev = 0.394), see Figure 5.5

Table 5.2 shows the parameters for the four different risk levels indicated in the request.

Table 5.2. Parameters and equivalent B_{lim} using 5% criterion for calculating the HCR at different survey results and risk levels. u = exp(lognormal standardised value). Based on the overall standard deviation for projection of SSB under a no fishing assumption.

Risk	b	b*u	1/u	Equivalent B_{lim} ('000 t) (5% criterion)
5%	0.33	0.17	1.91	200
10%	0.33	0.20	1.66	173
15%	0.33	0.22	1.50	157
20%	0.33	0.24	1.39	146

Figure 5.6 shows the average harvest expected as a function of survey results and for three different risk levels.

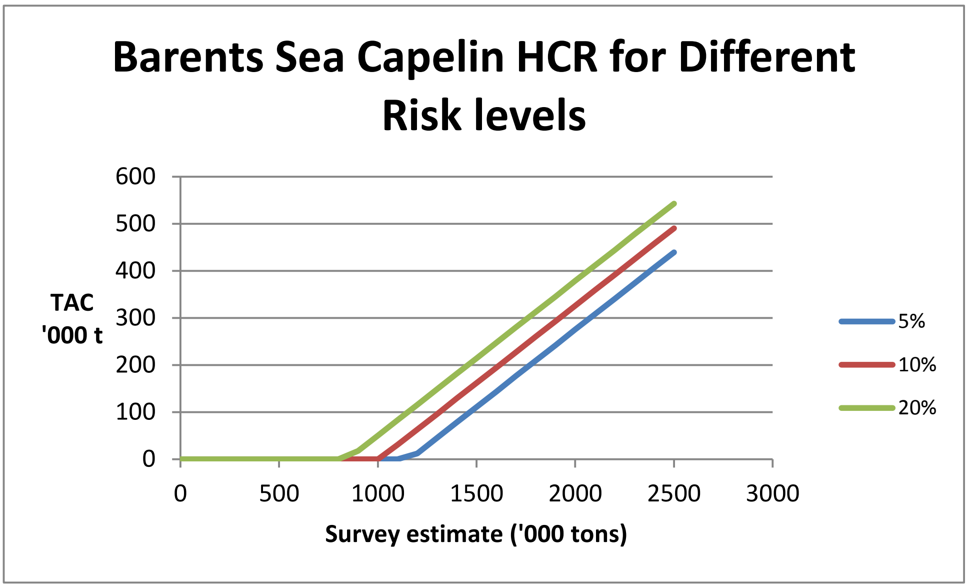


Figure 5.6. Theoretical change in capelin HCR using 5%, 10% and 20% criterion equivalent to probability levels of 95%, 90% and 80%. The projections represent the average cod biomass 2008–2015. The 85% risk level is not shown for clarity of the graph.

Figure 5.6 shows that for survey results above 1.2 mill tonnes doubling the risk level is equivalent to adding about 50 kt to the TAC.

5.5 Issues with the prediction model CapTool

The current reference point B_{lim} was based on work done by Gjøsæter *et al.* (2002) and using cod predation levels around 2000, i.e. before the cod stock increased to the present level. The development in cod biomass is presented in Figure 5.7 and illustrates the increase in the immature cod biomass. Immature cod is considered the major determinant on capelin mortality in winter. B_{lim} is reflecting reproduction dynamics of the capelin stock and this may not have changed since 2000 and the predation model used to calculate cod predation is supposed to account for the cod increase.

The prediction of capelin biomass from October – April does only include predation by immature cod. That mature cod does not affect the capelin stock seems highly unlikely except for the last two months of the capelin life when maturing cod have left the areas where capelin occurs to gather at the cod spawning grounds. Ignoring the predation by maturing cod would not be a major problem if immature cod was a fixed proportion of the cod stock but the proportion has increased much since 2007 due to lowering the fishing mortality. To put things into context to show that this is not a small problem consider the "b" parameter (growth and predation in the capelin stock over the winter period 1 Oct–1 Apr). This would change from 0.33 as used in this presentation (average 2008–2016) while the individual value for 2016 is 0.22 i.e. a major decrease.

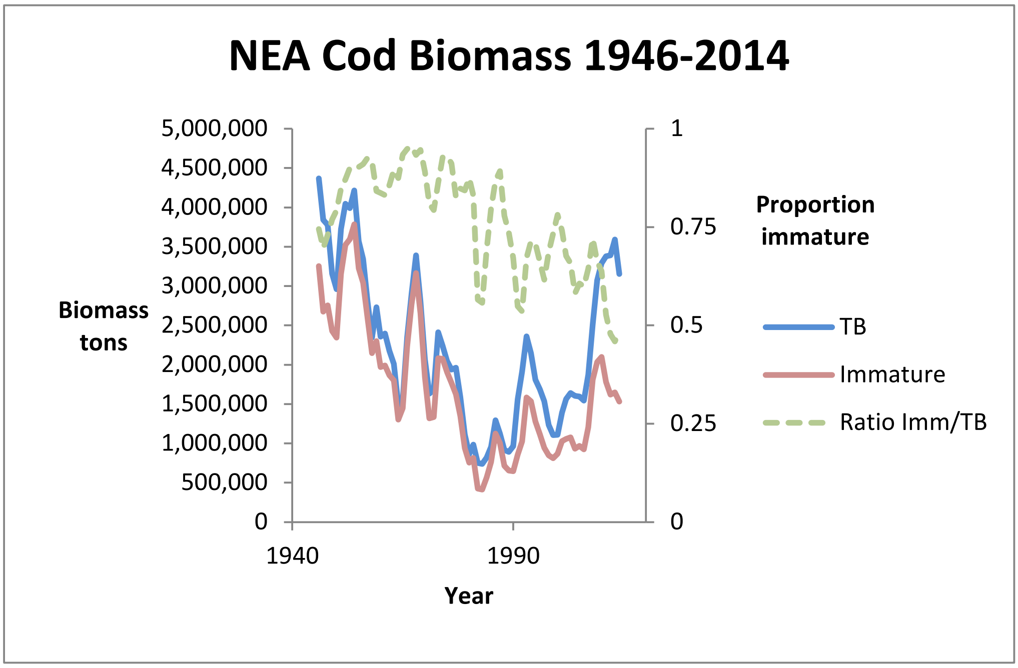


Figure 5.7. Total NEA cod stock (blue), immature part (violet) and ratio between the immature and the total biomass (green) 1946–2014. The spawning stock does not prey on capelin according to the model. Data from AFWG 2015 (ICES, 2015b Table 3.24a.

5.6 Relative importance of survey accuracy

The SSB prediction uncertainty stems from two sources: the survey measurement uncertainty and the projection uncertainty based on uncertainty in the cod assessment and the model uncertainty in the projection model. Currently, the survey CV is 0.20 and Figure 5.7 presents the advised TAC as a function of different CV for the surveys. The calculations were done using the simplified model presented above and the average estimates.

$$CV(projection) = \sqrt{0.395^2 - 0.2^2} = 0.339$$

The projection and the survey are independent processes. Therefore, the CV(projection) can be calculated for other CV(survey) values than the current 0.2 and the resulting TAC is presented in Figure 5.7 for three levels of risks and for the case that the survey result is 1200 kt.

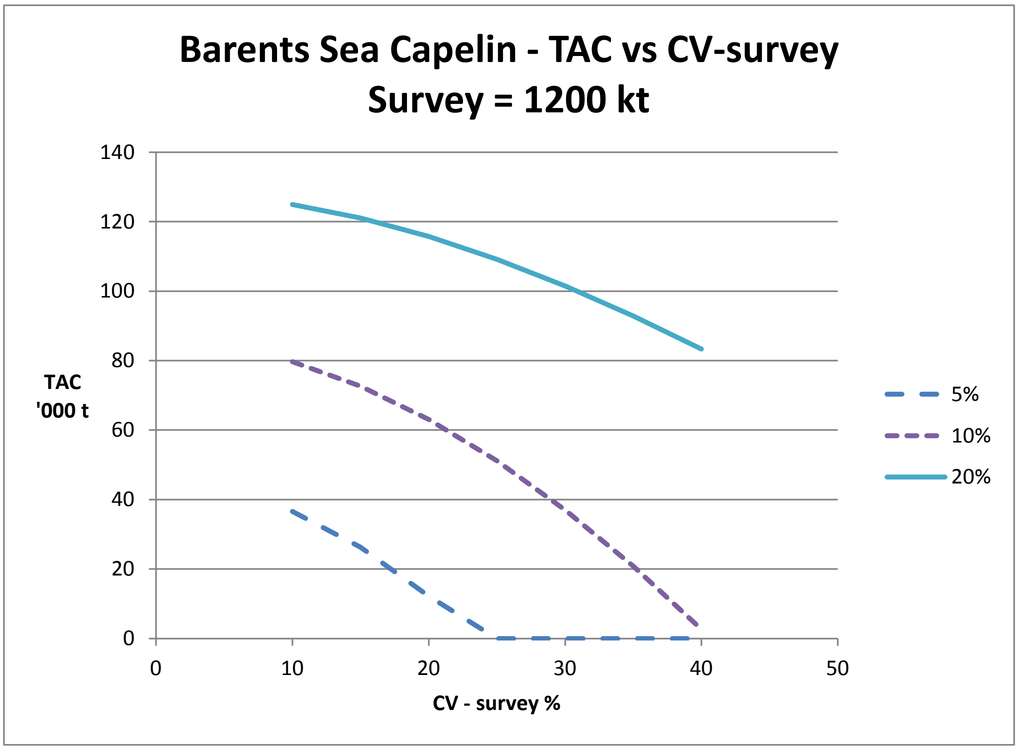


Figure 5.8. TAC as function of the CV(survey) % for three risk levels. The Figure presents the case that the survey result (maturing biomass) is 1200 kt and the parameters that are used are based on the average situation 2008–2016.

5.7 Comments on current stock situation and performance of harvest control rules in the short term

After the re-opening of the capelin fishery in 2009, the current management plan and HCR resulted in annual catches of 65–360 000 t of capelin. At the same time, the capelin stock in 2009–2013 was stable, despite the large numbers of cod and other predators.

Since 2014, the stock began to decrease significantly despite adequate recruitment and a relatively low fishery level. Also, indications of maturation at lower length than previously observed are found.

The current situation of the capelin stock dynamics is unclear. Perhaps there is a range of factors which are currently not taken into account in the present TAC model. It may need a new biological reference point or new predictors in the model. Also note that parameters in recent CapTool models have not been re-estimated since 2003.

Testing of the existing HCR in the current situation is difficult. Any increase of the fishing pressure on capelin in the current situation may not correspond to a precautionary approach although the HCR in previous years has been precautionary.

The low abundance of immature capelin in 2015 will likely lead to low abundance of mature capelin in 2016 and a zero catch advice for 2017 according to all the suggested HCRs.

6 References

Anon. 2015. Protocol of the 45th Meeting of the Joint Norwegian-Russian Fisheries Commission, Astrakhan, Russia, 6-9 October 2015. (In Norwegian and Russian, Norwegian version available at https://www.regjeringen.no/no/aktuelt/enighet-om-norsk-russisk-kvoteavtale-for-2016/id2457679/)

Björnsson, H. 2016. Investigation of data and assessment methods for Barents Sea cod and haddock. WD1, WKNEAMP-2 (Given in Annex 4 of this report).

Gjøsæter, H., Bogstad, B., and Tjelmeland, S. 2002. Assessment methodology for Barents Sea capelin (*Mallotus villosus Müller*). ICES Journal of Marine Science 59:1086-1095.

Gjøsæter, H., Bogstad, B., Tjelmeland, S., and Subbey, S. 2015. A retrospective evaluation of the Barents Sea capelin management advice. Marine Biology Research 11(2):135-143.

Gjøsæter, H., Hallfredsson, E. H., Mikkelsen, N., Bogstad, B., and Pedersen, T. 2016. Predation on early life stages is decisive for year class strength in the Barents Sea capelin (*Mallotus villosus*) stock. ICES Journal of Marine Science 73(2):182-195.

ICES. 2003. Study Group on Precautionary Reference Points for Advice on Fisheries Management. ICES Headquarters, 24-26 February 2003. ICES C.M. 2003/ACFM:15, 85 pp.

ICES. 2012. Joint EU-Norway request to ICES on options to revise the long-term management plan for herring in the North Sea. *In* Report of the ICES Advisory Committee, 2012. ICES Advice 2012, Book 6, Section 6.3.3.6.

ICES. 2013a. Report of the Workshop on Guidelines for Management Strategy Evaluations (WKGMSE), 21–23 January 2013, ICES HQ, Copenhagen, Denmark. ICES CM 2013/ACOM:39, 121 pp.

ICES. 2013b. EU request on interannual quota flexibility for saithe in the North Sea. *In* Report of the ICES Advisory Committee, 2013. ICES Advice 2013, Book 6, Section 6.3.5.4.

ICES. 2013c. EU request on interannual quota flexibility for plaice in the North Sea. *In* Report of the ICES Advisory Committee, 2013. ICES Advice 2013, Book 6, Section 6.3.5.3.

ICES. 2013d. NEAFC request to ICES to evaluate the harvest control rule element of the long-term management plan for blue whiting. *In* Report of the ICES Advisory Committee, 2013. ICES Advice 2013, Book 9, Section 9.3.3.1.

ICES 2013e. Report of the Arctic Fisheries Working Group, Copenhagen, 18-24 April 2013. ICES C.M. 2013/ACOM:05, 682 pp.

ICES. 2014. Report of the EU workshop on the NEA Mackerel Long-term Management Plan (WKMACLTMP). 24-27 June and 17-19 November 2014, Copenhagen, Denmark. ICES CM 2014/ACOM:63, 120 pp.

ICES. 2015a. Report of the first Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-1), 24-26 November 2015, Murmansk, Russia. ICES CM 2015/ACOM:60, 27 pp.

ICES. 2015b. Report of the Arctic Fisheries Working Group (AFWG), Hamburg, 23-29 April 2015. ICES C.M. 2015/ACOM:05, 590 pp.

ICES. 2015c. Report of the Benchmark Workshop on Arctic Stocks (WKARCT), Copenhagen 26-30 January 2015. ICES C. M. 2015/ACOM:31, 126 pp.

ICES. 2015d. Cod (*Gadus morhua*) in Subareas I and II (Northeast Arctic). *In* Report of the ICES Advisory Committee, 2015. ICES Advice 2015, Book 3, Section 3.3.4.

Kovalev, Y., and Bogstad, B. 2005. Evaluation of maximum long-term yield for Northeast Arctic cod. In Shibanov, V. (ed.): Proceedings of the 11th Joint Russian-Norwegian Symposium: Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries. Murmansk, Russia 15-17 August 2005. IMR/PINRO Report series 2/2005, p. 138-157.

Kovalev, Yu. A. and Yaragina, N. A. 2009. The Effect of Population Density on the rate of Growth, Maturation and Productivity of the Stock of Northeast Arctic Cod *Gadus morhua morhua*. Journal of Ichthyology 49(1): 56-65.

Tjelmeland, S. 2005. Evaluation of long-term optimal exploitation of cod and capelin in the Barents Sea using the Bifrost model. Pp. 113-130 in Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries. Proceedings of the 11th Russian-Norwegian symposium, Murmansk 15-17 August 2005. IMR-PINRO report series 2-2005.

Åsnes, M. N. 2014. PROST users guide. In: ICES. 2014. Report of the Workshop on Redfish Management Plan Evaluation (WKREDMP), 20–25 January, Copenhagen, Denmark. ICES CM 2014/ACOM:52. 269 pp.

Annex 1 Harvest control rules to be evaluated (Appendix 19 in Report of 45th session of the Joint Norwegian-Russian Fisheries Commission)

Request from the Joint Norwegian-Russian Fisheries Commission to ICES

The Joint Norwegian-Russian Fisheries Commission (JNRFC) has previously agreed to revise the existing harvest control rules for Northeast Arctic cod and haddock and Barents Sea capelin by 2015. In order to provide background information for this revision, JNRFC asks ICES to explore the consequences of the following harvest control rules:

Northeast Arctic cod:

1. The existing harvest control rule, but with $F_{target} = 0.30$ instead of 0.40 and removing the F > = 0.30 constraint.

2. The existing harvest control rule ($F_{target} = 0.40$).

3. The existing harvest control rule, but with $F_{target} = 0.50$ instead of 0.40.

4. The existing harvest control rule ($F_{target} = 0.40$), but with maximum 20% variation in TAC from year to year.

5. The existing harvest control rule ($F_{target} = 0.40$) but with no constraint on maximum variation in TAC from year to year and removing the F > = 0.30 constraint.

6. The existing harvest control rule, but with increased F for high SSBs ($F = F_{target} = 0.40$ for SSB between B_{pa} and $2{*}B_{pa}$, then increasing linearly to F = 0.60 at SSB = $3{*}B_{pa}$, equal to 0.60 for SSB above $3{*}B_{pa}$) and with maximum 20% variation in TAC from year to year.

7. The existing harvest control rule, but with increased F for high SSBs ($F = F_{target} = 0.40$ for SSB between B_{pa} and $2{*}B_{pa}$, then increasing linearly to F = 0.60 at SSB = $3{*}B_{pa}$, equal to 0.60 for SSB above $3{*}B_{pa}$) and no constraint on maximum variation in TAC from year to year and removing the F > = 0.30 constraint.

8. The existing harvest control rule, but with increased F for high cod SSBs if the capelin stock is low. $F = F_{target} = 0.40$ for SSB between B_{pa} and $2{*}B_{pa}$, irrespective of capelin stock size. If the capelin stock is low, then F should be increased linearly from 0.40 at SSB = $2{*}B_{pa}$ to F = 0.60 at SSB = $3{*}B_{pa}$, and set equal to 0.60 for SSB above $3{*}B_{pa}$. Maximum 20% variation in TAC from year to year.

9. The existing harvest control rule, but with increased F for high cod SSBs if the capelin stock is low. $F = F_{target} = 0.40$ for SSB between B_{pa} and $2{*}B_{pa}$, irrespective of capelin stock size. If the capelin stock is low, then F should be increased linearly from 0.40 at SSB = $2{*}B_{pa}$ to F = 0.60 at SSB = $3{*}B_{pa}$, and set

equal to 0.60 for SSB above 3*B_{pa} and no constraint on maximum variation in TAC from year to year and removing the F > = 0.30 constraint.

10. The existing harvest control rule, but with increased F for high SSBs (F increasing linearly from F_{target} = 0.40 for SSB = B_{pa} to 0.60 at SSB = 5*B_{pa}, equal to 0.60 for SSB above 5*B_{pa}), no constraint on maximum variation in TAC from year to year and removing the F > = 0.30 constraint.

This gives a total of 10 different rules to be explored, one of which is the existing harvest control rule.

In cases 1–9 the following conditions should apply in the harvest control rule:

TAC for the quota year will be set to the average TAC level for the coming 3 years based on F_{target}.if the spawning stock in the quota year falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{target} at B_{pa}, to F = 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (quota year, the year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC.

In case of rule 10, the following conditions should apply in the harvest control rule:

TAC for the quota year will be set to the average TAC level for the coming 2 years based on F_{target}.

If the spawning stock in the quota year falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{target} at B_{pa}, to F = 0 at SSB equal to zero.

In cases 8 and 9, the capelin stock will be considered as low when the total stock is below 1 million tonnes and the immature stock is below 500 000 tonnes. The quota advice for cod would initially be given based on F = F_{target} = 0.40, for all cod SSB values exceeding B_{pa}, when the cod assessment is carried out. Then the possible adjustment in F related to capelin stock size would be applied after the capelin stock assessment has been carried out.

Northeast Arctic haddock

1. The existing harvest control rule, but with F_{target} = 0.27 instead of 0.35.

2. The existing harvest control rule.

3. The existing harvest control rule, but with F_{target} = 0.43 instead of 0.35.

4. The existing harvest control rule, but with a constraint of maximum 10% TAC variation from year to year instead of a 25% constraint which is presently used.

5. The existing harvest control rule, but with no constraint of maximum TAC variation from year to year.

6. The existing harvest control rule, but without limitation +25%.

This gives a total of 6 different rules to be explored, one of which is the existing harvest control rule.

Note: After clarification with clients, rule 6 should be interpreted as: 6. The existing harvest control rule, with a constraint of -25% in TAC reduction from year to year but with no constraint for increases in TAC.

In all cases the following condition should apply in the harvest control rule:

> *if the spawning stock in the quota year falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{target} at B_{pa}, to F = 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (quota year and the year before) there should be no limitations on the year-to-year variations in TAC.*

Barents Sea capelin

The existing harvest control rule with varying probabilities for the spawning stock biomass to be above 200 000 tonnes (i.e. 80, 85, 90 or 95%). This gives a total of 4 different rules to be explored, one of which corresponds to the existing harvest control rule.

The effect of each of the harvest control rules for cod stated above on the capelin yield should be explored.

For all stocks, information about yield, variability, risk levels, stock levels and size/age composition of catch and stock in a short, medium and long term perspective should be provided.

Annex 2 Participants list

NAME	ADDRESS	PHONE/FAX	E-MAIL
Asgeir Aglen	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 93630658	asgeir.aglen@imr.no
Höskuldur Björnsson	Marine Research Institute Skulagata 4, 121 Reykjavik, Iceland		hoski@hafro.is
Bjarte Bogstad Chair	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway	Phone +47 92422352 Fax +47 55 23 86 87	bjarte.bogstad@imr.no
Anatoly Chetyrkin	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(Pinro) 6 Knipovitch Street 183038 Murmansk Russian Federation		chaa@pinro.ru
Gjert Endre Dingsør	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway		gjert.endre.dingsoer@imr.no
Yuri A. Kovalev	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(Pinro) 6 Knipovitch Street 183038 Murmansk Russian Federation	Phone +7 8152 472962 Fax +7 8152 473 331	kovalev@pinro.ru
Hans Lassen	Møllevænget 7 3000 Helsingør Denmark		hans.lassen.nmtt@gmail.com
Alexey Russkikh	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(Pinro) 6 Knipovitch Street 183038 Murmansk Russian Federation		russkikh@pinro.ru
Dmitry Prozorkevitch	Knipovich Polar Research Institute of Marine Fisheries and Oceanography(Pinro) 6 Knipovitch Street 183038 Murmansk Russian Federation		dvp@pinro.ru

NAME	ADDRESS	PHONE/FAX	E-MAIL
Samuel Subbey	Institute of Marine Research PO Box 1870 Nordnes 5817 Bergen Norway		samuel.subbey@imr.no
Dmitry Vasiliyev	VNIRO, V. Krasnoselskaya, 17, 107140, Moscow, Russian Federation		dvasilyev@vniro.ru

Annex 3 Reviewer's Conclusions

Methodological approach and ACOM guidelines

WKNEAMP-2 followed the guidelines closely for evaluation of the cod and haddock Management Plans. The capelin request was an investigation of possible changes in the risk levels an evaluation for which there is no guidelines.

WKNEAMP-1 and WKNEAMP-2 made a considerable effort to define suitable evaluation models and reviewed the elements of the biological models in detail. WKNEAMP-2 also investigated the stochastic elements that are built into the simulation model. The reviewers were impressed by the thoroughness of this investigation and in general is satisfied with the evaluations. Some issues remain outstanding that are identified below.

Both the cod and haddock management plans are complicated and not easily tractable. It seems a step in the wrong direction to make the cod model even more complicated by adding an extra mechanism to increase F at high SSB. It might also be reflected that adding such an incentive might be counterproductive to the general aim of balancing fishing capacity with fishing possibilities. The increased fishing possibilities will attract addition capacity but the increased fishing possibilities will not be long lived leaving extra capacity without fishing options in the cod fishery after a few years. The complexity of the management plans initiated one of the reviewers (Höskuldur Björnsson) setting up an independent model as some of the results of the simulations required double checking.

The Reviewers agree with WKNEAMP-2 that the Implementation errors should not be part of the evaluations. It would seem strange to evaluate a Management Plan that by the inclusion of a significant implementation error is at the outset assumed to be ineffective. The reviewers noted that in other fisheries, deviations from the HCR (catch exceeding TAC) have often been the result of exceptions to the main HCR built into the system.

Cod

Ten different HCRs were tested including the current HCR. The suggested HCRs were variations of the current rule but with $F_{target} = 0.3$ and $F_{target} = 0.5$ instead of 0.4, Rules 1–3. Rules 4 and 5 investigated the effect of allowing a less restrictive TAC constraint, but maintaining the $F \geq 0.30$ constraint is investigated in HCR 4 ($\pm$20). The other proposed rules were to increase the fishing mortality above the target when SSB is large or SSB large and capelin stock low.

All ten rules are found to be precautionary, i.e. Prob(SSB < B_{lim}[220 kt]) < 0.05. However, B_{lim} is considered to be low compared to stocks with similar population dynamics. The trigger point does on the other hand seem appropriate for uses for the precautionary criterion, and the 10% stabilizer seems be OK. B_{lim} is probably an underestimate of SSB_{break} (see Figure A3.1) but Figure A3.1 also indicates that recruitment does not become impaired until at low levels of the spawning stock (compared to the productivity and longevity of the stock).

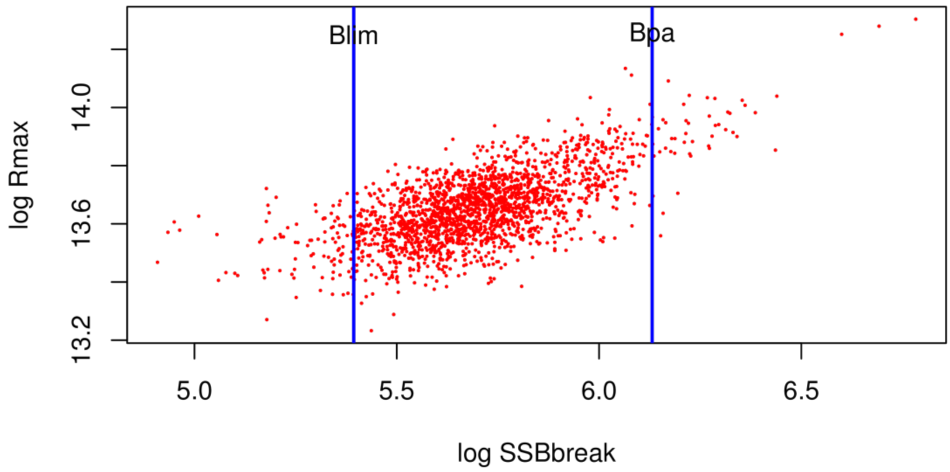


Figure A3.1. Northeast Arctic Cod. Distribution of log SSB_{break} and log R_{max} from hockey when fitting a Hockey stick function. B_{lim} (220 kt) and B_{pa} (460 kt) shown for reference.

The reviewers find that the current target fishing mortality (F_{target} = 0.4) is in the higher side of range of plausible values (0.3–0.4) when considering degree of precaution. Rules with increase of fishing mortality do lead to much more variability in catches. If these rules with increased fishing mortality at high SSB are for "ecosystem protection" the rules should be based on total biomass instead of spawning stock biomass.

The reviewers recognise that the maturity data have been thoroughly scrutinised but also feel that further analysis would be enlightening, Specifically, Figure 3.7 should include data from 1946. One of the reviewers (Höskuldur Björnsson) presented a preliminary analysis for the consideration of AFWG. The maturity ogive is critical in the evaluations because the precautionary criterion is built on the SSB.

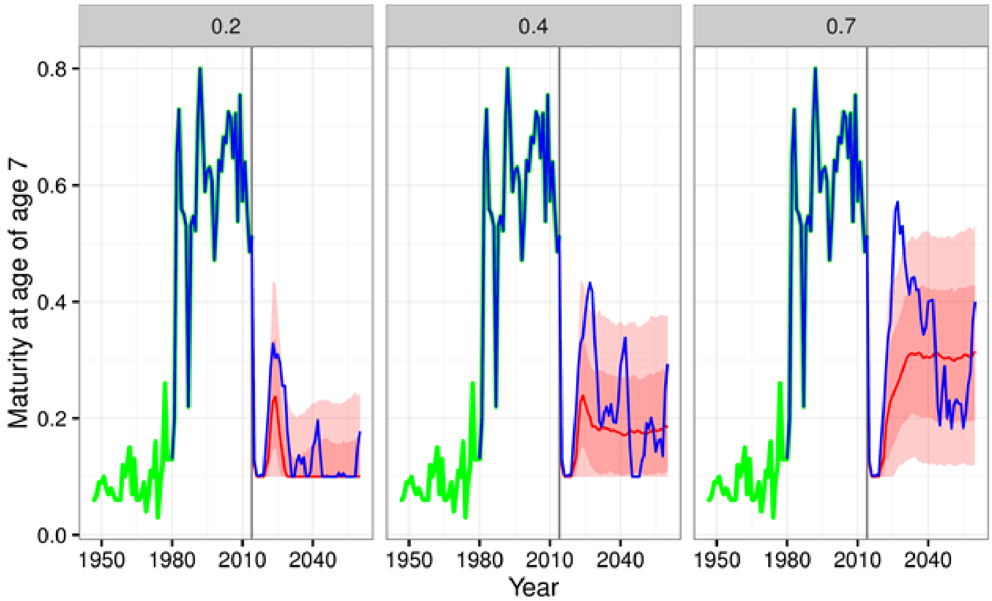
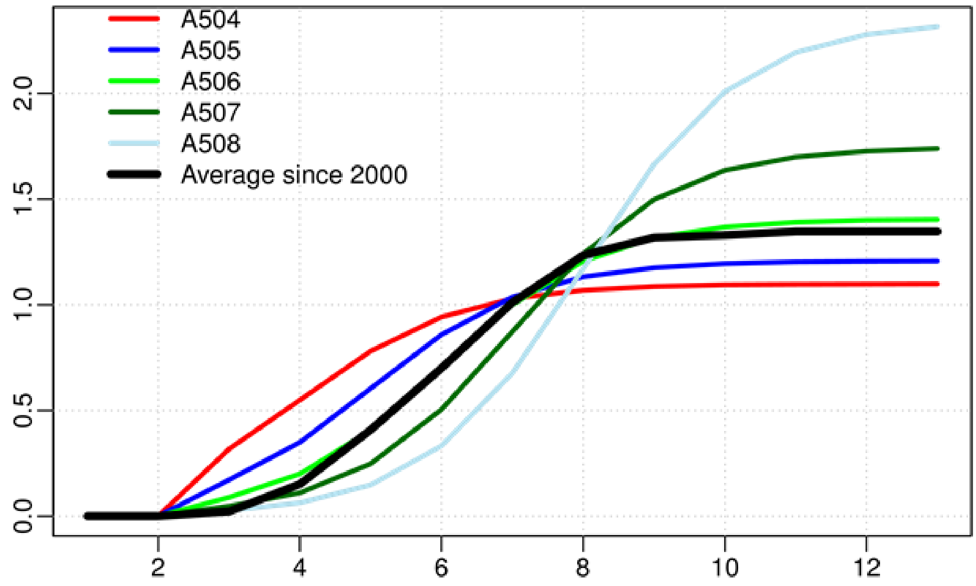


Figure A3.2. Predicted maturity at age for age 7. The results are shown for target fishing mortality 0.2, 0.4 and 0.7. Historical data shown for comparison. The vertical line is 2014 and 2015 and later data are based on maturity model 3.

The simulations are based on fixed selection pattern which is used to calculate TAC. At the same time the WKNEAMP-1 and WKNEAMP-2 reports demonstrated that the selection pattern includes some annual variation. Selection pattern used in prognosis has large effect on the calculated TAC, and the review group emphasizes that the same selection pattern used in the simulations should be used to calculate the annual TAC. The selection pattern of the fisheries will continue to be different and variable.



Selpath	Hrate C/Bio4+	SSB	Hrate C/SSB	F5-10
A504	0.29	944	0.71	0.4
A505	0.26	1145	0.63	0.4
A506	0.24	1371	0.57	0.4
A507	0.23	1614	0.51	0.4
A508	0.22	1870	0.47	0.4
Average since 2000	0.24	1463	0.55	0.4

Figure A3.3. Northeast Arctic Cod. Average harvest rate and spawning stock in long term deterministic prediction based on different selection pattern. All predictions based on F5–10 = 0.4.

The simulation of the assessment error was done using the "no autocorrelation" option. However, the reviewers find that a more realistic model should include an account of what is seen as autocorrelation in the assessments.

WKNEAMP-2 observed that the adopted TACs have exceeded the values dictated by the HCR by approximately 3.5% which impact the 10% catch constraint by shifting the reference upwards in contrast to catch exceeding advice which does not change the TAC reference. The Reviewers stress that the management plan evaluation is based on the assumption that the adopted TAC follows HCR results exactly and that this is a condition for the 10% catch constraint being accepted as precautionary.

The reviewers suggest that due to high variability in proportion mature and uncertainty about future development, the HCR should rather be based on a more "robust" biomass that would on the average be similar like biomass 6 or 7 and older or even fixed ogive. Even in the predictions three years ahead proportion mature becomes a major part of the uncertainty.

Haddock

For haddock, six different HCRs were tested, the current HCR (F_{target} = 0.35), the same rule with F_{target} =0.43 and F_{target} =0.27 and three rules where the interannual catch constraint (25%) was increased and decreased. All tests used $B_{trigger}$ = 80kt and the current value B_{lim} = 50 kt.

The result is that the current rule and the same rule with F_{target} =0.27 performed best in terms of variability of average catch, variable catch in the long and short term and Prob(SSB < B_{lim}) < 0.05.

Haddock shows large variability in recruitment but also show autocorrelation of yearclass strength between years. The B_{lim} estimate from stock-recruitment data is very uncertain and likely estimates are in the 50–150 kt range where 50 kt is B_{loss}. The Stock-Recruitment graph suggests a hockey stick relationship with breakpoint in the range of 100 000–200 000 tonnes. However, autocorrelation of the residuals is considerable (1 order lag = 0.5 on log-scale) and five of the lowest recruitment values observed are from the same period around 1980. Taking autocorrelation of residuals into account lowers the estimated breakpoint to around 65 kt but as expected the precision of the estimate decreases as autocorrelation decreases the effective number of data points. After considerable analysis if a higher value than B_{lim} = 50 kt would be appropriate, WKNEAMP-2 left B_{lim} unchanged for the simulations. This decision was supported by the reviewers who did not find the arguments for changing B_{lim} very strong. Using higher B_{lim}s increase variability in catches; a result of the recruitment variability caused by the spawning stock can become very low in periods of poor recruitment and therefore the HCR will reduce fishing mortality significantly.

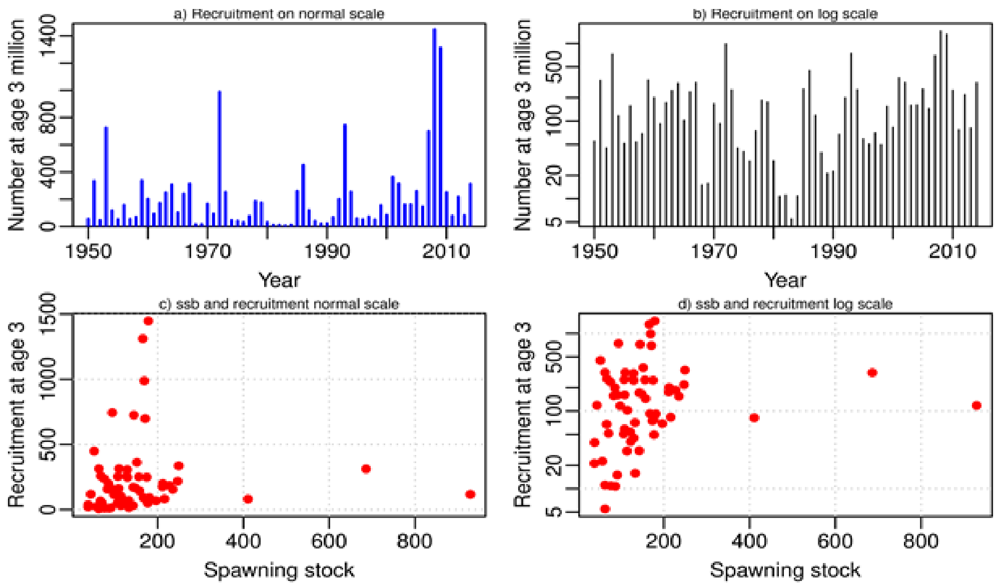


Figure A3.4. Northeast Arctic Haddock. Recruitment of Barents Sea haddock on normal scale and log-scale.

Large variability in recruitment and autocorrelation of recruitment give a much higher probability of spawning stock being less than B_{lim} compared to the cod.

The same comment on the selection pattern that was made for cod applies to haddock also.

The reviewers recommended an HCR with F = 0.3 (plausible range 0.27–0.35), a lower F_{target}, 0.3 instead of 0.35 as implemented in the current HCR. Low fishing mortality and low $B_{trigger}$ is the only way to achieve some stability in yield between years for stocks with high recruitment variability and long periods of poor recruitment.

The model that generates variation in mean weight at age as a result of variation in biomass seems to overreact, i.e. predict larger changes than what is observed based on a retrospective analysis, Figure A3.5. This leads to overestimation of F_{pa} and F_{MSY}.

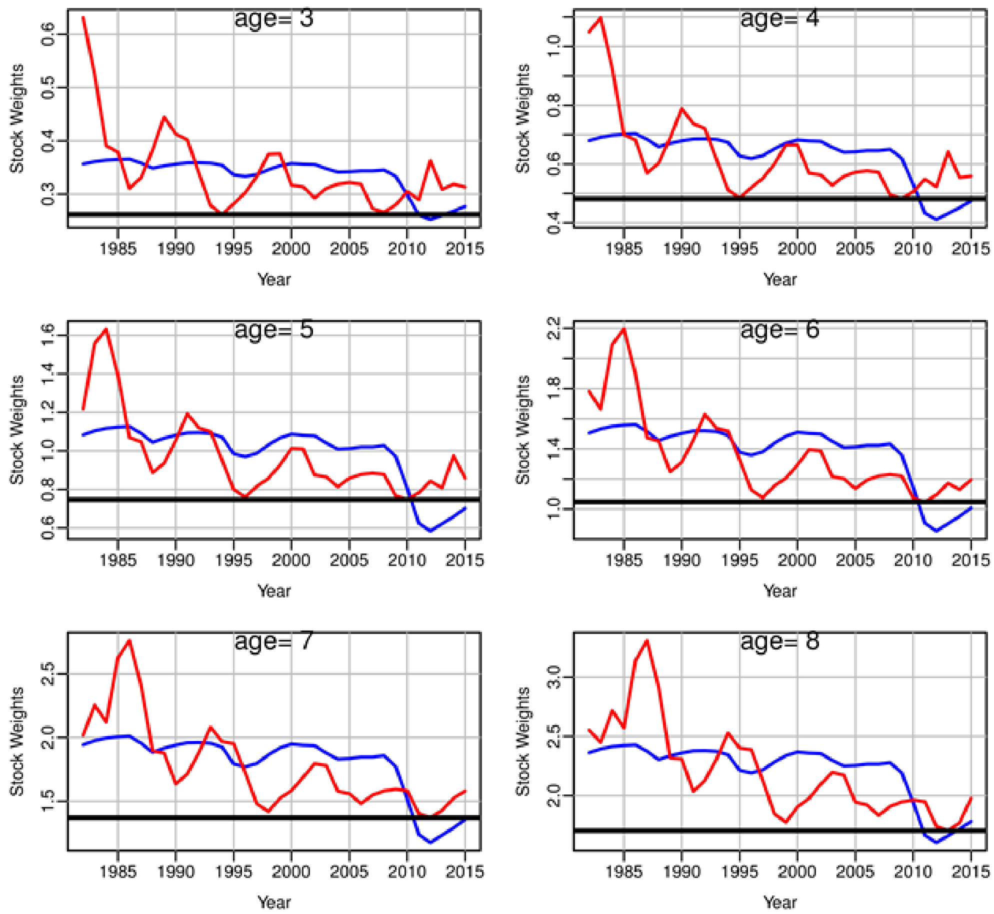


Figure A3.5. Predicted stock weights for age 3–8 (blue) vs. Observed (red). Min values shown as black horizontal lines.

Capelin

This request was an exploration of the current HCR under different risk options.

While the request considers increasing the risk, the reviewers concluded that risk has been underestimated in recent years and that increasing risk was not appropriate based on precautionary considerations.

As part of the exploration WKNEAMP-2 investigated if the B_{lim} value was still appropriate and concluded that data presented at the meeting did not support lowering B_{lim}.

The advice is built on a prediction of the SSB (1/4) from the survey result (1/10 previous year) and this step in the calculations might have overestimated the mortality in the capelin stock over this half year. However, on the contrary it was found that the model possibly underestimates predation in recent years when the spawning stock of cod has been high and the predation of mature cod is not included in the model. What was shown indicates that the risk of SSB < B_{lim} is already considerably underestimated. The reviewers recognize that there are indications that productivity of the capelin stock might be underestimated but those indications are ready to be used for generating TAC.

The prediction model is somewhat intractable and the reviewers found that the prediction error and how this is generated in the simulation might be better understood.

The predation model predicts a SSB that is not verified by direct observations. The larvae survey – discontinued in 2006 – might have served this function but the survey results showed poor correlation between the larvae index and the 0 group measurement. The analysis of the predation model is therefore based on check on the individual model elements without a general overall check of the model performance.

Methodology

WKNEAMP-2 developed a simplified model for answering the request. The simplified model was checked against the more complicated (and therefore less tractable) model as documented below

The check is based on results of the CapTool simulations not least Table A3.1 that shows the projection results under ‚no fishing‘. From these CapTool simulation results combined with the survey results we calculated the width of the projected biomass distribution as $\frac{SSB(75)-SSB(25)}{SSB(50)}$ where all SSB’s refer to the ‘no fishing’ option.

Table A3.1. Barents Sea Capelin. Prediction of SSB under the , 'no fishing' option. CapTool Results '000 tons for 2008–2016 (survey years 2007–2015).

Prob	2016	2015	2014	2013	2012	2011	2010	2009	2008
0.25	58.2	173.8	354.4	502.5	790.0	619.0	604.2	637.3	234.3
0.50	81.7	227.9	449.5	642.2	945.8	766.6	770.2	819.5	309.0
0.75	115.0	300.2	575.7	825.4	1148.7	964.3	1002.1	1074.6	401.5
Survey Result (year -1)	375	873	1471	1997	2115	2051	2323	2468	844
Width Projected biomass	0.696	0.554	0.492	0.503	0.379	0.450	0.517	0.534	0.541
SSB (proj 50%) / Survey (Maturing biomass)	0.218	0.261	0.306	0.322	0.447	0.374	0.332	0.332	0.366

The first check is whether the ratio $\frac{\text{SSB(projected)}}{\text{Survey result}}$ depends on the survey result, i.e. if the survival rate as predicted in the model changes with the capelin biomass.

Plotting and regressing gives Figure A3.6.

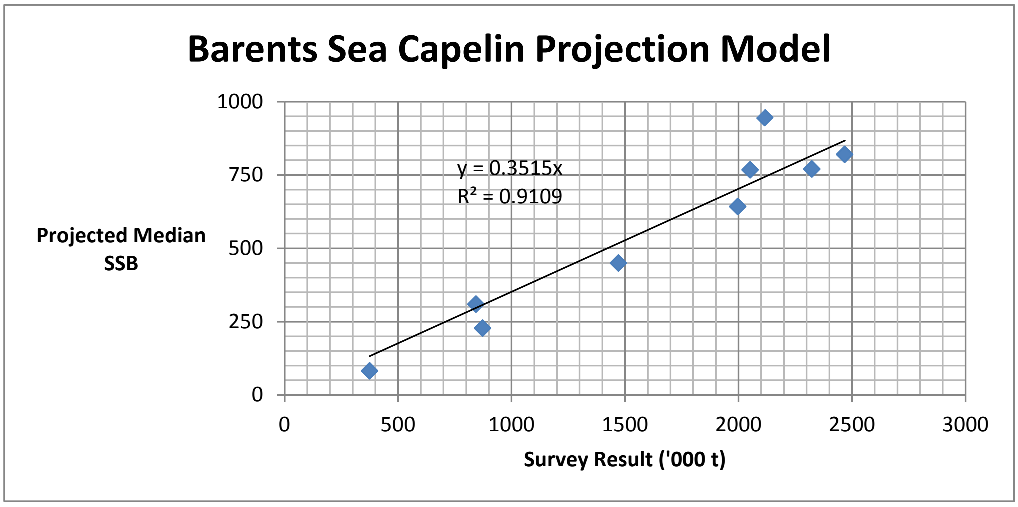


Figure A3.6. Performance of the projection model for the period 2008–2015 (survey results).

The outlier in Figure A3.6 is the 2012 survey. Figure A3.6 suggests that survival is a fixed proportion of the relevant survey biomass.

The error structure may well not be additive but rather as argued in the following multiplicative. If so the regression is not fully satisfactory. We therefore investigated the relative width $\frac{SSB_{75\%}-SSB_{25\%}}{SSB_{50\%}}$ of the projection against the survey biomass and found, Figure A3.7.

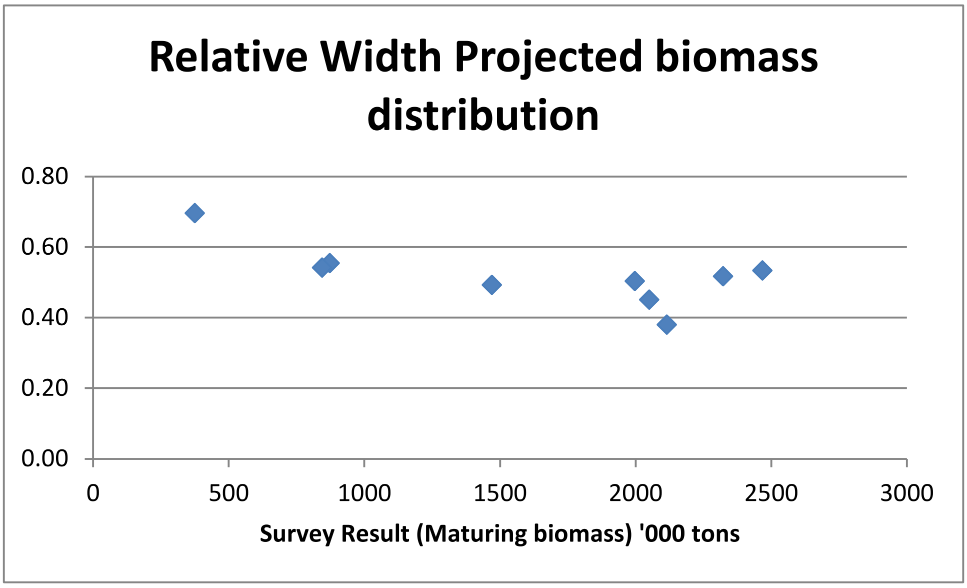


Figure A3.7. Relative width $\frac{SSB_{75\%}-SSB_{25\%}}{SSB_{50\%}}$ of the projected SSB distribution for the survey results in years 2008-2015. Based on simulations using CapTool.

Survey biomass results below approx. 500,000 tons are of little interest because these anyway will lead to TAC = 0 and the 2015 result therefore ignored. The conclusion from Figure A3.7 seems to be that for the interval [500 ; 2500kt] the relative width is fairly constant, i.e. that the model produces something like a lognormal distribution, the CV is around 0.5/1.45 or around 0.34.

On that basis the simplified model was formulated. It is a simplification of the full biological model and has just as much relevance to the Barents Sea Capelin as has CapTool and the underlying prediction model.

The model fit is presented in the body of the report as Figure 5.5.

Annex 4: Working Documents

WD 1: Investigation of data and assessment methods for Barentssea cod and haddock.

Höskuldur Björnsson

February 9, 2016

1 Introduction

This report is a summary of work done when looking at the data for Barents sea cod, haddock and capelin. The organisation is rather random but things were just added to it as work proceeded.

The report includes a number of shaded graphs with time on the horizontal axis and shading reflecting different probabilities. When there are 3 shading colours they represent 5, 10, 25, 75, 90 and 95th percentile but 2 colours represent 10, 25, 75 and 90th percentile. The average is also shown on the plots.

2 Assessment method cod

The assessment is tuned with 4 surveys

1. Bottom trawl survey in the Barentssea in February(#15).
2. Acoustic survey in the Barentssea and Lofoten in February(#16).
3. Ecosystem survey in the Barentssea in September (#007)

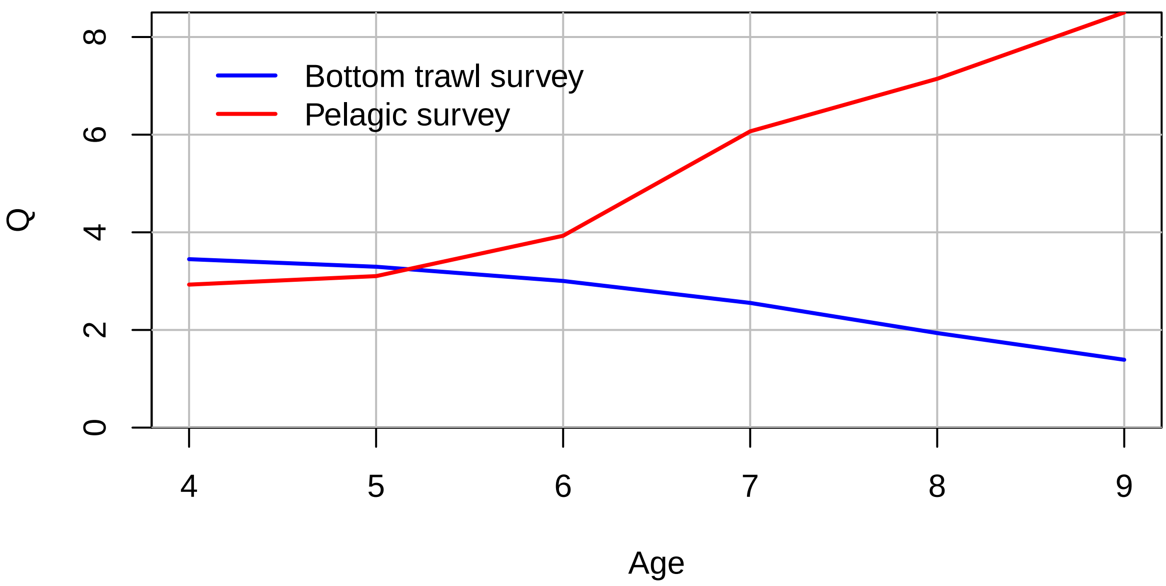
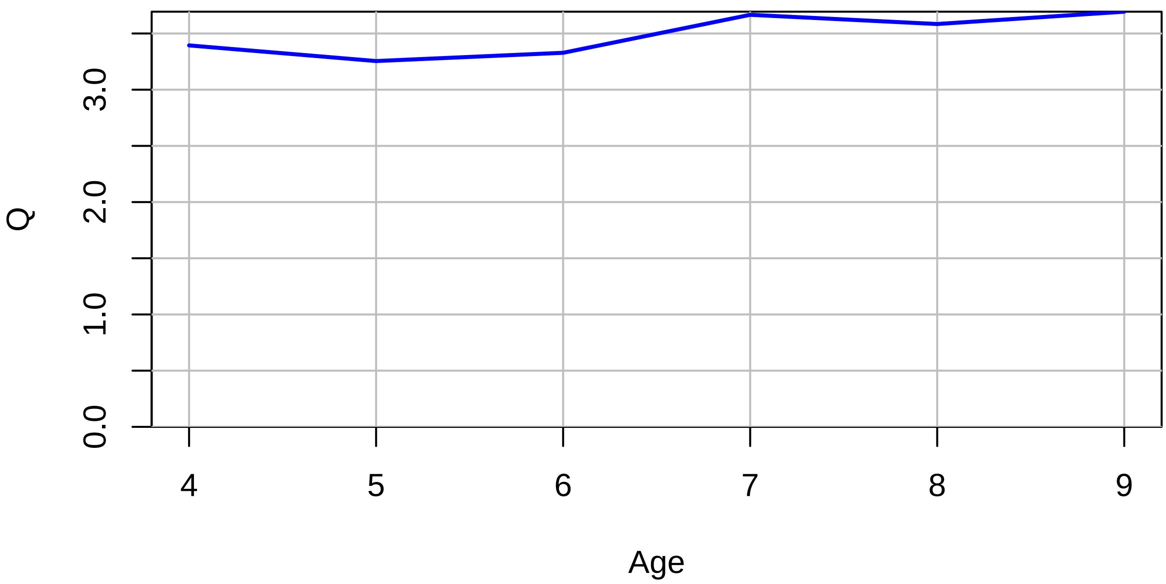


Figure 1: Estimated q for the bottom trawl survey and acoustic survey in February



The results (figure 2) show that older fish is most likely more pelagic than younger fish. A natural way would be to add the surveys, possibly with some weighting factor. By using a survey index of the form $I = I_{15} + I_{16} \times \delta$ the flattest curve is obtained by using $\delta = 0.7$ (figure 2).

Considerable difference can be seen between runs tuned with different surveys (figure 2).

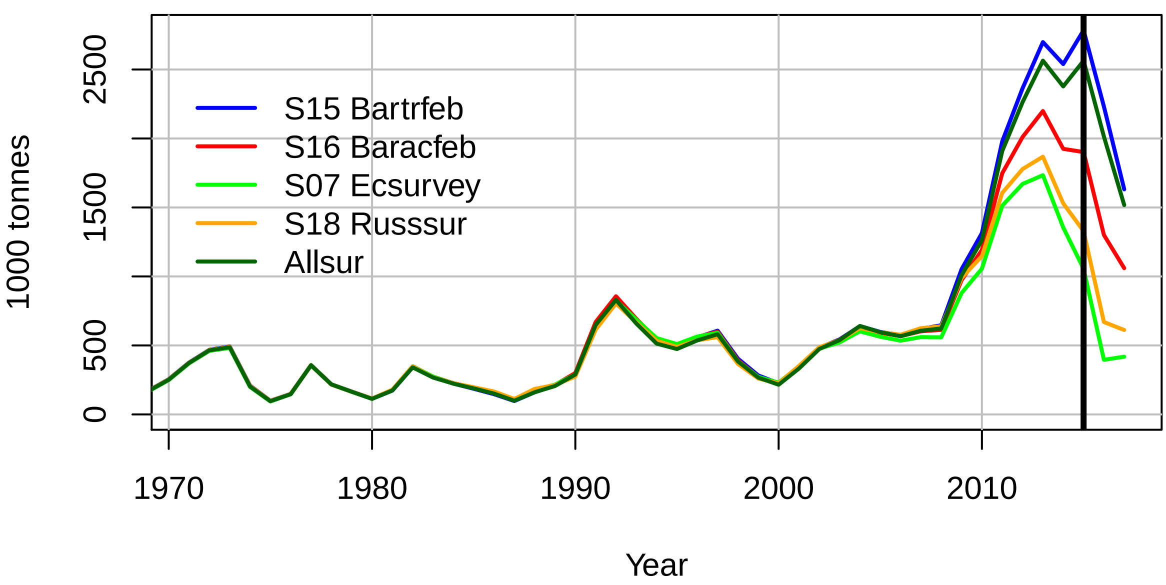


Figure 2: Estimated spawning stock from 5 different assessment runs

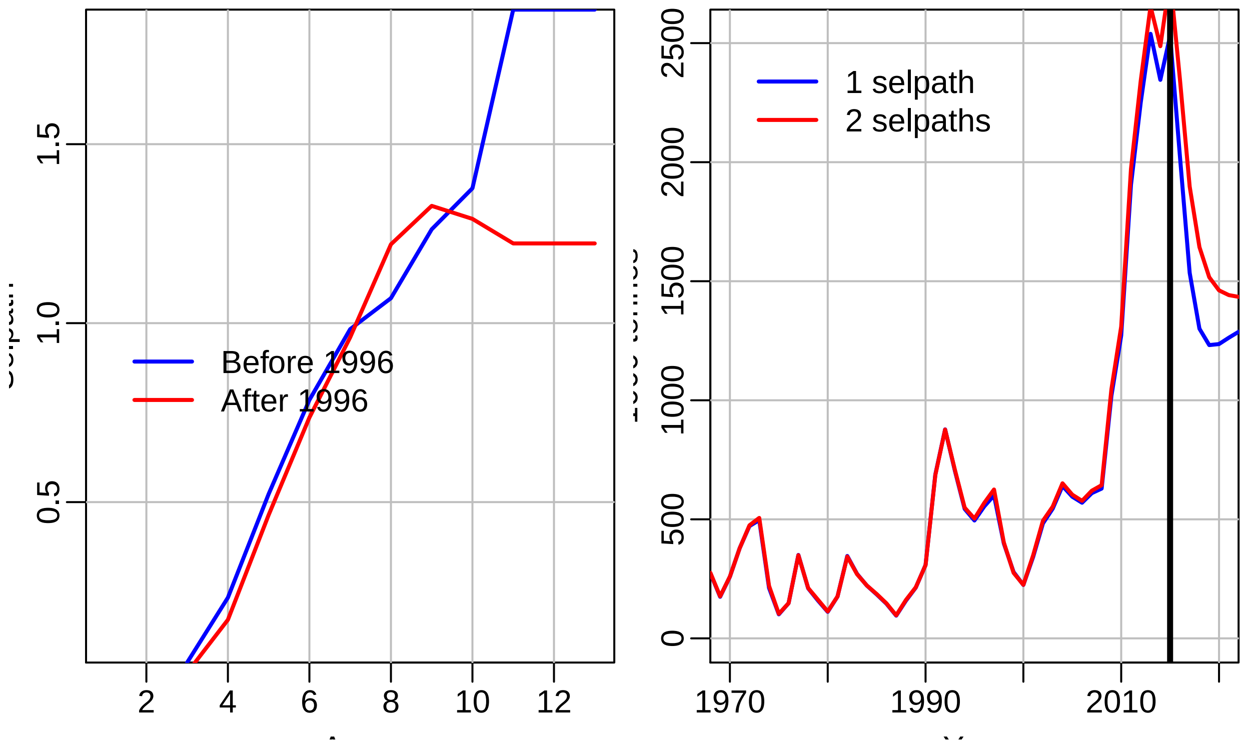


Figure 3: Spawning stock from runs based on 1 and 2 selection patterns

Estimating selection pattern before and after 1996 shows change in selection. The change is towards smaller fish, a change that leads to lower removals from the stock for given F. It need to be investigatded if things have changed back in recent years but using a biomass rule or basing the advice on preferred selection pattern would be preferrable. The Maturity curves are always lower than the selection, the difference is more in the earlier perios.

3 Harvest Control Rule Evaluations

Model that has in some form been used for HCR evaluations for Icelandic cod, haddock and saithe was used to test the HCR for Barents sea cod and haddock (for comparison with other models). The model that, is written in AD model builder is an assessment model that estimates a number of parameters. among them recruitment, selection patterns and stock -recruitment parametersþ

The variance - covariance matrix of the parameters is then used as proposal distribution in MCMC runs and every 500 - 1000th set of parameters saved. This saved set of parameters is then used as basis for stochastic simulations.

The assessment is based on data until the beginning of 2015 (assessment year). The model estimates uncertainty of stock in the assessment year and the stochasic replica estimate that uncertainty. Often, uncertainty estimated by the assessment model is lower than the "real uncertainty", often due to neglected correlations in the data but also structural uncertainty.

Due to this factor numbers in the assessment year are multiplied by a random number called "added uncertainty". The starting value for the number assessmenterror is then Estimated SSB from assessment divided by the "real" numbers in stock in the assessment year, taking into account the "added uncertainty".

The code for the Barents sea cod HCR had to be added to the model and some truncation of lognormals had to be done for Barents sea haddock due to relatively uneven recruitment.

The model generates a lognormal autocorrelated sequence of numbers called assessment error. For high CV the series is truncated to avoid very high assessment errors. The stock in the beginning of the asssessment year is multiplied by this assessment error and this estimated stock projected forward, 3 years for cod to find the appropriate TAC for next year according to the HCR. This Tac is then subtracted from the real stock.

The prediction for both stocks is based on Hockeystick stock recruitment function with autocorrelated errors. 3 parameters, R_{max}, SSB_{break} and σ are estimated, the log of σ and R_{max} but SSB_{break} is estimated on normal scale to avoid problems with priors on logscale that take over below SSB_{loss}.

The model can be run as VPA or forward running separable model(possibly with more than one period). The forward mode is most often used in HCR simulation with the selection in the last period used for the

HCR simulations. With F based rules the selection pattern has considerable effect on removal with selection targeting smaller fish leading to more removal (higher proportion of biomass) from the stocks for the same F. This is really a major problem with F based rules that should be based on specified selection pattern rather than following variable realised selection pattern (case to look at Icelandic saithe). Biomass rules are just rules with specified (age or length based) seletion pattern to generate advice but the fisheries possibly or usually following a different pattern.

Each value of the stochastic simulations is done with somewhat different settings of the parameters plus additional random noise. When parameters of the stock recruitment function different runs can have differentt stock -recruitment functios, some time the difference is considerable. Variablitiy in selection can be included at list with fishing mortality runles based on estimatde selection pattern each year but that error does usually have high autocorrelation.

Things like density dependent growth and natural mortality are easy to include as long as the equation are available. Inclusion of density dependent M for young fish changes the estimated stock - recruitment function but density denpendent M due to cannibalism is of course a part of the stock recruitment function.

4 Results cod

Simulations for cod were started from assessment based on data since 1980. Mean weight and maturity at age were averages of last 30 years with stochastic autocorrelated noise added to the weights. Maturity and selection were kept constant.

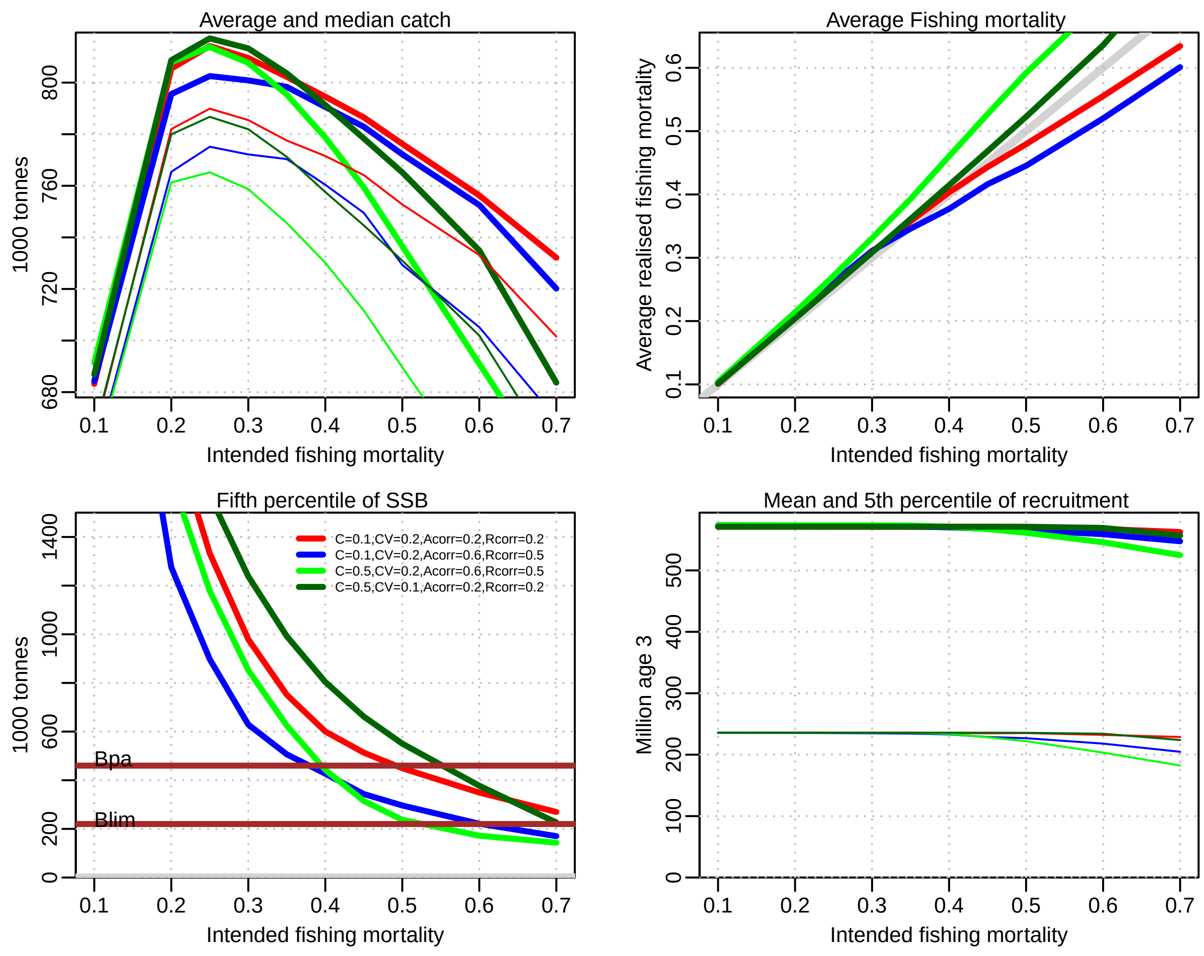


Figure 4: Result from 4 different runs of the 3 year ahead HCR for Barents sea cod.

Results from the HCR for Barents sea cod for different values of autocorrelation and CV of assessment error and recruitment variability are shown in figure 4. The runs shown in the figure differ in the following aspects.

1. Max catch change 0.1, assessment CV 0.2, Assessment autocorrelation 0.2, recruiement autocorrelation 0.2.

2. Max catch change 0.1, assessment CV 0.2, Assessment autocorrelation 0.6, recruitment autocorrelation 0.5.
3. Max catch change 0.5, assessment CV 0.2, Assessment autocorrelation 0.6, recruitment autocorrelation 0.5.
4. Max catch change 0.5, assessment CV 0.1, Assessment autocorrelation 0.2, recruitment autocorrelation 0.2.

The first two runs are the HCR, just tested with different error structure and recruitment pattern.

In all cases $B_{trigger} = 460$ thous. tonnes and the rule does not limit the change of catches when the stock is predicted to go below $B_{trigger}$ in any of the prediction years. The behaviour of the rule is complicated, MSY is at target F at or below 0.3. For higher F the catch constraints leads to realized F lower than intended. All the rules shown lead to $SSB < B_{lim}$ with less than 5% probability for $F < 0.5$ but increasing F above 0.4 does not look like a great idea. More analysis of the results regarding stability of catches and other things are still to be done. Also the value of B_{lim} is very low taking into account the productivity of the stock.

The Bcod harvest rule does not crash easily at high F, mostly because realised F is lower than intended F, due to the trigger and constraints.

Looking at candidate for F_{msy} by running constant F with no assessment error and not trigger show that $F_{msy} = 0.25$ (figure 5 red curve) The HCR behaves differently from F rules with and without $B_{trigger}$, blue, red and light green curves. The maximum catch according to the HCR is lower. Rules without trigger lead to more risk to the stock when a stabilizer is included. The main result does though seem to be to use $F < 0.4$ with stabilizer being a matter of taste, usually converting interannual variability to little longer term variability.

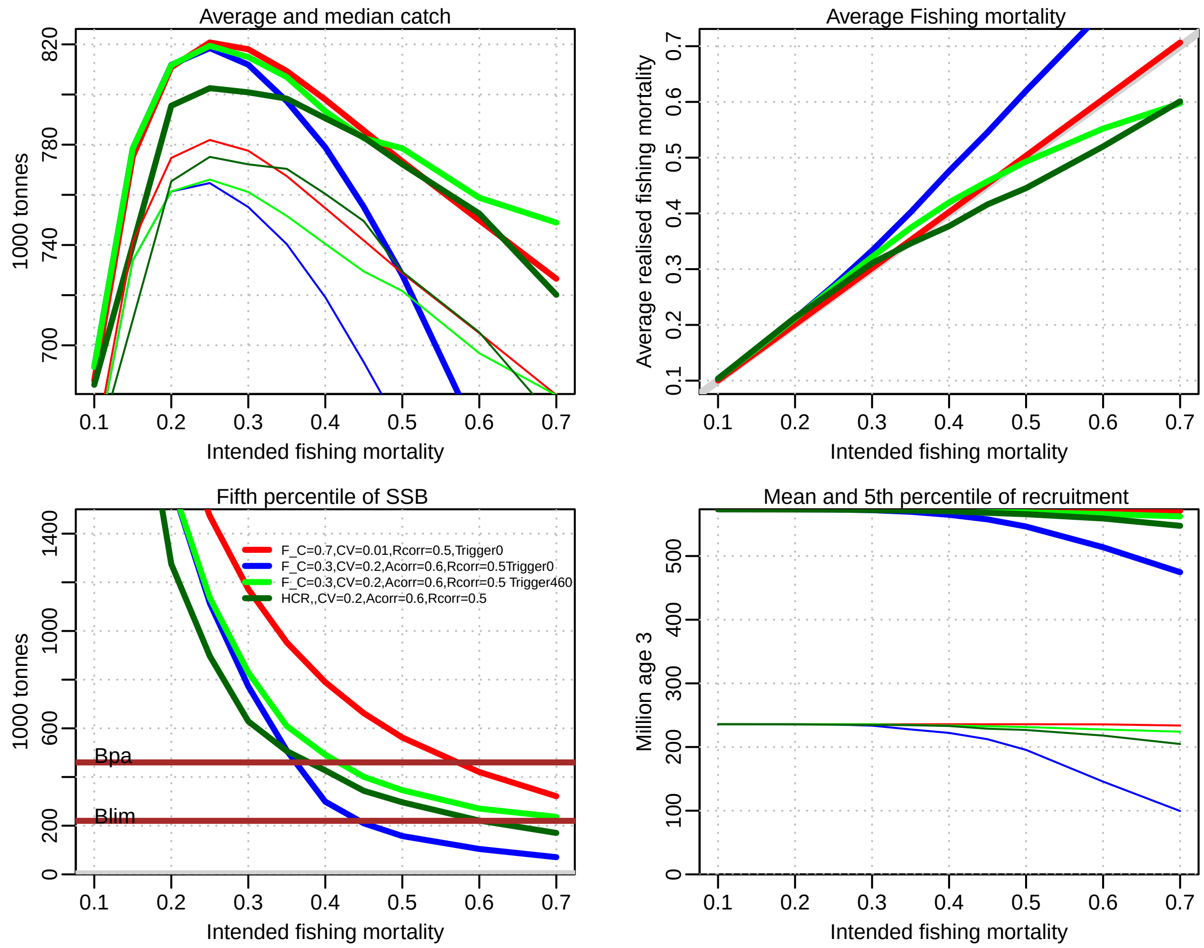


Figure 5: Result from 3 different run of normal F rule, with trigger and catch constraint compared to the Barents sea cod HCR

5 Barents sea haddock.

HCR of Barents sea cod were tested for $B_{trigger}$ values of 50 (B_{lim}), 80 (B_{pa})and 140 thous. tonnes. The recruitment of Barents sea haddock is extremely uneven ($\sigma_{log(R)} \approx 1.3$). Catch stabilisers have to be tested against transition from high to low recruitment and assessment errors. Autocorrelation in recruitment can be a major problem, the small yearclasses are really small so few of these in a row can cause risk of $SSB < B_{lim}$. Autocorrelated assessment errors are also a problem, especially if they occurr in transition periods from high to low recruitment periods.

Negative correlation between stock size and growth reduces variability in productivity as the growth is highest when the stock is small. It is not included here but would decrease risk of $SSB < B_{lim}$. The variability in growth does though seem much less than for Icelandic haddock where variability in recruitment much more. Variability in growth has often less effect if selection is size rather than age based.

The first 4 runs (figure 6) are.

1. Max catch change=0.25, assessment CV=0.2,recruitment autocorrelation=0.1, Btrigger= 50
2. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.5, Btrigger = 80
3. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.5, Btrigger = 140
4. Max catch change=0.25, assessment CV=0.01, recruitment autocorrelation=0.1, Btrigger = 80

The HCR is max change = 0.25 and $B_trigger = 80$. Comparing runs 2 and 4 in figure 6 shows substantial reduction in adviced fishing mortality if assessment error and recruitment correlation are included. (blud and dark green lines.) Something that could be called precautionary ,F giving $p(SSB < B_{lim} < 0.05)$ changes from 0.4 to 0.3. Higher F could be accepted by increasing $B_{trigger}$ but that would lead to sever reduction of cath and F when recruitment is small.

Maximum yield is obtained at $F < 0.3$ both due to yield per recruit and fewer recruits produced when spawning stock is smaller. The break point in the hockeystick recruitment functions is variable and certain proportion of the runs have high SSB_{break}.

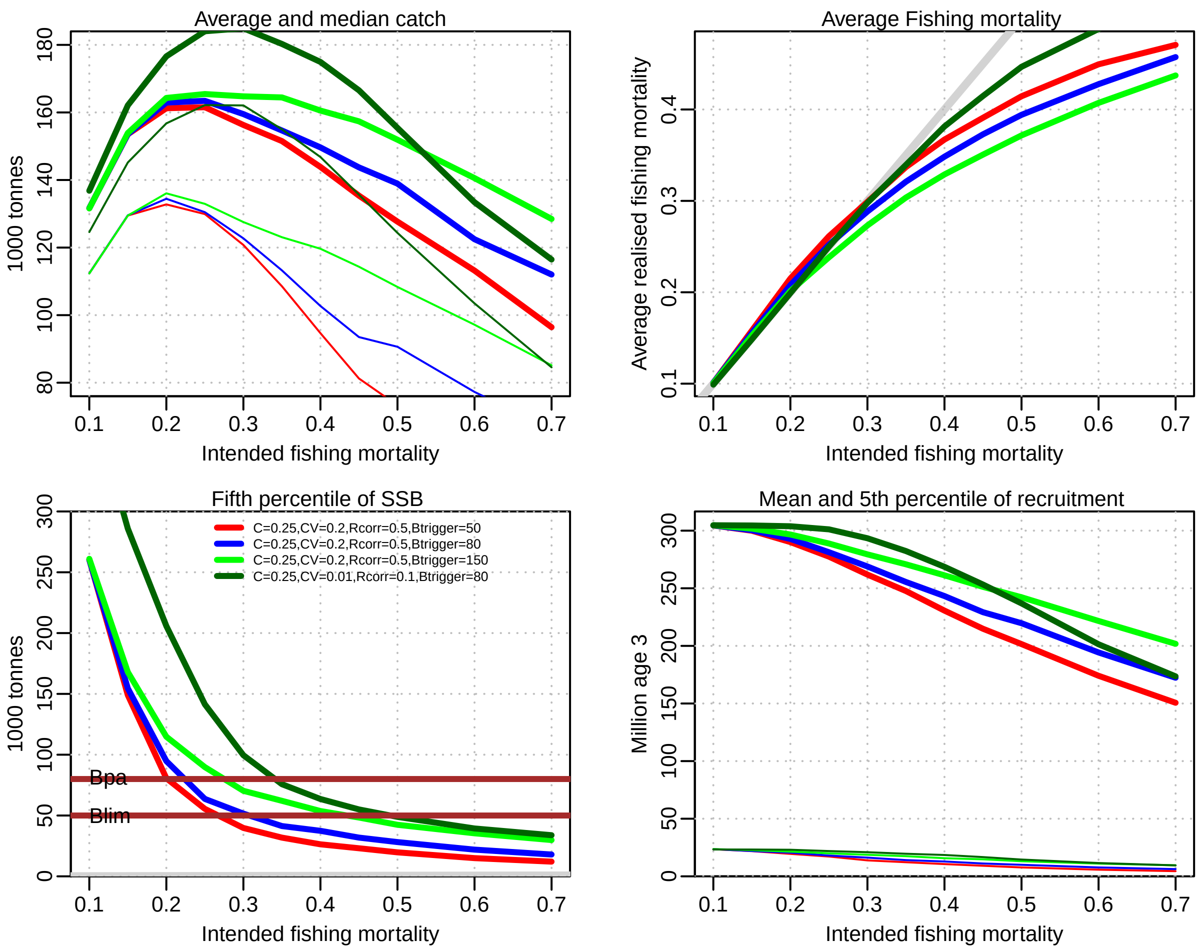


Figure 6: Results of 4 different runs of Barents sea haddock

The effects of the constraint on changes in catch need to be checked for this stock. In figure 7 the effect of changing the constraint on change in catches from 0.25 to 0.5 is shown for 2 values of assessment error. In both cases autocorrelationo of recruitment varialility and assessment error is included. Removing the constraint on changes in catches, increases maximum possible catch and allows to have higher F for the same risk.

1. Max catch change=0.5, assessment CV=0.2,recruitment autocorrelation=0.5, Btrigger= 80
2. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.5, Btrigger = 80
3. Max catch change=0.5, assessment CV=0.3, recruitment autocorrelation=0.5, Btrigger = 80
4. Max catch change=0.25, assessment CV=0.3, recruitment autocorrelation=0.5, Btrigger = 80

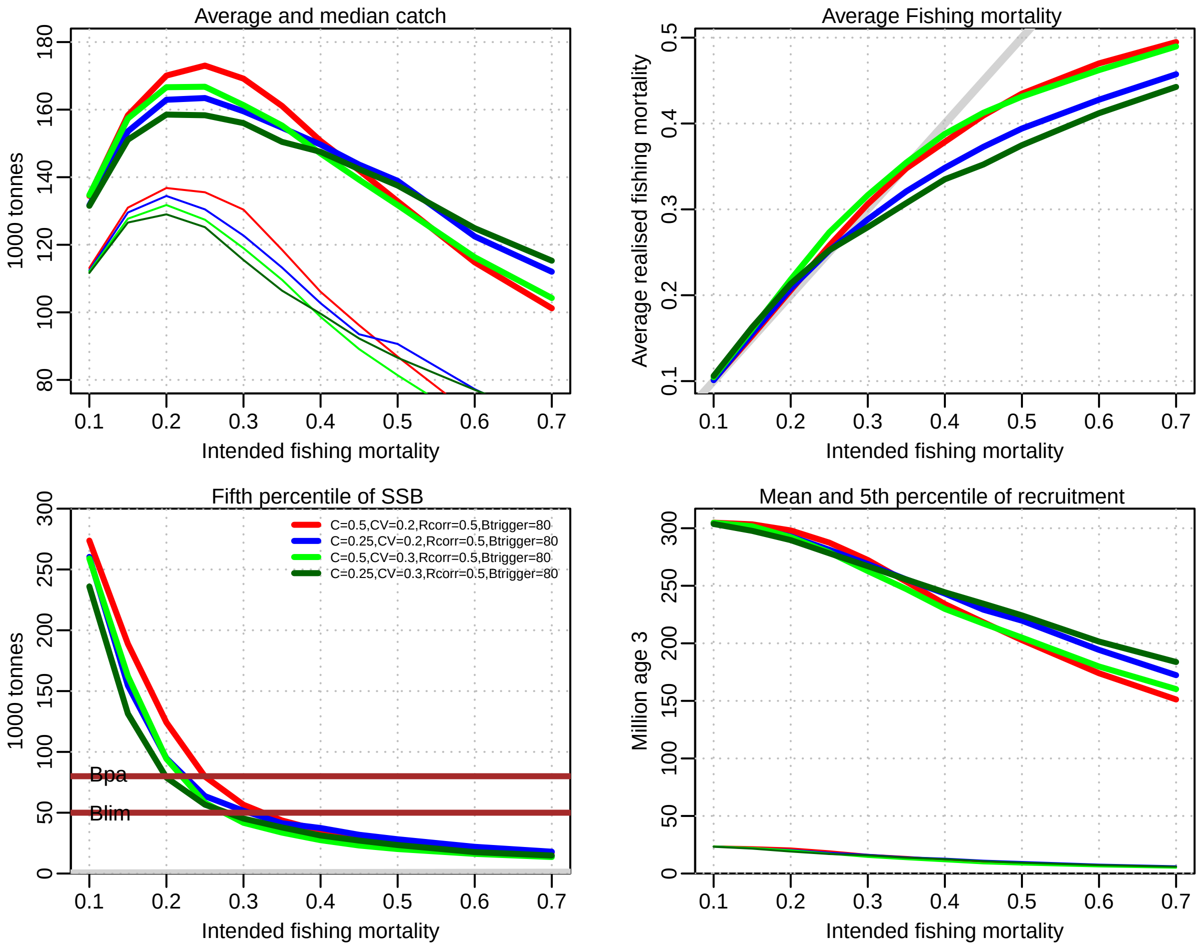


Figure 7: Results of 4 different runs for Barents sea haddock

In the last figure (figure 8) the effect of $B_{trigger}$ is tested for two values of recruitment correlation.

1. Max catch change=0.25, assessment CV=0.2,recruitment autocorrelation=0.5, Btrigger= 80
2. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.5, Btrigger = 140
3. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.1, Btrigger = 80
4. Max catch change=0.25, assessment CV=0.2, recruitment autocorrelation=0.1, Btrigger = 140

The result is that with higher trigger more catch can be obtained, and F can be higher. The main problem with higher trigger not shown in the figure is more variability in catches, both interannual and also that fishing mortality becomes very small when the stock is small. One of the factors that can affect desireable combination of F and $B_trigger$ is how much haddock is obtained as bycatch, more bycatch means lower F and higher $B_{trigger}$

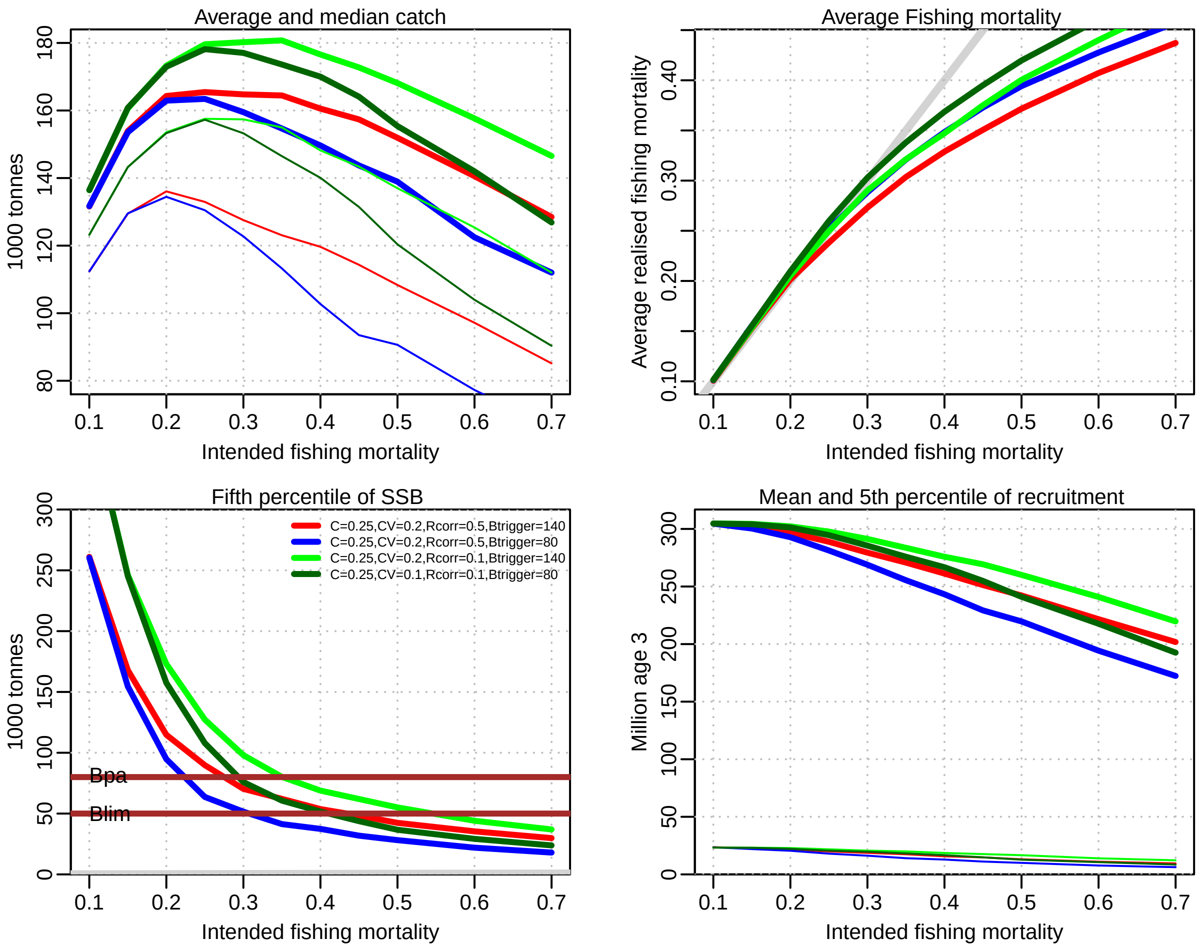


Figure 8: Results of 4 different runs of Barents sea haddock

6 Selection

Basing advice on average fishing mortality changing the selection pattern with selection pattern of the fisheries is a bad idea, increasing the removal rate when the pattern is towards younger fish and vise versa. HCR rules should be tested for one specific selection pattern and advice based on that pattern, what ever is the selection pattern of the fisheries. Biomass rule works more or less in the same way as rule with specified F.

To take an example 5 selection pattern are shown for NEA cod and compared with the average selection pattern for the last 3 years. The spawning stock, harvest rate as fraction of biomass 4+ based on catch weights (HCR for Icelandic cod) and yield/spawningstock is shown for the six pattern based on the same reference F=0.4 projecting 30 years ahead. (figure 6. The harvest ratio can vary from 0.22 - 0.29 and spawning stock from 900-1800 thous. tonnes for the same F but different selection pattern. The changes shown here are of course rather extereme but 25-30 % change in SSB for the same F could be expected, only due to selection.

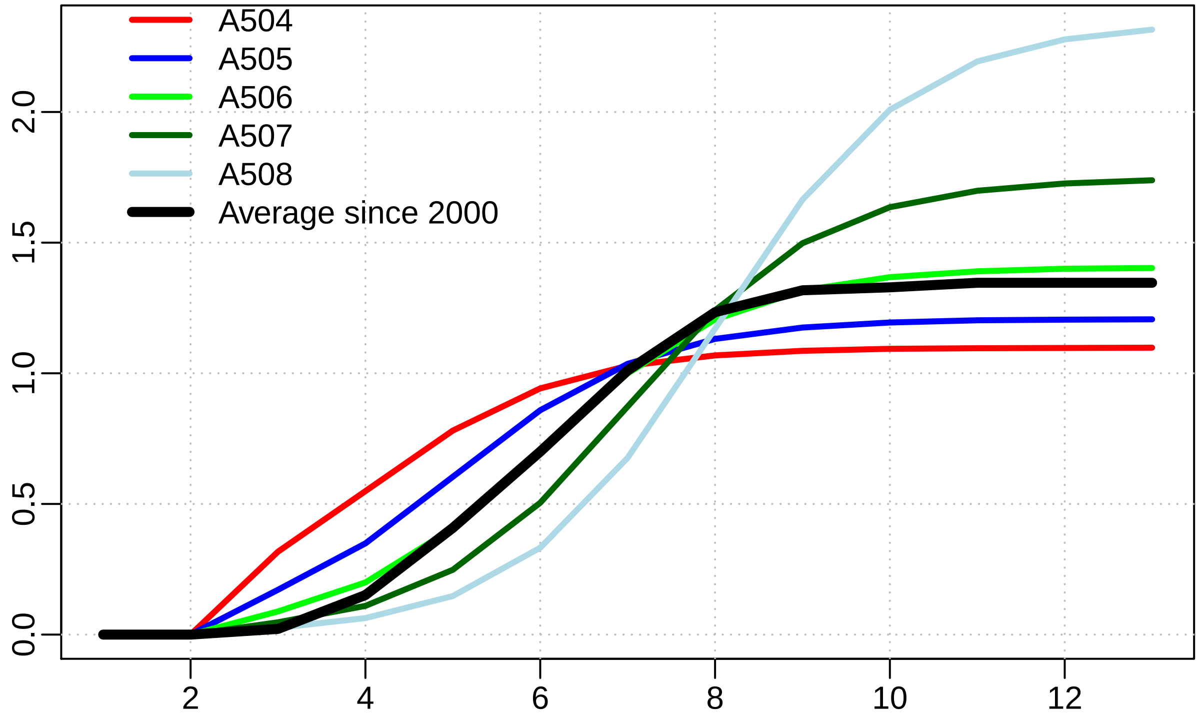


Figure 9: Selection patterns used to test effect of selection pattern on removal rate for F_{5-10}=0.4

	a50	Bio4+Hrate	Spawningstock	SSBHrate	F5-10
4	4	0.29	944.00	0.71	0.40
5	5	0.26	1145.00	0.63	0.40
6	6	0.24	1371.00	0.57	0.40
7	7	0.23	1614.00	0.51	0.40
8	8	0.22	1870.00	0.47	0.40
sel2000-2015	sel2000-2015	0.24	1463.00	0.55	0.40

Table 1: Spawning stock, Catch/Bio4+ and Catch/Spawningstock for various selection patterns and $F_{5-10} = 0.4$

7 Recruitment of Barents Sea Haddock

Recruitment of Barents Sea haddock is is extremely uneven. (figure 10a). The contrast in yearclass size is 1:260 (5.4/1447 million at age 3). Looking at the plot on log scale (figure 10b) illustrates clearly how poor yearclasses 1977 - 1981 are but their average is only 12 million recruits or 8400 tonnes assuming YPR = 700g/recruit.

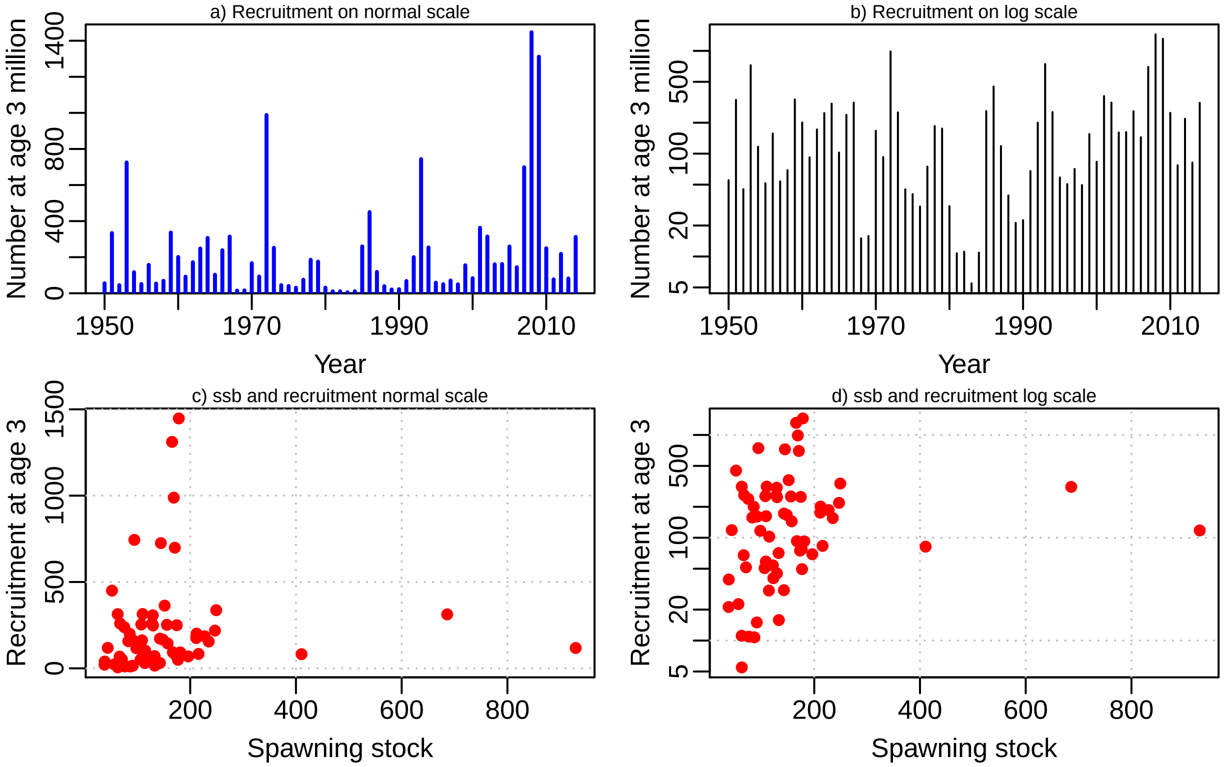


Figure 10: Spawning stock and recruitment of haddock

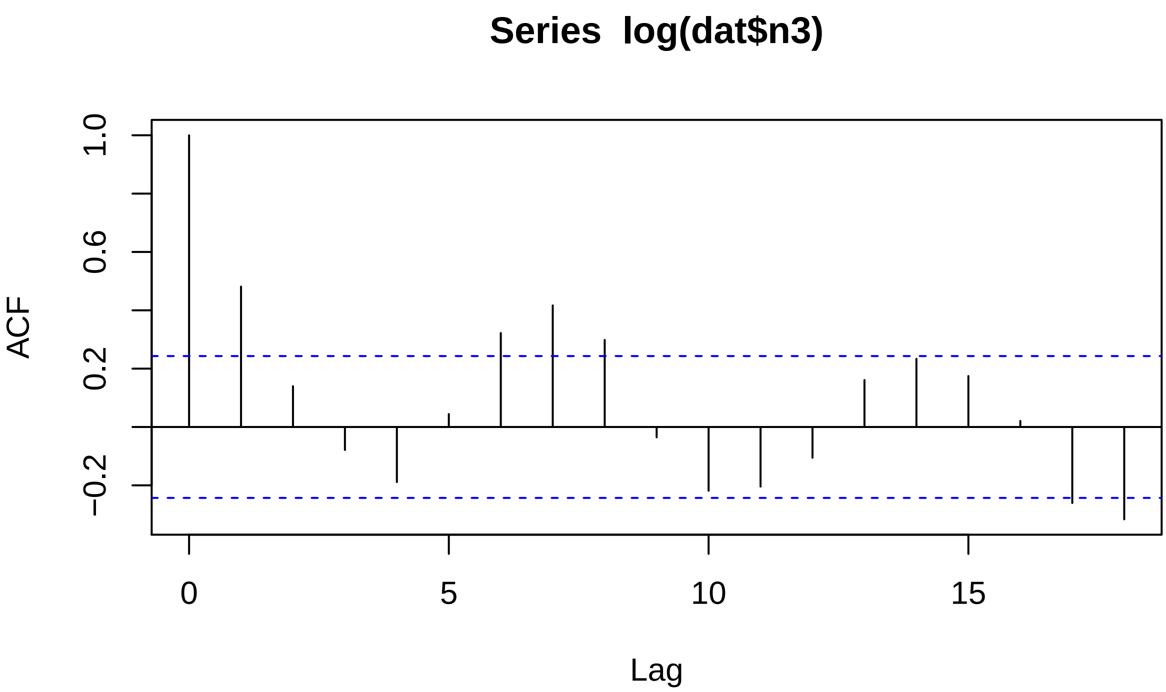


Figure 11: Autocorrelation of log(N3)

The HCR model was run using a Hockey stick model with R_{max}, SSB_{break} and CV estimated. One set of the parameters is used in each run and the values of SSB_{break} varies much. There is though a positive correlation between SSB_{break} and R_{max} so the consequences of lower SSB_{break} are complex.

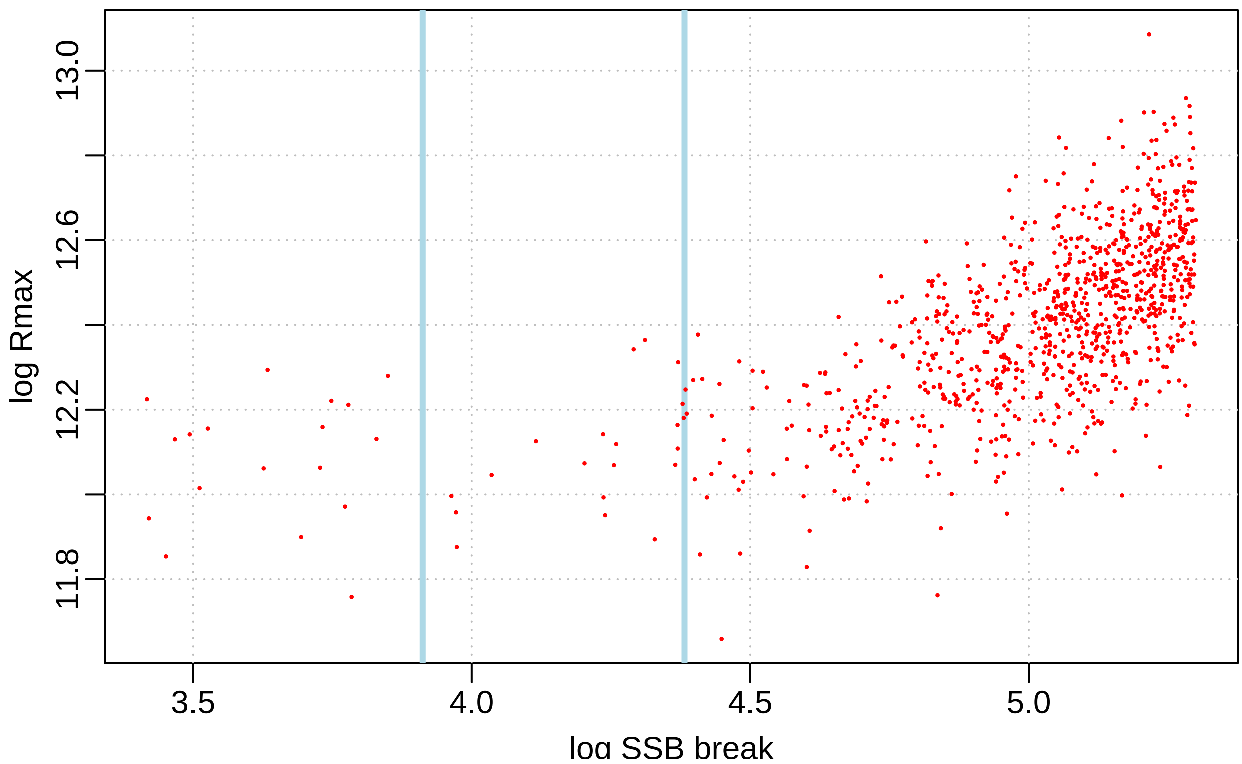


Figure 12: Log of SSB_{break} vs $log(R_{max})$, with B_{lim} and B_{pa} shown

First order autocorrelation of log(R) is around 0.5 (figure 11. This value is rather poorly estimated as shown by the confidence intervals. This value was used in HCR simulations as default. Fifth percentile of 5 year recuitment obtained from those simulations was around 37 million fishing at F=0.2 but 16 million fishing at F=0.7 while the observed average is 12 million (yearclasses 1977 to 1981). To approach the value of the 1977 - 1981 yearclasses fishing at 0.2 the autocorrelation would have to be 0.8 leading to $F_{pa} < 0.2$.

Estimating SSB_{break} with AR = 0.5 gives SSB_{break} = 60 thous. tonnes but with very high confidence intervals as AR=0.5 reduces effective number of data points.

8 Dependency dependent growth of haddock

The results shown for haddock sofar have been based on mean weighth at age varying randomly around the average of last 20 years. The variability is a $yearfactor$ with CV of 10% and $\rho = 0.6$. In simulations for the haddock a function where stock weights depend on total biomass and after that catch weight and maturity at age on stock weight has been used. The result of those simulations are shown in figures 13 to 11.

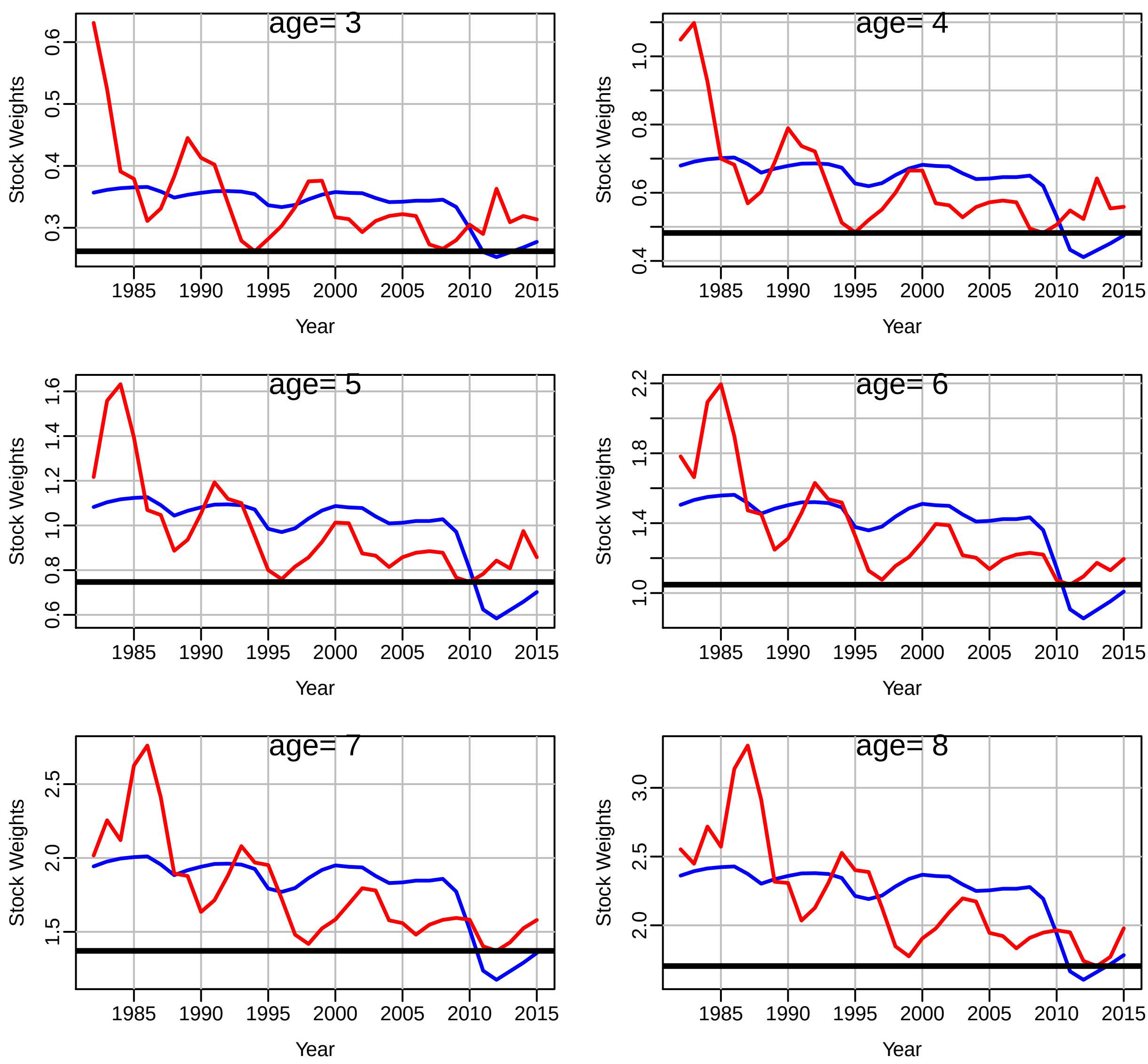


Figure 13: Predicted stock weights for age 3-8 (blue) vs observed (red). Min values shown as black horizontal lines.

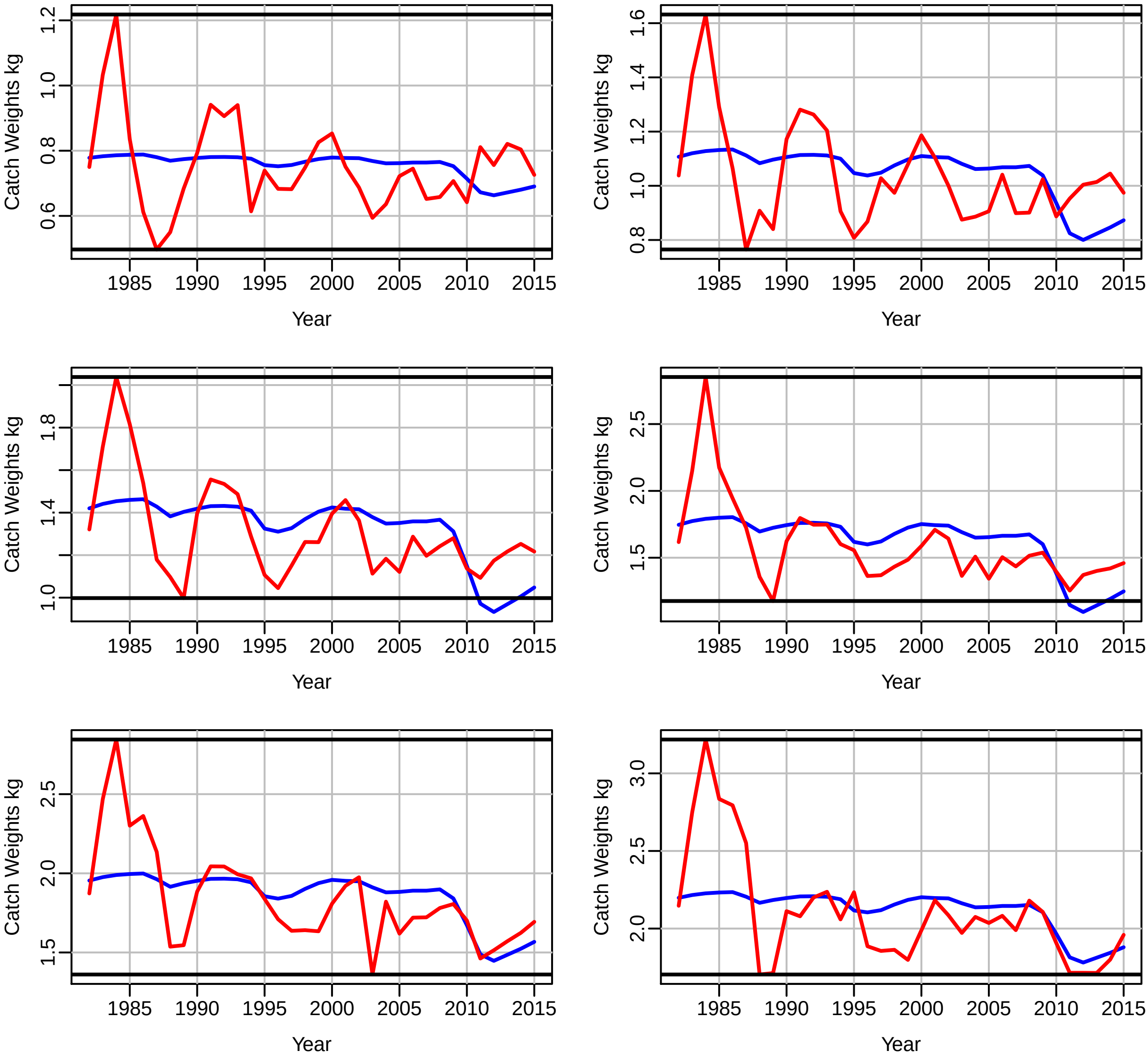


Figure 14: Predicted catch weights for age 3-8 (blue) vs observed (red). Min and max values shown as black horizontal lines.

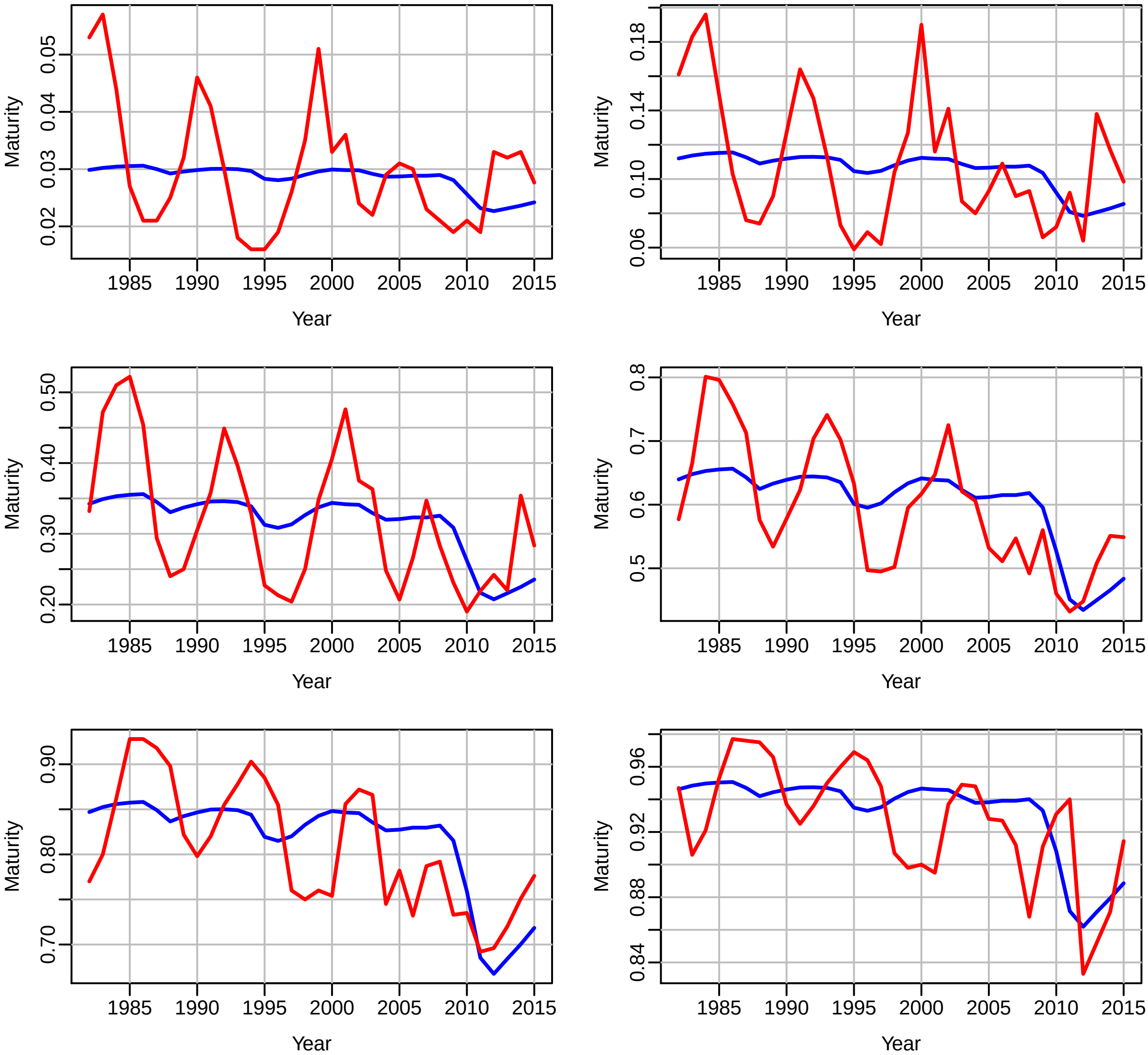


Figure 15: Predicted maturity at age 3-8 (blue) vs observed (red).

9 Few more runs of haddock

As shown above figure 12 the breakpoint of the hockeystick function piles between 100 and 200 thous. tonnes when running mcmc simulations. Basing the estimation on autocorrelation of 0.5 that is a likely value lead to a different pattern and the estimated breakpoint is near 60. The cloud of points does though extend somewhat up from that points. (figure 16). The deterministic estimate of SSB_{break} is 60 kt, on the lower edge of the cloud of points. (not unusual behaviour for this parameter)

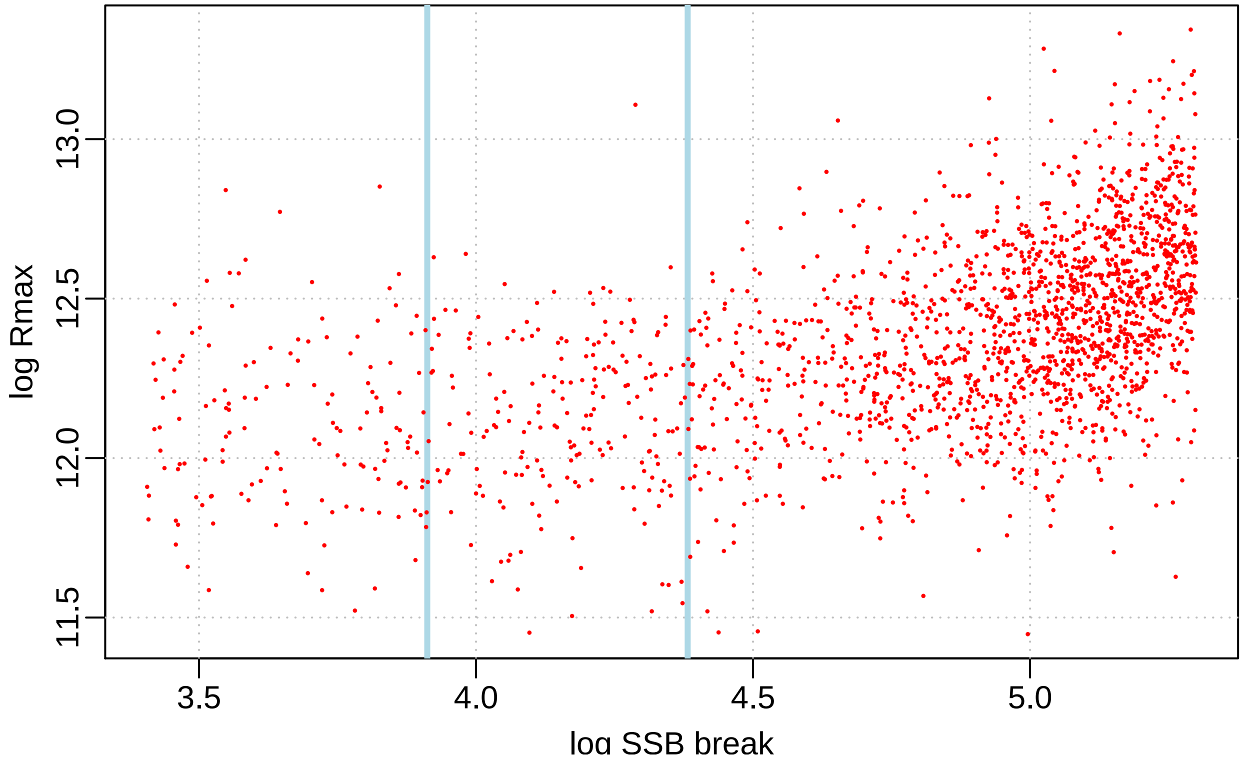


Figure 16: Log of SSB_{break} vs $log(R_{max})$, with B_{lim} and B_{pa} shown

Simulation of the HCR was done based on 3 different versions of the Hockeystick SSB-Recruitment.

1. Run 1. SSB_{break} estimated. Autocorrelation neglected in the estimation phase (figure 12)
2. Run 2. SSB_{break} estimated. Autocorrelation=0.5 in the estimation phase (figure 16)
3. Run 3. SSB_{break} fixed at 60 kt (value estimated deterministically. Autocorrelation=0.5 in the estimation phase

In all cases R_{max} and CV are estimated. Both cases are run with mean weights of last 20 years and density dependent weights.

Results are summarised in figure 9. They show that what assumption of mean weight and maturity at age is the major factor affecting the precautionary harvest ration i.e where SSB_{05} crosses B_{lim}. The crossing point is at $F = 0.3$ for constant weights (average of last 20 years) but 0.45 for the density depent weights. The harvest rate giving highest median yield varies from 0.2 to high value, and is mostly dependent on the stock recruitment function. If the break point is fixed at $60kt$ maximum yield is obtained at $F > 0.4$ else as 0.2-0.3. As shown earlier (figure 13) the density dependent weights change more with stock size than real weights and are usually higher. The "truth" might be somewhere between the two scenarios propably closer to the 20 years average.

The conclusion of these investigation based on those investigations is that $F = 0.3$ would be the selected target fishing mortality with $B_{trigger} = 80$ and 25% constraint but it could also be stated that anything in the range 0.25-0.35 is acceptable.

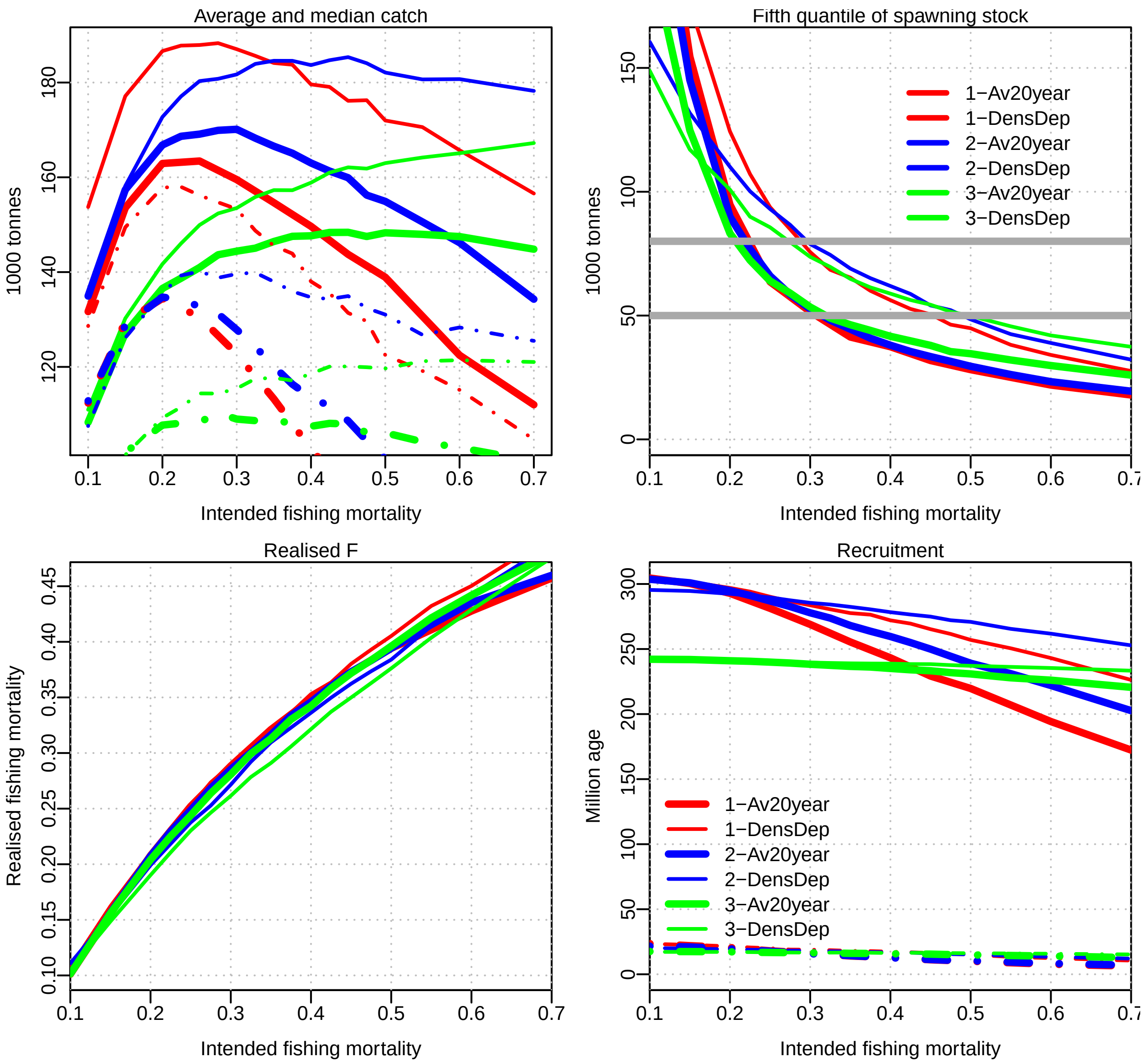


Figure 17: Summary of results from the runs listed above , with and without density dependent weight. Dashed lines show median catch and 5th percentile of recruitment

10 Capelin

Predation of capelin in Jan - April is supposed to be only from immature cod, whose biomass peaked from 2007-2010 (figure 18). Skipping the mature part of the stock does give a completely different picture of what is happening and makes the predation on capelin independent of fishing mortality but the size of the immature part of cod stock is much less affected by the fisheries than the size of the mature part.

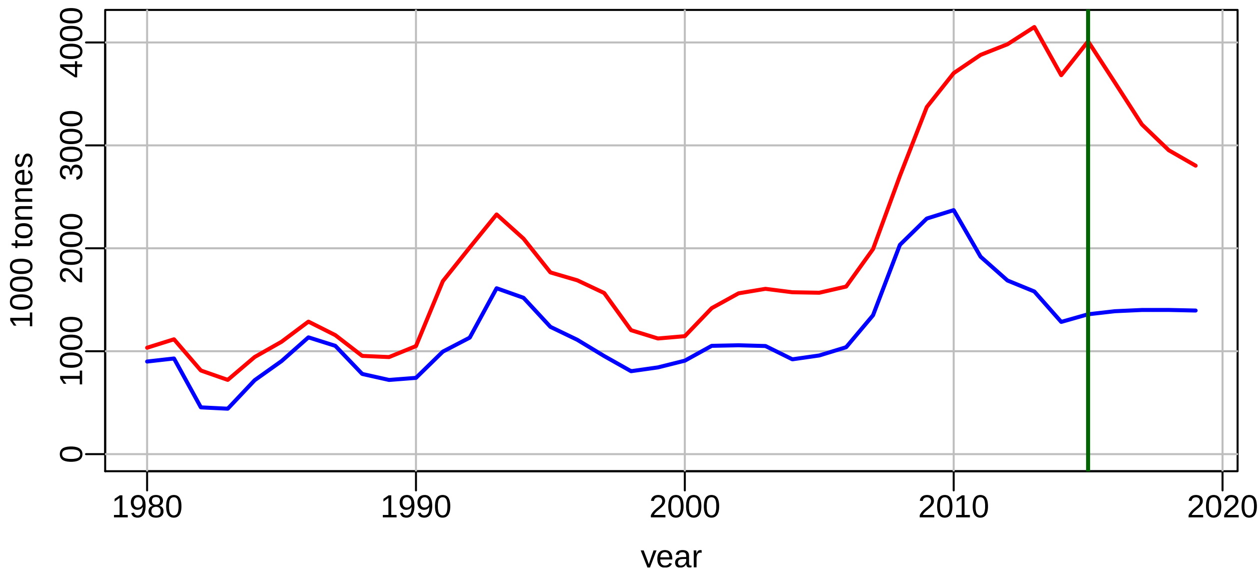


Figure 18: Development of total and immature stock of cod

11 Density dependent growth of cod

After looking at the weight predictions for haddock the same was done for cod. The equations are described in working paper ?? Two sets of predictions of stock weights are available, one based on data from 1946 and the other on data from 1980. The second one that shows less weight dependency was used, one reason is that stock weights before the survey is questionable. Stock weights are calculated from total biomass, 2 numbers for each agegroup plus minimum and maximum values that should not be exceeded.

Maturity is compiled, either based on total biomass around the birth of the yearclass (model 3) or from contemporary stock weights (model 2). Model 3 was used in the HCR simulations.

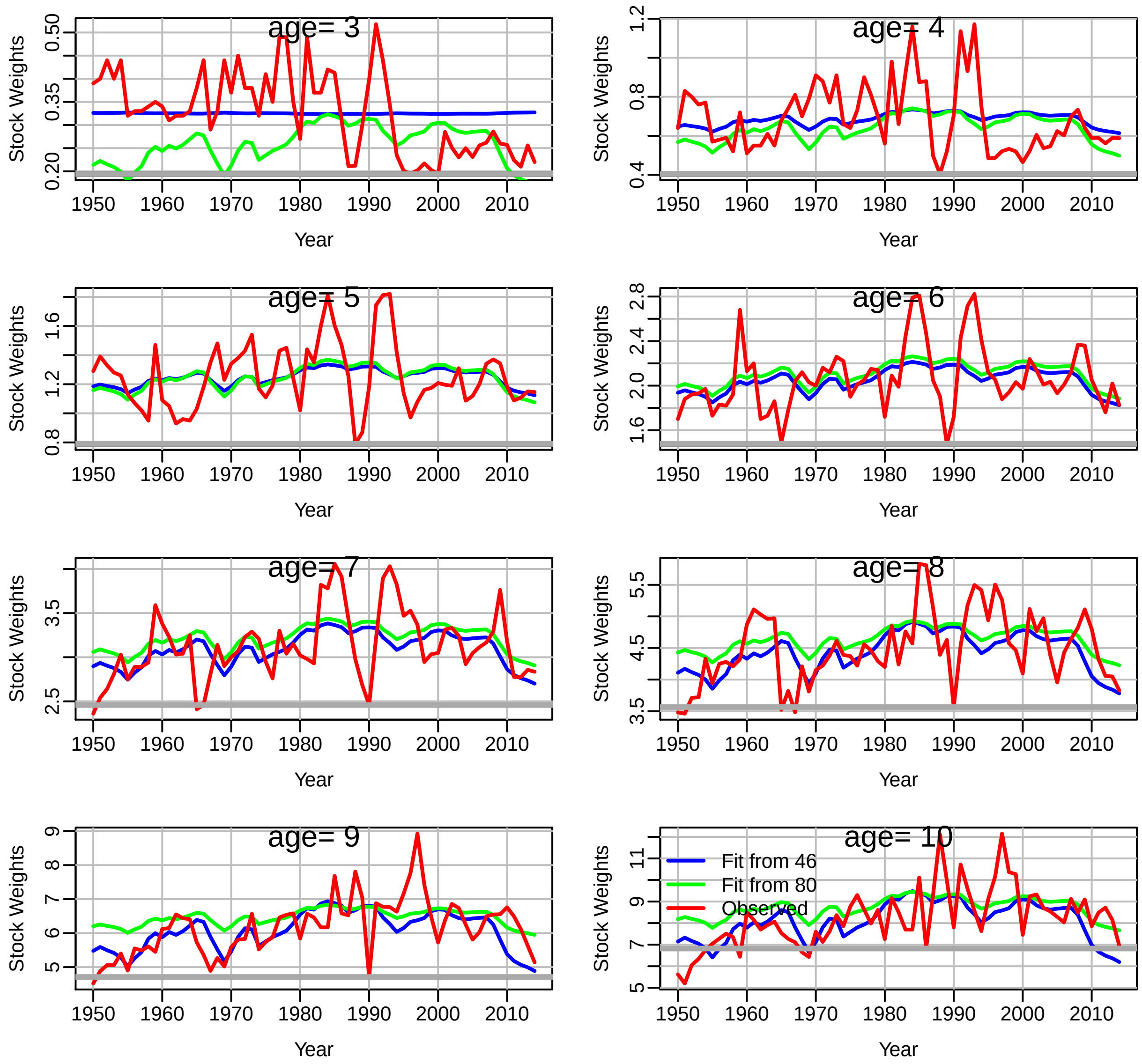


Figure 19: Stock weights since 1946 and predictions based on data from 1946 and data from 1980(used). Weights before 1982 might not be comparable to later weights that are from surveys.

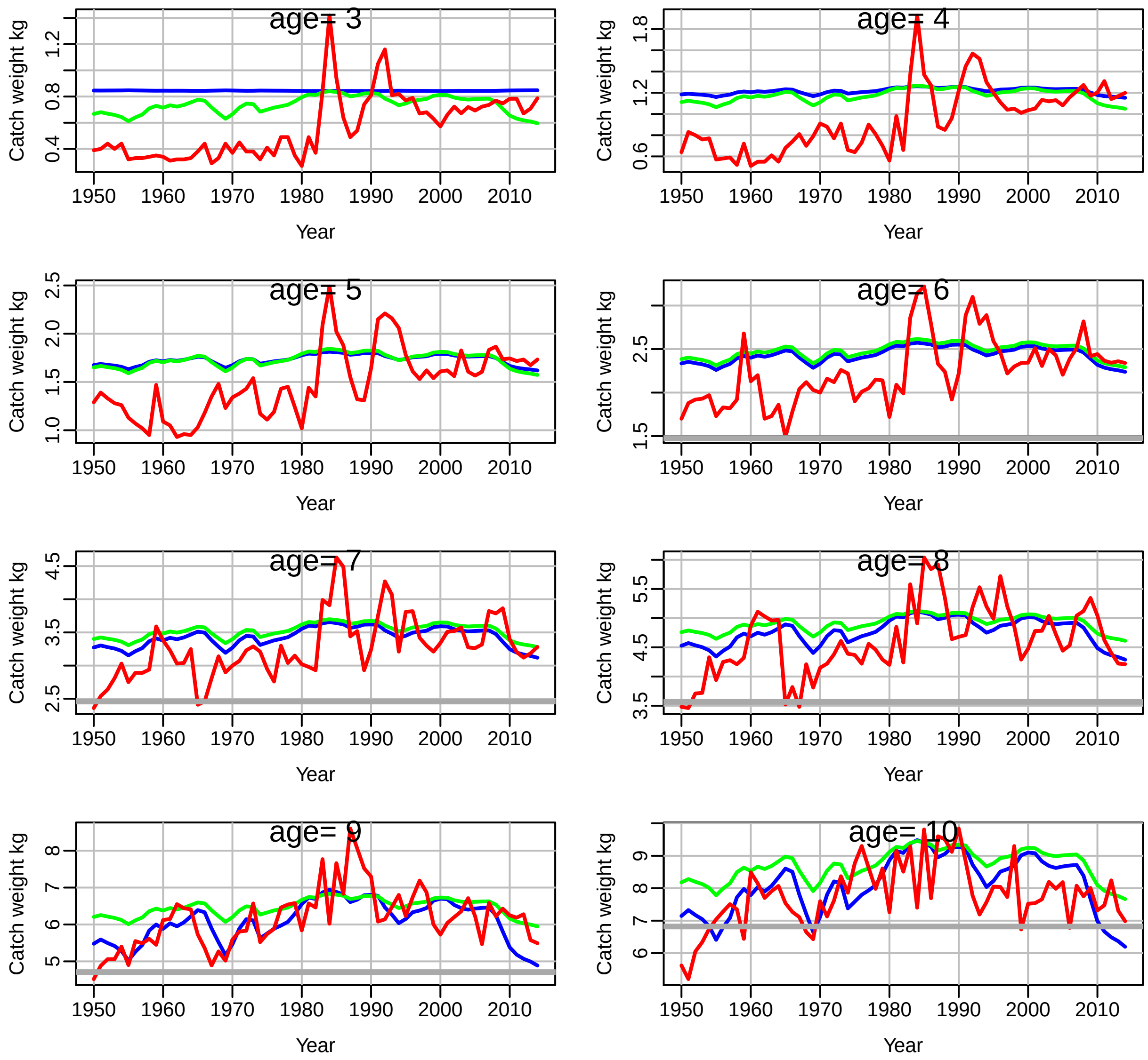


Figure 20: Catch weights since 1946 and predictions based on stock weights. The two different curves show prediction based on stock weights predicted based on data from 1946 and 1980.

Observed and predicted maturity at age is shown in figure 11. The model where a_{50mat} is based on stock size at the birth of the yearclass gives more contrast than the other models but does not reach the variability in the data. There are really 2 solutions for future prognosis

1. 1 - to assume that old history will never come back

2. 2 - to assume that maturity is inertial process and what we observed now is not normal situation. Cod need time to become to mature later

Both assumptions are most likely wrong but perhaps the best way would be to test both alternatives. The combination of maturity function 3 and the cyclic recruitment (period 6.7 years) might lead to strange behaviour but the total biomass of a yearclass is highest at age 5 to 7 with $F = 0.4$ and spawning stock at age 7-9. This could lead to proportion mature being lowest for the large cohorts as the biomass might peak when the next large cohort occurrs. Different fishing mortality might change this and this might be confounded with a model that large cohorts mature slower.

Running the HCR with much lower maturity at age than will be observed can become a problem. In the HCR simulations the catchconstraint will regularly be relaxed stock is predicted to be below B_{pa} but in real life (if maturity is considerably higher) this action will never be taken even though the total stock is similar. We should therefore look at results from run with lower $B_{trigger}$. But to repeat, the HCR depends too much on proportion mature that is highly variable leading unnessecary variability in catches. It looks like the area where recruitment starts decreasing is never approached for all sensible exploitation rates and hanging too much on the SSB might not be correct, rather use biomass 7+ or something that is on the average the same as SSB.

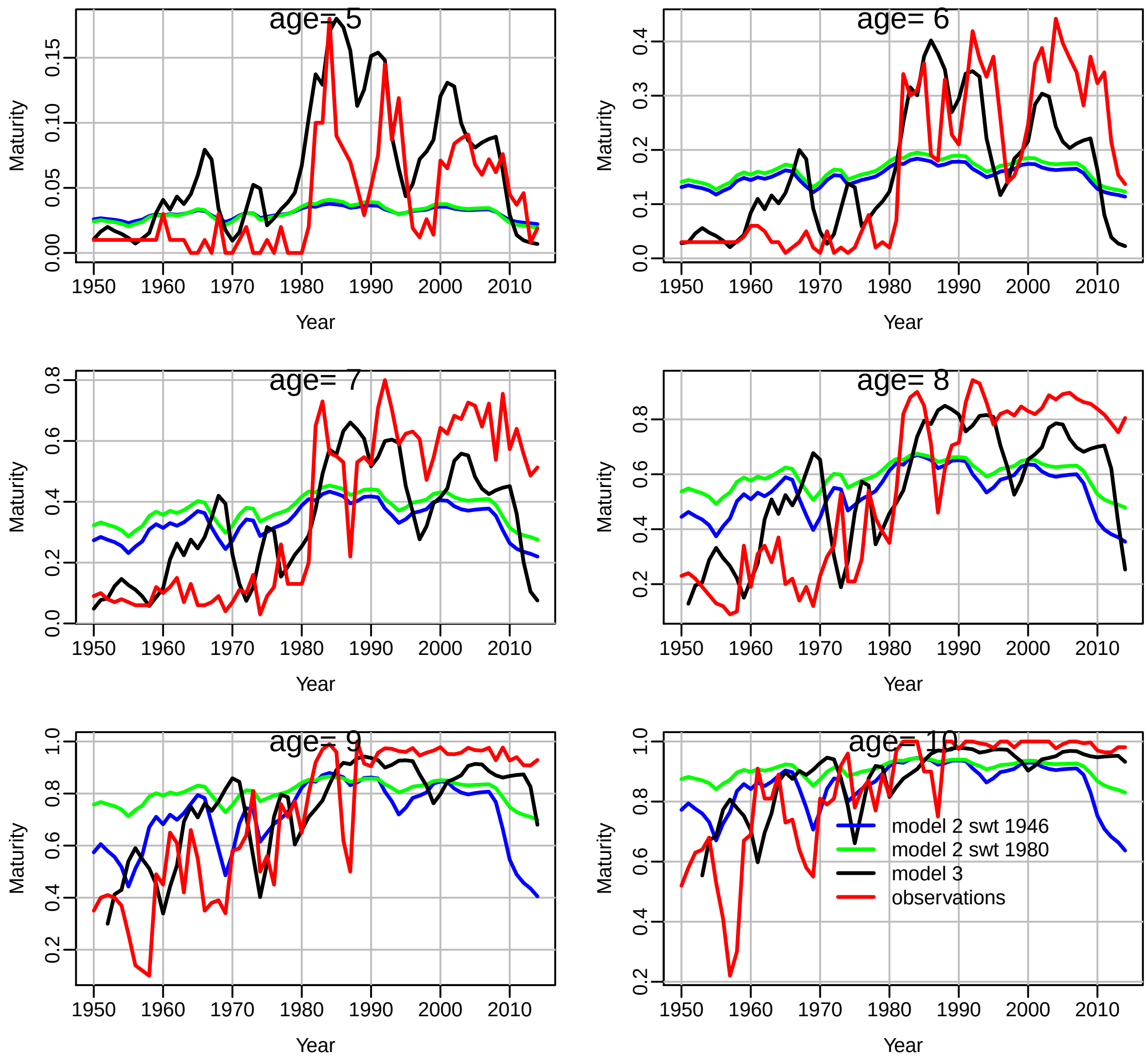


Figure 21: Maturity since 1946 and predictions based on stock weights (model 2) and total stock size near birth of the yearclass(model 3). The two different curves for model 2 show prediction based on stock weights predicted based on data from 1946 and 1980.

Looking at observed maturity from future simulations shows that they are lower than seen in recent years and approach the values between 1946 and 1980 when fishing mortatlity is low(figure 22)

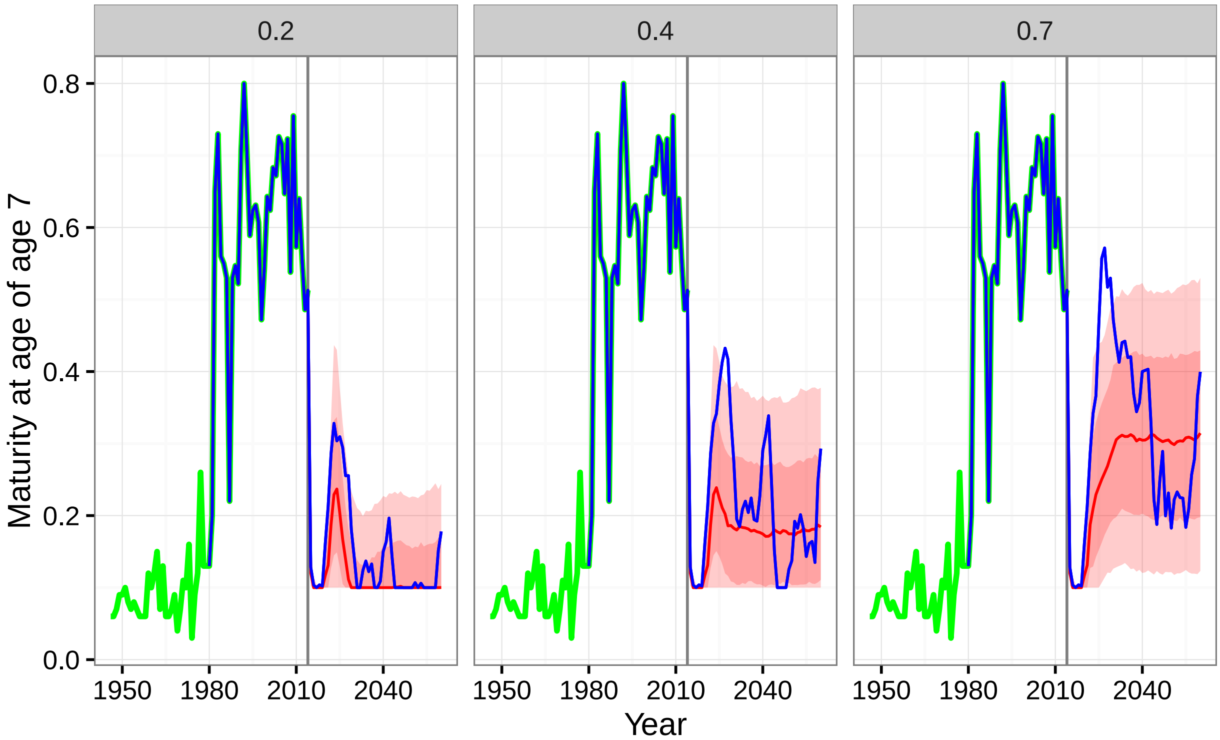


Figure 22: Predicted maturity at age for age 7. The results are shown for target fishing mortality 0.2, 0.4 and 0.7. Historical data shown for comparison. The vertical line is 2014 and 2015 and later data are calculated based on model 3.

The model for stock weights (figure 11) shows the main features in develpoment of weights but does not explain large part of the variability seen but most of the variation is explained by capelin. In HCR simulations additional variability needs to be included to reflect those variations. What was used here was autocorrelated lognormal noise with CV=0.12 and $\rho = 0.7$, same values as for Icelandic cod but σ is on the lower side for this cod stock. The models shown predict some decrease in recent years when stock size has been large, the model based on data since 1946 more decrease. Results from the simulations are shown in figure 23 show that stock weights change with fishing mortality. The lowest weigths are though controlled by the specified minimum that is one of the inputs.

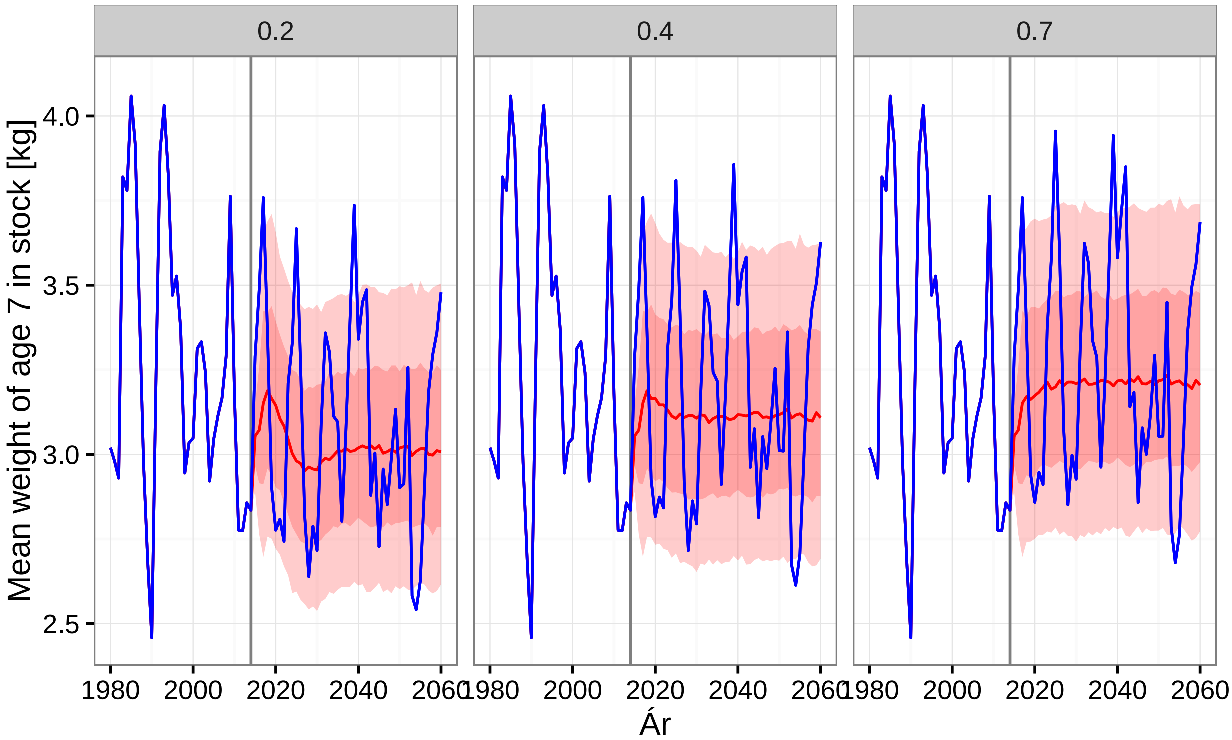


Figure 23: Weigth of age 7 cod in stock. The figure shows both historical data and predictions.

Catch Weights are derived from stock weights, the relatioship describing selection rather than growth. Future predictions with one scenarion and historical data are shown in figure 24.

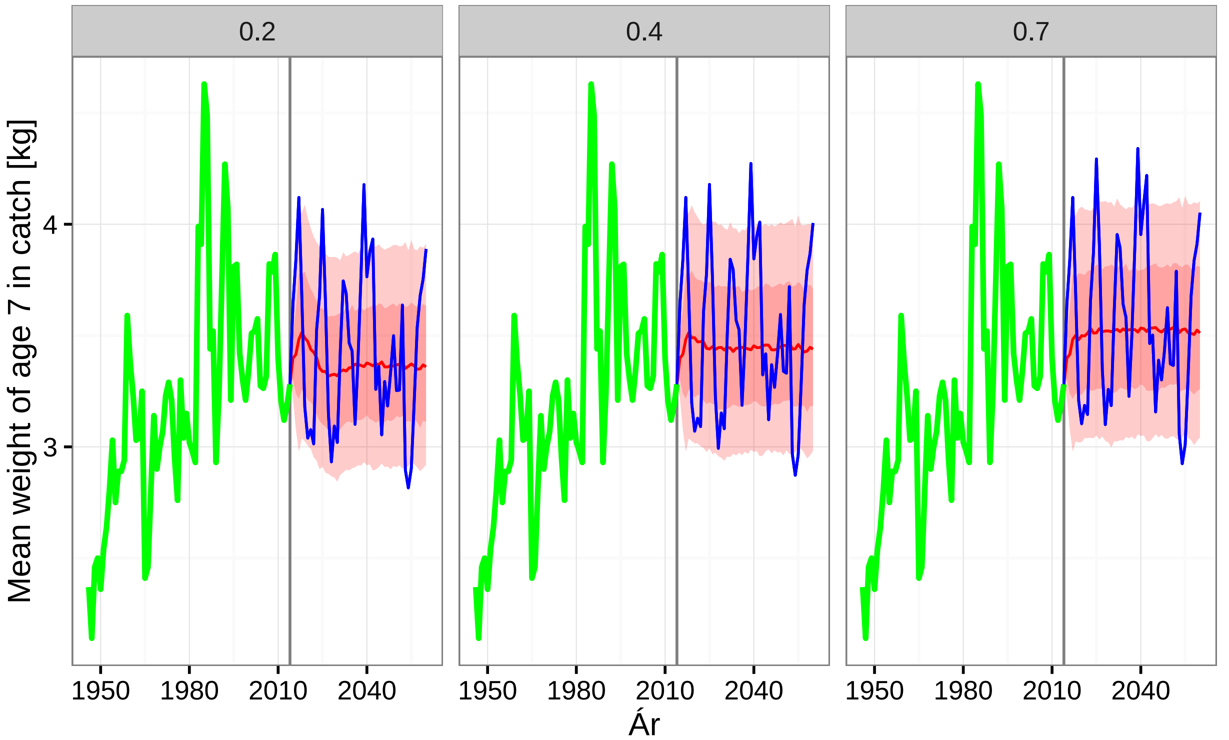


Figure 24: Weigth of age 7 cod in catch. The figure shows both historical data and predictions.

Description of run.

1. Mean weight and maturity at age are as show before.

2. The model runs stock assessment based on data from 1980-2015. The selection pattern is allowed to change in 1999 and the latter selection pattern is used in predictions.

3. M in assessment of age 7-5 is a function of biomass of 6 years and older fish as described in the working paper. This value gives negative log-likelihood that is higher than the value obtained using fixed M=0.2. The difference is +3 for the same number of parameters,nothing to worry too much about.

4. Hockey stick stock recruitment functions. R_{max}, SSB_{break} and σ on logscale estimated.

5. Predictions are based on CV of Assessment error = 0.2 and autocorrelation = 0.6, and recruitment autocorrelation = 0.05. Uncertainty in maturation and stock weights is included by using values in the assessment year for short term projection leading to the HCR based on those predicted values.

The results show that the value of F giving maximum avarage yield is poorly defined but the value is 0.5 (figure 25.) The value leading to $SSB_{05} < B_{lim}$ is 0.52. Runs based on M=0.2 and fixed weights (figure 5) give maximum yield with F in the range 0.3-0.4 and the value when $SSB_{05} < B_{lim}$ is between 0.5 and 0.65 due to relatively high maturity at age.

Reduced growth when stock is large might be counteracted by reduced size selective mortality of the fisheries an that the cannbalism might rather target slow growing cod that is vulnerable for predation over longer time.

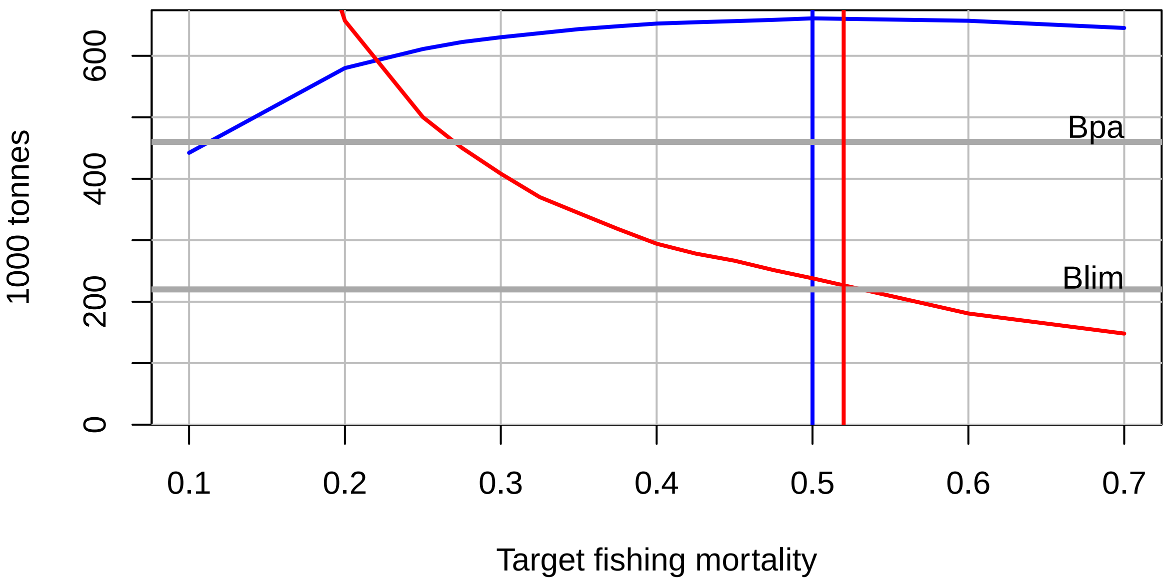


Figure 25: Average catch and fifth percentile of spawning stock based on the HCR and density dependent M3, mean weight and maturity

Looking at average recruitment against fishing mortality shows that it is very flat except for high F (figure 26). The plan is to add age 5 to see the effect of cannibalism (there is also some fishing on age 4.)

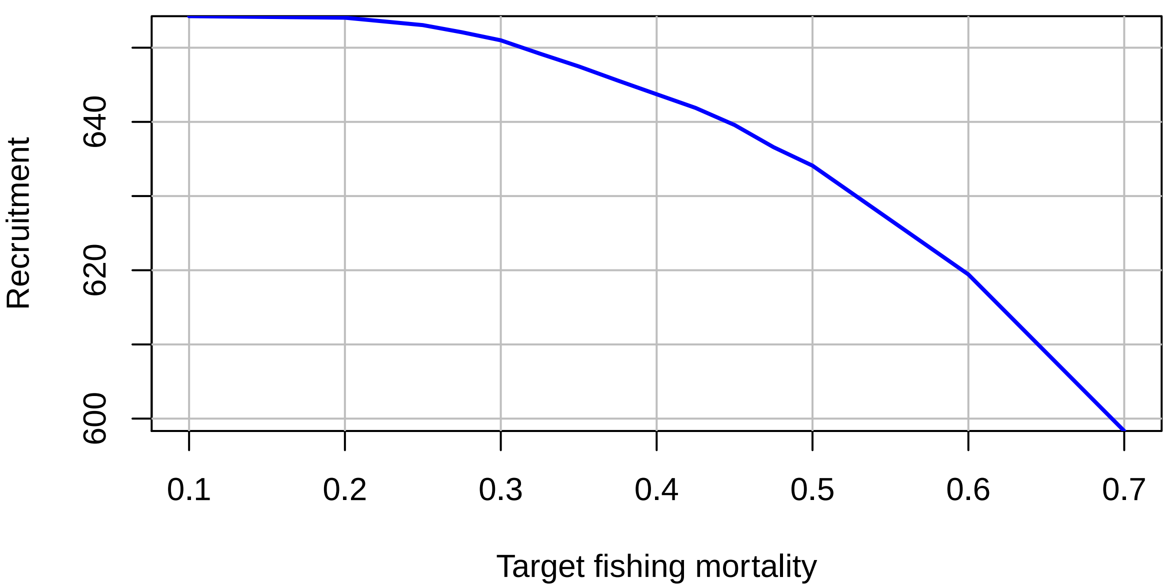


Figure 26: Average recruitment million at age 1 (M=0.2 at age 1 and 2) against fishing mortality

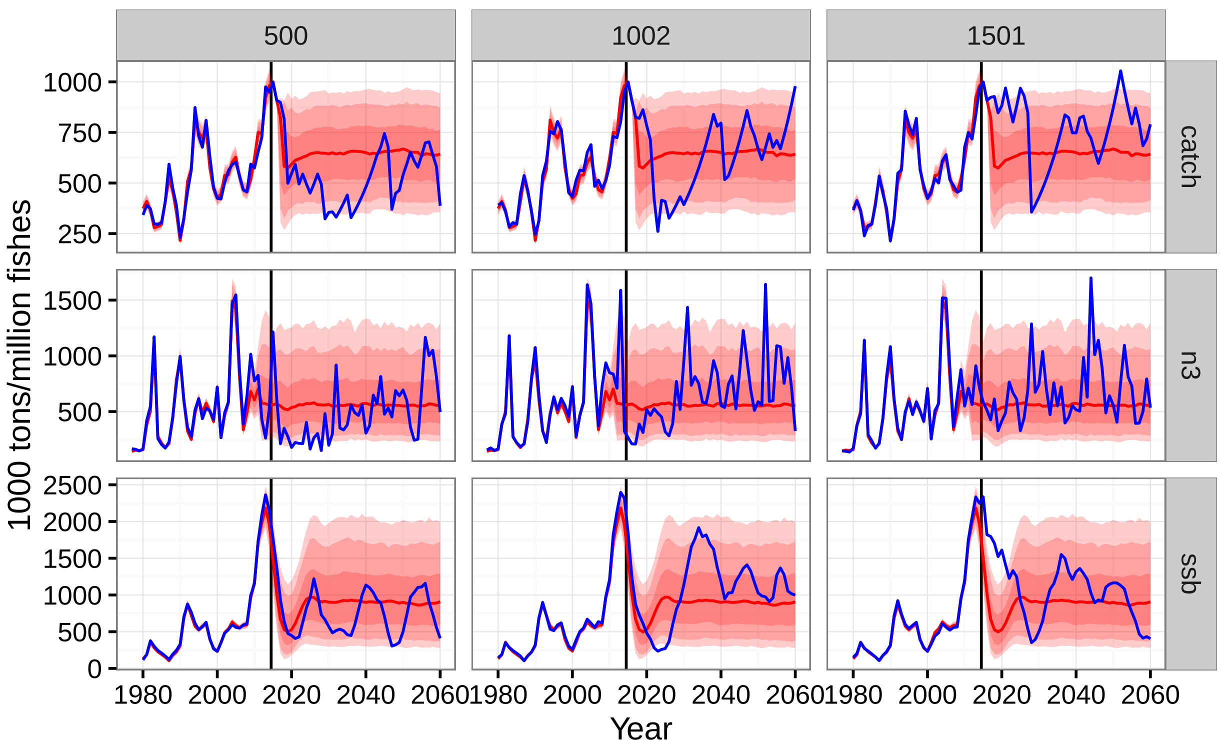


Figure 27: Development of catch, spawning stock and recruitment based on the current HCR. 3 individual realizations are shown.

Individual runs can be quite variable (figure 27) both because of the random noise added and each run is based on different value of the parameters.

Comparison of development of spawning stock and total biomass (29 and 30) show relatively little change in total biomass in the range 0.3-0.4 (the plausible range). The change in spawning stock is larger as the older part of the stock is more affected by the fisheries. This effect is though reduced by lower proportion at age when the total stock is larger.

Variablity in catches increases with higher F, (28) but the effect is not very strong. Part relatively modest change is because the fishing mortality ins not increasing as intended, (figure 31).

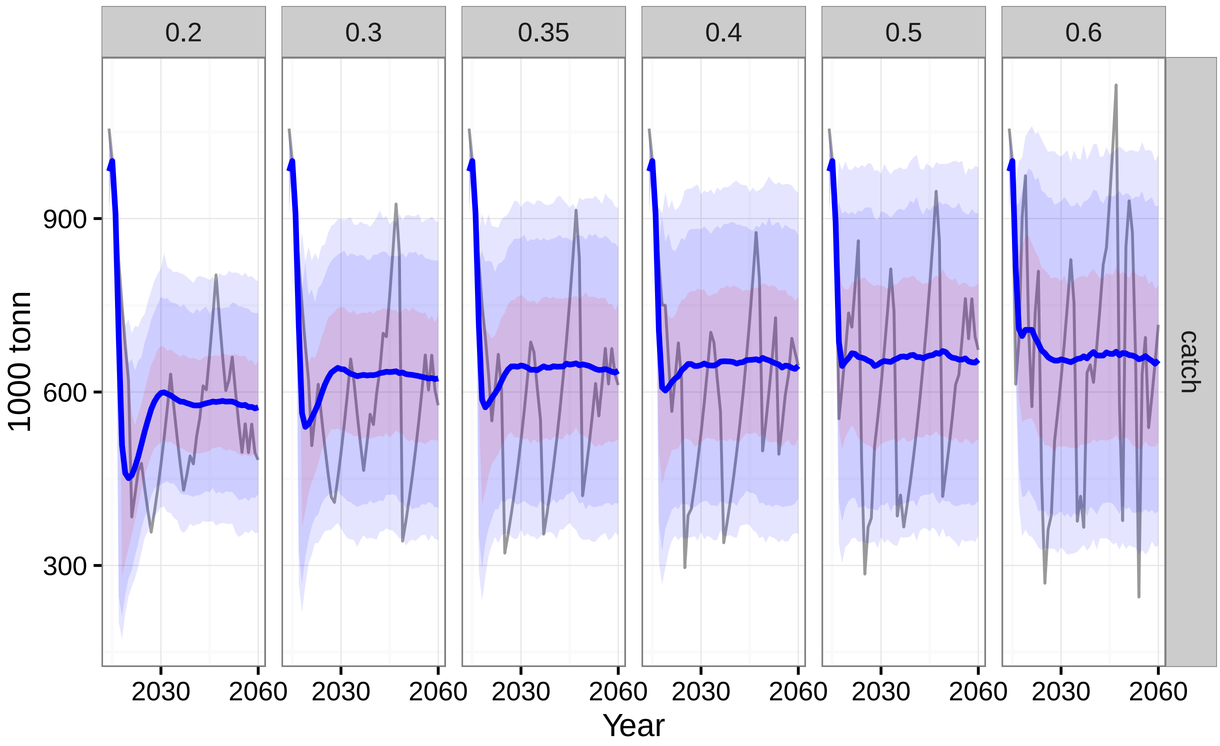


Figure 28: Development of catch for 6 selected target fishing mortalities. One individual run shown.

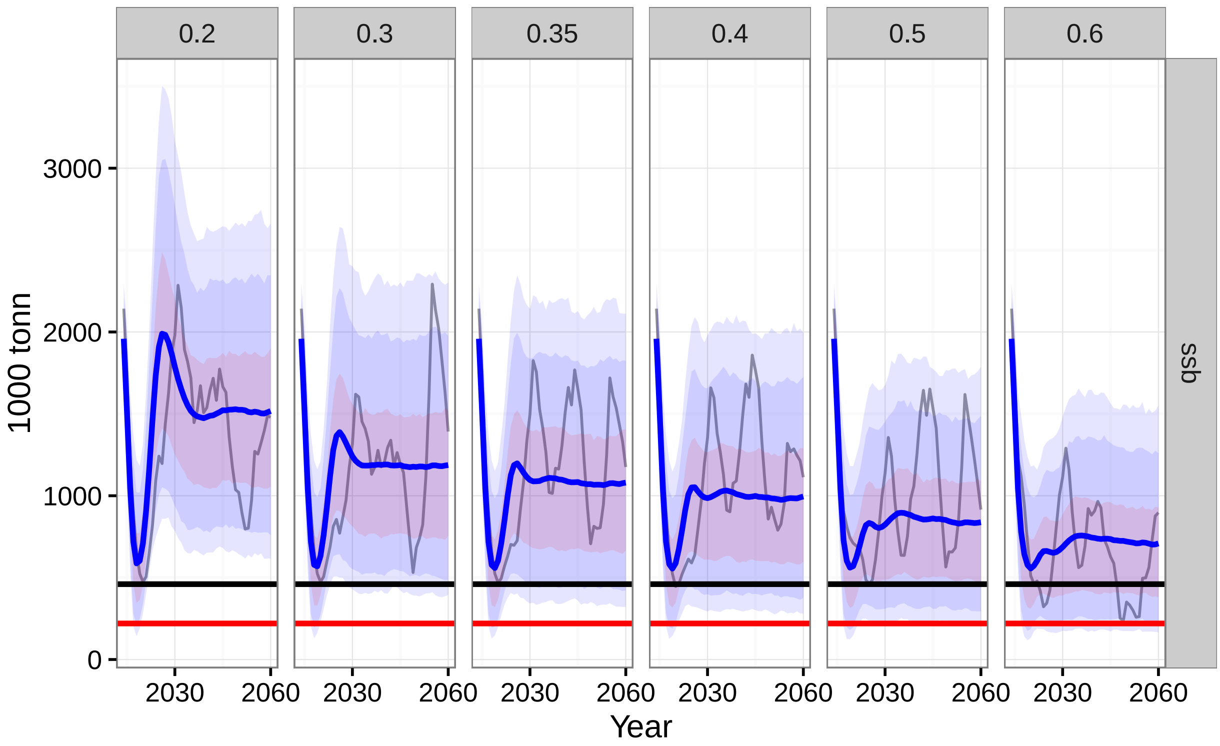


Figure 29: Development of spawning stock for 6 selected target fishing mortalities. One individual run shown. $B_{trigger}$ shown by black line and B_{lim} by a red line

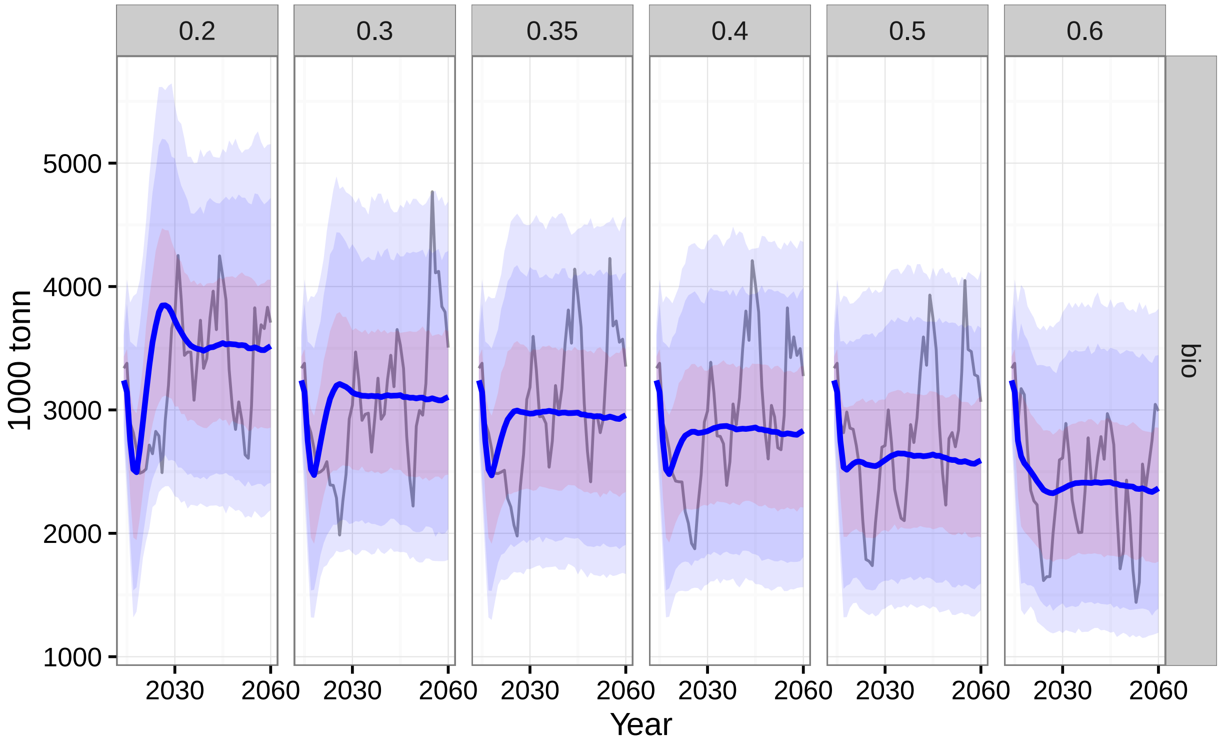


Figure 30: Development of total biomass for 6 selected target fishing mortalities. One individual run shown.

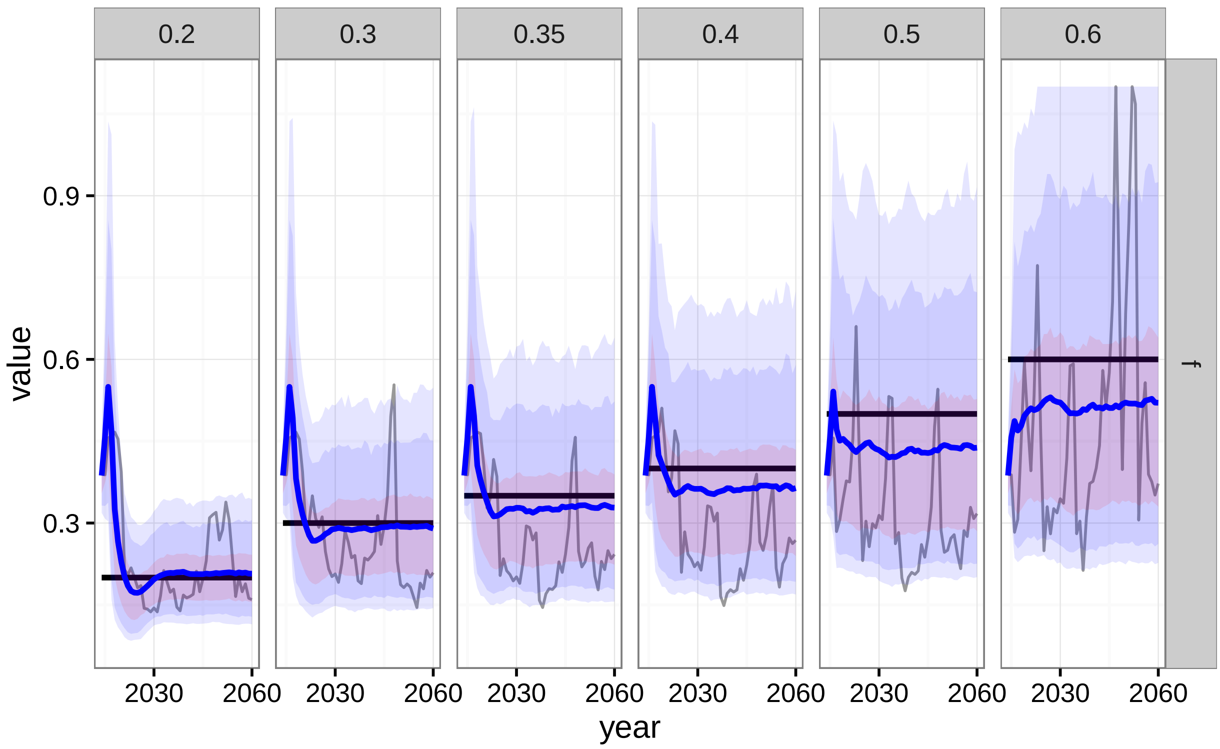


Figure 31: Development of fishing mortality for 6 selected target fishing mortalities. One individual run shown.

One factor that is not shown in figures 28 to 31 is interannual variablility that is calculated and shown in table 2

Estimated parameters in the stock - recruitment function are shown in figure 11 with vertical lines corresponding to B_{lim} and $B_{pa/trigger}$ shown. The breakpoint seems to lie somewhere in between, closer to B_{lim} on log scale but closer to $B_{pa/trigger}$ on normal scale. The estimated variable are $log(R_{max}$ and $log(SSB_{break})$.

	0.2	0.3	0.35	0.4	0.5	0.7
Average catch	575.50	624.70	637.10	643.70	654.30	649.30
Median catch	572.50	627.50	637.60	640.70	646.10	634.20
Fifth percentile of catch	355.80	348.60	350.70	345.90	341.20	297.00
Sdev of catch	134.80	165.90	177.80	186.60	198.10	226.10
Mean abs 1 year diff	51.20	67.00	73.80	81.20	97.50	134.90
Mean abs 3 year diff	101.30	135.30	148.20	158.00	174.50	200.90
Mean abs perc 1 year diff	9.00	11.10	12.10	13.30	15.90	22.60
Percent 1 year diff > 10%	1.80	8.20	11.90	16.50	27.50	54.40
Average SSB	1507.80	1182.50	1073.90	983.90	835.10	603.30
Fifth percentile of SSB	631.00	392.30	327.60	286.60	217.00	144.40

Table 2: Some summaries from the HCR for Barents sea as function of target fishing mortality.

Therefore the prior on those variables is uniform on log scale i.e more tendency towards lower values. But, lower the values are positively correlated so higher values of SSB_{break} promise more recruits if we fish carefully.

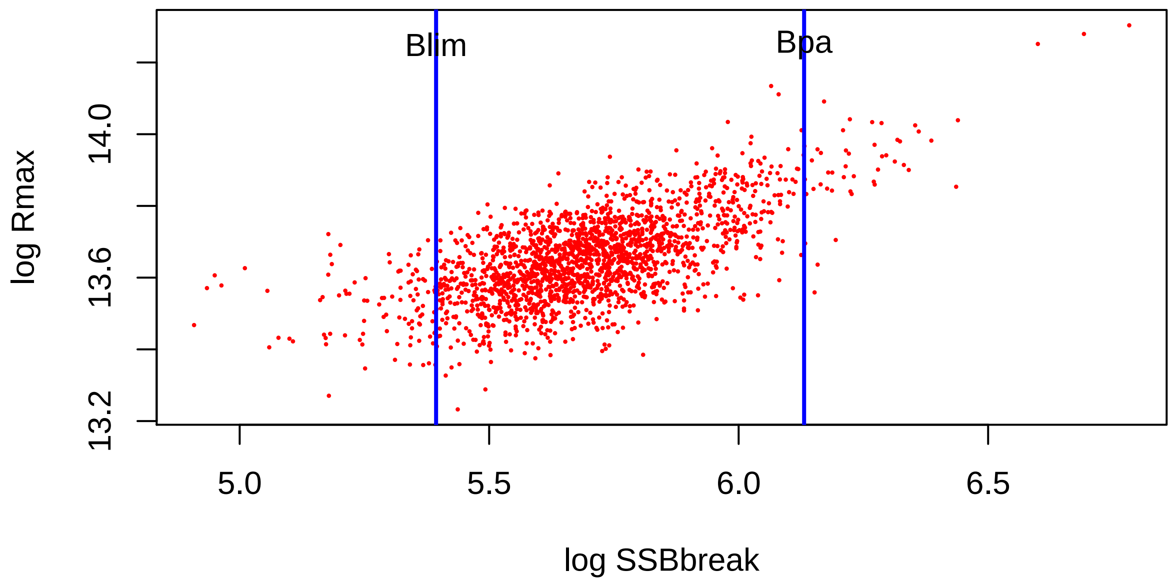


Figure 32: Distribution of estimated values of SSB_{break} and R_{max} from the hockey stick function

To summarize the analysis shown here show support what was presented at the meeting. The premises behind weights, M2 and maturity in predictions can be discussed but the main problem is the blind use of B_{lim} that is far to low as something to avoid with 5% probablitity. $B_{trigger} = 460$ is a much more appropriate value in this context leading to target F between 0.3 and 0.35 and relatively modest increase in total biomass (measure of ecosystem load). There are also indications that the breakpoint in the hockeystick regression is above 220 (figure 11), not that B_{lim} should be increased. Having it low can be convenient in the world of traffic ligtht that indicate the state of the stock. Low values should on the other hand not be used to justify overexploitation of the stocks.

The current state of the stock is caused by good recruitment and fishing mortality 0.3-0.35 due to underestimation and catch constraint. 0.4 would be too high if things turned the other way, the stock was overestimated for few years and recruitment was poor.

12 Additional material

Looking at few individual runs can sometime tell a lot about the behaviour of a HCR than summaries.

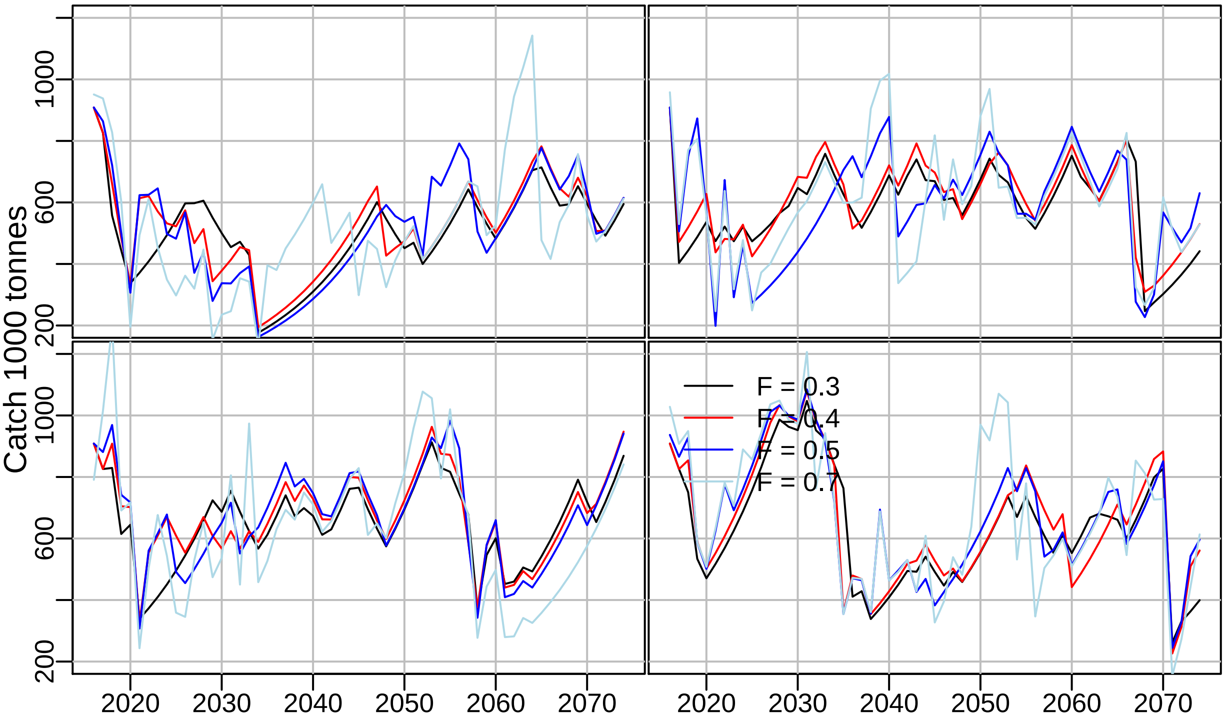


Figure 33: Development of catch from 4 different runs based F_{target}= 0.3,0.4,0.5,0.7)