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Report of the evaluation of the Icelandic haddock management plan

Björnsson, H.

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
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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

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Working document on Haddock for the AD hoc Group on Icelandic Saithe and Haddock HCR Evaluation (ADGISAHA)

Einar Hjörleifsson and Höskuldur Björnsson

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1 Introduction

The model is all written in AD-model builder but is divided in different submodels (figure 1). First the Historical assessment model is run, estimating biological parameters and selection pattern of the fisheries with confidence intervals on parameters, stocksize and fishing mortality calculated from the inverse Hessian matrix. The inverse Hessian matrix is then used as proposal distribution in MCMC simulations where the number of simulations are 2 millions and the parameters from every 1000th run saved to a file. (done with the command icesaithe -nox -mcmc 2000000 -mcscale -mcsave 1000). The saved sets of parameters are then used in 2000 stochastic runs, in each run the assessment model is run, feeding directly into the prognosis, observation model and Harvest Control rule that in the program are just simple functions in the prognosis function. The stochastic simulations are done with the command icesaithe -mceval which reads the file icesaithe.psv storing the 2000 sets of parameter values stored in the mcmc run. The model is written in such a way that it must do prediction for at least 4 years, even in the estimation mode. In the stochastic simulation mode the numbers of years simulated is usually incresed from around 5 to 50-100 but running the estimation with 50 years will increase the computation time as each mcmc evaluation involves 2 million function evaluations. In the estimation phase nondiffential functions are not allowed, and stochasticity in biological parameters is not allowed, at least not in values that affect the "likelihood function". In Admodel builder code the stochastic simulation phase is identified as mc_eval_phase and some functions are only active in this phase (checked in code with if(mc_eval_phase())

1.1 Historical assessment

This part includes both equations describing the evolution of the stock and fisheries and function to do the estimation.

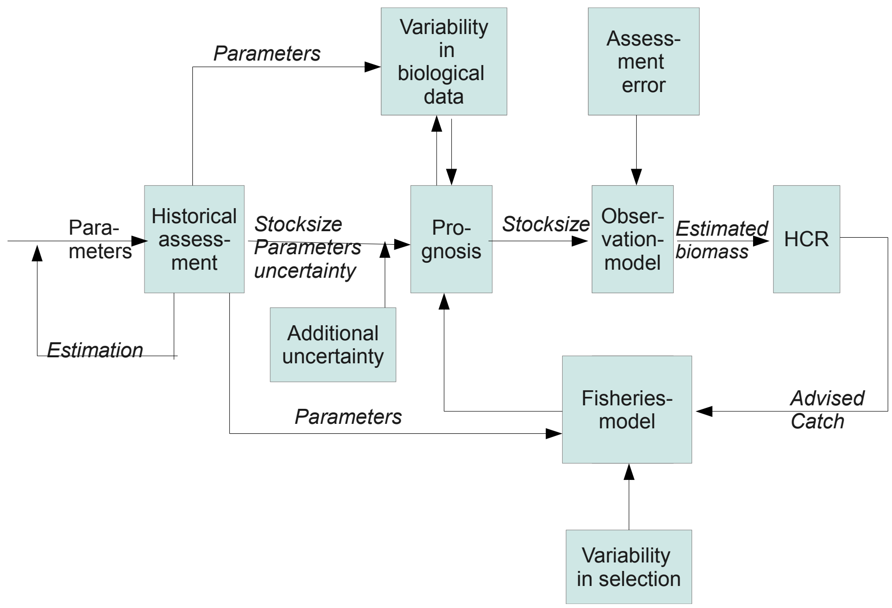

Figure 1: Structure of model.

1.1.1 Evolution of the stock and fisheries.

$$\hat{N}_{1,y} = f\left(SSB_{y-1}\right) \quad (1)$$

$$N_{1,y} = \hat{N}_{1,y} e^{\xi_y} \quad (2)$$

$$N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_{a,y})} \quad (3)$$

$$N_{A,y+1} = N_{a,y} e^{-(F_{a,y}+M_{a,y})} + N_{A,y-1} e^{-(F_{A,y-1}+M_{A,y-1})} \quad (4)$$

where A is the oldest age (plus group) in the bookkeeping system (not modelled for the saithe and haddoc stocks.)

Natural mortality was assumed fixed at the value of 0.2 for both species. The value used for precruits that are caught, age 1-2 for saithe and age 1 for haddock does of course not matter.

Catches removed from the stocks are are estimated from stock number by Baranov's equation.

$$\hat{C}_{a,y} = \frac{F_{a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y} \quad (5)$$

The fishery is simulated as a single fleet modeled as a non-parametric separable model:

$$F_{a,y} = F_y S_a \quad (6)$$

or

$$F_{a,y} = F_y S_{sW_{a,y}} \quad (7)$$

The first approach is used for saithe, while the second approach is used for haddock. Selection pattern is allowed to change as prespecified years during the simulation period.

Stock recruitment functions that were tested are

Hockey stick:

$$R_y = min\left\{R_{max}, R_{max}\frac{SSB_y}{SSB_{break}}\right\} \quad (8)$$

Ricker model:

$$R_y = R_{max}e^1\frac{SSB_y}{SSB_{max}}e^{\frac{-SSB_y}{SSB_{max}}} \quad (9)$$

and Beverton-Holt model:

$$R_y = R_{max}\frac{SSB_y}{0.2SSB_y + SSB_{max}} \quad (10)$$

1.1.2 Likelihood function

Catch at age

The error in the catch at age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_C = \sum_y \sum_a \left\{ \frac{\left(log\left[C_{a,y} + \epsilon_C\right] - log\left[\hat{C}_{a,y} + \epsilon_C\right]\right)^2}{2\sigma_{aC}^2} + log\left(\sigma_{aC}\right) \right\} \tag{11}$$

where ϵ_C is to reduce the effect of very small catches that are poorly sampled. Typical value of $\epsilon_c$would be catches corresponding to 2-4 sampled otholiths. The standard deviations σ_{aC} are estimated as a multiplier on prespecified pattern with age. The pattern was otained as residuals from a seprerable run using one separably period.

Total landings

As described above catch in numbers at age is one component in the objective function to be minimized. This does in many cases guarantee that the modeled catch in tonnes is close to the landed catch but in some years this is not the case. In all cases one has:

$$Y_y = \sum_a C_{a,y} cW_{a,y} \tag{12}$$

$$\hat{Y}_y = \sum_a \hat{C}_{a,y} cW_{a,y} \tag{13}$$

To let the model follow the "real" landed catch the following term is added to the objective function.

$$L_Y = \sum_y \left[\frac{\left(logY_y - log\hat{Y}_y\right)^2}{2\sigma_Y^2} + log\sigma_Y \right] \tag{14}$$

Where σ_Y is input from a file and is typically rather low (0.03 to 0.05). The statistical properties of this term as an addition to catch at age are somewhat questionable, but this formulation has often been used in statiscial catch at age models. The value of 0.05 was used for both saithe and haddock.

Survey at age

The predicted survey index $\hat{I}_{ay}$ is calculated from:

$$\hat{I}_{a,y} = \alpha_a N_{a,y}^{\beta_a} \tag{15}$$

where α_a and β_a are estimated parameters. For the saithe and haddock the β_a is set equal to 1 for all age groups, for haddock the relationship between stock abundance and index is close to linear while for saithe the data for age 4 and younger are too noisy to merit fitting 2 parameter curve to them. .The error in the survey at age is assumed to be lognormal and hence the likelihood is calculated as:

$$L_I = \sum_y \sum_a \left\{ \frac{\left(log\left[I_{a,y} + \epsilon_I\right] - log\left[\hat{I}_{a,y} + \epsilon_I\right] \right)^2}{2\sigma_{aI}^2} + log\left(\sigma_{aI}\right) \right\} \tag{16}$$

where ϵ_I is externally set and is to reduce the effect of very small survey indices that are poorly sampled. Typical value of ϵ_I would be indices that correspond to 2-4 sampled otholiths.

Since correlation between indices of different age groups is modelled the equation is changes to:

$$\mathbf{\Gamma} = log\left[I_{a,y} + \epsilon_I\right] - log\left[\hat{I}_{a,y} + \epsilon_I\right] \tag{17}$$

$$L_I = \sum_y \left\{ 0.5 log\left(det\Theta_I\right) + \mathbf{\Gamma}^T \Theta_I^{-1} \Gamma \right\} \tag{18}$$

In the model runs conducted here the matrix $\mathbf{\Theta_I}$ is generated by a 1st order AR model

$$\Theta_{Iij} = \sigma_{2i}\sigma_{2j}\kappa^{abs(i-j)} \tag{19}$$

whereκ is an estimated parameter which has been estimated in the range 0.3 to 0.7 for cod, haddock and saithe in the March groundfish survey. High value of κ indicates that the residuals in the survey approach a year factor. The standard deviations σ_{aI} are estimated by the model by giving the pattern, estimating an multiplier. The pattern is estimated in an Adapt type model (smoothed).

For haddock two surveys in March and October are used for tuning and all the parameters estimated independly for each survey. For saithe only the survey in March is used see equation20

Stock - recruitment likelihood function.

This component involves discrepancy between observed and modelled recruitment. The model allows for autocorrelation in residuals and CV of residuals can be a function of spawning stock size. The likelihood is calculated by the equations.

$$\hat{N}_{1,y} = f\left(SSB_{y-1}\right) \tag{20}$$

$$\mathbf{\Gamma_{SSB-R}} = log\left[N_{1,y}\right] - log\left[\hat{N}_{1,y}\right] \tag{21}$$

$$\sigma_{3y} = \sigma_3 \left(\frac{SSB_y}{SSB_{lim}} \right)^{\beta_3} \tag{22}$$

$$\Theta_{SSB-Rij} = \sigma_{3i}\sigma_{3j}\kappa_3^{abs(i-j)} \tag{23}$$

$$L_{SSB-R} = \sum_y \left\{ 0.5log\left(det\Theta_{SSB-R}\right) + \mathbf{\Gamma^T_{SSB-R}}\Theta^{-1}_{SSB-R}\Gamma_{SSB-R} \right\} \tag{24}$$

The parameters σ_3,$\kappa_3$and $\beta_3$are all among estimated parameters but estimating them all in addition to the 2 parameters of the SSB-rec function caused some difficulty so $\kappa_3$and $\beta_3$were set to zero in the estimation part but a fixed value of the autocorrelation parameter, estimated external to the model used in the stochastic simulations.

The choice of stock recruitment function has minor effets on the results of stock assessment but is very important in future simulations. Estimation of more two one parameter (usually $R_{max}$and is $\sigma_3$are estimated) leads to very little improvement of the likelihood function. Still both R_{max} and $SSB_{break}$are estimated in many run to get a set of those parameters to use in the stochastic simulations.

Estimated parameters

Estimated parameters in the assessment model are

- Initial numbers in stock.
- Recruitment at age 1 each year
- Parameters of the stock - recruitment function.
- Selection pattern of the fisheries.
- Fishing effort each year.
- $q_a$for the surveys
- σ_c, σ_I and $\sigma_{SSB-Rec}$
- Correlation parameter κ_{SSB-R}in the survey likelihook.

As described in the beginning the inverse Hessian matrix of the parameter estimates is used as a proposal distribution in MCMC runs. The number of runs was usually 2 million with the parameter set from every 1000th run saved. Probability distribution of spawning stock, reference biomass and other parameters is obtained by printing the respective values to a file in each of the stochatic simulations.

The exact settings of the historical assessment model do affect the estimate of stock in the assessment year (±20%) but have less effect on the results of the longterm simulation where the stock-recruitment parameters have most effect buto they have minor effect on the estimate of the stock in the assessment year. If the simulation were run in a closed loop with assessment model in the feedback loop those settings would have more effect, but to use it to infer about “correct” model settings would require a realistic observation model.

Scaling of stock in the assessment year.

Stochastic simulation give the probability distribution of the reference biomass, spawning stock and other values in the beginning of the assessment year. The standard deviation of these probability distributions is often too low compared to the assessment error obtained by other means. To make the assessment error comparable the stock numbers in the beginning of the assessment year are multiplied by a stochastic value.

$$N_{assyr,a} = N_{assyr,a} e^{cv_y \epsilon} \quad (25)$$

Where $\varepsilon = N(0,1)$. The value of $cv_y$is selected so the probability distribution of reference biomass has similar standard error as obtained from the analysis leading to specification of the assessment error. All variability in stock size in the beginning of the assessment year is anyway caused by assessment error. The estimated stock size from the most recent assessment is one of the inputs to the prediction and the first value of the assessment error is set as the log-ratio of that value and the reference biomass in the stochastic run. If the stock is small the assessment is an overestimate, leading possibly to still further depletion of the stock. The sequence of values $\xi_y$in equation 34 which starts in the assessmentyear is obtained by the equation.

$$\xi_{assyear} = log(\frac{B_{R.assessment}}{B_{R.simulation}}) \frac{}{\sigma_A} \quad (26)$$

Where $B_{R.assessment}$is the reference biomass from the assessment and $B_{R.simulation}$reference biomass from the simulation, different value in each stochastic simulation.

1.2 Prediction

The prediction occurs in few steps.

1. Calculate mean weight and maturity at age.
2. Calculate selection at age.
3. Calculate the assessment error.
4. Calculate recruitment residuals.
5. Estimate reference biomass/fishing mortality. Multiply it with assessment error.

6. Calculate TAC.
7. Calculate fishing mortality based on the TAC, number at age, selection at age, and mean weight at age in the catches. See description of fisheries model.
8. Calculate spawning stock.
9. Calculate recruitment.
10. Project the stock forward one year.

Some harvest control rules are based on “future stock size”, in those cases steps 5-10 need to be performed iteratively.

Mean weight at age, maturity at age, recruitment , selection at age and maturity at age can be multiplied with stochastic noise, generated as a first order AR model. For Icelandic saithe and haddock stochastic variability in maturity was not included as discussed seperately for each species.

Weight at age

The weights in the operating model for saithe are stochastically derived from mean weight at age using a yearfactor applied to all agegroups in the same year:

$$sW_{a,y} = s\hat{W}_{a,y} e^{\sigma_W \xi_{w,y}} \tag{27}$$

where is σ_w the size of the variability in weights and the term ξ_w is autocorrelated noise generated by a 1^{st}order AR model. $s\hat{W}_{a,y}$

$$\xi_{w,y} = \left(\rho_w \xi_{w,y-1} + \sqrt{1-\rho_w^2} \varepsilon_y \right) \tag{28}$$

$$\varepsilon_y = N\left(0,1\right)$$

The same equation is used for for stochasticity in catch weights and spawning stock biomass weights and the same error term is used.

The method to derive mean weight at age for haddock is based on a growth model and described in section 2.3.

Stochasticity in maturity and selection will have to based on logit transformed values as the result is limited between 0 and 1. Selection of haddock is described by a parametric function and stochasticity is put on one of the parameters.

Recruitment

The spawning stock biomass is calculated as:

$$SSB_y = \sum_a N_{a,y} ssbW_{a,y} p_{a,y} e^{(pM_a M_a + pF_a F_a)} \tag{29}$$

where $p_{a,y}$is the proportion mature by age and year , $ssbW_{a,y}$is the weight at age of mature fish, pM_aproportion of natural mortality before spawning and pF_aproportion of fishing mortality before spawning

The recruitment is generated from the spawning stock by

$$N_{1,y+1} = f(SSB_y)e^{\sigma_R \xi_{R,y}} \tag{30}$$

Where $f(SSB_y)$is one of the functions in equations 8 to 10. The parameters of the stock - recrutment functions as well as the variability σ_R are estimated in the Historical assessment model and uncertainty in the estimates reflected in the values used in stochastic predictions. The option to let $\sigma_R$depend on size of spawning stock was not used for saithe and haddock as the data did not allow estimation of that dependency. The recruitment error $\xi_{R,y}$is generated by a first order AR model.

$$\xi_{R,y} = \left(\rho_R \xi_{R,y-1} + \sqrt{1-\rho_R^2}\varepsilon_y \right) \tag{31}$$

$$\varepsilon_y = N(0,1) \tag{32}$$

The parameter ρ_R can in principle be estimated in the assessment phase and the uncertainty in the parameter transferred to the estimation phase. For saithe and haddock the data were not sufficient to estimate $\rho_R$in addition to the other three parameters of the stock-recruitment function so ρ_R was estimated from the output of the model and that value specified in the forward simulations.

1.3 Observation model

HCR based on biomass

The observation model in these simulations is rather simple, i.e only compilation of a refence biomass to base the TAC on and compilation of spawning stock that is used as trigger. Those values are then multiplied by an assessment error that has to be specified. The assessment error is one of the most important factors affecting the risk to the stock in the simulations. For the purpose of this work decribing assessment error by 1st order AR model is adequate.

$$\widetilde{B}_R = B_R e^{CV_A \xi_y} \tag{33}$$

where CV_b is the CV of the assessment error and the error term ${}_bE_y$is generated by the first order AR model.

$$\xi_y = \left(\rho_A \xi_{y-1} + \sqrt{1-\rho_A^2}\varepsilon \right) \tag{34}$$

where $\varepsilon = N(0,1)$. The spawning biomass in the observation model is equivalently calculated as:

$$S\tilde{S}B_y = SSB_y e^{CV_A \xi_y} \tag{35}$$

Three parameters are required for the AR model, bias, 1st order autocorrelation and standard deviation. If a bias is suspected it is treated seperately by increasing the harvest ratio. Even relatively small bias or 5-10% can have considerable effect on the preformance of the HCR. Large autocorrelation can also lead to increased risk of spawing stock going below B_{lim} except harvest ratio is very low. What is large autocorrelation depends on the longevity of the species, for longlived species with low mortality number of years with poor recruitment will not cause major problem.

Four methods are available to estimate assessment error, standard error from assessment model, analytical retros, real time retros and simulation with biological model, observation model and assessment model. The first method does not give autocorrelation nor bias.

For most stocks assessed by ICES real time retros are available for the time period where they have been assessed there. Getting comparable data for a long time is though difficult, methods to estimate maturity at age or weight at age might have changed, surveys have been started and become more informative as they have been conducted more years. But to summarize, most data series are painfully short to estimate characteristics of autocorrelated time series.

For the purpose of getting the assessment error analytical retros should preferably be run for 15-20 years for species reaching 10-15 years age. To do this requires at least 30 years of tuning data. If a F - rule or rule based on some future biomass is suggested analytical retros should be supplemented by prediction 1-2 years ahead.

The last method, combining biological model, observation model and assessment model is the best method to test how assessment error will change with decreased fishing mortality, effects of wrong assumed M etc. It does though not solve all problems, as setting up a good biological and observation model is not a simple task.

The type of HCR does affect the standard deviation of the assessment error and also the bias if there is any bias. Biomass in the beginning of the assessment year is better known than biomass in the beginning of the advisory year, how much better depends on the reliably of recruitment estimates, which agegroups are included in the biomass estimate and information about growth in the assessment year. A Standard deviation of fishing mortality in the advisory year for a given TAC is then still higher, though not comparable as the relationship between fishing mortality and ratio of biomass is not linear except for relatively low values.

Taking as an example the 2012 assessment of Icelandic haddock based on an Adapt type model tuned with the survey in March, the estimated biomass 3+ in 2012 is 106 thous. tonnes and the standard deviation of the estimate 12.5 th. tonnes or 12%. Tac constraint of 44 thous tonnes in 2012 leads to F in 2012 of 0.47 with standard error of 0.08 or 16% and biomass in 2013 of 85 thous. tonnes with standard deviation of 13.5 thous. tonnes or 16%. For spawning stock the standard error as proportion of biomass are little higher or 13 and 17%, for stock with poor recruitment estimates the uncertainty in spawning stock would be lower than in total stock.

In assessment models for Icelandic stocks TAC in the assessment year is usually specified. Higher TAC as proportion of stock size, leads to more increase in the relative uncertainty in stock size in the advisory year. With TAC in the advisory year of 10 thous. tonnes (F=0.045), relative error of biomass of haddock in the advisory and assessment year is estimated similar. This is to be expected as most of the removals from the stock i.e natural mortality are proportional, and important factors like variability in M and prediction of growth are not included in those analysis. Taking the other extreme the estimated standard deviation of biomass in the advisory year is 24% if 80 kt (F=1.05) are removed in 2012.

Estimated standard error in F for a given TAC in the advisory year is considerably higher than in the assessment year. TAC of 60 thous tonnels leads to F=1.07 with standard deviation of 0.34 or 30%. The error as proportion is lower when fishing mortality is lower. When TAC in 2013 is 30 kt estimated F is 0.4 and standard deviation 0.086 or 21%.

In all the error estimates for the biomass in the advisory year and fishing mortality in the advisory year, uncertainty in mean weight at age is not included. How much difference it makes depends on the magnitude of the uncertainty and if there is correlation between uncertainty in estimated numbers at age and uncertainty in mean weight at age. If the correlation is positive the standard deviations are added, when there is no correlation variances are added and with negative correlation the effects cancel partly out.

To see the effect of error in prediction of mean weight age age in the advisory year the CV of this error term for Icelandic haddock is around 10%. CV of the estimated standard error in biomass in the advisory year is estimated around 16% . Assuming no correlation the total CV is $\sqrt{0.16^2 + 0.1^2} = 0.19$ or relatively small increase for substantial uncertainty in mean weight at age.

The fishing mortality estimates shown here are based on an Adapt type model. For stocks like Icelandic haddock with large contrast in yearclass size, estimate of unweighted fishing mortaltity tends to be noisy. Two possible improvements are to do the assessment with model where selection is parametric or using weighted F. Weighted F are not really much different from proportion of biomass based on the same selection pattern.

Uncertainty increases much faster when making predictions with specified TAC than specified harvest ratio or fishing mortality, especially if large part of the stock is removed each year. For the Icelandic haddock example CV of the spawning stock in 2015 is 16% running with fixed fishing mortality (no error) but 34% running with fixed TAC, both cases with relatively low fishing mortality. Here a number of important sources of uncertainty are ignored but 2015 is selected as all the agegroups contributing to the spawning stock in 2015 had been observed in 2012.

The results shown above for Icelandic haddock are not supposed to give us the “real” uncertainty but rather to compare uncertainty in different values in relative sense. The most important results are.

- CV of biomass in the advisory year decreases with decreased catch in the assessment year. Factors not taken into account like stochasticity in natural mortality and growth have more effect.

- CV of fishing mortality in the adviory year for a given TAC is very high when fishing mortality is high but similar to CV in proportion of biomass when fishing mortality is low.

There are few important factors that need to be considered when evaluating a HCR or at least when doing an assessment following adoption of a HCR that leads to considerable reduction in fishing mortality.

- Historical assessment becomes worse as assumptions about M have more effect.
- Short term prediction improves, as larger part of the removals are proportional and dependence on recruitment estimates is less.
- Autocorrelation of assessment error increases with reduced fishing mortality.
- Assessment error increases if fishing mortality decreases relatively sharply and the stock increases beyond what has been observed recently. Assessment becomes an extrapolation.

The evaluation of assessment error will be done seperately in the sections for each stock based on available retrospective data.

1.4 Harvest control rule.

Harvest Control Rule is here a set of equation converting estimated of reference biomass, spawning stock and earlier advice into adviced catches for the text fishing year starting September 1 in the assessment year, ending August 31st in the year following the assessment year (referred to as advisory year in this text).

Characteristics of a stock that affect choice of HCR tested are.

1. Variability in yearclass size.
2. Variability in stock size
3. Quality of assessment of the adult part of the stock.
4. Quality of recruitment estimates
5. Noise in survey data
6. Availability of maturity data.
7. Coocurrence of recruits and adult part of the stock in the fisheries.
8. Mixed fisheries issues.

How these characteristics affect the type Of HCR is.

- With large variability in yearclass size care must be taken to increase TAC when large yearclass is entering the fishery, except the fisheries are really targeting this yearclass as much as older yearclasses.
- Large/rapid variations in stock size make catch stabilizers questionable.
- Large "high frequency" assessment error makes use of catch stabilizers suitable as too much unnessecary interannual variability in advice undermines the HCR.
- Poor recruitment estimates favour rules based on the part of the biomass that recruitment estimates do not affect too much.
- With good recruitment estimates, rule looking few years ahead is a possibility.
- For stock with large variations in mean weight at age the reference biomass or reference fishing mortality should in many cases be based on size rather than age. This applies specially to stocks where selection is more size than age based.
- With good survey data weights at age in the survey are more appropriate values than for calculations of reference biomass than values from landings. One problem with values from landings is that they overestimate the contributions of the youngest age groups where the fisheries only target the largest individuals.
- Same applies to maturity at age data that survey data are more appropriate values than catch values if survey is conducted in a season where maturity stage is easily identified. Here the problem of getting representative values for the stock is even larger than with weights at age as fisheries are often targeting the mature part of the stock in the season when maturity at age is easiest to detect. Getting ungutted fish from landings, required for registration of maturity stage is also a problem in many fisheries. How maturity is defined can affect trends in spawning stock but maturity from catches tend to be overestimate the contribution from young fish and therefore overestimate spawning potential when mortality has been high.

The types of harvest control rules that were tested are

1. Proportion of biomass above certain age.
2. Proportion of biomass above certain length.
3. Specified fishing mortality in the advisory year.

Biomass was either in the beginning of the assessment year or the advisory year.

All type of Harvest control rules are tested with and without a trigger. A final approved HCR must have trigger action but during testing behaviour of the HCR was investigated without a trigger. Two types of possible trigger action were tested, the first one the traditional one where the harvest ratio is reduced by the fraction $\frac{SSB}{SSB_{trigger}}$ where SSB refers either to spawning stock either in the advisory year, or the assessment year. This type of trigger is referred to as as $Trigger_1$ in what follows.

The second type of trigger rule is based on the fact that yearclass size of haddock is reasonably well known at age 1 so the spawning stock can be predicted 4 years ahead and action taken if poor recruitment has been seen. The rule is set up in the following way. Predict spawning stock 4 years ahead and if the spawning stock is predicted to be below B_{lim} with more than 5% probability the Harvest ratio is reduced as required but not more than to 2/3 of the base harvest ratio. If the SSB is below $SSB_{trigger}$ the base harvest ratio is multiplied by the ratio $\frac{SSB}{B_{trigger}}$ and the minimum harvest ratio is still 2/3 of the base harvest ratio. This type of trigger is referred to as $Trigger_2$ in what follows.

Catch stabilisers tested were to let current fishing years advice have 50% weight in the advice for the next fishing year.

1.5 Fisheries model.

The fisheries model transfers the advice, that is the output from the HCR into removals from the stock. This model could include black landings and dicards but in the simulations done here the fisheries model is nothing more than converting catch to removals by age using equations 5to7 and 13, in reverse mode as the total yield, stock in numbers, selection pattern and stock weights are known but fishing mortlity unknown. The solution is small minimization routine in the model using Newtons method and numerical differentiation, only one parameter is estimated.

Stochasticity in selection is modelled for haddock but not saithe. Sensitivity to different selection patterns is tested for saithe.

Bias in the fisheries model is treated in the same way as in the assessment model, by transferring it to the Harvest Control Rule, i.e increase harvest ratio.

1.6 Risk criterion

At the time of this writing it is not clear what minimum risk criterion ICES will use with respect to evaluting HCRs relative to the precautionary approach. Currently three criterions have in practice been used:

- A: Risk of going below some biomass criterion during a single specified future year.
- B: Maximum risk in any one year of going below some biomass criterion over a specified future periods of years.

- C: Risk of going below some biomass criterion at least once over a specified future period of years.

Because of the current uncertainty with regards to what ICES will set as the minimum criterion some variants are presented in the results. Insight into the author's view on the matter can be found in a WD that was presented to an ad-hoc ACOM group last year (included in Appendix A in this report).

2 Haddock

2.1 Model conditioning

- M = 0.2 for all age groups.
- Ages 1-14, age 14 not plus group. Age 12-14 haddock rare. Age1 just age 2 multiplied by 0.2 as no age 1 haddock are caught.
- Catch at age 2-14 year old , 1980-2011
- Surveydata from March 1985-2012 1-10 years old and October 1996-2012 (ages 1-9). Linear relationship for all agegroups.
- Selection pattern of the commercial fleet function of mean weight at age described by 2 parameters (equation 41).
- Stock-recruitment function Hockeystick. ξ_R1st order AR model with σ_R estimated in the model but$\rho_R = 0.25$ estimated outside the model
- Mean weight at age in spawning stock and reference biomass obtained from the survey in March. Available when the assessment is conducted
- Maturity at age from survey in March. Available when the assessment is conducted.
- Proportion of F and M before spawning (equation 29) set to 0. This selection is a tradition and B_{lim} is based on it. Haddock spawns in April-May so 0.4 would be appropriate values. Changing this would mostly scale down the spawning stock. If B_{lim} was scaled down acoordingly risk of going below B_{lim} would decrease as the proposed HCR calls for lowering of fishing mortality.
- Base values for mean weight in stock are from an equation where growth is related to stock size. Starting weight at age 2 is negatively correlated to yearclass size.
- Catch weight and maturity at age functions of mean weight at age in stock based on data from 1985-2011 and 1991-2012.
- Stochastic error in mean weight at age. $\sigma_w = 0.12$ $\rho_w = 0.2$, see equations 27and 28. Values estimated from residuals of a growth equation.

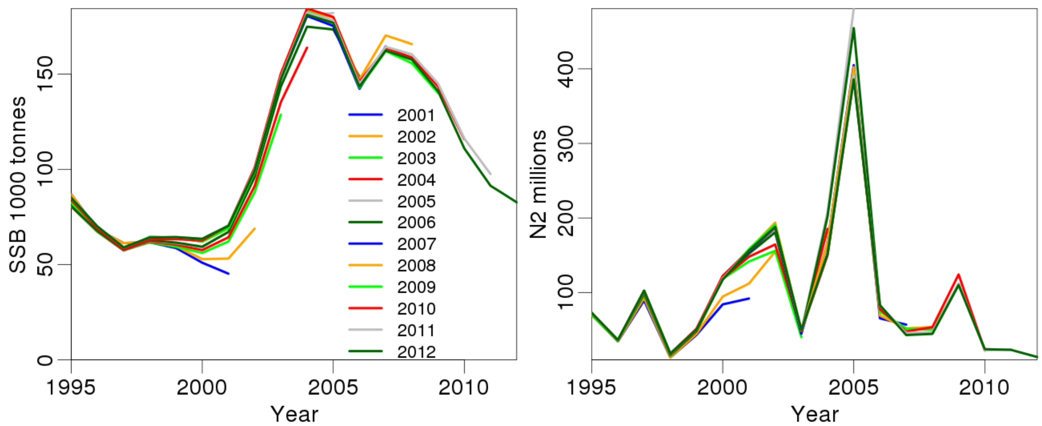

Figure 2: Icelandic haddock. Realtime retrospective pattern from assessments conducted 2001 - 2012.

- Prognosis run on the estimated selection with and error term added on weight at 50% selection.
- Harvest control rule tested, based on estimated biomass larger than 45cm in the beginning of the advisory year, 4 months into the fishery year that advice is given for.
- Assessment error lognormal with σ_A=0.22 and ρ_A=0.5 (equations 33and 34)

2.2 Assessment error

Icelandic haddock was taken as an example in deriving assessment error from catch at age models in section 1.3. The conclusion there was that σ_A=0.13 in the estimate of biomass in the assessment year , 0.16 (0.19 including weight prediction) in the estimate of biomass in the advisory year and 0.3 of fishing mortality in the advisory year for a given Tac.

The estimate obtained from the assessment model does not give any indication about autocorrelation. Some information might though be in the historical trajectories from the stochastic simulations, they are all based on the same tuningdata, so deviations are uncertainty. This is though not exactly the same uncertainty that we talk about in the context of assessment, it is much less and partly related to the level of the stock and would therefore affect reference points.

Realtime retrospecive pattern is easily available since 2000 when the stock has been assessed by ICES. They are reasonably consistent except for underestimation in 2001 caused by extremely low values from the survey in March, the only tuning data in that period. (figure 2.2).

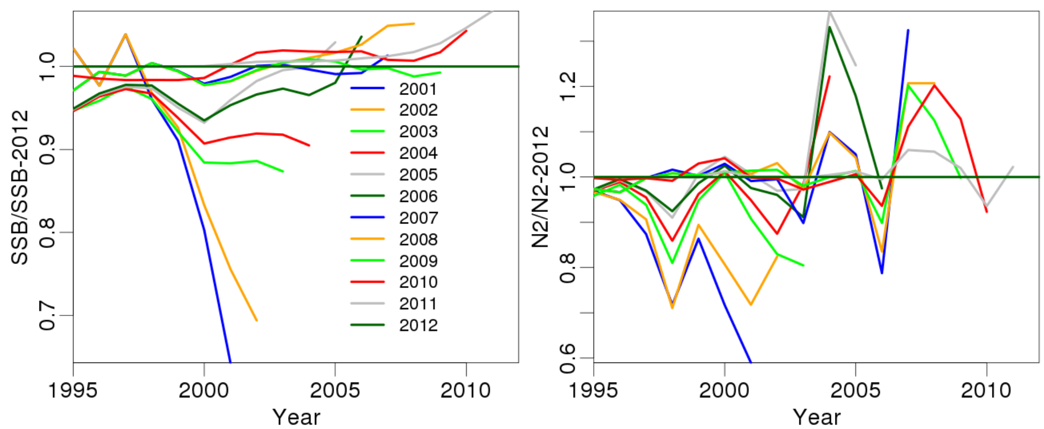

Figure 3: Real Icelandic haddock. Realtime retrospective pattern from assessments conducted 2001 - 2012. Size of spawning stock and number of recruits shown as proportion of the most recent estimates.

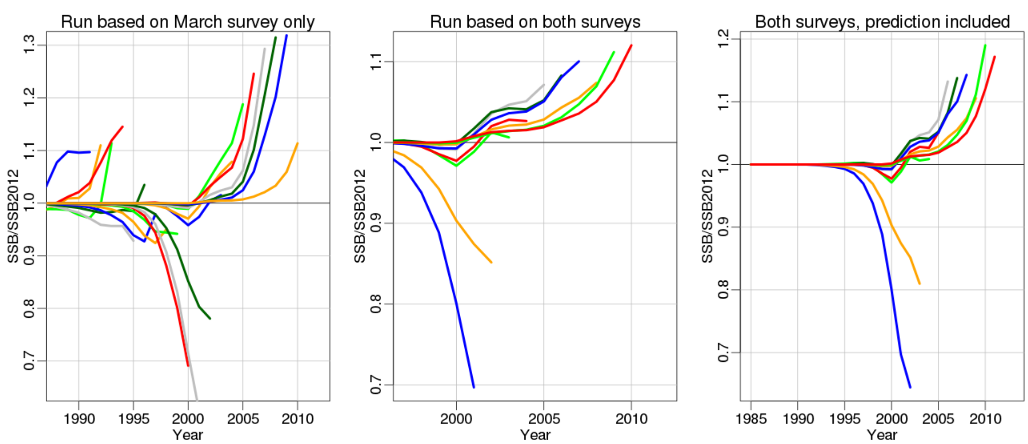

Figure 4: Analytical retrospective pattern from the Adapt type model used in assessment since 2007, The last figure shows prediction into the assessment year.

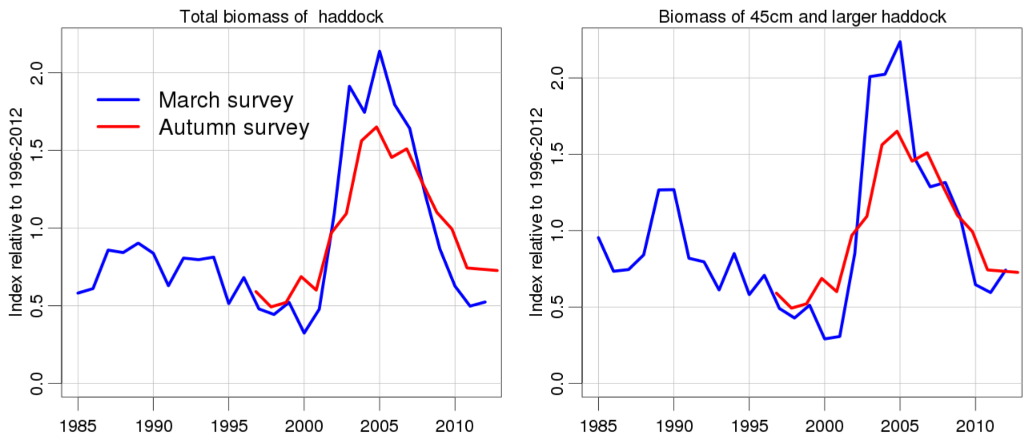

Figure 5: Total biomass and biomass of 45cm and larger haddock in the groundfish surveys in March and October.

The retrospective pattern shown in figures 2 and 3 is based on more than one type of model, and data. Until 2006 the models were only tuned with the survey in March but after that by both the surveys. In 2001 XSA with little shrinkage was used, TSA in 2002 , Statistical catch at age model with random walk constraint on fishing mortality 2003-2006 and Adapt type model 2007-2012. The choice of models was each year was taking ideas about state of the stock into account. In 2001 there were indications that the adult part of the stock was in really bad shape (figure 2.2) so a model following the data well was used. In 2002-2004 the stock size was increasing and was apparenly going well outside historical limits . Therefore models with inertia, i.e random walk on changes in fishing mortality were selected. Older data indicated that the stock had been very large in the early 1960's when the landings exceeded 100 thous. tonnes for 6 years, the stock needed to be quite large to sustain those landings. After 2007 VPA models were again used but then the autumn survey was also used in the tuning. The contrast in biomass in the autumn survey is less than in the March survey (figure 2.2). In the period 2005-2009 the 2003 yearclass that was more than twice as large as any yearclass since around 1957-1958 made the assessment again much of an extrapolation.

The story above is to explain why real time retrospective pattern shows less overestimation in from 2002-2006 than the analytical retrospective pattern with the model used since 2007 (figure 4). The choice of models each year was done taking into account state of the stock and results from other models. Also the assessment from 2003-2008 included extrapolation, increasing uncertainty. Changes in spatial distribution seen in that period are also likely to have increased the uncertainty.

Relative uncertainty in mean weight at age is estimated to be around 0.1 (section 2.3) , adding relatively little to the total uncertainty if the uncertainty in

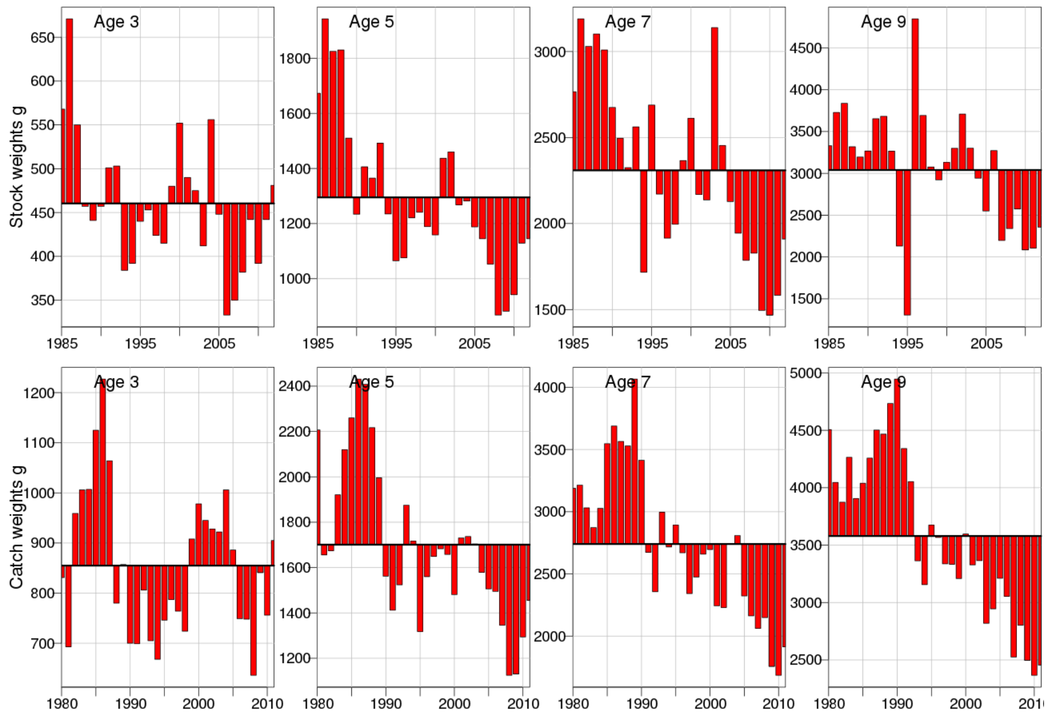

Figure 6: Mean weight at age in the stock and in the catches.

numbers and mean weight at age is assumed to be independent, $\sqrt{0.16^2 + 0.1^2} = 0.19$

The values used for $\sigma_A$in future simulations is 0.22 for stock biomass in the advisory year, 0.16 for stock biomass in the assessment year and 0.3 for fishing mortality in the the advisory year. The value used for autocorrelation $\rho_A$is 0.5. Higher and lower values can be justified based on the analysis presented (table 2.2)and sensitivity to substantially worse assessment error will be tested. No bias is assumed except the bias inherent in the lognormal distribution i.e $e^{\frac{\sigma^2}{2}}$. No upper limit is used on the assessment error but maximum annual harvest is set at 80% of total biomass, i.e close to depletion of the stock. Selection of maximum assessment error does though only affect quantiles lower than one percent.

2.3 Mean weight, maturity and selection at age.

Spawning stock and reference biomass of Icelandic haddock are based on weight and maturity at age from the groundfish survey in March, available at the time of the assessment. The assessment is used as basis for the next fishing year so predicting growth is unvoidable to estimate TAC for a given fishing mortality or

	$mean(log\frac{SSB_{y,y}}{SSB_{y,2012}})$	$\sigma(log\frac{SSB_{y,y}}{SSB_{y,2012}})$	$acf_1(log\frac{SSB_{y,y}}{SSB_{y,2012}})$
Real time retro. Estimates of SSB in assessment year 2001-2009 vs estimates 2012	-0.1	0.18	0.6
Analytical retro, Adapt tuned with both the surveys. Estimates of SSB in assessment year 2001-2009 vs estimates 2012	-0.007	0.155	0.45
Analytical retro, Adapt tuned with the March survey. Estimates of SSB in assessment year 2001-2009 vs estimates 2012	0.06	0.27	0.55
Analytical retro, Adapt tuned with the March survey . Estimates of SSB in assessment year 1990-2009 vs estimates 2012	0.02	0.2	0.75
Analytical retro, Adapt tuned with both the surveys. Estimates of SSB in advisory year 2001-2009 vs estimates 2012	0.007	0.2	0.48
Confidence intervals from MCMC simulations estimate of SSB in assessment year.		0.12	0.3-0.4*
Confidence intervals from MCMC simulations estimate of SSB in advisory year.		0.15	
Confidence of SSB in assessment year based on the Adapt type model used for assessment tuned wia.		0.13**	
Confidence of SSB in advisory year based on the Adapt type model used for assessment..		0.16**	

*Taken from 2009-2012 values from stochastic simulations. Result range from -0.7 to 0.5 with values around 0.4 most common.
** See section sub:Observation

Table 1: Results of different methods for getting assessment error.

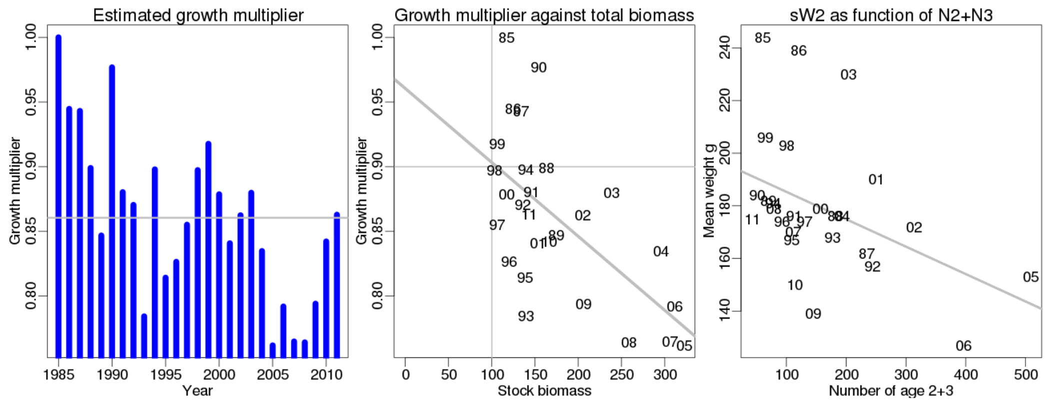

Figure 7: Estimated yearfactor from equation 36, yearfactor plotted against total biomass and mean weight of age 2 as function of number of age 2 + age 3.

given harvest ratio in the assessment year. With rules where TAC is proportion of biomass in the assessment year prediction of growth is in principle not needed, variability in growth would be needed in the testing phase of the rule.

Mean weight at age for Icelandic haddock has shown a decreasing trend for the last 30 years (figure 6) with the weights lowest when stock was largest in 2007-2009. Large yearclasses start as lighter at age 2, and growth could be negatively correlated to stocksize, at least the growth was slowest in 2006 - 2009 when the stock was large. The lowest mean weight at age is seen for the largest yearclass (2003) but the weights seem to be increasing again with the small most recent yearclasses and growth is improving. The change in weight at age since 1979 does look like trend. Some data are available from the period 1960-1965 when the stock was large, showing that mean weight at age was low in this period, though not as low as recently. Getting "comparable" catch at age and mean weight at age back to 1955-1960 would be very useful but is not easily done. But, the main assumption is really how much of the decrease in growth is permanent.

Growth was modelled by equation used for short term prediction since 2006

$$\log \frac{sW_{a+1,y+1}}{sW_{a,t}} = \alpha + \beta \log sW_{a,y} + \delta_{year} + \xi_{sW} \tag{36}$$

In short term prediction the parameter $\delta_{year}$is not available for the assessment year so the value from the year before the assessment year is used. In the simulations here $\delta_{year}$is linked to stock size and the equation used becomes

$$\log(\frac{sW_{a+1,y+1}}{sW_{a,y}}) = 2.645 - 0.30468 \log(sW_{a,y}) + log(min(0.960452795 - 0.0571546 B_{tot,y}, maxmult)) + \xi_{sW} \tag{37}$$

Where sW refers to stock weigths and $B_{tot,y}$total biomass in year y in million tonnes (always less than 0.5). One of the inputs to the model is the value $maxmult$ determining maximum growth, i.e to which extent mean weight at age can recover to earlier levels. In the default runs $maxmult$ is set to 0.9 the estimate when the stock is at its lowest level (figure 2.3). ξ_{sW} is 1st order AR with$\sigma_W = 0.12$ and $\rho_W = 0.4$. The dependence of growth on biomass is mostly based on the period 2005-2009 when growth was slow and the stock large. At the same time the stock of sandeel collapsed, that might have contributed to slow growth without haddock being to blame for the collapse of sandeel.

Starting weight at age 2 is given by

$$sW_{2,y} = 198 - 0.115(N_{2,y} + N_{3y})e^{\xi_{sW2}} \tag{38}$$

Where $N_{2,y}$ and $N_{3,y}$ are the number at age 2 and age 3 in millions. The inclusion of $N_{3,y}$is to account for the observation that mean weight at age 2 is usually low for a yearclass following a large yearclass. $\xi_{sW2}$is 1st order AR with $\sigma = 0.12$ and $\rho = 0.2$,uncorrelated with ξ_{sw}.

Catch weights are derived from stock weigths by an equation used in short terms prognosis. The equation is based on data in the period 2000-2011 (figure 2.3)

$$cW_{a,y} 8.65813 sW_{a,y}^{0.7388} e^{\xi_{cW}} \tag{39}$$

$\xi_{cW}$is 1st order AR with $\sigma_{cW} = 0.12$ and $\rho = 0.3$ uncorrelated with ξ_{sW}.

Relationship between catch weights and stock weights has some effects in the model as increased catch weights lead to fewer fishes being removed. Usually the factor explaining this relationship is selection, that is size rather than age based. In a proper length based model relationship between stock and catch weights does not have a large effects, removal of smaller fishes from a cohort will lead to the survivors being larger and vise versa.

Maturity at age is predicted from data 2000-2012

$$P_{a,y} = \frac{1}{1 + e^{17.314 - 2.644 log(sW)}} \tag{40}$$

No further stochasticity is added to maturity at age.

Selection at age was modelled by

$$S_{a,y} = \frac{1}{1 + e^{-\beta \log \frac{sW_{a,y}}{sW50}}} \tag{41}$$

Where β andsW_{50} are estimated parameters of the logit function. Equation 41 fits the data much better than any candidate equation as function of age. Estimated values are $sW_{50} = 1424$ and$\beta = 2.07$. The selection is plotted in figure 2.3 on the same plots as maturity, indicating that haddock matures earlier than it recruits to the fisheries. Similar observations have been interpreted that the fisheries can not cause any threat to the spawning potential of the stock, questionable interpretation. Stochasticity in the parameter $sW_{50}$is modelled

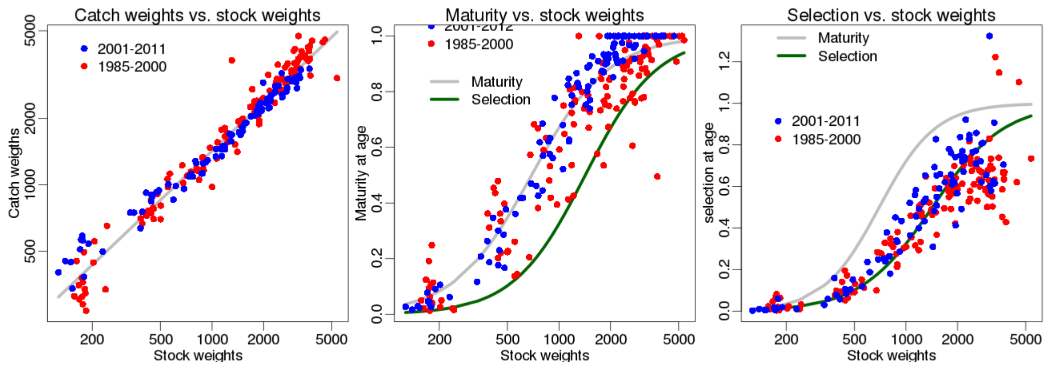

Figure 8: Catch weights, maturity at age and selection at age as function of stock weights. Values used in the model shown as lines in the figures. Data on selection are obtained from an Adapt type model a $\frac{F_{y,a}}{F_{4-7,y}}$, scaled further down to get the maximum in each year close to 1.

as first order lognormal AR with $\sigma = 0.2$ and $\rho = 0.8$. The effects of this stochasticity on size of spawning stock are neglible.

Resulting values from stochstic simulations show large variability in mean weight at age, values occasionally going outside historical limits. (Figure 2.3)

2.4 Recruitment estimates.

Recruitment of haddock is highly variable and dependence of recruitment on spawning stock is not easily observed from the data. A hockey stick relationship was fitted to the data, giving breakpoint close to B_{loss}. In the simulation model the both the breakpoint of the assumed hockey stick function and R_{max} were estimated, and the uncertainty transferred into the stochastic simulations (figure 10) confirming relatively poor information about SSB_{break} in the data. Above B_{loss}, positive correlation between estimate of R_{max} and SSB_{break} is observed so the run with higher SSB_{break}predict more yield from the stock. The value of SSB_{break}in the model is limited to the range 30-100 . The value estimated is $log(SSB_{break}$ so in the Bayesian simulations we start with uniform prior on $log(SSB_{break})$, favouring lower values where the model is uninformative.

Looking at distribution of modelled and observed recruitment they fit reasonably well. Average modelled recruitment is 56 million individuals while the average from yearclasses 1979-2011 is 60 million. The reason for the difference is not clear but bias problems in the relatively high CV lognormal distribution could play a role. The SSB recruitment realtionship is based on 32 points and just the 2003 yearclass contributes 10 millions to the average recruitment.

Residuals from the stock recruitment relationship are modelled as lognormal AR(1) with autocorrelation estimated from the model. Recruitment of Icelandic haddock is highly variable, $\sigma_R \approx 0.84$ but modelling it as lognormal is perhaps all right (figure 12). Estimating the coefficient of first order AR model based on

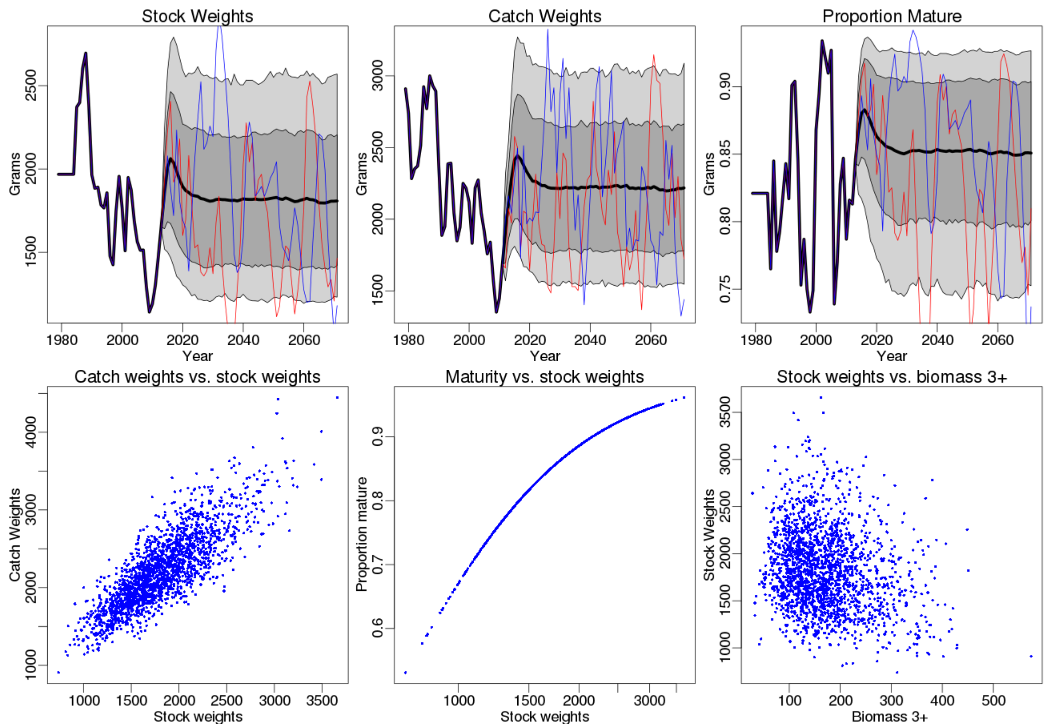

Figure 9: Results from a simulation based on proposed harvest control rule. Result apply to age 6.

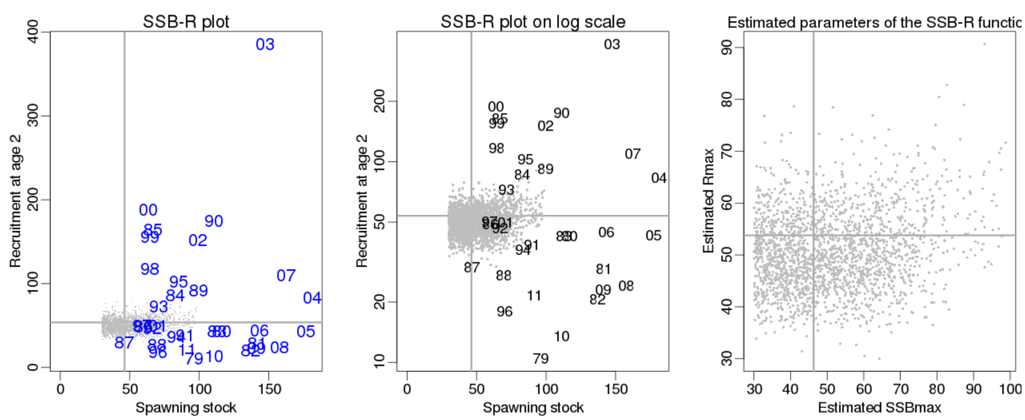

Figure 10: Relationship between spawning stock and recruitment.

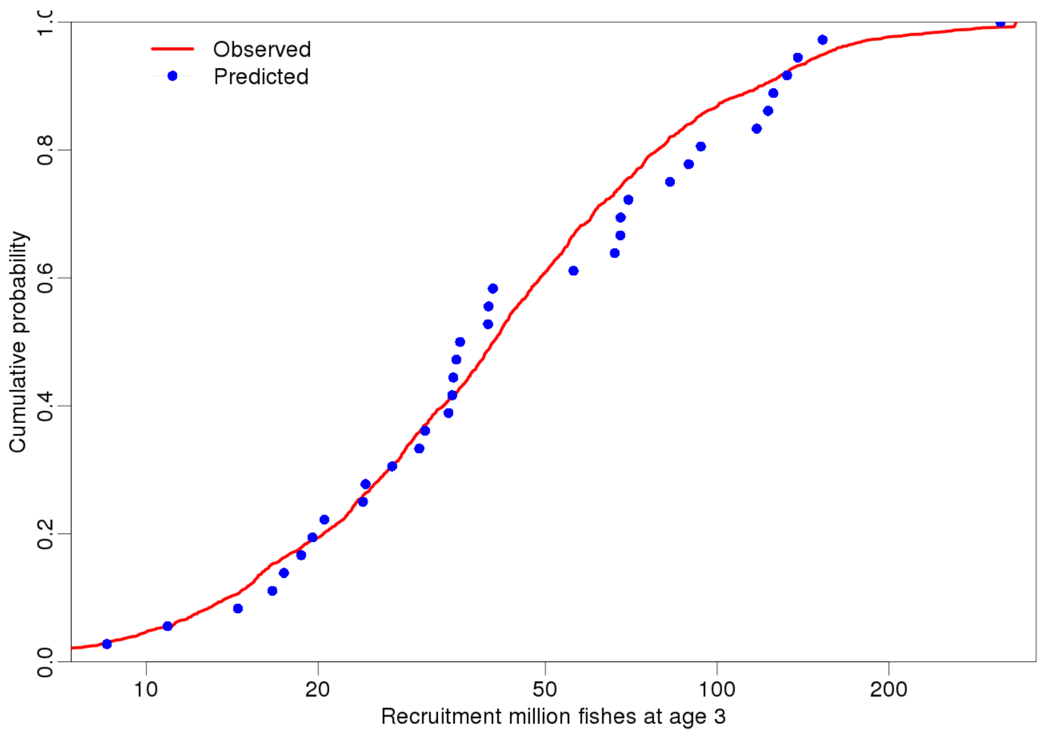

Figure 11: Observed and predicted recruitment at a

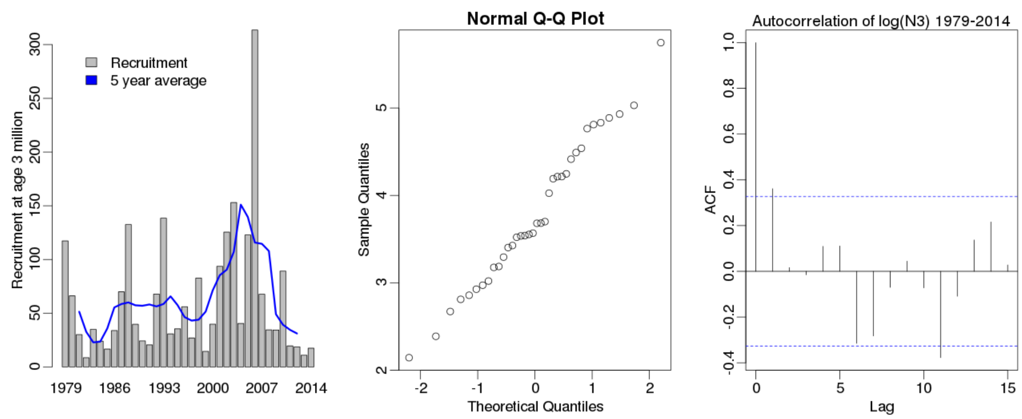

Figure 12: Characteristics of estimated recruitment from yearclasses 1976-2011 at age 3. To the left estimated recruiment at age 3 with 5 years average shown for comparison, in the middle autocorrelation of $log(N_3)$, and to the right estimated autocorrelation function of $log(N_3)$. N_2 is more commonly used in Icelandic haddock but is close to $N_3e^{0.2}$.

yearclasses 1976-2011$(ar(log(recrest)))$ gives an estimated coefficient of 0.35 but plotting the autocorrelation function the first order lag is 0.35 but the 2nd and 3rd order 0. (figure 12). The proposed HCR calls for reduced fishing mortality, leading to each yearclass contributing to the catches and the spawning stock for a number of years. What is most important to look at is the mean and 5/10 percentiles of total recruitment (not log-recruitment) over some time like 5 years. The data series are of course rather short for this kind of inference and the future might show us longer periods of poor recruitment than we have seen in last 30 - 50 years. The harvest control rule should be tested against this kind of recruitment scenarios but it is easy to visualize recruitment pattern that will lead to $SSB < B_{lim}$ even with realtively modest fishing mortality. One way to go, is what seems to be developing as the new ICES standard , to define more than 3 years of poor or good recruitment as "regime shift" and propose different B_{lim} for different "regimes". A better way would be to recognize that $SSB < B_{lim}$ is not a catastropic event, still less that 5% probability of $SSB < B_{lim}$ based on dynamics of recent decades can serve as design criterion for a HCR.

Looking at average recruitment over 5 year period the 10% quantiles from historical data is 28million , 32 million if we skip 2 first and 2 last years to get true 5 years average) For comparison

10 percentiles of average recruitment over 5 years period as function of $\rho_R$is

ρ_R	0.01	0.1	0.2	0.3	0.4	0.5
10 percentiles of average R over 5 years.	30.7	29.2	27.8	26.7	25.2	23.5

Values of $\rho_R$in the range 0.2 - 0.3 seem appropriate but currently the end of a period with 4 poor yearclasses has not been seen. The "base" simulations are still based on$\rho_R = 0.25$ but the HCR is of course also tested with real data from 1979. Minor change in in assumptions about the parameter $\rho_R$do not have large effect on mean catch as long as the harvest ratio is reasonable. The effects on low percentiles of SSB and catch are larger.

2.5 Harvest control rules

Icelandic haddock represents an interesting case for testing variety of Harvest control rules (see section 1.4). Variability in stock size and recruitment is relatively large and estimates of stock size and recruitment are relatively good. This means that catch stabilisers are not desireable in a HCR for Icelandic haddock and rules where spawning stock is predicted 3 years ahead are a possibility. In the assessment year age 1 is reasonably well estimated so all age groups contributing to the spawning stock 3 years later are known and the risk of spawning stock going below B_{lim} can be evaluated. Those lookahead HCR allow for much higher harvest ratio and can lead to some increase in total yield. The cost is more variability in yield as the yield is reduced rapidly when there are indications of reduction in spawning stock. The approach taken here was to look at mean yield, stability in yield (in terms of 5th percentile of yield) and probability of spawning stock going below B_{lim}, finding some compromise where the goals were contradictory.

Growth is highly variable and selection of the fishing fleet much better described as function of size rather than age. Therefore, rules based on biomass above certain size, or biomass based on size based selection pattern are better choice than rules based biomass of specified age groups or basing advice on average fishing mortality of certain age groups. Management measure used for Icelandic haddock that has been used for a number of years, is temporal closures of areas where the proportion of haddock under 45cm (900g) in catches exceeds 20%. Using smaller haddock than that to increase the TAC is not correct while those measures are in place, so a HCR based on biomass of 45cm and larger haddock in the beginning of the advisory year (4 months into the fishing year) is proposed. As haddock around 40cm grows 7cm per year on the average HCR based on biomass of 38cm and larger haddock in the beginning of the assessment year would be similar. Assessment is done by age based model, but a simple relatonship has been fitted to available data describing proportion of the biomass of a yearclass above certain size as a function of stock weights. (figure 2.5). A disadvantage of basing the rule on estimated biomass in the advisory year is that stakeholders might call for increase in quota if the stock was estimated larger than predicted the year before but decrease would not be accepted. Adjusting the quota when next years assessment becomes available might on the other hand improve the HCR (reduce effect assessment error) if done properly i.e in an unbiased way.

What is described here below are results from simulations of HCR is proportion of biomass 45cm and larger in the beginning of the advisory year (figure 14). MSY harvest ratio is around 0.5, PA harvest ratio ($SSB < B_{loss} < 0.05 = 0.46$) and ratio maximizing 10 percentiles of catch 0.36. All these values are sensi-

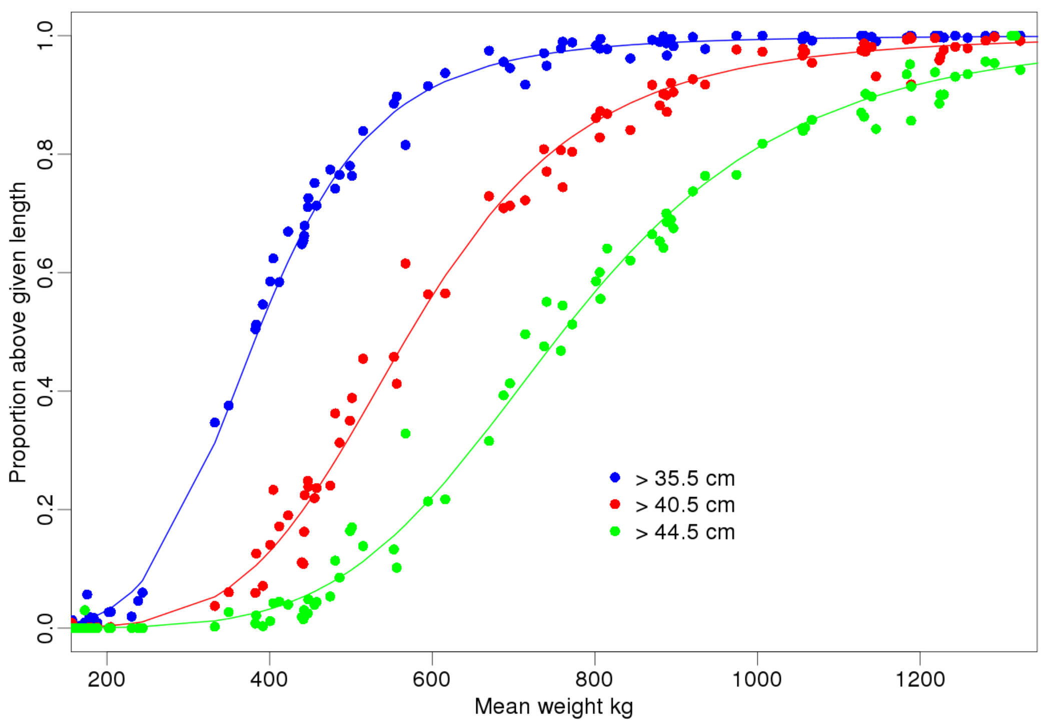

Figure 13: Proportion of a cohort above certain length as function of stock weights and fit from the equation $p_{y,a} = \frac{1}{1+e^{-25.224-5.307log(\frac{sW_{y,a}}{L_R^2})}}$ where the reference length $L_R$is 44.5cm in the proposed management plan (green curve) , based on stock size in the advisory year.

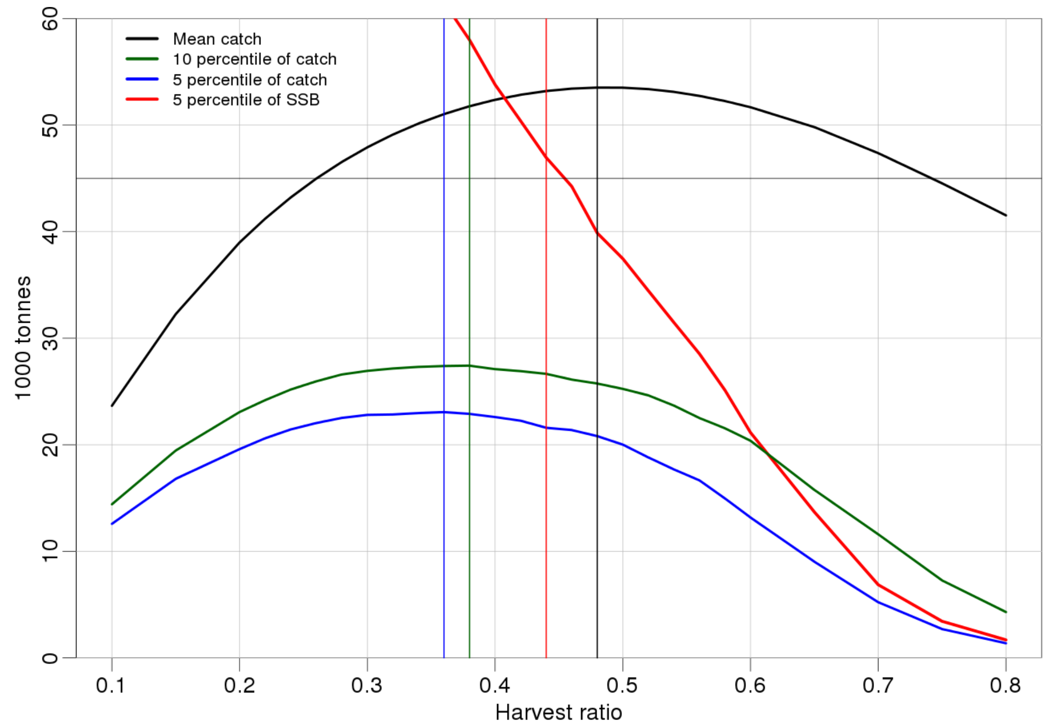

Figure 14: Yield, 5th and 10th percentiles of yield and 5th percentiles of spawning stock as function of Harvest ratio, with no trigger action. . The results apply to the period when the results have "stabilized".

tive to assumptions regardingρ_R and ρ_A, (autocorrelation of recruitment and assessment error) both relatively poorly estimated.

No trigger action is included in the results shown in figure 14. Including trigger will increase the harvest ratio that gives maximum yield as the harvest ratio is decreased when the spawning stock approaches the size where recruitment might be impaired. This is well demonstrated by comparing results of rules with and without a trigger (figure 15). The trigger has the effect of reducing the risk of being below B_{loss}even though the trigger is at B_{loss}as when SSB approaches B_{loss} assessment error causes the estimated SSB more and more often to be below B_{loss} , reducing average harvest ratio.

The choice of relatively low harvest ratio and low trigger can be looked at like stabilizing effect i.e the area where harvest ratio changes with stock size and catch with stock size squared is avoided with relatively high probability. Harvest rate and $B_{trigger}$ are two parameters in a HCR, positively correlated, looking at values giving fixed risk of $SSB < B_{lim}$.

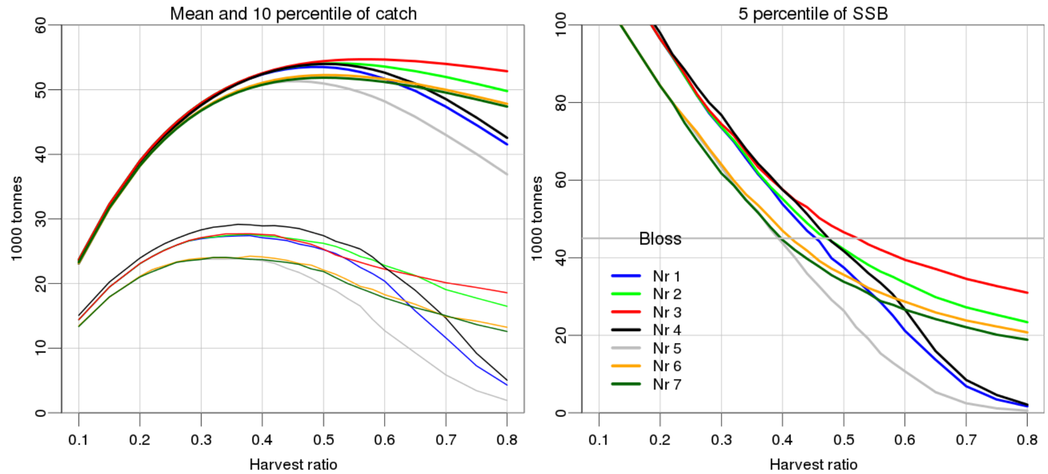

Figure 15: Mean and 10 percentile of catch and 5 percentile of spawning stock for few alternaitve. Nr 1 standard from figure 14, otherwise look at table below for explanations. . Result applies to the period when the results have "stabilized",.

Increased autocorrelation of recruitment residuals has substantial effect. A trigger does though reduce the effect if harvest rate is > 0.4 (figure 15 nr 5 vs. nr 6). Assessment error has less effects. (figure 15) The relatively "difficult" settings of run nr 7 make the proposed harvest ratio of 0.4 marginal with regard to long term PA criteria.

Run number	Trigger	ρ_A	σ_A	ρ_R
1	-	0.5	0.22	0.25
2	45	0.5	0.22	0.25
3	75	0.5	0.22	0.25
4	-	0	0.0	0.25
5	-	0.5	0.22	0.5
6	45	0.5	0.22	0.5
7	45	0.75	0.25	0.5

One of the criteria to look at is the probability of the spawning stock being below B_{lim}. It is less than 5% for the selected harvest ratio (0.4) as seen in the table below showing probability of $SSB < B_{lim} = 45kt$.The HCR might even pass the magic type 3 risk.

Harvest ratio	0.32	0.34	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5
2013	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2014	1.80	1.80	1.90	2.00	2.00	2.00	2.10	2.10	2.30	2.40
2015	2.70	3.20	3.50	4.00	5.00	6.00	6.90	7.50	8.70	9.60
2016	1.70	2.20	2.80	3.50	4.50	6.10	7.40	8.80	10.80	11.90
2017	1.60	2.10	2.50	3.60	5.10	5.90	7.00	8.10	9.20	10.40
2018	1.80	2.30	2.80	3.40	4.00	4.70	5.50	6.50	7.60	8.90
2019	1.60	2.10	2.60	3.10	3.50	4.20	5.20	6.00	6.90	7.80
2020	1.00	1.60	1.80	2.30	3.10	3.80	4.50	5.50	6.20	7.40
2021	0.70	1.20	1.60	2.00	2.80	3.60	4.30	5.10	6.20	7.50
2022	0.80	1.10	1.30	1.50	2.10	2.80	4.00	4.90	5.90	6.80
2023	0.60	1.00	1.20	1.70	2.10	2.90	3.90	4.90	6.10	7.40
2024	0.80	0.80	1.10	1.50	2.20	3.40	4.00	5.40	6.50	7.60
2025	0.40	0.60	1.20	1.70	2.40	3.10	3.60	5.10	6.20	7.40
2026	0.50	0.80	0.90	1.40	1.90	3.00	3.80	4.70	5.90	6.90
2027	0.50	0.80	1.10	1.70	2.10	2.80	3.80	4.60	5.80	6.60
2028	0.60	0.90	1.10	1.60	2.10	2.80	3.80	4.70	5.50	6.60
2029	0.60	0.80	1.00	1.50	1.70	2.60	3.50	4.70	5.90	7.10
2030	0.40	0.60	0.80	1.20	1.80	2.30	3.40	4.50	5.30	6.90

There are indications that the risk of stock going below B_{lim} is around 5% in coming years. Yearclasses 2008-2011 are all estimated poor and continued poor recruitment will of course increase the risk of $SSB < B_{lim}$. The runs that start with low biomass start with overestimation and due to autocorrelation in assessment error overestimation is likely to continue. The same runs will therefore experience $SSB < B_{lim}$more than once. The proportion of runs where $SSB < B_{lim}$is therefore not very high over 10 year period (see table 2.5).

Harvest ratio	0.32	0.34	0.36	0.38	0.4	0.42	0.44	0.46	0.48	0.5
2014-2023	7.20	8.80	10.40	12.60	15.70	19.10	21.70	24.80	28.40	31.40
2051-2060	2.40	3.60	5.30	6.70	9.20	11.70	14.40	17.20	20.40	24.60

Another thing of interest is the reponse if the stock for some reason collapses. Proposed harvest ratio is well below any candidate replacement line so no trigger action is needed for recovery. The trigger does though lead to faster recovery of the stock(figure 16).

Estimating if the management plan has reched it goals will be difficult as variability in stock recruitment and therefore stock size and landings will continue to be large (figures17and 2.5). Occasionally stock size and recruitment exceed anything seen historically and what happens in those cases can not be predicted, most likely there is an upper limit on the carrying capacity of the systems so stock size much above what has been observed historically will never be observed. Evaluations of the carrying capacity of Icelandic waters with respect to haddock are outside the scope of this work so this matter will not be discussed further.

Linking increased or decreased recruitment to the management plan will

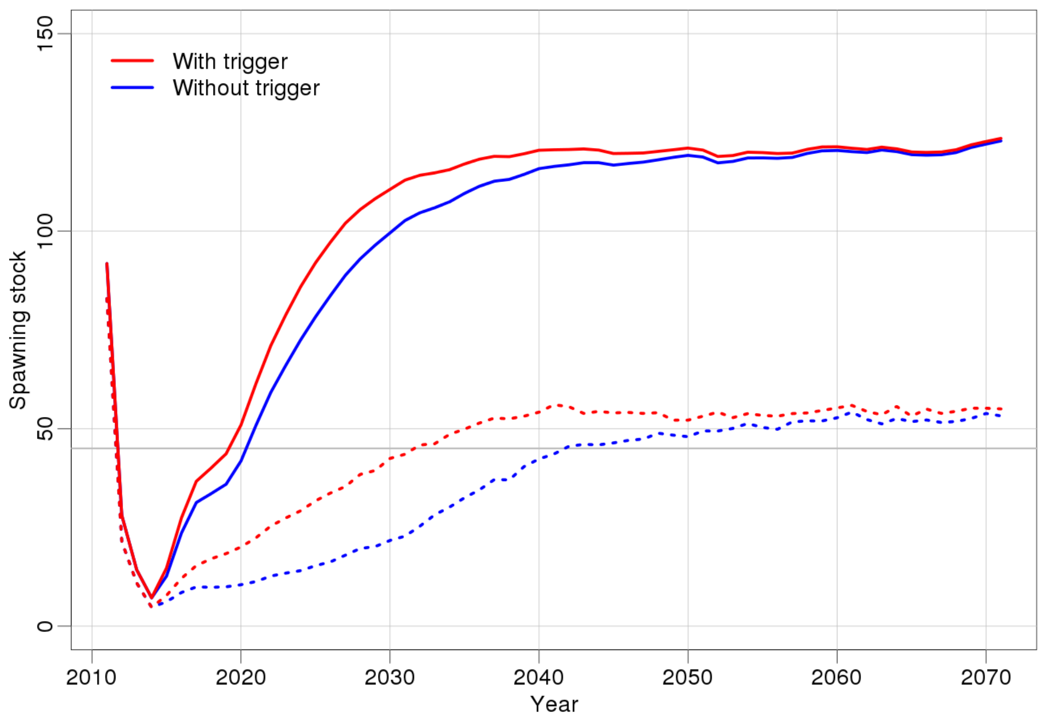

Figure 16: Development of the spawning stock after being reduced to 30% of estimated value in 2012 but harvested according to the proposed harvest control rule after that. The dashed lines show 5 percentiles but the continuous lines the mean.

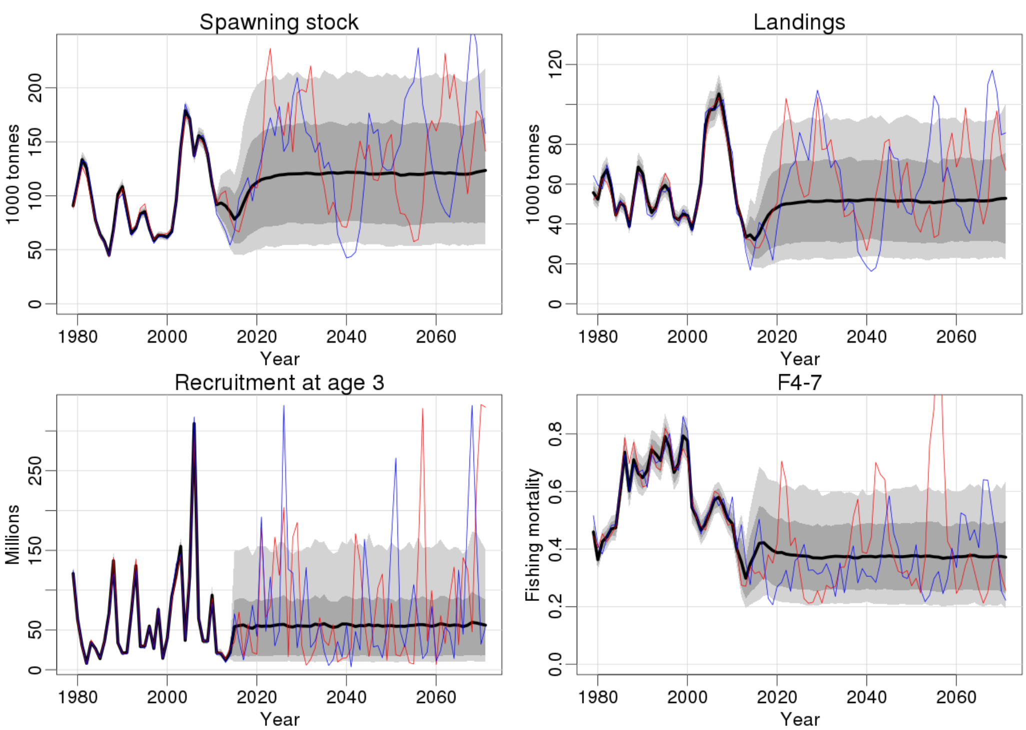

Figure 17: Results from proposed HCR with two realisations shown.

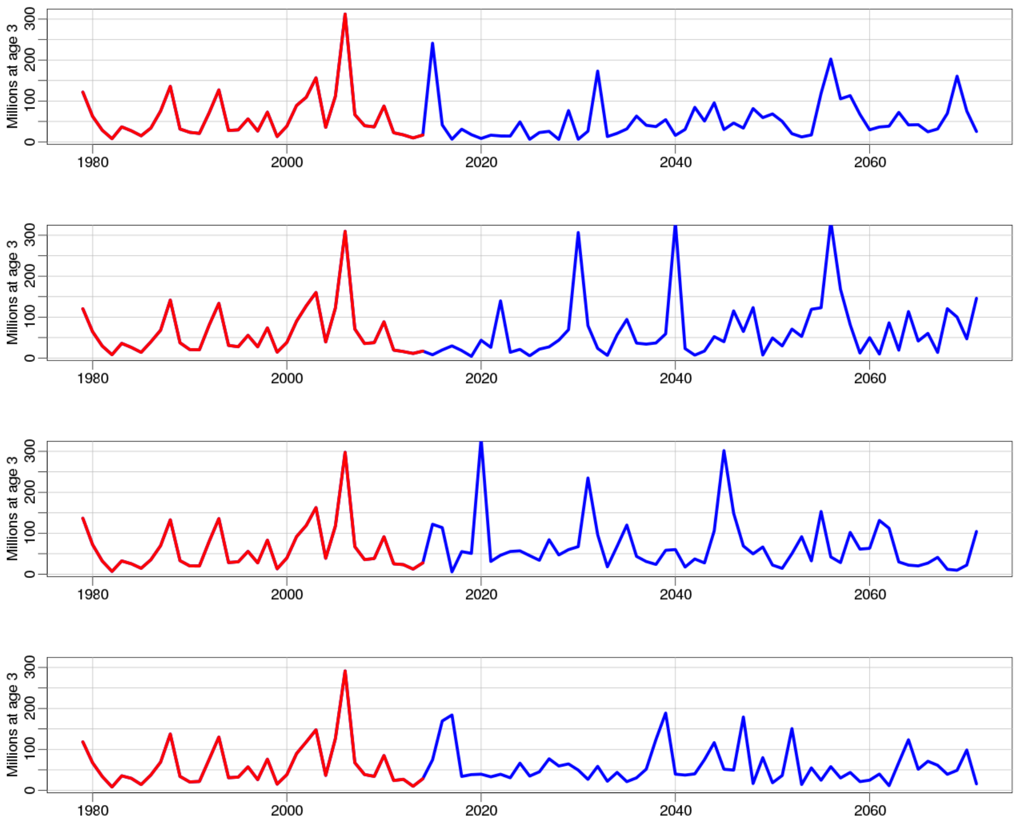

Figure 18: Four Recruitment sceanarios.

always be close to impossible so the only real measure of sucess of the management plan will be the observed harvest ratio and stock size and hopefully reduced cost of the fisheries. With reduced fishing mortality assessment takes longer time to converge so 3-5 year will pass before the harvest ratio and stock size in a given year will be "known" and a decade must pass before the sucess of the management plan can be evaluated, except something exceptional will happen.

One of the factors to look at is the distribution of various measures of stock size and fishing mortality (figure 19). They can be used to check the performance of the management plan, seeing where current values are compared to expected values. Distribution of average values over longer periods like 5-10 years is probably more important measure.

Even though the trigger point is at B_{lim} the trigger starts having effect when SSB is around 65 kt as proportion of cases where SSB is estimated $<$ B_{lim} increases gradually when the spawning stock approaches B_{lim}(figure 20). When correlation of assessment error is included average harvest ratio increases with decreased spawning stock but this effect is not seen when autocorrelation of assessment error is removed, indicating that periods of overestimation lead to depletion of the spawning stock and vice versa.

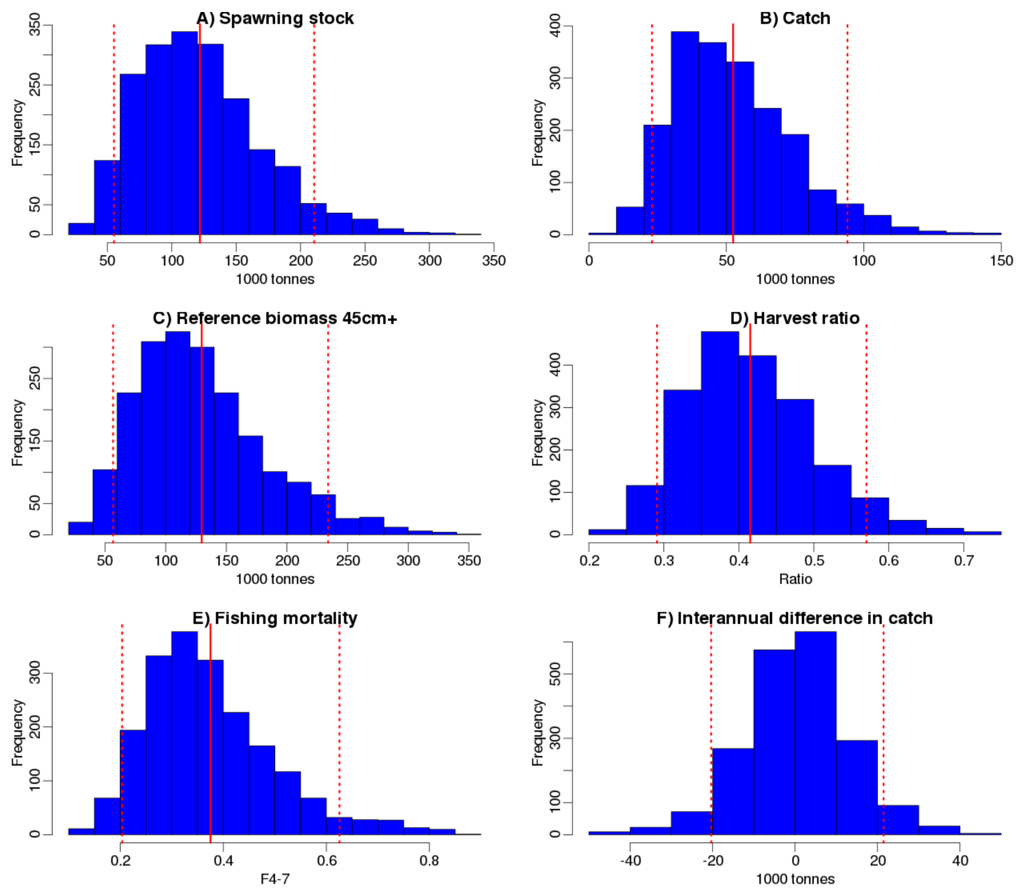

Figure 19: Distribution of predicted biomass (panels A and C), catch (panel B), measures of exploitation rate (panels D and E), and interannual difference in catch (panel F). Key metrics in this figure are summarized in table below.

	5th percentile	95th percentile	Mean
SSB (in thousand tonnes)	55	210	121
Refbio 45 cm and larger (in thousand tonnes)	56	233	129
Harvest ratio	0.29	0.57	0.42
Fishing mortality (F4–7)	0.21	0.67	0.37
Catch (in thousand tonnes	23	94	52
Interannual difference in catch in thous. tonnes			9.87

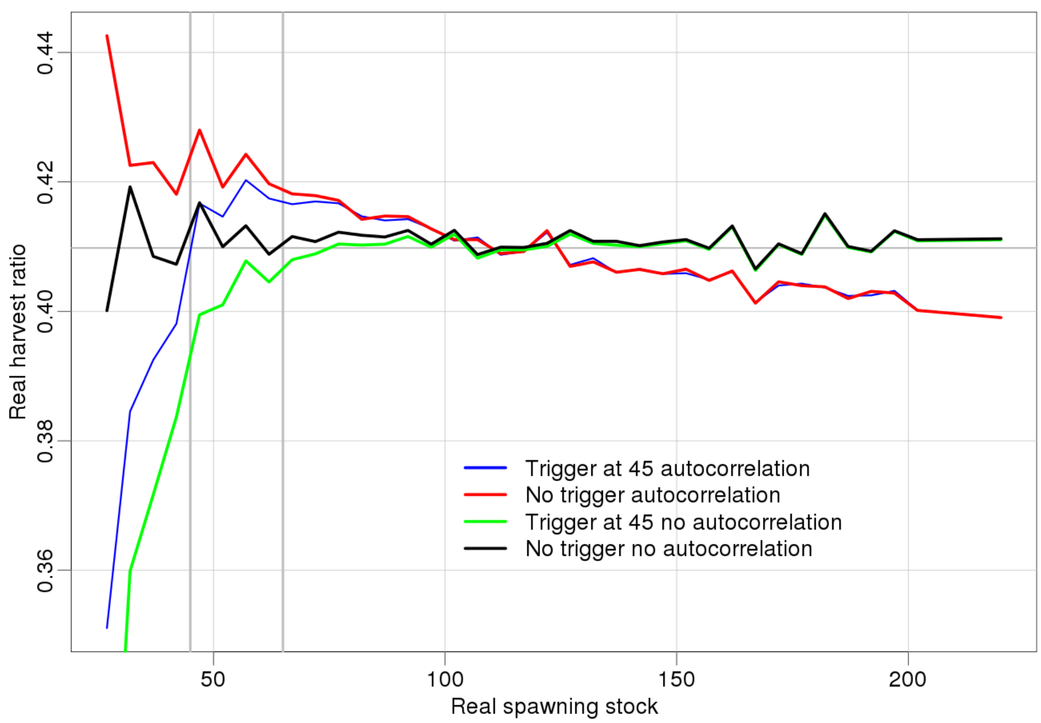

Figure 20: Harvest ratio as function of size of spawning stock.

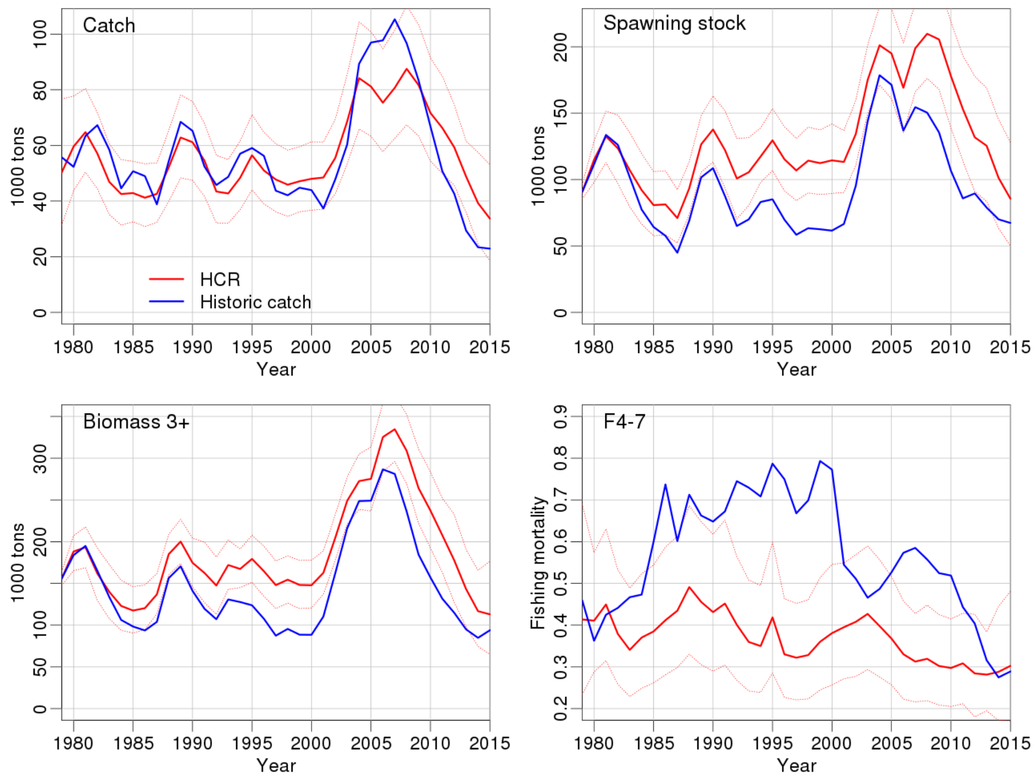

Figure 21: Comparison of results of realised catches and proposed HCR on historical data. Dashed lines show 5 and 95 percentiles.

2.6 Testing of HCR on historical data.

One of the test of proposed Harvest Control Rule is to see how it would have performed on historical data, i.e exactly the same stock weights, catch weights , maturity and recruitment as has been observed in the period 1979-2012. What is changed is that TAC is according to the HCR and assessment error as specified is added. It could be argued that all the exercises shown so far were unnessecary (except those to specify assesssment error), the real test is what is presented here. The result is that the probability of $SSB < B_{lim}$is 1% in the year with lowest SSB (1987) and neglible in other years. This is not unexpected as the proposed management plan calls for considerably reduced fishing mortality compared to last 35 years.

25 OKT. 2012

C.24.b

ATVINNUVEGA- OG NÝSKÖPUNARRÁÐUNEYTIÐ

Ministry of Industries and Innovation

Skúlagötu 4 150 Reykjavík Iceland
tel.: + (354) 545 9700 postur@anr.is www.anr.is

International Council for the Ecploration of the Sea
H.C. Andersen Boulevard 44-46
1553 Copenhagen V
Denmark

Reykjavík October 23, 2012
Reference: ANR12090104/11.2.3

Subject: Request for evaluation of long-term management plan and harvest control rules for Icelandic saithe and haddock

The Government of Iceland is in the process of formally adopting the following management plan for Icelandic saithe and haddock:

The management strategy for Iceland saithe and haddock is to maintain the exploitation rate at the rate which is consistent with the precautionary approach and that generates maximum sustainable yield (MSY) in the long term.

In accordance with this strategy the following harvest control rules are under consideration for implementation by Icelandic authorities:

Saithe

The annual total allowable catch (TAC) will be set by applying the following harvest control rule (HCR):

1. When spawning stock biomass in the assessment year (SSBy) is equal to or greater than 65 thousand tonnes (SSBtrigger),

TACy/y+1 = (á x B4+,y + TACy)/2

2. When SBBy is below 65 thousand tonnes (SSBtrigger),

TACy/y+1 = á x SSB/SSBtrigger x B4+,y

where y refers to the assessment year, y/y+1 the fishing year, B4+,y to the biomass of 4-year and older saithe in the assessment year, and á to the target harvest rate. á is set to 0.2.

Haddock

The annual total allowable catch (TAC) will be set by applying the following harvest control rule (HCR):

1. When SSBy+1 is equal to or greater than 45 thousand tonnes (SSBtrigger),

$TACy/y+1 = á \times B_{45cm}+,y+1$

2. When SSBy+1 is below 45 thousand tonnes (SSBtrigger),

$TACy/y+1 = á \times SSBy+1 / SSBtrigger \times B_{45cm}+,y+1$

where y refers to the assessment year, y/y+1 the fishing year, B45cm+ to the biomass of 45 cm and larger haddock, and á to the target harvest rate. á is set to 0.4.

These HCR formulations are based on work of national experts and the NWWG and have been considered to be accordance with the ICES MSY advisory framework.

The Government of Iceland requests ICES to evaluate whether these harvest control rules are in accordance with its objectives.

For haddock the evaluation should also include review of input data and the applied assessment methodology (Benchmark). For both haddock and saithe the evaluation should also address the appropriateness of current ICES reference points.

ICES is also invited to propose alternative rules or modified rules on its own initiative and to evaluate these.

On behalf of the Minister

Kristján Skarphéðinsson   Ingvi Már Pálsson

Annex 2 Icelandic haddock HCR evaluation: Technical Minutes

Review of the Icelandic haddock HRC evaluation, by Björnsson (2013) 19-21 March 2013

Reviewers:	Robert Mohn
	Jose De Oliveira
Secretariat:	Cristina Morgado

Reviewer 1

This review has two parts. The first is based on the comments sent to the Experts preparing the HCR evaluations before the RG/ADGISAHA. At the end of each comment, it is appended how the comments were responded to in parentheses. As the great majority of these were requests for clarification they were easily dealt with during the RG/ADGISAHA. The second part contains the conclusions after the meeting of Reviewer 1.

Many of the comments made for the Icelandic saithe HCR evaluation also applied to the haddock (ICES CM 2013/ACOM:60). Differences though will be highlighted.

Haddock_AGISAI_28 Feb_13

Many of the saithe comments apply here. Differences though will be highlighted.

Assessment error

Figure 2 would benefit by having the data superimposed as in saithe document. The problems in the early 2000's might then be more easily explained. Again this pattern is pretty good and its cohesion is a reassurance that the data are informative. The retrospective problems seen in Figure 4 show the sensitivity of backward projecting VPA's in the recent years. It would be beneficial to have the analogous figure to Figure 2 for the analytical retrospective. The good performance of ADAPT in Figure 2 for the recent years would be expected here, but Figure 4 show a 10-20% overestimation that seems to contradict this. Why?

Further on Figure 4, curious why in the runs with both surveys and the run with both surveys and prediction the retrospective patterns are so different, at least in magnitude. Does the prediction somehow remove some of the survey data? (*Figure 4 discussed with author and explained during meeting*.)

Of course any likelihood profile would now have to accommodate the second survey, but they still would be of interest. However, considering the similarity of the indices shown in Figure 5, not too much resolution between the two would be expected.

Mean weight

The change in weight at age in Figure 6 is quite large, although not as great as we experienced for haddock on the Scotian Shelf. The choice of weight at age for projections becomes of more importance, especially if the recent slow growth is thought to be a "regime" which would have an unknown time of return to long term values. (*Potential impact of regimes was discussed*.)

Could the slower growth affect natural mortality in sort of a Lorenzen way? (*Discussed during meeting*.)

Recruitment. It would be useful l to have a figure of the three candidate relationships with the data as was done for saithe. *(Discussed during meeting*.)

The very strong 2005(?) recruitment may affect selectivity. Again, in our haddock fisheries we have seen the tracking of effort with exceptional year classes. Also, we have seen that initial estimates of these exceptional year classes are higher when first observed than subsequently. Interestingly, there is no evidence f this in the N2 retro plot.(*Discussed but no action required.*)

HCR Figure 14 suggests to me that at any reasonable harvest rate (say <.5) these are indistinguishable. Especially when considered with the uncertainty in the projections. Although we are not shown the total, the component in weight alone looks like a cv of 20% or so. What does ICES or the authors suggest as selection criteria? *(Question of uncertainty addressed during meeting and new plots produced*. *Selection criteria were explained.*)

Part 2. Conclusions after meeting.

The authors responded to several of my enquiries before the meeting and in greater detail during the meeting. As most of the comments were requests for clarification or more information they were met during the meeting. A couple that would have required re-plotting of data as per the examples above, were not undertaken at the meeting. They were brought forward because they are commonly used in our assessments and as recommendations for potential summary plots in future work. Failure to produce them during the meeting does not affect the quality of the presentations nor my ability to draw conclusions on the work.

The analysis presented in the saithe and haddock documents was consistent with, and in some instances (e.g. the handling of correlated errors and retrospective errors in the projections) superior to, assessments I have reviewed in other *fora.* I have no outstanding issues and feel that the advice generated is reliable.

Reviewer 2

General

Bigger issues

1) I must say I found the documentation a bit hard-going, and it wasn't always clear whether some of the things being described/discussed were actually implemented. But that said, I didn't see anything that stuck out as being necessarily problematic.

Smaller issues

2) Eqn 4 (p 4): The subscripts are not correct and should look more like the following:

3) $N_{A,y+1} = N_{A-1,y}e^{-(F_{A-1,y}+M_{A-1,y})} + N_{A,y}e^{-(F_{A,y}+M_{A,y})}$

4) But I guess this didn't matter so much since you're not using plus group

5) Likelihood equations (Eqns 11, 14, 16, etc.): these equations are negative log-likelihoods rather than likelihoods *per se* (but to be pedantic, since you are leaving off constants, they are biased negative log-likelihoods).

6) Don't quite follow the level you're setting for the small constant added to the likelihoods (2-4 sampled otoliths?). I expect the behaviour is quite interesting in log space at the very small values.

7) Multiplier on age patterns for □ (e.g. Eqns 11 and 16): wondering whether this could be fixed initially (as done) but then freed up in a later phase of a multi-phase ADMB approach? Perhaps it is just not estimable?

8) Eqn 26 (p8): Don't follow this at all… it is not a form of equation I recognise.

9) Eqn 29 (p9): there is a negative missing from the exponential (in front of the parentheses). But then again , this doesn't matter because the parameters are set to zero.

10) Section 2.4, second last paragraph (p14-15): I don't quite follow the explanation for $Trigger_2$.

Haddock

Bigger issues

1) I miss some of the detail of the historic assessment, just to get a feel for what the assessment is like, how well it fits the data, what sort of data it is based on, etc. although I realise I could probably track it down somewhere. For example, in 3.1 is age 2 catch used at all (not clear from the 3rd bullet).

2) Section 3.3, maturity and selection at age: I presume the stock and catch weight modelling here is purely for the purposes of projecting these forward to allow calculation of the biomass in the advisory year, and the TAC? Furthermore, these short-term predictions could differ from the operating model? Given this, do you introduce assessment error into the calculation (e.g. because of the dependence on $B_{tot,y}$, $N_{2,y}$ and $N_{3,y}$)? This is not clear in the documentation.

3) Section 3.3, Fig. 9: Is it not a concern that distribution of future proportion mature is shifted higher than the historic observations? Is there an explanation for this?

4) Section 3.4: I see no comparison here of historic recruitment distribution to simulated recruitment distribution (e.g. such as in Fig. 9) – has this comparison been made?

5) Section 3.5: Harvest control rules: The first paragraph states "The approach take was to look at mean yield, stability in yield and probability of spawning stock going below B_{lim}…" I don't see anything on the second of these (stability in yield)?

6) Section 3.5, Figure 12: What is the basis for these calculations? There is nowhere that I could find that explains in more detail how you are calculating biomass above a certain length from an age-based assessment. Are you using a growth curve? Given that growth is so variable with haddock, how are you coping with this?

7) Section 3.5: Harvest control rules: The HCRs presented (Figs 13-16) seem to be on the basis of biomass of 45cm+ fish in the advisory year – was anything else tried (e.g. equivalent biomass in assessment year, reliant on fewer assumptions)?

Smaller issues

8) Section 3.2, Assessment error: what is said at the start (1st paragraph) seems to conflict with the final paragraph – I presume it is 0.22 for the advisory year biomass and 0.16 for the assessment year biomass?

9) Table 1 (p20) – not sure what the third column was.

10) Where is Figure 3.3?

11) Section 3.3, Mean weight, maturity and selection at age: this section is a bit of a mess. The function for □year in eqn 37 is not consistent with the middle panel of Fig. 7 – should 0.0571546 not be instead 0.60452795? Otherwise, there is no point to the dependence on $B_{tot,y}$. Also, in eqn 38, should the exponential term not be multiplying everything (i.e. you have missing brackets around everything to the right of "=" except the exp-term)? Need I say anything about eqn 39?

12) Section 3.5, Fig. 14: This was a challenge to follow, and I think a simple table such as I give below would go a long way to making this easier to follow (assuming □A and □A refer to the advisory year):

NR	TRIGGER	□R	□A	□A
1	-	0.25	0.5	0.22
2	45	0.25	0.5	0.22
3	75	0.25	0.5	0.22
4	-	0.25	0	0
5	-	0.5	0.5	0.22
6	45	0.5	0.5	0.22
7	45	0.5	0.75	0.25

However, I'm not sure I've got this right. Otherwise, I found this figure quite informative.