ICES AGICOD REPORT 2009

ICES ADVISORY COMMITTEE

ICES CM 2009\ACOM:56

Report of the Ad hoc Group on Icelandic Cod HCR Evaluation (AGICOD)

24-26 November 2009

ICES, Copenhagen, Denmark

ICES
International Council for the Exploration of the Sea
CIEM
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. 2010. Report of the Ad hoc Group on Icelandic Cod HCR Evaluation (AGI-COD), 24-26 November 2009 ICES, Copenhagen, DenmarkICES CM 2009\ACOM:56. 89 pp.

Contents

1 Introduction

The TAC of Icelandic cod has for the last 3 years been set by a HCR where the TAC for the next fishing year (September 1st to August 31st) is the mean of the TAC last fishing year and 20% of biomass of 4 year and older cod in the beginning of the assessment year. With the exception, that the Minister of Fisheries raised the TAC from 130 to 160 kt for the fishing year 2008/2009 in the last days of the outgoing government in January 2009. The set HCR rule was based on the recommendation by a group of experts appointed by the Minister. The objective was to evaluate a harvest control rule that lead maximum long term economic revenue of the fisheries. Their work was based on a model taking into account biological and economic factors. The results are described in a rapport that has been available in Icelandic since 2004, an English translation is included in the appendix of this report.

The factor having most effect of the outcome was the cost of the fisheries, but cost per kg caught is predicted to be inversely proportional to $B^{0.7}$ where B is the defined as available biomass. In addition, increase in price with fish size was included. The results showed that the revenue was maximized if the proportion in the HCR was between 18 and 23%. The group responsible for the modelling suggested 20% as the harvest ratio. This should be lower than F_{msy} due to the inclusion of cost of the fisheries. The following points give a short summary of the results presented by the HCR group in 2004:

1) The group tested two recruitment scenarios i.e. when the recruitment had decreased permanently and when recruitment improved again when the spawning stock increased. Optimal harvest ratio was similar in both cases but stock size and yield were different.

2) The stock assessment model used was a catch at age model written in AD-Model builder. Stock assessment and predictions were done in the same model and variability in recruitment, assessment error and stochasticity in mean weight at age were included in the MCMC runs within the model. An economic model to estimate cost and revenue of the fisheries was an inherent part of the model.

3) The factor affecting the optimal harvest rate most was cost of the fisheries. Wages of fishermen were not included as cost but rather considered as part of the social revenues.

4) HCR based on reference biomass using weight at age from the March survey were also tested as was different age range in the reference biomass. How the reference biomass was defined did not make much difference if the harvest proportion was adjusted appropriately. Therefore the group decided to stick to the reference biomass 4-14 based on catch weights that had been used as a basis for the HCR since 1994.

5) Other forms of HCR were not tested. This form where the TAC is the mean of the TAC last fishing year and certain proportion of the reference biomass in the beginning of the assessment year already was proposed by a similar group in 1994. The proportion proposed by that group was 0.22. The HCR implemented by the government in 1995 was that the TAC next fishing year was 25% of the mean of the reference biomass in the beginning of the assessment year and the year following the assessment year.

6) The HCR group did not look at the size of the spawning stock with regard to B_{lim} candidates. In the report they mention that B_{lim} need to be defined

and at the same time the rebuilding strategy when the stock approaches B_{lim} and the probability of being below B_{lim}.

The minister of fishery has sent a letter to ICES where he asks for an analysis of the likelihood that the spawning stock size in 2015 will increase from the current level of 220 kt when applying the 20% HCR. In addition a reference is made with regards spawning stock biomass increasing to that which gives maximum sustainable yield. The work in this report, unlike that of the report from 2004, is thus primarily focused on evaluation of the risk that the SSB falls below 220 kt. The 220 kt can for all practical purposes be considered as a proxy for B_{lim} or B_{pa} and as such the analysis done here can be considered an evaluation of the HCR relative to ICES precautionary approach. Additional evaluation of the HCR relative to likely B_{msy} candidates is also emphasised, reflecting the increasing focus of ICES to guide managers towards decision rules that meet the requirement of the Johannesburg agreement.

The rule formal rule being tested is:

$$Tac_{y/y+1} = \left(\frac{Tac_{y-1/y+} R\widetilde{B}_y^{ref}}{2} \right)$$

where R is the harvest ratio (0.2), B_{ref} is the biomass of 4 years and older based on catch weights and the years refer to the fishing year starting 1. September in year y and ending 31. August in year y+1.

2 Materials, methods and background information

2.1 Historical observation of relevance

2.1.1 Weight at age

The HCR for Icelandic cod is based on mean weight at age in the landings. Mean weight at age in the landings is available back to 1955. Prior to 1993 mean weight at age is compiled using fixed length - weight relationship as weighing of fish was relatively uncommon in that period. Since 1993 weighting of fish has been extensive with large proportion of cod sampled for otholiths weighted gutted and part of it ungutted. The weighting program has shown that the error in assuming fixed length-weight relationship is relatively small (<3%) and that most of observed changes in mean weight at age are really changes in mean length at age. Mean weight at age in the landings from 1975-2008 for age groups 3 to 9 are shown in figure 2.1.1.1. This is approximately the period where the official weight at age used by the NWWG can be double checked against recompiled raw data stored in the MRI data base. With regard to the reference biomass (B4+), age groups 4-8 have been over 90 % of the reference biomass in the period 1985-2009 and age groups 4-6 75 %. The effect of older age groups will increase if fishing effort will be reduced for number of years.

CATCH WEIGHT ESTIMATES IN THE ASSESSMENT YEAR (Y): The weight at age in the catches is used to calculate the reference biomass (B4+). The B4+ in the assessment year (y) is the basis for the calculation of the TAC in the advisory year (y+1). Since weight at age in the catches for this year is not available during the annual assessment/advisory cycle, they have to be based on predictions. In the last few years, the estimates of mean weights in the landings of age groups 4-9 in the assessment year (y) have been based on a prediction from the spring survey measurements in the advisory year that are available when the assessment is conducted. The relationship between survey and landings weights that is used is:

$$cW_{ay} = a + b * sW_{ay}$$

This relationship is used for age groups 3-9 but for ages 10-14 mean weight in the landings from the year before are used. In assessment done prior to 2005, the mean weights in the landings in the assessment year were predicted from mean weights in the landings one year before and predicted abundance of adult capelin. Prediction of the capelin stock size turned out to be problematic. The survey weights on which predictions are now based are more reliable predictors as they are measured 3-4 months before the weights in landings assuming they are on the average in the middle of the year.

CATCH WEIGHT ESTIMATES IN THE LONG TERM SIMULATION:

In recent years, the NWWG has simply set the catch weight in the advisory year the same as in the assessment year. It should be noted that the catch weights in the advisory year (y+1), is in effect not part of the HCR decision rule. Even though it would be known with certainty that the weights would change between the advisory year and the following year, the TAC according to the HCR would not change, even though fishing mortality in the year following the harvesting year would be considerably different from what is intended from the HCR. Being able to predict available food for cod (mostly capelin) is essential for prediction of catch weights one year ahead.

The historical weights at age (figure 2.1.1.1) show that there is some cyclical pattern in the mean weight at age and that the weights in recent years are at a historical low. The patterns in the weight at age indicate that there is substantial correlation between weights of different age groups within a year. This is highlighted when one standardized the weight by (figure 2.1.1.2):

$$\log W_{ay} - \log \overline{W}_{ay}$$

A first order AR model (AR1) gives autocorrelation coefficient around 0.6 for most age groups (figure 2.1.1.3) and with a cv ranging from 0.08 to 0.2, increasing with increasing age (figure 2.1.1.3). It is most likely that this increase is largely due to decrease in sample size with age.

The above auto-correlative patterns should by default be taken into account in the long term simulation for years beyond the assessment year. The question that remains is what should be the long term mean weight at age used as a basis in the simulation. It has been hypothesised that the cause for the historical patterns in the weight at age is linked to the abundance and/or availability of capelin. Looking at the data there are trends in mean weight at age. The estimated trends are caused by low mean weight at age in recent years but high in the late seventies when the capelin stock was very large and the capelin fishery was starting.

For numerous years the NWWG actually used the biomass estimates of capelin to make direct prediction of weight at age in the advisory year. This statistical approach has been abandoned in recent years mostly because changes in the capelin distribution relative to that of cod and due to uncertainty in the capelin assessment and projections. The causative explanation for the pattern in the cod weights are however still hypothesised to be largely driven by variability in capelin productivity.

If the above hypothesis with regards to the link between cod weight at age and capelin productivity, the argument for the basis of the mean weight will hinge on what is the likely future long term productivity of the capelin stock. And in particular given whatever productivity that may occur will it be available to the cod as prey, this being said in light of the recent claim of a more northwardly distribution of capelin. Given that any future scenarios with regards to capelin productivity and distribution will just be speculative at this time it may be argued that the recent mean average weights at age should be used in the long term simulations. If however long term average weights at age are to be used, the auto-correlative settings in the starting year should be set as negative, since it is unlikely that in the short term the weights at age will resume normal historical values.

In may be stipulated that if capelin feeding is being displaced northward due to climatic reasons that other species may replace the niece occupied by capelin. In recent years, observations have been made on numerous species showing northward displacement within the Icelandic ecosystem, including haddock and monkfish. Highly migratory pelagic species such as herring, blue whiting and mackerel have shown higher abundance in Icelandic waters than previously thought. In the latter case this may rather be because of higher abundance rather than any putative climatic events. All these species are however not really likely to take up the functional role of capelin as food for cod, at least not for cod of small and medium size. Anectodal information however indicates that larger cod can prey upon some of these species.

Until now weight at age has been presented as a year and age factor. Mean weight at age is the result of growth (G) for a number of years and sensible biological model is most likely $W_{a,y}=W_{a-1,y-1}+G_{a-1,y-1}$. Therefore mean weight at age could also depend on year class and there are some examples of clear year class effects in Icelandic cod although they are much less than for haddock and saithe. A Shephard Nicholson model could possibly be used to infer about the measurement error in the data.

In the simulations done here, two catch weights at age scenarios were used:

- Average weight at age based on 2006-2008, rho=0.6, cv=0.12
- Average weight at age based on 1985-2008, rho=0.6, cv=0.12

The same stochastic noise was applied to all age groups within each year. The first one may be considered as a reasonable proxy for the short term, the second one a reasonable proxy for the more medium/long term conditions.

SPAWNING STOCK BIOMASS:

For age groups 4-7 mean weight at age of mature fish was taken from the March survey but mean weight of age groups 8 and older from the landings. This is because relatively few mature age 8 and older fish sampled for otholiths in the survey, something that will probably change with reduced fishing effort.

A relationship between catch weight and survey weights of mature fish for the period 1985-2005 was used by the NWWG to estimate the spawning weights for age groups 4-7 prior to 1985 .

In the simulations done here, two spawning stock weights at age scenarios were used:

- Average weight at age based on 2006-2008, rho=0.6, cv=0.12
- Average weight at age based on 1985-2008, rho=0.6, cv=0.12

The first one may be considered as a reasonable proxy for the short term, the second one a reasonable proxy for the more medium/long term conditions. The same error structure as used in the catch weights were applied to the spawning stock weights in each iteration.

2.1.2 Maturity at age

Maturity at age in the current assessment set-up is derived from measurements in the spring survey. This was a change in practice from that done in the in assessment prior to 2005, when maturity at age was based on samples from landings The reason for the change was difficulty in getting ungutted fish from the landings. Maturity at age in the landings was obtained from catches in the period January – May when maturity stage can reliably be detected. As large part of the fisheries in the early part of the year is targeting spawning fish, maturity at age from the fisheries is overestimating proportion mature in the stock. In recent years maturity at age in the landing has been 2-10 times higher than in the survey for ages 4-5.

Since the survey only commenced in 1985, maturity values prior to that were obtained from a relationship between maturity at age in the landings and the survey from 1985-2004. The sampling procedures from the landings and the fisheries change in time so the spawning stock over a long time is not a standardized measure. The same applies of course to spawning stock based on "survey maturity at age compiled from catch maturity at age". Therefore the maturity data before 1985 is somewhat questionable, much more so than catch in numbers and age and catch weights which can be compiled from both samples of ungutted and gutted fish.

Maturity at age has not increased much since 1990 but has been higher than before 1990. Maturity at age has shown some oscillations with maturity at age reducing in periods of poor growth. Part of the oscillations could also be caused by sampling.

Sexual maturity in the medium term simulation done annual by the NWWG has for now been fixed to that observed in the short term prediction with no CV modelled. This procedure is repeated here, using the average maturity from the period 2006-2008. If the trend in maturity at age continues maturity at age might be expected to increase in the future. However, expected decreases in fishing mortality may also reverse this trend.

The conventional estimates of SSB are most likely only a crude proxy of the productivity of the stock. Another estimates of productivity evaluated here was to calculate a proxy for egg productivity (see chapter on stock recruitment function).

2.1.3 Natural mortality

Inter-annual variations in natural mortality compromise the premises of most assessment models. When natural mortality is above average stock size is overestimated and opposite. The effects are somewhat complicated and best tested by using a system model with certain pattern in M to generate data that is tested by traditional assessment model. Inclusions of variation in natural mortality make survey indices depreciate faster with time. When natural mortality is highly variable or changing systematically with time the HCR should be based directly on the latest survey measurements.

Survey data for Icelandic cod may be helpful in order to judge if the variations in natural mortality are substantial. For this purpose the relationship between age 3 and age 4 indices from the same year classes were investigated. Age group 3 has hardly entered the fisheries and since the fisheries of age group 4 is not substantial until after the March survey measurements, meaning that the variability in fishing mortality should have minimum influence. The correlation between the non-transformed indices from these two age groups is quite high (r_2=0.90, Figure 2.1.3.1) which requires both low variations in natural mortality and low measurement error in the survey. A time series plot of the log catch ratio of the two survey indices (Figure 2.1.3.2) indicates that some increase in discounting may have occurred in the beginning of the time period.

Given the above observation and in light of a lack for a plausible alternative, natural mortality has been fixed at 0.2 in all simulations.

2.1.4 Stock recruitment function

The development principal metrics of the iCod from 1955 to 2009 are shown in figure 2.1.4.1. Mean recruitment for the period is 173 million at age 3. The figure indicates a major change in recruitment after year class 1984, with the mean size of year classes 1952-1984 being 205 million and year classes 1985-2006 around 130 million. In the earlier period the smallest year classes were around 130 million but 70 million in the latter period.

The spawning stock was large in the beginning of the period but it reduced continuously until the early 1970's. The SSB then increased again due to reduced fishing effort (exclusion of the foreign fleet from the 200 m EEZ around 1976) and recruitment of the large 1973 year class to the spawning stock. From 1980 - 1983 the spawning stock dropped sharply due to increased fishing mortality, reduced weight at age and reduced influence of the large 1973 year class. After the natives managed to fully replace the foreign fleet fishing power with their own, the fishing mortality rose again to record levels around 1990. This resulted in the two large year classes from 1983 and 1984 hardly contributing to any spawning biomass increase in around 1990. Effectively the spawning stock has been relatively small since the early 1980's, though increasing a little since 1995 in spite of low average recruitment. Part of this recent increase is likely due to the implementation of a HCR, first set in place in 1994. This resulted in significant decline in fishing mortality in the last 10-15 years, relative to that taking place in the decade prior to the implementation of the HCR. The 4 consecutive average year classes from 1997-2000 have also contributed to this increase. Observed changes in the size/age composition in the SSB are discussed later in this chapter.

The relationship between spawning stock and recruitment is shown in figure 2.1.4.2. Some kind of relationship is apparent but it must be kept in mind that all the high values are in the beginning of the period and the recent low year classes are all clustered in the lower end of the recruitment scatter. The figure indicates that variability in recruitment might increase with reduced stock size although that could be an artefact of few numbers of observations when spawning was high. The figure also shows Ricker, Beverton-Holt and Segmented regression functions fitted to the data. The Ricker function is parameterised in terms or R_{max} (maximum recruitment) and SSB_{max} (spawning stock that gives maximum recruitment) as shown in equation 2 (see below). The residuals from the Ricker function (figure 2.1.4.3) show a time trend in the residuals, being mostly positive prior to 1985 and negative after that. Same patterns are apparent if one were to use the other two functions.

Those negative residuals have been recognized by the NWWG for numerous years. As an example, using the conventional Ricker function results in median prediction of the 2009 year class of around 180 million, the largest (or second largest) year class for 25 years. The NWWG has thus opted for using a Ricker function with time trend allowed in R_{max} the short/medium term prognosis of in recent years. The time trend terminates 5 years before the assessment year. The estimated time trend is around 1.4% per year from 1955-2005 leading to first estimate of a year class today being around 125 million fishes and future recruitment when the spawning stock becomes larger will not change much if timetrend in R_{max} is allowed. Rather than using a constant change in R_{max} with time, an alternative and likely better model would be to model R_{max} over the two time periods 1955-1984 and 1985-2007 as two separate parameters (keeping the value of SSB_{max} constant over the full period). Another option would be to just use the data from 1985. However the range of SSB in the period is so narrow compared to the variability in recruitment that there is no apparent relationship in data (figure 4.1.4.4). If a Ricker function is applied, the data would give little information about SSB_{max} and R_{max}. Uncertainty in parameters estimates would in such cases dominate implemented stochasticity in recruitment. Although it cannot be excluded that this could reflect the true state of our knowledge, an evaluation based on such high uncertainty would result in all but an ultra-conservational harvest rule to be considered precautionary.

Reduced value of R_{max} could indicate that the carrying capacity of the ecosystem has decreased and recruitment may not improve much with increased spawning stock. Environmental indicators, such as available long term hydrographical and zooplankton measurements in Icelandic waters (see appendix) do not seem to help in explaining neither the recruitment time series nor the time trend in the residuals. However, part of the time trend seen in the residuals could be a result of the change in the size/age composition of the spawning stock. In the early period, old and large fish were prominent part of the stock, having been replaced with younger and smaller fish in the last two decades. The development in the mean age in the spawning stock with time (Figure 2.1.4.5) reflects this change quite well. It is of note that the mean age in the spawning stock declines significantly at the same time as the reduction in recruitment occurred. Using age as a covariate in the estimation of recruitment will lead to less pronounced time trend in the recruitment residuals. It has been hypothesized that older and larger fish may be more effective spawners than younger smaller ones. However, hypothesis that mean spawning stock age may be a covariate that influences recruitment is most likely a proxy for some other unexplained variable.

Measurements from the spring groundfish survey show that egg production per unit biomass increase with the size of the fish (Figure 2.1.4.6), both because the roes in larger females are relatively larger (Figure 2.1.4.6b) and the proportion of females increases with cod size (Figure 2.1.4.6a). To get a proxy estimate of the total egg production in the cod stock the above observation can be applied to the mean weight in the spawning stock of each age group each year by applying the following function (Figure 2.1.4.6.c):

$$E_{year,age} = SSB_{year,age}\left(0.01 + \frac{SSBwts_{year,age}}{20000}\right) \quad (1)$$

where E is egg production, SSB spawning stock biomass and SSBwts weight at age in the spawning stock in grams. The estimated egg production (Figure 2.1.4.7) and the ratio of egg production and the conventionally estimated spawning stock (Figure 2.1.4.8) show that the egg production has decreased more since 1955. This is largely because the proportion of large fish in the spawning stock has reduced. Using egg production instead of the conventional spawning stock biomass will thus lead to a reduced time trend in the residuals and less predicted change in R_{max}.

The stock recruitment functions tested are:

The Ricker function: $\hat{N} = R_{\max} e \dfrac{SSB}{SSB_{\max}} e^{\left(-\frac{SSB}{SSB_{\max}}\right)}$ (2)

The Beverton and Holt function: $\hat{N} = R_{\max} \dfrac{SSB}{SSB + SSB_{50}}$ (3)

The segmented regression function: $\hat{N} = \min\left(R_{\max}, R_{\max}\dfrac{SSB}{SSB_{break}}\right)$ (4)

Egg production Ricker function: $\hat{N} = R_{\max} e \dfrac{E}{E_{\max}} e^{\left(-\frac{E}{E_{\max}}\right)-}$ (5)

Age covariate Ricker function: $\hat{N} = R_{\max} e \dfrac{SSB}{SSB_{\max}} e^{\left(-\frac{SSB}{SSB_{\max}}\right)-} e^{-\alpha Meanage}$ (6)

With constant R_{max} all the functions except the Ricker function with mean spawning stock biomass age as a covariate, it having 2 estimated parameters where α acts as a multiplier. This function can be considered as an alternative to the model suggested by Marteinsdóttir and Thorarinsson (1994), where the addition of Shannon index as covariate, representing the age diversity in the spawning stock was found to significantly improve the fit. Use of the Shannon index was considered but it is causes numerical problems when stochastic simulations area linked to optimization.

The functions were tested with constant R_{max} but a linear trend in R_{max} and change after 1985 R_{max} were also tested. The egg production function was set up as a Ricker function with Egg production on both sides, which would be interpreted as density dependent mortality. Another way would have been to put the exponential term in terms of spawning stock size or total biomass, interpreted as cannibalism.

Residuals lognormal. The CV was constant but allowing the CV to change with spawning stock was also tested. The equation for the CV was

$$CV = CV_0\left(\frac{SSB}{500}\right)^{\delta} \tag{7}$$

where δ and CV_0 are estimated parameters.

The function minimized was (note the use of Greek symbol to make the equations look more sensible).

$$\Psi = \sum \frac{\left(\log N - \log \hat{N}\right)^2}{2CV^2} + n_{years}\log\sigma \tag{8}$$

Table 2.1.4.1 shows the result of fitting the before mentioned stock-recruitment functions to the estimated SSB from 1985 – 2007. The value of the negative log-likelihood function is some indication on how well the function fits the data. It is though no measure of time trends in the data and the value of estimated change in R_{max} after 1985 is a better measure of the models ability to capture the change after 1985. The estimated change in R_{max} is smaller when the Ricker function is expressed in terms of egg production instead of spawning stock biomass and the estimated change in is R_{max} is also small when mean age in the spawning stock is used as a covariate (still referred to as Hjörleifsson function in the table) is used (20% reduction instead of 33-40%). Those functions will therefore lead to more optimistic prediction of recruitment in the future than by just modelling R_{max} as function of time, since in the latter model, the time cannot be reversed in future predictions! It is also interesting to note that the use of the Beverton and Holt function estimates more changes in R_{max} than the Ricker function.

When CV as function of spawning stock size is estimated the prediction is always that CV will increase with reduced stock size. The reduction in negative –log-likelihood is in the range 1 to 3 (2 is around the value that makes the change significant) if variability in CV is allowed, but the change in parameter values are small.

One of the products of the Ricker functions is an estimate of SSB_{max} that is a proxy for B_{msy} if yield per recruit is flat. For the segmented regression function the estimate of SSB_{break} can under certain criteria be used as proxy for B_{lim} or in some cases even B_{pa}. If the egg production function is used the value in the column indicates the egg production giving maximum recruitment. The parameter values given in the table change if assumption regarding constant R_{max} change.

Many of the stock-recruitment functions considered involve estimation of a number of parameters, often 3-4 if two levels in R_{max} are allowed. The parameter values are in some cases poorly estimated and there is substantial correlation between parameters. Uncertainty in those parameters is an important source of error in simulations where stock-recruitment parameters are not fixed.

The goal is not to select any base case in simulations but rather test the robustness of the HCR against different assumptions. If any model was to be selected as default the

Egg production model with two levels of R_{max} would be the choice. It is also a good compromise, somewhere in the middle with regard to predicted future recruitment.

In the final stages of this work the review group asked the working group to look at simulations where the future recruitment is modelled as having box distribution from 70-180 millions fishes (mean 125 million) independent of the spawning stock. This box distribution represents the distribution of year classes 1985-2007 reasonably well.

2.1.5 Selection pattern

In the annual stock assessment cycle the fishing mortality is estimated for every year and age. Fishing mortality of each age group was constrained with a random walk term with standard deviation specified as proportion of the estimated CV in the catch at age data. In the input file the process error (variability in F) is specified to be larger than the measurement error for the younger ages but the measurement error is specified to be larger for the older age groups.

In the predictions the NWWG has used the average selection patterns in the last 3 years both for the short term predictions (assessment and advisory year) and in the medium term simulations (y+6). This approach may not be appropriate for long term simulations since the intent of the HCR rule is to apply a lower fishing mortality than has been experienced in the recent past. Taking longer term average, like e.g. that experience on the average over the some past decades, is often considered as a default in HCR simulations.

The annual selection pattern in the iCod fisheries since 1955 is shown in figure 2.1.5.1, with figure 2.1.5.2 showing the average selection pattern relative to age for each 10 year block. In both cases the reference age is age 8 (selection =1), not in the age group used in calculating the reference fishing mortality (age groups 5-10). The choice of using age 8 is based on ad hoc analysis that indicated that this age group was the pivotal age group in the historical fishing pattern where estimated selection pattern older age groups in some year blocks declined. Using age group 8 as the reference to age thus gives a sense of the change in selection pattern in the younger age groups, independent to changes in the selection pattern of age groups older than 8 – which may be more prone to be a result of model setups/assumptions. These data indicate:

- The selection pattern in age groups 3 and 4 declined from 1955 to 1974 and has changed relatively little since then.
- A slight increase in the selection pattern of age group 6 and 7 has occurred from 1975 onwards.
- The selection pattern in the older age groups imply a dome shaped selection pattern in the period 1975-1994, followed by a more flat-based section in the period 1995-2004. The selection pattern in the most recent years (2005 onwards) imply a significant change compared with that implied in earlier years, with almost a monotonous increase in selection pattern by age.

The change in targeting of younger age groups in the beginning of the time series may be a result of changes in mesh size regulation during this time period (check) and because around 1974 (the extension of the EEZ to 200 miles) the fisheries changed from being international to national. Explanation with regards to the changes in the selection pattern in the older age groups is as present not available, and could thus potentially be a result of model settings. What is however most likely a model artefact is the fishing pattern estimated in the terminal years (2005-2008).

Although wrong assumption of the monotonous increase in fishing pattern used in the short term prediction (2006-2008 average) may have little influence on the results of the short term predictions, they are most likely not appropriate to use for the long term simulation.

In the ADCAM separable model used for the simulations (see later), the selection patterns for the period 1955-1975, 1976-1993 and 1994-2008 were modelled separately (figure 2.1.5.3). These periods coincide with foreign fleets being expelled from the Icelandic fishing grounds (1976) and the year when significant constraints on the fishery for cod took place (1994). For the future simulations the selections pattern from the most recent period (1994-2008).

In F based HCR the predicted selection at age affects the TAC for a given stock size and assumptions regarding selection can have major effects on the TAC. In the Icelandic HCR the TAC is predicted from biomass of age 4+ and assumed selection of the fisheries does not affect the TAC but of course the age distribution of the landings. This leads to the effects of assumed selection being much less in this rule than in F based HCR.

2.1.6 Assessment error

BACKGROUND

Indication of assessment error and bias can be obtained from two different sources:

1. A comparison of the historical estimates with that of the current estimates,
2. A retrospective evaluation using the current framework (data and method settings).

In both cases, the assumption is that the converged VPA actually reflects the truth, both in terms of the accuracy of the measurement data as well as model assumptions.

The catch rule dictates that the TAC in the advisory year (y+1) is determined from the B4+ in the assessment year (y). In this particular case the decision rule is thus not based on predicted stock in numbers in the beginning of the advisory year or the year after the advisory year (y+1). Hence, in the case of iCod estimates of assessment errors need only to be based on performance evaluation in the assessment year (y). The contemporary estimates of the reference biomass with that obtained from the NWWG 2009 assessment is shown in figure 1. The ratio $B_{4+,y} / B_{4+,2009}$ (Figure 2.1.6.2,) gives an indication of the bias, cv and autocorrelation in the historical performance of the MRI stock assessors. Figure 2 also includes the analytical retrospective ratio, based on the current model setup and data (catch at age and spring survey) used by the NWWG 2009. Those settings have a bias of 0 %, cv 7% and autocorrelation of 0.4% for the period 1998-2006 (there is a negative bias if the period is extended to 1992). Those estimates do not take into account error in the estimates of catch weight at age that is used in the calculation of the reference biomass. They are though relatively small after the catch weights at age are predicted from survey weights in the same year.

It should be noted, that the fisheries and fisheries independent stock indices have changed considerably with time. Until 1993 limitations on cod fisheries were relatively small so the vessels catching cod were really targeting it. After that TAC in the cod fishery have been more restrictive leading to more complicated behaviour of the fleet that is often trying to maximize the proportion of what has traditionally been bycatch species in cod fisheries. This has lead to much difficulty in interpreting data from the fishing fleet as an indicator of stock size. Using commercial CPUE series as a tuning fleet in annual assessment was practiced in the period up to and including the 2000 assessment year.

Over the recent years, the survey series in March that commenced in 1985 has become longer resulting in improvement in the precision in stock assessment, in particular of the incoming recruits (3 years and younger). In 1996 another survey in October started that has now been conducted for 13 years. Although the latter is not yet part of the tuning in the "final" annual assessment, it is used analytically for evaluation of alternative state of nature from that obtained using the spring survey. If the surveys will be continued, the assessment in coming years should be reasonably precise although it cannot be excluded that a number of unprecedented things could take place. Currently ``improvement" of the March survey has been discussed and at the same time the autumn survey may be conducted every second year. Improvement or any other manipulations of survey series can be a risky thing in times of change when a HCR based directly on survey indices might have to be used.

As noted above, there are indications that the analytical retrospective patterns are much less biased than the retrospective pattern based on contemporary observations. This is mostly due to changes in model setups that take place when overestimation becomes evident. The current setup is though very much what should be considered as the natural setup, tuning with relatively long survey series using it as one index. The same might be said about the way weights at age are now predicted it done by a very simple model including just few months of growth.

CV AND AUTOCORRELATION ESTIMATES USED IN THE SIMULATIONS

Bias in assessment can be implemented by increasing the proportion of the reference biomass that is caught each year. The bias has been on the order of 8% since 1990. The bias was however not modelled in the simulation per se in the hope/belief that longer survey series will lead to lesser tendency for overestimation than can be observed in the historical passed. The analytical retrospective pattern shows that this belief is reasonably well founded.

If assessment bias is to be considered it is reminded that for the Icelandic cod the bias is the assessment is equivalent to a higher harvest rate, each 1% increase in the harvest rate being equivalent to 5% implementation error. A range of harvest rates above and below 0.2 was thus explored.

Removing the bias, the standard error in the estimate from 1991-2005 is 14 % and autocorrelation with lag 1 is 0.45 (not significant) as the time series is so short. The next 3 terms in the autocorrelation function are negative so a smaller value than 0.45 might be considered. The final conclusion was to model the log of the assessment error as a first order AR model with a CV of 0.15 and autocorrelation of 0.45. In the first year (2009) an error was applied to the stock in numbers to encapsulate similar assessment errors in the starting year as those used in the future for B4+.

It must be born in mind that the autocorrelation can be changed by changing the assessment model and the lowest autocorrelation (and probably highest CV) will be obtained by using only the most recent survey results to calculate the reference biomass. The HCR for Icelandic cod has a the TAC of last fishing year included as a stabilizer and using assessment model with too much inertia might lead to a system that responds very slowly.

The HCR rule implies that future fishing mortality will be significantly lower than has been observed since 1990. The effect on the cv is unknown (depends on the constancy if M) but autocorrelation will most likely increase.

2.1.7 Implementation error

2.1.7.1 Discarding

Discarding of fish of economic value is banned in Icelandic waters. Estimates of annual cod discards (Pálsson *et al* 2006, Pálsson *et al* 2009, in press) since 2001 are in the range of 1.4-4.3% of numbers landed and 0.4-1.8% of weight landed. Mean annual discard of cod over the period 2001-2008 was around 2 kt, or just over 1% of landings. In 2008 estimates of cod discards amounted to 1.1 kt, 0.8% of landings, the third lowest value in the period 2001-2008. The method used for deriving these estimates assumes that discarding only occurs as high grading but larger fish is usually higher priced. Given that these low estimates can be applied over the time history since 2001 and assuming similar discarding practice (largely juvenile fish), discarding is likely to have no impact on the assessment of SSB and the reference fishing mortality estimates (mean of age 5-10), with only minor effect on the estimates of the size of the recruits at age 3.

Discarding over the whole time history from 1955 is unknown, but anecdotal information indicate that they may have substantial even up to and including the period around 1990. In the absence of any quantifiable data the impact of these discarding on potential bias in dynamics of cod can however not be evaluated.

2.1.7.2 Implementation error in constraining landings

Since the establishment of a 200 mile EEZ in 1976 a fishery management system based on scientific recommendation has been developed for the fisheries in Iceland. In the early years various experimental effort control system where tried, but they did not result in constraining catches of cod, for various reasons. In 1984 a mixture of a TAC and effort control system was introduced for vessels larger than 10 GRT. In the early period the entry into the TAC system for this vessel class was voluntary. Each fishing vessel in the TAC system received a fraction of the TACs, the fraction being based on average share in the catches in the three previous years. The effort options for the size classes larger than 10 GRT was fully abandoned with the Fisheries Management Act in 1990, that first came into full force for the fishing season 1991/1992. Vessels less than 10 GRT in size had until 1990 free access to the fisheries. They were under a mixed ITQ or effort control from 1991-2000. In 2001 boats larger than 6 GRT were all placed under an ITQ system. In 2003 most boast, including those under 6 GRT were under ITQ control.

Measurements of landings from the domestic fleet are considered relatively reliable. By law, all landed catch is measured, either at port or at point of entry into the fish processing factories. In addition, captains are required to keep a contemporaneous and compulsory log-book of catches. These log-books record entries as well as random spot checking of comparisons of output from processing factories relative to that which reported to enter are used as a double control measure. The system in the last 10 years has been fully computerized, with information on daily landings by vessel available on the internet in real time.

Management measures that aim at reducing incentives or likelihood of discarding have been in place since 1991. These include some allowance for individual vessels for changing quota from one species to another, although this measure does not apply to cod. A 5% overshoot of individual vessel quota in one fishing year is permitted, with the consequences that the vessels ITQ in the next year being reduced equivalently. In addition up to 20% of the quota in one year can be transferred to the next fishing year, without penalty. A quota leasing market is also in place, where individual vessel can lease quota from other vessel owners on a contemporary basis. The system operates in real time, effectively meaning that if overshoot of catch of a particular species occurs during a trip, the captain can lease quota prior to landing. The system is however somewhat limited to the supply relative demand at any particular time.

In addition to the above flexibilities additional measures to reduce incentives for discarding were set in place in 2001, by allowing vessels to report up to 5% of annual catches as outside their ITQ allowance. These measures have resulted in total landings of around 2 kt annually in the period 2002/2003 to 2006/2007 large portion being cod (around 85%).

Since the fishing year 1991/1992 the total allowable catch have been set as follows: Following the annual assessment and advice and prior to the start of the fishing year, the TAC is first set (since 1995/1996 based on a catch rule). From that a certain amount is set aside for various socioeconomic reasons as well that likely to be caught by the effort control fleet. The remainder is then allocated to the vessels in the ITQ system, based on their individual share.

A comparison of the set TAC and the landings over the time period since 1984 are shown in figure 2.1.7.1. A measure of the implementation error in landings can be derived by taking the ratio of landings to that of the set TAC (figure 2.1.7.2). Since 1991 the implementation error has been positive with two exceptions. The bias is quite significant in some years, reaching up to 15%-20%. The mean bias is just below 10%.

The overshoot in landings in the period 1991 to 2001 has been attributed to overshooting of catches of the fleet in the effort system. This is because the linkage between that estimated to be caught, and hence subtracted from the TAC prior to the remainder being allocated to the ITQ vessels, and the allocated effort (number of days) have been unrealistic. Data to substantiate this was however not available to the authors at the time of writing of this report.

The overshooting in the period 2001 onwards is however somewhat surprising, given that by that time almost all boats where under the ITQ system. An explanation of this is at the time of this writing pending. However, overall the bias in landings over the whole time period since 1991 is significant and persistent. The massive data that is collected and available on the operation of the Icelandic fleet should however mean that most of the landing bias observed are foreseeable and predictable.

As said earlier, the fishing allowance of foreign vessels has never been taken into account prior to allocation of the TAC. The catches within the Icelandic EEZ have over the time period been relatively small, within the order of 1-2 kt. In the beginning of century, Faroese vessels started fishing on the Faroe-Icelandic ridge, just inside their own EEZ. This resulted in significant catches of cod of Icelandic origin in some years (5 kt), accounting for additional landing in excess of that intended by the HCR (Figure 2.1.7.2). It is not known if this phenomenon will persist in the future, but the Icelandic management authorities are made fully aware of these catches and have been advised by MRI to take them as well as all other into account when allocating the TAC to the ITQ fleets.

2.1.8 Reference points

In the current ICES framework the basis for the annual advice is the precautionary approach. The concept was first formally introduced in the late 1990's when for a whole sweep of stocks that ICES gives advice on, limit (B_{lim} and F_{lim}) and precautionary reference (B_{pa} and F_{pa}) points were defined. At that time a harvest control rule (25% exploitation rate) for the Icelandic cod stock was already in force. Since it was at the time it was set (1994) evaluated by ICES to be in conformity with the precautionary approach, no limit reference points were defined for Icelandic cod.

ICES has used the original rule as the basis for the annual advice for Icelandic cod up to that applicable to the fishing year 2008/2009, where the basis of the advice was changed to $F_{0.1}$. The reason for the change was: "ICES evaluation of the harvest control rule was based on simulations that did not include implementation error. ICES has considered that this harvest control rule is consistent with the precautionary approach provided that the implementation error is minimal. Because of numerous in-year changes the original rule has not been used as a basis for short-term decision-making since 2000. ICES is at present unaware of the formal long-term management plan for this stock." In such cases, the default fallback position by ICES would be to base the short term advice on limit and pa-reference points. However, in the absence of those reference points, the basis for advice for iCod in the last two years has been $F_{0.1}$. The $F_{0.1}$ basis is a general reflection of current ICES development, which is to encourage managers towards decision rules that are based on long term considerations, including those based on the B_{msy} and F_{msy} proxies.

The shift from limit to MSY approach, as well as the recent establishment of HCR for many ICES stocks, should in the future lead to less reliance on limit and pa-points as being the basis for short term advice, which in some cases have implied draconian management measures if followed to the letter. However, it is unlikely that the limit reference points will be abandoned in the near future, for the following reasons: 1) They are defined in international agreements and guidelines; 2) They are currently the cornerstone of ICES classifications of contemporary stocks status, as e.g. reflected in the top table of single species stock summaries, 3) They are currently used by environmental NGO's as well as in "green" certification of fisheries, 4) They are getting increasing economic importance fishing sector. With regards to the first two cases mentioned, the limit reference points, and their sibling pa-reference points, have often served as useful triggers points in many HCR developments. With regards to the NGO's and the fishing industry, ICES classification of the current status of fish stocks is being used as a basis for consumer advice and decisions with regards to what fish to eat and/or buy.

The basis for the definition of B_{lim} by ICES is that point of the spawning stock below which recruitment becomes impaired. Any B_{lim} value, be it subjectively based or more objectively derived, will of course be an arbitrary point along a process that is biologically continuous. Some non-parametric or parametric statistical procedures have been invented to determine B_{lim} objectively. The prevailing approach used by ICES, when revising limit reference points in the early 2000's has been the segmented regression. Considering the stock recruitment pattern for the Icelandic cod over the whole time period 1955-2008 (figure x) the NWWG 2009 observed that the frequency of poor recruitment increases when the spawning stock is somewhere below the current level (220 kt). A more objective approach based on segmented regression gives a breakpoint of 245 kt. The cumulative probability distribution of SSB_{break} is shown in figure 2.1.8.1. There it can be seen that the median is a little below the maximum likelihood estimate or around 225 kt. The difference is though less than the difference that can be obtained from the results of different assessment models. The above analysis indicates that candidate value for B_{lim}, if based on the whole time series is in the range of 220-245 kt. The estimated mean recruitment above the segmented regression breakpoint is 200 millions.

Using the data for the whole time series as a basis for deriving B_{lim} may be questioned since the large shift in recruitment around 1985 is not easily explained by changes in size or composition of the spawning stock alone. It may be argued that the recruitment pattern in time may, in addition of course to the history of exploitation rate, be the controlling factor of the spawning stock biomass development. Factors that there may have resulted in a reduction in the environmental ``carrying capacity" of juveniles, or "regime-shift" with time could be:

- Reduction in nursery areas of juvenile cod with the deteriorating environmental conditions in Greenlandic waters, starting in the late 1960´s.
- Capelin fisheries. Capelin is considered to be the most important prey for cod. In the Barents sea reduction in capelin has been linked with increased cannibalism of cod. Although cannibalism in iCod of the same magnitude as observed in the North East Arctic cod has not been observed, the increasing harvesting of capelin in Icelandic waters, commencing in the 1970's may have taken place.
- Damming of major glacial rivers, that feed directly to the major cod spawning grounds in SW-Iceland, may have had detrimental effect on the natural environmental conditions, possibly affecting egg and larval survival rate and or affected natural drift routes during the larval phase.

Direct support for the last hypothesis is none. The capelin-cannibalism hypothesis is rather weak since cannibalism in iCod of the same magnitude as observed in the North East Arctic cod has not been observed, despite the increasing harvesting of capelin in Icelandic waters, commencing in the 1970's. There are however some observational support for the Greenland hypothesis. The conceptual framework of the life history model is that substantial amount of egg and larvae may drift from spawning ground in Iceland to Greenlandic waters in certain years/periods. When the fish mature they return back to the spawning grounds in Icelandic waters. Tagging experiments as early as the 1920's and 1930's showed that substantial migration of adult cod from Greenland to Iceland occurred. In these years Icelandic waters accounted for 40% of all recaptures of cod tagged in West Greenlandic waters, with as many as 70% of recaptures of fish tagged in the southernmost Greenland. At thist time fishing effort in Greenlandic waters was low compared to what is became after the war. Despite heavy fishing in Greenland afer the war, recaptures in Icelandic waters still occured, albeit at a much lower rate (7% of all recaptures from fish tagged in West Greenland). Limited tagging studies in East Greenland waters in the 1970's indicate adult immigration from that area as well, with limited recaptures being recorded from West Greenland waters. Recaptures in Greenlandic water of cod tagged in Icelandic waters have been relatively rare, despited extensive tagging experiments. Significant immigration of cod into Icelandic waters are also observed as anomaly in the catch at age matrix, both in the 1930's as well as after the war. These anomalies are actually used for "allowance" of immigration in particlar age classes in particular years in the assessment framework. The frequency of immigrants so estimated are quite high prior to 1970, but only two immigrations are being modelled since 1971. This is not surprising, because coninciding with the deterioration in the environmetal conditions in Greenlandic waters in the late 1970's the stock and the fisheries more or lessed collapsed. The larvae drift hypothesis from Iceland is supported by density distribution observation in annual 0-group surveys in the Icelandic and East Greenlandic water, which commenced in 1970. High densities of cod larvae were observed in East Greenlandic waters in 1973 and 1984. These year classes resulted in the two but brief pulse fisheries in Greenlandic waters around 1980 and 1990 as well as anomalies in the catch at age matrix from Icelandic waters in 1981 and 1990.

If "regime-shift" is a plausible scenario the definition of B_{lim} is not quite straight forward. Allowing R_{max} to change after 1984 the stock recruitment relationship leads to an estimate of SSB_{break} that is not significantly different from the B_{loss} or 127 kt. Similar values of the breakpoint are established if the recruitment period before and after 1984/1985 are analysed separately.

Whatever base for the derivation of B_{lim} is taken (whole period, two different periods, time trend) it is clear that it is worth the experiment to increase the spawning stock size above the current level of 220 kt. That value may thus at minimum be defined as a trigger point in a HCR, which act such that when the stock is below this level the default harvest rate is reduced, e.g. linearly to Bloss. All analysis undertaken here indicate that this can be done by reducing the exploitation level from that experienced in the recent decade, despite future recruitment remaining at the low level observed since 1985.

Estimates of B_{msy} are dealt with in the result chapter.

2.2 Technical description of setup and model runs

2.2.1 ADCAM framework

OPERATING MODEL

The operating model is the virtual world, which is supposed to reflect the true system in the evaluation framework. The virtual world here is very simple with constant M, no length based parameters etc.

The biological model is a simple single-species age structured population following the classical exponential stock-equation:

$$N_{a+1,y+1} = N_{ay} e^{-\left(F_{ay}+M_{ay}\right)}$$

The age groups in the model are 1 to 14 years with age 3 the youngest age in the landings. In the settings here the oldest group (14 years) is not a plus group.

Catches are taken according to the catch-equation:

$$\hat{C}_{ay} = \frac{F_{ay}}{F_{ay}+M_{ay}}\left(1-e^{-(F_{ay}+M_{ay})}\right)N_{ay}$$

$$\hat{C}_y = \sum_a \hat{C}_{a,y} W^c_{a,y}$$

Fishing mortality by year and age is modelled as:

$$F_{ay} = s_a F_y$$

The time period that where catch at age data are available can be divide in a number of subperiods with the selection pattern s_a estimated separately for each period. The selection pattern of ages 11-14 is assumed to be identical and defined as 1.

Spawning stock is calculated by first calculating the total mortality before spawning $pZ_{y,a} = pM_a M_{y,a} + pF_a F_{y,a}$

The values pM_a and pF_a are input from file and describe proportion of M and F before spawning. The spawning stock is then calculated by

$$SSB_y = \sum_a N_{y,a} W_{y,a}^{ssb}\ p_{y,a}\ e^{-pZ_{y,a}}$$

where $p_{y,a}$ is the proportion mature by year and age.

When the spawning stock by year and age has been obtained the egg production is calculated by equation 1 in section on spawning stock and recruitment (2.1.4).

The predicted recruitment is then calculated from any or the equations in section 2.1.4 generalized as

$$\hat{N}_{1,y+1} = f(SSB_y)$$

Reference biomass is calculated from

$B_y^{ref} = \sum_{a=4}^{a=14} N_{ay} W_{ay}^c$ where W_{ay}^c are the mean weight at age in the landings.

OBSERVATION MODEL.

The model parameters are estimated by minimizing a negative log-likelihood that is the sum of 4 components.

Landings in numbers.

$$\Psi_1 = \sum_{a,y} \frac{\log \dfrac{C_{ay} + \delta_a}{\hat{C}_{ay} + \delta_a}}{2(\Omega_1 \sigma_a)^2} + \log(\Omega_1 \sigma_a)$$ where Ω_1 is an estimated parameter but the pattern of the measurement error with age σ_a is read from the input files. The values δ_a are input from file. They are supposed to reflect the value where the error goes from being lognormal to multinomial. Typical value could be corresponding to 5 otoliths sampled.

Landings in tonnes.

$$\Psi_2 = \sum_{a,y} \frac{\log \dfrac{C_y}{\hat{C}_y}}{2\Omega_2{}^2} + \log \Omega_2$$ where C_y are the "real" landings in tonnes in year y, $\hat{C}_y$ the modelled landings and Ω_2 the assumed standard error of the landings. The value of 0.05 was used for Ω_2 in these runs. The likelihood component Ψ_2 is somewhat redundant as it is already incorporated in Ψ_1. Leaving Ψ_2 out will on the other hand lead to unacceptable deviation between observed and predicted landings in numbers.

Survey abundance in numbers.

$$\Psi_3 = \sum_{a,y} \frac{\log \dfrac{I_{ay} + \delta_a^s}{\hat{I}_{ay} + \delta_a^s}}{2(\Omega_3 \sigma_a^s)^2} + \log(\Omega_3 \sigma_a^s)$$

where Ω_3 is an estimated parameter but the pattern of the measurement error with age σ_a^s is read from the input files. The values δ_a^s are input from file and are similar to δ_a in Ψ_1. The predicted survey numbers $\hat{I}_{ay}$ are calculated from the equation $\hat{I}_{ay} = q_a N_{ay}^{b_a}$. The parameters q_a and b_a are estimated parameters. (could be estimated internally by regression). The parameters b_a are set to one for age 6 and older but estimated for the younger age groups. The estimated values b_a increase with decreased age.

Stock – recruitment parameters.

$$\Psi_4 = \sum_{a,y} \frac{\log \dfrac{N_{1y}}{\hat{N}_{1y}}}{2\Omega_4^2} + \log\Omega_4$$ where $\hat{N}_{1y}$ is the estimated recruitment from the stock – recruitment function and Ω_4 is an estimated parameter. As described in section xx Ω_4 can be set as a function of SSB but that option was not used in the simulations here.

The total objective function to be minimized is

$$\Psi = \sum_{i=1}^{i=4} \Psi_i$$

The estimated parameters in most of the runs are

Effort F_y for each year 1955 – 2008

Selection pattern s_a for ages 3-10 (set to 1 for ages 11-14) in 3 periods, 1955-1975, 1976-1993 and 1994-2008.

Number of age 1 cod 1956-2009.

Initial number in each age group (usually in 1955).

Migration events (from Greenland) 11 events since 1955, the last two in 1981 and 1990.

Parameters of the stock recruitment function (2-4 depending on the function used). In addition CV in the stock recruitment function is estimated.

Catchability and power for the survey q_a for ages 1-10 and b_a for ages 1-10. 3 CV parameters Ω_1 Ω_3 and Ω_4 for those components of the objective function.

After the estimation is done the estimated variance-covariance matrix was used as proposal distribution in MCMC simulations (see Admodel builder manuals). The number of runs was between 300 000 and 1 000 000 and the parameters values were saved every 250th or 500th time. The saved chain was then used in prediction.

PREDICTION MODEL.

Natural mortality was fixed.

Maturity at age was fixed.

Future weight at age in the stock (W^s_{ay}), the catch (W^c_{ay}) and spawning stock (W^{ssb}_{ay})are modelled as:

$$W^s_{ay} = \hat{W}^s_{ay} e^{E^w_y}$$

$$W^c_{ay} = \hat{W}^c_{ay} e^{E^w_y}$$

$$W^{ssb}_{ay} = \hat{W}^{ssb}_{ay} e^{E^w_y}$$

where,

$$E^w_y = \left(\rho_w E^w_{y-1} + \sqrt{1-\rho_w{}^2}\,\varepsilon_y\right)$$

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

The error in the weight at age in landings and spawning stock in 2009 was assumed to be 1/3 of the modelled value as the survey weights for 2009 that can help in predicting these values do already exist.

The mean values of $\hat{W}^s_{ay}$, $\hat{W}^c_{ay}$ and $\hat{W}^{ssb}_{ay}$ are read from file. The selection of those "average value" has considerable effect on the outcome.

In the prediction recruitment is generated by the estimated stock-recruitment function. Added to the estimated recruitment is random lognormal noise with CV estimated in by the assessment part of the model. Uncertainty in the stock – recruitment parameters can be an important part of the total uncertainty in the prediction. Exception is when future migration was modelled with the box distribution from 70-180 million individuals, in that case the parameters and the distribution were estimated outside the model by external experts.

The selection pattern used in the prediction is the selection pattern of the last "selection period" (1994-2008). No stochasticity is modelled in the selection pattern but the uncertainty in the estimated selection pattern is transferred to the prediction.

Assessment error is modelled as autocorrelated lognormal noise as done for the stochasticity in weight.

$$\tilde{B}^{ref}_y = B^{ref}_y e^{E^b_y}$$

where

$$E^b_y = \left(\rho E^b_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y\right)$$

The TAC for the next fishing year (y/y+1) is then calculated by

$$Tac_{y/y+1} = \left(\frac{Tac_{y-1/y+} R\tilde{B}^{ref}_y}{2}\right)$$ where R is the harvest ration (0.2).

No implementation error is included in the simulations so

$$C_{y/y+1} = Tac_{y/y+1}$$

Transferred to calendar years 1/3 of the TAC for the fishing year y/y+1 is put on calendar year y and 2/3 on calendar year y+1. Therefore $C_y = \frac{2}{3}C_{y-1/y} + \frac{1}{3}C_{y/y+1}$

2.2.2 FPRESS framework

Simulations based on modified version of FPRESS were run in parallel with that done in ADCAM as a quality check and to act as a dialogue platform. The outcome from the FPRESS runs were not used in the final evaluation of the HCR rule and are hence included in this report as an appendix. For comparative settings and recruitment models the simulation gave similar results in both frameworks.

3 Results

The major impact on the likely future trajectory of the spawning stock biomass besides fishing mortality are the trajectory in weight at age, likely current and future assessment errors, the recruitment productivity and it's hypothesised linkage with spawning stock biomass. What follows is firstly an illustration of the errors in the weight at age and assessment errors. Alternative hypothesis with regards to recruitment productivity are then dealt with in the overall evaluation of risk.

3.1 Errors in the weight at age

A sample of the simulation of the errors in the weights at age is provided in figure 3.1.1, showing the historical and future catch weights for age groups 6 and 8. As in many conditions provided for the iCod here, the future mean weights are conditioned around the current low observed weights. This means that in future scenarios the weights in the catch and the stock will in 50% of the simulation be below the lowest observed historical weights. Although it is likely that weights at age in the short term may remain low, the assumption that the weights in the medium term will remain low or lower than historically observed may be considered somewhat pessimistic. However, these low future weights are in part compromised with somewhat higher maturity at age (recent average) than what is observed in the long historical time series, still similar to what has been observed since 1990.

The weight pattern on all age groups is the same as the error term is applied to all age groups. This leads to more effects of the stochasticity in weights at age than if they were assumed to be random noise. This is on the other hand the logical way looking at the patterns in the data (figure 2.1.1.2)

Of note is that the weight error in the first year (2009) is lower than that observed in later years. This is a result of survey weights being available for 2009 but they are a reasonable predictor for the catch weights in 2009.

The historical assessment errors are calculated as:

$$error = \frac{contemporaryB_{4+}}{currentB_{4+}}$$

Effectively we are assuming that the converged part of the time-series analysis reflects the true state of nature. A measure of the future assessment error is represented by:

$$error = \frac{{}^{*}B_{4+,y}}{B_{4+,y}}$$

A sample of the assessment error is provided in figure 3.1.2. It shows the historical assessment performance in the reference biomass estimates as well as a random selection of 1 future iteration. Historically the 90% confidence boundaries cover all but the most extreme historical errors observed in the 1998-2000.

The CV of stock size estimated by the assessment model is considerably lower than the assessment error used in the prediction. To get the CV in line with assumed future errors a stochastic error term was added to the numbers in 2009. The number of all age groups in 2009 was divided by this error term. This addition leads to relatively wide confidence intervals of the SSB and reference biomass in 2009. (figure 2.2.2).

3.2 Risk evaluation of spawning stock size in 2015+

Unless explicitly stated all the results from the ADCAM framework represented here are based on the following settings.

- Stochasticity in mean weight at age CV=0.12, autocorrelation 0.6, the same number applied to all age groups each year.
- Assessment error lognormal CV=0.15, autocorrelation 0.5, with no bias.

Estimated historical stock trends, based on the separable assumption are shown in figures 3.2.1 to 3.2.3. The historical estimates match well those of the NWWG 2009 assessment (see figure 2.2.3), the latter being having a random walk process in the fishing mortality, thus changing selection patterns continuously with time. The close match is not unexpected, since both models use the same data, assume the same fixed M and have a relatively stringent criteria on following landed catches (CV=0.05). Current stock size is close to the official value from the NWWG 2009 assessment with, the spawning stock size estimated to be 240 kt in the separable framework compared with 220 kt estimated by the NWWG 2009 (figure 2.2.3). These results are not driven by difference in stock in number estimates (table 2.2.1) but by slightly different weights and maturity values used for 2009 and beyond, in this work, using the average values from 2006-2008 in the low weight scenario.

Under the 20% catch rule being tested, and the recent low mean weights the probability that the spawning stock size in 2015 and 2060 will be lower than 220 kt is less than 5%, irrespective of the recruitment models tested (tables 3.2.1 – 3.2.2). Also using the low weights the spawning stock in 2015 and 2045 will in all cases but one be below 245 kt (the segmented regression breakpoint based on all data) with less than 5% probability (tables 3.2.6 and 3.2.7). The exception is the spawning stock in 2015 using box distribution of recent recruits, excluding information about the 2008 year class but the probability then becomes 6%.

If the predictions are based on mean weight and maturity at age as mean of 1985 – 2008 the probability of SSB in 2015 or 2060 being below 245 kt is always small or less than 3% (tables 3.2.7 and 3.2.8).

Increasing the harvest proportion will have much on the size of the spawning stock and therefore on the probability of being below the reference values (table 3.3.3). A harvest rate at and above 25% is most likely not precautionary, neither in the short nor the long term. The runs using the most pessimistic assumptions regarding mean weight at age and recruitment indicate more than 5% probability of being below 245 kt in the long run if a 22% harvest rate is assumed but if the most pessimistic assumption of either mean weights or recruitment is relaxed the probability is less than 5%. The results by applying different harvest rates indicate that the HCR is robust to all the assumptions tested but any bias in implementation or assessment is undesirable.

Relative effect of the assumed assessment error, stochasticity in weight and selection is shown in table 3.2.11. The effect of the error terms is not negligible but the effect of selection is not large. The small effect of selection is explained by the fact that the TAC set is independent of the selection assumed.

3.3 Evaluation of Harvest control rule in relation to Bmsy

As described in the introduction one of the requirements of the Johannesburg's declaration is that management strategies, of which HCR are one element of, should in the long run result in spawning stock size that is greater than B_{MSY}. That is equivalent to saying that harvest rate should be less than that resulting in MSY in the long run. In addition, the Johannesburg's declaration states that by 2015 the spawning stock should not be less than B_{MSY}.

The AD model builder framework was used to evaluate B_{msy}, MSY, Harvest rates leading to MSY and SSB resulting from a harvest rate of 20%, 22% and 25%. The model was run with different harvest rate and landings and spawning stock biomass in 2060 were taken as a proxy for long term values. (table 3.3.1 and 3.3.2, figures 3.4.1 to 3.3.5). The results show very flat yield per recruit curve except when Ricker type spawning stock –relationship is used but in that case the peak in the Ricker function becomes Bmsy and in those cases the ratio corresponding to MSY is in the range 0.24-0.26. In other cases MSY ratio can be any number, as the curve is so flat. The committee appointed by the minister to find the optimum ratio in the HCR used a Ricker type stock-recruitment function and got MSY ration close to 25%.

The calculations of the MSY in the model was done in 3 different ways, taking the maximum value from deterministic optimization, mean of mcmc runs or median of mcmc runs. For the poorly defined models estimated MSY ratio could vary depending on which way it was calculated but the Ricker type models were relatively robust to which basis was used for the derivation of the MSY values.

For the Ricker type models Bmsy varies from 330-530 thousand tonnes, the range in large part being a result of alternative hypothesis regarding mean weight at age and the SSB-recruitment function used (egg production, SSB 1 or 2 levels of R_{max}).

To estimate MSY or really F_{max} properly length based models need to be used taking into account that the fishery is only targeting the largest individuals of the young age groups. Therefore increased fishery of incoming age group will decrease mean weight of the survivors as well as mean age in landings.

4 Conclusions

The work here has been done using relatively simple assessment models with the critical assumption that natural mortality has been and remains constant. The results obtained indicate that the 20% HCR will lead to an increase in spawning stock biomass with less than 5% probability of the spawning stock size being below 245 kt, both in the short (2015) and long term (2060). This applies also in cases where assumptions regarding future recruitment and growth are pessimistic (historical low).

Different scenarios tested lead to variable predicted yield and spawning stock biomass but the estimated harvest ratio resulting in MSY is relatively robust to those assumptions, the harvest value being 24-26% in the cases where MSY ratio can be estimated. The proposed HCR of 20% is therefore within the harvest ratio corresponding to MSY. Looking at the Ricker functions that have reasonably defined MSY ration a harvest ratio of 20% results in less than 20% chance that the spawning stock will be below B_{msy} in the long term and a 50% or greater probability that B_{msy} will be reached by 2015. B_{msy} used here is different for different recruitment functions and mean weight assumptions as shown in tables 3.3.1 and 3.3.2.

The analysis based on different harvest rates indicates that the 20% HCR seem to be robust to a combined bias in assessment and implementation error in the range of 5-15%, in all but the most pessimistic scenarios where there is not lea-way for more than 5% bias. Continued low mean recruitment or low mean weights at age (if HCR is followed) however mean that basing reference points on the upper bound of candidates of reference points is questionable.

5 Tables

Nr	Function	SSB_{max} or	Number of	Change	variableCV	negloglikeli
1	Ricker	506	3			-25.86
2	Ricker	413.8	4	-0.67		-32.6
3	Ricker	517.9	4		0.41	-28.5
4	Ricker	435.7	5	-0.69	0.26	-33.57
5	Bevh		3			-26.41
6	Bevh		4	-0.6		-37.29
7	Segreg	245.4	3			-23.6
8	Segreg	246.2	3		0.44	-26.62
9	Eggprod	17.9	3			-29.36
10	Eggprod	15.8	4	-0.77		-32.35
11	Eggprod	18.4	4		0.35	-31.29
12	Eggprod	16.6	5	-0.79	0.25	-33.25
13	Hjörleifsson		4			-33.11
14	Hjörleifsson		5		0.37	-35.09
15	Hjörleifsson		5	-0.8		-34.46

Table 2.1.4.1: Comparison of different stock recruitment functions. The last table shows the log likelihood function and with a difference of 2 meaning significant improvement for 1 parameter. (higher negative values better fit). Change in Rmax after year class 1984 is shown when it is estimated. Rmax after 1984 is multiplied by the exponential of the value shown. VariableCv shows the parameter estimated when CV is allowed to be a function of spawning stock size. (equation 7 in section 2.1.4). Positive values show increasing CV with reduced spawning stock.

Age	NWWG 2009	sADCAM	Difference	% difference
1	325	312	13	4%
2	148	145	3	2%
3	115	112	3	2%
4	107	105	1	1%
5	49	49	0	0%
6	53	50	3	5%
7	35	34	1	4%
8	8	8	0	-6%
9	8	9	-1	-13%
10	3	3	0	-16%
11	0.839	1.167	0	-39%
12	0.278	0.392	0	-41%
13	0.030	0.044	0	-48%
14	0.020	0.026	0	-29%

Table 2.2.1: Comparison in stock in numbers estimated by the NWWG 2009 (random walk ADCAM) and used in the current work (separable ADCAM, sADCAM)

220-2015	low weight										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution	0.02	**0.05**	**0.08**	**0.14**	**0.20**	**0.28**	**0.37**	**0.47**
1985-2008		Constant	Box distribution	0.01	0.01	0.02	0.03	**0.07**	**0.11**	**0.16**	**0.22**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**
1985-2008	SSB	Hockey	1 Rmax	0.01	0.01	0.02	0.04	**0.06**	**0.09**	**0.13**	**0.19**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.00	0.01	0.01	0.03	0.04	**0.06**	**0.09**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.04	**0.06**	**0.09**
1955-2008	egg productivity	Ricker	2 Rmax	0.00	0.01	0.01	0.02	0.04	**0.06**	**0.10**	**0.13**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.00	0.01	0.01	0.02	0.03	**0.05**	**0.08**
1955-2008	SSB	Ricker	2 Rmax	0.00	0.01	0.02	0.03	**0.05**	**0.08**	**0.11**	**0.16**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.01	0.01	0.02	0.04	**0.06**	**0.09**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.01	0.01	0.02	0.04	**0.07**	**0.10**	**0.16**	**0.21**

Table 3.2.1: Summary of the probability that SSB in 2015 falls below 220 kt under the assumption of low weights using different recruitment scenarios

220-2060	low weight										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution	0.01	**0.05**	**0.09**	**0.15**	**0.22**	**0.31**	**0.40**	**0.48**
1985-2008		Constant	Box distribution	0.01	**0.05**	**0.09**	**0.15**	**0.22**	**0.31**	**0.40**	**0.48**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.01	0.01	0.03	**0.06**	**0.10**	**0.15**	**0.21**
1985-2008	SSB	Hockey	1 Rmax	0.02	0.04	**0.07**	**0.12**	**0.19**	**0.27**	**0.35**	**0.45**
1955-2008	egg productivity	Ricker	1 Rmax	0.01	0.01	0.01	0.01	0.02	**0.05**	**0.09**	**0.17**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.03	0.03	0.04	**0.05**	**0.08**	**0.12**	**0.18**	**0.27**
1955-2008	egg productivity	Ricker	2 Rmax	0.01	0.02	0.03	0.04	**0.08**	**0.14**	**0.22**	**0.33**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.01	0.01	0.02	0.03	**0.05**	**0.08**	**0.14**
1955-2008	SSB	Ricker	2 Rmax	0.02	0.03	**0.05**	**0.08**	**0.13**	**0.19**	**0.27**	**0.37**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.01	0.02	**0.06**	**0.11**	**0.16**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.02	0.04	**0.08**	**0.14**	**0.20**	**0.29**	**0.37**	**0.46**

Table 3.2.2: Summary of the probability that SSB in 2060 falls below 220 kt under the assumption of low weights using different recruitment scenarios

220-2015	mean weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution								
1985-2008		Constant	Box distribution	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.09**	**0.14**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.00	0.00	0.01	0.01	0.03	**0.05**
1985-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**	**0.12**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.04
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.00	0.00	0.00	0.01	0.01	0.03	**0.05**
1955-2008	egg productivity	Ricker	2 Rmax	0.00	0.00	0.00	0.01	0.01	0.03	0.04	**0.07**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04
1955-2008	SSB	Ricker	2 Rmax	0.00	0.00	0.01	0.01	0.02	0.04	**0.06**	**0.09**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.01	0.01	0.02	0.03	**0.05**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.00	0.00	0.01	0.02	0.04	**0.06**	**0.09**	**0.14**

Table 3.2.3: Summary of the probability that SSB in 2015 falls below 220 kt under the assumption of average weights using different recruitment scenarios

220-2060	mean weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution								
1985-2008		Constant	Box distribution	0.01	0.01	0.04	**0.09**	**0.14**	**0.21**	**0.30**	**0.39**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.01	0.01	0.03	**0.07**	**0.11**	**0.16**
1985-2008	SSB	Hockey	1 Rmax	0.00	0.01	0.04	**0.07**	**0.12**	**0.19**	**0.26**	**0.34**
1955-2008	egg productivity	Ricker	1 Rmax	0.02	0.02	0.02	0.02	0.03	0.04	**0.06**	**0.10**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.03	0.04	0.04	0.04	**0.06**	**0.09**	**0.13**	**0.19**
1955-2008	egg productivity	Ricker	2 Rmax	0.03	0.03	0.04	**0.05**	**0.07**	**0.10**	**0.15**	**0.23**
1955-2008	SSB	Ricker	1 Rmax	0.01	0.01	0.01	0.01	0.02	0.04	**0.06**	**0.10**
1955-2008	SSB	Ricker	2 Rmax	0.02	0.02	0.03	**0.05**	**0.09**	**0.13**	**0.20**	**0.27**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.00	0.01	0.03	**0.06**	**0.12**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.00	0.01	0.04	**0.08**	**0.13**	**0.20**	**0.27**	**0.36**

Table 3.2.4: Summary of the probability that SSB in 2060 falls below 220 kt under the assumption of average weights using different recruitment scenarios

245-2015	low weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution	**0.06**	**0.10**	**0.16**	**0.23**	**0.31**	**0.40**	**0.52**	**0.61**
1985-2008		Constant	Box distribution	0.01	0.02	0.04	**0.08**	**0.12**	**0.18**	**0.25**	**0.34**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.01	0.02	0.04	**0.06**	**0.09**	**0.13**
1985-2008	SSB	Hockey	1 Rmax	0.01	0.02	0.04	**0.07**	**0.11**	**0.16**	**0.22**	**0.30**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.01	0.02	0.03	**0.05**	**0.08**	**0.11**	**0.14**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.01	0.02	0.02	0.04	**0.07**	**0.10**	**0.14**
1955-2008	egg productivity	Ricker	2 Rmax	0.01	0.02	0.03	**0.05**	**0.07**	**0.11**	**0.15**	**0.21**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.01	0.02	0.03	0.04	**0.06**	**0.09**	**0.13**
1955-2008	SSB	Ricker	2 Rmax	0.01	0.02	0.04	**0.06**	**0.08**	**0.12**	**0.18**	**0.24**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.01	0.02	0.03	0.04	**0.07**	**0.10**	**0.14**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.02	0.03	**0.05**	**0.08**	**0.12**	**0.18**	**0.24**	**0.33**

Table 3.2.5: Summary of the probability that SSB in 2015 falls below 245 kt under the assumption of low weights using different recruitment scenarios

245-2060	low weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution	**0.05**	**0.09**	**0.16**	**0.24**	**0.33**	**0.42**	**0.53**	**0.62**
1985-2008		Constant	Box distribution	**0.05**	**0.09**	**0.16**	**0.24**	**0.33**	**0.42**	**0.53**	**0.62**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.01	0.03	**0.06**	**0.10**	**0.16**	**0.22**	**0.28**
1985-2008	SSB	Hockey	1 Rmax	0.04	**0.08**	**0.13**	**0.20**	**0.28**	**0.35**	**0.46**	**0.56**
1955-2008	egg productivity	Ricker	1 Rmax	0.01	0.01	0.02	0.03	0.04	**0.08**	**0.14**	**0.23**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.04	**0.05**	**0.06**	**0.09**	**0.12**	**0.18**	**0.26**	**0.36**
1955-2008	egg productivity	Ricker	2 Rmax	0.02	0.03	0.05	**0.08**	**0.13**	**0.21**	**0.30**	**0.42**
1955-2008	SSB	Ricker	1 Rmax	0.01	0.01	0.02	0.03	**0.05**	**0.08**	**0.13**	**0.19**
1955-2008	SSB	Ricker	2 Rmax	0.03	**0.05**	**0.09**	**0.14**	**0.19**	**0.27**	**0.36**	**0.47**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.01	0.02	0.05	0.10	0.16	0.23
1955-2008	SSB	Beverton-Holt	2 Rmax	0.04	**0.08**	**0.14**	**0.22**	**0.30**	**0.40**	**0.49**	**0.58**

Table 3.2.6: Summary of the probability that SSB in 2060 falls below 245 kt under the assumption of low weights using different recruitment scenarios

245-2015	mean weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution								
1985-2008		Constant	Box distribution	0.00	0.01	0.02	0.03	**0.06**	**0.10**	**0.16**	**0.22**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**
1985-2008	SSB	Hockey	1 Rmax	0.00	0.01	0.02	0.03	**0.06**	**0.09**	**0.13**	**0.19**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.07**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**
1955-2008	egg productivity	Ricker	2 Rmax	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**	**0.11**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.00	0.01	0.01	0.02	0.03	**0.05**	**0.07**
1955-2008	SSB	Ricker	2 Rmax	0.00	0.01	0.01	0.02	0.04	**0.07**	**0.10**	**0.15**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.06**	**0.08**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.00	0.01	0.02	0.04	**0.06**	**0.10**	**0.15**	**0.21**

Table 3.2.7: Summary of the probability that SSB in 2015 falls below 245 kt under the assumption of mean weights using different recruitment scenarios

245-2060	mean weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution								
1985-2008		Constant	Box distribution	0.01	0.04	**0.09**	**0.15**	**0.22**	**0.31**	**0.41**	**0.50**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.01	0.03	**0.07**	**0.11**	**0.16**	**0.22**
1985-2008	SSB	Hockey	1 Rmax	0.01	0.03	**0.07**	**0.12**	**0.19**	**0.26**	**0.35**	**0.45**
1955-2008	egg productivity	Ricker	1 Rmax	0.02	0.02	0.03	0.03	0.04	**0.06**	**0.09**	**0.15**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.04	**0.05**	**0.05**	**0.07**	**0.10**	**0.13**	**0.18**	**0.27**
1955-2008	egg productivity	Ricker	2 Rmax	0.04	**0.05**	**0.06**	**0.07**	**0.11**	**0.14**	**0.21**	**0.30**
1955-2008	SSB	Ricker	1 Rmax	0.01	0.01	0.02	0.02	0.04	**0.06**	**0.09**	**0.14**
1955-2008	SSB	Ricker	2 Rmax	0.03	0.04	**0.06**	**0.09**	**0.14**	**0.20**	**0.27**	**0.37**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.01	0.02	**0.05**	**0.10**	**0.16**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.01	0.04	**0.07**	**0.13**	**0.20**	**0.29**	**0.38**	**0.48**

Table 3.2.8: Summary of the probability that SSB in 2060 falls below 245 kt under the assumption of mean weights using different recruitment scenarios

15<09	low weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution	**0.05**	**0.09**	**0.14**	**0.23**	**0.34**	**0.44**	**0.56**	**0.67**
1985-2008		Constant	Box distribution	0.01	0.02	0.04	**0.07**	**0.10**	**0.16**	**0.26**	**0.35**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.01	0.02	0.03	**0.06**	**0.09**	**0.13**
1985-2008	SSB	Hockey	1 Rmax	0.01	0.02	0.03	**0.05**	**0.09**	**0.15**	**0.22**	**0.31**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.00	0.01	0.01	0.03	**0.05**	**0.08**	**0.12**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**	**0.13**
1955-2008	egg productivity	Ricker	2 Rmax	0.00	0.00	0.02	0.03	**0.05**	**0.09**	**0.14**	**0.20**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.00	0.01	0.01	0.02	0.04	**0.07**	**0.11**
1955-2008	SSB	Ricker	2 Rmax	0.00	0.01	0.02	0.04	**0.06**	**0.12**	**0.17**	**0.23**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.09**	**0.13**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.01	0.02	0.03	**0.06**	**0.11**	**0.17**	**0.24**	**0.32**

Table 3.2.9: Summary of the probability that SSB in 2015 falls below the SSB in 2009 under the assumption of low weights using different recruitment scenarios

15<09	mean weights										
Time period	Data	Model	Assumptions	20	21	22	23	24	25	26	27
1985-2007		Constant	Box distribution								
1985-2008		Constant	Box distribution	0.00	0.01	0.02	**0.05**	**0.09**	**0.13**	**0.21**	**0.31**
1955-2008	SSB	Hockey	1 Rmax	0.00	0.00	0.00	0.01	0.02	**0.05**	**0.07**	**0.12**
1985-2008	SSB	Hockey	1 Rmax	0.00	0.01	0.02	0.04	**0.07**	**0.12**	**0.18**	**0.27**
1955-2008	egg productivity	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.01	0.03	**0.05**	**0.08**
1955-2008	SSB, mean age	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.06**	**0.10**
1955-2008	egg productivity	Ricker	2 Rmax	0.00	0.00	0.01	0.02	0.03	**0.06**	**0.10**	**0.14**
1955-2008	SSB	Ricker	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.03	**0.05**	**0.08**
1955-2008	SSB	Ricker	2 Rmax	0.00	0.00	0.01	0.03	**0.05**	**0.08**	**0.14**	**0.20**
1955-2008	SSB	Beverton-Holt	1 Rmax	0.00	0.00	0.00	0.01	0.02	0.04	**0.07**	**0.11**
1955-2008	SSB	Beverton-Holt	2 Rmax	0.00	0.01	0.02	0.04	**0.08**	**0.14**	**0.20**	**0.28**

Table 3.2.9: Summary of the probability that SSB in 2015 falls below the SSB in 2009 under the assumption of mean weights using different recruitment scenarios. The mean weights are applied to the 2009 values.

Time period	Data	Model	Assumptions	Bmsy	ssb20	ssb22	ssb25	rat
1985-2007		Constant	Box distribution					
1985-2008		Constant	Box distribution	280	384	328	259	0.73
1955-2008	SSB	Hockey	1 Rmax	391	541	459	361	0.72
1985-2008	SSB	Hockey	1 Rmax	357	419	357	278	0.85
1955-2008	egg productivity	Ricker	1 Rmax	518	632	560	432	0.82
1955-2008	SSB, mean age	Ricker	1 Rmax	381	520	446	349	0.73
1955-2008	egg productivity	Ricker	2 Rmax	411	508	444	341	0.81
1955-2008	SSB	Ricker	1 Rmax	468	627	547	432	0.75
1955-2008	SSB	Ricker	2 Rmax	334	446	391	306	0.75
1955-2008	SSB	Beverton-Holt	1 Rmax	790	659	548	410	1.20
1955-2008	SSB	Beverton-Holt	2 Rmax	649	400	340	267	1.62

Table 3.3.1: Estimates of Bmsy and SSB at 20%, 22% and 25% harvest rate. The last column is the ratio of Bmsy and SSB at 20% harvest rate. Based on low weights, agerage 2006-2008.

Time period	Data	Model	Assumptions	msyssb	ssb20	ssb22	ssb25	rat
1985-2007		Constant	Box distribution					
1985-2008		Constant	Box distribution	373	443	373	288	0.84
1955-2008	SSB	Hockey	1 Rmax	572	625	524	403	0.91
1985-2008	SSB	Hockey	1 Rmax	406	483	406	310	0.84
1955-2008	egg productivity	Ricker	1 Rmax	482	669	591	482	0.72
1955-2008	SSB, mean age	Ricker	1 Rmax	757	603	498	388	1.26
1955-2008	egg productivity	Ricker	2 Rmax	383	531	475	383	0.72
1955-2008	SSB	Ricker	1 Rmax	521	690	607	478	0.75
1955-2008	SSB	Ricker	2 Rmax	370	492	432	342	0.75
1955-2008	SSB	Beverton-Holt	1 Rmax	1035	775	635	467	1.34
1955-2008	SSB	Beverton-Holt	2 Rmax	387	461	387	298	0.84

Table 3.3.2: Estimates of Bmsy and SSB at 20%, 22% and 25% harvest rate. The last column is the ratio of Bmsy and SSB at 20% harvest rate. Based on mean weights 1985-2008.

	SSB 2015 < 220	SSB2015< 245	SSB 2015 <400	MeanSSB 2015	SSB2060<220	SSB2060<245	SSB2060 <400
Key run	0.005	0.014	0.323	459	0.015	0.038	0.436
Recruitment only	0	0	0.11	461	0	0.003	0.352
Recruitment and weight	0	0	0.232	462	0.005	0.015	0.397
Recruitment and assessment	0.002	0.003	0.273	458	0.002	0.015	0.422
Selection4plus	0.006	0.015	0.335	454	0.023	0.052	0.498
Selection6plus	0.01	0.018	0.32	459	0.025	0.056	0.445

Table 3.2.11: Summary of come deviations from the model based on segmented regression using data from 1985-2008 and average mean weight at age from 2006-2008.

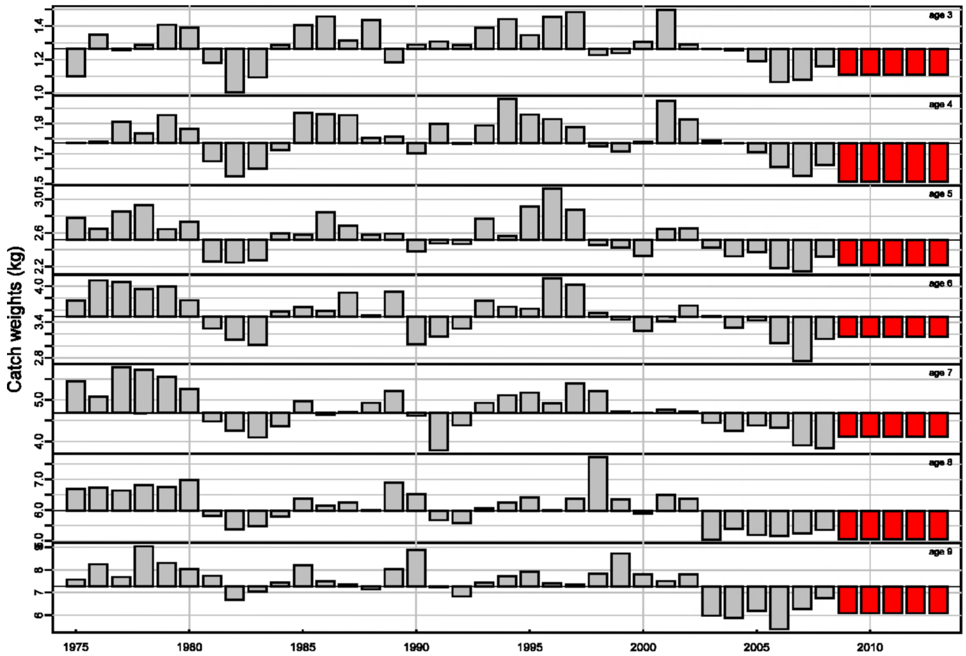

Figure 2.1.1.1: Mean observed weight at age (numbers indicate age classes) in the catches 1974-2008, with predicted and assumed mean weight at age for 2009 and beyond.

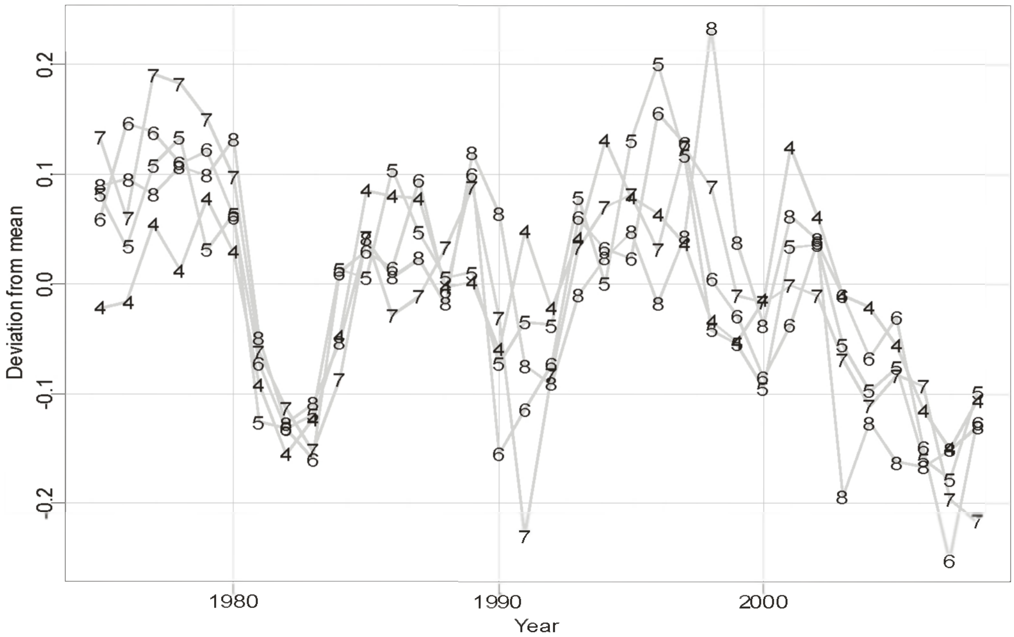

Figure 2.1.1.2: Deviation of log weight in each year from the mean log weight at age within each age group. The number refers to age classes.

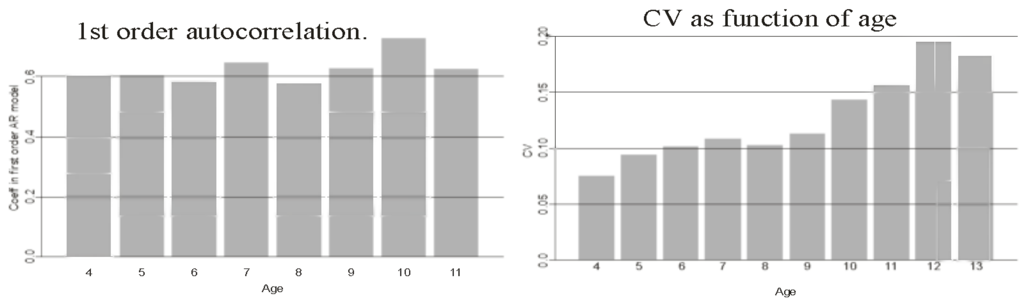

Figure 2.1.1.3: Autocorrelation and CV of mean weight at age in the catches from 1975-2008.

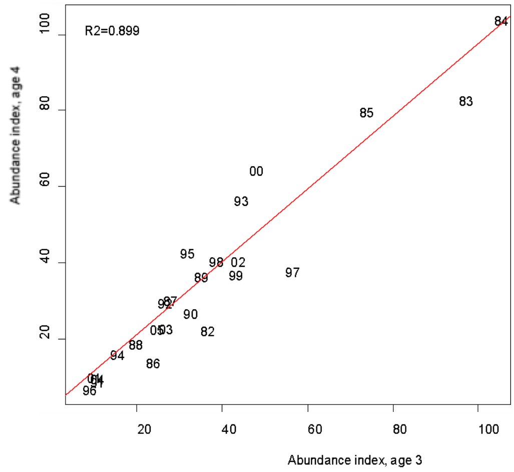

Figure 2.1.3.1: Correlation between abundance index from the spring survey, age 3 vs. age 4. The text refers to year class.

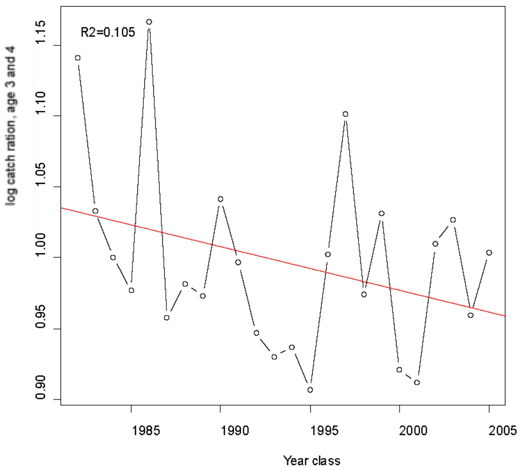

Figure 2.1.3.2: Log survey index ratio for age 3 and 4 of each year class as a function of time.

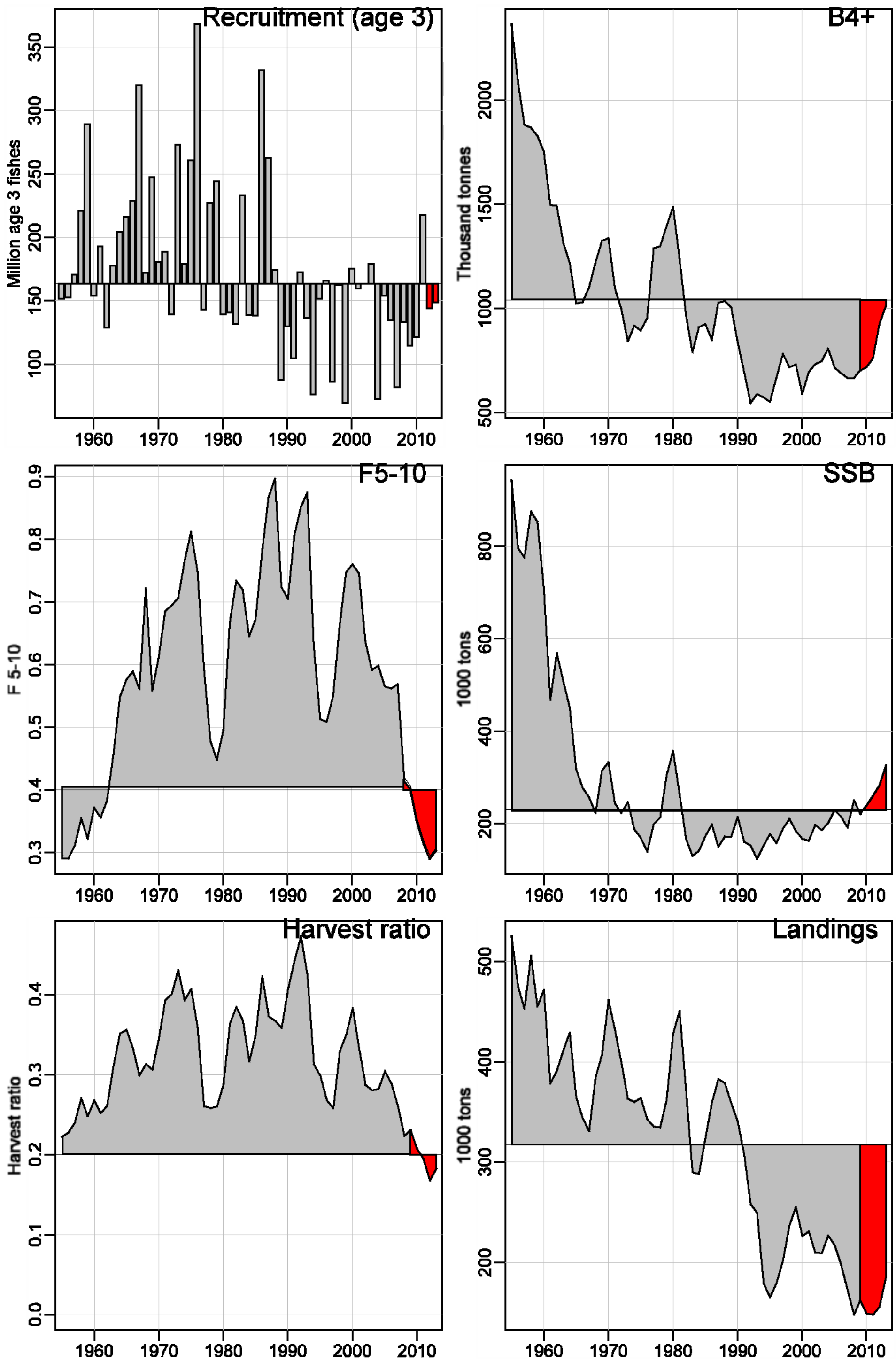

Figure 2.1.4.1: Icelandic cod stock dynamics summary figure, based on NWWG 2009. Red lines are short term predictions based on the 20% harvest rule.

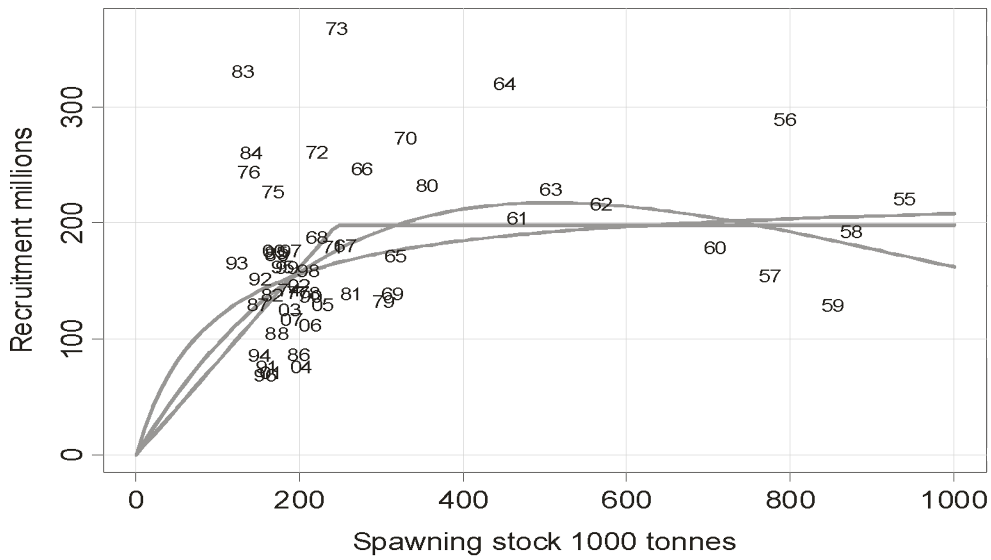

Figure 2.1.4.2: Recruitment vs. spawning stock for Icelandic cod from 1955-2007. The text labels denote year classes.

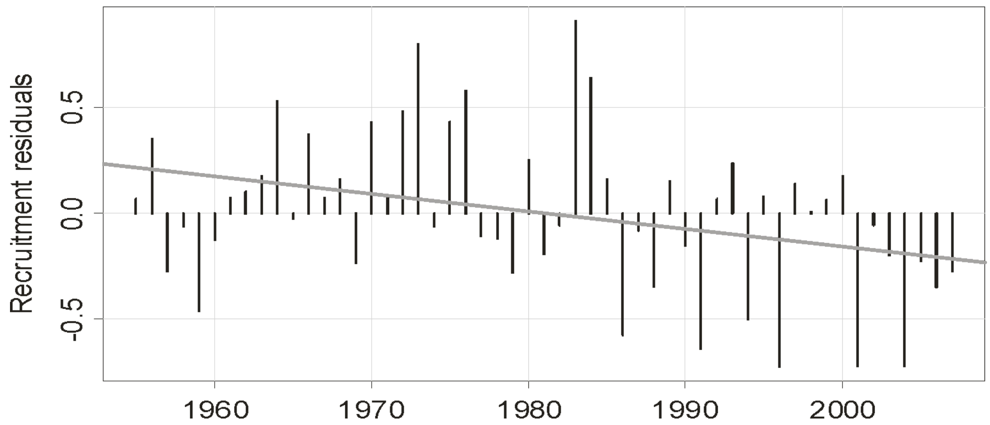

Figure 2.1.4.3: Residuals from the Ricker curve shown in figure 2 as a function of time

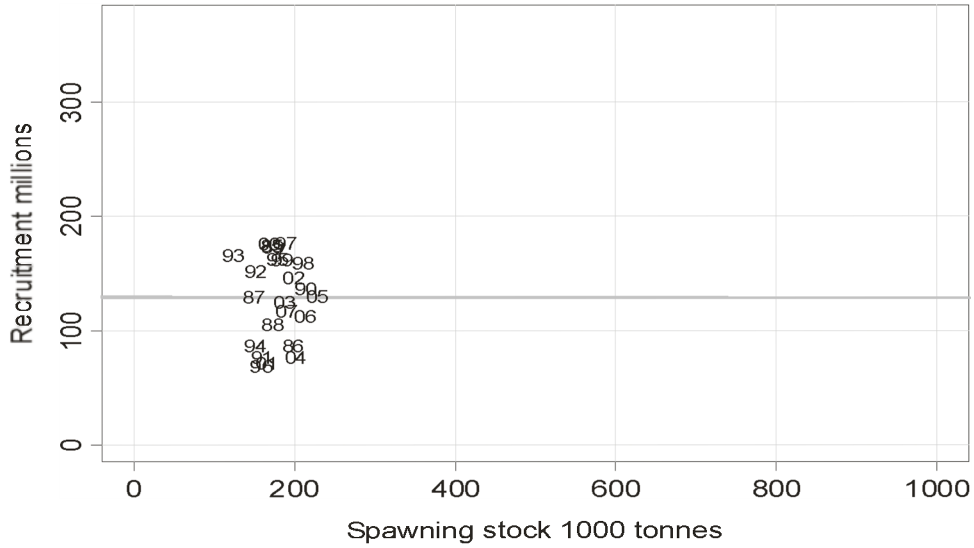

Figure 2.1.4.4: Recruitment vs. spawning stock for Icelandic cod from 1985 - 2007. The text labels denote year classes.

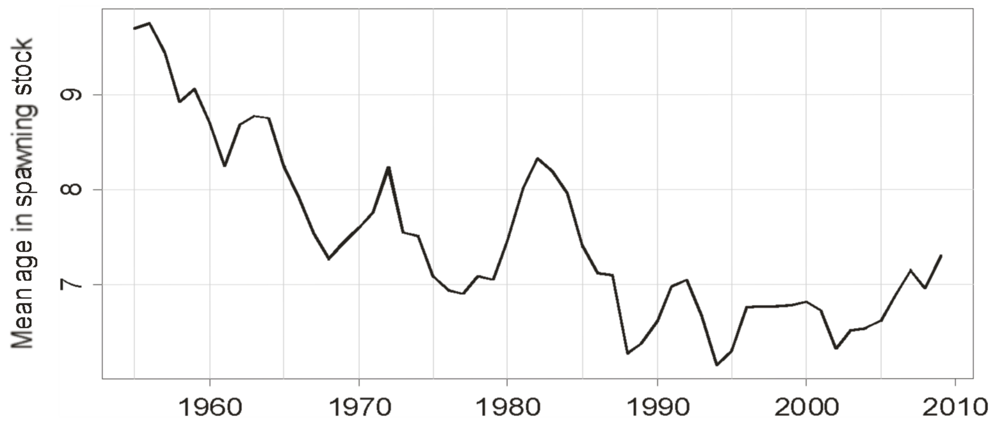

Figure 2.1.4.5: Mean age in the spawning stock.

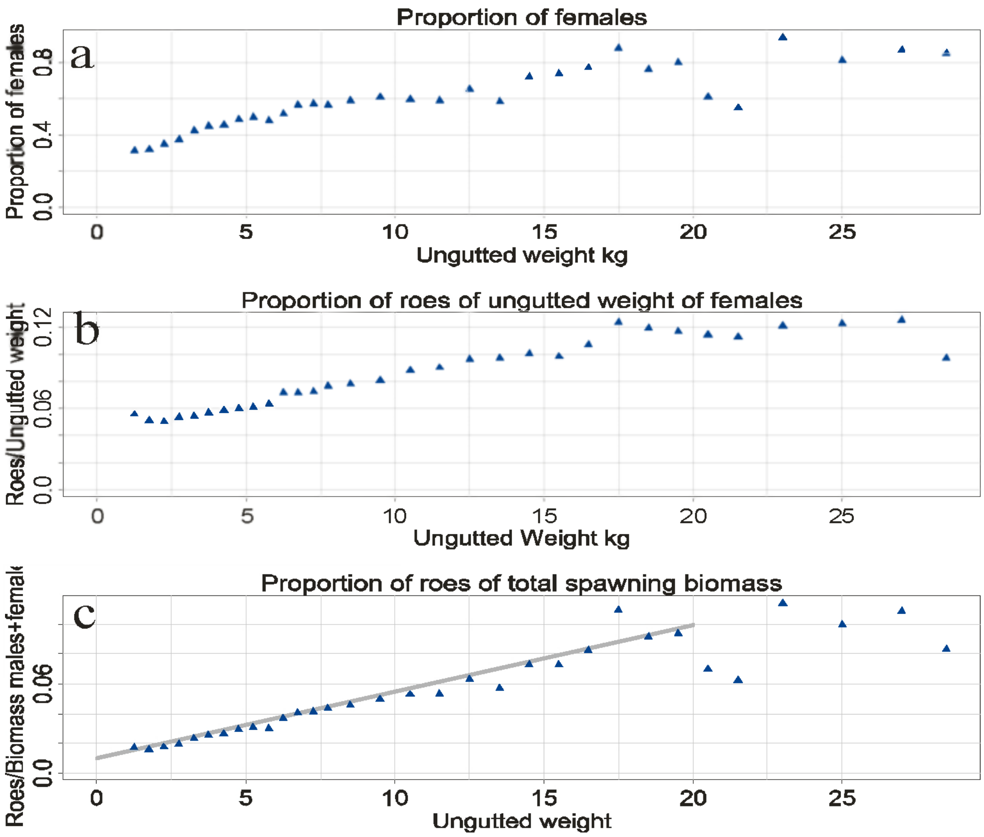

Figure 2.1.4.6 a) Proportion of females as function of ungutted weight b) Weight of roes as proportion of ungutted weight as function vs. ungutted weight c) The biomass of roes as proportion of spawning stock biomass as function of ungutted weight

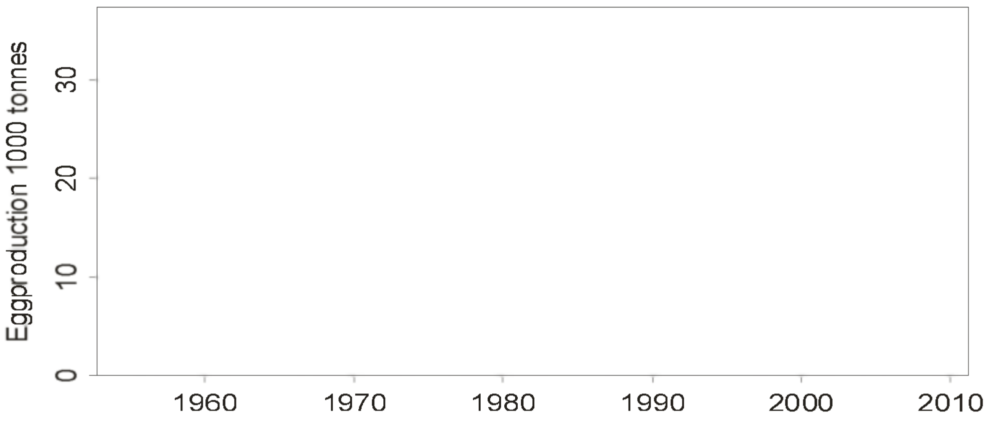

Figure 2.1.4.7: Estimated egg production from 1955 to 2009 in 1000 tonnes.

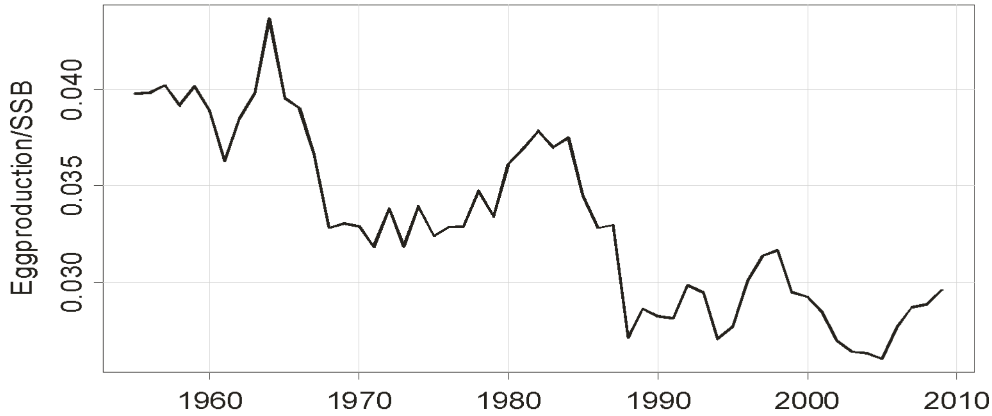

Figure 2.1.4.8: Egg production as proportion of spawning stock biomass from 1955 to 2009.

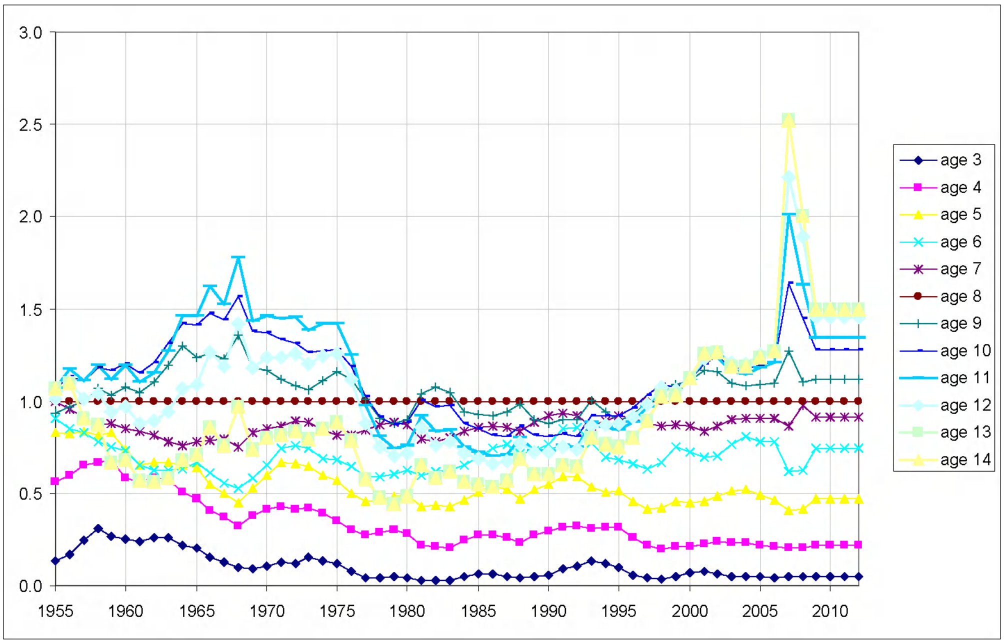

Figure 2.1.5.1: Annual selection pattern relative to age 8.

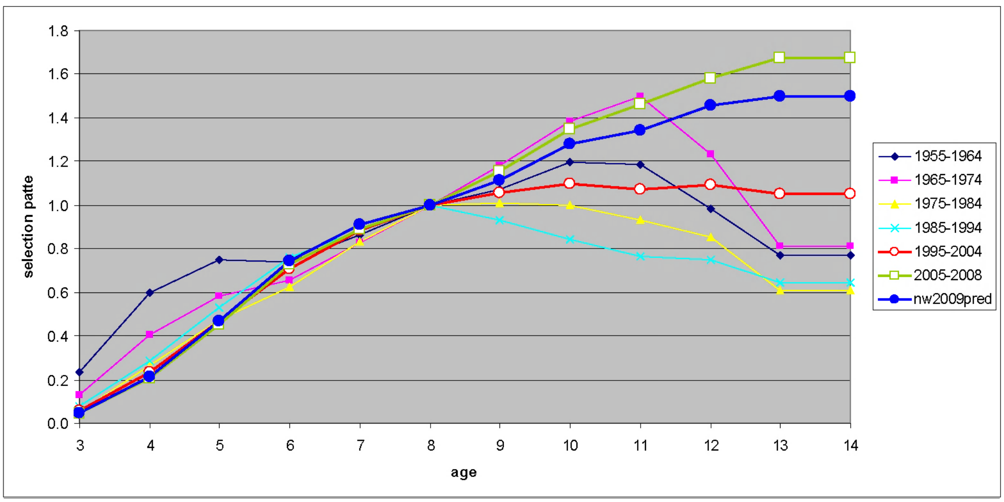

Figure 2.1.5.2: Selection pattern by age in 10-year blocks, starting with 1955-1964.

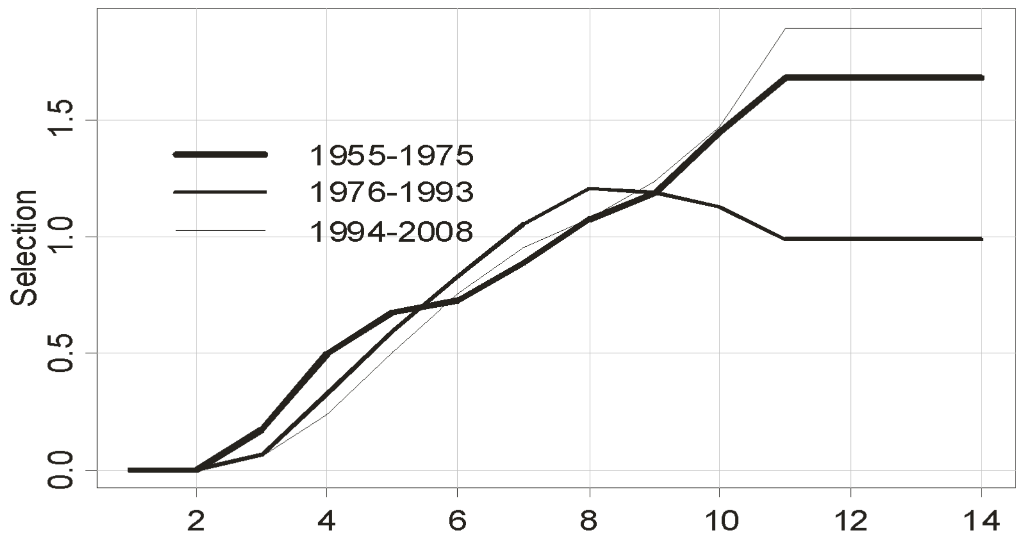

Figure 2.1.5.3: Estimated selection pattern based on the data from 1955. The estimates from 1994-2008 are used in the simulations.

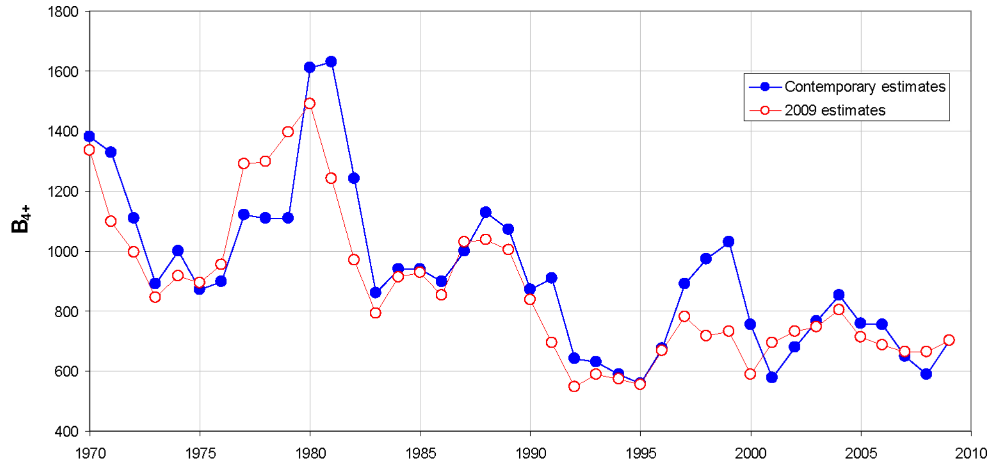

Figure 2.1.6.1: Contemporary and current estimates of the reference biomass (B4+).

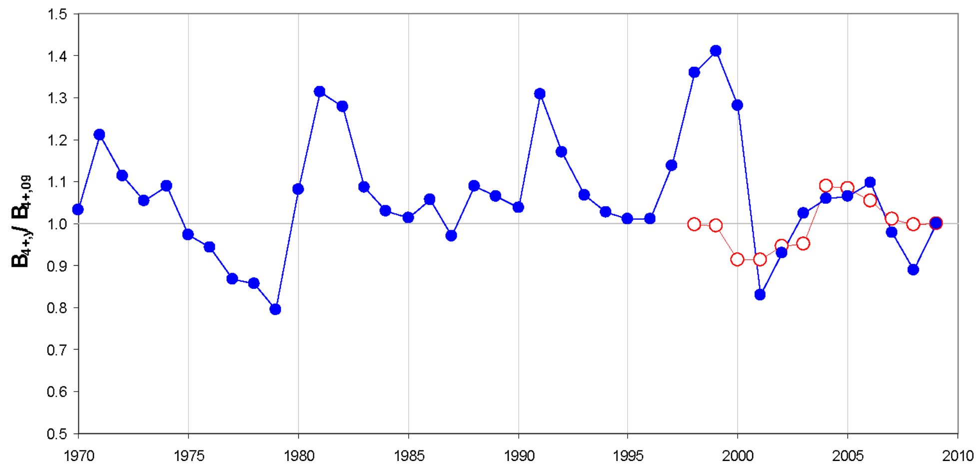

Figure 2.1.6.2: Historical and analytical assessment error of reference biomass (B4+). Shown is the ratio of contemporary biomass (estimated in the year indicated) relative to that estimated in the last assessment (2009). The filled points (blue) show the ratio based on the historical assessment, the open points (red) are based on the analytical retrospective patterns, only incorporating errors in numbers in stock.

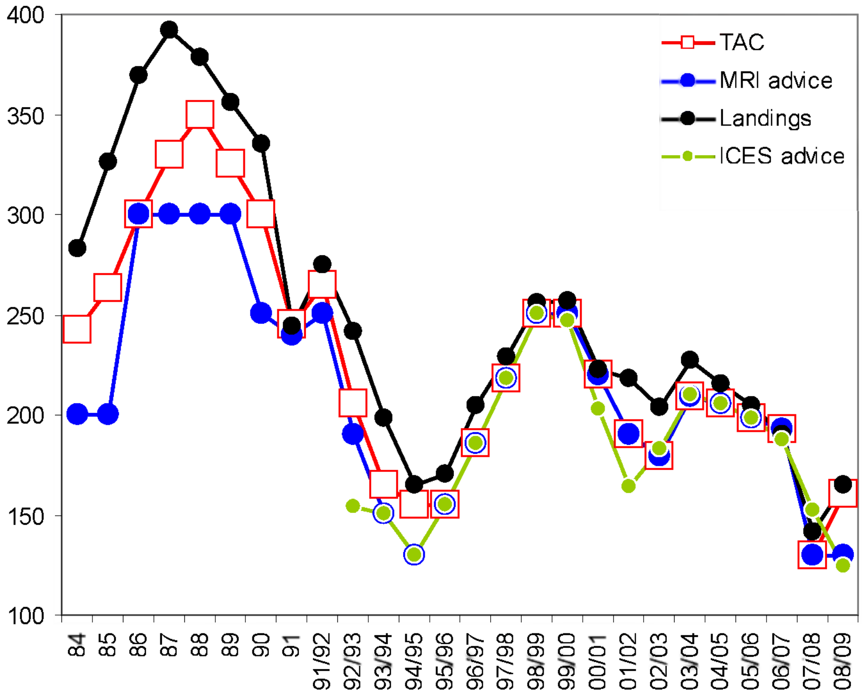

Figure 2.1.7.1: ICES advice, domestic advice, set TAC and recorded landings of Icelandic cod by calendar / fishing year.

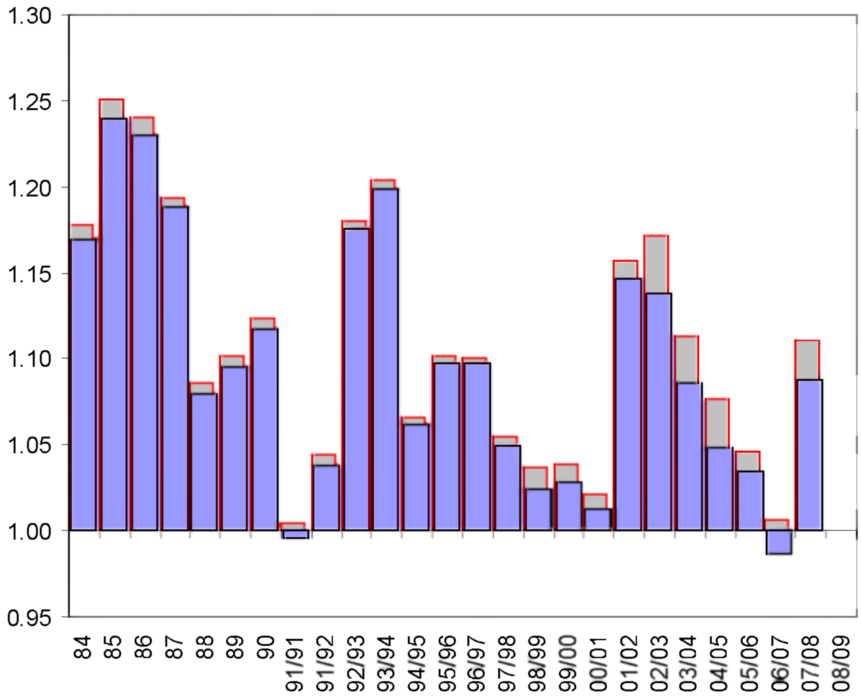

Figure 2.1.7.2: Measure of implementation bias in landings based on the ratio of recorded landings and set TAC of Icelandic cod by calendar / fishing year. The grey bars show the total recorded landings (domestic, foreign catches inside Icelandic EEZ and Faroese catches of Icelandic cod inside Faroese EEZ), the blue bars the landings of the domestic fleet only.

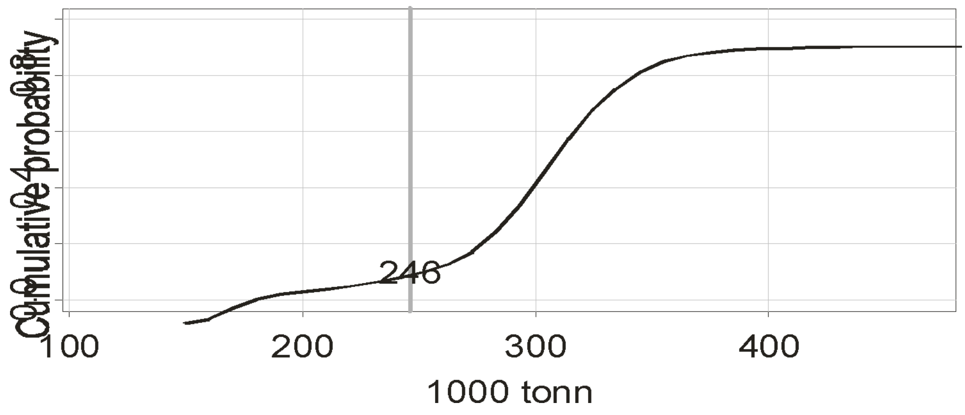

Figure 2.1.8.1: Cumulative probability plot of the breakpoint segmented regression SSB value based on recruitment from SSB and recruitment values from the whole time series.

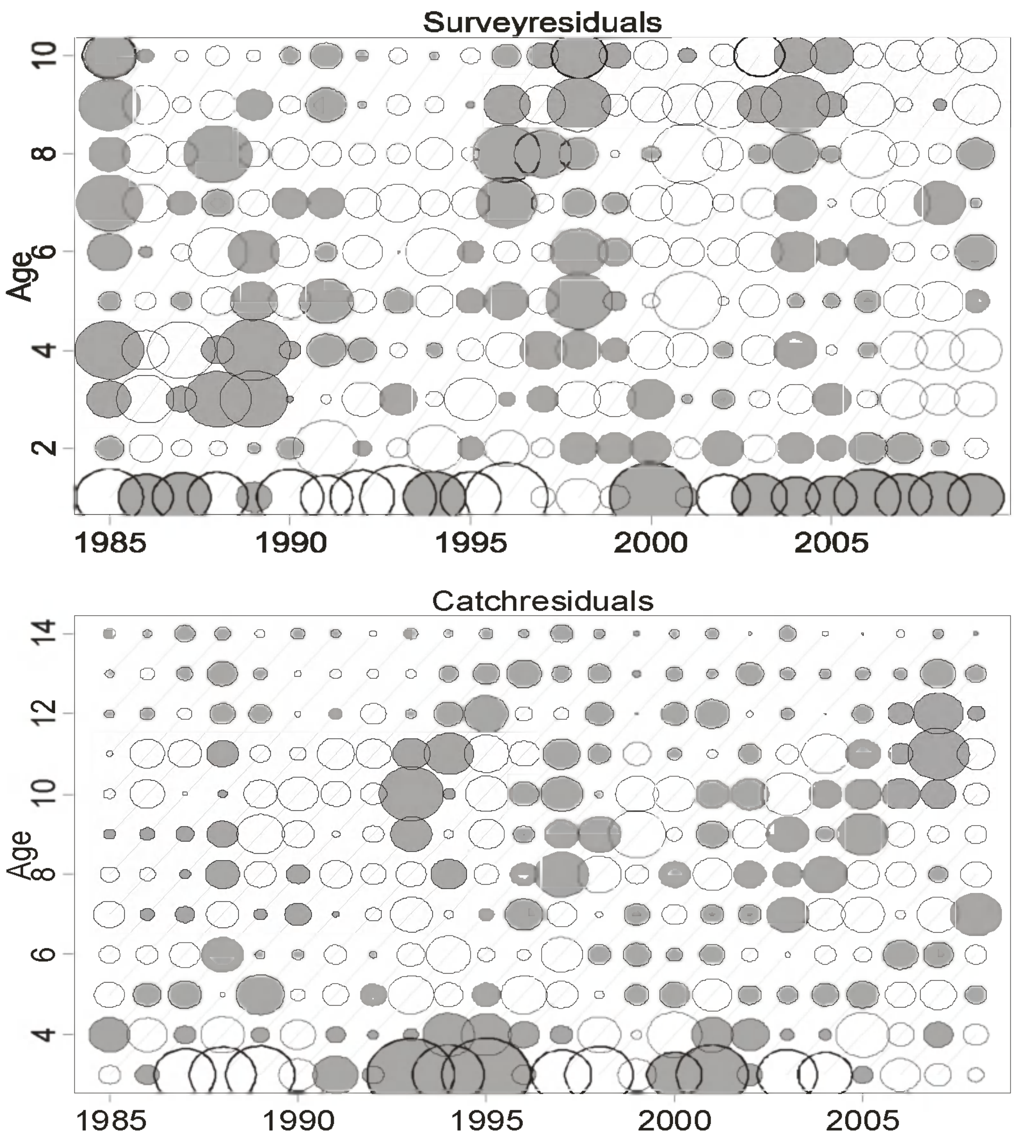

Figure 2.2.1: Survey and catch residuals from the ADCAM model. Shaded values represent positive residuals (observed higher than predicted), white values represent negative residuals.

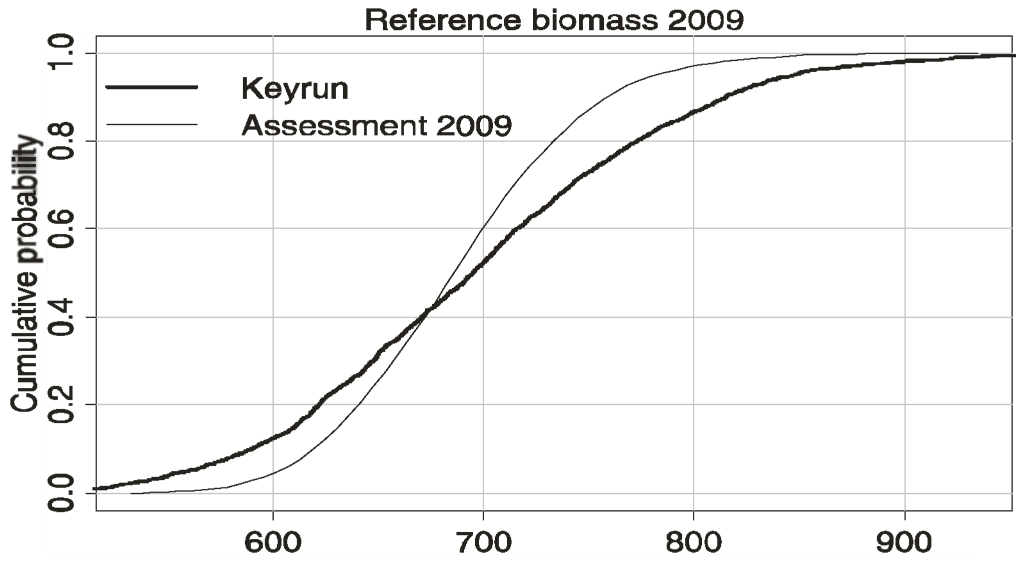

Figure 2.2.2: Probability distribution of the reference biomass as estimated by the NWWG 2009 (random walk ADCAM) and that based on the separable ADCAM model used in the simulation studies.

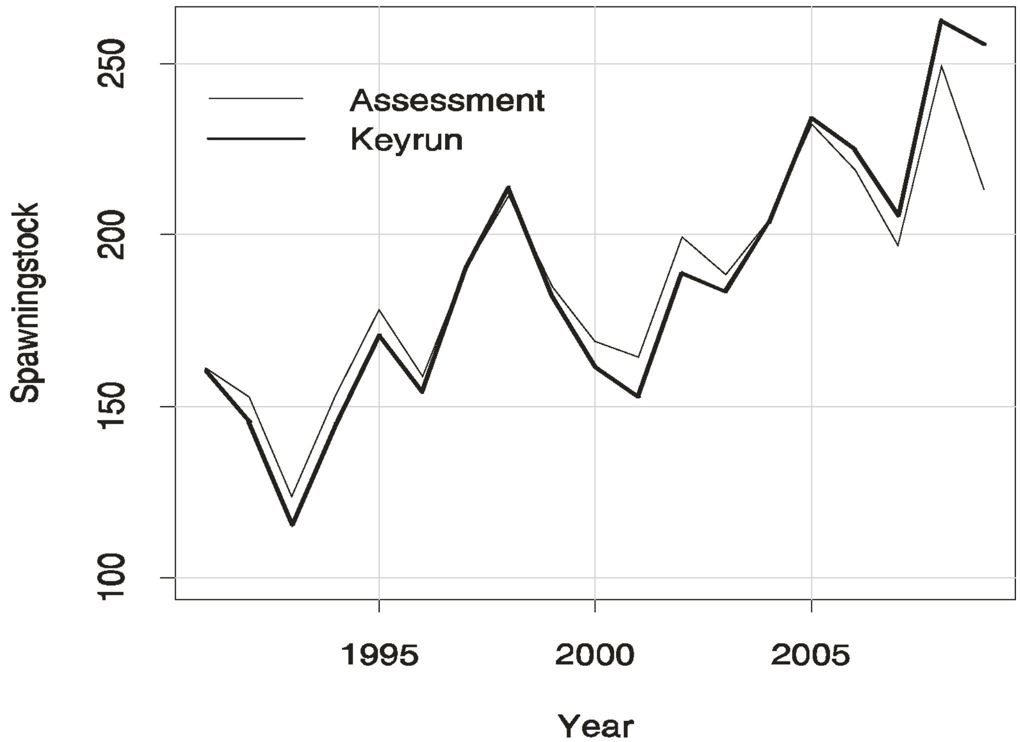

Figure 2.2.3: Comparison of the spawning stock biomass estimated by the NWWG 2009 (random walk ADCAM) and that based on the separable ADCAM model used in the simulation studies. The difference in the year 2009 is largely driven by the simulation using average maturity and weight at age from 2006-2008, but the NWWG using survey measurements from 2009.

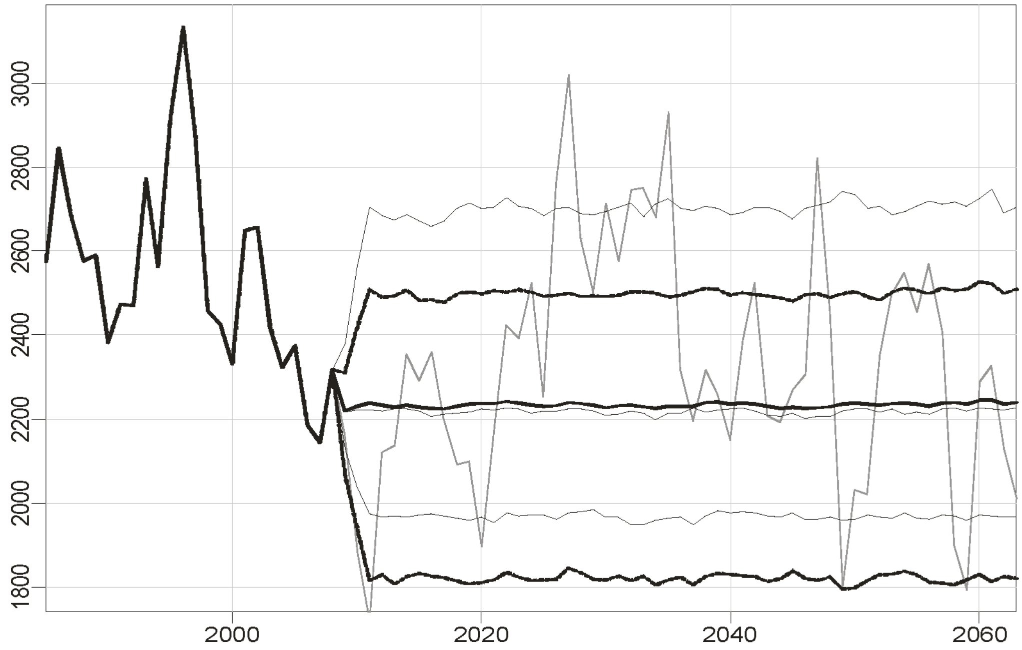

Figure 3.1.1: Historical and simulated value of catch weight at age, for age class 5 Future weights show the median value, ± 1 standard deviation, and the 5th and 95th percentile and one randomly chosen iteration.

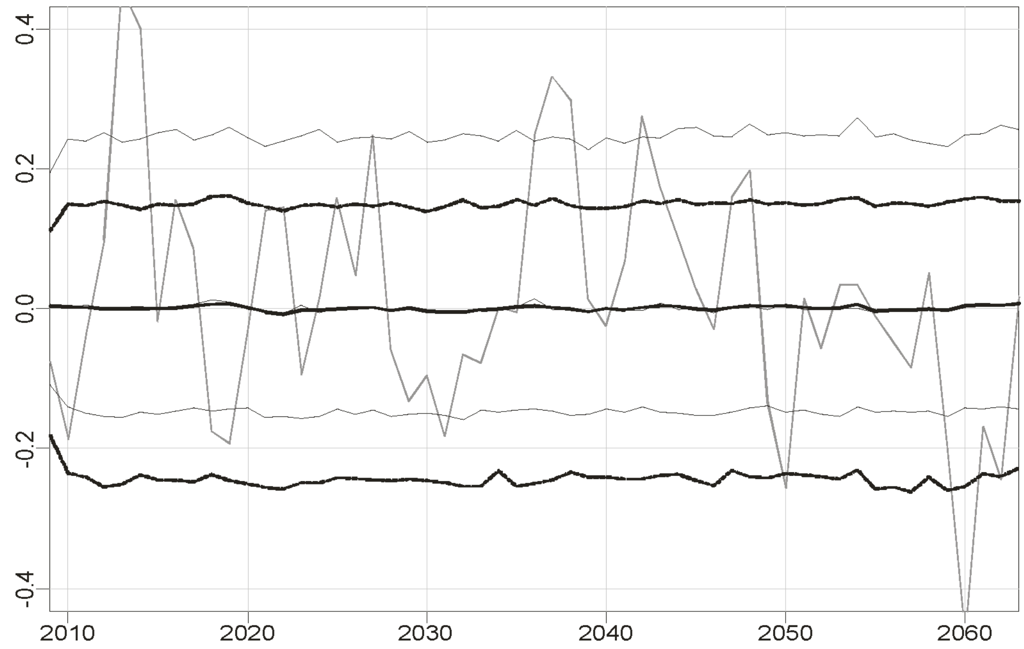

Figure 3.1.2: Simulated assessment errors (B4+) Future values show the median value (thick line) ± 1 standard deviation and the 5th and 95th percentile. One randomly drawn iteration is displayed. The error shown in 2009 is without the model error obtained from the inverse hessian that is used in each run.

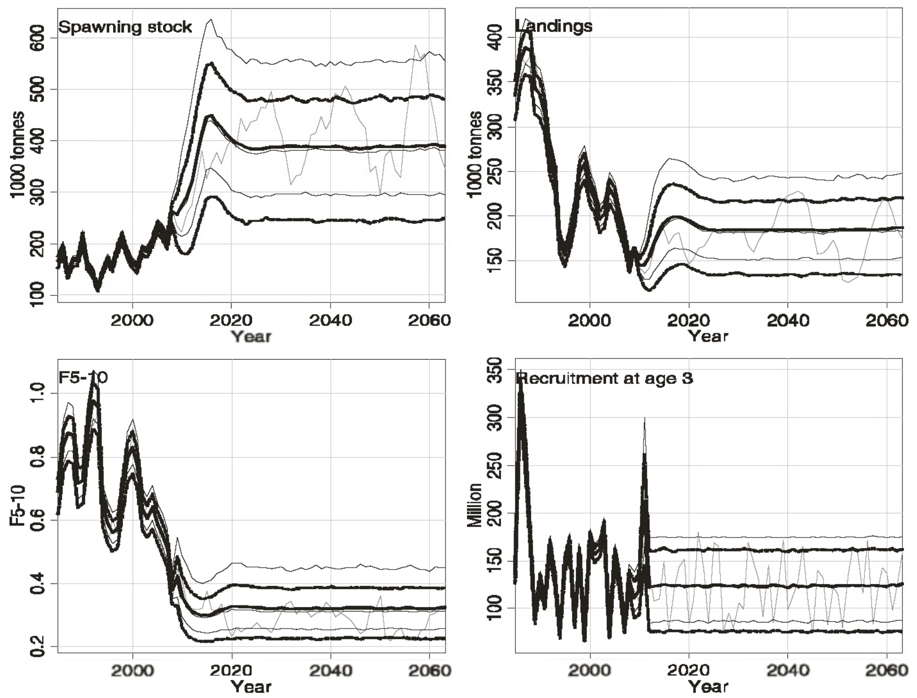

Figure 3.2.1: Simulation scenario assuming a recruitment scenario representing the low recruits observed after 1984. Future values show the mean, the median value (thick line) ± 1 standard deviation and the 5th and 95th percentile using harvest rate of 0.2. One randomly drawn iteration is displayed.

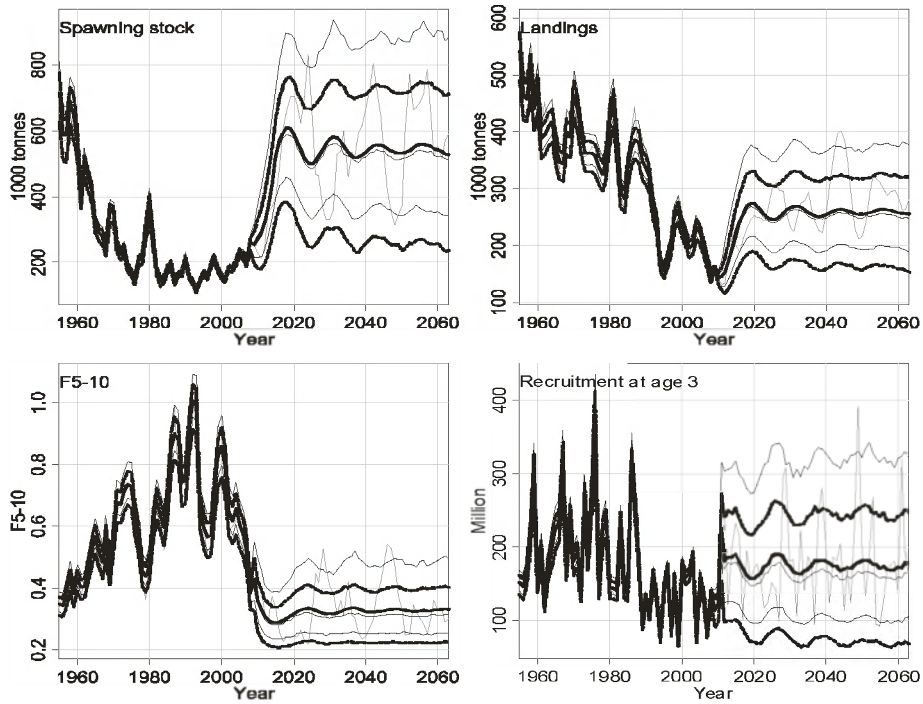

Figure 3.2.2: Simulation scenario assuming recruitment following a Ricker function using conventional SSB estimates and mean age in the spawning stock as a covariate. Future values show the mean, the median value (thick line) ± 1 standard deviation and the 5th and 95th percentile using harvest rate of 0.2. One randomly drawn iteration is displayed.

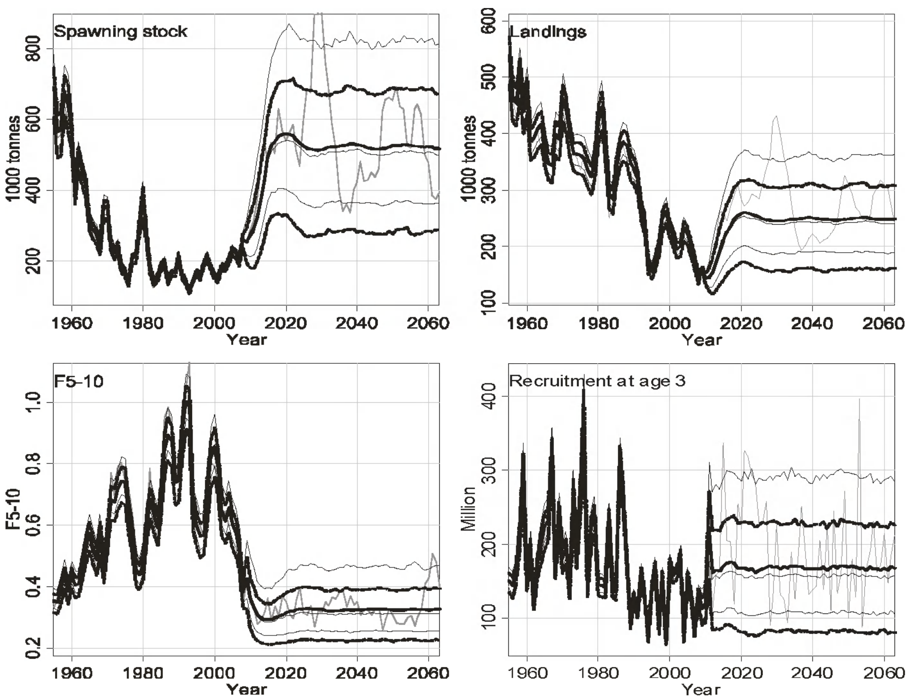

Figure 3.2.3: Simulation scenario assuming recruitment following a Ricker function using egg productivity and 2 Rmax parameters (before and after 1985). Future values show the mean, the median value (thick line) ± 1 standard deviation and the 5th and 95th percentile using harvest rate of 0.2. One randomly drawn iteration is displayed.

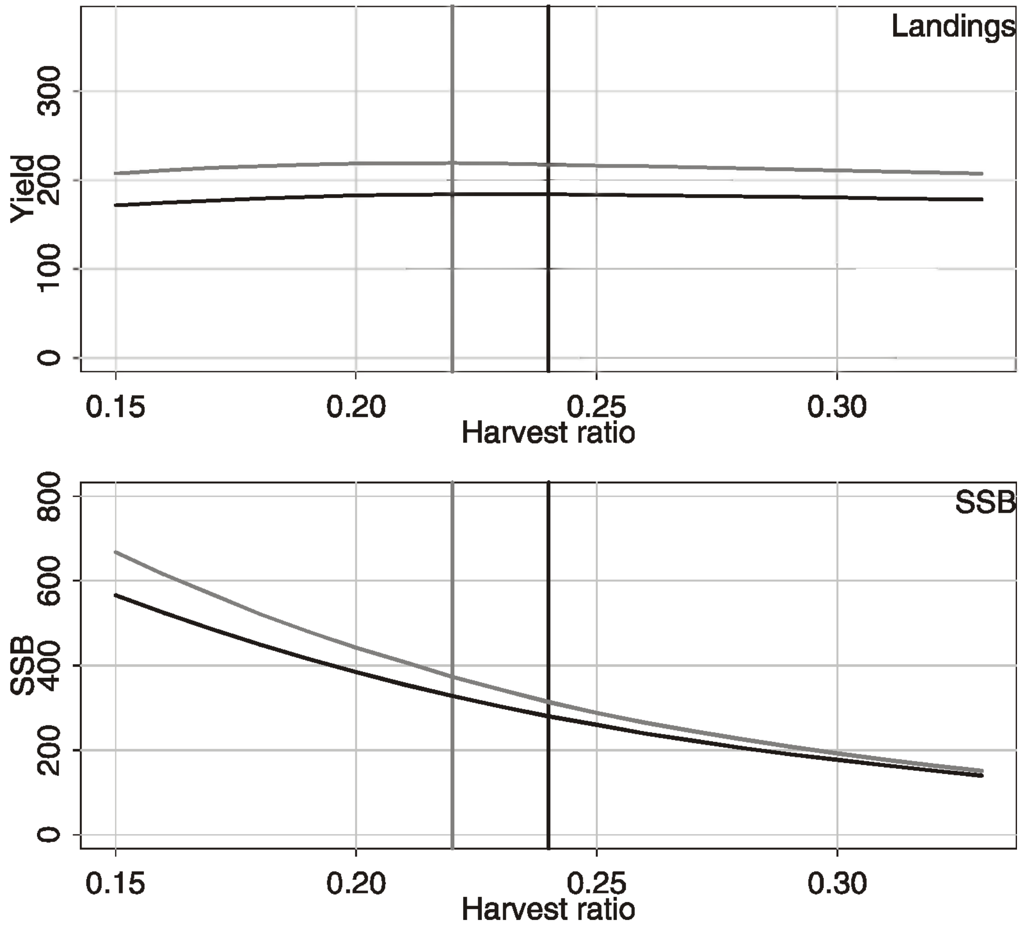

Figure 3.3.1: Landings and spawning stock as function of harvest rate assuming a box distribution of recruitment with the vertical lines showing Fmsy. Black lines refer to simulation based on low weights (average 2006-2008), grey lines refer to average weight at age from 1985-2008.

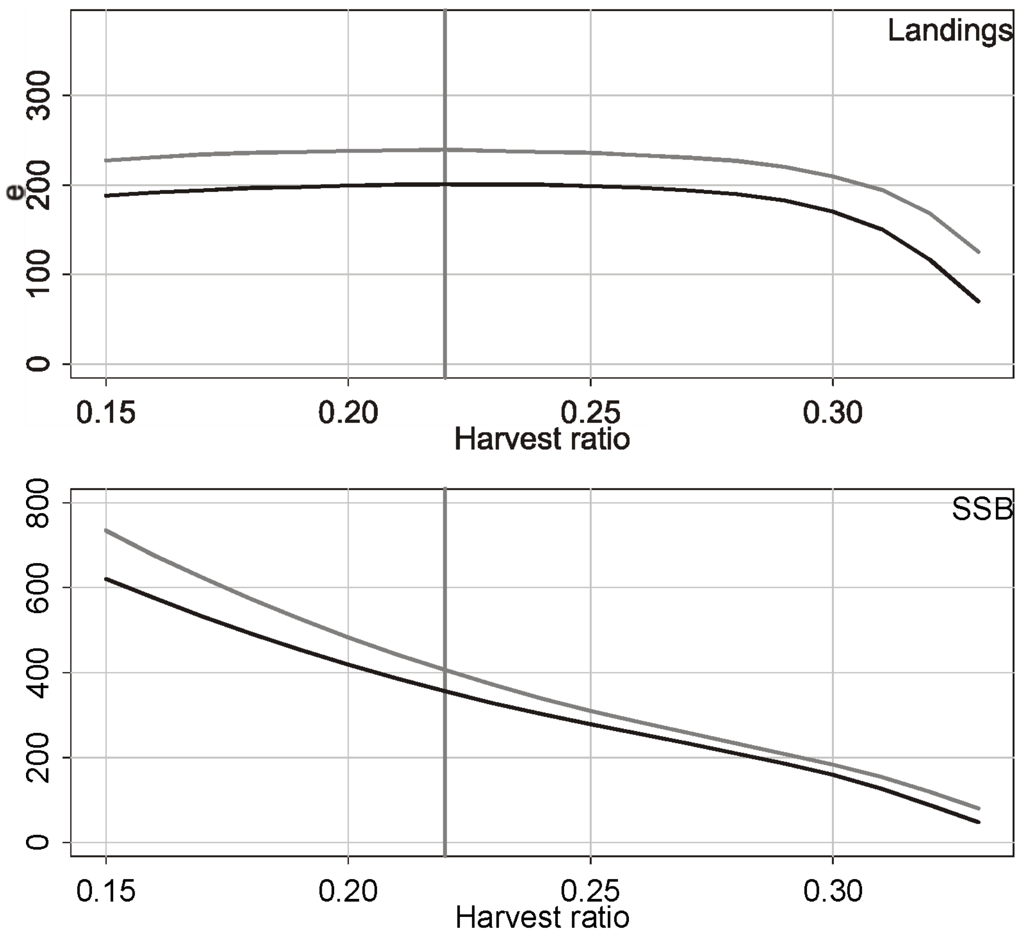

Figure 3.3.2: Landings and spawning stock as function of harvest rate assuming a segmented regression of recruitment using values from 1985-2008 with the vertical lines showing Fmsy. Black lines refer to simulation based on low weights (average 2006-2008), grey lines refer to average weight at age from 1985-2008.

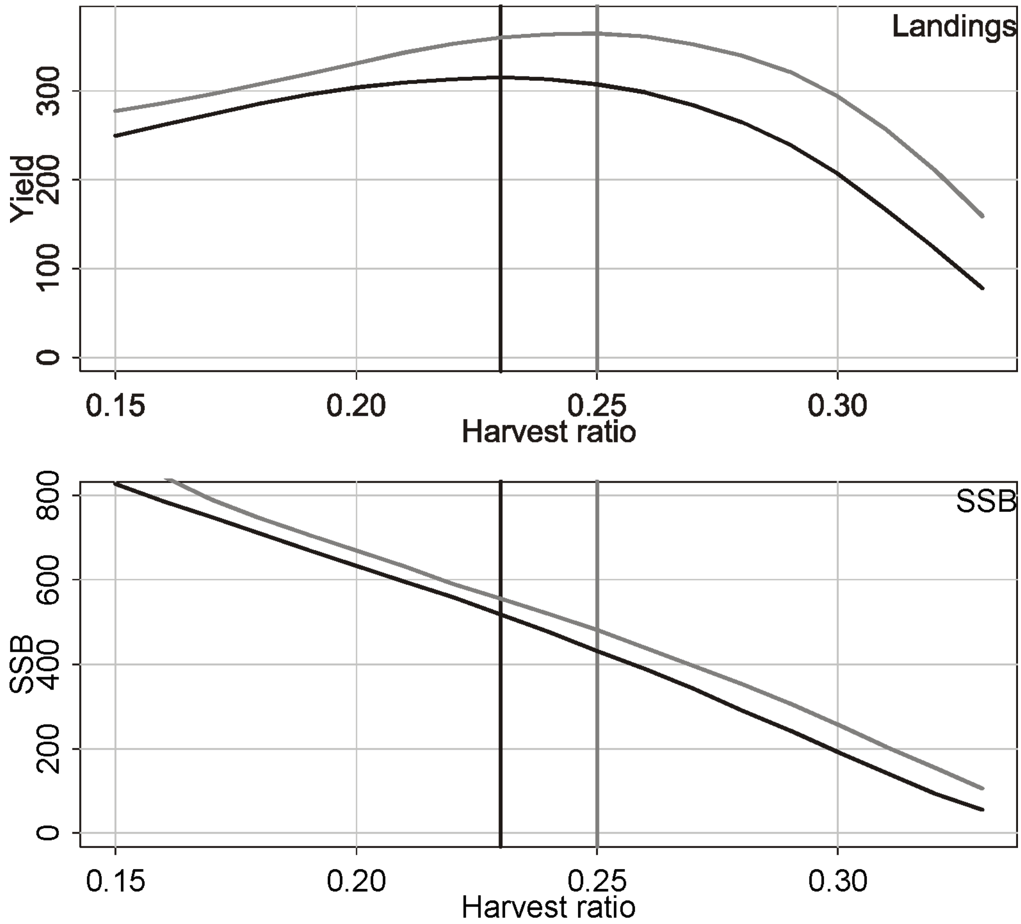

Figure 3.3.3: Landings and spawning stock as function of harvest rate assuming of recruitment being a function of Ricker egg productivity, with 1 Rmax. The vertical lines showing Fmsy. Black lines refer to simulation based on low weights (average 2006-2008), grey lines refer to average weight at age from 1985-2008.

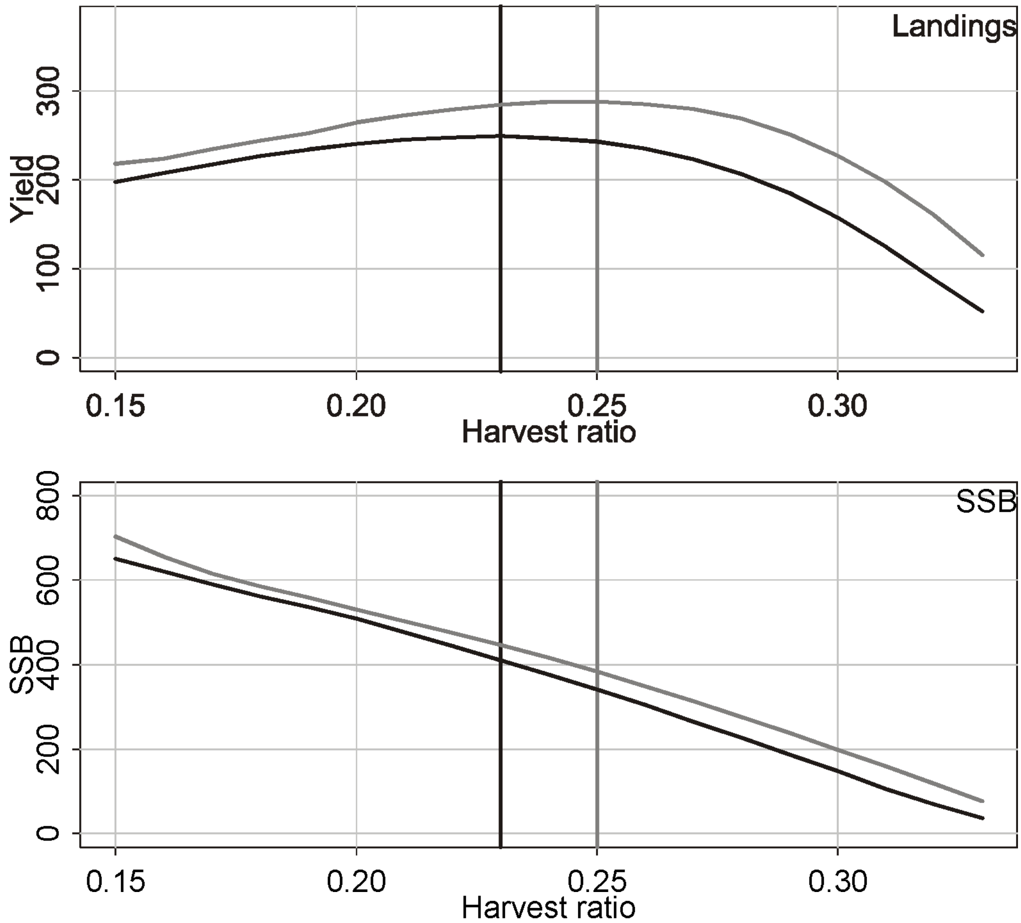

Figure 3.3.4: Landings and spawning stock as function of harvest rate assuming of recruitment being a function of Ricker egg productivity, with 2 Rmax. The vertical lines showing Fmsy. Black lines refer to simulation based on low weights (average 2006-2008), grey lines refer to average weight at age from 1985-2008.

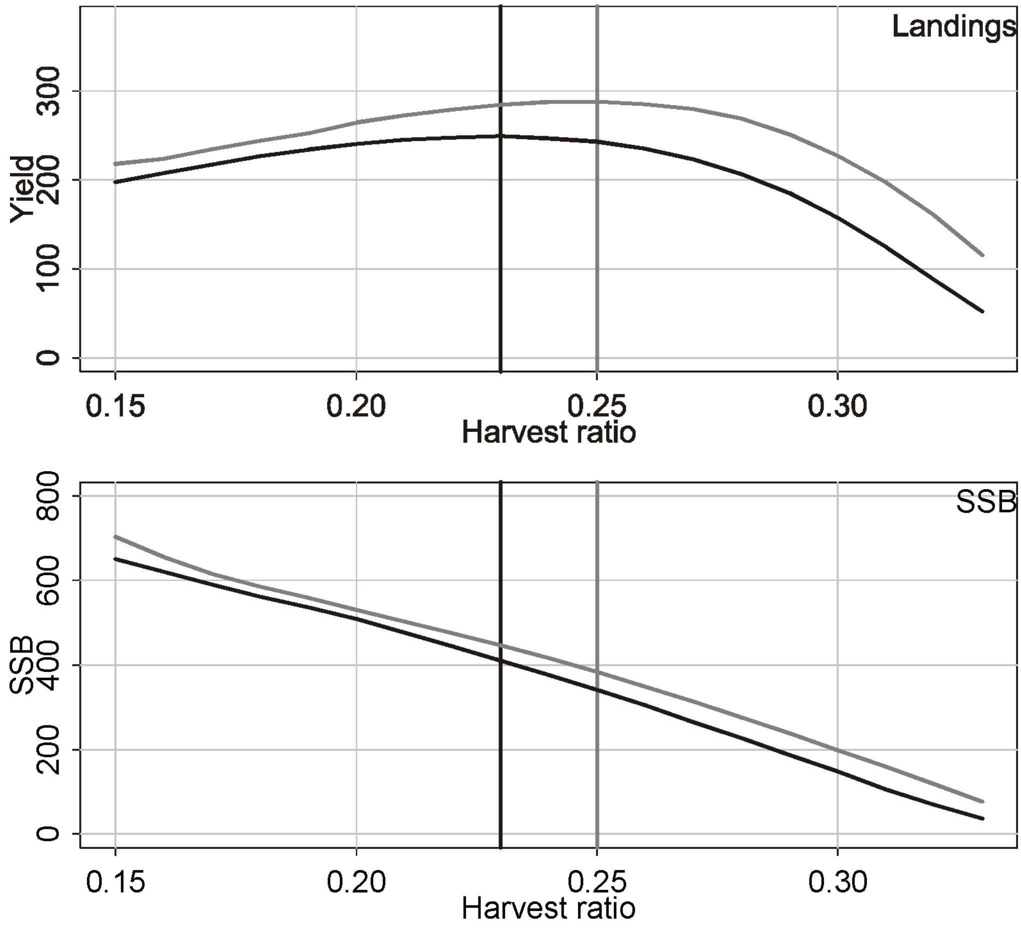

Figure 3.3.5: Landings and spawning stock as function of harvest rate assuming of recruitment being a function of Ricker SSB with mean age as a covariate. The vertical lines showing Fmsy. Black lines refer to simulation based on low weights (average 2006-2008), grey lines refer to average weight at age from 1985-2008.

Annex 1: List of participants

Name	Address	Phone/Fax	Email
Einar Hjörleifsson	MRI, Reykjavík, Iceland		einarhj.@hafro.is
Höskuldur Björnssson	MRI, Reykjavík, Iceland		hoski@hafro.is
Árni Magnússon	MRI, Reykjavík, Iceland		arnima@hafro.is

Annex 2: Agenda

Not applicable

Annex 3: Simulations based on the FPRESS platform

Harvest Control Rule evaluation of Icelandic cod based on the FPRESS platform

Einar Hjörleifsson

Marine Research Institute

Reykjavík, Iceland

Introduction

The purpose of this document is to provide some background, both procedural as well as technical details of the HCR evaluations as done in the FPRESS framework.

The FPRESS platform

FPRESS 2.0.0

FPRESS is introduced as a potential tool for HCR evaluation by SGMAS (ICES 2006, ICES 2007, 2008). It has been used for evaluation of harvest control rules in NEA Mackerel (ICES 2009a), North Sea cod stock (ICES 2009b) and Western Horse Mackerel Management Plan development. It has also been used for Irish Sea Cod and Sardine work.

The choice for using FPRESS out of the plethora of software packages available was first and foremost the familiarity of this author to R, the software language of R. Although FLR is also written in that language, lack of full depth knowledge of the object structure of that platform was considered as a hindrance, given the time frame of this work. In hindsight, the latter platform may have been more appropriate and efficient tool.

A FPRESS was conceived by Cirian Kelly and Andrew Campbell at Marine Institute, Galway. A generic source code (version FPRESS_2.0-0) was obtained from Andrew Campell, on 12.8.2009. It should be noted that the FPRESS_2.0-0 code obtained "rather old" and has not been maintained by the original team. Or as stated by Andrew Campell in e-mail correspondence:"This version of FPRESS is rather old at this stage. Despite my best intentions, it has been very difficult to find the means and the time to maintain a generic version of the model for distribution. Work has tended to focus on developing it for specific applications such as the NEA Mackerel LTM (as you mentioned below) and the Western Horse Mackerel Management Plan development. It has also been used for Irish Sea Cod and Sardine work."

In the obtained version of FPRESS (v 2.0.0) the various noise implementations are more or less white noise. Critical noise structures, such as autocorrelation in assessment errors and errors structures that may apply across age groups within a year (e.g. weight at age), patterns that are considered of importance in iCod, were thus implemented by this author.

Aside from the issue above the default error recruitment distribution in FPRESS 2.0.0 is normal, not log-normal. This is rather unfortunate, in particular since the stock-recruitment parameter estimation routine are based on lognormal errors structure in recruitment but no mention is then made in the adjoining manuals that the simulated errors are normally distributed.

It is rather unfortunate that the generic version has not been updated by the FPRESS team to include such error structures, in particular since e.g. the autocorrelation errors have been implemented by the authors in specific applications, such as NEA Mackerel (ICES 2009a). It is belief of this author that FPRESS deserves a future space in the shelf of alternative software platforms for HCR evaluations. The structure of the code is reasonably easy to follow, it provides a good bookkeeping feature and gui interface for controlling various setting. And although the language platform is the same as FLR, it does not require as in-depth understanding of the intricate features of R (S4 objects, methods).

Adaptation of FPRESS for iCod

For the reasons outlined above, as well as for some other reasons, the FPRESS 2.0.0 code was modified quite substantially by the current author. As much as was possible, the structure of the original program flow was maintained. However, during the debugging process for the adaptation of FPRESS to iCod HCR evaluation it was considered more efficient to delete or change blocks of options in the original code that were not relevant for current work. At later stages it was adapted to the Linux environment and run primarily in batch mode.

Material and methods

Operating model

The operating model is the virtual world, which is supposed to reflect the true system in the evaluation framework.

The biological model is a simple single-species age structured population following the classical exponential stock-equation:

$$N_{a+1,y+1} = N_{ay} e^{-\left(F_{ay}+M_{ay}\right)} \tag{1}$$

- *For the iCod HCR simulation the age groups used where 1 to 14, the latter acting as a plus group. Age groups enters the population in the start of the first year, but with natural and fishing mortality set to 0.0 for age classes 1 and 2. The mortality rates settings for these age groups were only done for the ease of coding.*
- *The starting year was 2009, and the starting population values were those estimated by the NWWG 2009 (see later).*

The catches taken according to the catch-equation:

$$C_{ay} = \frac{F_{ay}}{F_{ay}+M_{ay}}\left(1-e^{-\left(F_{ay}+M_{ay}\right)}\right)N_{ay} \tag{2}$$

Biological model – mortality, weights and maturity

In the FPRESS code stochasticity in natural mortality can be implemented by:

$$M_{a,y} = M_{ay}^{DET}(1 + cv_a^M \varepsilon_a) \tag{3}$$

where $\varepsilon = N(0,1)$.

- *For the iCod HCR simulation only deterministic values of M=0.2 where used for age groups 3-14 and 0.0 for age gropus 1 and 2 (table 1).*

Future weight at age in the stock (sWay) and the catch (cWay) are modelled as:

$$sW_{ay} = sW_a^{DET}\left(1 + E_y^W\right) \tag{4a}$$

or

$$sW_{ay} = sW_a^{DET} e^{E_y^W} \tag{4a}$$

and

$$cW_{ay} = cW_a^{DET}\left(1 + E_y^W\right) \tag{5a}$$

or

$$cW_{ay} = cW_a^{DET} e^{E_y^W} \tag{5b}$$

where,

$$E_y^W = cv^W\left(\rho^W \varepsilon_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y\right) \tag{6}$$

where $\varepsilon_y = N(0,1)$. I.e. same error is applied to both the stock and catch weight within a year and to all ages groups. The inclusion of autocorrelation in weights as well as all age groups giving the same error within a year is a modification from the generic FPRESS 2.0.0 code, were a simple random normal error is applied independently to each age group.

- *For the iCod HCR simulation the lognormal errors were applied (equation 4a and 5a). The catch weights are used in the historical calculation of the reference biomass (B4+), the stock weights are used in the calculation of the spawning stock biomass.*
- *Note, that the TAC set for year y+1 was based on B4+ estimates (including assessment error, see equation xx) in year y, based on catch weights in year y. In the year y+1, the catch weights in that year were however used when deriving actual removal rate (fishing mortality) from the population.*
- *The value used in the predictions were those from the NWWG 2009, using the terminal values, i.e. the catch weight predictions for 2009 and the stock weight measurements from 2009 (table 1). For 2010 and beyond a CV=0.12 and rho=0.6 was applied, for the 2009 see later.*

Maturity at age is modelled as:

$$MAT_{a,y} = MAT_{ay}^{DET}(1 + cv_a^{MAT} \varepsilon_a) \tag{9}$$

where $\varepsilon_a = N(0,1)$

- *For the iCod HCR simulation no stochasticity was emulated in the SSB (CV_a=0)*

- *The maturity set was the average maturity from the NWWG 2009 stock assessment from 1985-2009 (table 1).*

Reference biomass was calculated as:

$$B_y^{ref} = \sum_{a_{\min}}^{a_{\max}} N_{ay} cW_{ay} P_a \tag{10}$$

Where Pa represents a vector containing the proportional contribution of each age class to the reference biomass.

- *For iCod, the reference biomass is defined as B4+,i.e. the sumproduct of population numbers and catch weights for age group 4 and older.*

The conventional spawning stock biomass is calculated as:

$$SSB_y = \sum_{a_{\min}}^{a_{\max}} N_{ay} sW_{ay} MAT_{ay} \tag{11}$$

Spawning stock based on number of eggs is calculated as:

$$eggB_y = \sum_{a_{\min}}^{a_{\max}} N_{ay} sW_{ay} MAT_{ay} \delta sW_{ay} \tag{12}$$

where δ is a constant for all ages describing egg numbers as a function of weight. Mean age of the spawning stock biomass is calculated as:

$$meanAge_y^{SSB} = \frac{\sum_{a_{\min}}^{a_{\max}} aN_{ay} sW_{ay} MAT_{ay}}{SSB_y} \tag{13}$$

Biological model – recruitment

Various alternative recruitment models can implemented in FPRESS. Additional functions were also implemented specifically for the iCod. The following is a list of the models that were used in the iCod simulations.

Ricker model

$$N_{1y} = \alpha SSB_{y-1}^{\beta SSB_{y-1}} e^{CV*\varepsilon} \tag{14}$$

where $\varepsilon = N(0,1)$.

- *iCod HCR evaluation: CV=0.32*

Ricker model using mean age in the SSB as a covariate

$$N_{1y} = \alpha SSB_{y-1}^{\beta SSB_{y-1}} e^{\gamma AGE_{SSB_y}} e^{CV*\varepsilon} \tag{15}$$

where $\varepsilon = N(0,1)$.

- *iCod HCR evaluation: CV=0.32*

Constant recruitment – parametric bootstrap

This is simply modelled as:

$$N_{1,y} = \mathrm{Re}^{CV_a * \varepsilon_a} \tag{16}$$

where $\varepsilon = N(0,1)$

- *For the iCod HCR simulation, the only the recent recruitments (year classes 1985-2008) were used as a basis for the geometric mean: R=128, cv=0.32.*

Constant recruitment – non-parametric bootstrap

Here a simple random pick of 1 year from historical recruitment series is selected for each future year, where a subset of historical years can be specified.

- *For the iCod HCR simulation, only the recent recruitments (year classes 1985-2008) were used.*

Cyclical historical observations

Here the whole historical recruitment series is repeated in a repetitive fashion, i.e. the time-series is retained. In each run a random draw of the starting year is chosen and then a whole time block of observations is taken.

- *For the iCod HCR simulation, the time series of recruitment from year classes 1955-2008 were used.*

Biological model – starting conditions in 2009

The population in the first year are simply modelled as uncorrelated lognormal error for different age groups:

$$N_{a1} = N_{a1}^{DET} e^{CV_a \varepsilon_a} \tag{17}$$

where $\varepsilon_a = N(0,1)$.

- *For the iCod HCR FPRESS simulation the starting year was 2009. The starting values for Na and the CVa were those estimated by the NWWG 2009 for age groups 1 to 14 (table 1).*
- *The precision in population estimates by the NWWG is quite high, and is underestimating the true error in the stock estimates. An alternative starting values, intended to emulate potential overestimation in the stock was set to test the robustness of the conclusion to such likely scenarios. In these cases the population numbers in the starting year were discounted by 20% in all age groups.*

The weight at age in the first year are modelled as uncorrelated normal errors. This is the feature that is used in FPRESS 2.0.0.

$$sW_{a1} = sW_a^{DET}(1 + cv_a \varepsilon_a) \tag{18}$$

$$cW_{a1} = cW_a^{DET}(1 + cv_a \varepsilon_a) \tag{19}$$

where $\varepsilon = N(0,1)$

- *The reason for retaining the default FPRESS 2.0.0. settings for weight simulation in 2009 in the iCod HCR simulation is because stock weights in that year are known (spring survey estimates) and because catch weights are base on a prediction using the survey weights from that year and the historical relationship between survey and catch weights.*
- *The mean weights in the first year were the same used in the future predictions.*

Fisheries model

Fishing mortality by age is modelled as:

$$F_{ay} = s_a F_y \tag{20}$$

Stochasticity in the selection patter (sa) can be modelled by some random noise each year:

$$s_a = s_a^{DET}(1 + cv_a \varepsilon_a) \tag{21}$$

where $\varepsilon = N(0,1)$

- *For the iCod HCR simulations no stochasticity was modelled in the selection patterns*
- *For the iCod HCR simulation the selection pattern used was that estimated in the last fixed selection pattern period in the ADCAM framework (table 1).*

Management procedure

Assessment model

The HCR rule evaluation framework of FPRESS can be classified as simulation without an assessment feedback (ICES 2006), i.e. it is thus assumed that the simulation within the operating model represents the true stock dynamics. Errors in the assessment procedure that relate to harvest advice model are emulated as:

$$^*B_y^{ref} = B_y^{ref}\left(1 + E_y\right) \tag{22a}$$

or

$$^*B_y^{ref} = B_y^{ref} e^{E_y} \tag{22b}$$

where

$$E_y = cv\left(\rho\varepsilon_{y-1} + \sqrt{1-\rho^2}\,\varepsilon_y\right) \tag{23}$$

and $\varepsilon_y = N(0,1)$

The implementation of autocorrelation in assessment error is a modification from the FPRESS 2.0.0, where only a random process was implemented.

- *For the iCod HCR simulation lognormal stock assessment errors were used (equation 22b). CV = 0.15 and rho=0.45*

Harvest advice and decision-making model

The harvest control rule for the Icelandic cod is based on the following generic decision rule for the total allowable catch:

$$TAC_{y+1} = \left(hr\ ^*B_y^{ref} + TAC_y\right)/2 \tag{24}$$

Where hr represents harvest rate, i.e. the fraction of the reference biomass to be taken as catch. The resulting fishing mortality in year y+1 is obtained by solving the Baranov equation taking the simulated catch weights in year y+1 into account.

- *For iCod HCR evaluation, the reference biomass is based on sumproduct of abundance of age classes 4-14 and catch weights.*
- *In the current catch rule the harvest rate is set to 0.2. A range of values from 0.2 to 0.25 were tested.*

- *A TAC of 160 kt is already in place for the fishing year 2008/2009 and 150 kt for the fishing year 2009/2010.*
- *In FPRESS the TAC taken were set to the calendar year. I.e. the TAC of 150 kt is effective from 1.9.2009 to 31.8.2010 but in FPRESS it was set to be taken over the calendar year 2010.*

Implementation error model

Implementation error and bias can be modelled as:

$$^{*}TAC_{y} = bias * TAC_{y}(1+\varepsilon) \tag{25}$$

- *For iCod HCR evaluation implementation error was not modelled explicitly. However testing for various harvest rates (equation 24) effectively act as test of how robust the conclusions are to such biases. E.g. a bias of 0.05 in the TAC is equivalent to a harvest rate of 0.21.*

Performance measures

The only performance measure looked at here was the probability that SSB in 2015 and 2020 would be under a reference value of 220 and 245 kt. The probability was calculated as a percentiles based on 1000 simulations.

Results

The major impact on the likely future trajectory of the spawning stock biomass besides fishing mortality are the trajectory in weight at age, likely current and future assessment errors and the recruitment productivity and it's hypothesised linkage with spawning stock biomass. What follows is firstly an illustration of the errors in the weight at age and assessment errors. Alternative hypothesis with regards to recruitment productivity are then dealt with in the overall evaluation of risk.

Errors in the weight at age

A sample of the simulation in the errors in the weights at age is provided in figure 1, showing the historical and future catch weights for age groups 6 and 8. As in all conditions provided for the iCod here, the future mean weights are conditioned around the current low observed weights. This means that in future scenarios the weights in the catch and the stock will in 50% of the simulation be below the lowest observed historical weights. Although it is likely that weights at age in the short term may remain, the assumption that the weights in the medium term will remain low or lower than historically observed may be considered somewhat pessimistic. However, these low future weights are in part compromised with somewhat higher maturity at age (recent 1985-2009 average) than what is observed in the long historical time series.

The correlation in the weight pattern by different age groups is shown by plotting the weights from age group 6 and 8 from a single iteration. These patterns are supposed to emulate the pattern observed in the historical time series.

Of note is that the weight error in the first year (2009) is lower than that observed in later years. This is a result of weight errors being specified differently in the first year, the lower cv being a result of catch weights in the first year being estimated from survey measurements in that same year. Unlike in future years, the error between age groups is treated as an independent process in the 1st year.

Assessment errors

The historical assessment errors are calculated as:

$$error = \frac{contemporaryB_{4+}}{currentB_{4+}}$$

Effectively we are assuming that the converged part of the time-series analysis reflects the true state of nature. A measure of the future assessment error is represented by:

$$error = \frac{{}^{*}B_{4+,y}}{B_{4+,y}}$$

A sample of the assessment error is provided in figure 2. It shows the historical assessment performance in the reference biomass estimates as well as a random selection of 3 future iterations. The 90% confidence boundaries cover all but the most extreme historical errors observed in the 1998-2000.

Of note is that the confidence interval in the assessment error in the first year (2009) is much narrower than that observed in the future years. Although medium term analysis will not be influenced by these initial conditions, it is likely that spawning stock estimates in 2015 will be influence by the estimates of the younger fish in 2009. The estimates of the reference biomass in 2009 are based on the sumproduct of the catch weight by age population numbers by age. In the simulation the error in the starting numbers for each age group are treated as independent in the starting year (2009).

Within the FPRESS framework two possible remedies could be set in place to check for robustness of the performance of the Harvest Control rule to more realistic assessment errors in the first year. One is to set the cv estimates of the population numbers in each age to some arbitrary high number. Another option would be to lower the starting population numbers of all ages by applying a single arbitrary multiplier. Both are kind of ad hoc-ish, but in this report the robustness is tested using the latter feature. What was done was to effectively assume that all stock numbers were 20% lower than estimated by the NWWG 2009 (A 25% overestimation in stock size).

Risk evaluation of spawning stock size in 2015+

The results from the FPRESS framework simulations indicate by that by applying the 20% rule the probability of SSB falling below 220 kt and 245 kt are less than 5% in 2015 and 2020 (table 2). The conclusion are robust to the recruitment scenarios tested and to the assumption that 2009 population number are 20% lower than that estimated by the NWWG (table 3). A summary plot for each scenario is provided in figures 3 to 7 if assuming that the 2009 assessment is unbiased, and in figures 8 to 12 if one assumes a 25% overestimation in 2009.

The 5% risk level for the 220 kt values in 2015 holds for all harvest rates up to 25%, if no starting bias is assumed in the assessment (table 2a) but are sensitive to recruitment assumption for the year 2020 (table 2b). I.e. if recruitment patterns remain for the next 10 years as it has been since 1985 any harvest above 21% would result in a higher risk than the 5% cut-off value in 2020. Interestingly, in the biased scenario (table 3b) the risk in 2020 is somewhat lower, this being a result in how the inertia effects of TAC buffer acts on lowering the fishing mortality once an overestimation is discovered.

The analysis based on different harvest rates indicates that the 20% HCR seem to be robust to a combined bias in assessment and implementation within 5-15%. If recruitments and weights continue to be low, there is however not much lea-way for much bias.

Reference

ICES. 2006. Report of the Study Group on Management Strategies (SGMAS), 23-27 January, 2006. ICES Headquarters. ICES. CM 2006/ACFM: 15. 157 pp.

ICES. 2007. Report of the Study Group on Management Strategies (SGMAS), 22-26 January 2007. ICES Headquarters. ICES CM 2007/ACFM: 04. 59 p.

ICES. 2008. Report of the Study Group on Management Strategies (SGMAS), 17-21 November 2008, Lisbon, Portugal. ICES CM 2008/ACOM: 24. 74 pp.

ICES. 2009a. Report of the Working Group on NEA Mackerel Long-Term Management Scientific Evaluation (NEAMACKLTM), 12-13 April 2007, Amsterdam, The Netherlands. ICES CM 2008/ACOM: 54. 233 pp.

ICES. 2009b. Report of the Ad hoc Group on Cod Recovery Management Plan (AGCREMP), 18-19 August 2008, Copenhagen, Denmark, ICES CM 2008/ACOM: 61. 83 pp.

Ólafur K. Pálsson, Höskuldur Björnsson, Ari Arason, Eyþór Björnsson, Guðmundur Jóhannesson and Þórhallur Ottesen. Discards in demersal Icelandic fisheries 2008 [in icelandic]. Marine Research 147: 5-16

Age	Na,2009	cv Na,2009	sWay	cv sWa,2009	cWay	cv cWa,2009	Maturity	cv Maturity
1	218.000	0.183	0.001	0.05	0.001	0.05	0.000	0
2	121.319	0.100	0.001	0.05	0.001	0.05	0.000	0
3	114.940	0.082	1.017	0.05	1.115	0.05	0.004	0
4	106.802	0.069	1.440	0.05	1.515	0.05	0.049	0
5	48.724	0.074	2.027	0.05	2.217	0.05	0.227	0
6	53.005	0.064	2.871	0.05	3.16	0.05	0.482	0
7	35.202	0.074	3.909	0.05	4.122	0.05	0.679	0
8	7.630	0.092	5.073	0.05	5.073	0.05	0.809	0
9	7.971	0.109	6.091	0.05	6.091	0.05	0.800	0
10	2.858	0.145	7.648	0.05	7.648	0.05	0.954	0
11	0.839	0.204	8.282	0.05	8.282	0.05	0.979	0
12	0.278	0.288	11.181	0.05	11.181	0.05	0.985	0
13	0.030	0.440	14.266	0.05	14.266	0.05	0.993	0
14	0.020	0.744	17.320	0.05	17.32	0.05	1.000	0

Age	Selection pattern	cv Selection	pF before spawning	cv pF	Discard mortality	May	cv May	pM before spawning
1	0.000	0	0.000	0	0	0.0	0	0.00
2	0.000	0	0.000	0	0	0.0	0	0.00
3	0.021	0	0.085	0	0	0.2	0	0.25
4	0.094	0	0.180	0	0	0.2	0	0.25
5	0.205	0	0.248	0	0	0.2	0	0.25
6	0.325	0	0.296	0	0	0.2	0	0.25
7	0.397	0	0.382	0	0	0.2	0	0.25
8	0.436	0	0.437	0	0	0.2	0	0.25
9	0.486	0	0.477	0	0	0.2	0	0.25
10	0.559	0	0.477	0	0	0.2	0	0.25
11	0.585	0	0.477	0	0	0.2	0	0.25
12	0.635	0	0.477	0	0	0.2	0	0.25
13	0.654	0	0.477	0	0	0.2	0	0.25
14	0.654	0	0.477	0	0	0.2	0	0.25

Table 1: Input values in the simulations

a) p(SSB2015<220kt)

Rmodel \ HCR	16%	17%	18%	19%	20%	21%	22%	23%	24%	25%
Ricker					0.0	0.0	0.1	0.3	0.3	0.7
eggRicker					0.0	0.0	0.0	0.2	0.5	0.8
Bootstrap recent					0.0	0.3	0.5	1.3	1.8	3.2
R=126, cv=0.32					0.0	0.2	0.4	1.6	2.2	3.2
cyclical bootstrap					0.1	0.1	0.6	0.6	1.7	1.4

b) p(SSB2020<220kt)

Rmodel \ HCR	16%	17%	18%	19%	20%	21%	22%	23%	24%	25%
Ricker					0.0	0.0	0.2	0.3	0.7	1.9
eggRicker					0.0	0.0	0.1	0.5	0.6	2.0
Bootstrap recent					2.0	4.0	**7.3**	**13.4**	**20.1**	**28.6**
R=126, cv=0.32					2.1	1.8	**6.3**	**10.4**	**21.1**	**27.5**
cyclical bootstrap					0.0	0.8	2.1	4.7	**8.9**	**13.9**

c) p(SSB2015<245kt)

Rmodel \ HCR	16%	17%	18%	19%	20%	21%	22%	23%	24%	25%
Ricker					0.0	0.0	0.2	0.7	1.0	2.7
eggRicker					0.0	0.0	0.0	0.7	1.3	2.1
Bootstrap recent					0.1	0.9	1.1	2.4	3.7	**6.6**
R=126, cv=0.32					0.2	0.4	1.1	2.4	4.0	**6.1**
cyclical bootstrap					0.1	0.3	1.2	1.7	2.6	3.2

d) p(SSB2020<245kt)

Rmodel \ HCR	16%	17%	18%	19%	20%	21%	22%	23%	24%	25%
Ricker					0.0	0.0	0.4	0.5	0.9	3.4
eggRicker					0.1	0.1	0.2	0.9	1.3	3.7
Bootstrap recent					2.0	**7.2**	**12.0**	**19.6**	**29.3**	**38.6**
R=126, cv=0.32					3.5	3.7	**11.1**	**15.8**	**29.2**	**36.4**
cyclical bootstrap					0.4	1.6	4.2	**7.6**	**12.7**	**18.3**

Table 2: Summary of the probability that SSB in a certain year falls below a specified biomass under different recruitment scenarios and harvest rates assuming no bias in the starting values (year 2009). a) p(SSB_{2015})<220kt, b) p(SSB_{2020})<220kt, c) p(SSB_{2015})<245kt, d) p(SSB_{2020})<245 kt. The recruitment models are: 1) Ricker – Ricker model based on conventional SSB, 2) eggRicker – Ricker model based on egg productivity, 3) ageRicker – Ricker model using mean age in the SSB as a covariate, 4) Bootstrap recent – Recent low yearclasses from 1985-2008 bootstrapped. 5) R=126, cv=0.32 – Constant recruitment of 126 millions (average 1985-2008) with a cv of 0.32. 6) cyclical bootstrap – bootstrap of the whole recruitment time series from 1955-2008, where the time line is retained as a continuous loop.

a)

p(SSB2015<220kt)										
Rmodel \ HCR	**16%**	**17%**	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**
Ricker					0.5	1.5	2.6	**5.4**	**6.4**	**8.4**
eggRicker					1.2	1.5	3.1	**5.1**	**6.1**	**8.5**
Bootstrap recent					1.8	3.1	3.7	**7.4**	**10.6**	**15.1**
R=126, cv=0.32					1.9	3.0	4.9	**8.2**	**11.7**	**15.1**
cyclical bootstrap					0.3	1.1	1.7	4.1	**6.3**	**8.0**

b)

p(SSB2020<220kt)										
Rmodel \ HCR	**16%**	**17%**	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**
Ricker					0.0	0.0	0.1	0.8	2.3	4.2
eggRicker					0.2	0.3	0.5	0.5	1.9	3.2
Bootstrap recent					0.9	1.4	3.8	**7.4**	**12.6**	**19.4**
R=126, cv=0.32					0.7	1.7	4.4	**6.8**	**11.9**	**19.1**
cyclical bootstrap					0.0	0.6	0.9	3.1	**5.2**	**6.6**

c)

p(SSB2015<245kt)										
Rmodel \ HCR	**16%**	**17%**	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**
Ricker					2.0	3.9	**5.8**	**10.3**	**12.3**	**15.6**
eggRicker					2.8	4.0	**6.9**	**9.5**	**12.2**	**17.9**
Bootstrap recent					4.5	**8.0**	**9.6**	**15.8**	**20.3**	**25.3**
R=126, cv=0.32					**5.5**	**8.1**	**10.7**	**14.7**	**21.4**	**27.4**
cyclical bootstrap					0.9	2.5	4.3	**7.6**	**12.5**	**15.2**

d)

p(SSB2020<245kt)										
Rmodel \ HCR	**16%**	**17%**	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**
Ricker					0.0	0.0	0.4	1.3	3.8	**7.6**
eggRicker					0.2	0.4	1.0	0.9	3.9	**7.2**
Bootstrap recent					2.1	3.3	**6.2**	**13.1**	**19.1**	**29.8**
R=126, cv=0.32					1.3	3.9	**7.5**	**11.3**	**17.2**	**26.6**
cyclical bootstrap					0.2	1.1	2.4	4.5	**9.1**	**10.5**

Table 3: Summary of the probability that SSB in a certain year falls below a specified biomass under different recruitment scenarios and harvest rates assuming a 25% overestimation in the starting values (population numbers in year 2009 reduced by 20%). Further explanation of legends, see table 2.

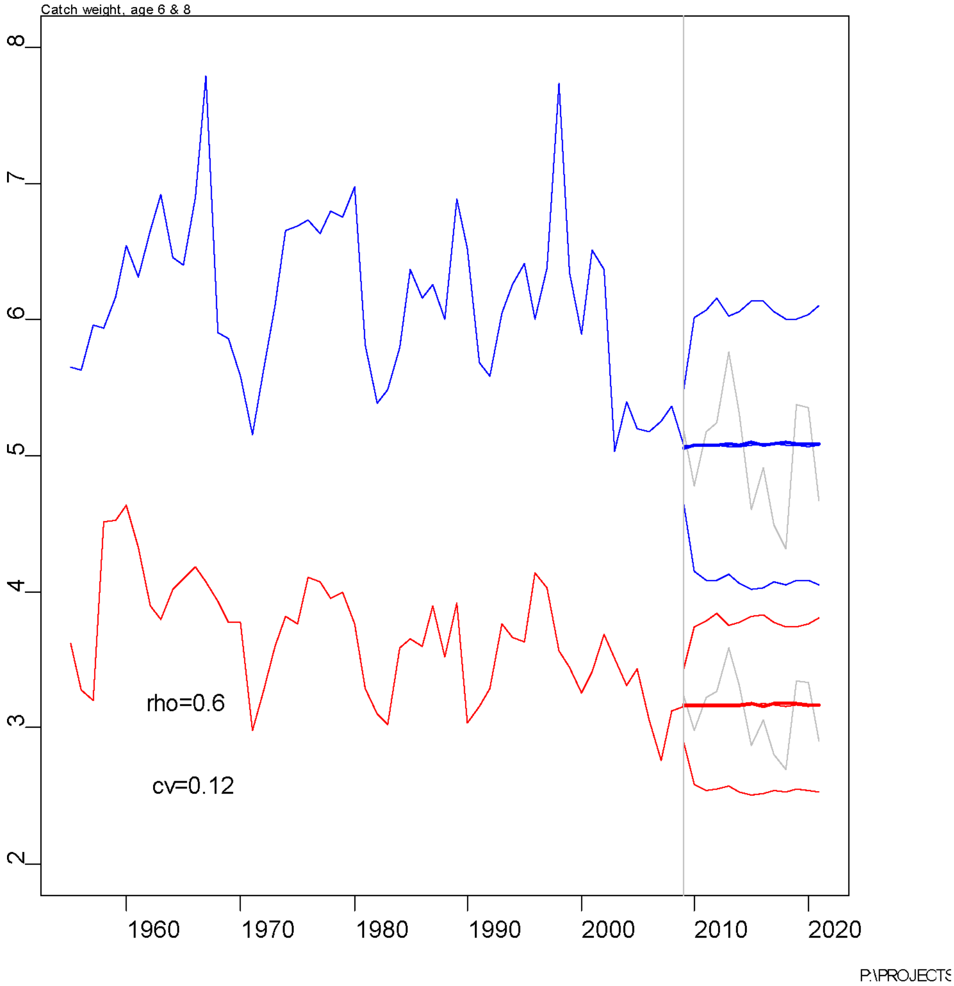

Figure 1: Observed and predicted catch weight at age for ages 6 (red) and 8 (blue). The confidence boundaries on the future weights are the 5th and 95th percentile. Projection from a single iteration is shown as a grey line.

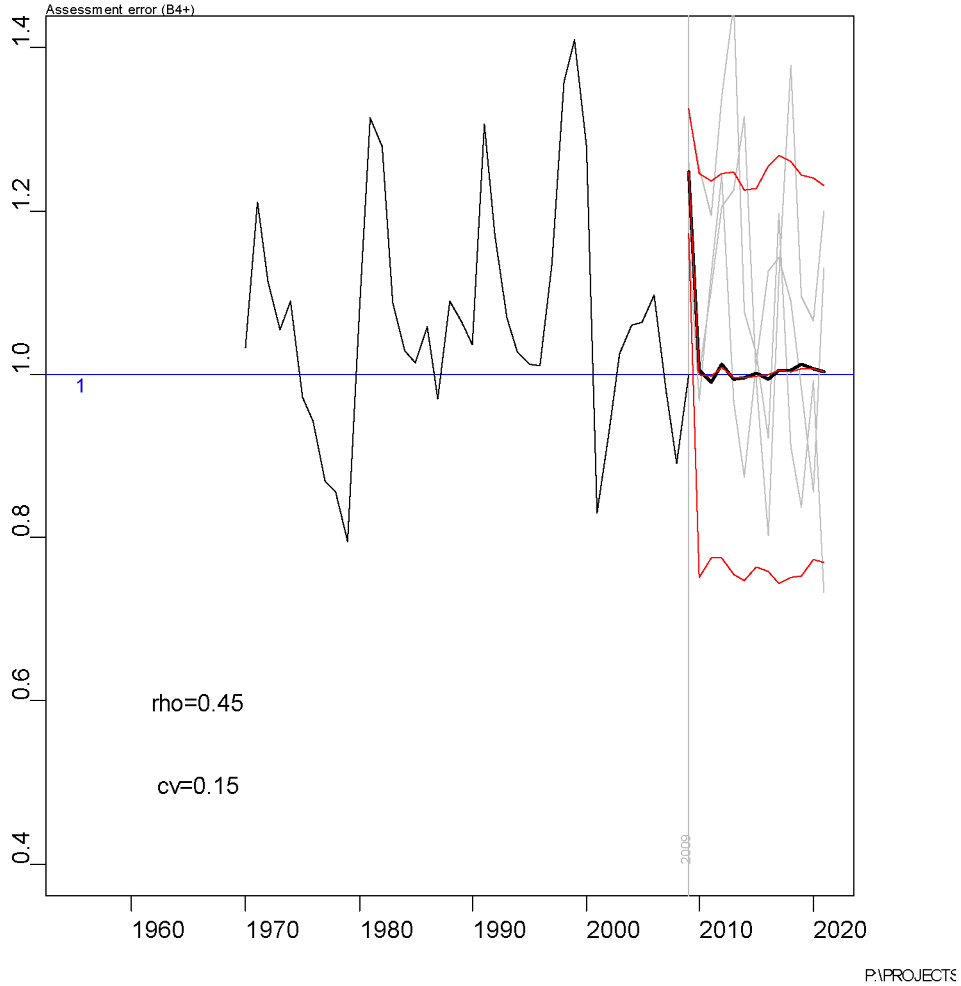

Figure 2: Reference biomass (B4+) assessment error. The confidence boundaries on the future assessment are the 5th and 95th percentile. Projections from a three randomly picked iteration are shown as grey lines. Assessment bias in the first year (2009) is arbitrarily set high, emulating a median overestimation error of 25% in that year.

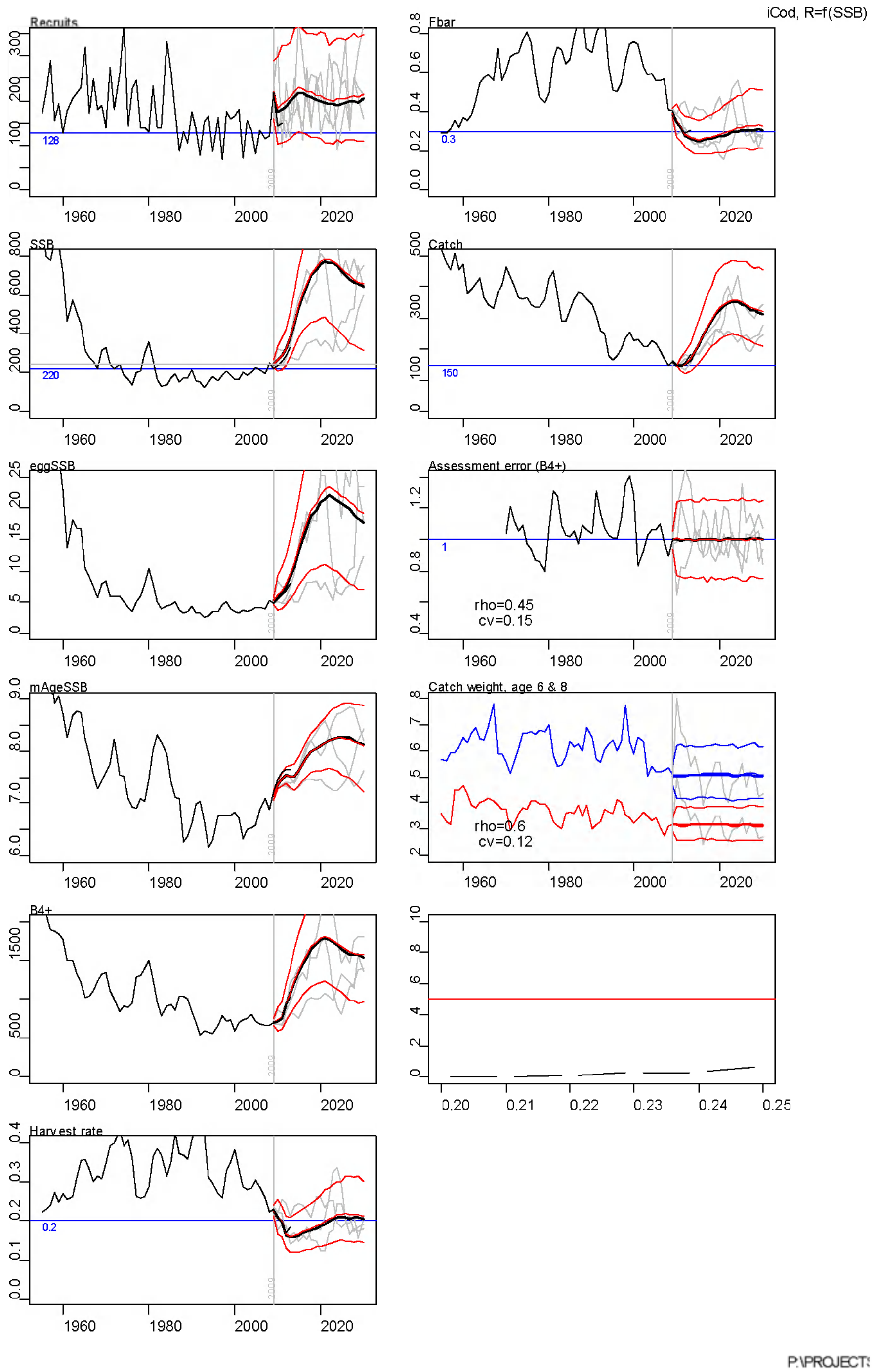

Figure 3: Summary plot. Ricker recruitment based on conventional SSB, no assessment bias in 2009. The time plot results refer to the 20% harvest rule. Panels from top to bottom, starting with column 1 and then proceeding to column 2. 1) Recruitment at age 1 [millions], but values effectively that of age 3 (M set to 0.0 for age groups 1 and 2. 2). 2) Spawning stock biomass in kt. 3) Spawning stock based on egg productivity, 4) Mean age [years] in the spawning stock 4) Biomass of age 4 and older [kt], 5) Harvest rate, calculated as the ratio of landings in year y and B4+ in the same year. 6) Fbar – reference fishing mortality age 5-10. 7) Catch [kt], 8) Assessment error (reference biomass B4+), 9) mean weight in age 6 and 8 year old fish. 9) Risk of falling below 220kt and 245 kt in 2015 when applying different harvest rate, 10) Risk of falling below 220kt and 245 kt in 2015 when applying different harvest rate. The values in the last two panels are shown in table 2 (and 3). Red lines indicate the 5th and 95th percentiles, grey lines show randomly drawn single iterations.

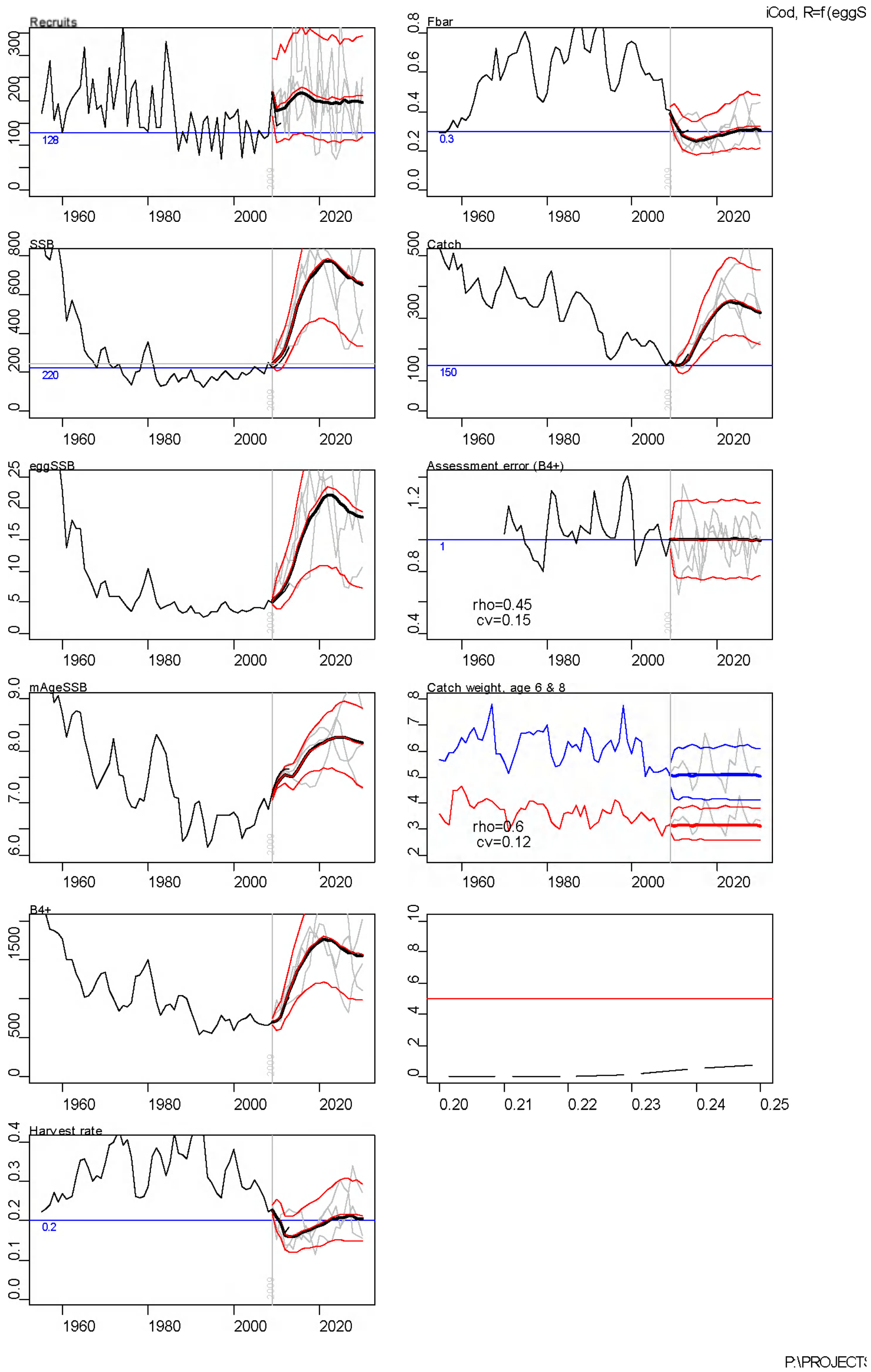

Figure 4: Summary plot. Ricker recruitment based on egg productivity, no assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

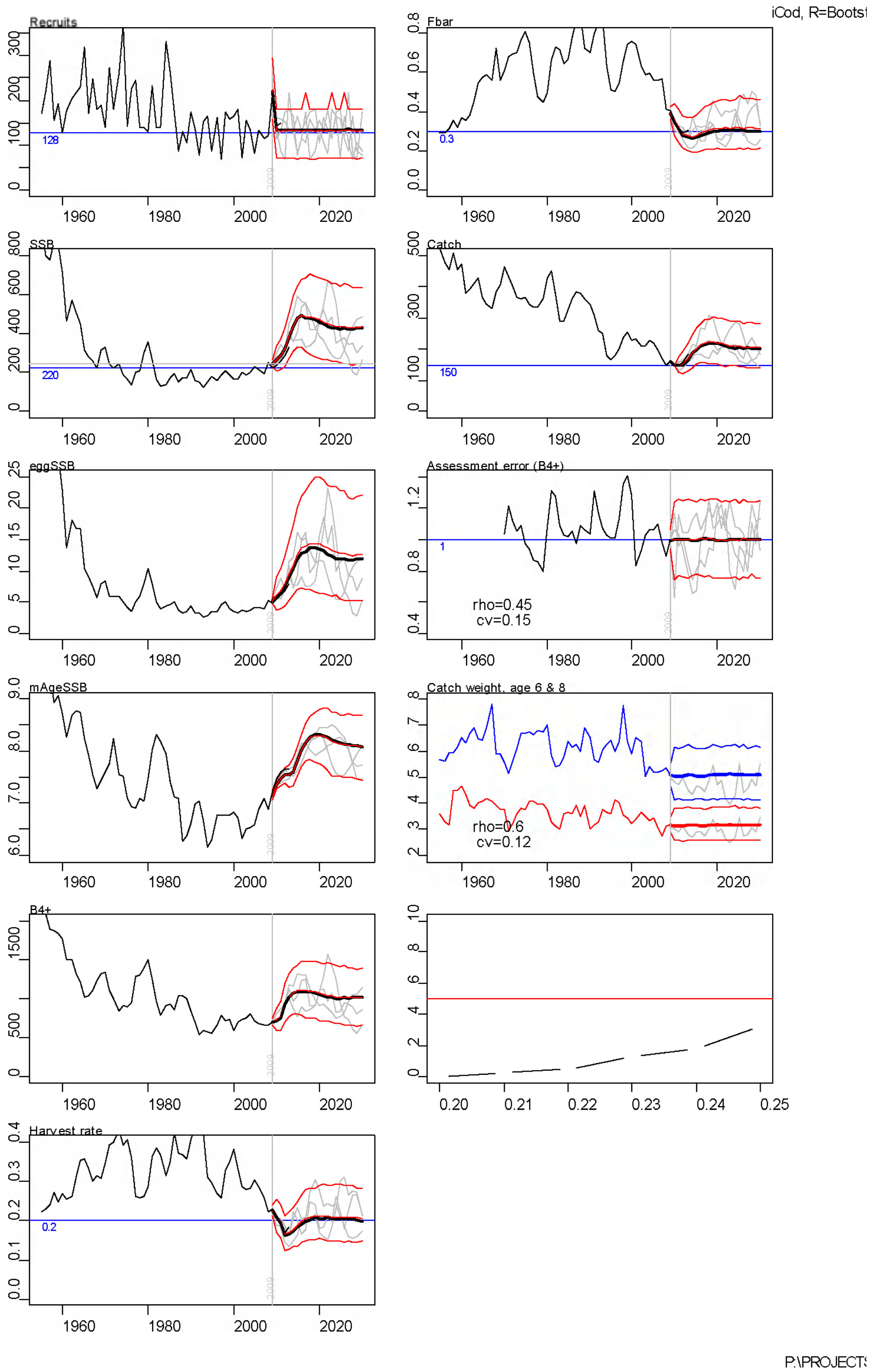

Figure 5: Summary plot. Recruitment based on bootstrapping the recent low year classes (year class 1985-2008), no assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

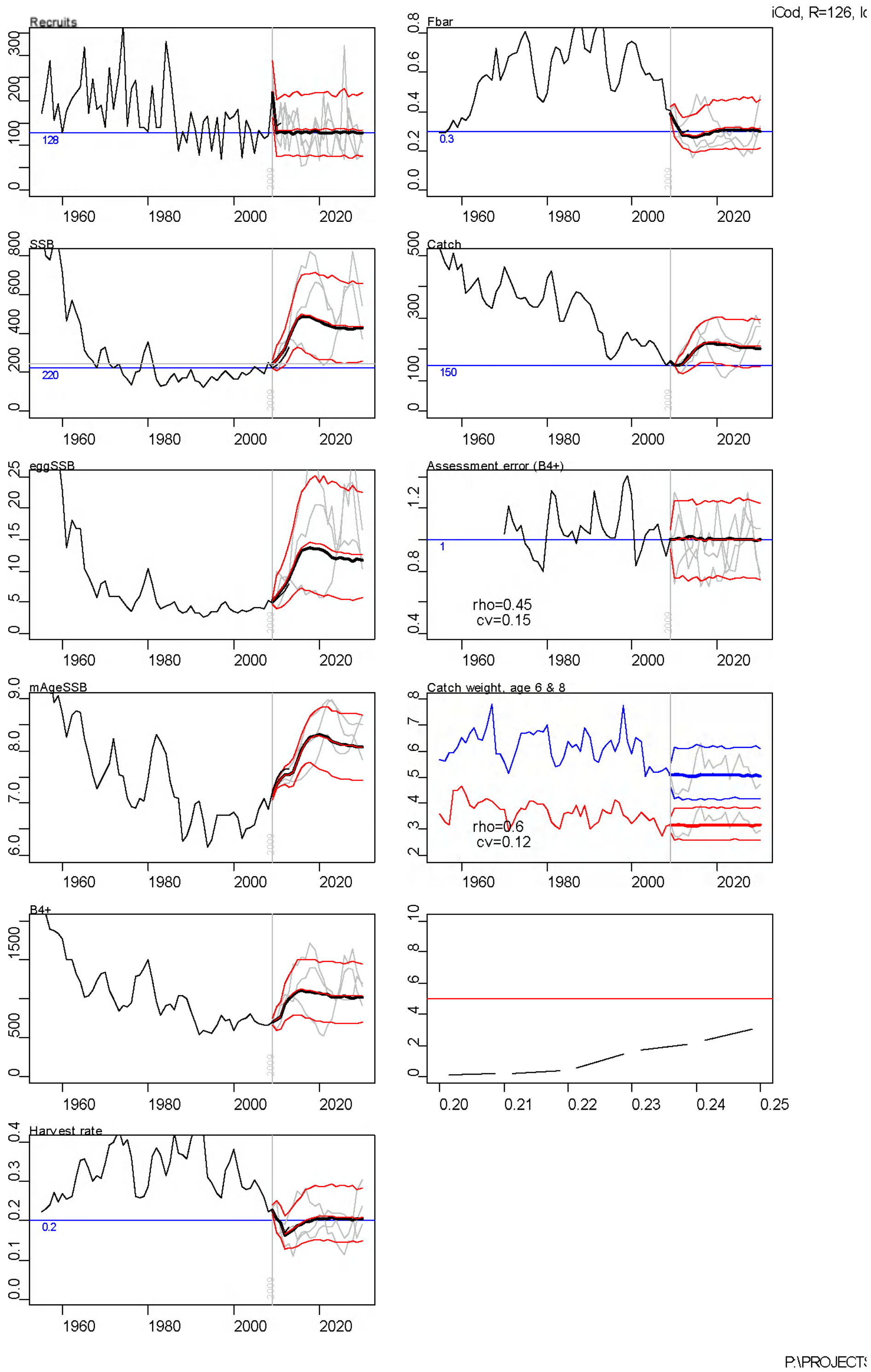

Figure 6: Summary plot. Recruitment based on mean of 128, no assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

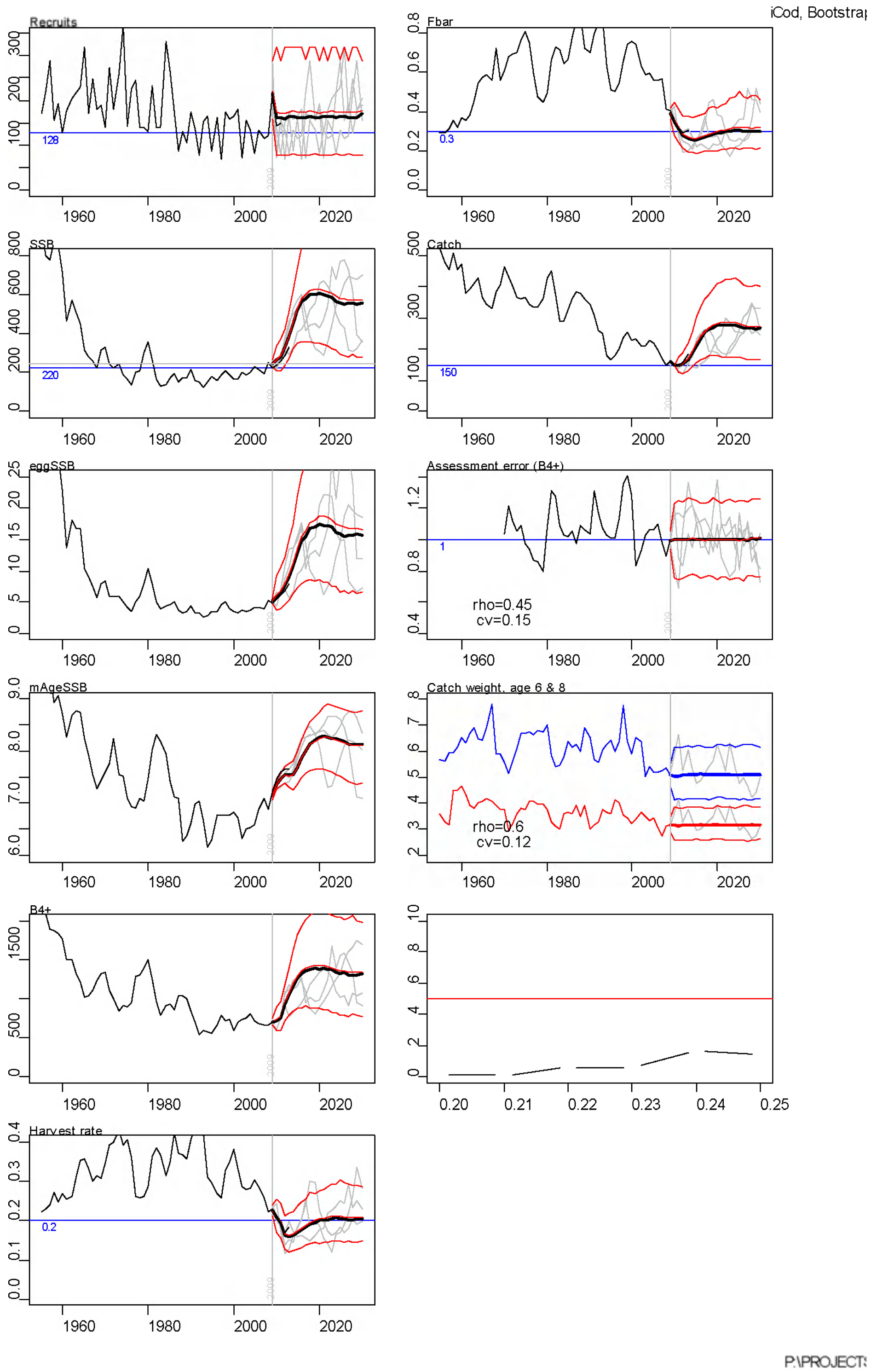

Figure 7: Summary plot. Recruitment based on bootstrapping the whole time series as a continuous loop, no assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

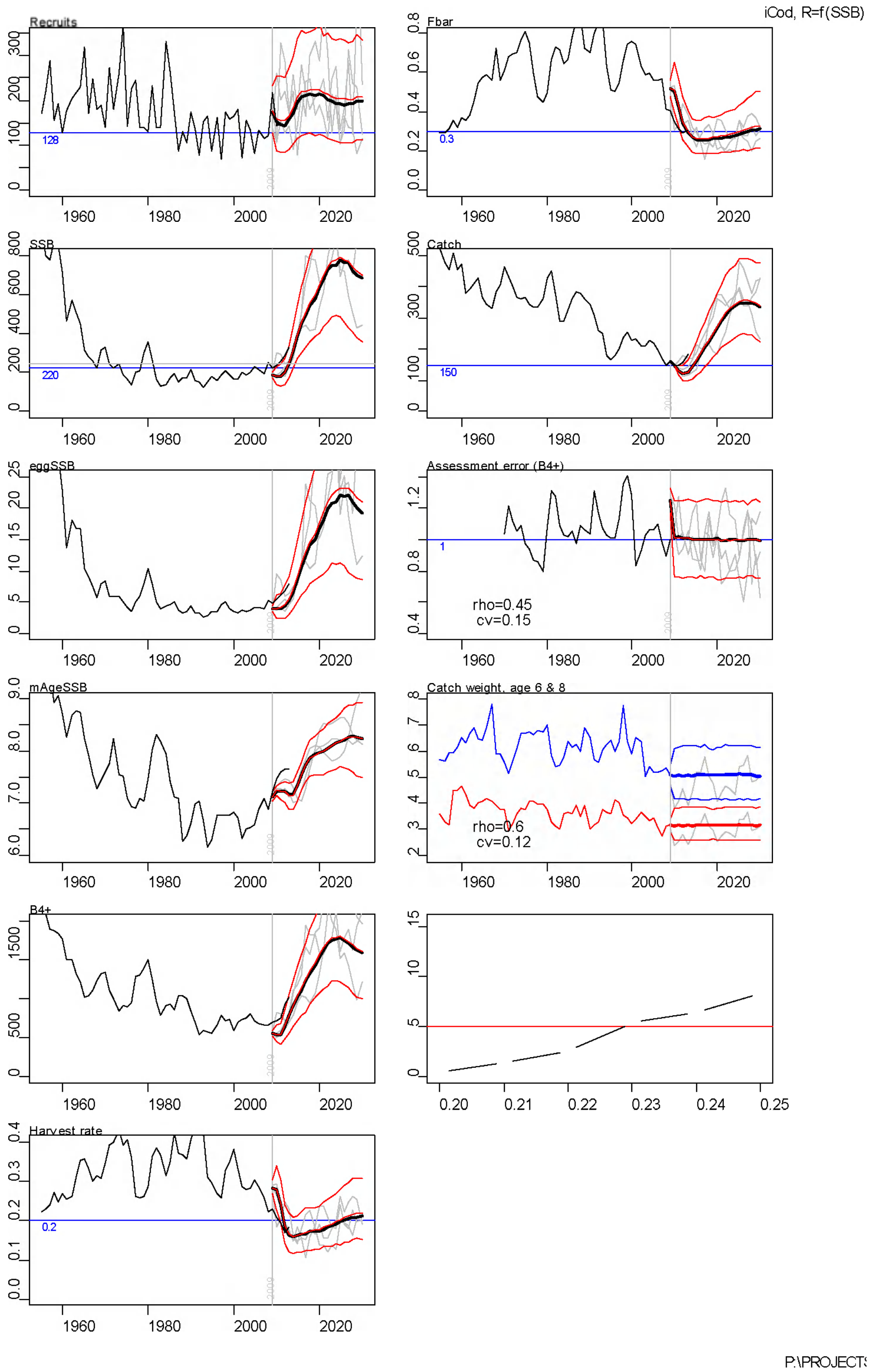

Figure 8: Summary plot. Ricker recruitment based on conventional SSB, 25% assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

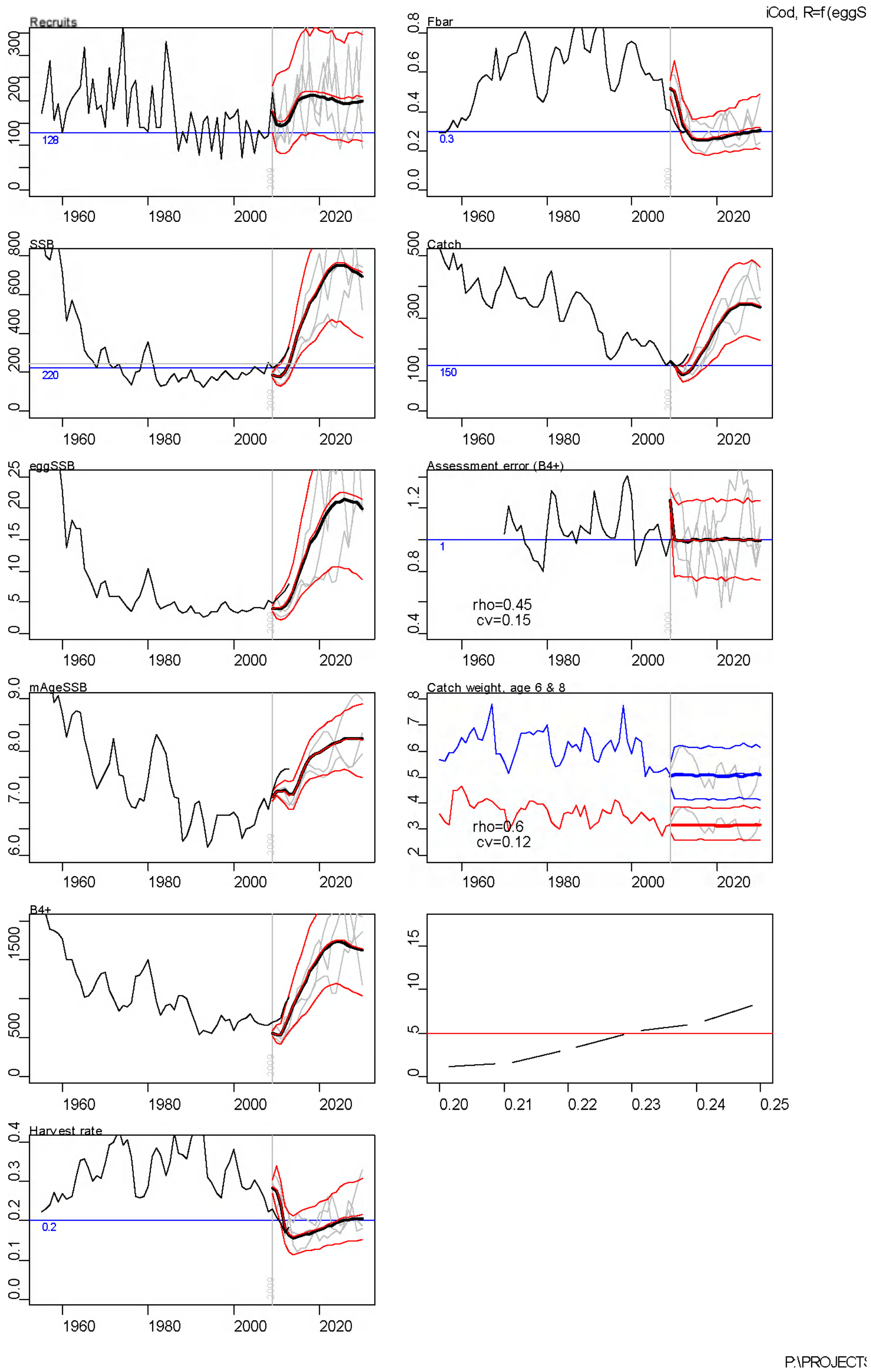

Figure 9: Summary plot. Ricker recruitment based on egg productivity, 25% assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

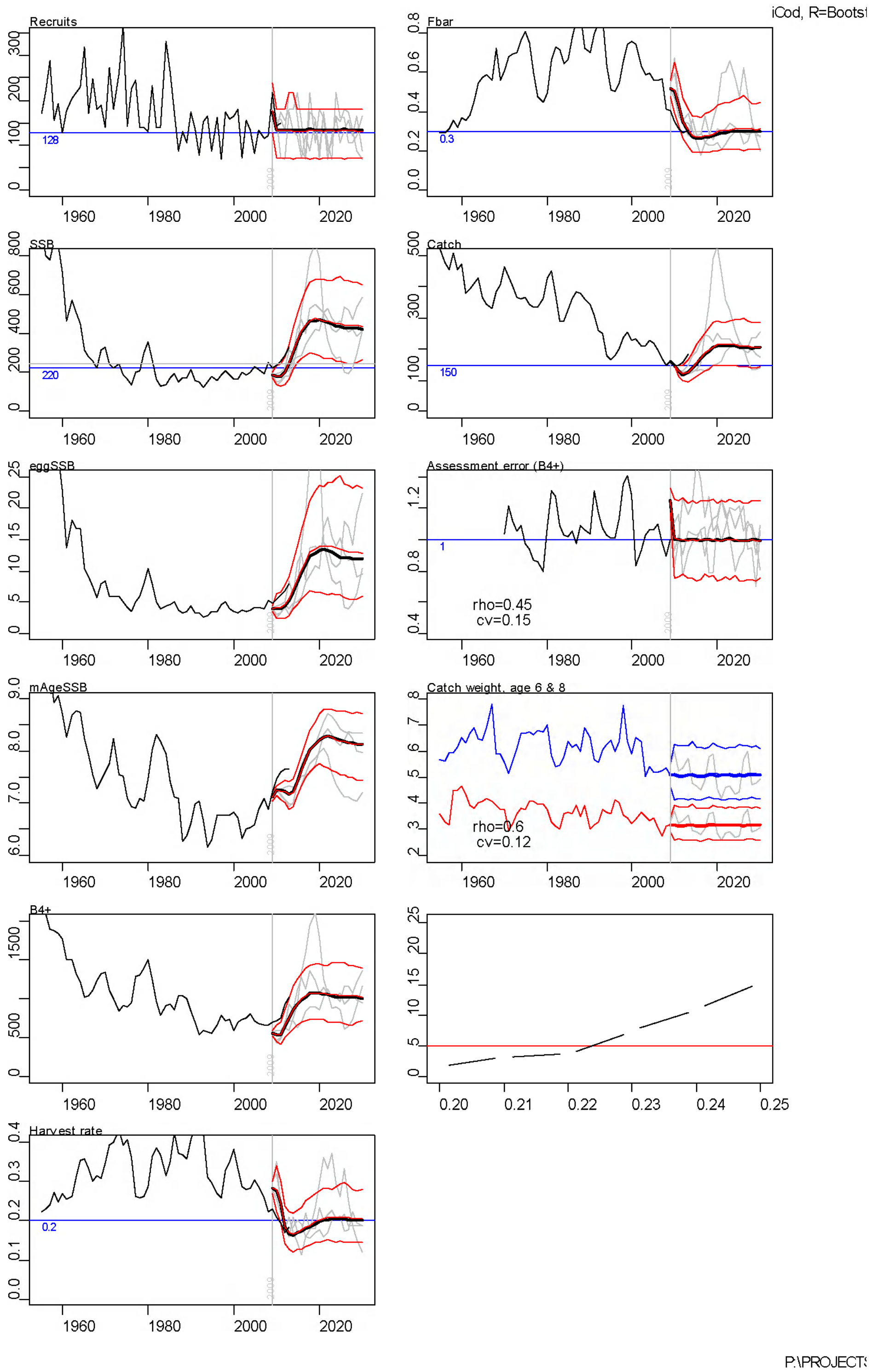

Figure 10: Summary plot. Recruitment based on bootstrapping the recent low year classes (year class 1985-2008), 25% assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

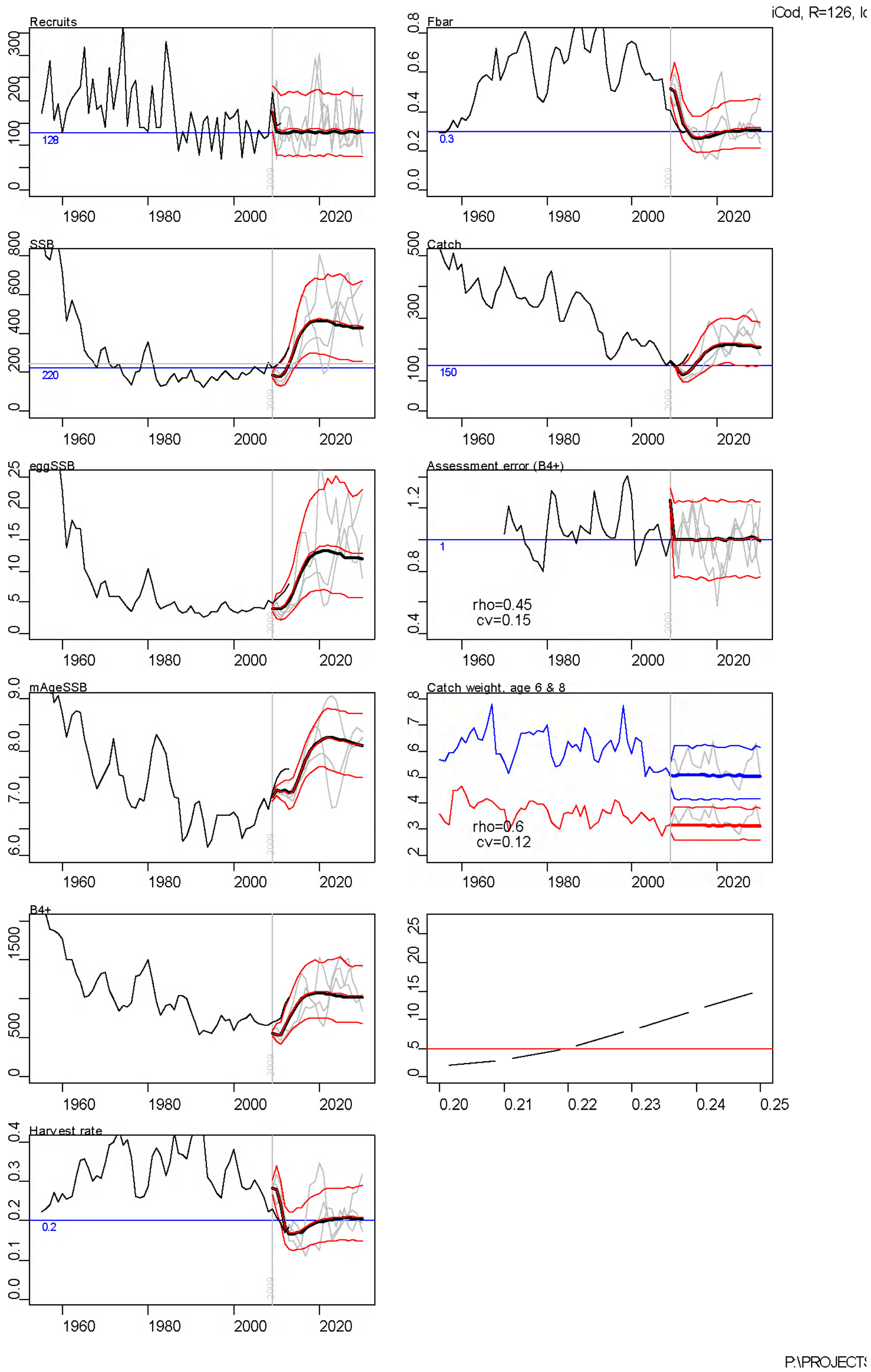

Figure 11: Summary plot. Recruitment based on mean of 128, 25% assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

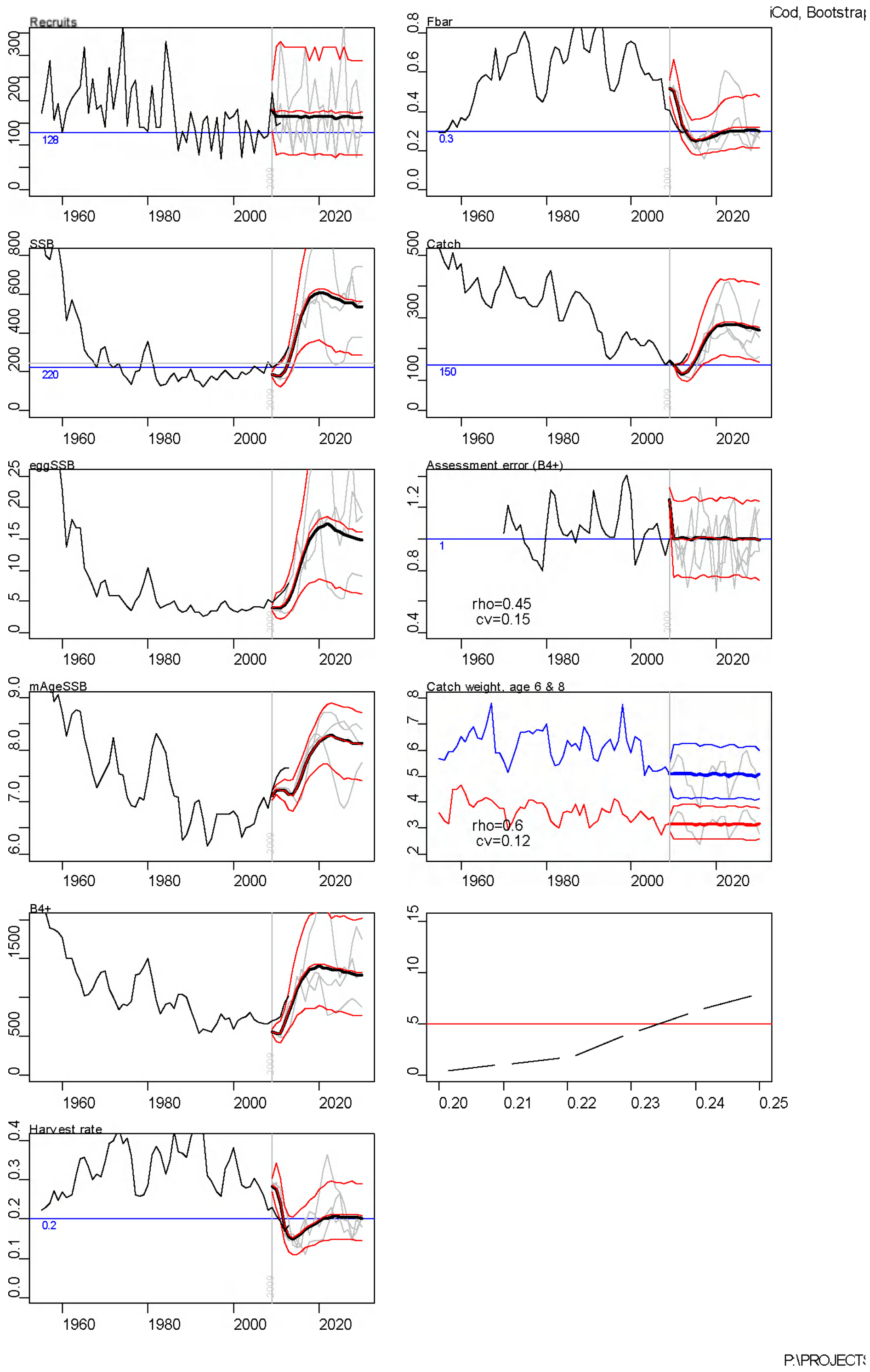

Figure 12: Summary plot. Recruitment based on bootstrapping the whole time series as a continuous loop, 25% assessment bias in 2009. The time plot results refer to the 20% harvest rule. For other legends, see explanation in figure 3.

Annex 4: Review Group Technical Minutes: RGICMP

Review of the Icelandic Cod Management Plan

24-26 November 2009

Participants:

Reviewers:

Dankert Skagen (chair) – Norway

Peter Shelton – Canada

José De Oliveira – United Kingdom

Preparation and presentation of Working Document (ICOD HCR Evaluation):

Höskuldur Björnsson – Iceland

Einar Hjörleifsson – Iceland

Secretariat:

Michala Ovens (Assistant secretary)

Mette Bertelsen (Professional support)

Background

The Review Group was set up following a request by the Icelandic Government to ICES to review the management plan that has been adopted for the next five fishing years, commencing from the 2009/2010 fishing season. The main objective of the plan is to ensure that SSB will, with a high probability (>95%), be above the present size of 220 kt (as estimated by the ICES North West Working Group in spring 2009) by the year 2015. This is to be achieved by applying the following HCR to the Icelandic cod stock:

$$TAC_{y/y+1} = (h^*B_{4+,y} + TAC_{y-1/y})/2$$

where h represents the harvest ratio of 0.2, $B_{4+,y}$ represents the biomass of cod aged 4 and older, and $TAC_{y/y+1}$ represents the TAC set for the fishing year commencing from 1/9 in calendar y to 31/8 in calendar year y+1.

The process leading up to the Review Group meeting on the 24-26 November 2009 was the preparation of an extensive working document by Icelandic scientists describing the management plan, presenting the appropriate simulations and the software used, and the decision that the Review Group (RG) would fulfil three roles. Firstly, it would act as a "shadow" group to the Icelandic scientists leading up to the RG meeting; secondly it would review the final document; and thirdly it would draft the advice.

The shadowing process was the first time such an approach to reviewing was adopted by ICES, and was intended to allow for earlier input by reviewers in the preparation of the work, so that outputs required by the review process and in the appropriate format would be available for the actual meeting. This would avoid the situation where work was rejected on the basis that it did not cover sufficient ground. The shadowing process was not intended to be too prescriptive in how work was conducted, and would not dictate outcomes or conclusions, but would instead focus on what needed to be done, and how material was to be presented, justified and documented.

The shadowing process took the form of two WebEx conference meetings with material disseminated through an ICES Sharepoint site. The main points from each of these meetings are listed below.

1st WebEx conference (6 October 2009)

- The ADCAM framework would serve as the main simulation tool, with FPRESS used as a backup for verification of results for a subset of scenarios
- A full MSE (with an assessment model embedded in the simulation loop in order to provide the HCR with an estimate of $B_{4+,y}$) is beyond the reach of the currently available software tools, so a short-cut MSE (where the fitting of the assessment model and estimation of $B_{4+,y}$ within the simulation loop is replaced by simply adding "assessment error" to the operating model $B_{4+,y}$) will instead by performed. How the "assessment error" is modelled is regarded as key, and needs to be documented and justified, and should also include autocorrelation.
- A full documentation of the software is mandatory
- Sensitivity of outcomes to the choice of assessment method should be explored
- Simulation period should reach at least 2015, but preferably go beyond this.
- Recruitment and mean weight- maturity- and selection-at-age used in the simulations should represent the situation in the most recent past
- The current natural mortality value is probably adequate
- No reference points are defined, and evaluations should be with respect to an SSB of 220kt, which is regarded as the rebuilding target. The rules should be regarded as precautionary if this target is reached with at least a 95% probability.
- Robustness to implementation error should be considered, so that the rule is still viable at the levels of implementation error experienced in the past.
- Extensions to the rule (e.g. reducing h if the stock falls below a certain limit) should not be considered, because this is considered a plan for rebuilding the stock. A separate process is required to design a rule to apply in the longer term once rebuilding is achieved.
- There should be a recommendation for a revision clause (if there are deviations from what is tested for)

2nd WebEx conference (17 November 2009)

- The operating model used for simulations differs from the assessment model used by NWWG, the former assuming separable selection, whereas the latter has temporally varying selection using a random walk. MRI to consider how much selection varies over time.
- Assessment error is introduced by a random auto-correlated multiplier but without bias, even though there is a bias of around 8% for B_{4+} when the current best assessment estimates of this variable is compared to contemporaneous final-year estimates from previous assessments. Since there is a

direct mathematical relationship between such a bias and *h*, this bias can be accounted for by considering higher *h* values than 0.2.

- Implementation error (e.g. removals exceeding the TAC corresponding to the HCR) would also lead to an effective *h* that is higher than that intended by the rule, and an investigation of past data showed this to be the case. Managers need to be made aware of this problem.
- Discards should be mentioned and discussed in the report. Discards are ignored in the assessment.
- The variance of initial numbers, taken from the inverse Hessian as estimated in the assessment, is much smaller than the assessment error assumed in the simulations, and it was recommended that this variance should be inflated so that the uncertainty in initial numbers was consistent with what is assumed for assessment error in simulations.
- Recruitment options should be limited to a small number of the most likely ones. Depensation should be considered as a possible mechanism, as well as drawing recruitments from the recent low values.
- Runs presented should be limited to what is essential.

Review Group Meeting (24-26 November 2009, ICES HQ)

The review of the Icelandic cod management plan was conducted by the three invited experts. Icelandic scientists, who were in attendance for part of the meeting and made initial presentations of their analyses, were consulted whenever clarifications or further outputs were required. Once the review was conducted, the invited experts formulated the draft advice.

At the start of the review, clarifications of the review process and drafting of advice were sought from the ICES Secretariat (Hans Lassen). Discussions centred around drafting the advice, how to handle reference points and the precautionary approach, and accounting for implementation error. The main points were:

- Drafting advice:

  Advice should be drafted as if it is the final text

  Refer to the working document for technical details

  Essentials should be picked out for easy interpretation by managers, but with sufficient details to allow other scientists to follow what was done.

  The status of the working document produced by the Icelandic scientists is the same as that of an expert group document, and it should accessible via the ICES website.

- Reference points and PA

  There were no clear conclusion on this, and the RG felt that, given the uncertainty about stationarity in biological processes (recruitment, mean weights, maturation, selectivity) and given the limited time of review and nature of material presented, they were not in a position to make comments about suitable reference points for this stock. The review group will focus instead on whether the management plan is able to recover SSB to above current (2009) levels (estimated by NWWG in spring this year to be 220kt) by 2015 with a probability exceeding 95%.

- Implementation error

  Paradoxical to account for implementation error in the evaluation
  Evaluation should rather be presented as assuming the rule will be fully implemented, and to highlight consequences if this is not the case.

The main points from the review conducted by the RG were as follows:

- Differences between operating model, and assessment model used by NWWG

  The operating model has abrupt changes in selection followed by long periods of constant selection, whereas the NWWG assessment has selection changing gradually over time. In terms of the most recent period, the main difference is at the oldest ages, which may be a minor issue for this stock at present.
  A comparison of residuals of model fits also showed some difference between the two models, but these did not appear to be large.
  Given that the differences between the operating model and the NWWG assessment model did not appear to be important, the RG concluded that the operating model was a suitable basis for conducting the evaluation.

- Short-cut vs. full MSE

  The premise for conducting a full MSE is that structural uncertainty (resulting in perceptions being somewhat different to reality) can be better accounted for. A full MSE option was not possible for this work, so a decision was taken early-on to follow the short-cut approach, taking care that the replacement for the component that was short-cut (in this case embedding the assessment model within the simulation loop) would be carefully modelled to approximate the behaviour of that missing component as close as possible. This behaviour was modelled by comparing current best assessment (treated as "reality") with assessments conducted in the past (treated as how we would "perceive" this reality when conducting assessments). This comparison led to estimates of a CV (0.15) and autocorrelation (0.45, both estimates based on the period 1990-2005, and ignoring the bias) that could be used in the simulation to convert the real-world B_{4+} value into the perceived B_{4+} value that was then used to set the TAC based on the HCR.
  It was nevertheless felt that this short-cut MSE, although not discrediting the evaluation as performed, limited it somewhat by not allowing a fuller investigation of structural uncertainty. A specific example were concerns expressed that the current estimate of M (0.2) was too high, and consequences of assuming the "wrong" M in the assessment (e.g. operating model=0.15 and assessment=0.2) could have been investigated.

- Modelling recruitment

  Hockey-stick formulation with flat portion corresponding to the mean of recent low values was initially the key run, assuming a log-normal distribution (CV=0.4, no autocorrelation). However, comparisons of the cumulative plots of the resultant distribution with that associated with "observations" showed that higher simulated recruitments were being obtained than have been observed recently, caused by the long tail of the lognormal distribution. It was therefore decided that simulated recruits would instead be drawn from a uniform distribution with a minimum and maximum covering the range of recent recruitments (70-180 million fish).

The 2008 year class is estimated to be large compared to recent recruitment, and this has an influence on simulation results, particular when considering the short- to medium-term (e.g. 2015), so it was decided that a further sensitivity test, reducing the size of the 2008 year class to the mean of recent values, would be included.

A third stock-recruit function to be considered was one with the mean SSB age as an additional covariate in a Ricker function. This option was preferred above one fitting a Ricker to egg production estimates because it performs better; in any case, both are proxies for the same process (the idea that older fish produce better spawning products), so it was felt only one was needed. Because of the increase in SSB in recent years, this option produces larger recruitments than seen in recent years, so it is regarded as an optimistic scenario.

A depensatory Ricker stock-recruit formulation was also considered, but attempts to estimate the third parameter were unsuccessful, so this option was rejected.

- Modelling mean weights-at-age

  A year class factor for modelling mean weights at age, such as may be required for haddock stocks, is not appropriate for this stock

  The mean over 2006-2008, reflecting recent low values, with a CV (0.12) and autocorrelation (0.6) estimated on the basis of a wider range of years, is used to generate future mean weights at age, using a lognormal distribution. The consequence of using such a distribution is that around 50% of future simulated weights at age will be below the lowest values seen in the past. This is a very conservative scenario.

- Modelling maturation

  The mean of 2006-2008 was used and kept constant in future simulations.

  There have been changes in maturity-at-age historically that may counterbalance the effects on SSB of a drop in mean weight-at-age.

  There have been issues related to the source of data used for the early maturity at age estimates (sourced from landings)

- Initial number

  The estimation error for the initial numbers used in the simulations are derived from the variance-covariance matrix obtained using the inverse Hessian. This error is regarded as too narrow, so the variance of initial numbers were inflated so as to give a spread initially that was consistent with assessment error (CV=0.15)

- Handling assessment error bias

  The assessment error used to convert B_{4+} from the operating model to the value used in the HCR ignores bias, which has implications for the h value used in the advice. Since this bias (8%) was not explicitly incorporated in the evaluation, it was decided that any results given in the advice should be adjusted to incorporate the effects of this bias. This was done by assuming that for h=0.2, a 10% bias would result in an effective h of 1.1*0.2=0.22. Therefore, all results shown in the advice as h=0.2 actually correspond to the h=0.22 results in the working document. In this way, the advice incorporates the effects of assessment bias.

- SSB in 2015 relative to 2009

  The original request states the management objective of SSB in 2015 being above the present size of 220 thousand tons with a probability greater than 95%. The 220kt value is taken from the 2009 NWWG assessment, and is the estimate of SSB in 2009. Because the operating model differs from the model used in the assessment, the equivalent operating model estimate for SSB in 2009 differs from this value. It was therefore decided to interpret the management objective as SSB in 2015 exceeding the level in 2009 with a probability of greater than 95%.

- Plus group

  The operating model (and also NWWG assessment) does not include a plus group, and assumes all fish die after age 14. Although this assumption may be adequate while the number of fish encountered at that age is small, there may be implications for the longer term if the stock recovers, in particular for MSY and PA reference point considerations. "Back-of-the-envelope" calculations indicate that the plus group contributes around 3% to YPR if F=0.3. For F=0.1, this increases to 8.5%. Furthermore, since 1966, the contribution of age 14 is less than 5kt to spawning stock, but in 1959, this was 90kt due to huge yc which appeared at age 8 (thought to originate from Greenland).

- MSY

  As one management objective was stated as "to increase the size of the cod stock towards the size that generates maximum sustainable yield" the working document by MRI considered estimates of MSY and BMSY. The working document was critical of these estimates for several reasons, including the flat-topped shape of the yield per recruit curve and the sensitivity to the choice of stock-recruit function. The reviewers shared these concerns. Both for that reason, and because the ICES policy with respect to MSY objectives is in progress just now, the RG was hesitant to pursue this issue further. It was noted, though, that the reduction in fishing mortality resulting from implementing the rule would be a step in the right direction, and that the experience from some years with reduced fishing mortality would help to clarify how the stock can be expected to respond to a lower exploitation.
  Despite changes in historical weights at age and maturation rates, a back-of-the-envelope calculation of age-aggregated production ($B_{4+,y+1}$-$B_{4+,y}$+C_y) suggested a fairly stationary Schaefer production function from 1955 to 2004, but with large negative residuals in the last 4 years as a result of the very low weights at age.

Annex 5: Recommendations

We suggest that each Expert Group collate and list their recommendations (if any) in a separate annex to the report. It has not always been clear to whom recommendations are addressed. Most often, we have seen that recommendations are addressed to:

- Another Expert Group under the Advisory or the Science Programme;
- The ICES Data Centre;
- Generally addressed to ICES;
- One or more members of the Expert Group itself.

Recommendation	For follow up by:
1.	
2.	
3.	
4.	
5.	
6.	

After submission of the report, the ICES Secretariat will follow up on the recommendations, which will also include communication of proposed terms of reference to other ICES Expert Group Chairs. The "Action" column is optional, but in some cases, it would be helpful for ICES if you would specify to whom the recommendation is addressed.

Annex 6: ADCAM user manual

ADCAM User Manual

(Draft Version)

Hoskuldur Bjornsson
Arni Magnusson

November 22, 2009

Contents

Part I

Model overview

Chapter 1

Introduction

ADCAM is a statistical catch-at-age model, originally developed for Icelandic cod stock assessment. It is designed and written by Hoskuldur Bjornsson, with contributions by Arni Magnusson. The model is in continuous development and has many optional variations. This draft version of the manual does not describe all model variations in detail.

The main difference between the current version of ADCAM and recent versions is that the current model can handle projections many years into the future. Previous versions were designed to evaluate harvest rules that depend on future biomass estimates, but this model's harvest rule depends only on the current and previous year, which simplifies the model implementation.

Previous versions of ADCAM have been used in the Icelandic cod stock assessment in recent years (ICES 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009). It is written in the AD Model Builder programming language (ADMB Project 2008).

Chapter 2

Population dynamics

2.1 Annual step

The population dynamics are governed by the equation:

$$N_{t+1,a+1} = N_{t,a} e^{-(F_{t,a}+M_a)} \tag{2.1}$$

where $N_{t,a}$ is population size at time t and age a, F is fishing mortality rate, and M is natural mortality rate.

Plus group acccumulation is optional:

$$N_{t+1,A} \quad = \quad N_{t,A-1} e^{-(F_{t,A-1}+M_{A-1})} + N_{t,A} e^{-(F_{t,A}+M_A)} \tag{2.2}$$

where A is the oldest age in the model.

2.2 Initial stock structure

The population size at the start of the first year is modelled as free parameters, implemented as deviates from an overall geometric mean:

$$N_{\mathrm{init},a} = \mu_{\mathrm{init}} \times \exp({}_{\mathrm{init}}\varepsilon_a), \quad a \in \{2, \ldots, A\} \tag{2.3}$$

where 'init' is the first year, μ_{init} is the geometric mean population size across ages in the first year, ${}_{\mathrm{init}}\varepsilon_a$ are exponential deviates that are forced to sum to zero, $\sum {}_{\mathrm{init}}\varepsilon_a = 0$. The initial population size at age 1 is modelled as recruitment.

2.3 Recruitment

Historical recruitment is modelled as free parameters, implemented as deviates from a long-term geometric mean:

$$N_{t,1} = \mu_R \times \exp({}_R\varepsilon_t) \tag{2.4}$$

where μ_R is the long-term geometric mean recruitment and ${}_R\varepsilon_t$ are exponential deviates that are forced to sum to zero, ${}_R\varepsilon_t = 0$.

For cohorts that have few or no years of catch-at-age data, a likelihood component (Eq. 4.10) is used to pull the recruitment slightly towards a Ricker stock-recruitment function:

$$N_{t,1} = R_{\max} \times \frac{SSB}{SSB_{\max}} \times \exp\left(1 - \frac{SSB}{SSB_{\max}}\right) \tag{2.5}$$

where $R_{\max}$ is the deterministic maximum recruitment, SSB is spawning biomass, and $SSB_{\max}$ is the spawning biomass that gives $R_{\max}$.

Alternatively, the user can choose between several other recruitment functions, including Beverton-Holt, segmented regression, or a fixed geometric mean. Furthermore, egg production can be used instead of spawning biomass, and a negative time trend can be applied after 1985.

2.4 Migration events

Migration events can be modelled as free parameters, where fish in a specific year at a specific age can exit or enter the population permanently:

$$N_{t,a} = N_{t-1,a-1}e^{-(F_{t-1,a-1}+M_{a-1})} + \lambda_{t,a} \tag{2.6}$$

where $\lambda_{t,a}$ are migrants exiting (negative) or entering (positive) the population at time t and age a. In the case of Icelandic cod, this is used to estimate the magnitude of documented migration events from Greenland into Icelandic waters.

2.5 Fishing mortality and selectivity

Fishing mortality is a product of annual fishing mortality rate and age-specific selectivity:

$$F_{t,a} = F_t S_a \tag{2.7}$$

Annual fishing mortality rate is modelled as free parameters, implemented as deviates from a long-term geometric mean:

$$F_t = \mu_F \times \exp({}_F\varepsilon_t) \tag{2.8}$$

where μ_F is the long-term geometric mean fishing mortality rate (of fully selected ages) and ${}_F\varepsilon_t$ are exponential deviates that are forced to sum to zero, $\sum {}_F\varepsilon_t = 0$.

Selectivity is modelled as free parameters for ages a_r, the lowest age present in catch at age data (recruited), up to but not including a_f, the first age that is fully selected:

$$S_a = \begin{cases} 0, & a < a_r \\ \theta_a, & a_r \leq a < a_f \\ 1, & a \geq a_f \end{cases} \tag{2.9}$$

where S is selectivity and θ are estimated parameters.

Different selectivity patterns can be used for different periods. In the case of Icelandic cod, there is a priori reason to believe that the selectivity pattern changed around 1976 when the foreign fleets left, and again around 1994 after the

TAC was reduced considerably. With period-specific selectivities, the functions become:

$$F_{t,a} = F_t S_{t,a} \tag{2.10}$$

$$S_{t,a} = \begin{cases} 0, & a < a_r \\ \theta_{P,a}, & a_r \leq a < a_f, \quad t \in P \\ 1, & a \geq a_f \end{cases} \tag{2.11}$$

where P is a period, a defined set of years.

Chapter 3

Biomass calculations

3.1 Spawning stock

The spawning biomass is:

$$SSB_t = \sum_a N_{t,a}\phi_{t,a}w'_{t,a} \times \exp\left[-({}_{FS}p_a F_{t,a} + {}_{MS}p_a M_a)\right] \tag{3.1}$$

where ϕ is maturity, w' is weight at age during the spawning season, and ${}_{FS}p$ and ${}_{MS}p$ are proportions of annual fishing and natural mortalities that occur before spawning.

3.2 Reference stock

The reference biomass is the biomass of ages 4 and older:

$$B_{4+,t} = \sum_{a=4}^{A} N_{t,a}w_{t,a} \tag{3.2}$$

Chapter 4

Likelihood components

4.1 Objective function

The objective function consists of four likelihood components:

$$f = -\log L_Y - \log L_C - \log L_I - \log L_R \tag{4.1}$$

describing the model fit to landings, commercial catch at age, and survey catch at age, as well as recruitment process error. These likelihood components are described below.

4.2 Landings

The uncertainty about observed landings is assumed to be lognormal:

$$-\log L_Y = \sum_t \left[\frac{(\log Y_t - \log \hat{Y}_t)^2}{2_Y\sigma^2} + \log {}_Y\sigma \right] \tag{4.2}$$

where Y is the observed landings, $\hat{Y}$ is the predicted landings, and ${}_Y\sigma$ is the magnitude of the uncertainty. The predictions are calculated using the catch equation multiplied by the weight at age:

$$\hat{Y}_t = \sum_a N_{t,a} \frac{F_{t,a}}{F_{t,a} + M_a} \left[1 - e^{-(F_{t,a}+M_a)} \right] w_{t,a} \tag{4.3}$$

4.3 Commercial catch at age

The uncertainty about observed commercial catch at age is assumed to be lognormal:

$$-\log L_C = \sum_t \sum_a \left[\frac{(\log[C_{t,a} + \alpha_C] - \log[\hat{C}_{t,a} + \alpha_C])^2}{2_C\sigma_a^2} + \log {}_C\sigma_a \right] \tag{4.4}$$

where C is the observed commercial catch at age in numbers, $\hat{C}$ is the predicted commercial catch at age, α_C is a small log-transformation constant, and ${}_C\sigma$ is the magnitude of the uncertainty. The predictions are calculated using the catch equation:

$$\hat{C}_{t,a} = N_{t,a} \frac{F_{t,a}}{F_{t,a} + M_a} \left[1 - e^{-(F_{t,a}+M_a)}\right] \tag{4.5}$$

For estimation purposes, the magnitude of the uncertainty is separated into age-specific relative coefficients (ξ) and an overall scaler (τ):

$$_C\sigma_a = {_C\xi_a} \times {_C\tau} \tag{4.6}$$

4.4 Survey catch at age

The uncertainty about observed survey catch at age is assumed to be lognormal:

$$-\log L_I = \sum_t \sum_a \left[\frac{(\log[I_{t,a} + \alpha_I] - \log[\hat{I}_{t,a} + \alpha_I])^2}{2 {_I\sigma_a^2}} + \log {_I\sigma_a} \right] \tag{4.7}$$

where I is the observed survey catch at age in numbers, $\hat{I}$ is the predicted survey catch at age, α_I is a small log-transformation constant, and $_I\sigma$ is the magnitude of the uncertainty. The predictions are calculated using an optional power relationship:

$$\hat{I}_{t,a} = q_a \big(N_{t,a} \exp\left[-({_{FI}p} F_{t,a} + {_{MI}p} M_a)\right]\big)^{_I\beta_a} \tag{4.8}$$

where q is survey catchability, $_{FI}p$ and $_{MI}p$ are proportions of annual fishing and natural mortalities that occur before the survey.

For estimation purposes, the magnitude of the uncertainty is separated into age-specific relative coefficients (ξ) and an overall scaler (τ):

$$_I\sigma_a = {_I\xi_a} \times {_I\tau} \tag{4.9}$$

4.5 Recruitment

Process error recruitment deviates from the deterministic stock-recruitment function are assumed to be lognormal:

$$-\log L_R = \sum_t \left[\frac{(\log N_{t,1} - \log \hat{N}_{t,1})^2}{2 {_R\sigma_t^2}} + \log {_R\sigma_t} \right] \tag{4.10}$$

where $_R\sigma_t$ is the magnitude of this process error. The predictions are calculated using the stock-recruitment function (Eq. 2.5).

The time-specific magnitude of the process error is estimated with one overall scaler ($_RCV$) with an optional power relationship:

$$_R\sigma_t = \frac{_RCV}{(SSB_t/SSB_{\mathrm{ref}})^{_R\beta}} \tag{4.11}$$

where SSB_{ref} is a defined reference spawning biomass and $_R\beta$ is a power coefficient. When $_R\beta$ is zero, the relationship simplifies to $_R\sigma_t = {_RCV}$.

Chapter 5

Fitting the model

5.1 List of estimated parameters

In order of appearance in the ADMB model code and output files:

$\lambda_{t,a}$	Migration events
μ_R	Geometric mean recruitment
${}_R\varepsilon_t$	Recruitment deviates
μ_{init}	Geometric mean of initial population
${}_{\text{init}}\varepsilon_a$	Initial population deviates
θ_a	Selectivities
${}_C\tau$	Commercial catch at age uncertainty scaler
${}_I\tau$	Survey catch at age uncertainty scaler
${}_I\beta_a$	Survey catchability power coefficient
q	Survey catchability
μ_F	Geometric mean fishing mortality rate
${}_F\varepsilon_t$	Fishing mortality deviates
$R_{\max}$	Recruitment shape parameter
$SSB_{\max}$	Recruitment shape parameter
${}_RCV$	Recruitment process error scaler

5.2 Minimization

The objective function is minimized using automatic differentiation (ADMB Project 2008).

5.3 Uncertainty

Two different approaches can be used to evaluate the uncertainty about estimated parameters and other quantities of interest: the delta method and Markov-chain Monte Carlo (MCMC).

Chapter 6

Future projections

(Described in the report on Icelandic cod harvest rule.)

Part II

Running the model

Chapter 7

Command line interface

7.1 Prerequisites

ADCAM can be run on Windows and Linux machines. The source code is in one file, `islcod.tpl`, and the compiled version is one executable file called `islcod.exe` (Windows) or simply `islcod` (Linux). It requires several input files to run, as described below.

7.2 General run

The model fitting is invoked from the shell command line by typing the name of the executable:

```
$ islcod
```

Once the model has converged, output files have been created in the current directory. These include point estimates and standard errors of estimated parameters and other quantitites of interest.

7.3 MCMC analysis

To evaluate the uncertainty using Markov-chain Monte Carlo (MCMC) analysis, there are three command line options. First, the model is invoked with `-mcmc` and the desired number of MCMC iterations, as well as `-mcsave` and the interval between iterations that are saved to MCMC chains to be analyzed, e.g.:

```
$ islcod -mcmc 1000000 -mcsave 1000
```

Once the iterations are finished, usually after some hours, the chains are written to MCMC output files with `-mceval`:

```
$ islcod -mceval
```

Chapter 8

Input files

All input and output files are plain text files. Several input values are from previous versions of ADCAM and are ignored in the current version. The following description uses excerpts from input and output files from a model run called `RickerSeperable3periods1Rmax`.

8.1 islcod.dat

The main input file specifies the names of other input files, dimensions, flags, and parameters that the user is likely to change between runs:

```
catchandstockdata.dat
catchresiduals.dat

1955  2008 55 2008
1 14 3 0 0

stockparameters.dat
catchparameters.dat
likelihoodparameters.dat
outputparameters.dat
# nsurveys
1
1985 2009  1 10 10 6 1 1
surveypar.dat surveydata.dat surveyresid.dat
# SSBRectype etc.
2  200000 500 1 0.1 0 0
2 2 3 -1 -1 -1
# Migrations
11 # number of
# Prognosisfile
codprognosis.dat
nofile1
3
```

The first block specifies the first and last assessment year, number of projected years, last year with catch at age data, first and last age in model, first age in catch data, plus group flag (0:no, 1:yes), and the delay between hatching and survey (0 if survey includes age 1 and survey conducted in the assessment year is included).

The second block specifies the number of surveys, first and last year of survey data, first and last age in survey data, first fully selected age in surveys, first age with survey catchability power coefficient set to 1, years between final catch data and final survey data, and the survey type (currently ignored).

The third block specifies the recruitment function (1:Beverton-Holt, 2:Ricker, 3:Ricker based on egg production instead of SSB, 4:Beverton-Holt based on egg production instead of SSB, 5:segmented regression, 6:fixed mean, all functions implemented with optional time drift), $R_{\max}$, $SSB_{\max}$, ${}_R CV$, autocorrelation of residuals (currently ignored), ${}_R\beta$, and a negative time trend in recruitment after 1985, followed by the estimation phases for the recruitment parameters (negative means not estimated).

The last block specifies the number of migration events and the number of selectivity periods.

8.2 catchandstockdata.dat

The catch and stock data file has one row per `year` and `age` combination:

```
# year age    cno      cwts     stockwts sexmat   ssbwts
1955    1        -1       -1     15       -1       -1
1955    2        -1       -1     141      -1       -1
1955    3        4790     827    250      0.019    645
1955    4        25164    1307   588      0.022    1019
...
2008    14       4        17320  17320    1        17320
```

where `cno` is catch at age (thousands), `cwts` is the average body weight (g) in the catch, `stockwts` is the average body weight in the spring survey, `sexmat` is the maturity ogive from the spring survey, and `ssbwts` is the average body weight (g) of mature fish in the spring survey.

8.3 stockparameters.dat

The stock parameters file specifies age-specific M, the proportion of M and F applied before spawning, youngest age included in the spawning biomass, and year and age of migrations arriving from Greenland:

```
# Natural mortality
#Natural mortality
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2  0.2
# PropofM and PropofF before spawning
0.085 0.180 0.248 0.296 0.382 0.437 0.477 0.477 0.477  0.477 0.477 0.477
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
# min ssbage
4
# 11 migrations
1958  1959 1960 1962  1964 1969 1970  1972 1980 1981 1990  # year
 9     9    10   9     10   8     8    9    7     8   6    #age
```

8.4 catchparameters.dat

The catch parameters file specifies the years when selectivity periods end, an age-specific vector called `ProcessError` (currently ignored) and a matrix called `basfunc` (currently ignored):

```
1976 1994
#ProcessError
# 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
#           1      2      3      4
 1.0000000000 0.00000000 0.00000000 0.0000000000
 0.7513148009 0.22539444 0.02253944 0.0007513148
```

```
0.5477084899 0.36513899 0.08114200 0.0060105184
0.3846731781 0.43275733 0.16228400 0.0202854996
0.2577009767 0.44177310 0.25244177 0.0480841473
0.1622839970 0.40570999 0.33809166 0.0939143501
0.0939143501 0.33809166 0.40570999 0.1622839970
0.0480841473 0.25244177 0.44177310 0.2577009767
0.0202854996 0.16228400 0.43275733 0.3846731781
0.0060105184 0.08114200 0.36513899 0.5477084899
0.0007513148 0.02253944 0.22539444 0.7513148009
0.0000000000 0.00000000 0.00000000 1.0000000000
```

8.5 likelihoodparameters.dat

The likelihood parameters file determines the likelihood functions in the model:

```
#SigmaCInp
1 1 0.181  0.144  0.122  0.110  0.105  0.106  0.114  0.130 0.157  0.202 ...
# CatchReslution should maybe set as  lower percent if robust
0.005
#Sigmatotalcatch
0.1
# CatchRobust - SurveyRobust surveyrobust might have to be a vector
0 0
# Likelihood weights 10.  Might have to have one for each survey so
# Number might change
1 1 1 1 1 1 1 1 3 1
```

where `SigmaCInp` is a vector with relative age-specific uncertainty about observed catch at age, `CatchResolution` is a small constant added to catch at age before log-transforming, `Sigmatotalcatch` is the uncertainty about observed annual landings, `CatchRobust` and `SurveyRobust` are flags to use alternative likelihood functions for commercial and survey catch at age, and the likelihood weights refer to (1) commercial catch at age, (2) recruitment, (3) survey catch at age, and (4) landings. Likelihood component 9 stabilizes the estimation of the geometric mean fishing mortality rate, and ends up very small.

8.6 codprognosis.dat

The cod prognosis file describes future projections:

```
# Data for prognosis
3       # Catcrule icecod
0.12    # CV in weights
0.6     # weightcorr
0.15    # Assessmentcv
0.45    # Assessmentcorr
5       # Selection in prognosis mean of last 5 years.
3       # Mean weight in prognosis mean of last 3 years.

# Only for harvest rule 3
0.2    #Ratio caught
150    #Current Tac
139    #Tac left.
```

The first block specifies the catch rule (1:TAC, 2:F, 3:current harvest rule for Icelandic cod), annual variability and autocorrelation in weight at age, annual variability and autocorrelation in assessment error, number of recent years to base future selectivity on, and number of recent years to base future weight at age on.

The second block specifies the annual harvest rate relative to B_{4+}, the current TAC, and how much of that TAC is remaining when future projections start.

8.7 outputparameters.dat

The output parameters file describes quantities that are reported, but do not play a role inside the model:

```
#MeanSel
0 0 0 1  1 1 1 1 1 1 1 1 1 1
#Refage1 # Refage2 WeightedF
5 10 0
```

where `MeanSel` is a selectivity to calculate vulnerable biomass, `Refage1` and `Refage2` are first and last age in the reference F, and `WeightedF` (currently ignored) is whether the reference F is the weighted average (0:no, 1:yes).

8.8 surveydata.dat

The survey data file has one row per `year` and `age` combination:

```
#year   age     ObsSurveyNr
1985    1       16.54
1985    2       111.11
1985    3       34.86
...
2009    10      1.15
```

where `ObsSurveyNr` is the survey catch at age (thousands).

8.9 surveypar.dat

The survey par file specifies the proportions of annual fishing and natural mortalities that occur before the survey, a small constant added to catch at age before log-transforming, a flag indicating whether a fourth column in `surveydata.dat` contains weight at age from the survey (0:no, 1:yes), first and last age in survey data, and a vector with relative age-specific uncertainty about observed catch at age:

```
0.2
0.2
# Resolution should probably be a vector
0.7
# Survey weight not given
0
1 10
0.413 0.156 0.207 0.224 0.189 0.158 0.191 0.235 0.270 0.265
```

Chapter 9

General output files

9.1 islcod.cor

The `islcod.cor` file contains the point estimate, delta-method standard error, and covariance for all estimated parameters and reported quantities.

```
The logarithm of the determinant of the hessian = 950.301
index   name                     value      std dev        1       2      ...
    1   lnMigrationAbundance    9.4092e+00 3.5989e-01   1.0000
    2   lnMigrationAbundance    9.6922e+00 4.5331e-01   0.0876  1.0000
    3   lnMigrationAbundance    9.2618e+00 5.2138e-01  -0.0082 -0.6575  ...
  ...
  838   RelSpawningstock        2.5081e+00 2.7979e-01  -0.0147 -0.0188  ...
```

It is a superset of the `.std` file, and is only created when the model converges properly, giving a positive definite Hessian.

9.2 islcod.par

The `islcod.par` file contains the number of estimated parameters, objective function value, maximum gradient component, and point estimates for all estimated parameters.

```
# Number of parameters = 184  Objective function value = -1121.19  Maximum ...
# lnMigrationAbundance:
 9.40918 9.69221 9.26176 9.73003 1.00002 10.3137 9.53212 9.72217 9.43828 ...
# lnMeanRecr:
12.4060687361
# lnRecr:
 -0.0154664092733 0.267555306899 0.626313604443 -0.0724797574865 ...
# lnMeanInitialpop:
10.2955049067
# lnInitialpop:
 1.77705402801 1.62950746585 1.96697675297 1.90341377097 1.31198416550 ...
# EstimatedSelection:
 -2.23909557205 -2.72795548271 -3.50883540331
 -1.18305725276 -1.11062367593 -2.11561791654
 -0.878030616784 -0.508396756090 -1.36068880508
 -0.803883974223 -0.178181932762 -0.964652823554
 -0.607736398687 0.0649039658054 -0.734913122800
 -0.415533031922 0.199999970168 -0.607228881334
 -0.319238766404 0.184727319530 -0.463207040934
 -0.126141415995 0.126572375191 -0.282024582086
# Catchlogitslope:
2.24819425926
# Catchlogitage50:
6.10462371836
```

```
# logSigmaCmultiplier:
0.278109181157
# AbundanceMultiplier:
0.00000000000
# SurveyPowerest:
 2.28657022593 2.06189629987 1.84623772560 1.85766498735 1.62460967376 ...
# SigmaSurveypar:
 -0.0712967697216
# SurveylnQest:
 -26.0900980774 -21.8357297819 -18.3956690963 -17.9763591528 ...
# lnMeanEffort:
-0.144435463543
# lnEffort:
 -0.410121410544 -0.414095021426 -0.305386586185 -0.187201062764 ...
# estSSBRecParameters[1]:
12.6337104382
# estSSBRecParameters[2]:
6.10228931516
# estSSBRecParameters[3]:
-1.04291648872
# estSSBRecParameters[4]:
-2.30258509299
# estSSBRecParameters[5]:
0.00000000000
# estSSBRecParameters[6]:
0.00000000000
```

9.3 islcod.rep

The `islcod.rep` file contains the value of each likelihood component and the age-specific uncertainty about observed survey catch at age.

```
LnLikelicomp -701.078 -29.3175 -269.462 -121.501 0 0 0 0 0.0572808 0

SigmaSurvey
 0.38458 0.145265 0.192755 0.208586 0.175994 0.147127 0.177856 0.218829 ...
```

9.4 islcod.std

The `islcod.std` file contains the point estimate and delta-method standard error for all estimated parameters and reported quantities.

```
 index   name                     value      std dev
   1   lnMigrationAbundance    9.4092e+00 3.5989e-01
   2   lnMigrationAbundance    9.6922e+00 4.5331e-01
   3   lnMigrationAbundance    9.2618e+00 5.2138e-01
 ...
 838   RelSpawningstock        2.5081e+00 2.7979e-01
```

It is a subset of the `.cor` file, and is only created when the model converges properly, giving a positive definite Hessian.

9.5 resultsbyage

The results by age file contains age-specific estimates.

```
age      meansel  progsel  SigmaC   SigmaSurvey1    SurveylnQ1      SurveyPower1
1        0        0        0        0.38458 4.6689e-12      2.28657
2        0        0        0        0.145265        3.28748e-10     2.0619
3        0.107698          0.0589687        0.239034         0.192755         ...
4        0.373905          0.237513         0.190171         0.208586         ...
5        0.605724          0.505301         0.161117         0.175994         ...
6        0.768261          0.750838         0.145269         0.147127         ...
```

```
7       0.958976        0.944758        0.138666        0.177856        ...
8       1.11998 1.07343 0.139987        0.218829        0.000592096     1
9       1.20135 1.23971 0.150552        0.25142 0.000559185     1
10      1.34571 1.48596 0.171682        0.246764        0.000587263     1
11      1.50554 1.97011 0.207339        0       1       1
12      1.50554 1.97011 0.266767        0       1       1
13      1.50554 1.97011 0.364494        0       1       1
14      1.50554 1.97011 0.529573        0       1       1
```

`meansel` is mean selectivity, `progsel` is the selectivity used in the projections, `SigmaC` is the uncertainty about observed commercial catch at age, `SigmaSurvey1` is the uncertainty about observed survey catch at age, `SurveylnQ1` is survey catchability, and `SurveyPower1` is the survey catchability power coefficient.

9.6 resultsbyyear

The results by year file contains year-specific estimates.

```
year     RefF    CalcCatchIn1000tons     CatchIn1000tons Spawningstock ...
1955    0.351866        538.463 545.25  706.431 27.0662 1599.42 1647.74 ...
1956    0.350471        461.147 486.909 565.53  21.0788 1396.57 1445.15 ...
1957    0.390718        454.707 455.182 556.447 20.826  1241.18 1321.39 ...
...
2063    0.303631        286.938 -1      614.502 19.4079 1156.91 1211.03 ...
```

`RefF` is the reference F_{5-10}, `CalcCatchIn1000tons` is modelled landings, `CatchIn1000tons` is observed landings, `Spawningstock` is spawning biomass, `Eggproduction` is egg production, `CbioR` is vulnerable biomass, `RefBio1` is B_{4+} using survey weight at age, `RefBio2` is B_{4+} using weight at age from commercial catch (current definition of B_{4+}), `PredictedRecruitment` is recruitment, `N1`, `N3`, and `N6` is numbers at age 1, 3, and 6, `CalcSurveyBiomass1` is modelled survey biomass, and `ObsSurveyBiomass1` is observed survey biomass.

9.7 resultsbyyearandage

The results by year and age file has one row per `year` and `age` combination.

```
year     age     N       Z       StockWeights    M       F       CalcCno ...
1955    1       240531  0.2     15      0.2     0       0       0       0 ...
1955    2       175003  0.2     141     0.2     0       0       0       0 ...
1955    3       150997  0.261197        250     0.2     0.0611973       ...
...
2063    14      529.338 0.798184        14291.7 0.2     0.598184        ...
```

`N` is numbers at age, `Z` is Z, `StockWeights` is weight at age in survey catch, `M` is M, `F` is F, `CalcCno` is modelled commercial catch at age, `CatchWeights` is weight at age in commercial catch, `SSBWeights` is weight at age of mature fish, `StockMaturity` is maturity, `ObsCno` is observed commercial catch at age, `CatchDiff` is the log difference between observed and modelled commercial catch at age, `CalcSurveyNr1` is modelled survey catch at age, `ObsSurveyNr1` is observed survey catch at age, and `SurveyResiduals1` is the log difference between observed and modelled survey catch at age.

Chapter 10

MCMC output files

All MCMC output files have the file extension `.mcmc`. They contain chains for analyzing in an external program, such as the R packages "coda" (Plummer et al. 2006) and "scapeMCMC" (Magnusson 2005).

Part III

Bibliography

ADMB Project. 2008. An introduction to AD Model Builder for use in nonlinear modeling and statistics. Version 9.0.0. Honolulu: ADMB Foundation.

ICES (International Council for the Exploration of the Sea). 2002. Icelandic cod (Division Va). In: Report of the Northwestern Working Group. ICES CM 2002/ACFM:20, pp. 141–149.

———. 2003. Icelandic cod (Division Va). In: Report of the Northwestern Working Group. ICES CM 2003/ACFM:24, pp. 144–227.

———. 2004. Icelandic cod (Division Va). In: Report of the Northwestern Working Group. ICES CM 2004/ACFM:25, pp. 208–268.

———. 2005. Icelandic cod. In: Report of the Northwestern Working Group. ICES CM 2005/ACFM:21, pp. 244–323.

———. 2006. Icelandic cod. In: Report of the Northwestern Working Group. ICES CM 2006/ACFM:26, pp. 258–333.

———. 2007. Icelandic cod. In: Report of the Northwestern Working Group. ICES CM 2007/ACFM:17, pp. 202–273.

———. 2008. Icelandic cod. In: Report of the Northwestern Working Group. ICES CM 2008/ACOM:03, pp. 255–290.

———. 2009. Icelandic cod. In: Report of the Northwestern Working Group. ICES CM 2009/ACOM:04, pp. 231–271.

Magnusson, A. 2005. R goes fishing: Analyzing fisheries data using AD Model Builder and R. Proceedings of the 2005 International Workshop on Distributed Statistical Computing.

Plummer, M., N. Best, K. Cowles, and K. Vines. 2006. CODA: Convergence Diagnosis and Output Analysis for MCMC. R News 6(1):7-11.