Stock Annex: Haddock (*Melanogrammus aeglefinus*) in Division 5.a (Iceland grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Haddock
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A. General

A.1. Stock definition

Icelandic haddock (Melanogrammus aeglefinus) is fairly abundant in the coastal waters around Iceland and is mostly limited to the Icelandic continental shelf, while 0-group and juveniles from the stock are occasionally found in East Greenland waters (ICES area 14). Apart from this, larval drifts links with other areas have not been found. In addition, minmial catches have been reported in area 14 (less than 10 tons in 2016). The nearest area to the Icelandic were haddock are found in reasonable abundance are in shallow Faroese waters, an area that constitutes as a separate stock. The two grounds are separated by a wide and relatively deep ridge, an area where reporting of haddock catches is nonexistent, both commercially and scientifically. Tagging studies (Jónsson 1996) conducted between 1953 and 1965 showed no migrations of juvenile and mature fish outside of Icelandic waters, with most recaptures taking place in the area of tagging (or adjacent areas) and on the spawning grounds south of Iceland. Information about stock structure (metapopulation) of haddock in Icelandic waters is limited, but it is unlikely to be as diverse as observed for cod.

The species is found all around the Icelandic coast, principally in the relatively warm waters off the west and south coast, in fairly shallow waters (50-200 m depth). Spawning has historically been limited to the southern waters. Haddock is also found off the north coast and in warm periods a large part of the immature fish have been found north of Iceland. In recent years a larger part of the fishable stock has been found off the north coast of Iceland than the last two decades of the 20th century (Fig. A1.1).

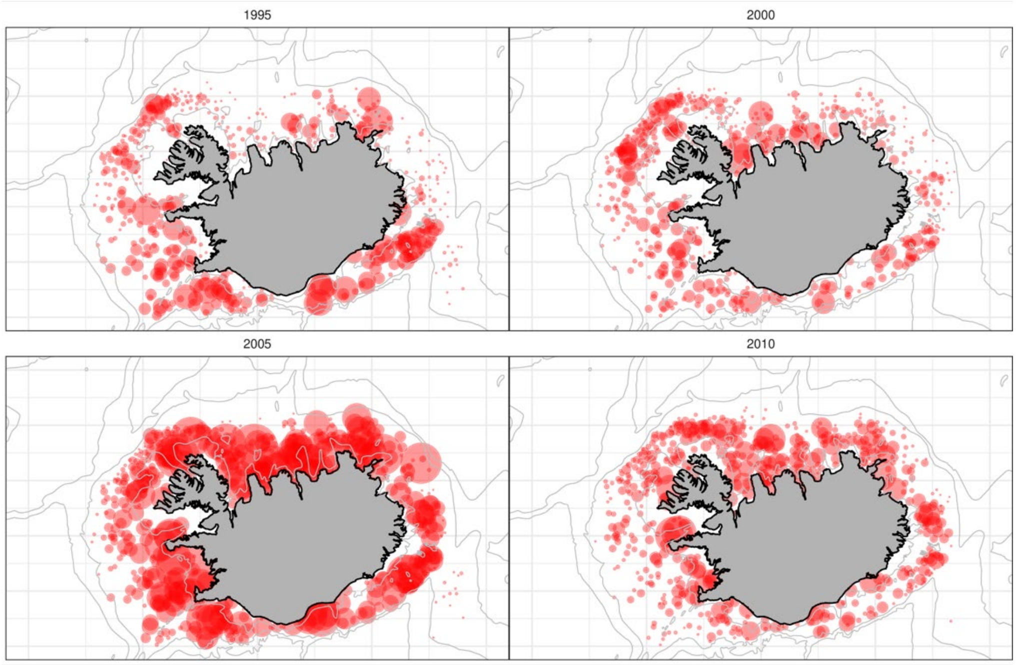

Figure A1.1. Haddock in 5a. Location of haddock in Icelandic waters as observed from the Icelandic spring survey. Size of the points is relative to the amoung caught, standardised to a tow mile.

Icelandic haddock can reach 15 years age or more but individuals older than 9-10 years are uncommon. They do though become more common after a period of low fishing effort as occurred in around 1980 and 1985-1986, 9 and 10 year old haddock accounted for substantial part of the catch. Individuals from the stock can reach 100cm but mean length at age approches 80cm (5kg) for 13-15 years old fish. Most haddock mature from 4-7 years age and 50% of age 4 haddock are mature on the average. Age 4 haddock is also approximately half recruited to the fisheries. Mean weight at age has been declining with time leading to yearclasses recruiting at a later age to the fisheries.

A.2. Fishery

The haddock fishery in 5.a is almost entirely Icelandic, with very small amounts reported by Faroese vessels. Icelandic haddock is caught in mixed demersal fisheries where the most important species is cod and other important bycatch species. Identifying target species in mixed fisheries is not always easy as the captains are often aiming for certain mixture of species. In some years more than 100 thous. tonnes of haddock are landed making it the most important species in many demersal fisheries although cod has always been the most important species in Icelandic demersal fisheries.

Spatial patterns of fishing activity and catch distribution are produced from logbook data with 100% coverage of all the fleet since 2001, but from the larger boats since 1991. Bottom trawl has usually been the most important gear for catching haddock but share of longline has increased since 1998 and in 2011 catches by longliners are on par with those of trawlers. The increase by longliners is caused by increase in their number, both of large vessels where each fishing trip take few days and smaller ones. Improvement of automatic baiting equipment has been a factor in this change of the fleet. Boats operating with longlines handbaited ashore have gotten “quota addition” as handbaiting is considered to create jobs. Haddock are also taken in Danish seines and gillnets. The share of Danish seine increased from 2000-2007 but has decreased since then. Share of gillnets has been neglible since 2002 but exceeded 20% 1985-1986 when a large yearclass from 1976 was 9 and 10 years old.

Haddock fishing areas were traditionally similar from one year to another, primarily along the south and the west coast. Since 2000 higher proportion of fishable part of the stock inhabits the waters north of Iceland and (Figure A.2.1). The share of longliners in the fisheries has also increased, which do not fish in the same areas as trawlers (figure A.2.2), partly because they can not operate in the same areas but also because shallow water areas that are closed for trawling are open for longliners.

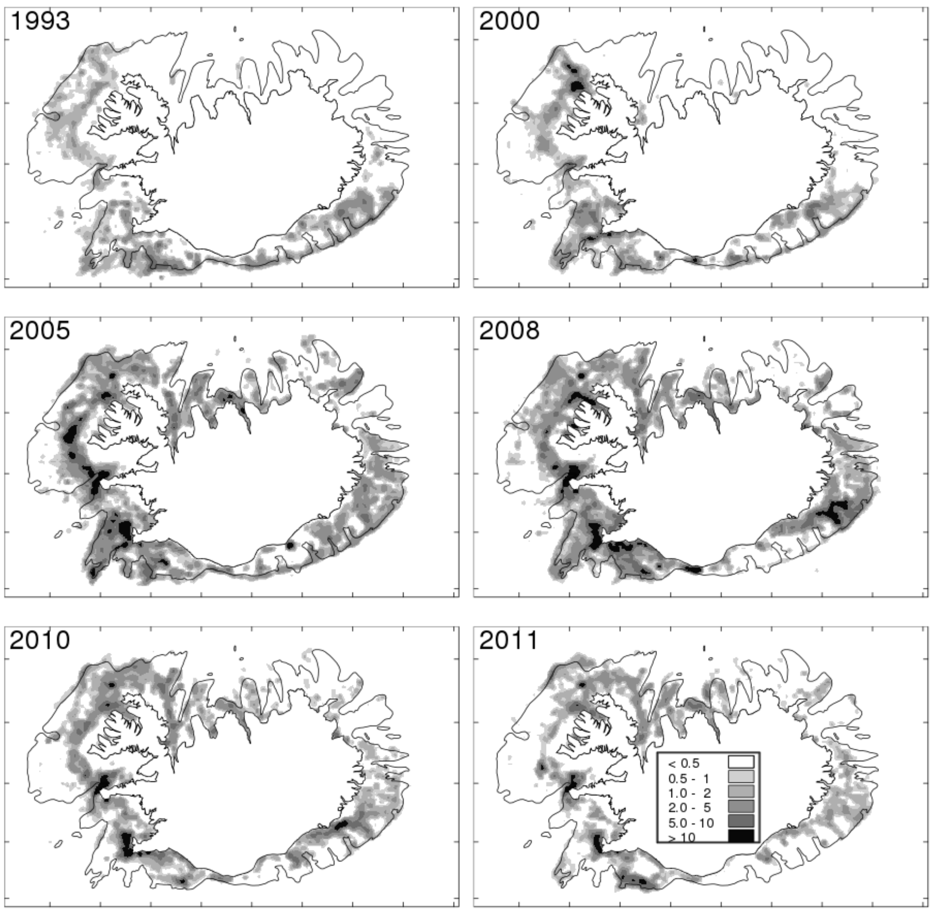

Figure A2.1. Spatial distribution of landings in 6 years since 1993. The legend shows tonnes per square nautical mile, data being based on logbooks. The 200 m depth contour is shown.

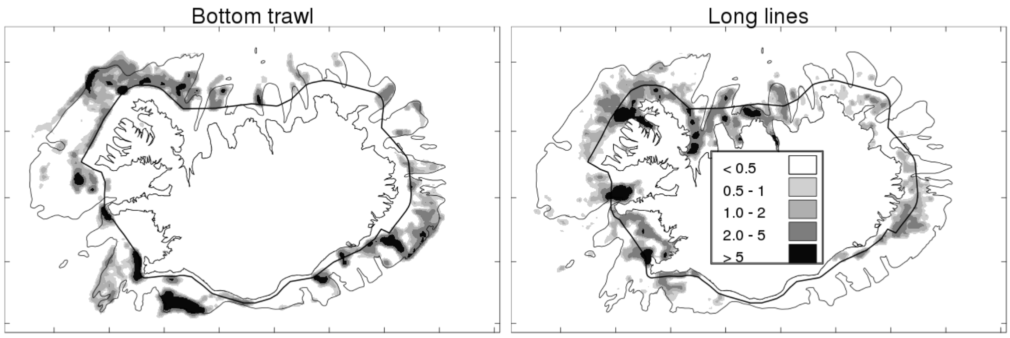

Figure A.2.2. Catch of haddock by longliners and trawlers 2010-2011. The legend shows tonnes per square nautical mile, data being based on logbooks. The 200 m depth contour and a line inside which trawling is not allowed are shown.

A.3. Ecosystem aspects

As noted above, considerable changes have occurred in the distribution of haddock in Icelandic waters. One reason for this shift may be related to the distribution and availability of prey. The abundance of a key prey species, sandeel (*Ammodytes marinus*), has been low in Icelandic waters since 2005 (Bogason pers. comm). Sandeel is an important part of the diet of many species, such as the common minke whale (Víkingsson et al. 2014), puffin and haddock. This poor abundance may have contributed to slow growth of haddock in the peak abundance years. Northwards shifts in the distribution of other fished species have also been observed, such as ling (*Molva molva*) and tusk (*Brosme brosme*) (e.g. see ICES 2014), which may be linked to increased temperatures.

B. Data

B.1. Commercial catch

Landings

Annual estimates of landings of cod from Icelandic waters are available since 1905 (Figure B.1.1). The historical information are largely derived from Statistical Bulletin, with unknown degree of accuracy. The more recent landings (from 1980 onwared) statistics are from the Directorate of Fisheries as annually reported to ICES.

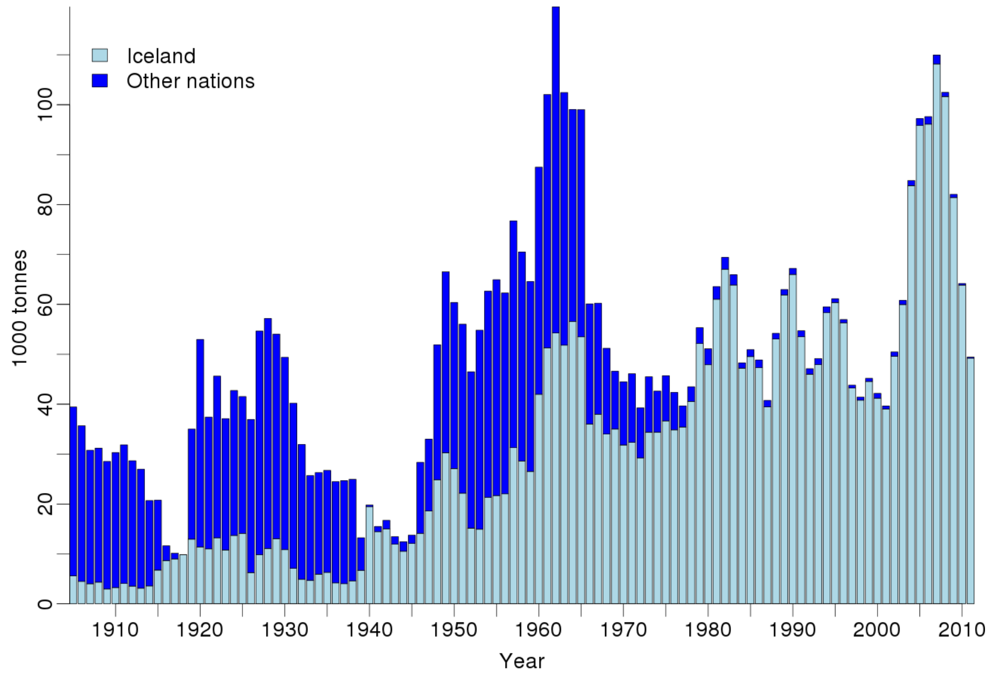

Figure B.1.1. Icelandic haddock. Landings 1905-2011.

Annual estimates of landings of haddock from Icelandic waters are available since 1905 (Figure 4). The historical information are largely derived from the Statistical Bulletin, with unknown degree of accuracy, and retrieved from Statlant. For the period between 1980 to 1993, landings of Icelandic vessels were recorded by Fiskifélagið (a precursor to the Directorate of Fisheries). The more recent landings (from 1993 onwards) are from the Directorate of Fisheries as annually reported to ICES. After 2013, all landings in 5a are recorded by the Directorate, while foreign vessel landings were obtained from Statlant.

The estimates by the Directorate of Fisheries are based on a full census by weighing fish at the dock when landed or in fish processing factories prior to processing. Information on the landings of each trip are stored in a centralised database of which the Marine and Freshwater Research Institutes (MFRI) employees have full access. Captains are required to keep up-to-date logbooks that contain information about timing (day and time), location (latitude and longitude), fishing gear and amount of each species in each fishing operation. The Directorate of Fisheries and the Coast Guard can, during each fishing trip, check if amount of fish stored aboard the vessel matches what has been recorded in the logbooks, in part to act as a deterrent for potential illegal and unrecorded landings. Nearly all haddock is landed gutted and converted to ungutted using the conversion factor 0.84. The real gutting factor can vary year to year so the amount of ungutted haddock landed may be different than the estimated value. All the bookkeeping of catch is in terms of gutted fish and the reference to ungutted catch is just ungutted divided by 0.84 so this does not matter in the assessment.

Discards

Discards are illegal in Icelandic waters but are assumed to take place to some degree. A discard monitoring program of the MFRI, designed to estimate highgrading, has been in place since 2001, but no estimates of discards exist prior to that period (MRI 2013). The method used since 2001 is based on getting comparable shore and sea samples, and using the difference in length distribution to estimate the amount of discards. It is based on ad hoc selection of boats where comparison of lengths measured at port is followed by length measured at sea of the same boat if fishing area is the same. This is however only feasible for boats that take short trips. For other fleet components the estimates are based on overall differences in lengths measured at sea vs. port. The results indicate that discard rate appears be greatest when haddock recruits are large and hence fish below commercial landing size compose a large part of the stock. This is evident from Fig. 5. Explorations into the effect of the discards on model results have suggested that including discards in the assessment does not alter the perception of the stock substantially (ICES 2013).

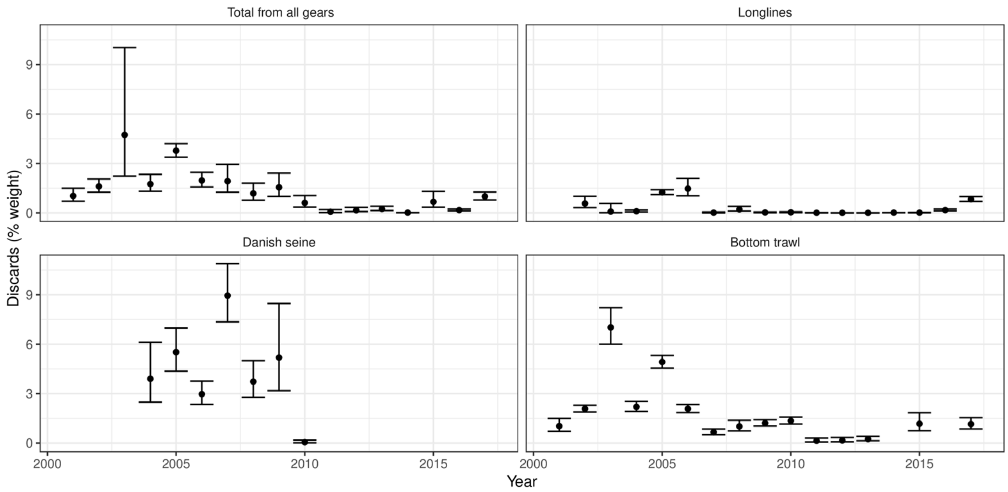

Figure B.1.1: Haddock in 5a. Esitmates of annual discards by gear. Verical lines indicate the 95 % confidence interval while dots the point estimates.

B.2. Biological

Sampling design for estimation of length and age composition of catches

The sampling design is based on getting a certain number of samples per tonnes landed stratified by area landed, gear and time. Sample timing is dictated by the amount landed by certain gear within a certain region. The daily landings records are linked to the sampling system, such that 'a call' for a sample occurs automatically. Getting the sample is often difficult as large part of the catch is length categorized at sea. In that case samples must be taken from each length category and they weighted by the amount landed in each category. Sometime, the crew of fishing vessels is asked to take aside for the MRI one tub of fish that has not been length categorized. The branches of MRI around Iceland that conduct the sampling tend to cooperate with the crew of certain vessels, and do often get most of their samples from those vessels. Investigation of the time and location of samples from each gear compared to amount caught show reasonable coherence. Sampling from catches is also done by employees of the Fisheries directoriate, both to monitor occurrence of fish below landings size but also to monitor discard due to high grading.

Annually catch in numbers is also calculated based on more than one region, different subsets of the data and results compared to what is obtained by the standard methods. Two different programs and two different persons are used, the objective is to reduce probability of mistakes. Length samples used are a mixture of port and sea measurements. Landings estimates from the Directory of Fisheries are however not raised to account for estimated discard. Sensitivity analysis done during the Benchmark 2013 showed that inclusion of discards had minor effect on estimates of stock trajectory, the effect being less than inclusion or exclusion of one or the other tuning surveys.

Calculation of catch and catch-weight at age

Since 2010 catch in numbers for 1979- onwards were recompiled using ages 2-14 because at that time the large yearclass from 2000 was 10 years old and in a few years the very large yearclass from 2003 would be 10 years old and could account for 10% of the landings in 2013. If fishing mortality is reduced, ages 10 and 11 might become significant but older fish than 11 years will always be rare. The goal is to include all agegroups in the catch in numbers data, users of different assessment models can then decide what they use and what they include as plus group. In VPA type models the oldest age groups should not be an important part of the stock, as the treatment of the right side of the catch at age matrix is somewhat problematic.

For haddock most of the length measurements for compilation of catch at age come from the discard monitoring program while most the age samples are taken from landings by the employees of the MRI . Catch in number is compiled by 3 - 4 gears (Longlines, gillnets, bottom trawl and Danish seine, one region and two time periods (January – May and June-December). The same condition factor is used for all years, seasons and gears: $W = 0{:}00885L^{3:02857}$. Since 1994 most haddock sampled for otoliths has been weighed gutted (ungutted in the few cases where it is landed ungutted). These data have not been included in compilation of catch in numbers by age but variability in condition is relatively small and using estimated condition for each cell each year has minor effect on catch in numbers as a time series. Comparison with survey samples indicate that the use of a constant condition factor is a reasonable assumption as average throughout the year (Figure B.2.1). The difference in condition factor must be kept in mind when comparing weights from catches and the stock weights (from March survey) .

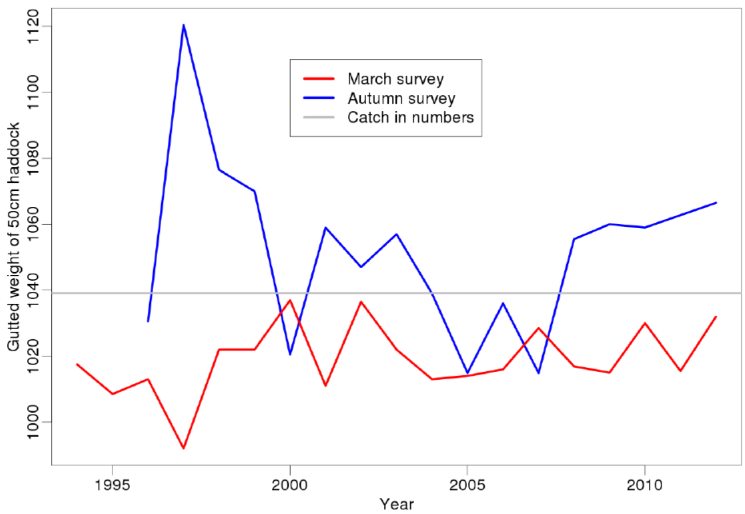

Figure B.2.1. Mean gutted weight of 50 cm haddock from the march and the autumn survey and weight used in compilation of catch at age.

Length distributions

Data used are length frequency samples taken in area **r**, season **t** and gear **g**. L_l is the number of fishes at length l.

One has the option to run the length distributions on 1 cm or 5 cm basis. If the latter one is chosen, a temporary variable *lemultfj* is assigned the value $l * L_l$ to be able to calculate the correct mean length in the length distribution. Then the grouping in 5 cm intervals is done in the way that the numbers get the middle value from the interval. As an example the values in the range 10-14 and 15-19 are assigned 12 and 17 respectively. Lengths are then in fact either

$$l \in \{1,2,3,...\} \, or \; l \in \{2,7,12,17,...\}$$

Age-length and maturity keys

Age length keys are based on 5cm length groups except for the largest haddock where 10 cm are used. When compiling catch in numbers all available age samples in the year are used as "base sample" that gets the weight 1/10000. That base sample is added to the age samples from each cell (region, season, gear) avoiding problems with length cells where no otholith samples are available.

Data used are age-determined data from otolith samples in area **r**, season **t** and gear **g**. If no otolith samples exist from this area, season and gear combination, they have to be borrowed from other season or gear for the same area or from other areas.

K_{la} is the number at length l and at age a, $a>0$.

M_{la} is the number mature at length l and at age a, $a>0$.

IM_{la} is the number immature at length l and at age a, $a>0$.

A fish is assigned to IM_{la} if is has a maturity value 1 in the database otherwise it is assigned to M_{la} .

Multiply the age-length and maturity keys with the length distribution

Sum of the numbers at length l over all ages:

$$K_{l.} = \sum_a K_{la}$$

Make a new key with the number of fishes:

$$C_{la} = \frac{K_{la}}{K_{l.}} \cdot L_l$$

And new maturity keys:

$$CM_{la} = \frac{M_{la}}{M_{la} + IM_{la}} \cdot C_{la} \quad \text{and} \quad CIM_{la} = \frac{IM_{la}}{M_{la} + IM_{la}} \cdot C_{la}$$

Average length and weight

In this step average length and weight at age are calculated. For each area, season and gear the condition factor (*cond*) and the power (*power*) in a length-weight relationship are input data.

$$\tilde{w}_{la} = C_{la} \cdot cond \cdot \exp(\, power \cdot \log(l)\,) \quad \text{(the weight in each cell)}$$

$$\tilde{l}_{la} = C_{la} \cdot l$$

Note that in the above 2 equations l is a midpoint if 5 cm grouping has been chosen.

The total frequency in the key is:

$$C_{..} = \sum_l \sum_a C_{la}$$

and total weight

$$\tilde{w}_{..} = \sum_l \sum_a \tilde{w}_{la}$$

So the mean weight in this area, season and gear combination is

$$\overline{w} = \frac{\tilde{w}_{..}}{C_{..}}$$

The ratio of weight and number by age from the total:

$$ratio\_w_a = \sum_l \tilde{w}_{la} / \tilde{w}..$$

$$ratio\_C_a = \sum_l C_{la} / C..$$

The mean weight and mean length at age and ratio mature at age are:

$$\overline{w}_a = \frac{\sum_l \tilde{w}_{la}}{\sum_l C_{la}}$$

$$\bar{l}_a = \frac{\sum_l \tilde{l}_{la}}{\sum_l C_{la}}$$

$$ratio\_M_a = \frac{\sum_l CM_{la}}{\sum_l (CM_{la} + CIM_{la})}$$

if the denominator > 0 otherwise the *ratio_*M_a *is set to -1.*

Catches in numbers

Input data for this module is the landings in tons (*catch*) for each area, season and gear.

The total number of fishes caught are:

$$C_{tot} = \frac{catch}{\overline{w}}$$

The catches in numbers and weight by age is then

$$C_a = C_{tot} \cdot ratio\_C_a$$

$$W_a = C_a \cdot \overline{w}_a$$

To derive the total catches in numbers and weight summation is done over all areas, seasons and gears.

Stock weights

Mean weight at age in the stock are obtained from the groundfish survey in March. Weights from 1993 onwards are based on weighing of fish in the groundfish survey each year. Weights for 1985–1992 when haddock in the survey was not weighed were calculated using a length-weight relationship which is the mean from 1993-2003. Stock weights prior to 1985 when the survey started have been taken to be the mean of 1985-2002 weights.

Maturity ogives

Data on maturity at age are obtained from the groundfish survey in March. The maturity staging is based on a 4-scale visual classification and the criterion for maturity are all stages except 1, which constitutes: Females: Ovaries small and translucent. Eggs not visible with the naked eye; Males: Testes (lobules) tiny, thin and translucent.

Prior to the commencement of the spring survey in 1985, the average from 1985-2002 is used.

Natural mortality

For assessment and advisory purpose the natural mortality is set to 0.2 for all age groups.

For assessment and advisory purpose the natural mortality is set to 0.2 for all age groups. This setting has been a long tradition for haddock. In principle the size of entry to the fishery is at age 3-5 when the haddock is around 45 cm long. At age 2, first age of entry, the mean weight in the stock is around 180 g and in the catch around 450 g. Following the recent intellectual stampede within ICES of using Lorenzen's formula to set M at age this would correspond to an M=0.75 for the stock and M=0.57 for the catch. For the older ages, like age 10 (3600 g) the Lorenzen's M is around 0.30. When M is estimated both in the TSA as well as the ADAPT framework the M for older fish is estimated much lower than 0.20.

It goes without saying that whatever fixed mortality value is set for the prerecruits (age 1 and 2) will in any case only act as a scaling to the numbers below the age of 3 and could in theory be set as any number without affecting the resulting SSB and other key metrics.

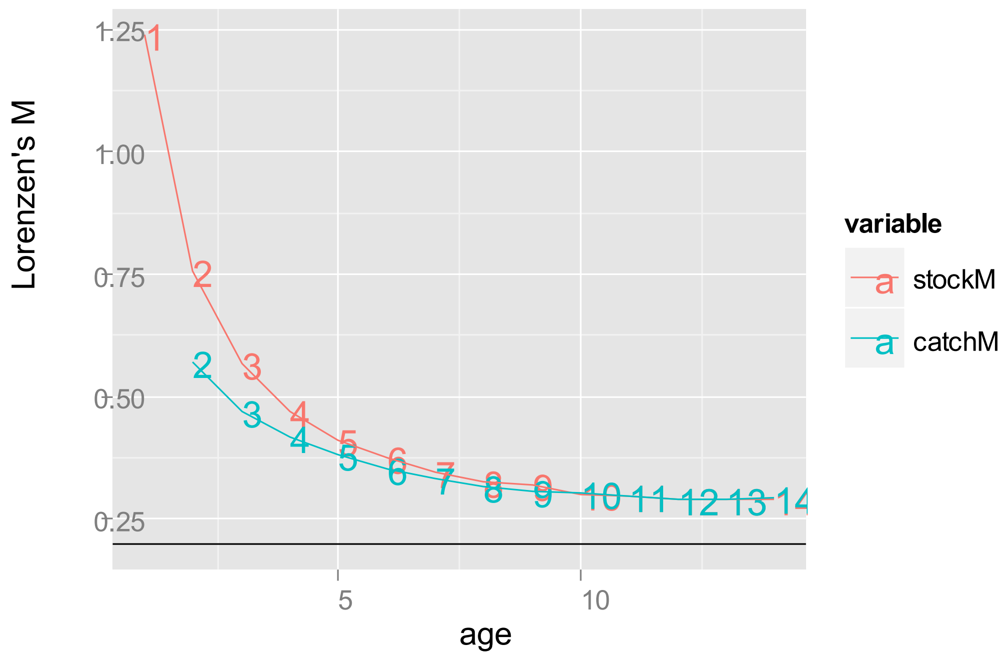

Figure B.2.2. Calculation of Lorenzen's M at age for haddock based on stock weights (stockM) and catch weights (catchM).

B.3. Surveys

Survey design

Two groundfish surveys are conducted annually in Icelandic waters, in March and October (figure B.3.1). Detailed information about the sampling protocol can be found in http://www.hafro.is/Bokasafn/Timarit/fjolrit-156.pdf .

Data from the surveys are used extensively in haddock assessment, age disaggregated abundance from both surveys for tuning and mean weight and maturity at age from the March survey as representative values for the stock in the beginning of the year. The March survey that started in 1985 has 570 stations between 25 and 400 m depth. The October survey that started in 1996 has fewer and lower density of stations or 380 between 25 and 1200m. Both surveys are stratified random design, the strata setting and the allocation of station numbers in the March survey being in part based on expected density of cod. The station location in the survey have been fixed since 1985. The October survey consists of a subsample of March survey stations as well as addition stations in deeper waters, the latter designed primarily for estimating Greenland halibut and redfish abundance. The October survey was not conducted in 2011 due to a strike.

Haddock is found at over 80% of the stations in the March survey, but 45% in the autumn survey where substantial part of the stations are deeper than 400m where haddock is not found at all. Haddock is the most abundant fish species in the Icelandic groundfish surveys in March and October, being caught in large number at age 1 and becoming fully recruited at age 2 or 3. The sampling protocol in the surveys is to length measure at least 4 times the range of the length distribution and count the rest. E.g. if the length distribution is between 13 and 70cm the minimum number measured is (70-13)x4 or 228.

When a subsample is measured from a large haul taking a representative subsample is difficult. All the fish from the trawl is poured in a large compartment with an opening in one end where the catch is gradually tapped from the compartment. The survey manual (ref) gives some guidance on sampling for length measurements, the most important one is to try to sample both from the beginning, center and end of the "haul" because small fish seems to show up at the end the process. Also where large and small haddock coexist on a table, the larger individuals seem to be more likely to be selected for measurement. Counting a large haul in a short time is also difficult, not least as the size distribution changes throughout the haul. Since the March survey started approximately 1/3 of the haddock caught has been length measured so proper subsampling is of great importance.

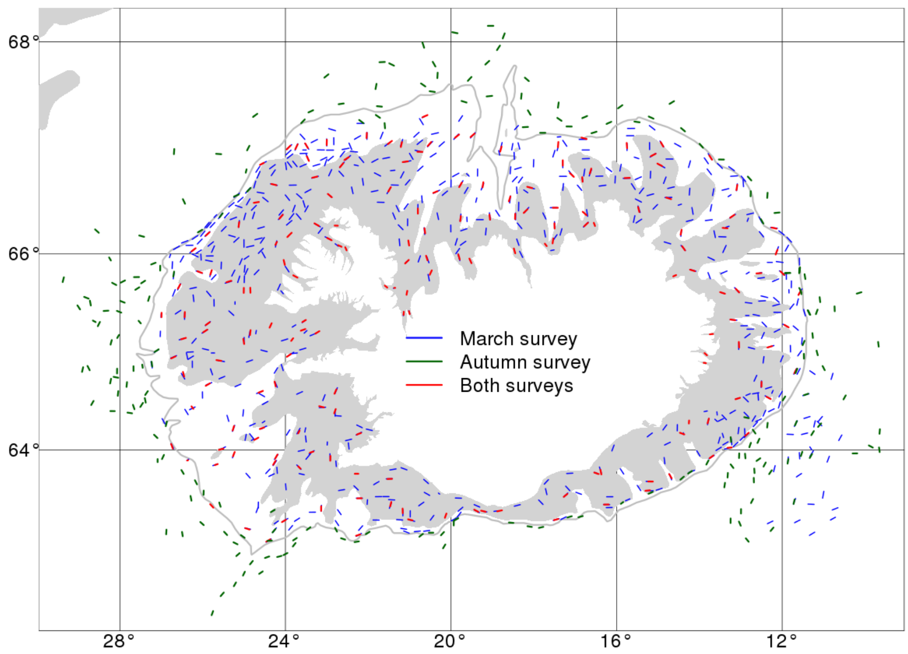

Figure B.3.1. Stations in the surveys is March and October. The shaded area is shallower than 200m, approximately the distributional area of haddock. Also shown is the 400 m depth line, approximately the outer boundary of the survey in March except in the south east. Most autumn survey stations shallower than 400 m are also taken in the March survey.

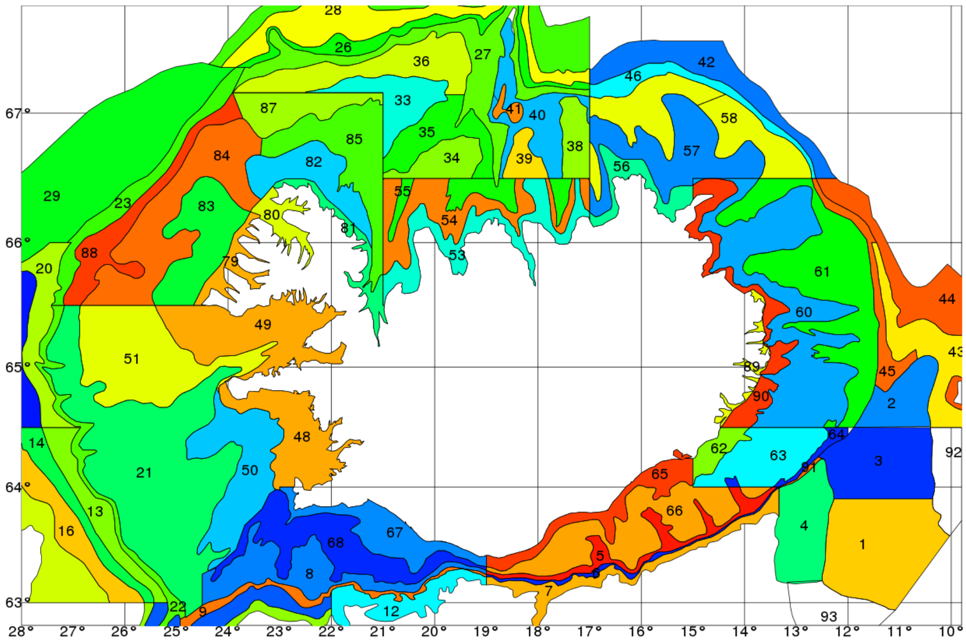

Figure B.3.2. Stratification still used for compiling spring survey indices.

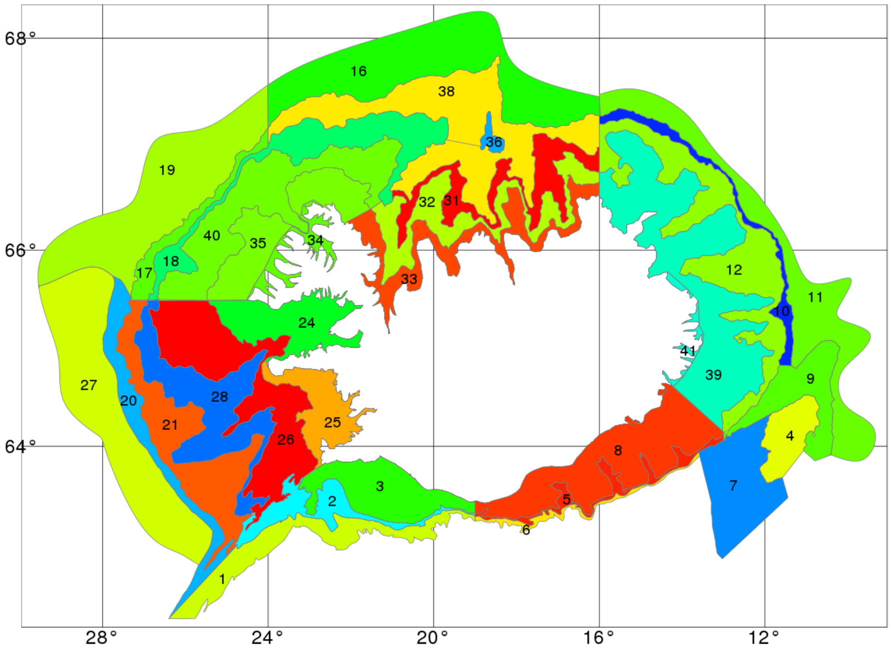

Figure B.3.3. Stratification used for compiling fall survey indices. Main idea was to reduce number of strata from what is shown in figure B.3.2.

Calculation of survey indices used in assessment

Survey indices are compiled in a number of steps:

1) Calculating length – weight relationship. Done via smoothing spline with 3 degrees of freedom, separately for the northern and southern area and each year since 1993 when weighing of fish sampled for otoliths started. For the years prior to 1993 the average condition 1994-2002 is used.

2) Calculating age-length keys separately for the northern and southern area each year. 5 cm length groups up to 60 cm, 10cm after that. In the March survey age-length-maturity keys are also compiled.

3) Using the age length keys, length distributions and length – weight relationship, number and biomass of each age class at each station are compiled. In the March survey number mature per age and biomass mature per agegroup are also calculated for each station. Maturity can not be detected reliably in the autumn survey.

4) Using the strata shown in figure B.3.2 (traditional) and B.3.3 (new) index of biomass, number, number mature and biomass mature are calculated. Which set of strata is used does not make much difference except when distribution is patchy. The effect of stratification is to give variable weight to stations and when distribution is patchy the weight of the hauls with large catch matters. Currently the traditional stratification is used in the March survey but the new one in the autumn survey. Survey indices according to both schemes are compiled each year for all species.

5) Mean weight is the biomass index divided by abundance index for each agegroup. Proportion mature is abundance index of mature fish divided by abundance index for each agegroup. Mean length at age and standard deviation in mean length at age are also calculated.

6) Indices of abundance in each length group, biomass of fish above certain size and number of fish below certain size are also calculated.

7) Estimation of uncertainty is included with all survey indices. It represents the part of the uncertainty that can be reduced by increasing the number of stations.

B.4. Commercial CPUE

Since 2000 all vessels fishing in Icelandic waters have been required to fill out logbooks where they list information about the location, catch and a number of other things for each tow (setting). Vessels larger than 12 tonnes have been required to return logbooks since 1991 and some trawlers started returning logbooks in the seventies. Since 2009 increasing number of vessels have used electronic logbooks where positions are recorded automatically and where position tracking is kept during actual fishing activity.

The logbook data have been used to compile catch per unit effort. Interpretation of those data have often been difficult for it is not always clear when haddock is being targeted but haddock has traditionally been caught in mixed fisheries with cod and some other species. Most often settings where selected by choosing records where haddock exceeds certain percent of the total catch (often 50%). The effect of this selection criterion when ratios between haddock and cod are changing is not clear.

Catch per unit effort data show much less increase after 2000 than survey data but much less decrease after 2007 (figures B.4.1 and 7.4). Reasons for this discrepancy are not clear but increased proportion of old haddock (2003 year class) in the stock in 2010 could reduce the problem of avoiding small haddock. Also the fisheries are not following expansion of the stock, but as described earlier the trawlers are not allowed to fish in the shallow waters off the north coast where haddock has been most abundant in recent years. Looking at the development of the stock the CPUE is remarkably stable compared to the stock size and is therefore not considered suitable for use in analytical assessment.

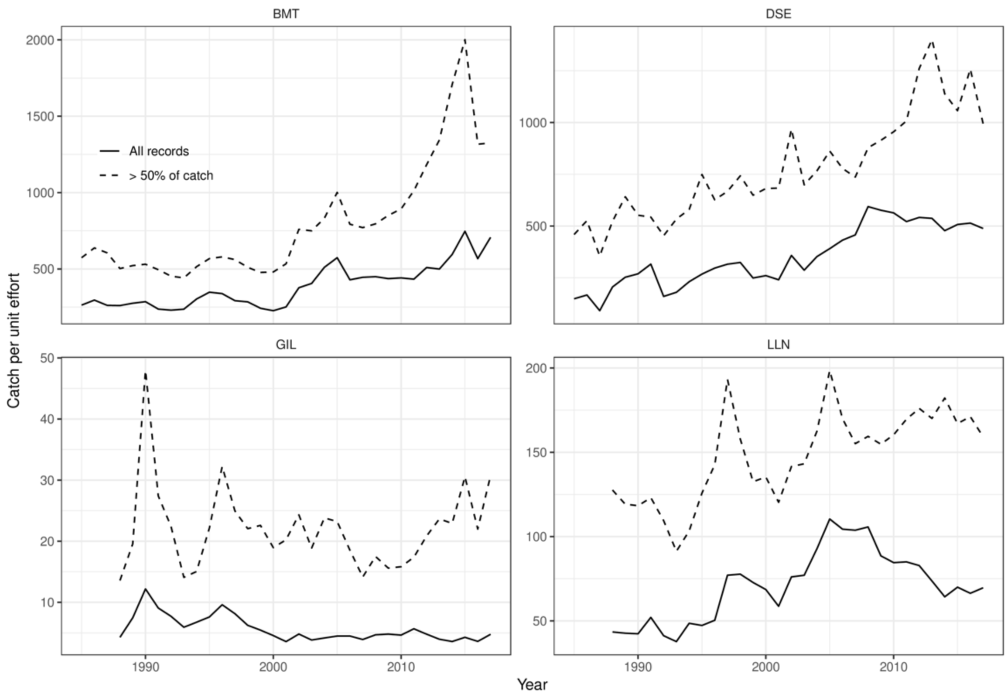

Figure B.4.1. Catch per unit of effort in the most important gear types. The dashed lines are based on locations where more than 50% of the catch is haddock and solid lines on all records where haddock is caught. A change occurred in the longline fleet starting September 1999. Earlier, only vessels larger than 10 BRT were required to return logbooks but later all vessels were required to return logbooks.

C. Historical Stock Development

Method

Model used: Statistical catch at age

Software used: MUPPET

The assessment of Icelandic haddock has since 2007 been conducted with an Adapt type model tuned with both the surveys. The only change done since then is recompilation of catch in numbers in 2010 to include ages 10-14. Treatment of the oldest agegroup was also changed that year but apart from that, the model settings describe here have been used since 2007.

The model is written in AD model builder with data read from one input file. Some settings in the model code are specific for this stock so it would not be applied to other stocks without some changes. Some important settings in the model are:

- Ages 1 - 10. Last age group is a plus group.

- Number of survivors at age 1-10 in the beginning of the assessment year estimated.
- F and M before spawning are set as 0.4 and 0.3 respectively

The stock dynamics are calculated according the following set of equations:

$$N_{0,y} = f(SSB_y)$$

$$N_{0,y} = N_{0,y}e^{\xi_y}$$

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

For the oldest age group (which is a plus group)

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

where A is the oldest age (plus group) in the bookkeeping system

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

$$C_{a,y} = \frac{F_{a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y}$$

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

$$F_{a,y} = F_y S_{a,t}$$

Where t refers to time interval. The simulation period is split into predetermined periods with fixed selection in each period. The fishery selection is set according to stock weights using

$$S_{a,y} = \frac{1}{1 + e^{-\alpha\left(log(sW_{a,y}) - log(W_{50})\right)}}$$

Estimation

The unknowns in the model described in last section are the number of survivors of age 1-10 in the beginning of the assessment year. Data used to estimate those values in the model are.

Age disaggregated survey abundance indices from groundfish surveys in March and October.

Catch at age

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

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

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

The selection of the ϵ_C parameter is very important for stocks like the Norwegian spring spawning herring where contrast in year-class strength is large and too small value of ϵ_C will cause low values where sampling error starts to dominate to have too high value. The same consideration applies to survey indices as described below. In the model ϵ_C is given as proportions that is then proportion of total catch in numbers.

Total landings

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

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

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

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

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

Where σ_Y is input from a file and was set to 0.1. The statistical properties of this term as an addition to catch at age are somewhat questionable, but this formulation has often been used in statistical catch at age models.

Survey at age

The predicted survey index I_{ay} is calculated from:

$$I_{a,y} = \alpha_a N_{a,y}^{\beta_a}$$

where α_a are estimated parameters while β_a was set to one for the herring. The error in the survey at age is assumed to be log-normal and hence the likelihood is calculated as:

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

where ϵ_I is externally set and is to reduce the effect of very small survey indices that are poorly sampled. Typical value of ϵ_I would be indices that correspond to 2-4 sampled otoliths. As described above for the catch likelihood this term very important in this stock where contrast in year-class size is large.

In the model runs conducted here the matrix Θ_I is generated by a 1st order AR model

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

where κ is an estimated parameter which has been estimated in the range 0.5 to 0.5 for the spring spawning herring in the May survey (survey 5). High value of κ indicates that the residuals in the survey approach a year factor while with $\kappa = 0$ equation becomes identical to equation .

The standard deviations σ_{aI} are estimated by the model by giving the pattern, estimating an multiplier. The pattern was estimated using an Adapt type model in 2018 for both surveys.

If there is more than one survey in the model the total survey likelihood is

$$L_I = sum_{i=1}^{i=N_s} W_i L_{I_i}$$

Stock-recruitment

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

$$N \quad_{0,y} = f(SSB_y)$$

$$\Gamma_{SSB-R} = log[N_{0,y}] - log\left[N_{0,y}\right]$$

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

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

$$L_{SSB-R} = \sum_y \left\{0.5 log(det\Theta_{SSB-R}) + \Gamma_{SSB-R}^{T}\Theta_{SSB-R}^{-1}\Gamma_{SSB-R}\right\}$$

The parameters σ_3, κ_3 and $\beta_3$are all among estimated parameters but estimating them all in addition to the 2 parameters of the SSB-rec function caused some difficulty so $\kappa_3$and $\beta_3$were set to zero in the estimation part but a fixed value of the auto-correlation parameter, estimated external to the model used in the stochastic simulations.

The choice of stock recruitment function has minor effect on the results of stock assessment but is very important in future simulations. Estimation of more than two one parameter (usually R_{max} and σ_3 are estimated) leads to very little improvement of the likelihood function. Addition of the 3rd parameter (SSB_{break}) is on the other hand important in stochastic simulations where the stock recruitment and the the uncertainty in the stock recruitment function start to matter.

One more parameter that can be estimated in the model is sudden change in productivity at certain time interval. This parameters might be used around the collapse as the selection pattern of the fisheries before and after the collapse is extremely different making relative estimated recruitment dependent on the level of M used for age 0-2.

The full likelihood

The most important likelihood components have be described above. There are in additions few other components that are not used very much but would rather be called constraints.

The total objective function to be minimised is the weighted sum of the log-likelihood values.

$$L_{tot} = W_C L_C W_{SSB-R} LSSB - R + W_I L_I + +W_Y L_Y$$

Input

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1979 -		Yes
Canum	Catch at age in numbers	1979 -	2-10	Yes
Weca	Weight at age in the commercial catch	1979 -	2-10	Yes
West	Weight at age of the spawning stock at spawning time.	1979 -	2-10	Yes
Mprop	Proportion of natural mortality before spawning	0.3	2-10	No
Fprop	Proportion of fishing mortality before spawning	0.4	2-10	No
Matprop	Proportion mature at age	1979 -	2 – 10	Yes
Natmor	Natural mortality	1979 -	2 – 10	No

Tuning data and estimated parameters:

Type	Name	Year range	Age range	Estimated parameters
Tuning fleet 1	Spring survey (SMB)	1985 -	1-10	q1,q2,q3,q4,q5,q6,q7,q8,q9,q10 rho correlation between adjacent age groups
Tuning fleet 2	Autumn survey (SMH)	1996 -	1-9	q1,q2,q3,q4,q5,q6,q7,q8,q9 rho correlation between adjacent age groups
				N1y, N2y, N3y, N4y, N5y, N6y, N7y, N8y, N9y, N10y, N11y, N12y, N13y (y = assessment year)
SSB-rec function				log(Rmax), log(CV)

Output

The model used to assess haddock in 5a is name Muppet and can be obtained from github.com/hoski/Muppet_HCR.

Three main outputfiles are generated by the model, called resultsbyyear, results by year and age and results by age, all with fixed number of columns with Tab as separator and names of columns in first file. Missing values are presented as -1.

Results by year has values that are function of year. There are number of columns there but values used are year, F4-7, SSB, CbioR, Cbio3,N2, Calcsurveybio, Calcsurveybio2, Obssurveybio and Obssurveybio2. Those meaning of those variables is:

F4-7	Average fishing mortality of age 4-7
SSB	Spawning stock 1000 tonnes
CbioR	Available biomass in the middle of the year, based on catch weights and selection pattern specified in the input file. 1000 tonnes
Cbio3.	Biomass of age 3 and older, based on stock weights. 1000 tonnes
N2	Recruitment at age 2 in thousands**.**
obscatch	Catches, 1000 tonnes
CalcSurveybio	Predicted biomass in March survey 1000 tonnes
CalcSurveybio2	Predicted biomass in Autumn survey 1000 tonnes
Obssurveybio	Observed biomass in March survey 1000 tonnes
Obssurveybio2	Observed biomass in Autumn survey 1000 tonnes

Results by year and age has values that are function of year and age, The most important columns here are year, age, N , Z, StockWts, M, F, CatchWts, SSBwts, StockSexmat, ObsCno, CalcSurveyNr, CalcSurveyNr2 , ObsSurveyNr, SurveyDiff, ObsSurveyNr2, SurveyDiff2

N	Number in millions
N	Number in millions
Z	Total mortality
StockWts	Weights in stock in g , from March survey.
M	Natural mortality (0.2).
F	Fishing mortality.
CatchWts	Mean weight from catches in g.
SSBwts	Mean weight in spawning stock in g. Same as stock weights.
StockSexmat	Proportion mature in stock.
ObsCno	Catch in numbers in 1000 fishes.
CalcSurveyNr	Predicted abundanc in the March survey in millions
CalcSurveyNr2	Predicted abundance in the October survey in millions
ObsSurveyNr	Predicted abundanc in the March survey in millions
ObsSurveyNr	Predicted abundance in the October survey in millions
Surveydiff	Residuals from the March survey.
Surveydiff2	Residuals from the October survey.

Results by age has values that are only function of age but do not change with time. The most important columns are age, M, surveysigma, SurveylnQ, SurveyPower, meansel, progsel, SurveySigma2, surveylnQ2, SurveyPower2.

M	natural mortality.
surveysigma	CV in March survey. Estimated.
SurveylnQ	Log Q for the March survey. Estimated.
SurveyPower	Power in the March survey. 1 for haddock i.e linear.
meansel	Average selection.
progsel	Selection used in prognosis (average of last 3 years).
SurveySigma2	CV in the October survey. Estimated.
surveylnQ2	Log Q for the October survey. Estimated.
SurveyPower	Power in the October survey. 1 for haddock.

D. Short-Term Projection

The model and the software for the prediction is the same as used in the assessment. It can either be based on specified fishing mortality or landings in future years. In the assessment year landings are always specified. Short term stochastic simulations can be done using the mcmc option in AD model builder.

Input data to the short term prediction are stock weights by age, stock maturity by age, catch weight at age and selection by age. They are given from the assessment year until 3 years after the assessment year. If the prognosis is for more than 4 years, input data from assessmentyear+3 are used after that year. For the Icelandic haddock stock weights and stock maturity in the assessment year are available at the time of assessment (from the March survey) while the other data have to be predicted. Fishing mortality given in the prediction is defined in the code to apply to ages 4-7, that has been the traditional reference for Icelandic haddock.

Estimate of yearclass strength for yearclasses that have been measured in the surveys comes from the assessment model. For unobserved yearclasses the model is a simple geometric mean. In stochastic simulations noise is added to stock and catch weight at age. This noise is defined in the code as lognormal yearfactor with CV=0.1 and autocorrelation 0.35 and applied as a multiplier on the weights given in the input files. When prediction is based on a F rule assessment error is applied as a multiplier on log F. The CV and autocorrelation of this multiplier is given in the input file.

Weight at age in the stock: Prediction of weight at age in the stock, weight at age in the catches, maturity at age and selection are based on work described in NWWG WD#19 in 2006. To summarize the findings of working paper the stock weights are predicted forward in time starting with the weights from the March survey in the assessment year . Growth is predicted as a function of weight at age multiplied by a year effect:

$$\log\frac{sW_{a+1,t+1}}{sW_{a,t}} = \alpha + \beta \log sW_{a,t} + \delta_{year}$$

Model including year class effect did not fit the data as well, this being because observed mean weight at age 2 is already a reflection of year-class strength. The same procedure i.e to use the estimated growth from the year before the assessment year is suggested as default for next years except something better will be cocked up.

Weight at age in the catch: Mean weight at age in the catches are predicted from mean weight at age in the stock the same year by an equation of the form

$$\log cW_{a,t} = \alpha + \beta \log sW_{a,t}$$

Using the data from 2000 is suggested as default for the next years.

Exploitation pattern: The predicted selection pattern is obtained from the expected catch weights by:

$$\log it(S_{a,t}) = \alpha + \beta s(\log sW_{a,t}, df = 3)$$

where s is a smoothing spline with 3 degrees of freedom.

Maturity: Advisory year and beyond the maturity at age is predicted from mean weight at age in the stock by an equation of the form:

$$\text{logit}(P_{a,t}) = \alpha + \beta \log sW_{a,t}$$

The fitting is done separately for the periods 1985 – 2000 and 2001 – 2012 with the latter relationship used for prediction. Maturity at age is predicted to increase in coming years with increased size at age. For the next years it is suggested to model maturity as function of mean weight at age in the stock based on the data since 2001.

F and M before spawning: same as in the assessment

Intermediate year assumptions: In recent years catch constraint has been used for catch in the assessment year, taking into account the quota left in the current fishing year and adding 1/3 of the expected TAC in next fishing year. Prognosis in the model used for HCR evaluation is based on fishing years and for the catch in the assessment year only the quota left in the beginning of the assessment year is specified.

The calculation of the advisory TAC is based on the following:

Reference biomass of haddock of 45cm and larger in the advisory year (y+1) is calculated from

$$B_{45+cm,y+1} = \sum_a N_{a,y+1} sW_{a,y+1} \frac{1}{1 + e^{-25.224 - 5.307 \log \frac{sW_{y+1,a}}{44.5^3}}}$$

When $SSB_{y+1} > B_{trigger}$

$$TAC_{y/y+1} = \alpha B_{45+cm,y+1}$$

When $SSB_{y+1} < B_{trigger}$

$$TAC_{y/y+1} = \alpha \left\{ \frac{SSB_{y+1}}{SSB_{trigger}} \right\} B_{45+cm,y+1}$$

where y is the assessment year, $y+1$ is the advisory year, $y/y+1$ refers to the fishing year (starting 1. September and ending 31. August) and α is the harvest rate. The proposal by the managers is to set $\alpha = 0.4$. This HCR was evaluated by ICES in March 2013. (WGISAHA 2013)

E. Medium-Term Projections

Model used: Statistical catch at age

Software used: Muppet

Initial stock size: From model

Natural mortality: 0.2

Maturity: Long term average or some other scenario

F and M before spawning: Same as in the assessment

Weight at age in the stock: Long term average or some other scenario

Weight at age in the catch: Long term average or some other scenario

Exploitation pattern: Recent or long term

Intermediate year assumptions: Catch constrain

Stock recruitment model used: Hockey-stick

Uncertainty models used:

Initial stock size: MCMC estimates

Natural mortality: None

Maturity: Long term or recent averages

F and M before spawning: None

Weight at age in the stock: Stochastic, autocorrelated (by age and time)

Weight at age in the catch: Stochastic, autocorrelated (by age and time

Exploitation pattern: Function of estimated stock weights

Intermediate year assumptions: None

Stock recruitment model used: Various types tested

TAC based on perceived stock estimates, autocorrelated error in time.

F. Long-Term Projections

Model used: Same as above

Software used: Same as above

Maturity: See above

F and M before spawning: See above

Weight at age in the stock: See above

Weight at age in the catch: See above

Exploitation pattern: See above

G. Biological Reference Points

	TYPE	VALUE	TECHNICAL BASIS
MSY			
Approach	HR_{MSY}	0.35	Multiplier on biomass 45 cm and larger in the beginning of the advisory year, constrained by HR_{p5}. Stochastic evaluation accounting for assessment and implementation errors (WKICSMSE 2019).
	MSY $B_{trigger}$	49.4 kt	B_{pa}
Precautionary	B_{lim}	35.5 kt	SSB(1987), corresponding to B_{loss}
Approach	HR_{lim}	0.63	HR corresponding to 50% long-term probability of SSB > B_{lim}
	F_{lim}	0.71	F corresponding to HR_{lim}
	F_{pa}	0.35	The fishing mortality including the advice rule that ,if applied as a target in the advice rule would lead to SSB ≥ B_{lim} with a 95% probability
	HR_{pa}	0.5	HR corresponding to F_{pa}
Management plan	HR_{mgt}	0.35	Multiplier on biomass 45 cm and larger in the beginning of the advisory year.
	Mgt. $B_{trigger}$	49.4 kt	Set as B_{pa} as the BHR_{MSY} < B_{pa}
	HR_{mgt}	0.23 – 0.57	Expected (90%) range of harvest rates when the updated management plan is applied

I. References

Anon. 2012. Nytjastofnar sjávar 2011/2012. Aflahorfur fiskveiðiárið 2012/2013. State of Marine Stocks in Icelandic Waters 2011/2012. Prospects for the Quota year 2012/2013 (In Icelandic, with English abstract). Marine Research in Iceland, 163: 1-189.

Björnsson , H., and Jónsson, E. 2004. Estimation of hidden mortality of Icelandic haddock caused by the fisheries. ICES CM 2004/FF:24, 24 s.

Pálsson, Ó.K, et. al., 2011. Mælingar á brottkasti þorsks og ýsu 2001-2010. Discards of cod and haddock in the Icelandic demersal fisheries 2001-2010. (In Icelandic, with English abstract). Marine Research in Iceland, 159

Pálsson, Ó.K., 2003 A length-based analysis of haddock discards in Icelandic fisheries. Fisheries Research, 59: 437-446

Bjornsson, H. 2013. Report of the evaluation of the Icelandic haddock management plan. ICES CM 2013/ACOM:59, pages 1–47.

Bjornsson, H., Hjorleifsson, E., and Elvarsson, B. Þ. 2019. Muppet: program for simulating harvest control rules. Technical report, Marine and Freshwater Researh Institute, Reykjavik.

ICES 2013. Report of the Benchmark Workshop on Roundfish Stocks (WKROUND). ICES CM 2013/ACOM:47, pages 1–213.

ICES 2014. Report of the working group on the biology and assessment of deep- sea fisheries resources (wgdeep), 4–11 april, 2014, copenhagen, denmark. ices cm 2014/acom:17. Technical report, International Council for the Exploration of the Seas.

Jónsson, J. 1996. Tagging of cod (Gadus morhua) in Icelandic waters 1948-1986;:

Tagging of haddock (Gadus aeglefinus) in Icelandic waters 1953-1965. Hafrannsóknastofnunin.

MRI 2013. Mælingar á brottkasti þorsks og ýsu (e. Measurments of discards of Cod and Haddock), 2013, Reykjavik, Iceland. Technical report, Marine Research Institute, Iceland.

Víkingsson, G. A., Elvarsson, B. Þ., Ólafsdóttir, D., Sigurjónsson, J., Chosson, V., and Galan, A. 2014. Recent changes in the diet composition of common minke whales (balaenoptera acutorostrata) in icelandic waters. a consequence of climate change? Marine Biology Research, 10(2):138–152.