WORKSHOP ON THE BENCHMARK ASSESSMENT AND MANAGEMENT PLAN EVALUATION FOR ICELANDIC HADDOCK AND SAITHE (WKICEMSE)

VOLUME 1 | ISSUE 10

ICES SCIENTIFIC REPORTS

RAPPORTS
SCIENTIFIQUES DU CIEM

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

ICES Scientific Reports

Volume 1 | Issue 10

WORKSHOP ON THE BENCHMARK ASSESSMENT AND MANAGEMENT PLAN EVALUATION FOR ICELANDIC HADDOCK AND SAITHE (WKICEMSE)

Recommended format for purpose of citation:

ICES. 2019. Workshop on the benchmark assessment and management plan evaluation for Icelandic haddock and saithe (WKICEMSE).
ICES Scientific Reports. 1:10. 107 pp. http://doi.org/10.17895/ices.pub.5091

Editors

Jim Ianelli • Morten Vinther

Authors

Höskuldur Björnsson • Bjarki Thor Elvarsson • Jim Ianelli • Christoph Konrad • Paul Spencer • Morten Vinther

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

Contents

i Executive summary ii
Haddock in 5a ii
Saithe in 5a iii
ii Expert group information v
1 Introduction 1
2 Description of the Benchmark Process 2
3 Haddock in 5.a 3
4 Icelandic Saithe 55
Benchmark and Harvest Control Rule evaluations of Icelandic saithe 55
Working document for WKICEMSE 2019 55
Höskuldur Björnsson 55
31 March 2019 55
4.1 Introduction 56
4.2 Stock 56
4.3 Stock assessment 62
4.4 Assessment 69
4.5 Short term projections 74
4.6 Reference points 74
4.7 Future research and data requirements 79
4.8 Harvest control rule evaluation 79
4.9 Results of HCR simulations 82
4.10 Comparison with long term results from 2013 90
References 91
5 Reviewers comments 92
Annex 1: List of participants 99
Annex 2: Request from Iceland 100
Annex 3: Clarifications of the request from Iceland 101
Annex 4: Terms of Reference 105
Annex 5: Stock Annex: Haddock (*Melanogrammus aeglefinus*) in Division 5.a (Iceland grounds) 106
Annex 6: Stock Annex: Saithe (*Pollachius virens*) in Division 5.a (Iceland grounds) 107

i Executive summary

On 16 October, 2018, ICES received the following request from Iceland *"to evaluate the historical performance of the management plans for haddock and saithe against their general aim of maintaining the exploitation rate at the rate which is consistent with the precautionary approach and are in conformity with the ICES MSY approach. ICES is also asked to evaluate the changes in the assessment methods and reference points (Benchmark) if the outcome of the consultations results in any changes. Similarly, to evaluate if the possible changes in the HCR are consistent with the precautionary approach and are in conformity with the ICES MSY approach …..".* On further correspondence received by ICES on 1 March, 2019, ICES was specifically requested to review two specified control rules for Icelandic haddock (had.27.5a) and saithe (pok.27.5a).

The WKICEMSE 2019 – Workshop on the benchmark assessment and management plan evaluation for Icelandic haddock and saithe – was held at ICES headquarters, Copenhagen, Denmark on 26–28 March 2019. The benchmark process was initiated by a WebEx on 4 March with participations of the external reviewers, chairs and the two stock assessors. Two working documents on the stock assessment and MSE were presented by the stock assessors. There were no major issues identified by the reviewers with respect to input data, assessment models and Management Strategy Evaluation for the two stocks. This might be due to the fact that there were no "issue list" made before the benchmark process, probably because WKICEMSE 2019 was a result of a request from the Icelandic Ministry of Industries and Innovation, rather than triggered from issues to be solved identified by ICES.

Haddock in 5a

The assessment method was updated during this benchmark. The previous assessment model was based on an ADAPT-type model. The new assessment model is a statistical catch at age model based on the previously used two survey series (the Icelandic spring and autumn groundfish surveys). The maximum age in the model is 10, which is a plus group whereas age 13 was used previously. The assessment results from the new model have similar characteristics as the previous assessments apart from the estimated spawning stock biomass. This change in the SSB is due to the assessment now incorporates natural and fishing mortality before spawning, which occurs in April to the end of May. Previously it was assumed in the assessment that spawning took place at the beginning of the year.

New reference points were calculated for the stock. This resulted in B_{lim} = 35.5 kt, based on B_{loss}, the lowest observed biomass (SSB in 1987 as estimated in the benchmark assessment), and B_{pa} = B_{lim}*1.4 = 49.4 kt. The proposed harvest control rule (HCR) is not based on F but on a harvest rate (HR) relative to stock biomass of 45+ cm. Given this, the fishing pressure reference points were estimated for harvest rate rather than fishing mortality, which resulted in HR_{lim} = 0.63 and HR_{pa} = 0.50. MSY reference points were also calculated and resulted in HR_{MSY} = 0.35 and MSY $B_{trigger}$ = 49.4 kt.

A Management Strategy Evaluation (MSE) was conducted for haddock in 5.a. The operating model, which generates the "true" future populations in the simulations, was the same as used in the annual stock assessment. The selection pattern used is the same as estimated within the model. Recruitment was projected using a log-normal distribution based on the distribution of CVs and autocorrelations estimated by the assessment model with MCMC resampling.

To account for observed density dependence in growth projected stock weights were based on the relationship with total biomass to derive next year's growth and numbers at ages two and three to calculate the weight at age 2. Maturity at age in the projections was based on the relationship between proportion mature and stock weights. In contrast with the 2013 MSE for haddock, the proportion mature by stock weights has been considerably lower in most recent years. This was taken into account in the MSE by only using the observations from 2013 to 2018 to simulate future proportion mature.

The assessment error of the reference 45+ cm stock biomass was assigned a CV = 0.2, based on the perceived error in the stock assessment. The assessment error was autocorrelated in time to emulate observed sequential periods of over- or under-estimation of stock biomass. The autocorrelation parameter, ρ, was set to 0.67, based on estimates of autocorrelation from historical retrospective estimates of SSB.

The proposed HCR for the Icelandic haddock fishery, which sets a TAC for the fishing year y/y+1 (September 1 of year y to August 31 of year y+1) based on a harvest rate of 0.4 on the 45+ cm biomass in the advisory year y+1 ($B_{ref,y+1}$), modified by the ratio SSB_{y+1}/MGT $B_{trigger}$ when SSB_{y+1} < MGT $B_{trigger}$, is not considered to be precautionary as it results in higher than 5% probability of SSB < B_{lim} in the medium and long term. In both the short and long term, a harvest rate of 0.35 maximizes median yield while still being precautionary. Therefore, a HCR with HR of 0.35 was determined to conform to the ICES MSY approach.

Saithe in 5a

The assessment method was not updated during this benchmark. The assessment model is a statistical catch at age model based on one survey series (the Icelandic spring groundfish survey). The maximum age in the model is 14.

New reference points were calculated for the stock. This resulted in B_{pa} = 61 kt, based on B_{loss}, the lowest observed biomass (SSB in 1996 as estimated in the benchmark assessment), and B_{lim} = B_{pa}/1.4 = 44 kt. The proposed harvest control rule (HCR) is not based on F but on a harvest rate (HR) relative to stock biomass of 4 and older using landing weights. Given this, the fishing pressure reference points were estimated for harvest rate rather than fishing mortality, resulting in HR_{lim} = 0.32 and HR_{pa} = 0.23. MSY reference points were also calculated and resulted in HR_{MSY} = 0.20.

An MSE was conducted for saithe in 5.a. The operating model, which generates the "true" future populations in the simulations, was the same as used in the annual stock assessment. The selection pattern used is the same as estimated within the model. Recruitment was projected using a log-normal distribution based on the distribution of CVs and autocorrelations estimated by the assessment model with MCMC resampling.

Mean weight and maturity at age at age was based on based on the average of last 10 years. Stochasticity in weight around this value was implemented as a lognormal year factor with CV = 0.13 and ρ = 0.5. Maturity at age was fixed in the simulations.

The assessment error of the reference stock biomass was assigned a CV = 0.22, based on analytical retrospective runs. The assessment error was autocorrelated in time to emulate observed sequential periods of over- or under-estimation of stock biomass. The autocorrelation parameter, ρ, was set to 0.5 based on estimates of autocorrelation from analytical retrospective estimates of the biomass of age 4 and older.

The implementation error on the total catch was included into the simulations to account for observed species transformations (transfer of quota from one species to another), based on the time-series of species transformations. Similar to the assessment error the implementation error was autocorrelated in time to emulate observed periods of catching more or less than the TAC. The CV and autocorrelation of the implementation error were set at 0.07 and 0.65.

The proposed HCR for the Icelandic saithe fishery, which sets a TAC for the fishing year y/y+1 based on a harvest rate of 0.2 on the 4+ years biomass in the advisory year y+1 ($B_{ref,y+1}$), modified by the ratio SSB_{y+1}/MGT $B_{trigger}$ when SSB_{y+1} < MGT $B_{trigger}$, is considered to be precautionary as it results in less than 5% probability of SSB < B_{lim} in the short, medium and long term. In the long term simulations of the management plan a harvest rate of 0.19 was found to maximize median yield.

ii Expert group information

Expert group name	Workshop on the benchmark assessment and management plan evaluation for Icelandic haddock and saithe (WKICEMSE)
Chairs	Morten Vinther, Denmark – ICES Chair
	Jim Ianelli, USA – External Chair
Meeting venue and dates	26–28 March 2019, Copenhagen, Denmark, (7 participants)

1 Introduction

On 16 October, 2018, ICES received the following request from Iceland *"to evaluate the historical performance of the management plans for haddock and saithe against their general aim of maintaining the exploitation rate at the rate which is consistent with the precautionary approach and are in conformity with the ICES MSY approach. ICES is also asked to evaluate the changes in the assessment methods and reference points (Benchmark) if the outcome of the consultations results in any changes. Similarly, to evaluate if the possible changes in the HCR are consistent with the precautionary approach and are in conformity with the ICES MSY approach".* The full text of the request can be found in Annex 2. On further correspondence received by ICES on 1 March, 2019, ICES was specifically requested to review two specified control rules for haddock and saithe (see Annex 3 for details).

As a response ICES established WKICEMSE 2019 – Workshop on the benchmark assessment and management plan evaluation for Icelandic haddock and saithe - to meet at ICES HQ, Copenhagen, Denmark on 26–28 March 2019 chaired by ICES Chair Morten Vinther (Denmark) and External Chair Jim Ianelli (USA) and attended by two invited external experts Paul Spencer (USA), and Christoph Konrad (Italy), to evaluate the benchmark assessments and management plan evaluations for Icelandic haddock (had.27.5a) and saithe (pok.27.5a). The Terms of reference for WKICEMSE 2019 can be found in Annex 4.

2 Description of the Benchmark Process

Two working documents "An assessment of haddock in 5a and evaluation of potential harvest control rules by" and "Benchmark and harvest Control rule evaluation of Icelandic Saithe" was produced by the stock assessors Bjarki Thor Elvarsson (haddock) and Höskuldur Björnsson (saithe) in February 2019. The final versions (after the WK) of the two documents can be found in Section 3 and Section 4 of this report.

The draft working documents were presented at a WebEx on 4 March with participations of the external reviewers, chairs and stock assessors. There were a few comments and requests from the reviewers for clarification and additional information which should be included in the WD. There were no major issues identified by the reviewers with respect to input data and assessment models for the two stocks. This might be due to the fact that there were no "issue list" made before the WebEx probably because the WK was a result of a request from the Icelandic Ministry of Industries and Innovation, rather than triggered from issues to be solved identified by ICES. For the Management Strategy Evaluation (MSE), it was accepted by the reviewers to use a "short cut" approach (simulation of the stock assessment), rather than a "full-feedback MSE", (using an operating model different from the assessment model and doing assessment model runs as part of the MSE) for the MSE.

The two working documents were updated and distributed in the period up to the physical meeting of WKICEMSE 2019, 26–28 March 2019.

The participants (see Annex 1) to the WKICEMSE 2019 included the workshop chairs, two external reviewers and the two stock assessors, but there were no participants from the industry, NGOs or additional ICES assessment biologists.

3 Haddock in 5.a

An assessment of haddock in 5a and evaluation of potential harvest control rules

Bjarki Þór Elvarsson and Höskuldur Björnsson

Demersal Division
Marine and Freshwater Research Institute, Reykjavík, Iceland
(bjarki.elvarsson@hafogvatn.is)

April 1, 2019

1 Haddock

1.1 Stock ID and sub-stock structure

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. 1).

1.2 Issue list

In a letter dated at October 18, 2018, the government of Iceland requested that ICES evaluate the performance of the harvest control rules for haddock and saithe in Icelandic waters that were established in 2013, and update the assessment method if appropriate.

1.3 Scorecard on data quality

Scorecard was not used.

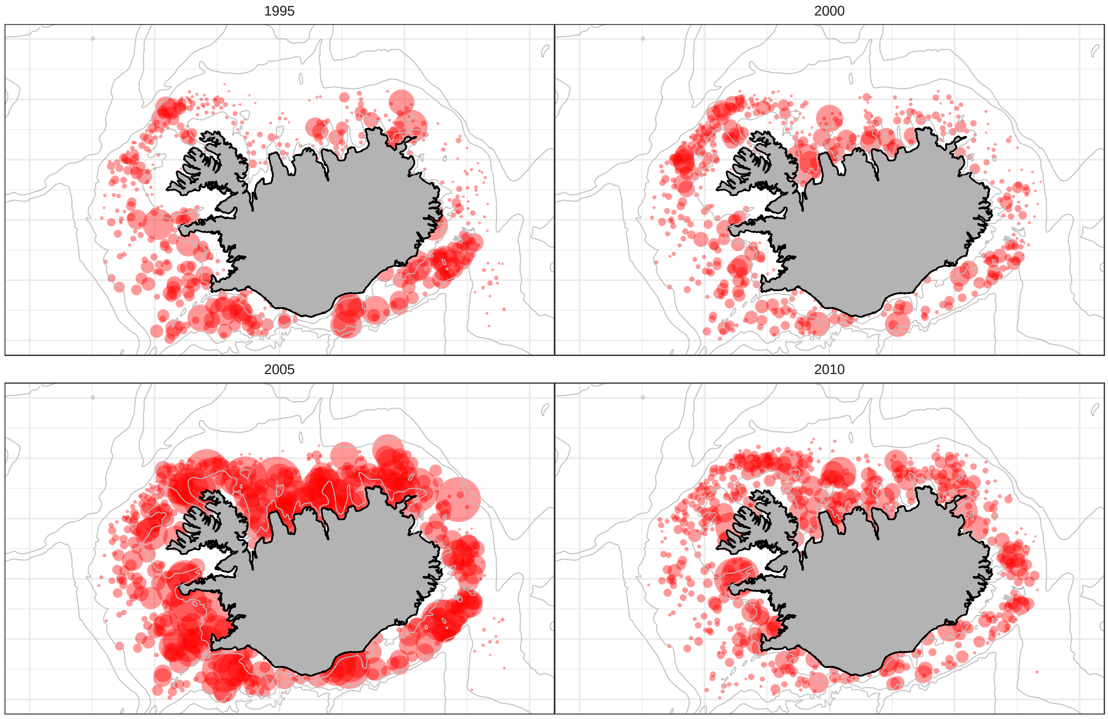

Figure 1: Haddock in 5a. Location of haddock in Icelandic waters as observed from the Icelandic spring survey. Size of the points is relative to the amoung caught, standardised to a tow mile.

1.4 Multispecies and mixed fisheries issues

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 key species, in terms of landed biomass, is cod. Identifying target species in those mixed fisheries is however not straightforward, as the fishers are often aiming for a certain mixture of species or size combinations, which may vary depending on market conditions.

The landings by gear are shown in Fig. 2. The bulk of haddock landings has historically been from bottom trawl but the share of longline landings has increased since 1998. Since 2011 catches by longliners have been on par with those of trawlers in recent years. The increase by longliners is caused by increase in their vessel number, both of large vessels where each fishing trip takes 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 a quota addition, as handbaiting is considered to create jobs. Haddock are also caught by Danish seines and gillnets (shown as other in Fig. 2), but the landings from these gears is considerably less than trawls and longlines. The share of Danish seines increased during 2000-2007 but has decreased since then. The 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. Timing of the catches within the year has not change substantially since 1992, as shown in the bottom panel on Fig. 2. The catches are in general evenly distributed to the months, with a slight increase in the spring and slight decrease in the autumn.

Fig. 3 shows the spatial changes in catch since 1993. Spatial patterns of fishing activity and catch distribution are produced from logbook data with 100% coverage of

Figure 2: Haddock in division 5a. Top two panels show the catch in tons and percent of total catch by gear and year. The bottom panel shows the proportion of catches by month, split by time periods. For reference a red solid line indicating evenly distributed catches across months is drawn.

all the fleet since 2001, but from the larger boats only since 1991. Haddock fishing areas were traditionally similar from one year to another, primarily along the south and the west coast. Since 2000, a higher proportion of the fishable stock has inhabited the waters north of Iceland. The share of longliners in the fisheries has also increased, which do not fish in the same areas as trawlers, partly because they cannot operate in the same areas, but also because shallow-water areas that are closed for trawling are open for longliners.

1.5 Ecosystem drivers

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

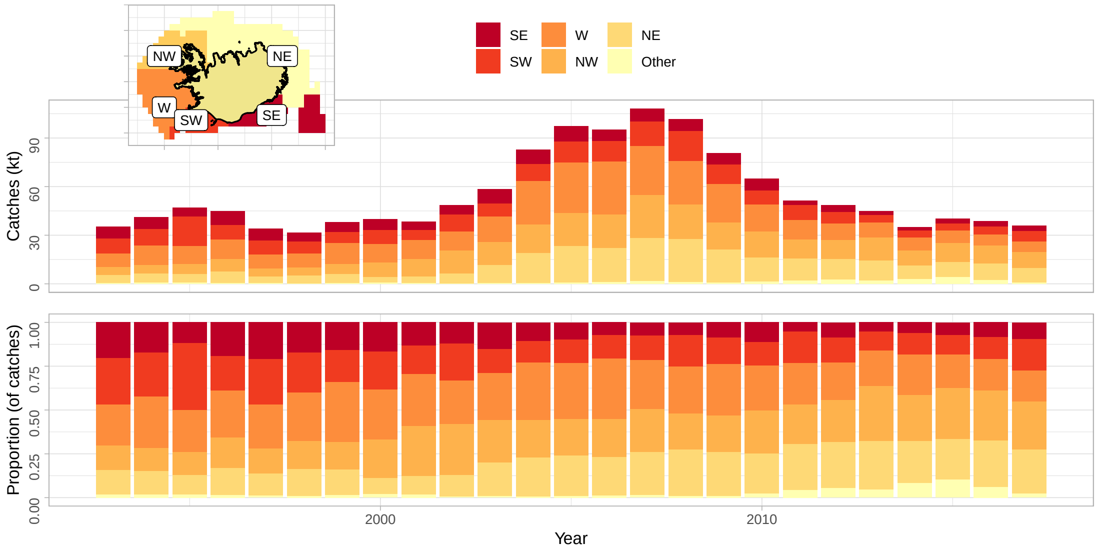

Figure 3: Haddock in 5a. Changes in spatial distribution of haddock catches as recorded in Icelandic logbooks.

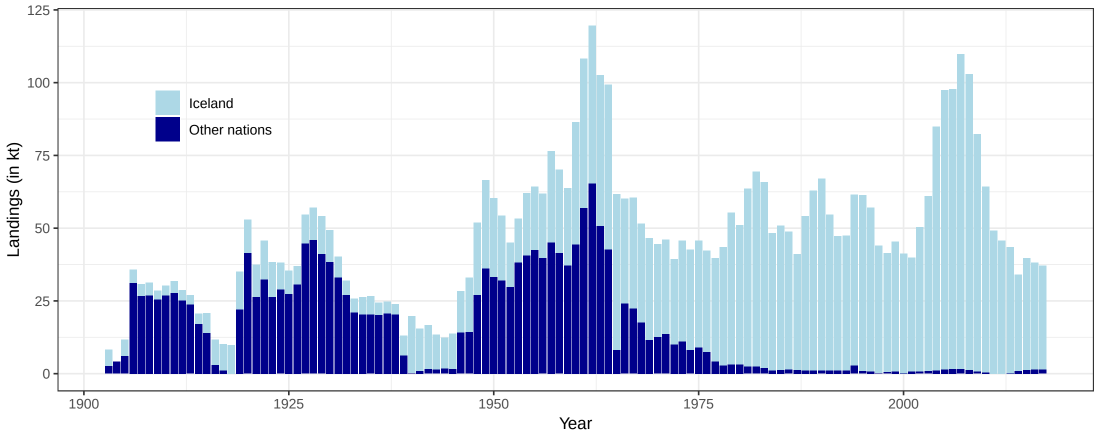

Figure 4: Haddock in 5a. Historical landings of Haddock in area 5a (Icelandic waters).

(*Brosme brosme*) (e.g. see ICES 2014), which may be linked to increased temperatures.

1.6 Stock assessment

1.6.1 Catch – quality, misreporting, discards

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. Informa-

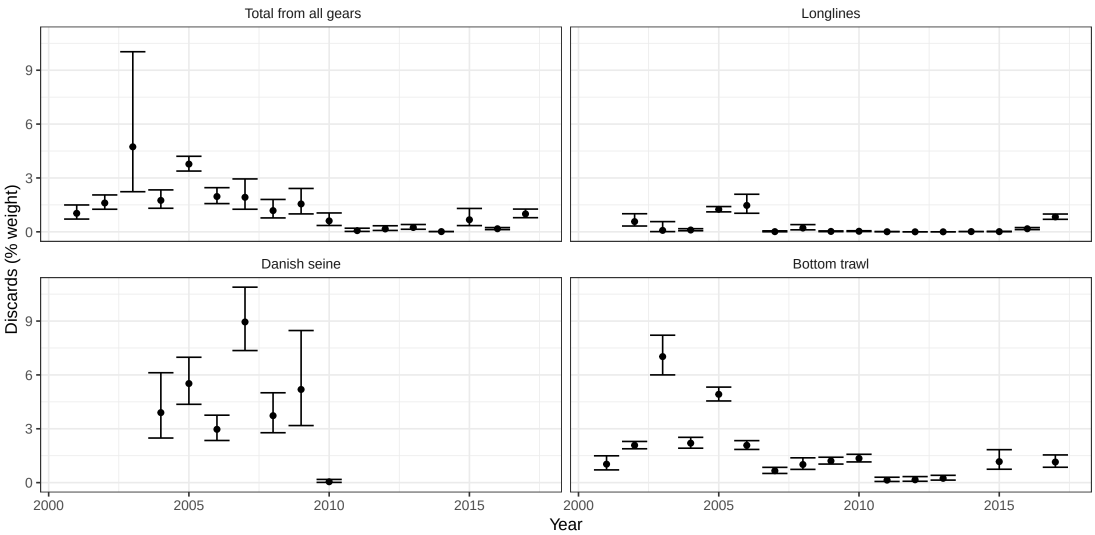

Figure 5: Haddock in 5a. Esitmates of annual discards by gear. Verical lines indicate the 95 % confidence interval while dots the point estimates.

tion 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 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).

1.6.2 Surveys

1.6.2.1 Research surveys Information on abundance and biological parameters from Haddock in 5a is available from two surveys, the Icelandic groundfish survey in the spring and the Icelandic autumn survey.

The Icelandic groundfish survey in the spring, which has been conducted annually since 1985, covers the most important distribution area of the haddock fishery. The autumn survey commenced in 1996 and expanded in 2000 to include deep water stations. It provides additional information on the development of the stock. The autumn survey has been conducted annually with the exception of 2011 when a full autumn survey could not be conducted due to a fisherman strike. Although both surveys were originally designed to monitor the Icelandic cod stock, the surveys are considered to give a fairly good indication of the haddock stock, both the juvenile population and the fishable biomass. A detailed description of the Icelandic spring and autumn groundfish surveys is given in the Stock Annex. Fig. 6 shows both a recruitment index and the trends in various biomass indices. Changes in spatial distribution observed in the spring survey are shown in Fig. 7. The figure shows that a larger proportion of the observed biomass now resides in the north (areas NW and NE).

Both surveys show much increase total biomass between 2002 and 2005 but considerable decrease from 2007–2010. The difference in perception of the stock between the surveys is that the autumn survey shows less contrast between periods of large and small stock. The 2015 estimate from the autumn survey exhibited substantially lower biomass compared to adjacent years. The contrast between the surveys appears to be starker when looking at the biomass of 60 cm and larger where the autumn survey index shows a downwards trend while the spring survey shows an upwards trend. The reason for these difference may be related to differences in behaviour, as large haddock appears to be harder to catch in trawls in the autumn.

Age disaggregated indices from the March survey are shown in Fig. 8. The index of oldest age groups (2003 cohort and younger) is much higher than seen before (a large part of 11+ in the March survey), that may be the result of reduced fishing pressure. Year classes 2008 and 2009 are now more abundant than comparable year classes (in terms of recruitment), mostly due to reduced fishing mortality in recent years as those year classes were originally small.

As shown in Fig. 9 and Fig. 10 the surveys can be considered to be both internally consistent and consistent with each other (Fig. 11).

1.6.2.2 Catch and effort series Catch per unit of effort data (Fig. 12) give a somewhat different picture of the development of the stock than the surveys and assessment. They indicate a much lesser increase after 2000 and much lesser decrease in recent years. The current assessment coupled with the relatively high CPUE, in recent years, confirms fishers view that it is currently easier to catch haddock than previous years. The discrepancy observed between CPUE and stock size has not been entirely explained, but a plausible explanation might be related to a few reasons. First the area inhabited by the stock increased so the density in the traditional fishing area did not increase in relation to the stock size. At the beginning of the increase, when the stock increased substantially, growth lead to larger proportion of the stock below regulatory size of 45 cm, thus limiting the areas where large haddock could be caught without too much bycatch of small haddock. Second, the opposite has happened in recent years, faster growth and poorer recruitment lead to the fisheries not being limited by small haddock. It therefore is fairly likely that the increase in CPUE observed in recent years is not entirely indicative of a stock increase. Fig. 3 shows a shift in fishing to the north following the observed trend in the survey to the north (Fig. 7).

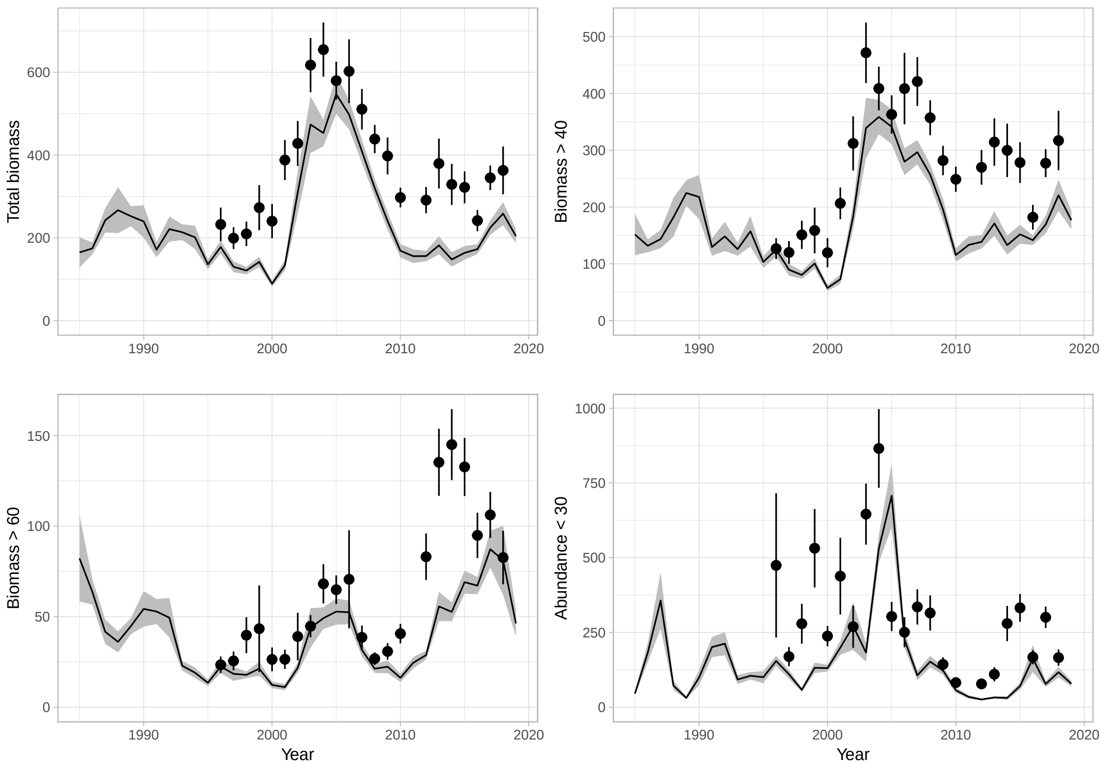

Figure 6: Haddock in 5.a. Indices in the Spring Survey (March) 1985 and onwards (line shaded area) and the autumn survey (point ranges).

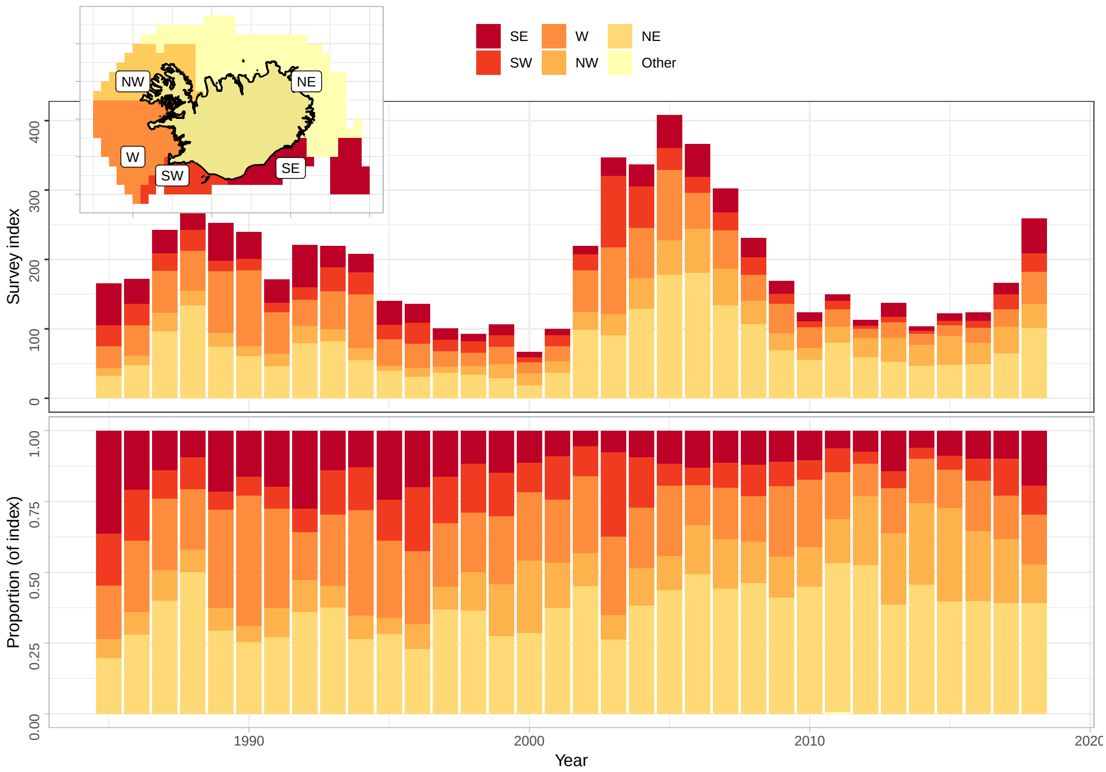

Figure 7: Haddock in 5.a. Changes in spatial distribution of haddock as observed in the Icelandic groundfish survey (in the spring).

Figure 8: Haddock in 5.a. Log transformed survey at age. The black line denotes the mean value of the survey index and the coloured bars indicate deviations from the mean. The colours denote the year class.

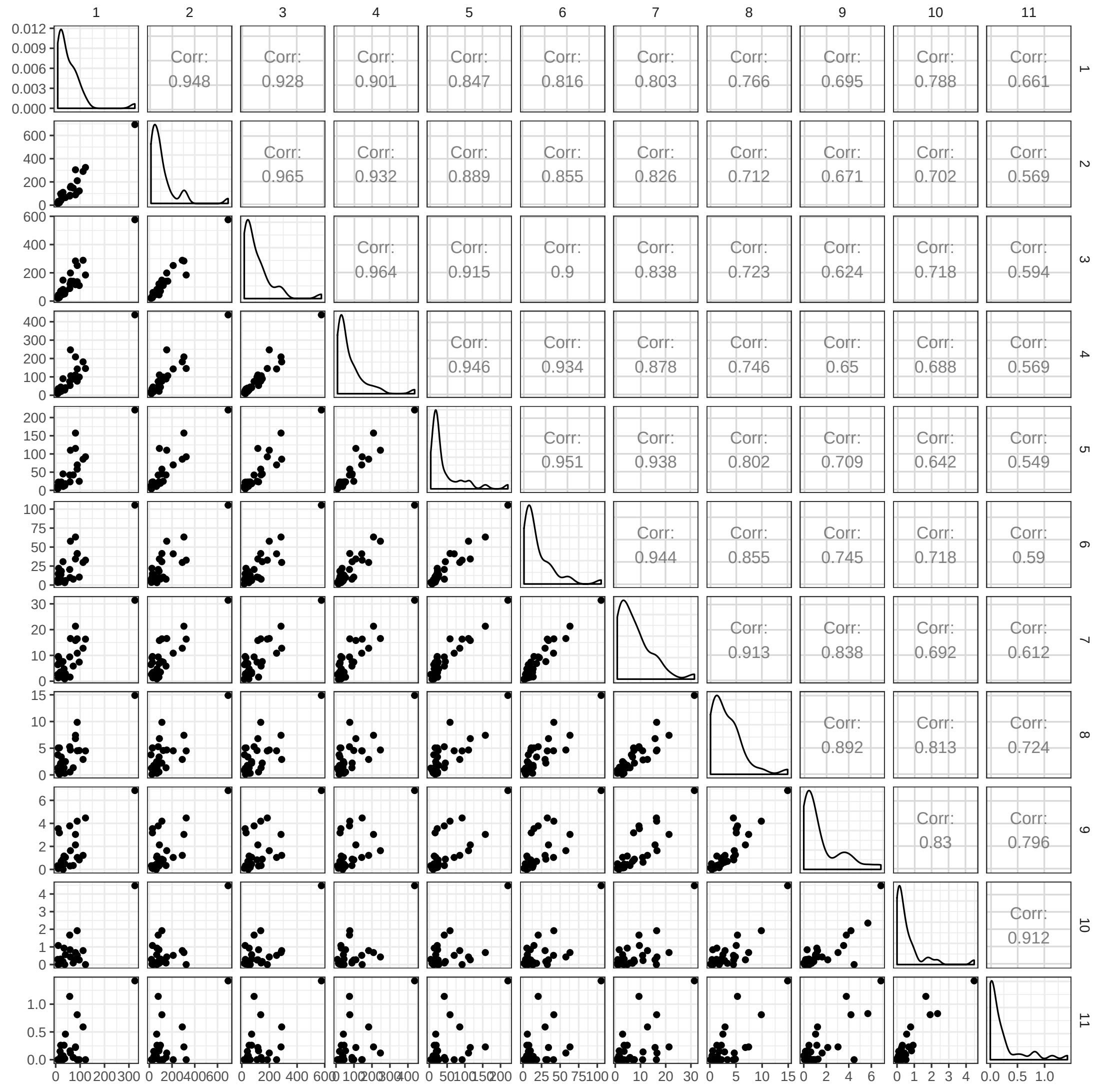

Figure 9: Haddock in 5a. Internal consistency between age based survey indices from the spring survey.

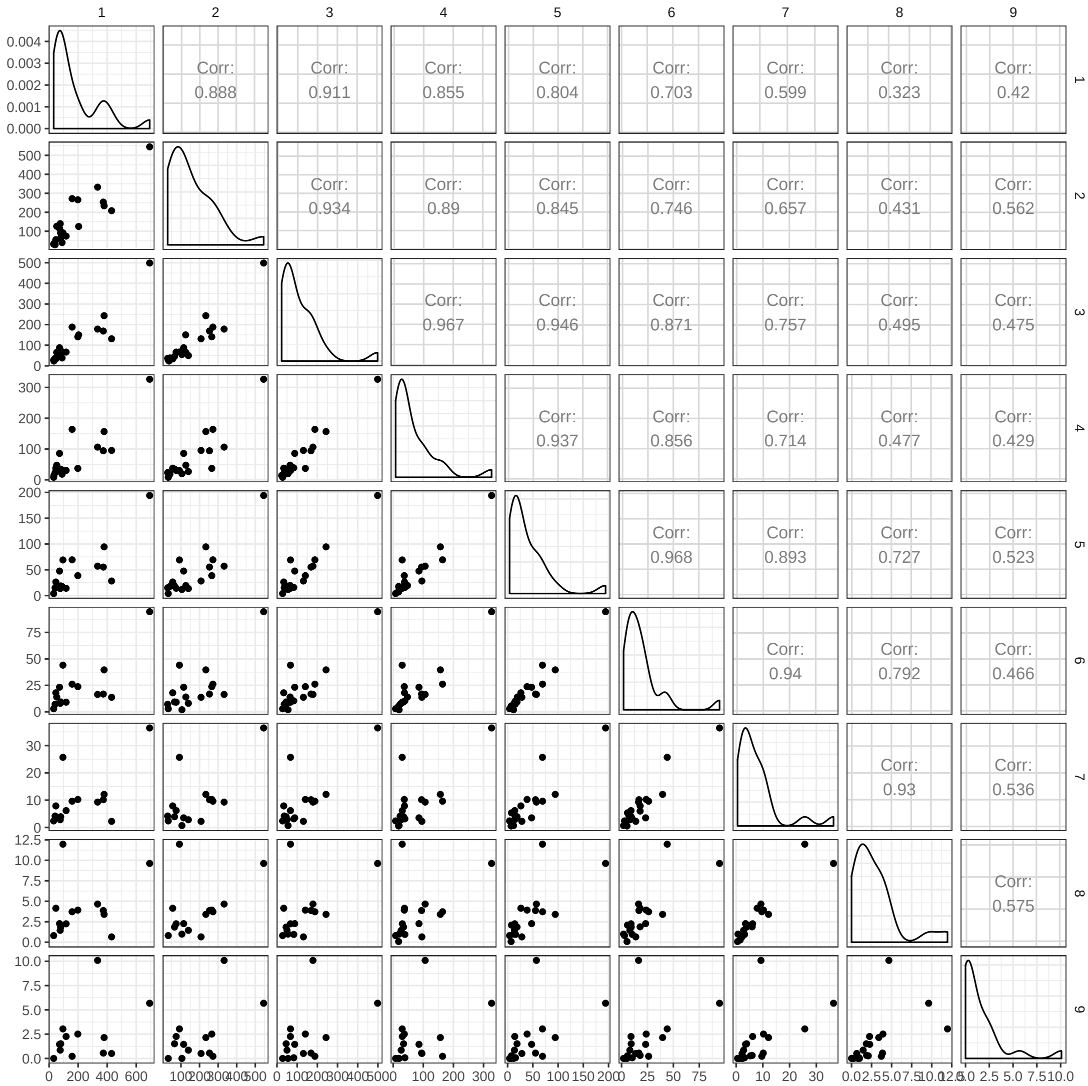

Figure 10: Haddock in 5a. Internal consistency between age based survey indices from the autumn survey.

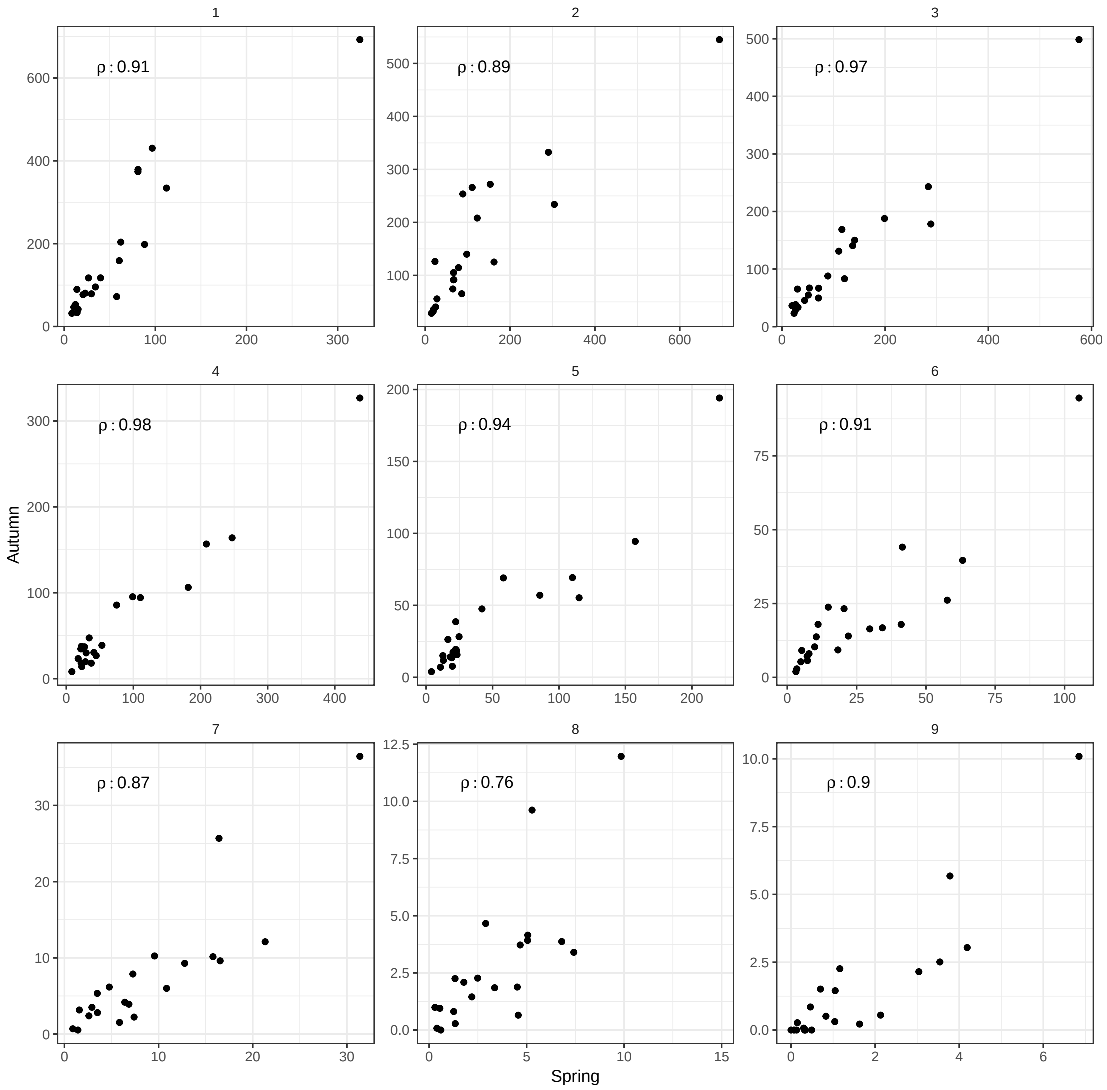

Figure 11: Haddock in 5a. Internal consistency between age based survey indices between the autumn and spring surveys.

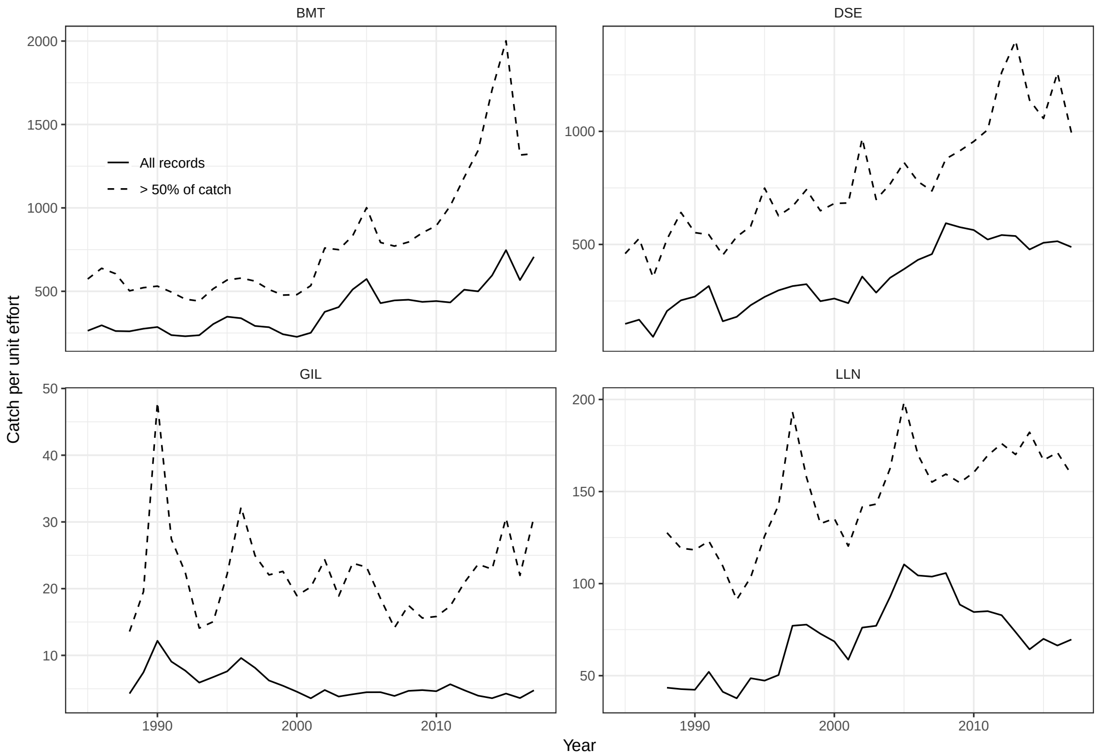

Figure 12: Catch per unit of effort in the most important gear types. The dashed lines are based on locations where more than 50% of the catch is haddock and solid lines on all records where haddock is caught. A change occurred in the longline fleet starting September 1999. Earlier, only vessels larger than 10 BRT were required to return logbooks but later all vessels were required to return logbooks.

1.6.3 Weights, maturities, growth

Icelandic haddock can reach 15 years of 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 100 cm 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 seen to fluctate with time leading to substantial variation in yearclass recruitment to the fisheries.

1.6.3.1 Growth Mean weight at age in the stock is shown in Fig. 13. Those data are obtained from the groundfish survey in March and are also used as mean weight at age in the spawning stock. Both stock and catch weights have been increasing in recent years, after being very low when the stock was large between 2005 and 2009. Higher mean weight at age is most apparent for the younger haddock from the small cohorts (2008–2013). Mean weight of the 2014 cohort was more lower than that of recent small year classes but above the average for a large cohort. In general stock and catch weights exhibit similar patterns in deviations from mean weight at age.

1.6.3.2 Maturities Maturity-at-age data are given in Fig. 14. Those data are obtained from the groundfish survey in March. Maturity-at-age of the youngest age groups has been decreasing in recent years while mean weight at age has been increasing (as observed in the March survey). Maturity by size has also been decreasing (Fig. 33), and the most likely explanation is that a large proportion of those age groups is situated in the north of Iceland, where proportion mature has historically been lower.

1.6.4 Assessment model

1.6.4.1 Model settings The assessment model used is a statistical catch–at-age model described in Bjornsson et al. (2019). The model runs from 1979 onwards and ages 1 to 13 are tracked by the model. Natural mortality is set to 0.2 for all age groups lower than 12, while ages 12 and 13 are set to 0.3 and 0.4 respectively. Selection pattern of the commercial fleet is defined in terms of mean stock weights at age, rather than age, based on a logit selection function:

$$S_{a,y} = \frac{1}{1 + e^{-\alpha(\log(\mathrm{sW}_{a,y}) - \log(\mathrm{W}_{50}))}} \tag{1}$$

The rationale for this choice, compared to a more traditional age based selection, is to account for observed changes in growth between year classes. Larger year classes tend to have have lower mean weight compared to smaller year classes, as observed in Fig. 13. As fishery selection is mainly size based, the assessment model using a size based selection only requires two parameters to estimate the selection pattern. In contrast an age based selection pattern would require parameter based on multiple selection time periods.

The weights to the survey data are based on a common multiplier to the variance estimates of each age group and survey obtained from a backwards calculation model (described in Bjornsson et al. 2019), shown in Fig. 21.

Figure 13: Haddock in 5a. Weight at age observed in the spring survey and from the commercial catches. The black line denotes the mean value of the survey index and the coloured bars indicate deviations from the mean. The colours denote the year class. Note different y-axis.

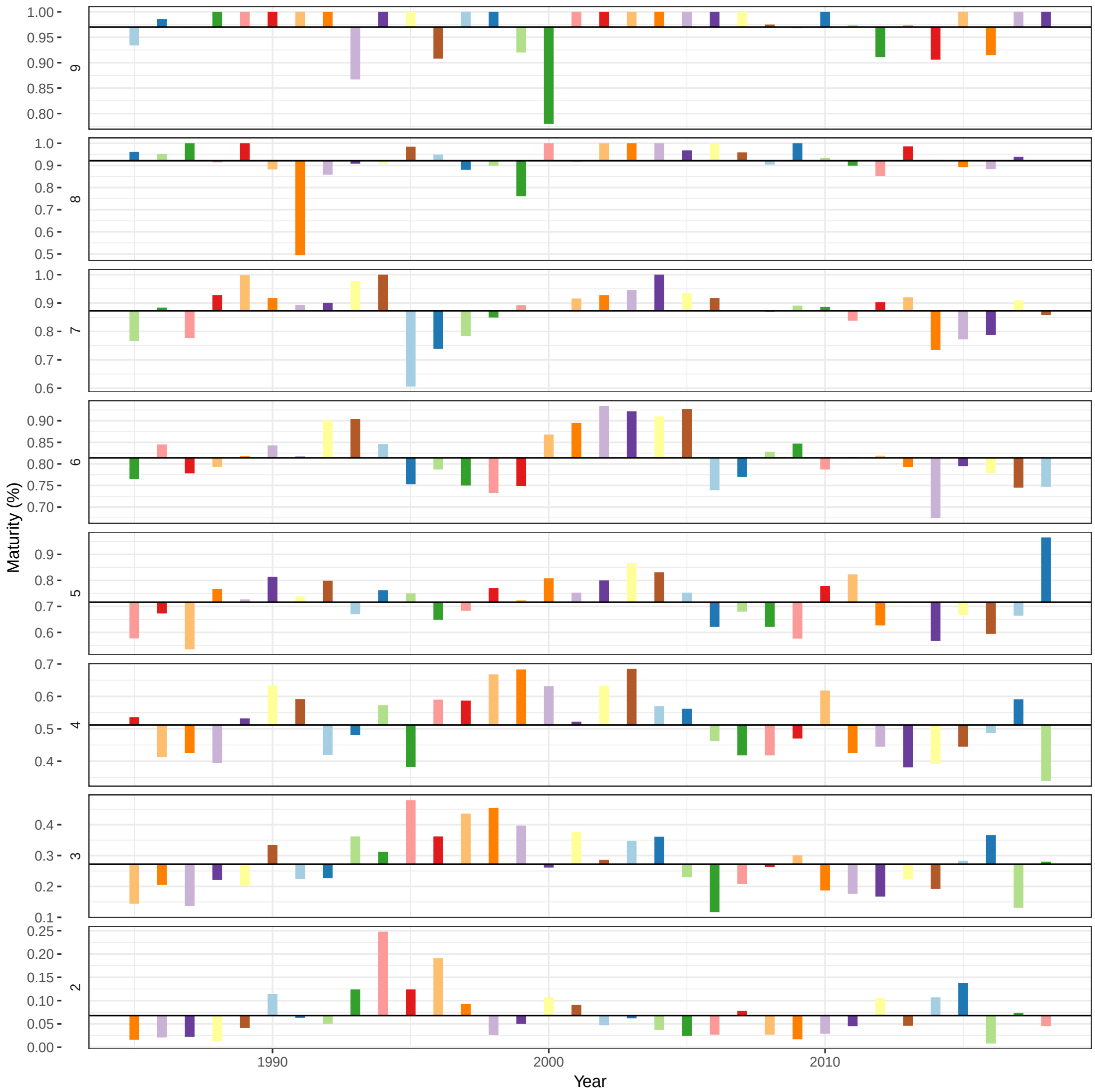

Figure 14: Haddock in 5a. Bar–plot of the maturity at age observed in the spring survey. Colour represent the different year classes.

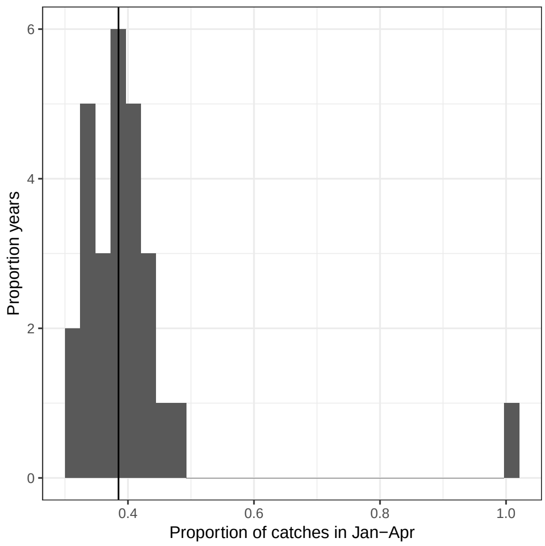

Figure 15: Haddock in 5a. Proportions of catches in the period between January and April.

The ratio of fishing and natural mortality before spawning was set at 0.4 and 0.3 respectively as haddock is known to spawn in the period between April till the end of May. The proportion caught in the period between January and April is shown in Fig. 15, with an estimate around 0.38.

1.6.4.2 Input data The assessment relies on four sources of data, that are described above. These are the two surveys, commercial samples and landings. The commercial data is used to compile catch at age data that enter the likelihood along with the survey at age from both surveys. Stock weights and catch weights at age are derived from the spring survey and catches respectively. The maturity data is similarly collected in the spring survey. Prior to 1985, when the spring survey started, stock weights and maturity at age were assumed constant at the 1985 values. The input data is shown in tables 6 to 11.

1.6.4.3 Baseline run The results of the assessment indicate that the stock decreased from 2008–2011 when large year classes disappeared from the stock and were replaced by smaller year classes (Fig. 16). Since 2011 the rate of reduction has slowed down as fishing mortality has been low. The spawning stock has, however, decreased more than the reference biomass as the proportion mature by age/size has been decreasing. Fishing mortality is now estimated to be low and is in line with the overall goal of the currently implemented HCR. The baseline assessment does indicate that a bottom has been reached and the stock size will increase in the coming years. The main features of the baseline assessment are the same as in the assessments used between 2011 to 2018. The current assessment indicates a marginally larger stock than the assessment presented at NWWG 2018 (Fig. 25) and the analytical retrospective (Fig. 23) indicates a slight updwards revision in the most recent years. The assessment can however be considered fairly stable and the estimated 5 year Mohns's ρ are within acceptable range or -0.092 for estimated recruitment, 0.07 for SSB and -0.065 for harvest rate.

The fit to data is illustrated in Fig. 17 where no concerning residual patterns. When looking at the combined fit (Fig. 18) the figure shows the observed vs. predicted biomass from the surveys and it indicates that historically the autumn survey biomass

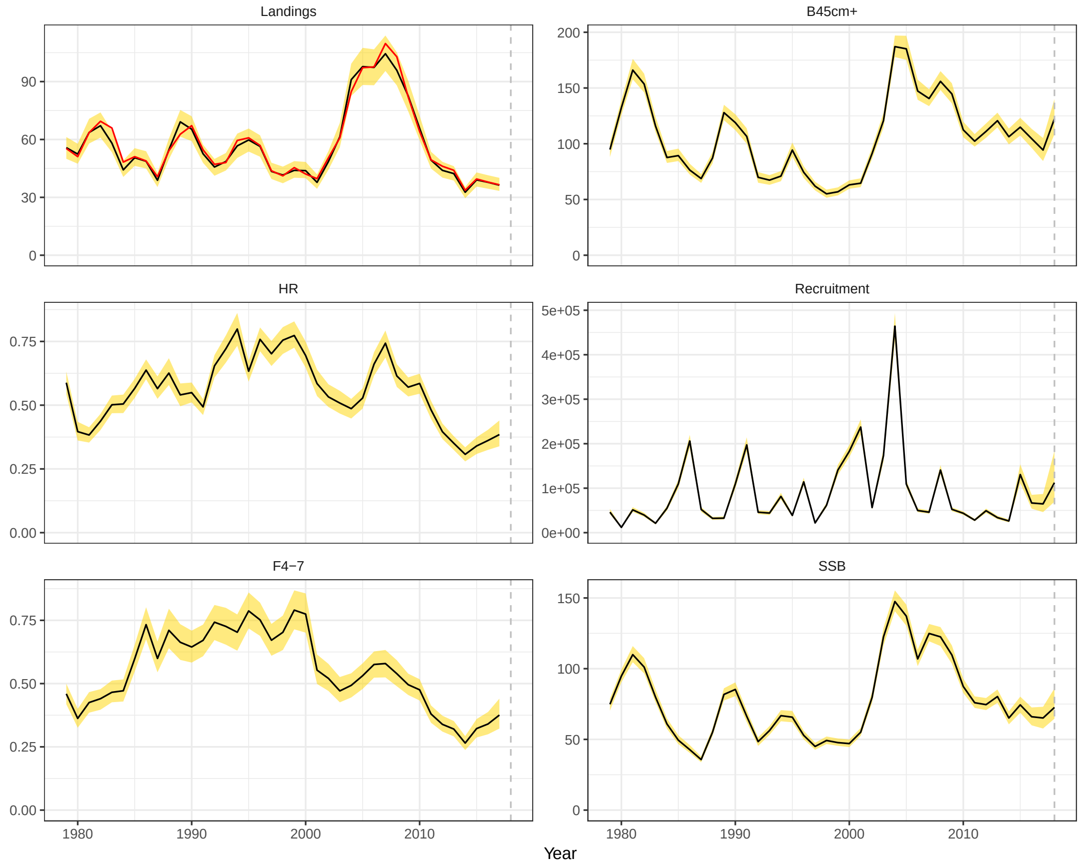

Figure 16: Haddock in 5a. Estimates of biomass, both spawning stock biomass and reference biomass (B_{45cm+}), harvest rate, fishing mortality (weighted average of ages 4 to 7), recruitment and landings from the baseline model. Black line represents the point estimates and golden ribbon the 90% confidence intervals.

has been closer to the prediction than corresponding values from the March survey, where the contrast in observed biomass is more than predicted from the assessment. The model accounts for this by estimating a stronger residual correlation for the spring survey (0.527) compared with the autumn survey (0.193). When contrasting the biomass levels before and after the mid 2000's peak the autumn survey suggests that the biomass level after the peak biomass is higher while the spring survey is at similar levels. Thus the model appears to fall in a region between the two surveys.

Fig. 21 shows the estimated catchability and CV as a function of age for the surveys. The estimated CV is generally lower for ages 2–6, whereas the CV increases faster by age for the autumn survey compared with the spring survey. Residuals from the assessment model are positive for the most recent October survey, but close to zero for the most recent March survey. The March surveys 2011-2015 are, on the other hand, below predictions. A similar appears in the fishery during 2012-2013 (Fig. 12), so there are indication that the stock might have been underestimated or availability of haddock was unusually high in that period.

Assessment in recent years has shown some difference between model runs where either of the two different tuning series, i.e. March and the October surveys, are omitted from the estimation. As shown in Fig. 25 the differences are mainly in last few years before the assessment, and mostly contained within the estimated ranges of uncertainty.

Parameter densities from the MCMC simulations are shown in Fig. 19 and the

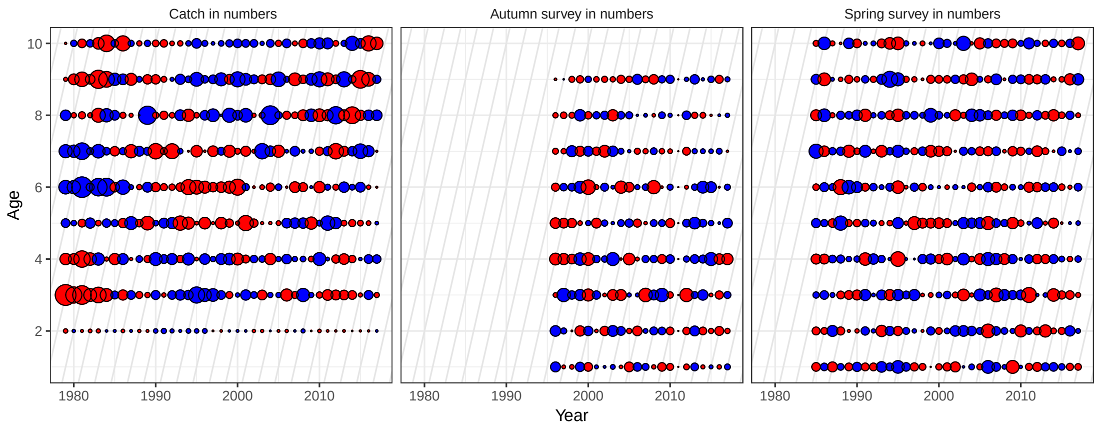

Figure 17: Haddock in 5a. Model residuals from the baseline run. Red circles indicates where the model estimates are higher than the observed while blue indicates models estimates lower than observed.

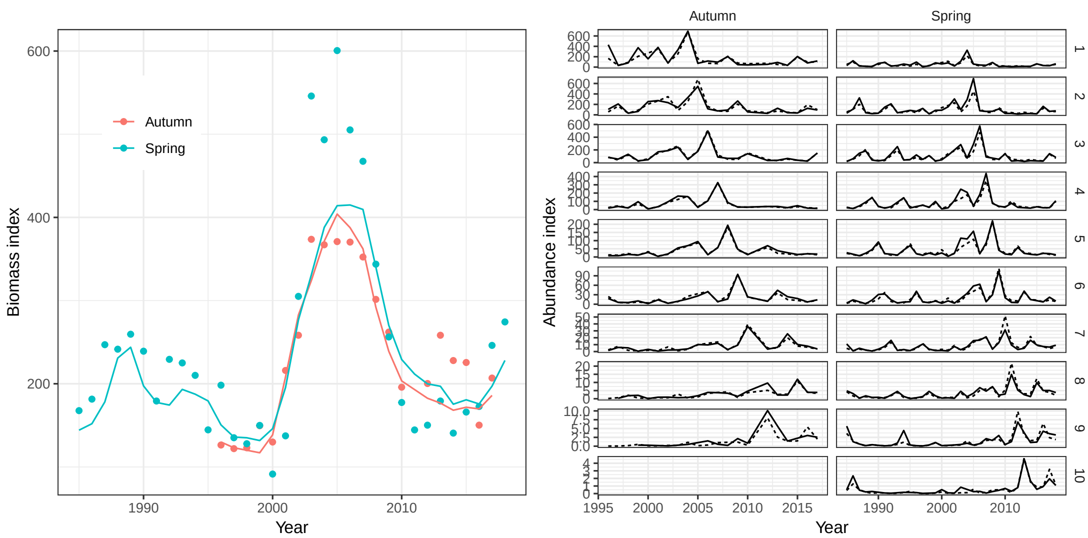

Figure 18: Haddock in division 5.a. Aggregated model fit to the total biomass indices (left) and fit to individual ages (right).

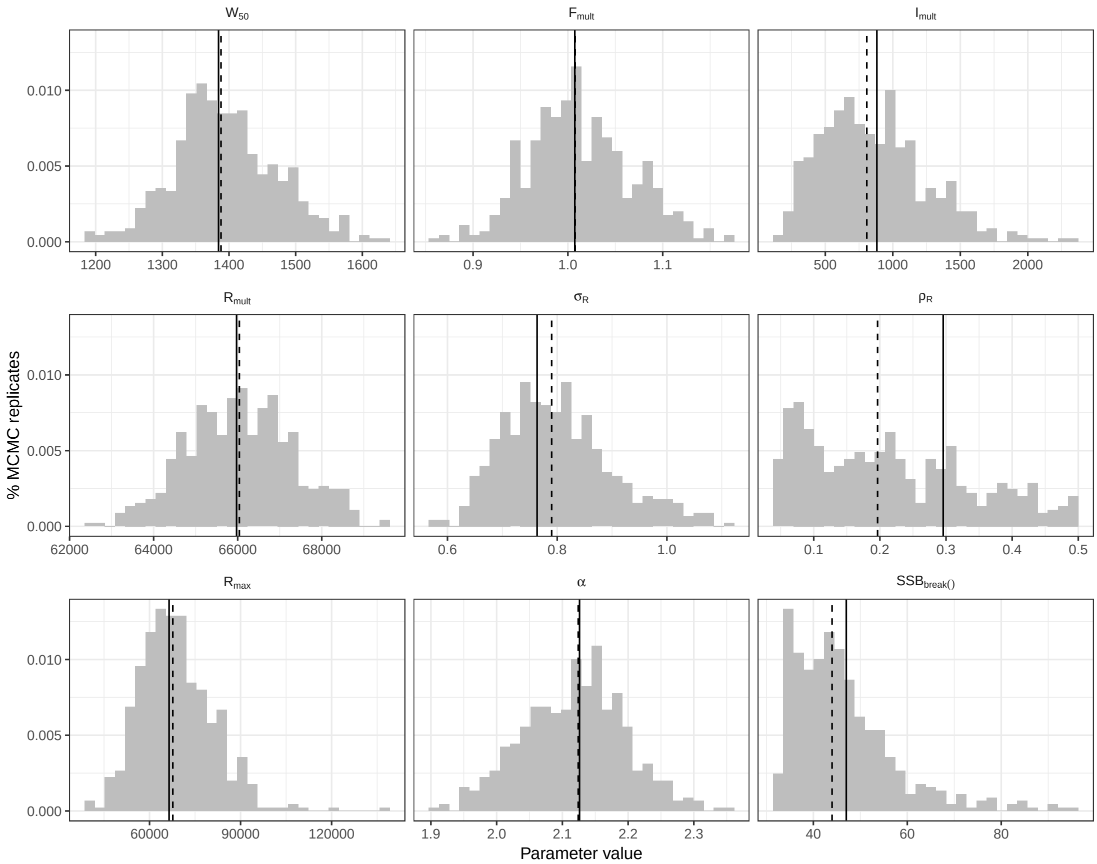

Figure 19: Haddock in 5a. Parameter MCMC density plots from the baseline run. Black vertical line indicates the point estimate while dashed vertical line the simulated median.

point estimates did not deviate substantially from the simulated median. Correlations between model parameters are illustrated in Fig. 20. The strongest correlations appear to be either related to estimates of fleet selection or the estimates of the spawning stock recruitment parameters. The remaining parameters have show fairly low correlation to all other parameters.

The estimated selection curve and stock recruitment relationship are illustared in Fig. 21, along with estimated survey CV and catchability. The selection is fairly well defined in the lower weights but uncertainty increases with size. There are few indications from the stock recruitment relationship that the spawning stock has been reduced to a level where impaired recruitment can be expected. The estimated density of the breakpoint in a hockestick recruitment function therefore appears to peak close to the lowest observed biomass. Fig. 22 shows the selection by age from the baseline assessment and the previous assessment. As expected the estimates of selection in the baseline model appear to be more stable when compared to the previous assessment (Adapt – type) as the previous assessment estimated fishing mortality at age freely. The selection in the baseline model appears to show periods of lower and higher selection at age, which corresponds to changes in stock weights. Similar periods are harder to distinguish in the previous assessment due to higher noise.

Fig. 24 shows the estimated values of σ_{mult}, the multiplication factor applied to the residual survey and catch variances ($\sigma_{pattern}$) shown in Fig. 21, estimated in the analytical assessment. The values of σ_{mult} for the catch appears be fairly stable in the

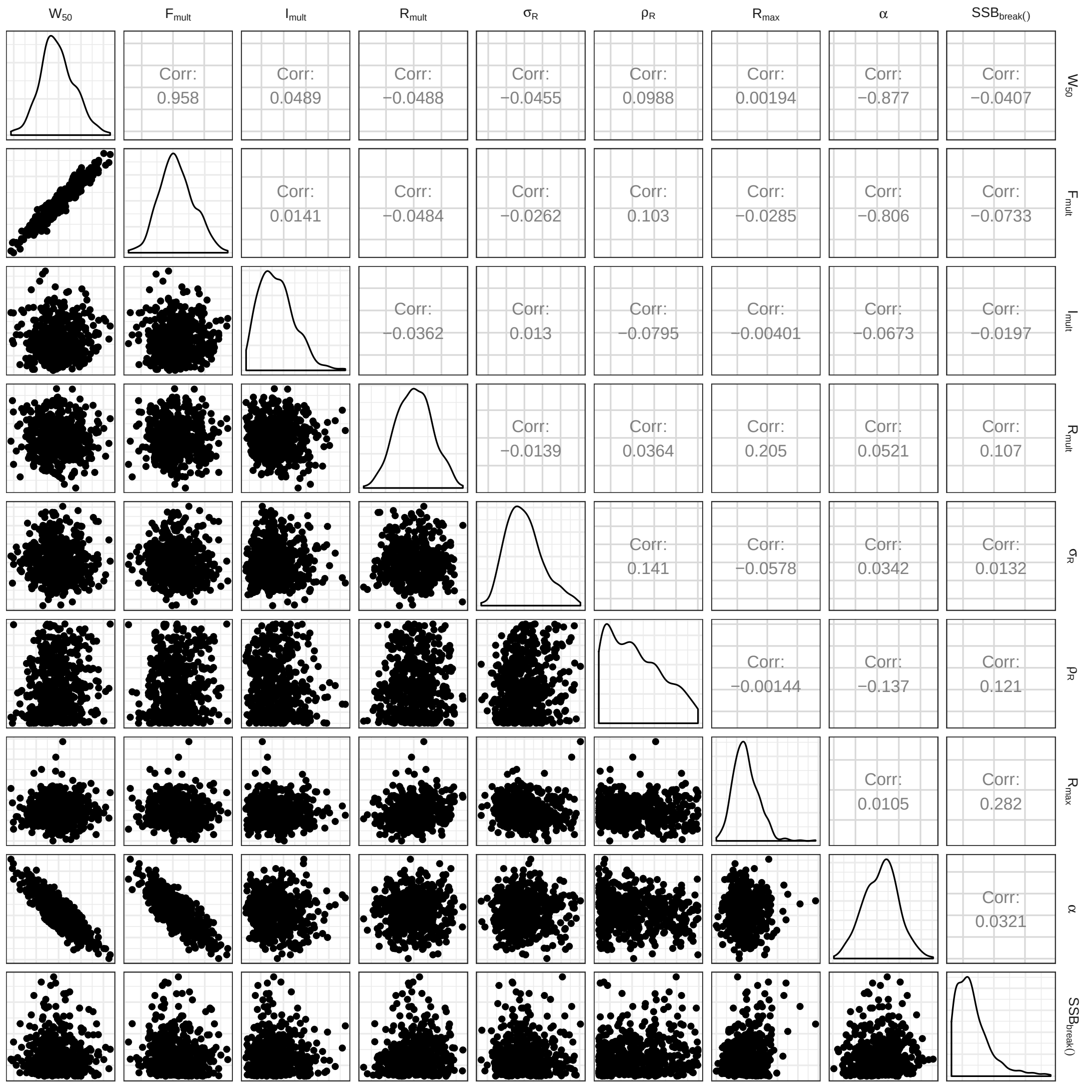

Figure 20: Haddock in 5a. Pairs-plot of all parameters except those related to the number of recruits and initial number at age

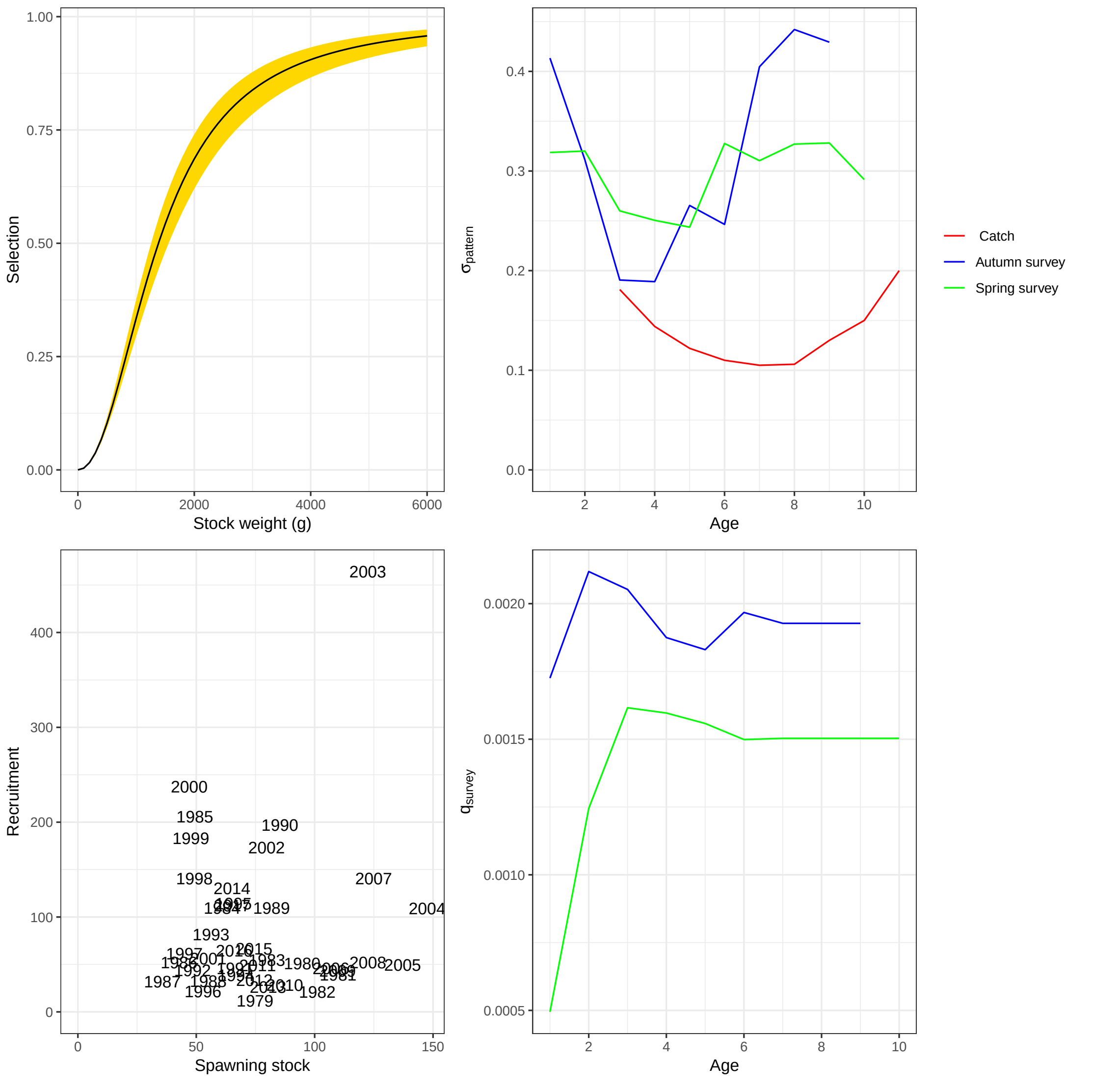

Figure 21: Haddock in 5a. Estimated selection (top left), spawning stock recruitment relationship (bottom left), estimated survey CV (top right) and survey catchability (bottom right).

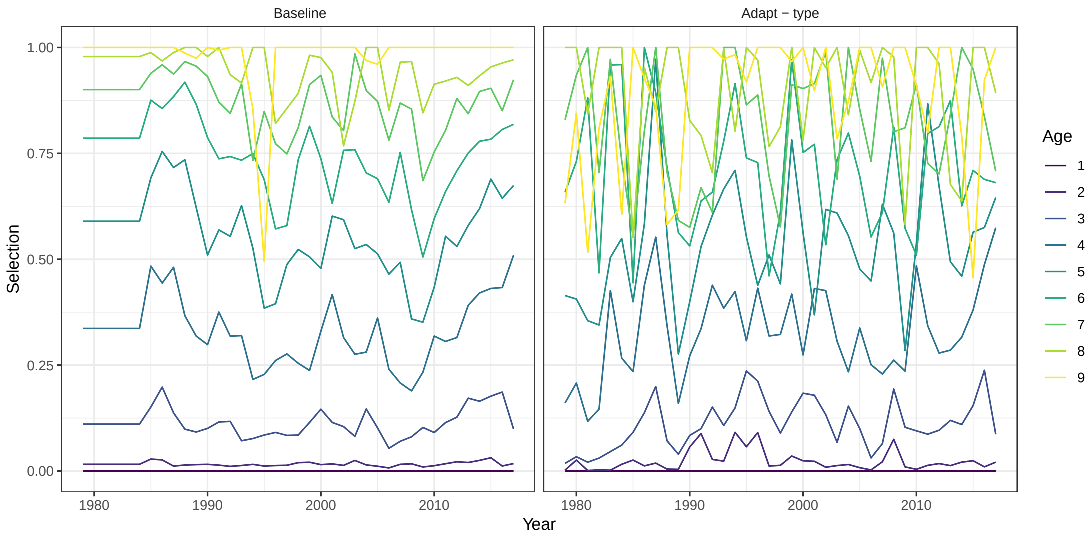

Figure 22: Haddock in 5.a. Estimated selection pattern at age by year and model approach.

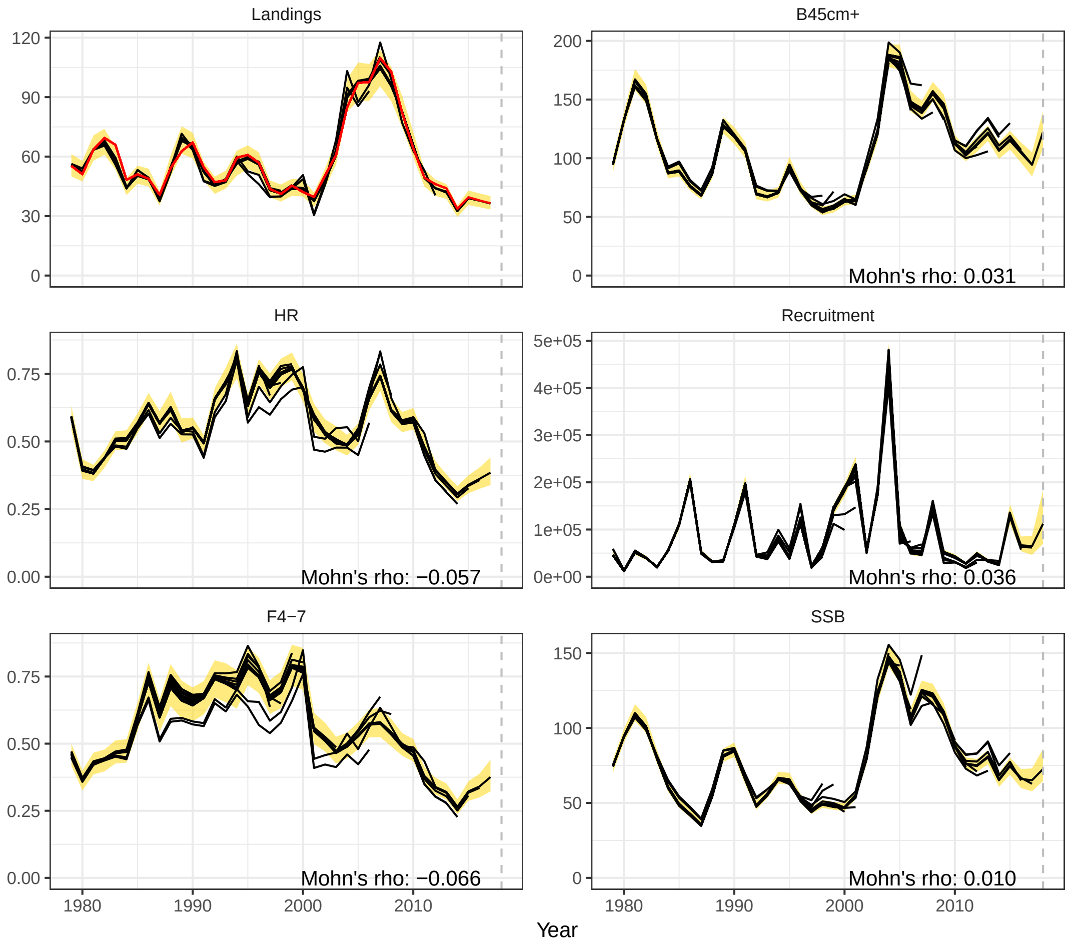

Figure 23: Haddock in 5a. Ten year analytical retrospective analysis of the baseline assessment. The shaded regions represent the 5th and 95th percentiles. A five year Mohns ρ shown on the figure.

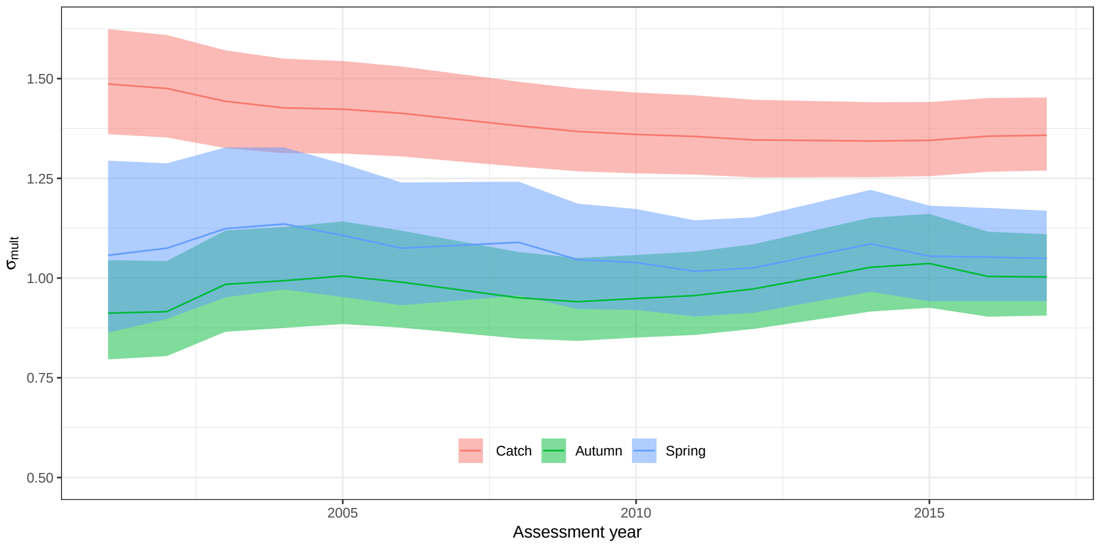

Figure 24: Haddock in 5a. Estimated multiplier (σ_{mult}) to the variance at age for both surveys and catch data by assessment year.

last 10 years, while σ_{mult} for the spring survey varies more and for the autumn survey it increases, indicating a lower weight to the autumn survey in recent years.

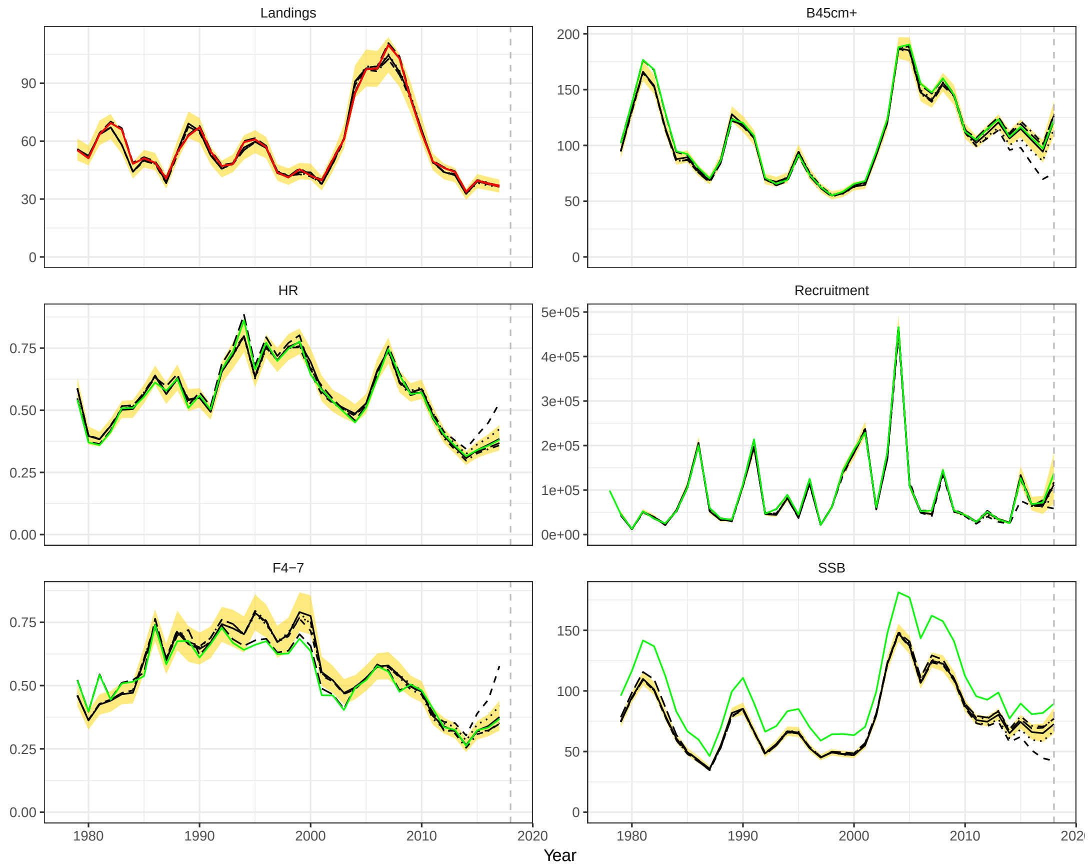

Figure 25: Haddock in 5a. Comparison of model variants (explained in the text). Green dashed line represents the current assessment method. Yellow shaded region denotes the 5th and 95th percentiles from baseline model.

1.7 Appropriate reference points (MSY)

According ICES technical guidelines, two types of reference points are referred to when giving advice for category 1 stocks:
precautionary approach (PA) reference points and maximum sustainable yield (MSY) reference points. The PA reference points are used when assessing the state of stocks and their exploitation rate relative to the precautionary approach objectives. The MSY reference points are used in the advice rule applied by ICES to give advice consistent with the objective of achieving MSY.

Generally ICES derives these reference points based on fishing mortality, but for some stocks the reference points are determined in terms of harvest rate, i.e. the amount of catches relative to a reference biomass (s.a. spawning stock biomass, or biomass of fish larger than a minimum size or older than a minimum age). For haddock in 5.a the currently implemented management plan is determined in terms of the harvest rate of the total biomass above 45 cm in the advisory year.

The following sections describe the derivation of the management reference points both in terms of harvest rate (HR) and fishing mortality (F). It further describes the model for stock–recruitment, weight and maturity at age, and assessment error which in combination with the MCMC results is used to project the stock stochastically in order to derive the PA and MSY reference points.

1.7.0.1 Management procedure in forward projections Observation error is addressed by the MCMC simulation approach employed in here. Current knowledge of the haddock in 5.a, discussed above, suggests that it should be assessed as a single stock unit. Analytical and historical retrospective analysis (Fig. 27) indicates a degree of autocorrelation in observation error. While this is a concern, the current assessment model is more stable than historical assessments. It is worthwhile noting that changes have been made to the assessment method over the year, both in terms of assessment method and tuning series. In the projections described below the effect of assessment model is modelled as autocorrelated log-normal variable with the mean as the true state of the stock. The values for the CV and correlation in the assessment error are 0.2 and 0.66. These values are based on the estimates derived from the historical retro listed in 2. When deriving the assessment error CV based on the assessment and analytical retrospective, the CV is estimated at around 0.07. The differences between the two estimates are considered here to be related to changes in the assessment methods applied to haddock in 5a since 2001, and therefore the assessment error CV would be more approriately estimated from the historical retrospective.

Illegal landings and discards by Icelandic fishing vessels are considered to be negligible (as noted above) and the foreign vessel catches in area 5a are a part of the management plan. Species transformation in the Icelandic quota system are the main source for deviations from the TAC, illustrated in Fig. 26. To account for the effects of the species transformation an additional log–normal error is added on top of the assessment error when determing next year catch. The CV and correlation, listed in table 2, were estimated based on the timeseries of TAC deviations for haddock. In the simulation it is assumed that the assessment error and species transformation are uncorrelated. While this may be conservative assumption, it is (as illustrated in Fig. 28) most likely incorrect as species transformations appears more likely when stock is underestimated.

The largest source of error outstanding is the extent of process error, in particular variation in the stock recruitment relationship, growth and maturity, and assessment

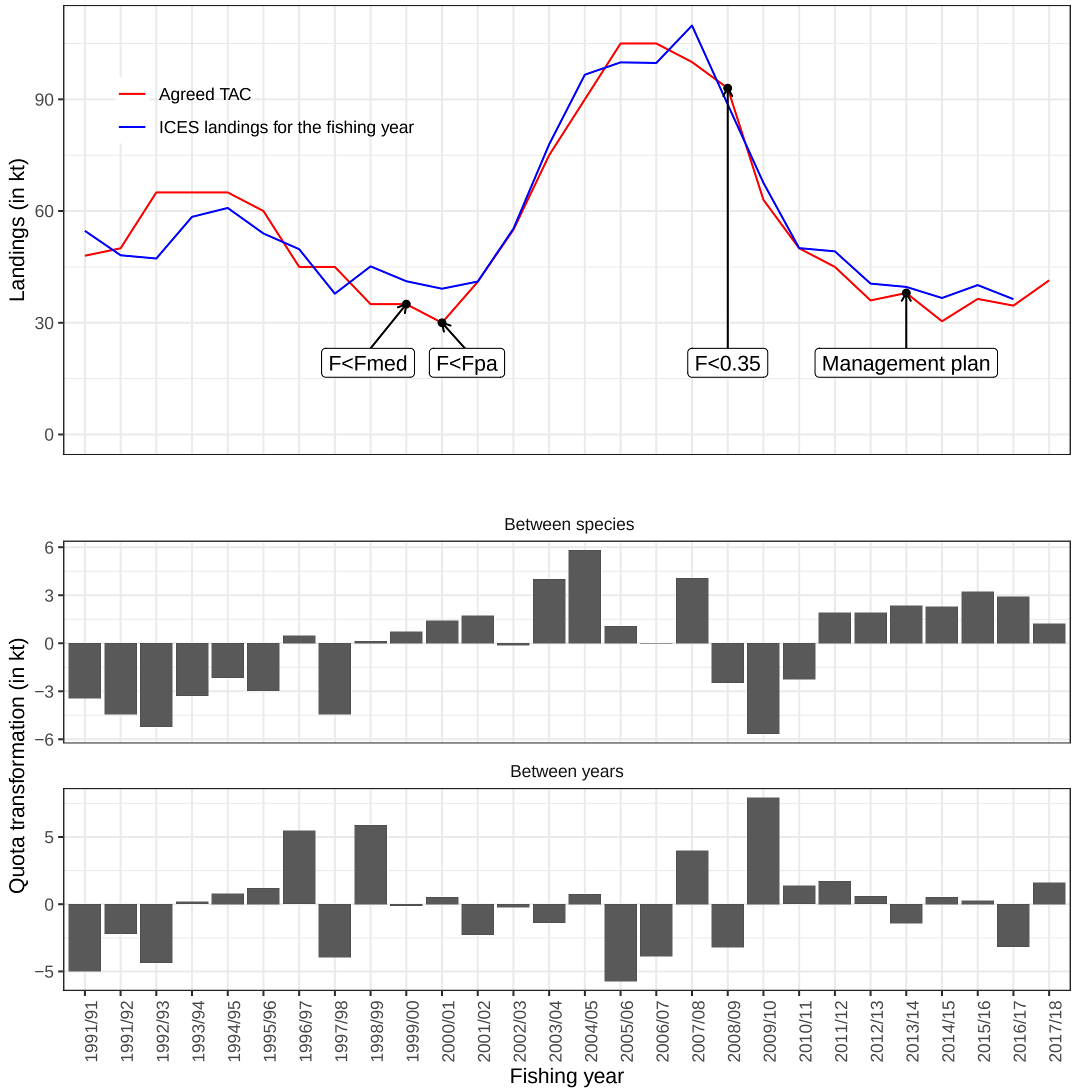

Figure 26: Haddock in 5a. Comparison of the realised catches and the set TAC for the fishing (top) and the effective species transformation per fishing year.

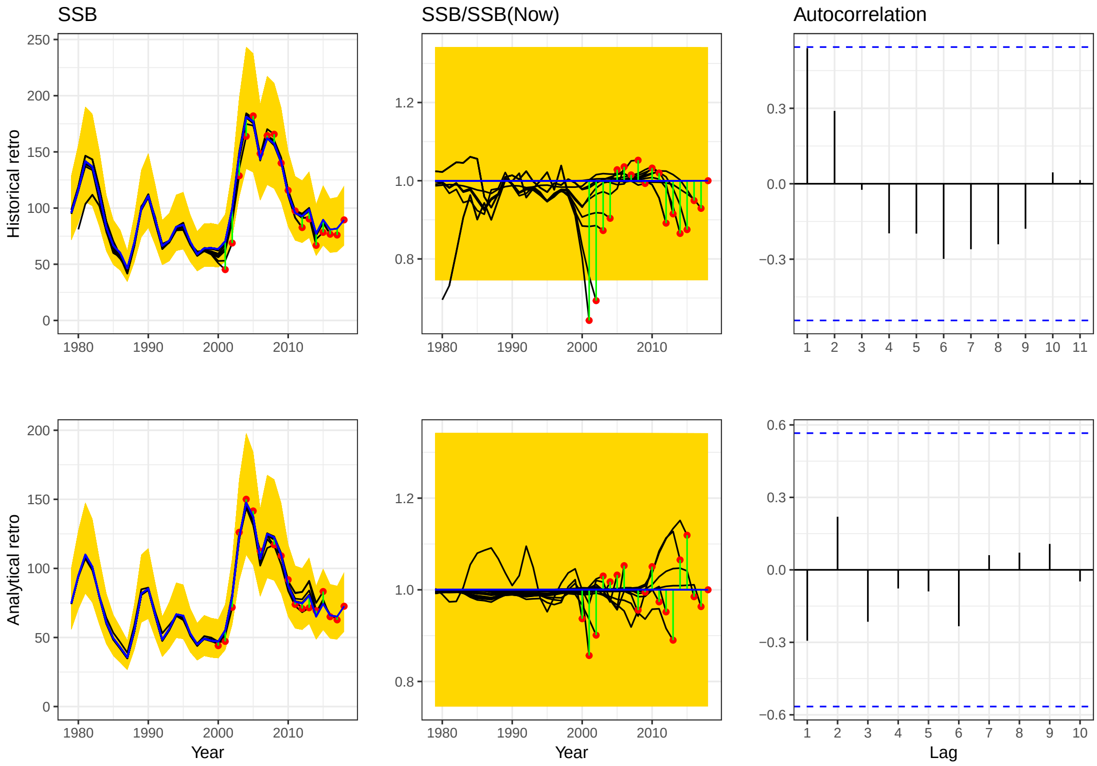

Figure 27: Haddock in 5.a. Contemporary assessment of SSB compared with the most recent assessment (blue). The shaded region indicates the assessment CV in the assessment year.

error, which are discussed in the following sections. The descision rule evaluated here is of the form:

$$\mathrm{TAC}_{y/y+1} = \begin{cases} 0.4 \times B_{45cm^+,y+1} & \text{if } SSB_{y+1} > B_{trigger} \\ 0.4 \times \left(\frac{SSB_{y+1}}{B_{trigger}}\right) \times B_{45cm^+,y+1} & \text{if } SSB_{y+1} < B_{trigger} \end{cases} \quad (2)$$

where $B_{trigger} = B_{pa}$. That is, for the fishing year $y/y+1$, the TAC is set as a predetermined harvest rate (HR) target times the reference biomass $(\hat{B}_{y+1,45cm^+})$ in the advisory year $(y+1)$ taking into account assessment and implementation error.

1.7.0.2 Setting B_{lim} and B_{pa} B_{lim} was considered from examination of the SSB–Recruitment (at age 1) scatterplot based on the estimates from the stock assessment, as illustrated in fig. 21. The figure shows no clear SSB – Recruitment relationship and no evidence of impaired recruitment. In this situation, according to the ICES technical guidelines, B_{lim} can not be estimated from these data and that the lowest observed SSB during that period (i.e. B_{loss} = SSB(1987) = 35.5 kt), which is the lowest observed biomass from the baseline model, is an appropriate value at which to set B_{lim}. In line with ICES technical guidelines B_{pa} is then calculated based on multiplying B_{lim} with the standard factor, $e^{\sigma*1.645}$ where σ is the CV in the assessment year of SSB or 0.07, used for calculating B_{pa} from B_{lim}. However, as noted above, this is not considered to reflective of the true assessment error and thus the CV used here to determine B_{pa} is 0.2, which is the default ICES value for assessment error. Therefore B_{pa} should be set at $B_{lim}e^{1.645*0.2} = 35.5kt \times 1.4 = 49.4kt$.

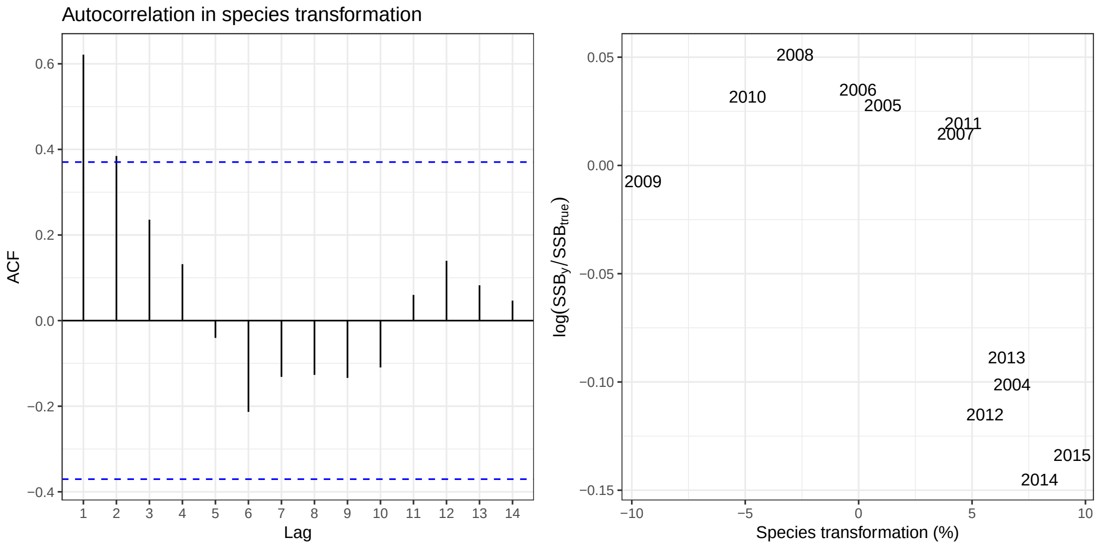

Figure 28: Haddock in 5a. Characteristics of the species transformation. The left panel show the estimated autocorrelation in percentage species transformations into haddock, while the right panel shows the assessment deviations as function of species transformations into haddock.

1.7.0.3 Stock recruitment relationship A variety of approaches are common when estimating a stock–recruitment relationship. In the absense of a stock-recruitment signal from the available historical data (Fig. 21), the ICES guidelines suggest that the "hockey-stick" recruitment function is used, i.e.

$$R_y = \bar{R}_y \min(1, S_y/B_{break}) \tag{3}$$

where R_y is annual recruitment, S_y the spawning stock biomass, B_{break} the break point in hockey stick function and $\bar{R}_y$ is the recruitment when not impaired due to low levels of SSB. Here $\bar{R}_y$ is considered to be drawn from an auto–correlated log–normal distribution with a mean, CV and ρ as illustrated in Fig. 19. This is done to account for possible auto-correlation in the recruitment time–series. Note that by adding auto–correlation to the projections it will increase the estimates of risk related to periods of poor recruitment.

1.7.0.4 Stock– and catchweights Prediction of weight at age in the stock and catch and the maturity at age follow the same procedure as in the last benchmark. In the projections, growth of a year class in weights is modelled, following the methodology used in Bjornsson (2013), as a linear function of last year's weight:

$$\log\left\{\frac{\mathrm{sW}_{a+1,y+1}}{\mathrm{sW}_{a,y}}\right\} = \alpha + \beta \mathrm{sW}_{a,y} + \delta_y + \xi_{a,y} \tag{4}$$

where sW represents the stock weight a age a at year y, δ_y is the year effect and $\xi_{a,y}$ is a 1^{st} order AR(1) process with variance σ^2_{sW} and correlation coefficient ρ_{sW}. Fig. 30 illustrates the fit to data. In the projections the annual effect will need to be projected. In order to do so δ_y was regressed as a function of total stock biomass (B_y):

$$\delta_y = \alpha_\delta + \beta_\delta B_y + \xi_{\delta,y} \tag{5}$$

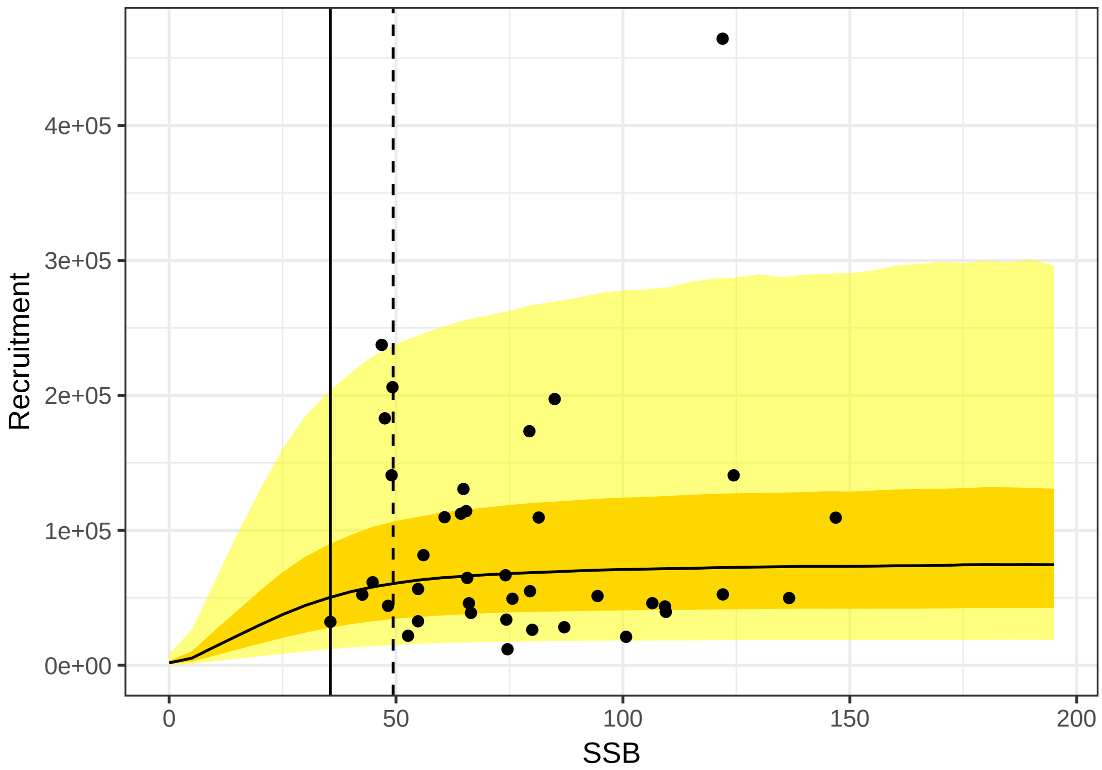

Figure 29: Haddock in 5a. Projections of recruitment as a function of spawning stock biomass in the projections. Black points are the estimated recruitment.

In the simulations δ_y is capped at 0.9, which close to the highest observed values (see Fig. 31), meaning that the extent of the density denpendence in the low abundance cases cannot exceed historical values. The starting value for the stock weights were determined by regressing the sW at age 2 with the abundance of age 2 and 3:

$$\mathrm{sW}_{2,y} = \alpha_I + \beta_I(N_{2,y} + N_{3,y})e^{\xi_I} \tag{6}$$

Removals from the stocks are determined based on the catch weights. The catch weights were simulated from stock weights as simple log-linear model:

$$\log(\mathrm{cW}_{a,y}) = \alpha_c + \beta_c \log(\mathrm{sW}) + \xi_c \tag{7}$$

where the parameters α_c and β_c were estimated with linear regression.

In the simulations the ξ's were simulated as a 1^{st} order AR process between years with a $\sigma = 0.3$ and $\rho = 0.3$.

1.7.0.5 Weight at age in shortterm projections The weights used in the short-term projections to calculate the SSB_{y+1} and $B_{45cm^+,y+1}$ are based on eq. 4 and subsequent equations without noise. The annual growth factor δ_y in the projections is set as the average of the (simulated) estimate of the growth factor for the last three years.

1.7.0.6 Maturity Maturity in the projections is a simple function of the stock weights:

$$m_{a,y} = \frac{1}{1 + e^{\alpha_m + \beta_m \log(sW_{a,y})}} \tag{8}$$

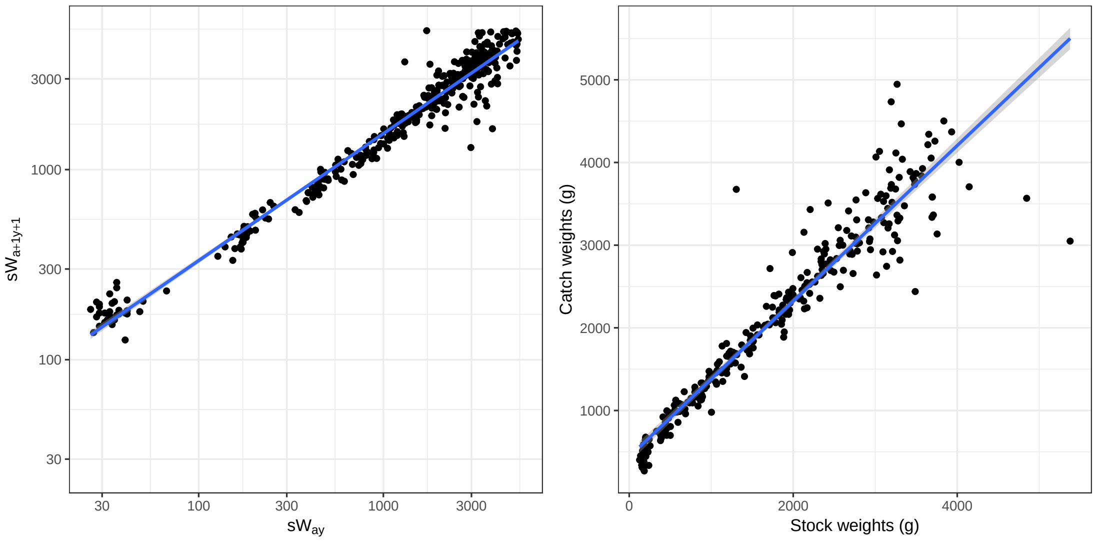

Figure 30: Haddock in 5a. Left panel shows the stock weights at age as a function of last years stock weigths in the same year class. Right panel shows the catch weigths as a function of stock weights

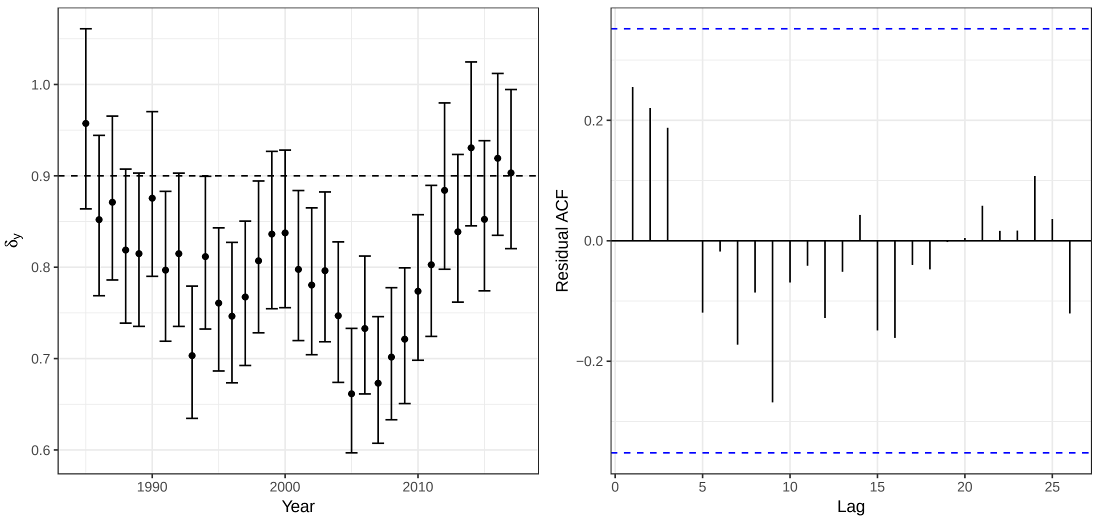

Figure 31: Haddock in 5a. Left panel shows the estimated value from model described in eq. 4 of the annual effect on growth in weight as a function of year. Right panel shows the estimated autocorrelation in the model residual

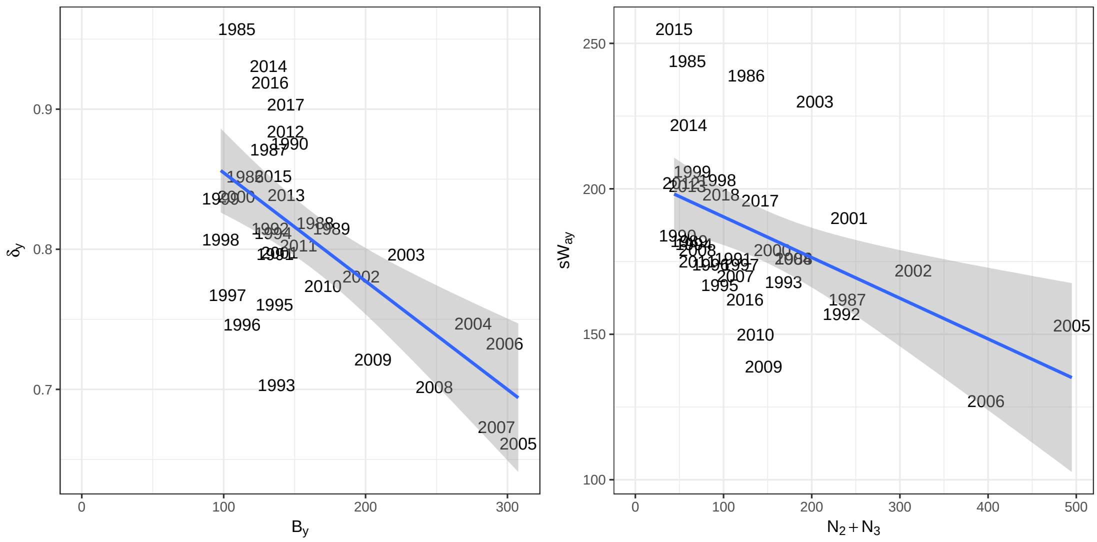

Figure 32: Haddock in 5a. Left panel shows annual effect on growth in weight as function of biomass. Right panel shows the weight at age 2 as function of the abundance of age 2 and 3.

Table 1: Haddock in 5a. Values of parameters used in the HCR simulations. See text for further details

Parameter	estimate	Model
α	3.093	Stock weights
β	-0.359	Stock weights
α_c	2.328	Catch weights
β_c	0.717	Catch weights
α_δ	0.932	Delta model
β_δ	-0.001	Delta model
α_I	204.354	Age 2 model
β_I	-0.140	Age 2 model
α_m	-18.943	Maturity
β_m	2.720	Maturity

where the maturity is estimated based on the relationship between maturity and stock weights illustrated in Fig. 33. No uncertainty is added to the maturity at weight relationship. Note that the timing of the recruitment in the model occurs at the beginning of the year, and thus no partial mortality is applied to the size of the spawning stock. In-line with ICES guidelines the maturity in the projections is based on the observation since 2013. Distribution of stock weights and maturities in the projections is shown in Fig. 34. The reason for the reduction in proportion mature by weight appears to be linked with geograpical differences, that is haddock north of Iceland is less likely to be mature than similar sized fish in the North (see Fig. 35). As noted above there has been a northward shift distribution of Haddock and thus a greater proportion is immmature.

1.7.0.7 Setting HR$_{lim}$ and HR$_{pa}$ According to the ICES guidelines, the precautionary reference points are set by simulating the stock using the stock-recruitment, growth and maturity relationship described above, based on a wide range of harvest rates, (see eq. 2), ranging from 0 to 1 and setting HR$_{lim}$ as the HR that, in equilibrium, gives a 50% probability of SSB > B_{lim} without assessment error. From this F_{lim} is set

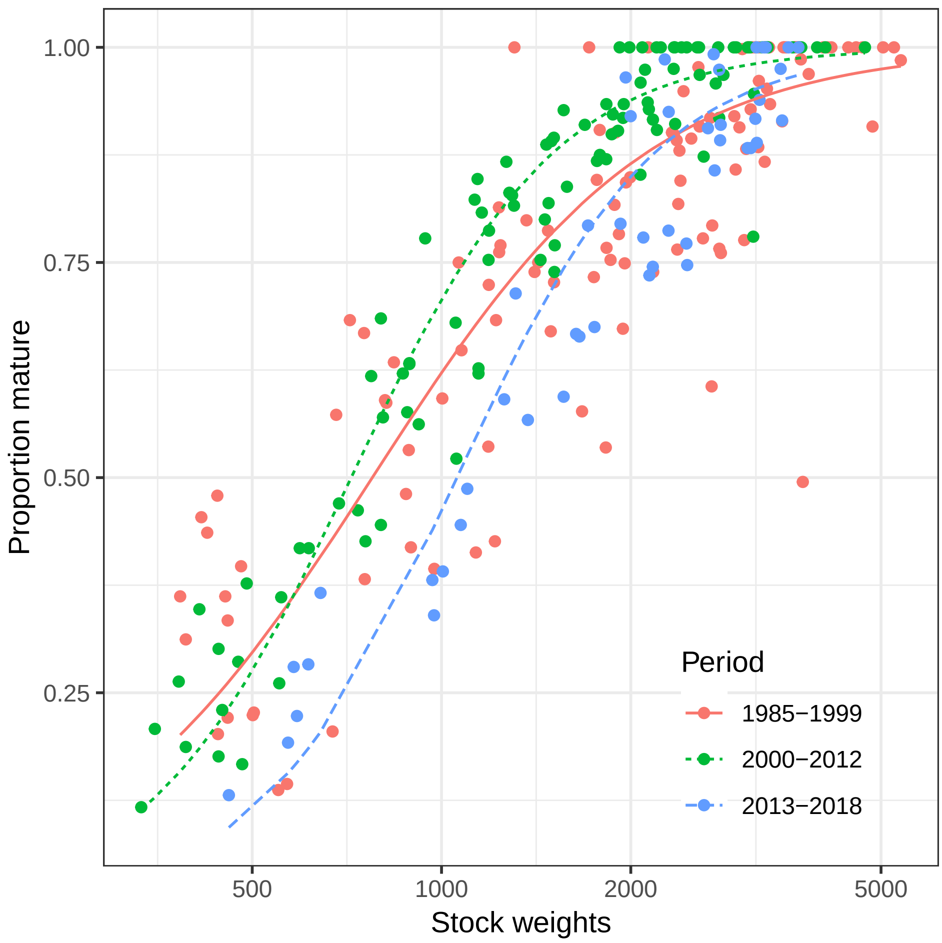

Figure 33: Haddock in 5a. Proportion mature as a function of weight, lines show the estimated maturity by period.

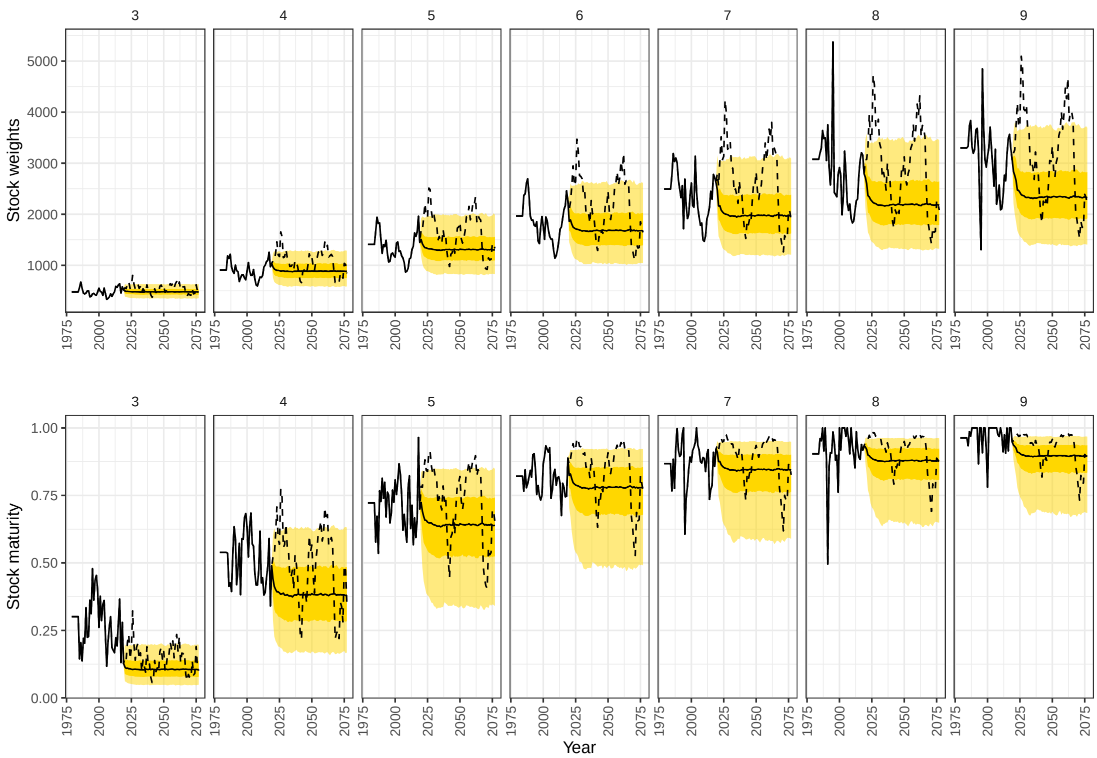

Figure 34: Haddock in 5a. Comparison of simulated and realised stock weights (above) and proportion mature (below) in the MSE. Shaded regions show the 5th and 95th quantiles, black solid line the median and dashed line one realisation from the simulation.

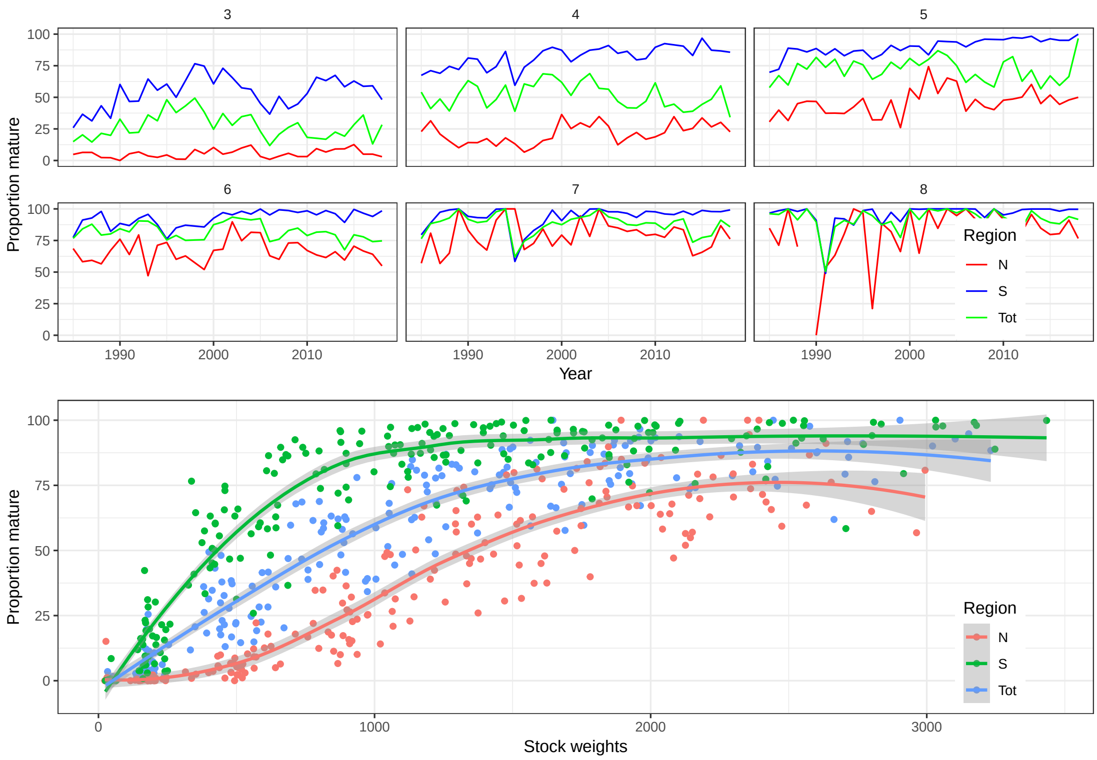

Figure 35: Haddock in 5a. Geographical differences in proportion mature by year and age (top), and stock weights (below).

Table 2: Haddock in 5a. Overview of the error parameters used in the MSE projections.

Source	Bias	CV	Auto correlation
Analytical retro	-0.011	0.076	0.0013262
Historical retro	-0.090	0.147	0.6683858
Species transformation	0.002	0.061	0.6113989
B45cm+		0.076	
F4-7		0.092	
SSB		0.087	

as the equilibrium fishing mortality when HR_{lim} is applied. HR_{pa} is then set as the harvest rate that would lead to the equilibrium fishing mortality of F_{pa}. F_{pa} is defined as the $F_{lim}/e^{1.645\sigma}$ where σ is the CV of the estimated fishing mortality in the assessment year.

For each MCMC replicate the stock status was projected forward 60 years as simulations. The spawning stock biomass was calculated based on model output after 2060. This is done to ensure that the stock had reached an equilibrium under the new fishing mortality regime.

The results from the long–term simulations are shown in the top panels of fig. 37; the value of HR, HR_{lim}, resulting in 50% long–term probability of SSB $> B_{lim}$ was estimated at 0.63 (an equivalent F of 0.71). As the CV assumed to be 0.2 (default ICES value), F_{pa} is estimated as $0.71/1.4 = 0.5$. The equivalent harvest rate is then $\text{HR}_{pa} = 0.5$.

1.7.0.8 MSY reference points As an additional simulation experiment where, in addition to recruitment and growth variations, assessment error was added. The harvest rate that would lead to the maximum sustainable yield, HR_{msy}, was then estimated. Annual total landings c_y were calculated after 2060. Average annual landings and 90% quantiles were used to determine the yield by HR. Fig. 38 shows the evolution of catches, SSB and fishing mortality for select values of HR. The equilibrium yield curve is shown in fig. 37, where the maximum average yield, under the recruitment assumptions, is 51.0 thousand tons with a 95% interval of for the yield 19.3 and 102.0 thousand tons. Table 5 shows the equilibrium results by harvest rate for select statistics.

In line with ICES technical guidelines, the MSY $B_{trigger}$ is set as B_{pa} as $B_{HRMSY} < B_{pa}$. Maximum yield is estimated to be obtained at 0.45, however HR_{p5}, i.e. the maximum HR that has less than 5% chance of going below B_{lim} when the advice rule is applied, is 0.35, thus limiting the estimate of HR_{msy} to a maximum of 0.35. Therefore the expected median yield is reduced to 50 thousand tons (23.5–91.3) The evolution of the spawning stock biomass is shown in figure 38 and quilibrium spawning stock biomass is shown in figure 37. The spawning stock biomass obtained at $\text{HR}_{msy} = 0.35$ is estimated at 85.2 thousand tons with an upper quantile of 168.0 thousand tons and lower quantile of 36.5 thousand tons.

1.8 Evaluation of the proposed management plan

In the autumn of 2018 the government of Iceland requested the re–evaluation of the management plan for haddock in 5a.

The request is based on the work of an ad-hoc group of managers, stakeholders, and scientists from the Marine and Freshwater Research Institute (MFRI), initiated

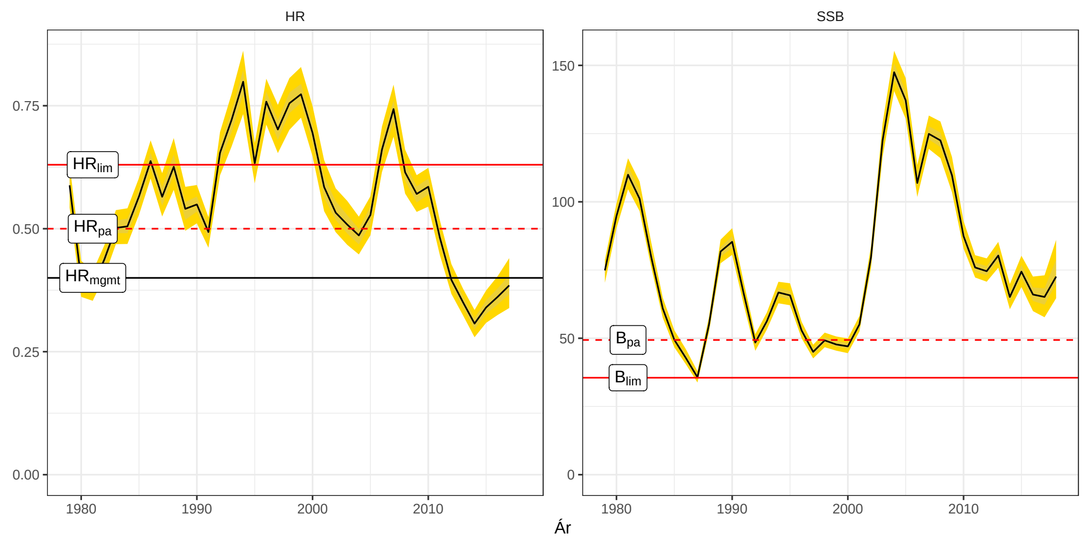

Figure 36: Haddock in 5.a. Harvest rate and SSB illustrated with precautionary reference points.

by the Icelandic Ministry of Industries and Innovation in the summer of 2018. The objective of the group was to investigate harvest control rules for haddock that would be in conformity with the precautionary approach and ICES MSY framework, and to maintain a long-term high sustainable yield.

The proposed HCR is based on a harvest rate approach using a reference biomass for haddock at 45 cm and above ($B_{45cm^+,y+1}$). This rule was evaluated previously in 2013 (see Bjornsson 2013). The results of simulations of the proposed HCR in terms of key population metrics (recruitment, yield, harvest rate, spawning biomass and $B_{45cm^+,y}$) are given in Fig. 39. The future dynamics are expected to be similar to those observed historically.

With an HR = 0.4, annual probabilities of SSB $< B_{lim}$ are higher than 5% in the medium to long term and thus not considered precautionary (see Table 5). The highest HR that can still be considered precautionary is 0.35, which further conforms to the ICES MSY approach. The proposed HCR is only a marginally different in terms of expected catch when compared with HR = 0.4 (see Fig. 37) while the SSB remains above B_{lim} with 95% probability.

The distributions of $B_{45cm^+,y}$, SSB, harvest rates and catches expected to result with the proposed HCR are shown in Fig. 39 and Table 4. These distributions should be used in the future to check that realised ranges are compatible with expectations. If future observed values were to go outside the range illustrated, this would indicate that there is a need to re-evaluate the assumptions of the simulations.

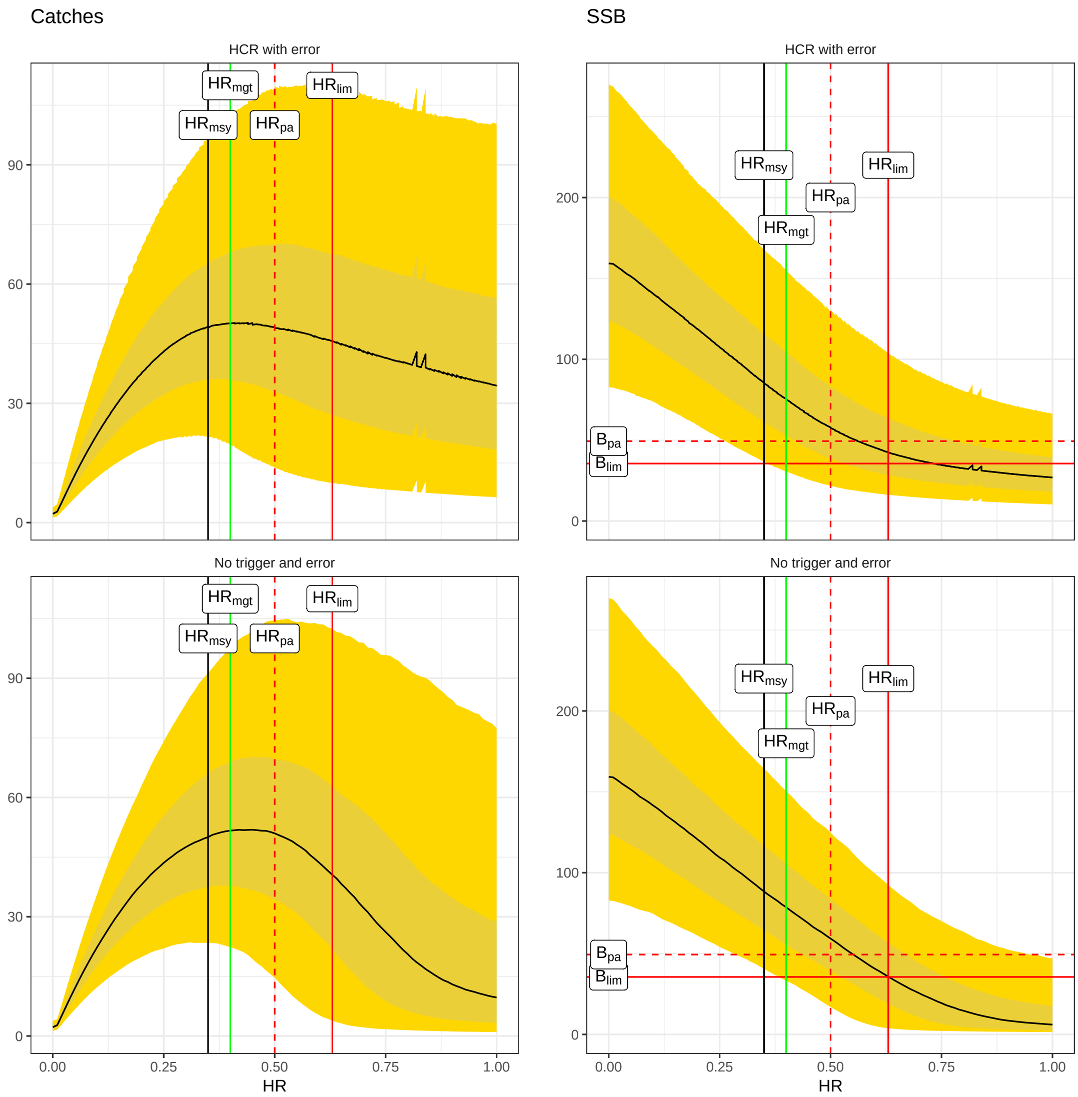

Figure 37: Haddock in 5.a. Long term average yield and SSB as function of HR targets. The top panel shows the results the HCR with a trigger at B_{pa}, with both implementation error and assessment error. The bottom panel shows results without management trigger and error.

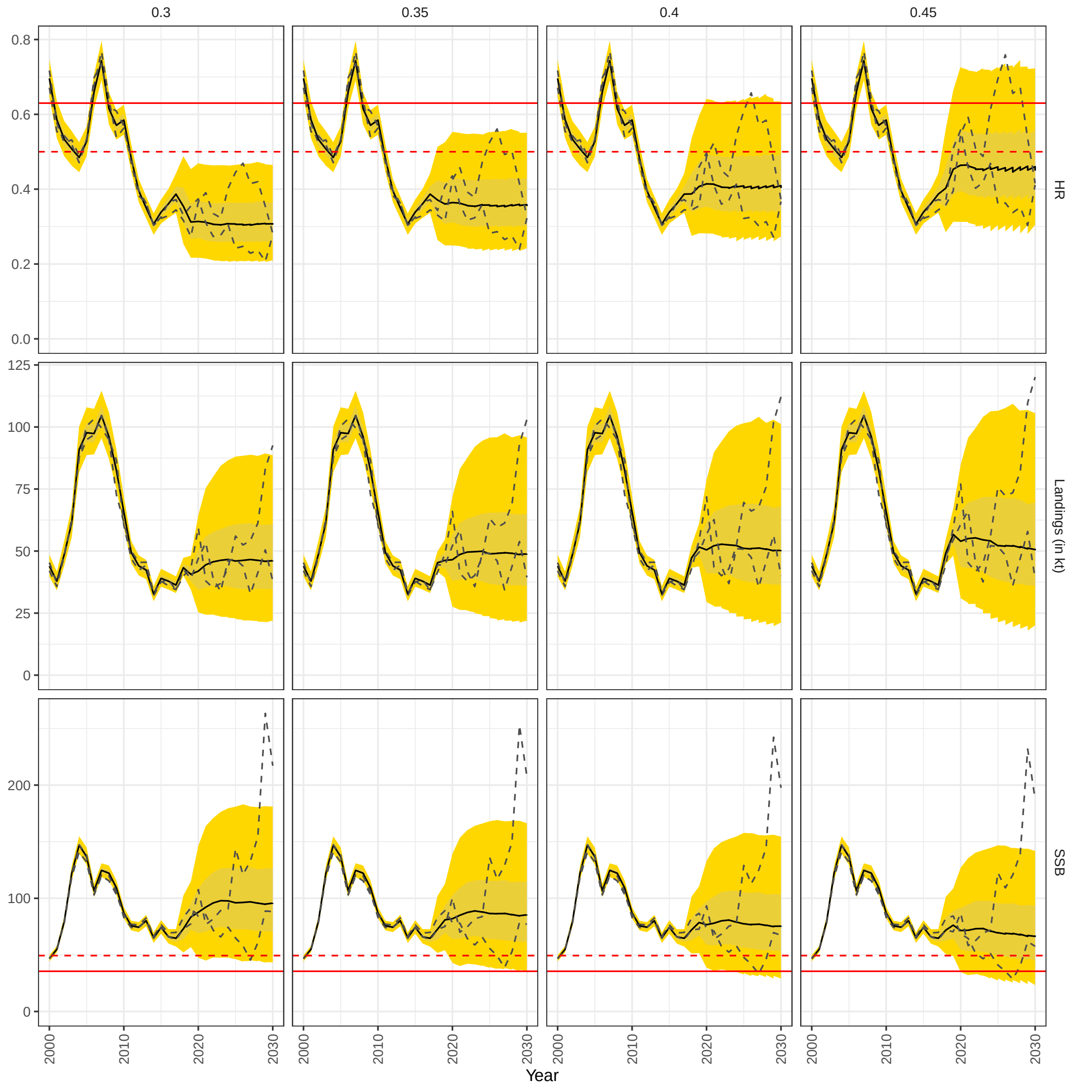

Figure 38: Haddock in 5a. Short term projections of realized harvest rates (HR), landings and SSB as a function of year for select target HR. The gold shaded region indicates the 5th and 95th percentiles and the black solid black line the median. Red solid and dashed lines indicate the HR and SSB limit and precautionary reference points respectively.

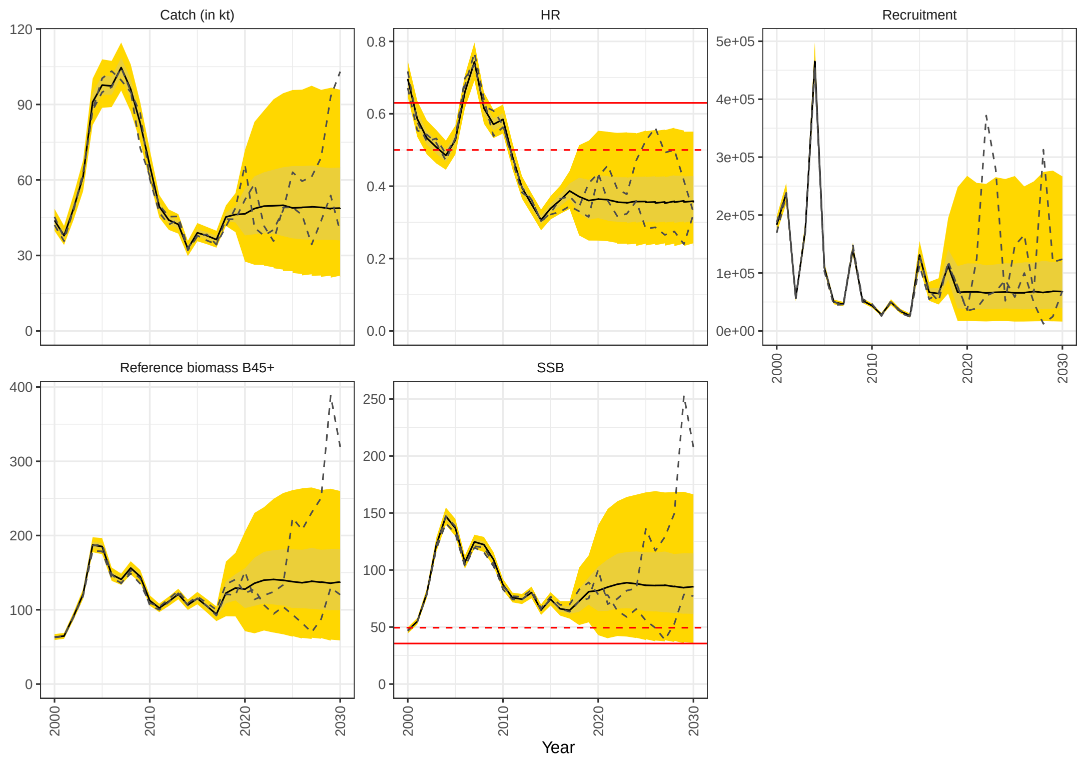

Figure 39: Haddock in 5a. Simulation results for the proposed HR_{mgmt} (0.35): Projected catches, spawning stock biomass, harvest rate relative to $B_{45cm^+,y+1}$, reference biomass and recruitment. The black solid lines are medians and the yellow bands cover from the 5th to the 95th percentile. Red and black dashed horizontal lines represent the limit and PA reference points, respectively, for SSB and harvest rate.

Table 3: Haddock in 5.a. Summary of reference point proposed for haddock in 5.a. The fishing mortality is relative to ages 4 to 7 and harvest rates correspond to the reference biomass of B_{45cm^+}.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	49.4 kt	B_{pa}
	HR_{msy}	0.35	The harvest rate that maximises the median long-term catch in stochastic simulations, limited by HR_{p5}
	F_{msy}	0.30	The median fishing mortality when an harvest rate of HR_{msy} is applied.
Precautionary approach	B_{lim}	35.5 kt	SSB(1987), corresponding to B_{loss}
	B_{pa}	49.4 kt	$B_{lim}e^{1.645\sigma}$ where $\sigma = 0.2$
	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}	0.50	$F_{lim}/e^{1.645\sigma}$ where $\sigma = 0.2$
	HR_{pa}	0.50	HR corresponding to F_{pa}
Management plan	HR_{mgt}	0.35	Proposed revision to the implemented HR in Icelandic waters (reduce from HR = 0.40)
	Mgt $B_{trigger}$	49.4 kt	Set as B_{pa} as the $B_{HRMSY} < B_{pa}$, a suggested revision from Mgt $B_{trigger} = B_{lim}$.
	HR_{mgt} range	0.23 – 0.57	Expected (90%)range of harvest rates when the updated management plan is applied

Table 4: Haddock in 5a. Median, 5th and 95th percentiles of the projected reference biomass, SSB, harvest rate and catches for the proposed HR_{mgmt} (0.35) and the previous management target (0.4).

HR_{target}		Catches (kt)	B_{45cm^+}	HR	SSB (kt)
0.35	Median	49.061	136.395	0.357	85.219
0.35	5th percentile	21.417	59.084	0.234	36.456
0.35	95th percentile	97.020	261.124	0.556	168.302
0.40	Median	50.096	122.641	0.403	75.184
0.40	5th percentile	19.496	49.700	0.259	30.569
0.40	95th percentile	102.548	244.902	0.647	154.850

References

Bjornsson, H. 2013. Report of the evaluation of the Icelandic haddok 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.

A Results by harvest rate

Table 5: Haddock in 5.a. Projection results by harvest rate for catch, SSB and HR. Type 3 probability of falling below B_{lim}/B_{pa} is shown for the first 5 years and all years in the simulation in the last two columns.

HR	Catch	SSB	1^{st} 5 years	All years
0.21 (0.15 - 0.32)	0.21 (19.01 - 71.75)	0.21 (57.61 - 206.31)	0.004 / 0.03	0.008 / 0.032
0.22 (0.16 - 0.34)	0.22 (19.53 - 74.09)	0.22 (55.98 - 204.02)	0.005 / 0.033	0.01 / 0.035
0.23 (0.16 - 0.35)	0.23 (20.04 - 76.51)	0.23 (54.46 - 201.35)	0.005 / 0.037	0.01 / 0.039
0.24 (0.17 - 0.37)	0.24 (20.38 - 78.80)	0.24 (52.89 - 199.15)	0.006 / 0.041	0.011 / 0.044
0.25 (0.17 - 0.39)	0.25 (20.74 - 80.80)	0.25 (51.16 - 195.95)	0.007 / 0.044	0.012 / 0.05
0.26 (0.18 - 0.40)	0.26 (20.98 - 82.73)	0.26 (49.79 - 193.00)	0.008 / 0.052	0.014 / 0.056
0.27 (0.19 - 0.42)	0.27 (21.23 - 84.69)	0.27 (48.19 - 190.73)	0.009 / 0.056	0.017 / 0.062
0.28 (0.19 - 0.44)	0.28 (21.42 - 86.61)	0.28 (46.47 - 188.14)	0.01 / 0.06	0.019 / 0.068
0.29 (0.20 - 0.45)	0.29 (21.33 - 87.85)	0.29 (45.06 - 184.77)	0.011 / 0.065	0.022 / 0.075
0.30 (0.21 - 0.47)	0.30 (21.42 - 89.56)	0.30 (43.72 - 182.54)	0.013 / 0.07	0.025 / 0.086
0.31 (0.21 - 0.49)	0.31 (21.57 - 91.09)	0.31 (42.33 - 179.33)	0.015 / 0.077	0.029 / 0.095
0.32 (0.22 - 0.50)	0.32 (21.75 - 92.69)	0.32 (40.79 - 176.51)	0.018 / 0.084	0.034 / 0.106
0.33 (0.22 - 0.52)	0.33 (21.80 - 94.43)	0.33 (39.53 - 173.94)	0.021 / 0.088	0.038 / 0.118
0.34 (0.23 - 0.54)	0.34 (21.64 - 95.86)	0.34 (37.97 - 170.51)	0.025 / 0.096	0.044 / 0.131
0.35 (0.23 - 0.56)	0.35 (21.42 - 97.02)	0.35 (36.46 - 168.30)	0.029 / 0.104	0.049 / 0.144
0.36 (0.24 - 0.58)	0.36 (21.18 - 98.10)	0.36 (35.04 - 165.48)	0.031 / 0.112	0.057 / 0.157
0.37 (0.24 - 0.59)	0.37 (20.94 - 99.12)	0.37 (33.82 - 163.05)	0.035 / 0.122	0.063 / 0.172
0.38 (0.25 - 0.61)	0.38 (20.43 - 100.28)	0.38 (32.86 - 160.58)	0.04 / 0.13	0.071 / 0.186
0.39 (0.25 - 0.63)	0.39 (20.06 - 101.51)	0.39 (31.55 - 157.61)	0.044 / 0.141	0.081 / 0.202
0.40 (0.26 - 0.65)	0.40 (19.50 - 102.55)	0.40 (30.57 - 154.85)	0.048 / 0.152	0.089 / 0.22
0.41 (0.26 - 0.66)	0.41 (18.93 - 103.42)	0.41 (29.56 - 152.27)	0.053 / 0.162	0.099 / 0.236
0.42 (0.27 - 0.68)	0.42 (18.26 - 104.00)	0.42 (28.35 - 149.08)	0.057 / 0.17	0.112 / 0.254
0.43 (0.27 - 0.70)	0.43 (17.64 - 104.89)	0.43 (27.42 - 147.09)	0.063 / 0.184	0.122 / 0.271
0.44 (0.27 - 0.71)	0.44 (16.95 - 106.01)	0.44 (26.40 - 144.73)	0.069 / 0.197	0.134 / 0.293
0.45 (0.28 - 0.73)	0.45 (16.20 - 106.92)	0.45 (25.59 - 142.40)	0.076 / 0.211	0.148 / 0.314
0.46 (0.28 - 0.74)	0.46 (15.74 - 107.65)	0.46 (24.73 - 139.56)	0.081 / 0.222	0.159 / 0.331
0.47 (0.28 - 0.76)	0.47 (15.30 - 108.13)	0.47 (23.97 - 137.49)	0.09 / 0.234	0.172 / 0.348
0.48 (0.29 - 0.77)	0.48 (14.84 - 108.65)	0.48 (23.04 - 135.11)	0.097 / 0.248	0.186 / 0.366
0.49 (0.29 - 0.78)	0.49 (14.29 - 109.11)	0.49 (22.39 - 132.96)	0.104 / 0.262	0.201 / 0.385
0.50 (0.29 - 0.80)	0.50 (13.83 - 109.69)	0.50 (21.63 - 130.91)	0.111 / 0.273	0.215 / 0.403
0.51 (0.29 - 0.81)	0.51 (13.40 - 109.89)	0.51 (21.03 - 128.88)	0.12 / 0.286	0.226 / 0.419
0.52 (0.29 - 0.82)	0.52 (12.85 - 109.85)	0.52 (20.47 - 126.54)	0.128 / 0.301	0.238 / 0.438
0.53 (0.29 - 0.84)	0.53 (12.48 - 109.62)	0.53 (19.82 - 124.01)	0.136 / 0.315	0.252 / 0.457
0.54 (0.30 - 0.85)	0.54 (12.13 - 109.65)	0.54 (19.36 - 122.01)	0.144 / 0.328	0.268 / 0.474
0.55 (0.30 - 0.86)	0.55 (11.79 - 109.79)	0.55 (18.96 - 119.76)	0.153 / 0.339	0.28 / 0.491
0.56 (0.30 - 0.87)	0.56 (11.48 - 109.78)	0.56 (18.55 - 117.99)	0.162 / 0.351	0.294 / 0.51
0.57 (0.30 - 0.88)	0.57 (11.24 - 109.31)	0.57 (18.17 - 115.96)	0.168 / 0.365	0.307 / 0.522
0.58 (0.30 - 0.89)	0.58 (10.94 - 109.15)	0.58 (17.77 - 114.06)	0.176 / 0.376	0.324 / 0.54
0.59 (0.30 - 0.90)	0.59 (10.68 - 109.37)	0.59 (17.46 - 112.48)	0.186 / 0.389	0.335 / 0.554

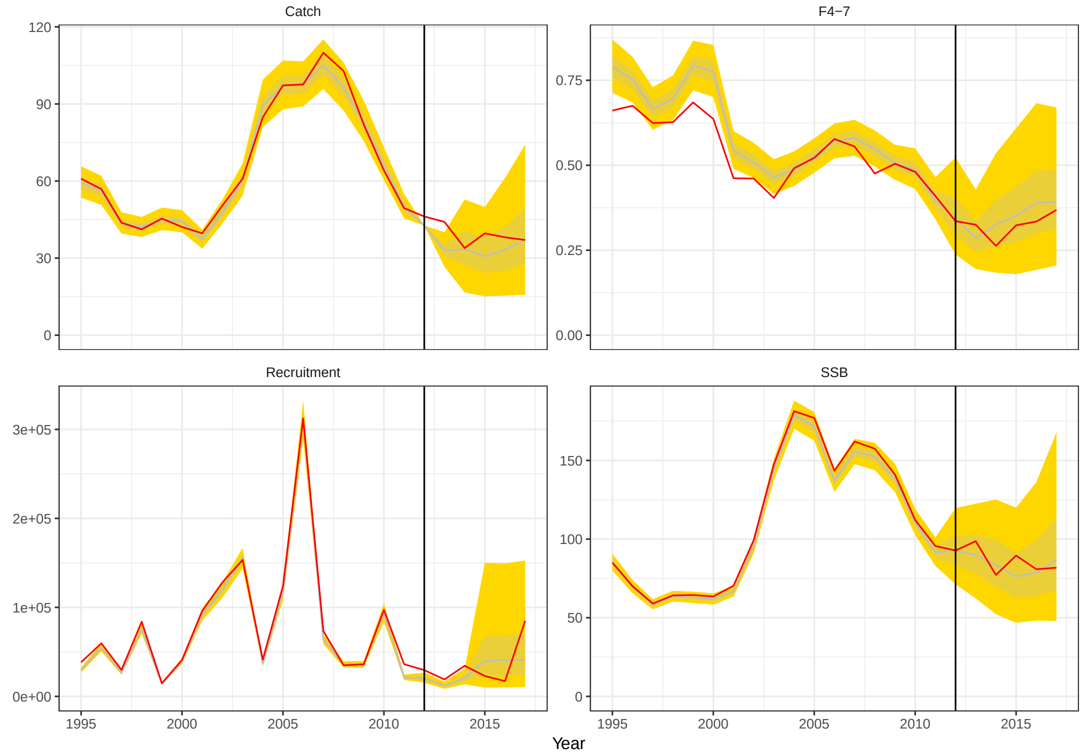

Figure 40: Haddock in 5.a. An illustration of the historical performance of the management plan. Red line indicates the current assessment of the stock, yellow shaded region the 5th and 95th percentiles and the gray line the median projections.

B Historical performance of the management plan

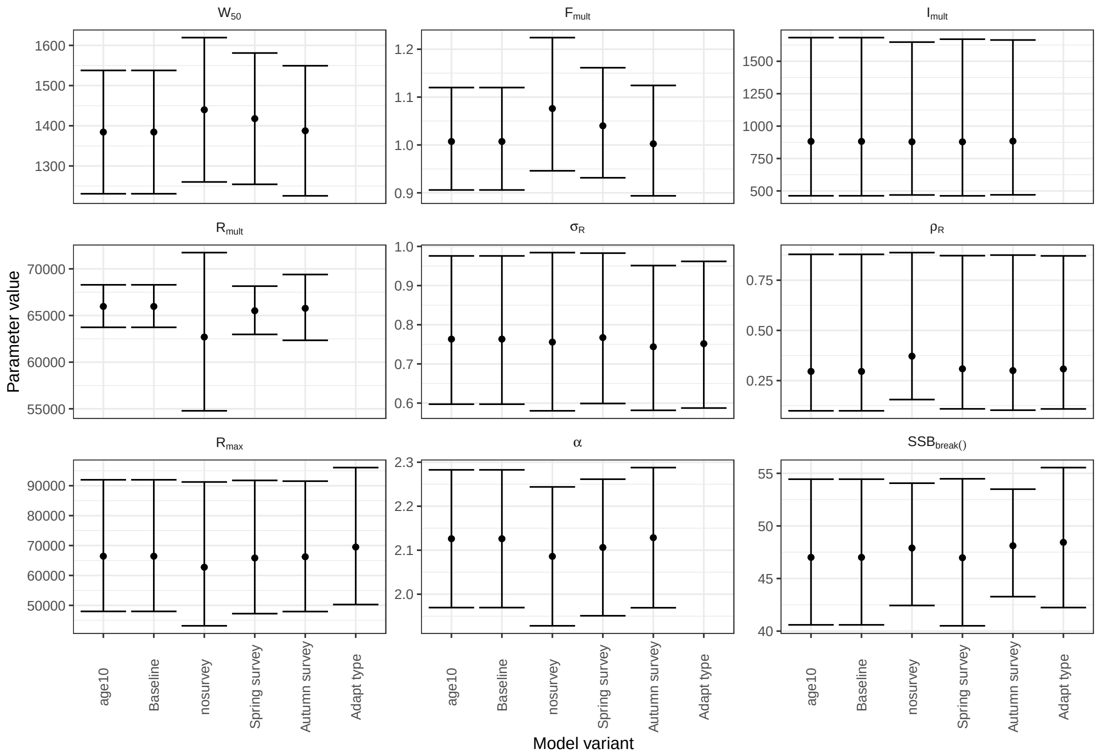

Figure 41: Haddock in 5a. Comparison of variable estimates for the different model variants. The black dots indicate the point estimate and the error bars the 95% confidence regions.

C Overview of the parameter estimates by model variant

D Input data

Table 6: Haddock in 5a. Survey at age from the spring survey.

Year	1	2	3	4	5	6	7	8	9	10	11
1985	29.91	32.25	17.67	23.26	26.30	3.72	11.01	4.88	5.69	0.50	0.12
1986	122.05	110.13	61.02	13.38	16.87	13.60	1.00	2.81	1.27	2.35	0.09
1987	21.49	324.64	148.07	44.68	7.77	7.53	4.77	0.40	0.62	0.44	0.83
1988	15.72	40.00	184.62	90.03	23.12	1.36	2.21	1.79	0.16	0.23	0.01
1989	10.45	23.09	40.59	145.62	45.09	12.91	0.79	0.81	0.42	0.28	0.14
1990	71.90	31.75	26.68	38.63	92.14	30.75	3.43	0.88	0.23	0.00	0.00
1991	88.46	146.96	42.89	17.87	20.20	32.76	7.59	0.31	0.10	0.08	0.00
1992	18.23	210.42	139.76	35.52	16.87	13.76	16.31	2.22	0.18	0.07	0.00
1993	30.66	39.06	251.81	88.66	11.37	3.89	1.68	4.50	0.89	0.00	0.00
1994	58.86	61.76	40.53	143.12	42.34	6.93	2.89	1.44	4.47	0.17	0.00
1995	37.07	84.74	47.17	19.83	69.87	7.69	1.31	0.12	0.34	0.00	0.00
1996	96.55	66.77	121.30	37.19	19.78	41.09	5.85	0.60	0.13	0.13	0.00
1997	8.41	122.60	51.08	53.10	10.80	7.28	10.85	1.34	0.07	0.03	0.06
1998	23.04	18.71	110.21	28.45	23.28	4.89	3.49	4.52	0.34	0.00	0.00
1999	80.92	86.14	25.79	98.86	12.99	9.88	1.43	1.78	1.04	0.09	0.00
2000	60.41	88.73	43.92	8.33	24.82	3.12	1.58	0.40	0.15	0.52	0.04
2001	81.03	153.29	116.21	21.70	4.03	10.45	0.89	0.55	0.00	0.10	0.00
2002	20.68	304.47	198.83	110.43	22.88	3.45	7.40	0.30	0.30	0.08	0.15
2003	112.22	97.95	283.79	247.07	115.13	18.26	2.60	4.57	0.49	0.84	0.07
2004	324.37	290.43	70.82	208.73	110.14	34.31	6.85	1.26	0.83	0.00	0.16
2005	57.55	693.57	288.64	44.58	157.39	57.69	15.78	3.36	0.32	0.26	0.02
2006	39.87	78.50	575.82	181.71	19.34	63.24	16.54	6.80	0.70	0.29	0.00
2007	34.23	65.13	89.00	437.40	85.58	7.84	21.32	4.67	2.13	0.07	0.00
2008	88.16	67.60	71.12	75.02	220.74	29.75	3.51	7.42	1.63	0.27	0.00
2009	10.54	110.79	53.20	41.11	42.02	105.22	12.77	2.19	3.04	0.43	0.22
2010	15.25	27.69	137.03	29.60	18.10	20.48	31.38	2.90	0.46	0.68	0.12
2011	8.76	27.46	24.34	76.75	13.96	5.88	9.40	14.89	1.22	0.31	0.23
2012	12.33	14.76	31.18	27.15	58.16	5.22	2.92	5.28	6.85	0.79	0.26
2013	13.93	23.05	19.60	22.66	22.27	41.50	4.76	2.49	3.78	4.47	0.59
2014	14.15	24.53	30.12	17.71	16.42	14.77	16.42	1.33	1.05	1.67	1.42
2015	62.08	19.53	26.50	34.10	12.62	11.11	9.57	9.85	1.16	0.56	1.14
2016	29.85	162.26	23.56	22.10	22.24	7.17	7.27	5.05	4.19	0.93	0.46
2017	26.67	66.65	140.89	23.02	20.29	22.02	6.41	5.06	3.54	1.92	0.26
2018	64.02	75.96	81.93	106.11	13.25	9.69	9.12	3.77	3.18	1.08	0.81

Table 7: Haddock in 5a. Survey at age from the autumn survey.

Year	1	2	3	4	5	6	7	8	9
1996	430.52	105.24	83.24	18.01	7.65	17.92	1.53	0.00	0.00
1997	31.81	208.25	54.89	38.84	7.00	5.68	6.00	0.28	0.00
1998	80.42	31.83	131.08	19.69	15.71	5.27	5.34	1.88	0.00
1999	373.73	65.40	28.03	95.33	11.73	10.33	0.53	2.09	0.31
2000	158.89	253.69	45.54	8.12	28.21	1.93	3.16	0.08	0.27
2001	379.10	271.99	168.76	34.62	3.91	13.72	0.69	0.95	0.00
2002	76.92	234.01	187.82	94.31	18.64	2.88	2.23	0.99	0.07
2003	334.20	140.01	243.08	163.92	55.26	9.29	2.39	0.65	0.00
2004	692.59	332.37	49.72	156.73	69.29	16.78	3.92	0.81	0.51
2005	72.16	544.95	178.23	26.74	94.44	26.13	10.15	1.85	0.00
2006	117.43	114.65	498.47	106.25	13.56	39.61	9.61	3.87	1.51
2007	95.41	74.43	87.93	326.72	57.05	8.01	12.11	3.72	0.55
2008	198.10	91.84	66.76	85.65	194.11	16.41	2.81	3.40	0.22
2009	46.72	265.96	67.08	30.46	47.53	94.56	9.28	1.45	2.15
2010	41.62	55.70	140.66	30.01	14.14	23.23	36.44	4.66	0.85
2012	52.90	28.47	33.57	37.03	69.06	9.11	3.51	9.62	10.09
2013	89.55	126.31	36.31	37.64	38.62	44.09	6.17	2.27	5.68
2014	33.49	40.44	65.26	23.35	26.30	23.77	25.69	2.25	1.45
2015	203.74	35.63	38.23	47.44	15.05	17.95	10.25	11.97	2.26
2016	78.90	125.27	23.15	18.18	19.41	7.15	7.88	3.92	3.04
2017	117.29	91.65	150.08	14.02	17.57	13.99	4.18	4.15	2.51

Table 8: Haddock in 5a. Commercial catch at age.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1979	149	1908	3762	6057	9022	1743	438	56	0	56	56	0	0
1980	595	1385	11481	4298	3798	3732	544	91	32	0	5	0	0
1981	10	514	4911	16900	5999	2825	1803	168	43	0	14	0	0
1982	107	245	3149	10851	14049	2068	1000	725	169	26	5	0	1
1983	34	1010	1589	4596	9850	8839	766	207	263	17	0	0	0
1984	241	1069	4946	1341	4772	3742	4076	238	58	19	3	0	0
1985	1320	1728	4562	6796	855	1682	1914	1903	212	31	49	4	0
1986	1012	4223	4068	4686	5139	494	796	897	344	27	29	0	0
1987	1939	8308	6965	2728	2042	1094	132	165	220	89	14	6	10
1988	237	9831	15164	5824	1304	1084	609	66	89	96	24	2	2
1989	188	2474	22560	9571	3196	513	556	144	34	40	36	14	17
1990	1857	2415	8628	23611	6331	816	150	67	45	13	7	2	7
1991	8617	2145	5397	7342	14103	2648	338	40	10	5	0	12	0
1992	5405	10693	5721	4610	3691	5209	999	120	10	4	2	0	0
1993	769	12333	12815	2968	1722	1425	2239	343	19	1	1	17	0
1994	3198	3343	28258	10682	1469	726	358	647	93	11	1	3	0
1995	4015	7323	5744	23927	5769	615	290	187	268	52	3	8	0
1996	3090	10552	7639	4468	12896	2346	208	79	60	51	14	0	0
1997	1364	3939	10915	4895	2610	5035	719	64	12	16	40	1	0
1998	279	8257	5667	7856	2418	1422	1897	261	17	16	4	3	5
1999	1434	1550	17243	4516	4837	915	620	481	63	0	0	1	0
2000	2659	6317	2352	13615	1945	1706	324	222	176	12	2	0	2
2001	2515	11098	6954	1446	6262	675	478	105	42	52	0	0	0
2002	1082	10434	15998	5099	1131	3149	262	169	42	33	19	6	0
2003	401	6352	16265	12548	2968	748	1236	91	48	11	6	5	0
2004	1597	4063	17652	19358	8871	1940	471	489	92	36	15	0	12
2005	2405	9450	6929	25421	13778	4584	809	251	212	3	19	3	0
2006	241	10038	21246	6646	18840	7600	2180	323	93	109	0	0	0
2007	782	3884	42224	22239	3354	9952	2740	519	62	30	33	24	32
2008	2316	4508	9706	53022	11014	1717	3033	815	167	20	5	0	0
2009	1066	3185	4886	8892	35011	5733	726	1381	395	97	17	0	0
2010	121	6032	7061	4806	6766	17503	1874	354	412	97	19	0	0
2011	253	1584	11797	5080	2853	3983	6220	494	112	58	13	0	0
2012	196	1322	3421	13107	2223	1231	2480	2662	241	49	56	19	5
2013	250	1042	2865	4008	9222	1206	668	1248	1367	149	54	17	12
2014	238	1478	1751	2725	2737	4742	447	387	586	652	90	27	48
2015	232	1532	4155	2317	2916	2623	2715	226	286	261	235	24	17
2016	481	1773	3437	4130	1727	1953	1420	1293	113	157	138	47	0
2017	573	3680	3079	3013	3135	1097	1182	751	623	126	62	86	43

Table 9: Haddock in 5a. Stock weights at age

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1979	37	185	481	910	1409	1968	2496	3077	3300	4000	5741	6171	4000	5213
1980	37	185	481	910	1409	1968	2496	3077	3300	4615	4000	7337	4000	4000
1981	37	185	481	910	1409	1968	2496	3077	3300	4898	4000	6376	4000	4000
1982	37	185	481	910	1409	1968	2496	3077	3300	3952	4958	5323	4000	5213
1983	37	185	481	910	1409	1968	2496	3077	3300	4463	5101	4000	4000	4000
1984	37	185	481	910	1409	1968	2496	3077	3300	3941	4138	5155	4000	4000
1985	36	244	568	1187	1673	2371	2766	3197	3331	4564	4930	4852	5209	4000
1986	35	239	671	1134	1943	2399	3190	3293	3728	4436	3863	5241	4000	4000
1987	31	162	550	1216	1825	2605	3030	3642	3837	3653	4877	3814	5279	4163
1988	37	176	457	974	1830	2695	3102	3481	3318	4169	4560	4631	5293	5293
1989	26	182	441	887	1510	2380	3009	3499	3195	5039	5015	4975	5338	4575
1990	29	184	457	840	1234	1965	2675	3052	3267	4115	4682	5220	5183	5204
1991	31	176	501	1003	1406	1884	2496	3755	3653	5243	3427	4000	5356	4000
1992	28	157	503	894	1365	1891	2325	2936	3682	4674	4503	5250	4000	4000
1993	41	168	384	878	1492	1785	2562	2573	3266	4047	5294	5294	4709	4000
1994	33	181	392	680	1235	1766	1717	2977	2131	3154	3897	5258	4190	4000
1995	37	167	440	755	1065	1857	2689	5377	1306	3119	3220	1640	3753	4000
1996	41	174	453	813	1076	1477	2171	2426	4847	3686	3846	3508	4000	4000
1997	50	174	424	817	1221	1425	1915	2390	3692	3508	4028	2815	4133	4000
1998	41	203	415	753	1241	1747	1996	2342	3076	3275	3701	3630	3806	4202
1999	33	206	480	715	1189	1956	2366	2782	2922	3534	4000	4000	2159	4000
2000	29	179	552	889	1159	1767	2612	2917	3132	3734	4142	5574	4000	1648
2001	36	190	490	1056	1437	1509	2169	2765	3300	4715	3849	4000	4000	4000
2002	67	172	475	889	1460	1949	2137	1990	3709	4078	4551	4479	5358	4000
2003	40	230	412	801	1268	1873	3139	2343	3301	3289	4157	5295	5313	4000
2004	34	176	556	807	1282	1690	2454	3236	2942	3957	3146	2827	4000	5249
2005	40	153	448	920	1188	1564	2128	2808	2550	2755	4053	4019	4158	4000
2006	33	127	333	736	1145	1512	1944	2232	3272	3617	3566	4000	4000	4000
2007	48	170	350	615	1053	1514	1786	2073	2198	2408	3360	2303	3338	5082
2008	27	179	382	595	868	1295	1828	2201	2340	2568	2840	2727	4000	4000
2009	29	139	442	687	882	1141	1495	1920	2574	3070	3016	3488	4000	4000
2010	32	150	392	773	942	1190	1468	1829	2086	2730	3016	3488	4000	4000
2011	35	175	442	757	1129	1304	1583	1865	2107	3094	2398	4146	4000	4000
2012	28	202	482	801	1145	1480	1909	2072	2353	2350	2207	3211	3054	4000
2013	33	201	589	967	1312	1710	1999	2265	2764	2709	2529	2885	1788	3352
2014	36	222	570	1005	1372	1751	2141	2298	2653	3104	3153	3162	4000	3582
2015	32	255	614	1073	1637	1926	2452	2774	3170	3173	3577	3356	4000	3718
2016	29	162	642	1099	1564	2094	2296	3068	3481	3248	3252	3932	3539	3411
2017	34	196	459	1258	1657	2168	2780	3205	3564	3462	4023	3426	4255	4570
2018	30	198	582	973	1963	2459	2719	3156	3278	3695	3697	2930	4255	4570

Table 10: Haddock in 5a. Catch weights at age

Year	2	3	4	5	6	7	8	9	10	11	12
1979	620	960	1410	2030	2910	3800	4560	4720	4000	5741	6171
1980	837	831	1306	2207	2738	3188	3843	4506	4615	4000	7337
1981	584	693	1081	1656	2283	3214	3409	4046	4898	4000	6376
1982	289	959	1455	1674	2351	3031	3481	3874	3952	4958	5323
1983	320	1006	1496	1921	2371	2873	3678	4265	4463	5101	4000
1984	691	1007	1544	2120	2514	3027	2940	3906	3941	4138	5155
1985	652	1125	1811	2260	2924	3547	3733	4039	4564	4930	4852
1986	336	1227	1780	2431	2771	3689	3820	4258	4436	3863	5241
1987	452	1064	1692	2408	3000	3565	4215	4502	3653	4877	3814
1988	362	780	1474	2217	2931	3529	3781	4467	4169	4560	4631
1989	323	857	1185	1996	2893	4066	3866	4734	5039	5015	4975
1990	269	700	1054	1562	2364	3414	4134	4946	4115	4682	5220
1991	288	699	979	1412	1887	2674	3135	4341	5243	3427	4000
1992	313	806	1167	1524	1950	2357	3075	4053	4674	4503	5250
1993	303	705	1333	1875	2386	2996	3059	3363	4047	5294	5294
1994	337	668	1019	1717	2391	2717	3280	3156	3154	3897	5258
1995	351	746	1096	1318	2044	2893	3049	3675	3119	3220	1640
1996	311	787	1187	1560	1849	2670	3510	3567	3686	3846	3508
1997	379	764	1163	1649	1943	2342	3020	3337	3508	4028	2815
1998	445	724	1147	1683	2250	2475	2834	3333	3275	3701	3630
1999	555	908	1101	1658	2216	2659	2928	3209	3534	4000	4000
2000	495	978	1333	1481	2119	2696	3307	3597	3734	4142	5574
2001	541	945	1456	1731	1832	2243	3020	3328	4715	3849	4000
2002	564	928	1253	1737	2219	2230	2911	3365	4078	4551	4479
2003	498	922	1283	1704	2274	2744	2635	2819	3289	4157	5295
2004	559	1006	1258	1579	2044	2809	3123	2945	3957	3146	2827
2005	339	886	1265	1506	1916	2323	3028	3211	2755	4053	4019
2006	402	749	1093	1495	1758	2163	2555	3054	3617	3566	4000
2007	510	748	988	1346	1840	2062	2350	2525	2408	3360	2303
2008	383	636	857	1125	1575	2149	2417	2802	2568	2840	2727
2009	452	841	960	1131	1352	1757	2364	2497	3070	3016	3488
2010	447	756	1092	1294	1448	1685	2188	2366	2657	2639	2439
2011	588	905	1122	1455	1688	1914	2094	2455	2919	2953	3706
2012	668	978	1222	1492	1903	2164	2366	2704	2765	3431	2924
2013	678	1084	1358	1675	2036	2400	2554	3097	3111	2838	3634
2014	536	1080	1433	1793	2121	2504	2624	3178	3272	3445	3254
2015	573	1084	1486	2011	2332	2823	3306	3258	3911	3926	3476
2016	513	1071	1590	2035	2607	2952	3616	3734	3679	4115	4370
2017	643	997	1587	2032	2546	3016	3518	3839	3817	4002	3889
2018	461	981	1407	2300	2693	2889	3207	3293	3581	3582	3044

Table 11: Haddock in 5a. Maturity at age

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1979	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1980	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1981	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1982	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1983	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1984	0.080	0.301	0.539	0.722	0.821	0.868	0.904	0.963	1.000	1.000	1	1	1
1985	0.016	0.144	0.536	0.577	0.765	0.766	0.961	0.934	1.000	1.000	1	1	1
1986	0.021	0.205	0.413	0.673	0.845	0.884	0.952	0.986	1.000	1.000	1	1	1
1987	0.022	0.137	0.426	0.535	0.778	0.776	1.000	0.969	1.000	1.000	1	1	1
1988	0.013	0.221	0.394	0.767	0.793	0.928	0.914	1.000	1.000	1.000	1	1	1
1989	0.041	0.202	0.532	0.727	0.818	0.998	1.000	1.000	1.000	1.000	1	1	1
1990	0.114	0.334	0.634	0.814	0.843	0.918	0.882	1.000	1.000	1.000	1	1	1
1991	0.063	0.224	0.592	0.739	0.817	0.894	0.495	1.000	1.000	1.000	1	1	1
1992	0.050	0.227	0.419	0.799	0.901	0.901	0.858	1.000	1.000	1.000	1	1	1
1993	0.124	0.362	0.481	0.670	0.904	0.977	0.908	0.867	1.000	1.000	1	1	1
1994	0.248	0.312	0.573	0.762	0.846	1.000	0.907	1.000	1.000	1.000	1	1	1
1995	0.124	0.479	0.382	0.750	0.753	0.606	0.985	1.000	1.000	1.000	1	1	1
1996	0.191	0.362	0.590	0.648	0.787	0.739	0.949	0.908	1.000	1.000	1	1	1
1997	0.093	0.436	0.587	0.683	0.750	0.783	0.880	1.000	1.000	1.000	1	1	1
1998	0.026	0.454	0.668	0.770	0.733	0.849	0.899	1.000	1.000	1.000	1	1	1
1999	0.050	0.397	0.683	0.724	0.749	0.892	0.761	0.920	1.000	1.000	1	1	1
2000	0.107	0.261	0.632	0.808	0.868	0.873	1.000	0.780	1.000	1.000	1	1	1
2001	0.091	0.377	0.522	0.753	0.895	0.916	0.918	1.000	1.000	1.000	1	1	1
2002	0.047	0.286	0.633	0.800	0.934	0.928	1.000	1.000	1.000	1.000	1	1	1
2003	0.062	0.347	0.685	0.867	0.922	0.946	1.000	1.000	1.000	1.000	1	1	1
2004	0.037	0.361	0.570	0.831	0.910	1.000	1.000	1.000	1.000	1.000	1	1	1
2005	0.024	0.230	0.562	0.753	0.927	0.936	0.968	1.000	1.000	1.000	1	1	1
2006	0.027	0.117	0.462	0.621	0.739	0.918	1.000	1.000	1.000	1.000	1	1	1
2007	0.078	0.208	0.418	0.680	0.770	0.875	0.959	1.000	1.000	1.000	1	1	1
2008	0.027	0.263	0.418	0.621	0.828	0.870	0.904	0.975	1.000	1.000	1	1	1
2009	0.017	0.301	0.470	0.576	0.847	0.891	1.000	0.968	1.000	1.000	1	1	1
2010	0.029	0.187	0.618	0.778	0.787	0.887	0.934	1.000	0.958	1.000	1	1	1
2011	0.045	0.176	0.426	0.823	0.816	0.838	0.899	0.974	1.000	1.000	1	1	1
2012	0.106	0.167	0.445	0.627	0.819	0.903	0.852	0.911	1.000	1.000	1	1	1
2013	0.046	0.223	0.381	0.714	0.793	0.920	0.986	0.974	0.992	0.945	1	1	1
2014	0.107	0.192	0.391	0.567	0.675	0.735	0.925	0.906	0.883	1.000	1	1	1
2015	0.138	0.283	0.445	0.667	0.795	0.772	0.892	1.000	0.889	1.000	1	1	1
2016	0.008	0.366	0.487	0.594	0.779	0.787	0.883	0.915	1.000	1.000	1	1	1
2017	0.073	0.131	0.591	0.664	0.745	0.910	0.939	1.000	0.975	1.000	1	1	1
2018	0.045	0.280	0.340	0.965	0.747	0.857	0.917	1.000	1.000	1.000	1	1	1

4 Icelandic Saithe

Benchmark and Harvest Control Rule evaluations of Icelandic saithe
Working document for WKICEMSE 2019

Höskuldur Björnsson

31 March 2019

4.1 Introduction

Assessment of Icelandic saithe was benchmarked in 2010 [2] and management plan for the stock was adopted in 2013 after being evaluated by ICES [3]. Reference points were evaluated by the working North Western Working group in 2016 [4]. Both the assessment and the management plan evaluation were done using the same model (Muppet) which is in principle a separable stock-assessment/prediction model. The goal is to review the assessment methodology and management plan and continue using them if they are accepted by ICES.

The current management plan is:

If $SSB_y \geq B_{trigger}$

$$Tac_{y/y+1} = \frac{Tac_{y-1/y} + 0.2 \times B_{4+,y}}{2} \tag{1}$$

If $SSBy \leq Btrigger$

$$Tac_{y/y+1} = \alpha \times Tac_{y-1/y} + (1-\alpha) \times \frac{SSB_y}{B_{trigger}} \times 0.2 \times B_{4+,y} \tag{2}$$

$$\alpha = 0.5 \times \frac{SSB_y}{B_{trigger}} \tag{3}$$

Where $Tac_{y/y+1}$ is the TAC for the fishing year starting September 1st in year y ending August 31st in year y +1. $B_{4+,y}$ the biomass of age 4 and older in the beginning of the assessment year compiled from catch weights. The latter equation shows that the weight of the last years Tac does gradually reduce from 0.5 to 0.0 when estimated SSB changes from $B_{trigger}$ to 0.

4.2 Stock

4.2.1 Stock ID and sub-stock structure

Saithe in Icelandic waters (Division 5.a) is managed as a separate unit, though taggings have demonstrated that in some years saithe migrate from other regions into Icelandic waters and vice versa [7]. Saithe is both demersal and pelagic. They can be found all around Iceland, but the most important fishing areas used to in the warm waters south and west of Iceland. In recent years the distribution of saithe has like for many species shifted to the north so large part of the fishing in conducted in the North - West (Figure 2). Saithe spawns in shallow waters south and west of Iceland in February–April. Less is known about the spawning time than for cod but it is believed to be little earlier. The larvae drift clockwise all around Iceland and by mid-June juveniles can be found in many coves, bays and harbours, then about 3–5 cm long. At age 2–4 they move to deeper waters. Saithe becomes mature at age 4–7 (Figure 16).

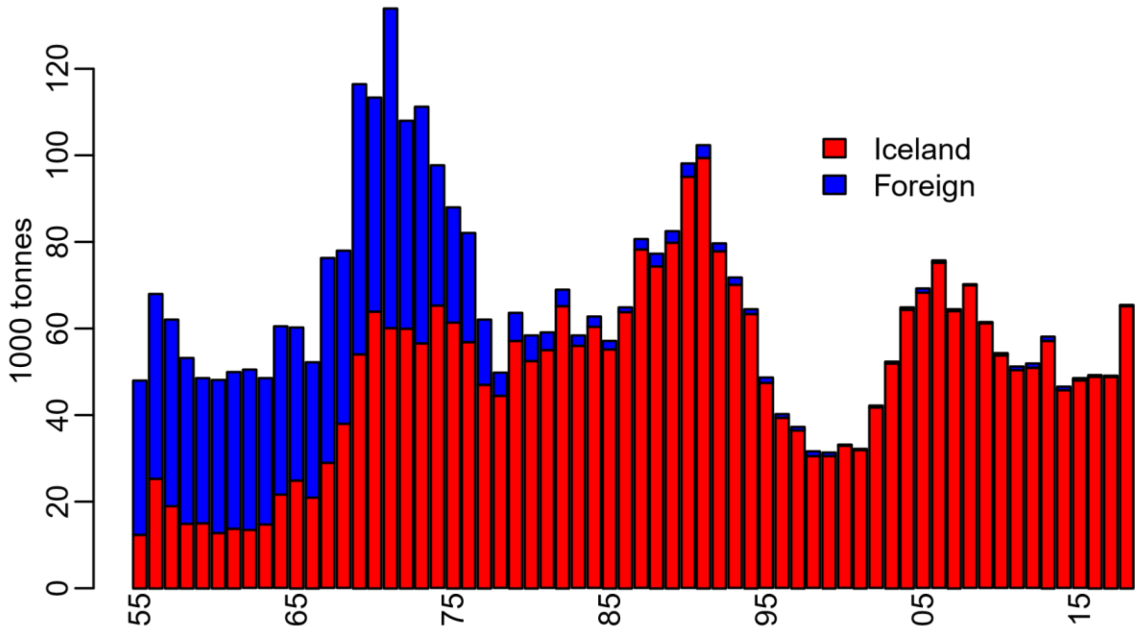

Figure 1: Catch of saithe in Icelandic waters.

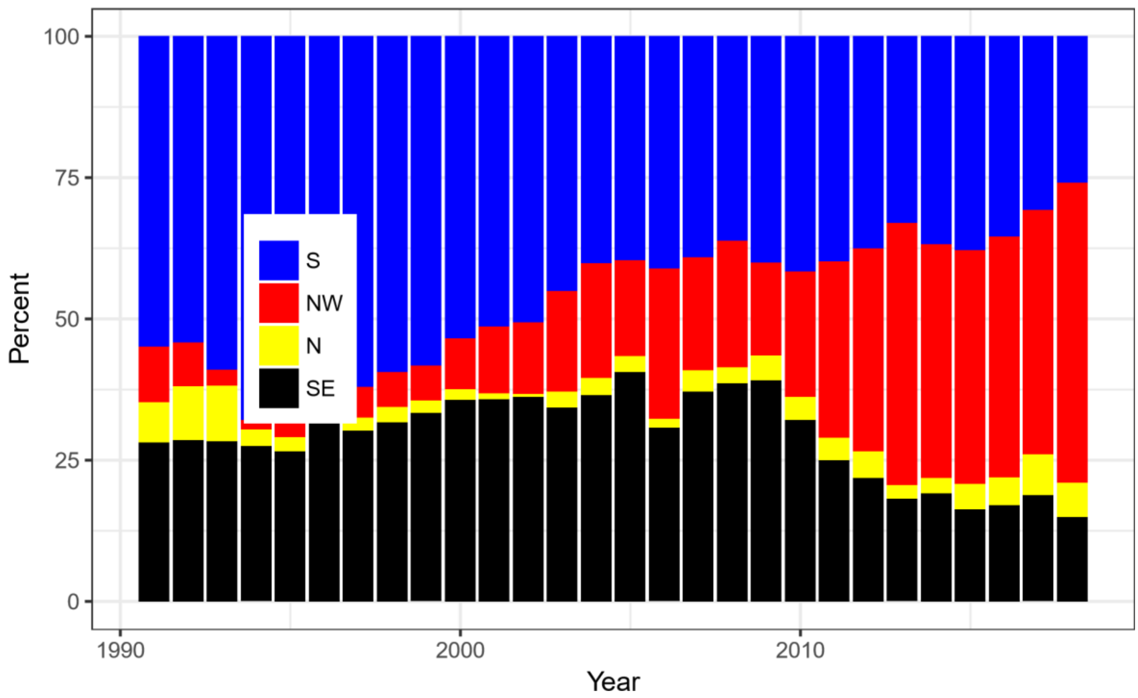

Figure 2: Proportion of saithe catch in each region.

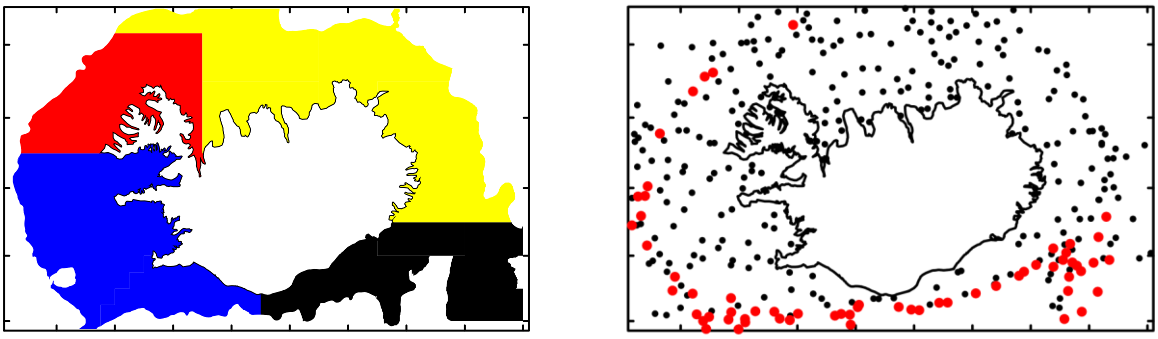

Figure 3: Left, definition of regions S, NW, N and SE used in Figure 2. Right, stations added in the autumn survey in 2000, shown as red symbols.

4.2.2 Issue list

- No change in assessment methodology nor weight projection is proposed. The methods are the same as used since the stock was benchmarked in 2010.
- The assessment is tuned with the March survey that commenced in 1985. The survey indices and results from the assessment have in recent years been compared with results from a bottom trawl survey that started in October 1996 and a gillnet survey that started in 1996. For the autumn survey consistent age based indices can be compiled since 2000 and since 2002 for the gillnet survey.
- Update estimates of uncertainty in assessment to be used in HCR evaluations.

4.2.3 Scorecard on data quality

4.2.4 Multispecies and mixed fisheries issues

The saithe fishery in 5.a is almost entirely Icelandic, with small amounts reported by Faroese vessels. Cod is by far the most important demersal species in Iceland so much of demersal fisheries are aimed at cod, sometime avoiding it, sometime getting cod without too much bycatch and sometime targeting certain mixture. In recent years ≈ 90% of the saithe has been caught by bottom trawl (Figure 4) in mixed fisheries where the goal is often to get as much saithe as possible. The reason is that saithe is more difficult to catch than cod and the captains want to catch most of the cod late in a fishing trip and land it fresh. Trawlers that freeze the catch aboard catch relatively more saithe compared to cod that those that land the catch fresh (Figure 5). Gillnet used to be an important gear in the saithe fisheries but its share has decreased since 1995, mostly due to general reduction in gillnet fisheries. At the same time longline fisheries have increased but longliners do not catch much saithe. Therefore the fleet is less of a saithe fleet than earlier.

Spatial patterns of fishing activity and catch distribution are produced from logbook data with 100% coverage of all the fleet since 2000, but from the larger boats since 1991. The data show that from 1991–2000 most of the fisheries were taken in the south , but since 2005 increasing part of the saithe fisheries is in the north - west, exceeding 50% in 2018 (Figure 2).

In many recent years the fleet has not caught the TAC (Figure 8). Part of the TAC is transferred to other species but part is unused (Figure 6). The reason for the unused quota is limitation in how much quota a company can transfer between species and that catching the saithe is not considered profitable. The price of saithe is low (≈ 1/3 of price of cod) so catch rates have to be reasonable to make the fisheries profitable. The constraint of wanting little bycatch of cod might also have an effect.

The saithe stock has been increasing in recent year and last fishing year (2017/2018) the TAC was caught (except what was transferred from earlier year) and there are indications that the TAC for 2018/2019 will be caught (Figure 7). This might indicate that increased stock size makes saithe fisheries economically feasible (higher CPUE).

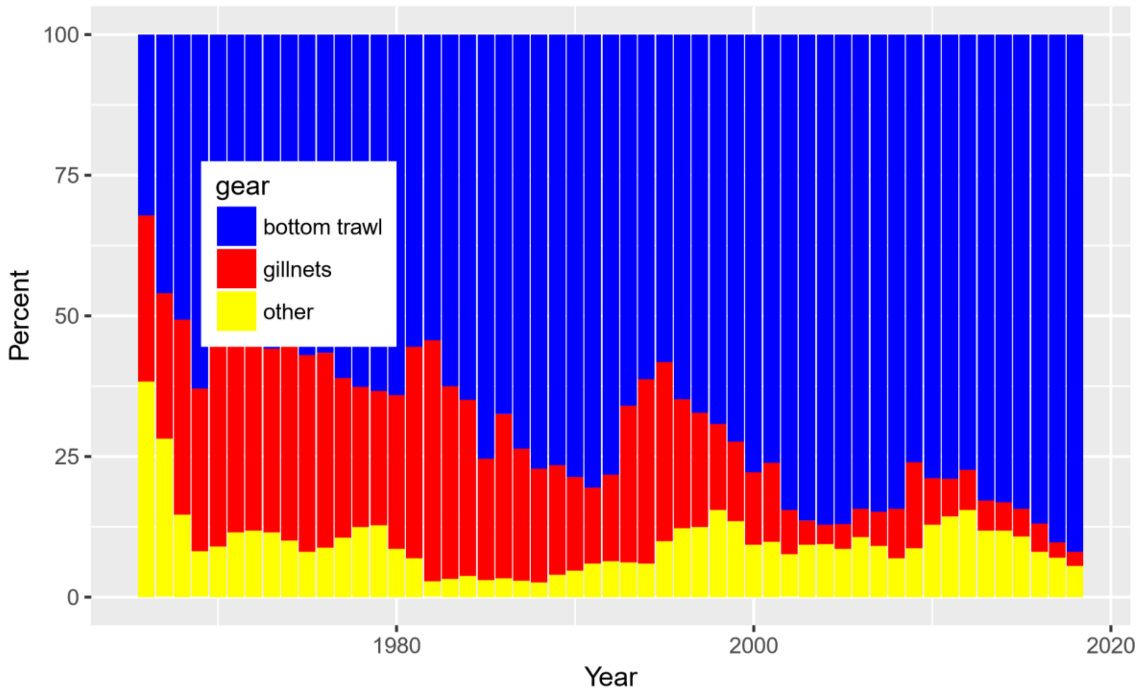

Figure 4: Development of the proportion of saithe catch caught by each gear.

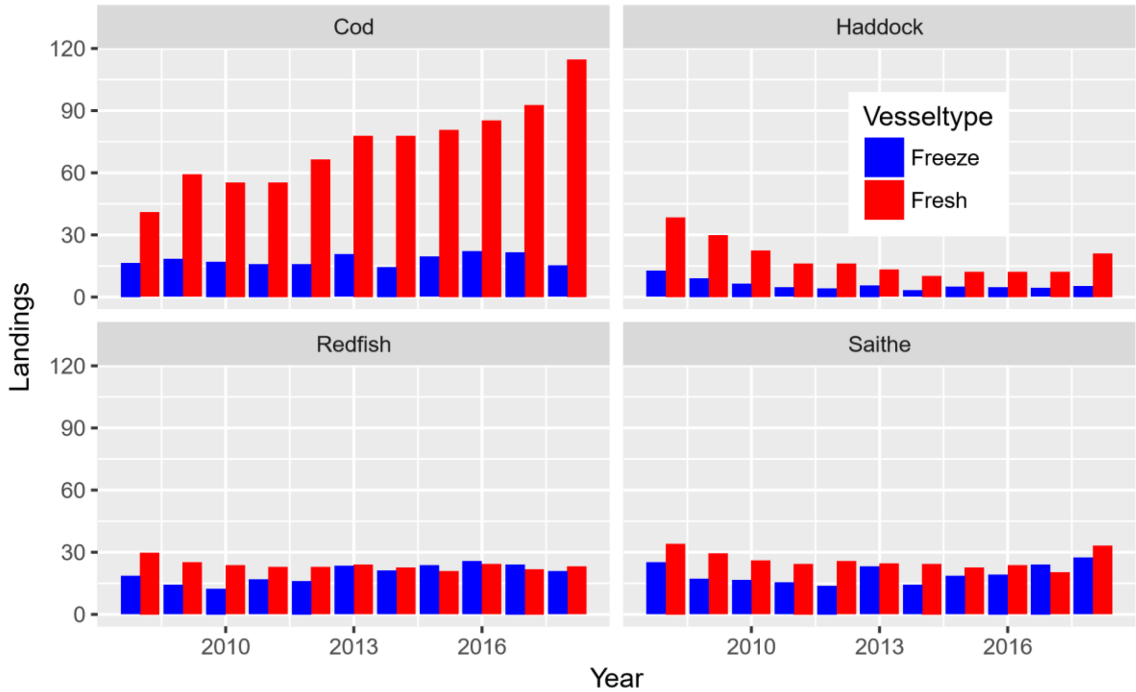

Figure 5: Catch of cod, haddock, redfish and saithe in bottom trawl by year and vessel type i.e. trawlers where the catch is frozen vs those where it is landed fresh.

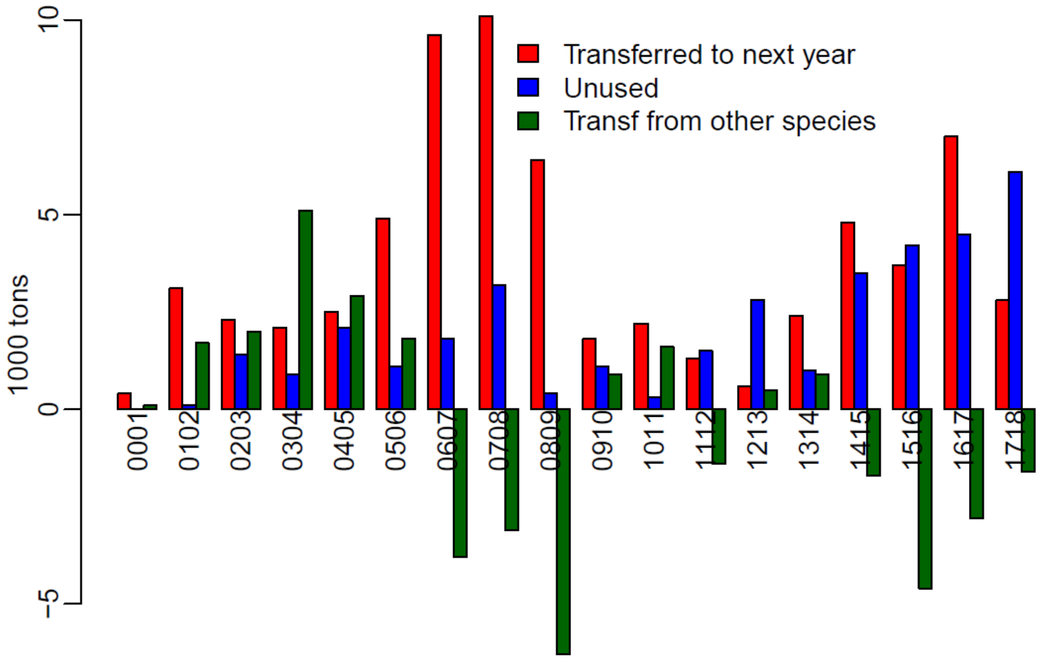

Figure 6: Saithe quota transferred to next fishing year, unused quota and transfer from other species. Last year negative quota was transferred from other species i.e. saithe was converted to other species. Some quota has been unused most of the time, especially in recent years.

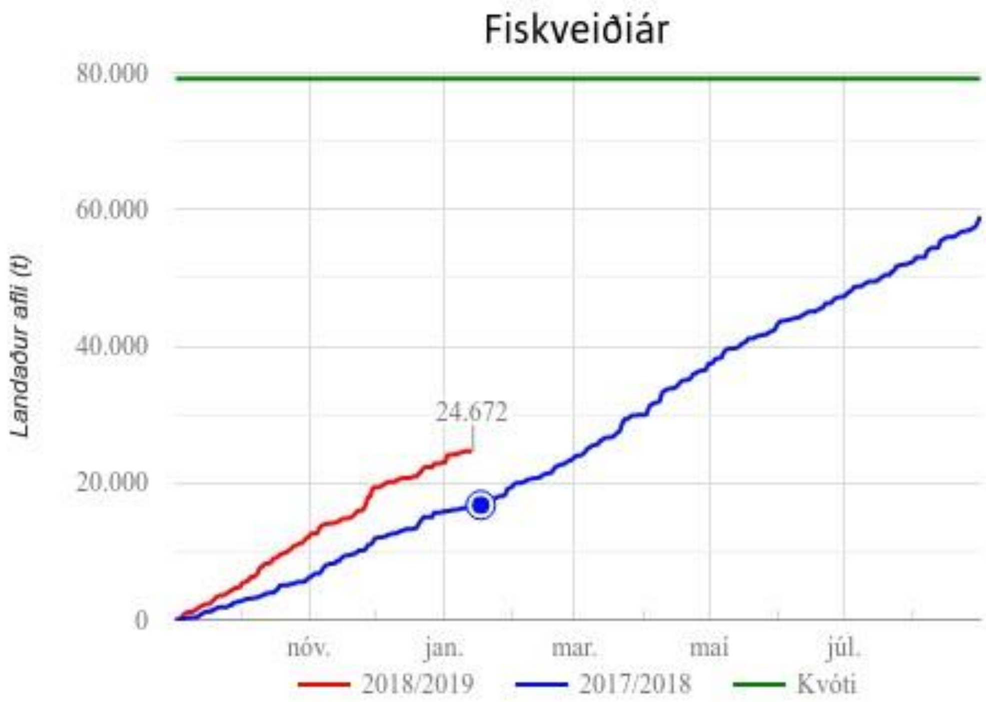

Figure 7: Development of landings in the fishing years 2017/2018 and 2018/2019. The horizontal line shows the TAC for 2018/2019. Since 2013 TAC has been set according to the Harvest Control Rule. Fiskveiðiár means Fishing year and Kvóti TAC.

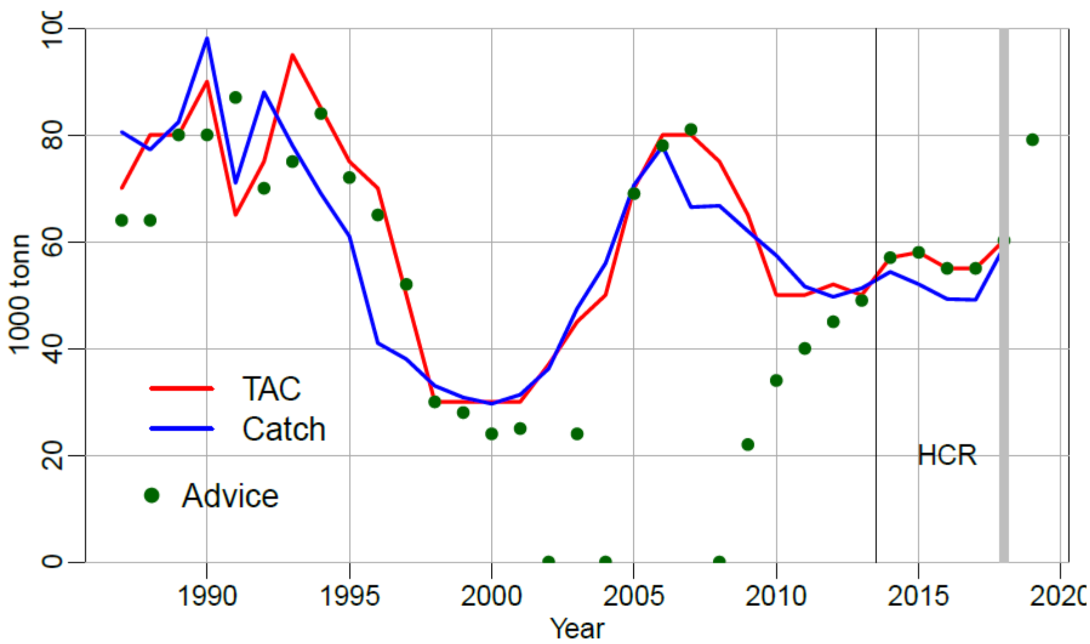

Figure 8: Advice, TAC and catch for saithe since 1987.

4.2.5 Ecosystem drivers

The diet of saithe indicates that it is pelagic during feeding. The most important prey species are capelin, krill, blue whiting, herring and sandeel. Changes in the distribution of pelagic stocks, can affect the propensity of saithe to migrate off shelf and between management units.

What is the most important prey depends on the sampling time and location. In March, capelin is the most important prey like it is for most Idemersal fish stocks in March. Samples taken by the crew of trawlers show higher proportion of krill than other samples. Most stomach samples from saithe are taken from demersal trawl catches.

Most of the stomach samples for saithe are taken after sandeel abundance reduced around 2005. Samples taken in the year 1992 show sandeel to be the most important prey in August and November but capelin in March.

In last decade substantial increase of saithe in the north western area has been observed. In large part of the year capelin is the most important prey in this area, even in recent years when amount of capelin in Icelandic waters has been estimated to be low.

4.3 Stock assessment

4.3.1 Catch – quality, misreporting, discards

Annual estimates of catches of saithe from Icelandic waters are available since 1905, but are here shown since 1955 (Figure 1). Information on origin of the data are listed in the haddock session of this report. Average catches since 1955 have been 64 thous. tonnes, 59 thous. tonnes in the period 1980–2017 that the HCR simulations are based on and 73 thous. tonnes 1955–1980.

Nearly all saithe is landed gutted and converted to ungutted using the conversion factor 0.84. The real gutting factor is on the average little lower so the amount of saithe landed is overestimated. That does though not matter as all the bookkeeping of catch is in terms of gutted fish and the reference to ungutted catch is just gutted divided by 0.84.

Discards are illegal in Icelandic waters. Discarding of saithe estimated annually from 2001–2007 was hardly detectable [1]. The tendency to dicard saithe has been considered to be minimal as the saithe quota has often been difficult to catch. For the same reason incentive for misreporting is considered to be small. Saithe is occasionally found as bycatch in pelagic fisheries, mainly for blue whiting. In 2005–2008, 2010 and 2012 registered bycatch was 1000–2000 tonnes each year.

Annual catch in numbers is based on splitting the fleet in two parts, bottom trawl and gillnets. Other gear are included with the bottom trawl. Conversion from length to weight is based on $W = 0.0024 \times L^{2.7567}$. The sampling system used by the MRI (SÝNÓ) calls for certain number of samples per 1000 tonnes per cell so in principle the number of cells in terms of number of regions and time intervals should not matter. To check if the sampling is working properly annual catch in numbers is also calculated in a more disaggregated way (2 regions , 2 time intervals) and the results compared (Figure 9). The results are usually similar.

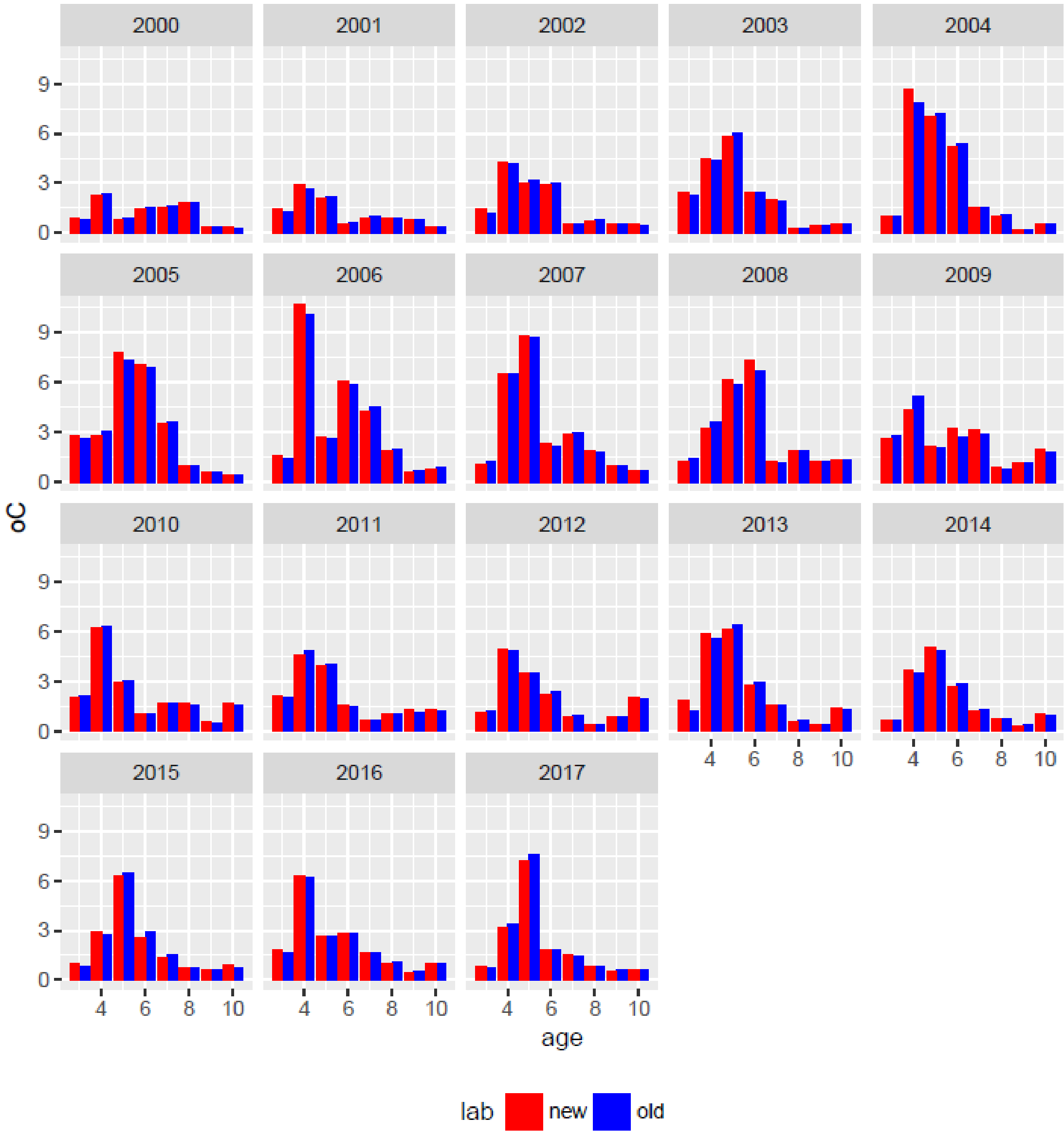

Figure 9: Comparison of traditional catch in numbers compiled by 1 region, 1 time interval and 2 gears (gillnets and trawl) and catch in numbers compiled by 2 regions and 3 gears (hand line, gillnets and trawl). Age 10 is a plus group (10–14 in the old data, 10+ in the new data).

4.3.2 Surveys

Annual survey cruises are conducted by the Marine Research Institute. Three surveys are considered appropriate for saithe. These are the spring survey (March survey commencing in 1985) and the autumn survey (October survey commencing in 1996/2000) that are stratified random bottom-trawl surveys and the gillnet survey conducted in April, commencing in 1996/2002. The spring survey focuses on depths shallower than 500 m and has a relatively dense station-net on the shelf (approximately 560 stations). The autumn survey has around 380 stations but also covers a much larger area including depths to below 1000 m and is also designed to cover Greenland halibut and *S. mentella*. As a result the distance between the stations is considerably greater than in the March survey. Saithe is found in the autumn survey at stations deep south of Iceland added in 2000 (Figure 3) so those stations have to be excluded if the survey since 1996 is used as a time series. The gillnet survey covers the spawning areas of cod (and saithe) during spawning time and most of the saithe caught there is relatively old and large. Saithe was not aged in the gillnet survey before 2002.

Results from the March survey have been used for tuning since 2002. CV in the survey is usually quite high (Figure 10) and the noise can also be seen by low internal consistency (figures 12 and 13). The indices in the March survey have been less variable since 1995 than before (Figure 10. Indices from the gillnet survey and the autumn survey have not been used for tuning but are used for comparison in the assessment.

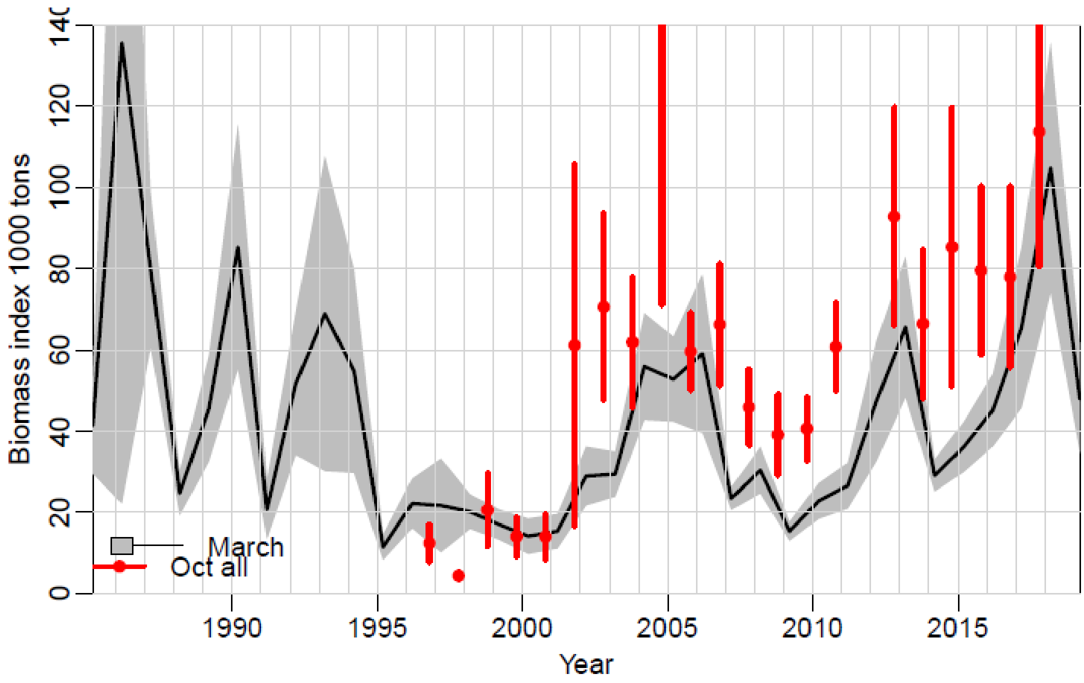

Figure 10: Index of total biomass from the surveys in March and October. The shaded areas and bars show 1 standard deviation in the estimates.

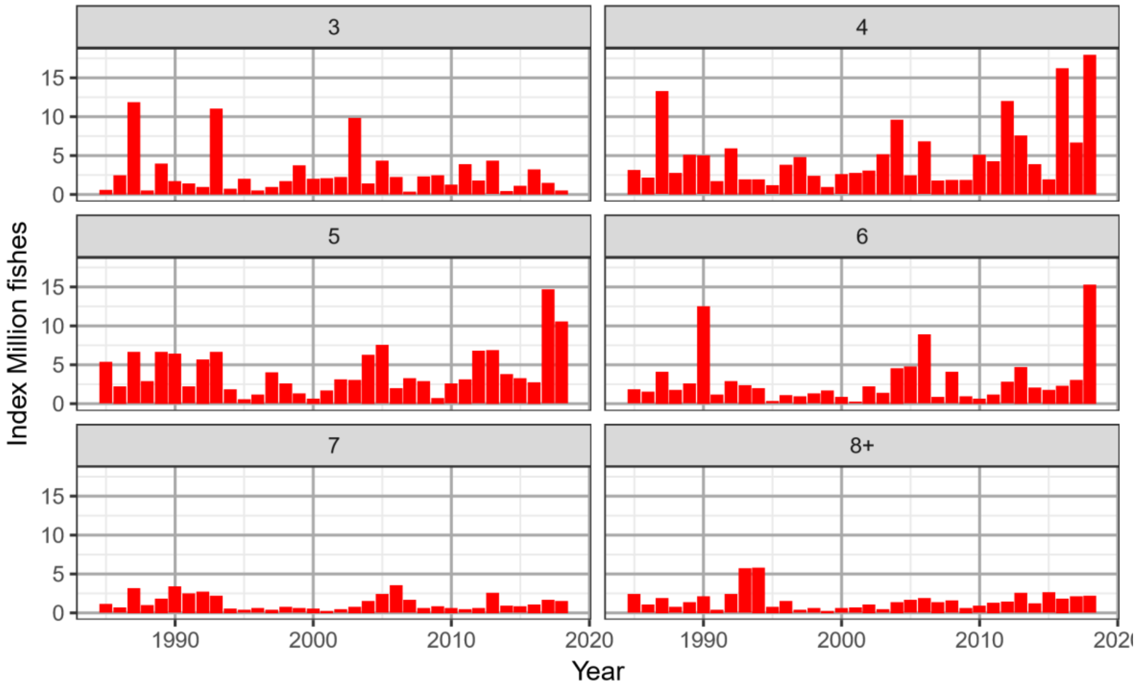

Figure 11: Age disaggregated index from the groundfish survey in March.

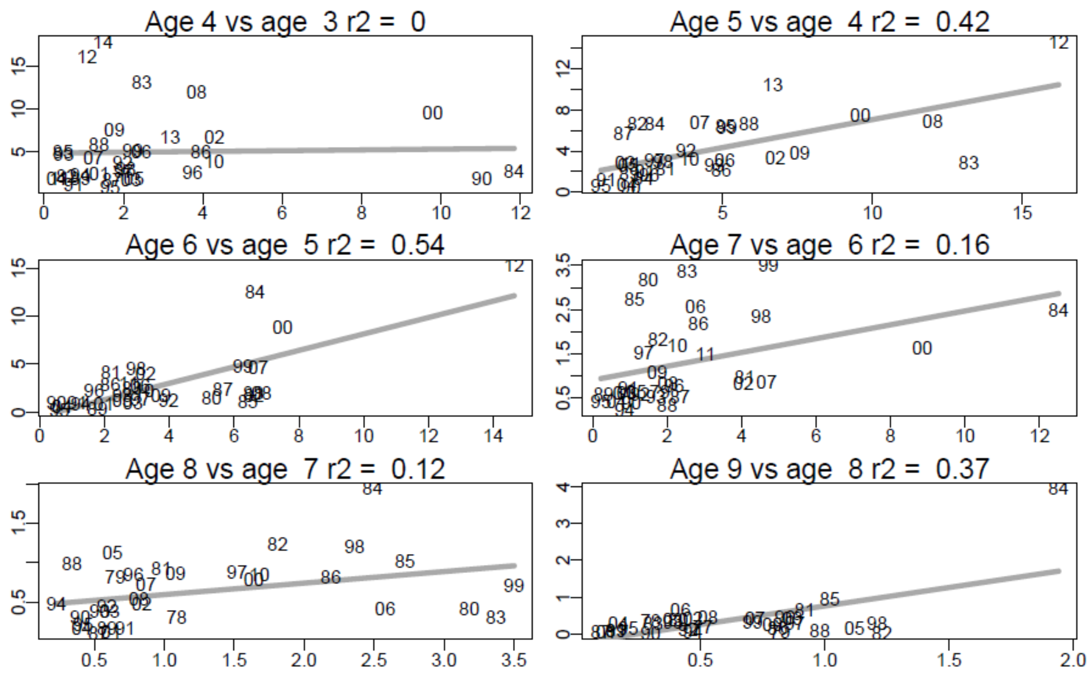

Figure 12: Indices from the survey in March plotted against indices of the same year class the year before. The labels denote year class.

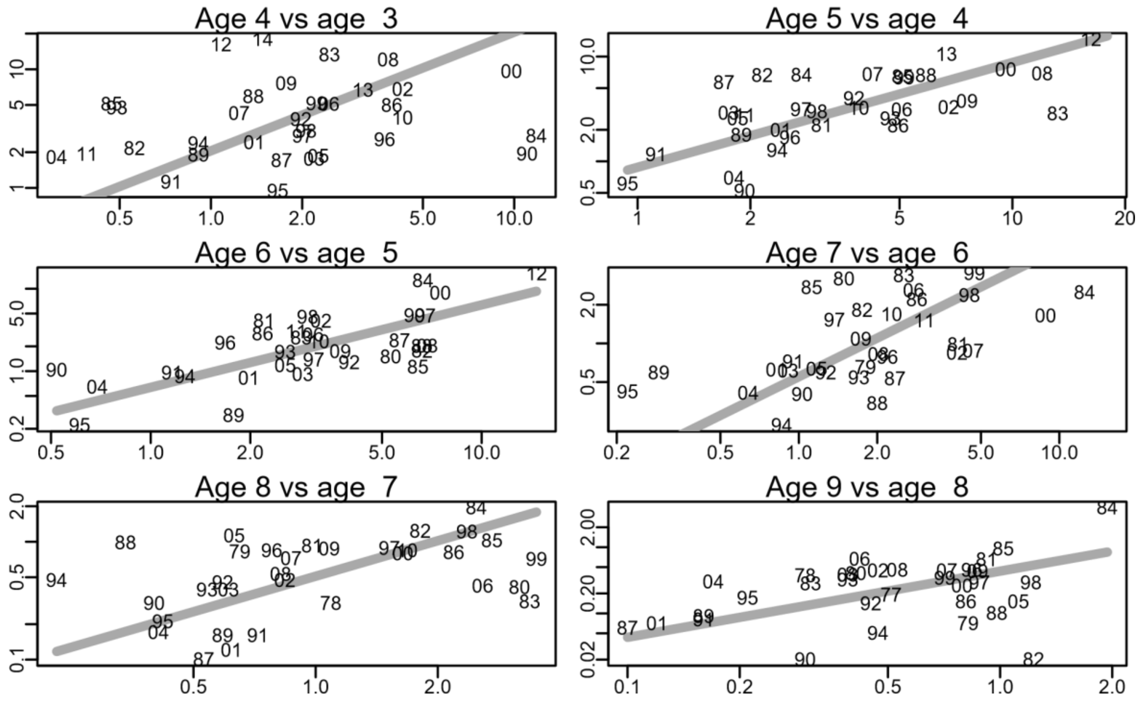

Figure 13: Indices from the survey in March plotted against indices of the same year class the year before on log scale. The labels denote year class.

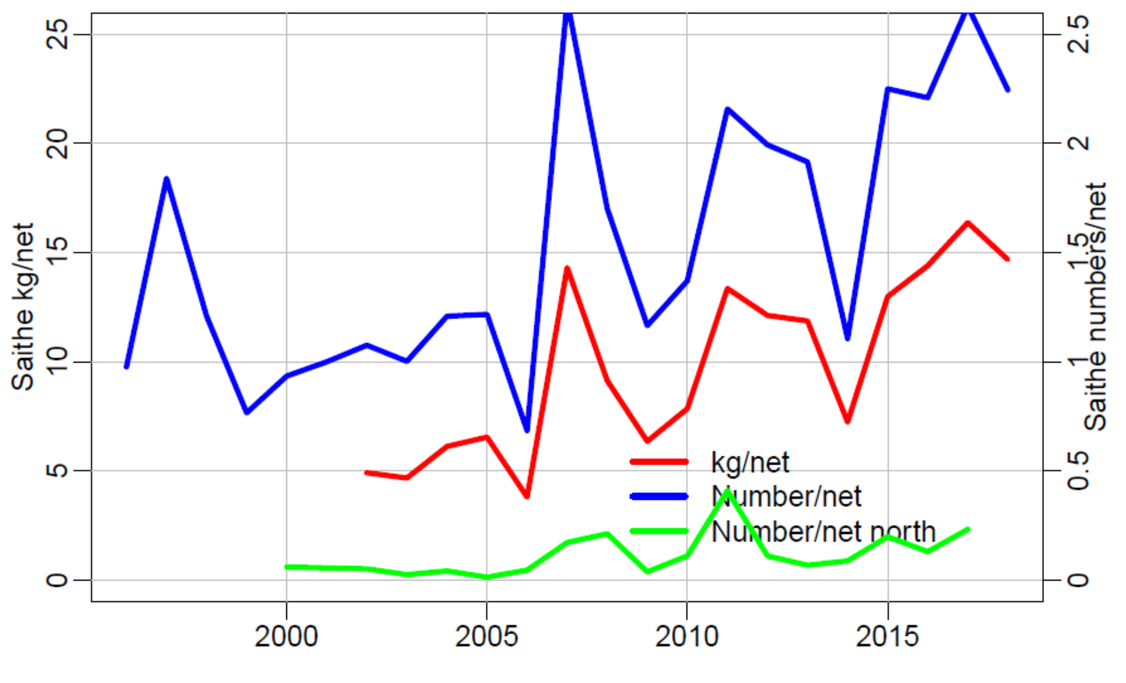

Figure 14: Saithe indices from the gillnet survey south and west of Iceland.

4.3.3 Weight and maturity at age

The advice for saithe is based on the reference biomass (B_{4+}) and $B_{trigger}$ is based on the estimated spawning stock. As described earlier abundance indices from surveys are very uncertain for saithe and the same applies to some degree to the biological parameters. Therefore, reference and spawning stock biomass are based on catch weights rather than survey weights.

Mean weight at age from the survey in March are available at the time of assessment, while the mean weight at age in catches are not. The survey weights at age are unlike mean weight at age in the catches based on condition of the fish each year. Catch weights in the assessment year are predicted from catch weights one year earlier and survey weights in the assessment year (see section on prediction).

Maturity at age is obtained from the survey and has the same problem with variability as other values obtained from the survey. In 2010, a smoother for maturity at age was presented and the plan is to continue to use that method. The prediction from the smoother for the assessment year is used for that year. A disadvantage of the method is that with addition of a new year the smoother can lead to minor change of older values. Maturity at age has been reducing in recent years and is in 2018 below average since the survey started (Figure 16).

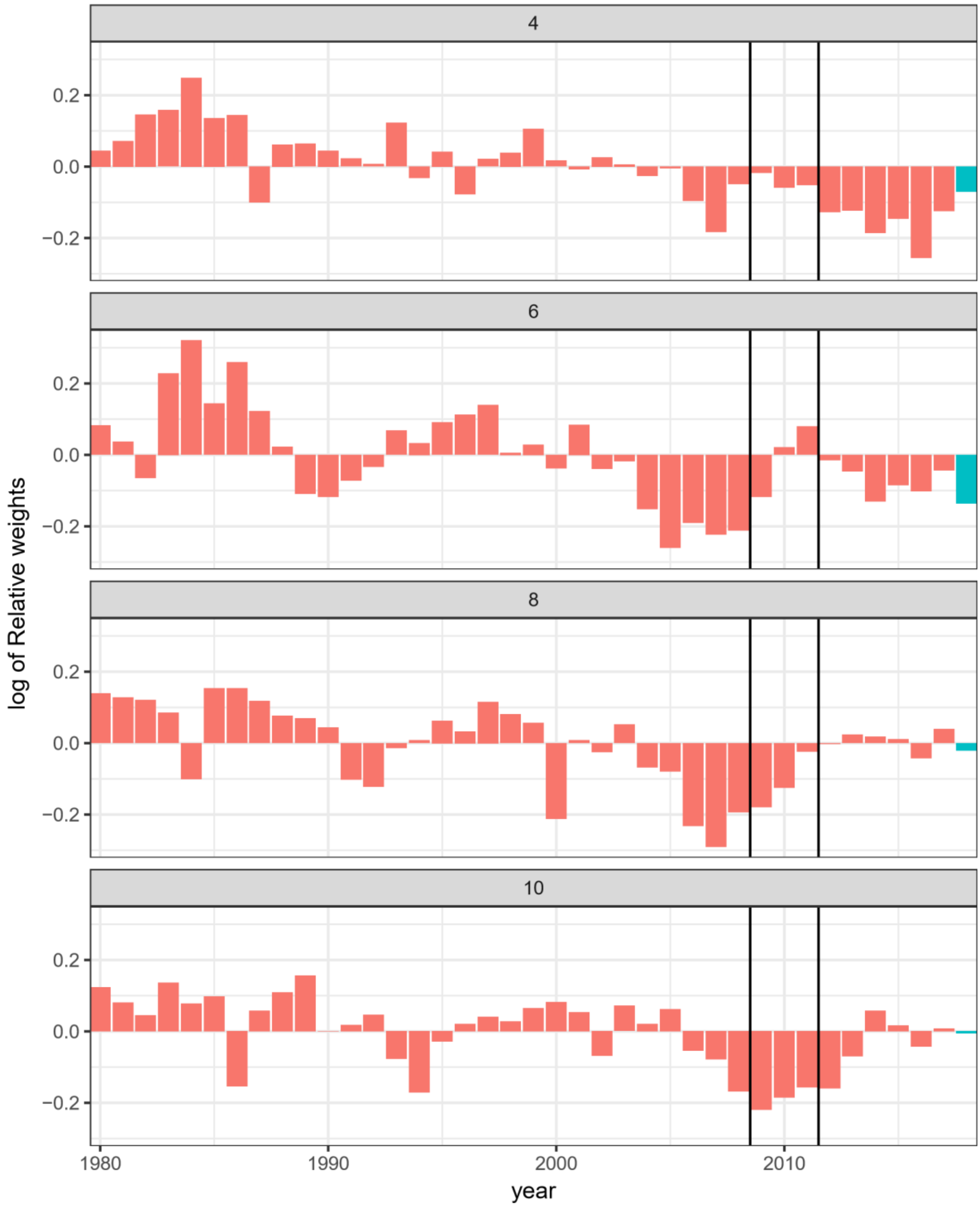

Figure 15: Development of mean weight at age in the landings shown as log of residuals from the average. Predictions are shown with blue colour. The black vertical lines mark the period used as average in the 2013 HCR evaluations.

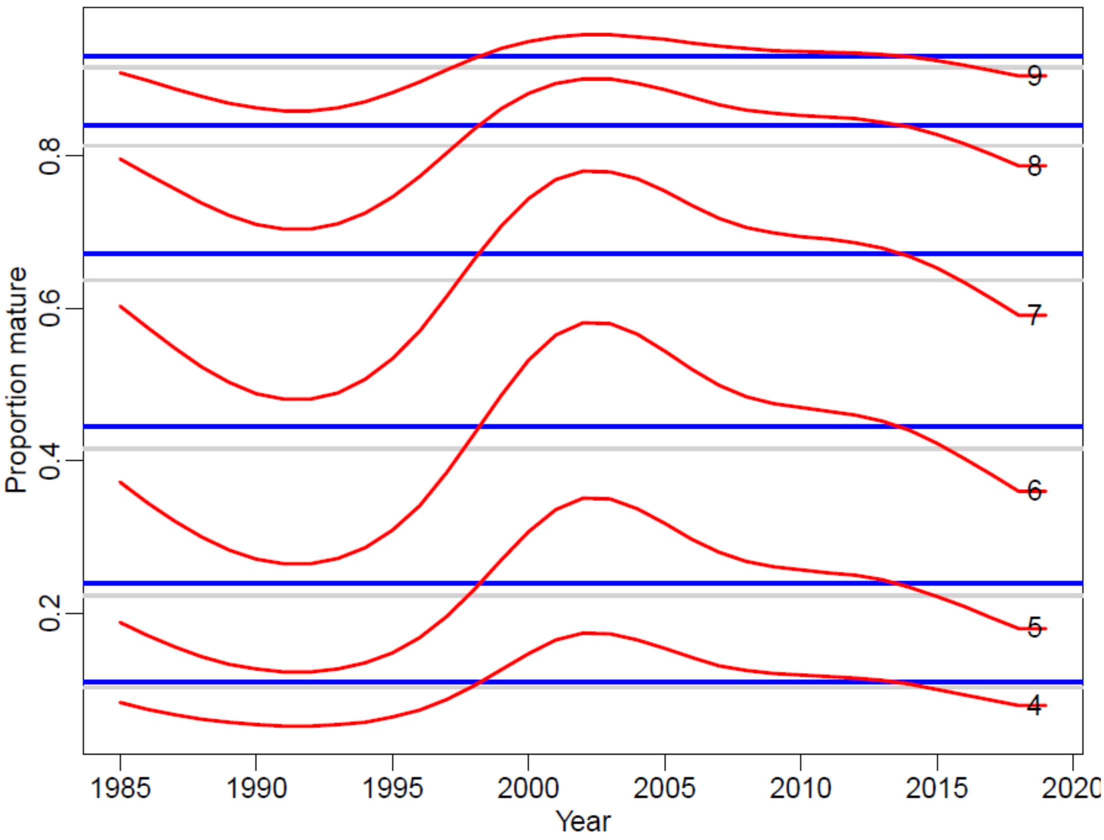

Figure 16: Development of smoothed maturity at age. The grey lines show the average 1985–2018 for each age group. The blue line shows the average of last 10 years and the grey lines average for the period 1985–2018.

4.4 Assessment

At the benchmark in 2010 a separable model was proposed as the main assessment model for saithe [2]. This model is the same as used for HCR evaluations of many Icelandic stocks (MUP-PET).

Selection pattern is estimated separately for predefined periods. For Icelandic saithe the periods are 1980–1996, 1997–2003 and 2004 onwards. The first change in selection is in a period where gillnet fisheries that target the largest fish decreased while the second change in selection was when increased targeting of young fish was noticed. Allowing for change in selection is somewhat delayed process, change in selection requires few years of pattern in catch residuals.

Residuals from the survey each year are modelled by an 1st order AR model with ρ estimated and what is minimized is $\frac{log(I+\epsilon)}{log(\widehat{I+\epsilon})}$ where is a value of the index corresponding to 2–4 otholits, used to reduce weight of low values.

The model can also be run as VPA model but that option was not considered suitable as basis for advice as the assessment is then only depending on the survey. The VPA version is used to evaluate the quality of the survey indices historically and to get an estimation of the pattern of CV with age in the survey.

The model does not have any time series model for fishing mortality. The main reason is that there is already a low pass filter in the HCR and too much low pass filtering is not necessarily desirable. The effect of constraint on variability in fishing mortality is also not obvious, sometime it might work sometime not.

Every year the assessment model is run with different settings and other models are also used (Figure 22). How those multiple runs are used is not certain but the idea from John Pope when reviewing the Icelandic cod assessment "Run multiple models and select results in the middle of plausible values" does not fit into recent ICES procedures.

The different models are all run with $M = 0.2$. Saithe is rarely found in stomachs of other fish so predation mortality would have to be caused by marine mammals that are poorly sampled. The available data give no possibility estimating M that is most likely not higher than 0.2 for the ages in the fisheries.

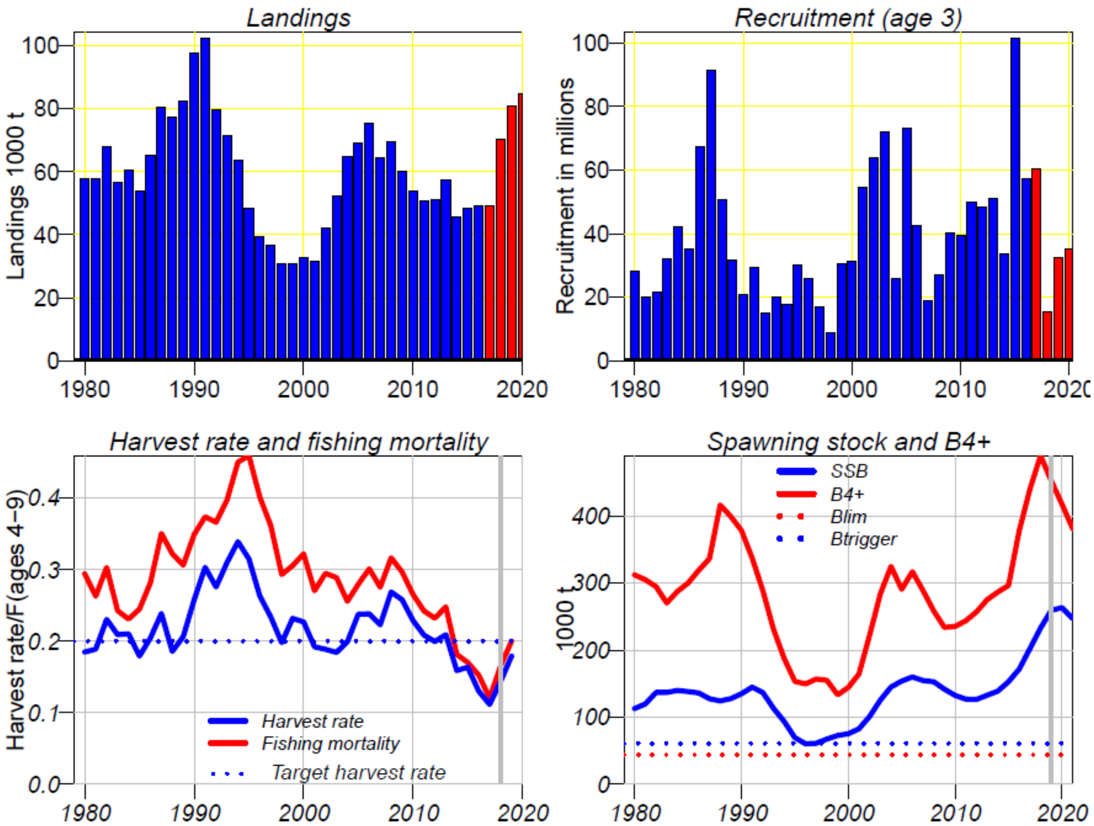

Figure 17: Summary of the 2018 assessment with predictions using the HCR.

4.4.1 Residuals

Observed survey biomass shows more contrast than predicted survey biomass (Figure 18). This is quite normal but usually the discrepancy is less than observed here. The Figure shows better relationship after 1995 than before. Survey biomass is here a derived number as the tuning is done with log residuals by age.

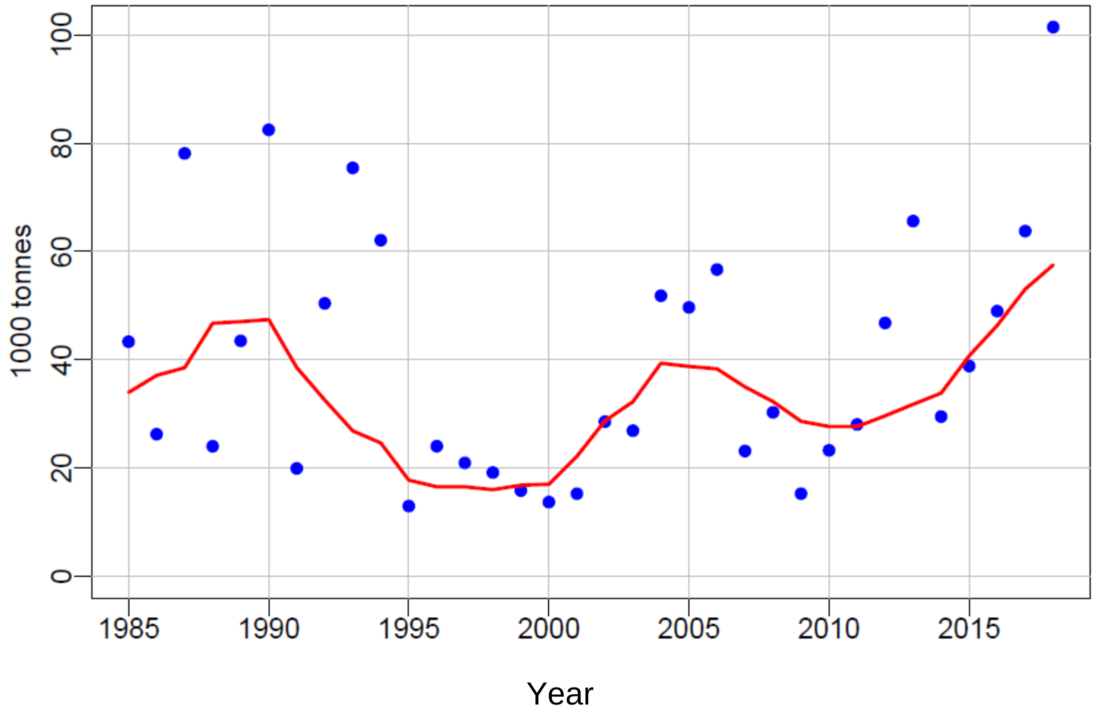

Figure 18: Observed and predicted survey biomass.

Survey residuals (Figure 19) show clearly the tendency for positive and negative blocks. The negative blocks occur in years where no large school of saithe is encountered. Correlation between age groups in the survey is modelled by 1st order AR model but the residuals shown are the input to the AR model. The estimated value of ρ for the survey residuals is 0.56 in the 2018 assessment.

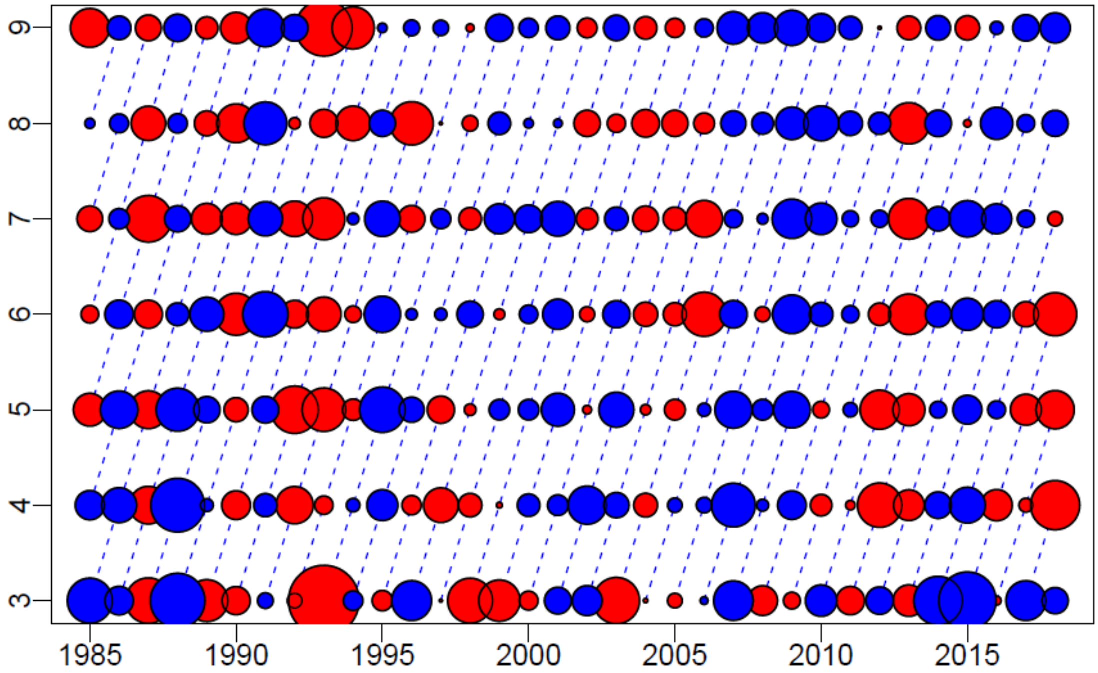

Figure 19: Survey residuals, largest circle corresponds to 1.92.

Selection by period demonstrates considerable difference between 2004–2017 and the other periods that are similar (Figure 21). Catch residuals indicate that there might be some change in selection in recent years with less caught of ages 3 and 4 (Figure 20).

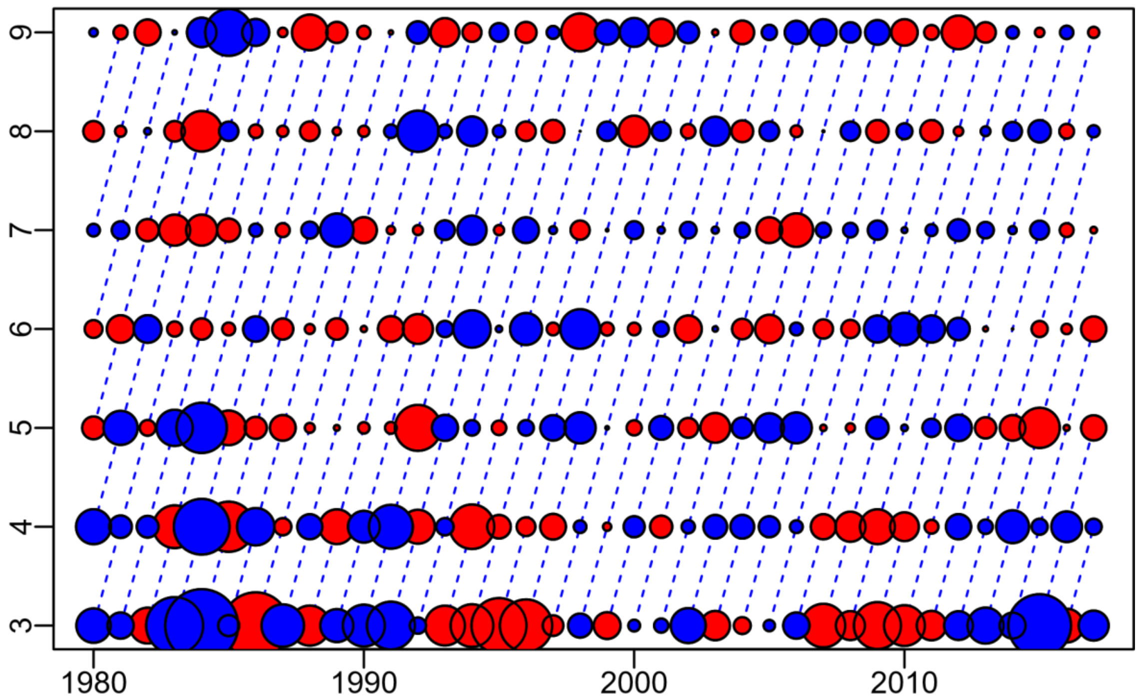

Figure 20: Catch residuals, largest circle corresponds to 1.07.

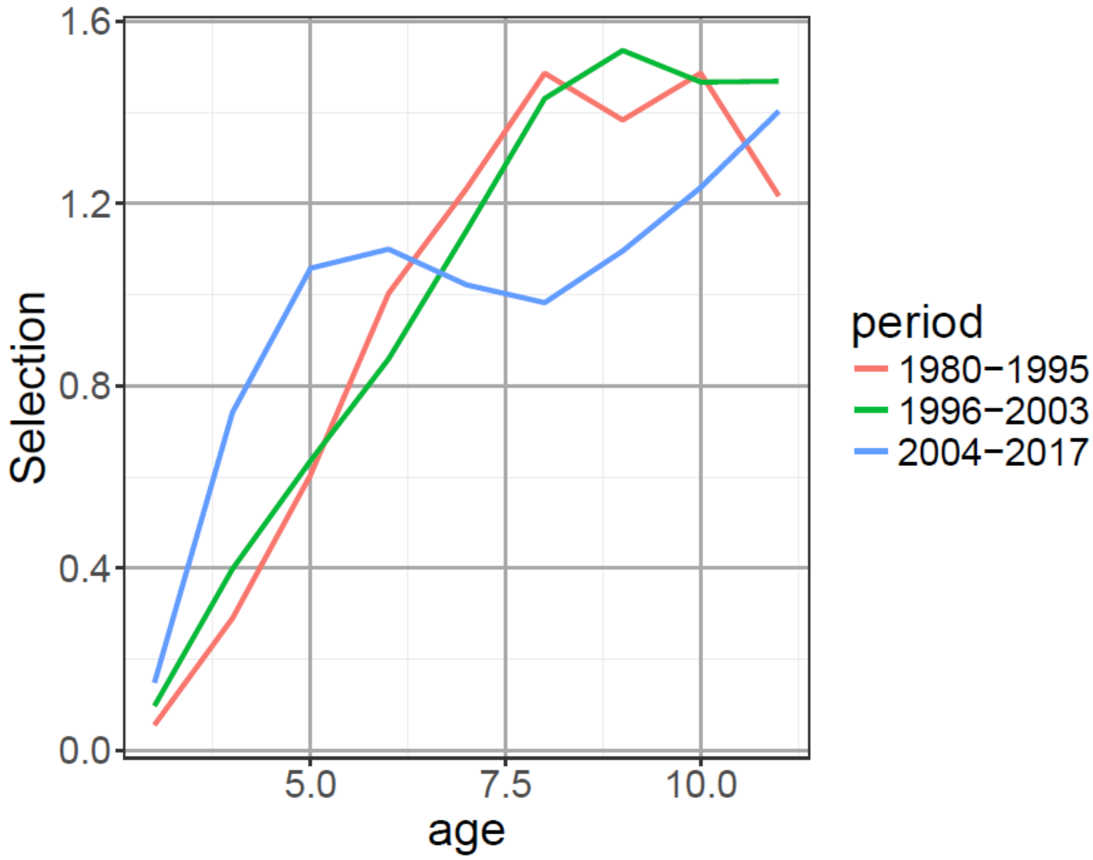

Figure 21: Selection at age for the 3 periods 1980–1995, 1996–2003 and 2004–2016.

4.4.2 Results from different assessment models

Different assessment model using the same data lead to biomass in 2018 (the basis for advice) between 420 and 530 thous. tonnes. Fishing mortality has been reducing so the models with penalty on changes in fishing mortality indicate lower biomass this time. The Adapt model depends more on survey data than the other models and does therefore show higher biomass this time when the survey indicates increased biomass.

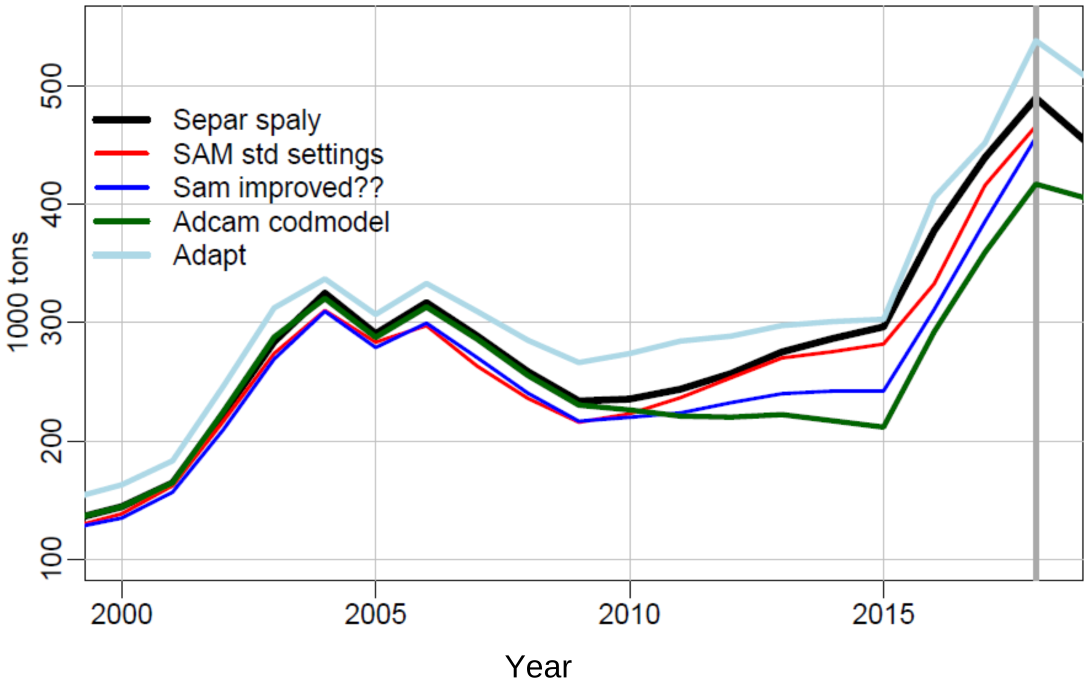

Figure 22: Results from few assessment models run on the data used in the 2018 assessment. Adcam codmodel is a model where fishing mortality is modelled as correlated random walk.

The difference shown in Figure 22 is not unexpected looking at uncertainty estimates from the selected assessment model where $\sigma_{log(B4+,2018)} = 0.16$ and $\sigma_{log(F4-9,2017)} = 0.156$. Other assessment models give similar uncertainty estimates.

4.5 Short term projections

The advice for the saithe is based on biomass (B4+ and SSB) in the beginning of the assessment year. Both biomasses are compiled based on catch weights that are predicted from catch weight in the year before the assessment year and the mean weight at age in the survey in March in the assessment year (see stock annex). Maturity at age is obtained from the March survey (smoothed see stock annex). No other projections are needed for compiling the advice.

Weight and maturity in the assessment year are used for the next few years in short term projection.

Selection from the most recent selection period is used in short term prediction that is done by the assessment model. Compilation of TAC does not depend on the selection that does therefore have relatively small effect.

4.6 Reference points

B_{lim} is the basis for the other reference points and is set based on the stock - recruitment relationship (Figure 23). Figure 23a is based on estimating autocorrelation of recruitment residuals but 23d is based on fixing the autocorrelaton at 0.1 in the estimation. The deterministic fit is the same in both cases with SSB_{break} estimated at B_{loss}. The scatter of the SSB_{break}/R_{max} pairs is as expected more when autocorrelation is estimated but the autocorrelation reduces the effective number of data points and the ρ_{rec} is poorly defined (Figure 25). Large part of the points in the simulation is based on breakpoint below B_{loss} but the Hockey stick function is completely uninformative if the breakpoint is at or below B_{loss}. The lower limit is set to 35 thous. tonnes and as the estimated parameter is on log scale the distribution of the values tends to be somewhat in the direction of lower values. As usually there is a positive correlation between SSB_{break} and R_{max} so the high SSB_{break} runs are also promising more productivity. The sensitivity of the assumed lower limit of SSB_{break} in the mcmc simulations on the resulting HR_{msy} was tested. Changing it to B_{lim} (44 thous. tonnes) lead to neglible change but setting the lower limit to 55 thous. tonnes reduced HR_{msy} by 0.01–0.02. The lower limit of 55 thous. tonnes is for this for this purpose very close to the estimated value of the breakpoint (60 thous. tonnes). This problem of having to describe lower bounds would not be as obvious with Beverton and Holt and Ricker SSB-recruitment relationships that are differentiable over the whole range. The problem is though there, it is somewhat hidden. *** Summary of average predicted recruitment vs spawning stock (Figure 24) shows that it starts reducing when SSB is below 100 thous. tonnes as some of the pairs show $SSB_{break} > 100$ thous. tonnes (figure-fig:ssb-reca).

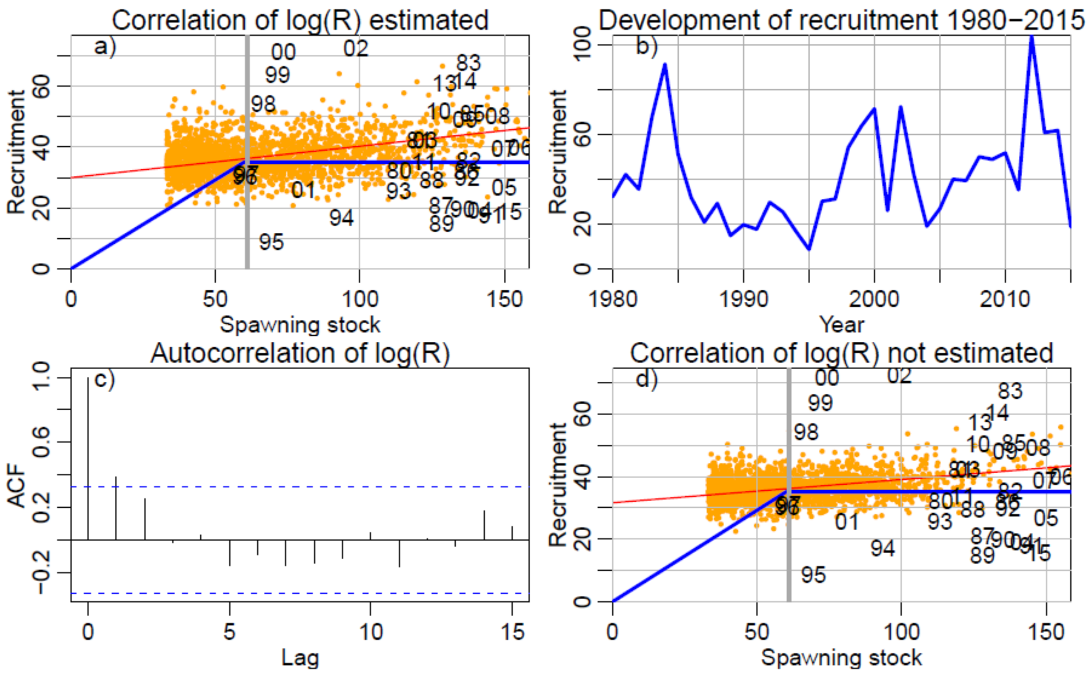

Figure 23: a) R_{max} and SSB_{break} from mcmc simulations where ρ_{rec} is estimated. b) Time series of recruitment. c) Autocorrelation of $log(R)$. d) R_{max} and SSB_{break} from mcmc simulations where ρ_{rec} is fixed at 0.1. Historical pairs of spawning stock and recruitment and estimated Hockey stick curves are shown in figures a and d. They are nearly identical as the the stock recruitment relationship does not affect historical stock assessment.

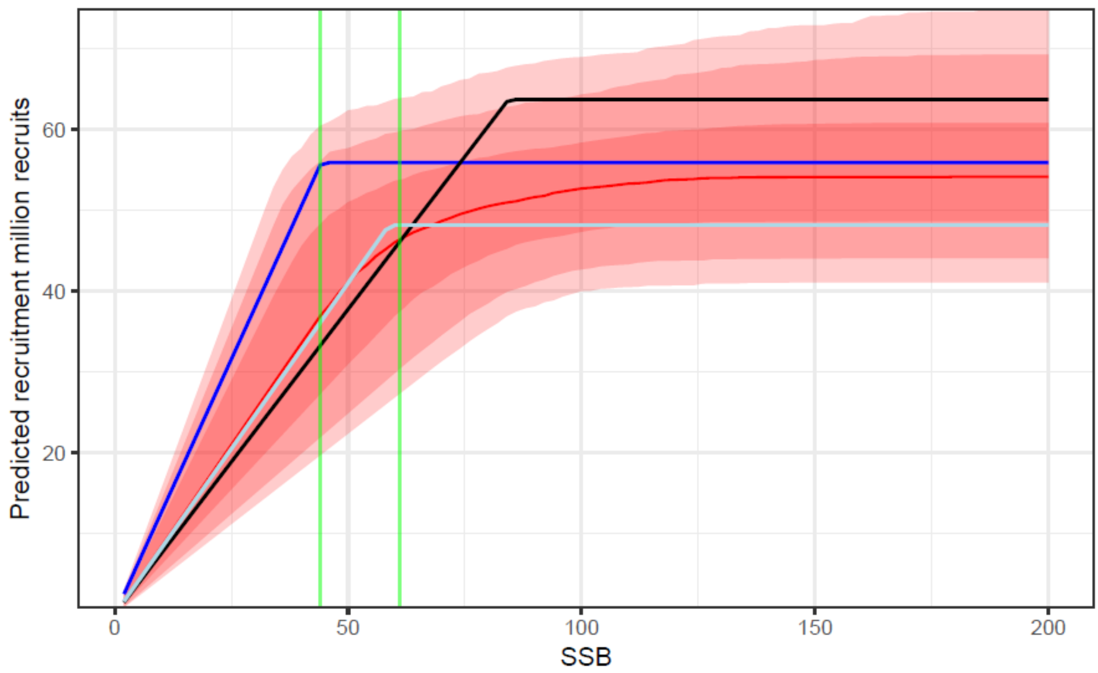

Figure 24: Distribution of predicted recruitment as function of spawning stock. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. The blue, black and light blue lines show 3 of the SSB-rec relationships that the figure is based on. The results are based on the point scatter in Figure 23a.

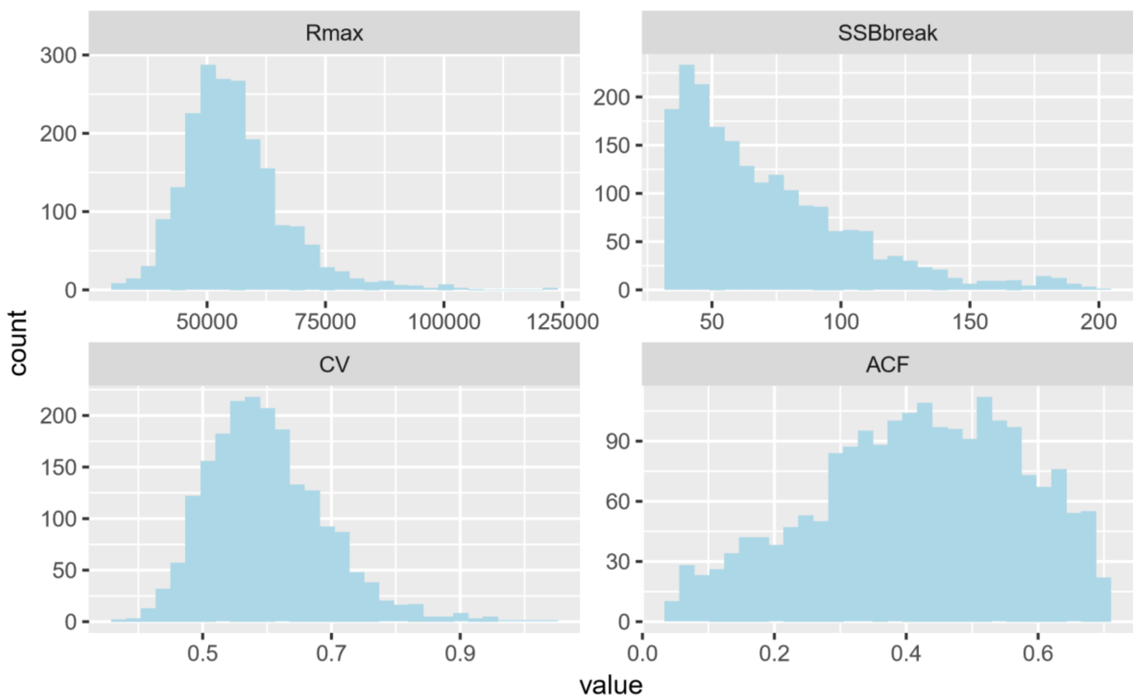

Figure 25: Distribution of the estimated stock-recruitment parameters.

When HCR was evaluated last time in 2013 B_{lim} was B_{loss} =≈ 61 thous. tonnes which was also the estimated breakpoint in the hockey stick function. In the current assessment B_{loss} is a little lower or 60 thous. tonnes due to minor changes in historical numbers and age. The smoothed maturity at age can also change slightly with addition of new points.

In ICES guidance for setting reference points [5] there is a category called Type 6 "Stocks with narrow dynamic range and showing no evidence of past or present impaired recruitment". The comments about this category is "No B_{lim} from this data, only the PA reference point. (B loss could be a candidate for B_{lim}, but this is dependent on considerations involving historical fishing mortality". In 2016 the North Western working group classified Icelandic saithe as type 6 stock and defined $B_{lim} = \frac{61}{1.4} = 44$ thous. tonnes. The 2013 HCR evaluations were based on $B_{lim} = B_{loss}$.

The range in spawning stock is approximately 1:2.5 (based on converged assessment i.e the years 1980–2015) for a stock where range in 5 years average of recruitment (approximately the number of cohorts in the spawning stock) is 1:3 (19 to 57 million).The Fishing mortality of ages 4–9 has been in the range 0.25–0.45 that is relatively moderate. Selection has changed in last decade toward smaller fish so $F_{4\text{–}9}$ from the period after 2004 is not comparable to earlier years (they are lower for the same fishing pressure). The highest average F during 5 years period was 0.41 (1991–1995) but for comparison F_{MSY} based on the selection pattern of the fisheries in those years is ≈ 0.3. (≈ 0.23 for the selection pattern after 2004).

Comparison of the historical fishing mortality of the Icelandic saithe stock and other stocks in the ICES area shows that it has been low compared to most ICES stocks and the stock has not been severely depleted [3]. Relatively modest historical fishing mortality seems to be a feature of the North Atlantic saithe stocks indicating that they might be difficult to catch. The main difference between the Icelandic and Faroese saithe stocks compared to the North Sea and Barents sea saithe stocks is less contrast in fishing mortality and spawning stock. Historical harvest rates are also not much higher than proposed by the HCR (Figure 32).

For the Icelandic and Faroese stocks the B_{loss} has been defined as B_{pa}, for the North sea stock B_{loss} is B_{lim} and for the NEA saithe stock B_{lim} is the defined as the breakpoint in hockey stick regression.

$B_{trigger}$ was defined as 65 thous. tonnes in 2013 that was not in conformity with ICES standards that call for $B_{trigger} \geq B_{pa}$. After the change of B_{lim} to 44 thous. tonnes $B_{trigger}$ of 61 thous. tonnes and higher is in conformity with ICES standards.

F_{MSY} is not defined for this stock but rather HR_{MSY}. The reason is that the management plan is defined in terms of harvest rates and changes in selection can lead considerable variations in F_{MSY} for a given HR_{MSY} [3].

The analysis done her indicate that B_{loss} is a canditate for B_{pa} and B_{lim} is derived as $\frac{B_{pa}}{1.4}$. In spite of minor change in B_{loss}, $B_{lim} = 44$ and $B_{pa} = 61$ will be continued. $B_{trigger}$ will be changed from 65 to 61 thous. tonnes to be in conformity with the standard ICES MSY $B_{trigger}$.

Running the model with average selection of last 40 year and no assessment error leads to $SSB_{50} > B_{lim}$ if $F_{4\text{–}9} < 0.50$ that is then candidate for F_{lim} (Figure 26) $F_{pa} = \frac{0.50}{1.4} = 0.36$. In terms of harvest rate $HR_{lim} = 0.32$. (Figure 27).$HR_{pa} = \frac{0.32}{1.4} = 0.23$.

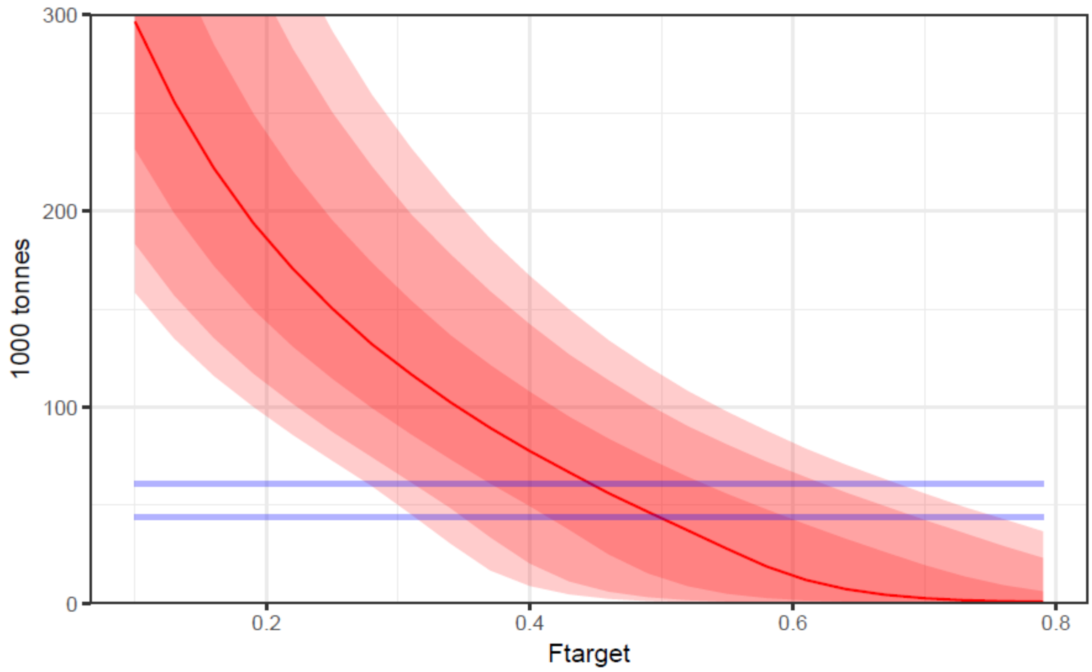

Figure 26: Spawning stock as function of F_{target} The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. No assessment error.

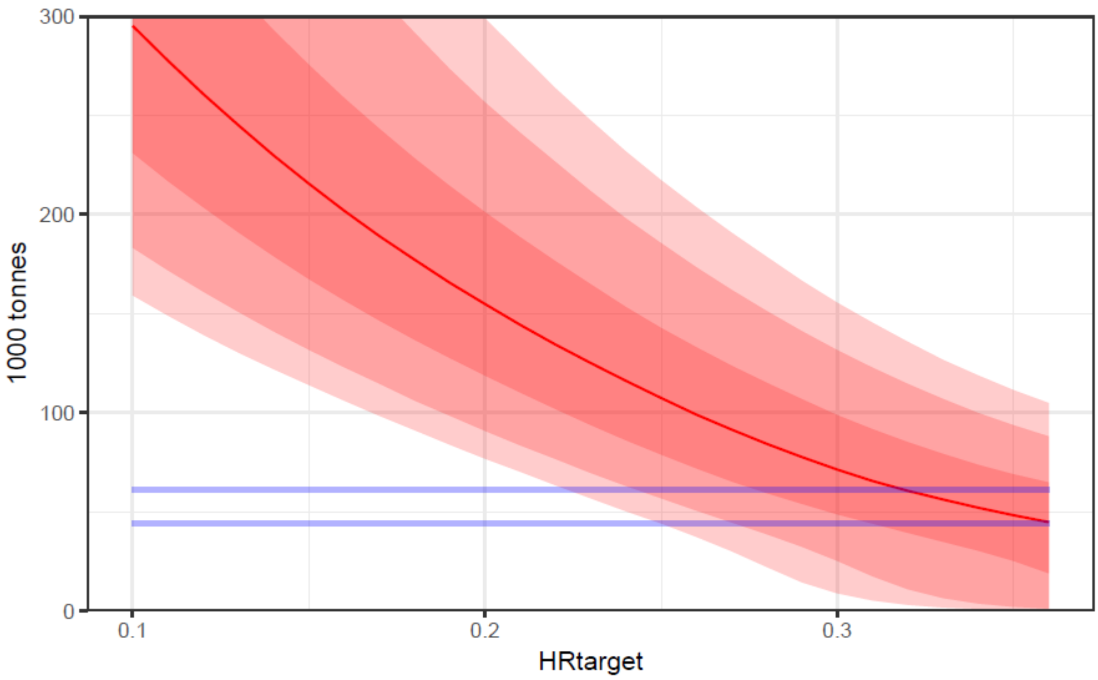

Figure 27: Spawning stock as function of HR_{target} The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. No assessment error.

4.7 Future research and data requirements

The main problem with saithe assessment relates to the observation problems. One of the reasons is that even in a survey with ≈ 560 stations like the Icelandic March survey relatively few stations can account for most of the saithe index. An option that will be tested is to include estimated uncertainty in the survey in the assessment model. Including the autumn survey and even the gillnet survey in assessment will also be tested.

4.8 Harvest control rule evaluation

Current work is similar to the 2013 work [3] with few more years of data added. The main change is that the autocorrelation of recruitment residuals is now estimated and ρ_{rec} is one of the parameters included in the simulations while in the 2013 work rho_{rec} was fixed at 0.4 in the simulation phase but the value 0.1 used in the estimation. The value estimated now is 0.4 but the uncertainty is large (Figure 25).

In 2013, average mean weights at age were stochastic around the average 2009–2011 (the 3 most recent years for catch weights in those simulations). This time the average of last 10 years is used, low for younger age groups, around average for older (Figure 15). The same period is used for future maturity, above average for all age groups (Figure 16). Stochastic variations are introduced around the average weights, a lognormal year factor with $\sigma = 0.13$ and $\rho = 0.5$. Maturity at age is fixed. Variations in weight at age are independent of stock/cohort size.

4.8.1 Assessment error

As described above estimate from the assessment model is $\sigma_{log(B4+,2018)} = 0.16$. Retrospective runs are useful alternatives to estimate uncertainty but they have to span relatively long time to be useful. They do also give an idea about autocorrelation of the assessment error.

Analytical retrospective pattern based on assessment years 2001–2018 demonstrates considerable uncertainty in estimated biomass (Figure 28). Using the assessment years 2000–2014 leads to estimated CV of B_{4+} in the assessment year ($log(\frac{B_{4+,y,y}}{B4+,y,2018})$) being 0.22, ρ in an AR_1 model estimated around 0.5 and bias around -0.07. Adding the years 1997–2000 increases the CV to ≈ 0.3 but the model performs poorly from 1997–2000. This is to be compared with the value of 0.16 from the assessment model. Estimated uncertainty of models is usually an underestimate of the real uncertainty, due to ignored correlations and wrong structure. Analytical retros are on the other hand based on shorter and shorter time series the further back that we go so they might overestimate the magnitude of the assessment error. In the 2013 evaluation CV of the assessment error was set tp 0.2 while the estimated CV from the model was 0.18 (fewer years in the survey than now, therefore higher CV).

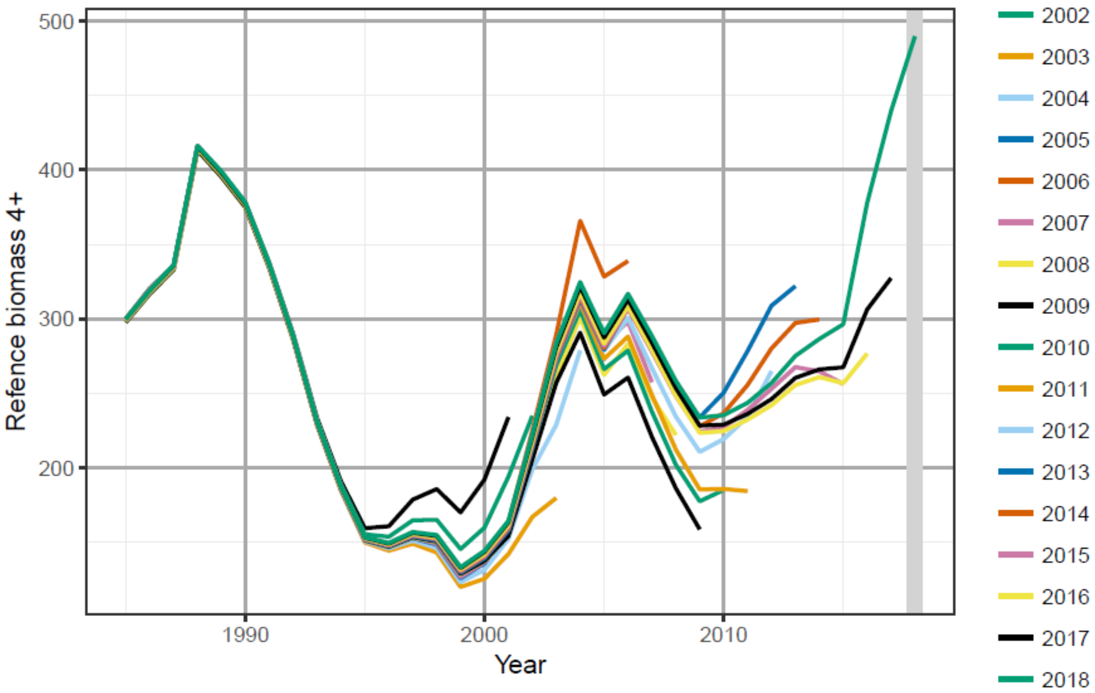

Figure 28: Retrospective pattern of reference biomass from the MUPPET model.

Based on those results the HCR simulations are based on an assessment error that is auto correlated lognormal with $\sigma = 0.22$ and $\rho = 0.5$. This is higher value than in the 2013 simulations but both higher and lower values could be argued for.

Mohn's ρ for $B4+$ is -0.088 base on last 5 years (default) but -0.085 based on last 17 years. Comparable value for the spawning stock are -0.02 for last 5 years and -0.08 for the last 17 years.

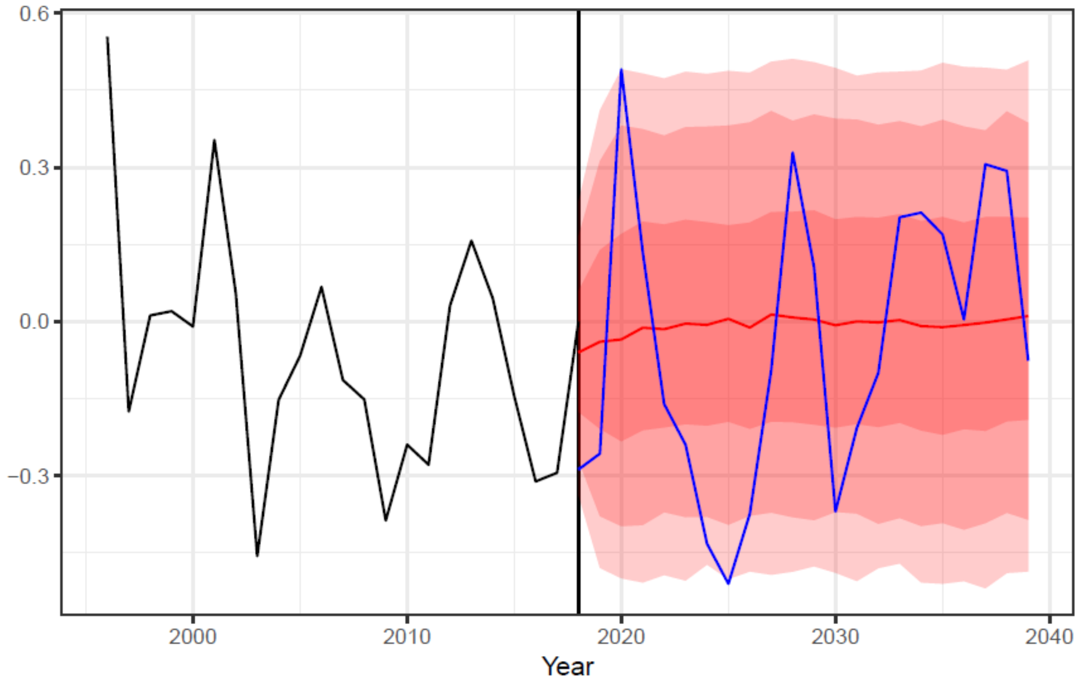

Figure 29: Assessment error (empirical), shown as ($log(\frac{B_{4+,y,y}}{B4+,y,2018})$. Lines for the period 2014–2018 are really wrong as the assessment has not converged. The 2018 assessment is by nature perfect in this figure. The blue line shows one realisation of future assessment error.

Comparison of the assessment error proposed (σ = 0.22) seems to indicate that it is in line with what has been observed historically (Figure 29).

Implementation error was included like in the haddock lognormal with σ = 0.07 and ρ = 0.65. As described above implementation error has been negative since the HCR was adopted in 2013.

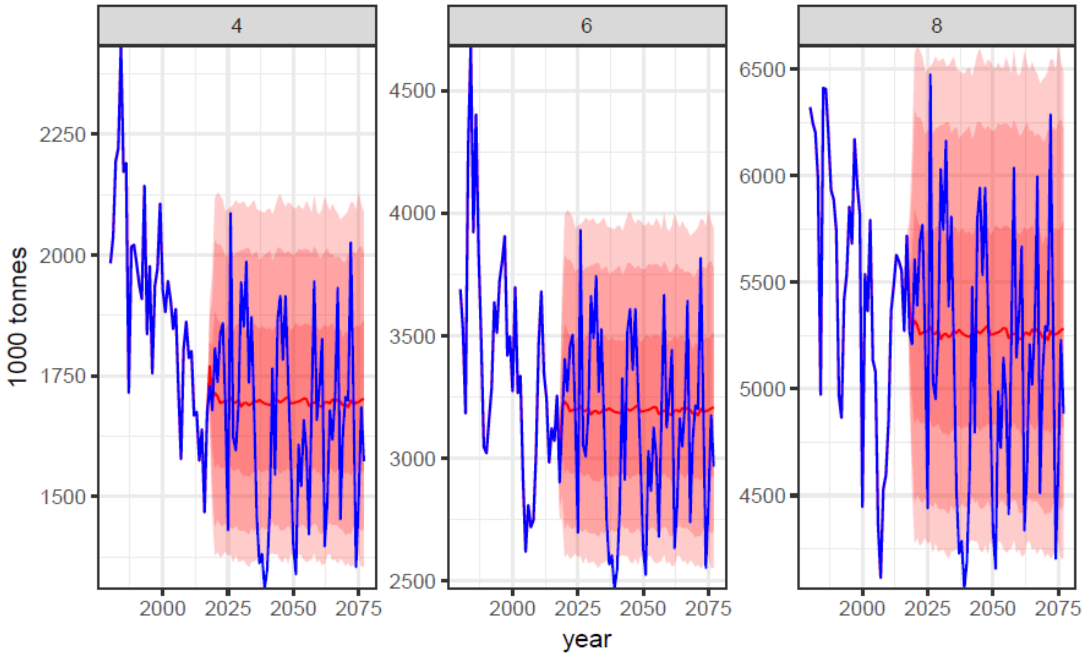

Figure 30: Development of mean weight at age is simulations compared to historical values.

4.9 Results of HCR simulations

The model was run using 3 million MCMC iterations saving 2000 values that were then the basis for stochastic simulations spanning 60 years from 2018–2077. ICES directives call for F_{MSY} being the lower of 2 value [6]

1. Fishing mortality giving maximum median yield using $B_{trigger} = 0$
2. Fishing mortality giving $P(SSB < B_{lim} = 0.05)$ using $B_{trigger} \geq B_{pa}$. Referred to as Fp_{05} but should perhaps be called F_{pa} (here HRp_{05})

If short or medium term is higher than long term risk F_{MSY} will be decided based on $P(SSB < B_{lim} = 0.05)$ for all years. Medium term risk is currently the highest risk for this stock (Figure 34) or 0.04 in the year 2027 (based on HR = 0.2, $B_{trigger} = 61$).

These criteria are carried over to Harvest rates and the stabiliser in the HCR is also included in the estimation. The first criterion leads to $HR_{MSY} = 0.19$ (Figure 31) while the latter one leads to $Hp_{05} = 0.22$ (Figure 31). The risk of $SSB < B_{trigger}$ is little higher than 0.05. The range of Harvest Rate where median catch is predicted to be > 95% of the maximum is 0.13–0.22 and > 98% from 0.16–0.21. ICES HR_{MSY} is defined based on no implementation error and no stabiliser. Those settings lead to $HR_{MSY} = 0.2$ but the median yield curve is very flat. For this stock the criterion of maximum median yield is currently the more restrictive part of the ICES MSY approach, one reason is selection towards young saithe in last 15 years (Figure 21) and low mean weight at age of the youngest fish last 10 years (Figure 15).

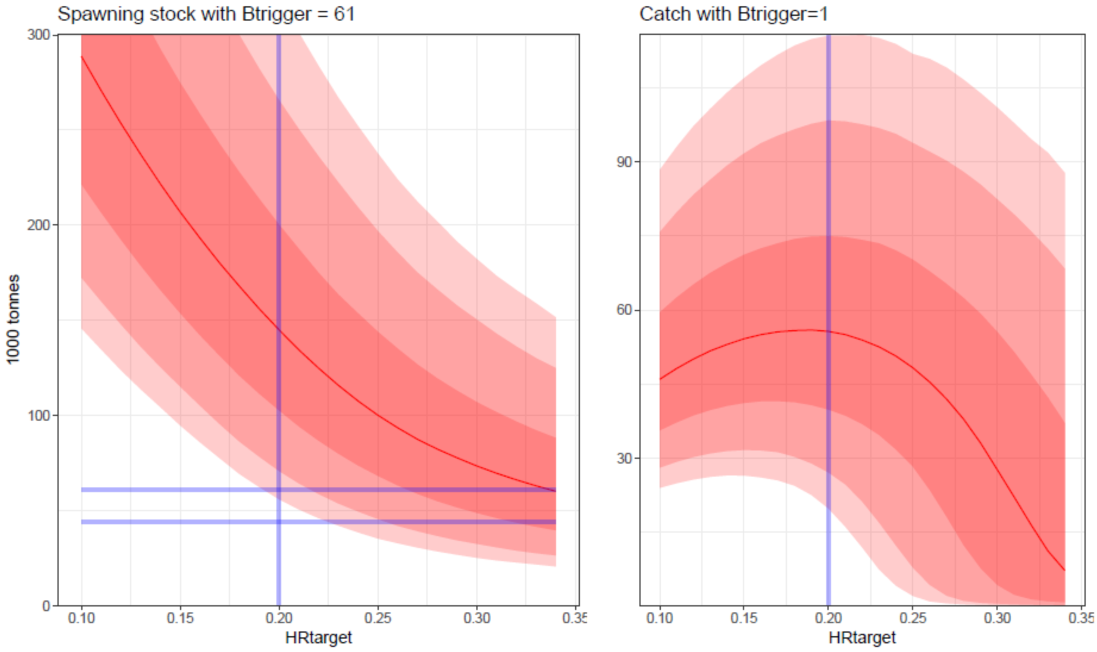

Figure 31: Spawning stock and catch as function of HR_{target} The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red. $B_{trigger}$ = 61 kt for the SSB figure but 1 for the catch figure.

Development of catch, spawning stock and recruitment seems to be in line with historical values but the harvest rates proposed are not very different from what they have been historically. (Figure 32). Occasionally the harvest rates exceed what has been observed historically, most likely a combination of the stabilizer and relatively high autocorrelation in recruitment. Interannual variability is on the average around 11% (36) but increases rapidly if harvest rate exceeds 0.2. Interannual variability would be larger if the stabilizer was not included in the Harvest Control Rule.

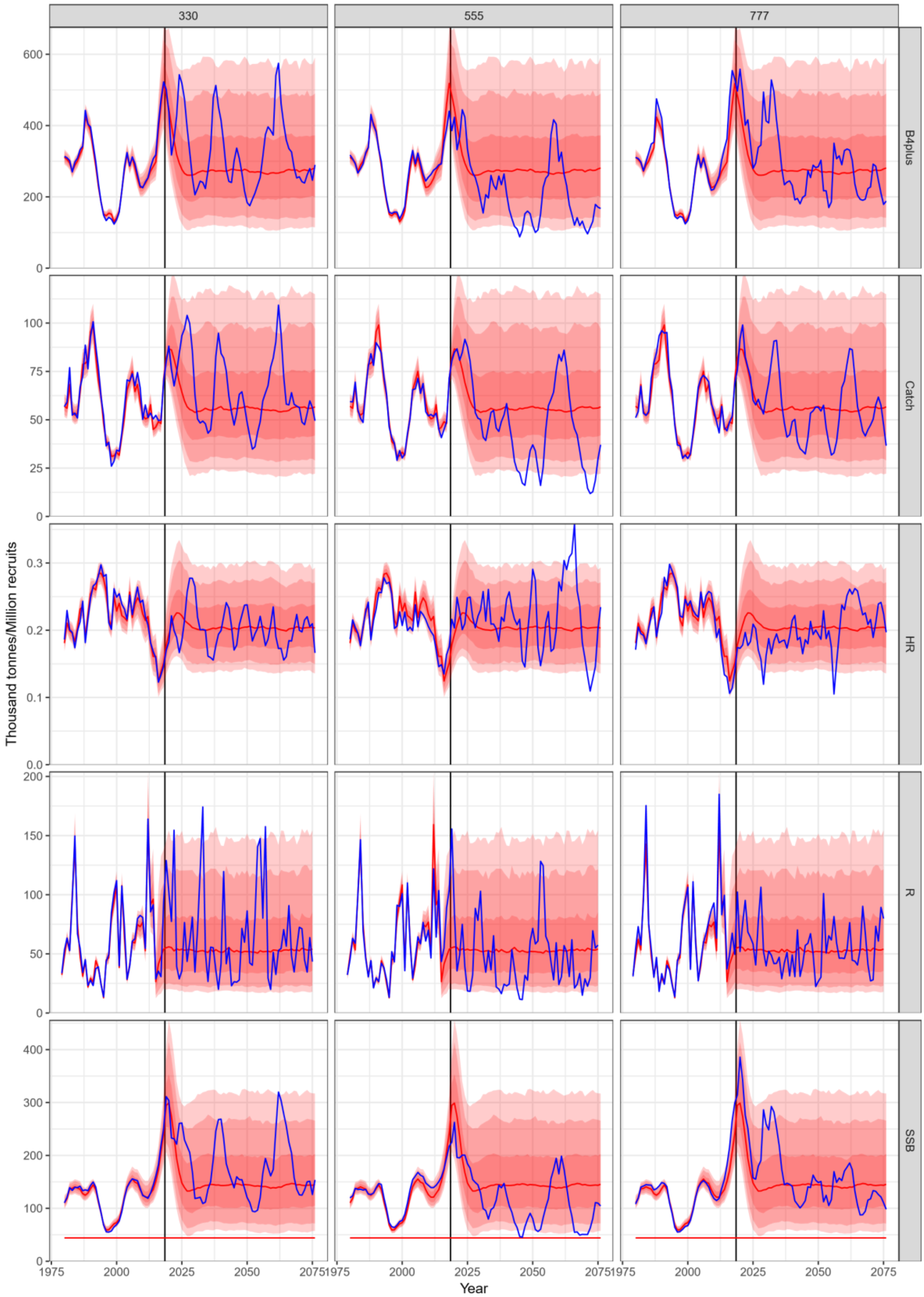

Figure 32: Summaries of spawning stock, recruitment, harvest rate and catch when target Harvest rate is 0.2 and $B_{trigger}$ 61 thous. tonnes. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. 3 individual runs are shown. Hockey stick function with autocorrelation of recruitment estimated. Horizontal lines shows B_{lim}.

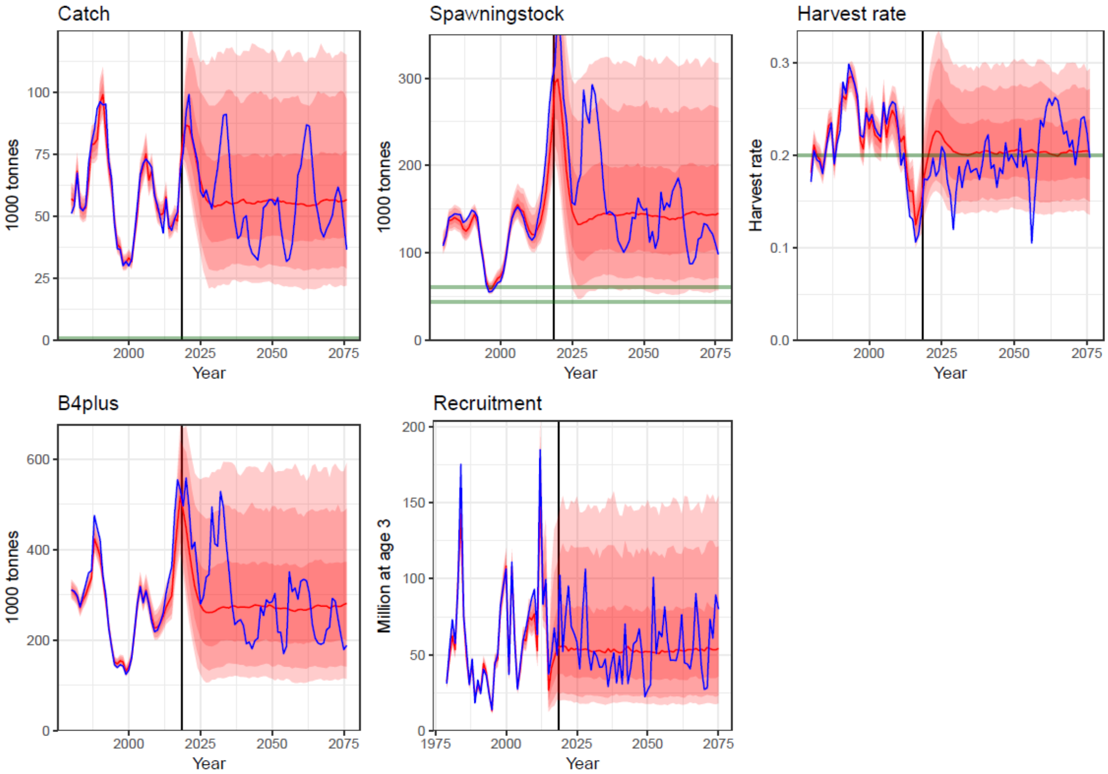

Figure 33: Historical and future values.

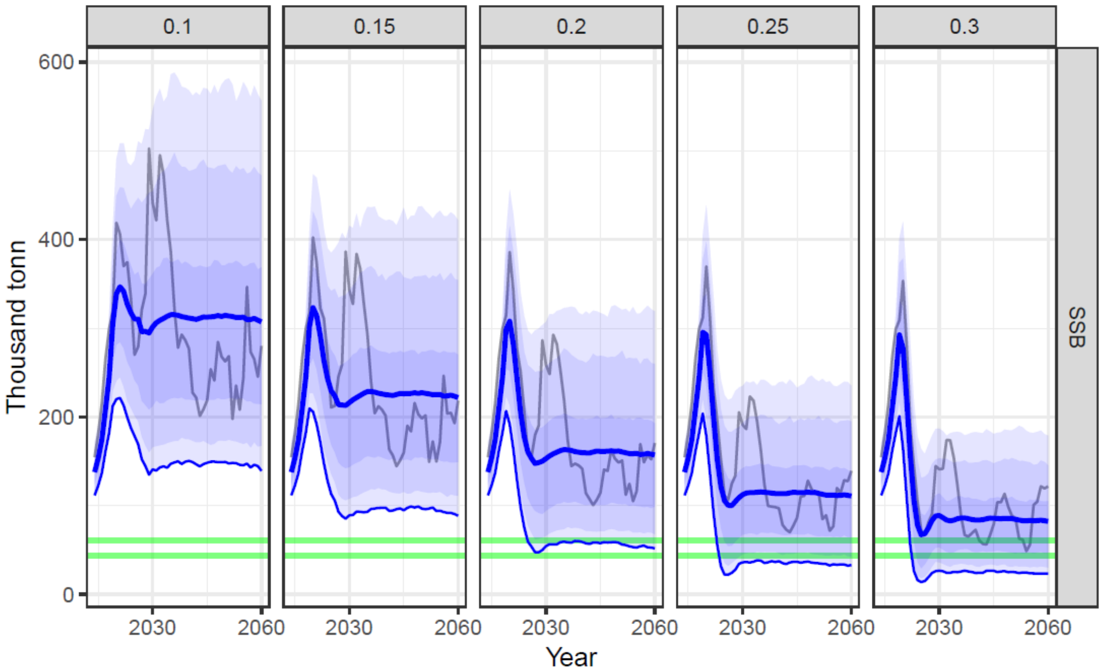

Figure 34: Development of spawning stock for 5 different target harvest rates. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the blue lines the median. One individual run is shown. The horizonal lines show B_{lim} = 44 thous. tonnes and $B_{trigger}$ = 61 thous. tonnes.

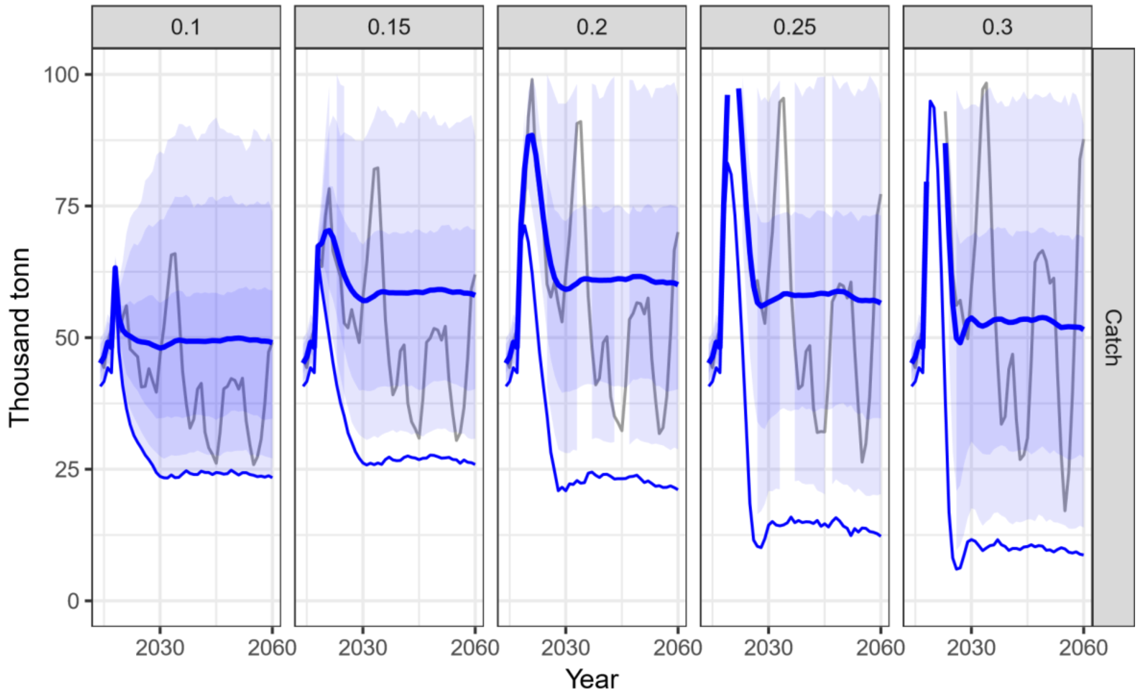

Figure 35: Development of catch for 5 different target harvest rates. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the blue lines the median. One individual run is shown.

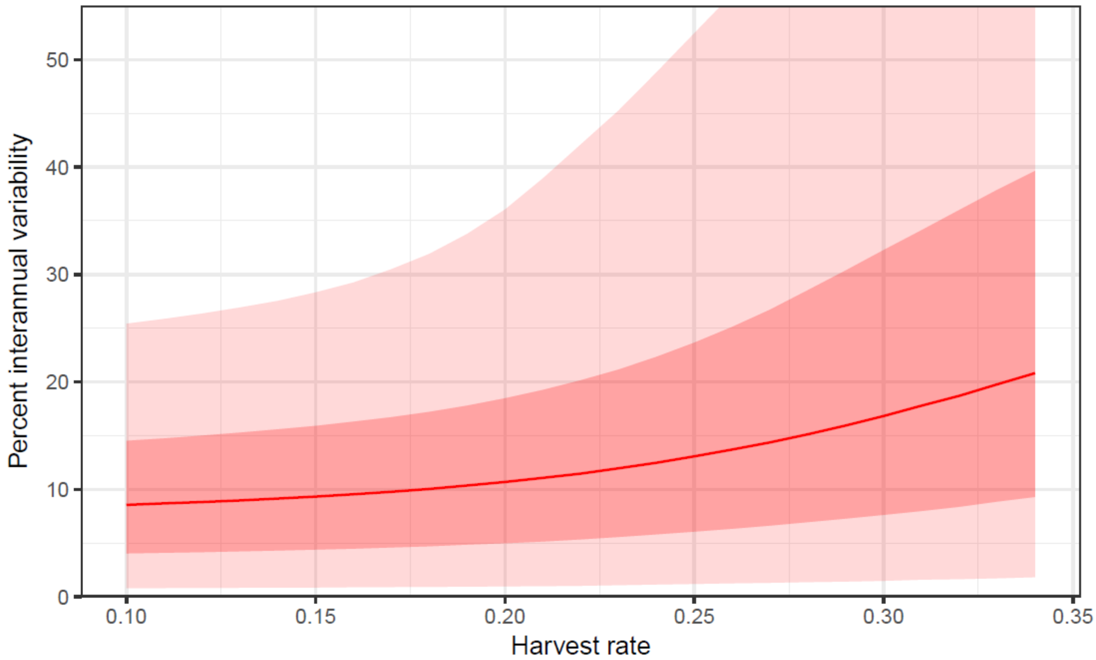

Figure 36: Interannual variability in catches expressed as $\left|\frac{Tac_{y+1}-Tac_y}{Tac_y}100\right|$.

4.9.1 Sensitivity to few assumptions

Sensitivity of the results to few alternative settings were tested. What is presented is the fifth percentile of SSB as function of Harvest Rate with $B_{trigger} = 61$ and median catch as function of harvest rate for $B_{trigger} = 1$.

Only the results in the long run are presented but as described earlier, risk in the medium term is a little higher than in the long term. The alternatives tested were.

1. The standard settings with ρ_{rec} estimated and $\sigma_{ass} = 0.22$.
2. Standard settings except $\sigma_{ass} = 0.30$.
3. $\rho_{rec} = 0.4$, $\sigma_{ass} = 0.22$. Same stock-recruitment treatment as 2013.
4. $\rho_{rec} = 0.4$, $\sigma_{ass} = 0.20$, same weights and maturity as 2013 i.e. 2013 settings.
5. Standard settings with maturity replaced by maturity at age 2018 that is lower than the average of last 10 years used in the standard settings.

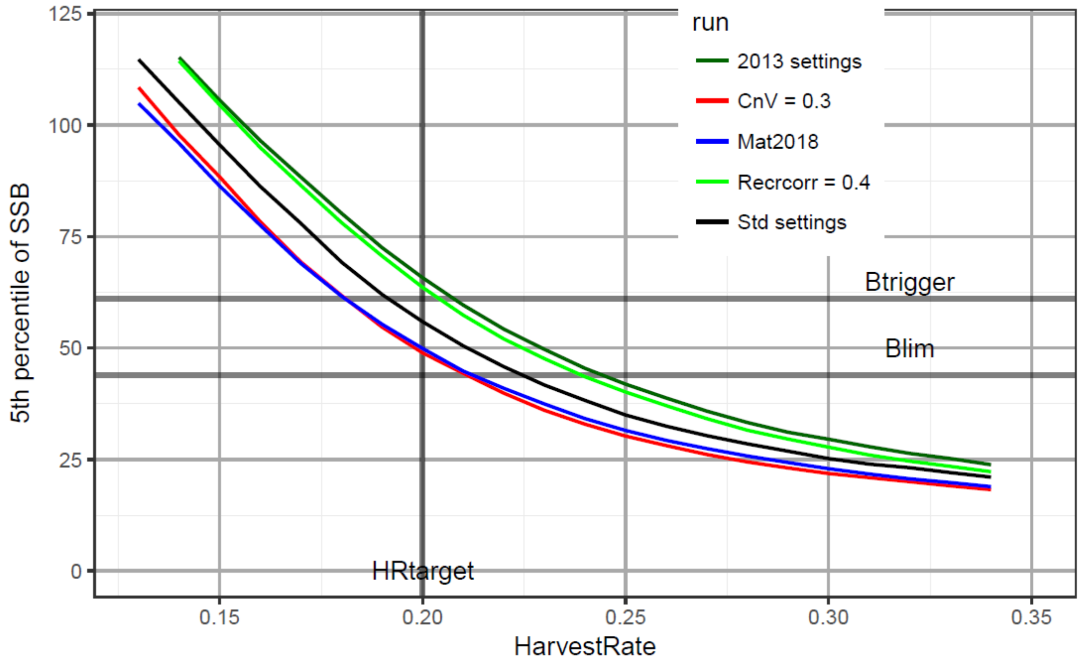

Figure 37: Fifth percentile of SSB as function of target harvest rate for few alternative runs. $B_{trigger}$ = 61. Implementation error included in all cases.

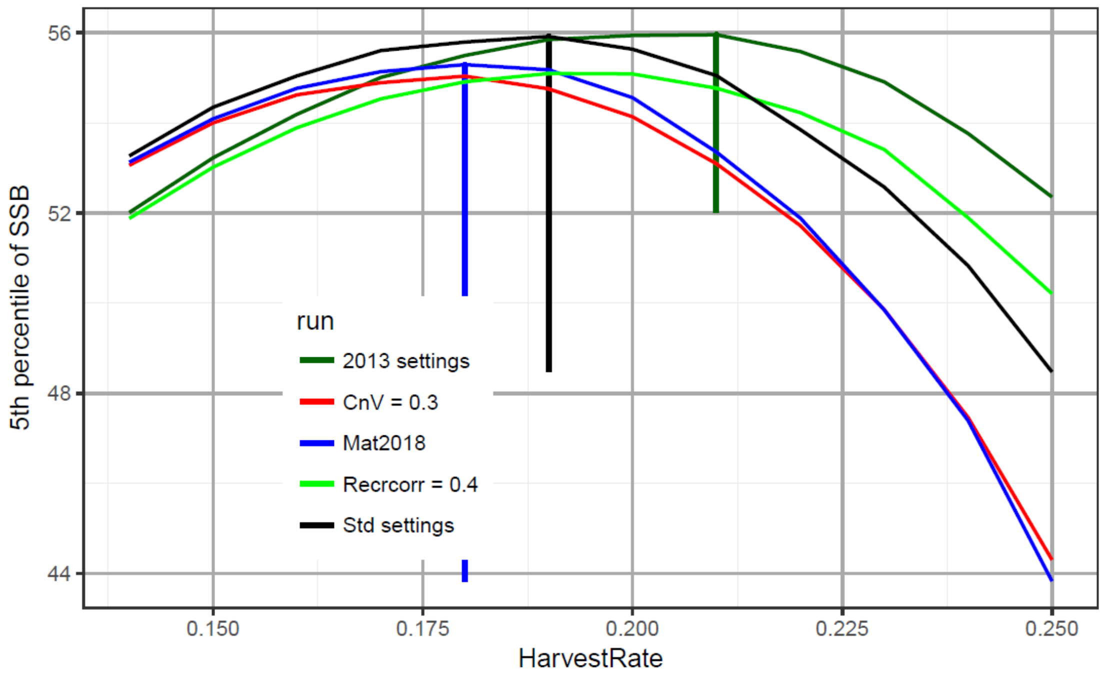

Figure 38: Median catch as function of target harvest rate for few alternative runs. $B_{trigger}$ = 1. The vertical lines show the harvest rate giving maximum yield. Implementation error included in all cases.

The results (figures 37 and 38) indicate that estimating ρ_{rec} decreases SSB_{05} considerably compared to fixing it at the estimated value (0.4). Increasing σ_{ass} to 0.3 reduces SSB_{05}, large part of the change is caused by the lognormal bias in the assessment error. All the combinations satisfy $P(SSB < B_{lim})$ < 0.05 in the long term. The Harvest rate giving maximum median yield is 0.19 with the standard settings (Figure 37). In all cases the peak in the yield curve (HR_{msy}) is lower than HRp_{05}. HR of 0.18–0.19 does lead to less than 5% probability of $SSB < B_{trigger}$ that is in itself a desirable property as it should lead to less than 5% probability of estimated

$SSB < B_{lim}$ i.e seldom getting the stamp that the stock is below B_{lim}.

All the results in figures 37 and 38 are based on implementation error with $\sigma = 0.07$ and $\rho = 0.65$. This implementation error does not have large effect on estimated HR_{MSY} and HR_{p05} (Figure 39). Implementation error can occasionally reduce HR_{MSY} by 0.01 but in those cases the change would be less if 3rd digit was included. The stabiliser does on the other hand have relatively large effect both on median yield and SSB. This is not unexpected, typical consequence of stabilisers, more so when the stabiliser is not removed abruptly, recruitment correlated and assessment error substantial. What is seen is the cost of stability and reducing the Harvest rate to 0.18 might be a better option than eliminating the stabiliser.

The stabiliser is desirable when a large cohort enters the fishable stock as has just happened but does of course have negative consequences when large cohorts leave the stock (Figure 34).

The combination no stabiliser, no implementation error is the only combination leading to $HR_{MSY} = 0.2$ and is probably candidate for ICES HR_{MSY}. Using the "old settings" leads to $HR_{MSY} = 0.21$ as the average weight of age 4 is higher in the period 2009–2011 than in last 10 years (Figure 15).

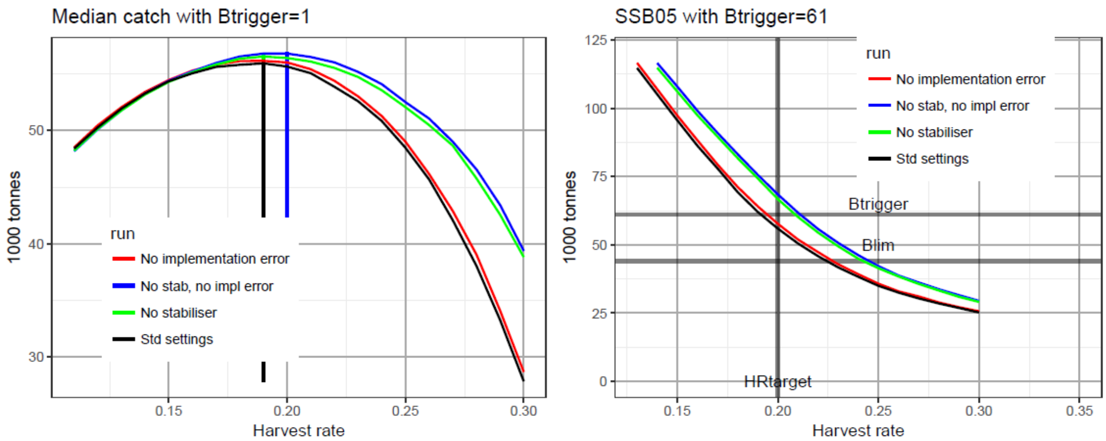

Figure 39: 5th percentile of spawning stock and catch as function of spawning SSB with and without implementation error and stabiliser.

Table 1: Summary of reference points

Reference point		Value
1	B_{pa}	61
2	B_{lim}	44
3	$B_{trigger}$	61
4	HR_{MSY} with implementation error	0.19
5	HR_{P05} with implementation error	0.22
6	HR_{MSY} without implementation error	0.19
7	HR_{MSY} without stabiliser and implementation error	0.20
8	$HR_{P(SSB < Btrigger = 0.05)}$	0.19
9	F_{lim}	0.5
10	F_{pa}	0.36
11	HR_{lim}	0.32
12	HR_{pa}	0.23

4.10 Comparison with long term results from 2013

Comparison of current results and the 2013 results in the long term shows promise for more catch and larger stock (Figure 40) but there is more risk and harvest rates must be lower (for same B_{lim}). This difference is a combination of different settings and additional data. Large year classes have been added to the stock since the 2012 assessment (large saithe year classes are first identified at age 3 or 4). The 2013 results were based on the 2012 assessment that used catch data from 1980–2011. 6 additional years with good recruitment can change estimated productivity much when the reference period is so short (since 1980). Different mean weights at age change the productivity of the stock, but can also affect the shape of the curve showing maximum median catch vs Harvest Rate. The older age groups have been heavier in recent years than in 2009–2011 while the younger age groups have been light (Figure 15). This pattern in the weights leads to more loss in catching the fish young which is exactly what has been done in recent years (Figure 21).

The lower plot in Figure 40 does not look exactly like Figure 31 as it is based on $B_{trigger}$ = 61. The reason is that results with $B_{trigger}$ = 0 but other setting the same were not found in the 2013 results.

Comparison with the old results (Figure 40) shows that in spite of increased productivity of the stock, values of the fifth percentile of the spawning stock are lower (ρ_{rec} is now estimated).

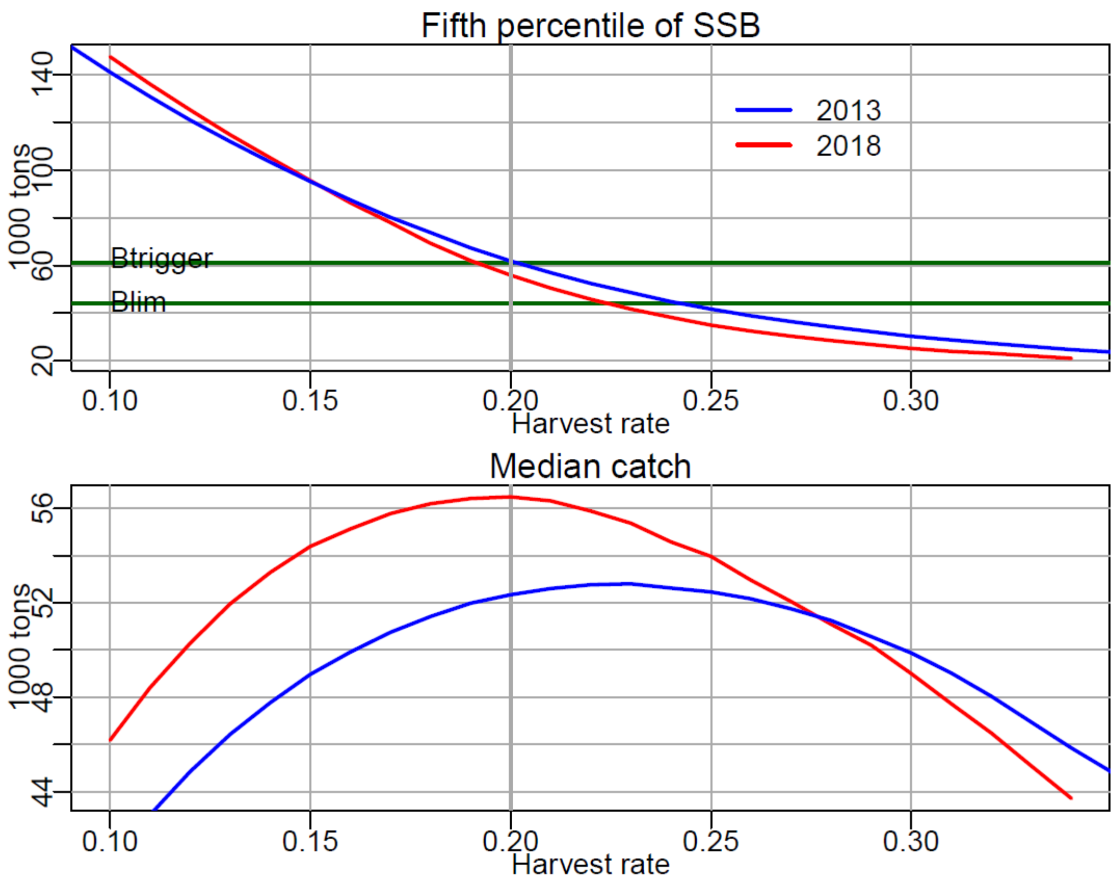

Figure 40: Comparison of short/medium term results 2013 and today.

4.10.1 Development since 2013 compared to 2013 prediction

Finally the development since 2013 is compared with the prediction since then (Figure 41). Things do not fit too well. First, harvest rate has been below prediction, both due to underestimation of the stock and that the TAC has not been caught. The HCR simulations in 2013 were based on perfect implementation. Also, what is shown here in recent and future years are "estimated values" not "real values" that the confidence intervals do really show. The estimated values can be quite far from real values for this stock.

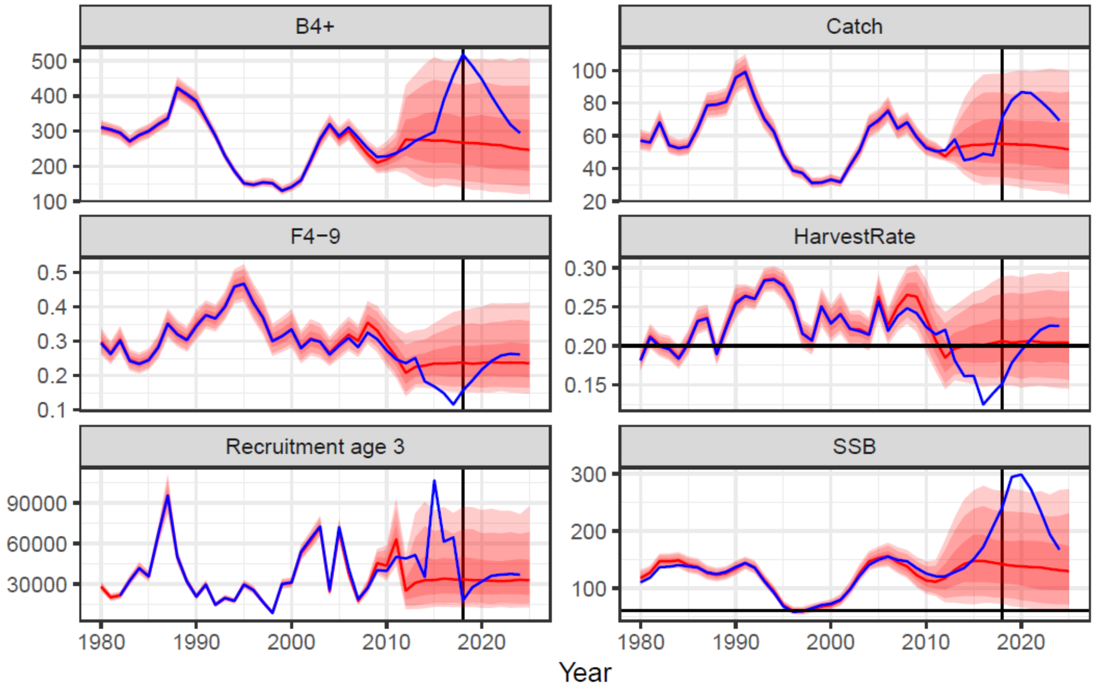

Figure 41: Comparison of the results from 2013 (red) and the 2018 results blue. The shaded areas show 5th, 25th, 75th and 95th quantile.

References

[1] MRI Iceland. Mælingar á brottkasti botnfiska 2007. Discard of demersal fishes 2007. MRI Report, MRI/142, 2008.

[2] ICES. Report of the Benchmark Workshop on Roundfish (WKROUND) . Technical report, ICES CM2010/ACOM:36, 2010.

[3] ICES. Report of the evaluation of the Icelandic saithe management plan. Technical report, ICES CM2013/ACOM:61, 2013.

[4] ICES. Report of the North-Western Working Group (NWWG). Technical report, ICES CM2016/ACOM:08, 2016.

[5] ICES. ICES Advice Technical Guidelines. Technical report, ICES, 2017.

[6] ICES. ICES Advice basis. Technical report, ICES, 2018.

[7] Sigurdur TH Jonsson. Saithe on a shelf. Two studies of Pollachius virens in Icelandic waters. *M.S. Thesis, University of Bergen.*, 1994.

5 Reviewers comments

General comments

Methods to specify the "conditioned operating model" were based on a reasonably specified stock assessment approach and allowed for generating projections based on assessment model uncertainty and, in particular, the stock-recruitment relationship specification and variability.

The "short-cut" approach to simulating future assessment modelling was carefully done and used appropriate future levels of assessment uncertainty and autocorrelation (including implementation uncertainty).

The MSE process omitted considerations of alternative approaches, rather the presentation and work was limited to basic approaches (one for each stock) were essentially tuned to satisfy ICES objectives within the Icelandic management system. A disadvantage of evaluating a single management approach is that robustness cannot be compared between alternative management plans. For example, in the saithe evaluation, the projections for evaluating BRP and other measures assumed average maturity at age. An evaluation of robustness to the case of the maturity schedules remaining at the most recent (low) levels was qualitatively evaluated and could not be compared to the robustness of other management plans. That is, such evaluation against other strategies might suggest a procedure that is more robust to such contingencies.

Regarding the process for this review, the following comments apply:

- Distributing documents in advance was useful as they were fairly complete
- Holding a web conference to discuss details in advance was helpful
- Having access files and code for muppet model (via github) was useful. This should also help with easing tasks such as this into a TAF framework.
- Additional time at the beginning to cover the process for running the model and generating results might have helped with both uncovering potential issues and helping with understanding the model.
- The time allotted for the work was relatively short, especially given the expanded tasks of evaluating the MSE.

Terms of reference

The following sections provide summary responses to the terms of reference provided to the WKMSE review

TOR a) appropriateness of data and methods

Full text:

> Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of (where applicable):
>
> - Stock identity and migration issues;
> - Life-history data;
> - Fishery-dependent and fishery-independent data;
> - Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook

Saithe

i. Stock identity and migration issues;

The stock is well defined, as immigration and emigration seems minimal. Tagging experiments were carried out to confirm this (the data was not presented during this WK). The bathymetry around Iceland prevent migration from the Faroese Islands. However, the stock has undergone a migration from the south, south-east of the island to the North-West. This can be seen in the origin of the landings as well as in the survey data.

The understanding of the stock is very good due to a very long landings data series (1966-) and two surveys covering the entirety of the stock expanse. The absence of immigration/emigration allows the stock assessment to proceed without violating or testing the assumption of a closed population. Juvenile catches are not an issue as the current geographical distribution of the stock does meant that juveniles and adults do not overlap.

ii. Life-history data;

The fish is a shoaling pelago-demersal fish. It has a life-span typical of most gadoids – with a tendency to find less old fish than in the past.

Maturity and weight at age are time-varying. Weights for younger ages have been recently declining although older ages are close to average values. The proportion mature shows a downward trend in recent years. The stock-recruitment is approximated with a hockey stick function as the stock has never been at levels during which recruitment depression occurs. The breakpoint is set to the lowest observed stock level, with accordance to ICES protocols; this was the level observed in 1996.

iii. Fishery-dependent and fishery-independent data;

Iceland has an obligatory landing and log book policy for all vessels, with very little high grading. Discards due to quota unavailability are unquantified. The log book contains the fishing sites as well as the catch composition by haul. The landings are nearly all in gutted weight and are converted into round weight using a gutted to round weight ratio of .84. The factor is not revised and kept constant. The fishery for saithe occurs all year around with catches accruing continuously throughout the year.

The stock is covered by 2 surveys. One in the spring and one in the autumn. The surveys are multi-species surveys and do not target specifically saithe. Due to the shoaling behaviour of saithe, few hauls during the survey account for most of the data, leading to large uncertainties in the survey indices. The between year-class consistency of the survey indices is low as is the between survey consistency.

iv. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics

As the southern waters around Iceland continue to warm, it is important to stay watchful about the niche which saithe can inhabit. The quota transfer system of Iceland can lead to large TAC increases for a short term, which is unlikely as the value and catchability of the species is relatively low compared to other available species.

Haddock

i. Stock identity and migration issues;

The Icelandic haddock stock is distributed all around the island. The historical origin of catches show that the North-West are of Iceland is an important fisheries area for the stock ~40% with the rest of the catches come from the other areas. The closest stock is around the Faroese Islands, migration between these two stocks has not been confirmed and is thought to not occur due to bathymetrie between Iceland and the Faroes.

The landing data series was started in 1903, but the assessment uses the time-series starting from 1979 due to data quality issues prior to that year. The two surveys, spring and autumn, started in 1985 and 1996 respectively. The only year the autumn survey did not run was in 2011 due to a strike.

ii. Life-history data;

Haddock do not have distinct separation between juvenile and adult habitat. This leads to a small amount of age 2 haddock being caught. The longevity of haddock is around 15 years, however, they are rarely found above the age of 10 years; albeit it they are becoming more common. The stock assessment model was adapted to reflect the lack of data and was changed to include a plus group at age 10, rather than keeping to the old structure of modelling ages until 14 explicitly.

The species is showing density-dependency in growth, which has caused weight at age to drop during high stock biomass years. Since the peak in the early 2000s the weight at age has been recovering as the stock biomass is going down. The growth projections are based on a year-, year-class and density dependant effect. The proportion of maturity at age has been dropping recently, as a result we have requested a projection run with historical maturities and weights at age.

The stock-recruitment function was a hockey stick with the breakpoint and R_{max} being estimated within the model. No clear SR relationship can be identified. The entire stock can be considered a type 5 stock and thus setting the B_{lim} at B_{los} (lowest observed level stock level) is appropriate.

iii. Fishery-dependent and fishery-independent data;

The fishery dependent data comes from landings and logbooks. The long time-series of landings started in 1903. However, due to a large proportion of the landings in the early parts being from foreign fleets and thus is suffering from data quality issues, the data is only being used from 1979. Logbook data starts in the 1970s with volunteered data, which became compulsory in 1991 for vessels over 20t and eventually for all vessels in 1999. The landings reported are all in gutted weight and are converted to round weight using the ratio 0.84. The fleets fishing for Haddock are either trawlers or longliners with a very small proportion of Danish seine catches.

Two surveys are covering the haddock stock: a spring survey that started in 1985 and an autumn survey that started in 1996 - both running on a yearly basis (except in the autumn in 2011 due to a strike). The functional form of the surveys is similar, with a smaller contrast in large vs small stock sizes during the autumn survey. The decline in the stock size from the peak in 2004 is greater in the spring survey. In large fish the surveys contradict each other as the biomass index in fish over 60 cm is going up in the spring survey but going down in the autumn survey - with the last point estimate being the same. The internal between age consistency of the autumn survey is high, with correlation values upwards of 0.88, with the exception of ages 8/9 (0.575); the spring survey exhibits similar consistency across all consecutive age pairs. Comparing the age based survey indices between the surveys, they show a good correlation (> .76).

iv. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics

The main prey species for haddock is the sand eel and its abundance has been low since 2005. As such, the slow growth and lower maturity at age could be confounded with this state. The effects of the warming waters to the South of Iceland on the stock need to be continued to be monitored and taken into account during the review of the plan.

TOR b) preferred method for evaluating stock status

Full text:

> Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

Saithe

Icelandic saithe are assessed with a separable, forward-projecting population, which was recommended in the 2010 benchmark assessment (ICES, 2010). The assessment model is fit to catch at age (1980 to present) and numbers at age from a spring trawl survey (1985 to present). Saithe are currently caught primarily with trawl gear, although gillnets contributed a higher proportion of the catch during the 1980s and 1990s. The model contains a single fleet, with changes in gear over time addressed with separate fishery selectivity curves for three time blocks. No change to the assessment methodology or short-term forecast methodology is proposed in this assessment.

Results from the current assessment model were compared to other assessment models, including an ADAPT VPA-type model and a SAM state-space assessment model. The various models give similar trends in estimated biomass, with the 2018 estimated biomass ranging from 420 kt to 530 kt. The 5-year Mohn's rho for the B_{4+} biomass was -0.088.

The assessment model is used for a short-term forecast, and the advice is based on the reference biomass (B_{4+}) and the spawning stock biomass (use for evaluating stock status relative to $B_{trigger}$). Weights at age, maturity at age, and fishing selectivity have varied over time, and the values estimated for the assessment year are used for the short-term projection. Projected recruitment is obtained from a hockey-stick stock-recruitment function, which results in projected value of R_{max} when the assessment year SSB is above SSB_{break}.

Haddock

Icelandic haddock are currently assessed with an ADAPT VPA-type model, and in this benchmark assessment it is proposed that a separable statistical catch at age model be used (the same described above for saithe with some modifications). One modification is that the fishery selectivity curve is modelled as a function of weight, which is an efficient way of modelling time-varying selectivity and reflects the size limits and targeting behaviour of fishers. This produced time series of estimated selectivity, by age, that were less variable than those from the ADAPT model. The assessment model is fit to catch at age (1979 to present) and numbers at age from a spring trawl survey (1985 to present) and fall survey (1996 to present).

Several aspects of the model and its application to haddock are similar to those discussed above for saithe. The variances of the survey indices and catch, by age, are estimated within the model. Weights at age and maturities at age have varied over time. There is little information that the stock has been reduced below SSB_{break}, although the estimated value of SSB_{break} appears to be slightly better informed than in the saithe assessment (based on distributions from MCMC simulations).

Estimated time series of B_{45cm+}, SSB, $F_{4\text{-}7}$, recruitment, and landings were very similar to the existing ADAPT model. The 5-year Mohn's rho for SSB was 0.075.

The assessment model is used for a short-term forecast, and the advice is based on the reference biomass (B_{45cm+}) and the spawning stock biomass (used for evaluating stock status relative to $B_{trigger}$). Projected recruitment is obtained from a hockey-stick stock-recruitment function, which results in projected value of R_{max} when the assessment year SSB is above SSB_{break}. The short-term forecast of weight at age is a function of the assessment year weight at age and a year effect. Projected catch weights, maturity, and fishery selectivity are modelled as functions of the projected weight at age. In the current model, a logistic curve predicting proportion mature as a function of stock weight is fit to data from 2000. In the proposed assessment, the data used for estimation of the logistic curve is based on data since 2013 due to temporal changes in the proportion mature over time. These temporal changes in maturity result primarily from the stock expanding north into regions with colder water than in the south (thus delaying maturation), although maturation within spatial areas (i.e., north and south) appear to have increased over time for ages 3 and 4.

Other changes between the existing ADAPT model and the proposed model include: 1) computing SSB at the time of peak spawning (thought to be April–May), incorporating the mortality between Jan 1 and peak spawning; 2) introducing a plus group for ages 10+ (the existing model has a terminal age of 14). The proposed model is the preferred method for evaluating stock status and conducting short-term projections.

c) Re-examine and update (if necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

This was shown for both stocks and the evaluations were considered sufficient. Clarification was made that the Icelandic management plan uses similar terms to those of ICES but were part of the management strategy, and the “evaluation” part is when comparisons are made to the ICES measures, e.g., of F_{msy} and F_{pa}.

d) Develop recommendations for future improving of the assessment methodology and data collection

During the course of the meeting, a number of suggestions for improving methods were discussed and a non-prioritized list is presented below.

- Including an approach that accounted for quota transfers between species and over time more explicitly. While the impact historically has been less than 5% (in terms of total catch estimates), adjusting for this (perhaps in a multi-species technical interaction way) may improve the realism in future projections. However, the implementation error used in the projection simulations does take this into account.

- Regarding data collection, the group discussed the variability in maturity at age used in both assessments and the degree to which they are driven by observation errors (i.e., limited data for some ages and years). While this is considered generally okay since small sample sizes generally correspond to abundances that are lower (and hence the errors matter less than for the more abundant age classes). However, such variable values can affect estimates of reference points which should be calculated based on some mean values. Such means should take into account sampling errors and perhaps should be modelled rather than using simply data at-age (e.g., use a logistic curve). Also, given maturity data are based on visual examinations of gonads, more robust approaches might be pursued (e.g., considering gonosomatic indices (GSI).

- For haddock, the relationship between the weight-at-age and selectivity was modelled for projections. Similarly, the projected weight-at-age (which is a function of stock abundance) was used to propagate future changes in maturity in a functional way (see equations in annex). Computing the weight-at-age and maturity relationship retrospectively indicated differences from the observed maturity data. Research to refine this discrepancy may improve the approach used in projections.

- Trends in maturity should be monitored carefully to evaluate the potential implications to reference points and the harvest control rule.

- For both stocks, the stock-recruitment scatterplot contains little information on SSB_{break}, which is currently constrained to be relatively close to the lowest SSB value observed (B_{loss}). This could underestimate recruitment at low stock sizes if SSB_{break} is lower than B_{loss}. An evaluation of the effect of setting SSB_{break} at values lower than B_{loss} should be conducted. This could include avoiding attempted estimation of SSB_{break} and model recruitment as R_{max} for all SSB values (recognizing that the ICES control rule would lower harvest rates at low stock sizes). Essentially, this would capture some of the discussion about saithe being in category 6 or 5 relative for SRR "type'.

- For both stocks, use of the design-based estimates of the variances of survey abundance should investigated (they are currently estimated in the model).

- Accounting for uncertainty in natural mortality should be investigated in future MSE work.

- Statistical catch-at-age models that are tuned to the survey biomass explicitly and treat the age composition for each year as proportions should be evaluated as an alternative. This may help with including more data such as the gillnet and autumn surveys for saithe (and avoiding issues related to age-specific indices having missing values in some years). This would also "bind" the catchabilities by age (via selectivity) in a more biologically sensible way.

- The autumn and gillnet survey for saithe was examined but ignored in the assessment/operating model. The group appreciated that this stock has highly patchy distributions and there are issues related to applying these survey data. However, some geospatial modelling may make these data applicable for future use in the assessment, particularly as more years of data become available. This should be investigated.

- The muppet model was made available on github and one of the reviewers was able to run the models for both stocks. Some technical aspects of the code were highlighted to the experts for future improvements (including improved approaches to diagnose and generate MCMC samples under ADMB version 12.0). Some differentiability issues related to the stock-recruitment "hockey stick" relationship were noted.

e) Evaluate the Icelandic management plans for the stocks listed in the text table below against precautionary and MSY criteria.

For both stocks, the Icelandic management plan, with adjustments as recommended from the workshop, achieves the objectives of the ICES precautionary approach.

For saithe, to summarise the differences from the 2013 assessment (as relates to ICES MSY and PA approach) we note that

1. There appears to be a high recruitment coming into the population giving near term biomass and projections indicate a significant increase.
2. Maturity estimates changed
3. Selectivity for projections differed from past values.
4. The weight-at-age estimates are slightly lower
5. The stock recruitment relationship (SRR) estimates are different both in the variability of the R_{max} and breakpoint as well as in the autocorrelation term in the SRR. This made things more precautionary

6. The impact of these changes resulted in the target harvest rate being changed from 0.20 to 0.19.

Relative to the saithe MSE, we noted that the "stabilizer" may result in implausible effort scenarios. This could possibly occur if the stock was at a high level (as is presently estimated) and dropped rapidly due to poor recruitment. Based on the TAC formula that carries over 50% of the previous year's TAC, the HCR may result in a TAC that is higher than warranted given stock status and require more effort than economically or feasibly available. Nonetheless, the MSE work showed that this approach satisfied the precautionary measures as detailed by ICES

Relative to the haddock MSE, the differences from the 2013 include:

1. Maturity at age (also by weight category) has decreased in recent years (~7yrs) and needed to be updated as it changed the PA reference points.
2. VPA/ADAPT model was changed to a statistical approach (which had been tested but not used).
3. Selectivity is modelled as weight-based instead of age (and differs from the VPA/ADAPT approach
4. Age 10+ was used instead of age 14
5. The stock recruitment relationship (SRR) estimates are different both in the variability of the R_{max} and breakpoint as well as in the autocorrelation term in the SRR
6. The estimate of sigma used for the BPA estimate in the past (0.18) was changed to a different default of sigma = 0.2 based on recommendation of the reviewers.
7. The HCR $B_{trigger}$ value was raised from B_{lim} to BPA

References

ICES. 2010. Report of the Benchmark Workshop on Roundfish (WKROUND), 9–16 February 2010, Copenhagen, Denmark. ICES CM 2010/ACOM:36. 183 pp.

Annex 1: List of participants

Name	Institute	Email
Bjarki Thor Elvarsson	Marine and Freshwater Research Institute, Iceland	bjarki.elvarsson@hafogvatn.is
Christoph Konrad	European Commission Joint Research Centre, EU	christoph.konrad@ec.europa.eu
David Miller	ICES Secretariat	david.miller@ices.dk
Höskuldur Björnsson	Marine and Freshwater Research Institute, Iceland	hoskuldur.bjornsson@hafogvatn.is
Jim Ianelli (External Chair)	National Oceanic and Atmospheric Administration - NOAA Fisheries, USA	jim.ianelli@noaa.gov
Morten Vinther (ICES Chair)	DTU Aqua -National Institute of Aquatic Resources, Denmark	mv@aqua.dtu.dk
Paul Spencer	National Oceanic and Atmospheric Administration - NOAA Fisheries, USA	paul.spencer@noaa.gov

Annex 2: Request from Iceland

ATVINNUVEGA- OG
NÝSKÖPUNARRÁÐUNEYTIÐ

Ministry of Industries and Innovation

Skúlagötu 4 101 Reykjavík Iceland
tel.: + (354) 545 9700 postur@anr.is
anr.is

ICES
H.C. Andersen Boulevard
DK-1553 Copenhagen V
Denmark

Reykjavík October 16, 2018
Reference: ANR18100255/11.02.00

Subject: Evaluation of management plan performance, input data and stock assessment for haddock and saithe in 5a.

In two letters dated on the 22nd of April, 2013 the Ministry of Industries and Innovation confirmed the adoption of the current management plans for Icelandic haddock and saithe for the period of 5 years. Additionally, in a letter dated 4th June 2018 the Ministry notified ICES that the current management plans for haddock and saithe in Icelandic waters would be extended for one year or until an evaluation of their performance against the management plans objectives has taken place.

The Ministry is in a process of consultation with stakeholders and the Marine and Freshwater Research Institute. The result of these consultations may lead to changes in the assessment method, reference points and the form of the HCR.

ICES is hereby asked to evaluate the historical performance of the management plans for haddock and saithe against their general aim of maintaining the exploitation rate at the rate which is consistent with the precautionary approach and are in conformity with the ICES MSY approach. ICES is also asked to evaluate the changes in the assessment methods and reference points (Benchmark) if the outcome of the consultations results in any changes. Similarly, to evaluate if the possible changes in the HCR are consistent with the precautionary approach and are in conformity with the ICES MSY approach.

The work will be carried out by national experts at the Marine and Freshwater Research Institute with input from managers and stakeholders. The evaluation of the HCR, along with technical documentation on the input data, assessment and reference points will be submitted to ICES for review by the 1st of February 2019. It is kindly requested that the review and the benchmark results will be available before the North Western Working Group (NWWG) meets in April 2019.

On behalf of the Minister of Fisheries and Agriculture

Jóhann Guðmundsson   Sigurgeir Þorgeirsson

Annex 3: Clarifications of the request from Iceland

ATVINNUVEGA- OG NÝSKÖPUNARRÁÐUNEYTIÐ

Ministry of Industries and Innovation

Skúlagötu 4 101 Reykjavík Iceland
tel.: + (354) 545 9700 postur@anr.is
anr.is

ICES - International Council for the Exploration of the Sea
Mr. Mark Dickey-Collas, ICES ACOM chair
H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
DENMARK

Reykjavík March 1, 2019
Reference: ANR18100255/15.09.00

Subject: Evaluation of the current management plan for saithe in Icelandic waters, input data and stock assessment.

In a letter (ANR18100255/11.02.00) from 16th of October 2018 the Icelandic Ministry of Industries and Innovation requested ICES to evaluate the historical performance of the management plan for saithe against their general aim of maintaining the exploitation rate at the rate which is consistent with the precautionary approach and are in conformity with the ICES MSY approach. ICES was also asked to evaluate possible changes in the assessment methods and estimated reference points.

In consultations between scientists from the Marine and Freshwater Institute, stakeholders and the Ministry of Industries and Innovation there was a consensus not to change the current harvest control rule (HCR) for haddock and saithe. Therefore, the Ministry requests ICES to evaluate if the harvest control rule is still consistent with the precautionary approach and in conformity with the ICES MSY-approach. Additionally, ICES is requested to

a) Re-evaluate the assessment framework and the harvest control rule for saithe (specified below) given the data and knowledge gathered since 2013.
b) If the harvest control rule is found not to meet its objectives to propose changes.
c) Report on the probability distribution of the realized harvest rate (HR) given the values of HR_{MGT} = 0.2 for saithe.

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

The annual TAC is set by a harvest control rule. The rule is based on the mean of the TAC in the current year ($TAC_{y-1/y}$) and 20% (HR_{MGT} = 0.2) of the biomass of 4 year and older saithe ($B_{4+,y}$) in the assessment year (y). The TAC for the fishing year y/y+1 (September 1 of year y to August 31 of year y+1) is calculated as follows:

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

If the spawning stock biomass (SSB) falls below 65 000 tonnes (MGT $B_{trigger}$), the harvest control rule dictates that HR_{MGT} shall be reduced linearly to zero based on the ratio of the SSB estimated and MGT $B_{trigger}$, the TAC for the fishing year *y*/*y*+1 is then calculated as:

$$TAC_{y/y+1} = (1 - SSB_y/(2 * MGT\ B_{trigger})) * HR_{MGT} * SSB_y \ / \ MGT\ B_{trigger} * B_{4+,y} \ +$$

$$TAC_{y-1/y} * SSB_y \ / \ (2 * MGT\ B_{trigger})$$

When HR_{MGT} is applied the realized harvest rate is expected to vary between 0.12 and 0.32 when following the HCR (ICES 2013). On average the realized HR should be close to HR_{MGT}. As stated above ICES is requested to report on the probability distribution of the realized harvest rate when HR_{MGT} = 0.2.

References

ICES 2013. Request from Iceland to ICES to evaluate the long-term management plan and harvest control rule for Icelandic saithe. ICES advice 2013, Book 2

On behalf of the Minister of Fisheries and Agriculture

Jóhann Guðmundsson
Director General

ATVINNUVEGA- OG
NÝSKÖPUNARRÁÐUNEYTIÐ

Ministry of Industries and Innovation

Skúlagötu 4 101 Reykjavík Iceland
tel.: + (354) 545 9700 postur@anr.is
anr.is

ICES - International Council for the Exploration of the Sea
Mr. Mark Dickey-Collas, ICES ACOM chair
H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
DENMARK

Reykjavík March 1, 2019
Reference: ANR18100255/15.09.00

Subject: Evaluation of the current management plan for haddock in Icelandic waters, input data and stock assessment.

In a letter (ANR18100255/11.02.00) from 16th of October 2018 the Icelandic Ministry of Industries and Innovation requested ICES to evaluate the historical performance of the management plan for haddock against the general aim of maintaining the exploitation rate at the rate which is consistent with the precautionary approach and are in conformity with the ICES MSY approach. ICES was also asked to evaluate possible changes in the assessment methods and estimated reference points.

In consultations between scientists from the Marine and Freshwater Institute, stakeholders and the Ministry of Industries and Innovation there was a consensus not to change the current harvest control rule (HCR) for haddock, apart from a revision of the management trigger from B_{lim} to B_{pa}. Therefore, the Ministry requests ICES to evaluate if the harvest control rule is still consistent with the precautionary approach and in conformity with the ICES MSY-approach. Additionally, ICES is requested to

a) Re-evaluate the assessment framework and the harvest control rules for haddock (specified below) given the data and knowledge gathered since 2013.
b) If the harvest control rule is found not to meet its objectives to propose changes.
c) Report on the probability distribution of the realized harvest rate (HR) given the values of $HR_{MGT} = 0.4$ for haddock.

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

The HCR is applied to calculate the annual total allowable catch (TAC) based on 40% ($HR_{MGT} = 0.4$) of the biomass of 45cm and larger haddock in the advisory year ($B_{45cm+,y+1}$). The TAC for the fishing year *y*/*y*+1 (September 1 of year *y* to August 31 of year *y*+1) is calculated as follows:

$$TAC_{y/y+1} = HR_{MGT} * B_{45cm+,y+1}$$

If the spawning stock biomass (SSB) falls below 64 800 tonnes (MGT $B_{trigger}$), the harvest control rule dictates that HR_{MGT} shall be reduced linearly to zero based on the ratio of the SSB estimated and MGT $B_{trigger}$, the TAC for the fishing year $y/y+1$ is then calculated as:

$$TAC_{y/y+1} = HR_{MGT} * SSB / MGT\ B_{trigger} * B_{45cm+,y+1}$$

When HR_{MGT} is applied the realized harvest rate is expected to vary between 0.29 and 0.57 when following the HCR (ICES 2013). On average the realized HR should be close to HR_{MGT}. As stated above ICES is requested to report on the probability distribution of the realized harvest rate when $HR_{MGT} = 0.4$.

References

ICES 2013. Request from Iceland to ICES to evaluate the long-term management plan and harvest control rule for Icelandic haddock. ICES advice 2013, Book 2

On behalf of the Minister of Fisheries and Agriculture

Jóhann Guðmundsson
Director General

Annex 4: Terms of Reference

The Workshop on the benchmark assessment and management plan evaluation for Icelandic haddock and saithe (WKICEMSE 2019) will meet at ICES HQ, Copenhagen, Denmark on 26–28 March 2019 chaired by ICES Chair Morten Vinther (Denmark) and External Chair Jim Ianelli (USA) and attended by two invited external experts Paul Spencer (USA), and Christoph Konrad (Italy), to evaluate the benchmark assessments and management plan evaluations for Icelandic haddock (had.27.5a) and saithe (pok.27.5a). The work will be to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of (where applicable):
   i. Stock identity and migration issues;
   ii. Life-history data;
   iii. Fishery-dependent and fishery-independent data;
   iv. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook
b) Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;
c) Re-examine and update (if necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);
d) Develop recommendations for future improving of the assessment methodology and data collection;
e) Evaluate the Icelandic management plans for the stocks listed in the text table below against precautionary and MSY criteria.

Stock	Stock leader
had.27.5a	Bjarki Thor Elvarsson <bjarki.elvarsson@hafogvatn.is>
pok.27.5a	Höskuldur Björnsson <hoskuldur.bjornsson@hafogvatn.is>

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

For the most up to date stock annex for this stock, please go here:
had.27.5a_SA

Annex 6: Stock Annex: Saithe (*Pollachius virens*) in Division 5.a (Iceland grounds)

For the most up to date stock annex for this stock, please go here:
[pok.27.5a_SA]