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

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Saithe
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A. General

A.1. Stock definition

Saithe in Icelandic waters (Division 5.a) is managed as a one unit, though taggings have shown that in some years saithe migrates from distinct waters into Icelandic waters and vice versa. Saithe is both demersal and pelagic. They can be found all around Iceland, but are most common in the warm waters south and southwest off Iceland. Spawning starts late January with a peak in February in shallow water (100-200 m) off the southeast, south and west coast of Iceland. The main spawning area is considered to be south/southwest off Iceland (Selvogsbanki, Eldeyjarbanki). The larvae drift clockwise all around Iceland and in mid-June juveniles can be found in many coves, bays, and harbors then about 3-5 cm long. At age 2 they move to deeper waters in winter. Saithe becomes mature at age 4-7.

According to available data, approximately 115 thousand saithe were tagged in the NE-Atlantic in the 20th century, most of them in the Barents Sea with total returns just under 20 thousand (Jonsson 1996). Around 6 000 saithe were tagged in Icelandic waters in 1964-65, the recapture rate being 50% (Jones and Jonsson 1971). Based on recaptures by area, approximately 1 in 500 of tagged saithe released outside Icelandic waters were recaptured in Icelandic waters, and 1 in 300 released in Icelandic waters were recaptured in distant waters (Jonsson 1996). For comparison, cod long-term emigration rate from Icelandic waters is 1 in 2000 tagged fish (Jonsson 1996), a rate almost an order of maginitude lower.

Other evidence of saithe migrations exist, albeit of a more circumstantial nature. Sudden changes in average length or weight at age and reciprocal fluctuation in catch numbers at age in different areas of the NE-Atlantic have been interpreted as signs of migrations between saithe stocks (Reinsch 1976, Jakobsen and Olsen 1987, Jonsson 1996). Since mean weight at age decreases along an approximately NW-SENE gradient, migration of e.g. northeast arctic saithe to Icelandic waters will, theoretically, be detectable as a reduction in size at age in the Icelandic saithe catches. Catch curves from some year classes, from different areas show some reciprocal variations. Inspection of the data based on the above indicate that the most likely years and ages for immigration are as follows: Age 10 in 1986, age 7 in 1991, age 9 in 1993 and the 1992 year class as age 7 saithe in 1999 and 8 in 2000.

A recent tagging program was conducted in Icelandic waters in 2000-2004 from which ~1750 of ~16000 tags released have been returned. The number of returns from areas other than the Icelandic EEZ has now reached 10 or around 2.5% of the recaptures outside the management area of the stock. Most were tagged at eastern localities. and recaptured in Faroes waters, with a pulse of tags recovered in early 2006. Other foreign returns have come from areas west of Scotland and east of Greenland. Figure A.1.1 shows the total returns from this tagging program (2007 ICES NWWG).

A.2. Fishery

Annual landings and overview of the major fleets

Annual estimates of landings of saithe from Icelandic waters are available since 1905 (Figure A.2.1). The historical information are largely derived from Statistical Bulletin, with unknown degree of accuracy. The more recent landings (from 1980 onward) statistics are from the Directorate of Fisheries as annually reported to ICES.

After WWII the fishery was initially dominated by foreign fleets, mainly English and German trawlers. The former were primarily targeting cod and catching saithe as a bycatch, while the latter were more directly targeting saithe as well as redfish. The domestic fleet has more or less been the sole exploiter of the saithe resource since 1978, following the expansion of the Icelandic EEZ from 50 to 200 miles in 1975.

Information on landings of the Icelandic fishing fleet by fishing gear is available since 1974, with the exception of the years 1979-1981 (figure A.2.2). Largest portion of the catch is taken by trawl, with gillnet fisheries playing a secondary role. The importance of the gillnet fisheries has declined, being between 13-43 % in the period 1974-1995, but only around 10% of the total landings since then.

Information from captains logbook records, available since 1991 show that gillnet and trawl fisheries are of mixed nature (see WD 04). Between 40-80% of the annual bottom trawl landings based on hauls where saithe is reported as catch constitutes 75% or more of the catches. During the 1990’s an increasing portion of the total annual saithe trawl landings was taken as bycatch, with the trend somewhat reversing in the since then. The less important gillnet fishery in terms of landings are somewhat more of a mixed mixed species fisheries compared with the trawl fishery. Here between 20-80% of annual gillnet catches are from settings where saithe constitutes 75% or more of the catches. Relatively speaking the gillnet fishery became more of a bycatch fisheries in 1996-2006 compared with that observed in the 1991-1995 (in a period when catches were higher). Since 2003 until 2008 the gillnet fishery, according to the logbook records have become increasingly a targeted fishery.

In the pelagic fishery a small amount of by-catch of saithe (~1%) has been reported in the blue whiting fishery in the Icelandic EEZ (NWWG report in 2009).

Attempts have been made at estimating discarding in the Icelandic fisheries since 2001 (Palsson et al. 2008) based on a method using length measurements taken by observers on-board and measurements taken of landed fish. Discarding of saithe is hardly detectable, while that observed e.g. for haddock has been around 8% of landings in numbers.

Spatial and temporal distribution catches

The saithe fishery in Icelandic waters is largely limited to the southern and western shores of Iceland (figure A.2.3), with an increase in share of the catches taken in the southeast and in the northwest relative to that obtained in the southwest (WD 04). The gillnet fishery occurs over a relatively narrower geographic range and in shallower water relative to the bottom trawl fishery. The saithe fishery takes place more or less continuously throughout the whole year, although catches in November through January tend to be lower than in other months, and somewhat higher in March.

Fleet composition

The fishing fleet operating in Icelandic waters consists of a diverse boat types and sizes, operating various types of gear. The largest share of the saithe catches (76% in 2008) are taken with trawler larger than 40 BRT. The bulk of the gill net catches are taken by 13 boats in the size classes 30-41 BRT. The top 50 trawler and boats took around 85% of the total saithe catch in 2008. The remainder of the saithe catch come from myriads of smaller boats, using handlines, jigging and Danish seine. These boats are largely targeting cod, haddock and flatfishes with saithe being only a bycatch.

Management

The fisheries in Icelandic waters have since 1984 been managed under a TAC system, where each boat owns a certain percentage of the TAC. The management year is from start of September to end of. August in the following year. The system is an ITQ system, allowing free transferability of quota between boats. This transferability can either be on a temporary (one year leasing) or a permanent (permanent selling) basis. This system has resulted in boats having quite diverse species portfolios, with companies often concentrating/specializing on particular group of species. The system allows for some but limited flexibility with regards converting a quota share of one species into another within a boat, allowance of landings of fish under a certain size without it counting fully in weight to the quota and allowance of transfer of un-fished quota between management years. The objective of these measures is to minimize discarding, which is effectively banned. Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis time by the Directorate of Fisheries (the native enforcement body). All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on landing is stored in a centralized database maintained by the Directorate and is available in real time on the internet (http://www.fiskistofa.is). Insignificant amount of the saithe caught in Icelandic waters is landed in foreign ports. The accuracy of the landings statistics are considered reasonable although some bias is likely.

All boats operating in Icelandic waters have to maintain a log-book record of catches in each haul. The records are available to the staff of the Directorate for inspection purposes as well as to the stock assessors at the Marine Research Institute.

A system of instant area closure is in place for many species, including saithe. The aim of the system is to minimize fishing on smaller fish. For saithe, an area is closed temporarily (for 3 weeks) for fishing if on-board inspections (not 100% coverage) reveal that more than 25% of the catch is composed of fish less than 55 cm in length. No minimum landing size of any fish species exist in Icelandic waters. The minimum allowable mesh size is 135 mm in the trawl fisheries, with the exception of targeted shrimp fisheries in waters north of the island.

The Marine Research Institute has issued a recommended annual TAC since 1984, with advice also given by ICES since 1987. The set TAC has often been set higher than the advice and no formal harvest control rule exists for this stock. The landings (by quota year) have in 6 out of 25 years exceeded the national TAC by more than 10%. With the exception of 1995/96 the landings in other years have been closed to or lower than the national TAC.

A.3. Ecosystem aspects

Changes in the distribution of the large pelagic stocks (blue whiting, Norwegian spring spawning herring) may affect the propensity of saithe to migrate off shelf and between management units. This is poorly documented but well known.

Significant changes in the length and weight at age have been observed in the Icelandic saithe. It is unknown if these factors are fisheries or environmentally driven.

B. Data

B.1. Commercial catch

Sampling from the Icelandic fleet

Sampling of size and age composition of saithe in the Icelandic fisheries only started in 1974 (Figures B.1.1 and B.1.2). In the years 1974 to 1977, the sampling was rather limited, with less than 50 independent samples taken each year. Thereof otoliths were taken in 15 samples or less, annually. In the years 1978 and 1979 a significant sampling occurred from the fisheries, with the primary objective to establish the relationship between length and weight. Since 1980 regular sampling, with the objective to calculate annual catch in number has taken place. During 1980-1998 the number of independent samples were 50-100 per year but have increased significantly in recent years being above 200 in the last four years. This increase is in part due to random samples taken by the staff of the Directorates of Fisheries, partly aimed at studying potential discarding.

Over the period the 1980-1998 the number of length measurements in each sample was around 200. Thereof, 100 fish were sampled for otoliths/age. In 1999 there was a change in the protocol within each sample, where the number of fish measured was reduced to 150, with 50 fish being weighted and sampled for otoliths. This did not result in fewer individuals being sampled, due to the increase in the sampling intensity that occurred at the same time. Systematic gutted weight measurements of fish sampled for otoliths commenced in 1995.

The sampling protocol by the staff of the Marine Research Institute has in the last years been linked to the progression of landings within the year. The system is fully computerized (referred to as "Sýnó" by the natives) and directly linked to the daily landings statistics available from the Directorate of Fisheries. For each species, each fleet/gear and each landing strata a certain target of landings value behind each sample is pre-specified. Once the cumulative daily landings value pass the target value an automatic request is made to the sampling team for a specific sample to be taken. The system as such should thus take into account seasonal variability in the landings of any species. An overview of the cumulative landings of the saithe and the cumulative sampling of saithe seem to be in reasonable sync (Figure B.1.3), although there seem to be lesser sampling intensity in the summer months, possibly associated with summer holiday of the staff. The sampling design is not per se linked to the geographical distribution of the fisheries. However the fishing location of the fish measured at harbour is known with reasonably accuracy, because fishing date is registered for each fish boxes and can hence be linked to geographic location of the fishing at that date, based on the captain's log-book record. An overview of the sampling of Saithe based on these information (Figures B.1.4 and B.1.5) show that overall, the geographical sampling intensity mirrors the geographical distribution of the fisheries (see Figures A.2.3).

Calculation of catch in numbers

The calculation of the annual catch in number of the Icelandic saithe has since 1989 been based on only 2 metiers, trawl and gillnet, with no splitting by season or geographic distribution of fishing. Catches in other gears (long line and Danish seine) are included with the trawl gear. For the saithe the length distribution are compiled into bins of 5 cm and used as such in the length age key. The parameters used to convert length to weights are:

Cond = 0.024498

Power = 2.7567

Otherwise the calculations of calculation of annual catch in number and weight at age for saithe have since 1980 been calculated in the same way as was done for other species assessed by age based methods at the Marine Research Institute. What follows is a general description of the algorithm used in the calculations in the unix software package (referred to as PAX: "Poplulation Assessment in uniX"):

PAX is a menu-based system where one has among other things the options of fetching data from a centralized database; calculate catches in numbers; make cpue indices and run a vpa program. It was first written late eighties and has been updated several times since then. Most of the modules in the system are prelude shellscrips which are run in unix/linux. Now the most used unit is the catches in numbers calculations. That module will be described here.

Catch in numbers are calculated for each area, a season and a gear combination and then combined to total catches in numbers over all areas, seasons and gears.

Length distributions

Data used are length frequency samples taken in area **r**, season **t** and gear **g**.

L_l is the number of fishes at length *l*.

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

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

Age-length and maturity keys

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

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

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

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

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

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

Sum of the numbers at length *l* over all ages:

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

Make a new key with the number of fishes:

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

And new maturity keys:

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

Average length and weight

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

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

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

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

The total frequency in the key is:

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

and total weight

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

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

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

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

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

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

The mean weight ate age, length at age, and maturity at age are:

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

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

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

if the denominator > 0 otherwise the *ratio_M*$_a$ *is set to -1.*

Catches in numbers

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

The total number of fishes caught are:

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

The catches in numbers and weight by age is then

$$C_a = C_{tot} \cdot ratio\_C_a$$
$$W_a = C_a \cdot \overline{w}_a$$

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

Historical catch in numbers and weight at age: 1960–1979

Tabulated annual catch in numbers at age of the Icelandic saithe catches can be found from 1960 onwards, with the earliest record found in the Report on the Saithe (Coalfish) Working Group 1976 (ICES CM 1976/F:2). However, it is obvious that the Coalfish working group members had compiled these historical numbers (from 1960 onward) already by 1973 (Report of the Saithe (Coalfish) Working Group, ICES CM 1973/F:10), this being deduced from the resulting VPA analysis done by the 1973 group, where a tabulation of stock in numbers and fishing mortality by age is given for the period 1960-1970. From the various recent ICES assessment reports dealing with Icelandic saithe, it can be deduced that the catch in numbers as originally reported in the Coalfish reports have remained unchanged, i.e no later revisions were done to the calculated numbers.

Description on how the annual age composition of the catch for the period 1960-1980 were compiled by the ICES working group at the time are very limited and the calculation cannot be repeated. Number of annual samples, fish measured and age composition by fleet (countries) is not stated in the ICES assessment report from this time. In the 1973 Coalfish report it is noted that catch in numbers for Icelandic saithe in this early period were based only on samples from the German and English fleet. In the report it is then stated: "As a result it had to be assumed that the catches of the countries for which no data were available had the same age composition as the countries for which data were available. For each year the available age distributions of national catches were summed and the resultant age composition was then raised by the ratio of total landed weight of all countries to landed weight of countries for which age composition were known." However, in the same report it is further noted that "young saithe recruited first to the Icelandic purse-seine and trawl fisheries, then to the English trawl fishery and finally to the German trawl fishery". Given this, the approach of raising the catch composition from the German/UK age distribution to the total landings will most likely lead to a bias in the total catch at age distribution to some unknown degree. In particular since the Icelandic fleet took the largest share of the catches from 1967 onwards (Figure A.2.1). The earliest account where age composition from the Icelandic fleet is used as a part of the total annual catch at age matrix is in 1977 (Report of the Saithe (Coalfish) Working Group. ICES CM 1978/G:3). This is understandable since samples from the Icelandic fleet prior to that year are very limited (see above).

No information is provided in the early working group reports on how weight at age in the catches were derived. In all cases, annual weight at age used is a constant value over the time period. However, as early as 1973 (Report of the Saithe (Coalfish) Working Group. ICES CM 1973/F:10) it was noted that "…in the English data there was a clear trend of reducing length at age over the past 10-12 years for saithe… The rate of reduction of average length has been about 1 cm per year, and over the period of 10 or 12 years this is equivalent to more than a year's growth. Similar but less marked trend is apparent in the German data." Given this observation, the use of a constant weight at age over this time period is obviously wrong. In addition it explains the significant discrepancy between sumproduct of catch numbers and weight at age vs that of the total landings exist, particularly in the early part of the time series. The catch weight at age has historically been used in the calculation of SSB. Using the constant weight at age results in significantly higher historical maximum SSB (Figure B.1.6, based on a simple VPA model) than if weights scaled so that the sumproducts of catch in number and weight at age are the same as the total landings (see WD02 for details of how rescaling was done).

Given that:

- The that samples of the catch composition from the Icelandic fleet is not available in the early time period
- Fixed weight at age used in the early time period
- Sumproduct discrepancy
- Consequences different derivations have on the perception on the dynamic range

data information prior to 1980 is not used, albeit at the cost of loosing information on the dynamic history of the stock and its response to fisheries. However, based on the VPA model (Figure B.1.6) the dynamic range of SSB in the period observed from 1980 is within the range observed in the long time series.

B.2. Biological

Natural mortalities

A fixed natural mortality rate of 0.2 is used both in the assessment and the forecast.

The proportion of natural mortality before spawning (Mprop) and the proportion of fishing mortality before spawning (Fprop) are set to 0.

Weight at age

Mean weights at age in landings are computed on the basis of samples of otoliths and lengths, along with length distributions and length-weight relationships. Weight at age in the landings is also used as weight at age in the stock.

Predicted weights for the assessment year are estimated by applying a linear model using current survey weights and weight of the year class in the previous year as predictors,

$$\log({}_{C}W_{t,a}) = \beta_0 + \beta_1 \log({}_{C}W_{t-1,a-1}) + \beta_2 \log({}_{S}W_{t,a})$$

where ${}_{C}W_{t,a}$ is the current year's catch weights, ${}_{C}W_{t-1,a-1}$ is the previous year's catch weights, and ${}_{S}W_{t,a}$ is this current year's survey weights. See Magnusson (2012) for details.

Maturity

A model using maturity-at-age data from the Icelandic groundfish spring survey (Figure B.2.1) is used to derive smoothed trends in maturity by age and year. Spawning of saithe starts late January with a peak in February, just before the spring survey. The survey time is thus close to the spawning time making visual detection of maturity stages optimal. Maturity-at-age data from surveys are considered to give better estimates of maturity at age in the stock than those from landings data, in particular because of limited ungutted samples in the landings (figure B.1.2).

Since the annual survey estimates of maturity at age are very noisy (Figure B.2.1), a model to smooth the maturity data is used. The model fitted (using R) is:

$$\text{logit}(P_{a,t}) = \alpha + \beta\, age + \text{ns}(year, \text{df}=6)$$

where P is the proportion mature at age a in year t, and ns are smoothing splines used to increase the flexibility of the model. Results for two age groups, 5 and 7, are shown in Figure B.2.2, along with the mean proportion mature for the same age groups from the survey data.

Ages 1-3 are assumed immature, and ages 10 and older are assumed mature. The average maturity in 1985-1998 is used for the early years 1980-1984, when survey data were not available. Future projections use the predictions for the assessment year.

B.3. Surveys

An account of the Icelandic March (Spring, 1985-onwards) and October (Fall, 1996-onwards) groundfish surveys were provided as a WD for the Benchmark 2010 (WD-03). The WD is a translation of a citable report (http://www.hafro.is/Bokasafn/Timarit/rall_2007.pdf) written in the native language. It will be formally published in non-native speaking language in spring 2010. In summary, the surveys design is a classical random stratified design with fixed stations with time. With the caveat that experienced captains given the freedom to choose particular stations within a certain predefined geographical constraint determined by the scientist. The number of stations in the spring survey are 530, the number of stations in the fall are 380. The spring survey covers depth to 500 meters, but the fall survey covers depths down to 1200 m.

The longer spring survey time series covers to a large degree the traditional fishing grounds of saithe (Figure A.2.3). The shorter fall survey covers almost the entire distributional range of the fisheries (Figure B.3.1), although with only half the station density. The coverage of both surveys is however very poor for juvenile saithe, which are thought largely to inhabit coastal areas very close to shore. Hence the surveys do not provide reliable measurements of incoming recruits.

The survey indices for saithe, that are used as tuning indices are derived using conventional methods. Year effects, particularly in the earlier period are very apparent in the survey biomass indices (Figure B.3.2) and result in age based indices, when plotted as "consistency plots" to look very non-informative (figures B.3.3 and B.3.4). The "year effect" seen in the surveys is largely thought to be a result of the schooling nature of the species, with an accompanying high cv estimates in the survey abundance indices. However, there are indication that the surveys are able to track cohorts to some degree, in particular when catch curves of survey indices are plotted on a the log-scale, the scale that the model "sees the data" (Figure B.3.5). Hence, in order to use the information in the cohort signal from the surveys for species such as Icelandic saithe in an assessment framework some measures must unfortunately be made to allow for the year effect in the survey to be "a parameter" in the model.

B.4. Commercial CPUE

Catch per unit of effort are routinely calculated during the annual assessment process (Figure B.4.1). The overall trend in catch rates show similar trend with time, irrespective of how the indices are derived (mean, median, <50% or >50% saithe per haul), but the absolute values differ. The indices increased sharply from 2000-2004 but have decreased since then, but are still above the level in 1988-2000. Although this trend corresponds roughly with the perceived stock dynamics, the CPUE for Icelandic saithe has not been considered a reliable unbiased index to be used quantitatively as a tuning series in an analytical model.

C. Historical Stock Development

Historical account of models used for saithe assessments

In the 1980s and early 1990s a traditional VPA was used for assessing the Icelandic saithe. The input terminal F for the VPA was estimated by various data sources and different ad hoc methods.

From 1993-2001 both XSA (except in 1999 and 2000) and TSA were run and compared. In all years cpue data were used as tuning series in XSA. Only catch data were used running TSA, except in 1997 and 1999 where cpue data were used as well. The decision taken each year was to use the terminal Fs estimated by TSA as input values for a traditional VPA.

In 2002 survey indices for saithe from the Icelandic groundfish survey in spring were used for the first time in an assessment. XSA, TSA and an ADAPT model were used. The conclusion was the same as in last years, Fs taken from TSA and put into a traditional VPA.

In 2003 Icelandic saithe was not assessed by ICES. Domestic TSA, ADAPT and camera (a separable model implementation in ADMODEL builder) were used as assessments programs. The decision taken this time was to use camera as the final run.

In 2004-2006 camera was used as a final run by ICES, but other models like TSA, cadapt (ADAPT type model implemented in ADMODEL builder), AMCI (a "flexable" separable model) and ADCAM (a forward running statistical catch at age model implemented in ADMODEL builder, allowing for "random walk" in Fay) were un as well. In 2006 XSA was also run again.

In 2007 Icelandic saithe was not assessed by ICES. Domestic TSA, camera and ADCAM were run. The use of camera was rejected due to shifts in the age composition of the landings and it was not considered realistic to assume a fixed selection pattern for the whole assessment period like camera did. Then ADCAM was adopted and since then it has been the assessment program giving the final results each year. For comparison TSA has also been run every year.

Current model used (3 selectivity periods)

A forward-running separable statistical catch at age model, allowing changes in selectivity to occur in specified years is used. The software used is AD Model Builder, adapted to the saithe by Höskuldur Björnsson, MRI. The source code and a Linux executable version are stored by ICES. The model is set up so that both stock assessment and predictions are run at the same time. The code is to a large extent the same as was used by ICES for the HCR evaluation of Icelandic cod in December 2009.

Operating model

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

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

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

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

Migration events are estimated at specific year and age, and are added to the number in stock at the beginning of the year. The size of migration events is estimated as an additional parameter, equivalently as annual recruitment estimates.

Catches are taken according to the catch-equation:

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

$$\hat{C}_{y} = \sum_{a} \hat{C}_{a,y} W_{a,y}^{c}$$

Fishing mortality by year and age is modelled as:

$$F_{ay} = s_a F_y$$

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

Spawning is assumed to occur in the beginning of the year so no mortality takes place before spawning. This is not strictly correct but a good approximation.

The spawning stock is then calculated by

$$SSB_y = \sum_{a} N_{y,a} W_{y,a}^{ssb}\ p_{y,a}$$

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

The predicted recruitment is calculated as a simple hockey-stick given the data available at the time.

Reference biomass is calculated from

$$B_y^{ref} = \sum_{a=4}^{a=14} N_{ay} W_{ay}^c$$

where W_{ay}^c are the mean weight at age in the landings.

Observation model and objective functions

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

1) Landings in numbers

$$\Psi_1 = \sum_{a,y} \frac{\log \frac{C_{ay} + \delta_a}{\hat{C}_{ay} + \delta_a}}{2(\Omega_1 \sigma_a)^2} + \log(\Omega_1 \sigma_a)$$

where Ω_1 is an estimated parameter but the pattern of the measurement error with age σ_a is read from the input files. The values δ_a are input from file. They are supposed to reflect the value where the error goes from being lognormal to multinomial. Typical value could be corresponding to 5 otoliths sampled.

2) Landings in tonnes

$$\Psi_2 = \sum_{a,y} \frac{\log \frac{C_y}{\hat{C}_y}}{2\Omega_2^{\ 2}} + \log \Omega_2$$

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

3) Survey abundance in numbers

Initially the survey likelihood was calculated by.

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

were Ω_3 is an estimated parameter but the pattern of the measurement error with age σ_a^s is read from the input files. The values δ_a^s are input from file and are similar to δ_a in Ψ_1. The predicted survey numbers $\hat{I}_{ay}$ are calculated from the equation $\hat{I}_{ay} = q_a N_{ay}^{b_a}$. The parameters q_a are estimated, but the parameters b_a are set to all set one as the survey indices are considered too noisy to estimate those extra parameters.

For Icelandic saithe year effects are apparent in the survey and were taken into account by modelling the survey residuals by a multivariate normal distribution.

$$\Gamma = \log \frac{I_{ay} + \delta_a^s}{\hat{I}_{ay} + \delta_a^s}$$

a=2:10 is the vector of survey residuals in a given year.

$$\Psi_3 = 0.5\sum_y \operatorname{logdet}\Theta_6 + \Gamma_y{}^T \Theta_6^{-1}\Gamma_y$$

The matrix Θ_6 is calculated from the equation. $\Theta_{6ij} = \Omega_3^2 \sigma_i^s \ \sigma_j^s \ \kappa^{abs(i-j)}$ where κ is an estimated parameter and the parameters Ω_3 and σ_a^s are explained above. When the value κ is high the equation approaches modelling the survey indices as a year factor.

4) Stock – recruitment parameters

$$\Psi_4 = \sum_{a,y} \frac{\log \frac{N_{1y}}{\hat{N}_{1y}}}{2\Omega_4{}^2} + \log\Omega_4$$

where $\hat{N}_{1y}$ is the estimated recruitment from the stock –recruitment function and Ω_4 is an estimated parameter. Ω_4 can be set as a function of SSB (usually increasing with smaller SSB) but that option was not used in the simulations in the 2010 Benchmark. Autocorrelation of the residuals are quite high for saithe exemplified by periods of good and bad recruitment. The modelling of the autocorrelation is done in the same way as the modelling of the yearfactor in the survey.

$$\Gamma_y = \log \frac{N_{1y}}{\hat{N}_{1y}}$$

y=1980:2009 is the vector of recruitment residuals in a given year.

$$\Psi_4 = 0.5\sum_y \operatorname{logdet}\Theta_7 + \Gamma_y{}^T \Theta_7^{-1}\Gamma_y$$

The matrix Θ_7 is calculated from the equation. $\Theta_{7ij} = \Omega_4^2 \ \rho^{abs(i-j)}$ where ρ is an estimated parameter and the parameters Ω_4 explained above.

The stock recruitment models used were either constant recruitment or Hockeystick recruitment with the breakpoint estimated.

5) Overall objective function

The total objective function to be minimized is ρ is in used to in a first order AR model in future predictions. The estimated value is 0.45 and inclusion of it does not have much effect on the outcome of prognosis.

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

Parameter estimated

The estimated parameters in most of the runs are:

- Effort F_y for each year
- Selection pattern s_a for ages 3-10 (set to 1 for ages 11-14) in 3 periods: 1980-1996, 1997-2003, and 2004 onwards.
- Number of age 2 saithe 1980 to the present.
- Initial number in each age group (2-14) in 1980.
- Migration events. Age 7 1991 is always include but diagnostics by allowing migration event at age 7 in 1999 is sometimes checked.
- Parameters of the stock recruitment function (2-4 depending on the function used). In addition CV in the stock recruitment function is estimated.
- Catchability the survey q_a for ages 1-7 with 8-10 same as 7. Three CV parameters Ω_1 Ω_3 and Ω_4, parameter κ for modelling yearblocks in the survey and parameter ρ to model recruitment residuals.

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

Prediction model

Natural mortality was fixed to 0.2

Stochasticity in future weight at age in the stock (W_{ay}^s), the catch (W_{ay}^c) and spawning stock (W_{ay}^{ssb}) are modelled as:

$$W_{ay}^s = \hat{W}_{ay}^s e^{E_y^w}$$
$$W_{ay}^c = \hat{W}_{ay}^c e^{E_y^w}$$
$$W_{ay}^{ssb} = \hat{W}_{ay}^{ssb} e^{E_y^w}$$

where,

$$E_y^w = \left(\rho_w E_{y-1}^w + \sqrt{1-\rho_w{}^2}\,\varepsilon_y\right)$$
$$\varepsilon_y = N(0,1)$$

The mean values of $\hat{W}_{ay}^s$, $\hat{W}_{ay}^c$ and $\hat{W}_{ay}^{ssb}$ in the 2010 Benchmark were the most recently observed values from 2009. The selection of those "average value" has considerable effect on the outcome and the selected values are around 12% below the average from the long term. Expert judgement by WG, based on future patterns may change the basis used.

In the prediction recruitment is generated by the estimated stock-recruitment function (hockeystick in the 2010 Benchmark). Added to the estimated recruitment is random lognormal noise with CV estimated by the assessment part of the model.

Autocorrelated residuals in recruitment are modelled in the same way as autocorrelated stochasticity in mean weight at age.

The selection pattern used in the 2010 Benchmark prediction was the selection pattern of the last "selection period" (1996-2009). No stochasticity is modelled in the selection pattern but the uncertainty in the estimated selection pattern is transferred to the prediction.

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

$$\tilde{F}_y^{ref} = F_y^{ref} e^{E_y^b}$$

where

$$E_y^b = \left(\rho E_{y-1}^b + \sqrt{1-\rho^2}\,\varepsilon_y\right)$$

When the stock is below $B_{trigger}$ intended fishing mortality was not reduced in the 2010 Benchmark. Could be replaced in the future by e.g.: …was reduced by linear reduction in fishing mortality according to:

$$F_y^{ref} = F_y^{ref0-} \frac{SSB_y}{B_{trigger}}.$$

(as suggested in the ACOM "default" approach in the new MSY concept.

The above implementation means that error in estimation of SSB is taken into account, when fishing mortality is underestimated and vice versa. The ultimate goal in using this assessment framework is to implement HCR based on biomass that leads to a definition of target fishing mortality in relation to the ICES Fmsy concept. Given that uncertainity in the assessment and the short term prediction is already taken into account, the estimates of the Fmsy proxy derived here are not comparable with that derived from a deterministic approach.

Of note is that no implementation error is included in the simulations.

CV of residuals in the catch and the survey estimated, with and one multiplier estimated the survey and one for the catch. The *a priori* set age group patterns (σs) and stabilizers (εs) are given in the text table below: δ_a is set to 0.7% of the total catch in numbers each year.

Age	Catch	Survey	Suvey
Group	σ_a	δ_a^s	σ_a^s
1			
2		1	0.50
3	0.17	0.5	0.30
4	0.13	0.5	0.22
5	0.11	0.5	0.19
6	0.10	0.5	0.16
7	0.10	0.3	0.19
8	0.10	0.3	0.24
9	0.11	0.3	0.35
10	0.12	0.3	0.45

11	0.15
12	0.19
13	0.26
14	0.37

Linear catchability relationship for all age groups in survey.

Weights and maturity have been given with matrices based on different data to produce alternative versions/flavours of stock and SSB biomass.

Migration is estimated for 1 events, i.e. for age group 7 in 1991. Four other events are hypothesised, i.e age 10 in 1986, 9 in 1993, 7 in 1999 and 8 in 2000, but were not used in the Benchmark 2010. The timing of these migration events and the age groups included are determined/based on loose indications from deviations from 'normal' weight at age, i,e. abnormally low. Potential future migrations will be evaluated using the same procedure.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1980-onward		Yes
Canum	Catch at age in numbers	1980-onward	3-14	Yes
Weca	Weight at age in the commercial catch	1980-onward	3-14	Yes
West	Weight at age of the spawning stock at spawning time.	1980-onward	3-14	Weca is used as West.
Mprop	Proportion of natural mortality before spawning	1980-onward	3-14	No, kept fixed at 0.
Fprop	Proportion of fishing mortality before spawning	1980-onward	3-14	No, kept fixed at 0.
Matprop	Proportion mature at age in the survey	1980-onward	3-14	Yes, but modelled with a smoother.
Natmor	Natural mortality	1980-onward	3-14	No, kept fixed at 0.2.

The input data used in the 2010 benchmark are archived on the 2010 Benchmark sharepoint site

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Icelandic spring groundfish survey	1985-onward	1-10

D. Short-Term Projection

Model used/software used: The same software is used for forward projections as the assessment. For parameter settings and input data see chapter C.

E. Medium-Term Projections

Model used/software used: The same software is used for forward projections as the assessment. For parameter settings and input data see chapter C.

F. Long-Term Projections

Model used/software used: The same software is used for forward projections as the assessment. For parameter settings and input data see chapter C.

G. Biological Reference Points

	Type	Value	Technical basis
MSY approach	Btrigger	65 kt	2013 HCR evaluation: hockey-stick
	umsy	22%	2013 HCR evaluation: max sustain yield
Precautionary approach	Blim	61 kt	Bloss as estimated in 2010
	utarget	20%	2013 HCR evaluation: 95% over Blim
	Bpa, ulim, upa	Not defined	

The time series used was shortened in the 2010 benchmark, to 1980 onwards. In addition, the maturity ogives now used are based on data from the survey, not from the catches as done in 1998. The result is that the SSB has been scaled downwards relative to that estimated in 1998.

Reference points and MSY considerations

Reference points for Icelandic saithe were defined in 1998. Fpa (mean F of ages 4-9) was set as 0.3 that was close to the mean value sustained in recent decades. The estimated value of Fmed was on the other hand 0.22 that was considered unrealistically low. That conclusion might on the other hand have been wrong.

Blim was set to the lowest value of SSB or 90 000 t and Bpa to 150 000 taking into account relatively uncertain assessment. There has been a discrepancy between the Fpa and the Bpa values used in recent years. One reason for the discrepancy is substantial autocorrelation of recruitment that is characterized with 5-10 poor year classes followed by 2-5 good ones. It must though be remembered that the data series is rather short for this kind of inference. The discrepancy between Fpa and the Bpa in recent years would not have been so large if the estimated value of Fmed (0.22) had been used.

The following text describes the work conducted in the benchmark (ICES 2010).

Yield per recruit was calculated using the same model as recommended for stock assessment. First the assessment model was run million time saving every 500th parameter set in the Markov chain. The model was then run forward for number of different fishing motalities, including factors like assessment error, stochastcity of weights at age and stochasticity in recruitment. CV and autocorrelation of residuals from the stock-recruitment function are estimated in the model and the recruitment residuals in the future simulations are lognormally distributed with the estimated parameter values. The model was run using two different stock-recrutment functions.

- Segmented regression with the breakpoint estimated (Figure 8.10).
- No SSB-recruitment relationship. Gives an indication of yield per recruit.

The stochastic factor multiplying the weights was common for all age groups in the same year, lognormal with standard deviation of 13% and autocorrelation of 0.5. The values are close to the average for the most important age groups (4-8). There is substantial correlation in the changes in mean weight at age (correlation between adjacent age groups in the best observed ages 0.75). The common year factor used is therefore more realistic than white noise but the model does not allow the in between approach. The approach selected does therefore exaggerate the effects of stochasticity in mean weight at age. The mean weight at age in the future simulations are centered around the 2009 values that are 87% of the mean since 1980 though 5% higher observed in 2007-2008.

The error in the assessment is assumed to be lognmormal with standard deviation of 0.25 and autocorrelation of 0.45. No implementation error is assumed nor bias in the assessment except the 4% bias implicit in the lognormal distribution. In the model implementation the estimated fishing mortalities are multiplied by the assessment error in the model. With a catch constraint applied in the year following the assessment year the estimated CV of the mean fishing mortality is 0.26 but 0.22 in the assessment year. The advisory fishing year is in between. Estimated CV on reference biomass is lower or 18-20%.

In the MCMC runs the 5percentile, 10percentile, median and mean of the landings in the last year were plotted against intended fishing mortality (Figure 8.12 and 8.13).

Looking at the estimated parameters the breakpoint was estimated at 80 kt with standard error in the estimate 12 kt. (Bloss is 65 kt)

The yield per recruit curves are very flat (Figure 8.12) but the model like all age based models ignores the fact that size selective fishing mortality of recruiting age groups lead to lower mean weight at age when heavy fishing on recruits occurs. $F_{0.1}$ in this curve is around 0.19 or very close to M.

The curves for the segmented regression (Figure 8.13) look quite different. They have a relatively well defined maximum and Fmsy is 0.28 and $F_{0.1}$ 0.19.

The reason for this difference is that when intended fishing mortality is much above 0.3 some of the stochastic runs will lead to spawning stock being below the estimated breakpoint so recruitment and subsequent landing will be reduced.

The assessment error included in the simulation is substantial. The intended fishing mortality deviates substantially from the resulting one and with lognormal distribution with CV of 0.25 a 4% bias is included in those simulations. In addition the assessment errors have autocorrelation of 0.45.

The path towards a harvest control rule

In 2009, the domestic advice for Icelandic saithe wa based on fishing at $F_{4\text{-}9}$=0.3, except when the spawning stock has been below 150 kt, then the ICES advice has been 0. In 2010 the advice was based on $F_{4\text{-}9}$=0.22 taking into account reduced growth, ignoring that the stock was below 150 kt. The maturity-at-age matrix was revised in the benchmark, using spring survey data instead of commercial catch data, resulting in substantially lower SSB values.

As shown in last section 0.3 is above stochastic Fmsy that is estimated to be around 0.28. A HCR will have to lead to fishing mortality below that value.

The MSY approach calls for a definition of trigger SSB, beoynd which the intended fishing mortality will be reduced linearly to 0. For Icelandic saithe the estimated breakpoint in hockey stick regression is 80kt which is a natural candidate for Btrigger.

SSB_{break} in stochastic simulation of the icelandic saithe was estimated at 80 kt (B_{loss}=65kt). The estimated SSB_{break} seems like a reasonable candidate for $B_{trigger}$. F_{msy} in simulations taking into account most sources of uncertainty was estimated as 0.28 a candidate for F_{msy} and F_{target}. Figure 8.15 shows the cumulative probability of the spawning stock in 2069 with intented F = 0.28, with and without reduction below the trigger point of 80kt. Uncertainty in the estimation of the trigger point is taken into account so when F is overestimated SSB is underestimated by the same amount.

The figure show that there is a minor change in the profile at low SSB but inclusion of the trigger point leads to probability of being below $B_{trigger}$ being around 10% instead of 15%. The mean fishing mortality in the stohastic simulations is 0.289 without the trigger but 0.283 with the trigger. The intended fishing mortality is 0.28.

As F based rules are difficult to present to managers, stakeholders and the public. Therefore managers in Iceland have been more interested in applying biomass based HCR rather than F rules and as saithe and cod grow similarly testing the HCR agreed for cod was considered appropriate first step.

The rule is $Tac_{y/y+1}$=($Tac_{y-1/y}$+0.2B_y)2 where B_y is biomass 4+ using Catch weights.

The rule was both tested with and without reduction of harvest rate below $B_{trigger}$. When the SSB is estimated below $B_{trigger}$ the weight of earlier Tac is reduced so the rule becomes.

$$\alpha = min(\frac{SSB}{B_{trigger}}, 1)$$

$$Tac_{y/y+1} = \alpha 0.5 Tac_{y-1/y} + (1-\alpha)0.5\alpha 0.2 B_y$$

In this equation the weight of last years Tac reduces gradually from 0.5 to 0 as the spawning stock reduces from $B_{trigger}$ to 0 and the effect of reference biomass changes from 0.5 to 1 at the same time.

One of the criteria with the gradual changes of the effect of lastyears TAC and harvest ratio is to avoid discontinuities in the HCR but all HCR where 1% change in stock size can lead to much higher change in TAC are problematic.

The rule without trigger leads to mean fishing mortality of 0.275 but 54.3kt with trigger the mean f is 0.265.

Figure 8.16 shows the cumulative probability profile of the spawning stock in 2069 for the 2 biomass rules compared to F rules.

The biomass rule with stabilizer and trigger has similar probability profile at low spawning stock a F based rule with trigger. The mean SSB is on the other hand higher in the biomass based rule as F is on the average lower. Lower F should lead to lower probability of being below Bloss or $B_{trigger}$ but the stabilizer works against that.

20% harvest control rule

In April 2013, the Icelandic government adopted a management plan for managing the Icelandic saithe fishery. ICES evaluated this management plan and concluded that it was in accordance with the precautionary approach and the ICES MSY framework. In the harvest control rule (HCR) evaluation (Hjorleifsson and Bjornsson 2013) B_{lim} was defined as 61 kt, based on B_{loss} as estimated in 2010, and $B_{trigger}$ was defined as 65 kt, based on an estimated hockey-stick recruitment function.

The TAC set in year *t* is for the upcoming fishing year, from 1 September in year *t*, to 31 August in year *t*+1. The 20% HCR consists of two equations, as follows.

When $SSB \geq B_{trigger}$, the TAC set in year *t* equals the average of 0.20 times the current biomass and last year's TAC:

$$TAC_t = 0.5{\times}0.20\,B_{t,4+} + 0.5\,TAC_{t-1} \qquad \text{(Eq. 1)}$$

When SSB is below $B_{trigger}$, the harvest rate is reduced below 0.20:

$$TAC_t = SSB_t/B_{trigger}\,[\,(1 - 0.5\,SSB_t/B_{trigger})\,0.20\,B_{t,4+}) + 0.5\,TAC_{t-1}\,] \qquad \text{(Eq. 2)}$$

Equation 1 is a plain average of two numbers. Equation 2 is continuous over $SSB_t/B_{trigger}$, so the rule does not lead to very different TAC when SSB_t is slightly below or above $B_{trigger}$ (Magnusson 2013).

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