Stock Annex: Saithe (*Pollachius virens*) in Division 5.b (Faroes grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Faroe saithe (Division 5.b)
Working Group:	North-Western Working Group (NWWG)
Created:	February 2010
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Last updated:	May 2017
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A. General

A.1. Stock definition

Saithe is widely distributed around the Faroes, from shallow inshore waters to depths of 500 m. The main spawning areas are found at 150–250 meters depth east and north of the Faroes. Spawning takes place from January to April, with the main spawning in the second half of February. The pelagic eggs and larvae drift with the clockwise current around the islands until May/June, when the juveniles, at lengths of 2.5–3.5 cm, migrate inshore. The nursery areas during the first two years of life are in very shallow waters in the littoral zone. Young saithe are also distributed in shallow depths, but at increasing depths with increasing age. Saithe enter the adult stock at the age of 3 or 4 years (Jákupsstovu 1999).

Saithe in Division 5.b is regarded as a management unit although tagging experiments have demonstrated migrations between the Faroes, Iceland, Norway, west of Scotland and the North Sea (Jákupsstovu 1999). Jakobsen and Olsen (1987) investigated tagging of saithe at the Finmark coast (off Northern Norway) during the 1960s–1970s. They found that emigration rates to the Faroe Area by some 2–3 % of the North-east arctic saithe stock was sufficient to explain the tagging results, and that the emigration likely occurred before sexual maturity. Bearing in mind that the North-east arctic saithe stock is larger than the saithe stock at the Faroes (by a factor of 1 to 6), up to some 20 % of the saithe stock at the Faroes may be of Norwegian origin, according to this study. However, it might be expected that the emigration rate of saithe from more southerly locations along the Norwegian coast could be higher than in Jakobsen and Olsen's (1987) study (see Jakobsen (1981) for emigration to the North Sea). On the other hand, the emigration rate in the opposite direction also has to be accounted for. English tagging experiments (Jones and Jónsson, 1971) with Faroe Plateau saithe in the 1960s indicated an emigration rate to the Faroe Bank of 5 % (2 out of 41), North Sea of 15 %, and a rate of 20 % to Iceland (2 % had unknown recapture site). Regarding the migration between Icelandic and Faroese waters, there have been tagged some 18463 juvenile saithe in Icelandic waters in 2000–2005 (Armansson *et al.*, 2007), and 1649 have been recaptured up to now, 7 of them in Faroese waters (Marine Research Institute, Iceland, pers. comm.). This indicates that emigration rate of saithe to Faroese waters might be limited. In conclusion, Faroe saithe seem to receive recruits from own waters as well as recruits from the North-east arctic saithe stock and probably also the North Sea stock. In addition, there might be a net emigration to Icelandic waters (Jones and Jónsson, 1971; Jakobsen and Olsen, 1987).

A.2. Fishery

Since the introduction of the 200 miles EEZ in 1977, the saithe fishery has been prosecuted mostly by Faroese vessels. The principal fleet consists of large pair trawlers (>1000 HP), which have a directed fishery for saithe, about 60% of the reported landings since 1992. The smaller pair trawlers (<1000 HP) and larger single trawlers have a more mixed fishery and they have accounted for about 30% of the total landings of saithe since 1997. The share of landings by the jigger fleet accounts for less than 3% of the total landings since 2000. Since 2011 single trawling has been replaced by pair-trawling caused largely to reduce operational costs and therefore increasing the total share of catches of pair-trawlers up to 90%. Nominal landings of saithe in Division 5.b have varied cyclically between 10 000 t and 68 000 t with three distinctive cycles of around 15 years period since 1961. The largest and poorest catches were recorded in the mid 2000's (~70 kt) and 1990's (~20 kt) respectively. Since early-1980s the bulk of catches consists of age groups 4 to 7 while the contribution of older age groups was more substantial from 1961 to 1980.

Catches used in the assessment include foreign catches that have been reported to the Faroese authorities and usually not officially reported to ICES at the time of the assessment. However, catch statistics are revised and updated according to the latest available information from ICES. Catches in Subdivision 2.a, which lies immediately north of the Faroes, have also been included. Little discarding is thought to occur in this fishery.

Spatial and temporal distribution catches

The saithe fishery in Faroese waters is distributed along the deeper waters around the Faroe shelf (Figure 1), with an increase in share of the catches taken in the west, south and southeast relative to that obtained in the northwest. The saithe fishery takes place more or less continuously throughout the whole year, although catches in February and March tend to be higher than in other months.

A.3. Ecosystem aspects

The rapid recovery of the cod stock in the mid-1990s strongly indicated that 'strange things' had happened in the environment. It became clear that the productivity of the ecosystem affected both cod and haddock recruitment and growth (Gaard *et al*., 2002), a feature outlined in Steingrund and Gaard (2005). The primary production on the Faroe Shelf (< 130 m depth), which took place during May-June, varied interannually by a factor of five, giving rise to low- or high-productive periods of 2–5 years duration (Steingrund and Gaard, 2005). Saithe, however, seem to be more affected by the productivity over the outer areas. The productivity over the outer areas seems to be negatively correlated with the strength of the Subpolar Gyre (Hátún *et al*., 2005; Hátún *et al*., 2009; Steingrund *et al*., 2010), which may regulate the abundance of saithe in Faroese waters (Steingrund and Hátún, 2008). When comparing a gyre index (GI) to saithe in Faroese waters there was a marked positive relationship between annual variations in GI and the total biomass of saithe lagged 4 years.

There is a negative relationship between mean weight-at-age and the stock size of saithe in Faroese waters. This could be due to simple density-dependence, where there is a competition for limited food resources. Stomach content data show that blue whiting, Norway pout, and krill dominate the food of saithe, and the annual variations in the stomach fullness are mainly attributable to variations in the feeding on blue whiting. There seemed to be no relationship between the ways stomach fullness is related to weights-at-age (Í Homrum *et al*., 2009). One explanation for this might be the influx of fish (3 to 5 years old) to Faroese waters from other saithe stocks given that weights-at-age are very similar, e.g. for NEA and Faroe saithe in years when the Faroe saithe stock is large (4 years after a high GI) whereas Faroe saithe has up to two times larger individual weights when the stock size is low.

B. Data

B.1. Commercial catch

In order to compile catch-at-age data, the sampling strategy is to have length, length-age, and length-weight samples from all major gears (pair trawlers < 1000 HP, pair trawlers > 1000 HP, single trawlers > 1000, jiggers, HP, and others) every three quarter of the year: January-April, May-August and September-December. When sampling was insufficient, length-age and length-weight samples were used from similar fleets in the same time period while avoiding if possible the use of length measurements. Landings statistics are obtained from the Fisheries Ministry Directorate (www.fisk.fo) and the National Statistical office (www.hagstovan.fo). Catch-at-age for fleets covered by the sampling scheme are calculated from the age composition in each fleet category and raised by their respective landings. Fleet based catch-at-age data was summed across all fleets and scaled to the correct catch.

Mean weight-at-age data are calculated using the length-weight relationship based on individual measurements of landing samples. Ageing of saithe is considered very precise and consistent across all ages.

B.2. Biological

B.3. Surveys

The spring bottom trawl groundfish surveys in Faroese waters were initiated in 1983 with the research vessel Magnus Heinason. Up to 1991 three cruises per year were conducted between February and the end of March, with 50 stations per cruise selected each year based on random stratified sampling (by depth) and on general knowledge of the distribution of fish in the area. In 1992 the first cruise was not conducted and one third of the stations used up to 1991 were fixed. Since 1993 all stations were fixed. The number of stations was increased to 100 since 1994.

The summer (August-September) groundfish survey was initiated in 1996 and covers the Faroe Plateau with 200 fixed stations. Effort for both surveys is recorded in terms of minutes towed (~60 min).

Both surveys are stratified (15 strata) and cover depths from 60 to 500 meters. The coverage of both surveys is however very poor for juvenile saithe, which is largely distributed in coastal areas very close to shore and therefore the surveys, do not provide reliable measurements of incoming recruits. Moreover as a result of the schooling nature of saithe variability in indices is higher than that for species like cod and haddock. Historical data dating back to early 1980's exist but are unfortunately not available for analysis although work is in progress to recover and compile these data in upcoming meetings. Both time series cover to a large degree the traditional fishing grounds of saithe in the Faroe shelf (Figure 1). TAs a result of the schooling nature of saithe variability in indices (high cv) is usually higher than that for species like cod and haddock. However, there are indications that the surveys are able to track cohorts to some degree when looking at the consistency with catch-at-age data. The summer index is considered more reliable than the spring index with a R^2 of over 0.7 for age groups 5–10 and around 0.3 for age classes 3 and 4.

The internal consistency of the summer survey measured as the correlation between the indices for the same year class in two adjacent years is good with R^2 ranging from 0.5 to 0.7 for the best-defined age groups, and R^2 varying between 0.3 and 0.4 for some other age classes. The internal consistency of the summer index is overall superior to the commercial CPUE index. The spring survey shows a weaker internal consistency with R^2 ranging from 0.40 to 0.56 for the best-defined ages. Age-disaggregated indices are calculated as stratified mean number. The age length key is based on otolith samples pooled for all stations. Due to incomplete otolith samples for the youngest age groups, saithe less than 20 cm is aged as 0 year old and between 20–40 cm as 1 year old. Since the age length key was the same for all strata, a mean length distribution is calculated by stratum and the overall length distribution calculated as the mean length distribution for all strata weighted by stratum area. Having this length distribution and the age length key, the number of fish at age per station was calculated, and scaled up to 100 and 200 stations in the spring and summer surveys respectively.

Maturity data

Maturity at age data from the spring survey is available since 1983. Some of the 1983– 1996 values were revised in 2003 but not the maturities for the 1961–1982 period (Steingrund, 2003). The proportion mature is obtained from the spring survey, where all aged individuals are pooled, i.e., from all stations, being in the spawning areas or not. Due to poor sampling in 1988 the proportion mature for that year was calculated as the average of the two adjacent years. The WKFAROE working group (2017) investigated several models in order to alleviate large fluctuations in maturity ogives for saithe. The method agreed upon in the last benchmark meeting (ICES 2010) was a smoother that caused relatively large revisions in maturity as new data points are available. The WKFAROE group agreed to use a 10-year moving average which is a trade-off between retaining the trend in maturities and reducing the noise in the data. The method causes minimal revisions in maturities as new time series of data are incorporated each year.

Historical maturities (1961–1982) are estimated as an average of maturity ogives from 1983 to 1996.

B.4. Commercial CPUE

The CPUE data from pair-trawlers have been used for tuning the assessment of saithe from 2000 to 2016. At the benchmark working group (WKAFAROE 2017) the series were replaced by fisheries-independent survey indices (see B.3 section). The following is a description of commercial CPUE data.

The CPUE series from pair trawlers were introduced in 1998 (ICES C.M. 1998/ACFM:19), and consists of saithe catch at age and effort in hours, referred to as the pair trawler series. All vessels use 135mm mesh size, the catch is stored on ice on board and landed as fresh fish. The vessels are greater than 1000 HP and have specialized in fishing on saithe and account for 5 000-20 000 t of saithe each year. The tuning series data are based on available logbooks of 4-10 trawlers since 1995. Data are stored in the database at the Faroe Marine Research Institute in Torshavn where they are quality controlled and corrected if necessary. Effort is estimated as the number of fishing (trawling) hours, i.e. from the time the trawl meets the bottom until hauling starts. It is not possible to determine effort in fishing days because day and time of fishing trips are not recorded in the logbooks. The effort distribution of the pair trawlers fleet covers most of the fishing areas in the deeper parts (bottom depth > 150 m) at the Faroes. Distribution of combined trawl catches (single- and pair-trawlers) from logbooks is shown in Figure 1.

During 2002-2005 four pairs of these trawlers were decommissioned. In 2004 and 2005 two new pairs of trawlers (>1000 HP) were introduced in the tuning series; one pair had been fishing saithe since 1986 and the other since 1995. These two new pairs showed approximately the same trends as the other pair trawlers in the series during 1999-2003. In 2009 two new pairs of trawlers were used to extend the tuning series. These trawlers were built in 2003 and 2004 and they show the same trends in CPUE as the others, but higher in absolute numbers. At the 2010 benchmark assessment the CPUE series were compiled based on hauls where saithe contributed more than 50% of the total catch, discarding a pair (pair-6) and constraining the spatial distribution to those statistical squares where most of the fishing activity takes place. A GLM model using year, month, pair and depth as explanatory variables was applied to the resulting input data. If 'fishing square' was added as an explanatory variable, the year-effect in the GLM model remained the same. However, 'fishing square' was excluded from the model in order to keep the number of the degrees of freedom as low as possible. In addition to the pairtrawler cpue, which is a measure of saithe density in the core area of saithe, the range of the spatial distribution of saithe was considered when constructing an abundance index for saithe. The pairtrawler cpue was scaled by the proportion of survey survey hauls in March and August (approximately 300 each year, except 100 in 1995) containing at least one saithe. The revised annual indices resulted in a substantial reduction in the bias observed in the retrospective pattern.

B.5. Other relevant data

C. Historical Stock Development

Historical account of models used for saithe assessments

The first benchmark assessment for Faroe Island saithe was conducted in 2005. The model explored during that benchmark workshop, an XSA model, was not used for interim assessments or to provide management advice after that workshop because of a retrospective pattern observed in model outputs at that time. It was hypothesized that the retrospective pattern was likely due to changes in selectivity due to changes in fish growth as it was observed that the average weight at age in the catch was dropping. The 2010 benchmark workshop further explored the XSA model as well as an ADAPT, TSA and separable statistical models. The CPUE series that was used in the assessment from 2000 to 2016 were introduced in 1998 (ICES C.M. 1998/ACFM:19), and consists of saithe catch at age and effort in hours, referred to as the pair trawler series. The commercial CPUE series was standardized and the density indices were multiplied by an area expansion factor to better represent a measure of total stock abundance (Sec. 6.2.5.2.) These data updates were found to significantly reduce the retrospective pattern previously observed in the assessment. The SSB, F and recruitment estimates generated by both models were comparable and the XSA (FLXSA, Extended Survivors Analysis for FLR) assessment was adopted as the benchmark assessment because it had been the model historically used for this stock.

At the 2017 benchmark working group (WKFAROE) the State-space Assessment Model (SAM, Nielsen and Berg, 2014) was chosen as the assessment framework for saithe. SAM offers a flexible way of describing the entire system, with relative few model parameters using random walks on fishing mortality and stock numbers and therefore allowing annual shifts in the exploitation pattern which do occur extensively in the saithe fisheries. SAM also provides a short term forecast that carries trends from the assessment into the forecast. Yet another benefit is that the assessment is stored online (www.stockassessment.org) and thus ready available for users. The current implementation (https://github.com/fishfollower/SAM) is an R-package that is based on the Template Model Model Builder (TMB) (Kristensen *et al.*, 2016). The states (α) are the log-transformed stock sizes (log of population numbers N at age) and fishing mortalities (log of fishing mortalities F at age). For saithe it is assumed that the fishing mortalities for ages 11 and older are the same. In any given year the state is the combined vector of population numbers and fishing mortalities. The transition equation describes the distribution of the next years' state from a given state in the current year. The transition equation is technically composed of a transition function (T) and an error term (actually the prediction noise or process error).

$$\alpha_y = T(\alpha_{y-1}) + \eta_y$$

The transition function is actually a set of equations that are outlined verbally below (but not that prediction noises are added to the equations):

Equation 1: LogN of age 3 = the logN of age 3 the previous year.

Equation 2a: LogN of ages 4-14 = LogN – F – M for the same cohort the previous year.

Equation 2b: LogN of age 15 = LogN – F – M for the same cohort the previous year PLUS the LogN – F – M for the same age the previous year.

Equation 3: LogF = LogF for the same cohort (ages 3-11) the previous year.

The prediction noise is assumed to be Gaussian (i.e., normally distributed) with zero mean and three separate variance parameters: one recruitment, one for survival and one for fishing mortality at age. The N-part of the prediction noise is assumed to be uncorrelated. The F-part is assumed to be correlated according to an ar (1) correlation structure, such that $cor(\Delta\log(F_{a,y}), \Delta\log(F_{\tilde{a},y})) = \varrho^{|a-\tilde{a}|}$.

The observation part of the state-space model describes the distribution of the observations for a given state α_y. Here the vector of all observations from a given year y is denoted x_y. The elements of x_y are age-specific log-catches $\log C_{a,y}$ and age-specific log-indices from scientific survey $\log I_{a,y}$. The combined observation equation is:

$$Xy = O(\alpha_y) + \varepsilon_y.$$

The observation function 'O' consists of the catch equations for total catches and scientific surveys. The measurement noise term ε_y is assumed to be Gaussian. An expanded view of the observation equation becomes:

$$\text{Log}\ (C_{a,y}) = \log(F_{a,y} / Z_{a,y}\ (1\text{-}e\text{-}Z_{a,y}) + \text{catch}\ \varepsilon_{a,y}$$

$$\text{Log}\ (\text{survey}\ I_{a,y}) = \log(\text{surveyQ}_a\ e^{-Z_{a,y}D/365}\ N_{a,y}) + \text{survey}\ \varepsilon_{a,y}$$

Here Z is the total mortality rate $Z_{a,y} = M_{a,y} + F_{a,y}$, D is the number of days into the year where the survey is conducted, Q_a are model parameters describing catchability coefficients. It is assumed that the catchability is the same for ages 9 and 10 within each of the two surveys. The variance of ε_y is the same for ages 9 and 10 within each of the two surveys. The variance of ε_y is set up in such a way that each data source (catch and the two scientific surveys) have their own covariance matrix.

Observation uncertainty is important e.g. to get the relative weighting of the different information sources correct, so a lot of effort has been invested in getting the optimal options into SAM. In Berg and Nielsen (2016) different covariance structures are compared for four ICES stocks.

The logarithm of the total catches at age is assumed independent Gaussian with the same variance for all ages. The logarithm of the age specific indices from the spring survey are assumed to be independent Gaussian with a separate variance for age 3 and 4 and a common variance for ages 5-10. The logarithm of the age specific indices from the spring survey is assumed to follow a multivariate Gaussian distribution with order 1 auto-regressive correlation. The variance parameters for the summer survey are couples in the same way as for the spring survey.

The residual calculation procedure in state-space assessment models can be difficult, but is extremely important when evaluating the assumed covariance structure. The standard practice of calculating the residuals (as 'observed' minus 'predicted' divided by an estimate of the standard deviation) is strictly only valid for models with purely independent observations. It is not valid for state-space models, where an underlying unobserved process is introducing a correlation structure in the (marginal) distribution of the observations. It is not valid if the observations are directly assumed to be correlated (e.g. multivariate normal, or multinomial for age compositions). The problem is that the resulting residuals will not become independent.

To get independent residuals the so-called 'one-observation-ahead' residuals are computed. The residual for the n'th observation is computed by using the first n-1 observations to predict the n'th. Details can be found in Thygesen *et al.*, (2017).

A likelihood function is set up by first defining the joint likelihood of both random effects (here collected in the α_y states), and the observations (here collected in the x_y vectors). The likelihood function, $L(\theta,\alpha,x)$ is a function of e.g. a vector of model parameters (θ). Since the random effects α are not observed inference must be obtained from the marginal likelihood $L_M(\theta,x)$ = integral of $L(\theta,\alpha,x)$ over α. Since the integral is difficult to calculate directly, the Laplace approximation is used. The Laplace approximation is derived by first approximating the joint log likelihood by a second order Taylor approximation around the optimum $\hat{\alpha}$ with regards to α. The resulting approximated joint log likelihood is then integrated by regarding it as a constant term and a term where the integral is known as the normalizing constant from a multivariate Gaussian distribution. The approximation is obtained by a complex formula and taking the logarithm gives the Laplace approximation of the marginal log likelihood (another complex formula).

The table below presents a summary of some key SAM configuration options. Hashmarks (“#”) represent comments.

Minimum and maximum age in model

3 15

Maximum age considered a plus group? (0 = No, 1= Yes)

1

Use correlated random walks for the fishing mortalities (0 = uncorrelated, 1 = correlated with CS, 2 = correlated with AR structure)

2

Rows represent fleets
Columns represent ages.

Coupling of fishing mortality STATES $keyLogFsta

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

0 1 2 3 4 5 6 7 8 8 8 8 8 # catch

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-2

Coupling of catchability PARAMETERS $keyLogFpar

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # catch

0 1 2 3 4 5 6 6 -1 -1 -1 -1 -1 # survey-1

7 8 9 10 11 12 13 13 -1 -1 -1 -1 -1 # survey-2

Coupling of power law model EXPONENTS $keyQpow

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # catch

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-2

Coupling of fishing mortality RW VARIANCES $keyVarF

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

0 0 0 0 0 0 0 0 0 0 0 0 0 # catch

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 # survey-2

Coupling of log-N RW VARIANCES $keyVarLogN

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

0 1 1 1 1 1 1 1 1 1 1 1 1

Coupling of OBSERVATION VARIANCES $keyVarObs

3 4 5 6 7 8 9 10 11 12 13 14 15 # age

0 0 0 0 0 0 0 0 0 0 0 0 0 # catch

1 2 3 3 3 3 3 3 -1 -1 -1 -1 -1 # survey-1

4 5 6 6 6 6 6 6 -1 -1 -1 -1 -1 # survey-2

$keyCorObs

3-4 4-5 5-6 6-7 7-8 8-9 9-10 10-11 11-12 12-13 13-14 14-15 # age

NA NA NA NA NA NA NA NA NA NA NA NA # catch

0 0 0 0 0 0 -1 -1 -1 -1 -1 # survey-1

NA NA NA NA NA NA NA -1 -1 -1 -1 -1 # survey-2

Stock recruitment model code (0 = RW, 1 = Ricker, 2 = BH) $stockRecruitmentModelCode

0

Fbar range $fbarRange

4 8

The options for "Coupling of fishing mortality STATES" show that random walk for F is independent by age for the ages 3-10, and combined for ages 11 to 15. Random walks are correlated with AR structure for each age group (option 2 for "Use correlated random walks for the fishing mortalities").

The "Coupling of catchability PARAMETERS" specifies the grouping of ages with respect to survey catchability. For the Faroese summer survey (survey-1) it is assumed an age dependent catchability for ages 3 to 8, and a combined (the same) catchability for ages 9–10. The same applies to the spring survey (survey-2). For both surveys a linear relation between CPUE and stock size is assumed ("Coupling of power law model EXPONENTS" are all set to -1).

The variance for the random walk for F ("Coupling of fishing mortality RW VARIANCES ") is assumed the same for all ages (set to 0)

The "Coupling of OBSERVATION VARIANCES" specifies the options for observation noise for both catches and survey indices. There is one variance component for the catch observations while for both the summer and the spring survey variances are different for ages 3 and 4 and coupled for older age groups.

There is no obvious relation between SSB and recruitment, but recruitment seems to be correlated between years ("Stock recruitment model code" is set to 0 = Random Walk).

The options for observation correlation coupling is an AR (1) (observation correlation structure). For the summer survey, observations are correlated for all age classes (3 - 10)

Input data types and characteristics:

TYPE	NAME	YEAR RANGE	AGE RANGE	VARIABLE FROM YEAR TO YEAR YES/NO
Caton	Catch in tonnes	1961-last data year	3 – 15+	Yes
Canum	Catch at age in numbers	1961-last data year	3 – 15+	Yes
Weca	Weight at age in the commercial catch	1961-last data year	3 – 15+	Yes
West	Weight at age of the spawning stock at spawning time.	1961-last data year	3 – 15+	Yes, assumed to be the same data as weight at age in the catch
Mprop	Proportion of natural mortality before spawning	1961-last data year	NA	No, set to 0 for all ages and years
Fprop	Proportion of fishing mortality before spawning	1961-last data year	NA	No, set to 0 for all ages and years
Matprop	Proportion mature at age	1983- last data year + 1 (2009)	3 – 15+	Yes. A 10-year moving average is applied to observed ogives. Data prior to 1983 is average of 1983-1996 values.
Natmor	Natural mortality	1961-last data year	3 – 15+	No, set to 0.2 for all ages and years

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1Faroese summer groundfish survey	1996- last data year	3–10	
Tuning fleet 2	Faroese spring groundfish survey	1994- last data year	3-10

D. Short-Term Projection

Model used: Age structured.

Software used: SAM forecast function.

Initial stock size: Recruitment is taken randomly from last 5 years.

Natural mortality: Set to 0.2 for all ages in all years.

Maturity: Average of last five years (including maturity in the assessment year) .

F and M before spawning: Set to 0 for all ages in all years.

Weight at age in the stock: weight for age groups 4 to 8 are predicted according to the model in Eq.1. Catch-weight in the assessment year is predicted by stock-weight (from survey) and catch-weight in the previous year. For other age groups an average of last three years is taken.

$$\log(CW_{y,a}) = \beta 0 + \beta 1 * \log(CW_{y-1,a-1}) + \beta 2 * \log(SW_{y,a}) \quad \text{(Eq.1)}$$

where $CW_{y,a}$ is catch-weight-at age *a* and year *y* and $SW_{y,a}$ is stock-weight-at age *a* and year *y*

Stock weights are assumed equal to catch weights.

Exploitation pattern: Average exploitation pattern in last three years.

Intermediate year assumptions: None

Stock recruitment model used: None

Procedures used for splitting projected catches: None

E. Medium-Term Projections

Not performed.

F. Long-Term Projections

Yield-per-recruit calculations are performed with the 'ypr' module of the SAM framework.

The average of last 15 years (SAM default) is used as input for biological parameters.

G. Biological Reference Points

Below is a brief description on the historical development of biological reference points for Faroe saithe.

2011

In the 2011 assessment for Faroe saithe a Management Strategy Evaluation (MSE) was performed using a harvest control rule in the FLR environment. In the 2012 assessment some changes were included in the simulation framework. Maturity by age and year were modified (and therefore SSB) according to the smoothing technique reported in Section 6.2.4. Extra stochasticity was added to weights at age in the form of autocorrelation and the constraint of running XSAs in the simulations was dropped to reduce the simulation running time. All these changes caused a upward revision of the F_{msy} point estimate from F_{msy}=0.28 to F_{msy}=0.32. The simulation framework is explained below.

The MSE approach requires mathematical representations of two systems: a 'true' system and an 'observed' one. The 'true' system is represented by the operating model (OM) that simulates the real world. In contrast, the 'observed' system represents the conventional management procedure (MP), from the data collection through stock assessment to the management implementation. The present MSE evaluation uses the working group stock assessment as the basis for the Operating Model and makes assumptions about the selection pattern of the fishing fleet and its dynamics. The model comprises a single stock that is fished by a single fleet. It implements a harvest control rule through a management procedure that explicitly models the stock assessment process and time lag in implementing the management advice (delay between the gathering of data and making a management decision, i.e. setting the current fishing effort) which explicitly address uncertainty in recent parameter estimates. The stock recruitment relation used is the Hockey-stick or segmented regression with random noise on top of it reflecting the high variability in historical recruitment estimates (CV=0.5). Fishing mortality is estimated from effort, catchability (constant) and the selection pattern. The observed selection pattern since 1996 is used in the simulations which correspond with the implementation of the fishing days quota in the Faroese management system. Maturity-at-age is fixed and taken from the smoothing method implemented in 2012 while stochasticity is included in weights-at-age with a CV=0.18 and autocorrelation of Rho=0.35 applied to all age groups to somehow replicate the observed fluctuations pattern. The data sampling of catches and tuning fleets is carried out by multiplying by random errors. Natural mortality is fixed to M=0.2. Simulations were performed 1000 times on a 40-year forward period with the historical period being replicated in the OM.

Unlike the flat curves obtained from traditional yield-per-recruit calculations simulations curve show a relatively well defined maximum at F_{msy} =0.32. The reason for this difference is that when fishing mortality is above certain level (>0.3) some of the stochastic runs will lead to spawning stock being below the break point in the stock-recruitment function so recruitment and subsequent landing s will be reduced. The breakpoint of 55 kt. in the segmented regression or the revised B_{pa}=60 000 t. (see Section 2. Demersal stocks in the Faroe Area, Subsection 2.1.7 Faroe saithe) could be candidates for $B_{trigger}$ the point at which fishing mortality should be reduced according to the MSY framework.

2014

In 2014 at the WKMSYREF2 workshop the EqSim simulation framework was used to explore candidates to Fmsy. The work was presented at the NWWG meeting in 2014 and the results agree with the previous simulations (see above) in that estimates of Fmsy are in the range of Fmsy=0.30 and Fmsy=0.34 and not as the present level of Fmsy=0.28. In the 2014 meeting ACOM adopted the EqSim framework and agreed to set Fmsy=0.30, which agrees with the estimation of Fmed=0.31. Below it is an excerpt from the WKMSYREF2 report:

The EqSim framework fits three stock-recruit functions (Ricker, Beverton-Holt and Hockey-stick) on the bootstrap samples of the stock and recruit pairs from which approximate joint distributions of the model parameters can be made. The result of this is projected forward for a range of F's values and the last 50 years are retained to calculate summaries. Each simulation is run independently from the distribution of model and parameters. Error is introduced within the simulations by randomly generating process error about the constant stock recruit fit, and by using historical variation in maturity, natural mortality, and weight at age, etc.

In the EqSim simulations the Hockey-Stick stock-recruit function were used assuming assessment and autocorrelation errors. Figures below illustrate the results of these simulations which suggest that candidates for FMSY are FMSY =0.34 (median yield) and FMSY =0.30 (F that gives the maximum mean yield in the long term) if autocorrelation and assessment errors are included in the simulation framework. If errors are ignored then estimates for FMSY are predicted to FMSY =0.38 (median yield), FMSY =0.35 (maximum mean yield). No Blim is defined for faroe saithe but for the purposes of the analysis a value of Blim=Bpa/1.4 was set for the simulations. More detailed information of the simulations is available under *http://www.ices.dk/community/groups/Pages/WKMSYREF2.aspx* A summary is given in the table below.

	F	SSB	Catch	Option
Flim	0.34	87327.43	36479.8	ass. Error
Flim	0.37	79116.87	35447.45	ass. Error
Flim	0.46	38905.3	22023.28	ass. Error
MSY:median	0.34	88565.78	36665.24	ass. Error
Maxmeanland	0.30	101372.9	37109.88	ass. Error
FCrash5	0.41	63312	31637.31	ass. Error
FCrash50	0.52	855.73	550.19	ass. Error
Flim	0.40	78435.72	38526.07	No ass. Error
Flim	0.42	73052.08	37660.27	No ass. Error
Flim	0.50	38910.57	24279.75	No ass. Error
MSY:median	0.38	82329.53	38694.43	No ass. Error
Maxmeanland	0.35	90688.34	39167.13	No ass. Error
FCrash5	0.43	69750.99	37114.99	No ass. Error
FCrash50	0.54	2847.53	1910.51	No ass. Error

2017

At the NWWG in 2017 reference points were revised according to the ICES guidelines (ICES fisheries management reference points for category 1 and 2 stocks, January 2017, http://ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/12.04.03.01_Reference_points_for_category_1_and_2.pdf). The software used to implement the calculations was EqSim. The procedure was as follows:

B_{pa}=$B_{trigger}$ was set to 50 kt (lowest historical SSB).

B_{lim} was calculated according the equation: $B_{pa} = B_{lim} \times \exp(\sigma \times 1.645)$ where σ= 0.23 (=sigmaF, see below)

The F_{msy} estimation process consisted of 3 simulations:

1. Simulation 1. Get F_{lim}

F_{lim} is derived from B_{lim} by simulating the stock with segmented regression S-R function with the point of inflection at B_{lim}.

F_{lim} is the F that, in equilibrium, gives a 50% probability of SSB > B_{lim}

The simulation was conducted with:

- fixed F (i.e. without inclusion of a $B_{trigger}$)
- without inclusion of assessment/advice errors.

2. Simulation 2. Get initial F_{msy}

   F_{msy} should initially be calculated based on:

   - a constant F evaluation
   - with the inclusion of stochasticity in population and exploitation as well as assessment/advice error.
   - SRRs (using all; Ricker, Beverton-Holt, Segmented)
   - Uncertainty parameters used:

     ## Assessment error

     sigmaF <- 0.18 # SAM value of uncertainty from 2016

     sigmaSSB <- 0.20 # 0.23 SAM value of uncertainty from 2017 ,changed to default=0.2

     ## Advice error

     cvF <- 0.39 ; phiF <- 0.81

     cvSSB <- 0.28 ; phiSSB <- 0.82

     ## Biological parameters and selectivity

     numAvgYrsB <- 20 # Biological

     numAvgYrsS <- 20 # Selection

To ensure consistency between the precautionary and MSY frameworks, F_{msy} is not allowed to be above F_{pa}, i.e., F_{msy} is set to F_{pa} if this initial F_{msy} estimate is higher than F_{pa}

3. Simulation 3. Get final F_{msy}

   MSY Btrigger should be selected to safeguard against an undesirable or unexpected low SSB when fishing at F_{msy}. The ICES MSY advice rule should be evaluated to check that the F_{msy} and MSY Btrigger combination adheres to precautionary considerations; in the long term, $P(SSB<B_{lim})<5\%$

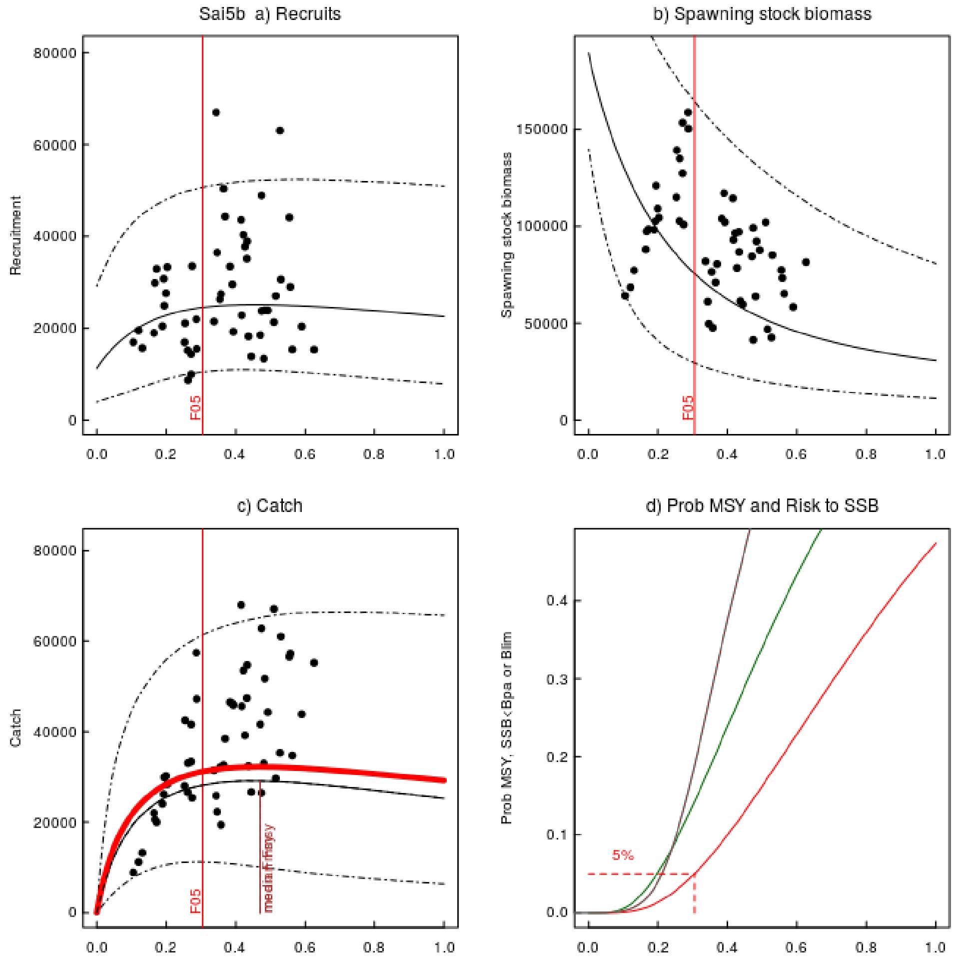
   The evaluation includes:

- realistic assessment/advice error (see above)
- stochasticity in population biology and fishery exploitation.
- SRRs (using all; Ricker, Beverton-Holt, Segmented)

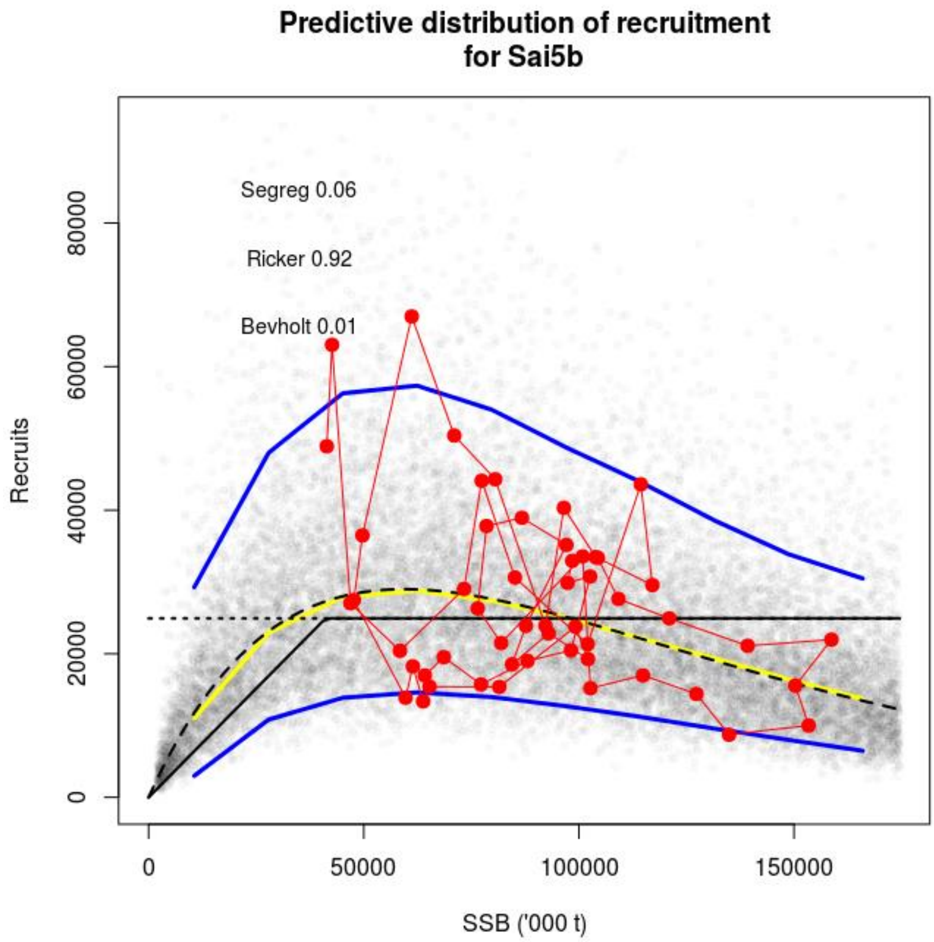
The new reference points are illustrated in the table below:

Biological reference points	NWWG 2017	Basis
Btrigger	41 400 t.	B_{loss}
Blim	29 571 t.	Bpa/1.4
Bpa	41 400 t.	B_{loss}
Flim	0.7	Stochastic simulations (ICES, 2017), F50% F that gives a 50% probability of SSB > Blim
Fpa	0.52	Flim*exp(-1.645*sigma) where sigma=0.18
Fmsy	0.30	Stochastic simulations (ICES, 2017).

Graphical output of the simulations is presented in the figures below:



. Output from the final EqSim simulation.



Stock recruitment relationships used in the Eqsim simulations.

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1Figure 1. Faroe Saithe 5.b. Distribution of combined trawl catches (single- and pair-trawlers) from 1995-2016 (logbooks.) Depth contour lines of 100, 200 and 400m are shown.