Stock Annex: Haddock (*Melanogrammus aeglefinus*) in Division 5.b (Faroes grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Haddock
Working Group:	North-Western Working Group (NWWG)
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A. General

A.1. Stock definition

Haddock in Faroese Waters, i.e. ICES subdivisions 5.b1 and 5.b2 and in the southern part of ICES Division 2.a, close to the border of Subdivision 5.b1, are generally believed to belong to the same stock and are treated as one management unit named Faroe haddock. Haddock is distributed all over the Faroe Plateau and the Faroe Bank from shallow water down to more than 450 m. Spawning takes place from late March to the beginning of May with a peak in the middle of April and occurs in several areas on the Faroe Plateau and on the Faroe Bank. Haddock does not form as dense spawning aggregations as cod and saithe, nor does it perform ordinary spawning migrations. After spawning, eggs and fry are pelagic for about 4 months over the Plateau and Bank and settling starts in August. This is a prolonged process and pelagic juveniles can be found at least until September. Also during the first years of life they can be pelagic and this vertical distribution seems to be connected to year class strength, with some individuals from large year classes staying pelagic for a longer time period. No special nursery areas can be found, because young haddock are distributed all over the Plateau and Bank. The haddock is considered very stationary as seen in tagging experiments.

A.2. Fishery

Landings statistics are available since 1903. During the first half of this century, foreign nations dominated the landings, especially England and Scotland, but since the early 1950s, the Faroese landings have increased considerably. After the introduction of the 200 nm EEZ in 1977, almost all landings have been by Faroese vessels.

Nominal landings of Faroe haddock increased very rapidly from only 4000 tonnes in 1993 to 27 000 tonnes in 2003; they have declined drastically since and amounted in 2012 to only about 2600 tonnes. The catches have slowly increased since then up to 3

500tonnes in 2016 Most of the landings are taken from the Faroe Plateau; the 2016 landings from the Faroe Bank (Subdivision 5.b2), where the area shallower than 200 m depths has been closed to almost all fishing since the fiscal year 2008–2009, amounted to only about 111 tonnes (Tables 5.1 and 5.2 in the NWWG 2017 report). Faroese vessels have taken almost the entire catch since the late 1970s. The longliners have taken most of the catches in recent years followed by the trawlers; the proportions in 2016 were: longliners 79% and trawlers 21%.

A.3. Ecosystem aspects

The waters around the Faroe Islands are in the upper 500 m dominated by the North Atlantic current, which to the north of the islands meets the East Icelandic current. Clockwise current systems create retention areas on the Faroe Plateau (Faroe shelf) and on the Faroe Bank. In deeper waters to the north and east and in the Faroe Bank channel is deep Norwegian Sea water, and to the south and west is Atlantic water. From the late 1980s the intensity of the North Atlantic current passing the Faroe area decreased, but it has increased again in the most recent years. The productivity of the Faroese waters was very low in the late 1980s and early 1990s. This applies also to the recruitment of many fish stocks, and the growth of the fish was poor as well. From 1992 onwards the conditions have returned to more normal values which also is reflected in the fish landings. There has been observed a very clear relationship, from primary production to the higher trophic levels (including fish and seabirds), in the Faroe shelf ecosystem, and all trophic levels seem to respond quickly to variability in primary production in the ecosystem (Gaard, E. *et al.,* 2002). A positive relationship has been demonstrated between primary production and the cod and haddock individual fish growth and recruitment 1–2 years later. The primary production indices was above average in 2008–2010 but this has, however, only marginally resulted in improved recruitment of haddock; the indices in 2011–2012 were below average. There seems to be a link between the primary production and growth of haddock. The primary production seems to be negatively correlated with the catchability of longlines, suggesting that haddock attack longline baits more when natural food abundance is low. Since longliners usually take the majority of the haddock catch, the total fishing mortality fluctuates in the same way as the long line catchability and thus there is a negative relationship between primary production and fishing mortality. It is, however, important to note that the relationship between the productivity of the ecosystem and the catchability of long lines depends on the age of the fish. For young haddock there apparently is no such relationship between productivity and catchability and overall this relationship has not been very clear in recent years.

B. Data

B.1. Commercial catch

Catch-at-age data are provided for the Faroese landings only. The sampling intensity in 2016 is shown in Table 5.3 and it was improved somewhat as compared to 2015. There is, however, a need to improve the sampling level. Reasons for the inadequate sampling level is a shortage of resources (people, money) but also that the total catches (and stock) are so small that it is difficult to obtain enough samples. From late 2011, a landing site has been established in Tórshavn close to the Marine Research Institute and it is the intention that technicians from the Institute will be sampling these landings regularly; In addition, a new technician will be hired to sample the landings in

Klaksvík, where a large proportion of the landings occur. This is expected to improve the sampling level considerable.

The normal procedure has been to disaggregate samples from each fleet category by season (Jan-Apr, May-Aug and Sep-Dec) and then raise them by the corresponding catch proportions to give the annual catch-at-age in numbers for each fleet This year, all longliners were grouped into 2 fleets (above and below 100 GRT), and all trawlers were also grouped into 1 fleet, and the samples had to be treated by using 2 seasons only (Jan-Jun, Jul-Dec.) The results are given in Table 5.3. No catch-at-age data were available from the foreign catch by trawlers and longliners and they were assumed to have the same age composition as the corresponding Faroese fleets. The most recent data were revised according to the final catch figures. The resulting total catch-at-age in numbers is given in Table 5.3 of the 2016 NWWG report, and in Figure 5.4 of the report the LN(catch-at-age in numbers) is shown for the whole assessment period from 1957 onwards in the stock annex.

In general the catch-at-age matrix in recent years appears consistent although from time to time a few very small year classes are disturbing this consistency, both in numbers and mean weights at age. The recent very small year classes need to be very carefully inspected when the FBAR is calculated. Also there are some problems with what ages should be included in the plus group; there are some periods where only a few fishes are older than 9 years, and other periods with a quite substantial plus group (10+). These problems have been addressed in former reports of this WG and will not be further dealt with here (See the 2005 NWWG report). The plus group problem may be solved by replacing the XSA method with SAM. No estimates of discards of haddock are available. However, since almost no quotas are used in the management of the fisheries on this stock, the incentive to discard in order to high-grade the catches should be low. The landings statistics is therefore regarded as being adequate for assessment purposes. The ban on discarding as stated in the law on fisheries should also – in theory – keep the discarding at a low level.

B.2. Biological

Mean weight-at-age data are provided for the Faroese fishery. In the period 1957–1976, constant weights have been applied, but from 1977 onwards they have been estimated each year. During the period, weights have shown cyclical changes, and have decreased during the most recent years to very low values in 2006; since 2007 mean weights at age have increased again but during the recent years they have been fluctuating without any trend. The mean weights at age in the stock are assumed equal to those in the landings.

Maturity-at-age data is available from the Faroese Spring Groundfish Surveys 1982–2017. The survey is carried out in February-March, so the maturity-at-age is determined just prior to the spawning of haddock in Faroese waters and the determinations of the different maturity stages is relatively easy. In order to reduce eventual year-to-year effects due to possible inadequate sampling and at the same time allow for trends in the series, the routine by the NWWG has been to use a 3–year running average in the assessment. For the years prior to 1982, average maturity-at-age from the surveys 1982–1995 was adopted.

B.3. Surveys

Two annual groundfish surveys are available on the Faroe Plateau, one carried out in February-March since 1982 (100 stations per year down to 500 m depth), and the other in August-September since 1996 (200 stations per year down to 500 m depth). 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 period was shortened by dropping the first cruise and one third of the 1991-stations were used as fixed stations. Since 1993 all stations are fixed stations. The surveyed area is divided into 15 strata defined by depth and environmental conditions. The distribution of haddock catches in the surveys in in the whole survey series are shown in Figure 5.9 (spring surveys 1994–2017 and summer surveys 1996–2016).

The standard abundance estimates is the stratified mean catch per hour in numbers at age calculated using smoothed age/length keys. This is a useful method but some artefacts may be introduced because the smoothing can assign wrong ages to some lengths, especially for the youngest and oldest specimen. As in recent years, the length distributions have been used more directly for calculation of indices at age (ages 0–2) since these ages have discrete length distribution without overlap. LN(numbers at age) for the surveys are presented in Figures 5.10–5.11 of the 2017 NWWG report and show consistent patterns.

Age disaggregated data are available for the whole summer series, but due to problems with the database (see earlier NWWG reports), age disaggregated data for the spring survey are only available since 1994 and for the summer survey since 1996.

In general, both surveys show a good relationship between the indices for one year class in two successive years. The same applies when comparing the corresponding indices at age from the two surveys.

B.4. Commercial CPUE

Several commercial catch per unit effort series are updated every year, but as discussed in previous reports of the NWWG they are not used directly for tuning of the VPA due to changes in catchability caused by e.g. productivity variations in the area (see Ecosystem aspects), a different behaviour of the fleets after the introduction of the effort management system with large areas closed for trawlers, and in years when haddock prices are low as compared to cod the fleets apparently try to avoid grounds with high abundances of haddock, especially the younger age groups areas. The opposite may also happen if prices of haddock become high as compared to other species. The data are based on logbooks. These are mostly mixed fisheries and not directly targeting haddock.

C. Historical Stock Development

Model used

Several different models have been applied to this stock but the basic method has for many years been the Extended Survivors Analysis.

At the benchmark meeting in February 2017 it was decided to replace the traditional XSA model with a SAM model as the assessment tool, although it was noted that the assessment results were data-driven and not so much by model choice. One benefit of using SAM was that the model provided uncertainty estimates. SAM also provided a short term forecast that carried the trends from the assessment into the forecast. Yet another benefit was that the assessment could be stored on the website (www.stockassessment.org) making it readily accessible for the site users.

SAM is a state-space assessment mode (Nielsen and Berg, 2014). 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 haddock it is assumed that the fishing mortalities for ages 7 years 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).

$$\alpha y = T(\alpha y\text{-}1) + \eta y$$

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 1 = the logN of age 1 the previous year.

Equation 2a: LogN of ages 2–9 = LogN – F – M for the same cohort the previous year.

Equation 2b: LogN of age 10 = 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 2–7) the previous year.

The natural mortality M of 0.2 for all ages was not changed at the benchmark, although tagging studies indicated that M could be slightly higher. M of the age 1 was also set at 0.2 realising the use of a higher value would not have any effect on the assessment results or forecast.

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(Δlog(Fa,y), Δlog(Fã,y)) = ϱ|a-ã|.

The observation part of the state-space model describes the distribution of the observations for a given state αy. Here the vector of all observations from a given year y is denoted xy. The elements of xy are age-specific log-catches logCa,y and age-specific log-indices from scientific survey logIa,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 εy is assumed to be Gaussian. An expanded view of the observation equation becomes:

Log (Ca,y) = log(Fa,y / Za,y (1-e-Za,y) + catch εa,y

Log (survey Ia,y) = log(surveyQa e-Za,yD/365 Na,y) + survey εa,y

Here Z is the total mortality rate Za,y = Ma,y + Fa,y, D is the number of days into the year where the survey is conducted, Qa are model parameters describing catchability coefficients. It is assumed that the catchability is the same for ages 8 and 9 within each of the two surveys. The variance of εy is the same for ages 8 and 9 within each of the two surveys. The variance of εy 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 options used for Faroe haddock are the following. The logarithm of the total catches at age are 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 one and a common variance for ages 2–9. The logarithm of the age specific indices from the summer survey are assumed to follw a multivariate Gaussian distribution with order 1 auto-regressive correlation structure, a separate variance for age one, and a common variance for ages 2–9.

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 αy states), and the observations (here collected in the xy vectors). The likelihood function, L(θ,α,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 LM (θ,x) = integral of L(θ,α,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 give the Laplace approximation of the marginal log likelihood (another complex formula).

The SAM model is run from the website (www.stockassessment.org). The input files are uploaded to the website on beforehand. The SAM model may also be run from the labtop. The R-package is used on the webpage as well as on the laptop.

Configuration in the SAMrun was the following (as obtained by the R-package):

attr(,"fleetNames")

[1] "Residual catch" "SUMMERSURVEY" "SPRINGSURVEY"

$conf

$conf$minAge

[1] 1

```
$conf$maxAge
[1] 10

$conf$maxAgePlusGroup
[1] 1

$conf$keyLogFsta
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]    0    1    2    3    4    5    6    7    8     8
[2,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1
[3,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1

$conf$corFlag
[1] 2

$conf$keyLogFpar
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1
[2,]    0    1    2    3    4    5    6    6   -1    -1
[3,]    7    8    9   10   11   12   12   -1   -1    -1

$conf$keyQpow
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1
[2,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1
[3,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1

$conf$keyVarF
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]    0    0    0    0    0    0    0    0    0     0
[2,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1
[3,]   -1   -1   -1   -1   -1   -1   -1   -1   -1    -1

$conf$keyVarLogN
 [1] 0 1 1 1 1 1 1 1 1 1
```

```
$conf$keyVarObs
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]    0    0    0    0    0    0    0    0    0     0
[2,]    1    1    1    1    1    1    1    1   -1    -1
[3,]    2    2    2    2    2    2    2   -1   -1    -1

$conf$obsCorStruct
[1] ID AR AR
Levels: ID AR US

$conf$keyCorObs
     1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10
[1,]  NA  NA  NA  NA  NA  NA  NA  NA   NA
[2,]   0   0   0   0   0   0   0  -1   -1
[3,]   1   1   1   1   1   1   1  -1   -1

$conf$stockRecruitmentModelCode
[1] 0

$conf$noScaledYears
[1] 0

$conf$keyScaledYears
numeric(0)

$conf$keyParScaledYA
<0 x 0 matrix>

$conf$fbarRange
[1] 3 7

$conf$keyBiomassTreat
[1] -1 -1 -1

$conf$obsLikelihoodFlag
```

[1] LN LN LN

Levels: LN ALN

$conf$fixVarToWeight

[1] 0

Input data types and characteristics

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1957– last data year		Yes
Canum	Catch at age in numbers	1957– last data year	0–10+	Yes
Weca	Weight at age in the commercial catch	1957– last data year	0–10+	Yes
West	Weight at age of the spawning stock at spawning time.	1957– last data year	0–10+	Yes
Mprop	Proportion of natural mortality before spawning	1957– last data year	0–10+	No
Fprop	Proportion of fishing mortality before spawning	1957– last data year	0–10+	No
Matprop	Proportion mature at age	1957– last data year +1	0–10+	Yes
Natmor	Natural mortality	1957– last data year	0–10+	No

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Summer survey	1996–last data year	1–8
Tuning fleet 2	Spring survey	1994– last data year +1	1–7

D. Short-Term Projection

Model used: Age structured. The SAM model was adopted at the benchmark in February and used as the assessment tool and for short-term and long-term forecast.

Maturity ogives: The maturity in the assessment year was estimated as the average of the maturity in the assessment year and the year before; in the forward simulation an average of the last 5 years including the assessment year was used.

Weight at age in the stock: The same values as weight-at-age in the catch. This procedure was investigated and confirmed at the benchmark meeting in February 2017.

Weight at age in the catch: The procedure was changed at the benchmark meeting in February 2017. Instead of using the average of the last 3 years weights for all ages to estimate the weights in the assessment year, it was decided to continue to use this procedure for ages 3 and younger and to use spring survey weights for ages 4 and older. A 5 years average including the assessment year was used in the forward simulation.

The forecast procedure used starts from the last year's (assessment year) estimate of the state (log(N) and log(F) at age). One thousand replicates of the last state are simulated from its estimated joint distribution. Each of these replicates are then simulated forward according to the assumptions and parameter estimates found by the assessment model. As stated above, in the forward simulations a 5 year average (years up to and including the assessment year) is used for catch mean weight, stock mean weight, proportion mature, and natural mortality. Recruitment is resampled from the long period 2000–2016 in order to include large year classes in the sporadic recruitment pattern. In each forward simulation step the fishing mortality is scaled, such that the median of the distribution is matching the requirement in the scenario (e.g. hitting a specific Fbar value or a specific catch).

E. Medium-Term Projections

F. Long-Term Projections

The yield per recruitment calculations are performed in the SAM model and were based on the last 20 years (up to the year before the assessment year).

G. Biological Reference Points

Since the assessment model was replaced at the benchmark in February 2017, it was necessary to recalculate reference points during the NWWG meeting in 2017.

The Blim was changed from 22 000 tonnes to 16 780, e.g. the lowest spawning biomass from which the stock had made a recovery.

The Bpa = Btrigger = 22 843 tonnes (changed from 35 000 tons). The uncertainty in the SAM assessment in the final year of SSB was found to be $\sigma = 0.188$ and the Bpa was found by using the formula Bpa = Blim × exp(σ × 1.645). The Btrigger was, according to ICES guidelines, set equal to Bpa since the stock had not been fished at Fmsy for five or more years.

Flim = 0.35 (changed from 0.4). Flim was derived from Blim. A stock was simulated with a segmented regression on the spawning stock – recruitment function having the point of inflection at Blim. Flim was set to the F that, in equilibrium, gave a 50% probability that SSB > Blim. This simulation was based on a fixed F, i.e., without inclusion of a Btrigger and without inclusion of assessment/advice errors.

Fpa = 0.26 (changed from 0.25). Fpa was derived from Flim in the reverse of the way Bpa was derived from Blim, i.e., Fpa = Flim × exp($-\sigma$ × 1.645), where $\sigma = 0.185$.

The calculations were conducted using EQSIM following ICES guidelines. Decisions made involved the spawning stock – recruitment relationship, the weights at age, the selection pattern and the level of advice error. The period since 1978 was used as basis for the spawning stock – recruitment relationship where the S-R function was based on the segmented regression (weight 0.7), Ricker (weight 0.24), and Beverton and Holt (weight 0.06). The autocorrelation between SSB-R data points was approximately 0.52. The weights at age were based on the last 20 years. The selection pattern was based on the last 5 years. The advice error was estimated from advice sheets back to 1999: cvF = 0.48, phiF = 0.37, cvSSB = 0.40, phiSSB = 0.43. In total 2000 iterations were performed that projected the stock 200 years into the future, of which, the last 50 years were kept to calculate 'equilibrium' values.

The result of the analyses was that Fmsy = 0.13 (changed from 0.25). The fishing mortality that is associated with a risk of 5% to fall below Blim, Fp0.5, was estimated to be 0.09.

H. Other Issues

I. References

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