Stock Annex: Haddock (*Melanogrammus aeglefinus*) in Subareas 1 and 2 (Northeast Arctic)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Haddock
Working Group	Arctic Fisheries Working Group (AFWG)
Created	
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A. General

A.1. Stock definition

The Northeast Arctic Haddock (*Melanogrammus aeglefinus*) is distributed in the Barents Sea and adjacent waters, mainly in bottom water temperatures above 2°C. Mixing between haddock in subareas 1 and 2 and haddock in other management areas is negligible. Haddock is known to spawn along the Norwegian coast and the continental slope, but the exact spawning locations are not known.The spawning areas are between 70° and 73°N, but spawning also occurs as far south as 62°N. Spawning takes place in March–June. Larvae are dispersed into the central and southern Barents Sea by Atlantic currents. The 0-group haddock drifts from the spawning grounds eastwards and northwards and in August–September it is observed over wide areas in the Barents Sea.

A.2. Fishery

Haddock are harvested throughout the year; in years when the commercial stock is low, they are mostly caught as bycatch in cod trawl fishery; when the commercial stock abundance and biomass are high, haddock are also harvested in a targeted fishery. On average approximately 65% of the catch is taken by trawl while 35% of the catch is with conventional gears, mostly longline, which are used almost exclusively by Nor- way. Part of the longline catches are from a directed fishery.

The fishery is restricted by national quotas. Catch quotas were introduced in the trawl fishery in 1978, and for the fisheries with conventional gears in 1989. A 10% quota flexibility (banking and borrowing) was introduced for Norway and Russia in 2014.

In recent years Norway and Russia have accounted for more than 90% of the landings. Each country fishing for haddock and engaged in the stock assessment provides catch statistics annually (see Section B.1). Summary sheets in the AFWG Report present total catches by ICES subareas 1, 2.a and 2.b, as well as catch by each country by year.

Catch levels have shown very large variation during the period 1950–present (21 000–322 000 tonnes), mostly connected with the large variation in recruitment for this stock, which occasionally produces very strong year classes. Catches fluctuated moderately before 1972, which an average level of around 150 000 tonnes. Catches then peaked at an all-time high of 322 000 tonnes in 1973 before decreasing to 21 000 tonnes in 1984. Then catches fluctuated related to the occurrence of the strong 1982–1983 and 1989–1991 year classes. Since 2004 catches have stayed above 150 000 tonnes, with a peak above 300 000 tonnes in 2011–2012.

The exploitation rate of haddock has been variable, with F varying between 0.15 and 0.46 in the last 30 years, with higher values in many of the years prior to 1990.

Estimates of unreported catches (IUU catches) of haddock have been added to reported landings for the years 2002–2008. In 2007–2008, two assessments were presented, based on Norwegian and Russian estimates of IUU catches, respectively. Both approaches showed an increase in IUU from 2002 to 2005 followed by a decline. In 2010 the Working Group decided to set the IUU estimate for haddock in 2009 to 0. During the benchmark meeting in 2011, it was decided to use Norwegian IUU estimates for the period 2002–2008, and setting IUU for the years thereafter to 0. This practice has been continued in the subsequent benchmarks.

The fisheries are controlled by inspections at sea, requirement to report to catch control points when entering and leaving the EEZs and by inspections of landed fish from all fishing vessels. Keeping a detailed fishing logbook on board is mandatory for all Russian vessels and for Norwegian vessels above 15 m, and large parts of the fleet report to the authorities on a daily basis. There is some evidence that the present catch control and reporting systems are insufficient to prevent discarding and underreporting of catches. However, since 2005 Port State Control (PSC) has been implemented, which should prevent IUU catches in the Barents Sea.

Since January 1997 sorting grids have been mandatory for the trawl fisheries in most of the Barents Sea and Svalbard area. Discarding is prohibited. The fishery is also regulated by a minimum landing size, a minimum mesh size in trawls and Danish seine, a maximum bycatch of undersized fish, closure of areas with high density/catches of juveniles and other seasonal and areal restrictions.

From 1 January 2011, the minimum catching size of haddock is 40 cm in the Russian Economic zone, the Norwegian Economic zone, an the Svalbard area. Up to 15% (by number) of the fish in a haul below the minimum catching size (this is counted for cod, haddock and saithe combined) is allowed, larger proportions of undersized fish lead to closure of areas. The minimum mesh size in trawl codends is 130 mm.Haddock begins to occur in catches from the age of 1 and a size of about 25 cm, but the total estimated catch of fish at the age of 1 and 2 is less than 1%, therefore, to simplify the calculations, it is assumed that the catches contain only fish at-age 3 years and older

A.3. Ecosystem aspects

Variation in the recruitment of haddock has been associated with changes in the influx of Atlantic waters into the Barents Sea shelf. Environmental conditions affect haddock recruitment, with a positive relationship between temperature and year-class strength (e.g. Bogstad *et al.*, 2013). A steep rise or fall of the water temperature shows a marked effect on abundance of year-classes (Landa *et al*., 2014). Nevertheless, water temperature is not always a decisive factor in the formation of year-class abundance (Filin and Russkikh, 2019). The warm period from 2005 onwards has produced some very strong year classes, but also some moderate or weak year classes, despite a very high SSB. In recent years (2009–2013), with a very large stock of older fishes, a high proportion of the sexually mature individuals has been observed to skip spawning (Skjæraasen *et al.*, 2015).

A large proportion of haddock diet is made up by benthic invertebrates (Dolgov *et al*., 2011; Tam *et al.*, 2016). During and after the spawning migration of capelin (*Mallotus villosus*) haddock prey on capelin and their eggs on the spawning grounds. Haddock growth rate depends on the population abundance, stock status of main prey species and water temperature (Russkikh and Dingsør, 2011).

Cod predation on younger haddock can be a considerable factor increasing natural mortality of younger haddock. Mortality due to cod predation is taken into account in the assessment of haddock (see Secion B.2 below).

Annual consumption of haddock by marine mammals, mostly seals and whales, depends on stock status of capelin as their main fish prey. In years when the capelin stock is large the importance of haddock in the diet of marine mammals is minimal, while at low capelin stock abundance a considerable increase in consumption by marine mammals of abundant gadoid species including haddock is observed (Korzhev and Dolgov, 1999; Bogstad *et al.*, 2000).

B. Data

B.1. Commercial catch

Norway

Norwegian commercial catch in tonnes by quarter, area and gear are derived from the sales notes statistics of The Directorate of Fisheries. Data from about 20 subareas are aggregated on six main areas for the gears gillnet, longline, handline, purse-seine, Danish seine, bottom trawl, shrimp trawl and trap. For the bottom trawl, the quarterly area distribution of the catches is adjusted by logbook data from The Directorate of Fisheries and the total bottom-trawl catch by quarter and area is adjusted so that the total annual catch for all gears is the same as the official total catch reported to ICES. No discards are reported or accounted for.

The sampling strategy is to have age and length samples from all major gears in each main area and quarter. The main sampling programme is sampling the landings. Additional samples from catches are obtained from the coast guard, from observers and from crew members reporting, according to an agreed sampling procedure (reference fleet). All fish taken for age reading were measured and weighed individually.

The ECA software (Hirst *et al.*, 2012) has been developed to utilize all sampling information to estimate catch-at-age for areas (1, 2.a, and 2.b), quarters and gear groups separately (bottom trawl, longline, gillnet, Danish seine and others). This method replaced the traditional method in 2006, and the time-series of Norwegian catch-at-age (early 1980s and onward) was updated based on the modelling approach. The traditional method involved allocating unsampled catches to sampled catches based on judgements on "distance criterias" (in area, time and sometimes gear) and the use of ALK's to fill holes in the sampling frame.

Russia

Russian commercial catch in tonnes by season and area are derived from the Russian Federal Research Institute of Marine Fisheries and Oceanography (VNIRO, Moscow) statistics department. Data from each fishing vessel are aggregated on three ICES subdivisions (1, 2.a, and 2.b). Russian fishery by passive gears was almost stopped by the end of the 1940s. Until late 1990s, relative weight (percentage) of haddock taken by bottom trawls in the total Russian yield exceeded 99%. Only in recent years an upward trend in a proportion of Russian longline fishery for haddock was observed to be up to 5% on the average, and longline catches were taken into account for estimation catch-at-age matrix.

The sampling strategy was to conduct mass measurements and collect age samples directly at-sea, on board both research and commercial vessels to have age and length distributions from each area and season. Data on length distribution of haddock in catches are collected in areas of cod and haddock fishery all year-round by a "standard" fishery trawl and summarized by three ICES subareas (1, 2.a, and 2.b).

Age sampling is done using a stratified by length sampling method (i.e. approximately 10–15 specimens per each 10 cm length group). All fish taken for age reading were measured and weighed individually.

Data on length distribution of haddock catches, as well as age–length keys, are generated for each ICES Subarea, each fishing gear (trawl and longline) for the whole year. Catches-at-age are reported to ICES AFWG by subdivision (1, 2.a, and 2.b) for the whole year. In the case of lack of data by ICES subareas, information on size–age composition of catches from other areas is used.

Germany

Catches-at-age were reported to the WG by ICES subdivision (1, 2.a, and 2.b) according to national sampling. Missing subdivisions were filled in by the use of Russian or Norwegian sampling data.

Other nations

Total annual catch in tonnes is reported by ICES subdivisions or by Russian and Norwegian authorities directly to WG. All catches by other nations are taken by trawl. The age composition from the sampled trawl fleets is therefore applied to the catches by other nations. The combined catch data were previously estimated by the SALLOC program (Patterson, 1998). The national data from 2009 and onwards are available in Intercatch (ICES database); earlier data should be found in the national laboratories and with the stock coordinator.

For 1983 and later years, mean weight-at-age in the catch is calculated as the weighted average for the sampled catches. For the earlier period (1946–1982) mean weight-at-age in catches is set equal to mean weight-at-age in the catch for period 1983–2009.

The resulting files can be found on ICES (SharePoint) and with the stock coordinator as ASCII files in the Lowestoft format, as well as at stockassessment.org.

The text table below shows which country supplied which kind of data:

			KIND OF DATA		
Country	Caton (catch in weight)	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	X	X	X	X	X
Russia	X	X	X	X	X
Germany	X	X	X		X
UK	X				
France	X				
Spain	X				
Portugal	X				
Ireland	X				
Greenland	X				
Faroe Islands	X				
Iceland	X				
Poland	X				
Belarus	X				

B.2. Biological

Weights and length-at-age in the stock and proportion of mature fish to ages 1–11 has been derived from Russian surveys in autumn (mostly October–December) and Norwegian surveys in January–March for the period from 1983 and onwards. In 2006, the AFWG, based on WKHAD06 investigations (ICES, 2006), decided to smooth raw data of stock weight-at-age and maturity-at-age using models in order to remove some of the sampling variability of the estimates. On benchmarks in 2011, 2015 and 2020 this practice was continued.

Mean length-at-age is calculated from the bottom-trawl surveys. A von Bertalanffy function is fitted to the data from age 1 onwards.

Eq. 1) $$L_{A,y} = L_{\infty} - L_{\infty}e^{(-K_y(A-A_0)}$$

with L and A being the length and age variables. L_{∞} and A_0 are constants, estimated on the entire time-series, while K_Y depends on year class. Weight-at-age is then fitted with:

Eq. 2) $$W=\alpha \cdot L^{\beta}$$

where α and β are constants and L are smoothed lengths.

Norwegian maturity data are smoothed by fitting a logistic function using both age, A, and length, L, as explanatory variables:

Eq. 3) $$\log\left(\frac{m_A}{1-m_A}\right) = I + \alpha A + \beta L$$

Russian maturity data are smoothed by fitting a logistic function using age, A, and year class dependent age at 50% maturity, $A_{50\%}$, as explanatory variables:

Eq. 4) $$Mat_{A,y} = \frac{1}{1+e^{(-\alpha(A-A_{50,y}))}}$$

Estimates were produced separately for the Russian autumn survey and the joint winter survey and were later combined using an arithmetic average. These averages are assumed to give representative values for 1 January.

At the WKDEM benchmark of 2020 (ICES, 2020), it was decided to recalculate the maturity and weight-at-age in the stock based on the winter survey data back to 1994. The proportion mature include individuals with developing or running gonads, skipped spawners is treated as immature. The proportion of spawners of ages 11–13+ is assumed to be 1.

From 2020 and onwards, smoothed weight-at-age and maturity-at-age are estimated from the joint winter survey data only. These estimates are then corrected by an age-specific constant to account for the lack of the Russian survey. The text table below shows the ratio adjustment for stock weight-at-age (RWa) and proportion spawners (RSa). The winter survey estimates by age should be divided by the ratio. No adjustments were made to ages >11.

Age	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Rwa	0.939	0.952	0.957	0.962	0.967	0.968	0.967	0.960	0.953
Rsa	0.898	0.985	0.998	0.973	0.954	0.958	0.97	0.98	1

Norwegian lengths-at-age are used to estimate mean weights-at-age and maturity-at-age for the period 1980–1982.

The combined data on weight-at-age in stock and proportion of mature fish by age for the period 1950–1979 are set equal to mean values for thhe period 1980–2010 as decided at the benchmark in 2011 (ICES, 2011).

Overview of method of calculating natural mortality in the SAM model

Natural mortality used in the assessment is assumed to be 0.2 + mortality from predation by cod. The method used for calculation of the prey consumption by cod described by Bogstad and Mehl (1997) is used to calculate the consumption of haddock by cod. The consumption is calculated based on cod stomach content data taken from the joint PINRO-IMR stomach content database (methods described in Mehl and Yaragina, 1992), and calculations are made for each cod age group (1–11+), half-year and three areas separately.

The estimated annual consumption by NEA cod of NEA haddock in biomass for each haddock length group (5 cm length groups for haddock <30 cm and 10 cm length groups for haddock >30 cm) is converted to number eaten by haddock age group (0–6) using age–length keys and length–weight relationships from surveys. The consumption of age 3–6 haddock is then incorporated into the SAM model as additional natural mortality.

In the SAM model the extra mortality caused by cod predation is added using a method suggested by A. Nielsen and Y. Kovalev:

1. Does an initial run without extra mortality from cod (M = 0.2 for all ages) and extract tables of numbers and fishing mortality-at-age.

2. Calculate the catch based on the estimated fishing mortalities, natural mortalities (0.2) and estimated numbers-at-age using the catch equation.

3. Using Pope's approximation, estimate $N_{a,y}$ and $M_{a,y}$ when including cod predation as an additional "catch". This method assumes that all fishing + consumption takes place instantaneously in the middle of the year. Here we go "backwards", i.e. using numbers in year y+1 to calculate numbers in year y based on catches and natural mortalities in year y:

$$N_{a,y} = N_{a+1,y+1}e^{M_{a,y}} + C_{a,y}e^{M_{a,y}/2} + C_{cod,a,y}e^{M_{a,y}/2}$$

4. Similarly, Pope's approximation is used to estimate M due to cod predation by taking the logarithm of the relative numbers in year y and y+1 and subtracting fishing mortality and the base natural mortality (0.2):

$$M_{cod,a,y} = log(N_{a,y}/N_{a+1,y+1}) - F_{a,y} - M_{a,y}$$

5. Then cod predation mortality is added to the base mortality. For the last year, we use the same mortalities as the year before. Natural mortality for the period without observations (1950–1983) is replaced by mean values for the period from 1984 to the year preceeding the year of assessment.

6. Finally, M from the first model run is replaced with M_(cod,a,y)+M_(a,y) that we have calculated, and the model is refitted.

Both the proportion of natural mortality before spawning (M_{prop}) and the proportion of fishing mortality before spawning (F_{prop}) are set to 0. The peak spawning occurs most years in the middle of April

B.3. Surveys

Russian surveys of cod and haddock in the southern Barents Sea started in the late 1940s as trawl surveys of young demersal fish. Since 1957 such surveys have been conducted over the whole feeding area including the Bear Island-Spitsbergen area (Baranenkova, 1964; Trambachev, 1981); both young and adult haddock have been surveyed simultaneously.

Duration of the survey has declined from 5–6 months (September–February) in 1946–1981 to 2–2.5 months (October–December) since 1982. The aim of the survey is to investigate both the commercially sized haddock as well as the young haddock. The survey covers the main areas where juveniles settle to the bottom, as well as the area where the commercial fishery takes place. In 1984, acoustic methods started to be implemented during surveys of fish stocks (Zaferman and Serebrov, 1984; Lepesevich and Shevelev, 1997; Lepesevich *et al.,* 1999). From 1995 onwards, there has been a substantial change in the method for calculating acoustic indices, which allowed the differentiation and registration of echo intensities from fish of different length (Shevelev *et al.,* 1998). The acoustic indices have for not been used for many years in tuning due to a strong "year effect" observed in years with incomplete area coverage. The trawl index, calculated as relative numbers per hour trawling (RU-BTr-Q4) is used in tuning. Based on the testing made during WKBENCH 2011 (ICES, 2011) and previous AFWG work, it was decided to use tuning indices only for the period 1991 and onwards. The Russian autumn survey was not run in 2016 and was discontinued in 2018.

The Norwegian winter (February) survey (from 2000 - Joint Barents Sea winter survey) started in 1981 and aims to cover all of the ice-free part of the Barents Sea. Two survey indices are estimated from the survey 1) acoustic (NoRu-Aco-Q1) for the period 1981–last year and 2) swept-area estimates from bottom trawl (NoRu-BTr-Q1) for the period 1981–last year. The indices from the survey currently used in tuning goes back to 1994. Before 2000, this survey was made without participation from Russian vessels, while in most years afterward Russian vessels have covered important parts of the Russian zone. Indices for years with incomplete coverage have been adjusted as described in Mehl *et al.* (2016; 2018). The survey area was extended towards the north and northeast in 1993 and again in 2014. At WKDEM 2020 (ICES, 2020), it was decided to include also data from the extended area in the tuning. Other changes in the survey methodology through time from 1981 are described by Jakobsen *et al*. (1997) and Mehl *et al.* (2016). The indices were recalculated from 1994 onwards using the StoX software (Johnsen *et al.,* 2019) presented in Mehl *et al.* (2016) for the bottom trawl data and in Mehl *et al.* (2018) for the acoustic data (ICES, 2018). The indices by age with CVs are estimated with the Stox software and presented in annual survey reports are available (e.g. Mehl *et al*., 2019).

Bottom-trawl estimates from the joint Norwegian-Russian ecosystem survey (Eco-NoRu-Btr-Q3) in August–September started in 2004, with annual survey reports being available (e.g. Prokhorova *et al.,* 2013). The survey covers the whole Barents Sea shelf with a regular grid with some notable exceptions especially in deeper areas and no predefined strata system. There have been some problems with area coverage, particularly in 2014 (ice restrictions in northern Barents Sea with minor impact on the haddock estimates) and 2016 (problems with coverage in eastern Barents Sea making the indices less reliable this year). In 2018 most of the eastern Barents Sea was not covered, and the indices were therefore not used in the assessment. Survey coverage and design is summed up in Johannesen *et al.* (2019). Indices by age is calculated using BIOFOX software and are presented as a WD to the AFWG each year (Prozoerkevich and Gjøsæter, 2014).

B.4. Commercial cpue

Russia

No Russian cpue data are used in the stock assessment.

Norway

Historical time-series of observations onboard Norwegian trawlers were earlier used for tuning of older age groups in VPA. The basis was catch per unit of effort (cpue) in Norwegian statistical areas 03, 04 and 05 embracing coastal banks north of Lofoten, on which approximately 70% of Norwegian haddock catch was taken. However, the proportion of haddock taken as bycatch is pretty high and thus it is difficult to estimate their actual catch per unit of effort. Since 2002, cpue indices have not been used in the assessment.

B.5. Other relevant data

No.

C. Assessment: data and method

The 2015 Benchmark (ICES, 2015a) adopted the SAM model (State–space assessment model) (https://www.stockassessment.org; Nielsen and Berg, 2014) as main model and recommended to expand the age range from 3–11+ to 3–13+ . At the benchmark in 2020, it was decided to add a plus group to all surveys and include indices for age 3 from the winter survey (NoRu-Aco-Q1, NoRu-BTr-Q1).

New SAM model settings were agreed during WKDEM 2020 (ICES, 2020). The settings include a newly developed option (Prediction–variance link) linking the variance and the predicted observations. Extra mortality caused by cod predation is added in SAM using the method described above (see Section B2).

Model Options chosen for SAM (Model.cfg).

```
# Configuration saved: Wed Feb 12 12:57:09 2020
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
#
$minAge
# The minimum age class in the assessment
 3

$maxAge
# The maximum age class in the assessment
 13

$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 1 1 1 1

$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
  0  1  2  3  4  5  5  5  5  5  5
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$corFlag

Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, 2 AR(1), 3 separable AR(1).

2

$keyLogFpar

Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).

```
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 0  1  1  1  1  1 -1 -1 -1 -1 -1
 2  3  3  3  3  4  4 -1 -1 -1 -1
 5  6  6  6  6  7  7  7 -1 -1 -1
 8  9  9  9  9  9  9 -1 -1 -1 -1
```

$keyQpow

Density dependent catchability power parameters (if any).

```
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 0  0  0  0  0  0 -1 -1 -1 -1 -1
 1  1  1  1  1  2  2 -1 -1 -1 -1
 3  3  3  3  3  4  4  4 -1 -1 -1
 5  5  5  5  5  5  5 -1 -1 -1 -1
```

$keyVarF

Coupling of process variance parameters for log(F)-process (normally only first row is used)

```
 0  1  1  1  1  1  1  1  1  1  1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

$keyVarLogN

Coupling of process variance parameters for log(N)-process

0 1 1 1 1 1 1 1 1 1 1

$keyVarObs

Coupling of the variance parameters for the observations.

```
 0  1  2  2  2  2  2  2  2  2  2
 3  3  3  3  3  3 -1 -1 -1 -1 -1
 4  4  4  4  4  4  4 -1 -1 -1 -1
```

5 5 5 5 5 5 5 5 -1 -1 -1

6 6 6 6 6 6 6 -1 -1 -1 -1

$obsCorStruct

Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"

"ID" "AR" "AR" "AR" "AR"

$keyCorObs

Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.

NA's indicate where correlation parameters can be specified (-1 where they cannot).

#V1 V2 V3 V4 V5 V6 V7 V8 V9 V10

NA NA NA NA NA NA NA NA NA NA

0 1 1 1 2 -1 -1 -1 -1 -1

3 3 3 3 3 4 -1 -1 -1 -1

5 5 5 5 5 6 6 -1 -1 -1

7 7 7 7 7 7 -1 -1 -1 -1

$stockRecruitmentModelCode

Stock–recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton–Holt, and 3 piece-wise constant).

0

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and higest age included in Fbar

4 7

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB index, 3 total catch, 4

total landings and 5 TSB index).

-1 -1 -1 -1 -1

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

"LN" "LN" "LN" "LN" "LN"

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

0

$fracMixF

The fraction of t(3) distribution used in logF increment distribution

0

$fracMixN

The fraction of t(3) distribution used in logN increment distribution

0

$fracMixObs

A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet

0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock–recruitment code 3)

$meanVarObsLink

Coupling of parameters used in a mean-variance link for observations.

```
 0  1  2  2  2  2  2  2  2  2  2
 3  3  3  3  3  3 -1 -1 -1 -1 -1
 4  4  4  4  4  4  4 -1 -1 -1 -1
 5  5  5  5  5  5  5  5 -1 -1 -1
 6  6  6  6  6  6  6 -1 -1 -1 -1
```

$meanVarFprocLink

Coupling of parameters used in a mean-variance link for log(F) process increments

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

XSA

Previously used model XSA (Darby and Flatman, 1994), will be kept until next benchmark as an additional model for consideration. Software used: – FLR suite (and VPA95 suite).

Model options chosen for auxiliary model XSA were choosen at last benchmark.

Tapered time weighting applied, power = 3 over 20 years

Catchability independent of stock size for ages > 8 Catchability independent of age for ages >8

Survivor estimates shrunk towards the mean F of the final 5 years or the 3 oldest ages

S.E. of the mean to which the estimate are shrunk = 1.5

Minimum standard error for population estimates derived from each fleet = 0.3 Prior weighting not applied

Shrinkage to the population mean (p-shrinkage) not applied due to the strong effect of highly abundant yearclasses.

The biomass estimates of XSA with these settings singnificantly deviated from estimates of main model SAM. During the WKDEM 2020 it was found that changing S.E. of the mean F shrinkage from 1.5 to 0.5 gives estimates of biomass dynamics close to SAM estimates. Furthermore this change improved XSA retrospective pattern.

Input data types and characteristics used in both models:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1950–last data year		Yes
Canum	Catch-at-age in numbers	1950–last data year	3–13+	Yes
Weca	Weight at age in the commercial catch	1950–last data year	3–13+	Yes, constant -> 1982
West	Weight at age of the spawning stock at spawning time.	1950 –last data yea	3–13+	Yes, constant -> 1982
Mprop	Proportion of natural mortality before spawning	1950–last data year	3–13+	No – set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1950–last data year	3–13+	No – set to 0 for all ages in all years
Matprop	Proportion mature at-age	1950–last data year	3–13+	Yes, constant -> 1981
Natmor (SAM)	Natural mortality	1950–last data year	3–13+	Yes– set to 0.2 all ages, + predation mortality* for ages 3-6

***There are no data on cod predation for 1950–1983. For these years age 3–6 mortality by age is set to the average for the period 1984–2017.**

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	RU-BTr-Q4	1991–2017	3–8+
Tuning fleet 2	BS-NoRU-Q1(Aco)	1994–last data year	3–9+
Tuning fleet 3	BS-NoRu-Q1 (BTr)	1994–last data year	3–10+
Tuning fleet 4	Eco-NoRu-Q3 (Btr)	2004–last data year	3–9+

D. Short-Term Projection

Model used: Age structured

Software used: standard MFDP with management option table and yield-per-recruit routines (alternatively R or excel implementation of MFDP).

This section presents the default settings for the short-term forecast. Given the variabilities inherent in these predictions, these values should be considered as defaults, which will be used unless there is evidence to deviate from the default.

The various regressions referred to below should be updated through time, but not necessarily each year.

TAC constraint for intermediate year is used for this stock. This is because the restriction (±25%) on changes in TAC from year to year in the HCR may, together with the large recruitment variations, cause the catch corresponding to F status quo to deviate considerably from the agreed TAC.

The SAM model estimates slow changes in the selection pattern and the last three year average Fs by age scaled by Fbar is used as input in the short-term prediction.

Last three year averages of natural mortalities are used for intermediate, quota year and the year after the quota year.

The proportion of F and M before spawning is assumed equal to 0 for all ages in all years.

Initial stock size: Estimated by the SAM model as abundance of individuals at the start of the intermediate year for age 3 and older.

Recruitment-at-age 3 for the quota year and the year after the quota year is estimated from survey data using RCT3 with indices for ages 1–2 from the following tuning series as input: BS-NoRU-Q1(Aco), BS-NoRu-Q1 (BTr) and Eco-NoRu-Q3 (Btr).

Weight-at-age in the stock: for intermediate year smoothed actual data for all ages (see eq. 1 and 2 Section B2 above). For the quota year, weight-at-age 4 and older and is calculated using the fitted parameters and lengths-at-age of each cohort as input, and the weight–length relationship. For the quota year +1, weight-at-age 4 is calculated use average for the three previous years and the weight-at-age 5 and older is calculated using the fitted parameters and lengths-at-age of each cohort as input, and the weight–length relationship. Weight-at-age 3 in the quota year and the year after the quota year, is predicted using the coefficient from the regression on the average of the recruitment in the actual year and the two previous years, to account for density-dependent effects.

Weight-at-age 3–7 in the catch (weca) is calculated using a linear regression between stock weight (west) -at-age and catch weight-at-age.

$$weca_{a,y} \sim west_{a,y}$$

weight-at-age 8–13+ in catches are predicted from the coefficients of the regression:

$$weca_{a,y} \sim weca_{a-1,y-1}$$

Maturity: for intermediate year smoothed from data (see B2) for the quota year age 4 and older, and quota year +1 age 5 and older; using the predictions from fitted parameters (see eq. 1 and 2 Section B2 above).). For age 3 quota year and quota year+ 1 and age 4 quota year +1: use average for the three previous years.

Stock–recruitment model used: Not required for short-term projection.

Procedures used for splitting projected catches: Not relevant.

E. Medium-Term Projections

Not required in assessment.

F. Long-Term Projections

MSY and HCRs in a long-term perspective have been investigated during special workshops (ICES, 2015b; ICES, 2016; WKDEM 2020) using long-term stochastic simulations. Population models with density-dependence in growth and maturation, described in ICES (2016) was realized in Excel-based model NE_PROST, which was developed in PINRO (Murmansk, Russia) and use the algorithm previously used for this purpose software PROST (Åsnes, 2014).

For the stock–recruitment relationship, it was decided to use a hockey-stick recruitment function with breakpoint of $B_{lim}(B_{loss})$ = 50 000 tonnes and a recruitment plateau of 151 million (geometric mean of historic recruitment) with log-normal error structure and some autocorrelation in abundance of year classes between years (see ICES, 2016). This approach will occasionally generate unrealistic large year classes and therefore a cap on the largest possible year class was introduced in the process. The cap was set to 1240 million (the highest observed).

Some changes to the haddock population model was done during WKDEM 2020:

Weight-at-age in the stock (west) for age 3 is calculated using a linear regression between the sum of the abundance of haddock at-age 3 from the same and the two previous year classes:

$$west_{age3,yearclass} \sim \sum_{yc}^{yc-2} N_{age\ 3}$$

For older ages, weight in the stock was calculated using a linear regression with weight in the stock at the same year class as in year before:

$$west_{a,y} \sim west_{a-1,y-1}$$

Weight-at-age in the catch (weca) is calculated using a linear regression between the stock weight-at-age and catch weight-at-age.

$$weca_{a,y} \sim west_{a,y}$$

Maturity is calculated based on eq. 2 and eq. 3 (Section B2).

Mat = f(Length, Age)

Length = f(west)

Simulations of long-term variations of the stock and catch with different target Fs were done in the NE_PROST program. Runs were made using constant F at all SSB levels instead of a HCR. Assessment error was not included. The results indicate that it is not likely to obtain increased yield by increasing the current target F = 0.35, and the simulations also indicate a reduced yield in tonnes at lower fishing mortalities.

G. Biological Reference Points

Biological and fisheries reference points for NEA haddock were last set following a thorough analysis as part of the WKNEAMP-2 (ICES, 2016) Harvest Control Rule evaluation in 2016. The revised SAM model developed during WKDEM produced better fits to the data but only a small change in the reconstructed stock. A brief analysis using long-term simulations in NE_PROST program done during WKDEM indicated that the reference points from the current model are very similar to the previously estimated values. Given the more thorough analysis at WKNEAMP-2 (ICES, 2016). this is taken as indicating that there is no evidence to deviate from the existing reference points. The reference points were kept unchanged by WKDEM, at B_{lim}=50 000 B_{pa}=80 000, F_{MSY}=0.35, F_{lim}=0.77, F_{pa} 0.47.

	TYPE	VALUE	TECHNICAL BASIS
MSY	MSY $B_{trigger}$	80 000 t	$B_{trigger}$=B_{pa}
Approach	F_{MSY}	0.35	Stochastic long-term simulations
	B_{lim}	50 000 t	B_{loss}
Precautionary	B_{pa}	80 000 t	B_{lim}*exp(1.645*σ), where σ=0.3
Approach	F_{lim}	0.77	SSB=B_{lim}, SPR value of slope of line from origin at SSB=0 to geometric mean recruitment
	F_{pa}	0.47	F_{lim}*exp(-1.645*σ), where σ=0.3

H. Other issues

H.1 Harvest control rule

The harvest control rule (HCR) was first evaluated by ICES in 2007 (ICES CM 2007/ACFM:16) and found to be in agreement with the precautionary approach. The agreed HCR for haddock with the last modifications is as follows (Protocol of the 40th Session of The Joint Norwegian Russian Fishery Commission (JNRFC), 14 October 2011 and Protocol of the 46th Session of JNRFC, 14 October 2016).

- TAC for the next year will be set at level corresponding to F_{MSY}.
- The TAC should not be changed by more than +/- 25% compared with the previous year TAC.
- If the spawning stock falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{MSY} at B_{pa} to F= 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year and a year ahead) there should be no limitations on the year-to-year variations in TAC.

As mentioned above F_{lim} and F_{pa} were revised in 2011. The new values of F_{lim}=0.77 and F_{pa}=0.47 were higher than the previous values (0.49 and 0.35, respectively). In the 2012 meeting of the JNRFC, the proposals of ICES were accepted and the current HCR management is based on F_{MSY} instead F_{pa}. This corresponds to the goal of the management strategy for this stock and should provide maximum sustainable yield.

At the 39th Session of the JNRFC in 2010, it was agreed that this HCR should be left unchanged for five years and then re-evaluated.

The JNRFC at its 46th meeting in 2016 decided not to change the HCR, and that the HCR should be used for the five following years.

H.2 Main sources of uncertainties in assessment and forecasts

The table below mainly reflects uncertainties in assessment and forecasts.

SOURCE OF UNCERTAINTY	DESCRIPTION	COMMENTS
Incomplete survey coverage (1)	Since 1997 all of the surveys used for tuning have been affected by an incomplete coverage for some of the years. (Due to Norwegian vessels not been given access to REZ, Russian vessels not been given access to NEZ). None of the surveys have a complete coverage of the stock. The proportion of a year class being outside the coverage varies between year classes (see also the WG report from 2002).	All indices affected have been corrected using a factor based on geographical distributions for each age group observed before and after the incomplete coverage. This procedure is likely to introduce increased uncertainty to the indices (see AFWG 2007 and 4.2).
Discards	The level of discarding is not known.	Discarding is known to be a possible problem in the longline and trawl fisheries related to the abundance of haddock close to, but below the minimum landing size.
Unreported catches	Estimates for unreported catches were provided and included in the assessment for 2002-2008, estimates for 2009- present are so close to zero that they were set equal to zero.	
Sampling error	Estimation of catch-at-age is based on sampling of catches. The error in the estimates caused by sampling can be considerable even if the total catch is known. The estimation of the abundance indices from surveys will also be affected by sampling error.	The effect of not taking sampling error into account when fitting models to data may introduce bias in the resulting estimates.

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