

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)

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A. General

A.1. Stock definition

The North-East Arctic Haddock (*Melanogrammus aeglefinus*) is distributed in the Barents Sea and adjacent waters, mainly in waters above 2°C. Tagging carried out in 1953–1964 showed that Northeast Arctic haddock inhabits the continental shelf of the Barents Sea, adjacent waters and polar front. The main spawning grounds are located along the Norwegian coast and area between 70°30' and 73°N along the continental slope, but spawning also occurs as far south as 62°N. Larvae are dispersed in the central and southern Barents Sea by warm currents. The 0-group haddock drifts from the spawning grounds eastwards and northwards and during the international 0-group survey in August it is observed over wide areas in the Barents Sea. Until maturity, haddock are mostly distributed in the southern Barents Sea being their nursery area. Having matured, haddock migrate to the Norwegian 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 harvested during their target fishery. On average approximately 75% of the catch is taken by trawl while 25% of the catch is with conventional gears, mostly longline, which are used almost exclusively by Norway. Part of the longline catches are from a directed fishery.

The fishery is restricted by national quotas. In the Norwegian fishery the quotas are set separately for trawl and other gears. 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.

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 indicate total yield of haddock by Subareas 1, 2.a and 2.b, as well as catch by each country by years.

Catch information by fishing gear used by Norway in the haddock fishery is used internally when making estimations at AFWG meeting. Catch quotas were introduced in the trawl fishery in 1978 and for the fisheries with conventional gears in 1989. Since January 1997 sorting grids have been mandatory for the trawl fisheries in most of the Barents Sea and Svalbard area. Discarding is prohibited.

From 01.01.2011, the minimum catching size of haddock is 40 cm in the Russian Economic zone, the Norwegian Economic zone, and the Svalbard area. It is allowed that up to 15% (by number) of the fish is below the minimum catching size of (this is counted for cod, haddock and saithe combined), larger proportions of undersized fish lead to closure of areas. The minimum mesh size in trawl codends is 130 mm. The fisheries are controlled by inspections at sea, requirement of reporting to catch control points when entering and leaving the EEZs and by inspections when landing the fish for all fishing vessels. Keeping a detailed fishing logbook on board is mandatory for most vessels, 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.

The historical high catch level of 320 000 tonnes in 1973 divides the time-series into two periods. In the first period, highs were close to 200 000 tonnes around 1956, 1961 and 1968, and lows were between 75 000 and 100 000 tonnes in 1959, 1964 and 1971. The second period showed a steady decline from the peak in 1973 down to the historically low level of 17 300 tonnes in 1984. Afterwards, landings increased to 151 000 tonnes before declining to 26 000 tonnes in 1990. A new increase peaked in 1996 at 174 000 tonnes. Three strong year classes (2004–2006) have caused peak catches in the recent years. The highest catch (315 000 t) was in 2012. The exploitation rate of haddock has been variable (F between 0.2 and 0.5 in the last 20 years).

The highest fishing mortalities for haddock have occurred at intermediate stock levels and show little relationship with the exploitation rate of cod, despite haddock being primarily a bycatch in the cod fishery. The exception is the 1990s when more restrictive quota regulations resulted in a similar pattern in the exploitation rate for both species. It might be expected that good year classes of haddock would attract more directed trawl fishing, but this is not reflected in the fishing mortalities.

Since 2007, estimates of unreported catches (IUU catches) of haddock have been added to reported landings for the years 2002 and onwards. In 2007–2008, two assessments were presented, based on Norwegian and Russian estimates of IUU catches, respectively. The basis for the Norwegian IUU estimates (N-IUU) is the annual ratio between cod and haddock in the international reported landings from Sub-area 1 and Division 2 b in 2002–2008. These ratios are assumed to be representative of the ratios in the IUU catches. The ratio is applied to the estimated IUU catches of cod in order to get the estimate for haddock. The estimates are similar to those made by the Norwegian Directorate of Fisheries for 2005–2008. The Russian estimates of IUU haddock are obtained by applying the same ratio, but using the Russian estimate of IUU catches of cod in 2002–2007. Both approaches show an increase 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, as in recent AFWG, it was decided to use Norwegian estimates for the period 2002–2008, because from 2009 onwards IUU catches equal Zero and only small differences exist in final estimates using both values of IUU.

A.3. Ecosystem aspects

The composition and distribution of species in the Barents Sea depend considerably on the position of the polar front which separates warm and salty Atlantic waters from colder and fresher waters of arctic origin. Variation in the recruitment of haddock has been associated with the changes in the influx of Atlantic waters to the large areas of the Barents Sea shelf.

Independently from age and season, haddock vary their diet and will prey on plankton or benthic organisms. During the spawning migration of capelin (*Mallotus villosus*) haddock prey on capelin and their eggs on the spawning grounds. When the capelin abundance is low or when their areas do not overlap, haddock can compensate by eating other fish species (e.g. young herring) or euphausiids and benthic organisms. Haddock growth rate depends on the population abundance, stock status of main prey species and water temperature.

Water temperature at the first and second years of the haddock life cycle is a fairly reliable indicator of year-class strength. If mean annual water temperature in the bottom layer during the first two years of haddock life does not exceed 3.75°C (Kola-section), the probability that strong year classes will appear is very low even under favourable effects of other factors. 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. Strength of year classes is also determined to a great extent by size and structure of the spawning stock. Under favourable environmental conditions, strong year classes are mainly observed in years when the spawning stock is dominated by individuals from older age groups with abundance at a fairly high level.

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

The appearance of strong haddock year classes usually leads to a substantial increase in natural mortality of juveniles as a result of cod predation.

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 6 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 program 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).

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 gears (bottom trawl, gillnet, Danish seine and longline/handline). This method replaced the traditional method in 2006, and the time-series of Norwegian catch-at-age (early 80's and onward) was updated based on the modelling approach. The old method involved allocating unsampled catches to sampled catches based on judgements on "distance criteria's" (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 1990's, 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, onboard 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 the year-round by a "standard" fishery trawl and summarized by three ICES Subareas (1, 2.a, and 2.b).

Age sampling was carried out in two ways: without any selection (otoliths were taken from any fish caught in one trawl, usually from 100–300 specimen or using a stratified by length sampling method (i.e. approximately 10–15 specimen per each 10 cm length group). The last method has been used since 1988.

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 formed 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 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 table below shows which country supplied which kind of data:

Country	KIND OF DATA				
	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				

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.

B.2. Biological

Weights and length-at-age in the stock and proportion of mature fish to ages 1–11 are 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, 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 and 2015 this practice was continued.

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

$$1) \quad L = L_{\infty} - L_{\infty} \cdot e^{(-K_Y(A-A_0))}$$

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:

$$W = \alpha \cdot L^{\beta}$$

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:

$$2) \quad \log\left(\frac{m}{1-m}\right) = I + \alpha A + \beta L$$

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:

$$3) \quad Mat = \frac{1}{1 + e^{(-\alpha \cdot (A - A_{50\%}))}}$$

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 the beginning of the year.

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 group for the period (1950–1979) are set equal to mean values for period 1980–2010 from the benchmark in 2011.

Natural mortality used in the assessment is estimated as $0.2 +$ 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). On average about 9000 cod stomachs from the Barents Sea have been analysed annually in the period 1984–2013.

The estimated consumption of NEA haddock by NEA cod is incorporated into the XSA analysis on first step by constructing catch-at-age matrix, adding estimated numbers of haddock eaten by cod to the catches for the ages 1–6, for years where such data are available (1984–present). The fishing mortality estimated by the XSA is split into the mortality caused by the fishing fleet (F) and the mortality caused by the cod's predation (M_2) according to the ratio of fleet catch and predation "catch". The new natural mortality dataset were then prepared by adding 0.2 (M_1) to the predation mortality. This new M matrix is used in the final XSA. Natural mortality for period without observations (1950–1983) is replaced by mean values for period 1984–2010.

In the SAM model the extra mortality caused by cod predation is added using the method suggested by A. Nielsen; i.e. add predation to the landings, and then track these separately in the outputs. The landing fraction is then defined as $Catch/(Catch+Predation)$.

The survey catchabilities are represented by power models, choosing linear models inflates the stock estimates far beyond any reasonable stock sizes. The recruitment model is represented by the Beverton-Holt equation.

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 commercial size 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. A total number of more than 400 trawl hauls are conducted during the survey (mainly bottom trawl, a few pelagic trawls). 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).

There are two Russian survey abundance indices at age available: 1) absolute numbers (in thousands) computed from the acoustics estimated by the new method (RU-Aco-Q4) for the period 1995–2009 (ages 0-10); 2) trawl index, calculated as relative numbers per hour trawling (RU-BTr-Q4) for the period 1983–2013 (ages 0-9).

The indices (RU-Aco-Q4) were not used for tuning the XSA due to a strong “year effect” observed in years with incomplete area coverage. This index needs further adjusting before it can be used for tuning.

The Norwegian winter (February) survey (from 2000 - Joint Barents Sea survey) started in 1981 and covers the ice-free part of the Barents Sea. Both swept-area estimates from bottom-trawl and acoustic estimates are produced. The survey is described in Jakobsen *et al.*, (1997) and Mehl *et al.*, (2013, 2014).

Before 2000 this survey was made without participation from Russian vessels, while in the three latest surveys Russian vessels have covered important parts of the Russian zone. The indices for 1997 and 1998, when the Russian EEZ was not covered, have been adjusted as reported previously (Mehl, 1999). The number of fish (age group by age group) in the Russian EEZ in 1997 and 1998 was interpolated assuming a linear development in the proportion found in the Russian EEZ from 1996 to 1999. These estimates were then added to the numbers of fish found in the Norwegian EEZ and the Svalbard area in 1997 and 1998.

It should be noted that the survey conducted in 1993 and later years covered a larger area compared to previous years (Jakobsen *et al.*, 1997). Other changes in the survey methodology through time are described by Jakobsen *et al.*, 1997. Note that the change from 35 to 22 mm mesh size in the codend in 1994 has not been corrected for in the time-series. This mainly affects the age 1 indices. There are two abundance indices at age from that survey available for stock assessment:

- 1) swept-area estimates from bottom trawl (NoRu-BTr-Q1) for the period 1981-last year (ages 1-10);
- 2) swept-area estimates from acoustic (NoRu-Aco-Q1) for the period 1981-last year (ages 1-10).

Bottom-trawl estimates from the joint Norwegian-Russian ecosystem survey in August-September started in 2004. This survey covers a larger portion of the distribution

area of haddock. The index (Eco-NoRu-Btr-Q3) for the period 2004–2015 and ages 1-8 was available for AFWG 2016. This time-series was accepted as a new tuning fleet in XSA during the benchmark in 2011. The survey methodology and results are described in annual survey reports (Prokhorova, 2013). Unfortunately, there is at present no agreed method for calculating bottom-trawl indices from this survey (Dingsør, WD17, WKARCT 2015 vs. ICES AFWG 2014 Table A14). Agreeing on a common methodology has very high priority.

Based on the test made during WKBENCH 2011 (ICES 2011a) and previous AFWG work it is decided to use only tuning indices for the period 1990 and onwards.

B.4. Commercial cpue

Russia

No Russian 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 XSA tuning.

B.5. Other relevant data

C. Assessment: data and method

The 2015 Benchmark Assessment (ICES 2015a) adopted the SAM model (State-space assessment model) (<https://www.stockassessment.org>; Nielsen and Berg, 2014) as main for NEA haddock stock assessment and recommended to expand the age range from 3-11+ to 3-13+ (WKARCT WD 4 and WD 12). Software used: AD Model Builder (ADMB) and R.

Previously used model XSA (Darby and Flatman, 1994), was kept for intermediate period as additional model for consideration. Software used: – FLR suite (and VPA95 suite).

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 year	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+	No – set to 0.2 for all ages in 1984- 2013; 1984-2010 average used for the years 1950- 1983
Natmor (XSA)	Natural mortality	1950 – last data year	3 – 13+	Includes annual est. of predation by cod from 1984, set to 1984-2010 average for the years 1950-1983
Landing Fraction	consumption	1984 – last data year	3-6	=C/(C+predation)

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	RU-BTr-Q4	1991 – last data year	3-7
Tuning fleet 2	BS-NoRU-Q1(Aco)	1992 – last data year	3-7
Tuning fleet 3	BS-NoRu-Q1 (BTr)	1992 – last data year	3-8
Tuning fleet 4	Eco-NoRu-Q3 (Btr)	2004 – last data year	3-8

The input data used for SAM are the same as for XSA. Although it is not required, winter survey tuning indices are backshifted as it is done for XSA. The extra mortality caused by cod predation is added using the method suggested by A. Nielsen (see above). The model fit for haddock is best when the individual log F-processes are allowed to develop correlated in time, and the correlation is set to reflect the intuition that neighbouring age classes should have more similar fishing mortalities. This correlation structure is commonly named AR(1) (Nielsen and Berg 2014). The survey catchabilities are represented by power models, choosing linear models inflates the stock estimates far beyond any reasonable stock sizes. The recruitment model is represented by the Beverton–Holt equation.

Technical mistake in settings for Fleet Eco-NoRu-Q3 (Btr) (grouping of observation variance parameters) was found and corrected during AFWG 2016. The configuration is given below.

Model Options chosen for SAM (Model.cfg).

```
# Min Age (should not be modified unless data are modified accordingly)
3
# Max Age (should not be modified unless data are modified accordingly)
13
# Max Age considered a plus group (0=No, 1=Yes)
1
# The following matrix describes the coupling
# of fishing mortality STATES
# Rows represent fleets.
# Columns represent ages.
#3      4      5      6      7      8      9      10     11     12     13
#flat F from age 9
1       2       3       4       5       6       7       7       7       7       7
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0
# Use correlated random walks for the fishing mortalities
# ( 0 = independent, 1 = symmetrical correlation estimated, 2=AR(1)-correlation estimated)
2
# Coupling of catchability PARAMETERS
0       0       0       0       0       0       0       0       0       0       0
1       1       2       2       2       0       0       0       0       0       0
3       3       4       4       4       0       0       0       0       0       0
```

5	5	6	6	6	7	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0

Coupling of power law model EXPONENTS (if used)

0	0	0	0	0	0	0	0	0	0	0
1	1	2	2	2	0	0	0	0	0	0
3	3	4	4	4	0	0	0	0	0	0
5	5	6	6	6	7	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0

Coupling of fishing mortality RW VARIANCES

1	2	2	2	2	2	2	2	2	2	2
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

Coupling of log N RW VARIANCES

1	2	3	4	4	4	5	5	5	5	5
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Coupling of OBSERVATION VARIANCES

1	2	2	2	2	2	3	3	3	3	3
4	4	5	5	5	0	0	0	0	0	0
6	6	7	7	7	0	0	0	0	0	0
8	8	9	9	9	10	0	0	0	0	0
11	11	12	12	12	13	0	0	0	0	0

Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)

2

Years in which catch data are to be scaled by an estimated parameter

0

first the number of years

Then the actual years

Then the model config lines years cols ages

Define Fbar range

4 7

Model options chosen For XSA:

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 = 1.500¹

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

Minimum standard error for population estimates derived from each fleet = 0.300

Prior weighting not applied

D. Short-Term Projection

Model used: Age structured

Software used: standard MFDP with management option table and yield-per-recruit routines.

Initial stock size: Estimated by model as abundance of individuals that survives the terminal year for age 3 and older.

Recruitment-at-age 3 for the start year and the 2 consecutive years is estimated from survey data in RCT3 using the tuning series as input.

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

Maturity: for current year smoothed actual data combined by Russian and Norwegian surveys are used; for subsequent years – using the fitted parameters and last year maturity as input.

Weight at age in the stock: for current year smoothed actual data combined by Russian and Norwegian surveys are used, for two years ahead, using the fitted parameters and last year lengths as input.

The Norwegian and Russian weight-at-age and maturity-at-age are then combined as arithmetic averages.

Weight at age in the catch show strong patterns related to periods of good recruitment and the practise has been to use three year averages from periods with similar trends in catch weights at age.

Last three year averages of natural mortalities are used in short term projections (STP). Attempts should be made to relate natural mortality to cod and capelin stock size.

The SAM model estimates slow changes in the selection pattern and it is decided to use the last three year averages as input in STP.

Intermediate year assumptions: Normally F status quo is used. If this corresponds to a catch which deviates considerably from the agreed TAC, one should consider other approaches. Due to the possibility of large changes in TAC ($\pm 25\%$) it is often preferable to use TAC constraint.

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

Procedures used for splitting projected catches: Not relevant.

¹ During the benchmark in 2011 (ICES 2011) it was decided that the AFWG 2011 should evaluate different options for this value and make the final decision on the appropriate value. The AFWG 2011 decided to change this setting from 0.5 to 1.5.

E. Medium-Term Projections

Not required in assessment.

F. Long-Term Projections

MSY and HCRs in long-term perspective have been investigated during special workshops (ICES 2015, ICES 2016) using long-term stochastic simulations. Population models with density-dependence in growth and maturation, described in Russkikh and Bogstad (2015) was realized in new Excel-based model NE_PROST, which evaluated in PINRO (Murmansk, Russia) and allows to use algorithm of previously used for this purpose software PROST (Åsnes, 2014) but with additional settings.

For the stock - recruitment relationship it was decided to use a hockey stick recruitment function with break point of $B_{loss} = 50\,000$ tonnes and a recruitment plateau of 136 million (geometric mean of historic recruitment) with log-normal error structure and some autocorrelation in abundance of yearclasses between years (see ICES 2016).

Simulations of long-term variations of SSB and catch using same settings as applied for HCR investigations with different target F s were done in NE_PROST program. Runs were made using constant F at all SSB levels instead of a HCR where F is reduced linearly from F_{target} at B_{pa} as done in all proposed HCRs. Assessment error was not included. The results indicate that it is not likely to increase the yield by increasing the current target $F = 0.35$, and the simulations also indicate a reduced yield in tonnes at lower fishing mortalities (economic yield is another issue).

G. Biological Reference Points

Based on the analysis of the stock recruitment plot it was proposed to keep $B_{lim} = 50\,000$ t and $B_{pa} = 80\,000$ t with the rationale that B_{lim} is equal to B_{loss} , and $B_{pa} = B_{lim} \cdot \exp(1.645 \cdot \sigma)$, where $\sigma = 0.3$. This gives a 95% probability of maintaining SSB above B_{lim} taking into account the uncertainty in the assessments and stock dynamics. For BMSY trigger was proposed equal B_{pa} , $B_{trigger}$ was then selected as a biomass that is encountered with low probability if FMSY is implemented, as recommended by WKFRAME2 (ICES CM 2011b). There is no standard method of estimating F_{lim} nor F_{pa} , and ACOM accepted to use geometric mean recruitment (146 million) and B_{lim} as basis for the F_{lim} estimate. F_{lim} is then based on the slope of line from origin at $SSB = 0$ to the geometric mean recruitment (146 million) and $SSB = B_{lim}$. The SPR value of this slope gives the F_{lim} value on SPR curve; $F_{lim} = 0.77$ (found using Pasoft). Using the same approach as for B_{pa} ; $F_{pa} = F_{lim} \cdot \exp(-1.645 \cdot \sigma) = 0.47$. $F_{MSY} = 0.35$ has been estimated by long-term stochastic simulation (WD 16, AFWG 2011).

	TYPE	VALUE	TECHNICAL BASIS
MSY	MSY $B_{trigger}$	80 000 t	$B_{trigger} = B_{pa}$
Approach	FMSY	0.35	Stochastic long-term simulations
	B_{lim}	50 000 t	B_{loss}
Precautionary	B_{pa}	80 000 t	$B_{lim} \cdot \exp(1.645 \cdot \sigma)$, where $\sigma = 0.3$
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	$F_{lim} \cdot \exp(-1.645 \cdot \sigma)$, where $\sigma = 0.3$

H. Other Issues

H.1 Harvest control rule

The harvest control rule (HCR) was 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, 14 October 2011:

- TAC for the next year will be set at level corresponding to F_{MSY} .
- The TAC should not be changed by more than $\pm 25\%$ 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 $F_{pa}=0.47$ are higher than the previous values (0.49 and 0.35, respectively). In the 2012 meeting of the Norwegian Russian Fishery Commission 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 Joint Norwegian Russian Fishery Commission in 2010 it was agreed that this HCR should be left unchanged for 5 years and then re-evaluated.

At its 45th session in October 2015, the Joint Norwegian-Russian Fisheries Commission (JNRFC) decided that a number of alternative harvest control rules (HCRs) for North-east Arctic haddock should be evaluated by ICES (Anon, 2015, Appendix 19). This was done by WKNEAMPs (ICES 2015, 2016) and following HCRs for NEA haddock were tested:

1. The existing harvest control rule, but with $F_{target}=0.27$ instead of 0.35
2. The existing harvest control rule
3. The existing harvest control rule, but with $F_{target}=0.43$ instead of 0.35
4. The existing harvest control rule, but with a constraint of maximum 10% TAC variation from year to year instead of a 25% constraint which is presently used
5. The existing harvest control rule, but with no constraint of maximum TAC variation from year to year
6. The existing harvest control rule, with a constraint of -25% in TAC reduction from year to year but with no constraint for increases in TAC.

Among the six HCRs tested, the current HCR (rule 2) performs best in terms of average yield, stability of yield and precautionarity.

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).	All indices affected have been corrected using a factor based on geographical distributions observed before and after the incomplete coverage. This procedure is likely to introduce increased uncertainty to the indices (see AFWG 2007 and 4.2).
Incomplete survey coverage (2)	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).	May appear as year-class dependent changes in survey catchability. Catches of haddock in Norwegian statistical areas 06 and 07 (coastal areas) are added to the NEA haddock. These include haddock of older ages compared to the landings of NEA haddock. Since the surveys do not cover the coastal regions the coverage of older ages may be poorer.
Correlated error structures	Year effects in a survey are quite common. The year effect introduces correlated errors between the age groups, but in this case also between survey series.	
Discards	The level of discarding is not known.	Discarding is known to be a (varying) problem in the longline and trawl fisheries related to the abundance of haddock close to, but below the minimum landing size.
Unreported catches	This year, estimates for unreported catches were provided for 2002-2008, 2009-2015 estimates equal to zero.	The estimates were considered quite uncertain, but the uncertainty has decreased in recent years.
Predation on young age groups	The mortality due to predation (to a large extent by cod) varies substantially from year to year.	The predictions of young age groups are very uncertain and depending on uncertainties in the cod assessment.
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. This bias is likely to increase with sampling error (see chapter 0).

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