Stock annex: Cod (*Gadus morhua*) in subareas 1 and 2 (North-east Arctic)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod
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A. General

A.1. Stock definition

The North-East Arctic cod (*Gadus morhua*) is distributed in the Barents Sea and adjacent waters, mainly in waters above 0°C. The main spawning areas are along the Norwegian coast between 67°30′ and 70°N. The 0-group cod 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.

A.2. Fishery

The fishery for North-east Arctic cod is conducted both by an international trawler fleet operating in offshore waters and by vessels using gillnets, longlines, handlines and Danish seine operating both offshore and in the coastal areas. 60-80% of the annual landings are from trawlers. Catch quotas were introduced in the trawl fishery in 1978 and for the fisheries with conventional gears in 1989. In addition to quotas the fisheries are regulated by mesh size limitations including sorting grids, a minimum catching size, a maximum bycatch of undersized fish, maximum bycatch of non-target species, closure of areas with high densities of juveniles and by seasonal and area restrictions. 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 minimum catching size of cod is 44 cm, and the maximum proportion of undersized fish allowed is 15% by number for cod, haddock and saithe combined. 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 not sufficient to prevent discarding and underreporting of catches, but it has improved considerably following the introduction of port state control in 2007.

A.3. Ecosystem aspects

Considerable effort has been devoted to investigate multispecies interactions in the Northeast Arctic. Some of these investigations have reached the stage where quantitative results are available for use in assessments. Growth of cod depends on availability of prey such as capelin (*Mallotus villosus*), and variability of cod growth has had major impacts on the cod fishery. Cod are able to compensate only partially for low capelin abundance, by switching to other prey species. This may lead to periods of high cannibalism on young cod, and may result in impacts on other prey species which are greater than those estimated for periods when capelin is abundant. In a situation with low capelin abundance, juvenile herring (*Clupea harengus)* experience increased predation mortality by cod. The timing of cod spawning migrations is influenced by the presence of spawning herring in the relevant area. The interaction between capelin and herring is illustrated by the recruitment failure of capelin coinciding with years of high abundance of young herring in the Barents Sea. Herring predation on capelin larvae is believed to be partially responsible for the recruitment failure of capelin when young herring are abundant in the Barents Sea.

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 some species including cod and capelin has been associated with the changes in the influx of Atlantic waters to the large areas of the Barents Sea shelf.

The annual consumption of herring, capelin and cod by marine mammals (mainly harp seals and minke whales) has been estimated to be in the order of 1.5–2.0 million tonnes (Bogstad *et al*., 2000; See also Table 1.9 ICES 2014).

However, estimates of total annual food consumption of Barents Sea harp seals are in the range of about 3.3–5 million tonnes (depending on choice of input parameters, Nilssen *et al.*, 2000). The applied model used different values for the field metabolic rate of the seals (corresponding to two or three times their predicted basal metabolic rate) and under two scenarios: with an abundant capelin stock and with a very low capelin stock.

If capelin was abundant the total harp seal consumption was estimated to be about 3.3 million tons (using lowest field metabolic rate). The estimated consumption of various commercially important species was as follows (in tonnes): capelin approximately 800 000, polar cod (*Boreogadus saida*) 600 000, herring 200 000 and Atlantic cod 100 000.

A low capelin stock in the Barents Sea (as it was in 1993–1996) led to switches in seal diet composition, with estimated increased consumption of polar cod (870 000 tonnes), other gadoids (mainly Atlantic cod; 360 000 tonnes), and herring (390 000 tonnes).

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 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, but there are several reports of discards.

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 IMR reference fleet (fishing vessels contracted for sampling), and the coast guard.

The ECA software (Hirst *et al*., 2012) has been developed to utilize all sampling information to estimate catch-at-age for areas (1, 2a and 2b), quarters and gears (bottom trawl, gillnet, Danish seine and longline/handline). This software also handles the splitting of catches into NEA cod and Coastal cod.

Russia

Russian commercial catch in tonnes by quarter and area are derived from the All-Russian Institute of fishery and oceanography (Moscow) statistics department. Data from each fishing vessel are aggregated on three ICES subdivisions (1, 2a and 2b). Russian fishery by passive gears was almost stopped by the end of the 1940s. At present the bottom-trawl fishery constitutes more than 95% of the cod catch.

The sampling strategy was to conduct length and weight measurements and collect age samples directly at sea, onboard of both research and commercial vessels to have age and length distributions from each area and quarter. Data on length distribution of cod in catches were collected in areas of cod fishery all year round by a "standard" fishery trawl (since 2011 the mesh size is 130 mm for the entire Barents Sea, previously it was 125 mm in the Russian Economic zone and Svalbard area and 135 mm in the Norwegian Economic zone) and summarized by three ICES Subareas (1, 2a and 2b). Previously the PINRO area divisions were used, which differed from the ICES subdivisions.

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

All fish taken for age-reading were measured and weighted individually.

Catch-at-age are reported to ICES AFWG by subdivision (1, 2.a and 2.b) and quarter (before 1984 – by subdivision and year). Data on length distribution of cod in catches, as well as age–length keys, are formed for each quarter and area. In the case when a catch is present in the area/quarter but a length frequency is absent, a length frequency for the corresponding quarter, summarized for the whole sea is used. If there is no data on length composition of cod in catches per a quarter within the whole sea, a frequency summarized for the whole year and whole sea is used. Gaps in age–length distributions in subdivisions are filled in with data from the corresponding quarter, summarized for the whole sea. Remaining gaps are filled in with information from the age–length key formed for the long-term period (1984–1997) for each quarter and for the whole sea (Kovalev and Yaragina, 1999). Before 1984, calculation of catch–in-numbers in subdivisions was based on the age–length keys for the whole year and length distribution in catches.

Germany and Spain

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

Other nations

Total annual catch in tonnes is reported by ICES subdivisions. 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 text table below shows which country supplied which kind of data for 2016 :

	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		
UK	x				
France[1]	x				
Spain	x	x	x		
Portugal	x				
Poland	x	x	x		
Ireland[1]	x				
Greenland[1]	x				
Faroe Islands[1]	x				
Iceland[1]	x				
	x				

[1] As reported to Norwegian and Russian authorities

Since 2008 the catch data has been handled by Intercatch. Earlier the nations that sample the catches, provided the catch-at-age data and mean weights at age on Excel spreadsheet files, and the national catches were combined in Excel spreadsheet files. Historic data should be found in the national laboratories and with the stock co-ordinator.

For 1983 and later years mean weight at age in the catch is calculated as the weighted average for the sampled catches for age 1-11. For age 12 and older some smoothing of data is needed but the procedure for that has not been settled yet, the AFWG 2017 report describes the approach taken in the 2017 assessment For the earlier period (1946–1982) mean weight at age in catches is set equal to mean weight at age in the stock (ICES 2001).

Since 2008 the catch data has been handled by Intercatch.

B.2. Biological

For 1983 and later years weight at age in the stock and maturity-at-age is calculated as weighted averages from Russian and Norwegian surveys during the winter season. Stock weights at age a (W_a) at the start of year y for ages 1-11 are calculated as follows:

$$W_{a,y} = 0.5(W_{rus,a-1,y-1} + (\frac{N_{nbar,a,y}W_{nbar,a,y} + N_{lof,a,y}W_{lof,a,y}}{N_{nbar,a,y} + N_{lof,a,y}}))$$

where

$W_{rus,a-1}$: Weight at age a-1 in the Russian survey in year y-1

$N_{nbar,a}$: Abundance at age a in the Norwegian Barents Sea acoustic survey in year y

$W_{nbar,a}$: Weight at age a in the Norwegian Barents Sea acoustic survey in year y

$N_{lof,a}$: Abundance at age a in the Lofoten survey in year y

$W_{lof,a}$: Weight at age a in the Lofoten survey in year y

Maturity-at-age is estimated from the same surveys by the same formulae, replacing weight by proportion mature.

For age 12 and older some smoothing of data is needed but the procedure for that has not been settled yet, the AFWG 2017 report describes the approach taken in the 2017 assessment.

The time series for weight and maturity at age should be revised in 2018 following the revision of the time series for the acoustic estimates in the Norwegian winter survey (see under *Surveys* below).

For the earlier period (1946–1982) the maturity-at-age and weight at age in the stock is based on Russian sampling in late autumn (both from fisheries and from surveys) and Norwegian sampling in the Lofoten spawning fishery. These data were introduced and described in the 2001 assessment report (ICES 2001).

Natural mortality (M) is assumed to be equal to 0.2 plus cannibalism mortality for ages 1–6.

The method used for calculation of the prey consumption by cod described by Bogstad and Mehl (1997) is used to calculate the consumption of cod by cod for use in SAM. 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 1984–2016.

These data are used to calculate the per capita consumption of cod by cod for each half-year (by prey age groups 3–6 and predator age groups 3-11+). It was assumed that the mature part of the cod stock is found outside the Barents Sea for three months during the first half of the year. Thus, consumption by cod in the spawning period was omitted from the calculations.

The number of cod predators at age is taken from the SAM, and thus an iterative procedure has to be applied. All occurrences of intra-cohort predation were removed from the dataset as these could possibly cause problems with convergence. The following procedure realized in R script was followed:

The 1st run of SAM is done without taking into account consumption with a mortality of 0.2. It gives a stock numbers, simulated catches and fishing mortality. Stage 2 - on the basis of the equation (1) which is similar to Pope's approximation, we calculate the number of the corresponding cohorts in terms of both consumption and catch (ages 3-6) for the period 1984- the last year and M=0.2:

$$N(y,a) = N(y+1,a+1) * e^{M} + C(y,a) * e^{M/2} + Cons(y,a) * e^{M/2} \qquad (1)$$

Where: N (y, a) is the number of cod at the age a, at the beginning of the year y,

M = 0.2,

C (y, a) - simulated catch from first run,

Cons (y,a) - the amount of young cod consumed at ages 3-6 and the period 1984-the last year calculated using the abundance of older cod from the last run and data on per capita annual consumption of cod

Stage 3 - Calculate the mortality rate from cod predation according to the equation (2):

$$M2 (y,a) = \ln (N (y,a) / N (y+1,a+1)) - F (y,a) - 0.2 \qquad (2)$$

F (y,a) - fishing mortality from last run.

4 stage -- Run the model with the natural mortality taken from the calculated mortality from predation (0.2 + M2).

5 stage – repeat from stage 2 onwards until difference between summary of cod abundance at ages 3-6 for period 1984-the last year from last iteration and previous ones becomes sufficiently low (formal convergence criteria was not used, in practice 5 iterations was used).

The process noise in N is captured in the SAM model. It may cause situations when the ad-hoc Ms becomes less than .2. In the current implementation they are then set to 0.2.

A process model for M2 should be developed before AFWG 2018.

Since 2015 hindcasted data on cod cannibalism for the historical period (1946–1983) are also available. These have been applied to make the VPA time-series with cannibalism consistent (Yaragina *et al.*, WD7 WKARCT 2015).

Both the proportion of natural mortality before spawning (Mprop) and the proportion of fishing mortality before spawning (Fprop) are set to 0. The peak spawning in the Lofoten area occurs most years in late March-early April.

B.3. Surveys

General: Use survey data up to age 15+, where available and considered reliable. Since the viable age range for each dataset will vary as the age structure of the stock varies, the choice of which age range to use for each dataset in a given year shall be made at the AFWG.

Russia

Russian surveys of cod 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 cod have been surveyed simultaneously. In 1984, acoustic methods started to be implemented during surveys of fish stocks (Zaferman and Serebrov, 1984; Lepesevich, Shevelev, 1997; Lepesevich *et al.*, 1999). In 1995 a new acoustic assessment method was applied for the first time, which allowed the differentiation and registration of echo intensities from fish of different length (Shevelev *et al.*, 1998). Methods of calculations of survey indices also changed, e.g. due to the necessity to derive length-based indices for the FLEKSIBEST model (Bogstad *et al.*, 1999; Gusev and Yaragina, 2000).

Survey duration has been reduced from 5–6 months (September-February) in 1946–1981 to 2–2.5 months (October-December) since 1982. The aim of conducting a survey is to investigate both the commercial size cod as well as the young cod and to receive reliable data to compose annual maturity ogives. The survey covers the main areas where juveniles settle down as well as the commercial fishery takes place, including cod at age 0+ - 10+ years. A total of more than 400 trawl hauls are conducted during the survey (mainly bottom-trawl hauls, a few pelagic trawl hauls).

There are two survey abundance indices at age: 1) absolute numbers (in thousands) computed from the acoustics and 2) trawl swept-area indices, calculated as absolute numbers registered in survey standard area (Golovanov *et al.,* 2006, 2007).

Joint Russian–Norwegian winter (February) survey

The 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 swept-area estimates are used in the tuning for ages 3–8, and the acoustic estimate are added to the Norwegian acoustic survey in Lofoten and used for tuning for ages 3–9. The survey is described in Jakobsen *et al.,* (1997) and Mehl *et al.*, (2013, 2014). The time series for the bottom trawl estimates has recently been revised back to 1994 (Mehl et al. 2016), and similarly the time series for the acoustic estimates will be revised before AFWG 2018.

Norwegian Lofoten survey

Acoustic estimates from the Lofoten survey extends back to 1985. The survey is described by Korsbrekke (1997).

Joint Russian–Norwegian Ecosystem survey (August–September)

This survey started in 2004, but is a continuation and integration of previous surveys conducted at this time of year (0-group survey, capelin survey, various bottom-trawl investigations). The survey methodology and results are described in annual survey reports (e.g. 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.

Commercial cpue

Russia

A cpue series based on PST vessel type (stern trawler, 2000 HP) was used in the assessment before 2015, but has now been excluded from the assessment.

Information from each fishing trawler was daily transferred to PINRO, including data on each haul (timing, location, gear and catch by species). Yearly catch of cod by the PST trawlers as well as number of hours trawling was summarized and cpue index (catch on tons per hour fishing) was calculated. The effort (hours trawling) was scaled to the whole Russian catch. The cpue indices were split on age groups by age data from the trawl fishery.

C. Estimation of historical stock development

Model used: SAM (Interbenchmark in 2017, ICES 2017).

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1946–last data year	3 –15+	Yes
Canum	Catch-at-age in numbers	1946 –last data year	3 –15+	Yes
Weca	Weight at age in the commercial catch	1982–last data year	3–15+	Yes, set equal to west for 1946-1981
West	Weight at age of the spawning stock at spawning time.	1946–last data year	3–15+	Yes
Mprop	Proportion of natural mortality before spawning	1946–last data year	3–15+	No, set to 0 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1946–last data year	3–15+	No, set to 0 for all ages in all years
Matprop	Proportion mature at age	1946–last data year	3–15+	Yes
Natmor	Natural mortality	1946–last data year	3–15+	No, values 0.2 for all ages in all years
	Additional natural mortality caused by cannibalism	1946–last data year	3–6	Yes, annual est. of cannibalism from 1984, for period 1946-1983 set to hindcasted values since 2015 WG (WD7 WKARCT 2015)

Tuning data (upper limit of age range is values used at AFWG 2017, these values are not fixed)

Type	Name	Year range	Age range
Tuning fleet 1	Joint Barents Sea survey, February	1981–last data year	4–12
Tuning fleet 2	Joint Barents Sea Acoustic, February+ Lofoten Acoustic survey in March	1985–last data year	4-12
Tuning fleet 3	Russian bottom-trawl survey, November	1984–last data year	3–12
Tuning fleet 4	Barents Sea ecosystem survey, September	2004–last data year	3–12

SAM settings

Min Age (should not be modified unless data are modified accordingly)
3
Max Age (should not be modified unless data are modified accordingly)
15
Max Age considered a plus group (0=No, 1=Yes)
1

(0 = independent, 1 = symmetrical correlation estimated, 2=AR(1)-correlation estimated)
2

Coupling of correlation in observations
(NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA),
(-1, 0, 1, 2, 3, 4, 4, 4, 4, -1, -1, -1),
(-1, 5, 6, 7, 8, 9, 10, 10, 10, -1, -1, -1),
(11, 12, 13, 14, 14, 14, 14, 14, 14, -1, -1, -1),
(15, 16, 17, 18, 19, 20, 20, 20, 20, -1, -1, -1)

Coupling of OBSERVATION VARIANCES
(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0),
(-1, 1, 1, 1, 1, 1, 1, 1, 1, 1, -1, -1, -1),
(-1, 2, 2, 2, 2, 2, 2, 2, 2, 2, -1, -1, -1),
(3, 3, 3, 3, 3, 3, 3, 3, 3, 3, -1, -1, -1),
(4, 4, 4, 4, 4, 4, 4, 4, 4, 4, -1, -1, -1)

Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)
0
Years in which catch data are to be scaled by an estimated parameter
0
Define Fbar range
5 10

Model options chosen for XSA
(used as an additional model for checking of results):
Tapered time weighting applied, power = 3 over 20 years
Catchability independent of stock size for ages > 12
Catchability independent of age for ages > 12
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
Shrinkage to the population mean (p-shrinkage) not applied
Minimum standard error for population estimates derived from each fleet = 0.3
Prior weighting not applied

D. Short-term projection

Model used: Age structured

Software used*:* R script prediction with management option tableSAM

Initial stock size: Taken from SAM for age 4 and older. The recruitment-at-age 3 for the initial stock and the following 2 years are estimated from survey data and environmental data using the "hybrid model" described in section 1.4.5 in AFWG 2014 (ICES CM 2014/ACOM:05)

Natural mortality: average of the three last years or set equal to the values estimated for the terminal year if there is a strong trend during the most recent years.

Maturity: average of the three last years

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

Weight at age in the stock: Predicted by applying 3-year average of annual increments by cohort on last year's observation.

Weight at age in the catch: Predicted by applying 10-year average annual increments by cohort on last year's observation.

Exploitation pattern: Average of the recent years taking into account stability of the pattern. 5 years average as default.

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.

Stock recruitment model used: None

Procedures used for splitting projected catches: Not relevant

E. Medium-term projections

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.

The PA and MSY reference points were considered to be adequate and the previously used values were not changed.

G. Biological reference points

Introduced 1998: B_{lim}=112 000 t, B_{pa}=500 000 t, F_{lim}=0.70, F_{pa}=0.42

Adopted in 2003: B_{lim}=220 000 t, B_{pa}=460 000 t, F_{lim}=0.74, F_{pa}=0.40

F_{MSY} is estimated at level of 0.40.

MSY $B_{trigger}$ is at the level of 460 000 t (B_{pa}), and used as a trigger point in HCR.

H. Harvest control rule

The HCR adopted by JNRFC in 2016 following evaluation of several rules in 2016 (ICES 2016) is a two-step rule where F increases if SSB goes above 2*B_{pa}. The rule now reads as follows:

The TAC is calculated as the average catch predicted for the coming 3 years using the target level of exploitation (F_{tr}).

The target level of exploitation is calculated according to the spawning stock biomass (SSB) in the first year of the forecast as follows:

- *if* $SSB < B_{pa}$*, then* $F_{tr} = SSB / B_{pa} \times F_{msy}$*;*
- *if* $B_{pa} \leq SSB \leq 2 \times B_{pa}$*, then* $F_{tr} = F_{msy}$*;*
- *if* $2 \times B_{pa} < SSB < 3 \times B_{pa}$*, then* $F_{tr} = F_{msy} \times (1 + 0.5 \times (SSB - 2 \times B_{pa}) / B_{pa})$*;*
- *if* $SSB \geq 3 \times B_{pa}$*, then* $F_{tr} = 1.5 \times F_{msy}$*;*

where F_{msy}*=0.40 and* B_{pa}*=460 000 tonnes.*

If the spawning stock biomass in the present year, the previous year and each of the three years of prediction is above B_{pa}*, the TAC should not be changed by more than +/- 20% compared with the previous year's TAC. In this case,* F_{tr} *should however not be below 0.30.*

H. Other issues

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