Stock Annex: Cod (*Gadus morhua*) in Subdivisions 24–32, eastern Baltic stock

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Cod in Subdivisions 24-32 (eastern Baltic stock)
Working Group:	Baltic Fisheries Assessment Working Group (WGBFAS)
Last updated:	8 February 2019
Last updated by:	WKBALTCOD2

A. General

A.1. Stock definition

Since 2003, there are two management areas for cod in the Baltic Sea, Western (ICES SD 22–24) and Eastern (ICES SD 25–32). This corresponds to the distribution areas of the Western and Eastern Baltic cod stocks, though both stocks occur in SD24. The stock separation has been confirmed in genetic studies (Hemmer-Hansen *et al.,* 2019 and ref therein) and is maintained primarily through differences in spawning areas, spawning time and egg characteristics. Tagging programs have also confirmed that the eastern and western Baltic cod stocks co-occur in the Arkona Basin (SD 24) (Aro, 1989; Nielsen *et al*., 2013). Qualitative evidence of occurrence of juvenile cod in the Bornholm Sea, but spawned in the western Baltic Sea, is also given by a study based on the microstructure of otoliths (Oeberst and Böttcher, 1998). Since 2015, ICES stock assessments are stock-specific, i.e. separate between Eastern and Western Baltic cod stocks in SD24, based on otolith shape analyses combined with genetics.

A.2. Spawning and distribution

The spawning of the Eastern Baltic cod starts in February–March and lasts until October–November (Wieland *et al.,* 2000). Peak spawning occurred between the end of April and mid-June in the 1970s and 1980s (MacKenzie *et al.,* 1996), and gradually changed to the second half of July during the 1990s (Wieland *et al.*, 2000). In the late 2000s, the main spawning expanded to spring, covering a 4 months period from May to August (Neumann *et al.,* 2014; Köster *et al.,* 2017). In most years since 2010, highest egg abundances have been recorded in June (ICES, 2018).

Spawning of the Eastern Baltic stock is confined to the deep areas where salinities are sufficiently high to allow egg fertilisation and to keep the fertilised eggs afloat. The eggs of Eastern Baltic cod reach neutral buoyancy at lower salinities (approximately 12–14 PSU) than other cod stocks, which is an essential adaptation to living in a brackish water area. Sufficient oxygen content in the deep, saline water layer where the fertilised eggs float is crucial to egg survival and recruitment success.

In the Eastern Baltic Sea, there are historically three main cod spawning grounds, in deeper areas of the Bornholm Basin (BB), Gdansk Deep(GD) and Gotland Basin (GB). Due to reduced salinity and oxygen, conditions for cod egg survival in GD and GB have deteriorated considerably since the mid-1980s (MacKenzie *et al.*, 2000; Köster *et al.,* 2009), and these spawning areas have presently a limited contribution to cod recruitment (Plikshs *et al.,* 2015; Köster *et al.,* 2017). At low stock sizes and reduced extension of spawning habitat, the stock is mainly concentrated in the southern Baltic (Casini *et al*., 2012).

A.3. Fishery

Cod in the eastern Baltic have traditionally been caught in a directed fishery, and bycatch of cod in pelagic fisheries has been very limited. The main fisheries for cod in the Eastern Baltic use demersal trawls, semi-pelagic trawls and gillnets. In the early 1980s, when the stock biomass substantially increased due to favourable reproductive environmental conditions, landings increased to 350–400.000 tons. During this time, a considerable share of the catches was taken in Subdivisions 28–32. However, the spawning stock subsequently declined from the highest level on record to a low level in the early 1990s as a result of the increased effort of the traditional bottom-trawl fishery, introduction of gillnet fishery, and decreased egg survival due to deteriorating environmental conditions including oxygen depletion of deep-water layers. During the 1990s, when the proportion of older cod in the stock was large, the gillnet fisheries expanded. However, with the change in the stock age- and size-composition towards younger and smaller cod, the share of the total catch of cod taken by gillnets has decreased. During the recent two decades, the cod catches were largely taken in Subdivisions 25 and 26 with 10–30% being taken by gillnets. A cod fishery with longlines has developed in some countries but is not taking a large share of the catches.

A.4. Fishery regulations

The intensive research on improving the selectivity in Baltic cod trawls has led to several legislative changes since 1995. A BACOMA codend with a 120 mm mesh was introduced by IBSFC in 2001 in parallel with an increase in diamond mesh size to 130 mm in traditional codends (Table A1). In October 2003, the regulation was changed to a 110 mm BACOMA exit window or a T90 codend (in which the mesh in the codend and extension piece is turned by 90°). These were expected to enhance the compliance by the fishing industry and to be in better accordance with the minimum landing size, which was changed from 35 to 38 cm in the same year. Implementation of the BACOMA window in the new EU countries (Estonia, Lithuania and Poland) was made in May 2004. In 2010, the BACOMA 120 mm was reintroduced in the Western Baltic. Since 2015, a discard ban is in place, obliging the fisheries to land the entire catch of cod, and cod with a size of ≥35 cm (minimum conservation reference size) are for commercial use. An overview of the historical changes in gear regulations is provided in Figure A1, and additional description can be found in Valentinsson *et al.,* 2019.

Table A1. Changes in gear regulations in Baltic cod trawls since the 1990s.

Year	Regulation change
pre 1994	Min. Mesh size (MMS) 105 mm, Minimum Landing Size (MLS) 33 cm
1994	MMS increase to 120 mm or 105 mm exit window (two variants)
1994	MLS increase to 35 cm
2002	MMS increase to 130 mm or 120 mm Bacoma panel
2003	MLS increase to 38 cm
2003	110 mm Bacoma panel only
2006	110 mm T90 introduced as alternative to Bacoma
2010	MMS increase to 120 mm in T90 and Bacoma
2010	Amendments of some technical specifications in council reg 2187/2005
2015	Landing obligation introduced, Minimum Conservation Reference Size (MCRS) of 35 cm replaces MLS
2018	115 mm T90 introduced in commission delegated reg (EU) 2018/47

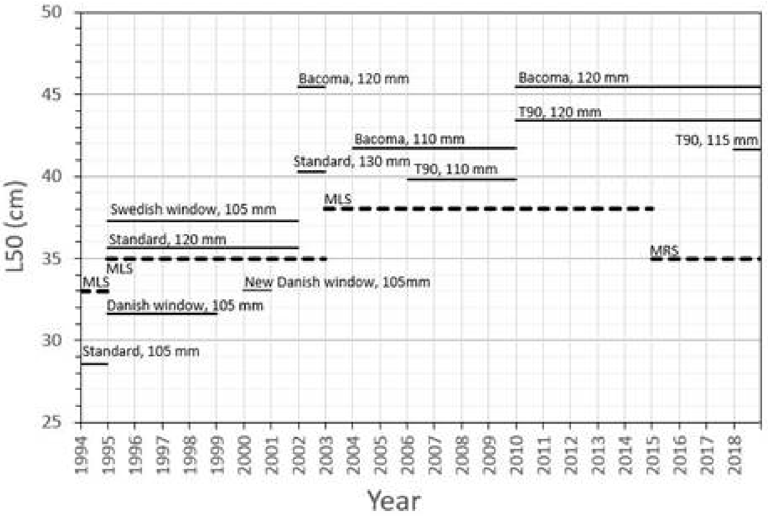

Figure A1. Changes in estimated codend selectivity (L50) in Baltic cod trawls during the past 25 years. Stipled lines show minimum landings size (MLS) or minimum conservation reference size (MRS) (from Valentinsson *et al.*, 2019 where also sources of the information can be found).

Effort limitations for the Baltic Sea cod fisheries have been in place in some years in the past (e.g. 2006, 2007). The intention was to reduce the allowed days at sea by 10% each year until the cod stocks were within safe biological limits.

In 2008, a first EU management plan for the Baltic Sea cod (EC No. 1098/2007) was introduced, and with that, the effort limitation scheme changed. In this first EU management plan, effort limitation in the Eastern Baltic Sea included a prohibition of all cod fisheries from 1 July to 31 August (seasonal closure). Additionally, the plan included a prohibition of any fishing activities in the three designated areas from 1 May to 31 October (area closures). In the new EU Baltic multi-annual management plan (Baltic MAP), seasonal closure in the Eastern Baltic Sea were lifted, while the area closures (1 May to 31 Oct) were maintained. According to the Baltic MAP, supplementary measures need to be applied when the stocks are in poor state. This implied that in the

Eastern Baltic Sea, a seasonal closure in SDs 25–26 was re-introduced for 2018. From 2019, it is restricted from 1 July to 31 July. There are exemptions in place for vessels <12 m.

A.5. Ecosystem aspects

Key controlling factors for Eastern Baltic cod recruitment have been identified to be:

i. Major inflows of saline and oxygen-rich water from the North Sea into the Baltic in combination with oxygen consumption in the Baltic (e.g. MacKenzie *et al.*, 1996; Köster *et al.*, 2005).
ii. Prey availability for first-feeding larvae, which is influenced by salinity and predation by sprat on zooplankton (Hinrichsen *et al.*, 2002; Möllmann *et al.*, 2005).

Second-order regulating factors were identified as (i) prey availability for adults affecting egg production (Kraus *et al.*, 2002); (ii) egg predation by sprat and herring, depending on salinity/oxygen and timing of spawning defining spatial and temporal overlap between predator and prey, respectively (Köster *et al.*, 2005; (iii) habitat availability for successful juvenile settlement (Hinrichsen *et al.*, 2003); and (iv) cannibalism on juveniles, depending on transport of juveniles, horizontal overlap with adults and abundance of alternative prey (e.g. Neuenfeldt and Köster, 2000; Uzars and Plikshs, 2000). A review of the ecosystem processes influencing Eastern Baltic cod recruitment can be found in Köster *et al.* (2017).

A number of changes in Eastern Baltic cod biology have been observed in later years, which include reduced nutritional condition of the fish, maturation at a smaller size and increased parasite infestation. Also, relative abundance of larger individuals in the population has sharply declined since 2012 (Eero *et al.*, 2015).

Nutritional condition of adult cod has been continuously declining since the early 1990s. However, since the mid-2000s, the proportion of cod with a very low condition index rapidly increased (Eero *et al.*, 2012; Casini *et al.*, 2016). The decline in cod condition is evident in all offshore areas of the central Baltic. Hypothesized main reasons for deteriorating nutritional condition include:

(i) Low availability of fish prey in the main distribution area of cod, as sprat and herring are more northerly distributed with little overlap with cod (Eero *et al.*, 2012). (ii) Poor oxygen conditions that can affect cod growth directly via altering metabolism or via shortage of benthic prey (Casini *et al.*, 2016).

(iii) Increased infestation with parasites, which is related to increased abundance of grey seals (Mehrdana *et al.*, 2014; Howbowy *et al.*, 2016; Sokolova *et al.*, 2018).

Growth of the Eastern Baltic cod has declined, likely associated with the above mentioned ecological processes, and additionally in relation to reduced size at maturation. The same factors have presumably contributed to an increase in natural mortality of the Eastern Baltic cod.

B. Data

B.1. Separation of catches in SD 24 between cod stocks

Data on proportions of Eastern and Western Baltic cod in Danish catches in SD24 are available from 1996 onwards, though with several gaps in the time series. The methodology used to identify relative proportions of the two stocks in Danish commercial catches is described in Hüssy *et al.* (2016 a and b). Stock splitting proportions are calculated separately for sub-areas 1 and 2 (Figure B1), due to east-west gradient in stock mixing proportions (Hüssy *et al.*, 2016b). Since WKBALTCOD2 (2019), proportions of Eastern and Western Baltic cod are additionally available for German commercial catches in SD24 for some later years. Only data from Active gears are used. For the historical period (1977–1995), proportions of Eastern and Western cod are available from German historical survey (1977–1986), supplemented by stock proportions derived from BITS survey (1992–1995). These stock proportions from surveys use only the cod above 30cm in length.

For a combined time series of stock proportions, DK and DE stock mixing proportions were combined. For the years, where stock split from both countries was available (2005, 2010, 2015-2016), these were averaged, weighted by landings of DK and DE (Active gears), respectively. For years where data on stock proportion were not available, extrapolations (averages of adjacent years) were applied.

Separating total cod landings in SD24 to stocks

For each country, relative proportion of cod landings in sub-areas 1 and 2 within SD24 were derived from national data. For earlier years, where this information was not available, extrapolations of the landings distribution from more recent years were applied.

For DK, the landings in SD 24 from 1996 onwards were split using DK stock proportions, separately by sub-areas. For example, the Eastern Baltic cod landings in sub-area 1 in a given year (y) were derived:

$$Catch\_EB\_Area1_y = Catch\_SD24_y * Prop\_Catch\_Area1_y * Prop\_EBcod\_Area1_y$$

where Catch_SD24 is total DK cod catch in SD 24 in a given year; Prop_Catch_Area1 is the proportion of DK cod catch in Area1, and Prop_EBcod_Area1 is the proportion of Eastern Baltic cod in Area1.

For years and sub-areas, where stock proportions in DE commercial catch were available (2005, 2010, 2015-2016), these data were applied to distribute DE commercial catches from Active gear to stocks, in a similar way as for DK data.

To distribute the cod landings between stocks in other years and for other countries (OTHER), first the combined proportion of international landings in sub-areas 1 and 2 was derived. This was calculated as an average for DK, DE, SWE and POL, weighted by the total landings of these countries in SD24. Combined stock proportions (using both DK and DE data on stock proportions) were applied, separately by sub-areas.

These steps resulted in stock specific landings for DK, DE and OTHER, by sub-areas 1 and 2, which where summed up to obtain total landings of Eastern and Western Baltic cod in SD 24.

For Eastern Baltic cod assessment, the split of landings in SD24 to stocks was extended further back to 1965. This was done applying average proportions of landings in sub-areas 1 and 2, and average stock mixing proportions from 1977-1979.

Separating total cod discards in SD24 to stocks

Cod discards in SD 24 are allocated to stocks from 1994 onwards. The total estimated discards in tons in SD24 were allocated to stocks using annual average stock mixing proportions. These were derived from averaging stock splitting keys in sub-areas 1 and 2, weighted by proportion of landings in these subareas, by years. The resulting proportions of Eastern and Western Baltic cod in SD 24 were multiplied with total cod discards in SD24, to obtain discards for both stocks in SD 24.

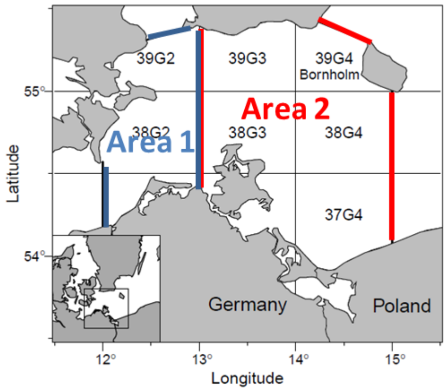

Figure B1. Map of SD 24 (mixing area of western and eastern cod) and subareas (Area1 and Area 2) for which separate mixing proportions were estimated.

B.2.Commercial catch

Landings

Data are nationally aggregated to quarter, subdivision and gear type (active, passive). Misreporting has been a significant problem from 1993–1996 and 2000–2006 and the reported catches have been increased by 35–40% (based on information from WG experts). Catch misreporting, mostly in the form of unreported landings, resulted from a combination of restrictive quotas, the absence of other fishing opportunities, and inadequate inspection. Since 2010, misreporting is not considered a major issue and no correction to reported landings are applied.

Discards

Information about discard data is available from internationally coordinated sampling since 1996 and is available in InterCatch since 2000. The discard in numbers by age for years prior to 1996 have been estimated assuming fixed discarding rates at-age based on the mean values for the period 1996 to 2001.

Discards are sampled by observers on board commercial fishing vessels. The selection of vessels/trips to sample has in the beginning of the time series been mostly opportunistic/ad hoc. Since 2010 there has been substantial work undertaken within ICES (ICES WKMERGE, SGPIDS, WKPICS, WGCATCH) to improve the design of sampling programmes and implement statistically sound sampling schemes with a random selection of vessels/trips. This has led to big improvements in recent years with most countries selecting samples randomly, documenting sampling designs, recording refusal rates, etc., but the work is still ongoing. All EU-countries sampling in the Eastern Baltic reported using random draw lists of vessels for selection of trips sampled at sea in 2017 (Work Plan 2017-2019) but since the sampling often suffers from various practical difficulties, such as refusals to take observers, vessels landing abroad, etc., it is likely that some ad-hoc sampling still occurs.

The sampling is conducted by haul and the weight of each catch fraction is recorded by the observers. In addition, the discard fraction is subsampled for biological parameters (length, age, individual weight). The exact discard estimation procedure can vary between countries since countries may have slightly different designs for their sampling programmes. Generally the discards observed in sampled trips are raised to fleet level with some auxiliary raising variable (for example landings of target species, landings of all species, effort).

Since not all reporting "strata" (country/subdivision/fleet/quarter) have a submitted discard estimate and/or a length distribution, some imputations have been made. The imputations of missing discards and length distributions have been carried out using the built-in "discard raising" and "allocation" modules in InterCatch. For active gears, as far as possible all countries submitted discard rates within one area, quarter and fleet have been combined to impute the missing values. For passive gears, which are often poorly sampled, a larger pool of strata have been used for imputations. Active and passive gears have always been kept separate in the imputation process.

Since not all countries have provided number of samples in the submitted data, and when it has been provided the sampling unit is often not stated, it is not possible to properly assess the overall discard sampling intensity. Data provided to the Regional Data Base show a decreasing trend of sampled trips since 2009 (the earliest year available in the RDB), especially for active gears for which the number of sampled trips in 2017 was reduced by almost 50% compared to 2009. However, it is important to note that this information does not reflect actual sample size, since that is depending on the national sampling designs (stratifications, sampling units, any extrapolations in national data, etc.) and should be assessed on the level of sampling. The total number of sampled trips can therefore only be considered indicative and as part of a larger pattern.

The proportion of landings covered by a discard estimate in the submitted data increased from around 35% in 2000 to almost 90% in 2014, only to decease again after the introduction of the landing obligation in 2015. In 2017 only 57% of the landings had an associated discard estimate in the uploaded data for the same country/fleet/quarter/area. This means that a larger part of the discards have to be imputed after national data submissions based on assumptions, implying even larger uncertainties in the final discard estimate. However, this information does not reveal anything about the quality of the submitted discard estimates, but only that discards are submitted. In theory, a stratum with very large landings could be sampled by only one trip. Therefore the information of discard coverage should be considered merely qualitative.

Discards and BMS landings

Since 2015, there is a landing obligation in place for cod in the Baltic Sea. As a consequence, all cod regardless of size should be landed and counted against the quota. Cod < MCRS (Minimum Conservation Reference Size) should be landed and registered separately as BMS (Below Minimum Size). The BMS landings have been very low, indicating that a large part of the BMS fraction is not landed. Most countries still carry out at-sea sampling and discards are still observed on board.

National total landings, discard and, since 2015, BMS landings are submitted to InterCatch to be compiled by the stock coordinator. In addition to catch in weight, estimated numbers at length and mean weight at length are also submitted. Data are provided by country, fleet (Active and passive gears), subdivision and quarter.

Since 2016, InterCatch provides two different options for uploading discards and BMS landings:

1) Discards and BMS are uploaded separately.

2) BMS landings are included in the discard estimate and are only submitted as "Official landings" to InterCatch (The "Official landings" field is merely informative and is not included in the catch estimate when data are extracted). This option can be used when discards and BMS are not separated in the estimation process, for example when an observer effect on the discard pattern is suspected. In this case the estimate provided as discards is actually an estimate of "unwanted catch" and includes all cod that was not landed for human consumption.

When the second option is used, the BMS landings reported as "Official landings" have to be subtracted from the "discards" in order to assess the actual discards. (However, this cannot be done for the length distributions of respective fraction).

Since discards are highly variable between trips and vessels, and the sampling coverage of the fishery is generally low, the estimates are uncertain. The introduction of the landing obligation in 2015 has also introduced further difficulties in sampling and estimation. However, considering the fact that almost all countries still report discards being observed on board, and the very low amount of reported BMS landings, it is clear that discarding still occurs after the introduction of the landing obligation. A comparison of the estimates with "Last haul" data from the European Fisheries Control Agency for some countries suggests that the estimated amount is reasonable.

B.3. Biological information

Age and length composition of commercial catch

Age composition of catches is included in the assessment only until year 2006 (effectively until 1999 as the age composition of catches for 2000-2006 is set to not contribute to the model likelihood and are treated as "ghost fleet" by Stock Synthesis). Age compositions for later years are not included due to increased discrepancies between different countries' age readings, which were identified to have occurred after 2007. Data on length compositions of catches in SD 25-32 are available from year 2000 onwards, by Active and Passive fleet and by Quarter. The national data are uploaded in Intercatch database (IC). The landings that have not been specified in IC as from active or passive fleets were all allocated to Active. The Eastern Baltic cod catches in SD 24 are assumed to have the same length distribution as in SD 25.

Growth information

Annual age- length-keys (ALK) are used in the assessment model from 1991 onwards to inform the estimated yearly deviations in Von Bertalanffy growth parameters. The ALKs are based on age readings from BITS surveys, available in DATRAS. Both the ALKs from Q1 and Q4 are included.

Age information from otolith age readings is considered uncertain, especially for later years. Nevertheless, WKBALTCOD2 (2019) concluded the ALKs used to provide a reasonable proxy for estimating changes in growth for the following reasons:

i. The estimated change in growth is in line with expected changes in growth due to observed changes in biology of the stock and environmental conditions, as well as with preliminary growth information from a recent tagging program.

ii. It is recognized that the exact values for Von Bertalanffy growth parameters estimated in the stock assessment are uncertain due to imprecise age information. This is affecting also natural mortality estimates, as growth and M are confounded. However, the results of the stock assessment in terms of stock status were found to be robust to the uncertainties associated with separating between M and growth (see ICES WKBALTCOD2 2019 for further details).

For these reasons, the ALKs presently used in the stock assessment are considered to provide a reasonable proxy for informing growth changes for stock assessment purposes. This is considered a temporary solution, until an alternative method for estimating growth becomes available (e.g. otolith microchemistry).

Natural mortality

Natural mortality is assumed to be age dependent and it was estimated using methods described in Then *et al.* (2015) and Lorenzen (1996) for the historical period (1946-1999). Then *et al.* (2015) estimation of M is based on maximum age (*tmax*) and parameters of the von Bertalanffy growth curve. The Lorenzen type (Lorenzen 1996) of M-at-age function assumes a declining relationship between M and the mean weight of fish in successively older age classes. Natural mortality used in the assessment is assumed to be equal to the average of the two methods (*tmax* and *growth*) scaled using Lorenzen (1996).

Maturity

The input for maturity is L_{50} (length at 50% mature) and the slope of the maturity ogive curve. These are estimated from BITS Q1 data, for females and males combined. L_{50} of the Eastern Baltic cod has substantially declined over time. The change in L_{50} estimated from BITS Q1 was validated with data from German CoBalt survey (WKBALTCOD2 2019), conducted closer to the spawning time. These results confirmed the decline in L_{50}.

B.4. Surveys

Stock abundance indices are available from Baltic International Trawl Surveys (BITS) conducted in 1st and 4th quarters of the year. The survey has been internationally coordinated since 2001, when major standardisations in the survey and gear design were introduced. Prior to this year, all research vessels used different trawls. The survey time series are standardized to account for these changes over time (WKBALTCOD2 2019). Additionally, ichthyoplankton surveys are used, to provide a time series of larval abundances and an estimate of SSB trends from annual egg production method, which are used as input to stock assessment. Several historical CPUE time-series are additionally used. An overview of all indices included in the assessment is given in the table below:

Fleet name	Years	Description
#BITSQ1	1991-onwards	Baltic International Bottom Trawl Survey, Q1, data for SD 25-32, including the area east of 13 degrees latitude in SD 24. Modelled indices of total abundance. Method for survey modelling is described in WD2_EBC of ICES WKBALTCOD2 2019.
#BITSQ4	1993-onwards	Baltic International Bottom Trawl Survey, Q4, data for SD 25-32, including the area east of 13 degrees latitude in SD 24. Modelled indices of total abundance. Method for survey modelling is described in WD2_EBC of ICES WKBALTCOD2 2019.
#TrawlSurvey1	1975-1992	CPUE (kg*h–1) by German RV Solea in SD 25 (Thurow and Weber, 1992)
#TrawlSurvey2	1978-1990	CPUE (g/hour) from bottom trawl surveys by the Swedish Board of Fisheries and Baltic Fisheries Research institute (BaltNIIRH), SDs 25–28, yearly average. The index refers to total cpue in biomass of all length groups caught in the survey (Orio *et al*., 2017).
#CommCpue1	1948-1956	Commercial CPUE (kg/h) of former USSR , February–June (Dementjeva, 1959)
#CommCpue2	1957-1964	Commercial CPUE (kg/h) of former USSR in Gdansk area, February-June (Birjukov, 1970)
#CommCpue3	1954-1989	Commercial CPUE (kg/day) of USSR (Latvian republic), SDs 26-28, annual average (Lablaika *et al.* 1991)
#SSBEggProd	1986-onwards	SSB indices based on annual egg production method. Used in SS model to represent spawning stock biomass trends (survey type 30 in SS). Data from ichthyoplankton surveys. Calculation of SSB indices described in WD3_EBC of ICES WKBALTCOD2 2019.
#Larvae	1987-onwards	Abundance of larvae during peak spawning, used in SS as pre-recruit survey (survey type 32). Data from ichthyoplankton surveys. Calculation of the index is described in WD4_EBC of ICES WKBALTCOD2 2019.

C. Assessment method and settings

Assessment of the Eastern Baltic cod (SD24-32) was conducted using the Stock Synthesis (SS) model (Methot and Wetzel, 2013). Stock Synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. The assessment was conducted using the 3.30 version of the Stock Synthesis software under the windows platform.

The Stock Synthesis model of Eastern Baltic cod is a one area quarterly model where the population is comprised of 15+ age-classes with both sexes combined. The model is a length based model where the numbers at length in the fisheries and survey data are converted into ages using the von Bertalanffy growth function. The model is run in quarterly steps to account for the growth of individual cod throughout the year.

Spawning stock and recruitment

Spawning stock biomass is estimated at spawning time (month 5 is used as an average for the time period). Sex ratio is set to 50% females and males. Recruitment was derived from a Beverton and Holt (BH) stock recruitment relationship (SRR) and variation in recruitment was estimated as deviations from the SRR, for years for which age and length compositions are available. Settlement time for recruitment is set to month 8 as an average for the time period.

Growth and weights

Growth parameters were fixed for the period 1946-1990, at values estimated using historical tagging data. The tagging estimates covered the period 1955-1970 (L_{inf} = 125.27, k= 0.10). Deviations in both L_{inf} and *k* are estimated from 1991 onwards, using age-length keys from BITS surveys. Age-Length Key (ALK) therefore is used to inform the estimation of growth deviations from 1991 onwards. Numbers of fish in ALK are used as sample size for each year. The variance in length-at-age was fixed for older fish and estimated for younger individuals. Length at minimum age (Amin) was first estimated in Stock Synthesis model, and then fixed at the estimated values.

The parameters *a* and *b* in length-weight relationships are estimated from Q1 BITS survey, pooled for SD 25-32. The parameters were estimated for each year, after which the data were averaged by 3-year blocks, to be used as input in the model.

Natural mortality

Natural mortality at age is kept constant for 1946-1999. Age break points 0.5, 1.5, 5.5 and 15.5 are used. Natural mortality from 2000 onwards for age break 5.5 is estimated within the model as annual deviations from the historical values. For the other age-breaks, M is kept constant for the entire time series.

Maturity

The input for maturity is L_{50} (length at 50% mature) and the slope of the maturity ogive curve. L_{50} of Eastern Baltic cod has substantially declined over time, which is captured in the model by using time blocks (Table C1). For the slope, a constant value is used for the entire time period.

Selectivity

Fishery selectivity is assumed to be length-specific and time-invariant. For both the trawlers (i.e. active gears) and the gillnetters (i.e. passive gears) selectivity was estimated assuming a logistic function that constrains the older age classes to be fully selected ("flat top"). A logistic selectivity was also used for BITS surveys (both quarter 1 and quarter 4). Selectivity of Trawlsurveys 1 and 2 was assumed to mirror selectivity of BITS Q1 survey, while selectivity for commercial CPUE1, 2 and 3 was assumed to mirror selectivity of the active gears.

Samples sizes, CVs, data weighting

The CV of catch was set to 0.05 for all years. No meaningful information is available on the annual sample size associated with age or length distribution data for commercial catches. Therefore, in Stock Synthesis, the same value (100) is applied for each quarter and fleet in all years.

The average CV of the BITS survey indices was assumed to be equal to 0.15 while the yearly deviation of the coefficient of variation of the BITS survey indices was estimated as part of the modelling of the survey indices. Numbers of hauls in BITS in each year were used as input for sample size in Stock Synthesis.

For the remaining surveys and CPUE indices, the CV was estimated internally for the reference model, except for the larvae index, for which the CV was set to 0.3. The weighting method used for the size-composition data followed the advice of Francis (2011) (Method TA1.8). For weighting the conditional age-at-length data we used the Francis-B approach described in Punt (2017). Iterative application of model fitting and reweighting occurred three times to explore the effects on successive estimates of the data weighting coefficient for each composition dataset. Weights from the second iteration were used for the results reported here because this iteration resulted in the smallest gradient for the objective function among the three iterations of the model. The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix, which was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

Table C1. Input data used in Stock Synthesis model.

Type	Name	Year range	Range	Time variant
Catches	Catch in tonnes split into Active/Passive and quarters	1946- onwards	0 - 15+	
Age compositions	Catch in numbers per age class of the fleets, by Q	1946- 2006	0 - 12+	
Length compositions	Catch in numbers per lenght class of the fleets, by Q, and BITS Q1 and Q4	2000- onwards	5 – 120 cm	
Maturity ogives	Size at 50%maturity(L50) and slope	1946-onwards		Yes (1998-onwards, Lmat)
Growth	Von Bertalanffy growth curve	1946-onwards		Yes (1991-onwards)
Natural mortality	Natural mortality by age class	1946- onwards	0 - 15+	Yes (2000-onwards)
Age length compositions	Age length keys from BITS Q1 and Q4	1991- onwards	0 – 12+	Yes (1991-onwards)
Surveys indices	CPUE from BITS Q1, Q4, and trawl surveys 1 and 2	1975- onwards		
Commercial CPUE indices	Commercial CPUEs 1-3	1948-1989		
SSB index	SSB from egg production method	1986- onwards		
Larval index	Larval abundance	1987- onwards		

Table C2. Settings of the Stock Synthesis assessment mode. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, the priors used. Parameters in bold are set and not estimated by the model.

Parameter	**Number estimated**	**Initial value**	**Bounds (low,high)**	**Prior**
Natural mortality (age classes 0.5, 1.5, 5.5, 15.5)		1.243, 0.857, 0.361, 0.215		
M (2000-2018) of age class 5.5	19	Estimated using random walk annual deviations	(0.1,2.0)	no prior
Stock and recruitment				
Ln(R_0)	1	14.8	(13,16)	no prior
Steepness (h)		0.99		
Recruitment variability (σ_R)		0.60		
Ln (Recruitment deviation): 1946-2016	71			
Recruitment autocorrelation		0		
Growth				
L_{inf} (cm) (1946-1990)		125.27		
L_{inf} (cm) (1991-2018)	28	Estimated using random walk annual deviations	(40-150)	no prior
k (1946-1990)		0.10		
k (1991-2018)	28	Estimated using random walk annual deviations	(0.07-0.45)	no prior
L at minimum age (0.5 years) t_0		12		
CV of young individuals	1	0.290	(0.05-0.8)	no prior
CV of old individuals		0.05		
Weight (kg) at length (cm)				
a (1946-1990)		6.58e-06		
b (1946-1990)		3.1353		

a (1991-1993, 1994- 1996, 1997- 1999, 2000 -2002, 2003-2005, 2006-2008, 2009-2011, 2012-2014, 2015-2018)		6.58E-06, 8.05E-06, 6.81E-06, 6.78E-06 6.76E-06, 7.47E-06 6.70E-06, 7.73E-06 8.90E-06		
b (1991-1993, 1994- 1996, 1997- 1999, 2000 -2002, 2003-2005, 2006-2008, 2009-2011, 2012-2014, 2015-2018)		3.1353, 3.0636, 3.1062 3.0992, 3.0972, 3.0637 3.0831, 3.0406, 3.0063		
Maturity				
Length (cm) at 50% mature (1946-1990)		38		
Slope of the length at maturity ogive		-0.23		
Length (cm) at 50% mature (1991-1997, 1998-2000, 2001-2007, 2008-2014, 2015-2018)		38, 36, 31, 26, 21		
Initial fishing mortality				
Active gears		0.60		
Selectivity (logistic)				
Active gears				
Time-invariant length based logistic selectivity	2	35; 12.68	(20,45; 0.01,50)	no prior
Passive gears				
Time-invariant length based logistic selectivity	2	35; 10	(20,65; -12,15)	no prior
BITS Q1 survey				
Time-invariant length based logistic selectivity	2	25,10	(15,50; -12,15)	no prior
BITS Q4 survey				
Time-invariant length based logistic selectivity	2	25,10	(15,50; -12,15)	no prior
Commercial CPUEs 1-3		Mirror active fleet		
Trawl surveys 1-2		Mirror BITS Q1		
Catchability				

BITSQ1				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation		0.01		
BITSQ4				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation		0.01		
Trawl survey 1				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,0.8)	no prior
Trawl survey 2				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,0.8)	no prior
Commercial CPUE 1				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,0.8)	no prior
Commercial CPUE 2				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,0.8)	no prior
Commercial CPUE 3				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,0.8)	no prior
Egg biomass index				
Ln(Q) – catchability		Float option used		
Extra variability added to input standard deviation	1	0.1	(0.0,1.2)	no prior
Larvae index				

Ln(Q) – catchability	Float option used
Extra variability added to input standard deviation	0.3

D. Short-term projection

The short-term projections are made with Stock Synthesis. The assessment period is set to the last year of the survey, which is one year later than the last year for which catches are available. Therefore, to be able to use the latest survey information in the assessment, catches for that year need to be assumed (corresponds to the intermediate year in the forecast). It is to be decided at WGBFAS on an annual basis, what is the reasonable assumption for catches in this intermediate year. Recruitment in the forecast period was decided to be set to the average from 2013 until the last year in the assessment time series for which recruitment deviations are estimated in the Stock Synthesis model.

As there is no F reference point for this stock, probabilistic forecast with MCMC is used. In this approach, catch and SSB levels corresponding to different F factors are calculated as in typical deterministic short term forecast but using MCMC to make it possible to also include the associated probability/risk of the SSB to be below biomass reference points, for each year of forecast.

E. Medium-term projections

Not relevant

F. Long-term projections

Not relevant

G. Biological reference points

Biomass reference points

The biological characteristics of Eastern Baltic cod likely to influence its reproductive capacity have gradually deteriorated since the 1990s (Figure G1). Therefore, the reproductive capacity of a specified amount (tons) of SSB today (consisting of small individuals at poor condition) is likely not equal to the reproductive capacity of the same amount of SSB in the past. Consequently, the size of spawning stock (SSB) in tons alone is not considered representative of the reproductive capacity for the stock at present, as the quality of the SSB needs to be considered as well (see ICES WKBALTCOD2 2019 for further details).

WKBALTCOD2 (2019) concluded that B_{lim} should presently not be set lower than the most recent SSB that was still able to produce a strong year-class, when much of the adverse developments affecting the quality of the SSB had already taken place. The latest relatively strong year-class was formed in 2012 from an SSB of 98 000 t. Therefore, B_{lim} was set to this level, i.e. 98 000 t.

Due to the presently very dynamic biology of the Eastern Baltic cod, the current B_{lim} at 98 000 t is considered to be applicable only in the short term. The reproductive capacity of the stock needs to be regularly monitored.

B_{lim} at 98 000 t corresponds to B_{pa} at 124 000 t ($B_{lim} \times \exp(1.645 \times \sigma)$, where $\sigma=0.14$).

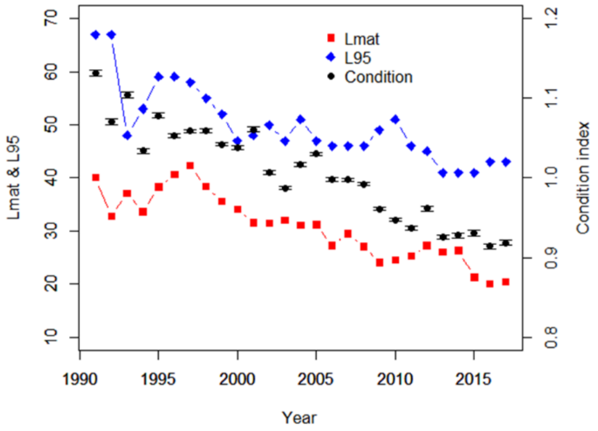

Figure G1. Changes in size at maturation (L_{mat}= L_{50}, in cm), size structure of the stock (L95- length at 95th percentile of the length distribution, in cm) and nutritional condition (Fulton K for 40-60 cm fish) of Eastern Baltic cod.

Estimation of F_{MSY}

The Eastern Baltic cod stock experiences large changes in productivity, which questions the applicability of the F_{MSY} concept, that assumes long-term equilibrium, for this stock. At WKBALTCOD2 2019, estimation of F_{MSY} was attempted using the ICES standard software Eqsim. The biology (weights, natural mortality, maturity) and selectivity were based on the latest years (2015-2018). For stock-recruitment, the hockey-stick function was applied, with a break point at B_{lim}.

The Eqsim analyses showed that even with F_{MSY} at 0 the SSB would not be kept above B_{lim} (98 000 t) in the long term, with 95% probability. For this reason, no F reference points were defined for this stock.

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