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Stock Annex – Western Baltic cod in subdivisions 22-24

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	cod in Subdivisions 22-24, Western Baltic stock
Last benchmarked:	IBPWEB, 2021
Working Group	Baltic Fisheries Assessment Working Group (WGBFAS)
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A. General

A.1 Stock definition

The distribution area of Western Baltic cod biological population is the ICES subdivisions 22-23 and partly SD 24. Subdivision 23, the Sound between Denmark and Sweden bordering Kattegat, was included in the Western Baltic stock in 1997.

Cod in the Baltic Sea has been managed as one stock until 2002. Since 2003, the management is based on two stock units, Western Baltic Cod (ICES SD 22 -24) and Eastern Baltic Cod (ICES SD 25 – 32). The individual cod was previously assigned to its stock of origin, Western or Eastern Baltic stock, only according to the area where they were caught and independently of its biological origin. There is evidence supporting the difference between the two populations, based on taggings (Berner, 1967; Bagge, 1969; Otterlind, 1985; Berner and Borrmann, 1985), phenotypic differences (Birjukov, 1969; Berner and Vaske, 1985; Müller, 2002) and genetics (Nielsen *et al.*, 2003; Nielsen *et al.*, 2005). However, the tagging programs also documented that Eastern and Western Baltic cod stocks co-occur in the Arkona Basin (SD 24) (Aro, 1989; Nielsen *et al.*, 2013). Also, qualitative evidence of occurrence of juvenile cod in the Bornholm Sea, that were spawned in the western Baltic Sea, is given by a study based on the microstructure analyses of otoliths (Oeberst and Böttcher, 1998). Different studies suggest that migration towards their natal areas takes place when the development of sexual maturity starts (Müller, 2002; Bleil and Oeberst, 2002).

Genetic analyses revealed that a large part of the cod found in SD 24 is genetically eastern Baltic cod (Eero *et al.*, 2014). This was confirmed by otolith shape analyses (ICES 2015a) and genetic analyses of both juveniles and adults from 2014 (Hemmer-Hansen *et al.*, 2019). The presence of eastern cod in SD 24 poses a number of challenges for fisheries management, related to potential depletion of one of the stocks fished in a mixed fishery.

WKSIBCA (ICES 2014) decided that splitting the assessment input data according to the proportions of eastern and western Baltic cod found in SD 24 would be appropriate. This was based on the assumption that, given the evidence available, the assignment of cod according the area of capture was obviously biased. The splitting approach was implemented at WKBALTCOD in 2015 and the assessment should be conducted for the biological population of the western Baltic cod (SD 22-23 plus a fraction of the cod found in SD 24), in contrast to previous assessments which had been conducted for a geographical area (SD 22-24). At the benchmark data evaluation meeting in 2018, it was decided to include a longer time-series. For the historical period (1977-1995), proportions of EB and WB cod were made available from German historical survey (1977-1986), supplemented by stock proportions derived from BITS survey (1992-1995). These stock proportions from surveys (BITS and German historic) use only the cod above 30cm in length. All recreational caught cod is considered to be of Western origin as study's has shown a much larger fraction of western Baltic cod in shallow waters were the main part of the recreational fishery is conducted.

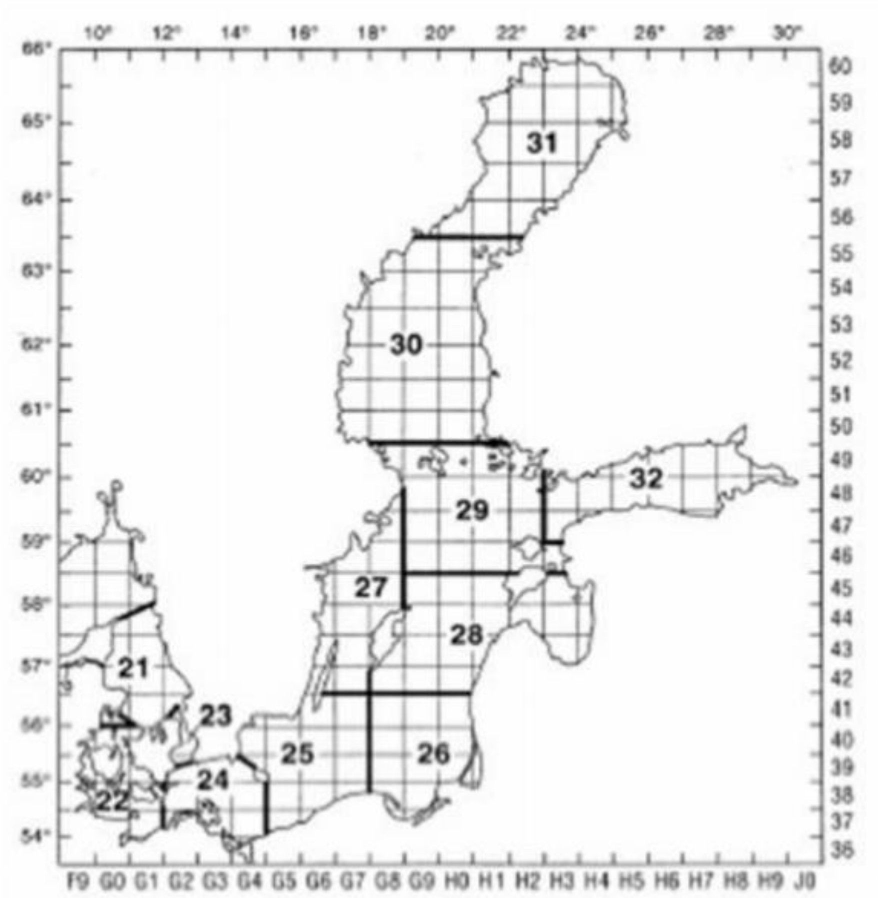

Figure 1. A1. Map of Subdivisions (SDs) in the Baltic Sea.

A.1.1 Spawning

The reproductive cycle starts at the end of October / beginning of November. The period until beginning of spawning takes about 4 months (Bleil and Oeberst, 1997).

Spawning areas of western Baltic cod are mostly in the deep, saline waters below 20–40 m, depending on area topography (Hüssy, 2011). The highly variable hydrodynamic conditions and the fact that cod eggs float in the water column cause their entrainment by currents, and their destination is determined by the prevailing winds and currents. Salinity limits the east–west exchange of eggs as a consequence of the stocks' differential salinity requirement for neutral buoyancy. Superimposed on this, water oxygen content and temperature have a significant effect on fertilization, egg/larva development, and survival (Hüssy, 2011). The analysis of environmental conditions allowing survival of western Baltic cod eggs indicates that favorable conditions predominantly occurred during the late spawning season in April/May. However, during the main spawning season in January to March, the suitability of the Arkona Basin for survival of this stocks' eggs is limited, owing to the low temperatures often prevailing at that time of the year (Köster *et al.*, 2017). Unsuitable time periods and habitats exhibiting the highest mortality rates are thus exclusively characterized by ambient water temperatures below the critical survival threshold. Despite the strong influence of water temperature on habitat suitability, the impact of habitat suitability on recruitment was not clearly defined, suggesting that other mechanisms regulate year class strength (Hüssy *et al.*, 2012).

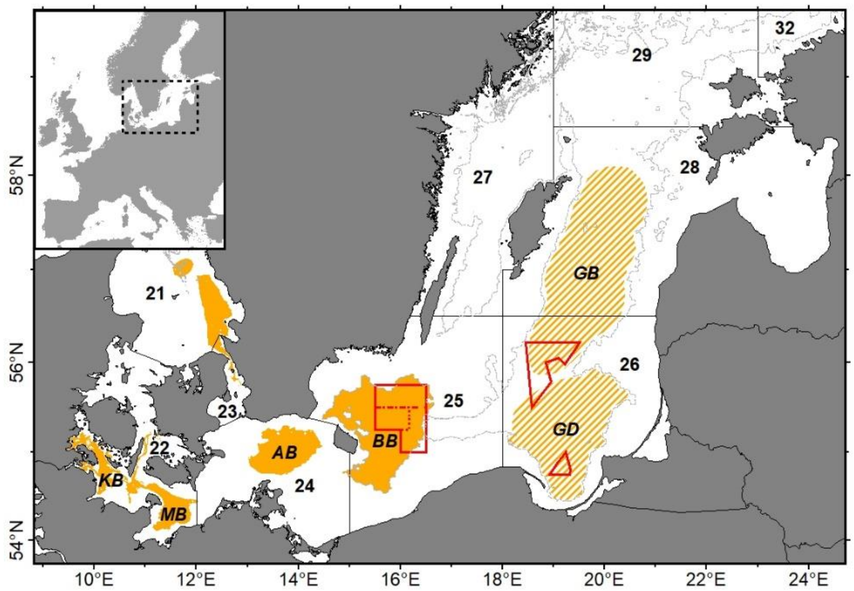

Figure 2. EB and WB Cod spawning areas (filled areas on the map) in the Baltic Sea in the Sound (23), Kiel Bay (KB), Mecklenburg Bay (MB), Arkona Basin (AB) and Bornholm Basin (BB); the shaded areas in Gdansk Deep (GD) and Gotland Basin (GB) indicate spawning areas that presently have limited spawning.

A.2 Commercial and recreational fishery

The Western Baltic cod stock has experienced large fluctuations in the landings over time. In the mid-1980s, landings were close to 50 000 t in the western Baltic management area decreasing to below 4000 t in later years. Cod catches in the Western Baltic are taken mainly by trawlers, gillnetters and, to a smaller degree, Danish Seiners in Sub-divisions 22 and 24.

In 1932 a trawling ban was implemented in Subdivision 23 (The Sound), due to the heavy shipping activity. Catches in SD 22-24 are predominantly Danish, German and Swedish, with smaller amounts occasionally reported by other Baltic coastal countries.

Discarding in the western Baltic management areas is estimated from observer programs in Denmark, Sweden and Germany. For the Western Baltic cod discard data have been included in the assessment since 2002. For a long period of time the discards of cod in the Baltic were considered relatively low compared to other areas. The average discard rate in the western Baltic cod stock was 6% (for the last 10 years (2010-2020) (ICES 2021).

Recreational cod catches are mainly taken by private and charter boats and to a smaller degree by land-based fishing methods. Rod-and-line fishing with artificial lures or live bait is the primary fishing method targeting cod (Weltersbach *et al.*, 2019). Cod angling takes place throughout the year in Baltic waters. A minority of catches are taken by recreational passive gear fishers. In the last 10 years (2010-2020) recreational catches has amounted to close to 30% of the total catches.

A.2.1 Fishery regulations

The Western Baltic cod is presently regulated according to the multiannual management plan for the Baltic (2016/1139). Besides the TAC regulation, historically the western Baltic cod has also been regulated by fishing effort; according to the former management plan (Council Regulation (EC) No 1098/2007) Besides effort and TAC regulations, seasonal area closures have also been used as a management tool. These seasonal closures have changed over time and are shown in Table 1

Year	Area (SD)	Time period	restricted distance from coast	Regulation	Baglimits (recreational fishery)	restricted depth
2016	22-24	15.02.-31.03. 1.5 months		2015/2072 17. Nov. 2015	No bag limit	
2017	22-24	01.02.-31.03. 2 months		2016/1903 28. Oct. 2016	5 cod/day 3 cod/day (1/2-31/3)	
2018	22-24	01.02.-31.03. 2 months		2017/1970 27. Oct. 2017	5 cod/day 3 cod/day (1/2-31/3)	
2019	22-24	No clouser		2018/1628 30. Oct. 2018	7 cod/day	
2020	22-23	01.02.-31.03. 2 months		2019/1838 30. Oct. 2019	5 cod / day in time period 01.02-31.03 2 cod / day	not deeper 20 m
	24	entire year 12 months	not further than 6 nm		5 cod / day in time period 01.02-31.03 2 cod / day	not deeper 20 m
2021	22-23	01.02.-31.03. 2 months		2020/1579 29. Oct. 2020	5 cod / day in time period 01.02-31.03 2 cod / day	
	24	entire year 12 months	not further than 6 nm			not deeper 20 m

Table 1. Seasonal closures affecting WBC. Modified after Eero *et al.*, 2019.

A BACOMA codend with a 120-mm mesh was introduced by IBSFC in 2002 in parallel to an increase in diamond mesh size to 130 mm in traditional codends. 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. There is no clear evidence of a difference in the selectivity between the two gears. Implementation of the BACOMA window in Estonia, Lithuania and Poland was made in May 2004. In 2010 the BACOMA 120 mm was re-introduced in the Western Baltic, and in 2018, T90 115 mm was introduced (Figure 2).

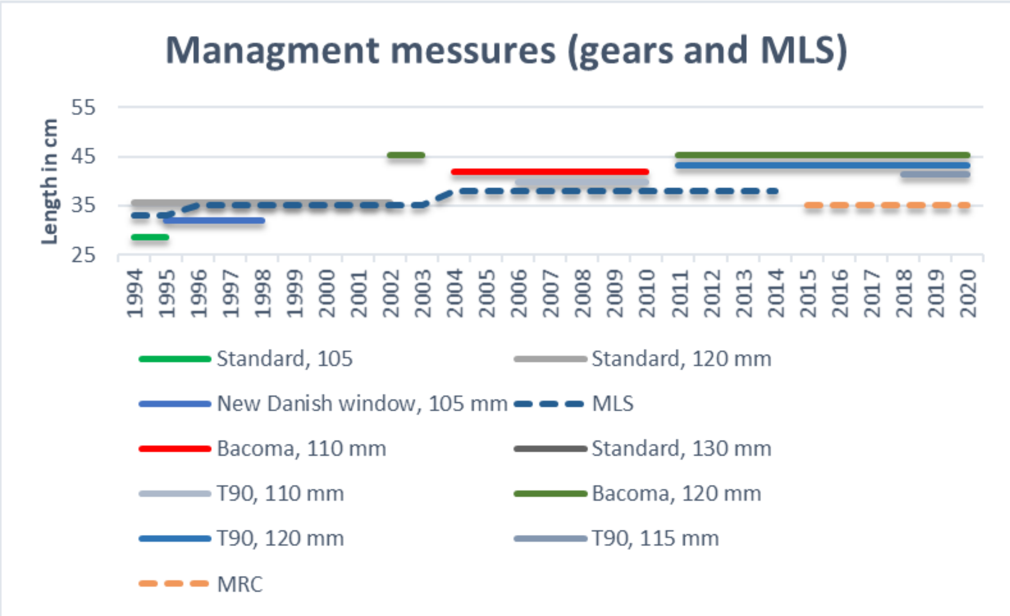

Figure 3. Different management regulation in the time from 1994 to 2020. Figure is modified from Valentinsson *et al.*, 2019.

In 2009 Denmark and Sweden agreed on a cod fishing ban in the northern part of the Sound in February and March. The minimum landings size (MLS) regulation applies only to the commercial fishery, however most recreational MLS follow the commercial regulation (but for example Germany has 35 cm as minimum landing size in the state of Mecklenburg-Western Pomerania and 38 cm in Schleswig-Holstein in the recreational fishery).

In Germany, the recreational fishing is under the jurisdiction of the federal states. Although recreational fishing licenses (does not distinguish between freshwater or saltwater fishing) are obligatory for fishing in the Baltic Sea, only the state of Mecklenburg-Western Pomerania (MV) demands a coastal fishing permit for the Baltic Sea allowing the estimation of anglers There are no seasonal or spatial closures regulating the marine recreational fishery for cod. The legal minimum landing size (MLS) for cod varies between countries and federal states and is 35 cm respectively 38 cm (in Germany). In Denmark recreational fishers require annual/ weekly or daily fishing licenses. In 2017, a bag limit was introduced limiting recreational cod harvest in Denmark, Germany and Sweden to 3 cod per day/angler during the closed season (February to March) and 5 cod per day/angler for the rest of the year. In 2019 the bag limit was raised to 7 cod per day/angler for the entire year.

Since 2015, a discard ban is in place, obliging the fisheries to land the entire catch of cod, with a “conservation reference size” of ≥35 cm (for commercial use) and a “Below minimum landing size” (BMS) of <35 cm.

A.2.2 Changes in fleet dynamics

Historically around half (but in some years up to 80%) of the total cod landings have been caught in the first quarter of the year, 2nd and 3rd quarter only accounting for 25% of the total landings. Furthermore, a very large part of the trips from which cod is landed have more than 30% cod in the landings compared to the total catch weight. This indicates that cod in the Western Baltic is mainly fished in a directed cod fishery and to a lesser degree caught as by-catch in other fisheries. Small vessels are important in the Western Baltic area, e.g. more than 60% of the Danish fleet operating in the Western Baltic are below 15 meters. Subdivision 22 is mainly fished in 1st quarter indicating a direct spawning fishery, while SD 24 is also fished for cod in the rest of the year. This changed in 2020 with a reduced quota and no directed cod fishery in SD 24.

A.2.3 Effort

Effort limitations for the Baltic Sea cod fisheries were included in the 2006 TAC regulation (EC No. 52/2006). The intention was to reduce the allowed days at sea by 10% each year until the cod stocks were within safe biological limits. Effort was primarily limited by seasons closed for fishery. The main closed season was included in the regulation but member states (MS) were also given a number of days of closure to implement when suitable in the national fisheries. For Western Baltic cod, fisheries were prohibited between 15 March to 14 May with an additional 30 days of closure to be allocated individually by the Member States (MS). In 2007 three closed seasons 1 to 7 January, 31 March to 1 May and 31 December were included in the TAC regulation (EC No. 1941/2006) and MS were given an extra 77 days to allocate individually. In 2008 the management plan for the Baltic Sea cod (EC No. 1098/2007) was introduced and the effort limitation scheme changed. The closed season in the western Baltic was restricted from 1 April to 30 April. Rules for how the number of allowed fishing days changed from year to year were coupled to fishing mortality and the F targets in the management plan. Since 2016, when the EU MAP (2016/1139) was implemented, the effort regulation has been terminated.

A.2.4 National regulations

In 2009 a fishing ban from 1/2 -31/3 was implemented in the Northern part of SD 23 (The Sound) to protect the Kattegat cod, by reducing F. As a consequence, the large cod catches in "Kilen" (SD 23) have been reduced in the 1st quarter accompanied by a 50% decrease in total catches in SD 23 compared to the time period 2002-2008, before the closure.

On 1 January 2007 a new individual right-based regulation system was introduced in Denmark. Before this time quotas were split into 14-days rations, which were continuously adjusted to the amount of quota left, particularly around the end of the year. In 2007 this system was changed to a rather complex rights-based system (FKA - Vessel Quota Share), whereby fishers are allocated a yearly share of the quota, and can subsequently trade it, exchange it or pool it with other fishers. They are still subject to usual EU-regulations such as closed seasons and fishing days.

A.3 Ecosystem aspects

Hydrodynamic conditions within the western Baltic Sea are extremely variable, particularly in the narrow Belt Sea, the Sound, and the Fehmarn Belt, through which all water passes in and out of the Baltic Sea (Matthäus and Franck, 1992; Schinke and Matthäus, 1998). The hydrography of the Arkona Basin resembles the conditions in the Bornholm Basin more than those of the Danish Straights and the Belt Sea in SD 22 (Matthäus and Franck, 1992; Lass and Mohrholz, 2003), with pronounced thermohaline stratification and stagnation in the deepest areas of the basin. Spawning areas of western Baltic cod are in the deep, saline waters below 20 m, depending on area topography (Hüssy, 2011).

B. Data

B.1 Stock separation in SD 24

Stock splitting is based on otolith shape in combination with genetics or spawning cod sampled during the respective spawning time in SD 22 or SD 25. In recent years otolith shape analysis has developed into a useful tool for stock identification purposes (Campana and Cassleman, 1993; Bolles and Begg, 2000; Cardinale *et al.*, 2004; Mérigot *et al.*, 2007). Stock-specific otolith shape description based on Elliptic Fourier Analysis provides a means for classifying individuals caught in a mixed-stock area to their respective natal stocks. For Baltic cod, this approach has been documented as a potential tool to separate individuals belonging to the eastern and western stock (Paul et al., 2013). This approach has been further developed and tested using genetically validated Baltic cod (Hemmer *et al.*, 2019) (Figure 5).

Stock splitting proportions are calculated separately for subareas 1 and 2 (Figure 4), due to an east-west gradient in stock mixing proportions (Hüssy *et al.*, 2016b). Three different approaches are currently used for stock splitting in SD24, all based on otolith shape analyses combined with genetics and spawning individuals.

Systematic differences in the proportion of mixing were found by sub-areas within SD 24, with a higher proportion of eastern cod closer to SD 25. The proportions of mixing in the easternmost rectangles in SD 24 and those in the middle of SD 24 were relatively similar (covering the Arkona basin). Thus, the proportions of eastern and western cod in SD 24 were estimated separately for 2 sub-areas, marked as Area 1 (Darss sill and entrance of SD 23) and Area 2 (Arkona basin) in Figure 4.

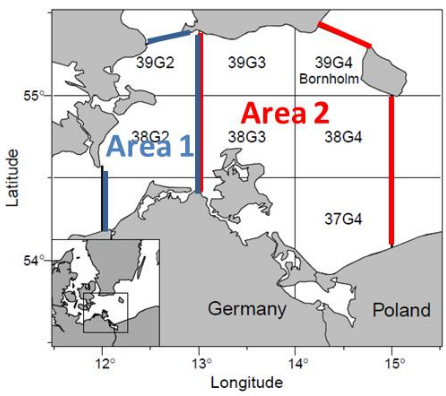

Figure 4. Map of SD 24 (mixing area of western and eastern cod) and sub areas (Area1 and Area 2) for which separate mixing proportions are estimated.

Method 1

This method has been used since the last benchmark in 2015. The methodology used to identify relative proportions of EB and WB cod in Danish commercial catches in 1996-2017 is described in Hüssy *et al*. (2016 a and b). The stock splitting proportions in Danish commercial data are available from 1996 onwards, however with several years of gaps in the time-series, 12 out of 22 years (1996-2017) (Figure 5). The baseline samples used in these analyses include both genetically validated fish, and fish for which stock origin was defined based on spawning activity at the time and in the area exclusive of either eastern or western cod.

Method 2

At the benchmark data evaluation meeting in October 2018, the Thünen Institute (DE) presented an alternative stock splitting approach using a balanced and genetically validated otolith baseline with a good spatial coverage in SD 24 and adjacent areas, which enables the individual assignment of unknown cod otoliths to their stock of origin. This method was used to derive historical mixing proportions of WB and EB cod from samples, originating from German trawl surveys (1977-1995) and German commercial catches (2005, 2010, 2015-2016, active gear only). For stock proportions from surveys, only cod above 30 cm in length were considered.

Method 3

At the benchmark meeting in 2019, a third method for splitting Danish catches to stocks was introduced, and selected to replace Method 1 in the future (from 2018 onwards). The new method is a single coherent statistical model correcting for the effects of fish length, season, and yearly environmental changes while estimating mixing proportions. The method is general and can include any covariate suspected to effect otolith shape. It is not limited to the currently included covariates. The present new method 3 uses maximum likelihood to estimate otolith shape, otolith shape effects and stock mixing proportions in a single coherent analysis. Consequently, confidence intervals incorporating directly all data sources are provided. At the benchmark meeting, evidence of different effects on otolith contour shape was presented, including effects of fish length, season, and year. For example, year effects could potentially also be associated with sampling design. Further, it was shown that ignoring these – or other important - effects will lead to incorrect mixing proportion estimates. The new method (3) has been tested through simulation studies, and the adequacy of model fit to data is validated by residuals.

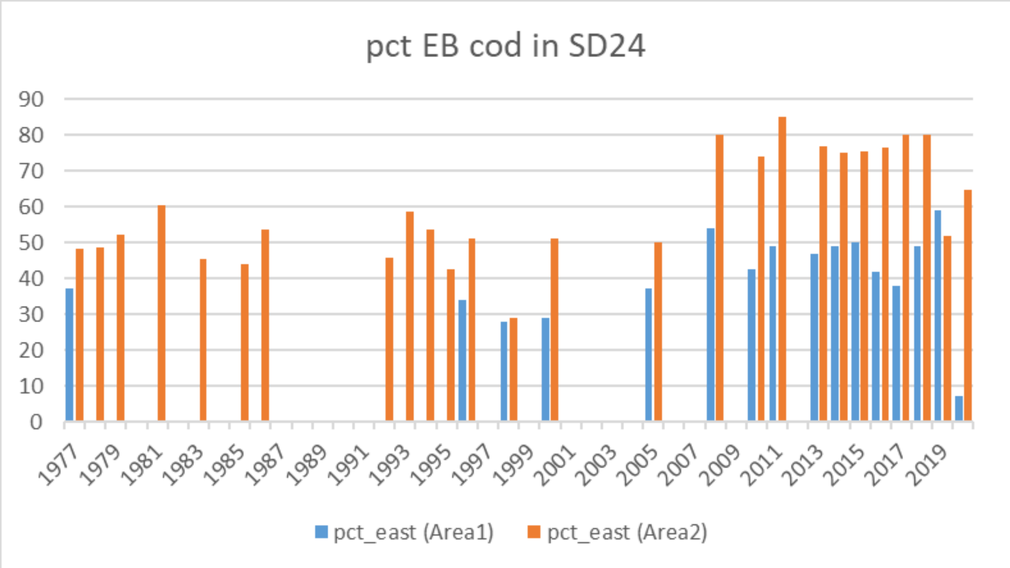

Figure 5. Proportion of EB cod in SD 24, by sub-areas.

B.2 Catch

Landings in tons by SD for 1985-2017 were obtained from WGBFAS reports. Total landings in SD 24 were adjusted to include only those representing the WB cod population. For each country, the 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. The weightings represented relative proportions of Danish, German, Swedish and Polish (main part of fisheries in SD 24) commercial cod landings taken in Areas 1 and 2. The landings in rectangles 39G2, 38G2 and 37G2 were used as representing Area 1 and landings in rectangles 39G3, 38G3, 37G3, 39G4, 38G4 and 37G4 were used as representing Area 2. The landings by rectangle from 2003 onwards were available from the STECF database (http://datacollection.jrc.ec.europa.eu/dd/effort/graphs). Danish landings by rectangle back to 1994 were derived from the national database. The relative distribution of German landings between Areas 1 and 2 from 1994-2002 was set to the average of that in the years 2003-2013. The total landings of Germany, Denmark, Poland and Sweden in SD 24 (derived from earlier ICES WGBFAS reports) were used as weighting factors to derive an average distribution of landings between Areas 1 and 2 separately by country for Denmark and Germany, and for the remaining countries, the information was combined. These average proportions of landings between Areas 1 and 2 were then used as weighting factors to derive an average splitting key for landings in SD 24 (from the two separate stock splitting keys for Areas 1 and 2).

B.2.1 Commercial landings

CANUM, WECA and CATON for landings at a national level are compiled by the national institutes. Data are in this stage nationally aggregated to quarter, subdivision and gear type (active and passive gear) even though the sampling in each country often is stratified on several fisheries (metiers). Not all landings strata have matching biological information (age from otoliths and length measurements) and biological information must therefore be extrapolated from other strata, e.g. Subdivisions or quarters. On the national level, data extrapolations of biological data for the strata where sampling is missing are only done in cases where biological information from other countries are not relevant. If biological information from other countries is relevant, only total landings in tonnes are given (i.e. no extrapolations are done nationally). The national data are submitted to InterCatch and the data coordinator compiles the data. The remaining extrapolations of age distributions and mean weight at age are made by applying the compiled data based on the countries that have performed sampling in the strata. All data extrapolations are recorded for later documentation (since 2012 in InterCatch).

Total landings in SD 24 were adjusted to include only those representing the WB cod population. To do this, weighted average of the proportions of WB cod in SD 24 in the 2 sub-areas (Area 1 and Area 2 in Fig. 1) was applied. The weightings represented relative proportions of Danish and German (main part of fisheries in SD 24) commercial cod landings taken in Areas 1 and 2, respectively. Landings at age for the entire western cod population (i.e. including landings in SD 24) were obtained by upscaling the landings at age in SD 22 by the ratio of landings of WB cod (SD 22+24) taken in SD 24. Landings at age in SD 23 were subsequently added, to get the landings at age of WB population for SD 22-24.

B.2.2 Discard in commercial fisheries

The amounts of cod discarded by the fishers are estimated based on data collected by scientific observers onboard commercial fishing vessels from 1996 onwards. All relevant biological information concerning discards is recorded by observers. Landing patterns have been compared from trips with and without observers onboard to see if there is an indication of changed behaviour when observers are on board.

The stratification is the same as for the landings and the discards are raised by the landings. In strata with landings but where no data on biological information exists on discards, data from other strata are used.

The following priorities were used when extrapolating the available biological information:

1) Same country, same quarter, adjacent Subdivision.
2) Same quarter, same Subdivision, another country.
3) Another country, same quarter, adjacent Subdivision

Cod discards in SD 24 are allocated to stocks from 1994 onwards, i.e. the time-series of stock assessment for WB cod in previous assessments (WGBFAS 2018). The total estimated discards in tons in SD24 in 1994-2017 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 proportion of EB and WB cod in SD 24 was multiplied with total cod discards in SD24, to obtain WB cod stock in SD 24.

Discards before 1996, when no discard data have been available, were extrapolated by an average discard ratio from the period 1999-2003 (Table 2).

Table 2. Overview of discard data used in the stock assessment.

Years	***A:*** SD 22-23 Tons	***B***: SD22-23 N@age	***C:*** SD24 Tons	***D:*** SD24 WBC Tons	***E:*** SD22-24 WBC N@age
2014-2017	From WGBFAS (IC)	From WGBFAS (IC)	From WGBFAS (IC)	***C*** multiplied by combined stock split key for SD 24	***B*** raised to account for tons in SD 24 (***D***)
2011-2013	Sumproduct of discards at age (***B***) and weight at age.	Annual discards at age in SD22-24 from former assessments adjusted with the average proportion of SD22-23 in the total discards in SD 22-24 in years 2008-2010.	Discard tons in SD22-24 from former assessments minus discard tons in SD 22-23 (***A***)	***C*** multiplied by combined stock split key for SD 24	***B*** raised to account for tons in SD 24 (***D***)
2002-2010	Sumproduct of discards at age (***B***) and weight at age.	Discards at age in SD22 and SD23 from previous WGBFAS assessments, summed.	Discard tons in SD22-24 from former assessments minus discard tons in SD 22-23 (***A***)	***C*** multiplied by combined stock split key for SD 24	***B*** raised to account for tons in SD 24 (***D***)
1996-2001	Sumproduct of discards at age (***B***) in SD 22 and weight at age.	Discards at age for SD22 from previous WGBFAS assessments.	Discard tons in SD22-24 from former assessments minus discard tons in SD 22 (***A***)	***C*** multiplied by combined stock split key for SD 24	***B*** raised to account for tons in SD 24 (***D***)
1980-1995	Sumproduct of discards at age (***B***) in SD 22 and weight at age.	Extrapolated: landing at age in SD 22 multiplied by average discard ratio in 1999-2003.	Not included	Not included	***B***

B.2.3 Recreational catch

Due to the large impact of the marine recreational fishery, it was decided to use recreational fisheries data in the assessment of the western Baltic cod (WKBALT ; ICES, 2013). The longest available time-series of recreational fisheries including biological data is from Germany. At that time (2013), only German recreational data was included in the assessment. During the benchmark (WKBALTCOD2) in 2019 Danish and Swedish recreational data were included in the time-series (Table 3).

DE : The German marine recreational fisheries data collection program follows a multiannual multistage survey design An off-site survey (mail-diary) is used to estimate effort. On-site, a stratified random sample of access points and days is used to estimate catch rates (cpue). Length distributions of recreational catches are collected by onboard measurements on charter vessel trips. Other data sources were self-reported length samples from fishing events. Commercial/BITS length-weight relationships and age-length keys were used for conversion of recreational catch numbers to biomass and length at age.

The German marine recreational fisheries data are grouped into sea-based (boat angling, charter boat angling, trolling) and land-based (shore angling, wading) fishing modes. Data are collected on a quarterly basis but grouped by semester to reduce variance. Further stratification is by German coastal states and Subdivision.

German marine recreational fisheries data are available from 2005 onwards. Recreational length distributions (SD 22 & 24) are available from 2009 onwards. Releases are also sampled since 2009 in a consistent way. Using these data, the average catch from 2005-2011 was used to extrapolate the years 1994 to 2004. To account for the historic development of marine recreational fishing in the former German Democratic Republic (GRD) after unification, recreational catches in Mecklenburg Western Pomerania were set at 20% of the average in 1991 with a linear increase by 20% until 1995. To convert recreational catches in numbers to CANUM, the recreational length distribution from 2010 is used for the years 1994 to 2008. From 2009 onwards, length distribution data from recreational catch is available. The ALK used for conversion are based on BITS data for the years 1994 to 2002 and on commercial sampling data from 2002 onwards.

DK: Danish annual recreational catch data from SD 22, SD 23 and SD 24 are derived from biannual Denmark Statistics recall surveys (DST) (2009-present) based on recreational fishers holding an annual fishing licence for either passive gears or angling. The respondents are randomly selected and initially 2500 – 3500 fishers of each license type are contacted by letter in each biannual survey wherein they are encouraged to answer the questions via the internet. Respondent rate is typically between 30 and 45%. The questionnaire contains questions on catch and release of cod and fishing effort within the last 6 months. The respondents are asked to provide information per SD and quarter. Further, since 2016 respondents have been asked about the number of trips in the Sound (SD23) on private boats, tour boats or by the coast, and how much cod (kg) they have caught from these different platforms. As a supplement to the biannual Denmark Statistics recall survey, an onsite survey (REKREA) in SD 23 has been conducted since 2016 to; 1) obtain biological information from the recreational fishery and 2) to have an independent estimate on cod catches in SD 23 as respondents may overestimate the effort in recall surveys (Sparrevohn and Storr-Paulsen, 2012).

The estimated values from the DST surveys were scaled to the on-site survey estimate. The adjusted catch estimated from the DST surveys was used as a basis for hindcasting the estimates for cod harvest back to 1980 for ICES SDs 22, 23 and 24 scaled to the observed value from the on-site studies in SD 23 in 2016-2018. For the time period 1985-2008, catch per year has been calculated as the mean catch per year for the period 2009-2018, weighted for each year with the number of Danish citizens being 18 – 65 years old (age range for which holding a fishing license is mandatory).

SE: Swedish annual recreational catches from SD 23 for the tour boat fleet were derived from an onsite survey program and logbooks for the time period 2011-2017. The 2017 value also estimated catches from private fishing boats, which was added to the tour boat catches. The estimated amount of Swedish recreational catches varied between 80 and 200 t during this time period. An average for the catch data in the time period with sampled data (2011-2017) is used for the historic time-series (1994-2011).

Release (Discards):

The amounts of recreational releases (discards) are estimated following two compilations methods:

Land-based releases are estimated assuming 100% mortality.

Sea-based releases are estimated applying 11.2% mortality based on a catch and release containment study from 2012 (Weltersbach & Strehlow 2013).

All recreational cod catches taken in SD 22, 23 and 24 were considered western Baltic cod and included in the assessment.

Table 3. Overview of recreational data assumptions used by country and data source.

	SD 22	SD23	SD24
CATON			
DK	1985-2008: Catch per year is calculated as the mean catch per year for the period 2009-2018, which is then weighted for each year with the number of Danish citizens being 18 – 65 years old.	Same as in SD 22	Same as in SD 22
	2009-2018: Statistics Denmark recall survey with adjusted estimates using correction factor from REKREA on-site studies on tour boats and private	2009-2018: Statistics Denmark recall survey with adjusted estimates using correction factor from REKREA on-site studies on tour boats and private boats in	Same as in SD 22

	boats in SD23 in 2016-2018.	2016-2018.	
DE	1980-2004: reconstruction of the time-series is based on the average catch from 2009-2015. To account for the historic development (former GDR) catches in Mecklenburg-Western Pomerania were set to 20% from 1980-1991 with an annual linear increase by 20% between 1991-1995		Same as in SD 22
	2005-2014: Annual catch is calculated on the basis of a mail-diary study (effort) corrected with annual license sales and using CPUE data from an annual on-site intercept survey.		Same as in SD 22
	2015-2017: Annual catch is calculated on the basis of a national telephone-diary study (effort) corrected with annual license sales and using CPUE data from an annual on-site intercept survey.		Same as in SD 22
SE		1985-2010: Catch per year was calculated as the mean catch per year for the period 2011-2018	No estimate for 1985-2016.
		2011-2018: Tour boat census 2011-2018	2017-2018; Marina sampling of pri-

		and marina sampling of private boats 2017-2018	vate boats
Length			
DK	Same as for German data	From on-site studies 2012, 2013, 2016, 2017 and 2018 used in combination with Danish and Swedish data. An average of the time-series was used to estimate the historic data (1985-2012)	Same as German data
DE	1980-2004: pooled length distribution from 2005-2017 on-site measurement from national survey onboard tour boats, private boats (sea-based), and from self-sampling during fishing competitions (land-based)		Same as in SD 22
	2005-2017: annual values from on-site measurement from national survey onboard tour boats, private boats (sea-based) and from self-sampling during fishing competitions (land-based)		Same as in SD 22
SE		Same as for Danish data	
Age			
DK	Same as for German data	Data from both Danish and Swedish recreational surveys, commercial landings and BITS survey.	Same as for German data

		Data lacking from 1985 – 1990 and 2001-2003. Age length key based on mean values of the years 1991-1994 applied to the years 1985-1990. Mean age length key based on mean values of the years 1997-2000 and 2004-2008 applied to the years 2001-2003. Face value from 2016-2017.	
SE		Same as for Danish data.	
DE	1980-2002: matching the recreational catch length distribution (total numbers-at-length) with ALK from BITS data for each year.		Same as in SD 22
	2002-2017: matching the recreational length distribution (total numbers-at-length) with ALK from German commercial sampling data for each year.		Same as in SD 22

B.3 Biological information

B.3.1 Weight information

- Catch weights are derived from a combination of commercial landings and discards (SD 22-23), and recreational catch (weighted by numbers).
- Weights-at-age in the stock for ages 1-3 are based on Q1 survey data (BITS, DATRAS) from SD 22-23. Weights at ages 4-11 in the stock were set equal to the annual weights in catches.

The calculation of mean weight at age from survey based on individual fish sampling data raised with total length frequencies is currently not available from DATRAS.

The calculation is currently done by the Danish national lab following the procedure described below:

i) pool the data for a stock area, i.e. SD 22-23

ii) calculate number of fish sampled (for weight) at length (l), by age-class (a), by sex (s) ($S_{l,a,s}$);

iii) calculate the sum of fish sampled at length, by sex ($T_{l,s}$); and the sum of all fish sampled at length (T_l)

iii) calculate total number of fish caught by length (length frequency) (N_l)

iv) calculate mean weight of sampled fish at length, by age, by sex ($W_{l,a,s}$)

Raise the weight of sampled fish with total length frequency as follows:

v) $$X1_{l,a,s} = \frac{S_{l,a,s}}{T_{l,s}} * N_l * \frac{T_{l,s}}{T_l}$$

vi) calculate the sum of $X1_{l,a,s}$ values over length classes within each age-group ($X1_{a,s}$)

vii) $X2_{l,a,s} = W_{l,a,s} * X1_{l,a,s}$

viii) Calculate the sum of $X2_{l,a,s}$ values over length within age-group ($X2_{a,s}$)

ix) Calculate mean weight at age (WAA), by sex

$WAA_{a,s}= X2_{a,s}/ X1_{a,s}$

x) use the sex ratio of fish in samples to combine $WAA_{a,s}$ estimates to an estimate of WAA_a (combined weight for females and males)

B.3.2 Maturity information

Spawning probability is used instead of proportion mature, to account for the fact that all fish that are mature may not contribute to spawning. This is indicated by the older larger fish (stage 5; 65,66; and IX in the table) Proportions mature at age for WB cod are based on BITS Q1 survey. Only data from SDs 22-23 are used, as SD24 consists of a mix of eastern and western Baltic cod.

SDs are defined based on coordinates given for individual fish data in DATRAS:

SD 22: ShootLat>53.5000 & ShootLat<=56.0000 & ShootLong>9.5000& ShootLong]<=12.0000
SD 23: ShootLat>=55.5000& ShootLat<=56.0000& ShootLong>12.0000& ShootLong<13.0000

The maturity stages by country uploaded to DATRAS database were interpreted as follows:

Country	Years	Stages in DATRAS	Interpretation
DK	1996-2002	1-5	1,5: non-spawner 2-4: spawner
	2004-2017	61-66	61, 65, 66: non-spawner 62-64 : spawner
DE	1999-2009	1-5	1,5: non-spawner 2-4: spawner
	2010-2017	I-IX	I,II, IX: non-spawner III-VIII: spawner

Due to very few sampled fish at age 5 and older, spawning probability for these age-groups was set to 1.

A constant maturity by age, estimated as an average from 1998-2021 is used in the final assessment.

B.3.3 Natural mortality

Natural mortality is estimated from von Bertalanffy K-based method ($M = 4.118\ K^{0.73}\ Linf^{-0.33}$, Then *et al*., 2015) using growth parameters from contemporary tagging data for Western Baltic cod from SD 22 (McQueen *et al.*, 2019). This gives and M= 0.156. The Lorenzen (1996) method was used to estimate age-dependent M values, i.e. Lorenzen M at age values were rescaled to give mean M at ages 10-15 equivalent to the Then *et al.* (2015) prediction of 0.156 from growth-based method.

B.4 Surveys

Three surveys are available for the Western Baltic cod stock; BITS-1, BITS-4 and a poundnet survey. The BITS surveys are conducted with two vessels, the Danish "Havfisken" and the German "Solea".

The surveys are coordinated by the ICES working group "Baltic International Fish Survey" (WGBIFS) and have been coordinated and designed in a similar way since 2001.

The data from the two vessels are combined into one cpue time-series per quarter.

Danish 'Havfisken' surveys in SDs 22 and23 in 1st and 4th quarter.

The Danish survey is conducted twice a year in The Sound (SD 23) and Western Baltic (SD 22) and to a smaller degree in SD 24, in March and November by "Havfisken" from DTU Aqua. The Danish survey is part of the BITS, and designed to provide annual abundance indices for cod, plaice and sole. The trawl is a standard TV3-520 with rubber discs of 10-cm diameter on the ground rope and with a trawl speed of 3 knots. The time-series starts in 1995 for the first quarter and in 1994 for the fourth quarter. The spatial coverage has changed over time; in the period 1994-2000 the survey covered SD 23 and 22 to Mecklenburg Bay, in 2001 the survey covered SD 23 and 22 to the Kiel Bay, and since 2004 the survey has covered SD 23 and from Little Belt and Great Belt to the Northern part of SD 22 (Figure B4.1).

German "Solea" survey in SDs 22 and24, 1st and 4th quarter.

The Bottom trawl Surveys have been carried out by the German RV Solea since 1992. The surveys covered the southern part of SD 22 (Kiel Bight and Mecklenburger Bight) and the Arkona Sea.

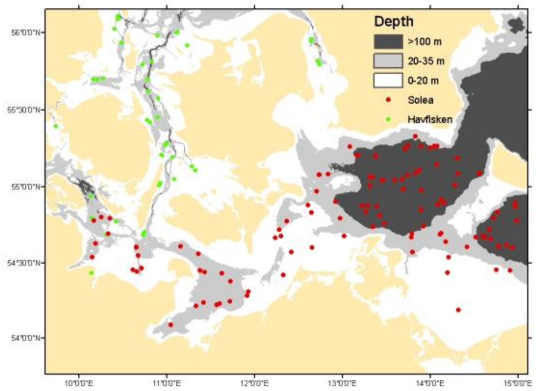

Figure B4.1. Example of area distribution of the two surveys Solea and Havfisken in both quarters.

Pound net survey

The survey is conducted in cooperation with German pound net fishers operating in shallow coastal waters around Fehmarn Island, and provides an 0-group abundance index from 2011-present (Figure B4.2). It was decided during the data evaluation workshop to test if the age-0 abundance index from the survey could be included in the stock assessment model, although it presently consists of a relatively short time-series and only covers a small area of the stock distribution area. The biological reasoning for including the pound net survey was that while the trawl survey covers areas in the western Baltic Sea deeper than 10 m (ICES, 2017), juvenile cod are reported to inhabit shallow inshore waters (Pihl and Ulmestrand, 1993) and may preferentially occupy shallow-water vegetated habitats (Freitas *et al.*, 2016) which are not adequately covered by the BITS.

Additionally, the scientific surveys are often criticised by fishers, as these surveys only cover a very short time period. This pound net survey has a four-month duration (samples are collected throughout September to December) and is therefore considered to provide a robust estimate. Sampling of the pound nets is planned to continue, so the time-series will continue to be extended. In future, the age-1 abundances estimated from the pound net sampling may also be considered for the stock assessment.

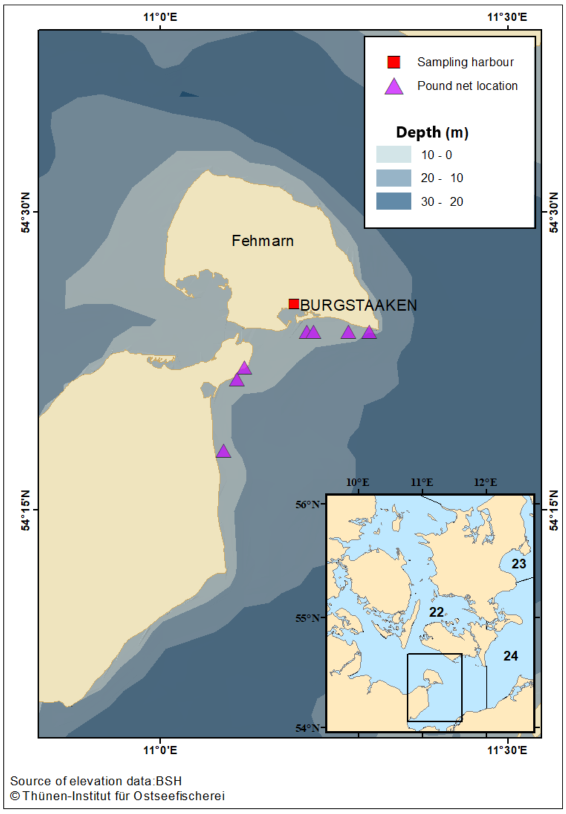

Figure B4.2. Location of pound nets off the coast of Fehmarn, from which samples were collected.

Calculation of survey indices

Survey indices are calculated using a model-based approach, following the methodology described in Berg and Kristensen (2012). The indices are calculated for SD 22-23 and including the westernmost part of SD 24 (until 13 degrees of longitude). The indices start from 1996 and 1999, for BITS Q1 and Q4 respectively. The Figures below (Figure B.4.3. and B.4.4.) show the average spatial distribution of cod in the years used in survey indices. The model is fitted separately for Q1 and Q4

The survey index is based on a Delta-Lognormal GAM model with time-invariant spatial effect, no ship effects (except for the externally estimated conversion for "Havfisken"), last age group 4+, and only using data collected with the TVS gear in years actually used in the assessment.

$$g(\_i) = Year(i) + f_1(lon_i; lat_i) + + f_3(time_i) + \log(HaulDur_i)$$

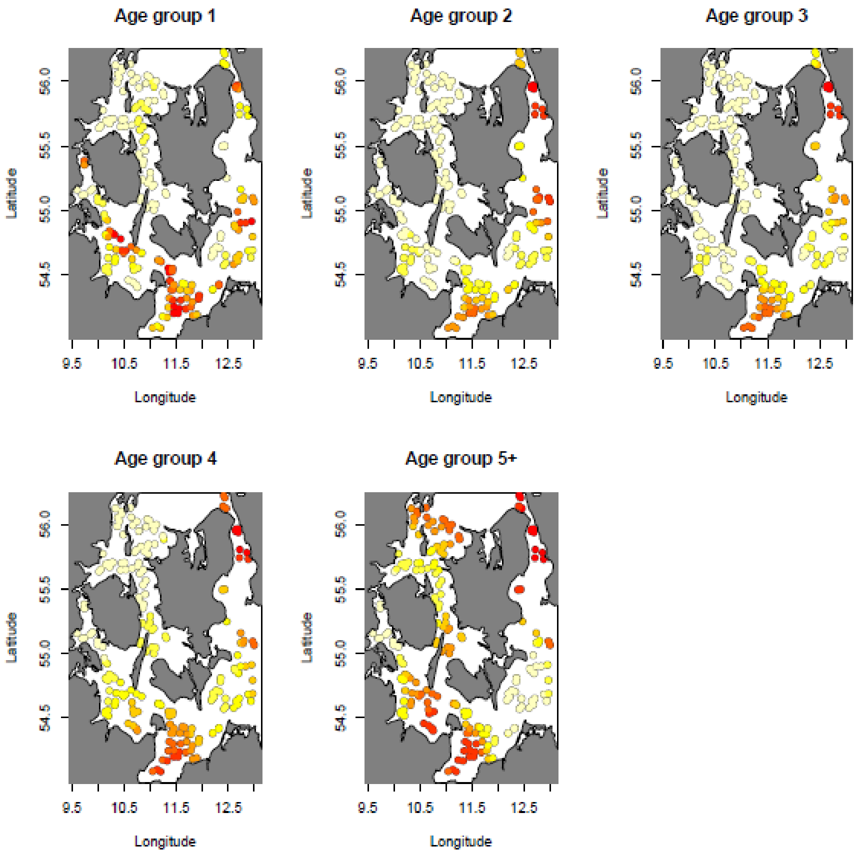

Figure: Q1

Figure B.4.3. Distribution map for ages 1-5 in Q1 (1996-2021). Increasing red colours indicate increased abundance.

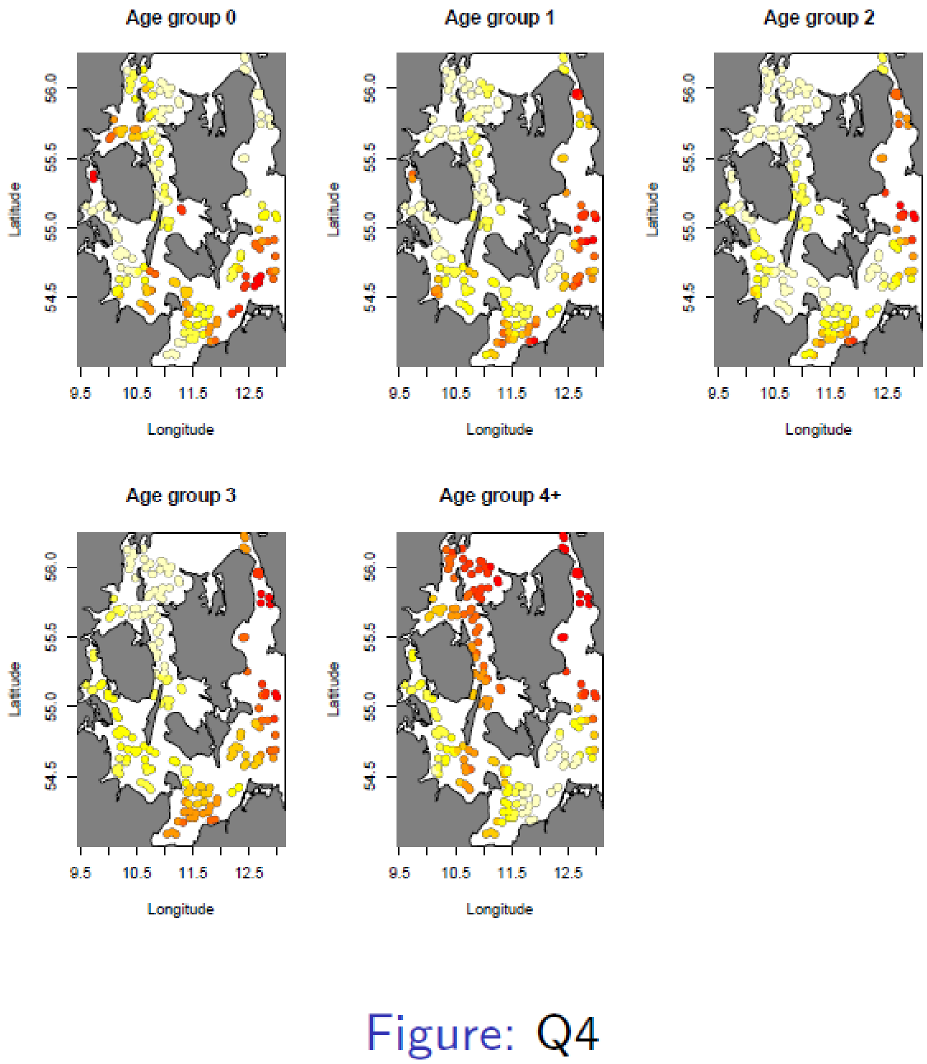

Figure B 4.4. Distribution map for ages 1-4+ in Q4 (1999-2021). Increasing red colours indicate increased abundance.

B.5 Other relevant data

VMS data are available for the Danish fleet since 2005. The VMS signal is transmitted once per hour for vessels above 12 meters and is combined with the Danish logbooks, thereby providing the gear used. VMS data has been used to indicate the main fishing area but is not used directly in the stock assessment.

C Model settings

Model used: SAM. The State-Space Assessment Model (Nielsen and Berg 2014). This model was run using the web interface that can be viewed at www.stockassessment.org.

Configuration of the model is specified below:

```
# Configuration saved: Wed Jun 16 15:49:38 2021
#
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
# Negative numbers indicate that the parameter is not included in the model
#
$minAge
# The minimium age class in the assessment
 0

$maxAge
# The maximum age class in the assessment
 7

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

$keyLogFsta
# Coupling of the fishing mortality states processes for each age (normally only
# the first row (= fleet) is used).
# Sequential numbers indicate that the fishing mortality is estimated individually
# for those ages; if the same number is used for two or more ages, F is bound for
# those ages (assumed to be the same). Binding fully selected ages will result in a
# flat selection pattern for those ages.
  -1   0   1   2   3   4   4   4
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1

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

```
# 0: independent means there is no correlation between F across age
# 1: compound symmetry means that all ages are equally correlated;
# 2: AR(1) first order autoregressive - similar ages are more highly correlated than
# ages that are further apart, so similar ages have similar F patterns over time.
# if the estimated correlation is high, then the F pattern over time for each age
# varies in a similar way. E.g if almost one, then they are parallel (like a
# separable model) and if almost zero then they are independent.
# 3: Separable AR - Included for historic reasons . . .  more later
 0

$keyLogFpar
# Coupling of the survey catchability parameters (nomally first row is
# not used, as that is covered by fishing mortality).
 -1  -1  -1  -1  -1  -1  -1  -1
  0   1   2   3   4  -1  -1  -1
 -1   5   6   7   8  -1  -1  -1
  9  -1  -1  -1  -1  -1  -1  -1

$keyQpow
# Density dependent catchability power parameters (if any).
 -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1

$keyVarF
# Coupling of process variance parameters for log(F)-process (Fishing mortality
# normally applies to the first (fishing) fleet; therefore only first row is used)
 -1   0   0   0   0   0   0   0
 -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1  -1

$keyVarLogN
# Coupling of the recruitment and survival process variance parameters for the
# log(N)-process at the different ages. It is advisable to have at least the first age
```

class (recruitment) separate, because recruitment is a different process than

survival.

```
0 1 1 1 1 1 1 1
```

$keyVarObs

Coupling of the variance parameters for the observations.

First row refers to the coupling of the variance parameters for the catch data

observations by age

Second and further rows refers to coupling of the variance parameters for the

index data observations by age

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

$obsCorStruct

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

```
"ID" "ID" "AR" "ID"
```

$keyCorObs

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

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

```
#V1 V2 V3 V4 V5 V6 V7 V8
 NA  NA  NA  NA  NA  NA  NA  NA
 NA  NA  NA  NA  NA  NA  NA  NA
 -1   0   1   1   1   1   1  -1
 -1  -1  -1  -1  -1  -1  -1  -1
```

$stockRecruitmentModelCode

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

```
0
```

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

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

$fbarRange

lowest and higest age included in Fbar

3 5

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB index, 3 total catch, 4 total landings and 5 TSB index).

-1 -1 -1 -1

$obsLikelihoodFlag

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

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

$fixVarToWeight

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

0

Input data types and characteristics:

Type	Name	Year range	Available Age range	Used Age range	Variable from year to year Yes/No
Canum	Catch at age in numbers (landings, dicards, recreational catch)	1985-last data year	1-10+	1-7	Yes
Weca	Weight at age in catch	1985-last data year	1-10+	1-7	Yes
West	Weight at age	Age 1-3 :1994-	1-10+	0-7	Yes

	in the stock. (age 1-3 survey data) Age 4-7 catch data	last data year 1985-1993=1994 Age 4-7: 1985-last data year Age 0 fixed to 0.005			
Mprop	Proportion of natural mortality before spawning	1985-last data year	1-10+	0-7	No - set to 0 for all ages and all years
Fprop	Proportion of fishing mortality before spawning	1985-last data year	1-10+	0-7	No - set to 0 for all ages and all years
Matprop	Spawning probability	2000-last data year	1-7	1-7	No. Average of hole period. Is not to be updated before next benchmark
Natmor	Natural mortality	Based on stock specific life history parameters	0-10+	0-7	No

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	BITS 1st quarter	2001-present	AG 1-4+
Tuning fleet 2	BITS 4th quarter	2001- present	AG 0-4+
Tuning fleet 3	Poundnet	2011-present	AG 0

D Short-Term Projection

The start year used in the short-term forecast is set to start one year prior to the last assessment year but then still use the last assessment year's recruitment estimate. In the last year of the assessment the estimates and their estimated uncertainties are used (including for recruitment), but for the following forecast years recruitment is sampled from the most recent 10 recruitment estimates (1000 times with replacement).

Selection pattern and stock weight is used in the short-term forecast and it is decided to use the latest 3 years' average.

When catch constrains is used in for the intermediate year the same procedure as in former times should be used, where the TAC for the management area is multiplied with the Western Baltic cod stock proportion from the area (based on genetics and otolith shape) and the discard rate is taken into account. Further the assumed recreational catches are added. This method has in the last 5 years been a relatively good estimate of the intermediate years catch.

E Medium-Term Projections

Not considered appropriate for this stock.

F Long-Term Projections

Not considered appropriate for this stock.

G Biological Reference Points

The stock recruitment relationship used included data from the whole time-series 1985-2020. The IBPWEB considered six different stock characteristic types documented by ICES in "ICES fisheries management reference point for category 1 and 2" (ICES, 2021). The stock recruitment plot did not indicate a clear S-R relationship, there is however evidence of recruitment being impaired at very low spawning stock levels, though it was not possible to estimate a breakpoint. As no breakpoint in S-R could be defined, IBPWEB decided by to use an average of the lowest SSBs (the lowest 50% median) were the recruitments were above average. The same approach was used at the last benchmark in 2019. Following the same approach the year classes 1990, 1991, 1993 and 2016 gave an above average recruitment and was in the lower 50% median of SSB. An average of these four SSB estimates producing the above average recruits was 15 067 t, similar to the value obtained at the previous benchmark. Using the ICES standard procedure this corresponds to a Bpa at 23 492 t (Bpa = 14067* exp (1.645*0.27). Sigma was derived from last year's SSB (2021). Fishing mortality reference points FMSY were calculated using ICES standard software EqSim. Stock–recruitment relationship was defined using a hockey-stick function, setting the breakpoint at Blim (15 067 t). The entire time-series was used for S-R. For the biology and selectivity, average values from last 3 years (2018-2020) were used. F_{MSY} is relatively well defined for this stock, and was estimated at 0.26 (ranges F_{MSY} low= 0.17, F_{MSY} high= 0.44). Precautionary fishing morality reference points were estimated to be at Fpa = Fp0.5 = 0.689 (with advice rule) and Flim = 1.23, equilibrium scenarios with stochastic recruitment: F value corresponding to 50% probability of (SSB < Blim).

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