Stock Annex: Celtic Sea Sole–Sol.27.7.fg

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Sole (division 7.f and 7.g)
Working Group	Working Group for the Celtic Seas Ecoregion (WGCSE)
Date	7 February 2014
Last updated	25 May 2020 by Bart Vanelslander

A. General

A.1. Stock definition

A description of the sole stock in the Celtic Sea was given in the leaflet "Fisheries information–cod, sole, plaice and whiting in the south west of the British Isles" published by CEFAS under a EU funded project (SAMFISH: EU Study Contract 99-009, Improving sampling of western and southern European Atlantic Fisheries) and is taken over here.

In the coastal waters of western England and Wales, sole are found in greatest abundance in the eastern Celtic Sea. The main spawning areas for sole in the Celtic Sea are in deep waters (40–75 m) off Trevose Head, where spawning usually takes place between March and May. Sole nursery grounds are generally located in shallow waters such as estuaries, tidal inlets and sandy bays. Juvenile sole (0 and 1 year old fish) are found mainly in depths up to 40 m, and adult sole (fish aged 3 plus) are generally found in deeper water. Spawning and nursery grounds are well defined.

Over 6000 sole were tagged on the nursery grounds of the Bristol Channel and the Irish Sea between 1977 and 1988. The majority of fish tagged in Swansea Bay and Carmarthen Bay were between 15 and 24 cm in length. Most of the recaptures of these tagged fish occurred two or more years after release, which meant that many fish tagged as juveniles were recaptured as adults. The majority of returned fish were reported off the north coasts of Devon and Cornwall, and over a wide area in the eastern Celtic Sea and St George's Channel. These results suggest that once an adult sole has recruited to an area, it tends to remain there, and that there is only limited movement of sole between the Celtic Sea and adjacent areas.

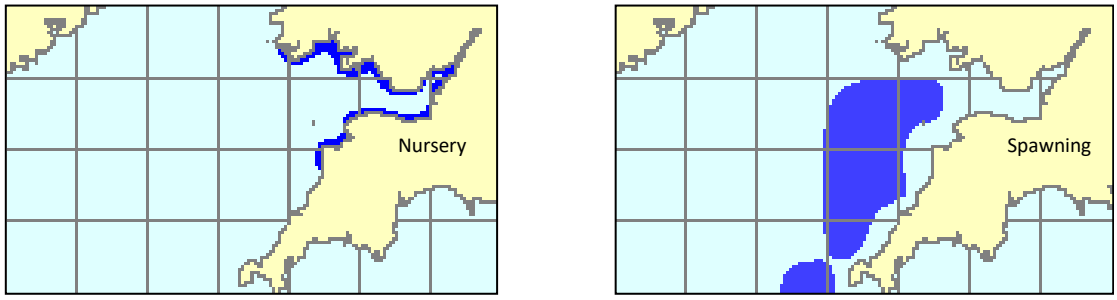


Figure A.1. Nursery and spawning areas of sole in the Celtic Sea (After Coull, K.A., Johnstone, R., and S.I. Rogers. 1998. Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.).

A study based on gene-linked single nucleotide polymorphisms (SNPs) suggested an isolated population of sole inhabiting the Celtic Sea and the Cardigan bay in the Irish sea (Diopere *et al*., 2016). There are indications for a geographic isolation of this stock. Biologically significant is the tide-driven coastal flow and baroclinic currents in the Irish and Celtic Sea. The Ushant tidal front separates the tidally mixed Channel waters from the stratified Celtic Sea (Diopere *et al*., 2016). Unpublished work by Delrue-Ricard and Vandecasteele based op SNPs show a separation between the Irish and Celtic sea stocks. In conclusion, there is evidence that the stock ID is biologically meaningful.

A.2. Fishery

Fisheries for sole in 7.f and 7.g involve vessels from Belgium, taking approximately 70–80%, the UK taking approximately 15–20%, and France and Ireland taking minimal amounts of the total landings. Nominal landings are available from 1971 onwards. Sole are mainly targeted by beam trawlers, and the fishery is concentrated on the north Cornish coast off Trevose Head and around Land's End (See also Figures A.2 and A.3). There is an average landing of 1109 tonnes throughout its history.

Discard information is being collated since 2004 and discard fractions were minor until 2016, and are recently increasing with an average discard rate of 11% for 2017–2019.

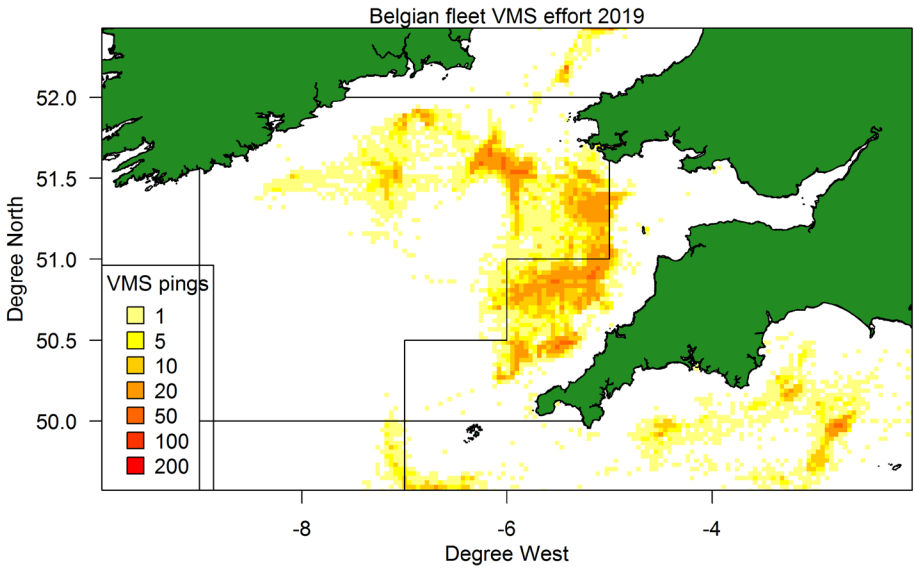


Figure A.2a. Effort distribution of the Belgian beam trawl fleet operating in the Celtic Sea (VMS data 2019).

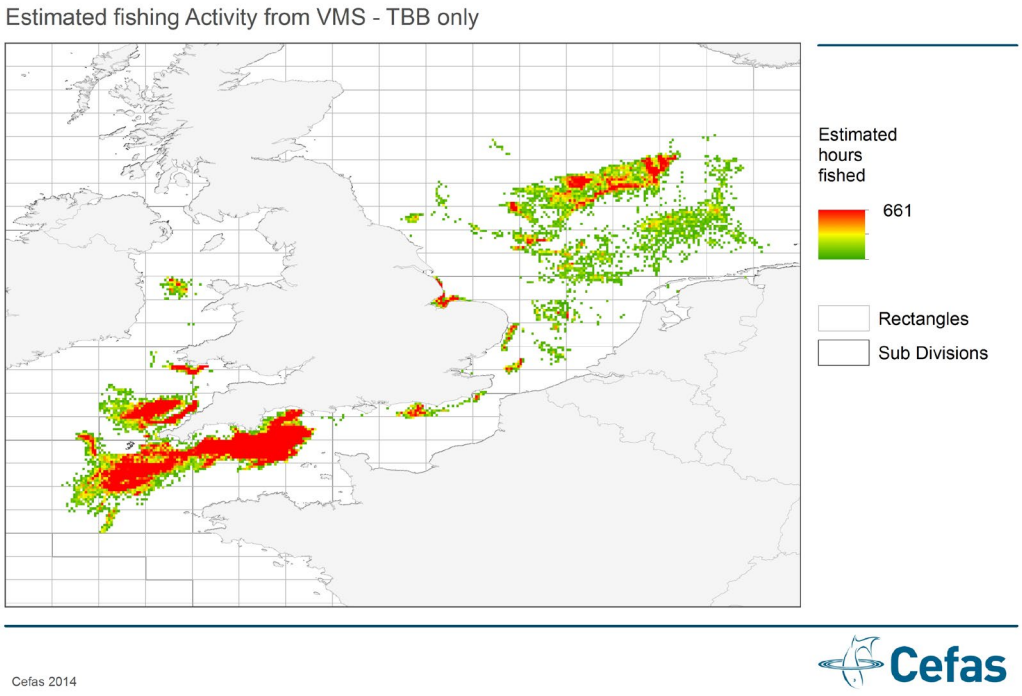


Figure A.2b. Effort distribution of the UK (E&W) beam trawl fleet operating in the Celtic Sea (VMS data 2012).

Management

Celtic Sea sole has been managed by TAC since 1983. Other management measures are technical measures including minimum landing size (24 cm and 25 cm for Belgian vessels from March 11th 2017 onwards; except for vessels <221 kW and/or < 70 GT) and minimum mesh sizes (80 mm for beam trawlers).

Furthermore national authorities can impose additional management measures, such as temporal closures, trip catch controls and monthly catch controls.

The area referred to in this report as the Trevose box, consists of the ICES rectangles 30E4, 31E4 and 32E3.

Council Regulation (EC) No 27/2005, Annex III, part A 12 (b) prohibited fishing in ICES rectangles 30E4, 31E4 and 32E3 during January-March 2005. This prohibition did not apply to Beam trawlers during March.

Council Regulation (EC) No 51/2006, Annex III, part A 4.2; (EC) No 41/2007, Annex III, part A 7.2; (EC) No 40/2008, Annex III, part A 6.2; (EC) No 43/2009, Annex III, part A 6.2 prohibited fishing in ICES rectangles 30E4, 31E4 and 32E3 during February and March 2006–2009 with derogations for vessels using pots, creels or nets with less than 55 mm mesh size. The prohibition does not apply within 6 nautical miles from the base line.

Council Regulation (EC) No 1288/2009, Article 1 stipulates that the prohibited fishing in ICES rectangles 30E4, 31E4 and 32E3 during February and March referred to in Council Regulation (EC) No 43/2009, Annex III, part A 6.2 shall be applicable until 30 June 2011.

Council Regulation (EC) No 579/2011, Article 2 stipulates that the prohibited fishing in ICES rectangles 30E4, 31E4 and 32E3 during February and March stipulated in Council Regulation (EC) No 43/2009, Annex III, part A 6.2, and prolonged in Council Regulation (EC) No 1288/2009, Article 1, shall be applicable until 31 December 2012.

Council Regulation (EC) No 227/2013, Article 29c of the European Parliament and of the Council of 13 March 2013 amending Council Regulation (EC) No 850/98 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms and Council Regulation (EC) No 1434/98 specifying conditions under which herring may be landed for industrial purposes other than direct human consumption.

A.3. Ecosystem aspects

The following description of the ecosystem in the Celtic Sea is taken from the MEFEPO atlas (Connolly, P.L., *et al*., 2009).

Physics

Bathymetry: Shelf sea south of Ireland, limited to the west by the slope of the Porcupine Seabight and the Goban Spur.

Circulation: Along the shelf edge, there is a poleward flowing „slope current"; on the shelf a weaker current flows north from Brittany across the mouth of the English Channel. Thermal stratification and tidal mixing generates the Irish coastal current which runs westwards in the Celtic Sea and northwards along the west coast of Ireland. Several rivers discharge freshwater into the ecoregion and influence the

circulation patterns. These are notably the River Loire, the Severn and the Irish rivers Lee and Blackwater.

Fronts: The Irish Shelf Front is located to the south and west of Ireland (at ca. 11°W), and consists of a tidal mixing front existing all year-round. On the shelf, there are the Ushant Front in the English Channel and the Celtic Sea front at the southern entrance to the Irish Sea.

Temperature: Sea surface temperatures measured in coastal stations northwest of Ireland since the 1960s show a trend of sustained positive temperature anomalies from 1990. An offshore weather buoy maintained off the southwest coast of Ireland (51.22°N 10.55°W) since mid 2002, indicated that 2003 and 2005 had the warmest summer temperatures of record, while 2007 saw the warmest winter temperatures. Temperatures in 2008 started above the time-series mean (2003–2008) until April and from July onwards, temperatures remained well below the time-series mean (WGOH, 2009).

Biology

Phytoplankton: Productivity is reasonably high on the shelf with a rapid decrease west of the shelf break. Continuous Plankton Recorder (CPR) data suggest a steady increase in phytoplankton over at least the last 20 years. Toxic algal blooms occur around Irish coasts especially along the southwest of Ireland.

Zooplankton: CPR data suggest an overall decline in the abundance of zooplankton in recent years. Calanus abundance is now below the long term mean.

Benthos, larger invertebrate, biogenic habitats: The major commercial invertebrate species is Norway lobster (*Nephrops norvegicus*). Two epibenthic assemblages predominate in the Celtic Sea: one along the shelf edge and the slope, dominated by the anemone *Actinauge richardi* and a more widely distributed assemblage on the continental shelf, dominated by *Pagurus prideaux* and other mobile invertebrates (shrimps and echinoderms).

Fish Community: The area is a spawning area for key migratory fish species, notably mackerel *Scomber scombrus* and horse mackerel *Trachurus trachurus*. On the continental shelf the main pelagic species are herring *Clupea harengus*, sardine *Sardina pilchardus* and sprat *Sprattus sprattus*. The groundfish community consists of over a hundred species with the most abundant 25 making up 99% of the total biomass. Surveys revealed a downward trend in the biomass and abundance of cod, whiting and hake.

Birds, Mammals and Elasmobranchs: Basking shark (*Cetorhinus maximus*) is seen throughout the area but the stock seems to be severely depleted. Blue sharks (*Prionace glauca*) are found during the summer. The Harbour porpoise *Hocoena phocoena* is the most numerous cetacean in the region. Bottlenosed dolphins (*Tursiops truncates*) occur in large numbers while the common dolphin (*Delphinus delphis*) is also widely distributed in the area. White-beaked dolphin and White-sided dolphin (*Lagenorhynchus albirostris* and *L. acutus*) occur over much of the shelf area. Grey seals (*Halichoerus grypus*) are common in many parts of the area. Petrels (fulmar and storm-petrel) dominate the seabird populations in the west of Ireland and Celtic Sea region but there are also large breeding colonies of kittiwake, guillemot and gannet.

Environmental signals and implications: Increasing temperature and changes in zooplankton communities are likely to have an impact on the life histories of many species. Cod in the Celtic Sea are at the southern limit of the range of the species in

the Northeast Atlantic. It is known that at the southern limits of their range, recruitment tends to decrease in warmer waters (above 8.5°C), and that cod are not found in waters warmer than 12°C. Celtic Sea cod has higher growth rates and mature earlier than other cod stocks. Although it is uncertain, Drinkwater (2005) has predicted that a sustained 1°C rise in sea bottom temperature, over the course of this century, could result in the disappearance of cod stocks from the Celtic Sea and the English Channel. Already there has been a northward shift in the distribution of some fish with an increase of seabass *Dicentrarchus labrax* and red mullet *Mullus surmuletus* populations around British coasts. The region also recently experienced an unprecedented increase in the numbers of snake pipefish, *Entelurus aequoreus*. Abundance of herring *Clupea harengus* and pilchard *Sardina pilchardus* occurring off the southwest of England, has been shown to correspond closely with fluctuations in water temperature. Sardines were generally more abundant and their distribution extended further to the east when the climate was warmer, whilst herring were generally more abundant in cooler times. The migration timing of squid (*Loligo forbesi*) and flounder (*Platichthys flesus*) off the southwest of England has also been linked to temperature (Sims *et al*., 2001; 2004). Zooplankton abundance has declined in the region in recent years and the overall substantial decline in Calanus abundance, which is currently below the long-term mean, may have longer term consequences given the fish community shift towards smaller pelagic species feeding on zooplankton.

Fishery effects on benthos and fish communities: Temporal analyses of the effects of fishing and climate variation suggest that fishing has had a stronger effect on size-structure than changes in temperature. A marked decline in the mean trophic level of the fish community over time has been documented and this has resulted from a reduction in the abundance of large piscivorous fishes such as cod and hake, and an increase in *Nephrops* and smaller pelagic species such as boarfish (*Capros aper*) which feed at a lower trophic level. In the Celtic Seas, discarding levels differ between the different fleets but can be as high as two thirds of the total catch with increasing trends in recent years. Discarding of undersized fish is a problem in several fisheries (e.g. cod, haddock, *Nephrops* and megrim). Improving the selection pattern should benefit the stocks and result in a higher long-term yield. Sole and plaice are predominantly caught by beam trawl fisheries. Beam trawling, especially using chain-mat gear, is known to have a significant impact on the benthic communities, although less so on soft substrates and in areas which have been historically exploited by this fishing method. Benthic drop-out panels have been shown to release around 75% of benthic invertebrates from the catches. Information from the UK industry (Trebilcock and Rozarieux, 2009) suggests that uptake in 2008 was minimal. The high mud content and soft nature of *Nephrops* grounds means that trawling readily marks the seabed, trawl marks remaining visible for some time. Despite the high intensity of fishing (some areas are impacted >7 times/year) burrowing fauna can be seen re-emerging from freshly trawled grounds, implying that there is some resilience to trawling. Cetacean bycatch has been noted in some fisheries, including the pelagic trawl fishery for mackerel and horse mackerel in the SW of Ireland, although the numbers caught were low.

B. Data

B.1. Commercial Catch

B.1.1. Before 2004

7.f and 7.g	BEL	IRL*	UK (E&W)	Derivation of international landings in 7.f and 7.g
Length composition	7.f and 7.g	7.f and 7.g	7.f and 7.g	The quarterly national catch numbers-at-age and catch weights-at-age were raised to the total international landings (including France, Northern Ireland and Scotland).
ALK	7.f and 7.g	7.f and 7.g	7.f and 7.g	
Age Composition	7.f and 7.g	7.f and 7.g	7.f and 7.g	

*** From 2005 to 2009 no Irish Length compositions or ALK's therefore from 2005 to 2009, BEL + UK age composition raised to total international landing.**

Numbers-at-age 1 in the catch are low in most years, therefore these were not considered to add useful information and are replaced by zeros.

B.1.2 From 2004 onwards

Catch data

InterCatch was used for estimation of both landings and discards numbers and age compositions, as input for the assessment. Data were disaggregated by quarter and métier (fleet). Catch data for the years 2004–2019 have been processed in InterCatch.

Raising discard data

If discards were not included for a particular year-quarter-country métier combination, they were raised. Discards on a year-quarter-country métier basis were automatically matched by InterCatch to the corresponding landings. The matched discards–landings provided a landings–discard ratio estimate used for further raising. The weighting factor for raising the discards was 'Landings CATON' (landings catch). Discard raising was performed on a gear level regardless of season or country. This approach was favoured over a more detailed one (e.g. using 1 or 2 quarters from one country to complete all other quarters of that country). The following groups were distinguished based on the gear:

- TBB
- OTB, OTT, SSC and SDN
- GTR and GNS

The remaining gears were combined in a REST group (including MIS, FPO, LLS, DRB, PTM and OTM). Raising within a gear group was performed when the proportion of landings for which discard weights are available, was equal or larger than 50% compared to the total landings of that group. For the TBB gear group the threshold was reached for the whole time-series and only the métier TBB_DEF_70-99_0_0 is providing a landing-discard ratio estimate. TBB_DEF_70-99_0_0 is the most important métier, representing more than 75% of the total landings. When the threshold was not reached for a gear group, it was pooled with the rest group to raise discards based on all available information (overall).

Raised discard data from InterCatch were available from 2004 onwards. To estimate discard mean weight-at-age and numbers-at-age prior to 2004, a constant ratio of discards to landings by age was applied using data from 2004–2018 (ICES, WKFlatNSCS 2020).

Age allocations

To allocate age compositions, landings and discards were handled separately; samples from landings were used only for landings and vice versa. When age distributions (both landings and discards) had to be borrowed from other métiers, allocations were performed on a gear level. The same gear groups (TBB; OTB-OTT-SSC-SDN; GTR-GNS; REST) as used for discard raising were applied. When the threshold of 50% was reached for the proportion of landings or discards covered by age (Lage_gear and Dage_gear respectively), allocation of age occurred with all available information within that gear group. For the TBB gear group the threshold was reached for the whole time-series. Age allocations for all métiers within that group (e.g. TBB_DEF_>120_0_0) were performed using the available sampled TBB data, in this case only the TBB_DEF_70-99 métier. When the threshold of 50% was not reached for the proportion of landings or discards covered by age for the gear groups, unsampled data were pooled in the REST group and ages were allocated

using all sampled data (overall). The weighting factor used with all scenarios was '*Mean Weight weighted by numbers-at-age*'.

Landings data

Early in the time-series officially reported landings included divisions 7.g–k for some countries and their total was higher than the WG estimate. Since 1999, official landings correspond to divisions 7.f and 7.g, and the total is lower than the working group estimate. During the period 2002–2005 the difference between the two estimates was substantial. This was mainly due to area misreporting, which was taken into account in the working group estimates (ICES, WKCELT 2014). In the recent years, the estimates are more similar.

During the inter-benchmark protocol on sole in in ICES divisions 7.f and 7.g in 2019, a revision of the Belgian commercial beam trawl tuning fleet occurred (ICES, 2019a). Investigating the Belgian sole landings data revealed that pure trips, i.e. trips in which fishing activity was limited to one of the sole stock areas (ICES divisions 7.f and 7.g), often a considerably different mean landing rate (kg.h-1) than mixed trips (i.e. trips in which fishing occurred in multiple ICES divisions). Further analyses during the WKFlatNSCS (ICES, 2020) showed substantial differences between estimated and reported sole landings in 7.f and 7.g in 2004–2007 and fishermen confirmed that there were compliance issues at that time. Therefore, these landing numbers were adjusted as the Belgian landings for sole in ICES divisions 7.f and 7.g are probably higher.

Weights-at-age

The catch weights-at-age are calculated by the sum of landing numbers*landing weight + discard numbers*discard weight divided by the sum of landing numbers and discard numbers, for each age.

The stock weights were obtained using the Rivard weight calculator (http://nft.nefsc.noaa.gov./) that conducts a cohort interpolation of the catch weights. The resulting stock weight for age 1 was very variable, and it was decided during the benchmark to set the stock weight of age 1 to the lowest estimated stock weight for age 2 for 1971–2019.

B.2. Biological

B.2.1. Natural Mortality and Maturity Ogives

Natural mortality was assumed to be 0.1 for all ages and years. This is consistent with natural mortality estimates used for other sole stocks (4, 7.d, 7.a, 8.a and 8.b) and consistent with estimates of M reported in Horwood (1993).

A new maturity ogive was estimated during the WKFlatNSCS (ICES, 2020) using only survey data of the UK (E&W)-Q1SWECOS. Maturity data are available for 2013–2019. The new maturity ogive is calculated with a length-based model with sex specific ALK. This new ogive indicates that >60% of the 2 and 3 year old individuals are mature, while this was not the case in the maturity ogive used until the WGCSE 2019. The maturity-at-age 1 was manually set to 0 as no mature sole at-age 1 were encountered at the UK (E&W)-Q1SWECOS survey.

Updated maturity-at-age based on data from the UK (E&W)-Q1SWECOS survey.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Maturity	0.0	0.67	0.91	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

B.3. Surveys

B.3.1. UK-BTS-Q3 survey

Target species

Flatfish species, particularly juvenile plaice and sole. Length data recorded for all finfish species caught; samples for age analysis taken from selected species.

Time Period

1988–2019: September (continuing)

Gear used

Commercially-rigged 4 m steel beam trawl; chain matrix; 40 mm codend liner.

Mean towing speed: 4 knots over the ground. Tow duration: 30 minutes. Tow duration for trips in 1988–1991 was 15 minutes; in 1992 comparative tows of 15 and 30 minutes length were carried out, and subsequent cruises used a standard 30 minute tow. The data from earlier years were converted to 30 minutes tow equivalent using relationships for each species derived from the comparative work in 1992.

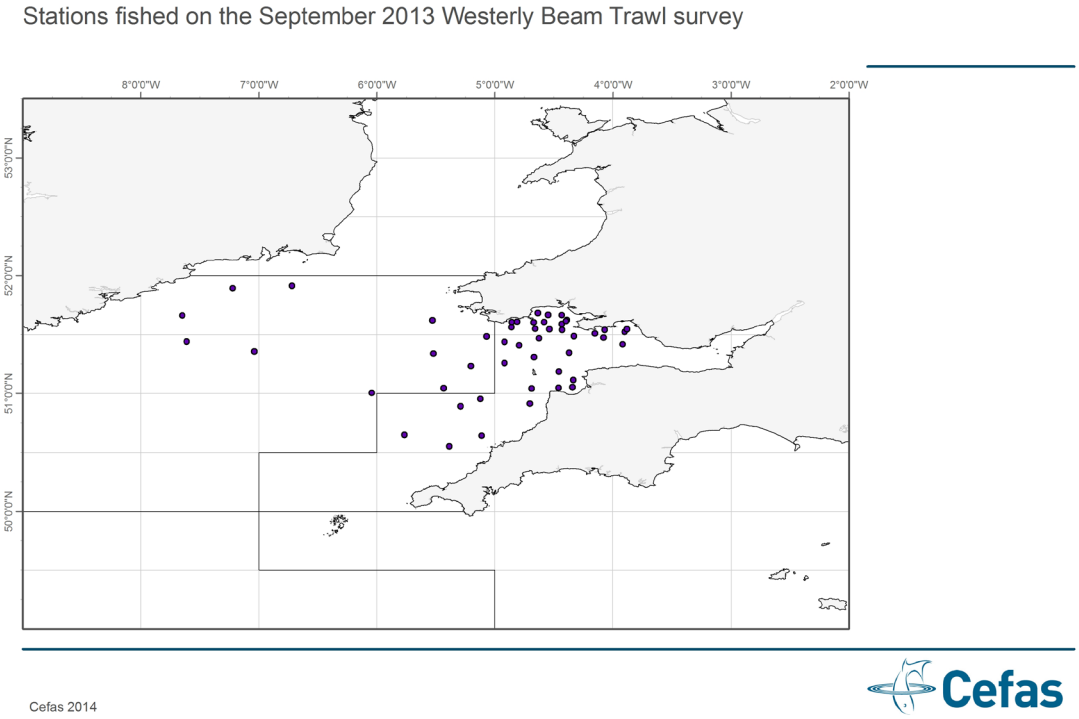
Vessel used: R.V. *Endeavour* (CEFAS).

Survey design

Survey design is stratified by depth band and sector (Depth bands are 0–20, 20–40, 40+). Station positions are fixed. There are 101 core fishing and hydrographic stations distributed around the Irish Sea, Bristol Channel and Celtic Sea between 50 to 55°N and between the English, Welsh and Irish coasts.

Method of analysis

Raised, standardized length frequencies for each station combined to give total length distribution for a stratum (depth band/sector). Sector age–length keys applied to stratum length distributions 1988–1994; stratum age–length keys applied 1995 onwards. Mean stratum cpue (kg per 100 km and numbers-at-age per 100 km) are calculated. Overall mean cpue values are simple totals divided by distance in metres (or hours fished). Population number estimates derived using stratum areas as weighting factors.



B.3.2. Potential other scientific survey information

The Irish Groundfish survey, held in the 4th quarter is available since 2003. The possible inclusion of the Irish Groundfish survey was examined at WKCELT 2014, but not retained because the consistency between ages is very poor.

The UK (E&W)-Q1SWECOS survey is conducted over a two week period in the first quarter of each year using a stratified random sampling design in ICES Division 7.e. In 2014, it was spatially extended into the Celtic Sea (including divisions 7f and 7g). The WKFlatNSCS (ICES, 2020) explored the possible inclusion of this survey in the assessment. With only six years of data and the index at-age showing a lot of variation in all age groups it is difficult to show good cohort tracking. The correlation between year classes is weak. The time-series is too short for any strong conclusions to be made on the indexes usefulness in a stock assessment. This survey has not yet been reviewed by ICES nor are the data uploaded in DATRAS. Although this survey could potentially add useful information from areas not covered by the UK (E&W)-BTS-Q3, it was decided not to use this survey for the calibration of the assessment. The next benchmark for this stock should reconsider the inclusion of this tuning-series.

B.4. Commercial cpue

Commercial cpue data are available from the Belgian, the UK (E&W) and the Irish beam trawl fleets, as well as the UK (E&W) and Irish Otter trawl fleets. There is also information on the cpue of the hardly significant Scottish seine fleet for the sole fisheries.

Two commercial tuning-series (UK (E&W)-CBT and BE-CBT) were incorporated in the WGCSE 2020 assessment. The Belgian commercial beam trawl tuning fleet consists of two parts (1971–1996 and 2006–2019, BE_CBT and BE_CBT3).

During the 2019 IBP, the Belgian commercial beam trawl tuning fleet (BE-CBT) was substantially revised. Prior to the IBP, the BE-CBT tuning-series consisted of two parts, which were included separately in the assessment: one with the original data from 1971 up to 1996 and one series with data from 1997 up to 2017. For the latter, the effort was corrected for engine power, based on a study carried out by Imares and Cefas in the mid-1990s (applicable to sole and plaice effort in the beam trawls fisheries). Currently, this method is outdated and during the IBP, a more realistic conversion factor for engine power was investigated to convert nominal fishing effort to effective effort.

The new Belgian index focussed on the period 2006–2019 for which information on ICES statistical rectangle, year, month, fleet segment and engine power (kW) was available. A series of data exploration steps revealed that spatial and temporal distribution parameters were needed in the model to account for the seasonal fisheries in the Trevose Box. ICES statistical rectangles 30E4, 31E4 and 32E3 are closed for fishing from February 1st until March 31st. This management measure is in place since 2006 and aims to protect spawning fish, cod and other demersal stocks such as sole in particular (ICES special request, 2007; Sys *et al.,* 2017). This measure has a significant effect on the behaviour of the fleet. The largest effort of the Belgian commercial beam trawl fleet is situated in this Trevose Box or on its edges during closure.

Further data exploration revealed two important drawbacks, which resulted in retaining only a subset of all Belgian commercial beam trawl data for sole in 27.7f and g for constructing the new index:

- The small fleet segment vessels (engine power <221 kW), which have quite limited effort and landings in divisions 27.7fg compared to the large fleet segment (engine power >221 kW), are likely to misreport effective engine power. Only the large fleet segment was considered for the new index.
- The Belgian beam trawl fleet has fishing opportunities spread over different ICES divisions. This flexibility creates an opportunity for noncompliance. It is generally known that fishers occasionally 'transfer' landings from one stock to another as a consequence of quota limitations (e.g. day limits). Only the 'pure' trips (i.e. with landings only in divisions 27.7fg) were considered for the new index.

The new commercial tuning fleet for Belgian beam trawlers was calculated using the following model:

$$\text{Log(lpue)} \sim \beta_0 + \beta_1 * \text{as.factor(Year)} + \beta_2 * \log(kW) + \beta_3 * \text{as.factor(IcesStatisticalRectangle)} + \beta_4 * \text{as.factor(Month)} + (1|\text{VesselName})$$

$$+ \text{Dispersion formula} : \sim \text{as.factor(IcesStatisticalRectangle)} + \text{as.factor(Month)}$$

The exponent of the estimated coefficients of the year effect is used as the landing rate for the tuning-series, which was standardised by the total weight landed by the pure trips of the large fleet segment per year. More information is provided in the IBP report and dedicated working document (ICES, 2019b).

The UK (E&W)-CBT tuning-series used in the WGCSE 2019 assessment was limited to 2012, because of effort reporting issues. As the hours fished became an optional field in the logbooks and not consistently filled, this field is inappropriate to use as a metric for effort.

During the WKFlatNSCS (ICES, 2020) an updated UK (E&W)-CBT tuning-series was introduced in the assessment. The new UK (E&W)-CBT series from 1987–2019 was generated using a random effects model. Activity days was used as an effort measure, since it is mandatory to record.

The model was an adaptation of the delta-Generalised Linear Mixed Model (delta-GLMM) that was developed to provide an index for 7D sole. This model was chosen as it can treat zeros and non-zero (positive catches) separately, while incorporating random effects to describe the distribution of catches. The model is formulated to describe the landings per days of activity in 7FG. The landings l i,j,t per activity day a i,j,t for the ith vessel on the jth voyage in the tth year was:

$$logl_{i,j,t} - loga_{i,j,t} \sim \begin{cases} N\left(\eta_{i,j,t}, \frac{\sigma^2}{a_{i,j,t}}\right) & wp\left(1-(1-p_{i,j,t})^{a_{i,j,t}}\right), \\ 0 & otherwise, \end{cases}$$

with

$$p_{i,j,t} = logit^{-1}\left(\eta_{i,j,t} + \theta\right),$$

where $\eta_{i,j,t}$ was the expected log landings per activity day,

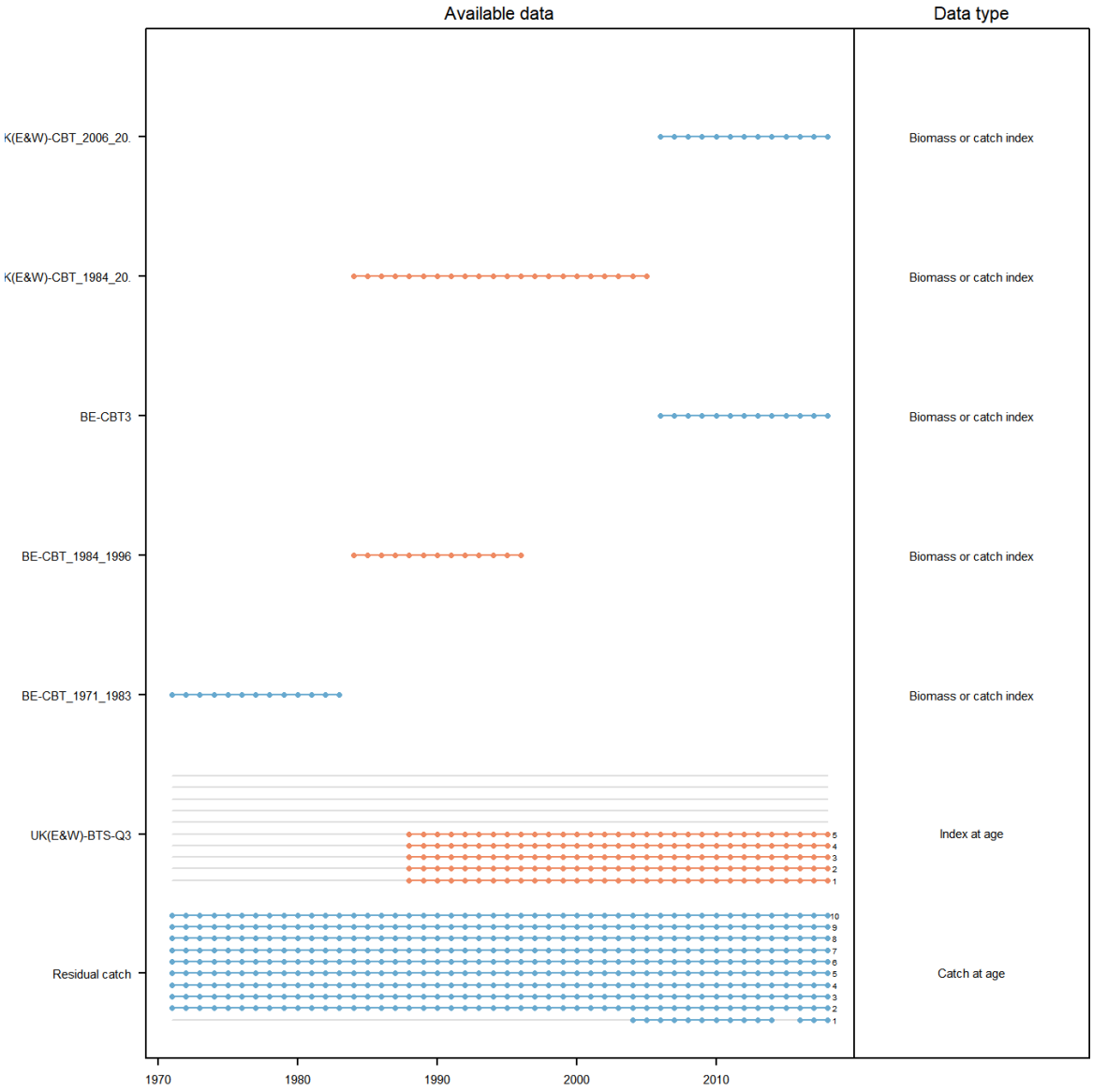
$$\eta_{i,j,t} = \omega_t,$$

with ω_t following a random walk,

$$\omega_t \sim N\left(\omega_{t-1}, \sigma_\omega^2\right),$$

The selected model includes a random vessel effect and fixed effects for month of the year and ICES rectangle.

These two commercial tuning-series were used as commercial biomass tuning-series in the assessment. The time-series of the commercial tuning-series were split in order to better account for changes in catchability due to e.g. technological creep (see figure below).



B.5. Other relevant data

No information.

C. Assessment

C.1. Tuning Data

The tuning data that are used in the historical assessment are:

Assessments until 2013

- UK Corystes September beam-trawl survey (UK (E&W)-BTS-Q3 survey) from1988 onwards.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1971–2003.
- UK beam trawl fleet (UK-CBT), Division 7.f, from 1991 onwards.

WKCELT 2014

- UK Corystes September beam-trawl survey (UK (E&W)-BTS-Q3 survey) from1988 onwards.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1971–1996.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1997 onwards.
- UK beam trawl fleet (UK-CBT), Division 7.f, from 1991 onwards.

The Belgian beam trawl tuning fleet was temporally discontinued in 2003. This is due to a change in the calculation of the effort statistics from the official logbooks and sale slip notes. At the 2014 benchmark assessment, a new derivation of the Belgium beam trawl data was available from 1997 onwards. The Belgian tuning-series was split into two separate fleets (WKCELT 2014 report): one with the original data from 1971 up to 1996, and the new series from 1997 up to 2012. The effort-series used to calculate cpue for the index is HP corrected. For the period 2003–2005, a correction for a substantial misreporting of Belgian landings into 7.j–k, was introduced. For the UK (E&W)-BTS-Q3 tuning-series, only ages 1 to 5 were retained.

WGCSE 2015–2018

- UK Corystes September beam-trawl survey (UK (E&W)-BTS-Q3 survey) from1988 onwards.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1971–1996.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1997 onwards.
- UK beam trawl fleet (UK-CBT), Division 7.f, from 1991–2012.

Due to effort reporting issues, the 2013–2018 UK-CBT indices were not available and could not be used in the assessment.

WGCSE 2019: first WG post-IBP

- UK Corystes September beam-trawl survey (UK (E&W)-BTS-Q3 survey) from1988 onwards.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1971–1996.
- New Belgium commercial beam trawl fleet (BEL-CBT3) from 2006 onwards.
- UK beam trawl fleet (UK-CBT), Division 7.f, from 1991–2012.

During the IBP 2019 inter-benchmark, it was decided to include the new Belgian tuning-series (BE_CBT3) from 2006 up until the last data year with ages 2–9. The old Belgian CBT from 1971–1996 was trimmed to ages 3–9. The BE_CBT2 series running from 1997 up until the last data year, was excluded. Finally, the UK (E&W)-CBT from 1991–2012 was also trimmed to ages 3–8. Due to effort reporting issues, the 2013–2018 UK-CBT indices were not available and could not be used in the assessment. Settings for the UK BTS Q3 survey remained unchanged. More information is provided in the 2019 IBP report (ICES, 2019b).

WKFlatNSCS (ICES, 2020) and WGCSE 2020

- Age-structured UK (E&W)-BTS-Q3 survey from1988 onwards.
- Belgium commercial beam trawl fleet (BEL-CBT) from 1971–1983 and 1984–1996, biomass index.
- New Belgium commercial beam trawl fleet (BEL-CBT3) from 2006 onwards , biomass index.
- UK beam trawl fleet (UK-CBT), Division 7.f, from 1984–2005 and 2006–onward, biomass index.

The age-structured UK (E&W)-BTS-Q3 scientific survey tuning-series is the only scientific survey used for tuning and the only tuning-series with age information.

During the WGCSE 2019, two age-structured commercial tuning-series (UK (E&W)-CBT and BE-CBT) were used in the assessment. The UK (E&W)-CBT tuning-series used in the WGCSE 2019 assessment was limited to 2012, because of effort reporting issues. As the hours fished became an optional field in the logbooks and not consistently filled, this field is inappropriate to use as a metric for effort.

C.2. Assessment methods and settings

Celtic Sea sole has been assessed with XSA until the WGCSE 2019. An overview of the changes in parameter settings of the XSA are given below:

	assessment 1998-1999			2000 assessment			assessment 2001-2002		
Fleets	Years	Ages	α-β	Years	Ages	α-β	Years	Ages	α-β
BEL-CBT commercial	71-asses-year-1	2-9	0-1	86-asses-year-1	2-9	0-1	86-asses-year-1	2-9	0-1
UK-CBT commercial	91-asses-year-1	2-9	0-1	87-asses-year-1	3-9	0-1	91-asses-year-1	2-9	0-1
UK(E&W)-BTS-Q3 survey	88-asses-year-1	1-4	0.75-0.85	88-asses-year-1	1-4	0.75-0.85	88-asses-year-1	1-4	0.75-0.85
-First data year	1989			1986			1986		
-Last data year	assessment year-1			assessment year-1			assessment year-1		
-First age	1			1			1		
-Last age	10+			10+			10+		
Time series weights	None			None			None		
-Model	Mean q model all ages			Power model (ages 1 & 2)			Power model (ages 1 & 2)		
-Q plateau set at age	7			7			7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages			5 years / 5 ages			5 years / 5 ages		
-s.e. of the means	0.5			1.5			1.5		
-Min s.e. for pop. Estimates	0.3			0.3			0.3		
-Prior weighting	None			None			None		
Fbar (4-8)									
	2003 assessment			assessment 2004-2005			assessment 2006-2012		
Fleets	Years	Ages	α-β	Years	Ages	α-β	Years	Ages	α-β
BEL-CBT commercial	87-asses-year-1	2-9	0-1	71-asses-year-1	2-9	0-1	71-asses-year-1	2-9	0-1
UK-CBT commercial	91-asses-year-1	2-9	0-1	91-asses-year-1	2-9	0-1	91-asses-year-1	2-9	0-1
UK(E&W)-BTS-Q3 survey	88-asses-year-1	1-4	0.75-0.85	88-asses-year-1	1-4	0.75-0.85	88-asses-year-1	1-9	0.75-0.85
-First data year	1987			1971			1971		
-Last data year	assessment year-1			assessment year-1			assessment year-1		
-First age	1			1			1		
-Last age	10+			10+			10+		
Time series weights	None			None			None		
-Model	Power model (ages 1 & 2)			Power model (ages 1 & 2)			Mean q model all ages		
-Q plateau set at age	7			7			7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages			5 years / 5 ages			5 years / 5 ages		
-s.e. of the means	1.5			1.5			1.5		
-Min s.e. for pop. Estimates	0.3			0.3			0.3		
-Prior weighting	None			None			None		
Fbar (4-8)									

	WKCELT2014		
Fleets	Years	Ages	α-β
BEL-CBT commercial 1	71-96	2-9	0-1
BEL-CBT commercial 2	97-asses-year-1	2-9	0-1
UK-CBT commercial	91-asses-year-1	2-9	0-1
UK(E&W)-BTS-Q3 survey	88-asses-year-1	1-5	0.75-0.85
-First data year	1971		
-Last data year	2012		
-First age	1		
-Last age	10+		
Time series weights	None		
-Model	Mean q model all ages		
-Q plateau set at age	7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages		
-s.e. of the means	1.5		
-Min s.e. for pop. Estimates	0.3		
-Prior weighting	None		
Fbar (4-8)			

	2014-2018 assessment		
Fleets:	Years	Ages	α–β
BEL-CBT commercial	1971–1996	2–9	0–1
BEL-CBT2 commercial	1997–2017	2–9	0–1
UK-CBT commercial	1991–2012	2–9	0–1
UK(E&W)-BTS-Q3 survey	1988– 2017	1–5	0.75–0.85

-First data year	1971
-Last data year	assessment year-1
-First age	1
-Last age	10+
Time-series weights	None
-Model	Mean q model all ages
-Q plateau set at age	7
-Survivors estimates shrunk towards mean F	5 years / 5 ages
-s.e. of the means	1.5
-Min s.e. for pop. Estimates	0.3
-Prior weighting	None
Fbar (4–8)	

	2019 assessment		
Fleets	Years	Ages	α-β
BE_CBT	71–96	3–9	0–1
BE_CBT3	06–18	2–9	0–1
UK (E&W)-CBT	91–12	3–8	0–1
UK (E&W)-BTS-Q3	88–18	1–5	0.75–0.85

-First data year	1971
-Last data year	2018
-First age	1
-Last age	10+
-Time-series weights	None
-Model	Mean q model all ages
-Q plateau set at age	7
-Survivors estimates shrunk towards mean F	5 years / 5 ages
-s.e. of the means	1.5
-Min s.e. for pop. Estimates	0.3
-Prior weighting	None
-Fbar	Ages 4–8

SAM

During the WKFlatNSCS (ICES, 2020) the assessment was transferred to a state–space stock assessment model (SAM). This was done by using the *stock assessment* package which enables to interface a performant SAM implementation (https://github.com/fishfollower/SAM/) in *Template Model Builder* (TMB)[1] from the R statistical software.

During the benchmark, it was decided to transfer the age-structured commercial tuning-series (BEL-CBT, BEL-CBT3 and UK (E&W)-CBT) into biomass indices. These time-series of the commercial tuning-series were split in order to better account for changes in catchability due to e.g. technological creep (Figure 36.8). The age-structured UK (E&W)-BTS-Q3 survey tuning-series was also included. The model was further optimized in terms of parameter configuration for the process and observation models (see table below).

The F_{bar} calculates the mean fishing mortality for the set age range and should represent a significant part of the catch. The F_{bar} in the WGCSE 2019 assessment was set at-age 4–8. However, as age 3 represents a large proportion of the catch (Figure 36.2), during the WKFlatNSCS it was decided to expand the F_{bar} to ages 3–8. The F_{bar} with ages 3–8 represents an average 77% of the catch, with a minimum of 48% and a maximum of 97%.

Discards are now included in the assessment (ICES, WKFlatNSCS 2020). Raised discard data from InterCatch were available from 2004 onwards. To estimate discard mean weight-at-age and numbers-at-age prior to 2004, a constant ratio of discards to landings by age was applied using data from 2004–2018 (ICES, WKFlatNSCS 2020). The fixed nature of the ratio to determine the historical discards may bias the variance estimation in SAM. The discard numbers of age 2 have proportionally the biggest impact on the catch numbers-at-age. Therefore different scenarios on how to handle the uncertainty of age 2 discard numbers prior 2004 were explored during the WKFlatNSCS (ICES, 2020). The final model sets the catch numbers-at-age 1 and 2 to NA for the catch prior to 2004, but retains the discard information for the other ages prior 2004. The discard data from 2004 onwards include all available ages.

The model configuration and the data that were used in the final SAM assessment model are shown in the table below.

[1] TMB offers a modelling framework for fast estimation of hierarchical models written in C code through the Laplace approximation. In addition, increased performance of nonlinear optimization procedures is achieved through the use of AUTODIFF (automatic differentiation), and performant C libraries for linear algebra (Eigen and CholMod).

DATA & SETTINGS	
tuning indices	
UK(E&W)-BTS survey	Age (1-5)
BE-CBT_1971-1983	Biomass
BE-CBT_1984-1996	Biomass
BE-CBT3_2006-2019	Biomass
UK(E&W)-CBT_1984-2005	Biomass
UK(E&W)-CBT_2006-2019	Biomass
catch numbers-at-age	Catch numbers for age 1 and 2 set to NA prior 2004
maturity ogive	Age1 = 0; Age2 = 0.67; Age3 = .91; Age4 = .98; Age5 = .99; Age6 = .99; Age6+ = 1
natural mortality	0.1 for all ages and years
prop. M < spawning	0 for all years
prop. F < spawning	0 for all years
Plus group	10
Fbar	3-8
MODEL CONFIGURATION	
stock-recruitment	plain random walk on logN(1)
correlation F-at-age	AR(1)
F parameters-at-age	6 = 0, 1, 2, 3, 3, 3, 4, 4, 5, 5
q parameters (-at-age)	
UK(E&W)-BTS survey	4 = 0, 1, 2, 3, 3, -1, -1, -1, -1, -1
BE-CBT_1971-1983	1
BE-CBT_1984-1996	1
BE-CBT3_2006-2019	1
UK(E&W)-CBT_1984-2005	1
UK(E&W)-CBT_2006-2019	1
σ^2 F parameters-at-age	1 = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
σ^2 N parameters-at-age	2 = 0, 1, 1, 1, 1, 1, 1, 1, 1, 1
σ^2 obs pars (-at-age)	
catch numbers-at-age	2 = 0, 0, 1, 1, 1, 1, 1, 1, 1, 1
UK(E&W)-BTS survey	3 = 2, 3, 3, 4, 4, -1, -1, -1, -1
BE-CBT_1971-1983	1
BE-CBT_1984-1996	1
BE-CBT3_2006-2019	1
UK(E&W)-CBT_1984-2005	1
UK(E&W)-CBT_2006-2019	1
ρ observations at-age	
catch numbers-at-age	"AR(1)" (single ρ for all ages)
UK(E&W)-BTS survey	"ID"
BE-CBT_1971-1983	-
BE-CBT_1984-1996	-
BE-CBT3_2006-2019	-
UK(E&W)-CBT_1984-2005	-
UK(E&W)-CBT_2006-2019	-

D. Short-term projection

During the WGCSE 2020, the Working Group decided to use TAC constraint settings for the intermediate year (2020) as recent landings have been close to the TAC or only slightly overshot.

The long-term median resampled recruitment (1971–2017) as estimated by a stochastic projection (SAM, 5187 thousand fish) was assumed for recruitment in 2020 and subsequent years.

Population numbers at the start of 2020, estimated for ages 2 and older, were taken from the SAM output.

The forecast was done using the forecast() function of the R package stock assessment which enables to interface a performant SAM implementation (https://github.com/fishfollower/SAM/) in Template Model Builder (TMB)2 from the R statistical software.

If age 2, solely assumed by the UK (E&W)-BTS-Q3 survey is exceptionally high, the estimate is reduced by 23% (calculated as the average reduction from the first year estimate to the converged estimate; 4 years later).

Standard procedure for setting the fishing mortality in the forecast is to take the mean over the last three years, not rescaled. If a trend occurs in fishing mortality (three consecutive higher or lower estimates), the Working Group may use a scaled F to the last year.

Weights-at-age in the catch and in the stock are averaged over the last three years.

WKCELT 2014, decided as an interim solution to change the standard procedure for setting the fishing mortality. In case such as in 2012, the estimate of fishing mortality is considered to be uncertain, the fishing mortality should not be rescaled to the last year, but taken as the mean of the last three years.

E. Medium-term projections

No medium-term projections were done since 2007.

F. Yield and biomass per recruit / long-term projections

No long-term projections were done in 2018.

G. Biological reference points

ICES carried out an evaluation of MSY and PA reference points for this stock in 2015 at WKMSYREF4 (ICES, 2016a). During the 2019 IBP, reference points have been re-estimated (ICES, 2019b). However, these values were rejected by the 2019 WGCSE and re-estimated at the Working Group (ICES, 2019a).

[2] TMB offers a modelling framework for fast estimation of hierarchical models written in C code through the Laplace approximation. In addition, increased performance of nonlinear optimization procedures is achieved through the use of AUTODIFF (automatic differentiation), and performant C libraries for linear algebra (Eigen and CholMod).

Previous biological reference point values are given in the text table below:

Reference points	ACFM 98 onwards	2016 onwards
F_{MSY}	0.31 (PLOTMSY, WG2010)	0.274 (Eqsim, WKMSYREF 4)
F_{lim}	0.52 (based on F_{loss}, WG1998)	0.488 (based on segmented regression with B_{lim} as breakpoint)
F_{PA}	0.37 (F_{lim} x 0.72)	0.34857 (F_{lim}/1.4)
B_{lim}	Not defined	1700 t (B_{loss} estimated in 2015)
B_{PA}	2200 t (based on B_{loss} (1991), WG1998)	2380 t (B_{lim} *1.4)
$B_{trigger}$	B_{PA}	2380 t

The biological reference points used during the WGCSE 2019.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	2228 tonnes	B_{pa}	ICES (2019a)
	F_{MSY}	0.297	EQsim analysis based on the recruitment period 1971–2017	ICES (2019a)
Precautionary approach	B_{lim}	1592 tonnes	B_{loss} estimated in 2018, corresponding to SSB in 1998	ICES (2019a)
	B_{pa}	2228 tonnes	$B_{lim} \times 1.4$	ICES (2019a)
	F_{lim}	0.587	EQsim analysis, based on the recruitment period 1971–2017	ICES (2019a)
	F_{pa}	0.420	$F_{lim} \times \exp(-1.645 \times 0.2) \approx F_{lim} / 1.4$	ICES (2019a)
Management plan*	MAP MSY $B_{trigger}$	2228 tonnes	MSY $B_{trigger}$	
	MAP B_{pa}	2228 tonnes	B_{pa}	
	MAP B_{lim}	1592 tonnes	B_{lim}	
	MAP F_{MSY}	0.297	F_{MSY}	
	MAP range F_{lower}	0.165–0.297	Consistent with ranges provided by ICES (2019a), resulting in no more than 5% reduction in long-term yield compared with MSY	ICES (2019a)
	MAP range F_{upper}	0.379–0.499	Consistent with ranges provided by ICES (2019a), resulting in no more than 5% reduction in long-term yield compared with MSY	ICES (2019a)

***EU multiannual plan (MAP) for the Western Waters (EU, 2019).**

The 2020 benchmark (ICES, WKFlatNSCS 2020) for sole in divisions 27.7f and 27.7g updated MSY and PA reference points according to ICES guidelines. The current reference points are shown below.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	3057	Tonnes; B_{pa}
	F_{MSY}	0.251	EQsim analysis based on the recruitment period 1971–2018
Precautionary approach	B_{lim}	2184	Tonnes; B_{loss} estimated in 2020, corresponding to SSB in 1997
	B_{pa}	3057	Tonnes; $B_{lim} \times 1.4$
	F_{lim}	0.543	EQsim analysis, based on the recruitment period 1971–2018
	F_{pa}	0.388	$F_{lim} \times \exp(-1.645 \times 0.2) \approx F_{lim} / 1.4$
Management plan	MAP MSY $B_{trigger}$	3057	Tonnes; MSY $B_{trigger}$
	MAP B_{pa}	3057	Tonnes; B_{pa}
	MAP B_{lim}	2184	Tonnes; B_{lim}
	MAP F_{MSY}	0.251	F_{MSY}
	MAP range F_{lower}	0.136–0.251	Consistent with ranges provided by ICES (2020), resulting in no more than 5% reduction in long-term yield compared with MSY
	MAP range F_{upper}	0.251–0.462	Consistent with ranges provided by ICES (2020), resulting in no more than 5% reduction in long-term yield compared with MSY

H. Other issues

An evaluation of the Trevose box closure (ICES rectangles 30E4, 31E4 and 32E3) was based on Belgian data that account for about 70% of the total international landings. Furthermore, the Belgian fleet is predominantly active in the Trevose Box (see map in Section A.2). This study showed that the cpue substantially increased in the month after the opening of the Trevose box. The quota uptake also increased substantially in that month, however as the Belgian fleet is subjected to a limited quota uptake by month, the overall uptake levels off at the end of the year. The annual quota has not or only limited been exceeded since the introduction of the closure.

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