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Stock Annex: Cod (*Gadus morhua*) in Division 6.a (West of Scotland)

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

Stock	Cod
Working group	Celtic Seas Ecoregion (WGCSE)
Created	WKROUND 2012
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Last updated	June 2020
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A. General

A.1. Stock definition

The latest evidence from genetic, tagging and otolith chemistry studies suggest that cod to the west of Scotland comprise of at least three subpopulations that remain geographically separate throughout the year. Some of these appear to be coastal groups with a tendency towards year-round residency, although there is some exchange between the southern inshore groups and the Irish Sea. Genetic studies have found no significant differentiation between cod sampled in the north of 6.a in depths >100 m and samples from Shetland in Division 4. Similarly, historic tag–recapture results also indicate some west to east movement across 4°W. This subpopulation region accounts for most of the cod landed in 6.a since 2010 (ICES, 2020, WD 4.1).

A.2. Fishery

A.2.1. General description

The demersal fisheries in Division 6.a are predominantly conducted by otter trawlers (typically using 120 mm mesh) fishing for haddock, anglerfish and whiting, with bycatches of cod, saithe, megrim, lemon sole, ling and skate spp. There is a substantial trawl fishery for *Nephrops* in more inshore waters which uses a smaller mesh (<100 mm) and also has a bycatch of cod. Fishing in the area is conducted mainly by vessels from Scotland, France, Ireland, Norway and Spain with Scottish vessels taking the majority of cod catch. Cod are no longer considered to be a target species in these fisheries with landings restricted through certain bycatch limits.

A.2.2. Fishery management regulations

Current regulations

The minimum conservation reference size of cod in this area is 35 cm (Regulation (EU) 2019/1241). Since 2019, cod in Division 6.a has been subject to the EU landing obligation established under Article 15 of Regulation (EU) No 1380/2013 (the revised CFP). This regulation also agreed the adoption of regional multiannual plans (MAP) for fisheries management. The EU MAP for stocks in Western Waters and adjacent waters was adopted in 2019 under Regulation (EU) 2019/472. Cod in Division 6.a are considered as a bycatch species within this regulation.

Previous regulations

Over the years, a significant number of regulations have applied to cod in this area. Although the EU landing obligation and the EU MAP have superseded many of these regulations, a summary (to maintain a historical record) is provided here.

Cod recovery plan

The first multiannual cod recovery plan which aimed to recover cod to the West of Scotland (along with cod stocks in the North Sea, Irish Sea and Baltic Sea) was agreed when the stock became severely depleted in the early 2000s. (Council Regulation (EC) No. 423/2004). This plan required the relevant biomass targets to be met by following a prescribed plan of effort reductions (days at sea) with effort being regulated across numerous individual métiers (specified by mesh, selectivity device and catch composition).

Cod management plan

The recovery plan had limited success, and reflecting a move towards a more regionalised, participatory approach to fisheries management, a revised cod management plan was developed (Council Regulation (EC) 1342/2008). The stated objective of the plan was 'to ensure sustainable exploitation of the cod stocks on the basis of maximum sustainable yield while maintaining a fishing mortality rate (F) of 0.4 or below'.

The new system of effort management adopted in this plan allowed Member States greater flexibility in managing the fleets exploiting cod by having an overall kilowatt-days limit for the main gear groupings (TR1, TR2, etc.) rather than for individual vessels. Annual effort reductions were specified through a harvest control rule (HCR) used to define the required reduction in fishing mortality (while fishing mortality remained above the target). Articles within the management plan provided incentives for cod avoidance in the form of an increase in allowable effort (Article 13) or total exclusion from effort restrictions (Article 11) if it could be shown that cod avoidance measures resulting in minimal cod bycatch were being undertaken by a group of vessels. Measures were not prescribed as part of the plan and it was left up to Member States and the industry to agree approaches, including the development and use of highly selective gears and spatiotemporal closures.

Under Article 13.2c of the cod management plan (EC 1342/2008), Scotland introduced a voluntary programme known as "Conservation Credits", which involved seasonal closures, real-time closures (RTCs) and various selective gear options. The scheme was designed to reduce mortality and discarding of cod, and was incentivised by rewarding participating skippers with additional days at sea. Closures were determined by landings per unit of effort, based on fine scale VMS data and daily logbook records and also by on-board inspections. The low number of RTCs west of Scotland (see below) in comparison to the North Sea resulted from few instances of high lpue in the area and the scheme was not considered to have been as effective as in the North Sea.

YEAR	2008	2009	2010	2011	2012
Number RTCs	4	17	27	4	9

Temporary and permanent spatial closures to protect cod have been a feature of cod recovery measures since the early 2000s. A seasonal closure (covering the main spawning period: February–April) in the Clyde was initially implemented as a temporary emergency EU measure to protect spawning cod. Since then, this measure has been implemented through a Scottish Statutory Instrument (SSI) and remains in place for 2020 and 2021. The 'Windsock' was also originally closed to bottom trawling under EU emergency measures in 2001. This became a permanent closure under EU legislation until mid-2019. Since 2009, there has been a seasonal closure (January–March and October–December) off the coast of Northern Ireland (now part of the new technical conservation legislation, Regulation (EU) 2019/1241).

A fuller description of the various cod plans and other cod recovery technical conservation measures can be found in ICES (2007) and Kraak *et al.* (2013).

Supply chain traceability

Under Council Regulation (EEC) No 2847/93 of 12 October 1993 "establishing a control system applicable to the common fisheries policy", Member States were requested to introduce legislation requiring that all fish buyers provide sales notes relevant to each purchase, which, amongst other information, details the species, weight, geographic origin, landing point of the landings and details of the vessel from which it was purchased.

Prior to 2006, there was no legislation in place establishing such a control system in a number of Member States and as a result there was significant under-reporting of demersal landings in Scotland. Statutory Instruments were introduced into the UK and Ireland in 2006, known in the UK as "Buyers and Sellers" and in Ireland as "Sales Note" regulations. These regulations made it more difficult for buyers to handle misreported landings, as they are legally obliged to provide information on the source, which must correspond with the official landings declaration of the vessel. Although unlikely to have completely eliminated the practice of under-reporting, these regulations are considered to have significantly improved the accuracy of the landings data compared to earlier years.

A.3 Ecosystem aspects

Seal predation

Cod consumption by seals (derived from diet composition studies and seal abundance estimates) is estimated to be 7632 tonnes (95% CI: 3542–13 937) in 2010 (Hammond and Wilson, 2016) compared to a TSB estimate of just under 6000 tonnes from the SAM assessment conducted at WKDEM in 2020. Cook *et al*. (2015) suggests that seal predation may be impairing the recovery of this stock. However, there is uncertainty as to whether the seals are actually exploiting the same population as the fishery. Seal foraging mostly occurs on the continental shelf (Russell *et al*., 2017) including rocky areas, which are unsuitable for trawl fishing and are not surveyed on RV trips, while most of the cod landings are taken along the Continental Shelf edge in the north of Division 6.a. Thus, the seals and fishery are largely operating in different areas. Given the complex stock structure and the presence of coastal cod populations (ICES, 2020, WD 4.1) it is clear there is potential for the seals and fishery to be exploiting different substocks. Natural mortality assumptions therefore remain an area of significant uncertainty for this stock.

Geographic location and timing of spawning

Spawning has occurred throughout much of the region in depths <200 m. However, a number of spawning concentrations can be identified from egg surveys in the 1950s, 1992 and from recent surveys of spawning adult distribution. The most commercially important of these, range from the Butt of Lewis to Papa Bank. There are also important spawning areas in the Clyde and off Mull. The relative contribution of these areas is not known. Based on recent evidence there are no longer any significant spawning areas in the Minch. Peak spawning appears to be in March, based on egg surveys (Raitt, 1967). Recent sampling suggests that this is still the case.

The main concentrations of juveniles are now found in coastal waters.

Fecundity

Fecundity data are available from West, 1970 and Yoneda and Wright, 2004. Potential fecundity for a given length is higher than in the northern North Sea but lower than off the Scottish east coast (see Yoneda and Wright, 2004). There was no significant difference in the potential fecundity–length relationship for cod between 1970 (West, 1970) and 2002–2003 (Yoneda and Wright, 2004).

B. Data

B.1. Commercial catch

B.1.1. Landings data

An overview of the data provided and used by the WG is provided in the following text table.

	Commercial Data			
	Landings		Discards	
	No.-at-age	Wght.-at-age	No.-at-age	Wght.-at-age
Available	1978–2014 Ages : 1–7+	1978 onwards Ages : 1–7+	1978 onwards Ages : 1–7+	1978 onwards Ages : 1–7+
Used	1981 onwards Ages : 1–7+	1981 onwards Ages : 1–7+	1981 onwards Ages : 1–7+	1981 onwards Ages : 1–7+
Note	1995–2006: uses age compositions only and estimates an annual scaling factor on total catch		1995–2006: uses age compositions only and estimates an annual scaling factor on total catch	

The problem of biased reported landings data is considered to have become serious from 1995. WKROUND 2012 considered that landings subject to underreporting could still be expected to yield unbiased age structures when sampled. Therefore, rather than exclude landings and discards data completely from 1995, it was agreed to make use of the information on age structure from the landings and discards data.

In the previous assessment agreed at WKROUND 2012, catch age composition only were used for 1991–2005 (modified to 2006 at IBPCod.6.a 2019) with catch scaling factor estimated for this period. To allow the model an overlap with a period considered to contain relatively unbiased commercial data the ‘age structure only’ period was started in 1991 (rather than 1995). In contrast at WKDEM in 2020, the agreed catch age composition only period was 1995–2006.

Area misreported landings

The introduction of the UK ‘Buyers and Sellers’ legislation in 2006 is believed to have significantly improved the accuracy of the reported landings data compared to earlier years. However, since then, area-misreported landings (landings taken in Division 6.a but reported elsewhere) are considered to represent a considerable portion of the total Scottish landings of cod from Division 6.a.

At the 2012 benchmark (ICES, 2012) data on area misreporting (by Scottish vessels) were provided by the Scottish enforcement organisation (Marine Scotland Compliance, MSC) and these data were used to adjust the reported landings used in the preparation of stock assessment input data. More recently, concerns have been raised about the use of the MSC data for the purposes of stock assessment, given that they are largely based on expert judgement. At the 2020 benchmark, a more objective approach to estimating area-misreported landings using Vessel Monitoring System (VMS) data linked to logbook data were agreed (ICES 2020: WD 4.4 for further details). The VMS data (fishing pings) are first pre-cleaned by removing duplicate records, points on land/in harbour and points associated with erroneous speeds. The approach is then as follows:

i) Identify fishing pings from the VMS data set (0.1–4.5 knots).

ii) Subset for fishing pings associated with trips landing cod.

iii) Subset for trips which spend at least some of their fishing time in the high cod abundance area (defined as the ICES rectangles responsible for 80% of total Division 6.a landings over the last ten years).

iv) The landings from these trips are distributed evenly across pings on a day/trip basis.

v) Estimated landings for each division are calculated by summing the landings over all pings by division to get an estimate of total landings (from these trips) by ICES division.

vi) The estimate of area misreporting is derived as the difference between the value obtained in iv) above and the landings reported in Division 6.a from those trips.

All analysis was conducted in R and using the VMStools package (Hinzen *et al.*, 2012).

Catch sampling data

As part of the benchmarking process for 2020, a data call was issued for sampling data back to 2002. Revised national data were submitted to InterCatch (including the new estimates of Scottish area-misreporting, see below). Age composition data for landings and discards are typically provided by UK (Scotland) and Ireland for the main métiers over the time-series (the exceptions being: 2006 for Ireland when there was no sampling and occasional years with no sampling of the Scottish *Nephrops* trawl landings which are in any case, very small). France have provided discard estimates for 2009 onwards, but no landings or discards age compositions have been provided. All three of these countries (Ireland, UK (Scotland) and France) submitted length composition data (both landings and discards) to InterCatch (IC) as part of the data call for WKDEM in 2020 (although these data were not processed at that time).

Landings- and discards-at-age for 2003 onwards were re-estimated based on the newly submitted data ahead of the 2020 benchmarking process. Some major issues were encountered while attempting to process the area-misreported landings in IC resulting in the correct quantity of landings being reallocated to Division 6.a, but potentially some of those landings being removed from an incorrect stock/area (ICES, 2020: WD 4.5).

The catch estimation in IC involves two stages: (i) allocating discard ratios to fleets for which only landings have been imported and (ii) age composition allocation by catch category (for unsampled catches). Age samples are allocated for landings and discards separately. Below Minimum Size landings are combined with discards for the purpose of age composition estimation.

Discard ratios

Discards are automatically matched to landings by country, area, métier and season (year or quarter) in IC. The resulting discard-landings ratios are then used to estimate discards for landings from fleets without discard estimates. Due to the mix of both quarterly and annual data submitted for each year, strata for allocating discard rates were independent of season. The strata were as follows (by year):

i) based on analysis conducted ahead of WKDEM (ICES, 2020: WD 4.4) which found no difference in discard rates from MSS observer data from 'misreporting' and 'non-misreporting' trips , the area-misreported landings are assumed to have the same discard proportion as the Scottish large mesh demersal target fleet (OTB_DEF>=120_0_0_all).

ii) other large mesh demersal target fleets were allocated a discard–landings ratio on the basis of the weighted average of all available ratios from large mesh demersal target fleets (weighted average of Scottish, Irish and French when available).

iii) small mesh fleets were allocated discard ratio on the basis of all available ratios from small mesh fleets (usually only Scottish *Nephrops* fleet).

iv) Longline fleets are allocated discard proportions from other longline fleets (and when not available are allocated zero discard rate as observed discard rates appear very low in comparison with other fleets).

v) all other fleets are given a weighted average of all available discard proportions.

Weighting scheme used: Landings CATON.

The approach described above differs (with respect to the area misreported landings) to that applied at WGs between 2013 and 2019. In those years, it was assumed that this component of the landings should have no discards associated with them on the grounds that area misreporting would mean there was no need to discard. The analysis carried out for WKDEM using Scottish observer data from 2009–2016 suggest this not to be the case.

Discard data are available from 1978 but sampling was very limited before 1981 and hence these years are not used in the stock assessment. Discards in years 1981–2003 raised according to Millar and Fryer (2005).

Age compositions

The allocation of age compositions to un-sampled landings and discards follows the same stratification as described for the allocation of discard ratios. The exception being the longline fleets which were included in the 'other fleets' category as there were no age composition data provided.

At the 2020 benchmark, Scottish sampling data were used to compare the mean size of cod between 'misreporting' fishing trips, and those which do not area-misreport. Length composition data for discards are available on a haul basis from the Scottish observer sampling programme, while length composition data at the trip level are available from both observer sampling and from on-shore market sampling. Mean size was therefore calculated at the haul level for discards and at the trip level for the landed component of the catch. Analysis is again limited to data from 2009 to 2016, and trips are matched in the two datasets (sampling and logbook data) on the same basis as for the discard rate comparisons. Mean sizes of cod from area-misreporting trips showed no systematic differences to other demersal target fishing trips taking place in Division 6.a, and therefore Scottish demersal fleet age compositions are allocated to the area-misreported landings and discards during the stock assessment data work up process.

This approach differs to that taken at the WGs occurring in 2017–2019. At this time, given that the misreported landings were assumed to have no discards associated with them it was considered by these WGs that they could potentially have a different landings age composition. The misreported landings were treated as a separate unsampled fleet in IC and were allocated a weighted average landings age composition (Scottish and Irish). The Irish landings comprise a substantially greater proportion of younger fish than the Scottish sampled landings, although given the relative landings weights of the two fleets, the allocated proportions-at-age were more similar to the Scottish sampled fleet. This approach was discontinued in 2020.

Observer sampling levels are given in the table below:

AREA 6					
	Scotland			Ireland	Northen Ireland
Year	TR1	*TR2*	Total	Total	Total
2008	9	8	17		
2009	10	22	32		
2010	5	6	11	9	
2011	8	7	15	15	
2012	10	13	23	14	37
2013	13	16	29	11	34
2014	11	21	32	18	39
2015	12	29	41	18	4

B.2. Biological sampling

B.2.1. Maturity

Proportion mature-at-age are given by:

Age	1	2	3	4	5	6	7+
Pre 2020 WG	0.0	0.52	0.86	1.0	1.0	1.0	1.0
2020 onwards	0.27	0.53	0.78	0.91	0.97	0.99	1.0

An analysis of Scottish survey data carried out in preparation for WKDEM in 2020 (following the approach advocated by ICES, 2008) indicated a proportion of individuals at-age 1 to be mature, but no temporal trend in maturity. A new ogive was therefore used for the full time-series (ICES, 2020: WD 4.2). Note that there was a typo for maturity-at-age 4 (0.48 instead of 0.78) in the WKDEM report.

B.2.2. Natural mortality

Age-dependent natural mortality was first implemented in the stock assessment for cod in Division 6.a at WKROUND in 2012. At this meeting, natural mortality-at-age was derived from mean stock weight-at-age over the full time-series of data using the Lorenzen parameters for fish in natural ecosystem (Lorenzen, 1996):

$$M_a = 3\overline{W_a}^{-0.29}$$

M_a is natural mortality-at-age a, $\overline{Wa}$ is the time averaged stock weight-at-age a (in grammes) and the numbers are the Lorenzen parameters for fish in 'natural ecosystems'.

WD 4.3 (ICES, 2020) provided a review of natural mortality ahead of WKDEM, and concluded that given the trends in observed mean weights, there was good reason to allow natural mortality also to vary over time. For 2020 onwards, natural mortality-at-age is derived from stock weight-at-age (modelled catch weight-at-age, see below).

Natural mortality (M) assumptions at recent WGs:

WG Year	Approach
Pre-2012	Fixed over ages and years (0.2)
2012–2019	Time invariant, age dependent, derived from time-series mean stock weights-at-age and Lorenzen (1996)
2020 onwards	Time varying derived from mean stock weight-at-age (which are modelled mean catch weights-at-age) and Lorenzen (1996)

B.2.3. Length and age composition of landed and discarded fish in commercial fisheries

Weights-at-age are supplied separately for landings and discards. Catch weights are derived using the sum of products from the landings and discards weights-at-age. There is evidence of a trend over time in catch weights-at-age but also significant interannual variability with estimates apparently becoming more noisy in recent years. Stock weights-at-age are derived by applying a GAM to smooth the catch weights-at-age (ICES, 2020: WD 4.3).

B.3. Surveys

B.3.1. Survey descriptions

The Scottish surveys used for this assessment changed vessel and tow duration in 1999. Although a correction has been made based on comparative tows, there will be an additional variance associated with this correction factor, which will affect the survey index. The spatial aggregation of the ScoGFS-WIBTS-Q1 survey (weighted arithmetic mean) can result in hauls catching large numbers of fish having a strong influence on index values (as was the case in 2008). This in turn has added noise to the indices and can lead to large residuals in the stock assessment.

Between 2011 and 2015, the assessment was run with no recent survey data. Due to a change in survey design in SCOGFSWIBTS.Q1, this survey came to an end in 2010. A new time-series was started in 2011: the UKGFSWIBTS.Q1.

For 2011, the rig and sampling design of the ScoGFS-WIBTS-Q1 survey was changed. A new ground gear was introduced broadly modelled around the rig used by Ireland for the IRGFS-WIBTS-Q4. The move to a more robust gear also allowed a move to a random stratified survey (which is again consistent with the IRGFS-WIBTS-Q4). WGCSE 2011 concluded the changes constituted a new abundance series. The ScoGFS-WIBTS-Q1 survey data therefore finish in 2010. The 2015 inter-benchmark analysed the effect of the inclusion of the new survey UKSGFS-WIBTS-Q1. It concluded that its inclusion would be beneficial to the assessment despite the poor internal consistency of the new survey The same changes to ground gear and survey design occurred for the ScoGFS-WIBTS-Q4 and the final year of data from the ScoGFS-WIBTS-Q4 series is 2009 (the survey did not take place in 2010).

The following surveys are available for the assessment:

ScoGFS – WIBTS – Q1: Fixed station design

ScoGFS – WIBTS – Q4: Fixed station design

IGFS – WIBTS – Q4: Random stratified design (Southern part of Division 6.a)

UKSGFS – WIBTS – Q1: Random stratified design

UKSGFS – WIBTS – Q4: Random stratified design

The survey strata for the UKSGFS-WIBTS-Q1 and UKSGFS-WIBTS-Q4 are shown in Figures H.1 and H.2 below. The strata were defined on the basis of cluster analysis of aggregated data from the earlier Scottish surveys (1999–2010) as well as the data collected from a dedicated gadoid survey, which took place during 2010. Species considered were cod, haddock, whiting, saithe and hake. Cluster analysis yielded four specific clusters. Two additional strata were added; the Clyde area and the 'windsock,' which is an area that was designated as a recovery zone and experienced no demersal mobile gear exploitation between 2002 and 2019. Each individual polygon is treated as a separate stratum and the number of survey stations for each is allocated according to polygon size and the variability of indices within each stratum.

Within strata, the station locations are chosen at random within strips of equal area. This ensures that (a) each possible sample point has an equal chance of being selected; and (b) that there is an even coverage of samples throughout the strata (avoiding clustering of samples and concomitant large open spaces without samples).

Strata means are weighted by surface area to build the final indices:

$$\bar{Y} = \frac{\sum_{s=1}^{M} A_s \bar{y}_s}{A}$$

where $\bar{y}_s$ represents the mean of stratum s, A_s the area of stratum s, M, the total number of strata and A the total area (i.e. sum of all A_s). The variance of the estimate is defined as:

$$Var(\overline{Y}) = \sum_{s=1}^{M} \frac{A_s^2 s_h^2}{A N_h}$$

where s_h is the sample variance in stratum s, and N_h is the number of hauls in stratum s and the assumption is that the sampling fraction is zero (i.e. the area surveyed is an infinitesimally small fraction of the area of each strata).

B.3.2. Survey data used

Prior to the 2019 IBP, only survey data from the quarter 1 surveys were included in the assessment. At IBPCod6.a in 2019, the data from the quarter 4 surveys were reconsidered. The three additional surveys show reasonable consistency (between and within survey) and it was agreed that the additional indices should be included in the assessment. The available data are specified in the table below.

No changes were made to survey indices at WKDEM in 2020.

	Survey Data					
	cpue at-age					
	ScoGFS-WIBTS-Q1	ScoGFS-WIBTS-Q4	IreGFS	IRGFS-WIBTS-Q4	UKSGFS-WIBTS-Q1	UKSGFS-WIBTS-Q4
Available	1985–2010 Ages: 1–7	1996–2009 Ages: 0–8	1993–2002 Ages: 0–3	2003 onwards Ages: 0–4	2011 onwards Ages: 1–7	2011 onwards Ages: 0–8
Used	1985–2010 Ages: 1–6	1996–2009 Ages: 1–4	NOT USED	2003 onwards Ages: 1–3	2011 onwards (including assessment year) Ages: 1–6	2011 onwards Ages: 1–6

WGCSE 2020

At WKDEM, the agreement was to include these five indices in the assessment with variance estimated within SAM and coupled across ages within each survey. During WGCSE in 2020 (i.e. the first assessment WG following the benchmark), it became apparent that the estimate of fishing mortality in 2019 (which was extremely high) from the update assessment was mostly due to the inclusion of the 2019 Scottish Q4 survey data point. Including the survey variance estimates in the SAM assessment (for the two current Scottish surveys) results in down-weighting of particularly uncertain/outlying points and in this case the influence of the 2019 data point was reduced. The WG therefore proposed that this approach should be adopted in future assessments. Following the 2020 WG, the modification was reviewed and supported by the WKDEM chairs and external reviewers.

B.4. Commercial cpue

No reliable data available.

B.5. Other relevant data

C. Assessment methods and settings

C.1. Choice of stock assessment model

Model used: SAM (Nielsen and Berg, 2014)

Software used: Run in stockassessment.org, model version 0.9.0.

C.2. Model used of basis for advice

The final SAM model configuration was chosen by consideration of a combination of model residuals, AIC and retrospective patterns. The configuration file is given in the table below. The configuration differs slightly from that agreed at In summary, the main features are as follows:

- Fishing mortality-at-ages 4 and above are assumed equal (See # Coupling of the fishing mortality states, below).
- Survey catchabilities are mostly freely estimated for each age with the exception of the two oldest ages (i.e. no survey catchability plateau assumed). The exception to this is the WIBTS.Q1 for which all catchabilities are independently estimated.
- Catch observation variance parameters are allowed to differ for age 1 and age 7+ while other age groups are coupled (# Coupling of the variance parameters for the observations). To allow for greater uncertainty in the catch data for 2006 onwards (when the fishery changes from being a landings fishery to largely discards), the estimated catch observation error standard deviation is doubled for 2006 onwards (based on inspection of the one step ahead residuals).
- Survey observation variance parameters differ between surveys. For the two current Scottish surveys, externally derived age dependent survey variance estimates are used in the assessment (as explained above). For the other surveys, estimates are coupled for all age groups within a survey.
- Recruitment is modelled as a random walk.
- A catch scaling factor is estimated for 1995–2006 when underreporting of landings was considered significant.
- Fishing mortality across ages is modelled with AR(1) and process variance parameters coupled across all ages with the exception of age 1. Process variance in stock numbers-at-age were assumed coupled with the exception of age 1 (the age at recruitment).

SAM configuration file agreed at the 2020 WKDEM:

```
# 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
#

$minAge
# The minimium age class in the assessment
 1
$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 0 0 0 0 0

$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
   0  1  2  3  3  3  3
  -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 -1 -1 -1

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

```
$keyLogFpar

# Coupling of the survey catchability parameters (normally first row is not used, as that is covered by fishing mortality).
 -1 -1 -1 -1 -1 -1 -1
  0  1  2  3  4  5 -1
  6  7  7 -1 -1 -1 -1
  8  9 10 10 -1 -1 -1
 11 12 13 14 15 15 -1
 16 17 18 19 20 20 -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 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1

$keyVarF
# Coupling of process variance parameters for log(F)-process (normally only first row is used)
  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 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1

$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1 1

$keyVarObs
# Coupling of the variance parameters for the observations.
  0  1  1  1  1  1  2
  3  3  3  3  3  3 -1
  4  4  4 -1 -1 -1 -1
  5  5  5  5 -1 -1 -1
  6  6  6  6  6  6 -1
  7  7  7  7  7  7 -1

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"
 "ID" "ID" "ID" "ID" "ID" "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).
#1-2 2-3 3-4 4-5 5-6 6-7
  NA  NA  NA  NA  NA  NA
  NA  NA  NA  NA  NA  -1
  NA  NA  -1  -1  -1  -1
  NA  NA  NA  -1  -1  -1
  NA  NA  NA  NA  NA  -1
  NA  NA  NA  NA  NA  -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.
 12
```

$keyScaledYears
A vector of the years where catch scaling is applied.
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

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

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

$fbarRange
lowest and highest age included in F_{bar}
2 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 -1 -1

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

$fracMixF
The fraction of t(3) distribution used in logF increment distribution
0

$fracMixN
The fraction of t(3) distribution used in logN increment distribution
0

$fracMixObs
A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet
0 0 0 0 0 0

$constRecBreaks
Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock–recruitment code 3)

Input data types and characteristics

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1981 onwards (excluded 1991–2006)	1 to 7+	Yes
Canum landings^	Landings-at-age in numbers	1981 onwards (age comps only 1991–2006)	1 to 7+	Yes
Canum discards^	Discards-at-age in numbers	1981 onwards (age comps only 1991–2006)	1 to 7+	Yes
Weca	Weight-at-age in the commercial catch	1981 onwards	1 to 7+	Yes
Weca landings^	Weight-at-age in the commercial landings	1981 onwards	1 to 7+	Yes
Weca discards^	Weight-at-age in the commercial discards	1981 onwards	1 to 7+	Yes
West=Weca	Weight-at-age of the spawning stock at spawning time.	1981 onwards	1 to 7+	Yes
Mprop	Proportion of natural mortality before spawning	1981 onwards	1 to 7+	No, set to 0 for all ages and years
Fprop	Proportion of fishing mortality before spawning	1981 onwards	1 to 7+	No, set to 0 for all ages and years
Matprop	Proportion mature at age	1981 onwards	1 to 7+	No
Natmor	Natural mortality	1981 onwards	1 to 7+	Yes

^ Input to SAM is in the form of total catch-at-age rather i.e. does not model landings and discards separately.

Survey indices

Type	Name	SAM survey acronym	Year range	Age range
Tuning fleet 1	ScoGFS – WIBTS – Q1	WCIBTS.Q1	1985–2010	1 to 6
Tuning fleet 2	IRGFS-WIBTS-Q4	IRGFS.Q4	2003 onwards	1-3
Tuning fleet 3	ScoGFS – WIBTS – Q4	WCIBTS.Q4	1996–2009	1 to 4
Tuning fleet 4	UKSGFS – WIBTS – Q1	SCO.Q1	2011 onwards (including assessment year)	1 to 6
Tuning fleet 5	UKSGFS – WIBTS – Q4	SCO.Q4	2011 onwards	1 to 6

D. Short-term prediction

Model used: Age-structured

Software used*:* Stochastic forecast in SAM. Forecasting in SAM takes the form of short-term stochastic projections. A total of 1000 samples are generated from the estimated distribution of survivors. These replicates are then simulated forward according to model and forecast assumptions, using the usual exponential decay equations, but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch-options scenarios. Prior to the 2020 assessment WG, forecasts had been conducted either using STF in R.

Initial stock size at start of intermediate year: Taken from SAM for age 1 and older. Note that the age 1 value (recruitment in intermediate year) in the SAM short-term forecast is the median from a normal distribution of the assessment estimate required for stochastic projections. This is slightly different to the assessment estimate, which appears in the assessment summary table.

Exploitation pattern and status quo fishing mortality: Average of the three last years fishing mortality-at-age; consideration should be given to scaling of F_{bar} and should be dependent on the assessment results (i.e. trend in F or not).

Discard pattern: Partition into landings and discards is typically be based on a three-year average. However, there should be consideration of the latest discard data and likely future fishery behaviour in the choice of appropriate year range. For example a sudden change in discarding behaviour was apparent in 2019 (following the implementation of the LO) and assuming this behaviour would continue, the forecast conducted in 2020 (for advice in 2021) partitioned the catch on the basis of the 2019 discards pattern only. (No partition was provided in the advice for 2020 due to uncertainty).

Stock–recruitment model used: None, recruitment in the intermediate year is taken from the SAM assessment, (the value is based largely on the Sco.Q1 survey datum from the terminal year). For the TAC year and following year the short-term (ten years excluding intermediate year estimate) geometric mean recruitment-at-age 1 is used which reflects the recent low recruitments (and is consistent with year range for the GM recruitment used in previous deterministic forecasts in R).

Weight-at-age in the landings and discards: Typically, average weight of the three last years is used. However, changes in discard practices (e.g. reduced high grading) can affect the mean weight-at-age in the landings and discards (as observed in the 2019 data), hence it may be appropriate to choose the year range to be consistent with the discard pattern year range (as done at the WG in 2020 for the 2021 advice).

Weight-at-age in the stock: Average stock weights for last three years.

Maturity: The same ogive as in the assessment is used for all years.

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

E. Medium-term prediction

Not considered.

F. Long-term prediction

Not considered.

G. Biological reference points

	Type	Pre 2016	2016–2018	2019	Current value (WKDEM 2020)	Technical basis
MSY Approach	MSY $B_{trigger}$	22 000	20 000 t	20 000 t	20 126 t	B_{pa}
	F_{MSY}	0.19	0.17	0.29	0.30	F giving max yield in the long term given current error, biology & fishery and applying the ICES advice rule (Seg reg with fixed breakpoint stock–recruitment fitted to full time-series)
	F_{MSY} lower			0.2	0.18	F at 95% MSY (below F_{MSY}) without ICES AR.
	F_{MSY} upper			0.41	0.49	F at 95% MSY (above F_{MSY}) without ICES AR.
	$F_{p.05}$			0.64	0.57	F that gives a 5% probability of SSB < B_{lim} when the ICES advice rule is applied.
Precautionary Approach	B_{lim}	14 000	14 000 t	14 000 t	14 376 t	SSB avoiding low recruitment (SSB in 1992 as estimated by WKDEM)
	B_{PA}	22 000	20 000 t	20 000 t	20 126 t	Considered to be the minimum SSB required to ensure a high probability of maintaining SSB above B_{lim}, taking into account the uncertainty of assessments. 1.4 x B_{lim}
	F_{lim}	0.8	0.82	0.77	0.73	Based on simulation with segmented regression recruitment with B_{lim} as the breakpoint: F at which 50% probability of being above B_{lim}
	F_{PA}	0.6	0.59	0.55	0.52	F_{lim}/1.4

H. Other issues

H.1. Change of Scottish Research Survey

For 2011, the rig and sampling design of the ScoGFS-WIBTS-Q1 survey was changed. A new ground gear capable of tackling challenging terrain was introduced broadly modelled around the rig used by Ireland for the IRGFS-WIBTS-Q4. The move to a more robust ground gear also allowed a move to a random stratified survey, which is again consistent with the IRGFS-WIBTS-Q4, as the previous repeat station survey format consisting of the same series of survey trawl positions being sampled at approximately the same temporal period every year was considered a bias prone method for surveying the area. It is hoped, the greater compatibility between Scottish and Irish surveys will facilitate both being used to assess gadoids West of Scotland.

New survey strata were designed using cluster analysis on aggregated data from the previous ScoGFS-WIBTS-Q1 data (1999–2010) as well as the data collected from a dedicated gadoid survey, which took place during quarter 1 of 2010. Species considered were cod, haddock, whiting, saithe and hake. Cluster analysis yielded four specific clusters. Two additional strata were added; the Clyde area and the ‘windsock,’ which is an area that has been designated as a recovery zone since 2002, and has therefore experienced no mobile gear exploitation during this time. The new strata are shown in Figure H.1. Each individual polygon was treated as a separate stratum, and the number of survey stations for each was allocated according to polygon size and the variability of indices within each stratum. Strata were weighted by surface area to build the final indices.

H.2. Biology of species

H.3. Stock dynamics, regulations in 20th century, historic overview

Assessment years: 2019 (IBPCod6.a)

Model used: TSA (Fryer, 2001; Fryer, 2011)

Software used: NAG library (FORTRAN DLL) and functions in R.

The main changes to the TSA configuration agreed at the IBPCod6.a in 2019 (ICES, 2019) included modifications to the age-specific measurement error assumptions in the commercial data (making use of estimates derived from market and observer sampling data as part of the assessment input data estimation process), allowing for greater flexibility in the estimation of fishery selectivity and the inclusion of three additional survey indices. The model configuration is given below:

Parameter	Setting	Justification
Age of full selection.	$a_m = 6$	To allow flexibility when estimating fishery selectivity.
Survey catchability model	WIBTS.Q1 & WIBTS.Q4: no transitory or persistent changes SCO.Q1, SCO.Q4 & IRGFS.Q4: transitory changes estimates	Allows for survey year effects
Multipliers on variance matrices of measurements.	$B_{landings}$(a, 1981–2005) = 2 for ages 1, 6 $B_{landings}$(a, 1981–2005) = 3 for ages 7+	Allows extra measurement variability for poorly-sampled ages (based on relative size of residuals).
	$B_{landings}$(1–7+, 2007 onwards) = (15.6,9.1,3.6,1.2,1.9,3.8,7.5) $B_{discards}$(1–4, 2007 onwards) = (0.96,0.62,0.91,0.87)	Allows extra measurement error post Buyers & Sellers legislation (based on external estimates of CV).
Multipliers on variances for fishing mortality estimates.	H(1) = 2	Allows for more variable fishing mortalities for age 1 fish.
	v.cvmult (1986) = 3	Allows for greater transitory change in fishing mortality year component.

Parameter	Setting	Justification
Downweighting of particular datapoints.	Landings: Age 2 in 1987 age 6 in 1982 age 4 in 2004 Discards: age 1 in 1988, 1992 and 2016 age 2 in 1988, 1992,1998,2002. Survey (WCIBTS.Q1): Age 1 in 1987 age 2 in 2007 and 2010, age 3 in 2008, age 4 in 2001 and 2008, age 5 in 2001. Survey IRGFS.Q4: age 1	CV multiplier set to 3 or 5 as necessary. Large values indicated by exploratory prediction error plots. Survey downweighting in 2001 resulted from a single large haul, 24 fish >75 cm in 30 minutes. In 2008 due to very large haul near 4°W line.
Discards	Discards are allowed to evolve over time constrained by a trend. Ages 1 to 4 are modelled independently. A step function is specified with the step occurring in 2006.	
Recruitment.	Modelled by a Ricker model, with numbers-at-age 1 assumed to be independent and normally distributed with mean $\eta_1 S \exp(-\eta_2 S)$, where S is the spawning–stock biomass at the start of the previous year. To allow recruitment variability to increase with mean recruitment, a constant coefficient of variation is assumed.	
Large year classes.	The 1986 year class was large, and recruitment at-age 1 in 1987 is not well modelled by the Ricker recruitment model. Instead, N(1, 1987) is taken to be normally distributed with mean $5\eta_1 S \exp(-\eta_2 S)$. The factor of 5 was chosen by comparing maximum recruitment to median recruitment from 1966–1996 for 6.a cod, haddock, and whiting in turn using previous XSA runs. The coefficient of variation is again assumed to be constant.	

Assessment years: 2004 to 2011.

Model used: TSA

Software used: Compaq visual FORTRAN using NAG library.

Model Options chosen:

Natural mortality (M) 0.2 at all ages.

Commercial data

- 1978–1994: treated as unbiased
- 1995–AY-1: omitted
- landings cvmult-at-age = c(1, 1, 1, 1, 1, 2, 2): extra variability for ages 6 and 7+

Discard model

- 1978–1994: ages 1and 2 modelled
- 1995–AY-1: omitted

Stock–recruit model

- Ricker
- large year class: 1986

Fishing selection model

- amat = 4: fishing selection flat (apart from noise) from age 4
- gudmundssonH1 = c(4, 1, 1, 1, 1, 1, 1): extra variability for age 1

Survey model (IBTS Q1)

- amat = 4: catchability flat (apart from noise) from age 4
- survey catchabilities up to amat assumed to follow a log-linear model
- survey cvmult-at-age = c(2, 1, 1, 1, 2, 2): extra variability for ages 1, 5 and 6
- ages 1 to 6 modelled
- only transitory changes in catchability allowed; modelled using the additive scale.

Summary of data ranges used in recent assessments (no accepted assessment in 2011)

Data	2007 assessment	2008 assessment	2009 assessment	2010 assessment
Catch data	Years: 1978–(AY-1) Ages: 1–7+	Years: 1978–(AY-1) Ages: 1–7+	Years: 1978–(AY-1) Ages: 1–7+	Years: 1978–(AY-1) Ages: 1–7+
Survey: WCIBTS.Q1	Years: 1985–AY Ages: 1–6	Years: 1985–AY Ages 1–6	Years: 1985–AY Ages 1–6	Years: 1985–AY Ages 1–6
Survey:	Not used	Not used	Not used	Not used
Survey:	Not used	Not used	Not used	Not used

Data	2012–2014 ASSESSMENT	2015–2018 assessment	2019 assessment
Catch data	Years: 1981–(AY-1) (1991–2005 age comps only) Ages: 1–7+	Years: 1981–(AY-1) (1991–2005 age comps only) Ages: 1–7+	1981–2005 & 2007 onwards (age comps only 1991–2005) Ages:2–7+
Survey: WCIBTS.Q1	Years: 1985–2009 Ages: 1–6	Years: 1985–2009 Ages: 1–6	Years: 1985–2009 Ages: 1–6
Survey: SCO.Q1	Not used	Years: 2010–AY Ages:1–6	Years: 2010–AY Ages:1–6
Survey:	Not used	Not used	

AY – Assessment year.

H.4. Current fisheries

H.5. Management and advice

H.6. Others (e.g. age terminology)

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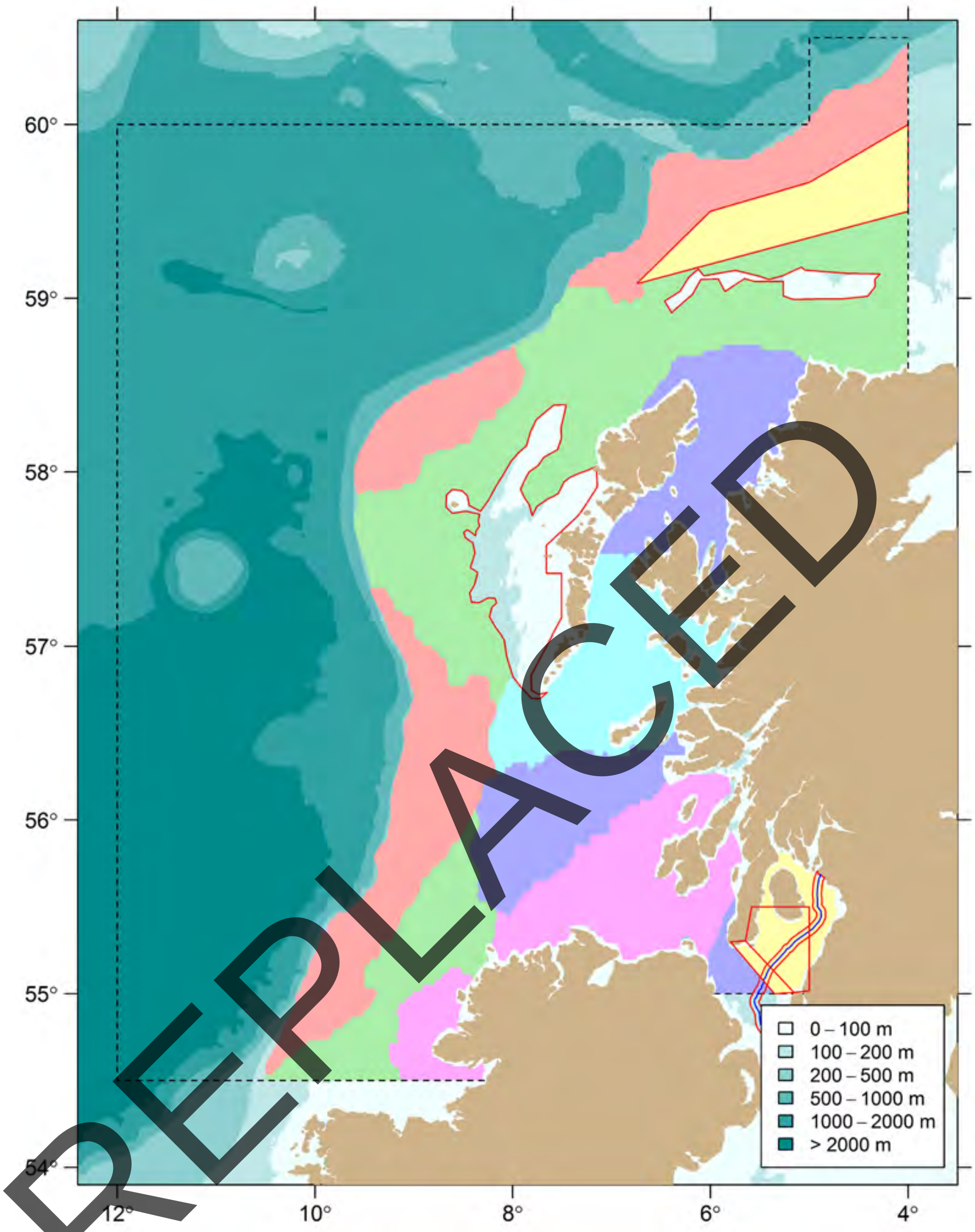

Figure H.1. Sampling strata of UKSGFS-WIBTS-Q1 survey.

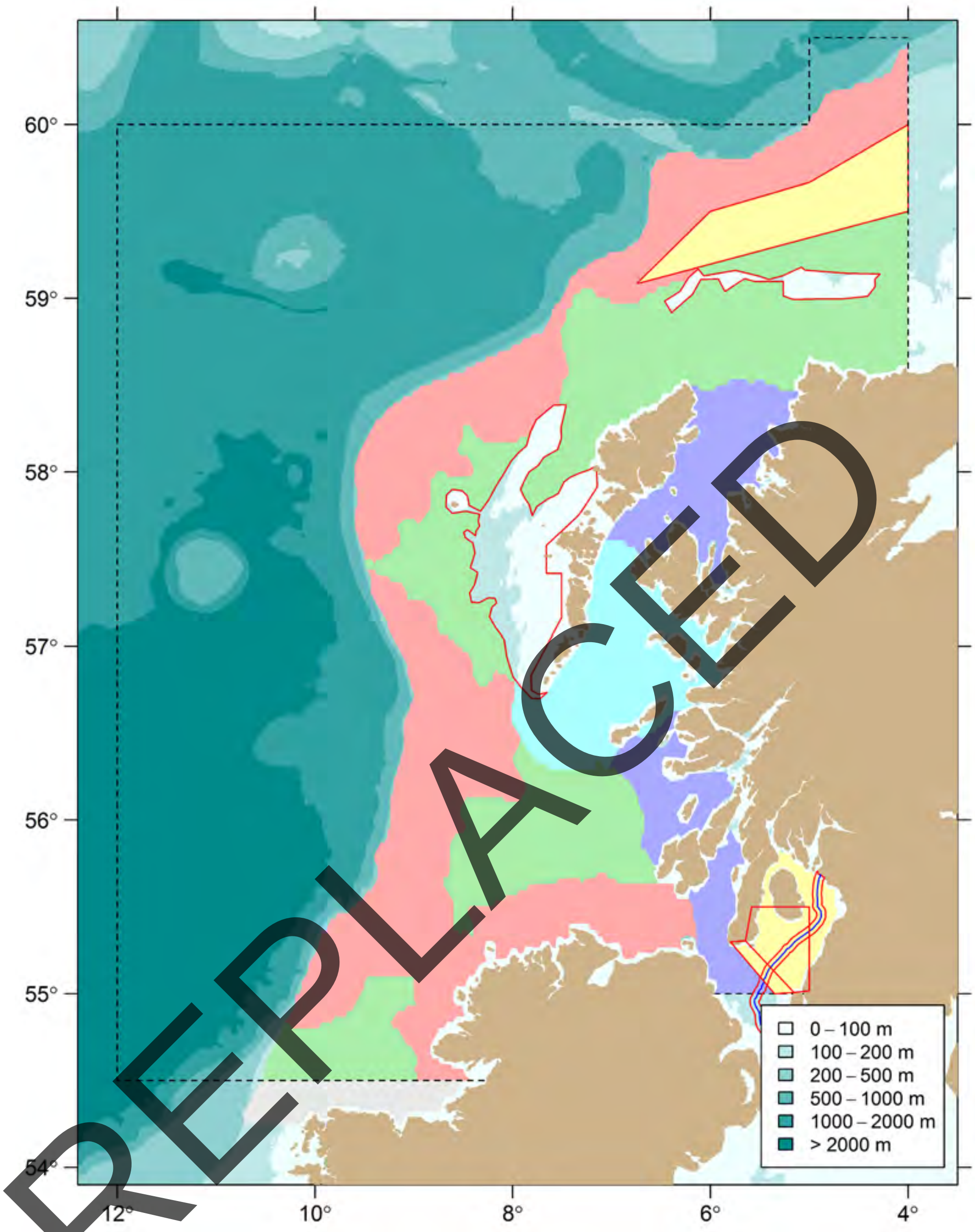

Figure H.2. Sampling strata of UKSGFS-WIBTS-Q4 survey.