BENCHMARK WORKSHOP ON NORTH SEA STOCKS (WKNSEA)

VOLUME 3 | ISSUE 25

ICES SCIENTIFIC REPORTS

RAPPORTS
SCIENTIFIQUES DU CIEM



ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371

This document has been produced under the auspices of an ICES Expert Group or Committee. The contents therein do not necessarily represent the view of the Council.

© 2021 International Council for the Exploration of the Sea.

This work is licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). For citation of datasets or conditions for use of data to be included in other databases, please refer to ICES data policy.



ICES Scientific Reports

Volume 3 | Issue 25

BENCHMARK WORKSHOP ON NORTH SEA STOCKS (WKNSEA)

Recommended format for purpose of citation:

ICES. 2021. Benchmark Workshop on North Sea Stocks (WKNSEA).
ICES Scientific Reports. 3:25. 756 pp. https://doi.org/10.17895/ices.pub.7922

Editors

Marie Storr-Paulsen

Authors

Larry Alade • Michael Andersen • Elena Balestri • Casper Willestoft Berg • Alan Baudron • Elliot Brown • Steve Cadrin • Kenny Coull • José De Oliveira • Gjert Endre Dingsør • Helen Dobby • Jim Ellis • Niall Fallon • Raphaël Girardin • Kieran Hyder • Andrzej Jaworski • Claudia Junge • Alex Kempf • Rosario Lavezza • Paul Macdonald • Geert Meun • Sander Meyns • Tanja Miethe • Sarah Louise Millar • Coby Needle • Anders Nielsen • Alessandro Orio • Alfonso Pérez-Rodriguez • Marie Storr-Paulsen • Giovanni Romagnoni • Henrik Sparholt • Klaas Sys • Lies Vansteensbrugge • Jasmine Vlietinck • Nicola Walker • Henning Wehde • Simon Weltersbach

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

Contents

i Executive summary v
ii Expert group information viii
1 Feedback to data call 1
2 How to judge by the diagnostics 3
3 Cod (27.47d20) 4
3.1 Summary 4
3.2 Stock ID 5
3.3 Data quality 6
3.3.1 Data evaluation meeting 6
3.4 Area-disaggregated commercial catch data, survey data and survey-based assessments 6
3.4.1 Data evaluation meeting 6
3.4.2 Benchmark workshop 9
3.5 Indices (fishery-independent) 12
3.5.1 Data evaluation meeting 12
3.5.2 Benchmark workshop 12
3.6 Maturity 17
3.6.1 Data evaluation meeting 17
3.6.2 Benchmark workshop 17
3.7 Recruitment 18
3.7.1 Benchmark workshop 18
3.8 Stock weight 19
3.8.1 Data evaluation meeting 19
3.8.2 Benchmark workshop 19
3.9 Recreational data 20
3.9.1 Data evaluation meeting 21
3.9.2 Benchmark workshop 22
3.10 Natural mortality 24
3.10.1 Data evaluation meeting 24
3.10.2 Benchmark workshop 24
3.11 Final model settings (SAM) 26
3.11.1 Benchmark workshop 26
Final assessment model 31
Data 31
Model settings 31
3.12 Short-term forecast 36
3.12.1 Benchmark workshop 36
3.13 Reference points 38
3.13.1 Benchmark workshop 38
Source of data 38
Stock–recruitment relationship and new B_{lim} and B_{pa} reference points 38
Methods and settings used to determine ranges for F_{MSY} 40
Final Eqsim run 41
Proposed MSY and PA reference points 44
3.14 Re-opening of advice 44
4 Spurdog (dgs.27.nea) 47
4.1 Summary 47
4.2 Earlier models and uncertainty 48
4.3 Surveys 49
4.3.1 Data evaluation meeting 49

4.3.2 Benchmark workshop 50
4.4 Growth parameters and age 55
4.4.1 Data evaluation meeting 55
4.4.2 Benchmark workshop 56
4.5 Reproductive parameters 56
4.5.1 Data evaluation meeting 57
4.5.2 Benchmark workshop 57
4.6 Other biological parameters in the model 58
4.6.1 Natural mortality 58
4.6.2 Length–weight relationship 58
4.7 Catch data and commercial size composition 58
4.7.1 Data evaluation meeting 59
Catch data 59
Commercial size composition 59
4.7.2 Benchmark workshop 59
Catch data 59
Commercial catch composition 60
4.8 Final model settings (length-based) 64
4.8.1 Benchmark workshop 64
Comparison: current assessment and final WNSEA 2021 benchmark assessment 64
Sensitivity analyses 66
Final benchmark assessment model fits and diagnostics 66
Sensitivity to the density-dependent fecundity parameter Q_{fec} 71
Final benchmark assessment estimates 74
4.9 Short-term forecast 76
4.9.1 Benchmark workshop 76
4.10 Reference points 76
4.10.1 Benchmark workshop 76
5 Whiting (whg.27.6a) 80
5.1 Summary 80
5.2 Stock structure 81
5.3 Catch data 81
5.3.1 Data evaluation meeting 81
5.4 Survey indices 81
5.4.1 Data evaluation meeting 81
5.4.2 Benchmark workshop 82
5.4.2.1 Index estimation 82
5.4.2.2 SURBAR analysis 84
5.5 Maturity 86
5.5.1 Data evaluation meeting 86
5.5.2 Benchmark workshop 86
5.6 Stock weight 87
5.6.1 Data evaluation meeting 87
5.6.2 Benchmark workshop 88
5.7 Mortality 89
5.7.1 Data evaluation meeting 89
5.7.2 Benchmark workshop 89
5.8 Final Assessment Model 90
5.8.1 Input Data 90
5.8.2 Sensitivity Analysis & Final SAM settings 90
5.8.3 Assessment Results 91
5.9 Short-term forecast 99
5.9.1 Benchmark workshop 99

Method 99
Recruitment 99
Biological and fishery parameters 100
5.10 Reference points 100
5.10.1 Benchmark workshop 100
PA reference points 100
MSY Reference points 102
6 Sole (sol.27.7d) 104
6.1 Summary 104
6.2 Catch data 105
6.2.1 Data evaluation meeting 105
6.2.2 Benchmark workshop 106
6.2.2.1 Preparation of catch data (InterCatch) 106
6.2.2.2 Reconstruction of the discards 107
6.3 Stock weight 111
6.3.1 Data evaluation meeting 111
6.3.2 Benchmark workshop 111
6.4 Subpopulations 112
6.4.1 Data evaluation meeting 112
6.4.2 Benchmark workshop 113
6.5 Indices of abundance 113
6.5.1 Data evaluation meeting 113
6.5.1.1 Commercial tuning fleets 113
6.5.1.2 Survey tuning fleets 114
6.5.2 Benchmark workshop 114
6.5.2.1 Commercial tuning fleets 114
6.5.2.2 Survey tuning fleets 120
6.6 Models to prepare for benchmark 120
6.6.1 Data evaluation meeting 120
6.7 Final model settings (SAM) 121
6.7.1 Benchmark workshop 121
6.8 Short-term forecast 128
6.8.1 Benchmark workshop 128
6.9 Reference points 129
6.9.1 Benchmark workshop 129
7 External reviewers 130
7.1 Cod (27.47d20) 130
7.1.1 Biological analysis 131
7.1.2 Data input 132
7.1.3 Model 133
7.1.4 Biological reference point 134
7.1.5 Short-term forecast 135
7.2 Spurdog (dgs27.nea) 136
7.2.1 Biological analysis 136
7.2.2 Data input 136
7.2.3 Model 137
7.2.4 Biological reference point 137
7.2.5 Short-term forecast 138
7.3 Whiting (whg.27.6a) 139
7.3.1 Biological analysis 139
7.3.2 Model 140
7.3.3 Biological reference point 140
7.3.4 Short-term forecast 141

7.4 Sole (sol.27.7d) 142
7.4.1 Major issues addressed at the benchmark 142
7.4.2 Data 142
French catch data 142
Belgian Comm BT fleet 142
Raising Discard Data 143
Reconstruction of discards (Pre-2004) 143
Stock weight 143
Tuning Indices 144
7.4.3 Biological analyses 145
Subpopulations 145
Assessment Models 146
7.4.4 Biological reference points 147
7.4.5 Short-term forecast 147
7.4.6 Future recommendations 147
8 References 149
8.1 References for spurdog section 151
Annex 1: Lists of participants 153
Data compilation workshop 153
Benchmark workshop 154
Annex 2: Recommendations 156
Annex 3: Issue lists 157
Cod in Subarea 4, Division 7.d and Subdivision 20 157
Spurdog 27 NEA 160
Whiting 6.a 162
Sole 27.7.d 165
Annex 4: Sensitivity runs for spurdog 167
1. Recruitment deviates 167
2. Recruitment variation 168
3. Length–frequency data weighting (commercial catch versus survey) 170
4. Survey observation CVs 172
5. Surveys included 172
6. Growth 173
Annex 5: Stock annexes 174
Annex 6: Working documents 175
Cod 175
Sole 175
Spurdog 175
Whiting 176
Annex 7: Additional External Reviews for North Sea cod 746

i Executive summary

Four stocks were included in the Benchmark: Cod (27.47d20), Spurdog (dgs.27.nea), Sole (sol.27.7d) and Whiting (whg.27.6a).

The data evaluation workshop was conducted 24–26 November 2020. However, some data were not available at the data evaluation meeting and therefore it was decided to have two additional one-day meetings before the benchmark on recreational cod data and cod indices from surveys. The actual benchmark was conducted from the 22–26 February 2021. Due to lack of time the final decisions on cod reference points and a decision on reopening of the advice was not taken within the regular benchmark meeting, and two extra days were allocated to these issues. All meetings were conducted online, and therefore the numbers of participants fluctuated through the meeting depending on the topic. The report is structured with a part reflecting the data meeting decisions in the beginning of each chapter followed by a part reflecting the decisions taken at the benchmark workshop.

The four stocks had some main issues that needed to be investigated before the benchmark. The issue list for all stocks are included in the annexes.

The North Sea **cod** stock was put forward for benchmark in 2021 due to conflicting signals in the underlying data and a developing retrospective bias in the assessment. In addition, the stock ID was put forward as an issue for North Sea cod. To address the latter, a four-day workshop on Stock Identification of North Sea Cod (WKNSCodID) was held in August 2020 to review information on the population structure of cod in the North Sea and adjacent waters. The workshop concluded that North Sea cod includes reproductively isolated Viking and Dogger cod populations, and the Dogger population has some phenotypic structure and extends to 6.a.N. However, the data evaluation workshop found unexplained discrepancies between the spatially-disaggregated data and the data as used in the current assessment, possibly caused by the very short timeframe for data providers to compile the data. Further, the spatially-disaggregated time-series started in 2002 which would truncate the time-series with 40 years. Therefore, the workshop concluded that development of spatial approaches would not be possible in time for a benchmark in 2021, although it was agreed that a spatial-disaggregated cod assessment would be preferable and work to archive this goal should be initiated in the next years. However, after consultation with the ACOM LS it was decided to improve the present combined assessment until a spatially-disaggregated time-series would be available. At this benchmark;

- recreational catches were considered but not included in the analytic assessment due to data quality issues.
- Updates were made to the base calculations for deriving the subarea-weighted maturity ogive. The first 15 years (1963–1977) were removed and the ogive not smoothed. Further, maturity is now modelled as a process.
- Stock weights have changed to IBTS Q1 survey weights for ages 1–2 and as Q1 catch weights for ages 3+.
- A high-resolution delta-GAM survey indices with a fixed spatial term and yearly independent deviances is now used.
- Introduction of a recruitment index based on the IBTS Q3 at age 0 and shifted to the beginning of the following year has been introduced.
- Smoothed M data from the 2020 SMS key run is included with an addition of adjusted Ms from 2011 for ages 3+ to mimic migration out of the stock area into 6aN.
- Several configuration adjustments were made to the model.

- New reference points were calculated based on a truncated time-series (1998–2019) and a type 6 S–R plot.
- Inclusion of both age 0 and age 1 in the protocol on the reopening of the advice.

The **spurdog** assessment is the only elasmobranch category 1 assessment with an integrated age–length-based assessment that includes catch data back to 1905. Survey indices included in the assessment was before the benchmark only covering a relatively small part (primarily divisions 6.a and 4.a) of the entire stock distribution area, and one of the main aims of the benchmark was to improve on this by including a number of eligible surveys in the assessment covering a much larger area. Further, the inclusion of new fecundity data along with improved information on growth was on the issue list. Finally, inclusion of fleet-based data (including length distributions), and better catch information since 2010 was to be addressed and a data-call was set up to request this information. Four main topics were considered in this benchmark (i) catch data (landings, discards and commercial size and sex composition), (ii) survey indices (biomass indices and size and sex composition), (iii) biological parameters, and (iv) reference points. Based on the discussion on the time of year and spatial coverage of the various surveys in DATRAS and those made available as part of the data call, the workshop agreed to derive three separate biomass indices, one per quarter (Q1, Q3, Q4):

- Q1 index, based on four survey time-series: NO-SH, NS-IBTS, SWC-IBTS, SCOWCGFS [1985–present].
- Q3 index, based on NS-IBTS [1992–present]
- Q4 index, based on five survey time-series: SWC-IBTS, SCOWCGFS, NIGFS, IE-IGFS, EVHOE [2003–present].

The quarter 1 and quarter 4 indices were modelled.

Survey length composition was changed to an index by sex and survey index.

Fecundity data used to inform the model were improved from having two data years (1960, 2005) to include 13 data years covering the timer period 1921–2020.

For reference points B_{lim} was set to 20% of B0 as the model goes back to 1905 were reporting of landings were relatively low and well before the high exploitation in the 1950s and onwards.

Prior to 2020, the **whiting 6a** was a category 1 stock with an analytical assessment (TSA). The stock previously went through a benchmarking process in 2020 (WKDEM; ICES, 2020) which was unsuccessful largely due to a lack of modelling preparedness and a reliance on TSA as the assessment method, which is slow to converge and difficult to optimise without developer assistance. At that meeting the reviewers rejected the latest TSA configuration and alternative configurations failed to converge, and as a result the benchmark fell back on the use of SPiCT for a category 3 'trends-only' assessment (3 v 2). During the 2020 advisory process, the approach agreed at the benchmark (and utilised by the assessment WG) was rejected by ACOM and the stock down-graded to category 5. However, throughout the benchmarking and advisory process, it was acknowledged that there was substantial informative data on this stock (both commercial sampling and surveys) and that a category 1 stock assessment ought to be possible for this stock. WGCSE therefore proposed this stock for immediate re-benchmarking in 2021. The current process builds on the progress in terms of data compilation made during the 2020 process and to change model to SAM as the assessment method. The data call provided revised catch data from 2003 onwards and included 0-group which have not previously been included in the stock assessment.

Five research vessel survey series were used in the previously accepted (2012–2019) category 1 stock assessment for whiting in 6.a. The possibility of combining two current Q4 surveys was explored within WGISDAA in 2018–2020 and a combined index was delivered as a result for the

assessment of the stock. The combined index was also approved at WKDEM 2020 and used by WGCSE in 2020. This benchmark proposed extending the analysis to include all the three Q4 surveys (ScoGFS-WIBTS-Q4, UK-SCOWCGFS-Q4 and IGFS-WIBTS-Q4). As a result, one index has been delivered for the Q4 surveys. The two Q1 surveys series remain to be treated as two separate series.

The stock weight used in the stock assessment was reviewed, it was decided during the data evaluation meeting that stock mean weights-at-age 0 to 2 should be obtained from survey data, while stock mean weights-at-age 3 and above should be obtained by averaging between survey and catch data. Further stock mean weight-at-age was also used to estimate natural mortality-at-age with the Lorenzen (1996) equation.

The model used for assessment was changed to SAM and sensitivity analyses were carried out on settings for: the stock–recruitment relationship used, fleet covariance configuration, survey catchability coupling, observation variance coupling, and fishing mortality states process coupling.

Reference points were re calculated and due to the gadoid outburst in the 1960s and 1970s which affected demersal stocks in the seas around the it was agreed that the four datapoints at the start of the time-series (1981–1984) should be excluded from further analysis. The stock then falls into the Type 3 category, which therefore requires a stock specific or expert judgement for setting B_{lim}. The recruitment time-series suggests a period of high recruitment pre-2000 and then lower recruitment since then. The approach was therefore to use the lowest SSB associated with this period (1999) which results in B_{lim} = 17 286 t with a B_{pa} = 25 597 t.

Sole in Division 27.7d had data issues with a commercial tuning series, and an inter-benchmark was set up in August 2019. At the end of the inter-benchmark, it was found that some commercial catch data for 2016 and 2017 were aggregated incorrectly for older ages. During the benchmark in February 2020 (WKFLATNSCS 2020), further data issues were discovered. As a result, the benchmark process was postponed to the WKNSEA 2021 benchmark, and in the data call, the commercial catch data time-series was corrected and re-uploaded. Discard data were available from 2004 onwards. Prior to 2004, discards were reconstructed using the ratio between discards and landings in the period 2004–2008. Stock weight-at-age were set to quarter 1 catch weight-at-age (2004–2019) to improve consistency. They were reconstructed prior to 2004 using the ratio between quarter 1 and yearly catch weight-at-age using data from 2004–2019.

Six tuning fleets are currently included in the assessment: three survey indices (UK BTS, FRA YFS and UK YFS) and three commercial indices (BEL CBT, UK CBT, FRA COTB). During the benchmark, the commercial indices were changed to biomass indices in the assessment instead of disaggregating them by age to avoid double counting of commercial data. The French commercial otter trawl fleet (FRA COTB) and Belgian commercial beam trawl fleet (BEL CBT) were revised using the adjusted catch data as input and following a model-based approach to derive an lpue index that is considered to reflect the fishable biomass of the stock.

A state–space assessment model (SAM) was chosen for this stock using the three commercial lpue indices as fishable biomass (FRA COTB, BEL CBT, UK CBT) and three scientific, age-structured survey indices (UK BTS, UK YFS, FRA YFS). Compared to the previous XSA assessment model, the spawning–stock biomass is estimated to be significantly lower, while the fishing mortality is estimated to be higher. Following the changes in the input data and assessment model, the reference points were re-calculated and F_{MSY} is now estimated at 0.193 (similar to previous estimate).

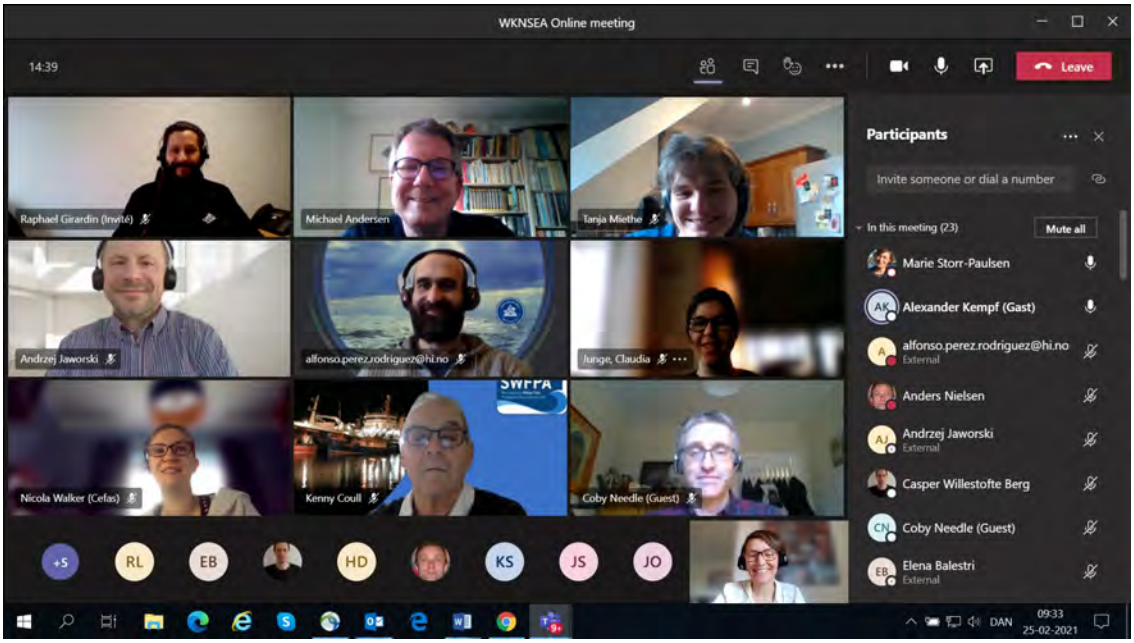
ii Expert group information

Expert group name	Benchmark Workshop on North Sea Stocks (WKNSEA 2021)
Expert group cycle	Annual
Year cycle started	2020
Reporting year in cycle	1/1
Chair	Marie Storr-Paulsen, Denmark
Invited Experts	Benoit Berges, Netherlands, Valerio Bartolino, Sweden and Larry Alade, US
Meeting venues and dates	24–26 November 2020, Data Compilation WK, Online
	22–26 February, Benchmark WK, Online

Data Evaluation meeting



Benchmark meeting



1 Feedback to data call

The data providers' experience with the data call for this benchmark was discussed during the data compilation workshop, and feedback to improve the process was requested.

There is a clear framework of set dates and formats for the annual provision of ICES advice. This allows both the secretariat and stock assessment and advice WGs to plan their work and provide timely advice. The data providers and WGCATCH recommend for future data calls:

That ICES include data calls into this framework, to allow data providers, and related ICES WGs, to plan their work and to ensure the best quality and quantity of data are provided. Specifically:

- A standard format and checklist for data calls is developed to ensure all information required by the data provided is included in a clear and standard structure.
- Stock assessment data calls should request only an update of the previous year's data and the deadlines for these data calls should be extended to two months.
- The deadlines for all data calls requiring time-series of data or new data, for example benchmark data calls, should be extended to four months. The extent of the time-series requested should be clearly specified.
- For time-series of data or new data requests, a preparatory data call should be released, before the data call is prepared, requesting information on sample sizes and years available.
- WGCATCH representatives are involved in preparation of the data calls in the same way as the stock assessors and stock co-ordinators.
- A standard timeline of dates is introduced for benchmark data calls as outlined in the table below.

Timeline for a benchmark in year y **Additional or changed timelines are included in bold.**

Date	Action
Spring y-2	WGs discuss benchmark stocks at their annual meetings
November y-2	WGs provide list of desired stocks for benchmarks for year y
March y-1	ACOM approves list of stocks with justification
Spring y-1	Secretariat, stock-assessors, WGCATCH formulate data calls
May y-1	Benchmark data calls released with four month deadlines
Summer y-1	WKbenchmarkname-DP online *described below
Late Oct y-1	Data call deadlines
Nov y-1	Data compilation WKs
Feb y	Benchmark WKs

Specific comments on the present data call:

A note in respect to 'as long as possible' – that would be a fair question to ask before the final data call e.g. at the meeting with the data providers and then settle for specific periods in the data call – if relevant there could also be different periods for discard, landings with biology and landing without (- and countries?). In respect to North Sea cod, it was not clear that CATON split by division / subdivision could be valuable further back in time without any biology. If this has been made clear many countries could have provided data further back in time.

It was difficult to get an overview what kind of data the group is after, many countries overlook the recreational data – the table from WKWEST 2021 data call gives a really nice overview.

For cod no reference to fleet definitions.

The area codes – 27.4.a.W and 27.4.a.E – are already in use for her.27.3a47d, but the split between west and east differs for the two stocks, which could be problematic. Further, these areas were not defined with a longitude in the ICES vocab, which would be preferable.

2 How to judge by the diagnostics

It was during the data evaluation meeting discussed which quality measures to evaluate different datasets and model settings by and it was decided to look at:

- Internal consistency on new survey indices
- Improved retro (Mohn's Rho)
- Log (L) / AIC
- Stability of model

3 Cod (27.47d20)

3.1 Summary

The cod stock in the North Sea (Subarea 4), the Skagerrak (Subdivision 20) and the eastern Channel (Division 7.d) was last benchmarked in 2015, and has been put forward for benchmark in 2021 due to conflicting signals in the underlying data and a developing retrospective bias in the assessment. In addition, the benchmark in 2015 identified stock ID as an issue for North Sea cod. To address the latter, a four-day workshop on Stock Identification of North Sea Cod (WKNSCodID) was held in August 2020 to review information on the population structure of cod in the North Sea and adjacent waters. The workshop concluded that North Sea cod includes reproductively isolated Viking and Dogger cod populations, and the Dogger population has some phenotypic structure and extends to 6.a.N. To facilitate development of spatial approaches to stock assessment, data were requested at a finer resolution (divisions 4b, 4c and 7d and subdivisions 4aE, 4aW and 3a20) to a new 'stock' in InterCatch (CDZ). However, the data compilation workshop found unexplained discrepancies between the spatially disaggregated data (CDZ) and the data as used in the current assessment (COD), possibly caused by the very short timeframe for data providers to compile the data. The workshop therefore concluded that development of spatial approaches would not be possible in time for a benchmark in 2021.

Nevertheless, it was decided to continue with the benchmark although we do not have the disaggregated data at a level where we can include it for a final assessment. Furthermore, the inclusion of 6.a (at least northern part) and 3.a.S (for younger ages) would also need to be investigated when new areas are considered.

It was acknowledged that we are still able to improve the stock assessment with the present stock areas by improving survey indices, maturity ogive, stock weight, natural mortality and investigation of recreational data, and choice of model settings, which will contribute to the data and assessment issues that triggered this benchmark process. We will continue with exploratory runs with the subareas and try to improve these disaggregated input data in a process that will continue beyond this benchmark, possibly in a dedicated additional series of workshops.

In addition to the information provided in the current report chapter, the reader is also referred to the following eight Working Documents that provide further details of the relevant datasets incorporated in the final assessment model:

1. Walker D. N. 2020. WD_cod_1_Catch data for COD. Summary of InterCatch data for North Sea Cod (COD) Working Document for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020, 2021; 6 pp.
2. Needle C. 2021. WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.
3. Walker D. N. and. Berg C. W. 2020. WD_cod_3_Survey abundance and indices. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 14 pp.
4. Berg C. W. 2021. WD_cod_4_NScod_surveyIndices. Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 102 pp.
5. Walker D. N. WD_cod_5_maturity. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 13 pp.

6. Walker D. N. WD_cod_6_stock weights. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 6 pp.
7. Armstrong M., Weltersbach S, Radford Z, and Hyder K. WD_cod_7_recreational cod catches. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 16 pp.
8. Nielsen A. WD_cod_8_Process model for biological parameters in SAM. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.

3.2 Stock ID

Conclusions and recommendations from the Workshop on Stock Identification of North Sea Cod (WKNSCodID) were presented and discussed. WKNSCodID reviewed information on population structure of cod in the North Sea and adjacent waters and concluded that North Sea cod appear to be isolated from the cod population on the Faroe Plateau (Subdivision 5.b.1) and Norwegian Coastal Cod (subareas 1–2), but cod in the North Sea include reproductively isolated populations of Viking cod and Dogger cod that have some spatial overlap and mixing after spawning. The Skagerrak and northern Kattegat appear to be a nursery ground for Viking and Dogger cod, with most cod in the Skagerrak being Viking cod. These genetically different groups have different rates of maturity and growth. Trends in biomass and recruitment are strongly correlated among subareas of the North Sea, but subarea trends diverged in the last decade, with no apparent rebuilding in the southern North Sea.

Viking cod inhabit the northeast North Sea (on and around Viking Bank, 4.a). The spatial distribution of Viking cod extends westward to the Shetlands (western part of 4.a) and southward to the Fischer and Jutland Banks (northern part of 4.b), with and a nursery area in the Skagerrak (20). Some Viking cod juveniles also inhabit the Kattegat (21). The Dogger cod population inhabits the south–central North Sea (on and around Dogger Bank, 4.b), along the Scottish coast to the north of Scotland (northern part of 6.a), and in the eastern English Channel (7.d), with some adults seasonally migrating to the western English Channel (7.e–k). The available information does not provide clear evidence of genetic heterogeneity within the Dogger cod population. However, the Dogger cod population appears to have some phenotypic spatial structure, approximately delineated by the 50 m bathycline in the central North Sea (4.b). Cod north of this boundary (4.a and parts of 4.b) exhibit differing rates of growth and maturity, as well as recent biomass trends, compared to those to the south (4.c). There is relatively little mixing of cod between 4.a and 4.b and sedentary behaviour along the British coast.

WKNSCodID recommended that ICES stock assessments recognize and account for Viking and Dogger cod populations and consider accounting for phenotypic stocks within the Dogger population. A range of spatial approaches to stock assessment methods and advice should be considered, including a single-area assessment of the current advisory unit, fleets-as-areas, spatially structured assessments, fully separated subarea assessments, and survey-based assessments; ideally with simulation testing to evaluate the relative performance of these alternatives. WKNSCodID recommended a minimum spatial resolution for fishery data (i.e. catch by major fleets) and survey data, over as long a time-series as possible, by ICES divisions (e.g. 4.a, 4.b, 4.c, 7.d) and subdivisions (e.g. 20), and a relatively simple division of the northern North Sea (4.a.West and 4.a.East, divided at the prime meridian, 0°longitude) to approximately represent the most plausible delineation between the Viking and Dogger cod populations.

The ability of the benchmark assessment to reflect the new paradigm of cod stock structure is limited by challenges of spatially disaggregating historical fishery data, the differences between the CDZ data and COD data, and the decision to consider connectivity of cod between 6.a. north

and 4.a.west in a future benchmark workshop. The WKNSCodID suggestion for fleet-based assessments was clarified to explain that historical fisheries can be modelled as a spatially-aggregated fleet, and recent fisheries can be modelled as spatially-defined fleets in a single integrated assessment model. Survey-based assessments of Viking and Dogger cod as well as exploratory assessments that include 6.a. north suggest that these approaches are promising, but several iterations of data compilation and modelling may be needed to clarify the data request (e.g. spatially disaggregated CATON as far back as possible), to resolve differences between CDZ and COD, and to develop assessments that accurately represent cod stock structure.

3.3 Data quality

3.3.1 Data evaluation meeting

Updates to the French discard data resulted in only minor differences compared to the present dataset. It is therefore unnecessary to raise data again.

For further information on the commercial data quality see WD_cod_1_Catch data for cod.

3.4 Area-disaggregated commercial catch data, survey data and survey-based assessments

3.4.1 Data evaluation meeting

The ICES WKNSCodID meeting (ICES, 2020a) concluded that the most biologically plausible split for the North Sea cod stock was between Viking (approximately 4aE) and Dogger (approximately 4aW, 4b, 4c7d, 3a20) cod (see Figure 3.4.1 and Section 3.2), and developed a data call for the subsequent benchmark data compilation meeting DEWK (ICES, 2020b) to collate catch and survey data separately for the 4aE, 4aW, 4b, 4c7d, and 3a20 areas. This has given rise to two separate InterCatch "stocks": COD, which is the current stock object covering the full North Sea, eastern Channel and Skagerrak; and CDZ, which is a separate stock object covering the same region but disaggregated to the areas determined for DEWK. This section presents the current situation with the collation of the CDZ stock object, before going on to cover survey-based trends for the northwest (4aW), Viking (4aE) and south (4b, 4c7d, and 3a20) areas.

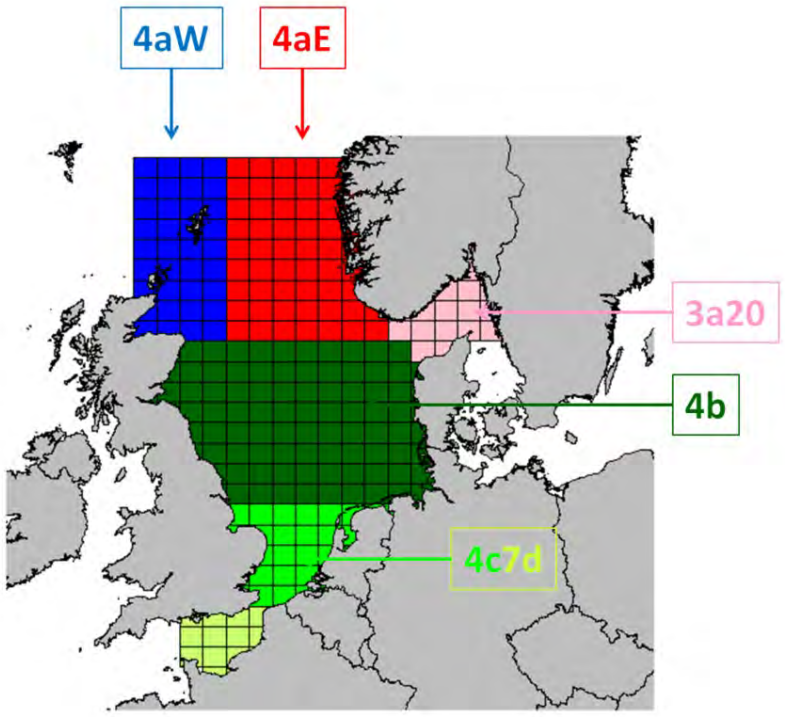


Figure 3.4.1. North Sea cod data areas as stipulated by ICES WKNSCodID (ICES, 2020a).

Following WKNSCodID, the data call published by ICES asked for data for "as many years as possible". The call was addressed by all nine relevant coastal nations (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, UK (England), UK(Scotland)), and data were received for the years 2002–2019. Data on both age and length were provided, although only age coverage is considered here as any subsequent assessment is likely to be based at least in part on age.

Data coverage by catch category (landings, discards), area and year was highly variable, with data provision being relatively sparse in the earlier years. Table 3.4.1 summarises the number of age samples submitted for different categories, countries and areas for 2019 (the most recent year) and 2002 (the first year with age samples). In 2019, both landings and discards age sampling were reasonable for all areas except 4c and 7d. In contrast, the number of age samples was reasonable for landings and discards probably only for 3a20 and 4b; we also note that the number of countries submitting data was much less for 2002.

Table 3.4.1. Summary of the number of submitted age measurements by catch category (B = below minimum size by-catch, D = discards, L = landings), country and area, for 2019 (top) and 2002 (bottom).

Sum of NumAgeMeasurement	Column Labels						
Row Labels	27.3.a.20	27.4.a.e	27.4.a.w	27.4.b	27.4.c	27.7.d	Grand Total
B			**36**				**36**
UK(Scotland)			36				36
D	**2115**	**1783**	**1234**	**1333**			**6465**
Belgium				173			173
Denmark	1212	482					1694
France		0	0				0
Germany		909		538			1447
Sweden	903						903
UK (England)				364			364
UK(Scotland)		392	1234	258			1884
L	**23693**	**6144**	**1170**	**10360**	**118**	**9**	**41494**
Belgium				256		9	265
Denmark	10608	3456		6670			20734
France		0	0				0
Germany	130	2098		1534			3762
Netherlands					115		115
Sweden	12955						12955
UK (England)				1765	3		1768
UK(Scotland)		590	1170	135			1895
Grand Total	**25808**	**7927**	**2440**	**11693**	**118**	**9**	**47995**

Sum of NumAgeMeasurement	Column Labels					
Row Labels	27.3.a.20	27.4.a.e	27.4.b	27.4.c	27.7.d	Grand Total
D	**1042**	**280**	**1105**			**2427**
Denmark	1042	280	205			1527
Germany			900			900
Sweden	0					0
UK (England)			0			0
L	**40349**	**811**	**52379**	**1769**	**808**	**96116**
Denmark	40349		31382			71731
Germany		811	1114			1925
Netherlands			317	1072		1389
UK (England)			19566	697	808	21071
Grand Total	**41391**	**1091**	**53484**	**1769**	**808**	**98543**

Figure 3.4.2 compares the total estimated catch across the full NS area following InterCatch allocations and raising, for both COD and CDZ stock objects. It can be seen that the total catch is not the same for COD and CDZ; and it should be. This issue will need to be addressed in future work.

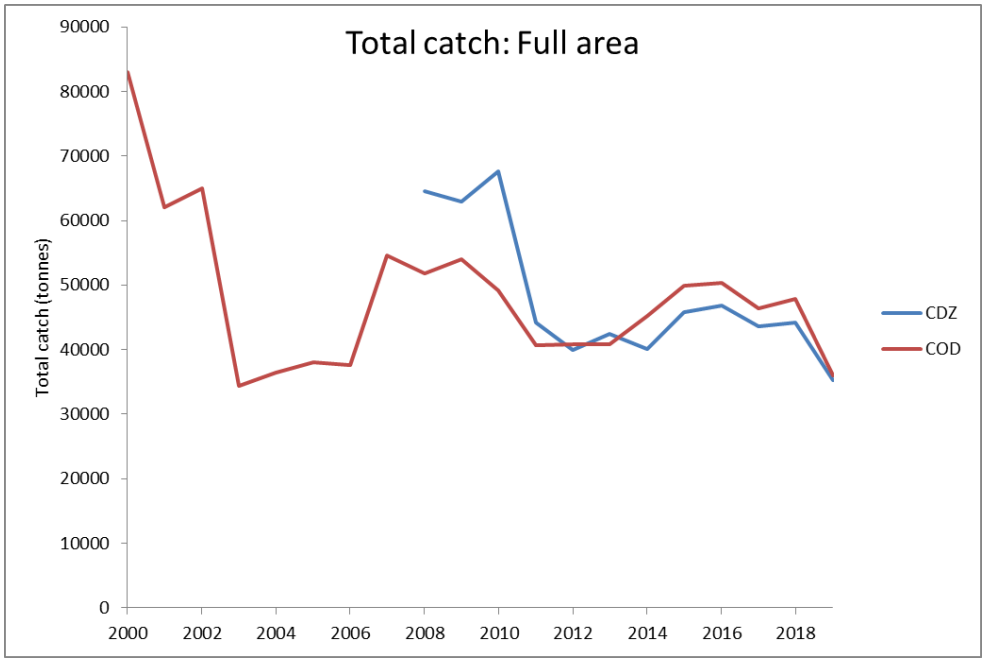


Figure 3.4.2. Total catch across the full NS area, as estimated through InterCatch for the COD and CDZ stock objects.

The DEWK meeting determined that there was unlikely to be sufficient catch data yet in the CDZ stock to enable full catch-based assessments for the separate stock areas. Data had been submitted from 2002 onwards only, and was only really representative from 2008 onwards. DEWK concluded that the length and coverage of the CDZ dataset was not sufficient to consider replacing the extant full-stock NS cod assessment with substock alternatives, and the main benchmark meeting was therefore to focus on the full-stock assessment.

However, it remains the case that there are biologically significant differences between (in particular) the Viking substock and the rest, and there are clear linkages between the North Sea stock(s) and the northern West of Scotland stock: neither of these points is reflected in the current full-stock assessment. A longer-term project is being planned to attempt to address these issues through a more holistic spatial assessment approach covering the North Sea *and* neighbouring areas.

3.4.2 Benchmark workshop

The current North Sea cod WG report and advice both include a survey-based biomass comparison between different areas. It is therefore relevant to consider new, updated survey-based assessments of the separate substock areas.

Needle (WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod substocks) considered three methods of generating substock-specific survey indices, fitted a survey-based assessment model (SURBAR) to each, and considered further how the outputs could be used to provide management advice should that prove necessary. The conclusions were similar across the methods, however, and only the third approach presented by Needle will be considered here.

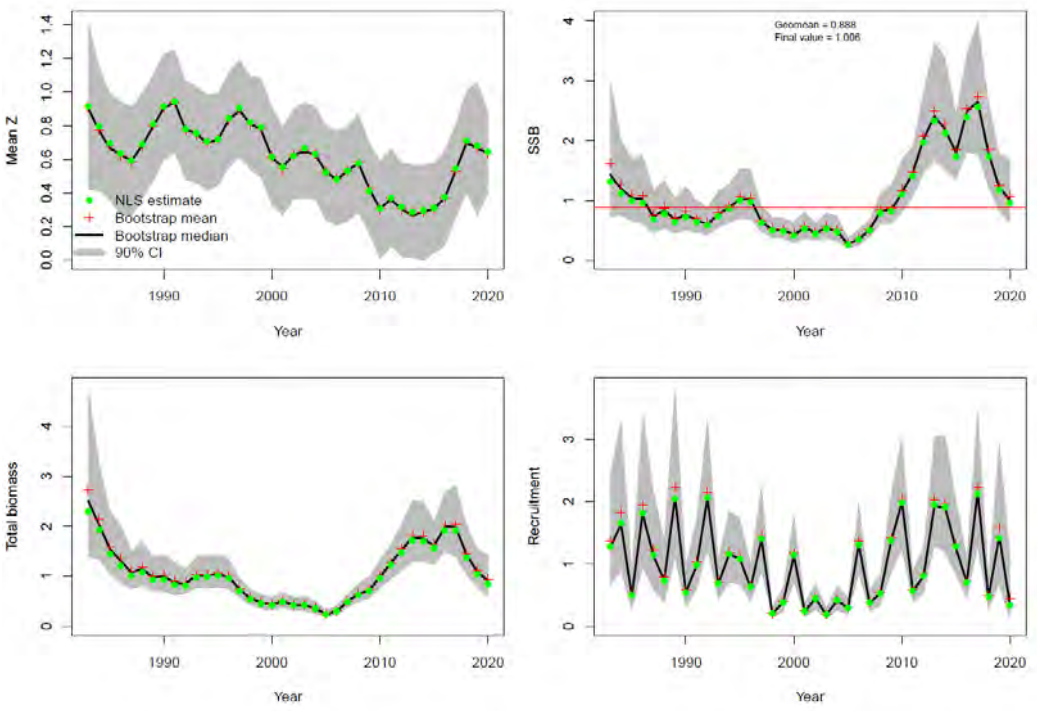


Figure 3.4.2.1. SURBAR assessment results for the northwest cod (northern Dogger) substock. Plots give the best (NLS) estimate, the bootstrap mean and median, and a 90% confidence interval. SSB, TSB and recruitment-at-age 1 are mean-standardised. The SSB plot (top right) includes the geometric mean (red line), and a legend giving the geometric mean and the final-year SSB estimate.

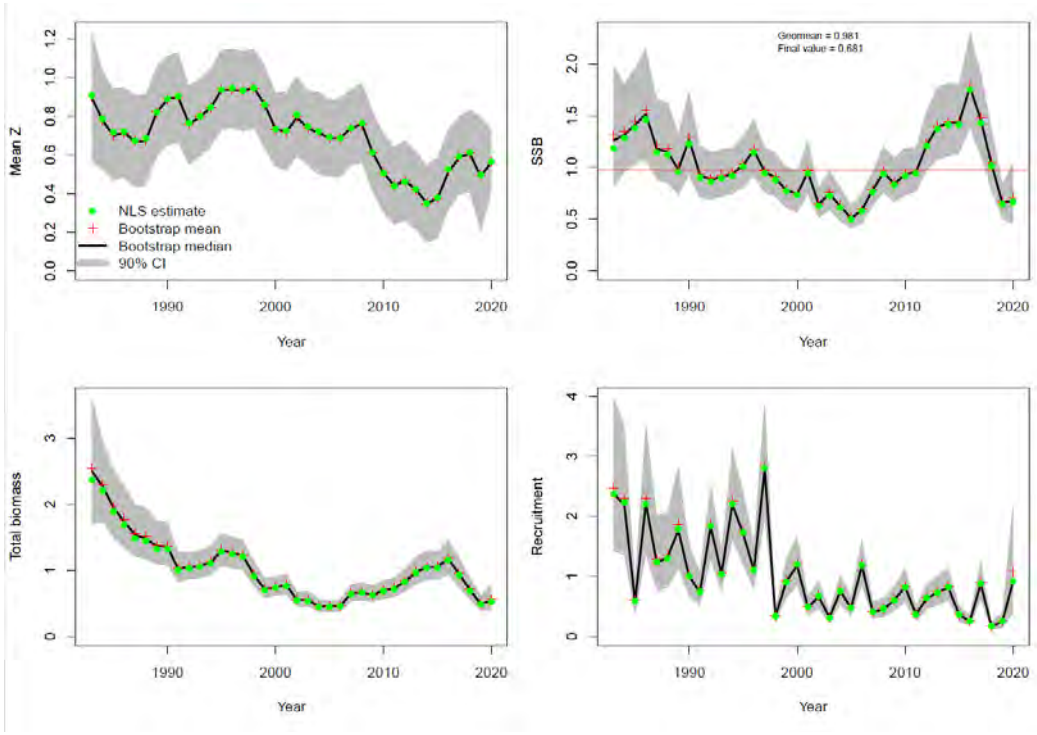


Figure 3.4.2.2. SURBAR assessment results for the Viking cod substock. For details see the caption for Figure 3.4.2.1.

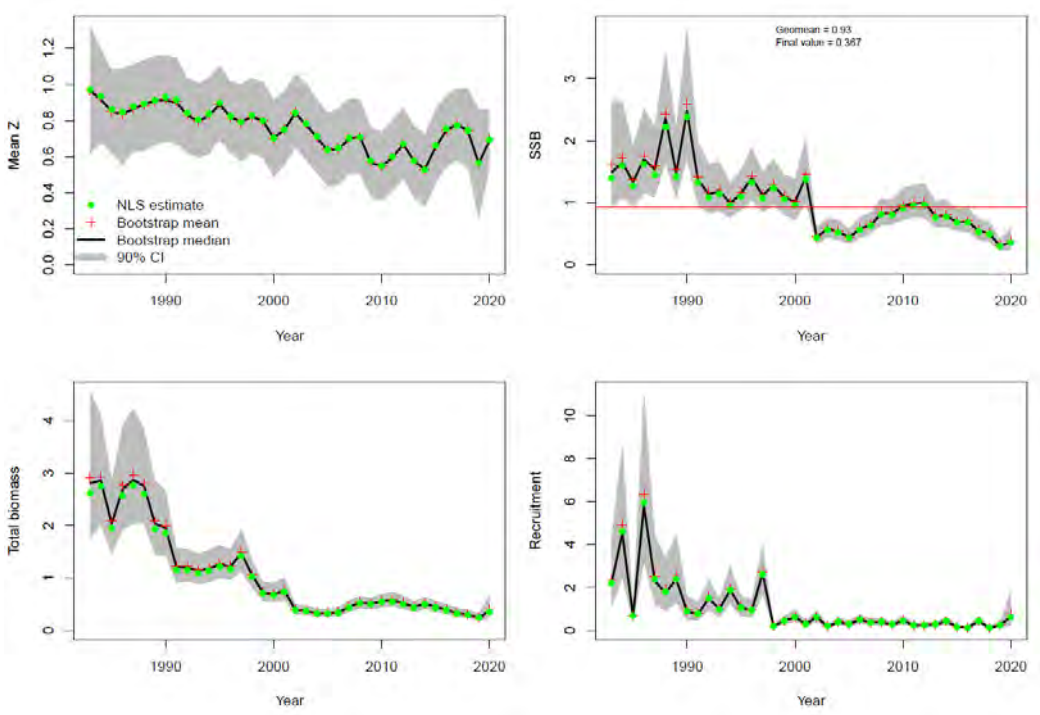


Figure 3.4.2.3. SURBAR assessment results for the south cod substock. For details see the caption for Figure 3.4.2.1.

Survey indices by age were generated for three areas: northwest (approximated by area 4aW), Viking (approximated by areas 4aE and 3a20) and south (approximated by areas 4b, 4c and 7d); see Figures 3.4.2.1–3.4.2.3. This grouping retains the split between Viking and Dogger cod that was indicated by WKNSCodID, and also includes the north–south split within Dogger cod for which there was some weaker evidence at WKNSCodID. For each area, indices for both IBTS Q1 and Q3 were generated. The method used here is the same as the new approach agreed by WKNSEA, and presented in Section 3.5.2.

The survey results given here (and the corresponding ones in Needle, WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod substocks) support the hypothesis of a concentration of cod in the northern North Sea during the latter part of the survey time-series. We have not generated formal proxies for MSY references points from these analyses, but the comparison with the time-series geometric means (see Figures 3.4.2.1–3.4.2.3) suggests that the southern area is in a more diminished state than the northwest and Viking areas.

This is not a new conclusion, and confirms the survey-based biomass trends given each year in the ICES WGNSSK report and corresponding advice sheet. However, the current analysis is based on a modelling approach that accounts for survey noise to a certain extent, and may be more robust and reliable as a consequence; it can also estimate total mortality. The development of area/substock-based survey indices is also a key step towards the development of more holistic spatial assessment approaches for cod stocks in the North Sea and neighbouring areas, as is the ongoing collation of area-specific catch data.

There is a clear need for further work on comprehensive spatial assessment methods for cod in the North Sea and neighbouring areas. These will need to be able to accommodate area-specific catch data for the years for which these exist, and be able to extend backwards in time to include years for which only full-area catches are available. The methods will also need to be able to account for different stock dynamics in different areas, in a flexible way that will permit modelling of evidenced exchange between areas. Such a method approach will address many of the

current stock structure issues that are hindering the extant single-area cod assessments conducted by ICES.

3.5 Indices (fishery-independent)

3.5.1 Data evaluation meeting

Possible updates to the model used to derive standardized indices of abundance by age were presented and discussed. Possible additional data sources were considered in addition to NS-IBTS, as well as alternative model formulations (WD_Cod_2_Survey abundances and indices). The additional surveys considered were Scottish West Coast surveys (WIBTS), BTS, BITS, FR-CGFS, and Danish national Cod and Sole surveys. These surveys could be included to provide better coverage of the stock, in particular areas 6a North, 3a, and 7d. Models with high-resolution space–time interactions should be considered as alternatives to the model currently used. An alternative modelling approach under development was also briefly presented, which in addition to numbers-at-age can provide estimates of length, weight, and maturity-at-age as well as their associated co-variances. The co-variance matrices can be used for providing better data weighting in SAM or other stock assessment models. Finally, it was considered to try to use available genetic samples from area 3a south (Kattegat) to include juvenile cod from this area to improve recruitment estimates. It was agreed to test several combinations of data sources and models, and at least the following combinations should be prepared for testing at the benchmark:

- Spaly area with new model in high resolution (only IBTS Q1 and Q3);
- New model including 6a north (WIBTS Q1 only);
- New model including 6a north (WIBTS Q1 and Q3 (IBTS) and Q4 (WIBTS);
- New model including 3aS (IBTS Q1 and IBTSQ3) – test could be also to include BITS Q1 or cod survey;
- For the 6a inclusion, we will need to check the change of catchability in the Scottish survey. 6a inclusion will be considered further at a dedicated WebEx meeting in January 2021 (before the main benchmark meeting).

3.5.2 Benchmark workshop

Various formulations of the model for producing standardized survey indices of abundance by age for North Sea Cod were tested, both in terms of model formulas as well as different data setups and survey index areas. The final model was based on NS-IBTS data only and using the standard assessment area (except ICES area 7d, the Channel, which did not have survey coverage in most years, and this area was also not included before.)

Five different model formulas were tested:

- Model 0: Current model. Time-invariant high resolution spatial effect.
- Model 1: Current subarea model. Time-variant spatial effect (low resolution).
- Model 2: As 2, but higher resolution.
- Model 3: High resolution, Fixed spatial + yearly independent deviances.
- Model 4: High resolution, Fixed spatial + autocorrelated deviances.

The first (Model 0) is the one currently used for the assessment of NS cod.

The spatial effect in Model 0 is assumed to be the same for all years.

Model 1 is the one currently used to provide estimates by subarea.

Model 1 has a time-varying spatial effect, but the model resolution in time and space is restricted to be quite low (the k-values specify the maximal number of effective degrees of freedom in the splines).

Model 2 is similar to model 1, except that it has a higher resolution in space and time, and it uses another spline basis (Duchon splines with first order derivative penalization).

Duchon splines of this type tend to be more appropriate for extrapolation outside the data range.

Models 3 and 4 decomposes the space-time effect into a fixed spatial high-resolution term (an average distribution), and a second term representing low resolution deviations from this average.

In model 3 the second term is independently estimated by year, whereas in model 4 the second term is assumed to be auto-correlated through time.

All models were estimated using a Delta-Gamma distribution (same as is currently used).

In addition, models 3 and 4 were tested with Delta-Lognormal and Tweedie distributions as well.

More details about the models can be found in WD_cod_4_NScod_surveyIndices.

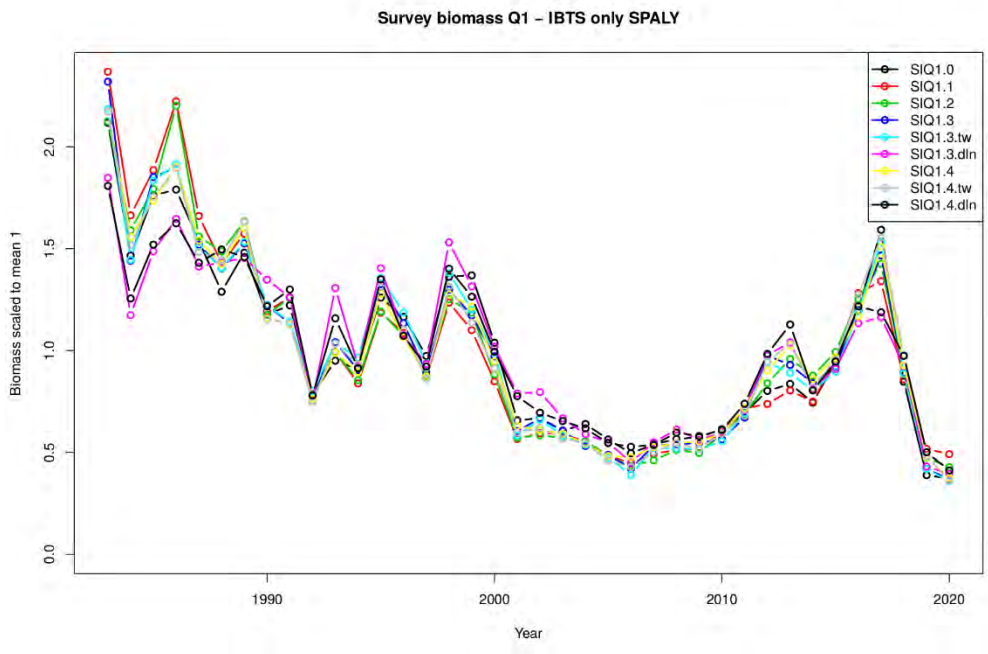


Figure 3.5.2.1. Survey biomass in Q1 according to the different model formulas tested.

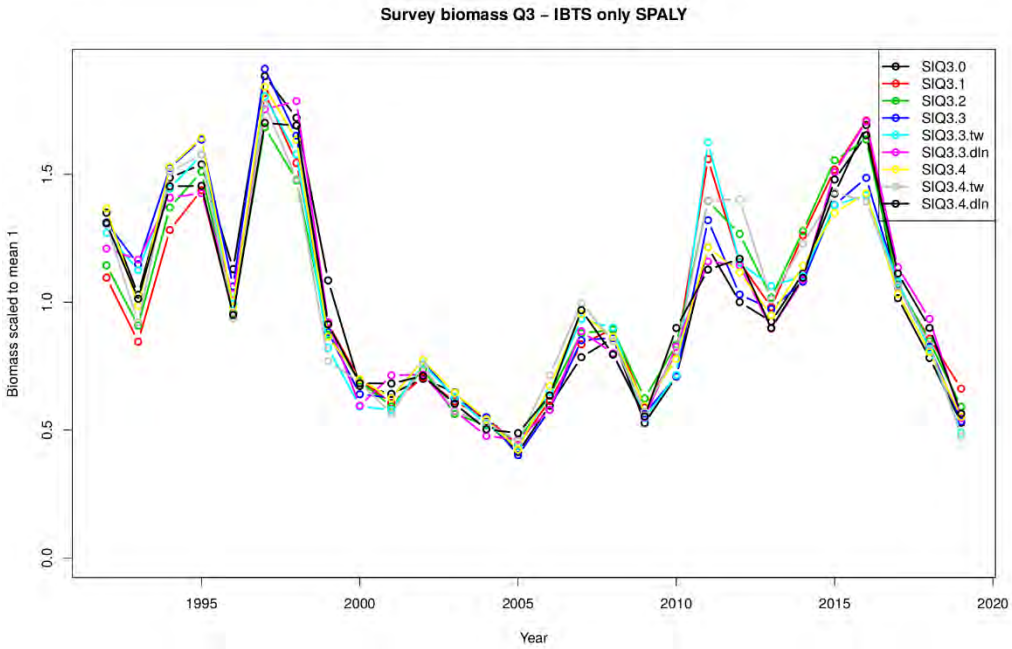


Figure 3.5.2.2. Survey biomass in Q3 according to the different model formulas tested.

All the indices showed similar trends in total biomass (see figures above).

The resulting indices were tested in the assessment model and evaluated by five criteria: AIC for the survey index models, internal consistency, AIC of the assessment model (SAM), and amount of retrospective patterns in the SAM model in terms of Mohn's rho.

The survey index model currently used was found to perform worse than most of the alternative models. While not all evaluation criteria pointed to the same model, Model 3 was chosen as the overall best one. All evaluation criteria were improved for this model compared to Model 0 (see

table below). Note, that the SAM configuration used for this evaluation was the one used for last year's assessment, except that variance weights for the survey indices were also used and the catch multiplier was removed. Similar tables without variance weights and with catch multiplier can be found in the working document. The use of variance weights and the removal of the catch multiplier was found to improve the SAM performance, and these settings were thus also adopted for the final SAM configuration chosen during the benchmark (see Section 3.11.1).

name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	243969.0	146958.4	0.783	0.764	455.1	0.254	-0.171	0.750
1	240712.4	145091.4	0.805	0.782	452.3	-0.023	-0.039	-0.009
2	234274.7	141126.2	0.807	0.789	462.5	0.011	-0.074	0.004
3	232431.1	140679.6	0.800	0.784	443.7	0.161	-0.133	0.295
3.tw	244198.0	154117.2	0.799	0.758	474.4	0.188	-0.156	0.274
3.dln	232148.1	140239.2	0.767	0.780	516.7	0.241	-0.157	0.413
4	234083.1	141267.4	0.799	0.778	446.6	0.093	-0.113	0.180
4.tw	242790.6	154414.8	0.789	0.759	483.1	0.099	-0.128	0.219
4.dln	233550.9	140682.4	0.760	0.772	510.4	0.123	-0.118	0.319
Avg	237573.1	144953.0	0.790	0.774	471.6	0.127	-0.121	0.272

The current index calculation procedure assumes that subarea 20 is purely NS cod while area 21 is not included.

New genetic data from areas 20 and 21 was used to explore alternative indices that assumed time-varying proportions of NS cod in these subareas as opposed to the current indices.

While the genetic information suggested that a substantial part of particular the juvenile cod population can be found in area 21, the alternative indices did not seem to improve evaluation criteria, but rather they appeared slightly worse.

Note that commercial catches were not split accordingly, which may be part of the explanation for the lack of improvement.

In addition to the indices presented so far, some extended indices, which included the Northern part of area 6a, were also computed. This was accomplished by using Scottish IBTS data in addition to the NS-IBTS survey. The main reason for investigating the extended indices was to evaluate a possible increase in abundance in 6aN due to migration from the NS stock.

The proportion of the total abundance located in area 6aN from Models 3 and 4 are shown in the figure below. It is seen, that there has been an increase in this proportion in both quarters from around 2010.

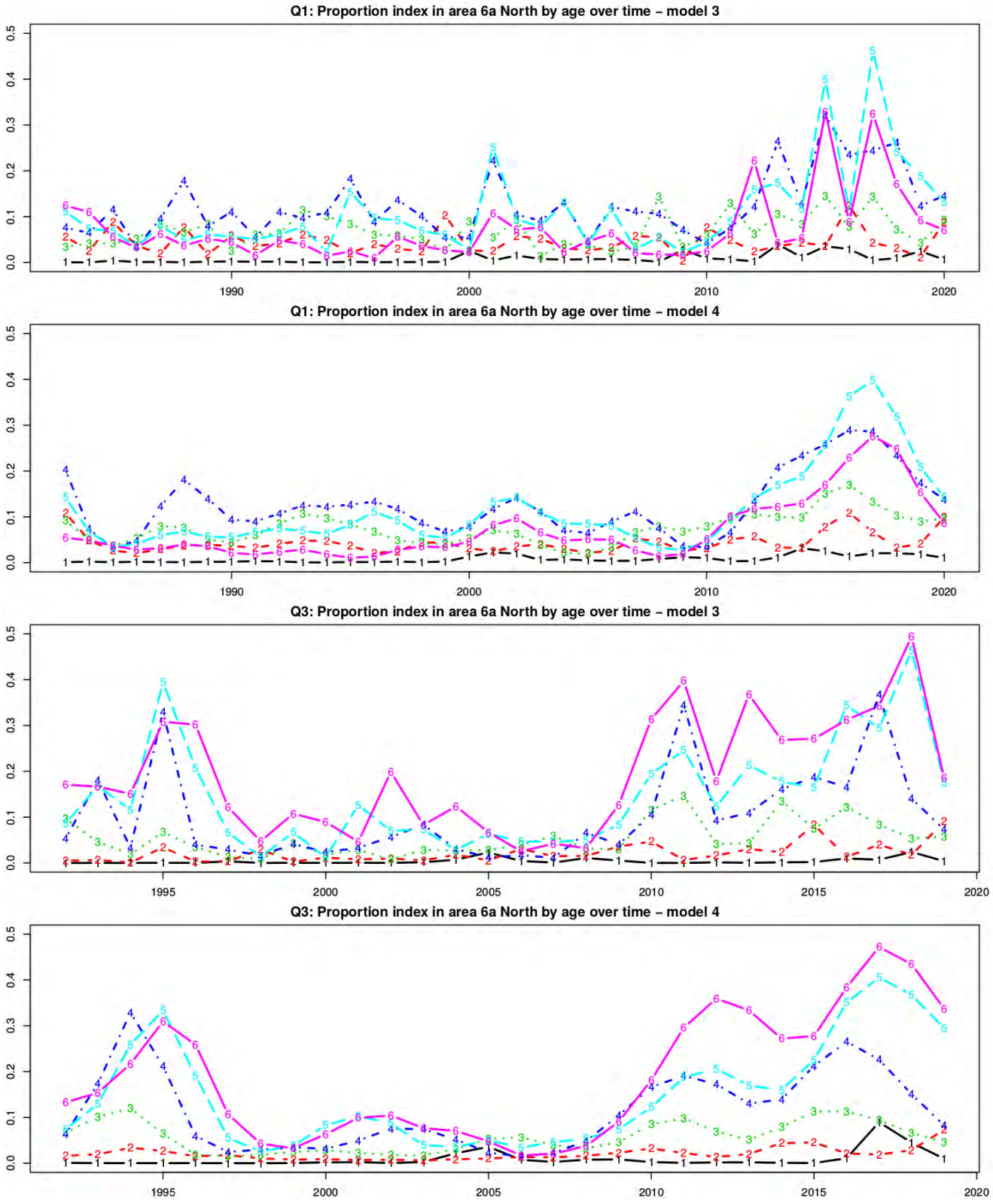


Figure 3.5.2.3. Proportions of the total abundance from extended indices in area 6aN over time.

3.6 Maturity

3.6.1 Data evaluation meeting

Until 2015 the maturity-at-age values were left unchanged from year to year. However, ICES, WKNSEA (2015) noted a change in maturity-at-age in the North Sea cod stock, with fish maturing at a younger age and smaller size. To address these changes in the stock, a smoothed area-weighted maturity-at-age key is constructed from NS–IBTS–Q1 data and applied to the estimation of spawning–stock biomass. Since its introduction and a review in 2017, two issues have been noted: (1) insufficient biological sampling in the Southern subarea coupled with disproportionate raising of maturity and (2) high sensitivity of the smoother to raw maturity estimates at the end of the time-series. Furthermore, concerns were raised regarding the exclusion of fish from the Skagerrak (3.a.N) from the current calculations (WD_cod_5_maturity). It was agreed to consider the following options for the benchmark:

1. Preferred solution is to have maturity estimates from Casper's updated survey model (Section 2.5.1) matching whatever stock area definition is used in the assessment model.
2. Spaly maturity run with and without 3aN.
3. Spaly maturity with weighting based on abundance (survey).
4. Spaly with running mean instead of smoother.

3.6.2 Benchmark workshop

Several SPALY type methods of calculating maturity were presented to the benchmark (WD_cod_5_maturity) and it was decided to modify the methodology as follows:

Omit the use of area-based raising factors. Given that the maturity-at-age key is calculated from NS-IBTS Q1 data, following a standardised design where each ICES statistical rectangle is typically sampled twice, survey-based numbers-at-age are representative of the population and sufficient to consider differing sizes of- and catch rates in- population subareas, as bigger subareas have a larger number of ICES statistical rectangles enclosed and will sum fish across a greater number of hauls. Furthermore, extrapolating to the size of the population via sea surface area increases the possibility to artificially inflate SSB due to disproportionate raising of samples from the larger but depleted Southern subarea, for which biological sampling of older ages has been poor in recent years.

Include fish from the Skagerrak in calculations from 1996. Until now, records from the Skagerrak have been excluded from maturity calculations as a consistent time-series of biological sampling records are available for this subarea only from 1991. Given that the Skagerrak is an important nursery area accounting for a large proportion of sampled 1–2-year-olds, and that inclusion appears to make little difference to the overall ogive (WD_cod_5_maturity), it was decided to include records from the Skagerrak in maturity calculations. However, the group noticed some abnormally low maturity estimates in the years 1991–1995 and, as the issues could not be resolved in time, decided to exclude these years.

Combine subareas into subpopulations when sample size (biological sampling) is low. Given recent difficulties estimating ALKs by subarea when biological sampling is low (WGNSSK, 2020), it was suggested to construct the maturity-at-age key by subpopulation, where the two Viking subareas (Viking 4.a and Viking 20) constitute a Viking subpopulation and the northwestern and southern subareas constitute a Dogger subpopulation. While these subpopulation definitions are consistent with the genetic findings of WKNSCodID (2020), they do not account for phenotypic differences within the Dogger cod population. It was therefore decided to

construct the maturity-at-age key by subarea where possible but combine subareas to subpopulations when less than five fish at each age (ages 1–5) are sampled in a subarea in any year.

Smooth the raw maturity-at-age key with a 5-year running mean. Due to high interannual variability, a simple GAM with a spline smooth over time has until now been fit to each age in the raw maturity ogive. However, re-smoothing the ogive in this way, with new information added each year, revises maturity back in time. It was therefore decided to instead use a running mean, as this will not revise estimates of maturity back in time and removes the potential for large or frequent changes to perception of the stock. A 5-year running mean was initially adopted, with five years chosen to track trends over noise, but was later dropped given new functionalities in SAM (Section 3.11.1).

The new maturity-at-age key is shown in Figure 3.6.2.1

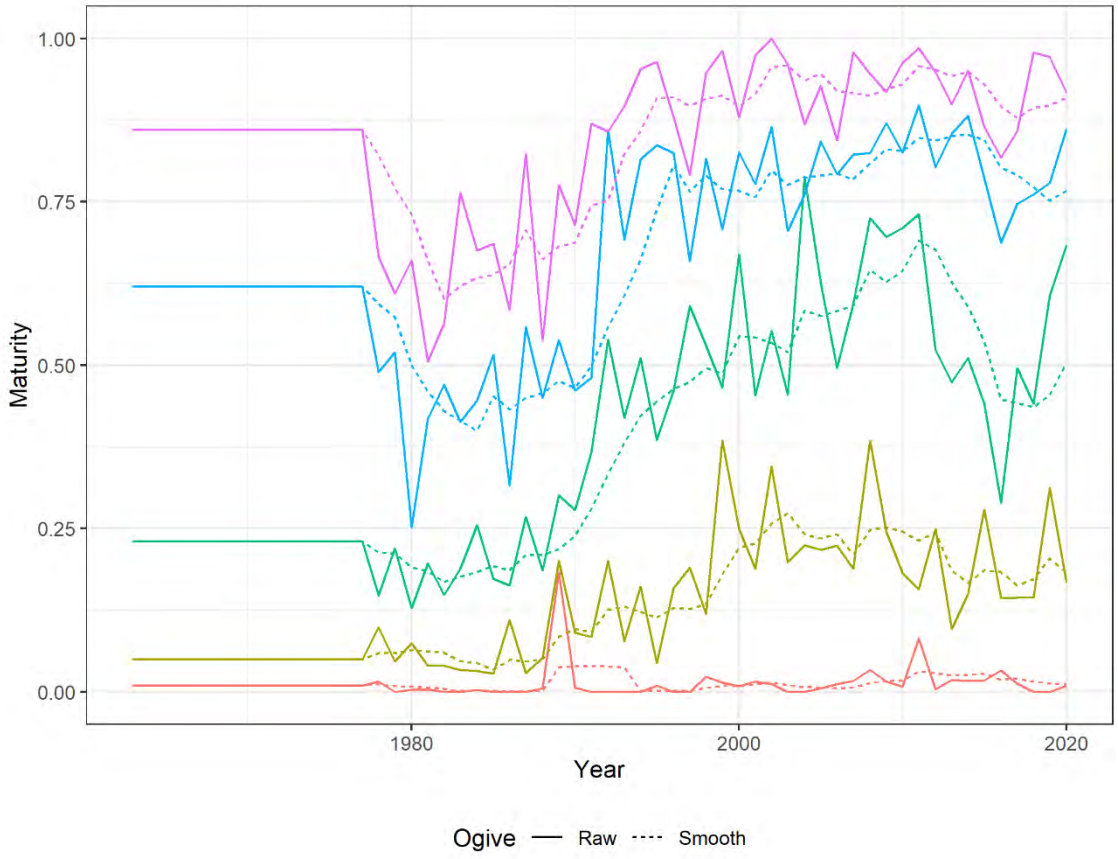


Figure 3.6.2.1. Raw (solid line) and smoothed (5-year running mean; dashed line) area-weighted maturity-at-age keys for North Sea cod. The first 15 years are the constant values used in the assessment prior to 2015, which are now removed and estimated within SAM (Section 3.11.1).

3.7 Recruitment

3.7.1 Benchmark workshop

Currently the first age in the assessment is age 1, although many 0 cod were noted in the Q3 survey data upon preparing indices. There are several issues with reducing the age of recruitment and including age 0 cod in the assessment explicitly:

- There are no observation data for age 0 cod for the first 29 years of the assessment: catch data for age 0 are available only from 2002 and the IBTS Q3 index begins in 1992;
- Multispecies *M*s are very high, uncertain and strongly driven by the abundance of grey gurnard (i.e. a doubling of *M* over the time-series based on sparse diet data);
- SAM estimates of age 0 in the historic period will be reconstructed based on *M*, which masks the signal observed at age 1 and will have implications for setting reference points.

Instead, it was decided to include the delta-GAM estimates of age 0 from the IBTS Q3 as a separate recruitment index for age 1 the following year, assumed to be taken on 1st January. This was justified via strong internal consistency between ages 0 and 1 (cor = 0.763), and similar to that between ages 2 and 3 (0.753) and 3 and 4 (0.766). Furthermore, inclusion in SAM made little difference to the assessment summaries but did result in a reduction of the Mohn's rho for recruitment. It was therefore argued that inclusion of this recruitment index could (1) improve forecasts by providing two observations to inform the intermediate year recruitment assumption (IBTS Q3 in year y-1 and IBTS Q1 in year y) and (2) gives potential to account for incoming year classes earlier via the reopening protocol (Section 3.14).

3.8 Stock weight

3.8.1 Data evaluation meeting

Currently, total catch mean weight-at-age values are also taken as stock mean weights-at-age. The alternative approach for deriving indices, which is currently under development (Section 2.5.1), can also provide estimates of weight-at-age in Q1 and may be a preferable option for stock mean weighs given that stock weights should correspond to 1st January. Given the IBTS survey is less representative of older ages, it may be necessary to consider a hybrid approach that uses survey data for younger ages and catch data for older ages. It was agreed to consider the following for the benchmark:

- Preferred solution is Casper's model for younger ages (e.g. 1–4; Section 2.5.1), commercial catch (Q1) ages 4+;
- Survey weights (ages 1–3);
- Outcomes of the previous benchmark, where this issue was covered extensively, to be considered again.

3.8.2 Benchmark workshop

The previous benchmark of North Sea cod found several issues with using survey weights as stock weights (WKNSEA 2015):

- Older ages are poorly sampled compared to the catch.
- No estimates are available prior to 1983, so an assumption of constant-weight-at-age must be made.

Furthermore, there are inconsistencies between the catch and survey data with survey weights generally being lower for ages 1–3, similar for ages 4–5 and larger for ages 6+ (WKNSEA 2015; WD_cod_6_stock weights).

In the assessment model, SSB is calculated at the beginning of the year; therefore, annual catch rates can lead to an overestimation of SSB because weights-at-age are expected to increase throughout the year. Furthermore, it was argued that catch rates may not reflect stock weights due to the size selection of the fishery, and for this reason the discrepancy between catch and survey weights for younger ages is to be expected.

Based on catch curves and the SAM F-at-age plot, which shows age 3 to be the dominant age in the fishery, it was decided to use survey weights derived from the IBTS Q1 for ages 1–2 and Q1 catch weights for ages 3+.

A complete survey time-series is not available for the period 1963–2020 and weight-at-age records are notably lower or non-existent prior to 2002. Where survey weights are scarce, the mean ratio-at-age from 2002–2019 between survey and annual catch weights was used to scale the annual catch weights to the level of the survey. Likewise, catches disaggregated to quarter were available only from 2002, so the mean ratio-at-age from 2002–2019 between Q1 and annual catch weights was used to scale the annual catch weights to the level of the Q1 catch weights back in time. The final stock weights are shown in Figure 3.8.2.1.

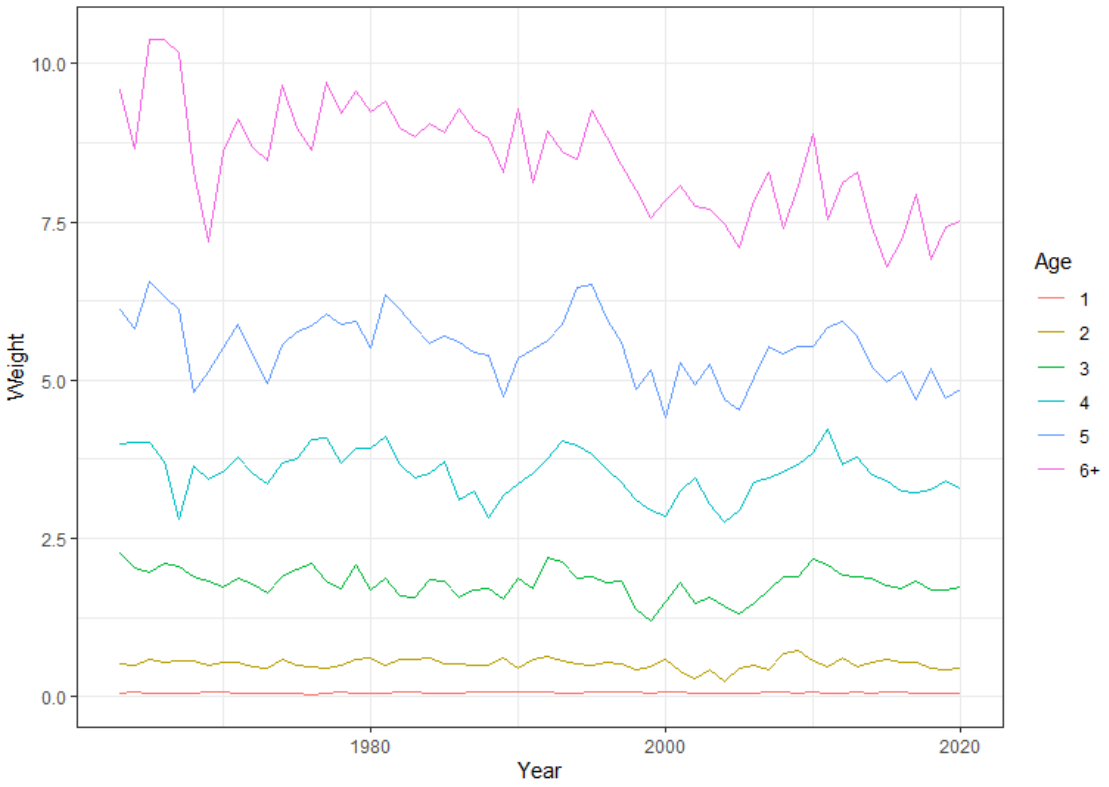


Figure 3.8.2.1 Stock weights-at-age for North Sea cod.

3.9 Recreational data

Cod is an important target for marine recreational fisheries (MRF) in the Channel, North Sea, and Skagerrak. Radford *et al*. (2018) analysed data available from recreational fisheries sampling in European countries and developed procedures to impute recreational catches where national data were missing. They concluded that biomass removed by MRF of North Sea, Eastern English Channel and Skagerrak cod (cod.27.47d20) accounted for around 10% of total commercial and recreational fishery removals. As a result, it is important to compile recreational data and consider how best to include it in the assessment process.

MRF data collection has been a requirement under the DCF since 2002, but many countries have recently started surveys, meaning that time-series are generally not available. This has led to a variety of approaches being developed for inclusion of MRF catches in stock assessments in Europe. The approach is dependent on the data available and the assessment approach, with good examples available for sea bass and western Baltic cod. For sea bass in 4bandc,7a,d–h, a single

year estimate of recreational removals is compiled for 2012 from national surveys. The assessment is done in Stock Synthesis 3, with the recreational fishing mortality adjusted iteratively until the estimate of removals in 2012 is achieved. The recreational fishing mortality is then assumed to be constant throughout the time-series, and a method has been developed to model the impact of management measures as no data are available (ICES, 2020). For western Baltic cod, German recreational catches have been included in the assessment since 2013 and at the latest benchmark in 2019 the Danish and Swedish recreational catches were included as well (WKBALTCOD2 2019). The data used for this benchmark were annual numbers by age (CANUM) and weight by age (WECA) for the three nations combined.

If the data cannot be included directly in the assessment model, then it is possible to consider how the data can be used to inform advice and management of the stock, meaning that MRF catches are captured in the assessment process.

A full description of the MRF data and approaches developed can be found in the working document on recreational catches produced for WKNSEA (WD_cod_7_Recreational catches).

3.9.1 Data evaluation meeting

MRF catches were provided by Belgium, Denmark, Germany, Sweden, Norway, Netherlands, and the UK, from sampling in ICES subareas 3aN and 4 and Division 7.d. France could not provide data with sufficient quality. The data cover the period 2009–2019 to varying extents (Table 3.9.1.1). In most cases the surveys have two components; a nationwide survey to estimate numbers of recreational fishers and/or their effort, and a separate onsite or offsite survey to estimate catch per unit effort (CPUE). The methods in most cases have been reviewed by the ICES Working Group on Recreational Fisheries, but are not fully coordinated across countries and are subject to varying biases which in general are poorly understood. Three countries did not supply precision estimates.

Table 3.9.1.1. Summary of recreational survey data for cod.27.47d20.

Country	Years	Sector	Retained weight	Released weight	Retained numbers	Released numbers	Length freq.
Belgium	2018–2019	All	Yes	Yes	Yes	Yes	Yes
Denmark	2009–2019	Residents	Yes	No	No	Yes	No
France	2006–20077	Residents	No	No	No	No	No
Germany	2014/2015	Residents	Yes	No	Yes	Yes	No
Netherlands	2010, 2012, 2014, 2016, 2018	Residents					Yes
Norway	2018/2019	Tourists / charter	Yes	No	Yes	Yes	Yes
Sweden	2013–2019	Residents	Yes	No	No	No	No
UK	2012 / 2016–2019	Residents	Yes	Yes	Yes	Yes	Yes / Yes

The cod assessment is done using SAM, so a time-series of the recreational removals is needed to include recreational catches in the assessment model. However, it may be possible to include in the broader assessment process if creation of a time-series is not possible with the existing

survey data. Given the variety of surveys and data available, it was unclear if an approach could be developed to generate a time-series for the whole assessment period.

A short workshop was held with recreational data collection and stock assessment experts in January 2021 to identify an appropriate approach. Experts from UK, Sweden, Netherlands, Norway, Denmark, Germany, France, and Belgium attended. It was clear that the limitations with the existing MRF data make it is impossible to create a series of international recreational catches for the cod stock for the whole period of the assessment without extensive imputations. This would inevitably lead to an accumulation of biases related to survey design, implementation, and analysis. Instead, the proposal was to develop a short time-series making the best use of the MRF data, generate an estimate of the magnitude of recreational catches compared to commercial fisheries, and then decide how best to include MRF catches within the assessment process as part of the benchmark workshop.

3.9.2 Benchmark workshop

A number of scenarios for reconstructing historical recreational catch values back to the 1960s were considered that may allow an investigation of the sensitivity of the ICES assessment and advice to inclusion of recreational catch data (WD_cod_7_Recreational catches).

Catch estimates were provided for all fishing platforms combined (shore, boat) except for Norway where estimates were from charter boats operated by tourist fishing businesses. The longest and most continuous time-series is from Denmark (2009–2019), which provided total catch weights for retained fish, not numbers, and total numbers of released fish, but not weights. The shortest dataseries were from Belgium, Germany, and Norway. The Netherlands surveys occur biennially, and provide weights and numbers for retained fish, but numbers only for released fish. Sweden provided retained weight estimates for the Skagerrak from 2013 to 2019, but no retained numbers and no data at all for released fish. The most complete data in terms of numbers and weights is from the UK, for years 2012 and 2016–2019. Due to the change in UK survey methods after 2012, and the large differences in estimates (especially releases) between 2012 and 2016 onwards, the 2012 data are not used for compiling international catch totals. Where provided, estimated RSEs are mostly moderate with most in the range 0.15–0.40.

A simple method was developed to impute missing annual national estimates of retained catch weight or numbers. It was assumed that the series of Danish estimates from 2009 to 2019 represented a "true" time-series in terms of relative abundance trends. For the other countries, a scaling factor was calculated as the sum of annual survey estimates of catch from that country divided by the sum of survey catches from Denmark for the years where both countries had survey estimates (e.g. 2010, 2012, 2014, 2016, 2018 for the Netherlands, 2016–2019 for the UK). Catches for years with no data for a country were then imputed by multiplying the Danish survey estimates for those years by the scaling factor for that country. This was done for retained and released catches separately, and mean fish weights were used to calculate tonnages, where only numbers were available.

No fisheries-specific studies on post-release mortality of recreationally caught North Sea cod are available. A study on post-release mortality of boat-based fishing for cod in the Gulf of Maine was the most relevant (Capizzano *et al*., 2016). As fishing from shore is likely to result in higher levels of post-release mortality, the upper confidence limit of the estimate of 31.5% was used. This was applied to the released component of the catch and added to the retained component to give a total MRF removal.

The percentage of total commercial and recreational removals represented by commercial fisheries (including imputations for missing countries each year), assuming 100% discard mortality in commercial fisheries, ranged from 3.4–8.9%, averaging 4.9% (Table 3.9.2.1). The accuracy of

this figure will be very variable due to the large amount of imputation which ranged from 3% in 2018 to 90% in 2012. The percentage of total removals due to recreational fishing was 4.8% in 2018, the year with least imputation, close to the average of the series (Table 3.9.2.1). The recreational catch estimates are subject to biases related to survey design, implementation, and analysis. This includes recall bias in some off-site surveys, incomplete coverage of the national fishery (e.g. Norway), missing national data, and methods of imputing missing values. The sensitivity of the approach to post-release mortality was assessed; the contribution of recreational fishing to total removals weight assuming 100% PRM remains below 10% in most years, averaging 6%.

Table 3.9.2.1. Annual total commercial landings and discards of cod in the North Sea, Skagerrak, and Eastern Channel, and recreational removals for countries supplying catch data (including imputed values from the present report). The %recr column gives recreational removals as a percentage of total commercial and recreational removals assuming 100% mortality in commercial discards and 35.1% PRM in MRF. The % of the total annual recreational removals tonnage derived from imputation is shown.

	commercial removals (t)			Recreational removals (t)				
Year	Landings	Discards	Total	Retained	Released	Total	% recr.	%imputed
2010	36029	12267	48296	1636	320	1955	3.9	56
2011	34042	10162	44204	1432	390	1822	4.0	87
2012	32527	7530	40057	1638	361	2000	4.8	90
2013	30870	10753	41623	2342	226	2569	5.8	80
2014	34816	10807	45623	3959	476	4434	8.9	60
2015	38080	13017	51097	2681	370	3051	5.6	82
2016	38794	12624	51418	2000	328	2327	4.3	15
2017	38522	9017	47539	1536	352	1888	3.8	37
2018	40082	8216	48298	2079	339	2418	4.8	3
2019	33385	4231	37616	1110	219	1330	3.4	36
Mean	35715	9862	45577	2041	338	2379	4.9	55

Historical recreational catches will be a function of the abundance and size composition of the cod stock, its spatio-temporal distribution, and the fishing effort, CPUE and size selectivity of the fisheries in each region. Recreational fishing effort is concentrated in coastal waters, where it can vary widely according to changes in abundance of stocks of interest. Unlike quota-controlled commercial fisheries, there are few controls historically on recreational fishing other than the minimum conservation reference size (MCRS) and local by-laws for example preventing certain fishing methods and fishing in specified areas.

Several scenarios are possible for historical catch reconstruction: setting the annual catch according to a fixed ratio of recreational to commercial fishing catches, established from the recent fishery data; setting a constant recreational catch; and assuming a trend in recreational fishing mortality and scaling it so that the catches generated by this in a statistical assessment model match the observed values from recent recreational fishing surveys as closely as possible. However, all the options are either not plausible (i.e. fixed ratio to commercial, constant recreational removals)

or not possible within the current assessment model (i.e. estimating a constant recreational fishing mortality).

At present, catch reconstruction for the whole assessment period for the cod.27.47d20 stock is impossible, and it is not possible to use the SAM model to explore historical recreational F and catch scenarios based on recent survey data as is done with sea bass. It is therefore recommended that simpler approaches be developed involving documenting the relevant catches on an annual basis in an appropriate format for inclusion in the management advice process through WGNSSK.

3.10 Natural mortality

3.10.1 Data evaluation meeting

Estimates of natural mortality are derived from multispecies analyses and are updated by the Working Group on Multi Species Stock Assessment Methods (WGSAM) every three years in so-called "key runs", accounting for improved knowledge of predation on cod by other species (mainly seals, harbour porpoises and gurnards) and cannibalism. The last update occurred in 2020 with the new key run and this data should be included in assessment runs prepared for the benchmark.

3.10.2 Benchmark workshop

Data from the new SMS key run were obtained although it was confirmed that this natural mortality data cannot not be provided for the new stock subareas (Viking, Dogger 4a and South). As before, the raw natural mortality data were smoothed to reduce the effects of interannual variability whilst maintaining overall trends. This resulted in an overall upscaling of the natural mortality on ages 1–2 but only minor differences to the natural mortality on ages 3+ (Figure 3.10.2.1) and assessment summaries.

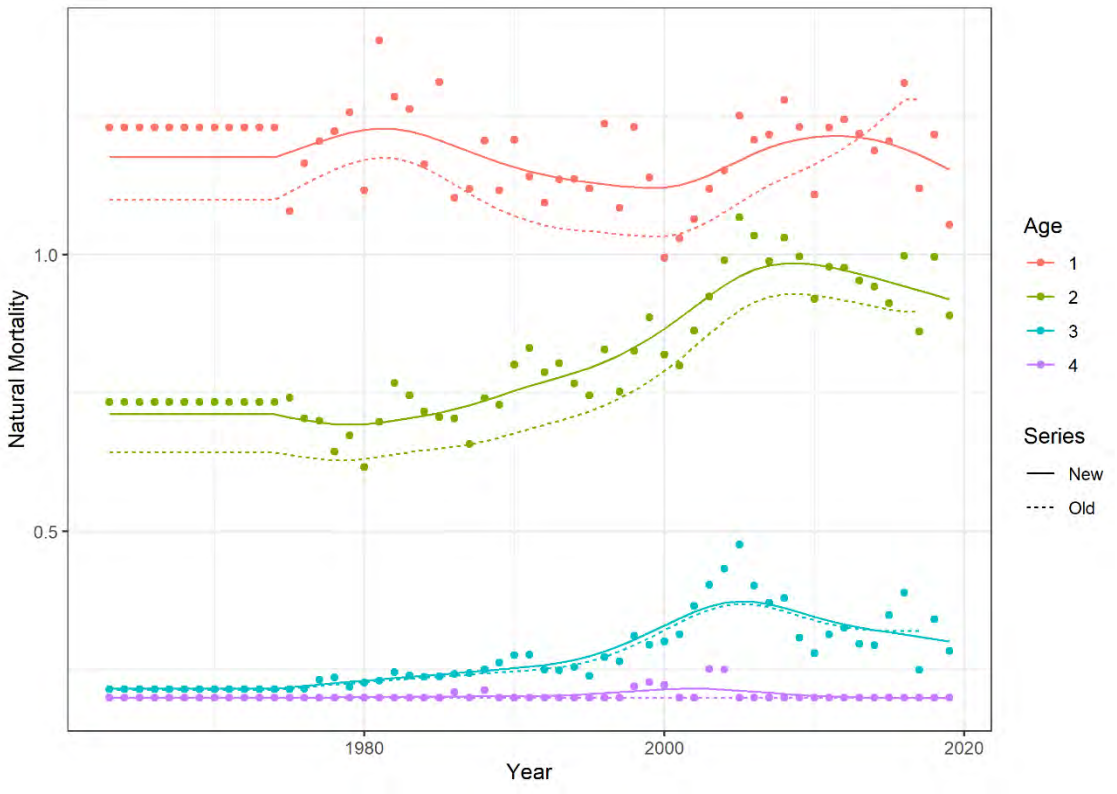


Figure 3.10.2.1. Smoothed annually varying natural mortality estimates for North Sea cod from the 2020 (solid) and 2017 (dashed) key runs. Points represent raw natural mortality estimates from the 2020 key run. Values for 1963–1973 are set equal to the 1974 value.

To deal with the migration of mature cod out of the current stock area into 6aN, a common natural mortality adjustment (M-adjustment) was estimated for ages 3+ to mimic the migration process and help deal with the current retrospective pattern. The issue of connectivity between 4a and 6aN was raised in the recent benchmark for West of Scotland cod (cod in 6a; WKDEM 2020) and was a firm conclusion of the ICES Workshop on Stock Identification of North Sea Cod based on genetics, tagging and trends in abundance (WKNSCodID 2020). Given the evidence, and that 6aN cannot yet be incorporated into the stock area (Section 3.2), the M-adjustment represents an interim solution that is within the scope of the current benchmark and addresses the issue of not dealing with a closed population, as assumed by the SAM assessment model. Approaches that model changes to commercial and survey catchability were considered (WGISDAA 2020). However, given that the perceived change in catchability is a consequence of spatial changes in the distribution of the stock beyond the management area, a removal of the migrated component better reflects the underlying biological processes. Essentially, the M-adjustment removes the fish that have migrated away from the North Sea from the modelled population in the North Sea, reducing the discrepancy between the catch and survey data and resulting in better model diagnostics (Section 3.11.1).

The selection of an appropriate M-adjustment was informed by an analysis of survey data that examined the proportion of an extended survey index that was constructed from observations in 6aN, finding substantial increased abundances of older cod in this area from around 2011 (Figure 3.5.2.3). This analysis was then used to define hypotheses about the years and ages where the migration to 6aN occurred. The final M-adjustment was selected by likelihood profiling: SAM was run with the final configuration settings (Section 3.11.1) for two time periods, 2011+ and 2015+, two age ranges, ages 3–5 and ages 3+, and for a range of migration rates, where the

migration was implemented via an increase in the natural mortalities of the relevant years and ages as follows:

$$M_{\mathrm{adj},a,y} = M_{a,y} - \ln(1-\alpha)$$

where α is the migration rate as a proportion. All scenarios with an assumed migration of up to 20% resulted in an improvement to SAM diagnostics, with an assumed migration of 15% of cod aged 3+ from 2011 selected as the best in terms of likelihood and AIC. This resulted in a reduction of Mohn's rho on SSB (ρSSB) from 17% to 8% (Figure 3.10.2.2). The approach taken was to select performance on the basis of AIC/likelihood only, rather than relying on the Mohn's rho statistic because the former is based on model fitting criteria, while good performance based on the latter does not necessarily guarantee this (although it is an important criterion for management).

Diagnostics without M-adjustment: log(L) = 662.24; AIC = -1248.49; ρSSB = 0.17

log(L)

Migration (%)	2011+		2015+	
	3to5	3+	3to5	3+
5	663.94	664.98	663.23	664.03
10	664.99	667.07	663.73	665.24
15	665.26	668.25	663.65	665.73
20	664.59	668.17	662.89	665.30
25	662.79	666.40	661.34	663.77
30	659.59	662.48	658.85	660.92
35	654.63	656.03	655.30	656.54
40	647.52	646.77	650.49	650.45

AIC

2011+		2015+	
3to5	3+	3to5	3+
-1251.88	-1253.96	-1250.46	-1252.06
-1253.98	-1258.14	-1251.47	-1254.48
-1254.52	-1260.51	-1251.31	-1255.45
-1253.19	-1260.34	-1249.79	-1254.60
-1249.59	-1256.79	-1246.67	-1251.53
-1243.18	-1248.96	-1241.71	-1245.83
-1233.26	-1236.06	-1234.59	-1237.09
-1219.03	-1217.54	-1224.99	-1224.89

ρSSB

2011+		2015+	
3to5	3+	3to5	3+
0.15	0.15	0.15	0.14
0.13	0.12	0.12	0.10
0.11	0.08	0.10	0.06
0.08	0.02	0.07	0.01
0.05	-0.03	0.05	-0.03
0.00	-0.09	0.02	-0.08
-0.06	-0.15	-0.02	-0.14
-0.13	-0.20	-0.06	-0.19

Table 3.10.2.1. Results of likelihood profiling to find an appropriate M-adjustment that accounts for migrations of older cod to 6aN.

3.11 Final model settings (SAM)

3.11.1 Benchmark workshop

SAM (State–space Assessment Model; Nielsen and Berg, 2014) has been used as the assessment model for North Sea cod since 2011 (WKCOD 2011; WGNSSK 2011). Two configurations of the SAM assessment model were tested in combination with various survey index formulations and considered in a separate workshop prior to the benchmark meeting. The first used the estimated variances from the survey index model as inverse weights in SAM and the second removed the catch multiplier; a yearly scaling estimated by SAM to account for misreporting in the years 1993–2005. While both configuration settings seemed to improve the stability of the assessment in terms of decreased Mohn's rho values, only the former was accepted at the index pre-meeting. The full analysis is described in WD_cod_4_NScod_surveyIndices.

The approach taken at the benchmark was to update the SAM model tested at the index pre-meeting with the final data and then test various configuration options, initially without an M-adjustment. Finally, a new SAM functionality to treat various biological data (maturity, natural mortality and catch and stock weights) as observations and model these as processes was explored.

Five updates to the input data were made: (1) updates to the natural mortality matrix based on the new SMS key run (Section 3.10.2); (2) derivation of survey indices with a high-resolution delta-GAM model with a fixed spatial term and yearly independent deviances (Section 3.5.2 and WD_cod_4_NScod_surveyIndices); (3) inclusion of an IBTS Q3 index at age 0 as an indication of recruitment-at-age 1 the following year (Section 3.7); (4) updates to the maturity ogive (Section 3.6.2) and (5) updates to stock weights (Section 3.8.2). Updates to the survey indices in combination with the two SAM configuration changes (i.e., inclusion of survey index uncertainty and removal of the catch multiplier) resulted in an overall upscaling of SSB and downscaling of

fishing mortality, particularly from 2009 onwards. In contrast, updates to the maturity ogive and stock weights resulted in a downscaling of SSB. Figure 3.11.1.1 combines all the data changes with the two SAM configuration changes tested at the pre-meeting.

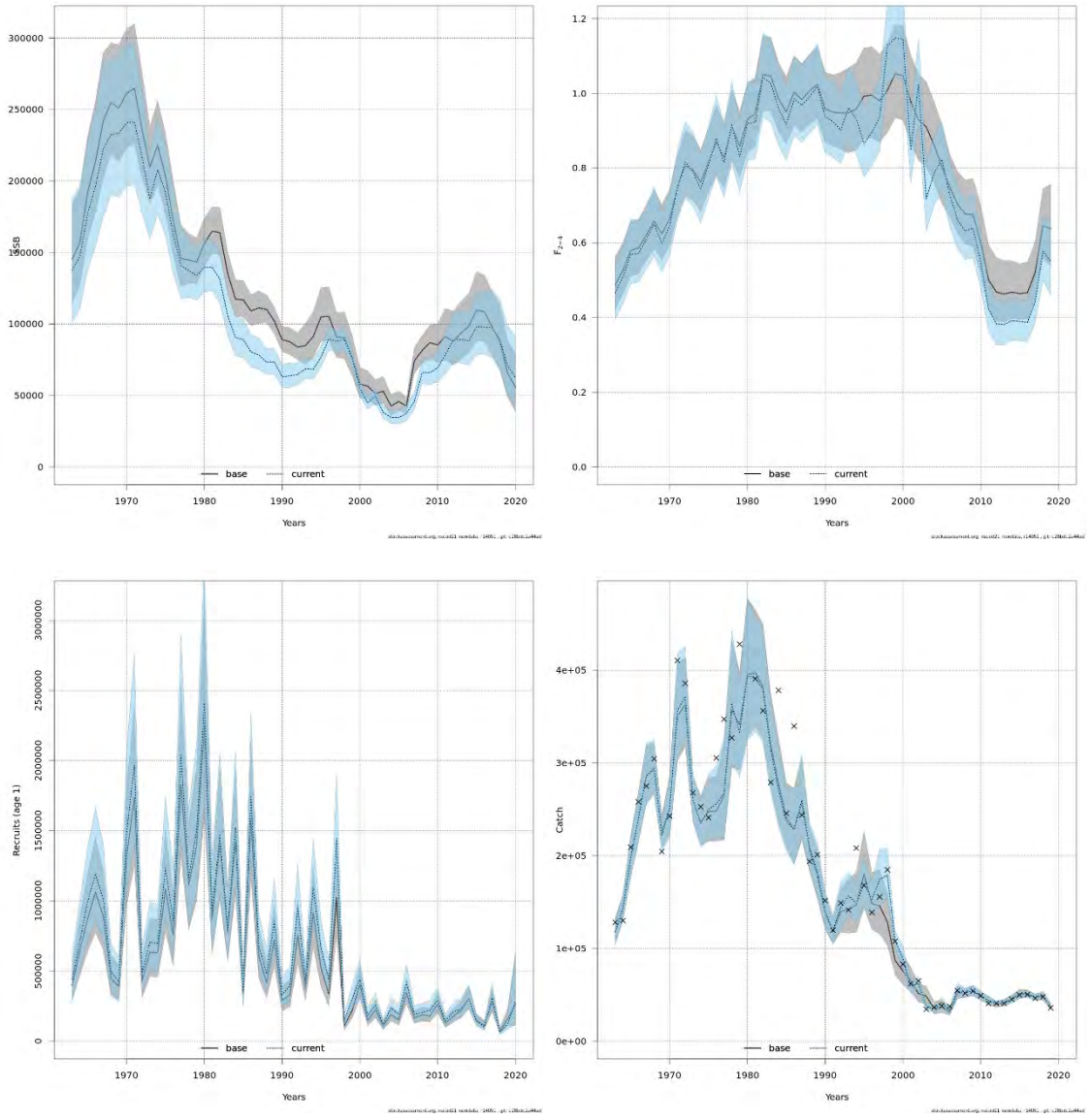


Figure 3.11.1.1. Impact of all data updates combined with two SAM configuration changes (inclusion of index uncertainty and removal of the catch multiplier; blue) compared to the WGNSSK 2020 assessment (black).

Once the final data were decided, the next step was to find the optimal SAM configuration. Different parts of the SAM configuration were evaluated independently and the best performing of those then put together into a combined configuration for testing. The four parts of the configuration tested were:

1. **Coupling of fishing mortality states and catchabilities.** Coupling the fishing mortality states of the oldest and / or youngest age groups did not improve model diagnostics, so all F states remain decoupled. A slight improvement to the AIC could be made by coupling the catchabilities of the oldest ages in the IBTS Q3 index but this resulted in a worse likelihood and, given the improvement to AIC was minimal, it was decided to keep all catchabilities decoupled.

2. **Coupling of variances for the fishing mortality process.** Decoupling the F variance of the plus group resulted in improved AIC and Mohn's rho. Accepting this change, the variances of the youngest and oldest age groups are decoupled while the variances of the intermediate ages (2–5) are coupled.
3. **Coupling of observation variances for the surveys and catch.** Three approaches to coupling of observation variances were tested: (1) a crude structure that estimates a common variance per survey; (2) a flexible structure with more free parameters and (3) a custom structure, with the custom variance structure resulting in the lowest AIC and lowest absolute values of Mohn's rho for SSB and fishing mortality. The custom variance structure is similar to that already in use, where the observation variances of all ages except age 1 are coupled, but gives a separate variance parameter to the plus group in the catch.
4. **Different covariance structures for the surveys.** Three covariance structures were tested: (1) an AR(1) structure; (2) unstructured and (3) a custom correlation structure that, for each survey, estimates a single parameter for the correlation between ages 1 and 2 and common correlation parameters between the older ages. The custom correlation structure resulted in the lowest AIC but also led to a Mohn's rho for SSB > 0.2.

Combining the best of parts 1–4 above into a single configuration did not result in a stable assessment (based on a jitter analysis and simulation study) due to having a free parameter for the variance of the plus group in both the fishing mortality process and catch observation. Based on a likelihood ratio test, it was decided to simplify the observation variance configuration (i.e. recouple the variances of the older ages in the catch) and leave the variance of the plus group decoupled in the fishing mortality process. These results were also verified in runs with an M-adjustment.

At the benchmark it was finally decided to remove the catch multiplier from the SAM assessment. This is because the scaling does not estimate a consistent bias during the period in which it is estimated, it has little influence on the current population estimates and stock status, and its removal results in a more stable assessment with lower retrospective bias. Furthermore, a sensitivity test was implemented in SAM to estimate an additional variance parameter for the period in which the catch scaling was previously applied. This did not indicate a significant scaling away from 1 when a common variance scaling was estimated for the period 1993–2005, indicating no increase in the uncertainty of the catch during that time.

Additionally, an increase in the age of the plus group was tested. Prior to the previous benchmark of North Sea cod in 2015, the last age in the assessment was a 7+ group. Due to worsening of a retrospective pattern immediately following the last benchmark (WKNSEA 2015), it became necessary to decouple the fishing mortalities of the two oldest age groups and reduce the plus group age from 7+ to 6+ (WGNSSK, 2015); however, WGNSSK have in recent years reported an increasing biomass in the plus group (WGNSSK 2019; 2020). SAM assessment models with a 7+ group were investigated with and without an M-adjustment and with two variations of the optimal configuration found above: one with the fishing mortality states of ages 6 and 7+ coupled and another with all fishing mortality states decoupled. The runs with decoupled fishing mortality states resulted in very domed F-patterns where the F on the 7+ group was at a similar level to the F on age 1, increasing the risk of a ghost stock given that very few fish at this age are observed in the catch. Coupling the F states of the 6 and 7+ groups reduced doming but resulted in higher AIC, increased retrospective bias and an unrealistically low level of uncertainty. It was therefore decided not to increase the plus group age.

Finally, a new SAM functionality to treat stock weights, catch weights, maturity and natural mortality as observations was presented (Section 3.12.1) but used only to model maturity as a process. Given this new functionality, it was decided to treat the first 15 years of maturity as NA,

rather than assume the constant values used in the assessment prior to 2015 (see Figure 3.6.2.1), and to let SAM estimate maturity back in time. Furthermore, it was no longer necessary to smooth the raw maturity values with a 5-year running mean (WD_cod_8_Process model for biological parameters in SAM).

Likelihood profiling over a range of M-adjustment scenarios showed an assumed 15% migration of 3+ cod from 2011 to be the optimal solution in terms of AIC and likelihood (Section 3.10.2) and reduced the Mohn's rho on SSB, F_{bar} and recruitment (Table 3.11.1.1). Furthermore, including the M-adjustment reduced doming in the exploitation pattern (Figure 3.11.1.2) and resulted in more balanced observation residuals, particularly for older ages in the catch (Figure 3.11.1.3).

Table 3.11.1.1. Comparison of diagnostics for runs of the final SAM configuration with and without an M-adjustment to account for migrations of older cod to 6aN.

Model	Log(L)	AIC	$\rho_{R(age1)}$	ρ_{SSB}	$\rho_{Fbar(2-4)}$
Base	662.24	-1248.49	0.17	0.17	-0.10
M-adj (final)	668.25	-1260.51	0.15	0.08	-0.04

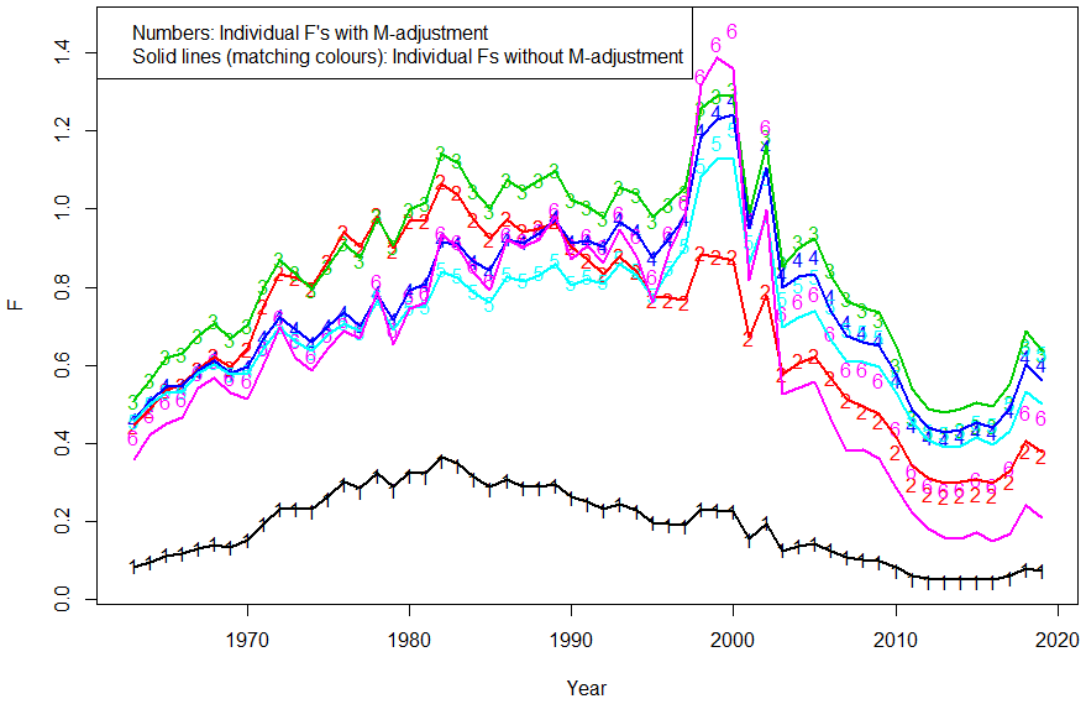


Figure 3.11.1.2. SAM estimates of fishing mortality-at-age including (numbers) or not including (solid lines) an M-adjustment to account for migrations of older cod to 6aN.

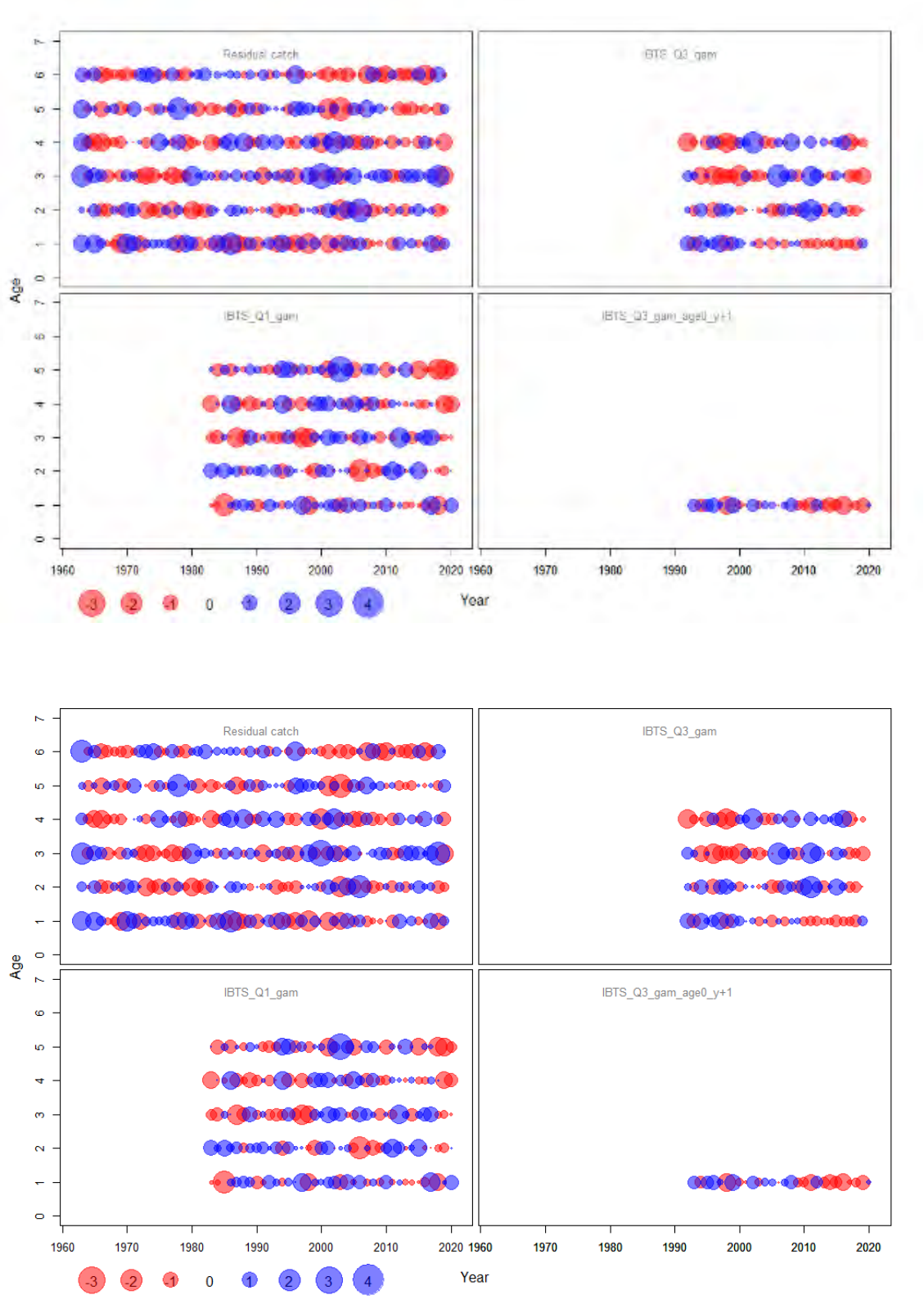


Figure 3.11.1.3. One step ahead (OSA) residuals for the total catch, IBTS Q1, IBTS Q3 and new recruitment index (IBTS Q3 age 0 forward shifted) for SAM runs without (top) and with (bottom) an M-adjustment to account for migrations of older cod to 6aN.

Final assessment model

The final assessment model for North Sea cod has the following features that differ from the assessment model used in 2020 (WGNSSK 2020):

Data

- Updates to the base calculations for deriving the subarea-weighted maturity ogive. The first 15 years (1963–1977) are removed and the raw ogive is not smoothed.
- Stock weights are taken as IBTS Q1 survey weights for ages 1–2 and as Q1 catch weights for ages 3+.
- High-resolution delta-GAM indices with a fixed spatial term and yearly independent deviances.
- Introduction of a recruitment index based on the IBTS Q3 at age 0 and shifted to the beginning of the following year.
- Smoothed M data from the 2020 key run with an adjustment made from 2011 for ages 3+ to mimic migration out of the stock area into 6aN.

Model settings

- Use estimated variances from the survey index model as inverse weights in SAM.
- Removal of the catch multiplier ($noScaledYears).
- Decouple the F variance of the plus group ($keyVarF).
- AR(1) correlation structure with custom configuration ($keyCorObs).
- Maturity modelled as a process ($matureModel and $keyMatureMean).

The full SAM configuration for the final assessment is given in Table 3.11.1.2. Summary plots of the final assessment in terms of population trends are shown in Figure 3.11.1.4, and the mean fishing mortality split into landings and discards, using landings fraction, and split into age is shown in Figure 3.11.1.5. Normalised residual plots, leave-one-out and retrospective runs are shown in Figures 3.11.1.6–3.11.1.8.

Table 3.11.1.2. SAM final run model specification for North Sea cod.

```
$`minAge`
[1] 1

$maxAge
[1] 6

$maxAgePlusGroup
[1] 1 0 0 0

$keyLogFsta
     V1 V2 V3 V4 V5 V6
[1,]  0  1  2  3  4  5
[2,] -1 -1 -1 -1 -1 -1
[3,] -1 -1 -1 -1 -1 -1
[4,] -1 -1 -1 -1 -1 -1

$corFlag
[1] 2

$keyLogFpar
     V1 V2 V3 V4 V5 V6
[1,] -1 -1 -1 -1 -1 -1
[2,]  0  1  2  3  4 -1
[3,]  5  6  7  8 -1 -1
[4,]  9 -1 -1 -1 -1 -1

$keyQpow
     V1 V2 V3 V4 V5 V6
[1,] -1 -1 -1 -1 -1 -1
[2,] -1 -1 -1 -1 -1 -1
[3,] -1 -1 -1 -1 -1 -1
[4,] -1 -1 -1 -1 -1 -1

$keyVarF
     V1 V2 V3 V4 V5 V6
[1,]  0  1  1  1  1  2
[2,] -1 -1 -1 -1 -1 -1
[3,] -1 -1 -1 -1 -1 -1
[4,] -1 -1 -1 -1 -1 -1

$keyVarLogN
[1] 0 1 1 1 1 1

$keyVarObs
     V1 V2 V3 V4 V5 V6
[1,]  0  1  2  2  2  2
[2,]  3  4  4  4  4 -1
[3,]  5  6  6  6 -1 -1
[4,]  7 -1 -1 -1 -1 -1

$obsCorStruct
[1] ID AR AR ID
Levels: ID AR US

$keyCorObs
     V1 V2 V3 V4 V5
[1,] NA NA NA NA NA
[2,]  0  1  1  1 -1
[3,]  2  3  3 -1 -1
[4,] -1 -1 -1 -1 -1

$stockRecruitment-
ModelCode
[1] 0

$noScaledYears
[1] 0

$keyScaledYears
numeric(0)

$keyParScaledYA
<0 x 0 matrix>

$fbarRange
[1] 2 4

$keyBiomassTreat
[1] -1 -1 -1 -1

$obsLikelihoodFlag
[1] LN LN LN LN
Levels: LN ALN

$fixVarToWeight
[1] 0

$fracMixF
[1] 0

$fracMixN
[1] 0

$fracMixObs
[1] 0 0 0 0

$constRecBreaks
numeric(0)

$predVarObsLink
     V1 V2 V3 V4 V5 V6
[1,] -1 -1 -1 -1 -1 -1
[2,] -1 -1 -1 -1 -1 NA
[3,] -1 -1 -1 -1 NA NA
[4,] NA NA NA NA NA NA

$stockWeightModel
[1] 0

$keyStockWeightMean
[1] NA NA NA NA NA NA

$keyStockWeightObsVar
[1] NA NA NA NA NA NA

$catchWeightModel
[1] 0

$keyCatchWeightMean
[1] NA NA NA NA NA NA

$keyCatchWeightObsVar
[1] NA NA NA NA NA NA

$matureModel
[1] 1

$keyMatureMean
[1] 0 1 2 3 4 5

$mortalityModel
[1] 0

$keyMortalityMean
[1] NA NA NA NA NA NA

$keyMortalityObsVar
[1] NA NA NA NA NA NA

$keyXtraSd
     [,1] [,2] [,3] [,4]
```

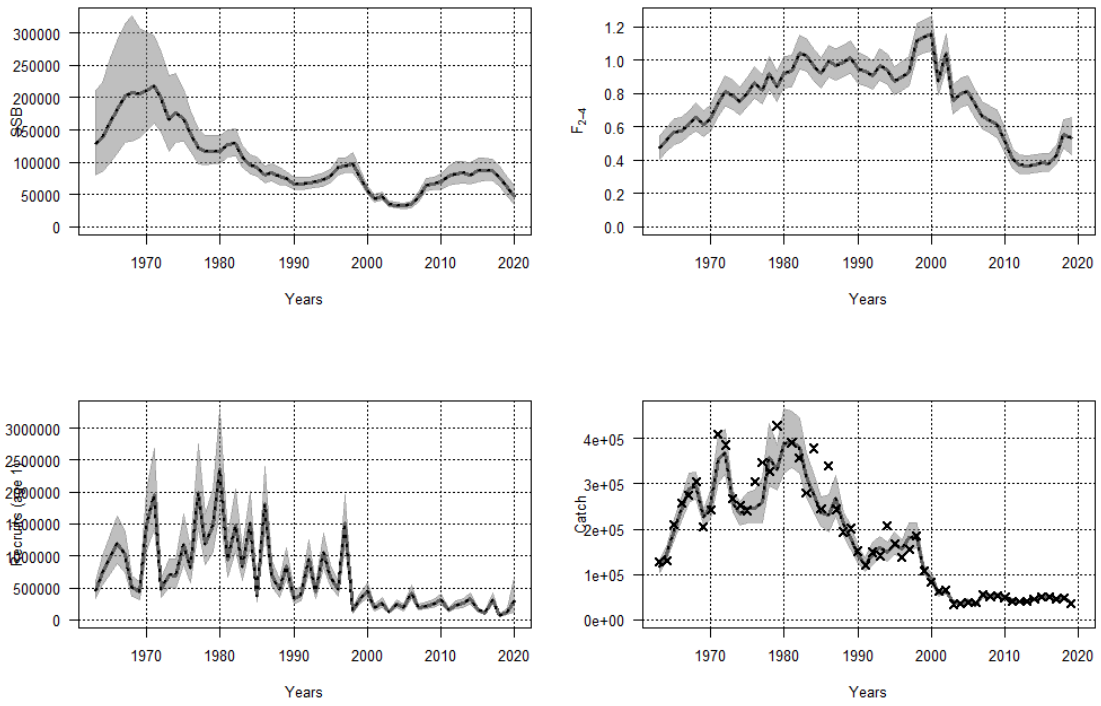


Figure 3.11.1.4. Estimated SSB, F(2–4), recruitment (age 1) and catch from the SAM assessment (black lines = estimate and shaded area = corresponding pointwise 95% confidence intervals).

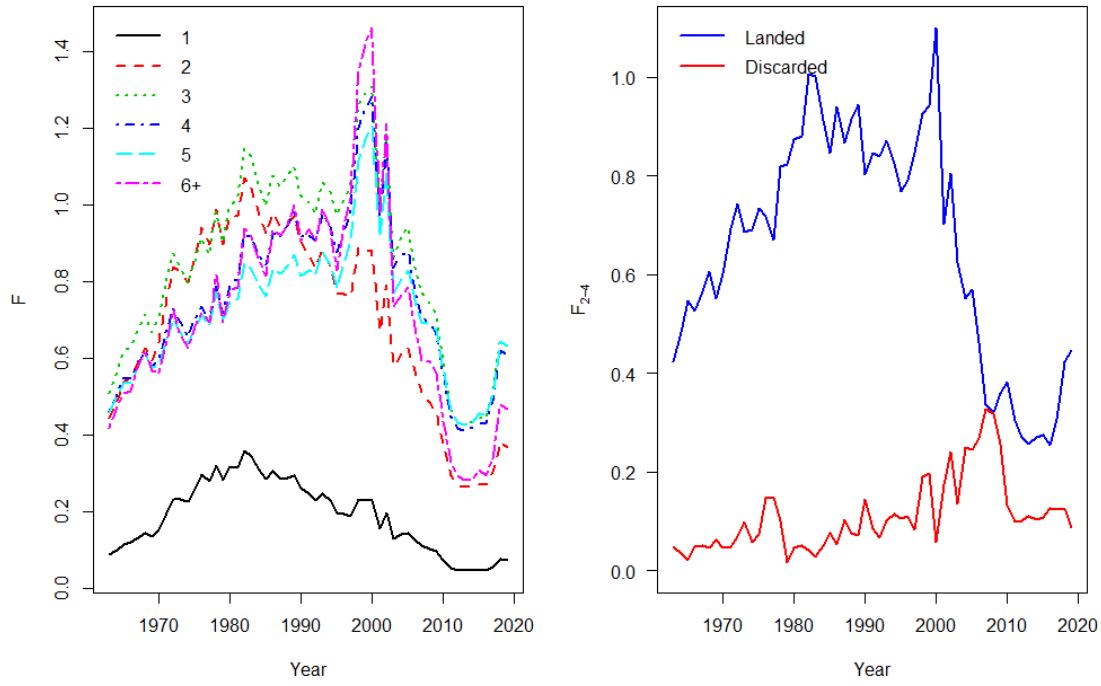


Figure 3.11.1.5. SAM estimates of fishing mortality. The left panel shows fishing mortality for each age while the right panel shows mean fishing mortality for ages 2–4 (shown in Figure 3.11.1.4) split into landings and discards components by using ratios calculated from the landings and discards numbers at age from the reported catch data.

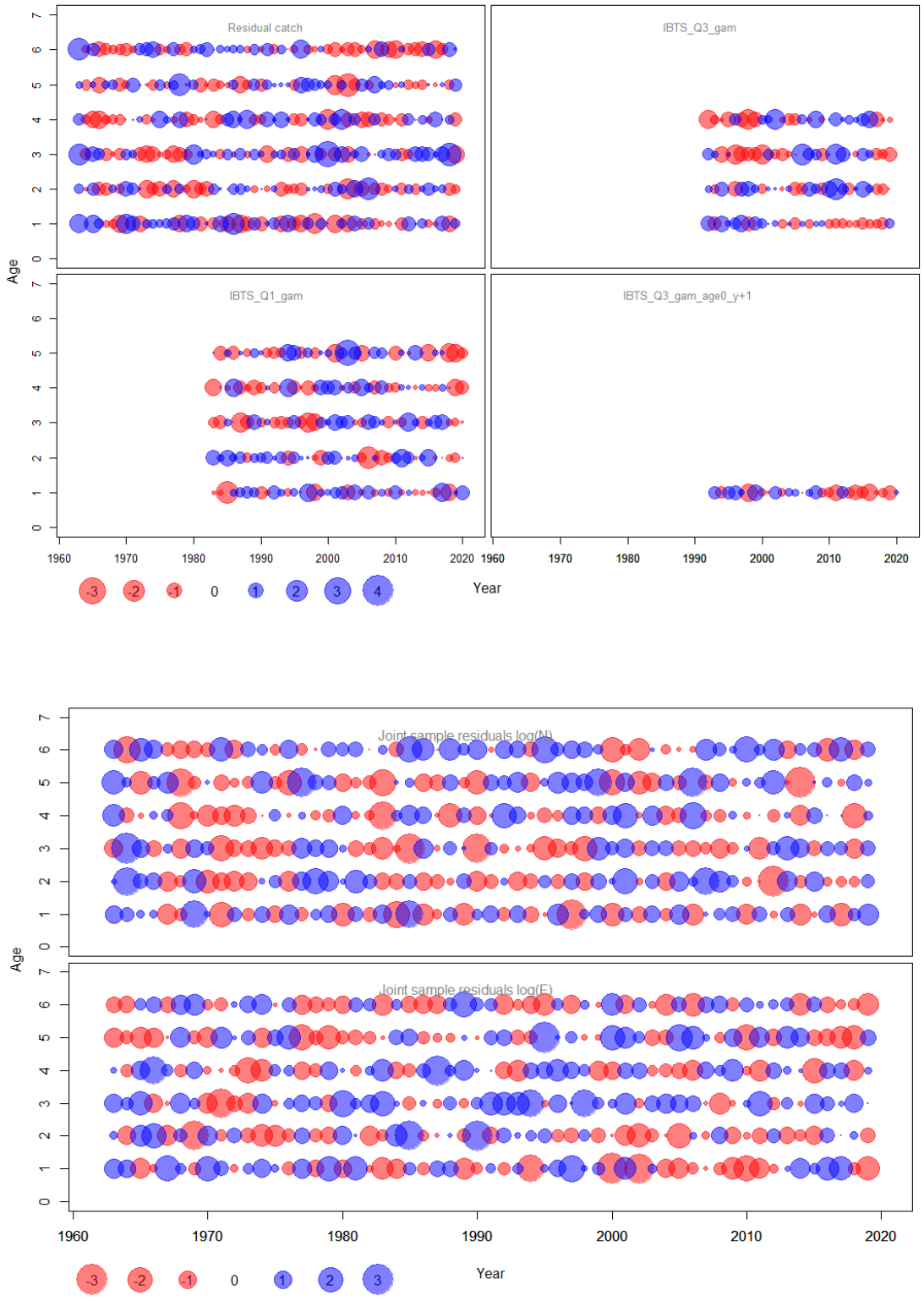


Figure 3.11.1.6. One step ahead (OSA) residuals for the (top) total catch, IBTS Q1, IBTS Q3, recruitment index (IBTS Q3 age 0 forward shifted) and (bottom) the process increments. Blue circles indicate positive residuals and red circles negative residuals.

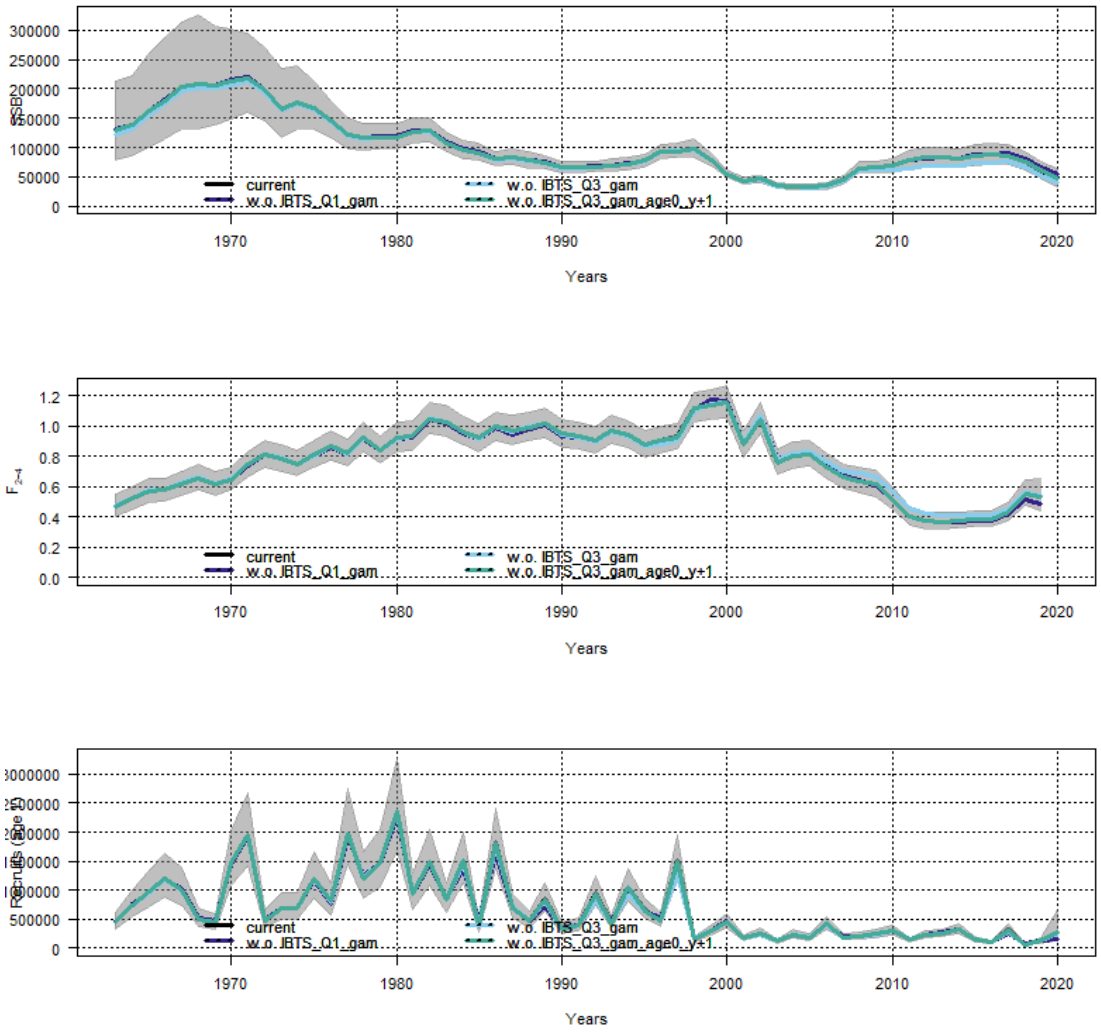


Figure 3.11.1.7. Leave-one-out estimates from the final SAM assessment showing (top) SSB, (middle) average fishing mortality (ages 2–4) and (bottom) recruitment.

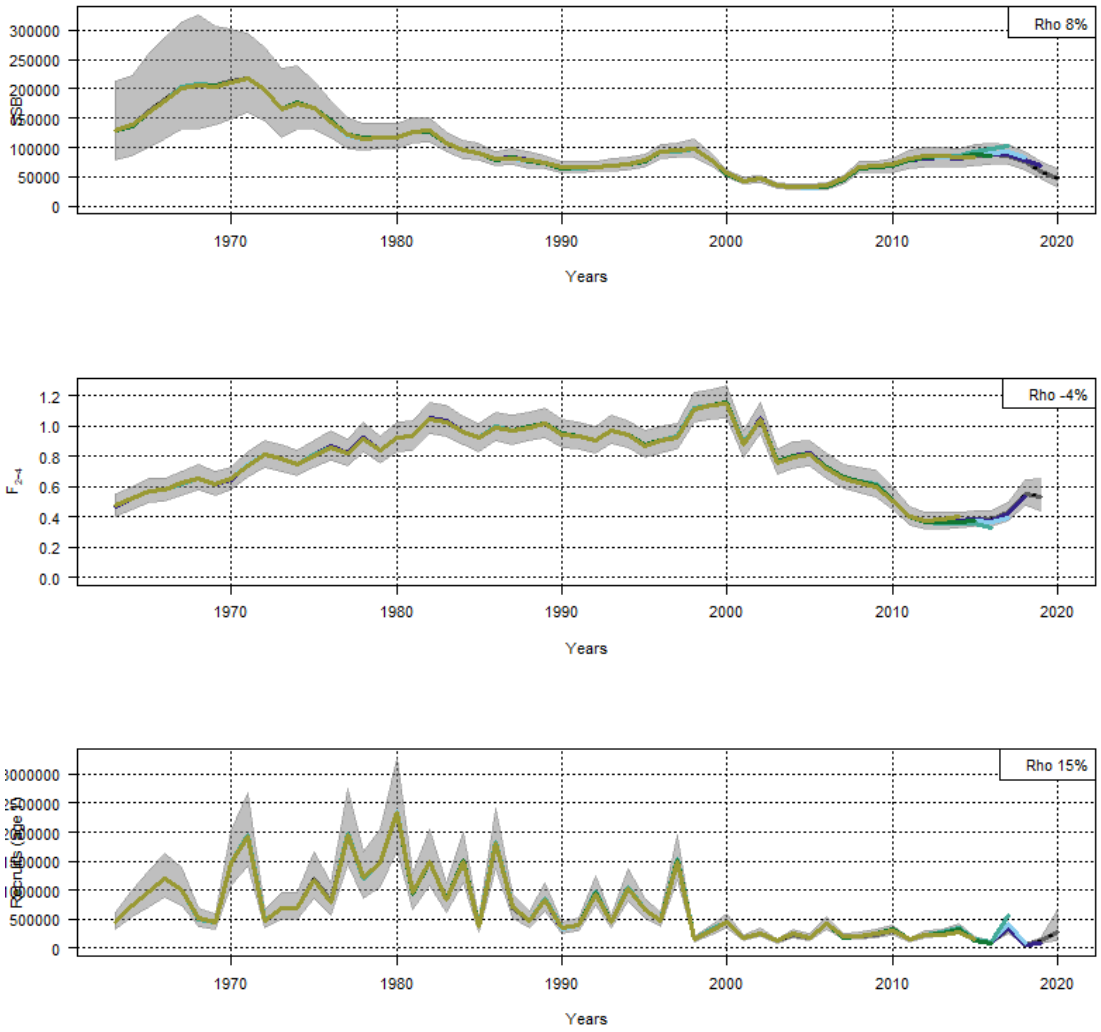


Figure 3.11.1.8. Retrospective estimates (five years) from the final SAM assessment showing (top) SSB, (middle) average fishing mortality (ages 2–4) and (bottom) recruitment.

3.12 Short-term forecast

3.12.1 Benchmark workshop

Forecasting takes the form of short-term stochastic projections using the forecast functionality of the *stockassessment* R package. 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 (Table 3.12.1.1) using the usual exponential decay equations but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch option scenarios.

A new SAM functionality to model stock weights, catch weights, maturity and natural mortality as independent processes was presented (WD_cod_8_Process model for biological parameters in SAM). This option uses the given data as observations to inform a Gaussian Markov Random Field (GMRF) process with cohort- and within year correlations. The new functionality has been tested on 14 different stocks, and can hindcast and forecast biological parameters in a model-

consistent way, potentially removing the need to take a three-year average in the short-term forecasts. The new facility works well for maturity and natural mortality but projected stock and catch weights tended to converge to the long-term mean relatively fast, potentially because of the number of fish in the plus group and / or recent trends in the weight data. Furthermore, the effect that the M-adjustment would have when using this facility to forecast natural mortality was uncertain, hence the new functionality was adopted for maturity only. It was also decided to use the default *forecast* setting, introduced since the benchmark in 2015, to model the exploitation pattern as a function of the SAM F processes (an average was used for cod prior to the current benchmark).

Given that there is a Q1 survey included in the assessment, SAM provides an estimate of recruitment-at-age 1 in the intermediate year. Until 2017, the procedure was to replace this SAM estimate of recruitment, based on a single IBTS-Q1 observation, with a resampled value from the year 1998 to the final year of catch data (a period during which recruitment has been low). Given that there is a high correlation between the IBTS–Q1 age 1 estimate and the IBTS–Q3 age 1 estimate the same year, and the IBTS–Q1 age 2 estimate the next year, WGNSSK in 2017 decided to use the latest estimate of recruitment from SAM in the intermediate year and resampled recruitments in subsequent years (WGNSSK, 2017). There has been a large retrospective bias associated with recruitment in recent years (Mohn's rho = 0.52 in 2020) relating to the large observation in 2017. Changes to the index calculations (Section 3.5.2) and introduction of the new recruitment index (Section 3.7.1) have both acted to reduce the Mohn's rho on recruitment (0.15) and provide a second observation to inform the intermediate year recruitment assumption (IBTS Q3 in year y-1 and IBTS Q1 in year y).

Table 3.12.1.1. Forecast assumptions for North Sea cod.

Variable	Assumption
Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Forecasted according to the SAM GMRF process for maturity.
Natural mortality	Average of final three years of assessment data with M-adjustment.
F and M before spawning	Both taken as zero.
Weight-at-age in the catch	Average of final three years of assessment data.
Weight-at-age in the stock	Average of final three years of assessment data.
Exploitation pattern	Forecasted according to the SAM F processes.
Intermediate year assumptions	Decision should be taken at the assessment WG meeting based on the best knowledge of the fishery at the time.
Stock–recruitment model used	Recruitment for the intermediate (the year the WG meets) is sampled from a normal distribution of the SAM estimate and reported as the median. Recruitment for the TAC year onwards is sampled, with replacement, from 1998 to the intermediate year.
Procedures used for splitting projected catches	The final year landing fractions-at-age are used in the forecast period.

3.13 Reference points

3.13.1 Benchmark workshop

Source of data

Data used to derive stock–recruitment relationships and to conduct the MSY analysis were taken from an FLStock object created from the final SAM benchmark assessment using the *FLfse* R package.

Stock–recruitment relationship and new B_{lim} and B_{pa} reference points

There was much discussion on which time-period should inform the stock–recruitment relationship. The previous reference points were based on recruitment from 1988 onwards; this was a period where recruitment levels were consistent with the previous B_{lim} (=SSB in 1996, the SSB associated with the last reasonable sized recruitment), excluded the "gadoid outburst" of the 1960s and 1970s and is consistent with what was thought to be a change in productivity (Reid *et al*., 2001; Beaugrand *et al*., 2004). However, given that recruitment from 1998 onwards has been lower than explained by SSB alone, the previous approach was to use this low productivity period from 1998 as a precautionary check on the F_{MSY} range (WKNSEA 2015; WGNSSK 2015).

Given that we are now over 20 years in a low recruitment regime, it was decided to base the stock–recruitment relationship on the period from 1998 onwards only. The decision to truncate the recruitment time-series was not taken lightly and justified due to: (1) the length of time in the low recruitment regime (over 20 years) despite similar numbers, weights, and maturities to earlier in the time-series; (2) literature suggesting cod recruitment to be influenced substantially by environmental effects related to regime shifts and climate change (e.g. O'Brien *et al*., 2000, Beaugrand *et al*., 2004; Kempf *et al*., 2009; Olsen *et al*., 2011; Akimova *et al*., 2016) (3) evidence that suggests an additional regime shift in the North Sea around 1998 (Weijerman *et al*., 2005; Alvarez-Fernandez *et al*., 2012; Beaugrand *et al*., 2014) and (4) substock considerations and analysis that suggest lower SSB and TSB in the South and almost no recruitment in that area since 1998 (WKNSCodID 2020). Given it is not yet possible to account for environmental effects and substock structure in the SAM assessment and stock–recruitment relationship, the group felt that a truncation of the recruitment time-series was appropriate (Figure 3.13.1.1).

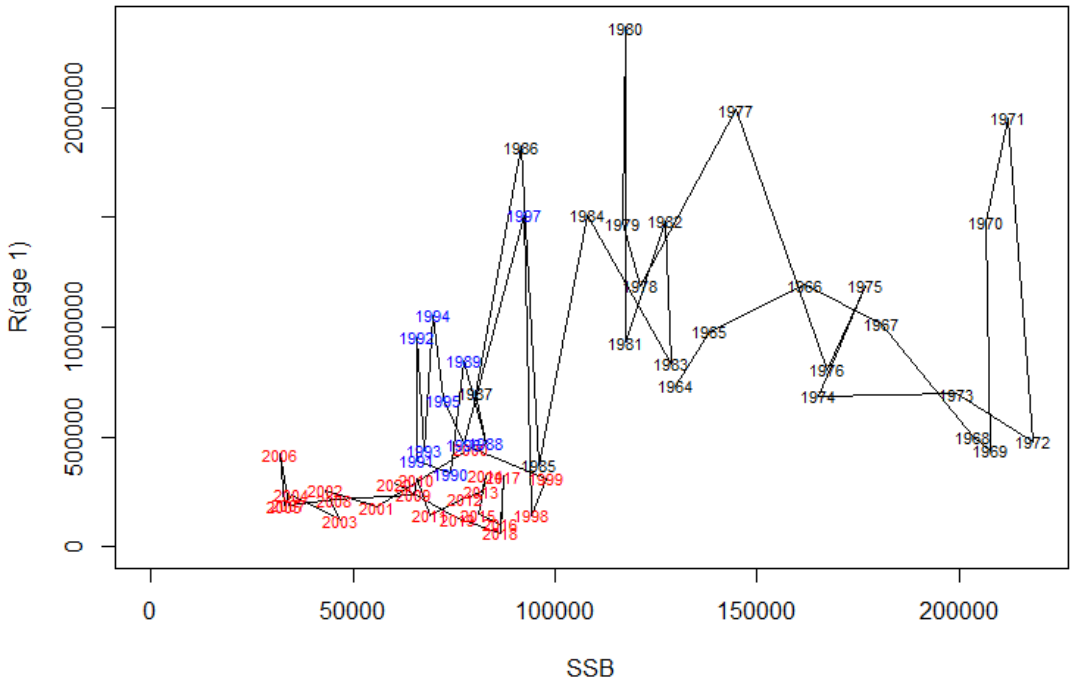


Figure 3.13.1.1. Stock–recruitment pairs from the final SAM assessment. Years coloured in blue correspond to recruitments between 1988–1997 and those in red to recruitments from 1998 onwards.

Truncation of the recruitment time-series lead to characterisation of the stock as either type 5: "stocks showing no evidence of impaired recruitment or with no clear relation between stock or recruitment", or type 6: "stocks with a narrow range of SSB and showing no evidence of past or present impaired recruitment". After much discussion, the variation in SSB displayed between 1997–2019 was considered relatively narrow compared to the SSB range observed further back in time and warranted classification as a type 6 stock. Given that constant recruitment relationships should not be included in the F_{MSY} estimation, the stock–recruitment relationship was taken as a segmented regression with the lowest observed SSB as the forced breakpoint, following the ICES guidelines for type 5 and 6 stocks (Figure 3.13.1.2). The guidelines state that B_{lim} cannot be derived from such data but were not clear on how to define B_{pa}. In the guidelines it is stated that:

"*If the stock is exploited at a high fishing mortality, above what seems reasonable based on other reference points (e.g. yield per-recruit reference points) or from experience with similar stocks, and if this has been the prevailing situation for most or all of the time-series for which data are available, then the stock should be considered as depleted and the estimated SSB as representing a stock that may not reproduce to its fullest potential. In this case, a reasonable* B_{pa} *will need to be defined based on the historical level of F. This* B_{pa} *is likely to be above the SSB observed for this stock if F has been above any possible candidate of* F_{pa}*.*"

Given that the 2020 assessment of North Sea cod (WKNSSK 2020) estimates fishing mortality to be higher than both F_{MSY} and F_{pa} throughout the whole time period between 1963–2020, the decision was to take the highest SSB corresponding to the 1998+ recruitment period as B_{pa}. Given a small SAM estimate of the standard deviation of ln(SSB) in the terminal year ($\sigma = 0.16$) not taking into account potential retrospective patterns and uncertainty in the short-term forecasts, the default of $B_{lim} = B_{pa}/1.4$ was used, equivalent to $\sigma = 0.2$. This gives B_{lim} = 69 841 and $B_{pa} = B_{trigger}$ = 97 777.

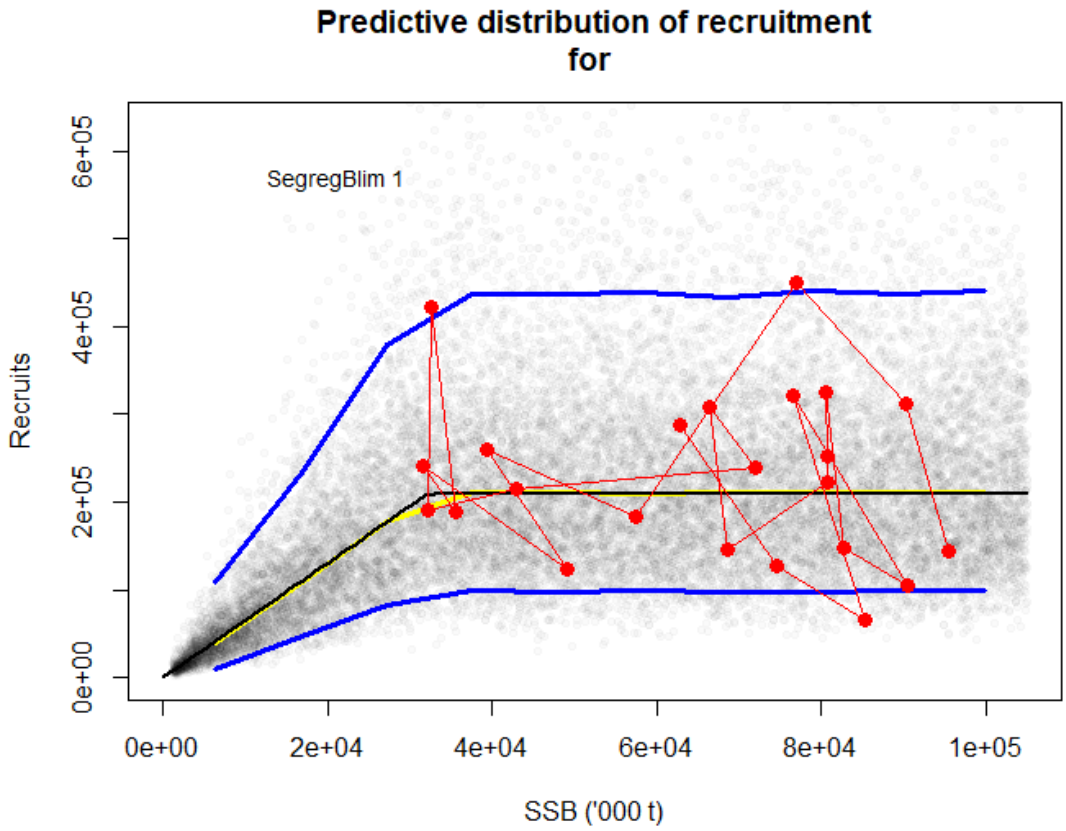


Figure 3.13.1.2. Truncated stock–recruitment relationship for year classes 1997–2019 (corresponding to recruitment-at-age 1 from 1998 onwards) with breakpoint forced at the lowest SSB.

Methods and settings used to determine ranges for F_{MSY}

All analyses were conducted with Eqsim in accordance with ICES guidelines. The assessment error in the advisory year and the autocorrelation was derived from the results of a recent evaluation of HCRs (WKNSMSE, 2019). The approach was to compare the intended target F (the F from application of the HCR) with the realised F:

$$F^{i}_{rat,y} = F^{i}_{realised,y} / F^{i}_{HCR,y}$$

This is derived for each projection year y and simulation i. Then for each simulation i, the error parameters are estimated by calculating the standard deviation and serial correlation of the vector $\ln(\underline{F}^{i}_{rat})$ (each element representing a year), taking the mean across simulations. The associated R code is as follows:

```
cv <- apply(log(f_OM/f_hcr), 6, sd)
rho <- apply(log(f_OM/f_hcr), 6, function(x) {
  acf(c(x), plot = FALSE, lag.max = 1)$acf[2]
})
cv <- cv*sqrt(1 - rho^2)
mean(cv)
mean(rho)
```

This leads to a cv of 0.14 and a phi of 0.44.

The new suggested values for B_{lim}, B_{pa} and $B_{trigger}$ were used in the Eqsim analyses. Settings for the analysis are given in Table 3.13.1.1.

Table 3.13.1.1. Model and data selections settings for the Eqsim analysis of North Sea cod.

Data and parameters	Setting	Comments
SSB–recruitment data	Truncated dataseries (years classes 1997–2019)	Over 20 years of low recruitment despite similar numbers, weights, and maturities to earlier in the time-series, with recent evidence for a regime shift in the North Sea around in the late 1990s. Following ICES guidelines for type 6 stocks, the stock–recruitment relationship was taken as a segmented regression with the lowest observed SSB as the forced breakpoint.
Mean weights, proportion mature and natural mortality	2015–2019	There is a decreasing trend in mean Weight-at-age over the last 10 years. There is also a decreasing trend in predation mortality in the latest years. Therefore, a five-year time-period was chosen.
Exploitation pattern	2015–2019	There is no change in exploitation pattern in the last 10 years. A five-year time-period was chosen for consistency with the biological parameters and what was done for this stock previously.
Assessment error in the advisory year. CV of F	0.14	Estimated from recent MSE simulations
Autocorrelation in assessment error in the advisory year	0.44	Estimated from recent MSE simulations

Final Eqsim run

For the final Eqsim run, yield excludes discards, with F_{MSY} being taken as the peak of the median yield curve. However, the observed discards for age 3+ were added to the landings. Under the landing obligation, former discards above the minimum conservation reference size are landed and sold and therefore belong to the "wanted catch". Discarded fish at age 3+ can be assumed to all be above the minimum conservation reference size.

The M-adjustment to account for recent migrations of older cod to 6aN was not included in the Eqsim analysis. Although there is strong evidence for increased abundances of North Sea cod in the West of Scotland (WKNSCodID 2020), it cannot be assumed that this will continue or that the fish will not migrate back. Furthermore, initial runs of Eqsim with an M-adjustment produced higher estimates of F_{MSY} (~0.40) because the model takes the elevated Ms as a true mortality and attempts to harvest those fish before they die. The M-adjustment is an interim solution to remove the fish that have migrated away from the North Sea from the modelled population in the North Sea, giving less biased estimates of the current population in the defined stock area. However, fish that have migrated are not unavailable and, given strong connectivity between the northern North Sea and the West of Scotland (WKDEM 2020; WKNSCodID 2020), still contribute to the stock from outside the North Sea.

The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve. $F_{P.05} = F_{pa}$ is the F value associated with a 5% risk upon application of the ICES MSY advice rule and F_{lim} is the F value associated with a 50% probability of SSB being above or below B_{lim}.

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.28 (Figure 3.13.1.3). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.45 and the lower bound at 0.186. The median of the SSB estimates at F_{MSY} was 163 738 t, a level which has not been observed since the 1970s (Figure 3.13.1.4). When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 97 777 t, the $F_{P.05}$ and F_{pa} value was 0.49 (Figure 3.13.1.5). Eqsim runs applying a fixed F harvest strategy without assessment or advice error (cv = phi = 0) and with the point of inflection of the stock–recruitment relationship forced at B_{lim} estimate an F_{lim} of 0.58.

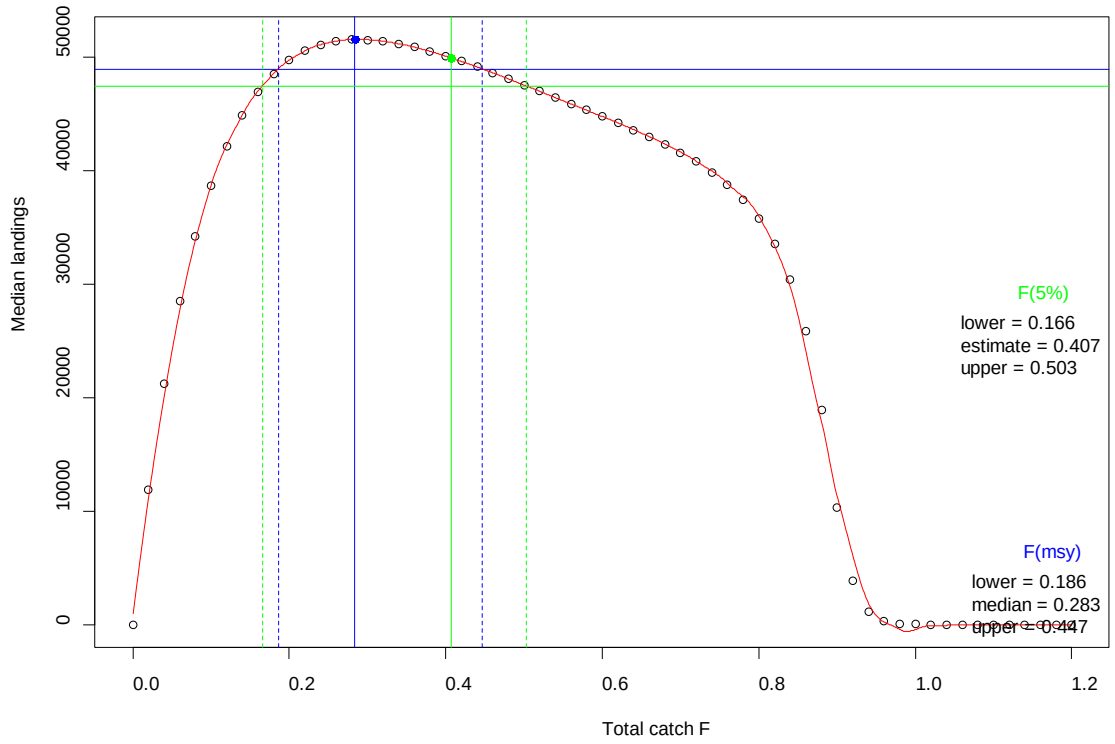


Figure 3.13.1.3. Cod with fixed F exploitation. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$=F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

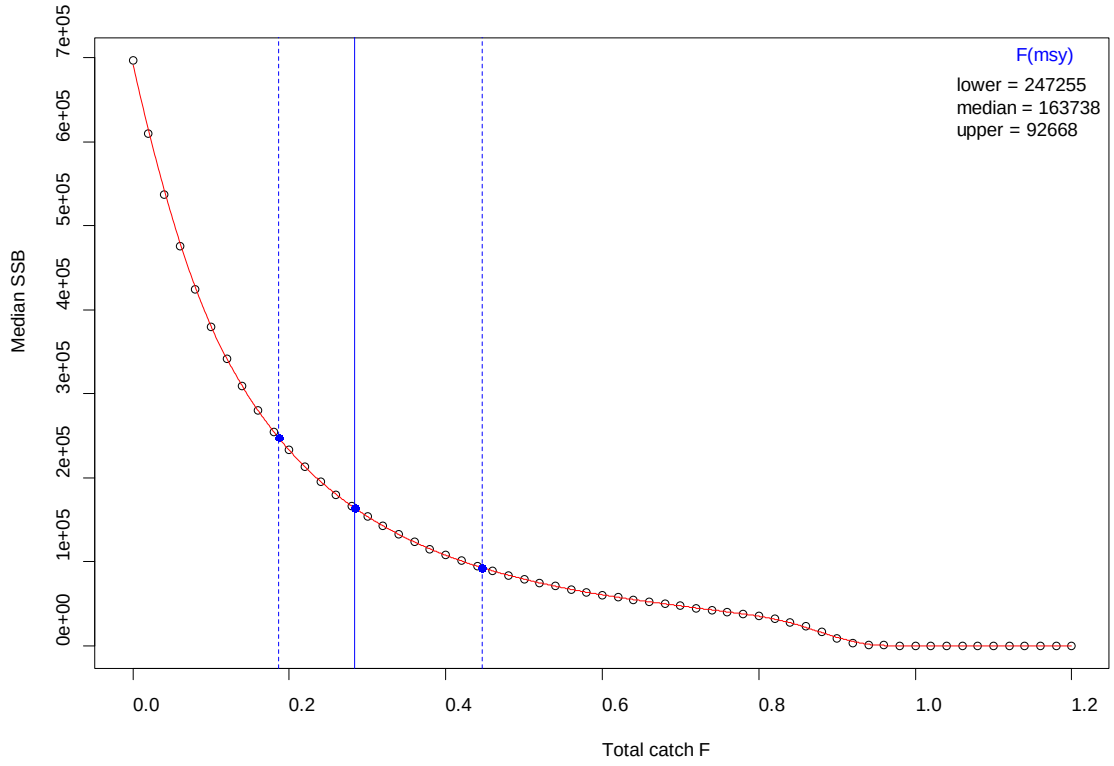


Figure 3.13.1.4. Cod with fixed F exploitation: median SSB. Blue lines show the location of F_{MSY} (solid) with 95% yield range (dotted).

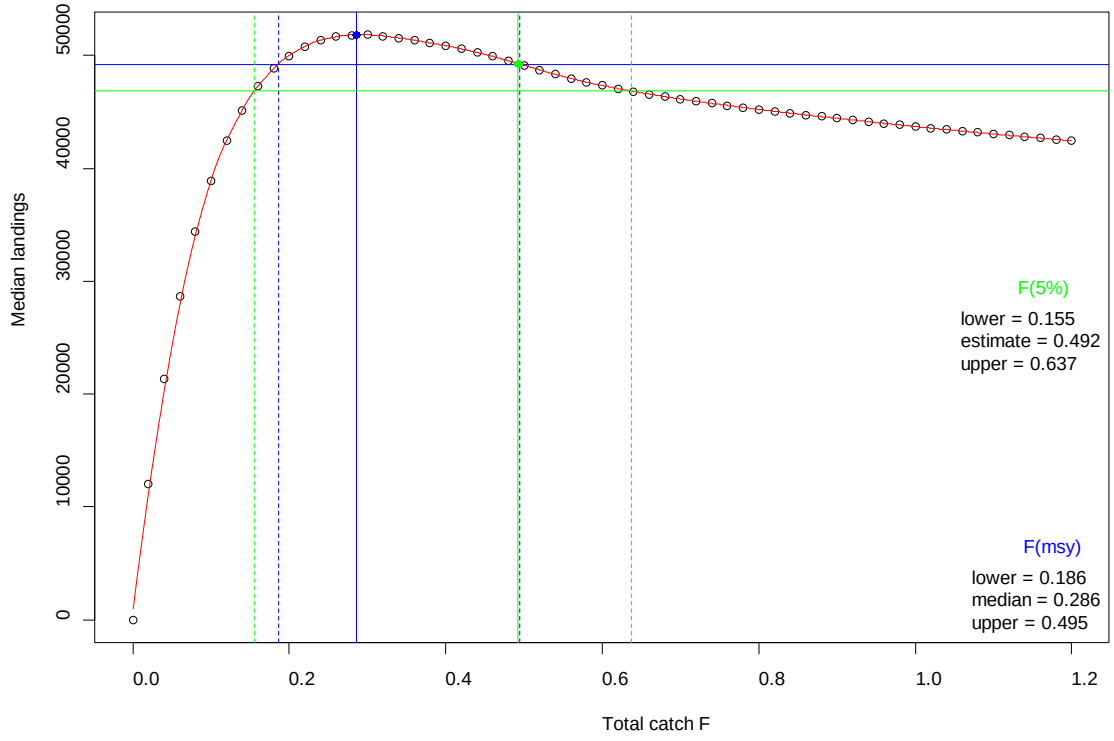


Figure 3.13.1.5. Cod when applying the ICES MSY harvest control rule with a $B_{trigger}$ of 97 777 t. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$=F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

Proposed MSY and PA reference points

Table 3.13.1.2. Summary table of proposed stock reference points for North Sea cod.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	97 777	B_{pa}
	F_{MSY}	0.28	Eqsim analysis based on the recruitment period 1998–2020
	$F_{MSYlower}$	0.186	95% of the peak of the median yield curve
	$F_{MSYupper}$	0.45	95% of the peak of the median yield curve
Precautionary approach	B_{lim}	69 841	B_{pa} / 1.4
	B_{pa}	97 777	Highest SSB corresponding to the 1998+ recruitment period
	F_{lim}	0.58	F giving 50% probability of SSB < B_{lim}
	$F_{P.05}$	0.49	Eqsim analysis with the ICES MSY AR
	F_{pa}	0.49	$F_{P.05}$

3.14 Re-opening of advice

Since the final SAM model includes two indices (as age 0, shifted to age 1 the coming year, is now a separate index) from the IBTS Q3, the assessment is subject to the AGCREFA protocol for reopening of advice in the autumn (AGCREFA 2008). Until now the procedure has been to re-apply the delta-GAM model to the full IBTS Q3 time-series, including the new data from intermediate year *y*, and to include both the IBTS Q1 and revised IBTS Q3 indices in an RCT3 check of the incoming year class (*y*-1) at age 1. Once it has been established that the advice should be re-opened, the procedure is to then re-run the assessment and forecast with the new Q3 data included. A recent workshop reconsidered the reopening protocol from ICES AGCREFA for North Sea stocks and recommended that for cod only the IBTS Q3 index be included in the RCT3 check, to avoid the circularity associated with using the IBTS Q1 index in both the May assessment and the October reopening check (WKNSROP 2020).

Introduction of the IBTS Q3 index for age 0 forward shifted to the beginning of the following year to represent recruitment-at-age 1 (Section 3.7.1) gives potential to account for year class *y* in a reopening, i.e. those fish that are born in intermediate year *y* and recruit at age 1 in TAC year *y*+1. The group decided that these fish should be included both in the RCT3 analysis to check for a reopening and in the assessment and forecasts if a reopening is triggered by either year class. This was justified by good internal consistency between ages 0 and 1 in the IBTS Q3 indices (cor = 0.763; Figure 3.14.1) and good external consistency between age 0 in the IBTS Q3 and age 1 in the IBTS Q1 (cor = 0.791; Figure 3.14.2).

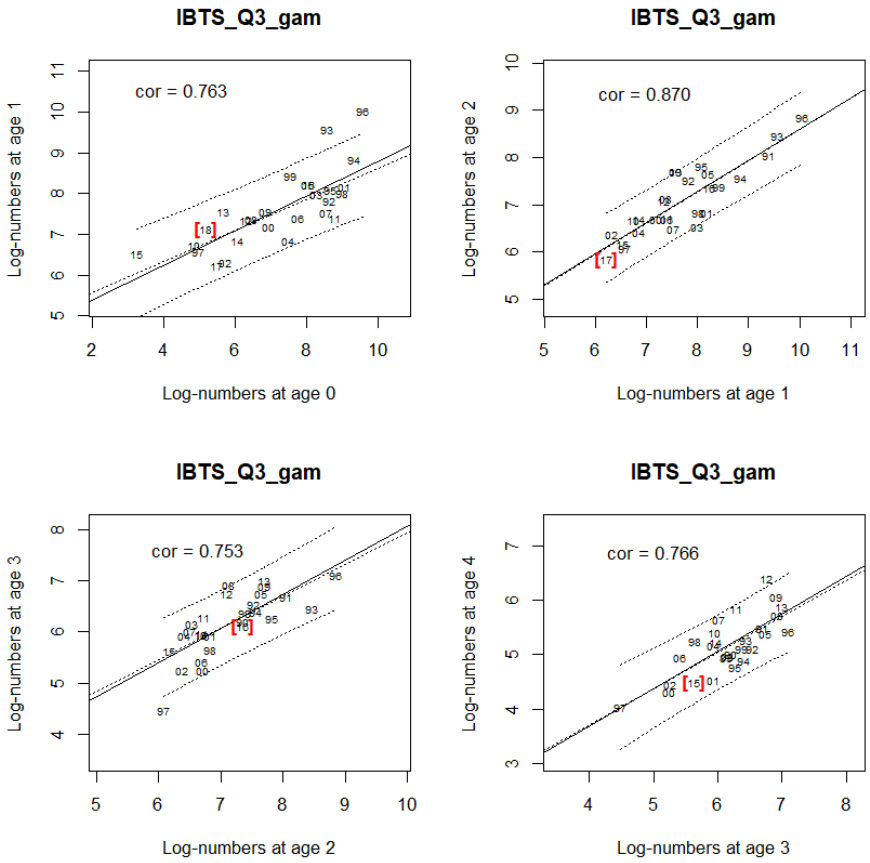


Figure 3.14.1. Within-survey correlations for the IBTS Q3 index for the period 1992–2019. Individual points are given by cohort (year-class), the solid line is a standard linear regression line, the broken line nearest to it a robust linear regression line, and "cor" denotes the correlation coefficient. The pair of broken lines on either side of the solid line indicate prediction intervals. The most recent datapoint appears in red square brackets.

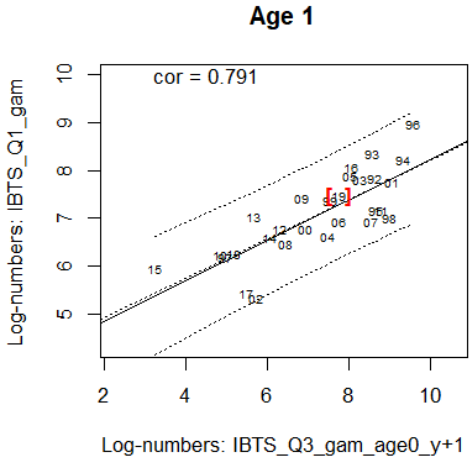


Figure 3.14.2. Between-survey correlations for the forward shifted IBTS Q3 index at age 0 and the IBTS Q1 index for age 1 for the period 1993–2020. See Figure 3.14.1 for a description.

In terms of the RCT3 analysis, it was acknowledged that the high internal standard error associated with age 0 would make it difficult for a reopening to be triggered based on year class *y*

alone. Nevertheless, this index is now included in the assessment and, as representation of recruitment-at-age 1, should be checked.

If a reopening is triggered, SAM will estimate recruitment-at-age 1 in the TAC year (y+1) based on the new observation of age 0 from the IBTS Q3 (year y), which will then be used in the forecasts instead of a resampled recruitment. Although this estimate of recruitment is based on a single observation of the incoming year class y, it is noted that the variance of the Q3 index is included as an inverse weight in the SAM estimation and that the uncertainty about this recruitment estimate will be carried through to the stochastic forecasts (Section 3.12.1). Furthermore, testing of extreme index values suggests that even very high or low estimates of recruitment will have little effect on the management advice as few of these fish will contribute to the SSB or catch when aged 1 in the TAC year. However, bigger differences in the forecasted SSBs are apparent in year y+2, which may become important if the stock is estimated below B_{lim}.

The proposed reopening protocol is:

1. Re-run the delta-GAM index for Q3 including the new data from the autumn survey.
2. Conduct an RCT3 check on age 1 for year classes y-1 and y including information from the IBTS Q3 only. Trigger a reopening if |D|>1 for either year class, where:

$$D = \frac{R - A}{S}$$

R = log weighted average prediction from RCT3;

A = Assumed year class strength in the May forecast;

S = internal standard error from RCT3.

3. If a reopening is triggered:

a) Rerun SAM with the updated Q3 index;
b) Populate and re-run the forecast procedure with the resulting assessment estimates, using the SAM estimate of recruitment in the TAC year (y+1) rather than a resampled recruitment, as done in May.

4 Spurdog (dgs.27.nea)

Spurdog *Squalus acanthias* (also known as picked dogfish, piked dogfish and spiny dogfish) is a medium-sized shark that is widespread in the Northeast (NE) Atlantic, with other stocks of this species occurring elsewhere in the world.

The NE Atlantic stock of spurdog is distributed over much of the ICES area, although the presence of the species in subareas 9–10 and Division 8.c is uncertain, as other species of *Squalus* may occur. The stock is distributed mainly in divisions 2.a, 3.a, subareas 4–7 and divisions 8.a–b,d, with the stock also extending to subareas 1 and 14 and divisions 2.b and 8.e.

Fisheries for spurdog expanded rapidly over the course of the 20th century, especially from the 1950s, which prompted a lot of biological investigations from UK and Norwegian scientists in the 1950s and 1960s. The history of the fishery has been provided in earlier reports of the Working Group on Elasmobranch Fishes (WGEF) and also by Pawson *et al.* (2009).

4.1 Summary

The spurdog assessment is a Category 1 integrated age–length-based assessment that includes catch data back to 1905. The first benchmarked model used fecundity data from two periods (1960 and 2005) to inform on the extent of density-dependence of pup production. Survey indices included in the assessment to date only covered a relatively small part (divisions 6.a and 4.a) of the entire stock distribution area, and one of the main aims of the benchmark was to improve on this by including a number of eligible surveys in the assessment covering a much larger area. A wealth of additional fecundity data has now also been collated (including published data from 1921, 1978, 1987, 1988, 1997 and recent biological sampling data from 2013/2014, 2019, and 2020), and these can now be included in the assessment, along with potentially improved information on growth. Finally, the lack of fleet-based data (including length distributions), and reliable catch information since 2010 were weaknesses in the more recent biennial assessments that had been conducted, and needed to be addressed. The data-call has requested this information, which will be collated and analysed to check its utility for the assessment.

In addition to the information provided in the current report chapter, the reader is also referred to the following six Working Documents that provide further details of the relevant datasets incorporated in the final assessment model:

1. Dobby, H. 2021. Survey indices for Northeast Atlantic spurdog. Working Document for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 23 pp.
2. Ellis, J. R. and De Oliveira, J. A. A. 2021a. Growth parameters for spurdog *Squalus acanthias.* Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 17 pp.
3. Ellis, J. R. and De Oliveira, J. A. A. 2021b. Contemporary length-frequency data for spurdog *Squalus acanthias.* Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 15 pp.
4. Junge, C., Tranang, C. A., Vollen, T. and Albert, O. T. 2020. A summary of spurdog (*Squalus acanthias*) data collected during the Norwegian Shrimp trawl survey (NO-shrimp). Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 13 pp.

5. Junge, C. 2021. A summary of spurdog (*Squalus acanthias*) landings and discards data collated. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 12 pp.
6. Silva, J. F. and Ellis, J. R. 2021. Life-history parameters of North-east Atlantic spurdog *Squalus acanthias*. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 42 pp.

4.2 Earlier models and uncertainty

Exploratory analyses of spurdog in the NE Atlantic were conducted during the DELASS project. From this work, a demographic model was developed (Hammond and Ellis, 2005), and the result of an initial, exploratory model indicated that the stock had declined, potentially to about 5% of virgin biomass.

Subsequent studies developed an age- and sex-structured stock assessment model that used length-based processes (e.g. maturation, pup production, growth and gear selectivity), with a length-at-age relationship used to convert length to age. This model, which was based on the approach developed originally by Punt and Walker (1998) for tope *Galeorhinus galeus,* relates pup production to numbers of pregnant females and allows for density-dependent effects.

The model was fitted originally to a combined Scottish groundfish survey biomass index, to proportion-by-length category data from both trawl surveys and commercial catch sampling from 'target' and 'non-target' fisheries, and to fecundity data. The model was run from 1905 to better reflect virgin conditions, and to allow early fecundity data to be fitted in order to estimate the extent of density-dependence in pup production.

The model was benchmarked following the 2010 meeting of WGEF, with the final model, and reviewer comments, included in the 2011 WGEF report (ICES, 2011). In addition to the ICES benchmark, the model and findings were also published in a peer-review journal (De Oliveira *et al.*, 2013), thus ensuring additional review.

The final model runs reported by De Oliveira et al. (2013) indicated that the "2010 population levels to be about 23% relative to 1955 and 19% relative to 1905. Results confirm that the stock is depleted, but not to the extent estimated in a previous assessment. Model projections showed that a TAC of 1422 t (the last non-zero TAC) would allow future population growth".

While this model has been re-run to provide the basis for the biennial stock advice since the benchmark in 2010, the subsequent management restrictions (including a zero TAC), and lack of discard input data, meant that reliable catch data were not available. Consequently, more recent model runs had used mean annual landings for the years 2007–2009 (= 2468 t) to represent the estimated annual catch for 2010 onwards. Consequently, there was a need to consider more robust estimates of recent catch for the 2021 benchmark.

ICES (2011) summarised that:

"the model is considered appropriate for providing an assessment of spurdog, though it could be further developed in future if the following data were available:

- *Selectivity parameters disaggregated by gear for the main fisheries (i.e. for various trawl, longline and gillnets);*
- *Appropriate indices of relative abundance from fishery-independent surveys, with corresponding estimates of variance;*
- *Improved estimates for biological data (e.g. growth parameters, reproductive biology and natural mortality);*

• *Information on likely values of MSYR for a species such as spurdog".*

The potential issues identified as areas of future consideration (ICES, 2011) were considered here across four main topics: (i) catch data (landings, discards and commercial size and sex composition, (ii) survey indices (biomass indices and size and sex composition), (iii) biological parameters, and (iv) reference points. These are discussed further in subsequent sections.

4.3 Surveys

It was noted previously that the survey data used in the model only covered part of the stock distribution, as the indices were based on four Scottish surveys. These surveys included the Scottish surveys in the North Sea IBTS, which occurred mostly in the northwestern parts of Subarea 4 (although the area sampled by Scotland is more extensive in Q3 than in Q1), and Scottish surveys (Q1 and Q4) in Subarea 6 (although the survey grid extended into the northern parts of Division 7.a in earlier years).

Reviews of the earlier model had rightly highlighted that the survey coverage did not provide information for all the stock range and that parts of the stock range that are known to be important areas for spurdog (e.g. Skagerrak, Norwegian waters, most of Subarea 7) were not incorporated.

Further details on the final input survey data, analysis and results are found in Dobby (2021; WD_Spurdog_1_Spurdog biomass indices). Junge *et al.* (2020; WD_Spurdog_4_Spurdog in NO shrimp survey), presented at the Data Evaluation Meeting, provides further information on spurdog caught during the Norwegian shrimp survey.

4.3.1 Data evaluation meeting

A number of modifications (and corrections) to the currently used 6.a/4.a biomass index based on Scottish survey data were presented, and it was initially concluded that a more transparent approach to deriving the survey index was to make use of data from DATRAS (rather than extracted from a Marine Scotland database). Additionally, it was agreed that using the survey Index R package for the delta-GAM statistical modelling (rather than the current bespoke R code) would make it easier to develop indices for other areas.

Following discussions on the time of year and spatial coverage of the various surveys in DATRAS and those made available as part of the data call, the workshop agreed to derive three separate biomass indices reflecting the seasonal (quarterly) nature of the surveys (Q1, Q3, Q4):

- Combined NS-IBTS-Q1 (1985–present; excluding divisions 4c, 7d), WIBTS-Q1 (1985–present; NI, SCO), NO-Shrimp-Q1 Norwegian Shrimp survey (2006–present);
- NS-IBTS-Q3 (1991–present);
- WIBTS-Q4 (4 countries) (2003–present; IRE, SCO, FRA, NI; excluding Subarea 8).

Some parts of the survey areas were excluded (i.e. divisions 4.c and 7.d from NS-IBTS-Q1; Subarea 8 from WIBTS-FRA-Q4), primarily to minimise the areas of lower abundance.

Details on the included surveys and their coverage are found in the *WD* by Dobby (2021).

The combined biomass indices will be accompanied by estimates of sampling error (CVs) and estimates of length composition (by sex, if possible, and length stages, as specified in the model, or by finer length bins which can then be combined). Estimates of length composition should be

accompanied by actual sample sizes (by sex, if possible) on which these length compositions are based in order to inform on effective sample.

Data deadline for all surveys in DATRAS format is the 10th of January 2021.

4.3.2 Benchmark workshop

Three survey indices were developed based on data as agreed at the Data Compilation Meeting (Section 4.3.1), the exception being that data from 1991 in quarter 3 were excluded from the analysis due to the variety of different gears being used in this year. Some of the data were not available in DATRAS (Q1 Norwegian shrimp survey and Q4 NI-GFS) but had been supplied as part of the data call for this meeting and these were reformatted to DATRAS format prior to analysis.

Catch weight per haul was derived from the length composition (by sex, 'HL' records in DATRAS) and a sex specific weight length relationship derived from the sampled individuals ('CA' records). On some hauls/surveys, individuals have been recorded without sex and in such cases the weight caught was derived using a combined sex length–weight relationship. Total weight per haul (the sum over male/female and unsexed) was then modelled using a GAM-based delta-lognormal model (Berg *et al*., 2014). A number of models with different subsets of explanatory variables (year, lat x lon, depth, time of day and ship) were fitted to the data and the best model for each quarter was chosen on the basis of AIC. No interaction between spatial distribution and year was considered. Sensitivity testing of the final models was conducted by running retrospective analysis and leave-one-out analysis where possible. Data extraction and manipulation made use of the 'DATRAS' R package while statistical modelling has been carried out using the 'surveyIndex' R package (Berg *et al.*, 2014).

In addition to the survey indices (and estimated CVs), the number of individuals by sex (sample size) and proportion at length by year (and sex) were calculated for use in the stock assessment.

A comparison of the estimated biomass indices from the three quarters is shown in Figure 4.3.2.1. While both the Q1 and Q4 indices showed a general increase since the late 2000s, this increasing trend is steeper in Q4. The Q3 index is noisier and estimated with large confidence intervals, but appears to have been at a minimum in the early 2000s and at a higher level since then.

Further details on the input data, analysis and results are found in the *WD* by Dobby (2021).

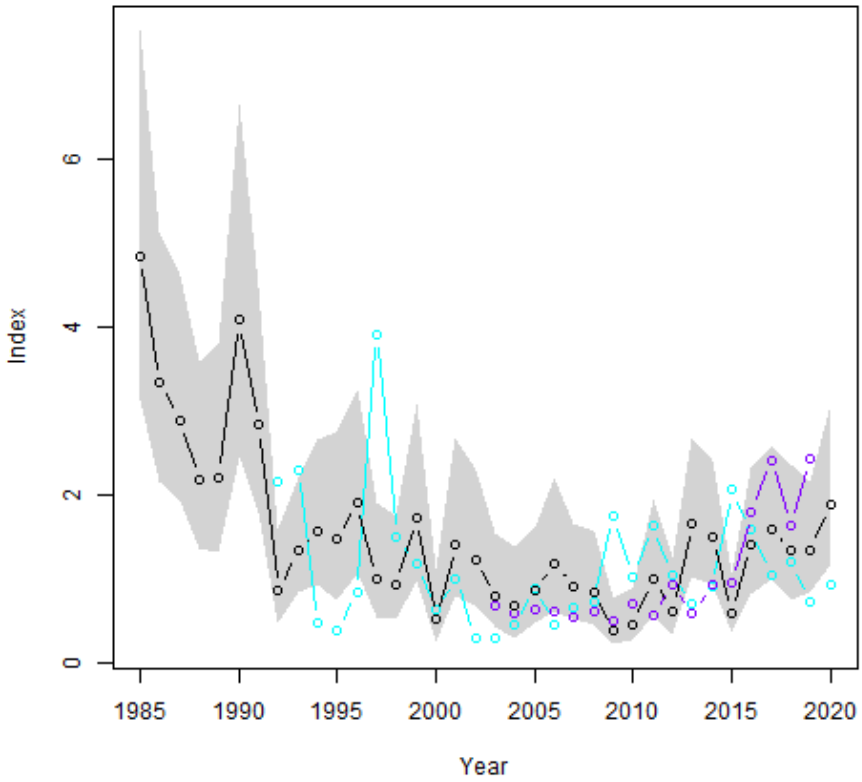


Figure 4.3.2.1. Spurdog in the North-east Atlantic. Comparison of mean standardised indices (Q1 – black, Q3 – blue, Q4 – purple).

Using a statistical modelling approach allows for multiple surveys with different designs and potentially using different gear to be combined in the estimation of biomass indices for spurdog. It therefore enables the provision of biomass indices covering a larger proportion of the stock area to be developed, and the surveys now used cover the main parts of the stock distribution. The retrospective analysis suggest that the indices are relatively robust to changes in the time-series of data included, particularly in Q1 and Q3.

Survey size compositions by sex, collated as proportions by length category (according to the established lifestage-based length bins used for spurdog), were compiled for each of the combined survey series (Q1, Q3, Q4). However, there were not sufficient samples for the Q3 survey to provide these data for several years; an extreme example is the sampling of just two males and no females in 2003 (Table 4.3.2.1). It was decided to only include those years which had at least ten individuals sampled by sex, and at least 30 individuals in total. This meant that the years 1995–2007 were not included for proportion by length category data for the Q3 survey (Table 4.3.2.1). Proportion by length category data for the three surveys are shown in Figures 4.3.2.2–4.3.2.4.

Table 4.3.2.1. Spurdog in the Northeast Atlantic. Sample sizes from the Q3 survey time-series.

Year	Male	Female	Total
1992	31	32	63
1993	19	13	32
1994	18	15	33
1995	6	9	15
1996	10	14	24
1997	11	13	24
1998	6	10	16
1999	29	4	33
2000	11	5	16
2001	3	3	6
2002	2	1	3
2003	2	0	2
2004	4	4	8
2005	15	4	19
2006	7	8	15
2007	9	13	22
2008	71	48	119
2009	18	28	46
2010	25	16	41
2011	92	47	139
2012	56	31	87
2013	26	52	78
2014	725	26	751
2015	58	53	111
2016	34	25	59
2017	102	92	194
2018	302	64	366
2019	53	51	104
2020	85	92	177

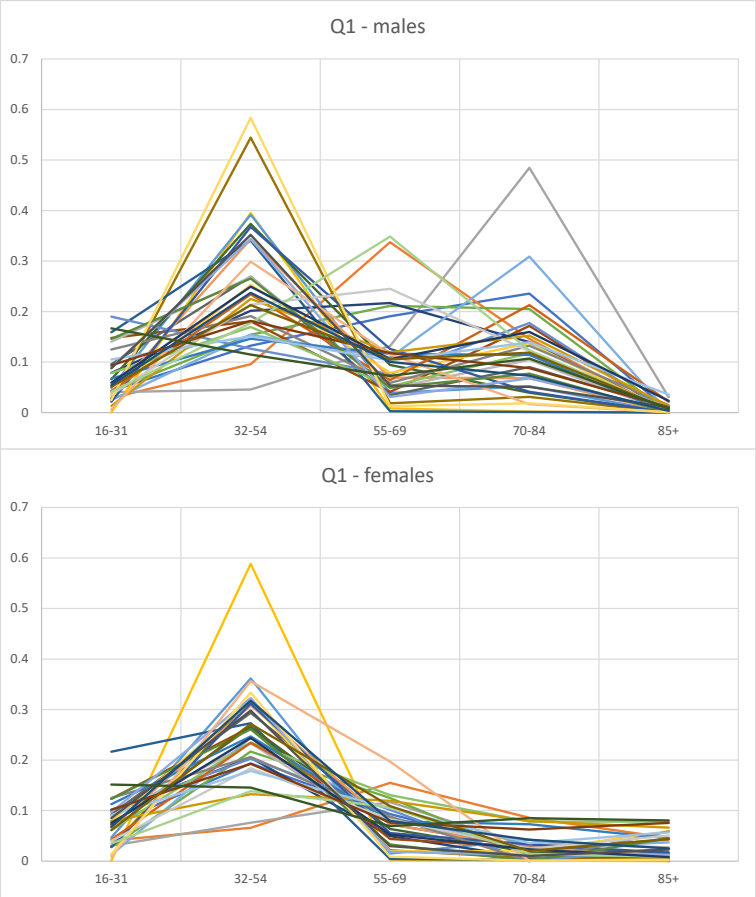


Figure 4.3.2.2. Spurdog in the Northeast Atlantic. Proportions by length category for the Q1 combined survey index for males and females.

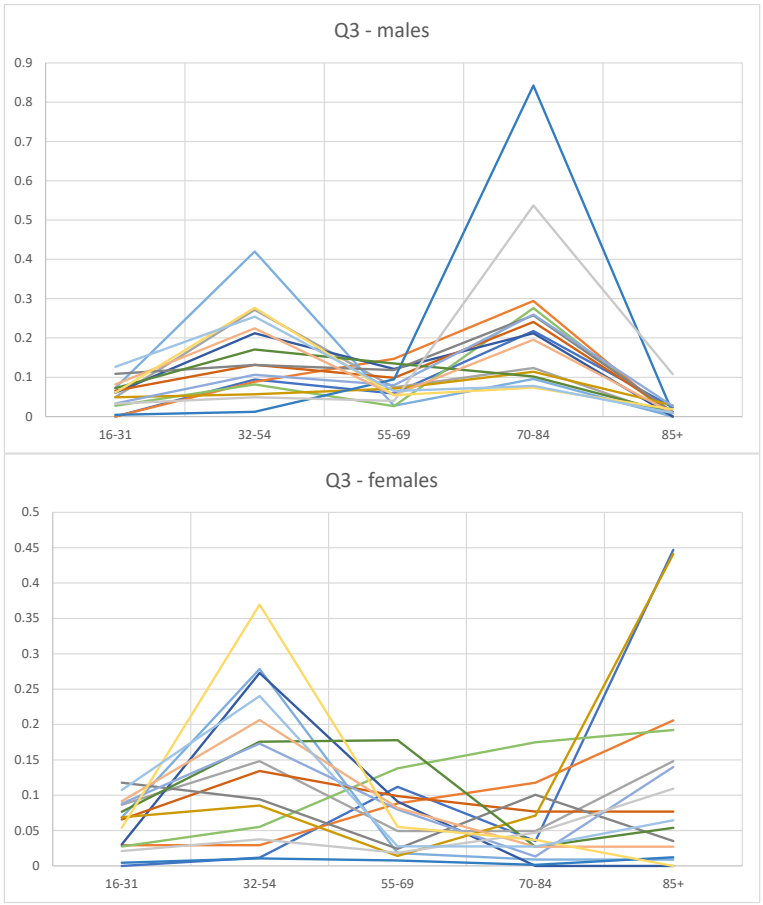


Figure 4.3.2.3. Spurdog in the Northeast Atlantic. Proportions by length category for the Q3 combined survey index for males and females.

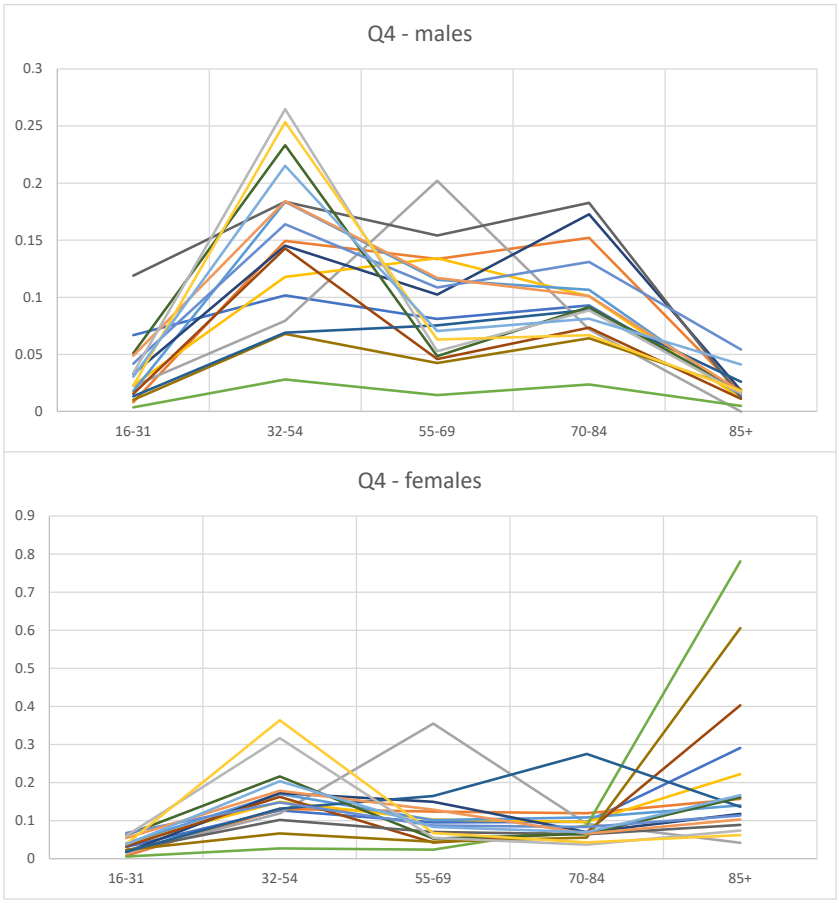


Figure 4.3.2.4. Spurdog in the Northeast Atlantic. Proportions by length category for the Q4 combined survey index for males and females.

4.4 Growth parameters and age

ICES (2011) noted that "*updated and validated growth parameters, in particular for larger individuals*" were required. However, there is no standardised sampling for age and growth of NE Atlantic spurdog, and so contemporary data are limited.

4.4.1 Data evaluation meeting

Since the previous benchmark, there have been additional published studies on the age and growth of spurdog, but only one of these related to the NE Atlantic stock (Albert *et al.*, 2019). A Working Document by Ellis and De Oliveira (2021a; WD_Spurdog_2_Spurdog growth parameters) summarised the various von Bertalanffy growth parameters (VBGP).

It was recommended that the benchmark assessment continues to use the averaged von Bertalanffy growth parameters (VBGP) used in the original assessment, but that additional model runs should also be undertaken using the upper/lower published estimates (providing that they are biologically plausible values). These values will be agreed by the 10 January 2021 deadline.

There will be several virtual meetings in December 2020 and January 2021 between contributing scientists (including IMR, Cefas, MSS) to maintain progress with this part of the work.

Consequently, it is suggested that model runs to better understand the sensitivity to VBGP should use three sets of parameters, as indicated in the WD.

a) the averaged VBGP from all the studies now compiled (excluding the male VBGP from Albert *et al.*, 2019), as the preferred base case;
b) the values used in the previous assessment (De Oliveira *et al.*, 2013) as an alternative scenario; and
c) the VBGP from Fahy (1988).

4.4.2 Benchmark workshop

An area of future improvement for the spurdog model is including variation in the age–length relationship in the model. The lack of progress in this regard during the benchmark (given the need to focus on other areas considered of higher priority, such as the substantial improvement in the data now included in the model) meant that it was not possible to explore sensitivity to alternative growth parameterisations. This was because the alternative growth models proposed meant that there were no longer animals in the smallest length classes, leading to zero values which were not possible to deal with during this benchmark. The growth parameters used for the final model therefore remains (b) in Section 4.4.1.

4.5 Reproductive parameters

The key reproductive parameters used in the assessment model are length-at-maturity of females and fecundity-at-length.

Previous authors have generally indicated that density-dependent changes in reproductive parameters of spurdog are more likely to occur in relation to fecundity (Silva, 1993; Fahy, 1989; Ellis and Keable, 2008) than maturity-at-length. It is also noted that purported temporal changes in maturity estimates of some elasmobranchs may be compromised by differences in the maturity stages used in individual studies and the interpretation of 'mature' (McCully *et al.*, 2012). Consequently, further consideration of fecundity-at-length data were considered of greater merit.

Most national fisheries laboratories have not had routine data collection of life-history parameters of spurdog over the longer term. Some biological information is now collected on various surveys coordinated by IBTS (ICES, 2019), but sample sizes are often low. Whilst there should be some contemporary data on individual length-sex-weight-maturity held by the various institutes, it is uncertain whether fecundity data are also collected. It should also be noted that some laboratories tag-and-release lively specimens of spurdog during surveys and, whilst individual length-sex-weight data are still collected, maturity data would not be available for all individuals.

There are numerous published studies on the reproductive biology of spurdog (Ford, 1921; Hickling, 1930; Aasen, 1961; Holden and Meadows, 1964; Sosiński, 1976, 1978; Gauld, 1979; Fahy, 1988; Jones and Ugland, 2001; Henderson *et al*., 2002; Stenberg, 2005; Albert *et al*., 2019), with a summary of these data and additional contemporary data provided in the WD by Silva and Ellis (2021).

The original assessment used fecundity-at-length from two studies, one from the 1960s and one more contemporary dataset based on the opportunistic sampling of a single large catch of mature females during a trawl survey (Ellis and Keable, 2008). Consequently, the inclusion of further information on fecundity-at-length were considered of greater relevance to the current assessment and requested during the Data Call. To this end contemporary fecundity data were collated as well as historical (published) information, as provided by Silva and Ellis (2021; WD_Spurdog_6_Spurdog life history) and detailed below.

4.5.1 Data evaluation meeting

Additional data on fecundity-at-length was collated from contemporary investigations from UK (WD_spurdog_6_Spurdog life history) and Norwegian studies (Albert *et al.*, 2019), with comparable data also collated from published studies. The available fecundity-at-length data now covers the years 1921, 1960 (current assessment), 1978, 1987/1988, 1997, 2005 (current assessment), and 2013–2020).

Some of the earlier data include information on both *ovarian fecundity* (i.e. the number of mature, yolk-filled follicles) and *uterine fecundity* (i.e. the numbers of developing embryos or pups). Whilst the current assessment uses only uterine fecundity, the inclusion of all fecundity data would provide for larger sample sizes for more time periods.

In general, ovarian fecundity may over-estimate fecundity slightly (as not all mature, yolk-filled follicles will be ovulated and develop through to the pup stage), whilst uterine fecundity may under-estimate fecundity slightly (as some pups can be shed on capture and thus not be accounted for). In the current assessment, some of the pup data were based on separate counts for left and right uterus, thus allowing for some instances of likely pup loss to be omitted. Such data resolution is not available for much of the newly collated data.

It was recommended that the benchmark assessment uses all available fecundity-at-length data (i.e. mature, yolk-filled follicles; developing embryos; and term pups), but avoid using multiple data from the same individuals. If time allows, additional model runs could usefully be undertaken (e.g. considering just uterine fecundity). However, given that fecundity estimates are very similar when derived from ovarian/uterine counts, such model runs are to be considered of lower priority than other model runs (e.g. VBGP).

The collated fecundity-at-length data have to be amalgamated into a consistent format, and the deadline for this is 10 January 2021.

4.5.2 Benchmark workshop

No updates to the length-at-maturity for male and female spurdog were introduced in the 2021 assessment, with the length at first (smallest mature), 50% and 95% maturity of female spurdog being 70, 80 and 87 cm, respectively (De Oliveira *et al.*, 2013).

New data on fecundity-at-length were included in the 2021 assessment. These data comprised contemporary data collected during Norwegian (Albert *et al*., 2019) and UK (Silva and Ellis, 2021 WD) studies, as well as additional historical data on fecundity-at-length from published sources (Ford, 1921; Gauld, 1979; Fahy, 1988; Walenkamp, 1988; Jones and Ugland, 2001; Henderson *et al*., 2002; Stenberg, 2005). Some of these studies provided fecundity by length group, and in such instances the fecundity was assumed to occur at the mid-point of the length group.

Fecundity data used in the assessment were generally limited to uterine fecundity (i.e. the number of embryos or pups in the uteri), as most published studies would provide ovarian and uterine fecundity for the same samples of fish. Given the limited fecundity data for the earliest years (Ford, 1921), and that the underlying data in this study appeared to be from different samples, both uterine and ovarian fecundity were used from this study. All other data sources were limited to uterine fecundity.

Most studies provided data for total uterine fecundity (i.e. the total number of pups or embryos for both uteri combined), whilst some of the more contemporary data collection reported data for each uterus. Following Ellis and Keable (2008), any specimens for which the difference in the number of embryos (or pups) between the two uteri was ≥4 were assumed to have aborted some young and were excluded from further analysis. Where only total fecundity data were available

(i.e. the number of embryos in the individual fish, combining both left and right uteri), then no such data filtering was possible.

4.6 Other biological parameters in the model

4.6.1 Natural mortality

ICES (2011) noted that "*better estimates of natural mortality*" were also desirable. However, there have been limited studies on natural mortality (M). In the absence of any robust estimates of natural mortality (M), the same values were used as in the original assessment.

4.6.2 Length–weight relationship

No changes were made to parameters a and b, which are used to estimate individual weight from length, based on:

$$W_T = a.L^b$$

Where W_T is total weight and L is the total length (cm).

The parameters used in the model are a = 0.00108 and b = 3.301 for females (Bedford *et al*., 1986), and a = 0.00576 and b = 2.89 for males (Coull *et al.*, 1989).

4.7 Catch data and commercial size composition

The management that has been applied to NE Atlantic spurdog has evolved in recent times. This is summarised below, to aid in the interpretation of available data.

Within EU waters, there was no TAC management for spurdog until 2000, when a TAC was first introduced for the North Sea area. Other TAC management units were introduced over the years 2007–2009. Footnotes in the EU fishing opportunities, in force during 2007–2010, were also used to prevent target fisheries, including stipulating bycatch ratios and a maximum landing length (100 cm).

The TACs were subject to annual reductions before being reduced to zero in 2010 (albeit with a 10% allowance of the previous year). The TAC was then specified as zero for 2011–2016 (in part). An in-year amendment to the quota regulations in 2016 allowed for limited dead bycatch to be landed from 'bycatch avoidance fisheries' in western waters (DGS/15X14). This caveat aside, the species has been listed as a prohibited species from 2017.

The WGEF had compiled estimates of total landings of NE Atlantic spurdog from 1905. Obviously, discards information for such a long time-series are unavailable. Consequently, the model required the assumption that landings equated with catch (i.e. that quantities of dead discards were negligible).

Given the lack of management for the main part of the longer time-series, there is no clear indication that there would have been regulatory discarding for most nations. However, it is noted that Norway has had a minimum landing size of 70 cm since 1964 (Pawson *et al.*, 2009). Furthermore, management measures for spurdog have become increasingly restrictive since the late 2000s and, whilst preventing target fisheries, will also have increased regulatory discards.

Consequently, the 2020 Data Call requested that discard estimates be provided. Landings data of spurdog, as with all elasmobranchs, were reviewed during a dedicated workshop in 2016 (ICES, 2016) and ICES estimates of landings available.

4.7.1 Data evaluation meeting

Additional commercial data were also provided under the Data Call, including estimates of discards for the main nations whose fleets interact with the stock, length-composition data from national observer and port sampling programmes, and effort data.

Catch data

The submitted national discards data (quantities) are to be collated before January in order to ascertain the utility of these data (e.g. are data available for all main nations, inter-annual variation in estimates). All landings data will be collated from WGEF and the Data Call.

If estimated catch data remain unreliable for the post-2010 period, then the submitted effort data will be examined to facilitate to the potential estimation of catches for this period (lower priority).

There will be several virtual meetings in December 2020 and January 2021 between contributing scientists (including IMR, CEFAS, MSS) to maintain progress with this part of the work.

Final catch data to be ready at the end of January 2021 for the stock assessor to start testing the model.

These catch data were subsequently summarised in a Working Document by Junge (2021; WD_Spurdog_5_Spurdog recent landings and discards).

Commercial size composition

At the time of the original benchmark, commercial length–frequency data were only available from UK market sampling. Commercial length–frequency data were available from UK (England), which related to longline-caught spurdog, and from UK (Scotland), which related to otter trawl. Consequently, the UK (England) length–frequency data were considered reflective for those nations with important 'target fisheries' for spurdog, whilst the UK (Scotland) length–frequency data were considered reflective for spurdog taken in mixed fisheries (i.e. 'non-target fisheries').

Consequently, the 2020 Data Call requested length–frequency data from nations to be provided, thus allowing for more robust information on the length composition to be included in the 2021 assessment.

The nationally submitted length–frequency data are also to be collated before January.

These length composition data were subsequently summarised in a Working Document by Ellis and De Oliveira (2021b; WD_Spurdog_3_Spurdog commercial length frequency).

4.7.2 Benchmark workshop

In summary, the 2021 benchmark assessment considered recent data on landings and discards, and contemporary size-composition data from more nations than just the UK.

Catch data

The landings data from 1905–2006 used in the original benchmarked assessment were retained in the benchmark assessment.

More contemporary landings data collated by ICES (e.g. ICES, 2016) and updated by WGEF (ICES, 2020) were used for the years 2007–2019 from 12 countries, and missing data were added from the data provided to the Data Call, as detailed in the WD by Junge (2021).

Discard data were used from 2007–2019 for nine countries, submitted to the Data Call, described in the WD by Junge (2021).

Commercial catch composition

Commercial catch length composition data for 2007–2019 were compiled for spurdog, using the collated length frequencies reported in the WD by Ellis and De Oliveira (2021b). The length composition data prior to 2007 representing targeted (England and Wales) and non-targeted (Scotland) fishing continued to be used as in the original benchmarked assessment; these proportion by length category data are illustrated in Figures 4.7.2.1–4.7.2.2.

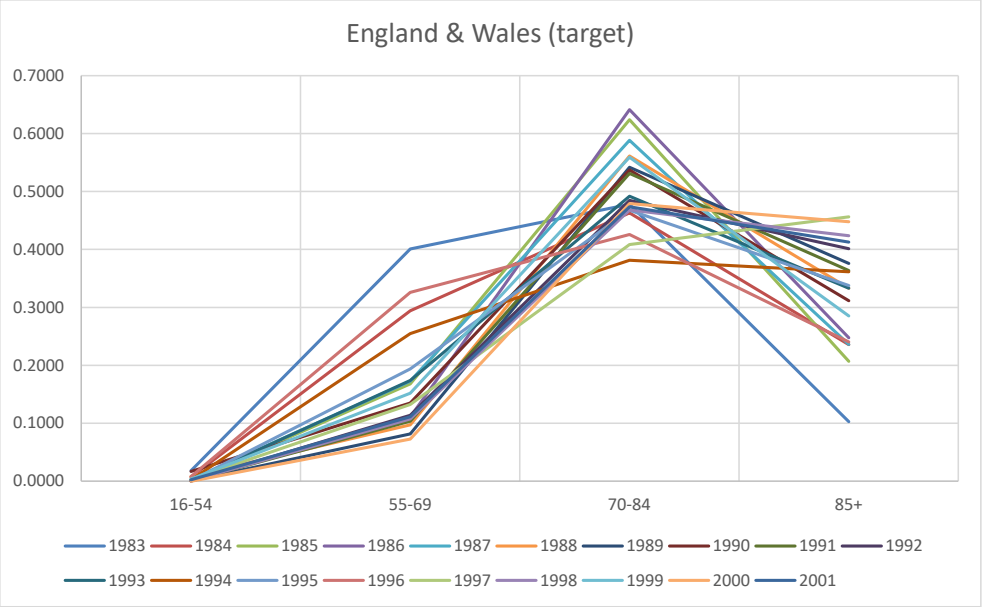


Figure 4.7.2.1. Spurdog in the Northeast Atlantic. The "targeted" proportion by length category data used in the assessment for the period prior to 2007.

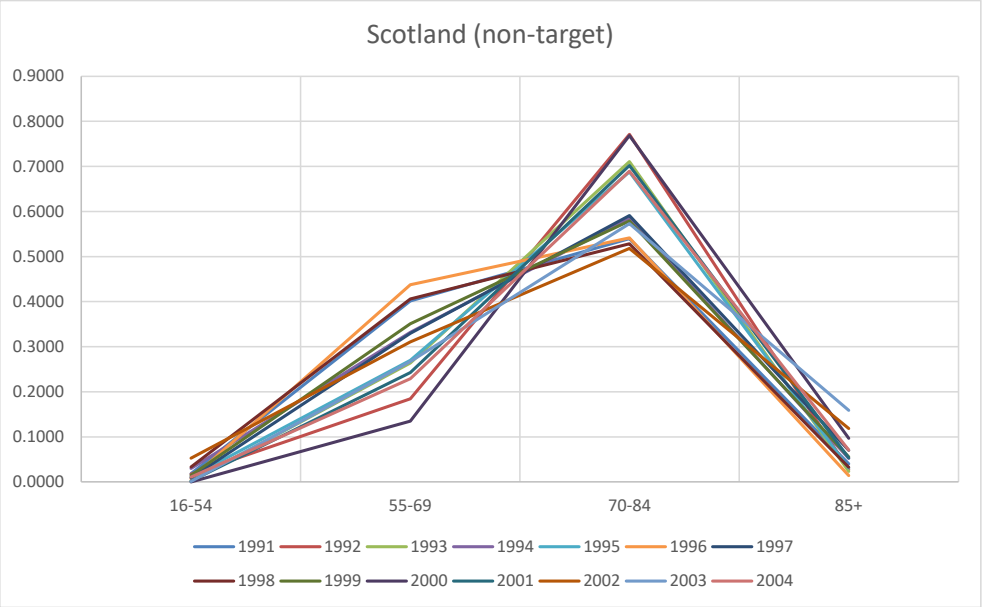


Figure 4.7.2.2. Spurdog in the Northeast Atlantic. The "non-targeted" proportion by length category data used in the assessment for the period prior to 2007.

For the period from 2007 onwards, two gear groupings were selected as representing the two main types of fishing activity, namely "trawls and other" and "nets and hooks". The length frequencies which formed the basis of the "trawls and other" fleet are shown in Figure 4.7.2.3; these

length frequencies were combined by first expressing them as proportions by length category (according to the established lifestage-based length bins used for spurdog), and then combining them by using weighted averaging using the relative contribution by nation to the fleet catches given in Table 4.7.2.1. The resultant proportions by length category are shown in Figure 4.7.2.4.

For the "nets and hooks" fleet, length frequencies from gillnet and trammelnets were combined with equal weighting (Figure 4.7.2.5), and the resultant proportions by length category are shown in Figure 4.7.2.6.

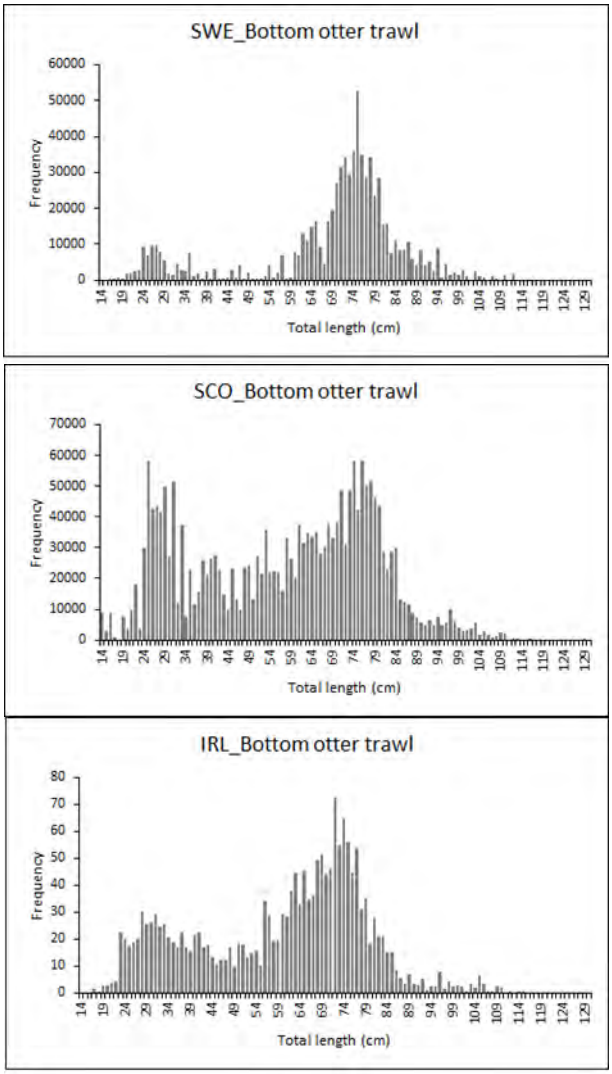


Figure 4.7.2.3 Spurdog in the Northeast Atlantic. Length frequency information used as a basis for compiling the proportion by length category data for the "trawls and other" gear category.

Table 4.7.2.1. Spurdog in the Northeast Atlantic. Relative contribution of Swedish, Irish and UK (GBR) bottom trawl catches used as a weighting with which to combine the corresponding length frequencies, expressed as proportions-at-length.

	Sweden	Ireland	GBR
2007	7%	35%	57%
2008	14%	40%	46%
2009	7%	19%	74%
2010	7%	43%	51%
2011	6%	46%	48%
2012	10%	31%	59%
2013	12%	21%	67%
2014	28%	12%	59%
2015	4%	20%	76%
2016	6%	28%	66%
2017	21%	41%	37%
2018	2%	40%	59%
2019	9%	18%	73%
average	10%	30%	59%

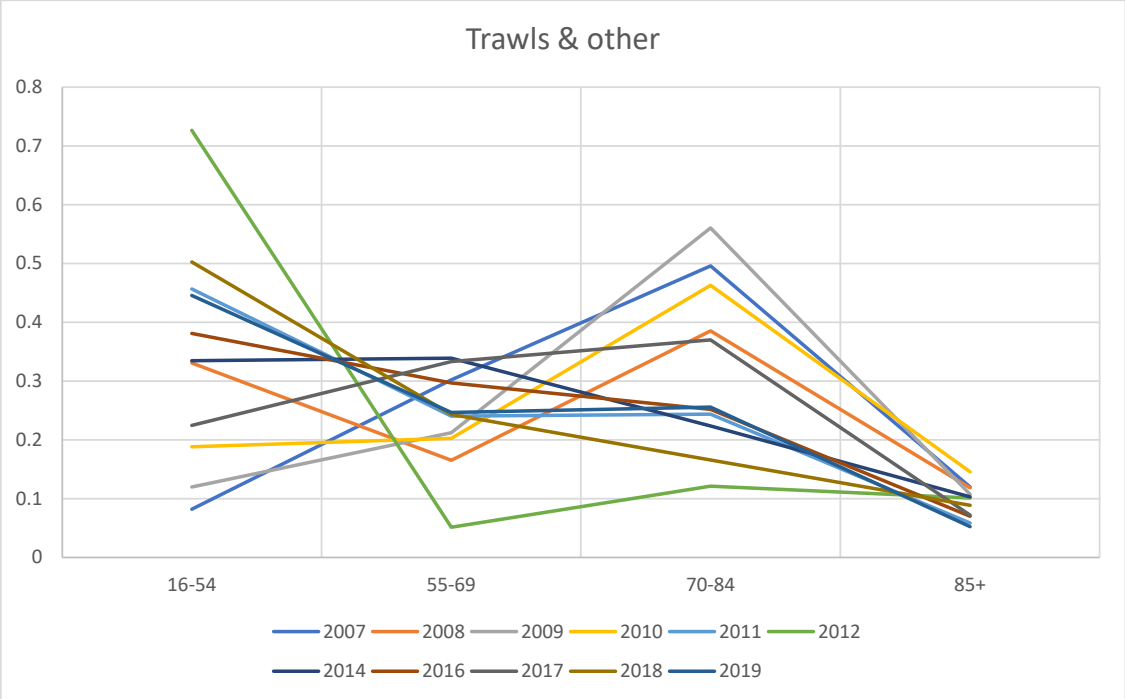


Figure 4.7.2.4. Spurdog in the Northeast Atlantic. The "trawls and other" proportion by length category data used in the assessment.

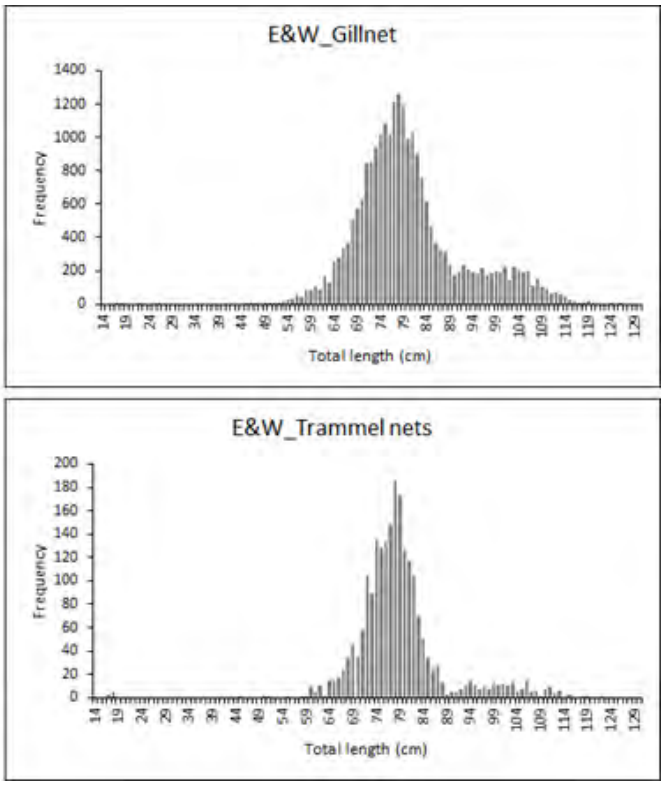


Figure 4.7.2.5. Spurdog in the Northeast Atlantic. Length frequency information used as a basis for compiling the proportion by length category data for the "nets and hooks" gear category. These data were simply combined with equal weighting.

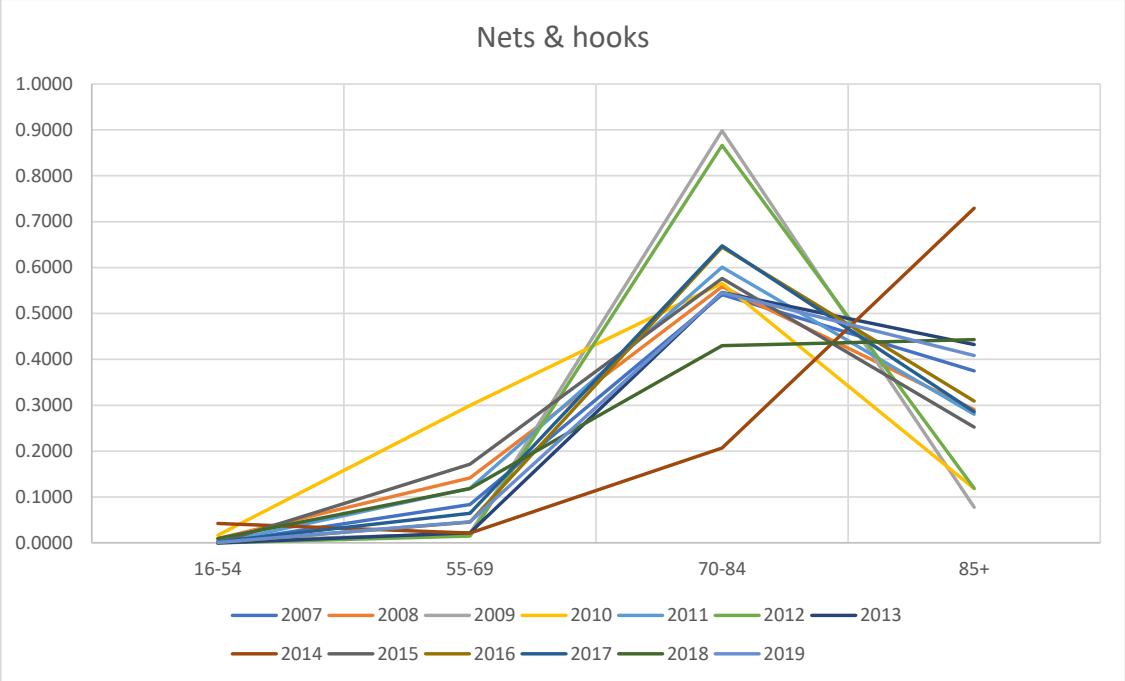


Figure 4.7.2.6. Spurdog in the Northeast Atlantic. The "nets and hooks" proportion by length category data used in the assessment.

4.8 Final model settings (length-based)

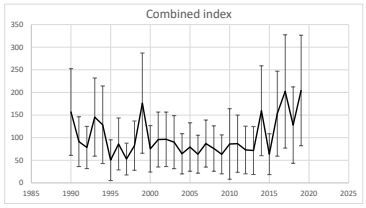
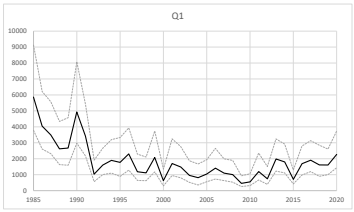
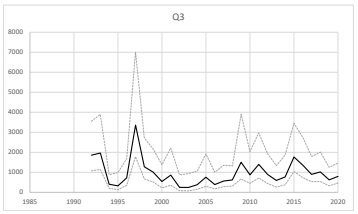
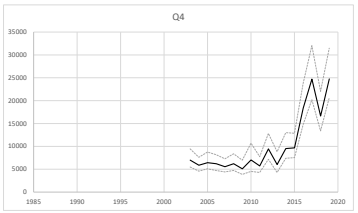
4.8.1 Benchmark workshop

Comparison: current assessment and final WNSEA 2021 benchmark assessment

Apart from the inclusion of new sources of data (see earlier sections), and a decision to change the year when recruitment deviates are estimated (following sensitivity analyses described in Annex 4), the assessment model itself has not changed and a full mathematical description is provided in the stock annex. Differences between the current assessment (used until 2020) and the final WKNSEA 2021 benchmark assessment are described in Table 4.8.1.1.

Table 4.8.1.1. NEA spurdog. A comparison between the current assessment and final WKNSEA 2021 benchmark assessment.

Category	Current assess (used until 2020)	Final WKNSEA 2021 benchmark assessment
Data		
Catches	1905–2009: International landings assumed to represent catches 2010–present: average of landings in 2007-2009, assumed to represent catches	1905–2006: International landings assumed to represent catches (discards considered negligible) 2007–present: estimates of landings and discards, as submitted following a data call for WKNSEA 2021
Commercial length composition	Two Commercial fleet selectivities: Non-targeted (Scottish: 1991–2004 Targeted (Eng and Wales: 1983–2001) [Targeted and non-targeted selection assumed for 1905–2007] [Non-targeted selection only assumed from 2008 onwards]	Four Commercial fleet selectivities: Non-targeted (Scottish: 1991–2004) Targeted (Eng and Wales: 1983–2001) [Targeted and non-targeted selection assumed for 1905–2006] Trawls and other (2007–present) Nets and hooks (2007–present)

Category	Current assess (used until 2020)	Final WKNSEA 2021 benchmark assessment
Surveys	 Combined index, based on 4 survey time-series: ScoGFS-WIBTS-Q1, ScoGFS-WIBTS-Q4, Sco-IBTS-Q1, Sco-IBTS-Q3 [1990–present]	 Q1 index, based on 4 survey time-series: NO-SH, NS-IBTS, SWC-IBTS, SCOWCGFS [1985–present]  Q3 index, based on NS-IBTS [1992–present]  Q4 index, based on 5 survey time-series: SWC-IBTS, SCOWCGFS, NIGFS, IE-IGFS, EVHOE [2003–present]
Survey length compositions	Combined index by sex: 1990–present	Q1 index by sex: 1985–present Q3 index by sex: 1992–1994, 2008–present Q4 index by sex: 2003–present
Fecundity data	1960: 783 samples 2005: 179 samples	1921: 81 samples 1960: 783 samples 1978: 58 samples 1987: 126 samples 1988: 25 samples 1997: 111 samples 2005: 179 samples 2010: 1 sample 2014: 109 samples 2016: 92 samples 2017: 297 samples 2018: 43 samples 2019/2020: 51 samples

Category	Current assess (used until 2020)	Final WKNSEA 2021 benchmark assessment
Model settings		
Start year for recruitment deviates	1960	1975

Sensitivity analyses

Sensitivity analyses are described in detail in Annex 4. The starting point for these was the inclusion of all the new sources of data described in Table 4.8.1.1, and the outcome was to change the current assessment setting of estimating recruitment deviates from 1960 to 1975, based on model-fitting criteria (Annex 4).

Final benchmark assessment model fits and diagnostics

Fits to the three combined survey indices are shown in Figure 4.8.1.1. There are reasonable fits to the Q1 and Q3 indices, but the model struggles to fit the steep increase in the Q4 index. Figure 4.8.1.2 shows the fits to the commercial and survey proportion by length category data; the averages (Figure 3.8.1.2(a)) are very close for the commercial proportions, and reasonably close to for the survey proportions, although there are some differences (notable the largest length category for males in the Q3 survey). There are some large residuals, and residual patterns (Figure 3.8.1.2(b)), but these data are quite variable. Fits to the fecundity datasets are shown in Figure 3.8.1.3(a) with associated normalised residuals in Figure 3.8.1.3(b); there is underestimation in some years (e.g. 1921, 1978) and overestimation (e.g. 1988, 2018), but generally these fits seem reasonable. Recruitment residuals appear to be positively biased, but this may be due to some conflict in the model trying fit the survey indices (this bias is largely removed when only the Q1 index is fitted; result not shown). Retrospective plots for total biomass, recruitment and harvest rate are shown in Figure 4.8.1.5, together with Mohn's rho statistic; these are within acceptable limits for total biomass and harvest rate, although it is on the limit for the latter.

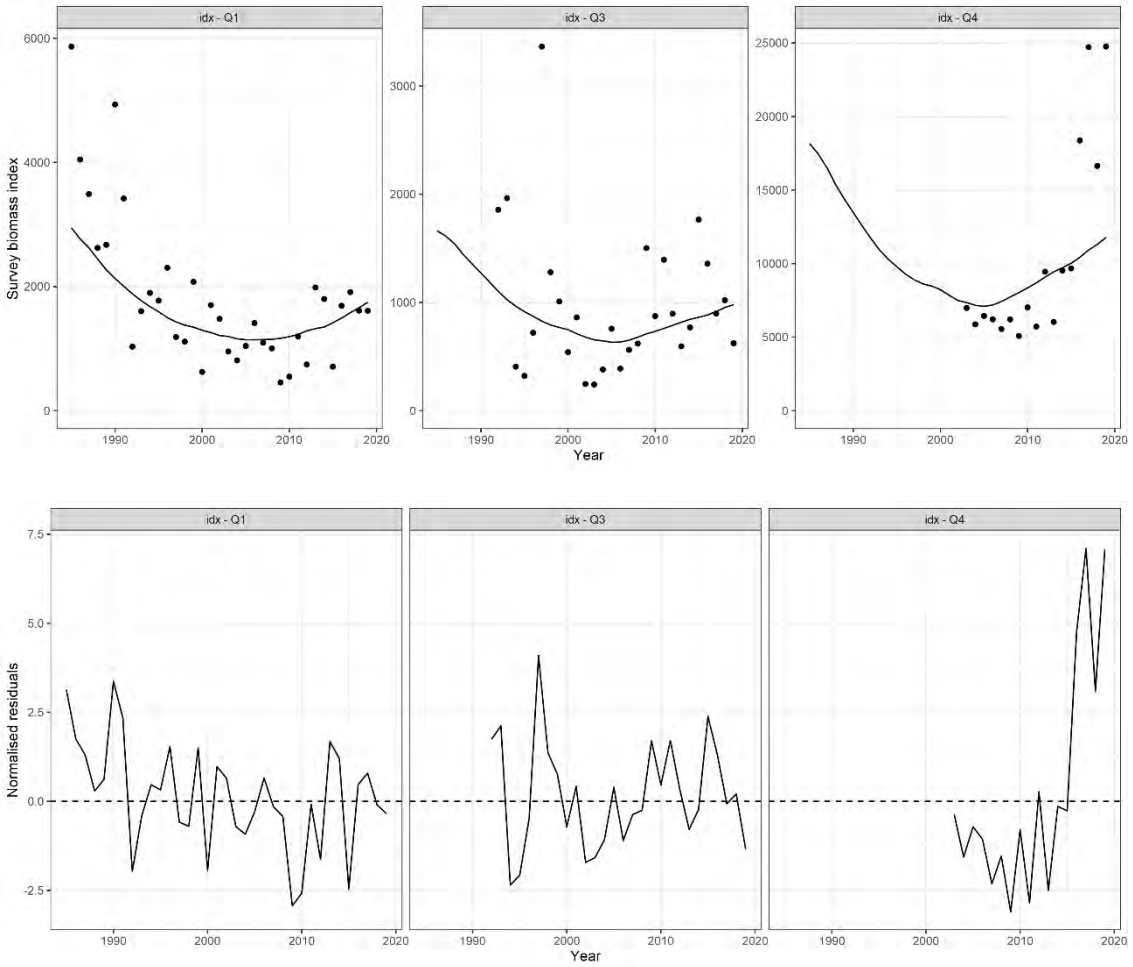
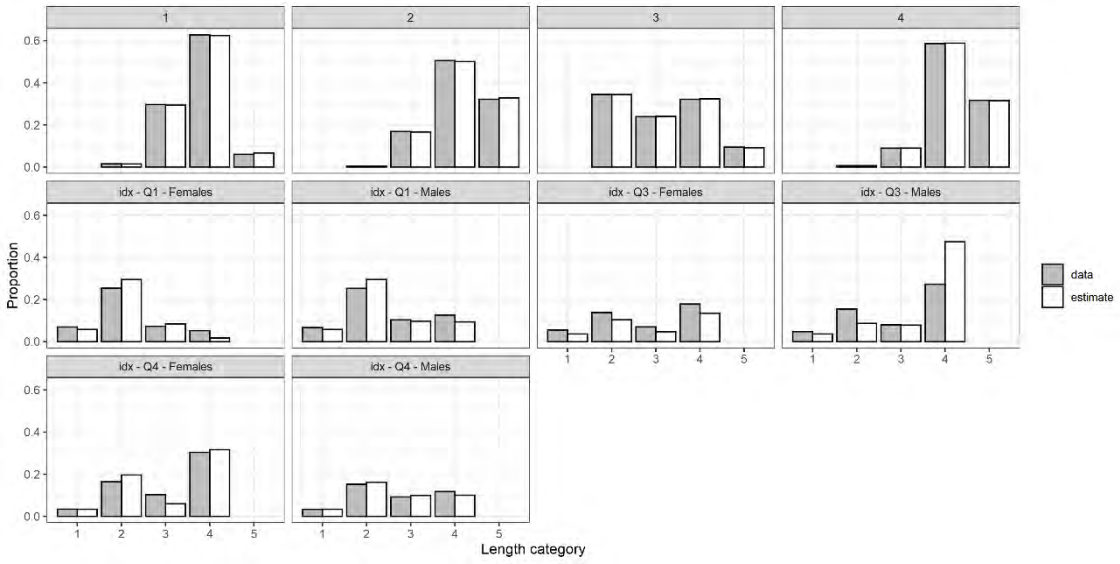


Figure 4.8.1.1. NEA spurdog. Fits to the three combined survey indices (top row) with associated normalised residuals (bottom row).

(a)



(b)

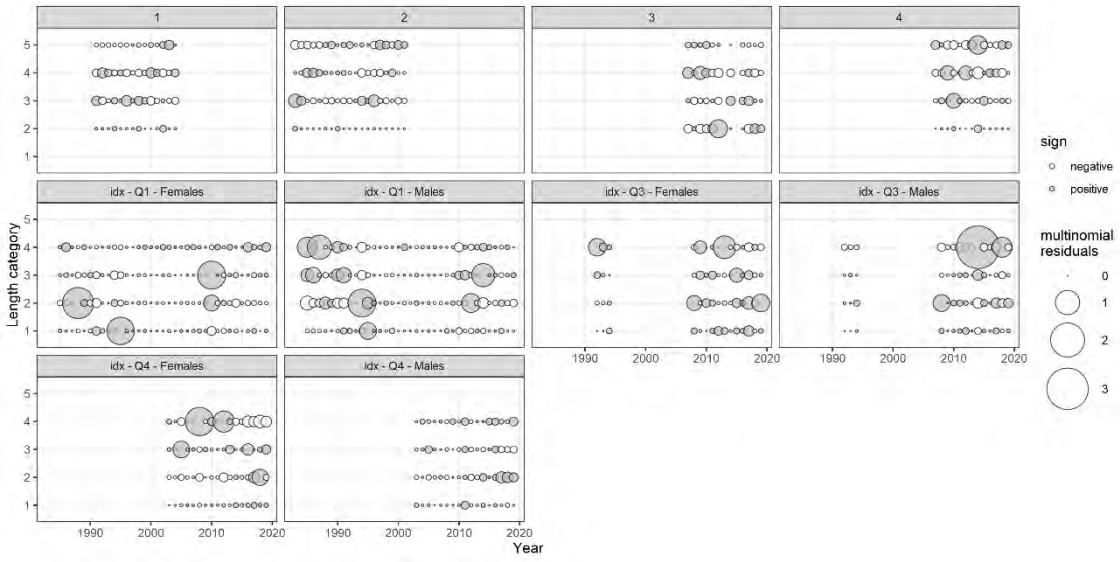
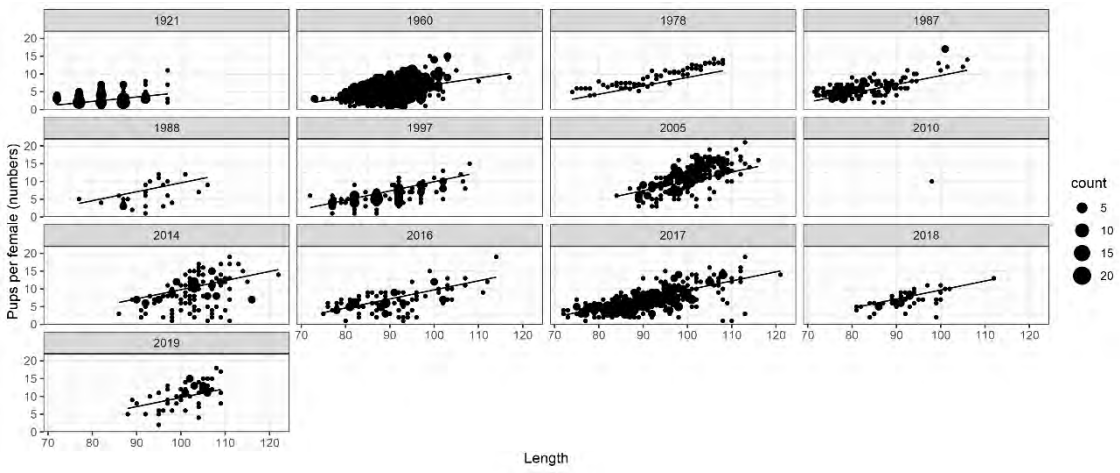


Figure 4.8.1.2. NEA spurdog. Fits to (a) proportions by length category data, averaged over the time period for which data are available with associated with (b) associated normalised residuals. In each set of plots ((a) and (b)) the top row shows fits to the commercial fleet compositional data (fleets 1–4), with the remaining rows showing fits to the survey compositional data by sex.

(a)



(b)

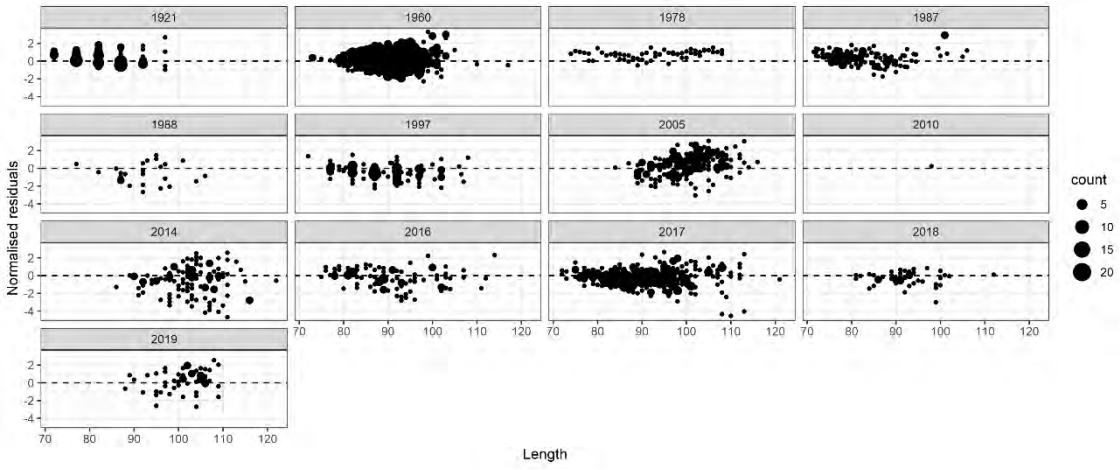


Figure 4.8.1.3. NEA spurdog. Fits to (a) fecundity data with (b) associated normalised residuals.

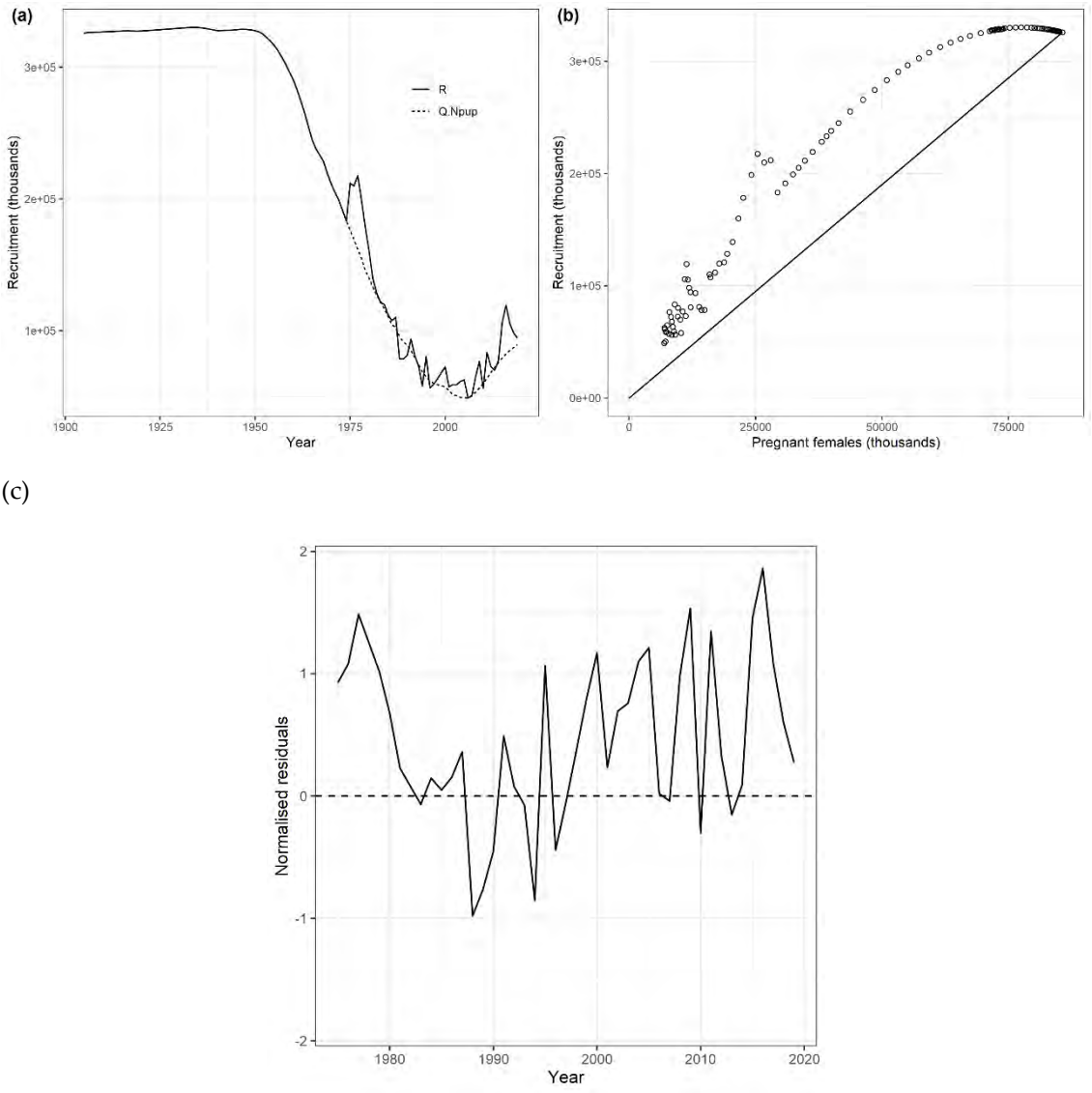


Figure 4.8.1.4. NEA spurdog. (a) recruitment (with deviates from 1975) over time; (b) the "stock–recruit" plot (recruitment plotted against pregnant females) with replacement line; and (c) normalised residuals associated with the deviates in (a).

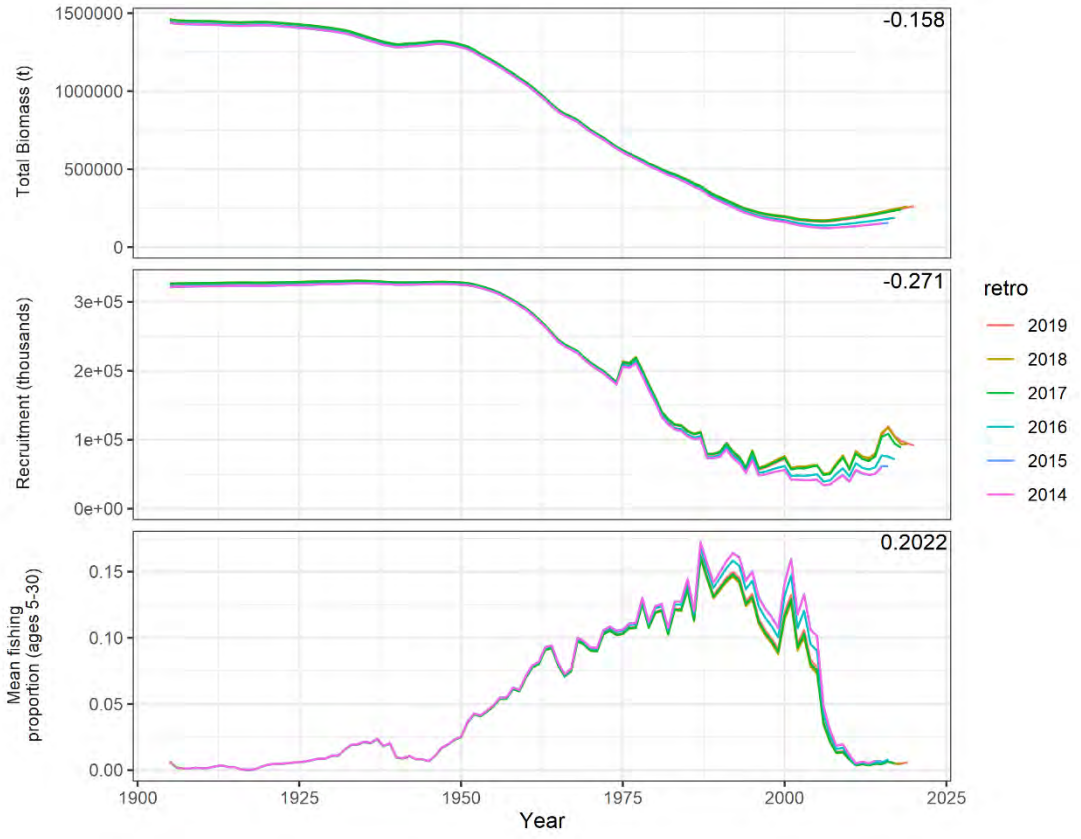


Figure 4.8.1.5. NEA spurdog. Six-year retrospective plots for the population trajectories (top row total biomass, middle row recruitment, bottom row harvest rate), together with estimates of Mohn's rho (top right in each plot).

Sensitivity to the density-dependent fecundity parameter Q_{fec}

Q_{fec} is a key parameter in the model, and cannot be estimated along with the other fecundity parameters a_{fec} and b_{fec}, so likelihood profiling over these is conducted and shown in Figure 4.8.1.6. This profiling indicates the best estimate for Q_{fec} to be 2.262 with 95% lower and upper confidence bounds (using the likelihood ratio test) of 1.938 and 2.827, respectively. Sensitivity to these alternative values is shown in Figure 4.8.1.7 for model fits to the three survey indices, and for population trajectories (Figure 4.8.1.8), and the latter do indicate sensitivity to this parameter. The final model takes the best estimate from the likelihood profiling of Q_{fec}=2.262.

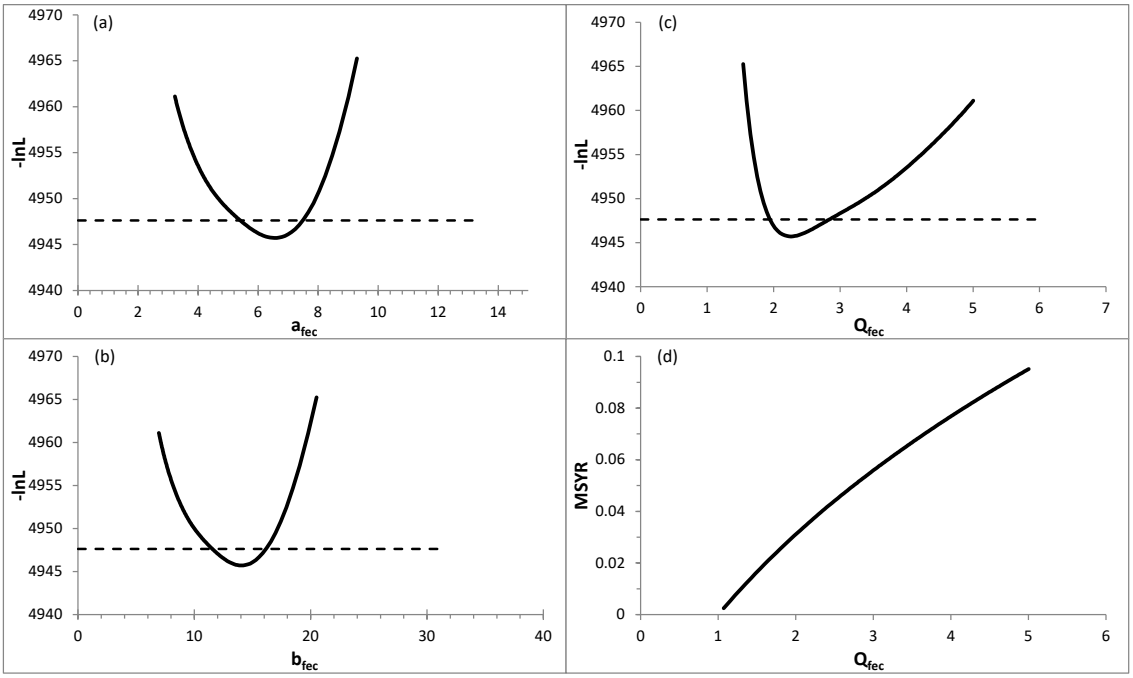


Figure 4.8.1.6. NEA spurdog. Likelihood profiles for the fecundity parameters (a) a_{fec}, (b) b_{fec}, and (c) the density-dependent fecundity parameter Q_{fec}., as well as (d) the MSYR (MSY rate) plotted against Q_{fec}. The likelihood profiling indicates a best estimate of Q_{fec}=2.262, which is adopted for the final assessment, and with a minimum and maximum within the 95% confidence bounds (based on the likelihood ratio test) of 1.938 and 2.827 respectively.

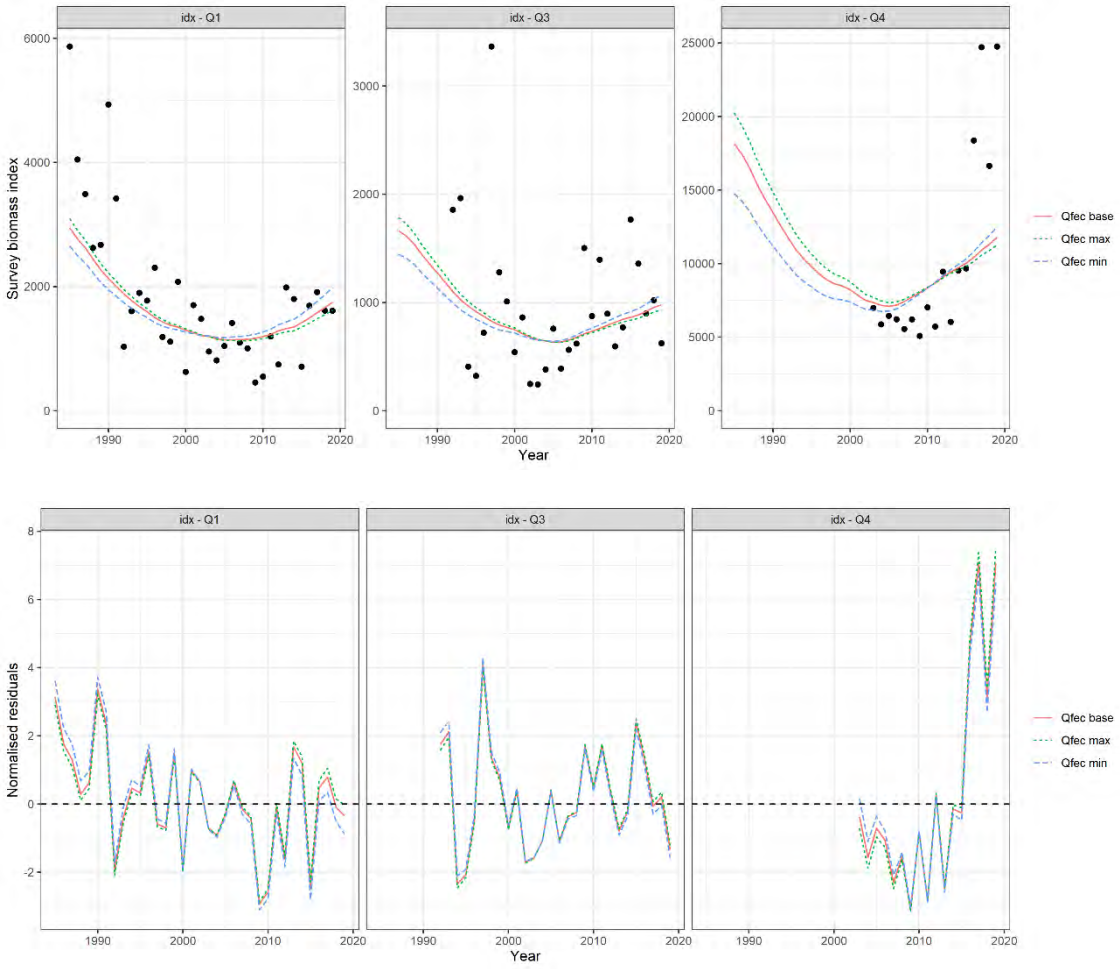


Figure 4.8.1.7. NEA spurdog. Fits to the three combined survey indices (top row) with associated normalised residuals (bottom row) for alternative Q_{fec} values based on likelihood profile ("Qfec base" is the best estimated [2.262; shown in Figure 4.8.1.1], "Qfec min" the minimum value [1.938] that is within the 95% confidence bound based on the likelihood ratio test, and "Qfec max" the maximum value [2.827] within these confidence bounds).

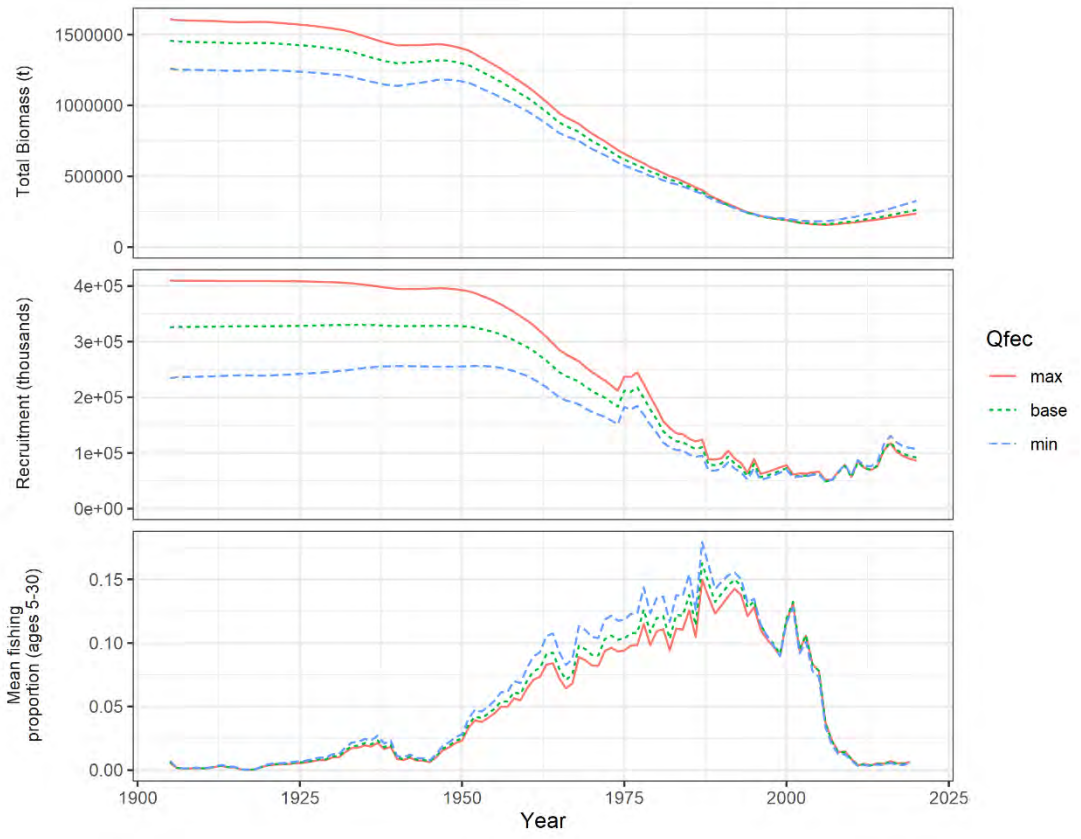


Figure 4.8.1.8. NEA spurdog. Population trajectories (top row total biomass, middle row recruitment, bottom row harvest rate) for alternative Q_{fec} values based on likelihood profile (see caption to Figures 4.8.1.6–4.8.1.7).

Final benchmark assessment estimates

A summary plot of population trajectories for the final benchmark assessment is shown in Figure 4.8.1.9, including reference points. Estimates of the selectivities by commercial fleets and surveys are shown in Figure 4.8.1.10.

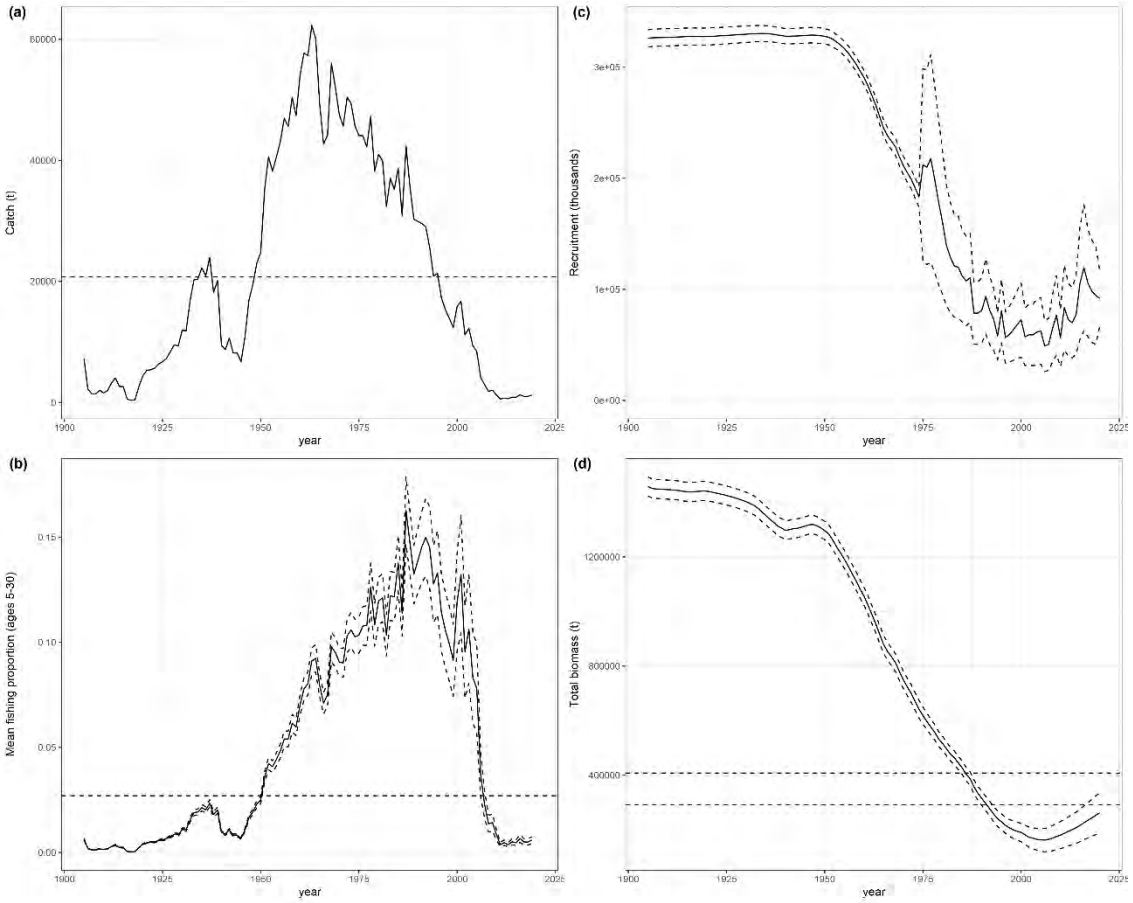


Figure 4.8.1.9. NEA spurdog. Summary plots for (a) catches (not catches prior to 2007 are actually landings, assuming discards are negligible), (b) harvest rate (mean fishing proportions over ages 5–30), (c) recruitment, and (d) total biomass. Reference points are included as horizontal dashed lines: (a) the MSY level, (b) HR_{MSY}, and (d) B_{lim} (bottom) and Bpa=MSY $B_{trigger}$ (top).

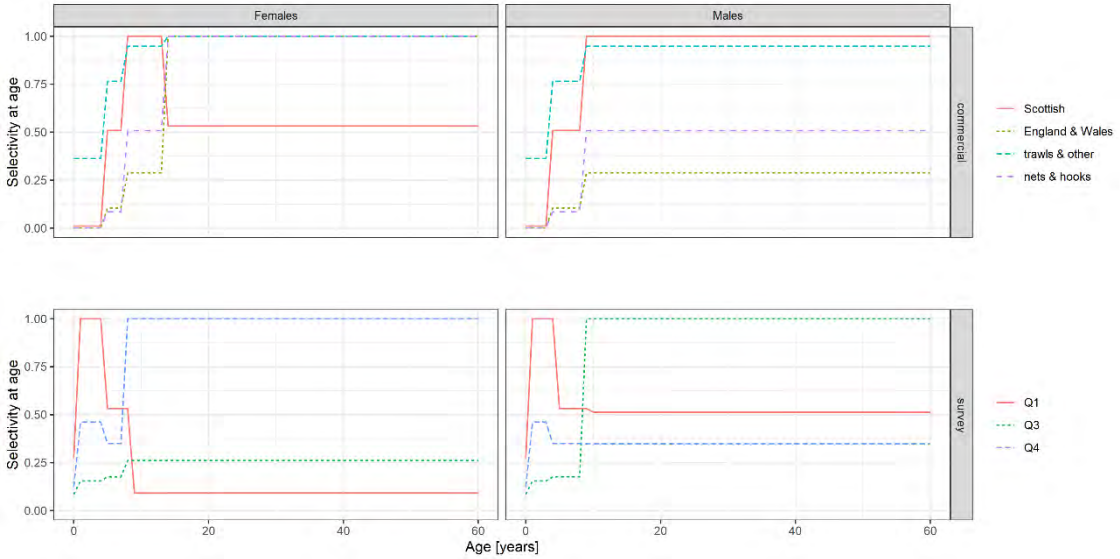


Figure 4.8.1.10. NEA spurdog. Estimated selectivities by age for commercial fleets (top) and surveys (bottom), separated by females (left) and males (right).

4.9 Short-term forecast

4.9.1 Benchmark workshop

Both short- and medium-term forecasts are conducted for spurdog, through a continued projection (propagating uncertainty into the future) within the stock assessment model. Biological processes (stock and catch weights, maturity, natural mortality) have functional forms related to the underlying size or age of animals (see e.g. Table 1 in stock annex), and recruitment is related to the number of pregnant females in the population (stock annex), and these continue to be used in the forecasts. Decisions about the intermediate year catch and selectivity of the fishery to be used in these forecasts are a decision taken by WGEF whenever the spurdog assessment and forecast is run. The catch scenarios considered for the forecast are also decided on at WGEF, but typically include (but may change during WGEF):

- The ICES MSY rule, which assumes a harvest rate of HR_{MSY}, but reduces it linearly to zero when total biomass is below MSY $B_{trigger}$ (by the extent to which total biomass is below MSY $B_{trigger}$);
- Zero catch (for comparison purposes);
- TAC_{2009} = 1422 t, the last non-zero TAC set for spurdog in 2009;
- Average landings for 2007–2009 = 2468 t, or HR_{SQ}: average harvest rate for 2007–2009; these are amount that could accommodate bycatch in mixed fisheries;
- Fishing at HR_{MSY}.

4.10 Reference points

4.10.1 Benchmark workshop

The spurdog model is an integrated assessment model that includes a function that relates pup production to mature females, and it is therefore possible to estimate reference points (such as B_{MSY}) from within the model (in much the same way that is done for biomass dynamic models) without relying on an approach such as EqSim. Furthermore, the model commences in 1905, when reported landings were relatively low, and well before the period of high exploitation experienced from the 1950s onwards, and so the model is considered to provide a reasonably reliable estimate of B_0 (the virgin total biomass level). It is therefore proposed that reference points continue to be directly based on assessment outputs (the current practice), which means that reference points are updated every time the assessment is re-run.

B_{lim}: set to 20% of B_0

Depletion-based reference points typically range from 20% to 30% (Preece *et al.*, 2011) and these reference points are considered the default level at which serious management action should be taken to rebuild the stock (Preece *et al.*, 2011). These reference points vary between management bodies, and the value selected may also be influenced by stock productivity and level of knowledge of the stock. Several organisations, including the International Whaling Commission (IWC) and Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), use B_{lim} as 20% of B_0, and this is the value considered here.

Depending on the time period considered and the generation time of the species, this value may also be comparable to an IUCN Critically Endangered listing under Category 2, for which "*An observed, estimated, inferred or suspected population size reduction of ≥80% over the last 10 years or three*

generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible…" (IUCN, 2012).

Alternative approaches could include:

a) using 0.3 B_{MSY}, which is used for biomass dynamic models within ICES (ICES, 2021a). However, this would translate to a value less than 0.2 B_0 (for spurdog, 0.185 B_0) which is considered too low for an elasmobranch stock, and therefore not in line with the precautionary approach.
b) Using 0.3 B_0, which was the value suggested by Sainsbury (2008) as a more precautionary approach and applicable to low productivity stocks.

Whilst the more conservative value of 0.3 B_0 could be considered for spurdog, given the low productivity of the stock, it was noted that this species is comparatively data rich (relative to other elasmobranchs), and the species is known to be capable of stock rebuilding, as seen in the NW Atlantic (e.g. Rago and Sosebee, 2013; Dell'Apa *et al*., 2015). Consequently, B_{lim} was defined as 0.2 B_0.

B_{pa}: set to 1.4 B_{lim}

We have adopted the ICES default formulation of 1.4 B_{lim} for B_{pa}, given that the CV of total biomass in the terminal years is 14%, which is considered too low for setting the buffer between B_{lim} and B_{pa}.

MSY $B_{trigger}$: set to B_{pa}

In the absence of sustained fishing at HR_{MSY}, we have adopted the ICES approach of setting *MSY* $B_{trigger}$ at B_{pa}.

HR_{MSY}: estimated within the model

The stock annex explains in detail how the MSY reference points, including HR_{MSY} (averaged over the ages 5–30) is calculated (Figure 4.10.1.1). The selection pattern is taken from the period when management measures started to become restrictive (2008 onwards). Figure 4.10.1.1 illustrates the associated B_{MSY} value, although this is not used as part of the suite of reference points for spurdog.

HR_{lim}: the harvest rate that leads to B_{lim}

It is possible to get this from the equilibrium total biomass versus harvest rate curves from within the model (Figure 4.10.1.1).

HR_{pa}: the harvest rate that provides a buffer to avoid B_{lim} with high probability

There are two candidates for this reference point, the one being the harvest rate that leads to B_{pa} (taken from the equilibrium total biomass versus harvest rate curve; Figure 4.10.1.1), and the other providing a buffer from HR_{lim} that acts to avoid B_{lim} with high probability (essentially HR_{lim}/1.4; red dot in Figure 4.10.1.1). Since HR_{pa} is more about avoiding B_{lim} with a high probability, we have opted for the second of these (i.e. HR_{lim}/1.4).

The reference points for spurdog are summarised in Table 4.10.1.1. The reference points are illustrated in the context of population trajectories in Figure 4.10.1.2.

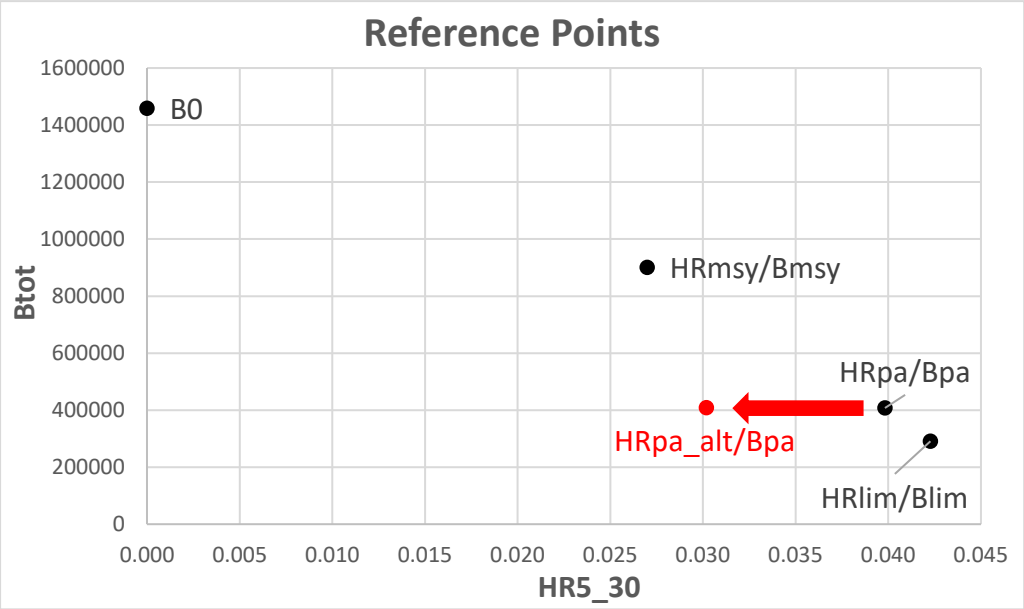


Figure 4.10.1.1. Spurdog in the Northeast Atlantic. Reference points based on the equilibrium total biomass versus harvest rate (average over ages 5–30) curve (black dots). An alternative harvest rate for HR_{pa} (based on HR_{lim}/1.4) is shown in red.

Table 4.10.1.1. Spurdog in the Northeast Atlantic. Reference point values and basis, along with other quantities and ratios of interest. The biomass-based reference points are in total biomass; the mature female component of the total biomass is shown in the final column.

	Value	Basis	Mature females
Reference points			
B_{lim}	**291622**	0.2 x B_0	44571
B_{pa}	**408270**	1.4 x B_{lim}	63554
MSY $B_{trigger}$	**408270**	B_{pa}	63554
HR_{MSY}	**0.027**	HR that leads to B_{MSY}	
HR_{lim}	**0.042**	HR that leads to B_{lim}	
HR_{pa}	**0.030**	HR_{lim}/1.4	
Other quantities			
B_0	1458110	estimated	304966
B_{MSY}	901108	estimated	154366
Ratios			
B_{2020}/B_0	18%		13%
B_{2020}/B_{lim}	90%		91%

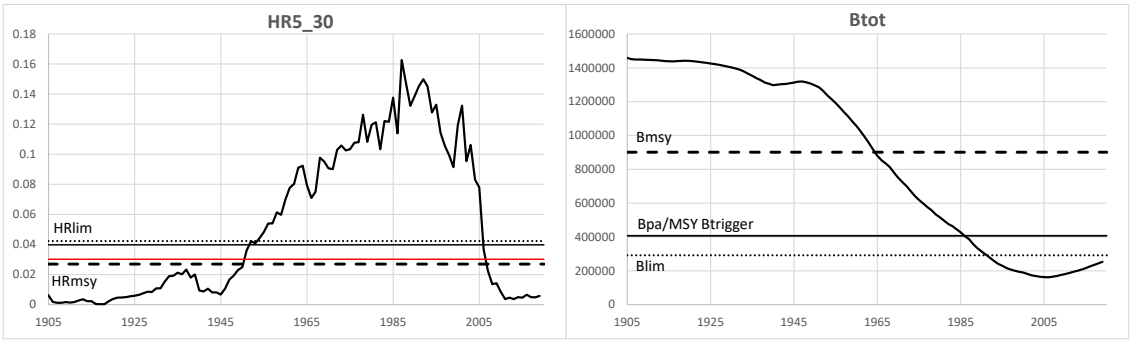


Figure 4.10.1.2. Spurdog in the Northeast Atlantic. Reference points in the context of population trajectories, with harvest rate (average over ages 5–30) on the left and total biomass (tonnes) on the right. The solid vertical lines in the HR plot illustrate the two candidates for HR_{pa}, with the red one being the one adopted and given in Table 4.10.1.1.

5 Whiting (whg.27.6a)

5.1 Summary

Prior to 2020, this stock was a category 1 stock with an analytical assessment (TSA), agreed at a benchmark process in 2012 (ICES, 2012). The stock previously went through a benchmarking process in 2020 (WKDEM; ICES, 2020) which was unsuccessful largely due to a lack of modelling preparedness and a reliance on TSA as the assessment method, which is slow to converge and difficult to optimise without developer assistance. At that meeting the reviewers rejected the latest TSA configuration and alternative configurations failed to converge, and as a result the benchmark fell back on the use of SPiCT for a category 3 'trends-only' assessment (3 v 2). During the 2020 advisory process, the approach agreed at the benchmark (and utilised by the assessment WG) was rejected by ACOM and the stock downgraded to category 5. However, throughout the benchmarking and advisory process, it was acknowledged that there was substantial informative data on this stock (both commercial sampling and surveys) and that a category 1 stock assessment ought to be possible for this stock.

WGCSE therefore proposed this stock for immediate re-benchmarking in 2021. The current process builds on the progress in terms of data compilation made during the 2020 process and plans to focus on SAM as the assessment method. A survey-based assessment (SURBAR) has also been developed, which could potentially be used as a category 3 assessment (along with length-based indicators) in the event that a cat 1 assessment cannot be agreed.

In addition to the information provided in the current report chapter, the reader is also referred to the following seven Working Documents that provide further details of the relevant datasets incorporated in the final assessment model:

1. Jaworski A. and Dobby H. 2020. WD 5.1 whiting 6a Catch data. Working Document for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 13 pp.
2. Jaworski A. and Dobby H. 2020. WD 5.2 whiting 6a Survey indices. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 21 pp.
3. Jaworski A. 2020. WD 5.3 whiting 6a Maturity ogive. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 6 pp.
4. Baudron A, Fallon N, Jaworski A, Miethe T and Dobby H. 2021. WD 5.4 6a whiting mortality and weights-at-age. Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 12 pp.
5. Jaworski A. 2021. WD 5.5 Whiting 6a SURBAR. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 23 pp.
6. Fallon N. G, Miethe T, Nielsen A., and Dobby H. 2021. WD 5.6 SAM whiting.27.6a. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 6 pp.
7. Miethe T, Jaworski A. and Dobby H. 2021. WD 5.7 whiting 6a LBIs. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 3 pp.

5.2 Stock structure

No change.

5.3 Catch data

5.3.1 Data evaluation meeting

Prior to the data compilation meeting for WKDEM (ICES, 2020) in October 2019, a data call was issued requesting historical national data on landings, discards, sample information (age and length compositions) and effort (disaggregated by quarter and métier). Those data, and the associated InterCatch raising process are described in further detail in WD 5.1 Whiting6a_Catch data.

The data call provided revised catch data from 2003 onwards and included 0-group which have not previously been included in the stock assessment. 0-group data are not available in the historical dataset (1981–2002), but the inclusion of a partial time-series of 0-group in the stock assessment will be explored in SAM ahead of the forthcoming benchmark meeting. Although this is unlikely to affect the historic development of the stock it may provide useful information on recruitment in the short-term forecast.

A further issue to be considered as part of the benchmark was the issue of area misreporting of landings (i.e. landings taken in 6a actually being declared in logbooks as taken in 4a) and whether this was likely to significantly impact the reliability of the reported landings for 6a whiting, as is the case for 6a cod. Marine Scotland Compliance have provided estimates based on their surveillance and monitoring programme which suggest area misreporting of whiting to be in the order of 10–15% of reported landings in recent years (23 t and 60 t in 2018 and 2019 respectively, compared to 180 t and 486 t reported landings in those years). Given this relatively low proportion, the issue is considered to be of relatively minor importance and no further analysis (based on, for example, VMS data) to derive a time-series of misreporting estimates which could potentially be used to adjust the landings used in the assessment has been conducted. Previously supplied estimates of misreporting and underreporting (ICES, 2012) suggest this also to have been a relatively minor issue (in the order of ~5%) in the past (since 2001).

5.4 Survey indices

5.4.1 Data evaluation meeting

Five research vessel survey series were used in the previously accepted (2012–2019) category 1 stock assessment for whiting in 6.a. These included two 'old' Scottish surveys (ScoGFS-WIBTS-Q1 and ScoGFS-WIBTS-Q4), which were discontinued at the end of 2010 and three surveys which are currently in operation in the assessment area. The three current surveys are: two 'new' (2011 onwards) Scottish surveys (UK-SCOWCGFS-Q1 and UK-SCOWCGFS-Q4) and one Irish survey (IGFS-WIBTS-Q4). The latter covers only the southern part of the Division 6.a WD 5.2 Whiting6a_survey indices.

The possibility of combining two current Q4 surveys was explored within WGISDAA in 2018–2020 and a combined index was delivered as a result for the assessment of the stock. The combined index was also approved at WKDEM 2020 and used by WGCSE in 2020.

This benchmark proposed extending the analysis to include all the three Q4 surveys (ScoGFS-WIBTS-Q4, UK-SCOWCGFS-Q4 and IGFS-WIBTS-Q4). Using a Delta-GAM was explored which

accounts for the temporal and area overlap in the surveys. As a result, one index has been delivered for the Q4 surveys. The two Q1 surveys series remain to be treated as two separate series.

5.4.2 Benchmark workshop

5.4.2.1 Index estimation

In response to the proposal of combining all the three Q4 surveys, an analysis of survey data was carried out which delivered one Q4 index.

The analysis was conducted with data downloaded from DATRAS for the following three survey series:

- ScoGFS-WIBTS-Q4 for the period 1996–2009 (SWC-IBTS in DATRAS);
- IGFS-WIBTS-Q4 for the period 2003–2019 (IE-IGFS in DATRAS);
- UK-SCOWCGFS-Q4 for the period 2011–2019 (SCOWCGFS in DATRAS).

These data were combined into one dataset spanning the period 1996–2019. Only hauls in Division 6.a were used in the calculations of the index.

To estimate numbers at age, age–length keys were applied that were estimated using the spatially varying continuation ratio logits (CRL) model described in Berg and Kristensen (2012). The ALKs were estimated for ages 0–7+.

The analysis of the combined index was conducted using a GAM-based delta-lognormal model. The model accounts for a number of explanatory variables and is described in Berg *et al*. (2014). It consists of two parts: one that describes the probability for a non-zero catch (binomial response) and another that describes the distribution of a catch given that it is non-zero (positive continuous). The response in the model is numbers at age per haul or 1/0 for the non-positive part of the model. Each age group in the given model was estimated separately.

A number of models with different subsets of explanatory variables were fitted to the data. The best model was chosen on the basis of AIC over all ages/models combined:

$$g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + f_3(time_i) + U(Ship_i) + \log(HaulDur_i)$$

where μ_i is the expected numbers-at-age in the ith haul, $g(\mu_i)$ is the link function, $Year_i$ is a categorical effect of the year, f_1 is the smoothing function of the interaction of longitude (Lon_i) and latitude (Lat_i) in the ith sampling location, f_2 is the smoothing function of depth, f_3 is the smoothing function of the time of day, U is a random vessel effect and $HaulDur_i$ is the effect of tow duration. Including a gear effect to account for the change in ground gear in the two Scottish surveys gave no improvement to model fit.

The indices were derived by summing predictions (over the spatial grid) from the selected model and are shown in Figure 5.4.1.

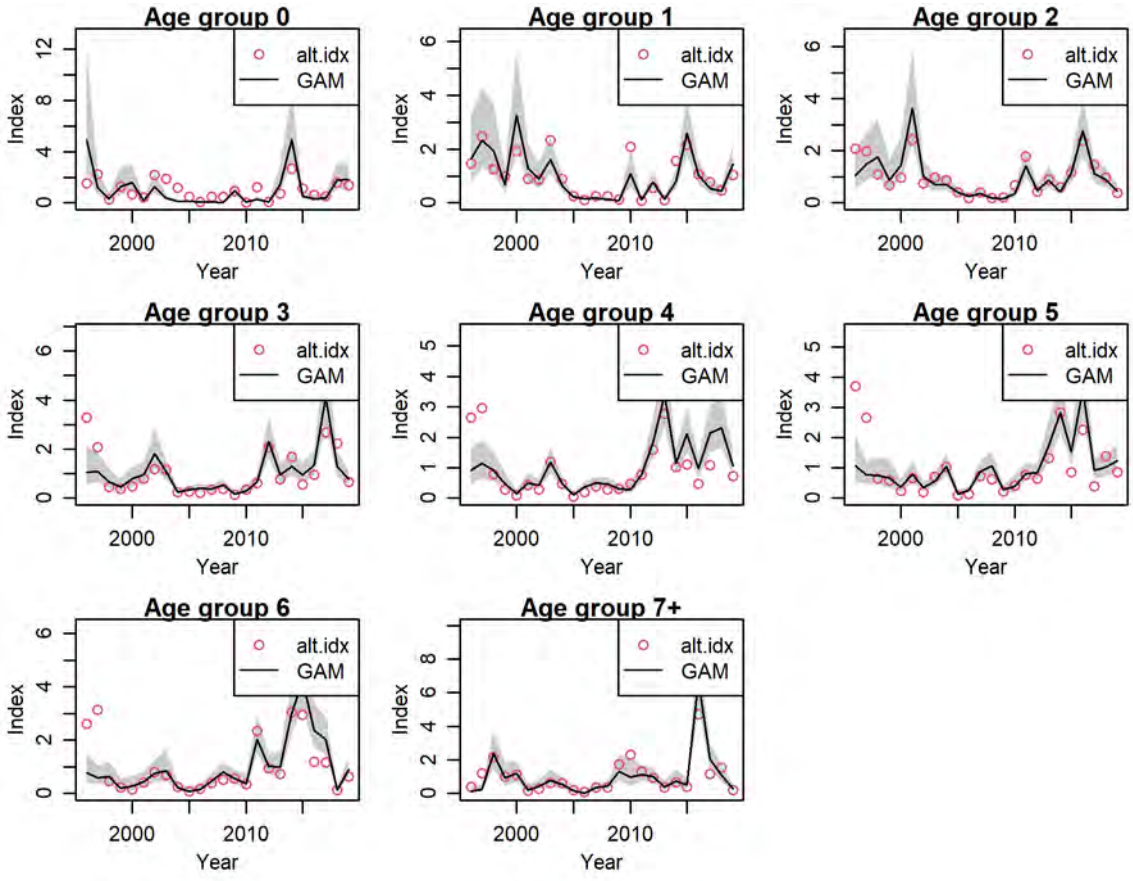


Figure 5.4.1. Whiting in Division 6.a. Indices derived from a delta-GAM model fit to data from the three Q4 surveys (black line) with 95% confidence limits (in grey). Indices are derived by summing model predictions on a spatial grid. The survey index calculated using the stratified mean method for ICES statistical rectangles as strata are shown as red points. The indices are mean-standardised.

During the benchmark meeting itself, the potential need for inclusion of an interaction term between year and geographical coordinates was discussed. Exploratory analysis suggested some temporal changes in the distribution of age groups, but it was found that the inclusion of the interaction term had little effect on the index values or the internal consistency. Additional analyses and careful sense checking of estimated covariates would be necessary to find optimal settings for such an augmented model, particularly given that there are a number of years without full spatial coverage (due to vessel breakdown). As a result, the model without the interaction term was retained.

The diagnostics for the three indices considered as tuning series for the assessment of the whiting stock, including the combined index, showed a relatively high between-survey and within-surveys consistency (WD 5.2 whiting 6a Survey indices). The log-catch curves were relatively linear and not very noisy. The within-survey correlation plots generally showed significant correlations between consecutive age groups. There was a general consistency in the estimates of year-class strength across age groups.

There are several advantages of using a combined index for assessments of fish stocks. In this particular case, the combined index provides a more complete representation of the population compared to the respective indices used on their own. The combined index simplifies, to some extent, the modelling procedure in the annual assessments of the stock (with potentially three rather than five indices in the following years) and also provides a longer continuous time-series.

Furthermore, using a modelled approach makes it possible to calculate a combined index in years with only partial survey coverage by one of the two surveys.

5.4.2.2 SURBAR analysis

At the benchmark workshop, an assessment of whiting in Division 6a was presented (WD 5.5 Whiting 6a SURBAR), which used SURBAR (Needle, 2015).

This method requires stock weights-at-age, maturity ogive and survey indices. Three tuning series were considered for the model:

- ScoGFS-WIBTS-Q1 for the period 1985–2010;
- UK-SCOWCGFS-Q1 for the period 2011–2020;
- Comb-WCGFS-Q4 for the period 1996–2019.

The final model used the following settings:

- Three survey series (as above);
- Reference age for separable model = 3;
- Lambda smoother = 1.0;
- All SSQ weightings and catchabilities q set to 1.0.

The model produced the output given in Figure 5.4.2. The stock summary plots show rather variable estimates of mean Z being generally lower from the mid-2000s onwards. SSB rose to a peak in the mid-1990s, before returning back down to the levels seen in the late 1980s with a substantial increase in the recent period. Also, it seems to fluctuate more in recent years compared to the historical period. The increase between 2019 and 2020 can be explained by relatively high recruitments in these two years and very low mean Z (associated with almost flat catch curves between 2019 and 2020 across a number of cohorts in the SCOWCGFS-Q1). Recruitment between 2005 and 2013 remained on a very low level. In recent years, it has been fluctuating, mostly above the average except for 2018.

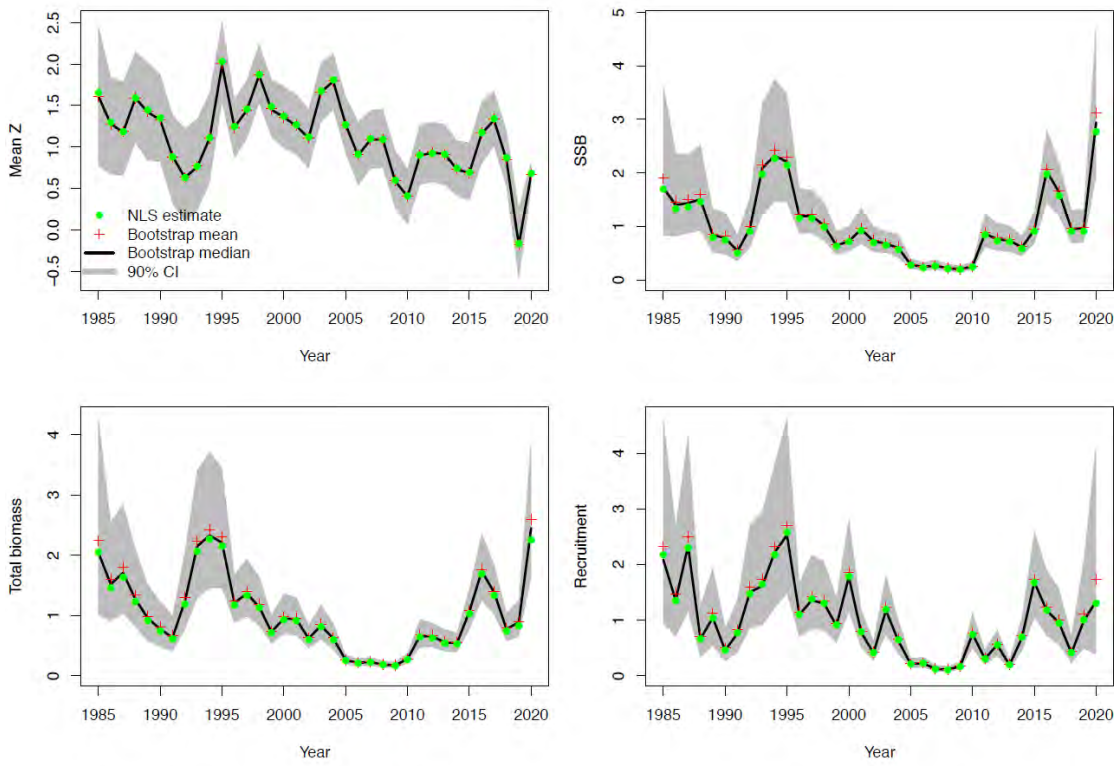


Figure 5.4.2. Whiting in Division 6.a. Results of SURBAR analysis (see legend on mean Z plot for details). SSB, TSB and recruitment are relative estimates.

Some additional SURBAR runs were done with different survey configurations other than "all three" selected for the final model (WD 5.5 Whiting 6a SURBAR). The trends were rather similar in the different survey configurations. However, using all the three tuning series provide more information compared to other survey configurations. The performance of the model was tested with different parameter values (for each parameter, all the other parameters being fixed). There was a very little impact of the fishery selectivity reference age on the model outputs and using age 3 as the reference age was a good choice (based on AIC). Similarly, the optimal λ=1 was selected trough the sensitivity analysis. There was no effect of different catchabilities (with one q value for all ages 1+) which effectively suggested q=1. A minor effect of using age-specific catchabilities could be observed, but the sensitivity analysis showed that this option to be less effective when tested with AIC.

In conclusion, the three-survey configuration was considered to be representative of the population. Comparing the SSB estimates made with SURBAR and SAM (Figure 5.4.3) further supports using SAM as the main model for the assessment of whiting in 6.a.

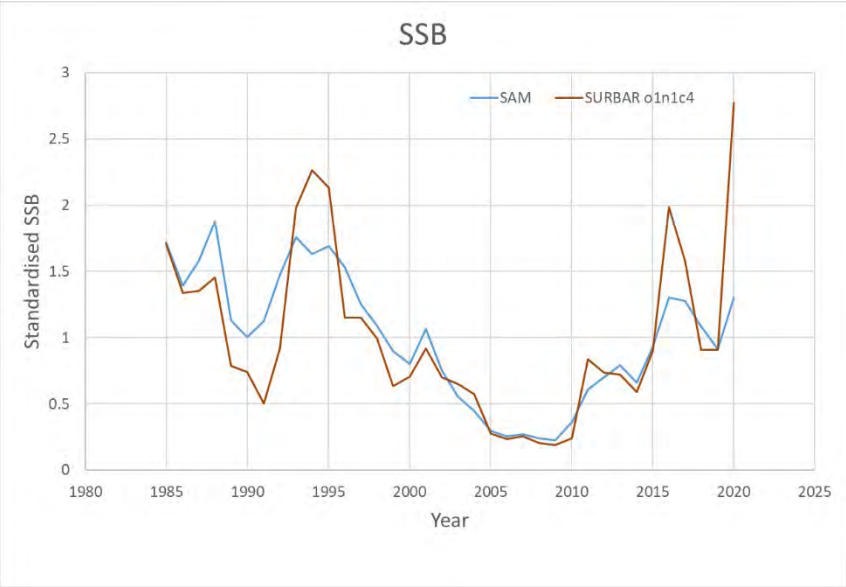


Figure 5.4.3. Whiting in Division 6.a. Comparison of the SSB estimates by SAM and SURBAR (final model run with three tuning series).

5.5 Maturity

5.5.1 Data evaluation meeting

The previously accepted assessment of whiting in 6a (in 2012–2019) was an age-based analytical assessment where information on sexual maturity was one of the input parameters. The maturity-at-age was assumed to be knife-edged. This was a source of criticism in assessments. It was reported that maturity of whiting in West of Scotland showed temporal variability; the lengths at maturity decreased significantly during 1986–2009 (Hunter *et al.*, 2015). Also, in the Irish Sea, there has been a noted increase in the incidence of precocious maturity-at-age 1 since 1998 (Armstrong *et al.*, 2004).

At WKDEM 2020 (ICES, 2020), it was decided to produce a revised maturity ogive in line with the recommendations of WKMOG 2008 (ICES, 2008). This benchmark delivers an updated ogive including the most recent survey data.

One maturity ogive was delivered for 1997–2020, which is an advancement in assessing the stock compared to the previous approximation. There was some interannual variability in maturity (given as age at 50% maturity, A50), but no clear trends could be found within the selected time frame (WD 5.3Whiting6a_Maturity ogive).

5.5.2 Benchmark workshop

The Hunter *et al*. (2015) study which suggests a very small but significant decrease in size at maturity over time, makes use of data from the mid-1980s along with the data used in this benchmark. Data from the early period were not available to this benchmark in an appropriate format and hence this potential trend could not be explored further. The benchmark meeting therefore agreed to use the fixed ogive based on survey data from 1997–2020 (WD_5.3 Whiting6a_Maturity ogive).

5.6 Stock weight

5.6.1 Data evaluation meeting

For the data evaluation meeting, the data that are used as stock weights-at-age were reviewed. Usually, stock mean weights-at-age are assumed to be equal to catch mean weights-at-age. Here, time-series of catch mean weights-at-age were compared with time-series of mean weights-at-age derived from survey data. This comparison revealed that, while the trends from both datasets were near identical from age 3 onwards, trends estimated from catch data showed a decline for age 1 and 2 while trends estimated from survey data showed an increase (Figure 5.6.1.1). Scientific surveys are likely to give a more accurate representation of young age classes compared to commercial fisheries which target older age classes and change in spatial fishing patterns over time. Therefore, it was decided during the data evaluation meeting that stock mean weights-at-age 0 to 2 should be obtained from survey data, while stock mean weights-at-age 3 and above should be obtained by averaging between survey and catch data (no weighting needed between data sources as both are highly similar for age 3 and above).

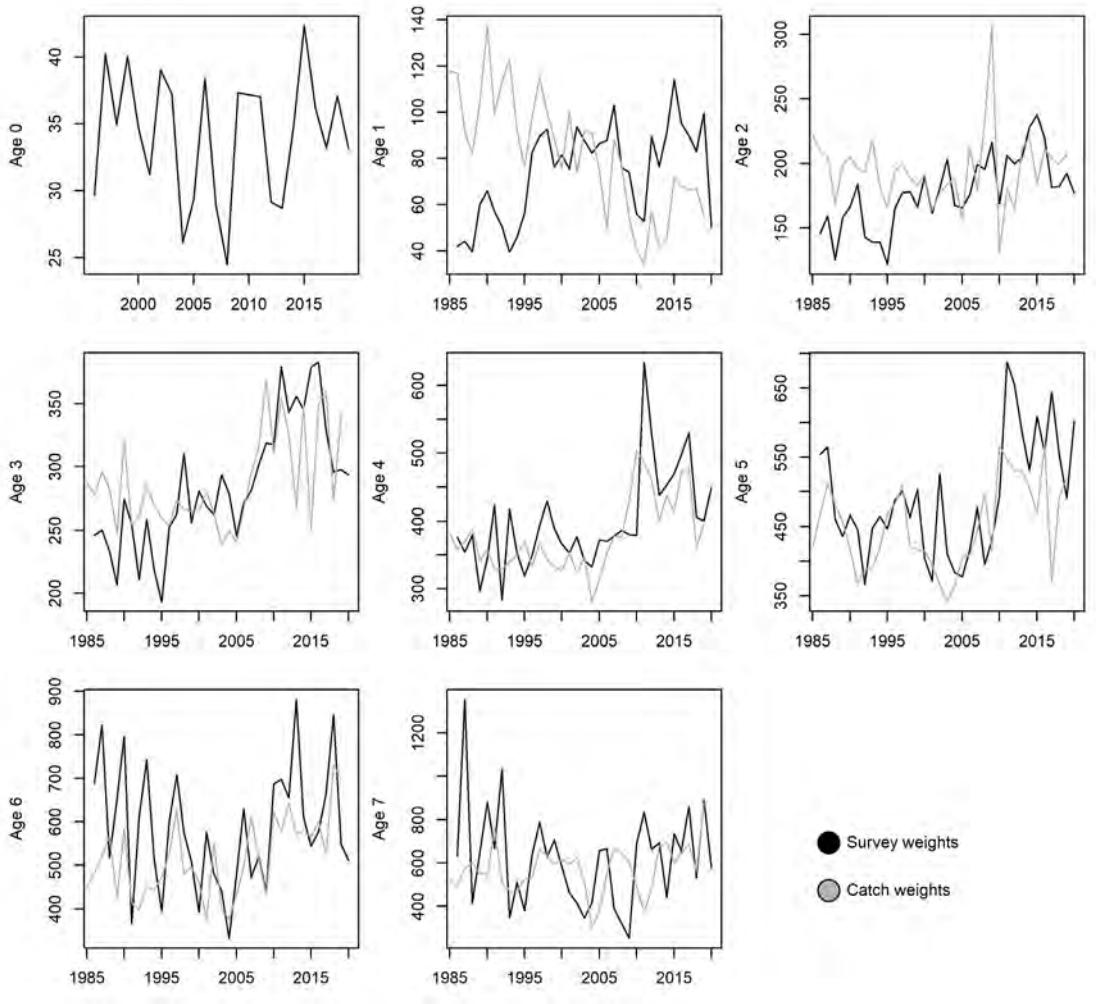


Figure 5.6.1.1. Combined Quarters 1 & 4 survey mean weights-at-age time-series for 6a whiting, together with catch mean weights-at-age time-series. Only Quarter 4 surveys contain data for the zero age class.

5.6.2 Benchmark workshop

Catch mean weights-at-age for the years 1980 to 2019 were taken from the 2019 assessment report (ICES, 2021b).

To obtain survey mean weights-at-age, data were extracted from DATRAS for the following surveys: IE-IGFS, SWC-IBTS, and SCOWCGFS. The SWC-IBTS survey ran from 1985 until 2010, and was replaced in 2011 by the SCOWCGFS survey. IE-IGFS only contains Quarter 4 data, while SWC-IBTS contains data for Quarter 1, 2 and 4, and SCOWCGFS contains data for Quarter 1 and 4. Only data pertaining to whiting (*Merlangius merlangus*) within the 6a ICES division were kept. The biological data (CA records, which are obtained from stratified sampling) were raised with a statistical weight accounting for the observed length distribution (HL records), following the method from the ICES Working Group on Maturity Ogive (WKMOG) Estimation for Stock Assessment (ICES, 2008) – see ICES (2021b; WD 5.4) for more details.

Both IE-IGFS and SCOWCGFS contain both length- and weigh-at-age data, however SWC-IBTS contains only length-at-age data. As a result, a length–weight relationship was fitted using the IE-IGFS and SCOWCGFS data. This relationship was fitted on a log scale to account for the increasing variability with size and abide by the homoscedasticity assumption, and the a parameter was then back-transformed into the normal scale and corrected for geometric mean bias (Hayes *et al*., 1995). The resulting parameters were a = 0.00488, and b = 3.168, and this length–weight relationship was then used to convert length-at-age values from SWC-IBTS data into weight-at-age values (ICES 2021b; WD 5.4).

Survey mean weights-at-age were obtained by calculating, for each year, the weighted average of weight at each age using the statistical weight as weighting factor. The stock mean weights-at-age were then obtained by taking the survey mean weights-at-age for age 0 to 2, and the average between survey mean weights-at-age and catch mean weights-at-age for age 3 and above, as agreed during the data evaluation meeting (see Section 5.6.1 above). Lastly, the stock mean weights-at-age time-series were smoothed using a General Additive Model (GAM) with REML.

It was decided to produce two sets of stock mean weights-at-age using this method: one to be used as stock weights-at-age input into the SAM stock assessment model, and one to be used to estimate size-dependent natural mortality-at-age using the Lorenzen (1996) equation (ICES, 2021b; WD 5.4).

To produce input for the SAM stock assessment model, stock mean weights-at-age were obtained using survey data from Quarter 1 only in combination with catch mean weights-at-age (as described in the methods above). The reason for including Quarter 1 survey data only is that the SSB is assumed to be calculated at the beginning of the year. However, the SAM stock assessment model also requires estimates of weight-at-age 0. Since age 0 data are not available from Quarter 1 surveys, Quarter 4 survey data was used to estimate stock mean weight-at-age for the age 0 class only.

To produce annual stock mean weights-at-age to be used to estimate natural mortality-at-age, survey data from all Quarters were used in combination with catch mean weights-at-age (as described in the methods above). The reason for including data from all Quarters is that growth changes have been observed for 6a whiting, with juveniles (age 1) increasing in size while adults (age 7) have decreased (Ikpewe *et al*., 2020). These changes in size-at-age are more likely to be captured by Quarter 4 data when fishes have grown throughout the year before moving on to the next age class. Since the mortality estimates used for 6a whiting are size-dependent, it is important to account for changes in growth by using a size which is most representative of the average annual size.

5.7 Mortality

5.7.1 Data evaluation meeting

Natural mortality-at-age time-series were previously obtained by using the smoothed catch mean weights-at-age time-series (assumed to be equal to stock mean weights-at-age) and the Lorenzen (1996) equation to calculate time-series of weight-dependent mortality-at-age estimates. However, data analyses performed for the data evaluation meeting showed contrasting trends between the mean weights-at-age from the catch and the mean weights-at-age from surveys for age classes 1 and 2, while the trends were highly similar for both data sources for age classes 3 and above (see Section 5.6.1 above). Therefore, it was decided that natural mortality-at-age should be estimated using stock mean weights-at-age from survey data for ages 0 to 2, and stock mean weights-at-age averaged between survey and catch data for ages 3 and above (see Section 5.6.1 above).

5.7.2 Benchmark workshop

Smoothed stock mean weights-at-age time-series were obtained using survey data from all quarters for ages 0 to 2, and the average between survey data from all quarters and catch data for ages 3 and above following the methods described in Section 5.6.2. These were then used in the Lorenzen (1996) equation to estimate time-series of weight-dependent mortality-at-age estimates, as follows:

$$M_a = 3\bar{W}_a^{-0.29}$$

Where M_a is the natural mortality-at-age a and $\bar{W}_a$ is the average weight-at-age a.

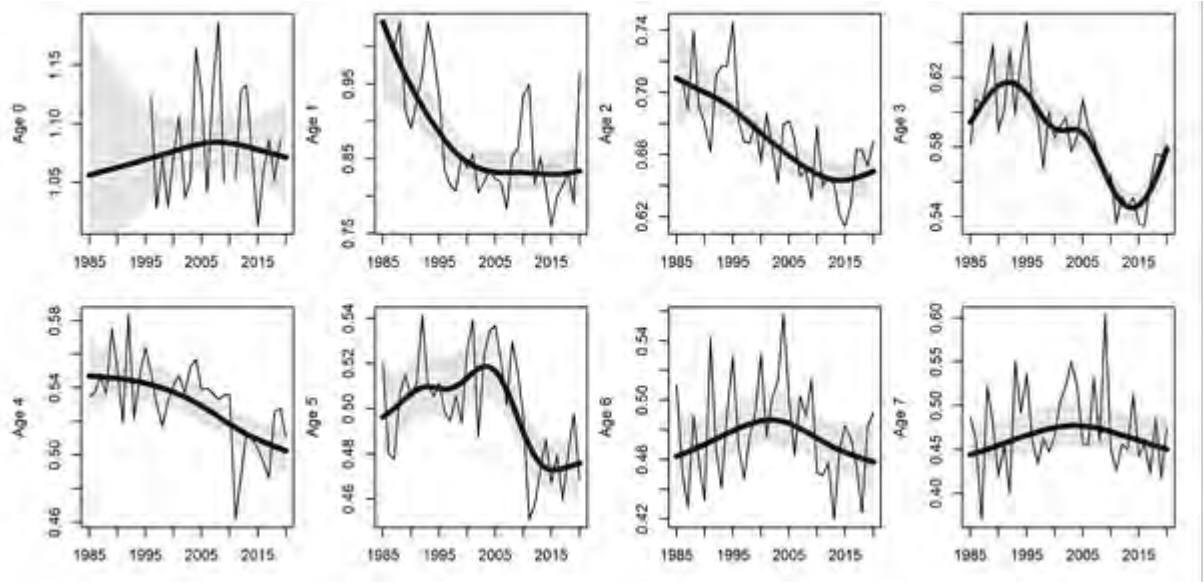


Figure 5.7.2.1. Time-series of natural mortality-at-age estimated with Lorenzen. The thick black line shows the natural mortality obtained with the smoothed mean weights-at-age with the corresponding 95% confidence interval shown in grey. The thin black line shows the natural mortality obtained with unsmoothed weights-at-age, for comparison.

The natural mortality-at-age estimates obtained with the new combined (survey and catch data) annual stock mean weights-at-age show a relatively flat dome-shaped trend for age 0, with a slight increase between 1995 and 2005 followed by a slight decrease (Figure 5.7.2.1). For ages 1

to 4, a clear declining trend is observed, while for older ages the natural mortality increases until circa 2000 after which it declines. In contrast, had the natural mortality-at-age been estimated with catch mean weights-at-age only, which show a decrease in weights-at-age 1 and 2 (Figure 5.6.1.1), the estimates would show an increase in natural mortality-at-age 1 and 2 (ICES 2021b; WD 5.4).

5.8 Final Assessment Model

5.8.1 Input Data

Following discussions at the benchmark meeting, it was decided that the model should be run over the entire time period for which catch numbers-at-age data were available in order to capture the earliest part of the time-series (during which catches were relatively high). To facilitate this in SAM, it was assumed that catch and discards mean weights-at-age zero between 1981 and 2002, and landings mean weights-at-age zero for the entire modelled time period, were equal to the average of mean weights-at-age zero between 2003 and 2019. In addition, stock mean weights-at-age and natural mortality-at-age between 1981 and 1984 were assumed to equal estimates for the equivalent quantity from the earliest available year (i.e. 1985). Catch numbers-at-age zero are only available from 2003 onwards (from the WKDEM data call) and therefore values between 1981 and 2002 were treated as missing and estimated in the assessment model. SAM input data characteristics are described in detail in the Tables 5.8.1 and 5.8.2, below.

5.8.2 Sensitivity Analysis & Final SAM settings

Configuration settings were explored through sensitivity analyses (full details in WD 5.6 SAM) that were carried out on a base model configuration which was generated using the defcon function in the stockassessment R package (Nielsen and Berg, 2014). To summarise, sensitivity analyses were carried out on settings for: the stock–recruitment relationship used, fleet covariance configuration, survey catchability coupling, observation variance coupling, and fishing mortality states process coupling. In the case of the stock–recruitment relationship, using Beverton–Holt and Ricker stock–recruitment models resulted in a slight decrease in AIC, but their requirement for two more parameters resulted in problems in estimating leave-one-out runs when included in the final model. As the magnitude and trends of estimates were very similar regardless of the stock–recruitment relationship used, the plain random walk was thus retained from the base model configuration. In the cases of fleet covariance structure, survey catchability, and observation variance, all plausible combinations of coupling vectors for each fleet were implemented as potential configuration matrices, and the best fit for each was identified by AIC. For the fishing mortality states process coupling, two configurations were tested: all ages decoupled apart from ages six and seven+ (i.e. the base model configuration), and all ages decoupled. The model with all ages decoupled provided a better quality fit (AIC = 1503.04) than the base configuration (AIC = 1534.85).

Settings for the final SAM run were chosen through the consideration of AIC, model residuals, and retrospective patterns. The full configuration of the final model is given in Table 5.8.3. The following list summarises the main features of the final model configuration which were informed by sensitivity analyses and discussions at the benchmark:

- Fishing mortality states processes are uncoupled for all ages.
- Catchabilities for each survey index are freely estimated with the exception of the two oldest age classes for each index; ages five and six in ScoGFS-WIBTS-Q1 and UK-SCOWCGFS-Q1, and ages six and seven+ in Comb-WCGFS-Q4.

- Catch observation variance parameters are allowed to differ for age zero and age seven+ while all other age groups are coupled.
- Survey observation variance parameters are coupled across all ages for ScoGFS-WIBTS-Q1 and UK-SCOWCGFS-Q1, whereas for Comb-WCGFS-Q4 observation variance parameters were uncoupled for age zero, and coupled for ages one to four and ages five to seven+.
- The catch, ScoGFS-WIBTS-Q1, and UK-SCOWCGFS-Q1 fleets are modelled with independent covariance structures, whereas the Comb-WCGFS-Q4 fleet is modelled with a first order autoregressive variance structure (AR1) with ages zero and one, ages one to six, and ages six and seven+ coupled.
- Recruitment is modelled as a plain random walk.
- The estimation of catch scaling was explored during the sensitivity analyses, due to suspected under-reporting of landings in the fishery between the mid-1990s and 2006. Model runs which allowed for the estimation of a catch scaling factor, as well as one model run freely estimating catch based on a censored dataset where data were removed between 1995 and 2006, estimated catches in some years to be approximately four to five times the observed catch. Given that under-reporting estimates in those same years are < 10% of total landings (ICES, 2012), the scaled model estimates were deemed unrealistic, and the implementation of a catch-scaling (or free-estimation of catch) model configuration was rejected.
- $\bar{F}$ was set at ages one to three in order to reflect changes in fishery selectivity, moving from a target fishery in the 1980s and 1990s to a bycatch & discard component of the *Nephrops norvegicus* trawl fishery from the early 2000s onwards. This is a change from previously accepted analytical assessments of this stock which used an $\bar{F}$ range of ages two to four.

5.8.3 Assessment Results

A summary of estimates from the final SAM run is shown in Figure 5.8.1., and the associated parameter estimates are presented in Table 5.8.4. The estimated $\bar{F}_{1\text{-}3}$ increases in the early part of the time-series until the late 1980s at which point estimates follow a U-shaped trend across the 1990s, decreasing and then increasing again to their highest levels. From the early 2000s onwards, estimated F follows a decreasing trend for the remainder of the modelled period, coinciding with changes in fishery selectivity patterns from a target fishery to a bycatch fishery. Estimated SSB follows a steep decline for the early part of the modelled time period, stabilising somewhat in the late 1980s, and declining again through the late 1990s and early 2000s. Estimates of SSB then remain at their lowest levels, before following an increasing trend from ~2010 through to the end of the modelled period.

The standardised one-observation-ahead residuals are shown in Figure 5.8.2. The model fits the catch-at-age data reasonably well with most residuals within ±3. The only relatively distinct pattern in the catch residuals can be seen across ages two to five, between the mid-to-late 1980s and the early 2000s, where a switch between generally positive values and generally negative values can be observed. This is reflective of the changes in fishery selectivity known to have happened during that time period. Earlier versions of the model showed some disparity in magnitude between the residuals for age seven+ and the younger age classes, but this issue was addressed reasonably well through the decoupling of the fishing mortality state processes for ages six and seven+. Implementation of a first order autoregressive covariance structure for the Comb-WCGFS-Q4 substantially reduced the tendency of the associated residuals towards negative values between ages two and seven+ towards the end of the modelled time period. Although the final years of these age classes still have negative residuals, values for the past ten years are

interspersed with positive values. Residuals for ScoGFS-WIBTS-Q1, and UK-SCOWCGFS-Q1 were also deemed satisfactory.

The retrospective analysis peels are shown in Figure 5.8.2. Trends in SSB and $\bar{F}_{1\text{-}3}$ are stable to the sequential annual removal of data working backwards from 2020 and 2019, respectively. Retrospective trends in recruitment showed slightly more variability than SSB and $\bar{F}_{1\text{-}3}$, but peels remained within the 95% confidence bounds, only diverging slightly from the final model estimates. The Mohn's ρ values for all three quantities were relatively low: ρ_{SSB} = 0.099, ρ_{F} = -0.050, ρ_{rec} = 0.116.

The leave-one-out runs for the final model are presented in Figure 5.8.3. Estimates of SSB appear the reasonably robust to the sequential exclusion of different survey indices, following very similar trends across the time-series within a relatively tight confidence interval. Removal of the ScoGFS-WIBTS-Q1 causes a divergence in estimates from 2010 onwards, with estimates falling below the lower confidence bound towards the end of the modelled period. Estimates of $\bar{F}_{1\text{-}3}$ follow very similar trends between 1981 and ~2000, showing some variability in estimates within the 95% confidence intervals thereafter. Estimates of recruitment again follow similar trends, remaining within the 95% confidence bounds with each sequential survey index exclusion, the only discernible difference being that exclusion of the Comb-WCGFS-Q4 index results in a smoother time-series of recruitment estimates.

Table 5.8.1. SAM input data types and characteristics.

Type	Name	Year range	Age range	Variable from year to year Yes/No
Canum	Catch numbers-at-age	1981 onward	0 to 7+*	Yes
Weca	Weight-at-age in the commercial catch	1981 onward	0 to 7+*	Yes
Weca discards†	Weight-at-age in the commercial discards	1981 onward	0 to 7+*	Yes
Weca landings†	Weight-at-age in the commercial landings	1981 onward	1 to 7+*	Yes
West=Weca	Weight-at-age of the spawning stock at spawning time	1985 onward	0 to 7+‡	Yes
Mprop	Proportion of natural mortality before spawning	1981 onward	0 to 7+	No
Fprop	Proportion of fishing mortality before spawning	1981 onward	0 to 7+	No
Matprop	Proportion mature at age	1981 onward	0 to 7+	No
Natmor	Natural mortality	1985 onward	0 to 7+‡	Yes

*** Commercial catch numbers- and weights-at-age zero were available from 2003 onwards only. For the period prior to 2003, weights-at-age zero were assumed to equal the catch/discards weights-at-age zero averaged over 2003–2019.**

† The assessment does not model landings and discards separately.

‡ Input data were required for these quantities for the entire time range of the model. Values between 1981 and 1984 were assumed to equal the earliest available value (i.e. 1985) for each age class.

Table 5.8.2. Survey indices used in SAM.

Type	Name	SAM acronym	Year range	Age range
Tuning fleet 1	ScoGFS-WIBTS-Q1	WCIBTS.Q1	1985–2010	1 to 6
Tuning fleet 2	UK-SCOWCGFS-Q1*	SCO.Q1	2011–onward	1 to 6
Tuning fleet 3	Comb-WCGFS-Q4*	SCO.Q4	1996–onward	0 to 7+

*** Variance estimates were included as weightings in SAM for these indices.**

Table 5.8.3. Final SAM settings for assessment of 6.a whiting agreed at WKNSEA 2021.

Model Setting	Setting name	Agreed configuration & details
Minimum age in model	$minAge	0
Maximum age in model	$maxAge	7
Maximum age plus group	$maxAgePlusGroup	Maximum age plus group applies to both the commercial catch data and modelled Q4 survey index
Coupling of the fishing mortality state processes	$keyLogFsta	Uncoupled across all age classes
Correlation of fishing mortality across ages	$corFlag	AR(1) first order autoregressive
Coupling of the survey catchability parameters	$keyLogFpar	WCIBTS.Q1: ages 1 to 4 uncoupled; ages 5 and 6 coupled SCO.Q1: ages 1 to 4 uncoupled; ages 5 and 6 coupled SWC.Q4: ages 0 to 5 uncoupled; ages 6 and 7+ coupled
Density dependent catchability power parameters	$keyQpow	n/a
Coupling of process variance parameters for *log*(F) process	$keyVarF	Coupled across all age classes
Coupling of the recruitment and survival process variance parameters	$keyVarLogN	Age 0 uncoupled; ages 1 to 7+ coupled
Coupling of the variance parameters for the observations	$keyVarObs	Catch: age 0 uncoupled; ages 1 to 6 coupled; age 7+ uncoupled WCIBTS.Q1: ages 1 to 6 coupled SCO.Q1: ages 1 to 6 coupled SWC.Q4: age 0 uncoupled; ages 1 to 4 coupled; ages 5 to 7+ coupled
Covariance structure for each fleet	$obsCorStruct	Catch: Independent (”ID”) WCIBTS.Q1: ”ID” SCO.Q1: ”ID” SWC.Q4: first order autoregressive (”AR1”)
Coupling of correlation parameters for fleet covariance	$keyCorObs	SWC.Q4: ages 0 and 1 coupled; ages 1-2, 2-3, 3-4, 4-5, and 5-6 coupled; ages 6 and 7+ coupled
Stock recruitment code	$stockRecruitmentModelCode	0; Plain random walk
Number of years where catch scaling is applied	$noScaledYears	0
Years where catch is scaled	$keyScaledYears	n/a

Model Setting	Setting name	Agreed configuration & details
Matrix specifying the couplings of scale parameters	$keyParScaledYA	n/a
Lowest and higest ages included in $\bar{F}$	$fbarRange	1, 3
Biomass survey configuration	$keyBiomassTreat	n/a
Observational likelihood	$obsLikelihoodFlag	Catch: ”LN” WCIBTS.Q1: ”LN” SCO.Q1: ”LN” SWC.Q4: ”LN”
Observation weighting configuration	$fixVarToWeight	0
Fraction of t(3) distribution used in logF increment distribution	$fracMixF	0
Fraction of t(3) distribution used in logN increment distribution	$fracMixN	0
Fraction of t(3) distribution used in distribution of fleets	$fracMixObs	Catch: 0 WCIBTS.Q1: 0 SCO.Q1: 0 SWC.Q4: 0
Break years between which recruitment is constant	$constRecBreaks	n/a
Coupling of parameters used in a prediction-variance link for observations	$predVarObsLink	n/a

Table 5.8.4. Parameter estimates from final SAM run for 6.a whiting.

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-5.893	0.156	0.003	0.002	0.004
logFpar_1	-5.921	0.156	0.003	0.002	0.004
logFpar_2	-6.068	0.159	0.002	0.002	0.003
logFpar_3	-6.159	0.166	0.002	0.002	0.003
logFpar_4	-6.761	0.175	0.001	0.001	0.002
logFpar_5	-5.861	0.246	0.003	0.002	0.005
logFpar_6	-5.711	0.259	0.003	0.002	0.006
logFpar_7	-5.441	0.254	0.004	0.003	0.007
logFpar_8	-5.713	0.264	0.003	0.002	0.006
logFpar_9	-6.251	0.259	0.002	0.001	0.003
logFpar_10	-4.756	0.222	0.009	0.006	0.013
logFpar_11	-5.172	0.180	0.006	0.004	0.008
logFpar_12	-5.113	0.179	0.006	0.004	0.009
logFpar_13	-5.475	0.183	0.004	0.003	0.006
logFpar_14	-5.868	0.200	0.003	0.002	0.004
logFpar_15	-6.106	0.243	0.002	0.001	0.004
logFpar_16	-6.846	0.294	0.001	0.001	0.002
logSdLogFsta_0	-1.016	0.143	0.362	0.272	0.482
logSdLogN_0	-0.513	0.165	0.599	0.430	0.833
logSdLogN_1	-1.810	0.265	0.164	0.096	0.278
logSdLogObs_0	-0.164	0.206	0.849	0.562	1.281
logSdLogObs_1	-1.029	0.080	0.357	0.305	0.419
logSdLogObs_2	-0.611	0.172	0.543	0.385	0.766
logSdLogObs_3	-0.330	0.066	0.719	0.630	0.820
logSdLogObs_4	0.741	0.102	2.098	1.712	2.572
logSdLogObs_5	0.941	0.156	2.563	1.876	3.502
logSdLogObs_6	0.829	0.133	2.291	1.756	2.988
logSdLogObs_7	1.131	0.106	3.098	2.506	3.831
transfIRARdist_0*	3.417	1382.267	30.464	0.000	Inf
transfIRARdist_1	-0.994	0.303	0.370	0.202	0.679
transfIRARdist_2	1.023	0.847	2.781	0.511	15.134
itrans_rho_0	1.652	0.208	5.218	3.444	7.906

***The relatively large standard deviation (and associated uncertainty) around the estimate of transfIRARdist_0, the coupled AR1 parameter for ages 0 and 1, indicates a weak to non-existent level of autocorrelation between age groups 0 and 1.**

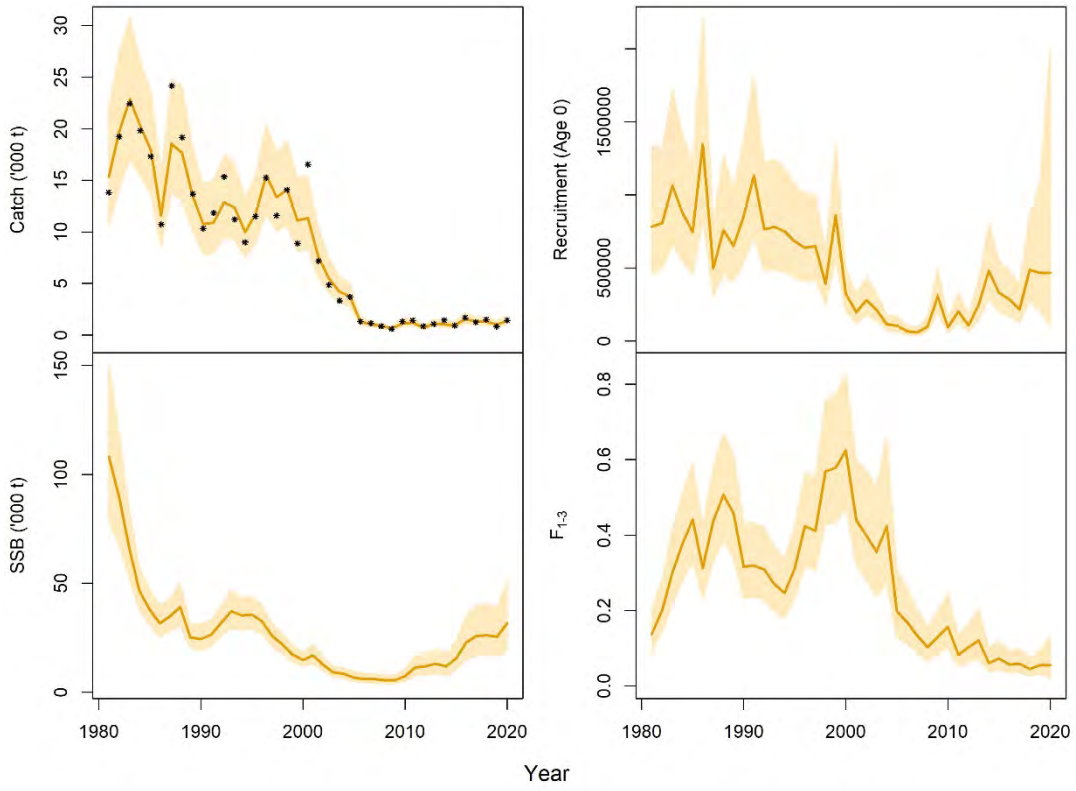


Figure 5.8.1. Summary of final whg.27.6a SAM run estimates with 95% confidence intervals.

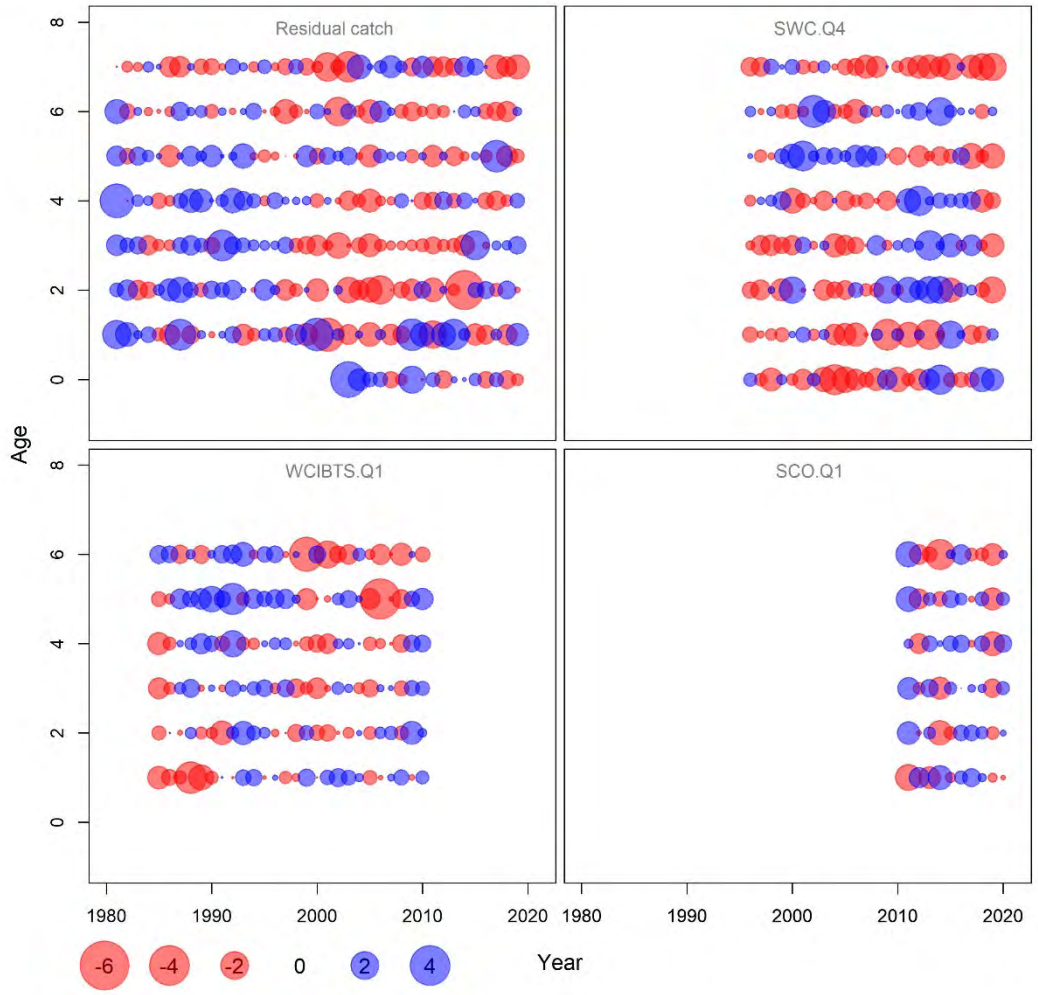


Figure 5.8.2. Standardized one-observation-ahead residuals from the final whg.27.6a SAM run for the catch (*top left*), ScoGFS-WIBTS-Q1 (*bottom left*), UK-SCOWCGFS-Q1 (*bottom right*), and Comb-WCGFS-Q4 (*top right*) fleets.

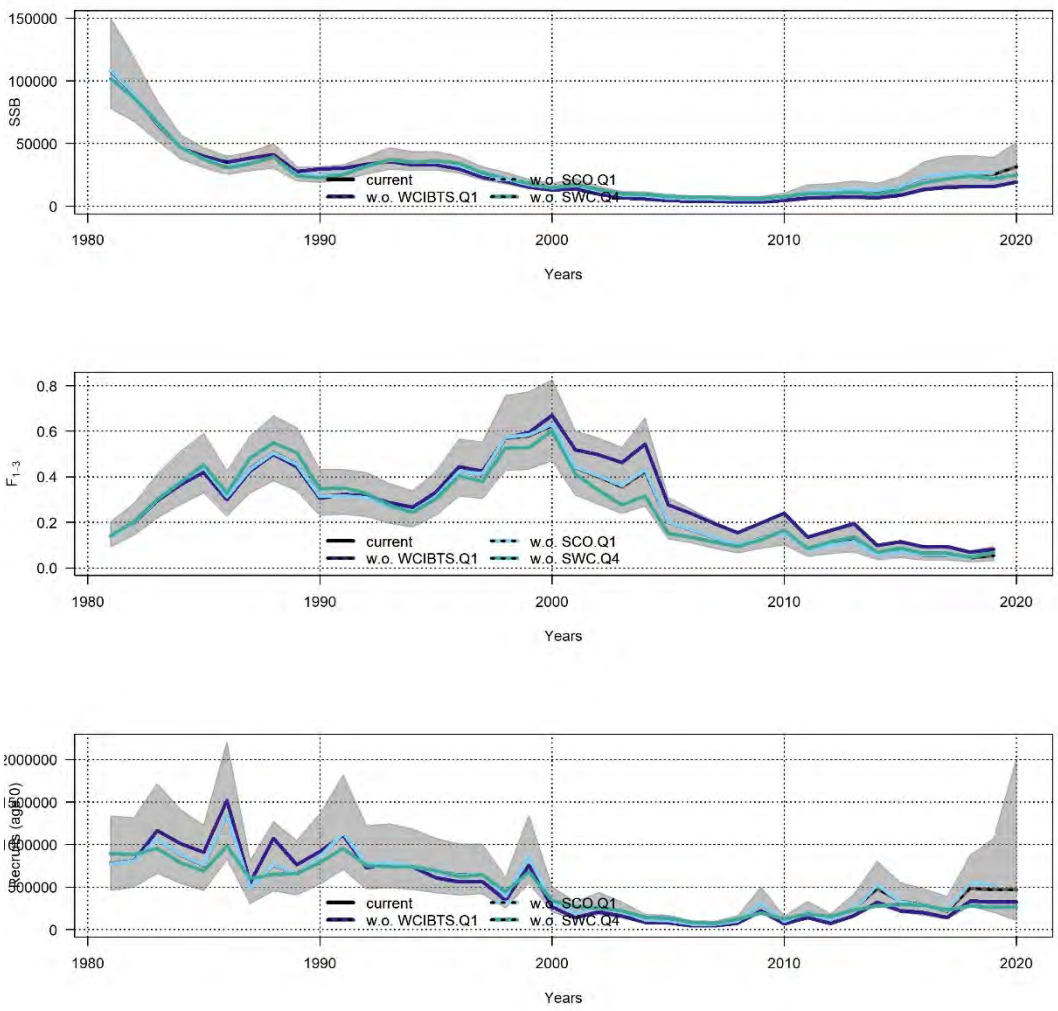


Figure 5.8.3. Leave-one-out runs based on the final whg.27.6a SAM configuration.

5.9 Short-term forecast

5.9.1 Benchmark workshop

Method

The WK agreed that stochastic short-term projections will be performed using the short-term forecast functionality of the "stockassessment" R package.

Recruitment

Given that there is a Q1 survey included in the assessment, SAM provides an estimate of recruitment-at-age 0 in the intermediate year although there are no data on age 0 in the Q1 survey and the estimate is based on a continuation of the random walk. Since there was no apparent retrospective bias associated with the random walk estimate of recruitment, it was agreed that this value should be used in the forecast as the intermediate year assumption, given that the alternative would be to make some other assumption such as a medium-term average.

For subsequent years of the forecast, it was agreed that recruitment would be resampled from the latest ten-year period (to roll forward in future years) including the intermediate year.

Currently this includes a few years when recruitment was very low (2011 and 2012), but also more moderate recent recruitment which has occurred as the stock has increased.

Biological and fishery parameters

Landings and discard weights-at-age are very noisy in recent years. It was therefore agreed to use five-year averages of the data for these input parameters in the forecast rather than three, which is the more usual assumption (will also apply to stock weights and natural mortality, although these have already been smoothed). Maturities are assumed constant.

Fishery selectivity appears relatively stable in recent years, however, the discard ogive (landings fraction by age) is very noisy, and hence these should also be averaged over a five-year period for use in the forecast. However, there is a need to monitor these data in future for any potential shorter term trends associated with changing fishing practices due to for example, the landing obligation or change in targeting.

The assumption of F in the intermediate year is a decision that should be taken at the assessment WG meeting based on the best knowledge of the fishery at that time.

5.10 Reference points

5.10.1 Benchmark workshop

In deriving F_{MSY}, a decision has to be taken about the definition of yield; ICES defines this as catch above MCRS which in the case of a stock with significant high grading (such as 6a whiting) is different to landings (which are assumed equal to yield in EqSim). After consideration of mean lengths-at-age in the catch (based on Scottish sample data), we define yield as all catch-at-age 3 and above plus 50% of age 2 catch (the mean length in catch-at-age 2 varied between 25 and 30 cm, and MCRS = 27 cm).

Eqsim provides MSY reference points based on the equilibrium distribution of stochastic projections. Stochasticity is included in biological and fishery parameters by resampling at random from the recent stock assessment. The fishery selectivity has been relatively stable since around 2000 and since then catch weights have varied substantially, but without trend (likely due to noise in the data). Therefore, a 10-year range for resampling these data was used with the exception of i) using the fixed discard proportion to approximate above MCRS yield (as described above) and ii) the use of catch mean weights instead of landings mean weights for ages 3 and above to avoid the use of mean landings weight affected by high grading. The default setting for inclusion of recruitment autocorrelation (TRUE) in the simulations was used.

PA reference points

One of the key decisions in defining reference points is the derivation of B_{lim}. Following the ICES guidance, this stock would be categorised as Type 2: a stock with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired. In such cases, the ICES guidance suggests that B_{lim} is set at the segmented regression change point (Figure 5.10.1). However, the resulting breakpoint is very high (outside the main cloud of S–R points) with very wide 95% confidence intervals (43 990, CI: 31 671–56 109). As a consequence, this would likely result in B_{lim} and B_{pa} at a level close to that at the start of the time-series (above all but three or four SSB points).

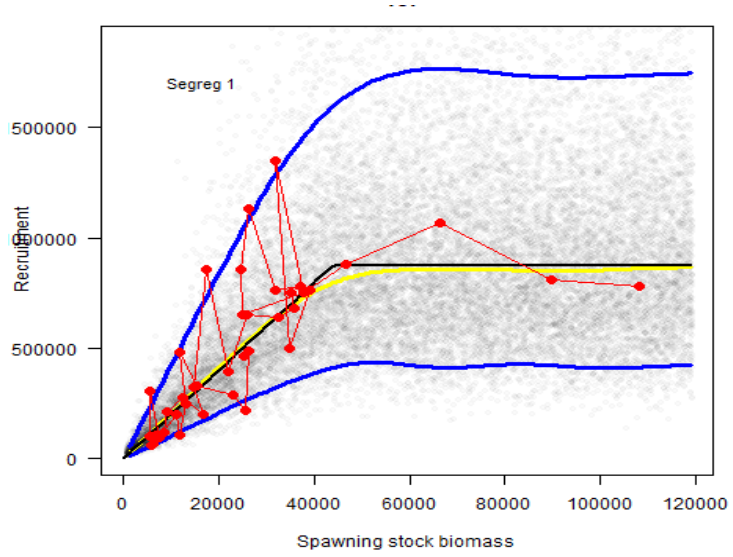


Figure 5.10.1. whg.27.6a. Stock–recruitment relationship - fitted segmented regression.

The gadoid outburst of the 1960s and 1970s which affected demersal stocks in the seas around the UK is well documented, and the reductions in biomass across demersal stocks during the early 1980s have previously been considered a return to more usual levels (Holden, 1991; Hislop, 1996). It was therefore agreed that the four datapoints at the start of the time-series (1981–1984) should be excluded from further analysis. The stock then falls into the Type 3 category (wide dynamic range of SSB and evidence that recruitment is or has been impaired but with no clear asymptote in recruitment at high SSB), which therefore requires a stock-specific or expert judgement for setting B_{lim}.

The recruitment time-series (Figure 5.10.2) suggests a period of high recruitment pre-2000 and then lower recruitment since then. The approach was therefore to use the lowest SSB associated with this period (1999) which results in B_{lim} = 17 286 t. The cv of the estimated biomass in the final year (σ) of the assessment is 0.239 (rounded) and therefore B_{pa} = 25 597 t (= Blim x exp(1.645 x σ)).

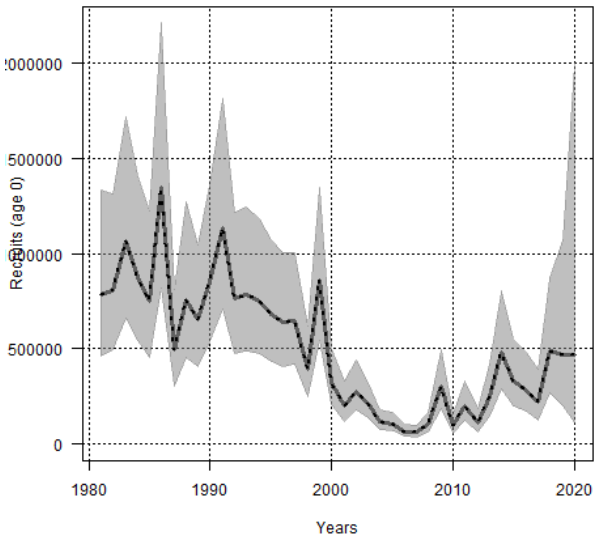


Figure 5.10.2. whg.27.6a. Recruitment time-series from final SAM model run.

F_{lim} estimation was performed using Eqsim (without assessment/advice error) to derive the F that has 50 % probability of SSB falling below B_{lim} using a segmented regression stock–recruitment relationship with the breakpoint fixed at B_{lim}. F_{lim} was estimated as 0.31.

MSY Reference points

In situations where the stock–recruitment relationship is uncertain, the ICES guidance suggests using the model averaging approach in the estimation of F_{MSY}. However, in this case model fits result in the Beverton–Holt plateau and peak in the Ricker curve occur well outside the range of historical data and therefore these stock–recruit relationships are excluded from the calculation of F_{MSY} and the segmented regression with fixed breakpoint was used.

F_{MSY} is initially calculated by running EqSim with assessment/advice error, but without application of the ICES advice rule (MSY $B_{trigger}$). The default values for assessment/advice error as suggested by WKMSYREF4 (ICES, 2017b): Fcv=0.212 and Fphi=0.423 are used. The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.23. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.27 and the lower bound 0.175.

The next step is to set MSY $B_{trigger}$. Given that this stock has been fished below F_{MSY} for more than five years, the 5th percentile of BF_{MSY} was considered. However, this is substantially lower than B_{pa} and hence MSY $B_{trigger}$ is set equal to B_{pa} (25 597 t).

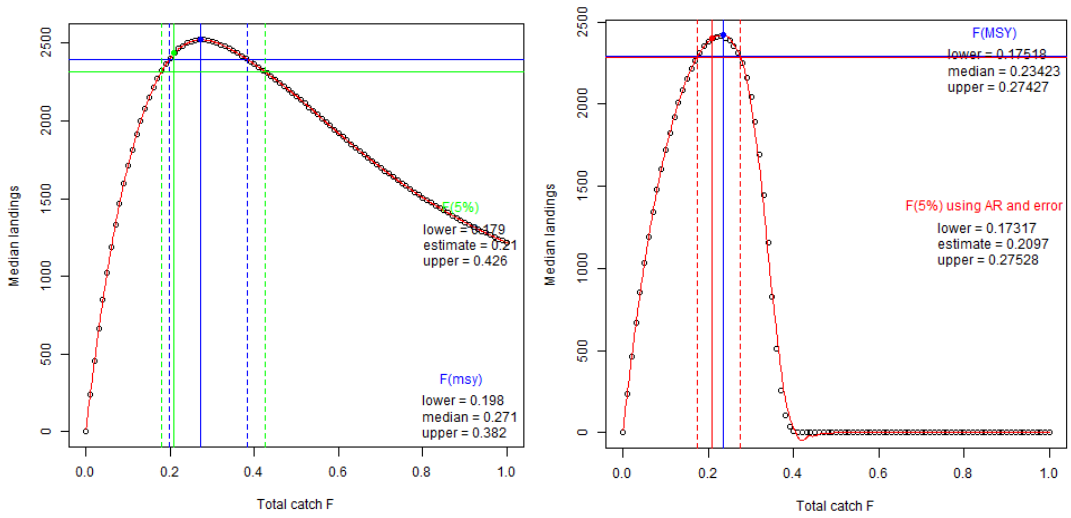


Figure 5.10.3. Median yield curve with estimated reference points for fixed F. a) including the ICES advice rule, b) excluding the ICES advice rule (the latter includes recalculation of $F_{MSY.lower}$ based on F_{MSY}=Fp.05).

The ICES MSY advice rule is then evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having a less than 5% annual probability of SSB < B_{lim} in the long term. The $F_{p.05}$ is calculated as 0.21 which is lower than the F_{MSY} without the advice rule and therefore the F_{MSY} reference points are limited by $F_{p.05}$ i.e. Fmsy = $F_{MSY.upper}$ = $Fp._{05}$ = 0.21 (Figure 5.10.3a). In such cases, the $F_{MSY.lower}$ must be recalculated as the F resulting in 95% of the yield at the capped F_{MSY} (0.21) in scenarios without the ICES advice rule applied. Figure 5.10.3b shows the new $F_{MSY.lower}$ to be 0.173, slightly lower than that derived from the uncapped F_{MSY}. (Note that this stock is considered only as a bycatch species in the Western Waters EU MAP).

The final reference points estimates are proposed in the table below.

Framework	Reference point	Value	RATIONALE
MSY approach	MSY $B_{trigger}$	25597	Tonnes; B_{pa}
	F_{MSY}	0.21	$F_{p.05}$ (F_{MSY} uncapped = 0.23)
	$F_{MSYlower}$	0.173	F resulting in no more than 5% reduction in long-term yield compared with MSY without ICES AR (95% yield at Fp.05).
	$F_{MSYupper}$	0.21	F_{MSY}
Precautionary approach	B_{lim}	17286	Tonnes; lowest SSB (1999) associated with period of high recruitment (pre-2000)
	B_{pa}	25597	Tonnes; B_{lim} x exp(1.645 x σ); σ = 0.239 (rounded)
	F_{lim}	0.31	F giving 50% probability of SSB<B_{lim}. Uses segmented regression with breakpoint=B_{lim} (EqSim)
	F_{p05}	0.21	Estimated from stochastic simulation (EqSim) including the ICES AR
	F_{pa}	0.21	$F_{p.05}$

6 Sole (sol.27.7d)

6.1 Summary

Sole in Division 27.7d was last benchmarked in 2017 (WKNSEA 2017). Due to data issues with the UK commercial beam trawl tuning series, an inter-benchmark was set up in August 2019. At the end of the inter-benchmark, it was found that French catch data for 2016 and 2017 were aggregated incorrectly for older ages, which meant that the catch-at-age data were not reliable for these years. During the benchmark in February 2020 (WKFLATNSCS 2020), it became clear that France raises its data by effort and that the way the effort was calculated had changed over the time-series. As a result, the benchmark process was postponed to the WKNSEA 2021 benchmark, and in the data call, France fixed the issues and updated its entire commercial catch data time-series (2002–2019) in InterCatch.

At this data compilation workshop, the Belgian landings were investigated and two different calculation methods revealed over-reporting of the sole landings in Division 27.7d. Belgian landings were therefore corrected for both the small (≤221 kW) and large (>221 kW) fleet segment. First, we only corrected when estimated landings were ≥20% lower than what was reported. However, reviewers argued for a correction of the entire time-series. This will be done in time for the benchmark.

Different sources of stock weights-at-age were used over the time-series (1982–present). To improve consistency, we aim to use quarter 1 catch/landing weights as input for the assessment. Results will be presented at the benchmark.

Six tuning fleets are currently included in the assessment: 3 survey indices (UK BTS, FRA YFS and UK YFS) and 3 commercial indices (BEL CBT, UK CBT, FRA COTB). The French commercial otter trawl tuning fleet is under revision. To standardise the French lpue index, a hurdle lognormal mixed model is used to correct for vessels, seasonality and spatial effects. The Belgian commercial beam trawl index will be revised in line with the correction of the landing data related to misreporting. During the benchmark, the commercial indices will be included as biomass indices in the assessment instead of disaggregating them by age to avoid double counting of commercial data. The Belgian commercial beam trawl index and the UK BTS survey index cover most of Division 27.7d. During the benchmark, reducing the amount of tuning fleets will be explored.

The French SMAC project provided evidence for the presence of three subpopulations in the stock. We will explore how the presence of subpopulations can be considered in the assessment by e.g. splitting the UK BTS index or weighing the commercial indices.

Several assessment runs will be carried out during the benchmark, starting with the XSA model including all new catch data, followed by several SAM runs where both settings of the SAM model and tuning fleets will be changed.

During the benchmark, the following additional decisions were made on the input data. No discards are available prior to 2004 and were therefore reconstructed using the ratio between discards and landings in the period 2004–2008. This period was considered as representative for the earlier part of the time-series. The stock weights-at-age were set as the quarter 1 catch weight-at-age. Prior to 2004, no quarter 1 information was available. Therefore, the mean proportion-at-age was calculated based on the ratio between quarter 1 weight-at-age and catch weight-at-age in the period 2004–2019 and multiplied by the catch weight-at-age for the beginning of the time-series. The French and Belgian commercial tuning series were revised. Both series followed a model-based approach to derive an lpue index that is considered to reflect the fishable biomass

of the stock. The subpopulation structure was not considered explicitly in the construction of the input data and assessment model, as there is insufficient data available on each of the three subpopulations (e.g. no catch data available per ICES rectangle).

It was decided to use a state–space stock assessment model (SAM) to provide advice for the eastern English Channel sole stock. The assessment model is tuned by three commercial lpue indices as fishable biomass, and three scientific, age-structured survey indices. Compared to the previous XSA assessment model, the spawning–stock biomass is estimated to be significantly lower, while the fishing mortality is estimated to be higher.

Following the changes in the input data and assessment model, the reference points were recalculated. The F_{MSY} is estimated to be 0.193 which is similar to the previous estimate (0.192).

In addition to the information provided in the current report chapter, the reader is also referred to the following seven Working Documents that provide further details of the relevant datasets incorporated in the final assessment model:

1. Sys K., Vanelslander B., Nimmegeers S. and Vansteenbrugge L. 2021. WD_Sole7D_1_Belgian landings. Working Document: Belgian commercial beam trawl landings data for sole in the eastern English Channel (ICES division 27.7.d) for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 10 pp.
2. Vansteenbrugge L. and Nimmegeers S. 2021. WD_Sol_7d_2_InterCatch. Working Document: Preparation of catch data for sole (*Solea solea*) in division 27.7.d (eastern English Channel) for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 11 pp.
3. Sys K. and Vansteenbrugge L. 2021. WD_Sole7d_3_BE_CBT. Working Document: Revision of the Belgian commercial beam trawl tuning fleet for sole in the eastern English Channel (27.7.d) for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 13 pp.
4. Girardin R. 2021. WD_sole7d_4_FRCOTB tuning series. Working Document: Commercial LPUE form French otter trawlers for sol.27.7d stock assessment for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 17 pp.
5. Sys K. and Vansteenbrugge L. 2021. WD_Sole7d_5_UK_BTS. Working Document: Revision of the UK (E&W) beam trawl survey (BTS) index for sole in the eastern English Channel (ICES division 27.7d) for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 29 pp.
6. Vansteenbrugge L. and Sys K. 2021. WD_Sole7d_6_Assessment_runs. Working Document: Assessment runs for sole in the eastern English Channel (ICES division 27.7d) for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 62 pp.
7. Vansteenbrugge L. and Sys K. 2021. WD_Sole7d_7_Reference_points. Working document: Calculation of appropriate reference points (MSY) for sole in division 27.7d for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22-26, 2021; 11 pp.

6.2 Catch data

6.2.1 Data evaluation meeting

Sole in Division 27.7.d had an Inter-benchmark in August 2019. It was found that **French** catch data for 2016 and 2017 were aggregated incorrectly for older ages, which meant that the catch-at-age data were not reliable for these years. Additionally, France raises its data by effort and during the 2020 WKFLATNSCS benchmark, it became clear that the way the effort was

calculated had changed over the time-series. As a result of the WKNSEA 2021 benchmark data call, France fixed the issues and updated its entire commercial catch data time-series (2002–2019) in InterCatch.

During the Inter-benchmark in August 2019, a revision of the **Belgian** commercial beam trawl tuning fleet occurred. Investigating the Belgian sole landings data revealed that pure trips, i.e. trips in which fishing activity was limited to one ICES division (e.g. 27.7.d), often had a considerably different mean landing rate (kg.h^{-1}) than mixed trips (*i.e.* trips in which fishing occurred in multiple ICES divisions). The Belgian commercial fishing fleet has fishing opportunities in several ICES divisions. To allow an efficient exploitation of the stocks over all these areas, vessels are allowed to fish in different quota areas within one trip. This flexibility might create opportunity for non-compliance. The working document on the Belgian commercial landings data describes the two methods that were used to investigate this issue WD_Sole7d_1_Belgian landings.

The first method uses landing and effort data as reported by fishers in the electronic logbooks. First, the annual landings of fishing trips from only one quota area (pure trips) were divided by the annual effort of pure trips per area to calculate a pure trip lpue by management area and year (2004–2019). Secondly, this lpue was used to estimate the landings from the mixed trips (a fishing trip within more than one quota area) by multiplying the effort (by management area and year) registered in these trips with the pure trip lpue derived in the first step. Finally, the estimated landings from the mixed trips were added to the registered landings from the pure trips to estimate the total landings per area per year. This method assumes that the effort as reported in the mixed (and pure) trips is reliable, and that lpue of pure trips is representative for the landing rate in mixed trips. This method does not account for additional sources of variation in lpue.

The second method uses the landings per unit of effort of pure trips, but gets the effort data for both the pure and mixed trips from the VMS dataset with data available from 2006 onwards. Similar to the first method, landings were estimated by multiplying the lpue of pure trips by the VMS derived effort of mixed trips and add landings from pure trips in this area.

Both calculation methods show similar differences between reported and estimated landings, i.e. over-reporting in 7d. These differences are bigger for the large fleet segment (>221 kW) than the small fleet segment (≤221 kW), again supporting the theory that the misreporting is mainly on fishing trips covering more than 1 quota area. A test run was therefore conducted where Belgian commercial catch data were corrected for area misreporting, decreasing the total catch. A 20% threshold was used, meaning that if the discrepancy was larger than 20%, then catches were corrected.

The correction was overall convincing, but the use of a 20% threshold is more difficult to defend. Reviewers asked to get an idea of the difference between 1) only correcting when the 20% threshold was exceeded or 2) correcting the entire time-series according to the first calculation method. Depending on the year, differences varied between 13 and 190 tonnes. It was therefore decided to correct the entire Belgian time-series (2004–present).

6.2.2 Benchmark workshop

6.2.2.1 Preparation of catch data (InterCatch)

Data were submitted to InterCatch, which was used for estimating both landings and discards numbers and age compositions, as input for the assessment (WD_Sol_7d_2_InterCatch). The countries contributing most to the landings of sole in Division 27.7.d are France (60 ± 4%), Belgium (25 ± 4%) and UK (England) (16 ± 2%). The remaining countries are responsible for less than 1% of the landings. Data were processed from 2004 onwards. Belgium was the only country providing both landings and discard age distributions for the entire time period (2004–2019), which resulted in the use of the Belgian strata to fill an important part of the gaps.

Discards were **raised** on a **gear** level regardless of season or country by 'Landings CATON' (landings catch) using the available strata. The following groups were distinguished based on gear:

- TBB;
- OTB including OTB, OTT, SSC, SDN;
- GTR including GTR and GNS.

The remaining gears were combined in a REST group (including MIS, FPO, DRB, LHM, LLS).

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. 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.

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 strata, allocations were performed on a gear level. The same gear groups (TBB, OTB, GTR and 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, allocation of age occurred with all available information within that gear group. When the threshold was not reached, unsampled data were pooled in the REST group and ages were allocated using all sampled data. The weighting factor was 'Mean Weight weighted by numbers-at-age'.

The WD_Sol_7d_2_InterCatch includes more information on InterCatch raising and allocation procedures. The main differences compared to previous procedures include:

1. High discard rates for the OTB group are now included. Before, these were excluded when being larger than 50%.
2. There is a difference in discard tonnage of 7–60% due to the new upload of the French dataseries.
3. The correction of the Belgian landings resulted in differences in discard tonnage up to 5%, with the exception for the year 2013. In this year, there was a 28% difference, because mistakes in the raw data were corrected.

6.2.2.2 Reconstruction of the discards

Due to the lack of discard information prior to 2004, discards were reconstructed for the period 1982–2003. Similarly, as during the previous benchmark (WKNSEA 2017), an average discard proportion-at-age was calculated for the period 2004–2008. This decision was motivated by the fact that discard behaviour-at-age changed after 2008 and a general increase in discarding was found in the most recent years (Figure 6.2.2.2.1).

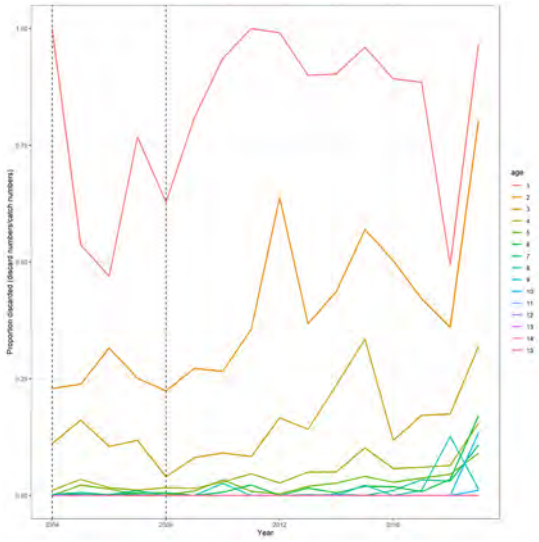


Figure 6.2.2.2.1. Proportion discarded at age calculated as discards numbers-at-age divided by catch numbers-at-age. Dashed lines indicate the period 2004–2008 which was used to reconstruct discards prior to 2004.

First, the InterCatch information from the most recent years (2004–2019) on discards and landings numbers-at-age, weights-at-age and overall tonnage was SOP corrected as follows. Numbers were multiplied with weights and summed per year. Then the ratio between the overall tonnage from InterCatch and this sum was calculated. This gave a SOP factor by year which was then multiplied by the numbers-at-age per year.

Subsequently, only the numbers-at-age were retained for the period 2004–2008 and the mean numbers-at-age were calculated. The ratio of the discards mean numbers-at-age and the landings mean numbers-at-age for 2004–2008 was then multiplied by the old landings numbers-at-age, which were also SOP corrected. This finally resulted in **discards numbers-at-age** for the period 1982–2003 (Figure 6.2.2.2.2).

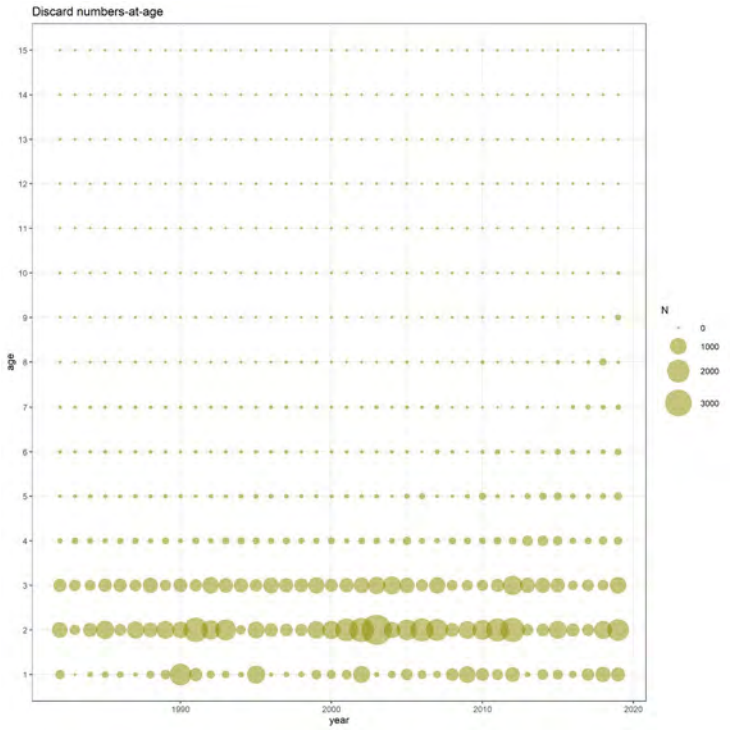


Figure 6.2.2.2.2. Discard numbers-at-age for the period 1982–2019.

The proportion of discarded sole for the whole time-series is plotted in Figure 6.2.2.2.3.

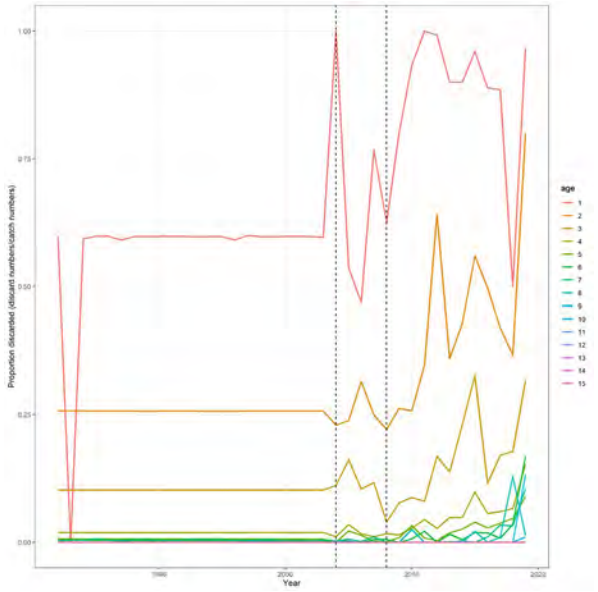


Figure 6.2.2.2.3. Proportion discarded-at-age calculated as discards numbers-at-age divided by catch numbers-at-age. Discards were reconstructed prior to 2004, using the period 2004–2008 as a reference. In 1983, no catch numbers-at-age were available for age 1 and therefore set to 0.

Discards weights-at-age were calculated in the same way. A ratio between discards and landings weight-at-age for the period 2004–2008 was calculated and multiplied by the landings weight-at-age for the period 1982–2003. This resulted in **discards weight-at-age** for the period 1982–2003 (Figure 6.2.2.2.4).

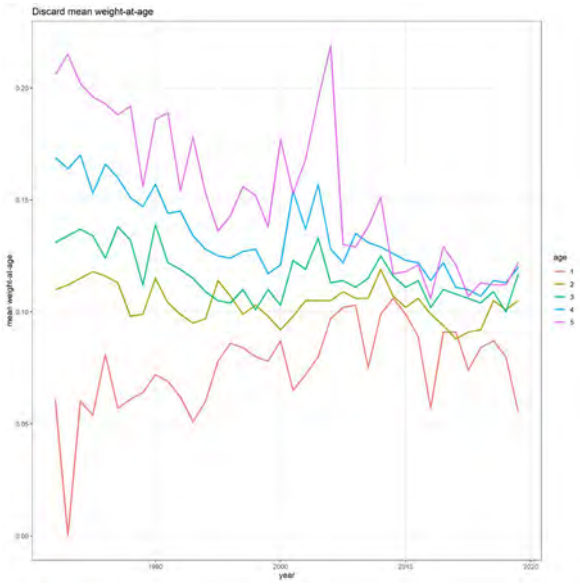


Figure 6.2.2.2.4. Mean weight-at-age for the discards (age 1–5), with reconstructed discards for the period 1982–2003 using the ratio between discard and landing weights over the period 2004–2008.

Two other scenarios were explored to reconstruct the discard weight-at-age. The first one assumes same weight-at-age for the period 1982-2003 as in the year 2004 (Figure 6.2.2.2.5a). For the second one, mean weight-at-age was calculated for the period 2004-2008 and the mean was used to fill 1982-2003 (Figure 6.2.2.2.5b).

a) b)

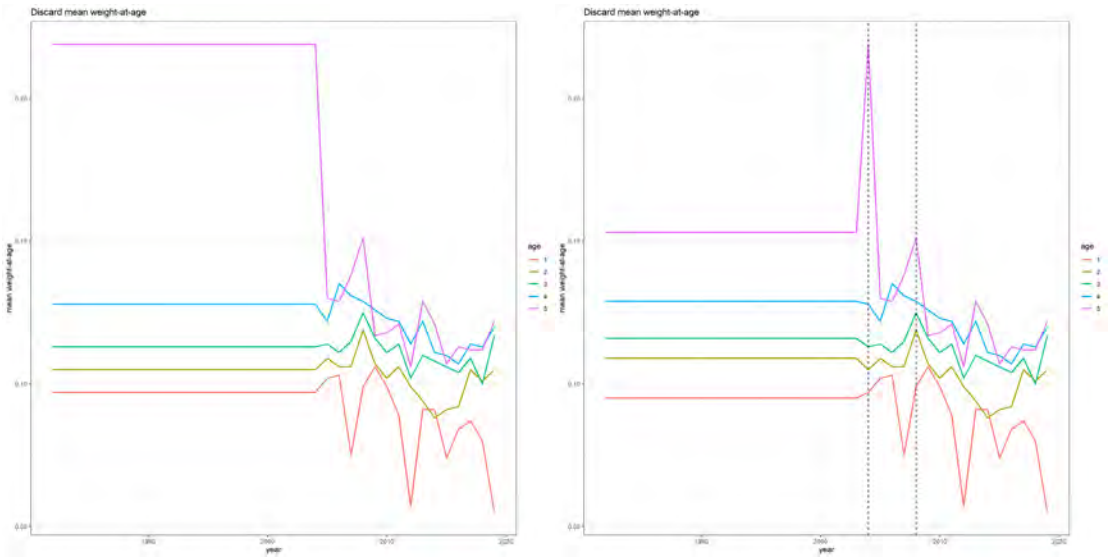


Figure 6.2.2.2.5: Mean weight-at-age for the discards (age 1-5), with reconstructed discards for the period 1982-2003 using a) the discard weights-at-age from 2004 and b) the mean of the discard weights over the period 2004-2008.

Assessment runs did not reveal differences in these calculation methods. The benchmark agreed to move forward with the initial calculation method using the ratio.

6.3 Stock weight

6.3.1 Data evaluation meeting

Currently, the stock weights-at-age in the assessment originate from three different sources. For the period 1982–1987, stock weights were obtained from a smoothed curve of landing weights interpolated to the 1st of January. From 1988–2003, quarter 2 landing weights are used to be in line with the sole in Division 27.4 assessment. From 2004–2019, quarter 2 catch weights are used. Preferably, stock weights should be measured at the beginning of the year, and data should be derived from surveys at least for younger ages. As there are no quarter 1 surveys available (only surveys in quarter 3), we aim to calculate quarter 1 catch weights for the period 2004–present and quarter 1 landings weights for the period 1982–2003.

6.3.2 Benchmark workshop

During the benchmark, two methods were explored to calculate the stock weights to the beginning of the year. The first method used the Rivard calculator, which allows the user to convert a matrix of mid-year weights-at-age to the beginning of the year (Figure 6.3.2.1). The programme uses the same algorithm as employed in the VPA programme and conducts a cohort interpolation of the catch weights (http://nft.nefsc.noaa.gov./).

For the second method, the mean proportion-at-age was calculated between the catch weight-at-age in quarter 1 and the overall catch weight-at-age for the period 2004–2019. This ratio was then multiplied by the catch weight-at-age for the period 1982–2003 to get the quarter 1 catch weight-at-age for 1982–2003 (Figure 6.3.2.1). Quarter 1 weight-at-age was extracted from InterCatch for the period 2004–2019. Note that Belgian catch information (numbers and mean weight-at-age) was added manually because Belgian data were uploaded per year (not quarter, with the exception of 2018).

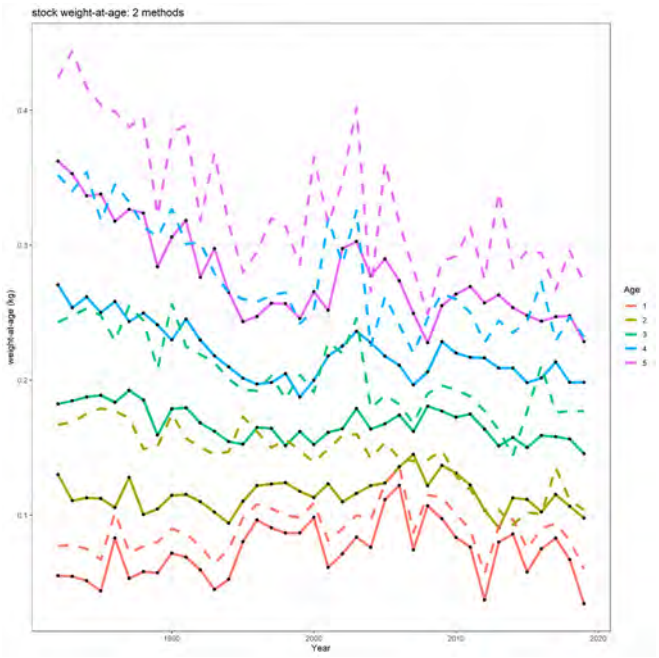


Figure 6.3.2.1. Stock weight-at-age (age 1–5) as calculated using the Rivard calculator (solid line) and using the ratio of quarter 1 catch weight-at-age and the overall catch weight-at-age for the period 2004–2019 multiplied by the overall catch weight-at-age for 1982–2003 (dashed line).

The Rivard calculated stock weights appear consistently lower. The Rivard calculation assumes mid-year weights-at-age as input data. However, we used overall catch weight-at-age. Moreover, we are unsure whether the information leading to these weights is not biased by the sampling design and fleet behavior of the different countries involved. Consequently, we decided to use the outcome of the second method in the assessment (dashed line in Figure 6.3.2.1).

6.4 Subpopulations

6.4.1 Data evaluation meeting

The French SMAC project provided evidence for the presence of three subpopulations in the stock (Figure 6.4.1.1). A tagging study showed minimal large-scale adult movements between the three subunits (Lecomte *et al.*, 2020). Growth and density-at-age analyses were analysed using data from the UK BTS survey and showed significant differences between subpopulations (Randon *et al.*, 2018). Finally, genetic and otolith shape analyses suggest a metapopulation structure at fine spatial scale, with one subunit (SW – Seine Bay) being more isolated (Randon *et al.*, 2020).

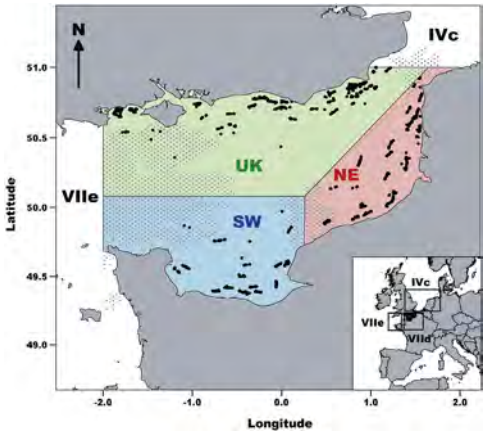


Figure 6.4.1.1. Map indicating the three subpopulations present in the 27.7d sole stock. Black dots represent sampling locations of the UK BTS survey.

The main goal of the benchmark is to have a working assessment on stock level (entire 27.7d division). However, we will explore how the presence of subpopulations can be considered.

6.4.2 Benchmark workshop

The subpopulation structure was not considered explicitly in the construction of the input data and assessment model, as there are insufficient data available on each of the three subpopulations (e.g. no catch data per ICES rectangle). However, when exploring assessment runs, different runs were done using a combination of the different commercial tuning fleets considering the area the subpopulations cover (§ 6.7 Final model settings (SAM)).

6.5 Indices of abundance

6.5.1 Data evaluation meeting

Presently, six tuning fleets are included in the sole 27.7.d assessment. There are three commercial indices (BEL commercial beam trawl (2004–present), FRA commercial otter trawl (2002–present) and UK commercial beam trawl fleets (1986–present)) and three scientific survey indices (UK beam trawl survey (1989–present), FRA YFS survey (1987–present), UK YFS (1987–2006)).

6.5.1.1 Commercial tuning fleets

The French commercial otter trawl series is revised according to the revision of the French catch data. During WKNSEA2017 (ICES, 2017), a raw French LPUE index was introduced in the sole.27.7d assessment to account for population dynamics along the French coast of the 7d. To account for dependencies in the landings and effort data, a new FRA commercial otter trawl index is developed (2005–present) based on a selected number of vessels practicing the OTB_DEF_70_99_0 métier. Only vessels accounting for the top 95% sole landings of OTB_DEF_70_99_0 were kept in the analysis and they had to be active in the fishery at least two thirds of the time-series (i.e. ten years as of 2019). To standardized the LPUE, a hurdle lognormal mixed model is used to correct for vessels, seasonality and spatial effects. Spatio-temporal interactions still need to be investigated in the model and a retrospective analysis will be performed. Once the method is approved, the new index will be provided as a biomass and age-structured index.

The Belgian commercial beam trawl index will have to be revised due to the correction in Belgian commercial data.

To avoid double counting of the commercial data (in catch matrix and in tuning fleets) we will change the commercial tuning indices to biomass indices. Furthermore, commercial indices will be investigated related to the presence of subpopulations. The French otter trawl fleet included in the COTB index currently fishes mainly in the south-western subpopulation, while the UK commercial beam trawl fleet is confined to the northern UK subpopulation. The Belgian commercial beam trawl index covers all three subpopulations. Weighing of commercial indices related to the surface area they cover, the effort that is done or catches that are realised are options to explore. This could however arise some problems, because the commercial tuning fleet from Belgium has the largest coverage but a shorter time-series (2004–present). In contrast, the UK index goes back to 1986 but it has a variable spatial coverage in time and, in recent years, it is geographically limited to the northern part of the eastern English Channel.

6.5.1.2 Survey tuning fleets

The UK BTS survey index covers the largest part of Division 27.7d. The French YFS is confined to the nursery ground in the Somme estuary and the UK YFS to the nursery at the south coasts of the UK. The French YFS survey gives information on age 0 and 1. We will investigate if the 0-group could be included in the assessment (currently not possible with the XSA model; 0-group only used in forecast).

To better account for the subpopulation structure within the larger stock area, we split the UK BTS index in three different indices. A model-based approach was presented that accounts explicitly for spatiotemporal variation in abundance, age–length relationship and length–frequency distribution. The model-based approach showed a high overlap between the age–length keys for age 3 and higher, which means that it is difficult to distinguish these age groups. In addition, a synchronous peak in 2013 for ages 3–5 was found, while this is not visible in the age 1 and 2 groups in the previous year. Questions were raised whether fish migrate from nearby areas such as Division 27.4c or whether there were changes in catchability. More analyses are required to understand where these individuals come from. The overall internal consistency of the model-based survey index was weaker than the non-standardized survey index currently used in the assessment. Calculation methods will be compared and internal consistency plots will be inspected. Reviewers also asked to verify any signal in bottom temperature that could have influenced catchability and to check survey abundances from the southern North Sea for same age groups / years and compare. The survey index of sole in the North Sea indicates similar abundance peaks of age 3–4 sole in the period 2013–2014. These peaks follow a peak in the abundance of age 1 species in 2010. Nevertheless, these peaks largely disappear in the revised, model-based index (ICES, 2020 WKFlatNSCS).

6.5.2 Benchmark workshop

6.5.2.1 Commercial tuning fleets

Belgian commercial beam trawl lpue index

The data and method to derive a tuning series for the Belgian commercial beam trawl fleet (BE-CBT) were revised (WD_Sole7d_3_BE_CBT).

In consistence with the correction of the Belgian catch data, the index was calculated using data from fishing trips in which fishing activity, as registered in the electronic logbooks, was restricted to the eastern English Channel (division 27.7d). To reduce the noise generated by the unbalanced sampling design of the logbook data, only observations from (*i*) fishing vessels that fished at least

five years in the eastern English Channel, and (*ii*) ICES statistical rectangles that where fished at least twice per year on average during the study period (2004–2019), were included in the analysis.

The statistical model used to standardize the landings and effort data was also modified. A logistic regression was applied to model the presence/absence of sole in the landings, whereas a lognormal model was used to standardize the positive catch rate. Both models included an intercept, a seasonal trend, and annual trend. The seasonal trend was introduced by means of a penalized smoothing spline and constrained to be cyclic. To reduce the number of parameters, the same seasonal model was used for both the presence/absence and positive catch rate model. The annual trend in both models was assumed to be a first order autoregressive process such that the year effects in both models were estimated as random effects. The model for the positive catch also included random effects (IID) on the ICES statistical rectangles and vessel reference number to account for respectively, spatial variation, and variation caused by skipper effects or technical characteristics of the vessel.

Finally, an index was derived by multiplying the probability of having a positive catch, and the expected positive catch rate for each year (Figure 6.5.2.1).

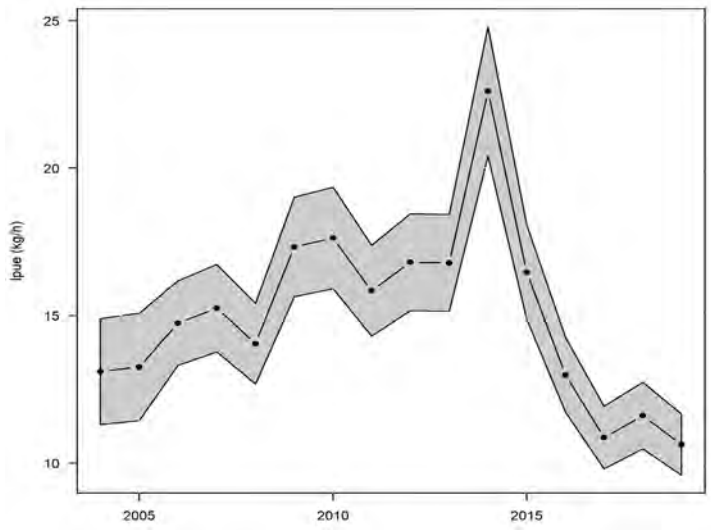


Figure 6.5.2.1. Belgian commercial beam trawl fleet index; grey shade represents the 95% confidence intervals.

French commercial otter trawl lpue index

Following on data compilation workshop recommendations, spatio-temporal interactions using various random effect models were explored in the hurdle lognormal model used to standardize the French commercial LPUE index. Most of the spatial effect is captured by the spatio-temporal interaction in both the occurrence model and the positive landings model thus the main spatial effect was dropped out in both components of the hurdle lognormal model. The best hurdle model formulation used a first order random walk to fit temporal trends in the main year effect and the spatio-temporal interaction, and the spatial correlation is constrained by a neighbourhood structure using a Besag model (Figure 6.5.2.2; WD_sole7d_4_FRCOTB tuning series). To reduce the retrospective pattern, the index is rescaled to its first-year value (i.e. 2005). During the benchmark, some concerns arose regarding the use of correlated random effects to capture temporal trends as it could smooth interannual variation; thus, a model formulation using IID (Independent and identically distributed) random effect to fit temporal trends was tested. However, the use of IID did not improve the model fit and increased the variability of the model retrospective. The group decided to keep the model formulation including a first order random walk.

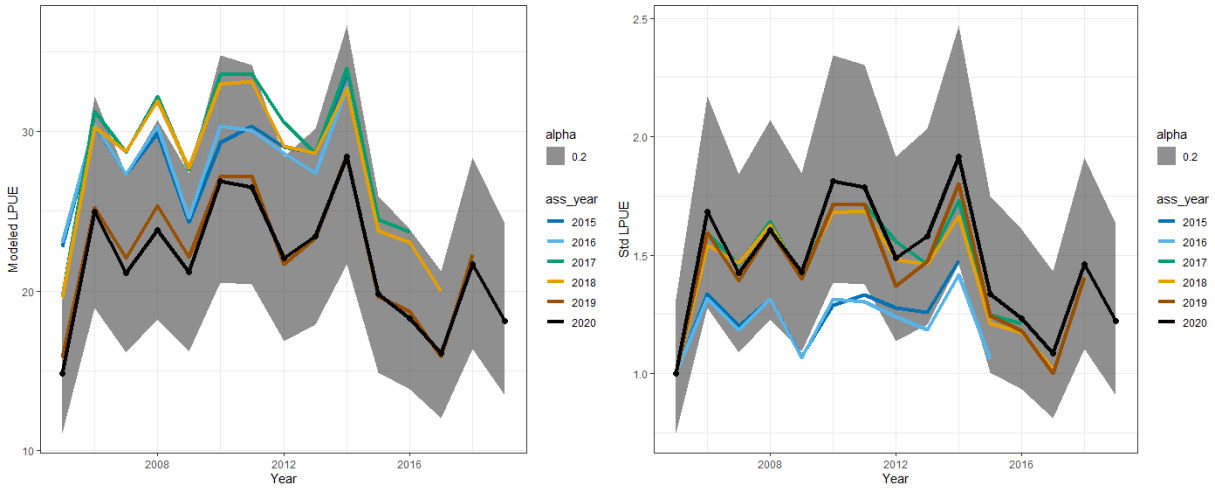


Figure 6.5.2.2. French commercial otter trawl fleet index (black) with indication of retrospective analysis outputs (coloured lines); shaded are is the estimated uncertainty from the 10 000 posterior resampling of the hurdle models fitted over 2005–2019; left graph shows output from each model prediction, right graph shows the rescaled index to the average value of 2005 for each model prediction.

Combined LPUE indices

To reduce the number of tuning fleets in the assessment model, it was investigated whether the commercial tuning series could be combined in a single index. Three methods were presented, each using truncated series starting in 2005, being the first year of the shortest index, the FR-COTB. First, the three indices where standardised by their mean so that they were without unit and at comparable scales. Next, the indices were combined in three different ways: (*i*) the arithmetic mean by year (Table 6.5.2.1), (*ii*) a weighted mean by landings by year (Table 6.5.2.2), and (*iii*) a weighted mean by area coverage by year (Table 6.5.2.3).

To weight by landings, the landings of the specific fleets involved in the index were used. The surface area of the ICES rectangles that were included in the index of the different fleets was determined to weigh by area.

Table 6.5.2.1. Arithmetic mean by year of the three standardised commercial tuning indices in the assessment of eastern English Channel sole.

Year	Arithmetic mean (FR-COTB, BE-CBT and UK-CBT)
2005	1.0194060
2006	1.1510680
2007	1.0888149
2008	1.0590035
2009	1.0091433
2010	1.1079898
2011	1.0500381
2012	0.9845073
2013	1.0193437
2014	1.2400335
2015	0.9934718
2016	0.9081905
2017	0.7537670
2018	0.8559133
2019	0.7593094

Table 6.5.2.2. Relative landing shares used to weigh the commercial tuning series in the assessment of eastern English Channel sole.

	FR-COTB	BE-CTB	UK-CTB
2005	0.328551	0.329109	0.34234
2006	0.356535	0.394177	0.249288
2007	0.371453	0.457923	0.170624
2008	0.405855	0.335192	0.258952
2009	0.347945	0.329858	0.322197
2010	0.490475	0.328693	0.180832
2011	0.475234	0.410844	0.113922
2012	0.513575	0.34651	0.139916
2013	0.450884	0.44813	0.100986
2014	0.281627	0.618395	0.099978
2015	0.366464	0.549385	0.084151
2016	0.284616	0.606906	0.108479
2017	0.315642	0.605343	0.079015
2018	0.430536	0.497868	0.071596
2019	0.419866	0.524607	0.055527

Table 6.5.2.3. Relative area shares used to weigh the commercial tuning series in the assessment of eastern English Channel sole.

	BE-CBT	FR-COBT	UK-CBT
2005	0.338105	0.396289	0.265607
2006	0.330679	0.387586	0.281735
2007	0.330679	0.387586	0.281735
2008	0.333334	0.390697	0.275968
2009	0.338966	0.397298	0.263735
2010	0.356893	0.418311	0.224796
2011	0.356893	0.418311	0.224796
2012	0.356893	0.418311	0.224796
2013	0.355938	0.417191	0.226871
2014	0.338966	0.397298	0.263735
2015	0.376607	0.441417	0.181976
2016	0.376607	0.441417	0.181976
2017	0.376607	0.441417	0.181976
2018	0.377278	0.442204	0.180518
2019	0.399378	0.468107	0.132515

The weighing methods resulted in similar indices. However, the area weighting was considered the most appropriate measurement of abundance. This method was therefore preferred to the other to test in the assessment models (Figure 6.5.2.2).

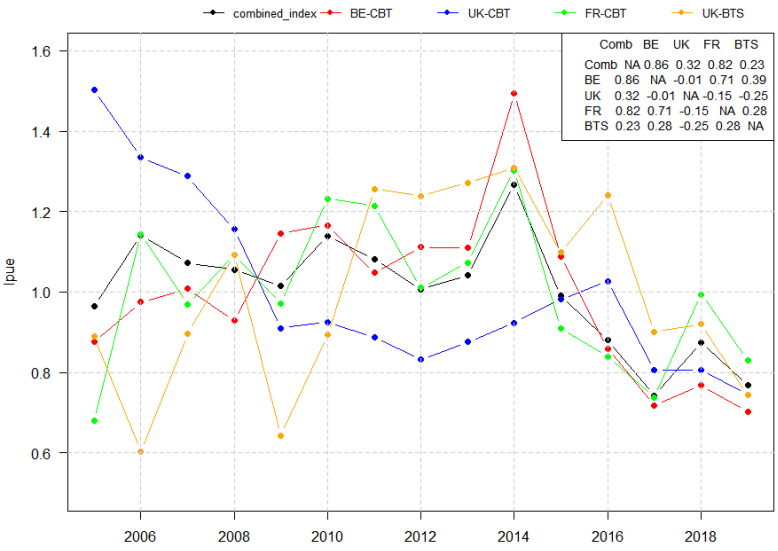


Figure 6.5.2.2. Combined commercial tuning index weighted by area (black line), individual commercial tuning series, and UK-BTS index for sole ≥24 cm). The matrix at the top right shows the correlation between the indices.

6.5.2.2 Survey tuning fleets

A model-based approach was presented to derive an index of abundance for the UK BTS (WD_Sole7d_5_UK_BTS). This comprised a three-step approach:

- A spatiotemporal regression model to predict the expected number of fish caught by swept area in space and time;
- The estimation of length–frequency distributions by year and subpopulation using kernel density estimation;
- A multinomial regression taking into account both annual trends and subpopulation effects to derive age–length keys from age 0 to age 7+.

Exchange data from DATRAS was used to fit all the models, and an age-structured index was derived by combining the three different models according to space/subpopulation/year.

Investigating the subpopulations revealed higher abundances in the southwestern subpopulation (FR-SW, Seine Bay), followed by the northern UK subpopulation, especially for ages 1–3. The overall lowest abundances were found in the French northeastern subpopulation. Trends between the subpopulations were similar over the time-series with minor differences in the most recent years.

Compared to the age-structured index provided by Cefas every year, the model-based index for the entire stock showed a higher internal consistency for the younger ages (up to age 3), but a lower internal consistency for the older ages. Overall the differences were minor between both indices. As the exchange data in DATRAS appeared to be incomplete (missing data in 1989 and 2012), it was decided not to use the model-based UK BTS tuning index in the assessment.

6.6 Models to prepare for benchmark

6.6.1 Data evaluation meeting

The following assessment runs will be prepared for the benchmark in February 2021:

- XSA with similar settings and tuning fleets as the last assessment (WGNSSK 2020, April 2020), but with new catch data and stock weights-at-age. Note that the Belgian commercial beam trawl tuning fleet will have to be revised, related to the revision of the Belgian commercial catch data.
- SAM with similar datasets as above and settings if possible.
- SAM same as above, but including the three commercial tuning fleets as biomass indices.
    - SAM same as above, but including the new French COTB index.
    - SAM same as above, but combining the three commercial tuning fleets -> investigate how they should be weighed against each other (effort? catch?); is it a problem that the indices have different time-series?
    - SAM same as above, but including only one (Belgian) biomass index.
- SAM same as above, but considering the impact of the three subpopulations.

During the benchmark, different settings of the SAM model will be explored, including truncating the catch data according to different plus groups.

6.7 Final model settings (SAM)

6.7.1 Benchmark workshop

For sole in division 27.7d, the XSA model (extended survival analysis) was used in the last assessment working group (WGNSSK 2020). One of the aims of this benchmark was to determine the performance of the current model against the new data and alternative stock assessment models.

Exploratory runs in XSA with updated input data were performed and compared with the WGNSSK 2020 assessment. Relevant exploratory runs are documented in the WD_Sole7d_6_Assessment runs. The applicability of the XSA framework to the sole in 27.7d stock was questioned because of the following assumptions/limitations:

- XSA assumes that catch data are known without error (no observation model for the catch data), which is highly unlikely because for instance only a subsample of the catch numbers-at-age is observed or misreporting of landings by fishers may occur.
- XSA requires that tuning fleets are age-structured, which results in a double use of the catch-at-age information in the model, thereby down weighing the information from other data sources.
- XSA cannot handle missing data in catch or tuning series and requires to make assumptions on missing observations.

To overcome these shortcomings, the applicability of a state–space stock assessment model (SAM) was explored during the benchmark. The main feature of SAM is that it includes both process models on survival, recruitment and fishing mortality (describing the internal states of the system), and observation models for catch and tuning data. Additionally, tuning data can be introduced in different ways, e.g. as SSB (spawning–stock biomass), FSB (fishable stock biomass) or TSB (total stock biomass). The random effects formulation of the process models resulting from the hierarchical nature of the state–space modelling framework can easily be used to handle missing observations. Finally, SAM allows to specify different model configurations, and parametrization of both process and observation models.

The final SAM assessment as agreed upon during the benchmark included:

- the revised catch data from France and Belgium;
- the reconstructed discards using the discard ratio for the period 2004–2008;

- the reconstructed stock weights using the Q1 to total catch weight-at-age for the period 2004–2019;
- three commercial tuning fleets as biomass indices: revised Belgian CBT LPUE index (2004–present), revised French COTB LPUE index (2005–present) and UK ENG CBT LPUE index (1986–present). All three fleets were included as separate indices (not combined), and treated as fishable biomass indices (FSB) and thus follow the selectivity of the fishery. The FSB setting was preferred as the decline in length-at-age observed over the time-series is likely to have changed the selectivity of the commercial tuning fleets. Moreover, the commercial tuning fleets make up significant part of the total landings, and are therefore assumed to mimic the selectivity of the entire fishery. Three age-structured survey tuning fleets: UK (E&W) beam trawl survey (1989–present), UK YFS (1987–2006) and French YFS (1987–present). The last two including only age 1 information.
- Maturity ogive as estimated during WKNSEA 2017.
- Natural mortality fixed at 0.1.

The plus group remained at age 11+. None of the age-structured tuning fleets included a plus group.

The model configuration of the final SAM model is summarised in the table below:

Settings	
Model	SAM
First data year	1982
Last data year	2019
Ages	1–11+
Plus group	Yes
Stock weights-at-age	Q1 catch weight-at-age; reconstructed for 1982–2003
Discards Numbers- and weight-at-age	Reconstructed for 1982–2003
Abundance indices	Commercial: BEL CBT LPUE (2004–present); FRA COTB LPUE (2005–present); UK CBT LPUE (1986–present)
	Survey: UK (E&W) BTS (1989–present); UK YFS (1987–2006); FRA YFS (1987–present)
Natural mortality	0.1
Maturity ogive	Age1 = 0.00; Age2 = 0.53; Age3 = 0.92; Age4 = 0.96; Age5 = 0.97; Age6-11+ = 1.00
Number of parameters describing F-at-age in catch (keyLogFsta) (columns represent ages)	0 1 2 3 4 5 5 6 6 7 7 (catch)
Correlation of F across ages (corFlag)	0 (independent)
Number of parameters describing F-at-age in surveys (keyLogFpar) (columns represent ages)	0 (BEL CBT LPUE; FSB) 1 (UK CBT LPUE; FSB) 2 (FRA COTB LPUE; FSB) 3 4 5 6 7 7 (UK BTS; age 1 -6) 8 (UK YFS; age 1) 9 (FRA YFS; age 1)
Density dependent catchability power parameters (keyQpow)	None
Coupling of process variance parameters for F (keyVarF)	0 0 0 0 0 0 0 0 0 0 0

Settings	
Coupling of process variance parameters for log(N) (keyVarLogN)	0 1 1 1 1 1 1 1 1 1
Coupling of variance parameters on the observations (keyVarObs) (columns represent ages)	0 1 2 2 2 2 2 2 2 2 2 (catch; age 1 – 11+) 3 (BEL CBT LPUE; FSB) 4 (UK CBT LPUE; FSB) 5 (FRA COTB LPUE; FSB) 6 7 8 8 8 8 (UK BTS; age 1 - 6) 9 (UK YFS; age 1) 10 (FRA YFS; age 1)
Covariance structure per fleet (obsCorStruct) (columns represent fleets: catch, BEL CBT LPUE, UK CBT LPUE, FRA COTB LPUE, UK BTS, UK YFS, FRA YFS) ID = independent AR = autocorrelated	AR ID ID ID AR ID ID
Coupling of correlation parameters (keyCorObs) (columns represent ages)	0 1 1 1 1 1 1 1 1 1 (catch; age 1/2–10/11+) 2 3 3 3 3 (UK BTS; age 1/2–age 5/6)
Stock recruitment code (stockRecruitmentModelCode)	0 (random walk)
Number of years where catch scaling is applied (noScaledYears)	None
Vector of years where catch scaling is applied (keyScaledYears)	None
Matrix specifying coupling of scale parameters (keyParScaledYA)	None
Fbar ranges	3–7
Type of biomass index (keyBiomassTreat)	2 (fishable stock biomass, FSB)
Option for observational likelihood (obsLikelihoodFlag)	LN LN LN LN LN LN LN
Treatment for weight attribute (fixVarToWeight)	/
Fraction of t(3) distribution used in log(F) increment distribution	/
Fraction of t(3) distribution used in log(N) increment distribution	/
Vector describing fraction for fleets (fracMixObs)	/
Vector describing break year between recruitment (constRecBreaks)	/
Coupling of parameters used in prediction-variance link for observations (predVarObsLink)	None

The SAM assessment estimated the catches quite well (Figure 6.7.1.1). Except in 1995–1997 and 2003–2009 catches were estimated lower than what was actually registered (outside the confidence bounds), while in 2016–2019, catches were estimated higher than what was registered. The SSB followed the same pattern as the catches and is estimated to be at one of the lowest levels of the time-series. The fishing mortality showed a decline from 2010 onwards and is currently estimated at the lowest point of the time-series. Recruitment on the other hand is found to be at the highest point of the time-series. However, there is considerable uncertainty around the estimate of the final year.

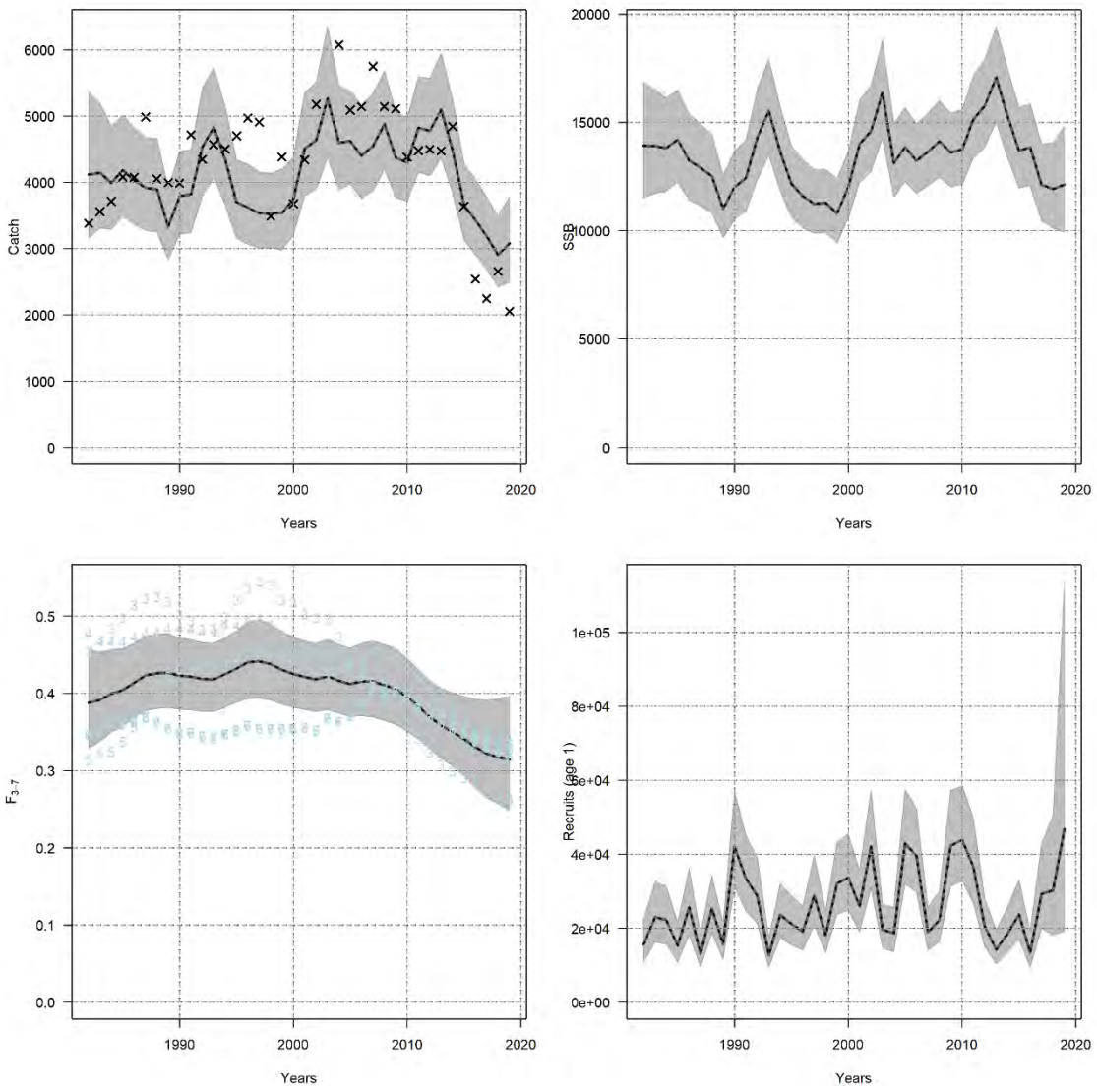


Figure 6.7.1.1. Summary plot of the final SAM assessment showing catch, spawning stock biomass, fishing mortality and recruitment. The shaded areas represent the 95% confidence bounds.

Model validation was performed by inspecting one-step ahead (OSA) (Figure 6.7.1.2) and process residuals (Figure 6.7.1.3), retrospective analysis (with peels up to five years) (Figure 6.7.1.4), and leave-one-out fits (Figure 6.7.1.5). Model stability and convergence were assessed through a simulation study (parametric bootstrap) and jitter analysis (WD_Sole7d_6_Assessment runs).

The OSA and process residuals do not indicate strong patterns, with the exception of the OSA residuals of the UK-BTS survey in the last six years especially for the younger ages, and the UK-CBT. The poorer fit to the UK-BTS and UK-CBT tuning fleets is also reflected in the leave-one-out runs. Removing the UK-BTS from the assessment results in a lower SSB in the final years, whereas removing the UK-CBT from the assessments results in periods with higher and lower SSB throughout the time-series. The UK-CBT is confined to the southern English coasts, and the UK BTS samples most stations along the coasts of Division 27.7d. This specific spatial coverage may cause that these fleets pick up different trends, resulting in a poorer fit of these tuning fleets.

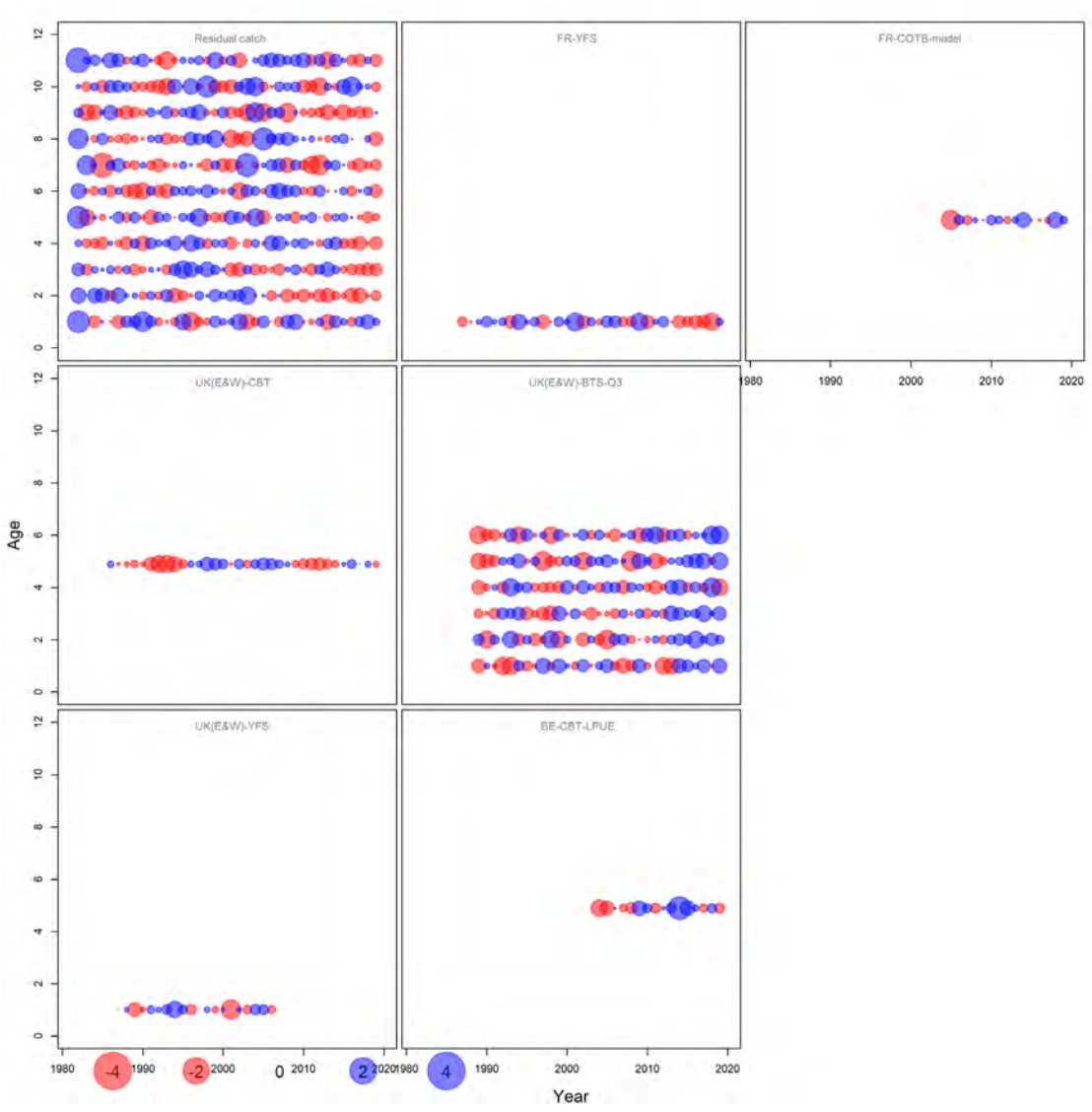


Figure 6.7.1.2. One-step-ahead residuals. Each panel represents a specific observation category (catch and tuning fleets). Blue circles indicate a positive residual, red circles a negative residual.



Figure 6.7.1.3. Process residuals of the N (upper panel) and F (lower panel) model.

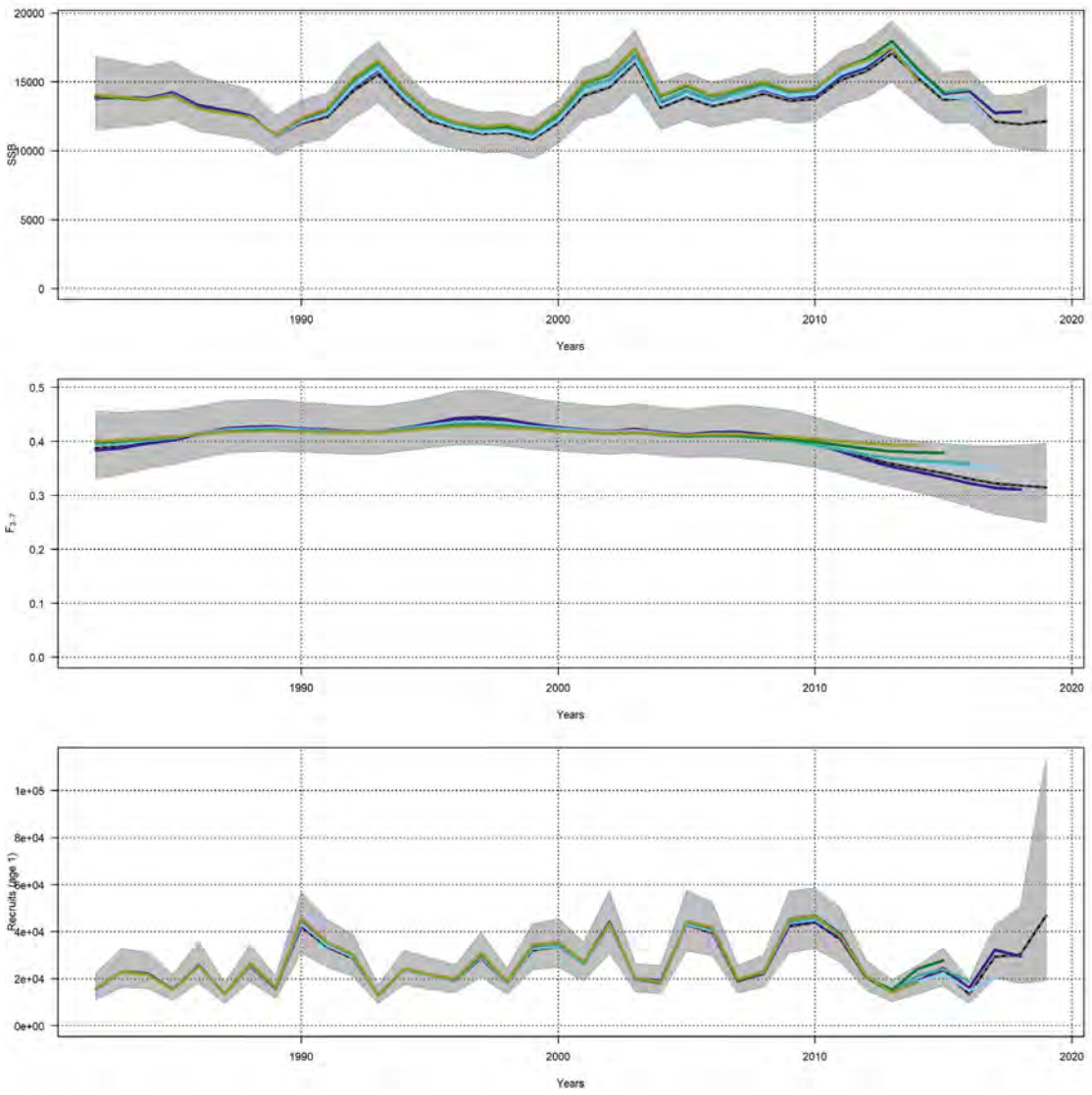


Figure 6.7.1.4. Retrospective analysis (up to five years) of SSB (upper, Mohn's rho = 0.026), Fbar (middle, Mohn's rho = 0.077), and recruitment (lower, Mohn's rho = 0.046).

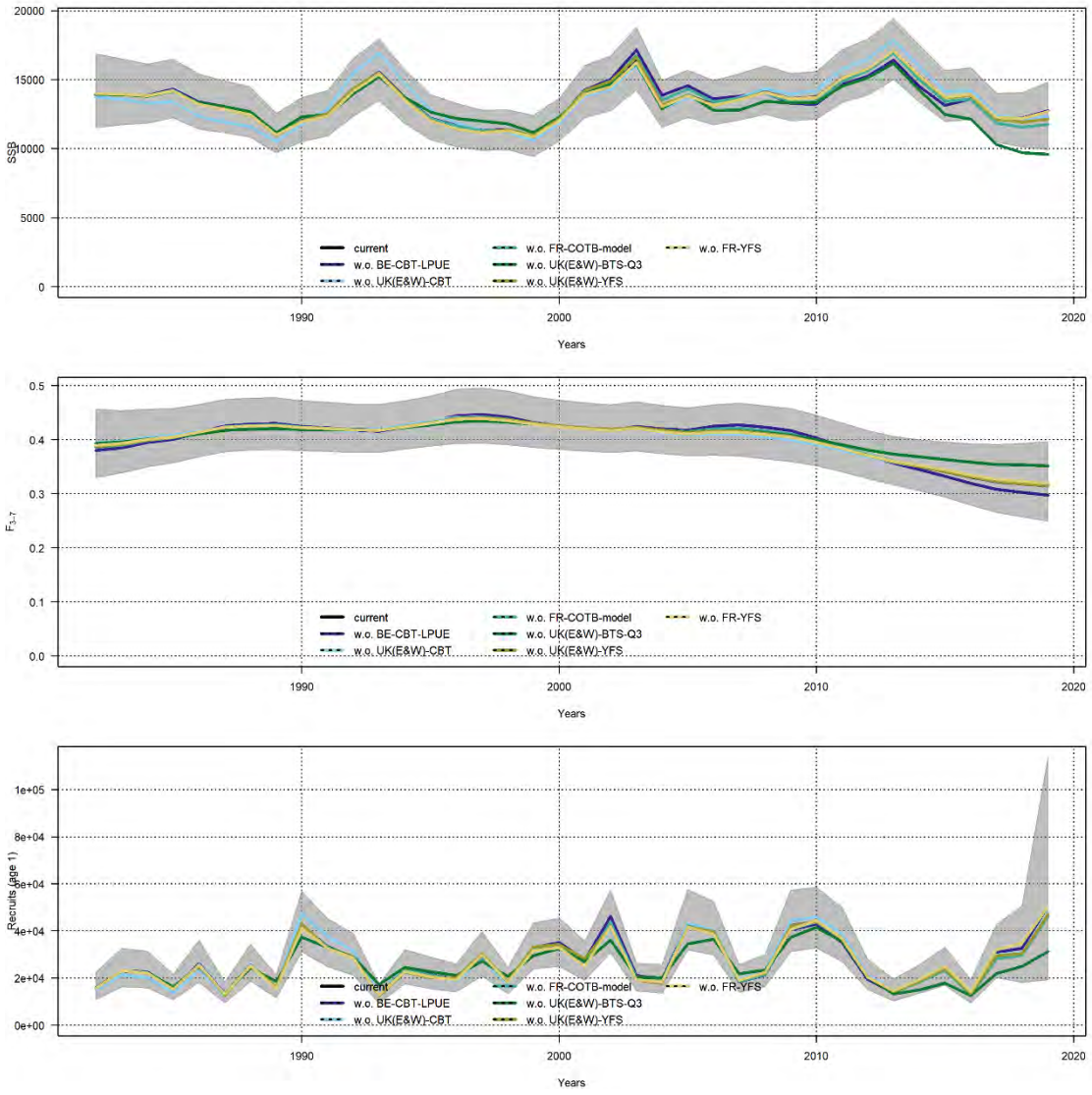


Figure 6.7.1.5. SSB (upper), F_{bar} (middle) and Recruitment (lower) of model refits excluding tuning series (leave-one-out analysis). In each refit, a tuning series is excluded from the data. The grey shade indicates the 95% confidence intervals of the assessment model including all tuning fleets.

6.8 Short-term forecast

6.8.1 Benchmark workshop

The short-term forecast was performed using the *stockassessment* package. Stock weights-at-age for the next three years was assumed to be the mean stock weight-at-age of the last five years. Selectivity of the fishery for the next three years was assumed to be the mean selectivity of the last five years.

Recruitment in the future years is resampled from the entire past recruitment estimates except for the last year (1982–2018). A stochastic forecast was conducted implying that the projections of the numbers and fishing mortality-at-age are characterized by process noise. The number of simulations was set at 5001.

During the assessment working group, the fishing mortality in the intermediate year is chosen. There are two possible scenarios: 1) status quo fishing mortality (Fsq) or 2) TAC constraint. For

the status quo fishing mortality, there are again two options: 1a) if the F_{bar} shows no trend over the last three years, the mean F_{bar} of the last three years is taken as intermediate year assumption, 1b) if the F_{bar} shows a decreasing or increasing trend over the last three years, we scale to the last data year, which means that the F_{bar} in the intermediate years is the same as the last data year. For the TAC constraint option, the F_{bar} is calculated in the intermediate year as if the TAC would be fully fished in that year.

Following the ICES advice rules, the target F in the advice year (2021) is set at F_{MSY} in case the SSB in the advice year (2021) is above $B_{trigger}$, else, the target F is set as F_{MSY} x ($SSB_{advice_year}/B_{trigger}$). In case the SSB is insufficient to bring the stock above B_{lim} in the advice year + 1 (2022), a zero TAC can be advised.

6.9 Reference points

6.9.1 Benchmark workshop

Reference points were re-estimated using the outcome of the final assessment. The Eqsim methodology was used as described in the ICES technical guidelines (ICES, 2017b). Model settings and data selection are specified in the WD_Sole7d_7_Reference_points.

The stock–recruitment relationship was evaluated as type 5, showing a stock with no evidence that recruitment has been impaired or with no clear relation between stock and recruitment. There is a narrow range in SSB, implying type 6 could be an option. However, given that the depletion level (SSB/B_0) of the stock was estimated to range between 13 and 18%, we are unable to determine whether the stock is depleted or stable.

B_{lim} was defined as the B_{loss} value, being 10 811 tonnes. B_{pa} was then derived using the standard multiplier of 1.4 (sigma was lower than 0.2), resulting in 15 135 tonnes. F_{lim} was derived simulating a stock with a segmented regression S–R relationship, with the inflection point fixed at B_{lim}, which resulted in a value of 0.422. F_{MSY} was estimated using the fit by the segmented regression model and setting $B_{trigger}$ to zero, which gave a value of 0.193.

MSY $B_{trigger}$ was set to B_{pa} (15 135 tonnes) as the stock was not fished at F_{MSY} for five or more years and the ICES MSY advice rule was evaluated. This resulted in a slightly lower F_{MSY} (0.192). However, as it was lower than the $F_{p0.5}$ value (0.379), F_{MSY} remains at the value initially calculated. New ICES rules state that F_{pa} should be set to $F_{p0.5}$ being 0.379.

Reference point	Value
B_{lim}	10811
$B_{pa\ (1.4)}$	15135
$B_{trigger}$	15135
F_{lim}	0.422
$F_{pa\ (1.4)}$	0.302
F_{MSY}	**0.193**
F_{MSY} lower	0.113
F_{MSY} upper	0.331
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$)	0.379
F_{pa} based on $F_{p.05}$	0.379

7 External reviewers

The external experts would need to report on: a) The issues raised by the reviewers throughout the process (i.e. during the preparatory work before the workshop and during the workshop). b) Statement confirming that the outcomes of the benchmark (i.e. the stocks annex) are appropriate to provide scientific advice; c) Recommendations for future work. This item is facultative and can be incorporated as a separate Annex as a generic recommendation for future work from all workshop participants.

7.1 Cod (27.47d20)

In 2020, in preparation for WKNSEA, a workshop on Stock Identification of North Sea Cod (WKNSCodID) was conducted. WKNSCodID evaluated a large body of literature and information on population structure for Atlantic cod in the North Sea and adjacent waters including results from genetic analyses, scientific surveys, fishery data, tagging, life-history parameters, distribution of early life stage, otolith microchemistry and shape, and parasites. WKNSCodID concluded that the current stock unit is not a closed homogeneous population. The genetic variation, supported by several other methods, indicates reproductively isolated populations of 'Viking cod' and 'Dogger cod' with limited mixing after spawning. Despite the lack of clear genetic differentiation, phenotypic variation and otolith chemistry suggest a latitudinal differentiation within the 'Dogger cod' population with separation of a northwest and a southern component which extend into the area 6aN and into the western English Channel, respectively. WKNSCodID recommended that the most plausible scenario of population structure with the separated 'Viking' and 'Dogger' components should be accurately represented in the stock assessment and advice. Further differentiation within the 'Dogger' population should be at least considered. Convenient boundaries to deal with such complex population structures were also proposed. Following the recommendations of WKNSCodID, a data call was issued in preparation of this benchmark to retrieve catch data disaggregated by ICES division (4.b, 4.c, 7.d) and subdivision (4.a.E, 4.a.W, 3.a.20) as far back in time as possible to consider the implementation of spatial approaches to stock assessment.

During the data evaluation meeting, it was found that:

- Disaggregated data were available only from 2002 onward;
- Age sampling was insufficient prior 2008 for catches in 4aW and for discards in 4aE;
- Unexplained discrepancies remained between the total catches currently used in the assessment and those compiled from the disaggregated data call.

The severity of the issues with the catch data were amplified by the lack of integrated spatial models available to the expert group at the time of the data evaluation meeting.

Thus, at the data evaluation meeting it became evident that some of the preconditions for the full success of the benchmark were lacking as a result of the structural issues related to stock identity and migration. Some ToRs as stated originally could not be resolved by the available framework. ACOM was inquired on the matter and following its indications, it was decided to lower the ambitions of the benchmark and use it as an opportunity to improvement the assessment. As a result, the benchmark focused on the improvement of some of the input data, and on the assessment model configuration with the objective to reduce the retrospective patterns affecting this stock assessment. It is important to mention that results from the benchmark model are valid within the assumption of a single cod stock for the entire North Sea which does not reflect the best available knowledge and conclusions from WKNSCodID. Work towards an assessment

which recognises explicitly the multiple stocks of cod in the North Sea, within stock variability and connectivity with adjacent areas is of utmost importance and recommended from this review. A focus group which could bring together expertise and coordinate work from both the North Sea and area 6a is seen as essential part of this process.

7.1.1 Biological analysis

- Extensive work has been presented to improve representativeness and quality of the **survey indices** of abundance of cod by age. The preparation and analytical treatment of the survey data aimed to:
  - Improve the spatial coverage of the distribution of the stock throughout the North Sea and adjacent areas by combining multiple surveys from the North Sea (NS-IBTS-Q1 and Q3), division 6a (ScoWCGFS-Q1 and ScoWCGFS-Q4) and the Kattegat (BITS-Q1 and Q4) to construct two separate time-series for quarter 1 and quarter 3–4.
  - Allow flexible estimation of biomass indices for different spatial domains to reflect differences in the development in different regions and for different populations.

A standardisation of the survey indices was achieved using a sophisticated delta-GAM model which calculates numbers-at-age from observed number-at-length and spatially variable age–length keys. Different formulations of the model were tested with overall consistent outcomes among the formulations which support confidence on the outcomes. Selection of the best standardisation model was strengthened by the use of multiple diagnostics: AIC and internal consistency of standardised models, AIC and model retrospective of the of the assessment model. The final model includes a vessel random effect to account for differences in survey catchability across different regions and a time-variable spatial effect to represent temporal changes in the distribution. The spatial effect is formulated in the final model with no temporal autocorrelation (i.e. deviations around the mean distribution are independent among years) which enhance the ability to capture interannual variability among sub-regions. The model estimates are considered reliable and appropriate to track changes in abundance in the different sub-regions. Both Q1 and Q3+4 surveys show an increase in the proportion of old fish in Division 6aN which is interpreted as movement of older cod towards the west of Scotland.

- A **recruitment index** derived from the abundance of age 0 in the IBTSQ3 was introduced at the benchmark. Because the model starts at age1, the age 0 index from the IBTS Q3 is assumed to inform the age 1 abundance at the beginning of the year. While the general impact on the assessment estimates is negligible, few positive effects are recognised:
  - Improved recruitment retrospective (Mohn's rho decreases from 29% to 17%);
  - Intermediate year recruitment supported by one extra observation;
  - In case of re-opening of the advice, the recruitment assumed for the advice year via resampling could be supported by the Q3 survey.
- **Maturity-at-age** is calculated from IBTS Q1 which is ideal in terms of spatial and seasonal coverage (spawning is between January and April). Maturity data from the Skagerrak have been evaluated at the benchmark and included (except data from 1991–1995 which had problems) in the new calculations of the maturity ogives. The Skagerrak is primarily a nursery area for the 'Viking population' and the impact on the maturity ogives is minor but its inclusion is still seen as an improvement of the quality of the input data. During the benchmark an area-based raising factor has been replaced by raising maturity based on numbers-at-age which seems more appropriate given the sampling design of the survey and the heterogeneous distribution of the stock (i.e. an area-based raising would risk to inflate the influence of maturity data from areas with few old fish). To reflect spatial differences in maturation between and within populations, it was found appropriate to calculate maturity ogives at a subarea level when sample size allows and at a population

level ('Viking' and 'Dogger') when sample size is <5 fish per age and sub-area. While this may help inference at a population level, it is recognised that important spatial differences in the maturity-at-age especially between the North and South component of the Dogger population would be neglected in those cases. Maturity ogives are highly variable from year to year and some form of smoothing is considered good practice to capture long-term patterns and stabilise the estimation of SSB. Consequently, estimates of maturity-at-age were smoothed internally in the assessment model.

- **Weight-at-age** in the catch and in the stock are assumed to be equal in the assessment of North Sea cod and derived from catch weight from the whole year. This may hide two issues:
  - Fishery-dependent weights may not be representative of the weight in the stock;
  - Weights in the stock are used to calculate SSB at the beginning of the year, hence they should be calculated from observations during the first quarter.

  Comparison of mean individual weights from the survey and the catch show discrepancies between the survey and the catch, with weights of age 1–3 lower in the survey, age 4–5 similar and age 6+ lower in the catches. Such inconsistencies appear even more pronounced when weights from the catches are limited to Q1 (only available from 2002) but in this case, age 3–4 are more similar between the two sources. In conclusion, it was decided to use survey weights for age 1–2 but not for the older ages which are considered poorly sampled by the survey. Catch weights from Q1 were preferred for age 3+ which is considered an improvement compared to the previously used weights-at-age.

- An updated **natural mortality** at age from a new key run of the SMS multispecies model for the North Sea were available from WGSAM. Natural mortalities are smoothed before inclusion in the model which is considered good practice to avoid tracking uninformative interannual variability. The analysis of the newly derived extended survey indices suggested a migration of old cod from the North Sea to the 6a area in recent years. To deal with the such presumed spill-over of fish from the assessment area natural mortality was inflated for age3+ from 2011–present (see Section 3.10 for methods of M-adjustment). Alternative approaches to temporarily deal with migration of fish were discussed at the benchmark but preference was given to the M-adjustment. These alternatives included: i) a catch multiplier, ii) adjustment of survey catchability. The use of an M-adjustment was presented as an interim solution in the absence of a spatial assessment which could explicitly account for the level of connectivity between the North Sea and 6a.

7.1.2 Data input

- **Recreational data** collected by different countries are highly diverse in terms of sampling methods (i.e. on site, diary, on-line recall) and variables collected (i.e. numbers, biomass, lengths). Studies on post-released mortality show high variability of results, also in relation to area and gears which would likely have large impact on the estimation of recreational catches. Estimates presented are in the range of 3–9% of the total catches for the period 2010–2019. The use of recreational data for the stock assessment of North Sea cod would require considerable work on standardisation (i.e. model-based standardisation) that in our understanding has not been performed in preparation of this benchmark, but should be given high relevance in future work. The expert group discussed the importance to still include considerations on recreational fisheries in the advice for the stock which seems relevant.
- The newly derived indices for IBTSQ1 and Q3 were tested as input to the stock assessment model and yielded a clear improvement in model diagnostics.

7.1.3 Model

- The assessment model covers ages 1–6 with age 6 as a **plus group** which is considered quite small for a gadoid. Moreover, recent increase in biomass in the plus group suggested the possible need to include more ages. An age 7+ was tested at the benchmark but no satisfactory model configuration was found. Decoupling F for age 7+ resulted in a pronounced dome-shaped F-pattern with increased risk of ghost biomass, while a coupled F on age 6–7+ resulted in poorer model fitting, increased retrospective and unrealistic low uncertainty estimates. Based on the tests presented, retaining the plus group at age 6 is considered appropriate.
- The assessment model previously used a yearly estimated **catch multiplier** for the period 1993 to 2005. Estimates of the multiplier suggest an erratic correction of the catches rather than a consistent bias. While in principle this is plausible because the catch correction should be interpreted in relation to the level of catch misreporting prior 1993, concerns were raised on the reliability and understanding of those estimates. Moreover, the use of the multiplier resulted in an increased retrospective pattern. Consequently, the catch multiplier was not included in the final formulation.
- The analysis of the newly derived extended indices suggested a **migration** of the population toward the 6a area. In order to account for this potential migration and the violation of the hypothesis of a closed area for the population, an interim solution was found in the form of inflating the natural mortality in the period 2011–present to account for (e)migration of fish. The level of inflation was based on the SAM model fit (likelihood profile) and led to a level of migration of 15% of older ages. While statistical fitting has no biological support and is not sufficient justification for the level of M-adjustment selected, the result is supported by analysis of the survey indices which suggest comparable levels of emigration from the North Sea. In addition, the M-adjustment resulted in a considerable reduction of the Mohn's rho SSB from 17% to 8%. While the approach seems able to reconcile the conflict between the catch rates of older fish in the surveys and those in the commercial catches which contributed to the retrospective pattern of the model, this comes at the expenses of additional assumptions (difficult to verify) and drawbacks which need few considerations:
  - fish migrating outside the North Sea are assumed to not return;
  - migration of cod from the North Sea stocks to 6a is not separated from possible migration of cod from the 6a stock to the North Sea and the M-adjustment attempt to capture only the net effect;
  - fish removed from the North Sea assessment because of presumed migration are not added to the assessment in Division 6a.
- Smoothing of the **maturity ogives** was handled internally in the assessment model by treating maturity as a state–space process. There are multiple advantages with this approach including: (i) the direct use of raw unsmoothed maturity data, (ii) no need to assume constant maturity for the first period of the assessment (1963–1977), (iii) estimation of uncertainty associated to maturity as part of the model uncertainties, (iv) forecast of maturity internally in SAM. For (iv), some caution is recommended given that the statistical process will tend always toward the long-term mean. In the case of trends or too rapid convergence towards the long-term mean, the procedure might not always be suited.
- **Model configuration** has focused around the four main groups of parameters of the SAM model: 1) coupling of fishing mortalities and catchabilities among ages, 2) coupling of variances for the fishing mortality process, 3) coupling of observation variances for both catches and surveys, 4) test of alternative covariance structures. The strategy for testing different model settings across these four sets of parameters was coherent and

appropriate to identify an optimal configuration. Model selection was based on a combination of metrics including model fitting (AIC), retrospective patterns, qualitative inspection of model residuals, plausibility in relation to the species ecology and fishery.

7.1.4 Biological reference point

- Cod is a stock that underwent large changes in SSB and is currently at a low point in the time-series. Of importance is the recruitment that has been low in the last ~25 years, suggestive of a regime shift (potentially as a result of climate change). When deriving precautionary reference points, it is paramount to consider potential productivity regime shifts in order to best account for current underlying processes. Whilst it is recommended to account for this type of regime shift mechanistically with the implementation of dedicated models, it is often the case that truncation of time-series is adopted as a solution. In the current implementation of SAM used for North Sea cod, there was no possibility to account for environmental effects and substock structure on recruitment. The practical solution was then to use a truncation of the time-series with the choice of the truncation year based on scientific studies and model results. At the previous 2015 benchmark, the 1988–onward period was used but this was revisited at the current benchmark, using the 1998–onward period. For cod, the year 1998 has been recognized as the most significant breakup point in the time-series for productivity regime shift which is also supported by few studies. In particular the expert group discussed that both intensity and variability in recruitment are markedly different for the periods before and after 1998 despite comparable SSB levels between the 1990s and 2010s. The 1998–onward period was already recognised at the 2015 benchmark but not used for the derivation of B_{lim}. The addition of five extra years for a total of over 20 years of low recruitments seems a reasonable time frame to interpret the post 1998 period as a low recruitment regime. However, it is important to note that the use of the 1998–present period for the derivation of the limit reference point has large consequences:
  - The range of SSB observed over the 1998–onward period is relatively narrow with a lack of knowledge at low SSB.
  - The stock–recruitment relationship is poorly defined over the 1998–onward period. As a result, it is not possible to fit or interpret a S–R relationship.
  - As a consequence of the two previous points, the stock was defined as type 6 following ICES guidelines. Because the stock has been under intense exploitation during this period (F has been between 0.6 and 1 throughout the 2000s) it seems reasonable to interpret the stock as depleted. In accordance with type 6, B_{pa} was chosen as the highest SSB in the 1998–present time-series. This is a precautionary and sound option in the context of the 1998-onward time-series truncation. The B_{lim} reference point was calculated based on B_{pa}.
  - The resulting B_{lim} reference point was significantly revised downward (from 107 000 to 69 841).
- The MSY reference points were calculated using the eqSim tool which is a standard in ICES. In contrast to the derivation for limit and precautionary reference points, there was more certainties in the derivation of the MSY reference points because the cod stock has been exploited at different fishing pressure. Though, an important aspect of MSY reference points calculations undertaken for this benchmark is the use revised M values to remove the M-adjustment. This was justified by the need for long-term outlook of MSY reference points whilst the M adjustment should also be viewed as an interim solution for a specific time period (2011–now). The M-adjustment was included to account for fish migration but nothing warrants that the currently observed migration will continue in the 6a area in coming years. Leaving out the M adjustment led to a lower F_{MSY} estimate

(~0.29 without M-adjustment and ~0.40 with M-adjustment). The decision of not using the M-adjustment in the final eqSim run is probably the most appropriate, especially because this M-adjustment should only be viewed as an interim solution.

- Together with the significant adjustment of the reference points, it is important to highlight the uncertainty in stock definition. In that context, indicators on the state of each individual stock should kept being monitored, e.g. using the SUBAR assessment or indices.

7.1.5 Short-term forecast

There was no change in the short-term forecast methodology except for the projection of the maturity ogives which now follows coherently the state–space process of maturity implemented within the historical part of the model.

7.2 Spurdog (dgs27.nea)

The benchmark process for spurdog was motivated by the need to add new data sources to the model and improve the advice overall.

7.2.1 Biological analysis

- New fecundity data (pup per female at length) were available at the benchmark. Previously available data spanned two time periods (1960 and 2005) and the newly available data expended it significantly (12 period from 1912 to 2019). The data suggest a somewhat lower fecundity in recent years. This dataset greatly improved the model with a density-dependence of pup production resolved at a much finer time scale.
- Growth. A thorough literature review was conducted to explore sex-specific growth for spurdog. As a result of this review, a range of von Bertalanffy growth parameters (VBGP) were compiled. Similarly, to the previous approach, the final age–length key was constructed as an average of VBGP across relevant studies for both male and females. At the hereby benchmark, this average was updated with the most recent studies. The update did not change the age–length key significantly. However, the current approach of using an average does not encompasses uncertainties around the range of growth parameters described in the literature.

7.2.2 Data input

The data call put in place prior to the benchmark provided catch data, survey data and life-history data (fecundity, age/length, maturity). This new wealth of data is the main improvement for the spurdog assessment, allowing the model to better capture stock dynamics and processes.

- New catch data. Prior to the benchmark, there were no catch data available after 2009 and recent catches were taken as a 3-year average. The new data are now up to 2019 with estimation of discards from 2007. Prior to 2007, discards are assumed to be small. Another improvement is the disaggregation by gear allowing better input to the assessment which now captures the exploitation of the stock more accurately.
- New survey indices. For spurdog, survey indices are disaggregated per sex and length group category. Previously, a single biomass index was derived from Scottish trawl survey data covering the West of Scotland and the northern North Sea from quarter 1 to quarter 4. This index combined surveys from quarter 1 to quarter 4 in the period 1990–present. However, the spatial extent of the survey index did not reflect the wide spatial distribution of spurdog across most of the ICES area. For the hereby benchmark, new data were made available and a new modelling framework could be used. Three separate survey indices were developed with each constructed using statistical modelling. For that exercise and for each survey, a range of models was tested. The final models were thoroughly investigated and chosen based on AIC, model retrospective and stability.
    - Q1 survey index. This index is a combination of several surveys: NS-IBTS-Q1, Scottish groundfish surveys and a Norwegian shrimp survey. As a result, it encompasses a wide spatial extend with the North Sea, Division 3a, West of Scotland and the southern part of the Norwegian coast. This index spans 1985–onward. Given the index is a combination of several surveys, a leave one out analysis was conducted, suggesting the NS-IBTS component is most influential. Though, there consistency in trends, suggesting the combination chosen is appropriate. The retrospective of re-scaled indices is low and trends are consistent.

- Q3 survey index. Making use of the data from the NS-IBTS-Q3 available from DATRAS, this index covers divisions 3a, 4a and 4b. The time span for this index is 1992–onward, not including for 1991 because of limited spatial coverage for that year. The level of model retrospective of rescaled indices was larger compared to the Q1 and Q4 indices but remains at low levels.
- Q4 survey index. This index makes use of data from Scottish, Irish and French surveys. The coverage extends from the North of Scotland to the Celtic sea, spanning the 2003–2020 period. The level of model retrospective of rescaled indices is low, exemplifying robustness.

The Q1 and Q4 indices both cover the bulk of the stock abundance and exemplify similar trends with an increase in recent years. In contrast, the Q3 index shows a decrease in recent years in the North Sea. The derivation of these new indices is a very significant improvement compared to previously with a better spatial coverage. Though the highest distribution of spurdog is located in the West of Scotland, the North Sea component is now accounted for. The temporal extend of the survey indices is also greatly improved and brings a better representation of the diversity in length–frequency at different time periods of the year.

7.2.3 Model

The model used for spurdog is described in Oliveira *et al*. (2013) and is the same that was used for the 2011 benchmark. It is age and sex structured with the modelling processes being expressed in length categories. An age–length key allows conversion from length to age explicitly modelling length-based processes. The model also uses fecundity data to include the density-dependence of pup production.

- The overall fit of the model is good despite residuals that are substantial for the Q3 index for males and the Q4 index in recent years. As a result of the latter, the assessment is not following the recent significant increase in biomass suggested by the Q4 index. An alternative run was conducted with the inclusion of only the Q1 index which shows the benefits of the additional Q3 and Q4 surveys in capturing patterns in length categories (related to age).
- It is important to note that a fixed age–length key is currently used (average of VBGP across relevant studies). No sensitivity tests were performed on that aspect (e.g. testing of alternative VBGP parameters) because of lack of time. It would be an overall improvement for the model to account for uncertainties in growth parameters and natural dispersion around the average growth trajectory described by the von Bertalanffy growth model.

7.2.4 Biological reference point

For spurdog, the reference points are derived from the model (instead of external estimation, e.g. using eqSim). This is because 1) the model estimates productivity internally and 2) there is a wealth of historical data to reliably estimate the virgin biomass. Previously, only MSY reference points were defined and alongside new calculations also limit and precautionary reference points were computed.

- The limit reference point B_{lim} was derived as 20% of B_0 which is appropriate and in line with general recommendations from relevant studies. The precautionary reference points (B_{pa} and pa harvest rate) are both indexed as 1.4 times the limit reference points.

In light of these newly derived limits, the stock is below B_{lim} and harvested well below the associated limit harvest rate.

- The MSY harvest rate is estimated as the harvest rate leading to B_{MSY}. The methodology is similar to that used in the previous benchmark but now makes use of additional catch data. Following the slight upward revision of B_{MSY}, the MSY harvest rate is revised slightly downward.

7.2.5 Short-term forecast

There was no update in the methodology used for short-term projections.

7.3 Whiting (whg.27.6a)

7.3.1 Biological analysis

- Whiting reach **maturity-**at-age 2, assumed knife-edge, but observations accumulated during the years have shown that a proportion of age 1 may already be mature in some years and areas. An analysis of maturity data from the Q1 surveys (ScoGFS-WIBTS-Q1 and UK-SCOWCGFS-Q1) was presented which included the use of a binomial GLM with logit link. The model showed no temporal trend in the A50% maturity so the final choice of a time invariant maturity ogive is considered appropriate. The new maturity vector estimates the proportion of age 1 mature whiting to be 0.254 compared to the previous assumption of a zero proportion of mature at age 1 and it is considered an improvement. Given the large number of age 1 fish estimated in the model, the new maturity ogive has a considerable impact on the estimated SSB of the stock.
- Surveys and commercial samples show considerably different patterns in the **individual weights** especially for ages 1–2. The survey shows a temporal increase in weights while the catch data suggest the opposite. The reasons for such discrepancies between the two sources remain unknown. The expert group decided to use the quarter 1 survey for age 1–2 while the average of survey and commercial weights from all quarters for age 3+. The choice of selecting weights from quarter 1 for age 1–2 is considered appropriate because SSB is calculated at the beginning of the year in the model, and the survey is more in line in terms of timing. On the contrary, the use an average of survey and catch weight for age 3+ from all the quarters is seen as suboptimal and should be re-considered in future benchmarks or data revisions. In principle, fishery-independent data should be preferred for calculation of the stock weight unless clearly documented limits or biases. Availability of a long survey time-series in Q1 with good catchability over most age groups (at least until age 6) and beginning of year timing, seem good reasons to prefer this survey time-series to derive stock weights. For age 0, only data from the Q4 survey were available.
- The pronounced long-term trends observed in the individual weights are expected to influence also **natural mortality**. Based on this assumption, the previous benchmark proposed the use of a time variable natural mortality calculated for whiting using the equation proposed by Lorenzen (1996). This is an empirical equation which links natural mortality-at-age to the individual weight-at-age. At the present benchmark, the same approach is applied but the time-series of weight-at-age used as input for the Lorenzen equation has been revised. Similarly, to the stock weight, age 1–2 were derived from survey while weights for age 3+ were computed from both survey and catch data. Differently from the stock weight, here the weights were calculated from all the available quarters (limited to Q1 and Q4 for the surveys) to provide a more representative annual mean weight for the calculation of natural mortality which is considered a good choice. Also, for weights-at-age 0, data were only available from the Q4 survey. While the treatment and selection of the individual weights for calculation of M is agreeable with its limitations, the use of a single model to calculate natural mortality appears as a strong assumption, and an important limit primarily driven by practice established at the previous benchmark. Because no evidence exists that the Lorenzen equation is appropriate for deriving natural mortality of whiting in area 6a and large uncertainty exists around the actual values of natural mortality a broader approach based on an ensemble of multiple alternative empirical relationships would have been preferable, and it is recommended for future developments of this assessment. Among the alternative methods available, it is worth to mention those based on life-history invariants such as Gulland (1987), Chen

and Watanable (1989), Abella *et al*. (1997), Gislason *et al*. (2008) and Brodziak *et al*. (2011). Similarly, to the approach by Lorenzen (1996), these other methods link mortality rates with different aspects of growth (i.e. von Bertalanffy growth parameters, longevity, mean weight and length at first maturity).

7.3.2 Model

- The final model is considered appropriate and reliable for the purpose of providing advice on whiting in area 6a. Final model configuration was reached through a number of sensitivity and comparative analyses. Main tests included:
  - Four alternative **stock–recruitment** relationships (i.e. Beverton–Holt, Piecewise Constant, Random Walk, Ricker). Model output were highly consistent between the four with some marginal statistical support in AIC for the Beverton–Holt and Ricker model. However, a Random Walk on recruitment was preferred because more parsimonious in terms of parameters and because the leave-one-out test failed for the Ricker model. While the choice has in practice little or no influence on the current assessment, future developments of the model with internal calculation of reference points should consider the benefits of using function form for the S–R relationship;
  - Extension of the **assessment period** to 1981 is considered appropriate and informative over a time period characterised by high SSB;
  - Tests on a **catch multiplier** to account for misreporting showed that the model had difficulty to provide reasonable estimates of the catch scaling factor beyond the year 2000, and that the retrospective patterns in the model were severely affected (Mohn's rho value more than doubled compared to equivalent model with no scaling factor) which well justify the use of no catch scaling factor;
  - **Additional tests** were performed on the fleet covariance structure, survey catchability coupling, coupling of the observation variance parameters;
  - change of $\mathbf{F_{bar}}$ from $F_{2–4}$ to $F_{1–3}$ is considered appropriate to reflect the more recent exploitation period when age1 represent the main part of the catch;
  - both the Q1 index from the UK-SCOWCGFS-Q1 survey and the combined index for Q4 are used in SAM with associated **variance** estimates for better representation of uncertainties.
- A SURBAR analysis was conducted using the 3-survey time-series input for the assessment. While this survey-based method has important limitations for the assessment of this stock (i.e. the selection pattern-at-age is assumed constant which is recognised inappropriate for whiting in 6a given that the stock passed from being a target to more of a bycatch species around the early 2000s), its purpose as an exploratory tool and as a mean for comparison and corroboration of the SAM assessment from this benchmark model output is seen as valuable addition.

7.3.3 Biological reference point

- High SSB values during the first few years of the assessment period in the early 1980s are interpreted as the last residual of the gadoid outburst which is documented for the 1970s and for this reason are removed from the S-R relationship for calculation of B_{lim} and reference points. The exact cut off remains subjective (e.g. the first four years of the time-series were removed) but the approach appears reasonable. Moreover, inclusion of +/- 1 year would not change the selected procedure on the reference points (type 3 according to the ICES guidelines).
- Type 3 S–R from the ICES guideline requires expert judgement for the definition of B_{lim}. In this specific case the experts proposed to select the SSB corresponding to the lowest R

in the period 1980–2000 which stand out as a period of consistently higher recruitment compared to the post-2000 period. The rational can be followed but the decision presents some level of subjectivity.

- Because of significant high grading the definition of yields as catches above MCRS (27 cm) may be substantially different from landings (yields and yields are assumed the same in EqSim). For this reason, yields were defined as 50% of age2 catches and 100% of age3+ catches. This is coupled with the use of catch weights instead of landing weights for age3+ which is considered appropriate.

7.3.4 Short-term forecast

- Short-term forecasts for whiting in area 6a are based on best practice; model uncertainties are coherently treated in the short-term forecasts via stochastic projections run within the SAM model.
- Forecasts are based on resampling of the last ten years R to capture the recent increase in recruitment increase but with precaution after the 2007 record low.
- Recruitment estimates from the model are used in the intermediate year which seems a good procedure given the lack of apparent retrospective pattern in the recruitment.

7.4 Sole (sol.27.7d)

7.4.1 Major issues addressed at the benchmark

- During the benchmark, the primary issues addressed include a revision in the stock weights-at-age to be calculated from the catch weights-at-age, based on the proportion between the catch weights-at-age in quarter 1, and the mean catch weights-at-age. The French and Belgian commercial tuning series were revised. Both series followed a model-based approach to derive an lpue index that is considered to reflect the fishable biomass of the stock. The subpopulation structure was not considered explicitly in the construction of the input data and assessment model, as there are insufficient data available on each of the three subpopulations. A change in stock assessment model was endorsed to use a state–space stock assessment model (SAM) to provide advice for the Eastern English Channel sole stock. The assessment model is tuned by three commercial lpue indices as fishable biomass, and three scientific, age-structured survey indices.

7.4.2 Data

French catch data

- In 2016–2017, French catch data were aggregated incorrectly for older ages and hence the CAA was not reliable (Noted in Inter-benchmark in 2019)
- Calculation used in raising has catch changed overtime. As a result, this led to a complete revision of the commercial catch data time-series and was considered an improvement to the French catch data in the assessment.

Belgian Comm BT fleet

- Landings data revealed that pure trips (defined as trips in a single ICES division) had a different landing rate compared to mixed trips (defined as trips occurring in multiple ICES divisions). Although vessels are allowed to fish in different quota areas within a trip, the EG felt that the flexibility might create opportunities for non-compliance.
- Two methods were proposed to address this issue:
    - Apply LPUE from pure trips by management area and year to derive landings from mixed trips. The LPUE from pure trips were multiplied with effort registered from the mixed trips (by area and year) to derive new landings for the mixed trips. The implied landings from the mixed trips were then added to the pure trips to derive estimate of total landings. This method assumes that effort as reported in the mixed (and pure trips) are reliable and the LPUE of pure trip is representative of the landings rate in mixed trips. The method does not account for additional sources of variation.
    - Second approach uses LPUE from pure trips but gets efforts data for both the pure and mixed trips from VMS dataset which is only available from 2006 onwards.
    - Both approaches resulted in over-reporting of landings, but the differences were more noticeable for the large fleet segment (>221 kW) compared to the small fleet (less than or equal to 221 kW).
    - EG conducted a test run by decreasing catch by 20, meaning if the discrepancy was greater than 20%. While the correction was deemed convincing, the 20% threshold was arbitrary and could not be justified. Hence, it was decided to correct the entire time-series from 2004–present.
    - (Future Recommendation) It is not clear from the report which of the methods were adopted for the analyses. Although VMS data are only available from 2006–

onwards, it is more likely that that the effort data from VMS will be more reliable compared to self-reporting effort data. Future analyses should evaluate the degree of disparity between self-reported effort and VMS effort data as a way to ground-truth the effort information from self-reporting. Future test runs should look at the impact of using VMS data.

Raising Discard Data

- It was noted during the review that Belgium was the only country to provide both landings and discard age distributions for the entire period of the assessment, resulting in using the Belgium strata to fill important gaps in the catch data.
- Discards were raised using major gear groupings (TBB, OTB and GTR) regardless of season and country. Other gear groupings were aggregated into the REST gear groupings. Discard raising was only conducted on proportion of corresponding landings for which available discard weights met the 50% threshold criteria.
- In the case of age allocation, same major gear groupings and the 50% threshold criteria were applied to landings and discards separately. For catches (landings or discards) that do not meet the minimum threshold for available age distribution were combined in the REST gear grouping category.
- The revision to the discards and age allocation data resulted in the inclusion of discard rates from the OTB group which in the past has been excluded due the exclusionary criteria (i.e. only landings with corresponding discards greater than 50%). Revision to the French data (remember effort raising) resulted in 7–60% difference in tonnage. Finally, the correction of the Belgian landings (remember Over-reporting) only resulted in negligible differences in discard tonnage with the exception of 2013 which resulted in a 28% difference due to corrected inaccuracies in the raw data.
- Overall, the approach taking here to revise the data was considered reasonable and an improvement to the data stream informing the assessment.

Reconstruction of discards (Pre-2004)

- Owing to the lack of discards information prior to 2004, the EG explored three different approaches to hind cast discard calculations. Preliminary evaluation was done to determine the set of years to be used in the hind cast explorations. It was noted that there was a shift in discard rate after 2008 based on expert opinion. It was assumed that discard behaviour for years 2004–2008 likely reflects the discarding behaviour in the earlier years and was used in the hindcast exercise. Three set of approaches were explored to reconstruct discards back in time. First approach used the average ratio of DAA to LAA for yea 2004–2008 and applied to the LAA to derive DAA for period 1982–2003. The same approach was also applied for weights. The second approach assumes constant weight-at-age for the period 1982–2003 as in year 2004. The third approach also assumes a constant mean weight-at-age for years 1982–2003 based on average weight-at-age calculated for years 2004–2008. Assessment runs were tested among the three approaches and resulted in no real differences in the results. As such, the benchmark agreed that option 1 was the most robust alternative.

Stock weight

- Revisions to the stock weights-at-age were carried out during the benchmark. It was noted that the time-series of the weights-at-age matrix originated from various sources and need to reflect measurements at the beginning of the year. Due to the lack of q1 surveys, catch weights for quarter 1 were recalculated for years 2004–present while q1 landing weights for 1982–2003. Two approaches were explored including the Rivard algorithm which back calculates stock weights to the beginning of the year. The second

method, uses the mean proportion-at-age for q1 catch weight-at-age to the overall catch weight-at-age for period 2004–2019. The average ratio was then applied to the catch weight-at-age for period 1982–2003 to derive the implied q1 weights-at-age. It was noted that that the Rivard approach resulted in a consistently lower weight-at-age for 1982–2003. It was discussed during the benchmark that the Rivard calculation is based on the assumption of mid-year catch-weights. However, the assessment uses overall catch weights which could possibly explain why the resulting January 1 weights appear lower in the earlier segment of the time-series. The benchmark discussed the merits of both approaches and ultimately agreed to the second approach for the assessment. It was pointed out during the benchmark that the weights used in deriving the mid-year weights could potentially be biased due to sampling design and fleet behaviour of different countries involved. However, there is no clear evidence to support or suggesting such bias.

- (Future Recommendation) It was also noted that sole exhibited a declining trend in the in the weights-at-age in recent year and more apparent in the older ages. It is not clear what mechanism is driving such decline and it is recommended that future work look into the potential causes for this declining trend.

Tuning Indices

Six tuning fleets were explored in this assessment, including three commercial indices (Bel commercial beam trawl (2004–present), FRA commercial otter trawl (2002–present), UK commercial beam trawl (1986–present) and three scientific survey indices (UK beam trawl survey (1989–present), FRA YFS survey (1987–present) and the UK YFS (1987–2006).

Concerns about the use of commercial indices in the assessment due to issues about hyper-depletion and hyper-stability. But given the limited scientific data for sole especially for older age classes justified the inclusion of commercial LPUE in the assessment.

The commercial indices were included as biomass indices in the assessment instead of disaggregating them by age to avoid double counting of commercial data. This reflects an improvement over previous assessments in the utility of the commercial tuning indices. Both the French and Belgian commercial tuning indices were standardized appropriately to account for spatio-temporal interactions using various random effects models. The Belgian commercial beam trawl index was revised due to the correction in the Belgian commercial catch data. Appropriate criteria were applied in the selection of participating vessels to account for unbalanced sampling design of logbook observations. Statistical model used to standardized landings and effort was modified and accounted for seasonal and annual trends in the catch rates.

The French commercial tuning fleet also underwent revision and a hurdle log normal model was used to generate the LPUE by imposing a first order random walk to fit temporal trends in the main year effect and spatio-temporal interaction. At the benchmark, there were some concerns about the use of correlated random effects to capture temporal trends as it could smooth inter-annual variation. The EG followed up on this concern to test a model formulation allowing for independent (IID – Independent and identical distributed) random effect to fit the temporal trends. Evaluation of the IID model formulation did not result in an improvement to the model fit and increased the variability in model's retrospective diagnostic. To that the extent, the benchmark decided to maintain the original model formulation.

During the benchmark review, attempts to reduce the number of commercial tuning fleets in the assessment model were investigated. This raised a number of concerns during the benchmark due to the differences in spatial coverage and length of the time-series. For instance, the commercial tuning fleet for Belgium has the largest coverage but a shorter time-series (2004–present). In contrast, the UK index exhibits the longest running time-series going back to 1986 but it has

variable spatial coverage in time, and in recent years it is geographically limited to the Northern part of the eastern English Channel. Despite these issues, three methods of combining the indices were explored which partially addressed the differences in coverage and length of time-series for each of the commercial tuning indices. The indices were truncated to 2005 to reflect the starting year for the commercial indices in the series. The first approach was based on a simple arithmetic mean while the two other approaches weighted the means by landings or size of the area for each year. Overall, the differences among the approaches for combining the indices resulted in minor among differences. Following deliberations at the benchmark, it was assumed that the area weighting approach is the most appropriate method to combining the commercial indices.

While there are merits to using area weighting for combining indices, but the area assumption requires available habitats to be correctly delineated or that fishing mortality be uniformly applied across the population. Another approach that could be considered for future analyses is a hierarchical modelling framework by Conn (2018) for estimating a single time-series from multiple indices, particularly for indices with noisy trends. The approach works by assuming fishery catch rates is attempting to sample relative abundance but subjected to both sampling and process error with the latter due to temporal variability in index-specific catchability and possibly differences in selectivity between gear types.

For the survey tuning fleet, a modelled-based approach was explored to generate index of abundance for the UK BTS. Age-structured index was derived by from the model-based approach by accounting for spatial and temporal effects. A comparison of age-structured data index provided by Cefas to the modelled approach showed a high degree of internal consistency for younger ages up to age 3 and lower internal consistency for the older age group. It was pointed out at the benchmark that data used in the model-based approach appeared to be incomplete and missing data in 1989 and 2012. However, given the overall consistency between the indices derived from the model-based approach and index provided by Cefas, the benchmark decided not to use the model-based UK BTS tuning index in the assessment.

Relative to the YFS, there were concerns about the spatial coverage of the survey and if these indices provided a representative index of abundance for age-1 fish. It was pointed out during the benchmark that these localized areas represent important nursery grounds for sole, and therefore justifies the inclusion of the YFS as an indices of abundance for age-1 fish.

7.4.3 Biological analyses

Subpopulations

Review of the French SMAC project suggest that there is evidence of three subpopulations in the stock based on tagging data, growth and density-at-age analyses from the UK BTS survey. Genetics and otolith morphometrics suggest a metapopulation structure but at a fine spatial scale, with one subunit in the SW-Seine Bay being more isolated. However, it was pointed out that the main goal of the benchmark is to have a working assessment on a stock level, but considered how the presence of subpopulations can be considered based on the UK BTS survey. The Terms of reference for each of the stocks in WKNSEA required a review of their stock definitions. These were conducted mostly during the data evaluation workshop and results were brought forward to the benchmark. A concern with such ToR is that changes in stock definitions can have consequences throughout the management system and should not be undertaken without significant consideration of all sources of information. One could expect that there would be considerable reluctance to change stock definition without substantial evidence to the contrary. I will point out that this does not appear to be the case for sole. Alternatively, one could envisage that a change in stock definition may not be sufficiently supported by available data given the existing sampling design for data collection. In my view, it seems to me that the review of stock

definition could be potentially benefit from being taken out of the normal operating benchmark process and on a schedule that will allow for significant changes if these were felt warranted.

Other biological analyses such as maturity, growth and natural mortality could not be addressed during the benchmark for practical reasons and time constraints. As such previous values of maturity, growth and natural mortality were maintained in this benchmark. It is recommended that future work should revisit this biological information to ensure that it aligns with contemporary stock dynamics. The declining weights-at-age as discussed previously should also be investigated within this context as it could also possibly be related to a change in fish condition and could influence selectivity of the fishery over time.

Assessment Models

- One of the objectives of this benchmark was to examine the existing model performance against new data and consider alternative stock assessment model. XSA was last approved in the 2017 benchmark (WKNSEA 2017) and was last used in the WGNSSK 2020 assessment update. However, the utility of XSA was challenged due to some strong assumptions and limited flexibility to in handling input data streams. To that extent, the EG considered a major change in assessment model by exploring SAM model. SAM model has a number of features including process errors on the stock dynamics (i.e. recruitment, survival and fishing mortality) and observation models for catch and tuning indices. Additionally, SAM provides the additional benefit of utilizing tuning data in variety of options that was not available within the XSA modelling framework. The random effects formulation of process models can easily be used for handling missing observations. To that extent SAM allows the user to specify different model configurations and parametrization of both process and observation models.
- To allow for transition between XSA and SAM, the EG conducted appropriate bridge runs in XSA with new updated data and compared to previous update. Basic stings for the SAM model were then presented and reviewed.
- Model results from the XSA generally showed similar trends in SSB, F and Recruitment. Model diagnostics show strong patterning in the tuning indices, however, the retrospective Mohn's rho statistics were within acceptable limits.
- Several model configurations were considered in SAM including emulating the settings of the XSA model, allowing for autoregressive correlation structure in the F-at-age, examining a number of variance parameters on the age-structured observations and final run that combined the commercial tuning indices into a single fleet weighted by area. Model performance and diagnostics were evaluated and presented across the range of model configurations.
- The final SAM model run included (Run 6):
  - Revised catch data from France and Belgium.
  - Reconstructed discards using discard ratios for period 2004–2008.
  - Reconstructed stock weights using Q1 to total catch weight-at-age for the period 2004–2019.
  - Inclusion of three commercial tuning indices, treated as fishable biomass and to follow the selectivity of the fishery and three age-structures survey tuning indices.
  - Plus group was maintained at 11+, however none of the age-structured fleets included a plus group.
  - Maturity and natural mortality values were maintained from previous assessments.
- A final model validation of run 6 was conducted by inspecting one-step ahead and process residuals, retrospective analyses and leave one out fits. Model stability and convergence were assessed through parametric bootstrap simulations and jitter analyses.
- With the exception UK-BTS survey in the final years and UK-CBT, the process errors and process residuals did not show strong patterning and was an improvement over other

model runs. The lack of fit in both UK tuning indices was also reflected in the leave one out analyses. The removal of either UK tuning indices resulted in conflicting trends in SSB (higher for excluding UK-CBT and lower for UK-BTS). The poor diagnostics for the UK tuning indices is likely related to the low spatial coverage reflecting different trends among the indices. The retrospective Mohn's rho diagnostics were quite reasonable and were well within the acceptable limits. Although model run 6 resulted in second to the lowest AIC score among other model runs, none of the model validation analysis provided additional support to the robustness of the model.

- The SAM assessment estimated catches to be more stable over the time-series compared to the actual input data Especially in 1995–1997 and 2003–2009 catches were estimated lower than what was registered (outside the confidence bounds), while in 2016–2019, catches were estimated higher than what was registered. The SSB followed the same pattern as the catches and is estimated to be at one of the lowest levels of the time-series. The fishing mortality showed a decline from 2010 onwards and is currently estimated at the lowest point of the time-series. Recruitment on the other hand is found to be at the highest point of the time-series. However, there is considerable uncertainty around the estimate of the final year.

7.4.4 Biological reference points

- Reference point estimation was re-examined based on the final SAM model selection in Eqsim and following the ICES technical guidelines. The stock–recruitment relationship was evaluated as a Type-5, indicating a stock with no evidence that recruitment has been impaired or with no clear relationship between stock and recruitment. There is also a narrow range in SSB, implying a possible Type 6 relationship. However, it is not clear that there is enough contrast in the data to estimate a reasonable stock–recruitment relationship at all as the stock appears to have been fluctuating around nearly constant level. Considering the decline in recent weights-at-age, it was suggested at the benchmark to use a five-year average of recent ogives (weights-at-age, maturity and selectivity-at-age).

7.4.5 Short-term forecast

- A Stochastic forecast was conducted and presented at the benchmark. Assumptions about stock weights-at-age and selectivity were based on the recent five years while recruitment was sampled from the entire past recruitment estimates. Catch in the bridge year was based on 2019 catch while catch in the advice year was based on Fsq in 2021 given the TAC has not been taken in the last five years. Following ICES advice rule, target F in the advice year was derived consistent to levels that will bring SSB above B_{lim} in 2021. The benchmark felt that the approach and assumptions for the forecast were biologically reasonable and is consistent with ICES advice rules.

7.4.6 Future recommendations

- It was also noted that sole exhibited a declining trend in the in the weights-at-age in recent year and more apparent in the older ages. It is not clear what mechanism is driving such decline and it is recommended that future work look into the potential causes for this declining trend.
- It is not clear from the report which of the methods were adopted for the analyses. Although VMS data are only available from 2006–onwards, it is more likely that that the effort data from VMS will be more reliable compared to self-reporting effort data. Future analyses should evaluate the degree of disparity between self-reported effort and VMS

effort data as a way to ground-truth the effort information from self-reporting. Future test runs should look at the impact of using VMS data.

- Given the many uncertainties, in the input data, biological and environmental processes it is recommended that these uncertainties be explored and reviewed for potential use in a model.
- To improve estimation of discards in the assessment, it is recommend that the EG consider the discard mortality studies by gear type.
- In the previous benchmark, there were concerns about source of maturity estimates derived from commercial landings as this could potential introduce bias. The recommendation still stand to consider the use of fishery-independent data if available for developing the analyses.
- Biological analyses such as maturity, growth and natural mortality could not be addressed during the benchmark for practical reasons and time constraints. As such previous values of maturity, growth and natural mortality were maintained in this benchmark. It is recommended that future work should revisit these biological information to ensure that it aligns with contemporary stock dynamics.

8 References

Akimova, A., Nuñez-Riboni, I., Kempf, A., Taylor, M.H. 2016. Spatially-resolved influence of temperature and salinity on stock and recruitment variability of commercially important fishes in the North Sea. PLoS One 11(9):e0161917.

Alvarez-Fernandez, S., Lindeboom, H., and Meesters, E. 2012. Temporal changes in plankton of the North Sea: community shifts and environmental drivers. Marine Ecology Progress Series. 462: 21–38.

Beaugrand, G. 2004. The North Sea regime shift: evidence, causes, mechanisms and consequences. Progress in Oceanography. 60: 245–262.

Beaugrand, G., Harlay, X., and Edwards, M. 2014. Detecting plankton shifts in the North Sea: a new abrupt ecosystem shift between 1996 and 2003. Marine Ecology Progress Series. 502: 85–104.

Berg, C. W., Kristensen, K. 2012. Spatial age–length key modelling using continuation ratio logits. Fisheries Research 123-130, 119–126.

Berg, C. W., Nielsen, A., and Kristensen, K. 2014. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. Fisheries Research 151, 91–99.

Capizzano, C.W., Mandelman, J.W., Hoffman, W.S., Dean, M.J., Zemeckis, D.R., Benoît, H.P., Kneebone, J., Jones, E., Stettner, M.J., Buchan, N.J., Langan, J.A., Sulikowski, J.A. 2016. Estimating and mitigating the discard mortality of Atlantic cod (*Gadus morhua*) in the Gulf of Maine recreational rod-and-reel fishery. ICES J. Mar. Sci. 73, 2342–2355.

Hislop, J R. G. 1996. Changes in North Sea gadoid stocks. ICES J. of Marine Science, 53: 1146–1156.

Holden, M. J. 1991. North Sea cod and haddock stock in collapse or the end to the 'gadoid outburst'? ICES CM 1991/G:41.

Hunter, A., Speirs, D. C., Heath, M. R. 2015. Fishery-induced changes to age and length dependent maturation schedules of three demersal fish species in the Firth of Clyde. Fisheries Research, 170: 14–23. 10.1016/j.fishres.2015.05.004.

ICES. 2008. Report of the Ad hoc Group on Criteria for Reopening Fisheries Advice (AGCREFA), 20–22 August 2008, Copenhagen, Denmark. ICES CM 2008/ACOM:60. 30 pp.

ICES. 2008. Report of the Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG), 3–6 June 2008, Lisbon, Portugal. ICES CM2008/ACOM:33. 72 pp.

ICES. 2011. Report of the Workshop on the Analysis of the Benchmark of Cod in Subarea 4 (North Sea), Division 7.d (Eastern Channel) and Division 3.a (Skagerrak) (WKCOD 2011), 7–9 February 2011, Copenhagen, Denmark. ICES CM 2011/ACOM:51: 94 pp.

ICES. 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 4–10 May 2011, ICES Headquarters, Copenhagen. ICES CM 2011/ACOM:13. 1197 pp.

ICES. 2015. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 28 April–7 May 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/ACOM:13. 1182 pp.

ICES. 2015. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 2–6 February 2015, Copenhagen, Denmark. ICES CM 2015/ACOM:32. 253 pp.

ICES. 2017. Report of the Working Group on Assessment of Demersal Stocks in the North Sea and Skagerrak (2017), 26 April–5 May 2017, ICES HQ. ICES CM 2017/ACOM:21. 1077 pp.

ICES. 2017. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 6–10 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:34. 673 pp.

ICES. 2017b. Report of the Workshop to consider FMSY ranges for stocks in ICES categories 1 and 2 in Western Waters (WKMSYREF4), 13–16 October 2015, Brest, France. ICES CM 2015/ACOM:58. 187 pp.

ICES. 2019. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 1:7. 1271 pp. http://doi.org/10.17895/ices.pub.5402

ICES. 2020. Working Group on Improving use of Survey Data for Assessment and Advice (WGISDAA).

ICES. 2020. Benchmark Workshop for Flatfish stocks in the North Sea and Celtic Sea (WKFlatNSCS). ICES Scientific Reports. 2:23. 975 pp. http://doi.org/10.17895/ices.pub.5976.

ICES. 2020. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1140 pp. http://doi.org/10.17895/ices.pub.6092.

ICES. 2020. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548.

ICES. 2020. Workshop on Stock Identification of North Sea Cod (WKNSCodID). ICES Scientific Reports. 2:89. 82 pp. http://doi.org/10.17895/ices.pub.7499

ICES. 2020. Workshop on the North Sea reopening protocol (WKNSROP). ICES Scientific Reports. 2:108. 74 pp. http://doi.org/10.17895/ices.pub.7576.

ICES. 2021b. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. 1461 pp. http://doi.org/10.17895/ices.pub.5978

Kempf, A., Floeter, J., Temming, A. 2009. Recruitment of North Sea cod (*Gadus morhua*) and Norway pout (*Trisopterus esmarkii*) between 1992 and 2006: the interplay between climate influence and predation. Canadian Journal of Fisheries and Aquatic Sciences. 66:633–648.

Lecomte, J.-B., Le Pape, O., Baillif, H., Nevoux, M., Vermard, Y., Savina, M., Veron, M., Lehuta, S., Hunter, E., Rivot, E. 2020. State–space modelling of multidecadal mark–recapture data reveals low adult dispersal in a nursery-dependent fish metapopulation. Can. J. Fish. Aquat. Sci., 77: 342–354. Dx.doi.org/10.1139/djfas-2019-0037.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology, 49: 627–647.

Needle, C. L. 2015. Using self-testing to validate the SURBAR survey-based assessment model. Fisheries Research, 171: 78–86.

Nielsen, A. and Berg, C. W. 2014. Estimation of time-varying selectivity in stock assessments using state–space models, Fisheries Research, 158, 96–101.

O'Brien, C.M., Fox, C.J., Planque, B., and Casey, J. 2000. Climate variability and North Sea cod. Nature, 404: 142.

Olsen, E. M., Ottersen, G., Llope, M., Chan, K.-S., Beaugrand, G., and Chr. Stenseth,N. C. 2011. Spawning stock and recruitment in North Sea cod shaped by food and climate. Proceedings of the Royal Society B, 278: 504–510.

Radford, Z., Hyder, K., Zarauz, L., Mugerza, E., Ferter, K., Prellezo, R., Weltersbach, M. S. 2018. The impact of marine recreational fishing on key fish stocks in European waters. PLOS ONE 13: e0201666.

Randon, M., Réveillac, E., Rivot, E., Du Pontavice, H., Le Pape, O. 2018. Could we consider a single stock when spatial sub-units present lasting patterns in growth and asynchrony in cohort densities? A flatfish case study. Journal of Sea Research, 142, 91–100.

Randon, M., Le Pape, O., Ernande, B., Mahé, K., Volckaert, F.A.M., Petit, E.J., Lassale, G., Le Berre, T., Réveillac, E. 2020. Complementarity and discriminatory power of genotype and otolith shape in describing the fine-scale population structure of an exploited fish, the common sole of the Eastern English Channel. Plos One, https://doi.org/10.1371/journal.pone.0241429.

Reid, P.C., Borges, M., and Svendson, E. 2001. A regime shift in the North Sea circa 1988 linked to changes in the North Sea horse mackerel fishery. Fisheries Research, 50: 163–171.

Weijerman, M., Lindeboom, H., and Zuur, A.F. 2005. Regime shifts in marine ecosystems in the North Sea and Wadden Sea. Marine Ecology Progress Series. 298: 21–39.

8.1 References for spurdog section

Albert, O. T., Junge, C., and Myrlund, M. K. 2019. Young mums are rebuilding the spurdog stock (*Squalus acanthias* L.) in Norwegian waters. ICES Journal of Marine Science, 76: 2193–2204.

Aasen, O. 1961. Pigghåundersøkelsene. Fisken og Havet 1: 1–9.

Bedford, B.C., Woolner, L.E, and Jones, B.W. 1986. Length–weight relationships for commercial fish species and conversion factors for various presentations. Data Report, MAFF Directorate of Fisheries Research Lowestoft, 10: 41pp.

Berg, C. W., Nielsen, A., and Kristensen, K. 2014. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. Fisheries Research 151: 91–99.

Coull, K. A., Jermyn, A. S., Newton, A. W., Henderson, G. I and W. B. Hall. 1989. Length–weight relationships for 88 species of fish encountered in the North East Atlantic. Scottish Fisheries Research Report Number 43.

Dell'Apa, A., Bangley, C.W. and Rulifson, R.A. 2015. Who let the dogfish out? A review of management and socio-economic aspects of spiny dogfish fisheries. Reviews in Fish Biology and Fisheries, 25: 273-295.

De Oliveira, J. A. A., Ellis, J. R., and Dobby, H. 2013. Incorporating density dependence in pup production in a stock assessment of NE Atlantic spurdog *Squalus acanthias*. ICES Journal of Marine Science, 70: 1341–1353.

Ellis, J. R., and Keable, J. 2008. The fecundity of Northeast Atlantic spurdog (*Squalus acanthias* L., 1758). ICES Journal of Marine Science, 65: 979–981.

Fahy, E. 1988. The spurdog *Squalus acanthias* (L.) fishery in southwest Ireland. Irish Fisheries Investigations Part B: Marine, 32: 22 pp.

Fahy, E. 1989. The value of alterations in fecundity to an exploited shark population, illustrated by *Squalus acanthias* (L.). ICES Document CM 1989/Mini: 2; 10 pp.

Ford, E. 1921 A contribution to our knowledge of the life-histories of the dogfishes landed at Plymouth. Journal of the Marine Biological Association of the United Kingdom, 12: 468–505.

Gauld, J. A. 1979. Reproduction and fecundity of the Scottish Norwegian stock of spurdogs, *Squalus acanthias* (L.). ICES Document CM 1979/H: 54; 15 pp.

Hammond, T. R., and Ellis, J. R. 2005. Bayesian assessment of North-east Atlantic spurdog using a stock production model, with prior for intrinsic population growth rate set by demographic methods. Journal of Northwest Atlantic Fishery Science, 35: 299–308.

Henderson, A. C., Flannery, K., and Dunne, J. 2002. Growth and reproduction in spiny dogfish *Squalus acanthias* L. (Elasmobranchii: Squalidae), from the west coast of Ireland. Sarsia, 87: 350–361.

Hickling, C. F. 1930. A contribution towards the life-history of the spurdog. Journal of the Marine Biological Association of the United Kingdom, 16: 529–576.

Holden, M. J., and Meadows, P. S. 1964. The fecundity of the spurdog (*Squalus acanthias* L.). Journal du Conseil Permanent International pour l'Exploration de la Mer, 28: 418–424.

ICES. 2011. Report of the Working Group on Elasmobranch Fishes (WGEF), 20–24 June 2011, Copenhagen, Denmark. ICES CM 2011/ACOM:19, 492 pp.

ICES. 2016. Report of the Workshop to compile and refine catch and landings of elasmobranchs (WKSHARK2), 19–22 January 2016, Lisbon, Portugal. ICES CM 2016/ACOM:40, 69 pp.

ICES. 2019. International Bottom Trawl Survey Working Group (IBTSWG). ICES Scientific Reports. 1:60, 159 pp. (http://doi.org/10.17895/ices.pub.5596).

ICES. 2020. Working Group on Elasmobranch Fishes (WGEF). ICES Scientific Reports. 2:77. 789 pp. (http://doi.org/10.17895/ices.pub.7470).

ICES. 2021a. ICES fisheries management reference points for category 1 and 2 stocks; Technical Guidelines. In Report of the ICES Advisory Committee, 2021. ICES Advice 2021, Section 16.4.3.1. https://doi.org/10.17895/ices.advice.7891.

ICES. 2021c. Workshop of Fisheries Management Reference Points in a Changing Environment (WKRP-Change, outputs from 2020 meeting). ICES Scientific Reports. 3:6. 39 pp. (https://doi.org/10.17895/ices.pub.7660).

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32 pp.

Jones, T. S., and Ugland, K. I. 2001. Reproduction of female spiny dogfish, *Squalus acanthias*, in the Oslofjord. Fishery Bulletin, 99: 685–690.

McCully, S. R., Scott, F., and Ellis, J. R. 2012. Length at maturity and conversion factors for skates (Rajidae) around the British Isles, with a critique of earlier studies. ICES Journal of Marine Science, 69: 1812–1822.

Pawson, M. G., Ellis, J. R., and Dobby, H. 2009. The evolution and management of spiny dogfish (Spurdog) fisheries in the North-East Atlantic. In "*Biology and Management of Dogfish Sharks*" (V. Gallucci, G. McFarlane & G. Bargmann, eds) pp. 373–390. American Fisheries Society, Bethesda, 435 pp.

Preece, A., Hillary, R. and C. Davies. 2011. Identification of candidate limit reference points for the key target species in the WCPFC. 39pp. Doi: 10.13140/2.1.2631.2643.

Punt, A. E., and Walker, T. I. 1998. Stock assessment and risk analysis for the school shark (*Galeorhinus galeus*) off southern Australia. Marine and Freshwater Research, 48: 719–731.

Punt, A. E., Pribac, F., Walker T. I. and B.L. Taylor. 2001. Population modelling and harvest strategy evaluation for school and gummy shark, Report of FRDC 99/102. CSIRO Marine Re-search, Hobart.

Rago, P. and Sosebee, K. 2013. Update on the status of spiny dogfish in 2013 and projected harvests at the F_{MSY} proxy and P_{star} of 40%. Mid Atlantic Fishery Management Council Scientific and Statistical Committee.

Sainsbury, K.J. 2008. Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority, Canberra, Australia, 156 pp.

Silva, H. M. 1993. Reproductive strategies of spiny dogfish, *Squalus acanthias* in the NW Atlantic. ICES Document CM 1993/G: 51, 18 pp.

Sosiński, J. 1977. Polish investigations on the Scottish Norwegian spurdog (*Squalus acanthias*) in 1974. Annales Biologiques (Copenhagen), 32: 178–179.

Sosiński, J. 1978. Characteristics of the North Sea spurdog (*Squalus acanthias* L.) stock. Acta Ichthyologica et Piscatoria, 8: 9–22.

Stenberg, C. 2005. Life history of the piked dogfish (*Squalus acanthias* L.). Journal of Northwest Atlantic Fishery Science, 35: 155–164.

Walenkamp, J. H. C. 1988. Life history and fishery of the spurdog, *Squalus acanthias*, in the Irish Sea. MSc Thesis, University College of North Wales, Bangor, 146 pp. + plates.

Annex 1: Lists of participants

Data compilation workshop

Name	Institute	Country	Email
Michael Andersen	Danish Fishermen Producer Organisation	Denmark	ma@dkfisk.dk
Elena Balestri	Scottish Fishermen's Federation	UK	e.balestri@sff.co.uk
Valerio Bartolino Invited Expert	SLU	Sweden	valerio.bartolino@slu.se
Casper Berg	DTU Aqua	Denmark	cbe@aqua.dtu.dk
Liz Clarke	Marine Laboratory	UK	liz.clarke@gov.scot
Kenny Coull	SWFPA	UK	kenny@swfpa.com
Jessica Craig	Marine Laboratory	UK	Jessica.craig@gov.scot
José De Oliveira	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	UK	jose.deoliveira@cefas.co.uk
Helen Dobby	Marine Scotland Science	UK	h.dobby@marlab.ac.uk
Jim Ellis	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	UK	Jim.ellis@cefas.co.uk
Raphaël Girardin	Ifremer	France	Raphael.Girardin@ifremer.fr
Holger Haslob	Thünen Institute	Germany	Holger.haslob@thuenen.de
Kieran Hyder	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	UK	Kieran.hyder@cefas.co.uk
Andrzej Jaworski	Marine Laboratory, Marine Scotland Science	UK	jaworskia@marlab.ac.uk
Alex Kempf	Thünen Institute	Germany	alexander.kempf@thuenen.de
Tanja Miethe	Marine Scotland Science	UK	t.miethe@marlab.ac.uk
Marie Storr-Paulsen Chair	DTU Aqua	Denmark	msp@aqua.dtu.dk
Stephen Shaw	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	UK	Stephen.shaw@cefas.co.uk
Klaas Sys	Research institute for Agriculture, Fisheries and Food (ILVO)	Belgium	klaas.sys@ilvo.vlaanderen.be
Lies Vansteenbrugge	Research institute for Agriculture, Fisheries and Food (ILVO)	Belgium	lies.vansteenbrugge@ilvo.vlaanderen.be

Name	Institute	Country	Email
Nicola Walker	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	UK	Nicola.walker@cefas.co.uk

Benchmark workshop

Name	Institute	Country	E-mail
Larry Alade	Northeast Fisheries Science Center	US	larry.alade@noaa.gov
Michael Andersen	Danish Fishermen Producer Organisation Fredericia	Denmark	ma@dkfisk.dk
Elena Balestri	Scottish Fishermen's Federation	UK	e.balestri@sff.co.uk
Valerio Bartolino Invited Expert	SLU	Sweden	valerio.bartolino@slu.se
Casper Willestoft Berg	DTU Aqua	Denmark	cbe@aqua.dtu.dk
Benoit Berges Invited Expert	Wageningen University	Netherlands	Benoit.berges@wur.nl
Alan Baudron	Marine Scotland Science	UK	Alan.Baudron@gov.scot
Elliot Brown	DTU-Aqua	Denmark	elbr@aqua.dtu.dk
Steve Cadrin	School for Marine Science and Technology University of Massachusetts Dartmouth	US	scadrin@umassd.edu
Kenny Coull	SWFPA	UK	kenny@swfpa.com
José De Oliveira	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	England, UK	jose.deoliveira@cefas.co.uk
Gjert Endre Dingsør	The Norwegian Fishing Vessel Owners Association	Norway	gjert@fiskebat.no
Helen Dobby	Marine Scotland Science	Scotland, UK	h.dobby@marlab.ac.uk
Jim Ellis	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	England, UK	Jim.ellis@cefas.co.uk
Niall Fallon	Marine Laboratory Marine Scotland Science	UK	niall.fallon@gov.scot
Raphaël Girardin	Ifremer	France	Raphael.Girardin@ifremer.fr
Kieran Hyder	Cefas	UK	Kieran.hyder@cefas.co.uk
Andrzej Jaworski	Marine Laboratory Marine Scotland Science	UK	jaworskia@marlab.ac.uk

Name	Institute	Country	E-mail
Claudia Junge	Institute of Marine Research	Norway	claudia.junge@hi.no
Alex Kempf	Thünen Institute	Germany	alexander.kempf@thuenen.de
Rosario Lavezza	Institute of Marine Research Tromsø	Norway	Rosario.Lavezza@hi.no
Paul Macdonald	Scottish Fishermen's Organisation	UK	paul.macdonald@scottishfishermen.co.uk
Geert Meun	VisNed	Netherlands	gmeun@visned.nl
Sander Meyns	Rederscentrale	Belgium	sander.meyns@rederscentrale.be
Tanja Miethe	Marine Scotland Science	Scotland, UK	t.miethe@marlab.ac.uk
Sarah Louise Millar	International Council for the Exploration of the Sea (ICES)	Denmark	Sarah-louise.millar@ices.dk
Coby Needle	Marine Scotland Science	Scotland, UK	needlec@marlab.ac.uk
Anders Nielsen	DTU Aqua	Denmark	an@aqua.dtu.dk
Alessandro Orio	SLU	Sweden	Alessandro.orio@slu.se
Alfonso Pérez-Rodriguez	Institute of Marine Research	Norway	alfonso.perez.rodriguez@hi.no
Marie Storr-Paulsen Chair	DTU Aqua	Denmark	msp@aqua.dtu.dk
Giovanni Romagnoni	University of Oslo	Norway	giovanni.romagnoni@ibv.uio.no
Henrik Sparholt	KU	Denmark	henrik.sparholt@gmail.com
Klaas Sys	Institute for Agricultural and Fisheries Research (ILVO)	Belgium	Klaas.sys@ilvo.vlaanderen.be
Lies Vansteenbrugge	ILVO	Belgium	lies.vansteenbrugge@ilvo.vlaanderen.be
Jasmine Vlietinck	Rederscentrale	Belgium	Jasmine.vlietinck@rederscentrale.be
Nicola Walker	Centre for Environment, Fisheries and Aquaculture Science (Cefas)	England, UK	Nicola.walker@cefas.co.uk
Henning Wehde	Institute of Marine Research	Norway	henningw@hi.no
Simon Weltersbach	Thünen Institute	Germany	simon.weltersbach@thuenen.de

Annex 2: Recommendations

For BIOP. We see in a lot of stocks that fish mature at an earlier age / length. If an annual maturity ogive is used, this will give an increase in the SSB. However, there are some uncertainties on the fecundity between ages and this is often not accounted for. Is it possible the give different species / stock different weighting by age to account for the different fecundity?

Annex 3: Issue lists

Cod in Subarea 4, Division 7.d and Subdivision 20

Stock	Cod in Subarea 4, Division 7.d and Subdivision 20	
Stock coordinator	Name: Nicola Walker	Email: nicola.walker@cefas.co.uk
Stock assessor	Name: Nicola Walker	Email: nicola.walker@cefas.co.uk
Data contact	Name: Nicola Walker	Email: nicola.walker@cefas.co.uk

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	Responsible expert from WG	External expertise needed at benchmark type of expertise / proposed names	Addressed at the data compilation WS
(New) data to be considered and/or quantified	Recreational catches are estimated to account for 10% of the total removals of this stock.	Investigate the possibility of including recreational catches in the assessment.	Recreational data that are consistent, available on a regular basis and meets sampling and data quality requirements.		Kieran Hyder and Zachary Radford	Partly Data call was made but the data or quality of the data were not presented at the WS
Tuning Series	Apparent changes in IBTS Q1 and Q3 catchability; discrepancies between stock trends implied by fishery dependent and independent sources.	Investigate perceived catchability problems in IBTS surveys (including conflicting information between surveys and catches). Re-evaluate specifications of the Delta-GAM model.	DATRAS database	Nicola Walker and Casper Berg	Experts on survey and commercial data collection that may be able to highlight any change in fishing practice (e.g. IBTSWG and WGCATCH).	New survey indices presented and discussed. Further options to be worked at before benchmark

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	Responsible expert from WG	External expertise needed at benchmark type of expertise / proposed names	Addressed at the data compilation WS
Biological Parameters	Maturity: accounting for an increase in maturity-at-age may give the impression that spawning stock biomass is in better condition than it is given possibility of lower fecundity of younger age groups and the potential for a maternal age effect on survival.	Investigate the significance of spawner age on reproductive potential. Re-evaluate the base approach for deriving maturity-at-age considering weighting of subarea differences and the importance of sampling intensity to interannual variation in maturity estimates.	Maturity data from surveys (IBTS Q1); information on survival rates of eggs and larvae from small fish maturing at a younger age and smaller size.		A maturity expert such as Peter Wright and others.	Maturity ogive was discussed and different alternative to calculate suggested
Assessment	Residuals for the last two years of IBTS-Q1 and Q3 survey data (bar age 1) are all negative.	Explore model configurations that correlate survey observations.	Stock assessment inputs	Anders Nielsen, Casper Berg and Nicola Walker.		Not addressed at the data compilation workshop
	Retrospective analyses indicate a tendency to overestimate SSB and recruitment and underestimate fishing mortality.	Investigate potential causes of retrospective patterns, considering recommendations from the recent WKFORBIAS workshop.	Stock assessment inputs	Nicola Walker, José De Oliveira and Anders Nielsen.		Partly addressed (stock area)
	The proportion of fish in the plus group is increasing (41%) resulting in an increasing loss of cohort information.	Explore increasing the plus group age.	Stock assessment inputs	Anders Nielsen and Nicola Walker.		Not addressed at the data compilation workshop Should be looked at ??
Forecast	Short-term forecasts tend to be more optimistic than realised values in subsequent years.	Explore potential biases in the forecast and how to deal with these.	Stock assessment outputs	Nicola Walker and José De Oliveira		Not addressed at the data compilation workshop

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	Responsible expert from WG	External expertise needed at benchmark type of expertise / proposed names	Addressed at the data compilation WS
	The SAM estimate of recruitment in the intermediate year (used as the forecast assumption) is uncertain and retrospective analyses indicate a strong tendency for it to be overestimated.	Investigate the intermediate year recruitment assumption.	Stock assessment outputs	Nicola Walker and José De Oliveira		Not addressed at the data compilation workshop
Biological Reference Points	Reference points will need to be re-evaluated based on new assessments.	Determination of suitable reference points following the determination of the most appropriate stock assessment method.	Stock assessment outputs.	Nicola Walker		Not addressed at the data compilation workshop
Other	Genetic work may indicate the need to reconsider stock identification and / or account for a spatial dimension in modelling.	Consider genetic vs non-genetic evidence for multi-stock hypotheses (in a dedicated meeting prior to the benchmark?). Investigate the possibility of conducting assessments that allow for multiple stocks, either separately or within a single framework.	Methods and data available to separate catches and survey data from different components of the stock and account for uncertainty in areas of overlap or substantial mixing. Methods and data available to model multiple stocks in a single assessment framework that estimates mixing rates.		Peter Wright, Jakob Hemmer Hansen, David Righton, Chris Griffiths, Anders Nielsen and Casper Berg.	Was addressed in the stock ID workshop and presented at the data compilation workshop.

Spurdog 27 NEA

Stock		
Stock coordinator	Name: Claudia Junge	Email: claudia.junge@hi.no
Stock assessor	Name: José de Oliveira	Email: jose.deOliveira@cefas.co.uk
Data contact	Name: Graham Johnston	Email: graham.johnston@marine.ie

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation workshop
Increase number of surveys included	Only four Scottish surveys are currently used in the assessment (Q1 and Q4 west coast, and Q1 and Q3 in the North Sea). Other surveys should be included to account for possible spatial variability within this widely-distributed stock. This is the most critical issue to be addressed at the benchmark	Inclusion of IGFS, NIGFS, other surveys within the IBTS and Norwegian surveys. The use of EVHOE and Spanish data should also be investigated	These data are available, either through national laboratories or through DATRAS. National laboratories should be contacted for background data, non-DATRAS survey information or for missing data.		Was addressed at the data compilation workshop. Suggestions for new combined survey indices.
Lack of accepted reference points.	The assessment does not have a calculated value for Blim. Without this value, the ICES system does not fully allow PA advice to be used. The stock is therefore not fully in line with the normal ICES advice procedure.	The use of a proxy for Blim should be investigated. Proxies have been proposed but these need benchmark agreement.	The model should be used to test against proposed reference points. However, the use of proxy reference points will need to be discussed at WGEF 2019 and at the data-scoping exercise in Q3/4 2019.		Was not addressed during the data compilation workshop
Variation in Btrigger	The value of Btrigger has changed from that used in previous assessments.	A clearer explanation in how Btrigger is derived is required.			Was not addressed during the data compilation workshop

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation workshop
Recruitment information	Some surveys have seen more evidence of young spurdog, following what was perceived as a period of impaired recruitment. A Norwegian study showed a much steeper increase in year class strength from 2002-2007 than estimated in the assessments.	Analyses of survey data to examine utility of a recruitment index. Norwegian data can be used.	Relevant data should be held on DATRAS and is found in Albert *et al*. 2019.		Was not addressed directly during the data compilation workshop, but such information would be available from the newly collated survey data (see above).
Earlier fecundity data	The current assessment used fecundity data from two periods (1960s and 2005) to allow for density-dependent effects to be included. Additional fecundity data could usefully be included.	Additional fecundity data are available for more recent years, and some earlier historical data have also been identified.	Recent data held at CEFAS and IMR.		Was presented at the data compilation workshop and additional data now available.
Growth parameters	The effect of the selected growth parameters could usefully be determined.	Whilst updated age determination is limited for the NE Atlantic, the appraisal of work from the NW Atlantic could be considered. If the growth parameters are shown to be having a strong influence, there would be a rationale for existing samples of vertebrae/spines to be read in the future.	Data collation from scientists at CEFAS and IMR		Was presented at the data compilation workshop and new values suggested
Assessment model	Variation of age at length	Currently, there is a deterministic relationship between length and age. This rigid assumption should be loosened and variation of length at age should be modelled	Model improvements by stock assessor		Was not addressed during the data compilation workshop
Reference points	Currently the model produces a restricted number of reference points (Bmsy, Fmsy, MSY), whereas ICES needs other additional reference points (including Blim)	The model should be explored to derive the necessary reference points, or this should be derived in other ways if not possible.	Method development.		Was not addressed during the data compilation workshop

Whiting 6.a

Stock		
Stock coordinator	Name: Andrzej Jaworski	Email: a.jaworski@marlab.ac.uk
Stock assessor	Name: Andrzej Jaworski/Niall Fallon/Helen Dobby	Email: a.jaworski@marlab.ac.uk; niall.fallon@gov.scot; h.dobby@marlab.ac.uk
Data contact	Name: Andrzej Jaworski	Email: a.jaworski@marlab.ac.uk

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation WS
Tuning Series	There are three current (and two discontinued) surveys with coverage of this stock (one provides only partial coverage). At WKDEM 2020 a combined Irish/Scottish Q4 survey index was presented and agreed for use. However this results in a number of very short survey series all of which break between 2010 & 2011. Agree most appropriate combination of survey indices to include in any assessment.	Good within and between survey consistency has been shown previously in exploratory data analysis. Choice of survey indices to include in any stock assessment will be guided by assessment model performance (residuals, retros, leave-one out) & hence considerable sensitivity analysis will be required.	No additional data requirements	Familiarity with the survey data and stock assessment expertise (names as below)	Was addressed and a combined survey indices decided.
Assessment method	The previous analytical assessment of this stock (using TSA) was rejected at WKDEM in 2020 largely due to: i) the substantial increase in survey catchability over time across multiple surveys (which was considered unreasonable although had been apparent for many years, and ii) the assumption of an underlying stock-recruitment relationship which appeared to be a poor fit to the data.	Issue i) appears to be associated with differing signals between survey & catch data (and is interpreted in the TSA model as an increase in suvey catchability). This could potentially be due to bias in catch estimates, significant changes in fishery selectivity that the TSA was unable to account for and/or changes in and/or changes in natural mortaliy. Thorough exploration of these issues within stock assessment model is required including year range of unreliable catch data, age at full fishery selection , survey catchability,	No new catch data or survey indices are required as these data were prepared ahead of WKDEM2020 (i.e. no data call required).	Data compilation: Andrzej Jaworski (MSS), Helen Dobby (MSS) Stock assessment: Helen Dobby, Niall Fallon & Andrzej Jaworski (all MSS) plus	Was addressed and SAM will be tested at the benchmark and the survey indicies will be combined in 3 indicies

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation WS
	When conducting TSA sensistivity analysis at WKDEM, the difficulties getting the model to converge (at all or within a reasonable length of time) with an inappopriately chosen initial parameter space were extremely apparent. For these reasons (along with likely limited future development support for TSA) there is a need to move to an alternative assessment method such as SAM, for example.	assumptions about natural mortality and potentially truncation of the assessment time series. Note that catch data are currently considered unreliable during 1995-2006 (due to underreporting). Area misreporting not considered an issue (unlike 6a cod) although will be explored through analysis of recent VMS data. In addition it may be useful to explore a multi-fleet stock assessment (although fleet disaggregated data are only available since 2003). Model performance may also be improved by the inclusion of external estimates of the variance of survey indices and/or catch data (and this should also be explored). The latter (even if not formally included in a stock assessment) could inform whether uncertainty in catch-at-age estimates changes over time and/or age. Issue ii) - SAM allows for a variety of assumptions regarding stock-recruitment which can be compared. Most other assessment methods make no underlying assumptions about the relationship. An assessment can be set up relatively easily in SAM and the required sensitivity analysis can be conducted within that framework. However,	Data for a multi-fleet stock assessment are available in the Inter-Catch output files (2003 onwards) but require compiling. VMS data already available. Estimates of variance of Scottish survey indices already available. Variance estimates of Scottish landings and discards estimates also available but require compiling.	Anders Nielson or other SAM expert	

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation WS
		supporting or comparative analysis should also be conducted which could include the use of A4A and Surbar. If the issues with mismatch between catch and survey data cannot be resolved then a category 3 assessment will need to be agreed which could potentially be based on Surbar.			
Biological Reference Points	Refe rence points will be required to be calculated once an assessment is agreed.	For a category 1 assessment, new PA and MSY reference points calculated according to ICES guidelines & using EqSim.	Data for this are the same as for the assessment itself.	Expertise in EqSim (e.g Helen Dobby, MSS)	Not addressed at the data compilation workshop
		If a category 1 assessment cannot be agreed, the length-based indicators approach should be explored.	Catch-at-length data have been submitted to InterCatch. Processing requires completion.	Data provision: Andrzej Jaworksi (MSS). Help with LBIs: Tanja Miethe (MSS).	

Sole 27.7.d

Stock	**SOL 27.7d**	
Stock coordinator	Name: Lies Vansteenbrugge	Email: lies.vansteenbrugge@ilvo.vlaanderen.be
Stock assessor	Name: Lies Vansteenbrugge	Email: lies.vansteenbrugge@ilvo.vlaanderen.be
Data contact	Name: Lies Vansteenbrugge	Email: lies.vansteenbrugge@ilvo.vlaanderen.be

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation workshop
(New) data to be considered and/or quantified[1]	France to update entire time series (2002–2017) (note 2018 and 2019 were updated for WGNSSK2020)	France to upload revised data to InterCatch	On the national level: France to upload data using raising by landings and multinomial method for ALK.	French experts in data raising	Has been updated
	Strange behaviour of older ages in stock numbers and fishing mortality at age.	Investigate what causes this problem.	/	Stock coordinator, stock assessment experts	Not really sure this was addressed? decreased + group was addressed
	Revision of French commercial otter trawl tuning fleet	Calculate new tuning fleet considering the revised French time series	On the national level: France to model tuning fleet	French experts in tuning fleets	Was presented
	Investigate trends in stock weights	Decipher origin of stock weights (landing weights vs. catch weight; quarter 1 or 2?); model stock weights	ICES reports on history in stock weights	Stock coordinator	Was addressed and a Q1-Q2 catch data will be tested

[1] Include all issues that you think may be relevant, even if you do not have the specific expertise at hand.If need be, the Secretariat will facilitate finding the necessary expertise to fill in the topic. There may be items in this list that result in 'action points for future work' rather than being implemented in the assessment in one benchmark.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark type of expertise / proposed names	Addressed during the data compilation workshop
	Presence of subpopulations in the eastern English Channel	Await the final outcome of the SMAC project	Await the final outcome of the SMAC project	French experts involved in the SMAC project.	Was addressed
Tuning series	There are 6 tuning series in the assessment. Most of them are only covering a small part of Division 7d.	Check if all tuning fleets should be retained in the assessment. Explore leave-one-out runs.	Age disaggregated tuning fleets are available, however also biomass indices need to be explored.	UK (E&W), French and Belgian survey and commercial tuning fleet experts and stock coordinator	Was presented and a change to a survey biomass indices for the commercial tuning was suggested
Assessment method	Move away from XSA	Explore other assessment models, such as SAM or AAP	/	Experts on SAM or AAP	Was addressed and SAM will be tested for the benchmark
Biological Reference Points	Determine MSY reference points	Run EqSim functions	Using the final assessment	Experts in computation of reference points, stock coordinator	Was not addressed at the data compilation workshop
Forecast	Move from a deterministic to a stochastic forecast	Run the forecast using e.g. SAM	Using the final assessment	Stock coordinator, expert on SAM	Was not addressed at the data compilation workshop

Annex 4: Sensitivity runs for spurdog

The Annex describes the list of sensitivity runs explored for spurdog and listed in Table A4.1 once the model had been updated to include all the new datasets (fecundity and survey).

Table A4.1. NEA spurdog. List of sensitivity runs explored. In bold are the default scenarios previously used, while underlined are scenarios now considered the default (those both bold and underlined indicate no change in default scenario).

Category	Scenarios considered	Associated Tables & Figures
1. Recruitment deviates (year estimated from)	**1960**, 1965, 1970, 1975, 1980	Table A4.2; Figure A4.1
2. Recruitment variation	**0.2**, 0.5, 0.8	Tables A4.3, A4.4; Figures A4.2, A4.3
3. Length–frequency data weighting (commercial catch versus survey)	**20–10**, 20–20, 10–10, 10–20	Figures A4.4, A4.5
4. Survey observation CVs	**Included**, excluded	Table A4.5; Figure A4.6
5. Surveys included	Q1–Q2–Q3, **Q1 only**	Figure A4.7
6. Growth	Not possible to explore	

1. Recruitment deviates

The ability of the model to estimate recruitment deviates is dependent on available data, particularly that which is informative on recruitment strength, such as data by length category. The purpose of this sensitivity analysis was to explore when best to start estimating recruitment deviates, given that the earliest data by length category only starts in 1983. AIC/AICc was used to explore whether a selection could be made based on model-fitting criteria. This is shown in Table A4.2, which indicates that commencing the estimation of recruitment deviates from 1975 onwards results in the lowest AIC/AICc statistic, so this year was selected. The year 1960 was previously used, but Figure A4.1, which compares likelihood profiles over the density-dependent fecundity parameter Q_{fec}, indicates that the earlier the choice of year, the less stable the model becomes with ever-wider 95% confidence intervals (based on the likelihood ratio test) for Q_{fec}.

Table A4.2. NEA spurdog. A comparison of -lnL and AIC for different starting years for estimating recruitment deviates.

	1980	1975	1970	1965	1960
data	2621	2621	2621	2621	2621
params	66	71	76	81	86
-lnL	4953	4946	4942	4938	4933
AIC	10038	10033	10036	10039	10039
AICc	10041	10037	10040	10044	10045

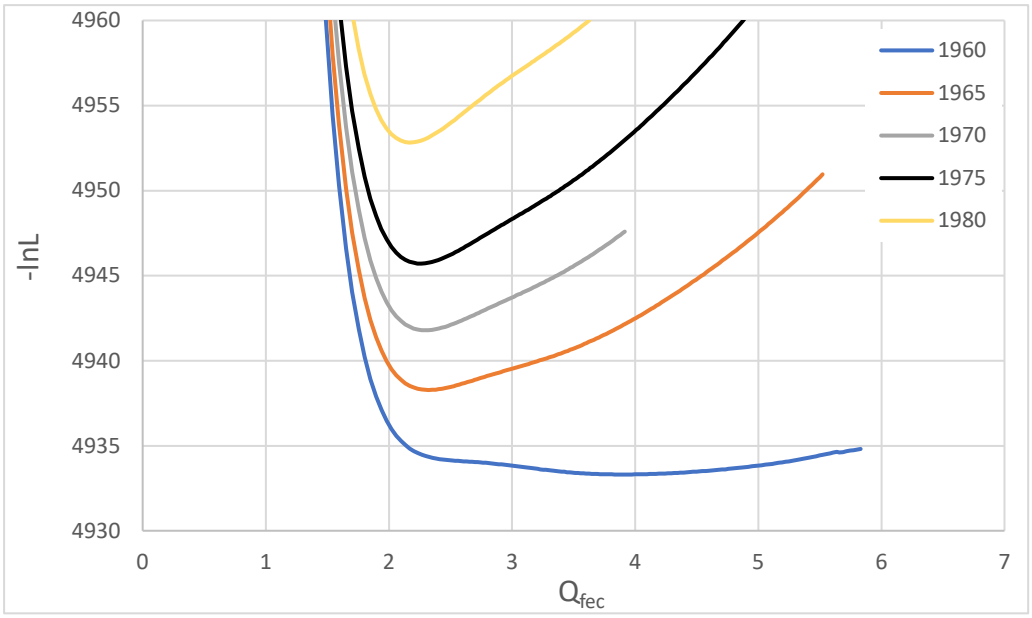


Figure A4.1. NEA spurdog. Likelihood profiles over the density-dependent fecundity parameter Q_{fec} for different starting years for estimating recruitment deviates.

2. Recruitment variation

Recruitment variation is an input parameter (σ_R), which has in the past been set at 0.2. This sensitivity run explored alternative values of σ_R. It was not possible to estimated σ_R (a common problem with this type of model; any attempt would result in an estimate that was at the lower bound. Forcing σ_R to increase to 0.5 and 0.8 led to an overall improvement in likelihood, and especially to the survey indices (Tables A4.3 and A4.4, Figure A4.2), but this was at the expense of fitting to noise rather than signal (and the data for spurdog are quite variable), resulting in recruitment variation that would be questioned for a low-productivity stock such as spurdog (Figure A4.3). Smoother model fits were preferred, and hence σ_R was kept at 0.2.

Table A4.3. NEA spurdog. Difference in likelihood components between σ_R=0.5 and σ_R=0.2. Negative values (shades of blue) indicate an improvement for σ_R=0.5 compared to σ_R=0.2, while positive values (shades of red) indicate a deterioration. "Llsur" are the three survey time-series, "Wpc*Lpcx_allfleets" the weighted commercial data by length category and fleet (length categories: x=2, 3, 4, 5), "Wps*Lpsx_allsurveys" the weighted survey data by length category and survey (length categories: x=1, 2, 3, 4), "LR" the recruitment deviates, "Lpfec_allsamples" the fecundity data by sample year, and "Ltot" the total negative log-likelihood.

Llsur_allsurveys	-6.627	-1.436	-28.154										
Wpc*Lpc2_allfleets	0.051	0.137	-0.650	0.348									
Wpc*Lpc3_allfleets	-2.342	-2.931	0.247	-0.568									
Wpc*Lpc4_allfleets	-0.924	-4.716	0.248	-0.111									
Wpc*Lpc5_allfleets	4.989	4.832	0.115	-1.206									
Wps*Lps1_allsurveys	-5.842	-1.217	0.574										
Wps*Lps2_allsurveys	-2.043	-0.650	-1.603										
Wps*Lps3_allsurveys	-4.299	0.149	-0.752										
Wps*Lps4_allsurveys	-3.067	-2.968	-0.302										
LR	60.628												
Lpfec_allsamples	-2.189	-5.660	-0.569	1.477	-0.810	-2.934	5.594	0.006	-0.695	-0.360	-1.331	-0.311	0.266
Ltot	-7.610												

Table A4.4. NEA spurdog. Difference in likelihood components between σ_R=0.8 and σ_R=0.2. See caption to Table A4.3 for further details.

Llsur_allsurveys	-7.944	-0.979	-41.303										
Wpc*Lpc2_allfleets	0.062	0.210	-1.104	0.497									
Wpc*Lpc3_allfleets	-3.364	-3.682	0.481	-0.734									
Wpc*Lpc4_allfleets	-1.041	-6.475	0.187	-0.101									
Wpc*Lpc5_allfleets	7.426	8.180	0.112	-1.877									
Wps*Lps1_allsurveys	-7.116	-1.506	1.086										
Wps*Lps2_allsurveys	-3.049	-0.685	-1.687										
Wps*Lps3_allsurveys	-5.540	0.026	-1.985										
Wps*Lps4_allsurveys	-3.932	-3.872	0.077										
LR	73.982												
LPfec_allsamples	-3.003	-7.600	-0.775	3.036	-1.176	-4.427	8.918	0.013	-1.582	-0.739	-2.749	-0.601	0.408
Ltot	-15.930												

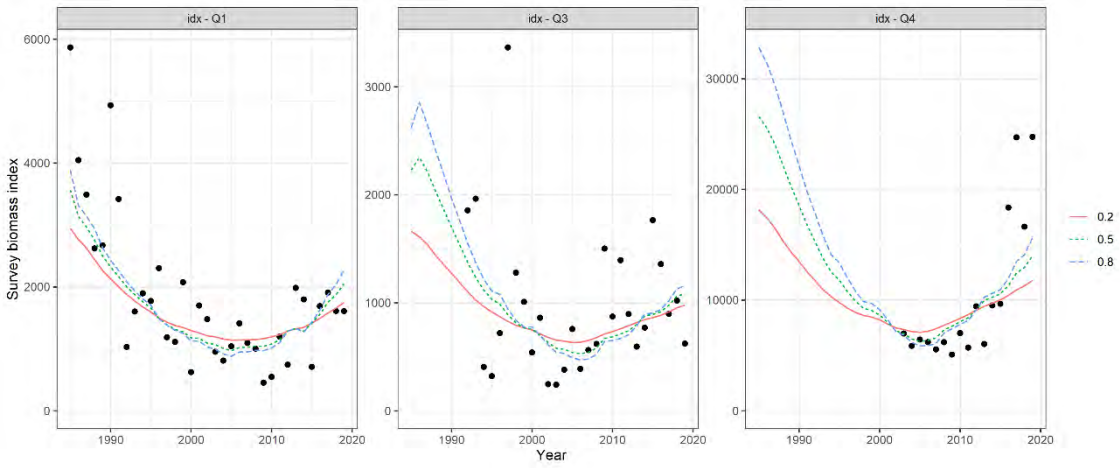


Figure A4.2. NEA spurdog. Fits to the survey indices for the three values of σ_R.

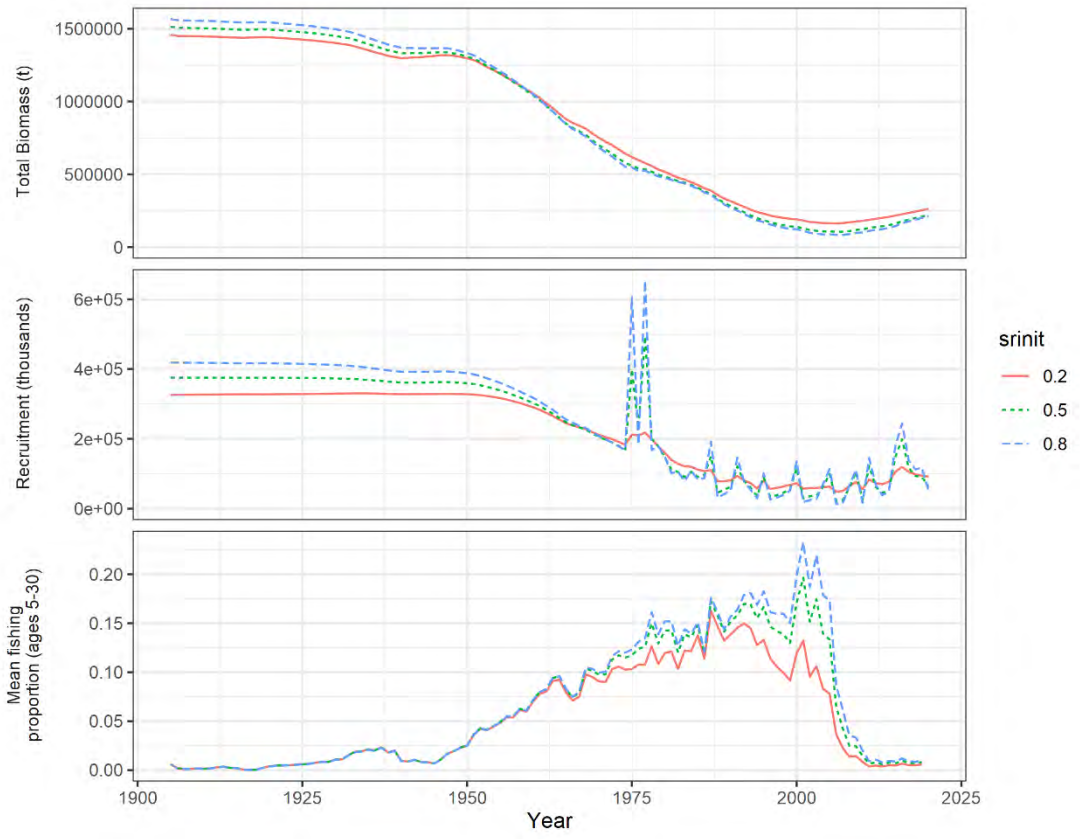


Figure A4.3. NEA spurdog. Total biomass (top), recruitment (middle) and harvest rate (bottom) for the three values of σ_R.

3. Length–frequency data weighting (commercial catch versus survey)

The effective sample size weighting for commercial (20) and survey (10) proportion by length category data previously used followed the recommendation of Punt *et al*. (2001), reflecting the lower sample sizes for surveys relative to commercial catch data. This sensitivity run explored alternative weightings (20–20, 10–10, 10–20). The alternative weightings only had a minor effect on the fit to the survey indices (slight deterioration for all three indices compared to 20–10, apart from a slight improvement for Q4 in the case of 10–10; Figure A4.4), and on population trajectories (Figure A4.5). The original weighting (20–10), following Punt *et al*. (2001), was therefore kept.

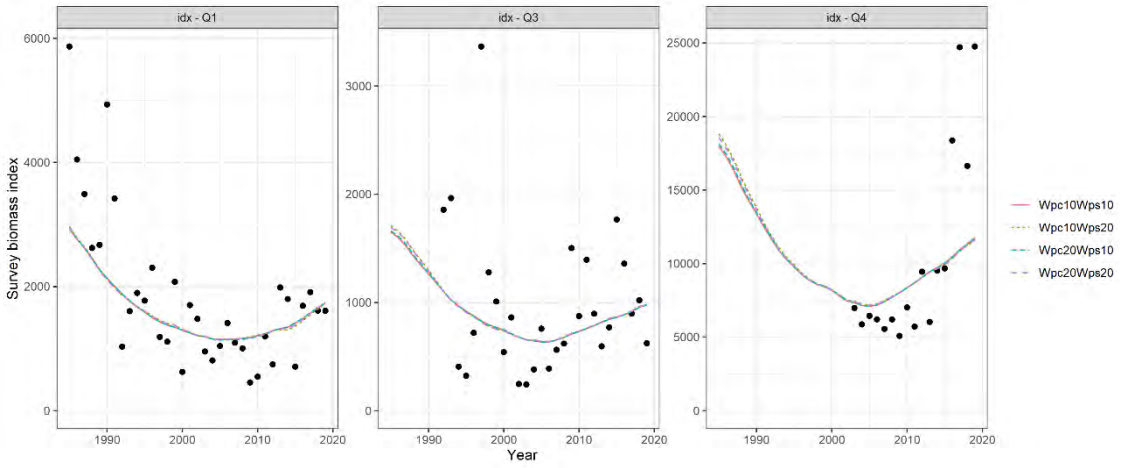


Figure A4.4. NEA spurdog. Fits to the survey indices for alternative weightings (effective sample size) of commercial (Wpc) versus survey (Wps) proportion by length category data.

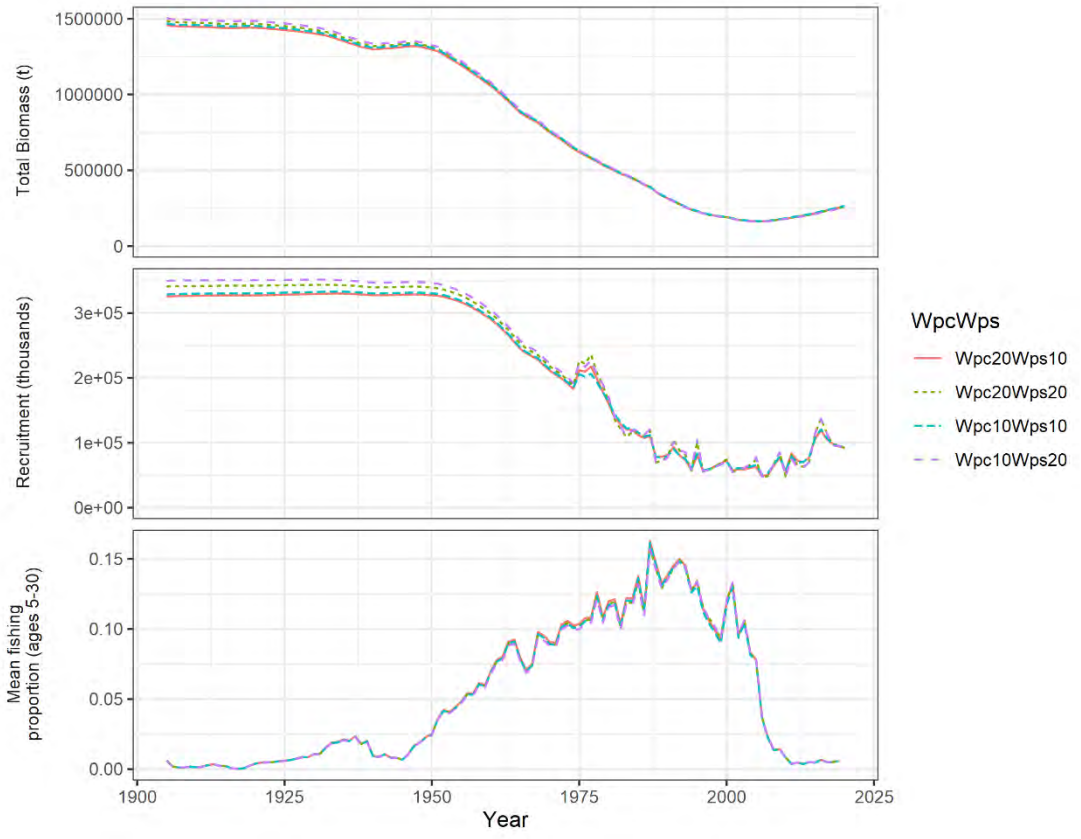


Figure A4.5. NEA spurdog. Total biomass (top), recruitment (middle) and harvest rate (bottom) for the alternative weightings (effective sample size) of commercial (Wpc) versus survey (Wps) proportion by length category data.

4. Survey observation CVs

This sensitivity run compared the use of annually varying survey observation CVs as inputs to the model (the current practice) versus ignoring these and estimating a single variance parameter per survey. Table A4.5 compares the difference between the average of the survey observation CVs and corresponding model-estimated standard deviation, and it is clear that ignoring the input CVs leads to a substantial down-weighting of the survey indices in the assessment, with a substantially poorer fit to the survey indices (Figure A4.6). It is important that the assessment model provides reasonable fits to the survey indices, so the current practice of including survey observation CVs as inputs was kept.

Table A4.5. NEA spurdog. A comparison of the average of the observation CVs per survey index and when observation CVs are ignored, and instead a single variance parameter (expressed as a standard deviation) estimated per survey index.

	Observation CVs (average)	Single variance (sd)
Q1	0.29	0.61
Q3	0.40	0.63
Q4	0.14	0.42

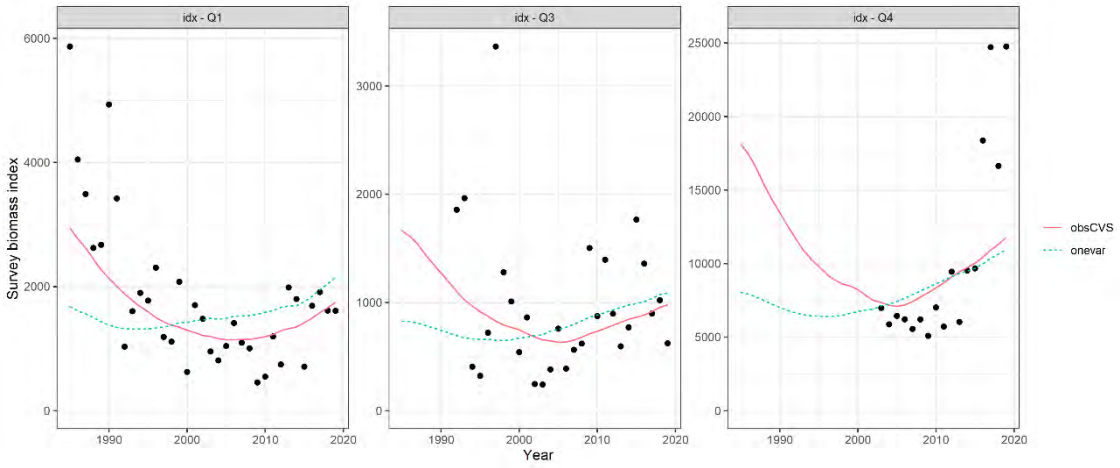


Figure A4.6 NEA spurdog. Fits to the survey indices for when using annually varying observation CVs for each survey index, and when excluding the observation CVs and estimating a single variance parameter per survey index.

5. Surveys included

This sensitivity run looked at including all three surveys versus including only the Q1 survey. Including only the Q1 survey leads to a more pessimistic assessment with higher depletion compared to virgin levels, lower recovery in recent years, and a slightly higher current harvest rate (Figure A4.7). However, the use of the Q1 survey only is not considered realistic because the assessment would then exclude survey indices from important areas of stock distribution (for example, ICES Subarea 7).

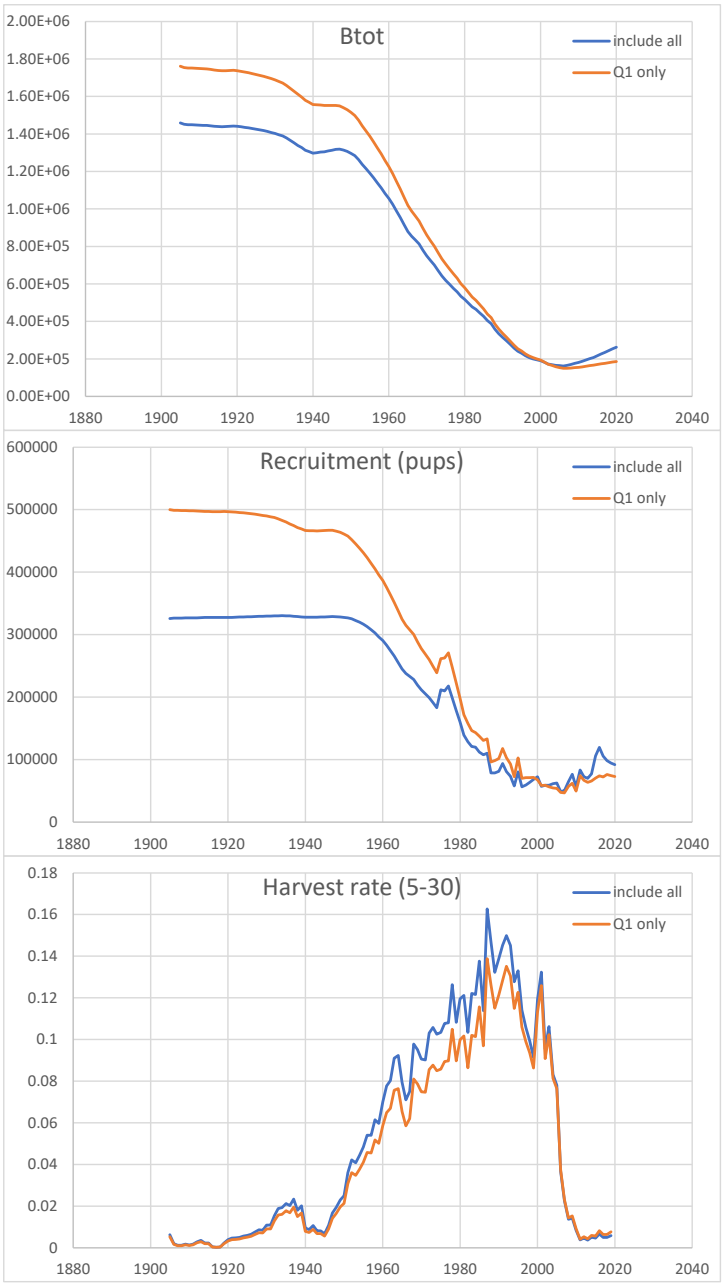


Figure A4.7. NEA spurdog. Total biomass (top), recruitment (middle) and harvest rate (bottom) for when all three surveys are included (blue) and when only the Q1 survey is included (orange).

6. Growth

An area of future improvement for the spurdog model is including variation in the age–length relationship in the model. The lack of progress in this regard during the benchmark (given other areas considered higher priority, such as the substantial improvement in the data now included in the model) meant that it was not possible to explore sensitivity to alternative growth parameterisations. This was because the alternative growth models proposed meant that there were no longer animals in the smallest length classes, leading to zero values which were not possible to deal with during this benchmark.

Annex 5: Stock annexes

The table below provides an overview of the Stock Annexes updated by WKNSEA 2021. Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species,* and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
cod.27.47d20	Cod (*Gadus morhua*) in Subarea 4 and divisions 7.d and 20 (North Sea, eastern English Channel, Skagerrak)	March 2021	Cod in 27.47d20
dgs-nea	Spurdog (*Squalus acanthia*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	March 2021	NEA Spurdog
sol.27.7d	Sole (*Solea solea*) in Division 7.d (eastern English Channel)	Update in preparation for WGNSSK in May 2021	Sole in 27.7d From 2019
whg.27.6a	Whiting (*Merlangius merlangius*) in Division 27.6.a (West of Scotland)	March 2021	Whiting in 27.6a

Annex 6: Working documents

The list of working documents below were presented at WKNSEA 2021 and are inserted in full in this annex.

Cod

Summary of InterCatch data for North Sea Cod; Nicola D. Walker, *et al*.

Commercial catch data collation and relative survey-based trends for North Sea cod substocks.

Survey Indices and Abundance Maps for North Sea Cod; Nicola D. Walker and Casper W. Berg.

North Sea cod survey indices; Casper W. Berg.

Maturity ogives for North Sea cod; Nicola D. Walker.

Weights-at-age of North Sea cod; Nicola D. Walker.

Recreational cod catches in the North Sea and Skagerrak; Mike Armstrong, Simon Weltersbach, Zachary Radford, and Kieran Hyder.

Process model for biological parameters in SAM; Anders Nielsen.

Sole

Belgian commercial beam trawl landings data for sole in the eastern English Channel (ICES Division 27.7.d); Klaas Sys, Bart Vanelslander, Sofie Nimmegeers and Lies Vansteenbrugge.

Preparation of catch data for sole (*Solea solea*) in Division 27.7.d (eastern English Channel); Lies Vansteenbrugge and Sofie Nimmegeers.

Revision of the Belgian commercial beam trawl tuning fleet for Sole in the Eastern English Channel (27.7.d); Klaas Sys and Lies Vansteenbrugge.

Commercial LPUE from French Otter Trawlers for sol.27.7d stock assessment; Raphael Girardin.

Revision of the UK (E&W) beam trawl survey (BTS) index for sole in the eastern English Channel (ICES division 27.7.d); Klaas Sys and Lies Vansteenbrugge.

Assessment runs for sole in the eastern English Channel (ICES division 27.7.d); Lies Vansteenbrugge and Klaas Sys.

Calculation of appropriate reference points (MSY) for sole in Division 27.7.d; Lies Vansteenbrugge and Klaas Sys.

Spurdog

Survey indices for Northeast Atlantic spurdog; Helen Dobby.

Growth parameters for spurdog *Squalus acanthias*; Ellis, J. R. and De Oliveira, J. A. A.

Contemporary length–frequency data for spurdog *Squalus acanthias*; Ellis, J. R. and De Oliveira, J. A. A.

A summary of spurdog (*Squalus acanthias*) data collected during the Norwegian Shrimp trawl survey (NO-shrimp); Claudia Junge, Caroline A Tranang, Tone Vollen, Ole Thomas Albert.

A summary of spurdog (*Squalus acanthias*) landings and discards data collated; Claudia Junge.

Life-history parameters of North-east Atlantic spurdog *Squalus acanthias*; Silva, J. F. and Ellis, J. R.

Whiting

Catch data for whiting in Division 6.a (West of Scotland); Andrzej Jaworski and Helen Dobby.

New combined Q4 index for whiting in Division 6.a; Andrzej Jaworski and Helen Dobby.

Estimation of the maturity ogive for whiting in Division 6.a; Andrzej Jaworski.

Review of natural mortality estimates and stock weights-at-age for whiting in division 6a; Alan Ronan Baudron, Niall Fallon, Andrzej Jaworski, Tanja Miethe and Helen Dobby.

Survey-based analyses with SURBAR for whiting in Division 6a; Andrzej Jaworski.

SAM assessment model for whiting in Division 6a (West of Scotland); Niall G. Fallon, Tanja Miethe, Anders Nielsen, and Helen Dobby.

Length-based indicators for whiting in Division 6.a (West of Scotland); Tanja Miethe, Andrzej Jaworski, Helen Dobby.

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), Online, 24–26 November 2020

Summary of InterCatch data for North Sea Cod (COD)

Nicola D. Walker and many others

Introduction

Following the recommendations of the ICES Workshop on Stock Identification of North Sea Cod (WKNSCodID; ICES 2020) the data call for WKNSEA 2021 requested national data disaggregated by ICES division (4.b, 4.c, 7.d) and subdivision (4.a.E, 4.a.W, 3.a.20) as far back in time as possible, in order to consider spatial approaches to stock assessment. This necessitated the creation of a new cod 'stock' in InterCatch (CDZ) so as not to overwrite the existing time series of data for the current assessment and definition of the stock (COD). Given the focus on finer-scale disaggregation of data for CDZ, and aside from corrections to Swedish landings in Subarea 4 in 2019, no new data were submitted or raised for COD. Hence this document describes the current raising procedures for North Sea cod (COD) and any changes since the last benchmark (ICES, 2015).

Catch data for 2002–2019

InterCatch was used for estimation of landings age composition, as well as the estimation of both discards numbers and age composition. Each year, data co-ordinators input data for their nation into InterCatch, disaggregated by area (4, 3.a.20 and 7.d), quarter and métier. The data from Norway excludes Norwegian coastal cod. Tables 1–2 and Figure 1 summarise the data that have been imported into InterCatch while Table 3 indicates the level of discard ratio coverage of the landings, together with the age coverage of both the landings and observed discards. Allocations of discard ratios and age compositions for unsampled strata are then performed to obtain the data required for the assessment.

The approach used for discard ratio allocations is to do it by area (4, 3.a.20 and 7.d) and treat FDF métiers separately (note, FDF métiers were not available prior to 2009 and there have been very few FDF métiers since termination of the cod specific FDF scheme at the end of 2016), giving six broad categories (only three prior to 2009 and from 2017). Annual discards are first matched to quarterly landings. Then, within each of these six categories, ignoring country and season, where métiers have adequate samples these are pooled and allocated to unsampled records within that métier; this is done only for the most important métiers (those with greater than 1% of the landings in Subarea 4, 2.5% in Subdivision 3.a.20, and 5% in Division 7.d). At the end of this process, any remaining métiers are allocated an all-samples pooled discard ratio for the given area. Because no discard sampling was available for area 7.d in 2002-3, and only minimal age-sampling, areas 4 and 7.d were combined in these years. Table 4 shows the volumes and proportions of discards that were either imported to InterCatch or raised.

A similar approach is used for allocating age compositions, except that there are 12 broad categories (only six prior to 2009 and from 2017) because discards are treated separately to landings. Since 2017, there has been no sampling of discards in 7.d, so discard age allocations were based on

Subarea 4. Table 5 shows the volumes and proportions of landings, discards and BMS landings either input with age distributions or with age distributions estimated following the allocation scheme.

The final estimates of landings, discards (including BMS landings) and catches for 2002–2019 are shown in the total columns of Table 4 while Figures 2–3 show the catches (split into landings and discards) and mean weights that form the basis of the assessment.

The InterCatch raising procedure is a laborious one for NS cod, each year taking anything from 1.5 to 4 hours to complete (depending on number of strata and difficulties encountered). Furthermore, it is currently not possible to save the discard ratio allocations (although age allocations can be saved) – this, combined with the length of time for raising, makes simple sensitivity testing difficult to achieve in InterCatch.

Changes to management

Since the last benchmark (ICES, 2015) there have been several changes to management that may affect catches of North Sea cod and the subsequent raising of catch data (see Stock Annex for details of the below measures):

- The Scottish Conservation Credits scheme was suspended on 20 November 2016.
- The cod specific FDF scheme was terminated at the end of 2016. While some FDF métiers still report catches of North Sea cod, it is no longer possible to allocate discard ratios and ages separately as there has been no sampling of these métiers.
- The days-at-sea regulation, which was part of the cod recovery plan (EC 1342/2008), was discontinued in 2017 (EC 2094/2016).
- The EU landing obligation was implemented from 1 January 2017 for several gears, including otter trawlers with >100mm mesh, beam trawlers >120mm mesh and fixed gears. From 2018, cod is fully under the EU landing obligation in Subarea 4 and Subdivision 3.a.20. The landing obligation introduced two new catch categories to InterCatch: BMS landing and Logbook Registered Discard. So far, all logbook registered discards uploaded to InterCatch have been zero. BMS landings uploaded to InterCatch are currently negligible (Table 1) and are raised with discards as unwanted catch.

References

ICES. 2015. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 2–6 February 2015, Copenhagen, Denmark. ICES CM 2015/ACOM:32. 253 pp.

ICES. 2020. Workshop on Stock Identification of North Sea Cod (WKNSCodID). ICES Scientific Reports. 2:89. 82 pp. http://doi.org/10.17895/ices.pub.7499

Tables

Table 1: Imported landings, discards and BMS landings by area.

	27.4				27.3.a.20				27.7.d			Total			
Year	Landings	Discards	BMS	%Discards	Landings	Discards	BMS	%Discards	Landings	Discards	%Discards	Landings	Discards	BMS	%Discards
2002	42193	3184		7.0	6854	3041		30.7	3139		0.0	52187	6224		10.7
2003	24083	1682		6.5	3979	816		17.0	2131		0.0	30194	2498		7.6
2004	22529	2454		9.8	3914	2295		37.0	1014	19	1.8	27457	4767		14.8
2005	22855	3078		11.9	3998	2809		41.3	1259	33	2.6	28113	5920		17.4
2006	21078	3681		14.9	3258	3884		54.4	1479	34	2.2	25815	7599		22.7
2007	19056	13496		41.5	3020	3467		53.4	2147	93	4.2	24223	17056		41.3
2008	21657	13252		38.0	3393	1623		32.4	1629	250	13.3	26679	15125		36.2
2009	27634	7742		21.9	3794	2614		40.8	1887	3701	66.2	33315	14057		29.7
2010	30980	7496		19.5	4057	1660		29.0	1708	279	14.0	36746	9435		20.4
2011	26675	4782		15.2	3956	1656		29.5	1319	375	22.1	31950	6813		17.6
2012	26627	4523		14.5	4327	1561		26.5	1120	80	6.7	32074	6164		16.1
2013	25315	6329		20.0	4154	1310		24.0	916	97	9.6	30386	7737		20.3
2014	28550	5170		15.3	4687	1701		26.6	1436	526	26.8	34673	7398		17.6
2015	31244	7587		19.5	4563	2315		33.7	1398	16	1.1	37205	9918		21.0
2016	33035	8514	10	20.5	4774	1318	0.0	21.6	421	56	11.8	38230	9888	10	20.6
2017	33109	6781	16	17.0	4715	663	0.0	12.3	170	5	3.0	37994	7449	16	16.4
2018	34444	5387	26	13.6	5484	785	0.5	12.5	84	0	0.0	40012	6172	26	13.4
2019	28558	2463	30	8.0	3478	288	0.0	7.7	36	0.03	0.1	32072	2751	30	8.0

Table 2: Imported landings and discards (including BMS landings from 2016) by country. Countries reporting < 1 tonne are excluded.

Year	Belgium	Denmark	Faroe Islands	France	Germany	Netherlands	Norway	Sweden	UK (England)	UK(Scotland)
Imported landings										
2002	2673	15049		4919	2095	4114	3639	1336	3222	15140
2003	1538	8050		2555	1985	2070	3324	749	2319	7604
2004	1673	9292		1143	2216	1574	2418	721	1980	6440
2005	1774	9674		1520	2649	1509	2160	795	1452	6579
2006	1389	7919		1506	2551	1469	1903	681	1759	6637
2007	1086	5932		2508	1974	1529	2405	758	1627	6403
2008	1037	6635	16	2144	1792	1916	3681	804	1691	6963
2009	943	7788	44	3281	2439	2650	3756	837	2125	9452
2010	741	9318	32	2026	2927	2670	3963	822	1855	12393
2011	712	8285		1704	2283	2005	3746	796	1488	10930
2012	905	8287		1322	2462	1873	3939	991	1222	11072
2013	1124	7839		1013	1989	1140	3617	860	815	11988
2014	1324	9190		1865	2341	1300	4055	969	967	12663
2015	1302	9647		1693	2221	1389	4921	994	1414	13625
2016	1145	10494		666	2177	1392	5186	1014	757	15398
2017	712	10082		484	2381	655	5145	947	397	17191
2018	825	10008		602	1596	556	5347	948	351	19780
2019	726	7911		462	864	738	4683	702	213	15771
Imported discards (including BMS)										
2002		3867			76			293	492	1496
2003		1144			32			67	197	1058
2004	116	1930			318			837	297	1270
2005	253	3106			71			1191	156	1143
2006	705	4259			33			583	376	1644
2007	273	4355			25			273	214	11916
2008	1502	1588	13		39			420	495	11068
2009	246	2955	20	3663	17			282	130	6744
2010	108	1915		259	69			170	246	6669
2011	12	1722		43	290	242		158	397	3949
2012	11	1570		68	29	162		285	525	3513
2013	407	1290		90	10	128		440	89	5282
2014	104	1186		438	52	54		782	236	4546
2015	59	2102		4	9	170		531	81	6960
2016	214	1486		37	4	13	10	259	109	7764
2017	8	798		17	16	11	16	78	30	6493
2018	2	778		20	16	13	6	151	11	5201
2019	26	376		4	5	37		27	37	2268

Table 3: Proportion of landings (as a percentage) taken in each of the three areas together with discard ratio coverage of the landings, age coverage of the landings and age coverage of the observed discards. Shaded cells indicate where there has been less than 50% coverage.

	Landings proportions (%)			Discard ratio coverage			Landings age coverage			Discards age coverage		
Year	4	3.a.20	7.d	4	3.a.20	7.d	4	3.a.20	7.d	4	3.a.20	7.d
2002	81	13	6.0	50%	73%	0%	64%	83%	0%	88%	69%	0%
2003	80	13	7.1	57%	67%	0%	59%	93%	3%	88%	42%	0%
2004	82	14	3.7	54%	67%	6%	68%	93%	7%	81%	94%	100%
2005	81	14	4.5	58%	55%	5%	75%	91%	4%	81%	82%	100%
2006	82	13	5.7	75%	66%	6%	77%	91%	14%	85%	96%	100%
2007	79	12	8.9	58%	60%	5%	71%	90%	11%	99%	92%	100%
2008	81	13	6.1	65%	59%	10%	73%	89%	16%	95%	100%	100%
2009	83	11	5.7	57%	85%	81%	72%	95%	80%	97%	93%	100%
2010	84	11	4.6	70%	77%	81%	80%	95%	84%	100%	90%	100%
2011	83	12	4.1	75%	83%	74%	72%	95%	74%	93%	90%	100%
2012	83	13	3.5	70%	79%	77%	79%	88%	81%	96%	89%	100%
2013	83	14	3.0	76%	75%	78%	82%	88%	81%	92%	96%	97%
2014	82	14	4.1	69%	75%	83%	78%	90%	84%	99%	100%	100%
2015	84	12	3.8	72%	75%	83%	80%	89%	86%	95%	97%	100%
2016	86	12	1.1	80%	75%	71%	82%	92%	51%	97%	79%	88%
2017	87	12	0.4	76%	84%	57%	82%	69%	37%	99%	100%	0%
2018	86	14	0.2	76%	81%	51%	87%	93%	17%	99%	96%	0%
2019	89	11	0.1	76%	76%	43%	88%	96%	39%	94%	98%	0%

Table 4: The volumes (and associated proportion) of landings, discards and BMS landings that were imported or raised.

Year	Wanted	Unwanted					Total Catch	Discard rate
	Landings	Imported	Raised	%Raised	BMS	Total		
2002	52187	6224	5686	47.7		11911	64098	18.6
2003	30194	2498	1583	38.8		4081	34274	11.9
2004	27457	4767	4035	45.8		8802	36259	24.3
2005	28113	5920	4167	41.3		10087	38200	26.4
2006	25815	7599	4412	36.7		12011	37826	31.8
2007	24223	17056	13394	44.0		30450	54673	55.7
2008	26679	15125	9955	39.7		25080	51759	48.5
2009	33315	14057	6907	32.9		20965	54280	38.6
2010	36746	9435	3054	24.5		12488	49234	25.4
2011	31950	6813	1932	22.1		8745	40695	21.5
2012	32074	6164	2526	29.1		8689	40763	21.3
2013	30386	7737	2588	25.1		10324	40710	25.4
2014	34673	7398	3268	30.6		10666	45339	23.5
2015	37205	9918	2645	21.1		12562	49767	25.2
2016	38230	9888	2417	19.6	10	12315	50544	24.4
2017	37994	7449	1266	14.5	16	8731	46725	18.7
2018	40012	6172	1626	20.8	26	7824	47836	16.4
2019	32072	2751	826	22.9	30	3607	35679	10.1

Table 5: The volumes (and associated proportion) of landings, discards and BMS landings with age distributions sampled or estimated.

Year	Landings			Discards				BMS			Total		
	Sampled	Estimated	%Estimated	Sampled	Estimated	Raised	%Estimated	Sampled	Estimated	%Estimated	Sampled	Estimated	%Estimated
2002	32859	19328	37.0	4900	1324	5686	58.9				37759	26338	69.8
2003	17887	12307	40.8	1829	669	1583	55.2				19716	14558	73.8
2004	19063	8394	30.6	4175	593	4035	52.6				23238	13022	56.0
2005	20711	7402	26.3	4810	1110	4167	52.3				25521	12679	49.7
2006	19402	6412	24.8	6885	714	4412	42.7				26287	11539	43.9
2007	16536	7687	31.7	16680	376	13394	45.2				33216	21457	64.6
2008	19164	7515	28.2	14495	630	9955	42.2				33659	18101	53.8
2009	25098	8217	24.7	13644	414	6907	34.9				38742	15538	40.1
2010	30228	6518	17.7	9238	196	3054	26.0				39466	9768	24.8
2011	23815	8135	25.5	6294	519	1932	28.0				30109	10586	35.2
2012	25821	6253	19.5	5798	366	2526	33.3				31619	9144	28.9
2013	25299	5087	16.7	7106	630	2588	31.2				32405	8305	25.6
2014	27838	6835	19.7	7336	62	3268	31.2				35174	10165	28.9
2015	30134	7071	19.0	9467	451	2645	24.6				39601	10166	25.7
2016	31948	6281	16.4	9353	535	2417	24.0	0.0	10.1	100.0	41301	9243	22.4
2017	30785	7209	19.0	7422	28	1266	14.8	0.0	16.1	100.0	38207	8518	22.3
2018	36434	3578	8.9	6104	68	1626	21.7	0.8	25.4	96.9	42539	5297	12.5
2019	28565	3507	10.9	2697	54	826	24.6	29.7	0.3	1.0	31292	4388	14.0

Figures

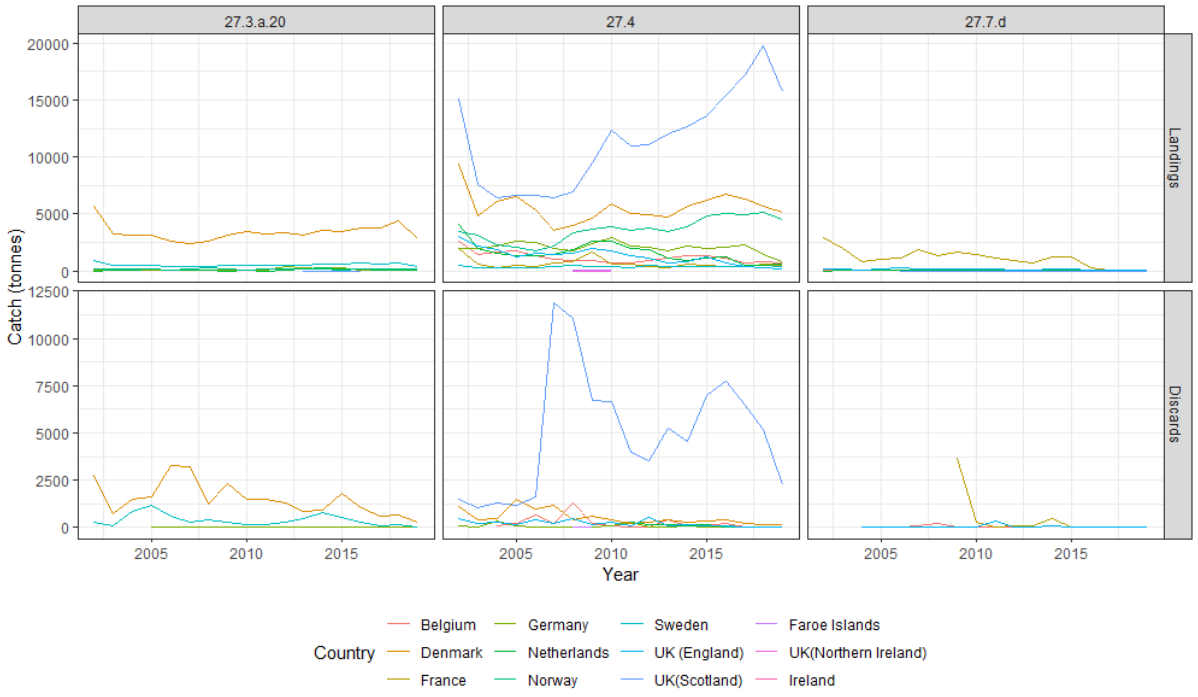


Figure 1: Imported landings and discards (including BMS landings from 2016) by country.

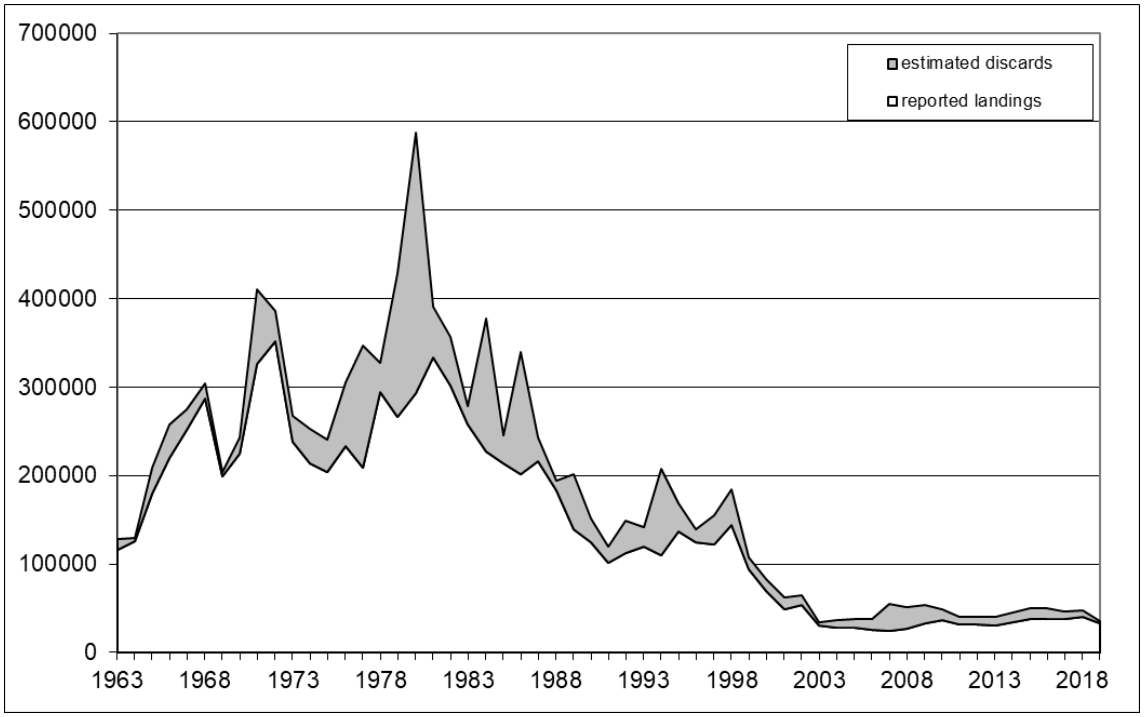


Figure 2: Stacked area plot of reported landings and estimated discards (including BMS landings; in tonnes).

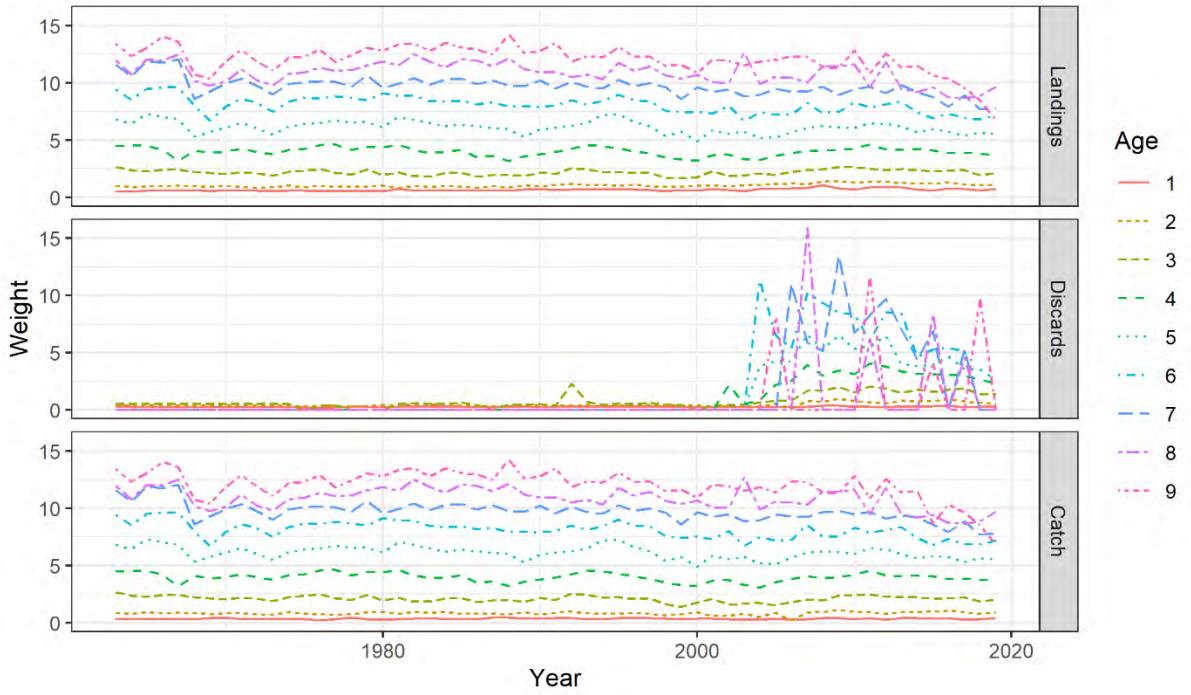


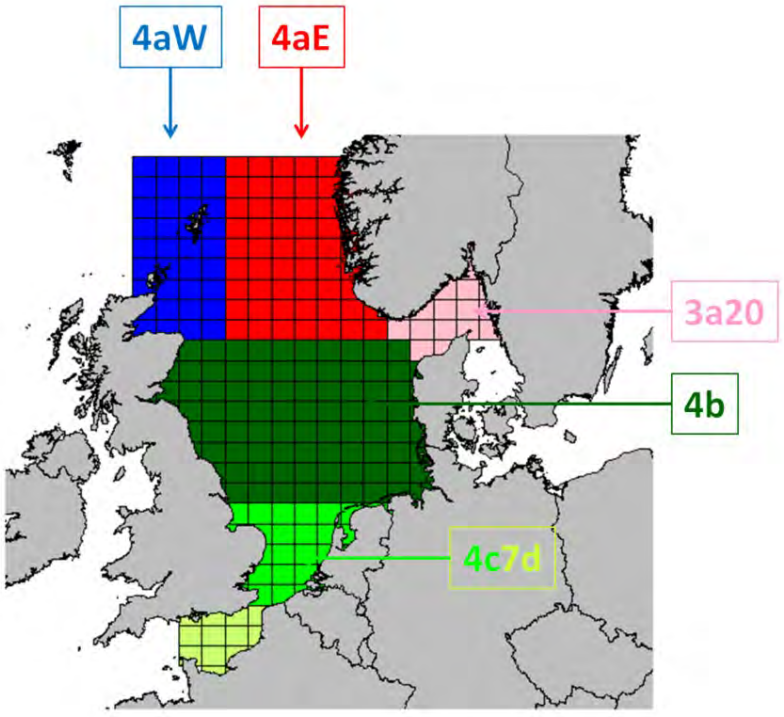
Figure 3: Mean weights-at-age in the landings, discards and catch.

WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod substocks

1 Background

The ICES WKNSCodID meeting (ICES 2020a) concluded that the most biologically plausible split for the North Sea cod stock was between Viking (4aE) and Dogger (4aW, 4b, 4c7d, 3a20) cod (see Figure 1), and developed a data call for the subsequent benchmark data compilation meeting DEWK (ICES 2020b) to collate catch and survey data separately for the 4aE, 4aW, 4b, 4c7d, and 3a20 areas. This has given rise to two separate InterCatch "stocks": COD, which is the current stock object covering the full North Sea; and CDZ, which is a separate stock object covering the areas determined for DEWK. This section presents the current situation with the collation of the CDZ stock object, before going on to cover survey-based trends for the northwest (4aW), Viking (4aE) and south (4b, 4c7d, and 3a20) areas.

Figure 1. North Sea cod data areas as stipulated by ICES WKNSCodID (ICES 2020a).



2 Commercial catch data collation

Following WKNSCodID, the data call published by ICES asked for data for "as many years as possible". The call was addressed by all nine relevant coastal nations (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, UK (England), UK(Scotland)), and data were received for the years 2002-2019. Data on both age and length were provided, although only age coverage is considered here as any subsequent assessment is likely to be based at least in part on age.

Data coverage by catch category (landings, discards), area and year was highly variable, with data provision being relatively sparse in the earlier years. Table 1 summarises the number of age samples submitted for different categories, countries and areas for 2019 (the most recent year) and 2002 (the

first year with age samples). In 2019, both landings and discards age sampling were reasonable for all areas except 4c and 7d. In contrast, the number of age samples was reasonable for landings and discards probably only for 3a20 and 4b – we also note that the number of countries submitting data was much less for 2002.

Table 1. Summary of the number of submitted age measurements by catch category (B = below minimum size bycatch, D = discards, L = landings), country and area, for 2019 (top) and 2002 (bottom).

Sum of NumAgeMeasurement	Column Labels						
Row Labels	27.3.a.20	27.4.a.e	27.4.a.w	27.4.b	27.4.c	27.7.d	Grand Total
B			**36**				**36**
UK(Scotland)			36				36
D	**2115**	**1783**	**1234**	**1333**			**6465**
Belgium				173			173
Denmark	1212	482					1694
France		0	0				0
Germany		909		538			1447
Sweden	903						903
UK (England)				364			364
UK(Scotland)		392	1234	258			1884
L	**23693**	**6144**	**1170**	**10360**	**118**	**9**	**41494**
Belgium				256		9	265
Denmark	10608	3456		6670			20734
France		0	0				0
Germany	130	2098		1534			3762
Netherlands					115		115
Sweden	12955						12955
UK (England)				1765	3		1768
UK(Scotland)		590	1170	135			1895
Grand Total	**25808**	**7927**	**2440**	**11693**	**118**	**9**	**47995**

Sum of NumAgeMeasurement	Column Labels					
Row Labels	27.3.a.20	27.4.a.e	27.4.b	27.4.c	27.7.d	Grand Total
D	**1042**	**280**	**1105**			**2427**
Denmark	1042	280	205			1527
Germany			900			900
Sweden	0					0
UK (England)			0			0
L	**40349**	**811**	**52379**	**1769**	**808**	**96116**
Denmark	40349		31382			71731
Germany		811	1114			1925
Netherlands			317	1072		1389
UK (England)			19566	697	808	21071
Grand Total	**41391**	**1091**	**53484**	**1769**	**808**	**98543**

Figure 2 summarises the number of age measurements by area, year and catch component. For area 4aE, landings were poorly sampled before 2003, and discards were poorly sampled before 2008. In 4aW, the first years of good age-sampling were 2005 (for landings) and 2008 (for discards). Landings were reasonably well sampled for age in area 4b, although there were no discard age samples in 4b before 2002. Area 4c had reasonable landings samples until 2015 (which may reflect declining abundance in the southern NS), and no discards samples before 2003 or after 2014. 3a20 was by far the most well-sampled area, although with neither landings nor discards age samples before 2002. Finally, area 7d had reasonable landings age-samples until 2011, and no discards age-samples before 2004 or after 2014.

Figure 2. Number of submitted InterCatch age measurements, by area, catch component and year.

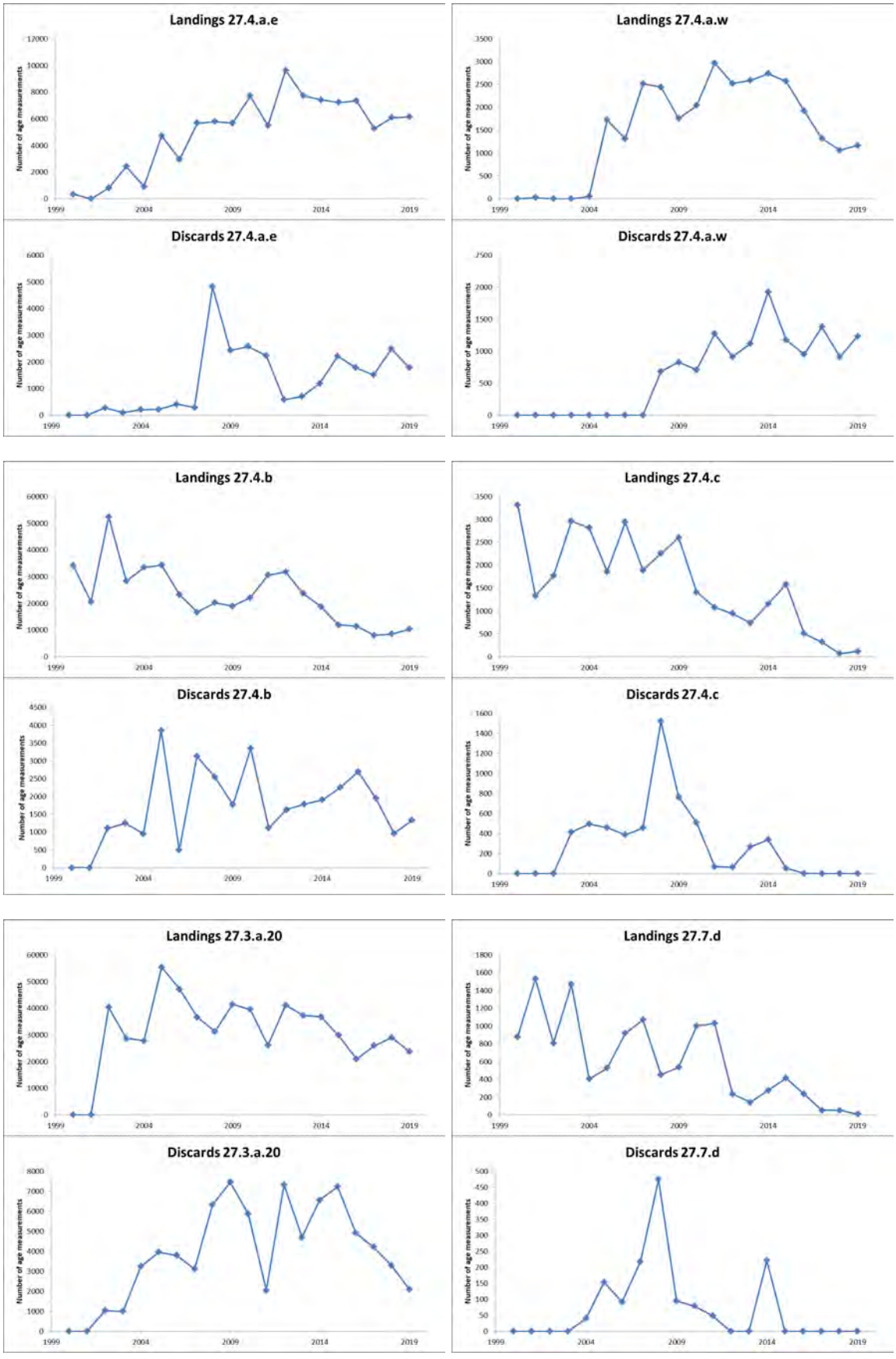
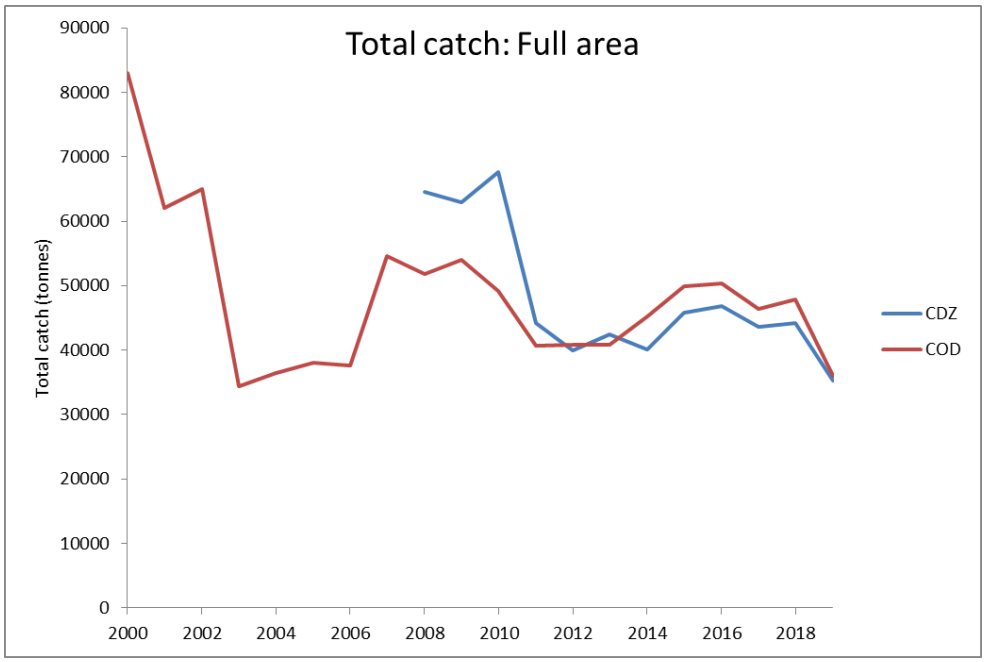


Figure 3 compares the total estimated catch across the full NS area following InterCatch allocations and raising, for both COD and CDZ stock objects. InterCatch data collation for each area and year is still proceeding at the time of writing, so this remains a work in progress, but it can be seen already that the total catch is not the same for COD and CDZ – and it should be. This issue will need to be addressed in future work.

Figure 3. Total catch across the full NS area, as estimated through InterCatch for the COD and CDZ stock objects.



The DEWK meeting determined that there was unlikely to be sufficient catch data yet in the CDZ stock to enable full catch-based assessments for the separate stock areas. Data had been submitted from 2002 onwards only, and was only really representative from 2008 onwards. DEWK concluded that the length and coverage of the CDZ dataset was not sufficient to consider replacing the extant full-stock NS cod assessment with substock alternatives, and the main benchmark meeting was therefore to focus on the full-stock assessment.

However, it remains the case that there are biologically significant differences between (in particular) the Viking substock and the rest, and there are clear linkages between the North Sea stock(s) and the northern West of Scotland stock: neither of these points is reflected in the current full-stock assessment. A longer-term project is being planned to attempt to address these issues through a more holistic spatial assessment approach covering the North Sea *and* neighbouring areas.

3 Area-specific survey indices

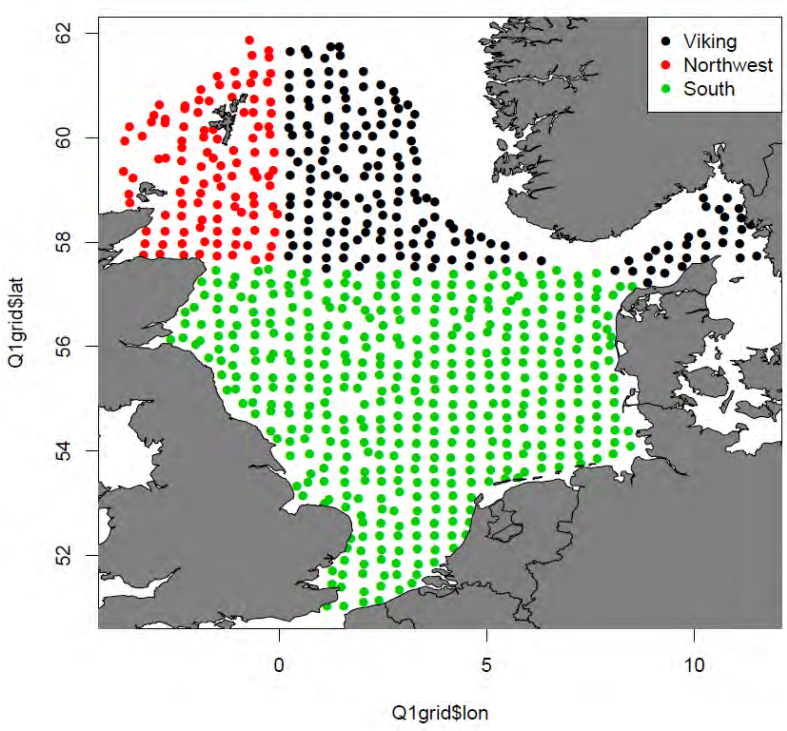
The current North Sea cod WG report and advice both include a survey-based biomass comparison between different areas. It is therefore relevant to consider new, updated survey-based assessments of the separate substock areas.

Three methods were considered of generating substock-specific survey indices, fitted a survey-based assessment model (SURBAR) to each, and considered further how the outputs could be used to provide management advice should that prove necessary. The conclusions were similar across the

methods, however, and only the third approach presented by Needle (WD XXX) will be considered here.

Survey indices by age were generated for three areas: north-west (area 4aW), Viking (areas 4aE and 3a20) and south (areas 4b, 4c and 7d); see Figure .4. This grouping retains the split between Viking and Dogger cod that was indicated by WKNSCodID, and also includes the north-south split within Dogger cod for which there was some weaker evidence at WKNSCodID. For each area, indices for both IBTS Q1 and Q3 were generated. The method used here is the same as the new approach agreed by WKNSEA, and presented in Section XXX.

Figure .4. Substock areas used for survey-index generation.



4. Survey-based assessments using SURBAR

The SURBAR method (Needle 2015) was used to generate estimates of total mortality *Z*, and relative mean-standardised estimates of SSB, TSB and recruitment, for each of the three areas separately (using indices from both Q1 and Q3). SURBAR applies a separable model to the survey index, and requires assumptions about catchability at age *q* (determined by scrutiny of catch curves) and an *ad hoc* smoothing parameter λ. In these analyses, the smoothing parameter $\lambda = 5.0$, and *q* was defined as follows:

- Northwest: $q_a = (0.01, 0.5, 1, \dots)$
- Viking: $q_a = (0.5, 1, 1, \dots)$
- South: $q_a = 1$

5 Results

Figures 5 – 7 give the SURBAR summary plots for the north-west, Viking and south areas respectively, while Figure 8 compares the summaries directly. It can be seen that:

- The mean total mortality Z_{2-4} is quite similar between the three areas, particularly when the wide uncertainty bounds around Z_{2-4} is considered.
- The relative SSB estimates show considerable differences between the areas. In the north-west, relative SSB maintained a fairly constant level from 1983 until around 2010. It rose rapidly to reach a peak in 2017, before declining again towards the end of the time-series. In the Viking area, SSB declined slowly from 1983 to 2006, before rising to a peak in 2016 and declining again. The peaks of SSB in the south, however, were in the late 1980s and in 1990, and SSB has since declined to a low level during recent years.
- The relative recruitment estimates in the north-west show little trend, with rapid fluctuation throughout the time-series apart from 5 low years during the 2000s. For the Viking area, recruitment started at a higher level before undergoing what appears to be a regime shift in 1998 to a lower mean level. This pattern is replicated in a more extreme form in the south, where recruitment has been extremely low since 1998.

Needle (WD XXX) presented an *ad hoc* attempt to infer biomass MSY proxy reference points for survey-based assessments from the relationship between the geometric mean of SSB in the full ICES assessment and the accepted B(msy) reference point. While this needs further development, the comparison of the most recent SSB estimate with the time-series geometric mean remains a valid comparison of the relative state of the cod stock in different areas. The SSB plots in Figures 5 – 7 therefore tabulate the time-series geometric mean and the final-year estimate of relative SSB. In the north-west region, the last-year SSB estimate (1.006) is greater than the geometric mean (0.888), with a ratio of 113%. In the Viking area, the last-year SSB (0.681) is less than the geomean (0.981), with a ratio of 69%; and in the south, the ratio is 39% (final-year SSB = 0.367, geomean = 0.93). We should not conclude too much from this, but the results indicate that the north-west area is likely to be in a better position in relation to plausible biomass reference points than the Viking or south areas.

Figure 5. SURBAR assessment results for the northwest cod substock. Plots give the best (NLS) estimate, the bootstrap mean and median, and a 90% confidence interval. SSB, TSB and recruitment at age 1 are mean-standardised. The SSB plot (top right) includes the geometric mean (red line), and a short table giving the geometric mean and the final-year SSB estimate.

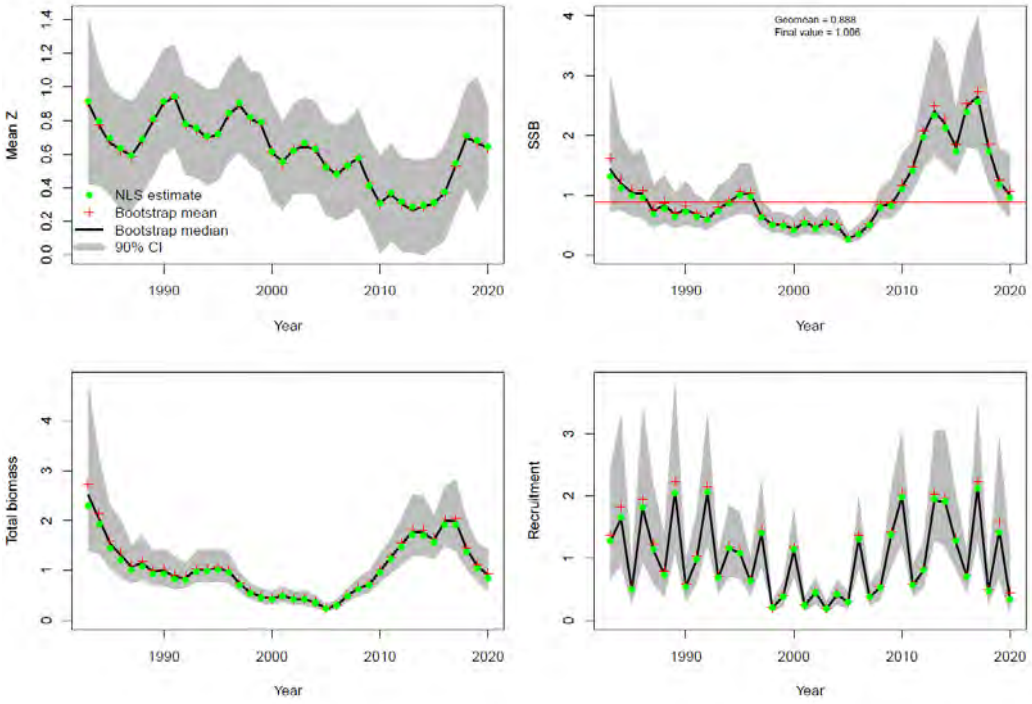


Figure 6. SURBAR assessment results for the Viking cod substock. For details see the caption for Figure 5.

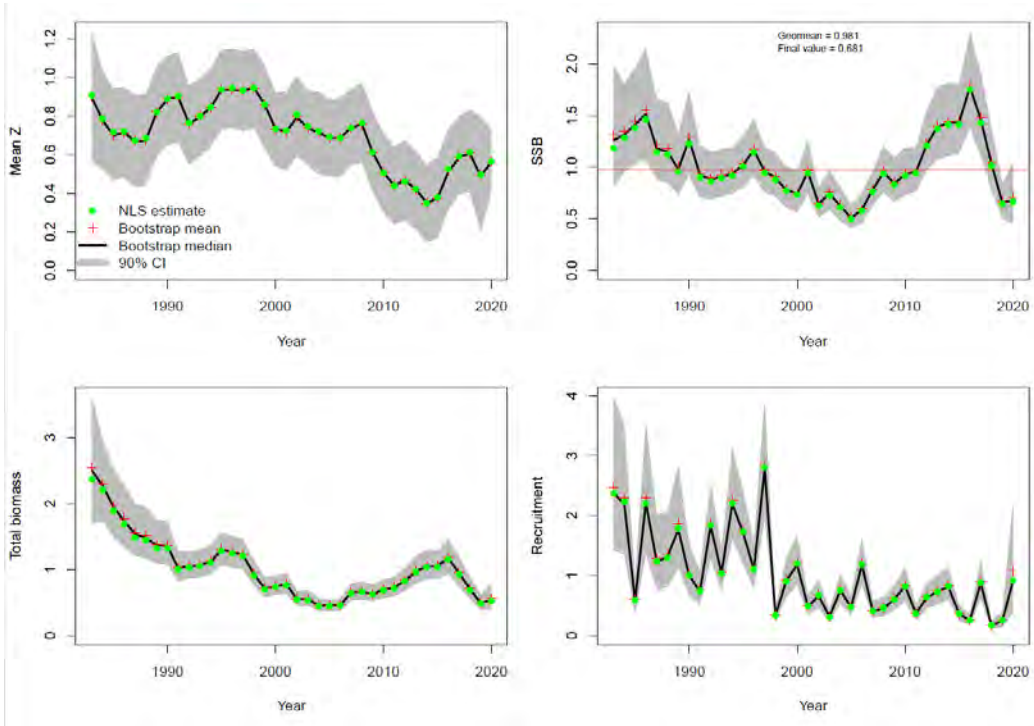
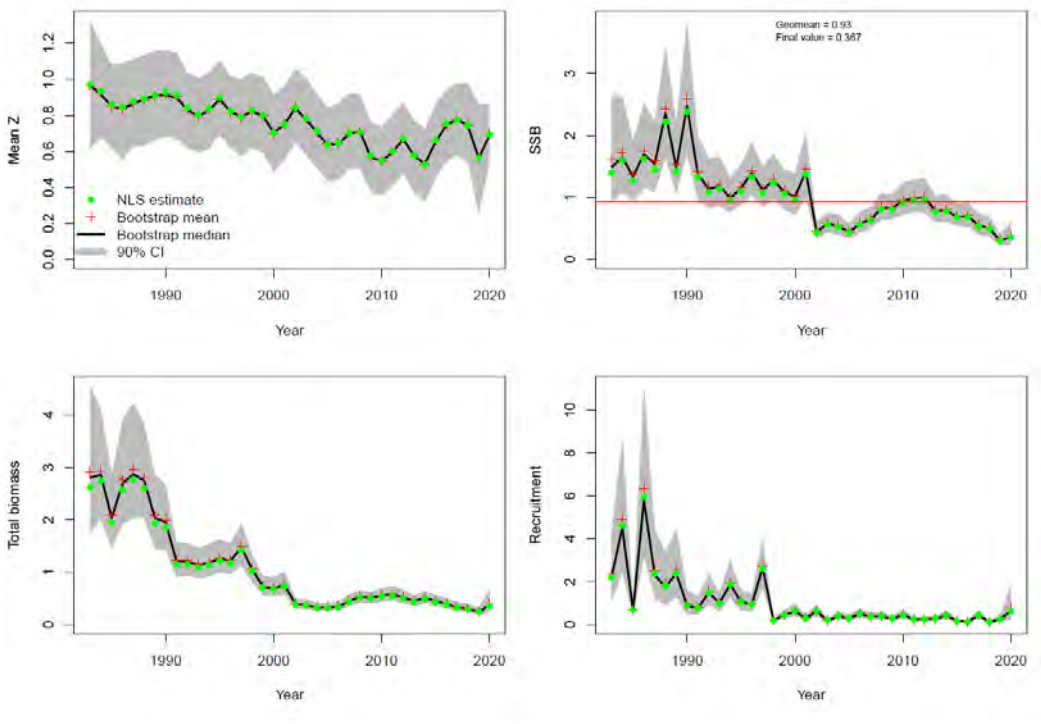


Figure 7. SURBAR assessment results for the south cod substock. For details see the caption for Figure XXX.5.



6 Conclusions

The survey results given here (and the corresponding ones in Needle, WD XXX) support the hypothesis of a concentration of cod in the northern North Sea during the latter part of the survey time-series. We have not generated formal proxies for MSY references points from these analyses, but the comparison with the time-series geometric means (see Figures 5 – 7) suggests that the southern area is in a more diminished state than the north-west and Viking areas.

This is not a new conclusion, and confirms the survey-based biomass trends given each year in the ICES WGNSSK report and corresponding advice sheet. However, the current analysis is based on a modelling approach that accounts for survey noise to a certain extent, and may be more robust and reliable as a consequence – it can also estimate total mortality. The development of area/substock-based survey indices is also a key step towards the development of more holistic spatial assessment approaches for cod stocks in the North Sea and neighbouring areas, as is the ongoing collation of area-specific catch data.

There is a clear need for further work on comprehensive spatial assessment methods for cod in the North Sea and neighbouring areas. These will need to be able to accommodate area-specific catch data for the years for which these exist, and be able to extend backwards in time to include years for which only full-area catches are available. The methods will also need to be able to account for different stock dynamics in different areas, in a flexible way that will permit modelling of evidenced exchange between areas. Such a method approach will address many of the current stock structure issues that are hindering the extant single-area cod assessments conducted by ICES.

7 References

ICES (2020a). Workshop on stock identification of North Sea Cod (WKNSCodID). 14 July 2020 and 3-6 August 2020 by webex.

ICES (2020b). Data Evaluation Meeting (DEWK) for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021). 24-26 November 2020 by webex.

Needle, C. L. (2015). Using self-testing to validate the SURBAR survey-based assessment model. *Fisheries Research* **171**: 78–86. DOI: 10.1016/j.fishres.2015.03.001.

Needle (WD XXX). Relative survey-based assessments for North Sea cod. Presentation to the ICES WKNSEA meeting, 22-26 February 2021. Online.

Working Document to the ICES Workshop on Stock Identification of North Sea Cod (WKNSCodID), Online, 3–6 August 2020

Survey Indices and Abundance Maps for North Sea Cod

Nicola D. Walker[1] and Casper W. Berg[2]

[1] Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft Laboratory, Lowestoft, NR33 0HT, UK
[2] Technical University of Denmark, National Institute of Aquatic Resources, Charlottenlund, Denmark

Summary

The current advisory unit for North Sea cod is ICES Subarea 4 (North Sea), Division 7.d (English Channel) and Subdivision 20 (Skagerrak), although many studies suggest finer scale population structuring. Given indications of subpopulations inhabiting different regions of the North Sea, the last benchmark for North Sea cod proposed four subregions for comparison of substock differences and recommended that these be monitored going forward. Here, we present updated biomass indices by subregion showing continued differences in trend between the South and subregions further north, but a high level of synchrony in recruitment with significant correlations in both biomass and recruitment between all subregions.

In recent years, assessments of North Sea cod have shown a persistent downward revision of SSB and upward revision of fishing mortality. This retrospective pattern is caused by lower catch rates of older fish in the surveys compared to commercial catches, with misconception of spatial structure being one possible cause. Here we combine survey data from the North Sea with adjacent Division 6.a (West of Scotland) and Subdivision 21 (Kattegat) to map the spatiotemporal distribution of cod in the North Sea and surrounding areas, indicating a north-westwards shift of older cod towards the west of Scotland. Although combined indices display the same trends associated with the retrospective pattern, they suggest considerable migration of older cod from the North Sea to 6.a.

Delta-GAM model

Analyses were conducted using a model-based approach to account for nuisance factors caused by changes or differences in experimental conditions. The methodology is described in Berg and Kristensen (2012) and Berg *et al*. (2014) but consists of (1) calculating numbers-at-age from observed numbers-at-length and spatially varying ALKs and (2) estimating abundance-at-age using a delta-GAM model:

$$g(\mu_i) = \mathrm{Year}(i) + \mathrm{Gear}(i) + U(i)_{ship} + f_1(\mathrm{Year}_i, \mathrm{lon}_i, \mathrm{lat}_i) + f_2(\mathrm{depth}_i) + f_3(\mathrm{time}_i) + \log(\mathrm{HaulDur}_i)$$

where μ_i are the expected numbers-at-age in the *i*th haul (or probability of non-zero catch for the presence-absence part), g is the link function, Year and Gear are categorical effects, U is a random vessel effect, f_1 is a three-dimensional tensor product spline, f_2 a thin plate spline and f_3 a cyclic cubic regression spline.

Maps were obtained by predicting abundance on a grid of haul positions while indices were obtained by summing model predictions over the relevant parts of the grid, where nuisance parts of the model, such as gear, ship, and haul duration, were held constant to remove their effect.

Subregion indices

Biomass indices by subregion were calculated from North Sea International Bottom Trawl data for Quarter 1 (NS-IBTS-Q1) and Quarter 3 (NS-IBTS-Q3) downloaded from the DATRAS database. The methodology follows that of the North Sea working group (WGNSSK): the delta-GAM was fit to the entire dataset then re-computed on subsets of the spatial grid corresponding to each subregion (Figure A1) to obtain indices-at-age. These were then multiplied by smoothed weight-at-age estimates and summed to get biomass indices.

Biomass indices continue to follow the same trends as noted by WGNSSK (ICES, 2020). There was a general decline in all areas prior to the mid-2000s, followed by an increase to 2015–2017 for the Viking and Northwest subregions and a sharp decline thereafter. Biomass in the South has declined steadily over the entire time series (Figure 1); however, there are high and significant correlations in first order differences between all subregions despite differing trends (Figure 2).

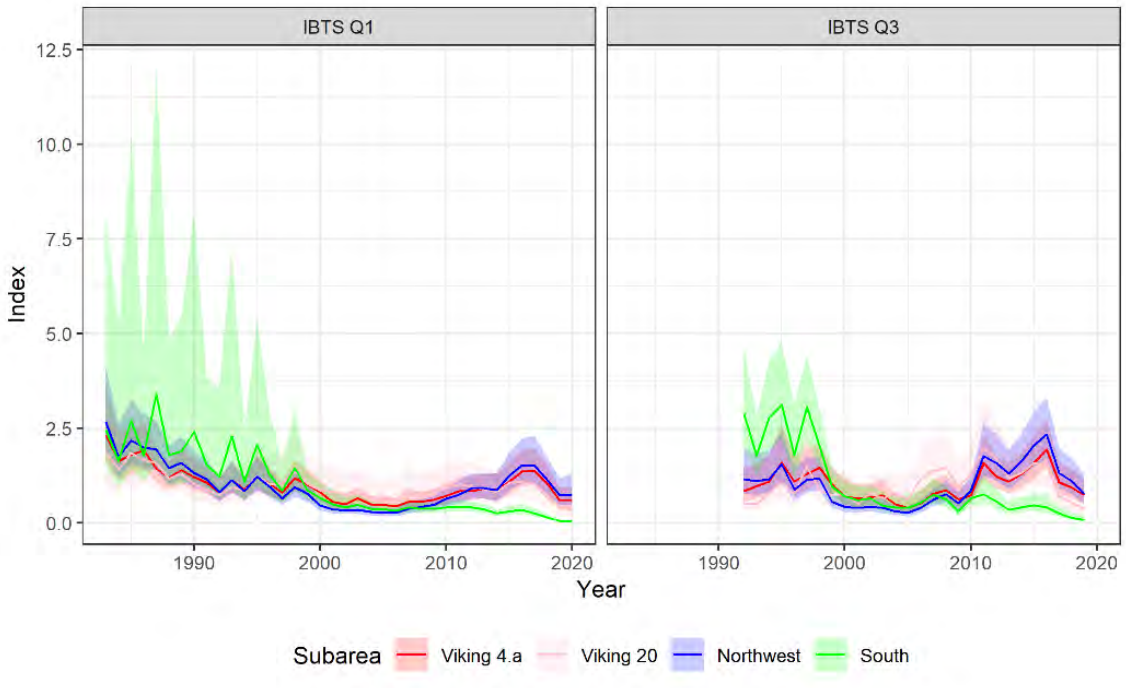


Figure 1: Biomass indices by subregion together with 95% confidence intervals based on NS-IBTS-Q1 and Q3 data. The indices and confidence intervals are standardised by the mean of the index for each subregion.

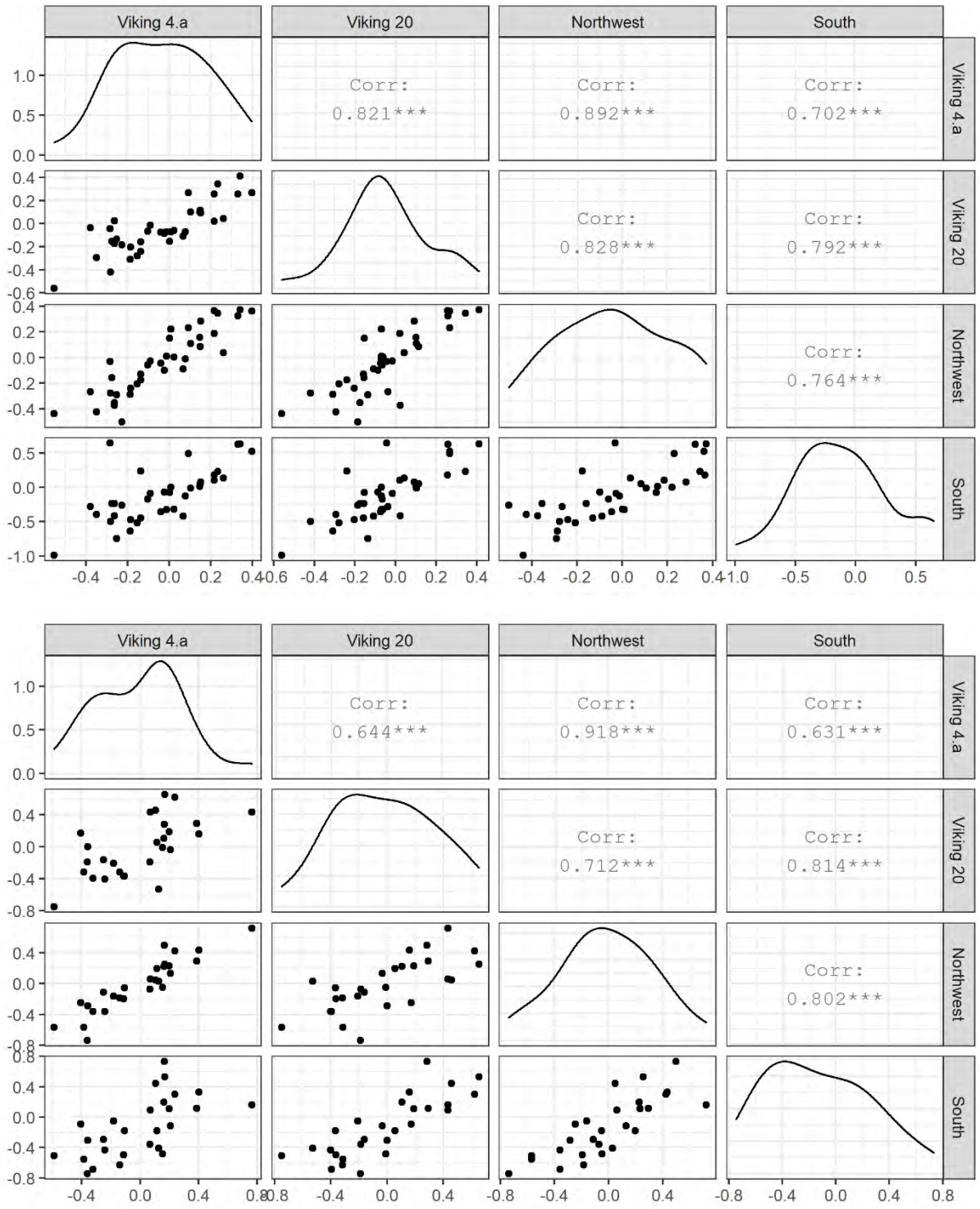


Figure 2: Correlations between differenced log biomass indices by subregion for (top) Quarter 1 and (bottom) Quarter 3. The lower triangle of subplots shows scatterplots of differenced log biomass for each pair of subregions, the top triangle the Pearson correlation coefficient and the diagonal the distribution of differenced log index values for each subregion.

Recruitment indices show similar trends in all subregions with no major asynchronies, but with indications of increased recruitment in the northern North Sea (Figure 3). Correlations between all subregions are strong and highly significant in both quarters (Figure 4).

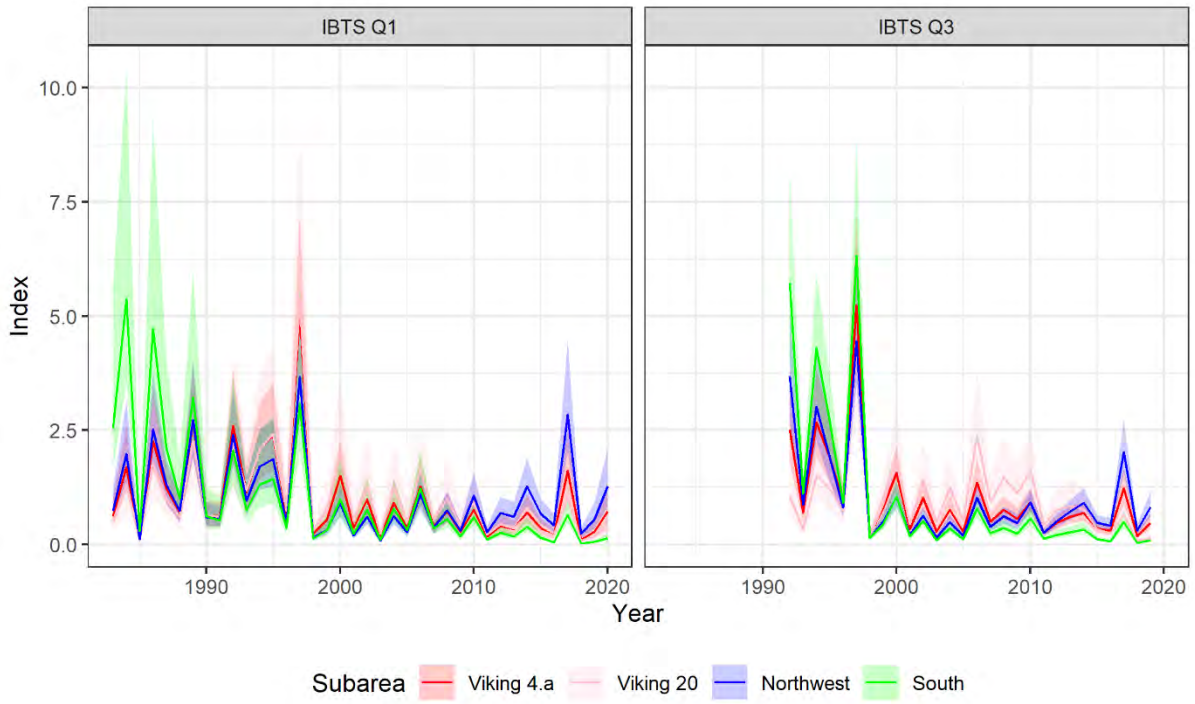
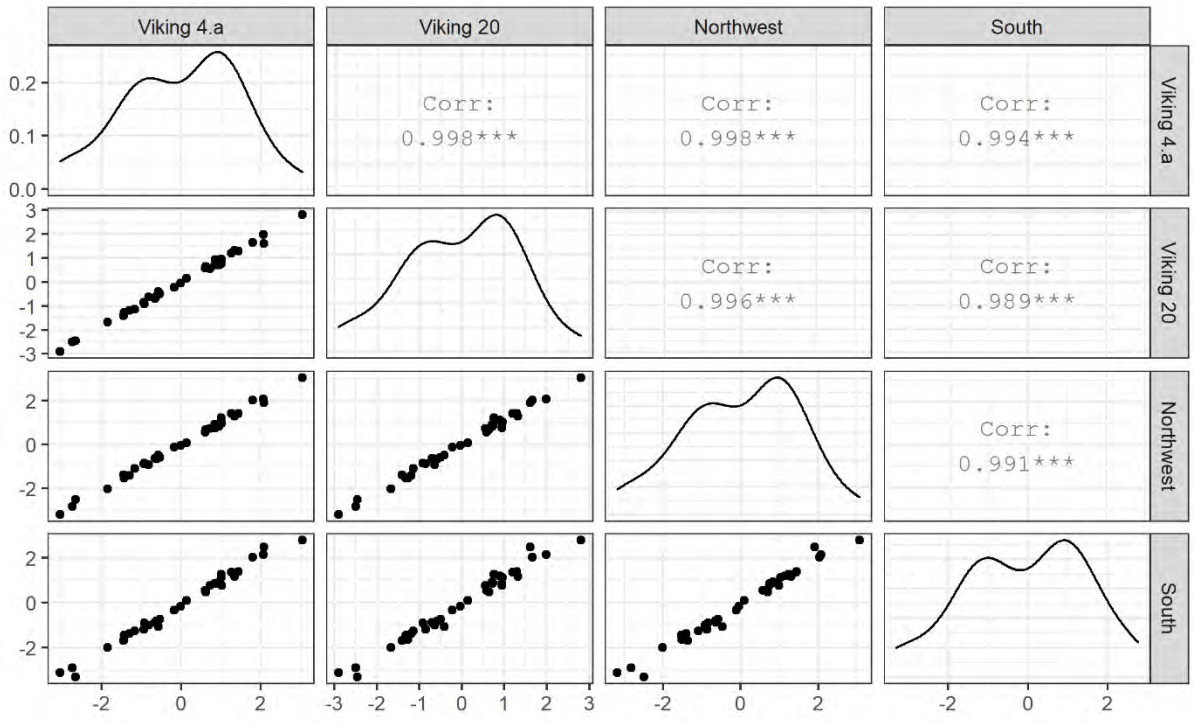


Figure 3: Recruitment (age 1) biomass indices by subregion together with 95% confidence intervals based on NS-IBTS-Q1 and Q3 data. The indices and confidence intervals are standardised by the mean of the index for each subregion.



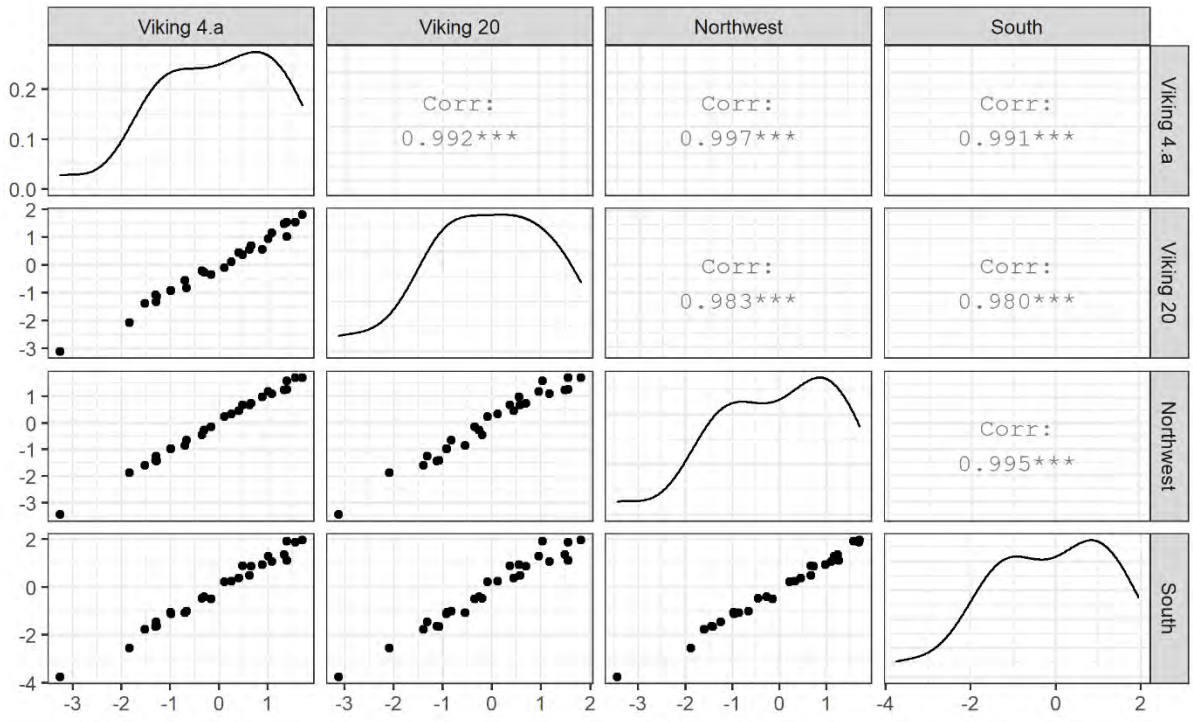


Figure 4: Correlations between differenced log recruitment (age 1) indices by subregion for (top) Quarter 1 and (bottom) Quarter 3. The lower triangle of subplots shows scatterplots of differenced log recruitment biomass for each pair of subregions, the top triangle the Pearson correlation coefficient and the diagonal the distribution of differenced log recruitment index values for each subregion.

Abundance maps

To obtain abundance maps, the delta-GAM model was fit to data from six surveys: the NS-IBTS-Q1 and Q3, the Scottish West Coast Groundfish Survey in Division 6.a (West of Scotland) in Quarter 1 (ScoWCGFS-Q1) and Quarter 4 (ScoWCGFS-Q4) and the Baltic International Trawl Survey covering Subdivision 21 (Kattegat) in Quarter 1 (BITS-Q1) and Quarter 4 (BITS-Q4). The model was applied separately to all data for Quarter 1 from 1983 and all data for Quarters 3 and 4 from 1992 (for consistency with assessment indices; Appendix 2) but maps are presented only for ages and years with adequate age sampling across surveys. A change to the rig of the ScoWCGFS gear in 2011 was accounted for via the ship effect of the delta-GAM model.

Maps for Quarter 1 from 1996–2020 (Figure 5 and Appendix 3) show the highest abundances of recruits (age 1) to be in the Skagerrak and Kattegat throughout the time series. There are also areas of higher recruitment extending the east coast of the UK, with hotspots appearing to the east of Scotland from 2010. Arcs of higher abundances of ages 1–3 from Flamborough across Fisher to the Viking Bank diminished during the 2000s while hotspots of age 2–4 abundance in the south disappeared. We did not consider surveys in the Channel, so cannot make inferences about whether this disappearance is a consequence of migrations or local depletion in the south. The distribution of older ages (3+) appears to have contracted north and west over the time series with relatively high abundances of 3+ cod to the north of Scotland over the last 10 years.

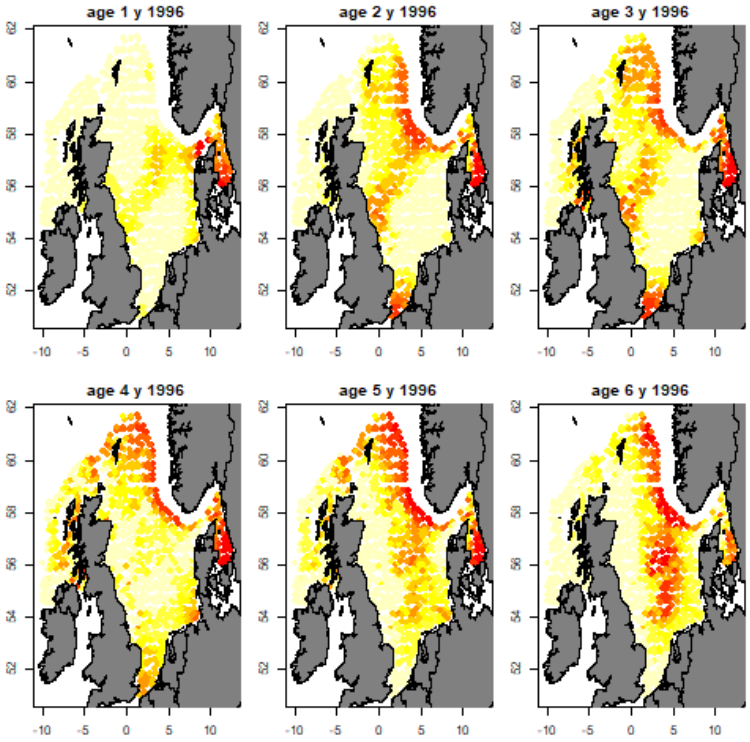


Figure 5: Animated abundance maps based on Quarter 1 data from the NS-IBTS, ScoWCGFS and BITS surveys (a subset of years are presented in Appendix 3). Individual subplots are produced separately hence the colours are indicative of trends only.

Maps for Quarters 3–4 from 1999–2019 and ages 1–4 (Figure 6 and Appendix 4) show similar trends to those of Quarter 1. Arcs of abundance from the east coast of the UK across Fisher to the Viking bank have diminished with a hotspot of recruitment appearing to the east of Scotland over the last 10 years. Although the model predicts slightly higher abundances of ages 1 and 2 in the south towards the beginning of the time series, this is not as strong as for the Quarter 1 analysis. Increased abundances of 2+ fish extending from the Skagerrak to Shetland appear to shift westwards over the time series.

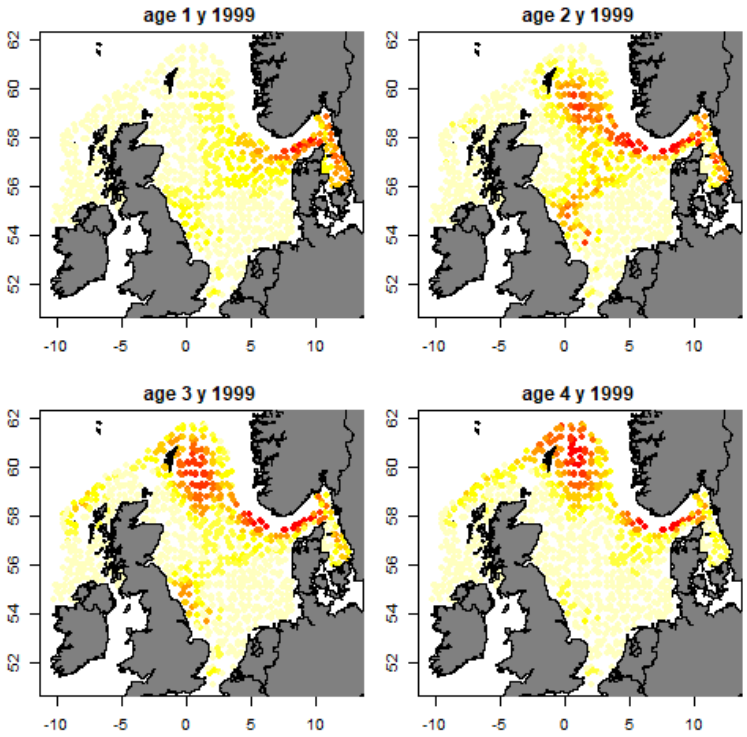


Figure 6: Animated abundance maps based on Quarter 3 data from the NS-IBTS survey and Quarter 4 data from the ScoWCGFS and BITS surveys (a subset of years are presented in Appendix 4). Individual subplots are produced separately hence the colours are indicative of trends only.

Boundary effects

West of Scotland

As the highest concentrations of older cod are found near the border of the assessment area towards the west of Scotland, it could be hypothesized that migrations in and out of the assessment area are causing year effects in the survey indices. The last benchmark for cod investigated this issue by combining the NS-IBTS survey with the ScoWCGFS survey to include a major part of Division 6.a in an alternative index (ICES, 2015). Here we derive similar alternative indices by summing model predictions from the combined delta-GAM over Subarea 4 (North Sea), Division 6.a (west of Scotland) and both areas combined, showing that abundance of 3+ cod in 6.a has increased more than in the North Sea in recent years (Figure 7). However, the combined index shows the same trends that have been associated with the retrospective pattern in the assessment of North Sea cod (ICES, 2020). That is a disappearance of the strong 2013 year-class coinciding with a peak in the 2012 year-class at age 5 in Quarter 1 and age 4 in Quarters 3 & 4. While this may not resolve the issues associated with the retrospective patten, relative differences between the combined and North Sea indices suggest that movements from the North Sea to 6.a could be important and should be investigated further (Figure 8).

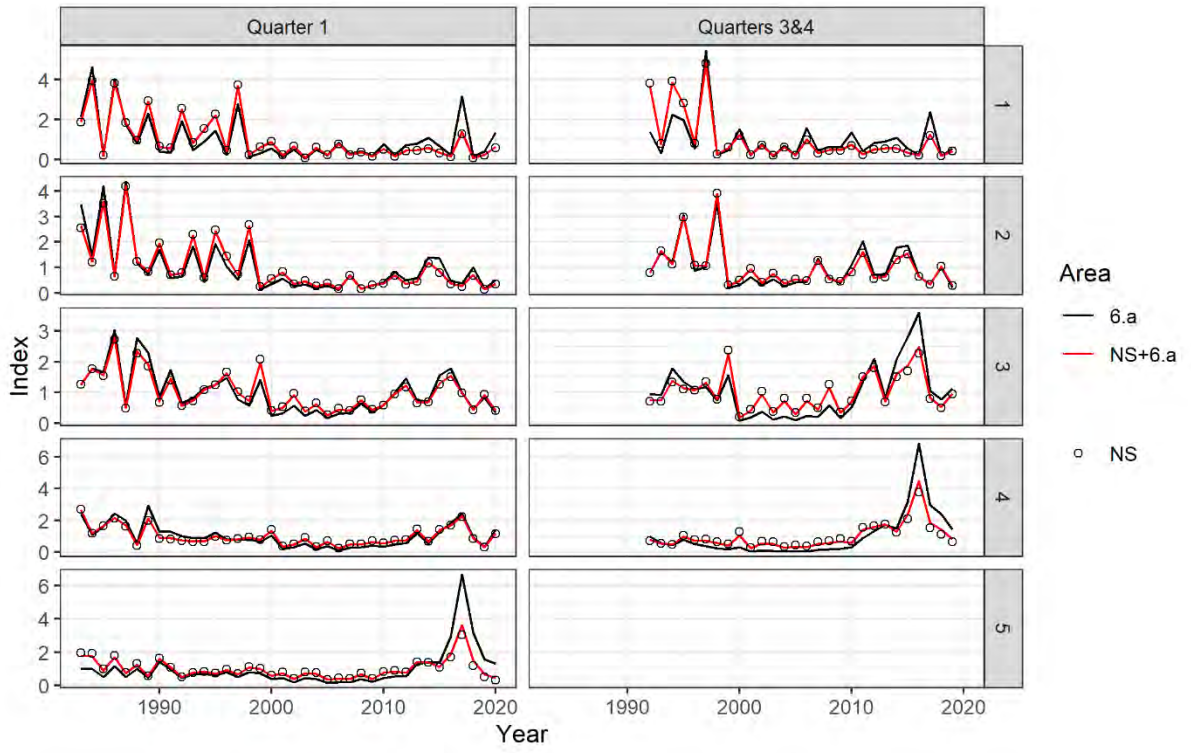


Figure 7: Indices derived from a delta-GAM model fit to data from the NS-IBTS, ScoWCGFS and BITS surveys. Indices are derived by summing model predictions on subsets of a spatial grid corresponding to the North Sea (NS), Division 6.a (6.a) and both areas combined (NS+6.a). Note that indices for the North Sea are not exactly the same as for the assessment due to inclusion of the Skagerrak in the assessment and a slightly different delta-GAM configuration (the assessment assumes a stationary spatial model). The indices are mean-standardised.

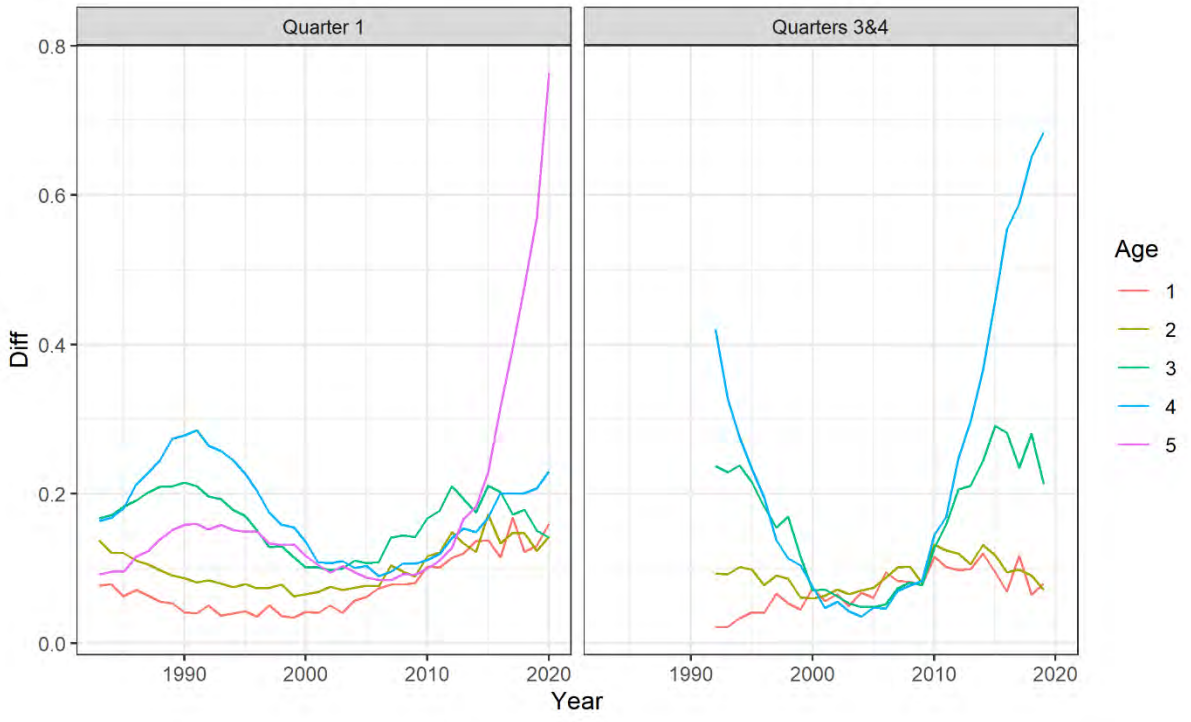


Figure 8: Relative differences between the untransformed indices for combined management areas (NS+6.a) and the North Sea (NS), calculated as (NS+6.a/NS) - 1. See caption to Figure 7 for details of the indices.

Kattegat

The same method was used to investigate potential links between the North Sea stock and adjacent Kattegat advisory unit. Again, predictions from the combined delta-GAM were summed over the relevant management areas: Subarea 4 and Subdivision 20 (North Sea and Skagerrak), Subdivision 21 (Kattegat) and both areas combined (Subarea 4 and Division 3.a). Differences between indices for the North Sea assessment area and combined management areas mostly appear small (Figure 9) but with a decrease in relative differences suggesting a larger increase of age 1 cod in the North Sea assessment area compared to the Kattegat in recent years (Figure 10).

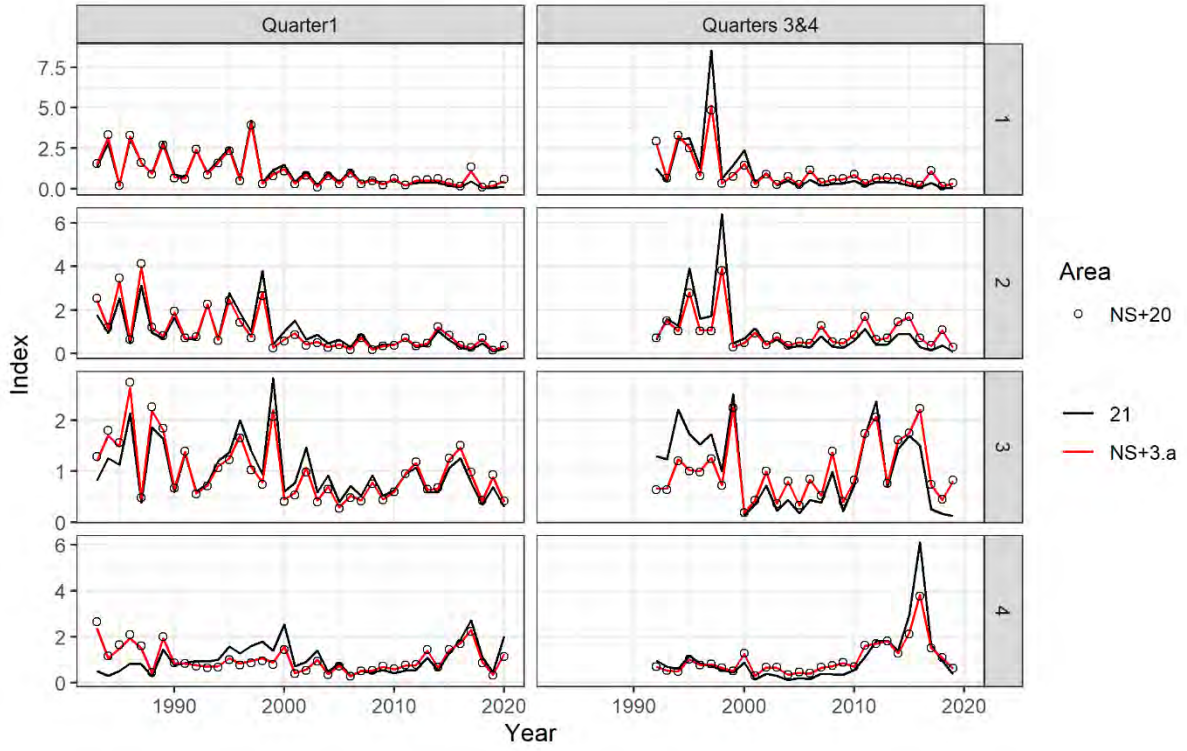


Figure 9: Indices derived from a delta-GAM model fit to data from the NS-IBTS, ScoWCGFS and BITS surveys. Indices are derived by summing model predictions on subsets of a spatial grid corresponding to the North Sea and Skagerrak (NS+20), Subdivision 21 (21) and both areas combined (NS+3.a). Note that indices for the North Sea and Skagerrak are not exactly the same as for the assessment due to a slightly different delta-GAM configuration (the assessment assumes a stationary spatial model). The indices are mean-standardised.

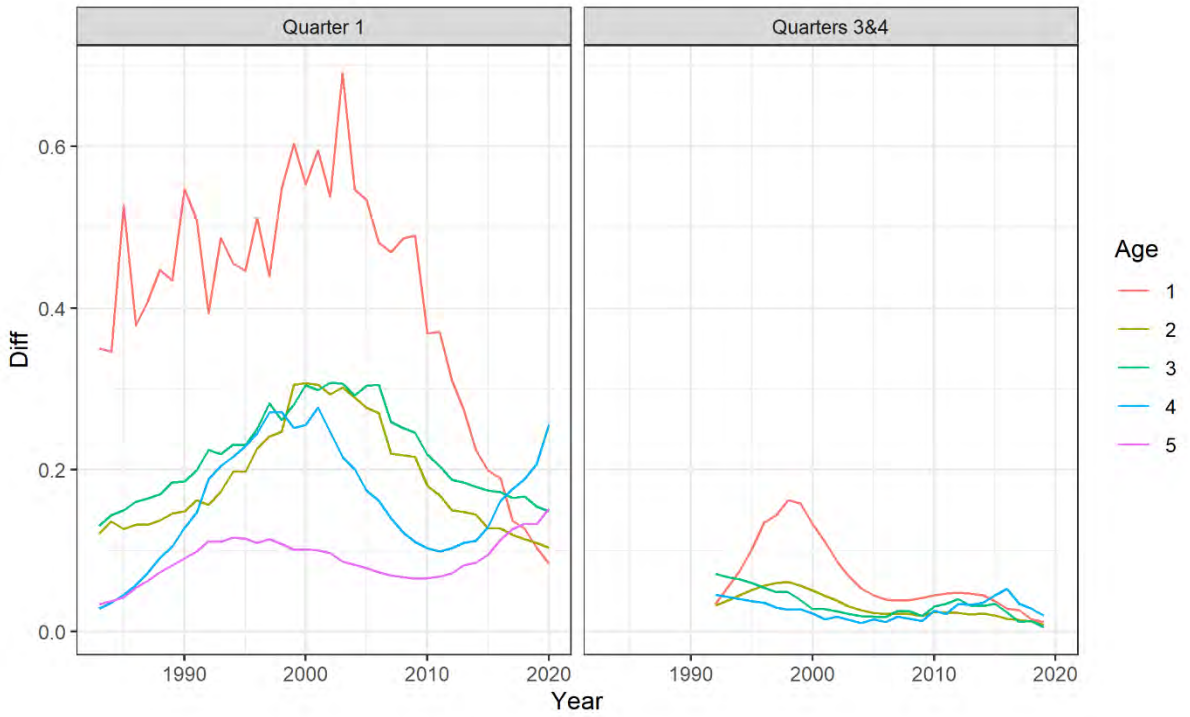


Figure 10: Relative differences between the untransformed indices for combined management areas (NS+3.a) and the North Sea and Skagerrak (NS+20), calculated as (NS+3.a/NS+20) - 1. See caption to Figure 9 for details of the indices.

Conclusions

- There are high correlations between subregion biomasses despite recent differences in index trends. Recruitment trends are similar in all subregions with no major asynchronies and strong and significant correlations.

- Maps of abundance show a perceived north-westwards shift of older cod and reduced abundances in the south. The highest abundances of recruits are in the Skagerrak and Kattegat with a hotspot of recruitment appearing to the east of Scotland over the last 10 years.

- Differences between indices for the assessment area and combined indices including adjacent management areas suggest increased movements of older cod towards the West of Scotland. While a combined North Sea and 6.a index may not resolve the issues associated with the retrospective pattern in the assessment, migrations from the North Sea into 6.a seem to be substantial and should be investigated further.

References

Berg, C.W. and Kristensen, K. 2012. Spatial age-length key modelling using continuation ratio logits. *Fisheries Research*, 129–130: 119–126.

Berg, C.W., Nielsen, A. and Kristensen, K. 2014. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. *Fisheries Research*, 151: 91–99.

ICES. 2015. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 2–6 February 2015, Copenhagen, Denmark. ICES CM/2015/ACOM:32. 253 pp.

ICES. 2020. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1140 pp. http://doi.org/10.17895/ices.pub.6092

Appendix 1: Subregions

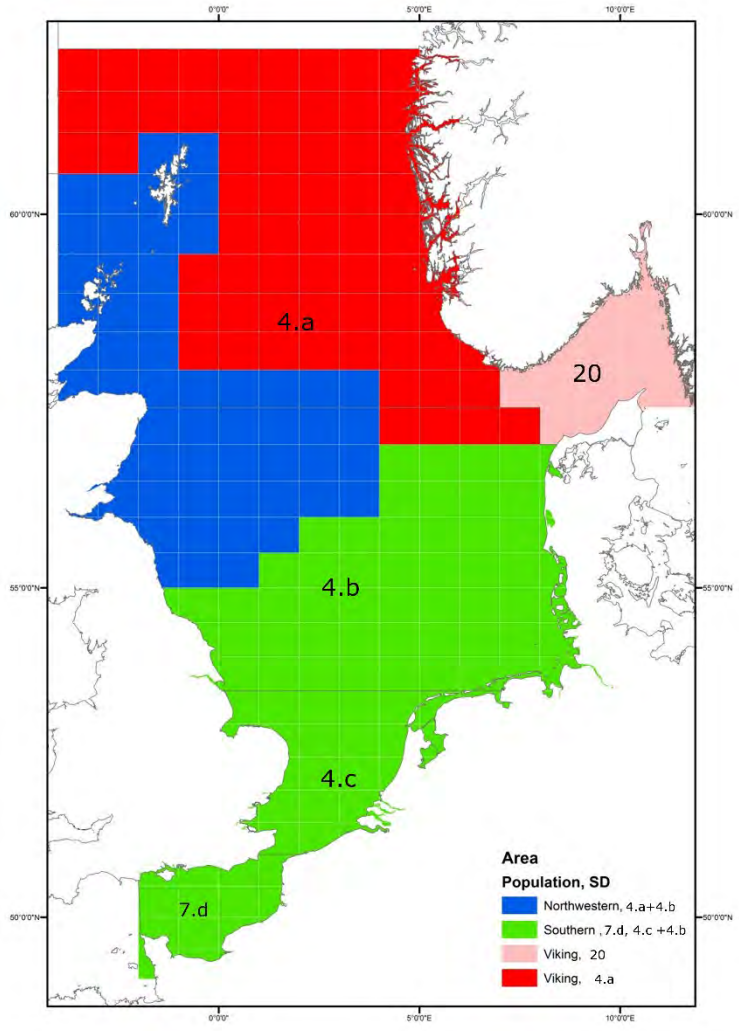


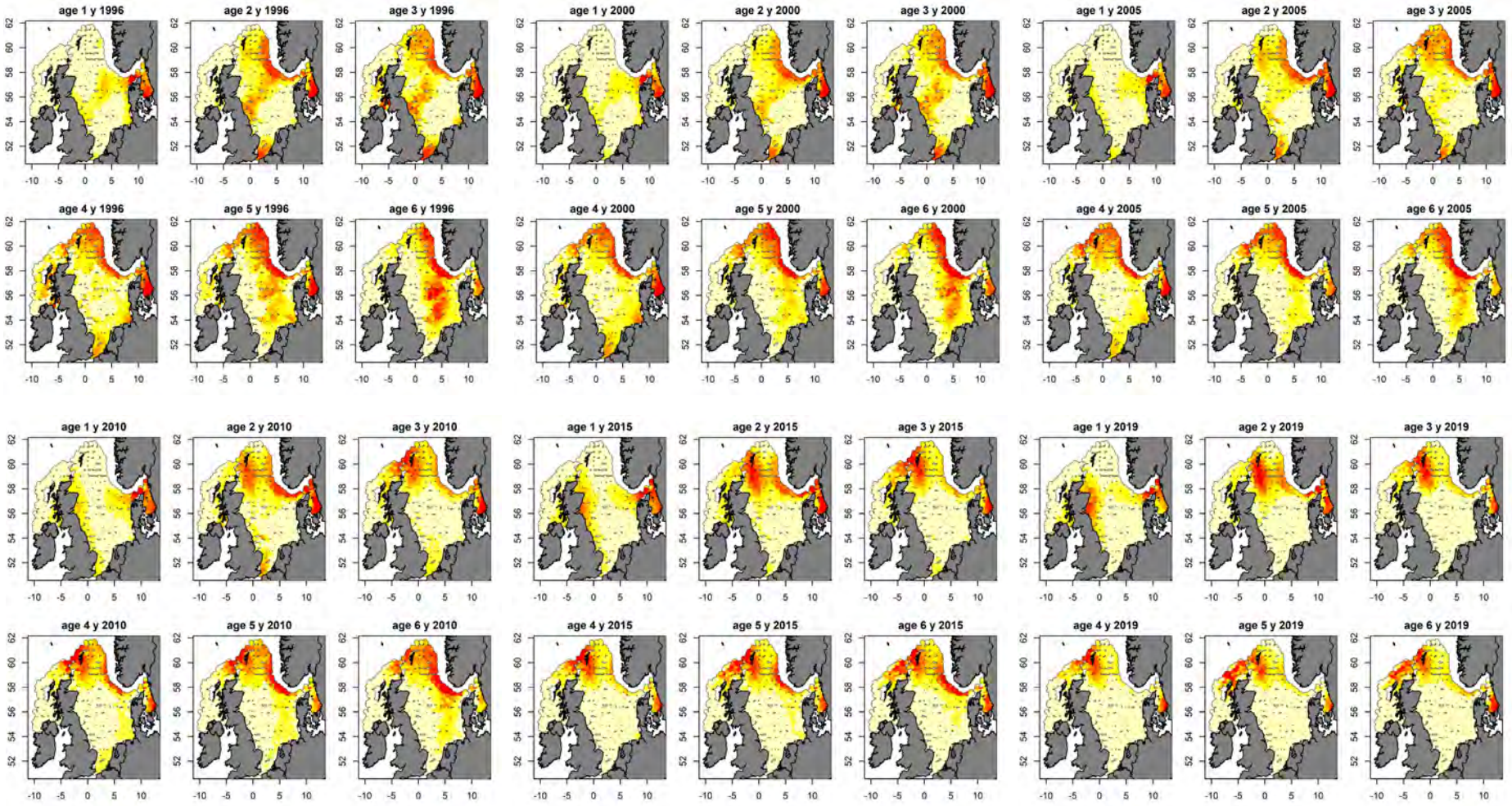
Figure A1: Subregions used to derive area-specific biomass indices for North Sea cod based on NS-IBTS-Q1 and Q3 data (ICES, 2015).

Appendix 2: Survey data

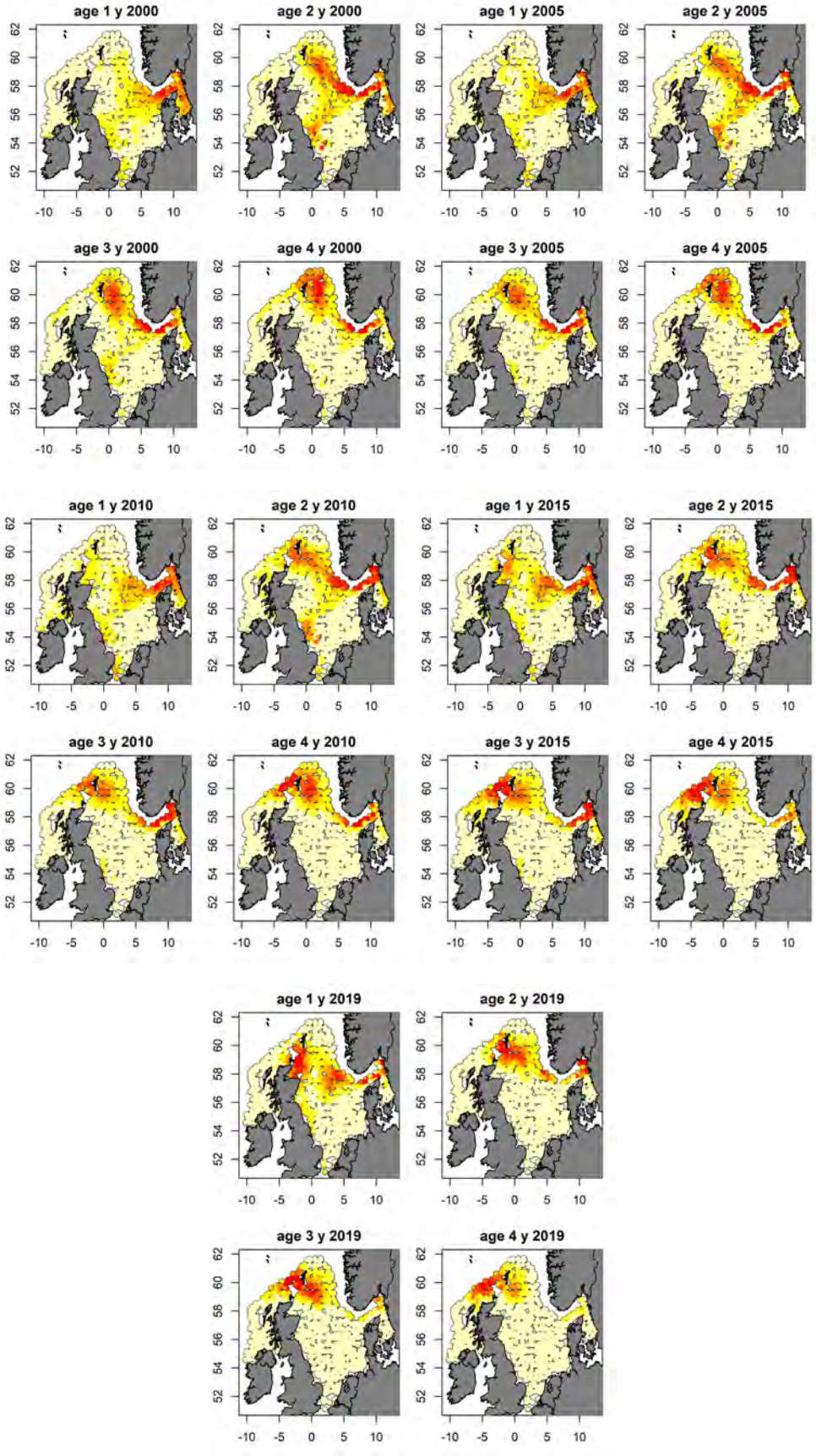
Table 1: Survey data used in the analyses together with management area covered, survey acronym (as used in this study), years with data for cod and years with age samples for cod.

Survey	Management area	Acronym	Years	Age sampling
North Sea International Trawl Survey – Q1	4, 3.a	NS-IBTS-Q1	1983+	1983+
Scottish West Coast Groundfish Survey – Q1	6.a	ScoWCGFS-Q1	1986+	1986+
Baltic International Trawl Survey – Q1	Only data for Subdivision 21 included	BITS-Q1	1992+	1996+
North Sea International Trawl Survey – Q3	4, 3.a	NS-IBTS-Q3	1992+	1992+
Scottish West Coast Groundfish Survey – Q4	6.a	ScoWCGFS-Q4	1992+	1996–2009 2011+
Baltic International Trawl Survey – Q4	Only data for Subdivision 21 included	BITS-Q4	1993+	1999+

Appendix 3: Quarter 1 Abundance Maps



Appendix 4: Quarter 3 & 4 Abundance Maps



North Sea cod survey indices

Casper W. Berg

February 21, 2021

1 Summary

Various formulations of the model for producing standardized survey indices of abundace by age for North Sea Cod were tested, both in terms of model formulas as well as different data setups and survey index areas. The resulting indices were tested in the assessment model and evaluated by five criteria: AIC for the survey index models, internal consistency, AIC of the assessment model (SAM), and amount of retrospective patterns in the SAM model in terms of Mohn's rho. The survey index model currently used was found to perform worse than most of the alternative models and should therefore be replaced. The models were presented at a meeting before the benchmark, and "Model 3" was chosen as the preferred one.

The current index calculation procedure assumes that subarea 20 is purely NS cod while area 21 is not included. New genetic data from areas 20 and 21 was used to explore alternative indices that assumed time-varying proportions of NS cod in these subareas as opposed to the current indices. While the genetic information suggested that a substantial part of particular the juvenile cod population can be found in area 21, the alternative indices did not seem to improve evaluation criteria, but rather they appeared slightly worse. Note that commercial catches were not split accordingly, which may be part of the explanation for the lack of improvement.

Three additional configurations of the assessment model (SAM) were tested in combination with the new indices as well. The first utilized the estimated variances from the survey index model as inverse weights in SAM, the second removed the so-called catch-multiplier, and the third applied both these changes. Both of these changes seemed to improve the stability of the assessment in terms of decreased Mohn's rho values, in particular the removal of the catch multiplier.

2 Data

The data set used is the NS-IBTS survey considering the GOV gear only. The year 1991 was left out of the Q3 data set (as done previously), because some other gears than GOV were used in this year. Data from area 21 (Kattegat) was included in the model (not done previously) to facilitate some extra runs that included this area. The extra runs used included the abundance from area 21 multiplied by the proportion of NS cod as indicated from the genetic data. In 1991-1996 NS-IBTS was carried out in all 4 quarters, and the data from Q4 in this period was combined with the data from Q3.

3 IIIa split

This section describes the genetic data used to derive the proportion of NS cod in areas 20 and 21. Note, that the indices that included area 21 are not presented here in detail, but only as summary tables showing the evaluation critera. The genetic data consists of 3531 genetic samples, 641 of these without age. There were 987 samples from quarter 1 and 2544 from quarters 3 and 4. The missing ages were imputed by using a simple age length key. The ALK used was quarter specific but all years were pooled, because some years had only few samples.

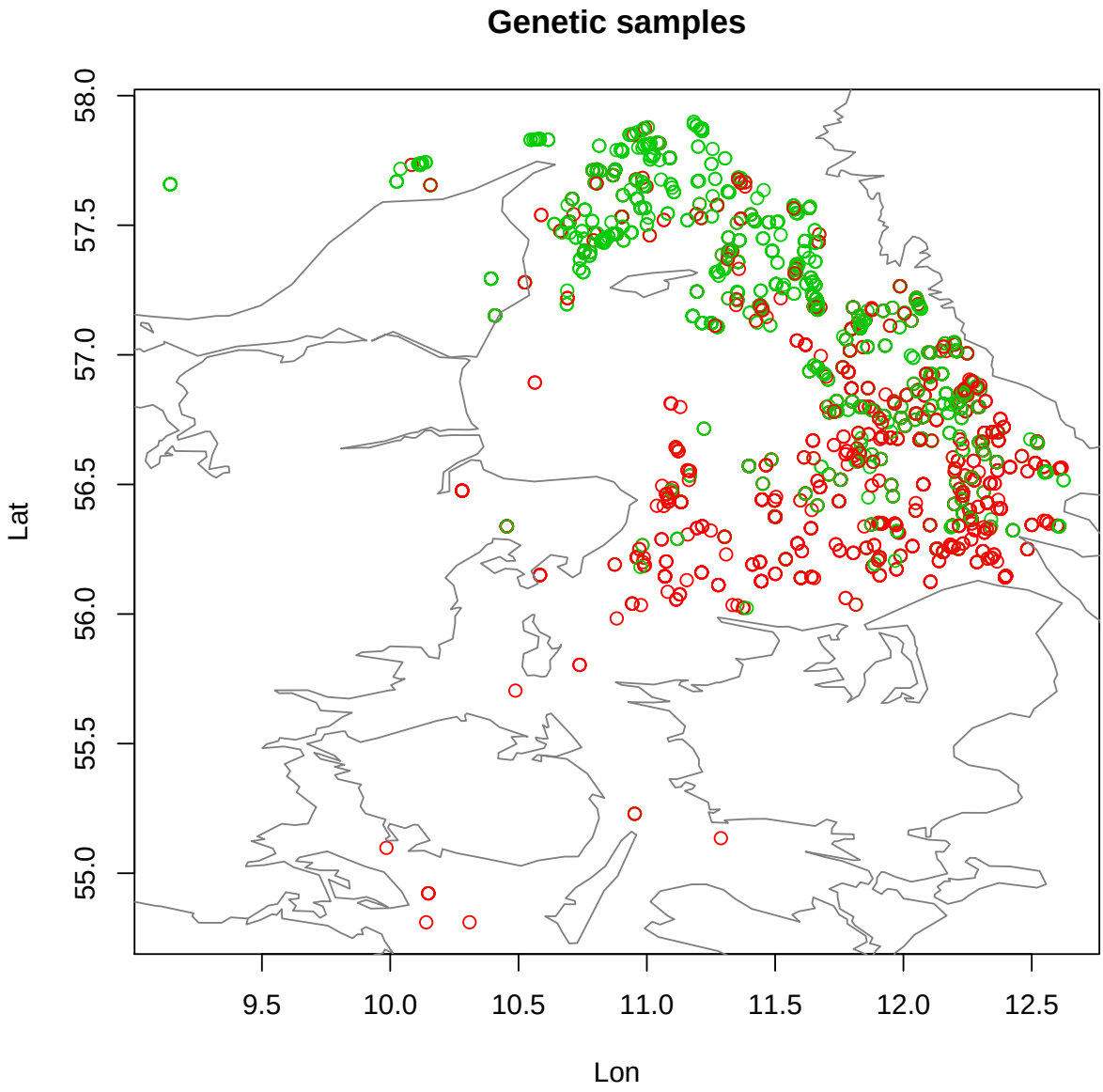


Figure 1: All genetic samples. Green points indicate North Sea Cod and red points Kattegat/Baltic cod.

A binomial GAM was used to model the probability of North Sea Cod versus of other origin (Kattegat or

	Year
1992	35
1998	110
1999	65
2001	29
2002	74
2003	12
2004	56
2005	80
2006	88
2008	92
2010	30
2011	107
2012	54
2013	299
2014	123
2015	657
2016	619
2017	382
2018	259
2019	360

Table 1: Number of genetic samples by year

Eastern Baltic). The model included quarter (Q) as a factor (quarters 3 and 4 were pooled), age as factor (fAge), spatial coordinates (lon,lat) and Cohort as a random effect. 100 fake data points (random selection of years and ages) of North Sea Cod taken in the North Sea (outside the range of the actual data points) were added to the input data of the model to ensure that the predicted probability of NS cod approached 100% in the North Sea. The model formula used is presented below:

```
Type ~ Q + fAge + s(lon,lat,bs='ds',m=c(1,0.5),k=50) + s(Cohort,bs="re",by=dum)
```

The following plots show the predicted probability of being NS cod for all the years, ages, and quarters.

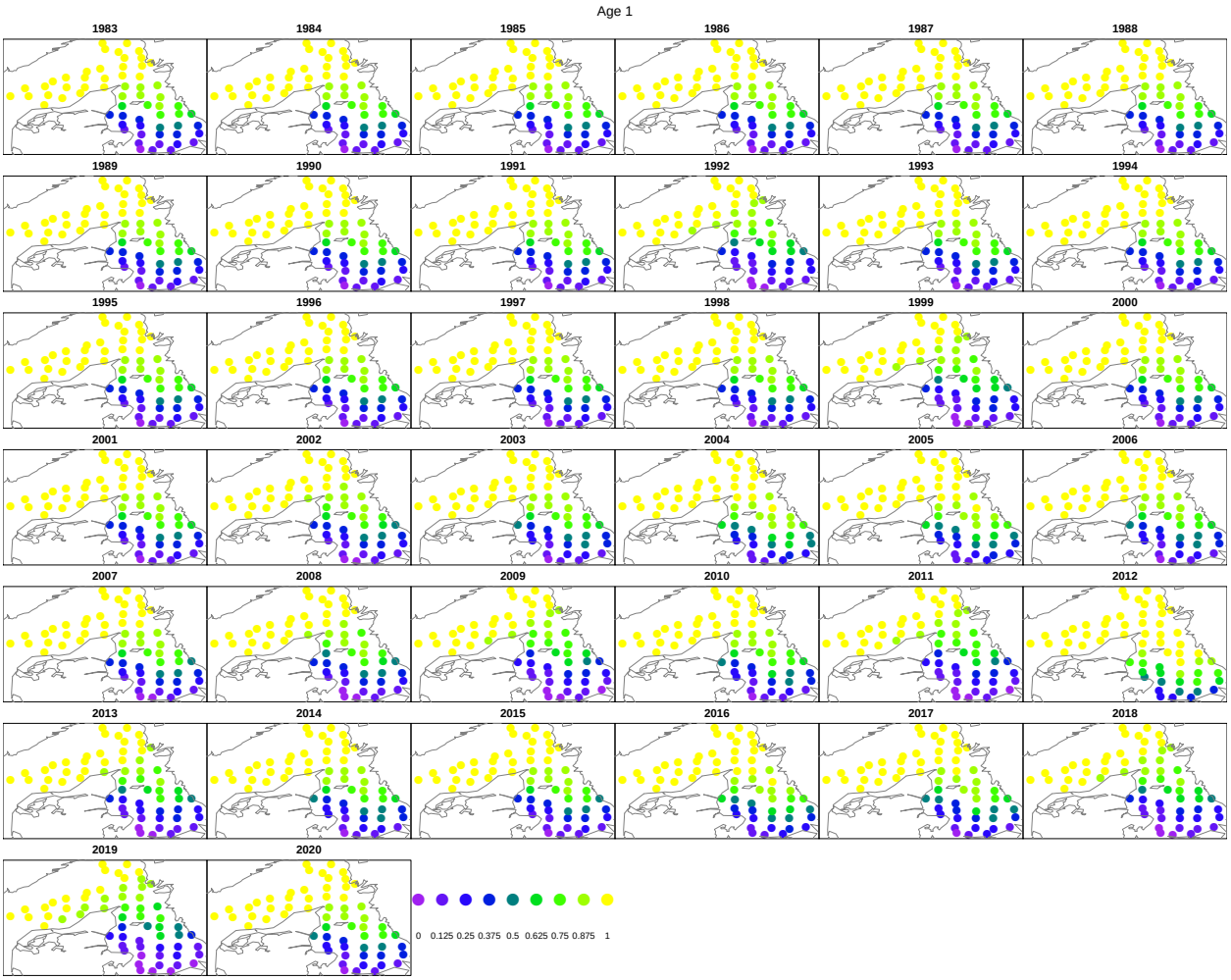


Figure 2: Q1 age 1

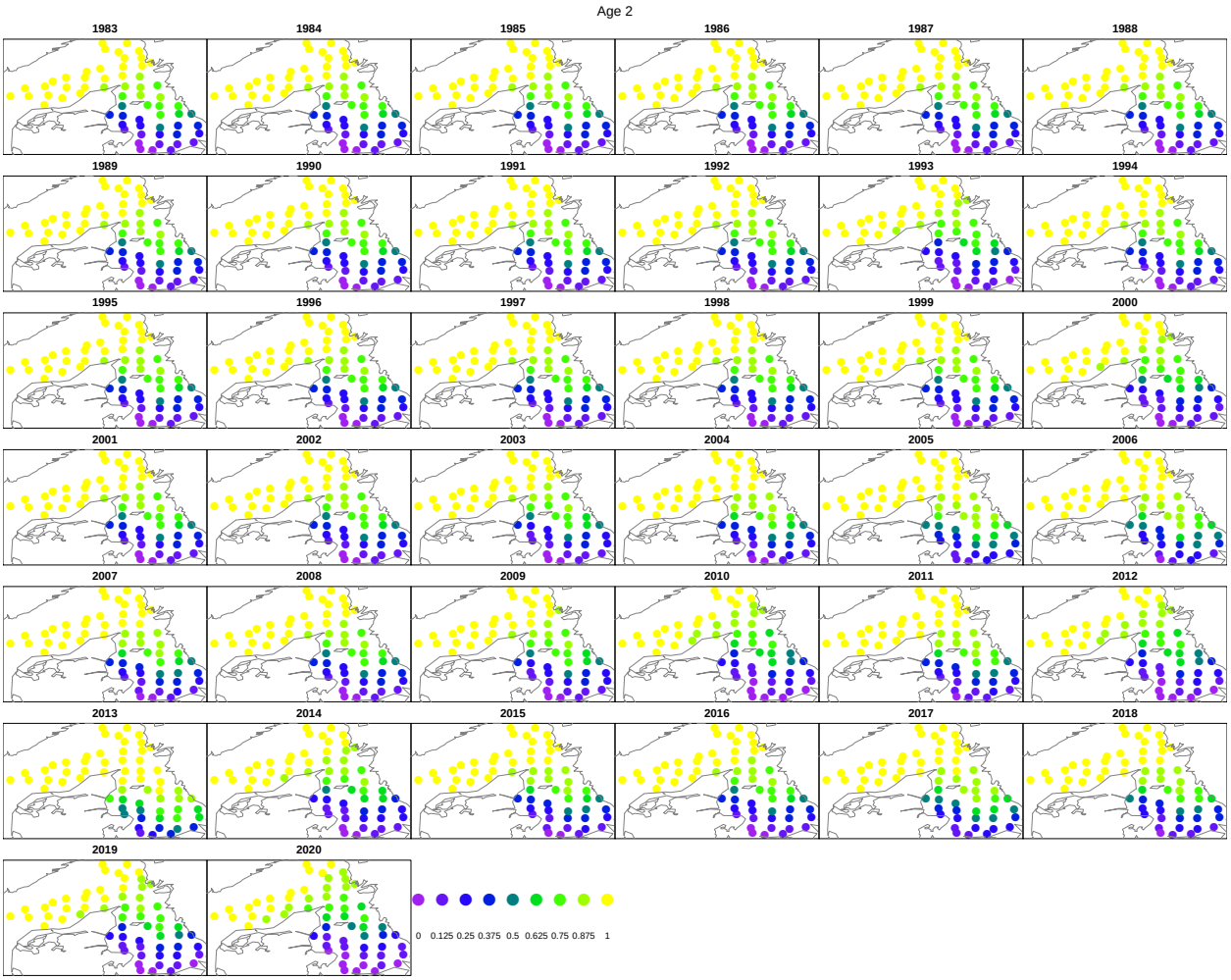


Figure 3: Q1 age 2

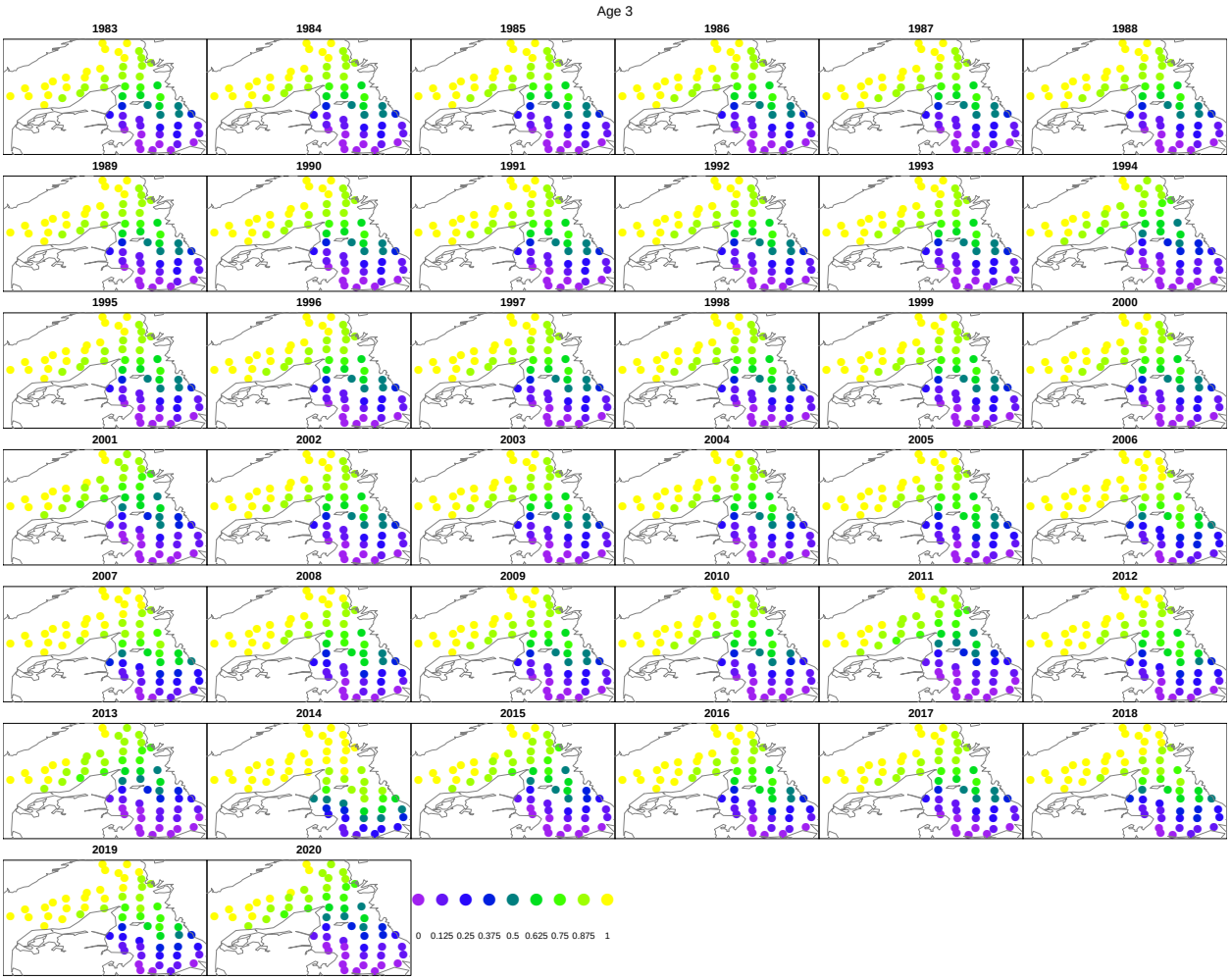


Figure 4: Q1 age 3

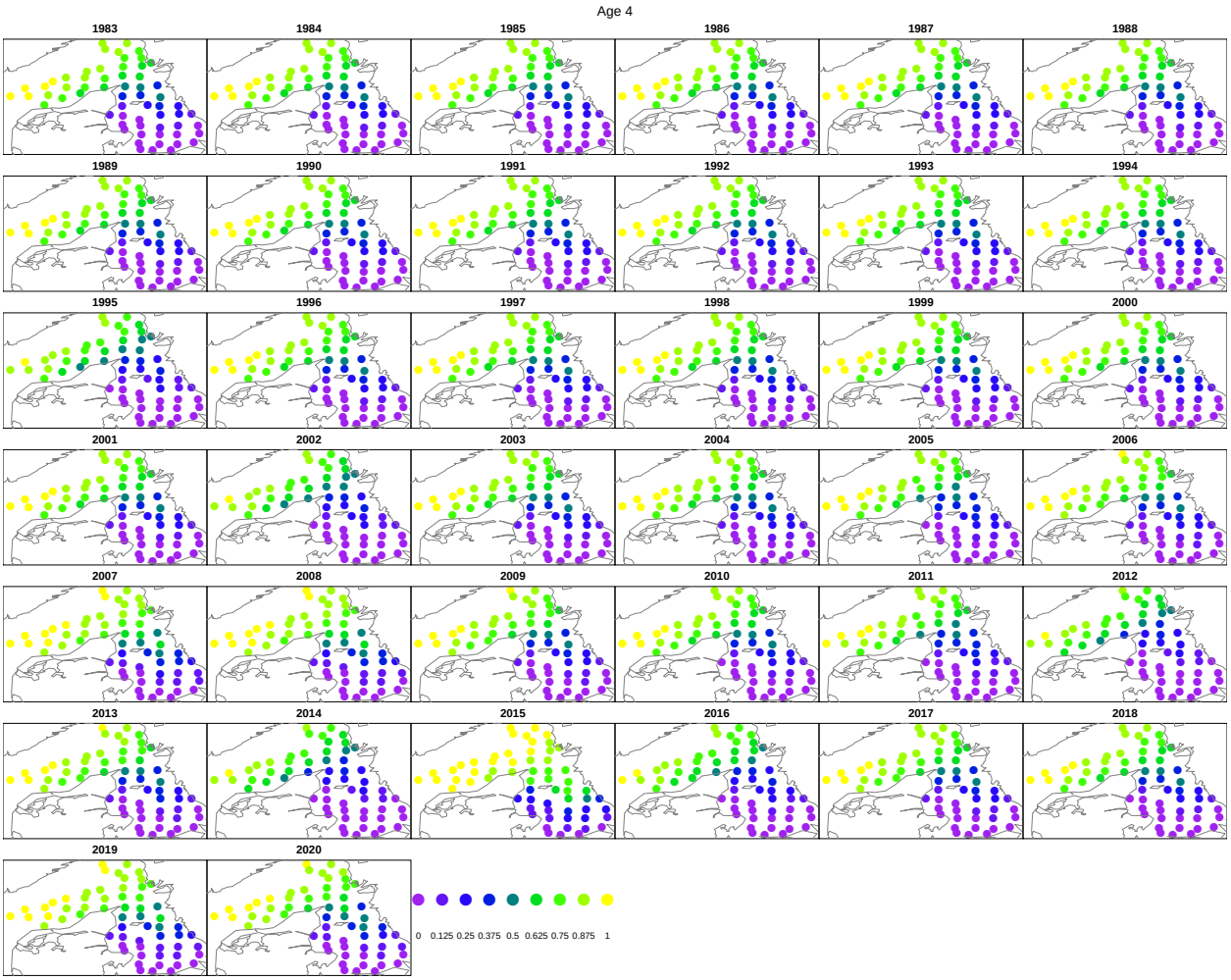


Figure 5: Q1 age 4

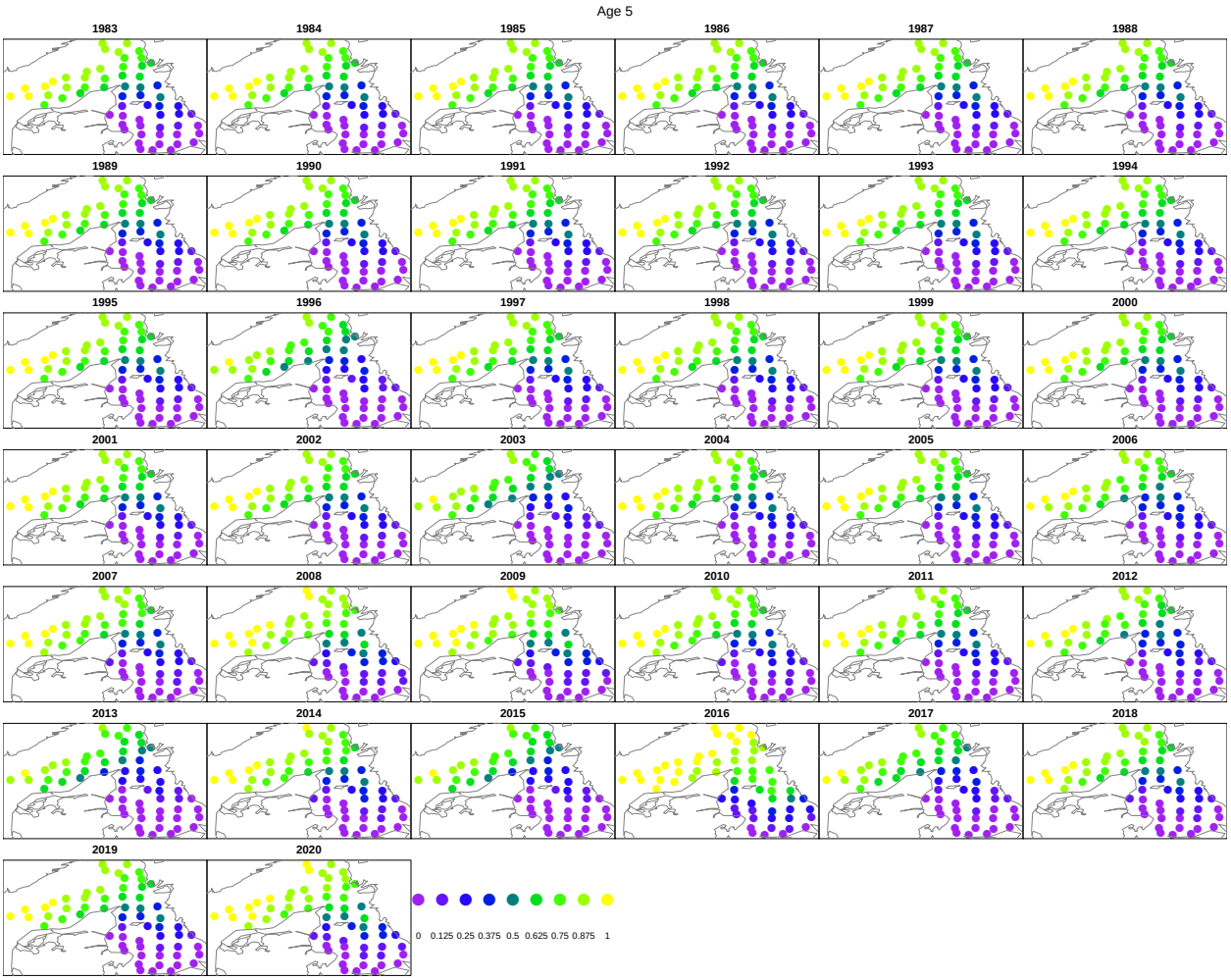


Figure 6: Q1 age 5

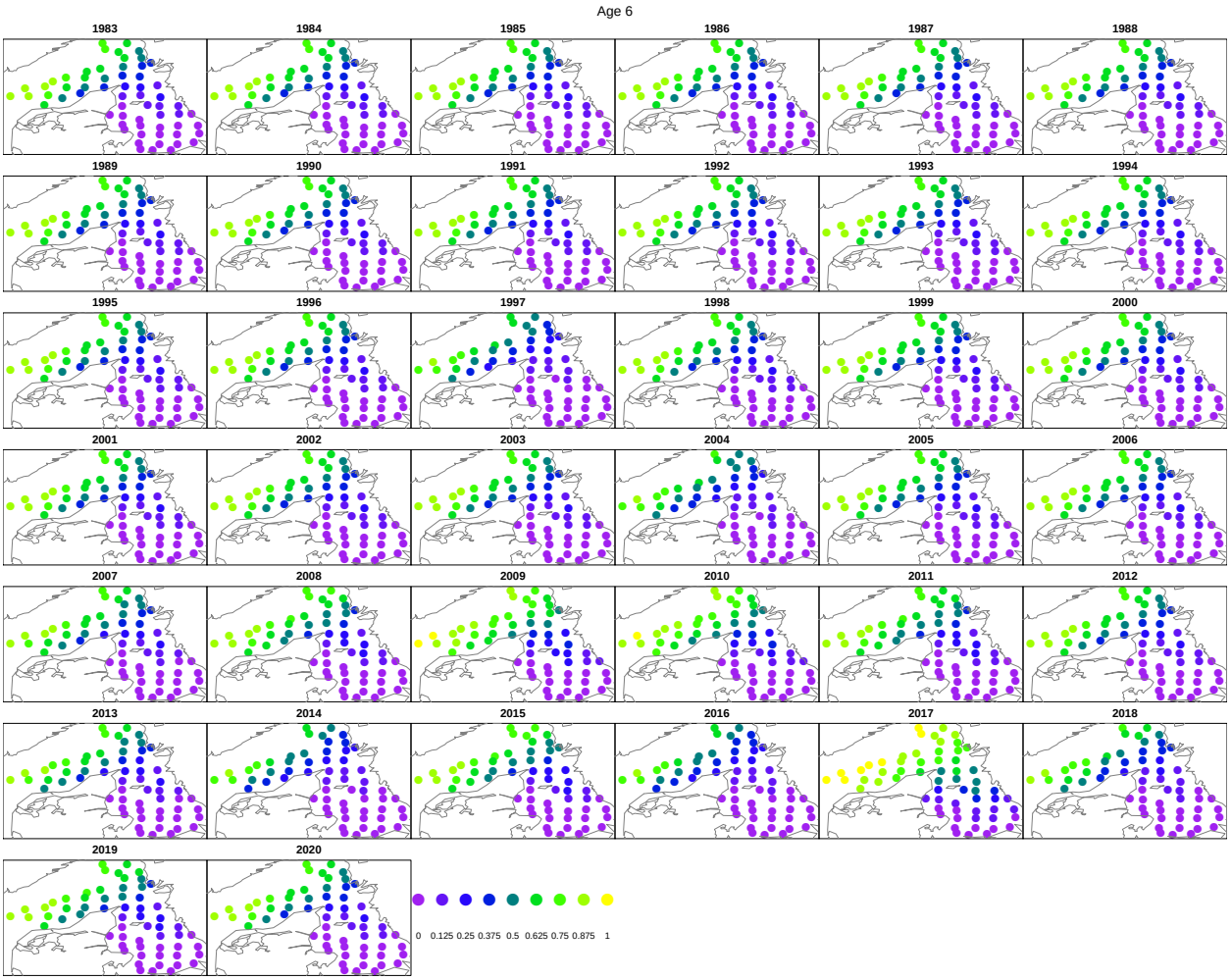


Figure 7: Q1 age 6+

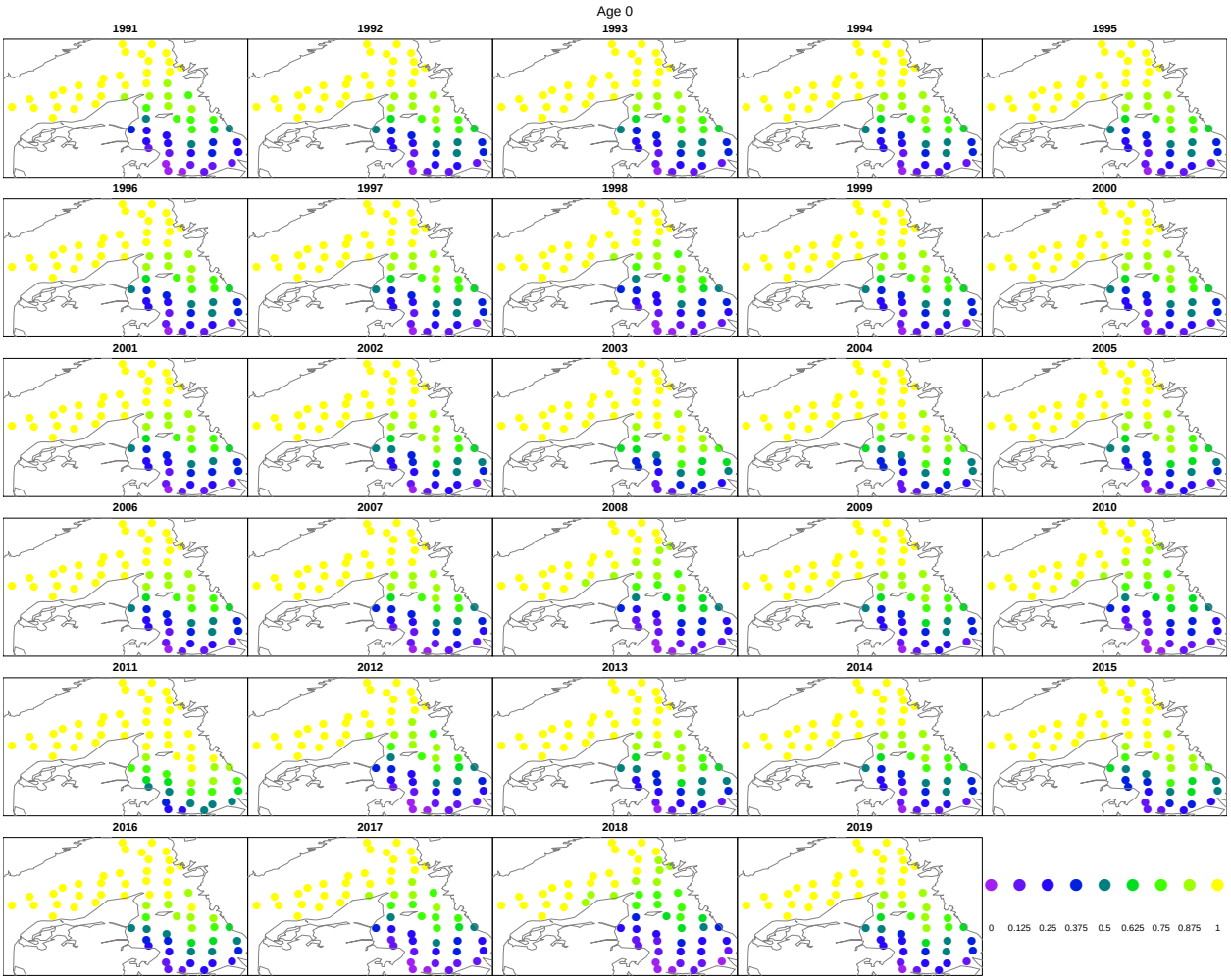


Figure 8: Q3 age 0

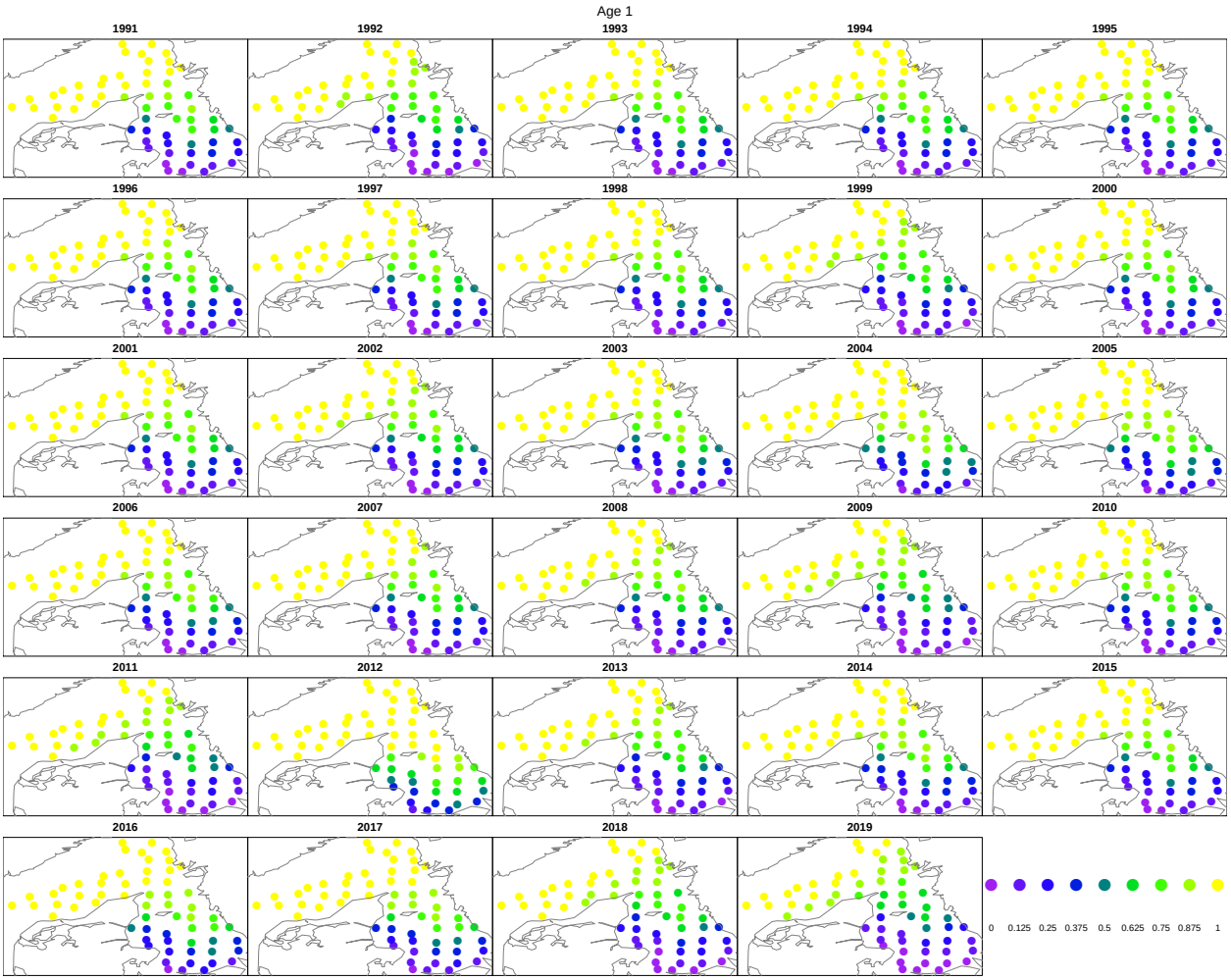


Figure 9: Q3 age 1

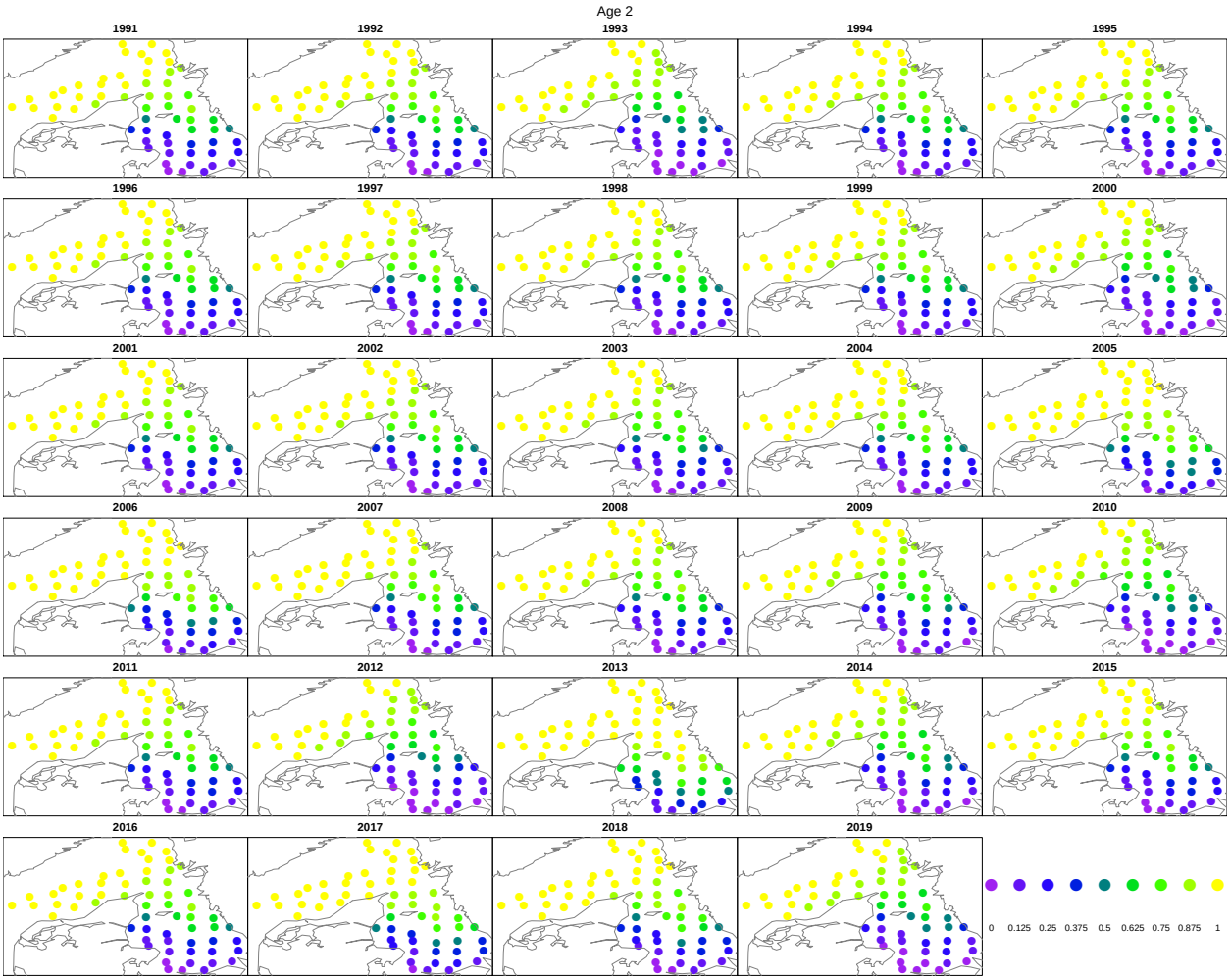


Figure 10: Q3 age 2

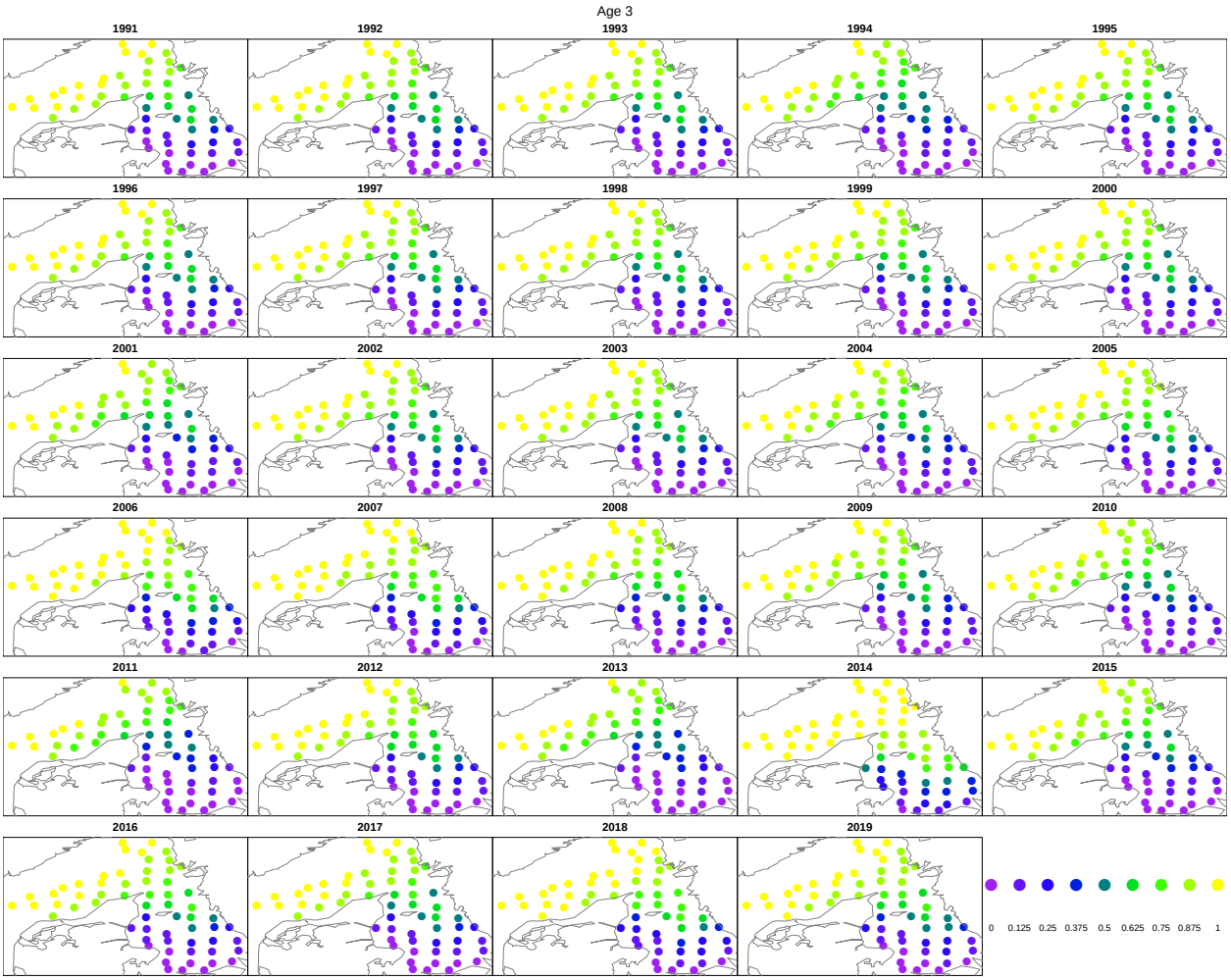


Figure 11: Q3 age 3

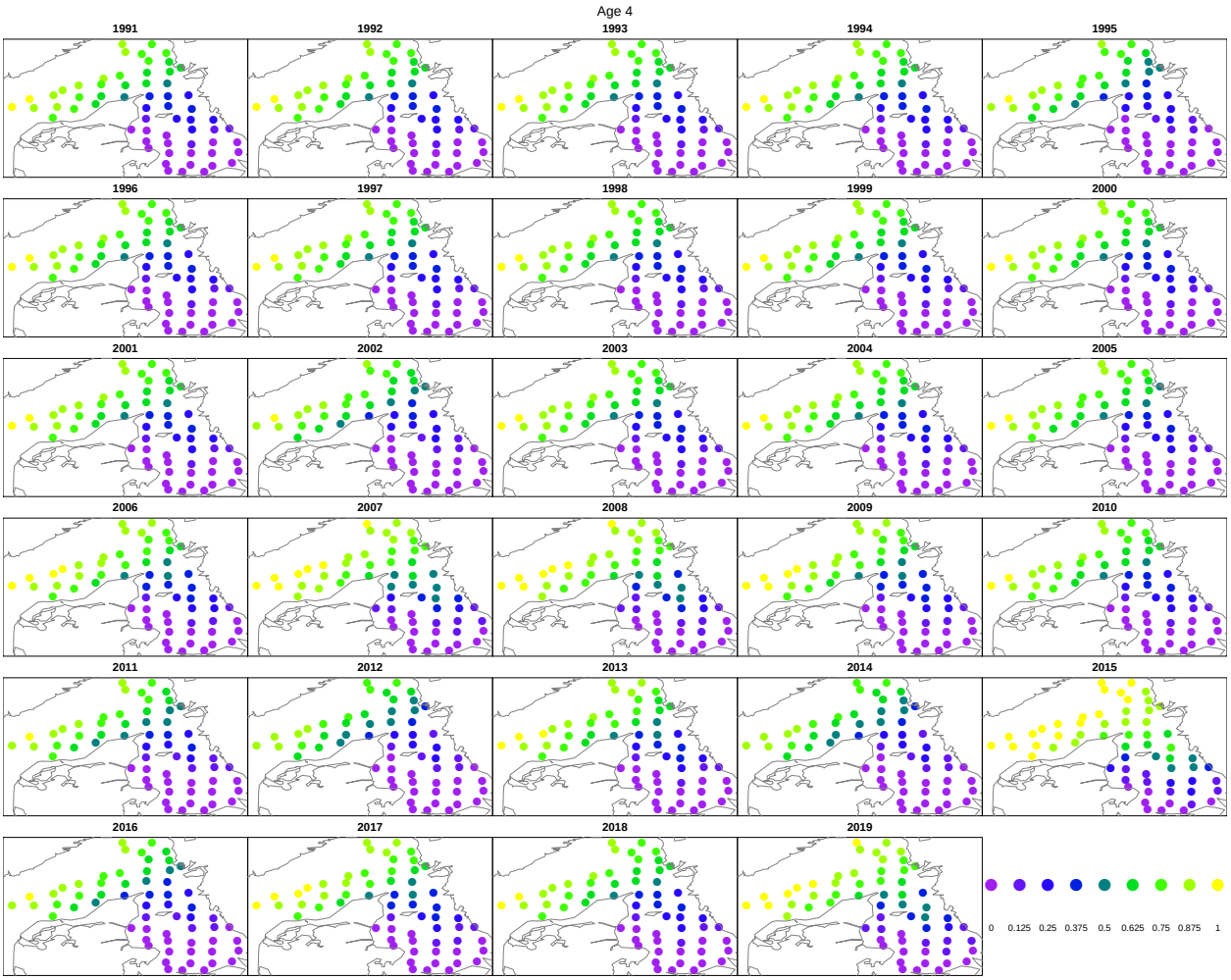


Figure 12: Q3 age 4

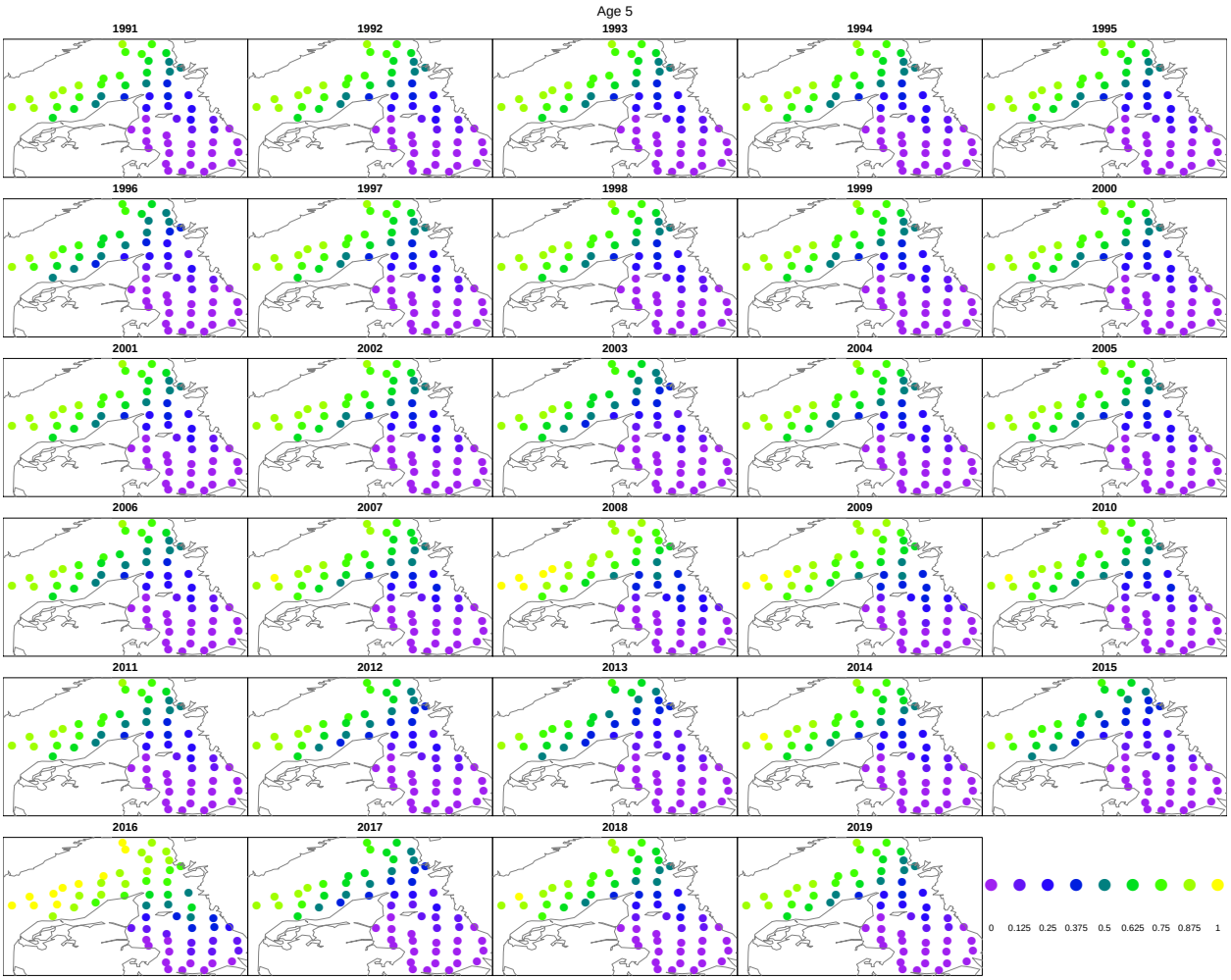


Figure 13: Q3 age 5+

4 Survey Index Models

All models were created using the `surveyIndex` R-package [2, 3]. Spatial ALKs were estimated using the methodology described in [1] and is unchanged since the last benchmark. Five different model formulas was tested. The first (Model 0) is the one currently used for the assessment of NS cod. The spatial effect in Model 0 is assumed to be the same for all years. Model 1 is the one currently used to provide estimates by sub-area. Model 1 has a time-varying spatial effect, but the model resolution in time and space is restricted to be quite low (the k-values species the maximal number of effective degrees of freedom in the splines). Model 2 is similar to model 1, except that it has a higher resolution in space and time, and it uses another spline basis (Duchon splines with first order derivative penalization). Duchon splines of this type tend to be more appropriate for extrapolation outside the data range. Models 3 and 4 decomposes the space-time effect into a fixed spatial high resolution term (an average distribution), and a second term representing low resolution deviations from this average. In model 3 the second term is independently estimated by year, whereas in model 4 the second term is assumed to be auto-correlated through time. All models were estimated using a Delta-Gamma distribution (same as is currently used). In addition, models 3 and 4 were tested with Delta-Lognormal and Tweedie distributions as well (denoted by ".dln" and ".tw" respectively).

Models

- Model 0: Current model. Time-invariant high resolution spatial effect.
- Model 1: Current sub-area model. Time-variant spatial effect (low resolution).
- Model 2: As 2, but higher resolution.
- Model 3: High resolution, Fixed spatial + yearly independent deviances.
- Model 4: High resolution, Fixed spatial + autocorrelated deviances.

The exact model formulas used for the delta-GAMs are listed below:

```
Model 0: Year + s(lon,lat,k=144,bs='ts') + s(Ship,bs='re') + offset(log(HaulDur))
Model 1: Year + te(ctime,lon,lat,d=c(1,2),bs=c('cs','tp'),k=c(5,25)) + s(Depth,bs='ts',k=6)
         + s(TimeShotHour,bs='cc',k=6) + s(Ship,bs='re') + offset(log(HaulDur))

Model 2: Year + te(ctime,lon,lat,d=c(1,2),bs=c('ds','ds'),m=c(1,0.5),k=c(10,64))
         + s(Depth,bs='ds',m=c(1,0),k=6) + s(TimeShotHour,bs='cc',k=6)
         + s(Ship,bs='re') + offset(log(HaulDur))



Model 3:
Positive:
          Year + s(lon,lat,bs='ds',k=120,m=c(1,0.5)) + s(lon,lat,bs='ds',m=c(1,0.5),k=9,by=Year,id=1)
          + s(Depth,bs='ds',m=c(1,0),k=6)+s(TimeShotHour,bs='cc',k=6)
          + s(Ship,bs='re') + offset(log(HaulDur))
Presence/absence:
          Year + s(lon,lat,bs='ds',k=80,m=c(1,0.5)) + s(lon,lat,bs='ds',m=c(1,0.5),k=7,by=Year,id=1)
          + s(Depth,bs='ds',m=c(1,0),k=6)+s(TimeShotHour,bs='cc',k=6)
          + s(Ship,bs='re') + offset(log(HaulDur))

Model 4:
Positive:
         Year + s(lon,lat,bs=c('ds'),m=c(1,0.5),k=120)
         + te(ctime,lon,lat,bs=c('ds','ds'),d=c(1,2),m=list(c(1,0),c(1,0.5)),k=c(nyears/2,16))
         + s(Depth,bs='ds',m=c(1,0),k=6) + s(TimeShotHour,bs='cc',k=6)
         + s(Ship,bs='re') + offset(log(HaulDur))
Presence/absence:
         Year + s(lon,lat,bs=c('ds'),m=c(1,0.5),k=80)
         + te(ctime,lon,lat,bs=c('ds','ds'),d=c(1,2),m=list(c(1,0),c(1,0.5)),k=c(nyears/2,9))
         + s(Depth,bs='ds',m=c(1,0),k=6) + s(TimeShotHour,bs='cc',k=6)
         + s(Ship,bs='re') + offset(log(HaulDur))
```

5 Results

The following plots show the different indices using the standard area (area 20 included but not 21 and no splitting using genetics).

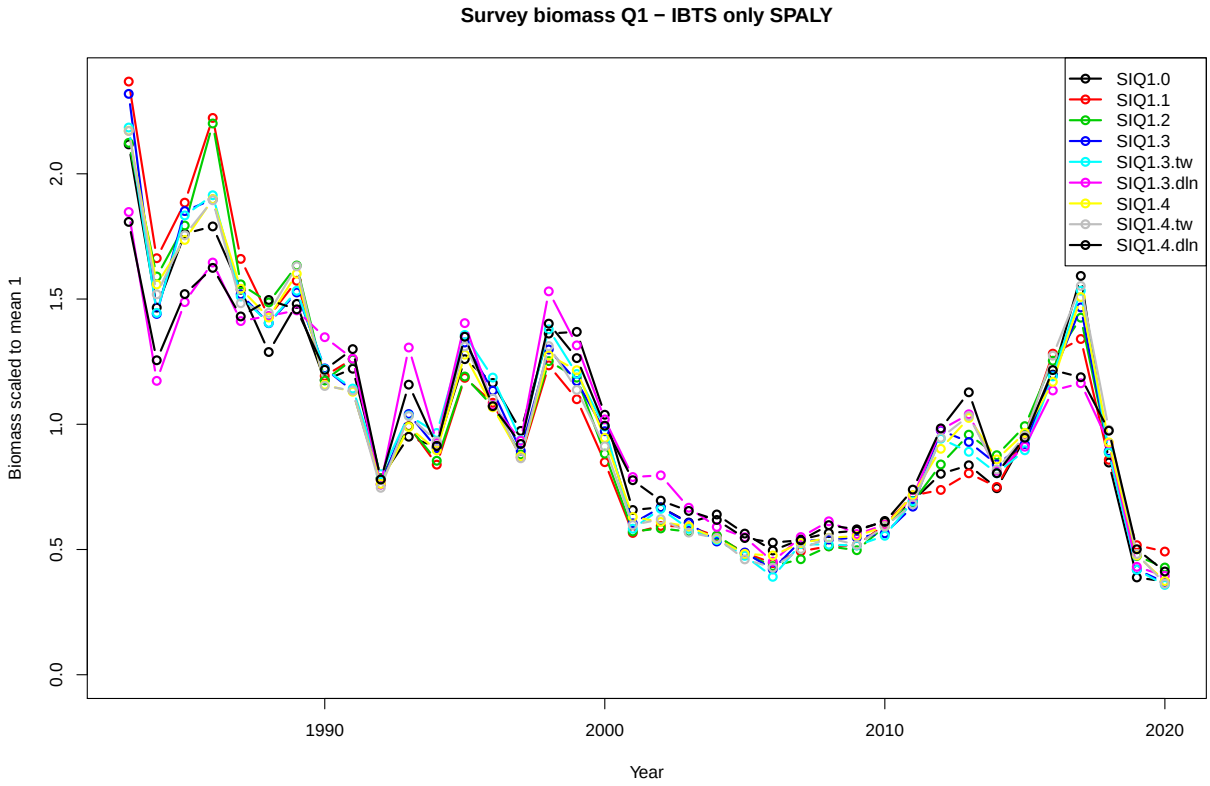


Figure 14

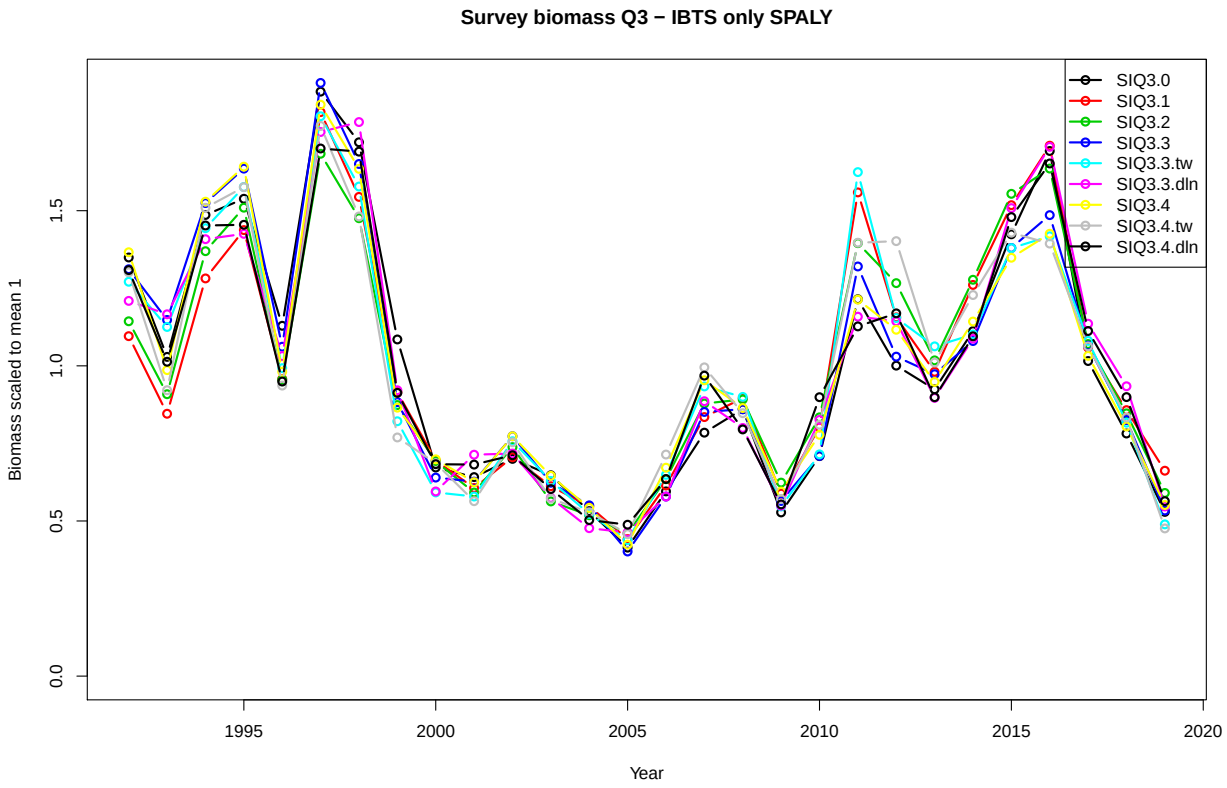

Survey biomass Q3 − IBTS only SPALY
Biomass scaled to mean 1
0.0
0.5
1.0
1.5
1995
2000
2005
2010
2015
2020
Year
SIQ3.0
SIQ3.1
SIQ3.2
SIQ3.3
SIQ3.3.tw
SIQ3.3.dln
SIQ3.4
SIQ3.4.tw
SIQ3.4.dln

Figure 15

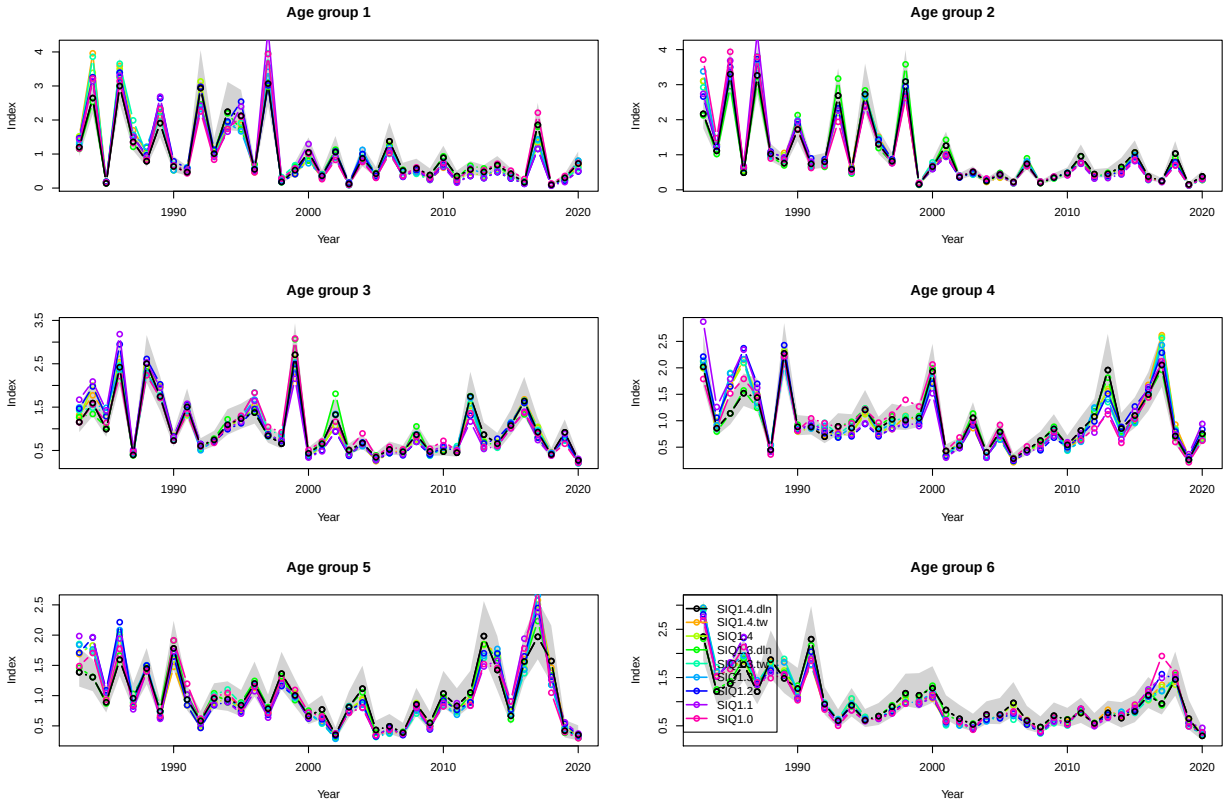

Age group 1
Age group 2
Age group 3
Age group 4
Age group 5
Age group 6
Index
Year
SIQ1.4.dln
SIQ1.4.tw
SIQ1.4
SIQ1.3.dln
SIQ1.3.tw
SIQ1.3
SIQ1.2
SIQ1.1
SIQ1.0

Figure 16

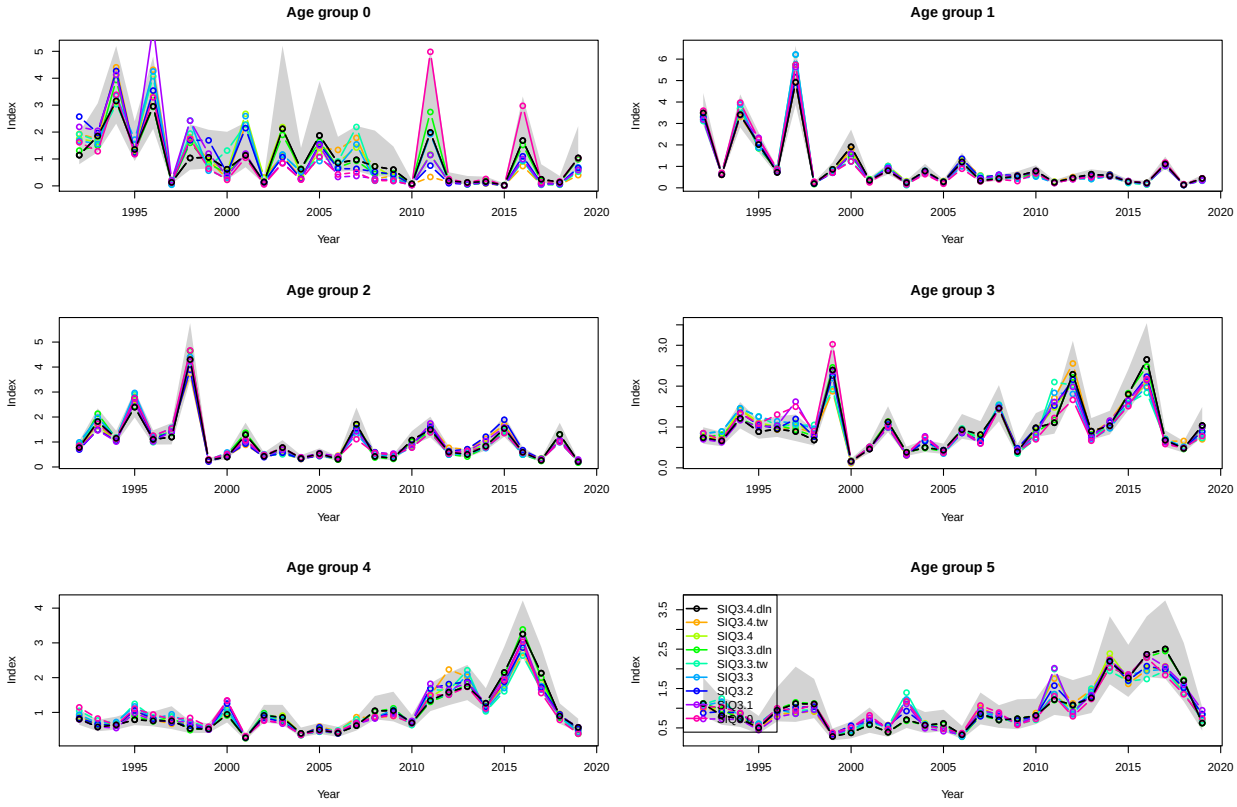

Age group 0
Age group 1
Age group 2
Age group 3
Age group 4
Age group 5
Index
Year
SIQ3.4.dln
SIQ3.4.tw
SIQ3.4
SIQ3.3.dln
SIQ3.3.tw
SIQ3.3
SIQ3.2
SIQ3.1

Figure 17

6 Model 3 results

The following plots are the results from using Model 3 with the standard assessment area. For each age group 4 figures are shown: Standardized abundance maps, spatial standardized residuals, further residual plots, and finally the estimated effects of bottom depth and time of day (TimeShotHour).

6.1 Q1

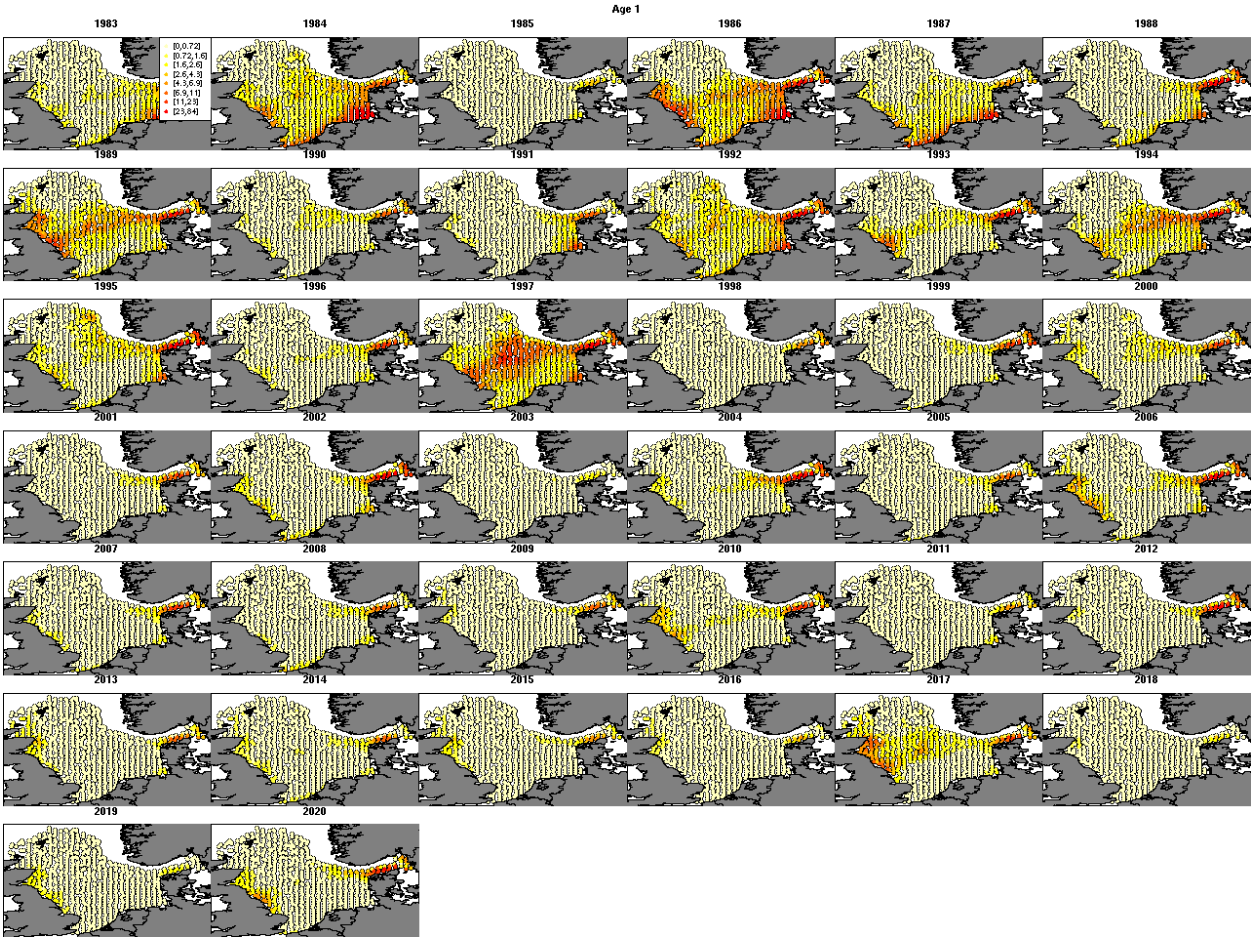


Figure 18

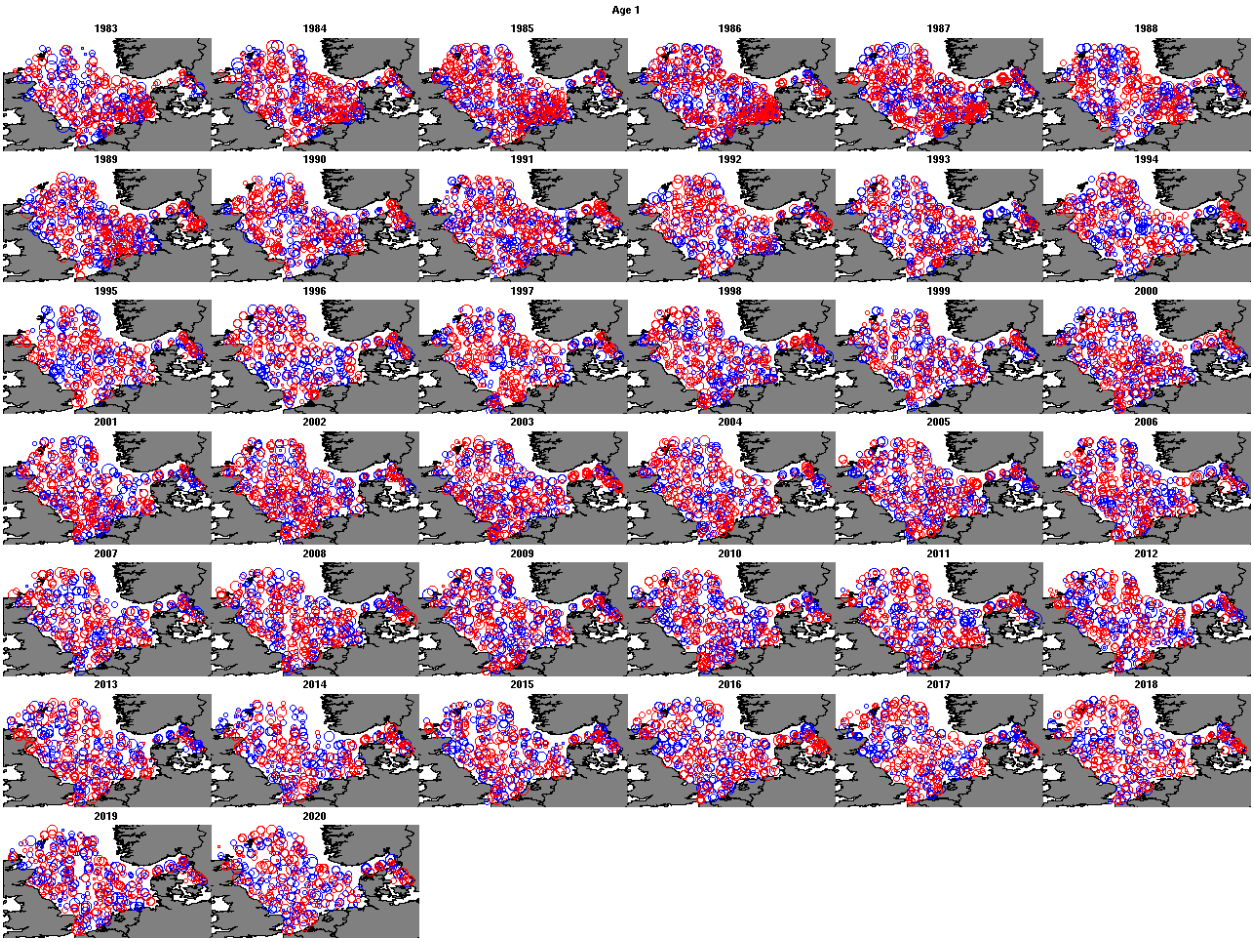

Age 1
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 19

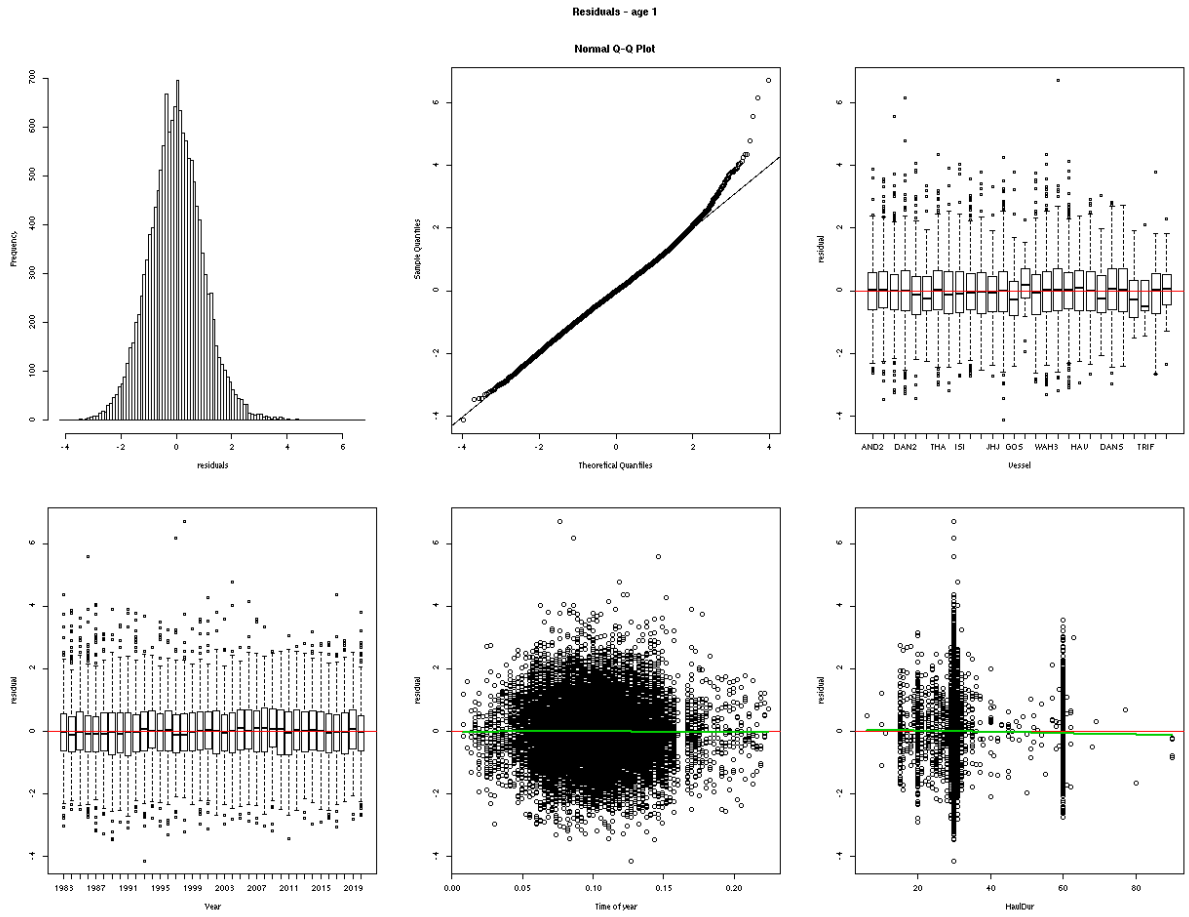

Residuals - age 1
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
AND2 DAN2 THA ISI JHJ GO5 WAH3 HAU DAN5 TRIF
Vessel
Year
Time of year
HaulDur

Figure 20

229

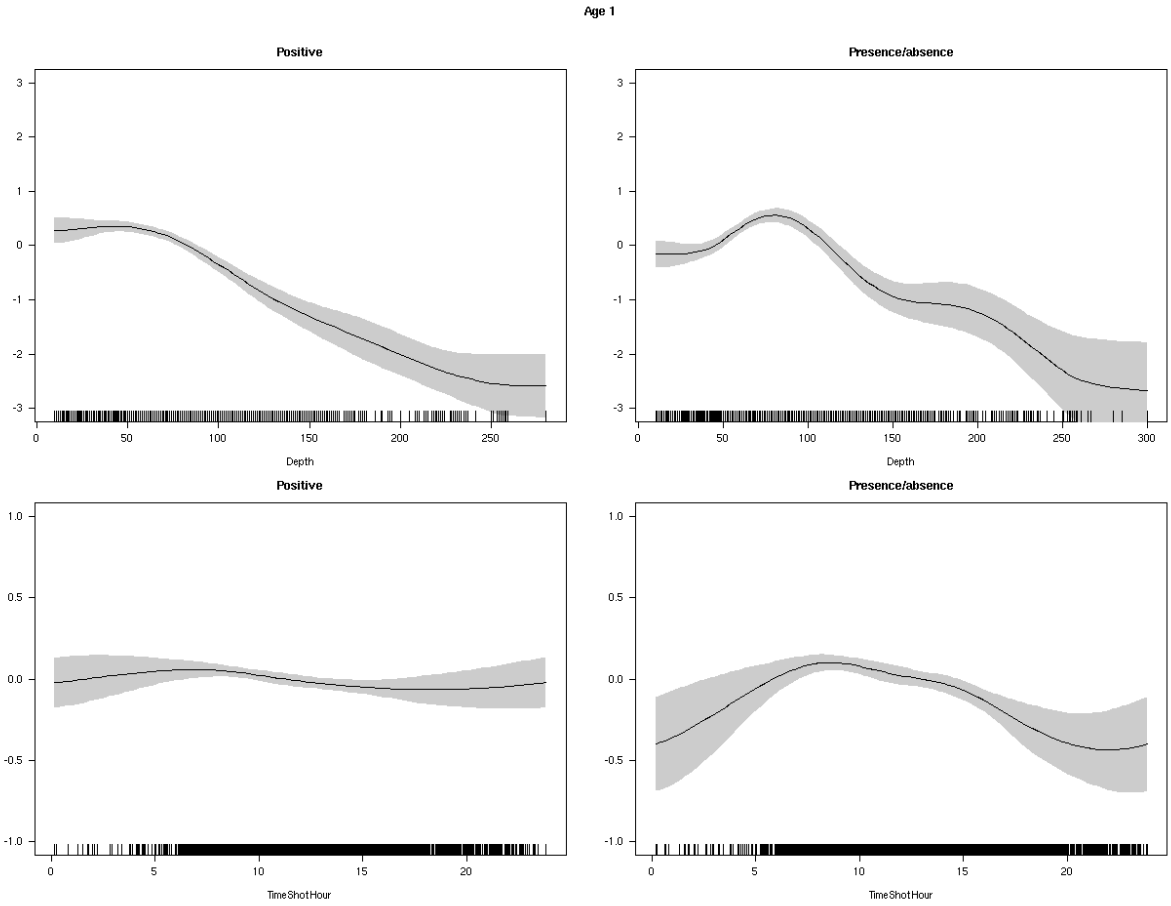


Figure 21

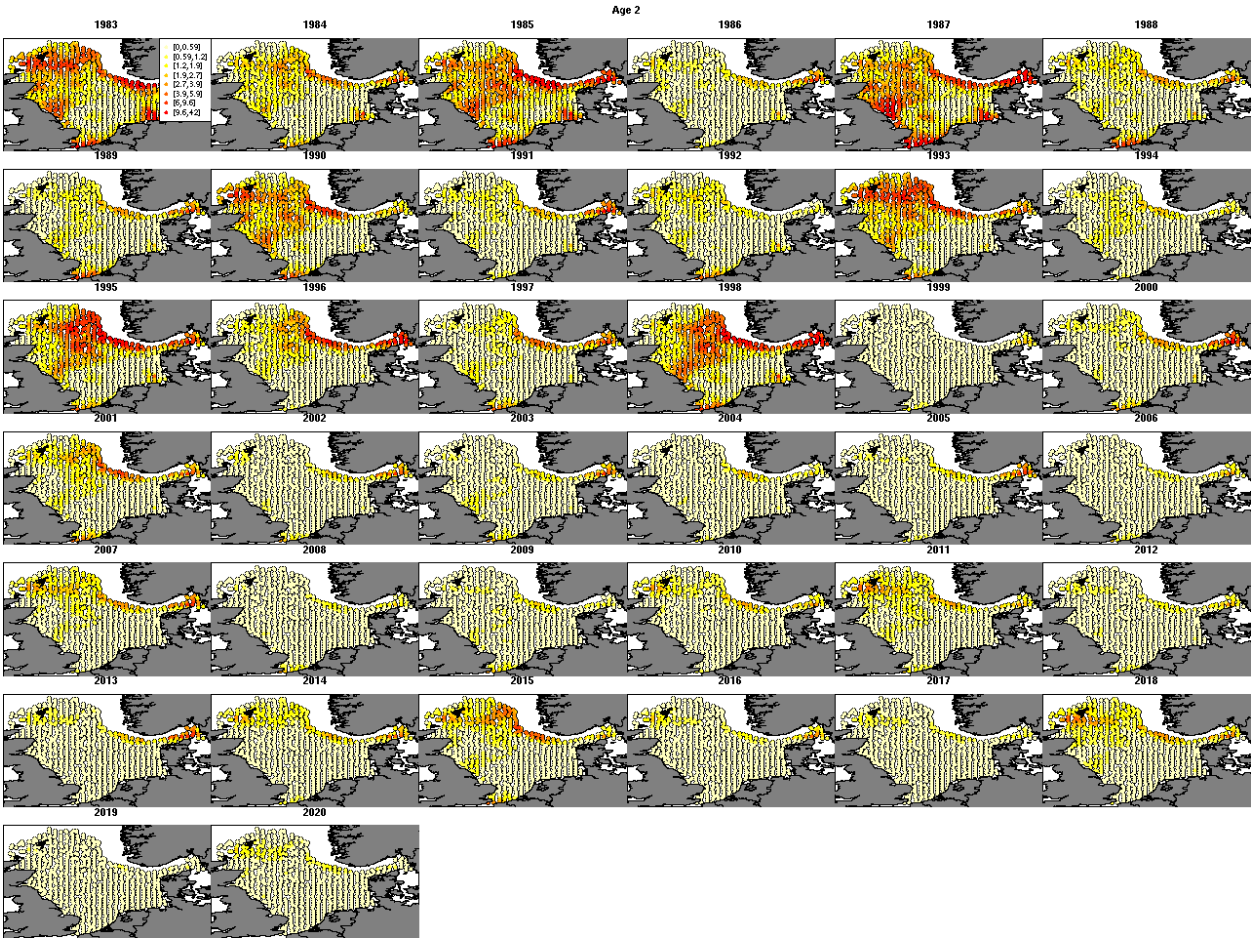

Age 2
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 22

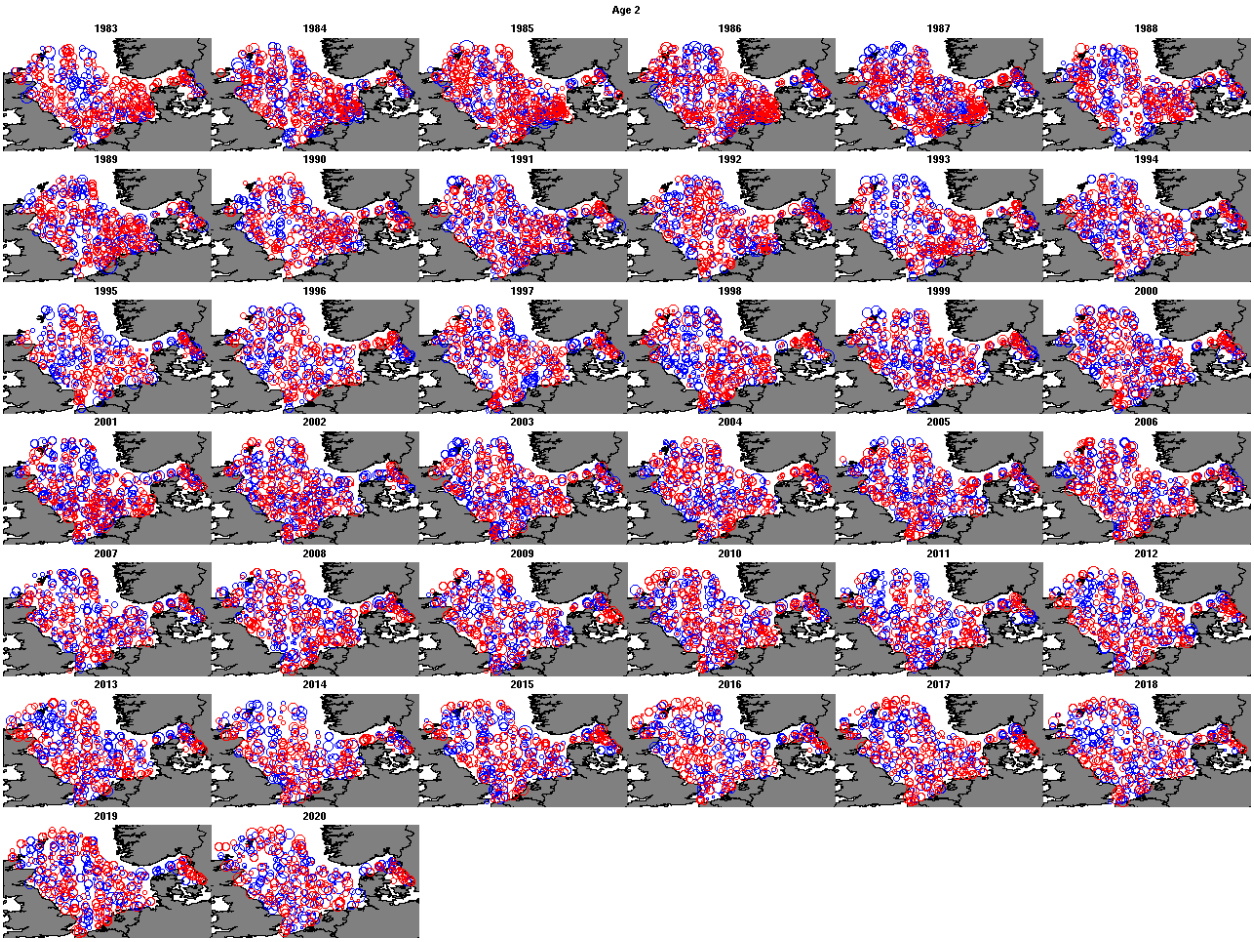

Age 2
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 23

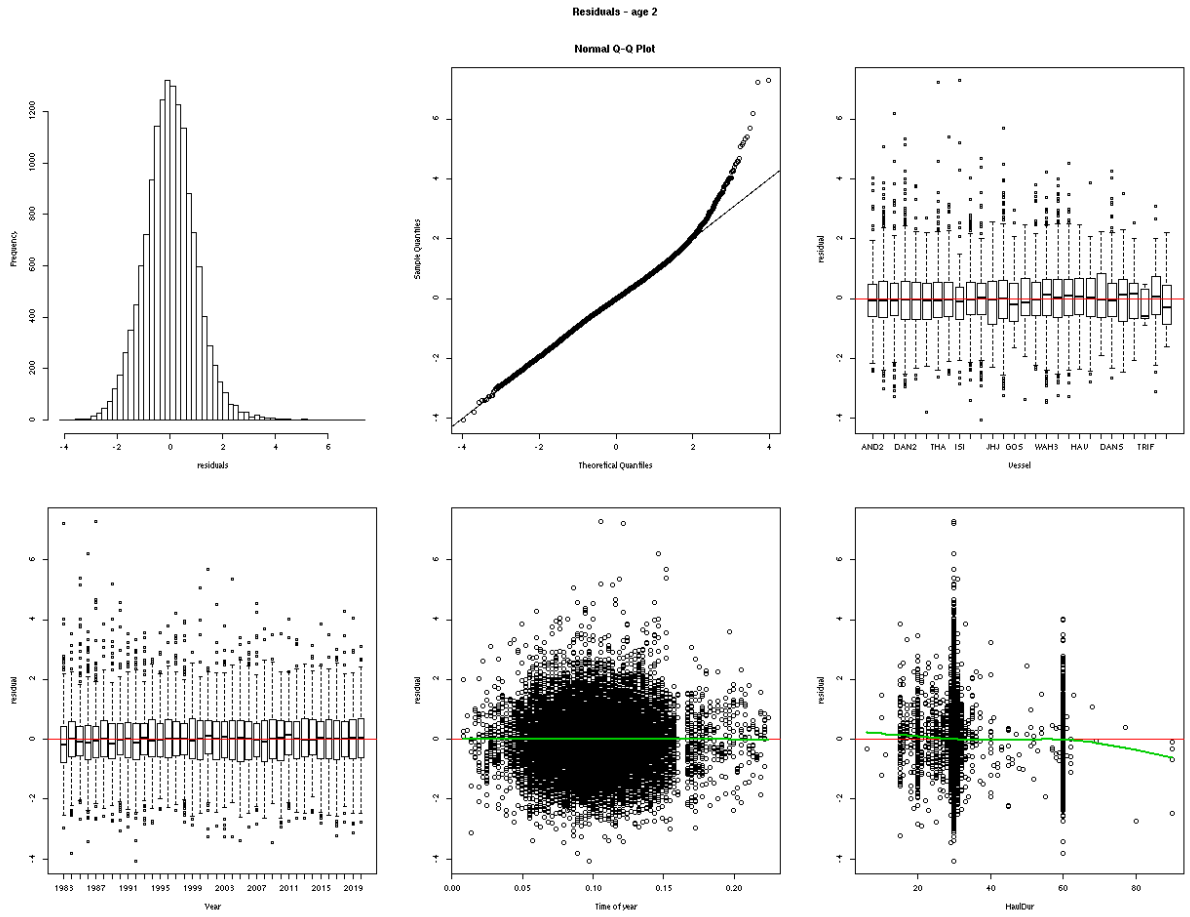

Residuals - age 2
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
AND2 DAN2 THA ISI JHJ GOS WAH3 HAV DAN5 TRIF
Vessel
Year
Time of year
HaulDur

Figure 24

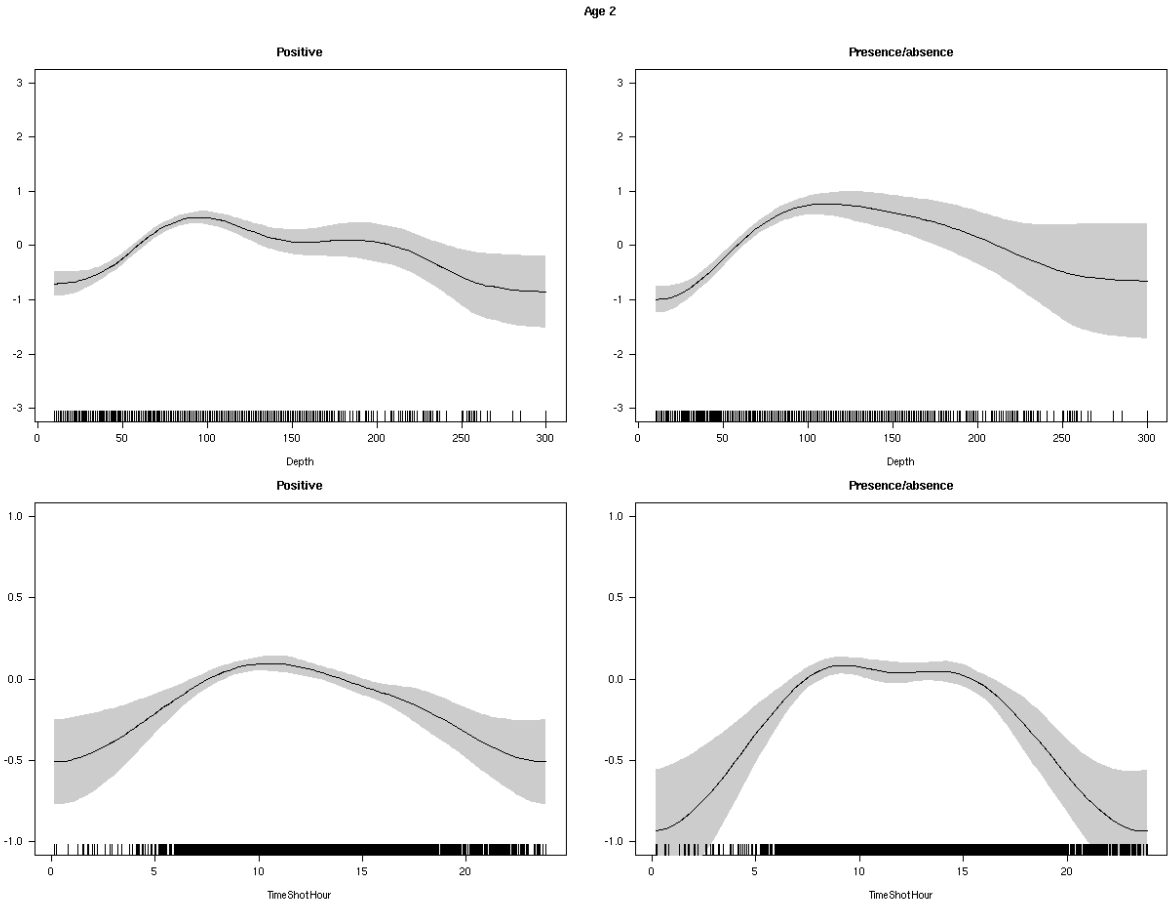

Age 2
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 25

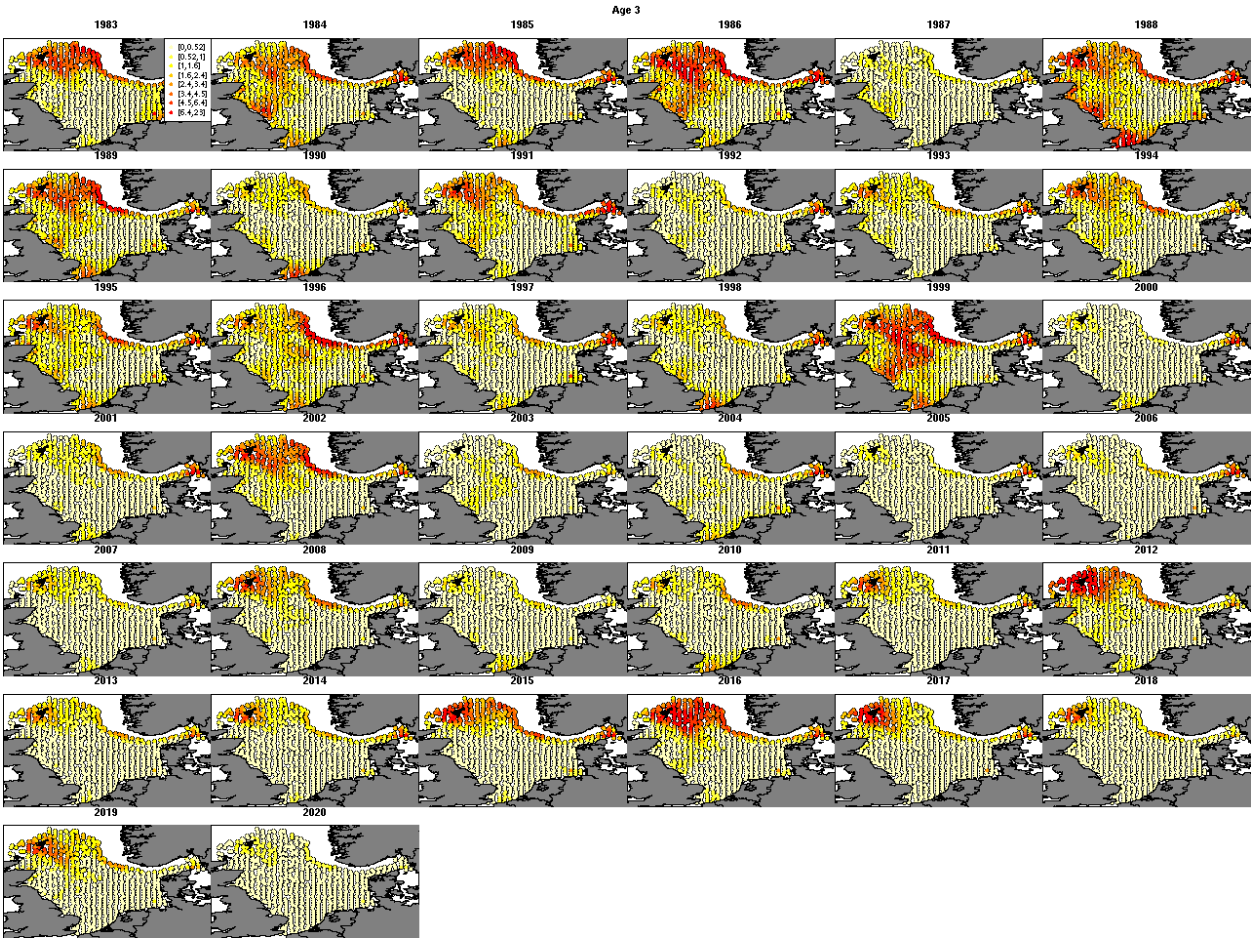

Age 3
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 26

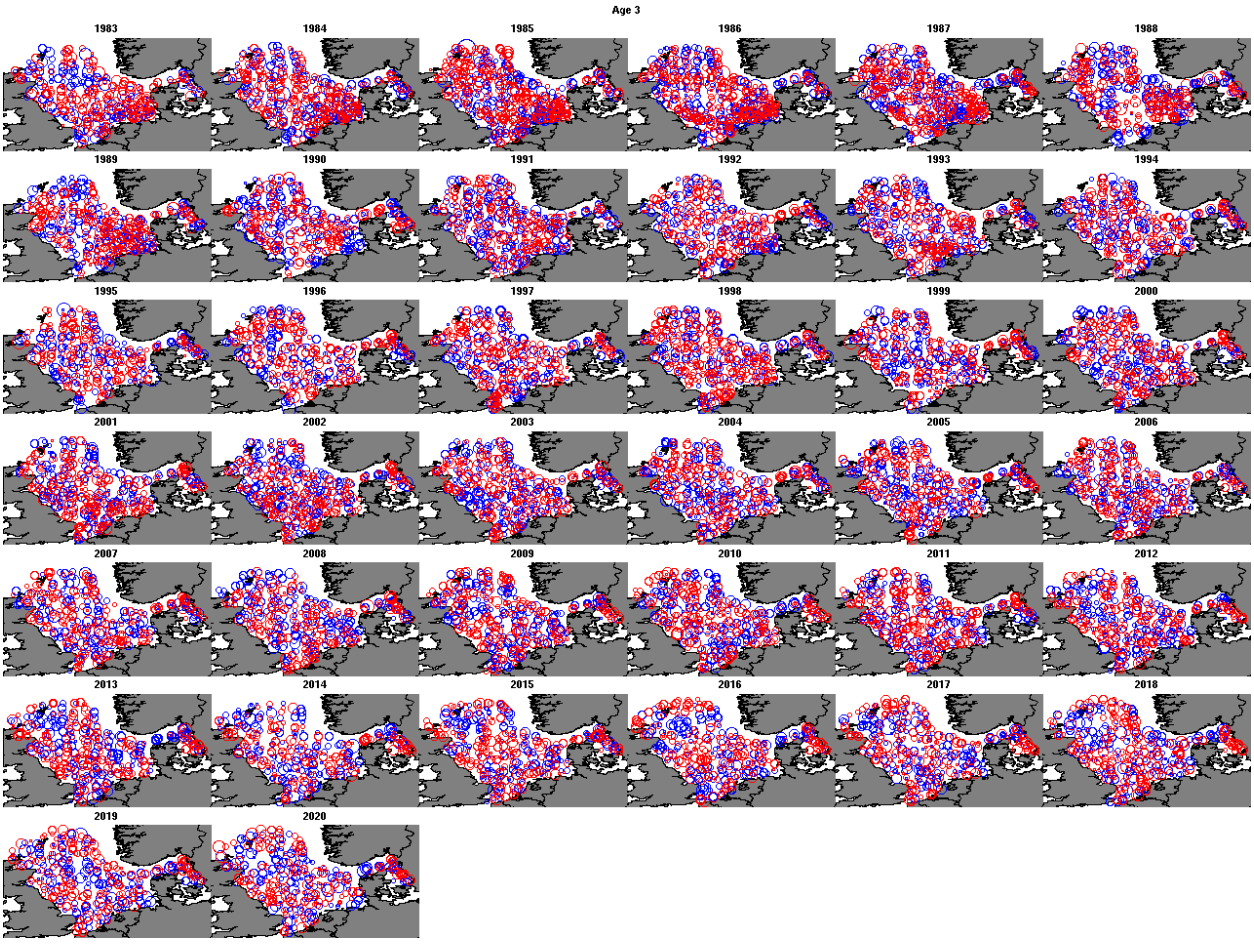

Age 3
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 27

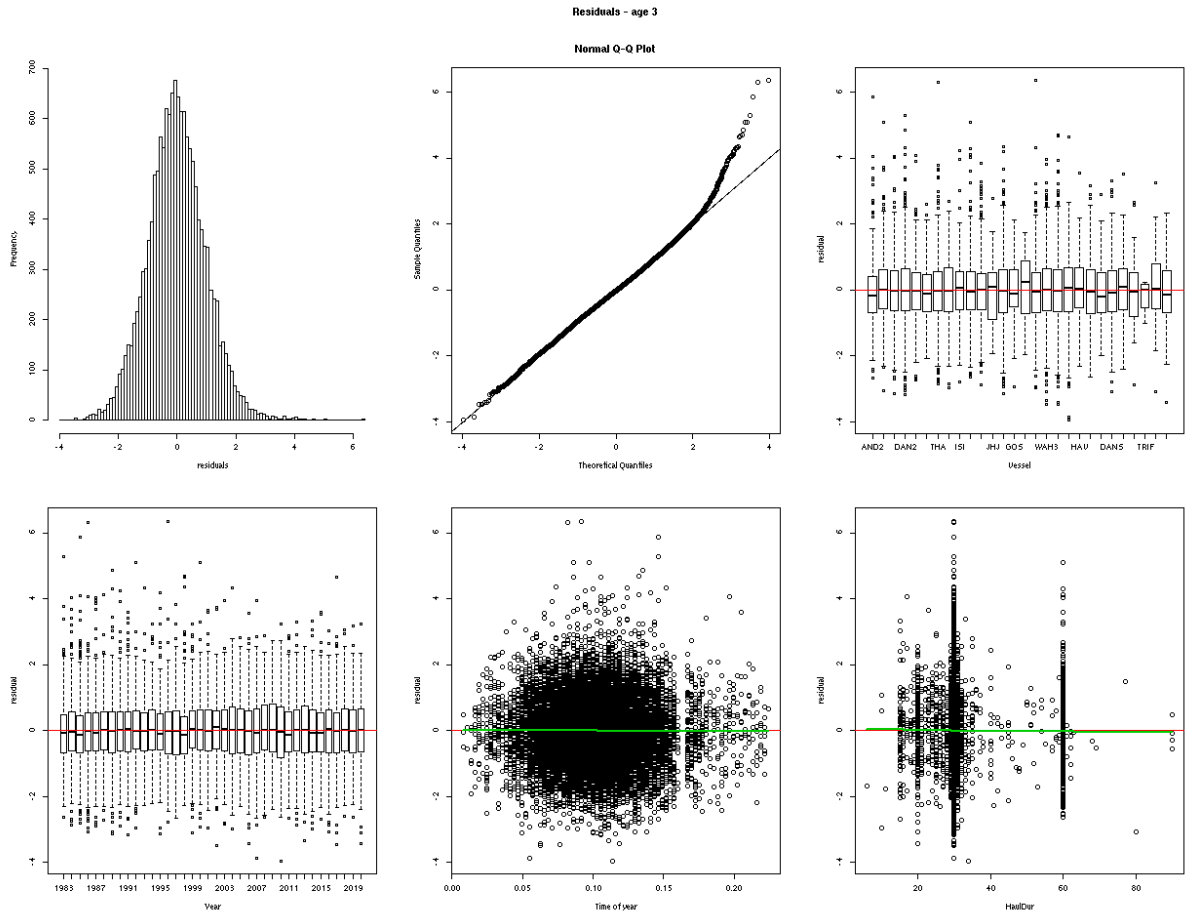

Residuals - age 3
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
AND2 DAN2 THA ISI JHJ GOS WAH3 HAU DAN5 TRIF
Vessel
Year
Time of year
HaulDur

Figure 28

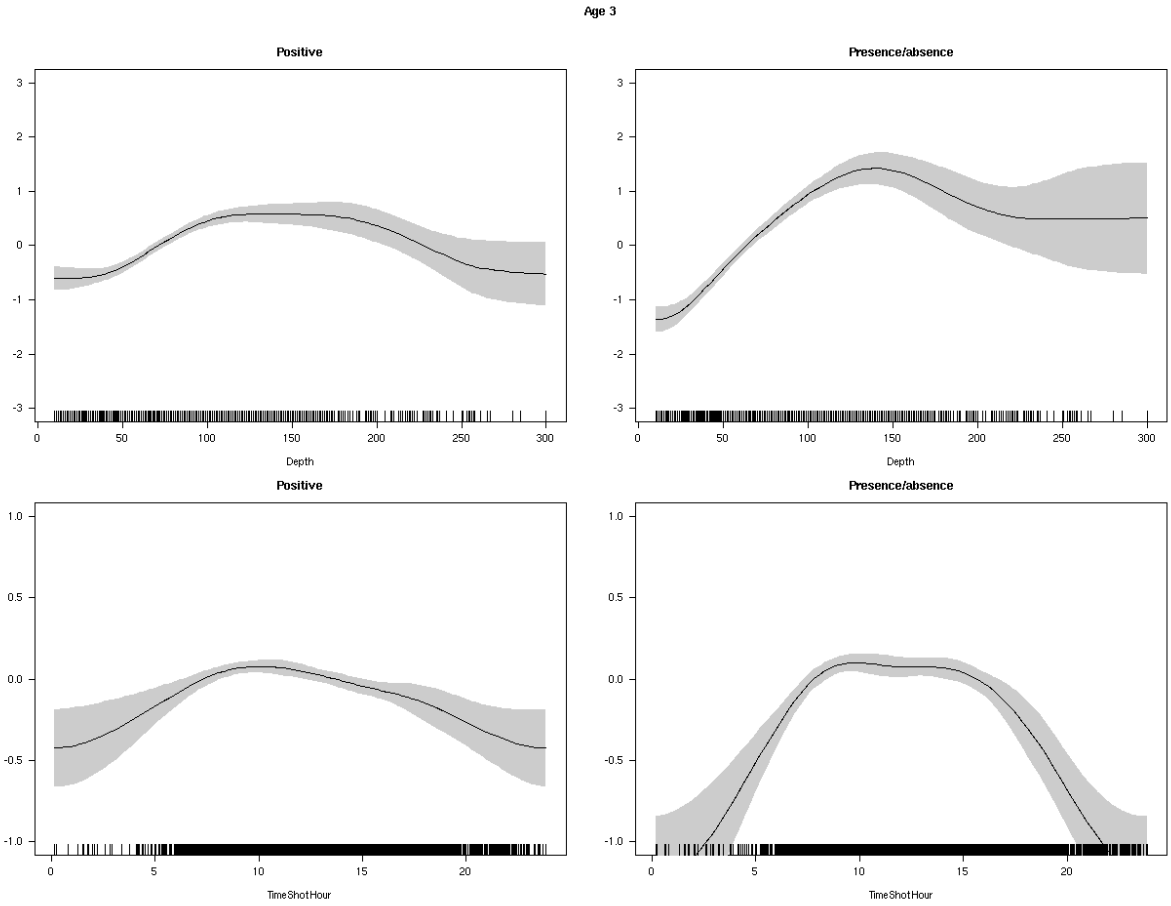

Age 3
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 29

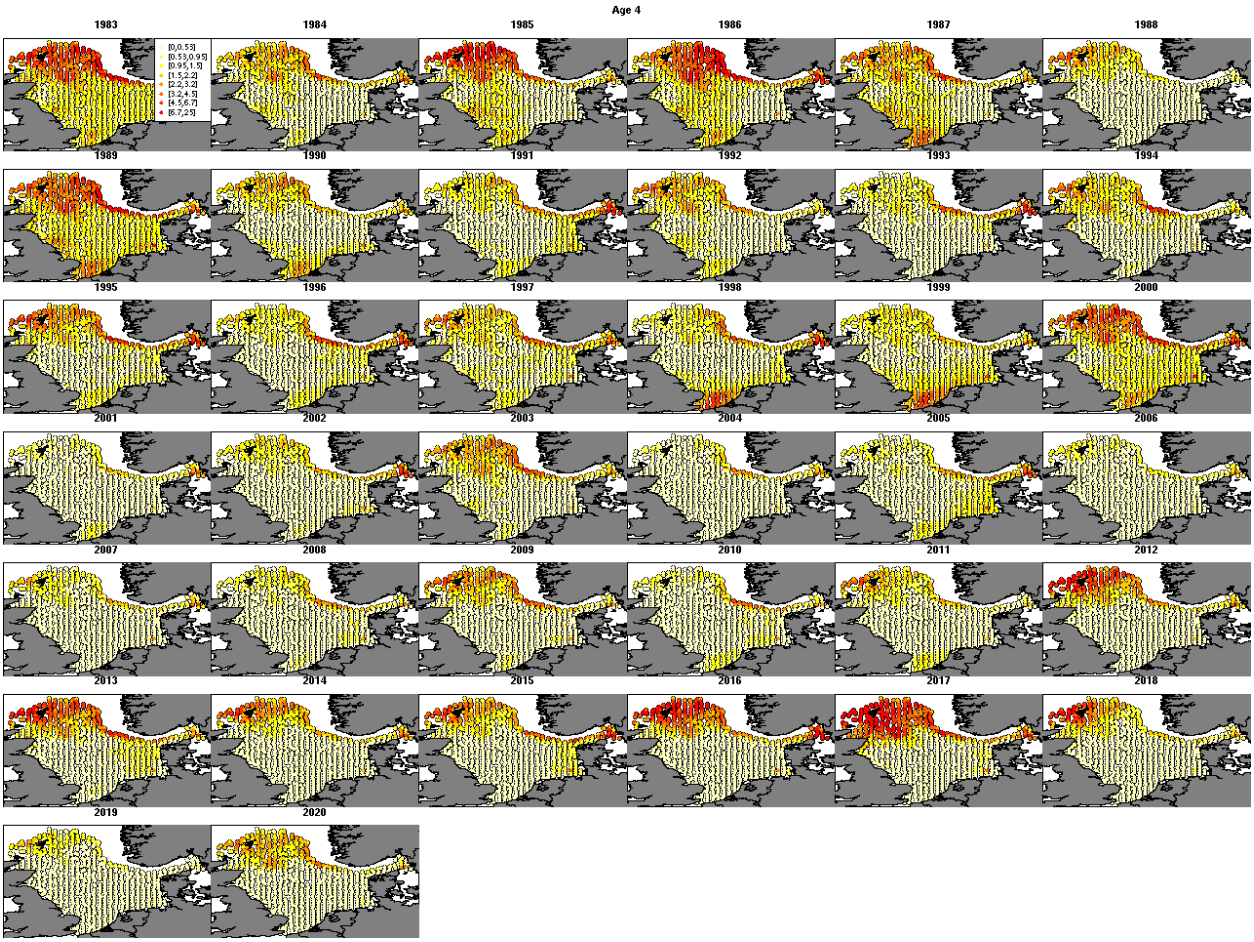

Age 4
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 30

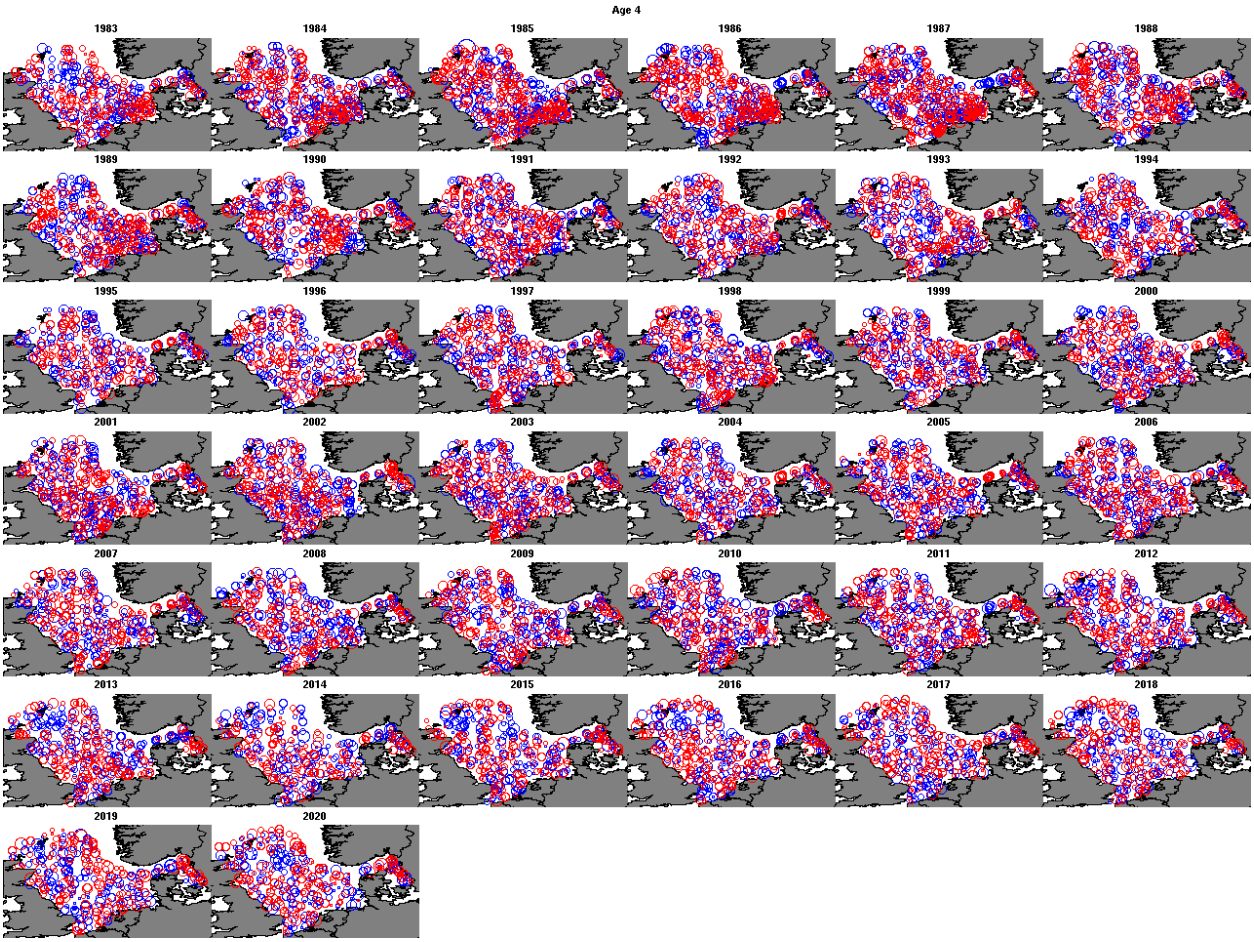

Age 4
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 31

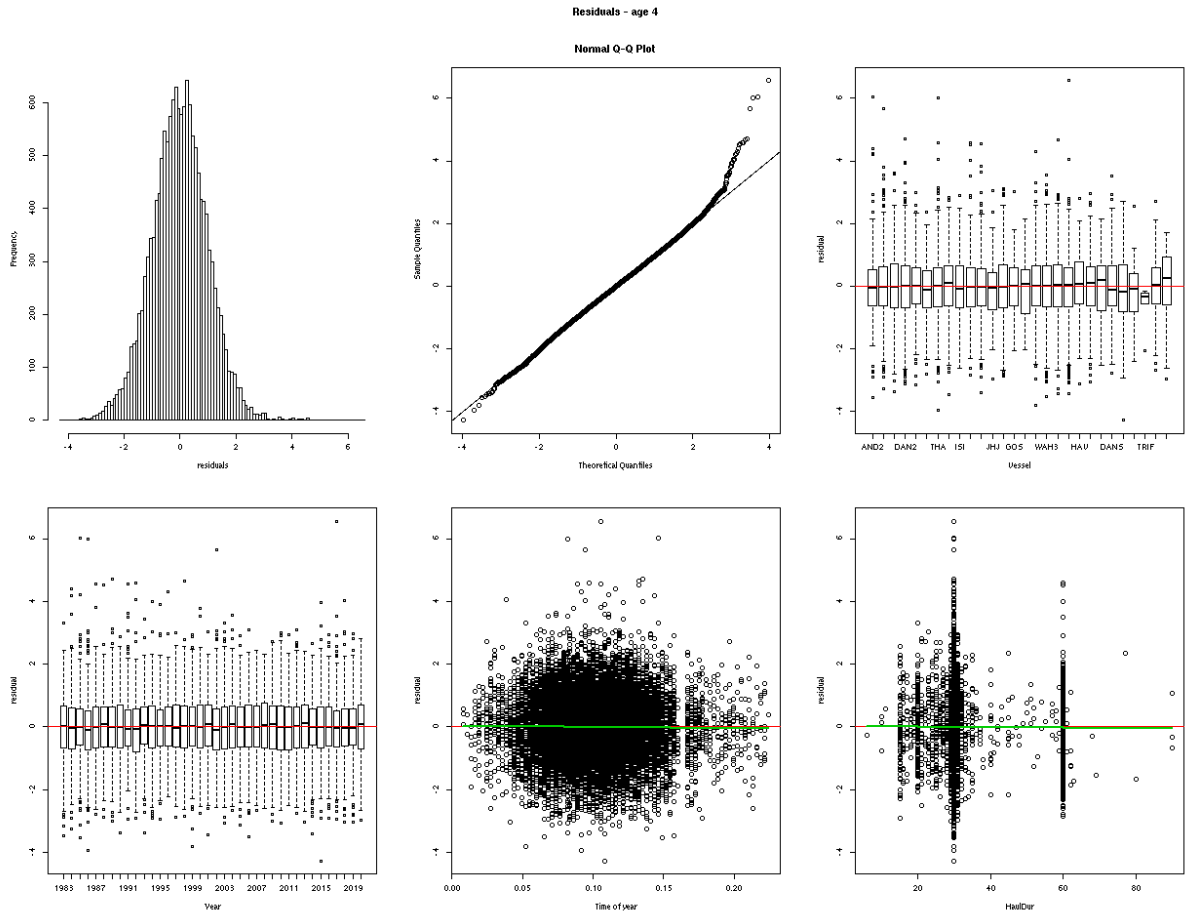

Residuals - age 4
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
AND2 DAN2 THA ISI JHJ GOS WAH3 HAU DAN5 TRIF
Vessel
Year
Time of year
HaulDur

Figure 32

241

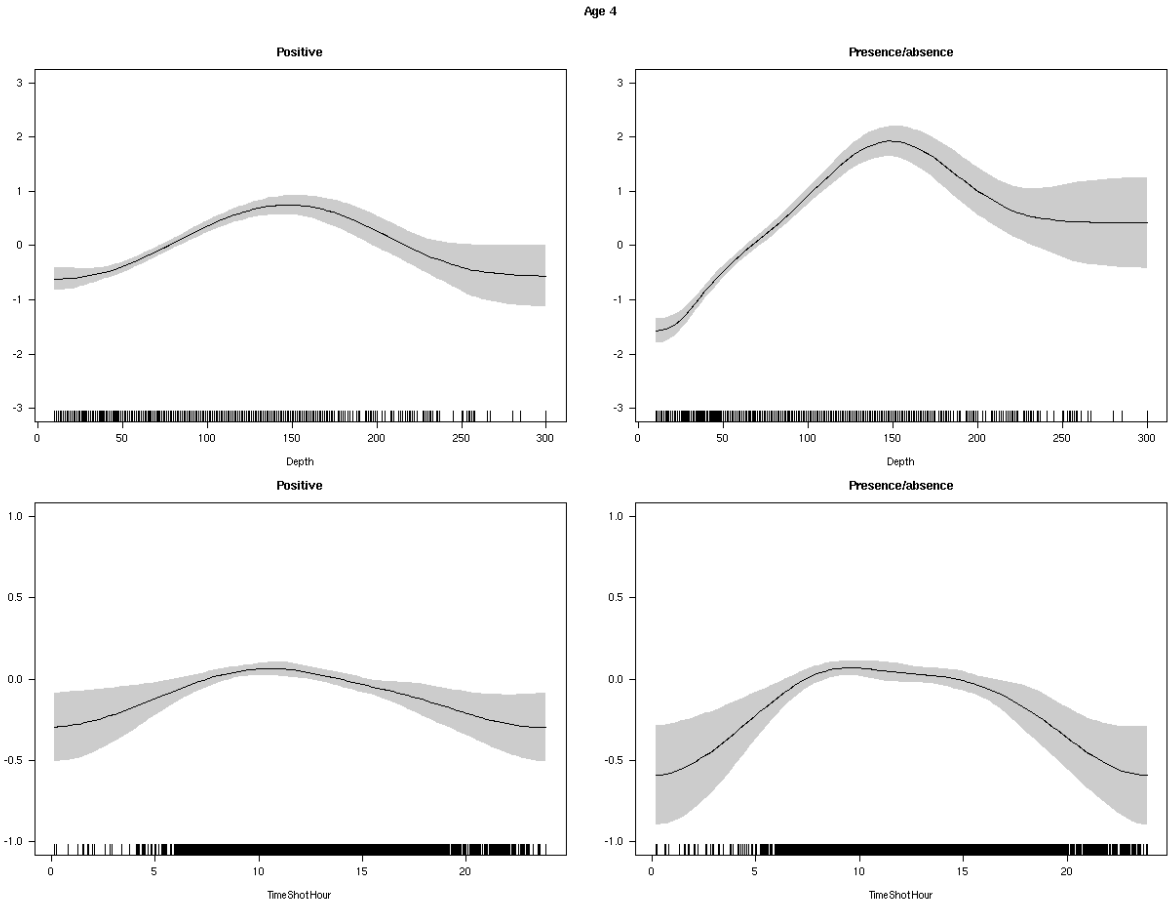


Figure 33

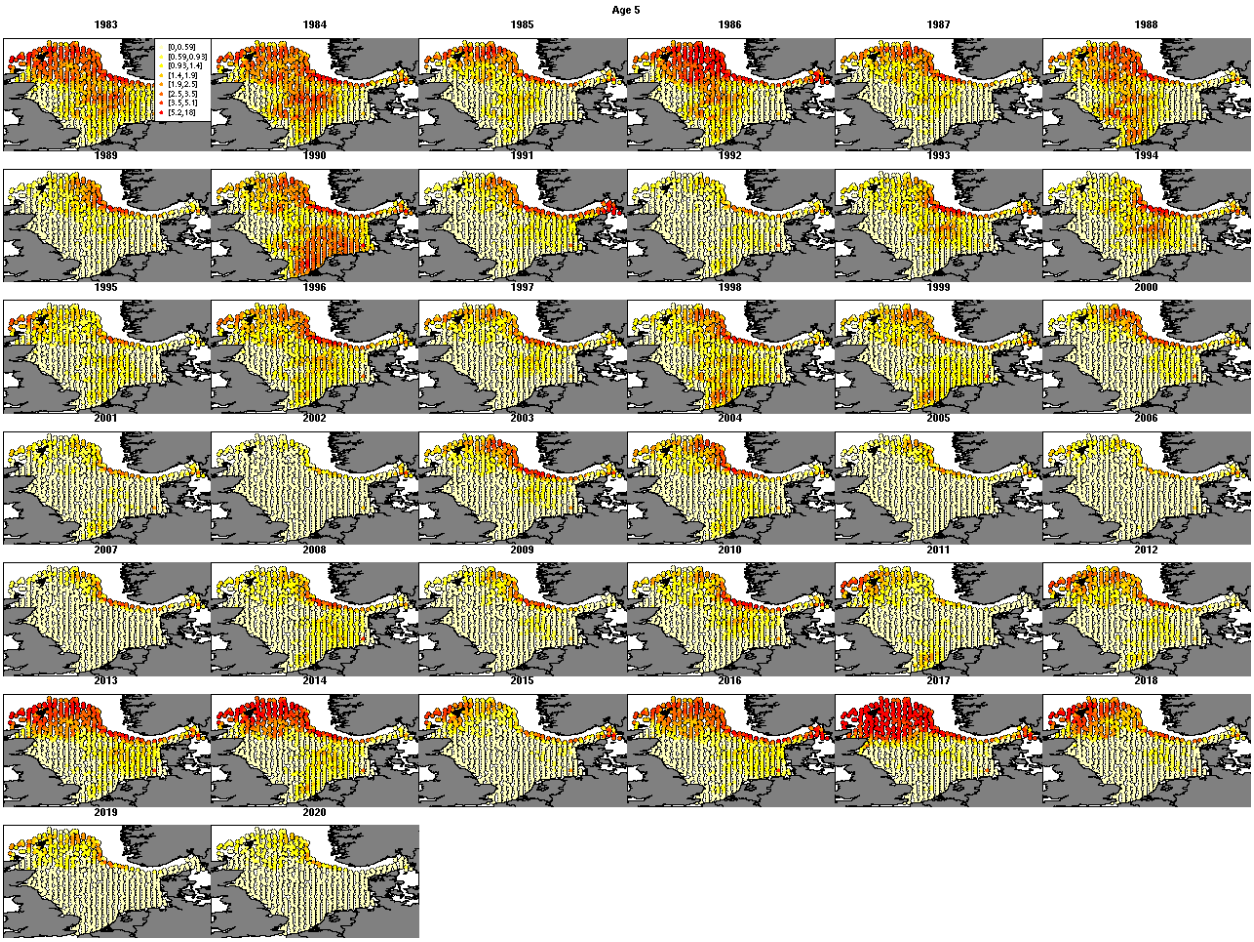

Age 5
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 34

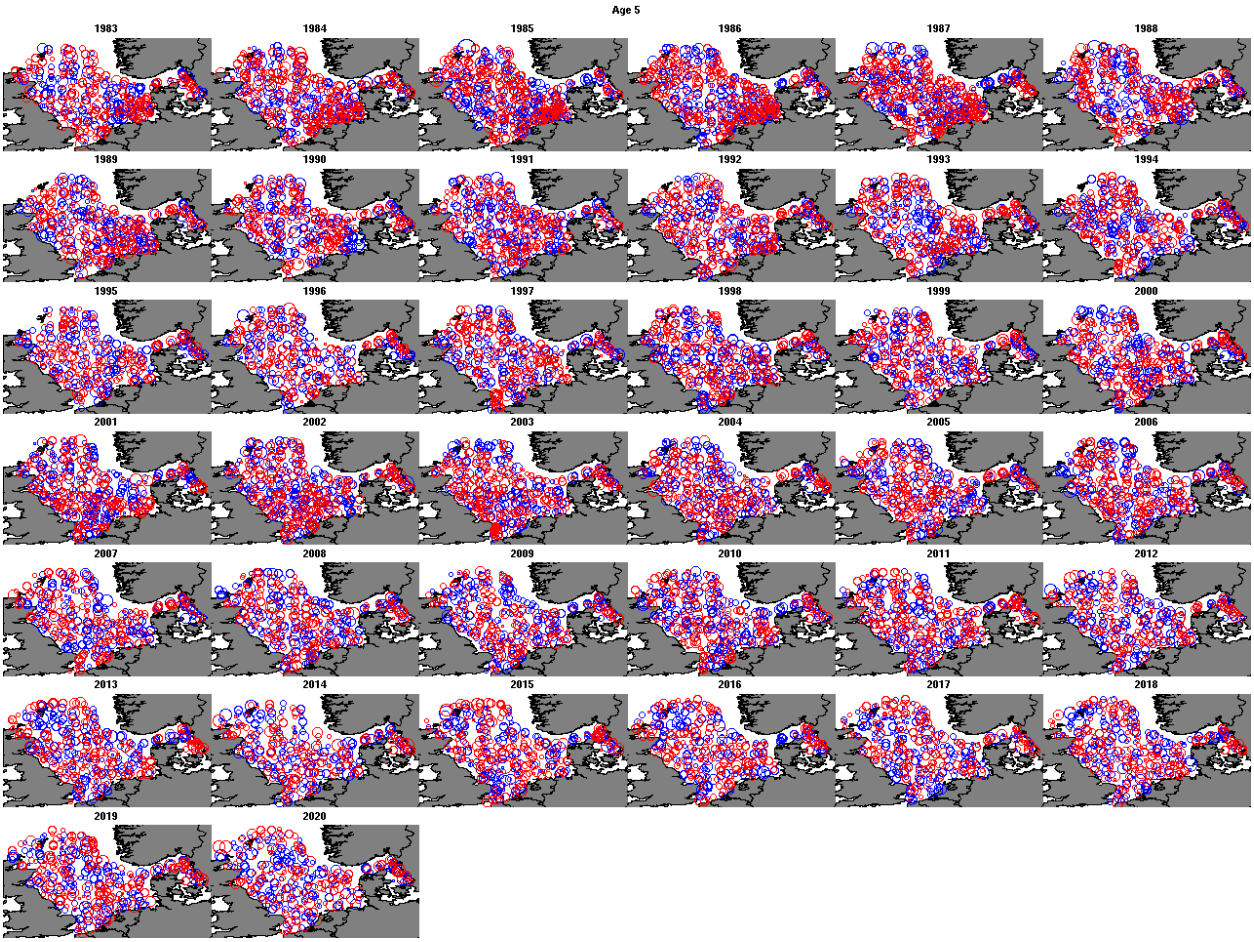

Age 5
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 35

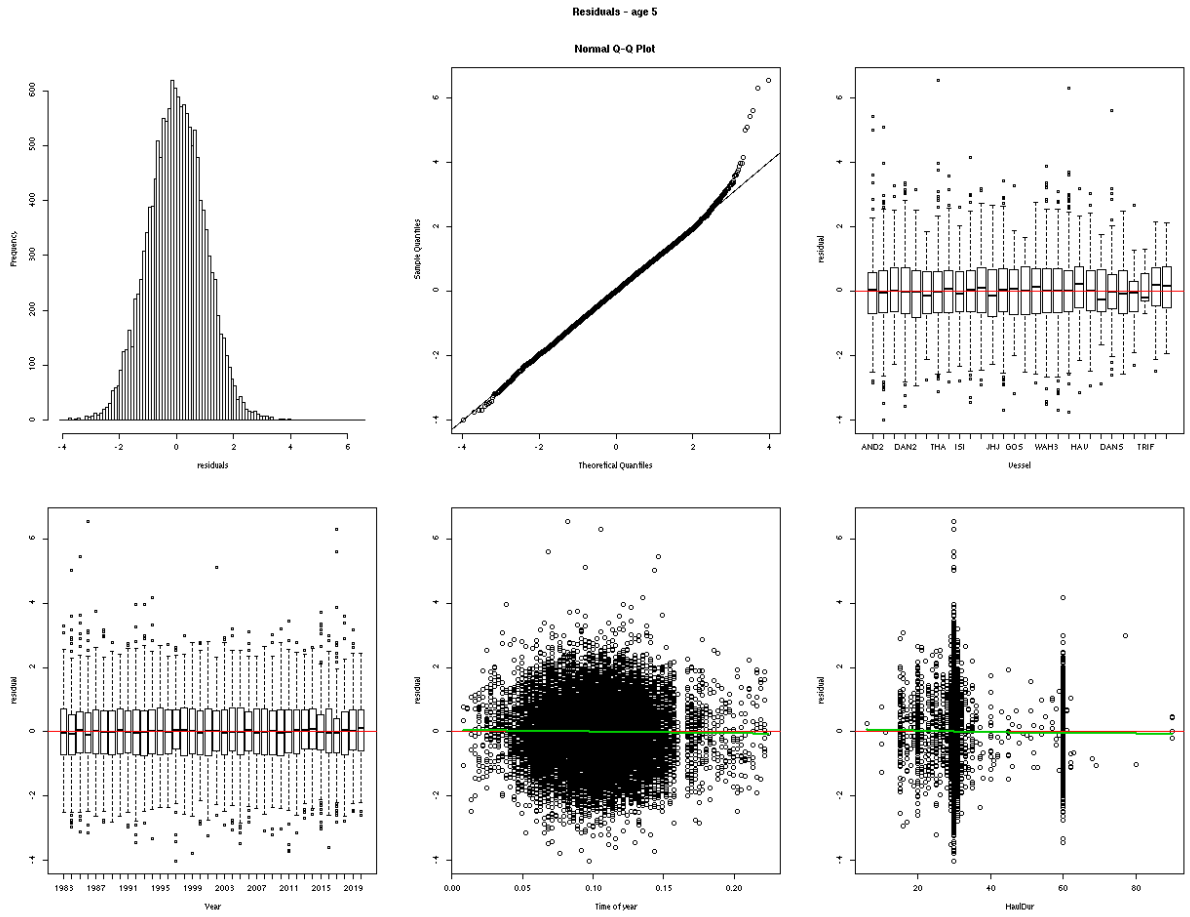

Residuals - age 5
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
Vessel
AND2
DAN2
THA
ISI
JHJ
GO5
WAH3
HAU
DAN5
TRIF
Year
Time of year
HaulDur

Figure 36

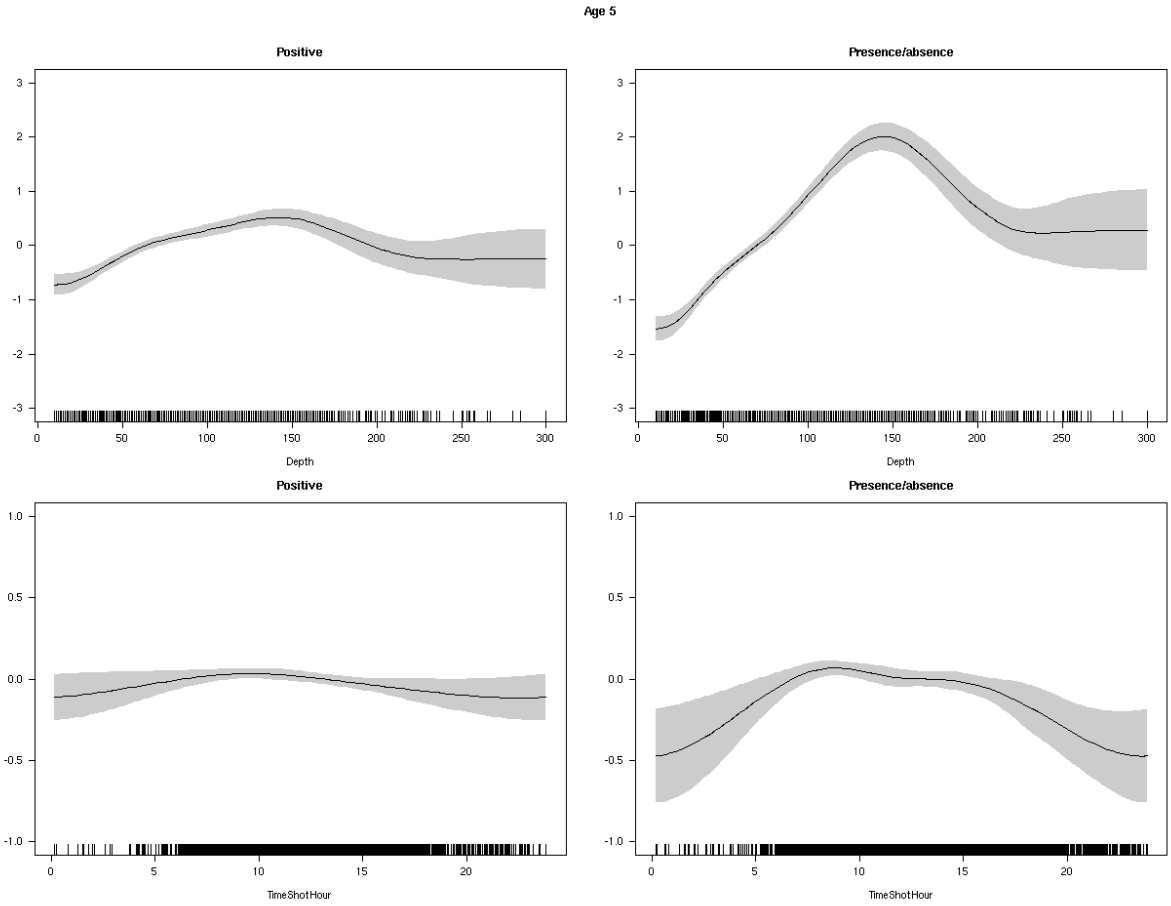

Age 5
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 37

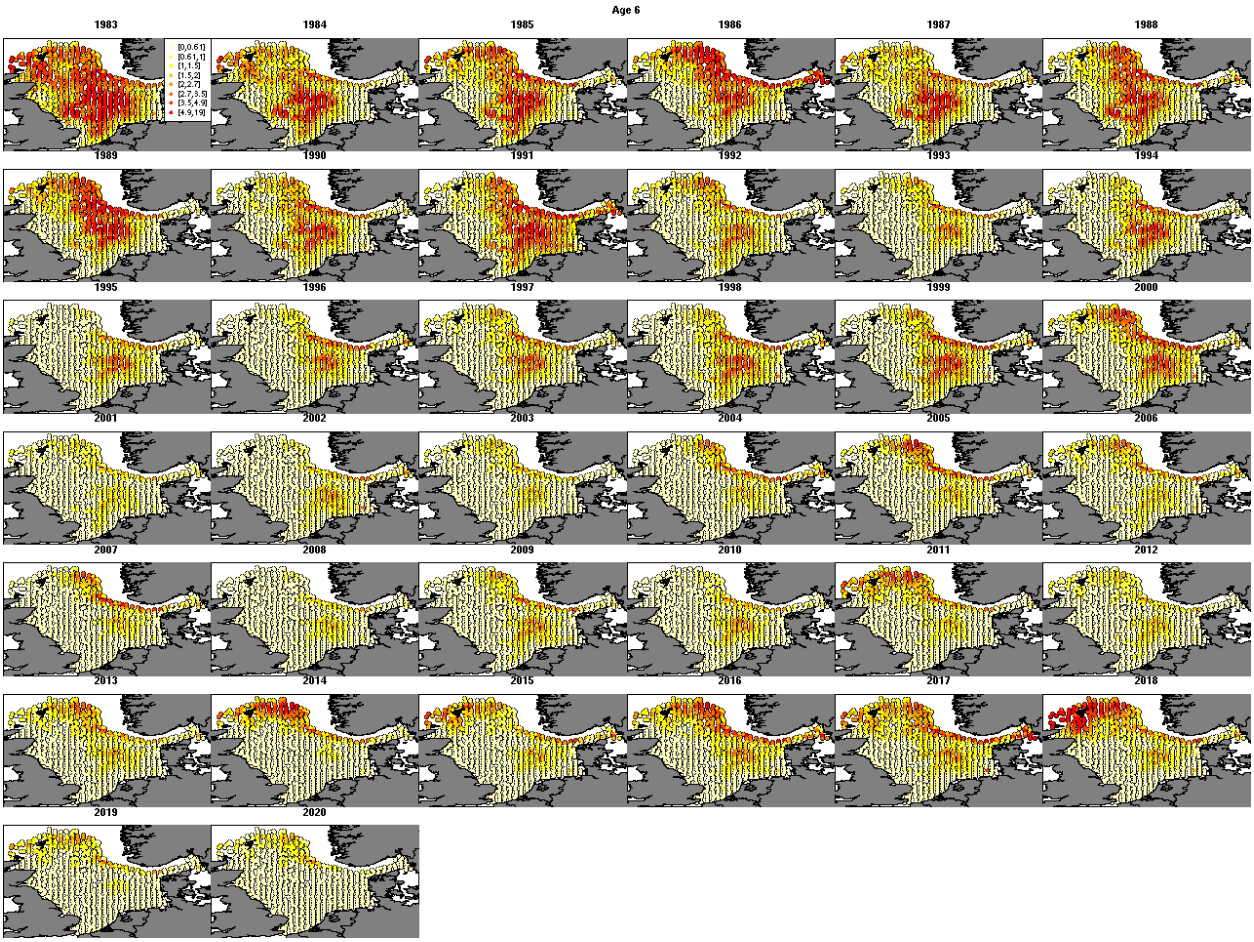

Age 6
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 38

247

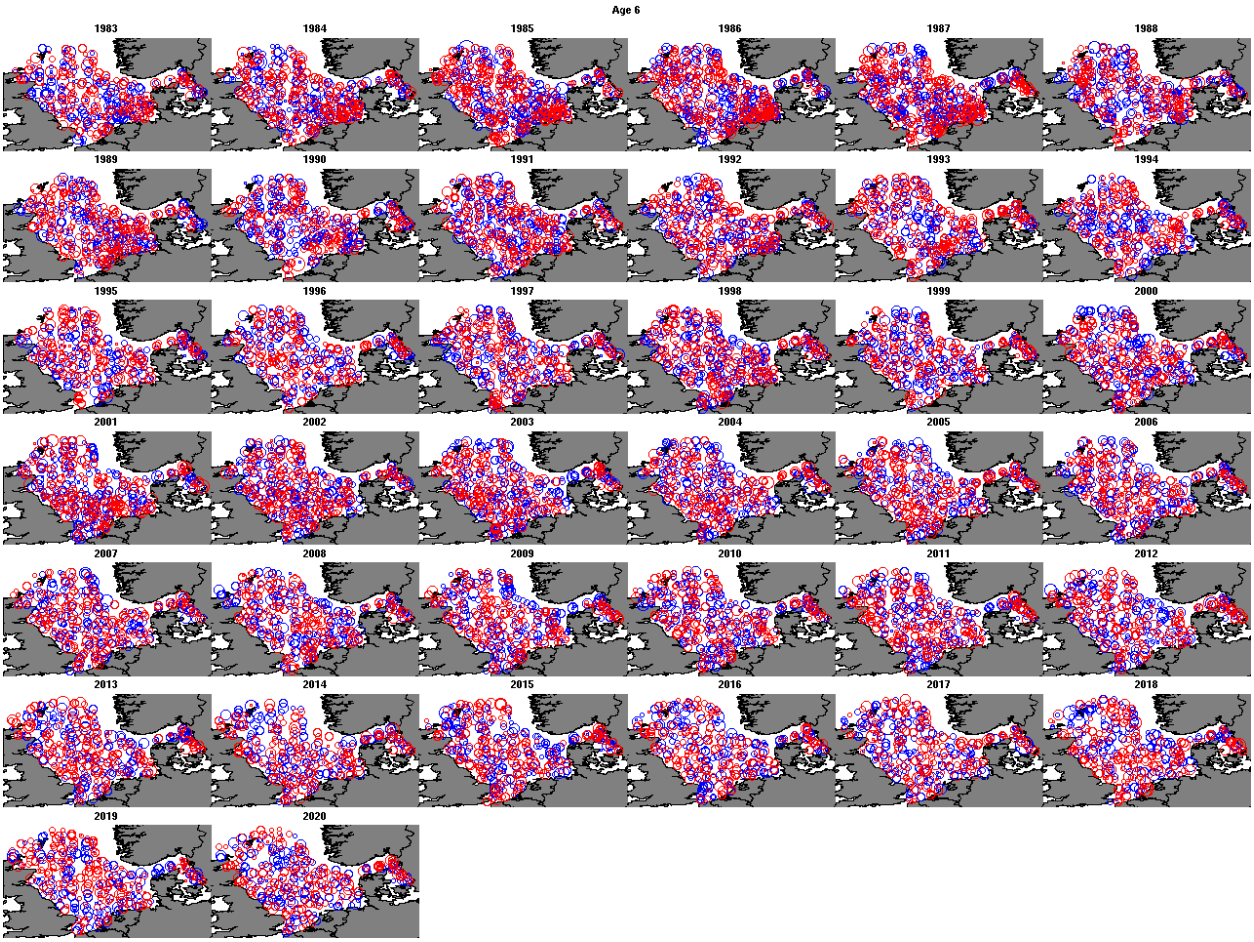


Figure 39

248

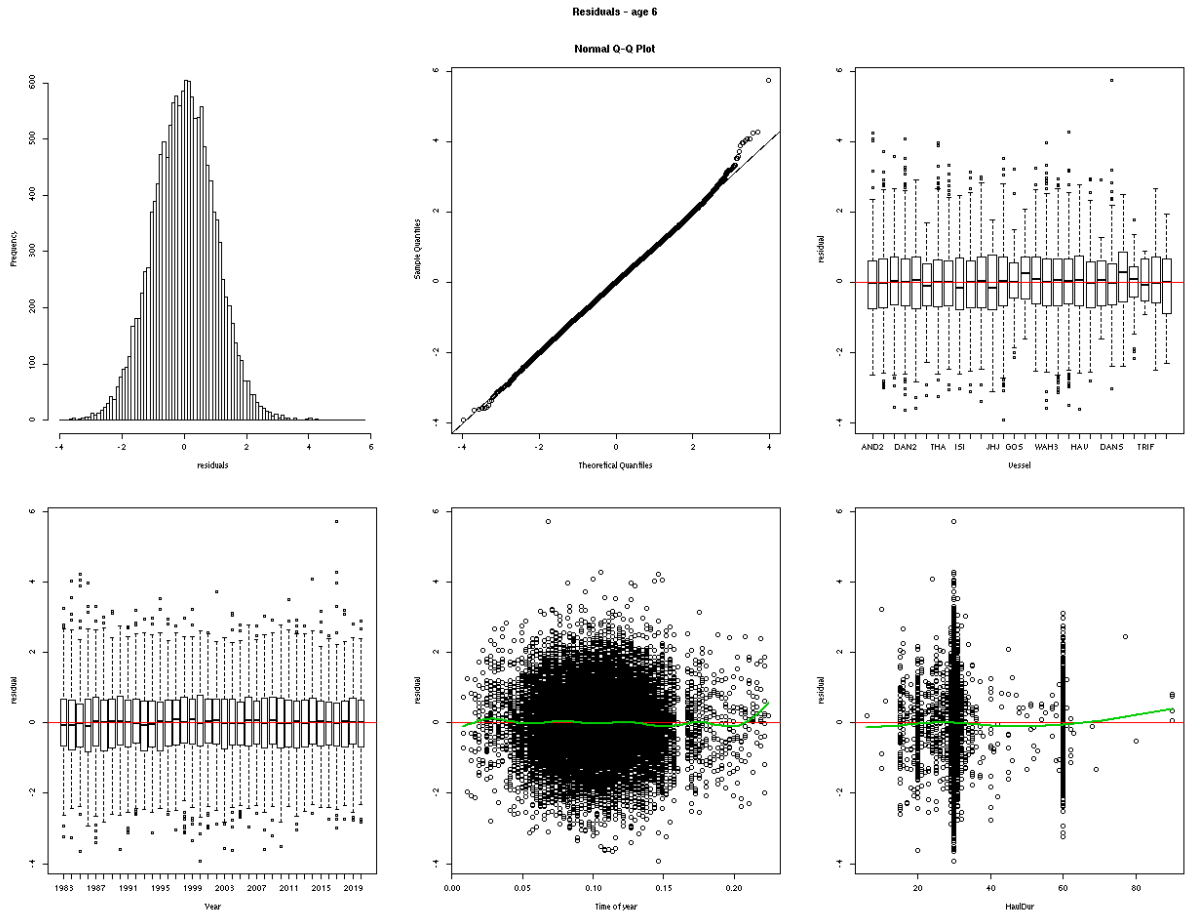


Figure 40

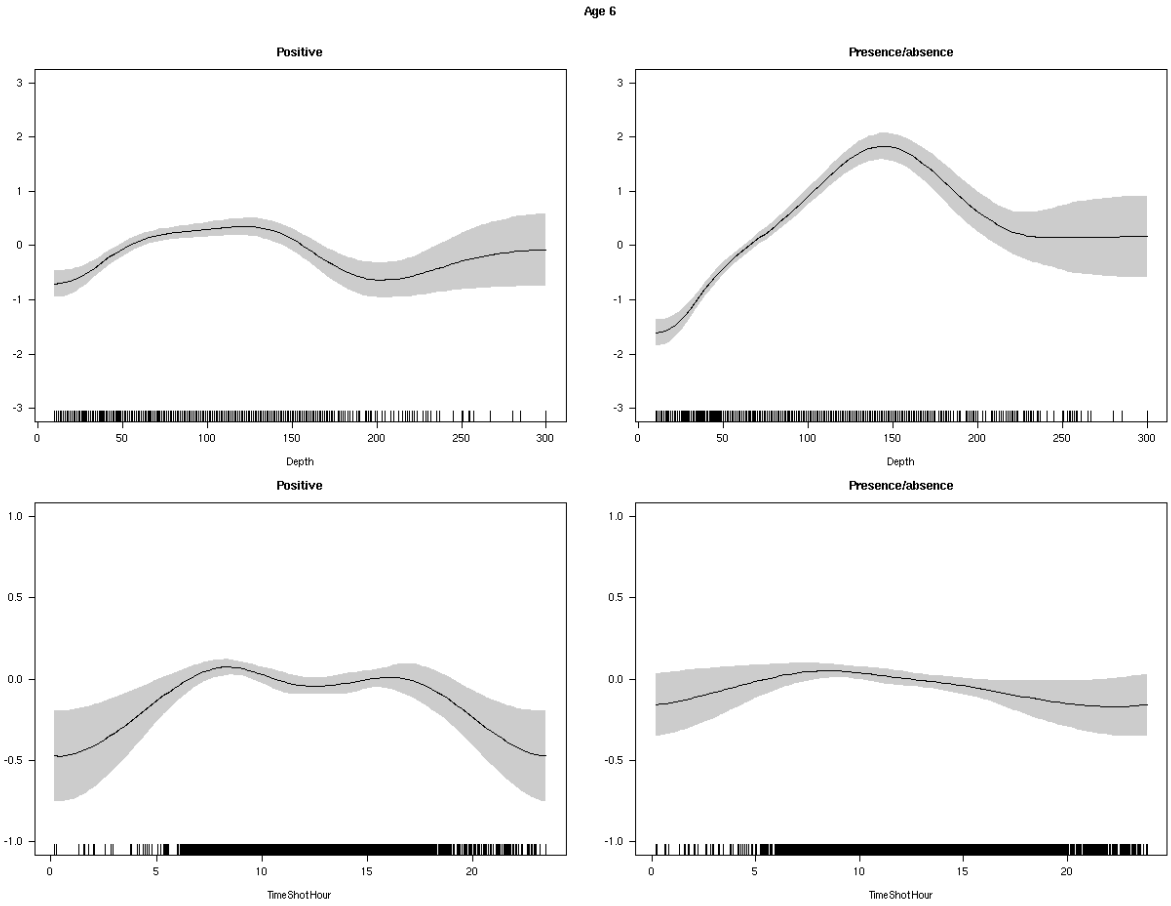

Age 6
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 41

6.2 Q3

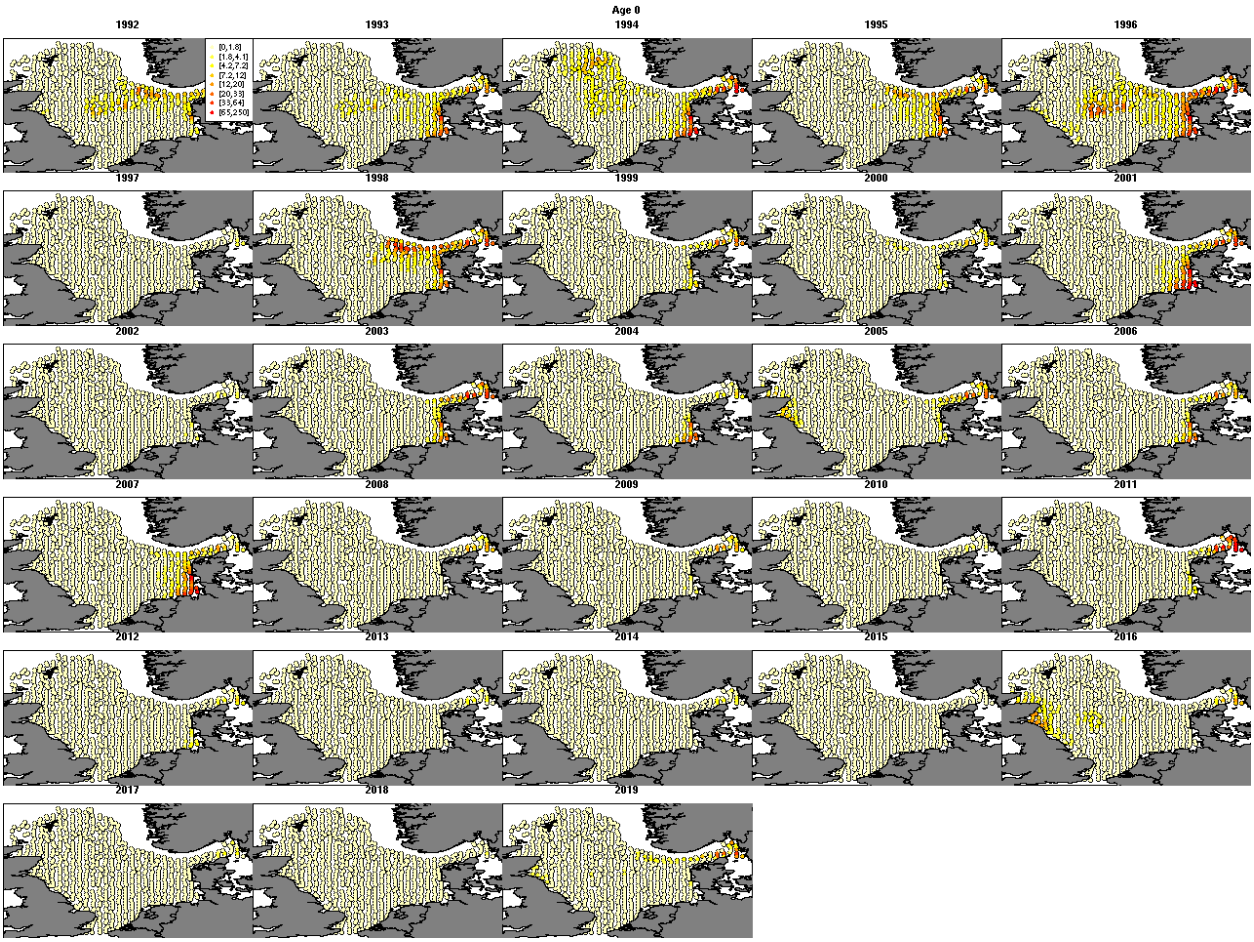


Figure 42

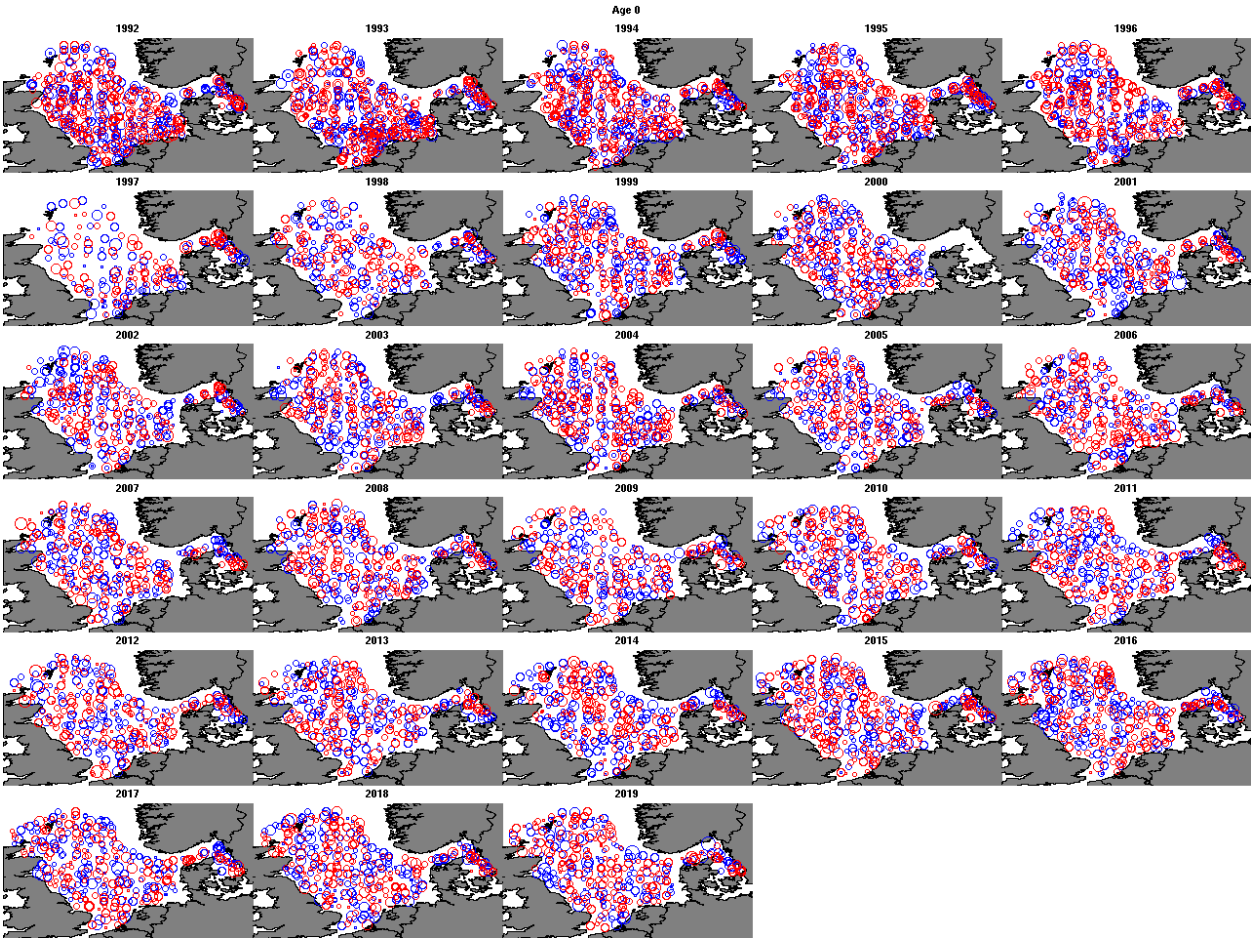

Age 0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 43

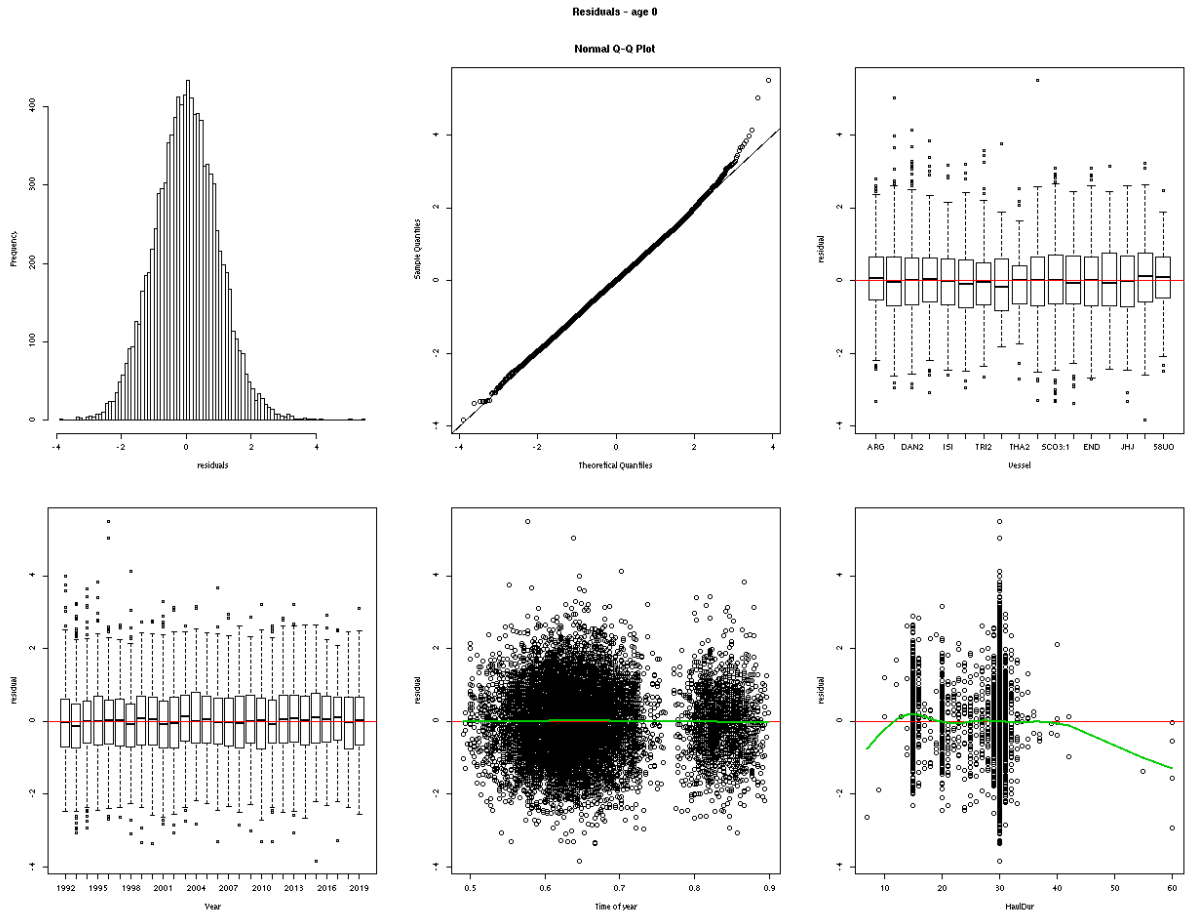

Residuals - age 0
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Vessel
Year
Time of year
HaulDur

Figure 44

253

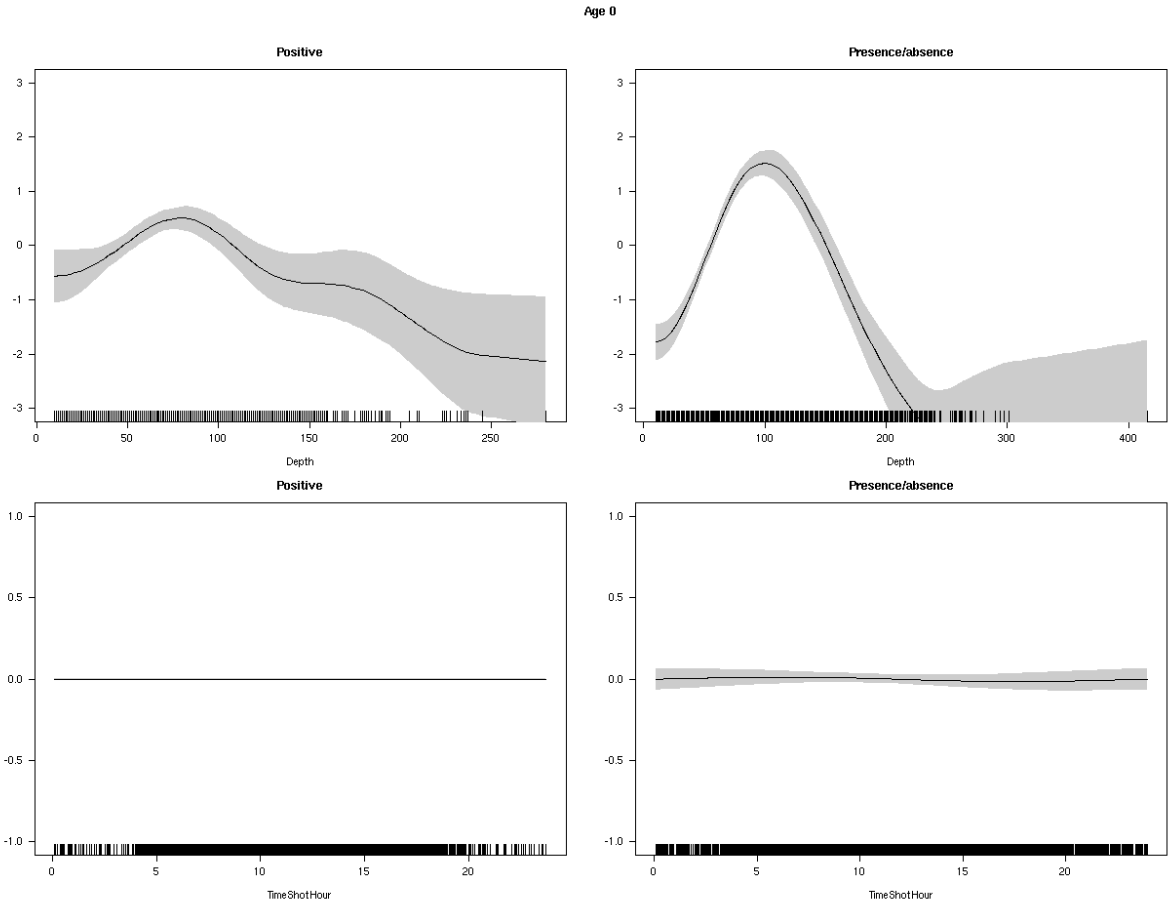


Figure 45

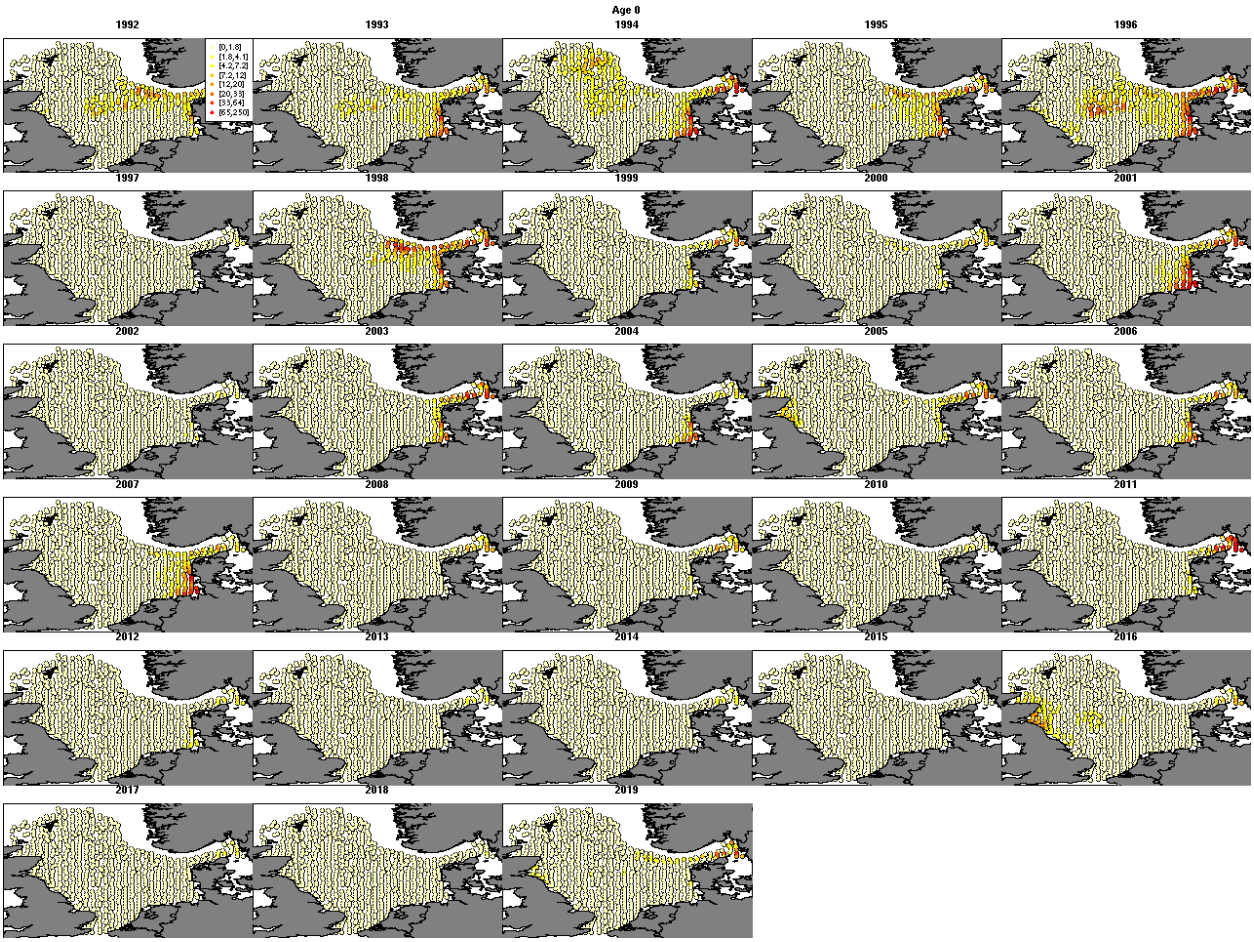

Age 0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 46

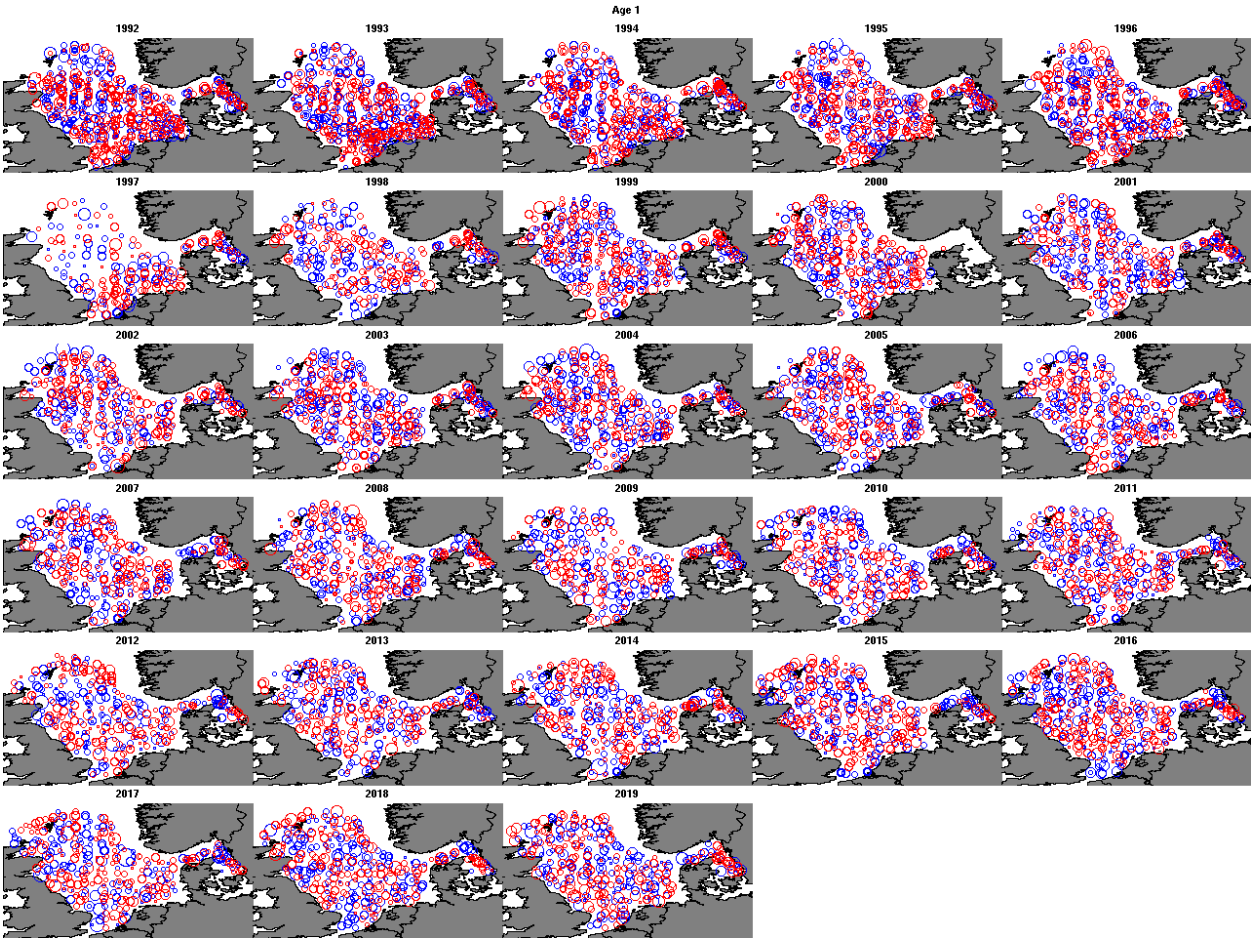

Age 1
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 47

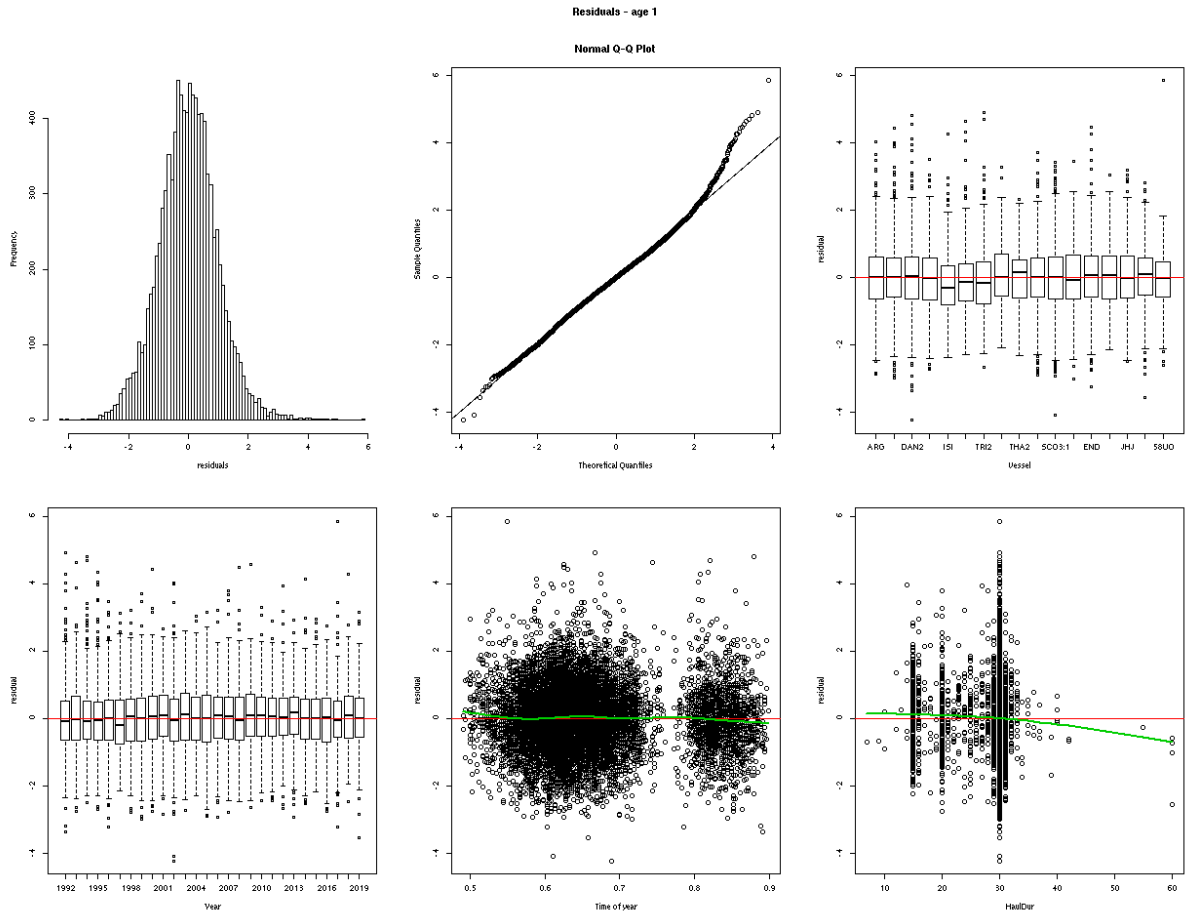

Residuals - age 1
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Vessel
Year
Time of year
HaulDur

Figure 48

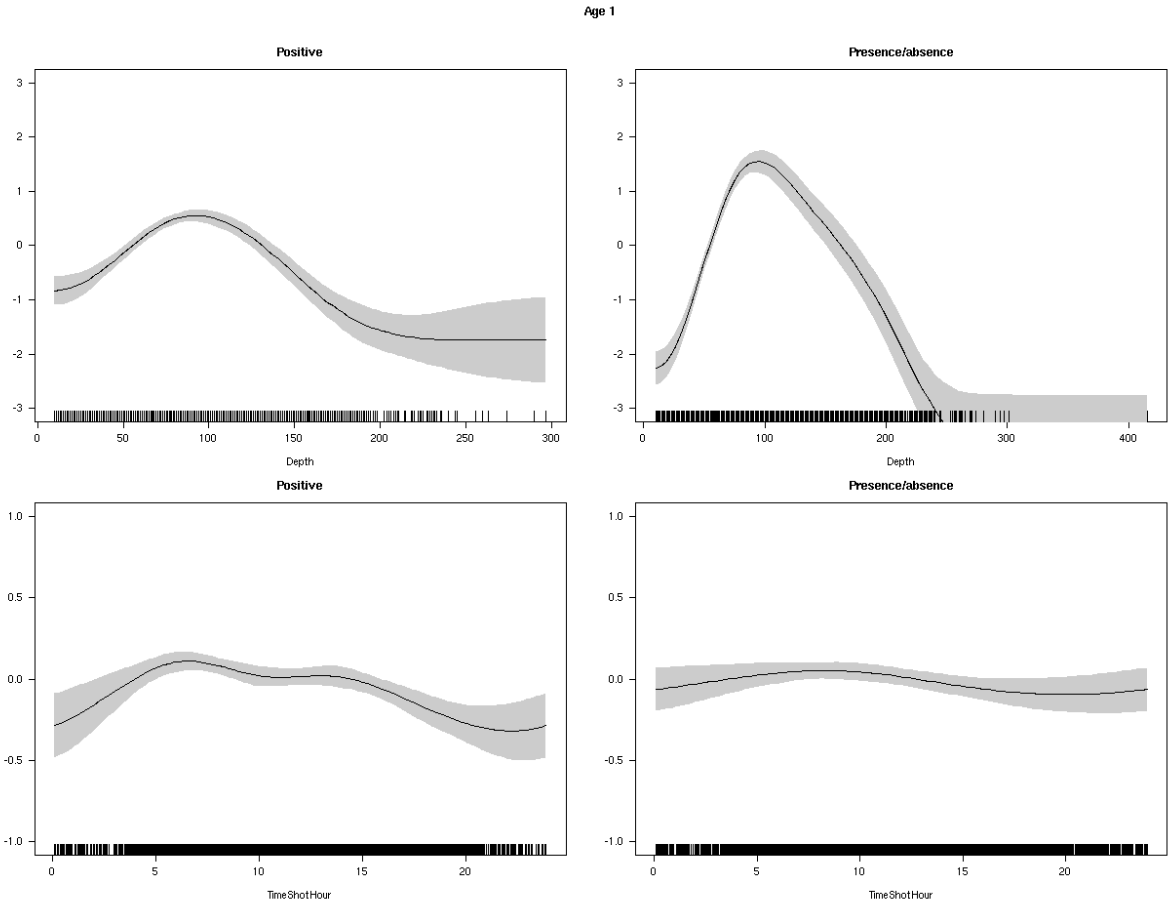

Age 1
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
TimeShotHour
TimeShotHour

Figure 49

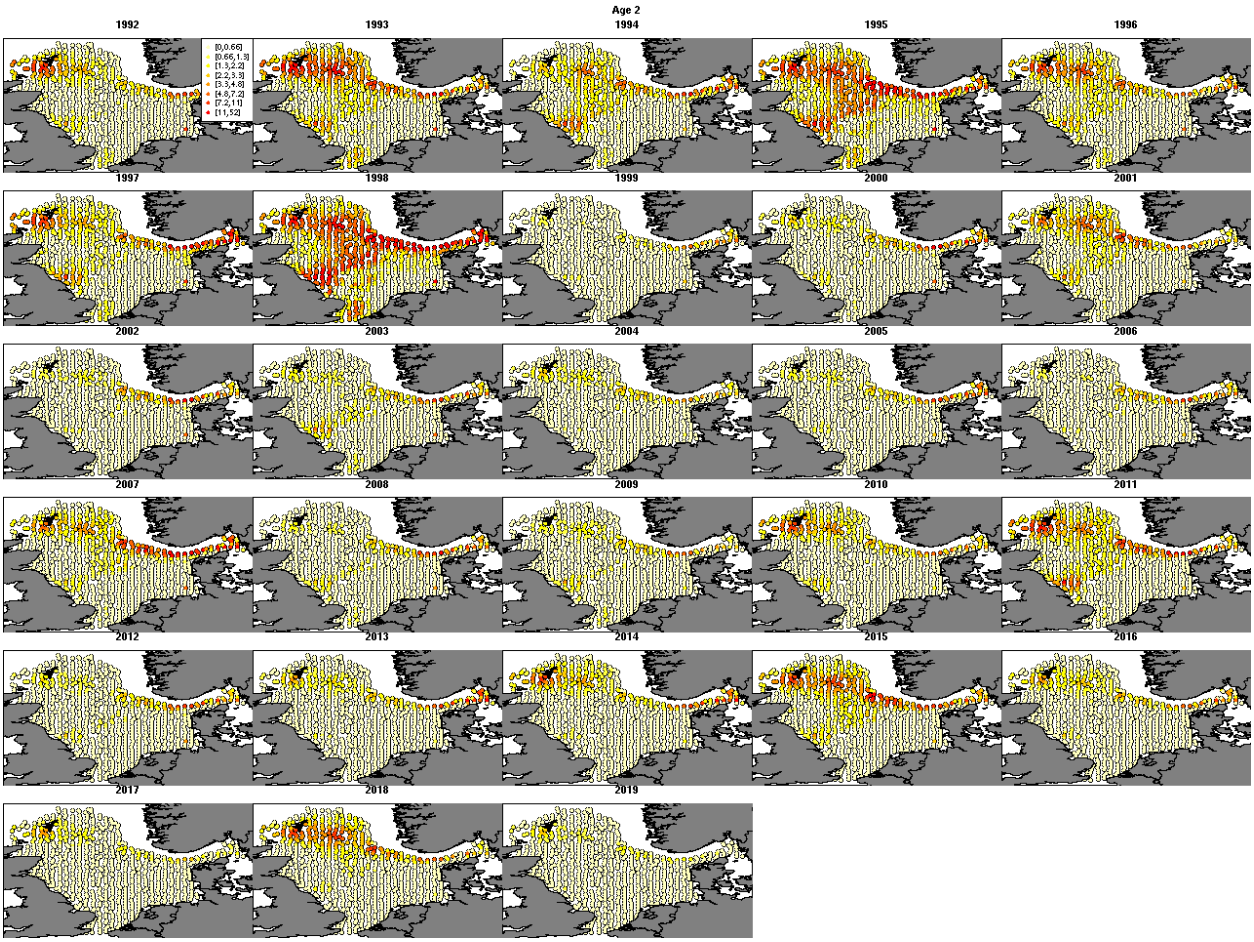

Age 2
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 50

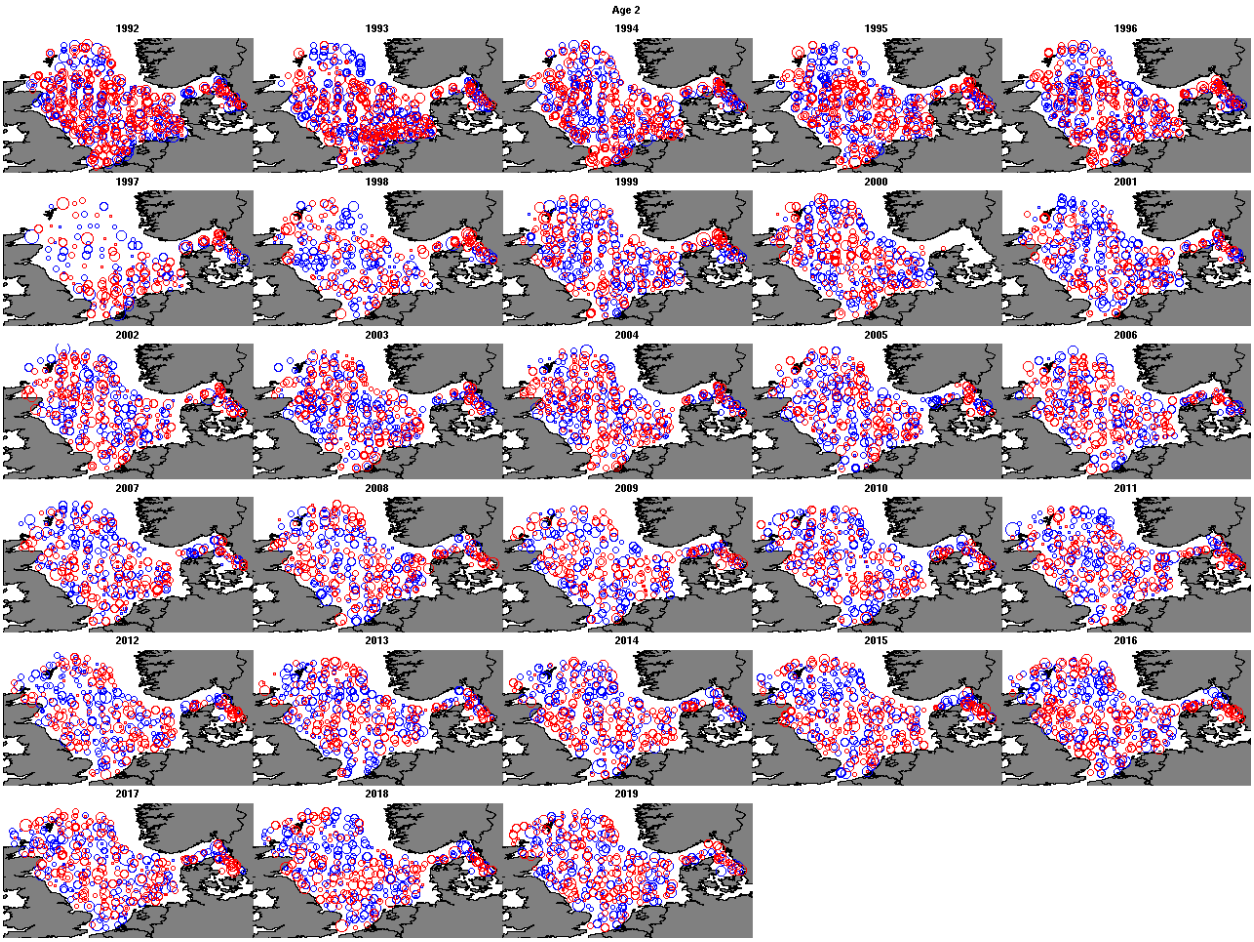

Age 2
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 51

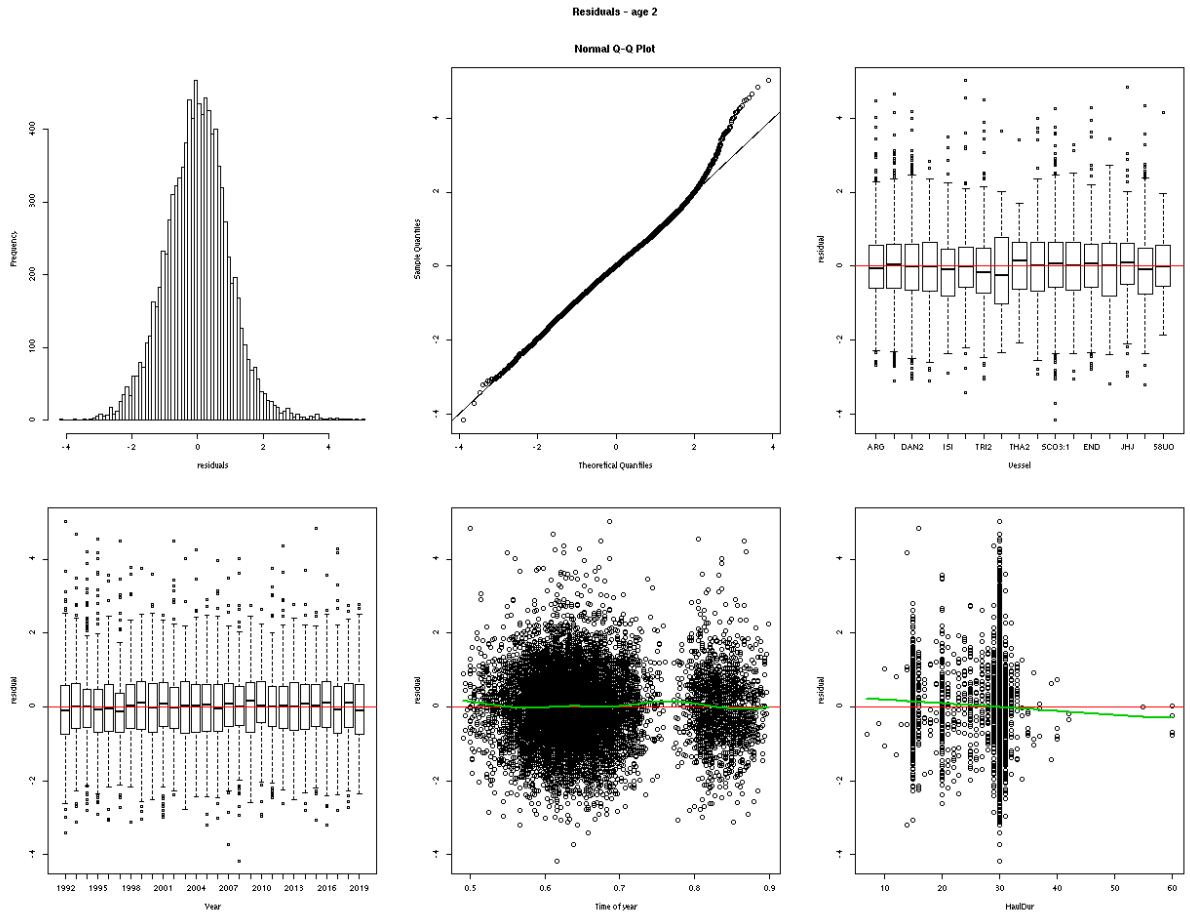

Residuals - age 2
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Vessel
Year
Time of year
HaulDur

Figure 52

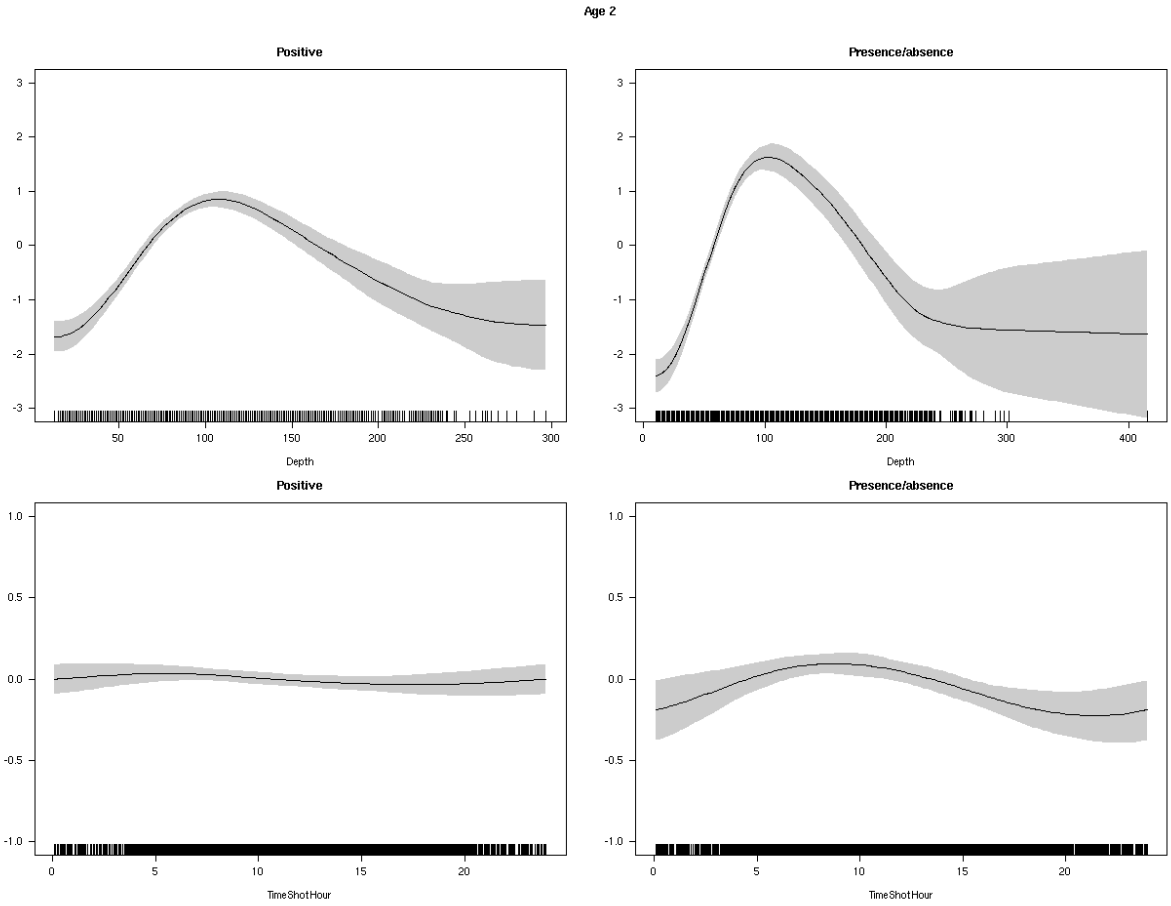

Age 2
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
TimeShotHour
TimeShotHour

Figure 53

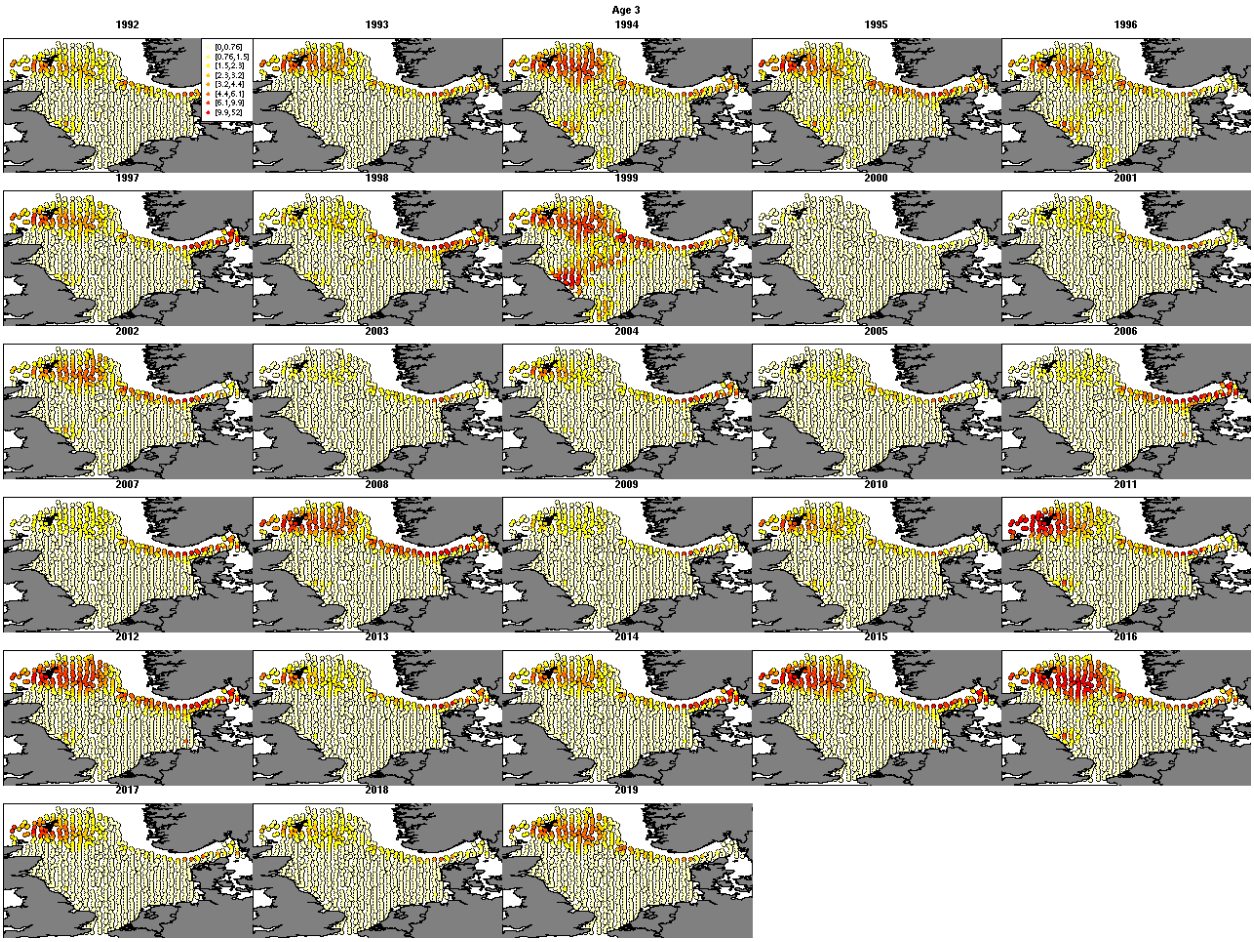

Age 3
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 54

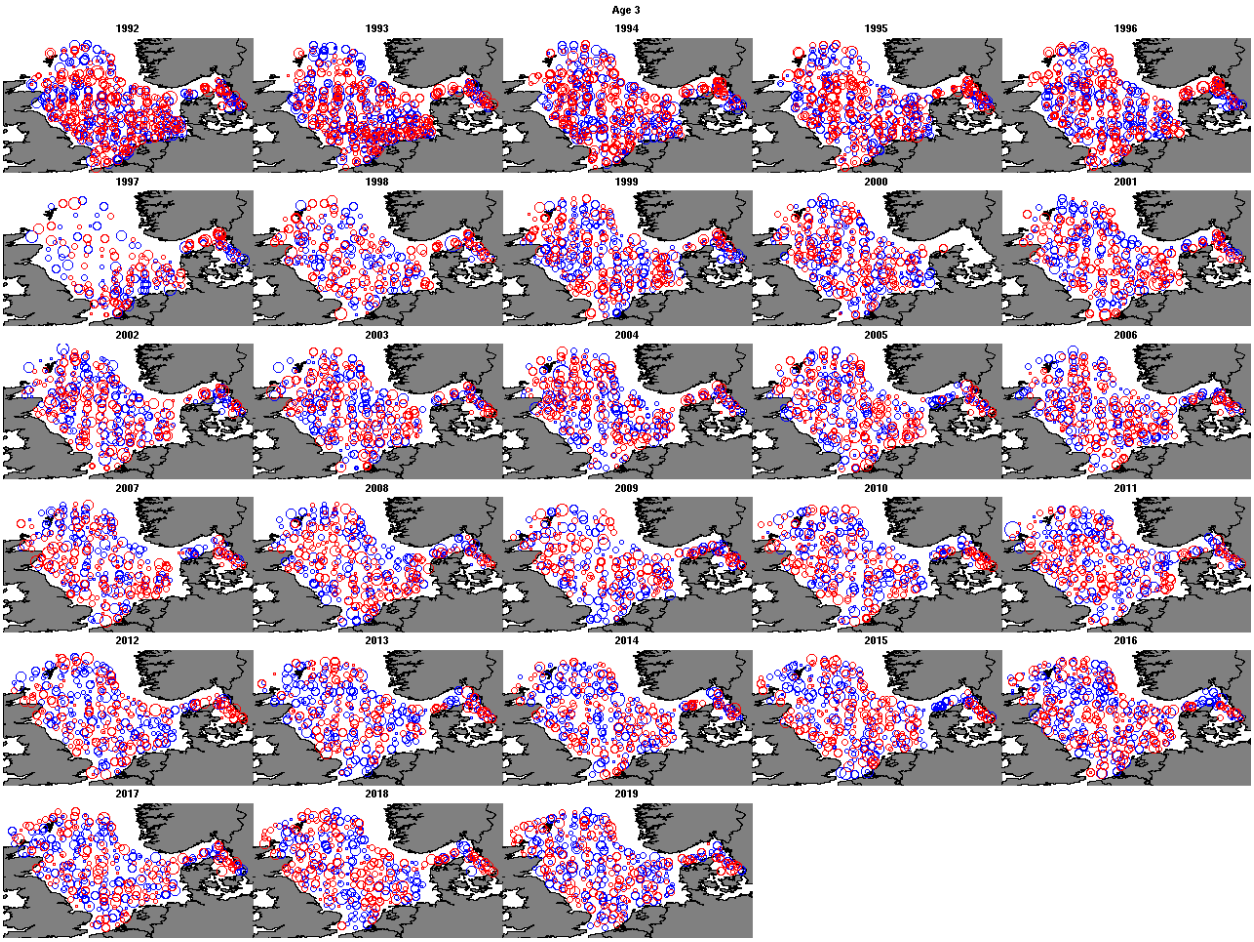

Age 3
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 55

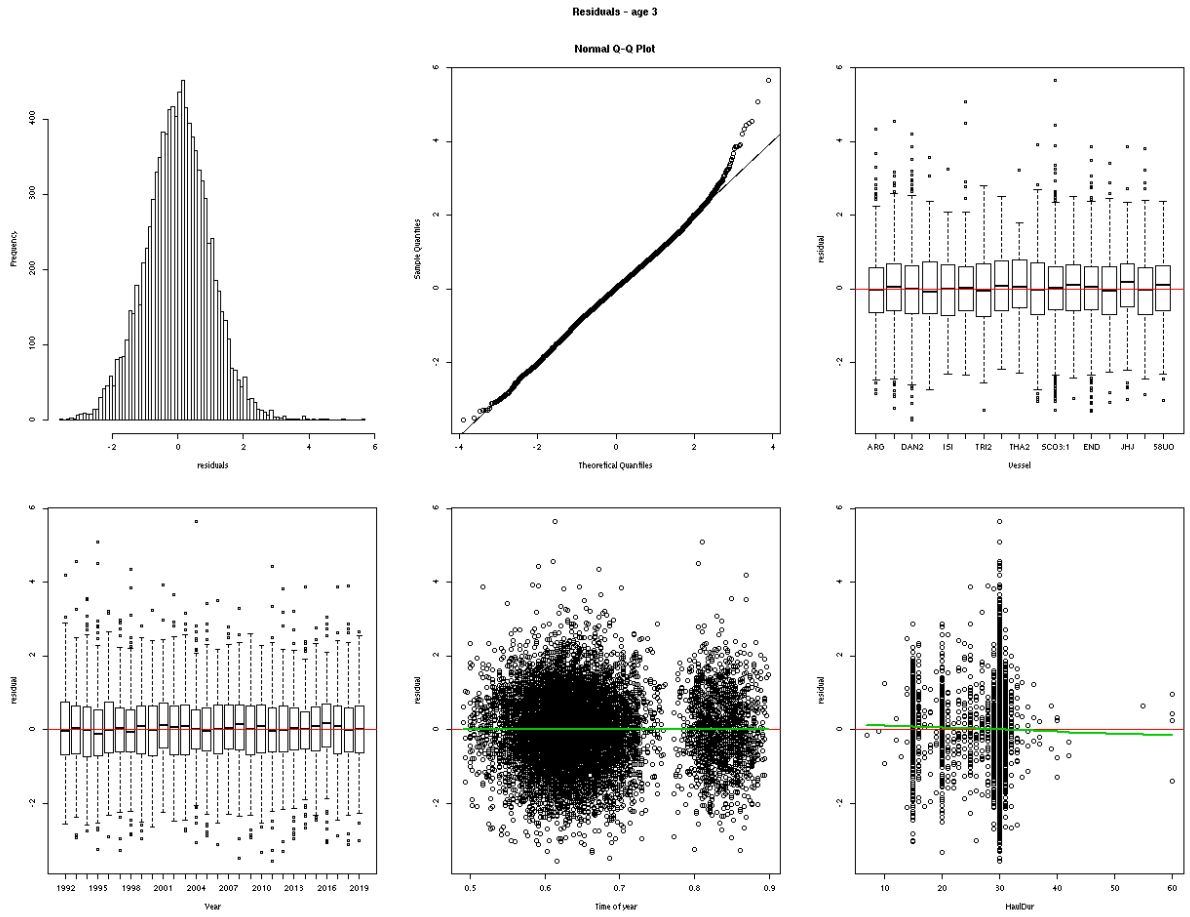

Residuals - age 3
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Vessel
Year
Time of year
HaulDur

Figure 56

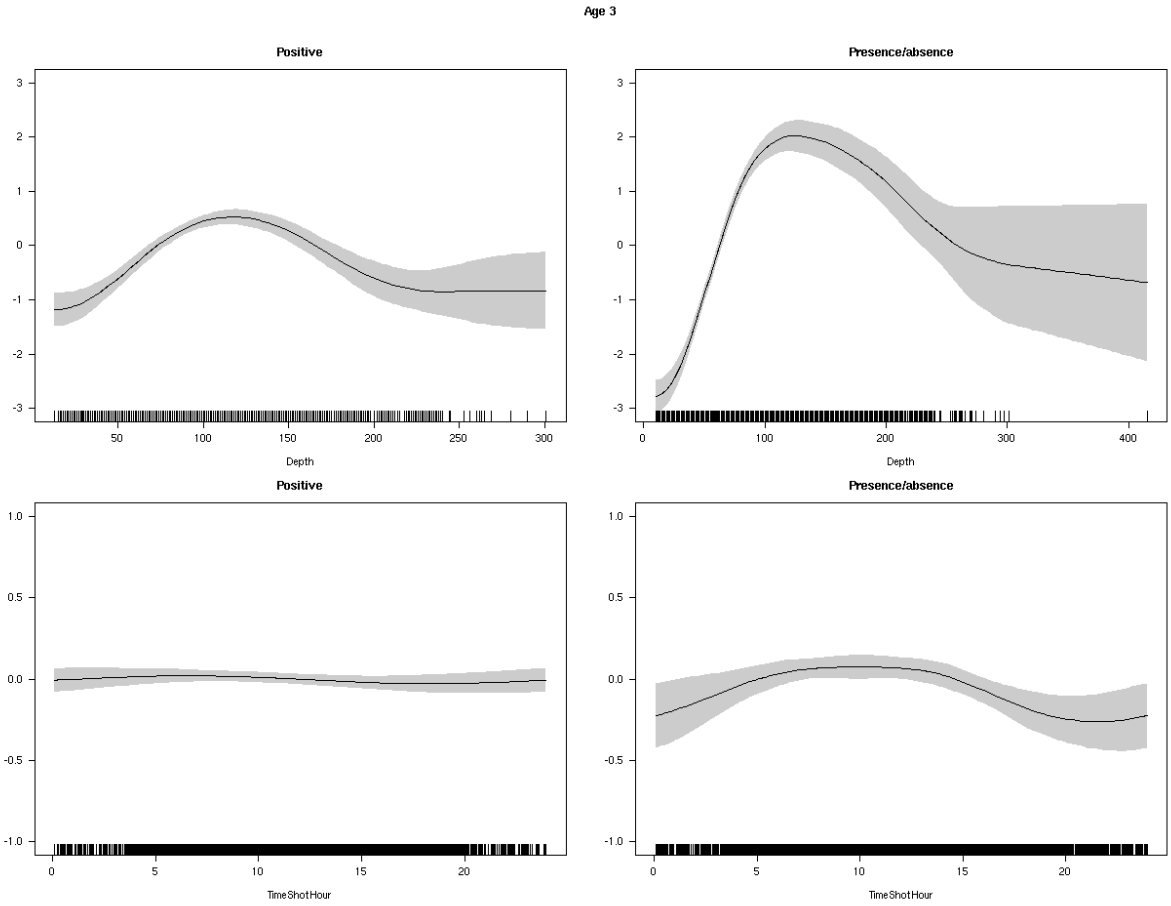

Age 3
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 57

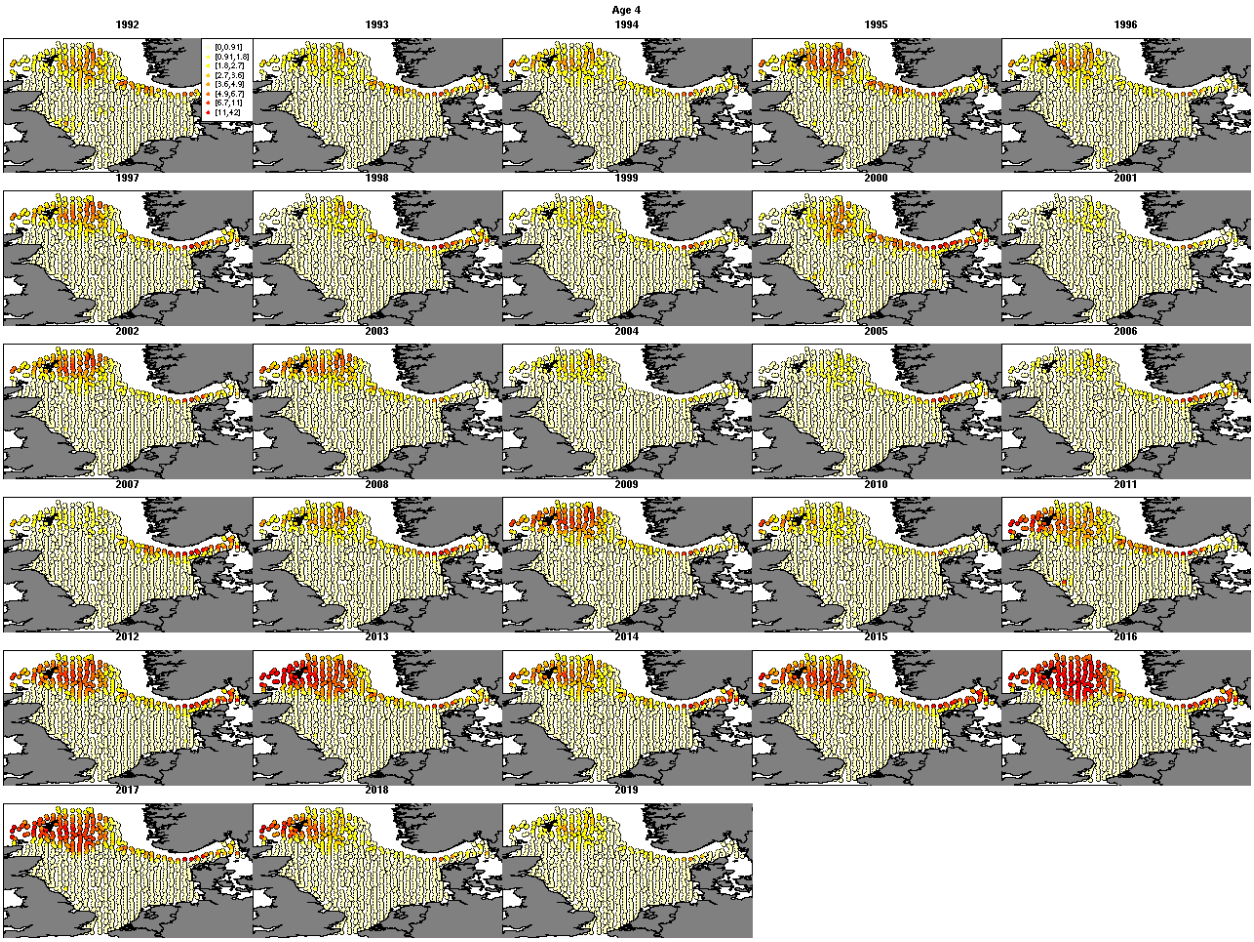

Age 4
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 58

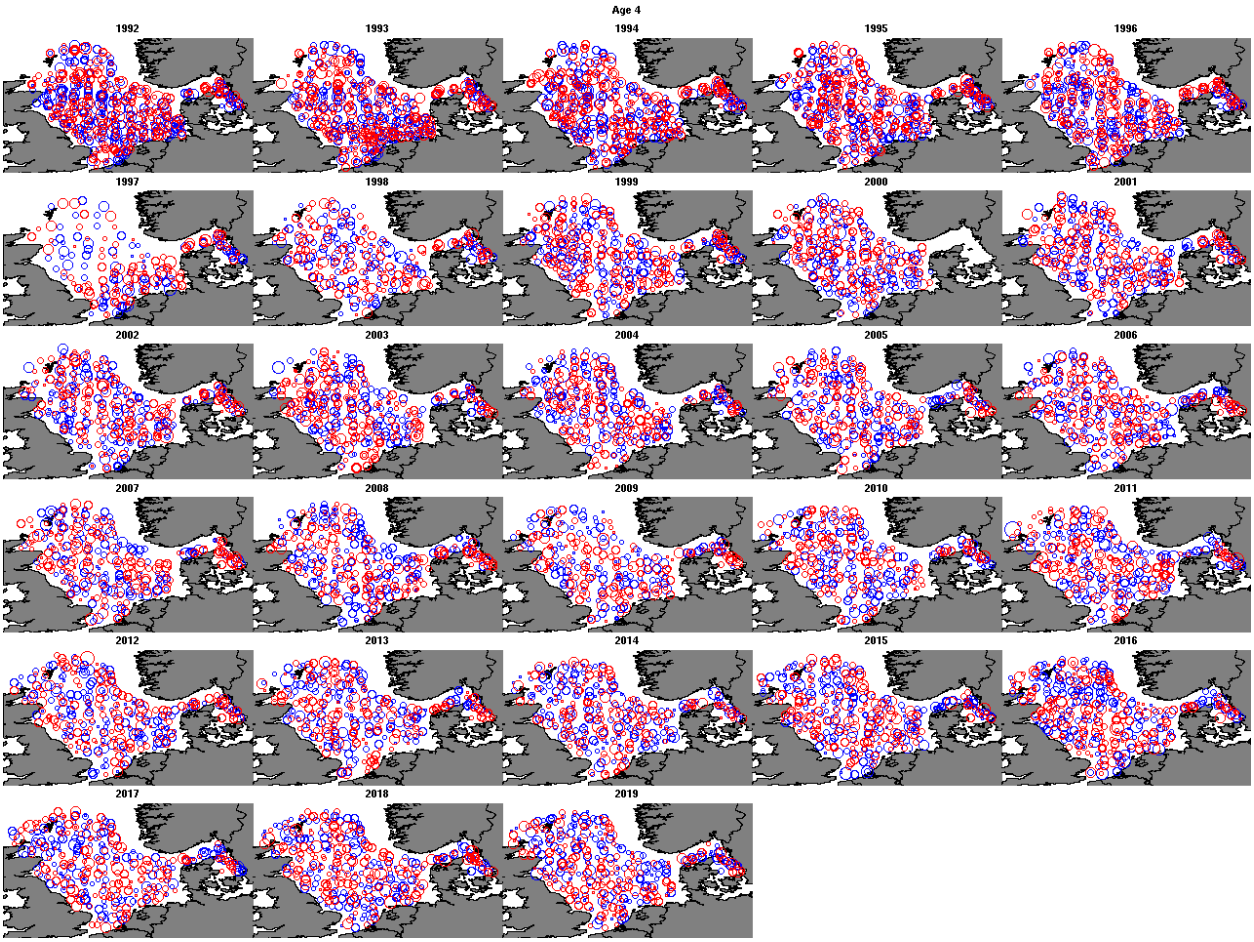

Age 4
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 59

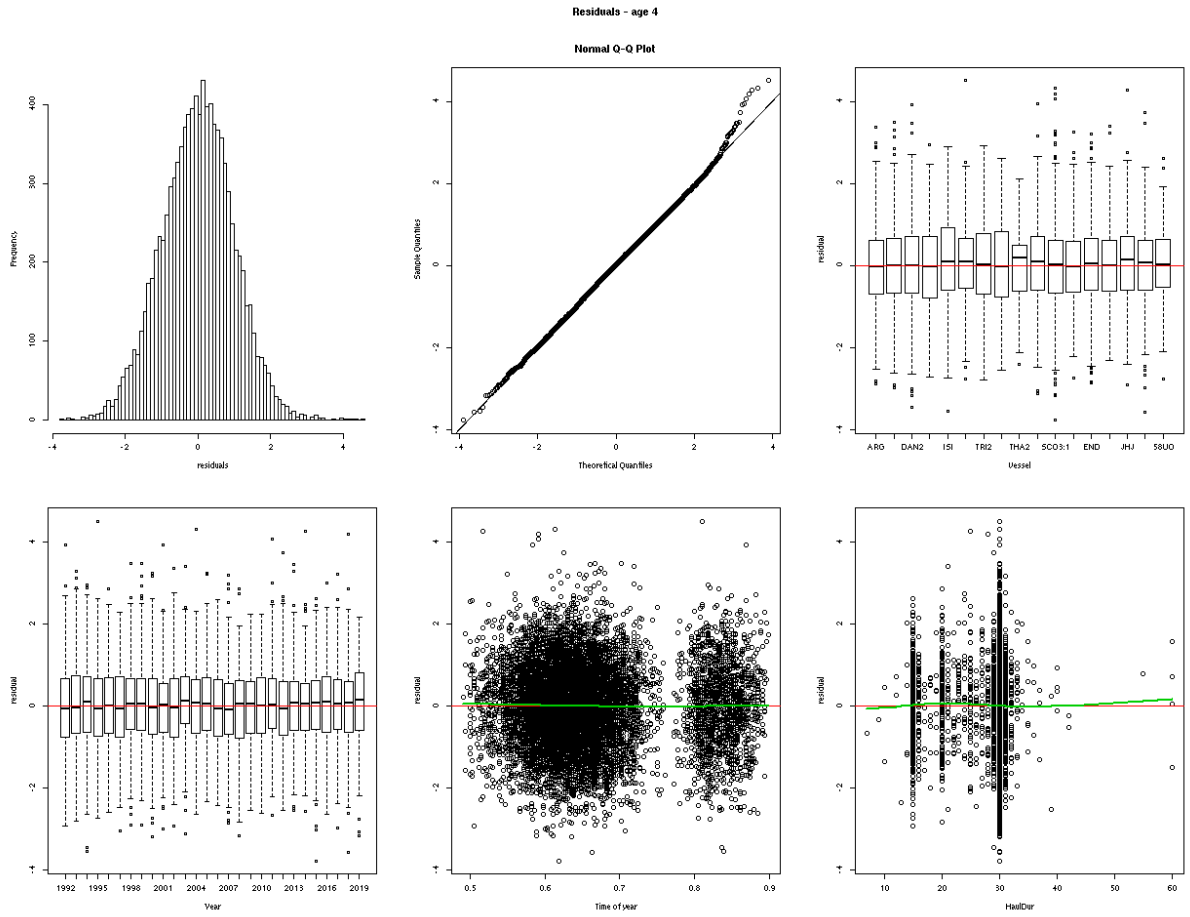

Residuals - age 4
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
Vessel
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Year
Time of year
HaulDur

Figure 60

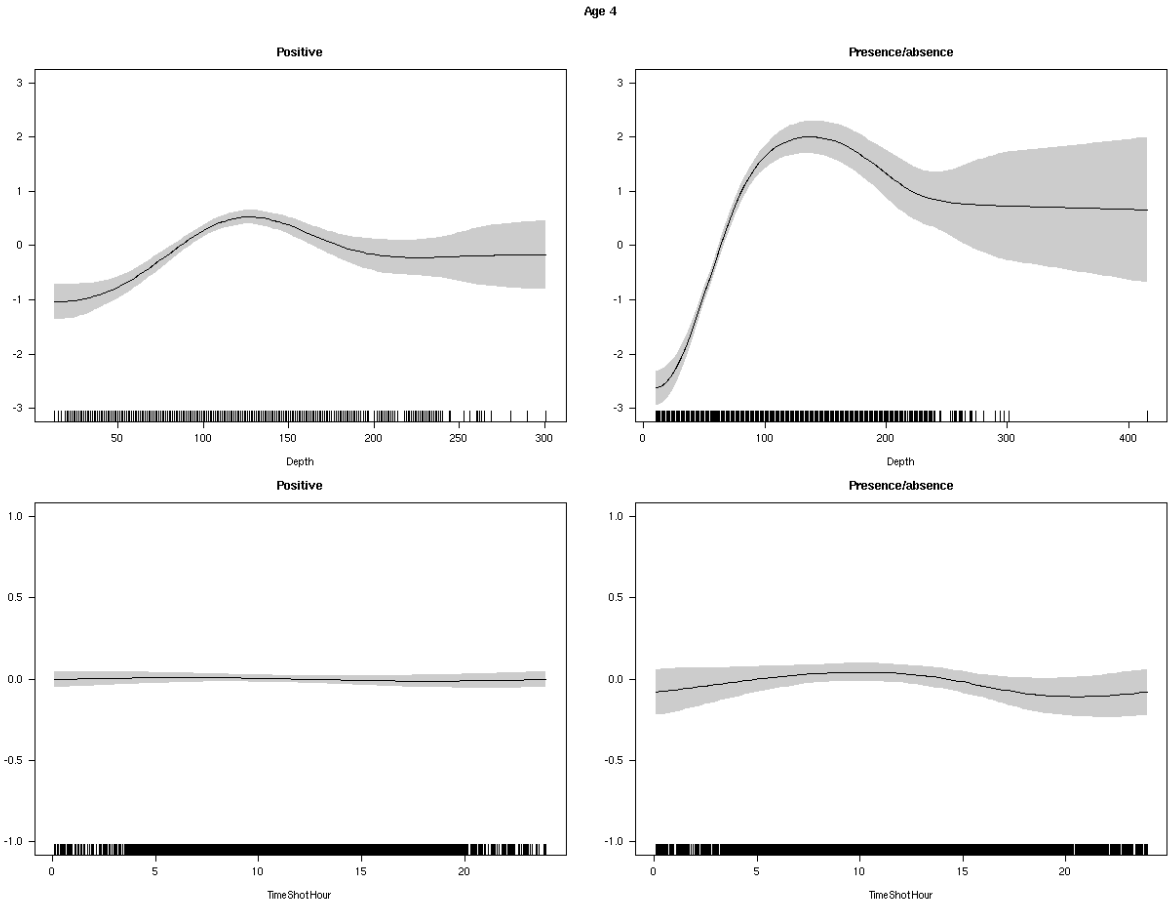

Age 4
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 61

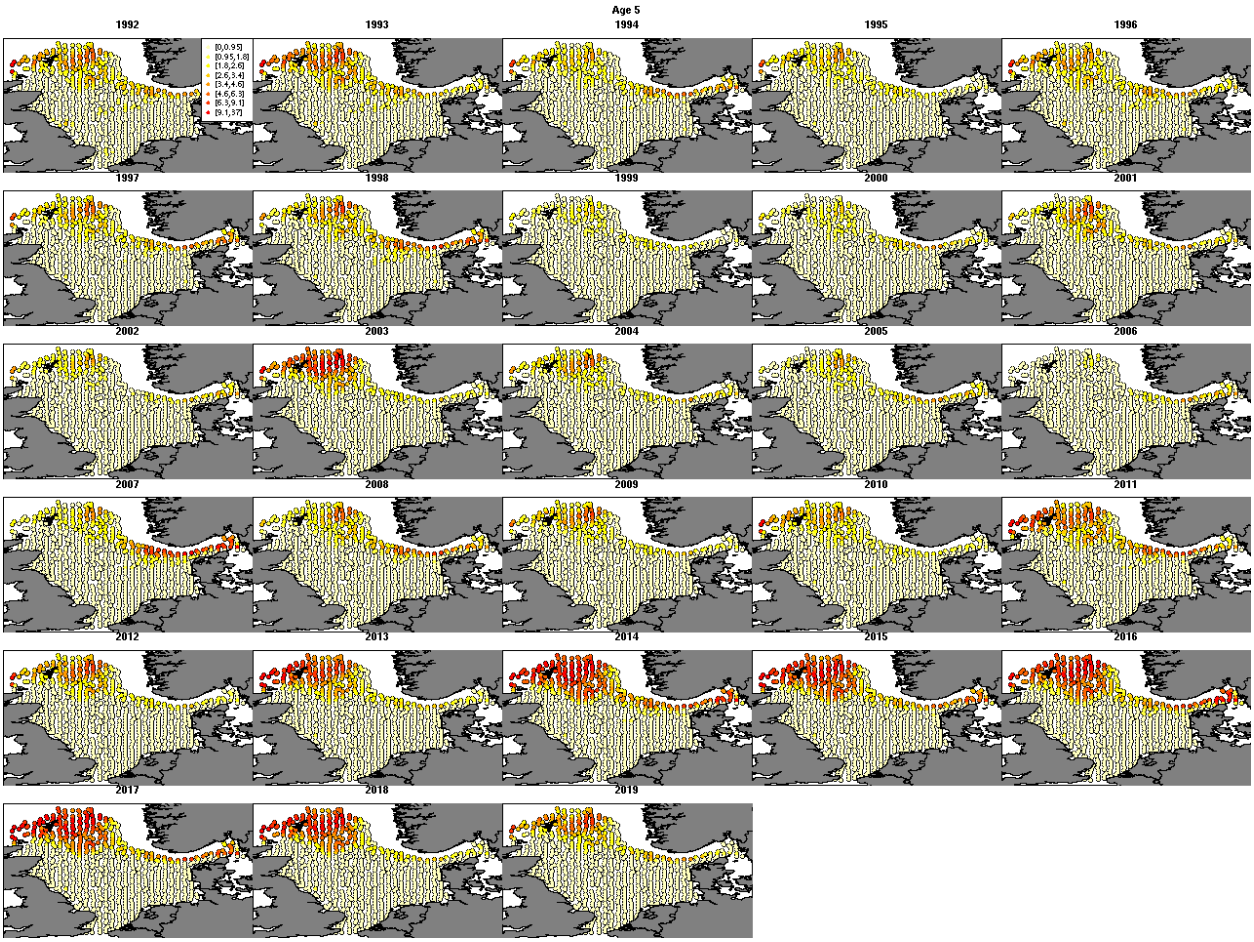

Age 5
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 62

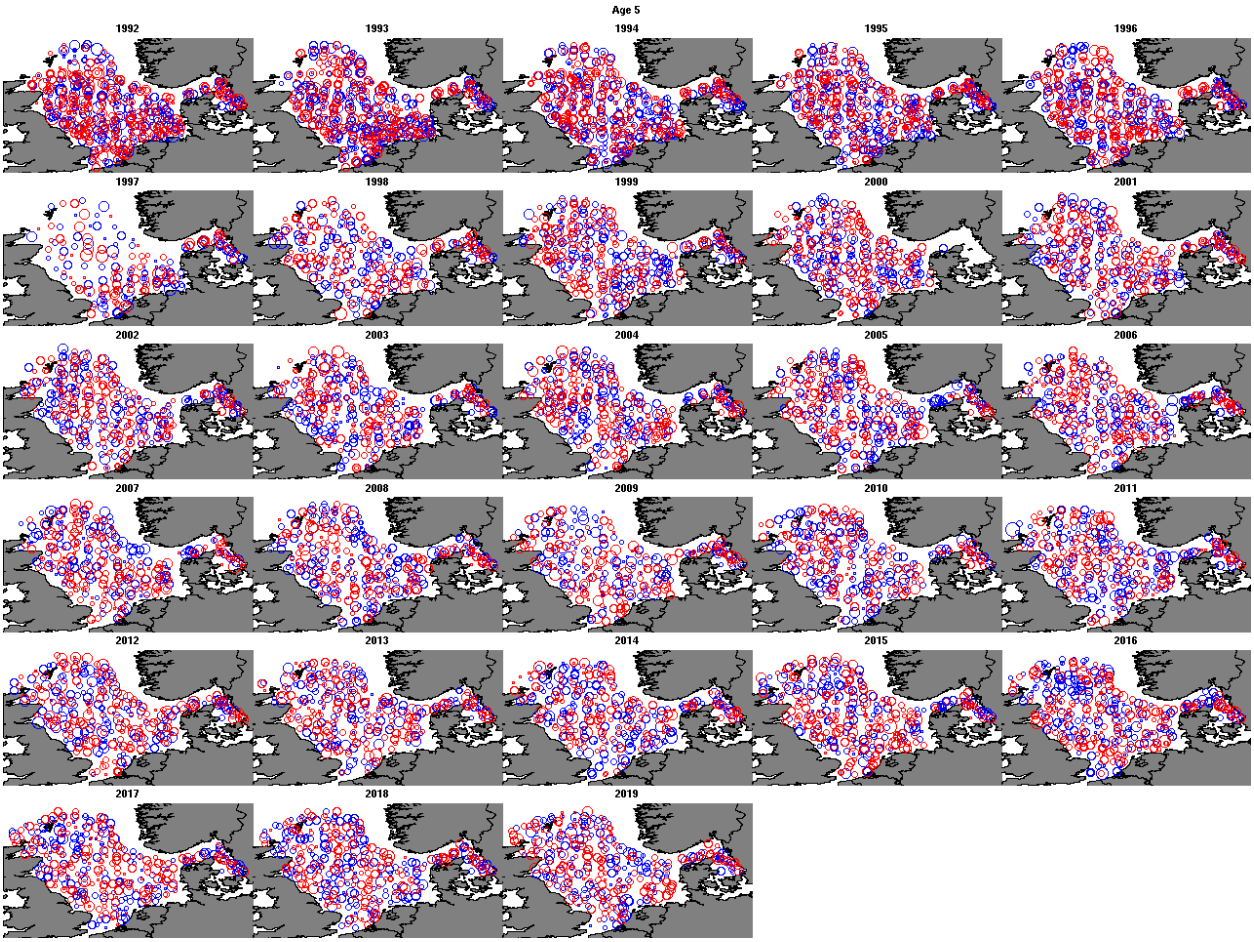

Age 5
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 63

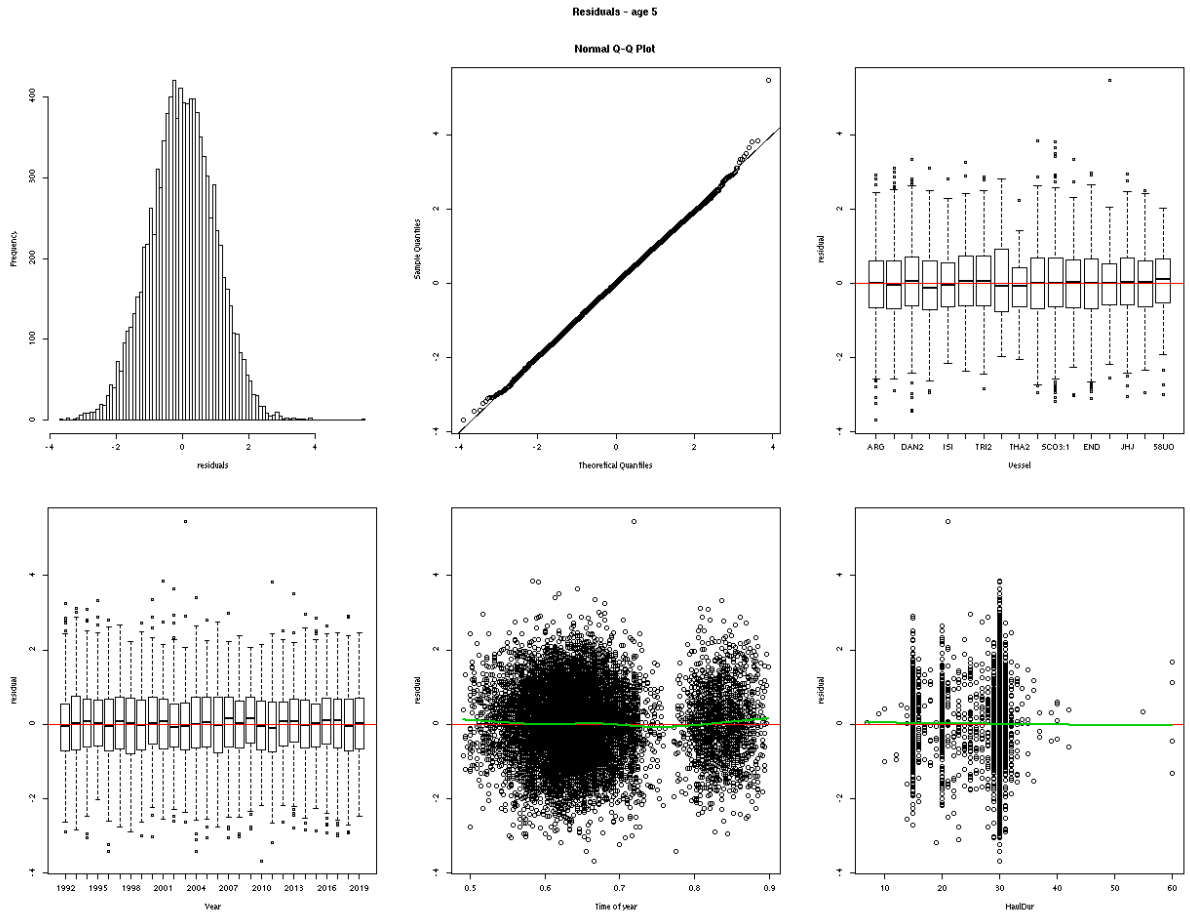

Residuals - age 5
Normal Q-Q Plot
Frequency
residuals
Sample Quantiles
Theoretical Quantiles
residual
Vessel
ARG
DAN2
ISI
TRI2
THA2
SCO3:1
END
JHJ
58UO
Year
Time of year
HaulDur

Figure 64

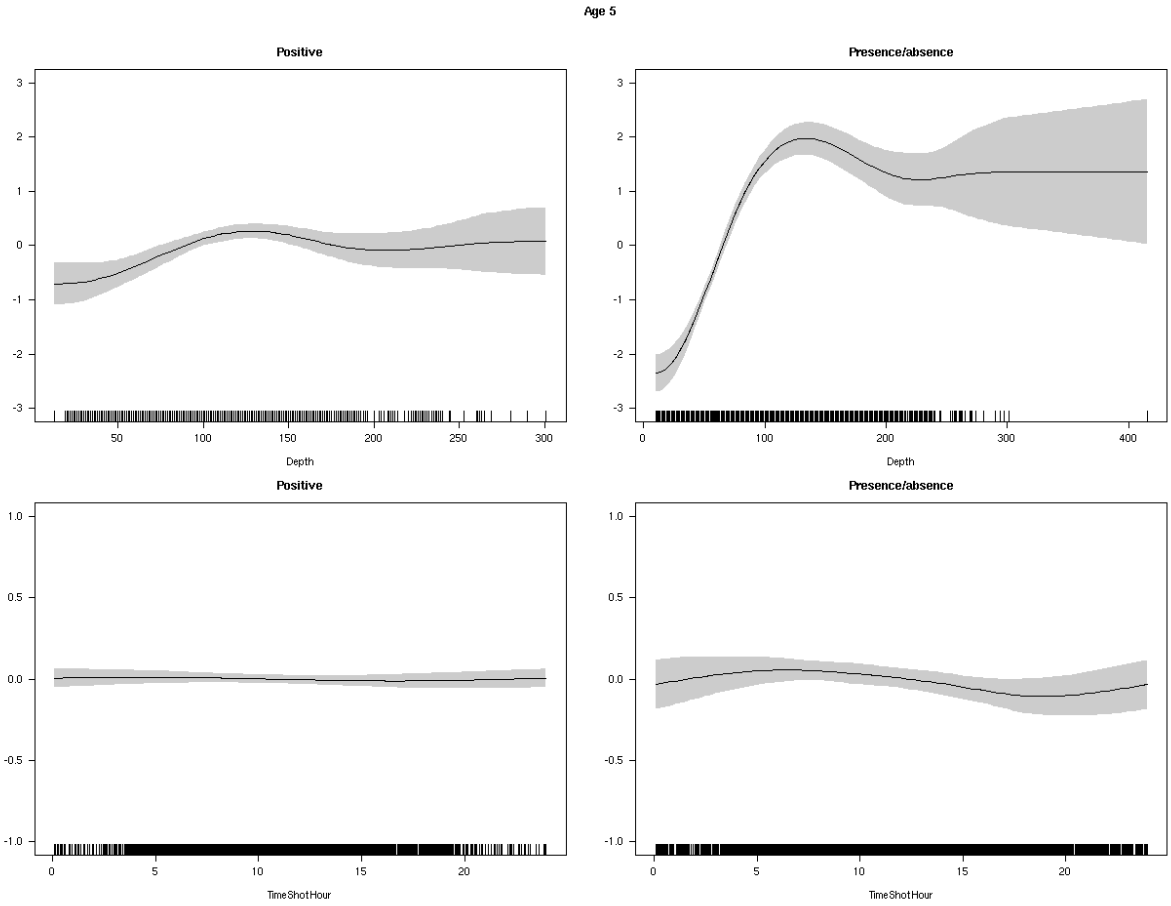

Age 5
Positive
Presence/absence
Depth
Depth
Positive
Presence/absence
Time Shot Hour
Time Shot Hour

Figure 65

7 SAM run summary tables

This section presents the evaluation critera: AIC for the survey index models, average internal consistency, AIC of the assessment model (SAM), and amount of retrospective patterns in the SAM model in terms of Mohn's rho for all the models.

7.1 Standard area

275

name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	243969.0	146958.4	0.783	0.764	444.5	0.283	-0.178	0.719
1	240712.4	145091.4	0.805	0.782	428.3	0.143	-0.115	0.019
2	234274.7	141126.2	0.807	0.789	434.6	0.182	-0.155	0.034
3	232431.1	140679.6	0.800	0.784	426.1	0.236	-0.168	0.270
3.tw	244198.0	154117.2	0.799	0.758	457.1	0.256	-0.181	0.224
3.dln	232148.1	140239.2	0.767	0.780	488.4	0.212	-0.143	0.330
4	234083.1	141267.4	0.799	0.778	423.1	0.191	-0.157	0.198
4.tw	242790.6	154414.8	0.789	0.759	469.4	0.219	-0.181	0.241
4.dln	233550.9	140682.4	0.760	0.772	485.8	0.166	-0.131	0.277
Avg	237573.1	144953.0	0.790	0.774	450.8	0.210	-0.157	0.257

Table 2: Standard area - current SAM configuration

name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	243969.0	146958.4	0.783	0.764	437.6	0.226	-0.155	0.726
1	240712.4	145091.4	0.805	0.782	429.2	0.121	-0.106	0.031
2	234274.7	141126.2	0.807	0.789	439.9	0.157	-0.139	0.048
3	232431.1	140679.6	0.800	0.784	422.1	0.206	-0.147	0.304
3.tw	244198.0	154117.2	0.799	0.758	458.4	0.207	-0.159	0.273
3.dln	232148.1	140239.2	0.767	0.780	489.4	0.180	-0.121	0.364
4	234083.1	141267.4	0.799	0.778	425.1	0.157	-0.139	0.199
4.tw	242790.6	154414.8	0.789	0.759	465.3	0.161	-0.153	0.237
4.dln	233550.9	140682.4	0.760	0.772	485.5	0.134	-0.110	0.299
Avg	237573.1	144953.0	0.790	0.774	450.3	0.172	-0.136	0.276

Table 3: Standard area - current SAM configuration but include variance weights.

name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	243969.0	146958.4	0.783	0.764	455.1	0.254	-0.171	0.750
1	240712.4	145091.4	0.805	0.782	452.3	-0.023	-0.039	-0.009
2	234274.7	141126.2	0.807	0.789	462.5	0.011	-0.074	0.004
3	232431.1	140679.6	0.800	0.784	443.7	0.161	-0.133	0.295
3.tw	244198.0	154117.2	0.799	0.758	474.4	0.188	-0.156	0.274
3.dln	232148.1	140239.2	0.767	0.780	516.7	0.241	-0.157	0.413
4	234083.1	141267.4	0.799	0.778	446.6	0.093	-0.113	0.180
4.tw	242790.6	154414.8	0.789	0.759	483.1	0.099	-0.128	0.219
4.dln	233550.9	140682.4	0.760	0.772	510.4	0.123	-0.118	0.319
Avg	237573.1	144953.0	0.790	0.774	471.6	0.127	-0.121	0.272

Table 4: Standard area - include variance weights and remove catch multiplier.

7.2 Including genetic split in areas 20/21

	name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	0	243969.0	146958.4	0.782	0.758	487.9	0.320	-0.188	0.734
1	1	240712.4	145091.4	0.809	0.791	519.5	-0.049	-0.030	-0.033
2	2	234274.7	141126.2	0.806	0.789	479.9	0.075	-0.115	-0.006
3	3	232431.1	140679.6	0.796	0.771	444.9	0.173	-0.159	0.273
3.tw	3.tw	244198.0	154117.2	0.791	0.725	491.7	0.204	-0.190	0.182
3.dln	3.dln	232148.1	140239.2	0.765	0.782	505.1	0.237	-0.166	0.400
4	4	234083.1	141267.4	0.802	0.781	450.5	0.102	-0.128	0.150
4.tw	4.tw	242790.6	154414.8	0.794	0.761	487.0	0.109	-0.133	0.189
4.dln	4.dln	233550.9	140682.4	0.760	0.774	510.9	0.131	-0.131	0.277

Table 5: Genetic split applied to area 21 - include variance weights and remove catch multiplier.

	name	AIC.Q1	AIC.Q3	ICQ1	ICQ3	SAM.AIC	mohn.SSB	mohn.F	mohn.R
0	0	243969.0	146958.4	0.782	0.758	487.3	0.322	-0.191	0.701
1	1	240712.4	145091.4	0.808	0.791	523.0	-0.056	-0.026	-0.029
2	2	234274.7	141126.2	0.804	0.789	478.8	0.062	-0.107	-0.020
3	3	232431.1	140679.6	0.796	0.772	446.2	0.168	-0.153	0.302
3.tw	3.tw	244198.0	154117.2	0.791	0.726	492.5	0.202	-0.186	0.191
3.dln	3.dln	232148.1	140239.2	0.766	0.783	506.9	0.232	-0.162	0.380
4	4	234083.1	141267.4	0.801	0.782	451.2	0.094	-0.119	0.152
4.tw	4.tw	242790.6	154414.8	0.792	0.762	485.4	0.113	-0.132	0.187
4.dln	4.dln	233550.9	140682.4	0.759	0.774	506.1	0.135	-0.129	0.291

Table 6: Genetic split applied to areas 21 and 20 - include variance weights and remove catch multiplier.

8 Model summaries

Model 3 summaries:

8.1 Q1

```
Age  1 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.6413     0.1772 -14.904  < 2e-16 ***
Year1984      0.5678     0.2179   2.606 0.009161 **
Year1985     -1.1796     0.1983  -5.949 2.70e-09 ***
Year1986      0.6449     0.2129   3.029 0.002450 **
Year1987      0.2090     0.1920   1.088 0.276502
Year1988      0.0984     0.2125   0.463 0.643302
Year1989      0.1667     0.2014   0.828 0.407841
Year1990     -1.1667     0.2028  -5.753 8.77e-09 ***
Year1991     -0.5554     0.2082  -2.668 0.007628 **
Year1992      1.0488     0.2471   4.245 2.19e-05 ***
Year1993     -0.2543     0.2285  -1.113 0.265647
Year1994      0.2826     0.2404   1.175 0.239818
Year1995      0.6508     0.2430   2.679 0.007389 **
Year1996     -0.2050     0.2199  -0.932 0.351393
Year1997      1.2113     0.2622   4.619 3.86e-06 ***
Year1998     -0.3412     0.2274  -1.501 0.133455
Year1999     -0.8742     0.2210  -3.955 7.66e-05 ***
Year2000     -0.4683     0.2126  -2.203 0.027594 *
Year2001     -0.8076     0.2200  -3.672 0.000241 ***
Year2002     -0.1312     0.2243  -0.585 0.558590
Year2003     -2.1349     0.2274  -9.390  < 2e-16 ***
Year2004     -0.6491     0.2206  -2.943 0.003254 **
Year2005     -0.6099     0.2201  -2.772 0.005575 **
Year2006     -0.3975     0.2198  -1.809 0.070498 .
Year2007     -0.7464     0.2226  -3.353 0.000801 ***
Year2008     -1.2984     0.2091  -6.210 5.29e-10 ***
Year2009     -1.5923     0.2168  -7.346 2.05e-13 ***
Year2010     -0.5343     0.2241  -2.385 0.017088 *
Year2011     -1.2188     0.2145  -5.681 1.34e-08 ***
Year2012     -0.7069     0.2336  -3.026 0.002482 **
Year2013     -0.9948     0.2291  -4.342 1.41e-05 ***
Year2014     -0.4652     0.2219  -2.096 0.036078 *
Year2015     -0.8231     0.2199  -3.743 0.000181 ***
Year2016     -1.9769     0.2372  -8.334  < 2e-16 ***
Year2017      0.1280     0.2341   0.547 0.584534
Year2018     -1.6058     0.2266  -7.087 1.37e-12 ***
Year2019     -1.4361     0.2190  -6.559 5.42e-11 ***
Year2020     -0.8351     0.2394  -3.488 0.000487 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                     edf Ref.df  Chi.sq  p-value
s(lon,lat)          69.421     79 958.365  < 2e-16 ***
s(lon,lat):Year1983  4.429      6  20.072 4.36e-05 ***
s(lon,lat):Year1984  4.289      6  35.285 2.02e-09 ***
s(lon,lat):Year1985  4.697      6  22.964 6.26e-06 ***
s(lon,lat):Year1986  4.441      6  38.675 6.31e-11 ***
s(lon,lat):Year1987  4.849      6  31.557 2.74e-08 ***
s(lon,lat):Year1988  4.453      6  43.942 1.58e-12 ***
s(lon,lat):Year1989  4.653      6   8.350 0.051599 .
s(lon,lat):Year1990  4.616      6  14.591 0.001402 **
s(lon,lat):Year1991  4.629      6  16.404 0.000775 ***
s(lon,lat):Year1992  4.022      6  11.052 0.010824 *
```

```
s(lon,lat):Year1993  4.250      6  26.574 2.76e-07 ***
s(lon,lat):Year1994  4.101      6  18.528 6.08e-05 ***
s(lon,lat):Year1995  4.017      6  33.268 1.49e-09 ***
s(lon,lat):Year1996  4.455      6   8.114 0.052515 .
s(lon,lat):Year1997  3.869      6  20.152 1.01e-05 ***
s(lon,lat):Year1998  4.385      6  61.974  < 2e-16 ***
s(lon,lat):Year1999  4.488      6   8.156 0.049287 *
s(lon,lat):Year2000  4.691      6  13.566 0.002179 **
s(lon,lat):Year2001  4.502      6  29.780 3.11e-08 ***
s(lon,lat):Year2002  4.472      6   8.693 0.032228 *
s(lon,lat):Year2003  4.321      6  31.132 8.55e-09 ***
s(lon,lat):Year2004  4.528      6  10.173 0.016088 *
s(lon,lat):Year2005  4.540      6   6.684 0.109367
s(lon,lat):Year2006  4.544      6  18.908 6.82e-05 ***
s(lon,lat):Year2007  4.479      6   7.344 0.076431 .
s(lon,lat):Year2008  4.719      6  30.270 4.78e-08 ***
s(lon,lat):Year2009  4.575      6   9.953 0.018029 *
s(lon,lat):Year2010  4.471      6  14.231 0.001060 **
s(lon,lat):Year2011  4.662      6  15.524 0.004999 **
s(lon,lat):Year2012  4.330      6  26.349 2.45e-07 ***
s(lon,lat):Year2013  4.400      6  38.098 7.40e-11 ***
s(lon,lat):Year2014  4.547      6   5.803 0.180514
s(lon,lat):Year2015  4.572      6  38.534 2.92e-10 ***
s(lon,lat):Year2016  4.292      6  32.779 1.35e-08 ***
s(lon,lat):Year2017  4.306      6  31.169 5.37e-08 ***
s(lon,lat):Year2018  4.437      6  29.263 1.44e-07 ***
s(lon,lat):Year2019  4.551      6  53.031 1.20e-13 ***
s(lon,lat):Year2020  4.290      6  31.575 1.06e-07 ***
s(Depth)             4.659      5 143.308  < 2e-16 ***
s(TimeShotHour)      2.834      4  33.793 8.62e-08 ***
s(Ship)             18.114     27 157.645  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.329   Deviance explained = 28.8%
-ML = 7704.1  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp1))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.84804    0.13661 -13.528  < 2e-16 ***
Year1984     0.64232    0.13230   4.855 1.23e-06 ***
Year1985    -1.54506    0.15827  -9.762  < 2e-16 ***
Year1986     0.72786    0.13348   5.453 5.11e-08 ***
Year1987    -0.04555    0.13274  -0.343 0.731489
Year1988    -0.43364    0.14184  -3.057 0.002242 **
Year1989     0.53801    0.13853   3.884 0.000104 ***
Year1990    -0.31253    0.16001  -1.953 0.050833 .
Year1991    -0.93734    0.15200  -6.167 7.32e-10 ***
Year1992     0.55873    0.14448   3.867 0.000111 ***
Year1993    -0.58575    0.15567  -3.763 0.000169 ***
Year1994     0.16701    0.15042   1.110 0.266900
Year1995     0.30025    0.15062   1.994 0.046242 *
Year1996    -0.90153    0.15709  -5.739 9.88e-09 ***
Year1997     0.79442    0.14696   5.406 6.65e-08 ***
Year1998    -1.61697    0.16002 -10.105  < 2e-16 ***
Year1999    -0.85400    0.16889  -5.056 4.37e-07 ***
Year2000    -0.24953    0.15948  -1.565 0.117701
Year2001    -1.23533    0.16480  -7.496 7.32e-14 ***
Year2002    -0.49241    0.15127  -3.255 0.001138 **
Year2003    -2.05217    0.21741  -9.439  < 2e-16 ***
Year2004    -0.48535    0.16324  -2.973 0.002956 **
Year2005    -1.36182    0.15917  -8.556  < 2e-16 ***
Year2006    -0.11473    0.15843  -0.724 0.468989
Year2007    -1.22024    0.16598  -7.352 2.16e-13 ***
Year2008    -0.57241    0.17093  -3.349 0.000815 ***
Year2009    -1.04443    0.18501  -5.645 1.71e-08 ***
Year2010    -0.51220    0.16081  -3.185 0.001453 **
```

```
Year2011    -1.21881    0.19112  -6.377 1.91e-10 ***
Year2012    -1.09428    0.18011  -6.076 1.29e-09 ***
Year2013    -0.96798    0.18790  -5.152 2.65e-07 ***
Year2014    -0.63134    0.17477  -3.612 0.000305 ***
Year2015    -1.18783    0.18394  -6.458 1.13e-10 ***
Year2016    -1.63521    0.22491  -7.271 3.93e-13 ***
Year2017     0.09219    0.16844   0.547 0.584180
Year2018    -2.19629    0.20932 -10.492  < 2e-16 ***
Year2019    -1.16596    0.19352  -6.025 1.77e-09 ***
Year2020    -0.45018    0.21380  -2.106 0.035269 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)          99.269    119  8.138  < 2e-16 ***
s(lon,lat):Year1983  6.797      8  2.391 0.000358 ***
s(lon,lat):Year1984  7.008      8 10.935  < 2e-16 ***
s(lon,lat):Year1985  6.559      8  1.834 0.004125 **
s(lon,lat):Year1986  7.059      8  7.432 6.16e-16 ***
s(lon,lat):Year1987  7.103      8 10.060  < 2e-16 ***
s(lon,lat):Year1988  6.902      8  4.081 5.91e-08 ***
s(lon,lat):Year1989  6.953      8  4.125 3.67e-08 ***
s(lon,lat):Year1990  6.484      8  3.146 6.60e-06 ***
s(lon,lat):Year1991  6.746      8  5.216 6.18e-10 ***
s(lon,lat):Year1992  6.967      8  3.660 4.11e-06 ***
s(lon,lat):Year1993  6.692      8  8.377  < 2e-16 ***
s(lon,lat):Year1994  6.798      8  4.168 3.77e-08 ***
s(lon,lat):Year1995  6.828      8  4.728 1.81e-09 ***
s(lon,lat):Year1996  6.639      8  2.231 0.000584 ***
s(lon,lat):Year1997  6.990      8  7.771  < 2e-16 ***
s(lon,lat):Year1998  6.805      8  4.138 3.85e-08 ***
s(lon,lat):Year1999  6.533      8  4.883 6.18e-10 ***
s(lon,lat):Year2000  6.764      8  3.404 1.61e-06 ***
s(lon,lat):Year2001  6.601      8  2.017 0.001392 **
s(lon,lat):Year2002  6.890      8  3.605 5.13e-07 ***
s(lon,lat):Year2003  5.748      8  0.869 0.160101
s(lon,lat):Year2004  6.666      8  4.155 4.46e-08 ***
s(lon,lat):Year2005  6.725      8  2.742 4.80e-05 ***
s(lon,lat):Year2006  6.739      8  1.458 0.022296 *
s(lon,lat):Year2007  6.548      8  3.585 6.95e-07 ***
s(lon,lat):Year2008  6.482      8  3.315 2.84e-06 ***
s(lon,lat):Year2009  6.240      8  2.017 0.001367 **
s(lon,lat):Year2010  6.663      8  1.943 0.002138 **
s(lon,lat):Year2011  6.329      8  1.989 0.010053 *
s(lon,lat):Year2012  6.509      8  3.073 1.64e-05 ***
s(lon,lat):Year2013  6.365      8  3.263 4.36e-06 ***
s(lon,lat):Year2014  6.630      8  3.260 6.60e-06 ***
s(lon,lat):Year2015  6.520      8  3.015 2.26e-05 ***
s(lon,lat):Year2016  5.822      8  4.635 2.54e-09 ***
s(lon,lat):Year2017  6.714      8  5.120 2.31e-09 ***
s(lon,lat):Year2018  5.991      8  3.425 1.08e-06 ***
s(lon,lat):Year2019  6.217      8  1.707 0.007737 **
s(lon,lat):Year2020  6.224      8  2.124 0.007818 **
s(Depth)             4.738      5 38.302  < 2e-16 ***
s(TimeShotHour)      1.803      4  1.976 0.008535 **
s(Ship)             19.204     27  5.263  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.209   Deviance explained = 60.2%
-ML =  18908  Scale est. = 2.1488    n = 8056
Age  2 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.52881    0.19301  -7.921 2.36e-15 ***
Year1984    -0.64942    0.21969  -2.956 0.003116 **
```

```
Year1985     0.06701    0.23003   0.291 0.770808
Year1986    -0.15785    0.22302  -0.708 0.479091
Year1987     0.07239    0.23283   0.311 0.755875
Year1988    -0.12924    0.23726  -0.545 0.585935
Year1989    -0.39648    0.23267  -1.704 0.088376 .
Year1990    -0.21039    0.24370  -0.863 0.387972
Year1991    -0.50226    0.23751  -2.115 0.034455 *
Year1992     0.12729    0.25532   0.499 0.618105
Year1993     0.05310    0.27253   0.195 0.845529
Year1994    -0.79253    0.23784  -3.332 0.000861 ***
Year1995     0.09788    0.26179   0.374 0.708500
Year1996    -0.49292    0.24932  -1.977 0.048037 *
Year1997    -0.44243    0.24401  -1.813 0.069812 .
Year1998     0.18820    0.25907   0.726 0.467566
Year1999    -1.20573    0.23984  -5.027 4.98e-07 ***
Year2000    -0.89078    0.23720  -3.755 0.000173 ***
Year2001    -0.78339    0.24218  -3.235 0.001218 **
Year2002    -0.33542    0.24649  -1.361 0.173589
Year2003    -1.30727    0.22547  -5.798 6.71e-09 ***
Year2004    -0.87430    0.23806  -3.673 0.000240 ***
Year2005    -1.06151    0.23539  -4.510 6.50e-06 ***
Year2006    -1.51830    0.22728  -6.680 2.38e-11 ***
Year2007    -0.76256    0.24347  -3.132 0.001736 **
Year2008    -1.45685    0.23211  -6.277 3.46e-10 ***
Year2009    -1.75253    0.22261  -7.873 3.47e-15 ***
Year2010    -1.26613    0.23289  -5.437 5.43e-08 ***
Year2011    -1.35087    0.23412  -5.770 7.93e-09 ***
Year2012    -0.63145    0.24344  -2.594 0.009491 **
Year2013    -1.31344    0.23351  -5.625 1.86e-08 ***
Year2014    -1.71935    0.23871  -7.203 5.90e-13 ***
Year2015    -0.81354    0.23601  -3.447 0.000567 ***
Year2016    -1.91780    0.23745  -8.077 6.65e-16 ***
Year2017    -1.55588    0.23331  -6.669 2.58e-11 ***
Year2018    -1.41339    0.23455  -6.026 1.68e-09 ***
Year2019    -1.81709    0.23357  -7.780 7.27e-15 ***
Year2020    -1.79241    0.24266  -7.386 1.51e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                     edf Ref.df  Chi.sq  p-value
s(lon,lat)          65.216     79 835.115  < 2e-16 ***
s(lon,lat):Year1983  3.244      6   3.566 0.323676
s(lon,lat):Year1984  3.712      6  21.011 1.02e-05 ***
s(lon,lat):Year1985  3.609      6   8.864 0.019780 *
s(lon,lat):Year1986  3.749      6  13.882 0.000803 ***
s(lon,lat):Year1987  3.566      6  14.222 0.000514 ***
s(lon,lat):Year1988  3.364      6  10.860 0.003693 **
s(lon,lat):Year1989  3.519      6   6.145 0.092714 .
s(lon,lat):Year1990  3.251      6   8.976 0.012909 *
s(lon,lat):Year1991  3.546      6   8.599 0.028354 *
s(lon,lat):Year1992  3.169      6  13.517 0.000928 ***
s(lon,lat):Year1993  2.924      6  22.117 4.60e-07 ***
s(lon,lat):Year1994  3.557      6   5.598 0.131910
s(lon,lat):Year1995  2.993      6   4.288 0.180918
s(lon,lat):Year1996  3.333      6   3.222 0.397875
s(lon,lat):Year1997  3.492      6   8.606 0.018606 *
s(lon,lat):Year1998  3.200      6  13.261 0.000471 ***
s(lon,lat):Year1999  3.683      6   9.386 0.013201 *
s(lon,lat):Year2000  3.756      6   2.835 0.540782
s(lon,lat):Year2001  3.651      6  14.130 0.000509 ***
s(lon,lat):Year2002  3.501      6   2.787 0.502106
s(lon,lat):Year2003  4.094      6  16.087 0.000292 ***
s(lon,lat):Year2004  3.751      6  38.033 2.86e-11 ***
s(lon,lat):Year2005  3.813      6  13.206 0.001270 **
s(lon,lat):Year2006  4.065      6  29.253 3.60e-08 ***
s(lon,lat):Year2007  3.571      6   3.179 0.435023
s(lon,lat):Year2008  3.922      6   4.696 0.248595
s(lon,lat):Year2009  4.209      6  31.907 6.33e-09 ***
s(lon,lat):Year2010  3.900      6   2.497 0.632733
s(lon,lat):Year2011  3.882      6  13.321 0.002969 **
s(lon,lat):Year2012  3.628      6   7.636 0.036425 *
s(lon,lat):Year2013  3.924      6   6.777 0.080088 .
s(lon,lat):Year2014  3.779      6  24.166 5.17e-07 ***
s(lon,lat):Year2015  3.861      6   9.027 0.024244 *
s(lon,lat):Year2016  3.865      6  14.663 0.000882 ***
s(lon,lat):Year2017  3.922      6  35.205 3.40e-09 ***
```

```
s(lon,lat):Year2018  3.854      6  12.947 0.002048 **
s(lon,lat):Year2019  3.962      6  22.755 8.37e-06 ***
s(lon,lat):Year2020  3.780      6  21.627 8.65e-05 ***
s(Depth)             4.435      5 107.597  < 2e-16 ***
s(TimeShotHour)      3.470      4  44.173 5.47e-09 ***
s(Ship)             16.921     27  99.901  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.254   Deviance explained = 23.3%
-ML = 7304.2  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp2))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.79466    0.13485  -5.893 3.92e-09 ***
Year1984    -0.76731    0.13279  -5.778 7.77e-09 ***
Year1985     0.09606    0.13140   0.731 0.464771
Year1986    -1.55260    0.13118 -11.836  < 2e-16 ***
Year1987     0.15702    0.13006   1.207 0.227353
Year1988    -1.14158    0.13653  -8.361  < 2e-16 ***
Year1989    -1.21568    0.13833  -8.789  < 2e-16 ***
Year1990    -0.62296    0.14019  -4.444 8.94e-06 ***
Year1991    -1.43542    0.14409  -9.962  < 2e-16 ***
Year1992    -1.51878    0.14482 -10.487  < 2e-16 ***
Year1993    -0.52722    0.14417  -3.657 0.000257 ***
Year1994    -1.84821    0.15245 -12.123  < 2e-16 ***
Year1995    -0.36362    0.14771  -2.462 0.013842 *
Year1996    -0.99098    0.15138  -6.546 6.20e-11 ***
Year1997    -1.38049    0.14942  -9.239  < 2e-16 ***
Year1998    -0.17709    0.14598  -1.213 0.225115
Year1999    -2.84468    0.16244 -17.513  < 2e-16 ***
Year2000    -1.39366    0.15480  -9.003  < 2e-16 ***
Year2001    -1.05588    0.15065  -7.009 2.56e-12 ***
Year2002    -2.10715    0.14723 -14.312  < 2e-16 ***
Year2003    -1.72486    0.15535 -11.103  < 2e-16 ***
Year2004    -2.32149    0.15626 -14.857  < 2e-16 ***
Year2005    -1.85022    0.15544 -11.904  < 2e-16 ***
Year2006    -2.42644    0.16117 -15.055  < 2e-16 ***
Year2007    -1.52696    0.15534  -9.830  < 2e-16 ***
Year2008    -2.47542    0.16176 -15.303  < 2e-16 ***
Year2009    -1.97004    0.16268 -12.110  < 2e-16 ***
Year2010    -1.88600    0.15789 -11.945  < 2e-16 ***
Year2011    -1.37465    0.17584  -7.817 5.94e-15 ***
Year2012    -2.07344    0.16018 -12.945  < 2e-16 ***
Year2013    -2.08565    0.16872 -12.362  < 2e-16 ***
Year2014    -1.71586    0.18383  -9.334  < 2e-16 ***
Year2015    -1.41101    0.16264  -8.676  < 2e-16 ***
Year2016    -2.31404    0.18690 -12.381  < 2e-16 ***
Year2017    -2.59978    0.17837 -14.575  < 2e-16 ***
Year2018    -1.46912    0.17274  -8.505  < 2e-16 ***
Year2019    -3.11569    0.17865 -17.440  < 2e-16 ***
Year2020    -2.56812    0.19919 -12.893  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                      edf Ref.df      F  p-value
s(lon,lat)        108.780    119 12.828  < 2e-16 ***
s(lon,lat):Year1983   6.396      8  6.429 5.21e-13 ***
s(lon,lat):Year1984   6.490      8  2.889 4.10e-05 ***
s(lon,lat):Year1985   6.680      8  2.971 1.99e-05 ***
s(lon,lat):Year1986   6.656      8  2.739 5.85e-05 ***
s(lon,lat):Year1987   6.729      8  6.370 3.33e-13 ***
s(lon,lat):Year1988   6.515      8  1.652 0.009855 **
s(lon,lat):Year1989   6.490      8  1.916 0.003013 **
s(lon,lat):Year1990   6.468      8  3.077 1.11e-05 ***
s(lon,lat):Year1991   6.480      8  1.403 0.038413 *
```

```
s(lon,lat):Year1992   6.466      8  4.359 1.95e-07 ***
s(lon,lat):Year1993   6.440      8  2.047 0.001627 **
s(lon,lat):Year1994   6.214      8  2.473 0.000214 ***
s(lon,lat):Year1995   6.374      8  2.636 7.99e-05 ***
s(lon,lat):Year1996   6.274      8  3.530 6.93e-07 ***
s(lon,lat):Year1997   6.378      8  1.306 0.037494 *
s(lon,lat):Year1998   6.616      8  2.630 8.59e-05 ***
s(lon,lat):Year1999   6.117      8  6.321 9.50e-14 ***
s(lon,lat):Year2000   6.348      8  2.579 9.34e-05 ***
s(lon,lat):Year2001   6.323      8  1.198 0.054977 .
s(lon,lat):Year2002   6.491      8  3.246 3.23e-06 ***
s(lon,lat):Year2003   6.229      8  3.157 3.44e-06 ***
s(lon,lat):Year2004   6.314      8  2.312 0.000441 ***
s(lon,lat):Year2005   6.295      8  1.624 0.009673 **
s(lon,lat):Year2006   6.113      8  1.323 0.032280 *
s(lon,lat):Year2007   6.288      8  2.383 0.000269 ***
s(lon,lat):Year2008   6.064      8  2.863 1.88e-05 ***
s(lon,lat):Year2009   6.014      8  2.492 9.40e-05 ***
s(lon,lat):Year2010   6.226      8  1.478 0.016372 *
s(lon,lat):Year2011   6.030      8  1.570 0.058258 .
s(lon,lat):Year2012   6.331      8  0.864 0.235909
s(lon,lat):Year2013   6.047      8  2.952 1.91e-05 ***
s(lon,lat):Year2014   5.696      8  1.160 0.063657 .
s(lon,lat):Year2015   6.308      8  3.478 2.64e-06 ***
s(lon,lat):Year2016   5.801      8  2.293 0.000585 ***
s(lon,lat):Year2017   5.910      8  1.679 0.021730 *
s(lon,lat):Year2018   6.050      8  1.713 0.008075 **
s(lon,lat):Year2019   5.863      8  1.776 0.005739 **
s(lon,lat):Year2020   5.698      8  5.569 2.77e-07 ***
s(Depth)              4.748      5 22.651  < 2e-16 ***
s(TimeShotHour)       3.369      4  9.136 6.89e-08 ***
s(Ship)              19.944     27  6.298  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.142   Deviance explained = 54.5%
-ML =  24185  Scale est. = 2.4798    n = 10281
Age  3 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.54989    0.17647  -8.783  < 2e-16 ***
Year1984    -0.68760    0.21240  -3.237 0.001207 **
Year1985    -0.52697    0.21225  -2.483 0.013037 *
Year1986    -0.71901    0.20911  -3.438 0.000585 ***
Year1987    -0.39253    0.21952  -1.788 0.073757 .
Year1988    -0.30473    0.22632  -1.346 0.178158
Year1989    -0.67370    0.22078  -3.051 0.002277 **
Year1990    -0.33527    0.22663  -1.479 0.139037
Year1991    -0.44634    0.22519  -1.982 0.047470 *
Year1992    -1.03812    0.21801  -4.762 1.92e-06 ***
Year1993    -0.34918    0.23996  -1.455 0.145620
Year1994    -0.70654    0.22254  -3.175 0.001499 **
Year1995    -0.07995    0.24344  -0.328 0.742601
Year1996    -0.39637    0.23297  -1.701 0.088878 .
Year1997    -0.98089    0.22077  -4.443 8.87e-06 ***
Year1998    -0.06140    0.23515  -0.261 0.794006
Year1999    -0.48362    0.22957  -2.107 0.035150 *
Year2000    -0.93149    0.21837  -4.266 1.99e-05 ***
Year2001    -0.58885    0.22944  -2.567 0.010273 *
Year2002    -0.82801    0.21973  -3.768 0.000164 ***
Year2003    -1.14276    0.21450  -5.328 9.96e-08 ***
Year2004    -0.89324    0.21788  -4.100 4.14e-05 ***
Year2005    -1.15991    0.21796  -5.322 1.03e-07 ***
Year2006    -1.56396    0.21479  -7.281 3.30e-13 ***
Year2007    -0.90550    0.22650  -3.998 6.39e-05 ***
Year2008    -1.03494    0.21837  -4.739 2.14e-06 ***
Year2009    -1.53551    0.21035  -7.300 2.88e-13 ***
```

```
Year2010    -1.41816    0.21159  -6.702 2.05e-11 ***
Year2011    -1.45134    0.21792  -6.660 2.74e-11 ***
Year2012    -0.76312    0.22294  -3.423 0.000619 ***
Year2013    -1.33572    0.21708  -6.153 7.59e-10 ***
Year2014    -1.78674    0.22739  -7.858 3.92e-15 ***
Year2015    -1.00674    0.22071  -4.561 5.08e-06 ***
Year2016    -1.25033    0.22229  -5.625 1.86e-08 ***
Year2017    -1.81309    0.22148  -8.186 2.69e-16 ***
Year2018    -1.67135    0.21932  -7.620 2.53e-14 ***
Year2019    -2.01804    0.22149  -9.111  < 2e-16 ***
Year2020    -2.31799    0.22735 -10.196  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                     edf Ref.df  Chi.sq  p-value
s(lon,lat)          63.859     79 659.265  < 2e-16 ***
s(lon,lat):Year1983  3.213      6   4.452 0.188499
s(lon,lat):Year1984  3.699      6   9.324 0.015266 *
s(lon,lat):Year1985  3.850      6   9.653 0.013806 *
s(lon,lat):Year1986  3.926      6  11.520 0.004399 **
s(lon,lat):Year1987  3.727      6  12.595 0.001844 **
s(lon,lat):Year1988  3.416      6   4.895 0.166528
s(lon,lat):Year1989  3.572      6  13.747 0.000654 ***
s(lon,lat):Year1990  3.460      6  10.062 0.007040 **
s(lon,lat):Year1991  3.524      6   6.045 0.098407 .
s(lon,lat):Year1992  3.793      6   6.336 0.106753
s(lon,lat):Year1993  3.277      6  18.255 1.55e-05 ***
s(lon,lat):Year1994  3.633      6   7.085 0.055895 .
s(lon,lat):Year1995  3.123      6   4.032 0.227590
s(lon,lat):Year1996  3.417      6   2.408 0.594158
s(lon,lat):Year1997  3.760      6   8.083 0.032711 *
s(lon,lat):Year1998  3.387      6  14.699 0.000219 ***
s(lon,lat):Year1999  3.584      6   9.710 0.009425 **
s(lon,lat):Year2000  3.888      6   7.626 0.046508 *
s(lon,lat):Year2001  3.635      6  13.476 0.000764 ***
s(lon,lat):Year2002  3.843      6   5.475 0.154666
s(lon,lat):Year2003  3.998      6  11.408 0.004929 **
s(lon,lat):Year2004  3.884      6  38.111 2.23e-11 ***
s(lon,lat):Year2005  3.889      6  17.159 8.59e-05 ***
s(lon,lat):Year2006  3.999      6  19.162 2.84e-05 ***
s(lon,lat):Year2007  3.656      6   5.780 0.114735
s(lon,lat):Year2008  3.906      6   8.688 0.024837 *
s(lon,lat):Year2009  4.157      6  34.056 8.56e-10 ***
s(lon,lat):Year2010  4.116      6  13.875 0.001106 **
s(lon,lat):Year2011  3.930      6   9.266 0.025161 *
s(lon,lat):Year2012  3.783      6   3.204 0.472927
s(lon,lat):Year2013  3.964      6   8.785 0.026298 *
s(lon,lat):Year2014  3.646      6  38.416 7.04e-12 ***
s(lon,lat):Year2015  3.850      6   4.647 0.253353
s(lon,lat):Year2016  3.800      6  10.834 0.007020 **
s(lon,lat):Year2017  3.841      6  25.787 3.50e-07 ***
s(lon,lat):Year2018  3.890      6  17.196 0.000139 ***
s(lon,lat):Year2019  3.851      6  30.682 2.00e-08 ***
s(lon,lat):Year2020  3.748      6  20.125 4.98e-05 ***
s(Depth)             4.605      5 203.824  < 2e-16 ***
s(TimeShotHour)      3.639      4  64.325 2.23e-13 ***
s(Ship)             12.427     27  53.085 8.22e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.234   Deviance explained = 21.2%
-ML = 7732.6  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp3))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.77016    0.11867 -23.343  < 2e-16 ***
```

```
Year1984     0.39985    0.12187   3.281 0.001039 **
Year1985     0.01936    0.12259   0.158 0.874528
Year1986     0.82362    0.12256   6.720 1.92e-11 ***
Year1987    -0.95665    0.12158  -7.868 3.99e-15 ***
Year1988     0.74230    0.12670   5.859 4.82e-09 ***
Year1989     0.50476    0.12967   3.893 9.98e-05 ***
Year1990    -0.44352    0.12927  -3.431 0.000604 ***
Year1991     0.24665    0.13195   1.869 0.061617 .
Year1992    -0.50290    0.13997  -3.593 0.000329 ***
Year1993    -0.44371    0.13413  -3.308 0.000943 ***
Year1994     0.00118    0.13844   0.009 0.993198
Year1995     0.18624    0.13681   1.361 0.173425
Year1996     0.46359    0.13753   3.371 0.000752 ***
Year1997    -0.01070    0.14166  -0.076 0.939784
Year1998    -0.29471    0.13544  -2.176 0.029588 *
Year1999     0.83571    0.14102   5.926 3.21e-09 ***
Year2000    -0.84537    0.14239  -5.937 3.01e-09 ***
Year2001    -0.43627    0.13773  -3.168 0.001542 **
Year2002     0.05134    0.13883   0.370 0.711549
Year2003    -0.82577    0.14243  -5.798 6.93e-09 ***
Year2004    -0.35544    0.14354  -2.476 0.013294 *
Year2005    -1.10923    0.14423  -7.691 1.61e-14 ***
Year2006    -0.52095    0.14953  -3.484 0.000496 ***
Year2007    -0.71932    0.14443  -4.980 6.46e-07 ***
Year2008    -0.35477    0.14366  -2.470 0.013547 *
Year2009    -0.73717    0.14741  -5.001 5.81e-07 ***
Year2010    -0.58526    0.14557  -4.020 5.86e-05 ***
Year2011    -0.71793    0.15916  -4.511 6.53e-06 ***
Year2012     0.03230    0.14750   0.219 0.826648
Year2013    -0.50607    0.15408  -3.285 0.001025 **
Year2014    -0.41883    0.17767  -2.357 0.018425 *
Year2015    -0.25942    0.15128  -1.715 0.086415 .
Year2016     0.18665    0.15925   1.172 0.241206
Year2017    -0.28621    0.17022  -1.681 0.092724 .
Year2018    -1.15240    0.16292  -7.073 1.62e-12 ***
Year2019    -0.24186    0.16969  -1.425 0.154089
Year2020    -1.20981    0.18829  -6.425 1.38e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)         104.618    119  8.656  < 2e-16 ***
s(lon,lat):Year1983   6.385      8  5.500 6.94e-11 ***
s(lon,lat):Year1984   6.497      8  3.282 5.84e-06 ***
s(lon,lat):Year1985   6.614      8  4.618 4.11e-09 ***
s(lon,lat):Year1986   6.570      8  2.428 0.000271 ***
s(lon,lat):Year1987   6.661      8  6.136 1.15e-12 ***
s(lon,lat):Year1988   6.481      8  2.259 0.000592 ***
s(lon,lat):Year1989   6.378      8  1.514 0.016853 *
s(lon,lat):Year1990   6.431      8  3.359 2.37e-06 ***
s(lon,lat):Year1991   6.502      8  1.490 0.026264 *
s(lon,lat):Year1992   6.224      8  2.385 0.000503 ***
s(lon,lat):Year1993   6.401      8  1.203 0.063092 .
s(lon,lat):Year1994   6.255      8  1.300 0.042607 *
s(lon,lat):Year1995   6.316      8  0.649 0.414809
s(lon,lat):Year1996   6.294      8  2.614 7.71e-05 ***
s(lon,lat):Year1997   6.201      8  2.146 0.000691 ***
s(lon,lat):Year1998   6.569      8  3.797 1.98e-07 ***
s(lon,lat):Year1999   6.325      8  4.204 1.68e-08 ***
s(lon,lat):Year2000   6.317      8  5.705 4.25e-12 ***
s(lon,lat):Year2001   6.367      8  2.075 0.001013 **
s(lon,lat):Year2002   6.373      8  2.150 0.000786 ***
s(lon,lat):Year2003   6.248      8  5.092 8.74e-11 ***
s(lon,lat):Year2004   6.280      8  3.857 1.29e-07 ***
s(lon,lat):Year2005   6.251      8  2.141 0.000841 ***
s(lon,lat):Year2006   6.041      8  2.305 0.000292 ***
s(lon,lat):Year2007   6.242      8  1.497 0.016388 *
s(lon,lat):Year2008   6.262      8  2.708 5.39e-05 ***
s(lon,lat):Year2009   6.085      8  2.638 4.98e-05 ***
s(lon,lat):Year2010   6.190      8  7.913  < 2e-16 ***
s(lon,lat):Year2011   6.022      8  1.641 0.034956 *
s(lon,lat):Year2012   6.306      8  3.557 1.24e-06 ***
s(lon,lat):Year2013   6.051      8  0.816 0.255994
s(lon,lat):Year2014   5.546      8  1.041 0.092637 .
s(lon,lat):Year2015   6.222      8  5.065 6.86e-10 ***
s(lon,lat):Year2016   6.087      8  2.938 3.66e-05 ***
```

```
s(lon,lat):Year2017   5.751      8  3.447 1.14e-05 ***
s(lon,lat):Year2018   5.927      8  4.762 1.60e-09 ***
s(lon,lat):Year2019   5.684      8  1.075 0.098886 .
s(lon,lat):Year2020   5.436      8  1.188 0.098938 .
s(Depth)              4.695      5 19.166  < 2e-16 ***
s(TimeShotHour)       3.255      4  6.966 3.30e-06 ***
s(Ship)              18.647     26  5.647  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.178   Deviance explained = 46.4%
-ML =  14981  Scale est. = 2.092     n = 9862
Age  4 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.2872     0.1504 -15.204  < 2e-16 ***
Year1984     -0.4947     0.1797  -2.754 0.005891 **
Year1985     -0.8997     0.1725  -5.215 1.84e-07 ***
Year1986     -0.3558     0.1801  -1.976 0.048167 *
Year1987     -0.6629     0.1747  -3.794 0.000148 ***
Year1988     -0.6665     0.1833  -3.637 0.000276 ***
Year1989     -0.1947     0.1892  -1.029 0.303506
Year1990     -0.4040     0.1893  -2.134 0.032848 *
Year1991     -0.1964     0.1940  -1.012 0.311411
Year1992     -0.8742     0.1874  -4.665 3.08e-06 ***
Year1993     -0.6256     0.1911  -3.275 0.001058 **
Year1994     -0.5586     0.1896  -2.947 0.003213 **
Year1995     -0.2328     0.1998  -1.165 0.243975
Year1996     -0.1884     0.1970  -0.957 0.338759
Year1997     -0.5897     0.1918  -3.075 0.002108 **
Year1998     -0.4026     0.1890  -2.130 0.033197 *
Year1999      0.1904     0.2017   0.944 0.345217
Year2000     -0.1986     0.1930  -1.029 0.303409
Year2001     -0.9577     0.1861  -5.146 2.65e-07 ***
Year2002     -0.6069     0.1899  -3.196 0.001392 **
Year2003     -0.5797     0.1886  -3.074 0.002114 **
Year2004     -0.8055     0.1894  -4.252 2.11e-05 ***
Year2005     -0.6056     0.1903  -3.182 0.001465 **
Year2006     -1.4226     0.1917  -7.423 1.15e-13 ***
Year2007     -1.3835     0.1936  -7.147 8.87e-13 ***
Year2008     -0.8890     0.1897  -4.687 2.78e-06 ***
Year2009     -1.1294     0.1869  -6.043 1.51e-09 ***
Year2010     -1.2625     0.1866  -6.765 1.33e-11 ***
Year2011     -1.3249     0.1913  -6.927 4.30e-12 ***
Year2012     -0.7375     0.1932  -3.818 0.000135 ***
Year2013     -0.7537     0.1932  -3.901 9.59e-05 ***
Year2014     -1.2814     0.2035  -6.296 3.05e-10 ***
Year2015     -1.3097     0.1977  -6.626 3.45e-11 ***
Year2016     -0.6479     0.1998  -3.242 0.001185 **
Year2017     -1.0971     0.1994  -5.503 3.74e-08 ***
Year2018     -1.6563     0.2020  -8.201 2.39e-16 ***
Year2019     -1.6648     0.2014  -8.268  < 2e-16 ***
Year2020     -1.7781     0.2093  -8.494  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                    edf Ref.df  Chi.sq  p-value
s(lon,lat)          64.981     79 511.849  < 2e-16 ***
s(lon,lat):Year1983  3.779      6   4.000 0.333856
s(lon,lat):Year1984  4.046      6  11.909 0.004801 **
s(lon,lat):Year1985  4.365      6  27.317 2.68e-07 ***
s(lon,lat):Year1986  4.128      6  28.315 6.81e-08 ***
s(lon,lat):Year1987  4.314      6  35.217 1.03e-09 ***
s(lon,lat):Year1988  4.055      6  12.895 0.002239 **
s(lon,lat):Year1989  3.922      6   7.643 0.050810 .
s(lon,lat):Year1990  3.914      6  14.070 0.000948 ***
```

```
s(lon,lat):Year1991  3.850      6  10.808 0.008314 **
s(lon,lat):Year1992  4.085      6   4.447 0.328869
s(lon,lat):Year1993  3.954      6   5.876 0.141434
s(lon,lat):Year1994  3.981      6   9.327 0.019692 *
s(lon,lat):Year1995  3.716      6   5.606 0.139955
s(lon,lat):Year1996  3.828      6   5.256 0.179093
s(lon,lat):Year1997  4.005      6  14.542 0.000683 ***
s(lon,lat):Year1998  4.147      6  13.862 0.001204 **
s(lon,lat):Year1999  3.800      6  15.084 0.000318 ***
s(lon,lat):Year2000  4.038      6  11.375 0.005184 **
s(lon,lat):Year2001  4.174      6   7.326 0.068964 .
s(lon,lat):Year2002  4.074      6  10.821 0.007650 **
s(lon,lat):Year2003  4.142      6  14.260 0.000897 ***
s(lon,lat):Year2004  4.125      6  16.685 0.000188 ***
s(lon,lat):Year2005  4.101      6  18.731 4.24e-05 ***
s(lon,lat):Year2006  4.073      6   5.713 0.156735
s(lon,lat):Year2007  4.017      6   9.575 0.016196 *
s(lon,lat):Year2008  4.126      6  17.378 0.000110 ***
s(lon,lat):Year2009  4.230      6  19.335 3.14e-05 ***
s(lon,lat):Year2010  4.233      6  16.876 0.000167 ***
s(lon,lat):Year2011  4.129      6   7.480 0.095845 .
s(lon,lat):Year2012  4.061      6  11.852 0.004765 **
s(lon,lat):Year2013  4.062      6  12.624 0.003030 **
s(lon,lat):Year2014  3.803      6  24.023 7.79e-07 ***
s(lon,lat):Year2015  3.977      6  24.506 1.21e-06 ***
s(lon,lat):Year2016  3.894      6  18.879 5.10e-05 ***
s(lon,lat):Year2017  3.895      6  29.133 4.64e-08 ***
s(lon,lat):Year2018  3.880      6  23.277 2.82e-06 ***
s(lon,lat):Year2019  3.885      6  15.276 0.000628 ***
s(lon,lat):Year2020  3.747      6  23.796 1.13e-05 ***
s(Depth)             4.790      5 303.827  < 2e-16 ***
s(TimeShotHour)      3.142      4  23.840 2.21e-05 ***
s(Ship)             14.622     27  75.071 1.48e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.218   Deviance explained = 18.7%
-ML =   8611  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp4))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.09229    0.11125 -27.796  < 2e-16 ***
Year1984    -0.60928    0.12121  -5.027 5.10e-07 ***
Year1985    -0.11943    0.12687  -0.941 0.346540
Year1986     0.12212    0.12057   1.013 0.311165
Year1987    -0.22105    0.12341  -1.791 0.073305 .
Year1988    -1.56806    0.12975 -12.085  < 2e-16 ***
Year1989     0.15122    0.12587   1.201 0.229631
Year1990    -0.75727    0.12944  -5.850 5.10e-09 ***
Year1991    -0.63225    0.12996  -4.865 1.17e-06 ***
Year1992    -0.51513    0.14013  -3.676 0.000238 ***
Year1993    -0.73269    0.13513  -5.422 6.06e-08 ***
Year1994    -0.71215    0.13863  -5.137 2.86e-07 ***
Year1995    -0.39929    0.13762  -2.901 0.003725 **
Year1996    -0.77820    0.13594  -5.724 1.08e-08 ***
Year1997    -0.43466    0.14079  -3.087 0.002026 **
Year1998    -0.50029    0.13718  -3.647 0.000267 ***
Year1999    -0.68501    0.13727  -4.990 6.16e-07 ***
Year2000     0.05553    0.13860   0.401 0.688679
Year2001    -1.36321    0.14238  -9.575  < 2e-16 ***
Year2002    -1.02055    0.13931  -7.326 2.61e-13 ***
Year2003    -0.62767    0.14060  -4.464 8.15e-06 ***
Year2004    -1.49801    0.14627 -10.241  < 2e-16 ***
Year2005    -0.78061    0.14217  -5.491 4.12e-08 ***
Year2006    -1.54717    0.15625  -9.902  < 2e-16 ***
Year2007    -1.00299    0.15779  -6.356 2.18e-10 ***
Year2008    -1.19533    0.14687  -8.138 4.61e-16 ***
```

```
Year2009    -0.67458    0.14963  -4.508 6.63e-06 ***
Year2010    -1.11723    0.15075  -7.411 1.38e-13 ***
Year2011    -0.89301    0.16114  -5.542 3.09e-08 ***
Year2012    -0.88329    0.15020  -5.881 4.25e-09 ***
Year2013    -0.43767    0.15156  -2.888 0.003890 **
Year2014    -0.89891    0.17343  -5.183 2.24e-07 ***
Year2015    -0.54024    0.16671  -3.241 0.001198 **
Year2016    -0.60649    0.15711  -3.860 0.000114 ***
Year2017     0.07569    0.16509   0.458 0.646606
Year2018    -1.02166    0.17794  -5.741 9.73e-09 ***
Year2019    -1.76922    0.17184 -10.296  < 2e-16 ***
Year2020    -0.75670    0.18723  -4.042 5.36e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                      edf Ref.df      F  p-value
s(lon,lat)          93.265    119  4.781  < 2e-16 ***
s(lon,lat):Year1983  5.947      8  2.044 0.001655 **
s(lon,lat):Year1984  6.084      8  2.166 0.001001 **
s(lon,lat):Year1985  6.035      8  5.086 2.03e-10 ***
s(lon,lat):Year1986  6.204      8  4.504 5.38e-09 ***
s(lon,lat):Year1987  6.179      8  2.923 2.02e-05 ***
s(lon,lat):Year1988  5.950      8  3.688 2.71e-07 ***
s(lon,lat):Year1989  6.055      8  1.841 0.003694 **
s(lon,lat):Year1990  5.942      8  1.807 0.003935 **
s(lon,lat):Year1991  6.125      8  2.323 0.000634 ***
s(lon,lat):Year1992  5.703      8  2.835 3.09e-05 ***
s(lon,lat):Year1993  5.838      8  4.220 1.31e-08 ***
s(lon,lat):Year1994  5.713      8  2.429 0.000168 ***
s(lon,lat):Year1995  5.799      8  0.621 0.425171
s(lon,lat):Year1996  5.829      8  2.259 0.000344 ***
s(lon,lat):Year1997  5.709      8  0.733 0.287678
s(lon,lat):Year1998  6.017      8  5.779 1.93e-12 ***
s(lon,lat):Year1999  5.983      8  4.389 4.45e-09 ***
s(lon,lat):Year2000  5.981      8  0.678 0.369123
s(lon,lat):Year2001  5.686      8  2.398 0.000118 ***
s(lon,lat):Year2002  5.842      8  4.679 6.77e-10 ***
s(lon,lat):Year2003  5.803      8  1.161 0.055642 .
s(lon,lat):Year2004  5.622      8  1.743 0.003717 **
s(lon,lat):Year2005  5.785      8  3.602 2.90e-07 ***
s(lon,lat):Year2006  5.231      8  0.817 0.176926
s(lon,lat):Year2007  5.150      8  0.801 0.184206
s(lon,lat):Year2008  5.607      8  1.846 0.002361 **
s(lon,lat):Year2009  5.444      8  1.241 0.032486 *
s(lon,lat):Year2010  5.408      8  3.606 1.06e-07 ***
s(lon,lat):Year2011  5.301      8  2.392 0.001184 **
s(lon,lat):Year2012  5.614      8  3.655 3.23e-07 ***
s(lon,lat):Year2013  5.515      8  1.641 0.007437 **
s(lon,lat):Year2014  4.915      8  1.348 0.016984 *
s(lon,lat):Year2015  5.120      8  2.411 0.000127 ***
s(lon,lat):Year2016  5.544      8  8.834  < 2e-16 ***
s(lon,lat):Year2017  5.135      8  3.346 5.92e-06 ***
s(lon,lat):Year2018  4.866      8  2.997 3.77e-06 ***
s(lon,lat):Year2019  4.897      8  1.324 0.020828 *
s(lon,lat):Year2020  4.766      8  0.789 0.241866
s(Depth)             4.733      5 21.263  < 2e-16 ***
s(TimeShotHour)      2.846      4  4.307 0.000275 ***
s(Ship)             16.951     26  2.966 2.90e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.102   Deviance explained = 44.3%
-ML = 6756.7  Scale est. = 1.861     n = 8343
Age  5 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
```

```
(Intercept)  -2.8293     0.1326 -21.331  < 2e-16 ***
Year1984     -0.3634     0.1617  -2.248 0.024582 *
Year1985     -1.0034     0.1590  -6.311 2.77e-10 ***
Year1986     -0.5232     0.1609  -3.251 0.001148 **
Year1987     -0.7731     0.1581  -4.890 1.01e-06 ***
Year1988     -0.4389     0.1671  -2.627 0.008619 **
Year1989     -0.3115     0.1683  -1.851 0.064160 .
Year1990     -0.3323     0.1720  -1.931 0.053443 .
Year1991     -0.4299     0.1736  -2.477 0.013242 *
Year1992     -0.8371     0.1724  -4.855 1.21e-06 ***
Year1993     -0.4274     0.1745  -2.449 0.014315 *
Year1994     -0.6815     0.1738  -3.922 8.80e-05 ***
Year1995     -0.5386     0.1783  -3.020 0.002527 **
Year1996     -0.2588     0.1787  -1.448 0.147532
Year1997     -0.6694     0.1758  -3.808 0.000140 ***
Year1998     -0.5043     0.1716  -2.939 0.003293 **
Year1999     -0.3234     0.1782  -1.815 0.069519 .
Year2000     -0.6068     0.1775  -3.418 0.000631 ***
Year2001     -0.9874     0.1740  -5.674 1.39e-08 ***
Year2002     -1.4714     0.1814  -8.110 5.06e-16 ***
Year2003     -0.9033     0.1756  -5.144 2.69e-07 ***
Year2004     -0.9659     0.1802  -5.360 8.30e-08 ***
Year2005     -1.2630     0.1848  -6.834 8.27e-12 ***
Year2006     -1.4626     0.1849  -7.911 2.56e-15 ***
Year2007     -1.5928     0.1910  -8.341  < 2e-16 ***
Year2008     -0.9428     0.1794  -5.256 1.48e-07 ***
Year2009     -1.2805     0.1825  -7.015 2.31e-12 ***
Year2010     -1.1092     0.1767  -6.279 3.40e-10 ***
Year2011     -1.3033     0.1834  -7.105 1.20e-12 ***
Year2012     -1.0794     0.1836  -5.878 4.14e-09 ***
Year2013     -0.6144     0.1817  -3.382 0.000719 ***
Year2014     -1.1823     0.1952  -6.057 1.39e-09 ***
Year2015     -1.2894     0.1915  -6.734 1.65e-11 ***
Year2016     -0.5700     0.1883  -3.027 0.002470 **
Year2017     -0.8913     0.1897  -4.698 2.63e-06 ***
Year2018     -1.4523     0.1974  -7.359 1.85e-13 ***
Year2019     -1.9092     0.2004  -9.527  < 2e-16 ***
Year2020     -2.0169     0.2190  -9.209  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                    edf Ref.df  Chi.sq  p-value
s(lon,lat)          66.104     79 594.892  < 2e-16 ***
s(lon,lat):Year1983  4.081      6  23.000 2.76e-06 ***
s(lon,lat):Year1984  4.248      6  20.120 3.06e-05 ***
s(lon,lat):Year1985  4.413      6  29.993 4.16e-08 ***
s(lon,lat):Year1986  4.329      6  35.726 5.43e-10 ***
s(lon,lat):Year1987  4.440      6  36.040 6.15e-10 ***
s(lon,lat):Year1988  4.199      6  25.703 4.58e-07 ***
s(lon,lat):Year1989  4.173      6  16.295 0.000274 ***
s(lon,lat):Year1990  4.093      6  24.663 9.32e-07 ***
s(lon,lat):Year1991  4.108      6  16.959 0.000218 ***
s(lon,lat):Year1992  4.179      6   7.484 0.073138 .
s(lon,lat):Year1993  4.094      6   9.159 0.023676 *
s(lon,lat):Year1994  4.093      6  13.551 0.001510 **
s(lon,lat):Year1995  3.998      6   1.564 0.852833
s(lon,lat):Year1996  4.018      6   4.667 0.259489
s(lon,lat):Year1997  4.117      6  10.785 0.008311 **
s(lon,lat):Year1998  4.307      6  12.684 0.002921 **
s(lon,lat):Year1999  4.094      6   8.357 0.034790 *
s(lon,lat):Year2000  4.133      6   4.132 0.342310
s(lon,lat):Year2001  4.174      6   8.376 0.036259 *
s(lon,lat):Year2002  3.999      6   9.103 0.019912 *
s(lon,lat):Year2003  4.145      6   2.819 0.587406
s(lon,lat):Year2004  4.072      6  18.130 5.74e-05 ***
s(lon,lat):Year2005  3.972      6  20.830 7.39e-06 ***
s(lon,lat):Year2006  3.981      6  13.681 0.001033 **
s(lon,lat):Year2007  3.854      6  11.805 0.003148 **
s(lon,lat):Year2008  4.103      6  13.519 0.001334 **
s(lon,lat):Year2009  4.063      6  12.523 0.002306 **
s(lon,lat):Year2010  4.180      6   7.852 0.047992 *
s(lon,lat):Year2011  4.031      6  13.820 0.002414 **
s(lon,lat):Year2012  4.015      6  12.410 0.003195 **
s(lon,lat):Year2013  4.053      6  11.267 0.006755 **
s(lon,lat):Year2014  3.767      6  14.443 0.000593 ***
s(lon,lat):Year2015  3.884      6  21.743 6.17e-06 ***
```

```
s(lon,lat):Year2016  3.906      6  18.116 8.51e-05 ***
s(lon,lat):Year2017  3.882      6  31.985 5.35e-09 ***
s(lon,lat):Year2018  3.790      6  20.592 1.27e-05 ***
s(lon,lat):Year2019  3.701      6  13.144 0.001585 **
s(lon,lat):Year2020  3.434      6  27.740 1.89e-07 ***
s(Depth)             4.846      5 326.818  < 2e-16 ***
s(TimeShotHour)      3.051      4  17.912 0.000303 ***
s(Ship)             13.098     27  59.198 8.06e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =   0.23   Deviance explained = 19.6%
-ML = 8550.3  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp5))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.82807    0.10161 -37.673  < 2e-16 ***
Year1984     0.13119    0.11541   1.137 0.255718
Year1985    -0.13400    0.12492  -1.073 0.283445
Year1986     0.34036    0.11606   2.933 0.003374 **
Year1987    -0.43805    0.12055  -3.634 0.000281 ***
Year1988    -0.04532    0.12193  -0.372 0.710106
Year1989    -0.78712    0.12038  -6.538 6.71e-11 ***
Year1990     0.23541    0.12306   1.913 0.055806 .
Year1991    -0.35539    0.12483  -2.847 0.004426 **
Year1992    -0.67273    0.13409  -5.017 5.40e-07 ***
Year1993    -0.37957    0.12661  -2.998 0.002730 **
Year1994    -0.31431    0.13519  -2.325 0.020109 *
Year1995    -0.52549    0.13292  -3.954 7.79e-05 ***
Year1996    -0.22481    0.12940  -1.737 0.082386 .
Year1997    -0.56124    0.13502  -4.157 3.27e-05 ***
Year1998    -0.13797    0.13103  -1.053 0.292397
Year1999    -0.31401    0.13360  -2.350 0.018788 *
Year2000    -0.77632    0.13473  -5.762 8.70e-09 ***
Year2001    -0.57585    0.13691  -4.206 2.64e-05 ***
Year2002    -1.00111    0.14925  -6.708 2.15e-11 ***
Year2003    -0.45765    0.13768  -3.324 0.000892 ***
Year2004    -0.31889    0.14342  -2.223 0.026222 *
Year2005    -1.27978    0.14835  -8.627  < 2e-16 ***
Year2006    -0.73528    0.15511  -4.740 2.18e-06 ***
Year2007    -1.00117    0.15869  -6.309 3.00e-10 ***
Year2008    -0.42112    0.14073  -2.992 0.002779 **
Year2009    -0.85406    0.14780  -5.779 7.90e-09 ***
Year2010    -0.32359    0.14163  -2.285 0.022358 *
Year2011    -0.64321    0.15530  -4.142 3.49e-05 ***
Year2012    -0.33111    0.14798  -2.237 0.025289 *
Year2013     0.09893    0.14145   0.699 0.484309
Year2014     0.25735    0.16124   1.596 0.110542
Year2015    -0.49353    0.15857  -3.112 0.001864 **
Year2016     0.07173    0.14547   0.493 0.621932
Year2017     0.48242    0.15461   3.120 0.001816 **
Year2018     0.02552    0.16745   0.152 0.878852
Year2019    -0.76634    0.17434  -4.396 1.12e-05 ***
Year2020    -1.14684    0.19934  -5.753 9.18e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                      edf Ref.df      F  p-value
s(lon,lat)          83.481    119  4.124  < 2e-16 ***
s(lon,lat):Year1983  5.529      8  0.672 0.367909
s(lon,lat):Year1984  5.712      8  2.779 3.63e-05 ***
s(lon,lat):Year1985  5.378      8  2.214 0.000374 ***
s(lon,lat):Year1986  5.728      8  3.911 6.79e-08 ***
s(lon,lat):Year1987  5.598      8  2.280 0.000298 ***
s(lon,lat):Year1988  5.583      8  3.844 7.10e-08 ***
s(lon,lat):Year1989  5.627      8  1.148 0.064140 .
```

```
s(lon,lat):Year1990  5.511      8  1.895 0.001909 **
s(lon,lat):Year1991  5.623      8  5.255 8.84e-11 ***
s(lon,lat):Year1992  5.222      8  1.634 0.006354 **
s(lon,lat):Year1993  5.509      8  2.168 0.000482 ***
s(lon,lat):Year1994  5.124      8  2.377 0.000112 ***
s(lon,lat):Year1995  5.268      8  2.161 0.000348 ***
s(lon,lat):Year1996  5.420      8  0.446 0.638663
s(lon,lat):Year1997  5.231      8  0.851 0.163097
s(lon,lat):Year1998  5.554      8  2.496 7.51e-05 ***
s(lon,lat):Year1999  5.367      8  1.418 0.014612 *
s(lon,lat):Year2000  5.336      8  3.465 2.49e-07 ***
s(lon,lat):Year2001  5.166      8  1.147 0.041232 *
s(lon,lat):Year2002  4.708      8  2.499 2.30e-05 ***
s(lon,lat):Year2003  5.140      8  1.137 0.044027 *
s(lon,lat):Year2004  4.999      8  0.825 0.161111
s(lon,lat):Year2005  4.892      8  2.470 3.64e-05 ***
s(lon,lat):Year2006  4.604      8  0.700 0.212494
s(lon,lat):Year2007  4.342      8  2.199 8.06e-05 ***
s(lon,lat):Year2008  5.105      8  1.244 0.028566 *
s(lon,lat):Year2009  4.779      8  1.685 0.002264 **
s(lon,lat):Year2010  4.979      8  1.231 0.026318 *
s(lon,lat):Year2011  4.729      8  7.087 8.85e-14 ***
s(lon,lat):Year2012  4.917      8  1.596 0.005243 **
s(lon,lat):Year2013  5.172      8  0.787 0.220426
s(lon,lat):Year2014  4.571      8  3.628 6.02e-08 ***
s(lon,lat):Year2015  4.702      8  3.679 7.24e-08 ***
s(lon,lat):Year2016  5.247      8  3.595 6.87e-07 ***
s(lon,lat):Year2017  4.841      8  4.801 2.77e-09 ***
s(lon,lat):Year2018  4.497      8  1.700 0.002222 **
s(lon,lat):Year2019  4.181      8  1.940 0.000401 ***
s(lon,lat):Year2020  3.865      8  1.074 0.041418 *
s(Depth)             4.618      5 16.101  < 2e-16 ***
s(TimeShotHour)      1.940      4  1.538 0.029914 *
s(Ship)             15.331     26  1.880 4.16e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.117   Deviance explained = 36.4%
-ML = 2698.6  Scale est. = 1.3832    n = 6511
Age  6 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.4859     0.1255 -27.787  < 2e-16 ***
Year1984     -0.5840     0.1541  -3.790 0.000151 ***
Year1985     -0.7053     0.1550  -4.549 5.38e-06 ***
Year1986     -0.4753     0.1567  -3.033 0.002419 **
Year1987     -0.5097     0.1530  -3.332 0.000864 ***
Year1988     -0.4767     0.1617  -2.949 0.003187 **
Year1989     -0.2517     0.1610  -1.563 0.118079
Year1990     -0.3988     0.1640  -2.431 0.015037 *
Year1991     -0.1856     0.1671  -1.111 0.266591
Year1992     -0.5624     0.1682  -3.344 0.000826 ***
Year1993     -0.8920     0.1741  -5.124 2.99e-07 ***
Year1994     -0.7027     0.1721  -4.083 4.45e-05 ***
Year1995     -0.6215     0.1764  -3.523 0.000426 ***
Year1996     -0.6748     0.1795  -3.760 0.000170 ***
Year1997     -0.5583     0.1739  -3.210 0.001329 **
Year1998     -0.4329     0.1696  -2.553 0.010673 *
Year1999     -0.7097     0.1807  -3.927 8.61e-05 ***
Year2000     -0.4976     0.1783  -2.792 0.005244 **
Year2001     -0.6915     0.1714  -4.033 5.50e-05 ***
Year2002     -1.2205     0.1836  -6.649 2.95e-11 ***
Year2003     -1.1037     0.1833  -6.022 1.72e-09 ***
Year2004     -0.8223     0.1842  -4.464 8.05e-06 ***
Year2005     -1.2098     0.1920  -6.302 2.93e-10 ***
Year2006     -1.2224     0.1906  -6.415 1.41e-10 ***
Year2007     -1.3993     0.1998  -7.004 2.48e-12 ***
```

```
Year2008     -1.0789     0.1850  -5.832 5.48e-09 ***
Year2009     -1.0505     0.1861  -5.645 1.65e-08 ***
Year2010     -0.8621     0.1784  -4.832 1.35e-06 ***
Year2011     -0.8968     0.1820  -4.927 8.34e-07 ***
Year2012     -0.8852     0.1836  -4.820 1.43e-06 ***
Year2013     -0.4702     0.1806  -2.604 0.009207 **
Year2014     -1.1684     0.2064  -5.662 1.49e-08 ***
Year2015     -1.0196     0.1926  -5.295 1.19e-07 ***
Year2016     -0.4133     0.1870  -2.210 0.027105 *
Year2017     -0.6662     0.1905  -3.498 0.000469 ***
Year2018     -0.9620     0.1983  -4.850 1.23e-06 ***
Year2019     -1.9147     0.2208  -8.670  < 2e-16 ***
Year2020     -2.0177     0.2467  -8.177 2.90e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                    edf Ref.df  Chi.sq  p-value
s(lon,lat)          66.540     79 637.647  < 2e-16 ***
s(lon,lat):Year1983  4.202      6  33.391 2.83e-09 ***
s(lon,lat):Year1984  4.312      6  32.161 1.10e-08 ***
s(lon,lat):Year1985  4.380      6  19.049 6.21e-05 ***
s(lon,lat):Year1986  4.307      6  27.225 1.94e-07 ***
s(lon,lat):Year1987  4.424      6  40.624 2.40e-11 ***
s(lon,lat):Year1988  4.199      6  30.432 1.74e-08 ***
s(lon,lat):Year1989  4.221      6  16.359 0.000283 ***
s(lon,lat):Year1990  4.168      6  19.957 2.59e-05 ***
s(lon,lat):Year1991  4.173      6  23.267 3.98e-06 ***
s(lon,lat):Year1992  4.165      6   7.884 0.057106 .
s(lon,lat):Year1993  3.988      6  10.107 0.011889 *
s(lon,lat):Year1994  4.014      6  22.659 3.05e-06 ***
s(lon,lat):Year1995  3.954      6   5.257 0.185062
s(lon,lat):Year1996  3.910      6   2.546 0.621674
s(lon,lat):Year1997  4.054      6   6.480 0.099661 .
s(lon,lat):Year1998  4.236      6  11.531 0.005506 **
s(lon,lat):Year1999  3.942      6   3.651 0.397374
s(lon,lat):Year2000  4.033      6   8.002 0.039914 *
s(lon,lat):Year2001  4.126      6  12.525 0.002578 **
s(lon,lat):Year2002  3.872      6   8.245 0.030341 *
s(lon,lat):Year2003  3.880      6   3.850 0.351321
s(lon,lat):Year2004  3.902      6  11.250 0.004668 **
s(lon,lat):Year2005  3.796      6  19.788 1.11e-05 ***
s(lon,lat):Year2006  3.796      6  17.241 6.90e-05 ***
s(lon,lat):Year2007  3.641      6   8.991 0.015434 *
s(lon,lat):Year2008  3.912      6   8.648 0.025136 *
s(lon,lat):Year2009  3.914      6   5.465 0.155845
s(lon,lat):Year2010  4.048      6   4.315 0.300881
s(lon,lat):Year2011  3.972      6  11.485 0.008432 **
s(lon,lat):Year2012  3.935      6  14.150 0.000951 ***
s(lon,lat):Year2013  3.993      6  11.863 0.004453 **
s(lon,lat):Year2014  3.520      6  15.157 0.000271 ***
s(lon,lat):Year2015  3.823      6  14.598 0.000653 ***
s(lon,lat):Year2016  3.897      6  17.723 0.000112 ***
s(lon,lat):Year2017  3.817      6  34.083 1.25e-09 ***
s(lon,lat):Year2018  3.740      6  24.307 9.12e-07 ***
s(lon,lat):Year2019  3.340      6   5.544 0.118233
s(lon,lat):Year2020  3.092      6  22.583 2.17e-06 ***
s(Depth)             4.838      5 299.576  < 2e-16 ***
s(TimeShotHour)      2.000      4   8.217 0.010097 *
s(Ship)             12.917     27  50.761 6.97e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.204   Deviance explained = 18.5%
-ML = 8077.2  Scale est. = 1         n = 14775

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp6))

Parametric coefficients:
```

```
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.48700    0.12197 -28.589  < 2e-16 ***
Year1984    -0.32883    0.14549  -2.260 0.023857 *
Year1985    -0.07242    0.14525  -0.499 0.618102
Year1986     0.04505    0.13793   0.327 0.743977
Year1987    -0.39029    0.14312  -2.727 0.006414 **
Year1988    -0.18316    0.14727  -1.244 0.213691
Year1989    -0.41251    0.14368  -2.871 0.004110 **
Year1990    -0.58938    0.14904  -3.955 7.78e-05 ***
Year1991    -0.14042    0.14721  -0.954 0.340223
Year1992    -0.73396    0.15750  -4.660 3.25e-06 ***
Year1993    -1.01984    0.16314  -6.251 4.43e-10 ***
Year1994    -0.71297    0.16652  -4.282 1.89e-05 ***
Year1995    -1.12044    0.16324  -6.864 7.60e-12 ***
Year1996    -1.08183    0.16397  -6.598 4.63e-11 ***
Year1997    -0.88045    0.16118  -5.462 4.94e-08 ***
Year1998    -0.75895    0.15728  -4.826 1.44e-06 ***
Year1999    -0.58624    0.17016  -3.445 0.000575 ***
Year2000    -0.64311    0.16245  -3.959 7.64e-05 ***
Year2001    -1.05530    0.16230  -6.502 8.74e-11 ***
Year2002    -0.91014    0.17755  -5.126 3.08e-07 ***
Year2003    -1.18605    0.17495  -6.779 1.36e-11 ***
Year2004    -1.07133    0.17260  -6.207 5.87e-10 ***
Year2005    -0.67143    0.18350  -3.659 0.000256 ***
Year2006    -0.43744    0.18841  -2.322 0.020287 *
Year2007    -0.82116    0.19212  -4.274 1.96e-05 ***
Year2008    -1.39205    0.17710  -7.860 4.73e-15 ***
Year2009    -0.84341    0.17663  -4.775 1.85e-06 ***
Year2010    -1.15780    0.16838  -6.876 6.96e-12 ***
Year2011    -0.77251    0.17923  -4.310 1.66e-05 ***
Year2012    -1.17321    0.17617  -6.659 3.07e-11 ***
Year2013    -0.99241    0.16911  -5.869 4.70e-09 ***
Year2014    -1.06287    0.19815  -5.364 8.54e-08 ***
Year2015    -0.62735    0.18599  -3.373 0.000749 ***
Year2016    -0.60181    0.17296  -3.479 0.000507 ***
Year2017    -0.14198    0.18244  -0.778 0.436482
Year2018    -0.35033    0.18853  -1.858 0.063194 .
Year2019    -0.58335    0.22079  -2.642 0.008266 **
Year2020    -1.18778    0.26395  -4.500 6.96e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)          82.438    119  4.575  < 2e-16 ***
s(lon,lat):Year1983  4.636      8  3.733 4.69e-08 ***
s(lon,lat):Year1984  4.605      8  3.612 9.83e-08 ***
s(lon,lat):Year1985  4.565      8  1.588 0.004244 **
s(lon,lat):Year1986  4.903      8  4.008 1.14e-08 ***
s(lon,lat):Year1987  4.769      8  2.243 0.000171 ***
s(lon,lat):Year1988  4.622      8  1.464 0.007267 **
s(lon,lat):Year1989  4.795      8  2.686 1.79e-05 ***
s(lon,lat):Year1990  4.532      8  0.778 0.169389
s(lon,lat):Year1991  4.836      8  1.046 0.074017 .
s(lon,lat):Year1992  4.466      8  1.526 0.006246 **
s(lon,lat):Year1993  4.102      8  0.664 0.210518
s(lon,lat):Year1994  4.072      8  1.087 0.029788 *
s(lon,lat):Year1995  4.182      8  1.609 0.001966 **
s(lon,lat):Year1996  4.165      8  1.671 0.001339 **
s(lon,lat):Year1997  4.342      8  0.391 0.601333
s(lon,lat):Year1998  4.643      8  1.211 0.024533 *
s(lon,lat):Year1999  3.956      8  0.831 0.086474 .
s(lon,lat):Year2000  4.437      8  1.006 0.052814 .
s(lon,lat):Year2001  4.393      8  0.393 0.597212
s(lon,lat):Year2002  3.836      8  1.987 0.000143 ***
s(lon,lat):Year2003  3.893      8  0.506 0.340643
s(lon,lat):Year2004  4.070      8  3.090 4.58e-07 ***
s(lon,lat):Year2005  3.891      8  1.052 0.027231 *
s(lon,lat):Year2006  3.714      8  0.148 0.937060
s(lon,lat):Year2007  3.447      8  1.778 0.000294 ***
s(lon,lat):Year2008  3.933      8  0.717 0.146412
s(lon,lat):Year2009  3.880      8  0.692 0.153591
s(lon,lat):Year2010  4.146      8  0.581 0.287677
s(lon,lat):Year2011  4.006      8  1.362 0.017145 *
s(lon,lat):Year2012  4.034      8  1.091 0.027463 *
s(lon,lat):Year2013  4.312      8  0.214 0.898502
s(lon,lat):Year2014  3.456      8  3.661 7.39e-09 ***
```

```
s(lon,lat):Year2015  3.929      8  1.673 0.001463 **
s(lon,lat):Year2016  4.454      8  1.755 0.002817 **
s(lon,lat):Year2017  4.131      8  6.720 9.15e-14 ***
s(lon,lat):Year2018  3.905      8  3.598 2.78e-08 ***
s(lon,lat):Year2019  3.019      8  0.626 0.117655
s(lon,lat):Year2020  2.711      8  1.570 0.001043 **
s(Depth)             4.636      5 14.781  < 2e-16 ***
s(TimeShotHour)      3.506      4  4.247 0.000968 ***
s(Ship)             15.666     26  1.735 2.76e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.101   Deviance explained =   34%
-ML =   2344  Scale est. = 1.5018    n = 4961
```

8.2 Q3

```
Age  0 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.8505     0.1819 -21.174  < 2e-16 ***
Year1993      0.1179     0.1891   0.623 0.533001
Year1994      1.7445     0.2008   8.688  < 2e-16 ***
Year1995     -0.9851     0.2286  -4.310 1.64e-05 ***
Year1996      1.0824     0.1926   5.620 1.91e-08 ***
Year1997     -1.6606     0.3588  -4.628 3.68e-06 ***
Year1998     -0.8194     0.2696  -3.040 0.002369 **
Year1999     -0.7000     0.2185  -3.204 0.001356 **
Year2000     -2.0441     0.3389  -6.032 1.62e-09 ***
Year2001     -1.5198     0.2681  -5.668 1.44e-08 ***
Year2002     -3.0081     0.3783  -7.952 1.83e-15 ***
Year2003     -1.9252     0.3051  -6.309 2.81e-10 ***
Year2004     -2.0065     0.3068  -6.539 6.19e-11 ***
Year2005     -0.4597     0.2344  -1.961 0.049862 *
Year2006     -0.6652     0.2310  -2.880 0.003972 **
Year2007     -0.8602     0.2448  -3.514 0.000442 ***
Year2008     -2.6976     0.3570  -7.557 4.12e-14 ***
Year2009     -1.7582     0.2882  -6.102 1.05e-09 ***
Year2010     -1.9069     0.2788  -6.839 7.97e-12 ***
Year2011     -2.6081     0.3747  -6.960 3.39e-12 ***
Year2012     -1.8340     0.2924  -6.271 3.58e-10 ***
Year2013     -2.3872     0.3068  -7.782 7.15e-15 ***
Year2014     -1.9359     0.2831  -6.839 7.97e-12 ***
Year2015     -3.5839     0.4296  -8.343  < 2e-16 ***
Year2016     -1.3478     0.2699  -4.993 5.95e-07 ***
Year2017     -3.3087     0.3907  -8.469  < 2e-16 ***
Year2018     -2.8612     0.3534  -8.097 5.63e-16 ***
Year2019     -1.3137     0.2584  -5.084 3.70e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                        edf Ref.df  Chi.sq  p-value
s(lon,lat)          58.2909     79 542.237  < 2e-16 ***
s(lon,lat):Year1992  4.7748      6  16.773 0.000171 ***
s(lon,lat):Year1993  4.7439      6  24.138 8.67e-07 ***
s(lon,lat):Year1994  4.6547      6  57.284  < 2e-16 ***
s(lon,lat):Year1995  4.3747      6  41.761 7.65e-13 ***
s(lon,lat):Year1996  4.7635      6  36.952 2.28e-10 ***
s(lon,lat):Year1997  3.2338      6  15.753 8.91e-05 ***
s(lon,lat):Year1998  3.8622      6  15.792 0.000127 ***
s(lon,lat):Year1999  4.5308      6  16.126 0.000236 ***
s(lon,lat):Year2000  3.0564      6   7.100 0.026027 *
s(lon,lat):Year2001  3.9401      6  10.687 0.005430 **
s(lon,lat):Year2002  2.9823      6   3.812 0.201033
```

```
s(lon,lat):Year2003  3.7058      6   9.075 0.011466 *
s(lon,lat):Year2004  3.7316      6  18.802 9.68e-06 ***
s(lon,lat):Year2005  4.4587      6  12.457 0.002944 **
s(lon,lat):Year2006  4.5228      6  19.242 1.97e-05 ***
s(lon,lat):Year2007  4.3715      6  23.335 8.20e-07 ***
s(lon,lat):Year2008  3.2586      6  15.423 4.73e-05 ***
s(lon,lat):Year2009  3.8067      6   2.509 0.567773
s(lon,lat):Year2010  3.8757      6   9.907 0.007107 **
s(lon,lat):Year2011  3.0998      6  11.585 0.001199 **
s(lon,lat):Year2012  3.8255      6   7.036 0.054284 .
s(lon,lat):Year2013  3.6385      6   8.681 0.015488 *
s(lon,lat):Year2014  3.9400      6  20.341 5.14e-06 ***
s(lon,lat):Year2015  2.6191      6   7.240 0.012205 *
s(lon,lat):Year2016  4.1773      6  44.179 1.22e-13 ***
s(lon,lat):Year2017  2.9078      6   9.585 0.002624 **
s(lon,lat):Year2018  3.3685      6  39.073 6.67e-13 ***
s(lon,lat):Year2019  4.2251      6  17.632 9.19e-05 ***
s(Depth)             4.7129      5 304.606  < 2e-16 ***
s(TimeShotHour)      0.3615      4   0.454 0.273332
s(Ship)             12.0985     16 104.866  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.499   Deviance explained = 46.2%
-ML = 3417.9  Scale est. = 1         n = 9986

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp0))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.92197    0.27814  -3.315 0.000931 ***
Year1993    -0.13042    0.18348  -0.711 0.477270
Year1994     0.54225    0.17178   3.157 0.001616 **
Year1995     0.15989    0.22104   0.723 0.469541
Year1996     0.81367    0.18477   4.404 1.11e-05 ***
Year1997    -2.82213    0.39798  -7.091 1.75e-12 ***
Year1998    -0.17317    0.27602  -0.627 0.530458
Year1999    -0.48763    0.24465  -1.993 0.046357 *
Year2000    -0.66054    0.65867  -1.003 0.316040
Year2001    -0.18895    0.29387  -0.643 0.520309
Year2002    -1.36291    0.45262  -3.011 0.002630 **
Year2003    -0.37956    0.37682  -1.007 0.313904
Year2004    -1.02498    0.38289  -2.677 0.007480 **
Year2005    -0.41322    0.25914  -1.595 0.110938
Year2006    -1.09620    0.26208  -4.183 2.98e-05 ***
Year2007    -0.96973    0.26760  -3.624 0.000296 ***
Year2008    -1.03224    0.59210  -1.743 0.081401 .
Year2009    -0.92471    0.33588  -2.753 0.005948 **
Year2010    -3.36665    0.34963  -9.629  < 2e-16 ***
Year2011    -0.84977    0.49810  -1.706 0.088132 .
Year2012    -1.61516    0.39055  -4.136 3.66e-05 ***
Year2013    -1.57128    0.42198  -3.724 0.000201 ***
Year2014    -1.80564    0.40600  -4.447 9.09e-06 ***
Year2015    -3.01852    0.63453  -4.757 2.08e-06 ***
Year2016     0.05576    0.38474   0.145 0.884789
Year2017    -1.14281    0.61838  -1.848 0.064716 .
Year2018    -1.24533    0.61854  -2.013 0.044190 *
Year2019     0.04546    0.37872   0.120 0.904455
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                        edf Ref.df     F  p-value
s(lon,lat)          96.05355    119 5.182  < 2e-16 ***
s(lon,lat):Year1992  6.61343      8 4.971 2.31e-10 ***
s(lon,lat):Year1993  6.60367      8 1.185 0.042616 *
s(lon,lat):Year1994  6.79200      8 5.957 7.11e-14 ***
s(lon,lat):Year1995  5.98986      8 1.991 0.000624 ***
s(lon,lat):Year1996  6.66212      8 2.396 0.000170 ***
```

```
s(lon,lat):Year1997  4.34297      8 2.829 1.01e-06 ***
s(lon,lat):Year1998  5.22546      8 6.144 6.32e-15 ***
s(lon,lat):Year1999  5.78782      8 1.606 0.005171 **
s(lon,lat):Year2000  2.94341      8 0.341 0.401954
s(lon,lat):Year2001  5.12063      8 2.869 2.77e-06 ***
s(lon,lat):Year2002  3.37179      8 0.363 0.414126
s(lon,lat):Year2003  4.44868      8 0.757 0.125339
s(lon,lat):Year2004  4.41547      8 0.951 0.041537 *
s(lon,lat):Year2005  5.71684      8 2.211 0.000338 ***
s(lon,lat):Year2006  5.82918      8 2.177 0.000249 ***
s(lon,lat):Year2007  5.63676      8 2.740 6.97e-06 ***
s(lon,lat):Year2008  3.37471      8 0.340 0.433901
s(lon,lat):Year2009  4.47463      8 0.271 0.776249
s(lon,lat):Year2010  4.53643      8 1.033 0.031515 *
s(lon,lat):Year2011  3.91171      8 4.416 7.67e-11 ***
s(lon,lat):Year2012  4.61242      8 1.107 0.029772 *
s(lon,lat):Year2013  4.24474      8 1.372 0.005444 **
s(lon,lat):Year2014  4.59902      8 1.198 0.016575 *
s(lon,lat):Year2015  2.45268      8 0.217 0.537392
s(lon,lat):Year2016  4.99302      8 2.186 0.000119 ***
s(lon,lat):Year2017  2.79627      8 0.343 0.333074
s(lon,lat):Year2018  3.16397      8 0.499 0.186107
s(lon,lat):Year2019  5.17564      8 0.870 0.143200
s(Depth)             4.46187      5 8.259 5.81e-10 ***
s(TimeShotHour)      0.00221      4 0.000 0.958389
s(Ship)             13.92235     16 5.646 2.91e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0467   Deviance explained = 56.8%
-ML = 9030.8  Scale est. = 3.2464    n = 2663
Age  1 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.85887    0.21636  -3.970 7.20e-05 ***
Year1993    -0.86482    0.21299  -4.060 4.90e-05 ***
Year1994     0.25321    0.24555   1.031  0.30246
Year1995    -0.06654    0.23147  -0.287  0.77377
Year1996    -1.05828    0.21949  -4.822 1.42e-06 ***
Year1997     1.33411    0.44941   2.969  0.00299 **
Year1998    -1.40875    0.25030  -5.628 1.82e-08 ***
Year1999    -2.14999    0.22890  -9.393  < 2e-16 ***
Year2000    -1.06004    0.25400  -4.173 3.00e-05 ***
Year2001    -2.10993    0.22915  -9.208  < 2e-16 ***
Year2002    -1.97258    0.22859  -8.629  < 2e-16 ***
Year2003    -3.14530    0.24239 -12.976  < 2e-16 ***
Year2004    -2.09756    0.24413  -8.592  < 2e-16 ***
Year2005    -2.42122    0.23865 -10.145  < 2e-16 ***
Year2006    -1.36416    0.24640  -5.536 3.09e-08 ***
Year2007    -2.00319    0.24220  -8.271  < 2e-16 ***
Year2008    -2.42564    0.23872 -10.161  < 2e-16 ***
Year2009    -2.72896    0.24870 -10.973  < 2e-16 ***
Year2010    -1.59100    0.24912  -6.386 1.70e-10 ***
Year2011    -2.12746    0.24600  -8.648  < 2e-16 ***
Year2012    -2.43639    0.24492  -9.948  < 2e-16 ***
Year2013    -2.43668    0.24645  -9.887  < 2e-16 ***
Year2014    -1.92536    0.24415  -7.886 3.12e-15 ***
Year2015    -2.86467    0.25751 -11.125  < 2e-16 ***
Year2016    -3.48530    0.25616 -13.606  < 2e-16 ***
Year2017    -1.59233    0.25273  -6.301 2.97e-10 ***
Year2018    -3.27184    0.25287 -12.939  < 2e-16 ***
Year2019    -2.82773    0.24625 -11.483  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                     edf Ref.df  Chi.sq  p-value
```

```
s(lon,lat)          67.146     79 872.772  < 2e-16 ***
s(lon,lat):Year1992  3.155      6   6.964 0.040190 *
s(lon,lat):Year1993  3.521      6   2.761 0.540328
s(lon,lat):Year1994  2.840      6  21.069 9.30e-07 ***
s(lon,lat):Year1995  3.082      6   5.377 0.107792
s(lon,lat):Year1996  3.480      6  29.094 6.68e-08 ***
s(lon,lat):Year1997  1.135      6   2.893 0.044299 *
s(lon,lat):Year1998  3.004      6   7.223 0.021679 *
s(lon,lat):Year1999  3.502      6  34.417 7.08e-11 ***
s(lon,lat):Year2000  2.920      6   9.779 0.003697 **
s(lon,lat):Year2001  3.483      6   5.699 0.105305
s(lon,lat):Year2002  3.486      6  20.596 2.93e-06 ***
s(lon,lat):Year2003  3.360      6  11.178 0.002565 **
s(lon,lat):Year2004  3.358      6   4.353 0.215181
s(lon,lat):Year2005  3.469      6   6.892 0.051653 .
s(lon,lat):Year2006  3.257      6   2.951 0.420468
s(lon,lat):Year2007  3.384      6   4.775 0.163541
s(lon,lat):Year2008  3.457      6  12.236 0.001160 **
s(lon,lat):Year2009  3.232      6   3.288 0.346698
s(lon,lat):Year2010  3.229      6  13.396 0.000311 ***
s(lon,lat):Year2011  3.356      6   5.479 0.105381
s(lon,lat):Year2012  3.388      6   8.595 0.013928 *
s(lon,lat):Year2013  3.374      6   9.119 0.010063 *
s(lon,lat):Year2014  3.399      6  11.612 0.001839 **
s(lon,lat):Year2015  3.224      6  20.079 2.75e-06 ***
s(lon,lat):Year2016  3.294      6  15.802 9.95e-05 ***
s(lon,lat):Year2017  3.212      6   9.933 0.005107 **
s(lon,lat):Year2018  3.351      6  34.303 1.95e-10 ***
s(lon,lat):Year2019  3.442      6  33.354 7.23e-10 ***
s(Depth)             4.836      5 384.844  < 2e-16 ***
s(TimeShotHour)      1.486      4   4.795 0.036376 *
s(Ship)             13.427     16 117.391  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.417   Deviance explained = 36.7%
-ML = 4505.2  Scale est. = 1         n = 9986

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp1))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.26757    0.09873  -2.710 0.006744 **
Year1993    -1.49901    0.10414 -14.394  < 2e-16 ***
Year1994     0.04426    0.10096   0.438 0.661139
Year1995    -0.37881    0.10039  -3.773 0.000163 ***
Year1996    -1.24933    0.11048 -11.308  < 2e-16 ***
Year1997     0.46770    0.14649   3.193 0.001417 **
Year1998    -2.55919    0.13063 -19.590  < 2e-16 ***
Year1999    -1.25667    0.13222  -9.504  < 2e-16 ***
Year2000    -0.96378    0.21253  -4.535 5.88e-06 ***
Year2001    -2.26940    0.12967 -17.502  < 2e-16 ***
Year2002    -1.28696    0.12826 -10.034  < 2e-16 ***
Year2003    -2.47795    0.16071 -15.419  < 2e-16 ***
Year2004    -1.44071    0.14220 -10.132  < 2e-16 ***
Year2005    -2.37191    0.14413 -16.457  < 2e-16 ***
Year2006    -1.17376    0.13082  -8.972  < 2e-16 ***
Year2007    -2.03370    0.14111 -14.412  < 2e-16 ***
Year2008    -1.80515    0.14479 -12.467  < 2e-16 ***
Year2009    -1.69427    0.15988 -10.597  < 2e-16 ***
Year2010    -1.83644    0.13673 -13.431  < 2e-16 ***
Year2011    -2.38620    0.14561 -16.388  < 2e-16 ***
Year2012    -1.82139    0.15183 -11.996  < 2e-16 ***
Year2013    -1.80179    0.14951 -12.051  < 2e-16 ***
Year2014    -1.60197    0.14254 -11.238  < 2e-16 ***
Year2015    -2.28321    0.18209 -12.539  < 2e-16 ***
Year2016    -2.21524    0.17615 -12.576  < 2e-16 ***
Year2017    -1.00773    0.14447  -6.975 3.40e-12 ***
Year2018    -2.76439    0.17024 -16.238  < 2e-16 ***
```

```
Year2019    -2.05198    0.15815 -12.975  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)          101.270    119  8.333  < 2e-16 ***
s(lon,lat):Year1992   6.688      8  5.648 2.87e-12 ***
s(lon,lat):Year1993   6.492      8  2.140 0.000462 ***
s(lon,lat):Year1994   6.614      8  4.898 1.15e-10 ***
s(lon,lat):Year1995   6.597      8  6.915 1.29e-15 ***
s(lon,lat):Year1996   6.379      8  1.828 0.002626 **
s(lon,lat):Year1997   5.634      8  1.370 0.015358 *
s(lon,lat):Year1998   5.803      8  5.965 4.09e-14 ***
s(lon,lat):Year1999   5.873      8  1.955 0.000902 ***
s(lon,lat):Year2000   5.122      8  0.908 0.088147 .
s(lon,lat):Year2001   5.879      8  2.199 0.000252 ***
s(lon,lat):Year2002   5.881      8  4.662 1.63e-10 ***
s(lon,lat):Year2003   5.154      8  0.883 0.111169
s(lon,lat):Year2004   5.730      8  2.452 4.89e-05 ***
s(lon,lat):Year2005   5.683      8  1.095 0.058124 .
s(lon,lat):Year2006   6.062      8  3.141 1.42e-06 ***
s(lon,lat):Year2007   5.824      8  3.416 2.16e-07 ***
s(lon,lat):Year2008   5.583      8  1.828 0.001362 **
s(lon,lat):Year2009   5.201      8  1.404 0.008300 **
s(lon,lat):Year2010   5.916      8  4.565 2.53e-10 ***
s(lon,lat):Year2011   5.788      8  1.145 0.048814 *
s(lon,lat):Year2012   5.551      8  0.719 0.260291
s(lon,lat):Year2013   5.654      8  1.880 0.001177 **
s(lon,lat):Year2014   5.865      8  1.280 0.027048 *
s(lon,lat):Year2015   5.157      8  2.562 1.21e-05 ***
s(lon,lat):Year2016   5.022      8  0.886 0.105671
s(lon,lat):Year2017   5.948      8  2.289 0.000275 ***
s(lon,lat):Year2018   5.295      8  2.310 0.000102 ***
s(lon,lat):Year2019   5.494      8  3.590 1.15e-07 ***
s(Depth)              4.810      5 47.121  < 2e-16 ***
s(TimeShotHour)       3.465      4  8.582 6.03e-07 ***
s(Ship)              11.723     16  5.082 1.38e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.251   Deviance explained = 58.1%
-ML =  17493  Scale est. = 1.9133    n = 6057
Age  2 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.8526631  0.1639107 -11.303  < 2e-16 ***
Year1993     0.0705665  0.1875067   0.376 0.706663
Year1994     0.7554186  0.2026349   3.728 0.000193 ***
Year1995     0.5688629  0.1977235   2.877 0.004014 **
Year1996    -0.4411003  0.1848215  -2.387 0.017004 *
Year1997     1.0699089  0.3316435   3.226 0.001255 **
Year1998    -0.0007413  0.2254698  -0.003 0.997377
Year1999    -1.0358751  0.1970715  -5.256 1.47e-07 ***
Year2000    -1.1330420  0.2249587  -5.037 4.74e-07 ***
Year2001    -0.9360746  0.2024271  -4.624 3.76e-06 ***
Year2002    -0.9490333  0.1982158  -4.788 1.69e-06 ***
Year2003    -1.5569553  0.2067769  -7.530 5.09e-14 ***
Year2004    -1.3769334  0.2110689  -6.524 6.86e-11 ***
Year2005    -1.3190983  0.2092768  -6.303 2.92e-10 ***
Year2006    -1.0691418  0.2152109  -4.968 6.77e-07 ***
Year2007    -1.0008550  0.2194528  -4.561 5.10e-06 ***
Year2008    -1.0375432  0.2101032  -4.938 7.88e-07 ***
Year2009    -1.8861719  0.2215150  -8.515  < 2e-16 ***
Year2010    -0.4814600  0.2203129  -2.185 0.028863 *
Year2011    -0.9252189  0.2219539  -4.169 3.07e-05 ***
Year2012    -1.1491569  0.2144576  -5.358 8.39e-08 ***
```

```
Year2013    -1.6756754  0.2209110  -7.585 3.32e-14 ***
Year2014    -0.7508810  0.2221845  -3.380 0.000726 ***
Year2015    -0.9377593  0.2185317  -4.291 1.78e-05 ***
Year2016    -1.7329315  0.2200522  -7.875 3.40e-15 ***
Year2017    -1.4444798  0.2198847  -6.569 5.06e-11 ***
Year2018    -1.5183664  0.2198328  -6.907 4.95e-12 ***
Year2019    -2.1021251  0.2250364  -9.341  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                     edf Ref.df  Chi.sq  p-value
s(lon,lat)          68.864     79 973.386  < 2e-16 ***
s(lon,lat):Year1992  3.508      6  30.703 3.20e-09 ***
s(lon,lat):Year1993  3.386      6   4.468 0.220635
s(lon,lat):Year1994  3.056      6   9.105 0.007931 **
s(lon,lat):Year1995  3.139      6   3.474 0.323264
s(lon,lat):Year1996  3.450      6  29.876 1.38e-08 ***
s(lon,lat):Year1997  1.751      6   2.514 0.201503
s(lon,lat):Year1998  2.825      6  15.653 2.38e-05 ***
s(lon,lat):Year1999  3.385      6  15.244 0.000131 ***
s(lon,lat):Year2000  2.745      6   3.162 0.287671
s(lon,lat):Year2001  3.229      6   4.541 0.174579
s(lon,lat):Year2002  3.313      6  14.086 0.000284 ***
s(lon,lat):Year2003  3.293      6  13.208 0.000551 ***
s(lon,lat):Year2004  3.222      6   4.431 0.186355
s(lon,lat):Year2005  3.245      6   5.177 0.122903
s(lon,lat):Year2006  3.076      6   8.431 0.010235 *
s(lon,lat):Year2007  3.024      6   7.476 0.019666 *
s(lon,lat):Year2008  3.220      6   4.260 0.199137
s(lon,lat):Year2009  2.995      6  16.502 1.90e-05 ***
s(lon,lat):Year2010  3.026      6   4.061 0.196706
s(lon,lat):Year2011  3.019      6   7.302 0.023576 *
s(lon,lat):Year2012  3.211      6   5.244 0.112605
s(lon,lat):Year2013  3.071      6   8.261 0.013261 *
s(lon,lat):Year2014  3.012      6   6.514 0.039846 *
s(lon,lat):Year2015  3.126      6   8.698 0.009751 **
s(lon,lat):Year2016  3.152      6  11.803 0.001291 **
s(lon,lat):Year2017  3.128      6   7.420 0.027754 *
s(lon,lat):Year2018  3.130      6  23.619 1.85e-07 ***
s(lon,lat):Year2019  3.081      6  22.266 6.86e-07 ***
s(Depth)             4.835      5 345.067  < 2e-16 ***
s(TimeShotHour)      2.188      4  14.355 0.000507 ***
s(Ship)             12.050     16  76.193 2.23e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.412   Deviance explained = 36.5%
-ML = 4554.5  Scale est. = 1         n = 9986

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp2))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.40832    0.11723 -20.543  < 2e-16 ***
Year1993     0.71986    0.11910   6.044 1.60e-09 ***
Year1994     0.20901    0.11595   1.803 0.071512 .
Year1995     1.14133    0.11611   9.830  < 2e-16 ***
Year1996     0.42008    0.12727   3.301 0.000970 ***
Year1997     0.44224    0.17088   2.588 0.009676 **
Year1998     1.65305    0.14364  11.508  < 2e-16 ***
Year1999    -0.98707    0.14332  -6.887 6.31e-12 ***
Year2000    -0.26355    0.21848  -1.206 0.227761
Year2001     0.15963    0.14322   1.115 0.265089
Year2002    -0.53646    0.14261  -3.762 0.000171 ***
Year2003    -0.12558    0.16210  -0.775 0.438575
Year2004    -0.74383    0.16027  -4.641 3.54e-06 ***
Year2005    -0.52518    0.15922  -3.299 0.000978 ***
Year2006    -0.77287    0.15601  -4.954 7.48e-07 ***
```

```
Year2007     0.38779    0.15935   2.434 0.014984 *
Year2008    -0.49012    0.15496  -3.163 0.001571 **
Year2009    -0.39483    0.18247  -2.164 0.030522 *
Year2010    -0.27677    0.14958  -1.850 0.064318 .
Year2011     0.42256    0.15939   2.651 0.008043 **
Year2012    -0.41509    0.16225  -2.558 0.010544 *
Year2013    -0.41139    0.16917  -2.432 0.015056 *
Year2014    -0.26907    0.15727  -1.711 0.087152 .
Year2015     0.41564    0.16249   2.558 0.010557 *
Year2016    -0.48160    0.17326  -2.780 0.005460 **
Year2017    -1.19567    0.16964  -7.048 2.03e-12 ***
Year2018    -0.05448    0.16876  -0.323 0.746863
Year2019    -1.36360    0.18092  -7.537 5.56e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                      edf Ref.df      F  p-value
s(lon,lat)          102.939    119 10.320  < 2e-16 ***
s(lon,lat):Year1992   6.034      8  2.672 3.59e-05 ***
s(lon,lat):Year1993   5.887      8  2.773 1.38e-05 ***
s(lon,lat):Year1994   6.032      8  3.708 8.77e-08 ***
s(lon,lat):Year1995   5.998      8  1.798 0.002815 **
s(lon,lat):Year1996   5.669      8  2.605 4.35e-05 ***
s(lon,lat):Year1997   4.753      8  2.246 8.74e-05 ***
s(lon,lat):Year1998   5.207      8  0.821 0.152791
s(lon,lat):Year1999   5.304      8  1.948 0.000632 ***
s(lon,lat):Year2000   4.130      8  0.650 0.192199
s(lon,lat):Year2001   5.243      8  2.117 0.000242 ***
s(lon,lat):Year2002   5.259      8  1.658 0.003033 **
s(lon,lat):Year2003   4.886      8  2.604 9.71e-06 ***
s(lon,lat):Year2004   4.940      8  0.468 0.517563
s(lon,lat):Year2005   5.035      8  1.491 0.006292 **
s(lon,lat):Year2006   5.088      8  2.315 5.36e-05 ***
s(lon,lat):Year2007   5.020      8  1.350 0.010820 *
s(lon,lat):Year2008   5.088      8  2.463 2.51e-05 ***
s(lon,lat):Year2009   4.367      8  1.710 0.000859 ***
s(lon,lat):Year2010   5.298      8  1.903 0.000728 ***
s(lon,lat):Year2011   5.128      8  2.111 0.000242 ***
s(lon,lat):Year2012   5.057      8  1.101 0.045299 *
s(lon,lat):Year2013   4.858      8  2.106 0.000185 ***
s(lon,lat):Year2014   5.251      8  3.157 7.72e-07 ***
s(lon,lat):Year2015   5.119      8  1.515 0.005674 **
s(lon,lat):Year2016   4.851      8  0.969 0.071583 .
s(lon,lat):Year2017   4.995      8  1.969 0.000726 ***
s(lon,lat):Year2018   5.003      8  3.375 2.33e-07 ***
s(lon,lat):Year2019   4.632      8  1.745 0.001477 **
s(Depth)              4.857      5 56.659  < 2e-16 ***
s(TimeShotHour)       1.348      4  0.624 0.155700
s(Ship)              12.244     16  5.252 9.13e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.153   Deviance explained = 43.4%
-ML =  11630  Scale est. = 2.2557    n = 5996
Age  3 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -3.13186    0.12991 -24.108  < 2e-16 ***
Year1993     0.03185    0.16249   0.196 0.844607
Year1994     0.54668    0.16457   3.322 0.000894 ***
Year1995     0.31102    0.16149   1.926 0.054103 .
Year1996    -0.01093    0.16459  -0.066 0.947041
Year1997     0.21546    0.24115   0.893 0.371614
Year1998     0.84582    0.20651   4.096 4.21e-05 ***
Year1999    -0.21718    0.17750  -1.224 0.221119
Year2000    -1.23213    0.23974  -5.139 2.76e-07 ***
```

```
Year2001    -0.46868    0.19554  -2.397 0.016537 *
Year2002    -0.48315    0.18747  -2.577 0.009962 **
Year2003    -0.76930    0.19489  -3.947 7.90e-05 ***
Year2004    -0.80188    0.19583  -4.095 4.23e-05 ***
Year2005    -0.70829    0.19729  -3.590 0.000331 ***
Year2006    -0.98015    0.20242  -4.842 1.28e-06 ***
Year2007    -0.51929    0.21116  -2.459 0.013923 *
Year2008    -0.70776    0.20407  -3.468 0.000524 ***
Year2009    -1.36927    0.21407  -6.396 1.59e-10 ***
Year2010    -0.55151    0.20107  -2.743 0.006090 **
Year2011    -0.74524    0.21115  -3.529 0.000416 ***
Year2012    -0.41365    0.20059  -2.062 0.039193 *
Year2013    -0.98010    0.21202  -4.623 3.79e-06 ***
Year2014    -0.89741    0.22388  -4.009 6.11e-05 ***
Year2015    -0.32340    0.20688  -1.563 0.117999
Year2016    -0.69523    0.21193  -3.280 0.001037 **
Year2017    -1.90943    0.24218  -7.884 3.16e-15 ***
Year2018    -0.80553    0.21249  -3.791 0.000150 ***
Year2019    -1.94887    0.24547  -7.939 2.03e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df   Chi.sq  p-value
s(lon,lat)          67.817     79 1027.703  < 2e-16 ***
s(lon,lat):Year1992  4.388      6   48.549 1.93e-14 ***
s(lon,lat):Year1993  4.223      6   18.472 3.86e-05 ***
s(lon,lat):Year1994  4.182      6   20.774 7.17e-06 ***
s(lon,lat):Year1995  4.236      6   14.833 0.000484 ***
s(lon,lat):Year1996  4.199      6   29.612 1.51e-08 ***
s(lon,lat):Year1997  3.140      6    7.448 0.026030 *
s(lon,lat):Year1998  3.590      6   17.315 2.40e-05 ***
s(lon,lat):Year1999  4.103      6   25.683 1.31e-07 ***
s(lon,lat):Year2000  3.156      6    2.453 0.500686
s(lon,lat):Year2001  3.733      6    8.634 0.016888 *
s(lon,lat):Year2002  3.872      6    4.660 0.216378
s(lon,lat):Year2003  3.870      6   12.276 0.001682 **
s(lon,lat):Year2004  3.873      6   12.448 0.001459 **
s(lon,lat):Year2005  3.845      6    6.222 0.088472 .
s(lon,lat):Year2006  3.722      6   12.044 0.001507 **
s(lon,lat):Year2007  3.573      6    9.757 0.006365 **
s(lon,lat):Year2008  3.687      6    7.323 0.037994 *
s(lon,lat):Year2009  3.540      6   12.491 0.000903 ***
s(lon,lat):Year2010  3.776      6    7.401 0.039458 *
s(lon,lat):Year2011  3.637      6    9.211 0.011511 *
s(lon,lat):Year2012  3.837      6    5.544 0.136337
s(lon,lat):Year2013  3.642      6    5.343 0.134646
s(lon,lat):Year2014  3.449      6   19.382 5.24e-06 ***
s(lon,lat):Year2015  3.729      6   11.662 0.002338 **
s(lon,lat):Year2016  3.676      6   12.194 0.001548 **
s(lon,lat):Year2017  3.360      6   20.246 3.66e-06 ***
s(lon,lat):Year2018  3.630      6   17.377 3.67e-05 ***
s(lon,lat):Year2019  3.299      6   22.404 6.14e-07 ***
s(Depth)             4.854      5  402.611  < 2e-16 ***
s(TimeShotHour)      2.391      4   14.046 0.000853 ***
s(Ship)              9.330     16   41.545 3.77e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =   0.44   Deviance explained = 38.9%
-ML =   4540  Scale est. = 1         n = 9986

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp3))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -3.2141     0.1188 -27.057  < 2e-16 ***
Year1993     -0.2103     0.1282  -1.640 0.101048
Year1994      0.3804     0.1228   3.097 0.001965 **
```

```
Year1995      0.2105     0.1243   1.694 0.090383 .
Year1996      0.2397     0.1311   1.828 0.067687 .
Year1997      0.1275     0.1884   0.677 0.498601
Year1998     -0.1009     0.1459  -0.692 0.489159
Year1999      0.9532     0.1454   6.557 6.12e-11 ***
Year2000     -1.3984     0.2214  -6.316 2.95e-10 ***
Year2001     -0.5697     0.1487  -3.833 0.000129 ***
Year2002      0.2216     0.1474   1.504 0.132681
Year2003     -0.8633     0.1622  -5.323 1.07e-07 ***
Year2004     -0.1513     0.1616  -0.936 0.349158
Year2005     -0.8731     0.1619  -5.393 7.31e-08 ***
Year2006     -0.1509     0.1659  -0.910 0.363096
Year2007     -0.4871     0.1597  -3.050 0.002304 **
Year2008      0.4314     0.1646   2.621 0.008805 **
Year2009     -0.5263     0.1905  -2.763 0.005758 **
Year2010     -0.2755     0.1601  -1.720 0.085494 .
Year2011      0.2396     0.1664   1.440 0.150075
Year2012      0.6458     0.1622   3.982 6.94e-05 ***
Year2013     -0.1878     0.1692  -1.110 0.267128
Year2014     -0.0167     0.1719  -0.097 0.922593
Year2015      0.3880     0.1621   2.393 0.016765 *
Year2016      0.7966     0.1660   4.799 1.65e-06 ***
Year2017     -0.4466     0.1997  -2.236 0.025409 *
Year2018     -0.5389     0.1699  -3.173 0.001521 **
Year2019     -0.1153     0.2142  -0.538 0.590303
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)          91.7022    119  6.639  < 2e-16 ***
s(lon,lat):Year1992  5.7171      8  1.661 0.004620 **
s(lon,lat):Year1993  5.5656      8  1.464 0.010266 *
s(lon,lat):Year1994  5.8153      8  2.308 0.000157 ***
s(lon,lat):Year1995  5.7296      8  1.481 0.010600 *
s(lon,lat):Year1996  5.4631      8  4.172 4.83e-09 ***
s(lon,lat):Year1997  4.2282      8  2.158 7.10e-05 ***
s(lon,lat):Year1998  5.1576      8  1.106 0.039461 *
s(lon,lat):Year1999  5.2901      8  4.877 1.92e-11 ***
s(lon,lat):Year2000  3.8056      8  0.652 0.159811
s(lon,lat):Year2001  5.0389      8  1.922 0.000572 ***
s(lon,lat):Year2002  5.0871      8  1.103 0.042550 *
s(lon,lat):Year2003  4.8131      8  0.580 0.346862
s(lon,lat):Year2004  4.8316      8  2.039 0.000221 ***
s(lon,lat):Year2005  4.8600      8  1.566 0.003622 **
s(lon,lat):Year2006  4.7497      8  3.195 1.60e-07 ***
s(lon,lat):Year2007  4.9447      8  2.768 3.19e-06 ***
s(lon,lat):Year2008  4.8504      8  1.113 0.034676 *
s(lon,lat):Year2009  4.1095      8  0.637 0.201695
s(lon,lat):Year2010  4.9907      8  1.109 0.039553 *
s(lon,lat):Year2011  4.9109      8  4.105 1.64e-09 ***
s(lon,lat):Year2012  5.0681      8  0.763 0.202543
s(lon,lat):Year2013  4.7801      8  0.992 0.063812 .
s(lon,lat):Year2014  4.8076      8  1.870 0.000691 ***
s(lon,lat):Year2015  5.1302      8  2.139 0.000214 ***
s(lon,lat):Year2016  5.0202      8  2.247 0.000111 ***
s(lon,lat):Year2017  4.3038      8  1.933 0.000347 ***
s(lon,lat):Year2018  4.9041      8  0.322 0.773781
s(lon,lat):Year2019  3.8648      8  1.105 0.019408 *
s(Depth)             4.7315      5 26.249  < 2e-16 ***
s(TimeShotHour)      0.9684      4  0.358 0.223733
s(Ship)             11.5676     16  3.251 5.40e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.146   Deviance explained = 44.5%
-ML = 5529.1  Scale est. = 1.7745    n = 4565
Age  4 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))
```

```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -3.87394    0.11923 -32.491  < 2e-16 ***
Year1993    -0.60729    0.17143  -3.542 0.000396 ***
Year1994    -0.46429    0.16580  -2.800 0.005105 **
Year1995    -0.17983    0.16329  -1.101 0.270758
Year1996    -0.07487    0.16274  -0.460 0.645470
Year1997    -0.57106    0.25263  -2.260 0.023796 *
Year1998    -0.46267    0.20313  -2.278 0.022742 *
Year1999    -0.12696    0.17727  -0.716 0.473884
Year2000    -0.63946    0.23278  -2.747 0.006014 **
Year2001    -1.38377    0.21578  -6.413 1.43e-10 ***
Year2002    -0.45716    0.19588  -2.334 0.019604 *
Year2003    -1.01408    0.20589  -4.925 8.42e-07 ***
Year2004    -1.88859    0.25850  -7.306 2.76e-13 ***
Year2005    -0.65659    0.20108  -3.265 0.001093 **
Year2006    -1.49156    0.23701  -6.293 3.11e-10 ***
Year2007    -0.52220    0.20940  -2.494 0.012639 *
Year2008    -0.84864    0.21440  -3.958 7.55e-05 ***
Year2009    -1.42654    0.23172  -6.156 7.44e-10 ***
Year2010    -0.33771    0.19876  -1.699 0.089303 .
Year2011    -1.02257    0.21687  -4.715 2.41e-06 ***
Year2012    -0.53268    0.20854  -2.554 0.010639 *
Year2013    -0.68653    0.21574  -3.182 0.001462 **
Year2014    -0.87366    0.22835  -3.826 0.000130 ***
Year2015    -0.79586    0.22715  -3.504 0.000459 ***
Year2016    -0.30904    0.20940  -1.476 0.139992
Year2017    -1.59047    0.25210  -6.309 2.81e-10 ***
Year2018    -1.41026    0.22774  -6.192 5.93e-10 ***
Year2019    -2.25228    0.28770  -7.829 4.94e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df   Chi.sq  p-value
s(lon,lat)          66.340     79 1056.496  < 2e-16 ***
s(lon,lat):Year1992  4.266      6   41.671 8.21e-13 ***
s(lon,lat):Year1993  3.932      6    5.405 0.141446
s(lon,lat):Year1994  4.007      6   25.746 7.80e-08 ***
s(lon,lat):Year1995  4.093      6   18.186 2.71e-05 ***
s(lon,lat):Year1996  4.102      6   33.291 3.40e-10 ***
s(lon,lat):Year1997  2.869      6    9.377 0.003984 **
s(lon,lat):Year1998  3.454      6   10.845 0.002439 **
s(lon,lat):Year1999  3.935      6   19.326 9.22e-06 ***
s(lon,lat):Year2000  3.080      6    8.162 0.012599 *
s(lon,lat):Year2001  3.387      6    4.056 0.228390
s(lon,lat):Year2002  3.601      6    5.966 0.083272 .
s(lon,lat):Year2003  3.518      6    4.153 0.234736
s(lon,lat):Year2004  3.044      6   13.326 0.000182 ***
s(lon,lat):Year2005  3.613      6   12.696 0.000799 ***
s(lon,lat):Year2006  3.206      6   16.315 2.14e-05 ***
s(lon,lat):Year2007  3.464      6    6.129 0.066775 .
s(lon,lat):Year2008  3.413      6    3.974 0.246386
s(lon,lat):Year2009  3.152      6    6.975 0.029836 *
s(lon,lat):Year2010  3.637      6    7.112 0.042292 *
s(lon,lat):Year2011  3.435      6    5.393 0.111159
s(lon,lat):Year2012  3.553      6    5.575 0.107641
s(lon,lat):Year2013  3.422      6    7.158 0.034785 *
s(lon,lat):Year2014  3.281      6    9.010 0.008232 **
s(lon,lat):Year2015  3.368      6   19.806 2.59e-06 ***
s(lon,lat):Year2016  3.547      6    8.333 0.017447 *
s(lon,lat):Year2017  3.120      6   21.774 4.50e-07 ***
s(lon,lat):Year2018  3.361      6    6.597 0.048911 *
s(lon,lat):Year2019  2.797      6   19.190 1.66e-06 ***
s(Depth)             4.842      5  333.597  < 2e-16 ***
s(TimeShotHour)      1.547      4    3.831 0.073820 .
s(Ship)              5.764     16   13.934 0.003611 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.433   Deviance explained = 39.2%
-ML = 4125.7  Scale est. = 1         n = 9986

Family: Gamma
Link function: log
```

```
Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp4))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.85902    0.11494 -33.574  < 2e-16 ***
Year1993    -0.15881    0.14534  -1.093 0.274624
Year1994    -0.21414    0.14022  -1.527 0.126824
Year1995     0.19596    0.13686   1.432 0.152306
Year1996    -0.15787    0.14039  -1.124 0.260903
Year1997     0.02681    0.22087   0.121 0.903405
Year1998    -0.32570    0.16992  -1.917 0.055365 .
Year1999    -0.53769    0.14940  -3.599 0.000325 ***
Year2000     0.33395    0.22147   1.508 0.131689
Year2001    -0.87268    0.17281  -5.050 4.69e-07 ***
Year2002    -0.20277    0.15258  -1.329 0.183977
Year2003    -0.31923    0.17133  -1.863 0.062518 .
Year2004    -0.89025    0.20598  -4.322 1.60e-05 ***
Year2005    -0.68345    0.16572  -4.124 3.82e-05 ***
Year2006    -0.85077    0.19069  -4.462 8.44e-06 ***
Year2007    -0.48464    0.15959  -3.037 0.002412 **
Year2008    -0.18440    0.16993  -1.085 0.277940
Year2009     0.21096    0.20345   1.037 0.299857
Year2010    -0.43251    0.16195  -2.671 0.007613 **
Year2011     0.36160    0.17542   2.061 0.039358 *
Year2012     0.38236    0.16507   2.316 0.020608 *
Year2013     0.39348    0.16653   2.363 0.018200 *
Year2014     0.12134    0.17091   0.710 0.477778
Year2015     0.65500    0.17611   3.719 0.000204 ***
Year2016     0.83033    0.15940   5.209 2.03e-07 ***
Year2017     0.57710    0.19563   2.950 0.003203 **
Year2018    -0.19686    0.18402  -1.070 0.284810
Year2019    -0.51024    0.23764  -2.147 0.031866 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df      F  p-value
s(lon,lat)          80.0540    119  3.260  < 2e-16 ***
s(lon,lat):Year1992  5.5780      8  3.126 1.12e-06 ***
s(lon,lat):Year1993  5.0799      8  1.671 0.002005 **
s(lon,lat):Year1994  5.3116      8  0.624 0.328717
s(lon,lat):Year1995  5.4255      8  1.970 0.000569 ***
s(lon,lat):Year1996  5.3743      8  1.819 0.001361 **
s(lon,lat):Year1997  3.7325      8  0.099 0.982486
s(lon,lat):Year1998  4.5889      8  1.666 0.001178 **
s(lon,lat):Year1999  5.3364      8  1.008 0.072042 .
s(lon,lat):Year2000  4.1152      8  2.929 4.39e-07 ***
s(lon,lat):Year2001  4.5541      8  0.730 0.167709
s(lon,lat):Year2002  5.0649      8  1.265 0.018438 *
s(lon,lat):Year2003  4.6274      8  2.335 2.85e-05 ***
s(lon,lat):Year2004  3.7598      8  1.222 0.006009 **
s(lon,lat):Year2005  4.7505      8  1.229 0.017530 *
s(lon,lat):Year2006  4.0475      8  2.361 7.66e-06 ***
s(lon,lat):Year2007  5.0303      8  3.858 4.68e-09 ***
s(lon,lat):Year2008  4.7837      8  0.960 0.066929 .
s(lon,lat):Year2009  3.9467      8  0.451 0.404667
s(lon,lat):Year2010  5.0642      8  1.455 0.007047 **
s(lon,lat):Year2011  4.7395      8  3.077 4.85e-07 ***
s(lon,lat):Year2012  5.0468      8  1.291 0.017459 *
s(lon,lat):Year2013  4.9675      8  2.316 6.32e-05 ***
s(lon,lat):Year2014  4.9122      8  2.073 0.000234 ***
s(lon,lat):Year2015  4.8172      8  1.707 0.001333 **
s(lon,lat):Year2016  5.3147      8  3.803 1.83e-08 ***
s(lon,lat):Year2017  4.3403      8  1.315 0.009074 **
s(lon,lat):Year2018  4.4349      8  2.490 1.24e-05 ***
s(lon,lat):Year2019  3.3823      8  0.252 0.671998
s(Depth)             4.5895      5 17.083  < 2e-16 ***
s(TimeShotHour)      0.4614      4  0.122 0.332881
s(Ship)              9.1804     16  2.031 3.96e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
R-sq.(adj) =  0.163   Deviance explained =   46%
-ML = 1845.1  Scale est. = 1.378     n = 3218
Age  5 :

Family: binomial
Link function: logit

Formula:
A1 > 0.01 ~ Year + s(lon, lat, bs = "ds", k = 80, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", k = 7, m = c(1, 0.5), by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur))

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -5.0249     0.1472 -34.139  < 2e-16 ***
Year1993     -0.3380     0.2045  -1.652 0.098435 .
Year1994     -0.2617     0.1919  -1.364 0.172621
Year1995     -0.3893     0.2003  -1.944 0.051934 .
Year1996      0.1930     0.1865   1.035 0.300831
Year1997      0.1048     0.2688   0.390 0.696737
Year1998     -0.1874     0.2318  -0.809 0.418775
Year1999     -1.1722     0.2539  -4.616 3.91e-06 ***
Year2000     -1.0796     0.2840  -3.802 0.000144 ***
Year2001     -1.2773     0.2675  -4.775 1.80e-06 ***
Year2002     -0.3785     0.2329  -1.625 0.104090
Year2003     -0.5019     0.2373  -2.115 0.034429 *
Year2004     -1.1206     0.2774  -4.040 5.35e-05 ***
Year2005     -0.8814     0.2652  -3.323 0.000890 ***
Year2006     -1.0805     0.2581  -4.187 2.83e-05 ***
Year2007     -0.8133     0.2712  -3.000 0.002704 **
Year2008     -0.6245     0.2622  -2.382 0.017230 *
Year2009     -0.9594     0.2728  -3.516 0.000438 ***
Year2010      0.2777     0.2185   1.271 0.203733
Year2011     -0.6649     0.2532  -2.626 0.008648 **
Year2012     -0.6950     0.2619  -2.654 0.007959 **
Year2013     -0.4224     0.2503  -1.688 0.091456 .
Year2014     -0.0901     0.2505  -0.360 0.719043
Year2015     -0.3122     0.2618  -1.193 0.232938
Year2016      0.1582     0.2380   0.664 0.506394
Year2017     -0.7620     0.2730  -2.792 0.005246 **
Year2018     -1.1642     0.2808  -4.146 3.38e-05 ***
Year2019     -1.6808     0.3147  -5.341 9.27e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df  Chi.sq  p-value
s(lon,lat)          61.875     79 844.901  < 2e-16 ***
s(lon,lat):Year1992  3.672      6  25.895 6.37e-08 ***
s(lon,lat):Year1993  3.332      6   6.628 0.047186 *
s(lon,lat):Year1994  3.495      6  18.740 9.04e-06 ***
s(lon,lat):Year1995  3.403      6   9.542 0.006544 **
s(lon,lat):Year1996  3.638      6  25.820 7.07e-08 ***
s(lon,lat):Year1997  2.560      6   9.573 0.002636 **
s(lon,lat):Year1998  2.981      6  16.555 1.65e-05 ***
s(lon,lat):Year1999  2.843      6   4.737 0.105506
s(lon,lat):Year2000  2.320      6   9.083 0.002087 **
s(lon,lat):Year2001  2.707      6   4.782 0.089365 .
s(lon,lat):Year2002  3.094      6   0.311 0.998879
s(lon,lat):Year2003  3.034      6   3.390 0.289004
s(lon,lat):Year2004  2.713      6   3.908 0.163256
s(lon,lat):Year2005  2.825      6   4.454 0.124112
s(lon,lat):Year2006  2.798      6  12.698 0.000226 ***
s(lon,lat):Year2007  2.786      6  13.302 0.000132 ***
s(lon,lat):Year2008  2.821      6   6.958 0.020728 *
s(lon,lat):Year2009  2.615      6   1.903 0.547087
s(lon,lat):Year2010  3.334      6   5.071 0.125978
s(lon,lat):Year2011  2.943      6   6.351 0.040030 *
s(lon,lat):Year2012  2.910      6   2.944 0.352287
s(lon,lat):Year2013  2.940      6  11.749 0.000786 ***
s(lon,lat):Year2014  2.955      6  10.103 0.002695 **
s(lon,lat):Year2015  2.939      6  19.703 1.44e-06 ***
s(lon,lat):Year2016  3.162      6  11.826 0.001041 **
s(lon,lat):Year2017  2.802      6  20.949 5.85e-07 ***
s(lon,lat):Year2018  2.740      6  12.634 0.000296 ***
s(lon,lat):Year2019  2.444      6  12.602 0.000161 ***
```

```
s(Depth)             4.809      5 247.816  < 2e-16 ***
s(TimeShotHour)      1.530      4   4.472 0.046499 *
s(Ship)              7.214     16  22.979 8.27e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.399   Deviance explained = 39.4%
-ML = 3475.5  Scale est. = 1         n = 9986

Family: Gamma
Link function: log

Formula:
A1 ~ Year + s(lon, lat, bs = "ds", k = 120, m = c(1, 0.5)) +
    s(lon, lat, bs = "ds", m = c(1, 0.5), k = 9, by = Year, id = 1) +
    s(Depth, bs = "ds", m = c(1, 0), k = 6) + s(TimeShotHour,
    bs = "cc", k = 6) + s(Ship, bs = "re") + offset(log(HaulDur *
    splitp5))

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.78737    0.15339 -24.691  < 2e-16 ***
Year1993     0.08644    0.18919   0.457 0.647800
Year1994    -0.13785    0.18622  -0.740 0.459247
Year1995    -0.47214    0.18876  -2.501 0.012453 *
Year1996    -0.14324    0.18206  -0.787 0.431518
Year1997    -0.21724    0.26818  -0.810 0.418003
Year1998     0.06516    0.22625   0.288 0.773370
Year1999    -0.60413    0.23143  -2.610 0.009111 **
Year2000    -0.25711    0.27060  -0.950 0.342141
Year2001     0.10696    0.23704   0.451 0.651881
Year2002    -0.75933    0.20102  -3.777 0.000163 ***
Year2003    -0.02179    0.21914  -0.099 0.920816
Year2004    -0.35192    0.23127  -1.522 0.128254
Year2005    -0.54407    0.22573  -2.410 0.016029 *
Year2006    -0.80965    0.24416  -3.316 0.000929 ***
Year2007    -0.15235    0.21887  -0.696 0.486449
Year2008    -0.30011    0.21703  -1.383 0.166867
Year2009    -0.36455    0.24873  -1.466 0.142895
Year2010    -0.55350    0.20142  -2.748 0.006049 **
Year2011     0.28451    0.22315   1.275 0.202468
Year2012    -0.29718    0.21928  -1.355 0.175486
Year2013    -0.06331    0.21297  -0.297 0.766289
Year2014     0.46892    0.20398   2.299 0.021615 *
Year2015     0.40066    0.21366   1.875 0.060908 .
Year2016     0.37742    0.19911   1.896 0.058167 .
Year2017     0.48991    0.22375   2.190 0.028671 *
Year2018     0.27146    0.23722   1.144 0.252616
Year2019     0.04865    0.25731   0.189 0.850041
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                       edf Ref.df     F  p-value
s(lon,lat)          68.5215    119 2.170  < 2e-16 ***
s(lon,lat):Year1992  3.4186      8 0.791  0.06374 .
s(lon,lat):Year1993  2.9772      8 0.919  0.01846 *
s(lon,lat):Year1994  3.2626      8 0.687  0.09208 .
s(lon,lat):Year1995  3.0763      8 0.999  0.01230 *
s(lon,lat):Year1996  3.4078      8 0.676  0.11671
s(lon,lat):Year1997  2.2622      8 0.118  0.83637
s(lon,lat):Year1998  2.5969      8 0.160  0.77038
s(lon,lat):Year1999  2.2883      8 0.396  0.19246
s(lon,lat):Year2000  1.6911      8 0.276  0.23009
s(lon,lat):Year2001  2.3275      8 0.530  0.08715 .
s(lon,lat):Year2002  3.0424      8 0.947  0.01516 *
s(lon,lat):Year2003  2.8156      8 1.543  0.00026 ***
s(lon,lat):Year2004  2.4262      8 0.148  0.78199
s(lon,lat):Year2005  2.5066      8 0.513  0.11508
s(lon,lat):Year2006  2.3596      8 0.918  0.00684 **
s(lon,lat):Year2007  2.5984      8 2.160 2.64e-06 ***
s(lon,lat):Year2008  2.7377      8 1.149  0.00273 **
s(lon,lat):Year2009  2.1802      8 0.433  0.13493
s(lon,lat):Year2010  3.3344      8 0.385  0.41845
s(lon,lat):Year2011  2.7440      8 0.818  0.02262 *
s(lon,lat):Year2012  2.7541      8 0.510  0.15470
s(lon,lat):Year2013  3.0177      8 1.003  0.01049 *
```

```
s(lon,lat):Year2014  3.2800      8 0.600  0.15173
s(lon,lat):Year2015  3.0153      8 0.663  0.08079 .
s(lon,lat):Year2016  3.5281      8 1.249  0.00544 **
s(lon,lat):Year2017  2.8177      8 0.387  0.32166
s(lon,lat):Year2018  2.5322      8 0.683  0.04302 *
s(lon,lat):Year2019  2.0045      8 0.062  0.95845
s(Depth)             3.9237      5 4.302 3.05e-06 ***
s(TimeShotHour)      0.4081      4 0.105  0.33623
s(Ship)              9.0095     16 1.764 2.34e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.115   Deviance explained = 37.3%
-ML = 1333.2  Scale est. = 1.5084    n = 2202
```

References

[1] Casper W Berg and Kasper Kristensen. Spatial age-length key modelling using continuation ratio logits. *Fisheries Research*, 129:119–126, 2012.

[2] Casper W Berg, Anders Nielsen, and Kasper Kristensen. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. *Fisheries Research*, 151:91–99, 2014.

[3] Kasper Kristensen and Casper W. Berg. Datras package for r. `https://github.com/DTUAqua/DATRAS`, 2012.

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA), Online, 22–26 February 2021

Maturity ogives for North Sea cod

Nicola D. Walker

Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft Laboratory, Lowestoft, NR33 9LY

Summary

Until 2015 maturity-at-age values were left unchanged from year to year. However, ICES WKNSEA (2015) noted a change in maturity-at-age in the North Sea cod stock, with fish maturing at a younger age and smaller size. To address these changes in the stock, a smoothed area-weighted maturity-at-age key is constructed from NS–IBTS–Q1 data and applied to the estimation of spawning stock biomass. Since its introduction, two issues have been noted: (1) insufficient biological sampling in the Southern subarea coupled with disproportionate raising of maturity and (2) high sensitivity of the smoother to raw maturity estimates at the end of the time-series (ICES, 2017, 2020). Furthermore, the data evaluation workshop (DEWK) raised concerns regarding the current exclusion of the Skagerrak (3.a.20) from calculations. This working document explores several SPALY-type methods of calculating maturity and, in the absence of an alternative method, proposes that the current procedure be modified to (1) include records from the Skagerrak; (2) omit the step of raising standardised survey numbers-at-age to the population level via sea surface area; (3) consider aggregating subareas to subpopulations in construction of the maturity key and (4) smooth raw maturities with a 5-year running mean.

Calculation

A full description of the current methodology to calculate raw maturity ogives for North Sea cod is given in WD1 of ICES (2017) but consists of the following steps:

1. Assign all fish sampled for biological information (CA data) as either immature or mature following Table 1.
2. Scale length data (HL data; all fish caught) to 60 minutes of effort and assign to a population subarea.
3. Calculate numbers-at-age per subarea ($n_{a,y,p}$) by multiplying by the scaled numbers-at-length by ALKs fit to the CA data.
4. Calculate the proportion of fish mature-at-age per subarea ($M_{a,y,p}$) from the CA data.
5. Calculate maturity-at-age for the stock as:

$$M_{a,y} = \frac{\sum N_{a,y,p} \cdot M_{a,y,p}}{\sum N_{a,y,p}}$$

Where $N_{a,y,p}$ is the total number of cod-at-age in a subarea, obtained by raising the survey numbers-at-age ($n_{a,y,p}$) according to:

$$N_{a,y,p} = \frac{A_p}{A_s} \cdot n_{a,y,p}$$

Where A_p is the area of a population subarea (Table 2) and A_s is the swept area of the GOV (0.065 km^2; ICES, 2015).

Table 1: Finfish maturity key for the IBTS survey and assignment as immature or mature.

Code	Description	Mature
1	Juvenile/Immature (4-stage scale)	0
2	Maturing (4-stage scale)	1
3	Spawning (4-stage scale)	1
4	Spent (4-stage scale)	1
6	Abnormal (4-stage scale, additional option)	-
61	Juvenile/Immature (6-stage scale)	0
62	Maturing (6-stage scale)	1
63	Spawning (6-stage scale)	1
64	Spent (6-stage scale)	1
65	Resting/Skip of spawning (6-stage scale)	1
66	Abnormal (6-stage scale)	-
I	Immature	0
M	Mature	1

Raising factors

Since the last benchmark of North Sea cod, the subarea definitions have been updated such that the areas north and west of the Shetlands are now included in the Northwestern subarea rather than Viking 4.a (Figure 1). Updated raising factors (A_p) for each subarea were calculated based on (1) a summation of the areas (km^2) of enclosed ICES statistical rectangles derived from QGIS and (2) using R function *areaPolygon* from package *geosphere* (Hijmans, 2017; Table 2). As it was not possible to reproduce the WKNSEA raising factors, and summing many subsets of the subareas may lead to greater imprecision, it was decided to use the *geosphere* calculated areas in this WD.

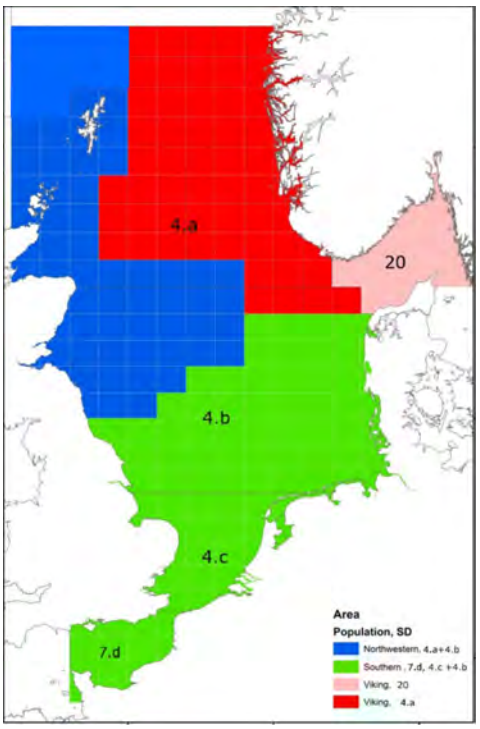


Figure 1: Updated subareas adopted for the spatial analysis of North Sea cod.

Table 2: Area (km^2) of the subareas shown in Figure 1 used as raising factors in the calculation of maturity. Note that the definitions of the Northwestern and Viking 4.a subareas have been updated since WKNSEA (2015) and that the Skagerrak was previously excluded from calculations.

Subarea	Method		
	WKNSEA (2015)	QGIS	geosphere
Northwestern	209822	243737	219959
Southern	732104	362308	357858
Viking 20		52410	52380
Viking 4.a	233372	163914	163570

During the data evaluation workshop (DEWK) concerns were raised regarding insufficient sampling of fish in the depleted Southern subarea coupled with disproportionate raising of maturity (Table 2). Here it is it is proposed that the step of multiplying standardised numbers-at-age from the survey ($n_{a,y,p}$) by an area-based raising factor (A_p/A_s) be omitted, i.e.:

$$M_{a,y} = \frac{\sum n_{a,y,p} \cdot M_{a,y,p}}{\sum n_{a,y,p}}$$

The IBTS follows a standardised design where each ICES statistical rectangle is typically sampled by two different nations. The only exception is the Skagerrak, which is fished solely by Sweden but who sample every rectangle more than once (ICES, 2015b). It is therefore argued that summing survey-based numbers-at-age is sufficient to consider the differing sizes of the population subareas, as bigger subareas have a larger number of ICES statistical rectangles enclosed and will therefore sum fish across a greater number of hauls. It is further argued that the survey is designed to be representative of the population and that raising to the population level may contribute to an overestimation of SSB due to poor biological sampling in the South coupled with large raising factors.

Figure 2 compares subarea-based maturity ogives calculated with differing raising factors. Employing the new raising factors (*geosphere*) mostly lowers the estimates of maturity due the smaller estimates of area for Viking 4.a and the South. Not raising to the population level via use of an area-based raising factor further lowers estimates of maturity-at-age, particularly for ages 2–4, due to less influence being given to the Southern subarea, where fish generally mature earlier.

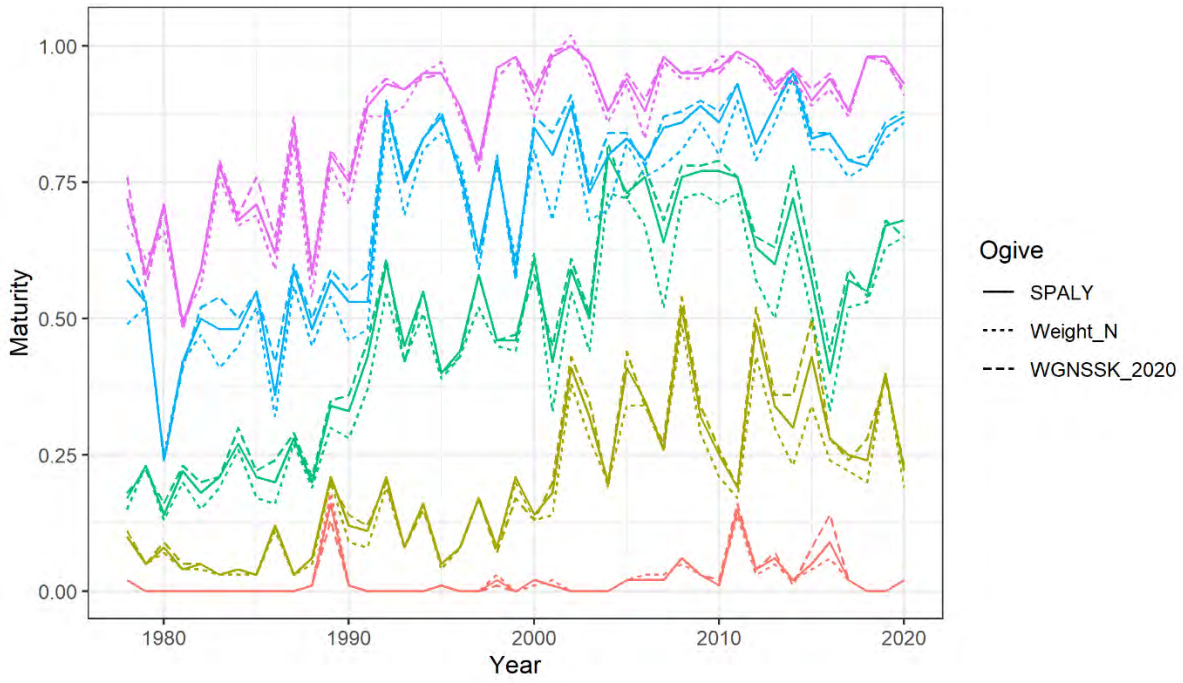


Figure 2: Comparison of subarea-based maturity ogives for ages 1–5 calculated with different raising factors: WGNSSK_2020 uses the WKNSEA (2015) areas; SPALY is the same procedure but employing the new raising factors (geosphere) and Weight_N is based on standardised survey observations alone (i.e., no area-based raising factor).

Subarea Ogives

Until now, records from the Skagerrak have been excluded from maturity calculations as a consistent time-series of biological sampling records are available for this subarea only from 1991. Figure 3 plots maturity ogives constructed with and without data from the Skagerrak included (from 1991). Addition of this data appears to make very little difference to the ogives for ages 3–5, likely due to a combination of low numbers of older ages in this subarea and a lower subarea raising factor (Table 2). While there are larger differences for ages 1–2, due to the Skagerrak being an important nursery area for North Sea cod, overall, the differences appear small.

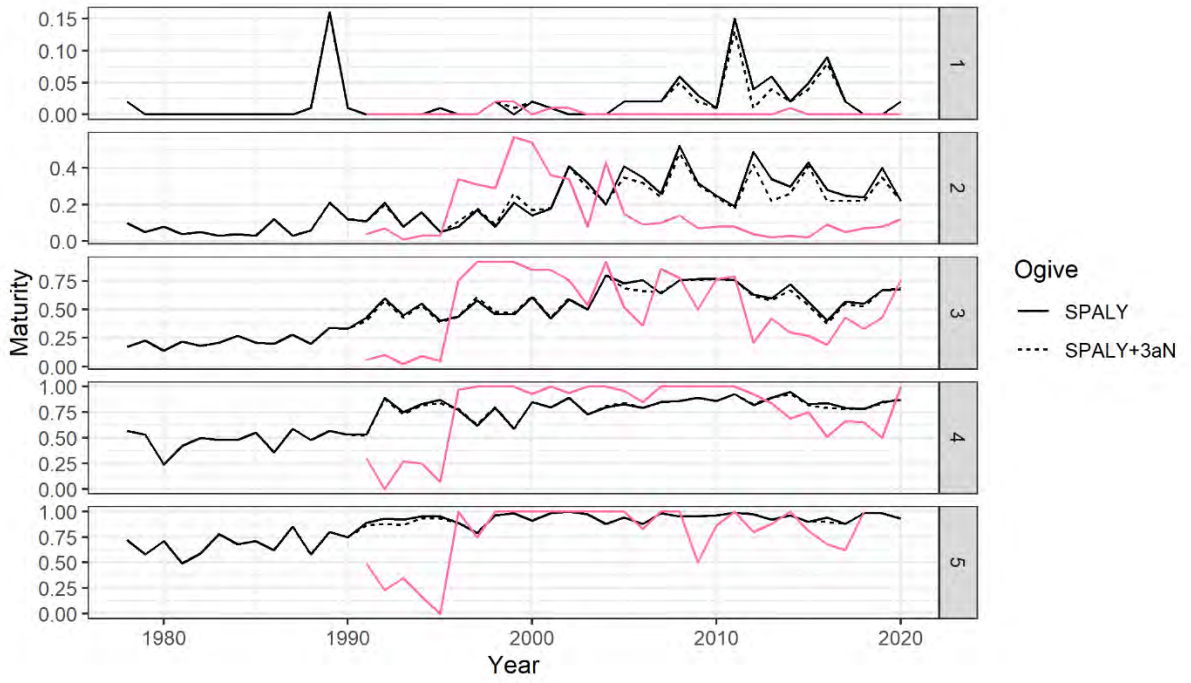


Figure 3: Comparison of subarea-based maturity ogives (calculated using the geosphere raising factors) either including or not including records from the Skagerrak. The maturity ogive for the Skagerrak itself is overlaid in pink.

Figure 4 plots maturity ogives for each subpopulation ($M_{a,y,p}$; calculated from the CA data) aggregated into 10-year time periods. These show that maturity-at-age is generally highest in the South followed by the Northwest and lowest in the two Viking subareas.

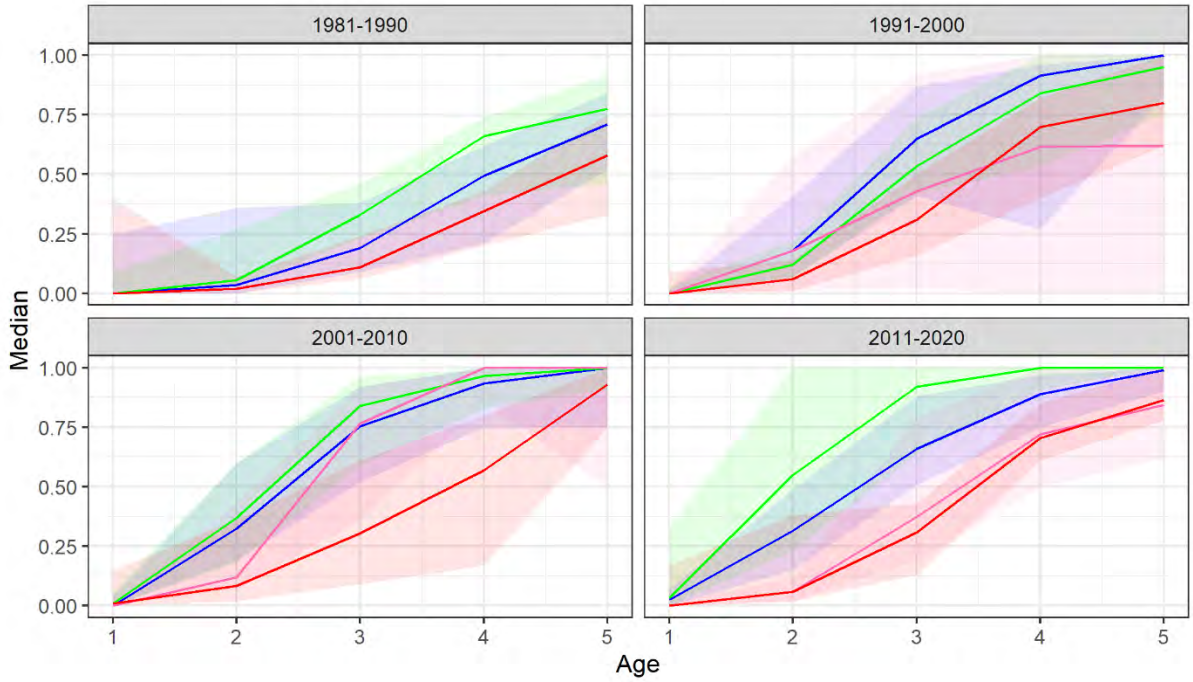


Figure 4: Maturity ogives constructed for each subarea over 10-year time periods. Solid lines correspond to the median over the relevant period while the surrounding polygons show the minimum and maximum values for the period. Subarea colours match those in Figure 1. Note the Skagerrak is excluded until 1991.

Figure 5 plots maturity ogives for each subarea against combined ogives for the stock. When raising to the population level via area-based raising factors, the combined ogive for ages 2–5 appears to be

dominated by the Northwest and Southern subareas, while the survey-based ogive appears to be more evenly distributed between subareas. A comparison of the two combined ogives, without the Skagerrak included, is given in Figure 2 (SPALY vs Weight_N).

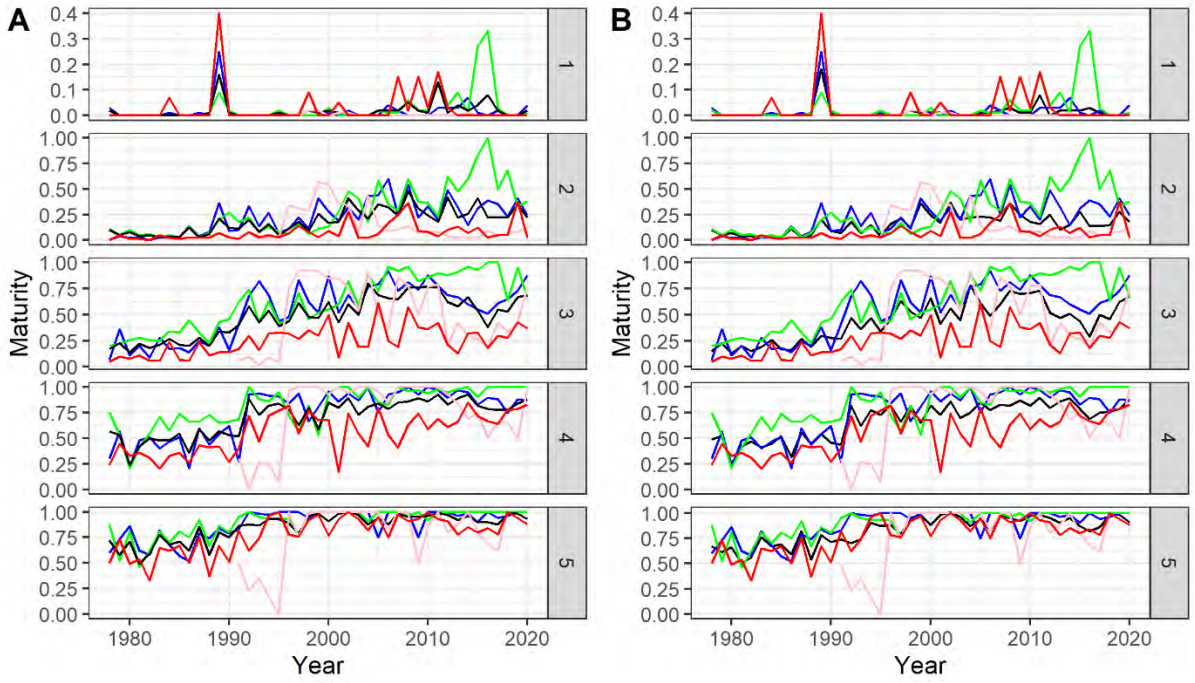


Figure 5: Contribution of each subarea to maturity-at-age keys for the stock with (A) numbers raised to the population level ($N_{a,y,p}$) via an area-based raising factor and (B) survey-based numbers-at-age ($n_{a,y,p}$). Subarea colours match those in Figure 1 and maturity-at-age keys for the stock are shown in black.

Population ogives

In 2020, there was insufficient biological sampling to estimate an age-length key for the Southern subarea (Figure 1) which necessitated borrowing the Northwest ALK to assign ages to fish surveyed in the South (ICES, 2020). A similar problem is encountered when considering the Skagerrak, as there were no age 5 fish recorded in 2019 and no fish older than age 4 in 2020. Time series of biological sampling levels show the number and proportion of older fish sampled in these subareas to have decreased in recent years (Figure 6), meaning that the issue of estimating ALKs for these subareas is likely to continue.

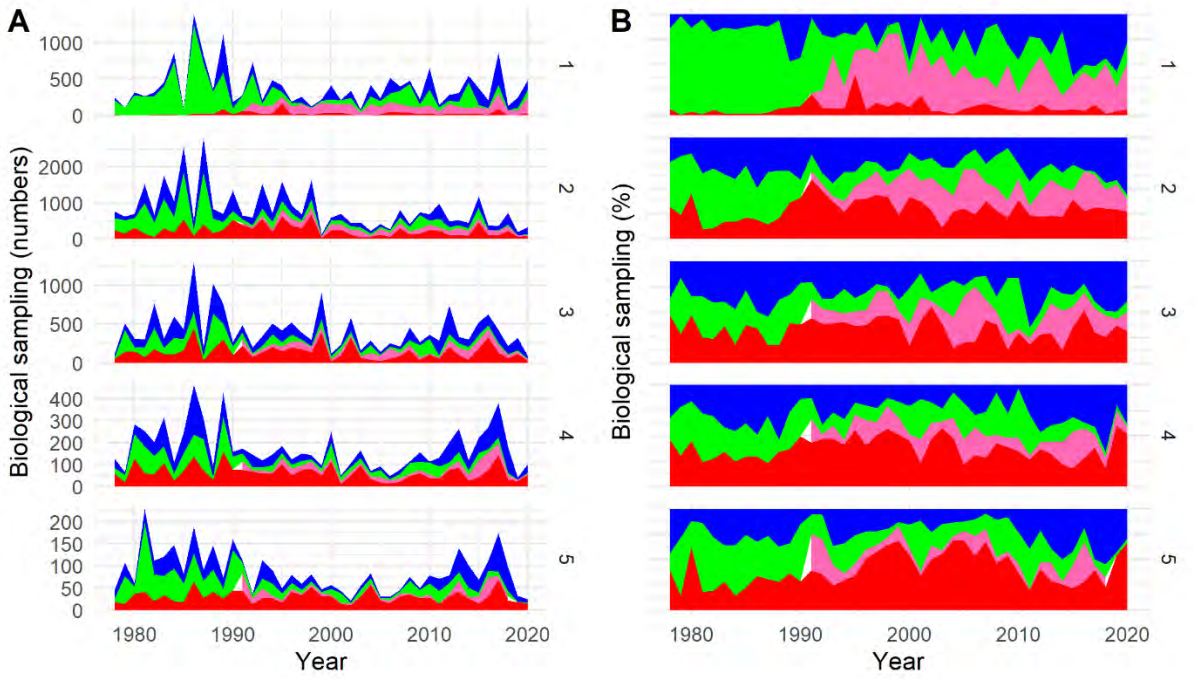


Figure 6: The (A) number of cod sampled for age and maturity in the IBTS-Q1 survey and (B) proportion of biological sampling across subareas. Subarea colours correspond to those in Figure 1.

The recent ICES WKNSCodID workshop (ICES, 2020b) found evidence of two reproductively isolated populations of cod within the current assessment unit: Viking cod (Viking 4.a and Viking 20/Skagerrak subareas in Figure 1) and Dogger cod (Northwestern and Southern subareas in Figure 1). Given recent low biological sampling of older ages in the South and Skagerrak, and similarity of maturity ogives for subareas within the two populations (Figure 4), it is suggested here to consider maturity ogives constructed by subpopulation rather than subarea.

Figure 7 compares subarea and subpopulation ogives with and without an area-based raising factor. There is little difference between the ogives when survey numbers are raised to the population level via an area-based raising factor (Figure 7A). This is because in both cases the larger areas of the Northwestern and Southern subareas, or Dogger subpopulation area, dominate the combined ogive. When considering survey-based numbers alone (i.e., no raising factor) there are some larger differences between the subarea and subpopulation ogives, particularly for ages 2–3, although no clear and consistent up- or downscaling across the time-series (Figure 7B). As for the subarea-based ogives, raising to the population level via an area-based raising factor increases the combined subpopulation-based ogive due to the larger area giving more weight to the Dogger subpopulation (Figures 7C–8), which generally mature earlier (Figure 9).

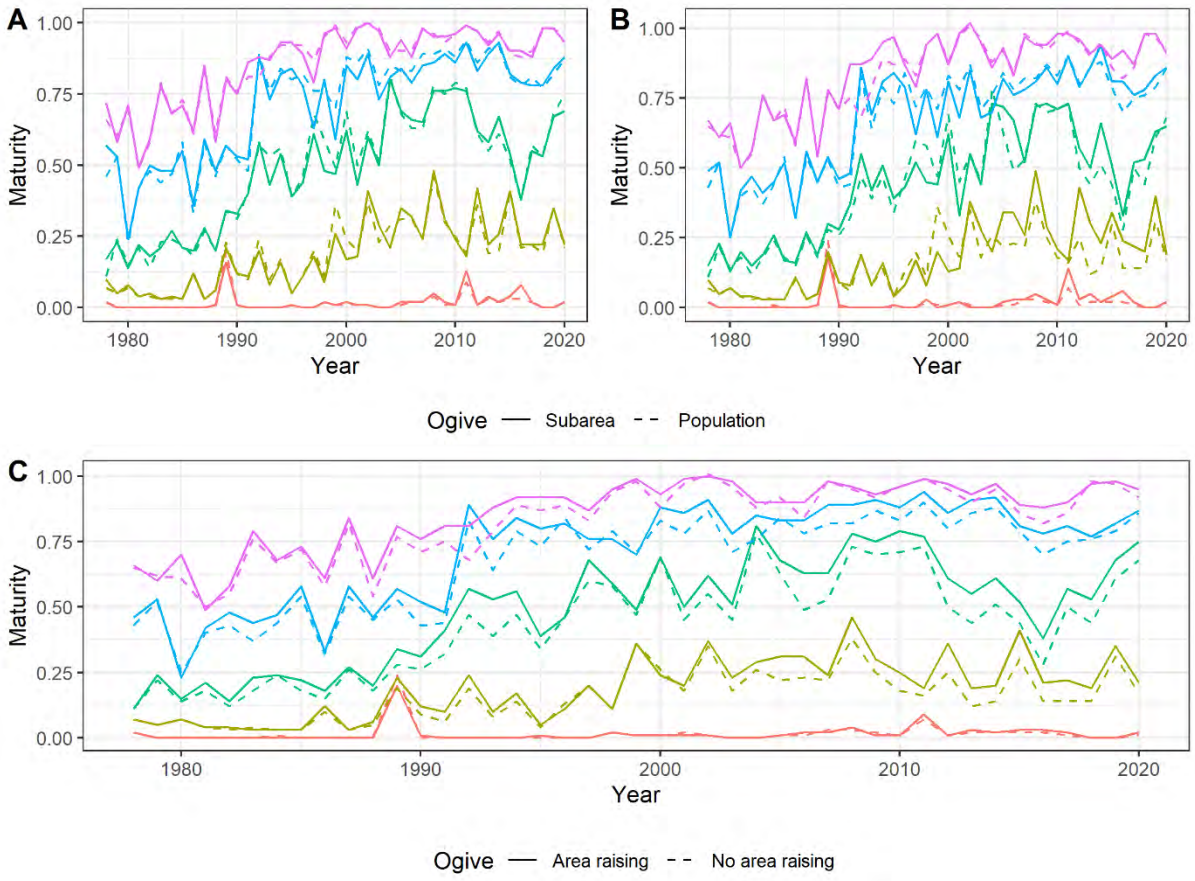


Figure 7: Comparison of combined maturity ogives constructed by subarea or subpopulation with (A) an area-based raising factor and (B) no raising factor. (C) Direct comparison of the two subpopulation ogives (dashed lines in A and B).

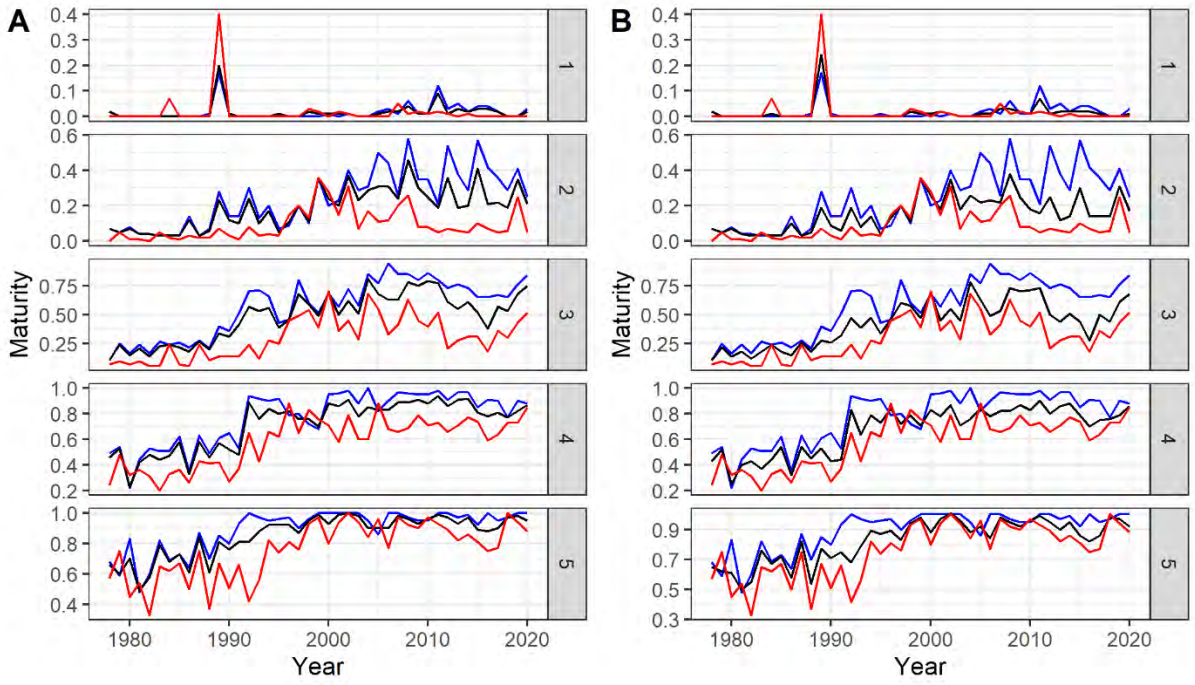


Figure 8: Contribution of each subpopulation to maturity-at-age keys for the stock with (A) numbers raised to the population level ($N_{a,y,p}$) via an area-based raising factor and (B) survey-based numbers-at-age ($n_{a,y,p}$). Blue=Dogger; Red=Viking; Black=combined.

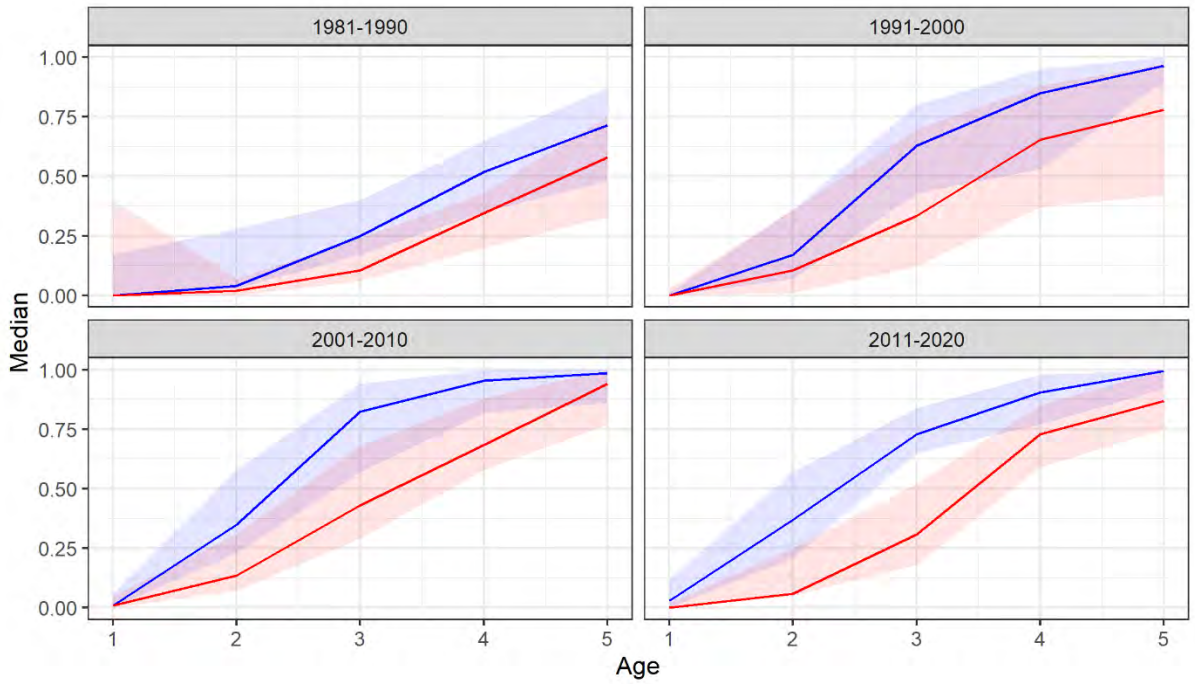


Figure 9: Maturity ogives constructed for each subpopulation over 10-year time periods. Solid lines correspond to the median over the relevant period while the surrounding polygons show the minimum and maximum values for the period. Blue=Dogger; Red=Viking.

Smoothing

Due to high interannual variability, the current procedure is to fit a simple GAM with a spline smooth over time (from 1973) to each age in the raw maturity ogive using the mgcv package in R (Wood, 2006). Re-smoothing the ogive in this way, with new information added each year, changes maturity back in time and therefore has the potential to cause annual changes to the perception of the stock (see WD1 in ICES 2017).

Figure 10 compares maturity ogives resulting from the current method of smoothing to those resulting from a simple running mean of three or five years. For ages 2–5, the running means follow the trends of the gam smoother well but for age 1 appear to be heavily influenced by an abnormally high estimate of maturity in 1989.

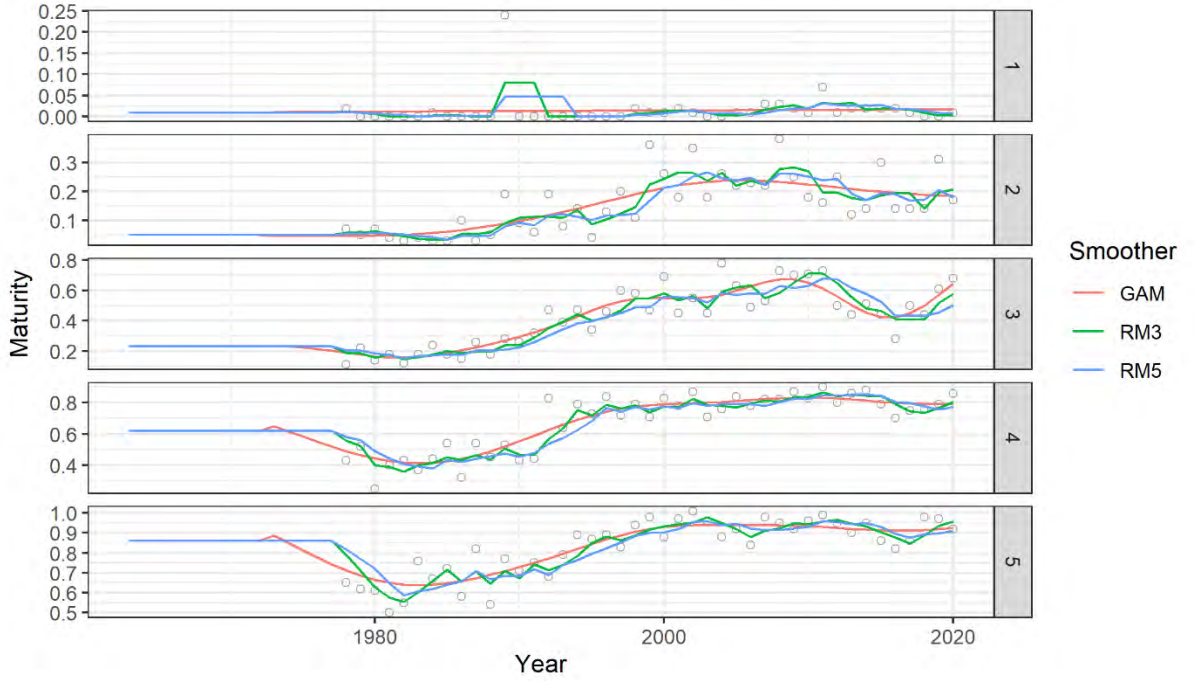


Figure 10: Comparison of maturity ogives resulting from smoothing the subpopulation ogives without raising factor based on either a simple GAM smooth or a running mean of 3 or 5 years.

Performance in SAM

Running the various maturity ogives through SAM will not affect the likelihood but may impact the scaling and retrospective pattern of SSB. Figure 11 shows the calculation of maturity to have some impact on the scale of SSB although the differences are mostly small (mean range = 13%; max range = 26%) and, while ogives calculated without raising to the population level tend to be higher overall, no raw ogive was consistently above or below the others. Figure 12 shows the method of smoothing to have little impact on the overall level of SSB.

Neither calculation nor smoothing of the maturity ogives appears to have much effect on the retrospective pattern with all options resulting in Mohn's rho values of ρ = 0.28–0.29 (2d.p.; range = 0.00993). Furthermore, no single method of calculation appears to perform better across all methods of smoothing in terms of ρ.

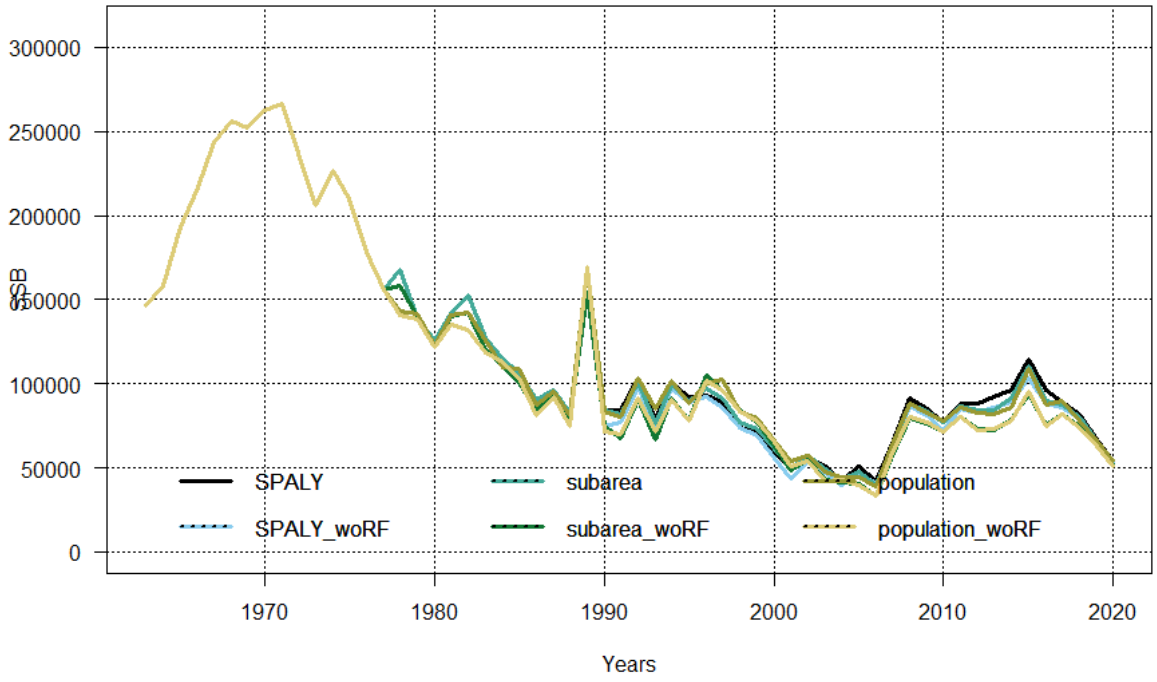


Figure 11: SAM estimates of SSB given the raw maturity ogives presented (i.e., without smoothing): SPALY=same procedure as last year but with new subarea definitions (Figure 1); subarea=subarea constructed ogives including the Skagerrak from 1991; population=subpopulation constructed ogives; woRF=calculated without the area-based raising factors in Table 2.

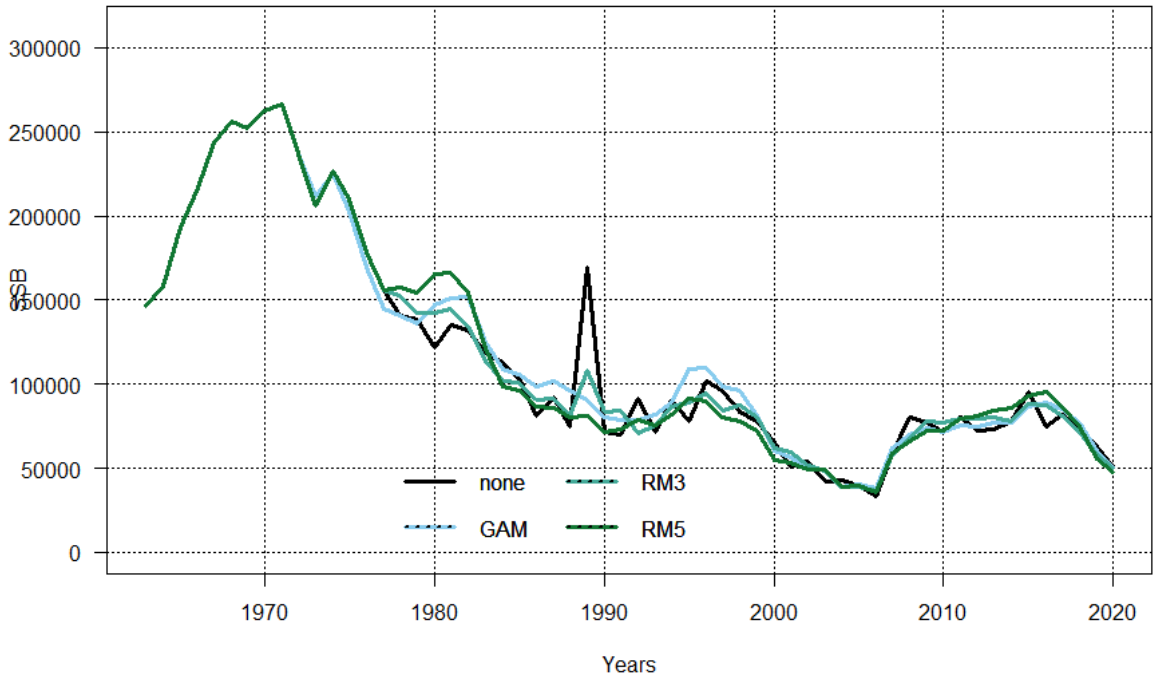


Figure 12: SAM estimates of SSB given the raw and smoothed maturity ogives presented in Figure 10 (based on a subpopulation ogive without area-based raising).

Conclusions

In the absence of an alternative method of derivation, and given no tangible influence on SAM diagnostics, it is suggested that the current procedure of deriving maturity be modified as follows:

1. **Fish from the Skagerrak be included in calculations**, following the recommendations of DEWK.
    a. Inclusion of records from the Skagerrak appears to make little difference to the overall ogive (Figure 3).
    b. The Skagerrak accounts for a large proportion of sampled 1–2-year-olds (Figure 6) and is an important nursery area for the stock.

2. **The step of multiplying standardised survey-numbers-at-age by an area-based raising factor be omitted**.
    a. The survey is designed to be representative of the stock.
    b. A form of area-weighting is already applied as larger areas will have more statistical rectangles enclosed and therefore more hauls from which to sum fish.
    c. Raising to the population level may artificially inflate SSB due to disproportionate raising of samples from the larger but depleted Southern subarea, for which biological sampling of older ages has been poor in recent years (Figure 6).

3. **Construction of maturity ogives by subpopulation (i.e., Viking and Dogger) be considered**.
    a. This is consistent with the findings of WKNSCodID (ICES, 2020b).
    b. While phenotypic differences within the Dogger population have been reported, ogives between the enclosed Northwestern and Southern subareas are more like each other than those of the Viking subareas (Figure 4), and a comparison of the resulting ogives shows no consistent up-or-downscaling (Figure 7).
    c. The combined sample sizes will prevent problems when estimating ALKs given the low numbers of older ages reported in the Southern and Skagerrak subareas.

4. **Smoothing is done using a running mean over 5 years**.
    a. The method of smoothing appears to have little impact on the overall level of SSB (Figure 12).
    b. A running mean will not revise historic estimates of maturity, removing the potential for large or frequent changes to the perception of the stock.
    c. A 5-year running mean is less reactive to outliers in the maturity data (Figure 10).

References

Hijmans, R. J. 2017. Geosphere: Spherical trigonometry. R package version 1.5-7. https://CRAN.R-project.org/package=geosphere.

ICES. 2015. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 2–6 February 2015, Copenhagen, Denmark. ICES CM 2015/ACOM:32. 253 pp.

ICES. 2015b. Manual for the International Bottom Trawl Surveys. Series of ICES Survey Protocols SISP 10 – IBTS IX. 86 pp.

ICES. 2017. Report of the Working Group on Assessment of Demersal Stocks in the North Sea and Skagerrak (2017), 26 April–5 May 2017, ICES HQ. ICES CM 2017/ACOM:21. 1077 pp.

ICES. 2020. Working Group of the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1140 pp. http://doi.org/10.17895/ices.pub.6092

ICES. 2020b. Workshop on Stock Identification of North Sea Cod (WKNSCodID). ICES Scientific Reports. 2:89. 82 pp. http://doi.org/10.17985/ices.pub.7499

Wood, S. N. 2006. Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC.

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA), Online, 22–26 February 2021

Weights-at-age of North Sea cod

Nicola D. Walker

Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft Laboratory, Lowestoft, NR33 9LY

Summary

Currently, weights-at-age in the stock are set equal to weights-at-age in the catch. At the data evaluation workshop (DEWK) there was some discussion about whether weights-at-age in the stock should be derived from the NS-IBTS Q1 survey data or a hybrid matrix with the survey providing weights for younger ages (1–4) and the catch providing weights for older ages (5+). This document details the reasons why such approaches were not adopted at the last benchmark of North Sea cod and examines the possibility of instead using catch weights from only the first quarter of the year.

Conclusions from WKNSEA 2015

The last benchmark of North Sea cod (ICES, 2015) compared the currently used stock weights (same as catch weights derived from the whole year) with stock weights derived from the NS-IBTS Q1 survey using the Berg methodology (see WD3 of ICES (2015); reproduced with recent years included in Figure 1); this indicates that the survey weights are lower for ages 1–3, are similar for ages 4–5 but are larger for ages 6 and above. The group found several issues with using the survey weights:

- The older ages are poorly sampled compared to the catch.
- No estimates are available prior to 1983, so an assumption of constant weight-at-age must be made.

Furthermore, the group concluded that a hybrid matrix of Q1 survey weights for the younger ages (1–4) and catch weights for the older ages (5+) would represent an inconsistent time-series and decided to continue with catch weights as stock weights (Table 2). Unsmoothed weights-at-age derived from the NS-IBTS Q1 survey are presented in Table 3.

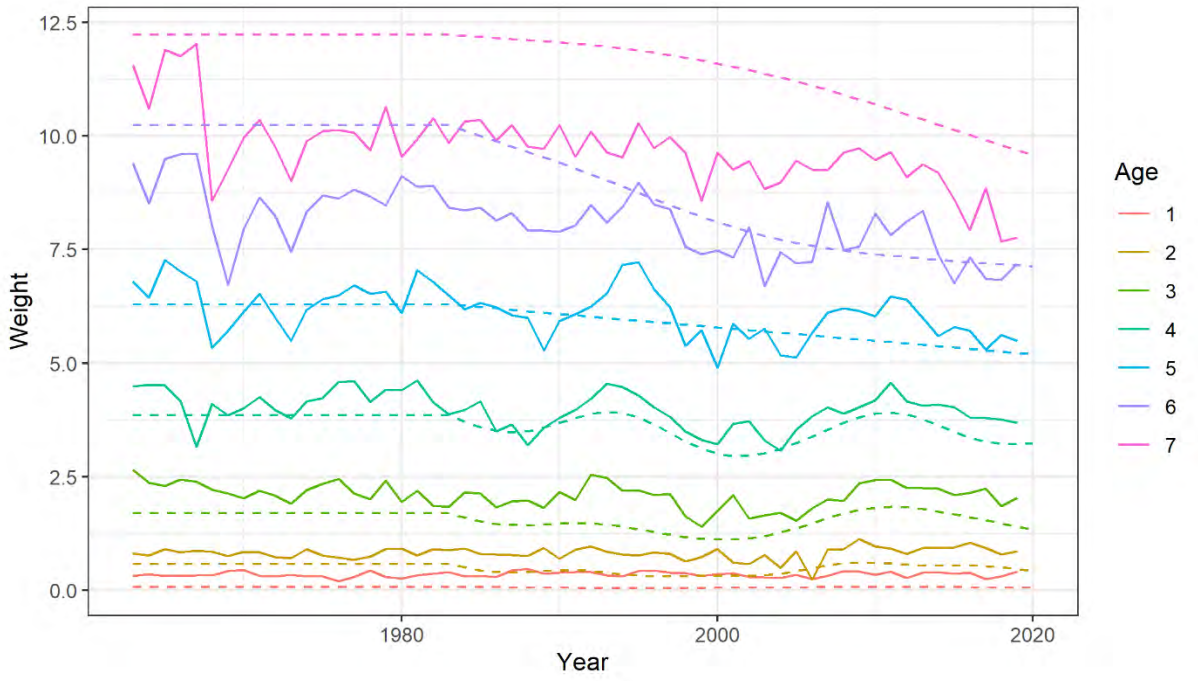


Figure 1: Currently used stock weights (=catch weights) given as solid lines, compared to the stock weights derived from the NS-IBTS Q1 survey, assuming that weights prior to 1983 are constant at the 1983 value.

Q1 catch weights

As stock weights should reflect the beginning of the year, an alternative is to use only Q1 catch weights as stock weights (Table 4). Catches disaggregated to season are available only from 2002; however, Figure 2 shows Q1 catch weights to reflect a proportion of annual catch weights. It may therefore be possible to reconstruct Q1 catch weights back to 1963, although the proportion has not necessarily been constant through time (Table 1).

Table 1: Q1 catch weights-at-age as a proportion of annual catch weights-at-age.

Year/Age	1	2	3	4	5	6	7
2002	0.968	0.884	0.931	0.925	0.889	0.895	0.960
2003	0.981	0.983	0.951	0.921	0.913	0.874	0.932
2004	1.009	0.724	0.833	0.898	0.909	0.921	0.945
2005	1.094	0.894	0.866	0.834	0.884	0.904	0.940
2006	1.057	0.384	0.823	0.883	0.891	0.907	0.989
2007	1.007	0.907	0.844	0.861	0.903	0.907	0.879
2008	1.162	1.033	0.961	0.911	0.871	0.857	0.901
2009	0.979	0.893	0.810	0.910	0.898	0.947	0.951
2010	1.142	0.753	0.902	0.922	0.918	1.044	0.948
2011	1.063	0.845	0.859	0.928	0.903	0.908	0.992
2012	0.797	0.799	0.848	0.884	0.927	0.923	0.947
2013	0.913	0.671	0.840	0.929	0.951	0.882	1.019
2014	0.752	0.807	0.837	0.861	0.931	0.912	0.954
2015	0.667	0.856	0.837	0.845	0.857	0.911	0.995
2016	0.698	0.775	0.801	0.855	0.900	0.885	0.959
2017	0.533	0.764	0.812	0.851	0.885	1.009	0.964
2018	0.447	0.724	0.908	0.872	0.920	0.860	1.007
2019	0.643	0.700	0.826	0.925	0.857	0.952	1.003
MEAN	0.884	0.800	0.861	0.890	0.900	0.916	0.960
STDEV	0.209	0.138	0.048	0.032	0.024	0.046	0.035

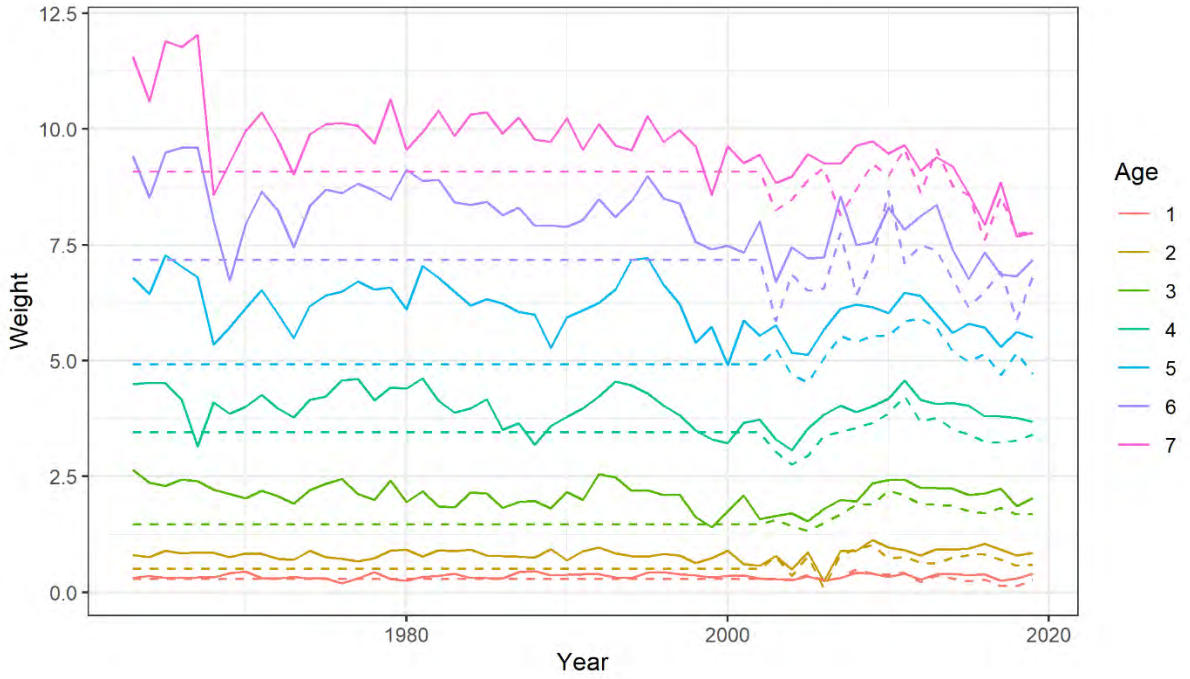


Figure 2: Currently used stock weights (=catch weights) given as solid lines, compared to stock weights derived from Q1 catch data only and assuming that weights prior to 2002 are constant at the 2002 value.

Figure 3 shows the inconsistencies between commercial and survey weights-at-age to be exacerbated when considering only the Q1 catch data, as the distance between survey and commercial weights becomes larger for the older ages (5+).

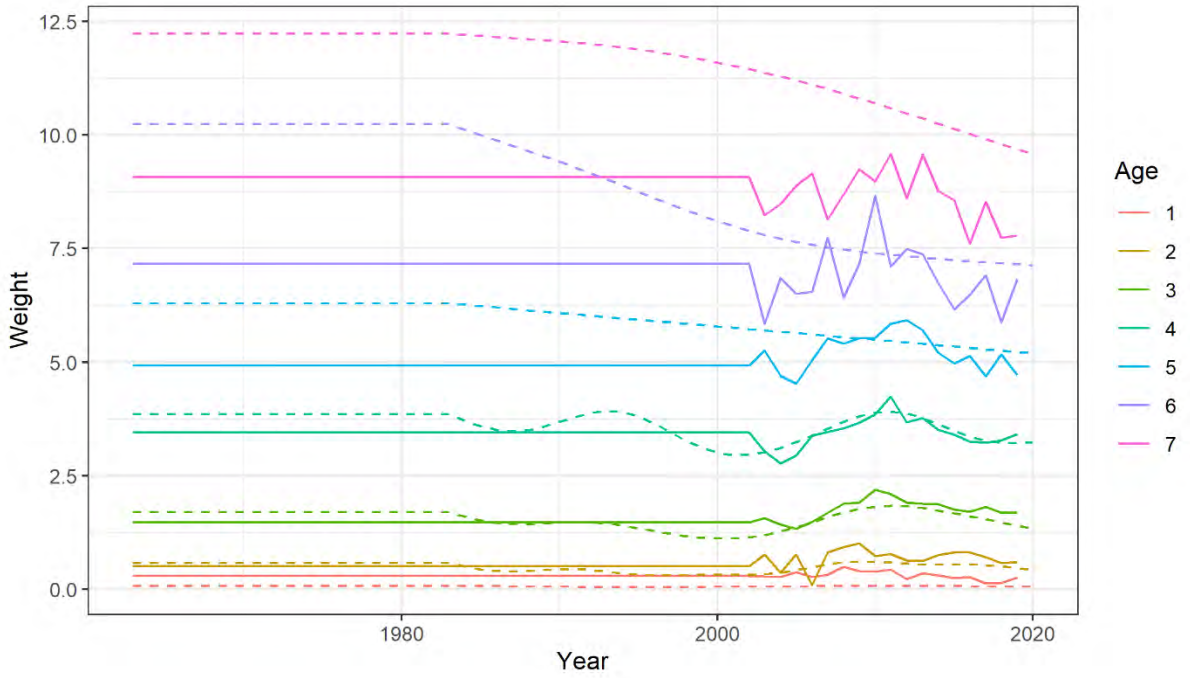


Figure 3: Stock weights derived from Q1 catch data given as solid lines, compared to stock weights derived from the NS-IBTS Q1 survey, assuming that weights prior to 2002 and 1983 are constant at the 2002 and 1983 values respectively.

Conclusions

- The reasons for not adopting survey weights-at-age at the last benchmark of North Sea cod (ICES, 2015) still hold.

- There are inconsistencies between the survey and commercial weights-at-age (both in Q1 and for the whole year) hindering use of a hybrid matrix.

- It is possible to calculate stock weights-at-age from the Q1 catch data, although this is available only from 2002.

References

ICES. 2015. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 2–6 February 2015, Copenhagen, Denmark. ICES CM 2015/ACOM:32. 253 pp.

Tables

Table 2: Catch weights-at-age of North Sea cod, currently assumed to represent stock weights.

Year/Age	1	2	3	4	5	6	7
1963	0.314	0.809	2.647	4.491	6.794	9.409	11.562
1964	0.357	0.761	2.366	4.528	6.447	8.52	10.606
1965	0.312	0.9	2.295	4.512	7.274	9.498	11.898
1966	0.313	0.836	2.437	4.169	7.027	9.599	11.766
1967	0.326	0.868	2.395	3.153	6.803	9.61	12.033
1968	0.327	0.848	2.215	4.094	5.341	8.02	8.581
1969	0.417	0.755	2.127	3.852	5.715	6.722	9.262
1970	0.449	0.845	2.028	4.001	6.131	7.945	9.953
1971	0.314	0.834	2.188	4.258	6.528	8.646	10.356
1972	0.3	0.729	2.08	3.968	6.011	8.246	9.766
1973	0.335	0.7	1.913	3.776	5.488	7.453	9.019
1974	0.304	0.901	2.206	4.156	6.174	8.333	9.889
1975	0.304	0.76	2.348	4.226	6.404	8.691	10.107
1976	0.198	0.722	2.449	4.577	6.494	8.62	10.132
1977	0.294	0.673	2.128	4.606	6.714	8.828	10.071
1978	0.432	0.743	2.001	4.146	6.53	8.667	9.685
1979	0.291	0.905	2.411	4.423	6.579	8.474	10.637
1980	0.257	0.917	1.948	4.401	6.109	9.12	9.55
1981	0.33	0.769	2.186	4.615	7.045	8.884	9.933
1982	0.358	0.908	1.856	4.13	6.785	8.903	10.398
1983	0.403	0.882	1.834	3.88	6.491	8.423	9.848
1984	0.305	0.921	2.156	3.972	6.19	8.362	10.317
1985	0.314	0.8	2.132	4.164	6.324	8.43	10.362
1986	0.293	0.782	1.822	3.504	6.23	8.14	9.896
1987	0.437	0.773	1.955	3.65	6.052	8.307	10.243
1988	0.466	0.753	1.975	3.187	5.992	7.914	9.764

1989	0.364	0.932	1.81	3.585	5.273	7.921	9.724
1990	0.382	0.69	2.165	3.791	5.931	7.89	10.235
1991	0.393	0.889	1.995	3.971	6.082	8.033	9.545
1992	0.395	0.97	2.546	4.223	6.247	8.483	10.101
1993	0.326	0.846	2.477	4.551	6.54	8.094	9.641
1994	0.305	0.788	2.188	4.471	7.167	8.436	9.537
1995	0.42	0.768	2.206	4.293	7.22	8.98	10.282
1996	0.433	0.831	2.095	4.034	6.637	8.494	9.729
1997	0.386	0.797	2.117	3.821	6.228	8.394	9.979
1998	0.372	0.634	1.622	3.495	5.387	7.563	9.628
1999	0.318	0.732	1.405	3.305	5.726	7.403	8.582
2000	0.354	0.903	1.747	3.216	4.903	7.488	9.636
2001	0.372	0.606	2.093	3.663	5.871	7.333	9.264
2002	0.298	0.572	1.576	3.726	5.537	8.006	9.451
2003	0.285	0.781	1.645	3.298	5.757	6.694	8.838
2004	0.269	0.496	1.712	3.075	5.175	7.449	8.974
2005	0.342	0.86	1.529	3.533	5.124	7.201	9.457
2006	0.25	0.236	1.804	3.828	5.665	7.229	9.262
2007	0.313	0.893	2.001	4.026	6.117	8.543	9.255
2008	0.424	0.904	1.966	3.89	6.207	7.491	9.644
2009	0.406	1.133	2.355	4.023	6.154	7.56	9.733
2010	0.335	0.965	2.426	4.18	6.033	8.299	9.472
2011	0.405	0.915	2.438	4.569	6.472	7.829	9.656
2012	0.274	0.8	2.252	4.154	6.392	8.117	9.095
2013	0.388	0.932	2.249	4.06	5.999	8.36	9.385
2014	0.398	0.927	2.237	4.083	5.598	7.392	9.19
2015	0.366	0.945	2.098	4.031	5.802	6.761	8.602
2016	0.387	1.049	2.138	3.803	5.712	7.332	7.928
2017	0.249	0.925	2.238	3.794	5.296	6.857	8.85
2018	0.3	0.79	1.853	3.759	5.624	6.829	7.683
2019	0.405	0.857	2.036	3.687	5.493	7.188	7.764

Table 3: Unsmoothed weights-at-age derived from the NS-IBTS Q1 survey data.

Year/Age	1	2	3	4	5	6	7
1983	0.066	0.624	1.678	3.983	6.633	10.745	11.618
1984	0.076	0.448	1.741	3.408	6.632	9.399	12.953
1985	0.048	0.441	1.743	4.077	6.067	10.143	11.851
1986	0.062	0.363	1.324	3.125	5.395	8.412	10.945
1987	0.078	0.390	0.959	4.116	6.083	10.719	12.266
1988	0.055	0.418	1.571	2.939	6.578	9.665	11.132
1989	0.063	0.473	1.207	3.275	5.150	9.425	12.448
1990	0.056	0.385	1.721	3.652	6.671	9.795	12.001
1991	0.055	0.455	1.228	3.224	5.119	9.131	12.025
1992	0.055	0.421	1.793	4.445	6.373	9.787	10.842
1993	0.044	0.397	1.804	4.248	6.604	10.053	13.014
1994	0.037	0.348	1.437	4.682	7.754	9.668	12.131
1995	0.045	0.321	1.130	3.493	6.448	9.046	13.272

1996	0.037	0.363	1.216	3.531	5.808	9.176	14.223
1997	0.025	0.254	1.228	3.271	5.431	7.707	10.974
1998	0.064	0.276	1.213	3.310	6.017	7.970	12.444
1999	0.049	0.291	0.774	2.746	5.415	8.185	10.943
2000	0.044	0.366	1.403	3.021	5.261	6.738	11.020
2001	0.067	0.321	1.257	2.918	5.051	6.536	9.689
2002	0.057	0.289	1.015	3.652	6.223	10.583	10.987
2003	0.058	0.431	0.825	2.508	5.588	6.495	12.054
2004	0.056	0.242	1.554	3.213	5.206	6.879	15.261
2005	0.060	0.445	1.274	2.937	4.899	7.920	9.508
2006	0.058	0.498	1.481	3.119	4.775	6.864	10.313
2007	0.072	0.436	1.244	3.867	5.693	7.339	10.833
2008	0.083	0.681	1.546	3.514	5.871	7.496	11.861
2009	0.056	0.734	2.275	3.753	5.381	6.925	11.017
2010	0.073	0.569	2.319	4.317	5.520	7.319	11.985
2011	0.062	0.479	1.805	4.581	6.484	8.061	11.640
2012	0.062	0.621	1.536	3.430	6.345	8.770	9.479
2013	0.068	0.466	1.606	3.496	4.924	6.645	9.903
2014	0.064	0.540	1.781	3.734	5.655	8.023	10.052
2015	0.068	0.587	1.662	3.490	5.142	7.213	8.012
2016	0.071	0.553	1.635	3.188	4.957	6.879	9.563
2017	0.057	0.551	1.716	3.457	4.533	7.164	10.862
2018	0.059	0.460	1.346	3.105	5.421	6.391	8.503
2019	0.056	0.421	1.254	2.940	5.849	7.790	10.051
2020	0.063	0.460	1.421	3.515	5.306	7.357	10.200

Table 4: Weights-at-age derived from Q1 catch data.

Year/Age	1	2	3	4	5	6	7
2002	0.289	0.506	1.467	3.448	4.922	7.167	9.077
2003	0.279	0.767	1.565	3.037	5.256	5.850	8.239
2004	0.271	0.359	1.427	2.762	4.705	6.862	8.479
2005	0.374	0.769	1.324	2.946	4.528	6.507	8.889
2006	0.264	0.091	1.484	3.379	5.046	6.555	9.161
2007	0.315	0.810	1.689	3.465	5.527	7.747	8.139
2008	0.493	0.934	1.889	3.546	5.404	6.421	8.693
2009	0.398	1.012	1.908	3.663	5.525	7.161	9.255
2010	0.383	0.726	2.188	3.852	5.539	8.664	8.979
2011	0.430	0.773	2.094	4.238	5.841	7.107	9.577
2012	0.218	0.639	1.910	3.673	5.923	7.495	8.609
2013	0.354	0.626	1.889	3.774	5.707	7.374	9.562
2014	0.299	0.748	1.873	3.516	5.211	6.740	8.771
2015	0.244	0.809	1.756	3.406	4.973	6.157	8.563
2016	0.270	0.813	1.712	3.253	5.143	6.486	7.606
2017	0.133	0.707	1.818	3.229	4.689	6.916	8.535
2018	0.134	0.572	1.682	3.276	5.173	5.876	7.738
2019	0.260	0.600	1.682	3.410	4.707	6.840	7.788

Recreational cod catches in the North Sea and Skagerrak: working document for the benchmark meeting (WKNSEA 2021)

Mike Armstrong, Simon Weltersbach, Zachary Radford, & Kieran Hyder
16 March 2021

Contents

1 Introduction 2
1.1 Existing knowledge of stock trends 2
2 National recreational fishery catch estimates 3
2.1 Belgium 3
2.2 Denmark 4
2.3 France 4
2.4 Germany 5
2.5 Netherlands 5
2.6 Norway 5
2.7 Sweden 6
2.8 United Kingdom 6
3 Estimates of retained and released catches 6
3.1 National data submissions 6
3.2 Imputation of missing catch estimates 7
3.3 Inclusion of post-release mortality 9
4 Comparison with commercial fisheries removals 11
5 Length composition data and selectivity 12
6 Potential scenarios for reconstruction 13
7 References. 15

1 Introduction

This working document summarises marine recreational fishery (MRF) catch estimates for cod (*Gadus morhua*) provided by European countries for use by the North Sea and Skagerrak benchmark meeting WKNSEA 2021 following a data call. The national estimates cover varying numbers of years between 2009 and 2019, and some are for retained fish only, others also include released fish. One country (Netherlands) conducts its surveys biennially. Some countries also provided raw length frequency data for retained and in some cases released cod. Quality issues also arise due to the differences in survey methods, sample sizes, and biases.

The estimates cannot simply be combined over countries each year since 2009 due to the large number of missing country-year data. Radford et al. (2018) analysed data available from recreational fisheries sampling in European countries and developed procedures to impute recreational catches where national data were missing. They concluded that biomass removed by MRF was low for several species, such as North Sea, Eastern English Channel and Skagerrak cod (cod.27.47d20), for which MRF accounted for 10% of total commercial and fishery removals.

Further data have become available since the Radford et al. (2018) study. This document uses a very simple method to impute missing data to allow calculation of total annual recreational removals from the cod.27.47d20 stock over a series of years, with estimated or imputed values for all countries providing at least some data (Belgium, Germany, Denmark, Sweden, Norway, Netherlands, United Kingdom). A number of scenarios for reconstructing historical recreational catch values back to the 1960s are considered that may allow an investigation of the sensitivity of the ICES assessment and advice to inclusion of recreational catch data.

1.1 Existing knowledge of stock trends

A strong driver of fishery catches is changes in abundance of fish from year to year, and this needs to be considered in evaluating time series of fishery catches. Stock estimates from the ICES assessment of cod.27.47d20 are derived from an analysis of a time series of commercial catch data starting in the 1960s together with trawl survey data (Fig. 1). Recreational catch estimates provided for WKNSEA 2021 only start in 2009, in a period following large reductions in recruitment and biomass.

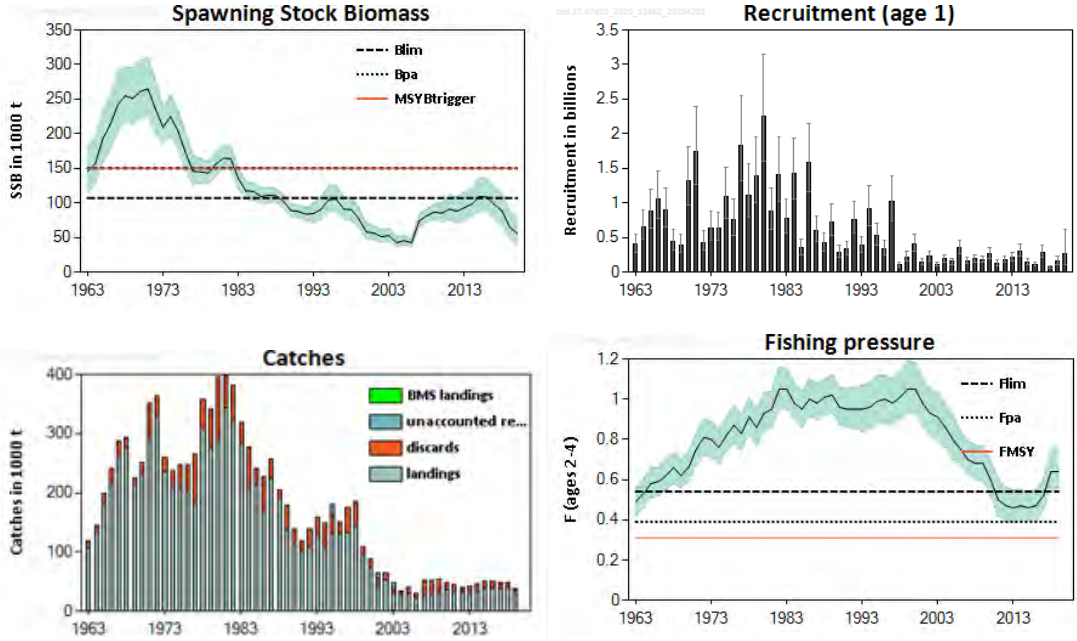


Fig. 1. Cod in Subareas III and IV and Division VIId: stock trends from the assessment (ICES 2020).

During this recent period commercial catches and recruitment have been very low but relatively stable. Commercial fishing mortality estimates have varied around F_{lim} since the late 2000s after a long-term decline from very high values in 1980s and 1990s. A recent upturn coincides with a reduction in biomass (Fig. 1).

Recreational catches are not subject to TACs and quotas, and the quantities caught in different areas of the North Sea would be expected to follow the abundance of fish in inshore waters to an extent depending on recreational fishing effort on cod, which may increase when local abundance is increasing. The ICES IBTS survey programme shows that in all areas except the southern North Sea the total biomass increased between 2005 and 2017 then declined, due to changes in recruitment. Trends in local abundance experienced by recreational fishing from the shore or small boats may differ to some extent from the wider North Sea areas.

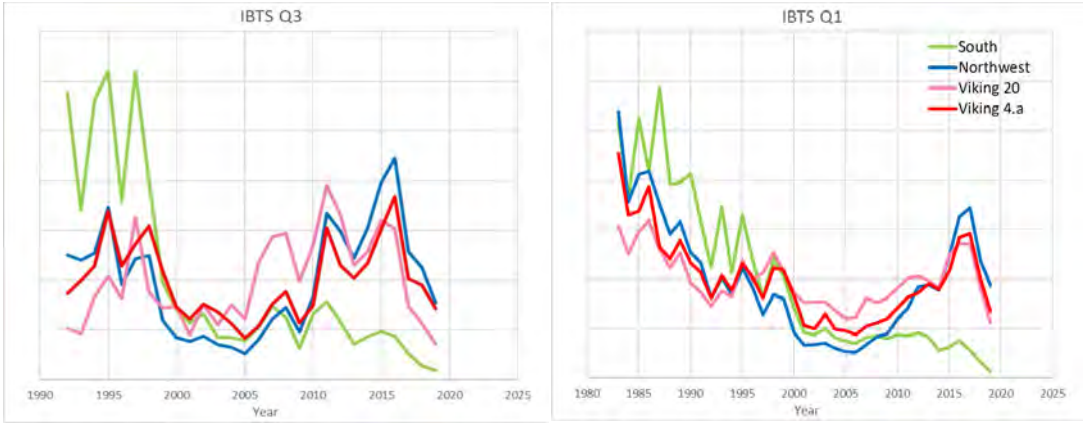


Fig. 2. Cod in Subarea 4, Division 7.d, and Subdivision 20 (Skagerrak). Biomass indices by subregion, based on the NS IBTS Q1 and Q3 survey data (ICES 2020)

2 National recreational fishery catch estimates

Recreational catch estimates were provided for the 2021 cod benchmark assessment by Belgium, Germany, Denmark, Sweden, Norway, Netherlands, and the UK, from sampling in ICES Subareas III and IV and Division VIId. France could not provide data with sufficient quality. The data cover the period 2009 – 2019 to varying extents (Table 1). In most cases the surveys have two components – a nationwide survey to estimate numbers of recreational fishers and/or their effort, and a separate onsite or offsite survey to estimate catch per unit effort (CPUE). The methods in most cases have been reviewed by the ICES Working Group on Recreational Fisheries, but are not fully coordinated across countries and are subject to varying biases which in general are poorly understood. Three countries did not supply precision estimates. Given these limitations, it is impossible to create a series of international recreational catches for the cod stock area over the period of data availability without extensive imputations. These will inevitably lead to an accumulation of biases related to survey design, implementation, and analysis. A summary of data provided is given in Table 1 and expanded in the subsequent text. Further information is available in annual reports of the ICES Working Group on Recreational Fisheries.

2.1 Belgium

Belgium has a continuous multispecies survey running from 2017 until 2021. Onsite surveys (beach, marinas, aerial, interviews) are combined with a logbook survey (on a trip basis) to estimate catches (numbers and weights) (Verleye et al. 2020). Self-reporting (logbook surveys) are extrapolated for the whole community using extensive field surveys to assess fishing effort (Verleye et al. 2020).

Areas and years: ICES area 4, two years: 2018, 2019.

Table 1. Summary of recreational survey data for cod.27.47d20.

Country	Years	Sector	Retained weight	Released weight	Retained numbers	Released numbers	Length freq.
Belgium	2018-19	All	Yes	Yes	Yes	Yes	Yes
Denmark	2009-19	Residents	Yes	No	No	Yes	No
France	2006-7	Residents	No	No	No	No	No
Germany	2014/2015	Residents	Yes	No	Yes	Yes	No
Netherlands	2010,12,14,16,18	Residents					Yes
Norway	2018/2019	Tourists/ charter	Yes	No	Yes	Yes	Yes
Sweden	2013-19	Residents	Yes	No	No	No	No
United Kingdom	2012 / 2016-19	Residents	Yes	Yes	Yes	Yes	Yes / Yes

2.2 Denmark

An online questionnaire survey (DST) carried out twice in each year targets license holders, with 30 - 45% response rates. An additional omnibus survey in 2009 and 2010 estimated numbers fishing without a license. The survey was presented during the ICES WKBALTCODII and benchmark assessment of the Western Baltic cod (Anon. 2019). The method is known to introduce recall bias. (Olesen and Storr-Paulsen, 2015; Sparrevohn and Storr-Paulsen, 2010, 2012). Bias correction factors for retained and released fish in the DST survey (avidity bias, recall bias, digit preference, telescoping, etc.) were calculated by comparing the results from an on-site interview survey (REKREA) performed on tour boats and harbours along the Danish coast of the Sound (ICES area SD23) with equivalent results from the DST survey for the same area. The REKREA multiplier is 0.7605 for harvest and 0.3538 for released cod. These multipliers are used in all ICES SD areas (SD22, 23 and 24) as well as in Subarea III. Catch estimates in the present report include these correction factors.

Areas and years: ICES sub areas 3 and 4. 11 years: 2009 – 2019 in each area.

2.3 France

France started a multispecies survey in 2017. The screening survey took place in November–December, and the diary survey was launched in 2018 and 2019. Fishers are recruited to describe their monthly catches based on logbooks. No data will be available because catches are not reliable (low number of panellists). A new national survey will be launched at the end of the year 2020. Particular attention will be paid to bias treatment and results quality.

Data on recreational fisheries from the 2017-19 survey was considered unreliable, so cannot be used to support stock assessment. In addition, as estimated cod catches are lower than the associated confidence interval (Herfaut et al., 2013), these values are considered unsound and should not be included in stock assessment models. Previous surveys regarding cod catches have led to the conclusion that few French fishers targeted this species in very localised areas (around 60 km of the French coastline), therefore cod recreational catches in France are considered negligible.

Areas and years: Area VIId and Subarea 4. Years 2006-7 and 2017-19.

2.4 Germany

The last recreational fisheries survey covering the German North Sea was conducted in 2014/2015. A representative, nationwide survey (50,000 households) using computer-assisted telephone interviews (CATI) based on random digit dialling (RDD) followed by a 1-year diary study with quarterly follow-ups was done. The survey revealed that about 32,000 German anglers fished at least once at the German North Sea resulting in a total of 147,000 angling days per year. Cod was mainly caught from private and charter boats. However, only very few North Sea anglers (n=15) participated in the diary study resulting in few reported fishing days (n=77). Therefore, cod catch estimates are uncertain. Recently, a similar but enlarged survey (150,000 households) has been started and will be used to update the data from 2014/2105 in 2021/2022. No biological catch data (e.g., length frequencies or weights) are available from the recreational fishery in the North Sea (Weltersbach et al., 2021).

Areas and years: ICES area subarea 4. One year: 2014/15.

2.5 Netherlands.

The screening survey is a panel survey used to estimate the number of recreational anglers, and is conducted every two years by a commercial marketing company. The demographics of the panel such as age, gender, education level and place of residence are controlled to ensure that it resembles the demographics of the Dutch population. In the screening survey, respondents were asked about their fishing habits and participating in a 12-month logbook survey. Participants for the logbook survey were recruited from the screening survey from the pool of participants who planned to fish. They were selected with a probability of inclusion based on an analysis of demographics including age, gender, and region of residence to match the ratios found in the screening survey. Participants maintained a logbook in which they recorded per fishing trip information on catch and effort. Catch composition was obtained using an onsite survey conducted at the same time as the logbook survey. Length data were collected from an onsite survey of anglers fishing from the shore and boats and were used for the number to biomass conversion, after combining across all years as the number of records in a single year was low. The large screening survey (50,000 households) was combined with the logbook survey (~ 2000 marine anglers) to estimate annual catches after correcting for avidity. Drop-out rate in the logbook survey is high (stated that they did not fish), especially in the latest years, resulting in low number of fishers reporting cod (van der Hammen, 2019).

Areas and years: ICES area subarea 4. Five years biennial surveys: 2010, 2012, 2014, 2016, 2018. Some additional years of length composition data were provided.

2.6 Norway

Tourist fishing businesses earning more than 50,000 NOK per year are registered and required to submit landings and released numbers of fish caught. There are quality issues: up to 2020, only 65% of businesses reported data and 12% went out of business or did not provide tourist fishing services. A probability-based survey in one county gave similar estimates of retained fish as given by the tourist businesses. Data provided for North Sea cod are for one year, spanning 2018 and 2019, and are numbers and weight of cod retained and numbers only for released cod. The landed weight was calculated by multiplying the estimated numbers with the estimated average weight of landed cod in Hordaland (1.28 kg; N=123) based on a roving creel survey and sampling of tourist fishing businesses in 2018 and 2019. As no recent average weight data for recreationally caught cod are available for the other counties in ICES area 4a, the weight estimate may be biased. More detail at https://www.fiskeridir.no/Tall-og-analyse/AApne-data/AApne-datasett/Turistfiskedata

Areas and years: ICES Sub Areas 3 & 4. One year covering 2018/19

2.7 Sweden

Recreational catches for most areas in Sweden are estimated by an annual household mail survey with 11.000 questionnaires sent to households in 2013-2017 (HaV 2019b) rising to 19,000 in 2018 (HaV 2018) and 22,000 in 2019 (HaV 2019a). Most fishing is concentrated in May to August and number of questionnaires are distributed accordingly (Jan-Apr: 25%, May-Aug: 50%, Sept-Dec: 25%). The survey results in few responses of catch per reported species per ICES subdivision. For Skagerrak (Area 3; SD20) the average number of observations of cod catches in this area was 19 for 2013-2019. Estimates have large variances. Released catches and size composition data were not available.

Areas and years: ICES Sub Area 3. Seven years 2013-2019

2.8 United Kingdom

Surveys in 2012 covered England only and utilised three surveys: 1) a stratified random roving-creel survey to estimate CPUE (catch per day) of retained and released fish for shore and private or rented boat fishing; 2) a nationwide randomised face-to-face omnibus survey to estimate shore and boat recreational fishing effort, and 3) a separate diary record of catches of charter boats selected randomly and with known probability each quarter from a comprehensive list of vessels (Armstrong et al., 2013). From 2016 onwards, a different off-site survey approach was adopted involving a UK-wide randomised face-to-face omnibus survey of water sports activities to estimate the number, demography and other characteristics of UK residents going sea angling during each year, and a panel of sea anglers volunteering each year to keep catch diaries to record number and sizes of fish retained and released in each fishing trip, from which annual catches per angler are estimated for each species (Hyder et al., 2020). Despite re-weighting the panel to make it more representative of the angling population in terms of characteristics such as avidity and age, the panel has given substantially larger catch estimates of catches in England, especially releases, compared with the onsite and charter boat surveys of England in 2012. As this has not been resolved yet, the 2012 data are not used in the evaluation of total European recreational catches of cod in this Working Document. It should be noted that the onsite UK estimates used in this analysis are likely to represent an overestimate of the actual levels of catch, so represent a worst-case scenario.

Areas and years: ICES Subarea 4 and Division 7d. Years 2012 (on-site surveys) and 2016 – 2019 (off-site surveys)

3 Estimates of retained and released catches

3.1 National data submissions

Catch estimates were provided for all fishing platforms combined (shore, boat) except for Norway where estimates were from charter boats operated by tourist fishing businesses. The longest and most continuous time series is from Denmark (2009 – 2019), which provided total catch weights for retained fish, not numbers, and total numbers of released fish, but not weights (Table 2). The shortest data series were from Belgium, Germany, and Norway. The Netherlands surveys occur biennially, and provide weights and numbers for retained fish, but numbers only for released fish. Sweden provided retained weight estimates for the Skagerrak from 2013 to 2019, but no retained numbers and no data at all for released fish. The most complete data in terms of numbers and weights is from the UK, for years 2012 and 2016-2019. Due to the change in UK survey methods after 2012, and the large differences in estimates (especially releases) between 2012 and 2016 onwards, the 2012 data are not used for compiling international catch totals. Where provided, estimated RSEs are mostly moderate with most in the range 0.15-0.40.

Table 2. Estimates of recreational catch numbers and catch weights provided by each country, with relative standard errors where available. NA = no data provided.

				Recreational Retained				Recreational Released				Total Recreational			
Country	ICES Area	Year	Platform	Weight (t)	RSE	Numbers	RSE%	Weight (t)	RSE	Numbers	RSE	Weight (t)	RSE	Numbers	RSE
Belgium	Subarea IV	2018	All	31	NA	21794	NA	1.70	NA	3597	NA	32.90		25391	NA
Belgium	Subarea IV	2019	All	3	NA	1834	NA	0.30	NA	678	NA	3.30		2512	NA
Germany	Subarea IV	2014-15	All	NA	NA	47391	0.13	NA	NA	20158	0.13	NA	NA	67365	0.13
Denmark	Subarea III	2009	All	172	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Denmark	Subarea III	2010	All	124	0.13	NA	NA	NA	NA	38105	0.20	NA	NA	NA	NA
Denmark	Subarea III	2011	All	140	0.11	NA	NA	NA	NA	36700	0.16	NA	NA	NA	NA
Denmark	Subarea III	2012	All	132	0.11	NA	NA	NA	NA	32431	0.25	NA	NA	NA	NA
Denmark	Subarea III	2013	All	249	0.16	NA	NA	NA	NA	21771	0.16	NA	NA	NA	NA
Denmark	Subarea III	2014	All	439	0.16	NA	NA	NA	NA	40273	0.13	NA	NA	NA	NA
Denmark	Subarea III	2015	All	273	0.12	NA	NA	NA	NA	27511	0.13	NA	NA	NA	NA
Denmark	Subarea III	2016	All	297	0.12	NA	NA	NA	NA	22801	0.15	NA	NA	NA	NA
Denmark	Subarea III	2017	All	200	0.15	NA	NA	NA	NA	34665	0.16	NA	NA	NA	NA
Denmark	Subarea III	2018	All	188	0.15	NA	NA	NA	NA	21014	0.18	NA	NA	NA	NA
Denmark	Subarea III	2019	All	133	0.10	NA	NA	NA	NA	16405	0.13	NA	NA	NA	NA
Denmark	Subarea IV	2009	All	119	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Denmark	Subarea IV	2010	All	88	0.21	NA	NA	NA	NA	9037	0.30	NA	NA	NA	NA
Denmark	Subarea IV	2011	All	91	0.18	NA	NA	NA	NA	15316	0.18	NA	NA	NA	NA
Denmark	Subarea IV	2012	All	58	0.19	NA	NA	NA	NA	13109	0.30	NA	NA	NA	NA
Denmark	Subarea IV	2013	All	116	0.24	NA	NA	NA	NA	5629	0.21	NA	NA	NA	NA
Denmark	Subarea IV	2014	All	202	0.26	NA	NA	NA	NA	17521	0.18	NA	NA	NA	NA
Denmark	Subarea IV	2015	All	156	0.17	NA	NA	NA	NA	20548	0.15	NA	NA	NA	NA
Denmark	Subarea IV	2016	All	145	0.15	NA	NA	NA	NA	16643	0.21	NA	NA	NA	NA
Denmark	Subarea IV	2017	All	77	0.18	NA	NA	NA	NA	23172	0.43	NA	NA	NA	NA
Denmark	Subarea IV	2018	All	98	0.19	NA	NA	NA	NA	11785	0.29	NA	NA	NA	NA
Denmark	Subarea IV	2019	All	83	0.18	NA	NA	NA	NA	10932	0.21	NA	NA	NA	NA

				Recreational Retained				Recreational Released				Total Recreational			
Country	ICES Area	Year	Platform	Weight (t)	RSE	Numbers	RSE	Weight (t)	RSE	Numbers	RSE	Weight (t)	RSE	Numbers	RSE
Netherlands	Subarea IV	2010	All	631	NA	522000	NA	NA	NA	168000	NA	NA	NA	690000	NA
Netherlands	Subarea IV	2012	All	737	NA	609000	NA	NA	NA	392000	NA	NA	NA	1001000	NA
Netherlands	Subarea IV	2014	All	945	NA	771000	NA	NA	NA	534000	NA	NA	NA	1305000	NA
Netherlands	Subarea IV	2016	All	191	NA	165000	NA	NA	NA	324000	NA	NA	NA	489000	NA
Netherlands	Subarea IV	2018	All	91	NA	120000	NA	NA	NA	67000	NA	NA	NA	187000	NA
Norway	Subarea IV	2018-20	Charter	68	NA	53164	NA	NA	NA	29050	NA	NA	NA	82214	NA
Norway	Subarea III	2018-20	Charter	46	NA	35829	NA	NA	NA	20667	NA	NA	NA	56496	NA
Sweden	Subarea III	2013	All	151	0.39	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2014	All	102	0.50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2015	All	104	0.32	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2016	All	61	0.33	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2017	All	63	0.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2018	All	30	0.39	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	Subarea III	2019	All	19	0.33	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
UK	Subarea IV&VIId	2012	All	280	0.28	233528	0.22	43	0.29	123209	0.23	323	0.25	356737	0.17
UK	Subarea IV&VIId	2016	All	1051	0.40	512630	0.38	618	0.31	953455	0.28	1670	0.28	1466085	0.22
UK	Subarea IV&VIId	2017	All	630	0.27	369363	0.23	610	0.23	1142710	0.22	1240	0.18	1512073	0.17
UK	Subarea IV&VIId	2018	All	1495	0.45	544762	0.27	844	0.38	687356	0.22	2339	0.32	1232118	0.17
UK	Subarea IV&VIId	2019	All	447	0.32	316385	0.28	446	0.44	755252	0.28	892	0.27	1071637	0.22

3.2 Imputation of missing catch estimates

Radford et al. (2018) used imputation methods based on "borrowing" of data from nearest-neighbour national fisheries to fill missing data cells. The present study uses a simpler method to impute missing annual national estimates of retained catch weight or numbers. It was assumed that the series of Danish estimates from 2009 to 2019 represented a "true" time series in terms of relative abundance trends. For the other countries, a scaling factor was calculated as the sum of annual survey estimates of catch from that country divided by the sum of survey catches from Denmark for the years where both countries had survey estimates (e.g., 2010, 2012, 2014, 2016, 2018 for the Netherlands, 2016-2019 for the UK). Catches for years with no data for a country were then imputed by multiplying the Danish survey estimates for those years by the scaling factor for that country.

Figures 3a-c show the relationship between estimates of annual catch weight from Denmark and the UK, Netherlands, and Sweden along with the imputed values. The R^2 values for the survey estimate correlations with Denmark were 0.18 (n=4) for the UK, 0.28 (n=7) for Sweden and 0.07 (n=5) for the

Netherlands. These show that the accuracy of imputed catch values is poor (and will be worse for Belgium, Germany, and Norway where there are only one or two years of data). However, they may be useful for evaluating the general magnitude of recreational catches compared with commercial catches.

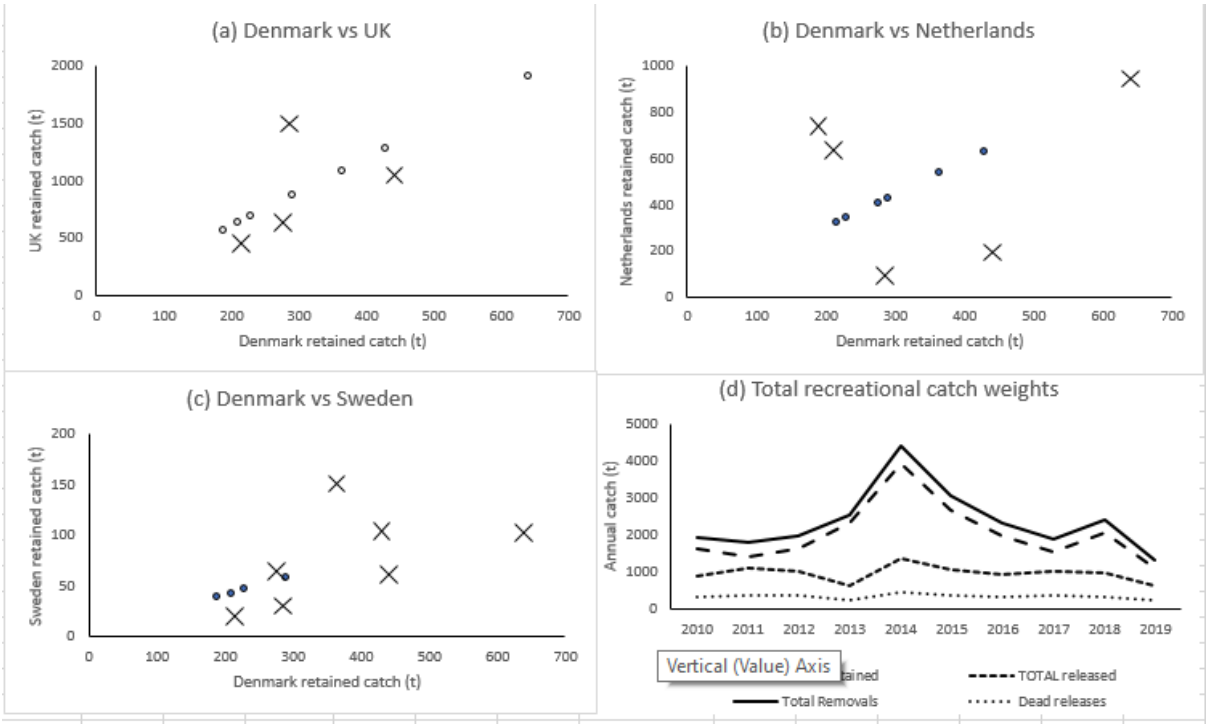


Fig. 3. Scatterplots of estimates of annual retained cod catch in Denmark against annual retained catch in (a) UK, (b) Netherlands and (c) Sweden. "X" symbols are the survey estimates supplied to ICES. The dots are the imputed values for the three countries for years with no estimates. Plot (d) shows the time series of total international catches and removals.

The same procedure was applied to the retained and released catch numbers, although Danish and Swedish retained catch numbers had to be calculated from the supplied survey estimates of catch weight by dividing by a value of mean weight of individual fish retained, as retained numbers were not supplied. This was obtained by averaging over the mean weight estimates for other countries (UK and Belgium) where estimates of annual catches were supplied in numbers and weights, allowing estimation of mean weights taking account of any effects of weightings in the survey data analyses. The resultant mean weight estimate for retained cod was 1.49kg.

Imputation of released catch weights was the most difficult exercise as only Belgium and the UK provided annual catch estimates by weight for released cod. Where other countries had provided release numbers but no weights, the catch weights were calculated by applying a value for mean weight of released fish (0.653kg) obtained from UK and Belgium data using the same procedure described for estimating mean retained individual catch weights. The imputation procedure described previously was then applied to fill in years with missing data for each country. Since Denmark did not supply released catch data for 2009, no imputations were done for 2009, and the catch series considered further was restricted to 2010 – 2019.

3.3 Inclusion of post-release mortality

No fisheries-specific studies on post-release mortality of recreationally caught North Sea cod are available. However, some studies investigating post-release mortality and potential sublethal effects have been conducted in other regions (Weltersbach and Strehlow, 2013; Ferter et al., 2015a, b; Capizzano et al., 2016). A telemetry study with nine cod in Norwegian coastal waters showed no mortality and no major behavioural changes when cod were caught and released under best practice conditions (Ferter et al., 2015a). Another study revealed no short-term mortality of cod experiencing barotrauma when cod were able to submerge and otherwise not substantially injured (Ferter et al., 2015b). Weltersbach and Strehlow (2013) estimated an overall mean mortality rate of 11.2% (SE ±22.0) for released cod in the western Baltic Sea recreational charter vessel fishery during an experimental containment study. A telemetry study in the Gulf of Maine (Capizzano et al., 2016) revealed an overall post-release mortality estimate of 16.5% (95% CI: 9.9%, 35.1%) for the GOM sea-based recreational cod fishery in 2013. This cod fishery has similar fishing characteristics to the North Sea boat-based recreational cod fishery. Therefore, the post-release mortality estimate of Capizzano et al. (2016) could be used for sea-based catches of North Sea cod.

A significant proportion of the recreational cod catch is taken by shore anglers who commonly use natural bait for fishing. Weltersbach et al. (2019) showed that the incidence of deep hooking and severe bleeding was significantly higher for cod caught with natural bait. In combination with rougher fishing conditions (e.g., surf, abrasion risk, longer fighting time) when fishing from shore, this results most likely in higher post-release mortality rates for shore fishing (Weltersbach and Strehlow, 2013). Therefore, it is likely that the overall post-release mortality is higher than the 16.5% estimated by Capizzano et al. (2016). Nevertheless, no studies on post-release mortality exist for land-based (bait) recreational cod fisheries and furthermore, little information on the proportion of bait use in different countries is available preventing a more accurate estimation. Therefore, as a precautionary approach the upper 95% confidence limit of 35.1% from the Capizzano et al. (2016) study is used as post-release mortality rate in the present document to derive recreational fishery removals of cod. Figures for removals due to dead releases and total removals including retained fish are given in Table 5 and Fig.3d.

Table 3. Estimates of total annual retained cod by numbers and weight. Survey estimates supplied to ICES are in bold typeface, other figures are imputed. Denmark and Sweden figures are derived from annual catch weights divided by a mean retained catch weight of 1.49kg.

		mean weight retained fish:	1.485					
	Retained numbers							
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL
2009	13712	*196172*	21539	287382	90580	39047	415822	1064254
2010	9969	*142628*	15660	**522000**	65857	28389	302326	1086829
2011	10857	*155325*	17054	227543	71720	30916	329239	842654
2012	8946	*127996*	14054	**609000**	59101	25477	271310	1115883
2013	17163	*245557*	26962	359729	113383	*101802*	520502	1385099
2014	30169	*431623*	**47391**	**771000**	199297	*68407*	914901	2462788
2015	20191	*288877*	31718	423190	133386	*69686*	612325	1579373
2016	20807	*297690*	32685	**165000**	137455	*40734*	**512630**	1207002
2017	13044	*186624*	20491	273396	86172	*42552*	**369363**	991642
2018	**21,794**	*192734*	21162	**120000**	**88993**	*20132*	**544762**	1009577
2019	**1,834**	*145313*	15955	212876	67097	*12658*	**316385**	772118
	Retained weight							
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL
2009	20	**291**	31.99	427	116	58	864	1808
2010	14	**212**	23.26	**631**	84	42	628	1636
2011	16	**231**	25.33	338	92	46	684	1432
2012	13	**190**	20.87	**737**	76	38	564	1638
2013	25	**365**	40.04	534	145	**151.2**	1082	2342
2014	44	**641**	**70.39**	**945**	255	**101.6**	1902	3959
2015	29	**429**	47.11	629	171	**103.5**	1273	2681
2016	30	**442**	48.55	**191**	176	**60.5**	**1051**	2000
2017	19	**277**	30.43	406	110	**63.2**	**630**	1536
2018	**31**	**286**	31.43	**91**	**114**	**29.9**	**1495**	2079
2019	**3**	**216**	23.70	316	86	**18.8**	**447**	1110
							mean 2010 on	2041

Table 4. Estimates of total annual released cod by numbers and weight. Survey estimates supplied to ICES are in bold typeface, others are imputations.

	Mean weight released fish:	0.653							
	Released numbers								TOTAL
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL	Ret. + Rel
2009		NA							
2010	3351	**47142**	16443	**168000**	71459	30487	1059751	1396632	2460886
2011	3698	**52016**	18142	346821	78847	33201	1169318	1702042	2788871
2012	3237	**45539**	15884	**392000**	69030	27359	1023730	1576779	2419433
2013	1948	**27400**	9557	182691	41533	109326	615948	988401	2104285
2014	4109	**57794**	**20158**	**534000**	87606	73462	1299222	2076351	3461450
2015	3416	**48059**	16762	320440	72849	74836	1080374	1616737	4079525
2016	2804	**39444**	13758	**324000**	59790	43745	**953455**	1436996	3016369
2017	4112	**57838**	20173	385641	87672	45697	**1142710**	1743842	2950844
2018	**3597**	**32799**	11440	**67000**	**49717**	21619	**687356**	873528	1865170
2019	**678**	**27337**	9535	182276	41439	13593	**755252**	1030110	2039687
	Released weight								TOTAL
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL	Ret. + Rel
2009		NA							
2010	2.2	*30.8*	10.73	109.6	46.6	19.9	691.5	911	2547
2011	2.4	*33.9*	11.84	226.3	51.4	21.7	763.0	1111	2542
2012	2.1	*29.7*	10.36	255.8	45.0	17.9	668.0	1029	2667
2013	1.3	*17.9*	6.24	119.2	27.1	71.3	401.9	645	2987
2014	2.7	*37.7*	13.15	348.4	57.2	47.9	847.7	1355	5314
2015	2.2	*31.4*	10.94	209.1	47.5	48.8	704.9	1055	3736
2016	1.8	*25.7*	8.98	211.4	39.0	28.5	**618**	934	2934
2017	2.7	*37.7*	13.16	251.6	57.2	29.8	**610**	1002	2539
2018	**1.7**	*21.4*	7.46	43.7	32.4	14.1	**844**	965	3044
2019	**0.3**	*17.8*	6.22	118.9	27.0	8.9	**446**	625	1735
							mean:	963	3004

Table 5. Estimates of total annual dead releases by numbers and weight, obtained by applying a post-release mortality of 0.351. Total removals are the sum of retained cod and dead releases.

Total release numbers x release mortality					Release mortality:		0.351		
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL	Total Removals
2009									
2010	1176	**16547**	5771	**58968**	25082	10701	371973	490218	1577047
2011	1298	**18258**	6368	121734	27675	11654	410431	597417	1440071
2012	1136	**15984**	5575	**137592**	24229	9603	359329	553449	1669333
2013	684	**9617**	3354	64124	14578	38373	216198	346929	1732028
2014	1442	**20286**	**7075**	**187434**	30750	25785	456027	728799	3191587
2015	1199	**16869**	5884	112474	25570	26267	379211	567475	2146848
2016	984	**13845**	4829	**113724**	20986	15354	**334663**	504385	1711387
2017	1443	**20301**	7081	135360	30773	16040	**401091**	612089	1603731
2018	**1263**	**11512**	4015	**23517**	**17451**	7588	**241262**	306608	1316185
2019	**238**	**9595**	3347	63979	14545	4771	**265093**	361569	1133686
Total release weight x release mortality									
Year	BE	DK	DE	NL	NO	SE	UK	TOTAL	Total Removals
2009		NA							
2010	0.77	*10.80*	3.77	38.48	16.37	6.98	242.71	320	1955
2011	0.85	*11.91*	4.16	79.43	18.06	7.60	267.81	390	1822
2012	0.74	*10.43*	3.64	89.78	15.81	6.27	234.46	361	2000
2013	0.45	*6.28*	2.19	41.84	9.51	25.04	141.07	226	2569
2014	0.94	*13.24*	4.62	122.30	20.06	16.82	297.56	476	4434
2015	0.78	*11.01*	3.84	73.39	16.68	17.14	247.44	370	3051
2016	0.64	*9.03*	3.15	74.21	13.69	10.02	**217.02**	328	2327
2017	0.94	*13.25*	4.62	88.32	20.08	10.47	**214.18**	352	1888
2018	**0.60**	*7.51*	2.62	15.34	11.39	4.95	**296.16**	339	2418
2019	**0.11**	*6.26*	2.18	41.75	9.49	3.11	**156.39**	219	1330
							mean:	338	2379

4 Comparison with commercial fisheries removals

The percentage of total commercial and recreational removals represented by commercial fisheries (including imputations for missing countries each year), assuming 100% discard mortality in commercial fisheries, ranged from 3.4 – 8.9%, averaging 4.9% (Table 6). The accuracy of this figure will be very variable due to the large amount of imputation which ranged from 3% in 2018 to 90% in 2012. The percentage of total removals due to recreational fishing was 4.8% in 2018, the year with least imputation, close to the average of the series (Table 6). The recreational catch estimates are subject to biases related to survey design, implementation, and analysis. This includes recall bias in some off-site surveys, incomplete coverage of the national fishery (e.g., Norway), missing national data, and methods of imputing missing values.

The discard mortality rate of commercially caught cod may be less than 100%, and the post-release mortality rate of 35.1 % for the recreational fishery releases is associated with uncertainty. Table 7a gives figures for recreational removals weight as percentage of total removals for a range of post-release mortality rates up to 100%. Even up to 100% PRM, the contribution of recreational fishing to total removals weight remains well below 10% in most years, averaging 6%. The figures are larger for catch numbers (Table 7b), but the average is still relatively low at 9%.

Table 6. Annual total commercial landings and discards of cod in the North Sea, Skaggerak, and Eastern Channel (ICES advice, 2020), and recreational removals for countries supplying catch data (including imputed values from the present report). The %recr column gives recreational removals as a percentage of total commercial and recreational removals assuming 100% mortality in commercial discards and 35.1% PRM in MRF. The % of the total annual recreational removals tonnage derived from imputation is shown.

	commercial removals (t)			Recreational removals (t)				
Year	Landings	Discards	Total	Retained	Released	Total	% recr.	%imputed
2010	36029	12267	48296	1636	320	1955	3.9	56
2011	34042	10162	44204	1432	390	1822	4.0	87
2012	32527	7530	40057	1638	361	2000	4.8	90
2013	30870	10753	41623	2342	226	2569	5.8	80
2014	34816	10807	45623	3959	476	4434	8.9	60
2015	38080	13017	51097	2681	370	3051	5.6	82
2016	38794	12624	51418	2000	328	2327	4.3	15
2017	38522	9017	47539	1536	352	1888	3.8	37
2018	40082	8216	48298	2079	339	2418	4.8	3
2019	33385	4231	37616	1110	219	1330	3.4	36
Mean	35715	9862	45577	2041	338	2379	4.9	55

Table 7. Effect on the % of total fishery removals comprising recreationally caught cod of using a range of values for post-release mortality used in the present study (commercial catch weights from ICES 2020 advice sheet; commercial catch numbers up to 2018 from ICES WGNSSK 2020 report).

(a) % of total catch weight

	Post-release mortality %				
Year	16.5%	35.1%	60%	80%	100%
2010	3.6	3.9	4.3	4.7	5.0
2011	3.5	4.0	4.5	5.0	5.4
2012	4.3	4.8	5.3	5.8	6.2
2013	5.6	5.8	6.2	6.4	6.7
2014	8.4	8.9	9.5	10.0	10.4
2015	5.3	5.6	6.1	6.5	6.8
2016	4.0	4.3	4.7	5.1	5.4
2017	3.5	3.8	4.3	4.7	5.1
2018	4.4	4.8	5.2	5.6	5.9
2019	3.1	3.4	3.8	4.1	4.4
Mean	4.6	4.9	5.4	5.8	6.1

(b) % of total catch numbers

	Post-release mortality %				
Year	16.5%	35.1%	60%	80%	100%
2010	3.7	4.4	5.3	6.0	6.8
2011	4.3	5.4	6.9	8.1	9.2
2012	4.5	5.4	6.6	7.5	8.5
2013	6.1	6.8	7.7	8.4	9.1
2014	8.5	9.6	11.0	12.1	13.1
2015	5.7	6.6	7.7	8.6	9.5
2016	5.7	6.7	8.0	9.0	9.9
2017	4.7	5.8	7.3	8.4	9.5
2018	4.0	4.5	5.2	5.8	6.4
2019					
Mean	5.2	6.1	7.3	8.2	9.1

5 Length composition data and selectivity

Sampling data on length compositions of recreational catches were supplied in raw form for retained catches (Belgium, Netherlands, UK, Norway) and released catches (Belgium, UK) in 1 cm intervals. The annual data were raised to the corresponding total catch numbers given in Tables 3 and 4, then summed over years with data. The percentage length compositions for retained fish appear similar for Belgium, UK, and Norway, but the Netherlands data indicate more retention in lengths below 40 cm (Fig 4). For released fish, the Belgian data show that almost all fish above 45 cm were retained, whilst in the UK, release rates varied between 10-40% on most length classes above 45 cm (Fig 5). For Belgium and the UK, release rates start to increase at the minimum conservation reference size (MCRS) of 35cm, and the length at 50% release rate was around 40cm (Fig 5).

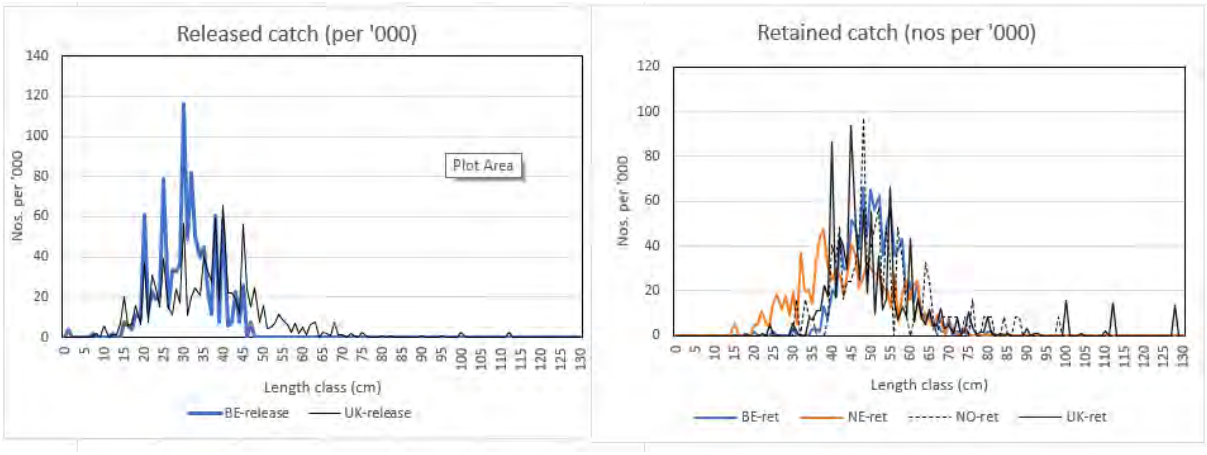


Fig. 4. Relative length compositions for released fish and retained catch, for combined, raised numbers per year for each country.

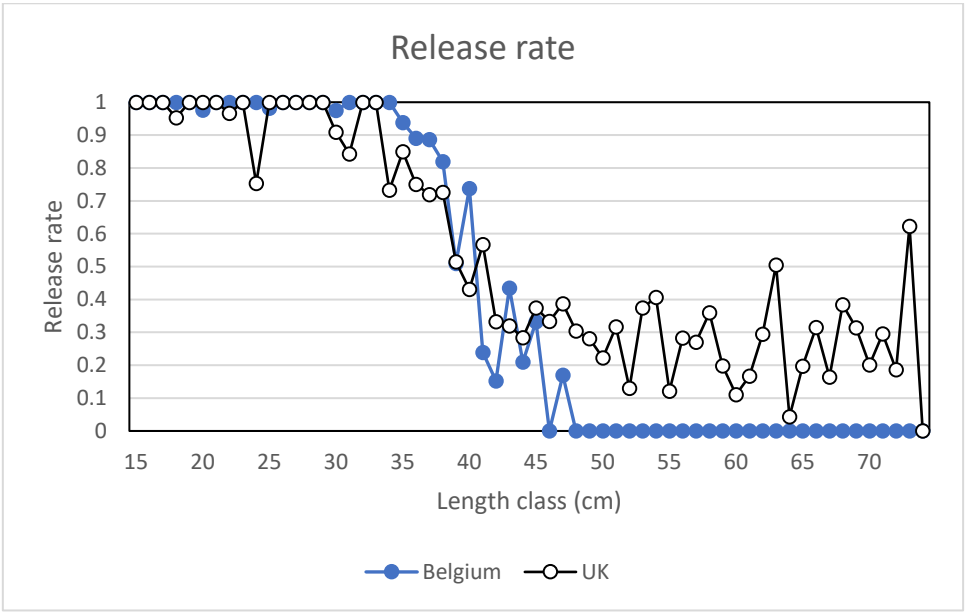


Fig. 5. Proportion released by length class in the Belgian and UK recreational catch, based on raw sample data raised to total catch numbers.

The SAM model for cod.27.47d20 is based on analysis of catch-at-age data. Whilst four countries have provided length compositions for MRF retained catch, only two provided data for released catch. Data quality can be relatively poor due to missing data, measurement and rounding errors. Any recalled data can be biased. The ICES assessment of seabass in ICES Areas IV and VII uses the Stock Synthesis model to estimate selectivity parameters for individual fisheries by generating model estimates of length compositions that match observed values as closely as possible. This cannot be done in the SAM assessment modelling framework and would have to be done externally to the model if required.

6 Potential scenarios for reconstruction

Historical recreational catches will be a function of the abundance and size composition of the cod stock, its spatio-temporal distribution, and the fishing effort, CPUE and size selectivity of the fisheries in each region. Recreational fishing effort is concentrated in coastal waters, where it can vary widely according to changes in abundance of stocks of interest. Unlike quota-controlled commercial fisheries, there are few controls historically on recreational fishing other than the minimum conservation

reference size (MCRS) and local by-laws for example preventing certain fishing methods and fishing in specified areas. Several scenarios are possible for historical catch reconstruction:

1) Setting the annual catch according to a fixed ratio of recreational to commercial fishing catches, established from the recent fishery data. This may be feasible if the fishing mortality in both fisheries have followed the same relative trend. In the absence of historical recreational catch and effort estimates, this would be difficult to establish. It is likely that the total removals due to recreational fishing may follow different trends to commercial fishing over decades given the large changes in commercial fishery F.
2) Setting a constant recreational catch. Given the large changes in stock biomass (Fig. 1), a scenario of constant catch is implausible.
3) Assuming a trend in recreational fishing mortality and scaling it so that the catches generated by this in a statistical assessment model match the observed values from recent recreational fishing surveys as closely as possible. This approach is adopted for seabass in ICES areas IV and VII, where the recreational F is assumed constant over the full assessment period. The first implementation of this treated recreational fishing as an additional constant rate of natural mortality (M) in an implementation of Stock Synthesis 3, using some survey data on historical participation in sea angling in England to justify the choice of trend. More recent SS3 implementations include a reconstructed series of recreational catch weights for the years with no survey estimates based on the same principles of constant recreational F. Other long-term trends in MRF fishing mortality could be assumed but ancillary data such as national population size and participation rates in MRF, and fishing effort, would be needed identify a plausible range of trends in recreational F.

At present, catch reconstruction for the whole assessment period for the cod.27.47d20 stock is impossible, and it is not possible to use the SAM model to explore historical recreational F and catch scenarios based on recent survey data as done with Seabass in Subareas IV and VII using the Stock Synthesis model. It is therefore recommended that simpler approaches be developed involving documenting the relevant catches on an annual basis in an appropriate format for inclusion in the management advice process through WGNSSK.

Further efforts are needed to improve international coverage and consistency of surveys, and evaluation of biases. Furthermore, more studies on fishery-specific post-release mortality rates are needed. It would be beneficial to highlight the challenges of using recreational data for the STECF review of the recreational pilot studies data collection programmes under the EU Data Collection Framework, and considered by the ICES WGRFS.

7 References.

Anon. (2019). Working document on Danish recreational fishing surveys to ICES WKBALTCODII and benchmark assessment for the western Baltic cod.

Armstrong, M., Brown, A., Hargreaves, J., Hyder, K., Munday, M., Proctor, S., Roberts, A., Roche, N., Williamson, K. (2013). Sea Angling 2012 – a survey of recreational sea angling activity and economic value in England. Defra, London, UK. 16pp.

Capizzano, C.W., Mandelman, J.W., Hoffman, W.S., Dean, M.J., Zemeckis, D.R., Benoît, H.P., Kneebone, J., Jones, E., Stettner, M.J., Buchan, N.J., Langan, J.A., Sulikowski, J.A. (2016). Estimating and mitigating the discard mortality of Atlantic cod (*Gadus morhua*) in the Gulf of Maine recreational rod-and-reel fishery. ICES J. Mar. Sci. 73, 2342–2355.

Ferter, K., Hartmann, K., Kleiven, A. R., Moland, E., Olsen E. M. (2015a). Catch-and-release of Atlantic cod (*Gadus morhua*): post-release behaviour of acoustically pretagged fish in a natural marine environment. Can. J. Fish. Aquat. Sci. 72: 252–261.

Ferter, K., Weltersbach, M. S., Humborstad, O.-B., Fjelldal, P. G., Sambraus, F., Strehlow, H. V., Vølstad, J. H. (2015b). Dive to survive: effects of capture depth on barotrauma and post-release survival of Atlantic cod (*Gadus morhua*) in recreational fisheries. ICES J. Mar. Sci. 72: 2467–2481.

Havs- och Vattenmyndigheten (HaV) (2018). Fritidsfiske i Sverige 2018. Sveriges officiella statistiska meddelanden. JO 57 SM 1901.

Havs- och Vattenmyndigheten (HaV) (2019a). Fritidsfiske i Sverige 2019. Sveriges officiella statistiska meddelanden. JO 57 SM 2001.

Havs- och Vattenmyndigheten (HaV) (2019b). Fritidsfiske i Sverige. En inblick i fritidsfiskets omfattning under åren 2013-2017. Havs- och vattenmyndighetens rapport 2019:5.

Hyder, K., Brown, A., Armstrong, M., Bell, B., Bradley, K., Couce, E., Gibson, I., Hardman, F., Harrison, J., Haves, V., Hook, S., Kroese, J., Mellor, G., MacLeod, E., Muench, A., Radford, Z., Townhill, B. (2020). Participation, catches and economic impact of sea anglers resident in the UK in 2016 & 2017. Cefas, Lowestoft, UK. 170 pp.

ICES (2019). ICES Advice on fishing opportunities, catch, and effort Greater North Sea ecoregion Published 30 June 2020. http://ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/cod.27.47d20.pdf

ICES (2020). ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. http://doi.org/10.17895/ices.pub.6092

Olesen, H. J., Storr-Paulsen, M. 2015. Eel, cod, and seatrout harvest in Danish recreational fishing during 2012. Institut for Akvatiske Ressourcer, Danmarks Tekniske Universitet. DTU Aqua Report, No. 293-2015.

Radford, Z., Hyder, K., Zarauz, L., Mugerza, E., Ferter, K., Prellezo, R., Weltersbach, M. S. (2018). The impact of marine recreational fishing on key fish stocks in European waters. PLOS ONE 13: e0201666.

Silva, J. F., Ellis, J. R., Ayers R. A. (2013). Length-weight relationships of marine fish collected from around the British Isles. Sci. Ser. Tech. Rep., Cefas Lowestoft, 150: 109 pp.

SLU 2019. Working paper on Swedish recreational catches from Skagerrak.

Sparrevohn, C. R., and Storr-Paulsen, M. (2010). Eel and cod catches in Danish recreational fishing. Survey design and 2009 catches. DTU Aqua report no. 217-2010. Charlottenlund. National Institute of Aquatic Ressources, Technical University of Denmark, 23 p.

Sparrevohn, C. R., and Storr-Paulsen, M. (2012). Using interview-based recall surveys to estimate cod *Gadus morhua* and eel *Anguilla anguilla* harvest in Danish recreational fishing. ICES J. Mar. Sci. 69: 323–330.

van der Hammen, T. (2019). Recreational fisheries in the Netherlands: Analyses of the 2017 screening survey and the 2016 - 2017 logbook survey. CVO report: CVO 20.025. 33pp.

Verleye, T. J., Vanelslander, B., Dauwe, S., Torreele, E. (2020). Recreatieve zeevisserij in België anno 2029 - Feiten en cijfers. VLIZ Beleidsinformerende Nota's, 2020-008. 38pp.

Weltersbach, M. S., Strehlow, H. V. (2013). Dead or alive — estimating post-release mortality of Atlantic cod in the recreational fishery. ICES J. Mar. Sci. 70: 864–872.

Weltersbach, M. S., Lewin, W.-C., Gröger, J. P., Strehlow, H. V. (2019). Effect of lure and bait type on catch, size, hooking location, injury, and bycatch in the western baltic sea recreational cod fishery. Fish. Res. 210: 121–130.

Weltersbach, M. S., Riepe, C., Lewin, W.-C., Strehlow, H. V. (2021). Ökologische, soziale und ökonomische Dimensionen des Meeresangelns in Deutschland. Johann Heinrich von Thünen-Institut, Braunschweig, Germany, Report 83. 254pp.

WD_cod_8_Process model for biological parameters in SAM.

Anders Nielsen DTU-Aqua (an@aqua.dtu.dk)

Purpose:

In assessment and forecast of fish stocks there is a lot of focus on the correctly modelling the catches from commercial and scientific fleets, which is important, but for management the stock-weights, catch-weights, and proportion mature in each age group are equally important. Common assessment models estimate stock-sizes in numbers at age, but management is based on spawning stock biomass (SSB) and on total catch in weight, so information on weights and maturities are needed to produce those interesting quantities. Within the data period direct observations are used, and even if these should strictly be considered as observations subject to observation noise, they are treated as known constants. In the forecast period, which is directly used in management, simple ad-hoc rules are applied (e.g. average of last 5 years), and the resulting weights and maturities are treated as if known without error. This is not optimal. The focus in this work package is on providing a better, model based, alternative.

Prediction based model selection study:

To test and select a the best model based approach for predicting the biological model parameters (weights and maturities) we selected a fairly large number of stocks to use as validation data sets. The stocks were selected based on their availability of fairly long data series of the biological parameters. The stocks selected are: Northeast Atlantic Blue Whiting and Mackerel; Faroe Haddock and Saithe; North East Arctic Haddock, Saithe, and Cod; North Sea Cod, Haddock, Herring, Plaice, Saithe, Sole, and Whiting. These 14 stocks were agreed upon by the group before the different models were suggested or developed.

The model structures developed were all designed for the purpose of predicting e.g. 1-3 years forward. A large number of different suggestions were implemented and subjected to the same validation procedure on all 14 data sets. The suggested model types can broadly partitioned into : 0) Current practice (e.g. 5-year average), 1) Gaussian Markov Random Field with optional correlation in age, year, and/or cohort direction. 2) Separable age and year AR(1) structure with or without added cohort effect. These models were further be branched out by transformation of observations (none, logarithmic, or Box-Cox), by observation error, (none, independent, or correlated), and by their use of covariates (none or N). Further some models were restricted to be increasing within each cohort. A total of 34 model structures were implemented, validated, and compared.

The data on stock weights from the 14 different stocks were used evaluate and compare the 34 different model structures. Stock weights were chosen, because they are the best data consistently available from the the 14 stocks. During the model evaluation and test runs the last 10 years of the data from each stock were not used. The last 10 years were trimmed off and saved for the final evaluation. In the remaining data the models were set to predict the last 10 years successively 1, 2, and 3 years ahead. In the final evaluation and comparative runs the same procedure was repeated for the last 10 years of data. This approach was taken to ensure that the models were not unintentionally tuned/developed to predict anything specific to the last 10 years.

Each of the models predict stock-weights in each age group, but it would be difficult to reach a coherent conclusion if different models predicted different age classes better, so to reach a joint conclusion, and to keep the evaluation focused on the real application of this modelling effort, it was decided to use the ability to predict SSB as the summarizing criteria. For each predicted year the age-specific predicted stock-weights are used to compute SSB (using maturities and N's from the assessment). This prediction is compared to the SSB calculated by using same maturities, N's, and the observed stock-weights. The comparison is done on logarithmic scale. Based on e.g. the 10 predictions calculated per stocks the root-mean-square-error (RMSE) is calculated and summarized by simple averages across stocks. 1, 2, and 3, year ahead predictions were compared.

Furthermore, it is important that the model structure is robust, so across all runs it was summarized how often the model converged (should be very close to 100%). Many of the suggested models would far too often not converge.

Model	nlogLik	AICc	AIC	RMSE.CV	Conv_rate_CV	RMSE.CV2	RMSE.CV3	jit
5-year Average	-244.9	-487.7	-487.7	0.086	1.00	0.101	0.118	0.00

GMRF age, cohort	**-375.1**	**-723.3**	**-724.3**	**0.068**	**1.00**	**0.088**	**0.102**	**0.01**
GMRF age, cohort, no obs noise	**-371.1**	**-717.5**	**-718.4**	**0.068**	**1.00**	**0.087**	**0.102**	**0.00**
ARxAR increasing	**-325.3**	**-616.7**	**-618.8**	**0.087**	**1.00**	**0.115**	**0.140**	**0.81**
GMRF increasing	**-316.4**	**-601.1**	**-602.9**	**0.089**	**0.98**	**0.115**	**0.139**	**0.58**
ARxAR, no cohort, increasing	**-397.2**	**-767.6**	**-768.6**	**0.069**	**1.00**	**0.093**	**0.111**	**0.20**

Table 4.1: Example output for the model comparison. 6 of the best model approaches compared.

The model structure selected was was the GMRF with correlations across ages within year and cohorts. This model is described in details below. In table 4.1 are shown the model performance output for some of the best performing models. Notice that the log-scale RMSE of the proposed model structure is 0.068 compared to 0.086 for the standard approach of using average over the last 5 years. This is a reduction of more than 20% averaged over 14 stocks.

The model for weights:

The weights, which are mean weight at age in the stock (SW) and mean weight at age in the catch (CW) are collected each year from surveys and from the commercial landings. The values are based on weighing age- and length-specified samples, so some uncertainty can be expected on the yearly observed values. However it must be expected that the true weights do vary from year to year, so simply averaging all years would likely lead to biases. Furthermore, we need to predict these weights a number of years forward (e.g. 3), because they are needed to calculate the important outputs from the explored management options. From our prediction based model selection study (described above) we selected a model, which include observation uncertainty, but also allow the true weights to develop over time, and further is the optimal for prediction. The details of the selected model are explained here:

The model is a state-space model, where the unobserved true weights by age and year are described by a so-called Gaussian Markov Random Field (GMRF). A GMRF is a stochastic process, where the correlation structure is expresses via the inverse covariance structure and the neighborhood structure. The inverse specification allows for fast computations, because the most time consuming part of evaluating a multivariate Gaussian is the part where the covariance matrix is inverted. The structure selected for weights is the structure where weights from neighboring age groups are correlated within a year and where weights from neighboring age classes are correlated within cohorts. Furthermore, mean weights are estimated for each age group (or combination of age groups). The process model for the true weights can be written precisely as:

$(\log W_{ay})_{a=1,\ldots,A;y=1\ldots Y} \sim N(m,\sigma^2 R)$, where $m_{ay}=\mu_a$ and

$$(R^{-1})_{ay,a'y'=}\begin{cases} -\phi_1, if\, y = y' \wedge |a-a'| = 1 \\ -\phi_2, if\big((y-y')=1 \wedge (a-a')=1\big) \vee \big((y-y')=-1 \wedge (a-a')=-1\big) \\ 1 - n_{ay}^{(a)}\phi_1 - n_{ay}^{(d)}\phi_2, if\, y = y' \wedge a = a' \\ 0, otherwise \end{cases}$$

Here $n_{ay}^{(a)}$ is the number of neighbors in the age direction a given age (a), year (y) combination has (1 if youngest of oldest age group 2 otherwise), and $n_{ay}^{(d)}$ is the same in the diagonal (cohort) direction.

The above is an exact formulation, but in more understandable terms the model has a mean level for each age group, a correlation parameter describing correlation between weight at age within a year (year effect) and a separate correlation parameter describing correlation between weight at age within a cohort (cohort effect).

Between all structures tested this process formulation gave the best forward prediction of unobserved log-weights. Furthermore the structure is sensible, because year-specific conditions (e.g. w.r.t. food availability) can affect the mean weight of many age groups within a year (year effect), and a given cohort can have experienced similar conditions in the past (e.g. in its first year), which will decrease or increase the weights of that cohort in many years following (cohort effect).

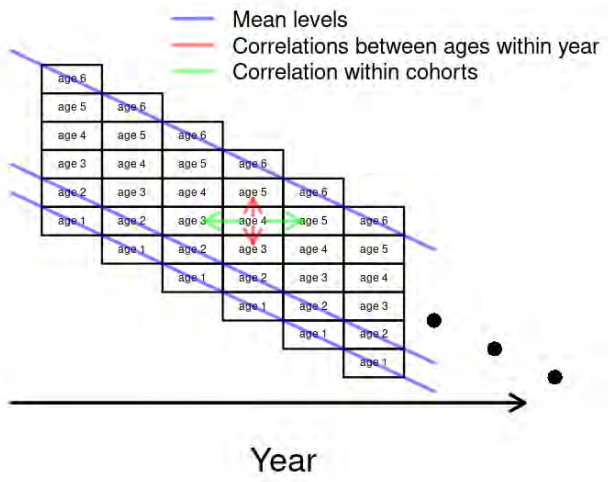


Figure 4.1: The structure of the process model, where a mean level is assigned to each age group, and the correlation is across cohort and across ages within year.

To allow and account for uncertainty in the observed weights, it is assumed that the observations of log-weights follow a normal distribution with mean given by the process described above. The observation variance can optionally be configured to be separate for some age groups.

The model for maturity:

Proportion mature (or "maturity ogive" (MO)) is a number between 0 and 1 indicating the fraction of spawning mature fish within a given group. It is sampled for each combination of year and age group. There are many challenges in setting up an appropriate model for the maturity data. The observations are bounded between zero and one and many observations exactly at the boundaries. As is often the case with fisheries data only a summary of the observations are available (here only the fraction is given and not the original samples, or even the number of samples used to estimate the fraction). Furthermore, for a given stock the working group may in the past have made decisions to substitute the yearly maturity proportion estimates with e.g. an average over many years, and the original yearly estimates are now unavailable. Hence it is important that the solution is pragmatic, as robust as possible, and able to supply plausible forecasts even in sub-optimal data situations.

Similarly to the model for the weights the model for the proportion mature is a state space model where the unobserved true proportions mature are described by a stochastic process. Since the observations themselves are known to be bounded between zero and one the process is setup at the logit scale. This allow the process to be unconstrained and constructed as a Gaussian Markov Random Field while at the same time predicting observations only within the interval from zero to one. The same correlation structure is used as was derived for weights (with correlations among ages within each year and within cohorts), but the correlation parameters are estimated separately for proportion mature.

The observations are assumed to be beta distributed. The beta distribution forms a very flexible distribution between zero and one. The beta distribution is parameterized such that for a given predicted mean proportion mature μ_{MO} the variance becomes $\mu_{MO}\,(1-\mu_{MO})/(1+\tau_{MO})$. Where τ_{MO} is a positive precision parameter, which is further bounded to be below 1000 for increased numerical stability. This mean variance-relationship mimics the observed pattern that proportions near one or zero are very certain and proportions in the middle of the range are the most uncertain. Such proportion mature observations each originate from a number of samples of mature or immature individuals. Estimating the proportion from such observations would result in the same mean-variance relationship (assuming independent samples).

Implementation in assessment model SAM:

The selected models for weights (stock weight (SW), and catch weight (CW)) and proportion mature (MO) are implemented as configurable options in the state-space assessment model SAM, and hence are ready to use for any assessment using SAM. By default the new options are turned off. This is not to be taken as an indication that the new options are not generally preferable – they are – but merely to ensure backwards compatibility (any previously defined assessment should keep giving the same results even with a new version of the program).

Previously the raw observations of weights and maturity were used by the assessment model simply as covariates, which means that they were treated as constants without uncertainty. Because of this the actual observations were already read into the program, so no change to the program was required for the data part.

The new configuration part is kept to a minimum to make these options easy to try out and use. Consider e.g. the case of stock weights. The default configuration is the following for a stock with 6 age classes:

```
$stockWeightModel
# Integer code describing the treatment of stock weights in the model (0 use as known, 1 use as
# observations to inform stock weight process (GMRF with cohort and within year correlations))
 0

$keyStockWeightMean
# Coupling of stock-weight process mean parameters (not used if stockWeightModel==0)
 NA NA NA NA NA NA

$keyStockWeightObsVar
# Coupling of stock-weight observation variance parameters (not used if stockWeightModel==0)
 NA NA NA NA NA NA
```

The code ‘0’ indicate that the stock weight model is turned off (stock weights are used as given and treated as know without uncertainty). Because the model is turned off there is no need to supply mean value or variance configuration, so they are not assigned ‘NA’. The fields are shown even when not assigned to make it simpler for the user to turn it on.

If the new option is to be turned on, then the configuration can be changed into the following:

```
$stockWeightModel
# Integer code describing the treatment of stock weights in the model (0 use as known, 1 use as
# observations to inform stock weight process (GMRF with cohort and within year correlations))
 1

$keyStockWeightMean
# Coupling of stock-weight process mean parameters (not used if stockWeightModel==0)
 0 1 2 3 4 5

$keyStockWeightObsVar
# Coupling of stock-weight observation variance parameters (not used if stockWeightModel==0)
 0 0 0 0 0 0
```

Here the stock weight model is turned on by setting the code to ‘1’. The model is further configured to use a separate mean value for each age class, but a common variance parameter (on log-scale).

The configuration options are set in the same way for catch weights and for proportion mature with the exception that the observation variance cannot be configured to be age-specific for proportion maturity. The options can be turned on or off individually, and separate parameters are estimated for each of the three extensions.

Whenever the new options for modelling weights and maturities are turned on they can be used in the forecasts. There are certainly benefits to using these options for the historic assessment of the stock alone (less randomly fluctuating estimates and more correctly estimated uncertainties), but the main reason to model weights and maturities is to be able to forecast them better.

The forecast function in the SAM package aims to forecast the stock in a model-consistent way, which was obviously problematic when there was no model included for weights and maturities and hence ad-hoc options like averaging previous years were used. If the new options for modelling weights and maturities are turned on when running the assessment, then the forecast function will by default use the process model to predict future weights and maturities. So for instance the following line:

```
mySQForecast <- forecast(fit, fscale=c(1,1,1,1))
```

which is a standard line for making a 'status quo' forecast with SAM. If the new options were turned on during the model fitting (described above), then line will produce a forecast of all relevant quantities (e.g. SSB, catch, F,…), based on weights and proportions mature predicted according to the new process models. This forecast will utilize the estimated correlations and mean values estimated from all data up to the current year. If the new process models were not used during the model fitting, then the weights and proportions mature will be predicted simply by averages of the last 5 years. This setup will make it effortless for the working groups to use this new approach.

For comparative purposes it is possible to turn off the new forecast options even if the new options were used during the model fitting. In the above example this can be done by

```
mySQForecast <- forecast(fit, fscale=c(1,1,1,1), useSWmodel=FALSE, useCWmodel=FALSE, useMOmodel=FALSE)
```

It is naturally not possible to turn the new options on in the forecast part if the new options were not used during the model fitting, and trying to will result in an error message.

Results (example):

In this section the results will be exemplified first for the individual parts, and then combined in the assessment model and in the forecasts.

The example used here is the North East Arctic Cod stock. This assessment is being bench-marked in early February 2021 and the model extension is being proposed for this stock (later in February it is being proposed for North Sea Cod). Turning the process modelling options on for North East Arctic Cod is done exactly as described above.

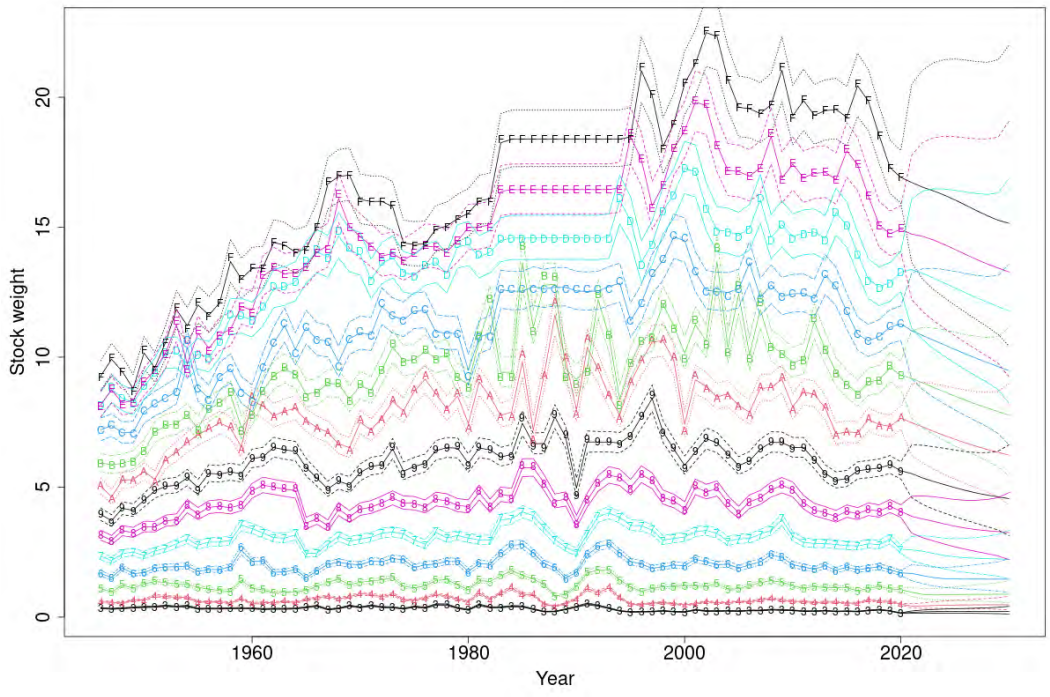


Figure 4.2: Stock mean weights for North East Arctic Cod (ages 3-15) and the predictions from the process model.

The process model for stock weights follow the observations fairly closely and predicts the stock weights some years forward (figure 4.2). To make the graph less clustered we will focus on a few age groups age 8, 11, and 14 (symbol

"8", "B", and "E" in figure 4.2). Removing the last 5 stock weight observations from all ages from the model fitting allow us to study how the model predicts these last 5 weights.

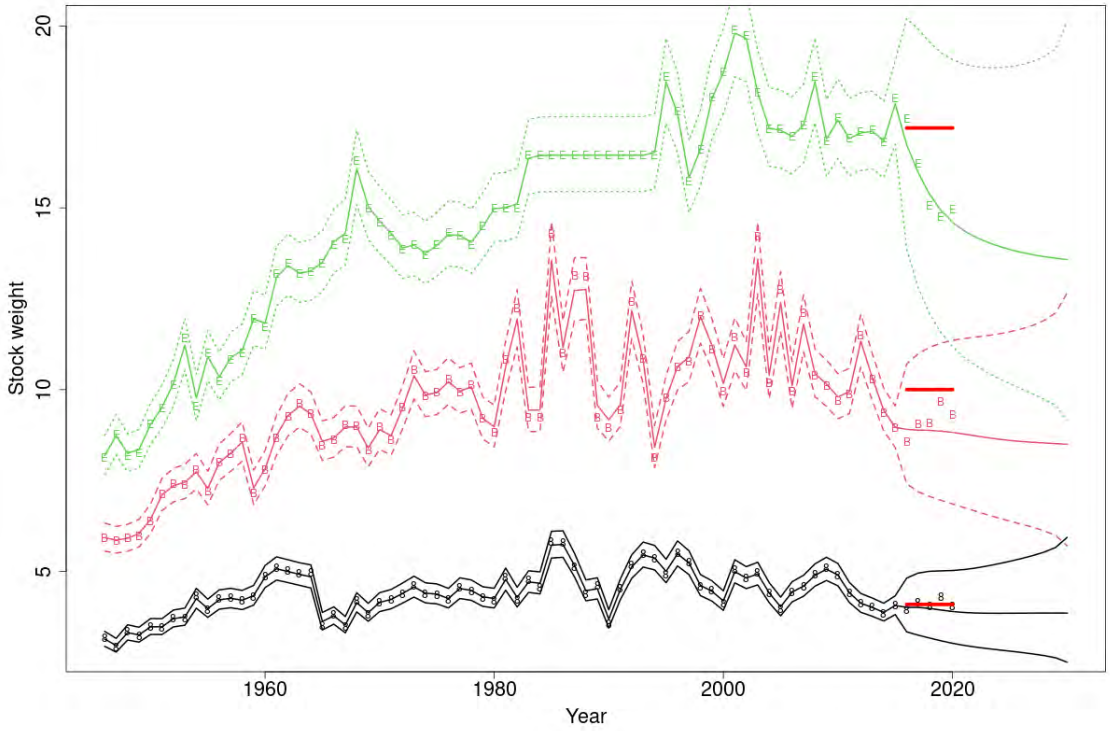


Figure 4.3: Stock weights for ages 8, 11, and 14. The last 5 observations are not used in the fitting procedure, but are predicted by the model (solid and dashed lines). The thick red lines show the standard prediction procedure of using average over the last 5 years.

The process model predicts the stock weights forward. Looking at the last 5 years the process based model gives a closer prediction compared to the standard procedure of using an average of the 5 most recent years (Fig. 4.3). Furthermore the prediction uncertainty is estimated. The process model is capable of producing these predictions, because the correlations within the cohort is used in combination with the overall means estimated in the historic period.

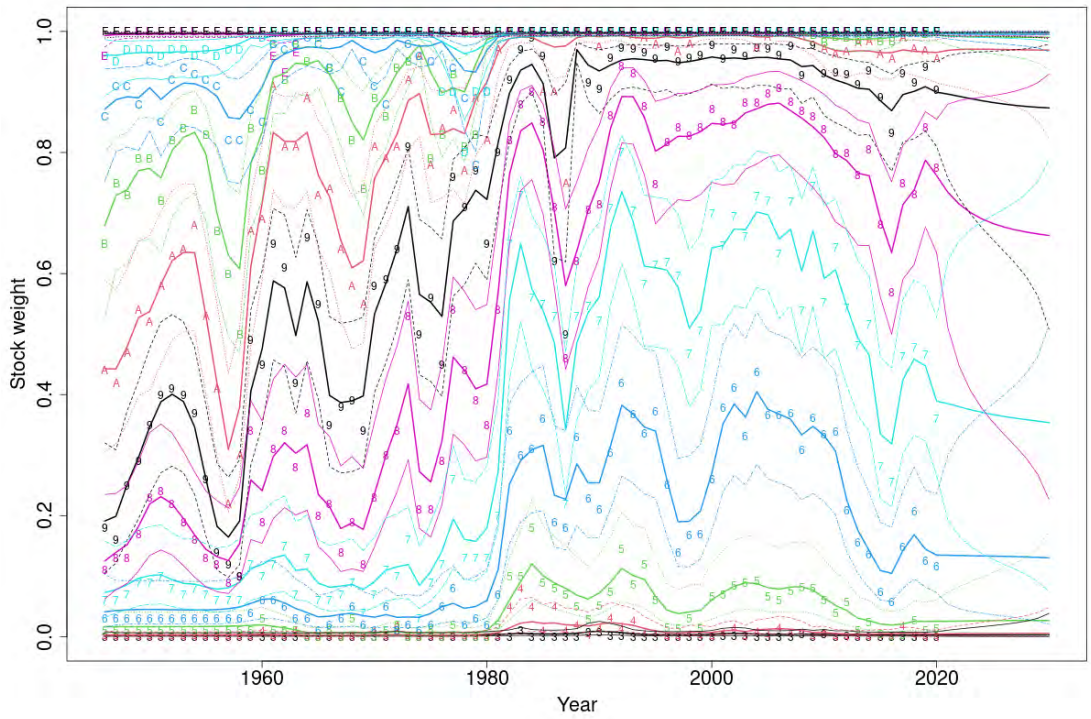


Figure 4.4: Proportion mature observed for North East Arctic Cod and the predictions from the corresponding process model.

The proportion mature can be studied in the same way. The process model is able to adapt to the historic observations and the confidence intervals are wide where the observations are very fluctuating, but very narrow where the proportion is either constant zero or one (Fig. 4.4). The model can provide predictions, but when inspected closely for certain ages they appear to be biased downwards. This is likely caused by the historic much lower proportion mature of these ages, which gives the process model a much lower mean values to revert to. A possible improvement would be to only use the observations from e.g. 1980 to fit the process.

As explained above all of these process models are included in the assessment model and can be used within. In the historic period we see little difference for North East Arctic Cod. The process model is closely fitting the observed weight and maturity data, so e.g. the spawning stock biomass is only slightly modified in the historic period (Fig. 4.5). The only difference seen (on close inspection) is that the SSB estimated with the process model options included is slightly smoother, because it assigns some of the fluctuations in weights and maturity to observation noise, but the difference is barely noticeable. The difference is however clear when the forecast period is also considered. The predicted SSB from the process model is below SSB predicted from the standard model (Fig 4.5).

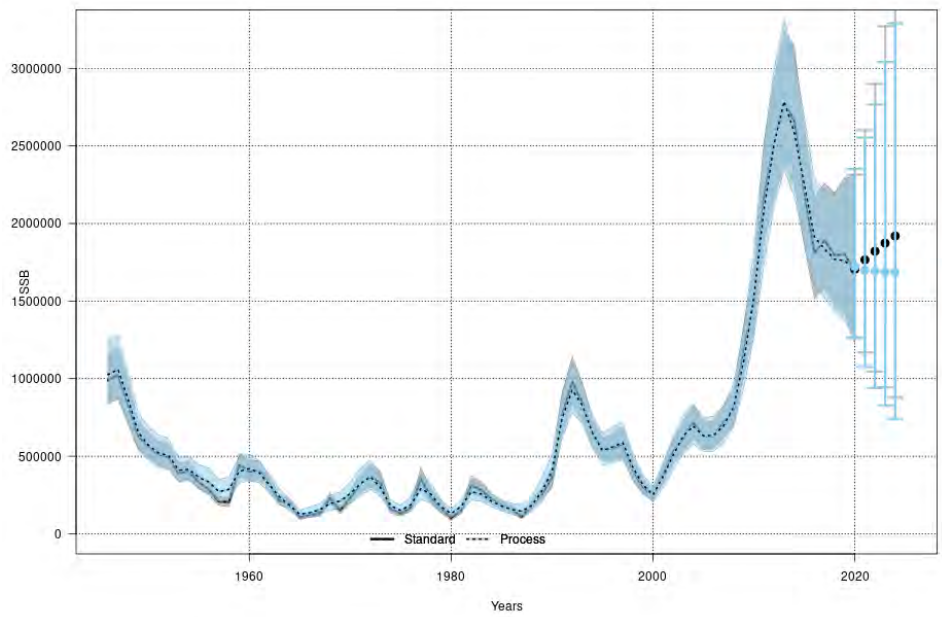


Figure 4.5: Spawning stock biomass for North East Arctic Cod estimated and predicted with status quo fishing pressure with and without process model for weights and maturity.

The estimated catch is again similar in the historic period, but the forecast shows a clear difference between using the recent five year average or the process model to predict the catch weights in the forecast period (Fig. 4.6).

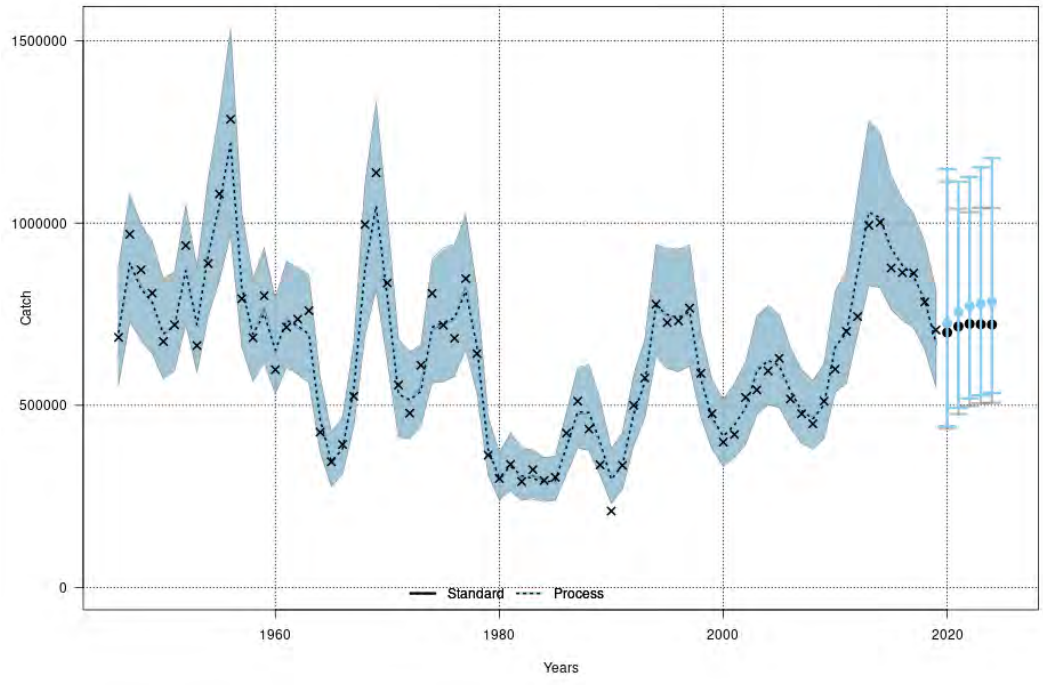


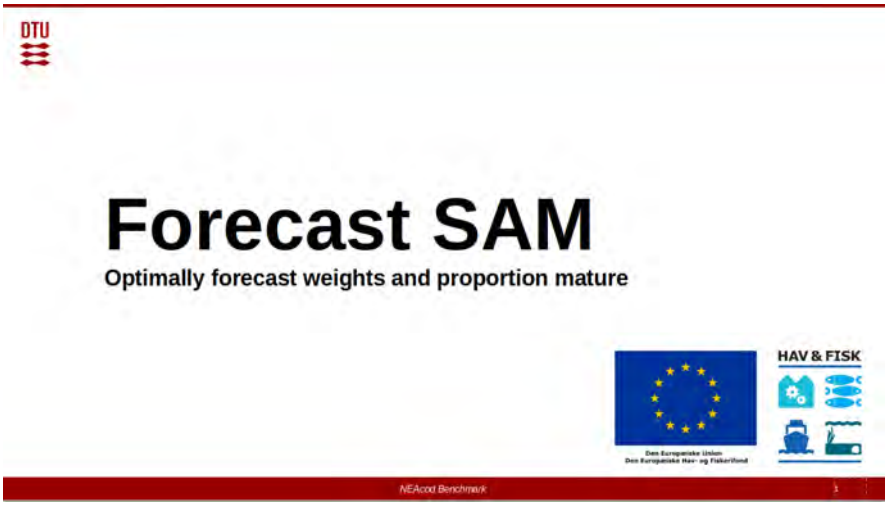
Figure 4.6: Predicted and observed catch for North East Arctic Cod. Status quo fishing pressure is used to forecast with and without process model included.

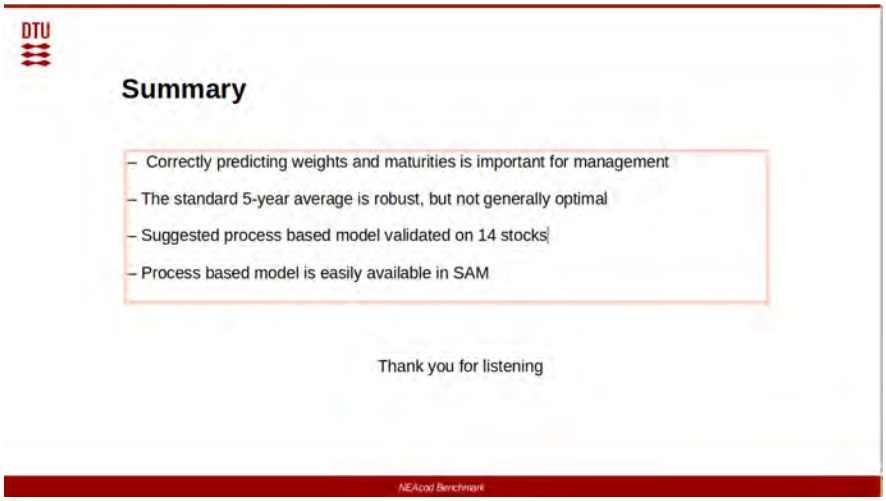
Conclusion:

The model extension to the state-space assessment model SAM to include a process model for weights (stock-weights and catch-weights) and proportion mature has been researched, developed, validated, and implemented. The process has further been added to the forecast, and it is expected that it will become the standard way to do forecasts from a SAM model, because it removes the subjectivity from selecting the number of years to average over, which was needed in the previous approach.

Appendix 4.1: Presentation at North East Arctic Cod Benchmark (3/2 – 2021)

First and last page of a presentation given at North East Arctic Cod Benchmark meeting.





A similar presentation is already scheduled to be given at the benchmark for North Sea Cod (late February 2021), and it expected that this model extension will be used in forecasting most stocks.

Working document: Belgian commercial beam trawl landings data for sole in the eastern English Channel (ICES division 27.7.d)

Authors: Klaas Sys, Bart Vanelslander, Sofie Nimmegeers and Lies Vansteenbrugge (ILVO, Belgium)

1. Introduction

The Belgian commercial fishing fleet has fishing opportunities in several ICES Divisions. To allow an efficient exploitation of the stocks over all these areas, vessels are allowed to fish in different ICES divisions within one trip (e.g. while steaming from a Belgian harbour to a foreign harbour). This flexibility of fishing in different ICES divisions might create opportunity for non-compliance. During the inter-benchmark protocol for sole in ICES division 27.7.d (eastern English Channel) in 2019, a revision of the Belgian commercial beam trawl tuning fleet occurred (ICES, 2019). 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 division 27.7.d), often had a considerably different mean landing rate ($kg.h^{-1}$) than mixed trips (*i.e.* trips in which fishing occurred in multiple ICES divisions). In this working document, we further explore this difference in landing rate. **This working document is the updated version of the WKFLATNSCS 2020 benchmark working document.**

2. Data sources

2.1. Logbook and sales notes data

Every period of 24 hours during a fishing trip, except while steaming, the skipper has to report his fishing activity in the electronic logbook. The logbooks contain the estimated weight (kg) for all commercial species landed, grouped by ICES statistical rectangle (if fishing activity occurred in more than one ICES statistical rectangle, the ICES statistical rectangle with the highest proportion of fishing effort must be reported) and by day. They also provide information on the hours spent fishing per day. The landed weights were divided by those fishing hours to calculate the landings per unit effort (lpue; in kg/h). Because the retained landings from the logbooks are estimated weights (with an upper and lower tolerance of 10%), the landed weights are derived from the quantities recorded in the sales notes. The sales notes contain information on the quantities auctioned by market category for all species landed, but there is no area information. Therefore, the percentage share of a species in an ICES statistical rectangle from the logbooks, is the basis for the distribution of the auctioned quantities on the ICES statistical rectangles.

2.2. VMS data

VMS (Vessel Monitoring by Satellite) data of all Belgian commercial vessels were used to analyse the fishing activity in ICES divisions 27.7.d. VMS is a satellite-based monitoring system which provides data to the fisheries authorities at regular intervals (approximately every 2 hours) on the location, data-time, course and speed of vessels. VMS equipment onboard is compulsory for all Belgian commercial fishing vessels. Belgian VMS data are collected by dienst Zeevisserij (Departement Landbouw en Visserij; Afdeling landbouw- en visserijbeleid) and can be analyzed by ILVO.

All data processing of combined VMS and logbook data was done in R using the vmstools package (Hintzen *et al.,* 2012). Only VMS records with speeds that corresponds with fishing activity were selected. VMS and logbook data were linked based on vessel identity and date-time. Using this link , we can combine data on fishing location, data and time, fishing speed and fishing gear. An extensive quality control of the data was performed. We checked for duplicated data, locations inside the harbours, impossible time, dates, headings and locations.

3. Pure versus mixed trips

Two fleet segments are actively fishing in ICES divisions 27.7.d: the small fleet segment with an engine power ≤ 221 kW and the large fleet segment with an engine power > 221 kW. Both fleet segments are known to carry out pure and mixed trips. Pure trips are defined as fishing trips during which a vessel registered fishing effort exclusively in ICES division 27.7.d. The mixed trips, on the other hand, are defined as fishing trips during which a vessel registered fishing effort in multiple ICES divisions. An overview of the number of trips in ICES division 27.7.d over the period 2004-2019 is provided in the table below.

	Total # trips	# pure trips	# mixed trips
≤ 221 kW	7166	2389	4777
> 221 kW	6106	1740	4366

Some of the mixed trips showed high lpue values (>100 kg.h^{-1}). This was less the case for the pure trips (Figure 1). This supports the hypothesis that fishers may misreport landings in mixed trips from one ICES division to another by fishing for a very short time in ICES division 27.7.d.

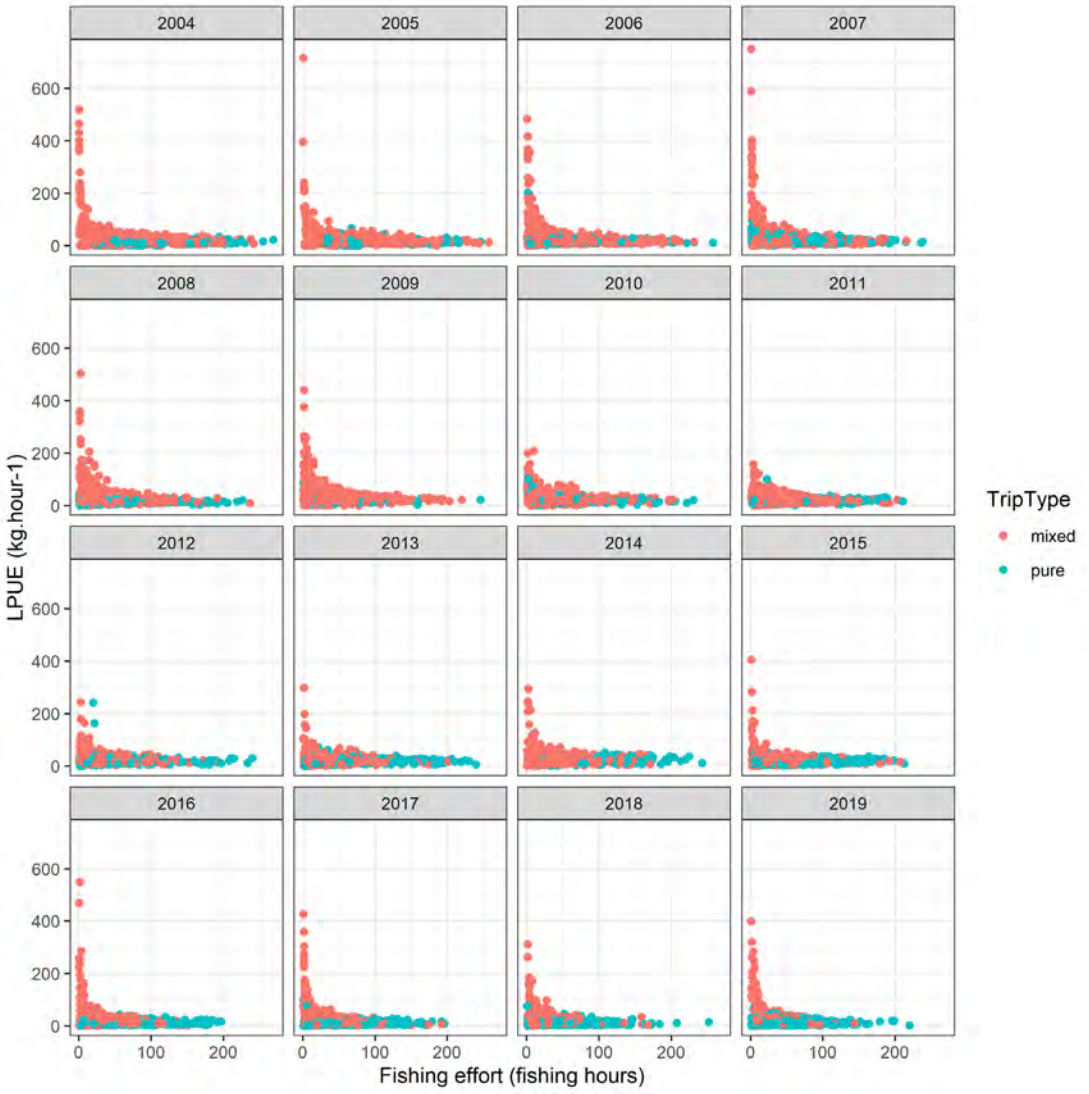


Figure 1: Scatter plot of fishing effort (in fishing hours) versus sole lpue per year based on logbook observations from the Belgian beam trawl fleet in ICES division 27.7.d. Observations of pure and mixed trips are indicated in blue and red, respectively.

4. Estimate the landings

Two methods were explored to estimate the landings of sole in ICES division 27.7.d. These were then compared to the reported landings in that area.

The first method uses landing and effort data as reported by fishers in the electronic logbooks. First, the annual landings of pure trips were divided by the annual effort of pure trips per area to calculate a pure trip lpue ($t \in$ pure,mixed) by management area ($a \in$ {7.d}) and year ($y \in$ {2004 to 2019}). Secondly, this lpue was used to estimate the landings from the mixed trips by multiplying the effort (by management area and year) registered in these trips with the pure trip lpue derived in step 1. Finally, the estimated landings from the mixed trips were added to the registered landings from the pure trips to estimate the total landings per area per year.

$$lpue_{a,y,t=pure} = \sum_{a,y,t=pure} landings / \sum_{a,y,t=pure} effort$$

$$landings_{a,y} = lpue_{a,y,t=pure} x\ effort_{a,y,t=mixed} + landings_{a,y,t=pure}$$

This method assumes that the effort as reported in the mixed (and pure) trips is reliable, and that lpue of pure trips is representative for the landing rate in mixed trips. In addition, this method does not account for additional sources of variation in lpue.

The second method uses the landings per unit of effort of pure trips, but gets the effort data for both the pure and mixed trips from the VMS dataset with data available from 2006 onwards. Similar to the first method, landings were estimated by multiplying the lpue by the total VMS derived effort in this area.

4.1. Using logbooks to estimate landings

The pure trip lpue is lower than the mixed trip lpue in all years considered in this analysis (Table 1).

Table 1: Effort (fishing hours), landings (tonnes) and lpue (kg.h^{-1}) from pure and mixed trips, and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the beam trawl fleet and from other fleets.

	PURE			MIXED			ALL		
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings	reported landings other métiers
2004	22854	309.3	13.5	51544	1096.7	21.3	1006.9	1406.0	53.9
2005	19025	263.7	13.9	47511	915.0	19.3	922.3	1178.8	34.6
2006	29096	452.5	15.6	53535	1041.4	19.5	1285.2	1494.0	36.1
2007	38867	602.9	15.5	44890	868.0	19.3	1299.2	1470.9	40.5
2008	26295	382.1	14.5	44834	931.5	20.8	1033.5	1313.6	35
2009	13394	241.0	18.0	47990	1167.6	24.3	1104.4	1408.6	53.1
2010	15258	261.7	17.1	46776	1007.3	21.5	1063.9	1268.9	35.6
2011	20036	341.1	17.0	39915	836.3	21.0	1020.8	1177.4	45.3
2012	14893	264.2	17.7	27743	627.8	22.6	756.4	892.0	47.7
2013	22423	417.7	18.6	22130	506.2	22.9	829.9	923.8	26.3
2014	28043	687.5	24.5	29511	744.4	25.2	1411.1	1431.9	58.5
2015	22773	421.8	18.5	31986	616.6	19.3	1014.1	1038.3	10.9
2016	31486	422.9	13.4	19320	373.9	19.4	682.4	796.8	3.3
2017	27494	308.2	11.2	20826	385.4	18.5	541.6	693.6	2.7
2018	26243	298.9	11.4	17448	353.8	20.3	497.6	652.6	0.2
2019	23071	275.0	11.9	16484	327.1	19.8	471.4	602.0	2.3

Consequently, the landings are estimated lower than what is reported (Figure 2). However, in the years 2014 and 2015, the estimated landings match well with the reported landings. In these years, Belgium overshot its original quota and the TAC was fished almost completely (>96%). In all other years considered in this analysis, the Belgian quota were not limiting, which could allow for reporting sole landings from other areas.

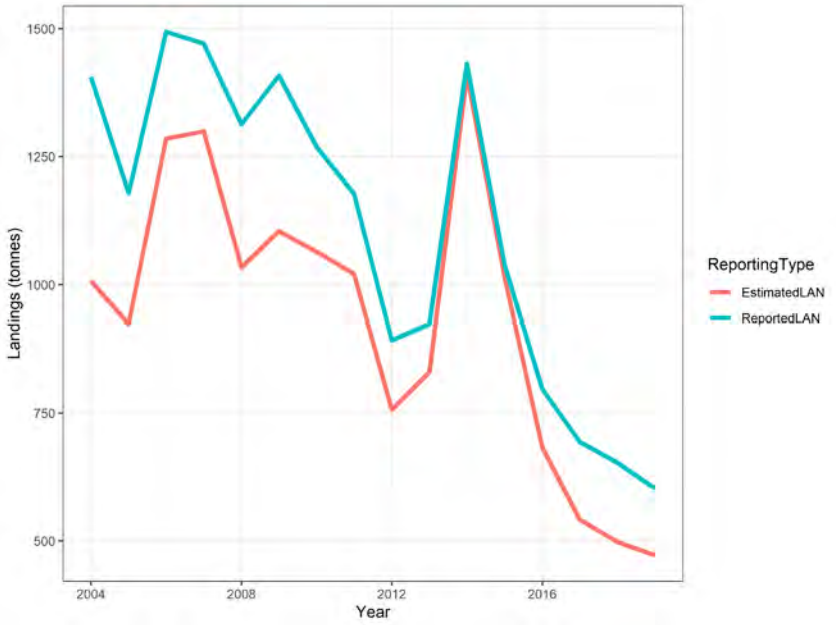


Figure 2: Reported (blue) and estimated landings (red) for sole in ICES division 27.7.d from the Belgian beam trawl fleet over the period 2004-2019 based on logbook data.

4.2. Using VMS data to estimate landings

This method gives a similar pattern compared to the first method (including the good match in 2014 and 2015), but there are some minor differences in absolute values (e.g. in 2006, the second method gives an estimate of 1353 tonnes, while the first method gives landings of 1285 tonnes) (Table 2, Figure 3).

Table 2: Effort (VMS derived fishing hours), landings (tonnes) and lpue (kg.h^{-1}) from pure and mixed trips, and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the beam trawl fleet and from other fleets.

	PURE			MIXED			ALL		
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings	reported landings other métiers
2006	17578	452.5	25.7	35076	1041.4	29.7	1353.2	1494	36.1
2007	32139	601.8	18.7	38746	869.1	22.4	1325.5	1470.9	40.5
2008	24428	381.3	15.6	41385	928.7	22.4	1026.7	1309.9	35.0
2009	12380	241	19.5	43170	1167.6	27.0	1083.2	1408.6	53.1
2010	15123	261.7	17.3	43526	1007.3	23.1	1014.6	1268.9	35.6
2011	18796	338.8	18.0	36183	838.6	23.2	989.6	1177.4	45.3
2012	13346	263.7	19.8	24145	629.2	26.1	742.3	892.9	47.7
2013	21215	417.7	19.7	20812	506.2	24.3	827.9	923.8	26.3
2014	27879	686.3	24.6	28106	748.2	26.6	1377.2	1434.5	58.5
2015	21682	421.8	19.5	30339	616.6	20.3	1014.4	1038.3	10.9
2016	29754	422.9	14.2	17724	373.9	21.1	674.2	796.8	3.3

2017	24910	308.2	12.4	20036	385.4	19.2	557.3	693.6	2.7
2018	22596	298.9	13.2	15745	353.8	22.5	506.1	652.6	0.2
2019	19360	275.0	14.2	14082	327.1	23.2	474.9	602.0	2.3

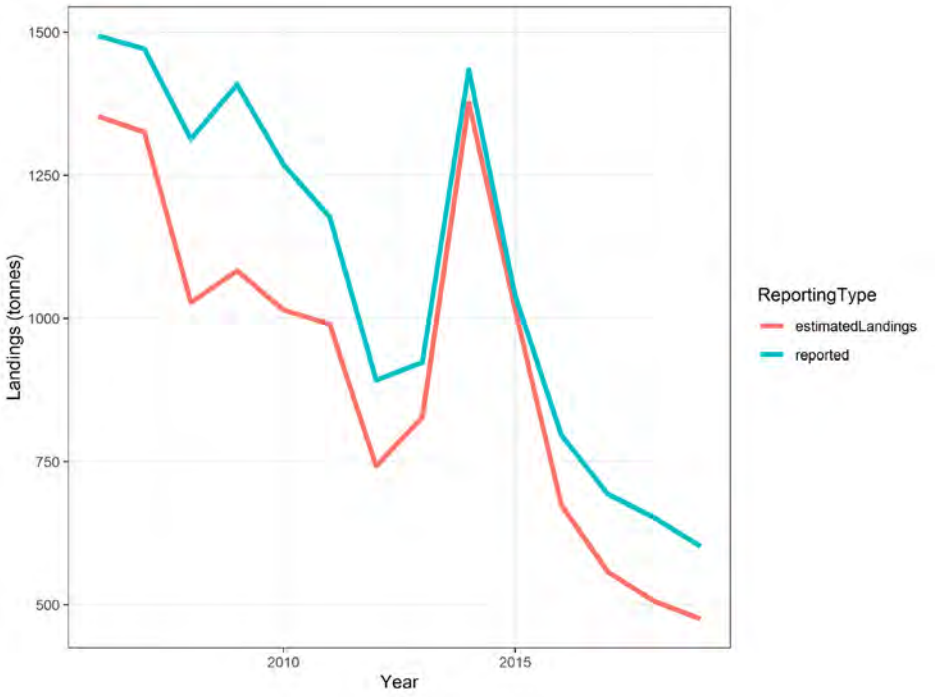


Figure 3: Reported (blue) and estimated landings (red) for sole in ICES division 27.7.d from the Belgian fleet over the period 2006-2019. Estimated landings based on VMS effort data.

4.3. Differences in fleet segment

The analyses on estimated landings are performed by combining data from both the small and the large fleet segment. Considering the differences between both fleet segments, the outcome of the above analyses could be confounded. Especially in ICES division 27.7.d, the small fleet segment is responsible for an important part of the sole landings.

4.3.1. Using logbooks to estimate landings per fleet segment

The first method using the logbook data shows that there is a rather constant deviation of the small fleet segment (≤ 221 kW) over the time series, where estimated landings are slightly lower than reported landings (Figure 4; Table 3). Therefore, our analysis shows less evidence for non-compliance by the small fleet segment. The deviation between estimated and reported landings is never larger than 20%, except for 2015, and could mainly be linked to the assumptions we made in this calculation method. The small fleet segment fishes in the North Sea and the eastern English Channel and has therefore less opportunity to misreport compared to the large fleet segment. For the large fleet segment, deviations were larger than 20% for 8 years in the time series (2004,2005,2008-2010 and 2017-2019) (Figure 4, Table 4). In contrast to the large fleet segment, the small fleet segment does not show a different pattern in 2014, where the quota were limiting. Nevertheless, in 2015, the largest difference between estimated and reported landings was noted for the small fleet segment.

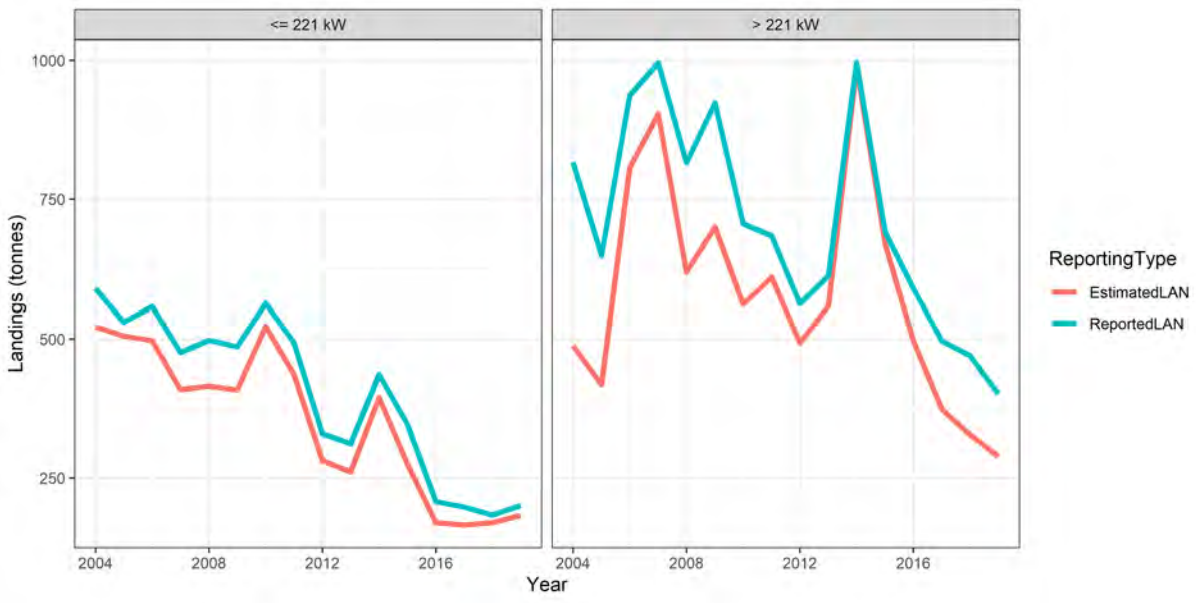


Figure 4: Reported (blue) and estimated landings (red) for sole in ICES division 27.7.d from the Belgian small beam trawl fleet segment (≤ 221 kW) and the large fleet segment (> 221 kW) over the period 2004-2019 based on logbook data.

Table 3: Effort (fishing hours), landings (tonnes) and lpue (kg.h^{-1}) from pure and mixed trips of the **small** fleet segment (≤ 221 kW), and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the small fleet segment.

	PURE			MIXED			ALL	
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings
2004	13120	173.3	13.2	26387	416.5	15.8	521.8	589.8
2005	13019	180.3	13.8	23426	349.6	14.9	504.7	529.9
2006	14587	205.2	14.1	20715	352.2	17.0	496.7	557.4
2007	15749	217.1	13.8	13896	258.4	18.6	408.6	475.5
2008	11099	157.5	14.2	18153	340.2	18.7	415.1	497.7
2009	6092	91.6	15.0	21087	394.4	18.7	408.5	486.0
2010	9436	141.0	14.9	25527	422.4	16.5	522.3	563.3
2011	11933	158.2	13.3	21008	335.2	16.0	436.7	493.4
2012	7994	107.1	13.4	12997	222.4	17.1	281.2	329.5
2013	8747	121.8	13.9	9999	189.8	19.0	261.1	311.7
2014	10247	173.2	16.9	13100	262.6	20.0	394.7	435.9
2015	5629	70.0	12.4	16500	276.8	16.8	275.2	346.8
2016	8949	86.3	9.6	8590	121.1	14.1	169.2	207.5
2017	7607	79.6	10.5	8181	117.9	14.4	165.2	197.5
2018	9292	100.5	10.8	6381	82.6	12.9	169.5	183.1
2019	10006	105.1	10.5	7375	95.3	12.9	182.5	200.4

Table 4: Effort (fishing hours), landings (tonnes) and lpue (kg.h^{-1}) from pure and mixed trips of the **large** fleet segment (> 221 kW), and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the large fleet segment.

	PURE			MIXED			ALL	
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings
2004	9734	136.0	14.0	25157	680.2	27.0	487.5	816.2
2005	6006	83.4	13.9	24085	565.4	23.5	418.1	648.8
2006	14509	247.3	17.0	32820	689.2	21.0	806.7	936.5
2007	23118	385.8	16.7	30994	609.6	19.7	903.0	995.3
2008	15196	224.6	14.8	26681	591.3	22.2	618.9	815.9
2009	7302	149.4	20.5	26903	773.2	28.7	699.8	922.6
2010	5822	120.7	20.7	21249	584.9	27.5	561.3	705.6
2011	8103	182.9	22.6	18907	501.0	26.5	609.8	684.0
2012	6899	157.1	22.8	14746	405.4	27.5	493.0	562.5
2013	13676	295.8	21.6	12131	316.3	26.1	558.2	612.1
2014	17796	514.3	28.9	16411	481.7	29.4	988.6	996.0
2015	17144	351.7	20.5	15486	339.8	21.9	669.5	691.5
2016	22537	336.6	14.9	10730	252.7	23.6	496.8	589.3
2017	19887	228.6	11.5	12645	267.5	21.2	373.9	496.1
2018	16951	198.4	11.7	11067	271.2	24.5	327.9	469.6
2019	13065	169.9	13.0	9109	231.7	25.4	288.3	401.6

4.3.2. Using VMS data to estimate landings per fleet segment

The second method to estimate the landings of both fleet segments uses the landings per unit of effort of pure trips for both segments separately, but gets the effort data for both the pure and mixed trips from the VMS dataset with data available from 2006 onwards.

Similar to the first method, using the VMS effort data shows that the small fleet segment (≤ 221 kW) estimated landings are consistently, but only slightly lower than the reported landings (Table 6, Figure 5). For the large fleet segment (> 221 kW) there is the same irregular pattern as derived with the first method (Table 7, Figure 5). Estimated landings are lower than reported landings with the exception of 2014 and 2015, when the Belgian quota were limiting.

Table 6: Effort (VMS derived fishing hours), landings (tonnes) and lpue (kg.h^{-1}) from pure and mixed trips of the **small** fleet segment (≤ 221 kW), and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the small fleet segment.

	PURE			MIXED			ALL	
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings
2006	7147	205.2	28.7	11666	352.2	30.2	539.9	557.4
2007	11718	217.1	18.5	11484	258.4	22.5	429.2	475.5
2008	10384	156.7	15.1	15881	341	21.5	396.6	497.7
2009	5817	91.6	15.7	19408	394.4	20.3	396	486
2010	9262	141	15.2	22833	422.4	18.5	487.8	563.3
2011	11166	158.2	14.2	19062	335.2	17.6	429.2	493.4
2012	7237	106.5	14.7	11200	223.9	20	271	330.4
2013	8421	121.8	14.5	9384	189.8	20.2	258.2	311.7

2014	10078	170.9	17	12854	266.4	20.7	389.8	437.4
2015	5992	70	11.7	16235	276.8	17	260.1	346.8
2016	8185	86.3	10.5	8419	121.1	14.4	174.3	207.5
2017	7108	79.6	11.2	7874	117.9	15	167.8	197.5
2018	7510	100.5	13.4	5783	82.6	14.3	178.1	183.1
2019	8481	105.1	12.4	6805	95.3	14.0	189.5	200.4

Table 5: Effort (VMS derived fishing hours), landings (tonnes) and lpue ($kg.h^{-1}$) from pure and mixed trips of the **large** fleet segment (> 221 kW), and estimated landings (tonnes) based on the lpue from pure trips compared to reported landings from the large fleet segment.

	PURE			MIXED			ALL	
Year	effort	reported landings	lpue	effort	reported landings	lpue	estimated landings	reported landings
2006	10431	247.3	23.7	23410	689.2	29.4	802	936.5
2007	20421	384.7	18.8	27261	610.6	22.4	896.4	995.3
2008	14044	224.6	16	25504	587.7	23	632.8	812.2
2009	6563	149.4	22.8	23762	773.2	32.5	691.4	922.6
2010	5861	120.7	20.6	20692	584.9	28.3	547	705.6
2011	7630	180.6	23.7	17121	503.3	29.4	586.6	684
2012	6110	157.1	25.7	12945	405.4	31.3	489.7	562.5
2013	12794	295.8	23.1	11428	316.3	27.7	559.5	612.1
2014	17801	515.4	29	15252	481.7	31.6	958.5	997.1
2015	15690	351.7	22.4	14105	339.8	24.1	667.4	691.5
2016	21569	336.6	15.6	9305	252.7	27.2	481.6	589.3
2017	17803	228.6	12.8	12163	267.5	22	383.6	496.1
2018	15086	198.4	13.1	9962	271.2	27.2	328.1	469.6
2019	10880	169.9	15.6	7277	231.7	31.8	283.2	401.6

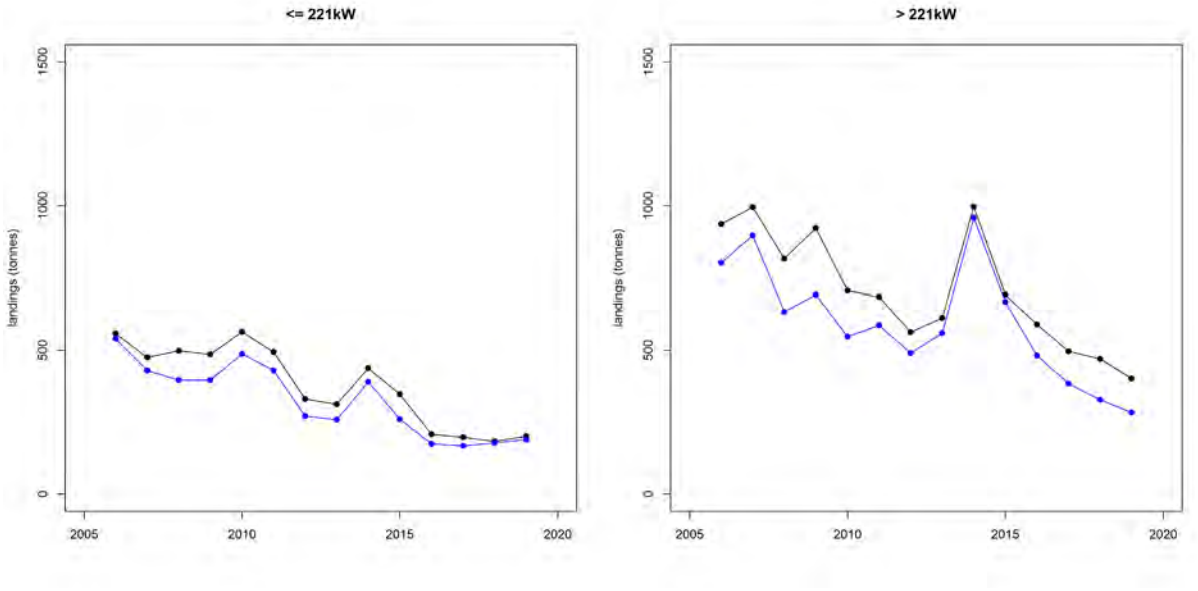


Figure 5: Reported (black) and estimated landings (blue) for sole in ICES division 27.7.d from the Belgian small beam trawl fleet segment (≤ 221 kW) and the large fleet segment (> 221 kW) over the period 2006-2019 based on VMS effort data.

5. Input from the Belgian fishing industry

During the data compilation workshop of the WKFLATNSCS 2020 benchmark, the Belgian fishing industry was briefly involved and further contacted in this matter. Discussions provided insights on the behaviour of fishermen in ICES divisions 27.7.d.

Fishermen pointed out that mixed trips in ICES division 27.7.d are very common. This division is sometimes crossed on the way to fishing grounds in the Western Waters, such as the Celtic and Irish Sea, and combined trips with the western English Channel and the North Sea are decided upon by skippers aiming for a successful fishery activity. Skippers indicate that they aim to make optimal use of their fishing opportunities in several ICES divisions. To decide where to operate, they take into account all aspects that can influence the success.

From the analyses and the assumptions described above, it seems not beneficial to move away from ICES division 27.7.d when lpue is high. Fishermen contradict this notion and state that several factors play a role in their fishing behaviour. Especially in ICES division 27.7.d, the tide is a very important factor. Fishing during neap tide for example results in less yield. Furthermore, fishermen admit that it is much more profitable to fish during the night and indicate that weather conditions are also crucial. Finally, when they have found a hotspot of sole for instance in a gully, and they have trawled it several times, the lpue could have been very high. Depending on what was caught earlier during that trip and whether or not the day limits in ICES division 27.7.d are reached, they might decide to remain in the area and try to find another hotspot or move to another ICES division.

The Belgian quota allocation is centrally managed by the authorities. For sole in ICES division 27.7.d a quantity per day in the area on a voyage basis is allocated. The quantity for the small fleet segment is mostly half of the large fleet segment.

6. Conclusion

The analyses show clear differences between estimated and reported landings. Estimated landings point towards over-reporting of sole in ICES division 27.7d, especially by the large fleet segment. Although the two methods that were used to estimate the landings depend on different assumptions, both pointed to a similar result. Belgian landings for sole in ICES division 27.7.d were therefore corrected when there was 20% difference between estimated and reported landings for both the small and large fleet segment. This 20% threshold was chosen, taking into account that there is an upper and lower tolerance of 10% to report the retained landings in the logbooks and the assumptions linked to the estimation process.

During the WKFLATNSCS 2020 benchmark it was decided not to adjust the landings for misreporting. However, the assessment working group (WGNSSK 2020 meeting) questioned this decision of the benchmark, especially because the differences between estimated and reported landings are substantial. Although not confirmed by fishers, different notifications also support the over-reporting hypothesis. Therefore, it was decided to make this adjustment during this benchmark workshop. The methodology for correction of the landings is similar as applied for the sole stock in ICES divisions 27.7.fg. during the WKFLATNSCS 2020 benchmark.

During the data compilation of the WKNSEA 2021 benchmark, reviewers argued that the 20% threshold is difficult to defend. They suggested to correct the entire time series using the estimated landings as calculated by the first method. This correction was done for the period 2004-2019.

361

7. References

ICES, 2019a. Inter-benchmark Protocol for sole in the Eastern English Channel (IBPsol7d). ICES Scientific Reports. 1-75. 88pp. http://doi.org/10.17895/ices.pub.5631.

Hintzen, N., T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., Deporte, N., Egekvist, J., Degel, H., 2012. VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data, Fisheries Research, 115, 31-43.

Working document: Preparation of catch data for sole (*Solea solea*) in division 27.7.d (eastern English Channel)

Authors: Lies Vansteenbrugge and Sofie Nimmegeers (ILVO, Belgium)

1. Introduction

Sole in the eastern English Channel was benchmarked in 2017 (WKNSEA 2017) to include a.o. discards in the assessment for the first time. In 2019, this stock went through an inter-benchmark to revise two commercial tuning fleets (UK CBT and BEL CBT). At the end of the inter-benchmark, it was found that the assessment model cannot reliably estimate the plus-group, which had an increasing contribution to the stock size in recent years. This could be assigned to the French data. In the most recent years, the French catch data were aggregated incorrectly for older ages. To fix this issue, the stock was part of the WKFLATNSCS 2020 benchmark. However, during that benchmark, other issues came to light and a thorough revision of the French raising procedures was needed (working document). Data were not ready in time for the WKFLATNSCS 2020 benchmark and therefore, sole in division 27.7.d was included in the WKNSEA 2021 benchmark. In the WKNSEA 2021 data call, the entire French time series was requested (2002-2019) disaggregated by quarter and fleet. Additionally, the Belgian fleet was investigated for misreporting (WD_Sole7D_1_Belgian landings). Over-reporting was found for the whole time series (2004-2019; some years more than others), and was therefore corrected. Consequently, a new Belgian time series was also uploaded.

2. Catch data

Data were submitted to InterCatch. The countries contributing most to the landings of sole in division 27.7.d are France (60 ± 4%), Belgium (25 ± 4%) and UK (England) (16 ± 2%). The remaining countries are responsible for less than 1% of the landings. From 2003 onwards, all three main countries submitted data to InterCatch (Table 1). However, for 2003, less than 7% of the landings had associated discards. Furthermore, very few age distributions were provided (less than 1% for the landings; none for the discards). Therefore, data were processed from 2004 onwards. Belgium could not provide quarterly data for the TBB_DEF_70-99 métier (except for the year 2018), and uploaded data on a yearly basis.

Table 1 Overview per country and year of available data in InterCatch.

Country	Landings data	Discard data	Age distributions Landings	Age distributions Discards
France	2004-2019	2004-2019	2007-2019	2009, 2012, 2015-2019
Belgium	2004-2019	2004-2019	2004-2019	2004-2019
UK (England)	2004-2019	2007, 2012-2019	2004-2019	2007, 2013-2018
Ireland	2004, 2005, 2018	No	No	No
The Netherlands	2004-2012, 2014, 2016-2019	No	No	No
UK (Scotland)	2008-2010, 2012, 2014, 2017-2019	No	No	No
UK (Northern Ireland)	2009	No	No	No

InterCatch was used for estimating both landings and discards numbers and age compositions, as input for the assessment.

3. Raising discard data

If discards were not included for a particular year-quarter-country-métier combination, they were assumed to be unknown (non-zero) and therefore raised. Discards on a year-quarter-country-métier basis were automatically matched by InterCatch to the corresponding landings. The matched discards-landings provided a landing-discard ratio estimate, which was then used for further raising (creating discard amounts) of the unmatched discards. 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 1 country to complete all other quarters of that country). The following groups were distinguished based on gear:

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

The remaining gears were combined in a REST group (including MIS, FPO, DRB, LHM, LLS).

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 (overview per year in Appendix 1). 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.

The TBB group reached the threshold for almost the entire time series (2005-2019; in 2004 only 45% of landings had discard weights). For the period 2004-2016, only the Belgian TBB_DEF_70-99 stratum per year provides a landing-discard ratio estimate. From 2017 onwards, also French TBB_DEF_70-99 strata are contributing.
Discard raising for the GTR group was done for the years 2009, 2010 and 2012-2019. In 2009 and 2010, only French strata were available. From 2012 onwards, both French and English strata contributed. This gear group received information from often up to 5 different strata.
The OTB group reached the threshold for the years 2007, 2010-2015 and 2017-2019 using French OTB_DEF_70-99, OTB_DEF_32-69 or OTT_DEF_70-99 strata. Discard rates were sometimes higher than 50% for these strata. However, these were perceived representative and were therefore included when estimating the discards of other strata in the OTB group.
For discard raising of the REST group, all available strata were considered, except for discard rates higher than 50% as sometimes found in the OTB group. An example is the 2016 French OTT_DEF_70-99 quarter 2 stratum with a discard rate of 2.866. This stratum just passed the French national threshold of 3 samples and was, in consultation with the French colleagues, not considered in raising the REST group.

4. 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 strata, allocations were performed on a **gear level**. The same gear groups (TBB, OTB, GTR and 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 (Appendix 1), allocation of age occurred with all available information within that gear group. When the threshold was not reached, unsampled data were pooled in the REST group and ages were allocated using all sampled data. The weighting factor was '*Mean Weight weighted by numbers at age'*.

4.1. Landings

The TBB group reached the threshold (50% of landings covered by age) for almost the entire time series (2005-2019). Age allocations for all métiers within that group (e.g. TBB_DEF_>=120_0_0) were performed using the available sampled TBB data. The age distribution of the Belgian TBB_DEF_70-99 stratum per year contributes for a large part to the overall age allocations of the TBB group. With the exception of the years 2009 and 2013-2019, it is the only stratum available.
Landings age allocations happened within the GTR group from 2008 onwards using several strata from France and UK (England). The OTB group reached the threshold in 2007 and from 2010-2018 using OTB_DEF_70-99, OTB_DEF_32-69 and OTT_DEF_70-99 strata from France and OTB_DEF_>=120 from UK (England).

4.2. Discards

The TBB group reached the threshold (50% of discards covered by age) for almost the entire time series (2005-2019). The age distribution of the Belgian TBB_DEF_70-99 stratum per year was the only stratum contributing to the overall age allocations of the TBB group. Furthermore, for the years 2004-2006, 2008 and 2010-2011, it was the only stratum contributing to the REST group as well. This means that for all strata the age allocations originated from the Belgian TBB_DEF_70-99 fleet.
The OTB group only reached the 50% threshold in 2012 (2 quarters of the French OTB fleet provided age distributions). The GTR group reached the threshold in 2016 and 2017 using samples from both French and English fleets.

4.3. BMS landings and Logbook registered discards

From 2018 onwards, BMS landings and logbook registered discards were available in InterCatch. Logbook registered discards were not considered for the age allocations. Age allocation of BMS landings was done together with discards. However, for sole in division 27.7.d only zeros were uploaded.

5. Quality check

The data currently available for the assessment differ in three ways from the data of the previous benchmark (WKNSEA 2017): 1) an adjustment to the discard raising procedures in InterCatch, 2) a new French time series and 3) adjusted Belgian data.

5.1. Adjusted discard raising procedure

The currently-used discard raising procedures did not differ too much from those of the previous benchmark (WKNSEA 2017). InterCatch raising procedures during the WKNSEA 2017 benchmark involved excluding discard rates higher than 50% (e.g. as was encountered for the French OTB fleet). The current InterCatch raising procedures do not exclude these higher rates for the specific gear groups (in this case OTB), as they were verified by France.
To have an idea of the impact, both scenarios were tested using the new French time series, but without the new Belgian data (WKNSEA 2021 uploaded data (Table 2). For 3 years, the impact was low (difference <2%), while for 2012 and 2019, differences of 6 and 12% were found. This is linked to the larger weighting factor of these high discard rates in the estimation process and the overall tonnage for which discards need to be estimated.

Table 2 Comparison of discard weights (tonnes), including or excluding high discard rates (DR) as found in French OTB strata in 2012, 2015, 2017-2019.

Year	Discards (t) WKNSEA 2021		Difference
	higher DR included	higher DR excluded	%
2012	481	453	6.18
2013	250		/
2014	220		/
2015	272	267	1.87
2016	114		/
2017	169	167	1.20
2018	285	280	1.79
2019	425	380	11.84

5.2. New French time series

The impact of the new French time series was verified by comparing the landings and discards overall tonnage with the values from the previous benchmark (WKNSEA 2017) (Table 3). Note that the new Belgian time series is not included.

Table 3 Estimating the impact of the new French time series by comparing WKNSEA 2017 data with WKNSEA 2021 data (excluding the new Belgian time series).

	WKNSEA **2017**		WKNSEA **2021 excl. new Belgian data**		Difference (%)	
Year	Landings (t)	Discards (t)	Landings (t)	Discards (t)	Landings	Discards
2004	6283	308	6222	269	-0.97	-12.66
2005	5056	319	5007	354	-0.97	10.97
2006	5040	229	5020	318	-0.40	38.86
2007	5588	379	5578	335	-0.18	-11.61
2008	5256	256	5242	203	-0.27	-20.70
2009	5251	360	5128	314	-2.34	-12.78
2010	4269	438	4293	295	0.56	-32.65
2011	4225	477	4267	352	0.99	-26.21
2012	4131	533	4176	481	1.09	-9.76
2013	4372	466	4399	250	0.62	-46.35
2014	4655	528	4675	220	0.43	-58.33
2015	3443	294	3479	272	1.05	-7.48
2016			2552	114		
2017			2239	169		
2018			2287	285		
2019			1779	425		

While landings did not change much, larger differences were present between the discards as estimated for the WKNSEA 2021 benchmark compared to the WKNSEA 2017 benchmark. For the years 2006, 2008, 2010, 2011, 2013 and 2014, these differences were larger than 20%. The most recent

French data are raised by landings instead of effort. More information on how French raising procedures were altered is available in the working document.

5.3. Adjusted Belgian data

Finally, the Belgian catch data were corrected for over-reporting (WD_Sole7D_1_Belgian landings), which resulted in an overall decrease of the Belgian landings over the whole time series. In the table below, a comparison is made between the time series with the new French data and the one with both new French and Belgian data. Landings have decreased over the whole time series except for 2018. Additionally, the discards decreased, with the largest difference in 2013 (28%). This could be explained by mistakes in the raw data, which were now corrected for.

	WKNSEA 2021 **new French data**		WKNSEA 2021 **new French and Belgian data**		Difference (%)	
Year	Landings (t)	Discards (t)	Landings (t)	Discards (t)	Landings	Discards
2004	6222	269	5819	258	-6.48	-4.09
2005	5007	354	4748	344	-5.17	-2.82
2006	5020	318	4830	315	-3.78	-0.94
2007	5578	335	5421	332	-2.81	-0.90
2008	5242	203	4963	183	-5.32	-9.85
2009	5128	314	4828	287	-5.85	-8.60
2010	4293	295	4108	273	-4.31	-7.46
2011	4267	352	4136	342	-3.07	-2.84
2012	4176	481	4058	445	-2.83	-7.48
2013	4399	250	4295	180	-2.36	-28.00
2014	4675	220	4626	216	-1.05	-1.82
2015	3479	272	3385	263	-2.70	-3.31
2016	2552	114	2433	106	-4.66	-7.02
2017	2239	169	2090	156	-6.65	-7.69
2018	2287	285	2395	263	4.72	-7.72
2019	1779	425	1648	404	-7.36	-4.94

6. Conclusions

In the earlier years, the Belgian TBB samples play a dominant role in the overall discard raising and age allocation for both discards and landings. OTB data originate most often from French sampling, while GTR data originate from both French and UK (England) sampling.

The changes in the French raising procedures (raising by landings instead of by effort) have a large impact on the overall discard tonnage. Additionally, the correction of Belgian landings resulted in an overall decrease of landings and discards.

The InterCatch procedures as described in this working document, will be used for raising and age allocations in the future.

Appendix 1: InterCatch overview for 2002-2019

2002

Countries	FRA (78%); ENG (21%) -> geen BEL
Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_>=120_0_0_all OTB_DEF_70-99_0_0 TBB_DEF_70-99_0_0_all GTR_DEF_100-119_0_0_all
LAN with age	3%
LAN with age per gear	GTR = 6%; OTB = 0%; REST = 0%; TBB = 0%
DIS with age	/
DIS with age per gear	/
LAN with DIS	/
LAN with DIS per gear	/

2003

Countries	BEL (24%); FRA (60%); ENG (16%); IRE (<1%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all TBB_DEF_>=120_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_all_0_0_all
LAN with age	<1%
LAN with age per gear	GTR = 2%; OTB = 0%; REST = <1%; TBB = 0%
DIS with age	/
DIS with age per gear	/
LAN with DIS	6.6%
LAN with DIS per gear	GTR = 2.6%; OTB = 38%; REST = <1%; TBB = 0%

2004

Countries	BEL (18%); FRA (63%); ENG (19%); IRE (<1%); NED (<1%); SCO (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all TBB_DEF_>=120_0_0_all GTR_DEF_all_0_0_all OTB_DEF_70-99_0_0
LAN with age	22%
LAN with age per gear	GTR = 11%; OTB = 0%; REST = <1%; TBB = 45%
DIS with age	74%
DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 45%
LAN with DIS	22%
LAN with DIS per gear	GTR = 0%; OTB = 33%; REST = 0%; TBB = 45%

2005

Countries	BEL (20%); FRA (68%); ENG (12%); IRE (<1%); NED (<1%); SCO (0%)

Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_all_0_0_all TBB_DEF_>=120
LAN with age	20%
LAN with age per gear	GTR = <1%; OTB = 0%; REST = <1%; TBB = 58%
DIS with age	58%
DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 58%
LAN with DIS	27%
LAN with DIS per gear	GTR = 4%; OTB = 42%; REST = 0%; TBB = 58%

2006

Countries	BEL (28%); FRA (59%); ENG (14%); IRE (0%); NED (<1%); SCO (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GNS_DEF_all_0_0_all
LAN with age	33%
LAN with age per gear	GTR = 15%; OTB = 0%; REST = <1%; TBB = 70%
DIS with age	59%
DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 70%
LAN with DIS	30%
LAN with DIS per gear	GTR = 0%; OTB = 19%; REST = 0%; TBB = 70%

2007

Countries	BEL (25%); FRA (60%); ENG (15%); IRE (0%); NED (<1%); SCO (0%)
Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0
LAN with age	54%
LAN with age per gear	GTR = 45%; OTB = 56%; REST = 3%; TBB = 68%
DIS with age	53%
DIS with age per gear	GTR = 11%; OTB = 0%; REST = 0%; TBB = 68%
LAN with DIS	42%
LAN with DIS per gear	GTR = 11%; OTB = 75%; REST = 0%; TBB = 68%

2008

Countries	BEL (21%); FRA (64%); ENG (15%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0 GNS_DEF_all_0_0_all
LAN with age	66%
LAN with age per gear	GTR = 84%; OTB = 36%; REST = 2%; TBB = 60%
DIS with age	99.6%

DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 60%
LAN with DIS	30%
LAN with DIS per gear	GTR = 16%; OTB = 7%; REST = 0%; TBB = 60%

2009

Countries	BEL (24%); FRA (60%); ENG (16%); IRE (0%); NED (<1%); SCO (<1%); NIRE (<1%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all GNS_DEF_all_0_0_all GTR_DEF_100-119_0_0_all
LAN with age	69%
LAN with age per gear	GTR = 82%; OTB = 45%; REST = <1%; TBB = 68%
DIS with age	52%
DIS with age per gear	GTR = 10%; OTB = 0%; REST = 0%; TBB = 64%
LAN with DIS	59%
LAN with DIS per gear	GTR = 62%; OTB = 49%; REST = 0%; TBB = 64%

2010

Countries	BEL (27%); FRA (56%); ENG (17%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GNS_DEF_all_0_0_all
LAN with age	73%
LAN with age per gear	GTR = 83%; OTB = 66%; REST = 0%; TBB = 72%
DIS with age	61%
DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 72%
LAN with DIS	66%
LAN with DIS per gear	GTR = 64%; OTB = 75%; REST = 0%; TBB = 72%

2011

Countries	BEL (26%); FRA (57%); ENG (17%); IRE (0%); NED (<1%); SCO (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GNS_DEF_all_0_0_all
LAN with age	77%
LAN with age per gear	GTR = 83%; OTB = 74%; REST = 6%; TBB = 79%
DIS with age	37%
DIS with age per gear	GTR = 0%; OTB = 0%; REST = 0%; TBB = 79%
LAN with DIS	57%
LAN with DIS per gear	GTR = 40%; OTB = 74%; REST = 0%; TBB = 79%

2012

Countries	BEL (20%); FRA (64%); ENG (16%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_all_0_0_all
LAN with age	78%
LAN with age per gear	GTR = 86%; OTB = 81%; REST = 0%; TBB = 73%
DIS with age	93%
DIS with age per gear	GTR = 14%; OTB = 55%; REST = 0%; TBB = 73%
LAN with DIS	73%
LAN with DIS per gear	GTR = 80%; OTB = 73%; REST = 0%; TBB = 73%

2013

Countries	BEL (20%); FRA (66%); ENG (14%); IRE (0%); SCO (0%)
Important gears	GTR_DEF_90-99_0_0_all TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_all_0_0_all
LAN with age	80%
LAN with age per gear	GTR = 87%; OTB = 73%; REST = 0%; TBB = 86%
DIS with age	56%
DIS with age per gear	GTR = 10%; OTB = 0%; REST = 0%; TBB = 72%
LAN with DIS	79%
LAN with DIS per gear	GTR = 90%; OTB = 73%; REST = 0%; TBB = 72%

2014

Countries	BEL (31%); FRA (55%); ENG (14%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_all_0_0_all
LAN with age	81%
LAN with age per gear	GTR = 85%; OTB = 69%; REST = 0%; TBB = 87%
DIS with age	80%
DIS with age per gear	GTR = 1%; OTB = 0%; REST = 0%; TBB = 81%
LAN with DIS	73%
LAN with DIS per gear	GTR = 73%; OTB = 69%; REST = 0%; TBB = 81%

2015

Countries	BEL (28%); FRA (58%); ENG (14%); IRE (0%); SCO (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GNS_DEF_all_0_0_all
LAN with age	85%
LAN with age per gear	GTR = 91%; OTB = 85%; REST = 0%; TBB = 86%

DIS with age	60%
DIS with age per gear	GTR = 15%; OTB = 18%; REST = 0%; TBB = 81%
LAN with DIS	76%
LAN with DIS per gear	GTR = 80%; OTB = 74%; REST = 0%; TBB = 81%

2016

Countries	BEL (28%); FRA (56%); ENG (16%); IRE (0%); NED (<1%); SCO (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_100-119_0_0_all
LAN with age	85%
LAN with age per gear	GTR = 89%; OTB = 91%; REST = <1%; TBB = 87%
DIS with age	94%
DIS with age per gear	GTR = 59%; OTB = <1%; REST = 0%; TBB = 81%
LAN with DIS	72%
LAN with DIS per gear	GTR = 92%; OTB = 15%; REST = 0%; TBB = 81%

2017

Countries	BEL (26%); FRA (57%); ENG (17%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_100-119_0_0_all
LAN with age	72%
LAN with age per gear	GTR = 64%; OTB = 85%; REST = 0%; TBB = 88%
DIS with age	74%
DIS with age per gear	GTR = 52%; OTB = 39%; REST = 0%; TBB = 82%
LAN with DIS	79%
LAN with DIS per gear	GTR = 85%; OTB = 76%; REST = 0%; TBB = 84%

2018

Countries	BEL (23%); FRA (58%); ENG (18%); IRE (<1%); NED (<1%); SCO (<1%); NOR (0%)
Important gears	TBB_DEF_70-99_0_0_all GTR_DEF_90-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_100-119_0_0_all
LAN with age	82%
LAN with age per gear	GTR = 93%; OTB = 68%; REST = 0%; TBB = 89%
DIS with age	73%
DIS with age per gear	GTR = 48%; OTB = 42%; REST = 0%; TBB = 84%
LAN with DIS	81%
LAN with DIS per gear	GTR = 86%; OTB = 82%; REST = 0%; TBB = 87%

2019

Countries	BEL (29%); FRA (57%); ENG (15%); IRE (0%); NED (<1%); SCO (<1%)
Important gears	TBB_DEF_70-99_0_0_all OTB_DEF_70-99_0_0 GTR_DEF_90-99_0_0_all GTR_DEF_100-119_0_0_all
LAN with age	74%
LAN with age per gear	GTR = 94%; OTB = 47%; REST = 0%; TBB = 87%
DIS with age	39%
DIS with age per gear	GTR = 0%; OTB = 24%; REST = 0%; TBB = 85%
LAN with DIS	71%
LAN with DIS per gear	GTR = 54%; OTB = 79%; REST = 0%; TBB = 87%

Working document: Revision of the Belgian commercial beam trawl tuning fleet for Sole in the Eastern English Channel (27.7.d).

Klaas Sys and Lies Vansteenbrugge (ILVO, Belgium)

1. Introduction and objective

The Belgian commercial beam trawl (BE-CBT) index is one of the tuning series used in the assessment of sole in the Eastern English Channel. The BE-CBT tuning series was revised during the benchmark in 2017 (WKNSEA) restricting the landings per unit of effort (LPUE) series to data from only the large fleet segment (>221 kW engine power) (ICES, 2017). During the inter-benchmark in 2019, the index was again revised and turned into an age-structured catch per unit of effort (CPUE) index using a model-based approach to better account for variation not related to the dynamics of the stock (ICES, 2019).

For the purpose of the current WKNSEA 2021 benchmark, the Belgian commercial index was investigated to avoid bias caused by potential misreporting of sole landings between different management areas within the same trip, and to modify it into a biomass index.

This document describes how commercial data of the Belgian beam trawl fleet was used to obtain an index of abundance based on the landings and specifies the pre-processing of the data and the model.

2. Data sources

Every period of 24 hours during a fishing trip, except while steaming, the skipper has to report his fishing activity in the electronic logbook. The logbooks contain the estimated live weight (kg) for all commercial species landed, grouped by ICES statistical rectangle (if fishing activity occurred in more than one ICES statistical rectangle, the ICES statistical rectangle with the highest proportion of fishing effort must be reported) and by day. They also provide information on the hours spent fishing per day. The landed weights were divided by those **fishing hours** to calculate the landings per unit effort (lpue; in kg/h). As the retained landings from the logbooks are estimated weights (with an upper and lower tolerance of 10%), the **landed weights** are derived from the quantities recorded in the sales notes. The sales notes contain information on the quantities auctioned by market category for all species landed, but no area information. Therefore, the percentage share of a species in an ICES statistical rectangle from the logbooks, is the basis for the distribution of the quantities auctioned on the ICES statistical rectangles.

3. Data preparation

3.1 Merge datasets

The landings of sole and effort data from beam trawlers (métier: TBB_DEF_70-99) active in ICES division 27.7.d were combined from 2004 onwards.

Information on ICES statistical rectangle, year, day of the year, fleet segment, engine power (kW), trip and vessel reference number is available for the analyses.

3.2 Large and small fleet segment

During the WKNSEA benchmark in 2017, only the large fleet segment was selected to construct the Belgian commercial index (ICES, 2017). The main reason for this was suspected misreporting of horse power by the small fleet segment (≤221 kW).

During the inter-benchmark in 2019, a model-based approach was used to derive the index in which a vessel effect accounted for potential misreporting of horse power so that both data of the large and small fleet segment (TBB_DEF_70-99) could be included in the analysis (ICES, 2019). By including both fleet segments, this index covers the major part of the Eastern English Channel, which was currently missing in the assessment. The small fleet segment vessels are allowed to fish within the 12 nautical mile zone, and thus fish closer to the coast in the most northern rectangles, while the large fleet segment vessels cover all rectangles (Figure 1).

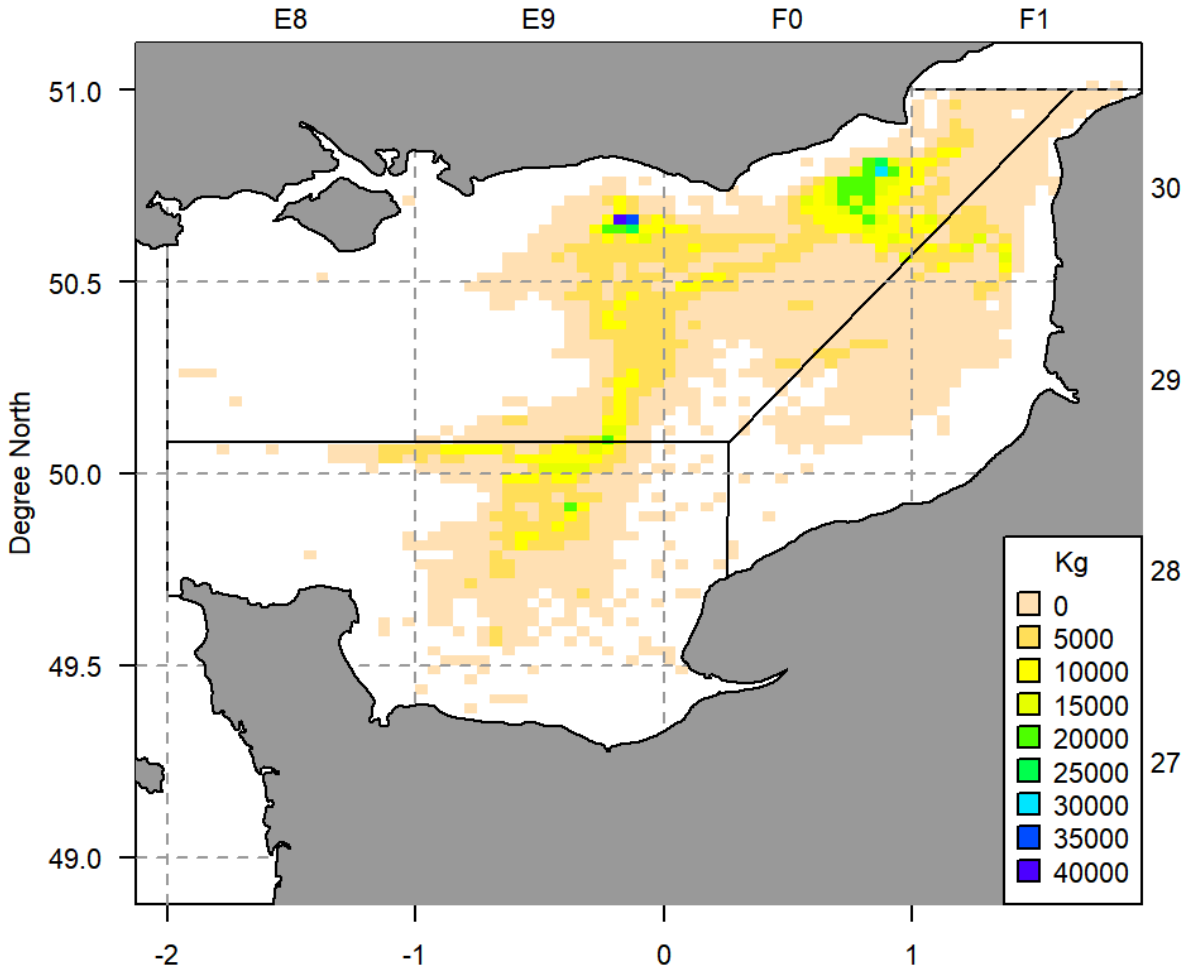


Figure 1: Spatial distribution of the landings (2006-2019) after merging with VMS data.

3.3 Including zero landings

The index as calculated during the WKNSEA benchmark in 2017 did not account for zero observations in the landings (ICES, 2017). The effort data was merged to the landings data, however, effort records without matching landings data were excluded.

During the inter-benchmark in 2019, landings records were matched with effort data, so that records without landings data were retained and considered as zero landings (ICES, 2019). We follow the same approach and keep the zero landings in the data for analysis.

3.4 From CPUE to LPUE

During the inter-benchmark in 2019, the index was modified into an age-structured CPUE index to better account for the observed changes (increase) in discard rates of the fleet in the most recent

years. The raw landings data were raised to catch data using an annual discard proportion that was estimated from the Belgian observer trips in the Eastern English Channel.

Nevertheless, this approach implies that both age distributions and discard proportions are used twice in the model (*i.e.* also used to derive catches at age). To avoid this, a biomass index based on the landings data is preferred. However, for the purpose of comparing assessment models, also an age-structured index will be constructed as the currently-used XSA model cannot deal with biomass indices.

4. Data analysis

4.1 Data preprocessing and exploration

Since the implementation of the landing obligation, fishers are required to report all catches of sole. Prior to 2018, only the landed fraction had to be reported. To account for this change in catch documentation, catches registered as Below Minimum Size (BMS) were removed from the dataset from 2018 onwards.

During the inter-benchmark in 2019, a high discrepancy was found between the LPUE of fishing trips that fished partially in the Eastern English Channel or exclusively (ICES, 2019). During this benchmark, a method was agreed upon to correct the Belgian landing statistics for this potential misreporting (cfr. WD Belgian landings). However, for the calculation of the BE-CBT tuning index, only fishing trips exclusively in Division 27.7d were retained (Table 1), because LPUE's from these trips were considered reliable.

Table 1: Number of fishing trips with fishing effort registered in the Eastern English Channel, by trip type and fleet segment, (2004-2019).

	<= 221 kW	> 221 kW
Partial 7d	4777	4366
Exclusive 7d	2389	1740

To reduce effects related to the unbalanced design of the data in terms of fleet and spatial coverage, it was decided to filter the data with the following criteria:

- Only observations were retained of vessels that registered activity in the Eastern English Channel for at least 5 years (57 of the 86 vessels were retained)
- Only observations were retained for which ICES statistical rectangle were at least fished twice per year on average. Ten of 12 ICES rectangles were retained. Rectangles 27E9 and 28E8 situated in the south-western part of the stock region were excluded from the analysis.

This criteria reduced the dataset from 6778 to 6374 observations.

Finally, visual data exploration was performed to detect potential anomalies. Inspection of the boxplots did not indicate problems in terms of outliers (Figure 2).

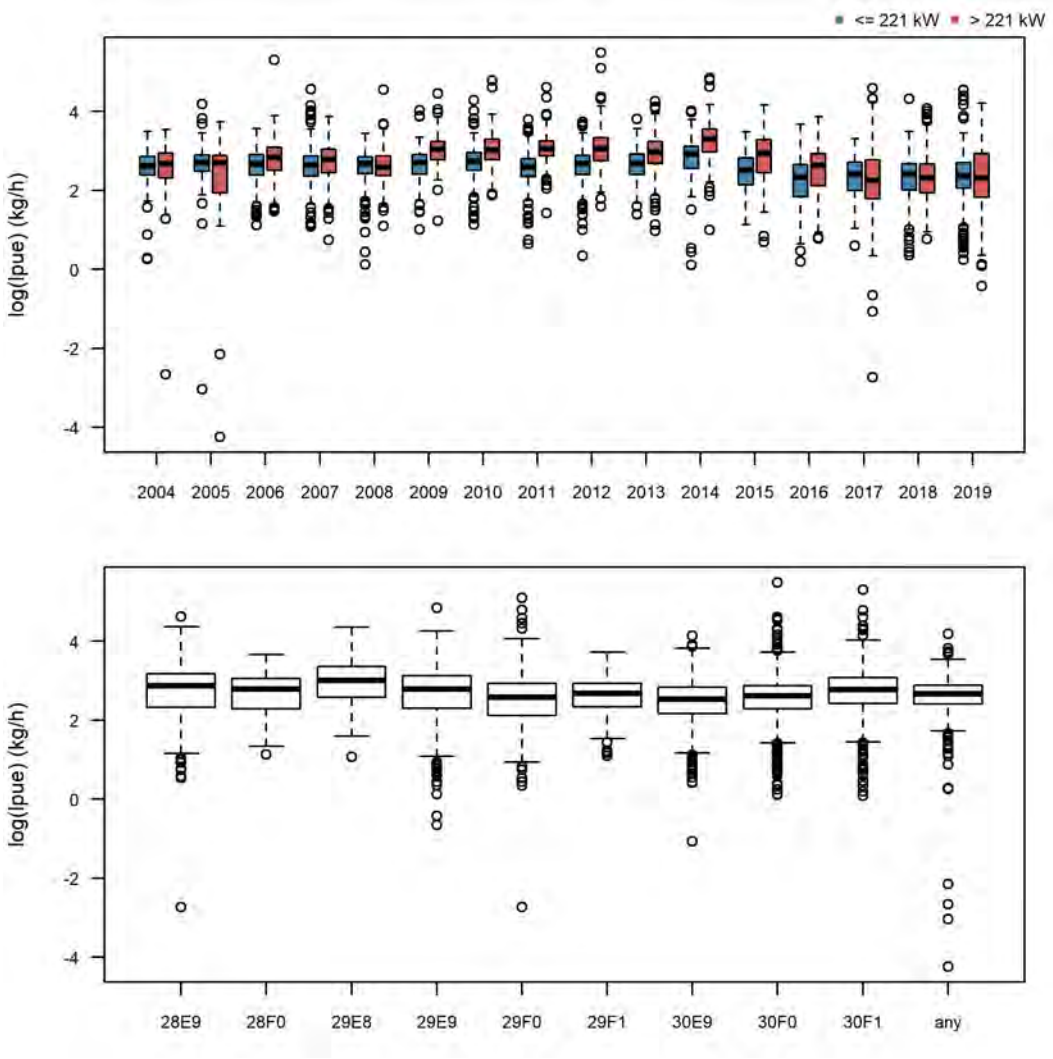


Figure 2: Boxplot of the observed log lpue (kg/h) by fleet segment and year (upper panel) and ICES statistical rectangle (lower panel).

4.2 Model

To analyse LPUE, the following delta-lognormal regression model was fitted to the data with the indices *y, r, v* indicating the year, month, ICES statistical rectangle, and vessel reference number of the observation.

The presence-absence model:

$$\Pr(kg_{y,yday} > 0) \sim \pi_{y,yday}$$

$$\pi_{y,yday} = logit(\beta_{\pi_0} + s(yday) + \delta_{\pi_y})$$

The positive catch rate model:

$$\log(kg_{y,m,r,v}) \sim N(\mu_{y,m,r,v},\ \theta_{obs})$$

$$E\left(\log(kg_{y,m,r,v})\right) = \mu_{y,m,r,v}$$

$$var\left(\log(kg_{y,m,r,v})\right) = \theta_{obs} = \sigma^2$$

$$\mu_{y,yday,r,v} = \beta_0 + s(yday) + \alpha_r + \gamma_v + \delta_y$$

$$\alpha_r \sim N(0, \theta_r)$$

$$\gamma_v \sim N(0, \theta_v)$$

$$\delta_y - \rho\ x\ \delta_{y-1} \sim N(0, \theta_y)$$

By using a random effects model for the ICES statistical rectangle, we could include spatial information without having to discard the years in which this information was not available (*i.e.* 2004 and 2005). For the seasonal effect, a smoothing spline was fitted to the data. The base functions of this spline model were constrained so that both the magnitude and the first derivative of the spline is equal in the endpoints (day 1 and 365). To reduce the number of estimated parameters, and after visual inspection of the data, the same spline model was used in both the presence-absence and positive catch rate model (Figure 3). Furthermore, a random vessel effect was included to account for skipper behaviour or technical vessel aspects that were not recorded in the data (including horse power misreporting). This random vessel effect allowed to remove the engine power covariate from the final model. To account for temporal correlation between years, a first order random walk model was specified over the years. Finally, the observation error was assumed to follow a negative binomial distribution with logarithmic link function. To account for different levels of fishing effort, the logarithm of the hours fished was included as an offset variable in the model.

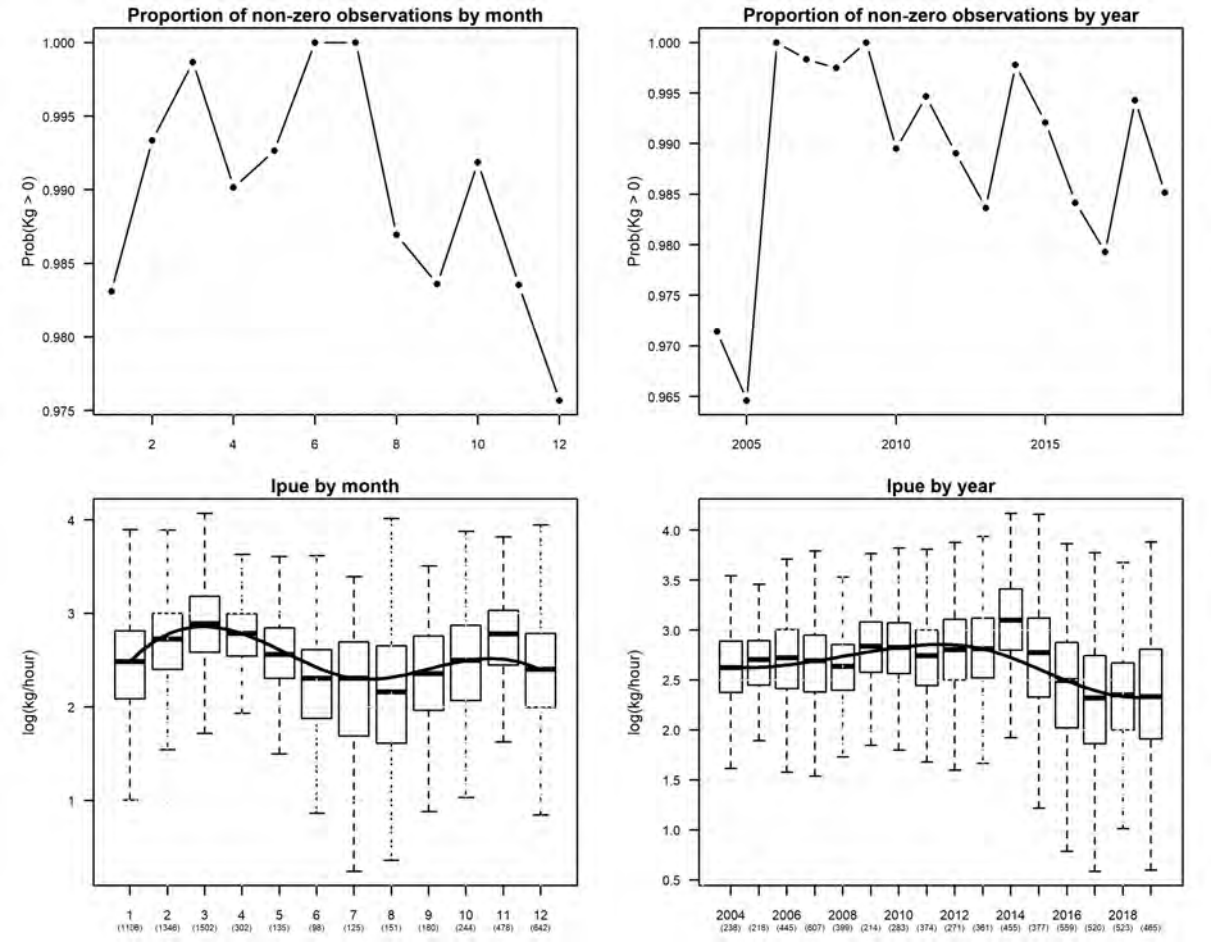


Figure 3: Upper panel: Proportion of non-zero observations by month and year and Lower panel: log LPUE by month and year. Between brackets are the number of observations.

4.3 Model estimation

The model was implemented in Template Model Builder (TMB) while optimization was performed in R. The TMB modelling framework is well suited to fit state-space models as it relies, amongst others, on cppAD to calculate first and second order derivatives for each parameter, and allows approximation of random effects parameters using the Laplace approximation, thereby achieving a greater speed compared to other numerical optimization methods.

In addition, derived quantities and the corresponding uncertainties can be calculated directly in the TMB modelling framework (Table 2 in Appendix). In case of the BE-CBT tuning series, the final index was calculated using the following formula:

$$index_y = logit\left(\beta_{\pi_0} + \delta_{\pi_y}\right) x\, e^{(\beta_0 + \delta_y)} x\, e^{(0.5\, x\, \sigma^2)}$$

The last term is the bias correction to account for the lognormal transformation (Figure 4; Table 3). The standardised age-structured BE-CBT LPUE index is shown in Table 4 in Appendix.

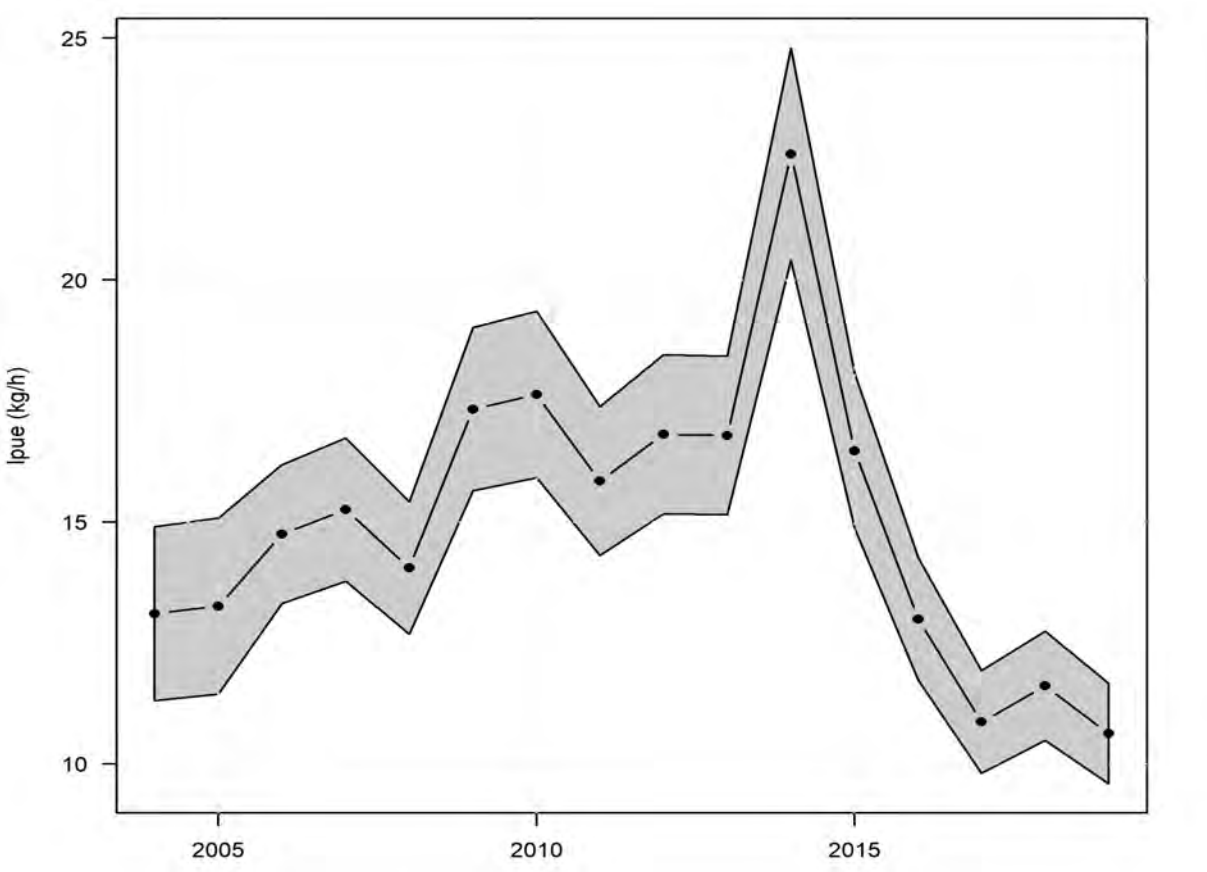


Figure 4: Index for the BE-CBT. The grey shade represents the 95% confidence intervals.

Table 3: Year estimates and standard errors of the model for the BE-CBT

Year	Year coefficient	±SE
2004	13.00847	0.94214
2005	13.28184	0.963955
2006	14.6679	0.734615
2007	15.15434	0.758393
2008	14.01434	0.702074

2009	17.1667	0.861608
2010	17.45203	0.877209
2011	15.63329	0.784173
2012	16.63905	0.837011
2013	16.69072	0.84053
2014	22.40997	1.122887
2015	16.379	0.821881
2016	12.87386	0.646549
2017	10.86163	0.546492
2018	11.52234	0.57755
2019	10.55132	0.529986

5. Model validation

One step-ahead residuals (Figure 5) were calculated for both models. The residuals for the positive catch rate indicate no clear problems, however, the residuals for the presence-absence model deviate from the theoretical quantile. This is probably related to the unbalanced design of the response variable with most observations (~99%) having an encounter.

Process residuals (Figure 6) were calculated by drawing a parameter sample from the posterior distribution of the random effects, and use this sample to calculate the appropriate residuals. Although sample sizes are small, the quantile-quantile plots of the process residuals fit well with the theoretical quantiles. The autocorrelation plots indicate that there is no residual correlation in the temporal effects (year effects).

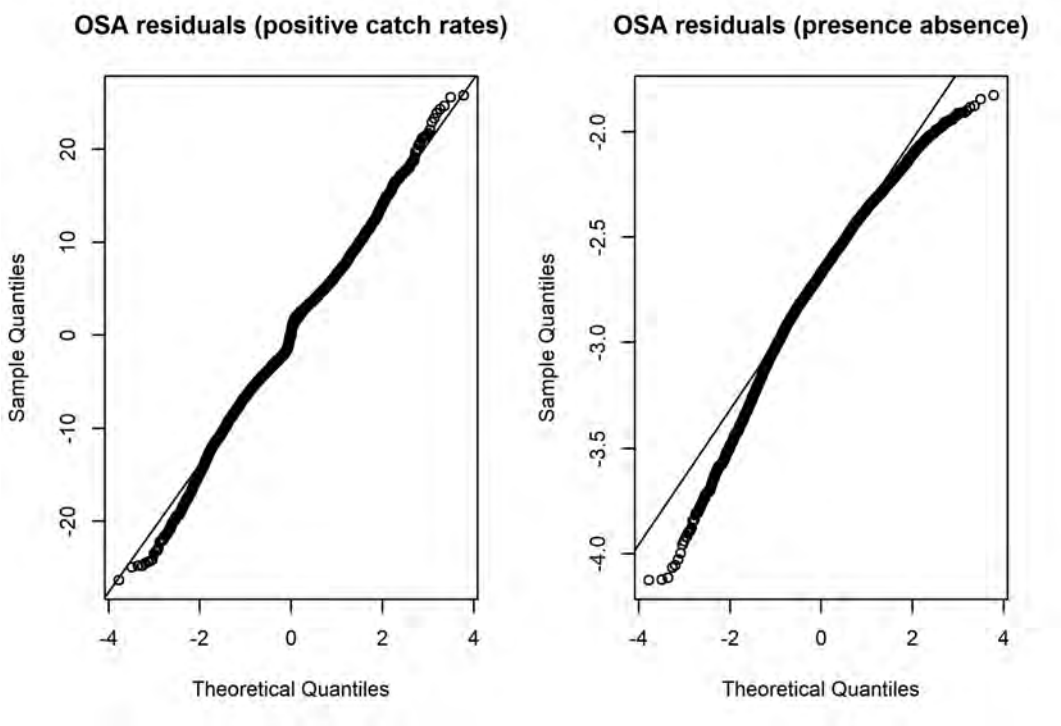


Figure 5: One-step ahead residuals.

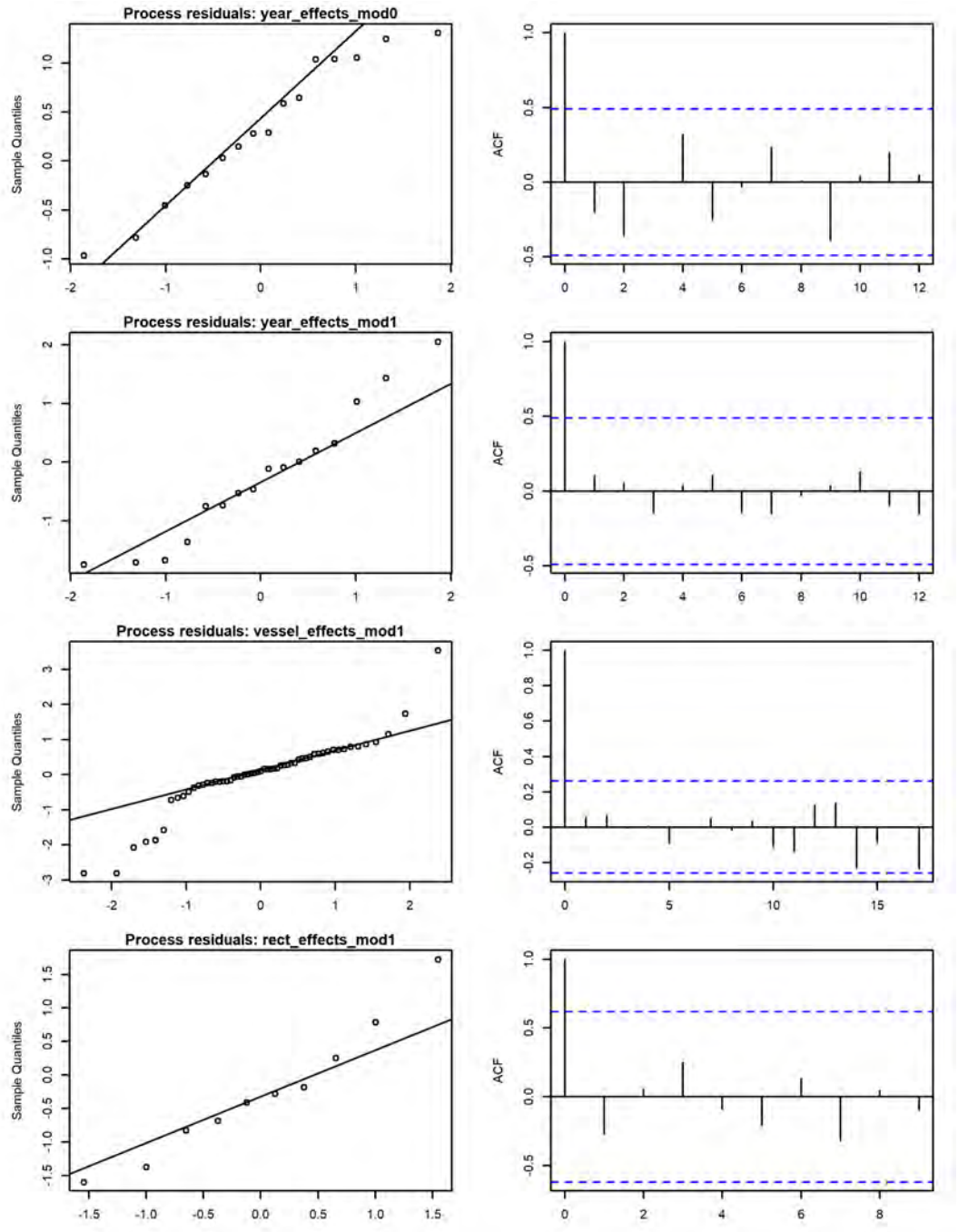


Figure 6: Process residuals.

6. Conclusion

The sales notes and logbooks of the Belgian beam trawl fleet (TBB_DEF_70-99) were used to calculate the sole landing rates (LPUE) in the Eastern English Channel. Landings and discards data from the small and large fleet segment were selected and zero landings were allowed for. Only observations from trips occurring exclusively in Division 27.7d were retained in the analysis. A regression model accounting for variance caused by spatial, seasonal and vessel effects was fitted to the landings data to identify annual trends of the Eastern English Channel sole stock.

7. References

ICES. 2017. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 6–10 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:34. 673 pp.

ICES. 2019. Inter-benchmark Protocol for sole in the Eastern English Channel (IBPsol7d). ICES Scientific Reports. 1:75. 88 pp. http://doi.org/10.17895/ices.pub.5631

8. Appendix

Table 2: Estimates and standard errors of the model parameters and derived quantities.

	Estimate	Std. Error
intercept_mod0	4.794412	0.319098
logSdRw_mod0	-0.24526	0.306528
rhotan_mod0	0.294361	0.389014
intercept_mod1	2.564176	0.124147
log_lambda_mod1	5.739542	0.500288
logSdObs_mod1	-0.93185	0.001898
logSdObs_mod1	-0.85947	0.001711
logSdRw_mod1	-1.96167	0.178331
rhotan_mod1	0.900735	0.369704
logSdRect_mod1	-2.82402	0.247166
logSdVessel_mod1	-1.05985	0.094355
year_effects_mod0	-1.07231	0.48296
year_effects_mod0	-1.19224	0.507001
year_effects_mod0	0.824736	0.648996
year_effects_mod0	0.975409	0.615501
year_effects_mod0	0.752235	0.662456
year_effects_mod0	0.695514	0.686925
year_effects_mod0	-0.05325	0.580493
year_effects_mod0	0.196572	0.542777
year_effects_mod0	-0.20963	0.5381
year_effects_mod0	-0.54083	0.504525
year_effects_mod0	0.501294	0.580514
year_effects_mod0	0.006659	0.52257
year_effects_mod0	-0.55684	0.435086
year_effects_mod0	-0.78604	0.433695
year_effects_mod0	0.193823	0.504433
year_effects_mod0	-0.39696	0.460492
betaSeasonal_mod1	-0.00207	0.001997
betaSeasonal_mod1	0.211862	0.001824
betaSeasonal_mod1	0.295376	0.001929
betaSeasonal_mod1	0.118766	0.003008
betaSeasonal_mod1	-0.33388	0.004383
betaSeasonal_mod1	-0.248	0.003751
betaSeasonal_mod1	0.003607	0.003156
betaSeasonal_mod1	0.078492	0.002567
year_effects_mod1	-0.05223	0.121939

year_effects_mod1	-0.02843	0.121952
year_effects_mod1	0.047558	0.114359
year_effects_mod1	0.079678	0.114353
year_effects_mod1	0.00225	0.114371
year_effects_mod1	0.205367	0.114389
year_effects_mod1	0.226422	0.114374
year_effects_mod1	0.114454	0.114371
year_effects_mod1	0.180182	0.114378
year_effects_mod1	0.187242	0.114372
year_effects_mod1	0.472782	0.114351
year_effects_mod1	0.162463	0.114367
year_effects_mod1	-0.07219	0.114355
year_effects_mod1	-0.23849	0.11436
year_effects_mod1	-0.19064	0.114354
year_effects_mod1	-0.27324	0.114349
rect_effects_mod1	0.11481	0.019843
rect_effects_mod1	-0.06314	0.020936
rect_effects_mod1	0.026503	0.021684
rect_effects_mod1	0.056782	0.01979
rect_effects_mod1	-0.01317	0.019817
rect_effects_mod1	-0.02717	0.021004
rect_effects_mod1	0.002153	0.019831
rect_effects_mod1	-0.08033	0.019779
rect_effects_mod1	-0.00368	0.019853
rect_effects_mod1	-0.01275	0.055162
vessel_effects_mod1	-0.54936	0.046137
vessel_effects_mod1	-0.07166	0.046106
vessel_effects_mod1	-0.24968	0.046189
vessel_effects_mod1	0.048752	0.046211
vessel_effects_mod1	-0.1391	0.046091
vessel_effects_mod1	-0.01954	0.04607
vessel_effects_mod1	-0.72351	0.046011
vessel_effects_mod1	-0.02367	0.046055
vessel_effects_mod1	0.383704	0.046962
vessel_effects_mod1	0.223838	0.048138
vessel_effects_mod1	0.241054	0.04619
vessel_effects_mod1	0.005203	0.046254
vessel_effects_mod1	-0.07452	0.046899
vessel_effects_mod1	0.000916	0.046038
vessel_effects_mod1	-0.03421	0.046145
vessel_effects_mod1	-0.08691	0.046225
vessel_effects_mod1	0.600683	0.046239
vessel_effects_mod1	0.00977	0.04628
vessel_effects_mod1	-0.11062	0.046073
vessel_effects_mod1	-0.98797	0.046752
vessel_effects_mod1	0.23022	0.046106
vessel_effects_mod1	0.311398	0.046336

vessel_effects_mod1	-0.9639	0.049718
vessel_effects_mod1	0.052256	0.046034
vessel_effects_mod1	-0.24388	0.04659
vessel_effects_mod1	-0.05614	0.046184
vessel_effects_mod1	-0.10753	0.046601
vessel_effects_mod1	0.099377	0.04649
vessel_effects_mod1	0.212426	0.046396
vessel_effects_mod1	-0.00845	0.046338
vessel_effects_mod1	0.084084	0.046206
vessel_effects_mod1	-0.66781	0.046499
vessel_effects_mod1	-0.06614	0.046415
vessel_effects_mod1	0.140528	0.046128
vessel_effects_mod1	0.294915	0.046151
vessel_effects_mod1	0.188706	0.046434
vessel_effects_mod1	1.21269	0.047035
vessel_effects_mod1	0.272936	0.046223
vessel_effects_mod1	0.251507	0.046084
vessel_effects_mod1	0.054208	0.046162
vessel_effects_mod1	0.1109	0.046113
vessel_effects_mod1	-0.17318	0.046228
vessel_effects_mod1	0.270791	0.046404
vessel_effects_mod1	-0.21806	0.046347
vessel_effects_mod1	0.023389	0.046105
vessel_effects_mod1	0.116422	0.046192
vessel_effects_mod1	-0.08474	0.047103
vessel_effects_mod1	0.031441	0.046171
vessel_effects_mod1	0.156381	0.046115
vessel_effects_mod1	0.241967	0.047259
vessel_effects_mod1	0.172253	0.046161
vessel_effects_mod1	0.088328	0.046501
vessel_effects_mod1	0.062611	0.046189
vessel_effects_mod1	-0.66154	0.046843
vessel_effects_mod1	0.056859	0.046168
vessel_effects_mod1	-0.08446	0.046262
vessel_effects_mod1	0.156065	0.046778
year_effects_mod0	-1.07231	0.48296
year_effects_mod0	-1.19224	0.507001
year_effects_mod0	0.824736	0.648996
year_effects_mod0	0.975409	0.615501
year_effects_mod0	0.752235	0.662456
year_effects_mod0	0.695514	0.686925
year_effects_mod0	-0.05325	0.580493
year_effects_mod0	0.196572	0.542777
year_effects_mod0	-0.20963	0.5381
year_effects_mod0	-0.54083	0.504525
year_effects_mod0	0.501294	0.580514
year_effects_mod0	0.006659	0.52257

year_effects_mod0	-0.55684	0.435086
year_effects_mod0	-0.78604	0.433695
year_effects_mod0	0.193823	0.504433
year_effects_mod0	-0.39696	0.460492
year_effects_mod1	-0.05223	0.121939
year_effects_mod1	-0.02843	0.121952
year_effects_mod1	0.047558	0.114359
year_effects_mod1	0.079678	0.114353
year_effects_mod1	0.00225	0.114371
year_effects_mod1	0.205367	0.114389
year_effects_mod1	0.226422	0.114374
year_effects_mod1	0.114454	0.114371
year_effects_mod1	0.180182	0.114378
year_effects_mod1	0.187242	0.114372
year_effects_mod1	0.472782	0.114351
year_effects_mod1	0.162463	0.114367
year_effects_mod1	-0.07219	0.114355
year_effects_mod1	-0.23849	0.11436
year_effects_mod1	-0.19064	0.114354
year_effects_mod1	-0.27324	0.114349
Index_2004	13.00847	0.94214
Index_2005	13.28184	0.963955
Index_2006	14.6679	0.734615
Index_2007	15.15434	0.758393
Index_2008	14.01434	0.702074
Index_2009	17.1667	0.861608
Index_2010	17.45203	0.877209
Index_2011	15.63329	0.784173
Index_2012	16.63905	0.837011
Index_2013	16.69072	0.84053
Index_2014	22.40997	1.122887
Index_2015	16.379	0.821881
Index_2016	12.87386	0.646549
Index_2017	10.86163	0.546492
Index_2018	11.52234	0.57755
Index_2019	10.55132	0.529986

Table 4: Standardised age-structured BE-CBT LPUE index

Year		Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	Age14	Age15
2004	1	0.000	0.620	1.428	0.632	0.911	0.325	0.070	0.065	0.059	0.053	0.020	0.030	0.007	0.020	0.015
2005	1	0.078	1.152	0.941	0.974	0.262	0.193	0.135	0.084	0.045	0.021	0.032	0.012	0.005	0.002	0.006
2006	1	0.058	1.131	0.824	0.752	0.695	0.294	0.280	0.141	0.055	0.054	0.036	0.020	0.023	0.008	0.011
2007	1	0.014	1.179	1.447	0.550	0.335	0.483	0.198	0.236	0.130	0.042	0.049	0.023	0.016	0.005	0.037
2008	1	0.162	0.375	1.489	1.754	0.318	0.230	0.183	0.101	0.036	0.051	0.015	0.007	0.000	0.000	0.031
2009	1	0.151	1.240	1.019	1.254	0.964	0.241	0.243	0.215	0.078	0.089	0.068	0.018	0.025	0.030	0.030
2010	1	0.023	1.338	1.340	0.466	0.714	0.813	0.159	0.083	0.135	0.045	0.106	0.046	0.037	0.000	0.050
2011	1	0.000	1.241	2.247	0.952	0.333	0.307	0.154	0.042	0.060	0.060	0.017	0.033	0.009	0.000	0.010
2012	1	0.000	0.298	2.404	1.797	0.542	0.170	0.230	0.235	0.039	0.022	0.039	0.010	0.029	0.026	0.031
2013	1	0.005	0.074	1.013	1.593	1.187	0.408	0.187	0.247	0.137	0.024	0.034	0.026	0.010	0.033	0.016
2014	1	0.027	0.255	1.015	1.665	1.759	0.878	0.282	0.141	0.157	0.097	0.012	0.027	0.043	0.027	0.029
2015	1	0.000	0.190	0.490	0.690	0.841	1.108	0.783	0.263	0.054	0.140	0.077	0.029	0.009	0.013	0.031
2016	1	0.008	0.147	0.544	0.380	0.511	0.484	0.511	0.394	0.078	0.113	0.067	0.074	0.016	0.005	0.032
2017	1	0.049	0.149	0.539	0.449	0.241	0.297	0.255	0.368	0.211	0.071	0.028	0.038	0.029	0.011	0.034
2018	1	0.002	0.216	0.481	1.006	0.392	0.333	0.256	0.240	0.270	0.214	0.043	0.010	0.034	0.056	0.043
2019	1	0.011	0.221	0.926	0.409	0.761	0.173	0.122	0.069	0.239	0.207	0.106	0.027	0.018	0.016	0.032

WD Commercial LPUE from French Otter Trawlers for sol.27.7d stock assessment: WKNSEA 2021.

Author: Raphael Girardin (Ifremer, France)

Date:17-02-2021

Introduction

Eastern English Channel (7d) Sole is currently assessed using 3 survey indices: UK(E&W) BTS, UK(E&W) YFS, and FR YFS; and 3 commercial indices: BE CBT, UK(E&W) CBT, and FR COTB. Recently, BE and UK CBT were reviewed and modified during the IBPsol7d in 2019 (ICES, 2019). BE-CBT moved from a LPUE to a CPUE index using the all fleet segment and UK-CBT was modified to account for UK effort database changes. However, FR COTB was not investigated even if the index is computed as a raw LPUE (ICES, 2017). For the purpose of WKNSEA benchmark, the French commercial LPUE index was standardized using a hurdle-lognormal mixed model to account for vessel, seasonal and spatial effect. This document reviews the data available from the French fleet and presents the method used to standardize French Otter Trawlers LPUEs time series that target sole seasonally and mainly in the French coast.

Data exploration and pre-processing

All the data used for the analyses were extracted from the French commercial fishery database: SACROIS version 3.3.8 (Source: DPMA et Ifremer SIH, traitement des données Ifremer - Système d'Informations Halieutiques). SACROIS dataset are built from a cross validation of VMS data, logbook information and record from fishing auctions.

Fleet and métier selected to compute LPUE biomass index

Sole in 7d is mainly catch in France by gillnetters (GNS and GTR) and bottom otter trawlers (OTB) (ICES, 2020). However, information on gear length used by netters during fishing operation is scarce in historical data which make difficult to compute a reliable effort proxy for that particular fleet, hence the commercial LPUE index is based on French OTB vessels and fishing kWhours is used as effort proxy for that fleet. Data from 2005 onward are used as before 2005 spatial effort information is scarce for the fleet considered. This analysis focus on the OTB main métier, the métier of otter trawlers that use gear of mesh size ranging from 70 to 99mm to target demersal fish (OTB_DEF_70_99_0) (Table A1). Most of the French demersal trawlers behave as a mixed fishery in the Eastern English Channel. Along with the change of fishing métiers during the year they are also changing target species. Over the 2005-2019 period, the main species landed in tonnage by French vessels practicing OTB_DEF_70_99_0 in 7d were whiting (*Merlangius merlangus*), small-spotted catshark (*Scyliorhinus canicula*), mackerel (*Scomber scombrus*) and plaice (*Pleuronectes platessa*); and in values the main species were sole (*Solea solea*), Seabass (*Dicentrarchus labrax*), whiting

and stripped red mullet (*Mullus surmuletus*). To filter vessels targeting sole over the period considered, the vessels that are contributing for less than 5% of the total landings of OTB_DEF_70_99_0 métier between 2005-2019 are removed, filtering 315 vessels out of 494 and removing 326 tons of sole out of 6609 tons landed (Figure 1a). In addition, to account for vessels moving in and out of sole fishery in 7d vessels that remain in the fishery at least two third of the time series duration are kept in the analysis, here at least 10 years (Figure 1b).

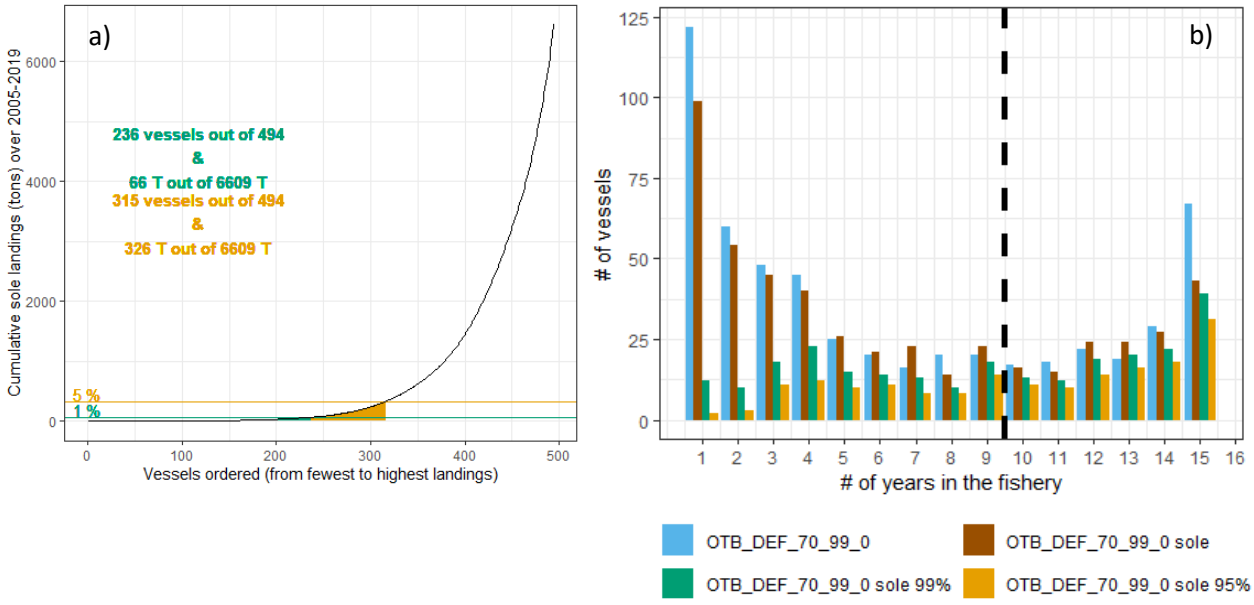


Figure 1 (a) Cumulative sole total landings in 7d over 2005-2019 ordered from the vessel with the fewest landing to the highest. In green, vessels with the fewest landing that represent 1% of the total landing and yellow that represent 5% of total landing. (b) Number of vessel per fleet that stay n year in the fishery. In Blue, all the bottom trawlers practicing OTB_DEF_70_99_0 métier, amongst them in brown vessels that catch at least once sole, in green the one representing the top 99% of sole catch and in yellow the one representing the top 95% of sole catch over the period 2005-2019. The black dotted line separate on the left vessels removed from the analysis.

The selected fleet practicing OTB_DEF_70_99_0 métier between 2005-2019 is composed of 100 vessels and represent 69% of sole total landing of OTB_DEF_70_99_0 (4547 tons). The total annual landings in 7d of the selected fleet are composed at least of 10% of sole every year at the exception of 2009 and 2019 (Figure 2).

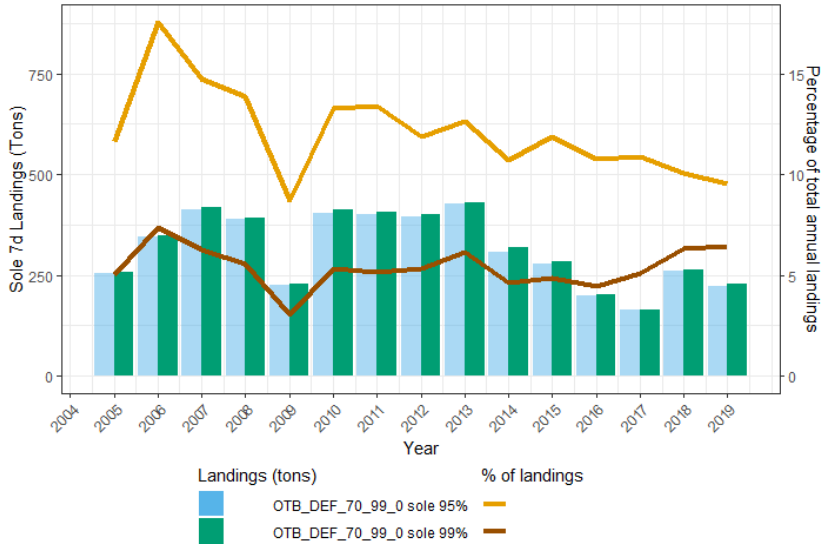


Figure 2 Proportion of sole in the total landings and landing of sole in 7d for the vessels practicing OTB_DEF_70_99_0 representing the top 95% of total sole landing of OTB_DEF_70_99_0 (respectively in blue and yellow) and representing the top 99% of total sole landing of OTB_DEF_70_99_0 (respectively in green and brown).

Selected fleet data exploration

OTB_DEF_70_99_0 métier is a seasonal activity for the selected fleet, effort (in kWhours) is mostly allocated during Q2 and Q3 and decreased during the period 2005-2019. Sole is landed between the month of May and October in 7d (Figure 3)and landings remain at a low level (below 250 tons) in the recent years except for 2018 (Figure 2).

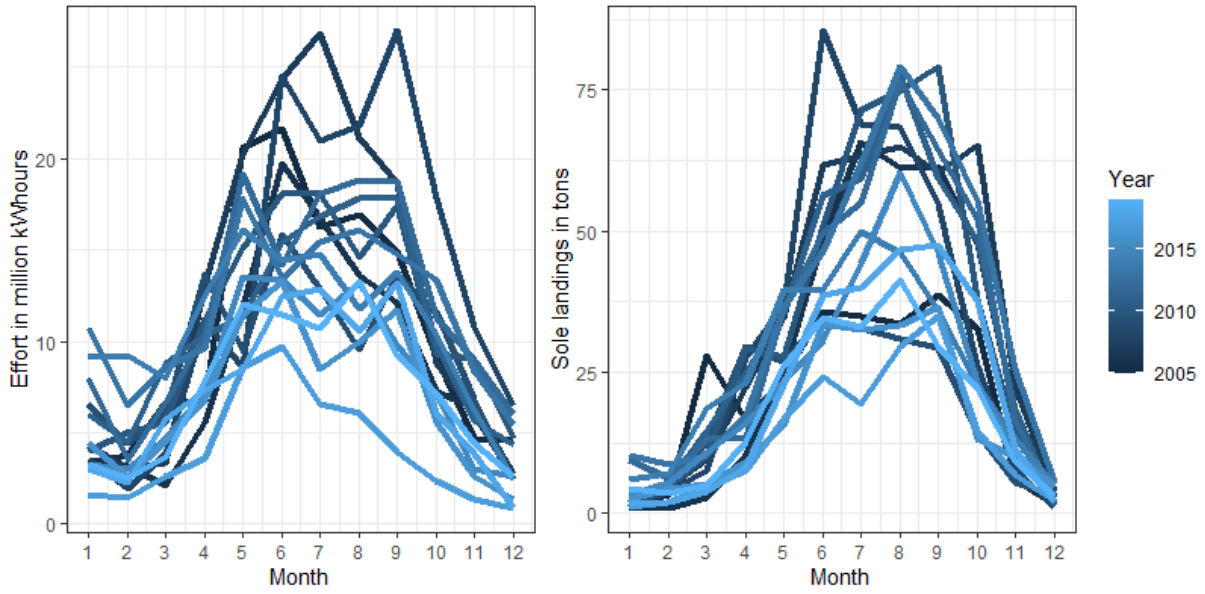


Figure 3 Distribution of effort in million kWhours hours and sole landings in tons of the selected fleet monthly per years.

Effort is allocated along the French coast, and concentrated in the Bay of Seine. Effort allocation have changed through time with a decrease of effort allocated to the North East Coast of 7d (Figure 4).

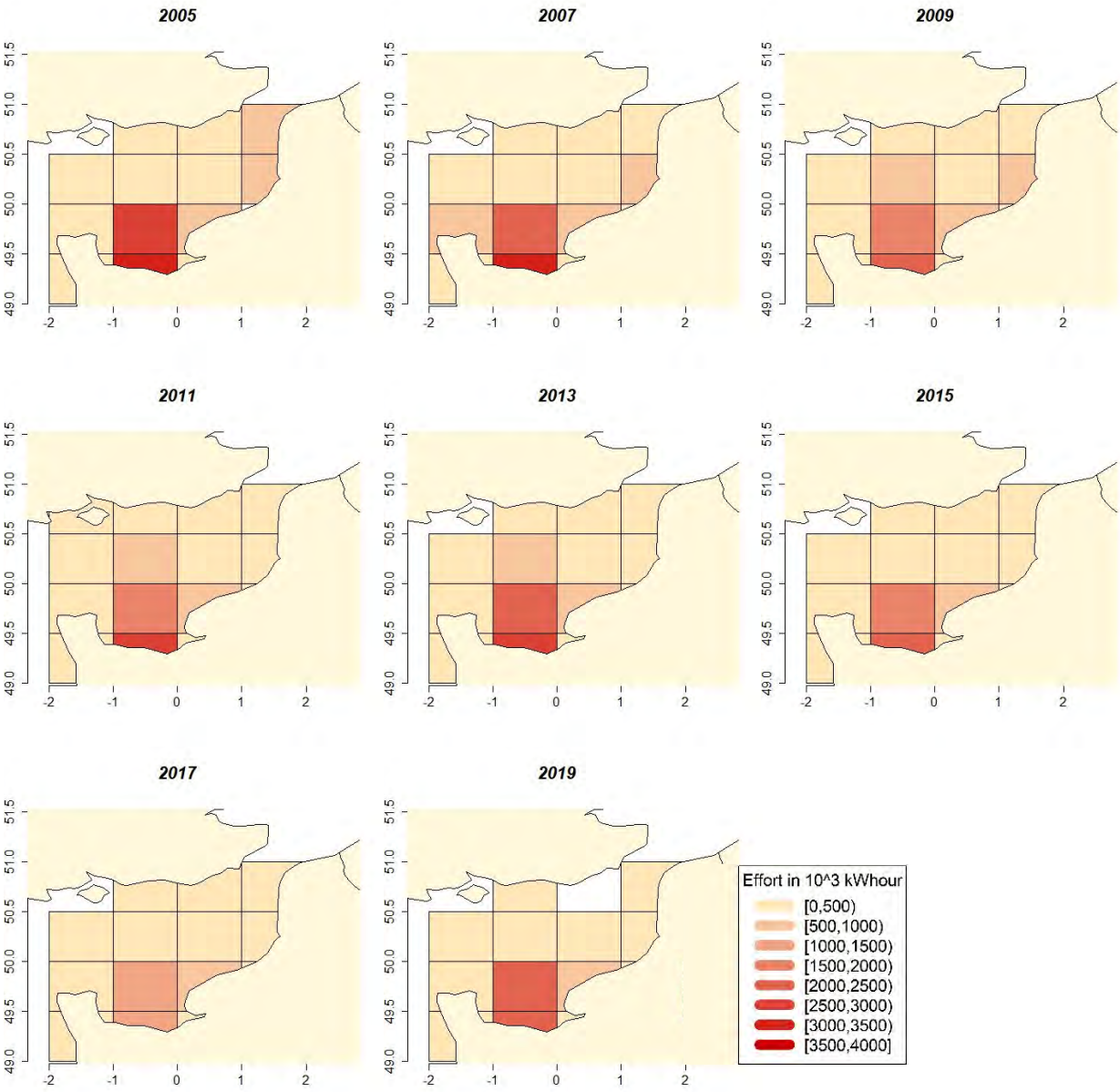


Figure 4 Spatial distribution of fishing effort per year and ICES rectangles allocated by the selected fleet (vessels practicing OTB_DEF_70_99_0 métier present in the fishery at least 10 years and responsible for the top 95% of total sole landings between 2005 and 2019).

Data pre-processing

All the trip performed by the 100 vessels selected are considered, trip with missing effort are excluded and zero landing of sole is attributed to trips with missing landings of sole. The month of return to the harbour is associated to each fishing trip. For this analysis, landing (in kg) and effort (in kWhours) are aggregated per fishing trips, vessels, ICES statistical rectangles, months and years. ICES statistical rectangle 30E8 and 30F2 are removed from the analysis as they are visited only 11 times over the 2005-2019 period by the selected fleet. To account for the seasonality of the fishery and the change in effort allocation through time, hurdle lognormal mixed models are tested.

LPUE standardization: Hurdle lognormal mixed model using INLA

To standardize FR-COTB index we decided to apply a hurdle modelling approach to account for zero landings. Several combinations of the full regression model presented below are fitted to data per trip, year *t*, month *m*, ICES statistical rectangle *r*, the vessel reference number *v*. The occurrence variable representing the occurrence of sole in the landing of a trip is defined as $z_{t,m,r,v}$:

$$z_{t,m,r,v}\begin{cases}1\ if\ y_{t,m,r,v} > 1\\ 0\ otherwise\end{cases}$$

and the amount variable $y_{t,m,r,v}$ representing the positive landings of a trip is given by:

$$y_{t,m,r,v}\begin{cases}NA\ if\ y_{t,m,r,v} = 0\\ y_{t,m,r,v}\ otherwise\end{cases}$$

We use a logistic regression to model the occurrence:

$$z_{t,m,r,v} \sim Bernoulli(p_{t,m,r,v})$$

$$logit(p_{t,m,r,v}) \sim intercept + power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$$

And a lognormal model for the positive landings with $effort_{t,m,r,v}$ in kWhours used as an offset:

$$\log(y_{t,m,r,v}) \sim N(\mu_{t,m,r,v}, \theta_{t,m,r,v})$$

$$\log(y_{t,m,r,v}) \sim intercept + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r} + \log(effort_{t,m,r,v})$$

Where the fixed effect $power_{t,v}$ is the vessels power in kW. All the others variables are random effects they are defined as a IID random effect to considered skipper behaviour or technical aspect that was not recorded in the data:

$$\gamma_v \sim N(0, \theta_v)$$

a seasonal random effect on month *m*:

$$\sum_{m=1}^{12} \beta_m \sim N(0, \theta_m)$$

A first order random walk to account for temporal correlation between years *t*:

$$\Delta\delta_t = \delta_t - \delta_{t-1} \sim N(0, \theta_t)$$

Spatial random effect is included following two different approaches, one considering no spatial correlation with a IID random effect u and another following the Besag-York-Mollier (BYM) method (Besag et al., 1991) that combine IID random effect and a besag model v imposing a correlation structure on the precision matrix between neighbours ICES statistical rectangles:

$$\alpha_r \sim u_r$$

or

$$\alpha_r \sim u_r + v_r$$

with

$$u_r \sim N(0, \theta_{r1})$$

$$v_i | v_j, i \neq j, \{i,j\} \in r \sim N(\frac{1}{n_i}\sum_{i\sim j} v_j, \frac{\theta_{r2}}{n_i})$$

where *i* and *j* are two different *r* ICES statistical rectangles, n_i is the number of neighbours of statistical rectangle *i*, and $i \sim j$ indicates that statistical rectangles *i* and *j* are neighbours.

Finally to consider change in spatial effort allocation through time several approach are tested to include $\varphi_{t,r}$ *the* interaction random effect between year *t* and statistical rectangle *r*:

$$\varphi_{t,r} \sim N(0, \theta_{rt})$$

where

$$\theta_{rt} = \frac{1}{\tau_{rt} R_{rt}} \; with \; R_{rt} = R_r \otimes R_t$$

τ_{rt} is a precision scalar while R_{rt} is the correlation structure matrix, identifying the type of temporal and/or spatial dependences of the interaction random effect. It can be factorized as the Kronecker product of the spatial structure matrix R_r and the temporal one R_t (Clayton 1996; Blangiardo and Cameletti, 2015). Different structure matrices are tested: (i) a IID random effect represented by $R_r = R_t = I$, and (ii) a neighbourhood structure for R_r and a first order random walk for the temporal structure for R_t.

Occurrence model selection and diagnostics

A Bayesian framework, as implemented by the RINLA software, is used to estimate the model parameters. The default INLA settings are used so that the prior distributions on the parameters are uninformative, while hyperparameters were estimated through Laplace approximation. The best model is selected based on the DIC and the CPO (cross validation score) during the estimation of the model (Table 1). Model 11 is selected, as the main spatial effect is captured by the structured spatio-temporal interaction and adding either IID spatial effect (model 8) or BYM spatial effect (model 10) do not improve significantly the selection criteria values. When a threshold of probability at P($z_{t,m,r,v} = 1$) > 0.5 is considered as an occurrence, the selected model has a good predictive power of positive landings however it underestimates the trip with zero landing. Adding an average depth of ICES statistical rectangles as an additional covariate was tested to try to improve the prediction of zero observations, however the model has issues of convergence and when it converged it did not improve the prediction of zero observations.

Table 1 Occurrence models fitted using INLA and their selection criteria: DIC and CPO.

model	covariates	Spatial effect	Spatio-temporal interaction	DIC	CPO
1	$\alpha_r + \beta_m + \gamma_v + \delta_t$	IID	-	70348	35173
2	$power_{t,v} + \alpha_r + \beta_m + \delta_t$	IID	-	82217	41109
3	$power_{t,v} + \alpha_r + \gamma_v + \delta_t$	IID	-	70628	35313
4	$power_{t,v} + \beta_m + \gamma_v + \delta_t$	-	-	71678	35839
5	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t$	IID	-	70255	35127
6	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t$	BYM	-	70104	35052
7	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	IID	IID:IID	68915	34456
8	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	IID	Besag:RW1	68892	34446
9	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	BYM	IID:IID	68915	34456
10	$power_{t,v} + \alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	BYM	Besag:RW1	68895	34447
11	$power_{t,v} + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	-	Besag:RW1	68895	34447

Table 2 Occurrence model 11 confusion matrix with a threshold P(z==1) > 0.5 considered as an occurrence.

Predicted \ Observed	0	1
0	5664	2520
1	11566	80341

Occurrence model posterior distribution of spatio-temporal random effects.

The monthly effect is well captured by the posterior distribution of the seasonal random effect with a higher probability of having positive landings from May to October. The posterior mean of the random walk estimates the lowest probabilities of having positive landings starting from 2016 with the exception of 2018 that is at the same level as 2014 and close to 2009 (Figure 5).

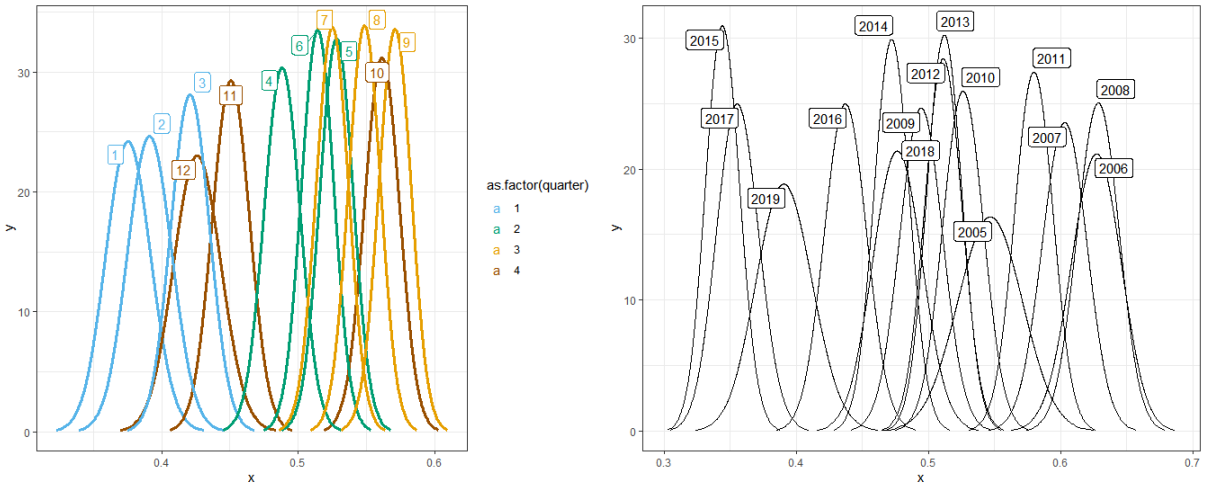


Figure 5 Posterior distribution of the seasonal random effect on the left and the year first order random walk effect on the right for the occurrence model. On the left side Q1 is in blue, Q2 green, Q3 yellow and Q4 brown, the number show the months. On the right the numbers show the years.

The interaction random effect present most of the time higher variability along the coast of England and a higher probability of positive landings in the Bay of Seine especially at the beginning of the time series were the selected fleet mainly fish (Figure 6). The posterior distribution of fixed effects, the vessel random effect and the hyperparameters are presented in the appendix (Figure A1, and A2).

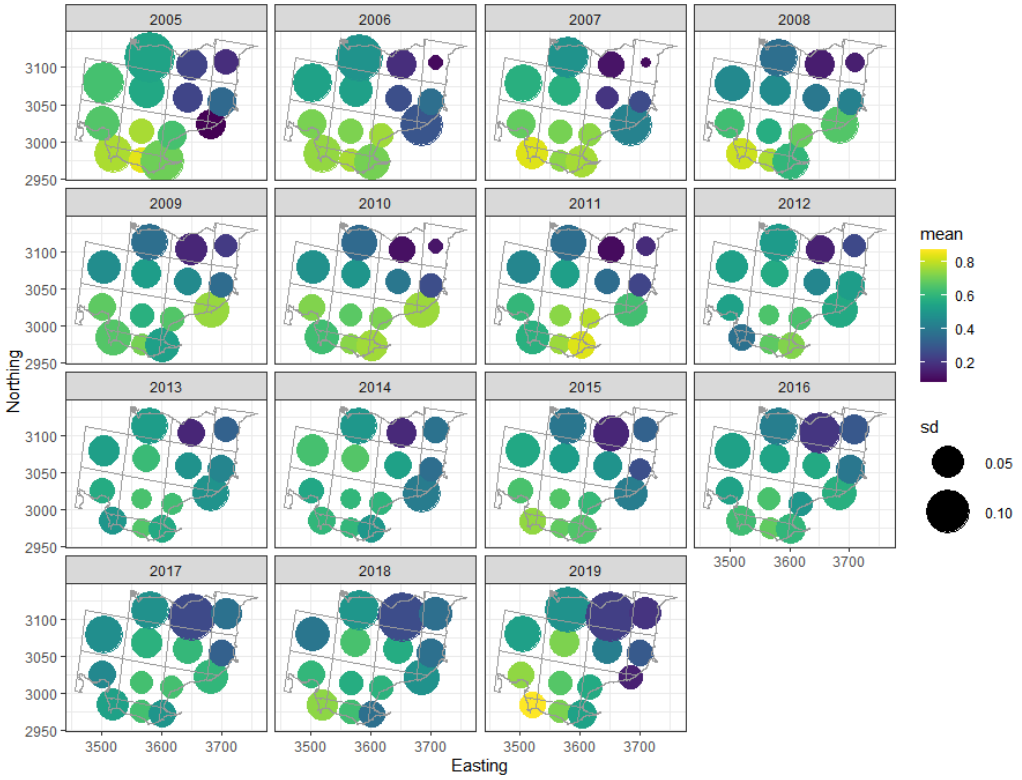


Figure 6 Posterior mean and standard deviation of the spatio-temporal structured random effect of the occurrence model.

Positive sole landings: Lognormal model selection and diagnostics

Models selection criteria

The same Bayesian framework was used to fit the lognormal mixed model on the positive sole landings and the same random effects are tested. However, the vessel power linear effect is drop out as it is accounted for in the effort in kWhours used as an offset.

The full positive model 9 using BYM spatial effect and structured spatio-temporal interaction effect has the best DIC and CPO. However, the addition of the BYM spatial effect only include an extra degree of variability around a common mode for each ICES statistical rectangle, and the spatial effect is mainly captured by the structured random spatio-temporal interaction. To simplify the model and ease its convergence, the spatial main effect is dropped out and model 10 is selected.

Table 3 Lognormal models fitted using INLA and their selection criteria: DIC and CPO.

model	covariates	Spatial effect	Spatio-temporal interaction	DIC	CPO
1	$\beta_m + \gamma_v + \delta_t$	-	-	788424	394223
2	$\alpha_r + \beta_m + \delta_t$	IID	-	836110	418058
3	$\alpha_r + \gamma_v + \delta_t$	IID	-	789048	394537
4	$\alpha_r + \beta_m + \gamma_v + \delta_t$	IID	-	787812	393920
5	$\alpha_r + \beta_m + \gamma_v + \delta_t$	BYM	-	779426	389731
6	$\alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	IID	IID:IID	785845	392966
7	$\alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	IID	Besag:RW1	777578	388772
8	$\alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	BYM	IID:IID	777586	388826
9	$\alpha_r + \beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	BYM	Besag:RW1	777431	388753
10	$\beta_m + \gamma_v + \delta_t + \varphi_{t,r}$	-	Besag:RW1	777578	388816

Lognormal mixed model fit

Pearson residuals of model 10 follow a normal distribution with some spread around the tails of distribution (Figure 7). There are no more temporal trends (months and years) in the residuals and most of the vessel effect is captured by the model (Figure 8). In Figure 9 however, we see that the model still as trouble fitting the annual variability of positive landings in the ICES statistical rectangle 30F0.

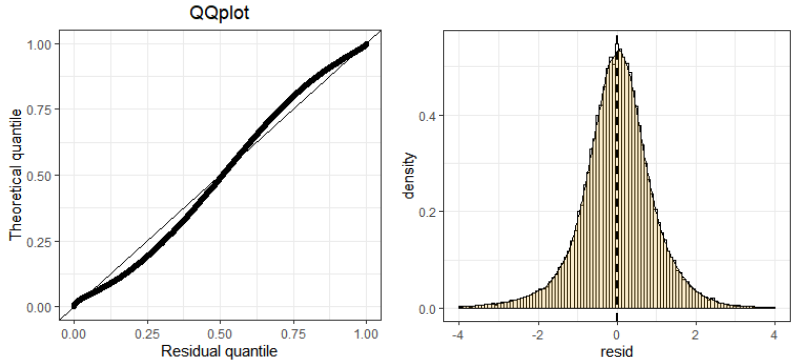


Figure 7 QQplot and histogram of lognormal model 10 Pearson residuals.

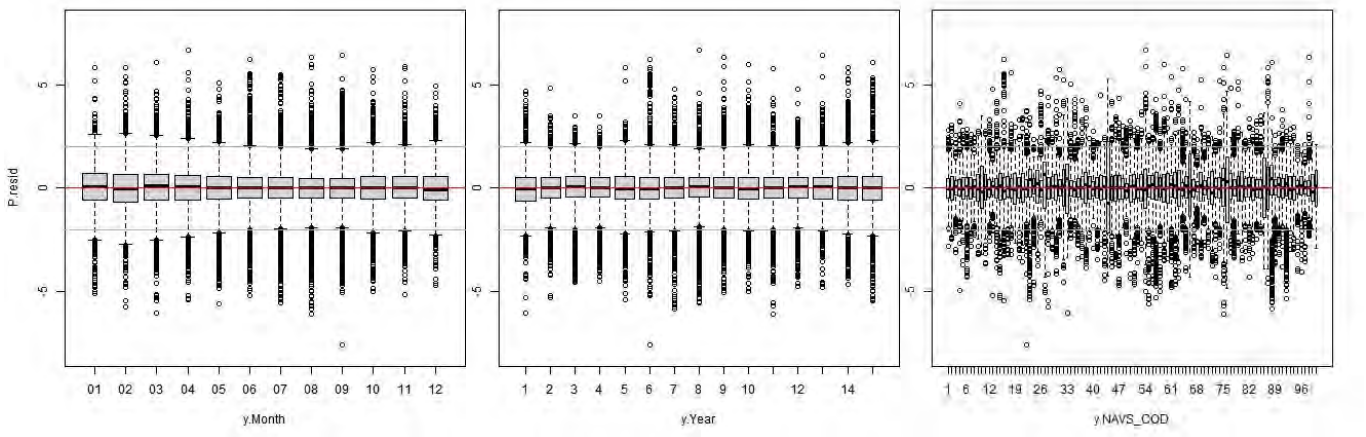


Figure 8 Lognormal model 10 Pearson residuals against month, year and vessel covariates.

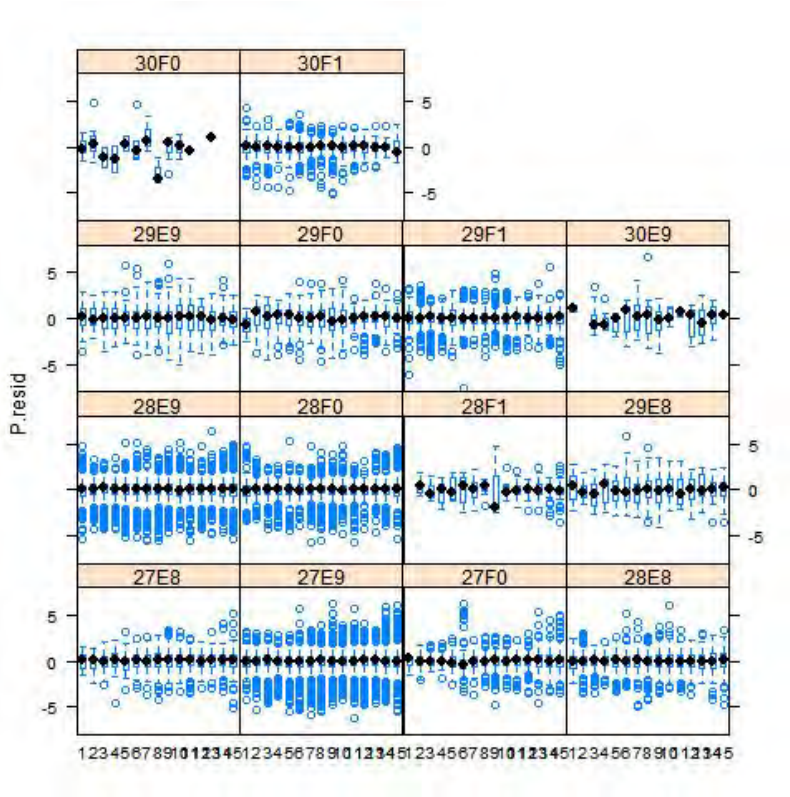


Figure 9 Lognormal model 10 monthly Pearson residuals distribution per year from 2005 to 2019.

Lognormal model posterior distribution of spatio-temporal random effects.

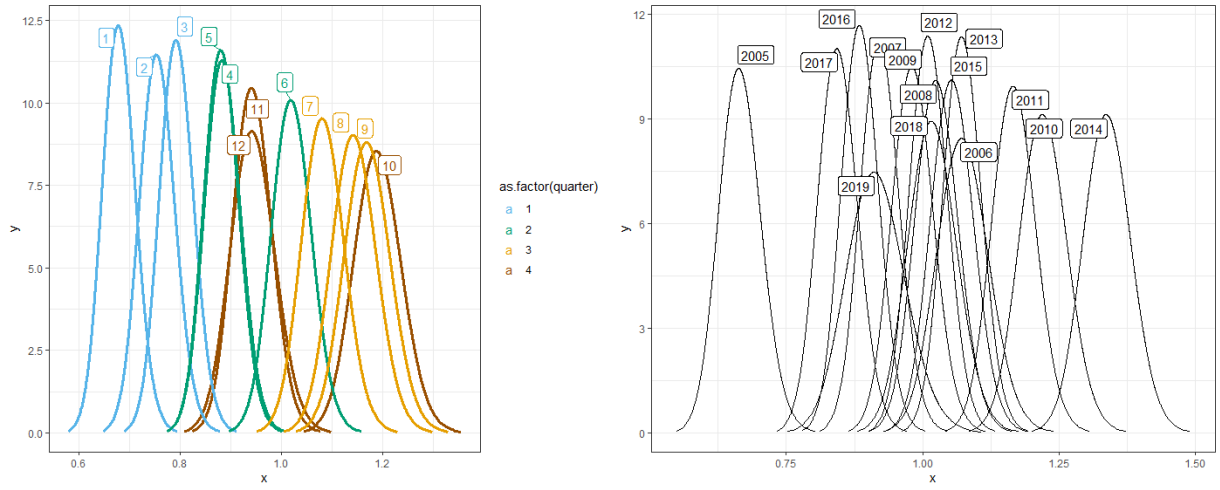


Figure 10 Posterior distribution of the seasonal random effect on the left and the year first order random walk effect on the right for the lognormal model. On the left side Q1 is in blue, Q2 green, Q3 yellow and Q4 brown, the number show the months. On the right the numbers show the years.

As for the occurrence model, the monthly seasonal effect is captured by the lognormal model with a higher LPUE probability from June to October. The posterior mean of the random walk estimates low LPUEs in recent years starting from 2016 with the exception of 2018, that are below the historical levels if we

exclude the year 2005 (Figure 10). At the exception of 2014, higher LPUEs are localised along the French coast for the fleet considered and mainly in the Southern part of 7d. Since 2015, higher LPUEs are concentrated to the Bay of Seine, before they were spreading also into the North East part (Figure 11). The posterior distribution of the fixed effect, the vessel random effect and the hyperparameters are presented in the appendix (Figure A3, and A4).

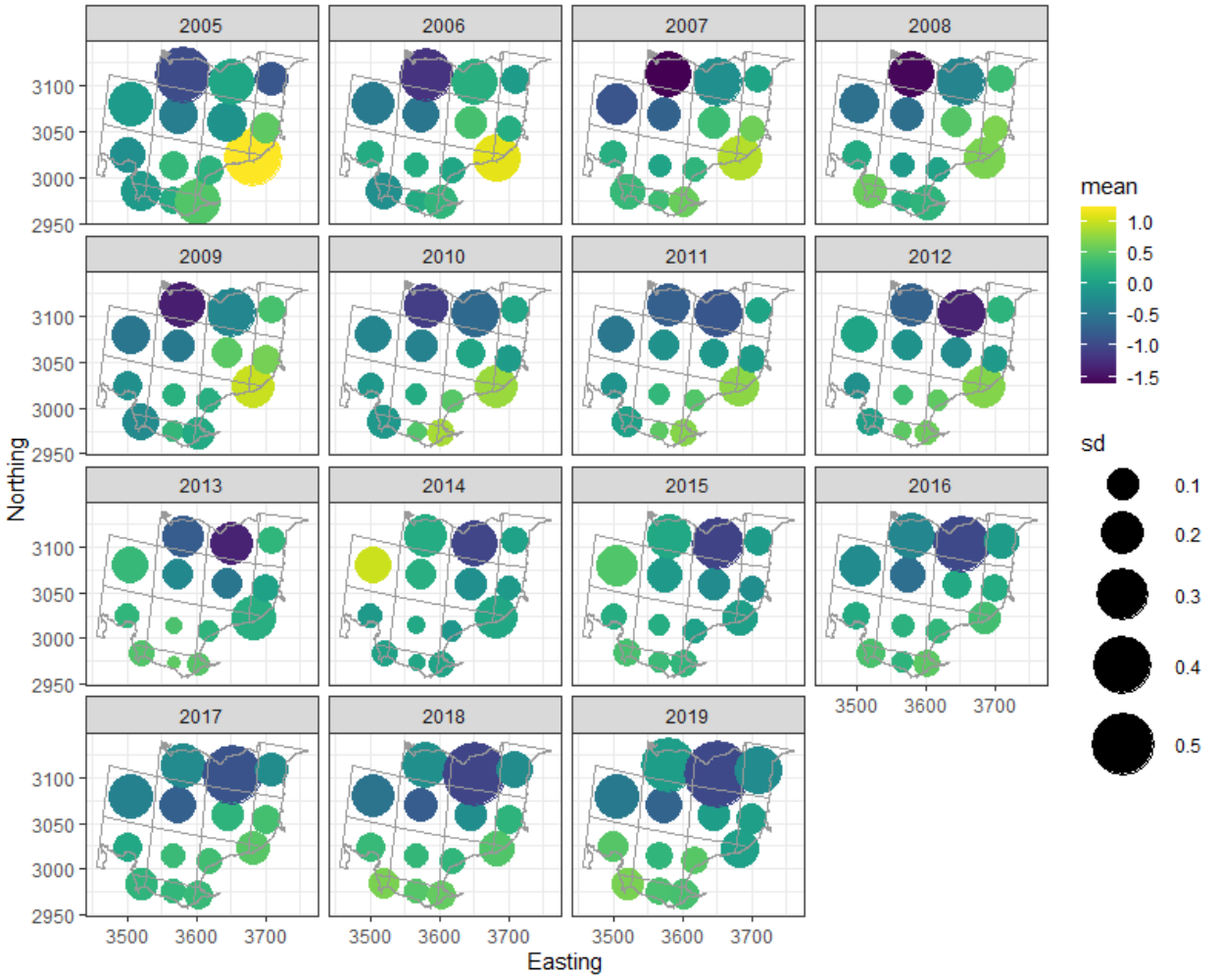


Figure 11 Posterior mean and standard deviation of the spatio-temporal structured random effect of the lognormal model on a log-scale.

Standardized LPUE index: hurdle model prediction of the temporal trend

To compute the FRCOTB LPUE index we combined the yearly prediction from the occurrence model and the lognormal model (Figure 12). Uncertainty around the hurdle model prediction are estimated from 10000 resampling of the model parameter posterior distributions. The retrospective analysis is run on the entire index estimation process, from the fleet selection up to the model prediction using the data available for a given assessment year (Figure 13).

The hurdle model predicts a decrease of the probability of occurrence of sole and oscillates around 0.78 since 2014 (Figure 12). 2018 is the highest predicted probability of occurrence in the recent period. The

positive part of the model predicts an increasing trend up until 2014 followed by a decreased up to 2017. Even if the model predicts an increase in 2018, both 2018 and 2019 values remains at a low level.

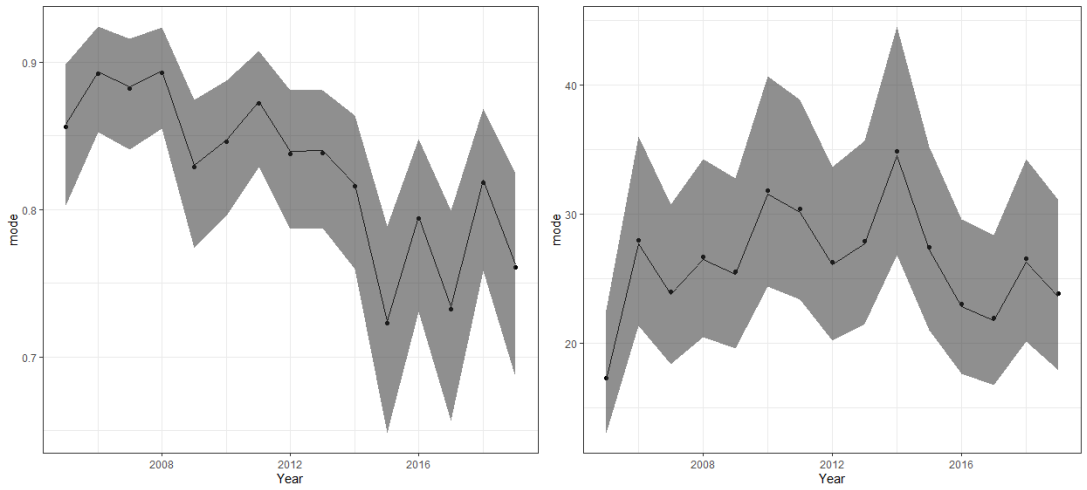


Figure 12 Yearly prediction of the probability of occurrence on the left and the LPUE (in 10^3 kWhours) on the right produced respectively by the Bernoulli and the lognormal mixed models.

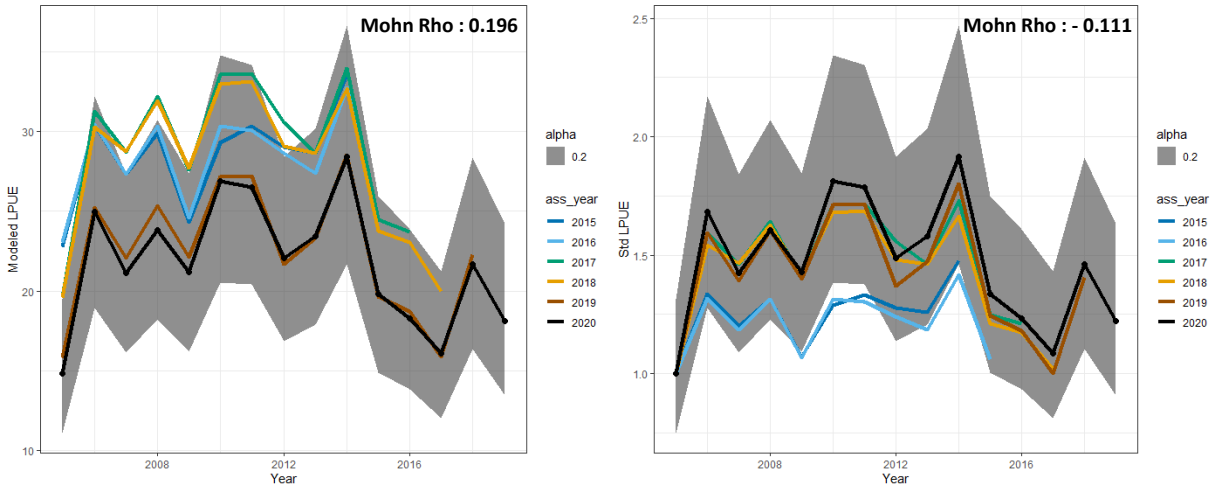


Figure 13 Standardized FRCOTB LPUE index and retrospective analysis outputs. The black line is the index calculated over the period 2005-2019, the colored lines represent the index calculated by the retrospective analysis. The shaded area is the estimated uncertainty from the 10000 posterior resampling of the hurdle models fitted over 2005-2019. The left side present the output from each model prediction, while on the right side the index is rescaled to 2005 average value for each model prediction.

2005 aside, the combined prediction depicts a relative stable index with peak in 2010, 2011 and 2014 (Figure 13). However, recent years are predicted at a low level even if the peak in 2018 is still occurring. The index shows retrospective pattern. To improve the method, we rescaled each time series to their first year (here 2005). Once standardized by a reference year, the 3 first peels remain consistent with the index going up to 2019. However, the addition of the 2016 data point shifts upward the index.

Conclusion

The FRCOTB was introduced in sol.27.7d assessment during WKNSEA 2017 as a raw LPUE (ICES, 2017). Logbooks, auction sales notes, VMS data, vessels characteristics of French OTB were used to calculate spatial landings and effort (Source: DPMA et Ifremer SIH, traitement des données Ifremer - Système d'Informations Halieutiques). A methodology is developed to filter the vessels that practice OTB_DEF_70_99_0 métier and target sole in the 7d. French OTB are targeting sole seasonally and their allocation of effort have changed through time. To account for that variability and the impact of skippers' behaviour on the LPUE, we fitted a hurdle lognormal mixed model using a Bayesian framework as implemented by INLA. Both part of the hurdle model used random effects on the month, year, vessel reference number and the interaction between ICES statistical rectangles and years. Spatio-temporal dependences are included using a neighbourhood structured model for space and a first order random walk for the years. In the occurrence model an extra fixed effect on vessel power is included. Yearly prediction from the occurrence and lognormal model are combined to calculated the standardized LPUE. The combined uncertainty is assessed using 10 000 posterior resampling. To account for retrospective bias in the hurdle model prediction, we rescaled the FRCOTB index by the first year (2005) average values.

References

Besag, J., York, J., and Mollie, A. (1991). Bayesian image restoration, with two applications in spatial statistics. Annals of the Institute of Statistical Mathematics, 43, 1–59.

Blangiardo, Marta; Cameletti, Michela (2015). Spatial and Spatio-temporal Bayesian Models with R - INLA (p. 232). Wiley. Edition.

Clayton, D. (1996). Generalised linear mixed models. In W. Gilks, S. Richardson, and D. Spiegelhalter, editors, Markov Chain Monte Carlo in Practice, pp. 275–301. Chapman & Hall.

ICES. 2017. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 6–10 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:34. 673 pp. http://doi.org/10.17895/ices.pub.5339

ICES. 2019. Inter-benchmark Protocol for sole in the Eastern English Channel (IBPsol7d). ICES Scientific Reports. 1:75. 88 pp. http://doi.org/10.17895/ices.pub.5631

ICES. 2020. ICES Working Group on the Assessments of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1249 pp. http://doi.org/10.17895/ices.pub.6092

Appendix

Table A1 Number of bottom otter trawler trips in 7d by métier and years.

métiers	2005	2006	2007	2008	2009	2010	2011	2012
OTB_DEF_>=120_0	21	19	1	0	12	10	71	5
OTB_DEF_0_0_0	268	157	226	211	59	20	7	49
OTB_DEF_0_16_0	10	41	7	27	31	36	15	65
OTB_DEF_100_119_0	44	17	207	77	198	148	55	28
OTB_DEF_16_31_0	173	49	72	86	117	126	147	111
OTB_DEF_32_69_0	929	740	315	444	553	401	654	712
OTB_DEF_70_99_0	9826	12791	14129	10350	9993	11155	11082	10293
	2013	2014	2015	2016	2017	2018	2019	
OTB_DEF_>=120_0	26	64	20	2	4	14	0	
OTB_DEF_0_0_0	50	277	534	393	196	68	38	
OTB_DEF_0_16_0	74	21	1	1	0	4	2	
OTB_DEF_100_119_0	25	23	17	51	27	51	80	
OTB_DEF_16_31_0	108	102	120	105	104	56	89	
OTB_DEF_32_69_0	469	525	620	371	335	385	258	
OTB_DEF_70_99_0	10522	10701	10331	8303	7692	8219	9056	

400

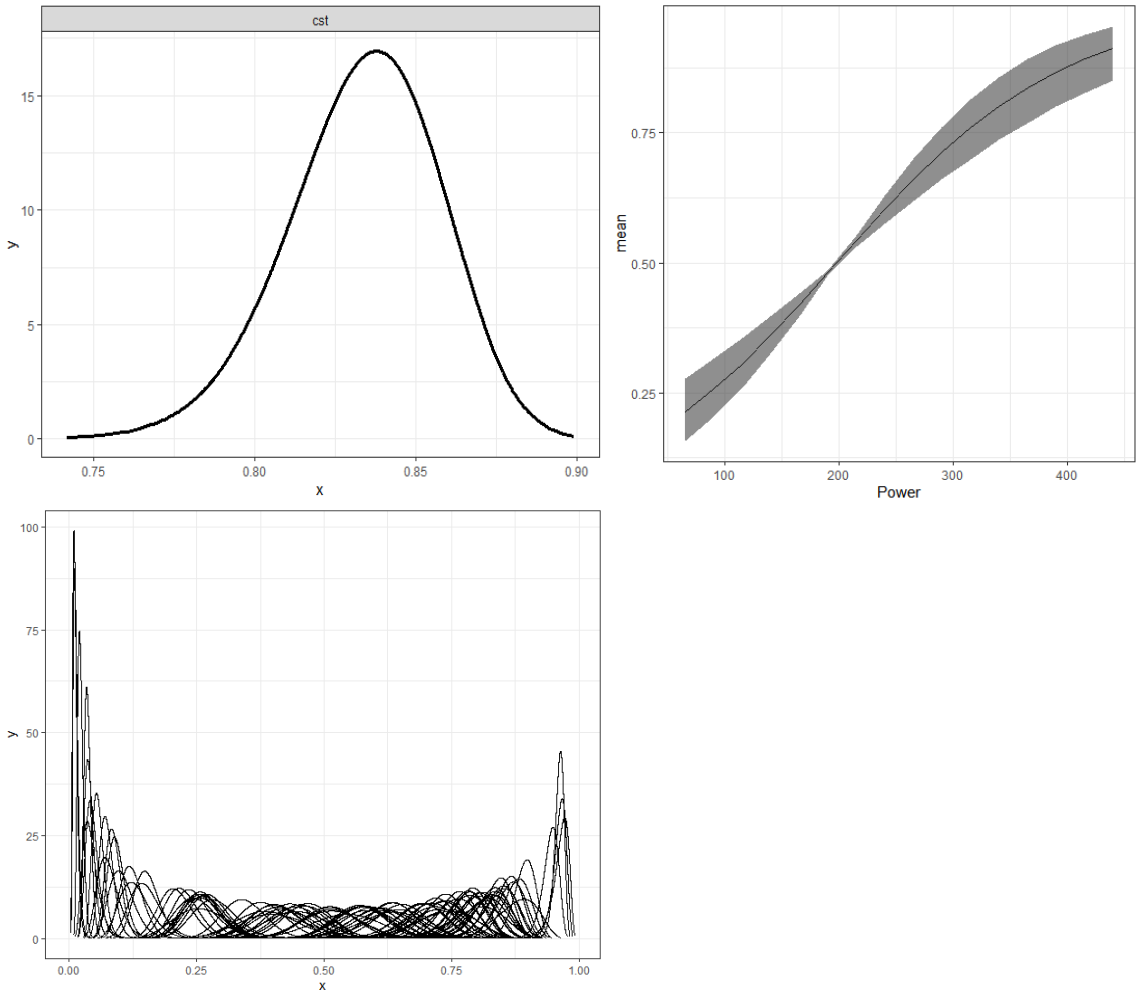


Figure A1 Posterior distribution of the fixed intercept on the top left, the fixed vessel power effect on the top right and the random vessel effect on the bottom left from the occurrence model.

401

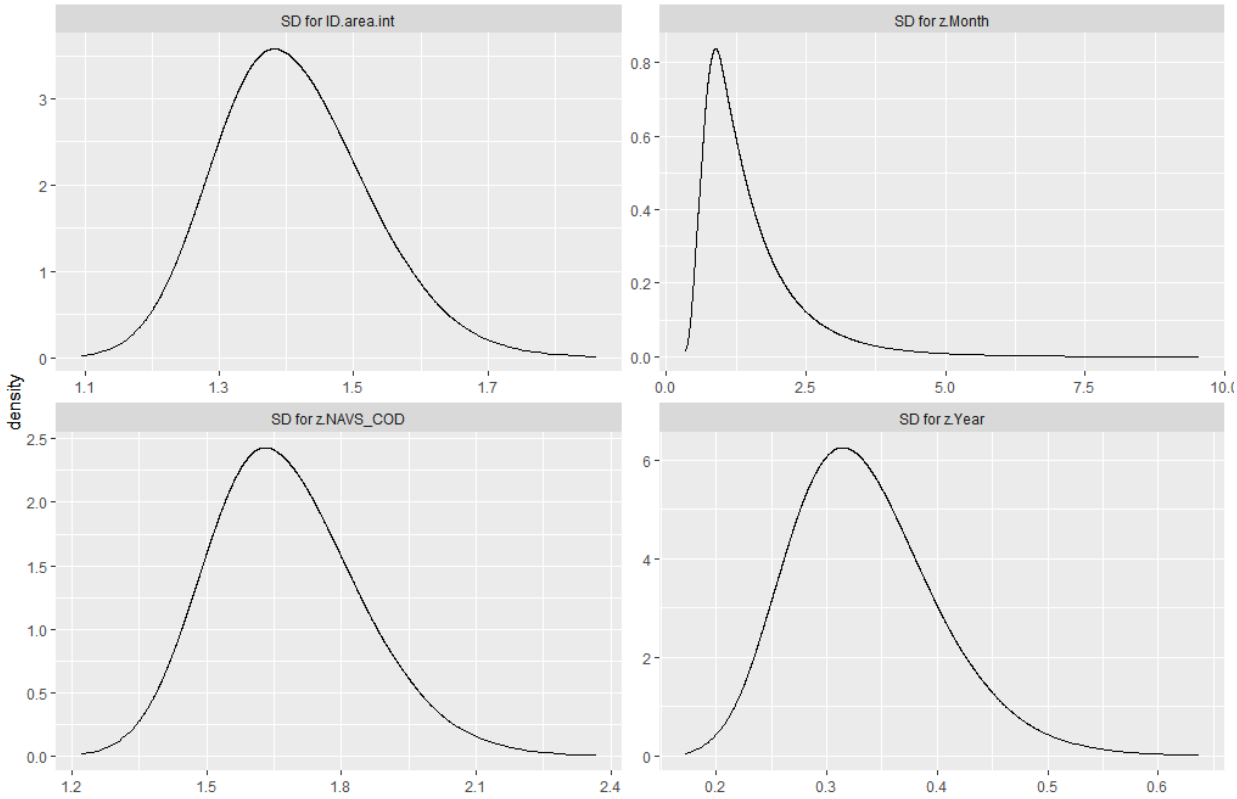


Figure A2 Posterior distribution of INLA hyperparameters from the occurrence model: on the top left the spatio-temporal interaction, on the top right the seasonal effect, on the bottom left the vessel effect and on the bottom right the year effect.

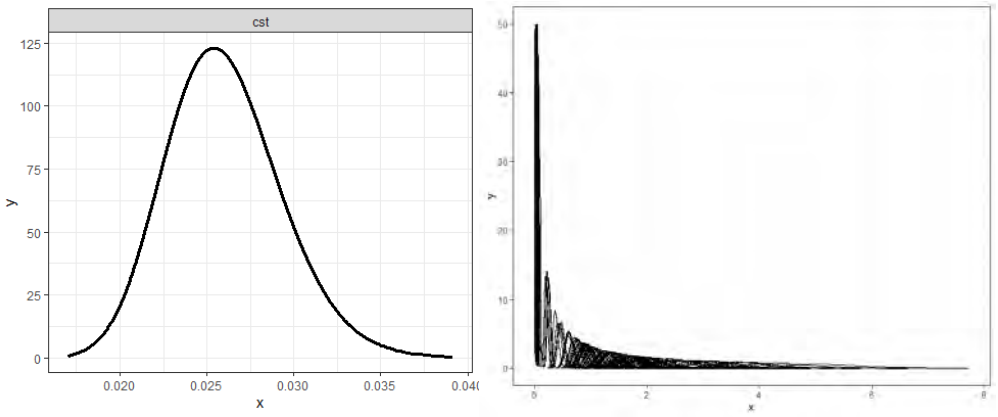


Figure A3 Posterior distribution of the fixed intercept on the left, and the random vessel effect on the right from the positive model.

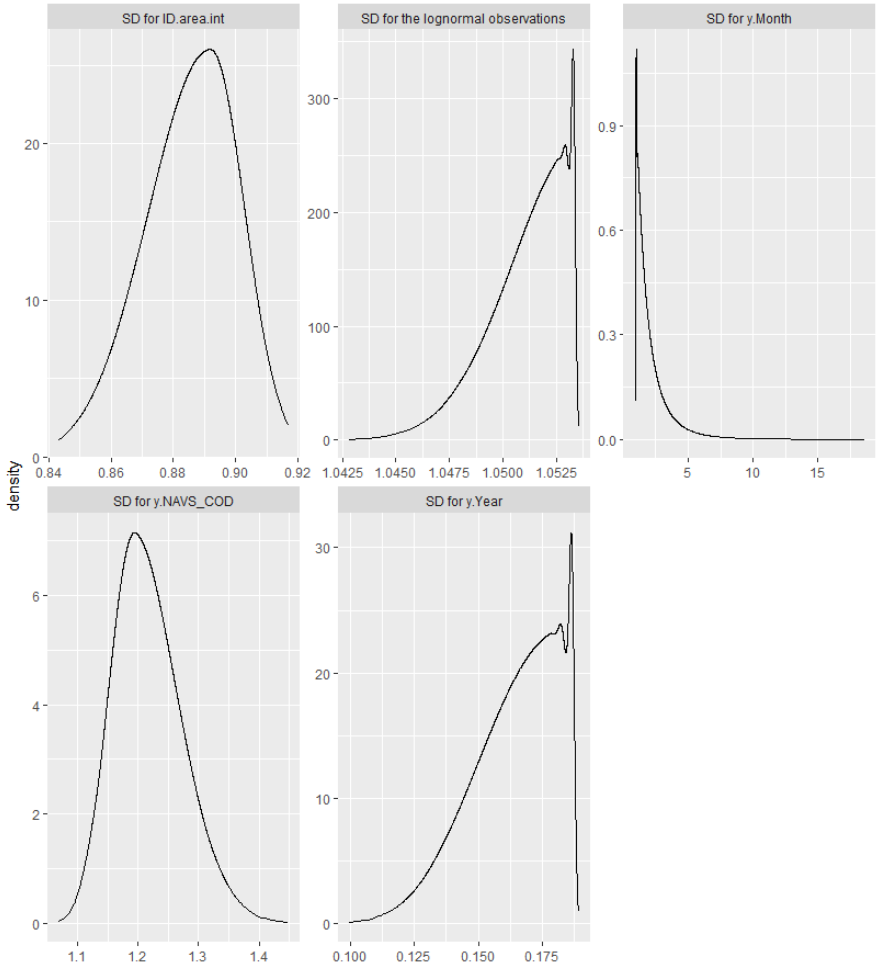


Figure A4 Posterior distribution of INLA hyperparameters from the positive model: on the top left the spatio-temporal interaction, on the top center lognormal precision, on the top right the seasonal effect, on the bottom left the vessel effect and the bottom center the year effect.

Working document: Revision of the UK (E&W) beam trawl survey (BTS) index for sole in the eastern English Channel (ICES division 27.7.d)

Authors: Klaas Sys and Lies Vansteenbrugge (ILVO, Belgium)

1. Introduction and objective

This document describes how a standardized age-structed survey index was derived for the UK (E&W) quarter 3 beam trawl survey (BTS) using DATRAS exchange data (HH, HL and CA datasets). The main objective of standardising the estimation of the index was to maximally acount for the perceived population structure within the eastern English Channel sole stock, and to create an index that provides information on how the different subpopulations relate to each other and the stock as a whole.

The process of calculating the index involved 4 steps: (*i*) estimating an age-unstructured cpue (numbers/km²) index, (*ii*) estimating length-frequency distributions, (*iii*) calculating age-length keys and (*iv*) projecting the models to the population, and combining them into an age-structured cpue index.

2. Data pre-processing

The HH data, comprising haul information, was filtered to the area of interest (ICES division 27.7.d) (Figure 1). For all records retained for analysis, the swept area by haul was calculated by multiplying the trawl length of each haul, calculated as the Haversine distance between the shoot and haul location, with the width of the beam (4 m) (Figure 2). Finally, the HH data was intersected with the subpopulation polygons as identified during the SMAC project to assign each record a subpopulation (Savina *et al.,* 2020; Randon *et al.,* 2018). A first subpopulation is situated in the northern part of division 27.7d, along the English coast and is referred to as UK-NO. A second subpopulation is located along the north-east coast of France (FR-EA) and the third subpopulation at the Seine Bay, along the south-west coast of France, which is referred to as FR-SW (Figure 3).

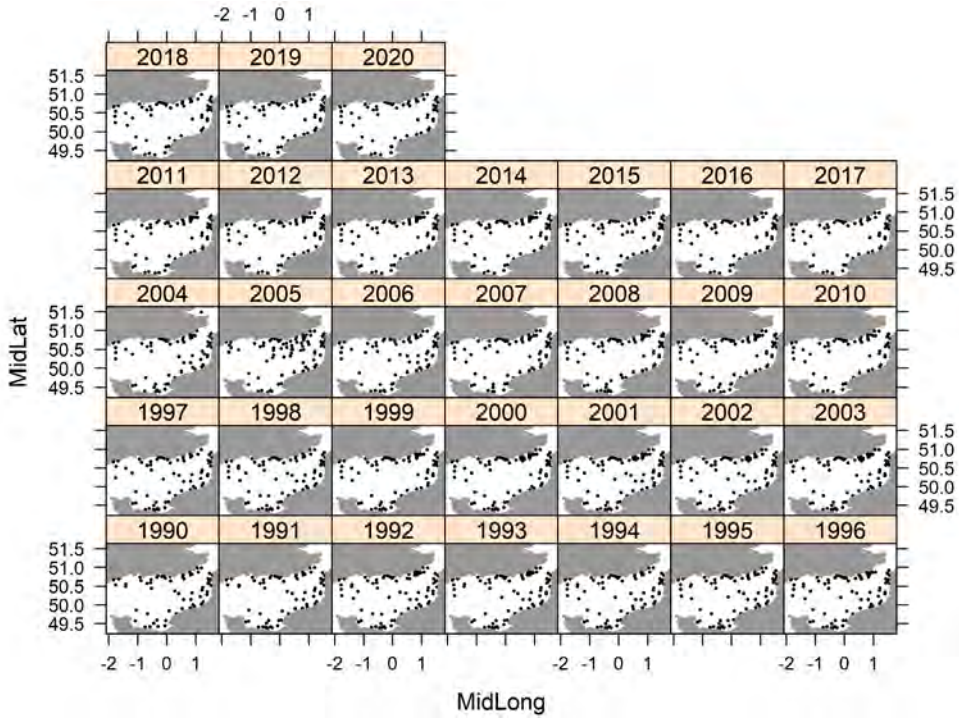


Figure 1: Haul position (midpoints) by year of the UK (E&W) Q3 BTS survey.

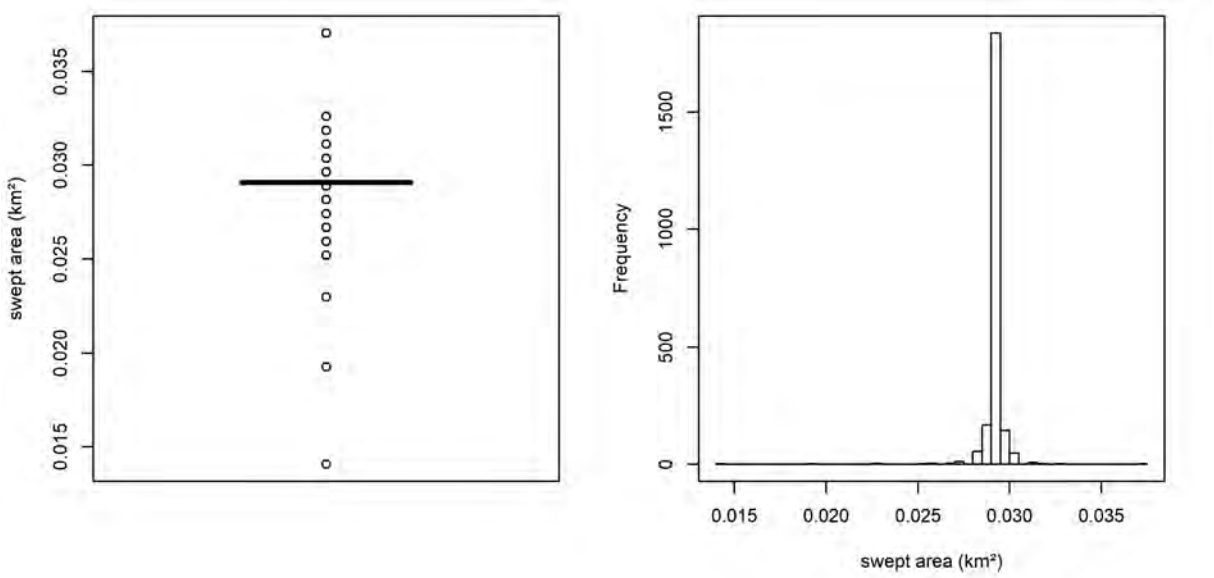


Figure 2: Distribution and frequency of the swept area for all hauls of the UK (E&W) Q3 BTS survey (1990-2020).

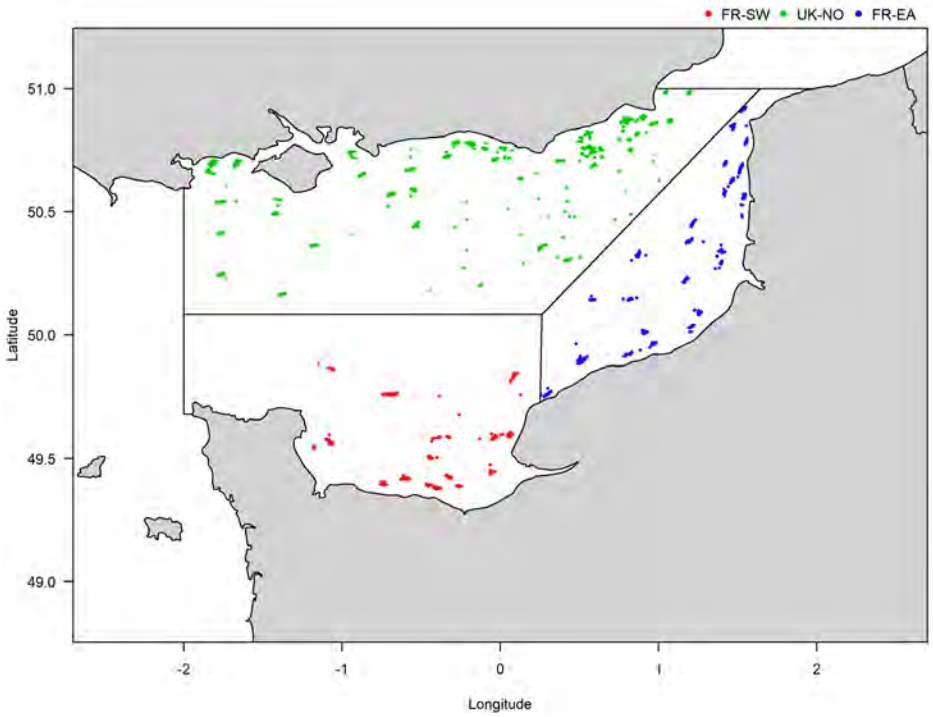


Figure 3: Haul positions of the UK (E&W) Q3 BTS survey with indication of the 3 subpopulations (green = UK-NO; blue = FR-EA; red = FR-SW)

3. Step 1: Age-unstructured CPUE index

The HL dataset, containing the length-strucutred catch information of sole, was merged with the HH dataset according to year and station number. This merged dataset was used to analyze the total number of fish caught per unit of swept area by haul using a spatiotemporal state space model.

This model comprised of an intercept, whereas the space-time component was represented as a random effects model in which a Matèrn correlation and first order autoregressive model govern the spatial and temporal processes. In such a case, the spatial continuous (Gaussian) field can be estimated by using a set of Stochastic Partial Differential Equation (SPDE), wihle the Finite Element Method as

implemented in INLA was used to approximate the solution of the SPDE using a set of piecewise linear functions formed by a triangulated mesh (Figure 4).

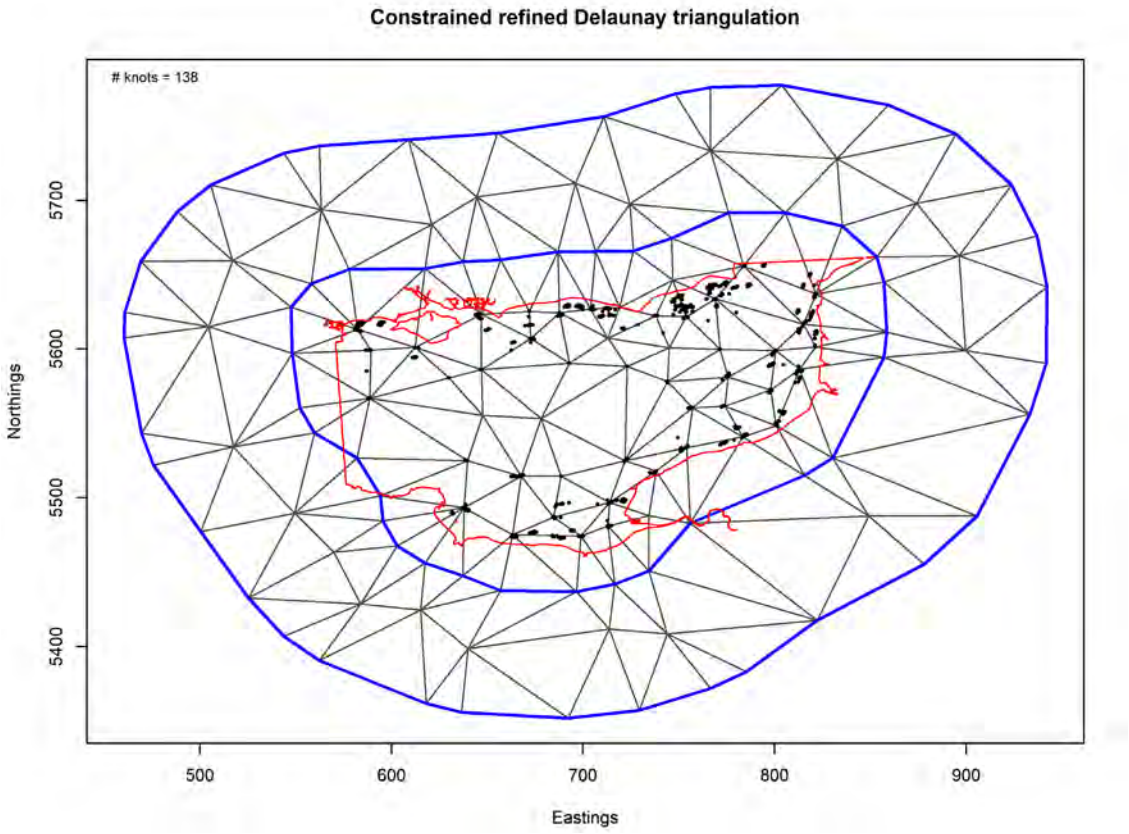


Figure 4: Triangulated mesh used for spatial interpolation. Black dots refer to the sampling locations while the red line indicates the borders of the eastern English Channel.

To account for additional year effects, the model was extended by including (i) an additional AR1 process over the years (independent from the spatiotemporal model), and (ii) an AR1 process by subpopulation to account for additional diverging time trends among the perceived subpopulations. However, these extra time trends did not improve the fit in terms of AIC, and therefore, these models were rejected (Table 1).

The observation error of the positive catch rate was assumed to follow a lognormal distribution, and no hauls were present without catches of sole.

Table 1: Akaike Information Criterion scores of 3 different spatiotemporal models.

	AIC
spde x AR1	6397
spde x AR1 + AR1	6399
spde x AR1 + $AR1_{subpopulation}$	6406

Visual inspection of the residuals indicates no violation of the assumption of normality (Figure 5).

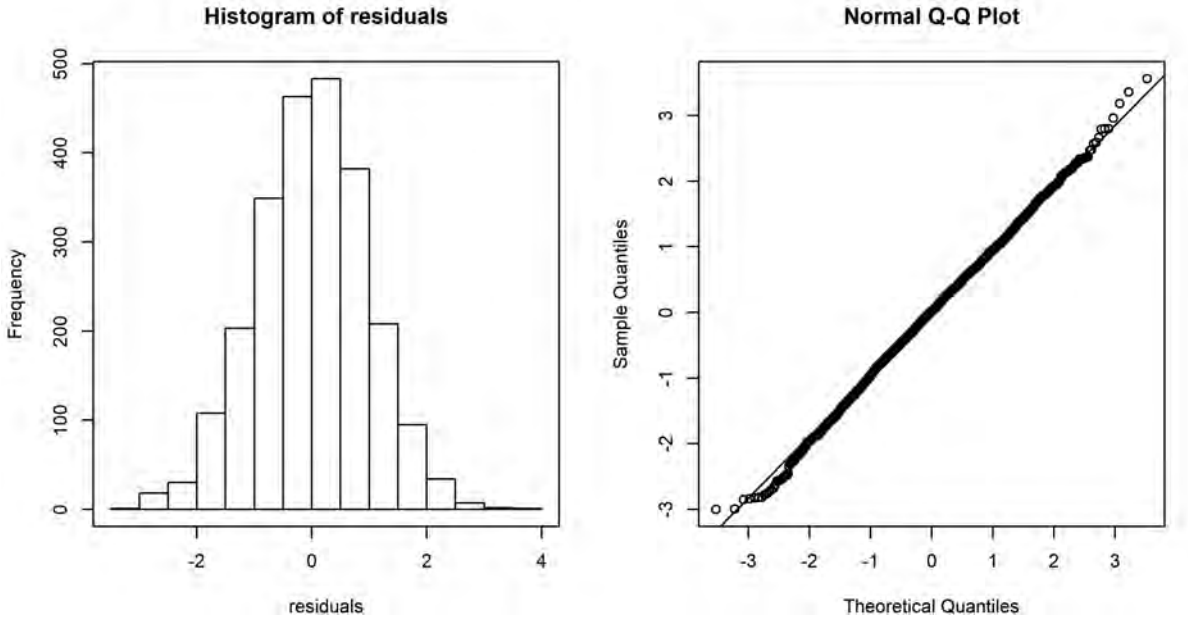


Figure 5: Histogram and quantile-quantile plot of the standardized residuals.

This model was used to calculate the expected numbers on a grid of 10x10 km covering the eastern English Channel. A bias correction was applied to account for the logaritmic data transformation. The resulting indices are shown in Figure 6.

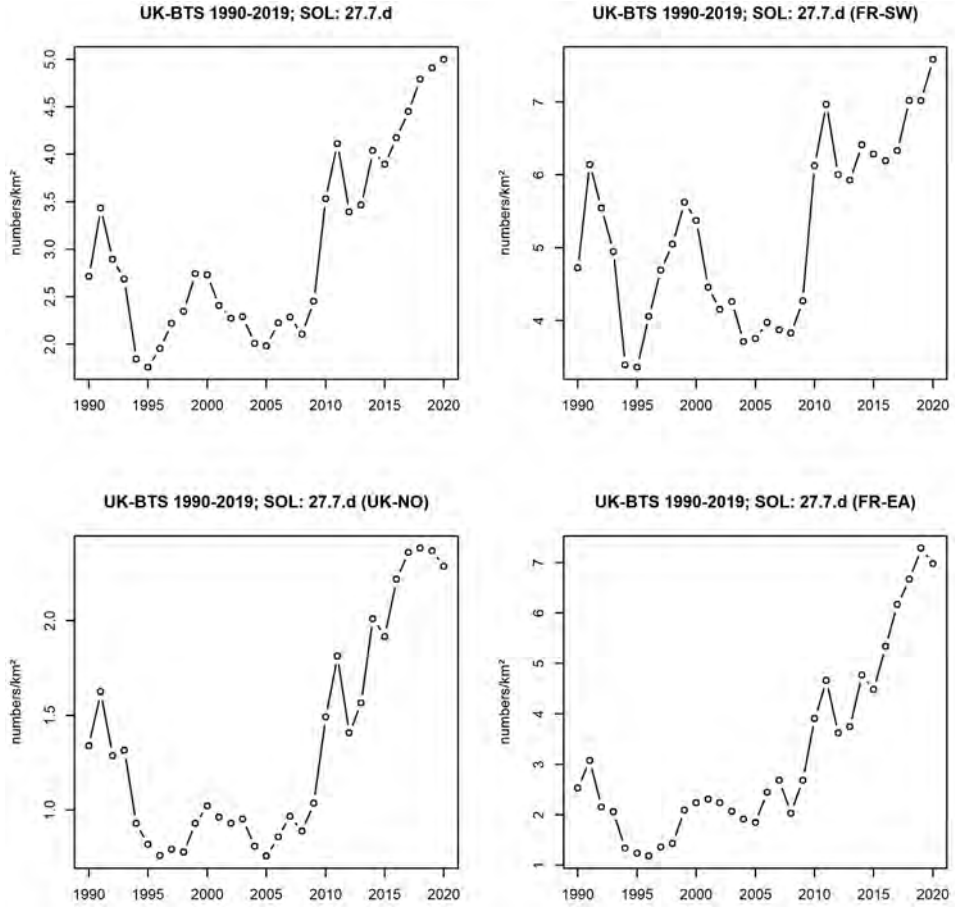


Figure 6: UK (E&W) Q3 BTS age-unstructured CPUE index (total numbers / km²) for the entire 27.7d division an per subpopulation.

4. Step 2: Length-frequency distribution

Length-frequency distributions by year and subpopulation where derived from the same dataset as used for the estimation of the CPUE. However, the length composition data was added to the total number of fish caught by haul. This data was grouped into strata determined by year and subpopulation. Subsequently, a kernel density estimation was applied to the length-frequency data by strata. A Gaussian kernel was used with bandwidth selected through Maximum Likelihood Cross-Validation to avoid too narrow bandwidth selections caused by rounding of the length measurements. A simulation approach was followed in which a small amount of noise (+/- 0.5 cm) was added to the length data during each simulation followed by bandwidth estimation (Figure 7). The mean bandwidth by strata was calculated from the simulations and used to derive continuous length-densities by strata (Annex, Figure 19). From these densities, the empirical cumulative distribution was calculated by length bins of 1 cm, and each length bin was assigned a probability mass. These length frequency distributions were matched with the expected numbers by subpopulation and year, to estimate the expected numbers by length bin (Figure 8; 9).

From these numbers by length bin, the relative share of fish equal or larger than the Minimum Conservation Reference Size (24 cm) of each subpopulation was calculated with respect to the total population (Figure 10; Annex, Table 5). These relative shares can be used to weigh the different commercial tuning fleets used in the assessment of the eastern English Channel sole stock.

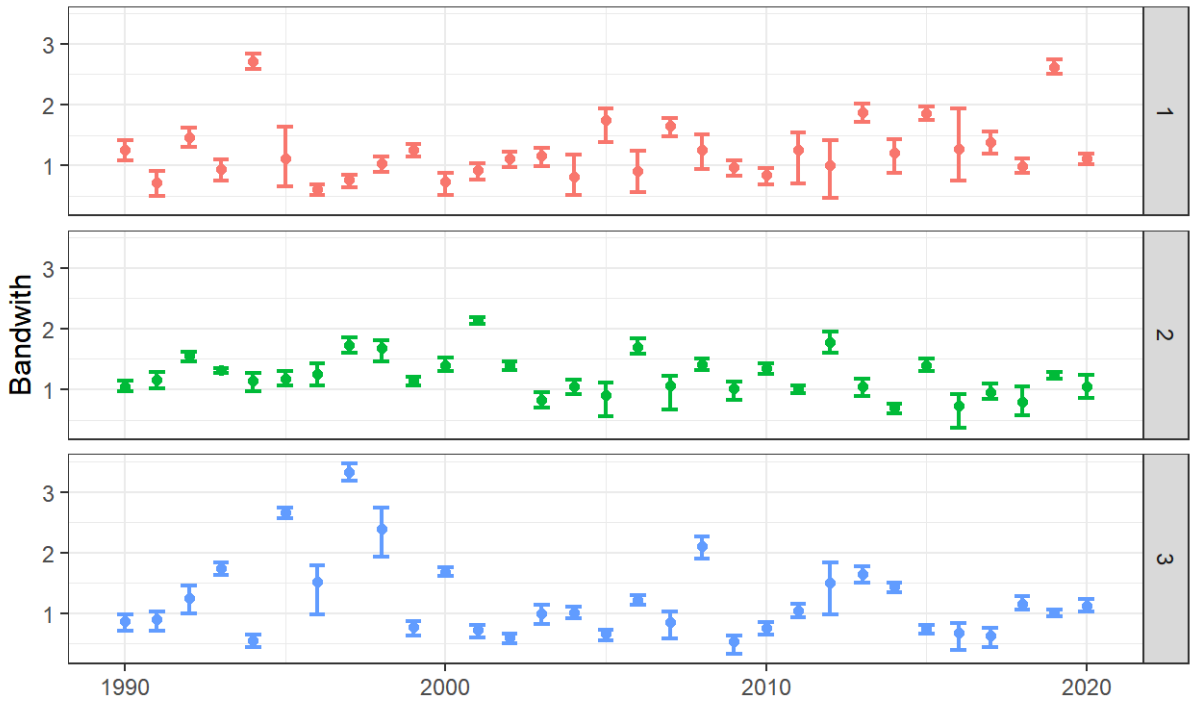


Figure 7: Mean, 0.025 and 0.975 quantile of the bandwidth estimates (1 = FR-SW; 2 = UK-NO; 3 = FR-EA).

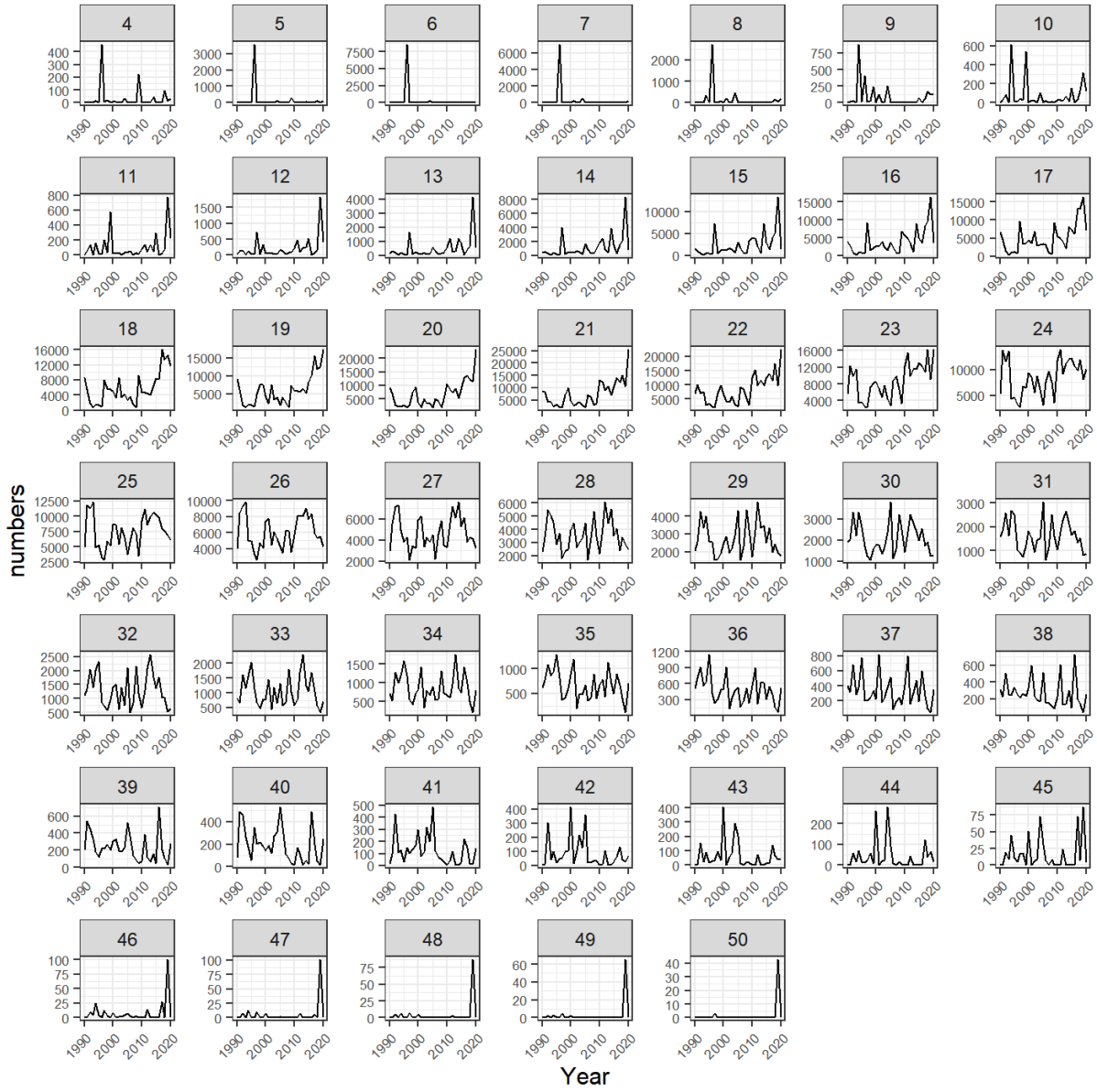


Figure 8: Expected numbers-at-length for the eastern English Channel sole stock.



Figure 9: Expected numbers-at-length by subpopulation for the Eastern English Channel sole stock.

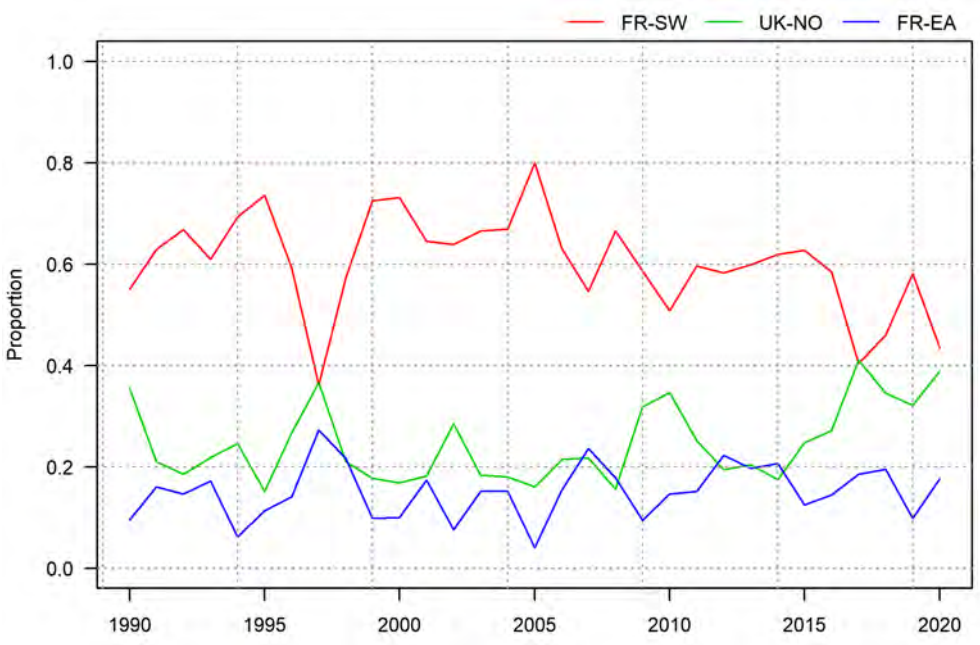


Figure 10: Proportion of fish ≥ 24 cm by subpopulation with respect to the total population.

5. Step 3: Age-Length keys

The age-length data was compiled by merging the CA data with the HH data (Figure 11). Up to age 6, there are sufficient observations or there is enough contrast between the length data of the different age groups. From age 7 onwards, the number of observations is much lower, as well as the contrast in the length information. Therefore, all observations of age 7 or higher were considered as a plus group in the statistical analysis.

Boxplots of the length-at-age indicated the presence of outliers in the length information for age 2 (Figure 11). Therefore, the observations from age 2 with lengths larger than 40 cm were removed from the data. Furthermore, the observations from 2012 and 2013 were assumed as unreliable. For 2012, only 48 observations were available in DATRAS, while for the other years, on average 549 (+/- 206) observations are available (Figure 12). In addition, the CA data from 2012 did not correspond with the other datasets available in DATRAS. In contrast, for 2013, sufficient data is present, but the length-at-age information seems unreliable because the length-age distributions are considerably lower for age 1 to 6 compared to the other years. This is biologically very unlikely and therefore, these data were not retained for further analysis.

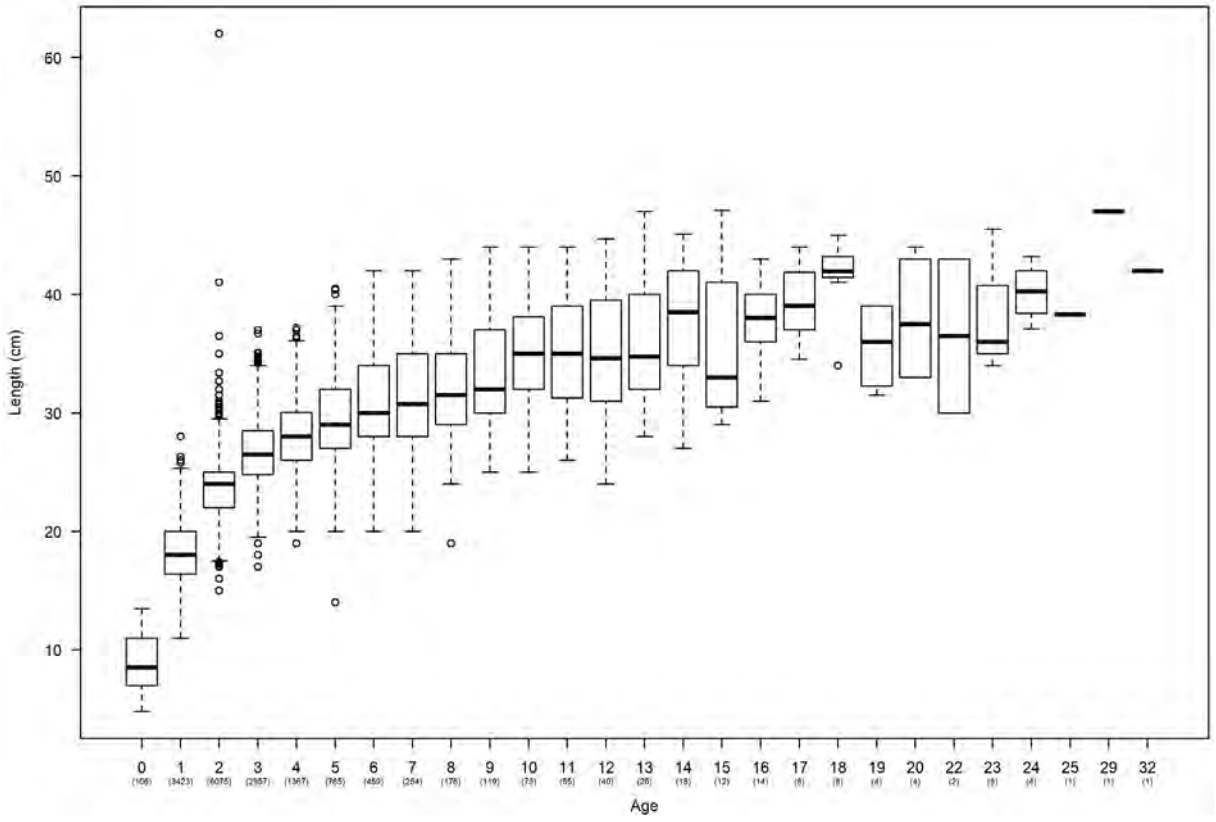


Figure 11: Boxplot of the length at age data. The number of observations at age is shown between brackets.

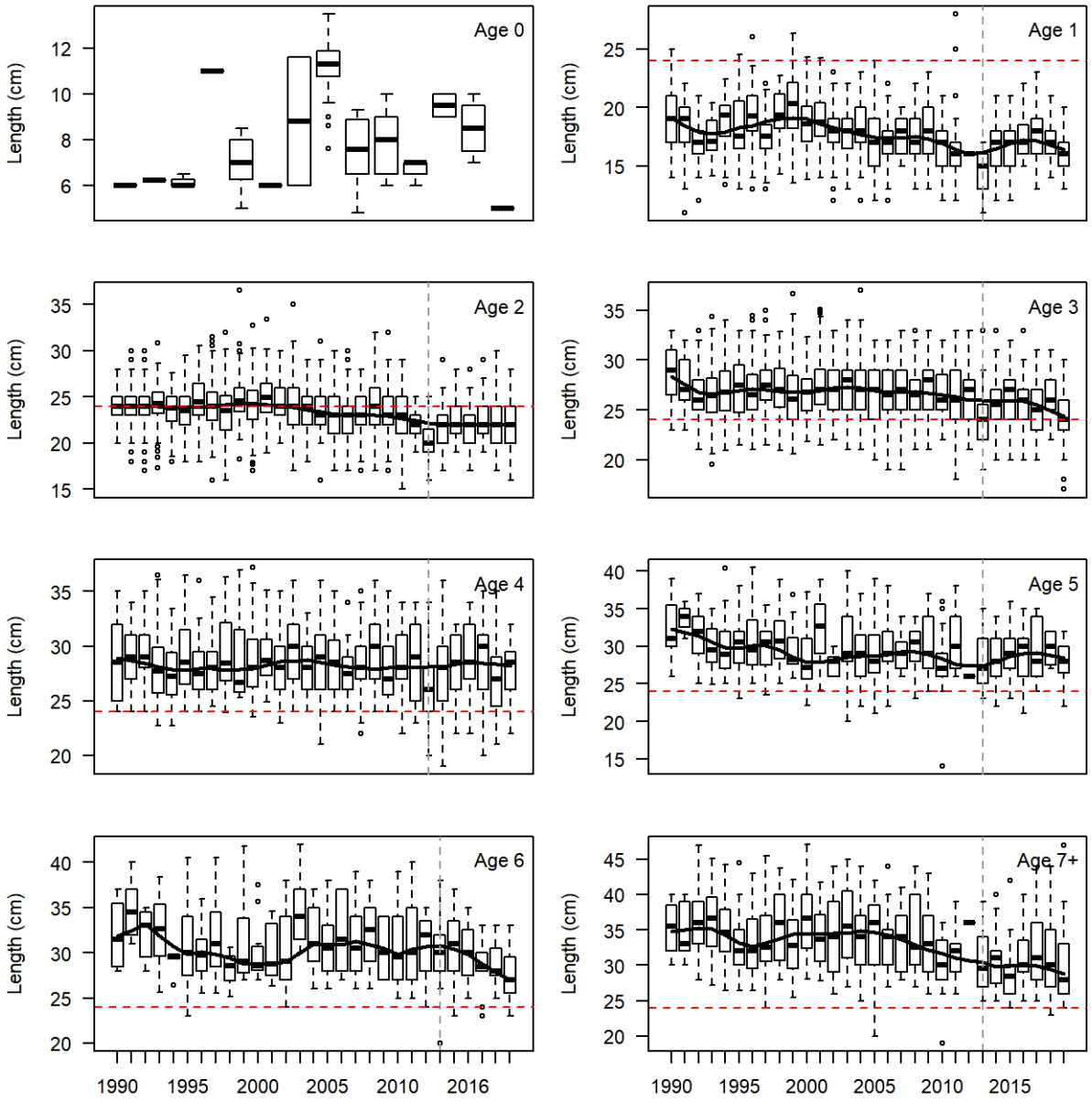


Figure 12: Boxplot of length observations by year. Each panel represents a distinct age. The horizontal red line indicates the Minimum Conservation Reference Size (24 cm), while the vertical grey line aids visualisation of the data in 2013.

A multinomial regression model was fitted to the data including the following linear effects by age:

$$\pi_0 = \beta_{0_0} + s_{0_l}(Length) + s_{0_y}(Year)$$

$$\pi_1 = \beta_{1_0} x\ subpopulation + s_{1_l}(Length) + s_{1_y}(Year)$$

$$\pi_2 = \beta_{2_0} x\ subpopulation + s_{2_l}(Length) + s_{2_y}(Year)$$

$$\pi_3 = \beta_{3_0} x\ subpopulation + s_{3_l}(Length) + s_{3_y}(Year)$$

$$\pi_4 = \beta_{4_0} x\ subpopulation + s_{4_l}(Length) + s_{4_y}(Year)$$

$$\pi_5 = \beta_{5_0} x\ subpopulation + s_{5_l}(Length) + s_{5_y}(Year)$$

$$\pi_6 = \beta_{6_0} x\ subpopulation + s_{6_l}(Length) + s_{6_y}(Year)$$

Note that for each age group, except for age 0, a subpopulation effect is estimated. The model terms with *s* refer to the use of penalized smoothing splines. For each age group, a smoothing spline is used to model the length and year effects.

The probabilities for each age group are then calculated using the following link function:

- For age *a* ϵ 1 to 6: $\Pr(Y_i = a) = \frac{e^{(\pi_a)}}{1+\sum_{a=1}^{6}\pi_a}$
- For age *a* = 7: $\Pr(Y_i = a) = \frac{1}{1+\sum_{a=1}^{6}\pi_a}$

An overview of the model output is given in Annex Table 2 and 3. Figure 13 and 14 show the output of the model. As an example Figure 13 shows the expected probability-at-age for a certain length in the UK-NO subpopulation in the year 2000. The length-based splines show a good discrepancy in length-at-age from age 0 to 2. From age 3 onwards, there is much higher overlap between the length distributions at age, implying that cohort tracking from age 3 onwards will become increasingly difficult for this survey. Figure 14 shows some major trends in the expected age for a given length over time. For example, a species of length 25 cm had the highest probability of being age 2 up to 2013, but from 2014 onwards the odds are higher for age 3 indicating a decline in growth rate over time.

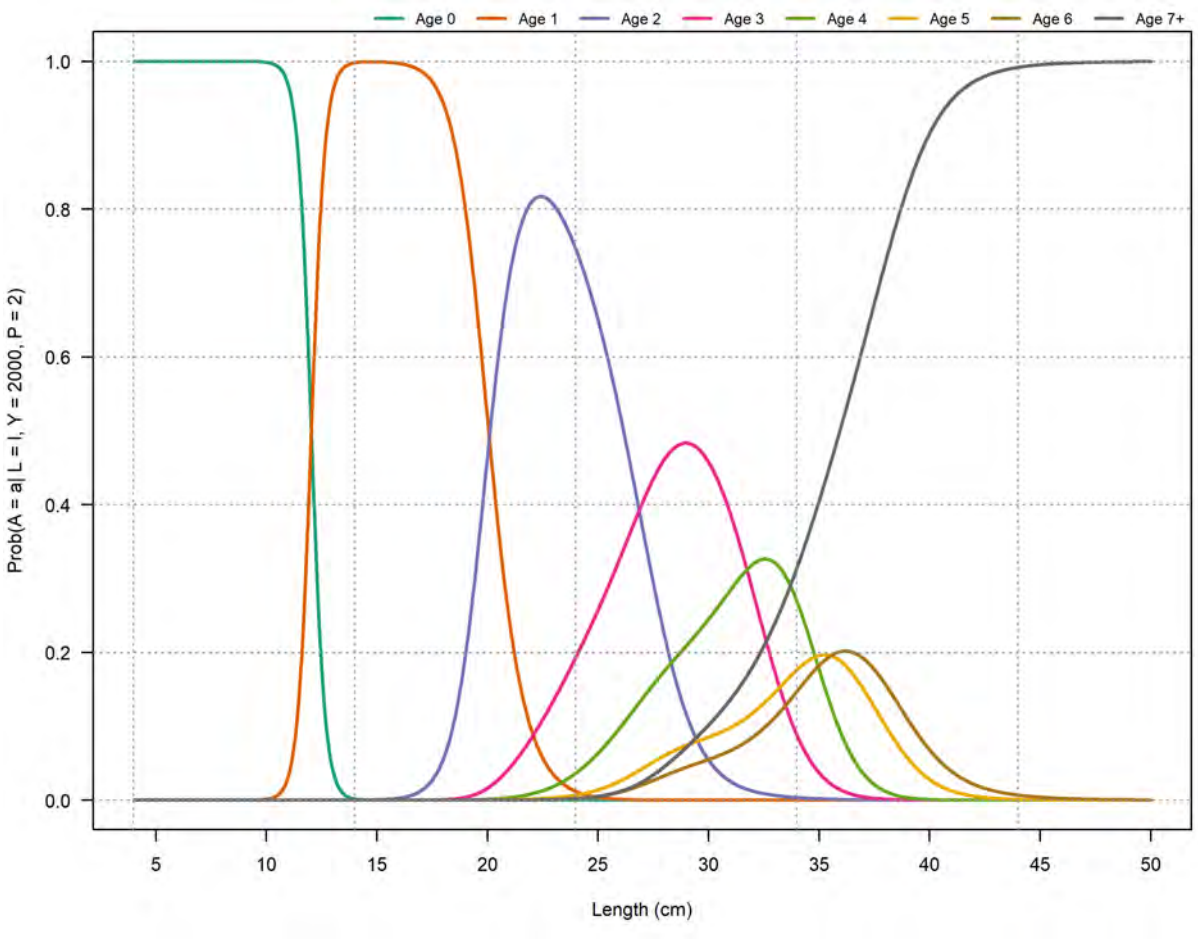


Figure 13: Expected probability-at-age for an observation at length sampled in the UK-NO subpopulation in the year 2000.

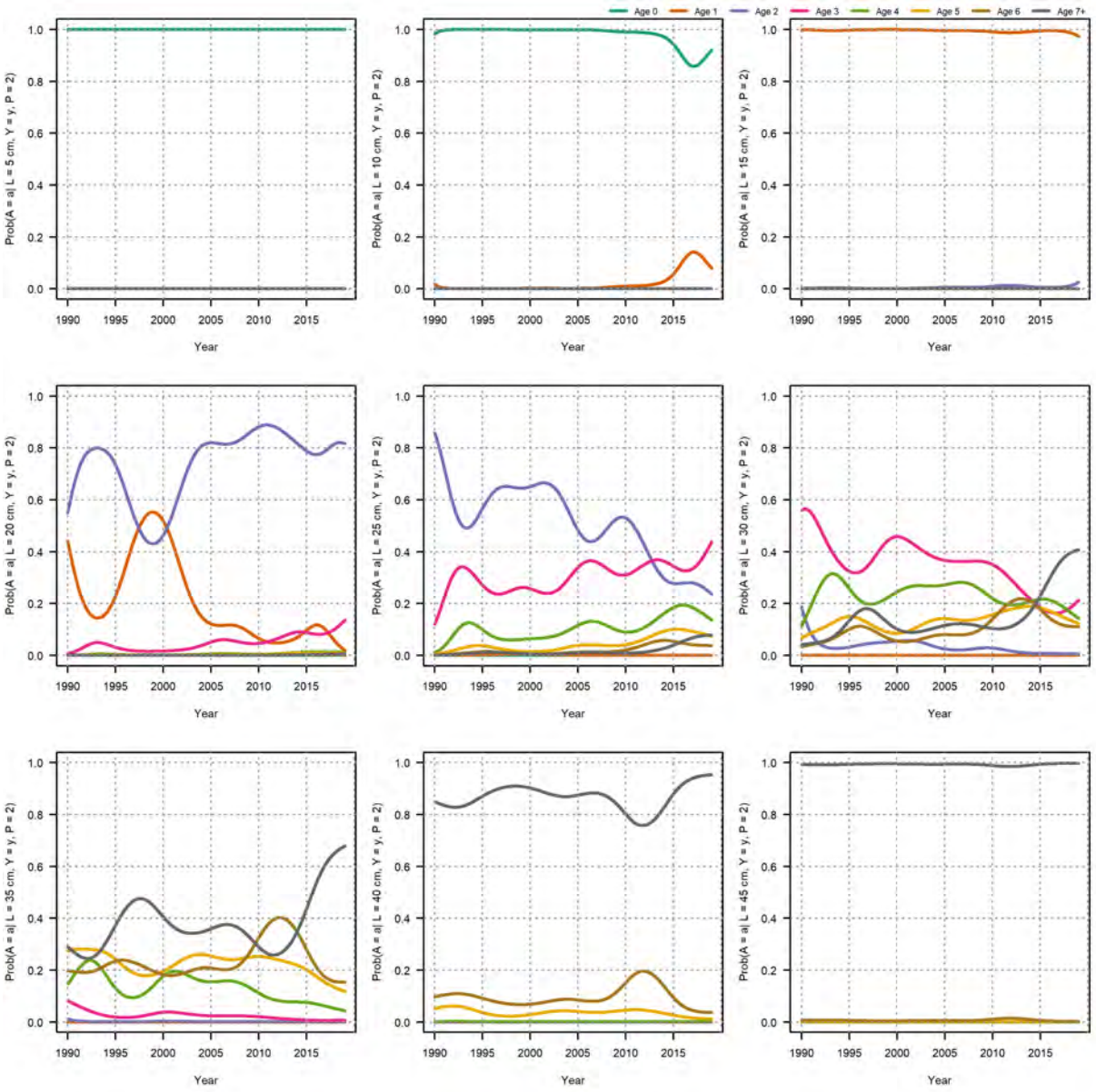


Figure 14: Expected probabilities-at-age for an observation with sampling length 5; 10; 15; 20; 25; 30; 35; 40; 45 cm over the years 1990 to 2020 in the UK-NO subpopulation.

6. Step 4: Age-structured cpue index

Expected numbers-at-age were obtained by multiplying the expected total numbers of fish caught, with the length distribution, and the age-length keys per strata. The expected numbers were then aggregated by year and eventually by subpopulation, to compile an annual index by division (Figure 15) and by subpopulation (Figure 16) (Annex Table 4).

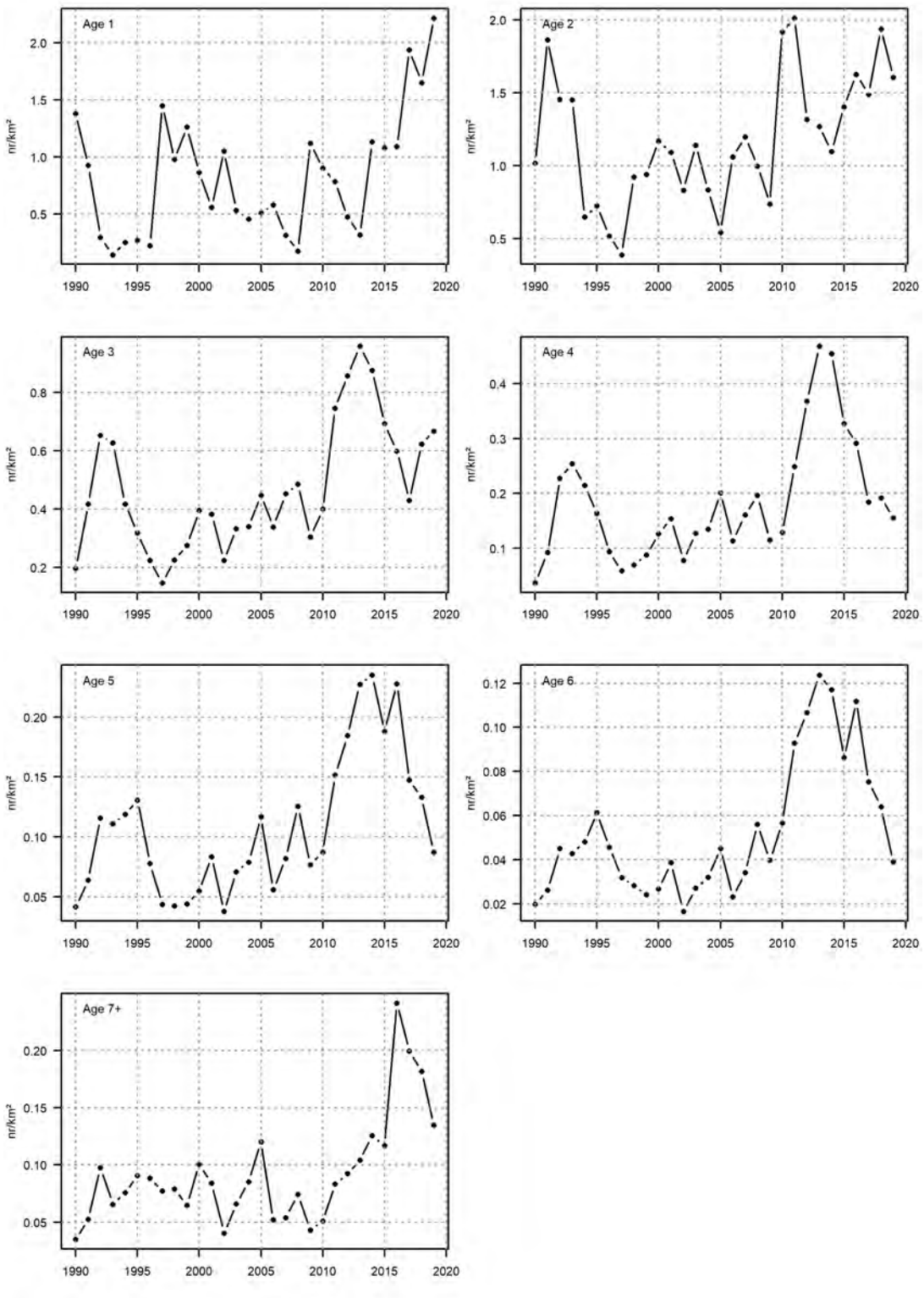


Figure 15: Index of relative abundance of eastern English Channel sole by age. Note that age 7 is a plus group.



Figure 17: Index of relative abundance of eastern English Channel sole by age and subpopulation. Note that age 7 is a plus group.

The index shows a high internal consistency for age 1 to 3, but lower from age 4 onwards (Figure 18).

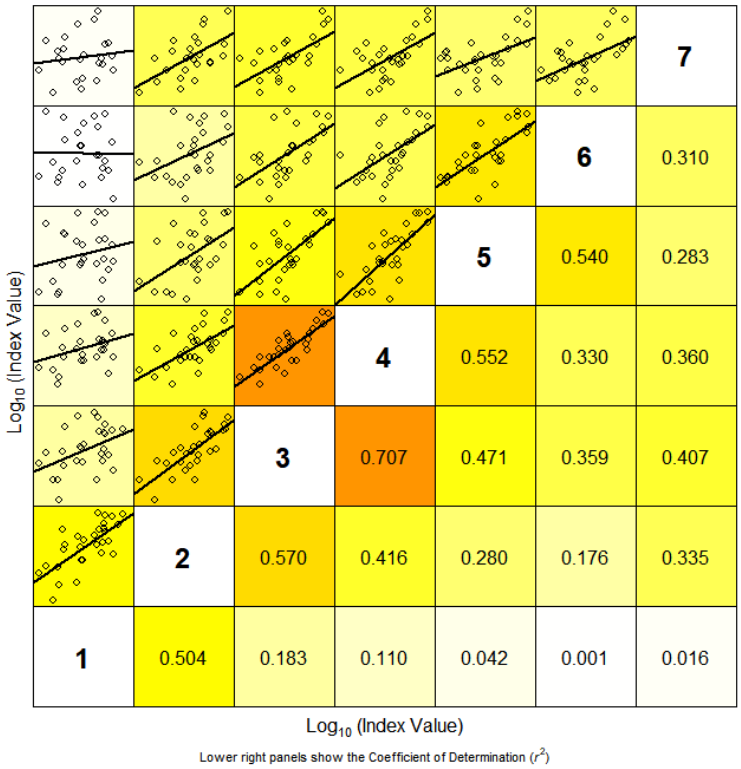


Figure 18: Internal consistency of the eastern English Channel sole relative abundance index. Note that age 7 is a plus group.

Relative contributions by subpopulation were calculated by dividing the numbers by subpopulation by the total numbers for an age group. Figure 19 shows the relative shares of each subpopulation with respect to the age 1 numbers. These shares can be used to weight the different Young Fish surveys in the assessment model (Annex, Table 6).

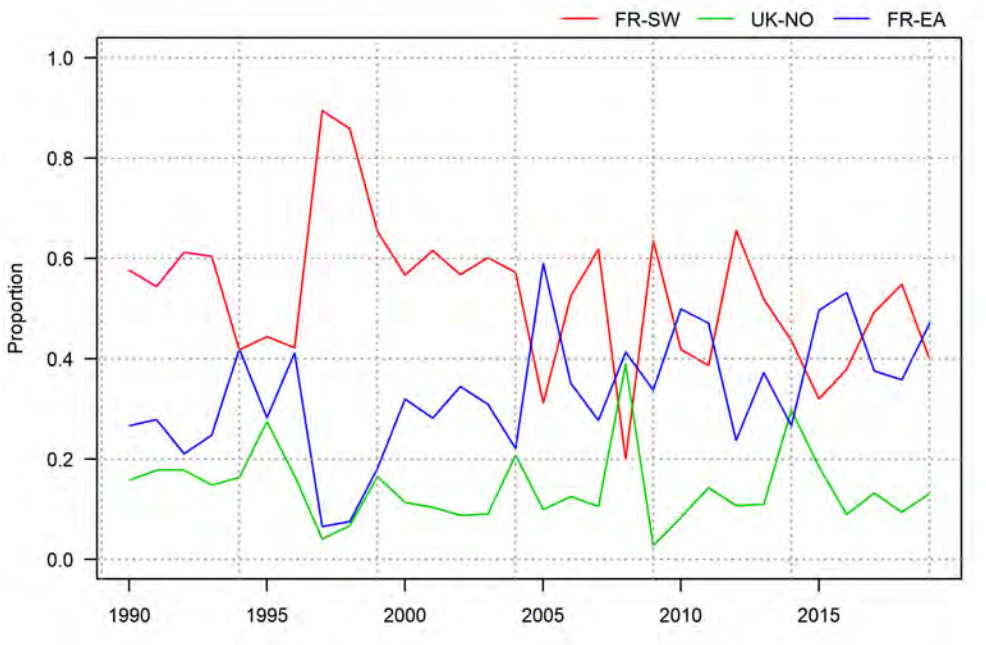


Figure 19: Proportion of age 1 fish by subpopulation with respect to the total population.

7. Conclusion

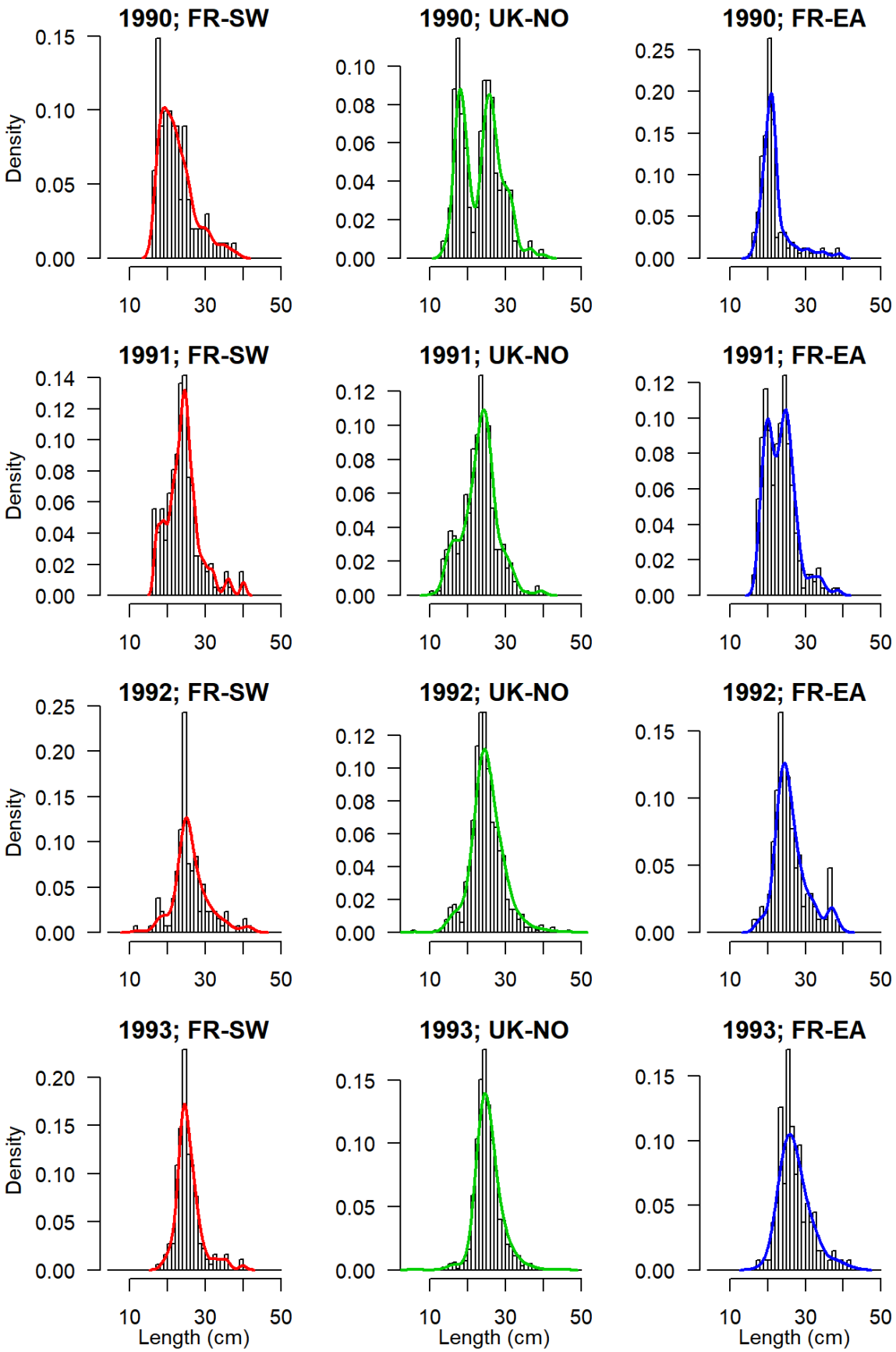
An age-structured index of relative abundance was calculated for the eastern English Channel sole stock using data from the UK (E&W) BTS Q3 survey. First, an aggregated index of abundance was constructed using a spatiotemporal model. This model was used to project the expected numbers of sole caught in squares of 10x10 km representing the eastern English Channel. Length frequency data was used to extract length structured information by subpopulation and year using kernel density estimation. The resulting length distributions were combined with the total number to calculate the expected numbers by length bin. Finally, a multinomial regression model was used to derive age-length keys by subpopulation. These age-length keys were applied to the expected numbers by length bin to calculate the expected numbers-at-age. Each of these steps considered the perceived population structure of the eastern English Channel sole. The derived quantities can be used to obtain relative weights of other tuning series used in the assessment of eastern English Channel sole.

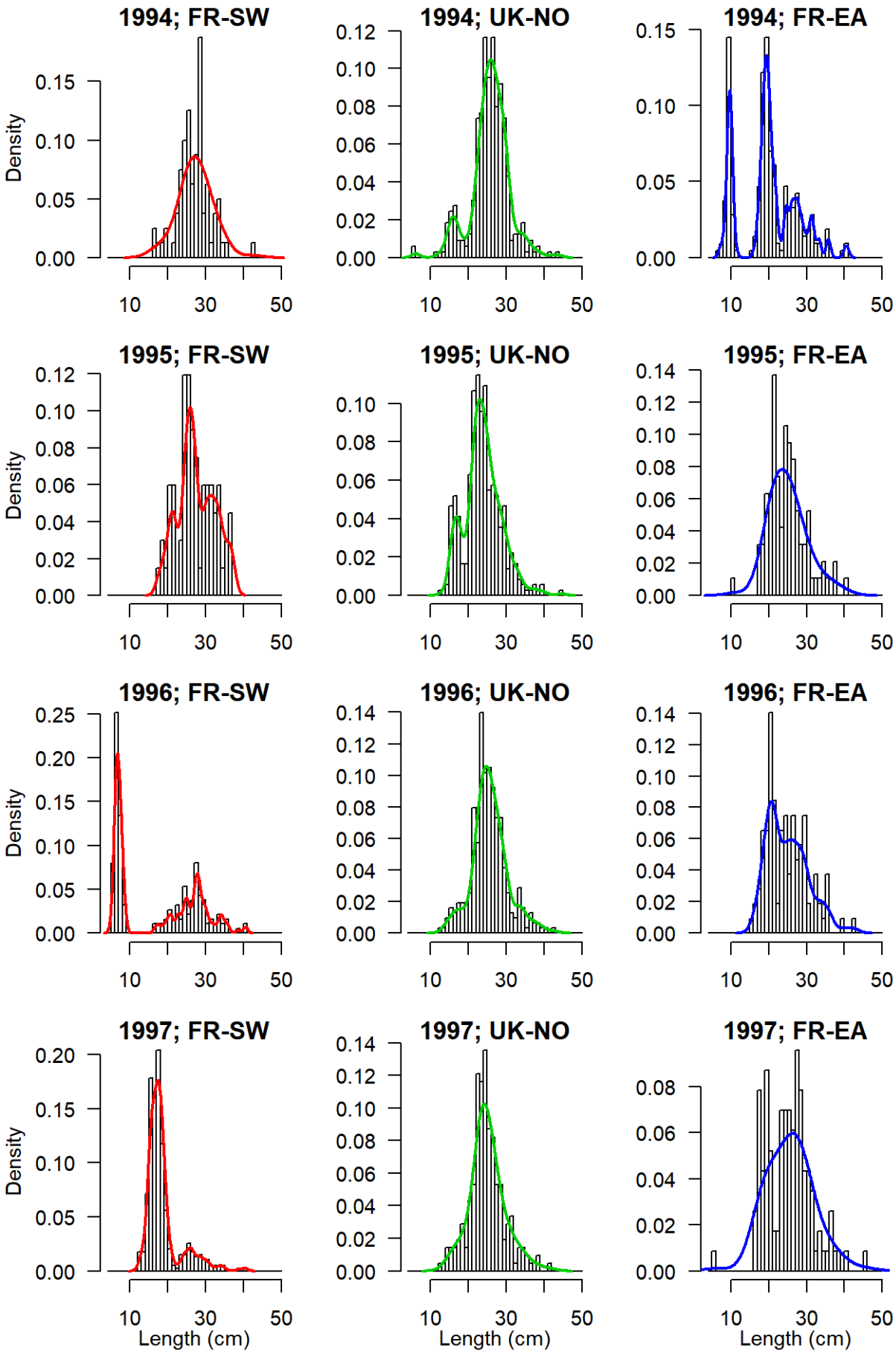
8. References

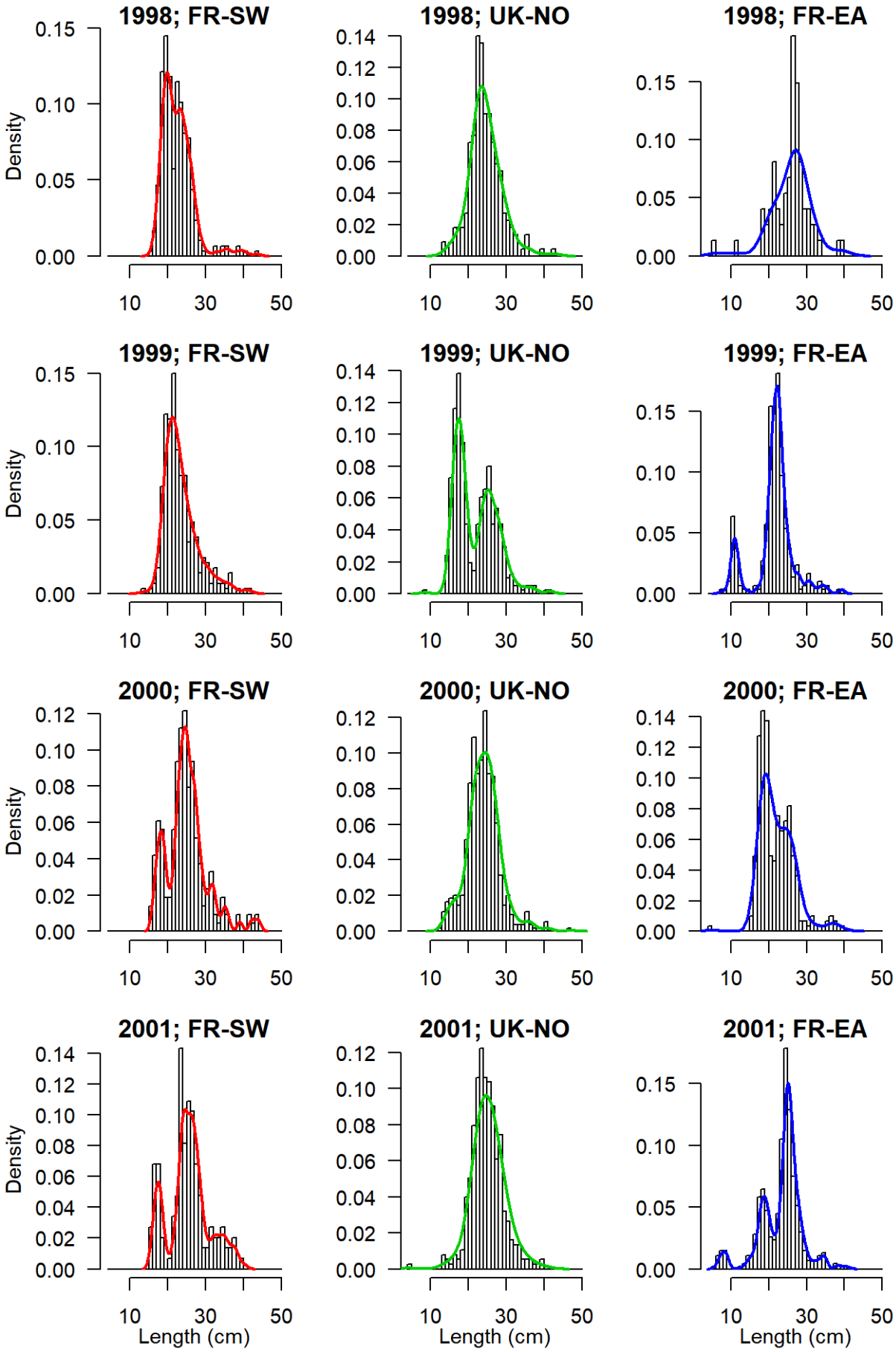
Savina, M., Vermard, Y. et al., 2020. Rapport final du projet SMAC: Sole de Manche Est: amelioration des connaissances pour une meilleure gestion du stock. Ifremer 66p.

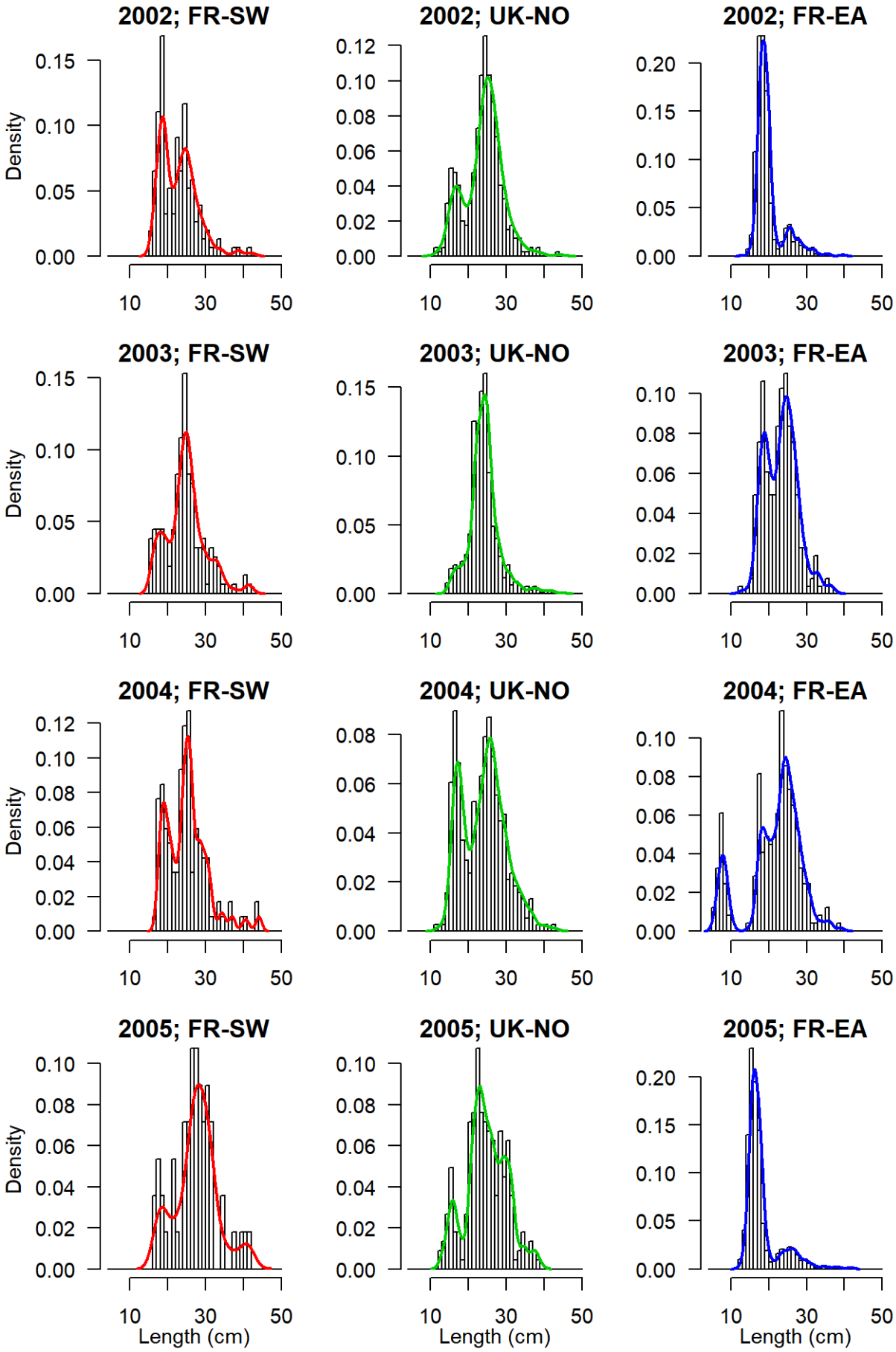
Randon, M., Réveillac, E., Rivot, E., Du Pontavice, H., Le Pape, O., 2018. Could we consider a single stock when spatial sub-units present lasting patterns in growth and asynchrony in cohort densities? A flatfish case study. Journal of Sea Research 142, 91-100. https://doi.org/10.1016/j.seares.2018.09.012

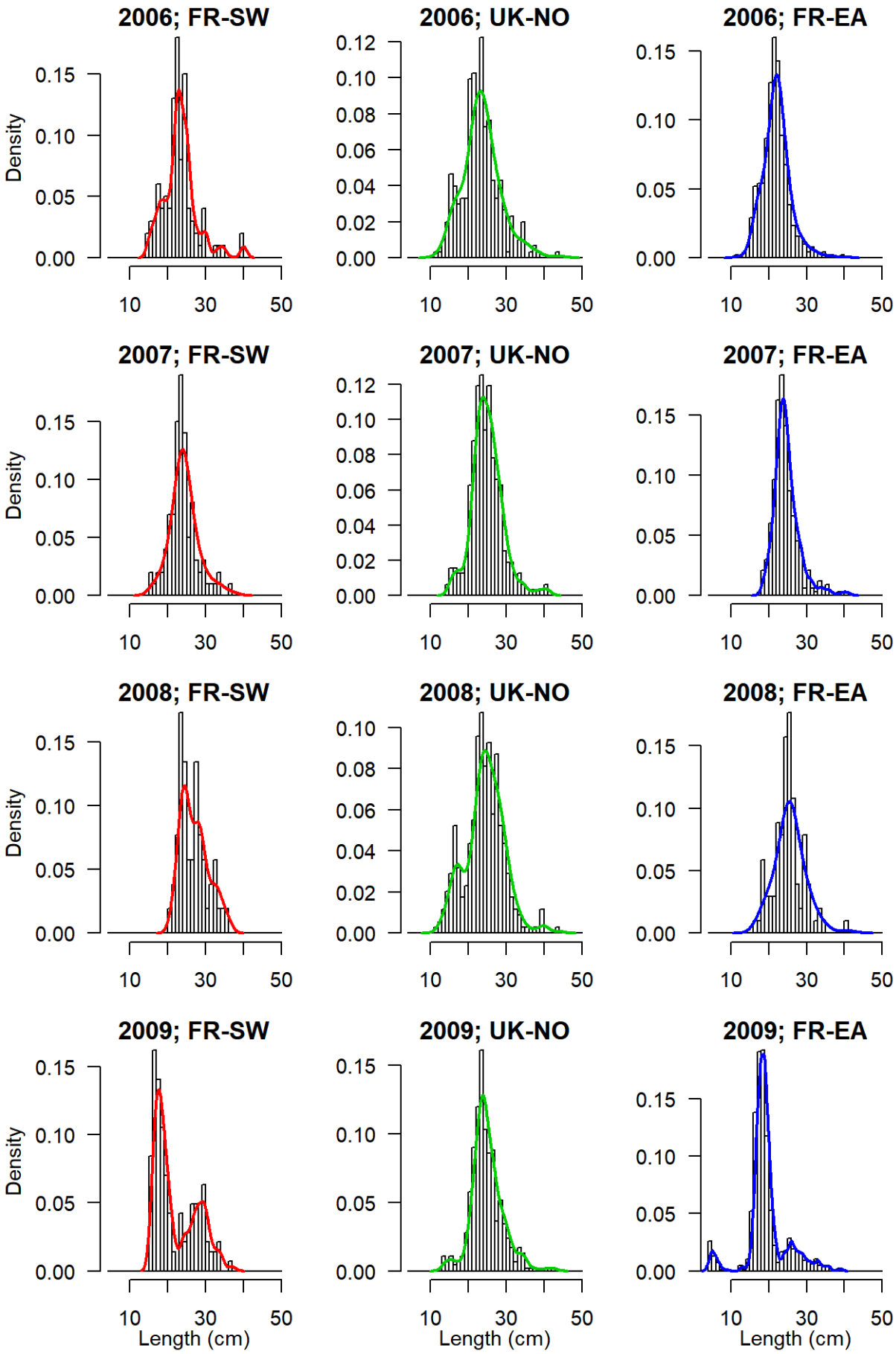
9. Annex

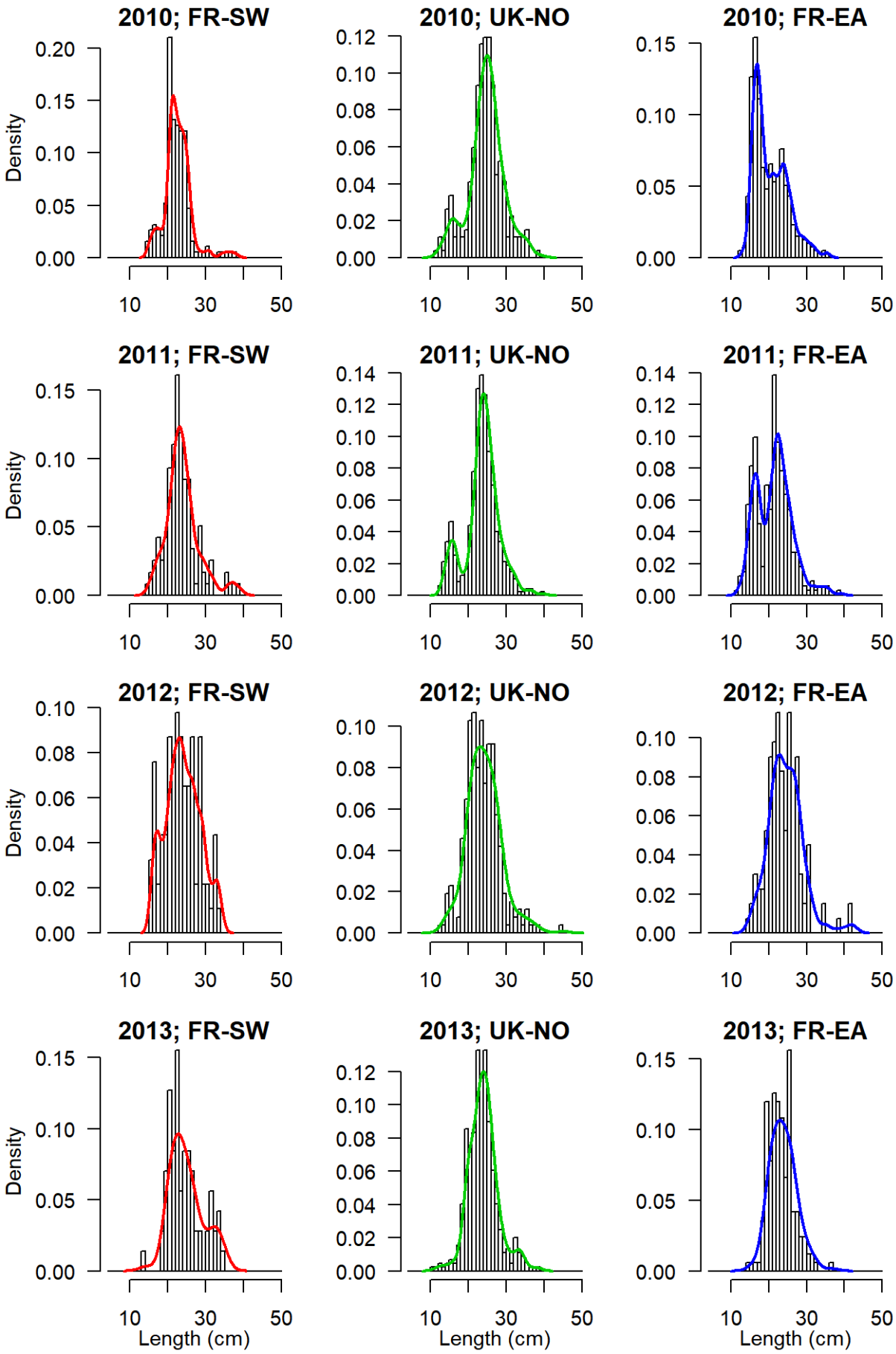

1990; FR-SW
1990; UK-NO
1990; FR-EA
1991; FR-SW
1991; UK-NO
1991; FR-EA
1992; FR-SW
1992; UK-NO
1992; FR-EA
1993; FR-SW
1993; UK-NO
1993; FR-EA
Density
Length (cm)

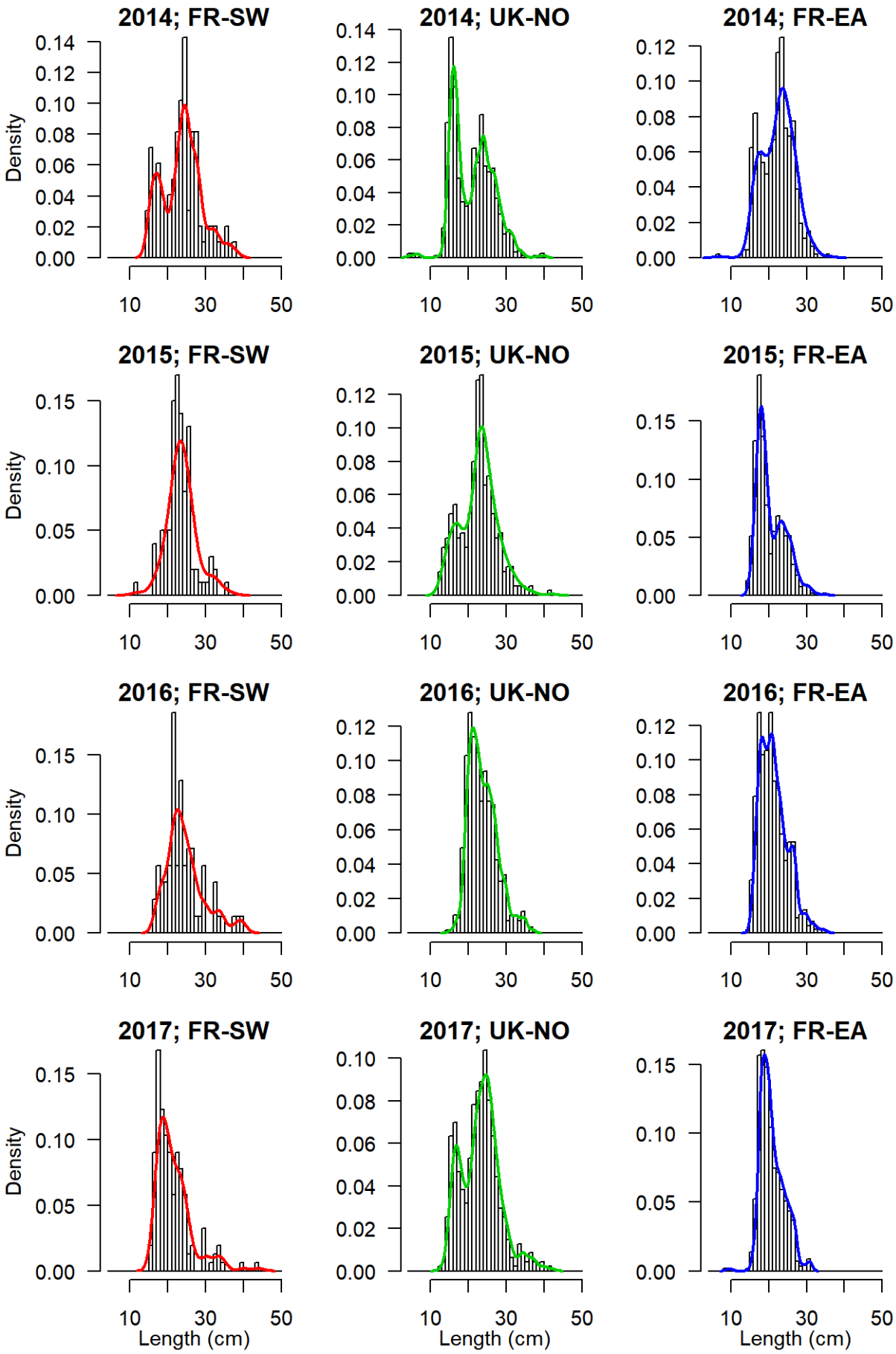

1994; FR-SW
1994; UK-NO
1994; FR-EA
1995; FR-SW
1995; UK-NO
1995; FR-EA
1996; FR-SW
1996; UK-NO
1996; FR-EA
1997; FR-SW
1997; UK-NO
1997; FR-EA
Density
Length (cm)


1998; FR-SW
1998; UK-NO
1998; FR-EA
1999; FR-SW
1999; UK-NO
1999; FR-EA
2000; FR-SW
2000; UK-NO
2000; FR-EA
2001; FR-SW
2001; UK-NO
2001; FR-EA
Density
Length (cm)


2002; FR-SW
2002; UK-NO
2002; FR-EA
2003; FR-SW
2003; UK-NO
2003; FR-EA
2004; FR-SW
2004; UK-NO
2004; FR-EA
2005; FR-SW
2005; UK-NO
2005; FR-EA
Density
Length (cm)


2006; FR-SW
2006; UK-NO
2006; FR-EA
2007; FR-SW
2007; UK-NO
2007; FR-EA
2008; FR-SW
2008; UK-NO
2008; FR-EA
2009; FR-SW
2009; UK-NO
2009; FR-EA
Density
Length (cm)
10
30
50
0.00
0.02
0.04
0.05
0.06
0.08
0.10
0.12
0.15


2010; FR-SW
2010; UK-NO
2010; FR-EA
2011; FR-SW
2011; UK-NO
2011; FR-EA
2012; FR-SW
2012; UK-NO
2012; FR-EA
2013; FR-SW
2013; UK-NO
2013; FR-EA
Density
Length (cm)


2014; FR-SW
2014; UK-NO
2014; FR-EA
2015; FR-SW
2015; UK-NO
2015; FR-EA
2016; FR-SW
2016; UK-NO
2016; FR-EA
2017; FR-SW
2017; UK-NO
2017; FR-EA
Density
Length (cm)

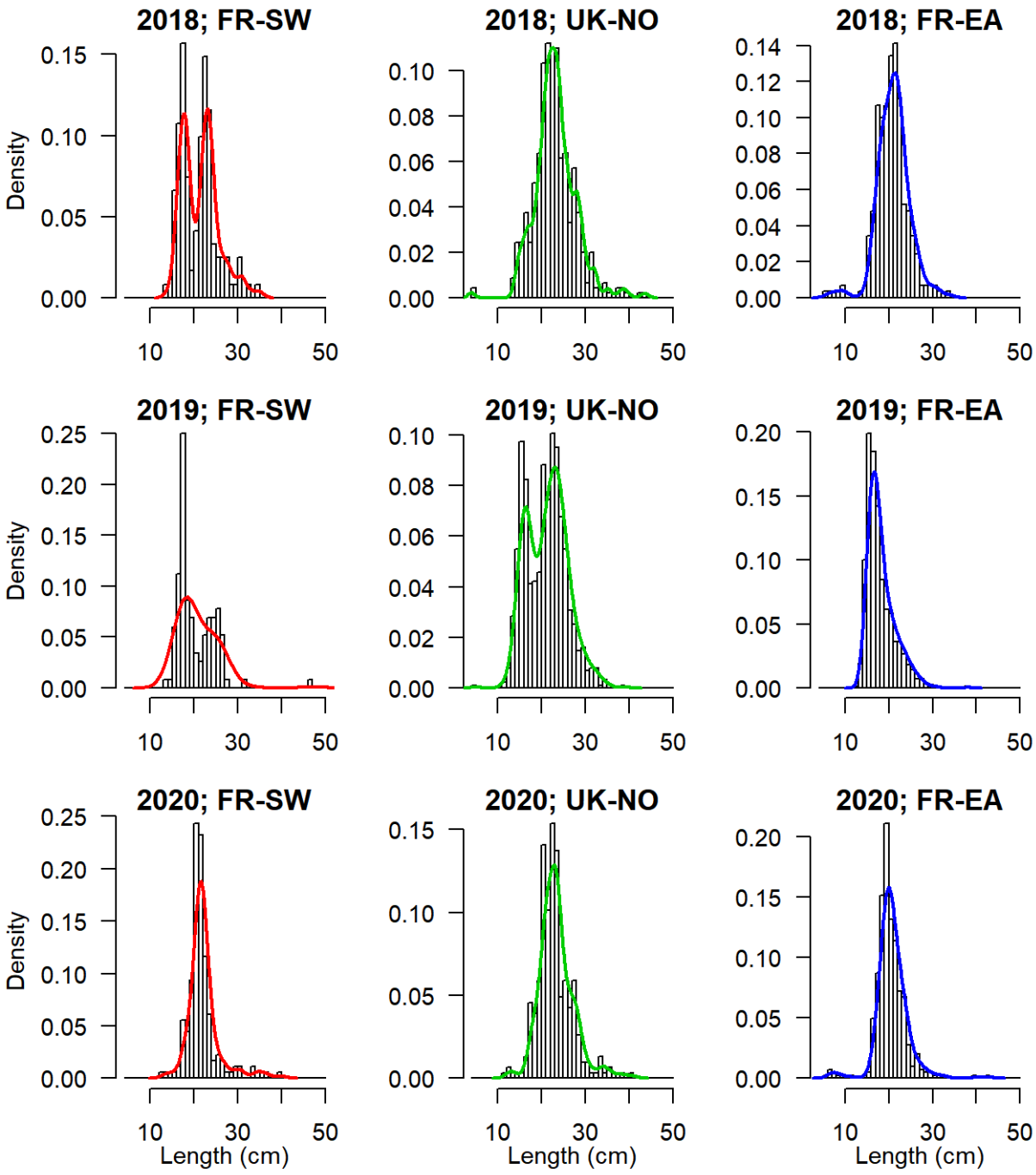


Figure 19: Histograms with estimated densities (solid lines) of the length composition data by year and subpopulation.

Table 2: Summary statistics of the parametric effects of the age-length models.

	estimate	std.error	statistic	p.value
(Intercept)	40.32943	6.407488	6.294108	3.09E-10
(Intercept).1	44.39867	6.414005	6.922144	4.45E-12
fsubpop2.1	1.468089	0.115987	12.65739	1.02E-36
fsubpop3.1	-1.52749	0.109734	-13.9199	4.80E-44
(Intercept).2	42.69392	6.415734	6.654565	2.84E-11
fsubpop2.2	2.252005	0.134141	16.78838	2.97E-63
fsubpop3.2	-1.27238	0.134805	-9.43861	3.78E-21
(Intercept).3	40.79968	6.418843	6.356236	2.07E-10
fsubpop2.3	2.828584	0.157275	17.98499	2.55E-72
fsubpop3.3	-0.59374	0.161953	-3.66615	0.000246
(Intercept).4	39.99162	6.416387	6.232731	4.58E-10
fsubpop2.4	2.962345	0.179721	16.483	4.86E-61
fsubpop3.4	-0.21836	0.1855	-1.17713	0.239142
(Intercept).5	37.78785	6.415937	5.889686	3.87E-09
fsubpop2.5	3.698861	0.224239	16.49521	3.97E-61
fsubpop3.5	0.403809	0.233857	1.726736	0.084215
(Intercept).6	37.93288	6.42541	5.903573	3.56E-09
fsubpop2.6	3.875963	0.210834	18.38391	1.77E-75
fsubpop3.6	0.732498	0.21756	3.366873	0.00076

Table 3: Summary statistics of the non-parametric effects of the age-length model

	edf	ref.df	statistic	p.value
s(LngtCm)	1.005032	1.007678	38.66775	5.03E-10
s(Year)	8.510274	8.807107	109.4979	1.33E-19
s.1(LngtCm)	4.288091	4.958116	109.4246	2.33E-20
s.1(Year)	7.981671	8.333356	68.40023	1.02E-11
s.2(LngtCm)	5.050268	5.588781	127.2249	5.82E-25
s.2(Year)	7.125865	7.636399	53.96514	3.94E-09
s.3(LngtCm)	4.615133	5.238863	125.3575	9.07E-25
s.3(Year)	7.53561	8.070923	69.7332	7.37E-12
s.4(LngtCm)	3.466772	4.192267	93.96977	4.55E-19
s.4(Year)	6.473762	7.233323	61.36023	1.54E-10
s.5(LngtCm)	1.081867	1.110892	97.29972	1.12E-21
s.5(Year)	6.603122	7.44883	58.93924	1.04E-09
s.6(LngtCm)	4.528441	5.241195	121.4456	5.96E-24
s.6(Year)	6.367916	7.184413	54.84772	2.60E-09

Table 4: Index of relative abundance at age (numpers/km²) for the entire sole stock, and by subpopulation, in the eastern English Channel based on the UK (E&W) Q3 BTS survey.

Year	subpop	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7
1990	all	1.372852	1.013411	0.19649	0.036672	0.041464	0.019737	0.034644
1991	all	0.922335	1.857136	0.414951	0.091965	0.063492	0.026115	0.052348
1992	all	0.292214	1.45038	0.651327	0.227131	0.115311	0.04498	0.097445
1993	all	0.142266	1.445451	0.625101	0.253673	0.110566	0.042669	0.065494
1994	all	0.251887	0.646559	0.415417	0.213695	0.118427	0.047961	0.075482
1995	all	0.267782	0.723973	0.317414	0.163527	0.130223	0.061109	0.090279
1996	all	0.222285	0.517379	0.222841	0.093197	0.077334	0.045508	0.088389
1997	all	1.441903	0.388936	0.146067	0.058332	0.04351	0.03179	0.076865
1998	all	0.974692	0.920421	0.224524	0.069509	0.042058	0.028137	0.078759
1999	all	1.256926	0.93814	0.274973	0.087348	0.043737	0.023999	0.064741
2000	all	0.859631	1.164709	0.39387	0.1264	0.054598	0.02675	0.10012
2001	all	0.557061	1.087244	0.381065	0.153272	0.083062	0.038562	0.083986
2002	all	1.046608	0.829627	0.223003	0.077498	0.037528	0.01649	0.040189
2003	all	0.528889	1.137451	0.331129	0.126755	0.070555	0.027031	0.065663
2004	all	0.453599	0.830879	0.338222	0.13473	0.078645	0.031897	0.085026
2005	all	0.507672	0.542689	0.445426	0.200273	0.116355	0.044997	0.119804
2006	all	0.5789	1.057317	0.337353	0.113151	0.055666	0.02303	0.051768
2007	all	0.310204	1.194396	0.450637	0.160216	0.08159	0.033985	0.053853
2008	all	0.174651	0.995043	0.483632	0.195845	0.125169	0.055833	0.073869
2009	all	1.115804	0.736017	0.303284	0.114863	0.076453	0.039644	0.042963
2010	all	0.895973	1.910912	0.398576	0.127974	0.086944	0.056394	0.050708
2011	all	0.78226	2.004191	0.743899	0.247997	0.151185	0.092644	0.083121
2012	all	0.472016	1.312506	0.855334	0.366847	0.183911	0.10631	0.092046
2013	all	0.314362	1.265211	0.955839	0.466813	0.226754	0.123423	0.103806
2014	all	1.127725	1.095044	0.874169	0.453685	0.23457	0.116702	0.125199
2015	all	1.076893	1.399231	0.691086	0.326186	0.187653	0.086044	0.116634
2016	all	1.085386	1.619867	0.597357	0.290344	0.227059	0.111418	0.240947
2017	all	1.930462	1.482896	0.427986	0.183573	0.146932	0.075031	0.199179
2018	all	1.644684	1.929703	0.621152	0.191081	0.132795	0.063884	0.181361
2019	all	2.206786	1.600509	0.665554	0.154836	0.086734	0.038958	0.134409
1990	FR-SW	2.352706	1.899472	0.28792	0.049834	0.068065	0.024985	0.040437
1991	FR-SW	1.490899	3.573231	0.697836	0.132405	0.112027	0.040397	0.095771
1992	FR-SW	0.53193	2.918919	1.23952	0.378398	0.204614	0.065776	0.175971
1993	FR-SW	0.255542	3.034265	1.071238	0.329245	0.147647	0.042983	0.069029
1994	FR-SW	0.312875	1.352446	0.856208	0.408883	0.238547	0.079937	0.131386
1995	FR-SW	0.35381	1.400328	0.680121	0.347247	0.293487	0.122136	0.16561
1996	FR-SW	0.278795	0.881892	0.400542	0.150026	0.13067	0.059932	0.118154
1997	FR-SW	3.835511	0.471025	0.160211	0.049632	0.037188	0.018425	0.04822
1998	FR-SW	2.485925	1.988954	0.333174	0.069026	0.047495	0.025635	0.096939
1999	FR-SW	2.444398	2.166857	0.577787	0.168845	0.091553	0.043636	0.125494
2000	FR-SW	1.44943	2.499846	0.812099	0.242214	0.110953	0.046548	0.215167
2001	FR-SW	1.0195	2.079345	0.698532	0.265642	0.168711	0.069622	0.156649
2002	FR-SW	1.767093	1.741711	0.388938	0.109082	0.058275	0.020764	0.067931
2003	FR-SW	0.945106	2.157476	0.625831	0.226408	0.134447	0.044463	0.127381

2004	FR-SW	0.771198	1.72686	0.658671	0.217485	0.132295	0.043483	0.163374
2005	FR-SW	0.470828	1.149365	1.045429	0.44583	0.268985	0.091611	0.282058
2006	FR-SW	0.902843	2.11161	0.598653	0.161802	0.0843	0.028615	0.084016
2007	FR-SW	0.570163	2.191986	0.715508	0.205211	0.107619	0.03382	0.046769
2008	FR-SW	0.103027	1.989177	0.969342	0.355864	0.232796	0.084578	0.095295
2009	FR-SW	2.110205	1.201068	0.544503	0.189563	0.129416	0.050424	0.046707
2010	FR-SW	1.113963	4.148669	0.565386	0.116853	0.091452	0.045317	0.044917
2011	FR-SW	0.899084	3.963298	1.261302	0.345621	0.238937	0.127037	0.130675
2012	FR-SW	0.920571	2.515918	1.541137	0.56348	0.272678	0.114755	0.071733
2013	FR-SW	0.484443	2.354143	1.645287	0.72679	0.378599	0.177171	0.145394
2014	FR-SW	1.463341	1.946308	1.580639	0.70349	0.379206	0.159931	0.17533
2015	FR-SW	1.022225	2.887538	1.296917	0.511709	0.298829	0.106092	0.136595
2016	FR-SW	1.222859	2.701636	0.95536	0.409677	0.355315	0.151359	0.395437
2017	FR-SW	2.829982	2.396749	0.504447	0.174462	0.154476	0.06204	0.207696
2018	FR-SW	2.678541	2.983772	0.838143	0.203208	0.143254	0.04963	0.124741
2019	FR-SW	2.620123	2.774514	1.060405	0.20556	0.117991	0.038502	0.158578
1990	UK-NO	0.464432	0.596148	0.180732	0.033203	0.026052	0.015497	0.0244
1991	UK-NO	0.35118	0.874158	0.260618	0.062739	0.028955	0.014444	0.022358
1992	UK-NO	0.111475	0.606168	0.327188	0.127865	0.04856	0.023627	0.037122
1993	UK-NO	0.045264	0.608456	0.370654	0.171536	0.058952	0.026681	0.03093
1994	UK-NO	0.088316	0.321097	0.232831	0.132983	0.06195	0.034467	0.046421
1995	UK-NO	0.157523	0.377938	0.130174	0.061372	0.034902	0.022321	0.033044
1996	UK-NO	0.07979	0.342662	0.139717	0.061898	0.042601	0.033137	0.057629
1997	UK-NO	0.12429	0.362109	0.134942	0.053097	0.033169	0.027665	0.053934
1998	UK-NO	0.139991	0.367967	0.141931	0.049233	0.022872	0.017662	0.037263
1999	UK-NO	0.444967	0.251589	0.12622	0.0461	0.017626	0.012916	0.028698
2000	UK-NO	0.209984	0.483792	0.188384	0.066302	0.022447	0.014616	0.033297
2001	UK-NO	0.123775	0.456432	0.19961	0.086895	0.032987	0.020433	0.03928
2002	UK-NO	0.197758	0.416496	0.166486	0.070838	0.029174	0.015811	0.027802
2003	UK-NO	0.102818	0.555436	0.164178	0.061534	0.026715	0.013713	0.028672
2004	UK-NO	0.20222	0.271885	0.149367	0.079114	0.041217	0.02307	0.040312
2005	UK-NO	0.107631	0.275056	0.171075	0.090392	0.044481	0.025097	0.041185
2006	UK-NO	0.155732	0.353143	0.176115	0.078129	0.035268	0.019416	0.034357
2007	UK-NO	0.070083	0.431252	0.247462	0.104953	0.047187	0.025677	0.04124
2008	UK-NO	0.145989	0.360734	0.186022	0.082298	0.043675	0.027372	0.040282
2009	UK-NO	0.064278	0.548822	0.214226	0.08526	0.049912	0.034815	0.040709
2010	UK-NO	0.159351	0.647697	0.332647	0.140701	0.084834	0.065669	0.05541
2011	UK-NO	0.239904	0.730089	0.455181	0.183784	0.088703	0.064957	0.046206
2012	UK-NO	0.108535	0.505071	0.387669	0.187657	0.085872	0.069066	0.059675
2013	UK-NO	0.074162	0.51537	0.491428	0.252529	0.099542	0.069571	0.056696
2014	UK-NO	0.721049	0.452136	0.371145	0.223233	0.097965	0.064252	0.065259
2015	UK-NO	0.426638	0.570954	0.383745	0.226565	0.120763	0.075995	0.106174
2016	UK-NO	0.207743	0.979771	0.417089	0.223347	0.147195	0.08906	0.153238
2017	UK-NO	0.545661	0.803851	0.384922	0.187855	0.138468	0.087393	0.211896
2018	UK-NO	0.332753	1.022099	0.465437	0.169814	0.111663	0.069155	0.205135
2019	UK-NO	0.621256	0.853706	0.494589	0.139625	0.073835	0.044023	0.13358
1990	FR-EA	1.843481	0.489727	0.078342	0.022486	0.032516	0.02079	0.048873

1991	FR-EA	1.29885	1.253483	0.297355	0.091977	0.062239	0.029291	0.049094
1992	FR-EA	0.309886	0.940933	0.414414	0.203561	0.120529	0.059836	0.105857
1993	FR-EA	0.177847	0.714953	0.465588	0.318328	0.168856	0.079687	0.140671
1994	FR-EA	0.532538	0.213033	0.096208	0.072018	0.04722	0.025388	0.048865
1995	FR-EA	0.380739	0.388876	0.141641	0.09167	0.07703	0.048639	0.096862
1996	FR-EA	0.461039	0.309133	0.116501	0.070268	0.068395	0.050082	0.110118
1997	FR-EA	0.474418	0.312636	0.148192	0.085392	0.078525	0.064156	0.179329
1998	FR-EA	0.370458	0.40458	0.234119	0.117946	0.07789	0.056983	0.145361
1999	FR-EA	1.148697	0.465398	0.110451	0.045922	0.023919	0.016707	0.046292
2000	FR-EA	1.384446	0.498144	0.166729	0.071005	0.034473	0.021649	0.061819
2001	FR-EA	0.789881	0.885132	0.268476	0.118471	0.055318	0.028429	0.065671
2002	FR-EA	1.817479	0.25208	0.074145	0.039545	0.021937	0.010832	0.022203
2003	FR-EA	0.8232	0.773352	0.223108	0.110816	0.065087	0.028727	0.047801
2004	FR-EA	0.505006	0.623215	0.237951	0.124912	0.075501	0.032966	0.057081
2005	FR-EA	1.509684	0.141712	0.071548	0.041622	0.026143	0.012631	0.029099
2006	FR-EA	1.022982	0.921959	0.272599	0.112839	0.05498	0.022041	0.037932
2007	FR-EA	0.432982	1.293746	0.478313	0.213644	0.118214	0.053774	0.095494
2008	FR-EA	0.363509	0.797695	0.358333	0.190964	0.133915	0.073893	0.116391
2009	FR-EA	1.897829	0.386462	0.103094	0.057625	0.048905	0.032691	0.041903
2010	FR-EA	2.255999	1.080147	0.270339	0.116954	0.084249	0.053408	0.049495
2011	FR-EA	1.857729	1.671854	0.54393	0.233132	0.14901	0.099302	0.089118
2012	FR-EA	0.564462	1.166603	0.789851	0.453989	0.263518	0.179446	0.202538
2013	FR-EA	0.589847	1.178314	0.876528	0.528884	0.267832	0.158682	0.14387
2014	FR-EA	1.513266	1.160332	0.856657	0.570988	0.309944	0.16652	0.180897
2015	FR-EA	2.696779	0.818813	0.384794	0.245317	0.156079	0.075625	0.107327
2016	FR-EA	2.913228	1.287393	0.413194	0.245183	0.196971	0.096144	0.184766
2017	FR-EA	3.656187	1.526842	0.399368	0.188976	0.15401	0.068046	0.154861
2018	FR-EA	2.971309	2.272477	0.618622	0.220447	0.164676	0.075695	0.221614
2019	FR-EA	5.228957	1.362112	0.397013	0.104483	0.063983	0.027838	0.095344

Table 5: Percentage of fish (≥ 24 cm) by subpopulation.

Year	%FR-SW	%UK-NO	%FR-EA
1990	55.05	35.41	9.54
1991	62.9	21.05	16.05
1992	66.76	18.57	14.66
1993	60.95	21.83	17.21
1994	69.25	24.54	6.21
1995	73.54	15.17	11.29
1996	59.27	26.68	14.05
1997	36.13	36.61	27.26
1998	57.31	21.02	21.67
1999	72.47	17.71	9.82
2000	73.07	16.88	10.04
2001	64.47	18.16	17.37
2002	63.89	28.47	7.64
2003	66.5	18.38	15.12

2004	66.88	17.96	15.15
2005	79.94	16.04	4.02
2006	63.08	21.5	15.42
2007	54.65	21.75	23.6
2008	66.58	15.63	17.79
2009	58.65	31.89	9.46
2010	50.81	34.59	14.6
2011	59.63	25.22	15.15
2012	58.26	19.43	22.31
2013	59.9	20.44	19.67
2014	61.9	17.45	20.64
2015	62.73	24.76	12.51
2016	58.45	27.13	14.42
2017	40.39	41.04	18.57
2018	45.97	34.51	19.52
2019	58.08	32.11	9.81
2020	43.49	38.87	17.64

Table 6: Percentage of fish (age 1) by subpopulation.

Year	%FR-SW	%UK-NO	%FR-EA
1990	57.64	15.75	26.61
1991	54.37	17.72	27.91
1992	61.22	17.76	21.02
1993	60.41	14.81	24.78
1994	41.78	16.32	41.9
1995	44.44	27.38	28.18
1996	42.18	16.71	41.11
1997	89.47	4.01	6.52
1998	85.78	6.69	7.53
1999	65.41	16.48	18.11
2000	56.71	11.37	31.92
2001	61.55	10.34	28.1
2002	56.79	8.8	34.42
2003	60.1	9.05	30.85
2004	57.18	20.75	22.07
2005	31.19	9.87	58.94
2006	52.45	12.52	35.02
2007	61.82	10.52	27.66
2008	19.84	38.91	41.25
2009	63.61	2.68	33.71
2010	41.82	8.28	49.9
2011	38.66	14.27	47.07
2012	65.6	10.7	23.7
2013	51.83	10.98	37.19
2014	43.64	29.76	26.6

2015	31.93	18.44	49.63
2016	37.89	8.91	53.2
2017	49.31	13.16	37.54
2018	54.78	9.42	35.81
2019	39.93	13.1	46.96

Working document: Assessment runs for sole in the eastern English Channel (ICES division 27.7.d)

Authors: Lies Vansteenbrugge and Klaas Sys (ILVO, Belgium)

1. Introduction

The current assessment model for sole in ICES divisions 7.d is an extended survival analysis (XSA). One of the aims of the WKNSEA21 benchmark is to assess the performance of the current model against the new data and alternative stock assessment models.

2. Input data

2.1 Catches

From 1982-2000, catches fluctuated around 4000 tonnes, but increased substantially in the period 2000-2014. From 2014 onwards there is a sharp decline, with the lowest catches registered in the most recent year (2019). The main countries contributing to the catches are France (60±4%), Belgium (25±4%) and UK England (16±2%).

Discard data are unavailable prior to 2004 and were therefore reconstructed using the discard to landings ratio from the period 2004-2008. After 2008 the proportion of sole being discarded at age appears to increase.

Sole in division 27.7d is fully under the landing obligation since 2018 with *de minimis* exemptions for certain fleets. The official catch statistics have reported BMS landings in 2017 (144 kg) and in 2019 (2.8 kg). However, no BMS landings have been uploaded to InterCatch.

Landings and discards numbers-at-age are presented in Figures 1 and 2 for the period 1982-2019. Landings and discards weight-at-age are presented in Figure 3. In the most recent years, a decreasing trend in weight-at-age can be observed, which most likely contributes to larger proportions of sole at age being discarded.

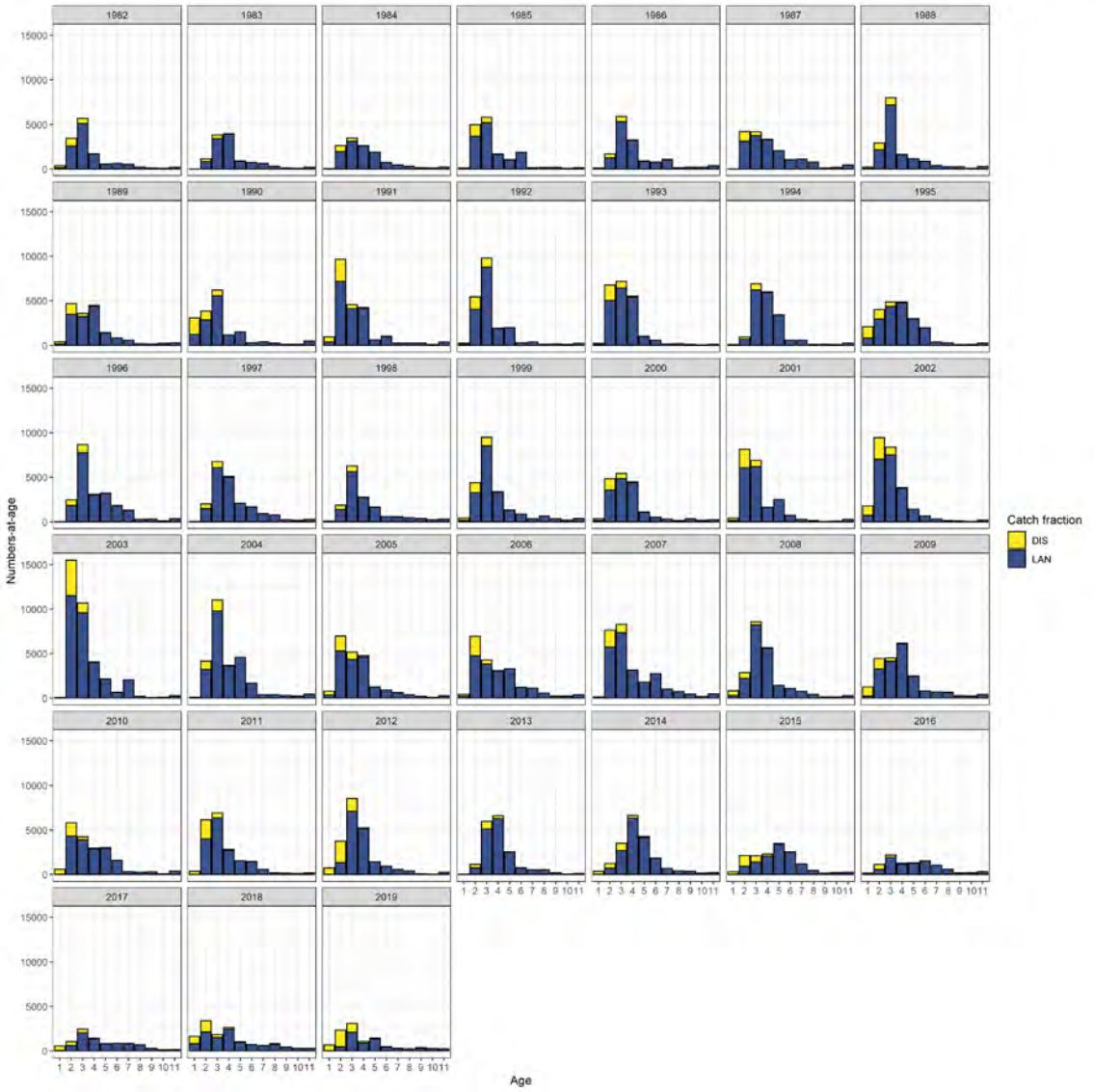


Figure 1: Landings (blue) and discards (yellow) numbers-at-age for the period 1982-2019.

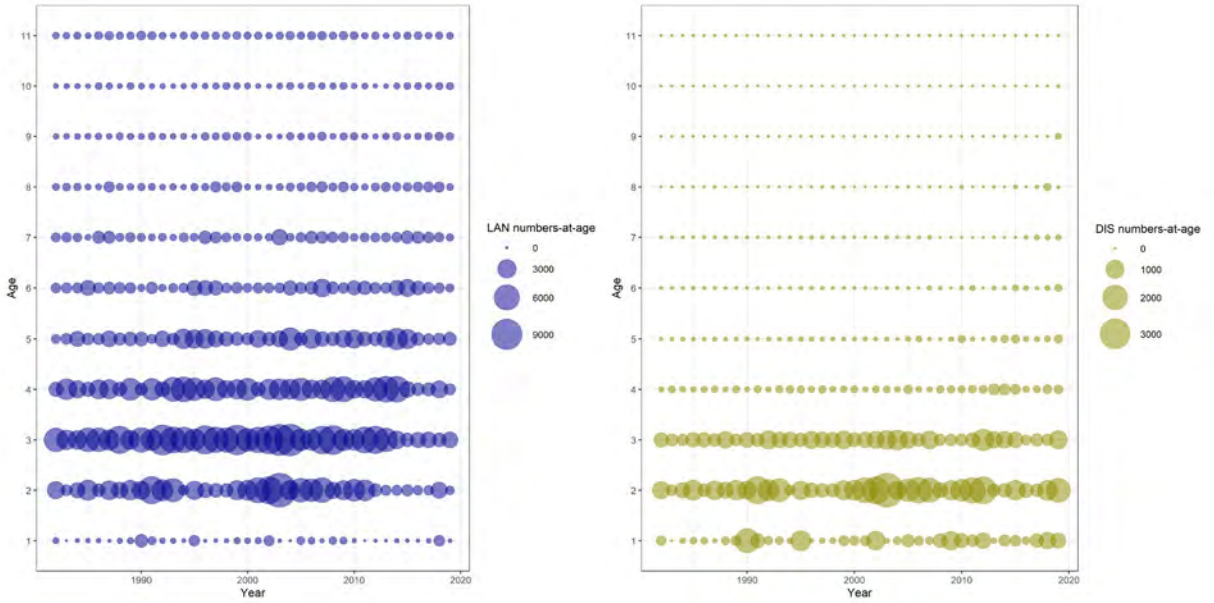


Figure 2: left: landings numbers-at-age; right: discards numbers-at-age for the period 1982-2019.

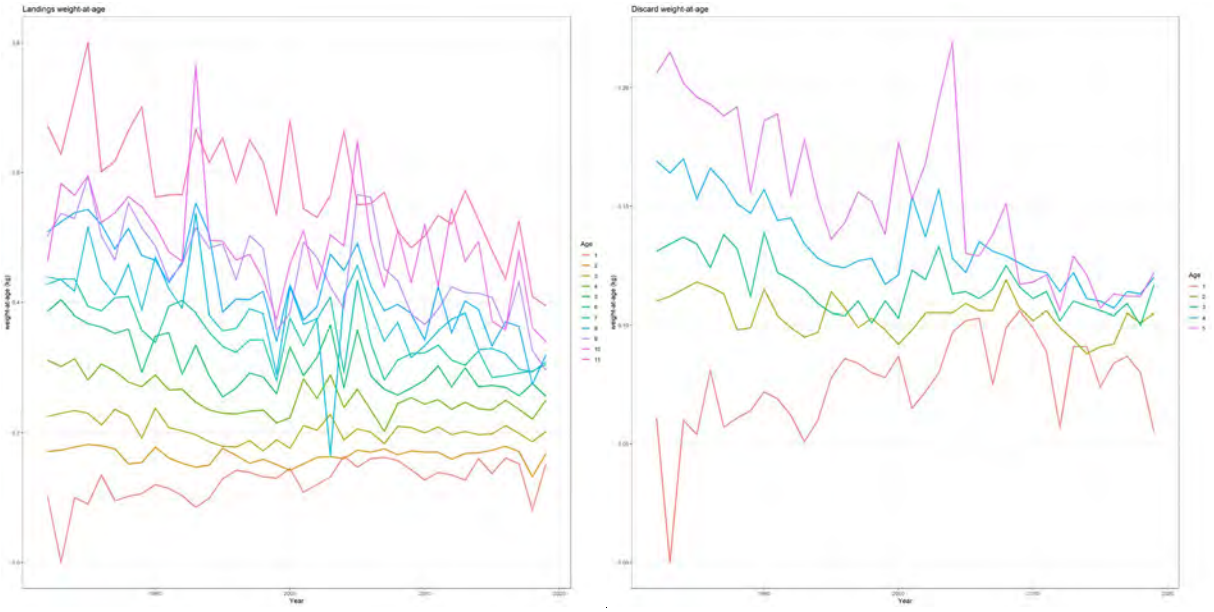


Figure 3: left: landings weight-at-age for age 1-11+; right: discards weight-at-age for age 1-5 for the period 1982-2019.

2.2 Life history

2.2.1 Stock weight-at-age

During the WKNSEA 2021 benchmark, the stock weight-at-age calculation was revised to improve consistency over the time series. They were set as the quarter 1 catch weight-at-age. Prior to 2004, no quarter 1 information is available. Therefore, the mean proportion at age was calculated based on the ratio between quarter 1 weight-at-age and catch weight-at-age in the period 2004-2019 and multiplied by the catch weight-at-age for the beginning of the time series (Figure 4).

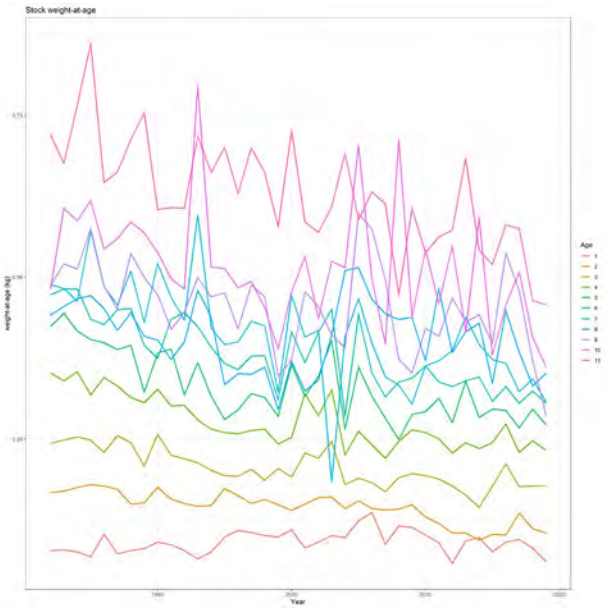


Figure 4: Revised stock weight-at-age for age 1-11+ over the period 1982-2019.

2.2.2 Natural mortality

Natural mortality is assumed constant over ages and years at 0.1. English and French tagging data were investigated, but two problems were encountered. First, most of the tagging data dated back to before the beginning of the sole 7d time series. Second, in the most recent years, there were too little recaptures which inhibited the calculation of a new estimate for natural mortality (Lecomte *et al*., 2019).

2.2.3 Maturity

During the WKNSEA 2017 benchmark, the knife-edged maturity ogive with full maturation from age 3 onwards was investigated. Using data from the French IBTS survey and commercial data form Belgium, France and the UK (15191 records), a new maturity ogive was constructed (Table 1). More information on how this was achieved is provided in the WKNSEA 2017 report and the associated working document (ICES, 2017). The maturity ogive was not revised during the WKNSEA 2021 benchmark.

Table 1: Sole 27.7d maturity ogive

Age	0	1	2	3	4	5	6	7	8	9	10	11(+)
Maturity	0.00	0.00	0.53	0.92	0.96	0.97	1.00	1.00	1.00	1.00	1.00	1.00

2.2.4 Proportion mortality before spawning

Both the proportion of natural mortality before spawning (Mprop) and the proportion of fishing mortality before spawning (Fprop) are set to 0.

2.3 Indices of abundance

The assessment of sole in the eastern English Channel is calibrated with three scientific survey (UK(E&W)-BTS-Q3, UK-YFS and FRA-YFS) and three commercial tuning series (FRA-COTB, UK-CBT and BE-CBT).

2.3.1 Survey tuning fleets

The scientific survey indices were not revised during this benchmark. All three surveys occur in the third quarter. The indices were included as age-structured fleets, with the UK BTS (1989-2019) from age1-6 (no plusgroup) and the UK YFS (1987-2006) and FRA YFS (1987-2019) only including age 1 (Figure 5 and 6).

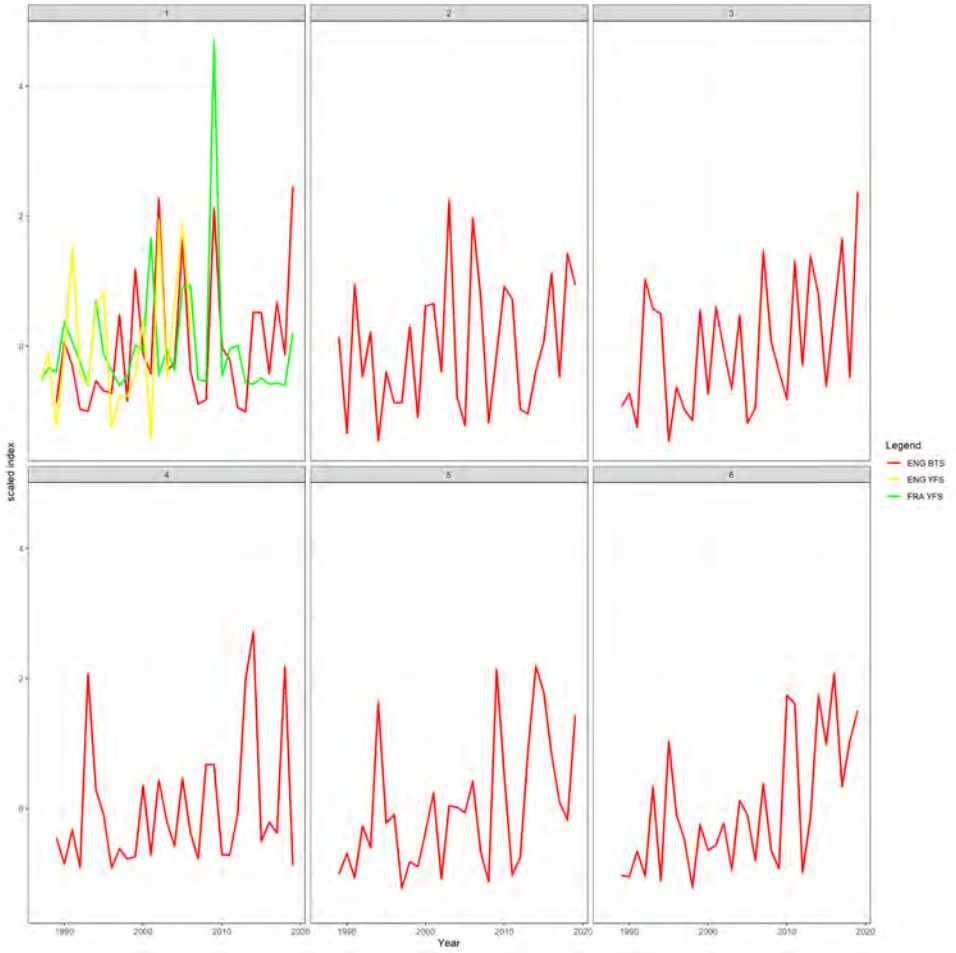


Figure 5: Scaled survey indices at age with UK (E&W) BTS (red), UK YFS (yellow) and FRA YFS (green).

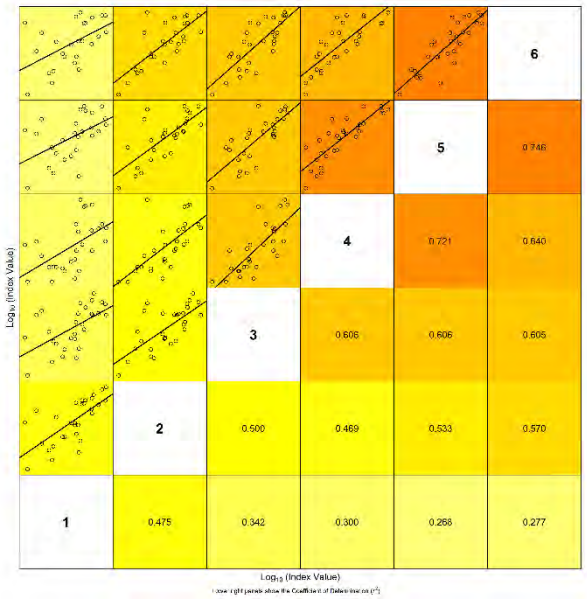


Figure 6: Internal consistency plot of the UK (E&W) BTS.

2.3.2 Commercial tuning fleets

During the 2019 IBP, the UK commercial beam trawl tuning fleet (UK-CBT) was substantially revised due to changes in the UK database (Figure 7). During this WKNSEA 2021 benchmark, the BE-CBT and FR-COBT were revised (Figure 7). For both tuning series, a model-based approach is applied, which accounts better for sources of variation other than changes in abundance and therefore reflects the fishable biomass of the stock.

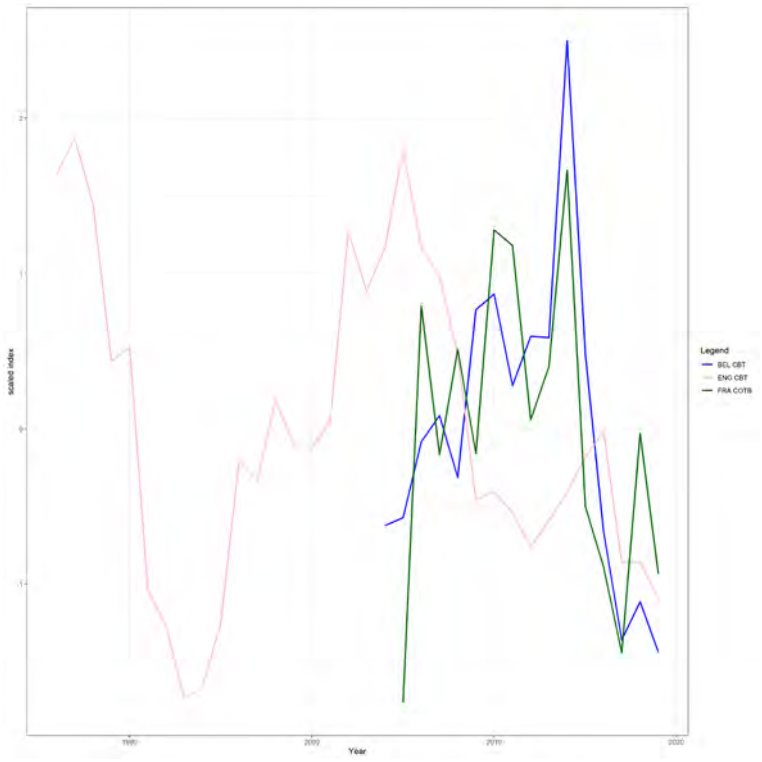


Figure 7: Scaled commercial tuning indices with BEL CBT (blue), ENG CBT (pink), FRA COTB (green).

3. XSA model

3.1 Differences in input data

First, the XSA model was used to run the assessment with the new input data (see above). However, the commercial tuning fleets needed to be inserted as age-structured indices (Figure 8 and 10). The new French COTB fleet was not available as an age-structured index (Figure 9). Consequently, the old index, as included in the WGNSSK 2020 assessment, is used.

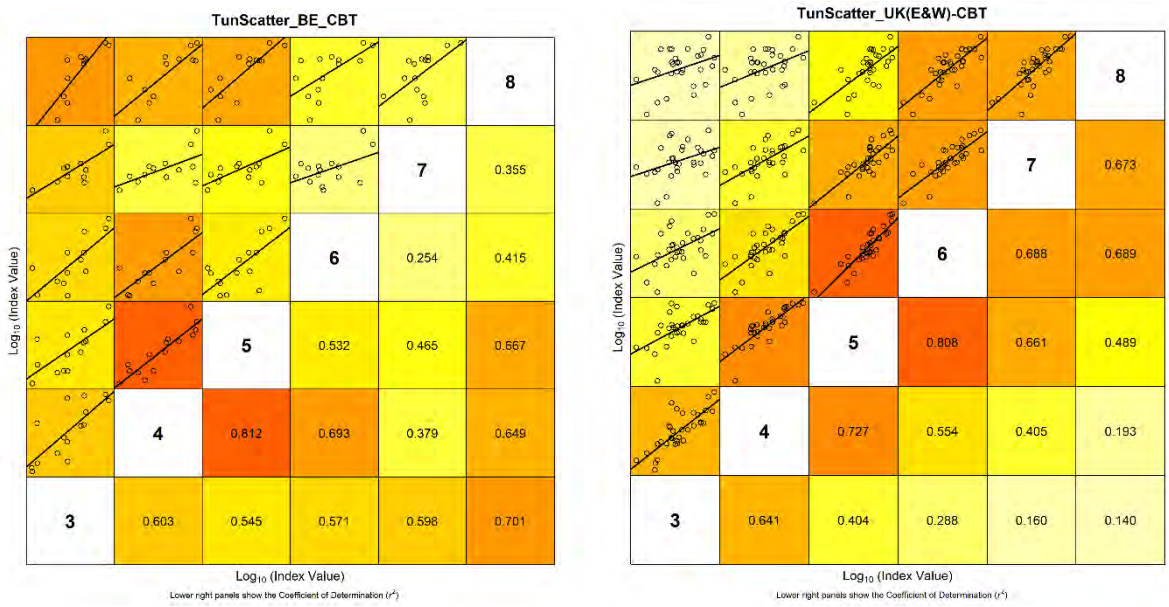


Figure 8: Internal consistency plots for age-structured commercial indices (left: new Belgian CBT, right: UK CBT).

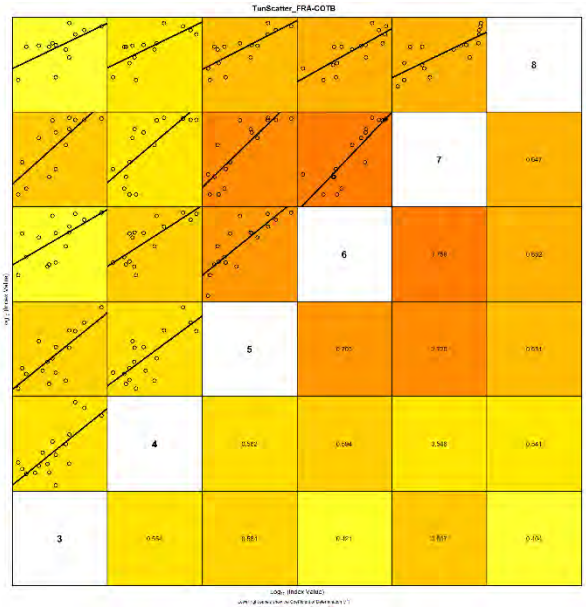


Figure 9: Internal consistency plot of the old age-structured French commercial otter trawl index (FRA COTB).

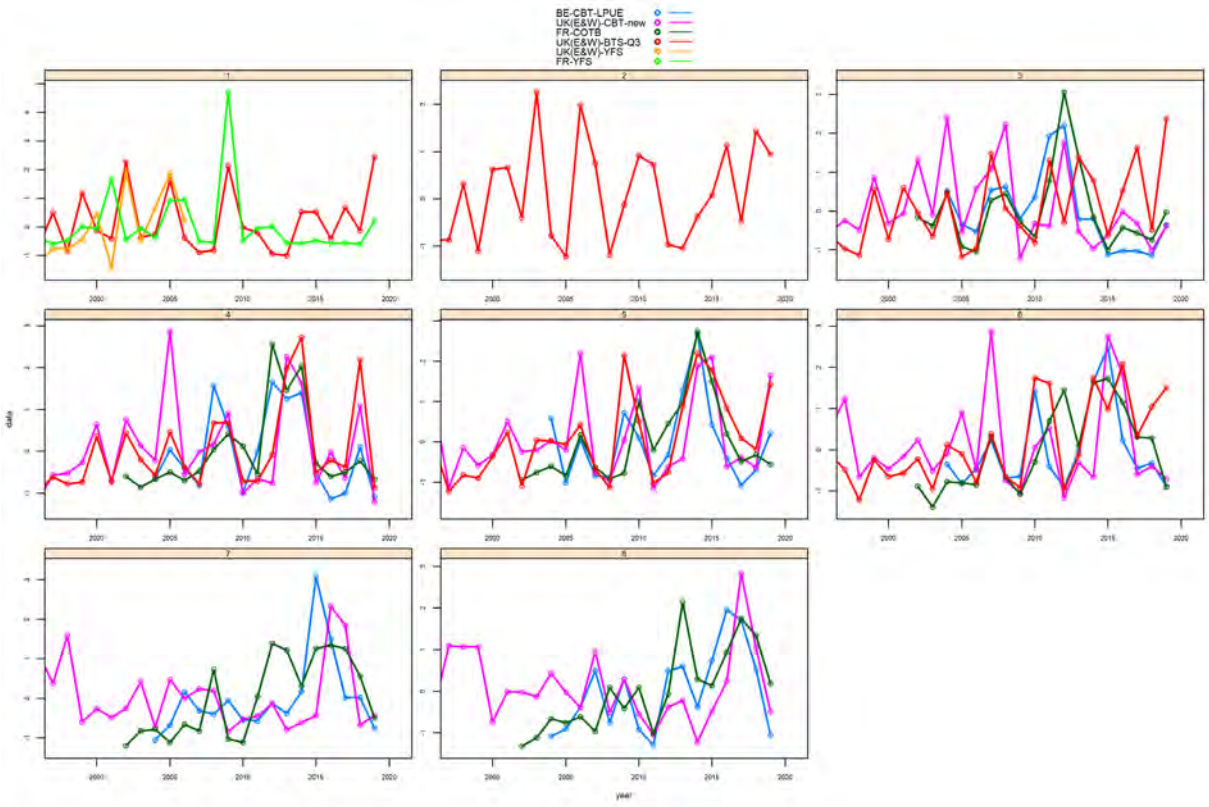


Figure 10: Similarity plot of the age-structured tuning fleets in the XSA assessment. Note in the XSA assessment, the old age-structured French commercial otter trawl index (FRA COTB) was used.

3.2 XSA model configuration

	2020 ASSESSMENT		
	Years	Ages	α-β
Commercial tuning fleets:			
new BE_CBT	04–19	3–8	0–1
FR_COT commercial	02–19	3–8	0–1
new UK(E&W)_CBT commercial	86–19	3–8	0–1
Survey tuning fleets:			
UK(E&W)_BTS survey	89–19	1–6	0.5–0.75
UK_YFS survey	87–06	1–1	0.5–0.75
FR_YFS survey	87–19	1–1	0.5–0.75

First data year	1982
Last data year	2019
First age	1
Last age	11+
Fbar	3-7
Time series weights	None
Model	No Power model
Q plateau set at age	7
Survivors estimates shrunk towards mean F	5 years / 5 ages
s.e. of the means	2.0

Min s.e. for pop. Estimates	0.3
Prior weighting	None

3.3 XSA model output

The summary of the XSA model output is shown in Figure 11 where a comparison is made with the last assessment as presented during WGNSSK 2020. The revision of the catch data is clear, showing lower catches in the most recent part of the time series. Spawning stock biomass (SSB) is generally higher for the entire time series compared to the previous assessment. However, in the most recent years it is substantially lower, while fishing mortality is estimated slightly higher in those years. Recruitment was estimated quite similarly also confirming the very large recruitment in 2019.

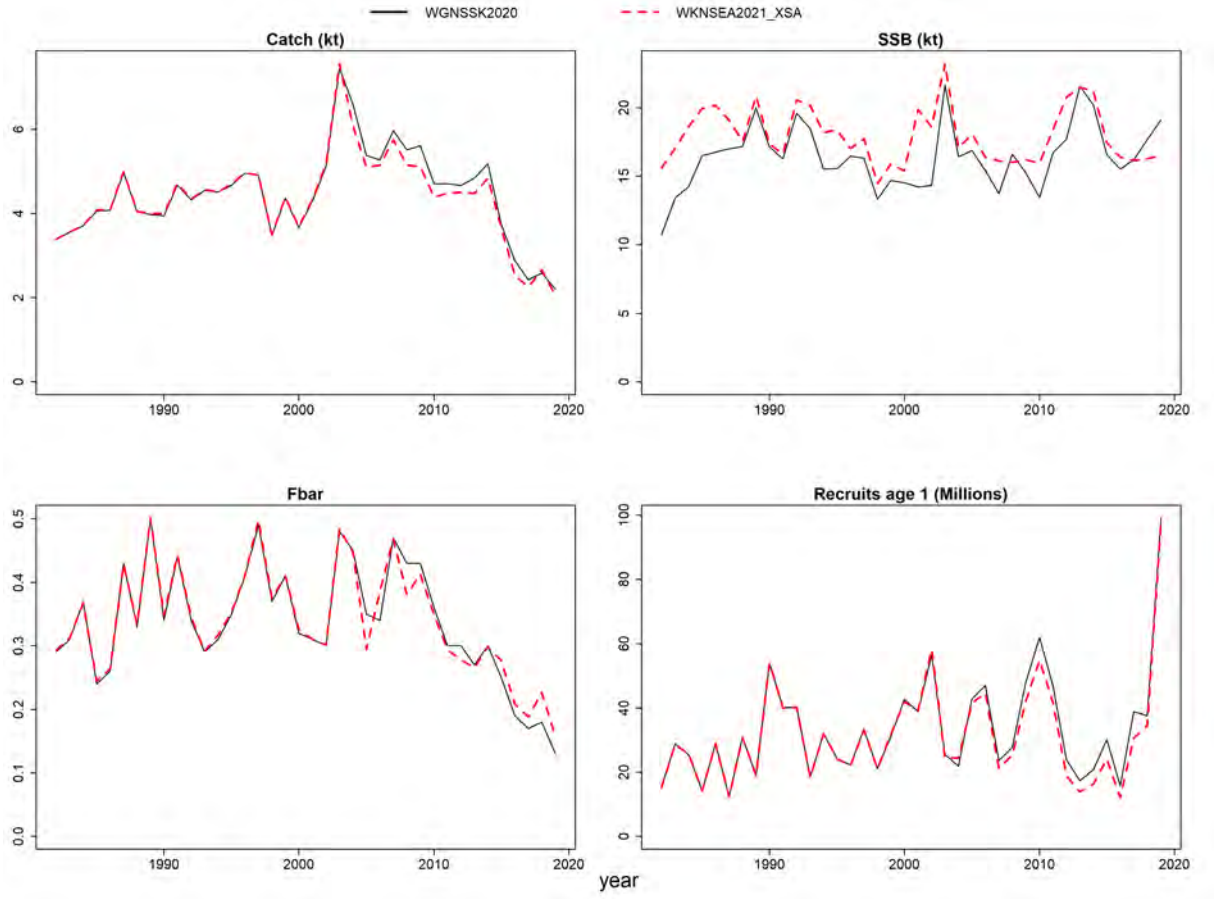


Figure 11: Comparison of the summary plots between the WGNSSK 2020 assessment and the WKNSEA 2021 XSA assessment.

Fishing mortality at age shows a strong decline for all ages (except age 1) over the last 15 years (Figure 12).

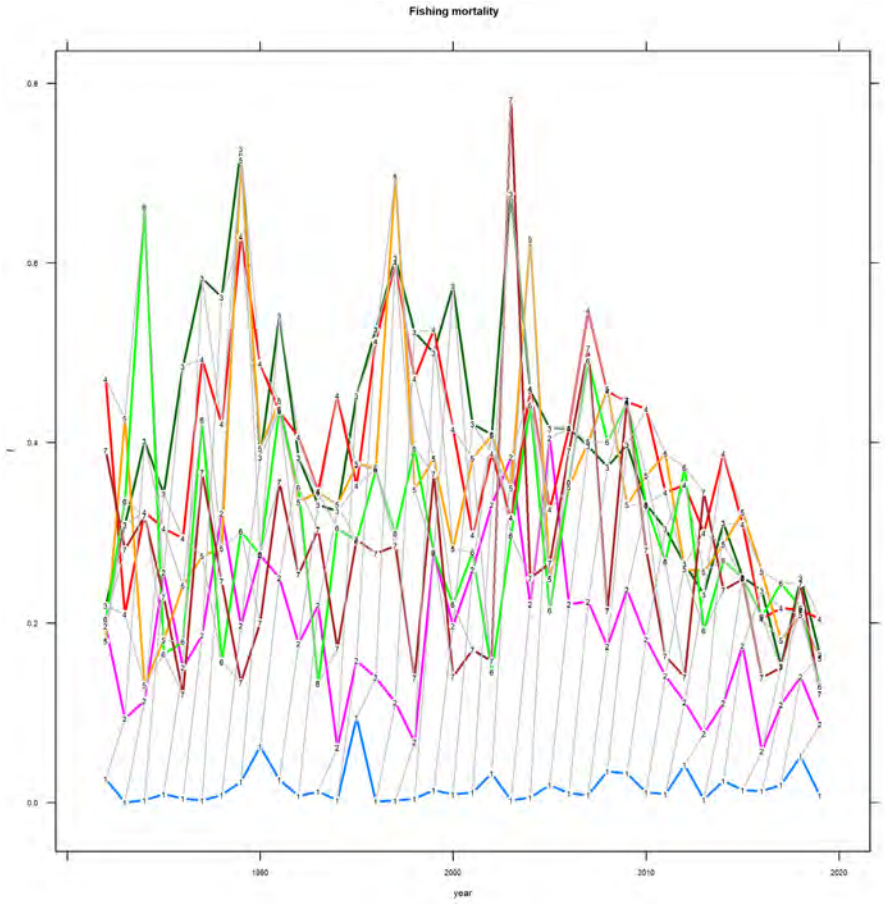


Figure 12: Fishing mortality at age (age 1-7) as estimated by the WKNSEA 2021 XSA assessment.

3.4 XSA model validation

The catchability residuals for the tuning fleet show patterns across ages and years for certain indices (Figure 13). The UK BTS shows positive residuals over the last 5 years for ages 1-3. A pattern across years is also visible for the French YFS survey. Although all commercial tuning fleets show small residuals, there are some patterns across ages for certain periods present in the UK CBT index.

There appears to be no apparent retrospective bias (Figure 14). Recruitment estimates are most uncertain. Mohn's Rho calculations for SSB, Mean F and Recruits were 0.172, -0.145 and 0.114 respectively, which are all within acceptable limits.

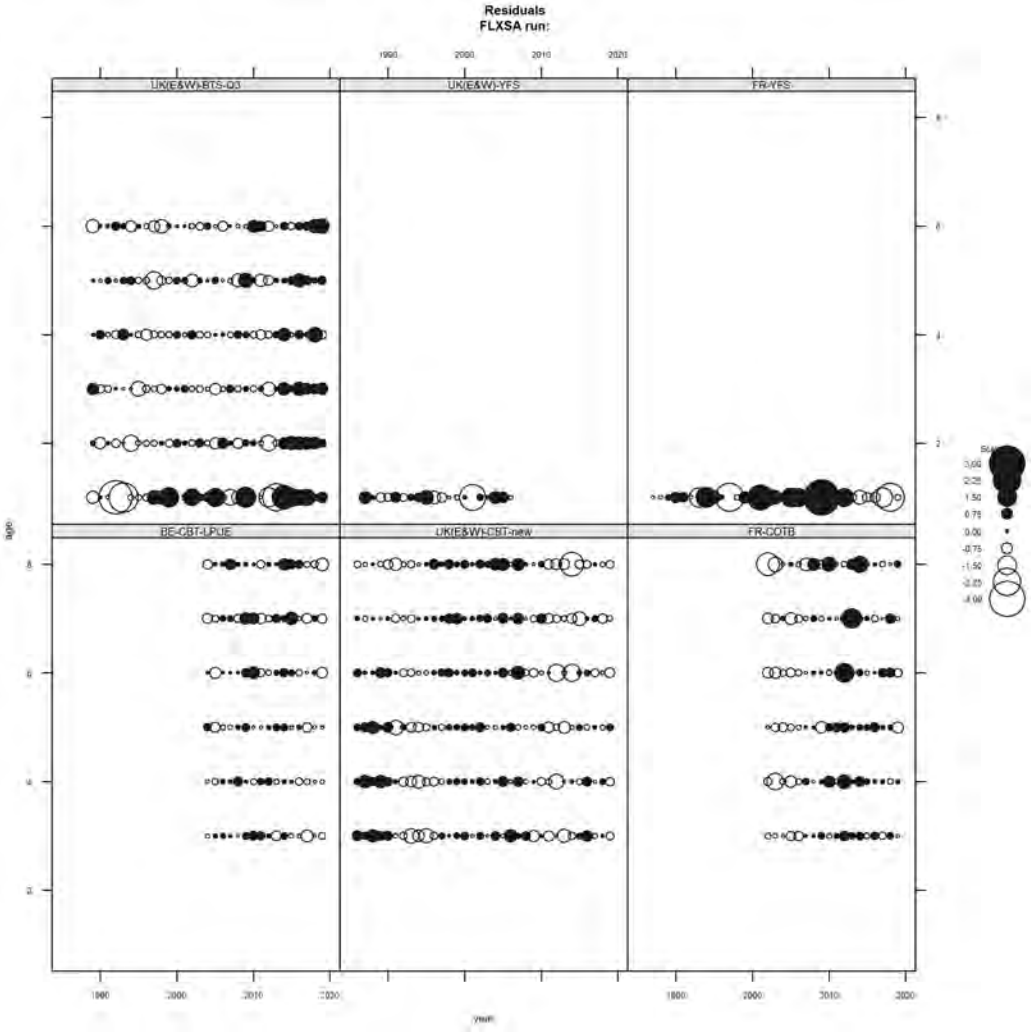


Figure 13: Catchability residuals of the tuning series from the XSA model.

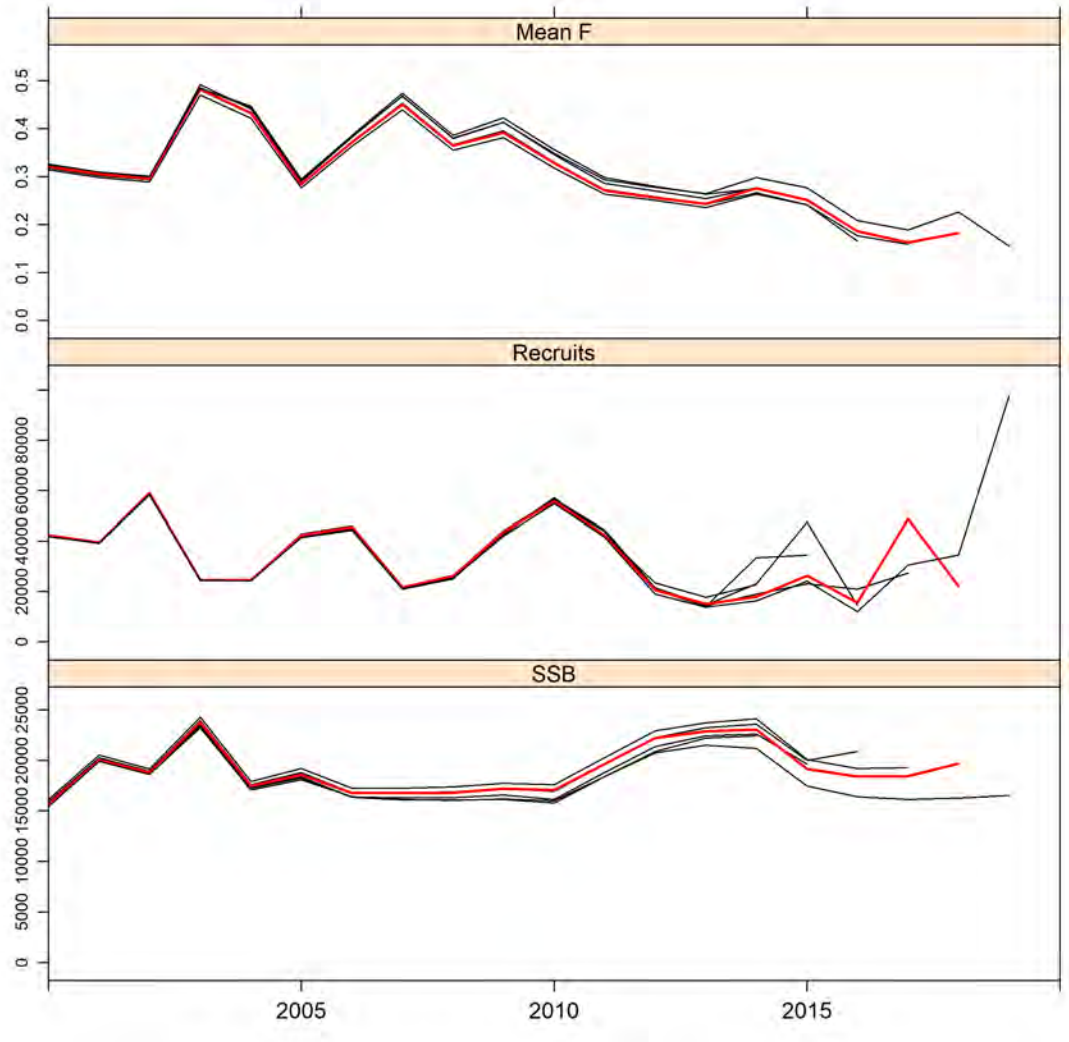


Figure 14: Retrospective pattern from the XSA model.

4. State space assessment (SAM) models

4.1 SAM versus XSA

The applicability of the XSA framework to the sole 27.7.d stock was questioned for the following assumptions/limitations:

- XSA assumes that catch data is known without error (no observation model for the catch data), which is highly unlikely because for instance only a subsample of the catch numbers-at-age is observed or misreporting of landings by fishers may occur.
- XSA requires that tuning fleets are age-structured, which results in a double use of the catch-at-age information in the model, thereby down weighing the information from other data sources.
- XSA cannot handle missing data in catch or tuning series and requires to make assumptions on missing observations.

To overcome these shortcomings, the applicability of a state-space stock assessment model (SAM) was explored during the benchmark. This was done by using the *stockassessment* package which enables to interface a performant implementation of SAM (https://github.com/fishfollower/SAM/) in

Template Model Builder (TMB)[1] from the R statistical software. In addition, the *stockassessment* package contains a vast set of tools to evaluate/validate state space models.

The main feature of SAM is that it includes both process models on survival, recruitment and fishing mortality (describing the internal states of the system), and observation models for catch and tuning data. Additionally, tuning data can be introduced as biomass fleets, e.g. as *SSB (spawning stock biomass), TSB (total stock biomass) or FSB (fishable biomass).* The random effects formulation of the process models resulting from the hierarchical nature of the state-space modelling framework can easily be used to handle missing observations. Finally, SAM allows to specify different model configurations, and parametrization of both process and observation models.

4.2 SAM model configurations

Table 2 and 3 show the different configurations of the SAM runs that were conducted during the WKNSEA 2021 benchmark. A first SAM model (RUN 1) was configured to mimic the settings of the XSA model that is currently used to assess the sole 7d stock as much as possible. Next, this model was adjusted by transforming the age-structured commercial tuning series into an SSB index (RUN 2; RUN 3) with an autoregressive correlation structure on the F-at-age process. RUN 2 and RUN 3 differ in terms of model configuration. More specifically, the number of variance parameters on the age-structured observations, and the correlation structure on the age-structured observations. RUN 4, RUN 5, and RUN 6 relax the correlation structure on the F-at-age process, and include additional variance parameters for the observations related to age 1, and age 2 (RUN 6). These models also differ with respect to the selectivity assumptions of the commercial tuning series. In RUN 4, the commercial tuning series are assumed to mimic the SSB trend, whereas in RUN 5 and RUN 6, the commercial tuning fleets are assumed to follow the selectivity of the entire fishery as estimated by the model. Finally, a run - with similar model configuration as RUN 6 - is presented in which the three commercial tuning fleets are combined into a single tuning fleet weighted by area (RUN 7).

All runs have a 'second name' which was used in the presentations during the benchmark (e.g. RUN 1 was referred to as 'Baserun'). To allow comparison with this working document and the presentations, we retained these second names in Table 2 and 3.

Table 2: Overview of the data used in the different SAM runs.

	Plusgroup	dn	dw	ln	lw	cn	cw	sw	mo	nm	pf	pm
RUN 1 Baserun	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 2 Run2	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 3 Run2b	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 4 Run4	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 5 Run4bis	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 6 Run4tris	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0
RUN 7 Run5e	11	sop corr	ratio	sop corr	ok	sop corr	ok	reconstr	ogive 2017	0.1	0	0

[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 non-linear optimization procedures is achieved through the use of AUTODIFF (automatic differentiation), and performant C libraries for linear algebra (Eigen).

Table 3: Overview of the model settings applied in the different SAM runs.

	catch /tuning data	tuning info	variance parameters observations (keyVarObs)	correlation on observations (obsCorStruct)	correlation age coupling parameters (keyCorObs)	correlation F-at-age (corFlag)	F-at-age parameters (keyLogFsta)	Process variance logF (keyVarF)	Process variance logN (keyVarLogN)	$logN_1$	AIC
RUN 1 (Baserun)	catch	/	$\sigma_{1\text{-}11}$	ID	/	ID	$F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	1678
	UK-BTS	age 1-6	$\sigma_{1\text{-}6}$	ID	/						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	age 3-8	$\sigma_{3\text{-}8}$	ID	/						
	BE-CBT	age 3-8	$\sigma_{3\text{-}8}$	ID	/						
	FR-COBT	age 3-8	$\sigma_{3\text{-}8}$	ID	/						
RUn 2 (Run 2)	catch	/	$\sigma_1; \sigma_{2\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	AR	$F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	894
	UK-BTS	age 1-6	$\sigma_1; \sigma_{2\text{-}6}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}6}$						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	SSB	σ_{SSB}	ID	/						
	BE-CBT	SSB	σ_{SSB}	ID	/						
	FR-COBT	SSB	σ_{SSB}	ID	/						
RUN 3 (Run2bis)	catch	/	$\sigma_{1\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	AR	$F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	1007
	UK-BTS	age 1-6	$\sigma_1; \sigma_{2\text{-}6}$	ID	/						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	SSB	σ_{SSB}	ID	/						
	BE-CBT	SSB	σ_{SSB}	ID	/						
	FR-COBT	SSB	σ_{SSB}	ID	/						
RUN 4 (Run4)	catch	/	$\sigma_{1\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	ID	$F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	926
	UK-BTS	age 1-6	$\sigma_1; \sigma_{2\text{-}6}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}6}$						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	SSB	σ_{SSB}	ID	/						
	BE-CBT	SSB	σ_{SSB}	ID	/						
	FR-COBT	SSB	σ_{SSB}	ID	/						
RUN 5 (Run4bis)	catch	/	$\sigma_{1\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	ID	$F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	931
	UK-BTS	age 1-6	$\sigma_1; \sigma_{2\text{-}6}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}6}$						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	FSB	σ_{FSB}	ID	/						
	BE-CBT	FSB	σ_{FSB}	ID	/						
	FR-COBT	FSB	σ_{FSB}	ID	/						
RUN 6 (Run4tris)	catch	/	$\sigma_1; \sigma_2$; $\sigma_{3\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	ID	$F_1, F_2, F_3, F_4, F_5, F_{6\text{-}7}, F_{8\text{-}9}, F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	$\sigma_{N_1}, \sigma_{N_2\text{-}11}$	RW	921
	UK-BTS	age 1-6	$\sigma_1; \sigma_2$; $\sigma_{3\text{-}6}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}6}$						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	UK-CBT	FSB	σ_{FSB}	ID	/						

RUN 7 (Run5e)	BE-CBT	FSB	σ_{FSB}	ID	/						
	FR-COBT	FSB	σ_{FSB}	ID	/						
	catch	/	σ_1; σ_2 ; $\sigma_{3\text{-}11}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}11}$	ID	F_1, F_2, F_3, F_4, F_5, $F_{6\text{-}7}$, $F_{8\text{-}9}$, $F_{10\text{-}11}$	$\sigma_{F_1\text{-}11}$	σ_{N_1}, $\sigma_{N_2\text{-}11}$	RW	902
	UK-BTS	age 1-6	σ_1; σ_2 ; $\sigma_{3\text{-}6}$	AR	$\rho_{1\text{-}2}$; $\rho_{2\text{-}6}$						
	UK-YFS	age 1	σ_1	ID	/						
	FR-YFS	age 1	σ_1	ID	/						
	comb	FSB	σ_{FSB}	ID	/						

4.3 SAM model: Run 1

4.3.1 Model output

The model estimates that the SSB ranged between 10000 and 20000 tonnes during the period 1982-2019 (Figure 15). In the most recent years, the SSB of the sole 7d stock is estimated to be at one of its lowest levels since the start of the observations. The catches predicted by SAM corroborate with the observed catches, except for the period 1995-2000 where SAM estimates the catches to be significantly lower in some years. In the final years of the assessment, the estimated catches are higher than the observed catches.

The fishing mortality (Fbar) remained rather stable over time with values ranging between ~0.3 and ~0.44 (Figure 15). Since 2005, Fbar has declined gradually, from ~0.44, to ~0.3 in 2019, the lowest level of the time series. The recruitment (age 1) is estimated to range between 10000 and 60000 individuals, and does not show clear trends over time except of a number of good recruitment events during the years 2000 (including 2019).

The fishing mortality-at-age shows that the age 1 group is hardly caught by the fishery (Figure 16), which is in strong contrast with all other age groups. The highest fishing mortality is exerted on age groups 3 to 7. Nevertheless, the F-at-age shows that the selectivity of the fishery changed remarkably over time. Before 2005, fishing mortality was always highest for age groups 3 and 4, while in the most recent years, fishing mortality for these ages declined strongly to the level of fishing mortality for age groups 5 to 8 and lower. In contrast, the fishing mortality for ages 6 to 11(+) remained rather stable over time.

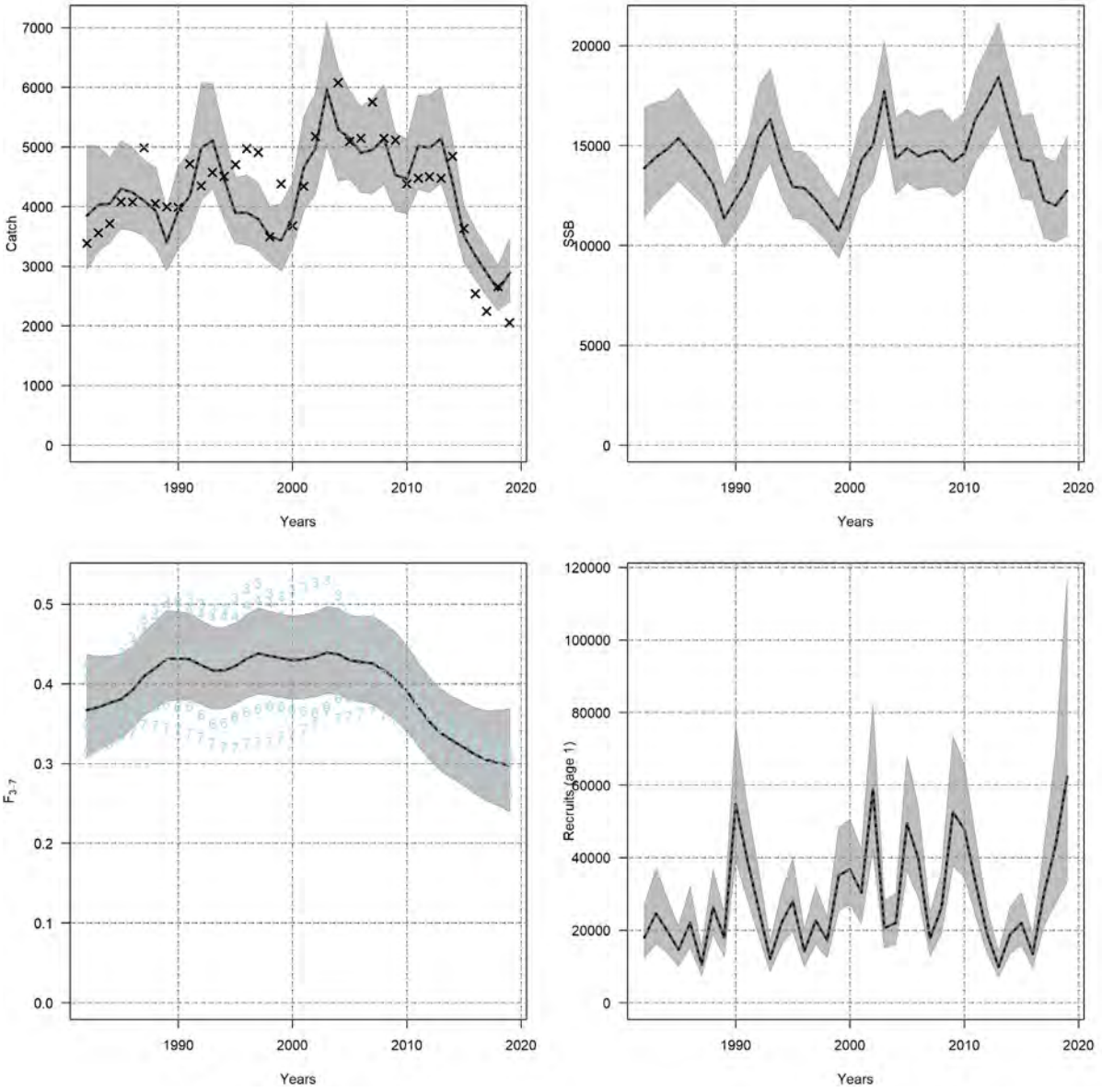


Figure 15: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

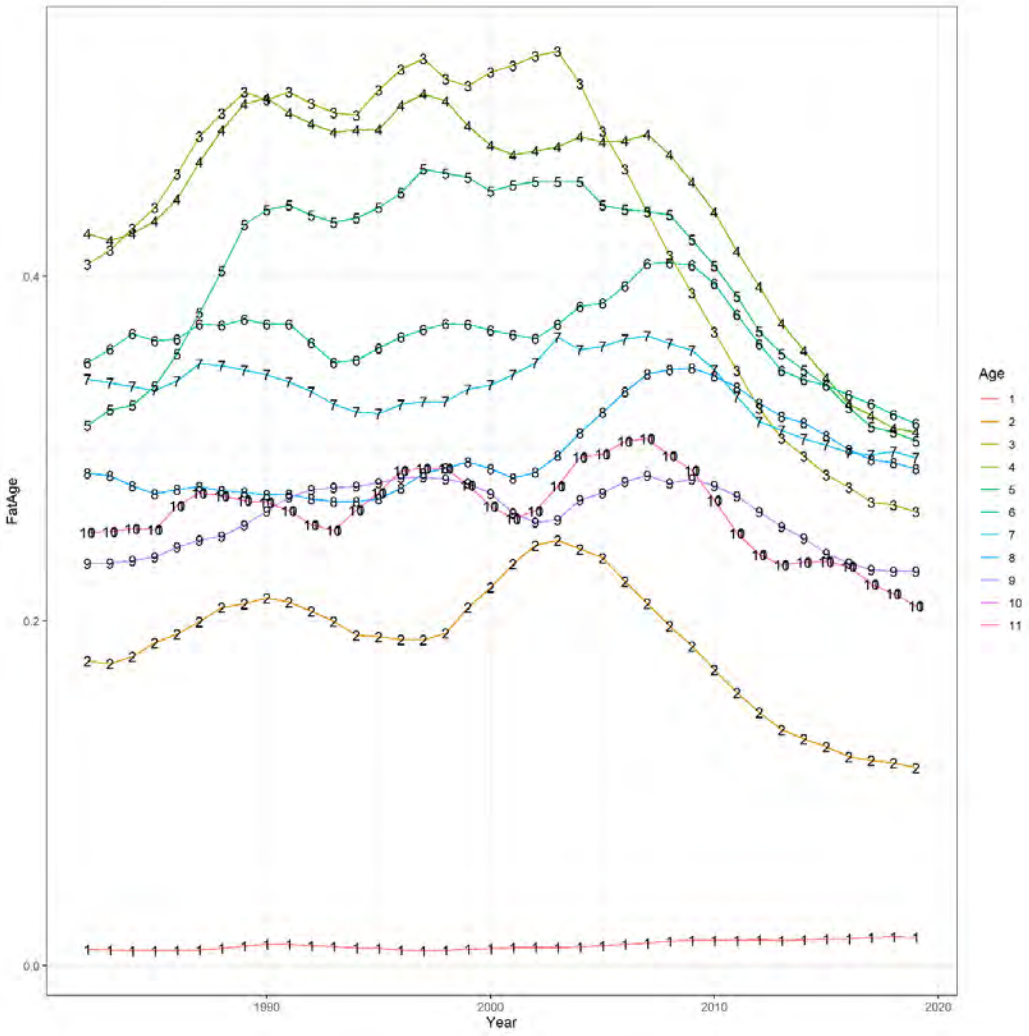


Figure 16: Fishing mortality by age group, note that age 10 and 11(+) overlap.

4.3.2 Model validation

The one step ahead residuals for the catch data do not indicate strong patterns within the ages (Figure 17). However, when comparing the residuals across the different age groups, it appears that the residuals for age 1 are larger which violates the assumption of homogeneity of variances.

The same patterns are visible in the OSA residuals for the UK-BTS data. The residuals for age 1 are larger than the residuals for ages 2 to 6. In addition, the UK-BTS data indicates a clear bias in the most recent years for all age groups. The higher magnitude of the residuals of age 1 observations is related to the model setup which has only a single variance parameter for each data stream independent from the age.

The process residuals do not indicate any problems with respect to the model configuration (Figure 18).

The retrospective analysis does not indicate large problems with the model with respect to the SSB and Fbar estimates (Figure 19). However, the retrospective analysis of the recruitment estimates performs poorer.

The leave-one-out runs show that the model is strongly dependent on the UK-CBT tuning series (Figure 20). Removing this fleet from the assessment results in a strong increase of the SSB in the most recent years, and a decline in Fbar.

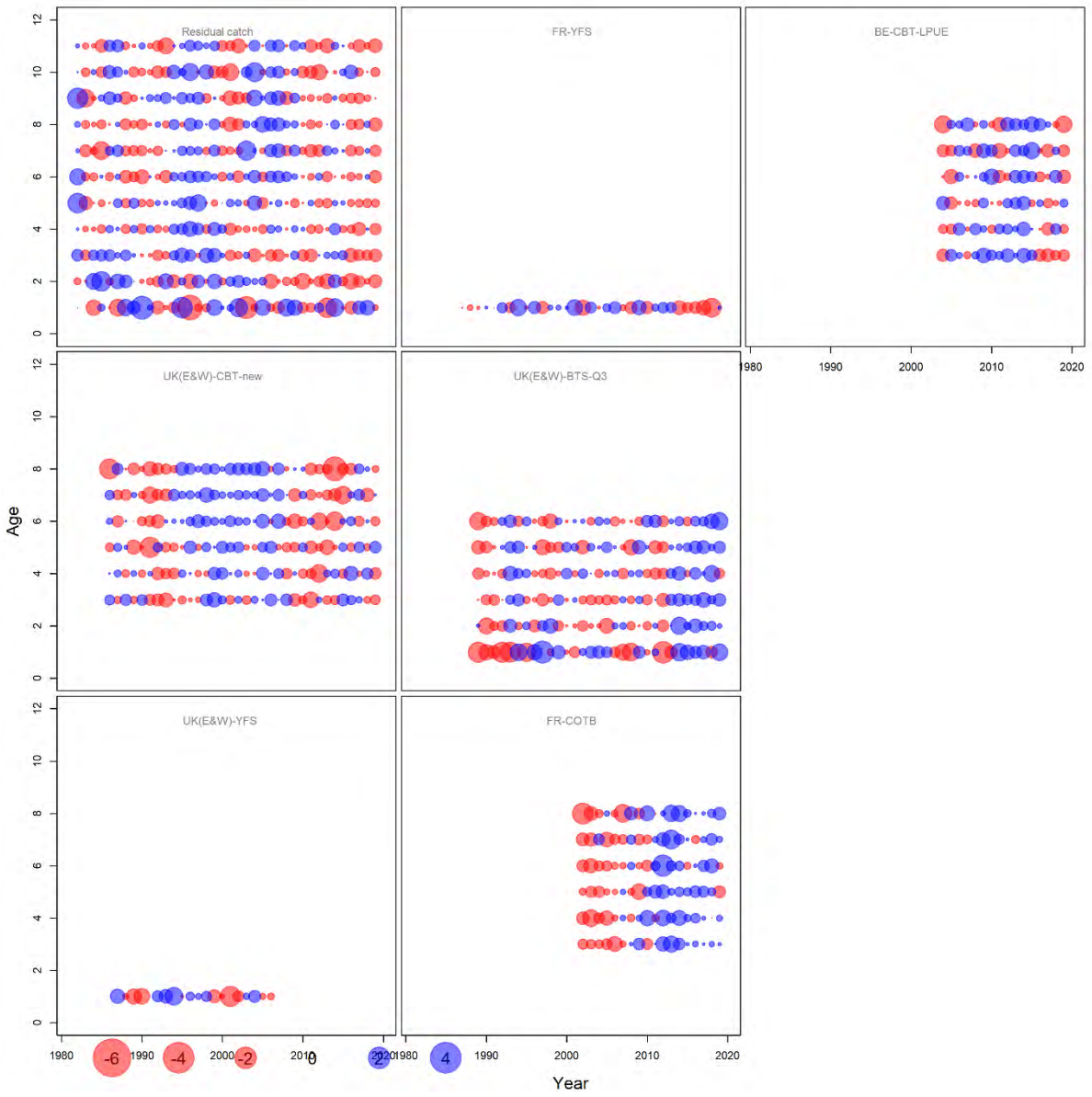


Figure 17: One-step ahead residuals by data stream.

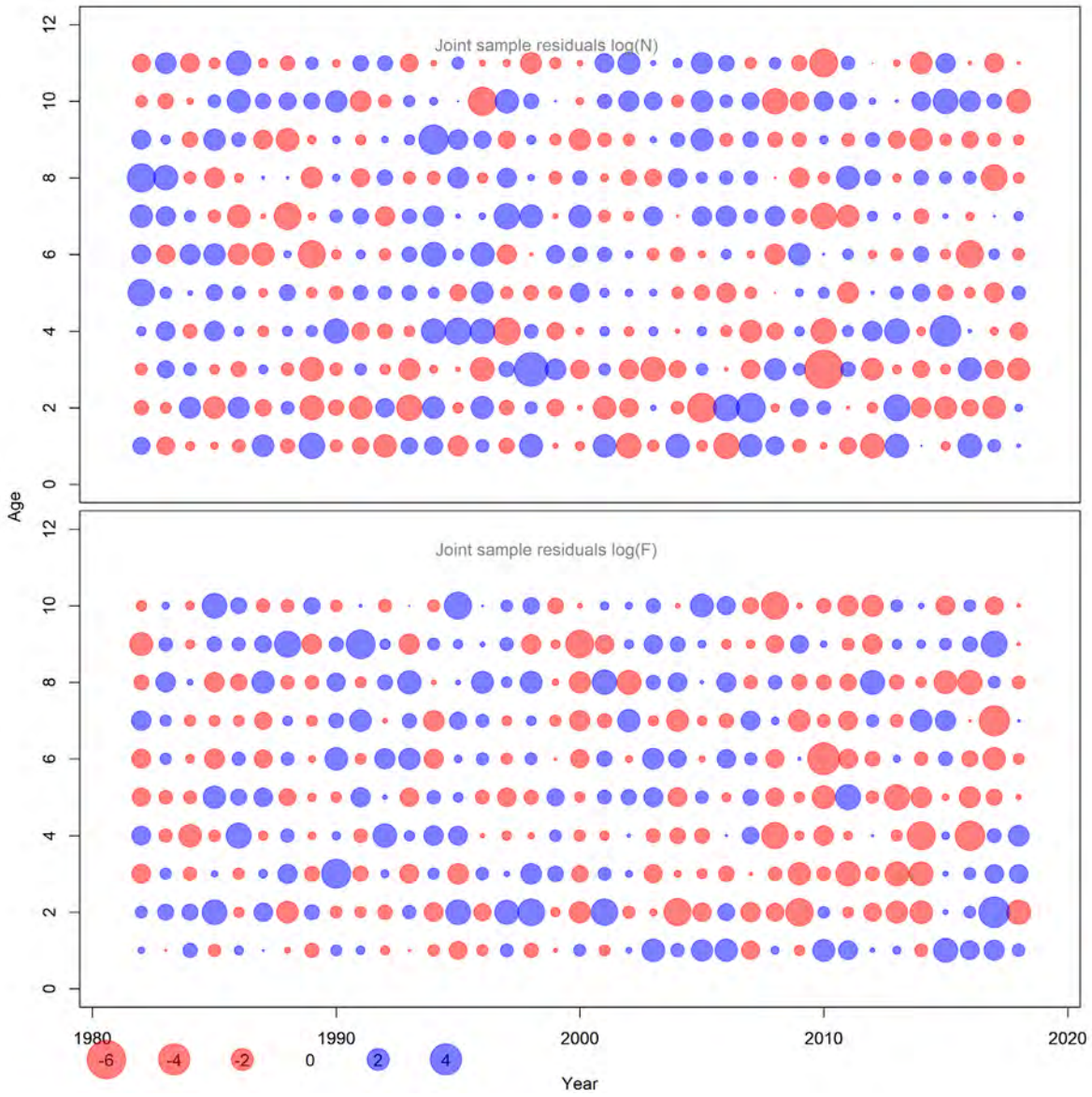


Figure 18: Process residuals for the survival (logN) and fishing mortality (logF) processes.

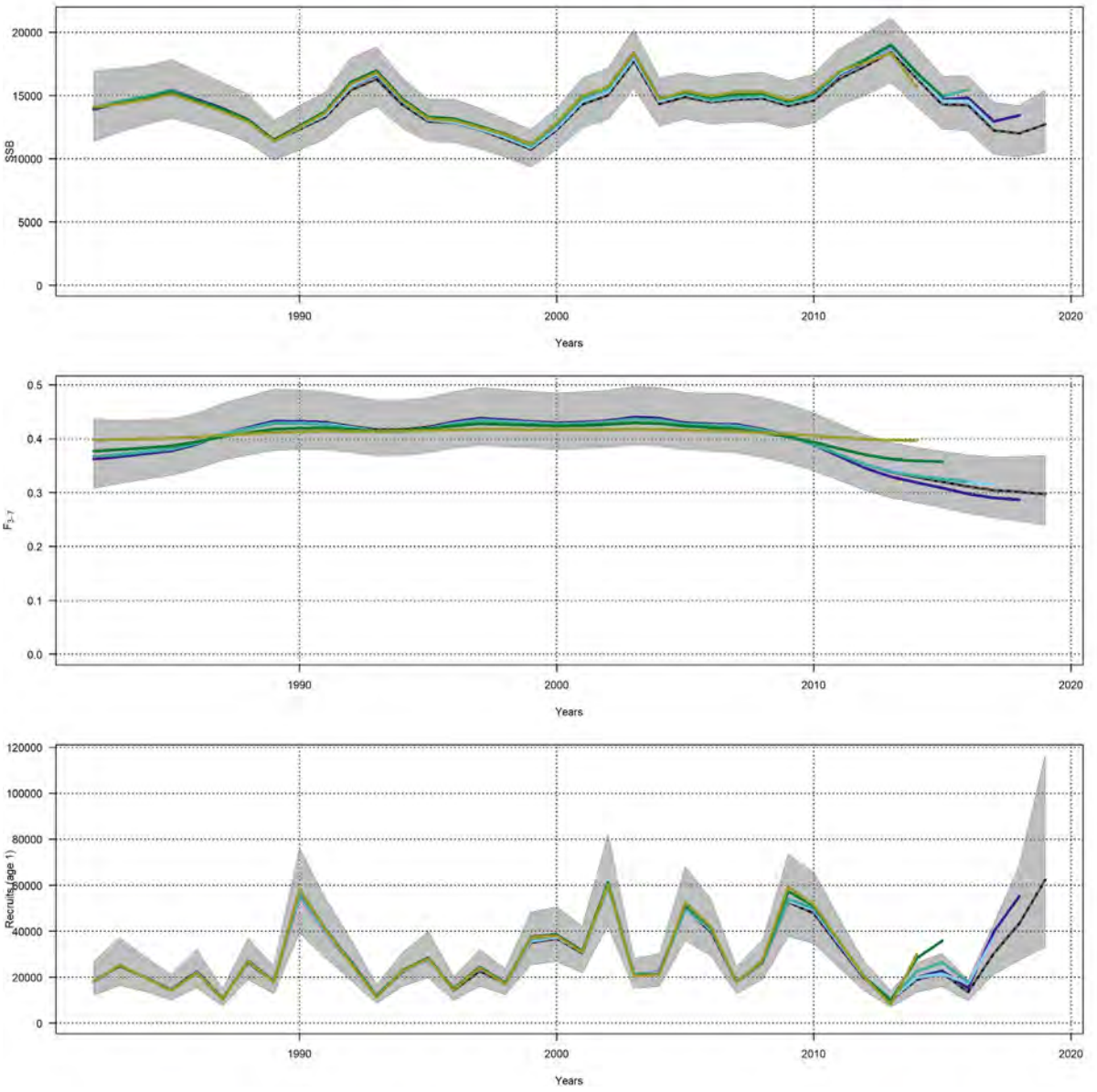


Figure 19: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.0494; ρFbar = 0.0682; ρR = 0.4081. The grey shades represent the 95% confidence intervals of the model including all data years.

.

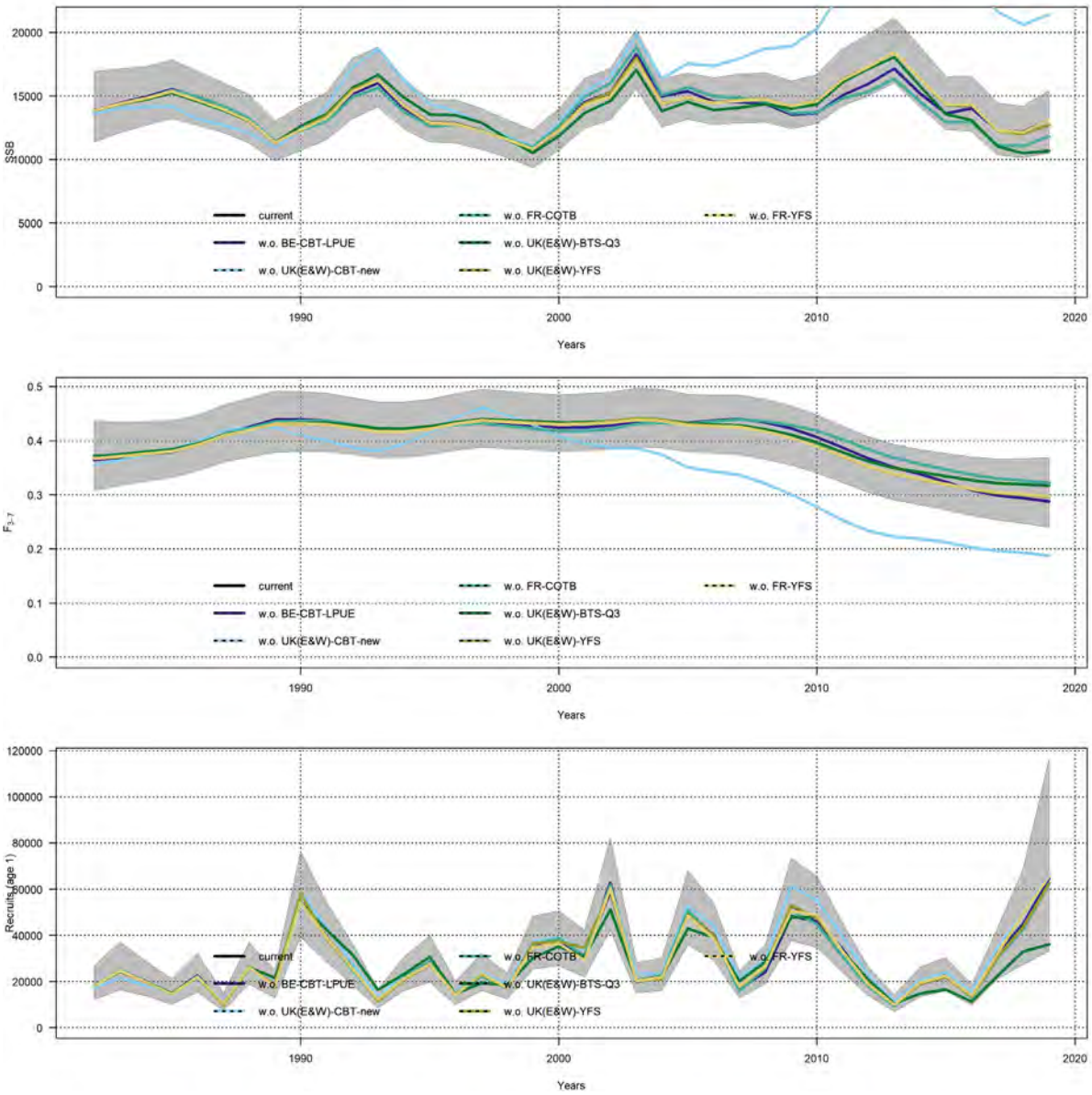


Figure 20: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.4 SAM model: Run 2

4.4.1 Model output

The trend of the SSB estimates in RUN 2 is similar to the trend observed in the SSB estimates of RUN 1 (Figure 21). In general, the SSB estimates are slightly higher in RUN 2 compared to RUN 1, but the values still range between 10000 and 20000 tonnes. According to RUN 2, SSB peaked in 2003 reaching almost 20000 tonnes, while in RUN 1 SSB was estimated to peak in 2013 (~17500 tonnes).

The higher SSB estimates are associated with a considerable drop of the Fbar (Figure 21). Compared to RUN 1, this decline starts later (2009 RUN 2 vs 2005 RUN 1), and is characterized by a steeper downwards trend with Fbar values going from ~0.5 (2009) to ~0.2 (2019) (compared to 0.5 (2005) to 0.3 (2019) in RUN_1). In addition, the trend in Fbar is much more erratic compared to RUN 1 resulting in a better fit of the catch data compared to RUN 1. The recruitment estimates are very similar to those of RUN 1 with 5 high recruitment events (~60000 individuals).

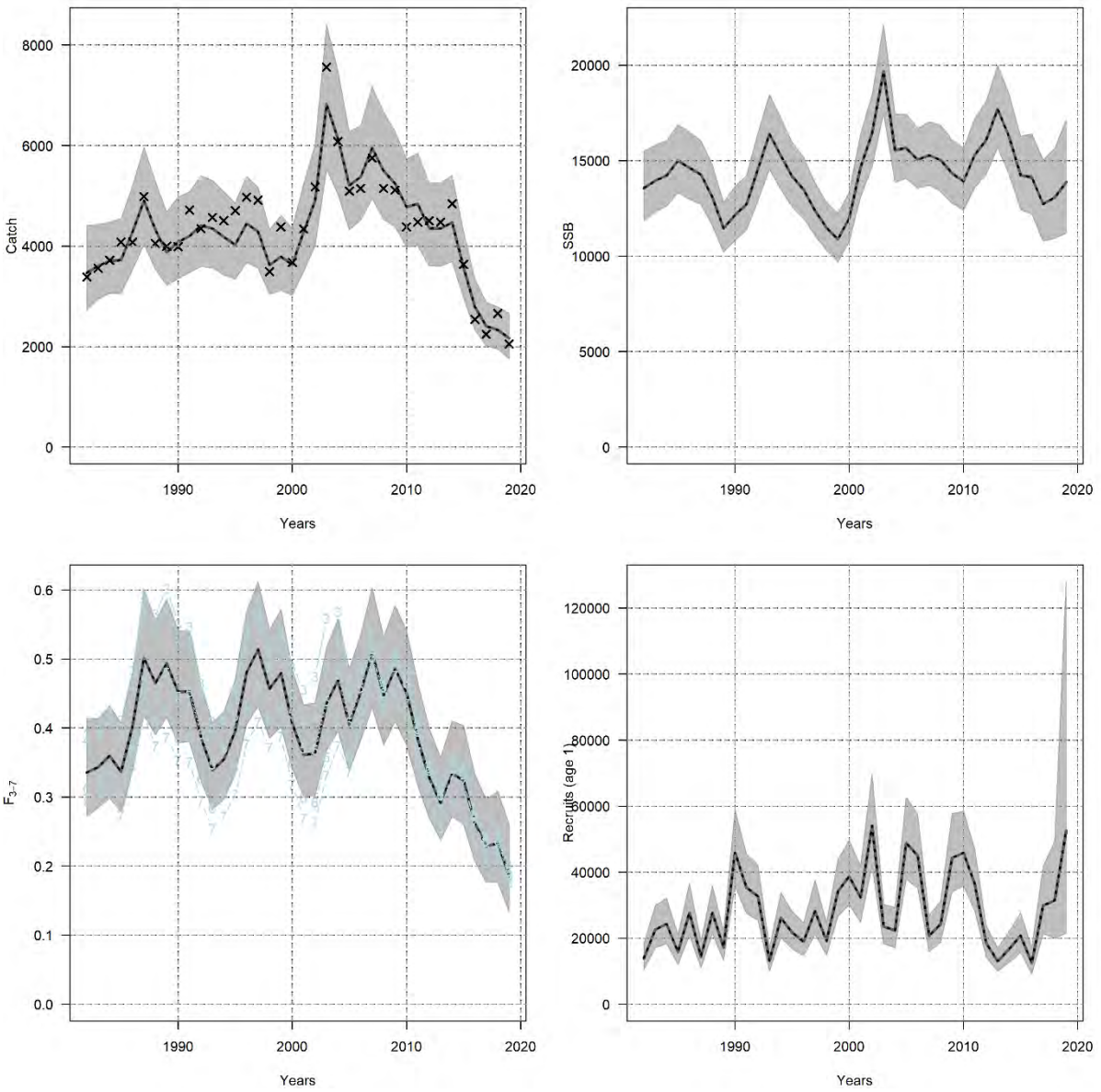


Figure 21: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

The AR correlation structure imposed on the logarithm of the fishing mortality-at-age results in major differences compared to RUN 1 (Figure 22). The F-at-age trends are strongly correlated with a declining trend for all age groups (except for age 1). Similar to RUN 1, the strongest drop is found in the fishing mortality on age groups 3 and 4. The trends in the fishing mortality of the individual ages are much more erratic compared to RUN 1.

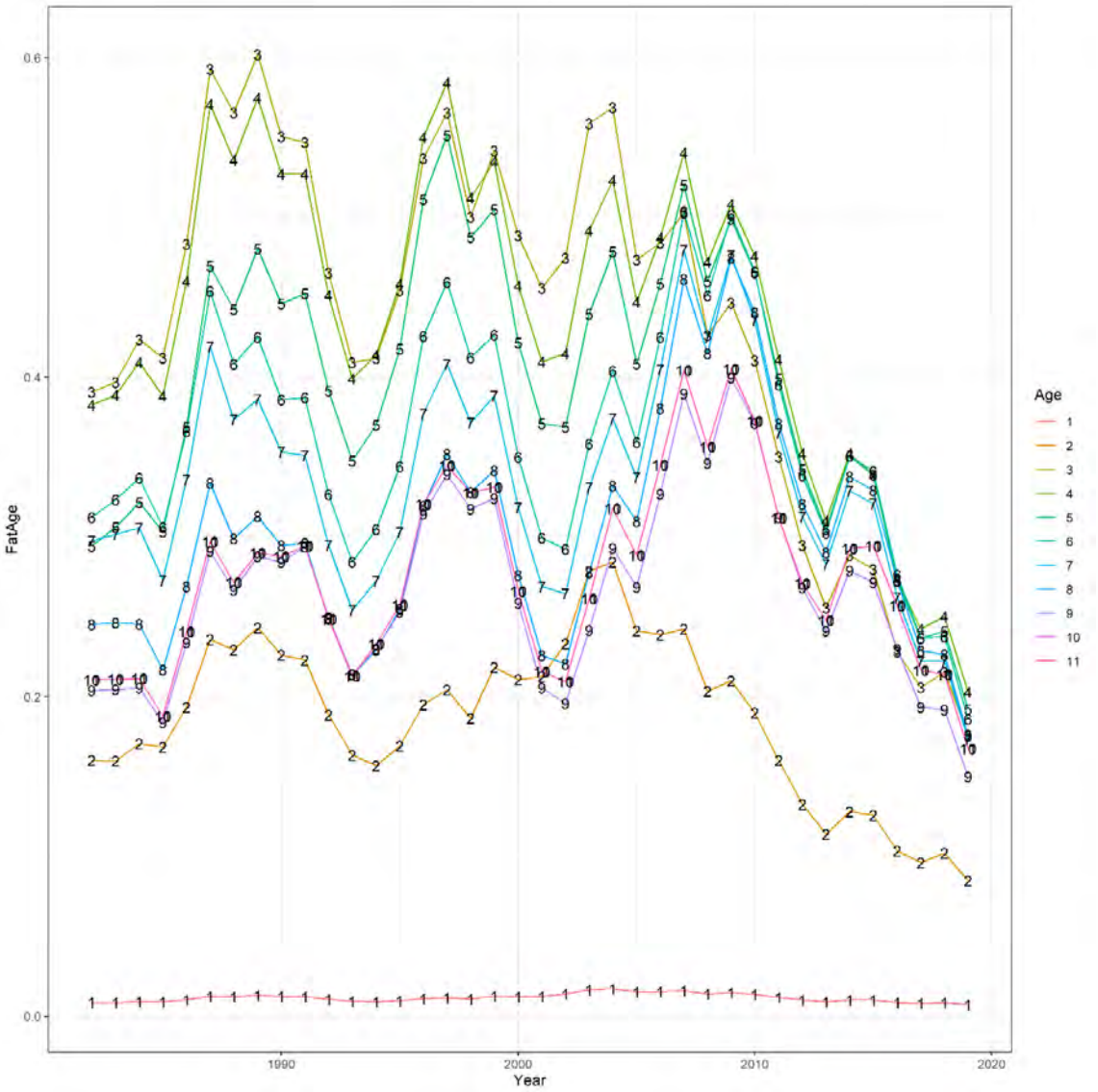


Figure 22: Fishing mortality by age group, note that age 10 and 11(+) overlap.

4.4.2 Model validation

The one step ahead residuals do not indicate major problems (Figure 23). Only for the UK-CBT tuning fleet, strong patterns in the residuals are present indicating a poor fit to the data. The process residuals do not indicate problems with respect to the process model (Figure 24).

The retrospective analysis indicates that the model tends to overestimate SSB and underestimate Fbar (Figure 25). In addition, the Mohn's rho's are higher than for RUN 1. The leave-one-out runs show that the model is strongly dependent from the UK-BTS survey (Figure 26). Removing this fleet from the assessment results in a decline of the SSB in the most recent years, and an increase in Fbar. Moreover, the leave-one-out analysis indicates problems with the stability of this model as some runs did not converge.

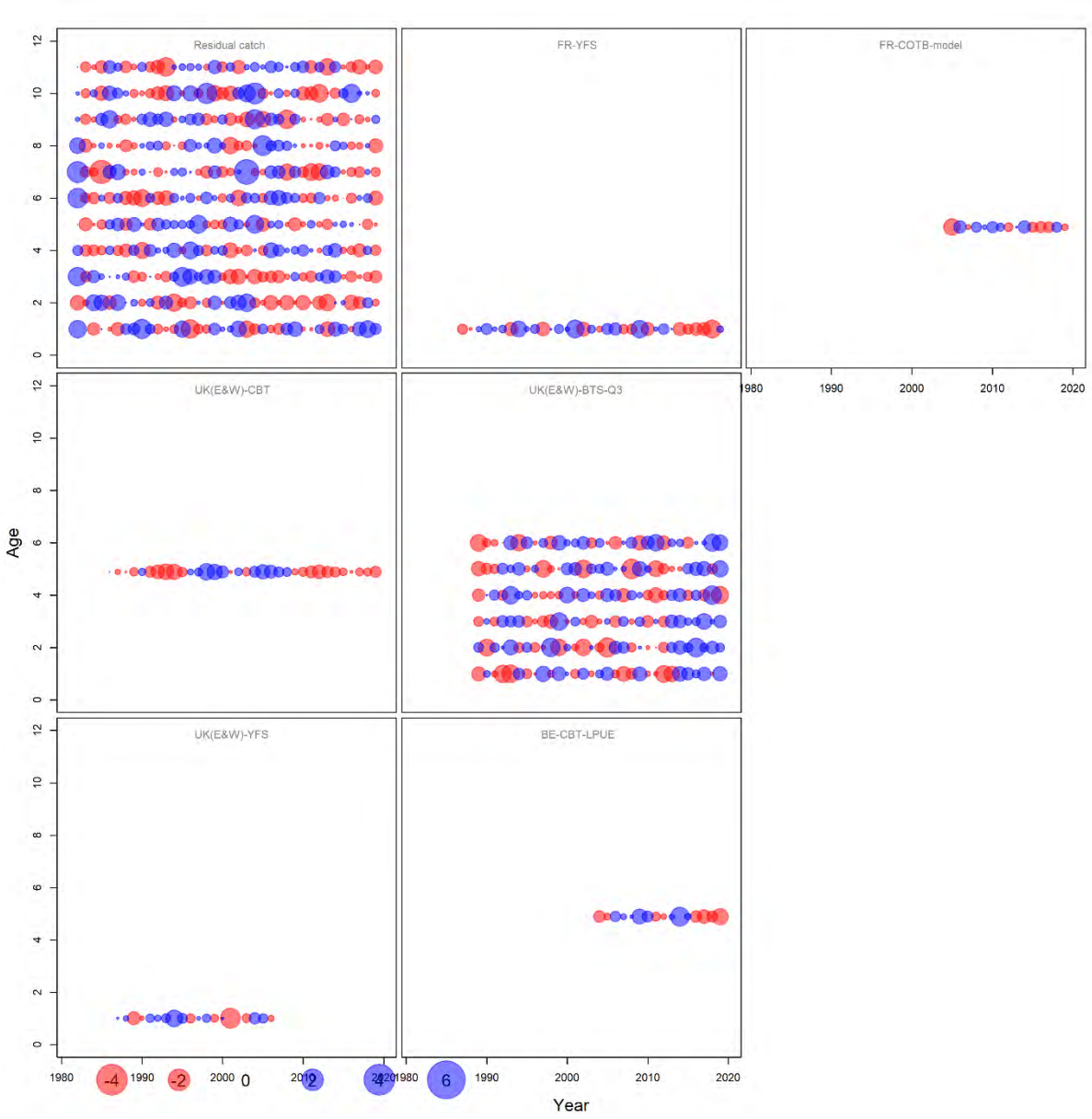


Figure 23: One-step ahead residuals by data stream.

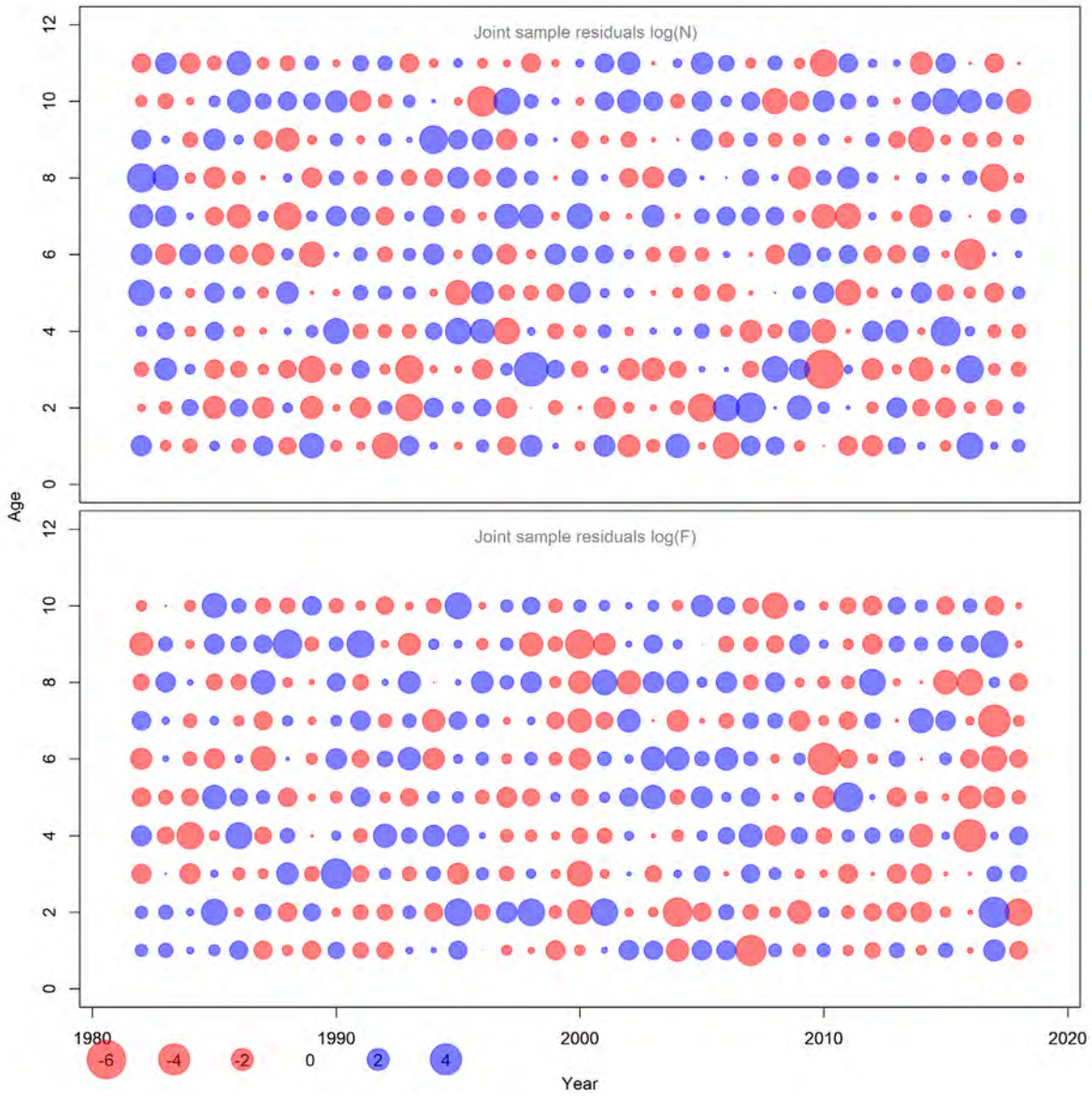


Figure 24: Process residuals for the survival (logN) and fishing mortality (logF) processes.

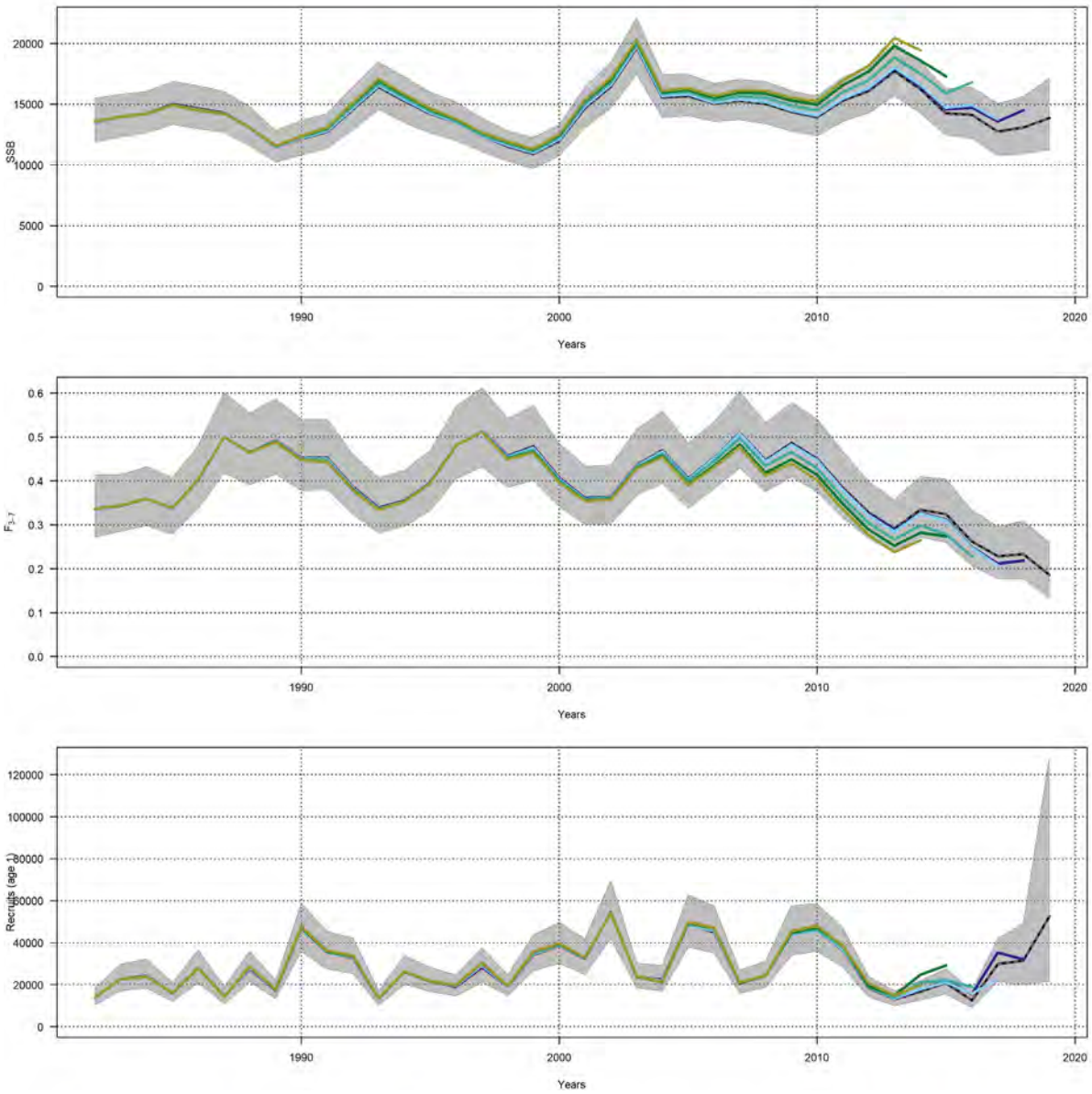


Figure 25: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.1734; ρFbar = 0.1573; ρR = -0.1298. The grey shades represent the 95% confidence intervals of the model including all data years.

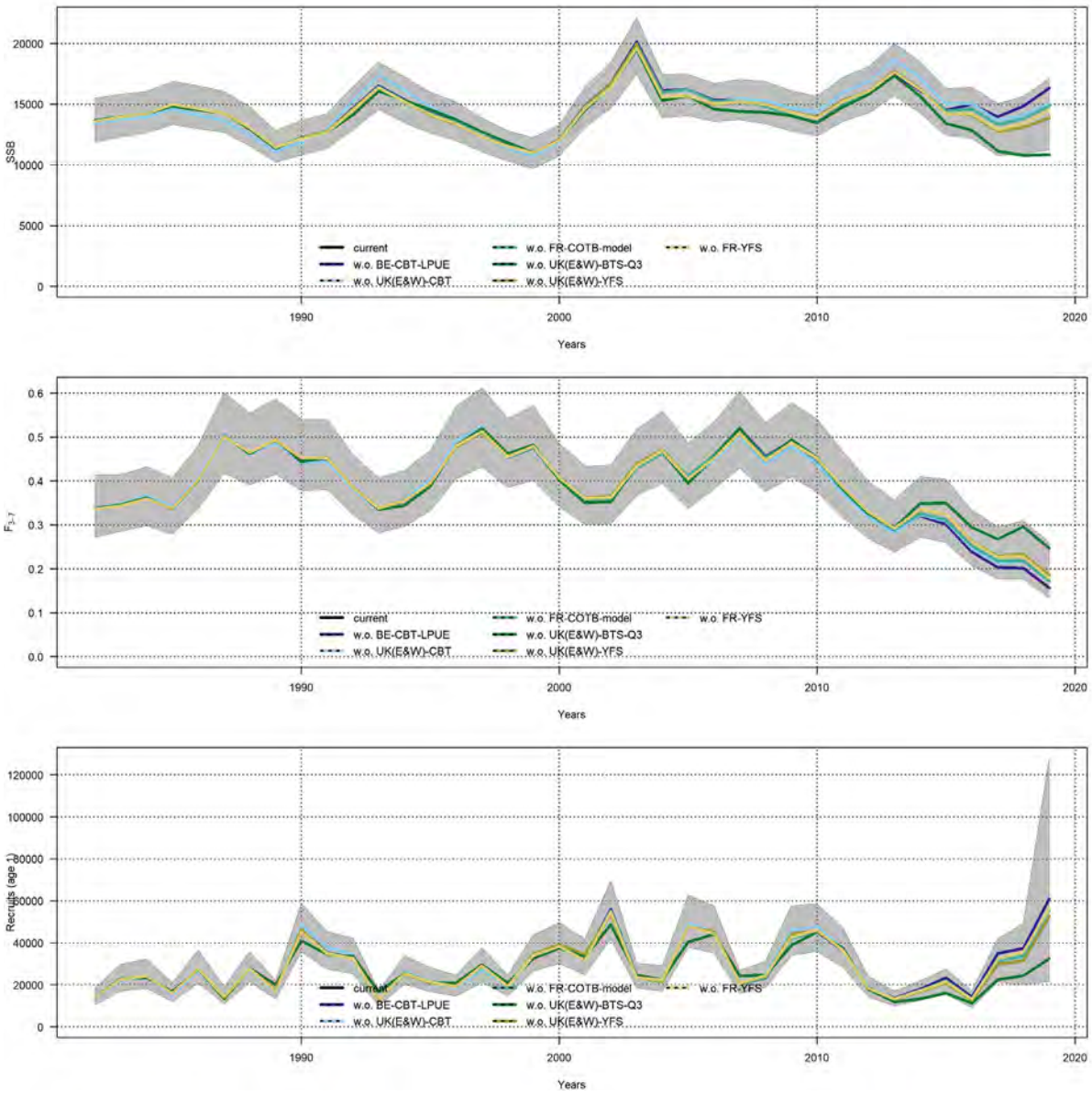


Figure 26: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.5 SAM model: Run 3

4.5.1 Model output

The SSB trend and magnitude of the SSB estimates of RUN 3 are similar to those of RUN 2 with values ranging between 10000 and 20000 tonnes during the period 1982-2019 (Figure 27). Similar to RUN 2, the SSB estimates in the most recent years are slightly higher compared to the SSB estimates of RUN 1 in the final years. The SSB estimates also differ at the start of the time series compared to RUN 1 and RUN 2, with SSB estimates >15000 tonnes prior to 1985. However, these SSB estimates are accompanied by wide confidence intervals, which also characterise the catch estimates.

The Fbar trend of RUN 3 is similar to the Fbar trend of RUN 1 (Figure 27). However, there are some minor differences between both models. In RUN 3, the maximum value of fishing mortality was estimated to be in 1989, while in RUN 1, the maximum estimate of Fbar was found in 2004. After this peak, the Fbar was estimated to remain stable until 2010, whereupon it started to decline to a level of approximately 0.31. In contrast, in RUN 1, Fbar was estimated to decline around 2005 reaching a value

of ~0.3 similar to the value of RUN 3. Also here the confidence intervals of the Fbar estimates of RUN 3 are much larger than those in RUN 1 and RUN 2. No remarkable differences appear in the recruitment estimates compared to the previous SAM models runs (RUN 1 and RUN 2) (Figure 27).

The F-at-age trends are very similar to those in RUN 1 except for the older age groups (9,10, 11+) which show a strong increase from values ranges around 0.25 to 0.4 with the fishing mortality on age 10 and higher being the highest of all age groups by the end of the time series (Figure 28).

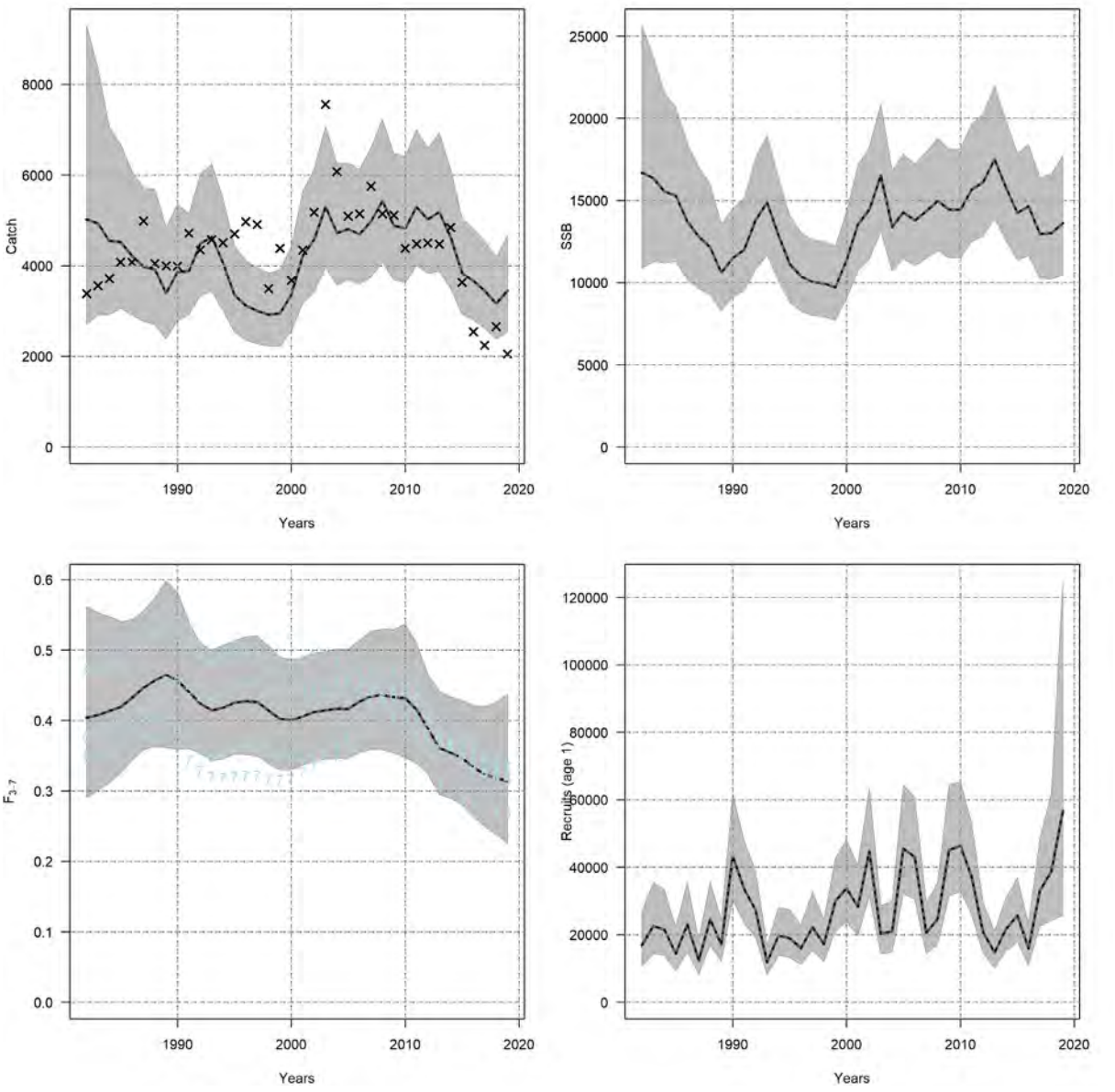


Figure 27: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

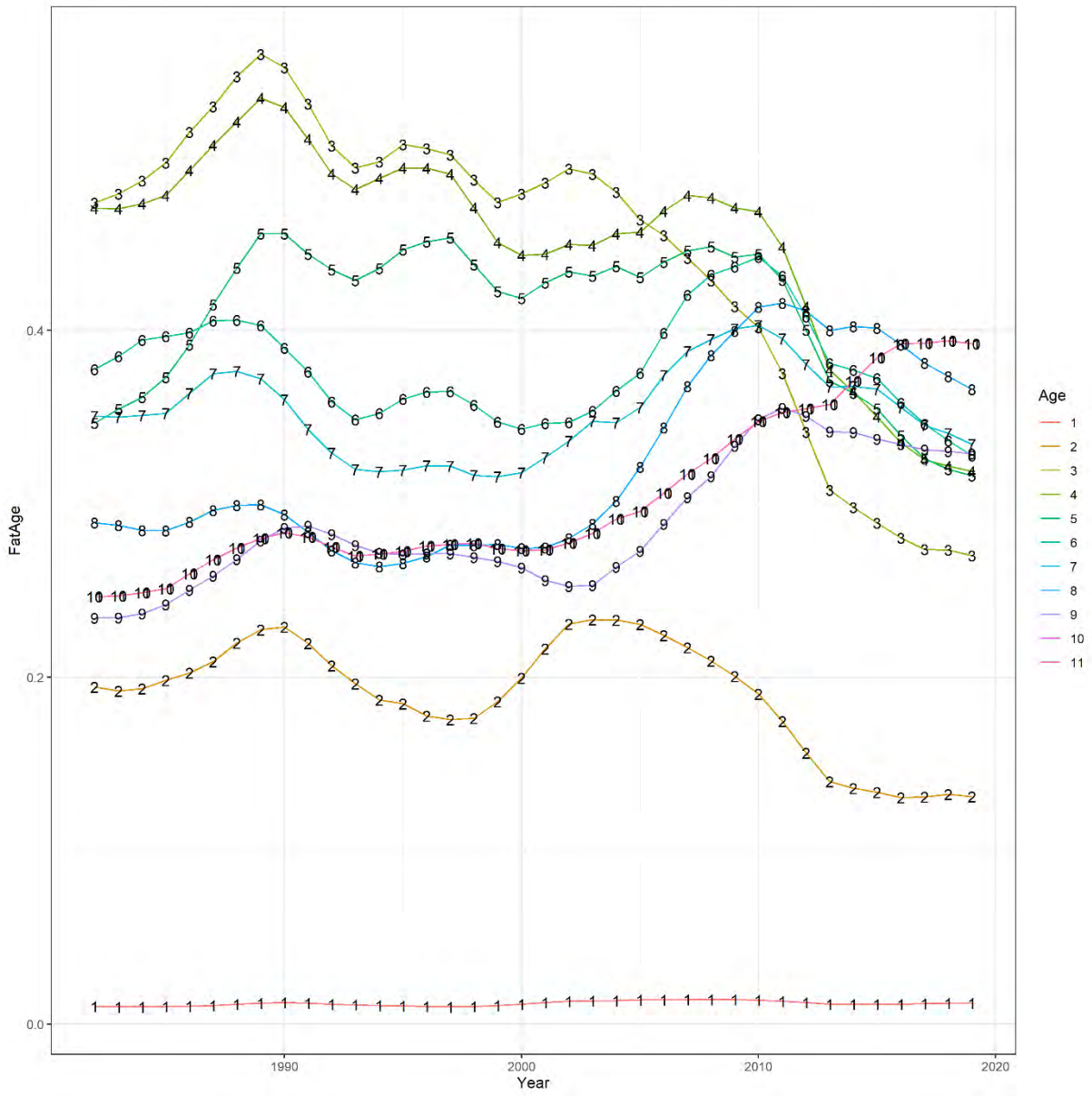


Figure 28: Fishing mortality by age group. Remark that age 10 and 11(+) overlap.

4.5.2 Model validation

The one step ahead residuals for the catch data do not indicate strong patterns within the age groups (Figure 29). However, when comparing the residuals across the different age groups, it appears that the residuals for age 1 are much larger which violates the assumption of homogeneity of variances. This is related to the fact that there is only a single variance parameter estimated for each of the observations.

Again, strong trends are present in the residuals of the UK-CBT tuning fleet, indicating a lack of fit to this time series data. Minor trends in residuals are also visible in the UK-BTS, in particular during the last 5 years of the assessment.

Again, the process residuals do not indicate any problems with respect to the model configuration (Figure 30).

The retrospective analysis shows that the model performs poorly with respect to the SSB and Fbar estimates, with especially a strong bias in the Fbar estimates for the fits with peels of 4 and 5 years (Figure 31). The retrospective analysis for the recruitment has the highest Mohn's rho so far (0.2014). The leave-one-out runs show that the model is dependent on the UK-BTS survey which pulls the SSB estimates down in the final years and results in an increase of the Fbar estimates in the last 5 years of the time series (Figure 32).

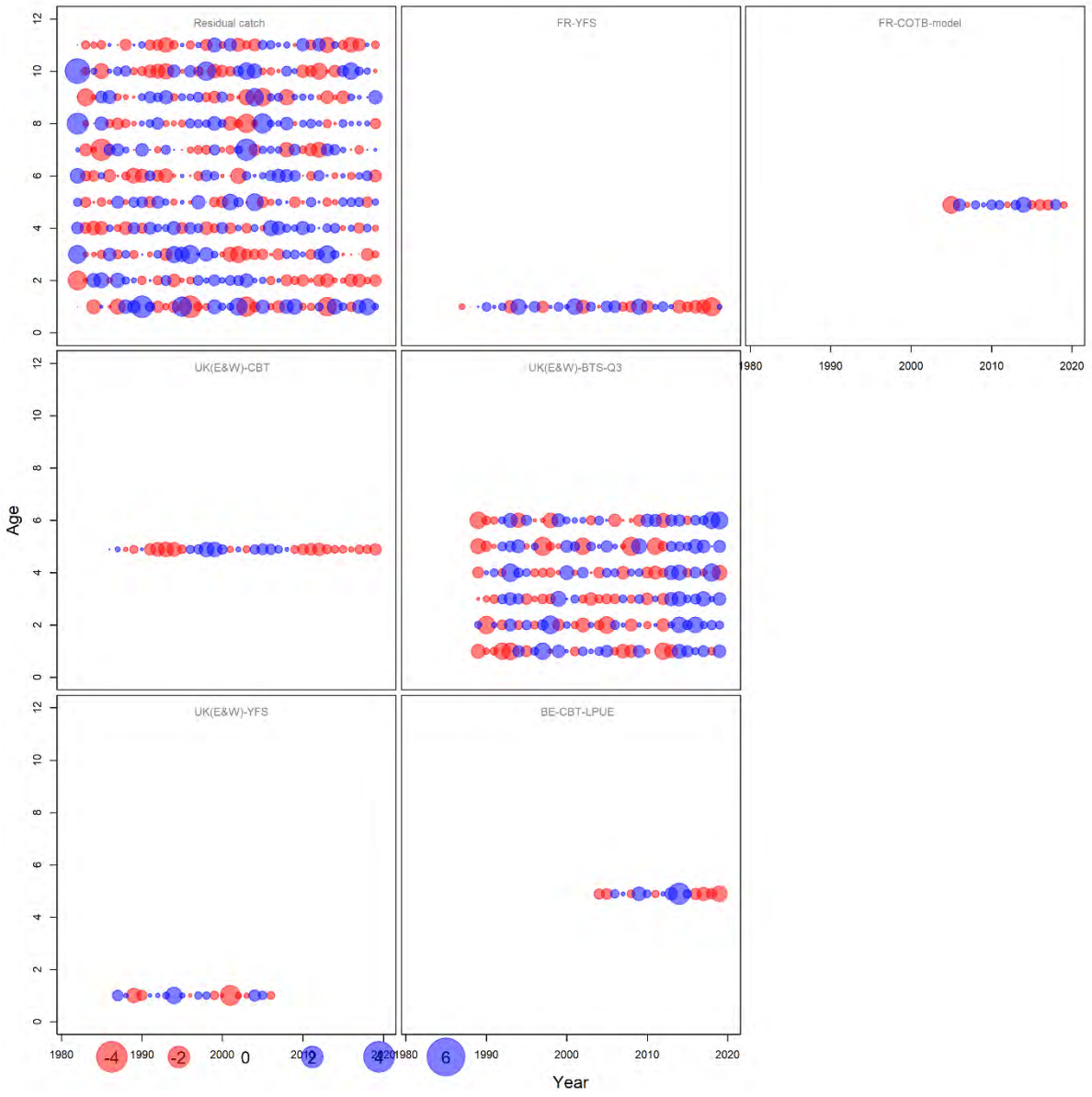


Figure 29: One-step ahead residuals by data stream.

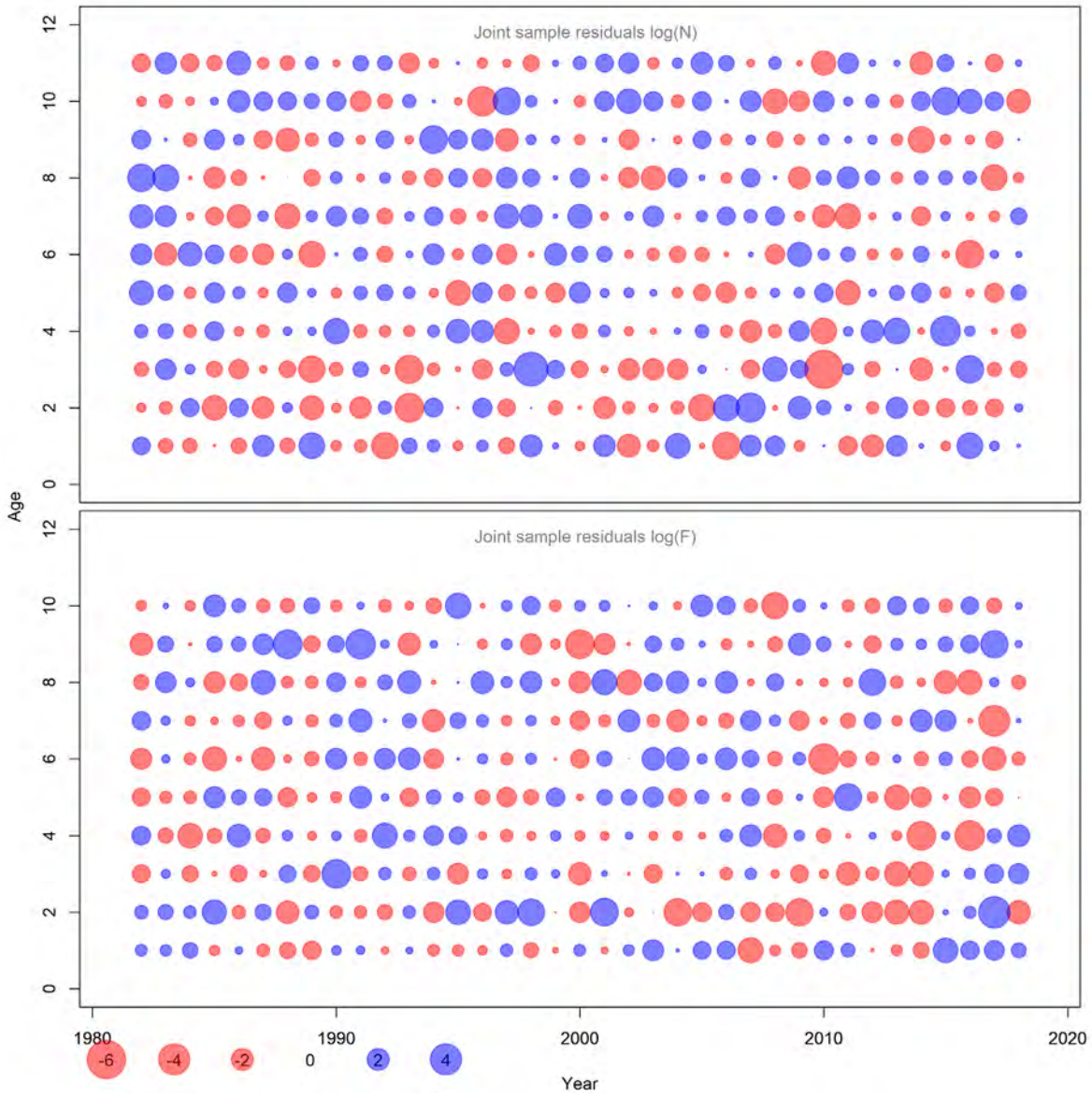


Figure 30: Process residuals for the survival (logN) and fishing mortality (logF) processes.

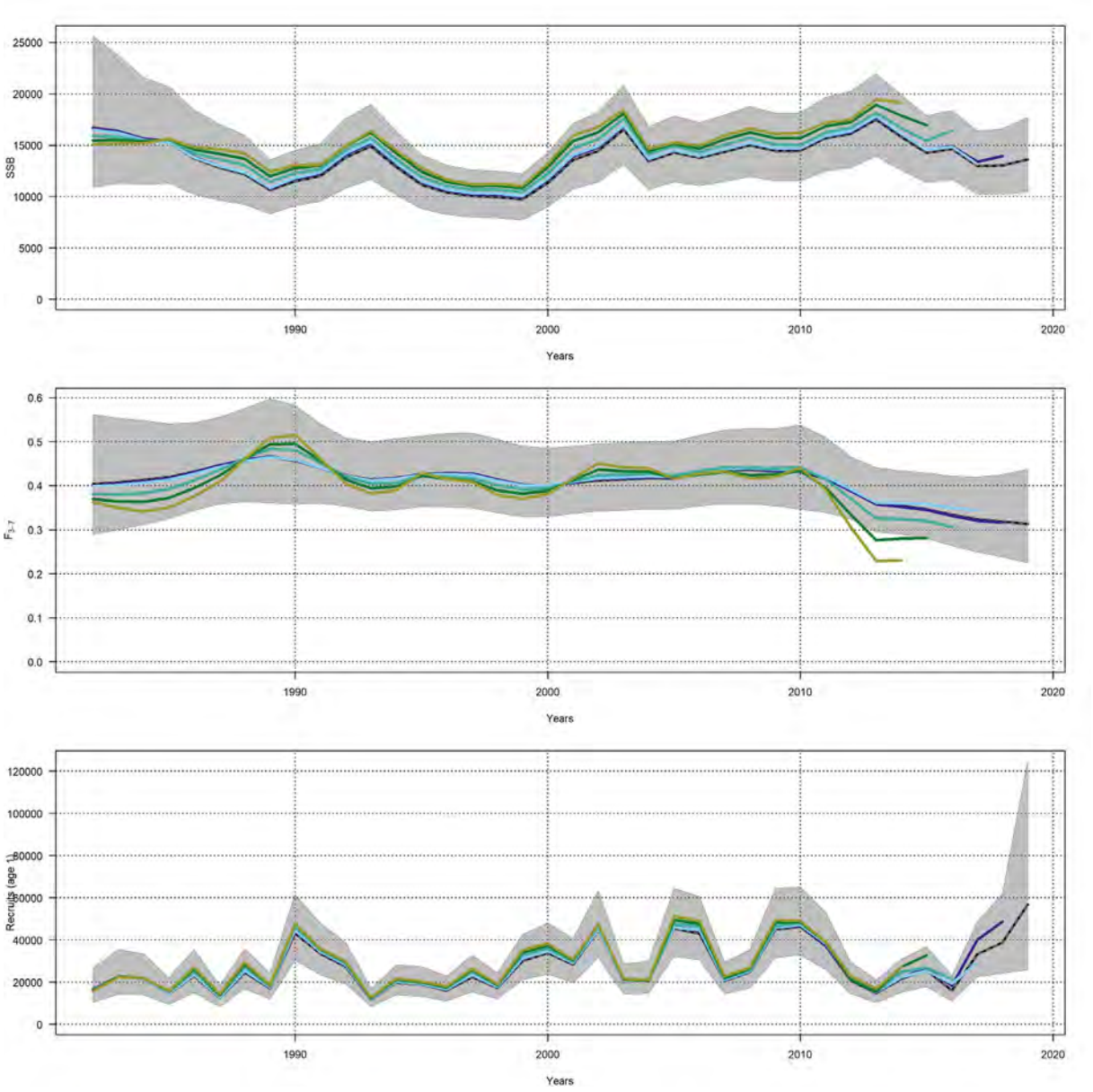


Figure 31: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.1218; ρFbar = -0.1136; ρR = 0.2014. The grey shades represent the 95% confidence intervals of the model including all data years.

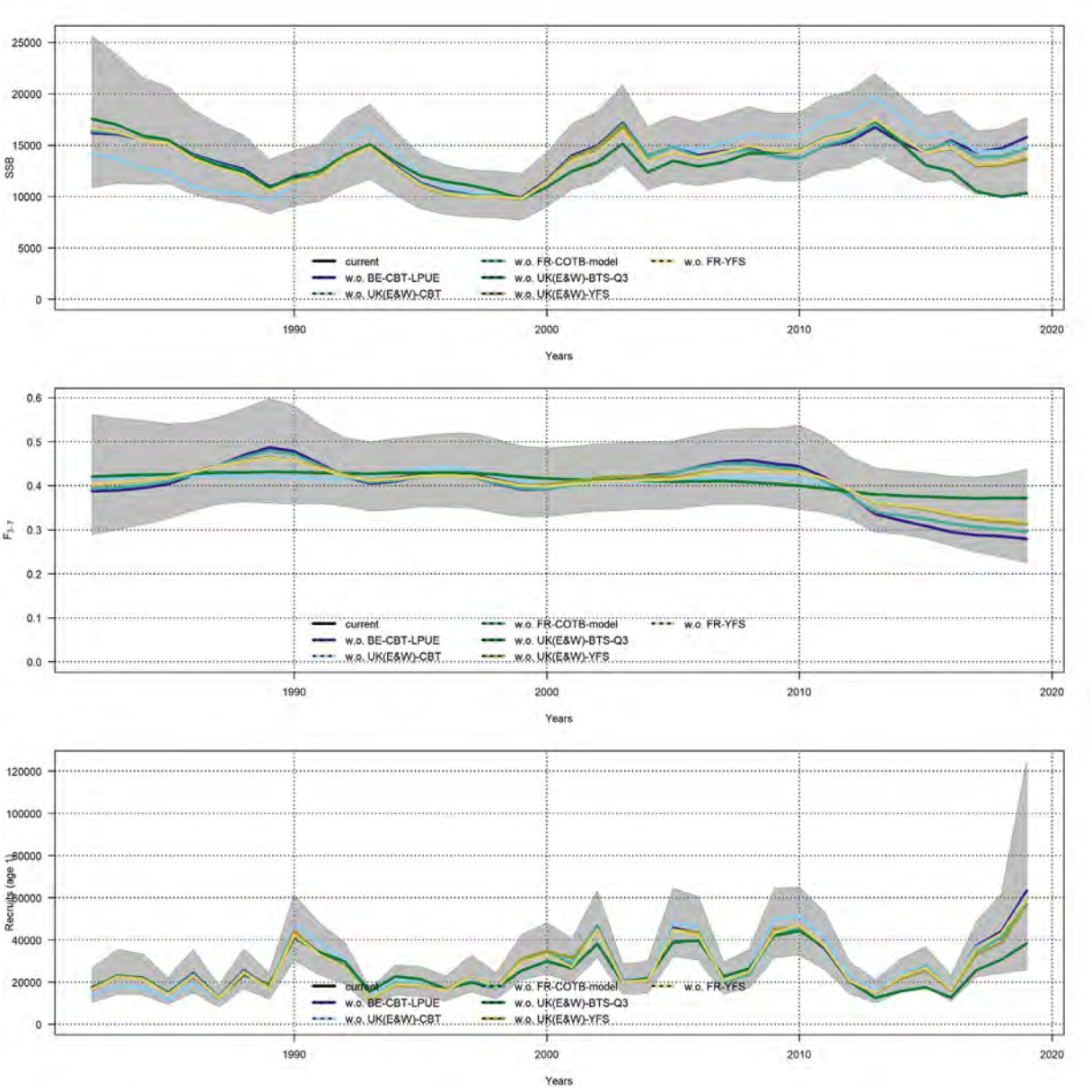


Figure 32: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.6 SAM model: Run 4

4.6.1 Model output

Overall, the SSB, Fbar, catch and recruitment estimates of RUN 4 are very similar to those of RUN 1 (Figure 33). The main difference is found in the Fbar estimates in the final year, which are slightly higher compared to the RUN 1 estimates. Again the catch estimates are lower and higher than the observed values during the periods 1995-2000, 2015 – 2019, respectively.

The higher Fbar estimates in the most recent years of the assessment compared to RUN 1 can be explained by the differences in F-at-age trends between both runs. The F-at-age for age 2 to 7 is rather similar to RUN 1 with a decline of the fishing mortality for ages 2 to 5 since 2005, while the fishing mortality for age 6 and 7 remained rather stable over time (Figure 34). In contrast, the fishing mortality

on age 8, 9, 10 and the plusgroup increased over time, to a similar level of fishing mortality exerted on the age groups 4 to 8.

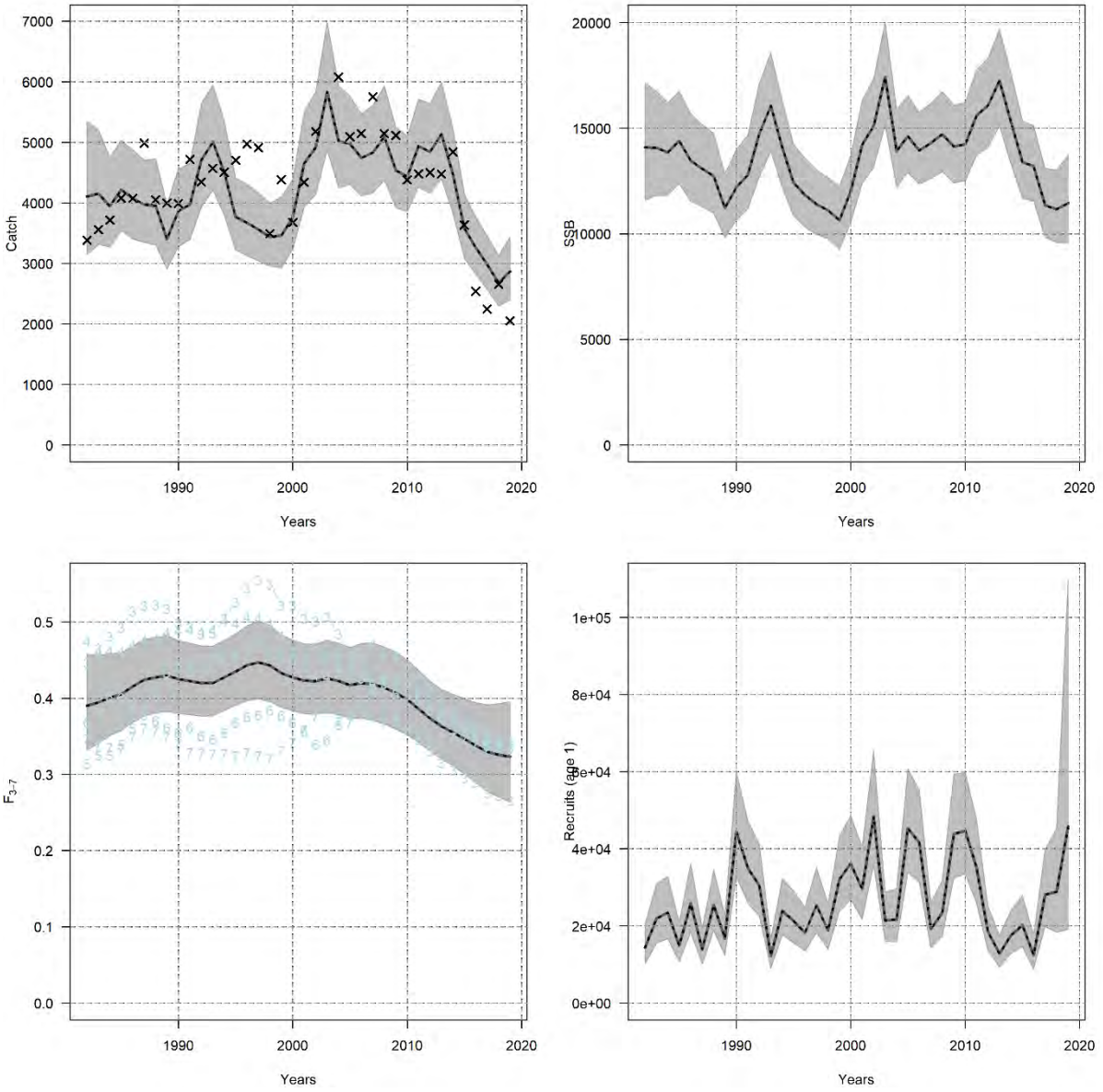


Figure 33: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

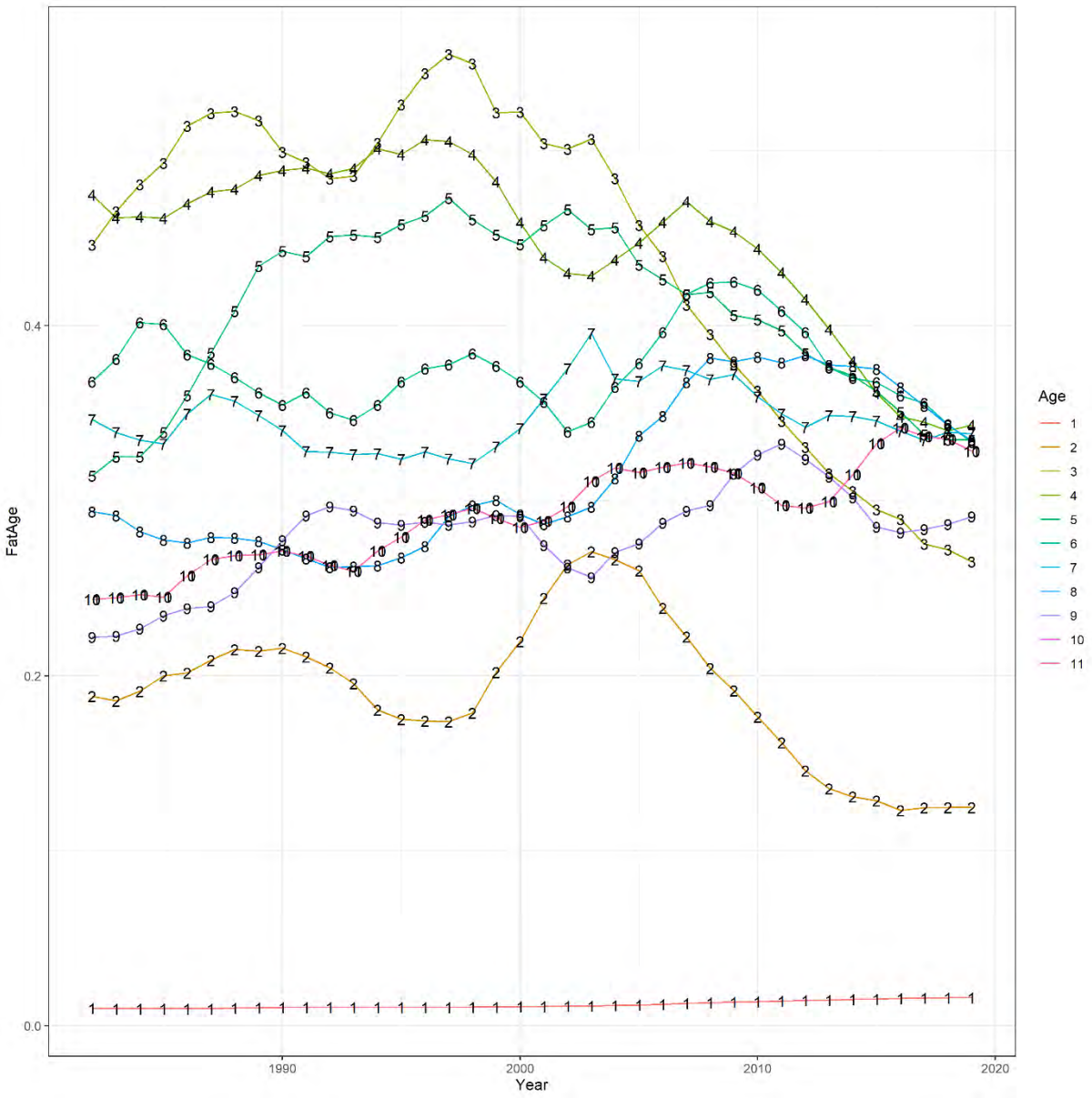


Figure 34: Fishing mortality by age group, note age 10 and 11(+) overlap.

4.6.2 Model validation

Both the OSA and process residuals of RUN 4 do not indicate major problems with the model (Figure 35 and 36). Only the OSA residuals of the UK-CBT fleet indicate some patterns, whereas the residuals of the UK-BTS in the last 5 years of the assessment also indicate a poor fit to the data. The latter is also visible in the leave-one-out fits, where removing the UK-BTS from the assessment results in a drop of the SSB and an increase of Fbar for the final years of the assessment (Figure 38).

The retrospective analysis does not indicate any problems (Figure 37).

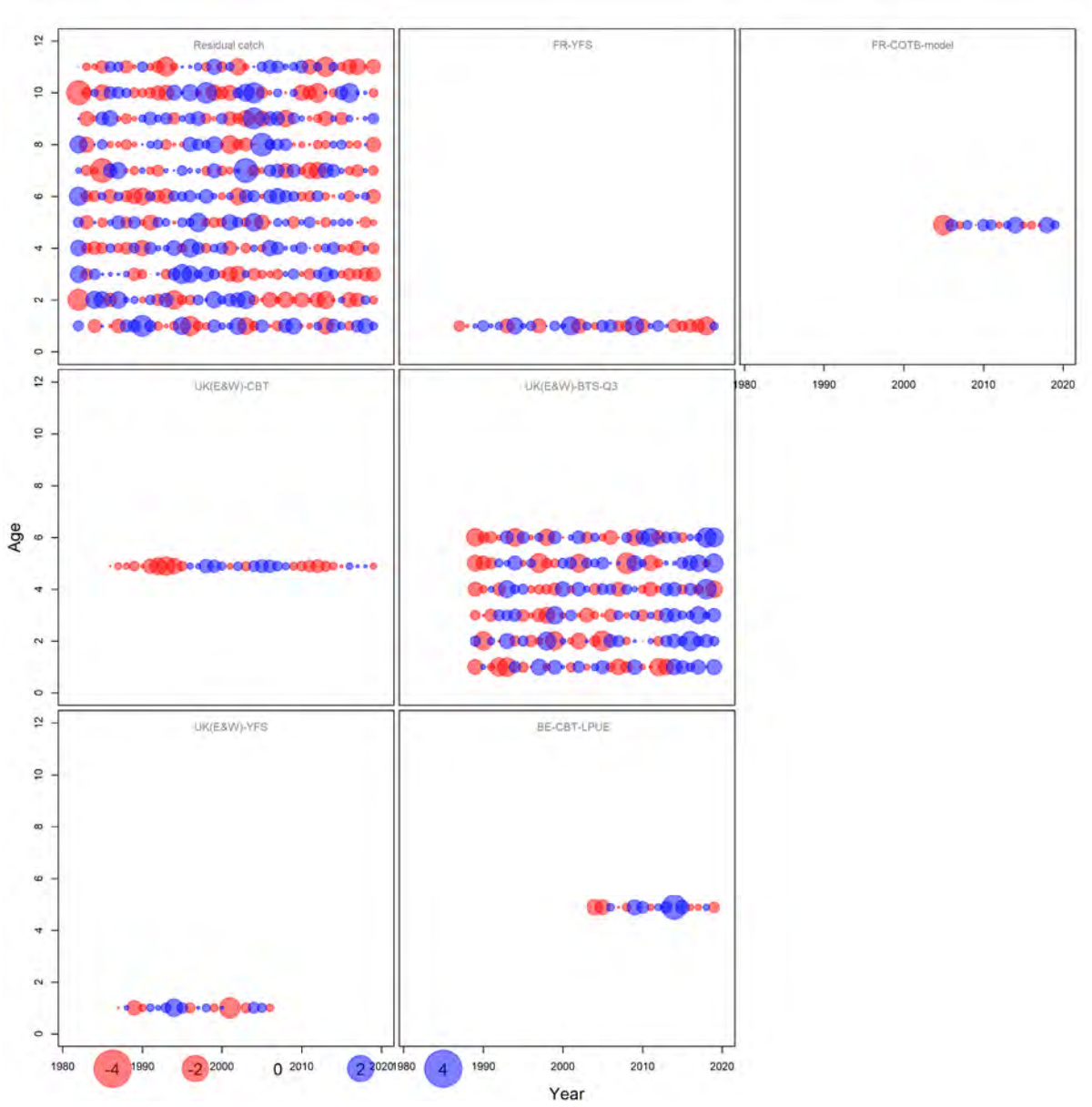


Figure 35: One-step ahead residuals by data stream.

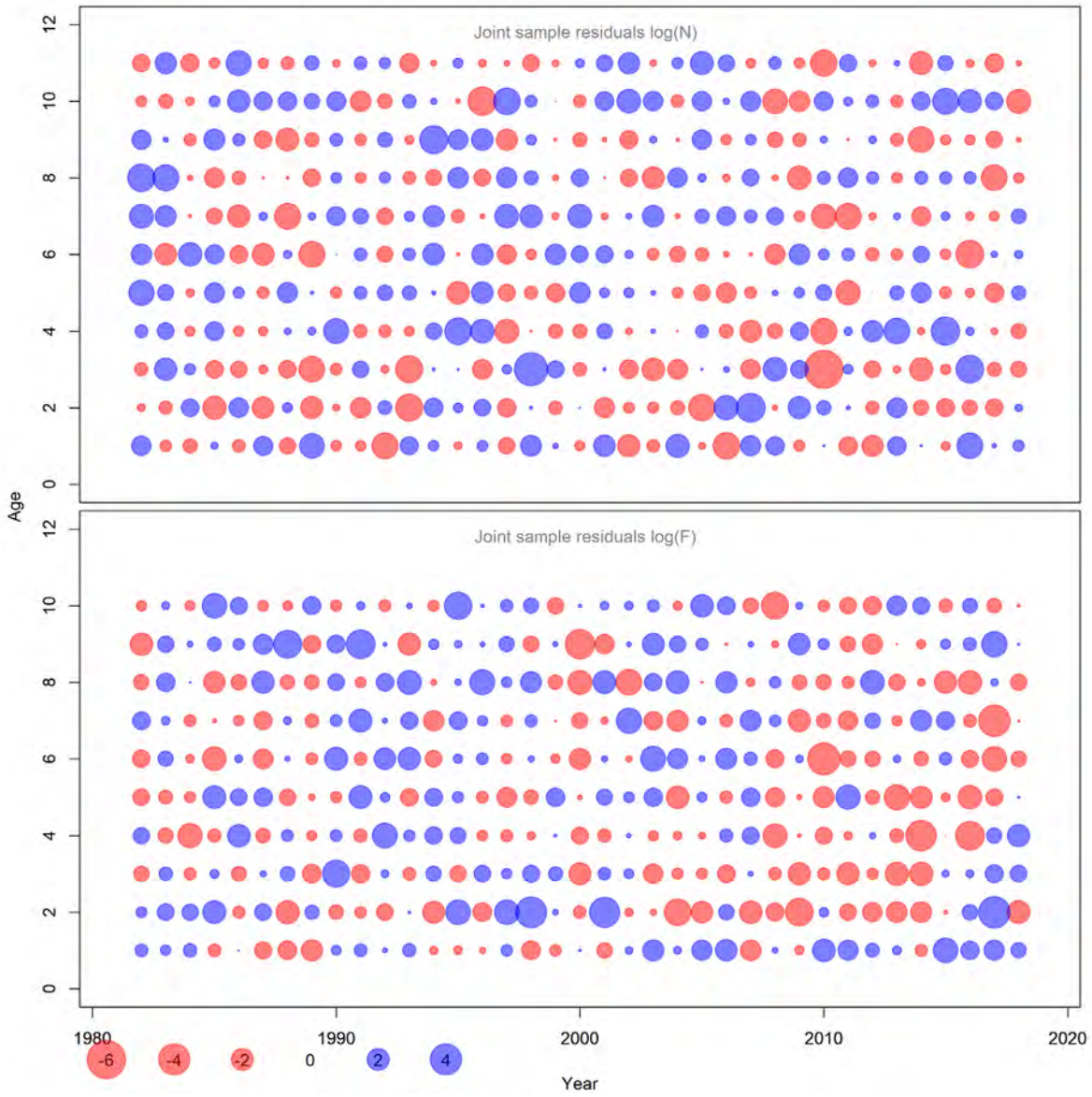


Figure 36: Process residuals for the survival (logN) and fishing mortality (logF) processes.

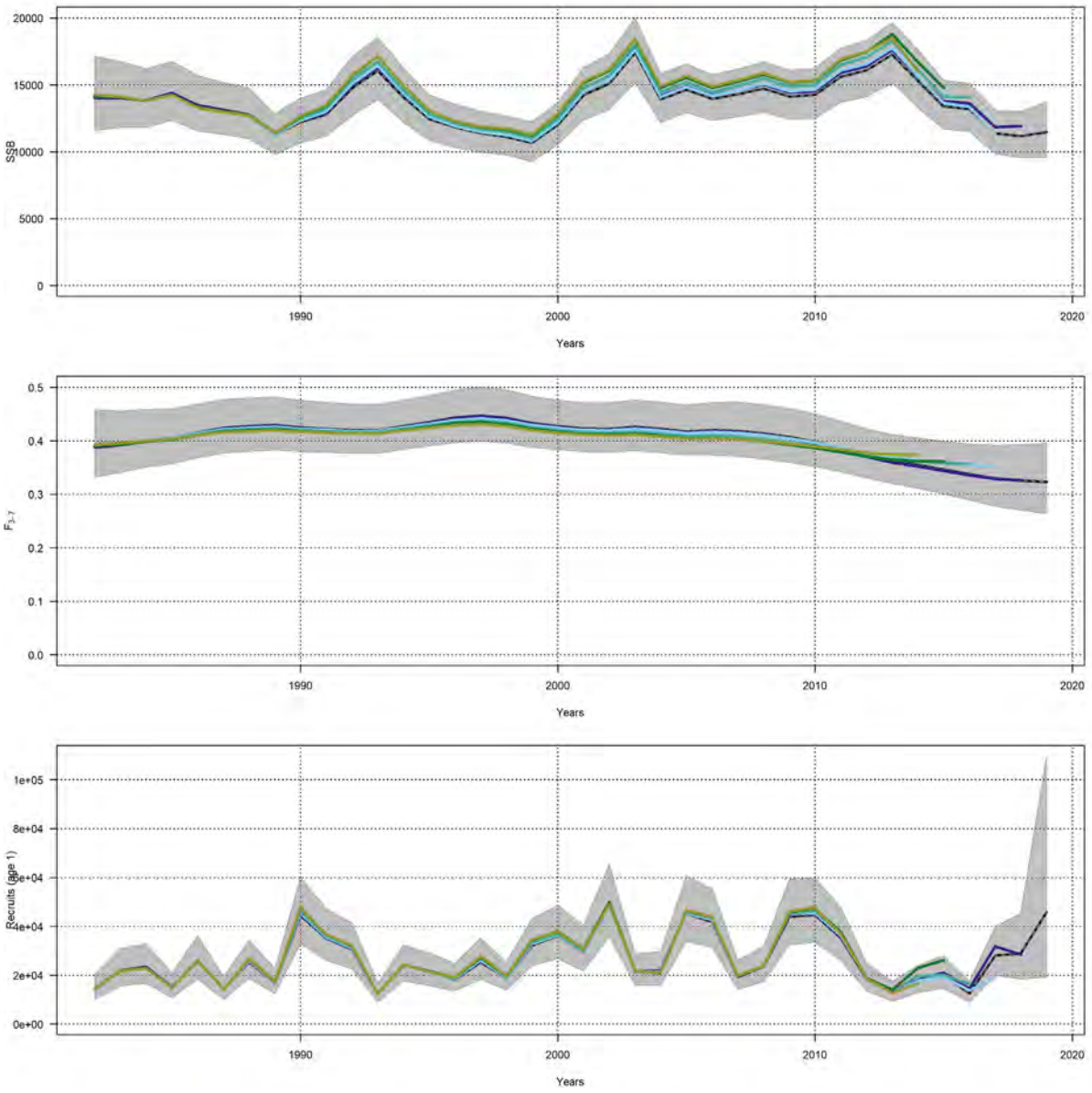


Figure 371: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.0562; ρFbar = 0.0447; ρR = 0.0444. The grey shades represent the 95% confidence intervals of the model including all data years.

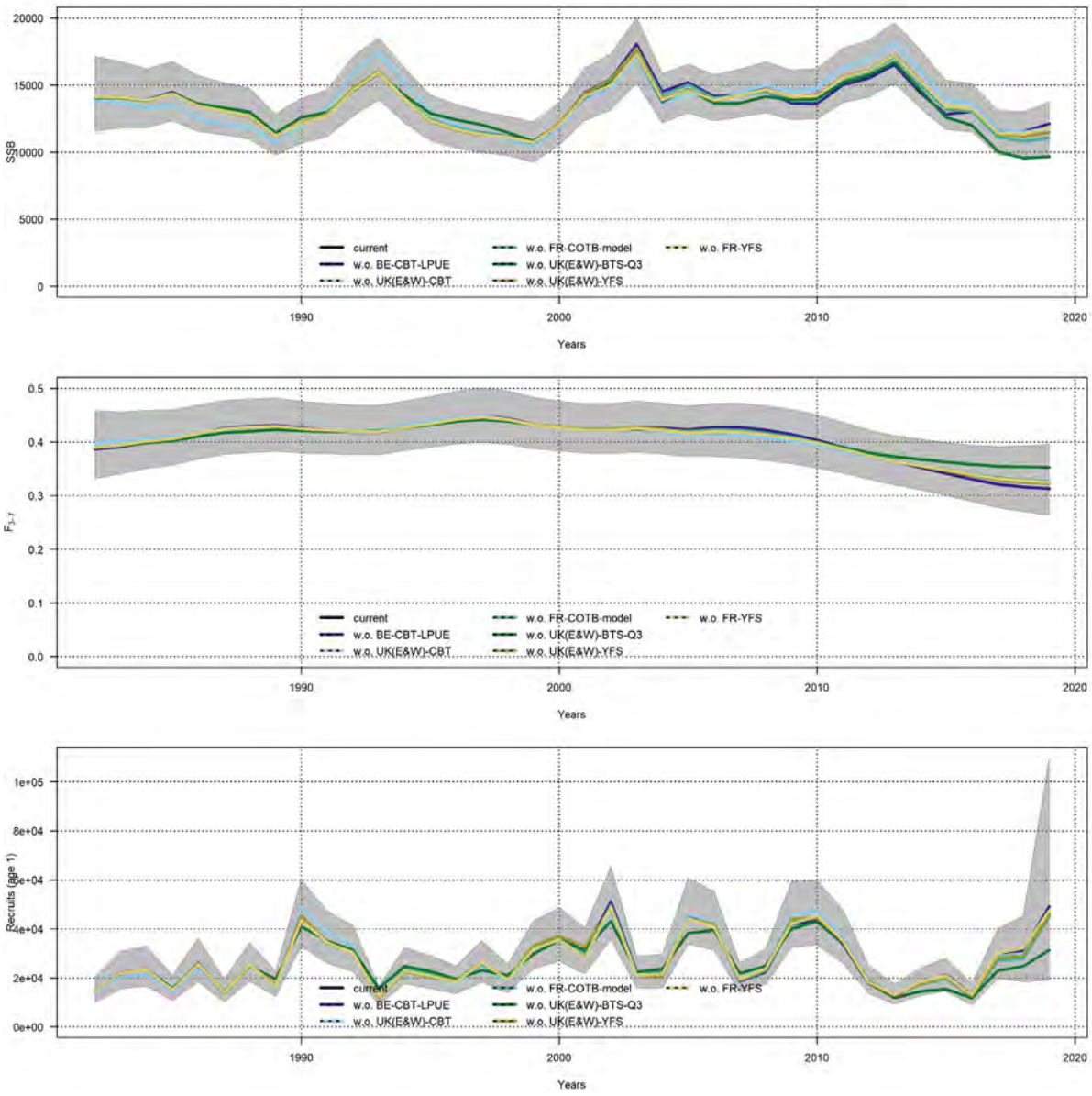


Figure38: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.7 SAM model: Run 5

4.7.1 Model output

Run 5 assumes that the relative indices of abundance of the commercial tuning fleets represent the fishable biomass thereby following the selectivity of the entire fishery as estimated by the model. The change from SSB to FSB indices results in minor changes with respect to the estimated quantities (Figure 39). Only at the end of the time series, the SBB is estimated to be slightly higher in case of the FSB tuning fleets while the Fbar is lower. This is also reflected in the catch estimates that are slightly higher in the most recent years of the assessment compared to RUN 4.

The patterns in F-at-age are very similar between RUN 4 and 5 (Figure 40). Only for age groups 2 and 3, the fishing mortality is estimated to be slightly lower in case of the fishable biomass indices (RUN 5).

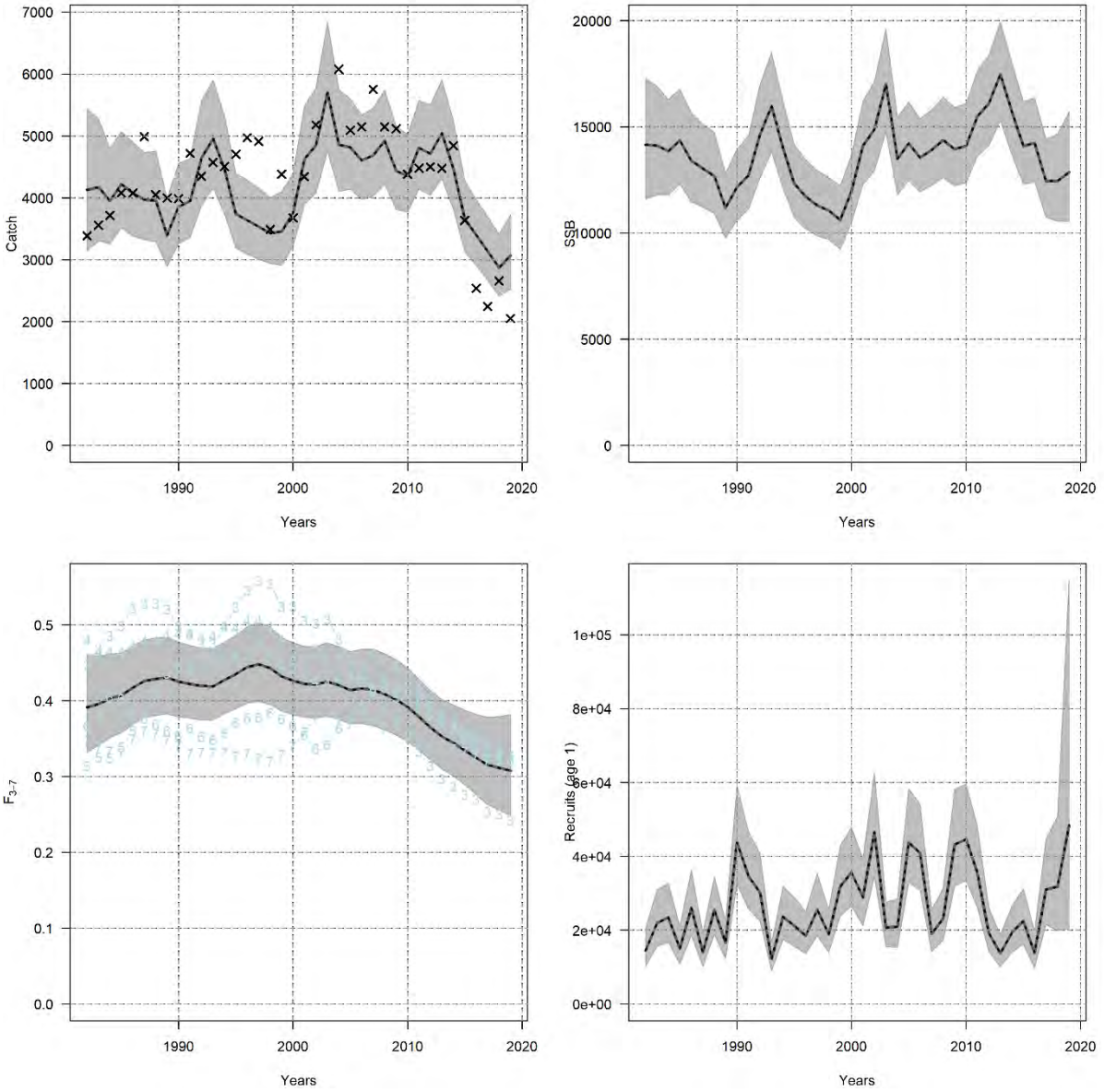


Figure 39: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

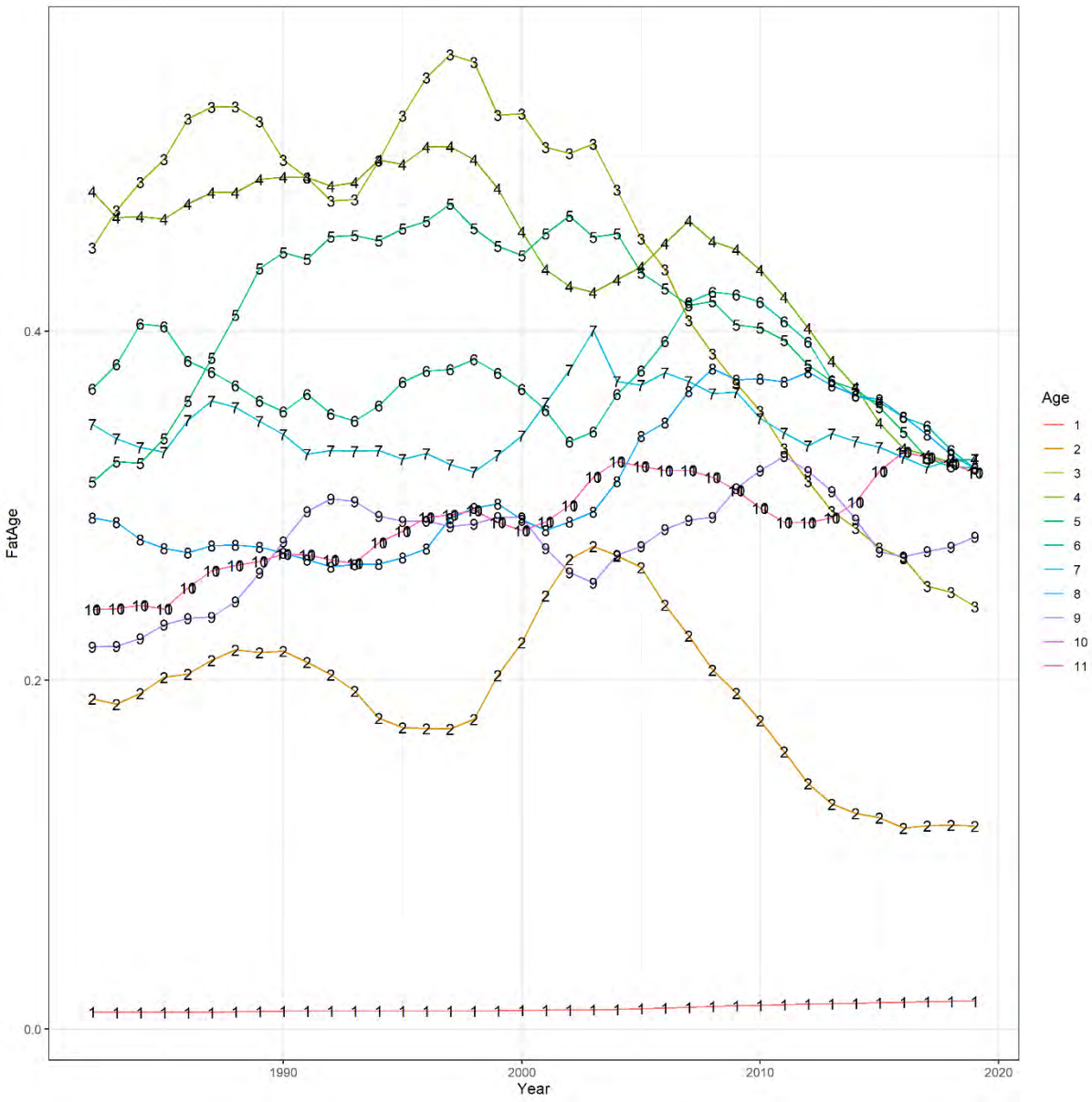


Figure 40: Fishing mortality by age group, note that age 10 and 11(+) overlap.

4.7.2 Model validation

Both the OSA and process residuals of RUN 5 do not indicate major problems with the model (Figure 41 and 42). Overall, the residual patterns look very similar to those of RUN 4.

The retrospective analysis does not indicate any problems, and the Mohn's rho values indicate that RUN 5 performs slightly better than RUN 4 (Figure 43). The results of the leave-one-out runs are similar to those of RUN 4, with a strong effect of removing the UK-BTS from the assessment resulting in a decline of the SSB and increase of the Fbar in the final years of the assessment (Figure 44).

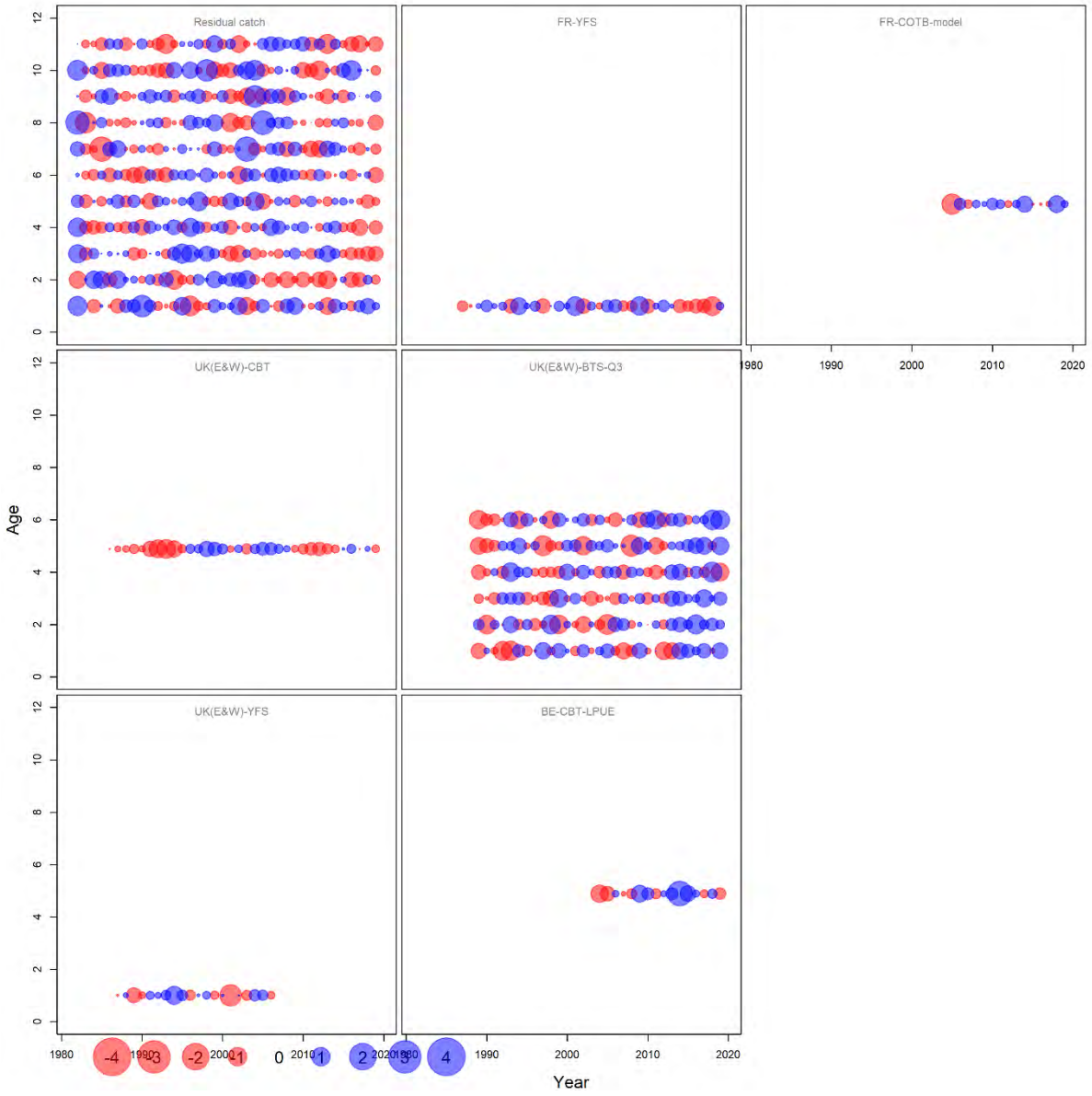


Figure 412: One-step ahead residuals by data stream.

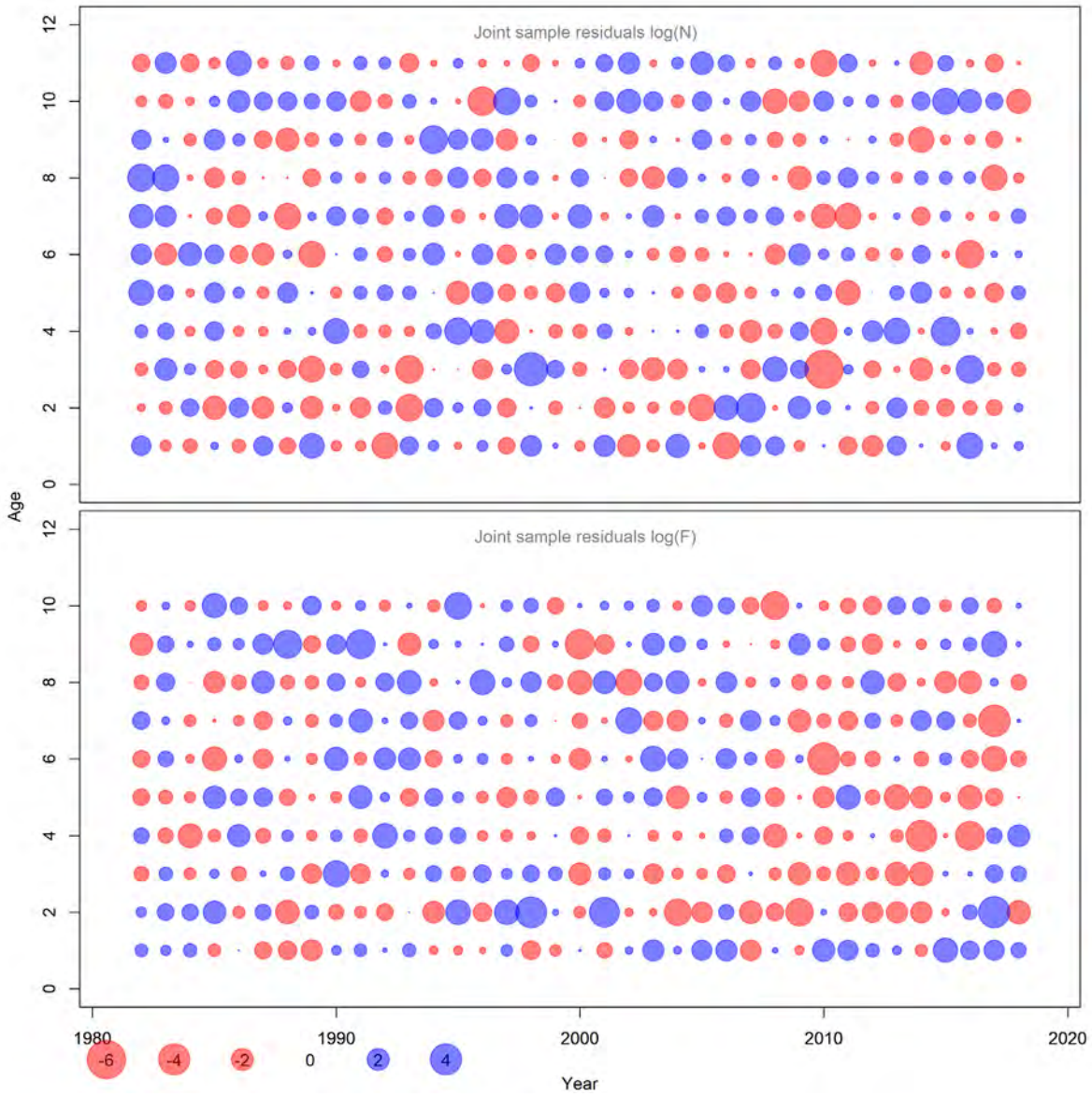


Figure 42: Process residuals for the survival (logN) and fishing mortality (logF) processes.

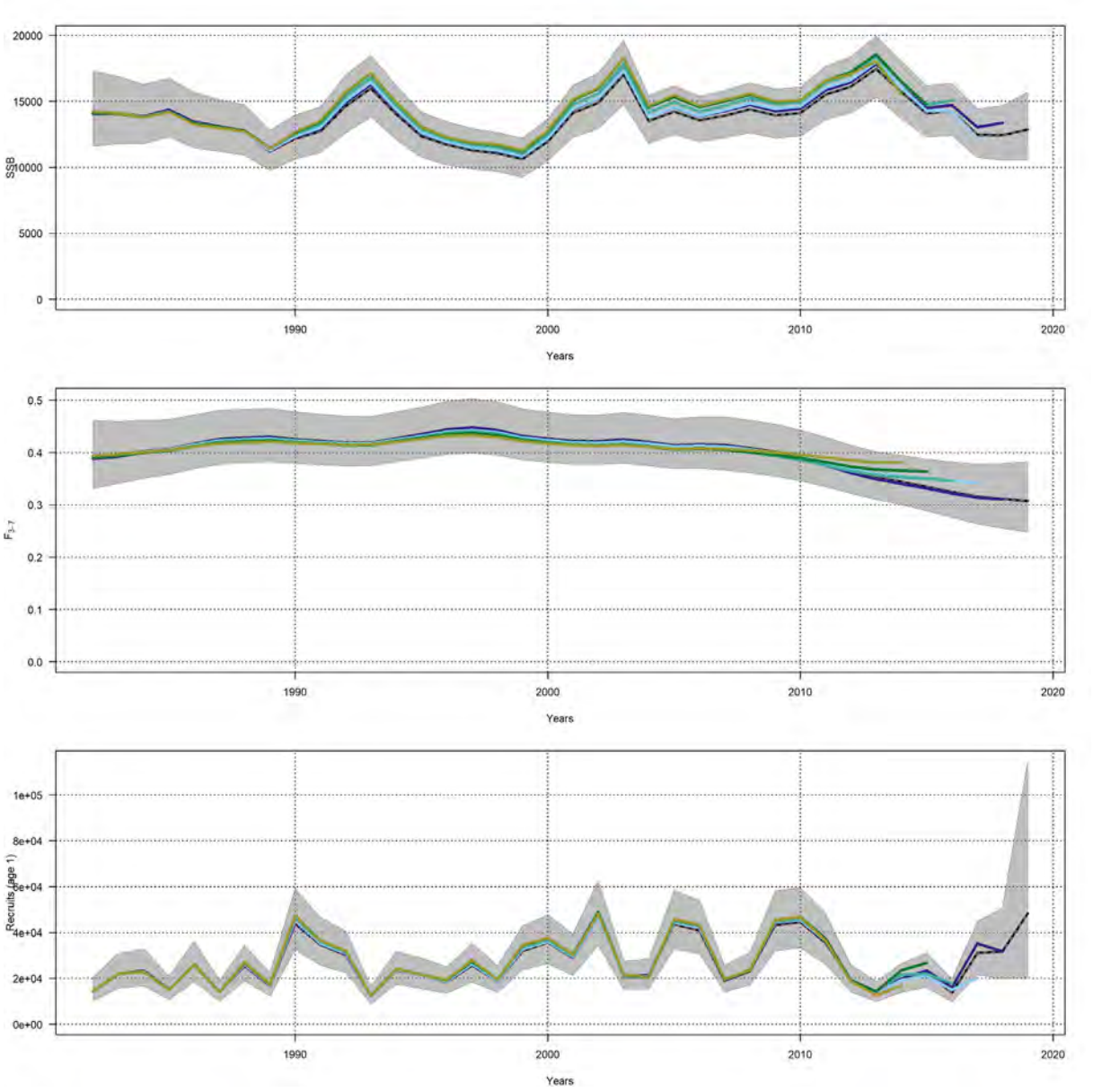


Figure 43: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.0296; ρFbar = 0.0695; ρR = -0.0005. The grey shades represent the 95% confidence intervals of the model including all data years.

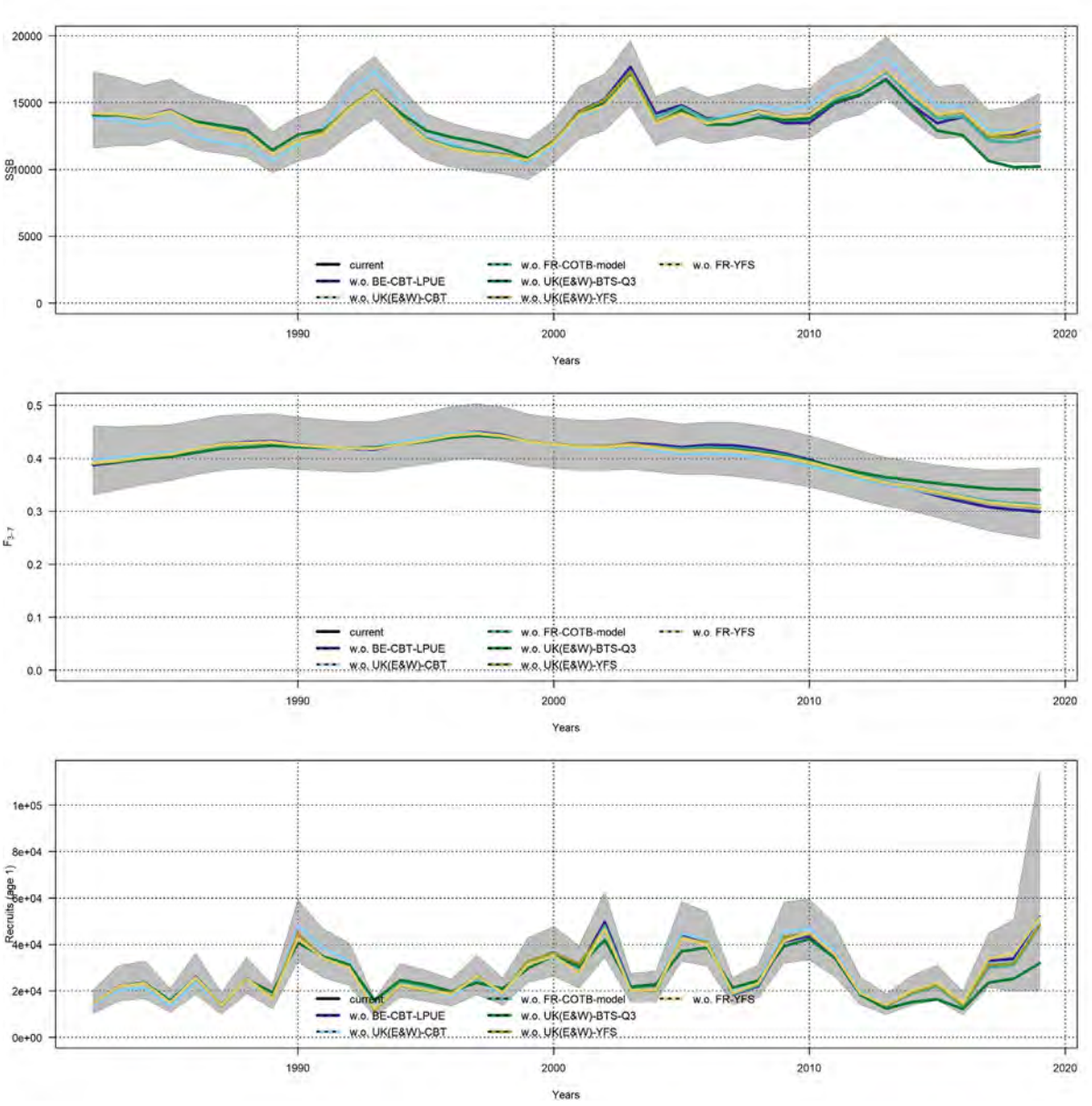


Figure 44: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.8 SAM model: Run 6

4.8.1 Model output

The changed parameter configuration of RUN 6 compared to RUN 5 has almost no effect on the estimated quantities (Figure 45). The SSB and Fbar estimates in the final year are slightly lower, higher, respectively compared to RUN 5, and overall the model has a lower AIC (-10) compared to RUN 5.

Regarding the trends in fishing mortality at age, grouping some of the fishing mortality parameters at age resulted in some minor differences with respect to RUN 5 (Figure 46). The grouping of age 6 and 7 has a limited effect, but grouping age 8 and 9 did affect the fishing mortality on age 9 since 2000. The increase in fishing mortality is more pronounced compared to RUN 5 and does follow the trend of age 8. The fishing mortality on age 10 and 11(+) is higher compared to RUN 5, and since 2015, age groups 10 and 11(+) experience the highest fishing mortality overall.

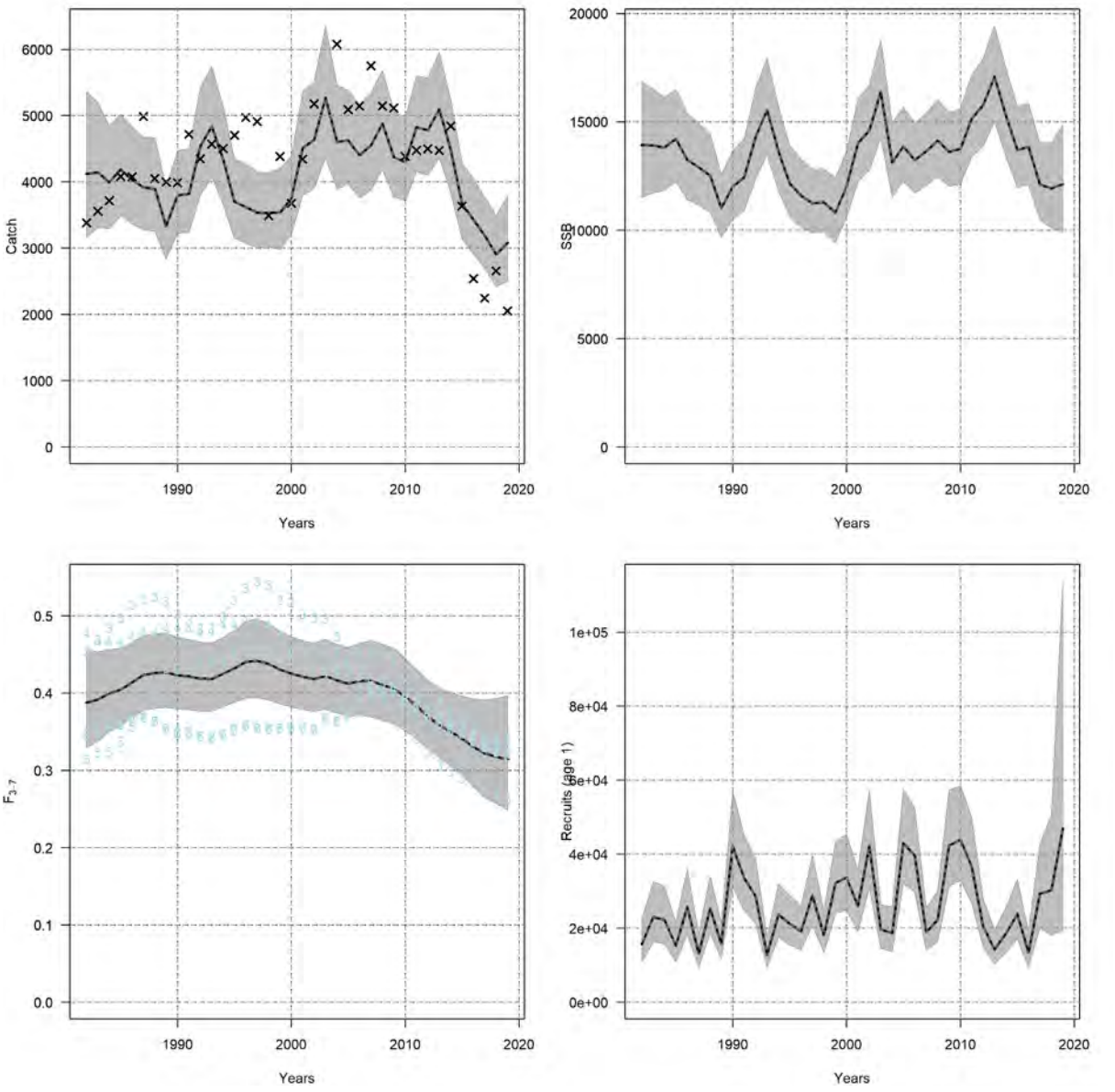


Figure 45: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

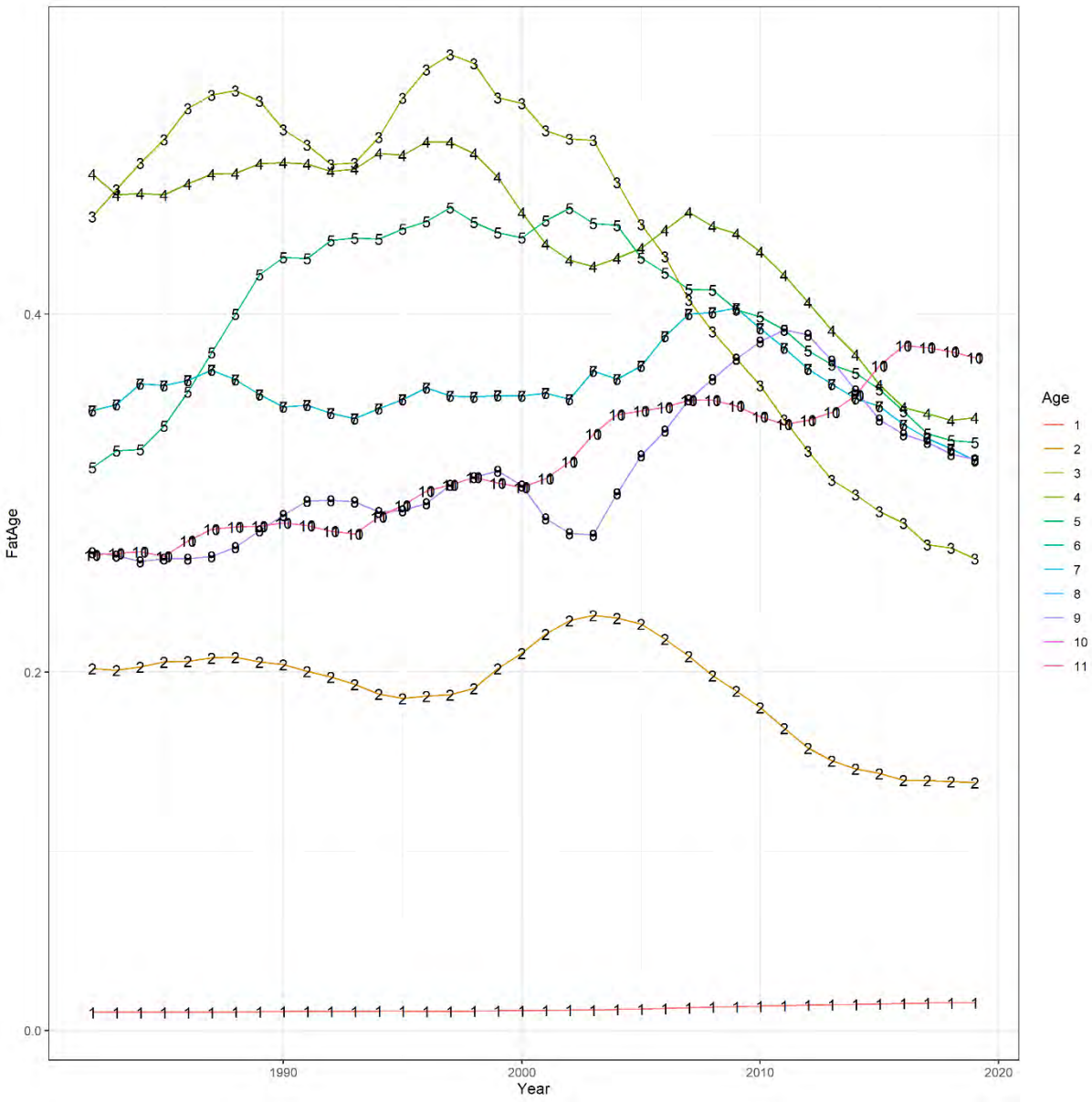


Figure 46: Fishing mortality by age group, note that age 6-7, 8-9 and 10-11(+) overlap.

4.8.2 Model validation

The OSA residuals of RUN 6 are very similar to those of RUN 4 and 5 (Figure 47). The process residuals are found to be slightly better as the model configuration used in RUN 6 removes the autocorrelation of the logF residuals with respect to the age (Figure 48). Note that the process residuals in the year 2000 are improved compared to the previous runs (RUN 1 – RUN 5) and are not dominated by red dots only as was the case in the previous models.

The retrospective analysis and the leave-one-out fits are very similar to the results of RUN 5 (Figure 49 and 50). Both validation analysis do not indicate problems with the model.

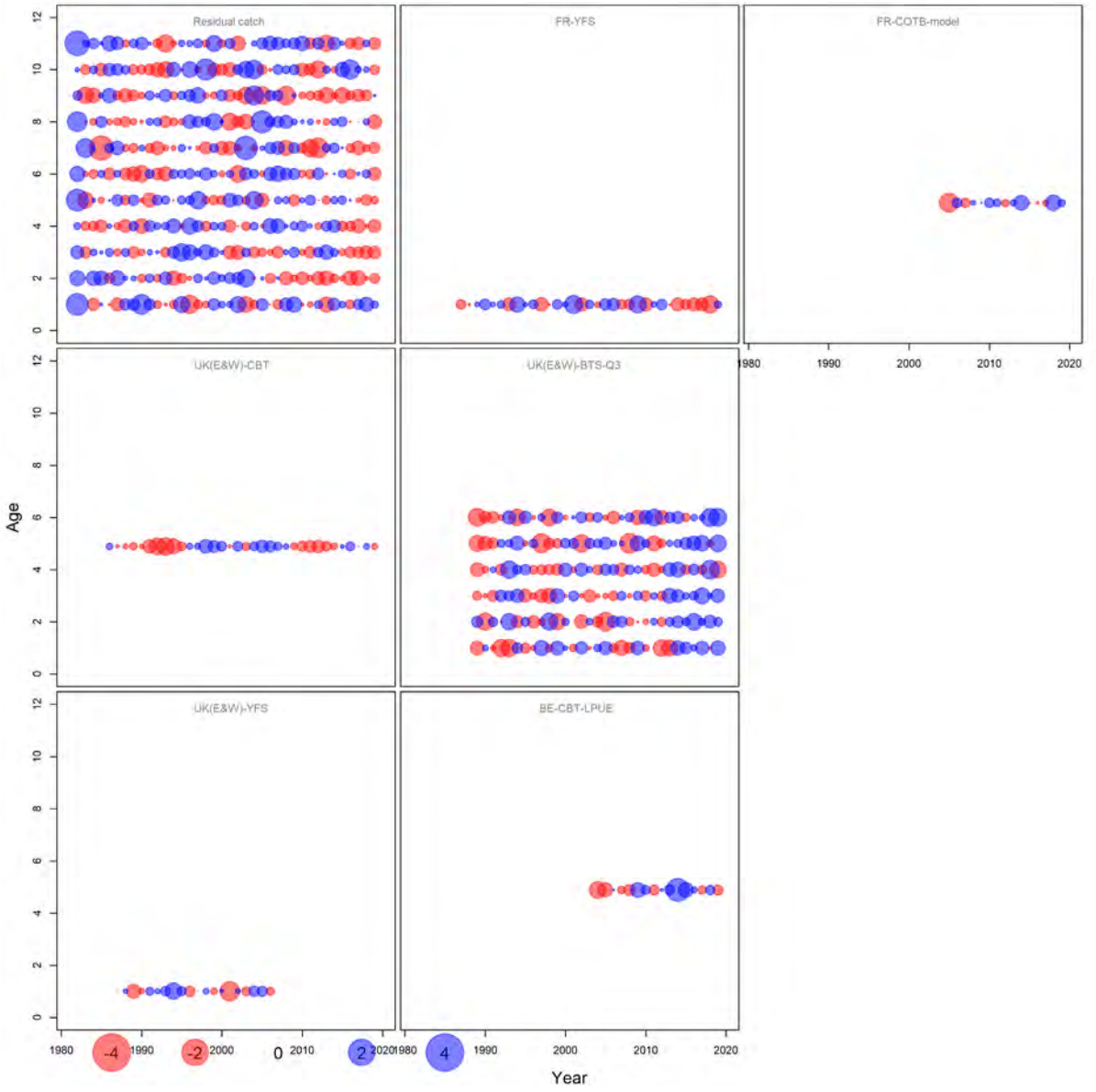


Figure 47: One-step ahead residuals by data stream.

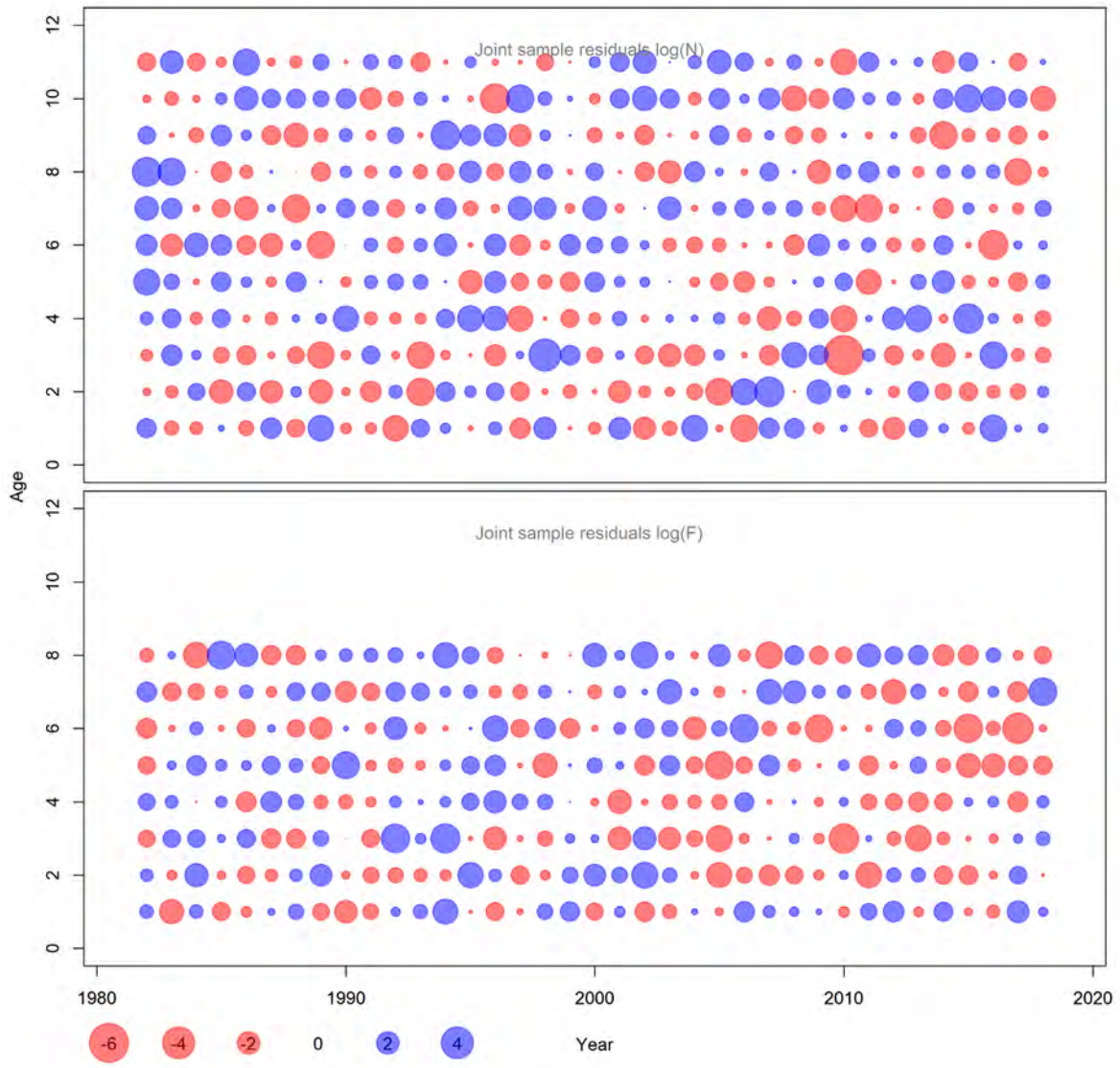


Figure 48: Process residuals for the survival (logN) and fishing mortality (logF) processes. Remark that y-axis for the logF process residuals corresponds to the parameter number.

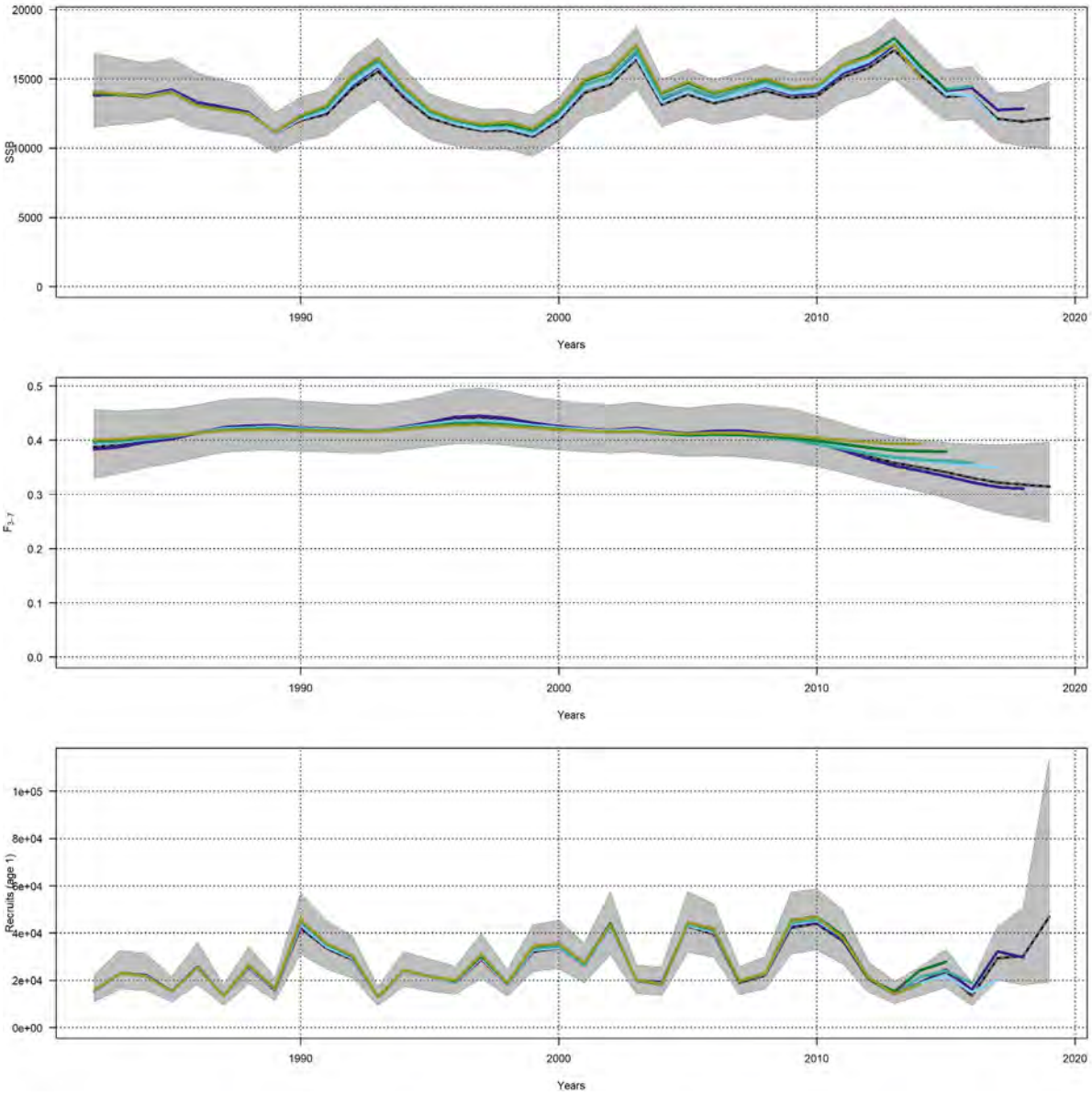


Figure 49: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.0258; ρFbar = 0.0767; ρR = 0.0456. The grey shades represent the 95% confidence intervals of the model including all data years.

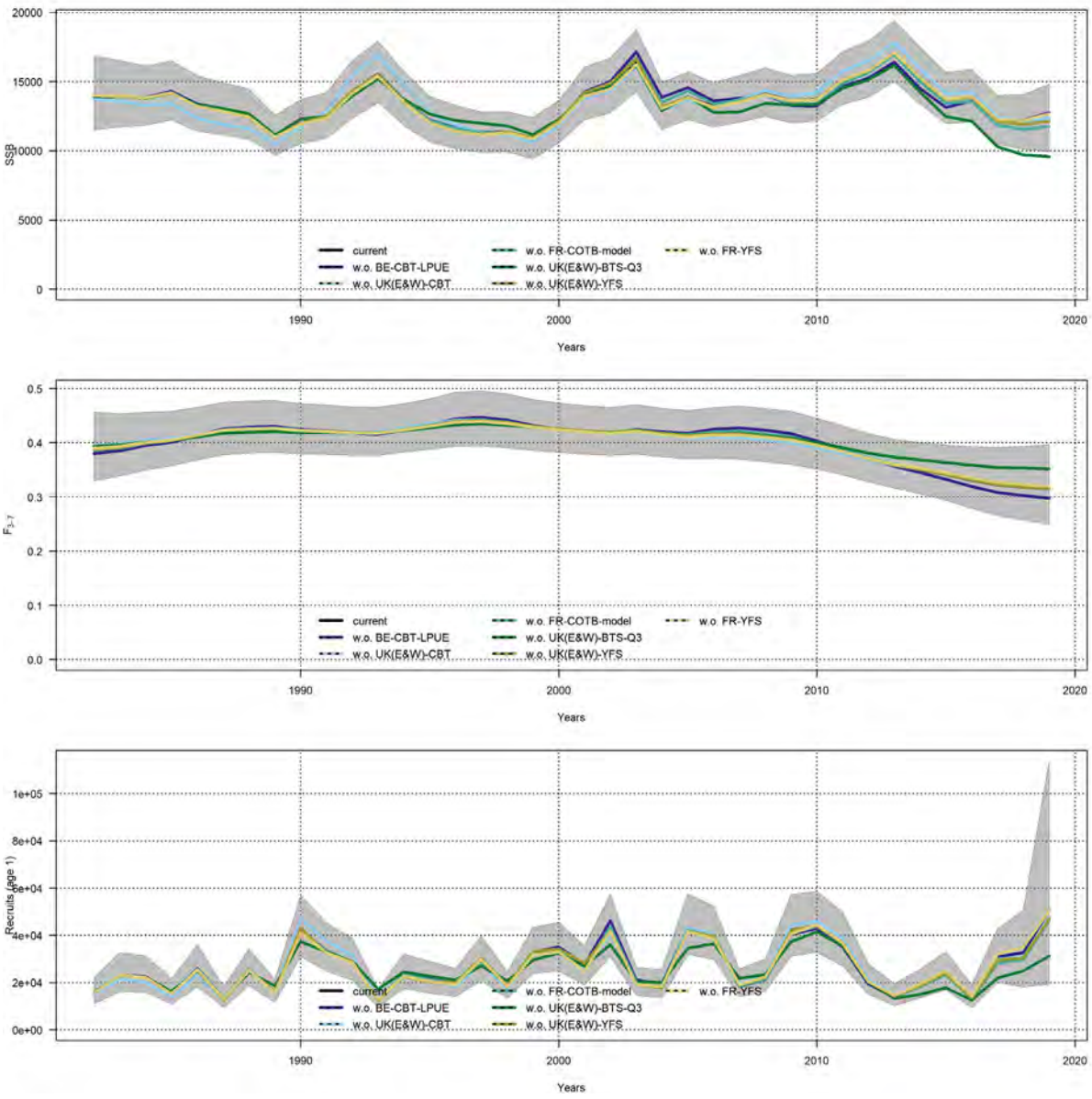


Figure 50: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.9 SAM model: Run 7

4.9.1 Model output

Replacing the separate commercial tuning fleets (UK-CBT, BE-CBT, FR-COTB) by a single combined commercial tuning fleet had little effect on the estimated quantities (Figure 51). Only in the final years of the assessment, the SSB is estimated to be lower compared to RUN 6, while the Fbar is estimated to be slightly higher. This is also visible in the catch estimates which are lower (<3000 tonnes) compared to RUN 6.

With respect to the fishing mortality at age, no clear differences are visible compared to RUN 6 (Figure 52).

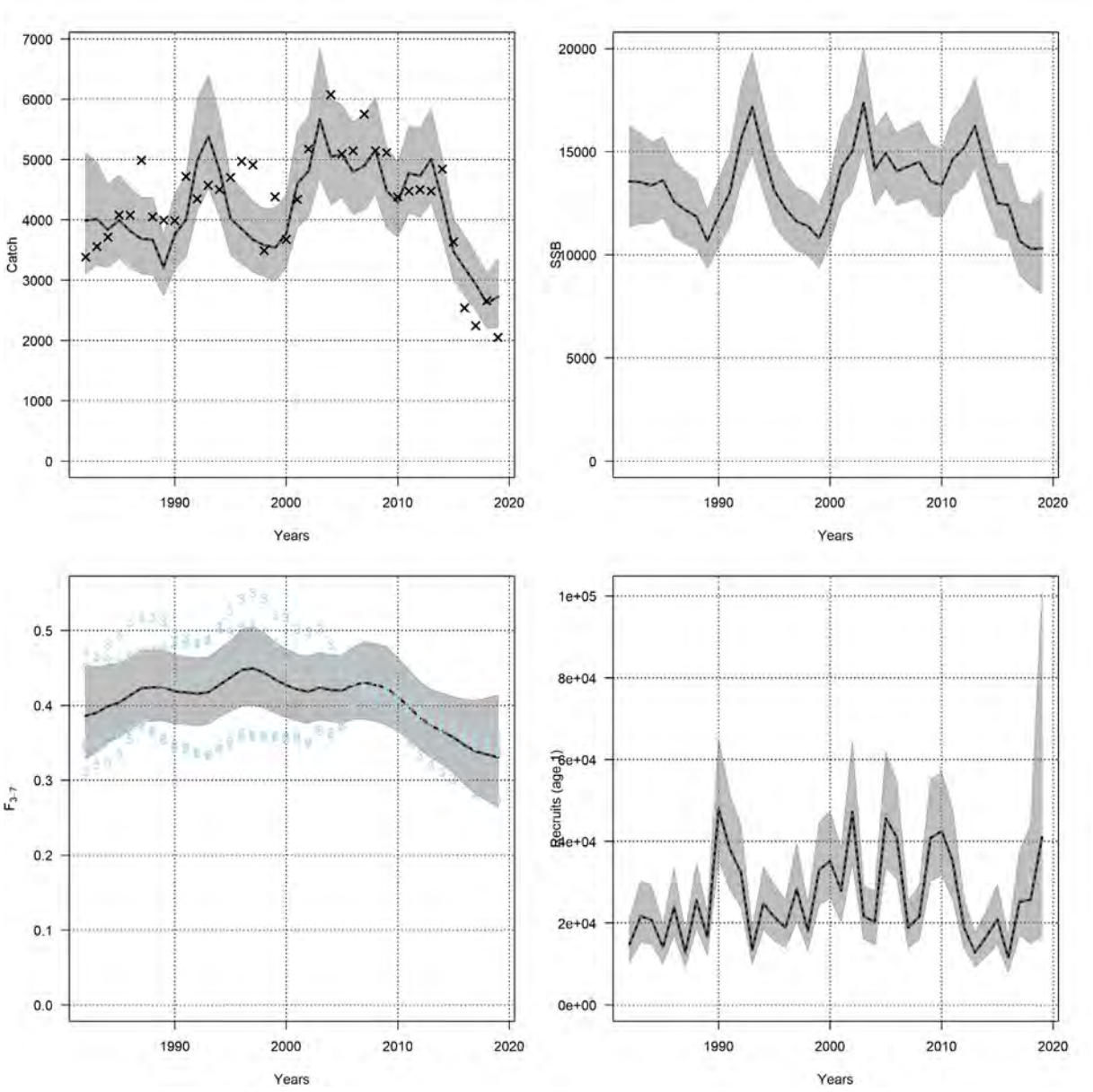


Figure 51: Estimated quantities (catches, SSB, Fbar and recruitment). The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

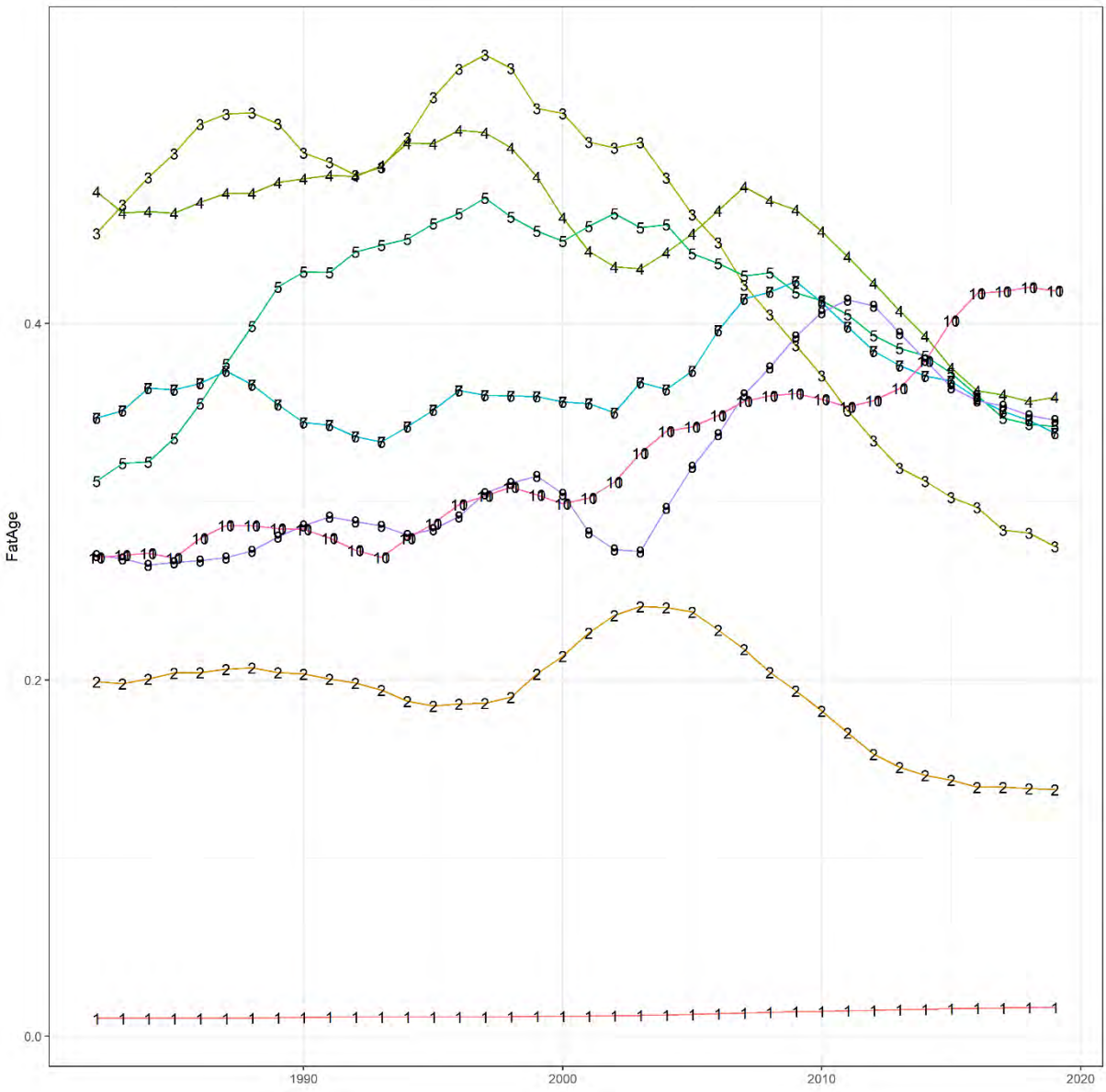


Figure 52: Fishing mortality by age group, note that age 6-7, 8-9 and 10-11(+) overlap.

4.9.2 Model validation

There are no clear differences between the OSA and process residuals of RUN 6 and RUN 7 that favour one of the models (Figure 53 and 54). Also regarding the retrospective analysis and the leave-one-out runs, no clear differences are visible between both runs (Figure 55 and 56).

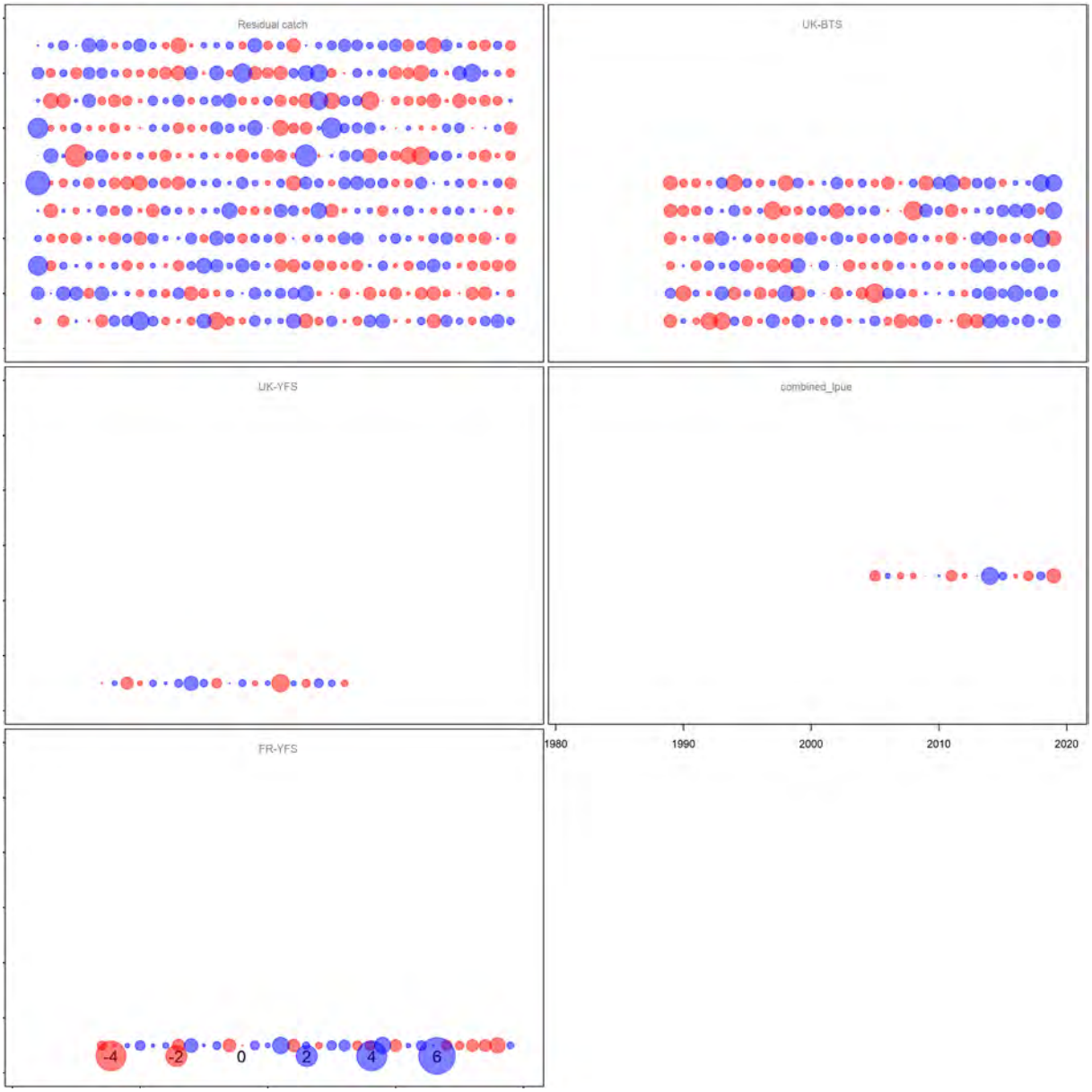


Figure 53: One-step ahead residuals by data stream.

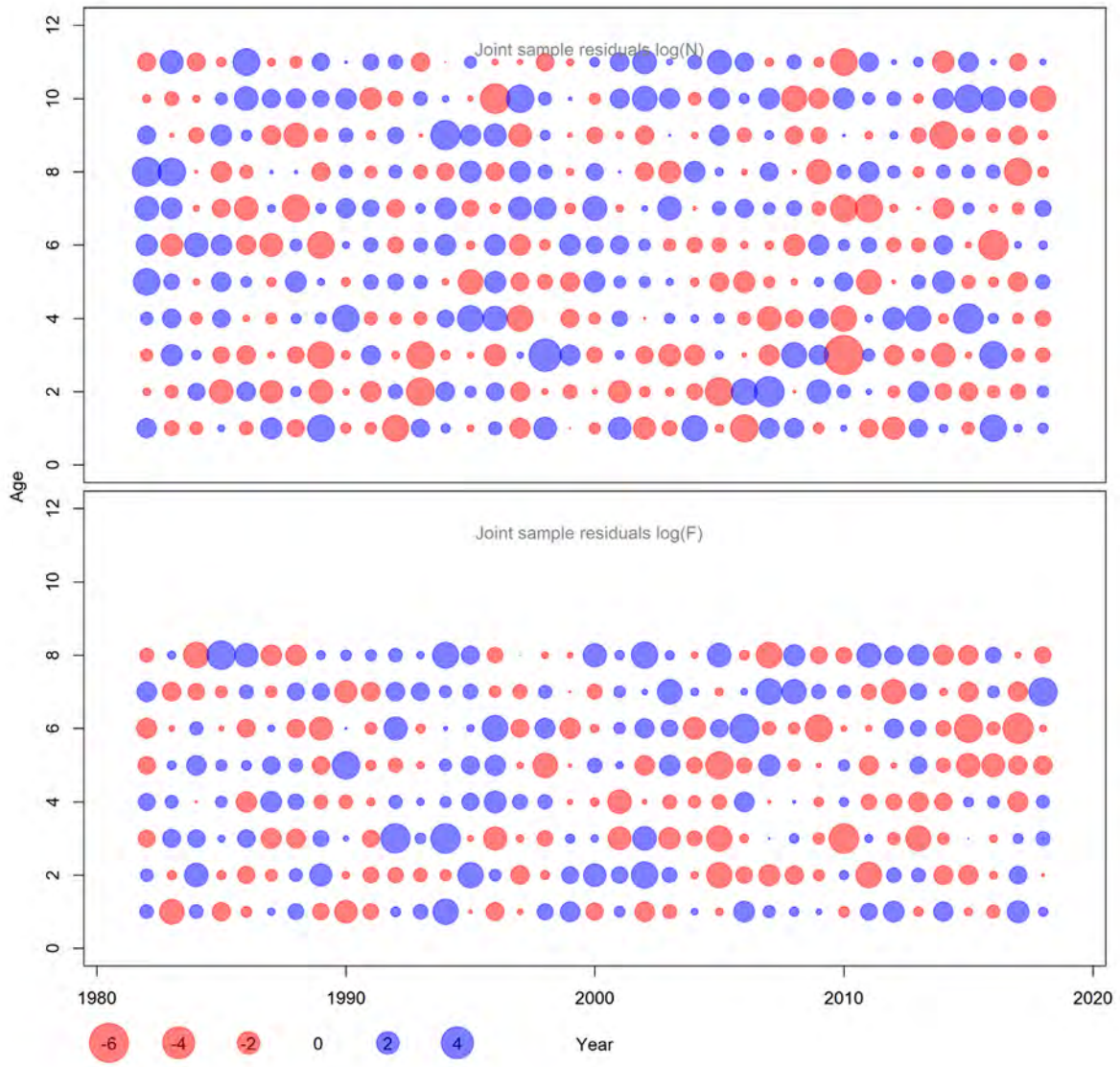


Figure 54: Process residuals for the survival (logN) and fishing mortality (logF) processes. Remark that y-axis for the logF process residuals corresponds to the parameter number.

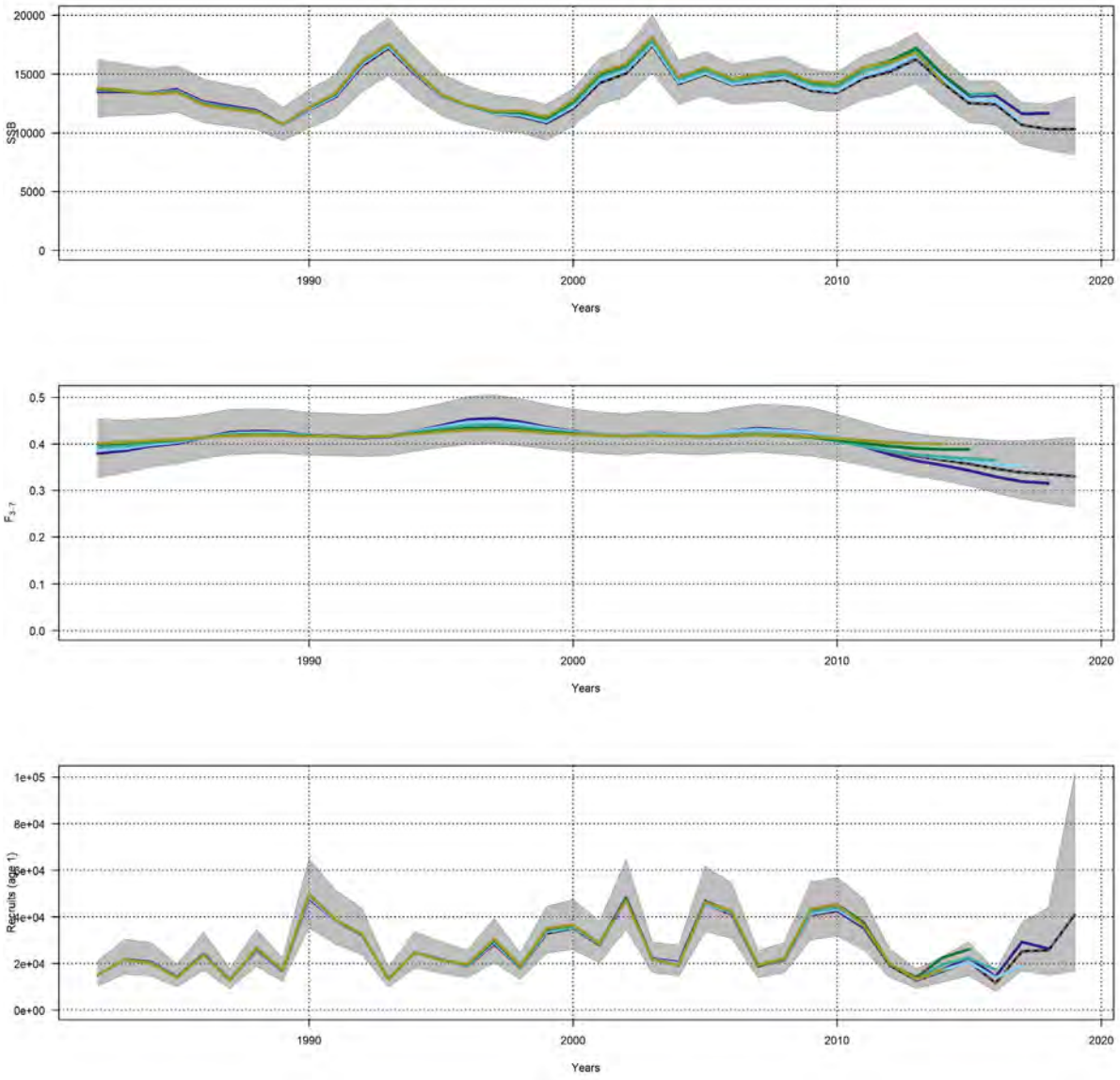


Figure 55: Retrospective analysis with peels 1 to 5 years. The corresponding Mohn rho's are: ρSSB = 0.1181; ρFbar = 0.0586; ρR = 0.0436. The grey shades represent the 95% confidence intervals of the model including all data years.

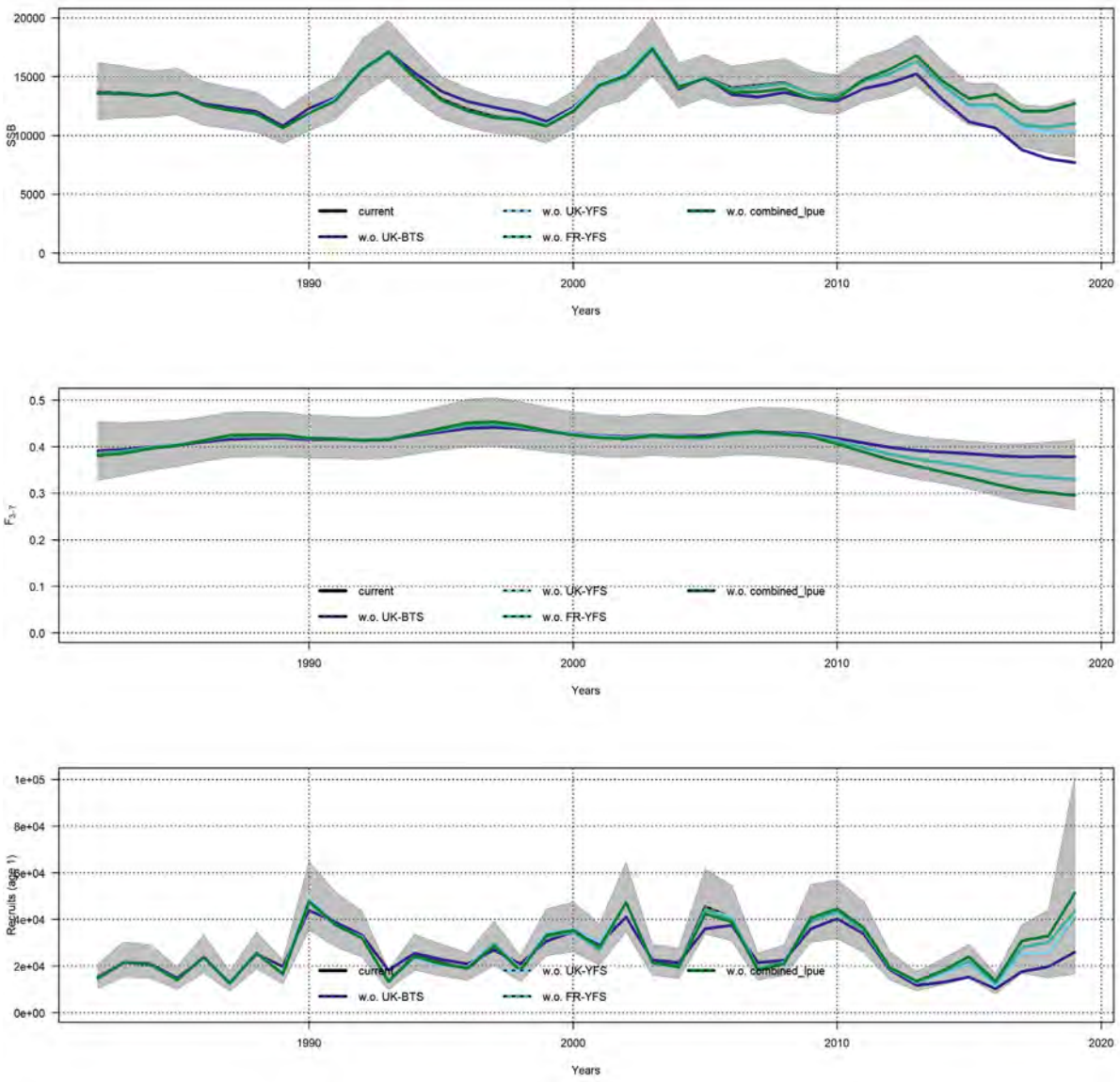


Figure 56: Leave-one-out analysis. Each coloured line refers to a model fit without the respective tuning fleet. The grey shades represent the 95% confidence intervals of the model including all tuning fleets.

4.10 Summary of the SAM assessments

Trends in SSB, Fbar, and recruitment were evaluated for all SAM model runs. The major differences are related to the settings of the process model on the log fishing mortality. In case an autoregressive correlation over the ages is assumed on the logF parameter matrix (RUN 2 and RUN 3), the SSB estimates are higher while the Fbar estimates are lower in the final years of the assessment. These models indicate a lack of stability with respect to the leave-one-out fits and require a single variance parameter of the catch observations to circumvent this issue. Nevertheless, such a parameterisation results in a model with large confidence intervals and poor residuals. Therefore, these models are rejected.

The model presented as RUN 1 depends strongly on the age-structured UK-CBT tuning series. The dependency on a single tuning series and the fact that the age-structured information is used twice in

the assessment model (to derive catch numbers-at-age, and age-structured tuning fleets) cause that this model is not found appropriate to assess the sole 7d stock.

The models with the commercial tuning fleets as separate biomass indices (RUN 4, RUN 5, and RUN 6) are very similar. In general, there is little effect of having the commercial tuning fleets as an SSB or an FSB index in the model. Only in the final years of the assessment model, when the F-at-age trends indicate a strong change in selectivity of the fishery, the models with FSB indices estimate SSB and Fbar, higher and lower, respectively. Considering that 1) the commercial tuning fleets used in the assessment contribute for a significant amount to the total sole catches in the eastern English Channel and are thus likely to mimic the selectivity of the entire fishery and 2) the UK-BTS (WD_Sole7d_5_UK_BTS) showed a decline in length-at-age of age 2 and age 3 fish during the last 10 years, it is assumed that the tuning fleets reflect the trends in the fishable biomass better than the trends of the spawning stock biomass.

The differences between RUN 5 and RUN 6 are also minor, and only visible in the F-at-age trends. Note that only the catch numbers-at-age provide information to track the cohorts from age 7 onwards. Therefore, a reduced number of parameters from age 6 seems a more robust approach. This is visible in the F-at-age trends for the older age groups. In RUN 5, the trends in fishing mortality for age 9 and age 10, 11(+) differ remarkably in the last 10 years, with a decline for age 9, and an increase for age 10, 11(+). This cannot be explained by e.g. difference in size-selectivity, or other biological processes. In RUN 6, the fishing mortality for the older age groups reveal similar trends which is more realistic. RUN 6 has also a lower AIC than RUN 5, and therefore this model is considered better than RUN 5.

The model of RUN 7 is very similar to the model of RUN 6, and none of the validation analysis indicate a clear winner. Therefore, model selection was based on the input data. Since there is no agreed method to combine different tuning fleets in a single relative index of abundance, it was decided to reject the model with the combined commercial tuning fleet.

As a final validation of model 6, three more analyses were performed: 1) a simulation study (n = 100) in which data was simulated from the fitted model and the model was fitted again to each of the simulated datasets (Figure 57), 2) a jitter analysis in which the model was fitted for 100 different sets of initial parameter values to test the robustness of the model to local minima (Figure 58), and finally, 3) the discard data for age 1 and 2 prior to 2004 were removed from the analysis to validate the manual back calculation of discard numbers-at-age during the period that these data was not available (Figure 59). None of these analysis indicated a problem, and therefore, RUN 6 is considered as an appropriate model to assess the eastern English Channel sole stock.

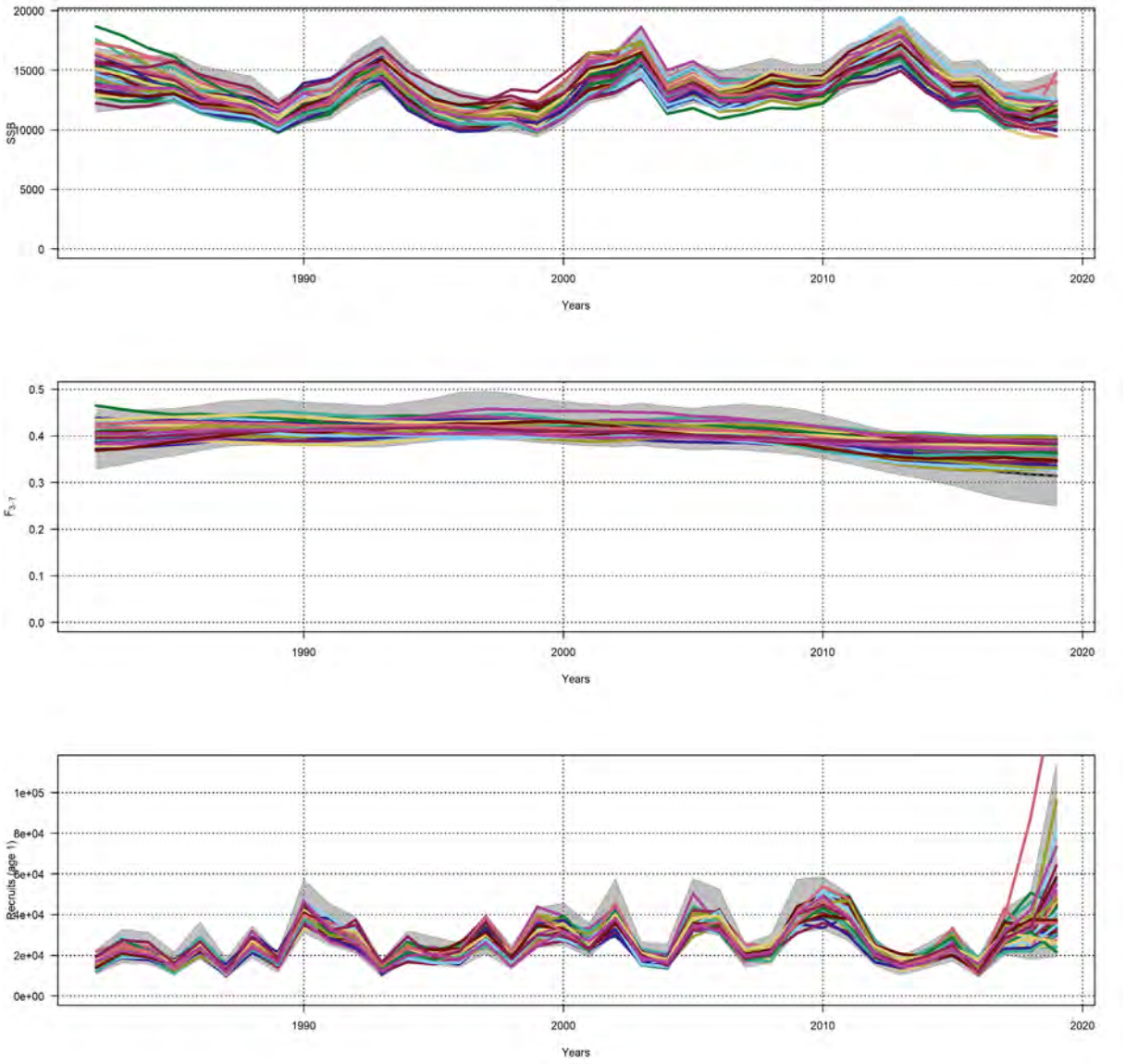


Figure 57: Simulation study (n=100) of RUN 6. The grey shade represent the 95% confidence intervals of the model fit to the real data.

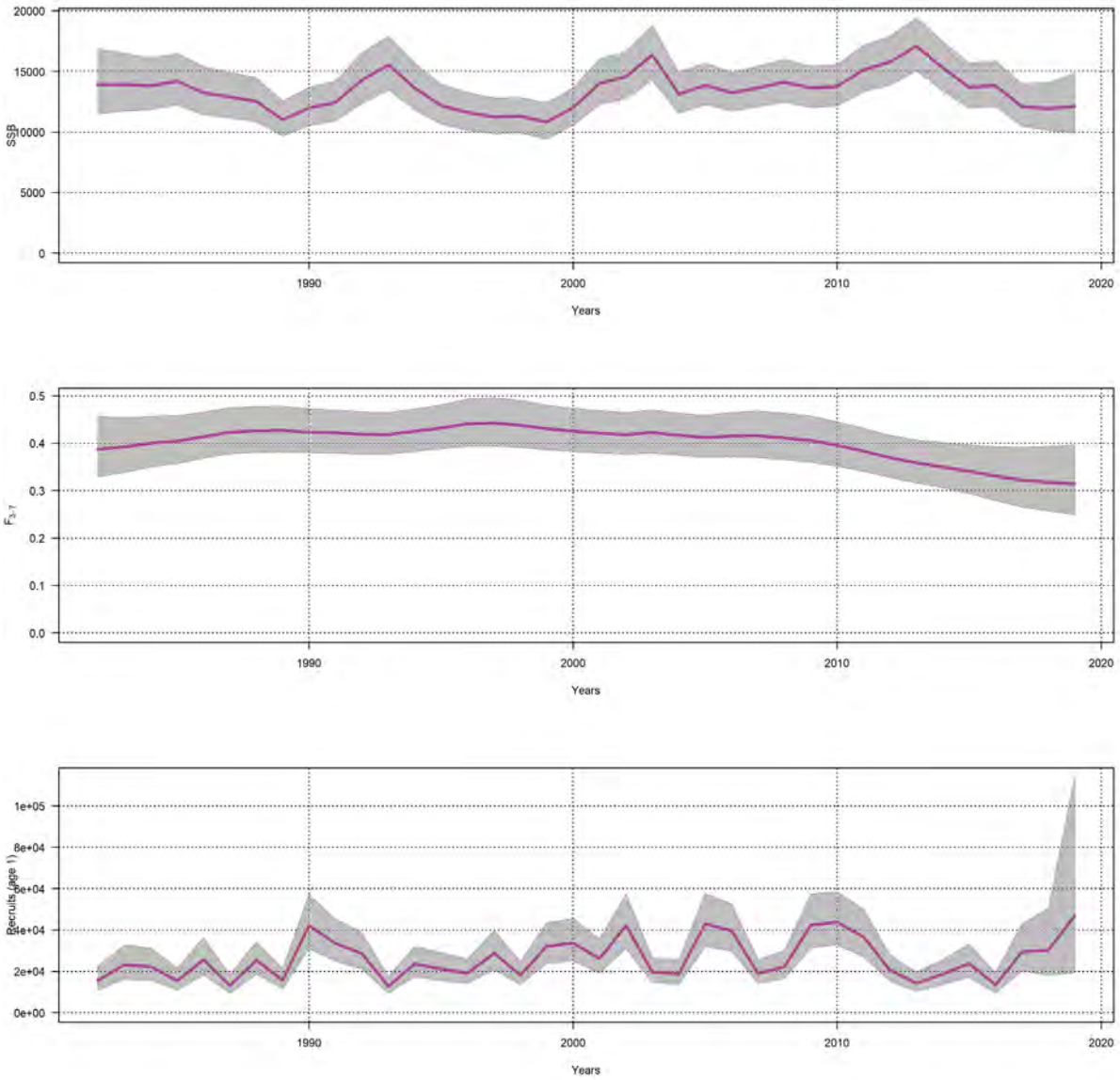


Figure 58: Output of the jitter analysis (n = 100) of RUN 6. The grey shade represents the 95% confidence intervals of the original model fit.

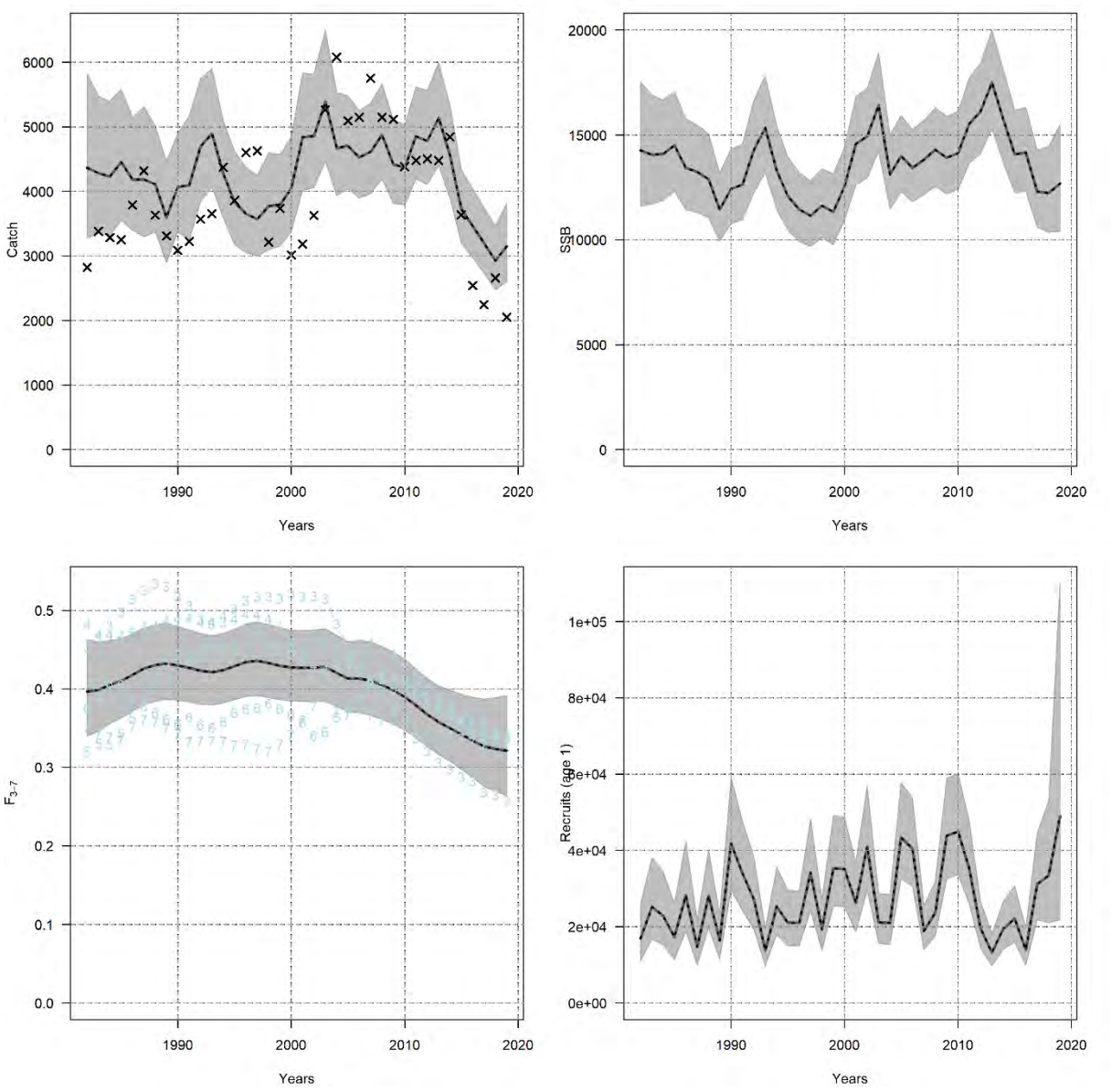


Figure 59: Estimated quantities (catches, SSB, Fbar and recruitment) for RUN 6 in absence of catch numbers at age for age 1 and 2 prior to 2004. The grey shade represent the 95% confidence intervals. The crosses in the catch plot refer to the observed catches.

5. References

ICES, 2017. Report of the Benchmark Workshop on North Sea Stocks (WKNSEA), 6-10 February 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:34, 673 pp.

Lecomte, J-B., Le Pape, O., Baillif H., Nevoux, M., Vermard, Y., Savina-Rolland M., Veron, M., Lehuta S., Hunter E., Rivot, E. 2019. State-space modelling of multi-decatdal mark-recapture data reveals low adult dispersal in a nursery-dependent fish metapopulation. Canadian Journal of Fisheries and Aquatic Sciences. https://doi.org/10.1139/cjfas-2019-0037

Working document: Calculation of appropriate reference points (MSY) for sole in Division 27.7.d

Authors: Lies Vansteenbrugge and Klaas Sys (ILVO, Belgium)

1. Introduction

During the WKNSEA 2021 benchmark, the sole 7d assessment was thoroughly revised. One of the ToRs was to re-examine and update MSY and PA reference points according to the ICES guidelines. This working document describes the calculation of the reference points.

2. Reference points prior to the benchmark

Reference points prior to the benchmark are listed in the table below. The management plan (MAP) that is referred to, is the EU multiannual plan (MAP) for the Western Waters (EU, 2019).

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	15072	B_{pa}
	F_{MSY}	0.192	EQsim analysis, based on the recruitment period 1982-2016
Precautionary approach	B_{lim}	10766	B_{loss}
	B_{pa}	15072	B_{lim} x 1.4
	F_{lim}	0.421	EQsim analysis, based on the recruitment period 1982-2016
	F_{pa}	0.300	F_{lim}/1.4
Management plan	MAP MSY $B_{trigger}$	15072	MSY $B_{trigger}$
	MAP B_{lim}	10766	B_{lim}
	MAP F_{MSY}	0.192	F_{MSY}
	MAP range F_{lower}	0.116-0.192	Minimum F which produces at least 95% of maximum yield
	MAP range F_{upper}	0.192-0.319	Maximum F which produces at least 95% of maximum yield

3. Source of data

Data used in the MSY analyses were taken from the SAM fit of the sole in division 27.7.d assessment as agreed upon during the WKNSEA 2021 benchmark and translated to an FLStock object.

4. Methods and settings

All analyses were conducted with Eqsim and following the ICES technical guidelines as described in ICES (2017). The R code is included in Annex 1. Model and data selection settings are listed in Table 1.

Table 1: Model and data selection settings.

Data and parameters	Settings	Comments
SSB-recruitment data	Whole time series minus last data year (1982-2018)	To be in line with the forecast and because the 2019 estimate of recruitment is very uncertain, the last data year was removed as the SAM model was used to make catch predictions.
Exclusion of extreme values (option extreme.trim)	No	
Mean weights and proportion mature; natural mortality	2015-2019	There is a pattern in the mean weight-at-age over the past ten years. Therefore, a shorter 5-year-period was applied.
Exploitation pattern	2015-2019	There is a pattern in the exploitation of this stock with age 2 and 3 decreasing and ages 7-11 increasing over the last 10 years. Therefore, instead of taking the default 10-year-period, only the last 5 years were selected (Figure 1).
Assessment error in the advisory year. CV of F	0.212	Default value for stocks where these uncertainties cannot be estimated
Autocorrelation in assessment error in the advisory year	0.423	Default value for stocks where these uncertainties cannot be estimated.

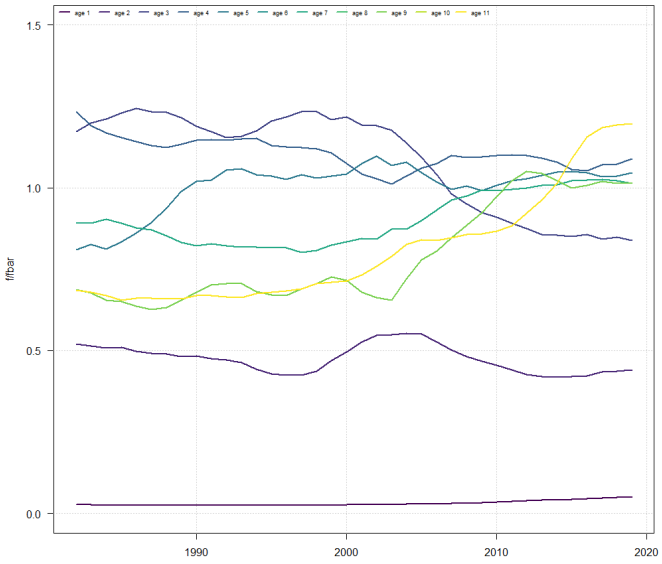


Figure 1: The exploitation pattern at age (the fishing mortality at age as estimated by the assessment divided by the Fbar (age 3-7) per year). Note that due to SAM model settings fishing mortalities overlap for certain ages.

5. Results

5.1 Stock recruitment relation and new B_{lim} and B_{pa} reference points

Stock recruitment relationships were plotted and in a first step, three models were used: Ricker, Beverton-Holt and segmented regression, weighted by the default 'Buckland' method (Figure 2).

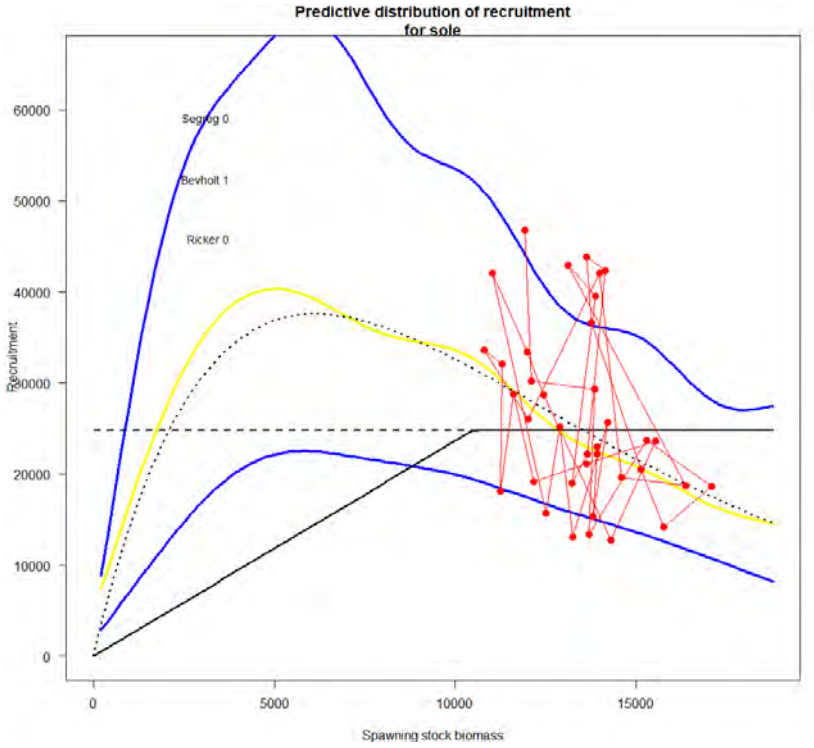


Figure 2: Stock recruitment relationships for sole in ICES division 7.d showing the estimation of three regression models over the entire time period minus the last data year (2019) (segmented regression: solid line; Beverton-Holt: dashed line; Ricker: dotted line; yellow line represents the best fit over the three models).

The stock-recruitment relationship was evaluated as **type 5**, showing a stock with no evidence that recruitment has been impaired or with no clear relation between stock and recruitment. There is a narrow range in SSB, implying type 6 might be an option, however we are unable to determine whether the stock is depleted or stable.

The B0 (virgin biomass) is estimated to be approximately 95000 tonnes. Currently the biomass is estimated at 12129 tonnes, which is just above 10% of this virgin biomass and thus not strongly depleted. On the other hand, the stock cannot be considered as stable as this would mean that the fishing mortality has been low over the time series, while it is estimated higher than 0.4 for a large part of the time series. This is a high value compared to other sole stocks.

Therefore, the B_{lim} should be defined as the B_{loss} value, being **10811** tonnes. B_{pa} was then derived using the standard multiplier of 1.4, resulting in **15135** tonnes. B_{pa} was not estimated using the formula $B_{pa} = B_{lim} \times \exp(1.645 \times \sigma)$, with σ estimated from the assessment uncertainty in SSB in the terminal year (σ is the estimated standard deviation of ln(SSB) in the final assessment year). When σ is lower than 0.2, the 1.4 multiplier should be used and this was the case (0.1003931).

5.2 Determine F_{lim} and F_{pa}

The preferred method to derive F_{lim} is simulating a stock with a segmented regression S-R relation (Figure 3) with the point of inflection fixed at B_{lim}, thus determining the fishing mortality (F) that, at equilibrium, gives a 50% probability of the SSB being larger than B_{lim}. This simulation was conducted based on a fixed F (*i.e.* without inclusion of a $B_{trigger}$) and without inclusion of assessment/advice errors (*i.e.* F_{cv} and F_{phi} set to zero).

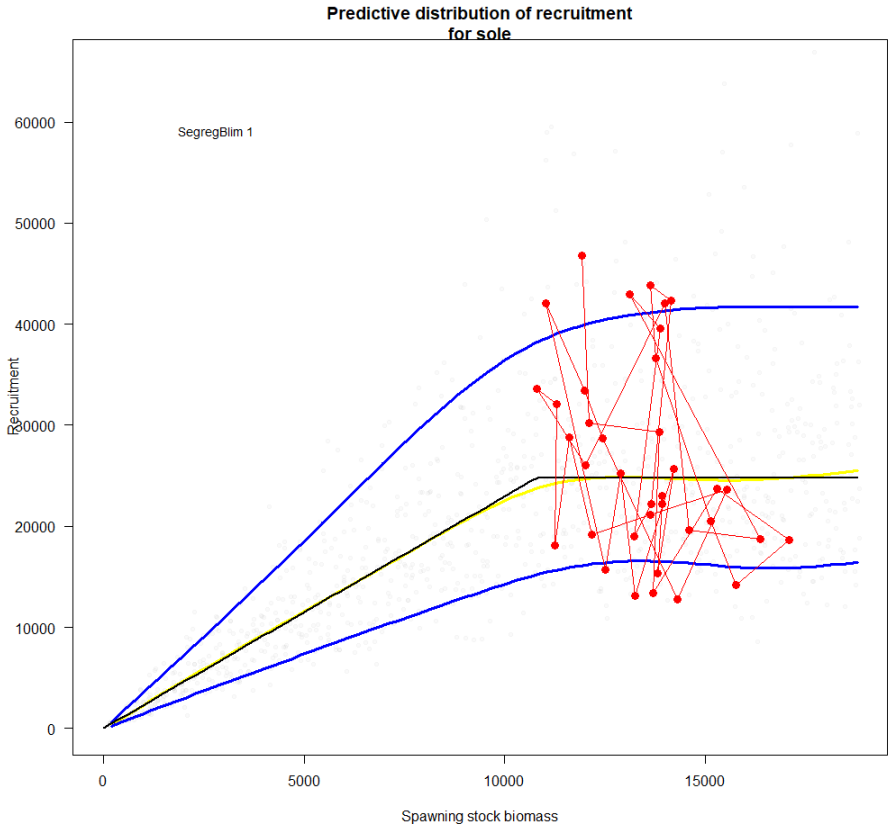


Figure 3: Stock recruitment relationship for sole in ICES division 7.d based on segmented regression over the entire time period minus the last data year (2019), where the inflection point was set to Blim.

F_{lim} was estimated at **0.422** (0.4221266) using the last 5 years of data (2015-2019) (see table below). F_{pa} was calculated at 0.302 when using the 1.4 multiplier. However, F_{pa} should now be set at F_{p05} including the advice rule and will therefore be shown in paragraph 5.4.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.337	0.355	**0.422**	NA	0.300	NA	NA	NA	NA
lanF	NA	NA	NA	0.191	0.200	0.107	0.116	0.340	0.355
catch	3832.480	3812.188	3462.724	NA	3849.985	NA	NA	NA	NA
landings	NA	NA	NA	2930.462	2923.975	2779.585	2799.733	2780.766	2797.477
catB	14483.907	13766.707	10782.513	NA	16102.957	NA	NA	NA	NA
lanB	NA	NA	NA	23576.706	22786.466	35661.666	NA	14394.581	NA

5.3 Determine initial F_{MSY} and its ranges

The initial F_{MSY} was calculated using the fit by the segmented regression model using the whole time-series minus the last data year (Figure 4).

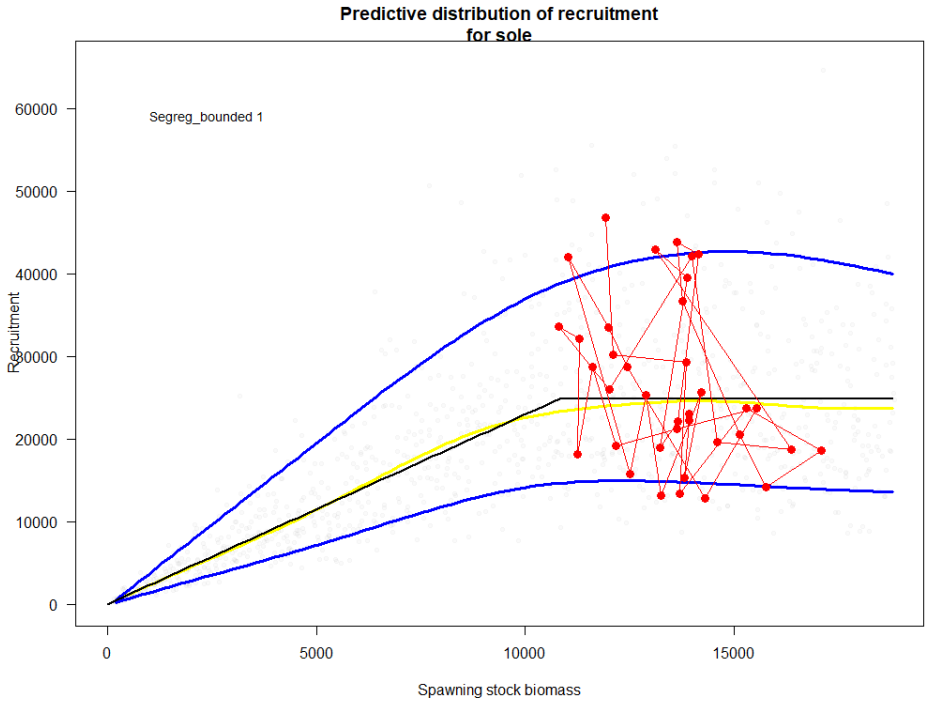


Figure 4: Stock recruitment relationship for sole in ICES division 7.d, based on segmented regression over the entire time period minus the last data year (2019).

For this simulation run, the assessment/advice errors were set to the default values (Table 1) and $B_{trigger}$ was set to zero. This resulted in a median F_{MSY} of **0.193** (0.1931932) (<F_{pa}). The median of the SSB estimates at F_{MSY} was 23060 tonnes. The upper bound of the F_{MSY} range, giving at least 95% of the maximum yield, was estimated at 0.331 and the lower bound at 0.113. The results of the Eqsim simulations are shown in the table below and Figure 5-7.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.307	0.329	0.406	NA	0.280	NA	NA	NA	NA
lanF	NA	NA	NA	**0.193**	0.200	**0.113**	0.114	**0.331**	0.333
catch	3773.635	3748.767	3290.626	NA	3783.093	NA	NA	NA	NA
landings	NA	NA	NA	2838.228	2835.469	2694.255	2799.887	2694.308	2797.146
catB	15558.983	14556.420	10773.174	NA	16872.271	NA	NA	NA	NA
lanB	NA	NA	NA	**23059.799**	22464.411	34266.967	NA	14452.061	NA

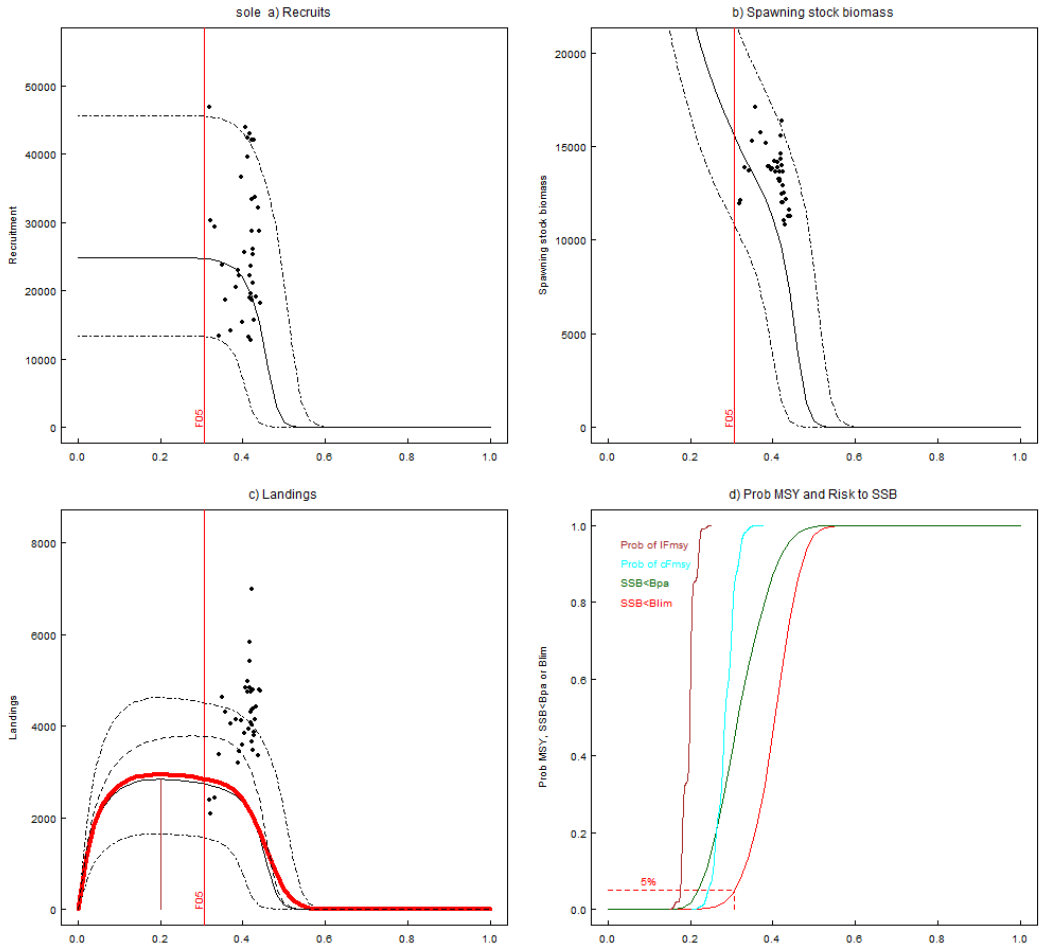


Figure 5: Eqsim summary plot for sole in ICES division 7.d (without Btrigger). Panels a-c: historic values (dots) median (soid black line) and 90% intervals (dotted black lines) for recruitment, SSB and landings for exploitation at fixed values of F (on x-axis). Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<Blim(red), SSB<Bpa (green), and the cumulative distribution of FMSY based on yield as landings (brown) and catch (cyan).

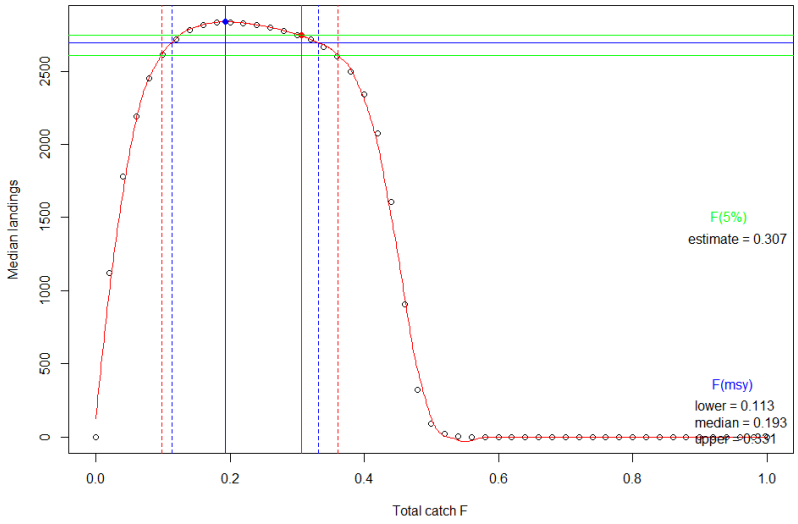


Figure 6: Median landings yield curve for sole in ICES division 7.d, with estimated reference points (without Btrigger) and with a fixed F exploitation from F=0 to 1.0. Blue lines: FMSY estimate (solid line) and range at 95% of maximum yield (dotted lines). Green lines: Fp0.5 estimate (solid line) and range at 95% of yield implied by Fp0.5 (dotted lines).

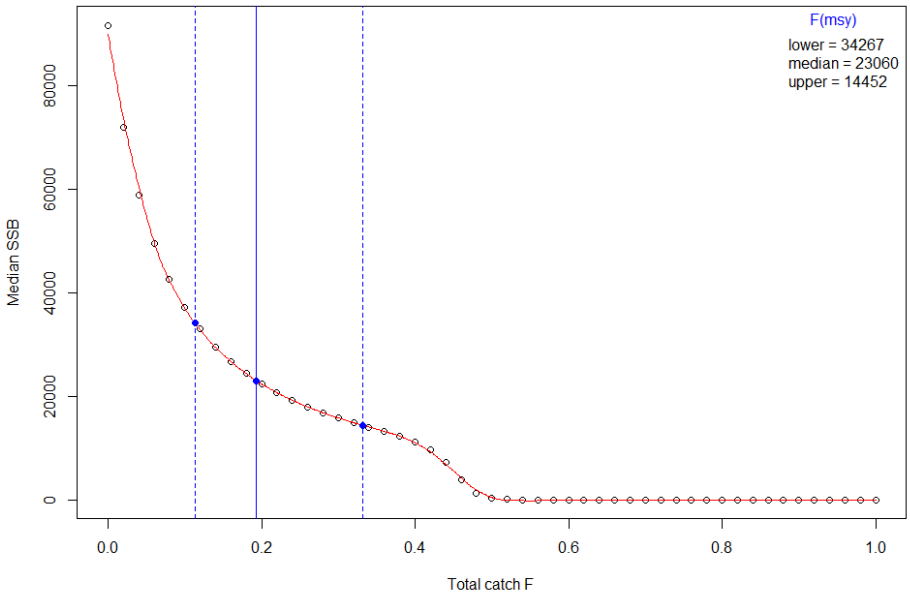


Figure 7: Median SSB curve over a range of target F values (without Btrigger) for sole in ICES division 7.d. Blue lines: FMSY estimate (solid line) and range at 95% of maximum yield (dotted line).

5.4 Determine MSY $B_{trigger}$ and evaluate ICES MSY Advice rule

Since the stock has not been fished at F_{MSY} for 5 or more years, MSY $B_{trigger}$ should be set at B_{pa}: **15135** tonnes.

To evaluate the reference points when enforcing the $B_{trigger}$, a final Eqsim run was performed. When applying the ICES MSY advice rule with a $B_{trigger}$ of 15135 tonnes, median F_{MSY} is 0.192 with a lower bound of the range at 0.113 and an upper bound at 0.376. The $F_{p0.5}$ value (0.379) is larger than the initial F_{MSY} (0.193). Therefore, F_{MSY} stays at the value initially calculated. $F_{p0.5}$ is larger than the estimate of the upper bound on F_{MSY} implying that fishing at this upper bound is precautionary. **F_{pa}** should be set to $F_{p0.5}$ being 0.379 (0.3789732).

The results of the Eqsim simulations are shown in the table below and in Figure 8-10.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	**0.379**	0.419	0.589	NA	0.300	NA	NA	NA	NA
lanF	NA	NA	NA	**0.192**	0.200	**0.113**	0.114	**0.376**	0.385
catch	3776.688	3741.398	3465.959	NA	3809.913	NA	NA	NA	NA
landings	NA	NA	NA	2836.972	2832.706	2693.870	2759.127	2691.591	2757.262
catB	13972.493	13199.516	10809.936	NA	16224.396	NA	NA	NA	NA
lanB	NA	NA	NA	23128.614	22442.878	34210.173	NA	14024.872	NA

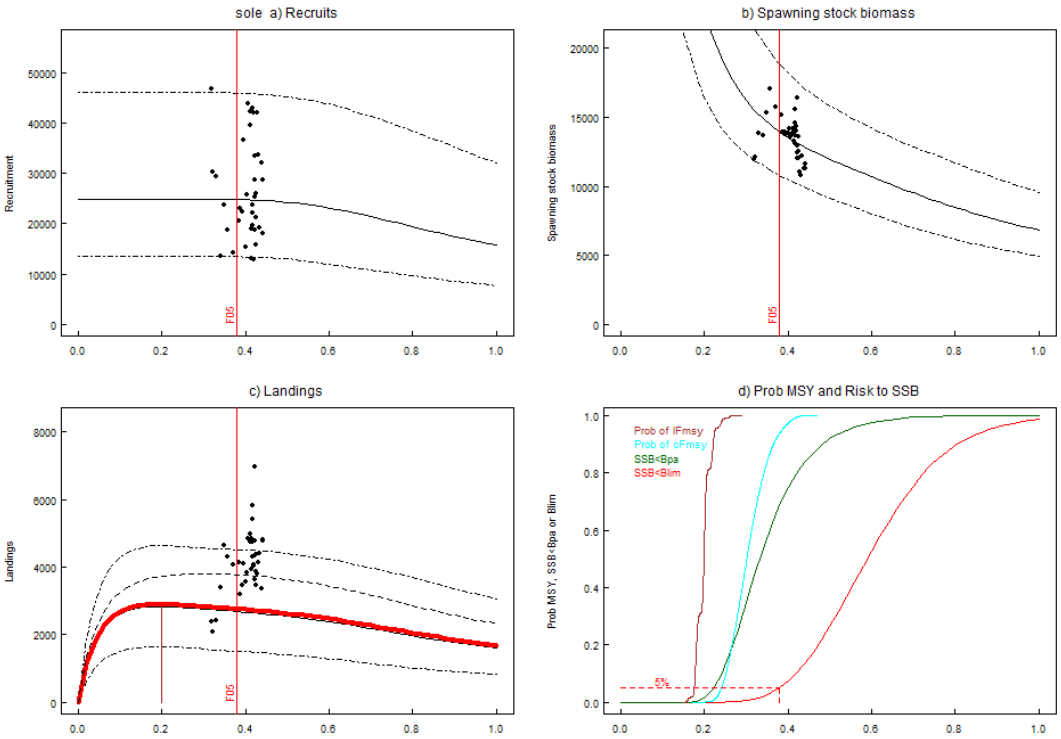


Figure 8: Eqsim summary plot for sole in ICES division 7.d (with Btrigger = 15135 tonnes). Panels a-c: historic values (dots) median (soid black line) and 90% intervals (dotted black lines) for recruitment, SSB and landings for exploitation at fixed values of F (on x-axis). Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<Blim(red), SSB<Bpa (green), and the cumulative distribution of FMSY based on yield as landings (brown) and catch (cyan).

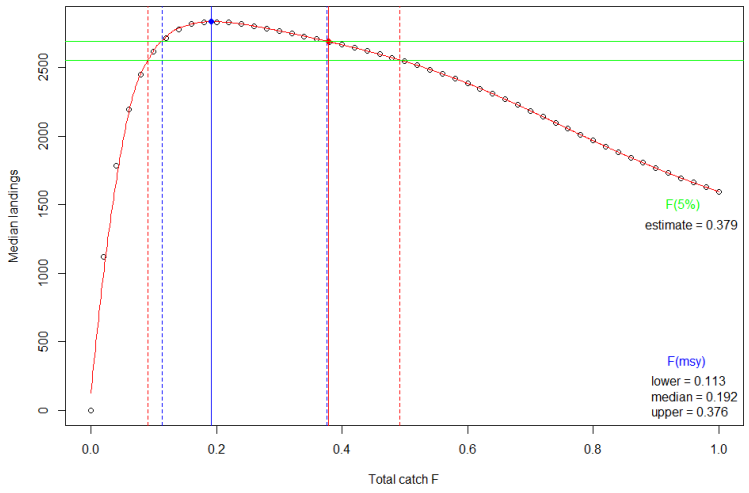


Figure 9: Median landings yield curve for sole in ICES division 7.d, with estimated reference points (Btrigger = 15135 tonnes) and with a fixed F exploitation from F=0 to 1.0. Blue lines: FMSY estimate (solid line) and range at 95% of maximum yield (dotted lines). Green lines: Fp0.5 estimate (solid line) and range at 95% of yield implied by Fp0.5 (dotted lines).

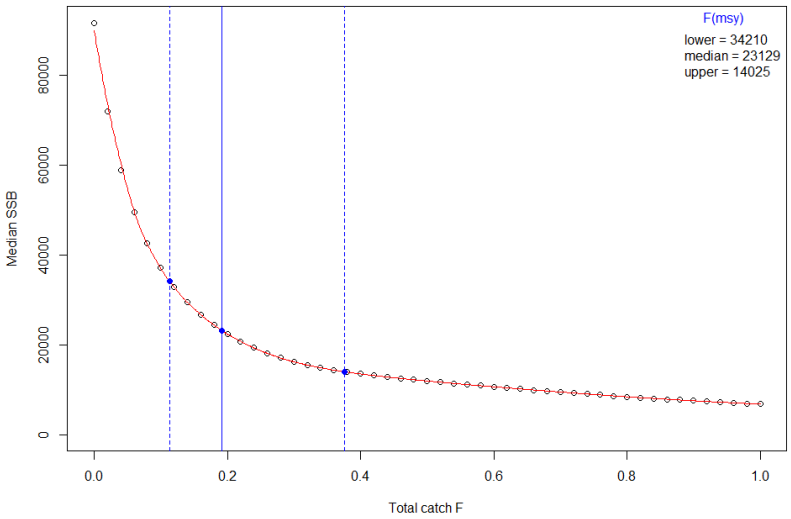


Figure 10: Median SSB curve over a range of target F values (Btrigger = 15135 tonnes) for sole in ICES division 7.d. Blue lines: FMSY estimate (solid line) and range at 95% of maximum yield (dotted line).

6. Proposed reference points

Reference point	Value
B_{lim}	10811
$B_{pa\ (1.4)}$	15135
$B_{trigger}$	15135
F_{lim}	0.422
$F_{pa\ (1.4)}$	0.302
F_{MSY}	**0.193**
F_{MSY} lower	0.113
F_{MSY} upper	0.331
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$)	0.379
F_{pa} based on $F_{p.05}$	0.379

7. Sensitivity runs

A sensitivity analysis was conducted which involved running Eqsim with a moving window of 5 years of selectivity data starting with 1990–2015 and ending with 2010-2015 (bio data year range 2015–2019 remained constant). The effect on the estimate of median F_{MSY} is shown in Figure 11. The estimate varies between 0.194 and 0.342 depending on the year range chosen and is thus variable over this time period with a decline in the most recent years. In the most recent years, the F_{MSY} estimate (0.193) lies within the confidence bounds of these sensitivity estimates (Figure 11).

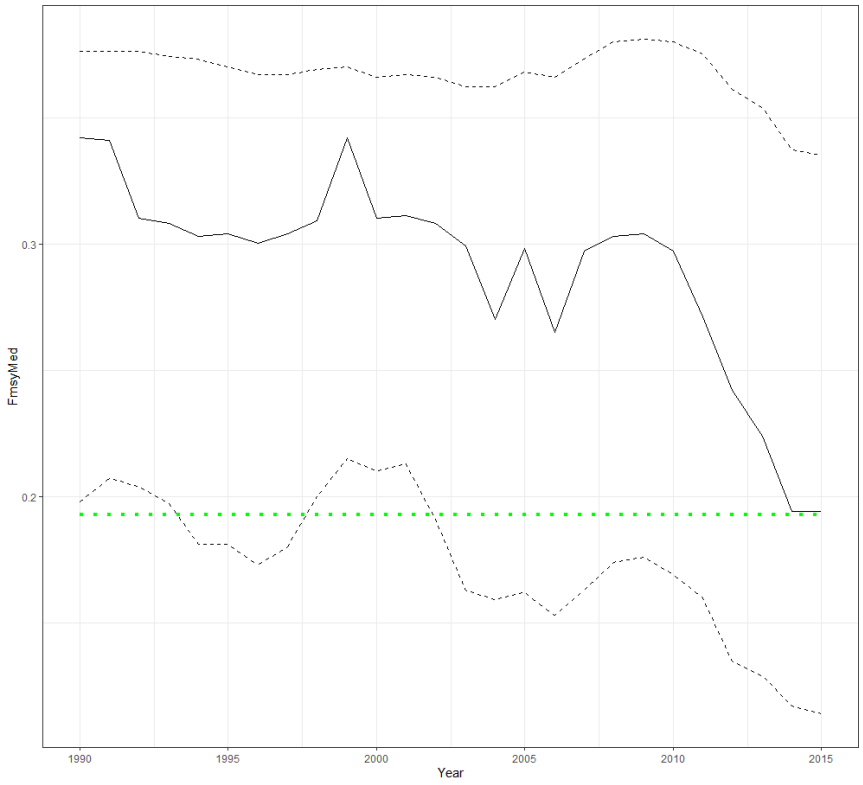


Figure 11: Sensitivity of F_{MSY} estimate (solid black line) to year range of selectivity data for sole in ICES division 7.d (Year label is 1st year of a 5 year range). Dotted lines represent the 5th and 95th percentiles of F_{MSY}. Green striped line represents the F_{MSY} value as estimated by the Eqsim analysis described above (=0.193).

8. References

- ICES, 2017b. ICES Advice Technical Guidelines, ICES fisheries management reference points for category 1 and 2 stocks. Published 20 January 2017.
- EU, 2019. REGULATION (EU) 2019/472 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a multiannual plan for stocks fished in the Western Waters and adjacent waters, and for fisheries exploiting those stocks, amending Regulations (EU) 2016/1139 and (EU) 2018/973, and repealing Council Regulations (EC) No 811/2004, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007 and (EC) No 1300/2008. 17pp. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0472

Annex 1: R script for the calculation of the reference points

```
##############################################
#
# Calculating Reference points for SOL 7d
# WKNSEA 2021 (Feb 2021)
#
# script via Jan Jaap Poos and Helen Dobby
##############################################

getwd()
setwd("~/Development/RStudio/D1VISBIO/NDGP")
path<-getwd()
setwd(paste0(path,"/ICES/ASSESSMENTS/SOL_7D/WKNSEA 2021/Refpoints/R/"))
source("eqsim functions.R")
source("msy_functions.R")
source("SAM_to_FLStock.R")

##############################
# Eqsim runs                 #
##############################

# when removing last data year, this is not visible in red dots, but model values change:
FIT1 <- eqsr_fit(sol7d,
            nsamp = 1e3,
            models = c("Segreg", "Bevholt","Ricker"),
            remove.years = ac(2019))

save(FIT1, file = "FIT1.RData")

eqsr_plot(FIT1,n=1e3)

# get estimate from sigma for calculation of Bpa with multiplier (1.4) or with formula
final_fit$sdrep$sd[names(final_fit$sdrep$value) == "logssb"] # take last value
final_fit$sdrep$sd[38]
sd_ssb <- final_fit$sdrep$sd[names(final_fit$sdrep$value) == "logssb"]
sd_ssb[length(sd_ssb)]
# [1] 0.1003931

# Type 5
Bloss <- min(ssb(sol7d))
Bloss
Blim <- Bloss
Blim

# determine Bpa
print(Bpa <- Blim * 1.4)

###################### Estimate Flim (=F50)
# -> based on stock with segmented regression SR relationship with inflection point at Blim
# Fix function to do segmented regression:

B<-Blim
SegregBlim <- function (ab, ssb) {
  log(ifelse (ssb>=B, ab$a*B, ab$a*ssb))
```

```
}

FIT2 <- eqsr_fit(sol7d, nsamp = 1e3, models = "SegregBlim", remove.years = ac(2019))
setwd("~/Development/RStudio/D1VISBIO/NDGP/ICES/ASSESSMENTS/SOL_7D/WKNSEA
2021/Refpoints/OUTPUT/Run4trisType5/")
save(FIT2, file = "FIT2.RData")
FIT2$sr.det # gives b = 1
#print(Blim <-  FIT2b[["sr.det"]][,"b"])

eqsr_plot(FIT2,n=1e3)
SavePlot("Flim_segreg" , getwd())

#simulation
SIM101 <- eqsim_run(FIT2,  bio.years = c(2015, 2019), bio.const = FALSE,
              sel.years = c(2015, 2019), sel.const = FALSE,
              Fcv=0, Fphi=0,
              Btrigger = 0,Blim=Blim,Bpa=NA,
              Fscan = seq(0,1.2,len=61),verbose=FALSE) #in 61 steps from F=0 to F=1.2
save(SIM101, file = "SIM101.RData")

eqsim_plot(SIM101,catch="FALSE")
SavePlot("eqsim_plot1" , getwd())

Coby.fit(SIM101,outfile='sole no Btrigger Blim set to find Flim Fcv=0 and Fphi=0')
# from this table get F50, catF
print(Flim <- SIM101$Refs2[1,3])
print(Fpa <- Flim/1.4)

###################### Calculate Fmsy

Segreg_bounded <- function(ab, ssb) {
 ab$b <- ab$b + Bloss
 Segreg (ab, ssb)
}

FIT3 <- eqsr_fit(sol7d,
            nsamp = 1e3,
            models = c("Segreg_bounded"), remove.years = ac(2019))

eqsr_plot(FIT3,n=1e3)
SavePlot("Fmsy_segreg_bounded" , getwd())

SIM1a <- eqsim_run(FIT3,  bio.years = c(2015,2019), bio.const = FALSE,
              sel.years = c(2015,2019), sel.const = FALSE,
              Fcv=0.212, Fphi=0.423,  # these are defaults, taken from WKMSYREF4, as used in Saithe assessments
              Btrigger = 0,Blim=Blim, Bpa=Bpa,Fscan = seq(0,1.0,len=51),verbose=FALSE)#in 51 stappen van F=0
naar F=1.0
save(SIM1a, file = "SIM1a.RData")
eqsim_plot(SIM1a,catch="FALSE")
SavePlot("eqsim_plot_Fmsy" , getwd())

Coby.fit(SIM1a,outfile='sol sim1')
#get median MSY from lanF
print(Fmsy <- SIM1a$Refs2[2,4])
#also get F05 from catF
print(F05 <- SIM1a$Refs2[1,1])


#EVALUATE
SIM2 <- eqsim_run(FIT3,  bio.years = c(2015,2019), bio.const = FALSE,
              sel.years = c(2015,2019), sel.const = FALSE,
              Fcv=0.212, Fphi=0.423,  # these are defauts, taken from WKMSYREF4, as used in Saithe assessments
              Btrigger      =      Bpa,Blim=Blim,Bpa=Bpa,Fscan      =      seq(0,1.0,len=51),verbose=FALSE,
extreme.trim=c(0.05,0.95))
save(SIM2, file = "SIM2.RData")
eqsim_plot(SIM2,catch="FALSE")
SavePlot("eqsim_plot_SIM2" , getwd())

Coby.fit(SIM2,outfile='sol sim2')

print(F05 <- SIM2$Refs2[1,1])
```

```
#SIM1$rbp


##########
#  Sensitivity to year range in selectivity
out <-NULL
sel.years <-c(2015,2019)

for(y in 1990:2015){
 cat(y,'\n')
 # What I am doing here is choosing different blocks of years (each 10 years long) from which to resample the fishery selectivity.
 # The first block (which is labelled '1990' in the output data) has a selectivity data year range from 1990 to 1999, the
 # next 1991 to 2000 and so on, until the last on is 2008 to 2017 (which is the same as your base run)
 sel.years[1] <- y
 sel.years[2] <-y+4
 #  setup$sel.years <- c(y-4,y)
 sim <- eqsim_run(FIT3, bio.years = c(2015,2019), bio.const = FALSE,
             sel.years = sel.years, sel.const = FALSE, Fscan = seq(0,1,0.02),
             Fcv = 0.212, Fphi = 0.423, Blim = Blim, Bpa = Bpa,
             Btrigger = 0, verbose = FALSE, extreme.trim = c(0.05,0.95))

 # For each iteration (i.e different block of selectivity data) we save the estimate of Fmsy and lower and upper bounds
 # So if selectivity has change significantly over time you might expect to see a significant change in your Fmsy
 # estimate (FmsyMed)

 out0 <- data.frame(y,
              Fmsy05 = sim$Refs2[2,6],
              Fmsy95 = sim$Refs2[2,8],
              FmsyMed = sim$Refs2[2,4]
 )
 out <- rbind(out,out0)
}

###################################
getwd()

save(out,file="out.rdata")
# save(out0,file="out0.rdata")
write.csv(out,file="out.csv")
# write.csv(out0,file="out0.csv")

out$Year <- out$y
out$FMSY <- 0.193 #aanpassen
library(ggplot2)
ggplot(out, aes(Year, FmsyMed))+geom_line()+theme_bw()+
 geom_line(aes(Year, Fmsy05), linetype=2)+
 geom_line(aes(Year, Fmsy95), linetype=2)+
 geom_line(aes(Year, FMSY), linetype=3, color="green", size=1.5)
```

Working Document for WKNSea, December 2020 & February 2021

Survey indices for Northeast Atlantic spurdog

Helen Dobby, MSS Marine Laboratory, Aberdeen

Introduction

The current assessment of Northeast Atlantic spurdog makes use of a biomass survey index (and sex disaggregated proportions by length category) derived from Scottish trawl survey data covering the West of Scotland and northern North Sea. The survey index was first used at WGEF in 2009(?) and was a development of work first presented in Dobby et al. (2005).

The survey index was derived using statistical modelling to obtain standardized annual indices of catch per unit effort (in biomass) by identifying explanatory variables which help to explain the variation in catch rate (which is not a consequence of changes in population size) and also to reduce the influence of occasional very high catches which might be unduly influential in an index based on a stratified mean catch rate. Due to the highly skewed distribution of catch rates and the presence of the large number of zeros, a 'delta' distribution approach was taken which combines two statistical models. (Lo et al., 1992 and Stefansson, 1996). In the first model, a binomial GLM (logit link) was used to model the probability of a positive observation and in the second, which models the catch rate conditioned on it being positive, a lognormal distribution was assumed. The overall year effect (annual index) can then be calculated by multiplying the estimates from the two models (with the binomial model predicted at 'standard' values for the other covariates). In addition to a year effect, other explanatory variables found to be significant were area (Scottish demersal sampling area, see Dobby et al. (2005) for further details) and time of year. Depth was not found to be significant (potentially due to correlation between depth and location).

This previous analysis made use of Scottish survey data covering the West of Scotland (Division 6.a) and the northern North Sea (4.a). However, it has consistently been acknowledged that these surveys cover only a small portion of the extent of the northeast Atlantic spurdog stock distribution. One of the main aims of the current benchmarking process was therefore to utilise survey data with greater coverage of the area of stock distribution in the derivation of survey biomass indices. Previous WGEF reports have identified additional surveys which catch a significant number of spurdog including EVHOE and Irish groundfish surveys in the Celtic Sea, Norwegian surveys and the wider (not only Scottish) North Sea IBTS.

During the WKNSEA data compilation meeting it was agreed to explore the development of three separate indices based on survey data collected on a number of different surveys from quarters 1, 3 and 4 separately and covering areas from as far south as the Celtic Sea to Division 3.a. (The previous index had been derived from analysis of data from multiple quarters and making use of a seasonal

effect). To improve transparency and reproducibility, it was also agreed to, as far as possible, make use of survey data directly downloaded from DATRAS.

Data and Methods

Q1 surveys

Data available for use in constructing a quarter 1 survey index consisted of: i) NS-IBTS covering the North Sea and Division 3a, ii) SWC-IBTS & SCOWCGFS (Scottish groundfish surveys covering the West of Scotland) and iii) NO-SH (Norwegian shrimp survey covering Divisions 3.a & 4.a around the Norwegian coast). The NO-SH data were provided to WKNSEA as part of the data call and subsequently reformatted to DATRAS Exchange format and collated with the remaining survey data which were downloaded directly from DATRAS. The full data set covers the North Sea, Division 3.a and the West of Scotland from 1985 onwards. The North Sea data were sub-setted for 4a and 4b given this is deemed to cover the main part of the spurdog stock in this area. (Table 1 provides a summary of surveys used in the analysis and Table 2, the number of hauls in the quarter 1 data set).)

Scottish survey data covering the west of Scotland are denoted using two separate survey identifier codes (Table 1 & 2). Prior to 2011, the survey (SWC-IBTS) was conducted using GOV trawl with ground-gear 'C', using a design based on fixed stations within ICES rectangles and one or two hauls per rectangle (to cover the depth range) (ICES, 2010). In 2011, a new random stratified survey design was implemented and the ground-gear was modified (to GOV 'D'). Strata were based on densities of the main demersal species and greater survey effort allocated to those strata with high within strata variance. The latter survey is known as SCOWCGFS. While the Scottish survey design has changed, the spatial extent of the survey within 6.a has not changed although the SCOWCGFS has no stations in Division 4.a (unlike SWC-IBTS). Further information on SCOWCGFS can be found in ICES (2012a).

The NS-IBTS is an internationally co-ordinated survey and operates according to standard procedures (ICES, 2012b). All of the quarter 1 surveys considered in this analysis use a GOV, although with a variety of modifications to the ground-gear (in the northern and western areas), to allow for trawling on rougher ground. These modifications are considered likely to have limited impact on catchability of spurdog and have not been accounted for in the analysis (Note that the 'GearExp' field in DATRAS is often null or otherwise unhelpful in identifying actual ground-gear modifications).

Q3 surveys

Data for Q3 were downloaded from DATRAS and consist of NS-IBTS data from 1991 onwards and routinely cover ICES divisions 3a, 4a and 4b (other areas are not considered in this analysis). This multi-vessel, multi-nation survey (ICES, 2012b) has generally been carried out using the GOV gear (and consistently so since 1998), but with some differences in the early years. In 1991, the 'DHT' gear was used by UK-SCO and 'GRT' was used by UK-ENG, while between 1992 to 1997, the 'ABD' trawl was used by UK-SCO. Given the limited usage of the DHT & GRT gears, these were removed and further analysis was limited to surveys using the GOV & ABD gear. Removing these minor gears,

resulted in very limited coverage of division 4a in 1991 and therefore the time-series was truncated to 1992 onwards for further analysis (Table 3).

Q4 surveys

A number of countries conduct Q4 trawl surveys in the Celtic Seas Ecoregion (Table 1). Data were downloaded from DATRAS in 'exchange' format for Scottish (SWC-IBTS, SCOWCGFS), Irish (IGFS) and French surveys (EVHOE). The Northern Irish survey data (NIGFS) which are held in DATRAS are incomplete and therefore data submitted to the data compilation workshop were reformatted (into 'exchange' format) and combined with the remaining Q4 survey data from DATRAS.

Data from sub-area 8 have been removed from the analysis to avoid the potential inclusion of other *Squalus* species and the analysis is limited to hauls in Divisions 6a, 7a, b, g, h & j (Table 4). A small number of hauls occur in other parts of Sub-area 7, but these are typically sampled only on an occasional basis and have therefore also been excluded). Coverage of the full area has been relatively consistent since the IGFS survey began in 2003 and hence the year range 2003-2019 is chosen for the delta-gam analysis. Note that the Scottish surveys in quarter 4 underwent similar changes in design in 2011 to those described for quarter 1.

With the exception of the NIGFS data which uses 'ROT' gear (rockhopper otter trawl), the remaining surveys in these areas use the GOV. While the NIGFS is confined to ICES division 7.a, this area is widely covered by the IGFS using GOV in 2003 and 2004 and to a lesser extent also by SWC-IBTS between 2003 and 2005.

Analysis

For each quarter, the survey dataset consists of numbers at length (mostly by sex) at each trawl station ('HL' records in Datras) and in addition, a subsample of individuals for which biological data such as weight are recorded ('CA' records). Catch weight per haul is derived from the length composition (by sex) and a sex specific weight length relationship derived from the sampled individuals. On some hauls/surveys, individuals have been recorded without sex and in such cases the weight caught is derived using a combined sex length weight relationship. Total weight per haul in grammes is then the sum over male/female and unsexed individuals. Data extraction and manipulation made use of the 'DATRAS' R package.

Statistical modelling has been carried out using the 'surveyIndex' R package (Berg, et al. 2014). This package has been used in ICES for deriving survey indices for a number of stocks including West of Scotland herring, North Sea cod and lemon sole. It implements a GAM modelling framework using data in the Datras format and allowing for a variety of different model assumptions including 'delta' models with lognormal and gamma distributions for positive observations and the Tweedie model.

Preliminary analysis indicated poor diagnostic plots (res v fitted, distribution of residuals) and higher AIC when using Tweedie and/or delta-gamma models. The analyses therefore used the delta-lognormal approach with the full model (for both the presence-absence and positive parts of the model) defined as follows:

$$g(\mu_i) = Year_i + Gear_i + U(Ship_i) + s_1(\mathrm{lon}_i, \mathrm{lat}_i) + s_2(\mathrm{depth}_i) + s_3(\mathrm{timeofday}_i) + \log(\mathrm{HaulDur}_i)$$

g is the logit link function for the binomial model (1/0 response), and the lognormal for the positive observations (implemented by log-transforming the response variable and using a normal distribution with identity link function). The model includes an offset to account for the effects of haul duration.

The full model includes both a depth and time of day effect in addition to spatial (lat-lon), Year and Ship effects. The spatial effect is modelled as a 2-dimensional thin plate regression spline (function s1) without year interaction, depth as a 1-d thin plate spline (s2) and a cyclic cubic regression spline used for time of day (s3). A ship effect was included as a random effect and in addition, a gear effect was also considered where relevant. No consideration was given to a time varying spatial effect.

A selection of models including different subsets of explanatory variables were fitted and compared, using AIC to evaluate which model gave the best fit to the data. The two components of the model were assumed to include the same covariates.

In order to calculate the final index, a spatial grid covering the survey area is chosen. The biomass is predicted within each grid cell at the haul nearest to the centroid of the cell (cells with no hauls are excluded) giving a spatial distribution map. Other effects such as gear and ship are fixed at each prediction i.e the prediction is made for a standard gear/ship. Summing over the grid points then provides the biomass index. Predictions are made for 30 min towing time and therefore, index values can be divided by the number of grid cells and multiplied by two in order to derive an index in g hr^{-1}.

Sensitivity testing of the final results was conducted by running retrospective analysis and leave-one-out analysis where possible. These were run manually rather than using the functions provided as part of the getSurveyIdx package as there appeared to be some issues with index scaling when using the latter. Additional model fitting was also carried out to explore the sensitivity of the estimated indices to the occasional very large hauls which are apparent in the data (Figures 1 to 3). For each of the three quarters, the very largest hauls were removed (in Q1 & Q4 > 1 t, Q3 > 0.5 t – 3 hauls in each case) and the final model refitted.

Results

The spatial distribution of raw survey catch rates in weight by quarter are shown in Figures 1-3 for all years combined (Note that scales are not comparable between plots). The quarter 1 surveys show catches to be highest to the north and west of Scotland (Figure 1), and a preponderance of zero hauls in the central/eastern North Sea. In quarter 3, there are fewer positive hauls, with relatively higher catches apparent in the northwestern and southern/central North Sea and along the Swedish coast. Spurdog appear to be relatively widely distributed across the area to the west of the British Isles in quarter 4. Some extremely high catch rates are apparent in the western Irish Sea while there are also areas of relatively high concentration to the south and west of Ireland and around the Outer Hebrides. The blank area with no hauls to the west of the Outer Hebrides is an area of rocky ground in which no trawling can take place.

In total, 87 % of hauls in the quarter 1 survey data set were zero, although this varied considerably by area and by year. Only 3 % of all hauls carried out during the period 1985-2020 in the Kattegat caught spurdog, while over 35 % of hauls to the West of Scotland were positive and in some years

this was over 50%. In quarter 3, an even smaller proportion of hauls catch spurdog (7%), although again there is some variability between ICES divisions and over time. The quarter 4 survey data have the greatest proportion of positive hauls (30% overall) and again this varies over time and between ICES divisions. Approximately 50% of hauls carried out in Division 6.a in quarter 4 during this time period (2003-2019) catch spurdog, which reduces further south - to around a third of hauls in each of Divisions 7.a, 7.b and 7.g, 25% in Division 7.h and only 6% in Division 7.j.

Based on AIC, the best model for quarter 1 is that which includes depth, time of day and a random ship effect, in addition to lat x lon and year (Table 5), although time of day appeared only to be significant in the binomial part of the overall delta-gam model. While the NS-IBTS is operational mainly during daylight hours, the NO-SH survey operates 24 hours per day and the SWC-IBTS (and to a lesser degree the SCOWCGFS) also have a proportion of their hauls during the hours of darkness. The chance of a positive haul is estimated to peak around the middle of the day and decline during the hours of darkness. The estimated distribution map shows the highest biomass to be to the north and west of Scotland with some indication of higher biomass in the coastal waters of Norway and the central North Sea. The estimated index shows a steep decline at the start of the time series with a gradual increase since the mid-2000s (Figure 4).

In contrast to quarter 1, in quarter 3 there is no improvement in AIC when time of day is included in the model in addition to lat x lon, depth, ship and gear (Table 6). This is likely because the standard operating procedure for NS-IBTS (which is the only survey used in the quarter 3 analysis) is for trawling during daylight hours only – trawling largely occurs between 0400 and 2000 but with some hauls out-with these hours north of ~56.5degN (i.e. still likely daylight in summer). Similar to the quarter 1 analysis, the effect of depth declines with increasing depth. The estimated distribution map shows areas of highest biomass to be in the central and northwester North Sea in addition to along the Swedish coast line. The estimated index shows no obvious trend although perhaps reaches a minimum in the early 2000s (Figure 5).

For quarter 4, the best model identified by AIC includes only lat x lon, gear and a random ship effect (Table 7). Depth does not appear to improve the model fit, potentially due to the correlation between longitude and depth, with depth greater in areas further west (which typically have lower catches). Including time of day also makes no improvement to model fit. The estimated distribution map shows high biomass to the west of Scotland (similar to quarter 1), but also in the Irish Sea and to the south in the Celtic Sea. The estimated index shows a significant increase since around 2010. (Figure 6).

The results of the retrospective analysis for the final models for each quarter are shown in Figure 7. The indices for quarters 1 and 3 are relatively consistent while quarter 4 shows a shift upwards with the inclusion of the additional years of data into the delta-GAM model. This is also apparent in the Mohn's rho (Tables 5-7). However, rescaling of the indices (mean standardising over the common year range) results in very small Mohn's rho values in all three quarters (Tables 5-7 & Figure 8). The leave one out analysis for quarter 1 shows the index to be relatively stable when alternative surveys are excluded from the model (Figure 9). The greatest impact is apparent when the NS-IBTS data are excluded which is the only survey covering the majority of divisions 4.a and 4.b. For quarters 3 and 4, leave one out analysis could not easily be performed while retaining the same statistical model.

Very large hauls of spurdog occasionally occur. In the quarter 1 and quarter 4 data there are three instances of hauls > 1 tonne and in quarter 3, three instances > 500 kg (all occurring in different years). The impact of these hauls on the survey stratified mean index values can be seen in Figures 1-3 (red points in index plots), for example 2010 in quarter 1. A comparison of indices estimated excluding these hauls from the analysis shows these points not to be unduly influential in the final biomass index estimates (Figure 10).

A comparison of the estimated biomass indices from the three quarters is shown in Figure 11. While both the quarter 1 and quarter 4 indices show a general increase since the late 2000s, this increasing trend is steeper in quarter 1. The quarter 3 index is noisier and estimated with large confidence intervals, but appears to have been at a minimum in the early 2000s and at a higher level since then.

Discussion

Using a statistical modelling approach allows for multiple surveys with different designs and potentially using different gear to be combined in the estimation of biomass indices for spurdog. It therefore enables the provision of biomass indices covering a large proportion of the stock area to be developed. The retrospective analysis suggest that the indices are relatively robust to changes in the time series of data included, particularly in quarter 1 and quarter 3.

The delta-GAM analysis makes use of data downloaded from DATRAS along with additional survey data provided to WKNSEA. The assessment WG will therefore need to ensure in future that these latter survey data are requested as part of the annual WG data call in order for these indices to be updated on an annual/biennial basis (whenever the assessment is to be updated). Additional historical trawl survey data (UK-E) were also provided to WKNSEA and potentially in future these could also be included in the analysis.

The quarter 4 index shows a significant increase in recent years, although this is a relatively short index in comparison to the other quarters. The quarter 1 index shows some consistency with quarter 4 in that it also shows an increase, although less steeply, in recent years.

Acknowledgements

Many thanks to Casper Berg for his help and willingness to respond to a myriad of probably stupid questions.

References

Berg, C. W., Nielsen, A., and Kristensen, K., 2014. Evaluation of alternative age-based methods for estimating relative abundance from survey data in relation to assessment models. Fisheries Research 151, 91- 99.

Dobby, H., Beare, D., Jones, E. & K. MacKenzie. 2005. Comparison of trends in long term survey data for Squalus acanthias with a preliminary stock assessment for this species. ICES CM 2005/N:01

ICES. 2010. Manual for the international bottom trawl surveys in the western and southern areas. Revision III. Addendum to ICES CM 2010/SSGESST:06. Lisbon, Portugal.

ICES. 2012a. Report of the International Bottom Trawl Survey Working Group (IBTSWG), 27–30 March 2012, Lorient, France. ICES CM 2012/SSGESST:03. 323 pp.

ICES. 2012b. Manual for the International Bottom Trawl Surveys. Series of ICES Survey Protocols. SISP 1-IBTS VIII. 68 pp

Lo, N. C., L. D. Jacobson and J. L. Squire. 1992. Indices of relative abundance for fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49, 2515-2526.

Stefansson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES J. Mar. Sci., 53, 577-588.

514

Table 1. Summary of survey data used in the analysis.

Quarter	Survey	Acronym	Gear	Spatial coverage	Years	Source
Quarter 1	North Sea International Bottom Trawl Survey	NS-IBTS-Q1	GOV	4.a, 4.b, 3.a	1985 – 2020	DATRAS
	Scottish West Coast Groundfish Survey	SWC-IBTS	GOV	6.a, 4.a (limited)	1985 - 2010	DATRAS
		SCOWCGFS	GOV	6.a	2011 - 2020	DATRAS
	Norwegian Shrimp Survey	NO-SH	GOV	3.a, 4.a	2006-2020	WKNSEA data call
Quarter 3	North Sea International Bottom Trawl Survey – Q3	NS-IBTS-Q3	Mainly GOV Some ABD	4, 3.a	1992 onwards	DATRAS
Quarter 4	Scottish West Coast Groundfish Survey	SWC-IBTS	GOV	6.a, 7.a (limited) & 7.b (limited)	2003 - 2009	DATRAS
		SCOWCGFS	GOV	6.a, 7.b (limited)	2011 - 2019	DATRAS
	Irish Groundfish Survey	IE-IGFS	GOV	6.a (South), 7.a, 7.b, 7.g, 7.j	2003 - 2019	DATRAS
	French EVHOE Survey	EVHOE	GOV	7.g, 7.h, 7.j	2003 – 2019 (excl 2017)	DATRAS
	Northern Irish Groundfish Survey	NIGFS	ROT	7.a	2003 - 2019	WKNSEA data call

Table 2. Quarter 1 survey data. Number of hauls per area and survey per year (NS-IBTS: North Sea IBTS, SWC-IBTS: Scottish West Coast Survey - old, SCOWCGFS: Scottish West Coast Survey – new, NO-SH: Norwegian Shrimp survey).

	By Area					By Survey			
	20	21	4.a	4.b	6.a	NS-IBTS	SWC-IBTS	SCOWCGFS	NO-SH
1985	19	11	151	286	59	467	59	0	0
1986	24	17	153	293	33	482	38	0	0
1987	33	17	147	306	45	498	50	0	0
1988	20	18	133	213	44	376	52	0	0
1989	24	19	114	236	41	388	46	0	0
1990	21	23	122	195	39	356	44	0	0
1991	25	15	133	220	47	385	55	0	0
1992	24	21	110	188	38	341	40	0	0
1993	24	21	114	183	39	340	41	0	0
1994	26	22	109	175	40	329	43	0	0
1995	26	22	95	168	27	310	28	0	0
1996	27	21	105	148	40	298	43	0	0
1997	27	19	109	161	37	314	39	0	0
1998	26	19	116	199	36	358	38	0	0
1999	27	19	105	179	45	327	48	0	0
2000	25	20	112	190	46	344	49	0	0
2001	26	19	111	217	38	371	40	0	0
2002	25	20	111	214	42	368	44	0	0
2003	27	19	112	203	53	359	55	0	0
2004	27	19	108	179	46	331	48	0	0
2005	31	19	113	185	47	346	49	0	0
2006	55	20	125	186	53	339	55	0	45
2007	61	20	134	169	65	316	67	0	66
2008	68	19	144	177	54	333	56	0	73
2009	77	19	170	172	53	330	55	0	106
2010	79	18	162	183	57	342	59	0	98
2011	76	16	162	181	57	334	0	57	101
2012	66	20	138	168	64	327	0	64	65
2013	81	19	158	171	66	328	0	66	101
2014	74	19	104	153	61	281	0	61	69
2015	90	20	141	164	62	323	0	62	92
2016	30	19	107	160	63	316	0	63	0
2017	87	19	169	162	62	329	0	62	108
2018	88	19	159	161	60	317	0	60	110
2019	87	18	164	153	62	309	0	62	113
2020	84	18	162	146	57	295	0	57	115

Table 3. Quarter 3 survey data. Number of hauls per area and gear per year.

	By Area				By Gear	
	20	21	4.a	4.b	ABD	GOV
1992	25	23	94	193	87	248
1993	28	22	85	179	87	227
1994	28	22	80	149	87	192
1995	28	23	78	107	87	149
1996	27	23	83	153	85	201
1997	27	16	81	111	87	148
1998	24	20	78	136	0	258
1999	28	19	123	174	0	344
2000	1	0	116	174	0	291
2001	27	20	115	159	0	321
2002	27	20	121	153	0	321
2003	27	20	112	150	0	309
2004	28	19	121	158	0	326
2005	27	20	116	154	0	317
2006	24	22	102	159	0	307
2007	24	22	116	140	0	302
2008	24	22	104	155	0	305
2009	24	22	77	139	0	262
2010	23	22	117	138	0	300
2011	22	23	114	148	0	307
2012	21	23	110	145	0	299
2013	23	22	118	135	0	298
2014	24	22	116	146	0	308
2015	28	22	125	153	0	328
2016	28	23	141	164	0	356
2017	25	22	124	142	0	313
2018	25	22	124	154	0	325
2019	23	24	125	149	0	321
2020	27	20	133	150	0	330

Table 4. Quarter 4 survey data. Number of hauls per area per year. Note NIGFS uses 'ROT' gear while others use the 'GOV'.

	By Area						By Survey				
	6.a	7.a	7.b	7.g	7.h	7.j	SWC-IBTS	IE-IGFS	SCOWCGFS	EVHOE	NIGFS
2003	99	103	29	48	21	57	78	150	0	72	57
2004	100	108	29	50	24	45	77	159	0	62	58
2005	95	71	41	47	23	60	81	132	0	67	57
2006	108	47	40	50	16	68	63	161	0	59	46
2007	122	60	38	56	23	71	81	161	0	69	59
2008	107	69	39	56	22	64	66	160	0	65	66
2009	120	64	43	45	19	60	74	157	0	59	61
2010	47	72	34	60	15	69	0	169	0	58	70
2011	104	61	21	67	22	67	0	159	55	70	58
2012	107	63	37	62	15	66	0	169	66	55	60
2013	72	61	36	58	26	66	0	173	25	63	58
2014	100	60	36	66	20	69	0	165	59	69	58
2015	102	65	28	53	14	66	0	146	58	62	62
2016	99	64	37	69	30	69	0	167	60	79	62
2017	100	60	28	36	0	38	0	149	55	0	58
2018	91	63	41	55	23	66	0	146	56	76	61
2019	104	63	30	63	25	66	0	157	62	69	63

Table 5. Quarter 1. Delta-GAM model summary (all models include a year effect). Grey shading denotes best model.

Model	Covariates	AIC	edfs	deltaAIC	Mohn	Mohn (rescaled)
Model 1	s(lat,lon), U(Ship), s(time), s(depth)	47108.9	168.7	216.2	-17.7%	0.7%
Model 2	s(lat,lon), U(Ship), s(depth)	47125.9	165.7	199.2	-17.2%	0.6%
Model 3	s(lat,lon), U(Ship),	47128.4	166.3	196.7	-17.2%	0.7%
Model 4	S(lat,lon)	47325.0	146.7	0.0	-17.2%	-0.9%
Model 5	S(lat,lon), s(depth)	47320.2	145.2	4.8	-18.0%	-1.5%

Table 6. Quarter 3. Delta-GAM model summary (all models include a year effect). Grey shading denotes best model.

	Covariates	AIC	edfs	deltaAIC	Mohn	Mohn (rescaled)
Model 1	s(lat,lon), U(ship), s(time), s(depth), Gear	15471.7	130.1	76.8	-9.8%	2.3%
Model 2	s(lat,lon), U(ship), s(depth), Gear	15471.7	130.1	76.8	-9.8%	2.3%
Model 3	s(lat,lon), U(ship), Gear	15497.2	129.9	51.3	-9.6%	3.2%
Model 4	s(lat,lon), U(ship)	15504.4	130.6	44.1	-8.6%	3.0%
Model 5	s(lat,lon)	15548.5	121.6	0.0	-10.0%	0.7%
Model 6	s(lat,lon), s(depth), Gear	15519.3	122.1	29.2	-11.1%	-0.7%
Model 7	S(lat,lon), s(depth)	15529.6	121.1	18.9	-10.1%	0.0%
Model 8	S(lat,lon), Gear	15536.7	122.6	11.8	-11.2%	0.4%
Model 9	s(lat,lon), U(ship), s(time), Gear	15494.7	129.4	53.8	-9.5%	3.2%

Table 7. Quarter 4. Delta-GAM model summary (all models include a year effect). Grey shading denotes best model.

	Covariates	AIC	edfs	deltaAIC	Mohn	Mohn (rescaled)
Model 1	s(lat,lon), U(ship), s(time), s(depth), Gear	42551.2	127.0	38.7	-27.9%	-1.3%
Model 2	s(lat,lon), U(ship), s(depth), Gear	42559.6	125.0	30.3	-29.0%	-0.9%
Model 3	s(lat,lon), U(ship), Gear	42549.8	133.9	40.1	-28.3%	-1.3%
Model 4	s(lat,lon), U(ship)	42550.3	132.0	39.6	-26.8%	-0.9%
Model 5	s(lat,lon)	42550.3	132.0	39.6	-26.8%	-0.9%
Model 6	s(lat,lon), s(depth), Gear	42559.6	125.0	30.3	-29.0%	-0.9%
Model 7	S(lat,lon), s(depth)	42560.0	123.2	29.9	-27.4%	-0.7%
Model 8	S(lat,lon), Gear	42549.8	133.9	40.1	-28.3%	-1.3%
Model 9	s(lat,lon), U(ship), s(time), Gear	42589.9	119.1	0.0	-28.2%	-1.5%

Figure 1. Quarter 1 survey data. Spatial distribution of total catch (in weight) by survey (all hauls 1985-2020). Bubble size proportional to total catch. Pale grey crosses indicate zero values.

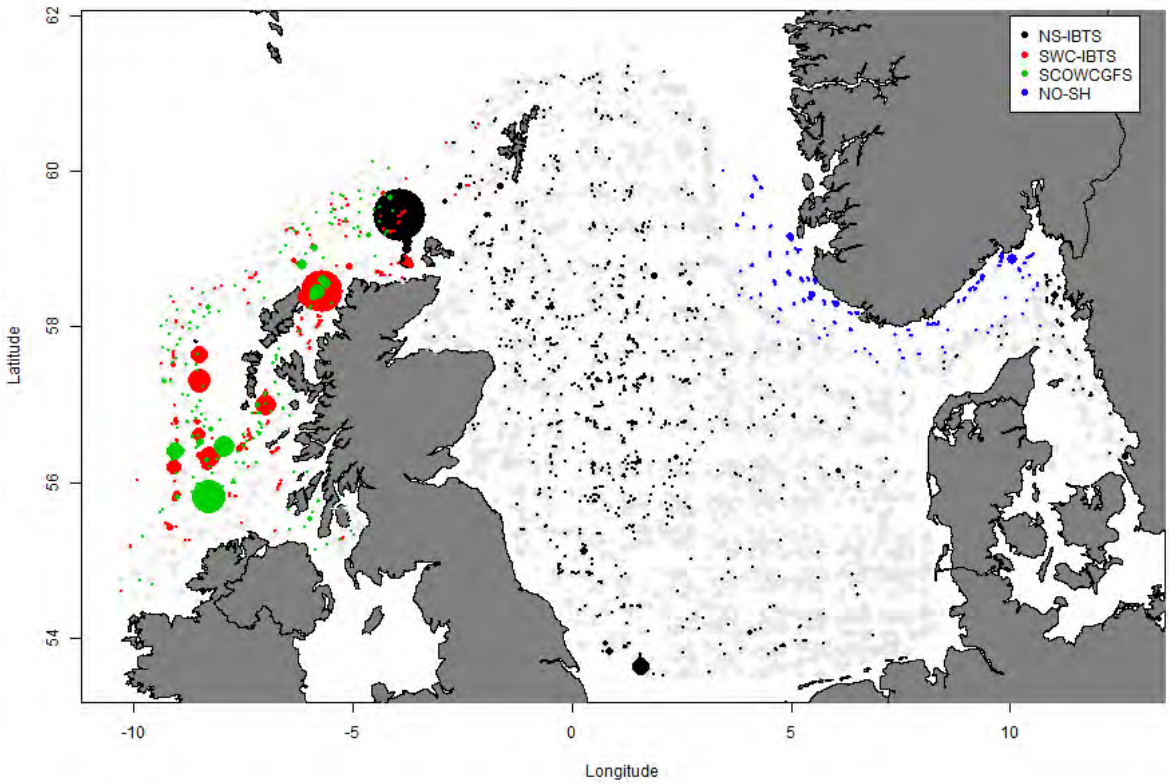
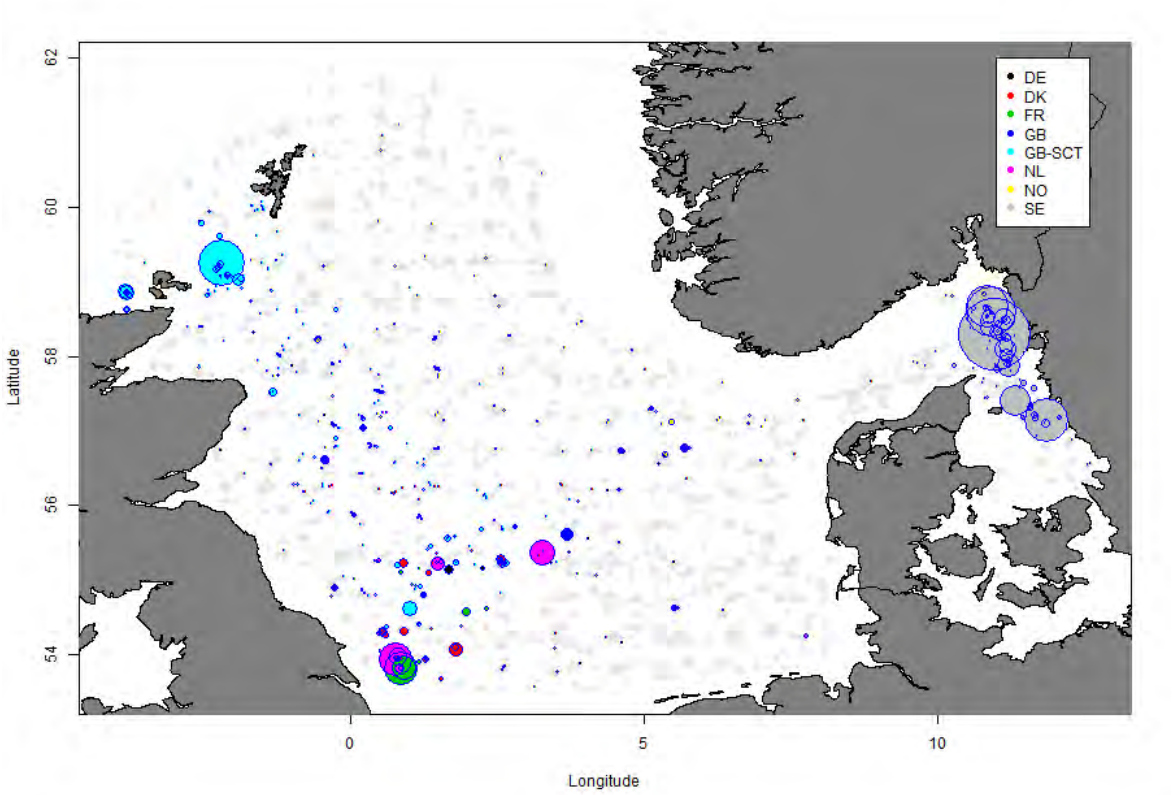


Figure 2. Quarter 3 survey data. Spatial distribution of total catch (in weight) by nation (upper plot) and by gear (lower plot) (all hauls 1992-2020). Bubble size proportional to total catch. Pale grey crosses indicate zero values



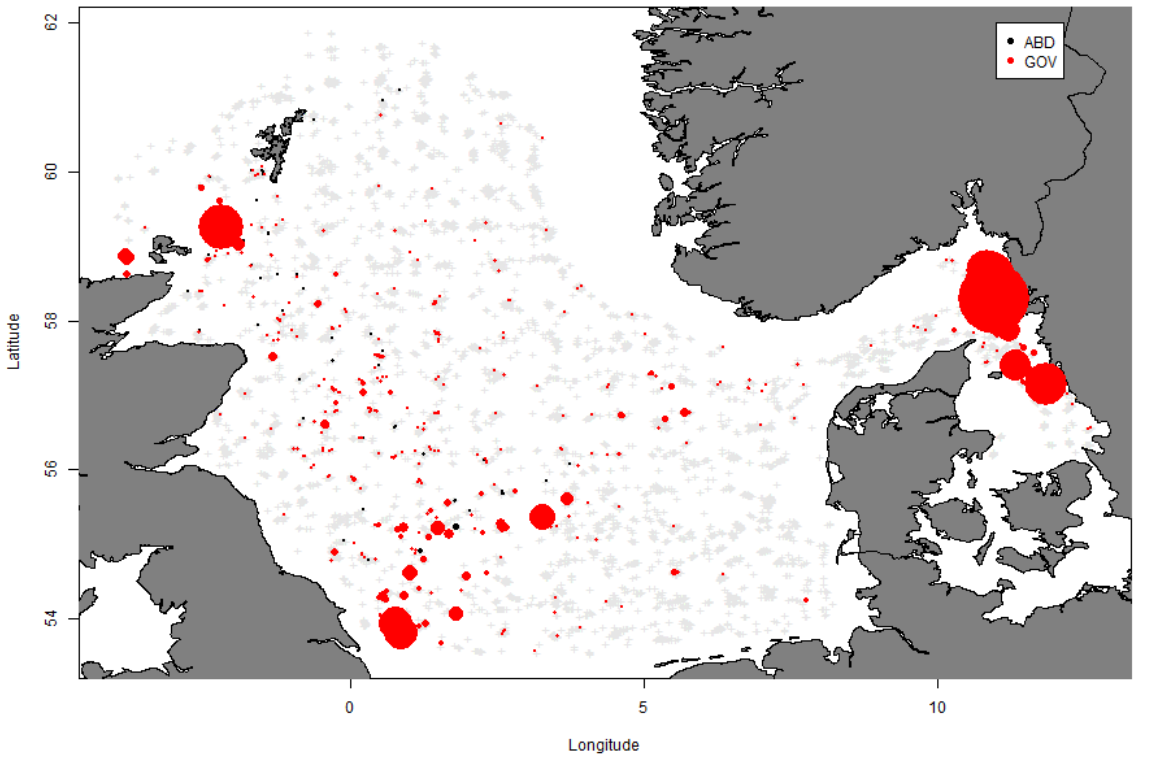


Figure 3. Quarter 4 survey data. Spatial distribution of total catch (in weight) by survey (left) and by gear (right). Bubble size proportional to total catch. Pale grey crosses indicate zero values.

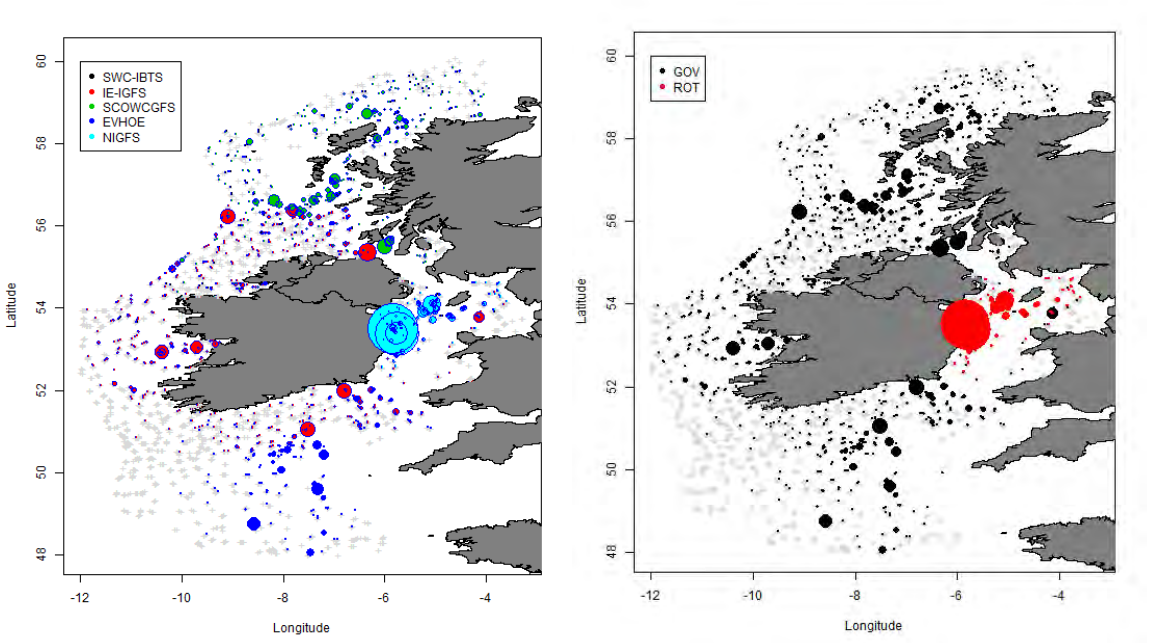


Figure 4. Quarter 1: i) estimated index , ii) biomass map, iii) fitted v residuals (logN model), iv) histogram of residuals, v) estimated depth effect, vi) time of day effect (binomial model).

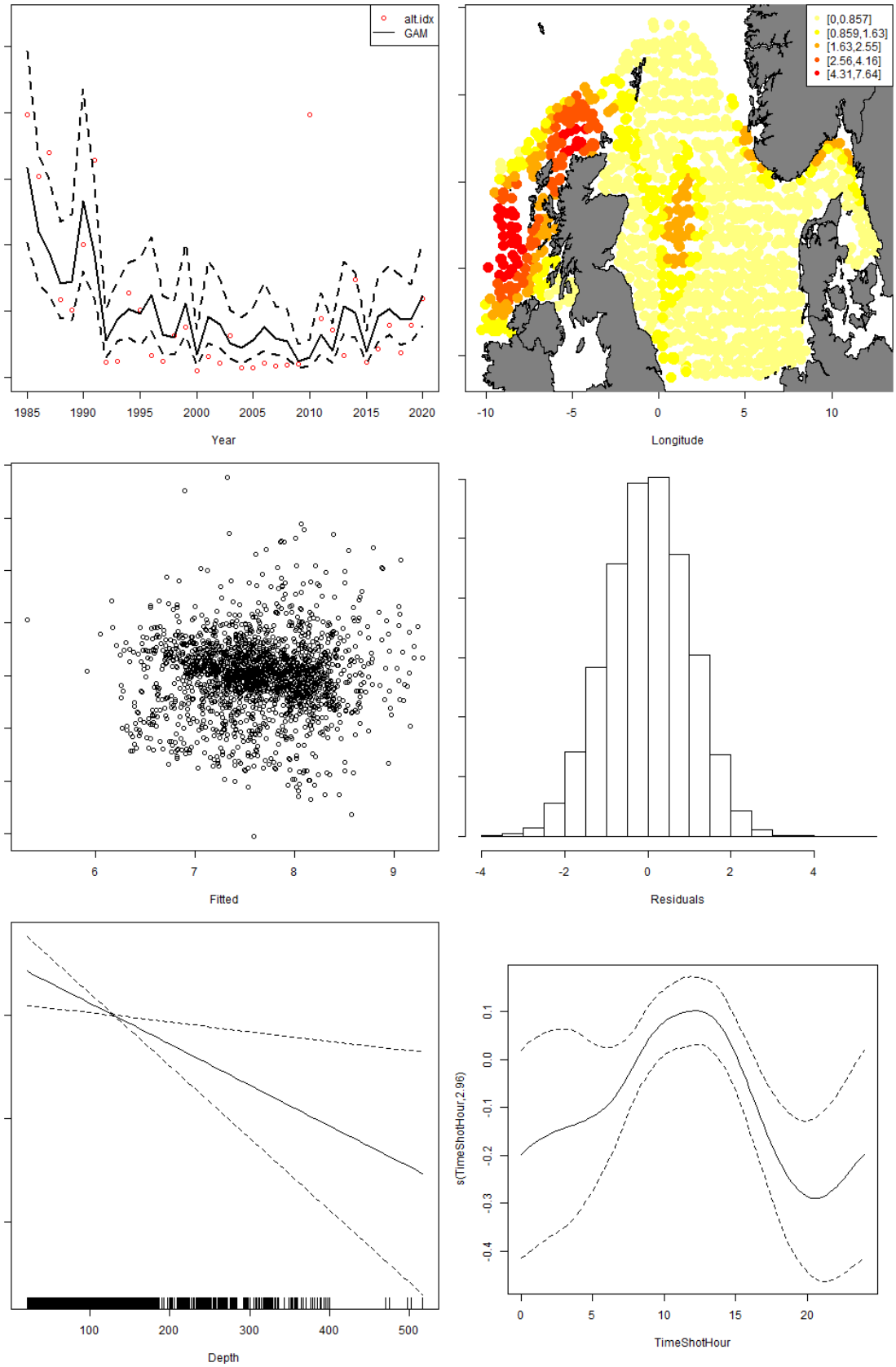


Figure 5. Quarter 3: i) estimated index, ii) biomass map, iii) fitted v residuals (logN model), iv) histogram of residuals, v) estimated depth effect, vi) time of day effect (binomial model).

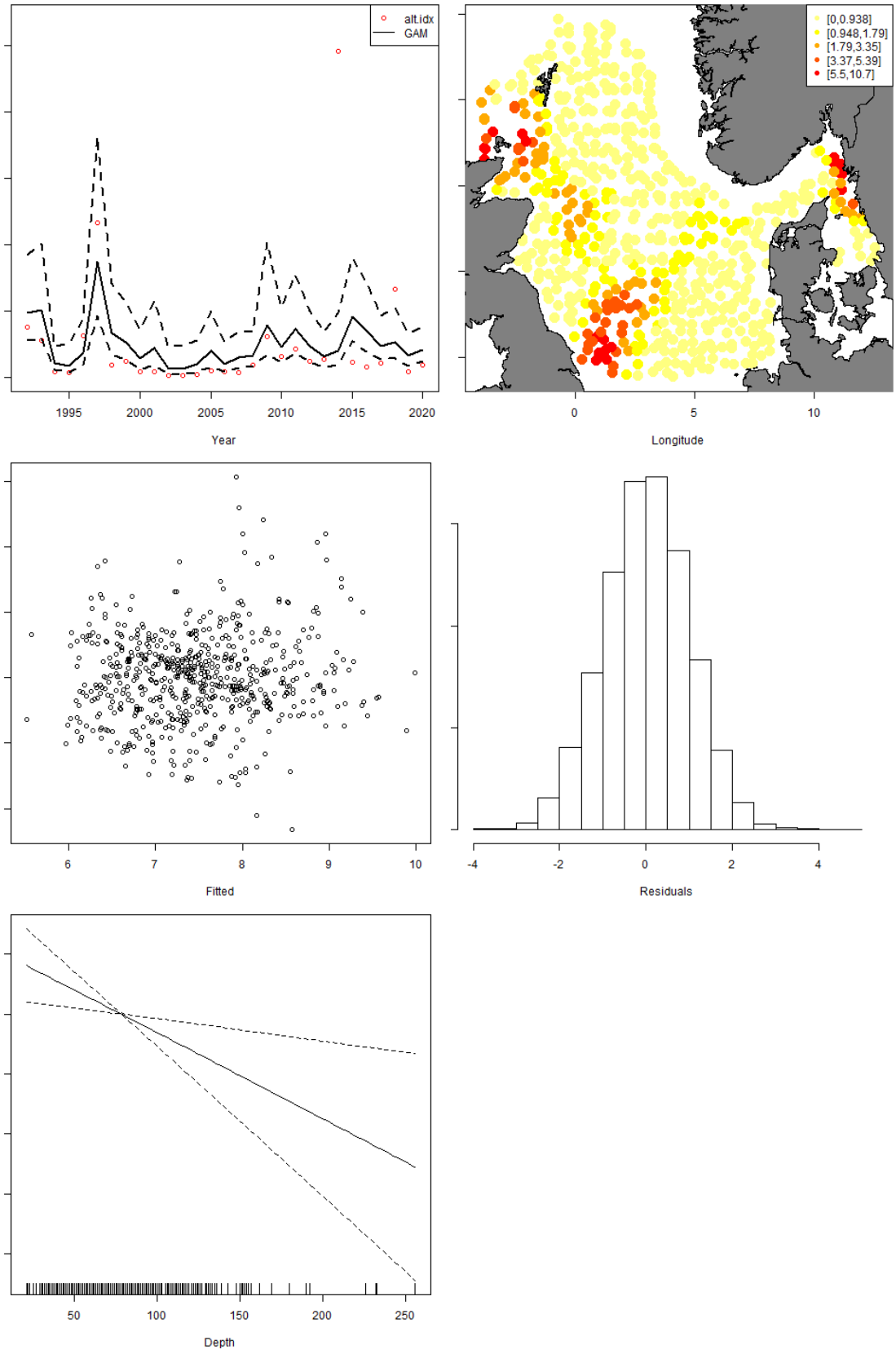
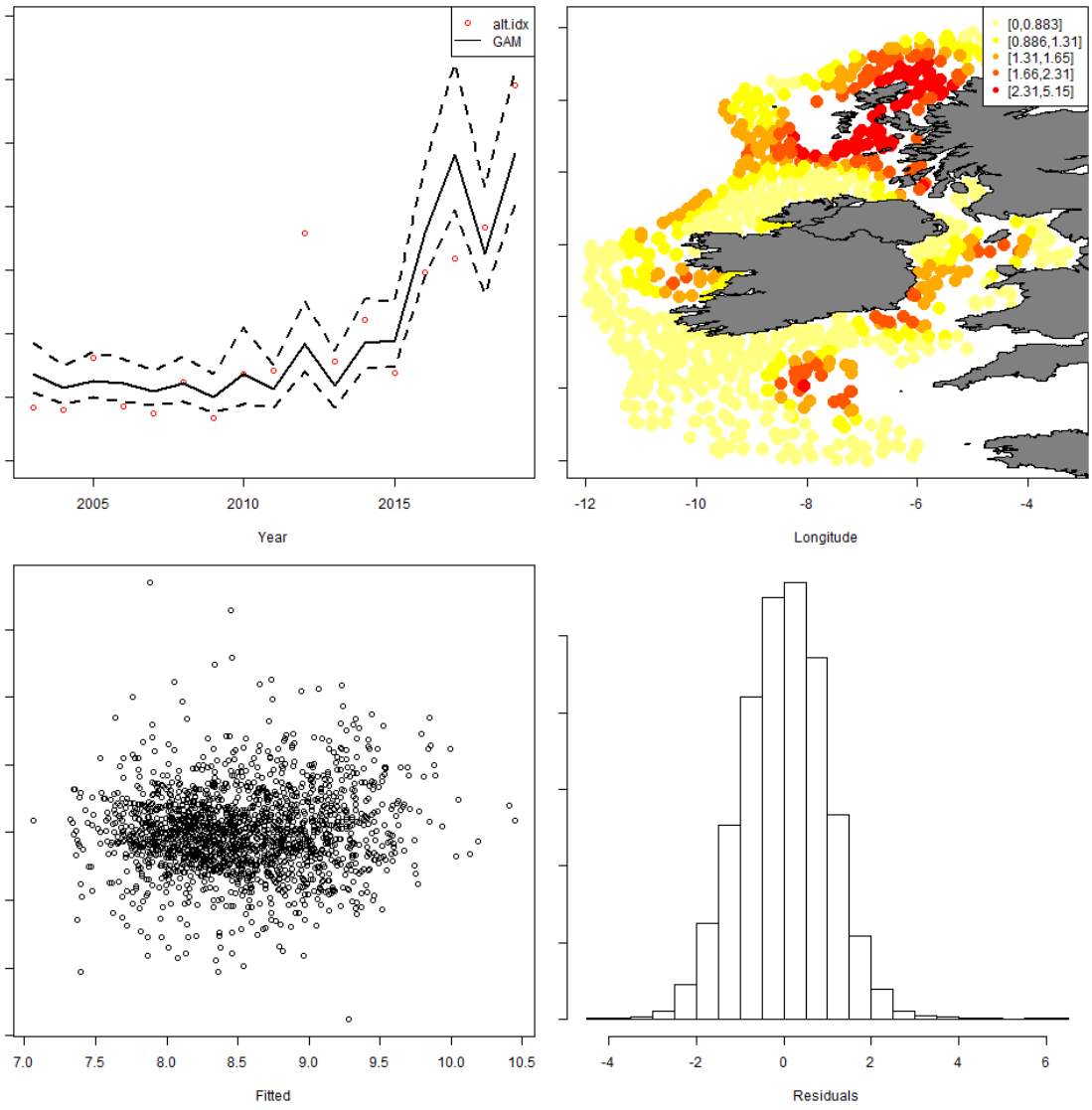
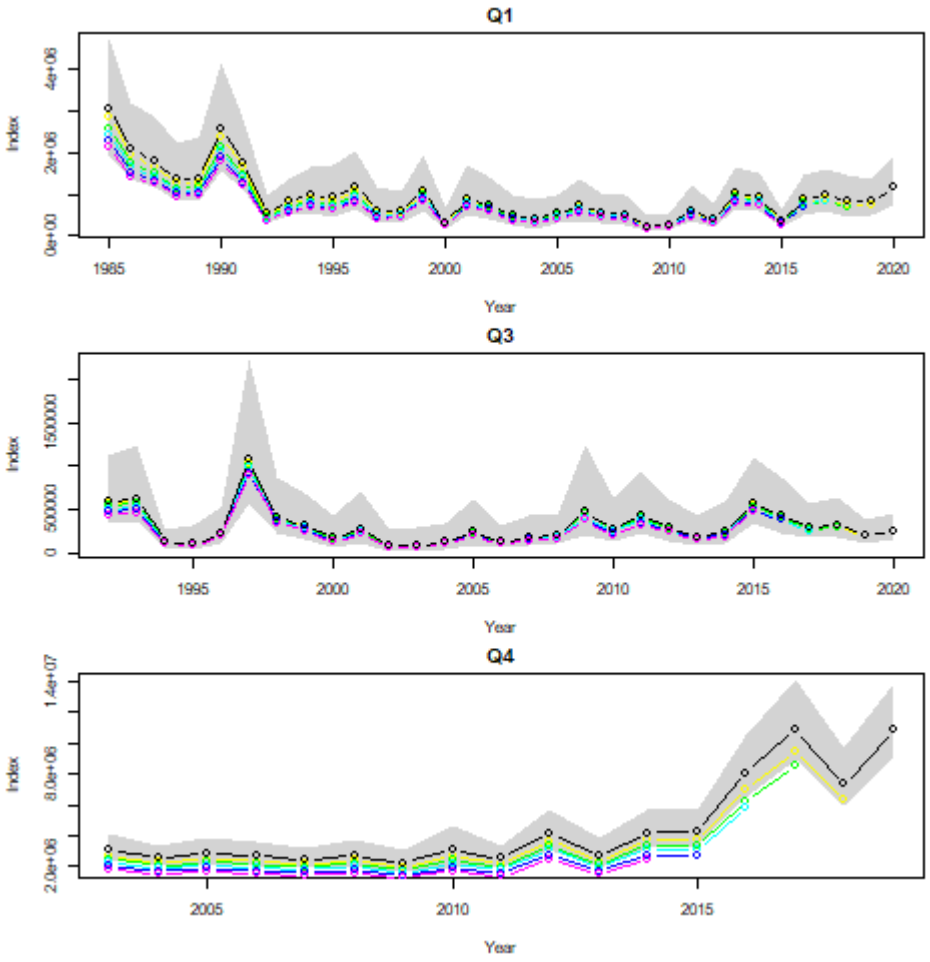


Figure 6. Quarter 4: i) estimated index, ii) biomass map, iii) fitted v residuals (logN model), iv) histogram of residuals, v) estimated depth effect, vi) time of day effect (binomial model).



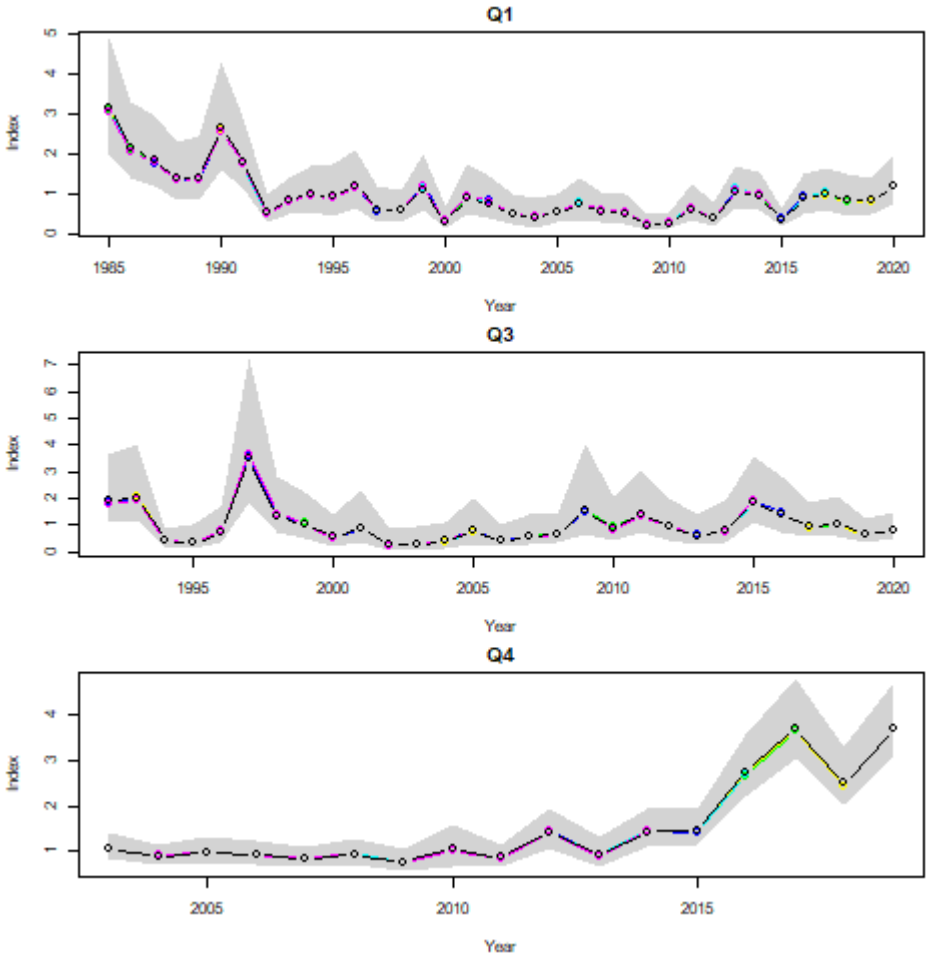
525

Figure 7. Retrospective analysis. (Y-axis values represent the total biomass integrated over all grid points and have not been converted to g hr-1).



526

Figure 8. Retrospective analysis with estimated indices rescaled over the common year range. (Y-axis values represent the total biomass integrated over all grid points and have not been converted to g hr-1).



527

Figure 9. Leave-one out analysis for quarter 1 survey index.

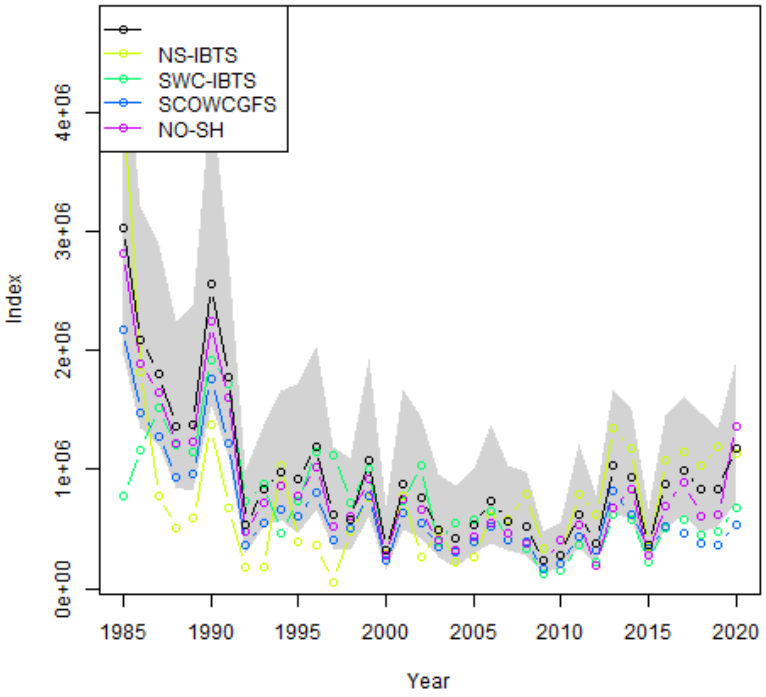
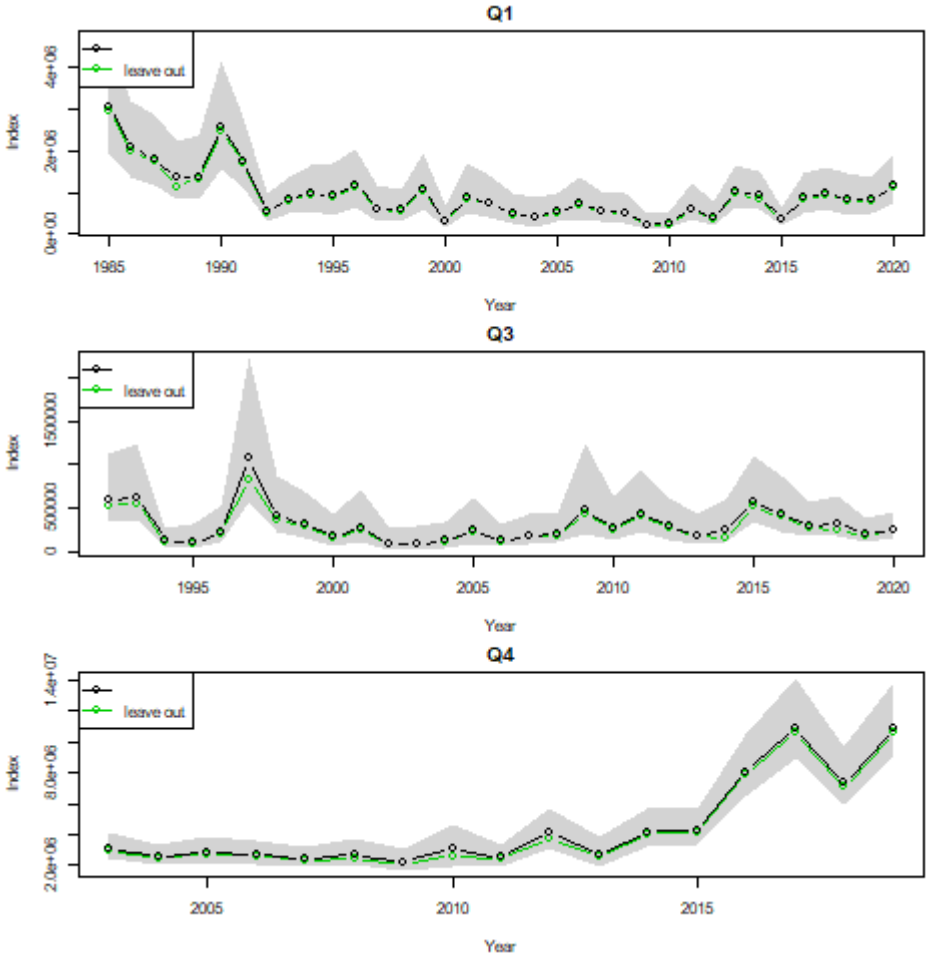
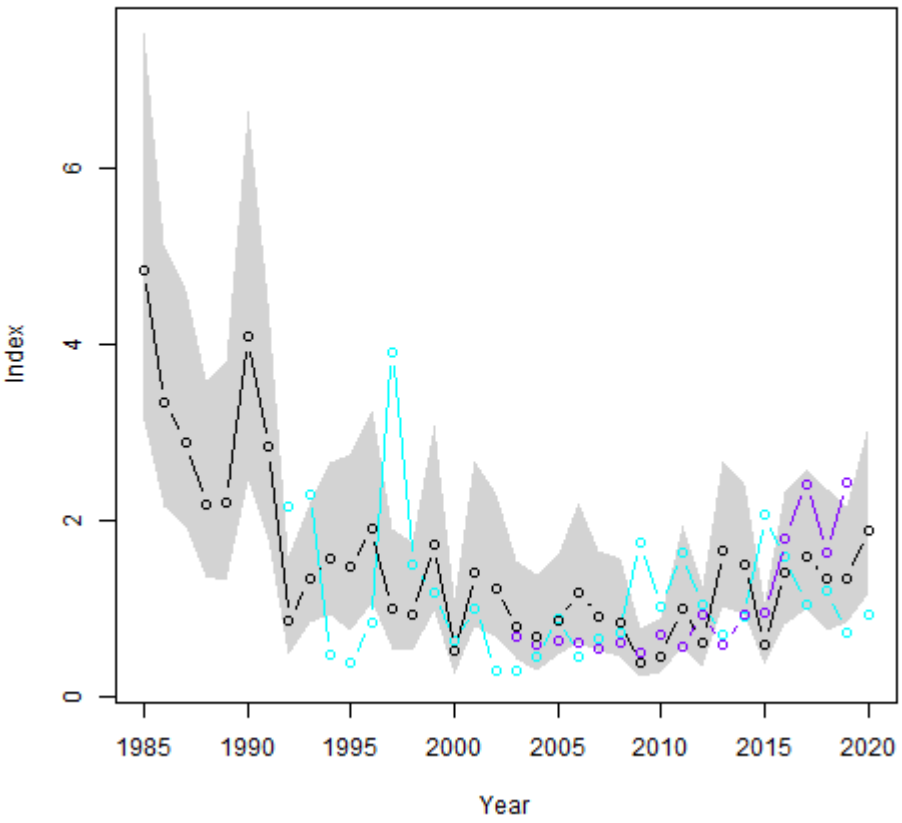


Figure 10. Comparison of estimated biomass indices when extremely large hauls are excluded (green) compared to original indices (black).



529

Figure 11. Comparison of mean standardised indices (Q1 – black, Q3 – blue, Q4 – purple).



Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021

Not to be cited without prior reference to the authors

Growth parameters for spurdog *Squalus acanthias*

Ellis, J. R. and De Oliveira, J. A. A.

Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

Abstract: A synthesis of published age and growth studies relating to spurdog *Squalus acanthias* is provided, including a summary of the von Bertalanffy growth parameters (VBGP).The reviews of the assessment have previously indicated that the potential impacts of alternative growth scenarios should be considered. Hence, it is proposed to explore three scenarios in the 2021 spurdog benchmark assessment. Firstly, using the averaged VBGP available from all the studies now available (base case), secondly using the VBGP from the earlier assessment (to determine whether there are significant changes in outputs) and thirdly using the VBGP of Fahy (1988), as an alternative set of growth parameters that reflect the lower bounds of the estimated growth curves.

Introduction

There have been numerous studies on the age and growth of spurdog *Squalus acanthias*, typically using the second dorsal fin spine (e.g. Tucker, 1985; Campana *et al.*, 2006), although some studies have used the vertebrae (Bubley *et al.*, 2012), and there have also been trials using the eye-lens (Siezen, 1989). In the absence of routine age determination by European fisheries laboratories, the current assessment for the North-east Atlantic *S. acanthias* stock uses sex-specific von Bertalanffy growth parameters (VBGP) that were averaged from the literature that was available at that time (females: L_{inf} = 110.66 cm; k = 0.086 y^{-1}; t_0 = –3.306 y; males: L_{inf} = 81.36 cm ; k = 0.17 y^{-1}; t_0 = –2.166 y; De Oliveira *et al.*, 2013). Given that there have been some more recent published studies on the age and growth of *S. acanthias*, available information is summarised in this Working Document.

In terms of published VBGP for *S. acanthias*, these are available for the North-east Atlantic (Holden and Meadows, 1962; Sosiński, 1977, 1978; Fahy, 1988; Henderson *et al.*, 2002; Albert *et al.*, 2019; with

one further unpublished study: Walenkamp, 1988) as well as the North-west Atlantic (Nammack *et al.*, 1985; Campana *et al.*, 2009; Bubley *et al.*, 2012) and the Mediterranean Sea (Yigin and Ismen, 2016; Bargione *et al.*, 2019), as summarised in Tables 1–3. Whilst there are some other studies that have provided growth information (e.g. Aasen, 1961; Soldat, 1982; Stenberg, 2005), these did not provide estimated growth parameters, although Aasen (1961) and Soldat (1982) provided information on length-at-age (Table 4).

There are also published studies for *S. acanthias* in the Black Sea (Avsar, 2001; Demirhan and Seyhan, 2007), but these studies are not considered here, due to the pronounced differences in the maximum size, with the Black Sea stock attaining a much greater maximum length. There are also numerous growth studies from the northern Pacific (Ketchen, 1975; Beamish and McFarlane, 1985; McFarlane and Beamish, 1987; Tribuzio *et al.*, 2010; Orlov *et al.*, 2011), ostensibly relating to *Squalus acanthias*, but recent taxonomic studies (Ebert *et al.*, 2010) consider the northern Pacific form to be a distinct species (*Squalus suckleyi*), and so these are not discussed further.

Whilst there are estimates for the VBGP of *S. acanthias* in the North-east Atlantic from six studies (Table 1; Figure 1), comparisons of these results are restricted to qualitative interpretations, given the different laboratories involved in the age determination and the differences in the underlying sample sizes and length ranges, as well as the years and locations of sampling. Comparative information for the North-west Atlantic is also provided (Table 1; Figure 2). The exact sample sizes used in age determination studies and the length range examined have not always been clarified in some of these studies, and the data summarised in Table 2 should be viewed as approximate.

Growth of female spurdog

Female *S. acanthias* attain a maximum length (L_{max}) of ca. 125 cm, with this value intermediate between the estimated L_{inf} of 137.12 cm (Sosiński, 1977, 1978) and remaining studies, which ranged from 98.8 cm (Fahy, 1988) to 112 cm (Henderson *et al.*, 2002).

The growth parameter *k* for female *S. acanthias* in the North-east Atlantic ranged from 0.0537 y^{-1} (Sosiński, 1977, 1978) to 0.11 y^{-1} (Holden and Meadows, 1962), and the mean *k* from the six studies was 0.081 y^{-1} (or 0.083 y^{-1} if the unpublished work of Walenkamp (1988) is excluded). The estimates of *k* for the North-west Atlantic stock of *S. acanthias* showed a similar range (0.042–0.12 y^{-1}) and mean (0.087 y^{-1}; Table 1).

The estimated lengths at age 0 (Table 3) from these studies ranged from 13.0 cm (Fahy, 1988) to 39.8 cm (Albert *et al.*, 2019), which should be viewed in comparison to the length-at-birth (L_{birth}) of ca. 24–

30 cm. Hence, the estimated length-at-age for 0-group spurdog may have been underestimated by Fahy (1988).

The growth curves had a broadly similar shape, except for Sosiński, (1977, 1978) which was more dissimilar to the other studies (Figure 1). This study aside, there was still some variation in the estimated lengths-at-age across the broader age range, which could relate to various factors (e.g. differences in underlying samples, methodological differences, temporal changes). Fahy (1988) and Albert *et al.* (2019) provided consistently lower and higher estimated lengths-at-age, respectively, whilst the results from Holden and Meadows (1962) and Henderson *et al.* (2002) were both within these bounds.

Growth of male spurdog

Male *S. acanthias* attain a L_{max} of ca. 92 cm, with this value higher than the estimated L_{inf} from available studies, which ranged from 76.6 cm (Albert *et al.*, 2019) to 81.66 cm (Sosiński, 1977, 1978).

The growth parameter *k* for male *S. acanthias* in the North-east Atlantic ranged from 0.15 y^{-1} (Henderson *et al.*, 2002) to 0.344 y^{-1} (Albert *et al.*, 2019), and the mean *k* from the six studies was 0.21 y^{-1} (and the same average value if Walenkamp (1988) was excluded). However, the higher value given should be treated with caution, as also noted by those authors (Albert *et al.*, 2019).

Due to the minimum landing size of spurdog in Norwegian waters, Albert *et al.* (2019) stated that the smaller spurdog in their study "*were probably underrepresented for each age group, which would tend to make the fitted growth curves too steep for the younger ages ... this seems to be the case especially for males*". Noting that Albert *et al.* (2019) acknowledged a lack of smaller fish in the samples may have affected their estimated growth parameters, especially in the case of males, the mean *k* (excluding Albert *et al.*, 2019) was 0.183 y^{-1}.

Published estimates of *k* for the North-west Atlantic *S. acanthias* stock ranged from 0.099–0.1481 y^{-1}, with a mean of 0.117 y^{-1} (Table 1).

The estimated lengths at age 0 from these studies (Table 3) had an overall range of 18.9 cm (Fahy, 1988) to 27.3 cm (Holden and Meadows, 1962), with all these studies much more similar to L_{birth}.

The growth curves of male *S. acanthias* were broadly similar for older age classes, though the published studies showed some differences for those fish <15 years (Figure 1).

Suggestions for the 2021 spurdog assessment

Undertaking alternative model runs with different growth parameters were considered appropriate, in order to better evaluate whether different VBGP would impact on assessment outputs.

The VBGP used in the initial study should be used as one scenario, and the results compared with the averaged VBPG from all the parameters now compiled in the present WD (based on six studies for females and five studies for males, with the results from Albert *et al.* (2019) excluded for males).

From the individual studies, the VBGPs provided by Fahy (1988) generally provided the lower bounds for the estimated lengths-at-age for female and male *S. acanthias.* Consequently, this study was also considered as an alternative scenario, especially as the averaged values resulted in growth curves that were generally nearer the upper bounds of the observed studies.

Consequently, it is suggested that model runs to better understand the sensitivity to VBGP should use:

(a) the averaged VBGP from all the studies now compiled (excluding the male VBGP from Albert *et al.*, 2019), as the preferred base case,

(b) the values used in the previous assessment (De Oliveira *et al.*, 2013) as an alternative scenario, and

(c) the VBGP from Fahy (1988).

References

Aasen, O. (1961). Pigghåundersøkelsene. *Fisken og Havet*, 1: 1–9.

Albert, O. T., Junge, C. and Myrlund, M. K. (2019). Young mums are rebuilding the spurdog stock (*Squalus acanthias* L.) in Norwegian waters. *ICES Journal of Marine Science*, 76: 2193–2204.

Avsar, D. (2001). Age, growth, reproduction and feeding of the spurdog (*Squalus acanthias* Linnaeus, 1758) in the South-eastern Black Sea. *Estuarine, Coastal and Shelf Science*, 52: 269–278.

Bargione, G., Donato, F., La Mesa, M., Mazzoldi, C., Riginella, E., Vasapollo, C., Virgili, M. and Lucchetti, A. (2019). Life-history traits of the spiny dogfish *Squalus acanthias* in the Adriatic Sea. *Scientific Reports*, 9(1): 10 pp.

Beamish, R. J. and McFarlane, G. A. (1985). Annulus development on the second dorsal spine of the spiny dogfish (*Squalus acanthias*) and its validity for age determination. *Canadian Journal of Fisheries and Aquatic Sciences*, 42: 1799–1805.

Bubley, W. J., Kneebone, J., Sulikowski, J. A., and Tsang, P. C. W. (2012). Reassessment of spiny dogfish *Squalus acanthias* age and growth using vertebrae and dorsal-fin spines. *Journal of Fish Biology*, 80: 1300–1319.

Campana, S. E., Jones, C., McFarlane, G. A., and Myklevoll, S. (2006). Bomb dating and age validation using the spines of spiny dogfish (*Squalus acanthias*). *Environmental Biology of Fishes*, 77: 327–336.

Campana, S. E., Joyce, W. and Kulka, D. W. (2009). Growth and reproduction of spiny dogfish off the eastern coast of Canada, including inferences on stock structure. In "*Biology and management of dogfish sharks*", 195–208.

Demirhan, S. A., and Seyhan, K. (2007). Life history of spiny dogfish, *Squalus acanthias* (L. 1758), in the southern Black Sea. *Fisheries Research*, 85: 210–216.

De Oliveira, J. A. A., Ellis, J. R., and Dobby, H. (2013). Incorporating density dependence in pup production in a stock assessment of NE Atlantic spurdog *Squalus acanthias. ICES Journal of Marine Science*, 70: 1341–1353.

Ebert, D. A., White, W. T., Goldman, K. J., Compagno, L. J., Daly-Engel, T. S., *et al.* (2010). Resurrection and redescription of *Squalus suckleyi* (Girard, 1854) from the North Pacific, with comments on the *Squalus acanthias* subgroup (Squaliformes: Squalidae). *Zootaxa*, 2612: 22–40.

Fahy, E. (1988). The spurdog *Squalus acanthias* (L.) fishery in south-west Ireland. *Irish Fisheries Investigations Part B: Marine*, 32: 22 pp.

Henderson, A. C., Flannery, K., and Dunne, J. (2002). Growth and reproduction in spiny dogfish *Squalus acanthias* L. (Elasmobranchii: Squalidae), from the west coast of Ireland. *Sarsia*, 87: 350–361.

Holden, M. J. and Meadows, P. S. (1962). The structure of the spine of the spurdog fish (*Squalus acanthias* L.) and its use for age determination. *Journal of the Marine Biological Association of the United Kingdom*, 42: 179–197.

Ketchen, K. S. (1975). Age and growth of dogfish, *Squalus acanthias*, in British Columbia waters. *Journal of the Fisheries Research Board of Canada*, 32: 43–59.

McFarlane, G. A. and Beamish, R. J. (1987). Validation of the dorsal spine method of age determination for spiny dogfish. In *Age and growth in fish* (Summerfelt, R. C. and Hall, G. E., eds.). International Symposium on Age and Growth in Fish, Des Moines, IA (USA), 9 Jun 1985, 287–300.

Nammack, M. F., Musick, J. A. and Colvocoresses, J. A. (1985). Life-history of spiny dogfish off the northeastern United States. *Transactions of the American Fisheries Society*, 114: 367–376.

Orlov, A. M., Kulish, E. F., Mukhametov, I. N. and Shubin, O. A. (2011). Age and growth of spiny dogfish *Squalus acanthias* (Squalidae, Chondrichthyes) in pacific waters off the Kuril Islands. *Journal of Ichthyology*, 51(1), pp.42–55.

Siezen, R. J. (1989). Eye lens aging in the spiny dogfish (*Squalus acanthias*) I. Age determination from lens weight. *Current Eye Research*, 8: 707–712.

Soldat, V. T. (1982). Age and size of spiny dogfish, *Squalus acanthias* , in the Northwest Atlantic. NAFO Scientific Council Studies, 3: 47–52.

Sosiński, J. (1977). Polish investigations on the Scottish Norwegian spurdog (*Squalus acanthias*) in 1974. *Annales Biologiques (Copenhagen)*, 32: 178–179.

Sosiński, J. (1978). Characteristics of the North Sea spurdog (*Squalus acanthias* L.) stock. *Acta Ichthyologua et Piscatoria*, 8: 9–22.

Stenberg, C. (2005). Life history of the piked dogfish (*Squalus acanthias* L.) in Swedish waters. *Journal of Northwest Atlantic Fishery Science*, 35: 155–164.

Tribuzio, C. A., Kruse, G. H., and Fujioka, J. T. (2010). Age and growth of spiny dogfish (*Squalus acanthias*) in the Gulf of Alaska: Analysis of alternative growth models. *Fishery Bulletin*, 108: 119–135.

Tucker, R. (1985). Age validation studies on the spines of the spurdog (*Squalus acanthias*) using tetracycline. *Journal of the Marine Biological Association of the United Kingdom*, 65: 641–651.

Walenkamp, J. H. C. (1988). Life history and fishery of the spurdog, *Squalus acanthias*, in the Irish Sea. MSc Thesis, University College of North Wales, Bangor, 146 pp. + plates.

Yigin, C. C. and Ismen, A. (2016). Age and growth of spiny dogfish *Squalus acanthias* (Squalidae: Chondrichthyes) in the North Aegean Sea. *Pakistan Journal of Zoology*, 48: 1185–1191.

Table 1: Summary of published growth parameters (L_{inf} (cm), k (y^{-1}), t_0 (y) and L_0 (cm)) for *Squalus acanthias.* Growth models used are VB = von Bertalanffy, G = Gompertz.

Area	Source	Growth model	Female				Male				Combined sexes		
			L_{inf}	k	t_0	L_0	L_{inf}	k	t_0	L_0	L_{inf}	k	t_0
NE Atlantic													
Scottish waters	Holden & Meadows (1962)	VB	101.4	0.11	–3.6		79.7	0.21	–2				
Northern North Sea	Sosiński (1977, 1978)	VB	137.12	0.0537	–4.7057		81.66	0.1887	–1.4672		101.54	0.0957	–3.4873
Western Ireland	Fahy (1988)	VB	98.8	0.09	–1.57		79.9	0.16	–1.69				
Irish Sea	Walenkamp (1988)	VB	109.972	0.074	–5.313		80.498	0.205	–1.62				
Western Ireland	Henderson *et al.* (2002)	VB	112	0.07	–3.37		79.5	0.15	–2.54				
Norwegian waters	Albert *et al.* (2019) [1]	VB	108.6	0.091	–5.017		[76.6]	[0.344]	[–0.995]				
NW Atlantic													
NE USA	Nammack *et al.* (1985)	VB	100.5	0.1057	–2.9		82.49	0.1481	–2.67				
Scotian shelf (Canada)	Campana *et al.* (2009) [2]	VB	119.5	0.042		25	78	0.099		25			
Gulf of Maine	Bubley *et al.* (2012) [3]	VB	100.76	0.12		25	94.23	0.11		25			
Gulf of Maine	Bubley *et al.* (2012) [4]	VB	107.17	0.08		25	91.46	0.11		25			
Mediterranean													
Aegean Sea	Yigin & Ismen (2016) [5]	VB	101.21	0.15	–0.68		72.85	0.27	–0.24		95.34	0.16	–0.69
Adriatic Sea	Bargione *et al.* (2019)	G	113	0.18			92	0.24					

[1] Albert *et al.* (2019) noted that a lack of smaller fish in the available samples may have affected the estimated growth parameters, especially in the case of males.
[2] Data reported, and as given here, based on fork length (L_F), with the authors also providing a formula to convert to total length (L_T) conversion ($L_T = 3.1 + 1.09 * L_F$).
[3] Data based on vertebrae.
[4] Data based on spines.
[5] Values given in the paper result in biologically implausible estimates of length at age 0, and so these parameters are not considered further here.

Table 2: Sampling details for studies on the age and growth of *Squalus acanthias*, including sample size (N), length range (in L_T) and maximum age observed (A_{max}). Values in square brackets indicate approximate values.

Area	Source	Females			Males		
		N	L_T	A_{max}	N	L_T	A_{max}
NE Atlantic							
Scottish waters	Holden & Meadows (1962)	317	–	21	445	–	19
Northern North Sea	Sosiński (1977, 1978)	410	–	19+	415	–	19+
Western Ireland	Fahy (1988)	1788	–	35	1070	–	35
Irish Sea	Walenkamp (1988) [6]	173	[54-97]	26	77	[57-82]	18
Western Ireland	Henderson *et al.* (2002)	132	–	30	122	–	22
Norwegian waters	Albert *et al.* (2019)	–	53–121	36	–	41–95	34
NW Atlantic							
NE USA	Nammack *et al.* (1985)	959	ca. 20–110	40	479	ca. 20–90	35
Scotian shelf (Canada)	Campana *et al.* (2009)	[525]		[31]			
Gulf of Maine	Bubley *et al.* (2012)_Vertebrae	248	25.0–102.0	24	147	32.5–84.0	17
Gulf of Maine	Bubley *et al.* (2012)_Spines			28			22
Mediterranean							
Aegean Sea	Yigin & Ismen (2016) [7]	203	17.1–117.5	142	<8	20.8–121.6	<8
Adriatic Sea	Bargione *et al.* (2019)	176	21.7–102.5	13+	150	21.9–87.5	9+

[6] Length range is an approximate, based on summarised data for the mean length-at-age

[7] The presence of males >100 cm suggest that either other *Squalus* spp., or *S. acanthias* from the Black Sea population, were included in the samples

Table 3a: Estimated length-at-age for *Squalus acanthias* using published von Bertalanffy growth parameters. Females in the North-east Atlantic.

Age	Holden & Meadows (1962)	Sosinski (1977, 1978)	Fahy (1988)	Walenkamp (1988)	Henderson *et al.* (2002)	Albert *et al.* (2019)
0	33.2	30.6	13.0	35.7	23.5	39.8
1	40.3	36.2	20.4	41.0	29.5	45.8
2	46.6	41.5	27.1	45.9	35.1	51.3
3	52.3	46.5	33.3	50.4	40.3	56.2
4	57.4	51.2	39.0	54.7	45.1	60.8
5	62.0	55.7	44.1	58.6	49.7	65.0
6	66.1	60.0	48.8	62.3	53.9	68.7
7	69.8	64.0	53.1	65.6	57.8	72.2
8	73.1	67.8	57.0	68.8	61.5	75.4
9	76.0	71.4	60.6	71.7	64.9	78.3
10	78.7	74.9	63.9	74.4	68.1	80.9
11	81.1	78.1	66.9	77.0	71.0	83.3
12	83.2	81.2	69.7	79.3	73.8	85.5
13	85.1	84.1	72.2	81.5	76.4	87.5
14	86.8	86.9	74.5	83.5	78.8	89.4
15	88.3	89.5	76.6	85.4	81.0	91.0
16	89.7	92.0	78.5	87.1	83.1	92.6
17	90.9	94.4	80.2	88.7	85.1	94.0
18	92.0	96.6	81.8	90.2	86.9	95.2
19	93.0	98.7	83.3	91.6	88.6	96.4
20	93.8	100.7	84.6	92.9	90.2	97.5
21	94.6	102.6	85.8	94.1	91.7	98.4
22	95.3	104.4	87.0	95.2	93.0	99.3
23	96.0	106.1	88.0	96.3	94.3	100.1
24	96.5	107.8	88.9	97.2	95.5	100.9
25	97.0	109.3	89.8	98.1	96.6	101.5
26	97.5	110.8	90.5	99.0	97.7	102.1
27	97.9	112.1	91.2	99.7	98.6	102.7
28	98.3	113.4	91.9	100.5	99.5	103.2
29	98.6	114.7	92.5	101.1	100.4	103.7
30	98.9	115.9	93.0	101.7	101.2	104.1
31	99.1	117.0	93.5	102.3	101.9	104.5
32	99.4	118.0	94.0	102.9	102.6	104.9
33	99.6	119.0	94.4	103.3	103.2	105.2
34	99.8	120.0	94.8	103.8	103.8	105.5
35	99.9	120.9	95.1	104.2	104.4	105.8
36	100.1	121.7	95.4	104.6	104.9	106.0
37	100.2	122.5	95.7	105.0	105.4	106.2
38	100.4	123.3	96.0	105.3	105.8	106.4
39	100.5	124.0	96.2	105.7	106.2	106.6
40	100.6	124.7	96.5	106.0	106.6	106.8
41	100.7	125.4	96.7	106.2	107.0	107.0
42	100.8	126.1	96.9	106.5	107.4	107.1
43	100.9	126.7	97.1	106.7	107.8	107.3
44	101.0	127.4	97.3	106.9	108.2	107.5
45	101.0	128.1	97.6	107.1	108.6	107.7

Table 3b: Estimated length-at-age for *Squalus acanthias* using published von Bertalanffy growth parameters. Males in the North-east Atlantic.

Age	Holden & Meadows (1962)	Sosinski (1977, 1978)	Fahy (1988)	Walenkamp (1988)	Henderson *et al.* (2002)	Albert *et al.* (2019)
0	27.3	19.7	18.9	22.7	25.2	22.2
1	37.3	30.4	27.9	33.5	32.8	38.0
2	45.3	39.2	35.6	42.2	39.3	49.3
3	51.8	46.5	42.2	49.3	44.9	57.2
4	57.1	52.6	47.8	55.1	49.7	62.9
5	61.4	57.6	52.5	59.8	53.8	66.9
6	64.8	61.7	56.6	63.6	57.4	69.7
7	67.7	65.1	60.0	66.7	60.5	71.7
8	69.9	68.0	62.9	69.3	63.1	73.1
9	71.8	70.3	65.5	71.4	65.4	74.1
10	73.3	72.3	67.6	73.1	67.4	74.9
11	74.5	73.9	69.4	74.4	69.1	75.4
12	75.5	75.2	71.0	75.6	70.5	75.7
13	76.3	76.3	72.3	76.5	71.8	76.0
14	76.9	77.2	73.4	77.2	72.8	76.2
15	77.5	78.0	74.4	77.8	73.8	76.3
16	77.9	78.6	75.2	78.3	74.6	76.4
17	78.2	79.2	75.9	78.7	75.3	76.4
18	78.5	79.6	76.5	79.1	75.8	76.5
19	78.7	79.9	77.0	79.3	76.4	76.5
20	78.9	80.2	77.4	79.5	76.8	76.5
21	79.1	80.5	77.8	79.7	77.2	76.6
22	79.2	80.7	78.1	79.9	77.5	76.6
23	79.3	80.9	78.4	80.0	77.8	76.6
24	79.4	81.0	78.6	80.1	78.0	76.6
25	79.4	81.1	78.8	80.2	78.2	76.6
26	79.5	81.2	78.9	80.2	78.4	76.6
27	79.5	81.3	79.1	80.3	78.6	76.6
28	79.6	81.3	79.2	80.3	78.7	76.6
29	79.6	81.4	79.3	80.3	78.8	76.6
30	79.6	81.4	79.4	80.4	78.9	76.6
31	79.6	81.5	79.5	80.4	79.0	76.6
32	79.6	81.5	79.5	80.4	79.1	76.6
33	79.6	81.5	79.6	80.4	79.1	76.6
34	79.7	81.6	79.6	80.4	79.2	76.6
35	79.7	81.6	79.7	80.5	79.2	76.6
36	79.7	81.6	79.7	80.5	79.3	76.6
37	79.7	81.6	79.7	80.5	79.3	76.6
38	79.7	81.6	79.8	80.5	79.3	76.6
39	79.7	81.6	79.8	80.5	79.3	76.6
40	79.7	81.6	79.8	80.5	79.4	76.6
41	79.7	81.6	79.8	80.5	79.4	76.6
42	79.7	81.6	79.8	80.5	79.4	76.6
43	79.7	81.6	79.9	80.5	79.4	76.6
44	79.7	81.7	79.9	80.5	79.5	76.6
45	79.7	81.7	79.9	80.5	79.5	76.6

Table 3c: Estimated length-at-age for *Squalus acanthias* using published von Bertalanffy growth parameters. Females in the North-west Atlantic.

Age	Nammack *et al.* (1985)	Campana *et al.* (2009; L_F)	Campana *et al.* (2009; converted L_T)	Bubley *et al.* (2012; vertebrae)	Bubley *et al.* (2012; spines)
0	26.5	25.0	30.4	25.0	25.0
1	34.0	28.9	34.6	33.6	31.3
2	40.6	32.6	38.6	41.2	37.1
3	46.6	36.2	42.5	47.9	42.5
4	52.0	39.6	46.3	53.9	47.5
5	56.9	42.9	49.9	59.2	52.1
6	61.3	46.1	53.3	63.9	56.3
7	65.2	49.1	56.6	68.1	60.2
8	68.7	52.0	59.7	71.8	63.8
9	71.9	54.7	62.8	75.0	67.2
10	74.8	57.4	65.7	77.9	70.2
11	77.4	60.0	68.5	80.5	73.1
12	79.7	62.4	71.1	82.8	75.7
13	81.8	64.8	73.7	84.8	78.1
14	83.7	67.0	76.1	86.6	80.4
15	85.3	69.2	78.5	88.2	82.4
16	86.9	71.2	80.8	89.7	84.3
17	88.2	73.2	82.9	90.9	86.1
18	89.5	75.1	85.0	92.0	87.7
19	90.6	77.0	87.0	93.0	89.2
20	91.6	78.7	88.9	93.9	90.6
21	92.5	80.4	90.7	94.7	91.9
22	93.3	82.0	92.5	95.4	93.0
23	94.0	83.5	94.2	96.0	94.1
24	94.6	85.0	95.8	96.5	95.1
25	95.2	86.4	97.3	97.0	96.0
26	95.8	87.8	98.8	97.4	96.9
27	96.2	89.1	100.2	97.8	97.7
28	96.7	90.3	101.6	98.1	98.4
29	97.1	91.5	102.9	98.4	99.1
30	97.4	92.7	104.1	98.7	99.7
31	97.7	93.8	105.3	98.9	100.3
32	98.0	94.9	106.5	99.1	100.8
33	98.2	95.9	107.6	99.3	101.3
34	98.5	96.8	108.7	99.5	101.8
35	98.7	97.8	109.7	99.6	102.2
36	98.9	98.7	110.6	99.8	102.6
37	99.0	99.5	111.6	99.9	102.9
38	99.2	100.3	112.5	100.0	103.2
39	99.3	101.1	113.3	100.1	103.5
40	99.4	101.9	114.2	100.1	103.8
41	99.5	102.6	115.0	100.2	104.1
42	99.7	103.4	115.8	100.3	104.4
43	99.8	104.2	116.6	100.4	104.7
44	99.9	104.9	117.5	100.5	104.9
45	100.0	105.7	118.3	100.5	105.2

Table 3d: Estimated length-at-age for *Squalus acanthias* using published von Bertalanffy growth parameters. Males in the North-west Atlantic.

Age	Nammack *et al.* (1985)	Campana *et al.* (2009; L_F)	Campana *et al.* (2009; converted L_T)	Bubley *et al.* (2012; vertebrae)	Bubley *et al.* (2012; spines)
0	26.9	25.0	30.4	25.0	25.0
1	34.6	30.0	35.8	32.2	31.9
2	41.2	34.5	40.7	38.7	38.1
3	46.9	38.6	45.2	44.5	43.7
4	51.8	42.3	49.2	49.6	48.7
5	56.0	45.7	52.9	54.3	53.1
6	59.6	48.7	56.2	58.4	57.1
7	62.8	51.5	59.2	62.2	60.7
8	65.5	54.0	62.0	65.5	63.9
9	67.8	56.3	64.4	68.5	66.8
10	69.9	58.3	66.7	71.2	69.3
11	71.6	60.2	68.7	73.6	71.6
12	73.1	61.8	70.5	75.7	73.7
13	74.4	63.4	72.2	77.7	75.6
14	75.5	64.7	73.7	79.4	77.2
15	76.5	66.0	75.0	80.9	78.7
16	77.3	67.1	76.3	82.3	80.0
17	78.0	68.2	77.4	83.6	81.2
18	78.6	69.1	78.4	84.7	82.3
19	79.2	69.9	79.3	85.7	83.2
20	79.6	70.7	80.1	86.6	84.1
21	80.0	71.4	80.9	87.4	84.9
22	80.4	72.0	81.6	88.1	85.6
23	80.6	72.6	82.2	88.7	86.2
24	80.9	73.1	82.8	89.3	86.7
25	81.1	73.5	83.3	89.8	87.2
26	81.3	74.0	83.7	90.3	87.7
27	81.5	74.3	84.1	90.7	88.1
28	81.6	74.7	84.5	91.0	88.4
29	81.7	75.0	84.8	91.4	88.7
30	81.8	75.3	85.2	91.7	89.0
31	81.9	75.5	85.4	91.9	89.3
32	82.0	75.8	85.7	92.2	89.5
33	82.1	76.0	85.9	92.4	89.7
34	82.1	76.2	86.1	92.6	89.9
35	82.2	76.3	86.3	92.8	90.0
36	82.2	76.5	86.5	92.9	90.2
37	82.3	76.6	86.6	93.0	90.3
38	82.3	76.8	86.8	93.2	90.4
39	82.3	76.9	86.9	93.3	90.5
40	82.3	77.0	87.0	93.4	90.6
41	82.4	77.1	87.1	93.5	90.7
42	82.4	77.2	87.2	93.6	90.8
43	82.4	77.3	87.4	93.7	90.9
44	82.4	77.4	87.5	93.8	91.0
45	82.5	77.5	87.6	93.9	91.1

Table 4: Length-at-age (cm) of *Squalus acanthias* in the North-east Atlantic (Aasen, 1961), and mean length-at-age (cm) and sample size (N) of *Squalus acanthias* in the North-west Atlantic (Soldat, 1982).

Age	Aasen (1961)	Soldat (1982)			
		Females		Males	
		Mean length, (L_T, cm)	N	Mean length (L_T, cm)	N
0	22.2				
1	29.1	27.1	24	26.8	25
2	34.1	34.0	19	34.2	18
3	38.6	39.5	13	40.9	18
4	42.8	47.1	17	45.7	18
5	46.8	50.6	17	49.5	19
6	50.7	53.5	17	53.0	17
7	54.6	59.0	22	59.5	19
8	58.3	63.7	19	64.0	20
9	62.1	70.9	17	66.6	14
10	65.7	72.6	14	69.8	12
11	69.4	77.0	7	73.0	6
12	73.1	80.5	11	74.3	14
13	76.6	82.8	12	76.2	6
14		85.2	9	77.3	9
15		86.3	9	77.0	3
16		85.7	6	77.5	2
17		87.5	4	76.5	4
18		87.0	3	80.7	3
19		92.0	4	81.0	3
20		93.2	6	85.0	1
21		93.3	8		
22		96.0	7		
23		97.5	2		
24		90.0	1		
25		99.5	2		
26		96.7	3		

543

Table 5: Suggested VBGPs for examination during the 2021 spurdog assessment, namely VBGP_2021 (the averaged parameters presented here, excluding Albert *et al.* (2019) for males), VBGP_2013 (the parameters used in the original assessment and as defined in De Oliveira *et al.*, 2013), and Fahy_1988 (using the results from Fahy (1988), which give the lower bounds of the growth curve).

Run	Parameter	Female	Male
VBGP_2021	L_{inf} (cm)	111.285	80.252
	K (y^{-1})	0.081	0.183
	t_0 (y)	-3.929	-1.863
VBGP_2013	L_{inf} (cm)	110.66	81.36
	K (y^{-1})	0.086	0.17
	t_0 (y)	-3.306	-2.166
Fahy_1988	L_{inf} (cm)	98.8	79.9
	K (y^{-1})	0.09	0.16
	t_0 (y)	-1.57	-1.69

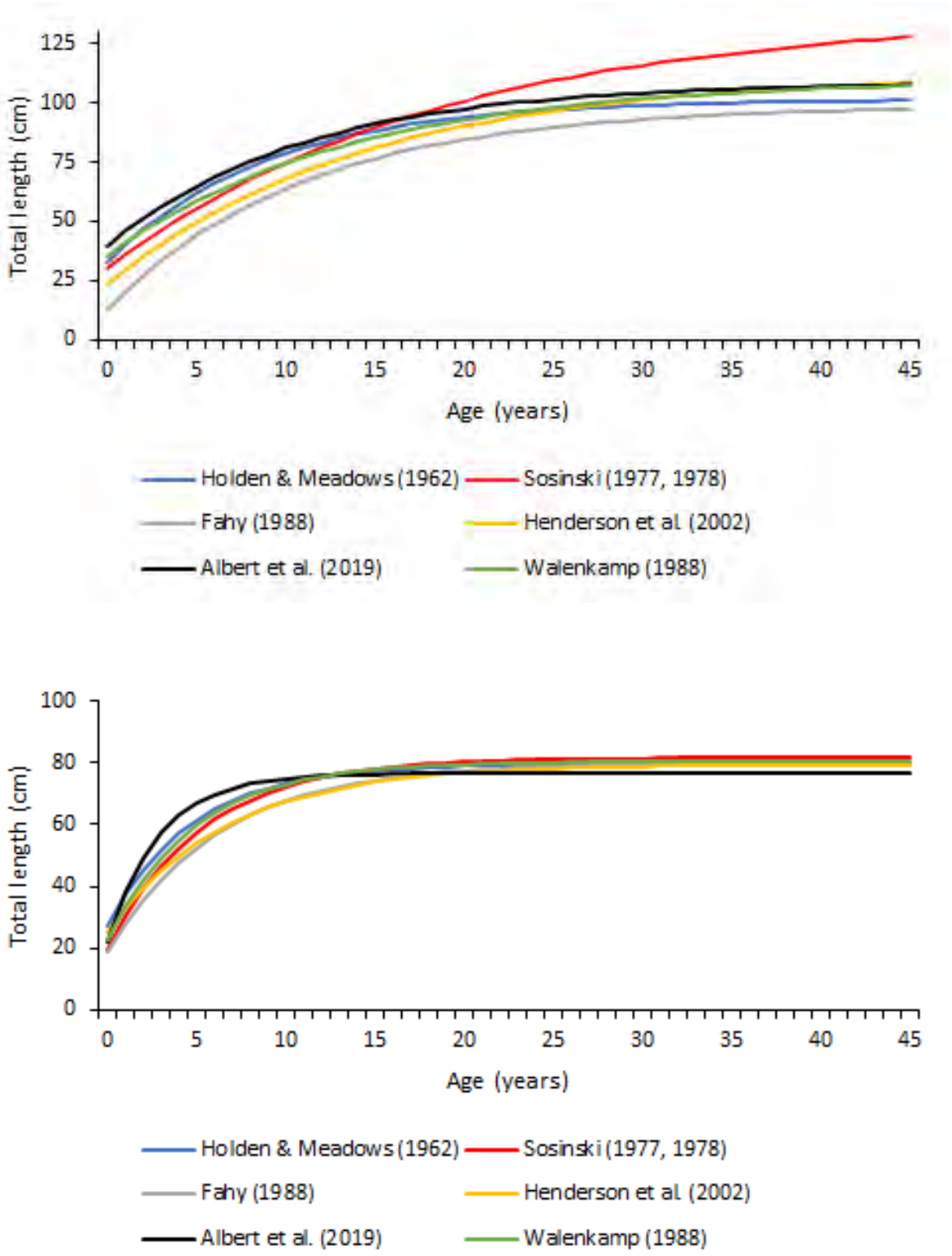


Figure 1: Length-at-age of North-east Atlantic spurdog *Squalus acanthias* (top: females; bottom: males), based on published studies.

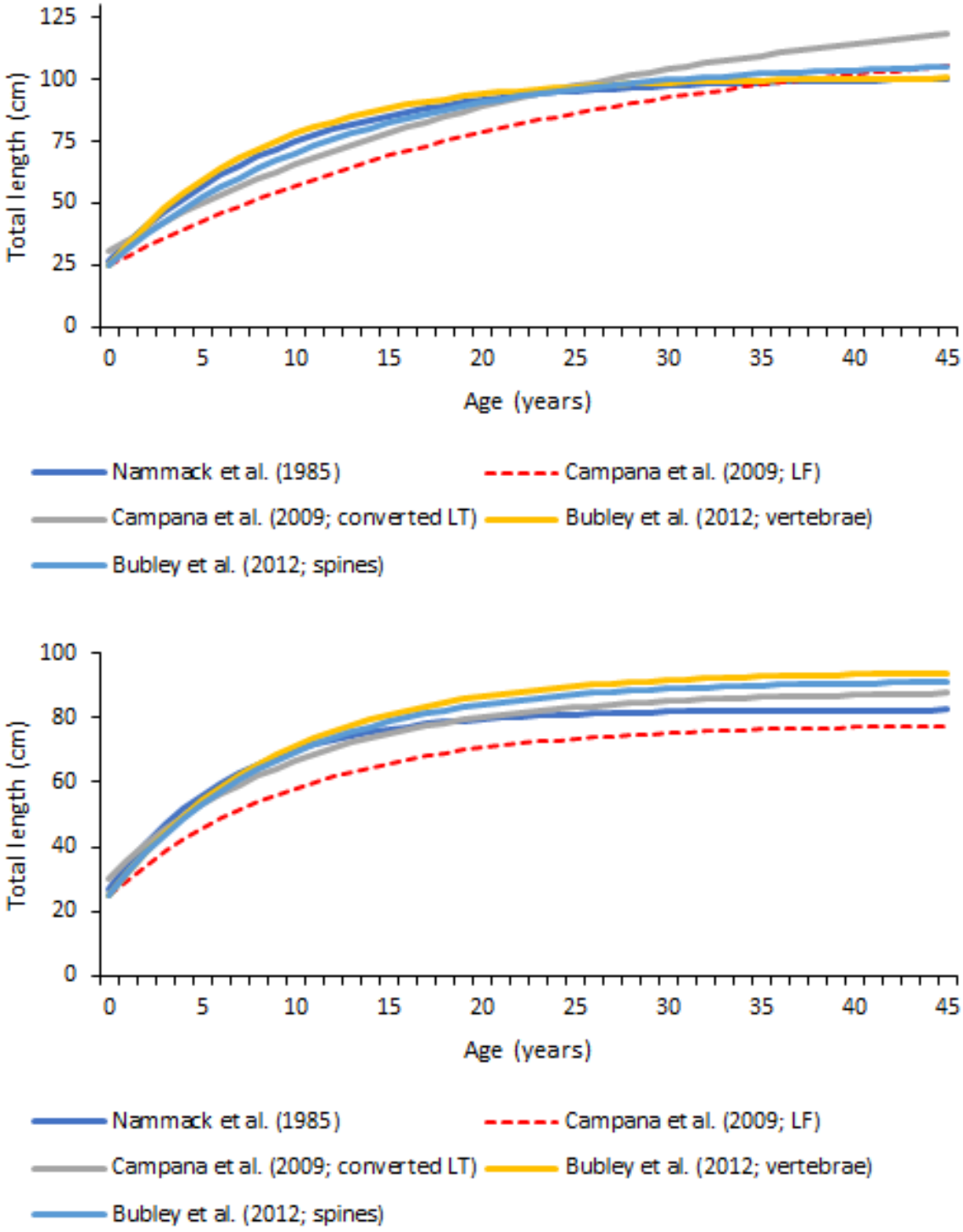


Figure 2: Length-at-age of North-west Atlantic spurdog *Squalus acanthias* (top: females; bottom: males), based on published studies. Note: Campana *et al.* (2009) provided the growth equation based on fork length (L_F; dashed lines), for which the estimated length-at-age was also converted to total length (L_T) using the equation $L_T = 3.1 + 1.09*L_F$ (Campana *et al.,* 2009). Both Campana *et al.* (2009) and Bubley *et al.* (2012) used modified equations, for which the length-at-birth (L_0) was set at 25 cm.

546

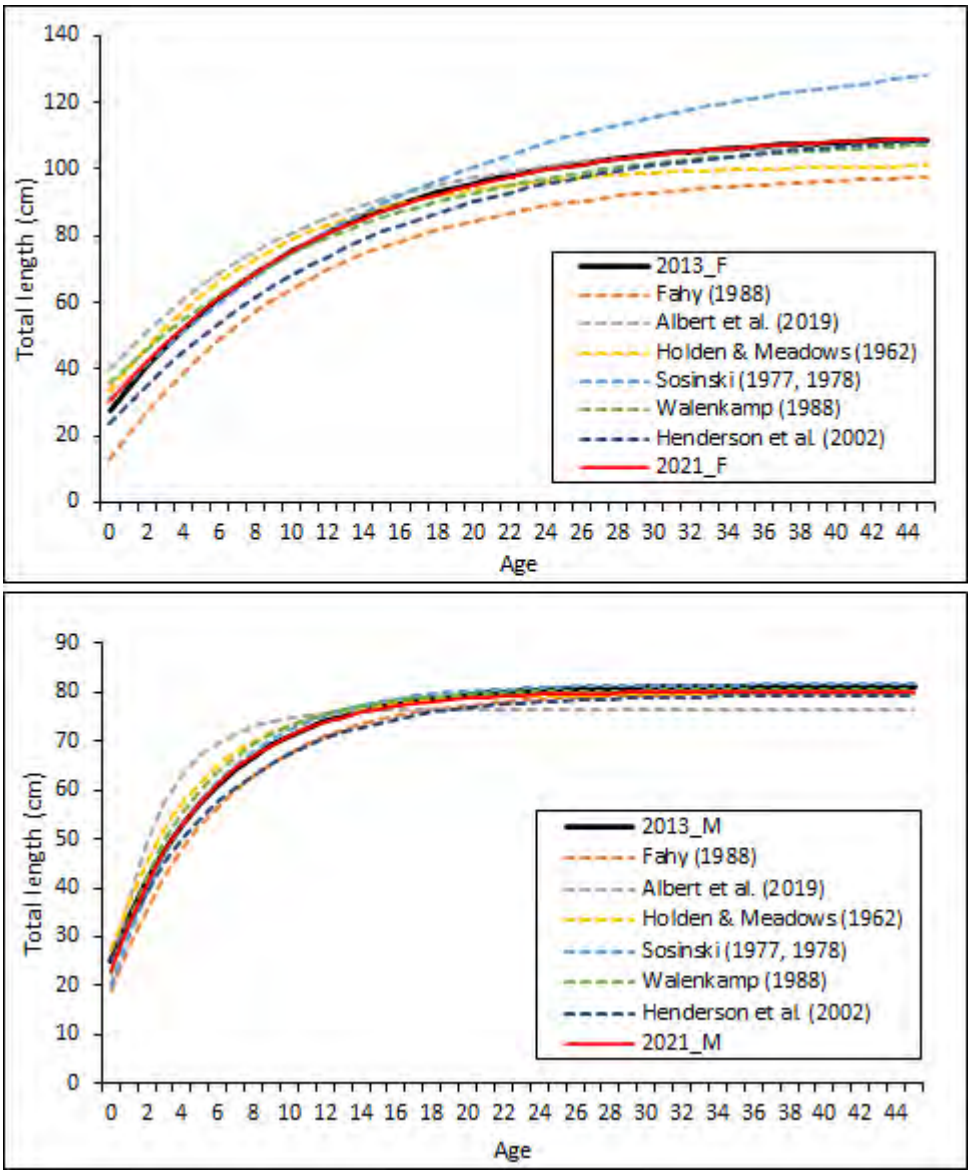


Figure 3: Length-at-age of North-east Atlantic spurdog *Squalus acanthias* (top: females; bottom: males) showing the parameters used in the earlier assessment (2013) and proposed parameters for updated assessment (2021), and individual studies, including Fahy (1988).

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021

Not to be cited without prior reference to the authors

Contemporary length-frequency data for spurdog *Squalus acanthias*

Ellis, J. R. and De Oliveira, J. A. A.

Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

The Data Call for the 2021 benchmark assessment for spurdog *Squalus acanthias* (dgs.27.nea) provided contemporary data on the length-frequency distribution from a range of gears, national fleets and data sources (i.e. market/port sampling and/or discard-observer programmes). Some of these data were submitted as raw (unraised) numbers, especially when sample sizes were limited, whilst other data had been raised by the data providers. Following submission and collation of these data, preliminary examination of the data was undertaken to summarise these data and to identify the more robust data to be considered for inclusion in the 2021 assessment.

1. Introduction

The stock assessment for spurdog *Squalus acanthias* Northeast Atlantic (dgs.27.nea) is based on an age- and sex-structured model that includes length-based processes (e.g. maturation, pup production, growth and gear selectivity) with a length-at-age relationship to convert length to age (De Oliveira *et al.*, 2013). Commercial length-frequency data used in the initial model were earlier market sampling data from UK (England), when there were important longline fisheries targeting spurdog (especially aggregations of large, mature females) and market sampling data from UK (Scotland), which was more reflective of trawl fisheries (considered to be more typical of some of the bycatch fisheries).

The current model also attributed data to five length groups: Pups (16–31 cm total length); juveniles (32–54 cm); sub-adults (55–69 cm); maturing fish (70–84 cm) and mature fish (85+ cm). Commercial data for the two smaller length groups were combined.

Contemporary data on the length-frequency of spurdog were highlighted as important for the updated assessment, and relevant data were submitted by most nations during the Data Call.

2. Data supplied

Data were supplied by the following: Sweden, Denmark, UK (Scotland), UK (England and Wales), Ireland, Germany, Netherlands, Spain (AZTI and IEO data) and Portugal. No data were supplied by UK (Northern Ireland), Belgium, France. This may be due to either low sample sizes (e.g. the Belgian beam fleet would be expected to have a low catchability of spurdog) or data-raising issues (e.g. where national laboratories raise observer data in relation to reported landings, which does not then account for species for which the TAC is zero or species that are prohibited).

2.1 Sweden

Data (raised) were supplied for landings/discards (2002-2019, no data in occasional years; not sex disaggregated). Data were limited for midwater otter trawls (OTM) and Danish seines (SDN), but more consistent data were available for otter trawls (OTB and OTT). The overall length range reported was 16-112 cm, and all data were from fisheries in Division 3.a.

Data from bottom otter trawl (OTB and OTT combined) showed a broad length range of spurdog from pups to adults, with a main peak at 70-80 cm L_T and a smaller peak (25-30 cm L_T) relating to pups (Figure 1). Few specimens >100 cm L_T were recorded. Data from anchor seines were more limited, but showed a similar modal peak to the bottom trawls.

The data from otter trawlers were considered appropriate for potential inclusion in the 2021 assessment, given that there was good temporal coverage (Figure 2). There was some inter-annual variation apparent, with proportionally more early stages recorded in some years (2010, 2011, 2016, 2018) and no or fewer observations of such stages in some other years (2002-2009). It is uncertain whether the increase in young stages related to changes in fishing patterns, spatial shifts in stock distribution, or increased recruitment success.

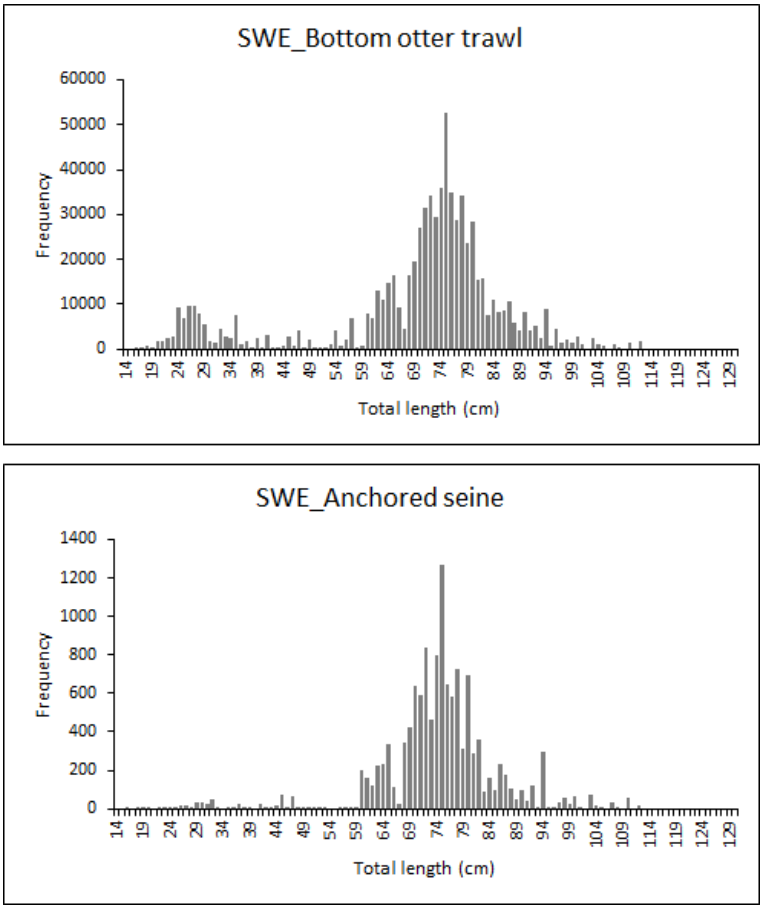


Figure 1: Aggregated length-frequency data for spurdog taken in Swedish fisheries in Division 3.a using bottom trawl and seine.

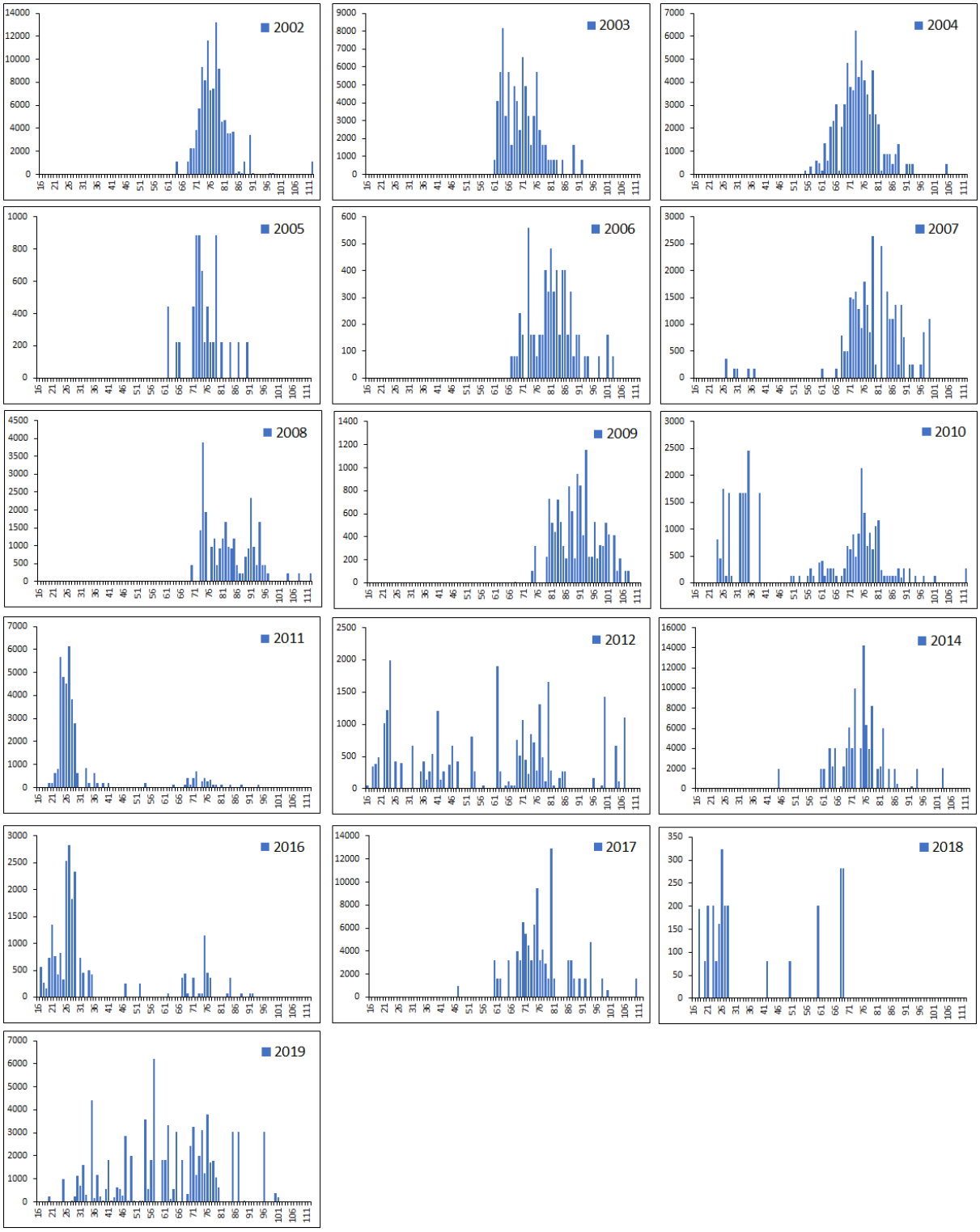


Figure 2: Length-frequency of spurdog taken in Swedish bottom trawl fisheries in Division 3.a by year (2002-2019, no data for 2013 and 2015).

2.2 Denmark

Data (raised) supplied for landings/discards (2006-2019, no data in some years; not sex disaggregated). Data were supplied for Danish seine, gillnets (GNS) and otter trawl (OTB). The overall length range observed was 19-125 cm (noting one erroneous value for 30 mm). Data were from fisheries operating in 3.a and 4.a-c.

Data from the various gears were all relatively limited and, whilst raised numbers were quite large, the absence of a continuous length-frequency profile and a lack of well-defined modes (Figure 3) would be indicative of the underlying data being from smaller sample sizes.

These data were not considered appropriate for inclusion in the 2021 assessment at the present time.

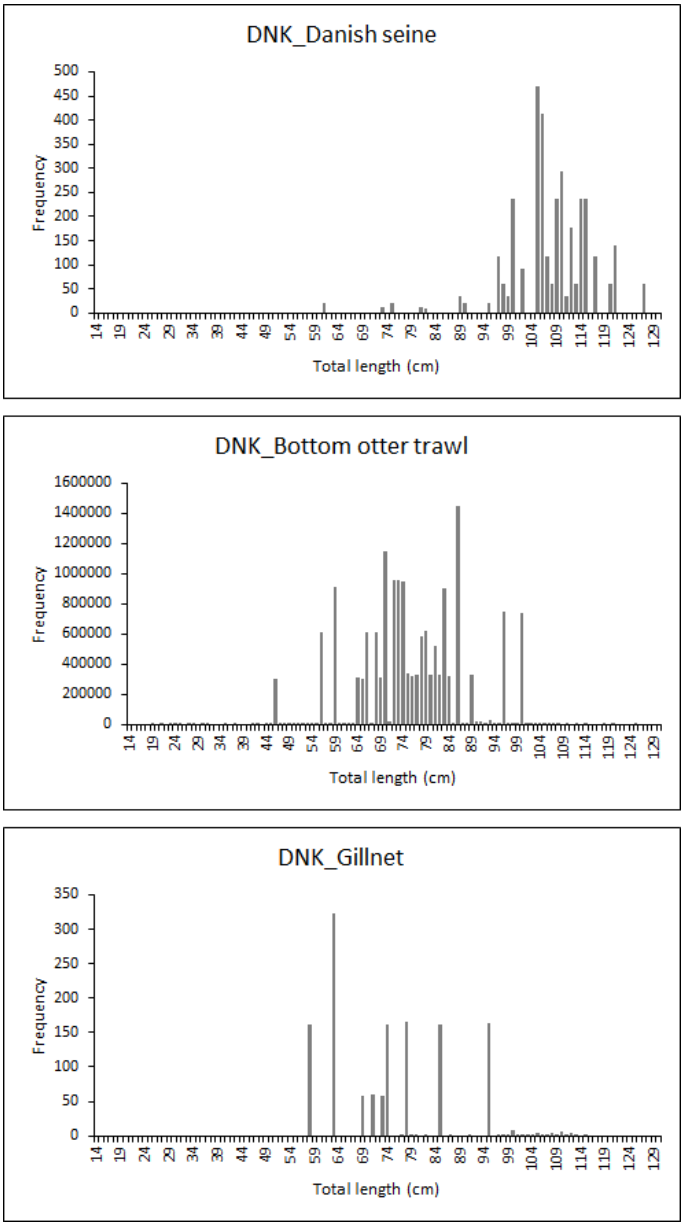


Figure 3: Aggregated length-frequency data for spurdog taken in from Danish fisheries in Divisions 3.a and 4.a-c using seine, bottom trawl and gillnet.

2.3 UK (Scotland)

Port sampling data were provided for 2009-2010, for OTB fisheries in Divisions 4.a-b and 6.a. The overall length range observed was 52-140 cm (though the 140 cm record is questionable and was excluded from the present analysis).

Observer data were provided for 2009-2019, for OTB fisheries in Divisions 4.a-b and 6.a-b. The overall length range observed was 14-129 cm.

Data from otter trawlers (Figure 4, showing aggregated from market sampling and observer trips and shown for illustrative purposes) showed a broad length range with modes equating with pups and the 70-80 cm peak. Scottish waters are known to include areas where juvenile spurdog are abundant.

The data from otter trawlers were considered appropriate for potential inclusion in the 2021 assessment, given that there was good temporal coverage (Figure 5). There was some inter-annual variation apparent, with proportionally more early stages recorded in 2011 and 2012. With a broad length range recorded in most years

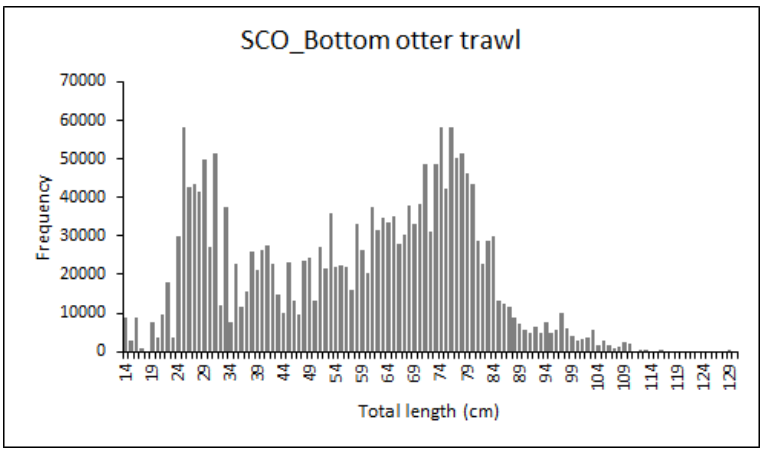


Figure 4: Aggregated length-frequency data for spurdog from Scottish otter trawl fisheries in Divisions 6.a and 4.a-b.

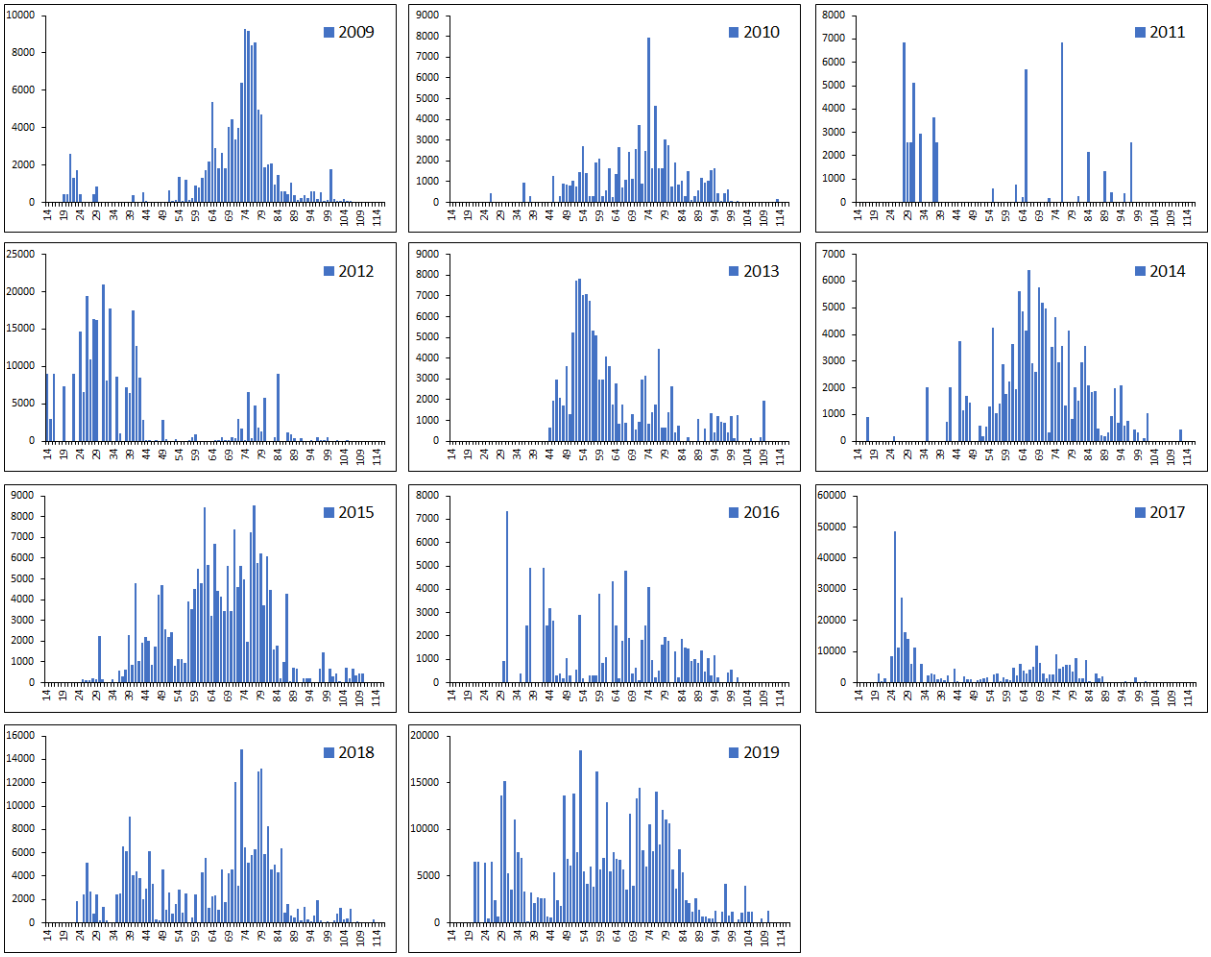


Figure 5: Length-frequency of spurdog taken in Scottish bottom trawl fisheries in Divisions 6.a and 4.a-b by year (2009-2019, data for 2009/2010 include data from market sampling and from discard observer trips, with discard observer trips from 2011 onwards. Data for spurdog of 129 cm (2019 only) not shown

2.4 UK (England and Wales)

Contemporary port sampling data provided as raw numbers (n = 408, sex disaggregated), from two metiers (GNS and OTB) for 2016-2019. These data were from Divisions 7.f-g and the overall length range observed was 59-116 cm.

Observer data (mostly sex-disaggregated) for Subarea 7 (2002-2019, six metiers) were also provided. Most data related to gill and trammel nets, and the selection patterns for these gears were broadly similar in terms of the main peal (Figure 6), although there appeared to be proportionally more large individuals (>90 cm) taken by gillnet. Data were also available for otter trawl, whilst data from beam trawl were more limited. The overall length range observed was 17-126 cm (a nominal record of 101 mm likely being an incorrect units).

Whilst annual data for otter trawlers was limited (Figure 7), the annual data from netters (Figure 8) were considered appropriate for potential inclusion in the 2021 assessment. This fleet provided good temporal coverage (Figure 5), though data were limited in occasional years (e.g. 2005).

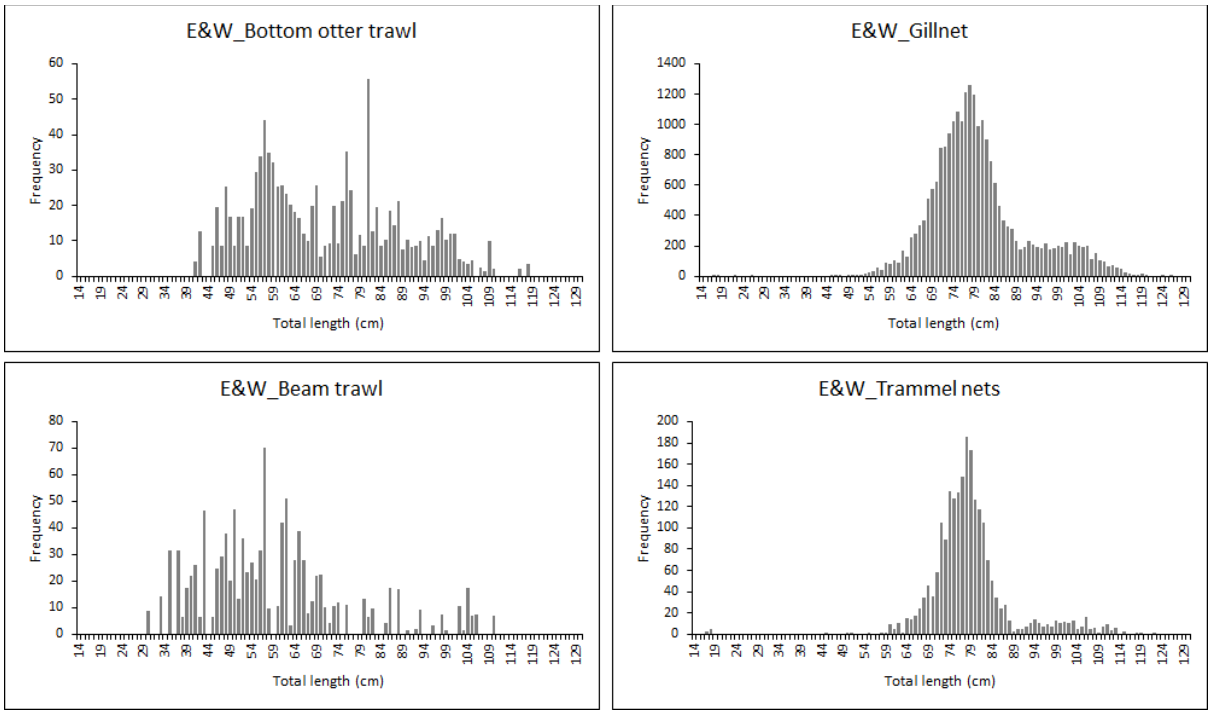


Figure 6: Aggregated length-frequency data for spurdog from UK (E&W) fisheries using Sottish otter trawl fisheries in Divisions 6.a and 4.a-b.

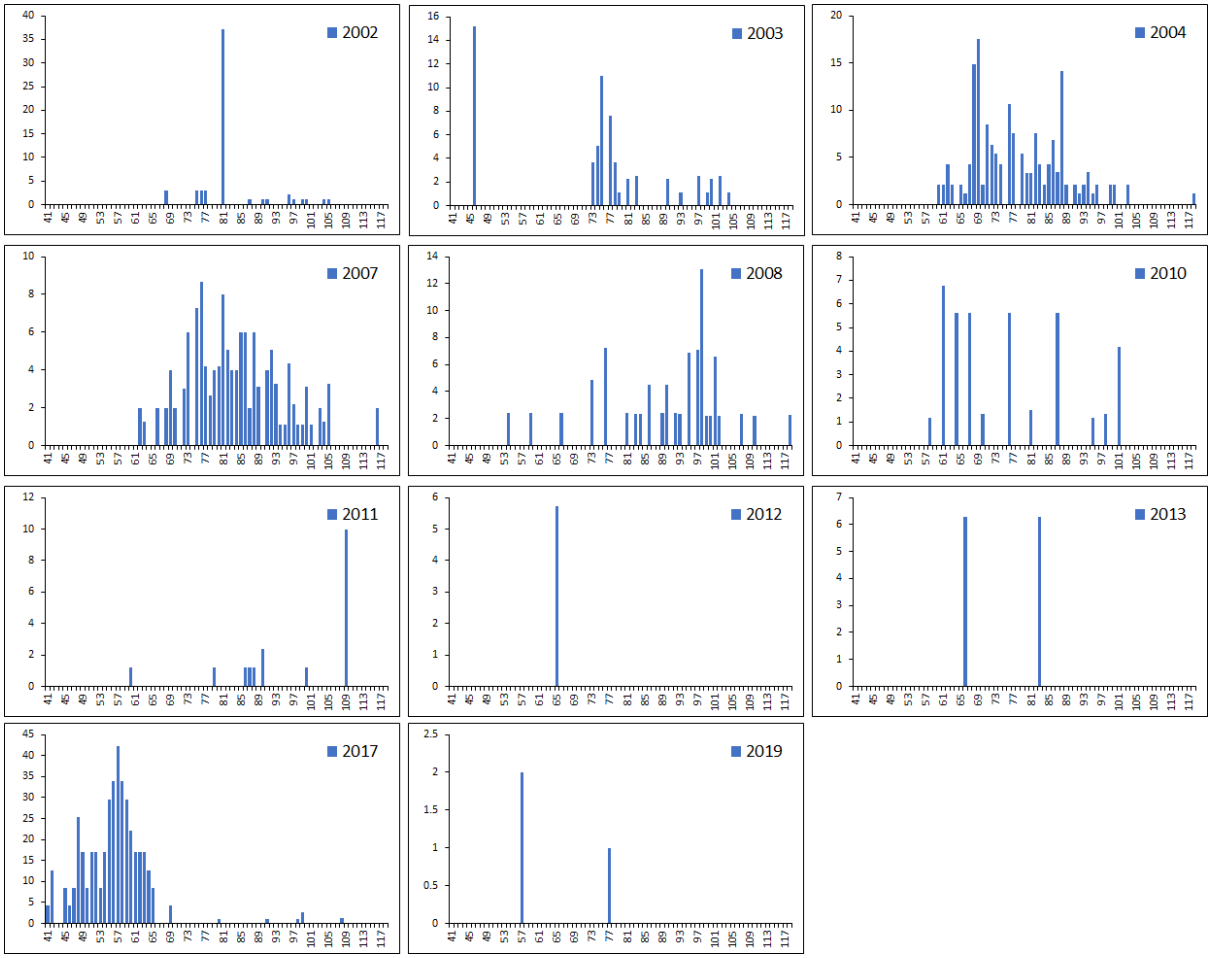


Figure 7: Length-frequency of spurdog taken in UK (E&W) bottom trawl fisheries by year (2002-2019) as recorded during discard observer trips. Spurdog were not recorded in 2005, 2006, 2009, 2014-2016 and 2018, and data were more comprehensive in 2004, 2007 and 2017.

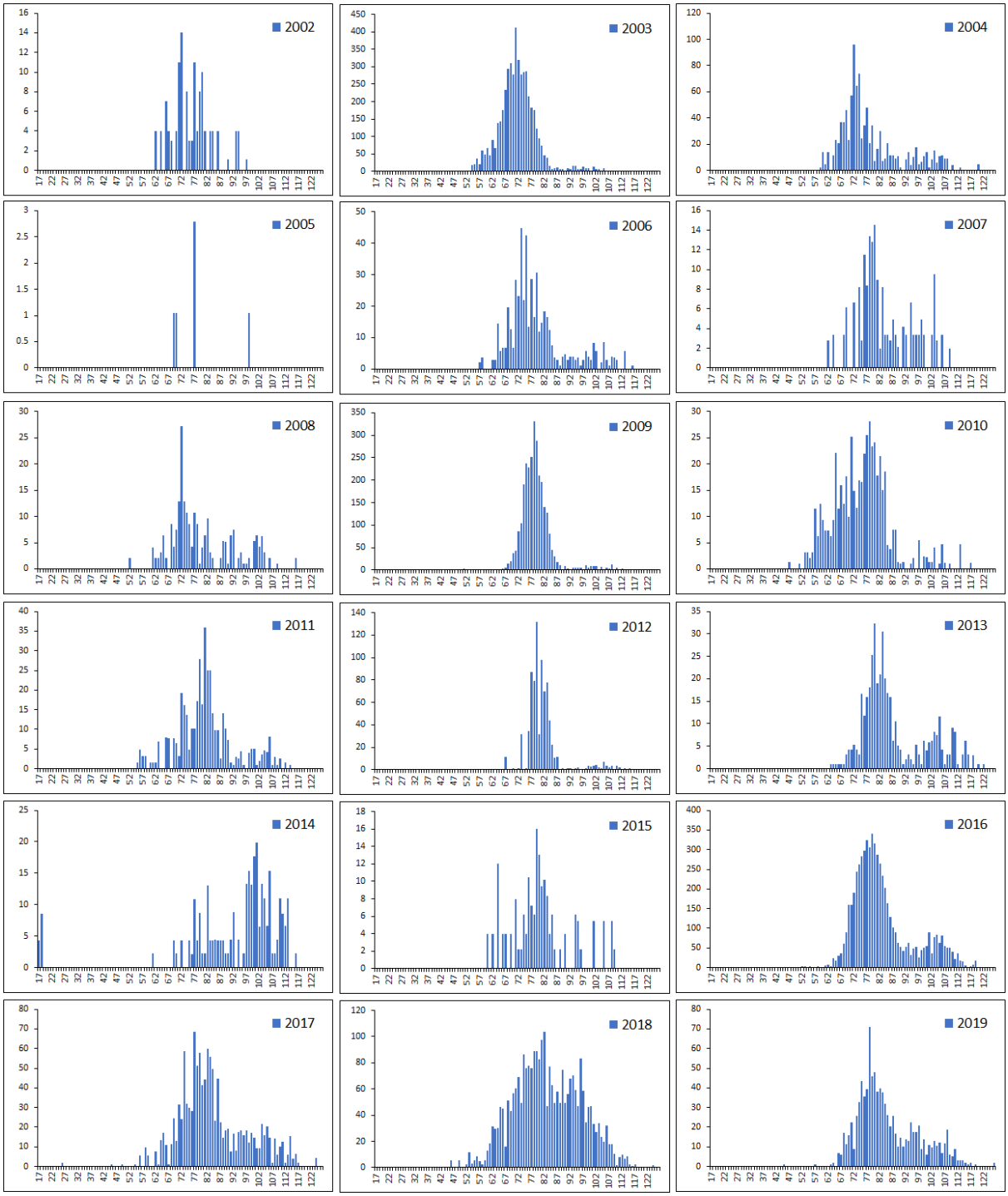


Figure 8: Length-frequency of spurdog taken in UK (E&W) gill- and trammel net fisheries by year (2002-2019) as recorded during discard observer trips.

2.5 Ireland

Port sampling data were limited and provided as raw numbers (n = 111) across three metiers (GN, OTB, TBB) in 2005-2009. These data were from Divisions 6.a, 7.a and 7.j. The overall length range observed was 48-106 cm.

More data from the Irish observer programme were available, from vessels operating in Subarea 6 and Divisions 7.a-b, g, j (2005-2019; six metiers). The Overall length range observed was 17-130 cm. The largest fish is very slightly higher than L_{max} in other studies, but not so excessive as to be excluded. Data were most consistent for OTB_CRU_70-99 and OTB_DEF_100-119. The aggregated data are shown in Figure 9.

The annual data from Irish trawlers (Figure 10) were considered appropriate for potential inclusion in the 2021 assessment. This fleet provided good temporal coverage, though data were limited in occasional years (e.g. 2006).

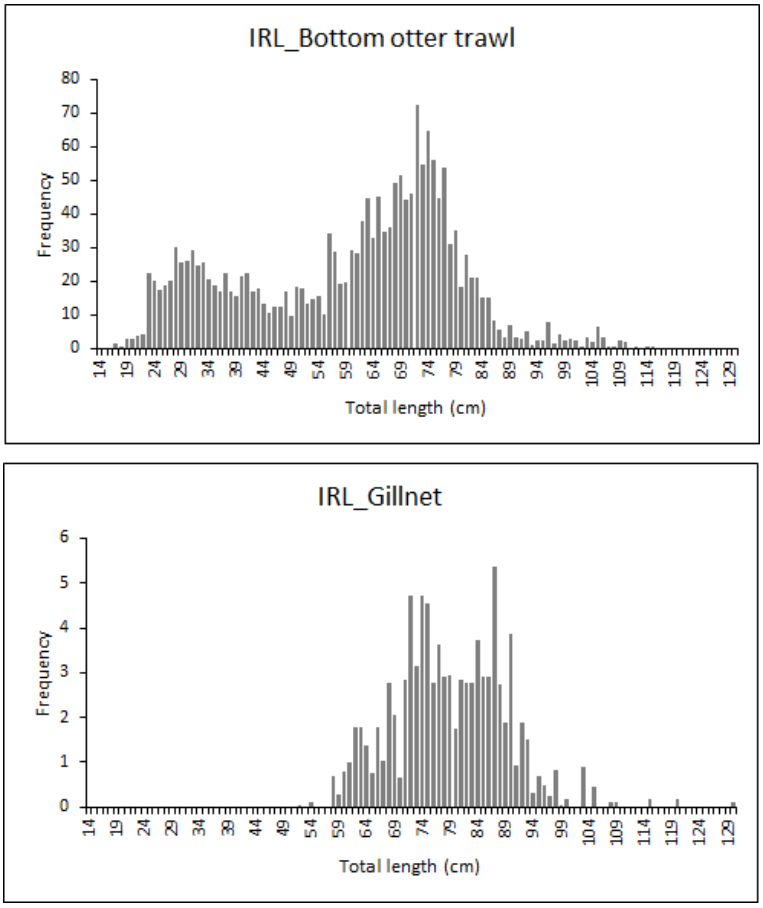


Figure 9: Aggregated length-frequency data for spurdog from Irish otter trawl and gillnet fisheries.

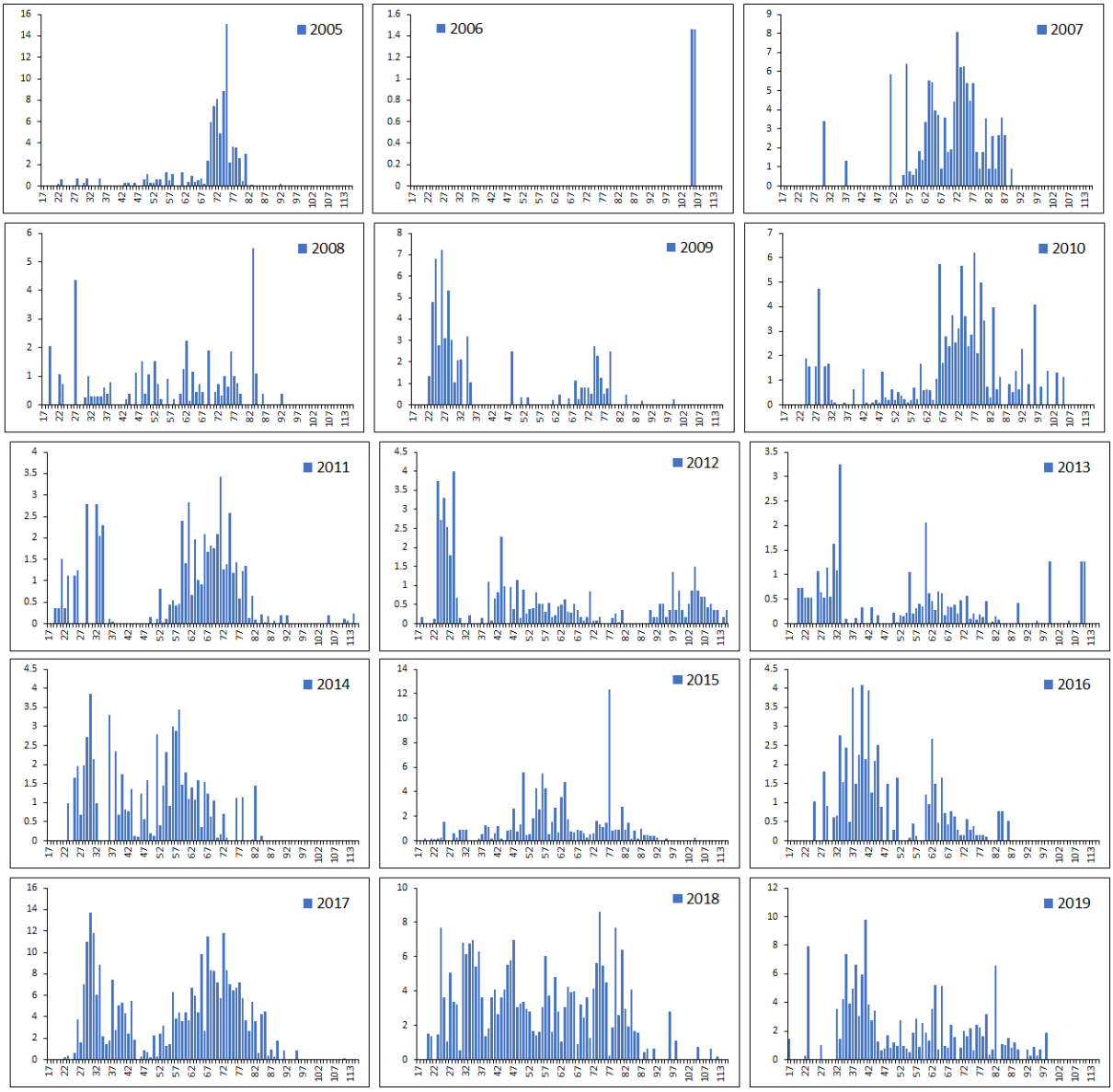


Figure 10: Length-frequency of spurdog taken in Irish bottom trawl fisheries in Subareas 6-7 by year (2005-2019), as recorded during discard observer trips.

2.6 Germany

Data (unraised) were supplied for landings/discards (2005-2019, no data in occasional years; not sex disaggregated). Data were from seven metiers across Divisions 14.a, 2.a, 3.a, 4 and 6.a. The overall length range observed was 36.5-118.5 cm. Most data were for "OTB_DEF_>=120_0_0_all" and "OTM_SPF_32-69_0_0_all", and these two metiers operated in Divisions 2.a and 6.a.

The somewhat limited data from midwater trawlers and bottom trawlers (Figure 11) indicated that spurdog were slightly smaller (mostly 50-80 cm) in midwater trawl than in otter trawl catches (mostly 70-90 cm).

These data were not considered appropriate for inclusion in the 2021 assessment at the present time.

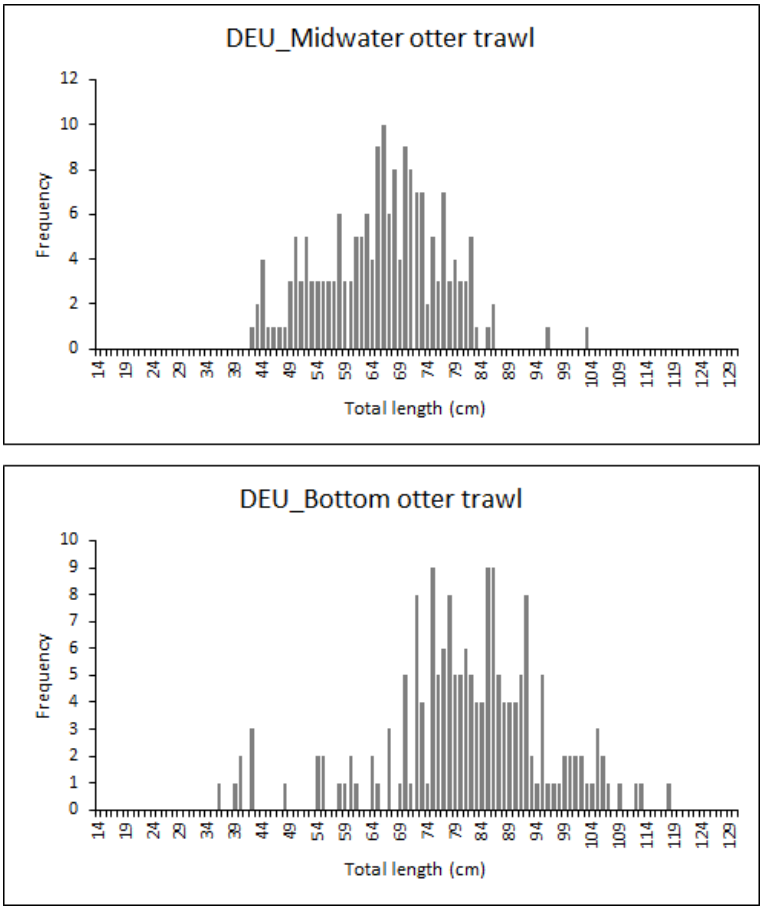


Figure 11: Aggregated length-frequency data for spurdog from German midwater and bottom otter trawl fisheries.

2.7 Netherlands

The numbers of spurdog sampled were below the threshold used by the Netherlands to raise the data. Raw observed numbers at length were provided. Data were limited from the demersal onboard programme, but more length measurements were available from the pelagic onboard programme (n = 115). These data spanned the period 2007-2019, and were from Subareas 4, 6-7. The overall length range observed was 25-102 cm. The limited data from midwater otter trawlers yielded a length-frequency distribution (Figure 12) similar to that reported by Germany (Figure 11).

These data were not considered appropriate for inclusion in the 2021 assessment at the present time.

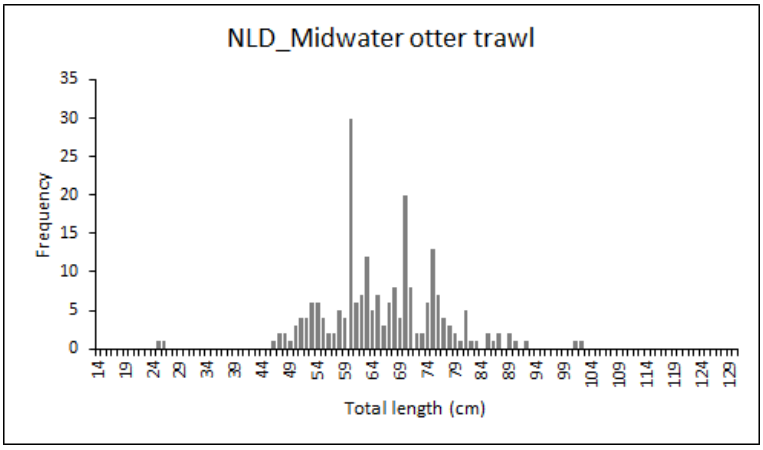


Figure 12: Aggregated length-frequency data for spurdog from Dutch midwater trawl fisheries.

2.8 Spain

Data were supplied by both AZTI and IEO. Data from Division 8.c were not considered, as multiple species of *Squalus* may occur in the area.

AZTI: Limited data were available for six metiers across the period 2006-2019. The overall length range observed was of 33-99 cm. Data were from 6.a and 8.b (though the southerly parts of the latter area could potentially include other species of *Squalus*).

IEO: Limited data were available for seven metiers across the years 2014-2019. Data were most consistent for OTB_DEF_70-99_0_0. The overall length range observed was 16-98 cm. Data from subareas 6-7 related to OTB_DEF_70-99_0_0), whilst data from other metiers were from Divisions 8.c and 9.a (these could potentially include other species of *Squalus*).

Both AZTI and IEO data from otter trawlers showed discontinuous length distributions (Figure 13), which could relate to low sample sizes and large raising factors. These data were not considered appropriate for inclusion in the 2021 assessment at the present time.

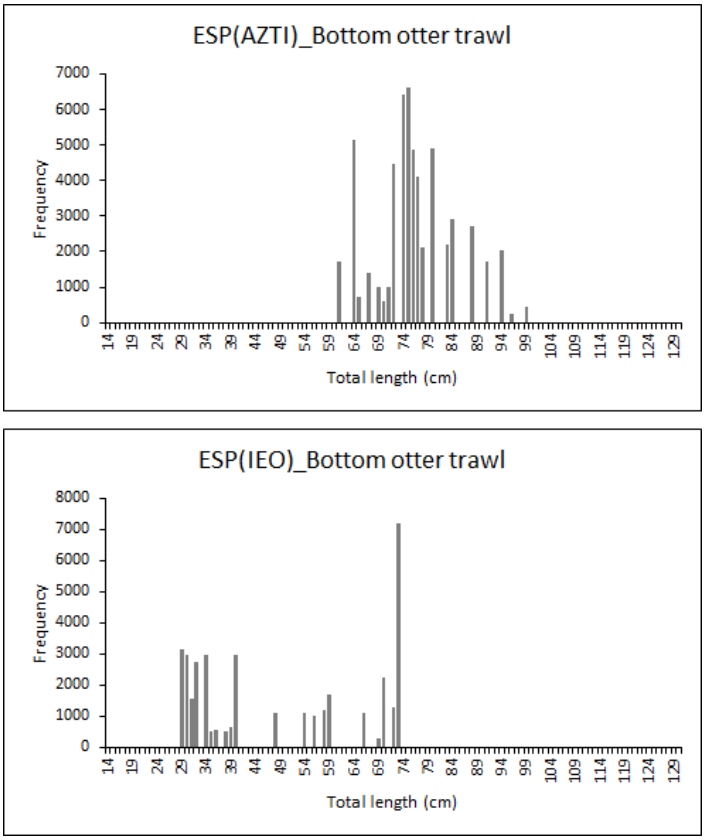


Figure 13: Aggregated length-frequency data for spurdog from Spanish fisheries.

2.9 Portugal

Limited market sampling data for seven metiers (2010-2018). Overall length range observed was 40-106 cm. Data were from fisheries operating in Division 9.a and so could potentially include other species of *Squalus*. These data were not considered appropriate for inclusion in the 2021 assessment at the present time.

3. Summary

Length-frequency data were most comprehensive for the following nations and gears:

(1) Swedish otter trawlers
(2) UK (Scottish) trawlers
(3) UK (English & Welsh) netters
(4) Irish trawlers (discard/retained data from observer trips)

Whilst annual data are available for some of the above, data can be limited in some years, and so there could be consideration of aggregating data across time periods.

Sex-disaggregated data were supplied by UK (England and Wales), with other data non sex-disaggregated.

Preliminary examination of the data relating to the mean annual proportion of numbers at length (plotted as a cumulative percentage; Figure 14) indicated that Irish and Scottish trawlers had broadly similar selection patterns, whilst Swedish otter trawlers caught proportionally fewer large juveniles (40-70 cm), whilst the netters (here shown for UK(E&W) were more selective for larger spurdog (mostly >68 cm) and caught proportionally fewer small individuals.

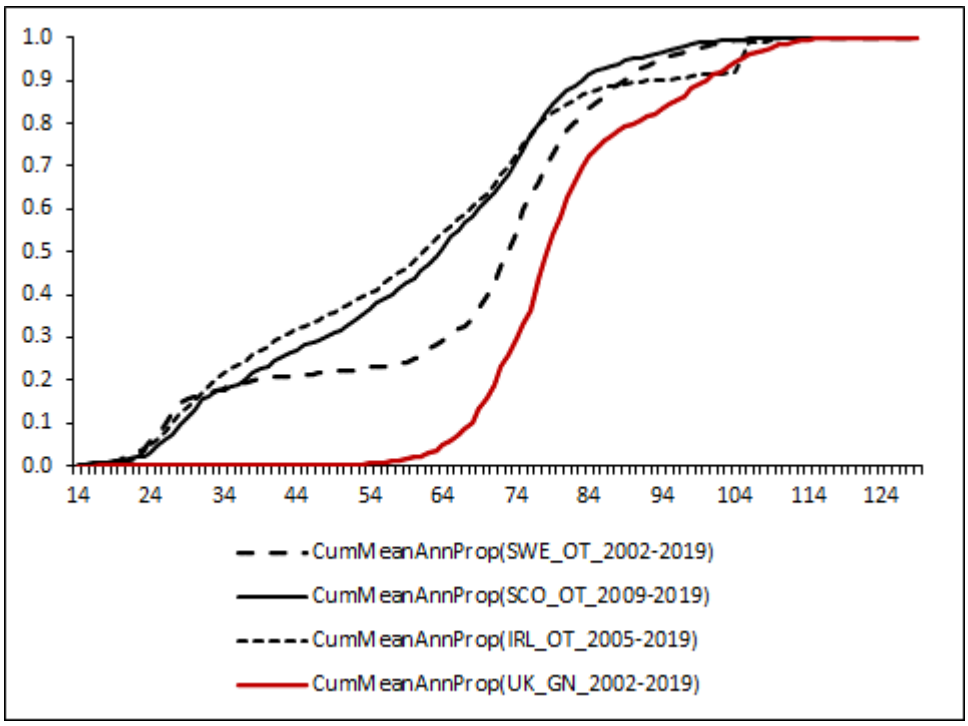


Figure 14: Mean annual proportion at length (plotted as a cumulative proportion) of spurdog taken in Swedish, Scottish and Irish bottom trawl fisheries and UK(E&W) gillnet fisheries.

4. References

De Oliveira, J. A. A., Ellis, J. R., and Dobby, H. (2013). Incorporating density dependence in pup production in a stock assessment of NE Atlantic spurdog *Squalus acanthias. ICES Journal of Marine Science*, 70: 1341–1353.

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020

Not to be cited without prior reference to the authors

A summary of spurdog (*Squalus acanthias*) data collected during the Norwegian Shrimp trawl survey (NO-shrimp)

Claudia Junge, Caroline A Tranang, Tone Vollen, Ole Thomas Albert
Havforskningsinstituttet (Institute of Marine Research, IMR), Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, Norway

Summary

The annual shrimp trawl survey (NO-shrimp) in the North Sea/Skagerrak is conducted by the Institute of Marine Research's (IMR). It started in 1984, and yearly covers Skagerrak and the northern parts of the North Sea north to 60°N. The time of the survey has changed from quarter 4 (1984-2003), via quarter 2 (2004-2005), to quarter 1 since 2006. Before 1989 the trawl was an unspecified bottom trawl with unknown mesh size. Since 1989 a Campelen 1800 Shrimp trawl with 40 meter sweeps and a rockhopper gear was used. Mesh size was 35 mm from 1989-1997, and 20 mm from 1998. Trawl time was variable between stations, but in general 1 hour from 1984-1988 and 30 minutes for later years.

Methods

Data for the survey series were extracted from The Norwegian Marine Datacenter (NMD) in September 2020 and the following information presented here:

(a) Number of trawl stations by month and year;
(b) Number of stations by gear and year;
(c) Mean CPUE by weight and numbers per year;
(d) Length composition by decade;
(e) Sex ratio by year;
(f) Length composition by sex

Results

Stations fished, gear and trawl time

Since its beginning, the survey has been subjected to a few changes in the time of year of survey execution (Table 1). During the time-series, the number of stations fished per year ranged from 63-139 for the years 1984-2003 (Q3), 62-94 (Q2) for the years 2004-2005, and 44-119 for the years 2006-2020 (Q1). The survey year 2016 was removed from the time series due to gear troubles.

Different gears have been used throughout the survey time series (Table 2). Included in the analysis were all Shrimptrawl. Campelen 1800 ma with 40 m sweeps, Rockhopper gear, i.e. with 20-35 mm mesh size, and with and without strapping.

Duration of trawl hauls was in general 60 minutes in 1984-1988, and 30 minutes in 1989-2020. All tows shorter than 10 minutes were removed = 16 hauls). In 1990, one trawl haul with towing time of 2.5 hours was removed.

The final dataset has 3086 stations with a total of 2317 spurdog caught. Figure 1.

Fishing effort, length composition and sex ratio

Catch per unit effort (CPUE) was calculated as catch numbers and catch weight per nautical mile (Table 3). Both are shown in Figure 2 and 3, respectively. CPUE based on catch numbers is shown per decade in Figure 4.

Length composition is shown by decade in Figure 5. Sex ratio is shown by year for 2011-2020 in Figure 6. Length composition by sex is shown for 2011-2020 in Figure 7.

NO-shrimp data included in spurdog survey indices

Data from IMR's annual shrimp trawl survey (NO-shrimp) in the North Sea/Skagerrak is included for the spurdog survey indices from 2005 onwards, all in quarter 1 (NO-shrimp-Q1).
Survey details: season=Q1; gear=Campelen 1800 Shrimp trawl with 40 meter sweeps, rockhopper gear, mesh size 20 mm; Trawl time=30 minutes (generally);
DATA supplied in DATRAS format for WKNSEA.

Tables

Table 1. Number of stations by month and year for shrimp survey. Red numbers were removed.

Year	Jan	Feb	May	Jun	Oct	Nov
1984					63	
1985					95	
1986					33	36
1987					70	42
1988					26	96
1989					100	
1990					85	
1991					120	
1992					101	
1993					124	
1994					66	46
1995					103	
1996					139	
1997					105	
1998					101	
1999					114	
2000					107	
2001					78	
2002					79	
2003					9	59
2004			62			
2005			38	56		
2006		44				
2007		65				
2008		73				
2009	48	55				
2010	94					
2011	98					
2012	63					

2013	101	
2014	68	
2015	82	8
2016	105	
2017	117	
2018	110	
2019	119	
2020	106	

Table 2. Number of stations by gear and year for shrimp survey. Red numbers were removed.

	Unspecified Bottom trawl	Langoustine trawl	Unspecified shrimp trawl	Shrimp trawl 1800 20mm/40m	Shrimp trawl 1800 30mm/40m RH	Shrimp trawl 1800 30mm/80m	Shrimp trawl 1400 35mm	Shrimp trawl 1800 20mm/40m RH	Shrimp trawl 1800 20mm/40m RH +	Shrimp trawl 1800 20mm/40m RH +	Unspecified Pelagic trawl	Pelagic trawl ("Harstad")	Pelagic trawl ("Åkra")
Year	3100	3134	**3230**	3233	**3236**	3238	3246	**3270**	**3271**	**3296**	3500	3513	3532
1984			62										
1985			86									3	
1986			62								1	1	
1987			104										
1988			114								5		
1989					97							1	
1990				1	77							2	
1991					110							6	
1992					98							1	
1993					110	1						6	
1994					106							1	
1995					96								
1996					103								36
1997	10				93								
1998		5						95					
1999		15						97					
2000		9						98					
2001		6						70					
2002		1						77					
2003			68										
2004								60					
2005							3	83	3				
2006								43					
2007								60	1				
2008									73				
2009		11						1	90				
2010									94				
2011									97				

2012			63	
2013			101	
2014			68	
2015		1	88	
2016			105	
2017			108	
2018			110	
2019				113
2020				104

Table 3. Mean CPUE by weight and numbers per year for shrimp survey.

year	CPUEweight	CPUEnumbers
1984	0.368	0.391
1985	1.115	1.128
1986	2.994	2.015
1987	0.349	0.320
1988	0.529	0.302
1989	0.184	0.136
1990	1.516	1.115
1991	0.242	0.251
1992	0.192	0.124
1993	0.112	0.092
1994	0.127	0.106
1995	0.148	0.108
1996	0.131	0.088
1997	0.182	0.136
1998	0.141	0.105
1999	0.084	0.048
2000	0.135	0.122
2001	0.093	0.056
2002	0.014	0.009
2003	0.470	0.444
2004	0.433	0.612
2005	0.079	0.093
2006	0.888	0.815
2007	0.374	0.296
2008	0.473	0.489
2009	0.321	0.383
2010	0.203	0.261
2011	0.263	0.238
2012	0.752	0.792
2013	1.960	1.882
2014	1.553	1.206
2015	0.559	0.593

2017	0.418	0.559
2018	0.445	0.705
2019	0.625	0.632
2020	0.263	0.557

Figures

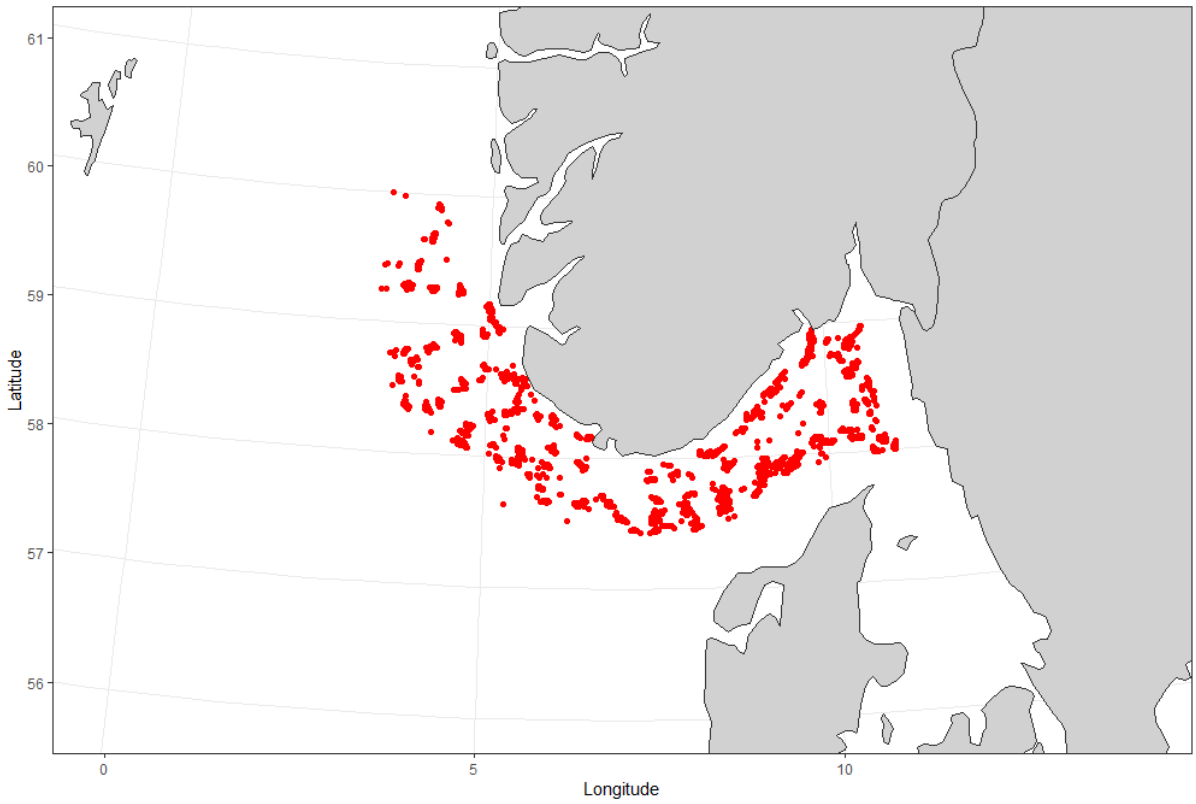


Figure 1. Position of trawl hauls for shrimp survey 1984-2020.

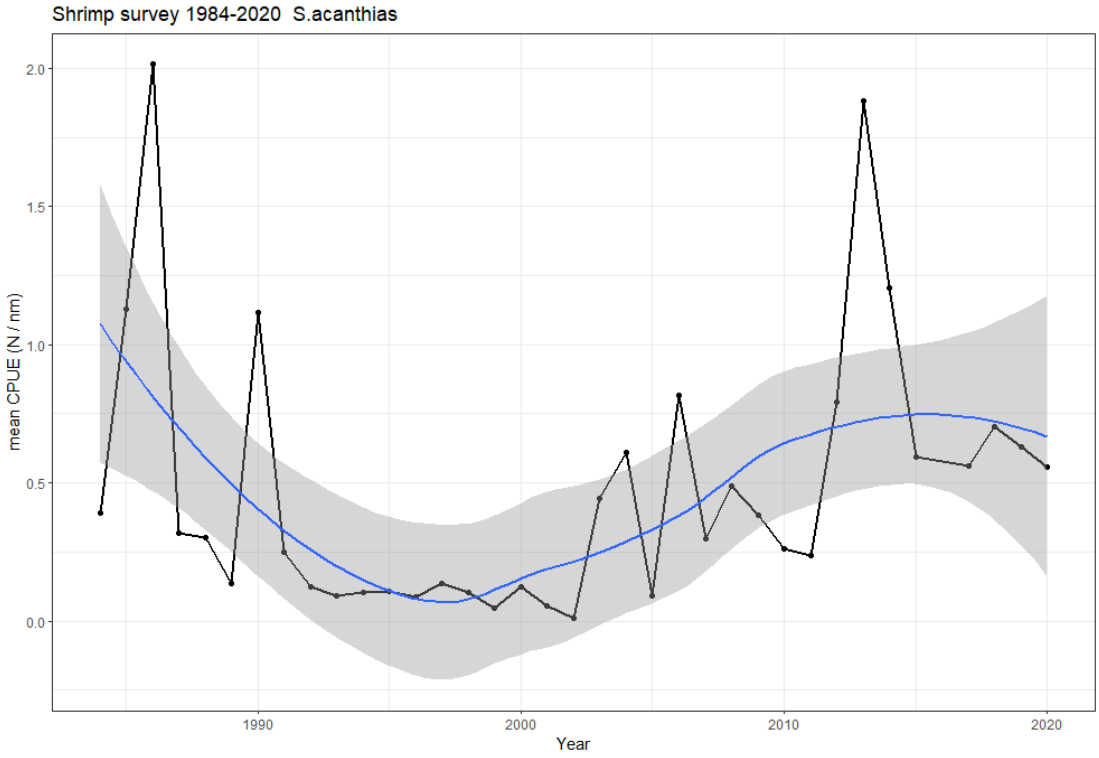


Figure 2. CPUE for catch numbers for shrimp survey for 1984-2020.

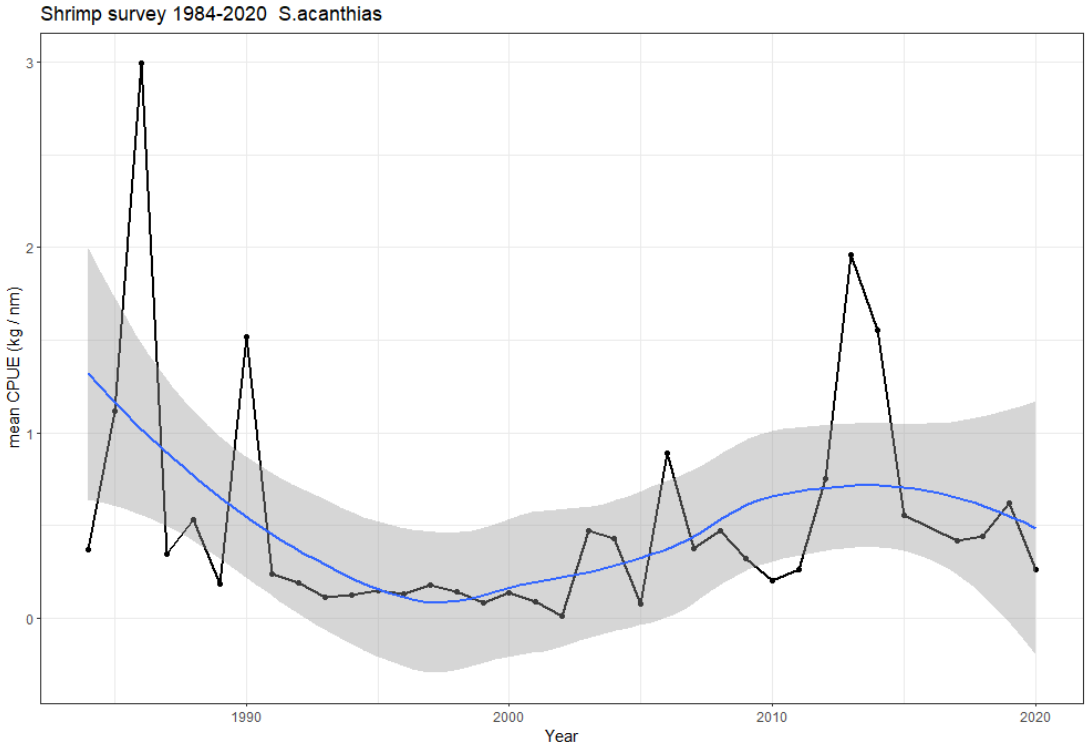


Figure 3. CPUE for catch weight for shrimp survey for 1984-2020.

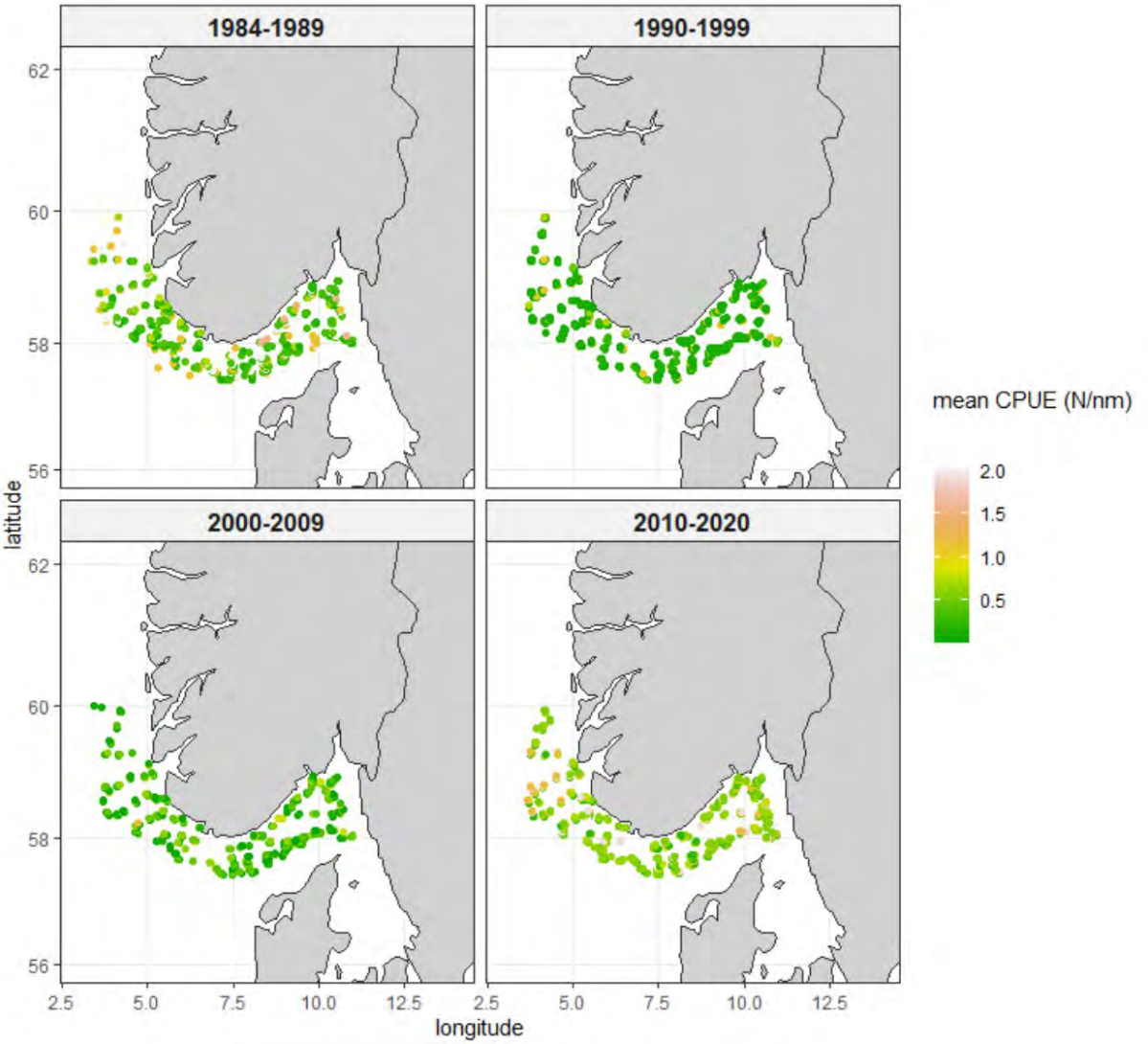


Figure 4. CPUE for catch numbers by decade for shrimp survey for 1984-2020.

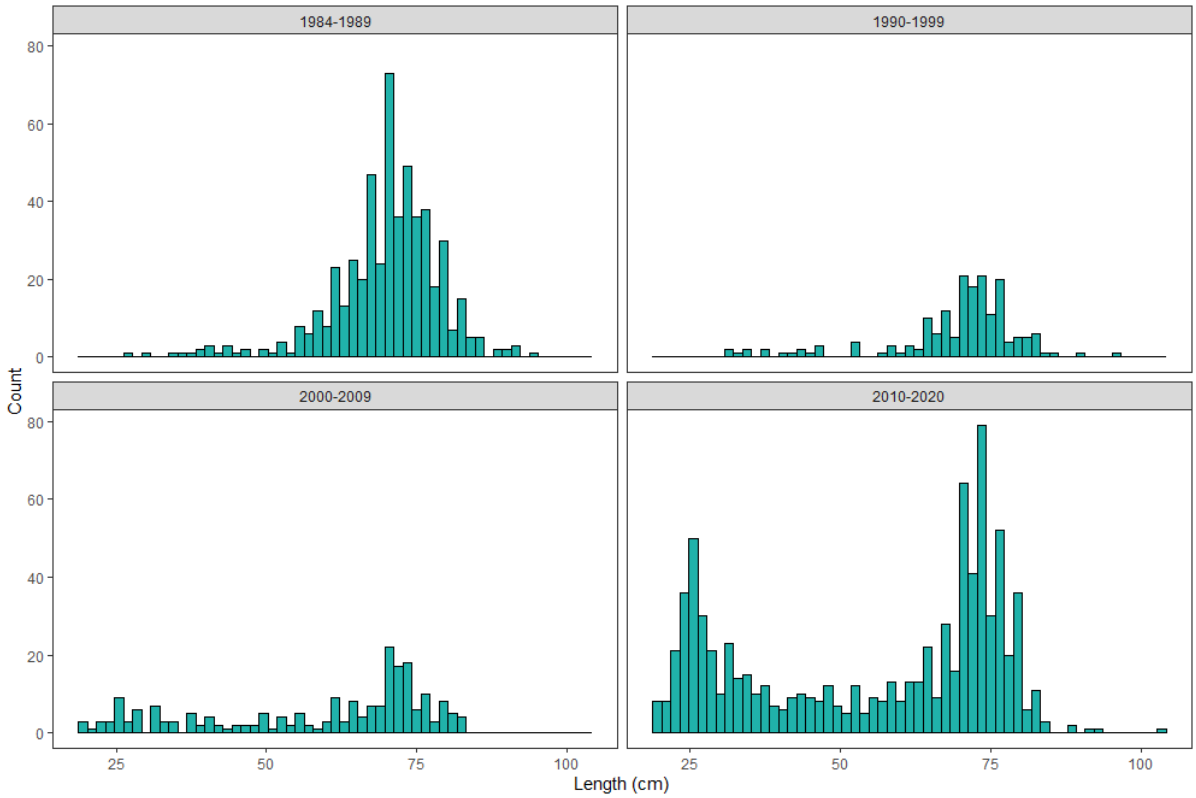


Figure 5. Length composition by decade for shrimp survey for 1984-2020.

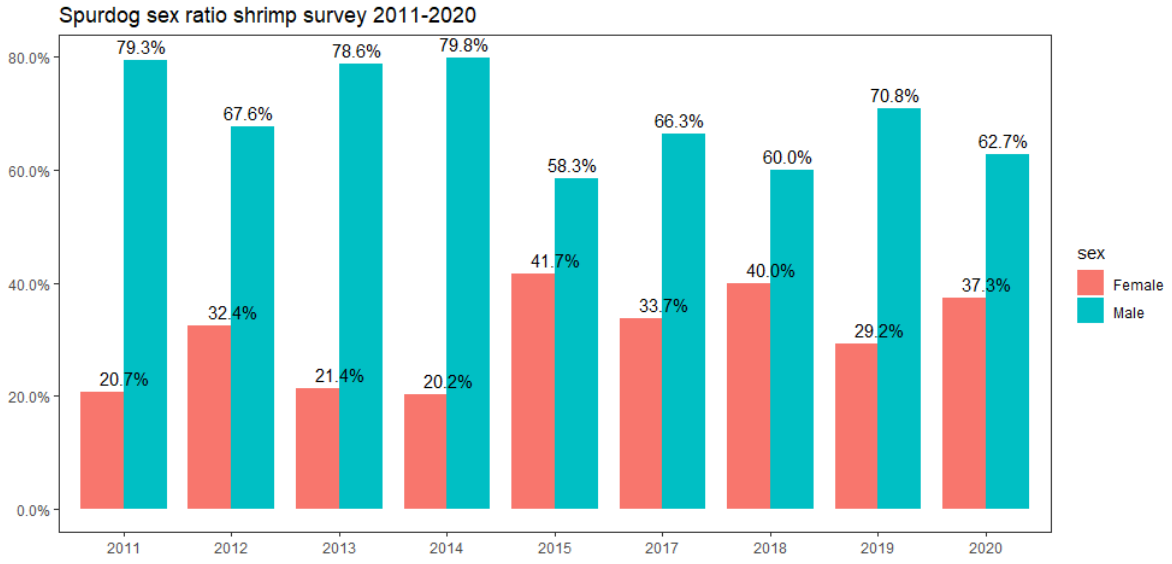


Figure 6. Sex ratio by year for shrimp survey for 2011-2020.

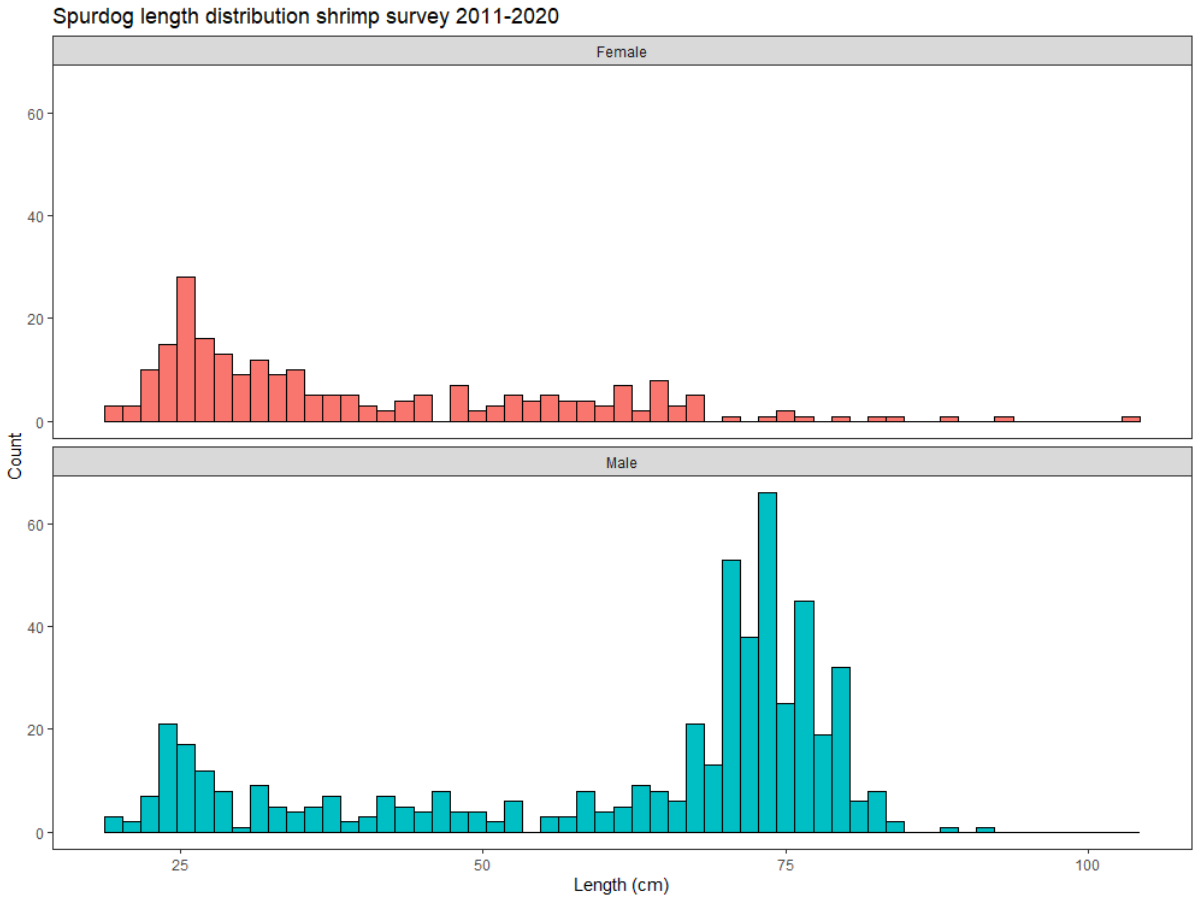


Figure 7. Length composition by sex for shrimp survey for 2011-2020.

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021

Not to be cited without prior reference to the authors

A summary of spurdog (*Squalus acanthias*) landings and discards data collated

Version: 21. Feb 2021

Claudia Junge

Havforskningsinstituttet (Institute of Marine Research, IMR), Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, Norway

Summary

Landings and discards data were analysed from ICES WGEF and the WKNSEA datacall (2020), evaluated and collated.

The final dataset contained i) all ICES WGEF landings from 2005-2019 for 12 countries with the addition of France, Spain and Iceland for 2019, and ii) all discards submitted to the datacall from 2005-2019 for 9 countries.

Methods

Data sources:

1. ICES WGEF – combined landings from 2005 to 2019

Those landings were quality controlled by WGEF and are available for the following countries: Belgium (BEL), Denmark (DEN), France (FRA), Germany (DEU), Iceland (ISL), Ireland (IRL), Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (*ESP), Sweden (SWE), United Kingdom of Great Britain and Northern Ireland (GBR*). Landings data from 2005 to 2019 compiled by ICES WGEF (status: Jun 2020) are found in summary Table 1.

2. WKNSEA datacall – landings submitted from 2005-2019

Those landings were submitted to the WKNSEA datacall in 2020 from the following countries: France (FRA), Netherlands (NLD), Spain_IEO (*ESP), Spain_AZTI (*ESP), Portugal (PRT), Sweden (SWE), and can be found in summary Table 2.

3. WKNSEA datacall – discards submitted from 2005-2019

Those discards were submitted to the WKNSEA datacall in 2020 from the following countries: Denmark (DEN), France (FRA), Germany (DEU), Ireland (IRL), Netherlands (NLD), Spain_AZTI (*ESP),

Spain_IEO (*ESP), Portugal (PRT), Sweden (SWE), UK-England (*GBR), UK-Scotland (*GBR), and can be found in summary Table 3.

* Landings were previously reported combined for: a) Spain (ESP): Spain-IEO, Spain-AZTI, and b) United Kingdom of Great Britain and Northern Ireland (GBR): UK-England, UK-Scotland. We therefore combined new landings and discards data accordingly as well.

Data evaluation and inclusion/exclusion:

Landings: We compared the landings between the ICES WGEF records and the datacall submitted landings and detected minor differences for some of the countries. We decided however to retain the full WGEF dataset because: 1) the differences were very small, and 2) the WGEF data has been quality controlled by WGEF experts and therefore ensures that the correct data are allocated to the correct stock and area. In addition, we added the landings data from Spain and France for 2019 that were missing from the combined WGEF landings and which were submitted to the datacall, and the landings for Iceland from 2019 based on their official website. Gears have been grouped into "trawls and other" and "nets and hooks" to account for different size selection patterns. Landings from the southern and westernmost areas (27.8c, 27.9a, 27.10a) have been excluded as they might be records from *S. blainville* instead of *S. acanthias*. The final landings dataset is in Table 3 by country, area and year.

Discards: All submitted WKNSEA datacall discard data have been included, as shown in Table 4 by country, area and year. Gears have been grouped into "trawls and other" and "nets and hooks" to account for different size selection patterns. Discards from the southern areas (27.8c, 27.9a) have been excluded as they might be records from *S. blainville* instead of *S. acanthias*. The final discards dataset is in Table 5.

Table 1: Landings data (in tonnes) for spurdog from 2005 to 2019, compiled by ICES WGEF (status: Jun 2020), except # and ## (see caption).

Countries	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BEL	20.6	17.4	10.9	12.0	6.9	1.3	0.2	0.0	0.0						
DEU	140.1	7.5	2.9	5.2	1.5	0.8	0.7	1.0	0.2	1.3	0.1	2.2	0.3	1.5	0.2
DNK	150.0	121.0	76.0	78.0	82.0	14.0	26.0	30.0	19.0	10.0	26.6	23.9	26.7	19.5	21.1
ESP	43.4	46.9	85.3	41.6	23.3	7.5	7.0	5.7	1.8	1.2	4.1	0.6	0.0	0.0	0.7#
FRA	946.2	701.6	504.9	368.1	411.8	163.6	83.8	33.9	13.4	19.3	1.7	1.4	3.3	1.0	1.1#
GBR	3480.6	1209.0	799.2	280.3	546.2	63.9	0.9	3.0	6.1	0.0		29.6	37.2	37.5	52.3
IRL	1021.9	859.3	651.5	136.5	175.1	26.1	12.6	36.6	33.6	17.6	2.5	34.1	0.5	24.5	10.9
ISL	76.4	81.5	42.7	68.3	101.8	61.8	52.6	51.1	5.8	18.9	8.0	8.4	3.8	1.8	1.1##
NLD	31.2	23.3	24.8	17.8	5.1	6.5	0.7	4.3	3.1	0.2	1.4	1.3	0.7	5.8	0.1
NOR	1015.8	790.4	615.5	711.4	543.0	540.3	247.3	285.0	249.8	313.3	216.8	270.2	222.0	270.5	369.6
PRT	5.1	9.2	10.2	3.9	2.6	1.9	3.0	2.1	2.3	1.4	2.0	1.0	1.4	0.8	
SWE	169.0	147.4	93.2	74.5	80.4	5.1	0.0	0.0				0.1	0.0	0.1	0.0

data added from WKNSEA data.call (see Table 2); **##** data added from official Icelandic landings website: https://px.hagstofa.is/pxen/pxweb/en/Atvinnuvegir/Atvinnuvegir__sjavarutvegur__aflatolur__afli_manudir/SJA01101.px/table/tableViewLayout1/?rxid=cf39754a-61b8-4587-9087-5aa4efc93f9c

Table 2: WKNSEA datacall – landings (in tonnes) submitted from 2005-2019

Countries	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
ESP	41.8	45.8	84.1	41.4	23.3	7.4	7.0	5.6	1.8	1.3	4.1	1.0	0.4	0.9	0.7
FRA	903.8	668.8	481.9	353.6	390.3	164.1	77.9	33.6	14.2	19.5	1.8	1.4	3.2	1.3	1.1
NLD	31.2	23.3	24.8	17.8	5.1	6.4	0.7	3.1	1.0	0.2	1.4	1.3	0.7	5.8	0.1
PRT	5.1	9.2	10.2	3.9	2.6	1.9	3.0	2.1	2.3	1.4	2.0	1.0	1.4	0.8	
SWE	168.2	148.0	94.9	74.5	80.1	5.1	0.0					0.0	0.0	0.0	0.0

Table 3: Final landings data (in tonnes) for spurdog from 2005 to 2019 by country, area and year.

Areas by country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BEL	**20.6**	**17.4**	**10.9**	**12.0**	**6.9**	**1.3**	**0.2**	**0.0**	**0.0**						
27.4.a	0.2	0.0	0.0	0.0	0.1										
27.4.b	0.7	1.0	0.8	1.2	0.3	0.2	0.0	0.0	0.0						
27.4.c	0.9	1.2	1.4	1.2	0.9	0.3	0.1		0.0						
27.7.a	7.1	8.1	3.9	2.8	0.5	0.2									
27.7.d	0.9	0.7	0.1	0.1	0.1	0.2	0.0	0.0	0.0						
27.7.e	0.3	0.1	0.1	0.1	0.0				0.0						
27.7.f	2.8	1.1	0.5	0.5	0.5	0.2									
27.7.g	7.6	5.3	4.1	6.1	4.6	0.3	0.0								
27.7.h		0.0	0.0												
27.8.b	0.0		0.0	0.0	0.0										
DEU	**140.1**	**7.5**	**2.9**	**5.2**	**1.5**	**0.8**	**0.7**	**1.0**	**0.2**	**1.3**	**0.1**	**2.2**	**0.3**	**1.5**	**0.2**
27.14														0.8	
27.2.a			0.0									0.1	0.2	0.0	
27.3.a	0.3	1.6	0.7	0.0	0.1	0.0	0.0	0.0		0.1	0.0			0.1	
27.3.c	0.0		0.0												
27.3.d			0.0												

27.4.a	0.4	0.1	0.2	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.0	2.1			
27.4.b	2.1	5.6	2.0	4.5	1.3	0.6	0.5	0.9	0.1	1.2	0.1		0.1	0.1	0.2
27.4.c	0.3	0.2	0.0	0.5	0.1	0.2	0.0							0.5	
27.5.a		0.0													
27.6.a	0.9														
27.6.b	1.2														
27.7.c	1.2														
27.7.j	57.7														
27.7.k	76.0														
DNK	**150.0**	**121.0**	**76.0**	**78.0**	**82.0**	**14.0**	**26.0**	**30.0**	**19.0**	**10.0**	**26.6**	**23.9**	**26.7**	**19.5**	**21.1**
27.2.a.2															0.0
27.3.a	68.0	52.0	35.0	49.0	52.0	5.0	17.0	12.0		1.0	14.4	9.4			
27.3.a.20													3.9	7.5	5.6
27.3.a.21													6.7	0.0	0.0
27.3.b												0.0			
27.3.c											0.0	0.0			
27.3.c.22														0.0	0.0
27.3.d											0.0				
27.4.a	25.0	24.0	19.0	5.0	9.0	6.0	4.0	7.0	8.0	4.0	4.5	5.2	5.7	6.6	6.1
27.4.b	57.0	44.0	22.0	24.0	21.0	3.0	5.0	11.0	11.0	5.0	7.7	9.2	10.5	5.4	9.4
27.4.c		1.0									0.0				
ESP	**41.0**	**39.7**	**70.8**	**38.8**	**14.4**	**2.4**	**1.9**	**2.6**	**0.1**				**0.0**	**0.0**	**0.0**
27.6.a	0.7	12.7	7.4	1.6	0.5										
27.6.b	0.1														
27.7	0.1				0.2										
27.7.b	7.3	0.9	14.7	7.5											
27.7.c	5.0	5.4	9.8												
27.7.c.2															0.0
27.7.e	0.3	0.0	0.1	0.2	0.1										
27.7.g	0.3	0.9	0.4	0.3	1.5										0.0

27.7.h	4.6	5.1	9.2	9.8	7.5		0.1								
27.7.j	8.7	9.8	25.3	15.9	1.6	1.1	1.6	2.4	0.1						
27.7.j.2															0.0
27.7.k	5.7	0.1	1.2	1.7											
27.8.a	2.8	0.5	0.5	0.1	1.6	0.0									
27.8.abd		0.0	0.7	0.2	0.0			0.1							
27.8.b	5.3	4.2	1.6	1.5	1.5	1.2	0.2	0.0							0.0
27.8.d	0.0	0.1	0.0												
FRA	**945.5**	**700.0**	**504.5**	**368.0**	**411.7**	**163.6**	**83.7**	**33.9**	**13.4**	**19.3**	**1.7**	**1.4**	**3.3**	**1.0**	**1.1**
27	0.0	0.1		0.0	0.0	0.0	0.0	0.0							
27.2.a	0.1	0.0	0.0												
27.4.a	1.7	0.5	0.7	0.0	0.0	0.0					0.0				
27.4.b	0.1	0.1	8.3	0.1	0.0	4.9	0.0	0.1	0.0	0.0					
27.4.c	3.9	1.3	0.6	2.6	0.3	1.4	0.3	0.7	0.2	0.2	0.0	0.0		0.0	
27.5.b	164.2	122.5	118.0	16.5	1.5	0.9				8.9	0.2				
27.6.a	149.0	153.9	99.6	28.6	46.1	36.6	2.6		0.0						
27.6.b	55.2	16.4	3.1	0.3	0.1										
27.7.a	22.6	12.0	5.5	0.4	0.2	0.0									
27.7.b	11.4	11.7	12.3	21.7	13.7	0.3		0.0							
27.7.c	0.8	0.7	0.6	0.7	0.8	0.1		0.0							
27.7.d	25.4	7.4	11.1	18.7	45.1	36.3	64.2	28.9	9.9	7.8	0.3	0.4	1.6	0.6	0.0
27.7.e	94.5	46.6	41.8	58.9	52.1	17.7	6.3	0.6	0.7	0.5	0.0	0.0	0.3	0.0	
27.7.f	13.9	21.7	11.4	7.4	7.4	1.0			0.0						
27.7.g	171.6	116.1	63.7	44.9	51.1	17.3	0.6	0.3	0.0						
27.7.h	113.8	111.4	82.9	93.9	133.4	34.3	0.7	0.6	0.0						0.4
27.7.j	6.2	4.2	5.3	7.1	4.8	0.4	0.0	0.0							
27.7.k	0.6	0.1	0.1	0.5	0.1	0.0	0.0								
27.8.a	82.9	39.9	26.4	42.9	35.8	9.8	6.3	1.2	2.4	1.1	1.0	0.4	0.5	0.1	0.6
27.8.b	21.3	31.4	11.9	21.0	18.2	2.3	2.6	1.4	0.1	0.5	0.1	0.5	0.9	0.2	0.1
27.8.d	2.7	1.3	1.2	1.8	0.9	0.1	0.0	0.0		0.1		0.0			

27.8.e												0.0			
27.12.a	3.5	0.6			0.0										
27.12.c															0.0
GBR	**3480.6**	**1209.0**	**799.2**	**280.3**	**546.2**	**63.9**	**0.9**	**3.0**	**6.1**	**0.0**		**29.6**	**37.2**	**37.5**	**52.3**
27	58.5														
27.2.a		0.1	0.1												
27.4.a	395.0	166.4	88.3	70.4	130.0	15.9		0.3	0.1			17.8	0.8		
27.4.b	85.6	30.2	24.5	20.0	21.1	1.6	0.3	0.0	0.2	0.0			0.4		
27.4.c	28.9	13.9	16.9	4.3	3.9	0.7	0.1	0.0	0.0						
27.5.b	3.3	0.0	0.1	1.4	0.1	0.4									
27.6.a	928.8	437.0	315.2	82.3	178.2	23.1		0.6							
27.6.b	257.0	2.1	0.0	1.1	0.6										
27.7.a	540.2	383.0	203.6	58.2	81.8	1.7									
27.7.b	13.1	14.4	2.7	0.7	0.3										
27.7.c	131.6	11.0	8.4		0.0	0.0									
27.7.d	23.0	18.2	13.4	12.4	24.6	15.2	0.5	1.8	5.6				0.0		
27.7.e	68.0	24.5	34.3	8.8	18.6	3.4	0.0	0.2	0.2				1.0	5.0	3.3
27.7.f	25.3	28.9	44.4	8.5	43.7	2.0	0.1	0.1				0.6	11.2	9.0	10.7
27.7.g	103.3	24.4	10.7	7.3	38.1	0.0		0.2				11.2	21.0	19.6	27.5
27.7.h	40.5	32.4	16.8	4.7	4.0								1.7	3.3	9.9
27.7.j	84.5	11.8	10.9	0.1	0.6								1.0	0.6	0.9
27.7.k	673.9	8.9	7.5		0.0										
27.8.a	18.0	1.7	1.1	0.3	0.5										
27.8.b	0.5		0.0												
27.8.d	1.8	0.0	0.3												
IRL	**1021.9**	**859.3**	**651.5**	**136.5**	**175.1**	**26.1**	**12.6**	**36.6**	**33.6**	**17.6**	**2.5**	**34.1**	**0.5**	**24.5**	**10.9**
27.2.a.2														0.0	
27.6.a	170.4	177.1	190.4	53.0	37.2	8.8					0.3	5.2		2.7	
27.6.b	17.8	31.0	3.5	1.7	0.2										
27.7.a	19.4	9.5	59.1	11.4	14.9	1.6	0.6	10.0	4.1	1.9	0.3	1.9		0.0	0.1

27.7.b	152.2	213.4	249.6	15.7	81.2	6.2	0.8	1.2				2.3			
27.7.c	9.5	11.0	1.1	1.4	0.4										
27.7.f	3.0	1.9	0.2	0.7		0.2									
27.7.g	259.5	95.7	48.2	17.8	12.0	8.4	0.4	23.6	27.5	15.6	0.2	24.0		20.9	5.9
27.7.h	0.1		0.0		0.1										
27.7.j	369.6	314.6	98.1	34.8	29.0	1.0	10.7	1.8	1.9	0.1	1.7	0.8			4.9
27.7.j.2													0.5	0.8	
27.7.k	20.4	5.1	1.3	0.1	0.1										
ISL	**76.4**	**81.5**	**42.7**	**68.3**	**101.8**	**61.8**	**52.6**	**51.1**	**5.8**	**18.9**	**8.0**	**8.4**	**3.8**	**1.8**	**1.1**
27.5.a	76.4	81.5	42.7	68.3	101.8	61.8	52.6	51.1	5.8	18.9	8.0	8.4	3.8	1.8	
27.5a															1.1
NLD	**31.2**	**23.3**	**24.8**	**17.8**	**5.1**	**6.5**	**0.7**	**4.3**	**3.1**	**0.2**	**1.4**	**1.3**	**0.7**	**5.8**	**0.1**
27.4.a						0.1									
27.4.b	1.8	3.6	4.0	7.6	0.5	2.5	0.4	0.4			1.2			0.1	
27.4.c	1.7	3.0	6.1	2.6	0.8	2.0	0.3	2.0	2.1	0.2	0.2	1.3	0.7	1.4	0.1
27.7.d	23.2	13.4	9.9	6.6	3.1	1.8	0.1	1.2	1.0					4.3	
27.7.e	4.5	3.3	4.8	0.9	0.6	0.0		0.8							
27.7.j					0.0										
27.8.b					0.0										
NOR	**1015.8**	**790.4**	**615.5**	**711.4**	**543.0**	**540.3**	**247.3**	**285.0**	**249.8**	**313.3**	**216.8**	**270.2**	**222.0**	**270.5**	**369.6**
27.1	0.0	0.0	0.0		0.0										
27.1.b						0.0	0.4	0.2	0.0				0.0		0.0
27.2.a	681.6	498.8	311.7	337.3	230.0	189.6	92.4	130.3	73.9	121.8	105.0	150.1			182.7
27.2.a.2													127.3	163.9	
27.2.b									0.0						
27.3.a	113.5	107.2	95.7	149.9	108.9	98.9	74.8	42.2	52.0	47.0	22.9	22.9	21.9	19.6	37.6
27.4.a	219.6	183.7	206.4	221.0	201.0	250.2	77.5	110.9	122.2	141.6	86.3	94.7	69.8	84.0	136.1
27.4.b	1.1	0.7	1.8	3.1	3.0	1.6	2.1	1.3	1.6	2.9	2.4	2.4	2.5	3.0	13.2
27.4.c											0.2				
27.5.a			0.0		0.1										

27.6.a													0.5		
SWE	**169.0**	**147.4**	**93.2**	**74.5**	**80.4**	**5.1**	**0.0**					**0.1**	**0.0**	**0.1**	**0.0**
27.2.a													0.0		
27.3.a	168.9	147.1	93.2	74.1	80.4	5.1	0.0					0.1	0.0	0.1	
27.3.a.20															0.0
27.3.b	0.0	0.0			0.0										
27.3.d		0.0			0.0										
27.4.a	0.1	0.0	0.0	0.0	0.0	0.0							0.0		
27.4.b	0.0	0.2	0.0	0.4	0.0	0.0							0.0		
TOTAL	**7091.9**	**3996.5**	**2891.9**	**1790.8**	**1968.1**	**885.8**	**426.6**	**447.5**	**331.1**	**380.6**	**257.0**	**371.3**	**294.4**	**362.0**	**456.3**

Table 4: WKNSEA datacall – discards (in tonnes) submitted for spurdog from 2005-2019 by country and year.

Countries	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
DEU	0.6	0.5	0.2	0.4		0.0	0.3	0.2	1.0	0.2	1.5	0.6	2.9	3.8	2.8
DNK	1.4	1.9		9.4						48.2	25.2	705.1	18.1	42.3	37.2
ESP		2.4			0.5	0.7	0.6		10.7	10.8	109.2	9.5	5.6	40.0	16.5
FRA	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IRL	10.6	0.0	28.4	31.4	6.5	150.8	53.2	63.3	32.7	39.2	95.9	29.7	291.0	210.6	122.4
PRT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWE	1.7	0.2	5.0	3.5	6.9	21.8	8.5	32.5	36.8	131.7	19.1	12.2	142.2	9.2	65.9
GBR	5.5	19.0	0.1	1.6	39.9	1326.7	66.3	4657.0	200.8	263.7	358.5	823.5	4324.8	2066.5	2922.4

Table 5: Final discards data (in tonnes) for spurdog from 2005-2019 by country, area and year.

Areas by country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
DEU	**0.6**	**0.5**	**0.2**	**0.4**		**0.0**	**0.3**	**0.2**	**1.0**	**0.2**	**1.5**	**0.6**	**2.9**	**3.8**	**2.8**
27.2.a								0.2				0.3	2.4	0.0	
27.3.a.20											0.0				
27.4.a	0.0	0.0	0.2	0.0		0.0	0.3			0.0		0.2	0.4	0.6	0.8
27.4.b	0.6	0.4		0.4		0.0	0.0	0.0	1.0	0.2	1.5	0.2	0.0	3.1	2.0
27.6.a	0.0									0.0	0.0	0.0	0.1	0.2	0.0
27.14.b		0.0													
DNK	**1.4**	**1.9**		**9.4**						**48.2**	**25.2**	**705.1**	**18.1**	**42.3**	**37.2**
27.3.a.20	0.0	0.0		0.0						9.2	21.2	50.4	17.6	25.3	15.9
27.3.a.21	0.0	0.0		0.0						10.7	1.1	654.3	0.1	10.8	9.2
27.3.b.23	0.0	0.0								0.0	0.0				
27.3.c.22	0.0	0.0		0.0						0.0	0.0	0.0	0.0	0.0	0.0
27.3.d.24	0.0	0.0		0.0						0.0	0.0	0.0	0.0	0.0	0.0
27.3.d.25	0.0	0.0		0.0						0.0	0.0	0.0	0.0	0.0	0.0
27.4.a	0.5	0.6		4.3						1.7	1.8	0.0	0.1	3.0	5.5
27.4.b	0.9	1.2		5.1						26.6	1.1	0.4	0.3	3.2	6.5

27.4.c		0.0								0.0			0.0		
ESP		**0.5**				**0.7**	**0.6**		**10.7**	**7.2**	**91.3**	**8.9**	**2.5**	**38.6**	**14.8**
27.6.a											86.8		0.5	14.6	13.2
27.6.b.2											0.1			0.0	0.0
27.7.b										0.0	0.3	0.7	0.1	0.0	0.0
27.7.c.2										0.0	0.7	0.3	0.1	0.6	0.2
27.7.g										0.1		0.1			0.1
27.7.h										0.2	0.4	1.1	0.1	0.1	0.1
27.7.j.2										1.2	3.0	6.7	1.3	1.7	1.2
27.7.k.2														0.1	
27.8.b		0.5				0.7	0.6		10.7	5.7			0.4	21.5	
FRA	**0.0**	**0.0**	**0.0**	**0.0**	**0.5**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
27.4		0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	
27.5.b					0.0					0.0					
27.6.a	0.0			0.0	0.0	0.0	0.0		0.0						
27.7.b					0.0										
27.7.c					0.0	0.0									
27.7.d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.7.e		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0		
27.7.f		0.0													
27.7.g	0.0	0.0			0.0	0.0									
27.7.h		0.0	0.0		0.5	0.0	0.0		0.0						
27.7.j	0.0					0.0	0.0								
27.8.a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.8.b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.8.d		0.0	0.0		0.0	0.0									
IRL	**10.6**	**0.0**	**28.4**	**31.4**	**6.5**	**150.8**	**53.2**	**63.3**	**32.7**	**39.2**	**95.9**	**29.7**	**291.0**	**210.6**	**122.4**
27.6.a	5.2	0.0	6.8	4.9	0.7	97.9	38.9	6.7	8.1	12.7	16.0	2.1	64.6	20.8	30.4
27.6.b	0.0	0.0	0.7	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.7.a	0.0	0.0	0.0	11.4	0.0	0.0	4.3	50.7	1.5	0.6	6.3	7.5	5.0	14.8	28.7

27.7.b	1.7	0.0	20.8	14.8	0.4	37.4	8.0	0.6	16.0	1.5	16.4	7.3	23.2	74.2	34.0
27.7.g	0.0	0.0	0.0	0.0	5.4	14.7	0.4	5.4	7.0	24.3	38.4	12.8	190.6	100.8	27.1
27.7.j	3.7	0.0	0.0	0.4	0.0	0.8	0.0	0.0	0.0	0.2	18.8	0.0	7.5	0.0	2.1
SE	**1.7**	**0.2**	**5.0**	**3.5**	**6.9**	**21.8**	**8.5**	**32.5**	**36.8**	**131.7**	**19.1**	**12.2**	**142.2**	**9.2**	**65.9**
27.3.a.20	1.7	0.2	4.8	3.5	6.7	21.8	7.0	29.7	35.1	124.1	16.3	7.3	140.4	8.5	26.4
27.3.a.21	0.0	0.0	0.3	0.0	0.2	0.0	1.5	2.9	1.7	7.6	2.7	4.9	1.8	0.7	39.5
GBR	**5.5**	**19.0**	**0.1**	**1.6**	**39.9**	**1326.7**	**66.3**	**4657.0**	**200.8**	**263.7**	**358.5**	**823.6**	**4324.8**	**2066.5**	**2922.5**
27.4.a					21.7	40.4	15.2	21.6	53.3	167.7	290.4	42.0	127.4	274.3	288.2
27.4.b					1.8	34.1	3.8	41.5	0.0	37.9	17.5	36.0	10.9	0.3	7.1
27.6.a					15.6	91.6	47.0	121.9	147.5	58.0	50.7	62.9	96.9	55.1	219.7
27.6.b.1							0.2	0.0		0.1				0.1	
27.6.b.2					0.0			0.0	0.0	0.0		0.0			1.1
27.7.f	0.0	0.3	0.0	1.0	0.0							596.7	3136.2	438.2	408.0
27.7.g	5.5	2.7	0.1	0.6	0.9	1160.6		4472.0				86.0	858.6	1158.1	1934.9
27.7.h		15.9			0.0								17.8	140.3	61.8
27.7.j													77.0		1.6
TOTAL	**19.9**	**22.0**	**33.6**	**46.3**	**53.8**	**1500.1**	**128.9**	**4753.0**	**281.9**	**490.1**	**591.4**	**1580.1**	**4781.4**	**2370.9**	**3165.5**

Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021),

22nd–26th February 2021, WebEx meeting

Not to be cited without prior reference to the author

Life-history parameters of North-east Atlantic spurdog *Squalus acanthias*

Silva, J. F. and Ellis, J. R.

Centre for Environment, Fisheries and Aquaculture Science (CEFAS)

Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK

Abstract

The present document shows results of recent biological investigations on spurdog (males and females), based on samples of dead bycatch provided by the fishing industry in 2013–2014, and on fresh samples from Cefas fishery-independent surveys and tagging programme since early 2000s. Data include length-weight relationships by sex and status (fresh or frozen), maturity at length, and fecundity at length. These data are being part of a manuscript currently in preparation by the authors of this working document.

Introduction

Spurdog was formerly an important commercial species that was targeted in longline and gillnet fisheries around the British Isles. These fisheries were unmanaged for several decades, and management measures may have only been restrictive since 2007 (Pawson *et al.*, 2009).

There have been some descriptive accounts including information on life-history parameters of spurdog (e.g. Fries, 1895, Poll, 1947), more intensive biological sampling of spurdog was undertaken in the North-east Atlantic in the 1960s (Holden & Meadows, 1962, 1964; Holden 1965, 1967), when the fishery was at its peak. There has also been some opportunistic studies of life-history parameters for more recent times, albeit with some limited in either sample size, study area or years (e.g. Jones & Ugland, 2001; Henderson *et al.*, 2002; Stenberg, 2005; Ellis & Keable, 2008; Ellis, 2015, Albert *et al*., 2019).

It has been suggested that life-history parameters may show density-dependent changes in relation to stock size and levels of exploitation (Sosebee, 2005) with the most recently benchmarked assessment for NE Atlantic spurdog incorporating historic and recent fecundity data (De Oliveira *et al.*, 2013).

This study shows a review of life-history parameters for spurdog in the North-east Atlantic (Silva & Ellis, *in prep*), with recent information from UK fisheries-independent surveys and fisheries-dependent surveys, with the preliminary results from fishing industry previously shown in Silva & Ellis (2015).

Methods

Trawl survey data

Cefas fishery-independent trawl surveys generally recorded the length frequency (measured to the cm below) and total catch weights of spurdog (by sex). However, from 2009–2012 individual weights were recorded, for determining length-weight relationships (Silva *et al.*, 2013) and, since 2009, additional biological sampling (length, weight, sex, maturity stage and uterine fecundity) started to be incorporated in some of the trawl surveys, and now routinely recorded on all fishery-independent surveys when caught. Data retrieved from Cefas Fishing Survey System (FSS) on the 12th November 2020 and includes all surveys from 2009 up to September 2020. These data will be hereafter referred also as fresh samples.

Tagged Fish Database

Spurdog, which was the subject of extensive tagging programmes in the 1960s, have also been tagged and released during contemporary fishery-independent trawl surveys (2003–2020), providing additional length-weight data (both female and male) and, maturity stage for males. For the present study, analyses of these data were limited to the years 2003–2008, in order to prevent duplication of biological data from the trawl survey data. Data retrieved from Cefas Tagged Fish Database on 4th May 2020, does not include all fish tagged and released during surveys in 2020. These data will be hereafter referred also as fresh samples.

Biological sampling from fishery-dependent surveys

Given the low numbers of spurdog taken in Cefas' scientific trawl surveys at that time, and restrictions on commercial landings, the specimens collected during the "*Shark, Skate and Ray Scientific Bycatch Fishery*" provided a unique opportunity to collect contemporary biological data to complement data collected by scientists at Lowestoft in the 1960s. Specimens were caught by trammel nets and gillnets off the south-west of the British Isles, with these only kept for scientific research and, frozen prior to biological sampling (Silva & Ellis, 2015).

Data collected included total length (cm), total and gutted weight (g), sex, maturity stage, gonad weight (0.1 g), weight of the stomach contents (0.1 g) and stomach "fullness" (a qualitative score of 0–10) and a description of the stomach contents. Additional data collected for females were nidamental gland (or shell gland) width (0.1 mm), number of mature ovarian follicles (ovarian fecundity), maximum follicle diameter (0.1 mm), uterine fecundity (by uterus), and the number of any atretic/undeveloped eggs. Data were also collected for pups including sex, total length (mm), total weight of the embryo and yolk sac, and weights of the embryo and yolk sac only (0.1 g). Additional data collected for males were the inner and outer lengths of the clasper (0.1 mm).

A selected number of parameters are shown in the present document according to their relevance towards improving the stock assessment model used for spurdog in the North-east Atlantic. Data were collated in Microsoft© Excel. These data will be hereafter referred also as frozen samples.

Maturity staging

The qualitative assignment of maturity stage was based on the visual inspection of reproductive organs (uterus, shell gland and ovaries for females; claspers, testes and degree of coiling in the epididymis in males). Given that there have been several studies purporting changes in length at maturity in elasmobranchs that may not have had standardised approaches to assigning maturity stage, quantitative data were also collected, as this helps validate the assignment of maturity stages. The maturity stage key used is described in TableS1. There are instances were maturity stage was determined as 'U' classified in all figures as undetermined and these relate to samples used for length-weight relationships only (Silva *et al.*, 2013), fish captured on trawl surveys and released alive

(females) including tagged fish, and potential outliers where data recorded were deemed unreliable. This stage (U – undetermined) was included in the analysis where deemed suitable.

Data analysis

Data from the three datasets were combined to provide the most available information in terms of different life history parameters. The length-weight distributions were calculated for total length (L_T, measured to the cm below) and total weight (W_T, g) (additional data available for gutted weight W_G, g, but are not presented here). These relationships were calculated using the exponential relationship ($W = a \times L^b$), with values for factor a and b obtained using a linear regression through natural logarithmic transformation. These length-weight relationships were also differentiated by fish having been processed while at sea (fresh samples) or post-capture (frozen samples). Length at 50% maturity (L50) was calculated following similar method described in McCully *et al.* (2012). Numbers at length assigned as immature (maturity stage A-B) and mature (females: C-G, males: C-D) were used to get the proportion of mature fish at length. Analyses were conducted using R software (2020).

A review of already published data on a range of life history parameters for spurdog in the North Atlantic are described in Table 1 and 2.

Results and discussion

Length distribution**:** A total of 3,354 specimens were examined (Figure 1), including 1,436 females (19–123 cm L_T) and 1,918 males (18–93 cm L_T).

Data from trawl survey data and tagged data were combined since these related to fresh data collected while at sea, and these included 1,129 females (19–123 cm L_T) and 1,115 males (18–93 cm L_T).

Data from fishery-dependent surveys collected post-capture from frozen samples included 307 females (47–122 cm L_T) and 803 males (53–92 cm L_T). Two extra males were captured but length data were unavailable and therefore excluded from the analysis.

Length-weight relationship**:**

Length-weight relationships between total length (L_T) and total weight (W_T) are presented by sex and maturity stage for fresh and frozen samples (Figure 2, Table 1).

Fresh samples (Figure 2, Panel B): The outlier on this figure was due to an abnormal male with only one clasper developed present. This fish was not considered for the length-weight relationship calculations.

Frozen samples (Figure 2, Panel C): The outlier on this figure was due to an abnormal female specimen that was emaciated, presumed to be a mature fish given the state of the nidamental gland, although no mature ovarian follicles were present and the uteri were not flaccid as would be observed in a post-partum specimen (stage G). It was also noted the presence of a hook in its liver. This fish was not considered for the length-weight relationship calculations.

Length-at-maturity of males**:**

Maturity data (samples combined) were available for 1,800 males (18–93 cm L_T). The smallest mature male was 59 cm L_T and the largest immature male was 90 cm L_T. Length at 50% maturity was estimated at 65.9 cm L_T (Figure 3), with fish all mature > 91 cm L_T. One male was recorded as abnormal at 70 cm L_T.

***Length-at-maturity of females*:**

Maturity data (samples combined) were available for 823 females (19–122 cm L_T). The smallest mature female was 76 cm L_T and the largest immature female was 89 cm. L_{50} was estimated at 81.7 cm L_T (Figure 3), with all fish mature > 89 cm L_T. The smallest female in an actively reproducing stage was 82 cm L_T. One female was recorded as abnormal at 103 cm L_T. The length at maturity of females seems unchanged from the earlier estimates of Holden and Meadows (1962), indicating that this life history parameter may not have changed in relation to recent overexploitation.

Fecundity data:

Fecundity raw data for both ovarian (number of mature ovarian follicles) and uterine (number of embryo and term pups) are presented for recent data (TableS2) and for historical and already published data (TableS3) by length. The supplementary material also shows recent records in TableS1 for uterine fecundity for females at stage D (candle stage), however for frozen samples in this study they could not be estimated in most cases and excluded from Figure 4 (Panel B).

The number of mature ovarian follicles (females stage C-G) was only recorded from frozen samples from commercially caught fish and ranged from two (a specimen at stage D) to 22 (a specimen at stage F) and, are shown in Figure 4.

To minimise the potential impact of aborted specimens on fecundity estimations, specimens where the difference in the number of pups between uteri was ≥4 (similar to Ellis and Keable, 2008) or with no pups in one of the two uteri were excluded from further analysis (Frozen: n = 17). An additional 45 fish from fresh samples were excluded from fecundity estimations here, as the total number recorded (embryos or term pups) was recorded without distinguishing between uterus side.

For the remaining specimens (n = 92), uterine fecundity ranged from 2–19 (Figure 4), although these values might still underestimate fecundity, as some females may have aborted pups from the uteri. In addition to possible abortion on capture, occasional aborted pups were found in the sample boxes or baskets and the maternal origin could not always be determined. The results of the linear model for the relationship between maternal length and uterine fecundity suggest the need for more data as the current data suggests the fecundity of some specimens may have been underestimated (Figure 4). Consequently, the question remains on which data to include and which data to exclude to provide the most reliable uterine fecundity data. A total of 478 term pups were observed ranging from 164 mm to 296 mm L_T, with maternal length ranging from 90 to 122 cm T_L.

The fecundity reported here is higher than reported in earlier studies (e.g. Ford, 1921; Holden and Meadows, 1964; Gauld, 1979), and provides further support to the hypothesis that there has been a density-dependent increase in fecundity (see Ellis and Keable, 2008 and references therein).

Acknowledgements

We thank our many colleagues for assisting in data collection, both in the laboratory and at sea, and with data retrievals where needed.

References

Aasen O (1961) Pigghåundersøkelsene. *Fisken og Havet* **1**, 1–9.

Albert OT, Junge C and Myrlund MK (2019) Young mums are rebuilding the spurdog stock (Squalus acanthias L.) in Norwegian waters. *ICES Journal of Marine Science* **76**, 2193–2204.

Avsar D (2001) Age, growth, reproduction and feeding of the spurdog (*Squalus acanthias* Linnaeus, 1758) in the south-eastern Black Sea. *Estuarine, Coastal and Shelf Science* **52**, 69–278.

Bargione G, Donato F, La Mesa M, Mazzoldi C, Riginella E, Vasapollo C, Virgili M and Lucchetti A (2019) Life-history traits of the spiny dogfish *Squalus acanthias* in the Adriatic Sea. *Scientific Reports* **9**(1), 1–10.

Bubley WJ, Sulikowski JA, Koester DM and Tsang PC (2013) Using a multi-parameter approach to reassess maturity of spiny dogfish, *Squalus acanthias*, following increased fishing pressure in the Western North Atlantic. *Fisheries Research* **147**, 202–212.

Capapé C and Reynaud C (2011) Maturity, reproductive cycle and fecundity of the spiny dogfish *Squalus acanthias* (Chondrichthyes: Squalidae) off the Languedocian coast (southern France, northern Mediterranean). *Journal of the Marine Biological Association of the United Kingdom* **91**, 1627–1635.

C**hatzispyrou A and Megalofonou P** (2005) Sexual maturity, fecundity and embryonic development of the spiny dogfish, *Squalus acanthias*, in the eastern Mediterranean Sea. *Journal of the Marine Biological Association of the United Kingdom* **85**, 1155–1161.

Colonello JH, Cortés F, Belleggia M and Massa AM (2016) Reproductive and population parameters of spiny dogfish *Squalus acanthias* in the south-western Atlantic Ocean. *Journal of Fish Biology* **88**, 1758–1775.

Coull KA, Jermyn AS, Newton AW, Henderson GI and Hall WB (1989) Length/weight relationships for 88 species of fish encountered in the North East Atlantic. *Scottish Fisheries Research Report* **43**, 81 pp.

De Oliveira JAA, Ellis JR and Dobby H (2013) Incorporating density dependence in pup production in a stock assessment of NE Atlantic spurdog *Squalus acanthias. ICES Journal of Marine Science* **70**, 1341–1353.

Demirhan SA and Seyhan K (2006) Seasonality of reproduction and embryonic growth of spiny dogfish (*Squalus acanthias* L., 1758) in the eastern Black Sea. *Turkish Journal of Zoology* **30**, 433–443.

Demirhan SA and Seyhan K (2007a) Maturity and fecundity of spiny dogfish (*Squalus acanthias* L., 1758) in the eastern Black Sea. *Turkish Journal of Zoology* **31**, 301–308.

Demirhan SA and Seyhan K (2007b) Life history of spiny dogfish, *Squalus acanthias* (L. 1758), in the southern Black Sea. *Fisheries Research* **85**, 210–216.

Dutton J and Gioia KA (2019) Fecundity and embryonic development of spiny dogfish in the Northwest Atlantic Ocean. *Transactions of the American Fisheries Society* **148,** 48–57.

Ellis JR (2015) Dogfish (Squalidae). In 'Fish atlas of the Celtic Sea, North Sea, and Baltic Sea' (Heessen, H. J. L., Daan, N. and Ellis, J. R., Eds.). Wageningen Academic Publishers / KNNV Publishing, 84–86.

Ellis JR and Keable J (2008) Fecundity of Northeast Atlantic spurdog (*Squalus acanthias*). *ICES Journal of Marine Science* **65**, 979–981.

Fahy E (1988) The spurdog *Squalus acanthias* (L.) fishery in southwest Ireland. *Irish Fisheries Investigations Part B: Marine* **32**, 22 pp.

Fahy E (1989) The value of alterations in fecundity to an exploited shark population, illustrated by *Squalus acanthias* (L.). ICES Document CM 1989/Mini: 2; 10 pp.

Ford E (1921) A contribution to our knowledge of the life-histories of the dogfishes landed at Plymouth. *Journal of the Marine Biological Association of the United Kingdom* 12, 468–505.

Gauld JA (1979) Reproduction and fecundity of the Scottish Norwegian stock of spurdogs, *Squalus acanthias* (L.). ICES Document CM 1979/H: 54; 15 pp.

Gračan R, Lazar B, Posavec I, Gregorović G and Lacković G (2013) Maturation, fecundity and reproductive cycle of spiny dogfish, *Squalus acanthias*, in the Adriatic Sea. *Marine Biology Research* **9**, 198–207.

Hanchet S (1988) Reproductive biology of *Squalus acanthias* from the east coast, South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **22**, 537–549.

Henderson AC, Flannery K and Dunne J (2002) Growth and reproduction in spiny dogfish *Squalus acanthias* L. (Elasmobranchii: Squalidae), from the west coast of Ireland. *Sarsia* **87**, 350–361.

Holden MJ and Meadows PS (1964) The fecundity of the spurdog (*Squalus acanthias* L.). *Journal du Conseil Permanent International pour l'Exploration de la Mer* **28**, 418–424.

ICES (2009) Report of the Joint Meeting between ICES Working Group on Elasmo-branch Fishes (WGEF) and ICCAT Shark Subgroup, 22–29 June 2009, Copenhagen, Denmark. ICES CM 2009/ACOM:16, 42233 pp**.**

Jensen AC (1966). Life history of the spiny dogfish. *Fishery Bulletin* **65**, 527–554.

Jones TS and Ugland KI (2001) Reproduction of female spiny dogfish, *Squalus acanthias*, in the Oslofjord. *Fishery Bulletin* **99**, 685–690.

Kirnosova IP (1989) Reproduction of spiny dogfish, *Squalus acanthias* in the Black Sea. *Journal of Ichthyology* **29**, 21–26.

Lage CR, Petersen CW, Forest D, Barnes D, Kornfield I and Wray C (2008) Evidence of multiple paternity in spiny dogfish (*Squalus acanthias*) broods based on microsatellite analysis. *Journal of Fish Biology* **73**, 2068–2074.

McCully SR, Scott F and Ellis JR (2012) Length at maturity and conversion factors for skates (Rajidae) around the British Isles, with a critique of earlier studies. *ICES Journal of Marine Science* **69**: 1812–1822.

Nammack MF, Musick JA and Colvocoresses JA (1985) Life-history of spiny dogfish off the northeastern United States. *Transactions of the American Fisheries Society* **114**, 367–376.

Natanson LJ, McCandless CT, James K and Hoey J (2017) Gestation period and pupping seasonality of female spiny dogfish (Squalus acanthias) off southern New England. *Fishery Bulletin* **115**, 473–483.

Oddone MC, Paesch L and Norbis W (2015) Population structure of the piked dogfish *Squalus acanthias* (Elasmobranchii: Squalidae), with preliminary reproductive observations. *Ichthyological Research* **62**, 463–473.

Pawson MG, Ellis JR and Dobby H (2009) The evolution and management of spiny dogfish (Spurdog) fisheries in the North-East Atlantic. In Biology and Management of Dogfish Sharks (V. Gallucci, G. McFarlane & G. Bargmann, eds) pp. 373–390. American Fisheries Society, Bethesda, 435 pp.

Poll M (1947) Poissons marins. *Faune de Belgique*, 452 pp.

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Silva HM (1993) Reproductive strategies of spiny dogfish, *Squalus acanthias* in the NW Atlantic. ICES Document CM 1993/G: 51, 18 pp.

Silva JF and Ellis JR (2015) Recent observations on spurdog *Squalus acanthias* life history parameters in the North-east Atlantic, Working document to the ICES Working Group on Elasmobranch Fishes, Lisbon, June 17–23, 2015, 12 pp.

Silva JF and Ellis JR (2019) Bycatch and discarding patterns of dogfish and sharks taken in English and Welsh commercial fisheries. *Journal of Fish Biology* **94**, 966–980.

Silva JF, Ellis JR and Ayers R (2013) Length-weight relationships of marine fish collected from around the British Isles. *Science Series Technical Report (CEFAS)* **150**, 109 pp.

Fries B, Ekström CU, Sundevall C, and Smitt FA (1895) A History of Scandinavian Fishes, 2nd edn. P. A. Norstedt and Sons, Stockholm. 1240 pp.

Soldat VT (1982) Age and size of spiny dogfish, *Squalus acanthias*, in the Northwest Atlantic. *NAFO Scientific Council Studies* **3**, 47–52.

Sosebee KA (2005) Are density-dependent effects on elasmobranch maturity possible? *Journal of Northwest Atlantic Fishery Science* **35**, 115–124.

Sosiński J (1978) Characteristics of the North Sea spurdog (*Squalus acanthias* L.) stock. *Acta Ichthyologica et Piscatoria* **8**, 9–22.

Stenberg C (2005) Life history of the piked dogfish (*Squalus acanthias* L.). *Journal of Northwest Atlantic Fishery Science* **35**, 155–164.

Templeman W (1944) The life-history of the spiny dogfish (*Squalus acanthias*) and the vitamin A values of dogfish liver oil. *Research Bulletin, Division of Fisheries Resources, Newfoundland* **15**, 102 pp.

Veríssimo A, Grubbs D, McDowell J, Musick J and Portnoy D (2011) Frequency of multiple paternity in the spiny dogfish *Squalus acanthias* in the Western North Atlantic. *Journal of Heredity* **102**, 88–93.

Yigin CC and Ismen A (2013) Reproductive biology of spiny dogfish *Squalus acanthias*, in the North Aegean Sea. *Turkish Journal of Fisheries and Aquatic Sciences* **13**, 169–177.

Table 1: Summary of published length-weight conversion factors for *Squalus acanthias* in the North-east Atlantic and Mediterranean.

Study area	Study period	Sex	Length range (cm)	Sample size	*a*	*b*	r^2	Source
British Isles	2003–2020	F	19–123	1129	0.0020	3.1758	0.9935	Silva & Ellis (in prep) (Fresh specimens)
		M	18–93	1113	0.0045	2.9550	0.9903	
		C	18–123	2242	0.0025	3.1063	0.9894	
	2013–2014	F	47–122	301	0.0005	3.4498	0.9815	Silva & Ellis (in prep) (Frozen specimens)
		M	53–92	796	0.0031	3.0136	0.9255	
		C	47–122	1097	0.0004	3.4668	0.9602	
British Isles	2009–2012	C	20–116	345	0.0017	3.2080	0.9858	Silva *et al.* (2013)
Scottish waters	Q1, 2, 4	F	–	–	0.00108	3.301	–	Coull *et al.* (1989)
	Q3	F	–	–	0.00595	2.889	–	
	Annual	M	–	–	0.00576	2.890	–	
Aegean Sea	1999–2000	C	27–70.5	32	0.0031	3.1056	0.9814	Filiz & Mater (2002)
Aegean Sea	2005–2008	F	17.1–115.0	312	0.0027	3.1280	0.975	Ismen *et al.* (2009)
		M	20.8–87.5	253	0.0072	2.8678	0.956	
		C	17.1–115.0	565	0.0037	3.0477	0.967	
Adriatic Sea	1997–2001	C	19.1–117.3	421	0.0020	3.150	0.987	Pallaora *et al.* (2005)
Adriatic Sea	2012–2016	F	21.7–102.5	176	0.001541	3.32	0.99	Bargione *et al.* (2019)
		M	21.9–87.5	150	0.001512	3.20	0.99	
North Sea	1974	F	–	743	0.0013	3.2732	–	Sosiński (1976)
		M	–	508	0.0032	3.0377	–	
		C	21–115	1251	0.0016	3.2180	–	
Aegean Sea	2005–2008	F	17.1–117.5	346	0.0075	2.86	0.98	Yigin & Ismen (2013)
		M	20.8–121.6 [1]	274	0.003	3.11	0.98	

Notes
[1] Most of the male *S. acanthias* reported by Yigin & Ismen (2013) were <90 cm. The presence of three males >100 cm could potentially relate to *Squalus* from the Black Sea.

Table 2: Summary of published reproductive parameters for *Squalus acanthias* giving the length at 50% maturity (L_{50}), maximum length of immature (L_{Imm_max}) and minimum length of mature (L_{Mat_min}) males and females, the minimum length at which females were in an active (gravid or post-partum) stage (L_{Act_min}), ovarian fecundity (F_O), uterine fecundity (F_U) and the length range of term pups (L_{Term_pups}).

Study area	Study period	Male			Female							Source
		L_{Mat_min}	L_{50}	L_{Imm_max}	L_{Mat_min}	L_{50}	L_{Imm_max}	L_{Act_min}	F_O	F_U	L_{Term_pups}	
NORTH-EAST ATLANTIC STOCK												
Plymouth											23–31 cm	Ford (1921)
Norwegian waters											23–31 cm	Aasen (1961)
Scottish waters	1960s					Ca. 82 cm			2–15	3–14	27.5 cm	Holden & Meadows (1964)
North Sea	1974	–	–	–	–	–	–	83 cm	–	6.88 (3–11)	23–27 cm	Sosiński (1976, 1978)
Scottish waters	1977–1979				71 cm	83 cm	93 cm		9.4 (4–17)	4–13	26.1 (19–30)	Gauld (1979)
SW Ireland	1987–1988	–	–	–		*ca.* 74 cm				[1]		Fahy (1988)
Skagerrak	1987, 1997	–	–	–	–	81 cm (17 y)	–	–	3–17	2–15	24.9 cm	Jones & Ugland (2001)
West of Ireland	1997–1998	55 cm	57.5 cm	61 cm	70 cm	78.5 cm (15 y)	87 cm		7.7 (4–13)	1–16		Henderson *et al.* (2002)
Norwegian waters	2014–2018	–	*ca.* 60 cm	–	68 cm	77.8 cm (9.5 y)	100 cm	–	–	6.6 (1–19)	24 cm (9–27)	Albert *et al.* (2019)
Skagerrak	1997	–	–	–	73 cm	77 cm (12–13 y)	83 cm	–	8.1 (4–13)	5.8 (1–13)	≤25 cm	Stenberg (2005)
British Isles	2003–2020	59 cm	65.9 cm	90 cm	76 cm	81.7 cm	89 cm	82 cm	2–22	2–19	16.4–29.6 cm	This study
NORTH-WEST ATLANTIC STOCK												
Canada		60 cm	*ca.* 64-65 cm	69 cm	74 cm	*ca.* 77-78 cm	88 cm	88 cm	2-7	1-9	25.5 cm	Templeman (1944)
										1–11	20–30 cm	Jensen (1966)
NW Atlantic	1980–1981	58 cm	59.5 cm (6 y)	62 cm	76 cm	77.9 cm (12.1 y)	85 cm		7.9 (1–18)	6.6 (2–15)		Nammack *et al.* (1985)

NW Atlantic	2006–2009	61.5 cm	63.1 cm (7.5 y)	64.5 cm	74.5 cm	76.9 cm (9.1 y)	82.5 cm	78 cm	–	–	–	Bubley *et al.* (2013)
NW Atlantic	2014–2015	–	–	–	–	–	–	–	4.1 (2–6)	4.1 (2–7)		Dutton & Gioia (2019)
MEDITERRANEAN SEA												
NW Mediterranean	1997–2005	63.5 cm		70 cm			80 cm	86 cm	10.4 (6–15)	8.2 (4–12)	24.5–27.1 cm	Capapé *et al.* (2011)
Adriatic Sea	2005–2007	50.0 cm	50.4 cm	51.1 cm	69.3 cm	72.5 cm	70.4 cm	90.1 cm	10.8 (4–18)	10.1 (6–18)	21.5 cm	Gračan *et al.* (2013)
Adriatic Sea	2012–2016	–	57.5 cm (5.5 y)	–	–	65.9 cm (7.5 y)	–	–	12 (6–18)	10.6 (1–20)	21–22 cm	Bargione *et al.* (2019)
Aegean Sea	2003–2004	47 cm	–	–	51.5 cm	*ca.* 51.8 cm	69 cm	57 cm		1–6	22 cm	Chatzispyrou & Megalofonou (2005)
Aegean Sea	2005–2008	52 cm	52.8 cm	57.8 cm	54.5 cm	56.4 cm	59.5 cm	–	–	1–9	≤22.3 cm	Yigin & Ismen (2013)

Footnotes
[1] Actual fecundity data not provided, but linear relationship given as $F_U = 0.2013\ L_T - 10.0157$ (candle stage) and $F_U = 0.1342\ L_T - 6.1045$ (pups)

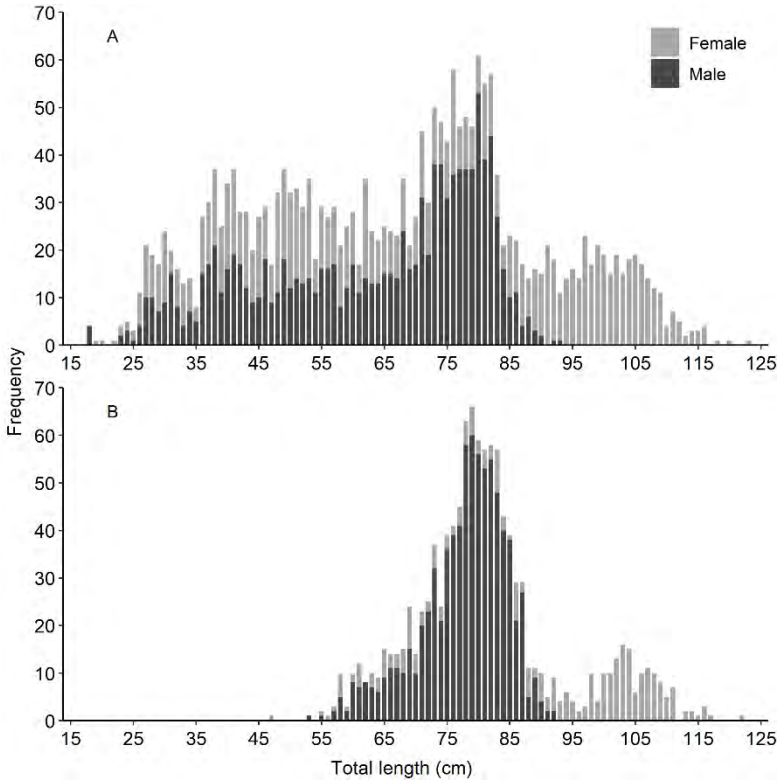


Figure 1: Length frequency of spurdog female (light grey) and male (dark grey) from (A) Cefas fishery-independent surveys and tagging programme (2003-2020) (B) fishery-dependent survey (2013–2014).

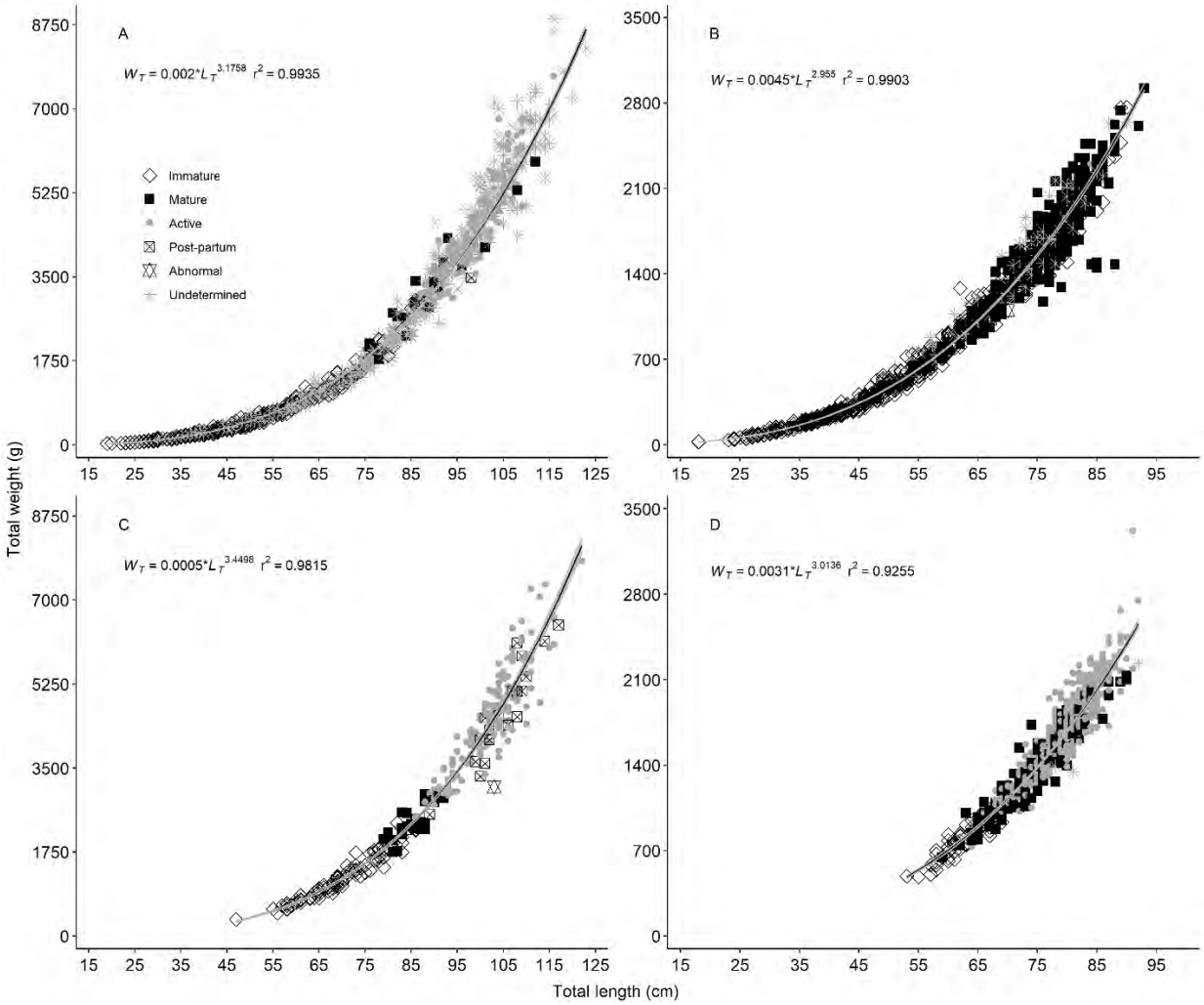


Figure 2: Relationships between total weight and total length by maturity stage for from (A) fresh females (N=1,129), (B) fresh males (N=1,113), (C) frozen females (N= 301) and (D) frozen males (N=796). **Note:** Fresh samples from Cefas fishery-independent surveys and tagging programme, with frozen samples from commercially caught fish. Abnormal fish are here presented but were not used in the linear regression (1 fresh male and 1 frozen female) and are not included in the values for N here described.

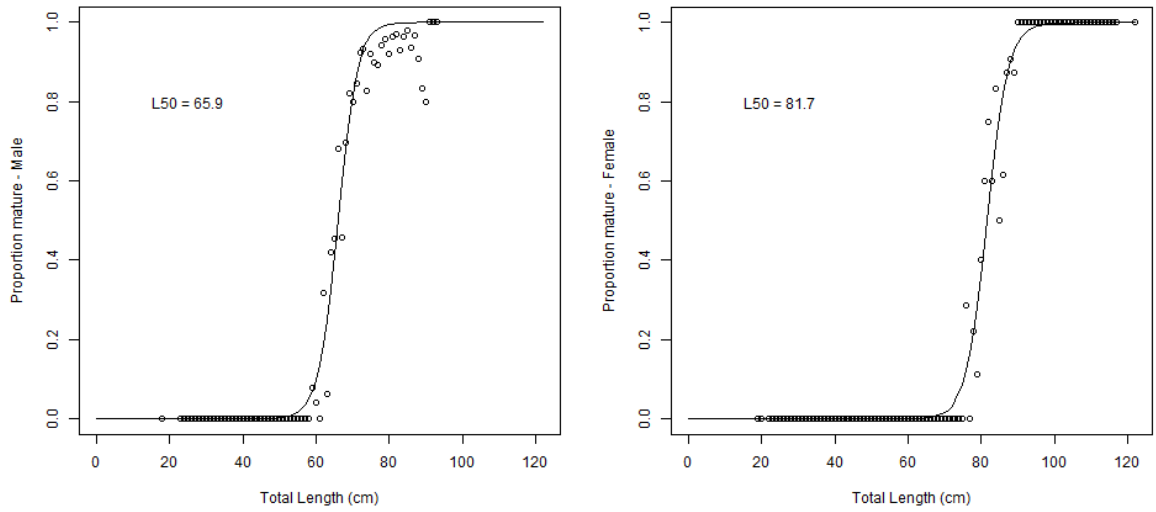


Figure 3: Proportion of mature fish at length and length at 50% maturity for male (N= 1,800; L_{50}=65.9 cm L_T) and female (N= 823; L_{50}=81.7 cm L_T)).

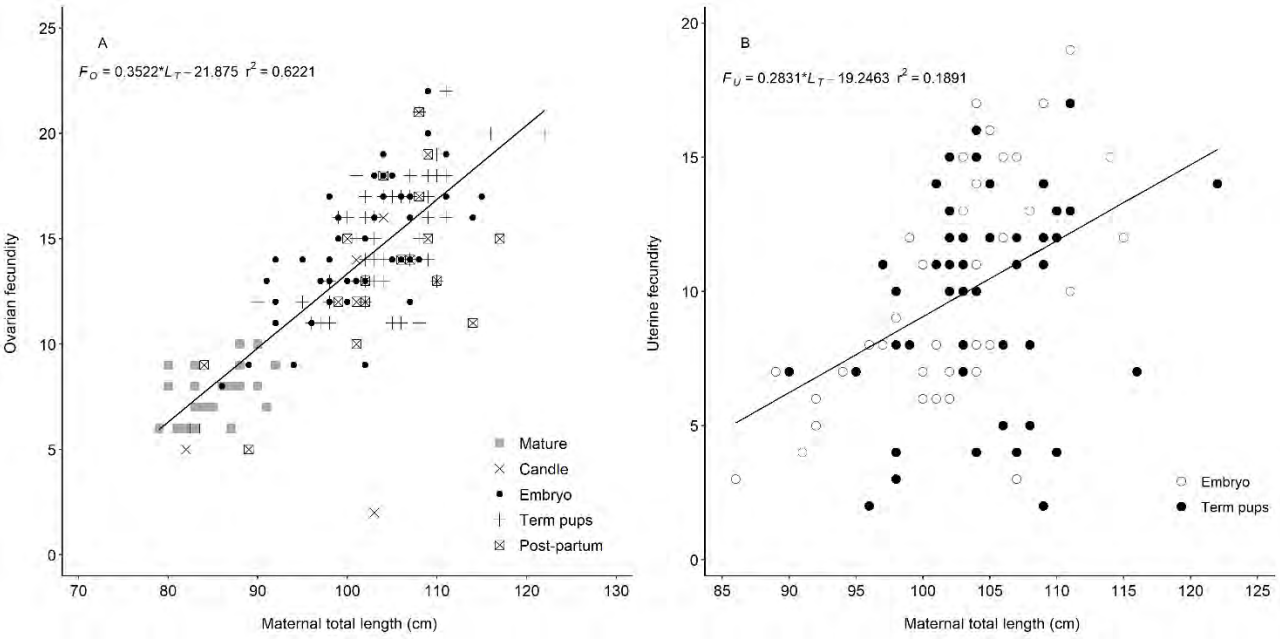


Figure 4: Ovarian (mature follicles) and uterine fecundity (embryos and term pups) in relation to maternal total length (n = 149 and 92, respectively) in spurdog. Some of these fish may have aborted some pups during capture and thus, fecundity observed be an underestimate.

SUPPLEMENTARY DATA

Table S1: Maturity stage adapted from ICES (2009)

Stage		Male	Female
A	**Immature**	**Immature**: Claspers undeveloped, shorter than extreme tips of posterior margin of pelvic fin. Testes small and thread-shaped, sperm ducts straight	**Immature**: Ovaries small, gelatinous or granulated, but no differentiated oocytes visible. Oviducts small and thread-shaped, width of shell gland not much greater than the width of the oviduct.
B		**Developing**: Claspers longer than posterior margin of pelvic fin, their tips more structured, but the claspers are soft and flexible and the cartilaginous elements are not hardened. Testes enlarged, sperm ducts beginning to meander.	**Developing**: Ovaries enlarged and with more transparent walls. Oocytes differentiated in various small sizes (usually <5mm) and pale in colour. Oviducts small and thread-shaped, width of the shell gland greater than the width of the oviduct, but not hardened.
C	**Mature**	**Mature**: Claspers longer than posterior margin of pelvic fin, cartilaginous elements hardened and claspers stiff. Testes enlarged, sperm ducts meandering and tightly filled with sperm.	**Mature**: Ovaries large with very large, yolk-filled oocytes, (> 5mm and often 10–30 mm in diameter). Shell gland fully formed and hard. Uteri fully developed but without yolky matter (stage D) or embryos (stages E-F) and not dilated (stage G).
D	**Active**	**Active**: Clasper reddish and swollen, sperm present in clasper groove, or flows if pressure exerted on cloaca.	**Early gravid**: Uteri filled with yolky matter, which may appear unsegmented, or if segmented, without visible embryos.
E			**Mid-term gravid**: Uteri filled with yolk sacs and small developing embryos that can be counted.
F			**Late gravid**: Uteri filled with well-developed term pups, and the yolk sac has been absorbed (or is very small).
G	**Post partum**		**Post partum**: Similar to stage C, but with a greater number of degenerating follicles and uteri dilated and flaccid.

Table S2: Contemporary fecundity-at-length data for North-east Atlantic *Squalus acanthias* (Silva & Ellis, in prep). Data are provided for ovarian fecundity, uterine fecundity (candles) and uterine fecundity (embryos and pups), where relevant.

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	79	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	80	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	80	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	81	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	82	Ovarian	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	82	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	83	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	83	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	83	Ovarian	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	83	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	83	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	84	Ovarian	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	84	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	85	Ovarian	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	86	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	86	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	87	Ovarian	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	87	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	88	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	88	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	88	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	88	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	88	Ovarian	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	89	Ovarian	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	89	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	90	Ovarian	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	90	Ovarian	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	90	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	91	Ovarian	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	91	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	94	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	95	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	95	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	96	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	96	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	97	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	97	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	100	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	103	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Ovarian	19	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	107	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	21	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	21	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Ovarian	21	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	19	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	20	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Ovarian	22	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Ovarian	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Ovarian	19	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Ovarian	18	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Ovarian	19	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Ovarian	22	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	114	Ovarian	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	114	Ovarian	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	115	Ovarian	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	116	Ovarian	20	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	116	Ovarian	20	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	117	Ovarian	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	122	Ovarian	20	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	90	Uterine (candle stage)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	91	Uterine (candle stage)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Uterine (candle stage)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	93	Uterine (candle stage)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	94	Uterine (candle stage)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (candle stage)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	113	Uterine (candle stage)	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	86	Uterine (embryos)	3	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	89	Uterine (embryos)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	91	Uterine (embryos)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Uterine (embryos)	3	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Uterine (embryos)	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	92	Uterine (embryos)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	94	Uterine (embryos)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	95	Uterine (embryos)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	96	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	97	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (embryos)	1	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (embryos)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (embryos)	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (embryos)	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Uterine (embryos)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	99	Uterine (embryos)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Uterine (embryos)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Uterine (embryos)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Uterine (embryos)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Uterine (embryos)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (embryos)	3	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (embryos)	6	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (embryos)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (embryos)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (embryos)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (embryos)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (embryos)	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (embryos)	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Uterine (embryos)	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Uterine (embryos)	1	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Uterine (embryos)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (embryos)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (embryos)	3	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (embryos)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (embryos)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Uterine (embryos)	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (embryos)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (embryos)	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (embryos)	1	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (embryos)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (embryos)	19	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	114	Uterine (embryos)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	115	Uterine (embryos)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	90	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	95	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	96	Uterine (pups)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	97	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (pups)	3	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	98	Uterine (pups)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	99	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	100	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Uterine (pups)	9	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	101	Uterine (pups)	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (pups)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (pups)	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	102	Uterine (pups)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	103	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2013-14	Individual length (observed)	103	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (pups)	10	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (pups)	15	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	104	Uterine (pups)	16	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	105	Uterine (pups)	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Uterine (pups)	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	106	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	107	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Uterine (pups)	5	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	108	Uterine (pups)	8	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (pups)	2	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (pups)	11	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	109	Uterine (pups)	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Uterine (pups)	4	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Uterine (pups)	12	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	110	Uterine (pups)	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (pups)	13	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	111	Uterine (pups)	17	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	116	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	116	Uterine (pups)	7	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed
2013-14	Individual length (observed)	122	Uterine (pups)	14	Fisheries-dependent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2010	Individual length (observed)	98	Uterine (embryos)	10	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	88	Uterine (embryos)	5	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	89	Uterine (embryos)	9	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	90	Uterine (embryos)	8	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	93	Uterine (embryos)	10	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	95	Uterine (embryos)	2	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	95	Uterine (embryos)	5	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	95	Uterine (embryos)	6	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	96	Uterine (embryos)	6	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	97	Uterine (embryos)	8	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	97	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	98	Uterine (embryos)	6	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	100	Uterine (embryos)	9	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	101	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	101	Uterine (embryos)	14	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	102	Uterine (embryos)	10	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	102	Uterine (embryos)	15	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	102	Uterine (embryos)	15	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	103	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	105	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	105	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	105	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	105	Uterine (embryos)	15	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	106	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	108	Uterine (embryos)	18	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2019	Individual length (observed)	109	Uterine (embryos)	17	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	92	Uterine (embryos)	5	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	95	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	97	Uterine (embryos)	9	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
2020	Individual length (observed)	97	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	99	Uterine (embryos)	8	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	99	Uterine (embryos)	10	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	100	Uterine (embryos)	10	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	100	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	101	Uterine (embryos)	6	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	101	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	101	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	103	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	104	Uterine (embryos)	4	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	104	Uterine (embryos)	7	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	104	Uterine (embryos)	8	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	104	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	104	Uterine (embryos)	14	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	105	Uterine (embryos)	13	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	106	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	106	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	106	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	106	Uterine (embryos)	15	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	107	Uterine (embryos)	12	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	107	Uterine (embryos)	15	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	109	Uterine (embryos)	11	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed
2020	Individual length (observed)	109	Uterine (pups)	8	Fisheries-independent surveys, Silva & Ellis (in prep)	Raw values observed

Table S3: Earlier fecundity-at-length data for North-east Atlantic *Squalus acanthias.* Data from Ford (1921; n = 81) and Stenberg (2005, n = 77) from tabulated data of fecundity-at-length by length group, for which the mid-point is used for the fecundity-at-length. Data from Walenkamp (1988, n = 52), Fahy (1988, n = 97) and Jones and Ugland (2001, n = 29 and 34) derived from the graphs included in the original source. Data from Gauld (1979) derived from graphs of the

mean fecundity by 1 cm length group, and the overall sample size was not reported. Data are provided for ovarian fecundity, uterine fecundity (candles) and uterine fecundity (embryos and pups), where relevant.

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1921	70-74 cm	72.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	70-74 cm	72.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	70-74 cm	72.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	70-74 cm	72.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	70-74 cm	72.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	3	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	6	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	6	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Ovarian	3	Ford (1921)	From original tabulated values

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1921	85-89 cm	87.0	Ovarian	4	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Ovarian	5	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Ovarian	6	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Ovarian	8	Ford (1921)	From original tabulated values
1921	95-99 cm	97.0	Ovarian	7	Ford (1921)	From original tabulated values
1921	70-74 cm	72.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	75-79 cm	77.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	1	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	1	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1921	85-89 cm	87.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (candle stage)	4	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (candle stage)	5	Ford (1921)	From original tabulated values
1921	95-99 cm	97.0	Uterine (candle stage)	2	Ford (1921)	From original tabulated values
1921	95-99 cm	97.0	Uterine (candle stage)	3	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	2	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	3	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	4	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	4	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	4	Ford (1921)	From original tabulated values
1921	80-84 cm	82.0	Uterine (embryos and pups)	4	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	1	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	2	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	3	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	3	Ford (1921)	From original tabulated values
1921	85-89 cm	87.0	Uterine (embryos and pups)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (embryos and pups)	3	Ford (1921)	From original tabulated values
1921	90-94 cm	92.0	Uterine (embryos and pups)	4	Ford (1921)	From original tabulated values
1921	95-99 cm	97.0	Uterine (embryos and pups)	11	Ford (1921)	From original tabulated values
1978	Mean fecundity per 1 cm length class	72	Ovarian	4.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	73	Ovarian	6.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	74	Ovarian	5.3	Gauld (1979)	Derived from a graph; data from 1977-1979

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1978	Mean fecundity per 1 cm length class	75	Ovarian	5.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	76	Ovarian	4.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	77	Ovarian	5.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	78	Ovarian	6.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	79	Ovarian	5.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	80	Ovarian	6.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	81	Ovarian	6.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	82	Ovarian	7.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	83	Ovarian	8.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	84	Ovarian	8.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	85	Ovarian	8.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	86	Ovarian	7.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	87	Ovarian	7.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	88	Ovarian	9.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	89	Ovarian	7.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	90	Ovarian	8.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	91	Ovarian	9.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	92	Ovarian	9.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	93	Ovarian	9.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	94	Ovarian	9.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	95	Ovarian	10.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	96	Ovarian	9.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	97	Ovarian	11.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	98	Ovarian	11.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	99	Ovarian	11.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	100	Ovarian	11.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	101	Ovarian	11.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	102	Ovarian	11.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	103	Ovarian	11.8	Gauld (1979)	Derived from a graph; data from 1977-1979

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1978	Mean fecundity per 1 cm length class	104	Ovarian	11.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	105	Ovarian	12.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	106	Ovarian	13.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	107	Ovarian	12.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	108	Ovarian	14.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	109	Ovarian	15.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	110	Ovarian	14.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	74	Uterine (candle stage)	4.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	75	Uterine (candle stage)	5.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	76	Uterine (candle stage)	5.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	77	Uterine (candle stage)	5.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	78	Uterine (candle stage)	5.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	79	Uterine (candle stage)	4.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	80	Uterine (candle stage)	7.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	81	Uterine (candle stage)	6.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	82	Uterine (candle stage)	6.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	84	Uterine (candle stage)	6.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	85	Uterine (candle stage)	7.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	86	Uterine (candle stage)	7.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	87	Uterine (candle stage)	7.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	88	Uterine (candle stage)	7.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	89	Uterine (candle stage)	7.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	90	Uterine (candle stage)	8.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	91	Uterine (candle stage)	9.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	92	Uterine (candle stage)	10.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	93	Uterine (candle stage)	9.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	94	Uterine (candle stage)	9.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	95	Uterine (candle stage)	11.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	96	Uterine (candle stage)	10.4	Gauld (1979)	Derived from a graph; data from 1977-1979

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1978	Mean fecundity per 1 cm length class	97	Uterine (candle stage)	10.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	98	Uterine (candle stage)	10.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	99	Uterine (candle stage)	11.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	100	Uterine (candle stage)	11.7	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	101	Uterine (candle stage)	12.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	102	Uterine (candle stage)	12.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	103	Uterine (candle stage)	12.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	104	Uterine (candle stage)	13.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	105	Uterine (candle stage)	13.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	106	Uterine (candle stage)	14.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	107	Uterine (candle stage)	13.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	108	Uterine (candle stage)	13.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	78	Uterine (embryos and pups)	3.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	83	Uterine (embryos and pups)	6.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	84	Uterine (embryos and pups)	7.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	85	Uterine (embryos and pups)	6.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	86	Uterine (embryos and pups)	6.1	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	87	Uterine (embryos and pups)	5.8	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	88	Uterine (embryos and pups)	6.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	89	Uterine (embryos and pups)	5.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	90	Uterine (embryos and pups)	7.0	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	91	Uterine (embryos and pups)	6.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	92	Uterine (embryos and pups)	7.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	93	Uterine (embryos and pups)	8.6	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	94	Uterine (embryos and pups)	9.4	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	96	Uterine (embryos and pups)	7.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	97	Uterine (embryos and pups)	10.3	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	98	Uterine (embryos and pups)	10.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	99	Uterine (embryos and pups)	9.7	Gauld (1979)	Derived from a graph; data from 1977-1979

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1978	Mean fecundity per 1 cm length class	100	Uterine (embryos and pups)	9.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	101	Uterine (embryos and pups)	11.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	102	Uterine (embryos and pups)	11.5	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	103	Uterine (embryos and pups)	11.2	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	104	Uterine (embryos and pups)	12.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	106	Uterine (embryos and pups)	12.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1978	Mean fecundity per 1 cm length class	108	Uterine (embryos and pups)	12.9	Gauld (1979)	Derived from a graph; data from 1977-1979
1987	Individual length (estimated)	71.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	72.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	72.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	72.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	72.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	73.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	73.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	73.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	74.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	74.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.5	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.5	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	75.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.0	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.5	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1987	Individual length (estimated)	76.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	76.5	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	77.5	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.5	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	78.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	79.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	80.0	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	80.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	80.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	80.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	80.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1987	Individual length (estimated)	80.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.0	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.5	Uterine (all stages)	3	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	81.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	82.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	82.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	82.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	82.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	82.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	83.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	83.0	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	83.5	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	84.5	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	84.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.0	Uterine (all stages)	2	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.0	Uterine (all stages)	5	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.5	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	85.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	86.0	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	86.0	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	86.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	86.5	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	87.0	Uterine (all stages)	2	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	87.5	Uterine (all stages)	4	Fahy (1989)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1987	Individual length (estimated)	87.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	87.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	88.0	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	88.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	89.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	89.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	90.0	Uterine (all stages)	7	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	91.5	Uterine (all stages)	9	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	92.0	Uterine (all stages)	9	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	92.5	Uterine (all stages)	6	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	94.5	Uterine (all stages)	8	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	94.5	Uterine (all stages)	10	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	99.5	Uterine (all stages)	13	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	100.0	Uterine (all stages)	11	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	101.0	Uterine (all stages)	17	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	101.0	Uterine (all stages)	17	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	105.0	Uterine (all stages)	12	Fahy (1989)	Derived from a graph
1987	Individual length (estimated)	72.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	77.5	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	78.0	Uterine (embryos and pups)	3	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	79.0	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	79.5	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	80.0	Uterine (embryos and pups)	9	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	82.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	82.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	82.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	83.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	84.0	Uterine (embryos and pups)	9	Jones and Ugland (2001)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1987	Individual length (estimated)	85.0	Uterine (embryos and pups)	10	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	86.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	88.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	88.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	88.0	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	89.0	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	89.5	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	90.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	90.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	91.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	91.0	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	92.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	92.5	Uterine (embryos and pups)	11	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	93.5	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	94.0	Uterine (embryos and pups)	10	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	101.5	Uterine (embryos and pups)	12	Jones and Ugland (2001)	Derived from a graph
1987	Individual length (estimated)	106.0	Uterine (embryos and pups)	14	Jones and Ugland (2001)	Derived from a graph
1988	Individual length (estimated)	71.0	Ovarian	3	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	73.0	Ovarian	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	75.0	Ovarian	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	77.0	Ovarian	4	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	79.0	Ovarian	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	82.0	Ovarian	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	83.0	Ovarian	6	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	83.0	Ovarian	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	84.0	Ovarian	4	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	84.0	Ovarian	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	85.0	Ovarian	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	86.0	Ovarian	7	Walenkamp (1988)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1988	Individual length (estimated)	87.0	Ovarian	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	87.0	Ovarian	8	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	87.0	Ovarian	16	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	88.0	Ovarian	8	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	90.0	Ovarian	9	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Ovarian	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Ovarian	8	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Ovarian	11	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Ovarian	12	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	95.0	Ovarian	9	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	97.0	Ovarian	10	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	97.0	Ovarian	12	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	98.0	Ovarian	10	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	101.0	Ovarian	15	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	106.0	Ovarian	13	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	77.0	Uterine (candle stage)	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	86.0	Uterine (candle stage)	6	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	87.0	Uterine (candle stage)	3	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	87.0	Uterine (candle stage)	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	89.0	Uterine (candle stage)	2	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Uterine (candle stage)	3	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Uterine (candle stage)	9	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	93.0	Uterine (candle stage)	10	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	95.0	Uterine (candle stage)	11	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	95.0	Uterine (candle stage)	12	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	96.0	Uterine (candle stage)	3	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	96.0	Uterine (candle stage)	9	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	104.0	Uterine (candle stage)	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	82.0	Uterine (embryos and pups)	4	Walenkamp (1988)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1988	Individual length (estimated)	87.0	Uterine (embryos and pups)	3	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	87.0	Uterine (embryos and pups)	4	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	88.0	Uterine (embryos and pups)	5	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Uterine (embryos and pups)	1	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Uterine (embryos and pups)	6	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	92.0	Uterine (embryos and pups)	7	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	97.0	Uterine (embryos and pups)	6	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	97.0	Uterine (embryos and pups)	10	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	98.0	Uterine (embryos and pups)	4	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	101.0	Uterine (embryos and pups)	12	Walenkamp (1988)	Derived from a graph
1988	Individual length (estimated)	106.0	Uterine (embryos and pups)	9	Walenkamp (1988)	Derived from a graph
1997	Individual length (estimated)	77.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	79.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	79.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	80.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	80.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	84.5	Uterine (embryos and pups)	3	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	84.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	84.5	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	86.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	87.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	87.5	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	88.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	89.0	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	90.0	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	90.5	Uterine (embryos and pups)	9	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	91.0	Uterine (embryos and pups)	9	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	91.5	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	92.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1997	Individual length (estimated)	92.0	Uterine (embryos and pups)	10	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	92.5	Uterine (embryos and pups)	6	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	93.0	Uterine (embryos and pups)	4	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	93.0	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	94.5	Uterine (embryos and pups)	5	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	94.5	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	95.0	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	95.0	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	97.5	Uterine (embryos and pups)	8	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	97.5	Uterine (embryos and pups)	10	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	98.0	Uterine (embryos and pups)	9	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	100.0	Uterine (embryos and pups)	11	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	100.5	Uterine (embryos and pups)	7	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	106.0	Uterine (embryos and pups)	12	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	106.5	Uterine (embryos and pups)	10	Jones and Ugland (2001)	Derived from a graph
1997	Individual length (estimated)	108.0	Uterine (embryos and pups)	15	Jones and Ugland (2001)	Derived from a graph
1997	70-74 cm	72.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	1	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	3	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	3	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	75-79 cm	77.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	1	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	2	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	3	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1997	80-84 cm	82.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	80-84 cm	82.0	Uterine (embryos and pups)	9	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	1	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	2	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	85-89 cm	87.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1997	90-94 cm	92.0	Uterine (embryos and pups)	3	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	90-94 cm	92.0	Uterine (embryos and pups)	11	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	4	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	6	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	7	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	9	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	9	Stenberg (2005)	From original tabulated values
1997	95-99 cm	97.0	Uterine (embryos and pups)	9	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	5	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values

Year	Length_Group	Length	Fecundity_Type	Fecundity_Value	Source	Notes
1997	100-104 cm	102.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	9	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	10	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	10	Stenberg (2005)	From original tabulated values
1997	100-104 cm	102.0	Uterine (embryos and pups)	13	Stenberg (2005)	From original tabulated values
1997	105-109 cm	107.0	Uterine (embryos and pups)	8	Stenberg (2005)	From original tabulated values

WD1 – Catch data for whiting in Division 6.a (West of Scotland)

Andrzej Jaworski and Helen Dobby, Marine Scotland – Science

November 2020

Introduction

Prior to the data compilation meeting for WKDEM (ICES, 2020a) in October 2019, a data call was issued requesting national data on landings, discards, sample information (age and length compositions) and effort (disaggregated by quarter and métier) for 2002 to 2018 to be uploaded to InterCatch (IC).

Since then, an additional year of data has been submitted to IC as part of the annual assessment WG process and total catches as estimated using the procedures described below were used in the 2020 stock assessment (ICES, 2020b).

Given that the last data call was so recent, no further data call was issued as part of this benchmarking process.

Data in InterCatch

Total official landings by country are shown in Figure 1. Major landings originated from the UK (mainly Scotland), Ireland and, to less extent, from France and the Netherlands. Small amounts are also occasionally reported by Belgium, Denmark, Faroe Islands, Norway and Spain. Landing weights were submitted to IC by all relevant countries for 2003 onwards. Figure 2 shows total landings (L) and discards (D) data availability in IC by country. The values for 'logbook registered discards' submitted by Ireland are all zero while the 'BMS landings' submitted by a number of countries since 2015 are < 5 tonnes in total (Table 1).

Age composition data for landings and discards were provided by UK (Scotland) and Ireland for the main metiers (demersal trawl and *Nephrops* trawl) over the time series (the exception being 2006 for Ireland when there was no sampling). Northern Ireland (and also France on occasions) have also submitted discard estimates, but with no associated age compositions.

Length compositions were also requested in addition to age composition data (for landings and discards) to potentially allow for the development of a length based indicator approach in the event that an analytical assessment cannot be agreed. Submissions were on the whole provided by the same countries as the age composition data.

The importance of the different métiers for landings and discards is shown in Tables 2 and 3, respectively. The majority of landings are taken by bottom otter trawls directed to demersal fish (OTB_DEF), while imported discards were mainly reported for bottom otter trawls directed to *Nephrops* (OTB_CRU). (Figures 3 and 4)

Sampling Coverage

Sampling coverage of the reported landings is shown in Figure 5. The proportion of landings which have an estimate of discards associated with them ranges from just under 50% to almost 100%. The poor coverage in 2006 (< 50%) is due to a lack of Irish sampling in this year, when Irish landings represented greater than 50% of the total. In recent years sampling coverage has been quite variable – this is related to the proportion of landings taken as by-catch in the small mesh fisheries (OTB_SPF_32-69 and OTM_SPF_32-69) for pelagic fish (largely reported by Netherlands, Denmark & Ireland) which are largely un-sampled. Sampling coverage in terms of landings age compositions is similar to that for discard estimates.

Figure 6 shows the proportion of discards imported to IC which have age compositions associated with them. Typically between 90 and 100 % of imported discards have sampled age compositions. However, during the period 2012–2016, estimates of total discards from the *Nephrops* target fishery were also provided by Northern Ireland (in addition to Scotland), however, no age compositions were provided, resulting in a lower proportion of discards with age composition data in these years.

Catch estimation in InterCatch

Estimation was conducted in IC for 2003 onwards. Catch-at-age estimates prior to that remain unchanged as no additional/new data were provided to the benchmark.

The catch estimation in IC involved 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 were allocated for landings and discards separately. BMS landings were combined with discards for the purpose of age composition estimation.

Discard ratios

Submitted annual discards were automatically matched to the respective available quarterly/annual landings by country and fleet. Only matched landings and discards were used to estimate discards:landings ratios to estimate discards for landings without provided discards. Figure 7 shows the discard proportion in the OTB_CRU fleet to be almost 100%, significantly greater than in the target demersal fisheries. For each year, gear stratification was used for OTB_DEF (gadoid fishery) and OTB_CRU (*Nephrops* fishery), with two ratios as a result, to raise discards for non-sampled métiers. The rationale for this stratification was the considerable difference in discard rates observed in the two fisheries. Hence, unsampled demersal target metiers were allocated a discard-landings ratio on the basis of all available ratios from sampled demersal target métiers (and similarly for unsampled *Nephrops* fleets) weighted using the option "Landings CATON". In recent years, there have been whiting landings reported by Denmark, Ireland and Netherlands as bycatch in fisheries directed at small pelagic fish (OTM_SPF_32-69 and OTB_SPF_32-69 gears). Given that these fisheries are not occurring in the very inshore waters where small whiting are found (and the OTB_CRU fleet operates), it seems likely that their discard rates are likely to be more similar to those from the OTB_DEF fishery despite the different mesh sizes. Hence, the OTB_DEF ratio is applied to the landings from the OTM_SPF and OTB_SPF.

Age compositions

Similarly, age allocations, in landings and discards, were carried out on the basis of two groups of fleets (OTB_DEF and OTB_CRU), with allocations to unsampled fleets following the same approach as for discard proportions The age structure in non-sampled landings was estimated from that in fleets with sampled landings (using the option "Mean Weight weighted by Numbers at Age or Length" available in InterCatch). Likewise, the age structure

in non-sampled discards was estimated from that in sampled discards. An example of the catch-at-age composition (after raising discards and allocating age compositions) is provided in Figure 8 (for 2016) and shows the typical importance of the unsampled data in the final catch-at-age data.

The resulting CATON (catch in tonnes), CANUM (catch numbers-at-age) and WECA (weight-at-age) files were extracted from IC (for catch, landings and discards separately) and used to update the catch time-series.

Final catch data

The new estimates of total landings and discards (for 2003–2018) derived at WKDEM (ICES, 2020a) and updated at WGCSE (for 2019) in 2020 (ICES, 2020b) did not differ substantially from those reported earlier (ICES, 2019). They are shown in Figure 9.

The estimated catch numbers-at-age are shown in Figure 10 and mean weights-at-age in landings, discards and catch are shown in Figure 11. Those for landings have been variable in recent years, mainly due to low whiting numbers that could potentially be sampled on the market (ICES, 2020b). Overall, the mean weights-at-age in landings, discards and catch did not differ substantially from those reported earlier (ICES, 2019).

References

ICES. 2019. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 1:29. 1604 pp. http://doi.org/10.17895/ices.pub.4982

ICES. 2020a. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

ICES. 2020b. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. xx pp. http://doi.org/10.17895/ices.pub.5978

Table 1. Total landings and discards imported into InterCatch.

Year	Discards	Landings	BMS landing	Logbook Registered Discard
2003	1876.5	1331.1	NA	NA
2004	2787.2	798.4	NA	NA
2005	935.9	334.6	NA	NA
2006	667.9	377.6	NA	NA
2007	366.2	480.7	NA	NA
2008	150.8	441.4	NA	NA
2009	825.6	479.6	NA	NA
2010	1090.9	345.1	NA	NA
2011	629.6	231	NA	NA
2012	740.9	300.1	NA	NA
2013	956.1	214.5	NA	NA
2014	743.3	180.9	NA	NA
2015	1413.5	221.4	3.3	NA
2016	919.4	226.7	0.9	0
2017	1244.8	167.8	NA	NA
2018	626.9	188.7	0	0
2019	694.2	483.9	0.3	0

Table 2. Proportion of landings by métier. Zero indicates a negligible value. No value indicates no reported landings in the given year.

Métier	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C-Allgears						0.004		0.002	0.001								
FPO_DEF																0	
GNS_DEF																0	
GNS_DEF_120-219_0_0_all	0	0.002	0	0	0.001	0.004		0	0		0.004				0		
LHM_DEF																0	
LLS_DEF										0					0.01	0.001	0.001
LLS_FIF_0_0_0_all			0														
MIS_MIS_0_0_0	0	0	0		0			0	0	0	0						
MIS_MIS_0_0_0_HC	0.012	0.006	0	0.001	0	0	0	0		0		0.002	0.001	0		0	0.045
OTB_CRU_100-119_0_0_all													0	0	0		
OTB_CRU_70-99_0_0_all	0.056	0.113	0.17	0.098	0.098	0.096	0.053	0.014	0.058	0.189	0.074	0.035	0.012	0.019	0.028	0.018	0.002
OTB_DEF																0.004	
OTB_DEF_>=120_0_0										0	0.001	0	0	0.018	0.007	0.001	0.011
OTB_DEF_>=120_0_0_all	0.501	0.432	0.304	0.376	0.783	0.738	0.685	0.696	0.288	0.491	0.463	0.42	0.536	0.415	0.529	0.554	0.444
OTB_DEF_100-119_0_0	0.002	0.001	0.009	0.005	0	0	0	0	0.004	0.001	0		0	0	0.001	0.003	0
OTB_DEF_100-119_0_0_all	0.375	0.414	0.472	0.509	0.117	0.099	0.261	0.287	0.647	0.312	0.436	0.505	0.247	0.234	0.246	0.309	0.175
OTB_DEF_70-99_0_0	0.001	0.001															
OTB_DEF_70-99_0_0_all	0	0	0					0									
OTB_DWS_>=120_0_0_all				0	0						0.003	0.008		0.002	0	0	0.001
OTB_DWS_100-119_0_0_all	0	0	0.001	0	0	0	0.001	0.001	0	0	0		0			0	0
OTB_MCD_70-99_0_0_all									0.001								
OTB_MOL_70-99_0_0_all											0.004						
OTB_SPF_32-69_0_0_all																0.01	0.115
OTM_DEF_100-119_0_0_all														0			
OTM_SPF_16-31_0_0																0	
OTM_SPF_32-69_0_0_all													0.047	0.208	0.106	0.024	0.050
OTT_DEF_100-119_0_0	0.001	0.001	0.001		0		0	0		0							
PTM_SPF_32-69_0_0_all		0											0.064	0.026	0.058	0.068	0.126
SDN_DEF																0	
SSC_DEF																0	
SSC_DEF_100-119_0_0_all	0.052	0.03	0.042	0.01	0	0.058				0.007	0.015	0.029	0.092	0.079	0.014	0.008	0.030
SSC_DEF_All_0_0_All																	
TBB_DEF_70-99_0_0_all	0	0									0						

Table 2. Proportion of discards by metier (before raising). Zero indicates a negligible value. No value indicates no reported discards in the given year.

Métier	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C-Allgears						0.005		0	0								
DRB_MOL_0_0_0_all										0							
GNS_DEF_120-219_0_0_all								0	0						0		
LLS_DEF										0					0.002		
MIS_MIS_0_0_0								0	0	0							
MIS_MIS_0_0_0_HC	0									0							0
OTB_CRU_100-119_0_0_all															0.014		
OTB_CRU_70-99_0_0_all	0.315	0.282	0.509	0.918	0.475	0.53	0.944	0.886	0.92	0.893	0.9	0.941	0.911	0.807	0.82	0.542	0.642
OTB_DEF_>=120_0_0										0					0.001		0
OTB_DEF_>=120_0_0_all	0.285	0.487	0.339	0.082	0.386	0.343	0.048	0.098	0.042	0.035	0.067	0.043	0.067	0.099	0.117	0.153	0.227
OTB_DEF_100-119_0_0								0	0	0					0		0
OTB_DEF_100-119_0_0_all	0.4	0.231	0.152		0.14	0.122	0.009	0.015	0.037	0.069	0.031	0.015	0.02	0.093	0.015	0.305	0.131
OTB_DWS_>=120_0_0_all															0		
OTB_DWS_100-119_0_0_all								0	0	0							
OTB_MCD_70-99_0_0_all									0								
OTB_MOL_70-99_0_0_all										0.001	0.002						
OTM_DEF_100-119_0_0_all																0	
OTM_SPF_16-31_0_0																0	
OTM_SPF_32-69_0_0_all													0.002	0.001	0.018	0	
OTT_DEF_100-119_0_0								0									
PTM_SPF_32-69_0_0_all														0	0.01		
SSC_DEF_100-119_0_0_all										0.001					0.002		0

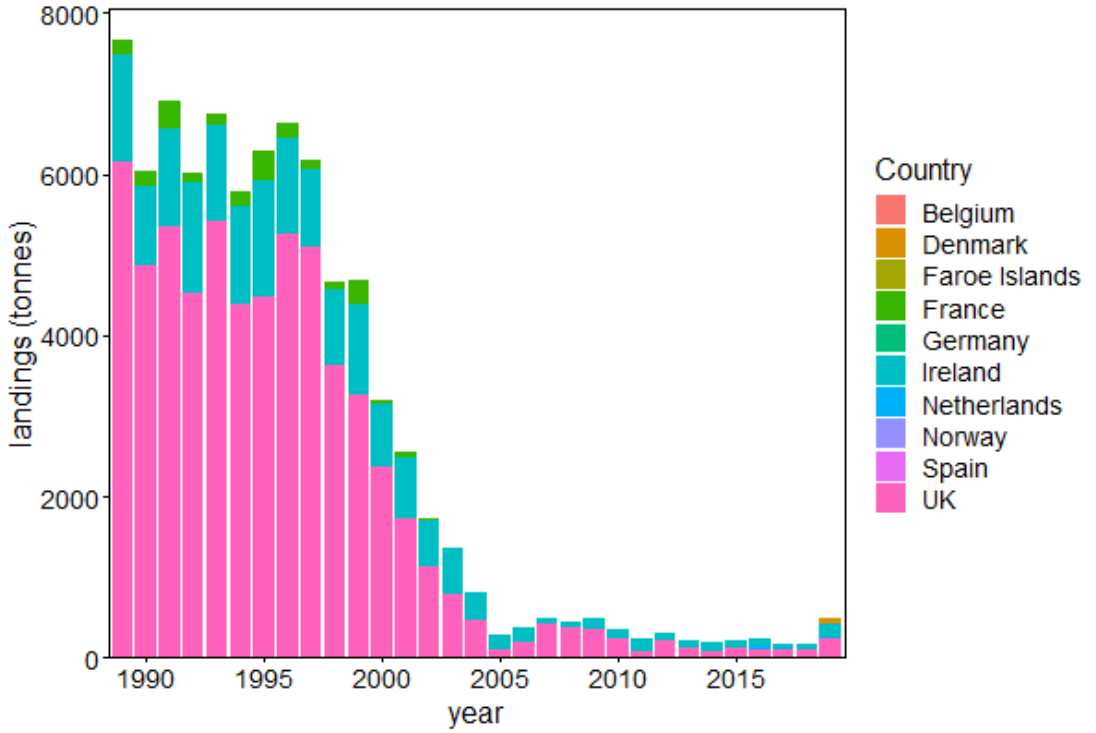


Figure 1. Official landings by country.

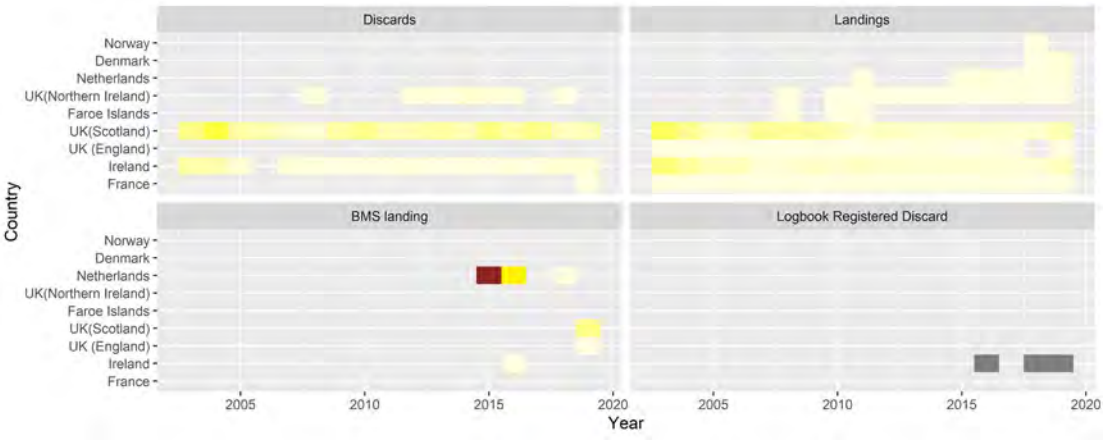


Figure 2. Catch imported to InterCatch by catch category and country (darker shading represents larger quantities, grey represents zero).

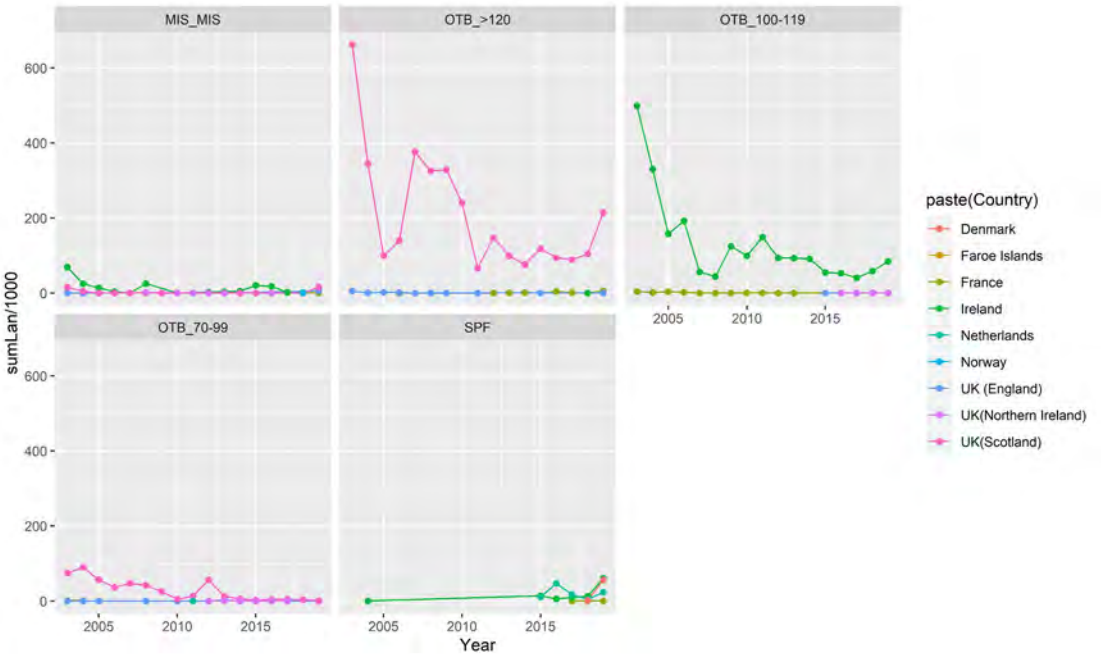


Figure 3. Imported landings by metier and country (tonnes).

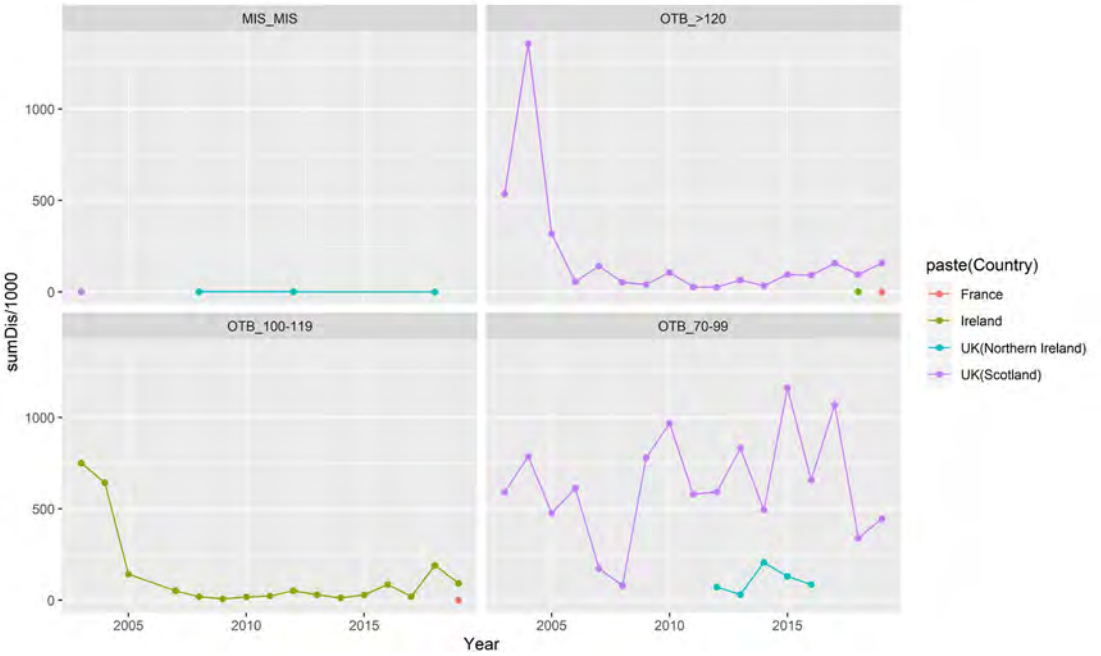


Figure 4. Imported discards by metier and country (tonnes).

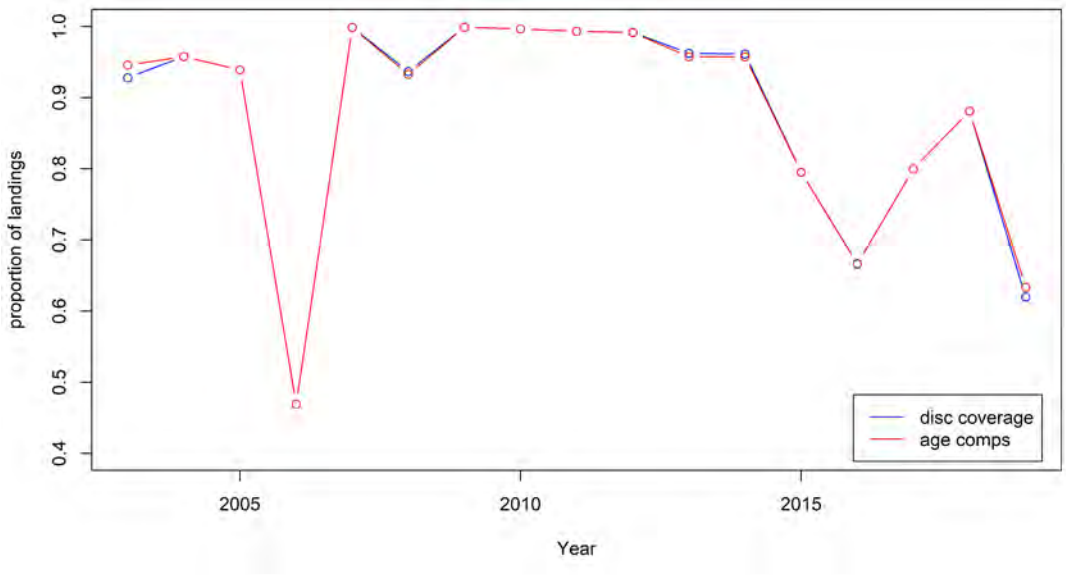


Figure 5. Proportion of reported landings in InterCatch for which i) an estimate of discards is available (blue) and ii) age composition data are available.

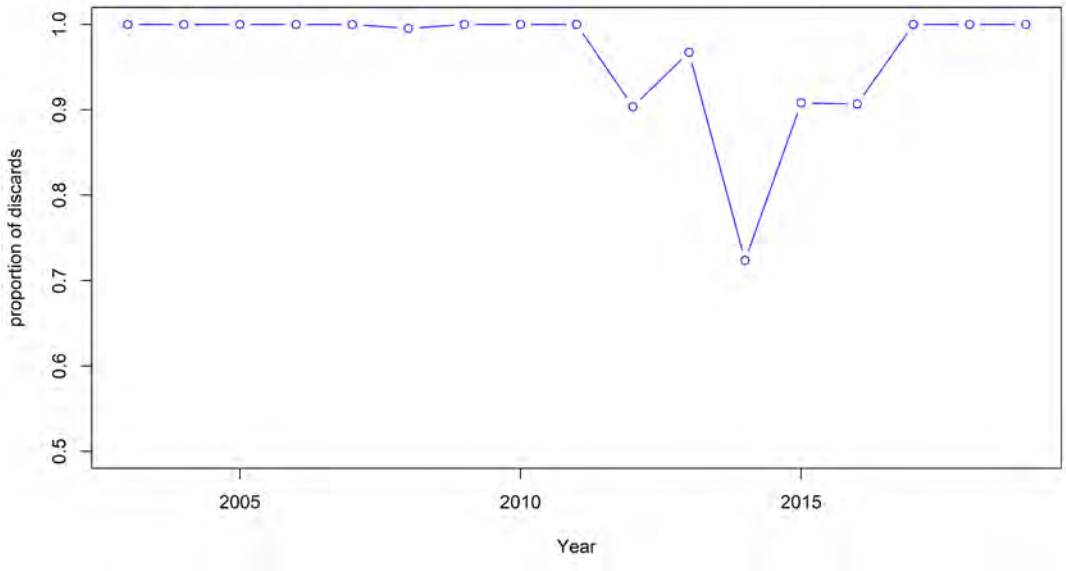


Figure 6. Proportion of imported discards with associated age composition data.



Figure 7. Discard rate by metier and country (data imported into InterCatch).

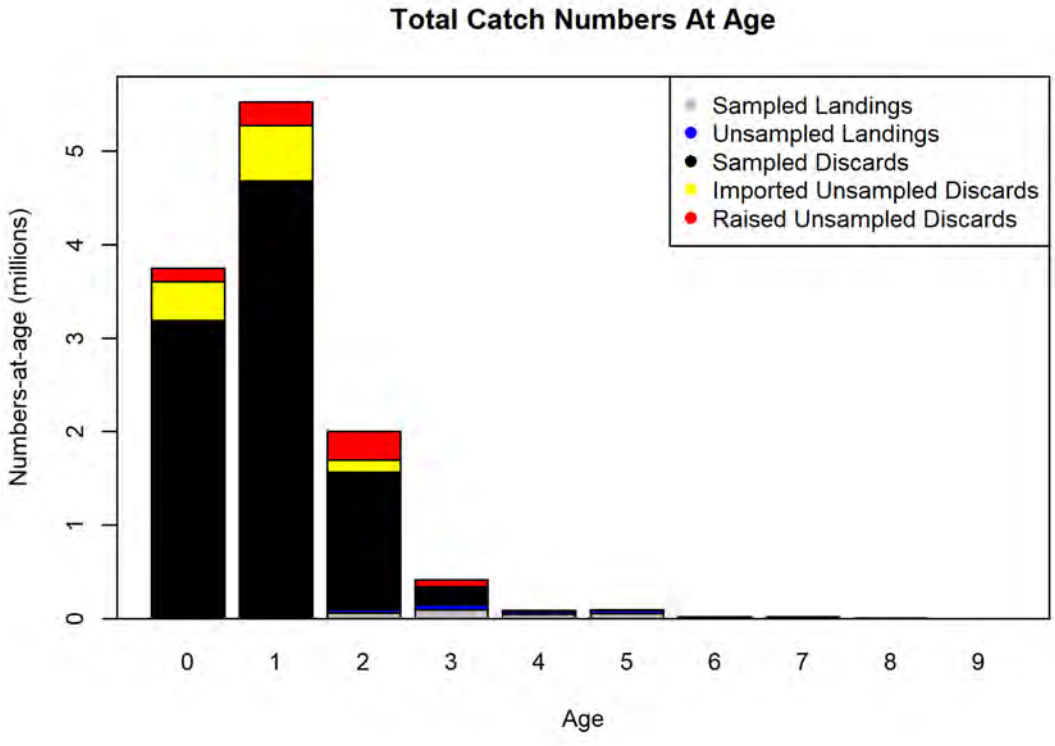


Figure 8. Final catch at age data (after raising discards and allocating age comps) for 2016 showing importance of raised/unsampled categories.

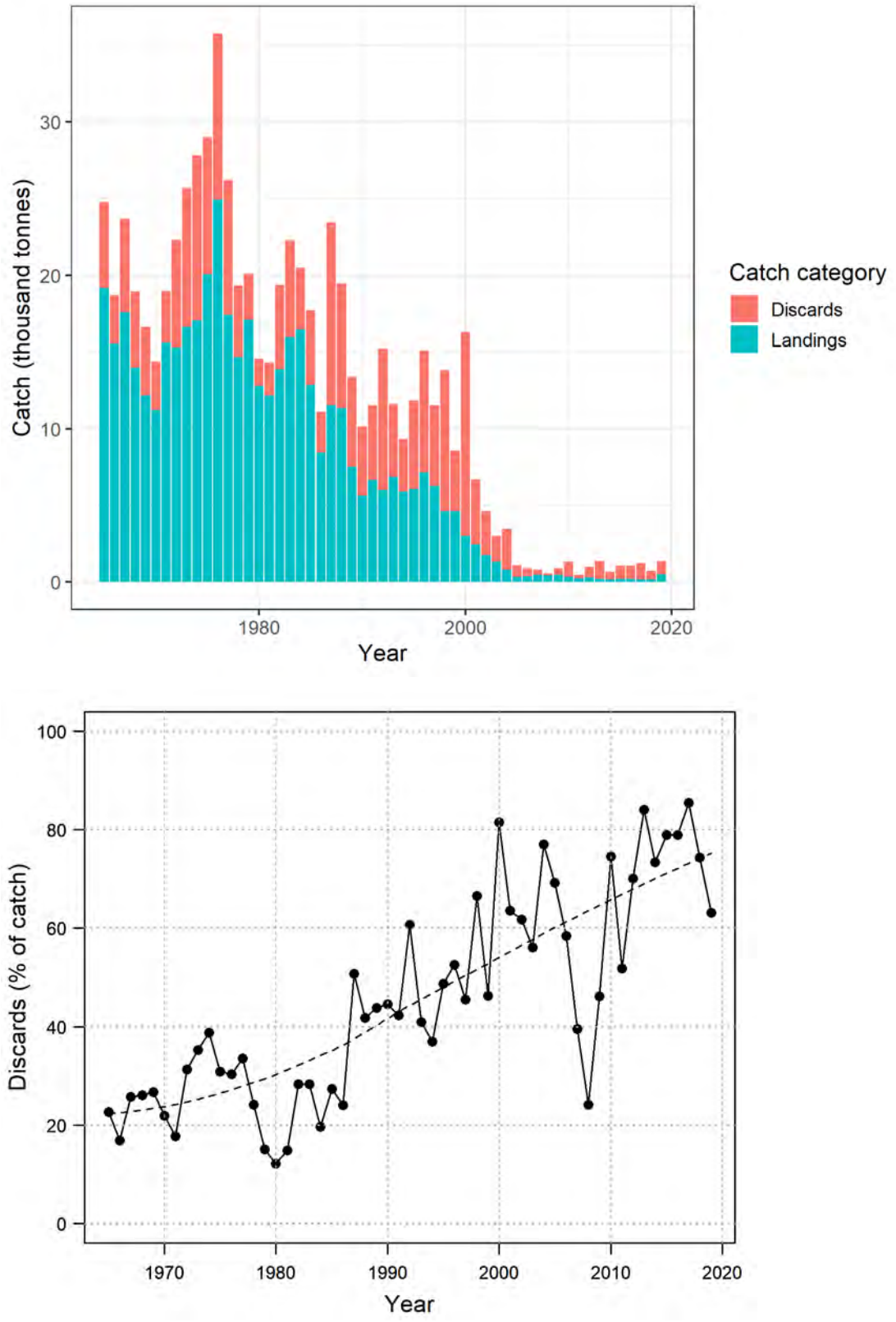


Figure 9. ICES estimates of landings, discards and catch (in tonnes, whiting at-age 1 and older) (upper panel) and discards as % of catch (lower panel).

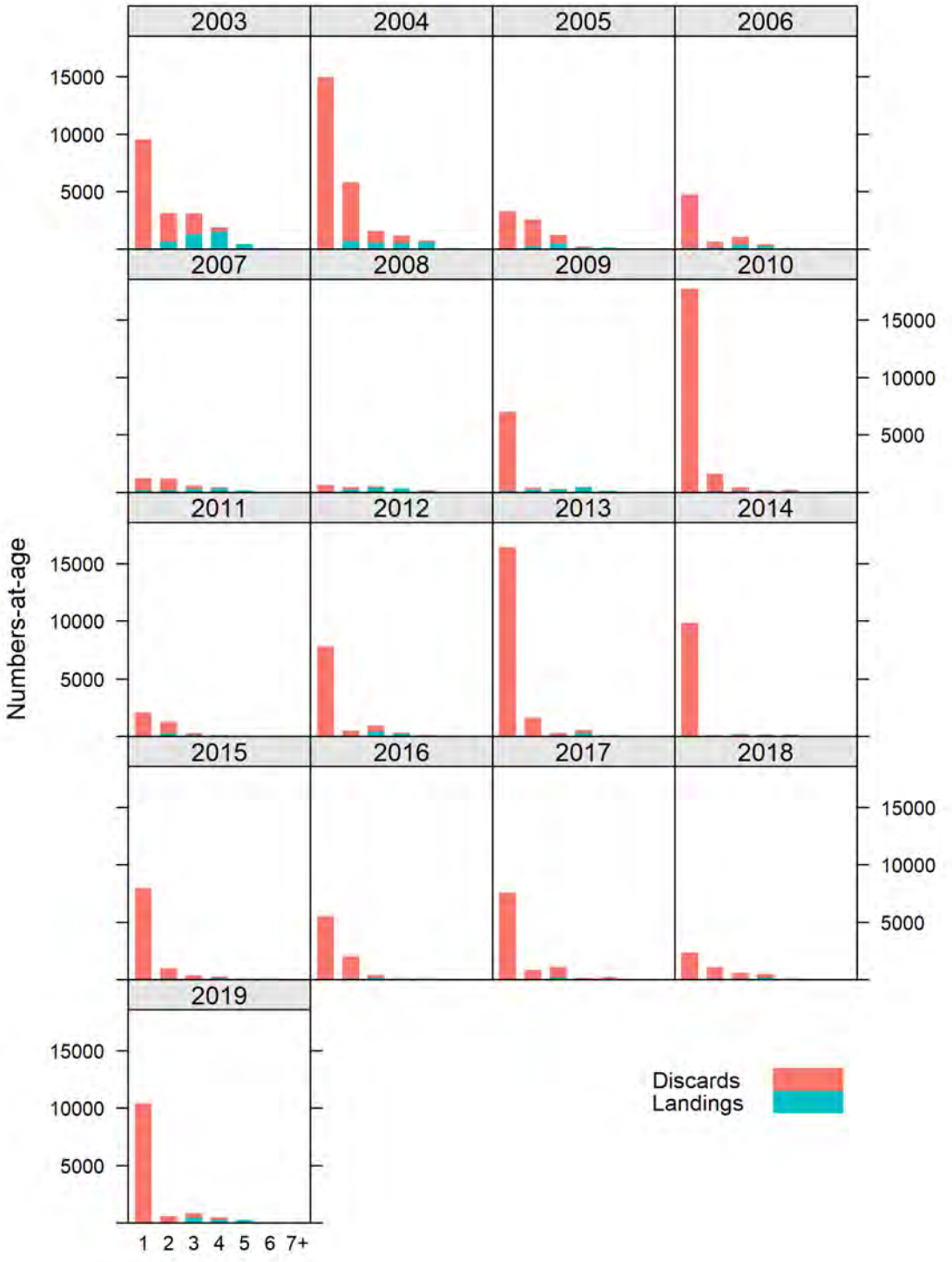


Figure 10. Catch numbers-at-age by year in 2003–2019.

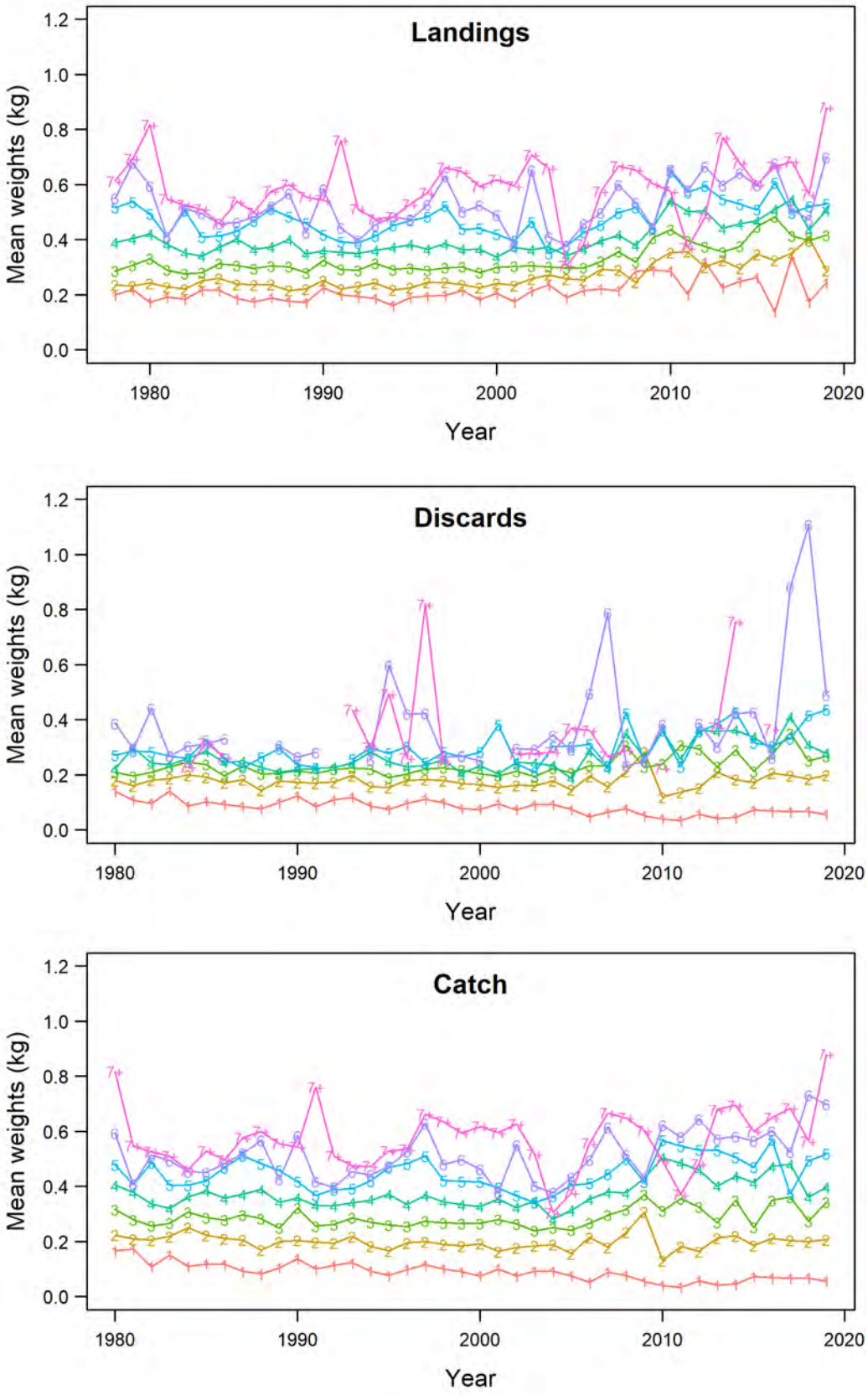


Figure 11. Mean weight-at-age in the landings, discards and catch.

WD 5.2 – New combined Q4 index for whiting in Division 6.a

Andrzej Jaworski and Helen Dobby, Marine Scotland – Science

January 2021

Introduction

The assessment of whiting in Division 6.a is carried out annually with catch and survey data (ICES, 2020a). Five research vessel survey series for whiting in 6.a were used in the previously accepted (2012–2019) category 1 stock assessment for whiting in 6.a. These included two 'old' Scottish surveys (ScoGFS-WIBTS-Q1 and ScoGFS-WIBTS-Q4), which were discontinued at the end of 2010 and three surveys which are currently in operation in the assessment area. The three current surveys are: two 'new' (2011 onwards) Scottish surveys (UK-SCOWCGFS-Q1 and UK-SCOWCGFS-Q4) and one Irish survey (IGFS-WIBTS-Q4).

Given the similarities in gear and timing of the two current Q4 surveys and that the Irish survey only covers the southern portion of the stock (Figure 1), IBPWS-Round 2015 considered using a combined index for the two surveys (ICES, 2015). Ultimately, the five separate indices were used in the following years for the assessment of the stock. The work on combining the two indices continued within WGISDAA in 2018–2020 (ICES, 2018) with a GAM modelling approach to derive Scottish/Irish 'adjustment' factors which were applied to the survey data before calculating a single survey index. At WKDEM 2020, it was agreed to use a combined Q4 index in the SPiCT assessment (ICES, 2020b). This index was also used by WGCSE in 2020. Following suggestions made at WGISDAA 2020, some minor modifications were made to the approach (for combining the two indices). WKDEM 2020 also recommended exploring other assessment approaches with the inclusion of this combined Scottish-Irish Q4 index which covers the full stock area (ICES, 2020b).

During the WKNSEA data compilation meeting, there was substantial discussion regarding statistical modelling of survey data across all stocks under review. It was suggested that for whiting, a statistical modelling approach using all Q4 survey data may represent a more useful and straightforward way to derive a single Q4 index. Including not only the current surveys series (the Scottish and Irish), but also the old Scottish Q4 survey series would provide a longer continuous survey index which would potentially be more useful (than multiple shorter indices) in the stock assessment. The method for deriving the new combined index follows the approach used in the assessment of herring in the North Sea and West of Scotland (ICES, 2019) and that used for the assessment of cod in the North Sea (Berg *et al.*, 2014).

This working document first describes the survey series that are available for the assessment of the whiting stock in Division 6.a. Subsequently, it presents the analysis of the Scottish and Irish Q4 surveys and provides diagnostics for combining them into one tuning series. The delivered index is intended to potentially be used, along with the Q1 indices, in annual assessments of the whiting stock.

Surveys

The following section gives an overview of the surveys (including Q1) conducted.in Division 6.a and a summary of available data.

The two 'old' Scottish surveys:

- Scottish first-quarter west coast groundfish survey (ScoGFS-WIBTS-Q1): all ages 1 and older, years 1985–2010;
- Scottish fourth-quarter west coast groundfish survey (ScoGFS-WIBTS-Q4): all ages including age 0, years 1996–2009.

were performed using a fixed station format with the GOV survey trawl together with the west coast groundgear rig 'C'. The Q4 survey was not carried out in 2010 due to an engine breakdown of the research vessel.

The indices for the above two surveys are shown in Tables 1–2.

The Irish Groundfish Survey has partly been conducted in Division 6.a:

- Irish fourth-quarter west coast groundfish survey (IGFS-WIBTS-Q4): all ages including age 0, years 2003–2019.

The Irish survey uses the RV Celtic Explorer and is part of the IBTS coordinated western waters surveys. The vessel uses a GOV trawl, and the design is a depth-stratified survey with randomised stations. This time-series has previously been considered long enough to be used in the assessment of whiting in Division 6.a, giving useful additional indications of year-class strength. The indices in the Irish survey were provided by the Marine Institute in Ireland (Table 3).

In 2011, the Q1 and Q4 Scottish Groundfish Surveys were re-designed. 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 not considered a sufficiently accurate method for surveying the division. Therefore, it was decided to develop a new survey design – stratified random sampling. This coincided with a change in the groundgear ('D' replacing 'C'), allowing for trawling on rougher ground, and also aimed at increasing the comparability between Scottish and Irish surveys that would facilitate both being used to assess gadoids west of Scotland. The introduction of the new design initiated two 'new' time-series:

- Scottish first-quarter west coast groundfish survey (UK-SCOWCGFS-Q1): all ages 1 and older, years 2011–2020;
- Scottish fourth-quarter west coast groundfish survey (UK-SCOWCGFS-Q4): all ages including age 0, years 2011–2019.

The Q4 survey in 2013 was not fully implemented due to adverse weather conditions – it covered only the northern half of Division 6.a and therefore the index for that year was not used in assessments prior to 2020. Ten years of data are currently available in the time-series for the Q1 survey and eight years of data for the Q4 survey (as valid indices).

The indices for these two surveys are provided with an estimate of variance in Tables 4–5.

In the index calculation for the Scottish surveys, numbers at length (the length frequencies, LF) per haul are standardised to numbers per hour towing. In the old surveys, all otoliths from all hauls in a given demersal sampling area were combined to create an age length key (ALK) for that area (Holmes, 2008). With the new survey design, all otoliths taken within each of the strata are combined to form an ALK. This ALK is applied to all LFs in the stratum individually to produce age frequencies for each haul. Then, for each stratum, the age

frequencies are summed and the values divided by the number of valid hauls to provide numbers at age per hour. For each age, the age frequency for each stratum is raised by the stratum area. These raised frequencies are then summed and the result divided by the total area in the assessment region (ICES, 2017).

Combined Scottish and Irish Q4 survey analysis

Data

Data for the analysis carried out here were downloaded from DATRAS for the following three survey series:

1. ScoGFS-WIBTS-Q4 (referred to in DATRAS as SWC-IBTS) for the period 1996–2009;

2. IGFS-WIBTS-Q4 (referred to in DATRAS as IE-IGFS) for the period 2003–2019;

3. UK-SCOWCGFS-Q4 (referred to in DATRAS as SCOWCGFS) for the period 2011–2019.

These data were extracted in the 'Exchange' format, i.e. they were in three segments:

- hydro data (HH records)

- length data (HL records)

- age data (CA records).

The HH records included haul data (such as date, vessel, gear, haul time, tow duration, depth, latitude and longitude). The HL records included fish numbers-at-length. The CA records included ALKs.

The data for the three surveys were combined into one dataset spanning the period 1996–2019. Only hauls in Division 6.a were used in the calculations of the index. During initial exploratory analysis, haul.id information was found to be missing from the period 1996–1999. This results in hauls being allocated a random haul location within the same statistical rectangle to get approximate spatial coordinates. This should only lead to a small error in 'lon' and 'lat' and hence should not have a major impact on model outputs (C. Berg, pers comm,, January 2021).

The same subset of data was used for both estimating the spatial ALKs and for fitting the survey index model. The DATRAS r package (Kristensen and Berg, 2018) was used to subset the data, and fit the ALK model, and the 'surveyIndex' package (Berg, 2016) was used to fit the index models.

Age-length keys

Age-length keys were estimated using the spatially varying continuation ratio logits (CRL) model described in Berg and Kristensen (2012). This approach combines GAMs and CRL to model the probability of age given length and spatial coordinates, and avoids basing the ALKs on any area stratification. The 'fitALK' function in the DATRAS r package (Kristensen and Berg, 2012) was used to estimate an ALK for each haul based on the age data available in the same subset of data described above. The ALKs are estimated for ages 0–7+.

Parameters are estimated separately for each combination of year y in order to account for population structure. The model used is:

$$\text{logit}(\pi_{ay}[\mathbf{x}_i])=\alpha_{ay}+\beta_{ay}l_i+s_{ay}\,(lon_i,lat_i)$$

where π is the conditional probability of a fish being of age a; i denotes the ith fish; l denotes the length of the fish; lon and lat are the geographical coordinates where the haul was taken;

s_a is a 2-dimensional thin plate spline; α_a and β_a are ordinary regression parameters to be estimated. BIC was used for selecting the amount of smoothness imposed on the spline.

Delta-GAM model

Analyses were conducted using a GAM-based delta-lognormal model. The model accounts for nuisance factors caused by changes or differences in experimental conditions and is described in Berg *et al*. (2014). The index calculation is implemented using the 'surveyIndex' R-package (Berg, 2016). This model was found to give a better fit compared to other GAM-based approaches in Berg *et al.* (2014), and have been used to calculate survey indices for herring stocks (North sea: Berg *et al*., 2014, and Baltic Sea: Berg, 2018) and North Sea cod. For this approach zero values are modelled separately and the positive values are assumed to follow a log-normal distribution. The model consists of two parts: one that describes the probability for a non-zero catch (binomial response) and another that describes the distribution of a catch given that it is non-zero (positive continuous). The response in the model is μ_i, numbers at age for haul i or 1/0 for the non-positive part of the model.

The tested model had the following form:

$$g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + f_3(time_i) + Gear_i + \mathrm{U}(Ship_i) + \log(HaulDur_i)$$

In the above model, $Year_i$ maps the ith haul to a categorical effect for each year. The function $f_1(lon_i, lat_i)$ is a two-dimensional thin plate regression spline on the geographical coordinates. The function $f_2(Depth_i)$ is a one-dimensional thin plate spline for the effect of bottom depth. The function $f_3(time_i)$ is a cyclic cubic regression spline on the time of day. An offset was used for the effects of haul duration, and is equivalent to saying that catch is proportional to haul duration. The function g is the link function, which is taken to be the logit function for the binomial model. The lognormal part of the model is fitted by log-transforming the response and using the Gaussian distribution with a unit link.

Exploratory model runs that preceded the main analysis revealed that the effect of time of year (survey timing) was negligible and was consequently omitted from the model.

Initial model runs included a survey categorical variable instead of gear and ship effects, however fitted models had a high number of estimated degrees of freedom and the 0-group indices were estimated with very high uncertainty. The use of a 'survey' effect was therefore not pursued further. Within DATRAS, all records within the 'gear' field for the three surveys included in this analysis are GOV. However, as described above, there have been modifications to the ground gear used with the GOV between the two Scottish surveys. In order to allow the model to potentially account for these changes, gear was set to 'GOVC' for SWC-IBTS and to 'GOVD' for the SCOWCGFS and IE-GFS.

A number of models with different subsets of explanatory variables (see below) were fitted to the data and compared with the best model being chosen on the basis of AIC over all ages/models combined.

Model 1: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + f_3(time_i) + Gear_i + \mathrm{U}(Ship_i) + \log(HaulDur_i)$

Model 2: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + f_3(time_i) + \mathrm{U}(Ship_i) + \log(HaulDur_i)$

Model 3: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + f_3(time_i) + \log(HaulDur_i)$

Model 4: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_2(Depth_i) + \mathrm{U}(Ship_i) + \log(HaulDur_i)$

Model 5: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + f_3(time_i) + \mathrm{U}(Ship_i) + \log(HaulDur_i)$

Model 6: $g(\mu_i) = Year_i + f_1(lon_i, lat_i) + \mathrm{U}(Ship_i) + \log(HaulDur_i)$

Each age group in the given model is estimated separately. The abundance estimates are obtained by first dividing the survey area into small subareas of approximately equal size. For each subarea, where at least one haul was taken, one representative haul position is selected (thereby leaving unsampled sub-areas out of the analysis), this process is included in the model by using the function 'getGrid' from the 'surveyIndex' package (Berg, 2016). The expected catches are summed for each year and age. These values are then divided by the number of grid points and multiplied by two to obtain the survey index in numbers per hour.

The model settings were chosen with reference to previous implementations (Berg *et al.*, 2014; ICES, 2019). The 'cutOff' was set as 0.1 (see Berg, 2016). All values below 'cutOff' were treated as zero. This is required because the length to age conversion may produce numbers that are very close to zero, which is problematic for the log-normal distribution.

Results

Model 2 which included year, geographical location, depth, time of day and haul duration was found to be the best choice for the stock in Q4, based on AIC, BIC and mean internal consistency (Table 6). The indices were derived by summing predictions from the selected model and are shown in Figure 2. It can be seen that the 2009 and 2014 year-classes were consistently strong with a detectable peak. The confidence intervals were relatively narrow in the time-series.

The effect of the explanatory variables on the model estimates can be seen in Figures 3 and 4. There was some age-specific variability in the spatial distribution (Figure 3). The 0-group were found in high concentrations along the coast and in the Clyde. Older age groups were more widely distributed with high densities in some locations. Depth was of little importance for whiting at age 0–1, while for ages 2–5, the catch rates increased with depth up to a maximum and decreased thereafter at greater depths (Figure 4). The oldest fish (at age 6 and 7+) showed preference for relatively deeper waters. Although, the effect of time of day was less influential compared to haul location and depth, it was well marked for ages 2–5 with a minimum during the day.

A residual analysis of the model showed no serious deficiencies (Figure 5). The combined index is shown in Table 7.

Maps of whiting distribution in Division 6.a (Figure 6) were obtained by predicting abundance on a grid of haul positions while indices were obtained by summing model predictions over the relevant parts of the grid, where nuisance parts of the model, such as survey, depth, time of day and haul duration, were held constant to remove their effect.

Index diagnostics

The index diagnostics that follow demonstrate the level of between and within-survey consistency for the six tuning series: ScoGFS-WIBTS-Q1, ScoGFS-WIBTS-Q4, IGFS-WIBTS-Q4, UK-SCOWCGFS-Q1, UK-SCOWCGFS-Q4 and Comb-WCGFS-Q4.

Figure 7 compares the calculated scaled indices. For the 0-group, the index was similar for the survey series involved, regardless of the area being surveyed. For older fish, there was less consistency among the surveys. However, some year effect could be discerned on catch rates with distinct peaks and valleys in the respective surveys.

The mean standardised catch proportions at age per year show some similarities among the six tuning series for the year-classes and years where the series overlap (Figure 8). The plots indicate strong year classes (2009 and 2014 year-classes), but also markedly weak year classes

(2012 and 2017 year-classes). In most cases, year class tracking were reasonably consistent. A clear year effect can be seen for ages 1+ in 2007 and 2008.

The log catch curves for the six tuning series are shown in Figure 9. The curves for the two Scottish surveys are relatively linear and not very noisy. They show a fairly steep and consistent drop in abundance. In the Irish survey, the patterns are less clear with a strong 'hook' in most cases. The combined index performs well for the most part. In the recent period, it performs considerably better compared to the single surveys.

The within-survey correlation plots in Figure 10 indicate that the surveys generally show significant correlation between consecutive age groups. For the six tuning series, there is a general consistency in the estimates of year-class strength across age groups, but the points are more scattered for old age groups. For the Scottish Q1 and combined Q4 series, the index values show the highest consistency.

Discussion

The present analysis of the whole Q4 data set results in a combined index which appears both relatively internally consistent. It also shows some consistency with the Q1 surveys. While the previous analyses conducted by WGISDAA (ICES, 2018) and WKDEM (ICES, 2020b) aimed at combining two currently run Q4 surveys (Scottish and Irish) on the West Coast, the analysis went one step further and delivered an index for three surveys, two Scottish surveys and one Irish survey.

In the previous analyses, the catch rates in the Irish survey were found higher, particularly for the young age groups. The reason for this discrepancy remains unclear, but it can potentially be subject to further investigation. While the observed differences were previously considered to result from the different survey timing (IBPWSRound; ICES, 2015), this effect could not be ascertained with the present analysis. Therefore, the effect was ultimately omitted from the current model.

There are several advantages of using a combined index for assessments of fish stocks. In this particular case, the combined provides a more complete representation of the population compared to the respective indices used on their own. This is supported by the diagnostics shown for the different survey series, with the combined index appearing less noisy and with better internal consistency than the individual Q4 indices. The combined index simplifies, to some extent, the modelling procedure in the annual assessments of the stock (with potentially three rather than five indices in the following years). Furthermore, it is possible to create a combined index in years with only partial survey coverage by one of the two surveys (as it was the case in 2013).

In conclusion, three survey series can potentially be used in the assessment of whiting in 6a. They cover a sufficiently long time period. The indices can be recalculated annually as new surveys are completed providing up to date fisheries independent information on the stock.

References

Berg, C. W., 2016. surveyIndex: Calculate survey indices by age from DATRAS exchange data.R package version 1.0.

Berg, C. W., 2018. Survey Index Calculations for Western Baltic Spring Spawning Herring from IBTS and BITS data.

Berg, C. W. and Kristensen, K., 2012. Spatial age-length key modelling using continuation ratio logits. Fish-eries Research 123-130, 119-126.

Berg, C. W., Nielsen, A., and Kristensen, K., 2014. Evaluation of alternative age-based methods for estimat-ing relative abundance from survey data in relation to assessment models. Fisheries Research 151, 91–99.

Holmes, S. J. 2008. ROAME MF0170: Alternative Survey Index Estimation. FRS Production of Scottish West Coast Survey Indices. Fisheries Research Services Internal Report No 10/08.

ICES. 2015. Report of the Inter-Benchmark Protocol of West of Scotland Roundfish (IBPWSRound), February–April 2015, By correspondence. ICES CM 2015/ACOM:37. 72 pp.

ICES. 2017. Manual of the IBTS North Eastern Atlantic Surveys. Series of ICES Survey Protocols SISP 15. 92 pp. http://doi.org/10.17895/ices.pub.3519

ICES. 2018. Report of the Working group on improving use of Survey Data for Assessment and Advice (WGISDAA). 3–5 July 2018. Copenhagen, Denmark. ICES CM 2018/EOSG: 15. 30 pp.

ICES. 2019. Interbenchmark Protocol for Herring in 6.a, 7.b-c 2019 (IBPher6a7bc). ICES Scientific Reports. 1:19. 74 pp. http://doi.org/10.17895/ices.pub.5261

ICES. 2020a. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. 924 pp. http://doi.org/10.17895/ices.pub.5978

ICES. 2020b. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

Kristensen, K. and Berg, C. W., 2018. DATRAS: Read and convert raw data obtained from http://datras.ices.dk/Data_products/Download/Download_Data_public.aspx. R package version 1.01.

Table 1. The abundance index with variance in the 'old' Scottish Q1 survey. The numbers are standardised to catch-rate per ten hours.

ScoGFS-WIBTS-Q1 – numbers									
Year	**Effort**	**Age**							
	(hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1985	10	0	3140.0	1792.0	380.0	85.0	23.0	156.0	18.0
1986	10	0	1456.0	1525.5	403.2	68.2	10.0	9.2	10.0
1987	10	0	6937.8	1054.4	583.5	142.4	36.0	1.9	1.4
1988	10	0	567.5	3468.9	653.6	189.3	42.0	5.3	1.3
1989	10	0	910.0	505.0	586.0	237.0	48.0	3.0	0.0
1990	10	0	1817.8	571.3	121.9	215.7	60.6	3.9	0.6
1991	10	0	3203.2	276.4	298.7	22.1	39.4	8.5	1.3
1992	10	0	4777.0	1597.0	410.0	517.0	56.0	18.0	0.0
1993	10	0	5531.9	6829.1	644.0	91.3	30.3	11.0	1.7
1994	10	0	6614.3	2443.0	1486.7	174.5	55.9	14.8	5.9
1995	10	0	5597.9	2830.6	1160.2	370.0	70.4	16.9	32.1
1996	10	0	9385.4	2236.6	635.3	341.0	135.1	29.9	4.4
1997	10	0	5662.5	2443.9	1530.8	354.8	101.7	17.5	4.0
1998	10	0	9850.6	1351.6	294.3	195.5	49.6	13.9	1.3
1999	10	0	6125.0	4952.1	489.1	102.6	16.1	0.9	0.4
2000	10	0	12862.2	470.7	152.0	33.9	10.0	11.4	0.0
2001	10	0	4653.1	1954.6	242.4	41.0	7.8	0.6	0.9
2002	10	0	5542.0	1028.0	964.1	88.5	15.2	1.1	1.1
2003	10	0	6934.0	746.0	436.0	300.0	32.0	2.0	4.0
2004	10	0	5887.2	1566.2	188.9	131.3	44.5	8.9	1.3
2005	10	0	1308.5	722.7	183.1	35.2	8.2	11.3	1.6
2006	10	0	1440.8	465.8	282.1	76.6	0.3	3.0	0.6
2007	10	0	614.0	522.0	127.4	75.3	16.1	3.4	2.2
2008	10	0	592.8	127.4	77.1	26.2	7.6	2.7	0.0
2009	10	0	905.8	387.0	102.9	105.2	20.0	8.8	6.9
2010	10	0	3523.4	339.8	108.4	51.7	40.3	3.9	3.2

Table 2. The abundance index with variance in the 'old'Scottish Q4 survey. The numbers are standardised to catch-rate per ten hours.

ScoGFS-WIBTS-Q4 – numbers									
Year	Effort	Age							
	(hours)	0	1	2	3	4	5	6	7
1996	10	5154.0	1908.0	1116.0	570.0	188.0	51.0	6.0	1.0
1997	10	8001.0	2869.0	951.0	323.0	160.0	46.0	12.0	1.0
1998	10	1852.4	2713.3	1124.6	149.9	99.5	20.3	1.0	0.0
1999	10	8203.0	2338.0	582.0	141.0	33.0	24.0	1.0	1.0
2000	10	4434.1	4055.6	788.8	160.1	9.4	6.7	1.3	0.0
2001	10	9615.0	1957.0	1420.0	155.0	40.0	12.0	2.0	0.0
2002	10	14657.5	1590.6	620.9	479.0	30.2	9.1	4.8	0.0
2003	10	9932.0	3446.0	567.0	338.0	83.0	27.0	4.0	0.0
2004	10	5923.0	1758.0	940.0	83.0	57.0	62.0	1.0	0.0
2005	10	2296.9	307.6	317.5	76.1	8.8	4.4	0.9	0.7
2006	10	415.1	295.9	139.7	100.6	34.9	8.0	2.7	0.5
2007	10	1893.8	433.9	326.2	99.5	82.6	48.1	0.6	0.0
2008	10	2296.7	207.5	77.6	109.7	28.1	24.2	4.1	0.0
2009	10	4832.5	236.2	177.9	49.8	57.8	12.0	5.6	6.4

Table 3. The abundance index in the Irish survey. The numbers are standardised to catch-rate per ten hours. For modelling purposes, the series was truncated to cover only the years 2003–2010.

IGFS-WIBTS-Q4 – numbers									
Year	Effort	Age							
	(hours)	0	1	2	3	4	5	6	7
2003	10	586.2	6860.3	1540.7	272.6	154.4	54.3	0.5	NA
2004	10	3462.0	1557.0	656.0	52.0	17.5	8.0	0.5	NA
2005	10	568.8	1392.5	703.8	56.9	3.1	2.5	0.0	NA
2006	10	39.3	419.2	366.0	85.0	10.7	1.2	0.0	NA
2007	10	70.3	1017.6	1217.3	369.3	86.7	128.6	62.2	NA
2008	10	12.7	2295.1	701.8	303.1	128.2	64.9	19.2	NA
2009	10	7361.3	622.8	430.7	141.5	29.4	9.0	17.9	NA
2010	10	50.2	4565.1	701.8	177.5	56.2	30.0	7.2	NA
2011	10	211.3	2074.2	2816.7	318.5	135.4	31.6	33.1	NA
2012	10	128.6	3226.4	499.0	969.7	276.5	24.0	10.7	NA
2013	10	11246.9	494.0	1865.5	497.7	554.6	65.1	5.6	NA
2014	10	14934.4	7929.8	1299.7	2618.4	299.6	355.6	30.0	NA
2015	10	1862.2	15266.8	3237.3	794.1	400.3	80.7	53.7	NA
2016	10	6403.9	5918.2	8839.7	1386.6	234.3	290.4	91.5	NA
2017	10	251.5	1968.5	1413.7	1873.5	331.5	38.7	44.7	NA
2018	10	8450.8	2356.5	2860.1	1853.4	712.5	41.8	0.0	NA
2019*	10	NA	NA	NA	NA	NA	NA	NA	NA

* The Irish index has not been updated since 2019.

Table 4. The abundance index with variance in the 'new' Scottish Q1 survey. The numbers are standardised to catch-rate per ten hours.

UK-SCOWCGFS-Q1 – numbers									
Year	**Effort**	**Age**							
	(hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2011	10	0	221.6	1884.5	396.9	64.2	36.7	44.6	11.7
2012	10	0	3440.8	293.2	738.4	72.2	13.8	5.1	6.5
2013	10	0	552.5	1031.3	302.5	463.5	61.4	7.4	3.4
2014	10	0	5804.7	124.6	246.3	110.1	73.9	7.0	0.7
2015	10	0	2544.8	759.7	284.6	259.5	65.2	57.5	8.5
2016	10	0	3226.0	3485.1	576.0	148.1	83.8	42.4	25.3
2017	10	0	4970.5	1981.1	1706.7	203.3	48.6	32.2	5.0
2018	10	0	1960.1	1826.9	1069.0	1141.5	132.3	13.6	1.6
2019	10	0	3230.9	666.0	577.3	190.9	99.2	24.7	0.0
2020	10	0	3795.5	2263.2	711.4	571.7	177.9	110.1	27.1

UK-SCOWCGFS-Q1-– variance									
Year	**Effort**	**Age**							
	(hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2011	10	0	6431.4	150861.5	5654.1	209.1	80.3	132.5	10.8
2012	10	0	600264.2	8104.4	18380.5	184.4	8.8	1.7	3.2
2013	10	0	62915.2	46671.6	5055.7	15023.4	443.1	7.0	1.1
2014	10	0	2230995.5	555.6	2133.1	657.0	332.7	2.2	0.3
2015	10	0	144266.1	46201.7	8598.7	4562.5	304.7	351.7	10.5
2016	10	0	397138.2	1880447.5	28775.8	690.9	259.8	95.3	47.9
2017	10	0	2335667.4	309372.8	227965.6	2958.3	171.6	99.0	3.3
2018	10	0	763992.2	330294.5	91345.8	108989.6	2137.9	69.5	0.4
2019	10	0	345197.0	29689.2	21446.9	1785.7	535.7	29.8	0.0
2020	10	0	1369852.5	699829.7	68242.2	27212.7	3694.3	1736.2	415.0

Table 5. The abundance index with variance in the 'new' Scottish Q4 survey. The numbers are standardised to catch-rate per ten hours.

UK-SCOWCGFS-Q4 – numbers									
Year	**Effort**	**Age**							
	(hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2011	10	3644.3	119.5	2095.8	109.2	30.0	13.8	9.6	0.7
2012	10	748.4	964.0	426.1	657.7	110.2	19.3	1.6	11.1
2013	10	NA	NA	NA	NA	NA	NA	NA	NA
2014	10	11569.4	1517.8	345.7	167.7	81.5	55.1	31.4	0.0
2015	10	4263.1	2793.6	727.1	114.9	90.8	20.2	27.1	1.2
2016	10	5262.3	2415.4	2300.2	259.4	83.2	115.4	29.2	13.2
2017	10	3306.2	2942.9	4138.7	1166.5	176.6	2.1	11.8	2.4
2018	10	6441.8	502.5	551.6	284.4	220.1	32.9	1.0	4.9
2019	10	7443.8	1955.3	271.6	305.5	42.6	33.9	4.9	1.0

UK-SCOWCGFS-Q4-– variance									
Year	**Effort**	**Age**							
	(hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2011	10	708399.4	1207.2	453242.9	1175.3	70.2	10.3	9.7	0.2
2012	10	6234.7	70422.2	9634.7	39648.7	1890.6	97.2	0.4	42.2
2013	10	NA	NA	NA	NA	NA	NA	NA	NA
2014	10	9659787.6	245781.4	11183.0	2109.8	610.2	196.6	155.4	0.0
2015	10	864512.1	271198.6	14052.9	398.2	320.4	17.9	24.4	0.3
2016	10	5322471.5	508169.1	564264.7	7532.8	1020.3	1149.2	133.1	61.1
2017	10	1201651.1	701958.3	947272.7	103555.0	5667.6	1.1	23.0	0.8
2018	10	4076427.9	17742.8	35407.4	12700.5	6142.1	120.9	0.3	3.6
2019	10	4337888.2	284404.3	6123.6	11785.3	164.7	141.4	2.4	0.6

Table 6. Summary of models 1–6. The columns 'ΔAIC' and 'ΔBIC' contain the change in AIC and BIC from Model 1The column 'edf' (effective degrees of freedom) contain the effective number of parameters.

	AIC	BIC	edfs	ΔAIC	ΔBIC	Mean internal consistency
Model 1	75536.6	81777.6	812.9	979.6	709.9	0.733
Model 2	75524.5	81651.7	798.0	991.7	835.8	0.729
Model 3	75577.7	81667.2	793.1	938.5	820.2	0.729
Model 4	75616.2	81574.3	776.0	900.0	913.1	0.726
Model 5	76435.7	82487.5	788.2	80.5	0	0.725
Model 6	76516.2	82407.8	767.3	0	79.7	0.723

Table 7. The abundance index with variance in the combined Scottish and Irish Q4 survey. The numbers are standardised to catch-rate.

Comb-WCGFS-Q4 – numbers									
Year		**Age**							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1996	1	8250.8	490.1	111.0	32.0	8.0	3.1	0.5	0.0
1997	1	1952.1	702.6	159.1	32.7	10.1	2.2	0.4	0.1
1998	1	567.3	587.5	188.1	20.2	8.1	2.1	0.4	0.8
1999	1	2111.8	204.2	93.4	13.9	4.3	1.9	0.1	0.3
2000	1	2621.5	979.2	154.3	23.7	1.3	1.0	0.2	0.4
2001	1	285.7	382.5	387.3	28.9	4.5	2.3	0.3	0.1
2002	1	2140.7	265.5	107.5	54.6	3.9	1.0	0.5	0.1
2003	1	588.4	485.8	74.7	32.6	10.5	1.6	0.6	0.3
2004	1	222.3	195.0	73.9	7.4	4.4	3.0	0.1	0.2
2005	1	180.8	65.7	42.5	10.3	1.0	0.4	0.1	0.1
2006	1	142.6	48.9	27.5	12.1	3.3	0.8	0.1	0.0
2007	1	118.8	55.1	37.3	11.0	4.4	2.5	0.3	0.1
2008	1	20.6	41.6	19.3	16.2	4.2	3.1	0.5	0.1
2009	1	1577.1	23.6	17.2	5.3	2.6	0.8	0.4	0.4
2010	1	88.0	328.1	37.8	9.1	2.6	1.1	0.2	0.3
2011	1	472.8	31.9	151.2	19.9	6.9	2.4	1.4	0.4
2012	1	110.9	232.6	49.8	69.3	16.2	2.4	0.7	0.3
2013	1	2416.3	39.9	92.9	28.7	29.9	5.0	0.7	0.1
2014	1	8304.7	242.7	46.7	38.7	10.1	8.1	2.0	0.3
2015	1	891.1	777.2	122.6	28.7	18.8	4.4	2.8	0.2
2016	1	563.9	311.6	295.6	40.3	8.7	10.2	1.6	2.3
2017	1	663.1	161.1	118.3	123.4	19.0	2.7	1.4	0.7
2018	1	3030.0	130.1	94.7	38.6	20.4	2.9	0.1	0.4
2019	1	3060.0	435.2	48.4	22.9	9.5	3.5	0.6	0.1

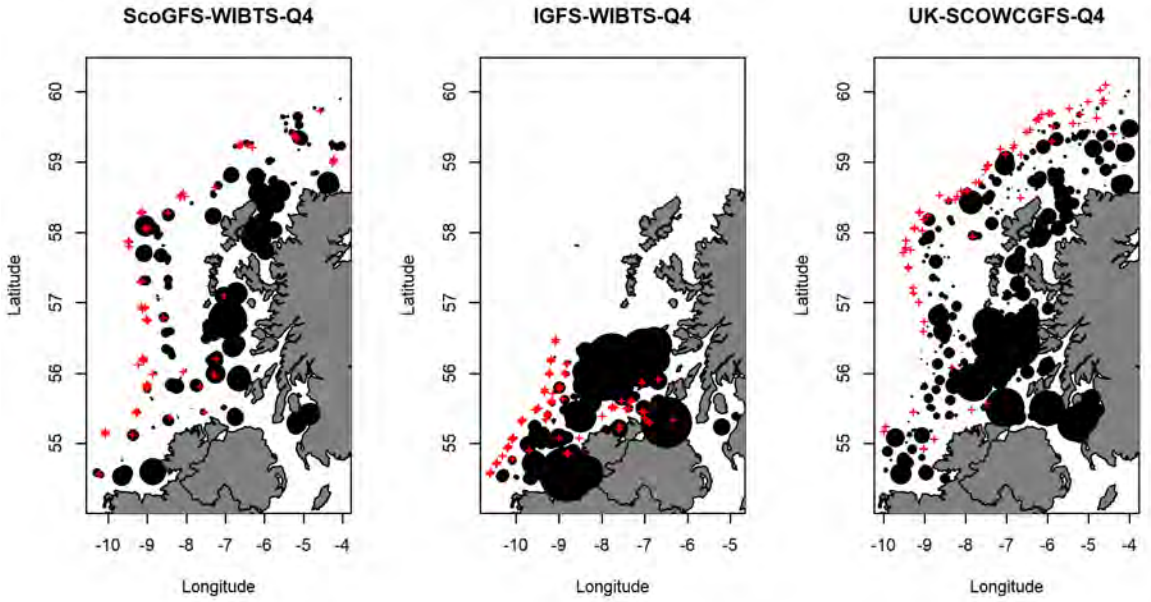


Figure 1. Catch weight per haul in three survey series: ScoGFS-WIBTS-Q4, IGFS-WIBTS-Q4 and UK-SCOWCGFS-Q4. Non-zero catch is shown as black bubbles and zero catch is shown as red crosses.

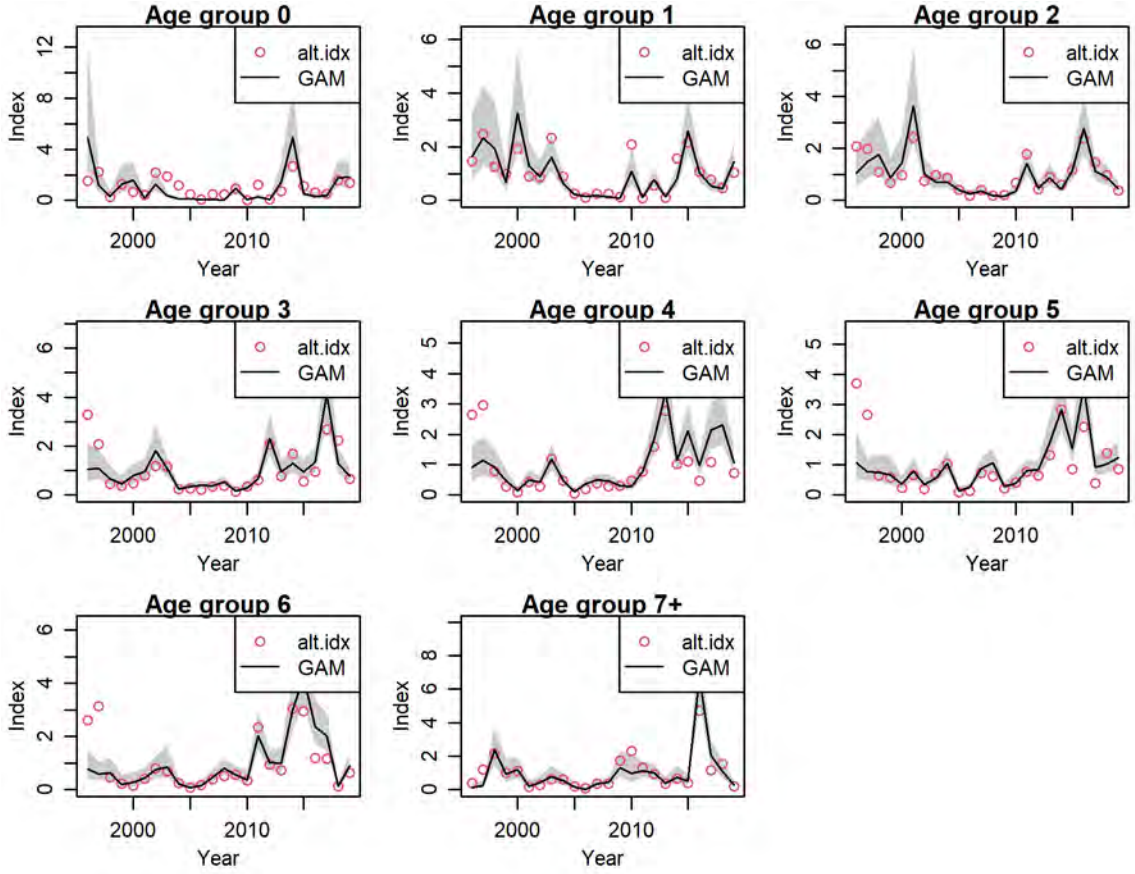


Figure 2. Indices derived from a delta-GAM model fit to data from the three Q4 surveys (black line) with 95% confidence limits (in grey). Indices are derived by summing model predictions on a spatial grid. The survey index calculated using the stratified mean method for ICES statistical rectangles as strata are shown as red points. The indices are mean-standardised.

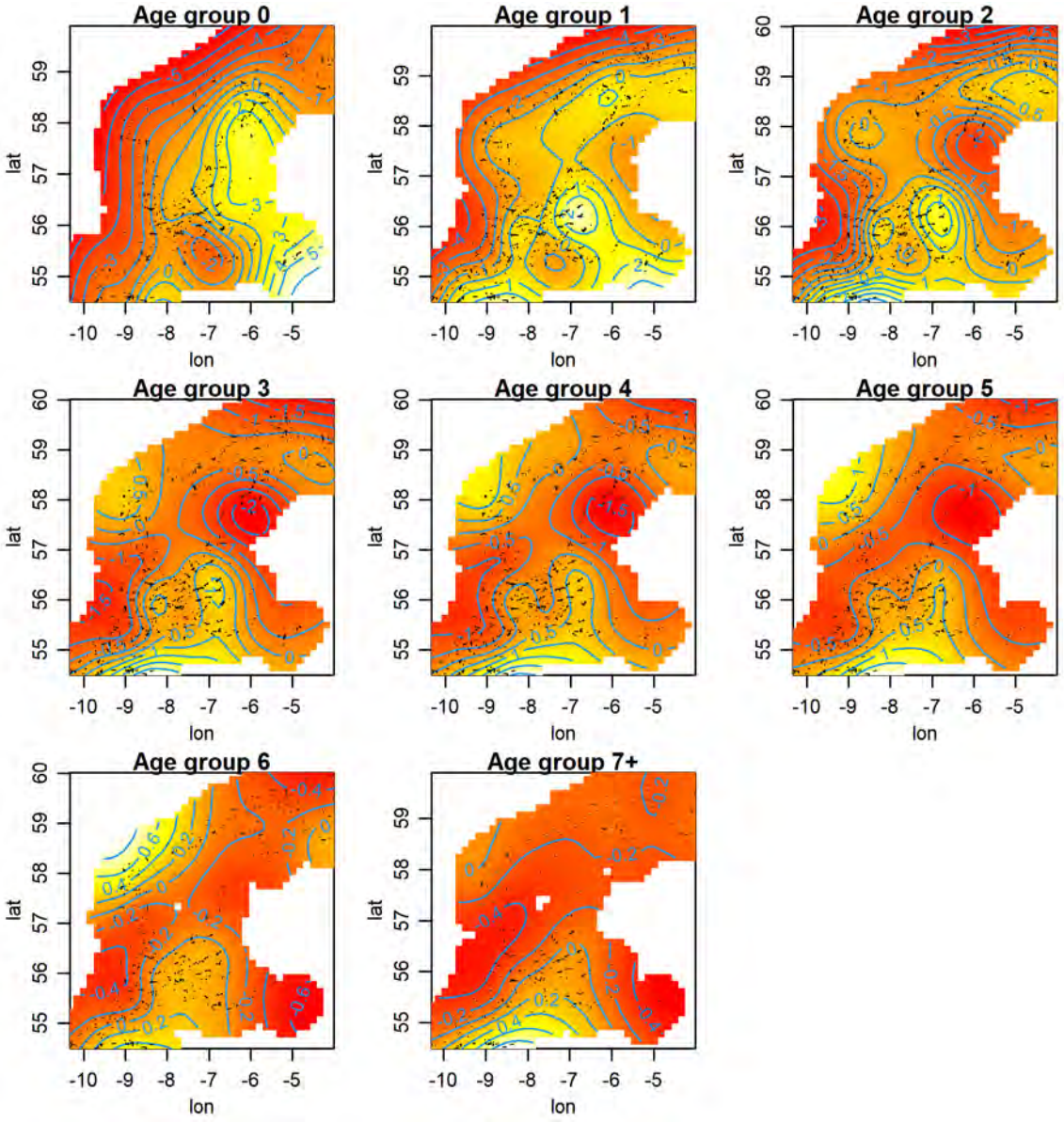


Figure 3. Effect of longitude and latitude by age group on log number per haul. The contours show the estimate of the smooth (red=low values, yellow=high values). The dots show the locations of the covariate values on the longitude-latitude plane. No confidence limits are displayed in this plot.

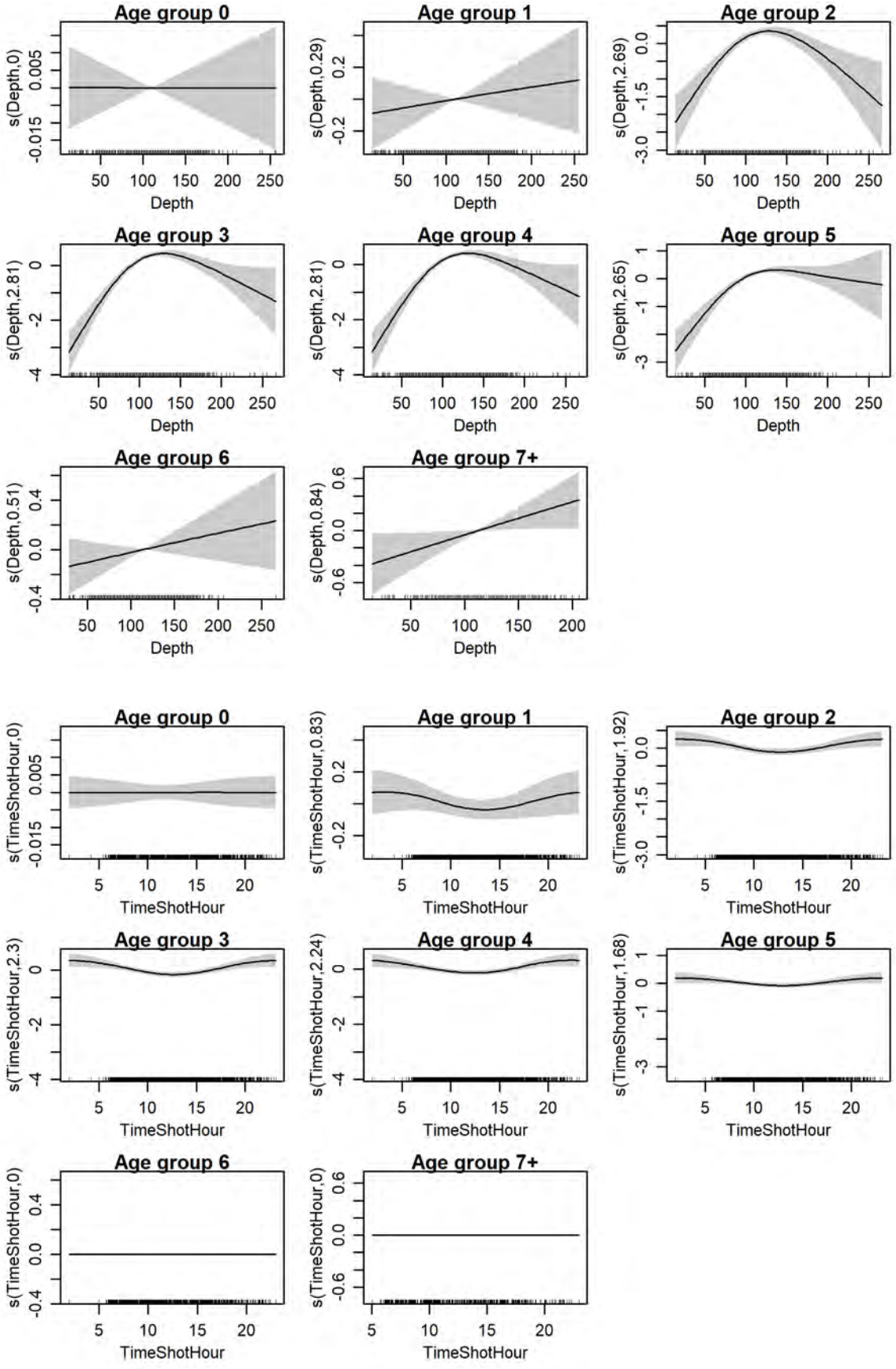


Figure 4. Effect of depth (upper panel) and time of day (lower panel) by age group on log number per (smoothing function). The grey bands are 95% confidence limits.

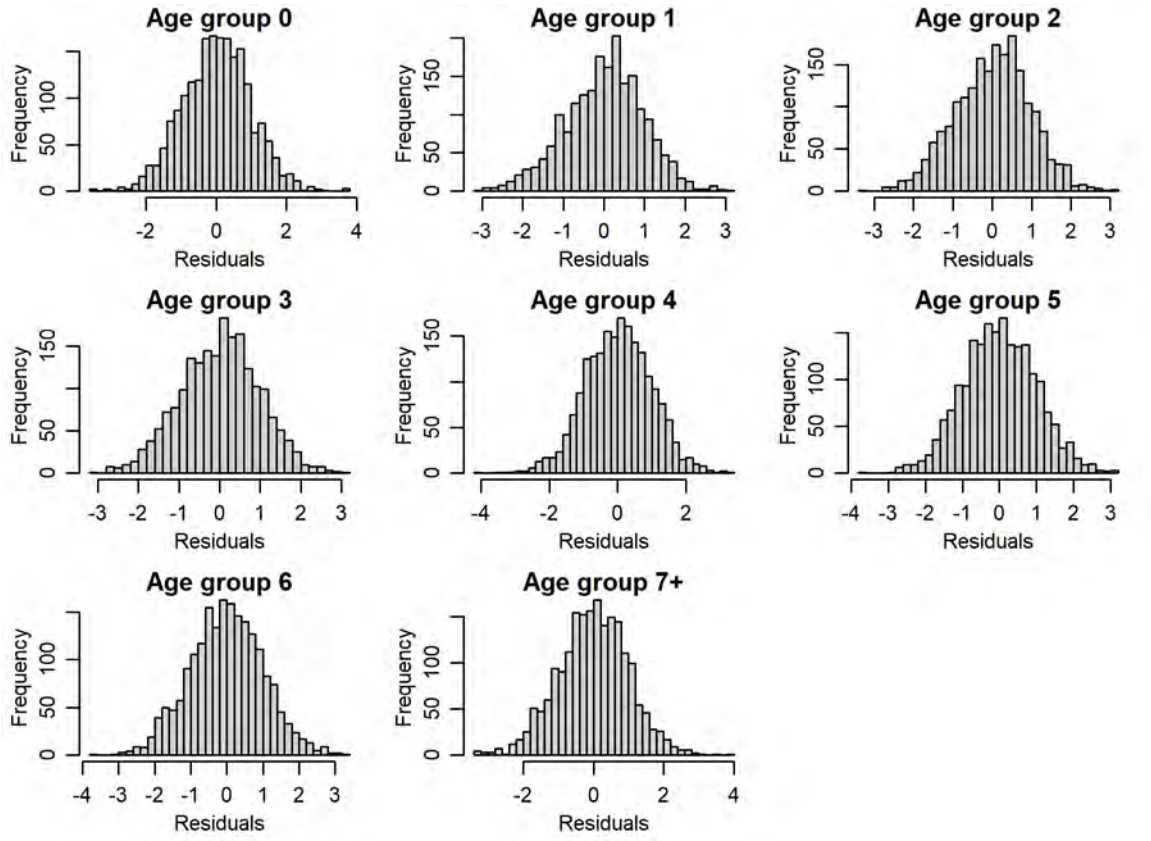


Figure 5. Normalised residuals by age group from fitting the delta-GAM model.

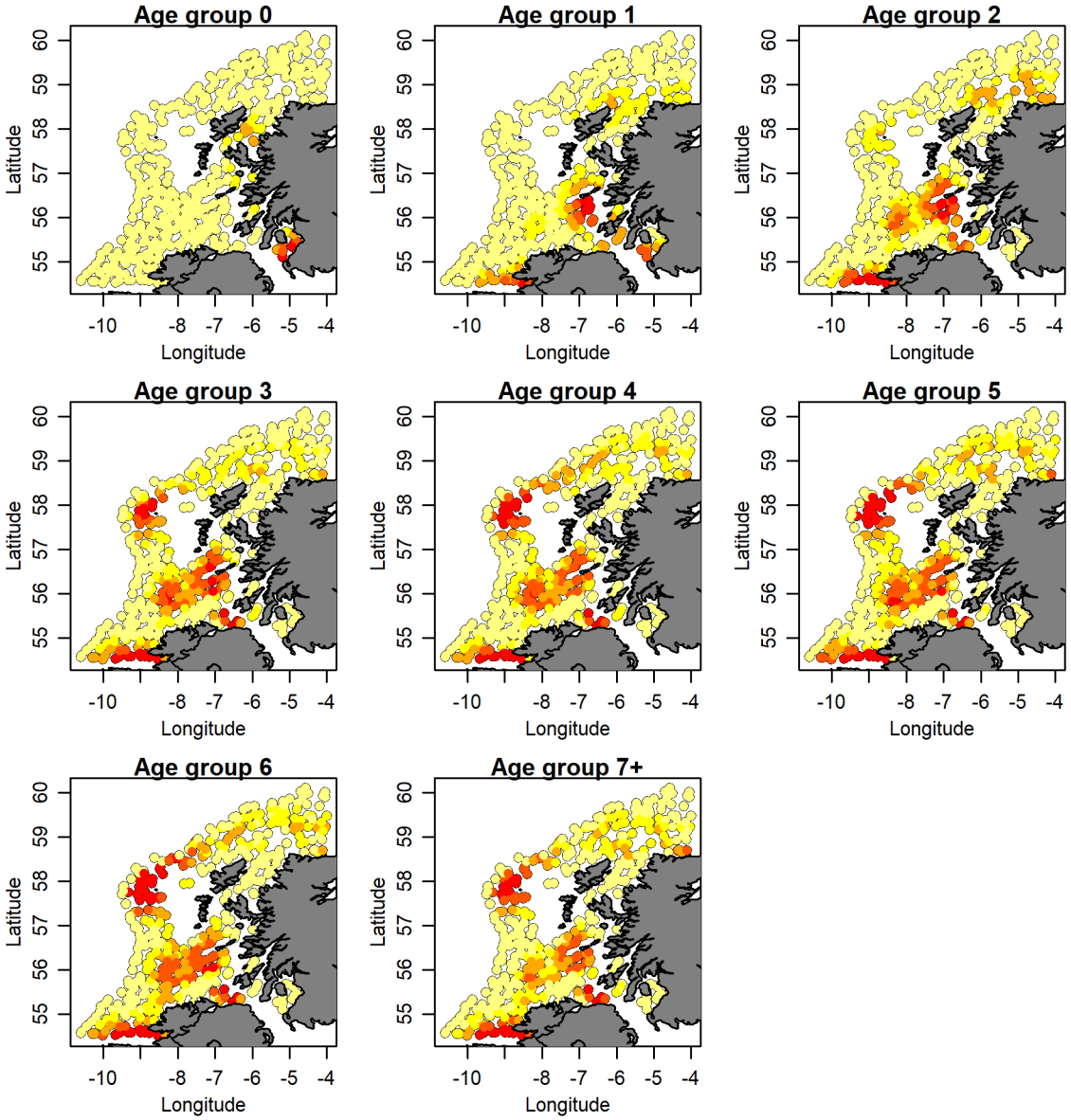


Figure 6. Abundance maps obtained by fitting the delta-GAM model.

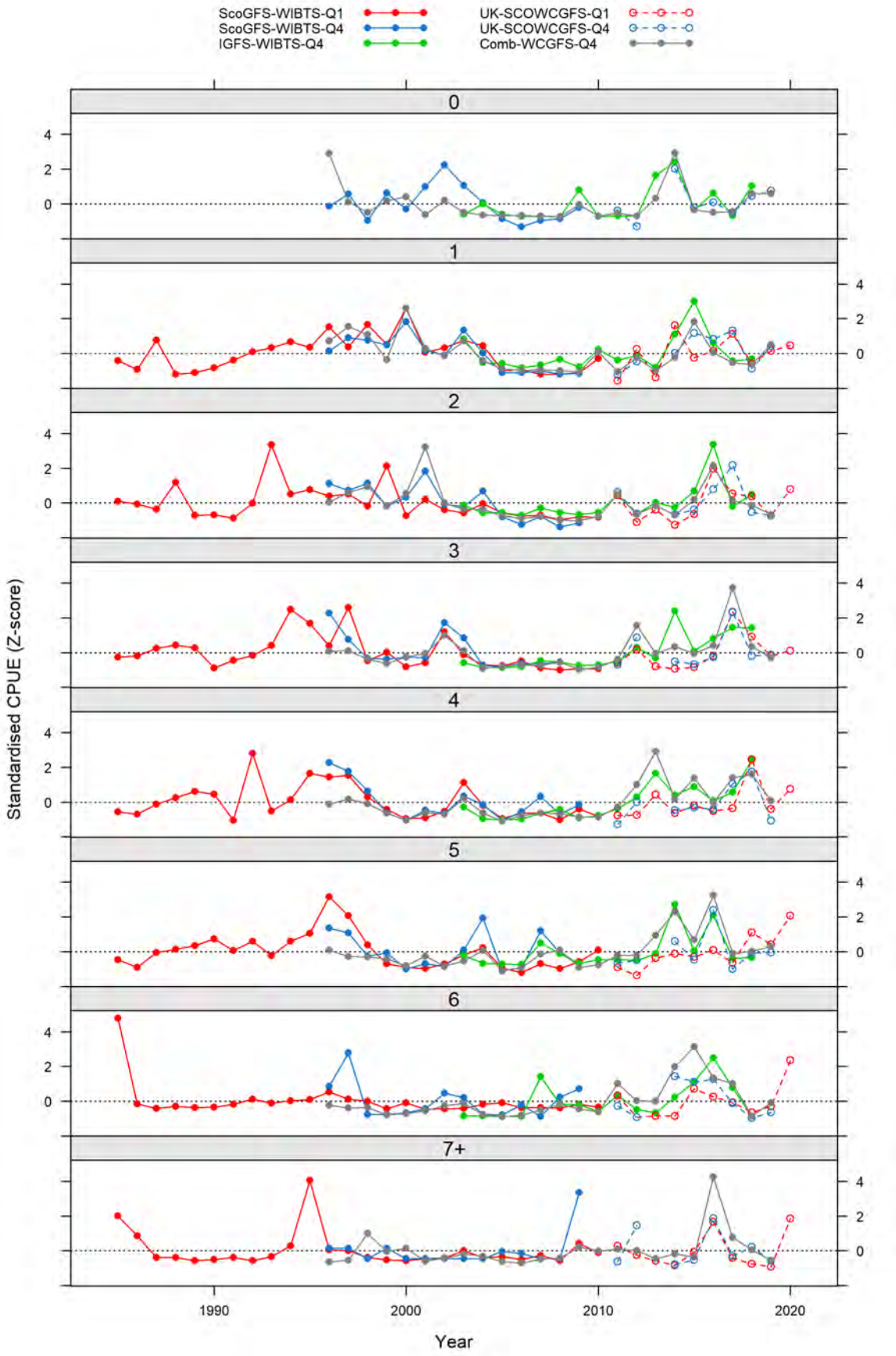


Figure 7. Scaled survey indices (Z-scores) from the six survey series. The abundance index for IGFS-WIBTS-Q4 is shown only for ages 0–6.

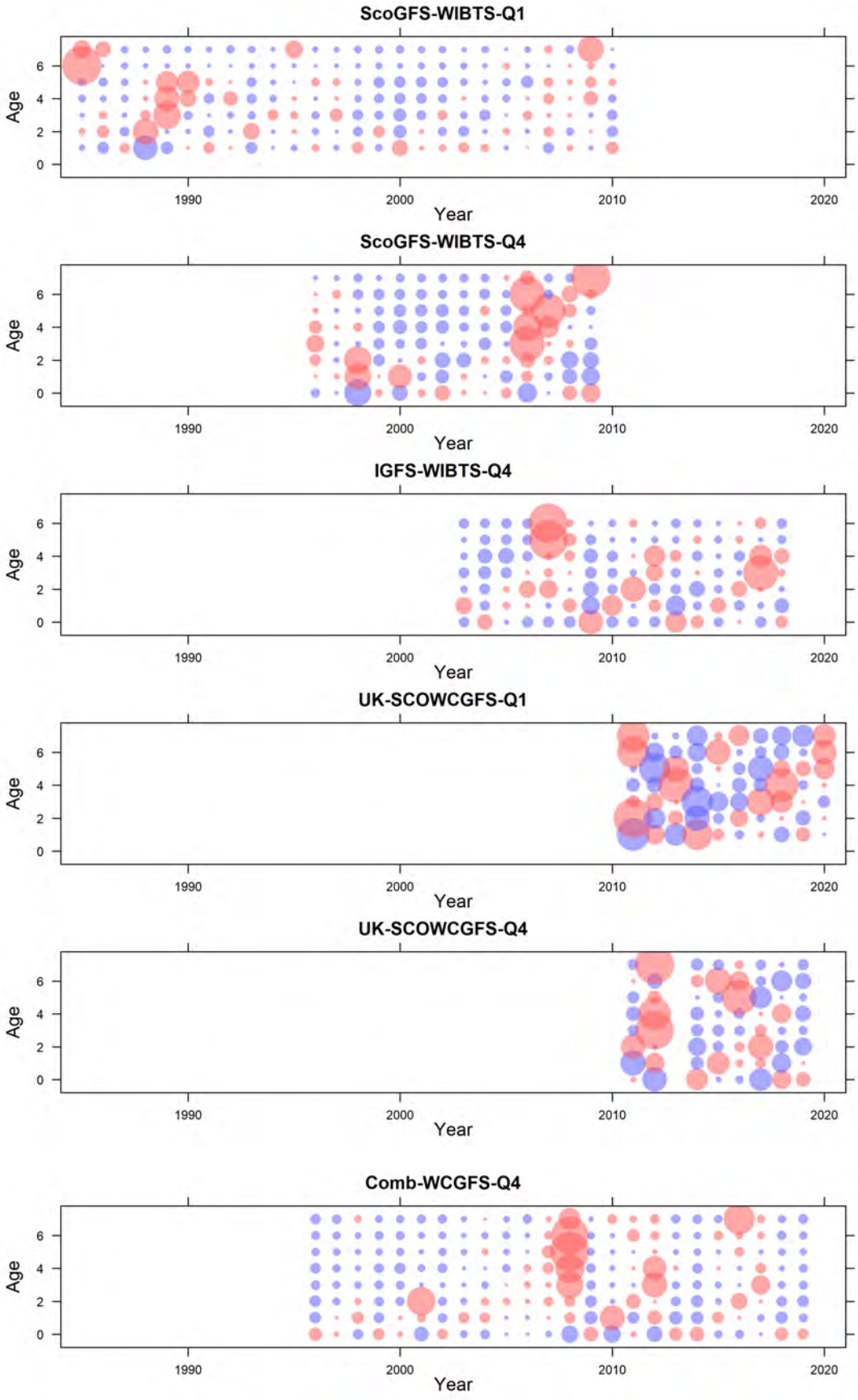


Figure 8. Standardised proportions at age per year ("spay") for the six survey series. The positive values are shown in red, the negative values are shown in blue.

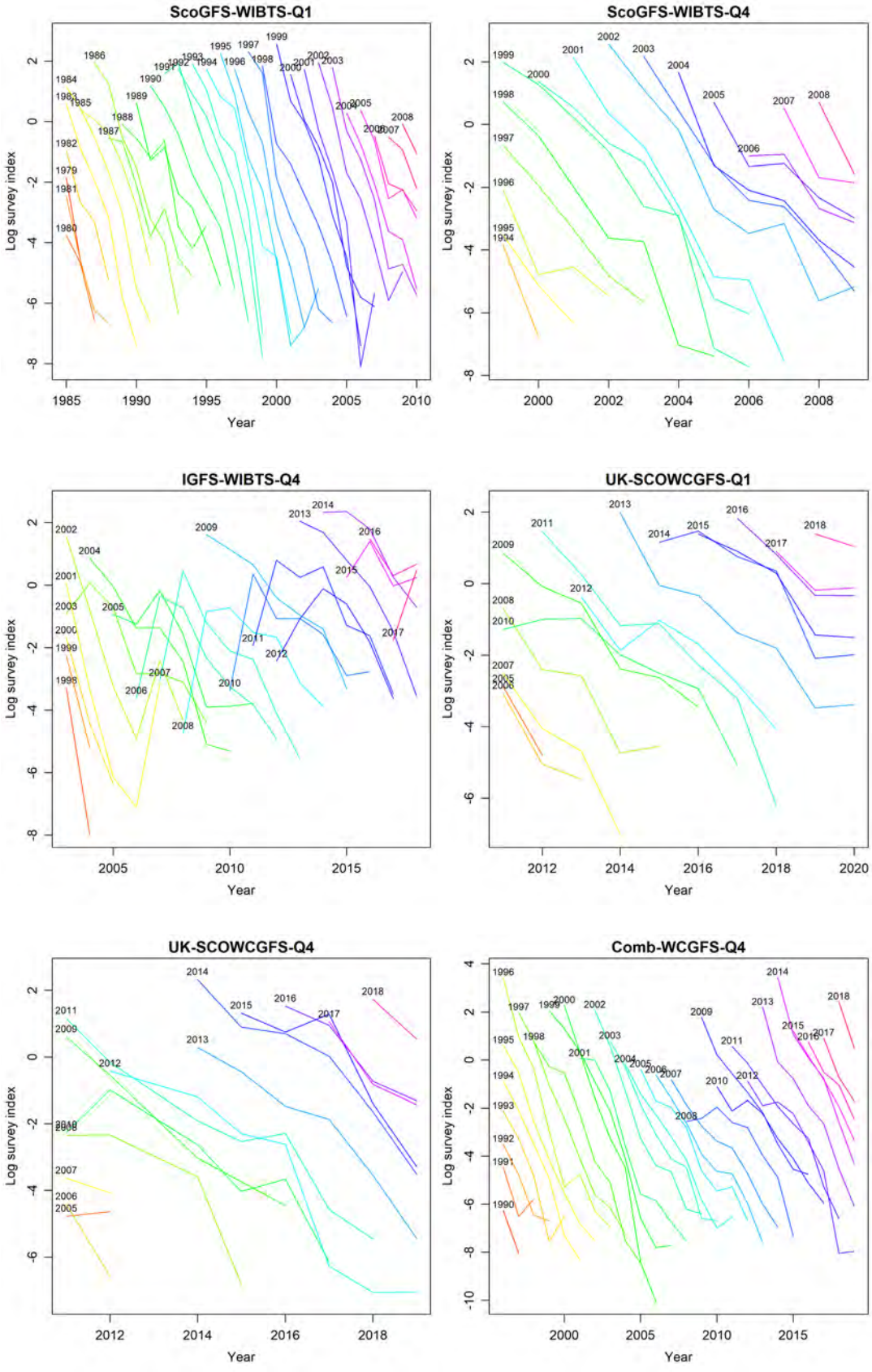


Figure 9. Log abundance indices by year with a line for each cohort, for the six survey series. The spawning date of each cohort is indicated at the start of each line.

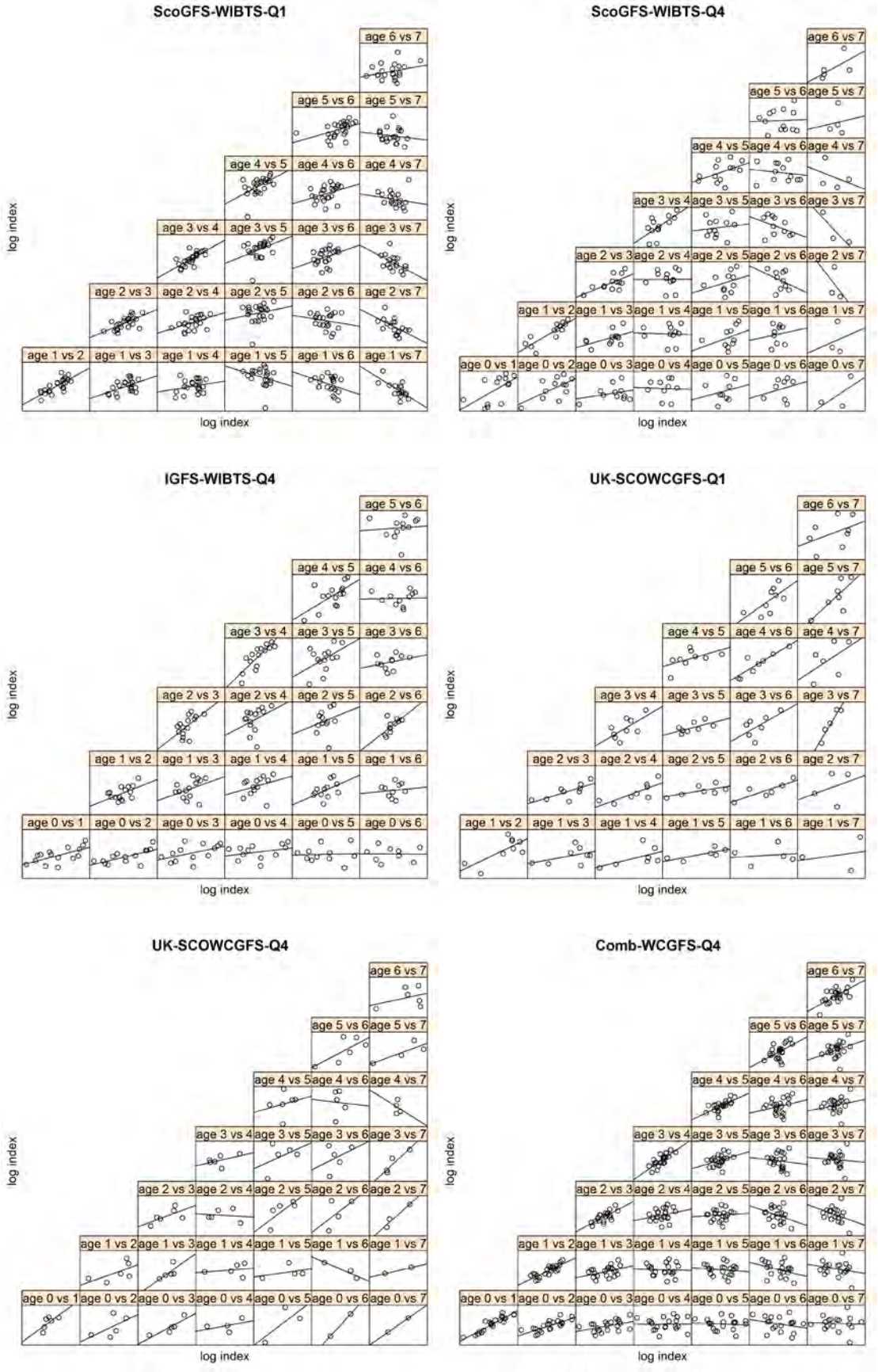


Figure 10. Within-survey correlations comparing index values at different ages for the same year classes for the six survey series. The straight line is a linear regression.

WD 5.3 – Estimation of the maturity ogive for whiting in Division 6.a

Andrzej Jaworski, Marine Scotland – Science

November 2020

Introduction

The previously accepted (2012–2019) category 1 assessment of whiting in West of Scotland (ICES Division 6.a) was an age-based analytical assessment. Information on sexual maturity is one of the input parameters for the assessment. Maturity ogives describe the proportion of mature individuals in a population as a function of age and/or size.

Until 2019, a combined sex maturity at age was assumed to be knife-edged. The use of a knife-edged maturity ogive was a source of criticism in assessments. For example, it was reported that maturity of whiting in West of Scotland showed in the past some temporal variability – the lengths at which whiting were likely to mature decreased significantly during 1986–2009 (Hunter *et al*., 2015). These authors found for that time span that almost all of the two year old whiting were mature, as were about half of the one year old males and a significant number of females. Similarly to West of Scotland, in the Irish Sea, there has been a noted increase in the incidence of precocious maturity-at-age 1, particularly in males since 1998 (Armstrong *et al*., 2004). Whiting in the Irish Sea tend to reach maturity when they are two years old, but one year old mature males are not uncommon (Gerritsen *et al*., 2003).

There was a compelling need to produce a revised maturity ogive in line with the recommendations of ICES (2008). This was accomplished during the data compilation for the Benchmark Workshop for Demersal Species (WKDEM) and was approved at the benchmark in February 2020 (ICES, 2020a). The whiting assessment carried out by WGCSE in May 2020 did not use maturity data (ICES, 2020b). The revised maturity ogive presented at WKDEM (with data up to 2019) could essentially be applied for the WKNSea benchmark. However, adding another year of data (2020) may increase the precision in the estimation of the maturity ogive.

This working document reports the results of the updated analysis of survey data collected by Marine Scotland – Science for whiting in West of Scotland since the 1990s, including the latest information, with the aim of providing a maturity ogive to be used in annual assessments.

Data and analysis

The maturity ogive used for the assessment of whiting in 6a has been assumed to be constant in time:

Age	0	1	2	3	4	5	6	7+
Maturity ogive	0	0	1	1	1	1	1	1

It was assumed to be knife-edge, with the value 0 at age 0 and 1 and full at age 2+. This ogive has been used since the 1990s and it is not known when or from what data the relationship was derived.

In the following analysis, maturity ogives were calculated using the West of Scotland IBTS data from Quarter 1. These data were downloaded from the ICES database, DATRAS, in exchange format. Although the period covered in the database are the years 1985–2020, the maturity data are only available from 1996 onwards and the biological data per haul (with length, age and maturity being of interest here) are only available from 1997 onwards. Consequently, only data from in the period 1997–2020 could be adequately analysed.

The imported data were available in three segments:

- hydro data (HH records)
- length data (HL records)
- age data (CA records).

The biological data (from the CA record) were reduced to whiting and maturity stages from the CA record were recoded as immature (0) and mature (1) according to the table below:

Previous code	Description	New code
1	Juvenile/Immature (4-stage scale)	0
2	Maturing (4-stage scale)	1
3	Spawning (4-stage scale)	1
4	Spent (4-stage scale)	1
61	Juvenile/immature (6-stage scale)	0
62	Maturing (6-stage scale)	1
63	Spawning (6-stage scale)	1
64	Spent (6-stage scale)	1
65	Resting/skip of spawning (6-stage scale)	1
-9	Missing value	Removed

The data on length distribution (derived from the HL records) represent random samples of the catch. A subsample of these fish are used to obtain biological data (length, age, weight, sex and maturity stage) that correspond the CA records. The length distribution data were standardised to account for varying effort (tow duration derived from the HH records). As a result, numbers per standard haul (30 min) were produced from numbers caught.

While there are a number of methods for raising of the information available in biological data (in this case on age and maturity) to length frequencies, the method described in the ICES WKMOG report and employed in the UK (ICES, 2008) was used in this analysis. It is a 3-step process:

1. For each fish with biological data, a raising factor is defined:

$$r_g = n_g / m_g \tag{1}$$

where n_g is the number of fish measured within a length group g, and m_g is the number of fish subsampled in the same length group.

2. The sum of the raising factors for each age group a are calculated

$$R_a = \sum_{a_i=a} r_g \tag{2}$$

where a_i denotes the age of fish i.

3. Statistical weight is assigned to fish i in length group g and age a.

$$w_i = m_a \times r_g / R_a \tag{3}$$

where m_a is the number of fish of age a with biological data.

The maturity ogive was produced by modelling maturity data as a binomial GLM with logit link as described by ICES WKMOG (2008), which is the current standard practice.

The log odds of being mature were modelled as a linear function of the explanatory variables:

$$\log(O_i) = \log\left(\frac{P_i}{1-P_i}\right) = g(x_i) \tag{4}$$

where $g(x_i) = \alpha + \beta_1 X_{1i} + \ldots + \beta_p X_{pi}$ is a linear function of the p explanatory variables X_i, α is the intercept and $\beta_1, \ldots, \beta_p$ are the slopes (Zuur *et al*., 2007). In this analysis, age and year where the only variables of interest.

In the general form, without temporal considerations, the midpoint of the modeled maturity ogive, A50 (age at 50% maturity) was estimated as

$$\text{A50} = -\alpha / \beta \tag{5}$$

The maturity ogive was produced as predictions from the fitted models. 95% confidence intervals were estimated for the ogive and A50 by bootstrap re-sampling of the original dataset.

Results

The best fit of maturity data was obtained with the model including an age effect, a year effect and their interaction (Table 1). The inclusion of a year effect delivered year-specific ogives that showed some variability with no clear temporal pattern (Figure 1). Similarly, there was some temporal variability in A50 (Figure 2), but these changes could not adequately be smoothed (for example, with GAMs) to provide trends. In consequence, one maturity ogive with an age effect only was chosen to represent the whole period.

The analysis delivered a maturity ogive that can be used as input in annual assessments of whiting in 6a. The following coefficients were found: -6.307 (intercept) and 5.228 (slope) for the logistic model. The obtained logistic curve is shown in Figure 3. The curve increases steeply with age, indicating that a considerable proportion of fish at age 1 (a quarter) and nearly all fish at age 2 were mature. There was little variability in the data resulting in relatively narrow confidence bands.

The midpoint of the modelled maturity ogive, A50, was estimated to be 1.206 (±0.031) years. The estimated proportions of mature whiting are shown in the table below:

Age	0	1	2	3	4	5	6	7+
Maturity ogive	0	0.254	0.984	1	1	1	1	1

Conclusion

The delivered maturity ogive, based on long-term estimates, is an advancement in assessing the stock compared to the previous approximation. There was some inter-annual variability in maturity, but no clear trends could be found within the selected time frame.

References

Armstrong, M., Bromley, P., Schön P.-J. and Gerritsen, H. 2004. Changes in growth and maturity in expanding and declining stocks: evidence from haddock, cod and whiting populations in the Irish and Celtic Seas. ICES CM 2004/K:09.

Gerritsen, H. D., Armstrong, M. J., Allen, M., McCurdy, W. J., Peel, J. A. D., 2003. Variability in maturity and growth in a heavily exploited stock: whiting (*Merlangius merlangus* L.) in the Irish Sea. Journal of Sea Research, 49: 69–82.

Hunter, A., Speirs, D. C., Heath, M. R. 2015. Fishery-induced changes to age and length dependent maturation schedules of three demersal fish species in the Firth of Clyde. Fisheries Ressearch, 170: 14–23. 10.1016/j.fishres.2015.05.004

ICES. 2008. Report of the Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG), 3–6 June 2008, Lisbon, Portugal. ICES CM2008/ACOM:33. 72 pp.

ICES. 2019. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 1:29. 1604 pp. http://doi.org/10.17895/ices.pub.4982

ICES. 2020a. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

ICES. 2020b. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. xx pp. http://doi.org/10.17895/ices.pub.5978

Marty, L., Rochet, M. J., Ernande, B. 2014. Temporal trends in age and size at maturation of four North Sea gadid species: cod, haddock, whiting and Norway pout. Marine Ecology Progress Series, 497: 179–197.

Zuur, A. F., Ieno, E. N., and Smith, G. M. 2007. Analysing Ecological Data. Springer, New York, 672 pp.

Zuur, A. F., Ieno, E. N., and Smith, G. M. 2007. Analysing Ecological Data. Springer, New York, 672 pp.

Table 1. Whiting in Division 6.a. Analysis of deviance for the glm fit of maturity data with an age and a year effect.

Model	Df	Deviance	Residual df	Residual deviance	Likelihood ratio test (*p*)
null model	18498			22564	
age	18497	13523	1	9041	<0.0001
year	18474	549	23	8492	<0.0001
age × year	18451	154	23	8338	<0.0001

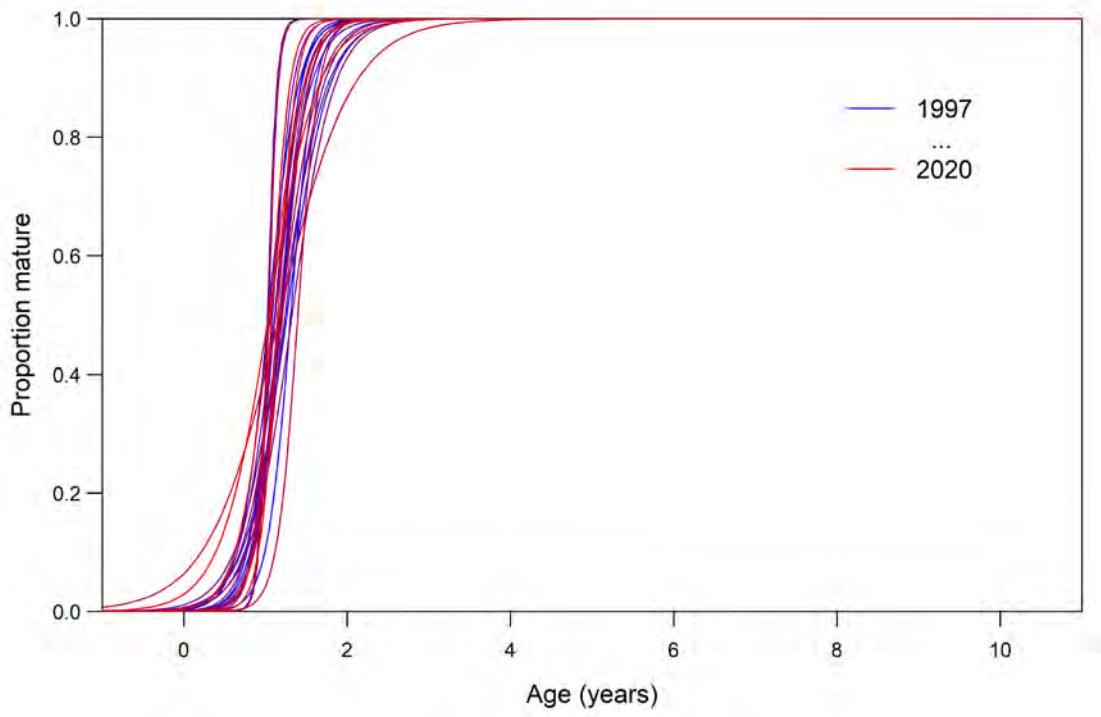


Figure 1. The time series of maturity ogives from 1997 to 2020.

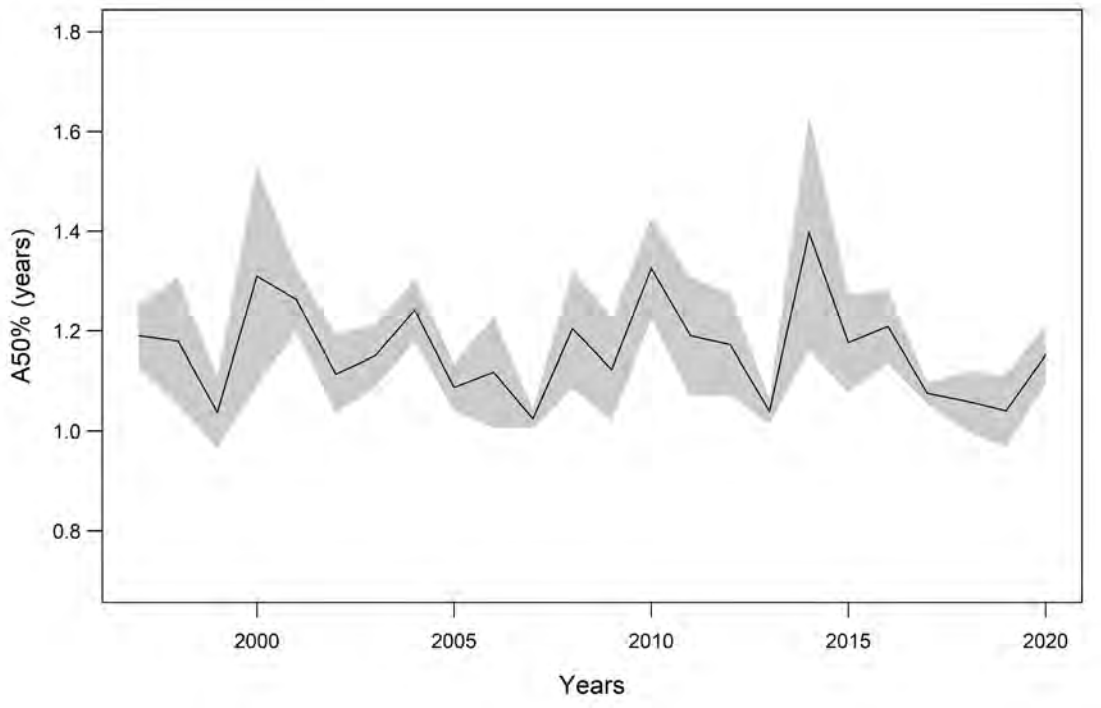


Figure 2. Time series of age at 50% maturity. The shaded area represents the bootstrapped 95% confidence intervals.

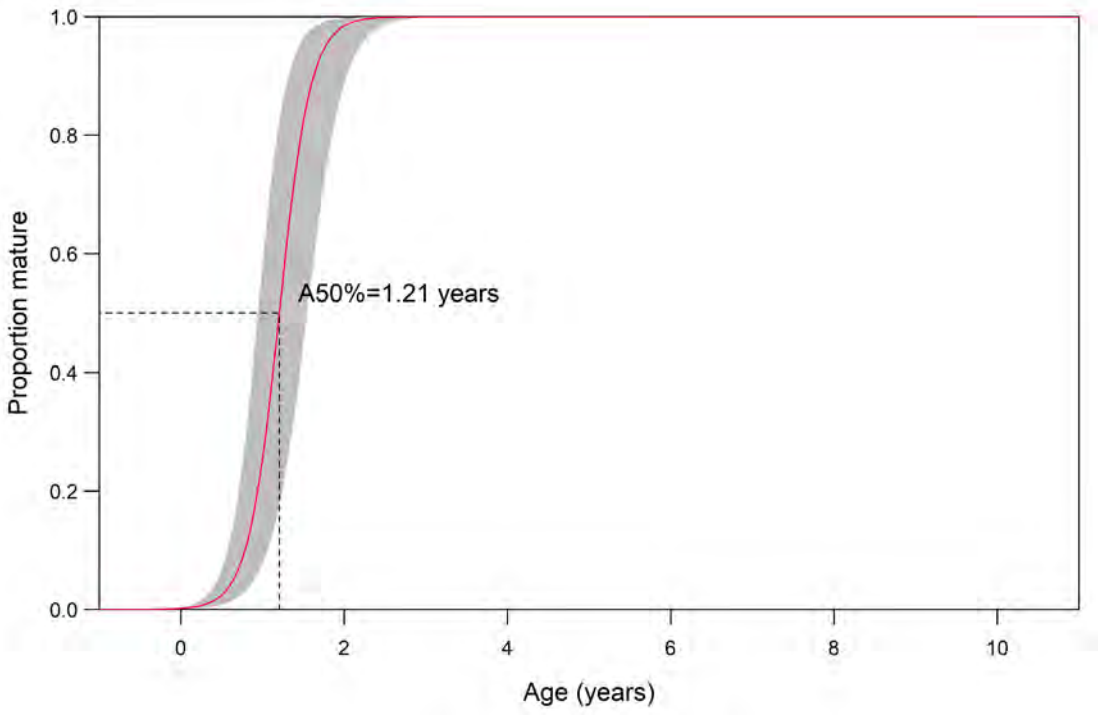


Figure 3. The estimated maturity ogive.

WD Review of natural mortality estimates and stock weights-at-age for whiting in division 6a

Alan Ronan Baudron[1], Niall Fallon[1], Andrzej Jaworski[1], Tanja Miethe[1] and Helen Dobby[1]

[1]Marine Scotland Science, 375 Victoria Road, AB11 9DB, Aberdeen, UK

1. Introduction

The last benchmark for whiting in 6a took place in 2020 (ICES, 2020). During this benchmark it was decided to account for the trends in mean catch weights-at-age (assumed to be equivalent to mean stock weights-at-age) by smoothing the catch weights-at-age time series and using these smoothed values in the Lorenzen (1996) equation to get size-dependent natural mortality-at-age estimates which are no longer fixed through time.

Here, we reviewed the catch weight-at-age time series used as stock weights-at-age and compared these to weights-at-age obtained from scientific surveys. To do so we explored length-weight relationships to convert length-at-age from surveys into weight-at-age. We also highlighted the difference in trends between catch weight-at-age and survey weight-at-age, especially for young age classes, and we explore the use of survey weights-at-age to estimate natural mortality-at-age. We also produced weights-at-age estimates to be used as input in the stock assessment model. Finally, we compare the natural mortality estimates obtained from other sources.

2. The Lorenzen equation

The equation defined by Lorenzen (1996) is as follows:

$$M_a = 3\bar{W}_a^{-0.29}$$

Where M_a is the natural mortality at age a and $\bar{W}_a$ is the average weight-at-age a.

In the 2020 benchmark, it was agreed to use smoothed catch weights-at-age which were subsequently used to estimate natural mortality rates using the Lorenzen (1996) equation (ICES, 2020).

3. Catch weights-at-age

Catch weight-at-age (which are usually assumed to be the same as stock weights-at-age) for the years 1980 to 2019 were taken from the 2019 assessment report (ICES, 2021). The trends in catch weights at each age, together with the smoothed trends (smoothed with a GAM with REML method) used as input into the Lorenzen equation are shown in Figure 1. A declining trend in weight can be seen for age 1, while for older ages a decline up to circa 2000 is followed by an increase (Fig. 1).

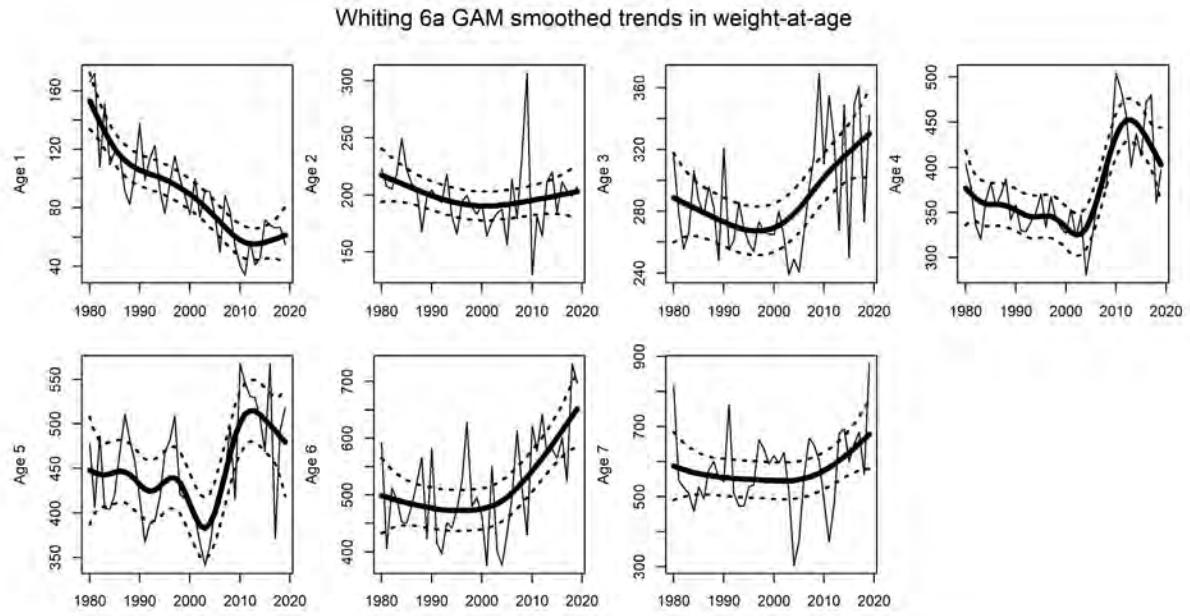


Figure 1. Catch weight-at-age time series (thin black lines) for whiting in Division 6a, ranging from age 1 to 7+, together with the smoothed trends (thick black lines) estimated with a GAM with REML method and the corresponding 95% confidence intervals (dashed lines)

4. Survey data

Data from bottom trawl surveys were obtained from the DATRAS database (https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx) from three scientific surveys:

- IE-IGFS spanning 2003-2019 which contains data for Q4, hereafter referred to as the Irish survey
- SWC-IBTS spanning 1986-2010 which contains data for Q1, Q2 and Q4, hereafter referred to as the old Scottish survey
- SCOWCGFS spanning 2011-2020 which contains data for Q1 and Q4, hereafter referred to as the new Scottish survey

Data were downloaded in exchange format which includes age data (CA records), hydro data (HH records) and length data (HL records). Only data pertaining to whiting (*Merlangius merlangus*) within the 6a ICES division were kept. It should be noted that the Irish survey only covers the southern edge of the 6a division, along the Irish coast.

Survey data are obtained via a two-stage stratified sampling: a large random sample of the catch is measured to produce a length distribution (HL records), and a stratified subsample of these fish (a fixed number per length class) is used to obtain biological data (age, weight, sex, maturity stage, corresponding to the CA records). As such, this biological data obtained through stratified sampling needs to be raised by a statistical weight accounting for the observed length distribution. The method used to raise data in each area is the one employed in the UK and detailed in the report of the ICES Working Group on Maturity Ogive (WKMOG) Estimation for Stock Assessment (ICES, 2008). This method comprises three steps, as follows:

1. For each fish with biological data, define a raising factor:

$$r_g = n_g / m_g$$

where n_g is the number of fish measured within a length group g, and m_g is the number of fish subsampled in the same length group.

2. Calculate the sum of the raising factors for each age group a

$$R_a = \sum_{a_i=a} r_g$$

where a_i denotes the age of fish i.

3. Assign statistical weight, to fish i in length group g and age a

$$w_i = m_a \times r_g / R_a$$

where m_a is the number of fish of age a with biological data.

This statistical weight w_i was used as weighting factor when calculating the length-weight relationships and the mean length-at-age, as described below.

5. Length-weight relationships

Only the Irish survey and the new Scottish survey contain length and weight data. Therefore, for these two surveys, length-weight relationships were fitted using data from all quarters available. Length-weight relationships are as follows:

Weight = a*Length^b

When growth is allometric, the b parameter is usually close to 3. The relationships were fitted on a log scale to account for the increasing variability with size and abide by the homoscedasticity assumption, as follows:

Log(Weight) = Log(a)+b*Log(Length)

The observations were weighted by the statistical weight w_i. The relationships were fitted to the Irish and new Scottish surveys separately, and to both surveys combined. The a parameter was then back-transformed into the normal scale and corrected for geometric mean bias (Hayes et al., 1995) as follows:

$$a = e^{a_1} e^{\left(\sigma^2 - Var(a_1)\right)/2}$$

Where a_1 is the intercept of the linear regression on log-transformed data, σ^2 is the residual variance of the regression model, and Var(a_1) is the standard error of the estimate a_1. Figure 2 shows the length-weight relationships obtained on both the normal and log scales, with the back-transformed parameters on the normal scale.

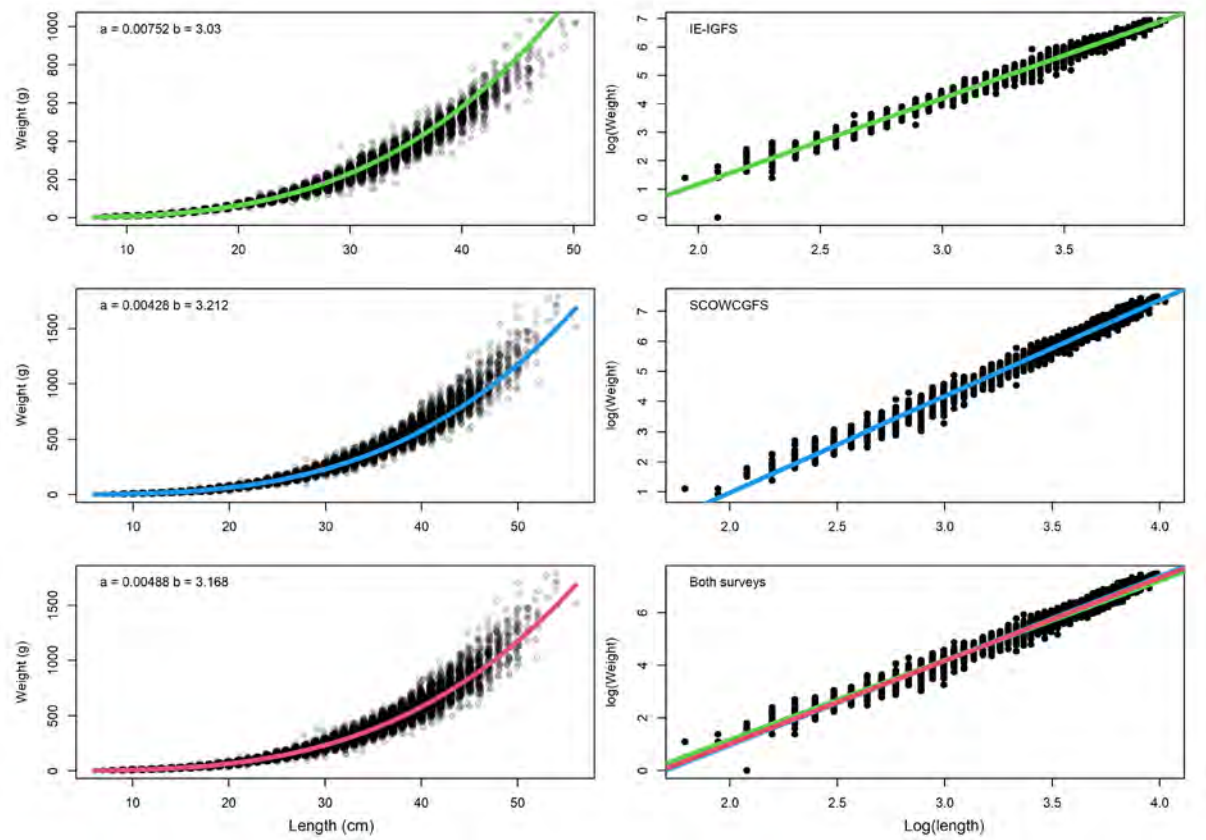


Figure 2. Length-weight relationships for 6a whiting. Black dots are the data, coloured lines are the fitted relationships on log and normal scales. The *b* and back-transformed, bias corrected *a* parameters are showed on the normal scale figure panels.

6. Mean length-at-age from surveys

For each survey, mean length-at-age time series were obtained by computing, for each year, the weighted average of length at each age using the statistical weight w_i as weighting factor. The resulting time series are displayed in Figure 3.

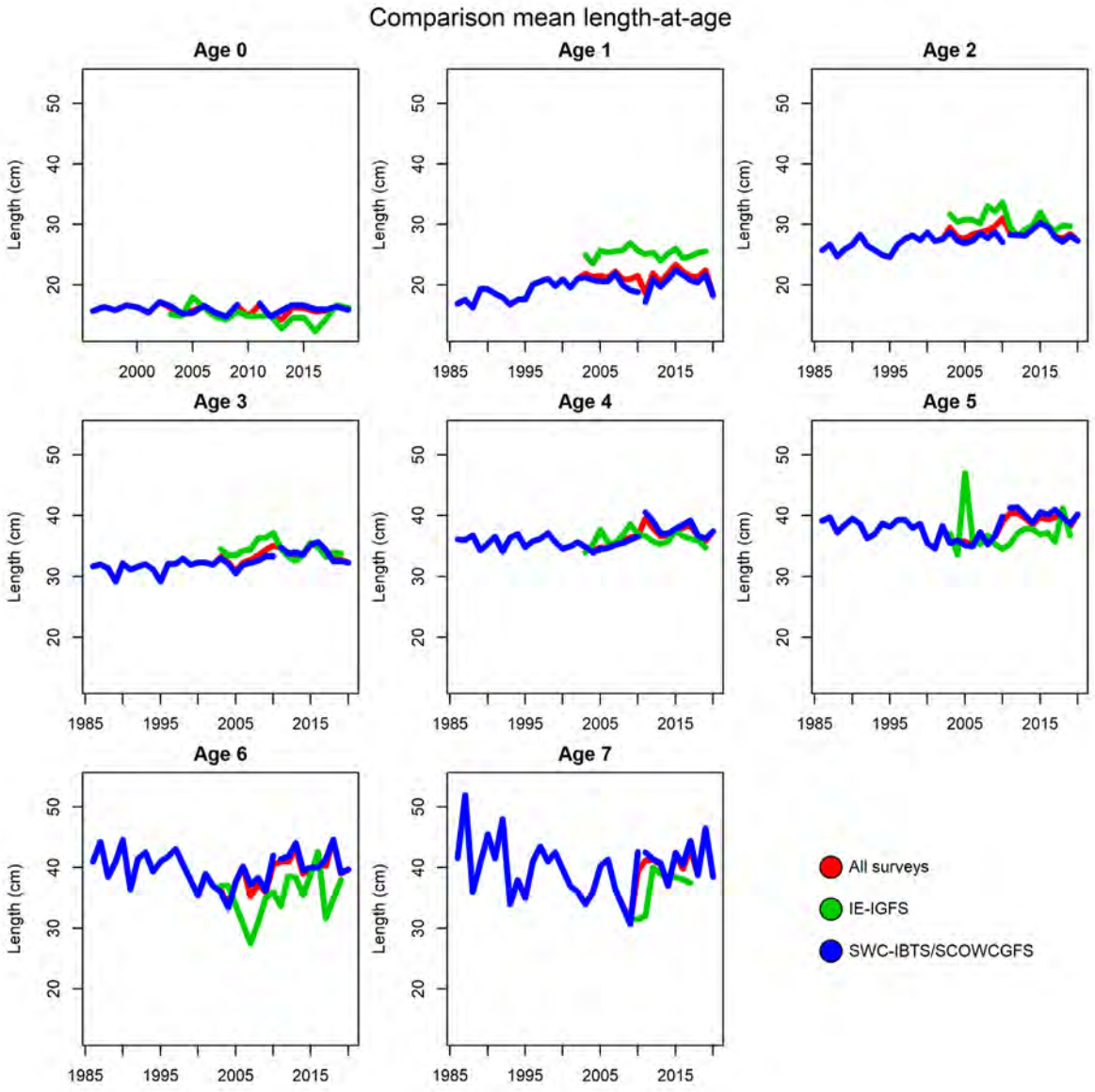


Figure 3. Mean length-at-age time series obtained in each survey. For Scottish surveys, the blue time series up to 2010 corresponds to the old survey, and to the new survey from 2011 onwards.

Similar trends in mean length-at-age were observed in the Irish and Scottish surveys (Fig. 3). For age 1, values from the Irish survey are significantly higher owing to the data being sampled at Q4, meaning fishes have had time to grow for a year, while the Scottish surveys are dominated by Q1. Also, no clear break in the time series between 2010 and 2011 could be discerned for Scottish surveys, despite the sampling protocol being different between the two surveys (change from fixed station to random stratified design). This suggests that, in this instance, data from both Scottish surveys can be collated without any data transformation.

7. Mean weight-at-age from surveys

Lengths-at-age from the old Scottish survey were converted to weights-at-age using the length-weight relationship fitted to all survey data (see section 5). Mean weight-at-age time series were obtained by computing, for each year, the weighted average of weight at each age using the statistical weight w_i as

weighting factor. Since the Irish survey covers only a small fraction of area 6a, only combined data from the old and new Scottish surveys is considered hereafter.

7a. Mean weight-at-age to calculate natural mortality

In order to estimate natural mortality, weight-at-age data from all quarters were used. This is to account for growth changes observed in 6a whiting (Ikpewe et al, 2020) which are more likely to be captured by Quarter 4 data, when fishes have grown throughout the year before moving on to the next age class. The justification for this is that since the mortality estimates used are size-dependent, it is important to account for changes in growth by using a size which is most representative of the average annual size. The resulting survey weights-at-age time series are displayed in Figure 4, together with the catch weights-at-age time series for comparison.

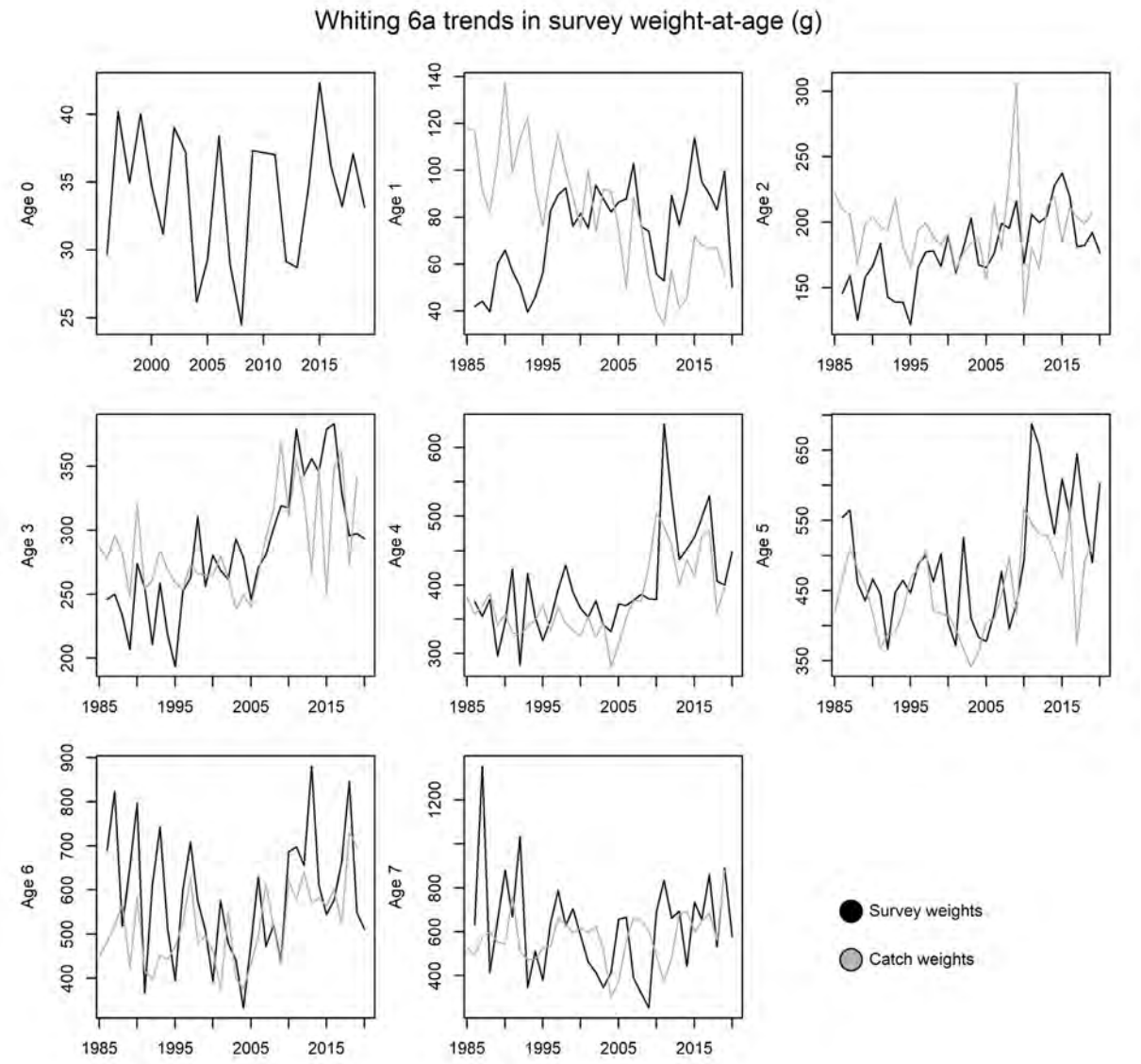


Figure 4. Combined Quarters 1 & 4 survey weights-at-age time series for 6a whiting, together with catch weights-at-age time series. Only Quarter 4 surveys contain data for the zero age class.

Survey weights-at-age time series for age 1 and 2 show an increase in weight over time, in contrast with the trends from the catch weights-at-age data which show a decline and no directional change for age 1 and 2, respectively (Fig. 4). Time series for age classes 3 and above were similar across both data sources. After considering the discrepancies between survey and catch data during the WKNSEAS data meeting, it was decided that, to estimate natural mortality, weights-at-age 0 to 2 would be obtained from surveys while weights-at-age 3 and above would be obtained from both survey and catch data sources. The justification for this is that scientific surveys are likely to give a more accurate representation of young age classes compared to commercial fisheries which target older age classes and change in spatial fishing patterns over time. Therefore, a new weights-at-age dataset comprising of survey weights-at-age for age 0 to 2, and the average between survey weights-at-age and catch weights-at-age for age 3 and above was compiled and used hereafter to estimate natural mortality (see section 8 below).

7b. Mean weight-at-age input for SAM stock assessment model

Only Quarter 1 survey data should be considered as stock weights-at-age input to the stock assessment model for use in estimating SSB as this is usually assumed to be calculated in the beginning of the year. Therefore, to produce input for the SAM model, a new stock weights-at-age dataset comprising of survey weights-at-age for age 1 to 2 from Quarter 1 only, and the average between survey weights-at-age and catch weights-at-age for age 3 and above was compiled. This dataset was then used to fit a REML GAM in order to predict smoothed estimates of mean weights-at-age. In addition, the SAM model requires estimates of weight-at-age 0. Since age 0 data are not available from Quarter 1 surveys, smoothed estimates of mean weights-at-age 0 were predicted using a REML GAM fitted to Quarter 4 data for this age class only. The resulting smoothed stick weights-at-age are shown in the Table 1 below.

Table 1. Smoothed stock mean weights-at-age estimates (kg) from REML GAM fitted to survey/catch weights-at-age time series to be used to calculate SSB

YEAR	AGE 0*	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7
1985	0.037	0.048	0.154	0.265	0.371	0.489	0.599	0.725
1986	0.036	0.048	0.154	0.258	0.367	0.484	0.598	0.714
1987	0.036	0.048	0.153	0.251	0.364	0.478	0.597	0.703
1988	0.036	0.048	0.152	0.246	0.362	0.473	0.596	0.691
1989	0.036	0.049	0.151	0.242	0.360	0.468	0.595	0.680
1990	0.036	0.049	0.150	0.239	0.359	0.462	0.594	0.668
1991	0.036	0.049	0.149	0.238	0.358	0.458	0.593	0.656
1992	0.036	0.049	0.147	0.237	0.357	0.454	0.592	0.645
1993	0.035	0.049	0.146	0.237	0.356	0.451	0.591	0.634
1994	0.035	0.049	0.144	0.236	0.355	0.449	0.590	0.623
1995	0.035	0.049	0.143	0.235	0.353	0.448	0.590	0.613
1996	0.035	0.049	0.141	0.234	0.350	0.446	0.589	0.604
1997	0.035	0.049	0.140	0.233	0.347	0.445	0.589	0.596
1998	0.035	0.049	0.139	0.232	0.343	0.444	0.589	0.588
1999	0.034	0.050	0.138	0.230	0.339	0.443	0.589	0.583
2000	0.034	0.050	0.138	0.228	0.335	0.443	0.589	0.578
2001	0.034	0.050	0.138	0.225	0.332	0.444	0.589	0.575
2002	0.034	0.050	0.138	0.223	0.331	0.447	0.590	0.573
2003	0.034	0.050	0.139	0.222	0.332	0.452	0.591	0.574
2004	0.034	0.050	0.140	0.224	0.337	0.459	0.592	0.576
2005	0.034	0.050	0.141	0.229	0.345	0.468	0.593	0.580

2006	0.033	0.050	0.143	0.238	0.357	0.479	0.595	0.585
2007	0.033	0.051	0.145	0.250	0.373	0.492	0.597	0.592
2008	0.033	0.051	0.148	0.265	0.390	0.505	0.599	0.600
2009	0.033	0.051	0.150	0.279	0.408	0.519	0.602	0.609
2010	0.034	0.051	0.152	0.293	0.426	0.532	0.604	0.619
2011	0.034	0.052	0.155	0.305	0.441	0.544	0.607	0.630
2012	0.034	0.052	0.157	0.313	0.454	0.555	0.610	0.641
2013	0.034	0.052	0.159	0.318	0.462	0.563	0.613	0.653
2014	0.034	0.052	0.161	0.319	0.466	0.570	0.615	0.666
2015	0.034	0.053	0.163	0.317	0.465	0.574	0.618	0.678
2016	0.034	0.053	0.165	0.311	0.462	0.577	0.621	0.690
2017	0.034	0.053	0.167	0.303	0.456	0.579	0.623	0.703
2018	0.035	0.053	0.168	0.293	0.448	0.579	0.626	0.715
2019	0.035	0.054	0.170	0.282	0.440	0.580	0.629	0.727
2020	0.035	0.054	0.171	0.271	0.431	0.580	0.631	0.739

***Estimates of stock weights-at-age zero from REML GAM fitted to Quarter 4 survey weights-at-age data, for input to the SAM assessment**

8. Natural mortality estimates

To obtain natural mortality estimates, the new weights-at-age time series (see section 7a) were first smoothed, as agreed during the WKDEM meeting (ICES, 2020) using a GAM with REML method. The smoothed times series were then used with the Lorenzen (1996) equation to obtain natural mortality-at-age estimates. These are displayed in Figure 5 and Table 2.

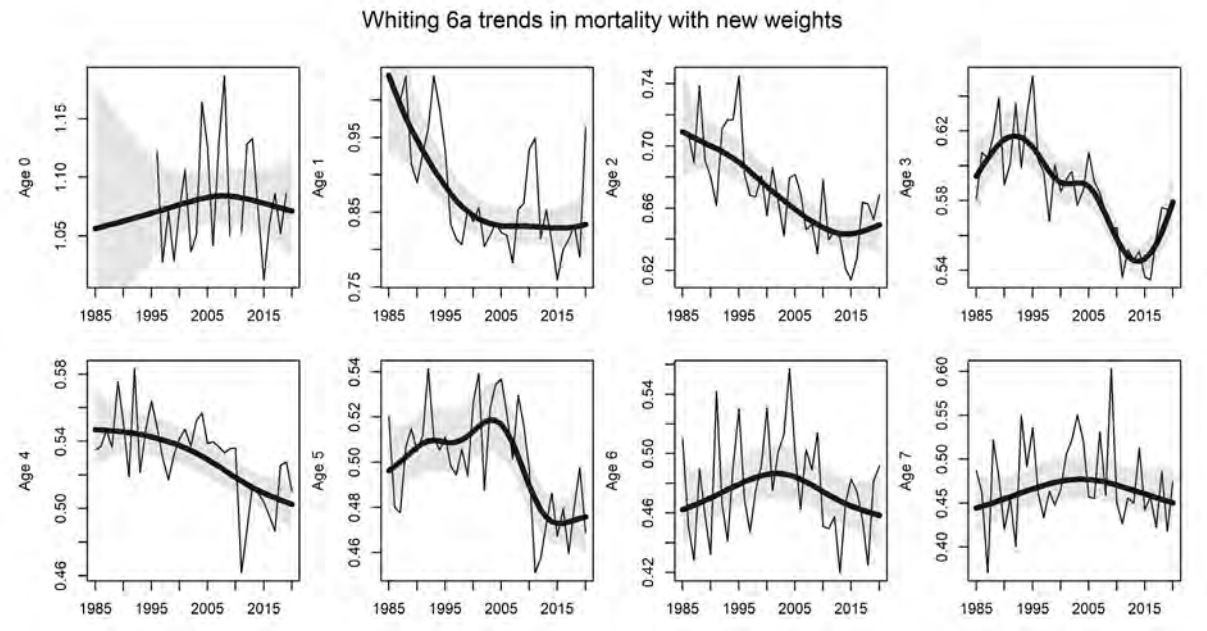


Figure 5. Time series of natural mortality-at-age estimated with Lorenzen. The thick black line shows the natural mortality obtained with the smoothed weights-at-age with the corresponding 95% confidence interval shown in grey. The thin black line shows the natural mortality obtained with unsmoothed weights-at-age, for comparison.

Table 2. Lorenzen Natural mortality-at-age values calculated using smoothed mean weight-at-age estimates from REML GAM fitted to survey/catch weights-at-age time series

YEAR	AGE 0	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7
1985	1.06	1.03	0.71	0.59	0.55	0.50	0.46	0.44
1986	1.06	1.01	0.71	0.60	0.55	0.50	0.46	0.45
1987	1.06	0.99	0.71	0.60	0.55	0.50	0.47	0.45
1988	1.06	0.98	0.70	0.61	0.55	0.50	0.47	0.45
1989	1.06	0.96	0.70	0.61	0.55	0.50	0.47	0.45
1990	1.06	0.95	0.70	0.62	0.55	0.51	0.47	0.45
1991	1.06	0.93	0.70	0.62	0.55	0.51	0.47	0.46
1992	1.07	0.92	0.70	0.62	0.54	0.51	0.47	0.46
1993	1.07	0.91	0.69	0.62	0.54	0.51	0.48	0.46
1994	1.07	0.90	0.69	0.61	0.54	0.51	0.48	0.46
1995	1.07	0.89	0.69	0.61	0.54	0.51	0.48	0.47
1996	1.07	0.87	0.69	0.61	0.54	0.51	0.48	0.47
1997	1.07	0.87	0.68	0.60	0.54	0.51	0.48	0.47
1998	1.07	0.86	0.68	0.60	0.54	0.51	0.48	0.47
1999	1.07	0.85	0.68	0.59	0.54	0.51	0.49	0.47
2000	1.08	0.85	0.67	0.59	0.54	0.51	0.49	0.47
2001	1.08	0.84	0.67	0.59	0.54	0.52	0.49	0.48
2002	1.08	0.84	0.67	0.59	0.53	0.52	0.49	0.48
2003	1.08	0.84	0.66	0.59	0.53	0.52	0.49	0.48
2004	1.08	0.83	0.66	0.59	0.53	0.52	0.49	0.48
2005	1.08	0.83	0.66	0.59	0.53	0.52	0.48	0.48
2006	1.08	0.83	0.66	0.58	0.53	0.51	0.48	0.48
2007	1.08	0.83	0.65	0.58	0.53	0.51	0.48	0.48
2008	1.08	0.83	0.65	0.57	0.52	0.50	0.48	0.47
2009	1.08	0.83	0.65	0.56	0.52	0.50	0.48	0.47
2010	1.08	0.83	0.65	0.56	0.52	0.49	0.47	0.47
2011	1.08	0.83	0.65	0.55	0.52	0.48	0.47	0.47
2012	1.08	0.83	0.64	0.55	0.51	0.48	0.47	0.47
2013	1.08	0.83	0.64	0.55	0.51	0.48	0.47	0.46
2014	1.08	0.83	0.64	0.55	0.51	0.47	0.47	0.46
2015	1.08	0.83	0.64	0.55	0.51	0.47	0.46	0.46
2016	1.08	0.83	0.64	0.55	0.51	0.47	0.46	0.46
2017	1.08	0.83	0.65	0.55	0.51	0.47	0.46	0.46
2018	1.07	0.83	0.65	0.56	0.51	0.47	0.46	0.45
2019	1.07	0.83	0.65	0.57	0.50	0.48	0.46	0.45
2020	1.07	0.83	0.65	0.58	0.50	0.48	0.46	0.45

Natural mortality-at-age estimates obtained with the new combined weights show a relatively flat dome-shaped trend for age 0, with a slight increase between 1995 and 2005 followed by a slight decrease (Fig. 5). For ages 1 to 4, a clear declining trend is observed, while for older ages the natural mortality increases until circa 2000 after which it declines. The changes at age through time are better seen on Figure 6 which displays the temporal shifts in natural mortality at age on the same plot.

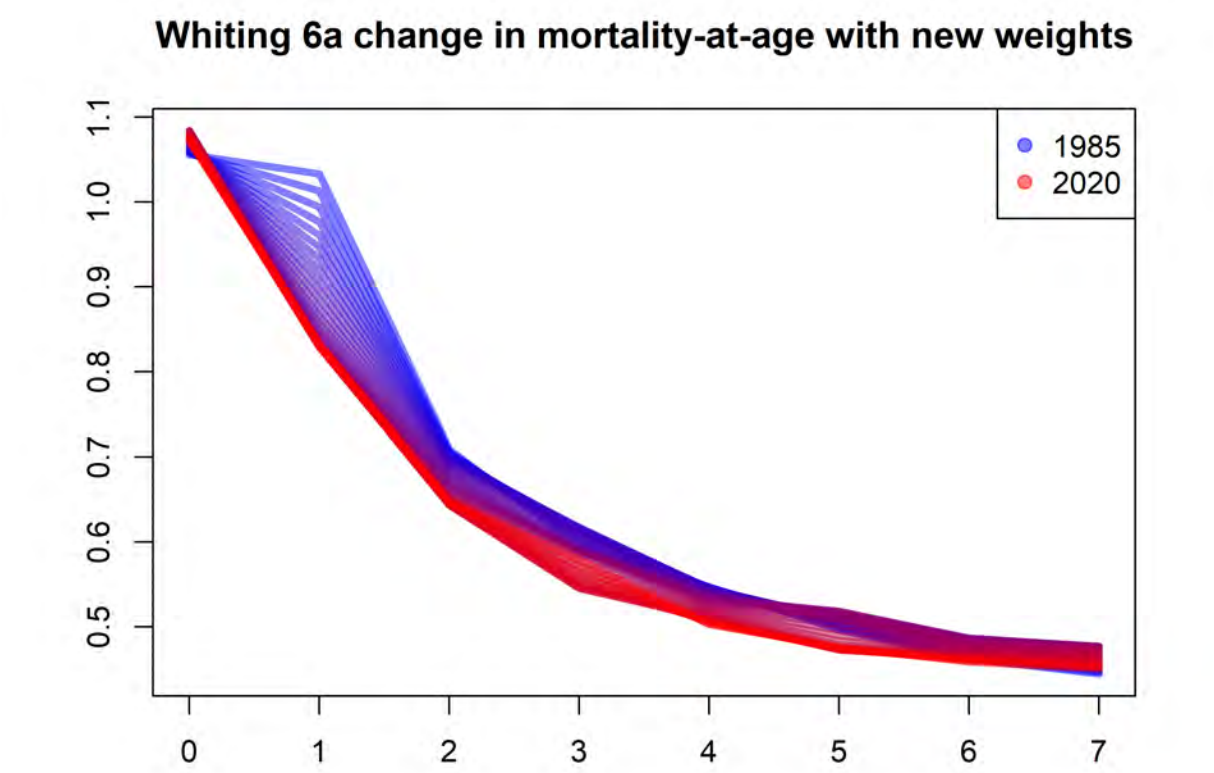


Figure 6. Temporal shifts in natural mortalities estimated with the new combined weights-at-age used in the Lorenzen equation.

A clear shift towards lower natural mortality can be seen for age 1 and 2 (Fig. 6). For age 0, the time series of estimates is reasonably constant, suggesting no significant change over time. For older ages, a slight shift towards lower mortalities can be discerned although the overlapping colours show a lack of directional trend.

9. Comparison with other sources of natural mortality estimates

The natural mortality-at-age estimates obtained with the new combined weights-at-age were compared with:

- natural mortality-at-age obtained with smoothed catch weights-at-age, as currently used in the assessment
- natural mortality-at-age estimates from the west of Scotland multispecies model from Trijoulet et al. (2018) which accounts for grey seal predation
- smoothed natural mortality-at-age estimates from the North Sea SMS model used in the assessment of whiting in subarea 4 and division 7d (ICES, 2019)

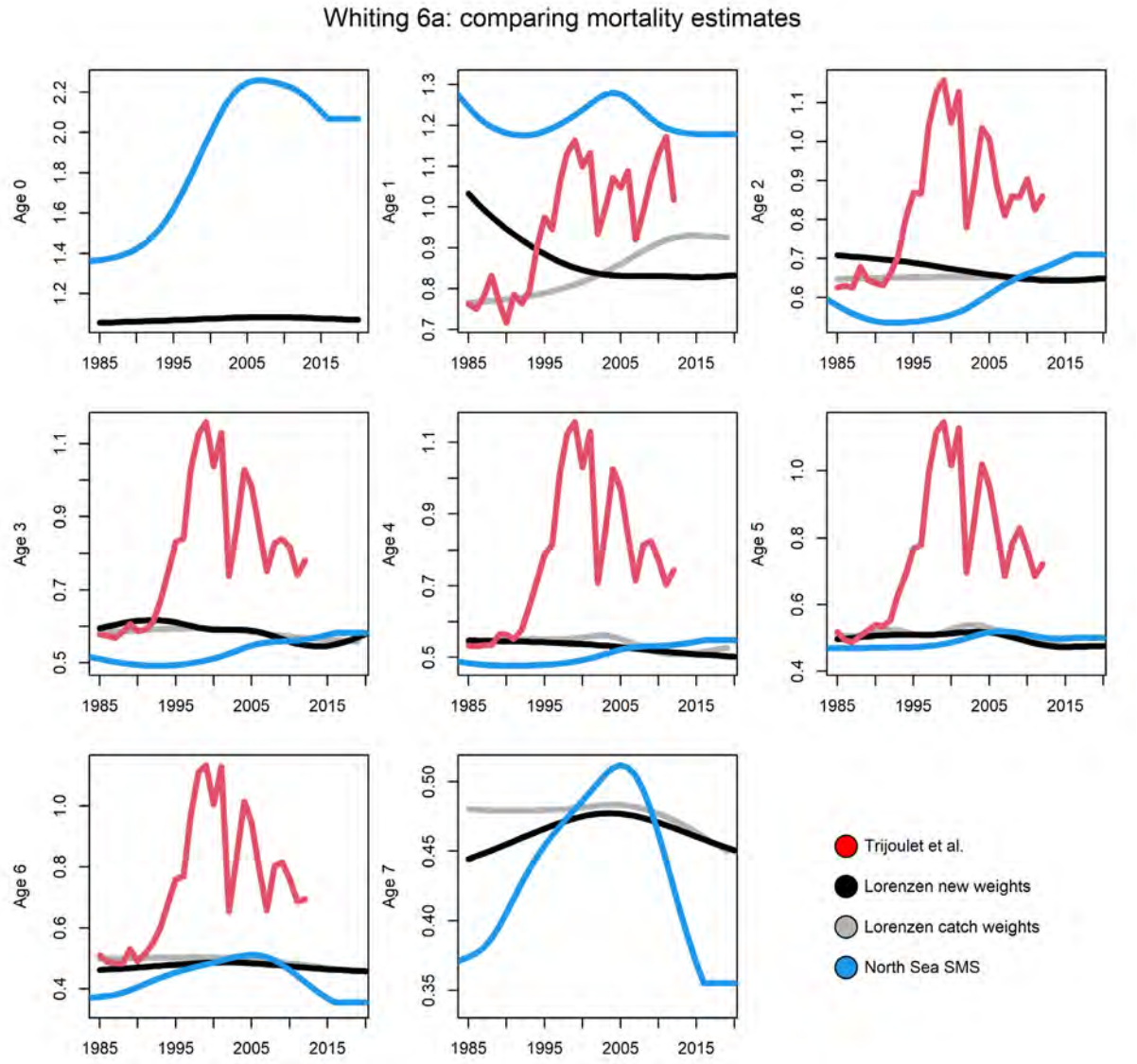


Figure 7. Comparison of natural mortality-at-age estimates

The natural mortality-at-age estimates obtained with the new combined weights-at-age and the catch weights-at-age showed contrasting trends for age 1 and 2, but similar trends and values for age 3 and above, as expected (Fig. 7). Estimates from the North Sea SMS model were far higher than estimates obtained with the new combined weights-at-age for age 0 and 1, but were in the same range of values for age 2 to 6. The estimates from Trijoulet et al. (2018) differed from the estimates obtained with the new combined weights-at-age. Interestingly, the estimates from Trijoulet et al. (2018) were similar to the estimates obtained with the catch weights-at-age until the early 1990s, after which the increase in grey seal predation modelled by Trijoulet et al. (2018) led to a dramatic increase in mortality.

10. References

Hayes, D. B., Brodziak, J. K. T., O'Gorman, J. B. 1995. Efficiency and bias of estimators and sampling designs for determining length-weight relationships of fish. Can J. Fish. Aquat. Sci. 52: 84-92

ICES. 2021. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. 1461 pp. http://doi.org/10.17895/ices.pub.5978

ICES. 2020. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

ICES 2019. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports, 1:7, 1271 pp.

ICES. 2008. Report of the Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG), 3-6 June 2008, Lisbon, Portugal. ICES CM2008/ACOM:33. 72 pp.

Idongesit E. Ikpewe, Alan R. Baudron, Aurore Ponchon, Paul G. Fernandes. 2020. Bigger juveniles and smaller adults: Changes in fish size correlate with warming seas. Journal of Applied Ecology, https://doi.org/10.1111/1365-2664.13807

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology, 49: 627–647.

Trijoulet, V., Holmes, S. J., Cook, R. M. 2018. Grey seal predation mortality on three depleted stocks in the West of Scotland: What are the implications for stock assessments? Can. J. Fish. Aquat. Sci. 75: 723–732 dx.doi.org/10.1139/cjfas-2016-0521

WD 5.5 – Survey-based analyses with SURBAR for whiting in Division 6a

Andrzej Jaworski, Marine Scotland – Science

February 2021

Introduction

SURBAR is one of the fishery-independent methods to assess fish stocks. It is an age-structured and survey-based assessment model that is used to indicate relative stock dynamics and provide advice for both data-rich and data-poor fisheries (Needle, 2015). SURBAR has been used in assessment of several fish stocks in the North Sea and West of Scotland, either as a main method or as a supplementary one (ICES, 2020a, 2020b). At WKROUND 2012, the model was used in exploratory analyses of whiting in Division 6a (ICES, 2012).

In the past, the survey data and commercial catch data for whiting in Division 6a contained contradicting signals concerning the stock (ICES, 2020b). This was particularly the case with the discontinued Scottish surveys before 2011. For years, assessments of the stock have been conducted using multiple surveys (Scottish and Irish surveys). The introduction of a new survey design by Scotland in 2011 resulted in two more survey series that could be used in the assessment. At WKDEM 2020, the option was agreed upon to use a combined index from two surveys, in addition to single-survey indices (ICES, 2020c).

The present analysis provides an assessment of whiting in Division 6a conducted with SURBAR, where the final model is selected based on the optimal survey configuration found in an exploratory analysis. Additionally, a sensitivity analysis is performed to evaluate the impact of different model settings.

Data and Methods

Data

Basically, to run the model, data from three main sources were required. They included stock weights-at-age, maturity ogive and survey indices. For the present analysis, stock weights-at-age were assumed to be equal to catch weights-at-age. The maturity ogive established during WKDEM 2020 (ICES, 2020c) was used to determine the proportion of mature whiting in the population.

Surveys

The assessments of the stock conducted in 2015–2019 used five tuning time-series. They included two “old” Scottish surveys:

- Scottish first-quarter west coast groundfish survey (ScoGFS-WIBTS-Q1): all ages 1 and older, years 1985–2010;
- Scottish fourth-quarter west coast groundfish survey (ScoGFS-WIBTS-Q4): all ages including age 0, years 1996–2009.

The Irish Groundfish Survey has partly been conducted in Division 6.a:

- Irish fourth-quarter west coast groundfish survey (IGFS-WIBTS-Q4): all ages including age 0, years 2003–2018.

This survey series was truncated at WKDEM 2020 (for modelling purposes, to cover only the years 2003–2010).

The introduction of the new survey design initiated two “new” time-series:

- Scottish first-quarter west coast groundfish survey (UK-SCOWCGFS-Q1): all ages 1 and older, years 2011–2020;

- Scottish fourth-quarter west coast groundfish survey (UK-SCOWCGFS-Q4): all ages including age 0, years 2011–2019.

At WKDEM 2020, it was decided to replace the index from the new Scottish Q4 survey with a combined index for the two Q4 surveys, the Irish and Scottish ones:

- Scottish/Irish fourth-quarter west coast groundfish survey (IGFS-UK-SCOWCGFS-Q4): all ages including age 0, years 2011–2019;

The combined index performed satisfactorily and it was considered to be representative of the stock.

During the WKNSea data compilation meeting, it was suggested that for whiting, a statistical modelling approach using all Q4 survey data (ScoGFS-WIBTS-Q4, IGFS-WIBTS-Q4 and UK-SCOWCGFS-Q4) may represent a more useful and straightforward way to derive a single Q4 index. Including not only the current surveys series (the Scottish and Irish), but also the old Scottish Q4 survey series would provide a longer continuous survey index which would potentially be more useful (than multiple shorter indices) in the stock assessment. Combining the three Q4 survey series resulted in one series:

- Scottish/Irish fourth-quarter west coast groundfish survey (Comb-WCGFS-Q4): all ages including age 0, years 1996–2019;

Age-0 fish were excluded from the SURBAR assessment and sensitivity analyses as weight data were not available for this age group in the whole time-series.

Model

SURBAR is a development of the earlier SURBA model (Needle, 2003; 2008; 2012; 2015) and was written using the R package (R Core Team, 2018). The basis of SURBA/SURBAR is a simple survey-based separable model of mortality (Needle, 2015). Total mortality is assumed to be a product of age and year effects. The parameters to be estimated when fitting the model are age, year and cohort effects. Abundance indices (age-structured) are mean-standardised. SURBAR can only estimate relative abundances.

Apart from stock weights-at-age, maturity ogive and survey indices, the model also requires some other parameters such as reference age, proportion mortality before spawning, index catchabilities, index weightings, index timings and penalty weightings (Needle, 2015). Three of these parameters: reference age, smoothing parameter λ and survey catchability q were tested in a sensitivity analysis. The baseline model (with five surveys) was run with a range of parameter values. The reference age was set in turn at 2–4 years. The parameter lambda was set at 1, 3, 5 and 10. The catchability q was set at 1, 0.75 and 0.5. The performance of the model evaluated with AIC tests.

Results

Exploratory analyses

In the exploration phase, the five previously used indices and the new combined Scottish and Irish index were tested. Figures 1 to 3 give a number of exploratory data analysis plots which were used to determine which survey series is sufficiently representative. Figure 1 indicates that the Irish survey (IGFS-WIBTS-Q4) data has more noisy catch curves than the Scottish surveys (ScoGFS-WIBTS-Q1, ScoGFS-WIBTS-Q4, UK-SCOWCGFS-Q1, UK-SCOWCGFS-Q4) and the combined survey (Comb-WCGFS-Q4). Figure 2 suggests that the old Scottish surveys and Irish survey are able to track year-class strength through time across all ages only to a limited extent. The plots for the new Scottish surveys and for the combined Q4 survey generally show the ability of these three surveys to reliably track year classes and to identify the stronger/weaker ones than the average. The within-survey correlation plots in Figure 3 indicate that the surveys show, in most cases, significant correlation between consecutive age groups. The combined Q4 survey performs better than the new Scottish Q4 survey, but it has to be noted that the latter has relatively few points (and consequently, relatively low correlations) as the year 2013 was excluded from this survey series (ICES, 2020b).

The above diagnostics suggest that the Irish survey is perhaps a less reliable indicator of whiting population dynamics than the Scottish surveys and the combined survey. Figure 4 compares the scaled indices and shows general consistency among the Irish and Scottish surveys for most ages and years. Distribution plots for whiting in Division 6a shown in the WGCSE report (ICES, 2020b) indicate significant areas of whiting in the south of the division. Thus, the Irish survey, which is limited in extent to the southern area, is still likely to provide useful information on the wider 6a whiting stock.

All the considered six survey series were deemed, to a varying extent, as representative of the stock. Among all the three Q4 survey series, the combined index was considered as the most representative one. There was no temporal overlap for the two Q1 surveys and they had to be treated as separate indices. Taking it all into consideration the three surveys, ScoGFS-WIBTS-Q1, UK-SCOWCGFS-Q1 and Comb-WCGFS-Q4 were candidates for the inclusion in the final model.

SURBAR assessment

A SURBAR analysis for 6a whiting was conducted using three survey series. The following settings were used in the final model run (based on a sensitivity analysis detailed in the next section)::

- Three survey series:
  - ScoGFS-WIBTS-Q1,
  - UK-SCOWCGFS-Q1,
  - Comb-WCGFS-Q4.
- Reference age for separable model = 3.
- Lambda smoother = 1.0.
- All SSQ weightings and catchabilities *q* set to 1.0.

SURBAR converged in five iterations for this analysis, and produced the output given in Figures 5 to 8. Stock summary plots (Figure 5) show rather variable estimates of mean Z being generally lower from the mid-2000s onwards. SSB rose to a peak in the mid-90s, before returning back down to the levels seen in the late 1980s with a substantial increase in the recent period. Also, it seems to fluctuate more in recent years compared to the historical period. The increase between 2019 and 2020 can be explained by relatively high recruitments in these two years. Recruitment between 2005 and 2013 remained on a very low level. In recent years, it has been fluctuating, mostly above the average except for 2018. Variance around parameter estimates (Figure 6) is reasonably consistent

across all ages, years and cohorts. Residual plots (Figure 7) indicate a slight upward trend in the old Sottish Q1 series, reversed, however, towards the end of the series. The two other survey series show no clear trends/patterns. Especially, the new Scottish Q1 survey series (which is relatively short) shows low variance and no major outliers. Finally, the retrospective plot (Figure 8) shows that the estimates of mean Z are more noisy than SSB, TSB and recruitment.

Sensitivity analysis

The exploratory analyses showed that all the six survey series were representative of the stock. However, some additional SURBAR runs were done with different survey configurations other than "all three" selected for the final model. These are shown in Figure 9. It can be seen that the trends were rather similar in the different survey configurations. It can be further seen that using two or three surveys provided more information compared to single surveys. The signal from single surveys added up to the combined signal across the time series. The survey configurations that include the new Scottish Q1 survey provide most up-to-date information on population levels, which is of importance when deciding which survey configuration to choose. SSB estimates made with three surveys (as in the final model) were found within the most extreme estimates, which further supports the choice of this configuration.

The performance of the model with different parameter values (for each parameter, all the other parameters being fixed) can be seen in Figures 10 to 12. There was a very little impact of the fishery selectivity reference age on the model outputs (Figure 10), but age 3 was effectively selected (based on AIC) as the reference age. The importance of the smoother lambda was greater (Figure 11) with higher smoother values giving results with less inter-annual variability in estimated Z and biomass. The optimal λ=1 was selected trough the sensitivity analysis (again based on AIC). There was no effect of different catchabilities (with one *q* value for all ages 1+) which was demonstrated in the sensitivity analysis with almost identical outputs. A minor effect of using age-specific catchabilities (with modified *q* for younger ages by setting *q* at 0.1 for age 1, at 0.5 for age 2 and at 1 for older fish) could be observed (Figure 12), but the sensitivity analysis showed that this option to be less effective when tested with AIC.

Conclusion

SURBAR provides an effective tool for assessment of whiting in Division 6a, if not as the main assessment method, then as a supporting method. The model output is to some extent dependent on which surveys are included, but the main trends are similar for the different survey configurations. The three-survey configuration was considered to be representative of the population. The optimal parameter settings for the model were chosen in a sensitivity analysis, but they ultimately had little impact on the model performance.

References

ICES. 2012. Report of the Benchmark Workshop on Western Waters Roundfish (WKROUND), 22–29 February 2012, Aberdeen, UK. ICES CM 2012/ACOM:49, pp. 283.

ICES. 2020a. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1140 pp. http://doi.org/10.17895/ices.pub.6092

ICES. 2020b. Working Group for the Celtic Seas Ecoregion (WGCSE). ICES Scientific Reports. 2:40. 924 pp. http://doi.org/10.17895/ices.pub.5978

ICES. 2020c. Benchmark Workshop for Demersal Species (WKDEM). ICES Scientific Reports. 2:31. 136 pp. http://doi.org/10.17895/ices.pub.5548

Needle, C. L. 2015. Using self-testing to validate the SURBAR survey-based assessment model. Fisheries Research, 171: 78–86.

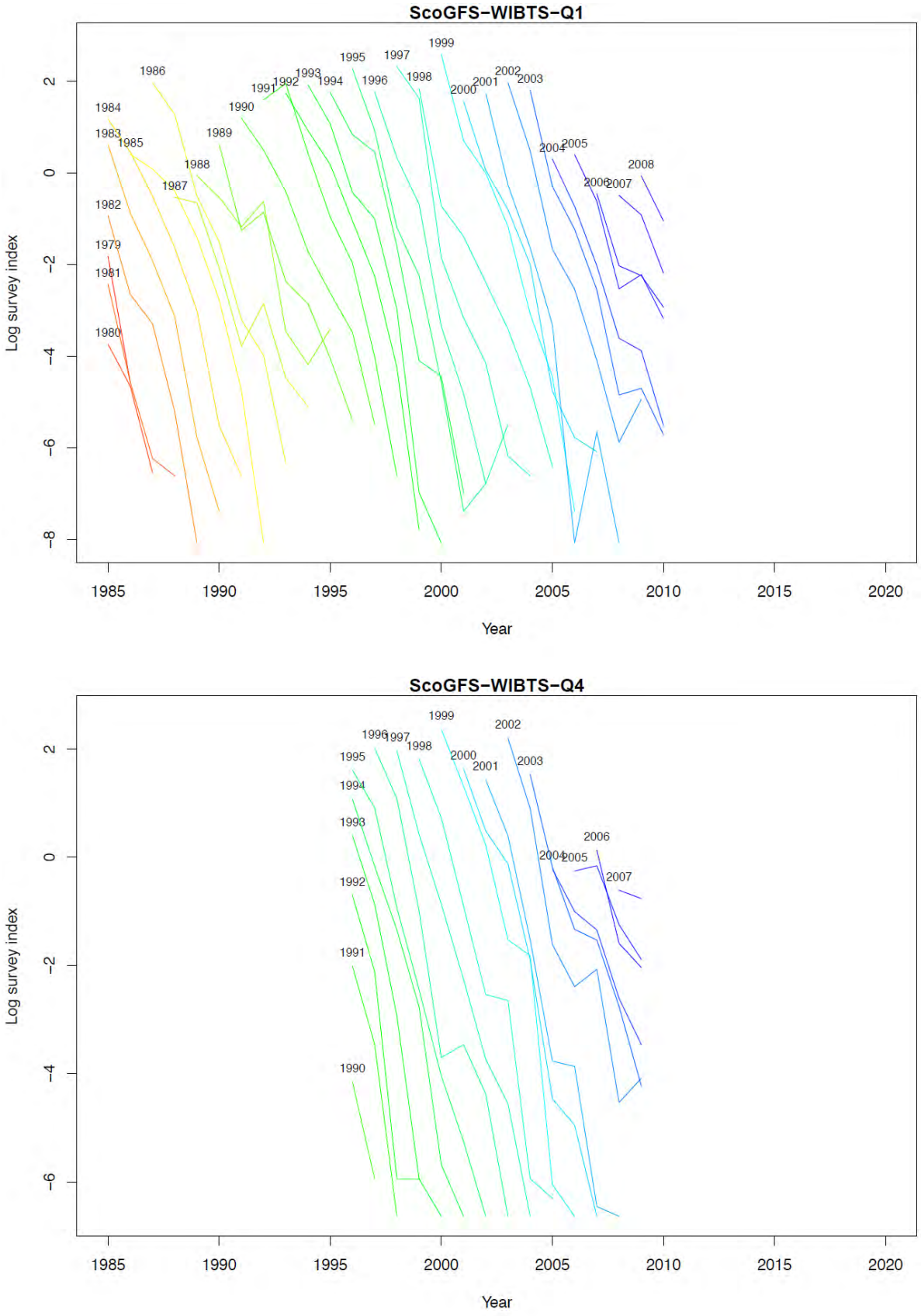


Figure 1. Whiting in Division 6a. SURBAR diagnostic plot: log abundance indices, by year with a line for each cohort, for each of the three survey indices. The spawning date of each cohort is indicated at the start of each line.

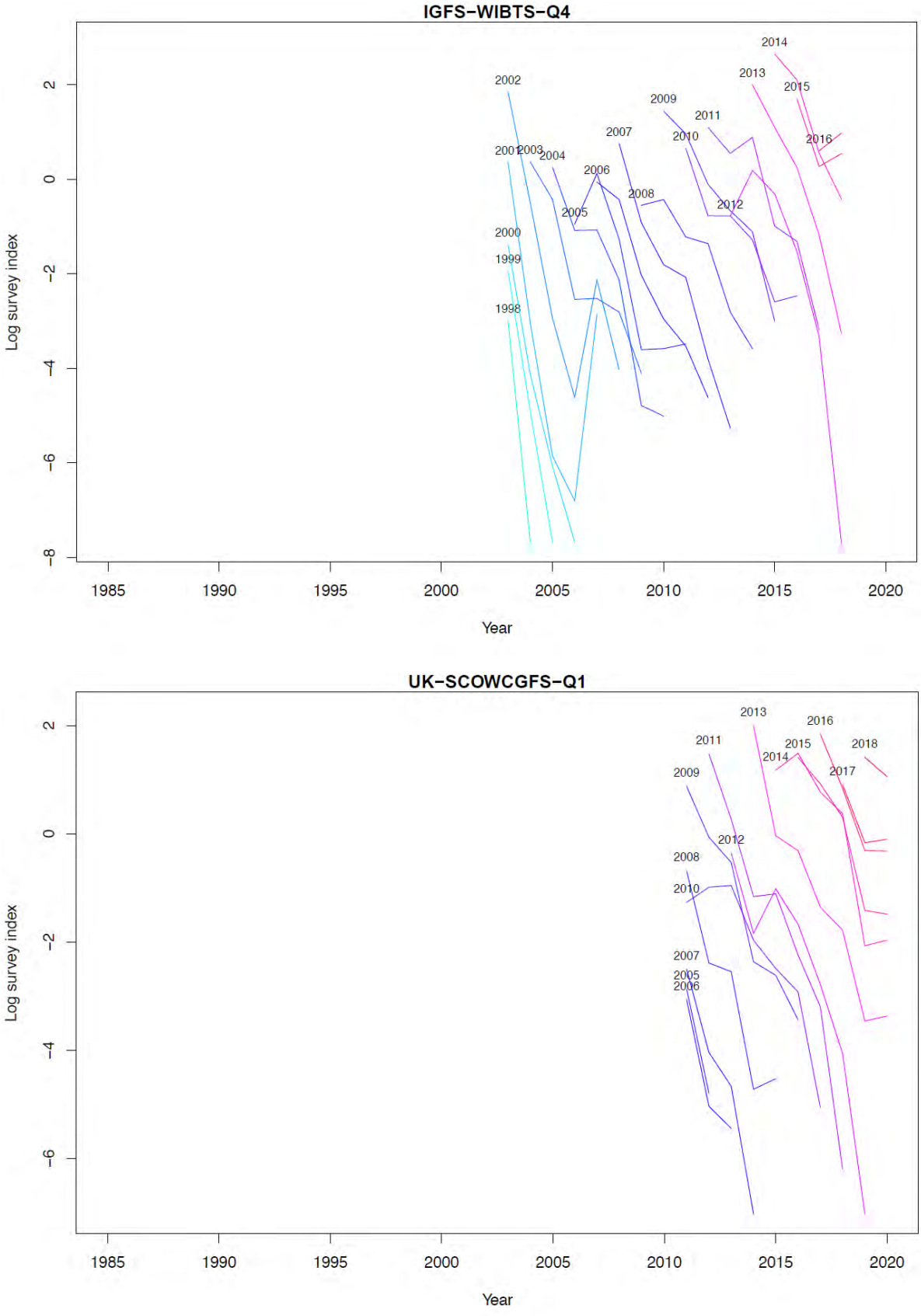
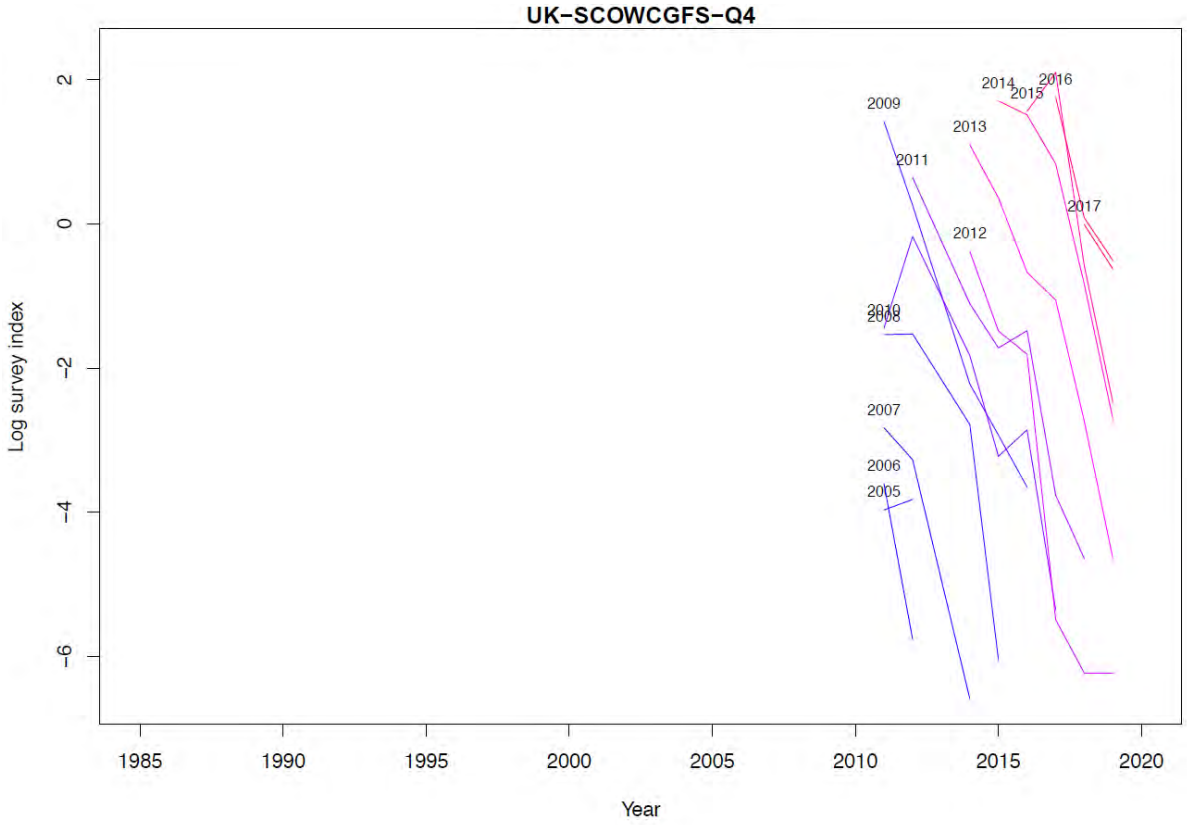


Figure 1. Continued.



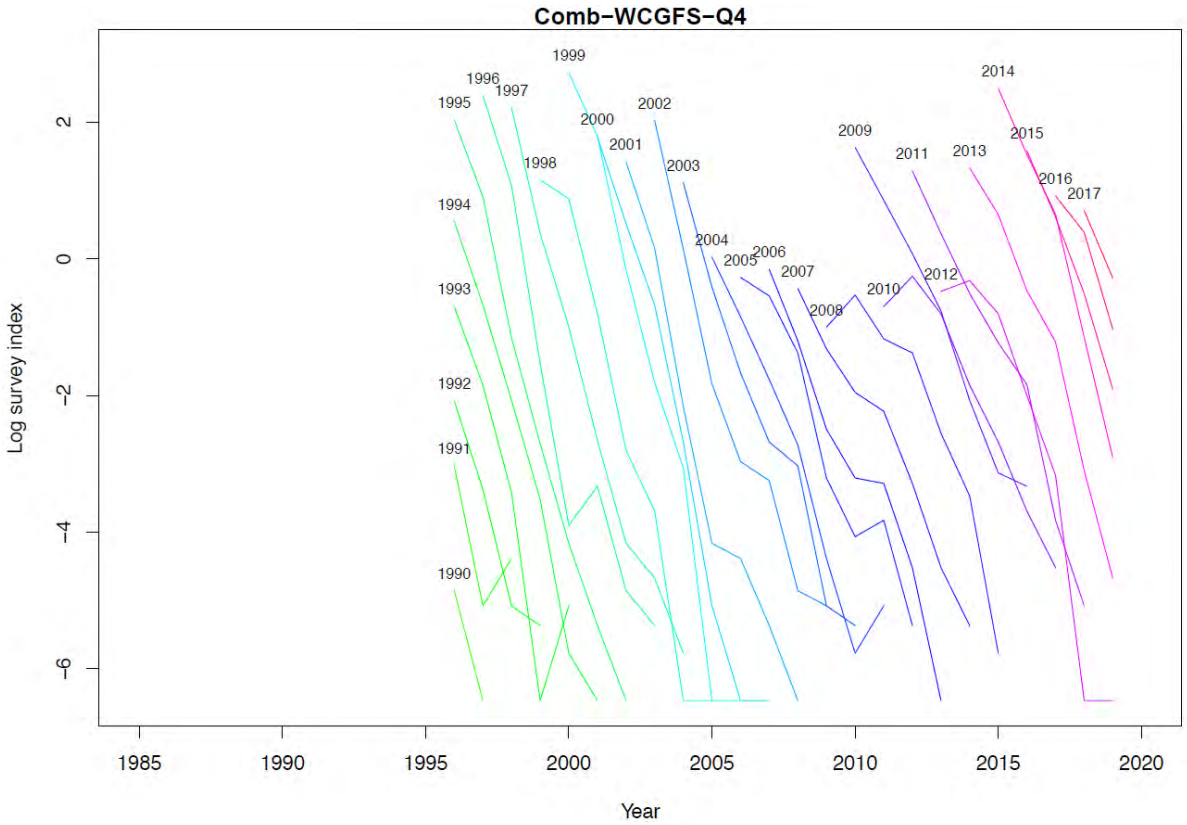


Figure 1. Continued.

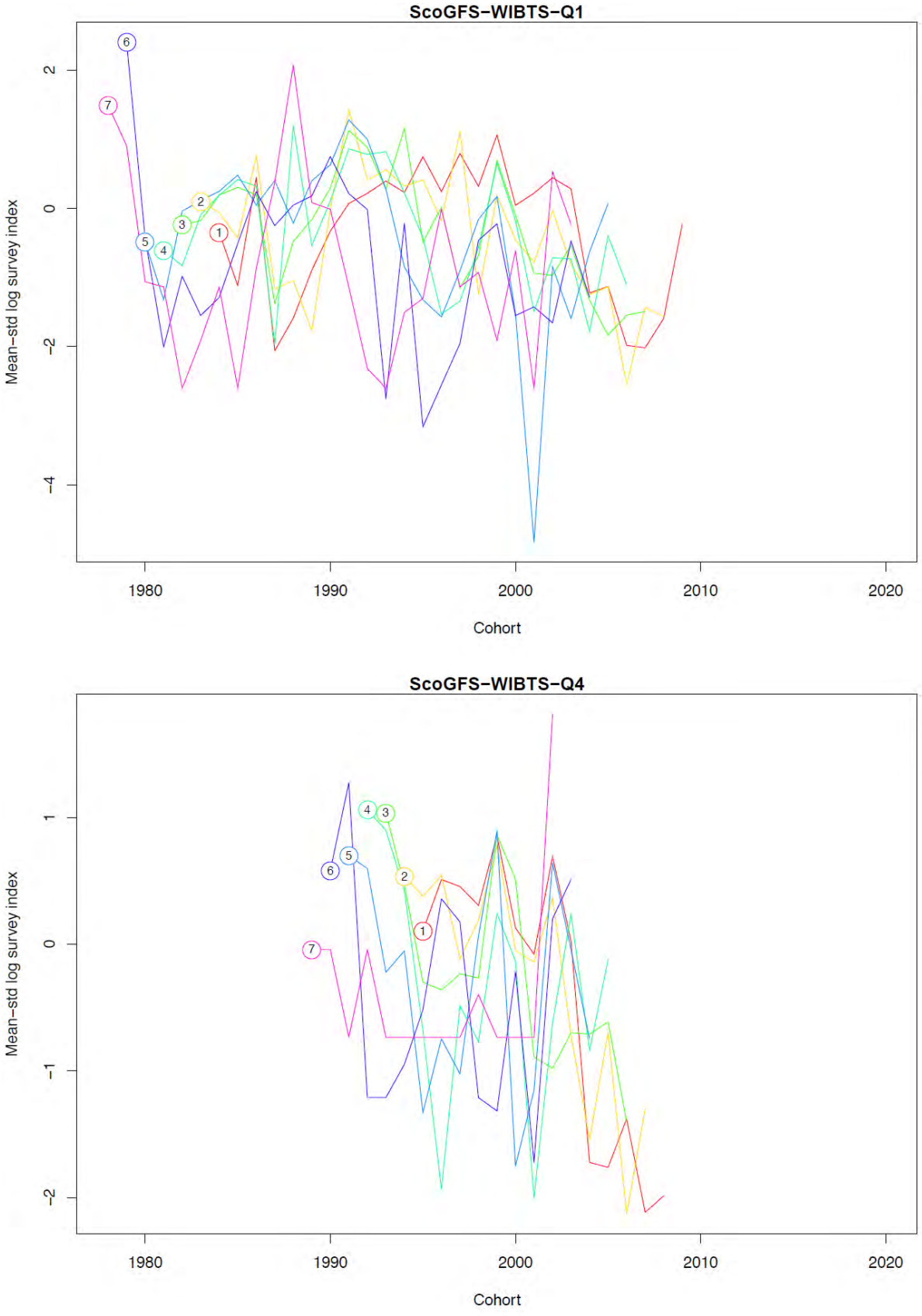


Figure 2. Whiting in Division 6a. SURBAR diagnostic plot: log abundance indices, by cohort with a line for each age, for each of the five survey indices. Colour-coded ages are indicated by a label at the start of each line.

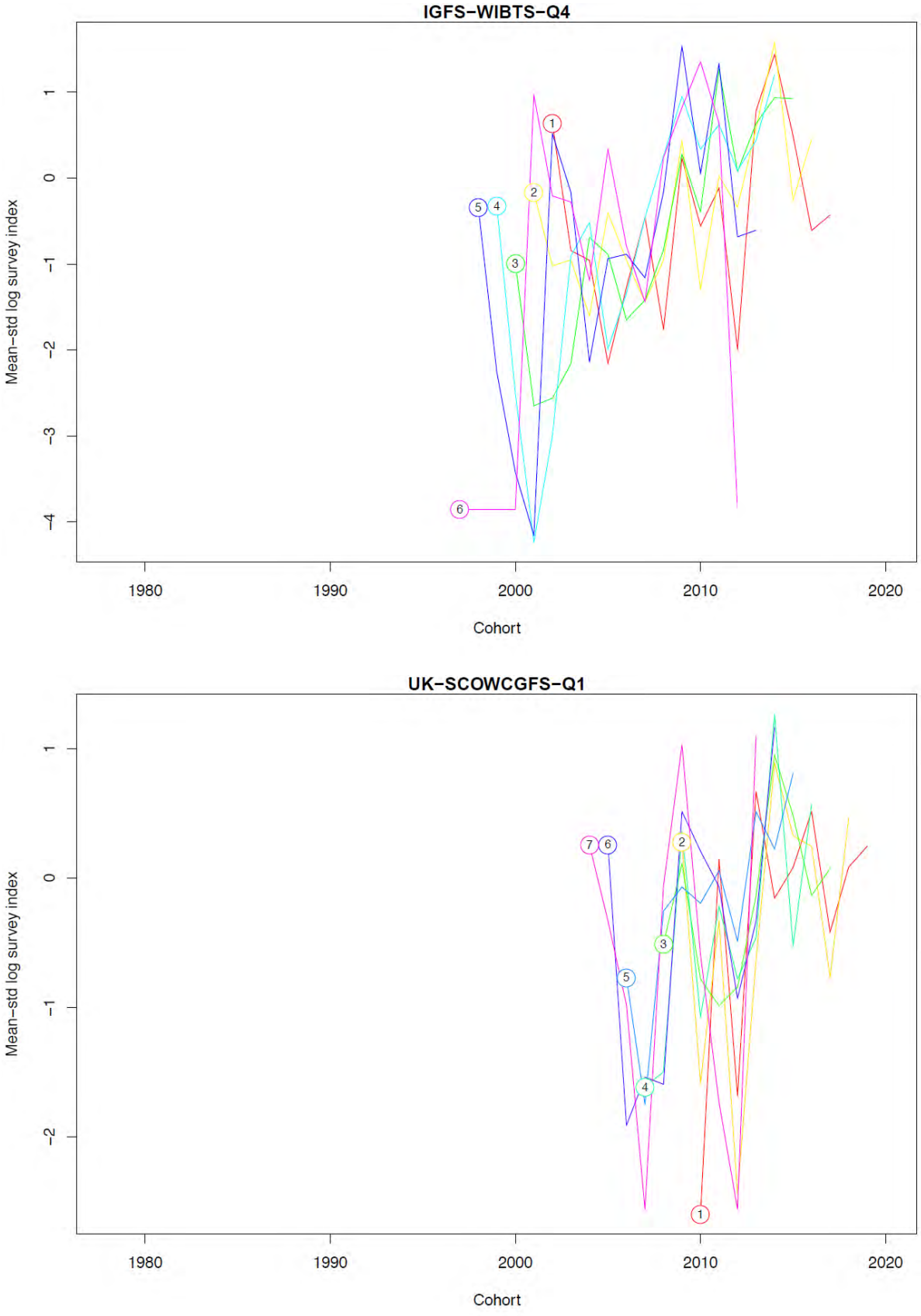
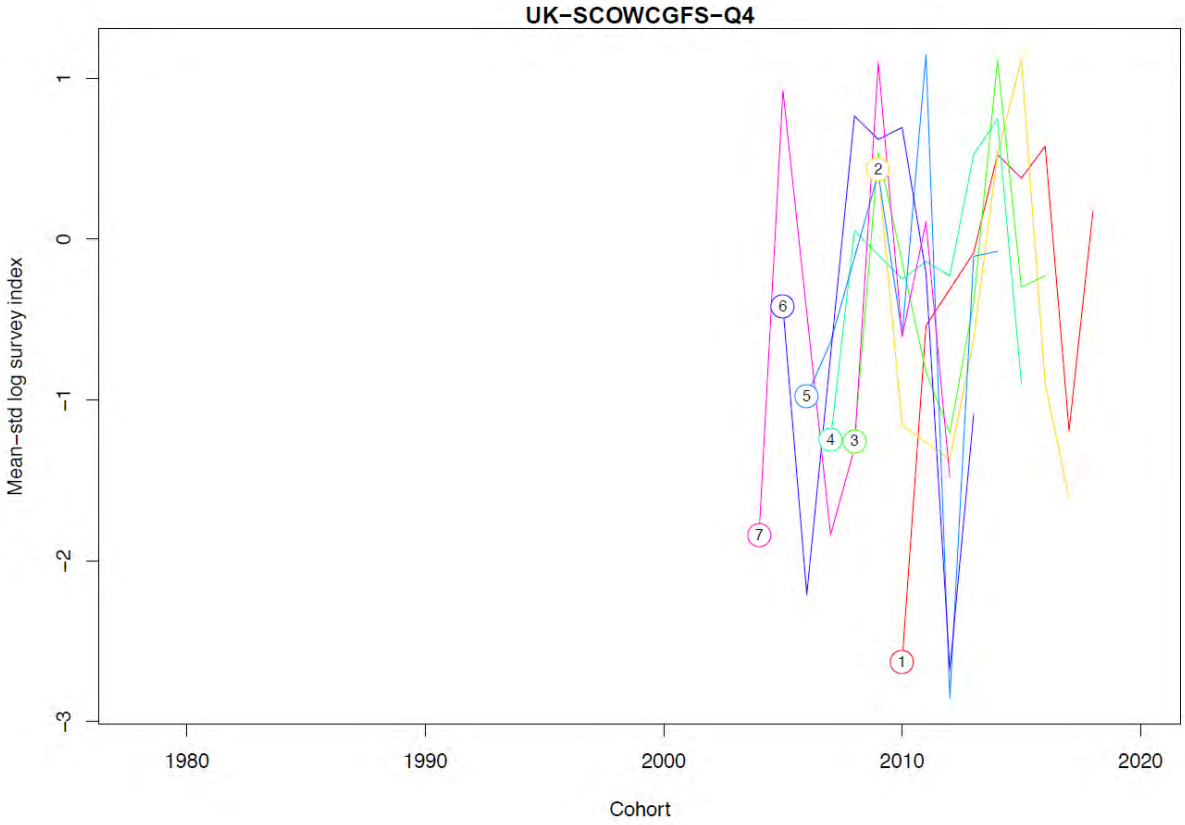


Figure 2. Continued.



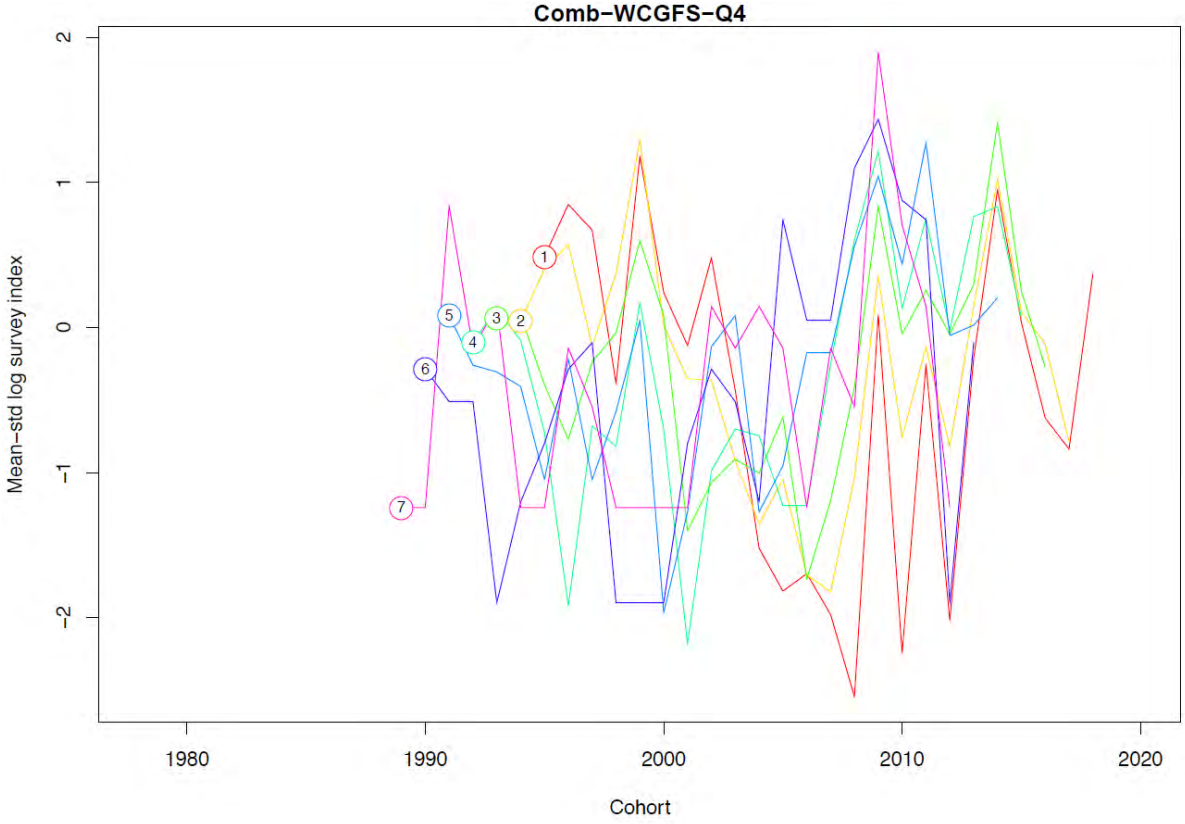


Figure 2. Continued.

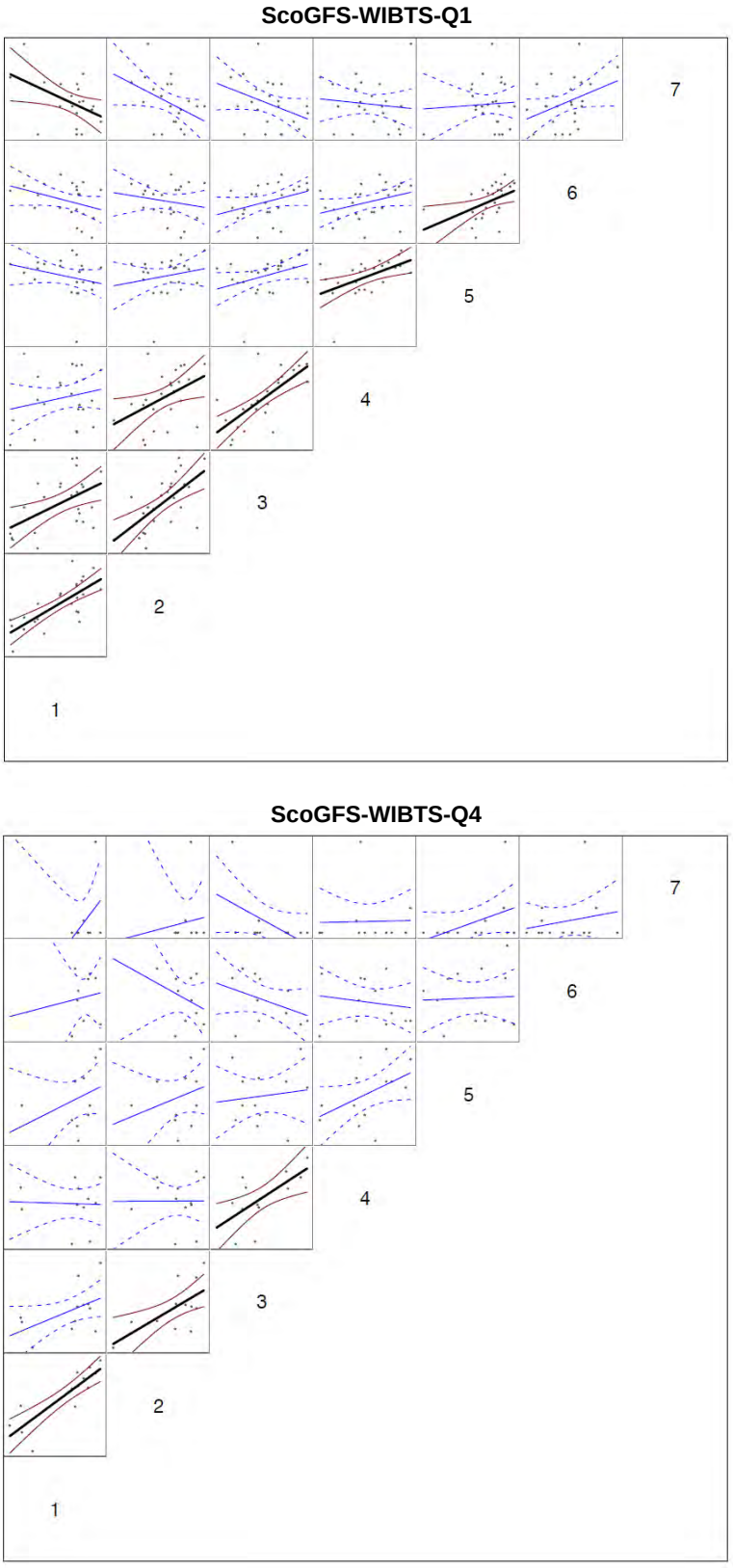


Figure 3. Whiting in Division 6a. SURBAR diagnostic plots for five survey series, comparing index values at different ages for the same year classes (cohorts). In each plot, the straight line is a normal linear model fit: a thick line (with black points) represents a significant ($p < 0.05$) regression, while a thin line (with blue points) is not significant. Approximate 95% confidence intervals for each fit are also shown.

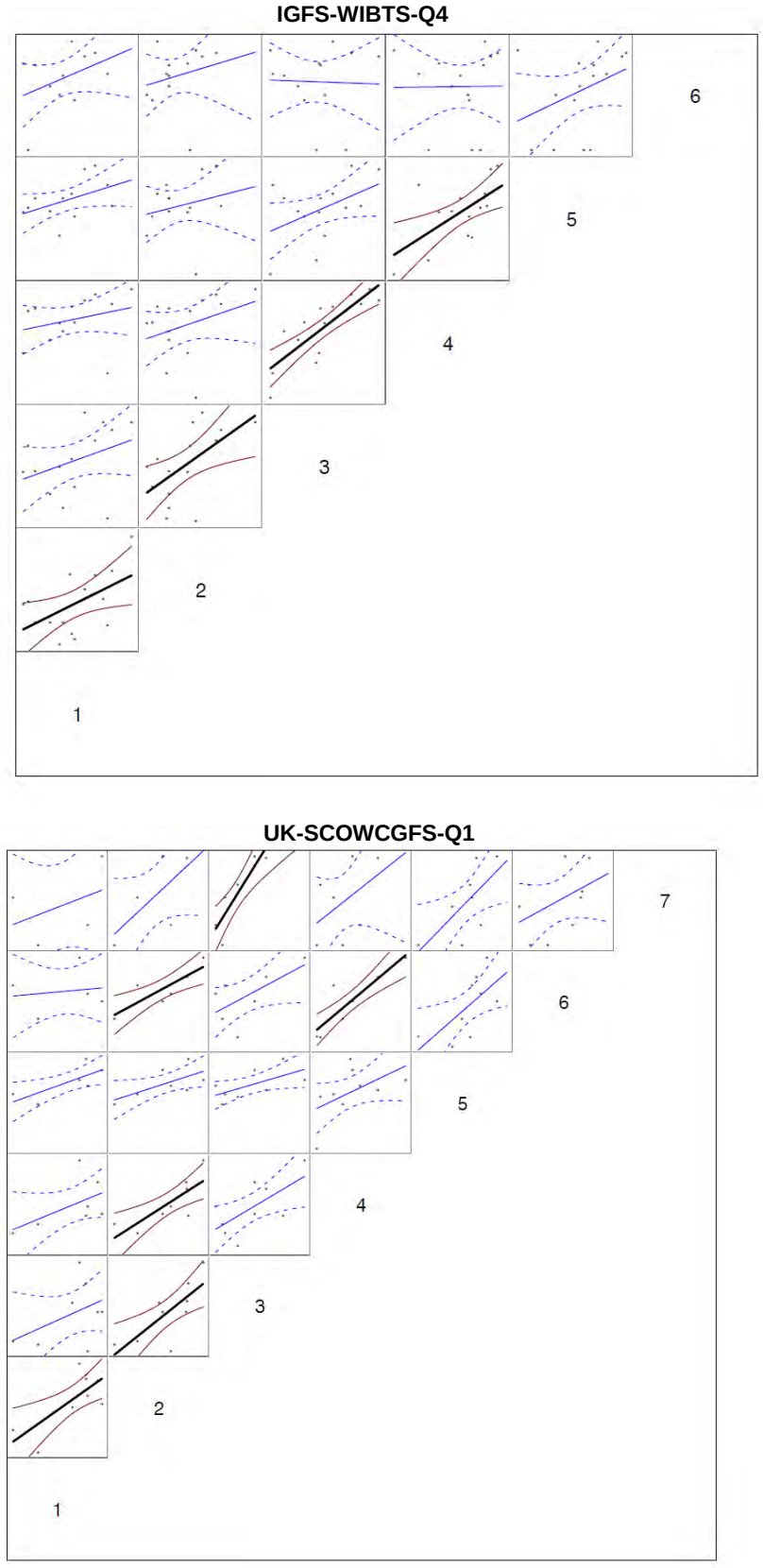


Figure 3. Continued.

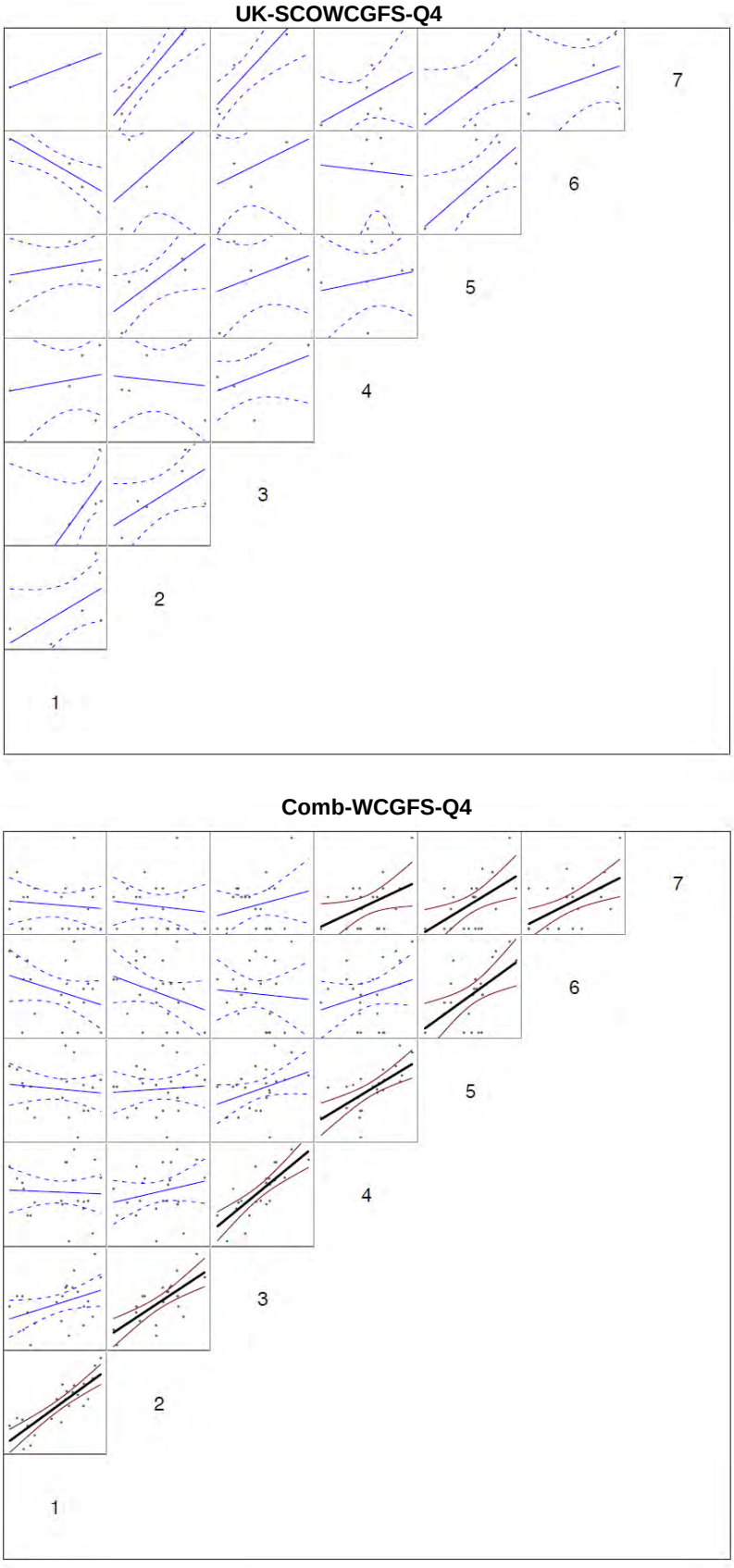


Figure 3. Continued.

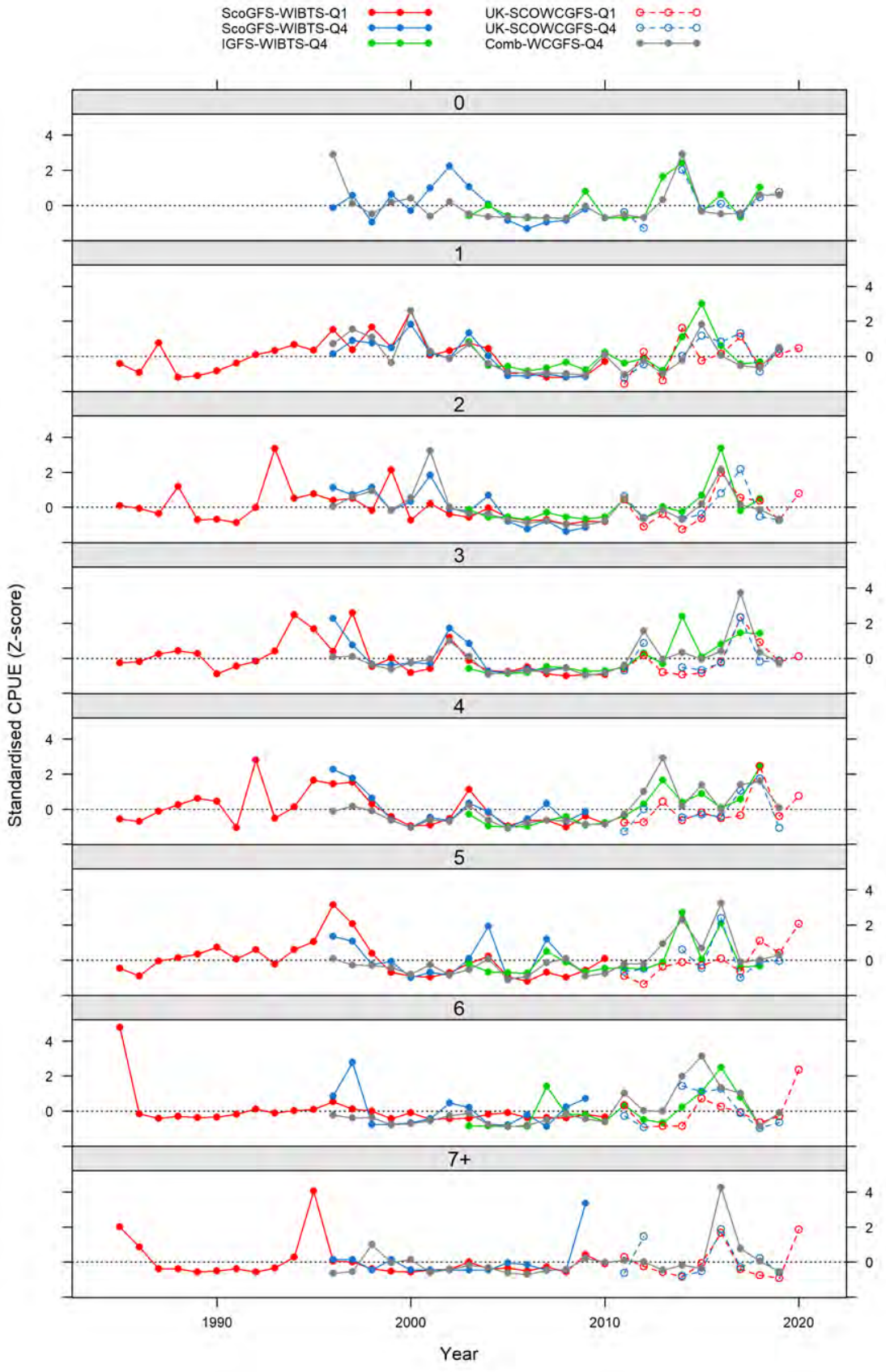


Figure 4. Whiting in Division 6a. Scaled survey indices (Z-scores) from the six survey series. The abundance index for IGFS-WIBTS-Q4 is shown only for ages 0−6.

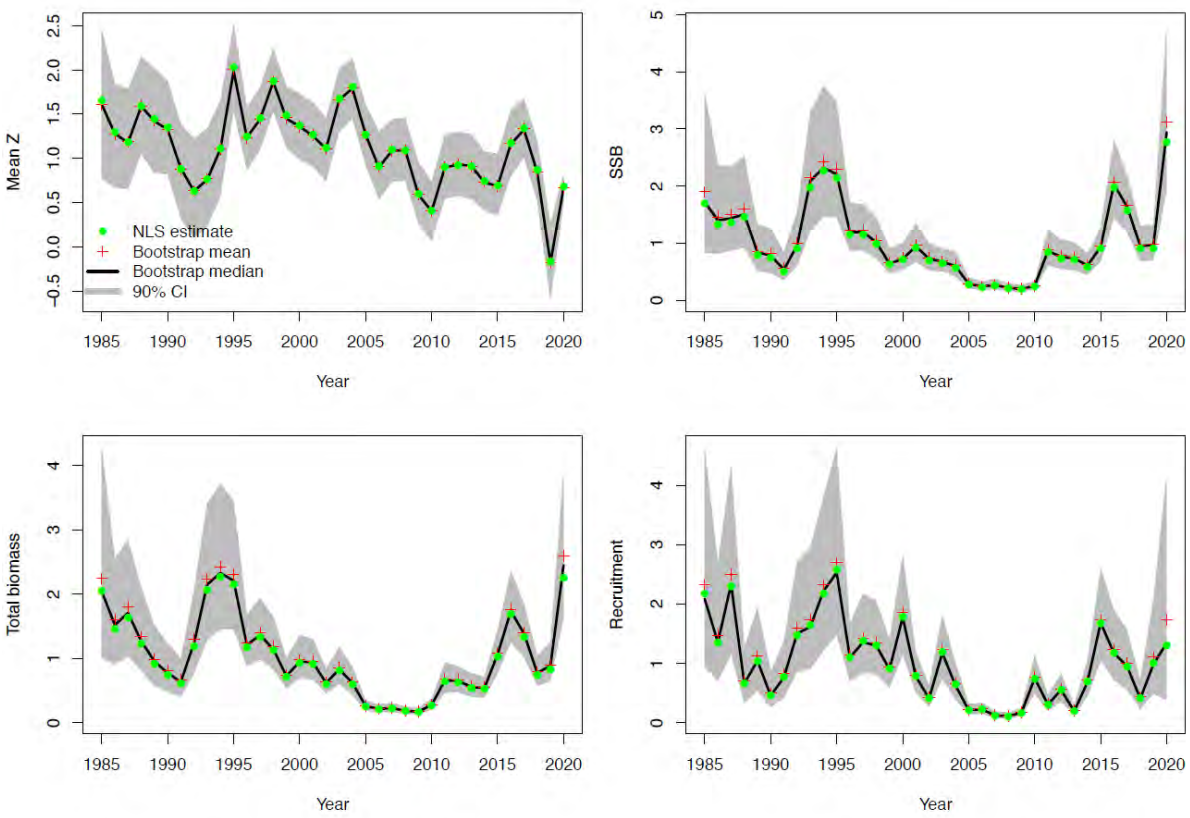


Figure 5. Whiting in Division 6a. Results of SURBAR analysis (see legend on mean Z plot for details). SSB, TSB and recruitment are relative estimates.

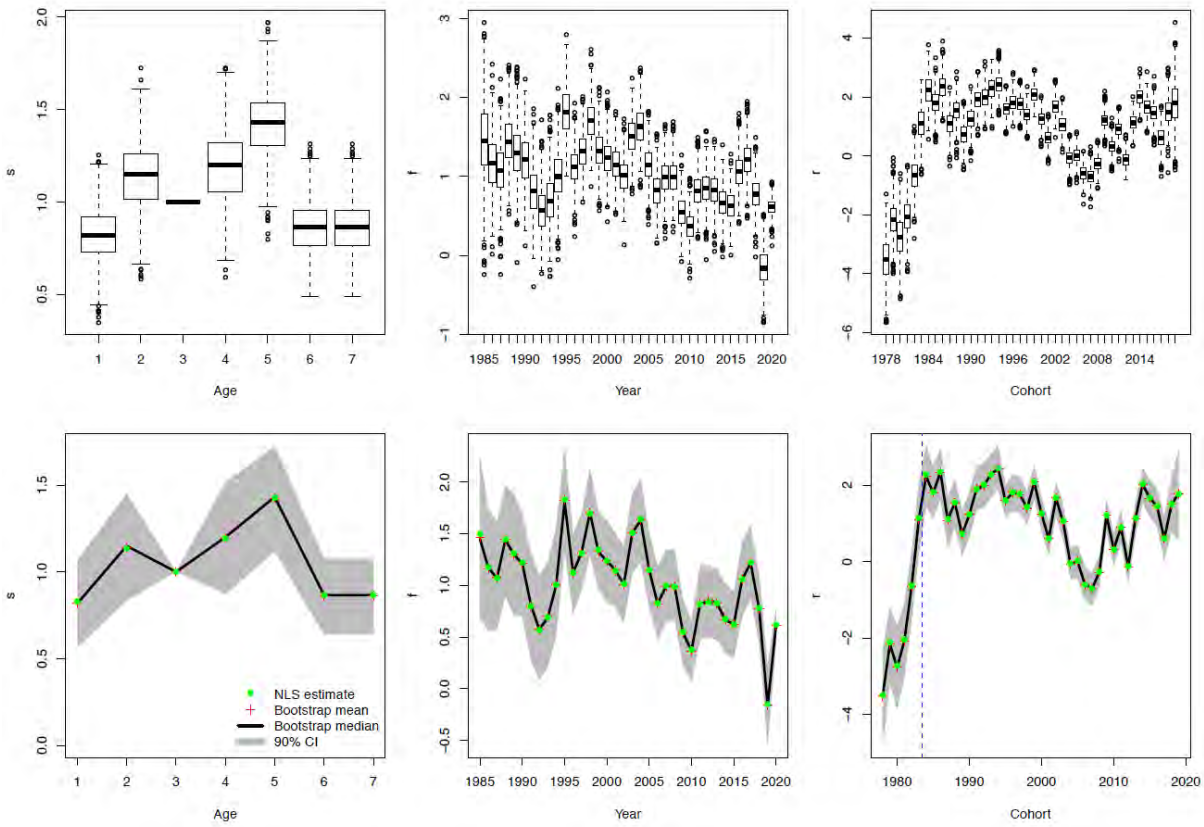


Figure 6. Whiting in Division 6a. Parameter estimates from SURBAR analysis. Top row: age, year and cohort effect estimates as box-and-whisker plots. Bottom row: estimates as line plots with 90% confidence intervals.

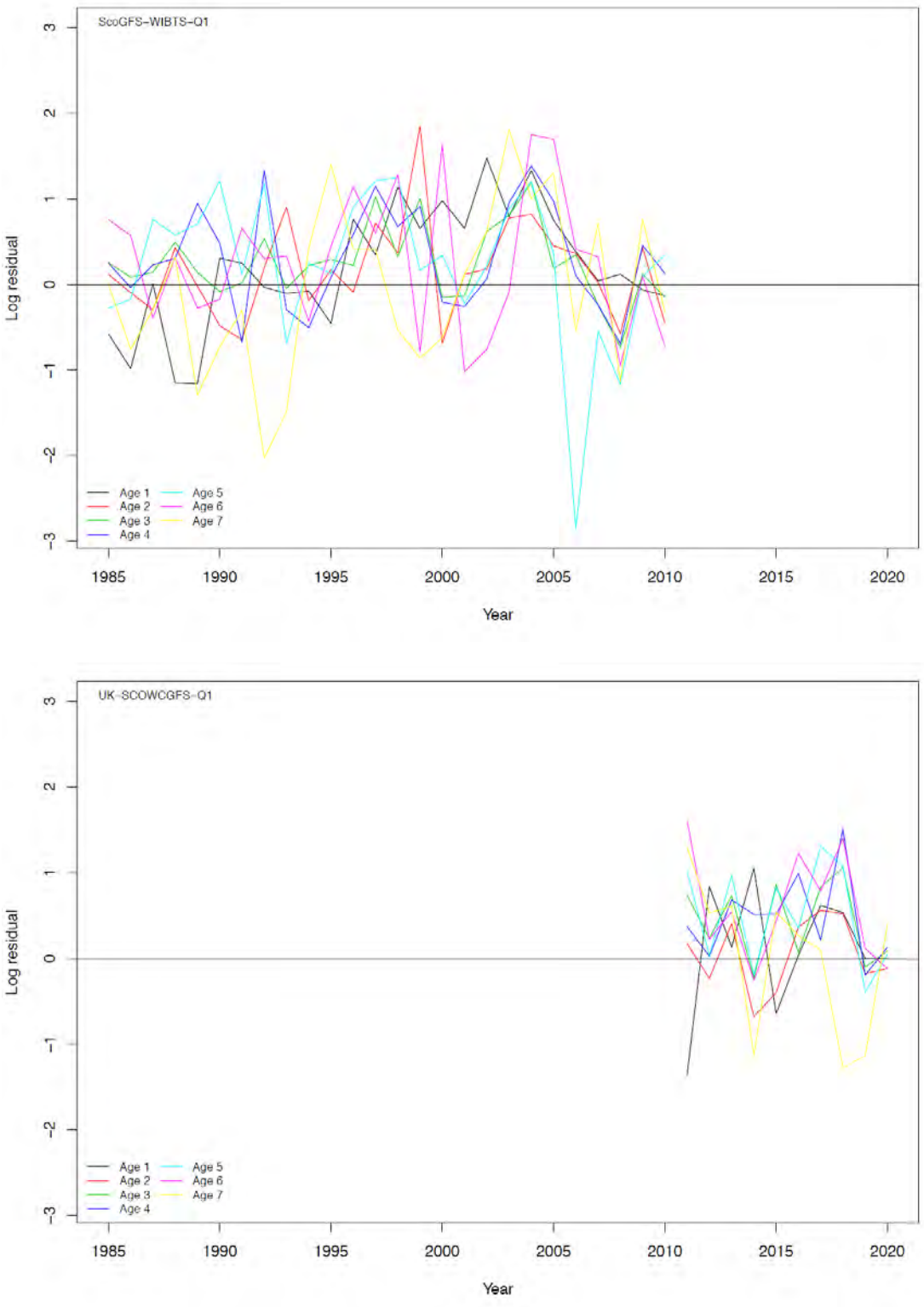


Figure 7. Whiting in Division 6a. Log survey residuals from SURBAR analysis. Ages are colour-coded.

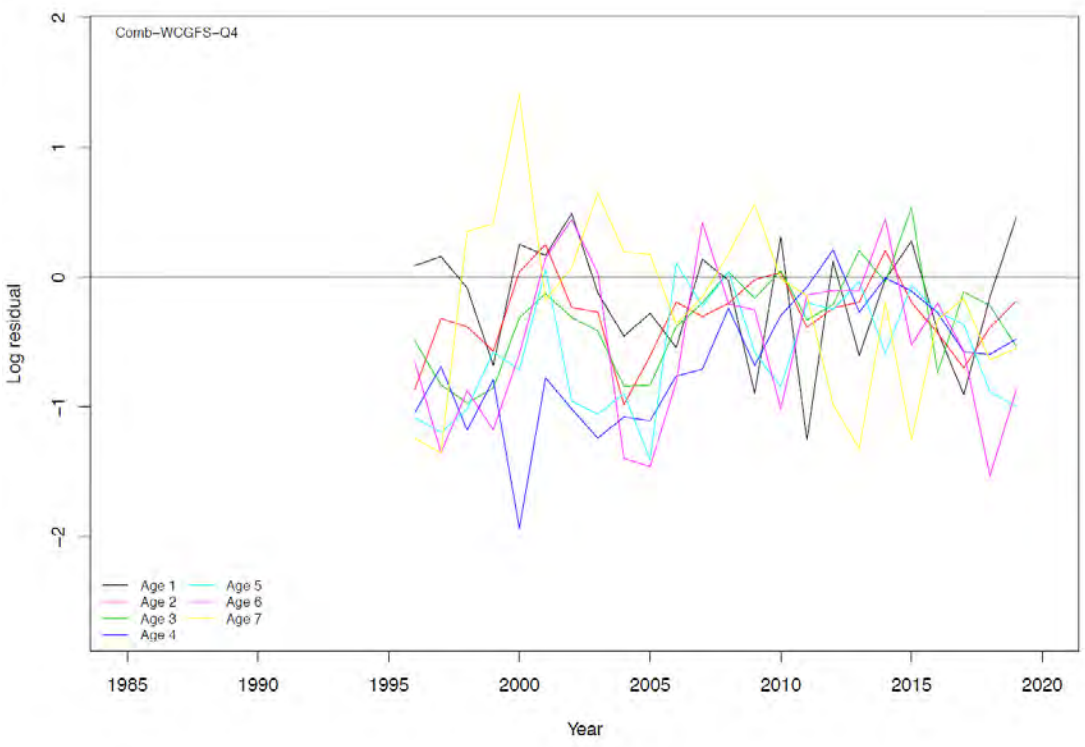


Figure 7. Continued.

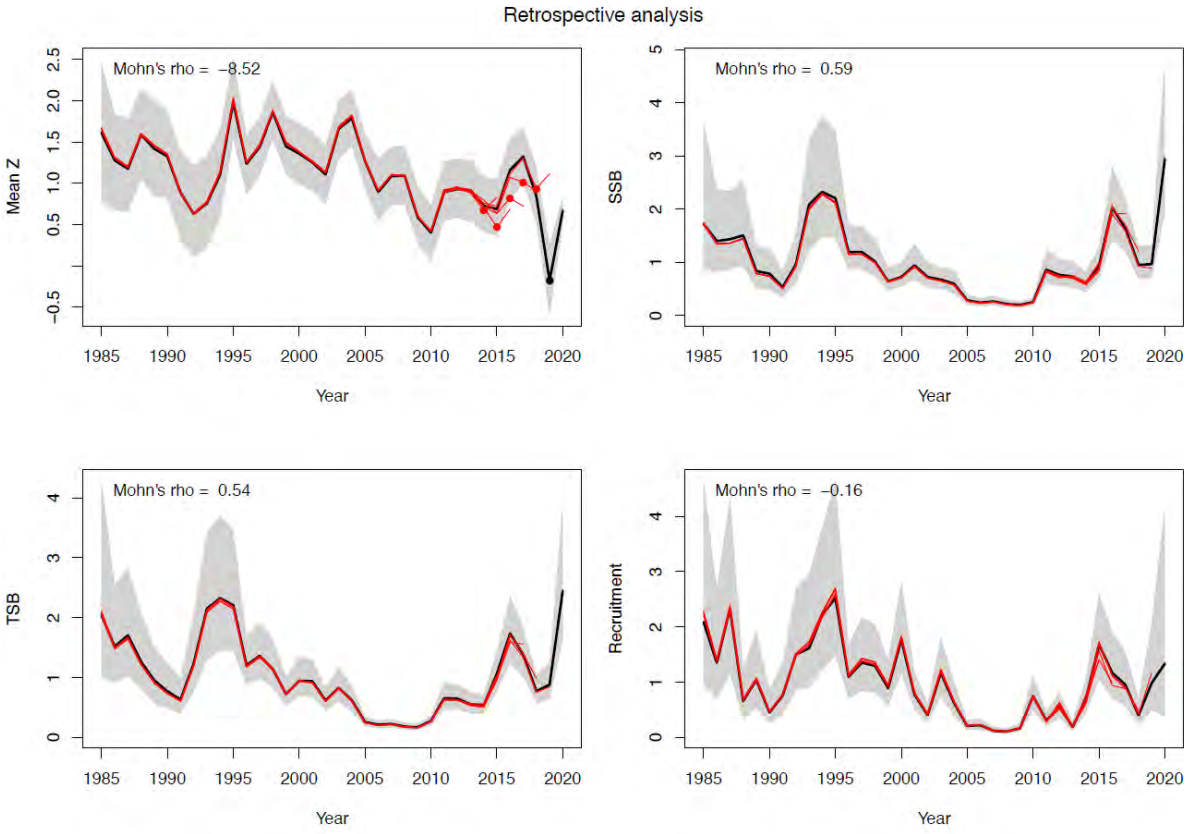


Figure 8. Whiting in Division 6. Results of retrospective SURBAR analysis. For each plot, the black line gives the full time-series estimate (with 90% confidence intervals shown by a grey band), while the red lines show the retrospective estimates. The points on the mean Z plot show the last true data-derived estimate for each time-series (the final point is based on a three-year mean). SSB, TSB and recruitment are relative estimates.

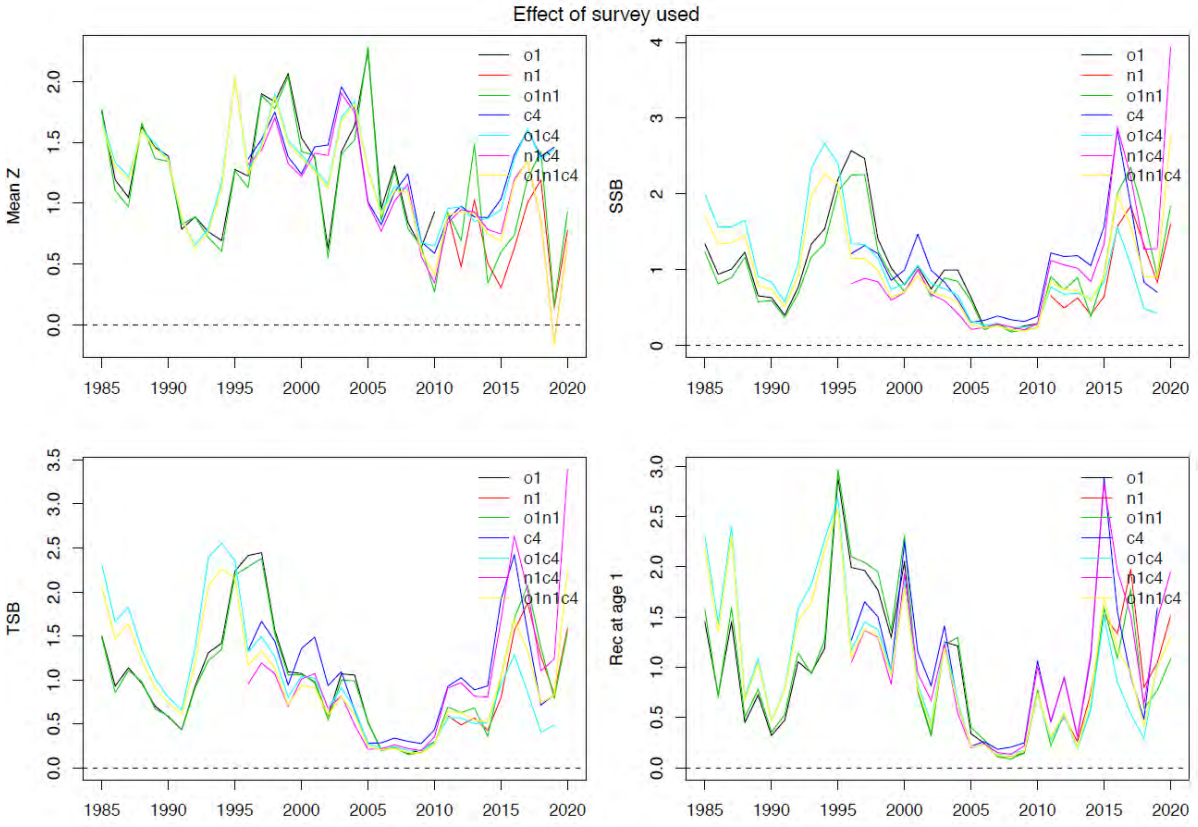


Figure 9. Whiting in Division 6a. Summary plots for different survey configurations in earlier surveys (upper panel) and recent surveys (lower panel). o1= old Scottish Q1, n1= new Scottish Q1, c4= combined Q4.

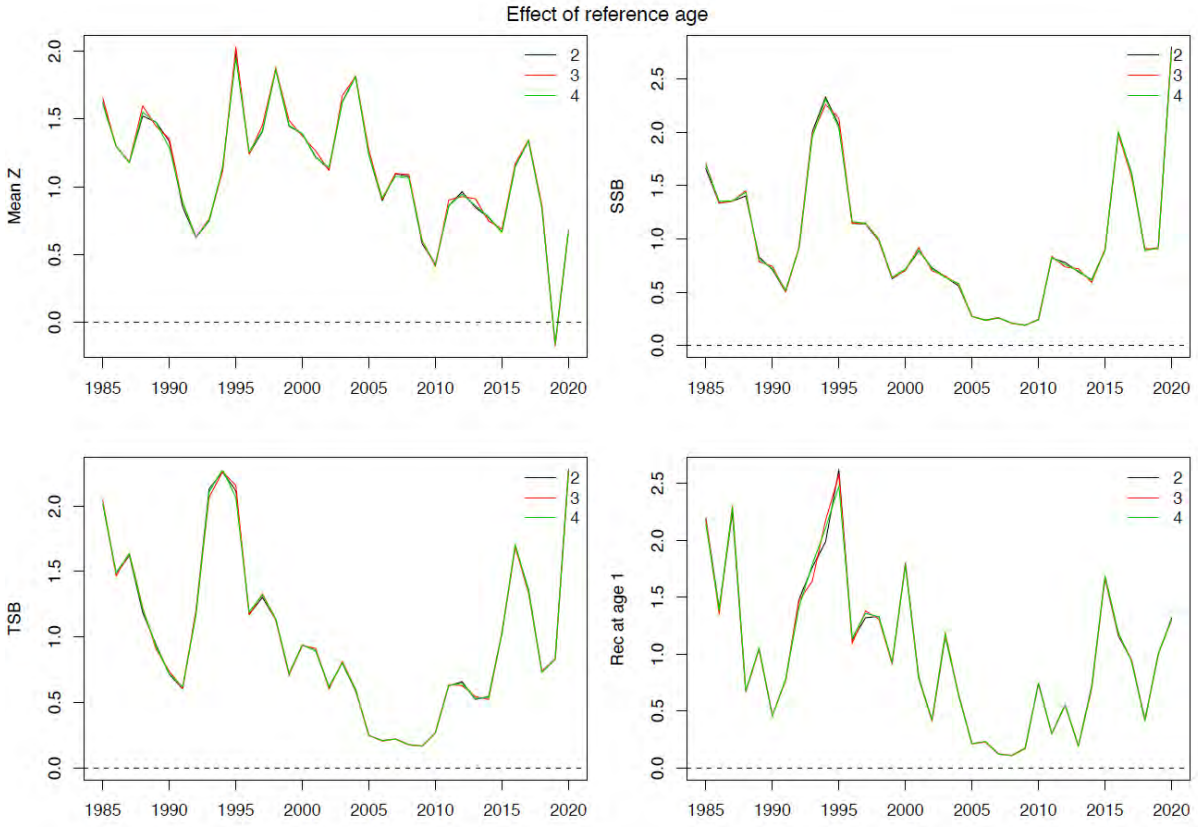


Figure 10. Whiting in Division 6a. The effect of reference age on the model performance.

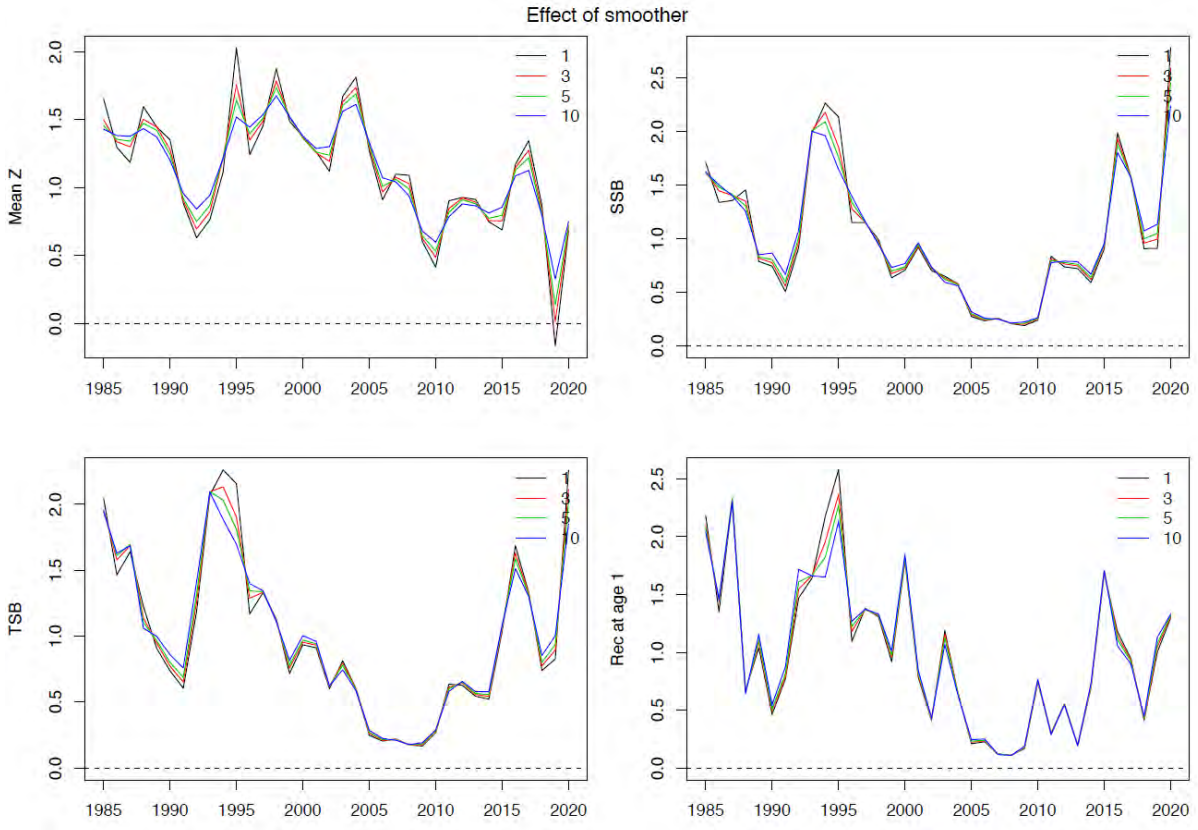


Figure 11. Whiting in Division 6a. The effect of lambda on the model performance.

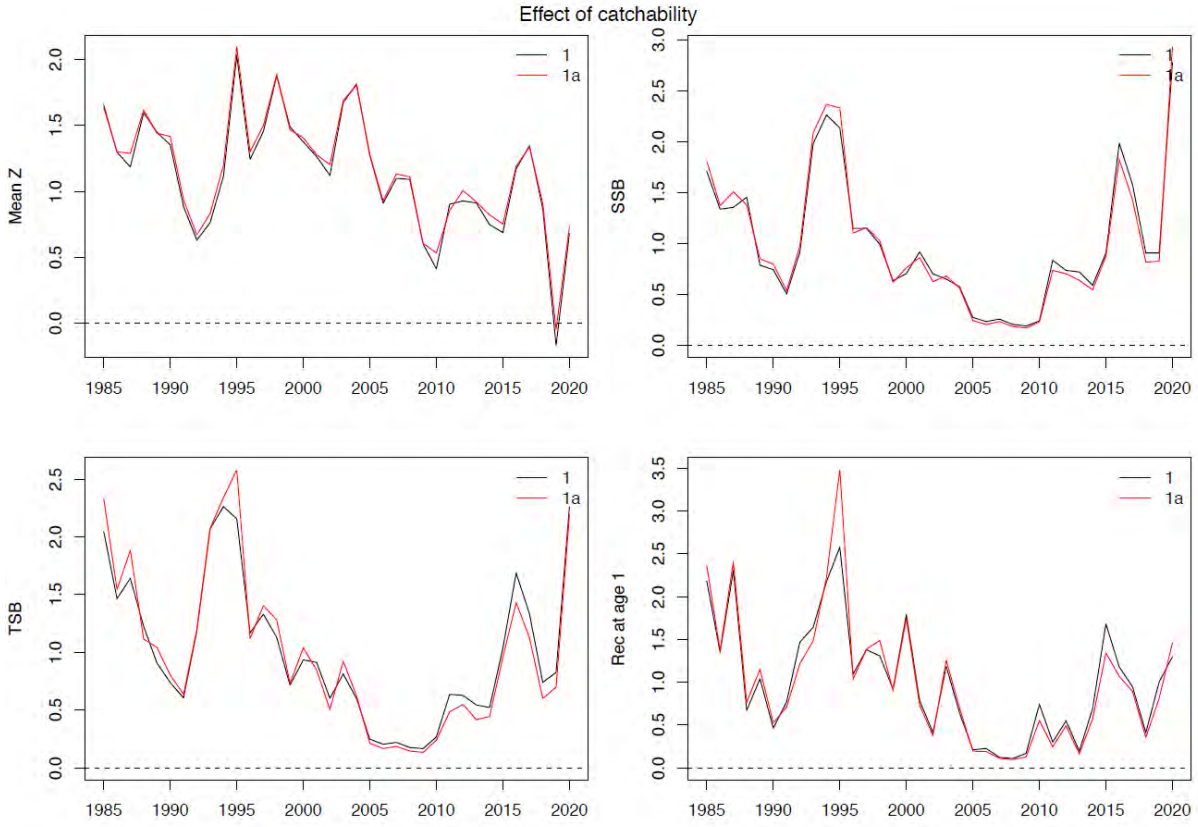


Figure 12. Whiting in Division 6a. The effect of single catchability (q=1, denoted as "1") vs. age-specific catchability (denoted as "1a") (lower panel) on the model performance.

WD 5: SAM assessment model for whiting in Division 6a (West of Scotland)

Niall G. Fallon[1], Tanja Miethe[1], Anders Nielsen[2], and Helen Dobby[1]

[1]Marine Scotland Science, 375 Victoria Road, AB11 9DB, Aberdeen, UK

[2]DTU AQUA, Kemitorvet Building 201, 2800 Kgs. Lyngby, Copenhagen, Denmark

1 Introduction

SAM, is a state-based assessment model described in detail by (Nielsen and Berg, 2014). It connects observed states (*log*-transformed survey indices and catches) to unobserved states (*log*-transformed stock size, fishing mortality). The underlying process in the model is considered as the unobserved random variables.

SAM allows for uncertainty in the observed states and produces estimates of the unobserved variables without the need to specify variances directly. Instead the distribution of process error can be defined. Prediction noise is assumed to be Gaussian with mean zero, and three variance parameters (recruitment, other age groups, fishing mortality). The component of prediction noise relating to stock size-at-age is assumed to be uncorrelated. A correlation structure for prediction noise in fishing mortalities-at-age can be specified. The model allows for time-varying selectivity which determines fishing mortality-at-age.

The observation function consists of catch equations for catch and survey fleets. Catchabilities in fleets can be coupled across age groups. Measurement error is assumed to be Gaussian with mean zero. Each data source (catch, survey indices Q1 & Q4) had its own covariance matrix. Where autocorrelation is implemented, parameters can be coupled across age groups. Model parameters are estimated from the observations, and the unobserved random variables can be predicted, conditioned on the observations. Laplace approximation is used to calculate the joint likelihood of observed and unobserved states. The software used to solve the high-dimensional non-linear models includes automatic differentiation and Laplace approximation.

2 Methods & Results

2.1 Base Model Configuration

In this section the Base SAM Model settings for whiting in Division 6.a are described. All of the investigations into model sensitivity, and the improvement of the overall model fit (Section 2.2) were compared to the following configuration. The minimum age in the assessment was set to 0 (model recruitment estimates at age 0). The maximum age was 7, representing a plus group. The stock recruitment relationship was modelled as a plain random walk.

The SAM model was fitted to catch data (catch total numbers-at-age), and three age-based survey indices (WCIBTS Quarter 1, UK-SCOWCGFS Quarter 1 with variance estimates, and a modelled Quarter 4 index), as well as input biological parameters estimated for the stock (i.e. natural mortality-at-age, maturity-at-age, and stock weights-at-age, both of which were updated as part of this benchmark

process) from survey data. The time range of the assessment included catch data from 1985 onwards, and survey data from 1985 for Q1 and from 1996 for Q4. There is no catch scaling included in the Base Model.

Due to a lack of data, some input biological parameters could not be estimated: stock weights-at-age 0 (all years), discard weights-at-age 0 (1985-2002), landing weights-at-age 0 (all years). In the Base Model configuration, the missing stock weights-at-age zero values were replaced with GAM-smoothed stock weights-at-age zero estimates based on Q4 survey data. Missing commercial weights-at-age zero were assumed to equal the mean catch weights-at-age zero.

Observed state process: Logarithms of total catches and survey indices were assumed to be independently distributed with error variance coupled for all ages in each fleet separately. The survey catchabilities were coupled only for the oldest two age groups in each survey separately (ages five and six for Q1, ages six and seven+ for Q4).

Unobserved state process: Fishing mortality states only the two oldest age groups, age six and seven+, were coupled. Process variance for fishing mortality was coupled across all age groups. The fishing mortality across ages was modelled with AR1 autocorrelation. Process variance of stock size was coupled for all ages except for age 0 (recruitment).

Table 1. SAM Base Model configuration settings. Where configuration settings are not specified, default configurations were used

CONFIGURATION SETTING	DETAILS
Assessment age range	0-7
Is maximum age considered a plus group	1 0 0 1
Coupling of the fishing mortality states	0 1 2 3 4 5 6 6
Correlation of fishing mortality across ages	AR1
Coupling of the survey catchability parameters	$\begin{pmatrix} - & - & - & - & - & - & - & - \\ - & 0 & 1 & 2 & 3 & 4 & 4 & - \\ - & 5 & 6 & 7 & 8 & 9 & 9 & - \\ 10 & 11 & 12 & 13 & 14 & 15 & 16 & 16 \end{pmatrix}$
Covariance structure for each fleet	Independent "ID" for all fleets
Stock recruitment code	0 (Plain Random Walk)
Number of years where catch scaling is applied	0
$\bar{F}$ range	2-4 (as per TSA assessment)

The Base Model estimates are summarised in Figure 1. Estimated catch and F2-4 follow declining trends over the course of the model time range. SSB and recruitment decline initially, with a period of relatively low value estimates between 2003 and 2011, before increasing again towards the end of the modelled period. There were some patterns observable in the Base Model one-observation-ahead fleet residuals (Figure 2). For the commercial fleet, the majority of residuals-at-age, mainly for fish between two and five years old, had positive values at the beginning of the modelled period (~1985-1992), moving to majority negative values between ~1997-2010. Larger catch residual values were observed in the youngest and oldest age classes (ages zero, one & seven+). Similarly, but to a lesser degree, WCIBTS Q1 tended towards positive values for the same early part of the modelled period, although there was less of a distinct pattern in the magnitude of residuals-at-age. The modelled Q4 index had a distinct band of negative residuals across all ages in the early-mid 2000s. There were no obvious patterns in the UK-SCOWCGFS Q1 index.

The leave-one-out analysis showed some level of disagreement in trends between the WCIBTS Q1 index and the others (Figure 3), particularly in estimation of SSB towards the latter part of the modelled period. The retrospective analysis (Figure 4) suggested that the model was reasonably robust to removal of up to five years of recent data (Rho_{rec} 0.14, Rho_{SSB} 0.21, Rho_{F} -0.15).

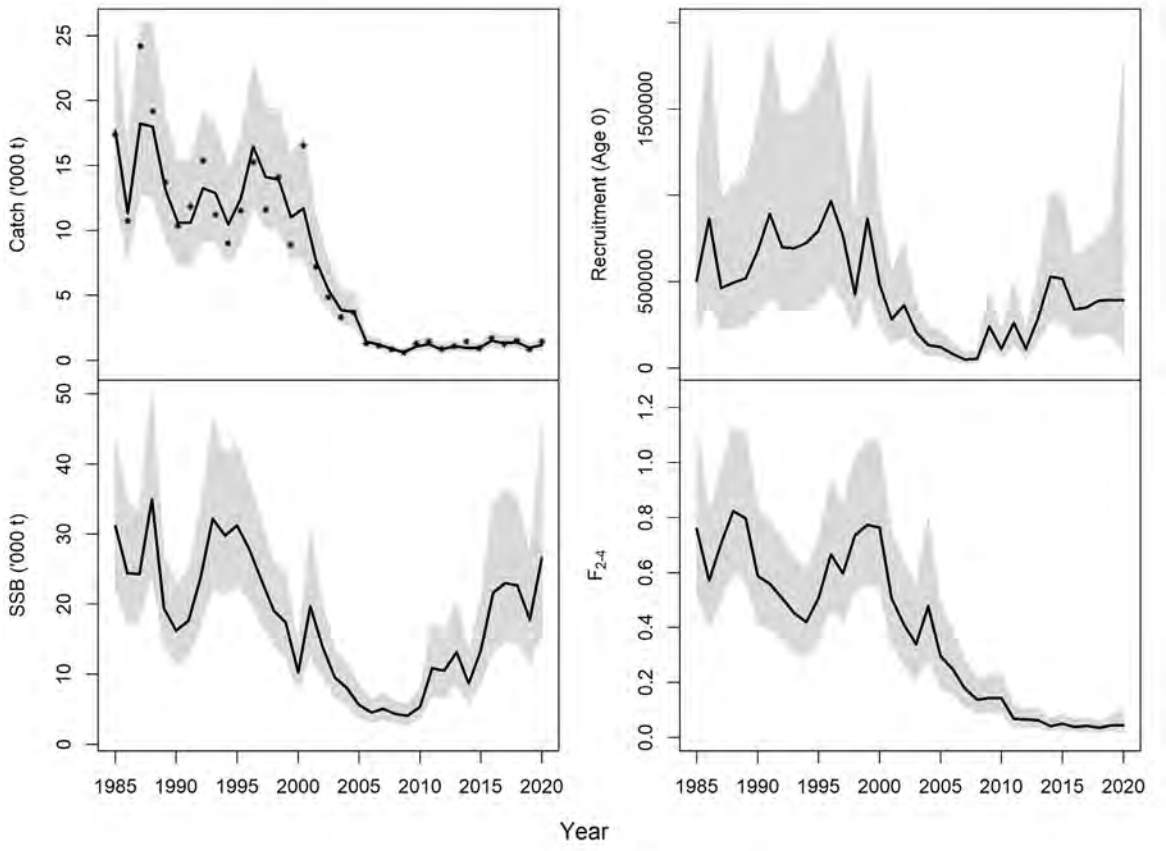


Figure 1. Summary of SAM estimates for the Base Model

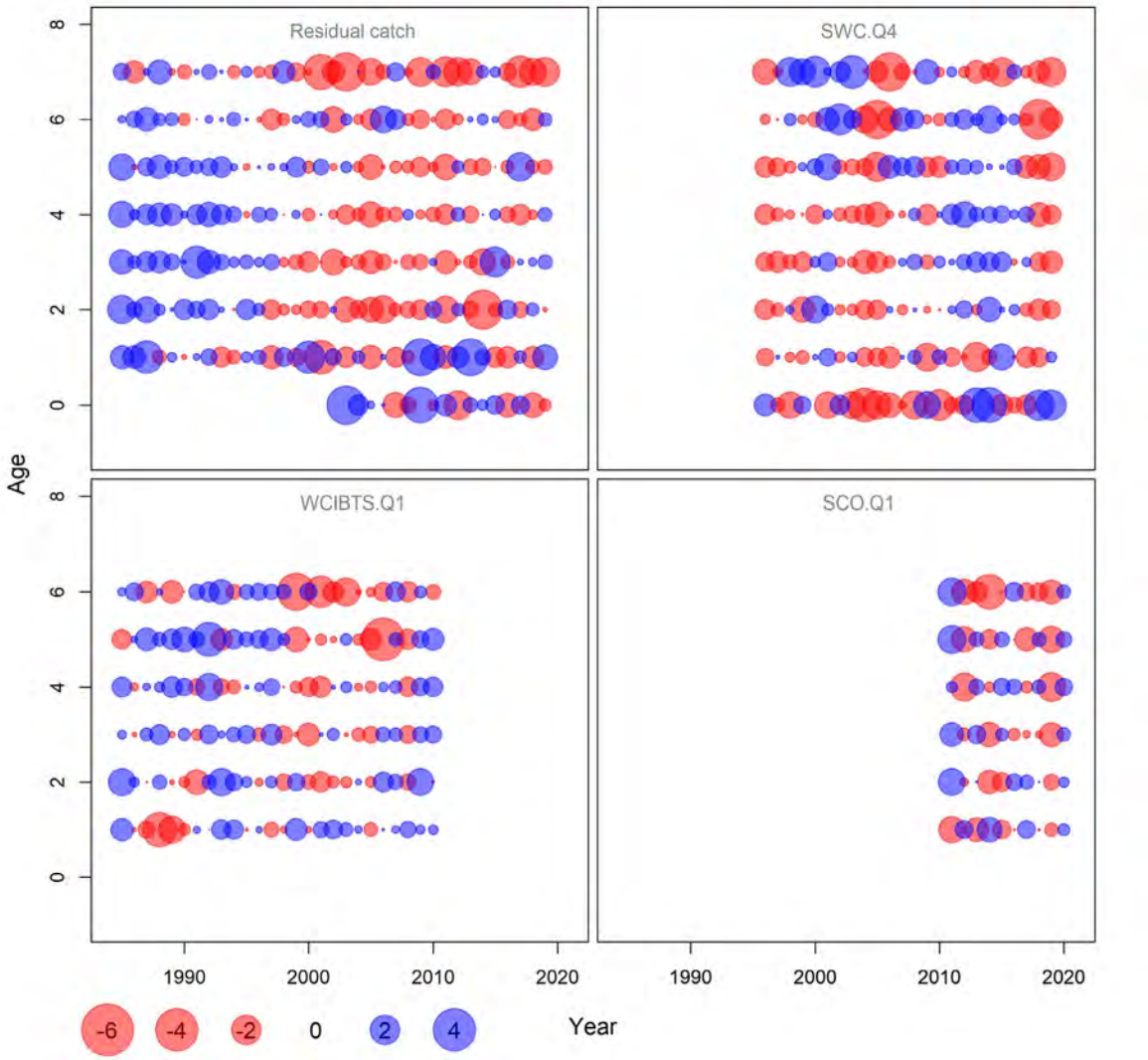


Figure 2. One-observation-ahead fleet residuals for SAM Base Model

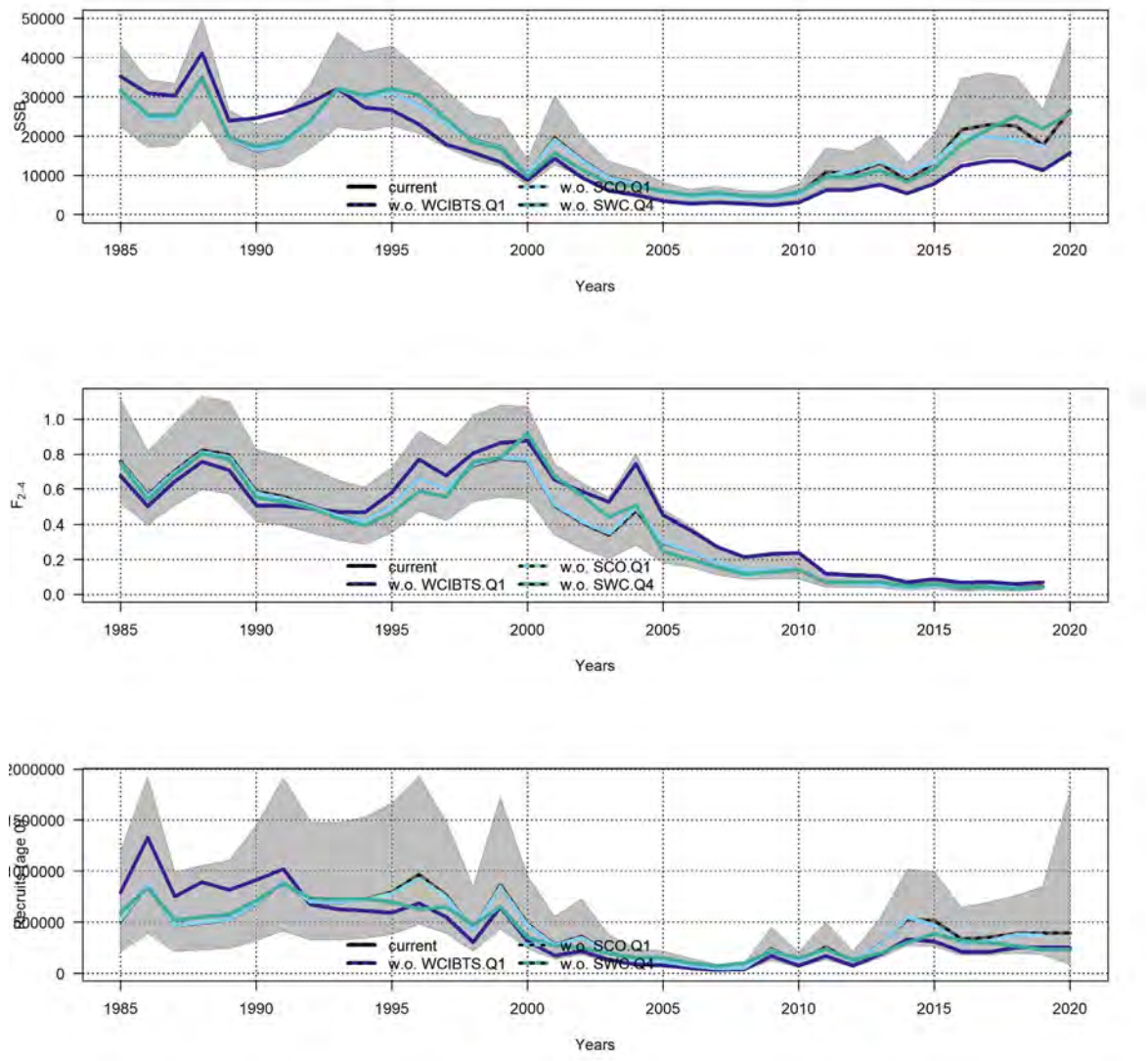


Figure 3. Leave-one-out analysis for the Base Model

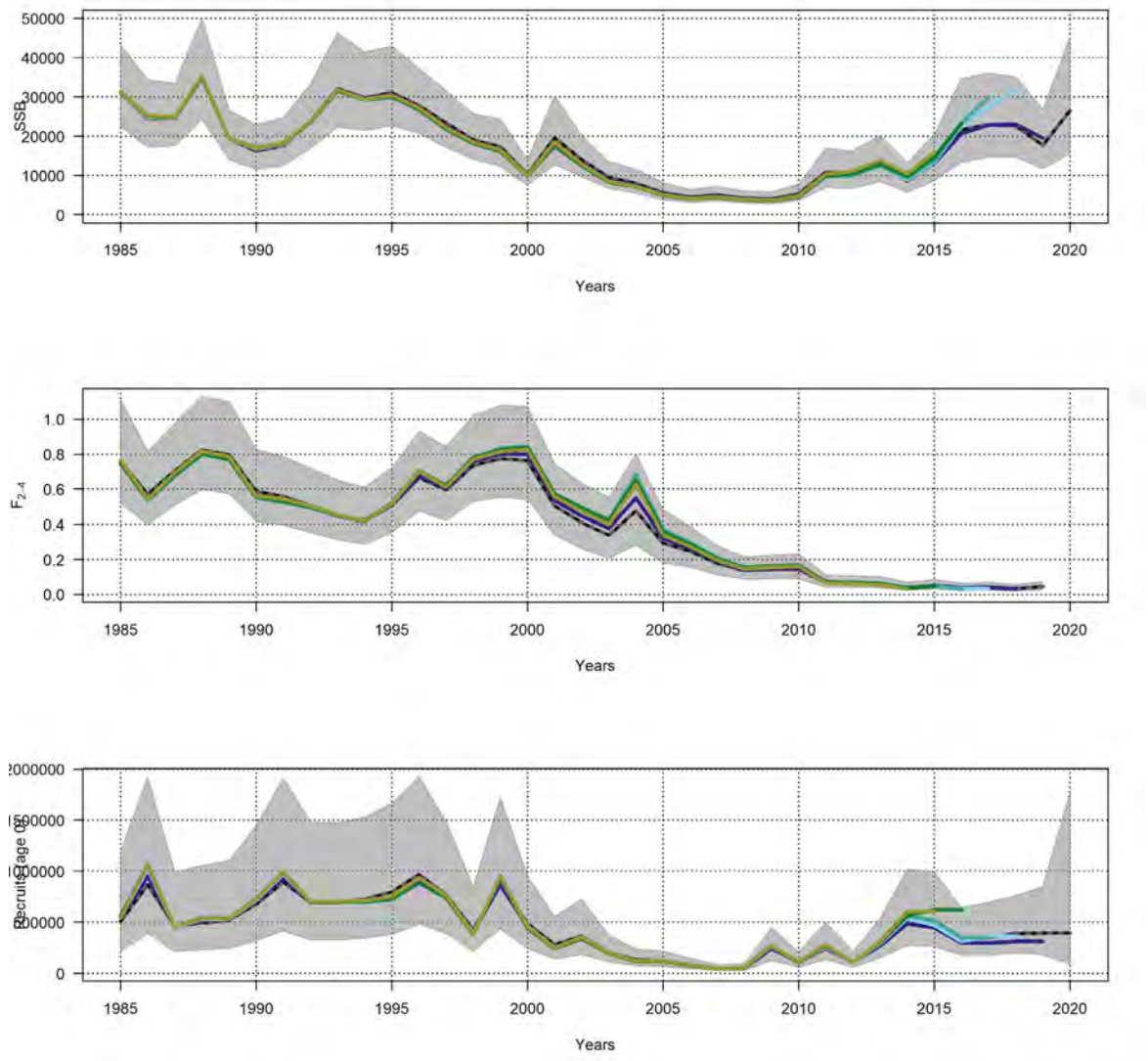


Figure 4. Retrospective pattern for the Base Model

2.2 Exploring Model Implementations

2.2.1 Missing Data Replacement

Base Model data replacement assumptions (see Section 2.1) were compared with two alternatives: replacement of missing catch-, landings- and discards-at-age zero with the minimum catch-at-age zero value, and replacement of missing stock weights-at-age zero with minimum stock weight-at-age zero from estimates derived from Q4 survey data; replacement of missing catch-, landings- and discards-at-age zero with the maximum catch-at-age zero value, and replacement of missing stock weights-at-age zero with maximum stock weight-at-age zero from estimates derived from Q4 survey data. Model fits were very similar for all data replacement assumptions, as only the catch weight estimates were affected (Figure 5).

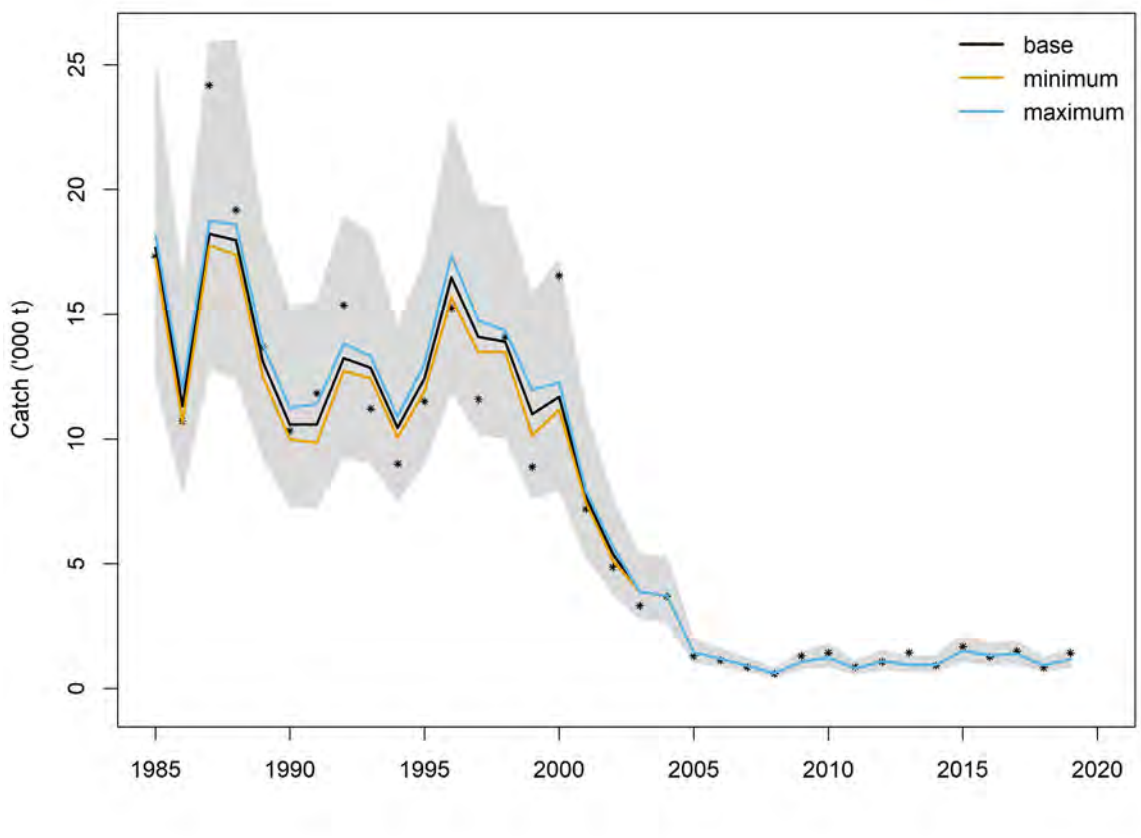


Figure 5. Comparison of SAM catch estimates based on different data replacement assumptions: replacement with the mean value (*black*) (as in the Base Model), replacement with the minimum value (*orange*), and replacement with the maximum value (*blue*)

2.2.2 Total Time Range of Assessment

The total time duration over which the model should be run was investigated due to differences in the length of data time-series' which were available. Specifically, commercial catch data is available from 1981, but the newly estimated stock mean weights-at-age and natural mortality-at-age (estimated from survey data) are only available from 1985. Due to the relatively high catches recorded in the early 1980s, there was some concern that the stock-recruit relationship might be affected by the removal of these data. Models were thus run for both time ranges using the Base Model configuration. The missing stock mean weights-at-age and natural mortalities-at-age (i.e. 1981-1984) were assumed to equal the earliest available value (i.e. 1985) for a given age group in the 1981- model. Each time-range was run with all four available recruitment models (i.e. Beverton-Holt, Piecewise Constant, Random Walk, Ricker). On comparison, there was little difference in model output regardless of the recruitment model (e.g. recruitment estimates from each model configuration from 1981-, Figure 6). Length of modelled period did somewhat to affect outcome, with the extended time-series models (e.g. 1981-) all suggesting an asymptotic stock-recruitment relationship (Figure 7). For the purpose of the final assessment model, both modelled time ranges yielded similar hind-casts of estimates in terms of magnitude, and so the shorter time-series (1985-) is deemed more appropriate for the assessment as fewer assumptions must be made regarding missing data. Models using Beverton-Holt and Ricker stock-recruitment relationships provided a slightly better quality fit for both modelled time-ranges (Table 2), however, a

plain random walk stock-recruitment relationship provides a comparable model fit with fewer parameters and is thus a favourable choice for the assessment.

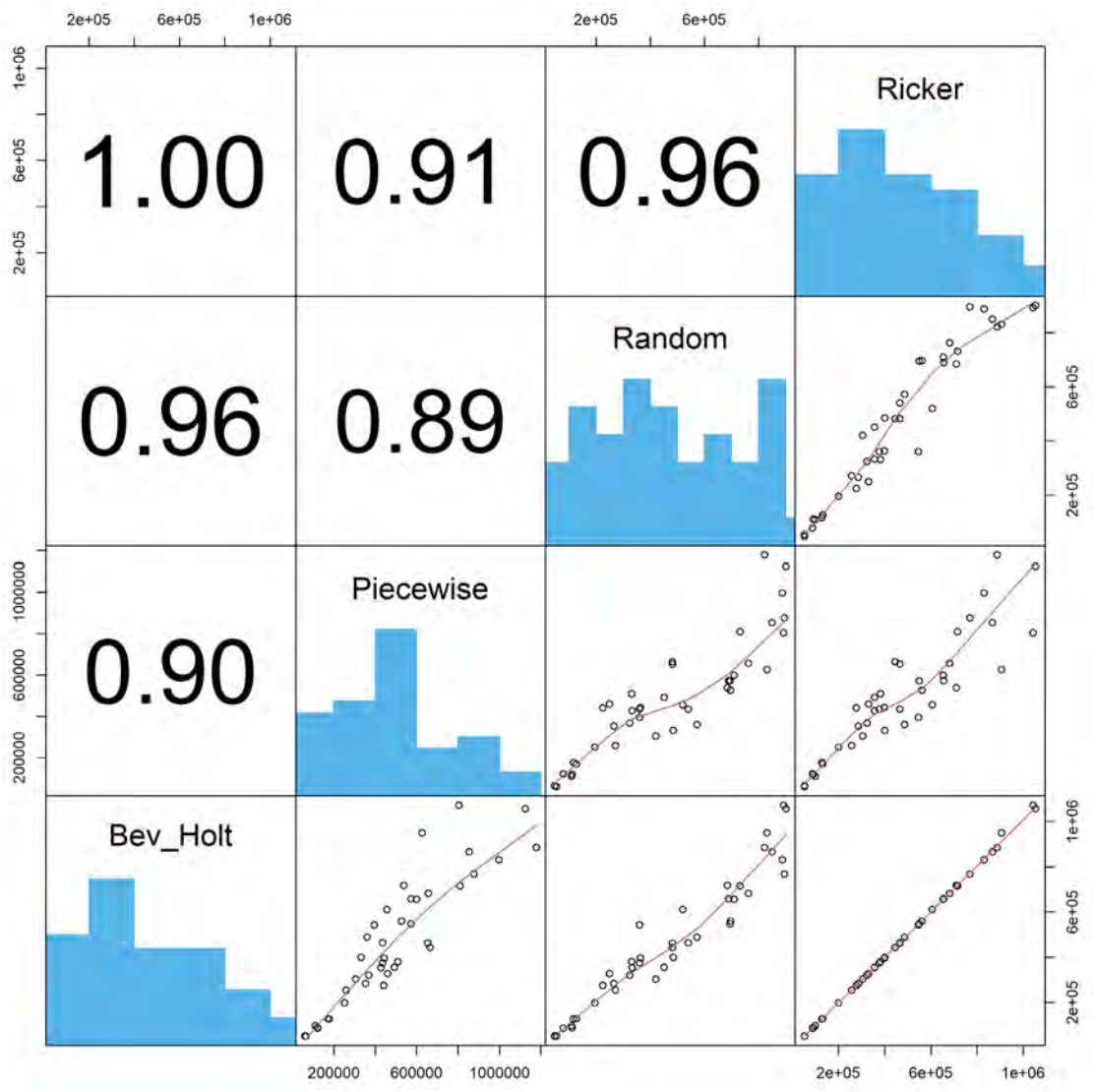


Figure 6. Pairwise comparison of recruitment (Age 0) estimates from 1981- model configuration using each of the stock recruitment available for implementation in SAM (Beverton-Holt, Piecewise Constant, Random Walk, Ricker). The panels above the diagonal show the absolute value of the Pearson correlation between model estimates, the panels below the diagonal show a scatterplot of the estimates from each pair of models

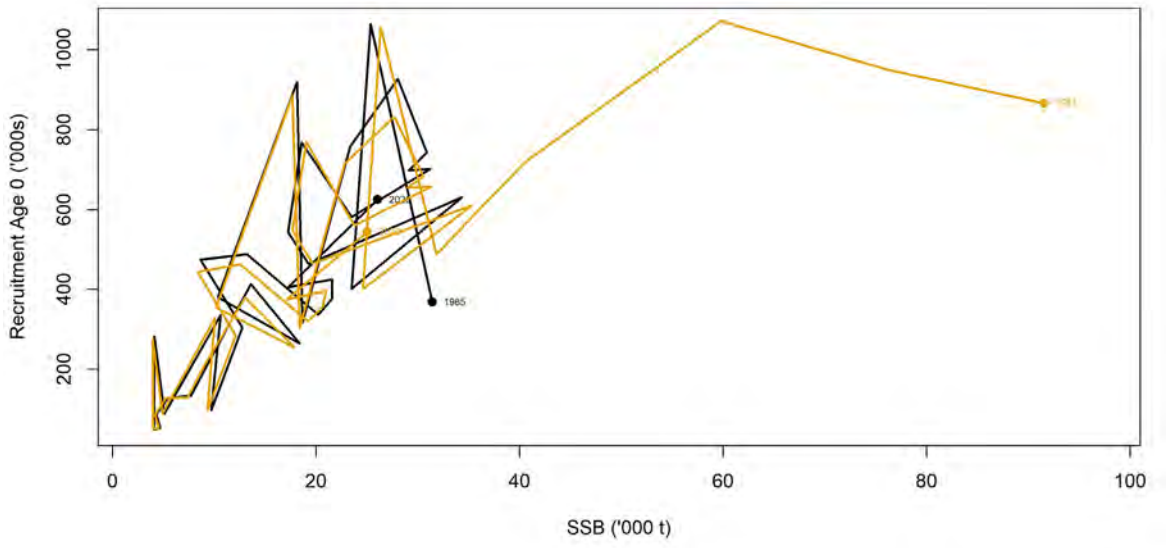


Figure 7. Comparison of Beverton-Holt stock-recruitment relationships from models using data from 1981- (*orange*) and 1985- (*black*), i.e. the Base Model.

Table 2. Summary of model fit quality based on different time-range and stock-recruitment assumptions

Model Time-Range	Stock-Recruitment Relationship	log.L	par	AIC	stockassessment.org reference*
1981-2020	Beverton Holt	-755.80	27	1565.59	Bev_1981
	Piecewise Constant	-768.92	26	1589.85	PWise_1981
	Random Walk	-765.51	25	1581.01	Rwalk_1981l
	Ricker	-755.68	27	1565.36	Rick_1981
1985-2020	Beverton Holt	-732.88	27	1519.77	Bev_1985
	Piecewise Constant	-744.16	26	1540.32	Pwise_1985
	Random Walk**	-742.09	25	1534.17	base_model
	Ricker	-732.88	27	1519.77	Rick_1985

* All model references are suffixes to “whiting_6a_benchmark_2021_”, apart from “base_model”

** Base Model configuration

2.2.3 Estimation of Misreporting

Catch data for the stock is believed to have been subject to under-reporting of landings for a period during the 1990s and early 2000s. The magnitude of under-reporting for most years is unknown, but appears to be relatively small (5-10% of total landings) between 2001 and 2005, based on estimates from Marine Scotland Compliance (ICES, 2012). Since the introduction of Buyers & Sellers legislation, underreporting is considered to have been minimal (since 2006). In the TSA assessment potential under-reporting was addressed by omitting total catch numbers-at-age data for a period (1995-2005), while still using the catch-at-age composition and mean weights-at-age which were thought to be accurate. Sensitivity of the base configuration SAM model to a selection of catch-scaling periods was tested (see Table 3). All catch-scaling configurations fit the data similarly, with the catch-scaling from 1995 to 2006 configuration exhibiting the best quality fit, but only slightly better than the second best (1998-2006). Each of the alternate catch-scaling configurations yielded similar overall trends in

estimates (Figure 8), although the models with longer catch-scaling periods tended to predict higher catches, recruitment and SSB in the mid-1990s than models with shorter catch-scaling periods.

Retrospective analyses were carried out where model results were compared through consecutive removal of the most recent five years of data. Model results proved robust to changes in data time-series. The leave-one-out analyses were fairly poor, however, suggesting the existence of some disparity in signal between the WCIBTS Q1 index and the other data (e.g. Figure 9).

In addition to testing a catch-scaling period, catch data was censored so as to exclude data between 1995 and 2006. Catch estimates were generally higher than the Base Model, particularly during the period of misreporting from which data was omitted, with large uncertainty bounds (Figure 10). The retrospective analysis was similar to the catch-scaled models (Table 3), and the leave-one-out analysis suffered from similar issues regarding the WCIBTS Q1 index.

Model runs which allow for the estimation of a catch scaling factor beyond the year 2000, as well as the model configuration with a censored dataset, estimated catches in some years to be ~ 4-5 times the observed catch. Given that under-reporting estimates in those years are < 10% of total landings, those model estimates were deemed unrealistic, and the implementation of a catch-scaling (or free-estimation of catch) model configuration was rejected.

Table 3. Summary of model fits for varying catch-scaling time periods, including Mohn's rho values from retrospective analysis (recruitment, SSB, and *F*).

CATCH-SCALING PERIOD	*N* PARAMETERS	LOG(*L*)	AIC	REC *RHO*	SSB *RHO*	*F RHO*	STOCKASSESSMENT.ORG REFERENCE*
None**	25	-742.09	1534.17	0.14	0.21	0.14	base_model
1990-2006	42	-716.52	1517.04	0.39	0.52	-0.31	CS1
1992-2006	40	-717.43	1514.86	0.38	0.49	-0.30	CS2
1995-2006	37	-718.39	1510.78	0.39	0.50	-0.31	CS3
1998-2006	34	-721.58	1511.15	0.39	0.50	-0.31	CS4
1995-2000	31	-740.21	1542.42	0.03	0.08	-0.04	CS5
Data censored	25	-652.88	1355.76	0.50	0.53	-0.32	data_censored

* All model references are suffixes to "whiting_6a_benchmark_2021_", apart from "base_model"

** Base Model configuration

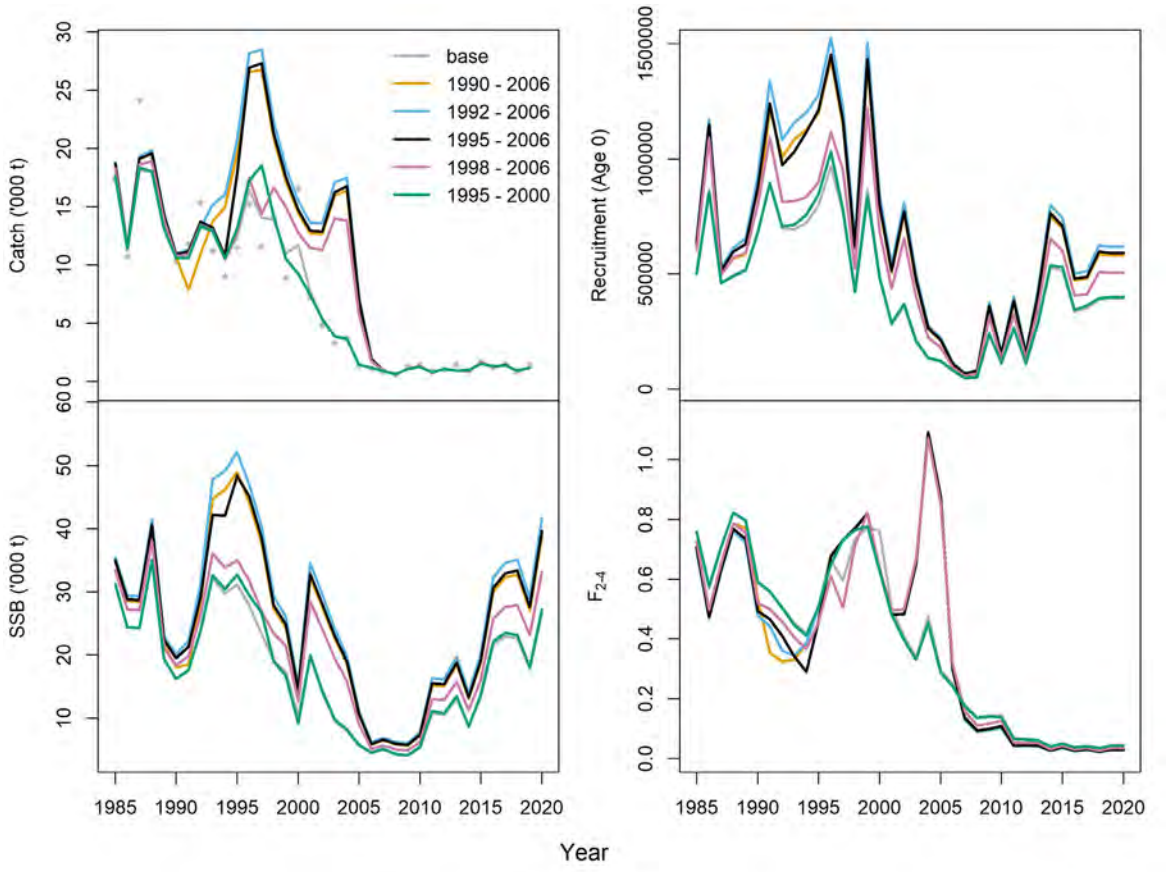


Figure 8. Comparison of SAM estimates based on different catch-scaling periods

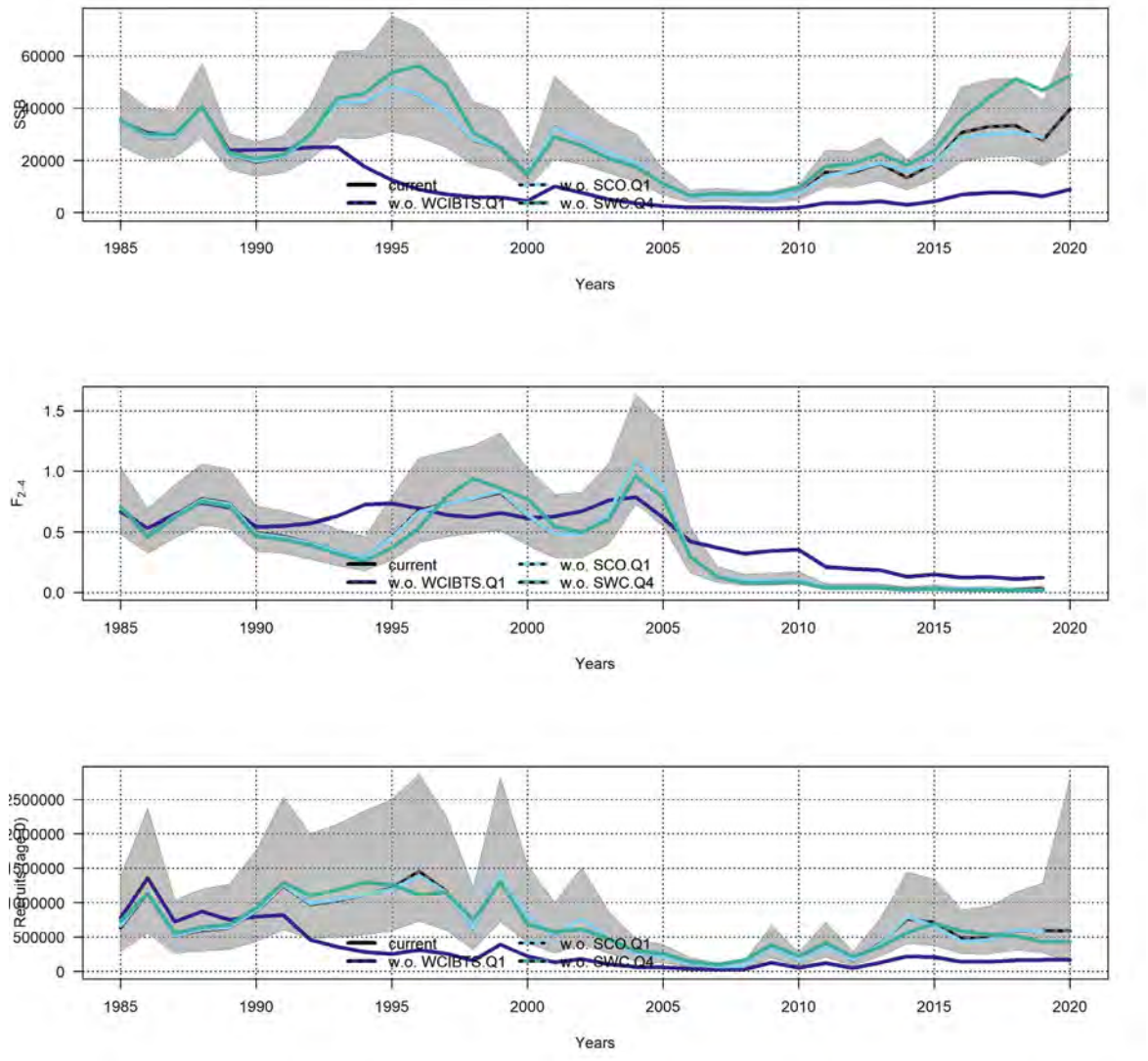


Figure 9. Leave-one-out analysis for base configuration model with catch-scaling between 1995 and 2006.

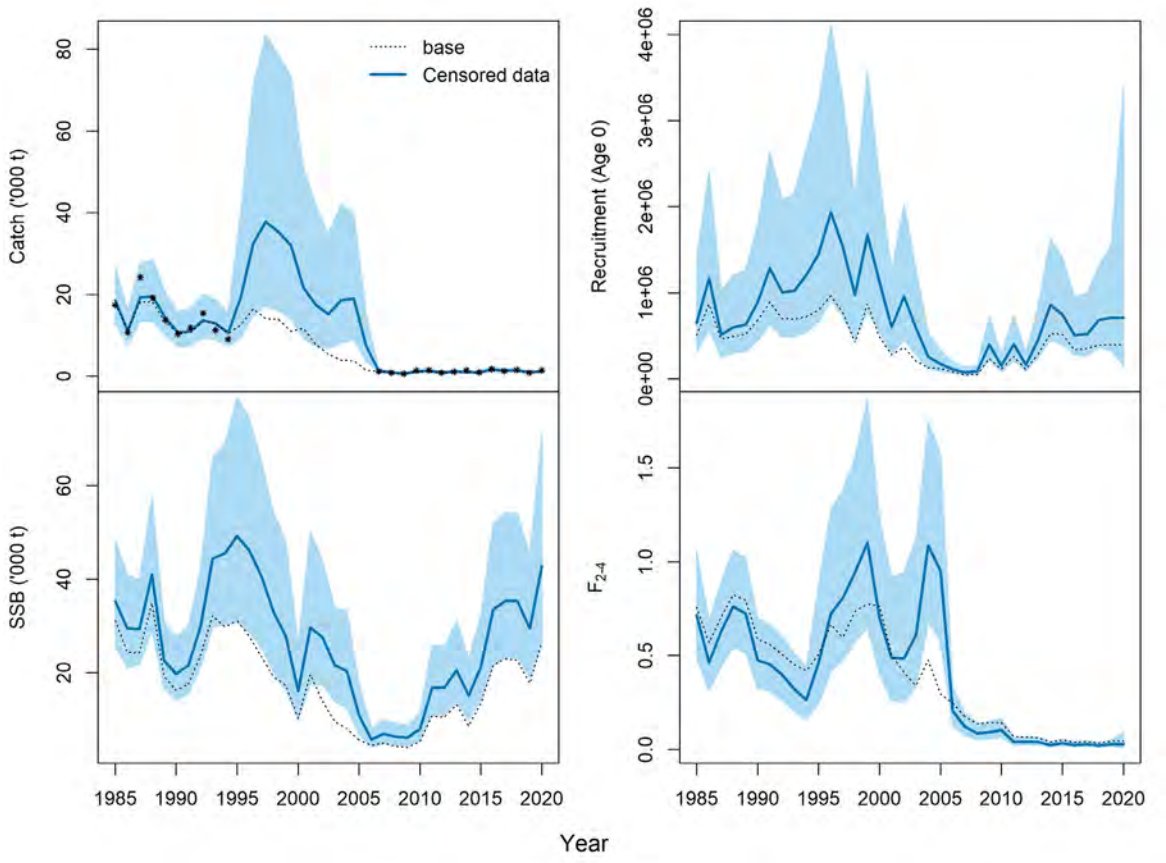


Figure 10. Comparison of SAM estimates from model using censored commercial dataset (*blue*) and the Base Model (*black dotted*)

2.2.4 Fleet Covariance Structure

Alternate fleet covariance structures were tested, whereby the commercial fleet had an independent fleet covariance structure, and the survey fleets were sequentially assigned an autocorrelated (AR1) covariance structures (Table 4). For each fleet covariance structure combination, a different coupling matrix was tested: coupling ages ≥ 1 (i.e. all ages apart from Age zero, where present), coupling ages ≥ 2 (ages 1 and zero were coupled, fleet dependent), coupling ages ≥ 3 (see Table 5).

With each successive fleet covariance structure combination the quality of model fit improved. Within each of those alternate fleet covariance combinations, quality of model fit deteriorated when coupling was moved up an age class (i.e. coupling ages ≥1 had a better quality fit than coupling ages ≥2, and so on; Table 5). The exception to this was with Alternate 4, whereby implementing the ≥2 coupling matrix gave a poorer quality fit than the ≥3 coupling matrix.

Estimates from the models based on Alternate 1 and Alternate 4 were reasonably similar to the Base Model (Figure 11 & Figure 14). Both Alternate 1 & 4 had only a single AR fleet, the modelled Q4 index and WCIBTS Q1, respectively. Model estimates deviated more from the Base Model estimates with the inclusion more than one AR fleets (i.e. Alternates 2 & 3; Figure 12 & Figure 13).

Patterns in fleet residuals for models based on Alternate 1 remained similar to those of the Base Model, with perhaps some reduction in magnitude (Figure 15, Figure 16 & Figure 17). Models based on Alternate 2 demonstrated some reduction in the tendency towards a majority of positive residuals in the early modelled years (Figure 18, Figure 19 & Figure 20). Models based on Alternate 3 showed little difference from Alternate 2 (Figure 21 & Figure 22). Models based on Alternate 4 showed some reduction in the trend towards positive residual values at the beginning of the modelled period (Figure 23 & Figure 24).

Fleet covariance configuration Alternate 1 had the most acceptable Mohn's retrospective values, specifically those models with ≥2 and ≥3 coupling matrices (Table 5). Retrospective peels for these models were reasonably robust to removal of up to five years of recent data (Figure 25 & Figure 26). Mohn's retrospective values for Alternate 2, 3 & 4 were generally poor.

The leave-one-out analyses for models using covariance configuration Alternate 1 showed generally poor agreement in trends between WCIBTS Q1 and other indices (e.g. Figure 27). Models using covariance configuration Alternates 2 & 3 showed somewhat better agreement in trends between indices (e.g. Figure 28).

Table 4. Fleet covariance structure combinations tested

	COMMERCIAL FLEET	MODELLED Q4 INDEX	WCIBTS Q1	UK SCOWCGFS Q1
Base Model	Independent	Independent	Independent	Independent
Alternate 1	Independent	AR1	Independent	Independent
Alternate 2	Independent	AR1	AR1	Independent
Alternate 3	Independent	AR1	AR1	AR1
Alternate 4	Independent	Independent	AR1	Independent

Table 5. Summary of model fit quality, and Mohn's retrospective values for fleet covariance & covariance coupling matrix configurations trialled

COVARIANCE STRUCTURE CONFIGURATION	COUPLING MATRIX CONFIGURATION	*N* PARAMETERS	*LOG* LIKELIHOOD	AIC	REC *RHO*	SSB *RHO*	*F RHO*	REFERENCE*
Base Model	-	25	-742.09	1534.17	0.14	0.21	0.14	base_model
Alternate 1	≥ age 1	27	-720.87	1495.74	0.14	0.19	0.14	FC1a
	≥ age 2	27	-724.54	1503.08	0.15	0.18	0.13	FC1b
	≥ age 3	27	-730.00	1514.01	0.20	0.21	0.15	FC1c
Alternate 2	≥ age 1	28	-701.48	1458.96	0.99	1.46	0.58	FC2a
	≥ age 2	29	-708.68	1475.40	0.37	0.43	0.27	FC2b
	≥ age 3	29	-709.80	1477.59	0.55	0.60	0.36	FC2c
Alternate 3	≥ age 1**	-	-	-	-	-	-	-
	≥ age 2	31	-691.95	1445.90	1.02	1.77	0.61	FC3b
	≥ age 3	31	-698.59	1459.18	1.62	2.61	0.72	FC3c
Alternate 4	≥ age 1**	-	-	-	-	-	-	-
	≥ age 2	27	-728.34	1510.67	0.21	0.27	0.19	FC4b
	≥ age 3	27	-724.06	1502.12	0.22	0.29	0.20	FC4c

* All model references are suffixes to “whiting_6a_benchmark_2021_”, apart from “base_model”

** Did not converge

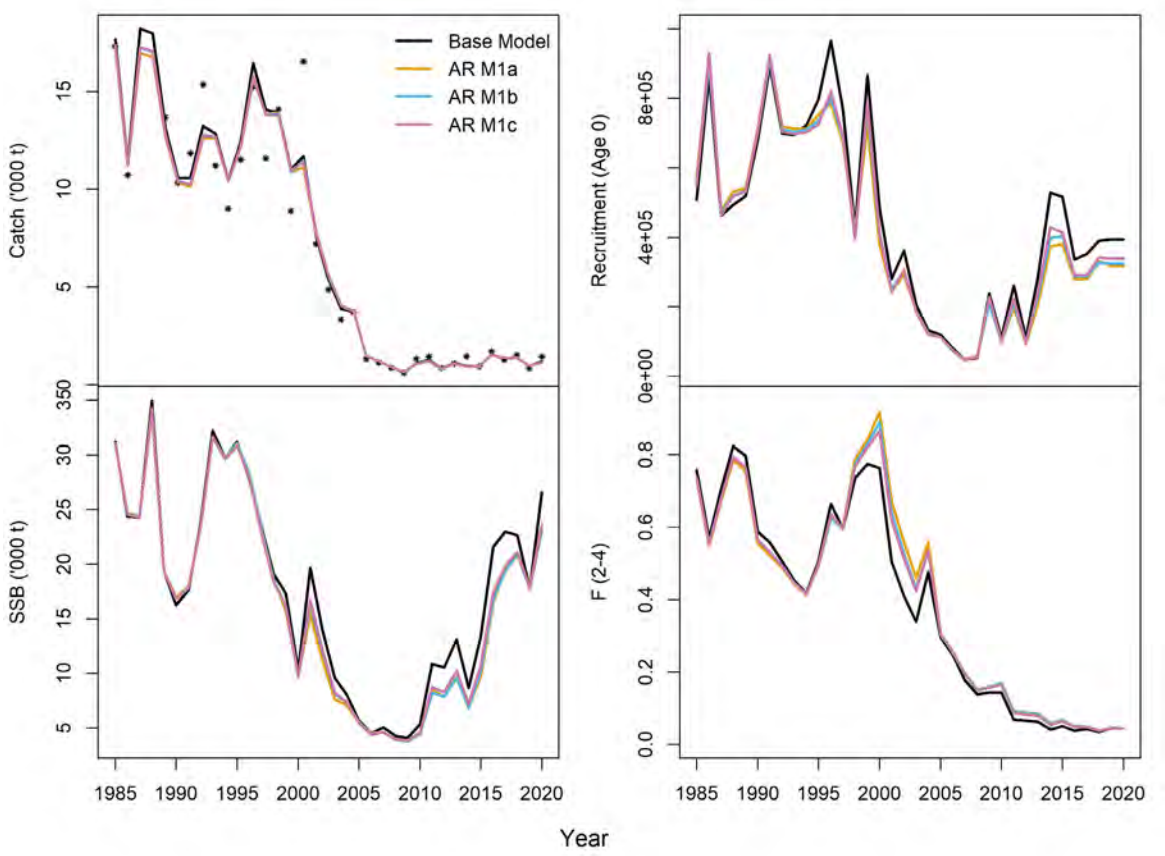


Figure 11. Comparison of SAM estimates using the Base Model configuration (*black*) and fleet covariance structure Alternate 1 with ages ≥1 coupled (AR M1a, *orange*), ages ≥2 coupled (AR M1b, *blue*), and ages ≥3 coupled (AR M1c, *pink*)

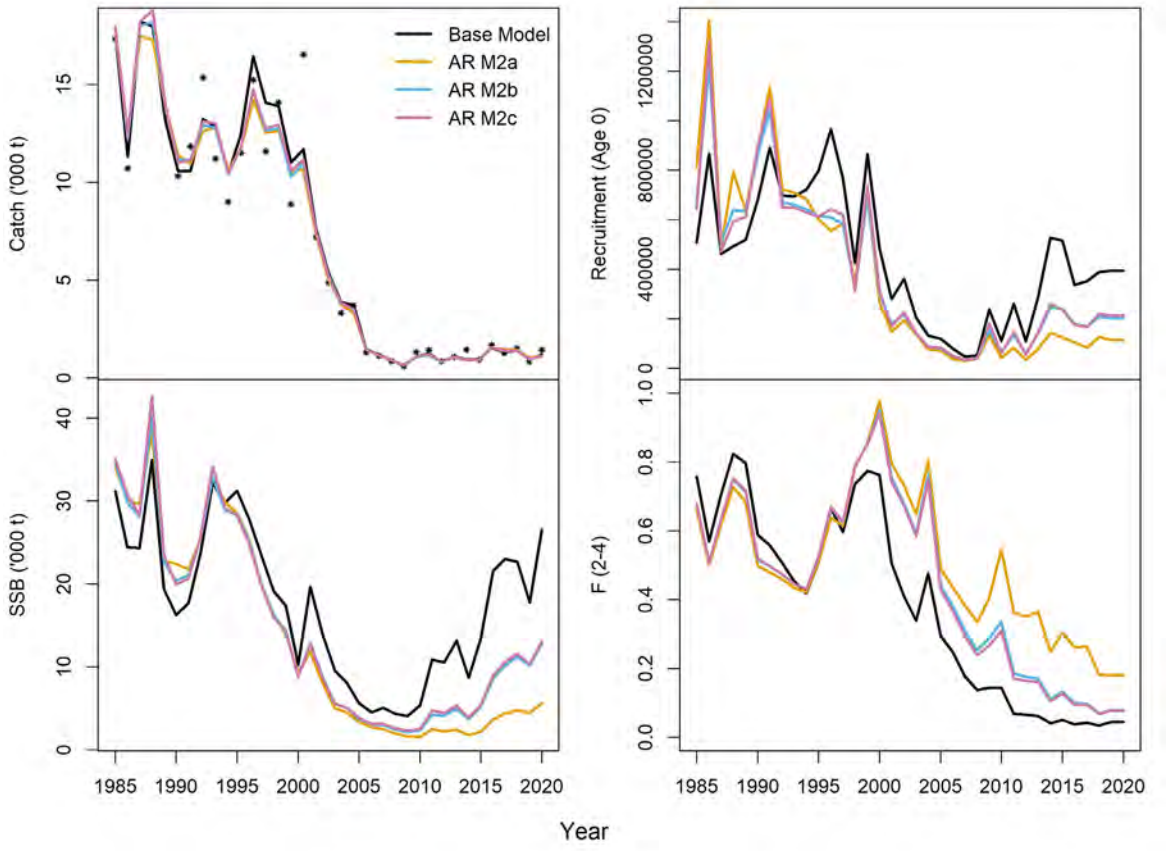


Figure 12. Comparison of SAM estimates using the Base Model configuration (*black*) and fleet covariance structure Alternate 2 with ages ≥1 coupled (AR M2a, *orange*), ages ≥2 coupled (AR M2b, *blue*), and ages ≥3 coupled (AR M2c, *pink*)

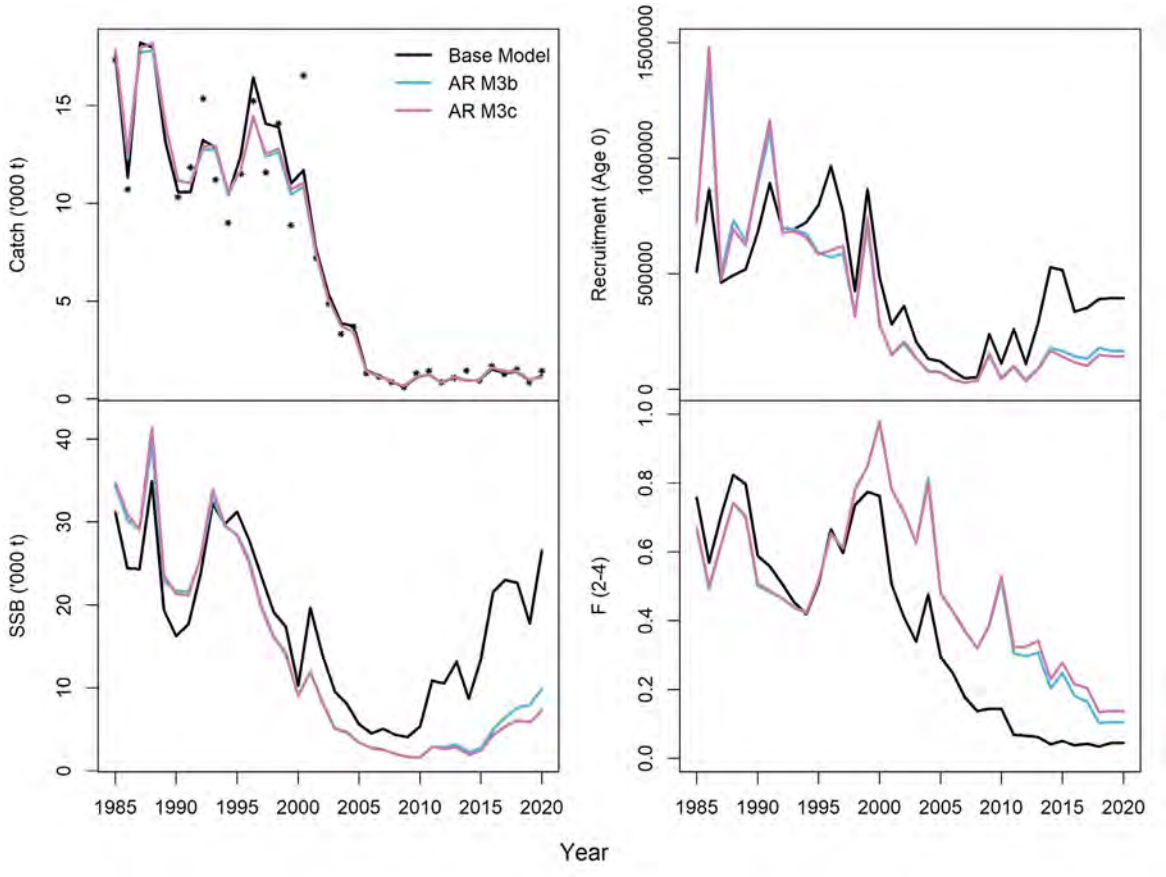


Figure 13. Comparison of SAM estimates using the Base Model configuration (*black*) and fleet covariance structure Alternate 3 with ages ≥2 coupled (AR M3b, *blue*), and ages ≥3 coupled (AR M3c, *pink*)

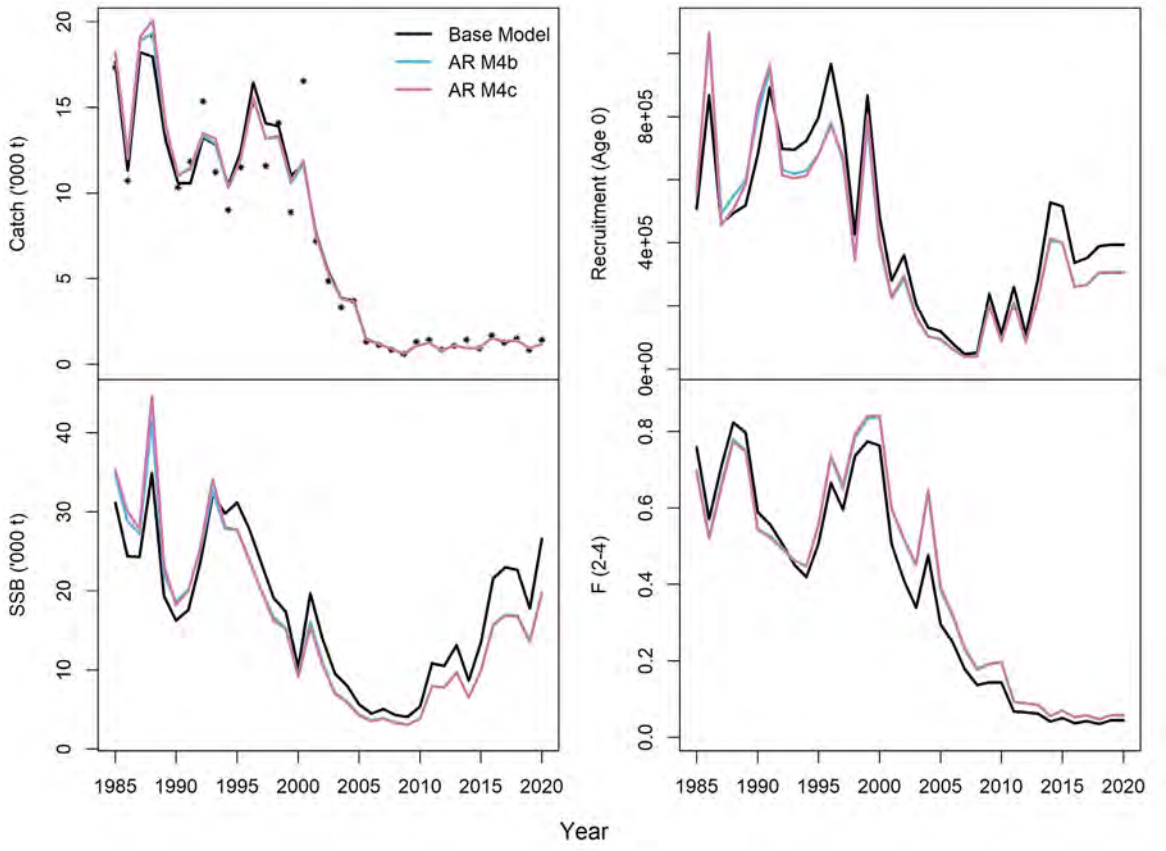


Figure 14. Comparison of SAM estimates using the Base Model configuration (*black*) and fleet covariance structure Alternate 4 with ages ≥2 coupled (AR M4b, *blue*), and ages ≥3 coupled (AR M4c, *pink*)

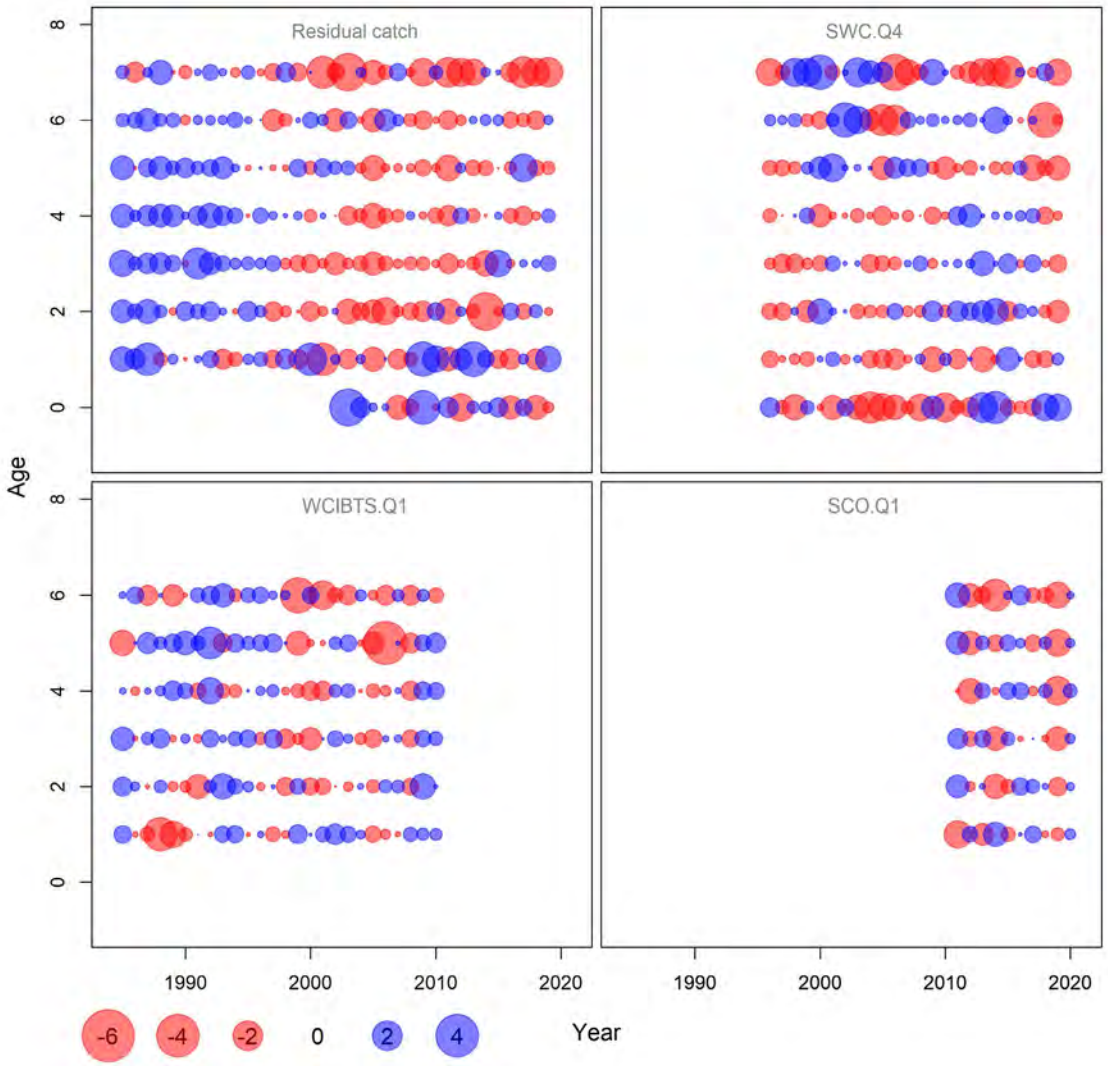


Figure 15. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 1 with ages ≥1 coupled

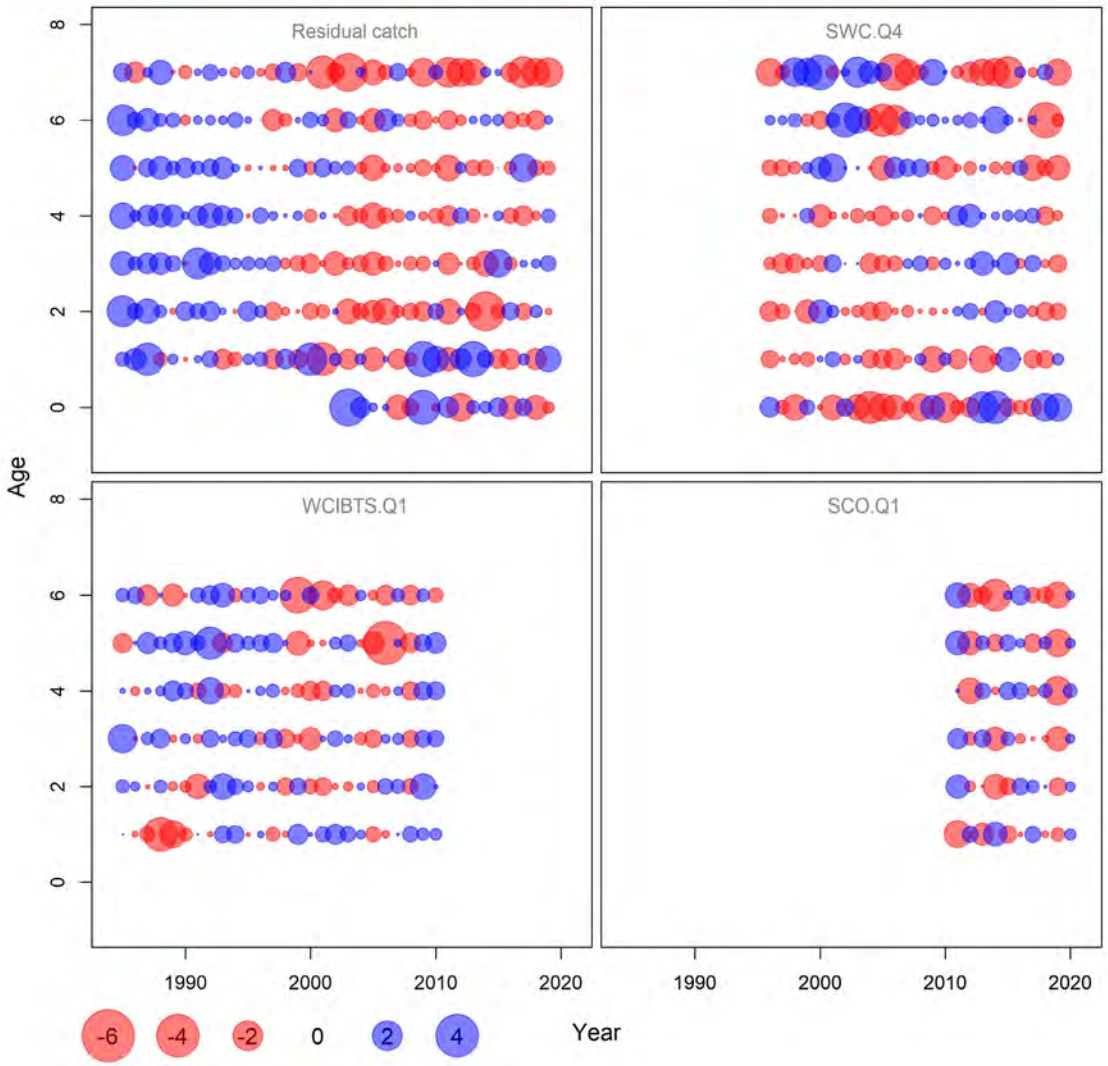


Figure 16. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 1 with ages ≥2 coupled

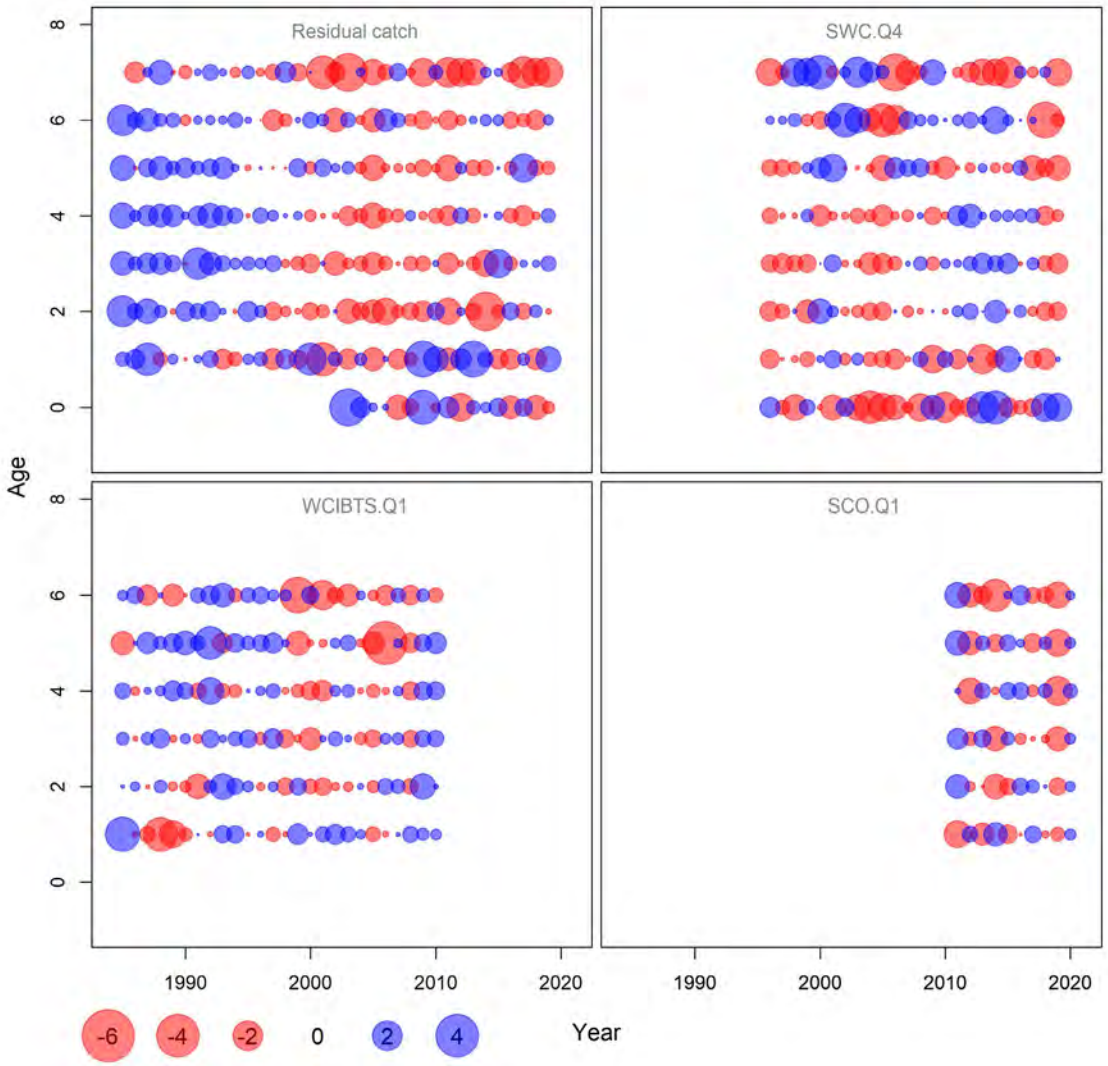


Figure 17. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 1 with ages ≥3 coupled

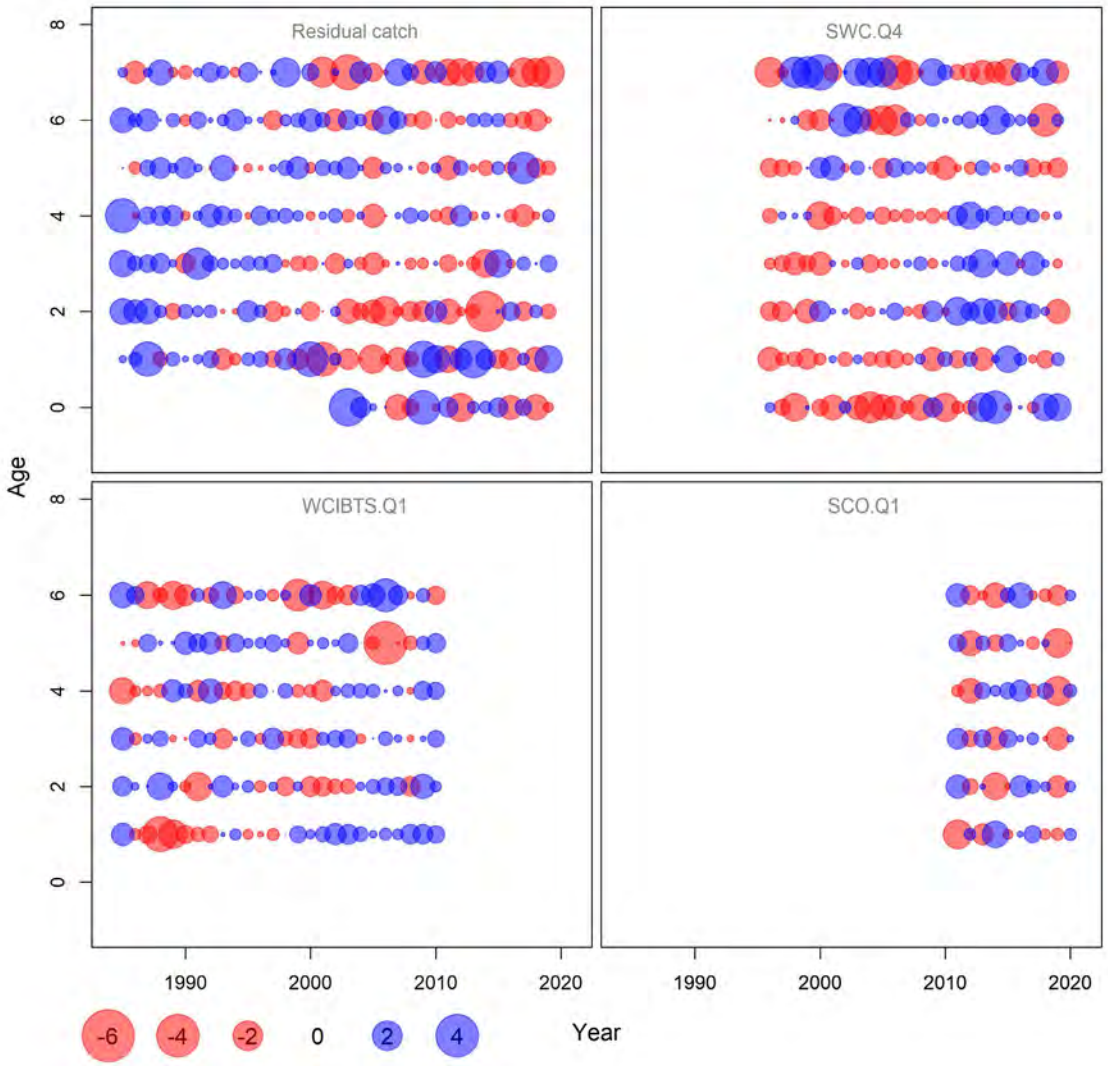


Figure 18. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 2 with ages ≥1 coupled

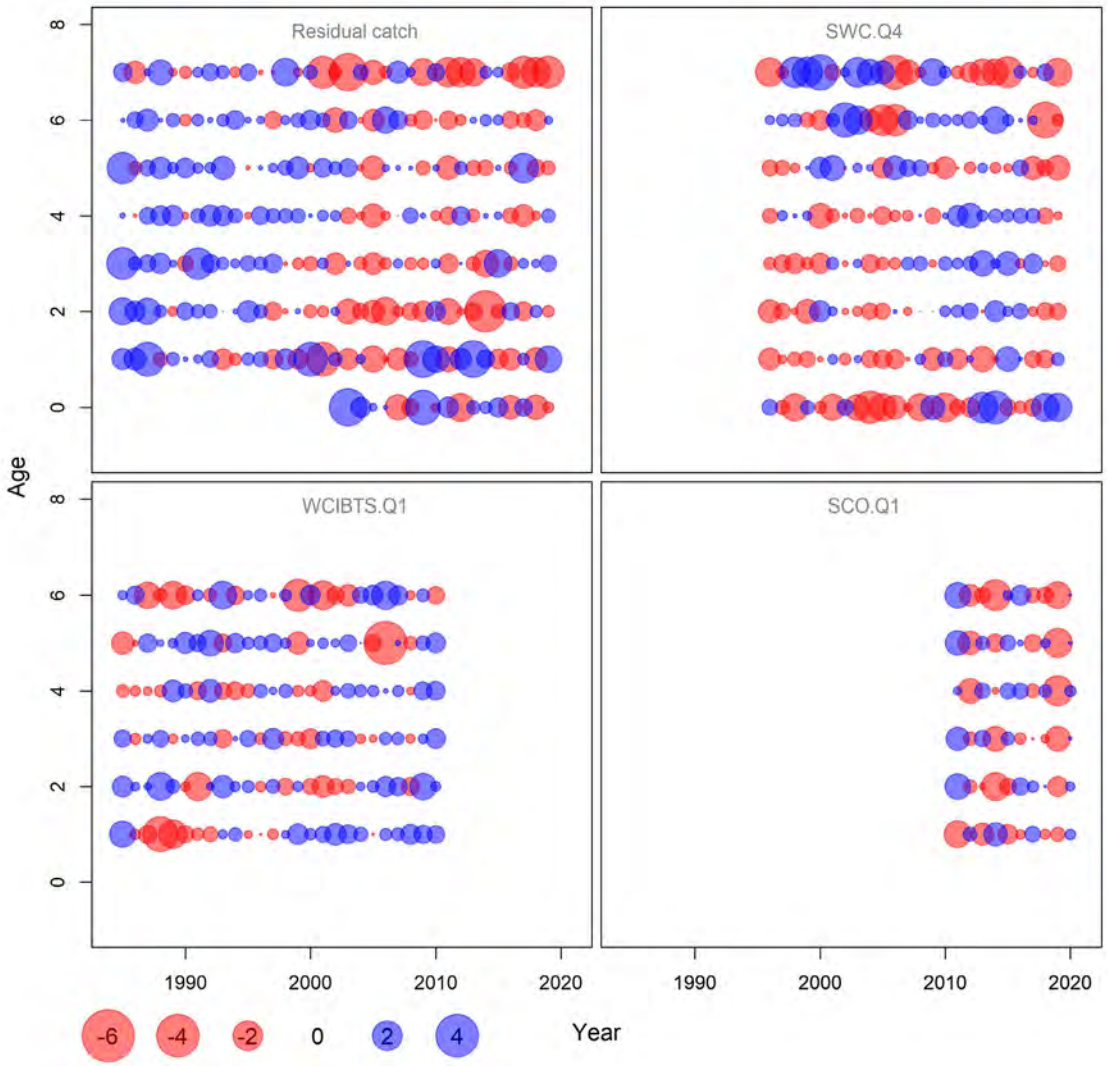


Figure 19. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 2 with ages ≥2 coupled

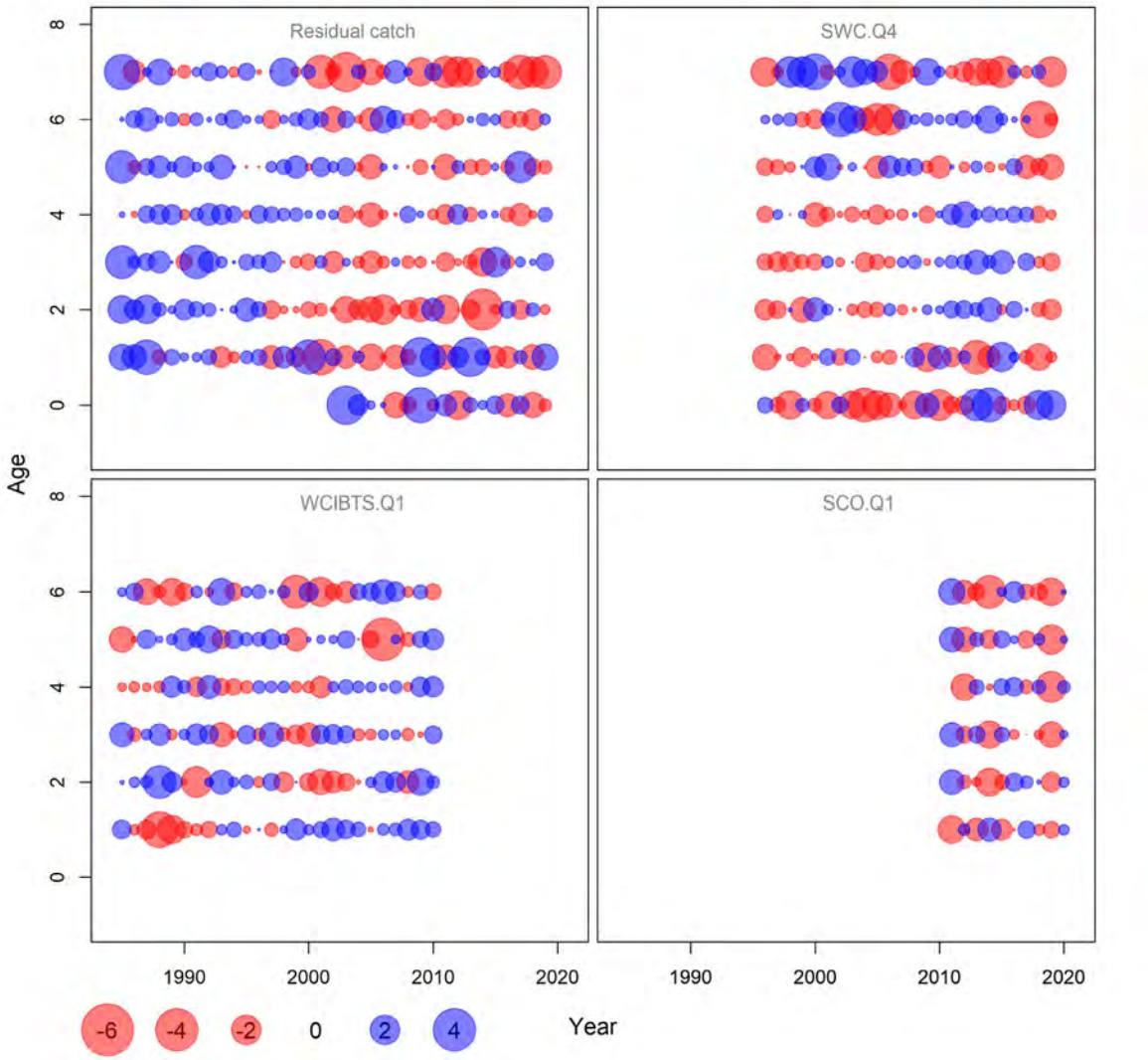


Figure 20. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 2 with ages ≥3 coupled

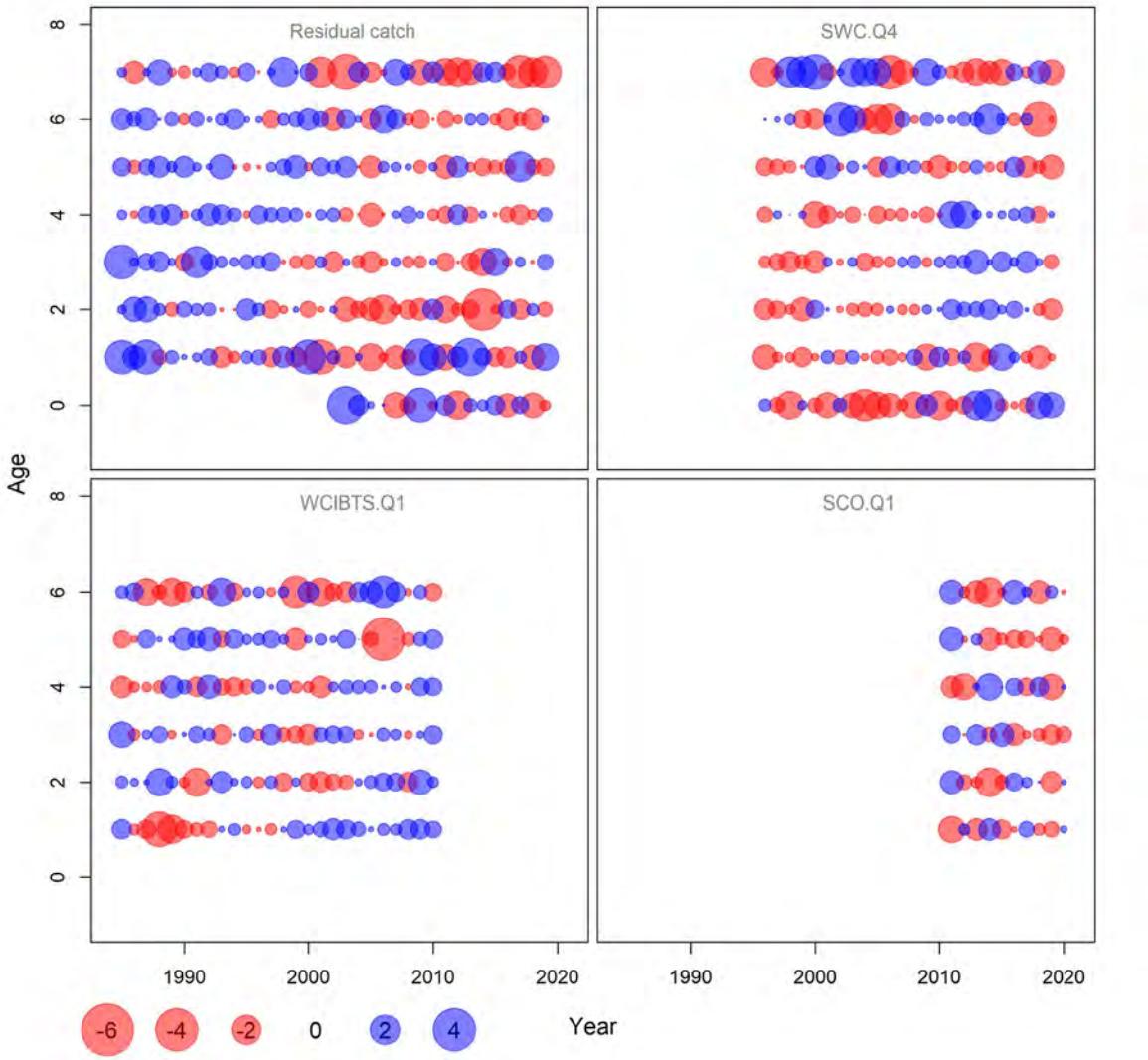


Figure 21. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 3 with ages ≥2 coupled

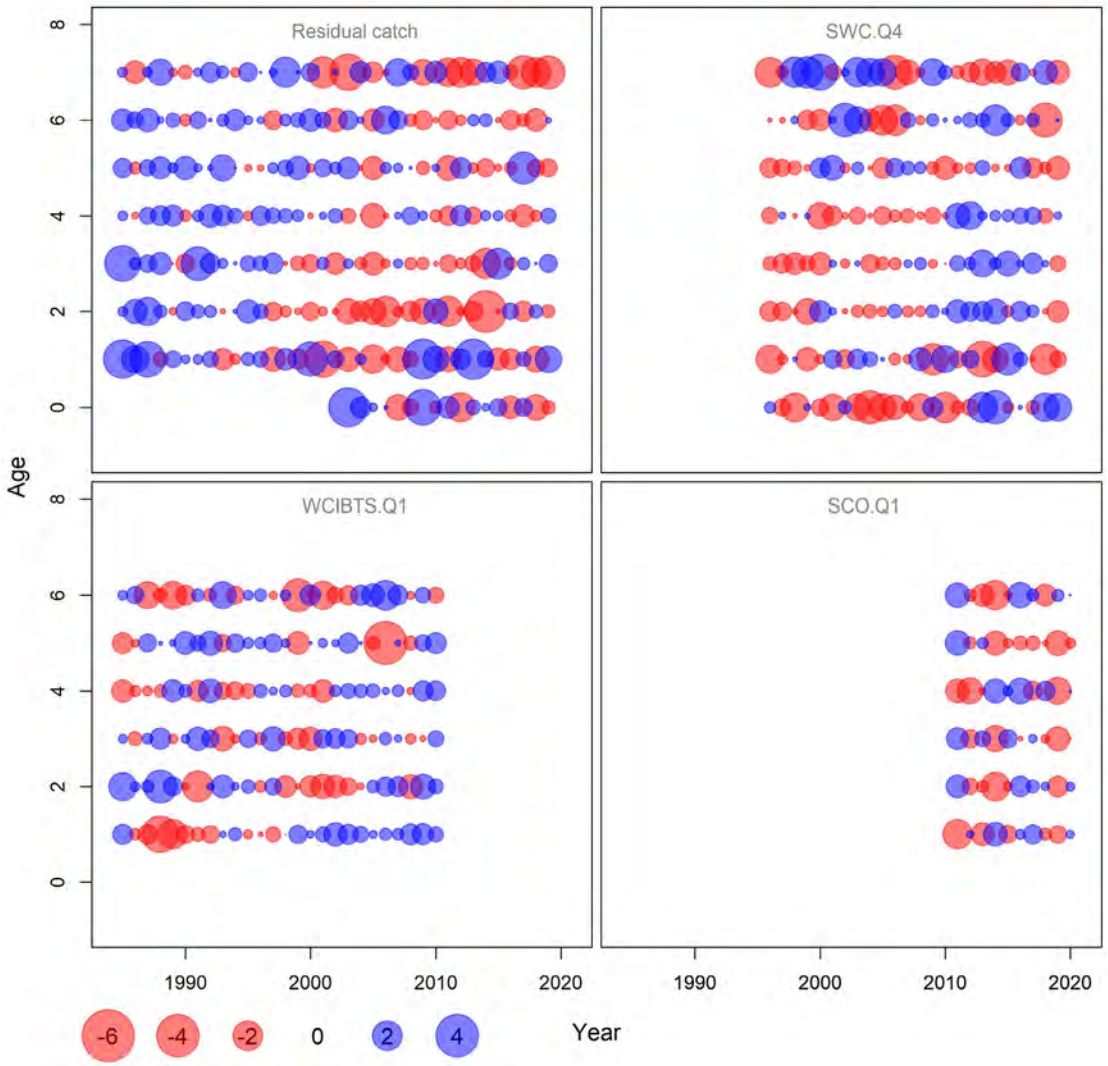


Figure 22. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 3 with ages ≥3 coupled

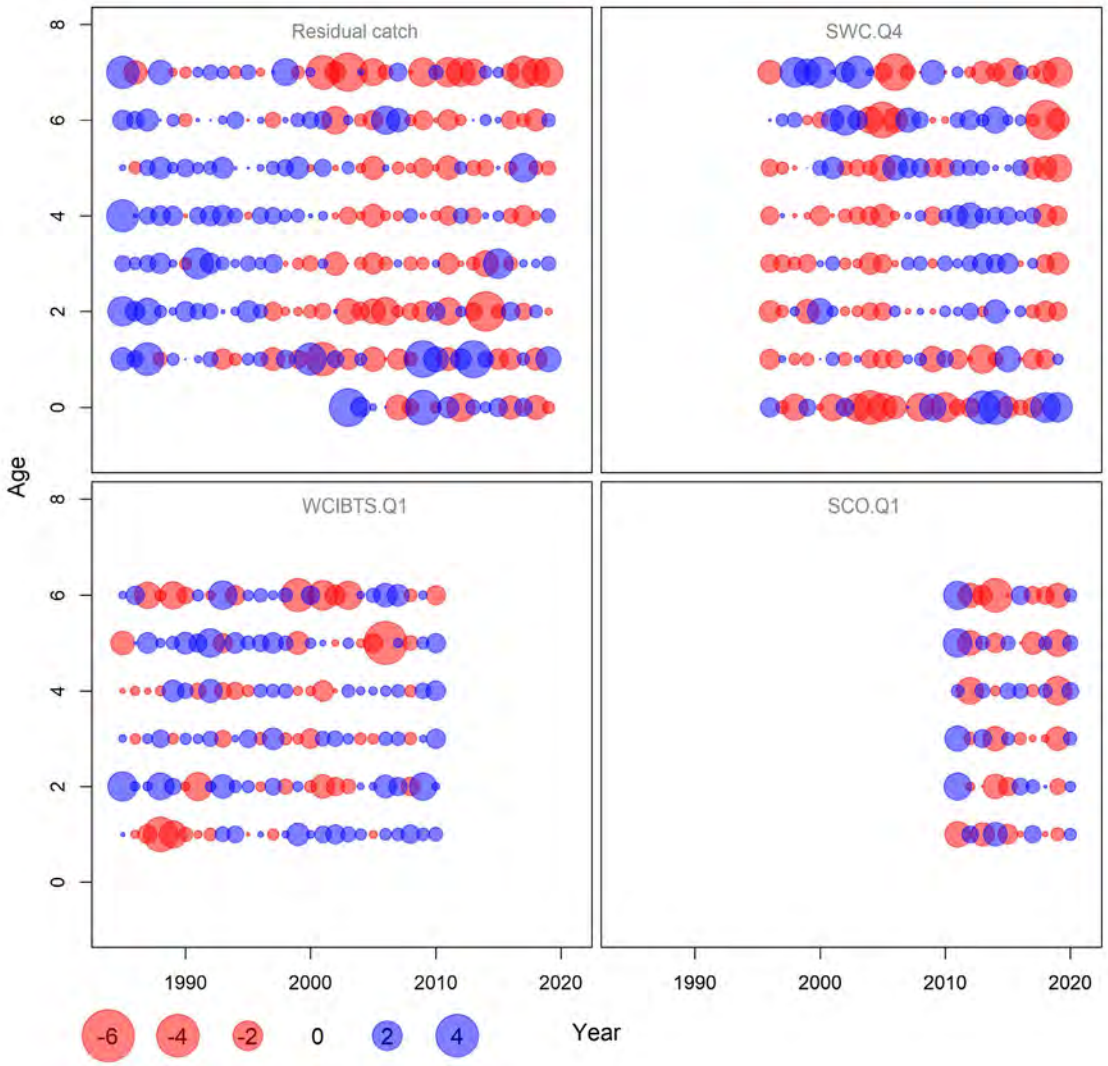


Figure 23. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 4 with ages ≥2 coupled

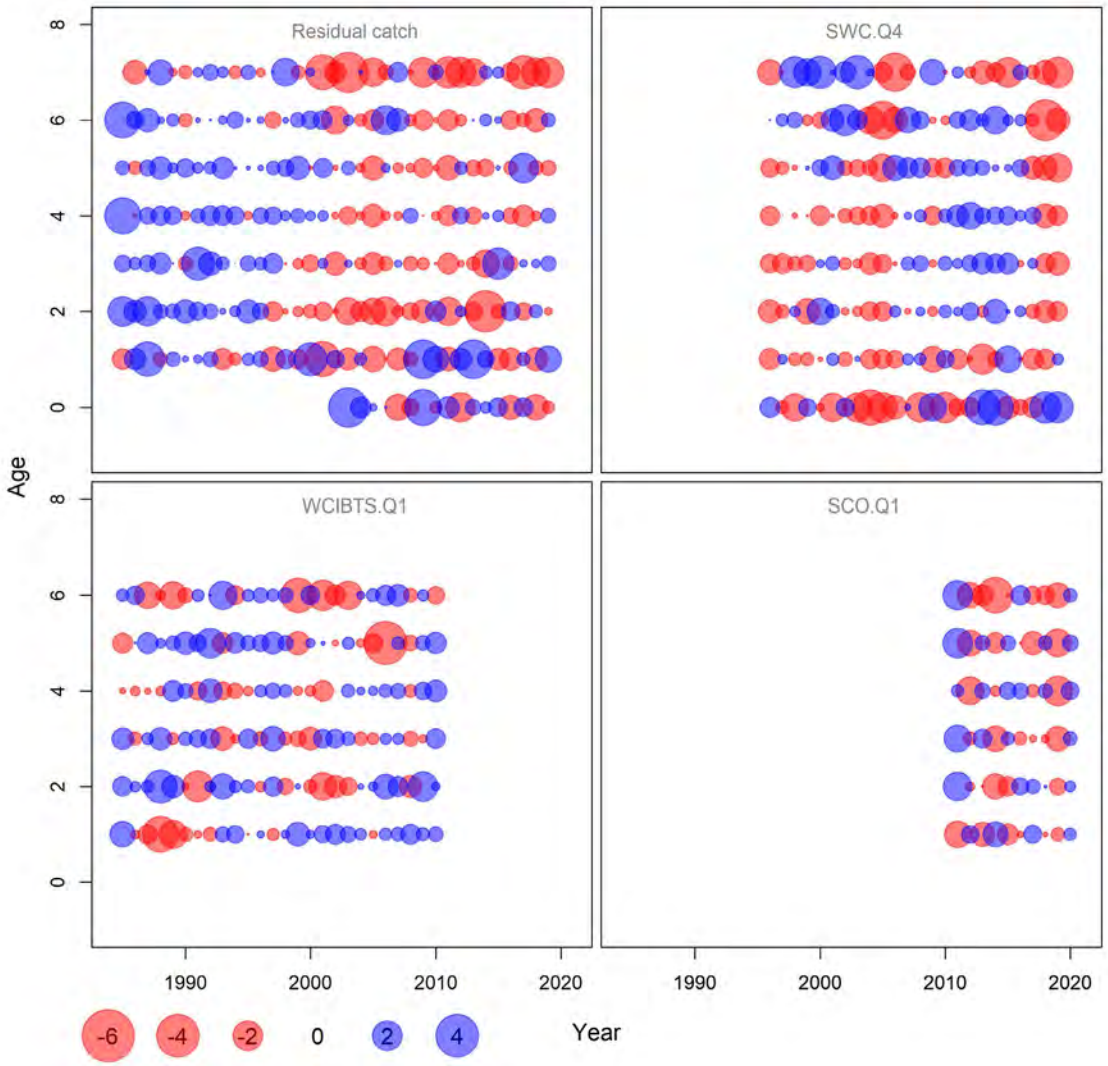


Figure 24. One-observation-ahead fleet residuals for fleet covariance configuration Alternate 4 with ages ≥3 coupled

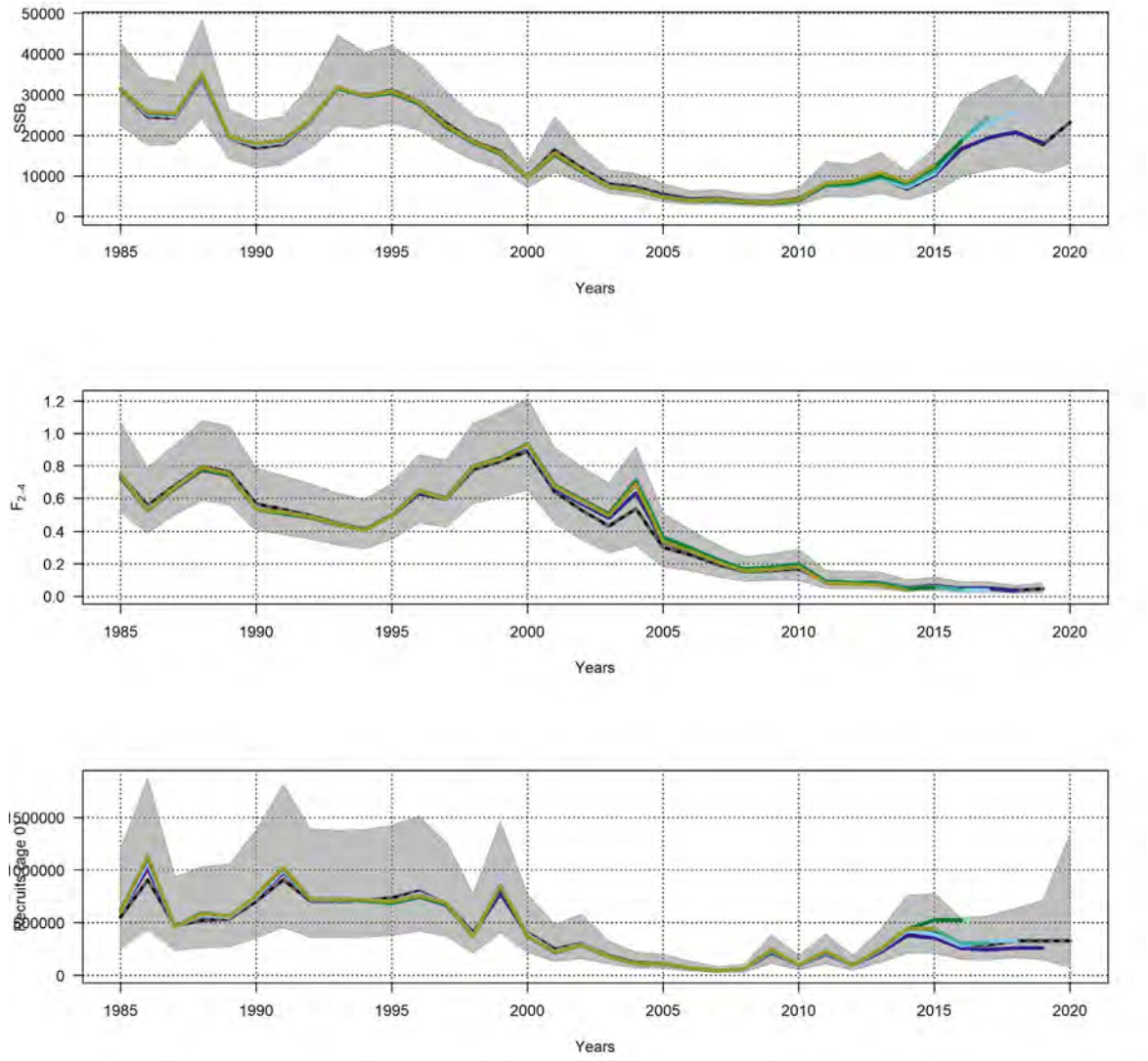


Figure 25. Retrospective pattern for model with fleet covariance configuration Alternate 1 with ages ≥2 coupled

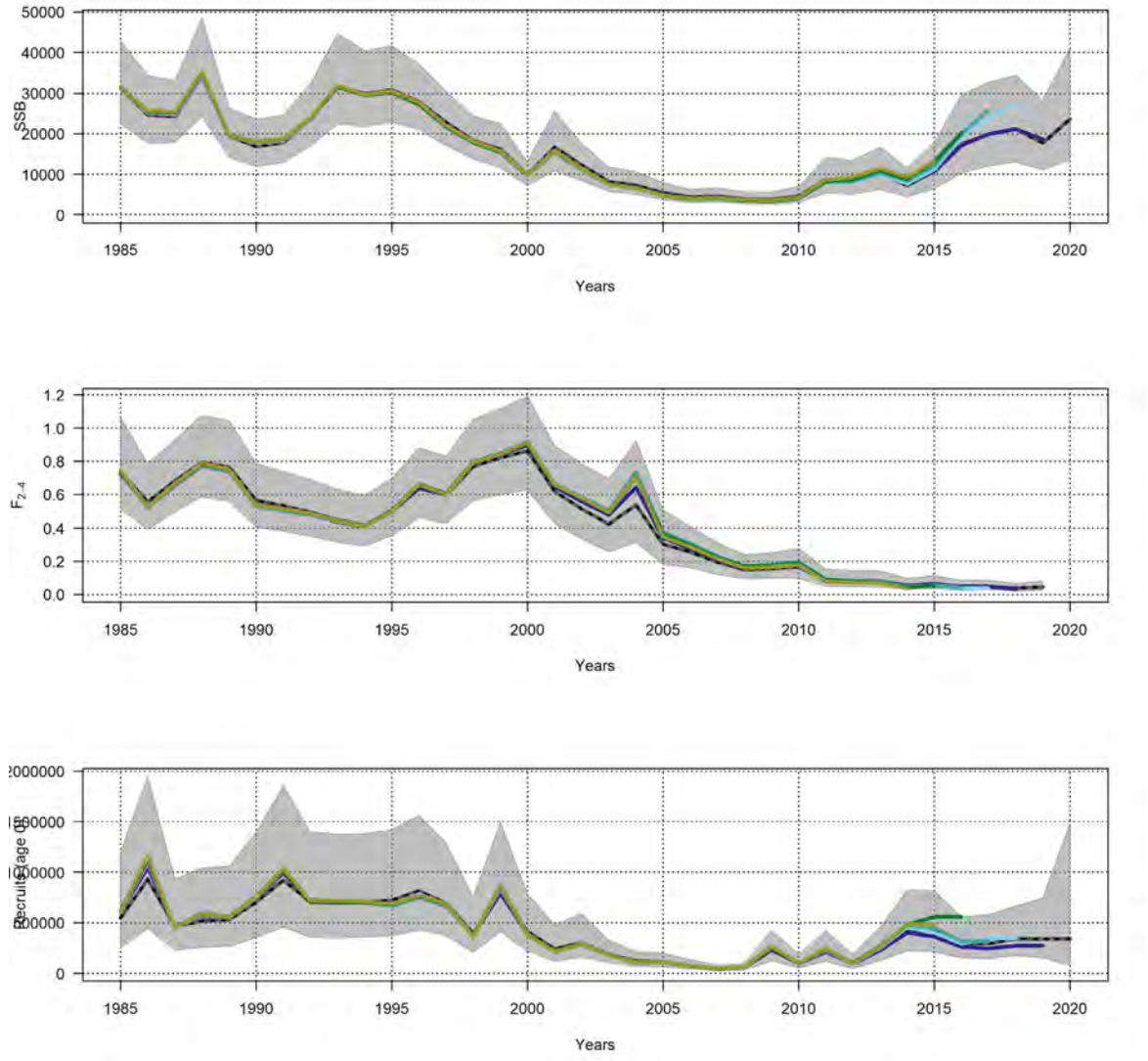


Figure 26. Retrospective pattern for model with fleet covariance configuration Alternate 1 with ages ≥3 coupled

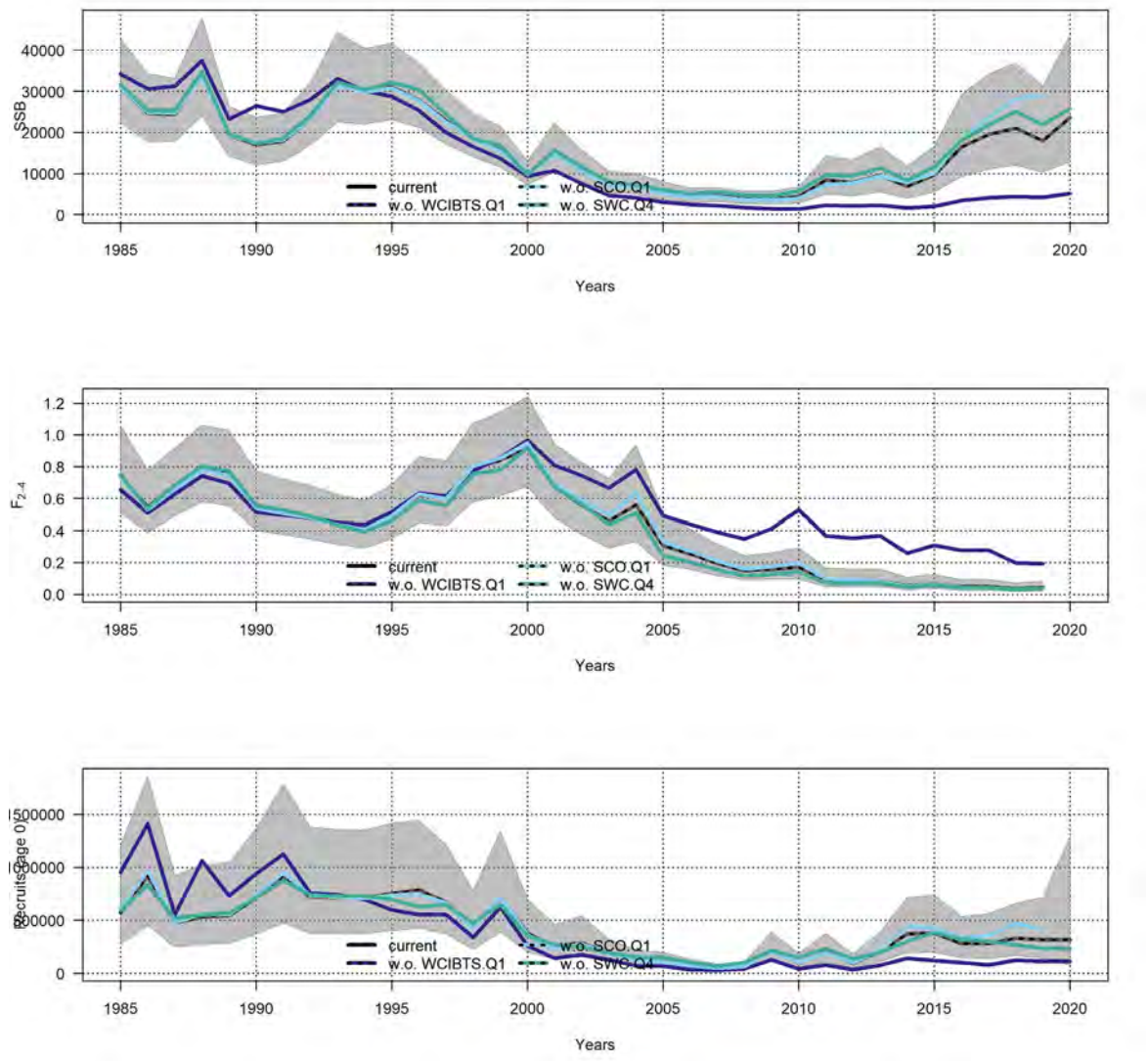


Figure 27. Leave-one-out analysis fleet covariance configuration Alternate 1, with ages ≥1 coupled

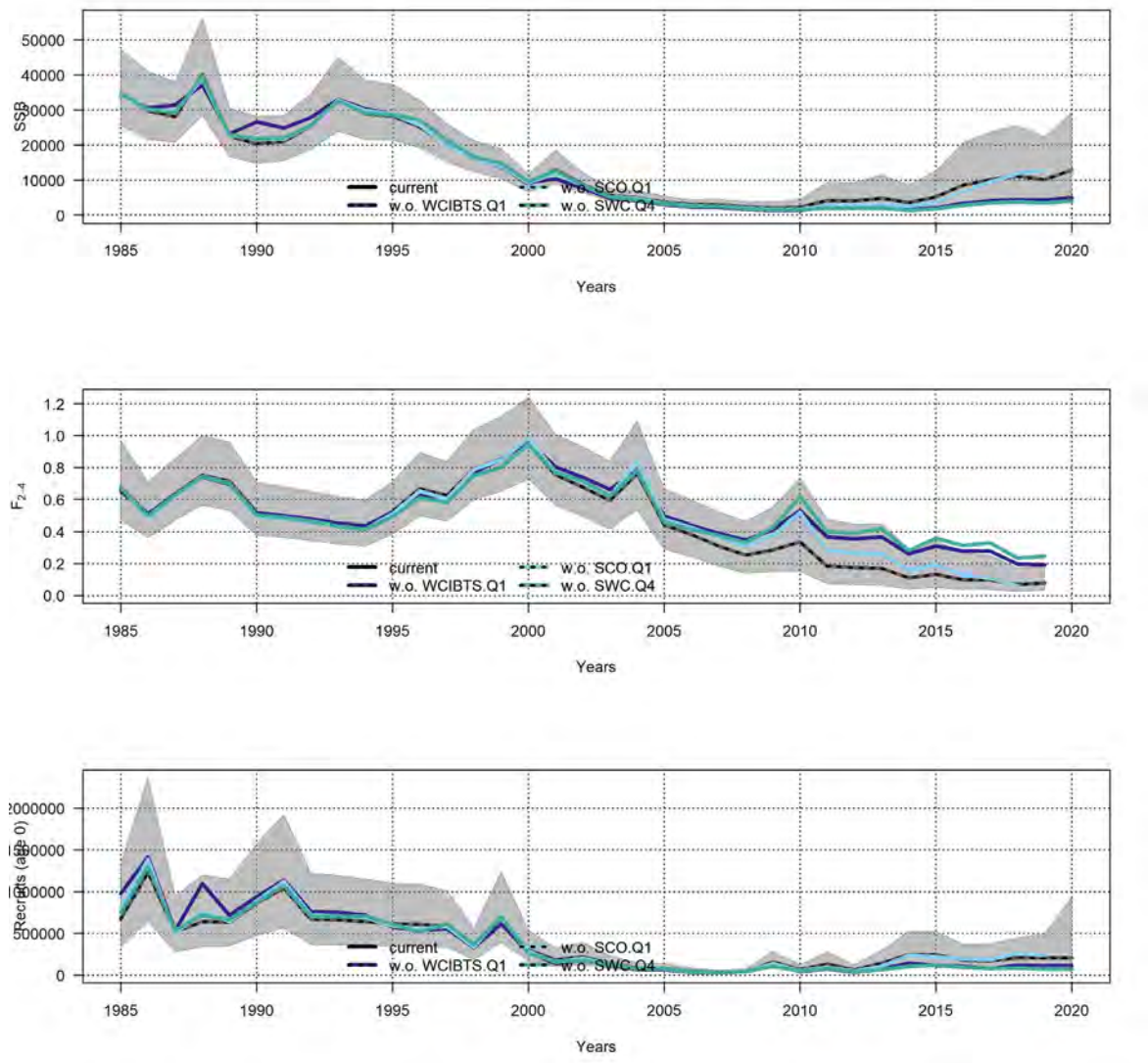


Figure 28. Leave-one-out analysis fleet covariance configuration Alternate 2, with ages ≥2 coupled

2.2.5 Survey Catchability Coupling

A number of survey catchability-at-age coupling configurations were compared to the Base Model. In alternative model runs, survey catchabilities were coupled from age five (in the Base Model configuration, survey catchabilities were coupled for the two oldest age classes, which are five and six for Q1 indices, and six and seven+ for Q4 indices), age four, or age three and upwards within each survey. Estimates of survey catchability (*log Q*) were very similar across model fits for WCIBTS Q1 and modelled Q4 indices, declining with age until reaching coupled estimates (Figure 29 & Figure 30). The SCOWCGFS Q1 *log Q* estimates had more of a dome-shaped pattern in the Base Model, peaking at age three (Figure 29), moving to a flat-topped set of estimates with increased coupling (Figure 30). Model fits were very similar, with the Base Model configuration providing the best fit (Table 6).

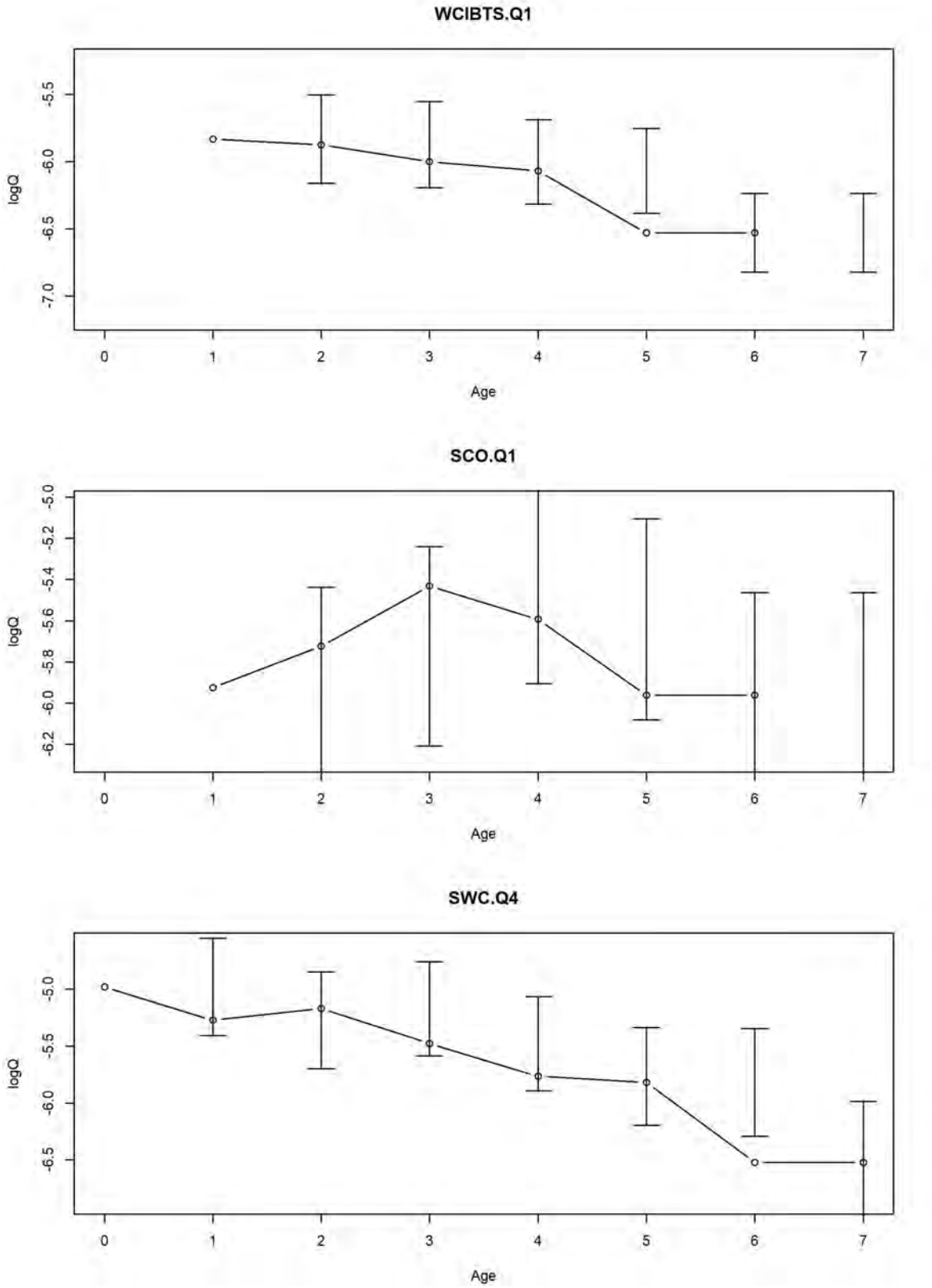


Figure 29. Survey index log Q estimates derived with Base Model configuration; catchability coupling for ages five and six for Q1 indices, and ages six and seven for Q4 indices

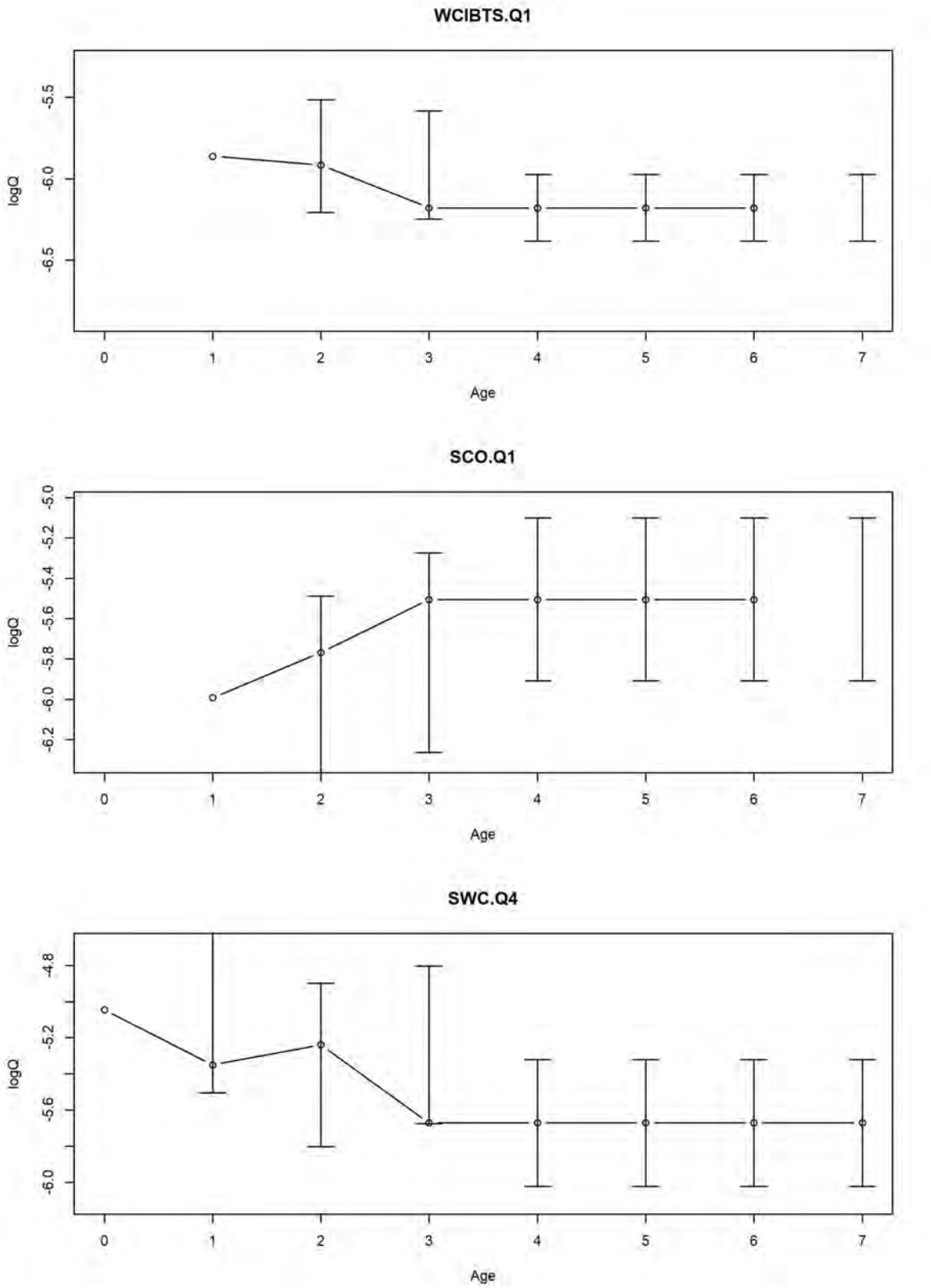


Figure 30. Survey index log Q estimates derived with alternate model configuration where catchability was coupled for ages three and upward for all indices

Table 6. Summary of model fits for different survey catchability coupling configurations, including Mohn's rho values from retrospective analysis (recruitment, SSB, and *F*).

Survey Catchability Coupling Configuration	*n* Parameters	log(*L*)	AIC
Base Model	25	-742.09	1534.17
Age 5 and upward	24	-747.67	1543.34
Age 4 and upward	21	-751.33	1544.69
Age 3 and upward	18	-753.79	1543.59

2.2.6 Coupling of Observation Variance Parameters

An array of alternate models were fitted with different observation variance coupling matrices (Table 7). All of the alternate configurations provided a better quality fit than the Base Model, particularly Alternates 3 & 4. Both Alternates 3 & 4 appeared to reduce the discrepancies in magnitude of residuals between age classes (Figure 31 & Figure 32), when compared to the Base Model (Figure 2).

Table 7. Summary of observation variance coupling configurations, and model fit quality

	Observation variance coupling					
Model	Commercial Fleet	Modelled Q4 Index	*n* Parameters	*log*(L)	AIC	Reference*
Base Model	All ages	All ages	25	-742.09	1534.17	base_model
Alternate 1	0; 1-7+	All ages	26	-736.80	1525.60	OV1
Alternate 2	0; 1-4; 5-7+	All ages	27	-735.11	1524.21	OV2
Alternate 3	0; 1-4; 5-6; 7+	0; 1-6; 7+	30	-712.46	1484.92	OV3
Alternate 4	0; 1-6; 7+	0; 1-6; 7+	29	-712.74	1483.49	OV4

* All model references are suffixes to "whiting_6a_benchmark_2021_", apart from "base_model"

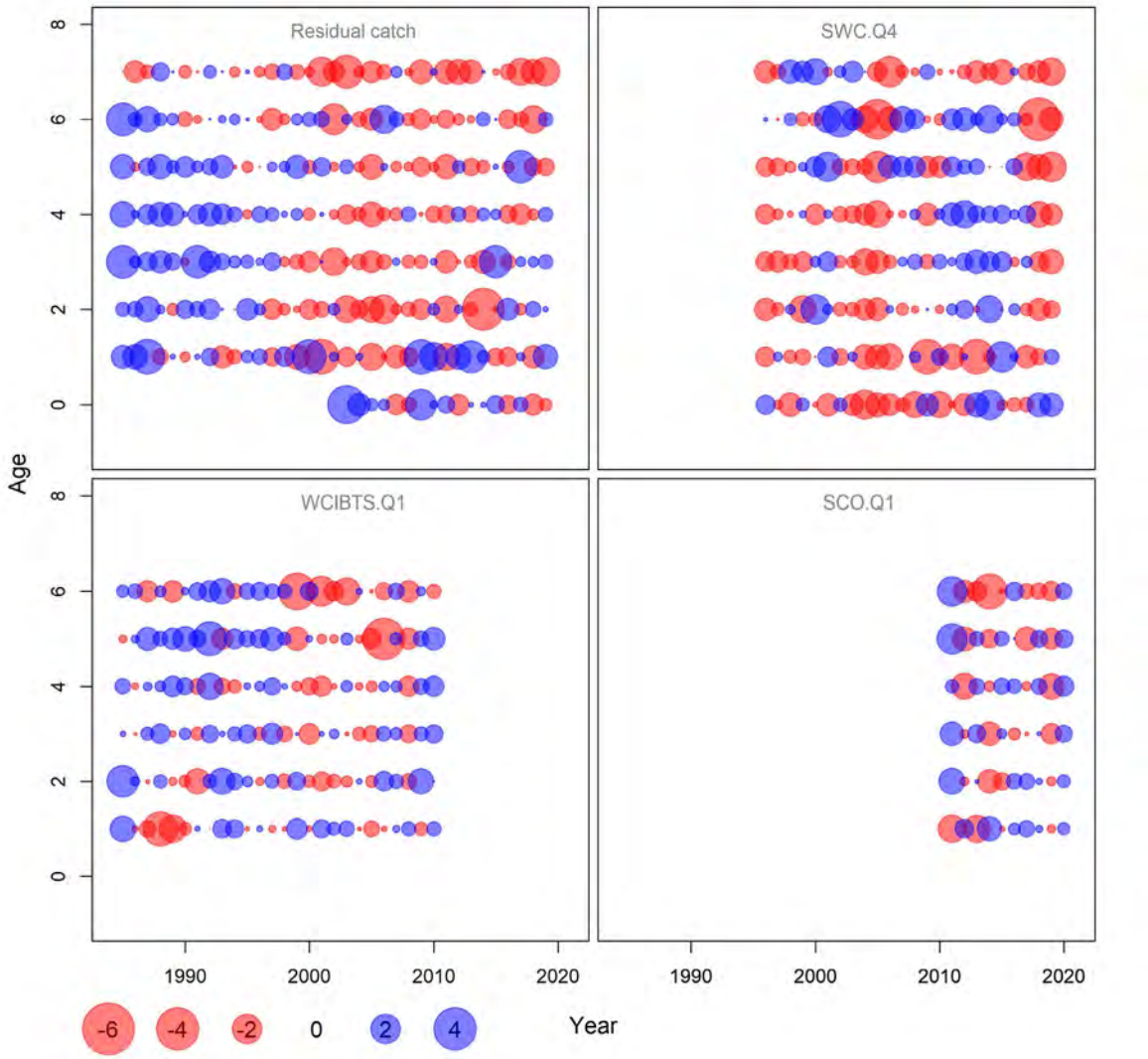


Figure 31. One-observation-ahead fleet residuals for observation variance coupling configuration Alternate 3

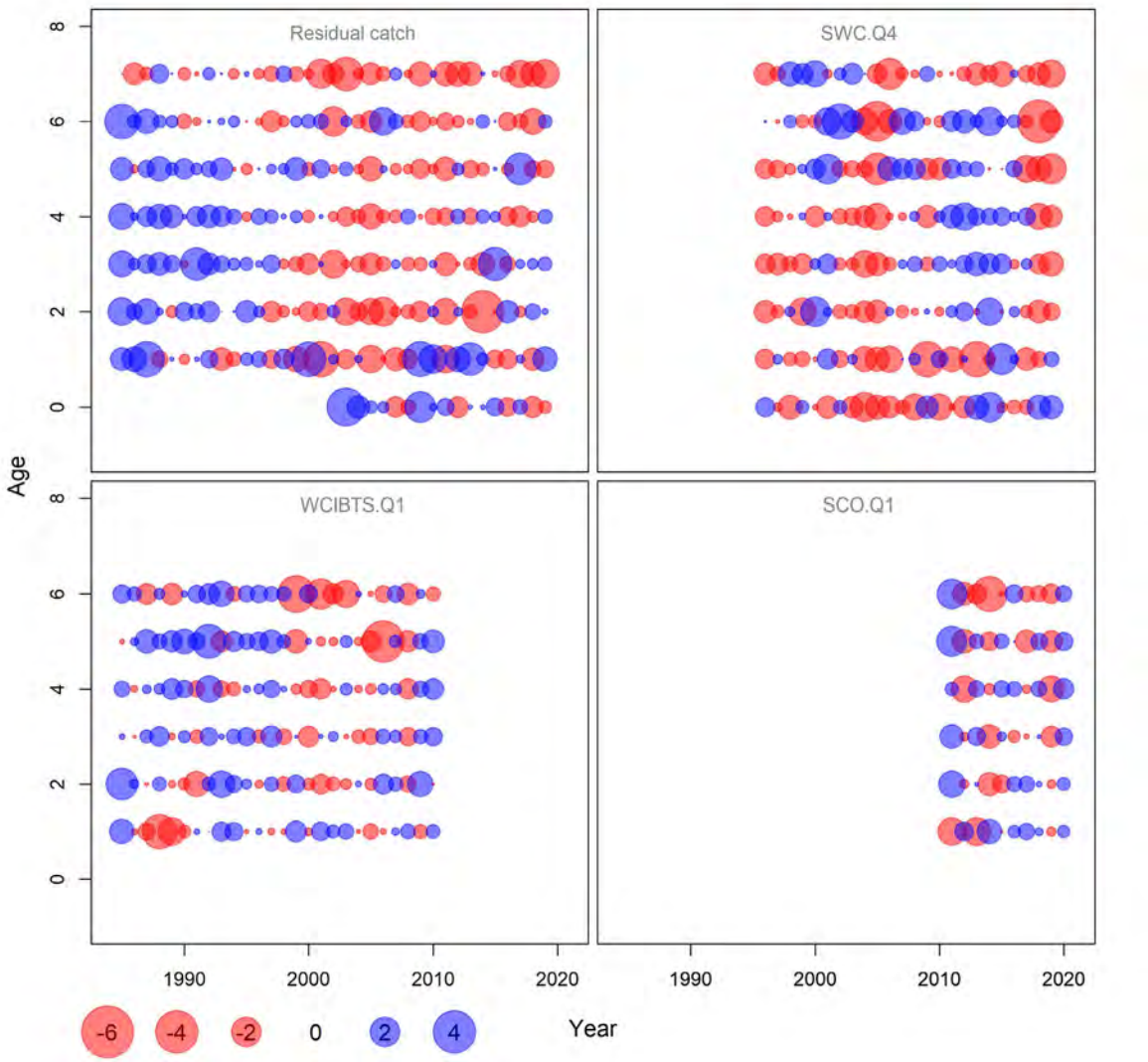


Figure 32. One-observation-ahead fleet residuals for observation variance coupling configuration Alternate 4

Bibliography

ICES. 2012. Report of the Benchmark Workshop on Western Waters Roundfish (WKROUND), 22–29 February 2012, Aberdeen, UK. 283 pp.

Nielsen, A., and Berg, C. W. 2014. Estimation of time-varying selectivity in stock assessments using state-space models. Fisheries Research, 158: 96–101. Elsevier B.V.

WD 4 Length-based indicators for whiting in Division 6.a (West of Scotland)

Tanja Miethe, Andrzej Jaworski, Helen Dobby

Marine Scotland Science, Marine Laboratory, 375 Victoria Road, Aberdeen AB11 9DB

Introduction

Length-based indicators (LBIs) and reference points have been proposed for assessment of data-limited fish stocks. A set of length-based indicators are here used to screen catch length compositions and to classify the stocks according to conservation/sustainability, yield optimization and MSY considerations (ICES, 2018). This method can be used to give an overall perception of stock status based on catch data. These indicators require data on catch length distributions, as well as estimates of life-history parameters of asymptotic length (L_{inf}) and length at first maturity (L_{mat}) to estimate reference points.

Data and Methods

Catch numbers at length and mean weights at age are available for the years 2003-2018. Length data for 2019 was incomplete and not available for 2020 (Figure 1). Indicators and reference points are calculated according to ICES guidelines for category 3 and 4 stocks (ICES, 2018). To estimate L_c, the length at first capture, the numbers at length were put into 2cm bins to remove multiple modes at lower lengths (Figure 2). The reference point L_{mat}=18.96 cm was calculated as the L_{50} of the maturity ogive, based on the Q1 survey estimates from 1997-2020. The L_{inf}=59.30 cm is based on the Q1 estimates from 1997-2020 and the Q4 survey estimates from 1999-2019. The original catch length distributions (Figure 1) were used to calculate the other LBIs.

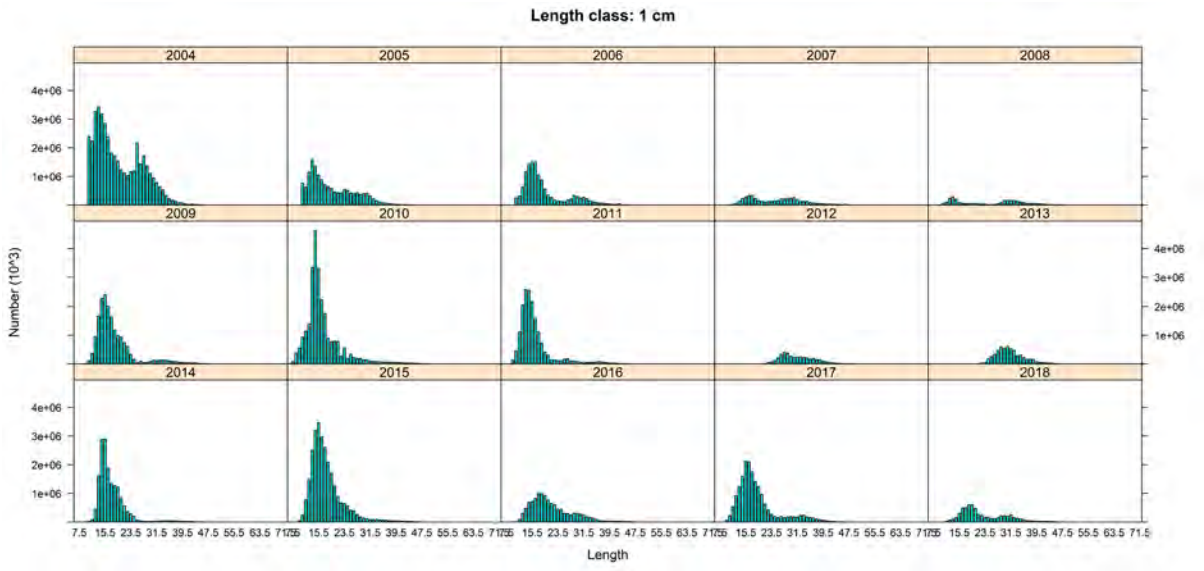


Figure 1. Whiting in Division 6.a. Numbers at length original data, using length class midpoints.

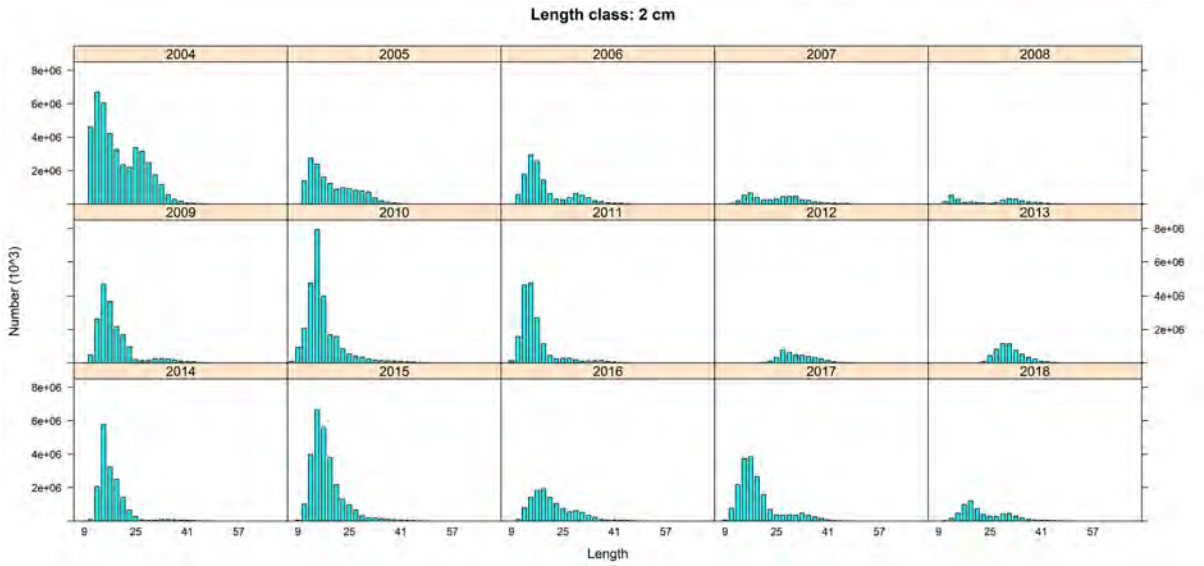


Figure 2. Whiting in Division 6.a. Numbers at length binned in 2cm length classes for estimation of L_c.

Results

Figure 3, shows the LBIs and LBI ratios to estimate status relative to reference point values (listed in Table 1). With regard to conservation, $L_{95\%}$ (length of the 95th percentile) and $L_{max5\%}$ (mean length of the largest 5% in the catch) indicate a lack of large fish in the catch (Figure 3a,b). Since 2014, these LBIs have shown some increase but values are well below the reference point $0.8L_{inf}$. P_{mega} describes the proportion of megaspawners in the catch, individuals larger than $10\%+L_{opt}$. The value is close to zero, well below the target of 30%. Here we assume asymptotic fisheries selectivity. If a change in catchability occurs, that would lead to less large fish being caught, the LBIs could underestimate presence of large fish.

Both $L_{25\%}$ (lower quartile length) and L_c are mostly lower that L_{mat}, showing that also immature individuals have been targeted by the fishery in most years since 2004. The mean size in the catch (L_{mean}) and the length of maximum yield (L_{maxy}) are around L_{mat} but below L_{opt} (length class at maximum biomass of an unexploited cohort, 2/3 L_{inf}) illustrating the suboptimal exploitation (Figure 3c,d).

The mean length is below the MSY proxy reference point $L_{F=M}$ in most years since 2003 (Figure 3 e,f). The reference point $L_{F=M}$ is calculated assuming M/k of 1.5 and depends on L_c, which varies over time. In some years (2003, 2012, 2013) the L_c increases. This can be caused by and change in selectivity, which affects both the mean length and the $L_{F=M}$ reference point

The downwards trend in the ratio $L_{mean}/L_{F=M}$ (lowest value in 2011 at 0.692) has stopped with stable (or slightly increasing) values in recent years. The ratio $L_{mean}/L_{F=M}$ shows high values in years 2007, 2008, 2012, and 2016. This could be caused by a low recruitment reducing small individuals in the catch affecting the mean length, which is sensitive to recruitment variability (compare in these years $L_{25\%}$ slightly higher than L_c).

The results show that whiting in 6.a is still overexploited, as all traffic light indicators are on read for the years 2016-2018 (Table 1).

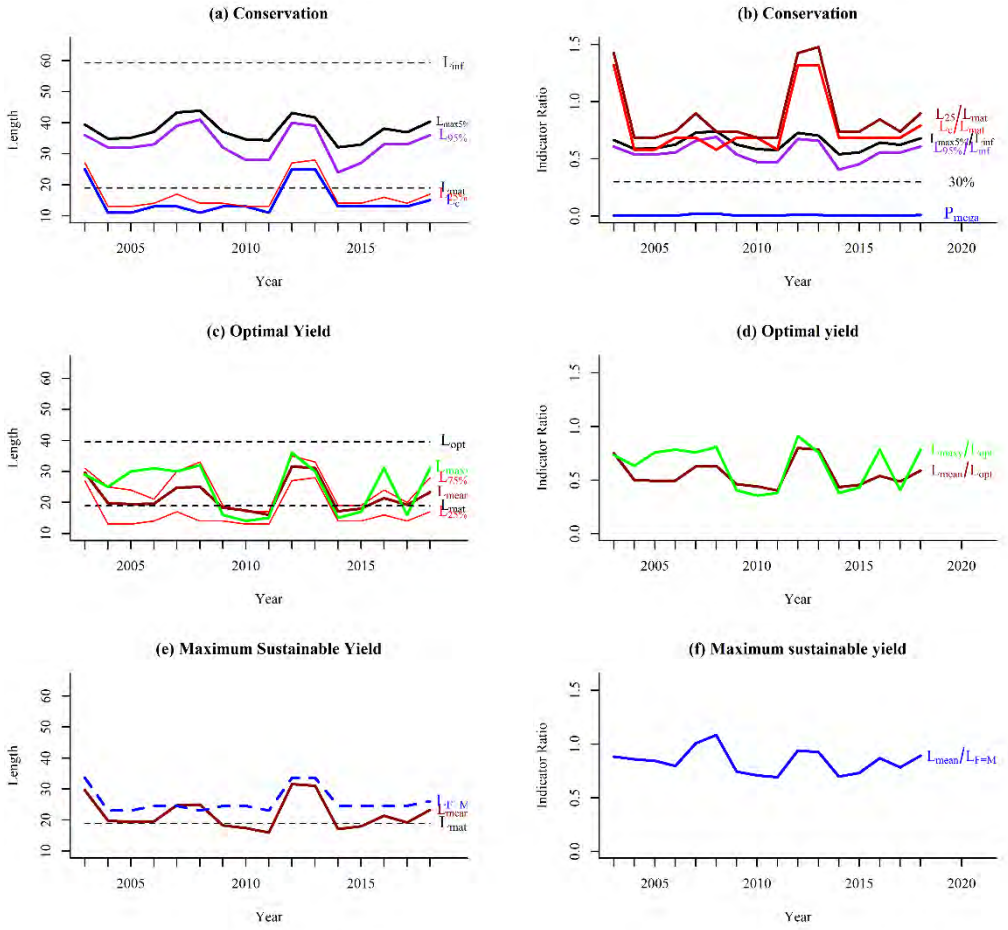


Figure 3. Whiting in 6.a, length-based indicators (LBIs, left) and LBI ratios (right).

Table 1. Whiting in 6.a. LBI ratios for recent three years of data.

Traffic light indicators

	Conservation				**Optimizing Yield**	**MSY**
	L_c/L_{mat}	$L_{25\%}/L_{mat}$	$L_{max5\%}/L_{inf}$	P_{mega}	L_{mean}/L_{opt}	$L_{mean}/L_{F=M}$
Ref	**>1**	**>1**	**>0.8**	**>30%**	**~1 (>0.9)**	**≥1**
2016	0.69	0.84	0.64	0.01	0.54	0.87
2017	0.69	0.74	0.62	0.00	0.49	0.78
2018	0.79	0.90	0.68	0.01	0.59	0.89

References

ICES 2018. ICES Techical Guidelines: 16.4.3.2 ICES reference points for stocks in categories 3 and 4. ICES Advice 2018, https://doi.org/10.17895/ices.pub.4128.

Annex 7: Additional External Reviews for North Sea cod

The following two reviews of the WKNSEA 2021 report are annexed here:

Review of some of the 2021 ICES benchmark decisions on the assessment model framework for North Sea cod.

Dr. Noel Cadigan
Centre for Fisheries Ecosystems Research (CFER)
Fisheries and Marine Institute of Memorial University of Newfoundland
St. John's, NL, Canada A1C 5R3

Executive Summary

- The space-aggregated NS cod assessment model does not address some important spatial assessment issues, primarily the potential for depletion of local spawning components.
- The workshop chose the best available approach to calculate NS cod stock size indices.
- Changes to the methodology (i.e. weighting and smoothing) to estimate maturities may not give more reliable estimates.
- The approach to including the IBTS Q3 index as a recruitment index for age 1 the following year is appropriate.
- The workshop chose the best available approach to calculate NS cod stock weight-at-age.
- Recreational catches were thoroughly addressed, and the best available information was used by the working group. I agree with their recommendation on the treatment of these data.
- Natural morality rates (Ms) were modified in SAM to account for migration of mature cod out of the current stock area into 6aN. I did not see much evidence for this migration conclusion. A change in spatial distribution does not necessarily mean migration.
- There is a retrospective pattern in SAM runs with baseline M values. WKNSEA decided to address this by adjusting M for ages 3+ since 2011. I am not sure why emigration is only considered since 2011. Is there any evidence that emigration has increased recently?
- There are other possible reasons for a retrospective pattern and I assume these mechanisms were considered implausible.
- I am concerned about the removal of the catch multiplier effect.
- Other changes to the SAM model (survey index variances, coupling of parameters) all seemed like reasonable incremental progress to an improved assessment model framework.

Background

On March 26, 2021 I agreed to provide additional external review on some benchmark decisions about how to address potential emigration of older fish out of the North Sea (NS) stock. I was provided access to the WKNSEA sharepoint site and on April 6 I was provided with further direction on specific documents to consider (see Appendix). I reviewed all the working documents plus the cod sections of the draft benchmark report. I was asked to spend a maximum of 2 days on my review, which was about all I could commit given the very short notice of the request.

There are several changes in assessment methodology described in the working group reports and I did not have time to consider all of these in detail. I focus on the decisions related to how to address then potential emigration of NS cod.

Review Summary

A workshop on Stock Identification of North Sea Cod (WKNSCodID) concluded that North Sea cod includes reproductively isolated Viking and Dogger cod populations, and the Dogger population has some phenotypic structure and extends to 6.a.N. I did not find a map showing the spawning locations of these two sub-populations.

It seems there was some interest by working group members to develop a spatial stock assessment model for cod in the North Sea, but sufficiently reliable spatial catch data were not available. This may continue to be a problem because there may be substantial errors in the reported spatial locations of catches. A consideration of this was not described in the working documents I was provided.

Survey analyses by Walker and Berg (2020; WD3) indicate that time-trends in survey trawlable biomass are substantially different in three northern regions compared to a southern region. In the Northern regions, survey biomass appears to be slightly below average (Q1, since 1983) whereas in the south the biomass appears to be near the historical minimum. Similar conclusions were reached with SURBA models applied to spatially dis-aggregated survey indices (Needle, 2021; WD2). Depending on how quotas are spatially allocated, this suggests there is a potential for depletion of local spawning components which is a serious issue that could affect the total productivity of the stock, as a sum of spawning components. The same trends occur in the spatial recruitment indices (age 1) which indicates a relationship between total biomass and recruitment. However, there are remarkably high correlations in recruitment deviations between the four subregions considered in Walker and Berg (2020; WD3) which suggests to me that there is high spatial correlation in factors affecting early life-stage survival.

Unfortunately, **the space-aggregated assessment model that was provided by the working group does not address these spatial assessment issues**.

The assessment workshop investigated improvements to the total stock assessment model by improving survey indices, maturity ogive, stock weights, natural mortality and investigation of recreational data, and choice of model settings, which is the focus of my review.

Improved survey indices

Overall, I agree with some of the modelling choices. The working group preference is Model 3: High resolution, Fixed spatial + yearly independent deviances. This involves fitting a delta-gamma model. This is like the VAST modelling approaches used for US West Coast model-based indices (Thorson, 2019). The delta-gamma distribution was recently recommended as a default approach when design-based indices are not available (Thorson et al., 2021). Although model 4 may possibly fit better, accounting for the index autocorrelation in a stock assessment model will need to be considered carefully.

An area for improvement is how age-structure is treated. As I understand it, the survey catch-at-age for each tow are estimated from catch-at-length and a spatial age-length key (ALK). A reference was given for the spatial ALK which I did not consider in this review. However, it will be very important that the spatial ALKs are reliable. The conversion from catch-at-length to catch-at-age involves uncertainties that

model M3 does not include. Also, one anticipates some between-age correlation in the spatial distribution of cod. The indices at older ages have more uncertainty and accounting for between-age correlations in spatial distributions may produce more reliable stock size indices.

How to treat length and age compositions in spatial survey models is an active area of research. In addition, survey model selection needs more research. For example, Thorson et al. (2021) found that model selection using AIC may not be reliable. I also have concerns about using assessment models and retrospective patterns to decide on the best survey model – this seems to be prone to confounding with other assessment model misspecifications and could potentially lead to masking of such misspecifications.

However, overall, I agree with the workshop decisions on the choice of available approaches to calculate NS cod stock size indices.

Maturity ogive

I found some of the notation in this working paper too obscure, so I am not sure I understand the recommended approach. I did not understand some of the figures also.

It seems the recommendation is to drop area-weighting of sub-areas. This does not seem appropriate. For example, if there is a small sub-area with high cod densities then their maturities will get a large weight in determining overall stock maturity, even if the population size in the small area is only a small part of the total population.

In terms of smoothing, there is sometimes large between-year changes in the proportion mature at some ages. There could be cohort effects to this that need to be investigated. If total mortality rates for mature and immature fish are the same then cohort maturity should be an increasing function of age. The uncertainty in point estimates of maturity were not provided, and this should be considered when deciding how much smoothing is appropriate.

Overall, I conclude some smoothing of the maturity data is warranted, but more research is necessary to choose a more reliable approach.

Figures 11 and 12 in Walker (2021; WD5) suggest that estimation of maturity is a non-ignorable source of uncertainty when calculating SSB in a stock assessment model. I think this is now possible using a recent innovation for SAM and this should be pursued at a future benchmark meeting.

Recruitment

I conclude that the approach to including the IBTS Q3 index as a recruitment index for age 1 the following year is appropriate.

Stock weights

The working group noted that “there are inconsistencies between the catch and survey data with survey weights generally being lower for ages 1–3, similar for ages 4–5 and larger for ages 6+”. If the survey is better at catching young and small fish then we expect survey weights will be lower than catch weights at these ages and for the same season. Similarly, if the fishery has a domed length selectivity pattern, then we expect survey weights for older fish to be greater than catch weights. The SAM model indicates some dome in the age-selectivity pattern which suggests the potential that there is some dome in the

length selectivity. However, the SAM F age-patterns could also be caused by ontogenetic changes in the availability of cod to the fishery. Hence, additional information is required to assess if the differences in weights for older ages in the catch and survey are expected or just due to sampling errors.

It is also possible to model the seasonal patterns in length and weight at age in the fishery and surveys to predict weight-at-age at the time of spawning to calculate SSB.

However, among the methods available to the WKNSEA, I conclude that the approach taken was the best available.

Recreational data

The magnitude of recreational catches and how to include this information in the assessment received considerable attention during the working group meetings. I conclude the issues were thoroughly addressed and the best available information was used in the working group. Without having additional information on the size of historical recreational catches relative to the commercial catches, then I agree with the working group decision that "it is not possible to use the SAM model to explore historical recreational F and catch scenarios based on recent survey data". I suspect that recreational catches will be a very small fraction of historical catches because recreational effort does not scale like commercial effort. During 2010-2019 the recreational catches ranged from 3.4%-8.9%.

SAM model settings

The natural morality assumption was an important change in the SAM model setting. From what I can tell, the SMS-derived M is a predation M. In some Northwest Atlantic cod stocks there is some evidence of change in M at older ages that may not be directly related to predation. Variable fractions of cod are sampled in spring surveys in very poor and even lethal condition. This seems to correspond somewhat with inter-annual variations in survey Z's. This should be investigated for NS cod, especially considering the recent reductions in the weights at older ages for this stock. However, these changes may simply be associated with changes in growth rates and length-at-age and may not reflect changes in condition.

M's were further modified to account for migration of mature cod out of the current stock area into 6aN. I did not see much evidence of this migration conclusion. A change in spatial distribution does not necessarily mean migration. If there is movement of cod from the North Sea to the West of Scotland then I would expect to see different trends in survey Z's, and possible even negative West of Scotland survey Z's at older ages as cod immigrants recruit to cohorts at older ages. Evidence of this was not provided. However, maybe a combination of different recruitment trends among subregions, some movement, and different F's and M's among the regions, will conspire to make Z trends similar even though there is movement.

Nonetheless there is a retrospective pattern in SAM runs with baseline M values. WKNSEA decided to address this by adjusting M for ages 3+. They applied M changes for two time-periods, 2011+ and 2015+, two age ranges, ages 3–5 and ages 3+, and for a range of migration rates, and selected the most appropriate M configuration as the one that minimized AIC. The changes in fit were "significant" although the improvements in residuals patterns (Figure 3.11.1.3 in WKNSEA report) were less obvious. I assume the difference in fits is related to a reduction in the process error standard deviation.

The estimated M values should have been tabulated or plotted. I think the increase in M is 0.16. If cod are leaving the North Sea forever at ages 3+ then accounting for this with a change in M is appropriate. However, I am not sure why emigration is only considered since 2011. Is there any evidence that emigration has increased recently? Is this just because northern sub-populations have always moved west as they get older, but the southern sub-population does not do this, and as a result emigration is now more of a concern because the southern subcomponent is much smaller in size recently?

Other possibilities for the retrospective pattern and lack of fit to survey indices include mis-reported catch or a change in survey catchability within the management unit such that the cod are available to the fishery but not the survey. However, no evidence for this was presented and I assume these mechanisms were considered implausible. The substantial reductions over time in the survey weights at older ages indicates a potential that length at age has also changed, perhaps even a little more than weights at age. If the SAM index catchabilities (Qs) are primarily caused by variation in length at age, then this suggests there is some potential that Q's have decreased. Insufficient information was presented in the workshop report to assess this but it is something that could be explored in the future. However, these changes may not be abrupt enough to account for the SAM lack-of-fit to survey indices and the retrospective patterns.

Other changes to the SAM model were described (survey index, maturities, stock weights, coupling of parameters) and the working group decisions all seemed like reasonable incremental progress to an improved assessment model framework. However, the removal of the catch multiplier effect is a concern for me. Presumably, this was introduced to fix a problem with reported catch, and I did not understand why this problem was addressed differently in the 2021 SAM model formulation. Removing the scaling to reduce retrospective patterns does not seem like a good rationale.

Recommendations

The survey information can be estimated for a wide range of spatial domains. The difficult issue is the catch; how much information exists on the size and spatial distribution of landings and discards, and the length and age compositions of the landings and discards? The spatial quality of fishery catch records and length/age sampling may be quite different. My recommendation is that there needs to be a research project to first address these issues, and then to consider what is a realistic spatial assessment model that can be estimated with the available data but also address the important population dynamics issues. This may require an assessment model that fits catch estimates separately from their length and age compositions. It may be unrealistic to provide good quality catch-at-age for spatial subdomains.

A spatial SURBA approach would be my initial focus. This could involve something like Kumar et al. (2020), but with some directed spatial movements of ages classes. A SURBA model with assumptions about M can be used to predicted catch trends, and this provides a good basis to consider how to include catch information (totals and age compositions) that could be dis-aggregated by spatial divisions or aggregated across divisions, depending on what is available and reliable.

Present time-series (age-based if possible) of the distribution of cod condition in surveys. Consider computing M_K (e.g. Casini et al., 2016) and if this could be used to improve the stock assessment.

Literature Cited

Casini, M., Eero, M., Carlshamre, S. and Lövgren, J., 2016. Using alternative biological information in stock assessment: condition-corrected natural mortality of Eastern Baltic cod. ICES Journal of Marine Science, 73(10), pp.2625-2631.

Kumar, R., Cadigan, N.G., Zheng, N., Varkey, D.A. and Morgan, M.J., 2020. A state-space spatial survey-based stock assessment (SSURBA) model to inform spatial variation in relative stock trends. Canadian Journal of Fisheries and Aquatic Sciences, 77(10), pp.1638-1658.

Thorson, J.T., 2019. Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. Fisheries Research, 210, pp.143-161.

Thorson, J.T., Cunningham, C.J., Jorgensen, E., Havron, A., Hulson, P.J.F., Monnahan, C.C. and von Szalay, P., 2021. The surprising sensitivity of index scale to delta-model assumptions: Recommendations for model-based index standardization. Fisheries Research, 233, p.105745.

Appendix: Documents Reviewed

Draft Report of the Benchmark Workshop on North Sea Stocks WKNSEA 2021

Walker D. N. 2020. WD_cod_1_Catch data for COD. Summary of InterCatch data for North Sea Cod (COD) Working Document for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020, 2021; 6 pp.

Needle C. 2021. WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod . Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.

Walker D. N. and. Berg C. W. 2020. WD_cod_3_Survey abundance & indices. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 14 pp.

Berg C. W. 2021. WD_cod_4_NScod_surveyIndices. Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 102 pp.

Walker D. N. WD_cod_5_maturity. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 13 pp.

Walker D. N.WD_cod_6_stock weights. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 6 pp.

Armstrong M., Weltersbach S, Radford Z, & Hyder K. WD_cod_7_recreational cod catches. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 16 pp.

Nielsen A. WD_cod_8_Process model for biological parameters in SAM. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.

Review of chapter 3 on North Sea cod (cod 27.47d20) of the report of WKNSEA 2021 by Eskild Kirkegaard. 16th April 2021.

Introduction

The reviewer was requested to consider whether the assessment approach suggested by WKNSEA is suitable as basis for the advice on North Sea cod.

The review is based on the following documents:

1. Draft WKNSEA report of 8th April 2021
2. Walker D. N. 2020. WD_cod_1_Catch data for COD. Summary of InterCatch data for North Sea Cod (COD) Working Document for the Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020, 2021; 6 pp.
3. Needle C. 2021. WD_cod_2_Commercial catch data collation and relative survey-based trends for North Sea cod . Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.
4. Walker D. N. and. Berg C. W. 2020. WD_cod_3_Survey abundance & indices. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), November 24–26, 2020; 14 pp.
5. Berg C. W. 2021. WD_cod_4_NScod_surveyIndices. Working Document to the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 102 pp.
6. Walker D. N. WD_cod_5_maturity. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 13 pp.
7. Walker D. N.WD_cod_6_stock weights. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 6 pp.
8. Armstrong M., Weltersbach S, Radford Z, & Hyder K. WD_cod_7_recreational cod catches. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 16 pp.
9. Nielsen A. WD_cod_8_Process model for biological parameters in SAM. Working Document for the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2021), February 22–26, 2021; 9 pp.

Conclusion

Accepting that the available data did not allow a spatial assessment approach, WKNSEA did a good job in improving the current assessment model. The conclusions and decisions made by the Workshop were in general appropriate and well justified and the final assessment model suggested by the Workshop constitutes an improvement compared to the current model.

The current forecast is overestimating catches and underestimating fishing mortality compared to the assessment. This persistent forecast error or discrepancy between assessment and forecast is at a level where I do not think the current assessment should be used as basis for the advice.

The retrospective bias and discrepancy between forecast and assessment may be related to the migration of mature cod out of the assessment area and the assessment suggested by WKNSEA is to some extent accounting for the migration. As such, the suggested assessment model is an improvement compared to the current model. However, it is unclear if the discrepancy will be reduced to an acceptable level with the suggested assessment.

If the suggested assessment is accepted the reference points should be updated accordantly. Accepting the regime shift in recruitment, as suggested by WKNSEA, will lead to significant changes to the biomass reference points.

The evidence available supports the existence of two (three) sub-stocks with different population dynamics and I think it is unlikely that the assessment problems can be solved in a single stock assessment model. Priority should be given to the development of a spatial approach that take account for the differences in dynamics between the sub-stocks.

Comments

WKNSEA addressed the following issues;

- Stock identification and assessment units,
- Survey based assessments of separate stocks,
- Fisheries independent indices,
- Maturity ogive,
- Recruitment,
- Stock weights,
- Recreational catches,
- Predation mortality,
- Migration of North Sea cod into 6aN,
- Configuration of the assessment model,
- Reference points.

<u>Stock identification.</u>

WKNSEA agreed with the recommendation of the Workshop on Stock Identification of North Sea Cod (WKNSCodID) that ICES in its assessment of North Sea cod should recognise and account for the two cod populations, Viking and Dogger, and should consider accounting for phenotypic stocks within the Dogger population. However, the workshop concluded that the quality of the catch data available by population was too low to support analytical assessments of the separate population. The workshop was therefore not able to provide assessments by populations and focused therefore on improvement of the current "one stock" assessment.

This conclusion to continue to assess the North Sea cod as one stock seems justified given the quality of the catch data.

<u>Survey based assessments of separate stocks</u>

WKNSEA presented, based on a WD by Needle (WD 3 above), one method of generating survey indices by sub-stock. The results presented in the WKNSEA show the same stock developments as the survey based biomass trends provided in the advice sheet for North Sea cod. WKNSEA stated that the approach presented at the workshop may be more robust and reliable than the biomass trends currently shown in the advice sheet but does not provide a clear conclusion on whether or not to replacing the current biomass trends with the new approach.

<u>Fisheries independent indices</u>

Four models for producing standardised survey indices of abundance were tested and compared to the current model. All models gave similar trends and WKNSEA's choice of model 3 as the best was based on evaluation of the performance of the models in the assessment model.

The choice of model 3 seems justified but the change of index model will likely not have a major impact on the final assessment.

Maturity

The Workshop agreed to:

- Omit the current use of area based raising factors when using IBTS Q1 data to estimate maturity for North Sea cod. The justification for the change seems sound.
- Include records from Skagerrak in the maturity calculation. Again, the justification seems sound.
- Construct maturity at age by subarea and combine subareas to subpopulations when less than five fish at each age are sampled in a subarea in any year. It is not clear what this means in practise.
- Use a 5-years running mean by age to smooth the maturity by age over time. The justification seems sound.

Recruitment

The Workshop agreed to include the age group 0 index from the IBTS Q3 as a separate recruitment index for age 1 the following year. This was well justified.

Stock weight

The Workshop agreed to used IBTS Q1 weight data for age 1 and 2 as stock weights for the two age groups. For older age groups it was decided to use mean catch weights for the first quarter as stock weights. In the current assessment annual mean catch weights at age are used as mean stock weight at age.

Weight data from the IBTS Q1 is incomplete prior to 2002 and catch data are not available by quarter prior to 2002. The Workshop therefore decided to estimate survey mean weight data for the period prior to 2002 by using the ration by age between survey and annual catch weights to scale the annual catch weights to the survey level. For ages 3+ the mean ration at age between 1st quarter catch weights and annual catch weights were used to scale the annual catch weights at age to 1st quarter weights for the period prior to 2002.

The biological rational for revising the stock weights at age to be more representative for the stock weights at 1st January may be good. However, information was not presented allowing to judge how it affects the assessment and the forecast. The change may be justified if it reduces the variance associated with the stock weights. If it only results in an up or down scaling of the biomass estimates you can question the added value of the change. The current biomass reference points will have to be revised to reflect the new stock weights but it may not necessarily have any impact on the advice.

Recreational catches.

The Workshop decision not to include recreational data in the assessment due to data quality issues seems appropriate.

Predation mortality

The predation mortalities by age were updated based on the latest SMS key run. No change in approach.

Migration of cod into 6aN

The approach to address the migration of mature cod into 6aN by adjust the natural mortality for ages 3+ seems appropriate as an interim solution. Removal of mature fish from the North Sea by increasing natural mortality on ages 3+ corresponds to introducing a migration parameter reflecting the migration of cod out of the assessment area. The choice of time period (from 2011) and the use of a constant migration rate of 15% for all age groups and throughout the period can be questioned. However, given the available information it is difficult to suggest alternatives.

The adjustment of M to mimic the migration of cod to 6aN may influence the estimation of both biomass and fishing mortality reference points as the migrating cod are "assumed" to die.

Configuration of assessment model

I am not able to evaluate the choice of final SAM configuration.

The decision to removing the catch multiplier from the assessment seems entirely based on model considerations and not on evaluation of the process originally intended to be mimicked by the multiplier. That the removal has very limited impact on the current stock status is not a valued argument for removing the multiplier.

Short term forecast

Approach seems appropriate. No comments.

Reference points

The Workshop argue for a regime shift in recruitment with a low recruitment regime since 1998. The decision to only use data from 1998 and onwards has significant impact on the biomass reference points, with much lower estimates of Blim and Bpa.

The stock recruitment relationships may vary significantly between sub-stocks and the single stock reference points may not necessarily represent a good basis for the advice rule.