INTER-BENCHMARK PROTOCOL ON SOLE (*SOLEA SOLEA*) IN DIVISIONS 7.f and 7.g (BRISTOL CHANNEL, CELTIC SEA) (IBPBRISOL 2019)

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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

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Editors

Noel Cadigan

Authors

Noel Cadigan • Helen Dobby • Sofie Nimmegeers • Bart Vanelsander • Lies Vansteenbrugge • John Wiedenmann

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i Executive summary

The Inter-benchmark Protocol on Sole (*Solea solea*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea (IBP-Brisol) met by correspondence during four skype meetings, chaired by Noel Cadigan (Centre for Fisheries Ecosystems Research (CFER), Fisheries and Marine Institute of Memorial University of Newfoundland, Canada) and attended by invited external expert John Wiedenmann (Department of Ecology, Evolution and Natural Resources, Rutgers University, New Jersey, USA). The focus of this inter-benchmark was to improve the quality of the tuning series that are included in the current assessment. ToRs on the UK CBT tuning fleet and additional survey information were postponed to the upcoming benchmark in 2020.

A new Belgian commercial tuning index was constructed focusing on the landings and effort data of pure trips from the large fleet segment of the Belgian beam trawl fleet fishing in divisions 7.f and 7.g. Several models were tested and a GLMM including a categorical year effect, a log-linear relationship between the engine power of a beam trawler and the landing rate, a categorical temporal effect ‘month’ and a categorical spatial effect ‘ICES statistical rectangle’ were retained. Also, a variable dispersion factor was added, including ‘month’ and ‘ICES statistical rectangle’. This tuning fleet provides information from 2006–2017 and focusses on ages 2–9 with a good internal consistency.

Several XSA assessment runs were trialled at the inter-benchmark. The final run included the new Belgian CBT series from 2006–2017 (ages 2–9), the original Belgian CBT series from 1971–1996 (ages 3–9), the UK CBT from 1991–2012 (ages 3–8) and the UK BTS Q3. This resulted in an increase of the SSB and a decrease of F in recent years.

New reference points were estimated. F_{MSY} analyses were conducted with Eqsim.

Future research and data requirements were identified, also by the external reviewers.

ii Expert group information

Expert group name	Inter-benchmark Protocol on Sole (*Solea solea*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea) (IBPBrisol)
Expert group cycle	Annual
Year cycle started	2019
Reporting year in cycle	1/1
Chair(s)	Noél Cadigan, Canada
Meeting venue(s) and dates	29–31 January 2019, by correspondence, seven participants

1 Introduction

The Inter-benchmark Protocol on Sole (*Solea solea*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea (IBP-Brisol), chaired by External Chair Noel Cadigan (Centre for Fisheries Ecosystems Research (CFER), Fisheries and Marine Institute of Memorial University of Newfoundland, Canada) and attended by invited external expert John Wiedenmann (Department of Ecology, Evolution and Natural Resources, Rutgers University, New Jersey, USA) met by correspondence to:

Tor a. Evaluate the present analytical assessment method of sole with emphasis on:

i. Estimate and provide the basis for a suitable time-series of effort data for the UK commercial beam trawl to account for the recent change in e-logbook effort recording;
ii. Evaluate the appropriateness of the selectivity pattern used to calculate the indices derived from the Belgian commercial tuning fleet over time and provide updated time-series if applicable;
iii. Investigate if additional survey information (e.g. UK-Q1SWBeam, started in 2006) is available and can be incorporated in the assessment;

Tor b. Update the stock annex as appropriate.

Tor c. Re-examine and update MSY and PA reference points according to ICES guidelines.

Tor d. Develop recommendations for future improving of the assessment methodology and data collection.

2 Description of the Benchmark Process

The Inter-benchmark Protocol on Sole in divisions 7.f and 7.g included the following steps:

A Skype meeting was held on January 31, 2019 to go through the ToRs. The ICES code of conduct was described and all participants declared no conflict of interest.

> ToR a: 'Estimate and provide the basis for a suitable time-series of effort data for the UK commercial beam trawl to account for the recent change in e-logbook effort recording', will be addressed in the upcoming 2020 benchmark workshop.
>
> There was some confusion about ToR b: 'Evaluate the appropriateness of the selectivity pattern used to calculate the indices derived from the Belgian commercial tuning fleet over time and provide updated time-series if applicable'. The objective provided for this ToR was 'to investigate a more realistic conversion factor for engine power to convert nominal fishing effort to effective effort for the Belgian commercial beam trawl (BE-CBT)'. The IBP-Brisol agreed that this ToR will be reviewed in terms of the stated objective. First model output was presented.
>
> ToR c: 'Investigate if additional survey information (e.g. UK-Q1SWBeam, started in 2006) is available and can be incorporated in the assessment', will be reconsidered in the upcoming 2020 benchmark as the UK-Q1SWBeam tuning series is not long enough to be included in the assessment at this time.

A Skype meeting was held on February 11 and 21, 2019 to check on progress. The IBP_Brisol discussed in particular on how the tuning indices were calculated from the model output.

A Skype meeting was held on March 1, 2019 to determine a preferred XSA model formulation from sensitivity analyses and examination of the model diagnostics. A final version of the working document on engine power correction Belgian Commercial Beam trawl tuning fleet for Sole in the Celtic Sea (27.7.fg) (Annex 2) was available. The IBP_Brisol agreed that additional justification for the proposed calculation method of the tuning indices will be provided by email and will be added to the working document. Also, the final eqsim output to determine the reference points will be provided by e-mail.

3 Stock Sole (*Solea solea*) in divisions 27.7.f and 27.7.g (Bristol Channel, Celtic Sea)

3.1 Stock ID and substock structure

No results were presented on the stock ID during the Inter-benchmark Protocol.

3.2 Issue list

The issue list is taken from Section 36.9 of ICES, WGCSE (2018). The issues related to the Commercial BE-CBT fleet were addressed at the Inter-benchmark Protocol. The other issues are scheduled for the upcoming benchmark in 2020.

Tuning series

Problem / Aim	Work needed / Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?
Commercial UK(E&W)-CBT fleet The UK beam trawl tuning-series is in the current assessment used up to 2012, because of effort reporting issues. A new tuning series was provided with effort in days instead of hours up to 2015. The inclusion of this new tuning series results in a significant upward revision of F and downward revision of SSB from late 1990s up until now, compared to the original tuning series.	*Need to review the new UK-CBT tuning series with effort in days	*UK-CBT tuning series calculations
Commercial BE-CBT fleet There's a retrospective bias in estimating F and SSB in the most recent years, at which F was underestimated and SSB was overestimated. Moreover, the 2018 assessment shows a substantial downward revision of the SSB and a substantial upward revision of the F back to 2003. This might be related to a change in the selectivity of the Belgian commercial tuning fleet over time. Moreover, in recent years the older ages in this tuning fleet have greater influence on the assessment as the UK(E&W)–CBT fleet doesn't provide information after 2012.	*investigate new calculation method of CPUE index *Investigate if commercial tuning fleets should still be used in future assessments of sole in 7.f and 7.g.	*BE-CBT tuning series calculations
UK-BTS-Q3 survey The UK-BTS-Q3 survey is the only survey used in the current assessment and is solely providing information on the recruiting age (age 1)	*Investigate if additional survey information (e.g. UK-Q1SWBeam, started in 2006) is available and can be incorporated in the assessment. *Additional survey data can confirm the info provided by the UK-BTS-Q3 survey.	*UK-Q1SWBeam tuning series *other available survey data

Fisheries and ecosystem issues and data

Trends in mean weights The mean weights have dropped over time (2000–2010) and recently increased again.	*What drives this change? *Is it driven by an ecosystem change? *Is there a similar trend in the weights from other stocks?	*information on the evolution in the Celtic Sea ecosystem

Assessment method

Alternative assessment models to XSA. The current assessment has a developing retrospective pattern that could create issues in the forecast. It would be preferable to use a statistical method and propagated the main uncertainties into the forecasts properly.	*Explore the use of A4A, ASAP and SAM as alternatives to XSA for this stock.	*Standard assessment inputs

3.3 Scorecard on data quality

A scorecard was not used for this Inter-benchmark Protocol.

3.4 Multispecies and mixed fisheries issues

No new information was presented at the Inter-benchmark Protocol.

3.5 Ecosystem drivers

No new information was presented at the Inter-benchmark Protocol.

3.6 Stock Assessment

3.6.1 Catch–quality, misreporting, discards

Total international **landings** are estimated at 776 tonnes in 2017, of which Belgium landed 71% (549 t), UK 19% (148 t), France 6% (50 t), Ireland 4% (28 t) and the remainder by Northern Ireland and Scotland. This is the lowest landing figure in the time-series, corresponding to an international uptake of 91.8% of the agreed TAC in 2017 (845 t).

Discards are not included in the assessment, but given the low discard rates of sole (average discarding by weight is 5.1% of the catch) it is unlikely that the inclusion of discards would change the perception of the stock.

The Belgian fleet (especially beam trawlers) fishes the largest part of the TAC of this stock. The Belgian beam trawl fleet consists of a small fleet segment (Eurocutter and coastal vessels; engine power <221 kW) and a large fleet segment (engine power >221 kW). On average 95% of the fishing hours in the ICES divisions 27.7.f and 27.7.g can be attributed to the large fleet segment. In the working document (Annex 2), we explored the possibilities to include a new Belgian tuning fleet to the assessment.

There were two important drawbacks that we had to consider:

- The vessels belonging to the small fleet segment are likely a group that is misreporting effective engine power (personal communication).
- The Belgian beam trawl fleet has fishing opportunities spread over different ICES divisions. This flexibility creates an opportunity for noncompliance. It is generally known that fishers occasionally 'transfer' landings from one stock to another as a consequence of quota limitations (e.g. day limits).

The occurrence of these drawbacks were explored in the working document, which resulted in a new commercial tuning fleet for Belgian beam trawlers focusing on the large fleet segment and their pure trips (Annex 2).

3.6.2 Surveys

The Celtic Sea sole stock was assessed during the WGCSE 2018 using one survey index: UK (E&W)-BTS-Q3 (1988–2017), that focuses on age 1 to 5. It is the only index providing information on the recruiting age (age 1). ToRc stated: 'Investigate if additional survey information (e.g. UK-Q1SWBeam, started in 2006) is available and can be incorporated in the assessment'. The UK-Q1SWBeam was only extended into the Celtic Sea (including Divisions 7f and 7g) in 2013 and in the first two years, the coverage was limited due to bad weather conditions and operational difficulties, meaning there are only four years of data to provide a LPUE index for the divisions 7.f and 7.g sole assessment. Therefore, the IBP_Brisol decided to reconsider the inclusion of this tuning series during the upcoming benchmark in 2020.

3.6.3 Weights, maturities, growth

Analysing the available data on biological parameters revealed that the mean weights have dropped over time (around 2003) and recently show large variability at a lower level (Figure 1, Figure 2). Those fluctuations will be evaluated at the 2020 benchmark.

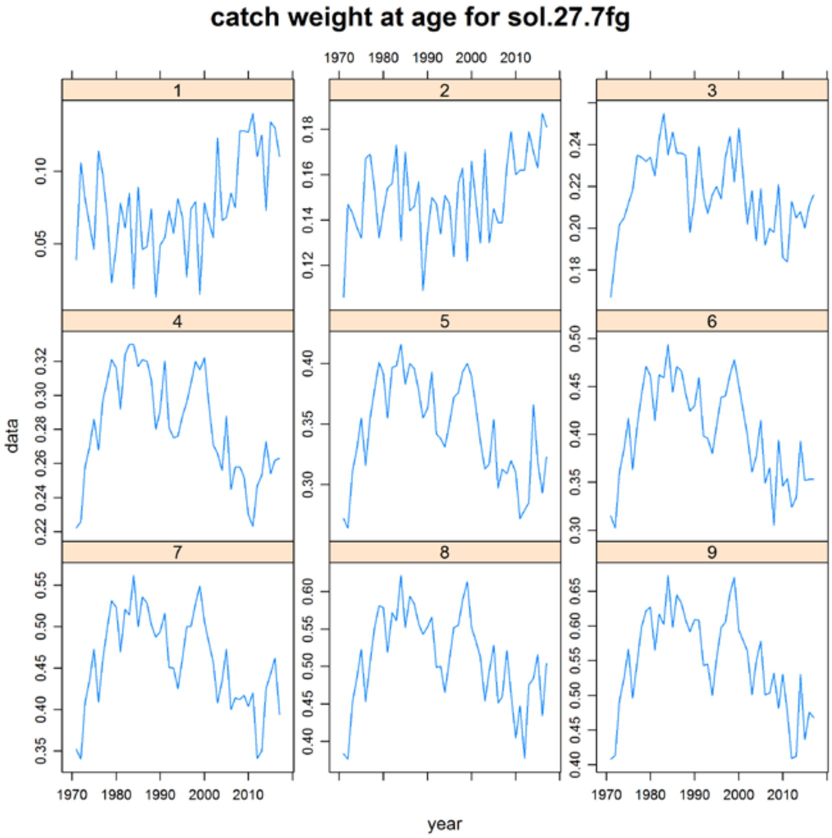

Figure 1. Catch weight-at-age.

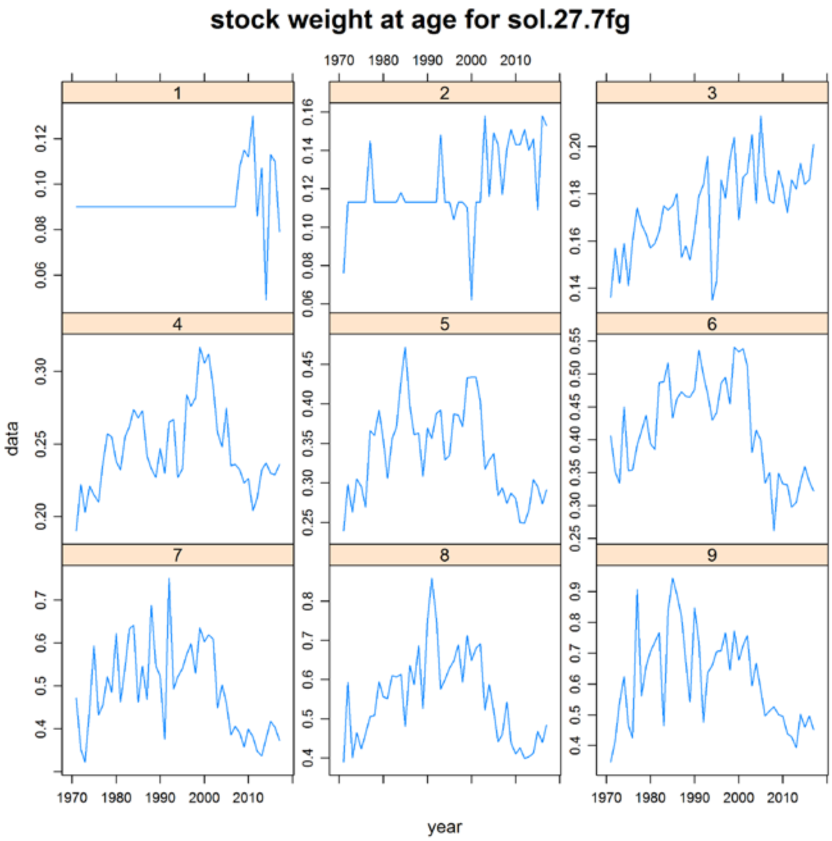

Figure 2. Stock weight-at-age.

During the upcoming benchmark in 2020, a thorough analysis of all available maturity data will be executed, to come up with a maturity ogive that is supported by recent data.

3.6.4 Assessment model

The model used to assess Celtic Sea sole is an extended survival analysis (XSA). No new assessment models were tested during this IBP_Brisol, this will be one of the aims of the benchmark in 2020.

3.6.4.1 WGCSE 2018 - current assessment (baserun)

During the WGCSE 2018, an XSA model was used to assess Celtic Sea sole. One scientific survey (UK(E&W)-BTS-Q3) and two commercial tuning series (UK(E&W)-CBT and BE-CBT) were incorporated in the assessment. In the WGCSE 2018, the Belgian commercial beam trawl (BE_CBT) tuning fleet was split into two parts (period 1971–1996 and 1997–2017). The final settings used in the WGCSE 2018 assessment are listed in Table 1.

With the addition of the 2017 data (WGCSE 2018), F was upscaled, whereas SSB was downscaled between 2003 and 2016 (Figure 3). In the WGCSE 2017 assessment, F and SSB for 2016 were estimated to be 0.37 and 2525 t respectively; while the WGCSE 2018 estimates for 2016 were 0.44 and 2218 t, an upward revision of 18% for F and a downward revision of 12% for SSB. This raised concerns about the uncertainty in the assessment.

Table 1. XSA diagnostics using during the WGCSE 2018.

	WGCSE 2018 (Baserun)		
Fleets	Years	Ages	α-β
BE_CBT	71–96	2–9	0–1
BE_CBT2	97–17	2–9	0–1
UK(E&W)-CBT	91–12	2–9	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85
-First data year	1971		
-Last data year	2017		
-First age -Last age	1 10+		
-Time series weights	None		
-Model	Mean q model all ages		
-Q plateau set at age	7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages		
-s.e. of the means	1.5		
-Min s.e. for pop. Estimates	0.3		
-Prior weighting	None		
-Fbar	Ages 4–8		

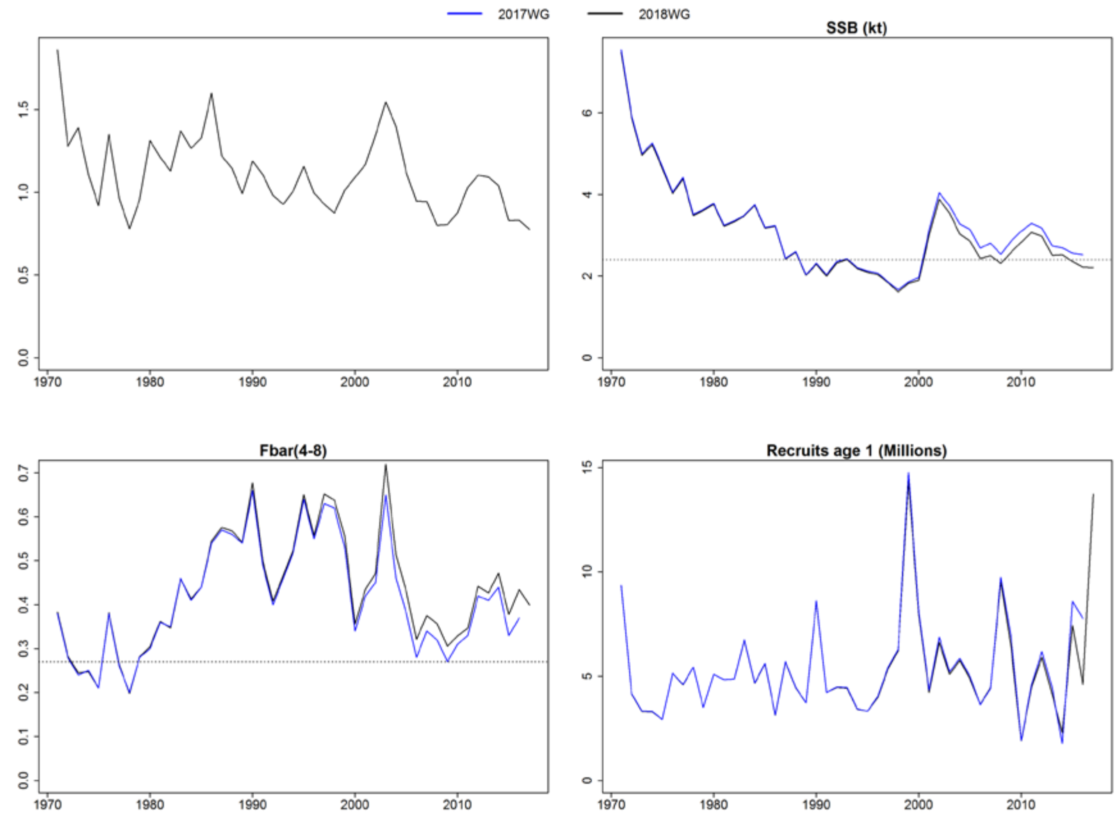

Figure 3. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2017 assessment and the WGCSE 2018.

In the working document on engine power correction Belgian Commercial Beam trawl tuning fleet (BE-CBT) for Sole in the Celtic Sea (27.7.fg) (Annex 2), the Belgian commercial tuning series was investigated and modified. This commercial tuning series was included in several exploratory assessment runs described below.

3.6.4.2 Run 1 (All2_9)

Data

Same catch data (total weight, mean weight- and number-at-age for landings) as used in the WGCSE 2018 assessment.

Biological parameters

Same biological parameters as used in the WGCSE 2018 assessment.

Tuning series

The same 1971–1996 BE_CBT, UK(E&W)-CBT and UK(E&W)-BTS-Q3 tuning series were used as in the WGCSE. The second Belgian tuning series (BE_CBT2) used in the baserun (1997–2017) was split into two parts. The first part consisted of a part of the old BE_CBT2 tuning series from 1997–2005, and the new second part (2006–2017) was a new series that was created for this inter-benchmark (BE_CBT3). More information can be found in the working document on the horse power correction of the Belgian commercial beam trawl tuning fleet (Annex 2). The ages used for all CBT tuning series were set at 2–9 as in the WGCSE 2018 assessment. The ages used for the UK(E&W)-BTS-Q3 and UK(E&W)-CBT were the same as in the WGCSE 2018 assessment. Model settings for run 1 are listed in Table 2. The internal consistency plots for the tuning series and their similarity are shown in Figures 4–9.

Figures 10–13 present the model output for this second run. Figure 11 shows the residuals for each index and age. Figure 12 shows mean squared natural logarithm transformed residuals and shows that for age 2 there is a MSE >0.3 for BE_CBT, BE_CBT2 and UK(E&W)-CBT. Overall, BE_CBT2 showed high MSE. The UK(E&W)-CBT also shows high MSE for age 9. Figure 13 shows a moderate retrospective pattern for Mean F, recruits and SSB.

Table 2: XSA diagnostics used for run 1 (All2_9).

	Run 1: All 2–9		
Fleets	Years	Ages	α-β
BE_CBT	71–96	2–9	0–1
BE_CBT2	97–05	2–9	0–1
BE_CBT3	06–17	2–9	0–1
UK(E&W)-CBT	91–12	2–9	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85
-First data year	1971		
-Last data year	2017		
-First age -Last age	1 10+		
-Time-series weights	None		
-Model	Mean q model all ages		
-Q plateau set at age	7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages		
-s.e. of the means	1.5		
-Min s.e. for pop. Estimates	0.3		
-Prior weighting	None		
-Fbar	Ages 4–8		

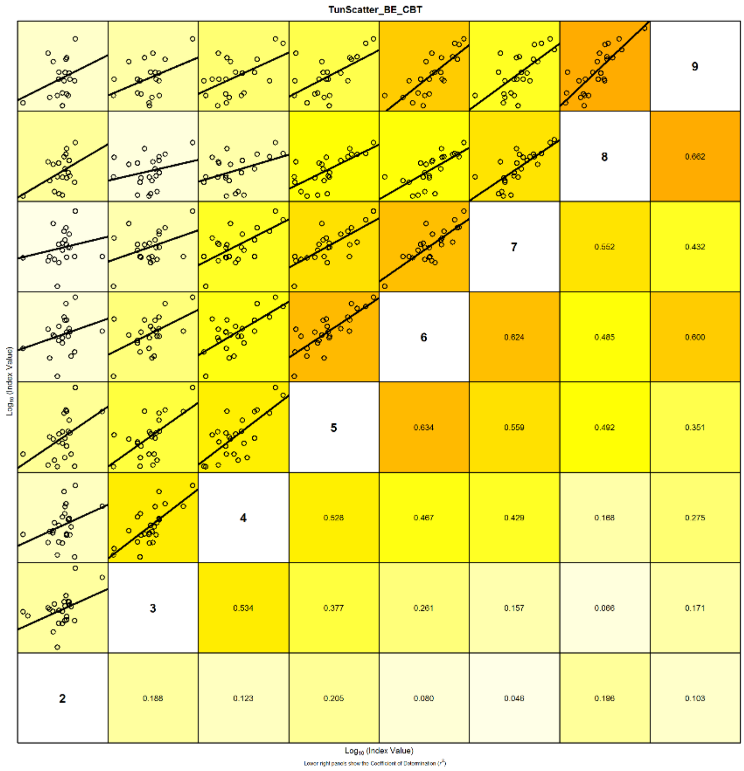

Figure 4. Internal consistency plot of the BE_CBT (1971–1996) tuning series.

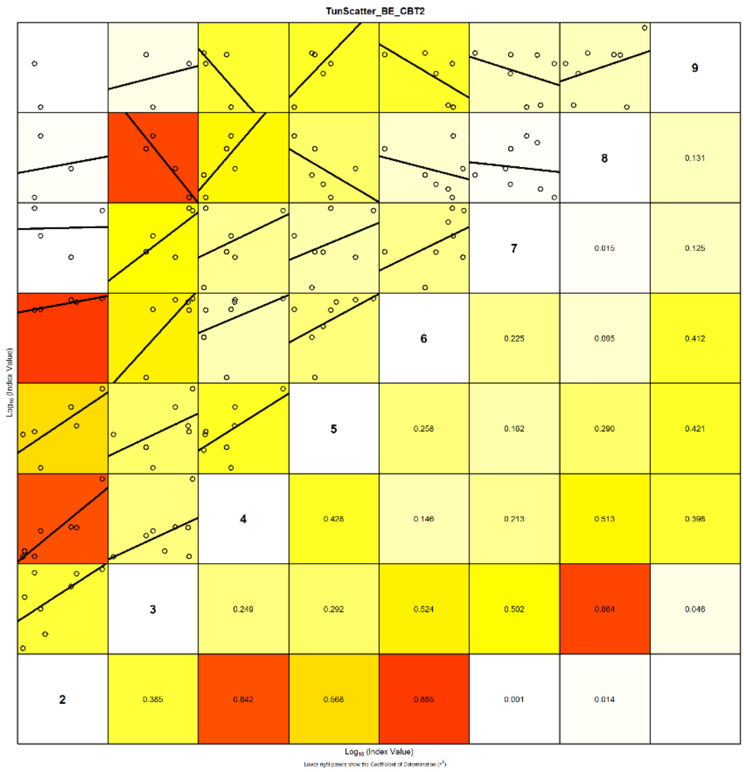

Figure 5. Internal consistency plot of the BE_CBT2 (1997–2005) tuning series.

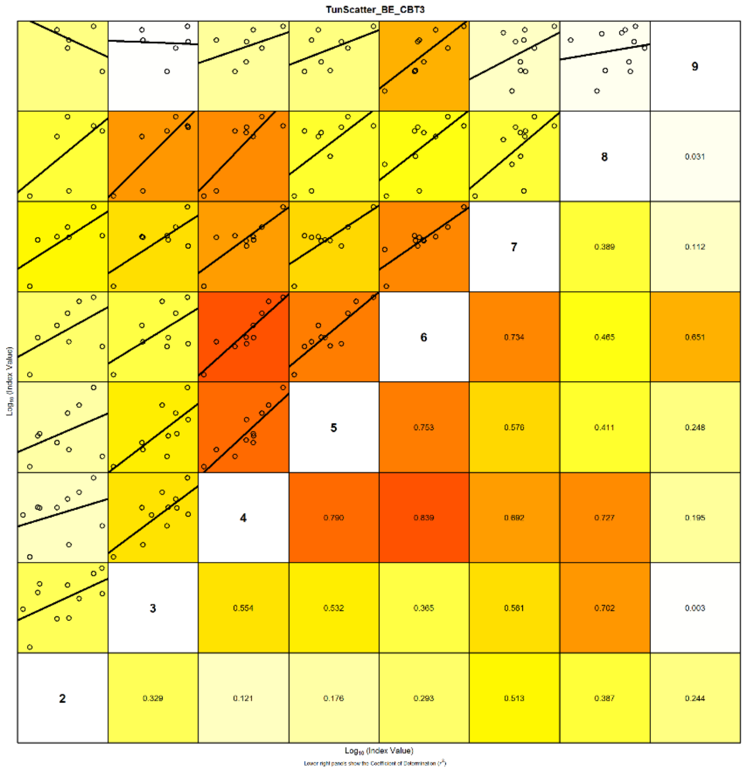

Figure 6. Internal consistency plot of the BE_CBT3 (2006–2017) tuning series.

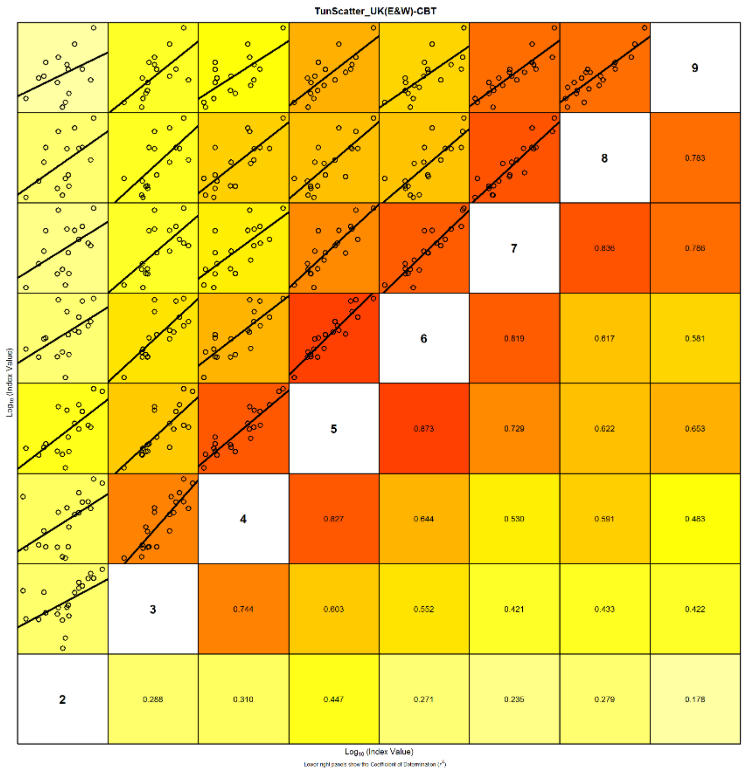

Figure 7. Internal consistency plot of the UK(E&W)-CBT (1991–2012) tuning series.

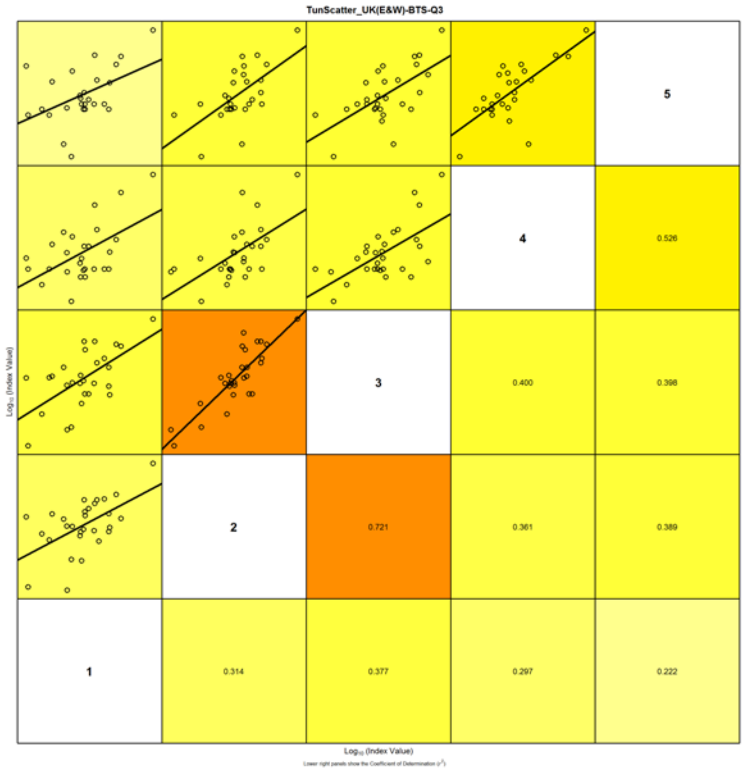

Figure 8. Internal consistency plot of the UK(E&W)-BTS-Q3 (1988–2017) tuning series.

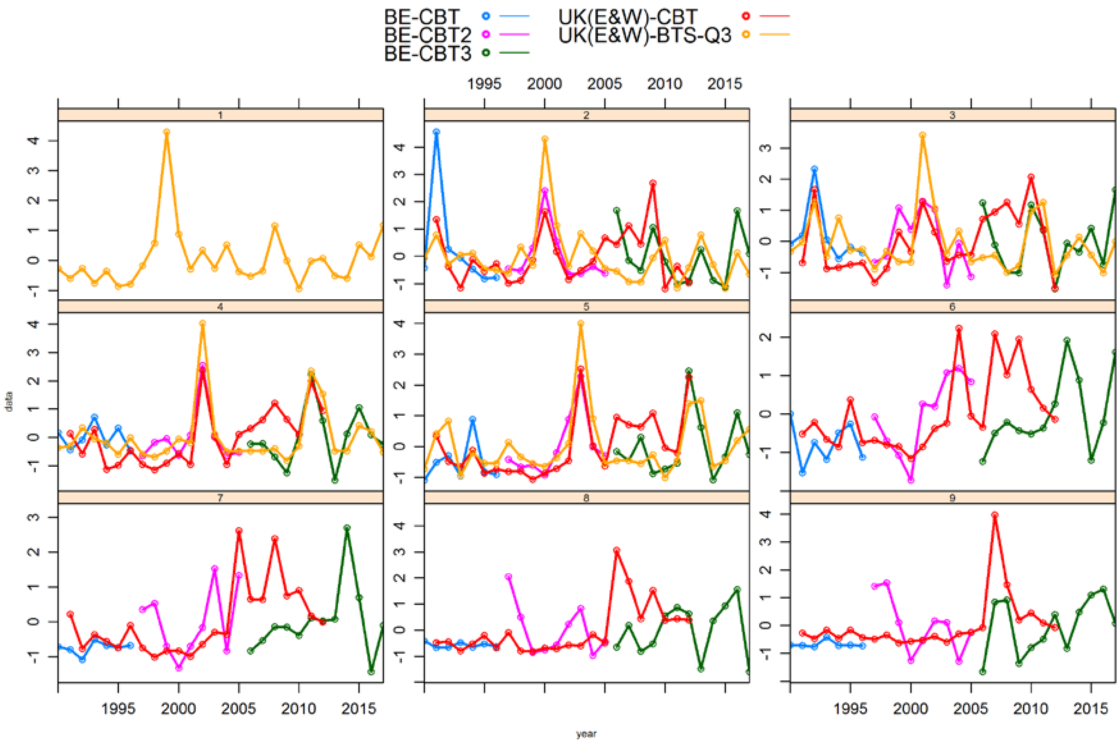

Figure 9. Standardized indices by age of the tuning series for run 1 (All2_9).

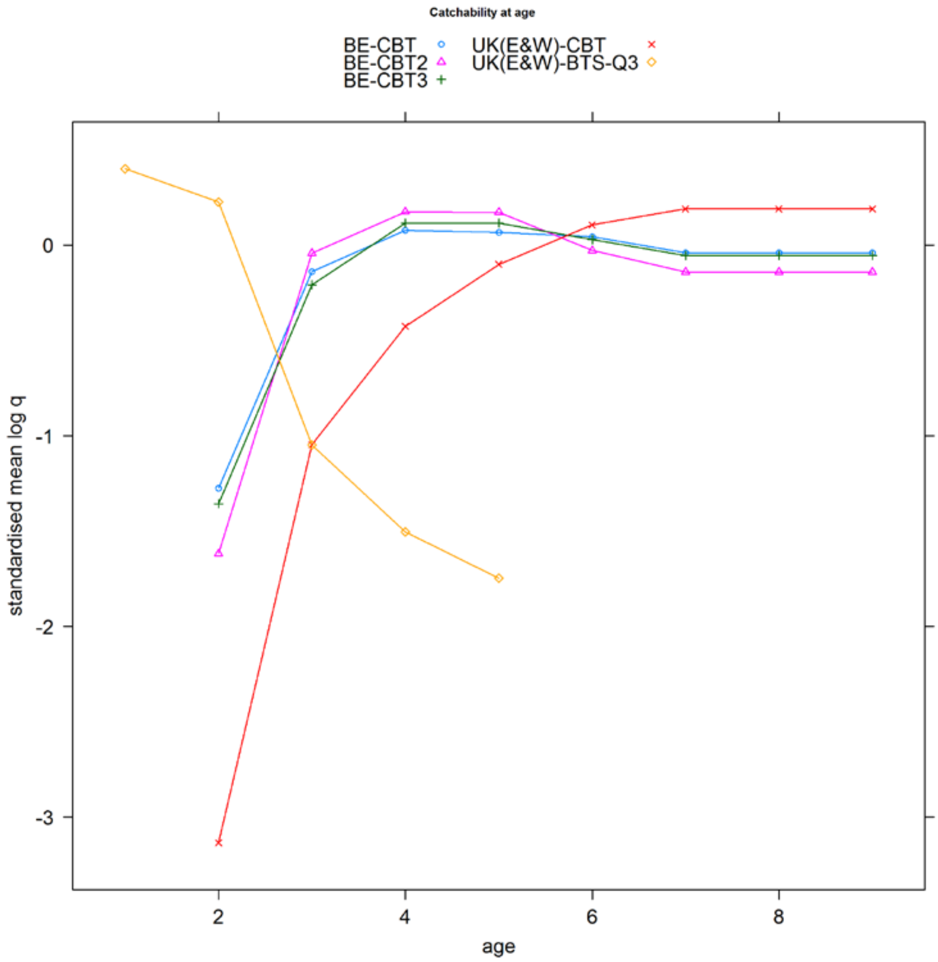

Figure 10. Standardized mean log Q by age of the tuning series for run 1 (All2_9).

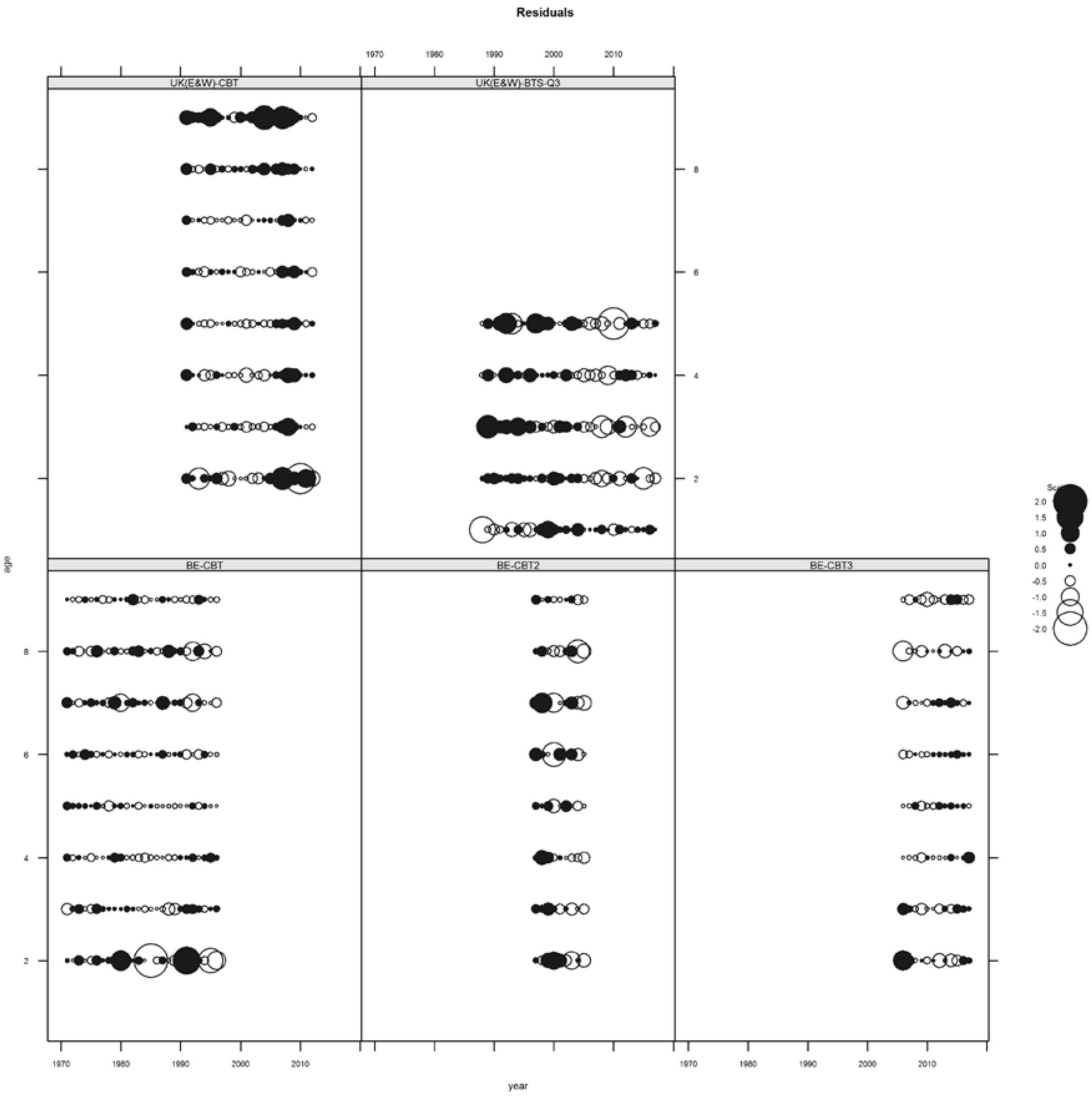

Figure 11. Catchability residuals for the different tuning series for run 1 (All2_9).

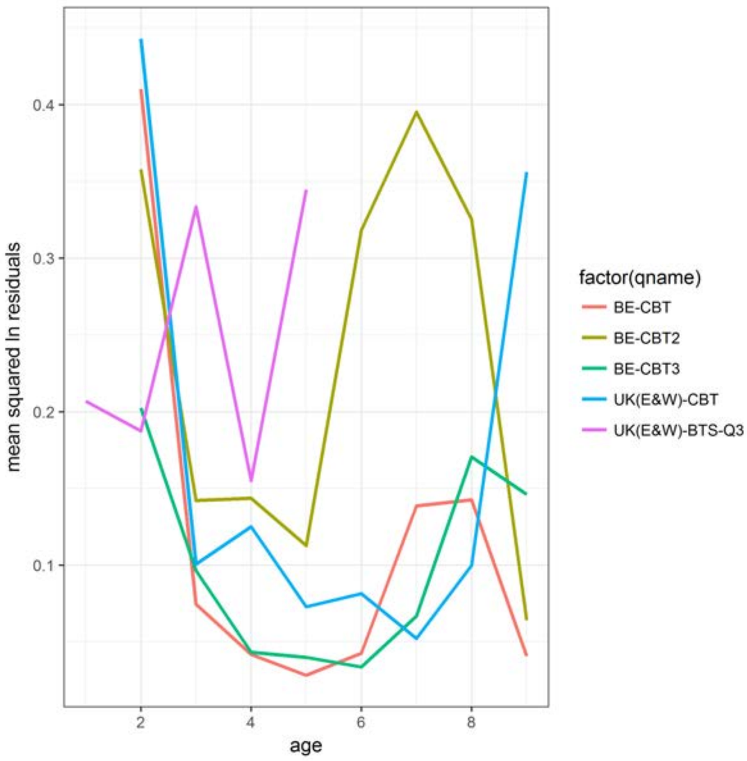

Figure 12. Mean squared residual for each index and age for run 1 (All2_9).

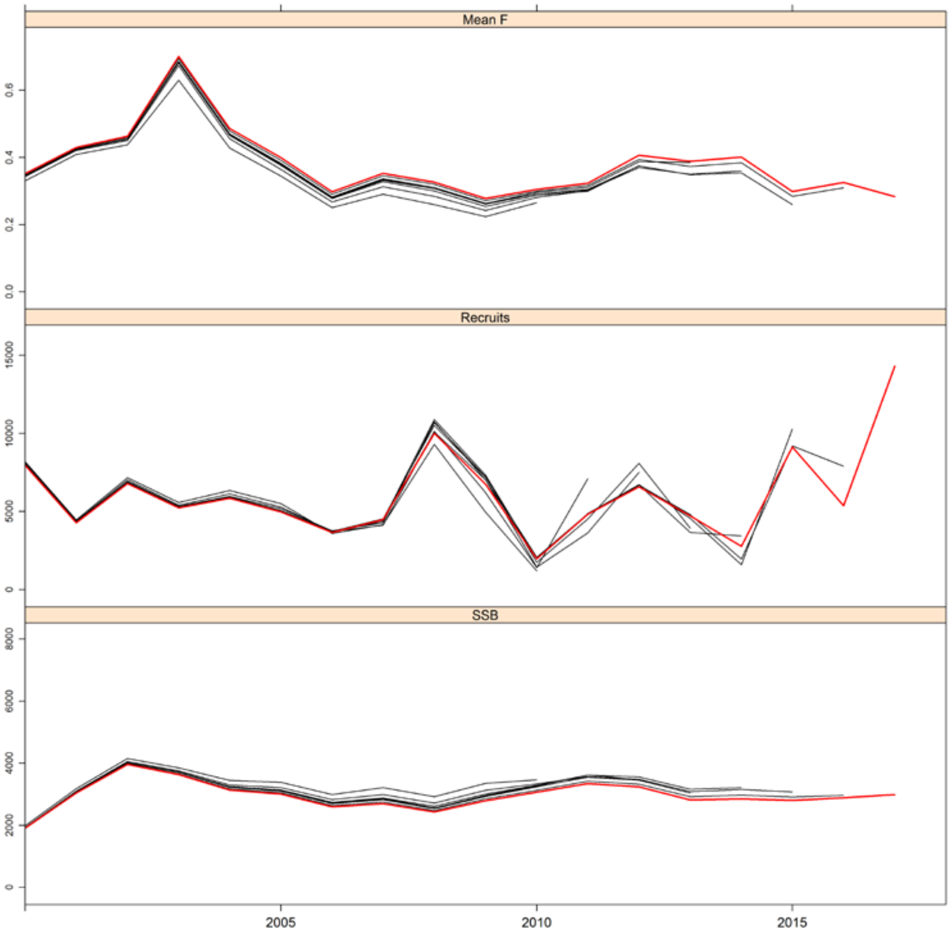

Figure 13. Retrospective XSA analysis (shinkage SE=1.5) for run 1 (All2_9).

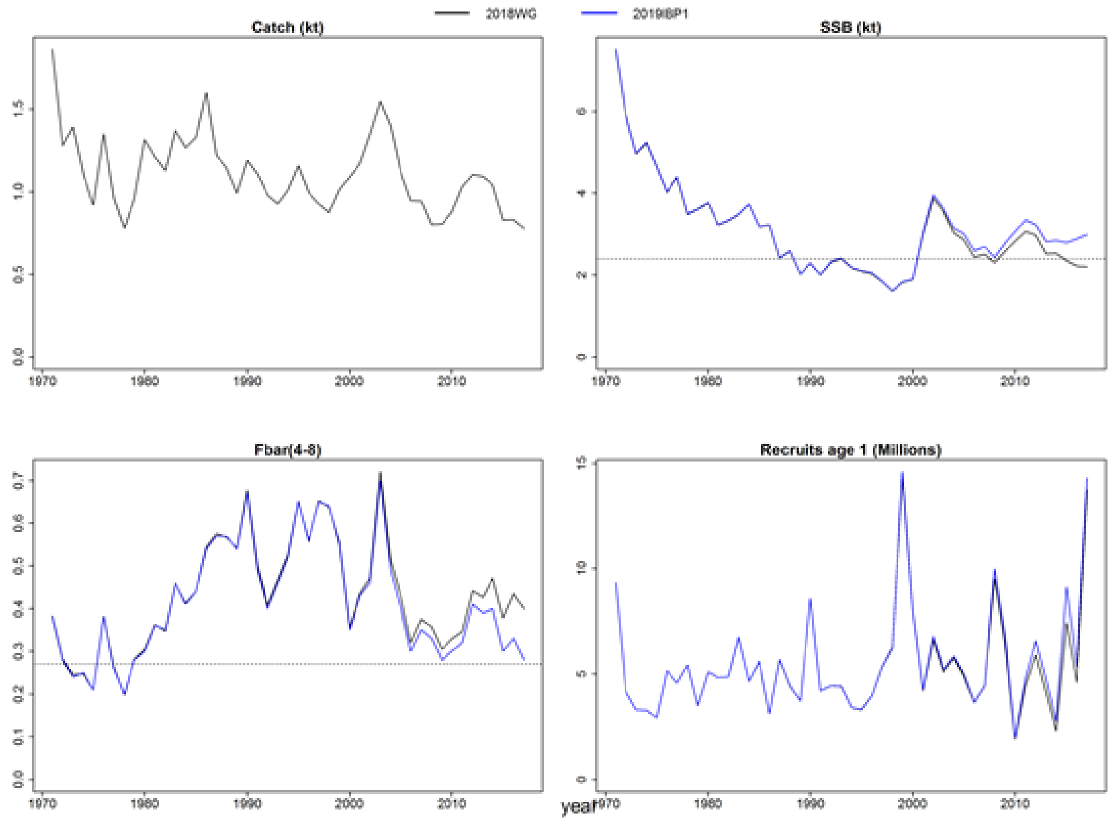

Figure 14. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and run 1 (All2_9).

Differences between the WGCSE 2018 assessment and run 1 can be observed in Figure 14. The SSB of run 1 show an upward shift from 2003 onwards, especially in the more recent years. The F_{bar} is estimated to be lower from 2003 onwards and this difference increases in more recent years. The recruitment is estimated to be slightly higher for some recent years.

3.6.4.3 Run 2 (Agemod)

Data

Same catch data (total weight, mean weight- and number-at-age for landings and discards) as used in the WGCSE 2018 assessment.

Biological parameters

Same biological parameters as used in the WGCSE 2018 assessment.

Tuning series

The same 1971-1996 BE_CBT, UK(E&W)-CBT and UK(E&W)-BTS-Q3 tuning series were used as in the WGCSE. The second Belgian tuning series (BE_CBT2) used in the baserun (1997–2017) was split into two parts. The first part consisted of a part of the old BE_CBT2 tuning series from 1997–2005, and the new second part (2006–2017) was a new series that was created for this inter-benchmark (BE_CBT3). The ages used for the 1971–1996 CBT tuning were kept at 2–9. In contrast to run 1, the ages for the BE_CBT2 tuning series were set at 2–7 and for CBT3 the selected ages were 2–8. This selection was based on the internal consistency plots which showed poorer consistency at higher ages for these two tuning indices. The ages used for the UK(E&W)-BTS-Q3 and UK(E&W)-CBT were the same as in run 1. Model settings for run 2 are listed in Table 3.

Figures 15–18 present the model output for this second run. Figure 16 shows the residuals for each index and age. Figure 17 shows mean squared natural logarithm transformed residuals and show that for age 2 there is a MSE >0.3 for BE_CBT, BE_CBT2 and UK(E&W)-CBT. Overall, BE_CBT2 showed high MSE. In contrast to run 1, the UK(E&W)-CBT now shows lower MSE for age 9. Figure 18 shows a moderate retrospective pattern for Mean F, recruits and SSB.

Table 3. XSA diagnostics used for run 2 (Agemod).

	Run 2: Agemod		
Fleets	Years	Ages	α-β
BE_CBT	71–96	2–9	0–1
BE_CBT2	97–05	2–7	0–1
BE_CBT3	06–17	2–8	0–1
UK(E&W)-CBT	91–12	2–9	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85

-First data year	1971
-Last data year	2017
-First age -Last age	1 10+
-Time series weights	None
-Model	Mean q model all ages
-Q plateau set at age	7
-Survivors estimates shrunk towards mean F	5 years / 5 ages
-s.e. of the means	1.5
-Min s.e. for pop. Estimates	0.3
-Prior weighting	None
-Fbar	Ages 4–8

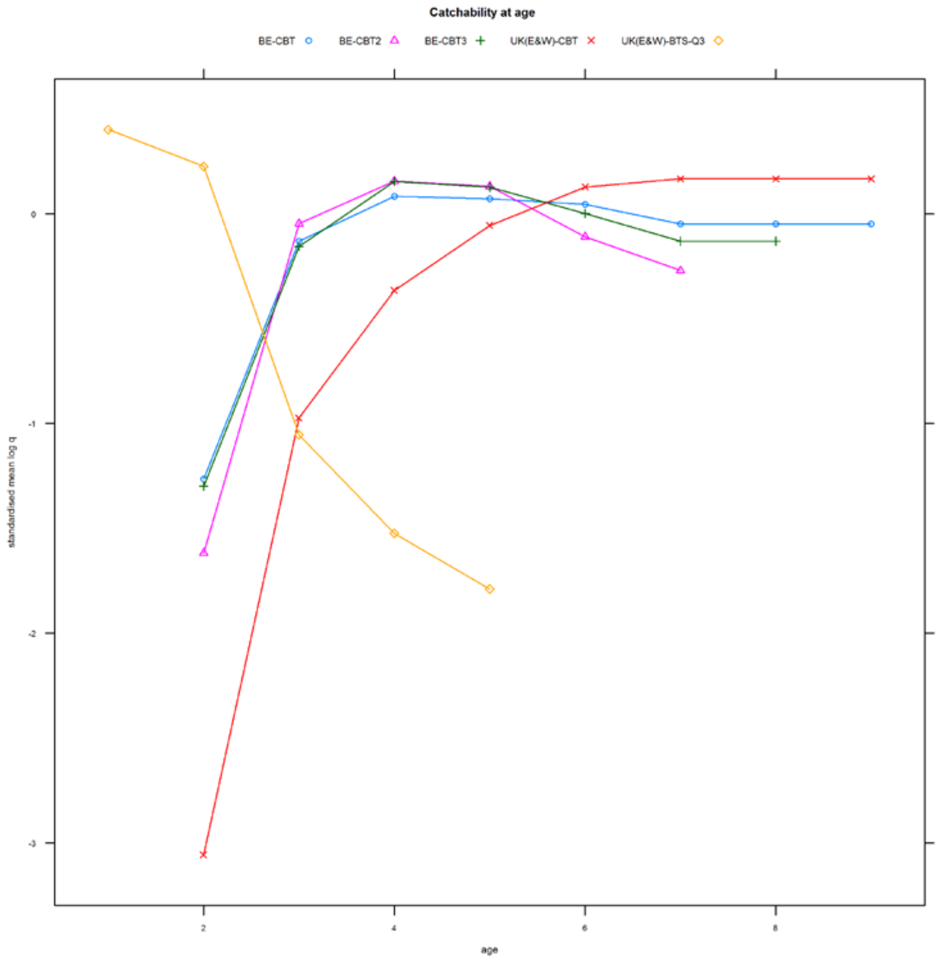

Figure 15. Standardized mean log Q by age of the tuning series for run 2 (Agemod).

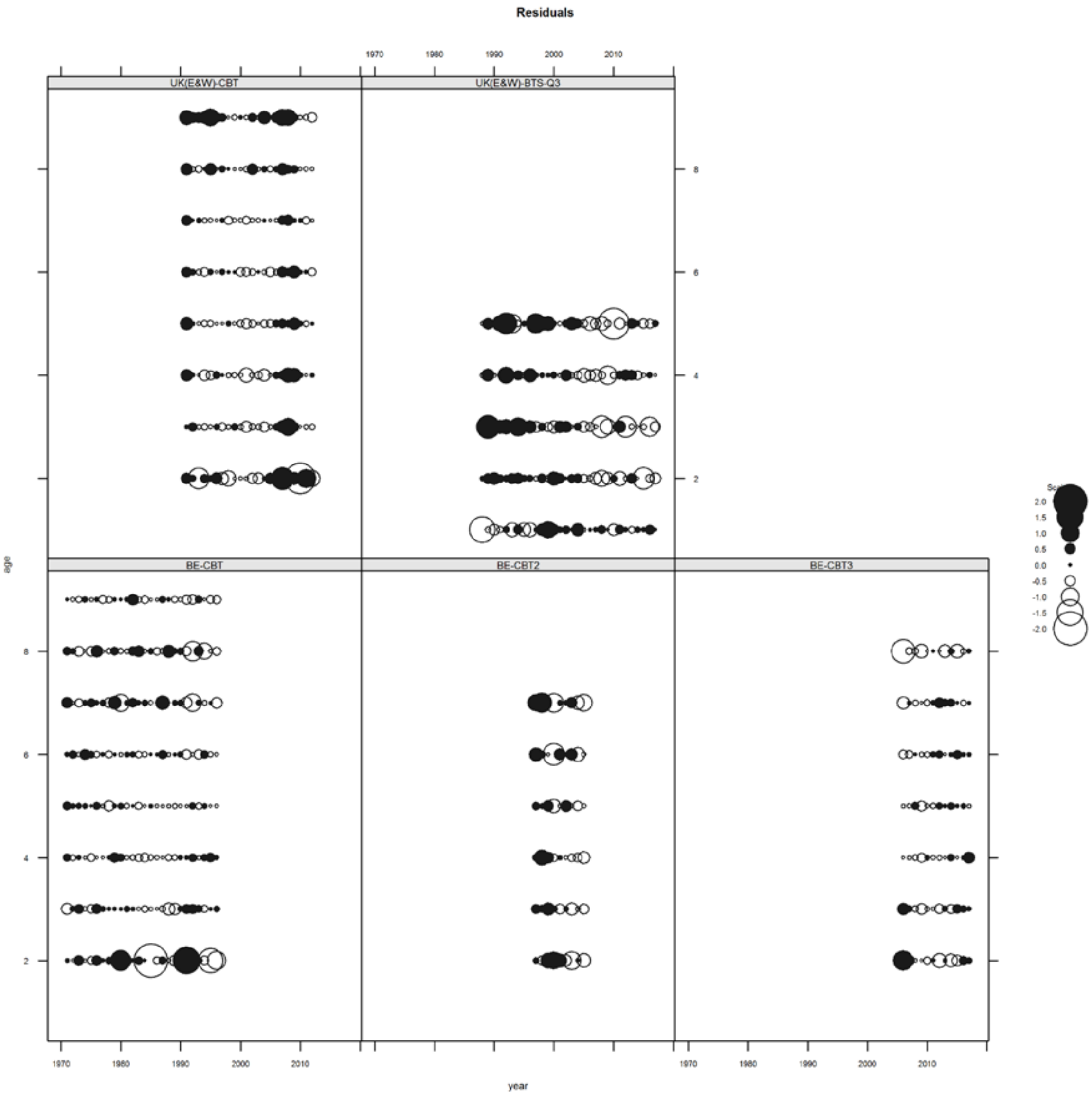

Figure 16. Catchability residuals for the different tuning series for run 2 (Agemod).

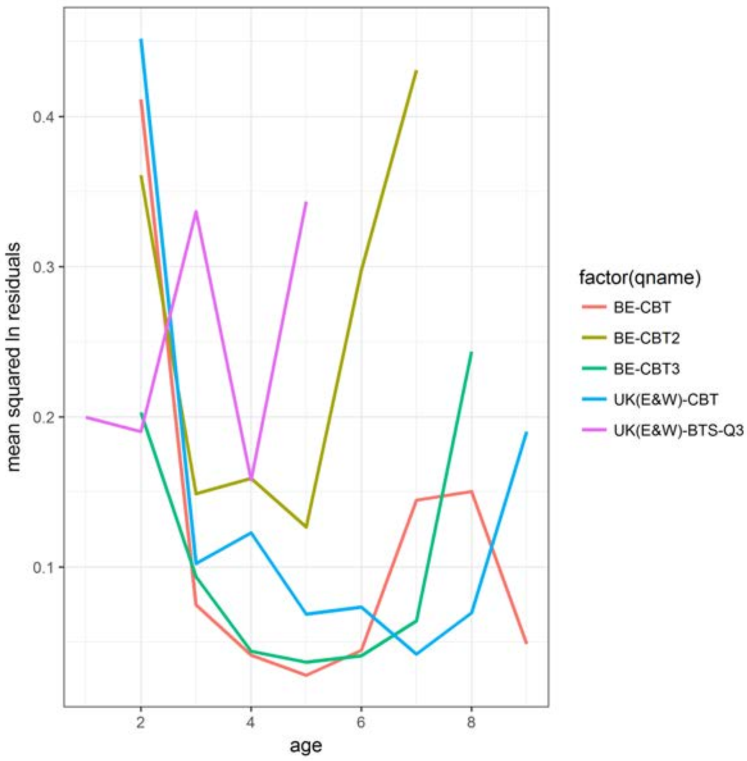

Figure 17. Mean squared residual for each index and age for run 2 (Agemod).

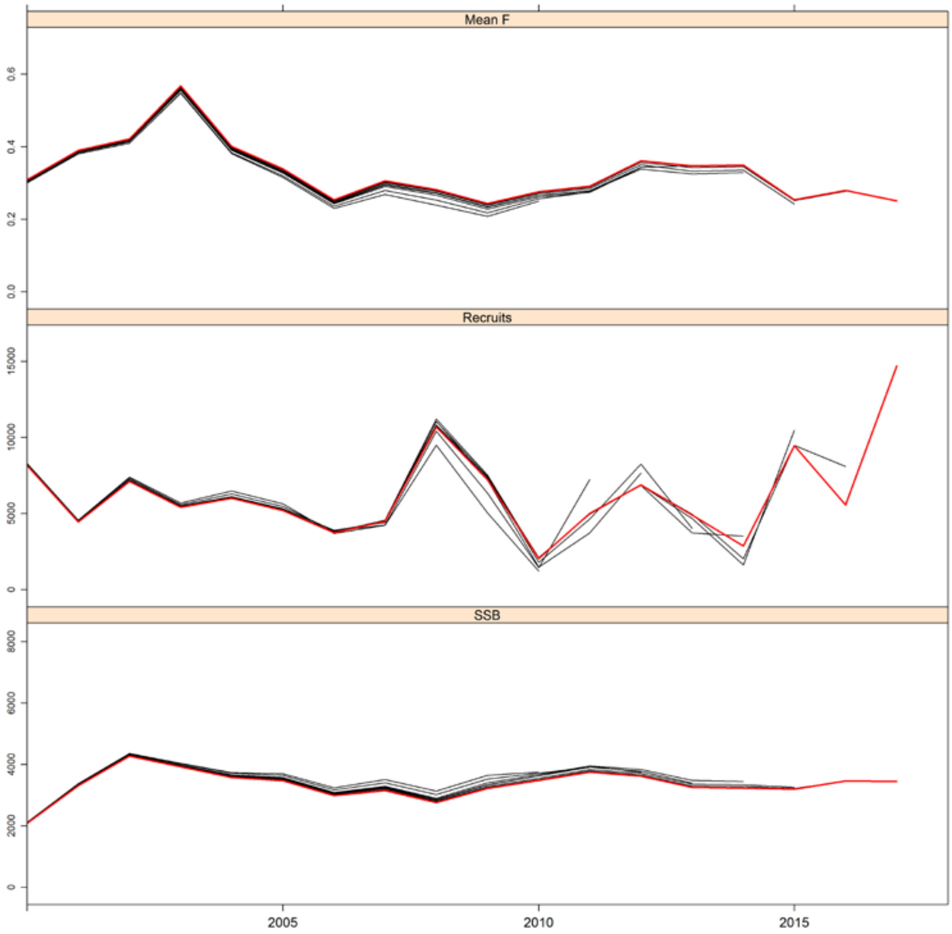

Figure 18. Retrospective XSA analysis (shinkage SE=1.5) for run 2 (Agemod).

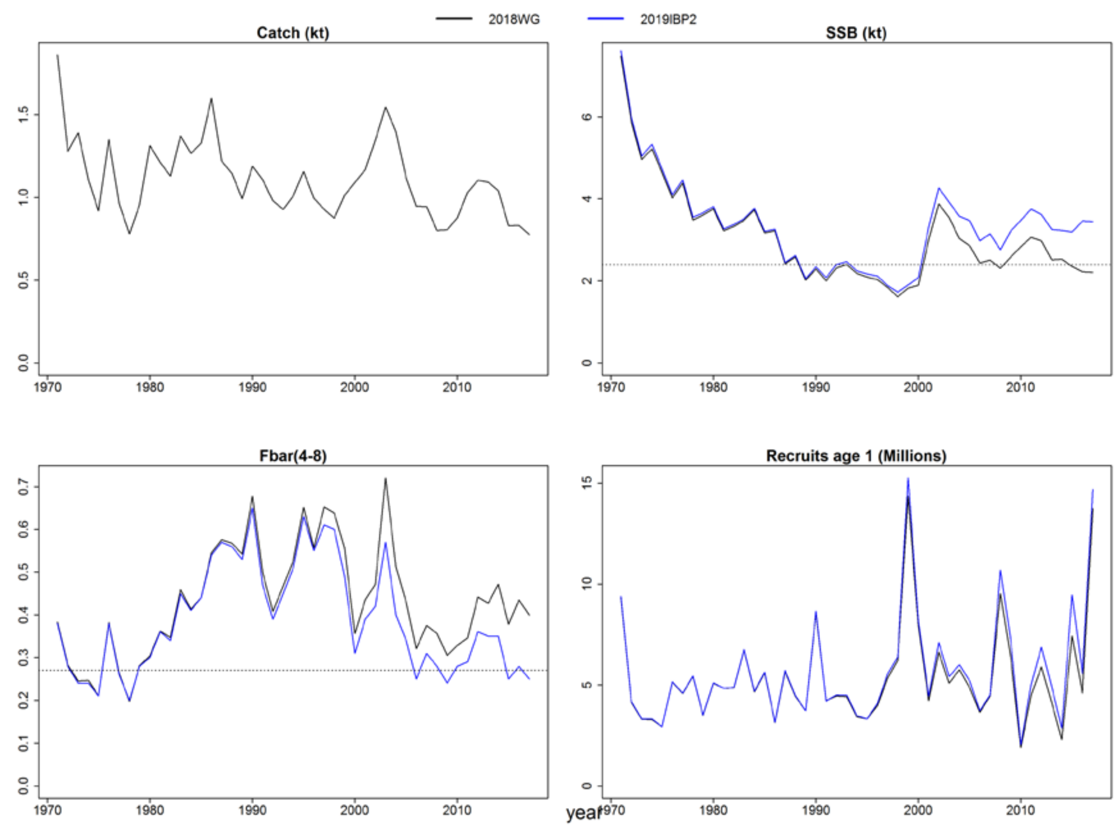

Figure 19. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and run 2 (Agemod).

Differences between the WGCSE 2018 assessment and run 2 can be observed in Figure 19. Altering the selected ages of the different tuning series and adding a third Belgian CBT caused a substantial upward shift in SSB from 2003 onwards. The F_{bar} is estimated to be substantially lower from 1996 onwards and this difference increases in more recent years. The recruitment is estimated to be slightly higher for some recent years.

3.6.4.4 Run 3 (BECBT_OUT)

Data

Same catch data (total weight, mean weight- and number-at-age for landings and discards) as used in the WGCSE 2018 assessment.

Biological parameters

Same biological parameters as used in the WGCSE 2018 assessment.

Tuning series

The 1971–1996 BE_CBT tuning was excluded in this run to evaluate its importance in the assessment. All other settings and tuning series were the same as in run 1 (Table 4).

Figures 20–23 present the model output for this second run. Figure 21 shows the residuals for each index and age. Figure 22 shows mean squared natural logarithm transformed residuals and show that for age 2 there is a MSE >0.3 for BE_CBT2 and UK(E&W)-CBT. Overall, BE_CBT2 showed high MSE. In contrast to run 1, the UK(E&W)-CBT now shows lower MSE for age 9, while the BE_CBT3 now shows higher residuals compared to run 1. Figure 23 shows a moderate retrospective pattern for Mean F, recruits and SSB.

Table 4. XSA diagnostics used for run 3 (BECBT_OUT).

	Run 3: BECBT_OUT		
Fleets	Years	Ages	α-β
BE_CBT2	97–05	2–9	0–1
BE_CBT3	06–17	2–9	0–1
UK(E&W)-CBT	91–12	2–9	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85
-First data year	1971		
-Last data year	2017		
-First age -Last age	1 10+		
-Time series weights	None		
-Model	Mean q model all ages		
-Q plateau set at age	7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages		
-s.e. of the means	1.5		
-Min s.e. for pop. Estimates	0.3		
-Prior weighting	None		
-Fbar	Ages 4–8		

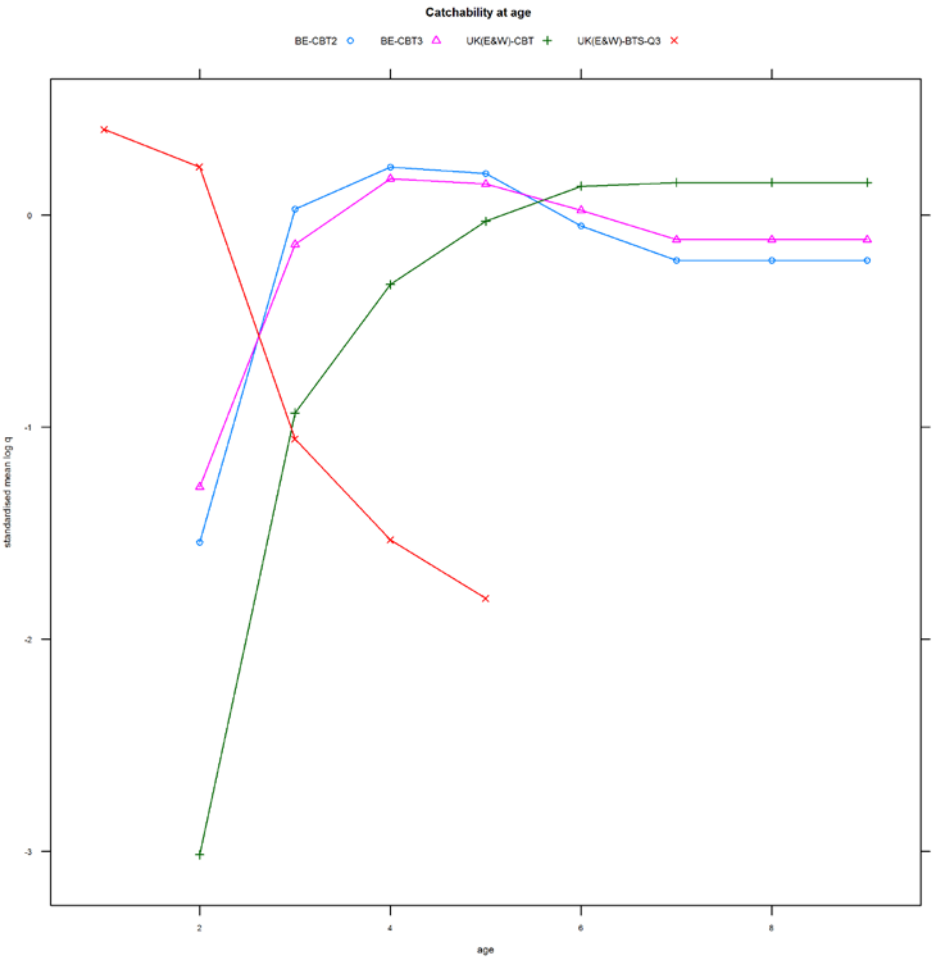

Figure 20. Standardized mean log Q by age of the tuning series for run 3 (BECBT_OUT).

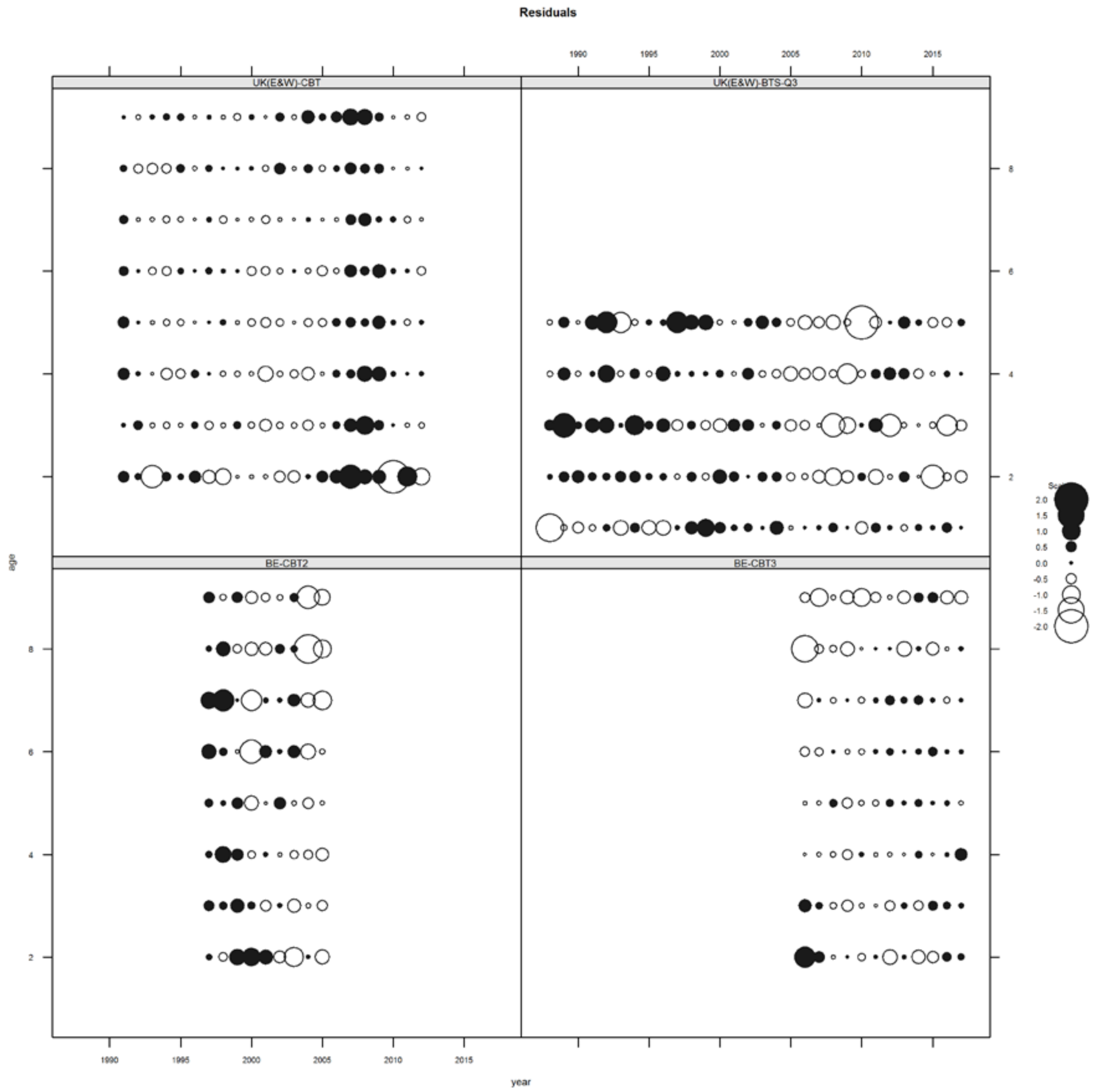

Figure 21. Catchability residuals for the different tuning series for run 3 (BECBT_OUT).

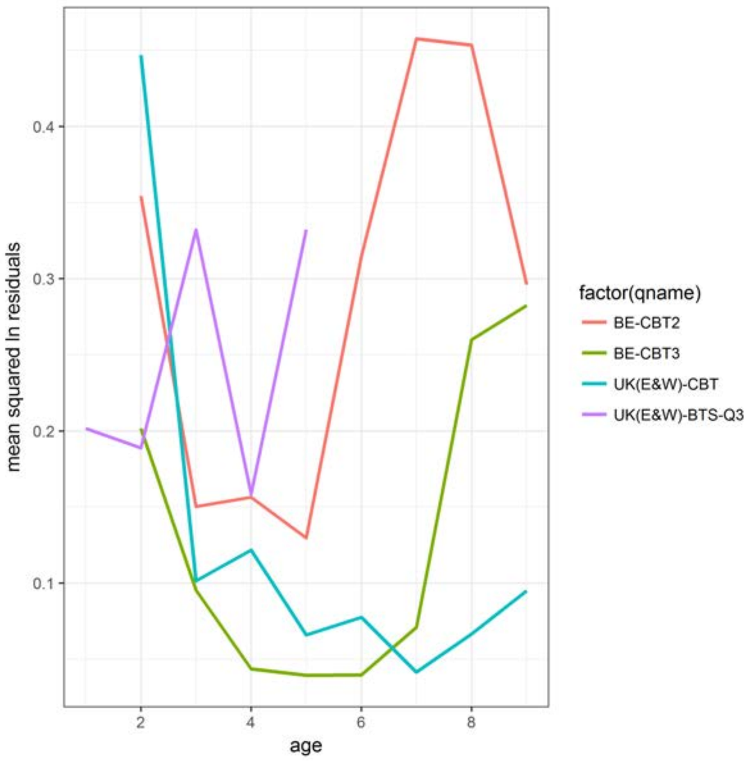

Figure 22. Mean squared residual for each index and age for run 3 (BECBT_OUT).

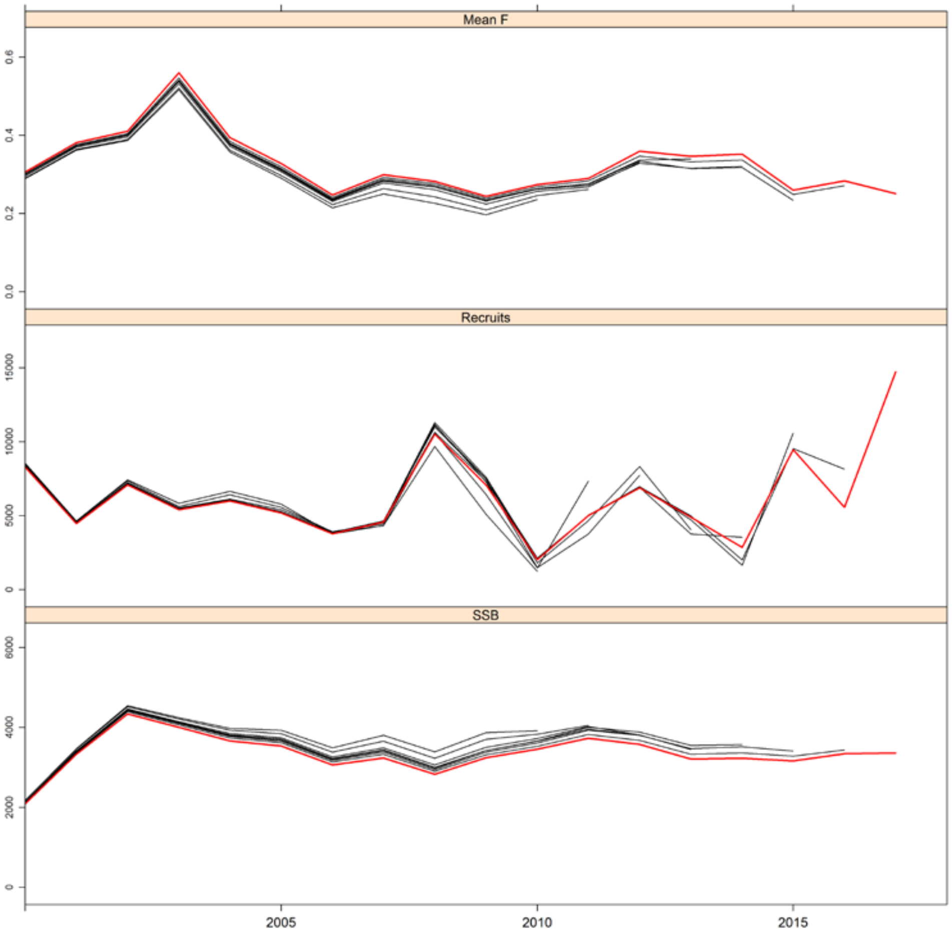

Figure 23. Retrospective XSA analysis (shinkage SE=1.5) for run 3 (BECBT_OUT).

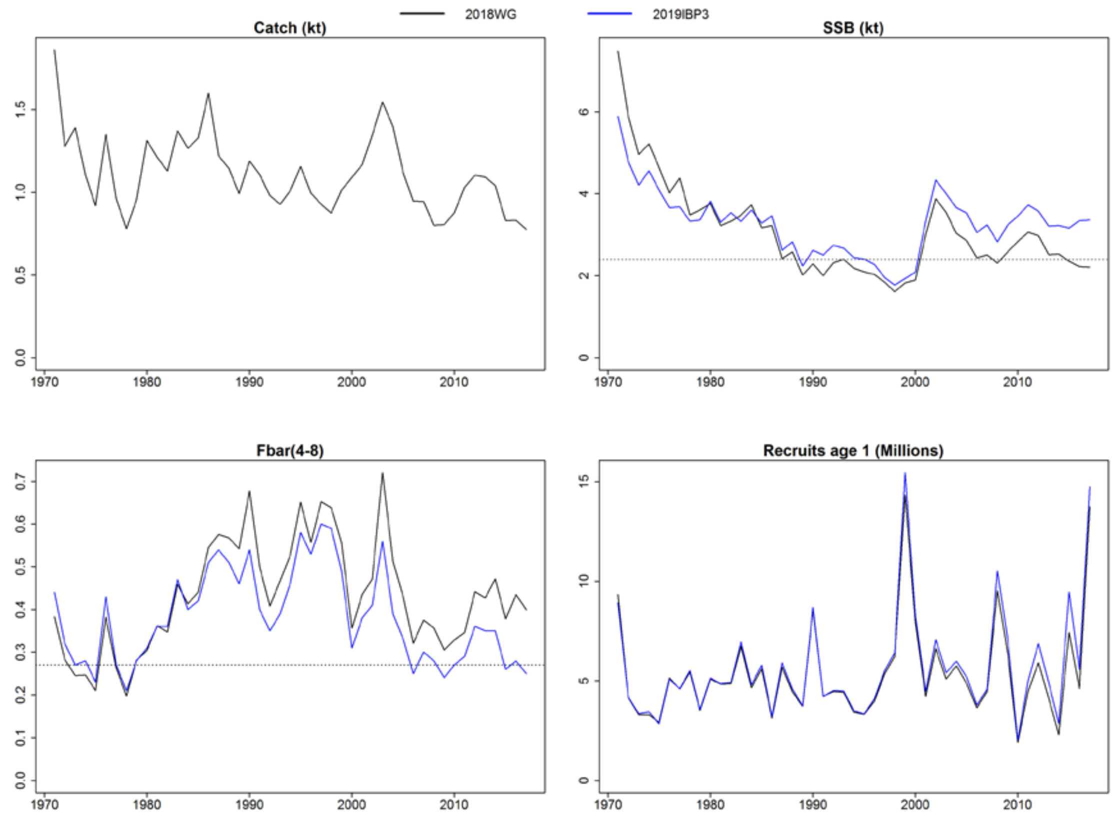

Figure 24. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and run 3 (BECBT_out).

Differences between the WGCSE 2018 assessment and run 3 can be observed in Figure 24. Removing the old BE_CBT and adding a new Belgian CBT series caused the SSB estimates to be lower in the beginning of the time-series, while since 1980 the SBB is estimated to be higher compared to the WGCSE 2018 output. The F_{bar} is estimated to be lower from 1985 onwards and this difference increases in more recent years. The recruitment is estimated to be slightly higher for some recent years.

3.6.4.5 Run 4 (BECBT2_out)

Data

Same catch data (total weight, mean weight- and number-at-age for landings and discards) as used in the WGCSE 2018 assessment.

Biological parameters

Same biological parameters as used in the WGCSE 2018 assessment.

Tuning series

The 1997–2005 BE_CBT2 tuning was excluded in this run to evaluate its importance in the assessment. This tuning series shows a low internal consistency and show high mean squared residuals for most ages. All other settings and tuning series were the same as in run 1 (Table 5).

Figure 25–28 present the model output for this second run. Figure 26 show the residuals for each index and age. Figure 27 shows mean squared natural logarithm transformed residuals and show that for age 2 there is a MSE >0.3 for the BE_CBT and the UK(E&W)-CBT. In contrast to run 1, the UK(E&W)-CBT now shows lower MSE for age 9. Figure 28 shows a moderate retrospective pattern for Mean F, recruits and SSB.

Table 5. XSA diagnostics used for run 1 (All2_9).

	Run 4: BECBT2_OUT		
Fleets	Years	Ages	α-β
BE_CBT	71–96	2–9	0–1
BE_CBT3	06–17	2–9	0–1
UK(E&W)-CBT	91–12	2–9	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85

-First data year	1971
-Last data year	2017
-First age -Last age	1 10+
-Time series weights	None
-Model	Mean q model all ages
-Q plateau set at age	7
-Survivors estimates shrunk towards mean F	5 years / 5 ages
-s.e. of the means	1.5
-Min s.e. for pop. Estimates	0.3
-Prior weighting	None
-Fbar	Ages 4–8

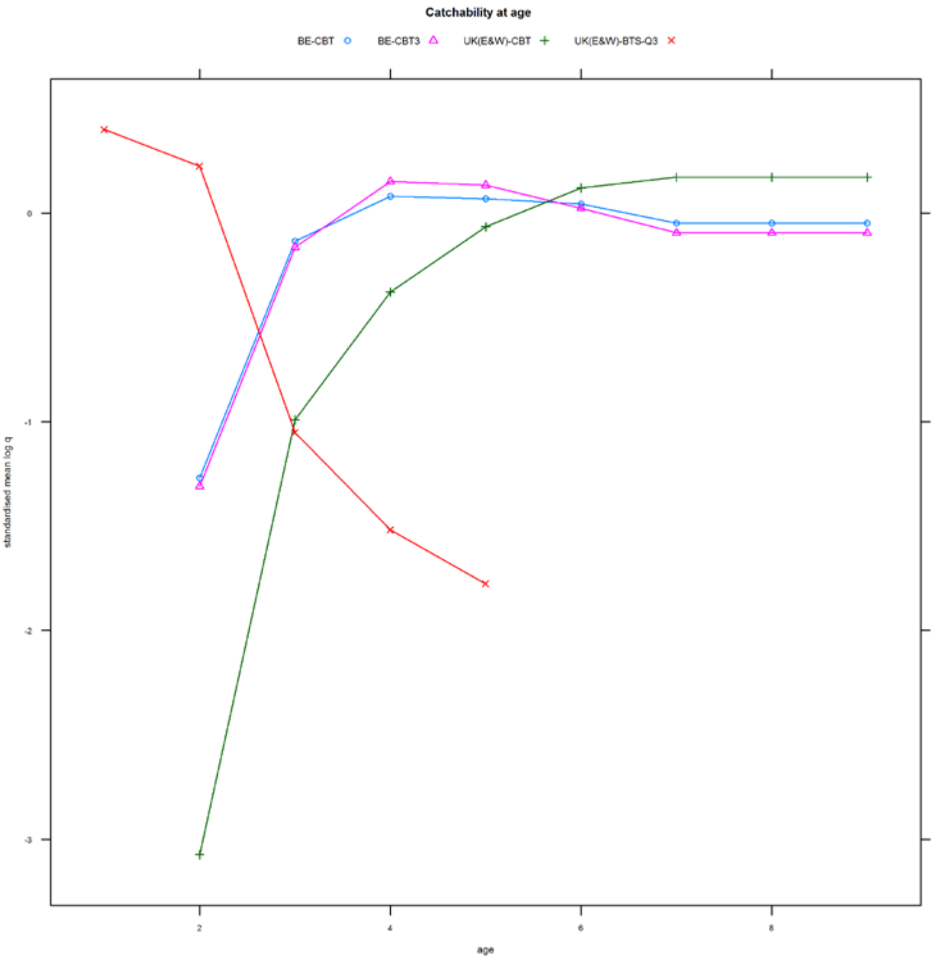

Figure 25. Standardized mean log Q by age of the tuning series for run 4 (BECBT2_OUT).

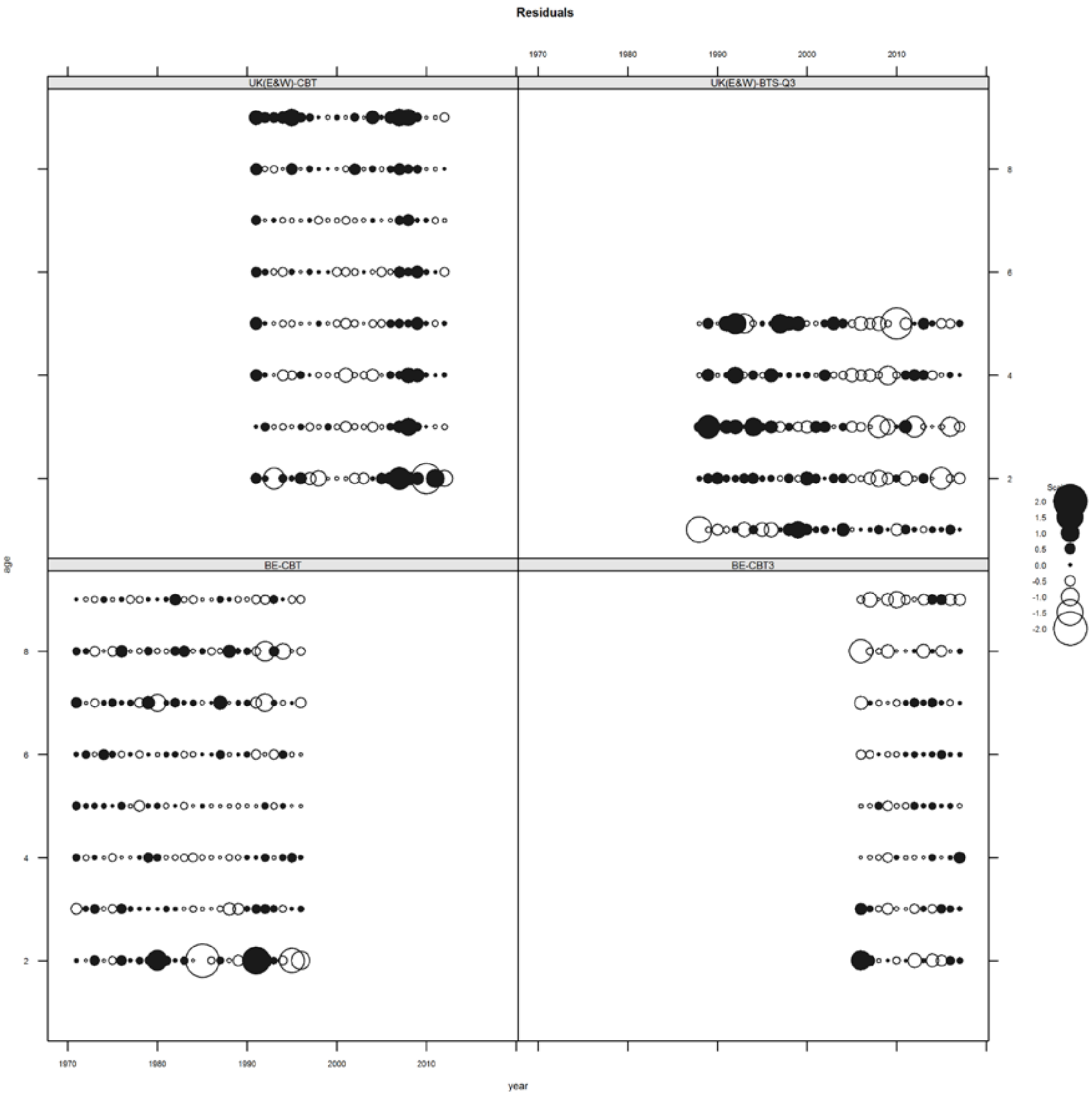

Figure 26. Catchability residuals for the different tuning series for run 4 (BECBT2_OUT).

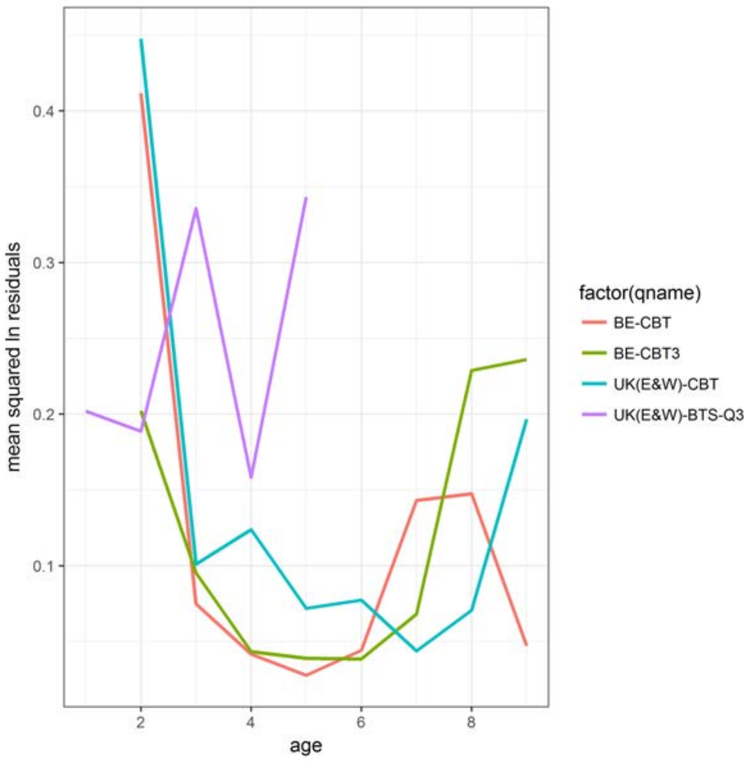

Figure 27. Mean squared residual for each index and age for run 4 (BECBT2_OUT).

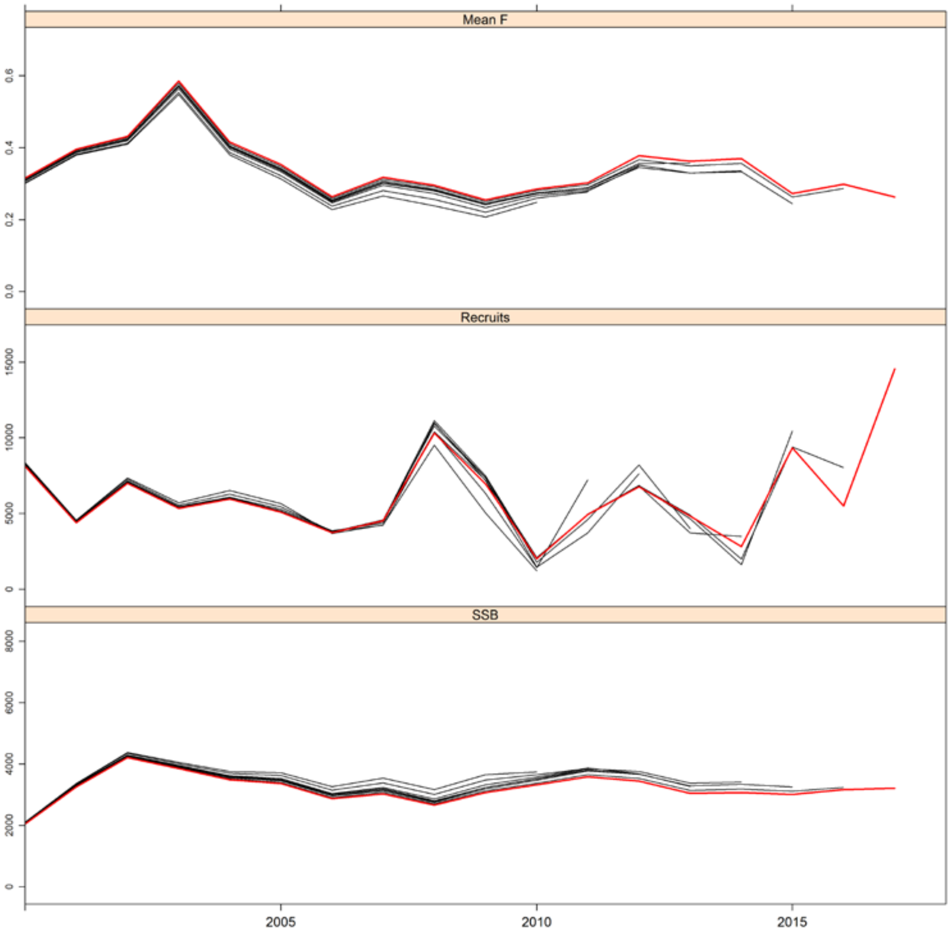

Figure 28. Retrospective XSA analysis (shinkage SE=1.5) for run 4 (BECBT2_OUT).

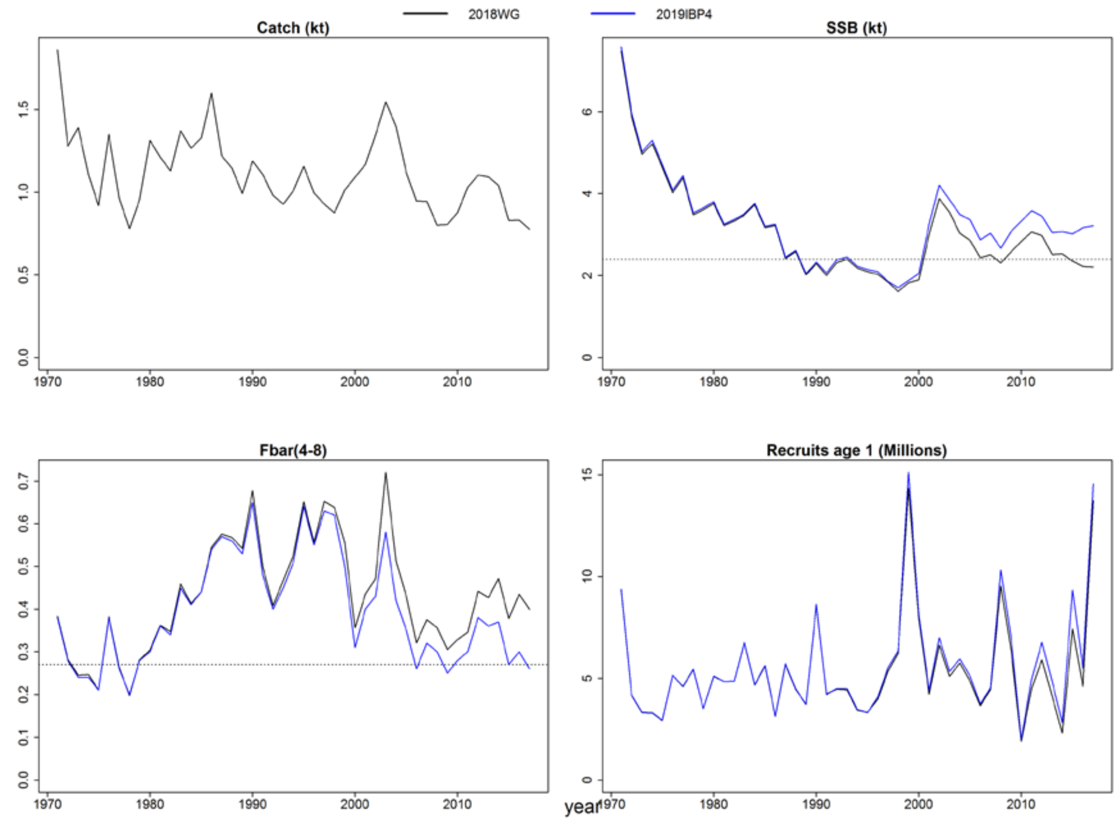

Figure 29. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and run 4 (BECBT2_out).

Differences between the WGCSE 2018 assessment and run 4 can be observed in Figure 29. Removing the short 1997–2005 BE_CBT2 tuning series and adding a new Belgian CBT series caused the SSB estimates to be higher from 2003 onwards compared to the WGCSE 2018 output. The F_{bar} is estimated to be lower from 1998 onwards and this difference increases in more recent years. The recruitment is estimated to be slightly higher for some recent years.

3.6.4.6 Run 5 (Adjusted ages + BECBT2_out)

Data

Same catch data (total weight, mean weight- and number-at-age for landings and discards) as used in the WGCSE 2018 assessment.

Biological parameters

Same biological parameters as used in the WGCSE 2018 assessment.

Tuning series

As it is unsure how XSA responds to really noisy tuning indices, it was decided to excluded ages with MSE>0.3 as a pragmatic solution. Therefore, age 2 for BE_CBT and UK(E&W)-CBT and age 9 for UK(E&W)-CBT were removed. Because of its low internal consistency and the high mean squared residuals for most ages, the 1997–2005 BE_CBT2 tuning series was excluded in this run (Table 6).

Figure 30–33 present the model output for this second run. Figure 31 shows the residuals for each index and age. Figure 32 shows mean squared natural logarithm transformed residuals.

Overall most MSE are <0.3 except for two ages of the UK(E&W)-BTS-Q3. Figure 33 shows a moderate retrospective pattern for Mean F, recruits and SSB.

Table 6. XSA diagnostics used for run 5 (Adjusted ages + BECBT2 out)).

	Run 5: Adjusted ages + BECBT2_OUT		
Fleets	Years	Ages	α-β
BE_CBT	71–96	3–9	0–1
BE_CBT3	06–17	2–9	0–1
UK(E&W)-CBT	91–12	3–8	0–1
UK(E&W)-BTS-Q3	88–17	1–5	0.75–0.85
-First data year	1971		
-Last data year	2017		
-First age	1		
-Last age	10+		
-Time series weights	None		
-Model	Mean q model all ages		
-Q plateau set at age	7		
-Survivors estimates shrunk towards mean F	5 years / 5 ages		
-s.e. of the means	1.5		
-Min s.e. for pop. Estimates	0.3		
-Prior weighting	None		
-Fbar	Ages 4–8		

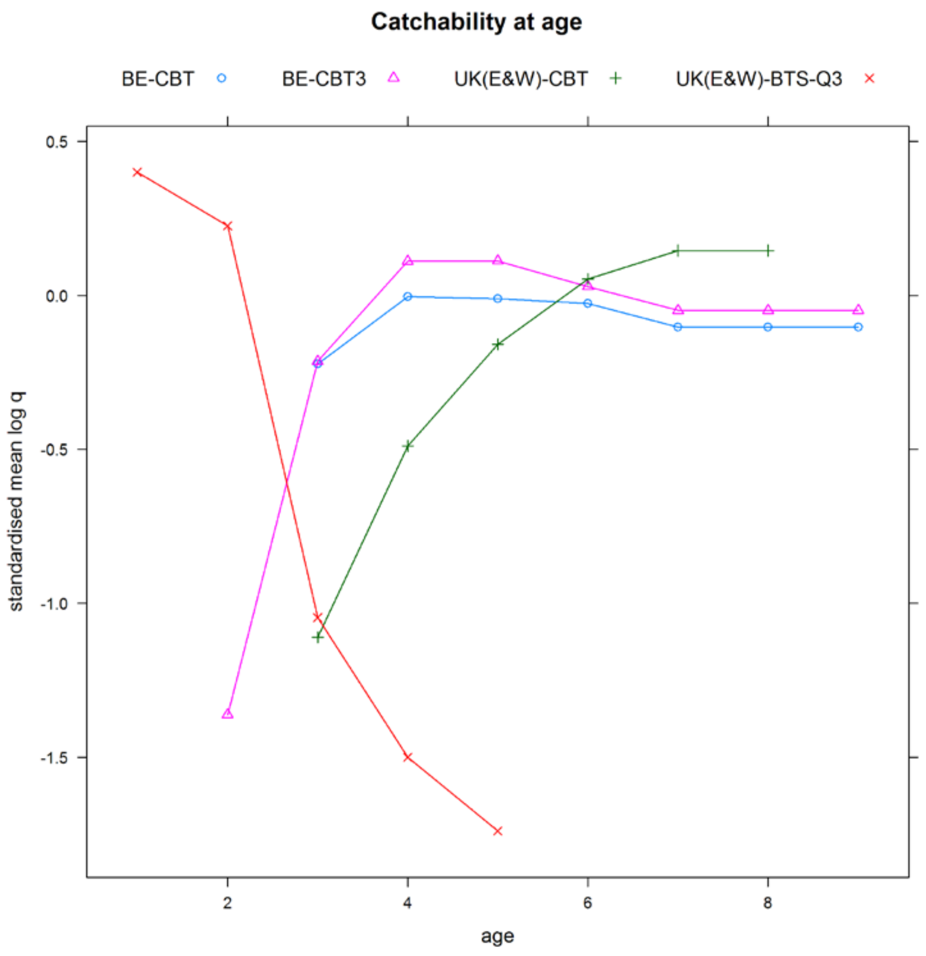

Figure 30. Standardized mean log Q by age of the tuning series for run 5 (adjusted ages + BECBT2_OUT).

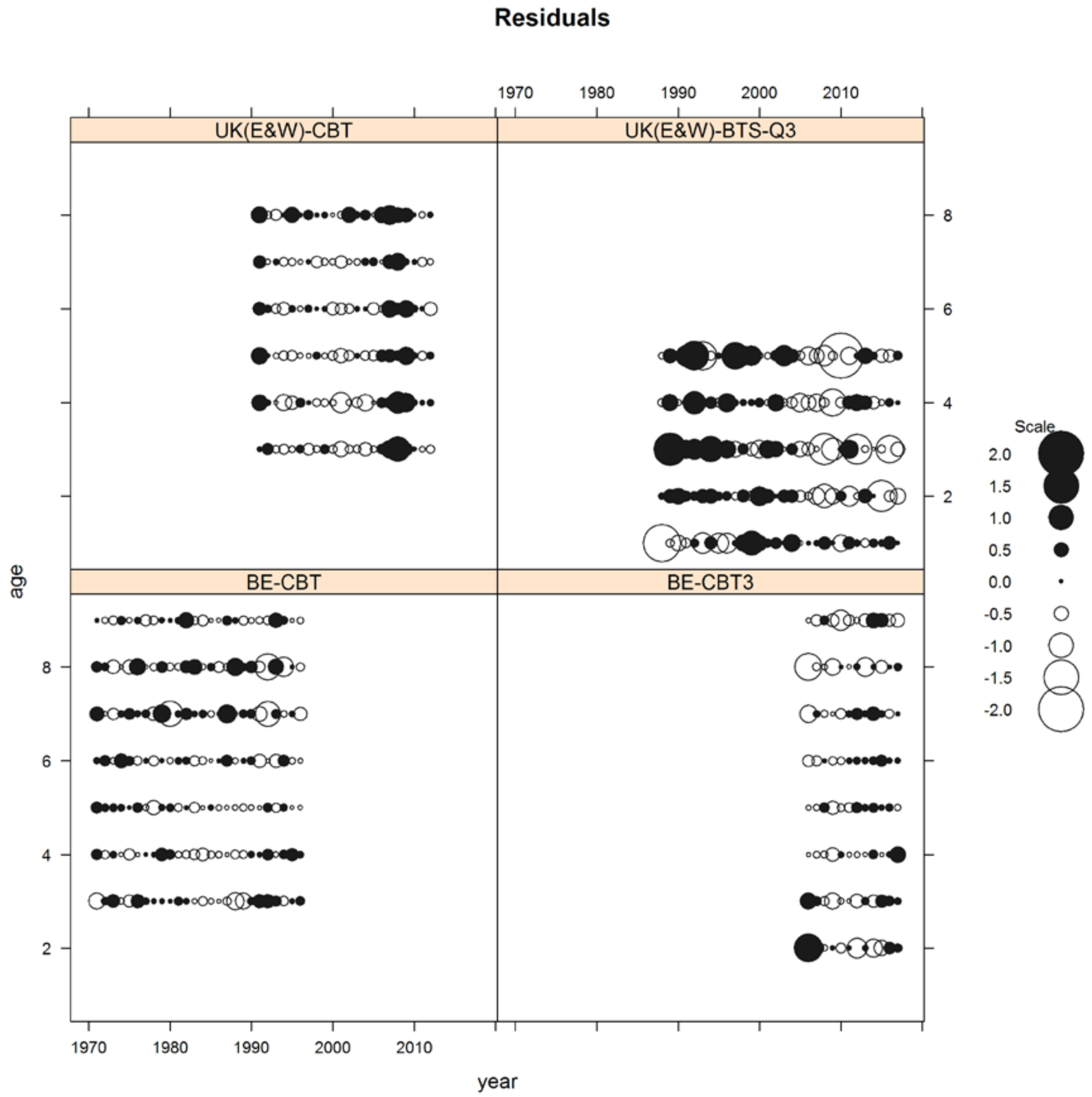

Figure 31. Catchability residuals for the different tuning series for run 5 (adjusted ages + BECBT2_OUT).

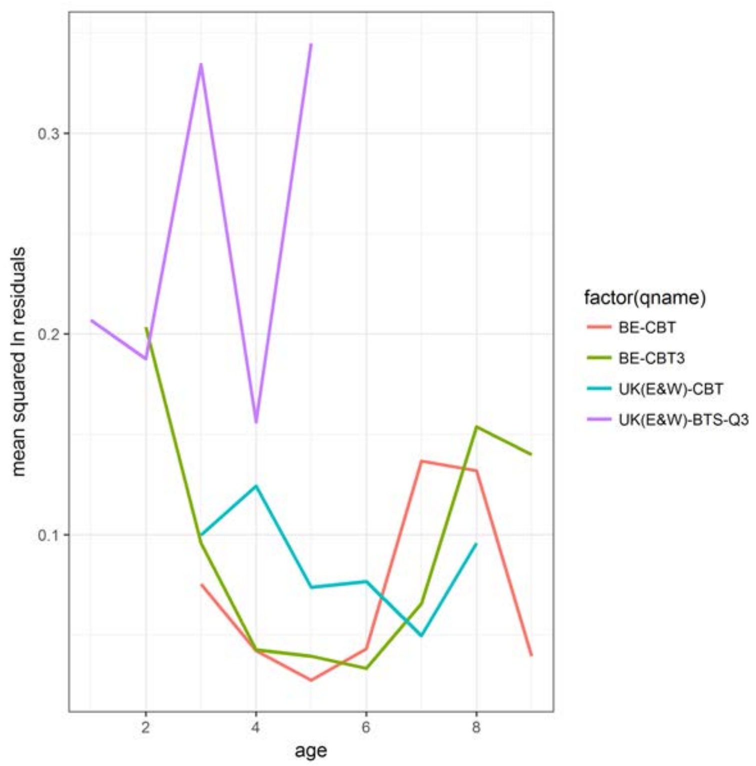

Figure 32. Mean squared residual for each index and age for run 5 (adjusted ages + BECBT2_OUT).

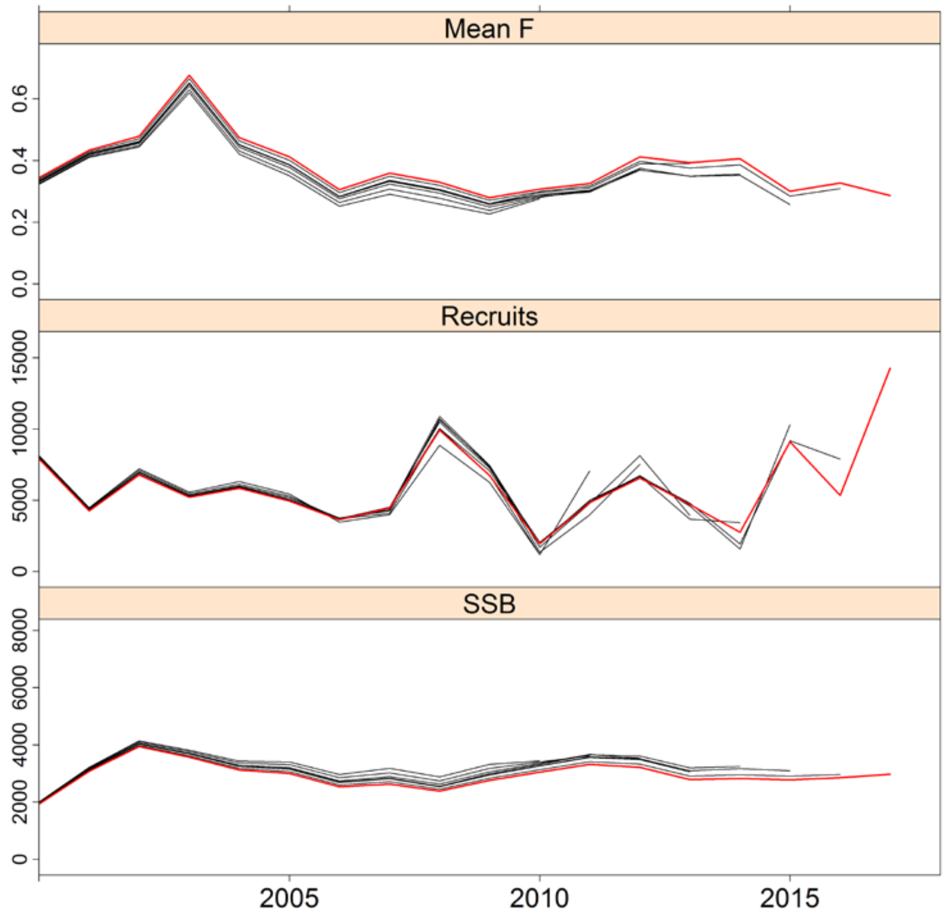

Figure 33. Retrospective XSA analysis (shinkage SE=1.5) for run 5 (adjusted ages + BECBT2_OUT).

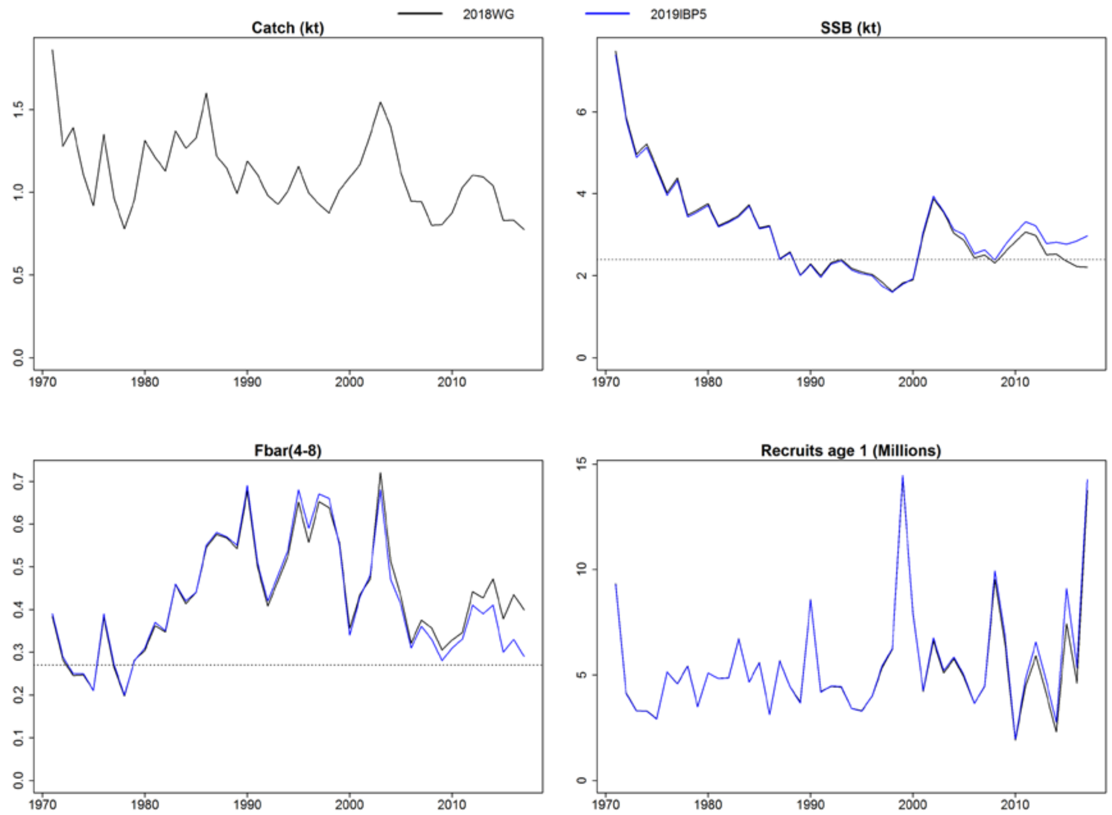

Figure 34. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and run 5 (Agemod + BECBT2_out).

Differences between the WGCSE 2018 assessment and run 5 can be observed in Figure 34. Removing the short 1997–2005 BE_CBT2 tuning series, adjusting the selected ages for the different tuning series and adding a new Belgian CBT series caused the SSB estimates to be slightly higher from 2003 onwards compared to the WGCSE 2018 output. The F_{bar} is estimated to be slightly different from 1995 onwards and is consistently lower in more recent years. The recruitment is estimated to be slightly higher for some recent years.

3.6.4.7 Summary text/final run

Figure 35 shows the comparison of the summary plots of the WGCSE 2018 assessment and the five runs performed during the IBP inter-benchmark. All five runs resulted in a upward estimation of the SSB in recent years and a downscaling in F in recent years. Run 3, in which the 1971–1996 BE_CBT tuning series was removed, caused a deep divergence until the beginning of the time-series. The different runs were compared by looking at the mean squared residual for each index and age for the different model runs and also take into account the retrospective analyses. During the IBP 2019 inter-benchmark, it was decided to use the settings of run 5 in future assessments. Run 5 uses the new Belgian BE_CBT3 tuning series, excluding the short BE_CBT2 and removing age 2 for BE_CBT and UK(E&W)-CBT and age 9 was for UK(E&W)-CBT. The effect on future stock advice is described Section 3. 7. Short-term projections.

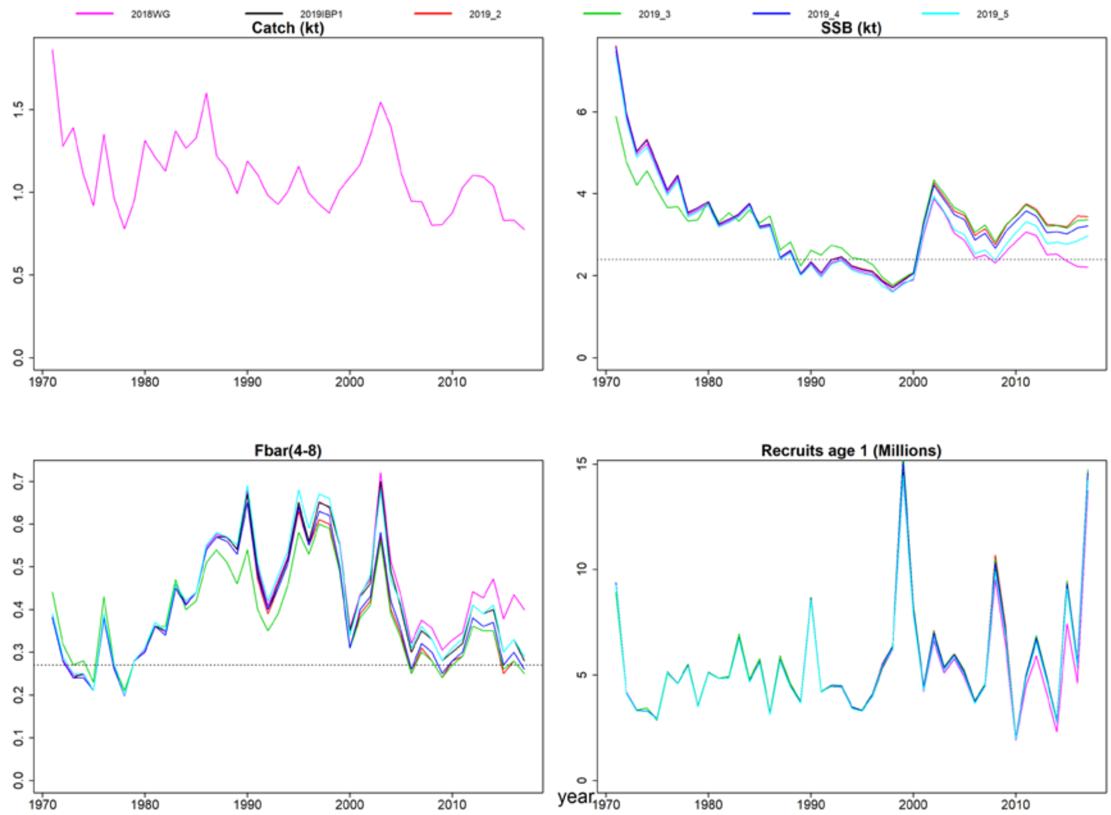

Figure 35. Comparison of the summary plots for catch, SSB, F_{bar} and recruits between the WGCSE 2018 assessment and the five different runs performed during the IBP.

3.7 Short-term projections

The 2016 year class is estimated at 14 265 thousand fish at age 1, which is the second highest of the time-series and 197% higher than the GM (4802 thousand fish) used in last year's forecast. The estimate is solely coming from the UK(E&W)-BTS-Q3 survey. As this strong year class may be overestimated, the XSA age 1 estimate was revised down by 23% (10 984 thousand fish at age 1). The exponential decay model was applied to calculate the age 2 survivors of this cohort (9939 thousand fish).

The long-term GM71-15 recruitment (4922 thousand fish) was assumed for the 2017 and subsequent year classes.

Population numbers at the start of 2018, estimated for ages 3 and older, were taken from the XSA output.

The estimates of year-class strength used for prediction can be summarised as follows:

Year class	At age in 2018	XSA	GM	Source
2015	3	4159		XSA
2016	2	9939		XSA
2017	1	-	4922	GM 1971–2015
2018 & 2019	recruits	-	4922	GM 1971–2015

Fishing mortality was set as the mean over the last three years not scaled to 2017. Weights-at-age in the catch and in the stock are averages for the years 2015–2017.

It was decided to use a TAC constraint for the intermediate year (2018) as recent landings have been close to the TAC or only limited overshot. Moreover, *status quo* fishing mortality gives higher landings (1102 t) in the intermediate year than the agreed TAC (920 t).

Assuming a TAC constraint for 2018 of 920 t, implies a fishing mortality in 2018 of 0.25. The assumed landings using a status quo fishing mortality in 2019 is 1242 t. This results in a SSB of 4032 t in 2019 and 4250 t in 2020.

3.8 Appropriate Reference Points (MSY)

3.8.1 Reference points prior to inter-benchmark

Reference points prior to the inter-benchmark are listed in the table below. The management plan that is referred to, is the EU multiannual plan for the Western Waters.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	2400 t	B_{pa}
	F_{MSY}	0.27	Stochastic simulations with a segmented regression stock–recruitment relationship
Precautionary approach	B_{lim}	1700 t	B_{loss} estimated in 2015
	B_{pa}	2400 t	B_{lim} x 1.4
	F_{lim}	0.48	F with 50% probability of SSB < B_{lim}
	F_{pa}	0.34	F_{lim}/1.4
Management plan	MAP MSY $B_{trigger}$	2400 t	MSY $B_{trigger}$
	MAP B_{pa}	2400 t	B_{pa}
	MAP B_{lim}	1700 t	B_{lim}
	MAP F_{MSY}	0.27	F_{MSY}
	MAP range F_{lower}	0.15	Minimum F which produces at least 95% of maximum yield
	MAP range F_{upper}	0.42	Maximum F which produces at least 95% of maximum yield

3.8.2 Source of data

Data used in the MSY analyses were taken from the FLStock object created by the final assessment run during the inter-benchmark.

3.8.3 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 the Annex 3. Model and data selection settings are listed in Table 7.

Table 7. Model and data selection settings.

Data and parameters	Settings	Comments
SSB-recruitment data	Truncated time series by removing the last year (2017)	The last year was removed to avoid evaluating the high recruitment value, which often showed to be uncertain and overestimated in previous years.
Exclusion of extreme values (option extreme.trim)	No	
Mean weights and proportion mature; natural mortality	2008–2017*	Over the last ten years, mean weight-at-age has been variable, but not showing any clear trend. Therefore, the last ten years (default) were selected.
Exploitation pattern	2008–2017*	Over the last ten years, no clear pattern in exploitation at age was observed. Therefore, the last ten years (default) were selected.
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.

*** The time period for which the analysis was run focussed on the last ten years (2008–2017), which is the default setting. The default setting was used in this analysis after verifying that no obvious patterns in catch or stock weight (Figures 1 and 2) or exploitation (at age) (Figure 36) were detected.**

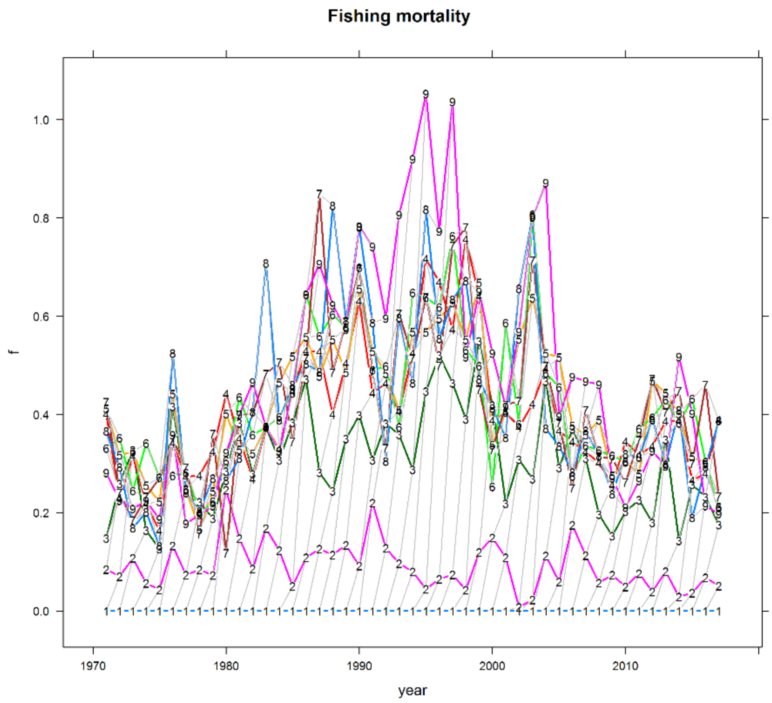

Figure 36. Fishing mortality-at-age for sole in area 27.7.f and 27.7.g.

3.8.4 Results

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

To fit stock–recruitment models, the available time-series was truncated by removing the last data year (2017) to avoid evaluating the high, most recent recruitment value. In previous years, this value has often shown to be uncertain and overestimated. First, all three stock–recruit models were used (Ricker, Beverton–Holt, and segmented regression), weighted by the default 'Buckland' method (Figure 37).

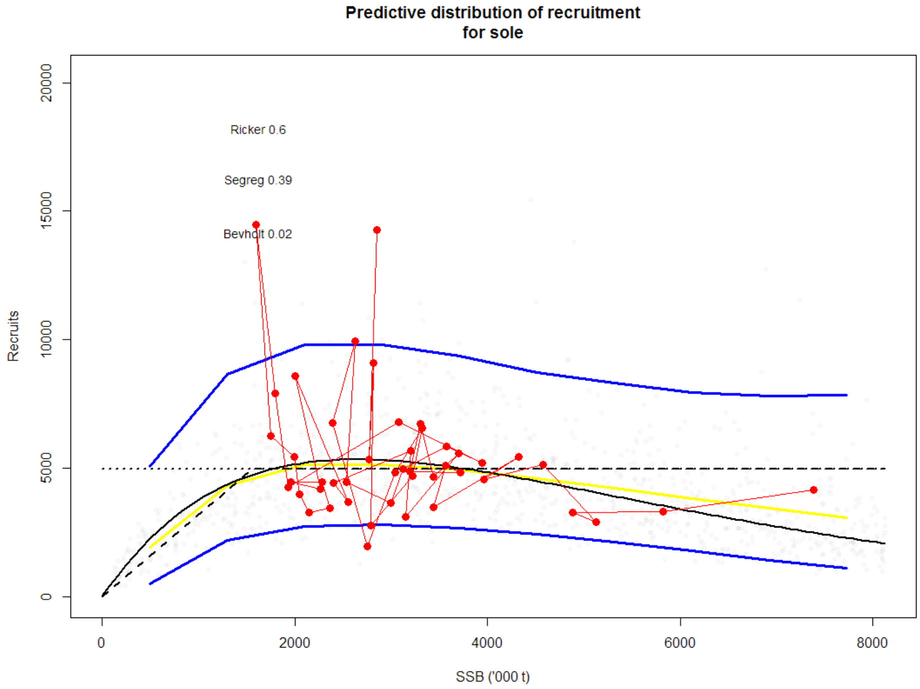

Figure 37. Stock–recruitment relations for sole in area 27.7.f and 27.7.g showing the estimation of the three regression models over the truncated time period (excluding 2017) (Ricker: full black line; Beverton–Holt: dotted line; segmented regression: dashed line; yellow line represents the best fit over the three models).

The stock–recruitment relation was evaluated as **type 5**, showing a stock with no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent S–R signal). Therefore, B_{lim} should be set to B_{loss}, being 1592 tonnes. B_{pa} was then derived using the standard multiplier of 1.4, resulting in 2229 tonnes.

3.8.4.2 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 38) with the point of inflection 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).

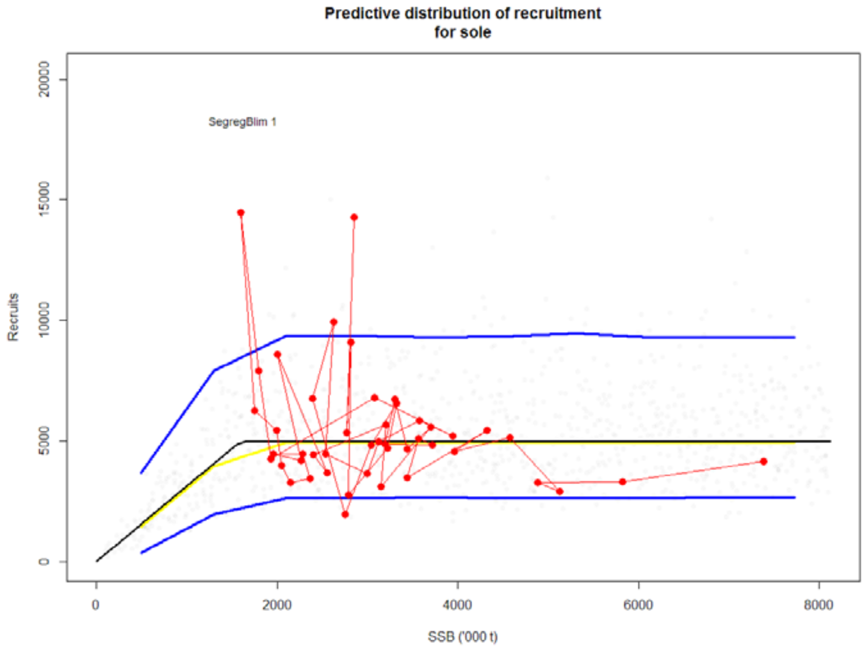

Figure 38. Stock–recruitment relationship for sole in area 27.7.f and 27.7.g based on segmented regression over the truncated time period (excluding 2017), where the inflection point was set to B_{lim}.

F_{lim} was estimated at 0.578 using the last ten years of data (2008–2017) (see table below). F_{pa} was estimated at 0.413 from the equation $F_{pa} = F_{lim}/1.4$.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.476	0.500	**0.578**	NA	0.300	NA	NA	NA	NA
lanF	NA	NA	NA	0.306	0.300	0.168	0.166	0.541	0.533
catch	948.017	940.639	847.316	NA	970.285	NA	NA	NA	NA
landings	NA	NA	NA	970.577	970.285	922.712	940.477	921.929	939.897
catB	2116.005	2006.758	1589.600	NA	3384.034	NA	NA	NA	NA
lanB	NA	NA	NA	3313.010	3384.034	5716.561	NA	1827.366	NA

3.8.4.3 Determine initial F_{MSY} and its ranges

The initial F_{MSY} was calculated using the fit by the segmented regression and Ricker regression models (Beverton–Holt did not contribute much to the S–R relation, see Figure 37) using the whole time-series with the exclusion of 2017 (Figure 39).

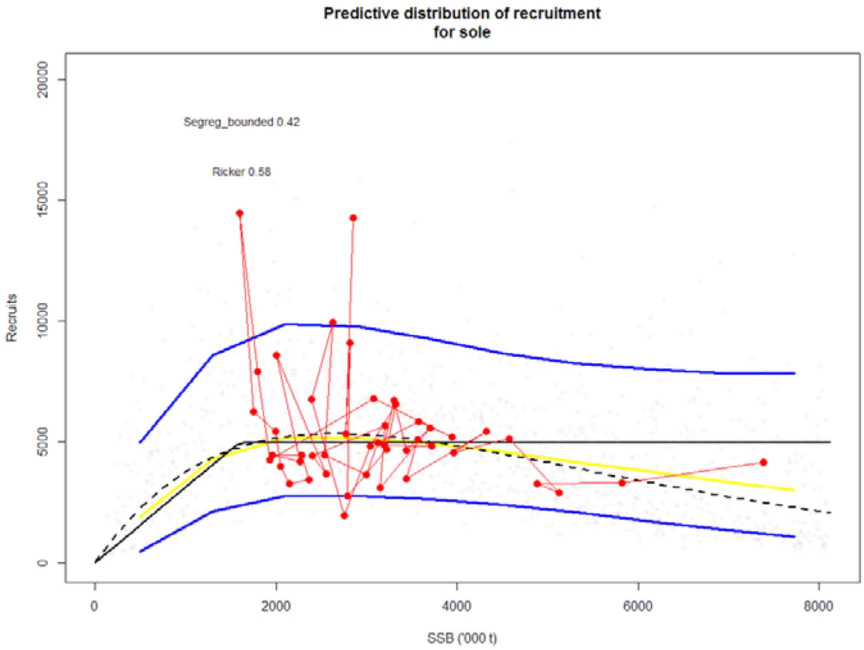

Figure 39. Stock–recruitment relation for sole in area 27.7.f and 27.7.g, based on segmented regression and Ricker over the truncated time period (excluding 2017).

For this simulation run, the assessment/advice errors were set to the default values (Table 7) and $B_{trigger}$ was set to zero. This resulted in a median F_{MSY} of 0.379 (<F_{pa}). The median of the SSB estimates at F_{MSY} was 2726 tonnes. The upper bound of the F_{MSY} range, giving at least 95% of the maximum yield, was estimated at 0.514 and the lower bound at 0.251. $F_{p0.5}$ was estimated at 0.429, which is lower than the estimate of the upper bound on F_{MSY} implying that fishing at this upper bound is not precautionary. The F_{MSY} upper precautionary without $B_{trigger}$ should therefore be set to $F_{p0.5}$ (0.429). The results of the Eqsim simulations are shown in the table below and Figures 34–42.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	**0.429**	0.461	0.576	NA	0.380	NA	NA	NA	NA
lanF	NA	NA	NA	**0.379**	0.380	**0.251**	0.253	**0.514**	0.512
catch	971.529	961.318	840.624	NA	978.082	NA	NA	NA	NA
landings	NA	NA	NA	978.330	978.082	929.721	960.475	929.648	960.745
catB	2406.906	2228.600	1591.429	NA	2722.037	NA	NA	NA	NA
lanB	NA	NA	NA	**2726.413**	2722.037	3863.504	NA	1946.848	NA

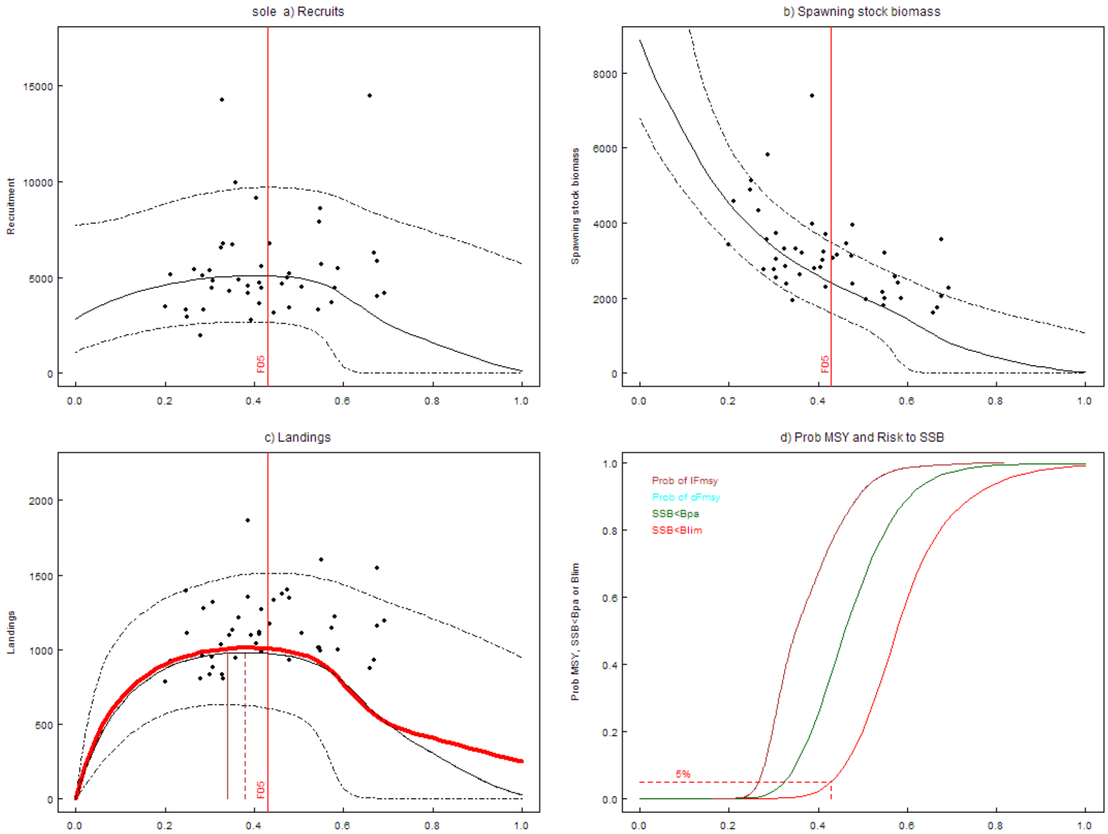

Figure 40. Eqsim summary plot for sole in area 27.7.f and 27.7.g (without $B_{trigger}$). Panels a–c: historic values (dots) median (solid black line) and 90% intervals (dotted black lines) for recruitment, SSB and landings for exploitation at fixed values of F (on x-axis). Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim}(red), SSB<B_{pa} (green), and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan). The brown and cyan line overlap, as only landings are considered in this assessment.

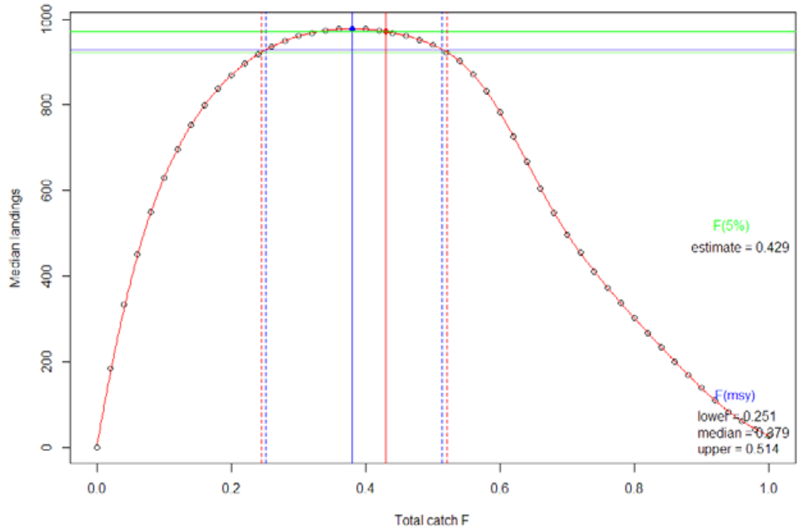

Figure 41. Median landings yield curve for sole in area 27.7.f and 27.7.g, with estimated reference points (without $B_{trigger}$) and with a fixed F exploitation from F=0 to 1.0. Blue lines: F_{MSY} estimate (solid line) and range at 95% of maximum yield (dotted lines). Green lines: $F_{p0.5}$ estimate (solid line) and range at 95% of yield implied by $F_{p0.5}$ (dotted lines).

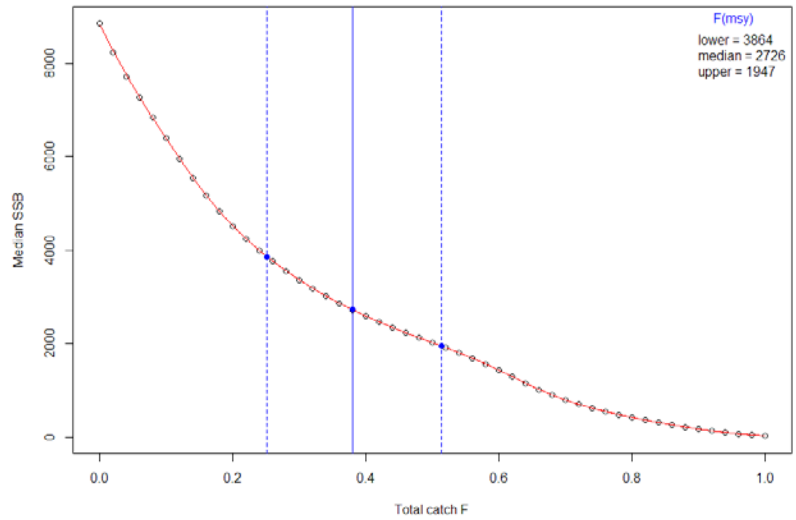

Figure 42: Median SSB curve over a range of target F values (without $B_{trigger}$) for sole in area 27.7.f and 27.7.g. Blue lines: F_{MSY} estimate (solid line) and range at 95% of maximum yield (dotted line).

3.8.4.4 Determine MSY $B_{trigger}$ and evaluate ICES MSY Advice rule

If the stock has not been fished at F_{MSY} for five or more years, MSY $B_{trigger}$ should be set at B_{pa}: 2229 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 2229 tonnes, median F_{MSY} increased to 0.404 with a lower bound of the range at 0.26 and an upper bound at 0.645. The $F_{p0.5}$ value (0.537) is larger than the initial F_{MSY} (0.379). Therefore, F_{MSY} stays at the value initially calculated.

The results of the Eqsim simulations are shown in the table below and in Figures 43-45.

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	**0.537**	0.591	0.831	NA	0.400	NA	NA	NA	NA
lanF	NA	NA	NA	**0.404**	0.400	**0.26**	0.258	**0.645**	0.681
catch	969.610	955.096	877.075	NA	988.261	NA	NA	NA	NA
landings	NA	NA	NA	988.085	988.261	939.50	956.744	939.055	956.412
catB	2089.890	1967.184	1592.587	NA	2621.744	NA	NA	NA	NA
lanB	NA	NA	NA	2596.756	2621.744	3771.02	NA	1866.135	NA

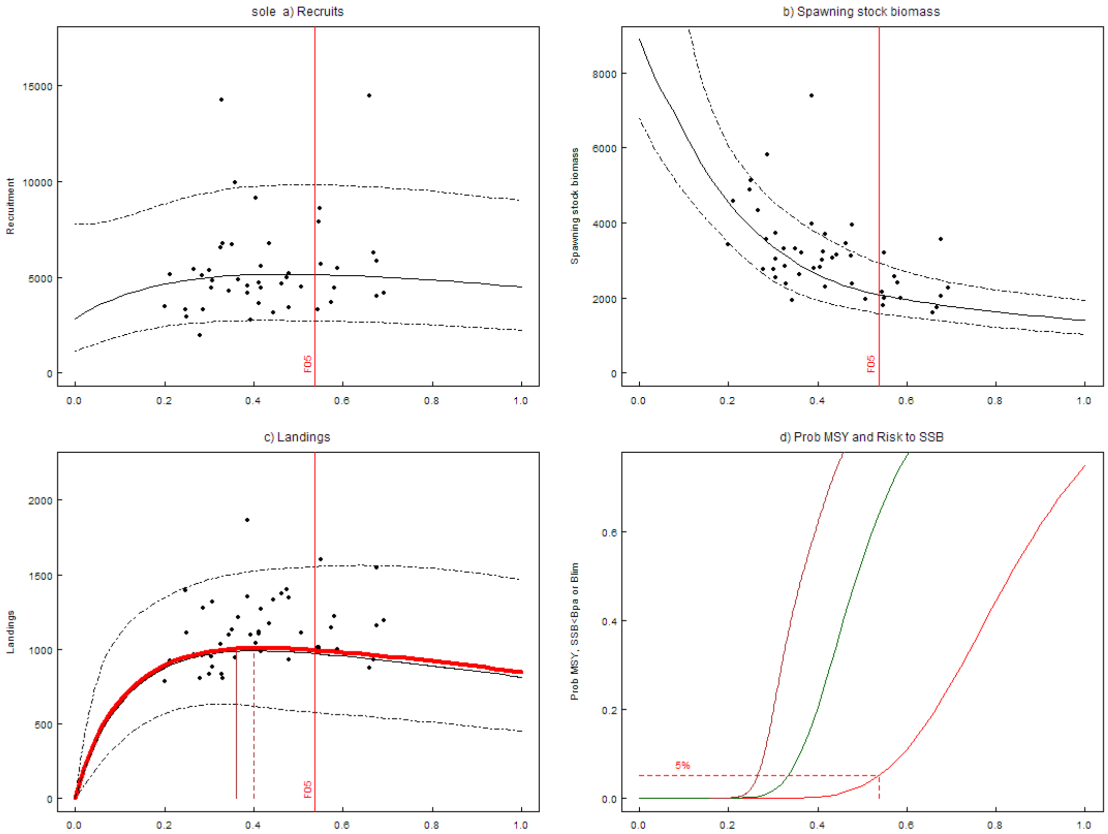

Figure 43. Eqsim summary plot for sole in area 27.7.f and 27.7.g (with $B_{trigger}$). Panels a–c: historic values (dots) median (soid black line) and 90% intervals (dotted black lines) for recruitment, SSB and landings for exploitation at fixed values of F (on x-axis). Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim}(red), SSB<B_{pa}

(green), and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan). The brown and cyan line overlap, as only landings are considered.

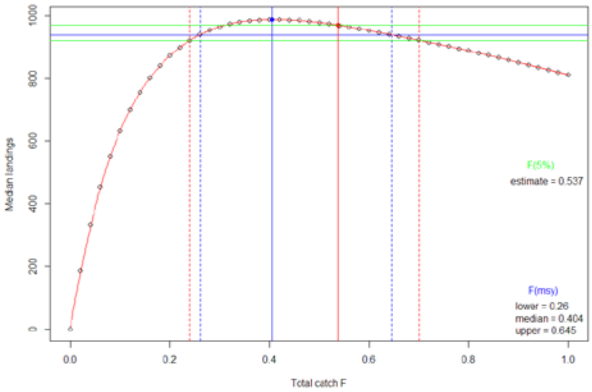

Figure 44. Median landings yield curve for sole in area 27.7.f and 27.7.g, with estimated reference points ($B_{trigger}$ = 2229 tonnes) and with a fixed F exploitation from F=0 to 1.0. Blue lines: F_{MSY} estimate (solid line) and range at 95% of maximum yield (dotted lines). Green lines: $F_{p0.5}$ estimate (solid line) and range at 95% of yield implied by $F_{p0.5}$ (dotted lines).

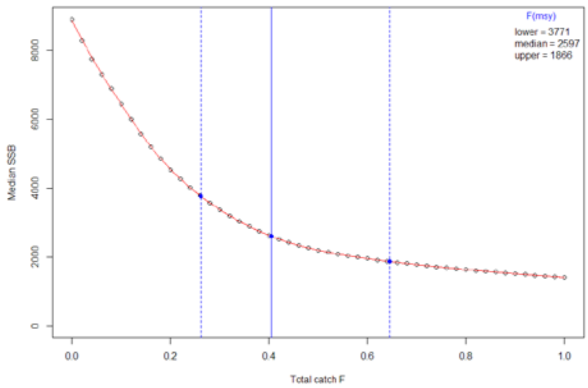

Figure 45. Median SSB curve over a range of target F values ($B_{trigger}$ = 2229 tonnes) for sole in areas 27.7.f and 27.7.g. Blue lines: F_{MSY} estimate (solid line) and range at 95% of maximum yield (dotted line).

3.8.5 Proposed reference points

Reference point	Value
B_{lim}	1592
$B_{pa\ (1.4)}$	2229
$B_{pa\ (sigma)}$	/
$B_{trigger}$	2229
F_{lim}	0.578
$F_{pa\ (1.4)}$	0.413
$F_{pa\ (sigma)}$	/
F_{MSY} without $B_{trigger}$	**0.379**
F_{MSY} without $B_{trigger}$ precautionary	0.379
F_{MSY} lower without $B_{trigger}$	0.251
F_{MSY} upper without $B_{trigger}$	0.514
New $F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.429
F_{MSY} upper precautionary without $B_{trigger}$	0.429
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$)	0.537
F_{MSY} lower with $B_{trigger}$	0.260
F_{MSY} upper with $B_{trigger}$	0.645
F_{MSY} upper precautionary with $B_{trigger}$	0.537

3.8.6 Sensitivity runs

A sensitivity analysis was conducted which involved running Eqsim with a moving window of ten years of selectivity data starting with 1990–1999 and ending with 2008–2017 (bio data year range 2008–2017 remained constant). The effect on the estimate of median F_{MSY} is shown in Figure 46. The estimate varies between 0.331 and 0.382 depending on the year range chosen and shows an upward trend towards the most recent years. Given the trend and changes in selectivity in the fishery from 1990 until 2017 (Figure 36), this upward trend is to be expected. Still, it is logical to use a recent selection pattern (last ten years) in the initial Eqsim runs as we suspect that the current selectivity is most likely to persist into the future.

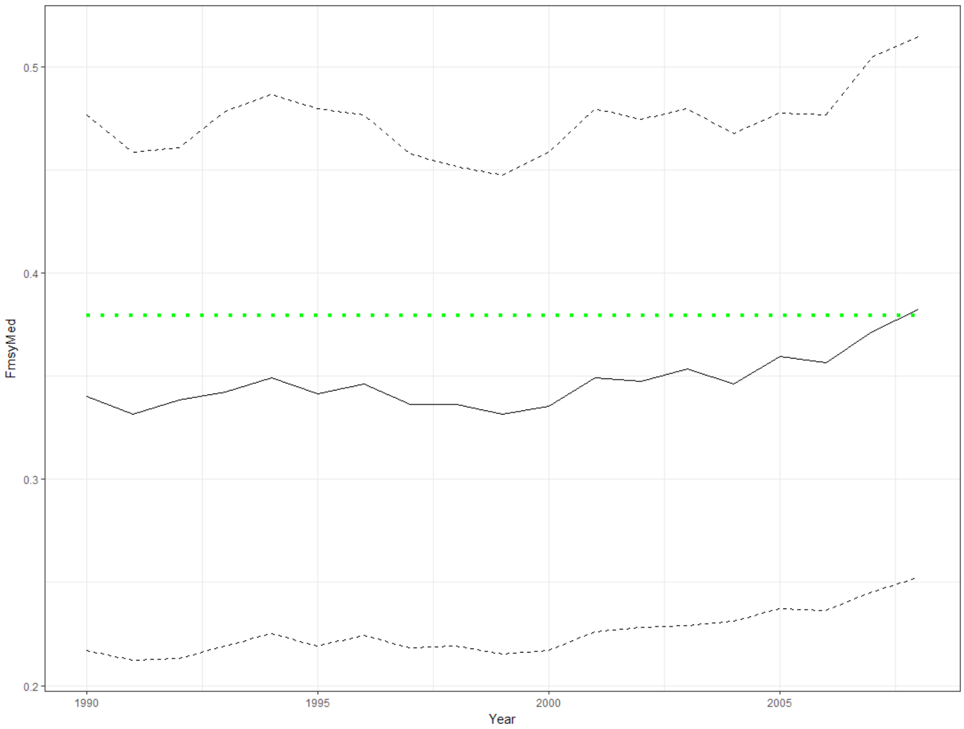

Figure 46. Sensitivity of F_{MSY} estimate (solid black line) to year range of selectivity data for sole in area 27.7.f and 27.7.g. (Year label is 1st year of a 10 year range). Dotted lines represent the 5th and 95th percentiles of F_{MSY}. Green striped line represents the F_{MSY} value as estimated by the Eqsim analysis described above (=0.379).

3.9 Future Research and data requirements

A benchmark is scheduled for 2020 where the following issues will be addressed:

- Estimate and provide the basis for a suitable time-series of effort data for the UK commercial beam trawl to account for the recent change in e-logbook effort recording;
- Investigate if additional survey information (e.g. UK-Q1SWBeam, started in 2006) can be incorporated in the assessment;
- Life-history data: maturity parameters and fluctuations in mean weights-at-age will be explored;
- Examine alternative assessment models to XSA (e.g. A4A, ASAP, SAM, CASAL, SS3).

Advice on the Celtic Sea sole stock (and eventually the adjacent sole stocks in the Western English Channel and Irish Sea) could be improved by accounting for potential misreportings of sole landings as illustrated in the working document on engine power correction Belgian Commercial Beam trawl tuning fleet (BE-CBT) for Sole in the Celtic Sea (27.7.fg) (Annex 2). An initial analysis showed that it is likely that some sole landings reported to be caught in the Celtic Sea where actually caught in the Western English Channel or Irish Sea where Belgian fishers have limited catch opportunities for sole.

To estimate the quantity of misreported sole landings, logbook data can be used to model the landings per unit effort of fishing trips where fishing activity was limited to the Celtic Sea. Whereas VMS data can be used to estimate the true fishing activity in the Celtic Sea from fishing trips where fishing activity occurred in multiple ICES divisions. Finally, the regression model and the estimated fishing effort can be used to predict the sole landings in Celtic Sea. As such, the difference between the sum of the predicted landings and the reported landings provides an estimate of misreporting.

An alternative approach would be to estimate the models for the Western English Channel, Celtic Sea and Irish Sea sole stock simultaneous in a single estimation model. In this case, two extra parameters should be estimated to allocate a proportion of the Celtic Sea sole landings to the Western English Channel and Irish Sea, whereas the total landings should add up to the total observed landings of the stocks.

There is a duplication of age-composition information used to derive the Belgian Commercial Beam trawl tuning fleet (BE-CBT) indices and the fishery catch-at-age. IBP-Brisol recommends that assessment models be explored at the 2020 Benchmark meeting that may make more appropriate use of the ageing data. One option is to investigate models that use BE-CBT age-aggregated LPUE series, rather than the age-disaggregated series required by the current XSA assessment model.

3.10 External Reviewers Comments

Chair (Noel Cadigan) review

I appreciate the efforts of the IBP participants during this review. A considerable amount of work was conducted over four WebEx meetings and I feel we made substantial progress towards most of the ToRs. The exception was the ToR related to 'time-series of effort data for the UK commercial beam trawl' which we were told would be addressed at the 2020 full benchmark for this stock. I conclude that the updated XSA model and the MSY and PA reference points are the best available information to provide harvest advice for this stock.

However, as usual there are many areas of research that could result in better information for harvest advice. Some important ones are outlined under Section 3.9 above. In particular, I recommend that alternative assessment models be explored during the 2020 Benchmark process. We did not have this option during the IBP. XSA was the only option. I am not an XSA experts and I don't fully understand this stock assessment model tuning algorithm. XSA is rarely used outside of the ICES forum. Hence, I felt I could not provide good advice on the details of the XSA settings. During the IBP, we simply omitted series and ages that were not fit well by XSA. This was a pragmatic decision aimed at reducing retrospective patterns. However, in general it is not a good idea to omit data that do not fit a model unless we have good reasons to think that the data are practically useless. A better approach is to modify the model to fit the data. More modern assessment models such as SAM and CASAL are much more useful in this regard. I recommend during the 2020 Benchmark process that alternative assessment models and assumptions be explored to produce a more reliable assessment model that provides realistic quantifications of the uncertainty of stock status estimates.

Review by John Wiedenmann

Over the course of four remote meetings, we reviewed various aspects related to the ToRs of the inter-benchmark assessment for sole in 7f and 7g. Most of the review centred around the standardization of the commercial Belgian beam trawl data (ToR a.ii), and the analyses made considerable progress towards this ToR. ToR a.i. regarding the UK beam trawl data was not addressed during this review. We also evaluated the assessment (XSA) ouput of the different runs, focusing on diagnostics such as the internal consistency in the individual tuning indices, the mean squared error and residuals in the age compositions, and the retrospective patterns in SSB, F and recruitment. Due to the high mean squared error, relatively short time-series, and poor internal consistency, we agreed that removal of the Belgian "CBT2" index was reasonable, and that Run 5 be used as the basis for management advice. Based on this output, we agreed that the reference points be calculated with an assumed type 5 stock–recruitment relationship. I concur with the chair's conclusion that the updated XSA model and the MSY and PA reference points are the best available information to provide harvest advice for this stock.

With regard to the chair's comments on exploration of additional assessment models, I fully agree. I too am unfamiliar with XSA and its inner workings, so I could not provide advice on the tuning in the model and how it could be modified to account for some of the issues identified in the BE-CBT2 series. Exploration of some of the statistical catch-at-age models listed in Section 3.9 is certainly warranted in the upcoming 2020 benchmark. In general, I agree that issues with a given tuning series should be dealt with within an assessment model if possible, as opposed to omitting the series from the assessment. Alternatively, development of objective criteria for exclusion of certain indices (e.g., length of time-series, spatial coverage, mean squared error thresholds, consistency of catchability estimates for a split series) could also benefit future assessments for this stock and other ICES stocks.

4 Conclusions

The focus of this inter-benchmark was to improve the quality of the tuning fleets currently included in the assessment of sole in divisions 7.f and 7.g. Effort issues with the UK commercial beam trawl index and inclusion of additional survey information were postponed to consider during the upcoming 2020 benchmark.

A new Belgian tuning series was constructed by focusing on the landings and effort data from pure trips of the large fleet segment of the Belgian commercial beam trawl fleet fishing in divisions 7.f and 7.g. The index that shows a good internal consistency, provides information for the period 2006–2017 and ages 2–9.

The final XSA assessment run included the original Belgian CBT series from 1971–1996 (ages 3–9), the UK CBT from 1991–2012 (ages 3–8), the UK BTS Q3 and the new Belgian CBT series from 2006–2017 (ages 2–9). This resulted in an increase of the SSB and a decrease of F in recent years.

New reference points were calculated using the Eqsim functions.

5 Updated stock annex

The stock annex will be updated during the WGCSE 2019.

6 References

ICES. 2017. ICES Advice Technical Guidelines, ICES fisheries management reference points for category 1 and 2 stocks. Published 20 January 2017.

Annex 1: List of participants

Name	Institute	Country	E-mail
Sofie Nimmegeers	Institute for Agricultural and Fisheries Research (ILVO)	Belgium	sofie.nimmegeers@ilvo.vlaanderen.be
Bart Vanelsander	Institute for Agricultural and Fisheries Research (ILVO)	Belgium	bart.vanelslander@ilvo.vlaanderen.be
Lies Vansteenbrugge	Institute for Agricultural and Fisheries Research (ILVO)	Belgium	lies.vansteenbrugge@ilvo.vlaanderen.be
Helen Dobby	Marine Scotland Science	UK	h.dobby@marlab.ac.uk
John Wiedenmann Invited Expert/Reviewer	Rutgers-The State University of New Jersey Dept of Ecology, Evolution and Natural Resources	USA	john.wiedenmann@gmail.com
Noel Cardigan Chair	Centre for Fisheries Ecosystems Research (CFER), Fisheries and Marine Institute of Memorial University of Newfoundland,	Canada	Noel.Cadigan@mi.mun.ca
Ruth Fernandez ICES Secretariat	International Council for the Exploration of the Sea	Denmark	ruth.fernandez@ices.dk

Annex 2: Working document: Engine power correction Belgian Commercial Beam trawl tuning fleet for Sole in the Celtic Sea (27.7.fg)

Sofie Nimmegeers, Klaas Sys, Lies Vansteenbrugge and Bart Vanelslander.

Objective

The assessment of sole in the Celtic Sea is tuned with one survey (UK(E&W)-BTS-Q3) and two commercial tuning series (UK(E&W)-CBT and BE-CBT). The BE-CBT (Belgian commercial beam trawl) tuning series was split into two parts at WKCELT 2014 (ICES, 2014) and both series are included separately in the current assessment: one with the original data from 1971 up to 1996 and an updated series from 1997 up to 2017. The effort is corrected for engine power, based on a study carried out by IMARES and CEFAS in the mid-1990s (applicable to sole and plaice effort in the beam trawl fisheries). This method is outdated and therefore the objective of this working document for the IBP-Bristol was to investigate a more realistic conversion factor for engine power to convert nominal fishing effort to effective effort. This document describes how commercial data of the Belgian beam trawl fleet were used to obtain an index of abundance and specifies the pre-processing of the data, the model selection, and the upscaling and coupling with observer data.

Available 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 of 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.

Data exploration

Introduction

The landings of sole and effort data from beam trawlers (métier: TBB_DEF_70-99) active in the ICES divisions 27.7.f and 27.7.g were combined to calculate the LPUE of sole from 2006 onwards.

Information on ICES statistical rectangle, year, month, fleet segment and engine power (kW) is available for the analyses.

Spatial effort distribution over time

Landings data are available by ICES statistical rectangle from 2006 onwards. Therefore, we focus on the period 2006–2017 in this document. Landings (kg) and fishing effort (fishing hours) are concentrated in a few ICES statistical rectangles (Figure 1).

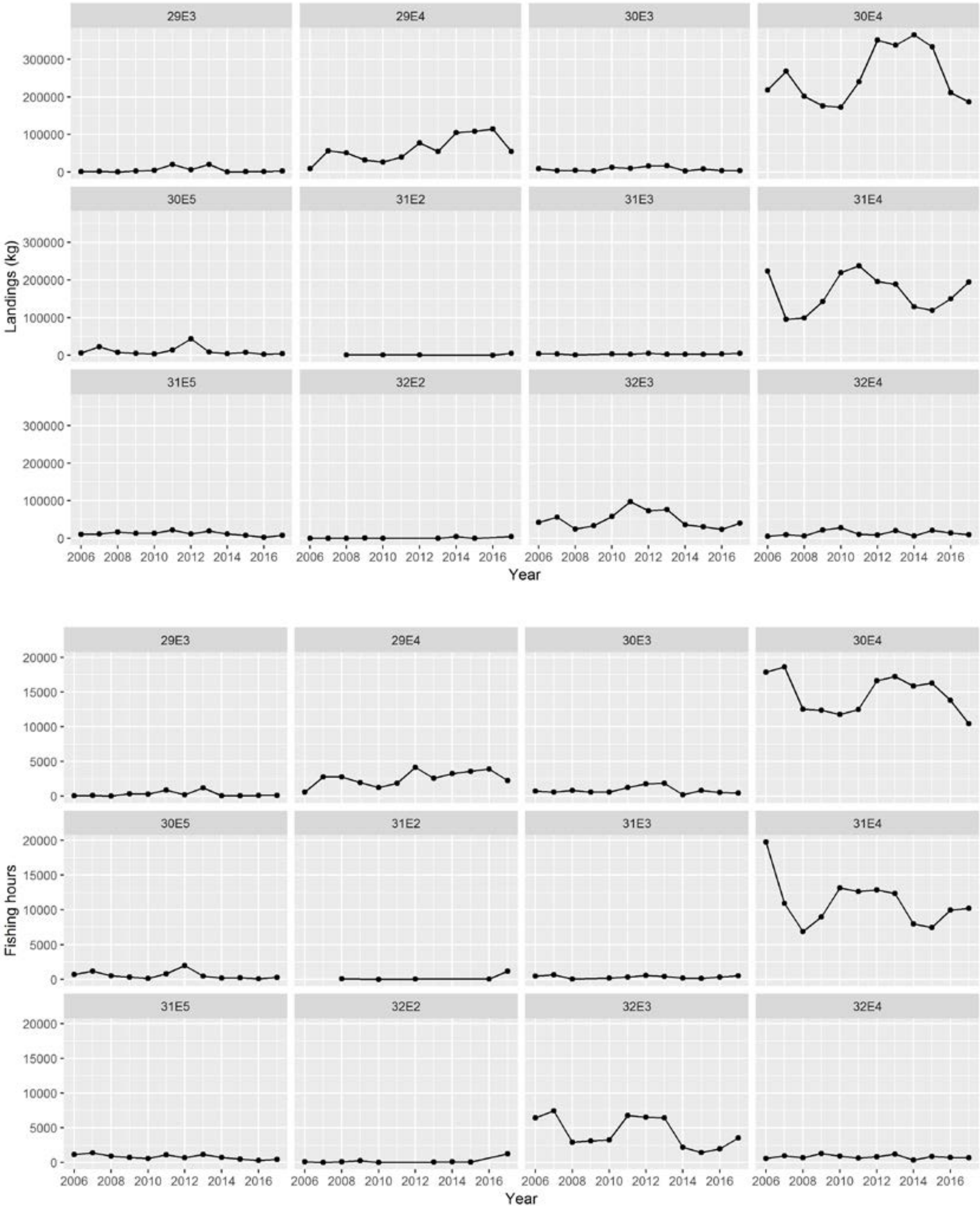

Figure 1. Upper graph: Sole landings in kg by ICES statistical rectangle and year for the Belgian commercial beam trawl fleet in area 27.7.fg for 2006–2017. Lower graph: Effort in fishing hours by ICES statistical rectangle and year for the Belgian commercial beam trawl fleet in area 27.7.fg for 2006–2017.

ICES rectangles 30E4, 31E4 and 32E3 form the Trevose Box, which is closed for fishing from February 1st until March 31st. This management measure is in place since 2006 and aims to protect spawning fish, cod and other demersal stocks such as sole in particular (ICES special request, 2007; Sys *et al.*, 2017). This measure has a significant effect on the behaviour of the fleet. The largest effort of the Belgian commercial beam trawl fleet is situated in this Trevose Box or on its edges during closure (Figure 2). For a detailed description of the effect of the Trevose Box closure on the Belgian beam trawl fishery, we refer to Sys *et al.*, 2017.

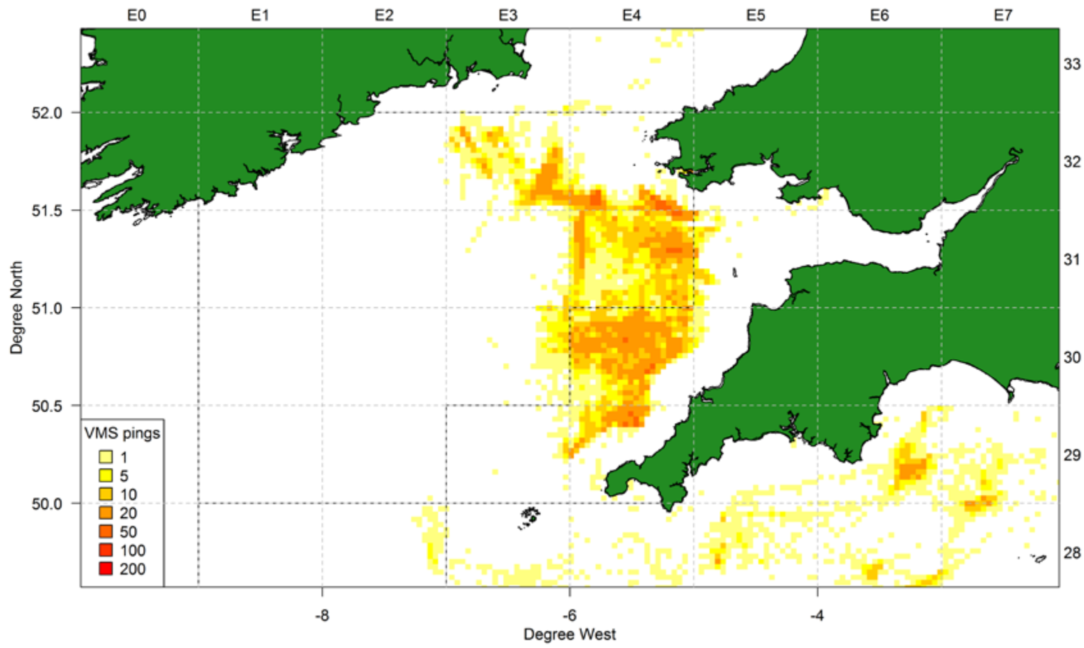

Figure 2. Map giving an indication of the effort of the Belgian commercial beam trawl fleet in area 27.7.fg based on VMS pings. ICES statistical rectangles enclosed by the blue box comprise the Trevose Box.

Raw lpue data by ICES statistical rectangle and year are shown in Figure 3.

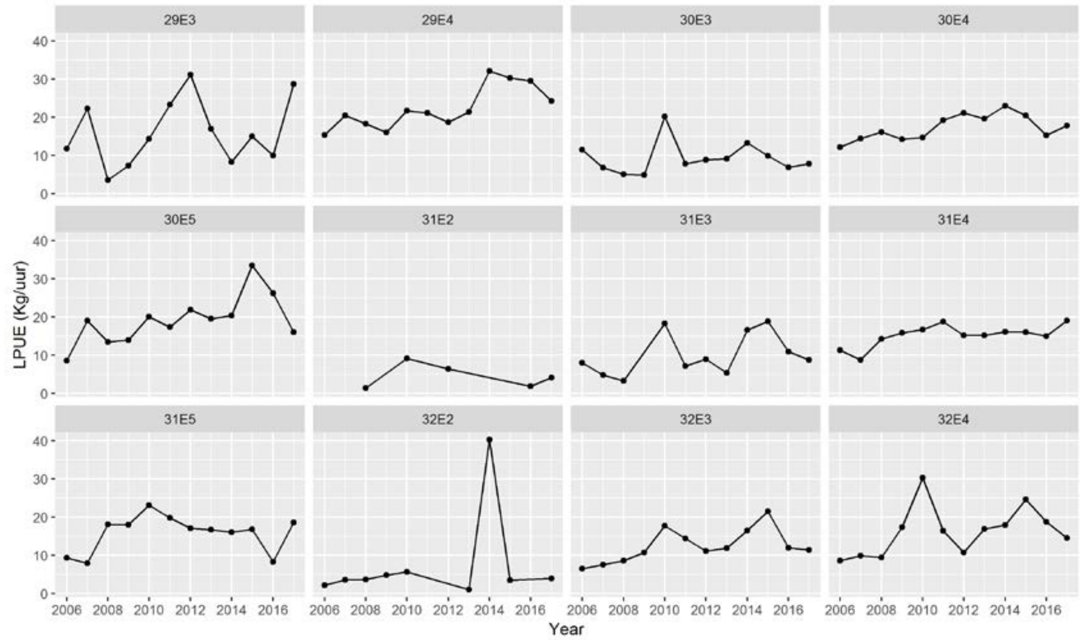

Figure 3. Raw lpue (kg/h) of sole caught by the Belgian commercial beam trawl fleet in area 27.7.fg by ICES statistical rectangle and year.

Temporal effort distribution

Prior to 2006, fishing effort and sole landings by the Belgian beam trawl fleet were concentrated during winter, from November until April. However, the implementation of the Trevose box closure in 2006, which meant a temporal closure of ICES statistical rectangles 30E4, 31E4 and 32E3 during the months February and March, resulted in a remarkable temporal reallocation of fishing effort and landings of sole. Since 2006, a strong peak of both effort and sole landings is noted in April each year and lasts approximately three weeks (Figure 4).

During the first week after re-opening of the Trevose box, catch rates are estimated to be twice as high with respect to the situation before the closure of the Trevose Box (prior to 2006). However, as a result of this period with high fishing intensity, catch rates return quickly to a normal level. For a detailed description of the effect of the Trevose Box closure on the Belgian beam trawl fishery, we refer to Sys *et al*., 2017.

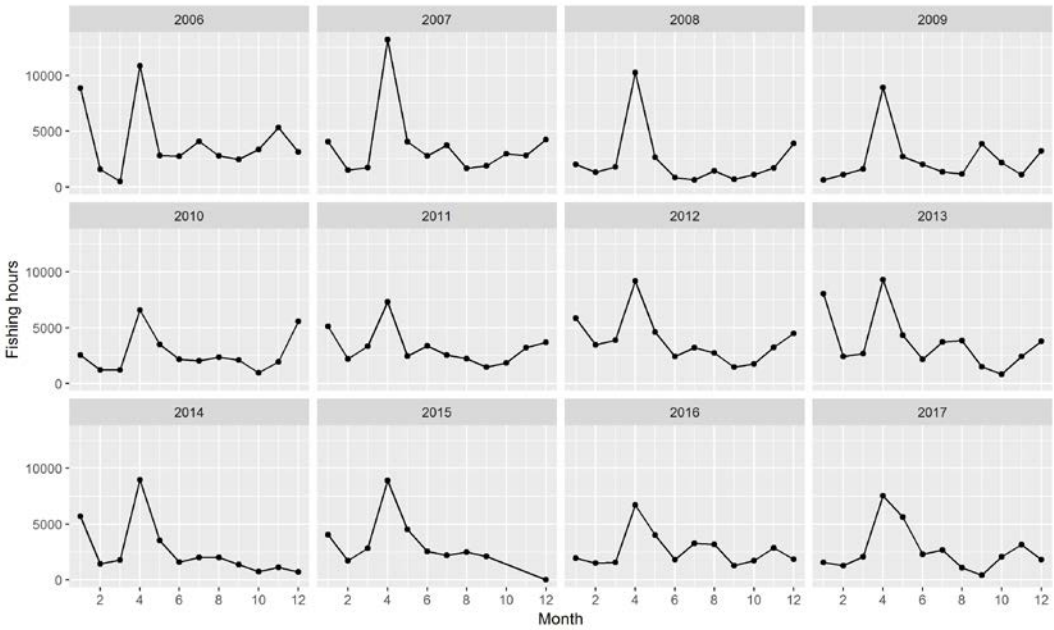

Figure 4. Effort in fishing hours by month and year for the Belgian commercial beam trawl fleet in area 27.7.fg.

Fleet segment

The Belgian beam trawl fleet consists of a small fleet segment (Eurocutter and coastal vessels; engine power ≤221 kW) and a large fleet segment (engine power >221 kW). On average 95% of the fishing hours in the ICES divisions 27.7.f and 27.7.g can be attributed to the large fleet segment.

The number of trips and fishing hours per year for each fleet segment for the years 2006-2017 are shown in Table 1 and Table 2.

Table 1. Number of trips per year and for each fleet segment.

	Number of trips	
Year	Small fleet segment	Large fleet segment
2006	18	348
2007	35	328
2008	16	207
2009	22	245
2010	13	247
2011	28	294
2012	50	344
2013	27	352
2014	21	279
2015	16	263
2016	7	276
2017	11	303

Table 2. Fishing hours per year and for each fleet segment.

	Fishing hours	
Year	Small fleet segment	Large fleet segment
2006	2526	46 545
2007	4324	40 668
2008	1365	27 140
2009	1496	28 837
2010	994	31 225
2011	2731	36 021
2012	3985	42 221
2013	2063	42 976
2014	1948	29 222
2015	1029	30 550
2016	432	31 557
2017	732	32 177

When plotting the log transformed lpue against engine power, there is a clear difference between the small (engine power ≤221 kW) and large fleet segment (engine power >221 kW) (Figure 5). The vessels belonging to the small fleet segment are likely a group that is misreporting effective engine power (personal communication). Whereas for the vessels from the large fleet segment, there is an increasing linear correlation between LPUE and engine power.

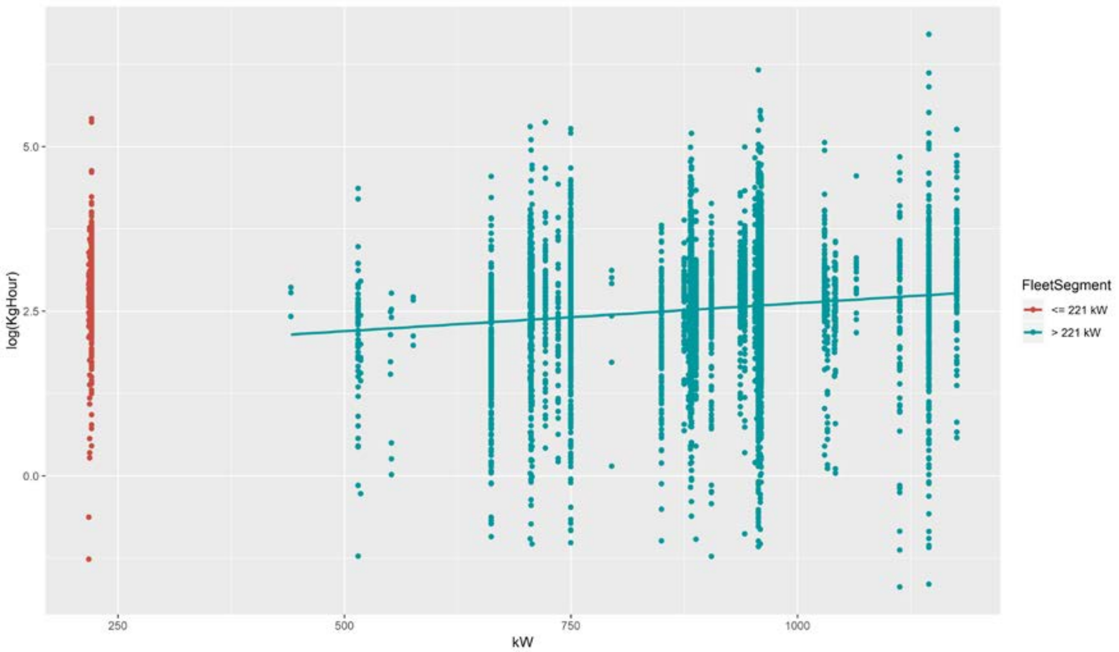

Figure 5. Nominal log transformed sole lpue (kg/h per trip + ICES statistical rectangle) by engine power (kW) for vessels grouped into class <= 221 kW (red) and >221 kW vessels (blue). Linear fit for log LPUE versus engine power.

Based on visual inspection of the data in boxplots (Figure 6), one obvious outlier was detected with a landing rate or lpue of >800 kg/h. This observation was removed from the dataset for the rest of the analysis.

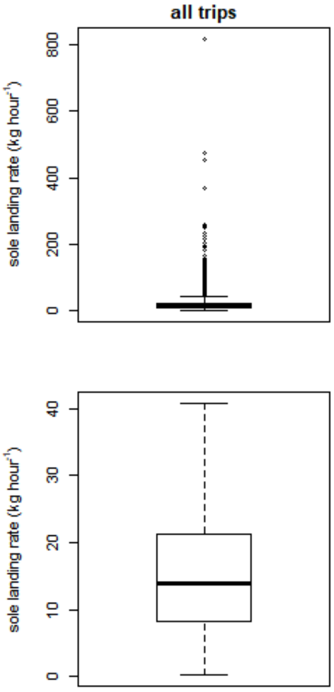

Figure 6. Boxplots of the sole landing rate (kg/h). The upper panels include all observations while the lower panels exclude all outliers.

The raw LPUE of the large fleet segment by year is shown in Figure 7.

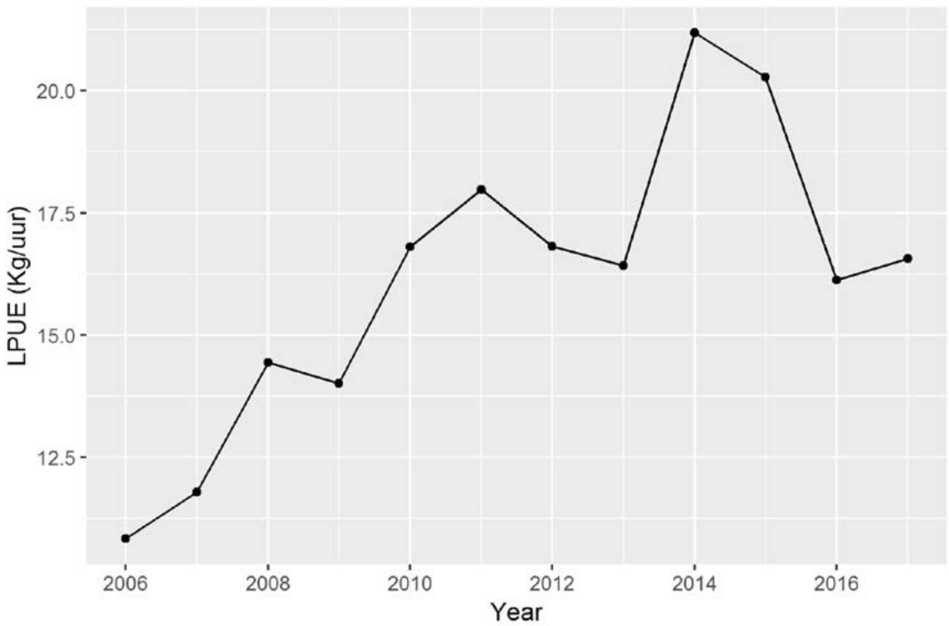

Figure 7. Raw lpue (kg/h) of sole data by year for the large fleet segment.

Trip type

The Belgian beam trawl fleet has fishing opportunities spread over different 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). Nevertheless, an important drawback is that this flexibility creates an opportunity for noncompliance. It is generally known that fishers occasionally 'transfer' landings from one stock to another as a consequence of quota limitations (e.g. day limits). Obviously, such misreporting undermines the veracity of the data.

To detect the occurrence of this phenomenon in the Celtic Sea data, the dataset was divided in two subsets. One dataset (*n*= 3185) was created consisting all fishing trips during which fishing activity was registered both in the Celtic Sea (27.7.f and/or 27.7.g) and other ICES subdivisions (Figure 8). The other subset of the data (*n*= 2673) included only those fishing trips in which fishing activity was limited to the Celtic Sea (Figure 9). For the remainder of this document, we refer to the first dataset as 'mixed', and to the latter as 'pure'.

Figure 10 shows the relative proportion of number trips per trip type. Figure 11 shows the relative proportion of landings per trip type.

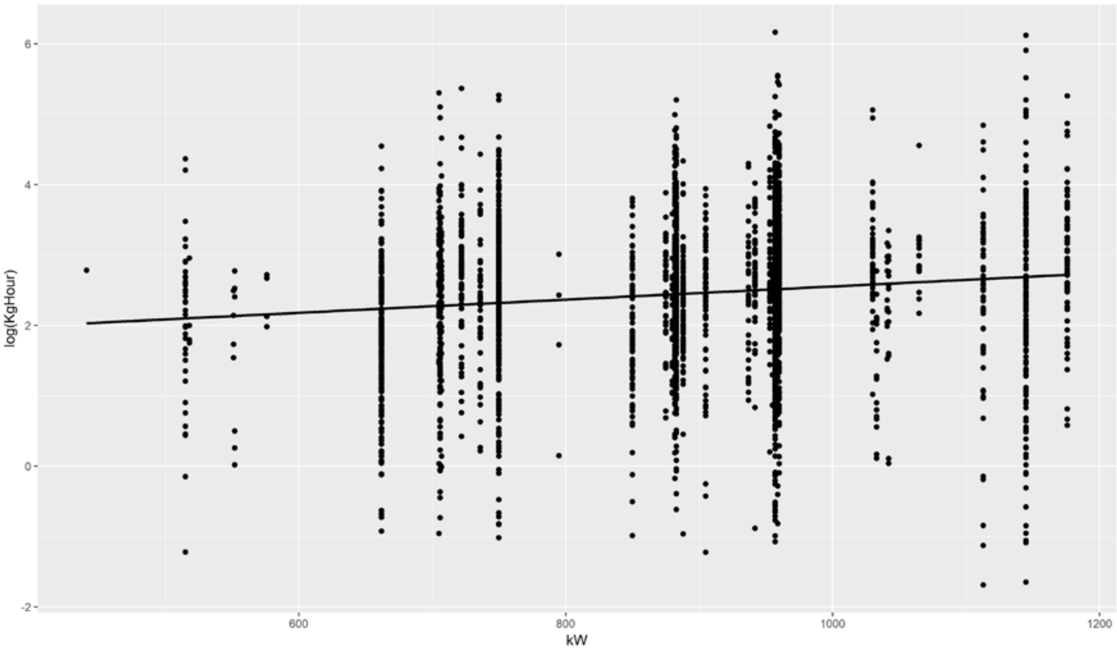

Figure 8. Nominal log transformed sole LPUE (kg/h per trip + ICES statistical rectangle) against engine power (kW) in mixed trips (only large fleet segment). Linear fit for log LPUE vs engine power.

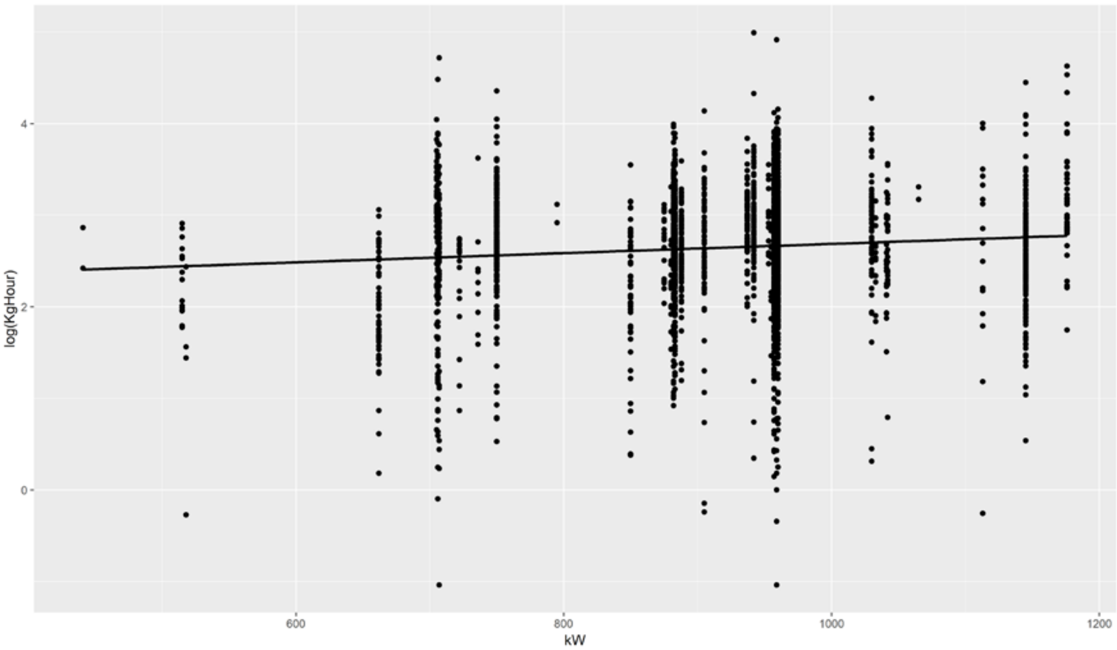

Figure 9. Nominal log transformed sole LPUE (kg/h per trip + ICES statistical rectangle) against engine power (kW) in pure trips (only large fleet segment). Linear fit for log LPUE vs engine power.

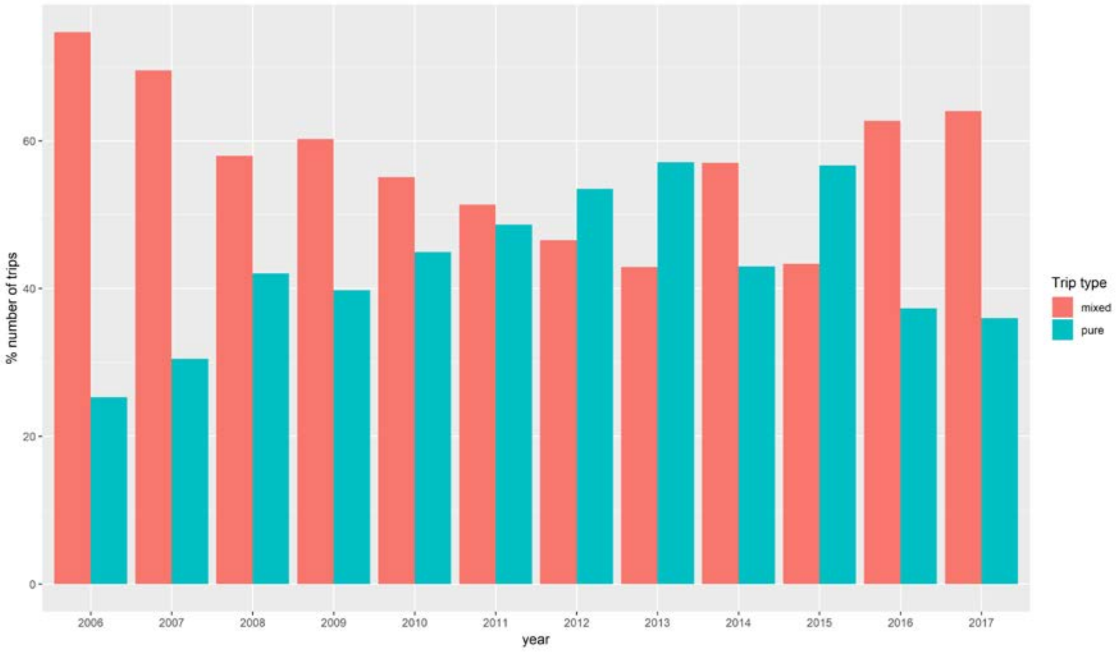

Figure 10. Relative proportion of the number of pure and mixed trips.

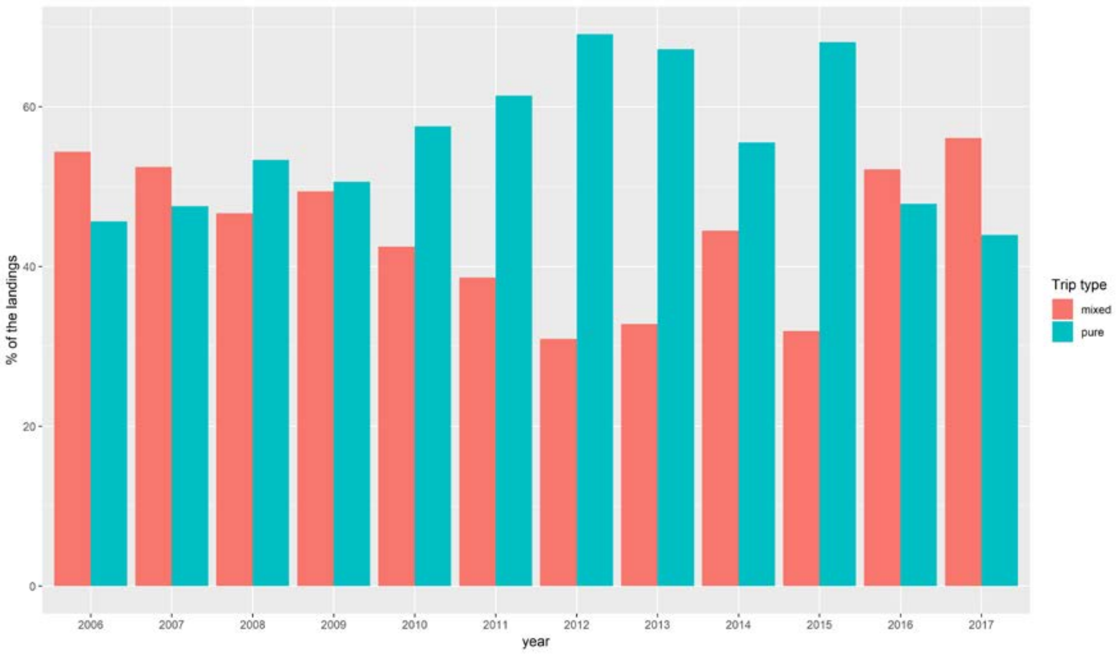

Figure 11. Relative proportion of landings per trip type.

In the absence of misreporting through the transfer of landings between ICES subdivisions, it can be expected that both datasets are a random subsample from the total population, and consequently have similar characteristics. Hence, the distribution of landing rates in both datasets should be similar. Bootstrapping was applied to compare both datasets. To assure an appropriate comparison between both datasets in terms of effects related to covariates, the mixed and pure trip observations were reduced so that only comparable observations were selected with respect to the month, ICES statistical rectangle, year, and vessel reference number of the observation. From this reduced dataset (n= 991), the landings per hour (kg/h) of both mixed and pure trips were resampled 10 000 times whereupon the variance, mean, and median of each random sample was calculated. Based on the vectors of derived quantities, the 2.5% and 97.5% quantiles were calculated to construct a 95% confidence interval for the variance, mean and median for both subsamples.

Figure 12 illustrates that the sole landing rate of pure and mixed trips differs significantly in terms of each test statistic. The variance and mean in the pure trips (blue) is considerably lower compared to the mixed trips (red), while the opposite is true for the median landing rate. Although this result does not provide direct evidence, misreporting of landings through transfers from one ICES subdivision to another seems a plausible explanation for the observed differences in landing rates between both types of trips.

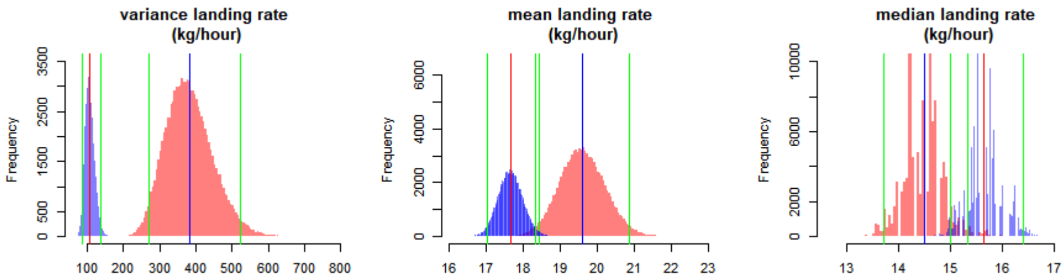

Figure 12. Histograms of the distribution of the variance, mean and median of resampled data of the sole landing rate in pure (blue) and mixed (red) trips. The green vertical lines are the 95% confidence intervals of each value, while the blue and red line indicate the observed value of the mixed and pure trips, respectively.

As shown in the scatter plot of Figure 13, a lot of mixed trip observations have rather high landing rates while fishing hours in the Celtic Sea are low. This may indicate that some fishers spend a short time in the Celtic Sea during a trip to register some fishing activity while mainly fishing in adjacent ICES subdivisions during that trip. This provides them the opportunity to transcribe landings to the Celtic Sea. This practice is also supported by the fact that it does less occur when fishing hours in the Celtic Sea increase. Obviously, if fishers spend more time in the Celtic Sea, they are likely to fish less in adjacent areas. Hence, if misreporting occurs in this case, it's magnitude will be lower, and is spread over more fishing hours.

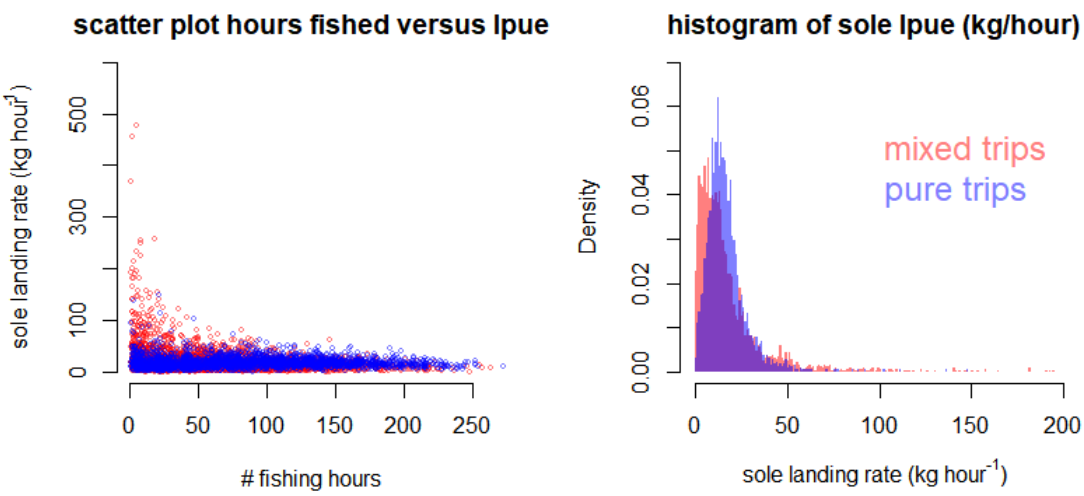

Figure 13. Visualization through a scatterplot and histogram of the sole landing rate per hour in mixed and pure trips.

The raw LPUE of the pure trips of the large fleet segment by year is shown in Figure 14.

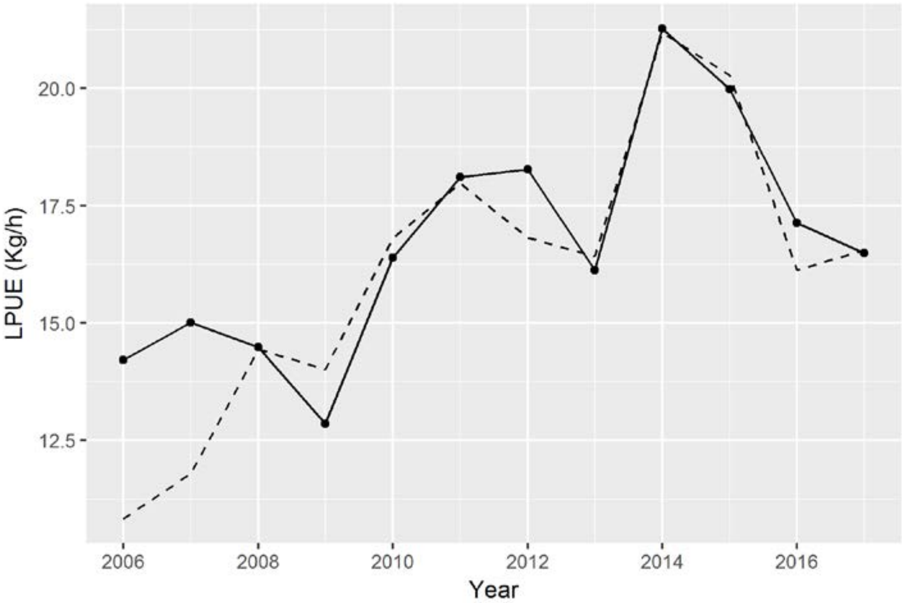

Figure 14. Raw LPUE (kg/h) of sole data by ICES statistical rectangle and year for pure trips of the large fleet segment (solid line) and for pure + mixed trips of the large fleet segment (dashed line).

Standardization of the sole landing rate

Model input and approach

The analysis of the landing rate focussed on the data of *pure trips* by vessels from the *large fleet segment* (Table 3). Different regression models were fitted to the data to standardize the landing rate of sole.

Table 3. Summary statistics of the data per year.

year	n	n_trips	n_vessels	mean_kW	mean_lpue	sd_lpue
2006	156	88	36	906.7	14.58	7.547
2007	173	100	34	935.6	15.06	9.084
2008	167	87	29	960.3	14.64	8.846
2009	166	97	36	918.1	13.08	6.415
2010	190	111	27	940.4	16.36	6.757
2011	273	143	25	934.9	18.08	11.47
2012	340	184	27	922.6	19.04	12.72
2013	376	201	28	925.1	15.1	8.165
2014	220	120	25	902.8	21.36	15.42
2015	243	149	26	900.1	19.07	11.03
2016	174	103	26	866.6	17.32	11.41
2017	195	109	25	872.4	16.97	12.53

The analysis was performed with an increasing degree of model complexity in terms of hierarchical structure and process error (Table 4). The following explanatory variables were included in the analysis: (i) a categorical **year** effect to account for annual changes in abundance, (ii) the log-linear **relationship** between the engine power of a beam trawler and the landing rate (Rijnsdorp *et al.*, 2000), (iii) a categorical temporal effect, **month**, and (iv) a categorical spatial effect (**ICES statistical rectangle**) to account for spatiotemporal variation within a year.

$$lpue = \beta_0 + \beta_1 \, x \, log(kW) + \beta_{2_y} \, x \, year_y + \beta_{3_m} x \, month_m + \beta_{4_r} x \, rectangle_r$$

Different statistical distributions were specified to account for the stochastic component in the data (*i.e.* unexplained variance between the predicted and observed response). Every model, in terms of fixed effects and stochastic component, was fitted with and without a **random vessel effect**. This was done to account for the dependency between landing rate observations from the same vessel that arise from individual vessel characteristics that are not included in the data (e.g. configuration fishing gear, skipper effect). For the statistical distributions that included a **dispersion factor** (Gamma and negative binomial[1] families), analysis was performed with a constant dispersion factor and a variable dispersion parameter governed by a pre-specified formula (see caption Table 4).

[1] TWO NEGATIVE BINOMIAL MODELS WERE INCLUDED IN THE ANALYSIS:

- NBINOM1: VARIANCE (Σ2) INCREASES LINEARLY WITH MEAN (MU): Σ2=MU*(1+PHI); DISPERSION PARAMETER (PHI)
- NBINOM2: QUADRATIC INCREASE OF VARIANCE (Σ2) TO MEAN (MU): Σ2=MU*(1+MU/PHI)

Table 4. Overview of regression models used to standardize the sole landing rate. Formulas of explanatory variables and dispersion parameter are given under the table. Model selected for further calculation of the Celtic Sea sole index shown in bold.

Response variable	Explanatory formulas	Random effect	Dispersion*	Family / (link function)
log(KgHour)	(1)/(2)/(3)/(4)	-	-	Gaussian / (identity)
log(KgHour)	(1)/(2)/(3)/(4)	VesselName	-	Gaussian / (identity)
KgHour	(1)/(2)/(3)/(4)	-	Constant	Gamma / (log)
KgHour	(1)/(2)/(3)/(4)	VesselName	Constant	Gamma / (log)
KgHour	(1)/(2)/(3)/(4)	-	Constant	nbinom 1 / (log)
KgHour	(1)/(2)/(3)/(4)	VesselName	Constant	nbinom 1 / (log)
KgHour	(1)/(2)/(3)/(4)	-	Constant	nbinom 2 / (log)
KgHour	(1)/(2)/(3)/(4)	VesselName	Constant	nbinom 2 / (log)
KgHour	(1)/(2)/(3)/(4)	-	variable	Gamma / (log)
KgHour	(1)/(2)/(3)/**(4)**	**VesselName**	**variable**	**Gamma / (log)**
KgHour	(1)/(2)/(3)/(4)	-	variable	nbinom 1 / (log)
KgHour	(1)/(2)/(3)/(4)	VesselName	variable	nbinom 1 / (log)
KgHour	(1)/(2)/(3)/(4)	-	variable	nbinom 2 / (log)
KgHour	(1)/(2)/(3)/(4)	VesselName	variable	nbinom 2 / (log)

1)~ $\beta_0 + \beta_1$ *as.factor(Year) + β_2 *log(kW)

2)~ $\beta_0 + \beta_1$ *as.factor(Year) + β_2 *log(kW) + β_3 *as.factor(IcesStatisticalRectangle)

3)~ $\beta_0 + \beta_1$ *as.factor(Year) + β_2 *log(kW) + β_4 *as.factor(Month)

4)~ $\beta_0 + \beta_1$ *as.factor(Year) + β_2 *log(kW) + β_3 *as.factor(IcesStatisticalRectangle) + β_4 *as.factor(Month)

***dispersion formula ~**

(A)~as.factor(IcesStatisticalRectangle) + as.factor(Month)

(B)~as.factor(IcesStatisticalRectangle) + as.factor(Month) + as.factor(Year)

(C)~as.factor(IcesStatisticalRectangle) + as.factor(Year)

(D)~as.factor(Month) + as.factor(Year)

Model comparison and selection

To ensure accurate model comparison, both models were estimated using Marginal Maximum Likelihood based on the Laplace approximation of the marginal log-likelihood, while the random effects were predicted by maximizing the joint density function of the observations and random effects, as implemented in the R package *glmmTMB* (Brooks *et al., 2017*).

All models, except the linear regression models with a log transformed response variable were compared using the Akaike Information Criterion (AIC). The model with the lowest AIC criterion was evaluated in terms of dispersion and patterns in the residuals. The performance of the linear models was evaluated through visual inspection of the residuals with respect to the assumptions of normality underlying these models.

Linear models

The **best linear model** (in terms of AIC) was the model with all explanatory variables included in the fixed effects formula and a random vessel effect (marked in blue in Table 4; marked in bold in Table 5):

log(lpue)~ $\beta_0 + \beta_1$ *as.factor(Year) + β_2 *log(kW) + β_3 *as.factor(IcesStatisticalRectangle) + β_4 *as.factor(Month) + (1|VesselName)

Table 5. Difference in AIC and degrees of freedom of the linear (mixed) models. The indexes refer to the fixed effect formulas as provided in Table 4 (i.e. column "Explanatory formulas"). If 'mixed' is included in the model name, a random vessel effect was included.

	ΔAIC	No of estimated coefficients
lm_4_mixed	0.0	39
lm_2_mixed	102.4	28
lm_4	148.1	38
lm_2	284.0	27
lm_3_mixed	637.9	26
lm_3	759.9	25
lm_1_mixed	787.7	15
lm_1	928.5	14

Nevertheless, visual inspection of the residuals indicates that the assumptions of homogeneity and normality were violated (Figure 16).

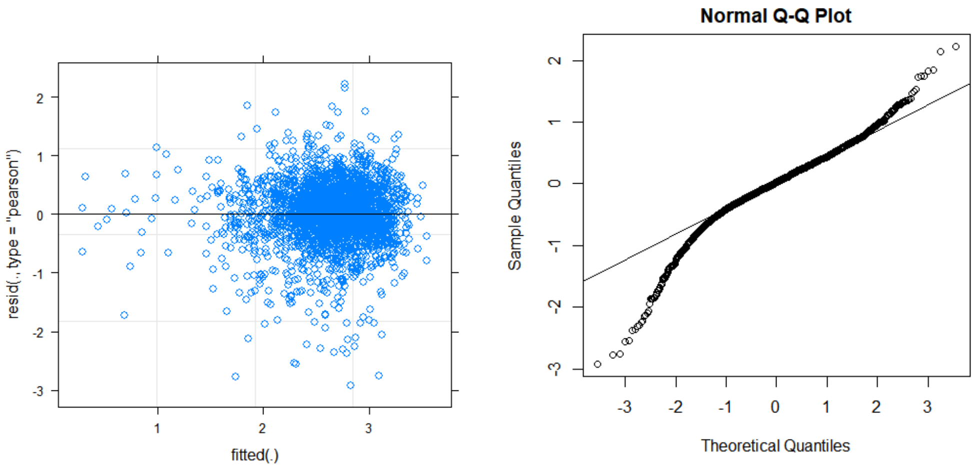

Figure 15. Residuals plots of the best performing linear mixed model.

GLMs and GLMMs

AIC comparison of the **GLMs and GLMMs** shows that the following model has the lowest AIC value (shown in bold in Table 4 and shown in orange in Table 6):

Log(lpue) ~ β_0 + β_1*as.factor(Year) + β_2*log(kW) + β_3*as.factor(IcesStatisticalRectangle) + β_4*as.factor(Month) + Dispersion formula : ~as.factor(IcesStatisticalRectangle) + as.factor(Month) + as.factor(Year)

Although the model that included the *year* effect in the dispersion model performed slightly better in terms of AIC (Table 6), we decided not to keep this model for the final index calculation. The improvement found by including the year effect in the dispersion model could not be explained biologically. This may suggest that it is a data artefact rather than a true process. Therefore, we continued our analysis with the following model (shown in bold in Table 6):

Log(lpue) ~ β_0 + β_1*as.factor(Year) + β_2*log(kW) + β_3*as.factor(IcesStatisticalRectangle) + β_4*as.factor(Month) + Dispersion formula : ~as.factor(IcesStatisticalRectangle) + as.factor(Month)

Table 6 shows that including a **random vessel effect** in the model results in a remarkable improvement in terms of AIC compared with no random vessel effect (cfr. models including "mixed" in their name in Table 6).

Regarding the **stochastic component** of the model, the models with a Gamma distribution performed better in terms of AIC than similar models with a negative binomial distribution (*negbin2:* quadratic increase between variance and mean) when a **variable dispersion** model is included (cfr. models including "variable" in their name in Table 6). In contrast, when the dispersion model is constant (cfr. models including "constant" in their name in Table 6), the models with a negative binomial distribution perform slightly better than similar models with a Gamma distribution in terms of AIC.

Table 6. Difference in AIC and degrees of freedom of the various generalized linear (mixed) models fitted to the LPUE data. The model in bold is kept to calculate the index. NAs in the ΔAIC column indicate that the model did not converge. The model names are specified corresponding to the indexes provided in Table 4 (cfr. Column "Explanatory formulas" in Table 4). E.g. Gamma_4_mixed_variable_B refers to a Gamma error distribution, with fixed effect formula (4), mixed indicates that a random effect is included, variable indicates that a variable dispersion model is included and the letter (e.g. (B)) refers to the dispersion formula.

	ΔAIC	No of estimated coefficients
Gamma_4_mixed_variable_B	0.0	70
Gamma_4_mixed_variable_A	87.6	59
negbin2_4_mixed_variable_C	190.0	59
Gamma_3_mixed_variable_B	196.0	59
Gamma_4_variable_B	204.2	69
negbin2_4_variable_B	253.6	69
negbin2_4_mixed_variable_D	265.9	59
Gamma_4_variable_A	268.8	58
Gamma_2_mixed_variable_B	290.1	59
negbin1_3_mixed_variable_B	298.4	59
negbin2_2_mixed_variable_B	335.2	59
negbin2_4_mixed_constant	355.8	37
negbin1_4_variable_A	358.1	58
Gamma_4_mixed_constant	*370.1*	*37*
negbin1_2_mixed_variable_B	371.5	59
Gamma_3_variable_B	393.2	58
negbin2_3_variable_B	463.8	58
negbin1_3_variable_B	464.2	58
negbin1_4_mixed_constant	478.1	37
negbin2_2_mixed_constant	519.4	26
Gamma_2_mixed_constant	525.6	26
Gamma_2_variable_B	534.6	58
negbin2_4_constant	544.3	36
Gamma_4_constant	558.2	36
negbin2_2_variable_B	584.5	58
Gamma_1_mixed_variable_B	588.8	48

	ΔAIC	No of estimated coefficients
negbin1_2_mixed_constant	589.5	26
negbin1_2_variable_B	592.0	58
negbin1_4_constant	617.2	36
negbin2_1_mixed_variable_B	640.0	48
negbin1_1_mixed_variable_B	678.8	48
negbin2_2_constant	742.9	25
Gamma_2_constant	747.7	25
negbin1_2_constant	762.5	25
negbin2_3_mixed_constant	813.8	26
Gamma_1_variable_B	817.2	47
Gamma_1_mixed_constant	845.8	26
negbin2_1_variable_B	870.5	47
negbin1_1_variable_B	876.5	47
negbin1_3_mixed_constant	948.4	26
negbin2_3_constant	985.4	25
Gamma_3_constant	1004.5	25
negbin2_1_mixed_constant	1027.9	15
Gamma_1_mixed_constant	1048.1	15
negbin1_3_constant	1089.5	25
negbin1_1_mixed_constant	1106.9	15
negbin1_3_constant	1225.8	14
negbin1_1_mixed_constant	1233.3	14
negbin2_1_constant	1265.5	14
negbin1_4_variable_B	NA	69
negbin2_4_variable_A	NA	58
negbin1_4_mixed_variable_B	NA	70
negbin1_4_mixed_variable_A	NA	59
negbin2_4_mixed_variable_B	NA	70

Comparison of GLMM with constant and variable dispersion: model diagnostics

In the following, we discuss the mixed models (with all fixed effects, *i.e.* explanatory formula 4 in Table 4) with a *constant* Gamma dispersion model and a *variable* Gamma dispersion model that includes month and ICES statistical rectangle according to the following formula:

$$dispersion\sim \lambda_0 + \lambda_{1_m} x\ month_m + \lambda_{2_r} x\ rectangle_r$$

The coefficient of λ_0 represents the intercept and includes the first levels of the categorical variables *month* and *ICES statistical rectangle* so that λ_{1_m} and λ_{2_r}represent the change of the other levels of the month/ ICES statistical rectangle effect with respect to the intercept.

In terms of AIC score, the model with variable dispersion (AIC = 17 952; Gamma_4_mixed_variable_A in Table 6) performed better (ΔAIC 283) than the model with constant dispersion (AIC = 18 234; Gamma_4_mixed_constant_A in Table 6). The goodness-of-fit of both models was evaluated through visual inspection of the diagnostic plots of the residuals (Figure 16).

Inspecting the diagnostics of the residuals corroborates the AIC score. Due to the hierarchical structure of the model, a simulation study was performed in which 1000 datasets were drawn from the fitted models (Gelman and Hill, 2006; Hartig, 2018). Subsequently, residuals were calculated and compared with the observed residuals. Both QQ plots of the residuals illustrate that none of the models are exactly mimicking the data generation process[2] (left panels Figure 16). However, a remarkable gain is achieved by including a variable dispersion term in the model. The predicted versus observed scaled residuals are characterized by horizontal lines (quantile regressions) indicating that most important mechanisms are included in the model (right panels Figure 16). Again, the model with variable dispersion parameter shows less deviation from the expected quantile regression lines indicating a better fit to the data. The improvement is mainly found in the lower quantile of the residuals plot.

[2] IF THE MODEL IS EXACTLY MIMICKING THE DATA GENERATION PROCESS, THE OBSERVED DATA CAN BE THOUGHT OF AS A RANDOM DRAW FROM THE FITTED MODEL AND FIT THE DIAGONAL THROUGH THE ORIGIN.

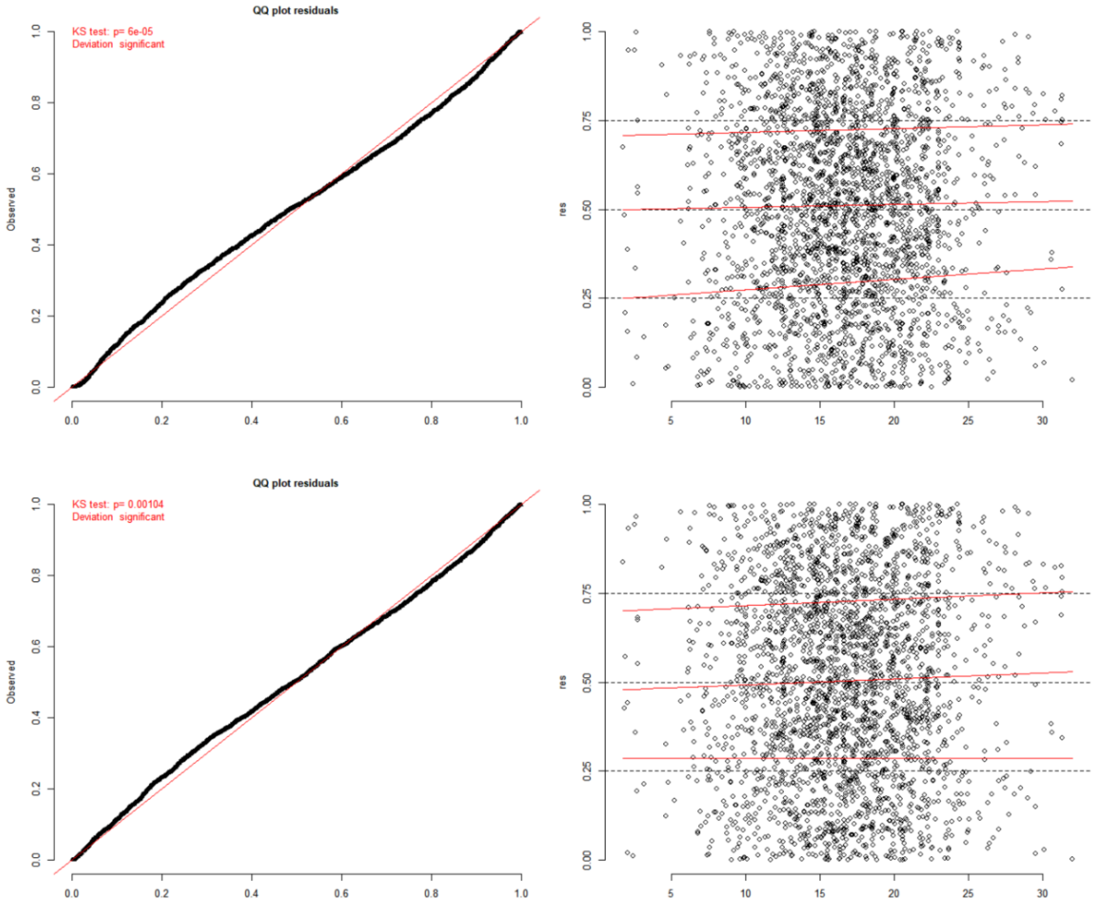

Figure 16. Residual plots (QQ plots and quantile regression of predicted vs standardized residuals) of the model with constant dispersion factor (upper panels) and with variable dispersion (lower panels).

To check if the model with variable dispersion parameter was not overfitting the data (shrunk towards outliers in the data), boxplots were made in which the residuals were displayed by year, month and ICES statistical rectangle (Figure 17, Figure 18 and Figure 19). Visual inspection indicates that the model with variable disperion factor is not affected by potential outliers in the data.

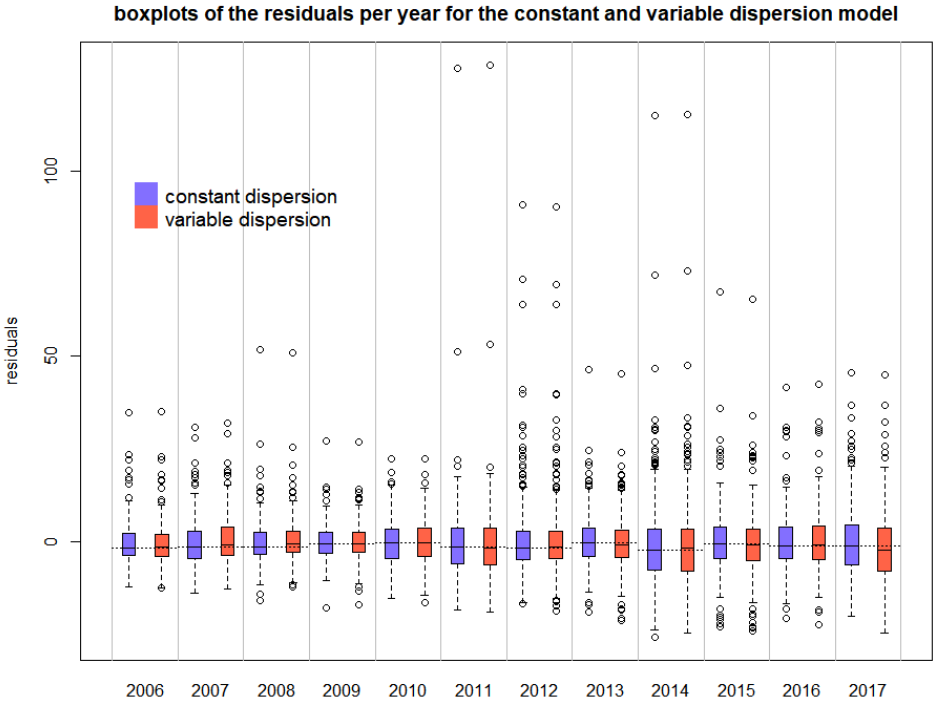

Figure 17. Boxplot of the residuals of the models with constant and variable dispersion parameter by year.

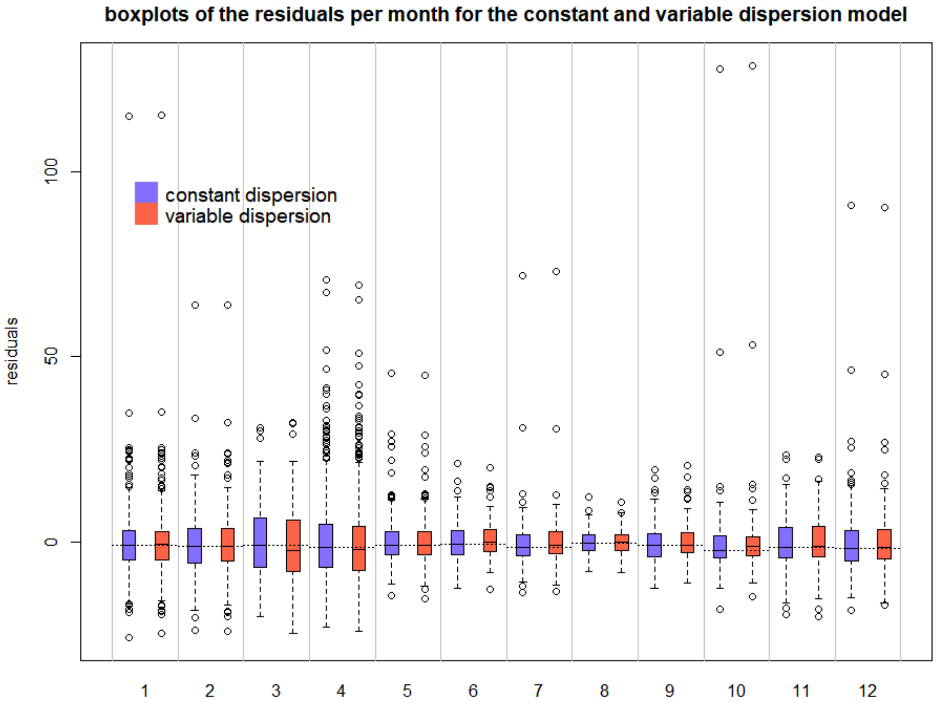

Figure 18. Boxplot of the residuals of the models with constant and variable dispersion parameter by month.

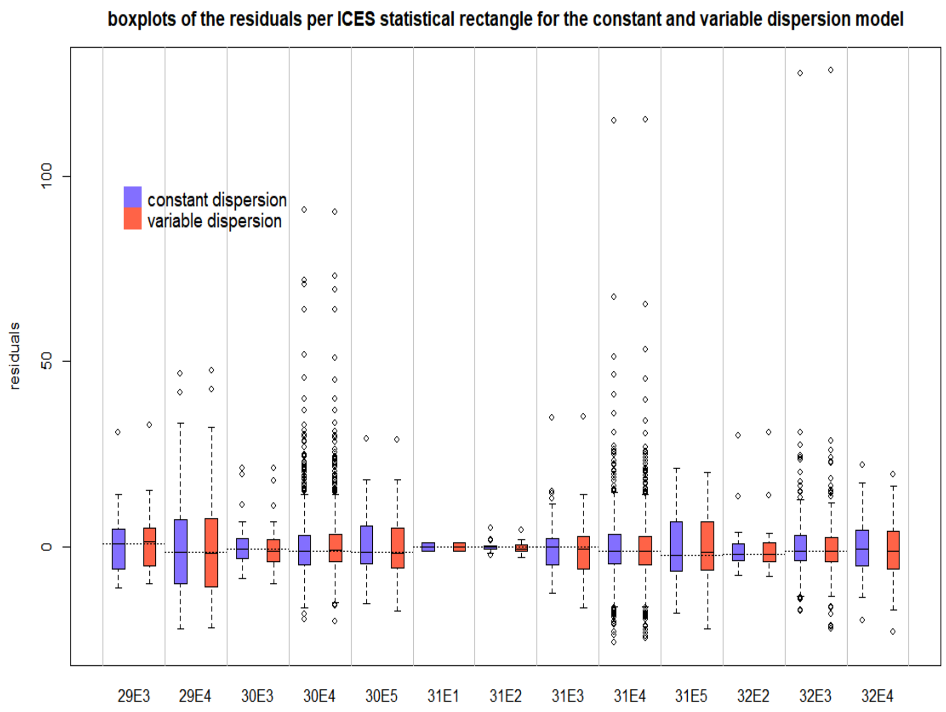

Figure 19. Boxplot of the residuals of the models with constant and variable dispersion parameter by ICES statistical rectangle.

In terms of estimated coefficients of the fixed effects, both models are rather similar (Table 7). However, the standard errors of the model with variable dispersion are slightly lower for the temporal effects (year and month) (see also Figure 20), but slightly higher for the spatial effects (ICES statistical rectangle). This can be regarded as an improvement with respect to the veracity of the data: the values of the year and month effects are exactly known, whereas reporting of the ICES statistical rectangle is not always accurately reflecting fishing activity since fishers only have to report one ICES statistical rectangle per day, whereas fishing may have occurred in multiple ICES statistical rectangles.

Table 7. Estimated coefficients, standard error, z value and p value of the fixed effects of both models (with constant and variable dispersion factor). Significant effects at the 5% threshold are indicated in bold.

	Constant dispersion model				Variable dispersion model			
	Estimate	Std. Error	z value	Pr(>|z|)	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.43	1.04	-0.41	0.68	-0.13	1.00	-0.13	0.90
2007	-0.04	0.06	-0.64	0.52	-0.09	0.05	-1.87	0.06
2008	-0.06	0.06	-1.06	0.29	**-0.11**	**0.05**	**-2.10**	**0.04**
2009	**-0.18**	**0.06**	**-3.06**	**0.00**	**-0.18**	**0.05**	**-3.53**	**0.00**
2010	0.05	0.06	0.85	0.39	0.01	0.05	0.19	0.85
2011	**0.18**	**0.05**	**3.42**	**0.00**	**0.16**	**0.05**	**3.30**	**0.00**
2012	**0.19**	**0.05**	**3.81**	**0.00**	**0.15**	**0.05**	**3.19**	**0.00**
2013	0.01	0.05	0.28	0.78	0.01	0.05	0.31	0.75
2014	**0.29**	**0.06**	**5.19**	**0.00**	**0.23**	**0.05**	**4.61**	**0.00**
2015	**0.20**	**0.05**	**3.60**	**0.00**	**0.17**	**0.05**	**3.45**	**0.00**
2016	**0.18**	**0.06**	**3.13**	**0.00**	**0.13**	**0.05**	**2.52**	**0.01**
2017	**0.23**	**0.06**	**3.97**	**0.00**	**0.25**	**0.06**	**4.56**	**0.00**
log(kW)	**0.43**	**0.15**	**2.81**	**0.00**	**0.37**	**0.15**	**2.54**	**0.01**
February	-0.02	0.06	-0.32	0.75	0.01	0.06	0.10	0.92
March	0.02	0.07	0.28	0.78	0.07	0.07	0.96	0.34
April	0.06	0.03	1.84	0.07	**0.11**	**0.03**	**3.88**	**0.00**
May	**-0.22**	**0.04**	**-5.29**	**0.00**	**-0.21**	**0.04**	**-5.51**	**0.00**
June	**-0.18**	**0.05**	**-3.34**	**0.00**	**-0.23**	**0.04**	**-5.25**	**0.00**
July	**-0.21**	**0.05**	**-4.48**	**0.00**	**-0.24**	**0.04**	**-5.69**	**0.00**
August	**-0.39**	**0.05**	**-7.84**	**0.00**	**-0.43**	**0.03**	**-12.74**	**0.00**
September	**-0.25**	**0.06**	**-4.49**	**0.00**	**-0.32**	**0.05**	**-6.84**	**0.00**
October	0.00	0.06	0.01	0.99	-0.07	0.06	-1.16	0.24
November	0.08	0.04	1.78	0.08	0.02	0.04	0.59	0.55
December	**0.11**	**0.04**	**2.79**	**0.01**	**0.08**	**0.03**	**2.48**	**0.01**
29E4	**0.57**	**0.11**	**5.21**	**0.00**	**0.65**	**0.16**	**4.03**	**0.00**
30E3	**-0.49**	**0.11**	**-4.33**	**0.00**	-0.31	0.17	-1.87	0.06
30E4	**0.32**	**0.11**	**3.02**	**0.00**	**0.40**	**0.16**	**2.48**	**0.01**

	Constant dispersion model				Variable dispersion model			
30E5	**0.56**	**0.12**	**4.62**	**0.00**	**0.64**	**0.17**	**3.86**	**0.00**
31E2	**-1.80**	**0.16**	**-10.88**	**0.00**	**-1.76**	**0.23**	**-7.76**	**0.00**
31E3	**-0.27**	**0.13**	**-2.09**	**0.04**	-0.07	0.20	-0.34	0.74
31E4	**0.21**	**0.11**	**1.96**	**0.05**	**0.36**	**0.16**	**2.23**	**0.03**
31E5	**0.33**	**0.12**	**2.75**	**0.01**	**0.47**	**0.17**	**2.67**	**0.01**
32E2	**-0.84**	**0.17**	**-5.00**	**0.00**	**-0.72**	**0.28**	**-2.56**	**0.01**
32E3	-0.02	0.11	-0.17	0.86	0.16	0.16	0.98	0.33
32E4	0.14	0.12	1.16	0.25	**0.34**	**0.17**	**2.04**	**0.04**

Effect of the Trevose Box closure on lpue of the Belgian beam trawl fleet

Inspecting the estimated coefficients of the dispersion model (Table 8) shows that most of the significant (5% level) coefficients are related to the closure of the Trevose Box, month effects March and April, and the ICES statistical rectangles in and neighbouring the Trevose Box. Therefore, we suggest that the improvement of the model with variable dispersion parameter is related to the effect of the Trevose Box closure on the fishery.

Figure 18 and Figure 19 illustrate that most of the positive 'outliers' in the residuals are found in April and ICES statistical rectangles 30E4 and 31E4 which is strongly related with the re-opening of the fishery inside the Trevose Box (30E4, 31E4 and 32E3).

The southern ICES statistical rectangles of the Trevose Box are known to be important spawning areas of the Celtic Sea sole stock from February until April. We hypothesize that in absence of the fishery since 2006, the formation of spawning aggregations is enhanced. As a result, the stock is subjected to considerable changes in spatial distribution throughout the year, which affects the relationship between abundance and LPUE (due to temporal hyperstability). The improvement related to the inclusion of a variable dispersion model seems mainly driven by the closure of the Trevose Box (months: March, April, ICES statistical rectangles: 29E4; 30E4; 30E5) (Table 7). This suggests that the model with variable dispersion parameter accounts for the temporal changes in the fishery (temporal "race for fish" caused by high catch rates) related to the Trevose Box closure.

The significant effect of the month August in the variable dispersion model may be related to few observations found within this month, as well as a change in targeting behaviour during summer (Table 8). Including the year effect in the dispersion model caused a further improvement in terms of AIC (-82.7) with significant year effects in 2014, 2016 and 2017. However, due to the weak effect on the model and the absence of a clear explanation, we decided not to include this effect in the dispersion model.

Table 8. Estimated coefficients, standard error, z value and p value of the dispersion model (model with variable dispersion). Coefficients significant at the 5% level are indicated in bold.

	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	1.123	0.282	3.987	0.000
February	-0.354	0.168	-2.099	0.036
March	**-0.701**	**0.174**	**-4.039**	**0.000**
April	**-0.659**	**0.088**	**-7.510**	**0.000**
May	-0.183	0.118	-1.549	0.121
June	0.143	0.150	0.955	0.340
July	-0.146	0.131	-1.111	0.267
August	**0.812**	**0.146**	**5.562**	**0.000**
September	0.148	0.157	0.941	0.347
October	-0.198	0.161	-1.235	0.217
November	-0.049	0.125	-0.394	0.694
December	-0.053	0.112	-0.468	0.640
29E4	**0.787**	**0.296**	**2.662**	**0.008**
30E3	0.347	0.305	1.140	0.254
30E4	**1.033**	**0.275**	**3.750**	**0.000**
30E5	**1.401**	**0.331**	**4.229**	**0.000**
31E2	0.245	0.439	0.558	0.577
31E3	-0.398	0.339	-1.174	0.240
31E4	0.512	0.276	1.856	0.063
31E5	0.001	0.312	0.002	0.998
32E2	-0.506	0.424	-1.192	0.233
32E3	0.235	0.283	0.830	0.406
32E4	0.413	0.305	1.353	0.176

Finally, we compared the annual index of both models. Figure 20 shows the exponent of the estimated coefficients of the yearly fixed effects (intercept, and year fixed effects) of both models. To ease visual comparison, both indices were standardized so that they both start at 1. Both indices show a similar trend with (nearly) equal values in 2009 and 2013. In between these years, the model with variable dispersion parameter has a slightly lower index, except for the final year,

2017. The model with variable dispersion is slightly less erratic compared to the model with constant dispersion. Also in terms of width of the bounds of the 95% confidence intervals, the model with variable dispersion parameter performs slightly better.

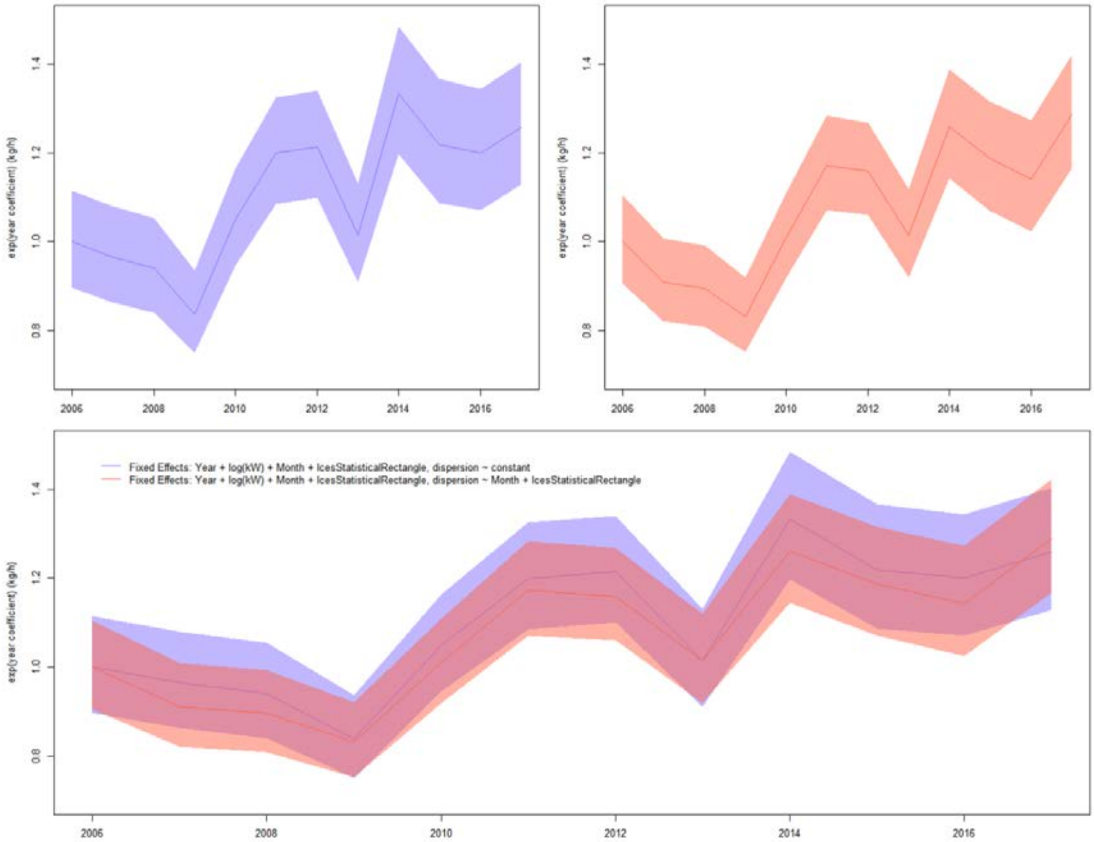

Figure 20. Annual index of both models (exponent of the yearly fixed effects). The shaded area represents the bounds of the 95% confidence interval. Blue constant dispersion model; orange: variable dispersion model.

Figure 21, Figure 22 and Figure 23 show the predicted landing rates of the **dispersion model** against the nominal (observed) landing rates. The model predicted lower catch rates for the higher catch rates (>40 kg/hour).

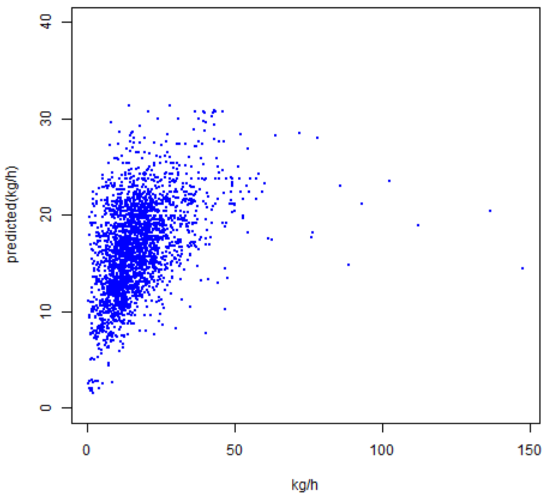

Figure 21. The predicted sole landing rates versus the nominal sole landing rates ((kg/h) per trip + ICES statistical rectangle). Note different scales on axes.

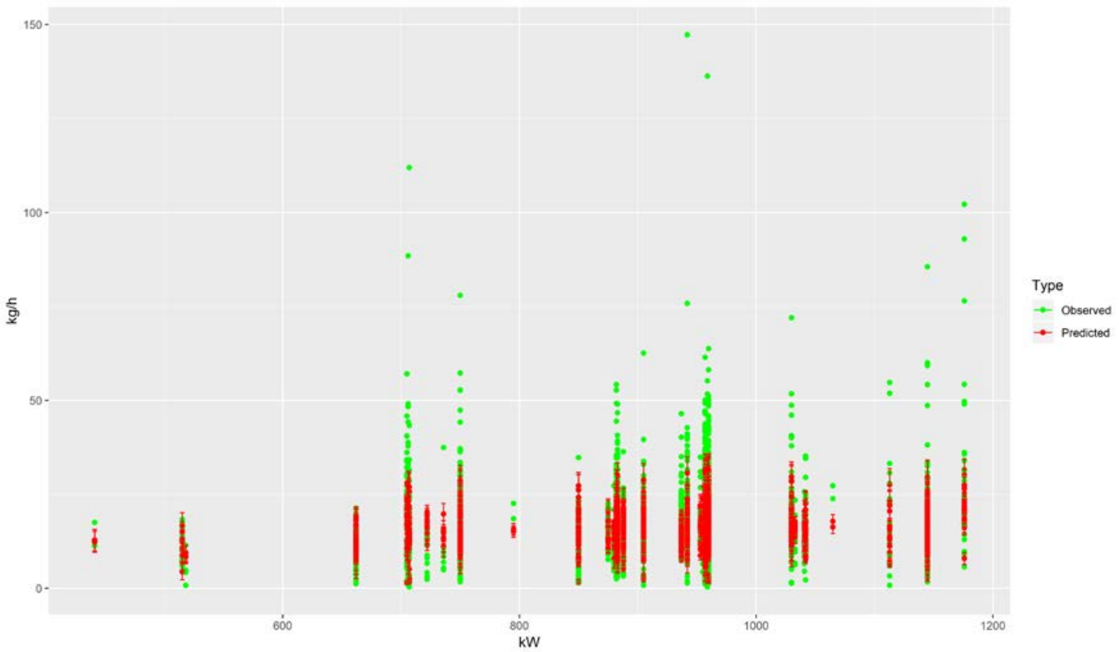

Figure 22. The predicted sole landings rates (red) versus the nominal sole landing rates (green) ((kg/h) per trip + ICES statistical rectangle).

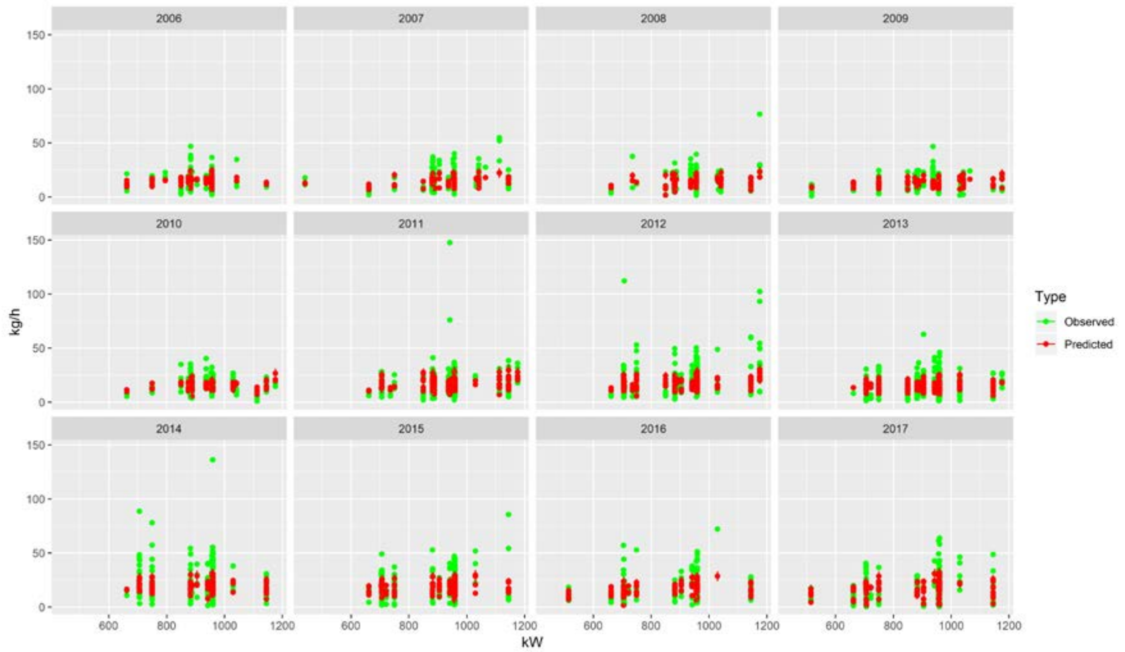

Figure 23. The predicted sole landing rates (red) versus the nominal sole landing rates (green) in 2006-2017 ((kg/h) per trip + ICES statistical rectangle).

Calculation of the tuning series

The exponent of the estimated coefficients of the year effect are used as the landing rate for the tuning series. Year does not interact with any other covariates and thus provides a standardised estimate of the LPUE trend across years.

To convert this landing rate per year to the annual sole age compositions (age 1 to 15 (plus group)) of the Belgian beam trawlers (TBB_DEF_70-99) active in the ICES divisions 27.7.f and 27.7.g, we standardised by the total weight landed by the pure trips of the large fleet segment per year. Therefore, we divided the total weight landed (by the large fleet segment, pure trips, Figure 24 column T) per year by the year coefficient standardised to 2006 (Figure 24 column AA). This results in column AC in Figure 24.

T	U	V	W	X	Y	Z	AA	AB	AC
for large fleetsegment pure trips			total fleet fishing for sole in 7FG			Year coefficient	Year coefft standardised to year 1		Effort (standardised)
Total weight (tonnes)	Total fishing hours		Total weight (tonnes)			x			Fleet total
226.6605432	16001		579.6336			0.879805213	1		226.6605432
226.0823552	15060		567.0546			0.80064226	0.910022181		248.4360929
208.0820976	14368		467.0148			0.78814432	0.895816833		232.2819688
201.417684	15672		512.868			0.73174393	0.831711291		242.1725979
301.4063624	18394		618.823			0.888384983	1.009751897		298.4954653
397.0270928	21923		779.77744			1.03142625	1.172334778		338.6635798
490.0809264	26825		786.3336			1.019781021	1.159098634		422.812099
473.3263912	29350		746.751			0.89242785	1.01434708		466.6315903
342.1963896	16086		666.183			1.108810423	1.260290807		271.5217691
418.8015312	20965		640.168			1.044013931	1.186642128		352.9299366
241.5355572	14096		525.63			1.004665436	1.14191803		211.5174214
224.3769168	13607		522.954			1.133428226	1.288271777		174.1689299

Figure 24. Calculation method for converting the estimated coefficients of the year effect by the model to actual indices.

The annual sole indices by age were obtained by:

1. correcting the age distribution of the large fleet segment all trips (pure + mixed) by the ratio of the total weight of the pure trips of the large fleet segment and the total weight of all trips of the large fleet segment (This ratio is obtained by dividing column T by column W in Figure 24).
2. These resulting numbers-at-age are then divided by the standardised total weight per year (column AC in Figure 24).

Table 9 shows the resulting tuning series for the Belgian commercial beam trawl fleet for the period 2006–2017.

Table 9. Belgian commercial beam trawl tuning series from 2006–2017.

BE-CBT3															
2006	2017														
1	1	0	1												
1	15														
1	0.0421	0.9961	1.7829	0.8362	0.5960	0.1611	0.1178	0.0836	0.0307	0.0129	0.0057	0.0027	0.0014	0.0007	0.0004
1	0.0249	0.4289	1.0361	0.8400	0.4924	0.2801	0.1508	0.1169	0.1007	0.0093	0.0097	0.0012	0.0065	0.0053	0.0000
1	0.0398	0.3167	0.5503	0.6659	0.7603	0.3263	0.1929	0.0772	0.1025	0.0839	0.0246	0.0011	0.0000	0.0000	0.0000
1	0.0000	0.8001	0.5408	0.4559	0.3468	0.2917	0.1915	0.0887	0.0391	0.0525	0.0731	0.0190	0.0055	0.0000	0.0175
1	0.0087	0.4142	1.7526	0.9616	0.4009	0.2765	0.1665	0.1320	0.0549	0.0463	0.0146	0.0117	0.0233	0.0000	0.0061
1	0.0110	0.1594	1.2939	1.7616	0.4637	0.3016	0.2212	0.1443	0.0634	0.1057	0.0245	0.0295	0.0110	0.0000	0.0179
1	0.0001	0.1961	0.2567	1.1473	1.5100	0.4042	0.2120	0.1351	0.0881	0.0544	0.0647	0.0216	0.0317	0.0389	0.0245
1	0.0000	0.5544	1.0665	0.3549	0.8718	0.6721	0.2167	0.0497	0.0540	0.0221	0.0142	0.0155	0.0103	0.0167	0.0224
1	0.0081	0.2058	0.9090	0.9700	0.2774	0.5041	0.5013	0.1238	0.0906	0.0418	0.0328	0.0353	0.0235	0.0243	0.0611
1	0.0000	0.1350	1.3350	1.3172	0.5352	0.1660	0.2846	0.1472	0.1075	0.0436	0.0492	0.0174	0.0204	0.0134	0.0150
1	0.0401	0.9883	0.6915	0.9605	1.0386	0.3252	0.0531	0.1720	0.1137	0.0056	0.0121	0.0083	0.0068	0.0028	0.0150
1	0.0000	0.5061	2.0149	0.8321	0.5650	0.6229	0.1977	0.0456	0.0793	0.0707	0.0115	0.0016	0.0085	0.0096	0.0267

Conclusion

The sales notes and logbooks of the Belgian beam trawl fleet were used to calculate the sole landing rates in the Celtic Sea. To account for misreporting, only the data from vessels with HP >221 Kw and only those fishing trips in which fishing activity was limited to the Celtic Sea were retained for statistical analysis.

The GLMM model with all explanatory variables (year, month, ICES statistical rectangle and log-linear effect of a vessel's engine power), a random vessel effect, a variable dispersion parameter governed by monthly, and spatial effects, a logarithmic link function between the linear predictors and response variable, and a Gamma distributed error term showed the best model fit.

The exponent of the estimated coefficients of the year effect are used as landing rate for the tuning series. To convert this landing rate per year to the annual sole age compositions (age 1 to 15 (plus group)) of the Belgian beam trawlers (TBB_DEF_70-99) active in the ICES divisions 27.7.f and 27.7.g, we standardised by the total weight landed by the pure trips of the large fleet segment per year.

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Annex 3: Eqsim R code

```
##########################################
#
# Calculating Reference points for SOL 7fg
# IBP 2019 (jan 2019)
#
# script via Jan Jaap Poos and Helen Dobby
##########################################
# open R versie 3.3.1
# install.packages("msy")
library(msy);
load(file='xsastock.Rdata')
source("eqsim functions.R")
#####################
name(xsa.stock) <- "sole"
FIT1 <- eqsr_fit(xsa.stock,
          nsamp = 1e3,
          models = c("Ricker", "Segreg", "Bevholt"),  remove.years=ac(c(2017)))
eqsr_plot(FIT1,n=1e3)
# we choose type 5
# determine Blim = Bloss
Bloss <- min(ssb(xsa.stock))
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(xsa.stock, nsamp = 1e3, models = "SegregBlim", remove.years=ac(c(2017)))
FIT2$sr.det # gives b = 1
#print(Blim <-  FIT2b[["sr.det"]][,"b"])
eqsr_plot(FIT2,n=1e3)
#simulation
SIM101 <- eqsim_run(FIT2,  bio.years = c(2008, 2017), bio.const = FALSE,
          sel.years = c(2008, 2017), sel.const = FALSE,
          Fcv=0, Fphi=0,
          Btrigger = 0,Blim=Blim,Bpa=NA,
          Fscan = seq(0,1.2,len=61),verbose=FALSE) #in 61 steps from F=0 to F=1.2
eqsim_plot(SIM101,catch="FALSE")
Coby.fit(SIM101,outfile='sole no Btrigger Blim set to find Flim Fcv=0 and Fphi=0')
# from this table get F50, catF
print(Flim <- SIM101$Refs2[1,3])
print(Fpa <- Flim/1.4)
###################### Calculate Fmsy
Segreg_bounded <- function(ab, ssb) {
 ab$b <- ab$b + Bloss
 Segreg (ab, ssb)
}
#fit
FIT3 <- eqsr_fit(xsa.stock,
         nsamp = 1e3,
         models = c("Segreg_bounded", "Ricker"), remove.years=ac(c(2017)))
eqsr_plot(FIT3,n=1e3)
SIM1a <- eqsim_run(FIT3,  bio.years = c(2008,2017), bio.const = FALSE,
          sel.years = c(2008,2017), 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
eqsim_plot(SIM1a,catch="FALSE")
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$Refs2[1,1])
#EVALUATE
# Gezien stock nog niet 5 of meer jaar op Fmsy wordt gevist, wordt MSYBtrigger op Bpa gezet.
# Om Advice rule nu te evalueren dienen we run te doen met bekomen Btrigger waarde ingevuld:
SIM2 <- eqsim_run(FIT3,  bio.years = c(2008,2017), bio.const = FALSE,
              sel.years = c(2008,2017), sel.const = FALSE,
              Fcv=0.212, Fphi=0.423,  # these are defauts, taken from WKMSYREF4, as used in Saithe assessments
              Btrigger = Bpa,Blim=Blim,Bpa=Bpa,Fscan = seq(0,1.0,len=51),verbose=FALSE, extreme.trim=c(0.05,0.95))
eqsim_plot(SIM2,catch="FALSE")
Coby.fit(SIM2,outfile='sol sim2')
print(F05 <- SIM2$Refs2[1,1])
#SIM1$rbp
##########
#  Sensitivity to year range in selectivity
out <-NULL
# 2008–2017 was the default year range for the Fmsy calculation
# the eqsim resamples fishery selectivity from these years (default is usually last 10 years)
# You use the same year range for the bio data - which includes mean weights, M, etc
sel.years <-c(2008,2017)
for(y in 1990:2008){
  cat(y,'\n')
# What I am doing here is choosing different blocks of years (each 10 years long) from which to resample the fishery selectivity.
# The first block (which is labelled '1990' in the output data) has a selectivity data year range from 1990 to 1999, the
# next 1991 to 2000 and so on, until the last on is 2008 to 2017 (which is the same as your base run)
  sel.years[1] <- y
  sel.years[2] <-y+9
  #  setup$sel.years <- c(y-4,y)
  sim <- eqsim_run(FIT3, bio.years = c(2008,2017), 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)
}#################################
```