BENCHMARK WORKSHOP ON CELTIC SEA STOCKS (WKCELTIC)

VOLUME 2 | ISSUE 97

ICES SCIENTIFIC REPORTS

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ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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ISSN number: 2618-1371 I

// ICES Scientific Reports

Volume 2 | Issue 97

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Recommended format for purpose of citation:

ICES. 2020. Benchmark Workshop on Celtic Sea Stocks (WKCELTIC).
ICES Scientific Reports. 2:97. 166 pp. http://doi.org/10.17895/ices.pub.5983

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i Executive summary

A Benchmark Workshop on Celtic Sea Stocks (WKCELTIC) to evaluate the appropriateness of data and assessment parameterization of three stocks: Cod in divisions 7.e–k (cod.27.7e–k), Whiting in divisions 7.b–c and 7.e–k (whg.27.7b–ce–k) and Haddock in divisions 7.b–k (had.27.7b–k).

The procedure to calculate catch in number and weight-at-age were revised in a data-compilation workshop. The approach was standardized and streamlined across countries and stocks as much as possible using a common R-script, ensuring transparency and reproducibility. Natural mortality and maturity-at-age were updated.

For all stocks survey indices were calculated based on the VAST software in attempt to address issues of missing survey coverage in some years. As before the indices were based on the IGFS-WIBTS-Q4 and EVHOE-WIBTS-Q4 surveys. This resulted in the new indices having a higher internal consistencies among stocks compared with the conventional calculation that had been in use previously.

The assessment framework for all stocks was based on SAM (https://www.stockassessment.org) because of availability, reproducibility, statistical handling of discard estimates where needed and familiarity of the external reviewers with the method and software. The approach consisted of gradual introduction of new data to identify the influence on stock dynamics and configuration of the model setup based on diagnostic comparisons. The reference points were updated based on the final results using ICES standard procedures. Forecast is produced internally within SAM to ensure consistency.

ii Expert group information

Expert group name	**Benchmark Workshop on Celtic Sea Stocks (WKCELTIC)**
Expert group cycle	Annual
Year cycle started	2019
Reporting year in cycle	1/1
Chair	Einar Hjörleifsson, Iceland
Meeting venue and dates	6–8 February 2019, Galway, Ireland, 19 participants for first data evaluation meeting
	1–3 October 2019, Copenhagen, Denmark, 17 participants for second data evaluation meeting
	10–14 February 2020, Copenhagen, Denmark, 11 participants for Benchmark meeting

1 Introduction

The workshop was done in two phases. A Data Evaluation Workshop (ICES Chairs Jonathan White, Ireland, and Ana Ribeiro Santos, UK) was held in Galway on 6–8 February 2019 and Copenhagen on 1–3 October 2019 and a Benchmark meeting (ICES Chair Einar Hjörleifsson, Iceland and external expert Casper Berg, Denmark) in Copenhagen on 10–14 February 2020. This was followed up by two WebEx meetings on 8th July 2020 and 11th September 2020 (additional external expert Simon Fisher, UK).

The commercial catch, survey data and updates on natural mortality and maturity were made available at the February benchmark meeting. These were then used in exploratory runs and analysis, both using the previous assessment framework and SAM, the decision of inclusion of data sources and model setup in SAM being based on those data. During the end of the February meeting an error was discovered in the compilation of the commercial catches of one fleet, resulting in postponement in finalizing the task. Following intersessional work by the data evaluation team the final model configurations of the February meeting were re-evaluated based on the corrected commercial data during two WebEx meetings. An additional minor error was discovered in whiting stock after the benchmark meeting and these have been reviewed and taken into account in this report.

In the body of this report, the reviewers' report is presented first (Section 2) followed by sections for each stock (3–5), providing a summary of the analysis performed and the conclusions reached. Working documents referred to in the text are included in Annex 2. All document related to the work covered are retained on the WKCELTIC ICES SharePoint.

2 Reviewers' reports

2.1 Review 1

The benchmark process was halted at a late stage because of issues with the French commercial data compilation. These issues were not minor, and the updated data led to substantial changes in the assessments.

Many analyses and decisions made during the benchmark were thus made using a "wrong" dataset, and there was simply not time re-evaluate all these decisions again after the data issue had been resolved.

While most decisions probably would have been the same, and the new assessment models constitute a clear improvement compared to the previous, this situation was obviously not ideal.

The final decisions regarding the assessment such as determination of reference points, had to be made several months after the benchmark meeting, at which point the reviewer had trouble remembering all the details of the stocks involved.

This was a very unfortunate situation, and ICES should try to ensure that similar events do not happen in the future.

2.1.1 Commercial catch

All stocks are now raising catches based on a unified approach, a shared R markdown document.

This is a good step towards more transparent handling of the commercial catches and ensures that the results are reproducible.

The cod assessment utilized SAMs ability to handle missing data to deal with missing discard information in the past.

Based on the selectivity in the year with observed discards and the observed cohort strengths, the discarded age groups are automatically "backcalculated" by SAM and the increased uncertainty is accounted for.

This is a more sound approach than the usual way of filling in discards in the data directly prior to running the model, because this does not account for the increased uncertainty by the fill-in procedure.

This method should be considered for other assessments with similar issues with past discards.

2.1.2 Commercial tuning indices

An updated French commercial index was presented, which addressed issues concerning a change in targeting behaviour of the fleet.

In general commercial tuning indices should be used with care for several reasons.

One problem is that it is not statistically independent of the catch-at-age.

This problem was mitigated by using them as biomass indices rather than age based CPUEs.

When included in the assessment models, the commercial indices tended to give more stable assessments with less retrospective patterns.

For this reason it was decided to include them.

However it is concerning that the index only covers the French part of the fleet, which is operating in other areas than the Irish.

This can lead to bias in the index if there are changes in the stock and/or the commercial fleet behaviour.

For this reason it must be recommended to develop combined French-Irish commercial CPUE indices in the future.

2.1.3 Survey indices

All the assessments introduced a new way of calculating the survey indices.

The design based estimators were replaced with a modelling approach based on the VAST software.

The modelling approach can, unlike the design based, deal with missing data and changes in survey design. This was a problem in 2017 and 2019 for example, where the French vessel covered less area than usual. The switch to a model-based approach is therefore appropriate, and the new indices also showed higher degrees of internal consistency.

However, complex models like VAST are harder to operate and understand, and issues such as model convergence may arise.

The request by the reviewers for a retrospective analysis during the benchmark actually revealed that the initially proposed model was not stable, and the model was revised to overcome this issue.

It must therefore be recommended always to perform retrospective analyses of modelled survey indices.

2.1.4 Assessments

Prior to the benchmark cod and whiting were using the XSA method for the assessment, while haddock was using the ASAP model.

XSA is fast and relatively simple, but it lacks the ability to quantify uncertainties and commercial catches are assumed to be without error, which gives less stable assessments. ASAP can quantify uncertainties and is a more sound approach than XSA, but the SAM model has some useful additional features such as time-varying selectivity, and no ASAP experts were present at the meeting.

The original assessments all had retrospective patterns, but these patterns were reduced to acceptable levels in the new SAM runs, although the cod assessment still showed some patterns.

In some peels, the fishing mortality process is estimated to be almost constant, while in others there is some variation over time.

The former simply indicates that there is too much noise in the data to reliably detect changes in F within the confidence band.

However, the overall conclusion from the assessment namely that the stock is at its lowest SSB and that F has been way too high historically appears robust and sound.

2.1.5 Reference points

The determination of reference points using the ICES guidelines did not go as smoothly as one could have hoped. While this is inherently difficult for many stocks for various reasons, the ICES guidelines are difficult to follow because they are quite complex, while they in many places leaves a lot of room for subjective decisions, e.g. with respect to various tuning parameters.

It should be considered to simplify this procedure. Integrating reference point calculations within the assessment model would be preferable, but alternatively developing a common well commented code script implementing the ICES guidelines that only required a few inputs from the user could be useful.

2.1.6 Other considerations

Much work was put into configuring the SAM assessments during the benchmark. This was time well spent, considering the achieved reduction in retrospective patterns for all the stocks. However, other potential important aspects of the assessments were not explored in as much detail.

In particular, spatial considerations were lacking. Maps of survey and commercial catches by age and year and perhaps season for the stock area as well as the surrounding areas should be presented and compared. Such maps could for instance be used to assess the appropriateness of using separate French commercial CPUEs, and to reveal if migration in or out of the assessment area is likely. The decline of cod in the assessment area could partly be due to migration of cod to colder waters as it has been observed for North Sea cod.

This could be a possible reason for the observed retrospective patterns in the cod assessment.

2.2 Review 2

The WKCELTIC 2020 benchmark workshop was set up to agree on new stock assessment models for three Celtic Sea gadoid stocks:

- Cod (*Gadus morhua*) in divisions 7.e–k (eastern English Channel and southern Celtic Seas);
- Whiting (*Merlangius merlangus*) in divisions 7.b–c and 7.e–k (southern Celtic Seas and eastern English Channel);
- Haddock (*Melanogrammus aeglefinus*) in divisions 7.b–k (southern Celtic Seas and English Channel).

The process started in 2019 with data evaluation workshops and proceeded into 2020 to parameterise new stock assessments.

The request to review this benchmark was sent late and after the start of the process. Therefore, this review focuses on the stock assessment model formulation and parameterisation and does not include a review of the processing of underlying data.

The benchmark process in 2020 suffered from the impact of the Covid-19 pandemic, and meetings were held remotely via WebEx spread over the year. The work and effort of the benchmark participants, in particular the stock coordinators, in such challenging times, is appreciated. However, the benchmark process lacked vital discussions and interactions which might have occurred in physical meetings. Results of analyses were mainly presented with draft report sections on the benchmarks SharePoint site.

Providing these analyses in the form of presentations during remote meetings could have sparked additional discussion and participation. Due to a lack of specific deadlines or adherence to them, the benchmark might have been stretched longer than necessary.

2.2.1 Data

The data going into the stock assessments for the three stocks were revised. International catch data were extracted from the ICES InterCatch platform and post-processed in a similar manner with R-Markdown documents for all stocks.

For the stock assessment prior to this benchmark, natural mortality for the three stocks had already been calculated with the formulation of Lorenzen (1996) and was therefore based on life-history considerations. The updates to natural mortality-at-age during this benchmark were minor and did not influence the outcome of the assessments. The choice of using Lorenzen's (1996) formulation in favour of, e.g. Gislason (2010), is arbitrary, but similarly appropriate due to the absence of empirical stock-specific natural mortality data.

Maturity-at-age was updated for all three stocks. Previously, maturity was knife-edged for haddock and whiting. The changes for haddock were negligible, and largest for whiting, where maturity-at-age 1 (second age in the assessment after age 0) was increased from 0 to 61%.

Stock assessment models, reference points and forecast procedure

Previously, stock assessments for cod and whiting were conducted in XSA and for haddock in ASAP. The approach to set up new models for all stocks followed a similar approach. The approach consisted of gradually replacing old data with new data (e.g. survey or catch data, biological data, etc.) and therefore allowed the identification of which data caused changes in the stock perception.

The stock assessments models for all three stocks were moved in the State-Space Assessment Model (SAM, Nielsen and Berg, 2014). The assessments were run online on https://www.stockassessment.org, and this allowed easy access and review of the models, including standardised diagnostics.

Comments, issues and additional suggestions for analyses raised by the reviewers and participants were already addressed during the benchmark and are therefore not included in detail here.

The stock assessment models for haddock and whiting showed good model fits, and results are similar to previous estimates.

The final cod stock assessment showed worrying retrospective patterns and Mohn's rho values are at the upper limits recommended within ICES. Furthermore, the stock is in a poor condition with a very low and declining SSB. This assessment is based on sparse data and therefore, might not be able to model current stock dynamics accurately.

New reference points were estimated based on the results of the new SAM stock assessments using EqSim and following ICES guidelines (ICES, 2017).

The workshop decided to use SAM's internal stochastic short-term forecasting functionality. This approach is logical and coherent with the stock assessment methodology, propagating uncertainty and model structure of the stock assessment into the forecast.

2.2.2 Documentation

The trial and final new stock assessments are documented for the three stocks in their respective report sections. The benchmark process and analyses are detailed and well documented for haddock and whiting. The report section for cod is in parts difficult to follow, however, due to standardised approaches between all three stocks, inferences can be made from the other stocks and the report section improved during the benchmark after comments from the review.

The stock annex for whiting has been updated to reflect the changes in the stock assessment and forecast procedures. The stock annexes for haddock and cod were not provided for review.

2.2.3 Recommendations for the future

The inclusion of multispecies consideration for estimates of natural mortality could be considered in the future when such models become available (e.g. Spence *et al.,* 2020).

The stock assessments and forecast were available from an online platform (stockassessment.org). In the future, it might be desirable to apply the same principle to all analyses of the benchmark process (data processing, reference point calculations, etc.). One obvious choice would be the ICES transparent assessment framework (TAF) so that the analyses between stocks can be more easily compared and changes within the analysis of a stock can be tracked by version control.

It would be good to present the results of the final stock assessment in a way that is consistent with the presentation of the results in an ICES advice sheet and a comparison with the previous results used for the advice. In particular, the visualisation of stock metrics relative to reference points should be included. Such a presentation was only prepared after the benchmark for the working group responsible for drafting the advice (WGCSE).

2.2.4 Conclusion

It is good to see that the stock assessments and forecasts for all three Celtic Sea gadoid stocks were run on the same platform (stockassessment.org), which ensured transparency, reproducibility and facilitated the review. Stock assessments, reference point estimations and forecasts could be reproduced based on the material provided. The decision to implement a stochastic stock assessment model (SAM) and forecast can be regarded as a positive step forward. This also allows the easier application of management strategy evaluation in the future because the same model for the three main Celtic Sea gadoid stocks is used and uncertainty estimates required for realistic simulation are already provided from the stock assessment model. The use of a stochastic forecast might make mixed-fisheries consideration of ICES WGMIXFISH more challenging; however, the benchmark decided not to simplify the forecast purely for the sake of mixed-fisheries work, which could have otherwise impaired the progress of the single-species approach.

The stock assessments for haddock and whiting showed good model fits and appear appropriate for advice purposes.

The new SAM stock assessment model for cod estimates the stock to be in a poor condition, with SSB well below all biomass reference points. This situation is likely to lead to a very low or zero catch advice and is unlikely to change in the near future. Providing non-zero catch advice in the short term based on the suggested forecast procedure of the benchmark might be possible when ICES guidelines are blindly followed but are likely caused by overestimating productivity of the stock. The stock assessment can be considered the best available science (when using a data-rich

stock assessment); however, the low stock size, low catches and the corresponding limited availability of data and samples, in combination with the considerable retrospective uncertainty, cast doubts for the appropriateness of the model for providing catch advice different from zero. Should the stock start to recover and exceed biomass limit reference points, effectively leading to non-zero catch advice, the stock assessment model might have to be revisited to ensure this does not lead to the application of a model on autopilot which has been conditioned on the current situation without considering new developments.

2.2.5 References

Gislason, H., Daan, N., Rice, J. C., and Pope, J. G. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries, 11: 149–158.

ICES. 2017. ICES fisheries management reference points for category 1 and 2 stocks. *In* ICES Advice Technical Guidelines. ICES Advice 2017, 19 pp.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology, 49: 627–642.

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

Spence, A., Thorpe, R. B., Blackwell P. G., Scott, F., Southwell, R. and Blanchard J. L. 2020. Quantifying uncertainty and dynamical changes in multi-species fishing mortality rates, catches and biomass by combining state-space and mechanistic multi-species models. arXiv:2008.02765, 06/08/2020, preprint: not peer-reviewed, https://arxiv.org/abs/2008.02765.

3 Cod in divisions 7.e–k

3.1 Overview of data sources

Data from 2004 to 2018 were provided to InterCatch ICES database (IC) by France (Laviale *et al.*, 2019a), Ireland, UK, Belgium, Spain, and the Netherlands, in response to the data call formulated as part of the WKCELTIC 2020 Benchmark.

a) Landings

Data were then extracted from IC and international allocations to fill in missing strata were processed using an R script. This script will be used to process the data in the following years. Scripts and data are available on the SharePoint to be used by MIXFISH group.

In order to fill in missing sample data, a hierarchical decision tree was set up. In a first step, as gadoids growth in length within a year, for a same supra:fleet, season and year, age-structured were borrowed from other countries. The season was then disregarded. In a final step, when no other match were found, métier was disregarded. Proposition of allocated versus sampled data per catch category and year (over the period available at WKCELTIC 2020), are shown in Figure 1. Figure 1 also shows proportion of catch per fleet as well as landings and discards per fleet over the time-series. The same kind of approach was used for Celtic sea haddock and whiting, which has improved the consistency between the three stocks. This will benefit the mixed-fisheries advice processes.

The hierarchical decision tree coded in R has improved the between year consistency in data processing at national and international level. This data update leads to minor revisions in landings data (Figures 2–4).

b) Discards

1. From 2004 to 2018

One objective of the benchmark was to include discards in the assessment. Discards data were extracted from InterCatch and international allocation to fill in missing strata were processed using an R script. This script will be used to process the discards data in the following years. Scripts and data are available on the SharePoint to be used by MIXFISH group.

To fill in missing discard weights, we first calculate mean discard ratio by country, gear and year. Then, we calculate mean discard ratio by gear and year. Finally, for fleets that have no discard data at all, we use overall ratio per year. These hierarchical decisions were based on differences observed between countries and fleets versus a more flat signal on quarterly discard ration.

The assessment will now be derived based on catch data instead of landings data only. The new catch matrix at-age is shown Figure 3.

2. Before 2004

Discards number: Prior to 2004 only landings data are available for Celtic Sea Cod and it is unknown whether discards practices have changed over time. Gerritsen *et al.*, 2019a WD Backfill discard describes a proposed approach to estimate the historic discard numbers-at-age. Discards of Celtic Sea cod are mainly confined to ages 1 and 2. For older ages, the catch numbers were assumed to be the same as the landings numbers. Discard estimates are available since 2004 and therefore catch numbers are known for all age classes in recent years. A separable model was fitted (using the selection pattern for age 1 and 2 from the recent period) to estimate the catch numbers-at-ages 1 and 2 in the historic period (Figure 5). By subtracting the observed landings

numbers-at-age from the estimated catch numbers, the discards could be estimated for the period before 2004 (assuming the separable assumption is valid; i.e. selectivity is constant over time). There were no clear trends in the proportion of the catch-at-age that was discarded.

SAM model allow reconstructing discards. Discards estimated values between the two methods were compared, and were quite similar. At WKCELTIC 2020, the decision was made to let the model back filled the discards instead of using the discards reconstructed time-series because it allows to account for uncertainties around pass discards levels. Discards weight: Discard weights-at-age were back filled using mean discard weight-at-age from 2004–2018.

The first ten years of the time-series were omitted (1971–1979) because of inconsistent trend in cohort tracking. Exploratory runs on xsa were performed on the 2004–2018 time-series and compared to the longer time-series. Little differences were observed. At WKCELTIC 2020 the final decision was to run the cod assessment on the 1980-onward to keep tracks of historical perspectives of the stock, which is need to management perspective and reference points calculation.

c) Surveys tuning fleets

Issues were raised on the way the two survey indices from EVHOE and IGFS were combined and the lack of transparency it its calculation. In order to account for spatial autocorrelation between the two data sources, VAST modelling were performed which the objective of providing new and more robust survey index. This modelling exercise was also carried out for the haddock and whiting in the Celtic sea. Details on modelling approaches, trials and sensitivities analysis are given in the WKESIG report (ICES, 2020 http://doi.org/10.17895/ices.pub.7574)

Comparison of runs were performed using XSA and SAM (see below) models between the old and new survey index calculation. The final decision was to use the new VAST index which was found to be more robust and reliable and could overpass years with missing data (as it was the case in recent year with the French EVHOE survey).

The script used to provide the index is available on the SharePoint at https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/SitePages/HomePage.aspx?RootFolder=%2FExpertGroups%2Fbenchmarks%2F2019%2Fwkceltic%2F2014%20Meeting%20docs%2F03%2E%20Report%202020%2FCOD%207EK&FolderCTID=0x012000565F2AD47EFA9043943C68C5D7EEE25D&View=%7B770CEDCB%2D9C5B%2D4BDC%2DB477%2D289E1B934C9A%7D

d) Commercial tuning fleets

A new French commercial OTB OTT DEF tuning fleet for cod has been made available. The WD Laviale *et al.*, 2019b (see annex) detailed the issues raised regarding the previous commercial tuning fleet and the work done to provide the new index. In summary, the list of species and the threshold used to select fishing trips has been modified to better account for the fact that cod is no longer a target, but more a bycatch of whiting and haddock directed fisheries. Moreover, the commercial tuning now accounts for both landings and discards. The new series is shown in Figure 6.

Comparison of runs were performed with XSA and SAM models using or not using the new candidate French commercial tuning series. The final decision was to use the French commercial index as a biomass index, rather than a numbers-at-age index to avoid 'double dipping', i.e. using some of the same age composition data in the catch and the index (see below).

e) Natural mortality

In the assessment, natural mortality is assumed to be constant for the whole range of years and is age-dependent. Before the WKROUND 2009, it was assumed a value of M=0.2 across all ages for Celtic Sea cod. At WKROUND 2012, the Lorenzen approach (1996) was applied where:

$$M@age = Mu * W@age^{b} \text{ with } Mu = 3.69 \text{ and } b = -0.305$$

Those values come from the Lorenzen paper as values for oceanic ecosystem. The data source was the EVHOE time-series from 2006 to 2011.

Previous values

Age	0	1	2	3	4	5	6	7	8	9	10
M	1.12	0.51	0.37	0.30	0.269	0.247	0.233	0.223	0.216	0.210	0.207

As part of the WKCELTIC 2020, natural mortality estimates were revisited (see annex WD Pawlowski, 2019. Natural mortality in the Celtic sea gadoids). Considering that more biological data have been collected, the Lorenzen approach applied directly on the mean weight-at-age data from EVHOE and IRGFS was calculated. Except for M at age 0, which is uncertain due to the lack of data in comparison to other age classes, values of M at age are quite similar to those estimated in 2012.

The table below shows the adopted values of M according to age.

New values

Age	0	1	2	3	4	5	6	7	8	9	10
M WKCELTIC 2020	0.967	0.501	0.330	0.264	0.233	0.211	0.211	0.211	0.211	0.211	0.2

f) Weight-at-age
Catch, discards, landings and stock weights-at-age from 2004–2018 were derived from IC outputs (Figure 7). Stock weights were calculated for quarter 1. Landings weight-at-age from 1980 to 2004 were kept as there were before. Discards, catch and stock weights were calculated as the mean of the 2004–2018 time-series.

g) Maturity
The maturity ogive, applied since 1999, was estimated from the datasets of the UK-WCGFS survey (1st quarter). . It replaced an assumed ogive used for the year prior to 1999, derived from Irish Sea cod data, when both stocks (7.a and 7.fg) were assessed in the Irish Sea and Bristol Channel WG up to 1992.

Previous values

Age	1	2	3	4	5+
Before 1999	0.00	0.05	1.00	1.00	1.00
Current	0.00	0.39	0.87	0.93	1.00

WKCELTIC 2020 reviewed the data using data collected since the last benchmark (see annex WD 2019 DC WKCELTIC Cod.27.7.e–k, Had.27.7e–k, Whg.27.7b–k IE 2004–2019 Maturity Ogives). The table below shows the adopted values of maturity ogives.

New values

Age	1	2	3	4	5+
WKCELTIC 2020	0.00	0.54	0.93	1.00	1.00

h) Tagging data

Between 1964 and 2018 a number of tagging studies have been conducted to understand the migratory behaviour and stock identity of cod in areas 6.a, 7.a and 7.e–k. In combination the studies included 2500 datapoints of tagged and re-captured fish. Studies involved using both, external marker tags as well as DST tags. There is little evidence of fish migrating from area 7.e–j into are 7.a, however there is considerate evidence of fish first tagged in area 7.a to be re-captured in 7.e–g. This is particularly evident for mature, older fish (3+ years) of which in the latest study 20% were seen to migrate from 7.a into 7.e–g. However, estimation of exchange flux between areas are too uncertain to be used as advisory bases.

3.2 Assessments

a) Outline of known problems

The main issues the before the benchmark process were:

- discards should be included into the assessment to overpass inconsistencies in the way high-grading was incorporated in the landings data over the years.
- survey index : streamlining data compilation procedures for survey data. The benchmark should develop a standardized, reproducible method for combining the IGFS and EVHOE survey data for cod and if possible produce a catch-at-age index with realistic measure of uncertainties.
- commercial tuning index : over the years, several issues have been pointed out regarding the French commercial tuning fleet. i) The tuning indices are being built upon landings only, ii) The selection criteria for the vessel was based on threshold of proportion of landed gadoids among a fixed set of species (14 species). In case of strong recruitment events of one of these species, the approach selects additional vessels that are normally not catching enough gadoids to be considered as reference vessels. The above point has led to a use in the recent years of a frozen set of vessels IDs from 2009. The benchmark should review current calculation procedure and proposed an improved one.
- Catch-at-age: simplification of the complexity of métiers and the raising process in InterCatch. This is error prone and places a significant onus on the stock coordinator as the last stage in the data raising process in the narrow window before the assessment. The benchmark should review current sampling levels and adjust stratification levels accordingly and provide updated historical time-series.
- Fisheries & ecosystem issues and data: Cod, haddock and whiting in the Celtic Sea should be benchmarked together in 2018. The aim of the benchmark is to examine mixed-fisheries interaction for the three species together. The working group should develop a consistent approach for data compilation which satisfies the objectives of WGCSE and WGMIXFISH.
- Assessment method: The working group should examine alternative assessment models to XSA. It would be preferable to use a statistical method and propagated the main uncertainties into the forecasts properly. The working group should explore the potential of using A4A, ASAP and SAM as alternatives to XSA for this stock.

- reference points: The reference points would need to be updated to be consistent with the final assessment method.

WGCSE report stipulates in the uncertainties and bias in assessment and forecast section:

> WGCSE recommend that cod, haddock and whiting in the Celtic Sea should be benchmarked together in 2019. The focus of the benchmark would be on streamlining data compilation procedures for fishery-dependent and survey data. This will improve transparency and diagnostics surrounding commercial tuning fleets and surveys. The benchmark should also review the assessment methods and diagnostics given the potential for changes in selectivity in the commercial fishery. The benchmark should also investigate mixed fisheries and multispecies interactions as well as environmental drivers that may be impacting on growth and recruitment of all three species.

Issues that might causes retrospectives bias are:

i. the non-inclusion of undersized discards (and high-grading in recent years) in the assessment. However, high-grading is estimated at a very low level in recent year because the TACs were not constraining (undershoot TACs).
ii. Sensitivity analysis of the assessment to commercial tuning series calculation should be investigating during the next benchmark process.

Discards normally constitute about 10% of the total catch, but discard rates in recent years have fluctuated substantially due to variable recruitment and TACs constraints. This prevents the forecast of future discard rates with any certainty.

b) Trial assessments

1. XSA

Models runs comparison were performed using XSA. The main objective was to investigate the improvement in retrospective patterns of F_{bar} and SSB. The models comparisons were performed on the 2004–2018 time-series. Changes in catch-at-age matrix, natural mortality and maturities were not investigated at that point.

XSA setting were kept as in the current assessment, except the year range of the survey index, which was changed to 1–4. It is believed that the survey does not catch enough old fish to be relevant (a lot of zero in the index provided for old ages).

Model Options agreed at WKROUND 2012:

- Taper : no
- Age s catch dep. Stock size : none
- q plateau : 3
- F shrinkage se : 1
- F shrinkage year range : 5
- F shrinkage age range : 3
- F shrinkage age range of mean F: 2–5
- Fleet SE threshold : 0.3
- Prior weights : No

```
xsa.control <- FLXSA.control(tol = 1e-09, maxit = 30,  min.nse = 0.3,  fse  = 1.0, rage = -1,   qage  = 
3,   shk.n   = TRUE, shk.f = TRUE, shk.yrs = 5, shk.ages= 3, window  = 100,  tsrange = 99,
tspower = 0)
```

Model comparisons focused on tuning indices. The Ssx runs are shown in Figure 10 and retro calculated for the last six years as well as Mohns rho indices (Table 1). Figure 8 showed that the two tuning indices bring conflicting information resulting in significant differences in the F_{bar} and SSB estimates in the final years. The use of VAST combined survey index seems to improve the retro patterns compared to the old grid index calculation (Figure 9).

2. SAM

The following section provides a narrative of the SAM assessments that were explored during the workshop. They are all available on stockassessment.org All these trial assessments used data up to 2018.

Cod_WKCeltic_2020

This is the initial SAM run presented to WKCELTIC with the following inputs and configuration:

- Full time-series of catch data(1971 to 2018, ages 1 to 7+)
- Back-filled discards for ages 1 and 2 in 1971-2003 (see WD: backfilldiscards.pdf)
- Commercial index in numbers-at-age 3–7 and grid-based survey index for ages 1–4
- Fishing mortality states were bound for ages 4+
- Catchability for ages 4+ were bound for the commercial index
- Catchability for ages 2+ were bound for the survey index
- Default settings for remaining configuration

The model fit appeared reasonable, retrospective patterns improved from XSA but still a big change when adding 2018 data. It was pointed out that the commercial index includes discards so the younger ages could be included as well.

Cod_WKCeltic_2020_2

It was agreed to replace the grid-based index with the VAST index and to use the commercial index as a biomass index, rather than numbers-at-age, to avoid 'double-dipping', i.e. the index uses of the same age data that contribute considerably (approximately 30%) to the catch numbers. The biomass 'treatment' was set to 'SSB'. The index is not truly an SSB index, but the selection pattern is similar to the maturity ogive (The French fleet has lower catchability of young fish than the Irish fleets as they do operate less in inshore waters). The observation of catches-at-ages 1 and 2 in 1971–2003 were down-weighted because these data were estimated by inflating the landings numbers, and therefore considered uncertain.

Other changes from the previous run:

- Fishing mortality states were bound only for ages 6 and 7+
- Observation error on the first age in the survey was estimated separately from the older ages (i.e. ages 2, 3, 4 were bound).

The retrospective pattern did not improve much but the input data were considered to be more appropriate.

The survey and the commercial index show some conflict in the recent biomass; leave-one-out runs show that without the survey the SSB in the last few years is somewhat higher and without

the commercial index the SSB would be lower. Removing the commercial fleet made the estimates quite imprecise and variable from year-to-year, so this was not pursued.

Cod_WKCeltic_2020_3

Some small updates to the input data, no change in perception.

Cod_WKCeltic_2020_4

Instead of backfilling discards for the years where no data are available (before 2004), it was decided to try to set these catch numbers to 'missing' (NA) and allow the model to estimate the catch, based on the selectivity for these ages (1 and 2) in the period before 2004 (no need now to down-weigh these observations anymore, because these are now omitted).

Additionally, it was agreed to truncate the first few years of the catch data: cohort tracking was poor and there were strong year-effects. Additionally, the residuals indicated that there was a disproportionate amount of noise and year-effects in these years. The new period for the catch data is 1980–2018.

Truncating the time-series removed the period of relatively low F. F in the remaining was quite constant over time and the model switched from 'believing' that interannual variability is real to 'believing' that is was noise and therefore the resulting F became much smoother over time. This smoother F also suffered less from retrospective bias. The retro in SSB and recruits are very minor in this run.

Cod_ WKCeltic_2020_4a3NA

Some more tweaks:

- Some more tidying of input data
- The survey age range was reduced to ages 1–3 (due to higher residuals at age 4) resulting in further improvement in retro.
- Covariance in the survey index was set to 'AR', ages 1–2 and 2–3 were bound.
- F_{bar} range set to 2–5 (back to the range used by WGCSE 2019).

Cod_7ek_4a3NA

- coupling of variance parameter for the observations after age two in the catch-at-age matrix have improve the AIC value.

Cod_7ek_4a3NA_VASTonly

A trial was made to run the above settings (Cod_7ek_4a3NA settings) with the VAST survey only. As in previous comparison between runs with the two or one tuning indices, assessment is more stable with the commercial tuning in than without. The retro pattern were strongly affected, especially for F.

Cod_7ek_4a3NA_1993landings

There were some doubts about discarding in the past; signs that it could have been considerably less at the start of the time-series. We investigated this by assuming zero discards before 1993 (year where TAC regulation was introduced). It made no perceptible difference to the SSB estimate and recruitment was estimated to be slightly higher at the start of the TS. However F retrospective pattern increased in this run, and selection pattern seems unexpected. If we do not use the full time-series in the stock–recruit for the ref points this may have little impact. Reference points sensitivity runs on the length of the time-series will be performed.

Conclusion

Themodel Cod_7ek_4a3NA reduces retrospective patterns to a minimum, as well as good qualities of other diagnostics and parameters estimates. This model is proposed as the updated assessment for Celtic Cod. The results and diagnostic of the new proposed SAM assessment (with data up to 2018) are shown in Figure 11–16 and Table 2–5.

c) Final assessment

1. Settings

WKCELTIC rejected the current XSA assessment because of its very bad retrospective patterns. The proposed assessment method is a SAM model, which appeared suitable to carry analytical assessment of the Celtic sea cod stock (category 1).

The final accepted SAM run is detailed below in terms of model setting and models diagnostics.

```
# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive
#
$minAge
# The minimium age class in the assessment
 1

$maxAge
# The maximum age class in the assessment
 7

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

$keyLogFsta
# Coupling of the fishing mortality states (nomally only first row is used).
  0  1  2  3  4  5  5
 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1

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

$keyLogFpar
# Coupling of the survey catchability parameters (normally first row is not used, as that is covered by
fishing mortality).
 -1 -1 -1 -1 -1 -1 -1
  0 -1 -1 -1 -1 -1 -1
  1  2  3 -1 -1 -1 -1

$keyQpow
# Density-dependent catchability power parameters (if any).
 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1
 -1 -1 -1 -1 -1 -1 -1
$keyVarF
# Coupling of process variance parameters for log(F)-process (normally only first row is used)
  0  0  0  0  0  0  0
```

```
 -1  -1  -1  -1  -1  -1  -1
 -1  -1  -1  -1  -1  -1  -1

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

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

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"
 "ID" "ID" "AR"

$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#1-2 2-3 3-4 4-5 5-6 6-7
  NA  NA  NA  NA  NA  NA
 -1  -1  -1  -1  -1  -1
  0   0  -1  -1  -1  -1

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

$noScaledYears
# Number of years where catch scaling is applied.
 0

$keyScaledYears
# A vector of the years where catch scaling is applied.

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

$fbarRange
# lowest and higest age included in Fbar
 2 5

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

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

$fixVarToWeight
```

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

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

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

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

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

2. Results and comparison with previous assessment

Comparison of SSB F_{bar}, catch and recruitment estimated with XSA (run from WGCSE 2019) and the proposed SAM model (with data up to 2018) is shown Figure 17. SSB and catch were revised a bit higher as the combination of discards being included in the assessment and small change in maturity ogive. However, trends and orders of magnitude seem consistent between the two assessments outputs. Nevertheless, median F_{bar} estimates is smoother with the SAM model than XSA, which F estimated were more variable across years. Nonetheless, the magnitude of XSA F changes over time seems to be, for most of them, included in the SAM uncertainty bounds.

3. Model and results updates with one more year of data (2019 data included)

Cod_7ek_4a3NA_Final_Benchmark_with2019data

Due to delay in the benchmark procedure, the proposed SAM model was also run with the 2019 data. The addition of one year of data has decreased the stability of the assessment and increasing retrospective bias. F trend is more contrasted and F was revised upward from 0.923 to 1.134 and in 2018. The results and diagnostic of the SAM model with data up to 2019 are shown in Figures 18–22 and Table 6–9.

The retrospective patterns are unsatisfactory and close to the 20% bounds of the Mohn'rho indicator. The assessment is uncertain and especially the last year. However, despite this uncertainty, it is quite clear that the cod stock is well below SBB limits and well above F target. Given that situation and the recommendations of WKBIAS 2020, the WKCELTIC validated the proposed assessment model.

4. Recommendations for future developments

The two tunnings fleets are conflicting (see leave one out run). There is room for development of a modelled commercial tuning fleet instead of the current method based on catch thresholds. Indeed, despite the work performed to improve the commercial tuning fleet, it is never easy to account for changes in fisheries targeting behaviours. Indeed in recent years, cod is not targeted anymore by most of the fisheries.

Even if the survey index combined two surveys, it is based on few fish. Further work and sensitivity analysis on the VAST assumptions might also be performed and documented in the future to ensure that the model will converge for all ages and show low retrospective patterns.

3.3 Short-term predictions

a) Method

Stochastic short-term projection will be performed using the short-term forecast functionality of the "stockassessment" package.

1. Recruitment

Celtic Sea cod stock had a few sporadic events of high recruitment. Given the lower recruitment regime in recent years, the recruitment is sampled over the period 2005 onward. The 2005 year corresponds to the lowest recent SSB that has allowed the stock to recover.

Recruitment period needs to be updated if recurrent changes in recruitment regime is observed in the future.

2. Weight and maturity

Maturities are assumed constant. Stock and catch weights are based on the average from the last three years.

3. Assumption for intermediate year

Based on WGCSE expertise, the more appropriate assumption between F status quo and Catch= TAC will be used.

Catches were split into landings and discards using the proportions of the catch that were discarded over the last three years.

4. Implication for reference points

Due to the substantial changes in the assessment model and parameters, reference points had to be recalculated (see script in the annex).

This step followed the ICES guidelines for categories 1 and 2 stocks using the eqsim tool to gradually estimate the new biological reference points. The reference run used was the adopted one: Cod_7ek_4a3NA_Final_Benchmark_with2019data.

Key decisions had to be taken regarding the type stock–recruitment (S/R) relationship considering the last decade of low recruitment and the initial assumption on B_{lim}. Three types of S/R relationships were considered:

- Type 1: stocks with occasional large year classes where B_{lim} is based on the lowest SSB where large recruitment is observed. In that case, B_{lim} = 5600 t (SSB in 2010).
- Type 2: stocks with a wide dynamic range of SSB and evidence that recruitment is or has been impaired. B_{lim} is estimated as change point in the segmented regression. In that case B_{lim} = 10 600 t.
- Type 5: stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment. B_{lim} is then equal to B_{loss}. In that case, B_{lim} = 4200 t. In that approach, B_{lim} corresponds to the SSB in 2005 which is the lowest observed SSB for which a strong recruitment was later observed in the time-series.

From the discussions during the WKCELTIC meeting regarding which type to consider, it appears most of these relationships share traits with the current shape of the estimated SSB and R from the runs (Figure 23) but type 5 was considered the most plausible. Several estimates of BRPs were presented in Table 10 including changes in Eqsim settings and length of the time-series used for R.

Eqsim final settings were set as follow:

- The selectivity period was set to 5 years (unchanged from EqSim default proposed value).
- SigmaF and SigmaSSB were both set to 0.2. These values were considered more realistic than model outputs and default proposed values.
- The time-series for R was used from 1980–2019. (The assessment time-series).
- Autocorrelation in recruitment was set to true as autocorrelation in recruitment is substantial (Figure 23).

Final reference point estimates are proposed in the table below. Additional output plots from eqsim are on Figures 24 and 25:

Framework	Reference point	Value	RATIONALE
MSY approach	MSY $B_{trigger}$	5800	Tonnes; Bpa
	F_{MSY}	0.29	Segmented regression with Blim (EqSim)
Precautionary approach	B_{lim}	4200	Tonnes; Bloss, lowest observed SSB (2005) rounded value
	B_{pa}	5800	Tonnes; Blim*1.4; rounded value
	F_{lim}	1.13	Segmented regression with Blim (EqSim)
	F_{p05}	0.77	Estimated from stochastic simulation (EqSim)
	F_{pa}	0.81	Flim/1.4
Management plan*	MAP MSY $B_{trigger}$	5800	Tonnes; MSY Btrigger
	MAP B_{lim}	4200	Tonnes; Blim
	MAP F_{MSY}	0.29	F_{MSY}
	MAP range F_{lower}	0.17	Consistent with ranges provided by ICES (2017), resulting in no more than 5% reduction in long-term yield compared with MSY.
	MAP range F_{upper}	0.41	Consistent with ranges provided by ICES (2017), resulting in no more than 5% reduction in long-term yield compared with MSY.

* **Proposed EU multiannual plan (MAP) for the Western Waters (EU, 2018).**

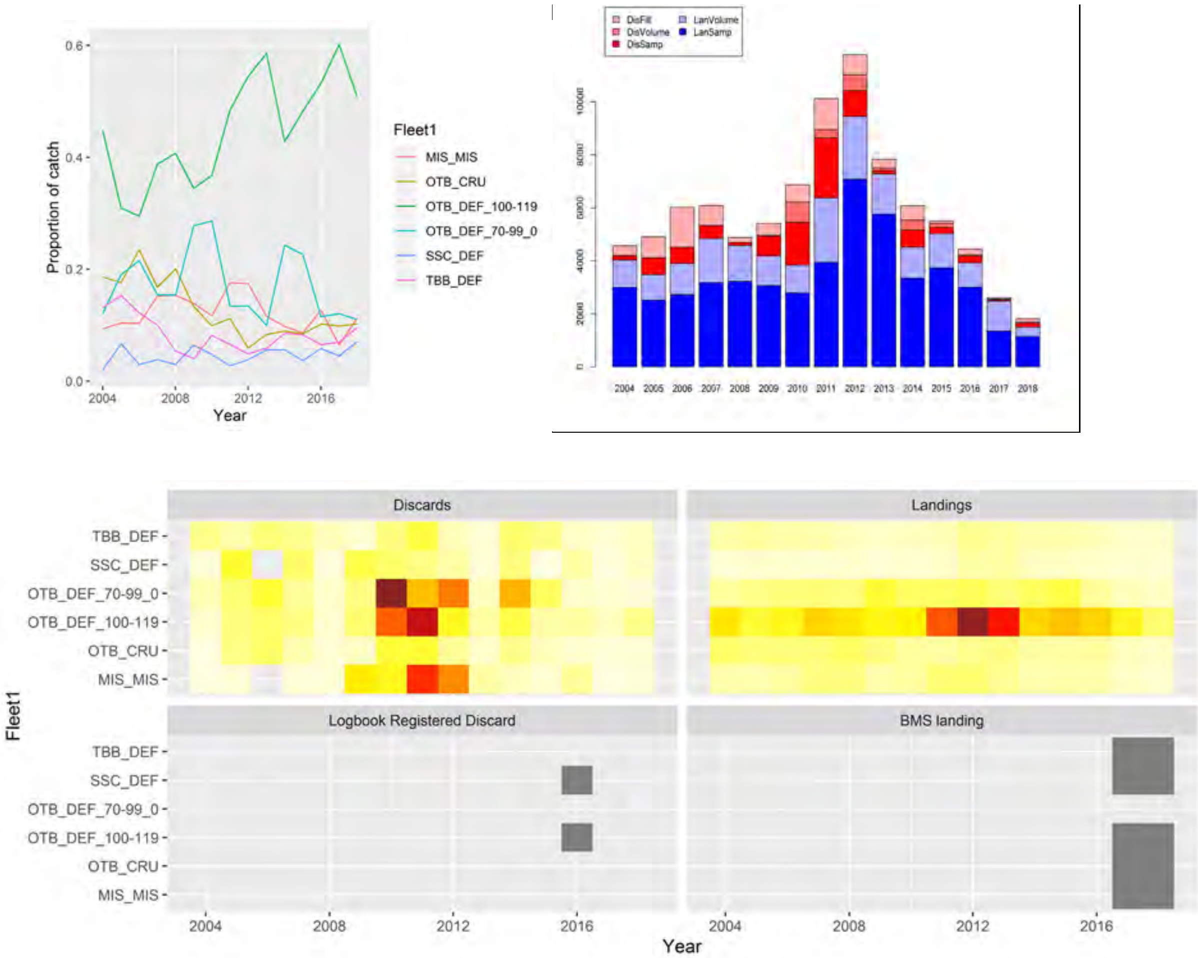

Figure 1. Data presentation. The top left panel represents the proportion of the catch per fleets. The top right panels indicate the proposition of the landings and discards (in tons) submitted to IC and filled in. The bottom panel illustrates the landing and discards per fleets over the time-series 2004–2018.

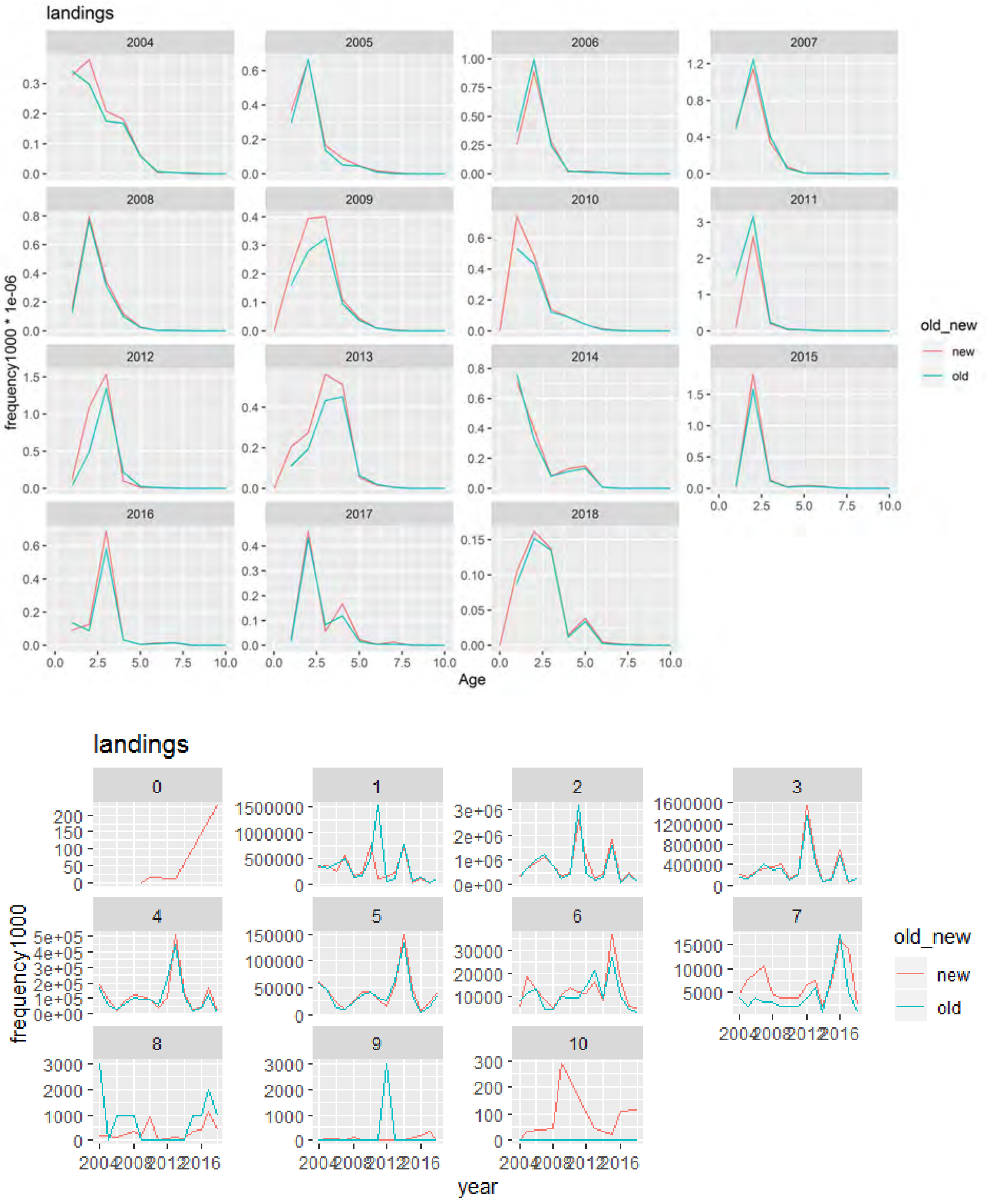

Figure 2. Comparison of landings number-at-age between the old and the new series.

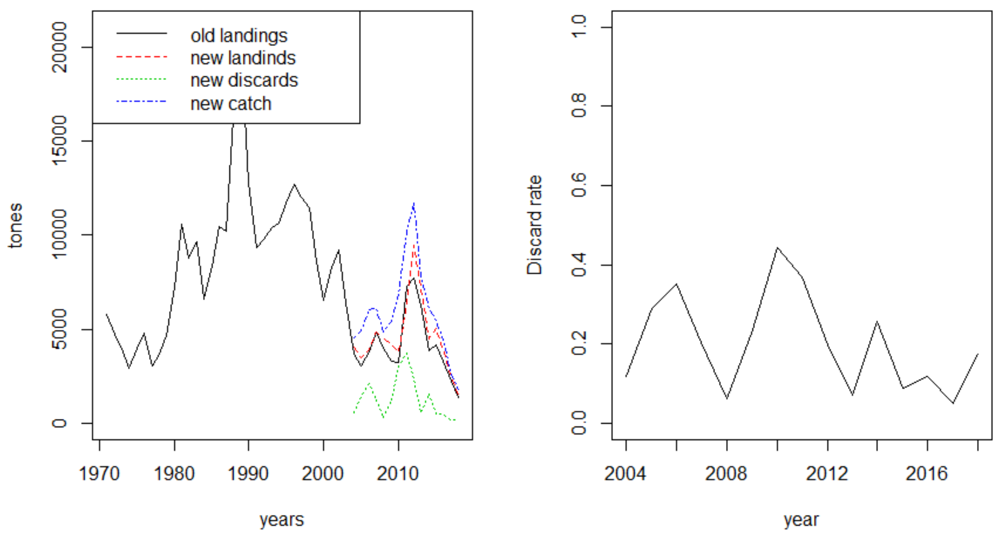

Figure 3. Landings and discards in tons (left panel) and discards rate (left panels).

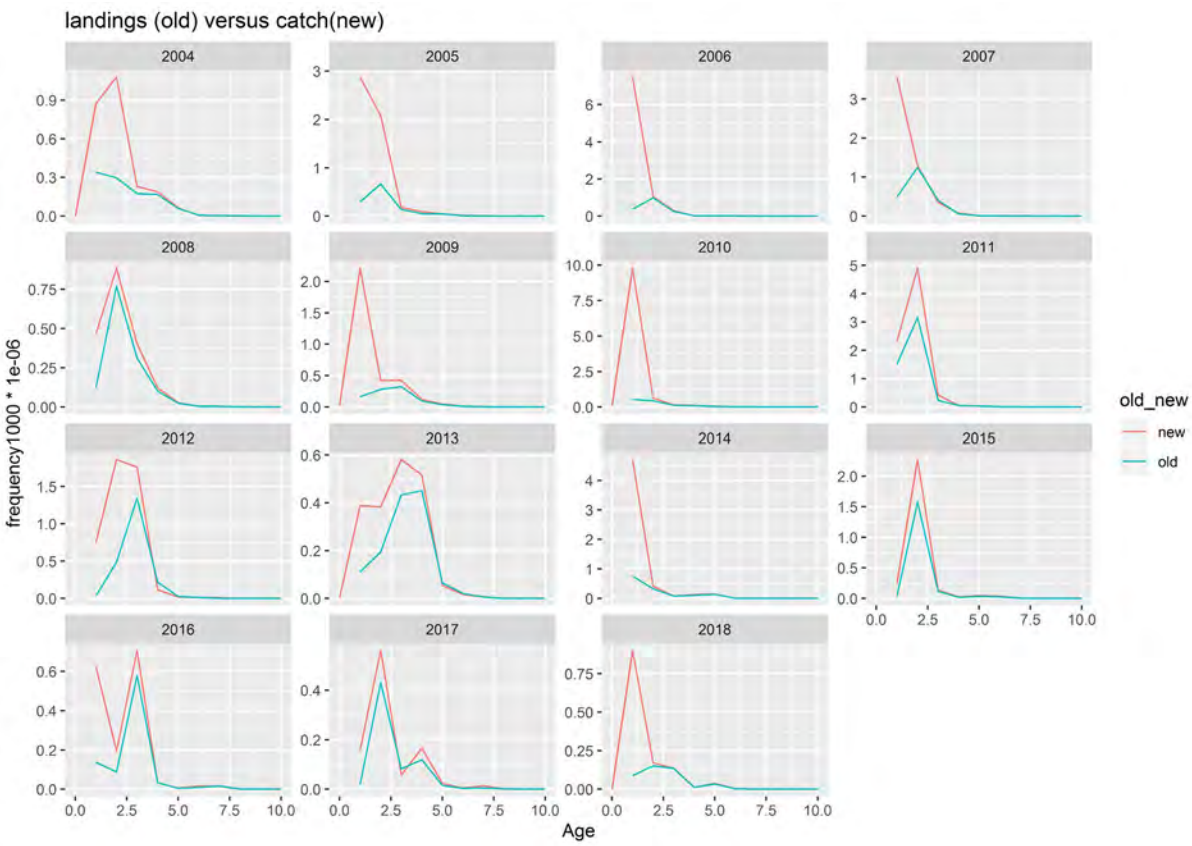

Figure 4. Comparison of inputs data between the previews and new assessment: landings number-at-age versus catch number-at-age.

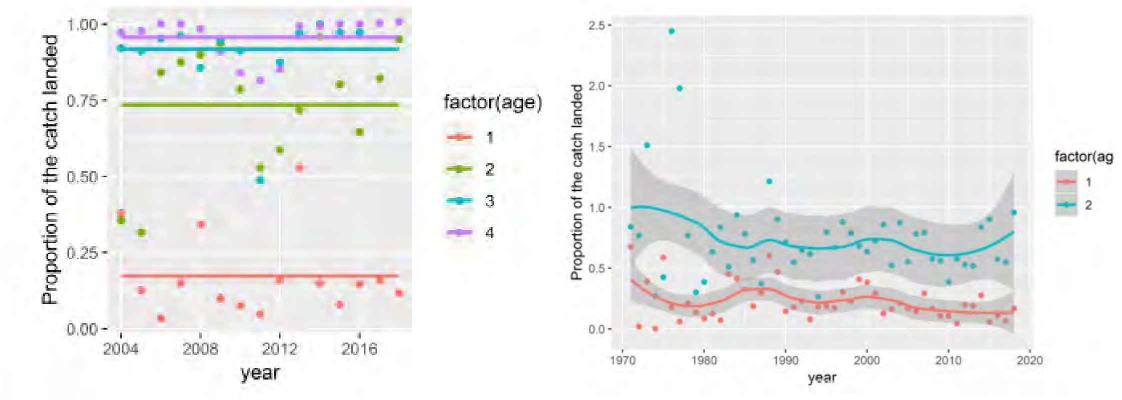

Figure 5.Left panel: Proportion of the catch number at age that were landed. Right panel: Modelled proportion of the catch that were landed.

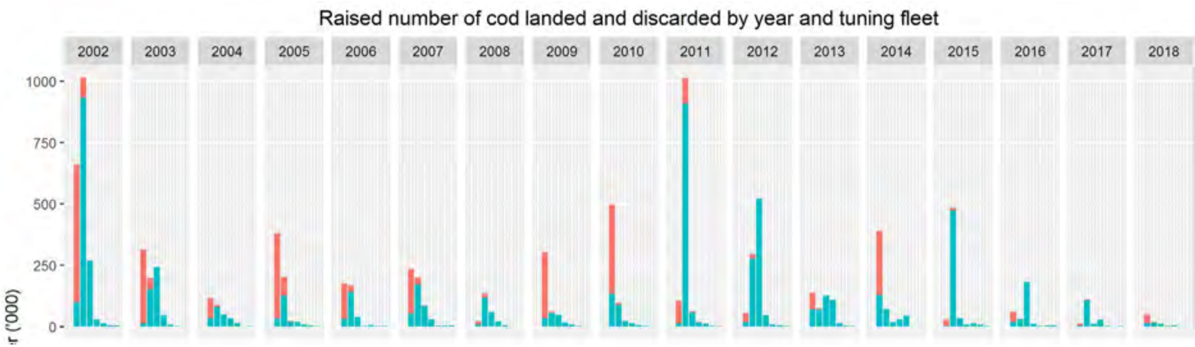

Figure 6. Catch-at-age at age matrix for the French commercial tuning fleet (Number in '000). Discards are in red and landings in blue.

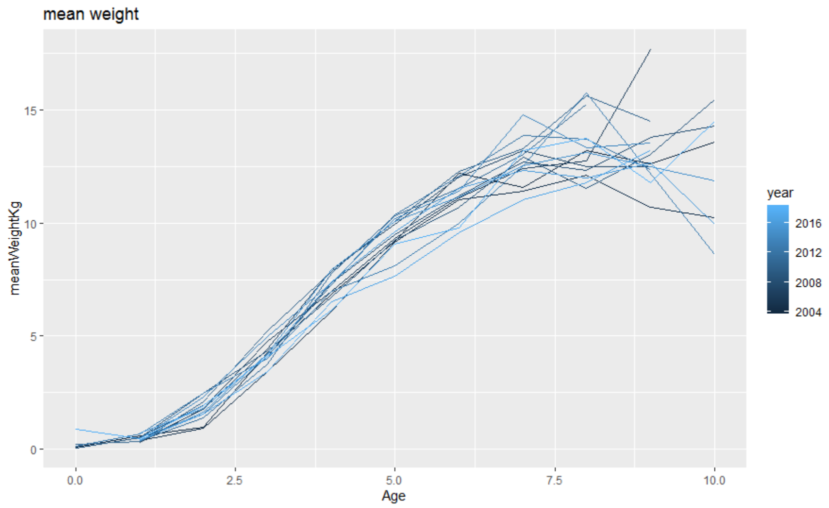

Figure 7. Mean weight of the catch per year and age.

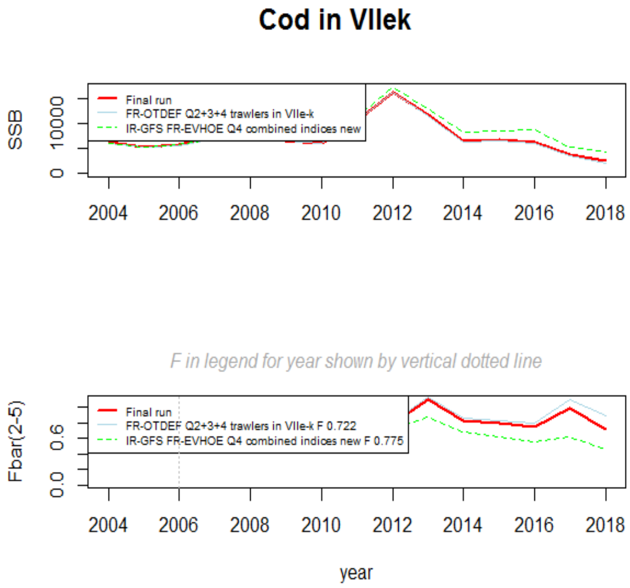

Figure 8. Comparison between xsa runs with the two tuning indices, with only the survey indices and with only the commercial tuning inex.

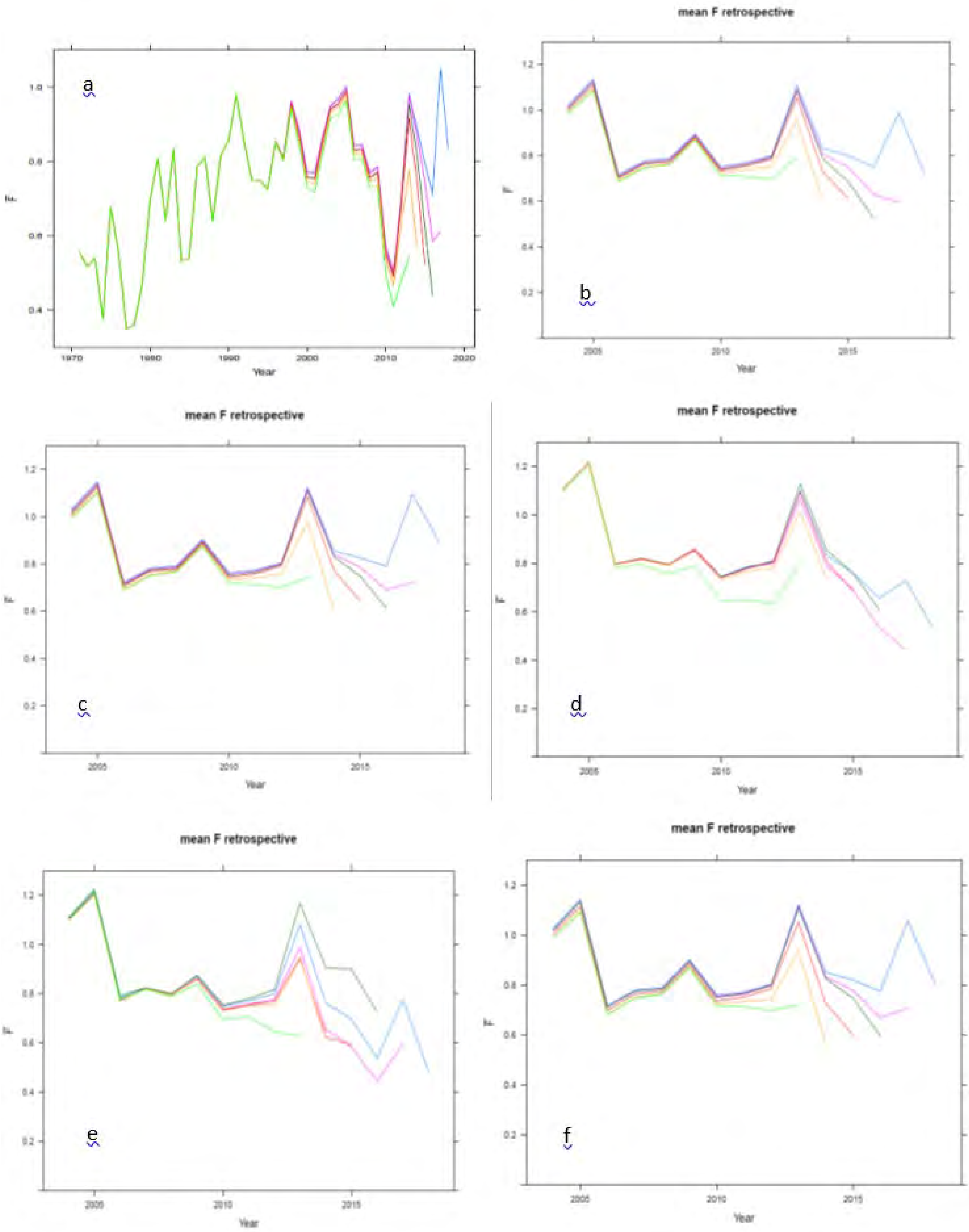

Figure 9. Retrospective pattern in SB for the 6 xsa runs a) WGCSV2019 b) New 2004–2018 time-series (catch-at-age, biological parameters) – Run with two tunings : old survey index (Age range survey 0–4) and new French commercial fleet; c) b) New 2004–2018 time-series (catch-at-age, biological parameters) – Run with French commercial tuning indice only; d) New 2004–2018 time-series (catch-at-age, biological parameters) – Run with old survey indice only; e)) New 2004–2018 time-series (catch-at-age, biological parameters) – Run with new VAST survey indice only; f) New 2004–2018 time-

series (catch-at-age, biological parameters) – Run with two tunings : new VAST survey indice and new French commercial tuning.

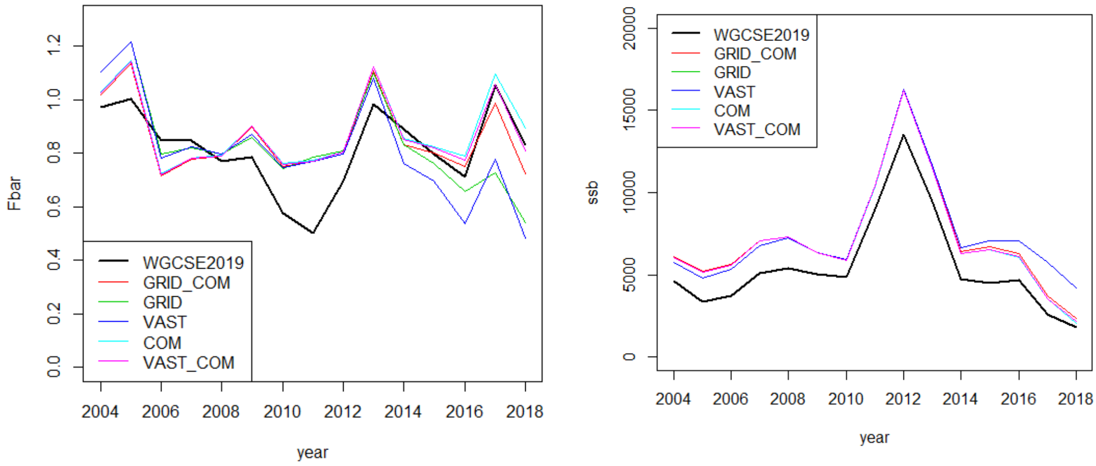

Figure 10. Comparison between xsa runs on F_{bar} and SSB estimates.

WGCSE2019 = scenario run at WGCSE2019, no discard in the assessment, old commercial tuning fleet and survey index calculated on a grid

GRID_COM= scenario run with discard included, survey indices calculated on a grid based (as before the bench-mark), and updated commercial tuning series

GRID= scenario run with discard included and survey indices calculated on a grid based

VAST= scenario run with discard included and survey indices calculated using VAST modelling

COM= scenario run with discard included and updated commercial tuning series

VAST_COM= scenario run with discard included and survey indices calculated using VAST modelling and up-dated commercial tuning series.

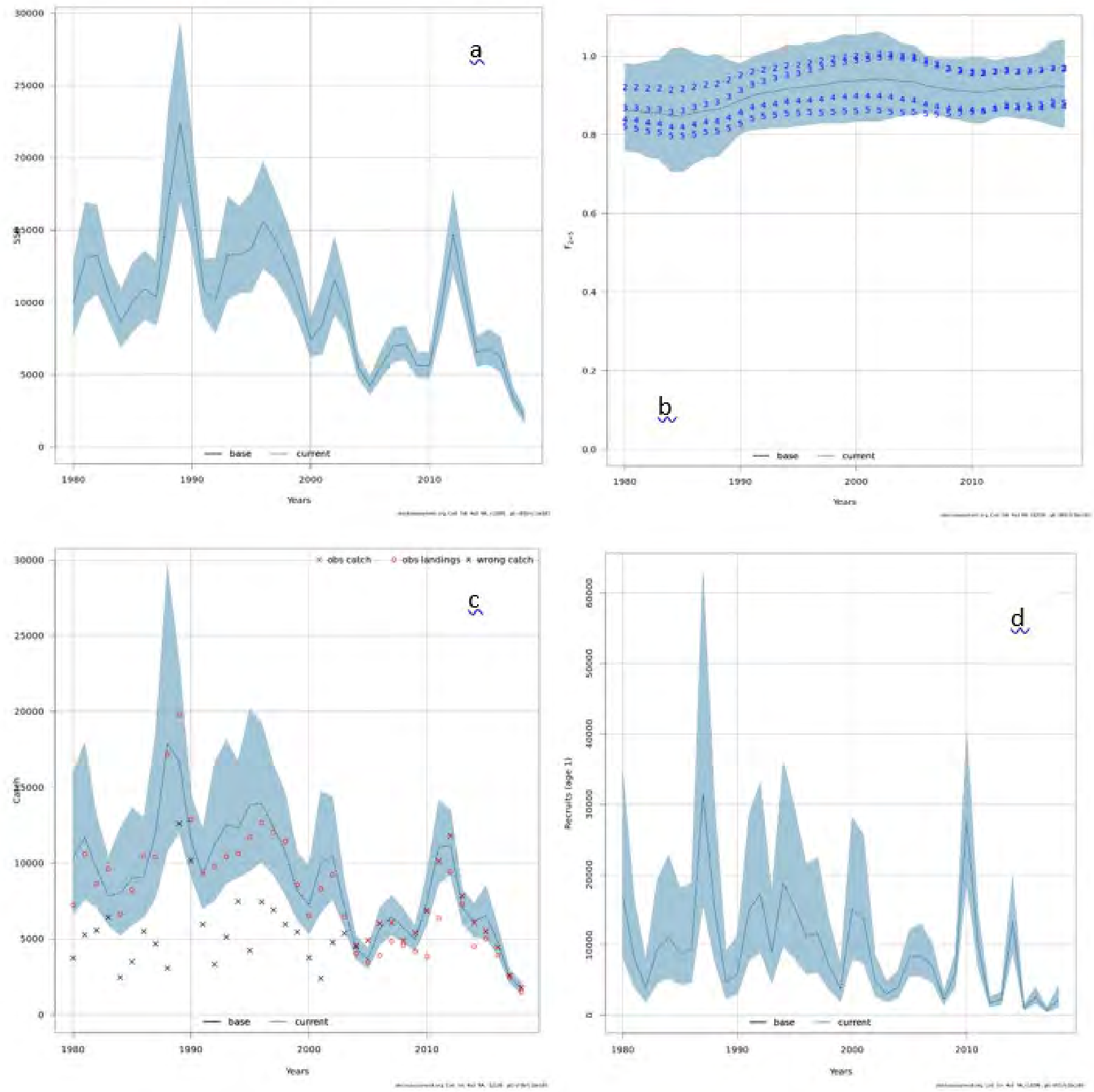

Figure 11. Results of the new accepted SAM assessment (data up to 2018). Solid line represents median and blues polygons the 95% confidence intervals. A) SSB, b) F_{bar}, c) Catch and d) Recruitment.

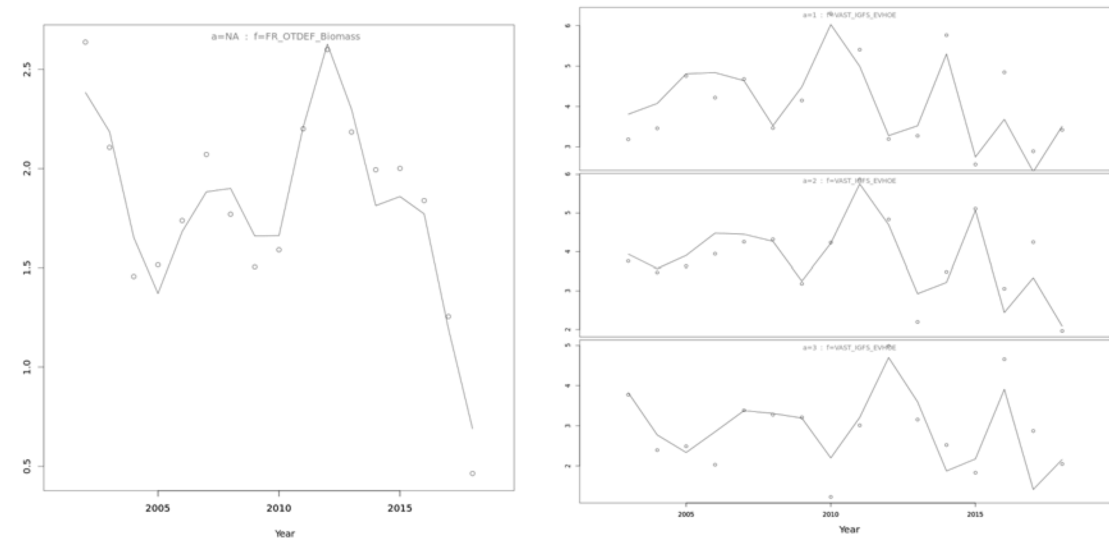

Figure 12. Results of the new accepted SAM assessment (data up to 2018). Fits to data. Left panel: French commercial tuning fleet and right panel: Survey index.

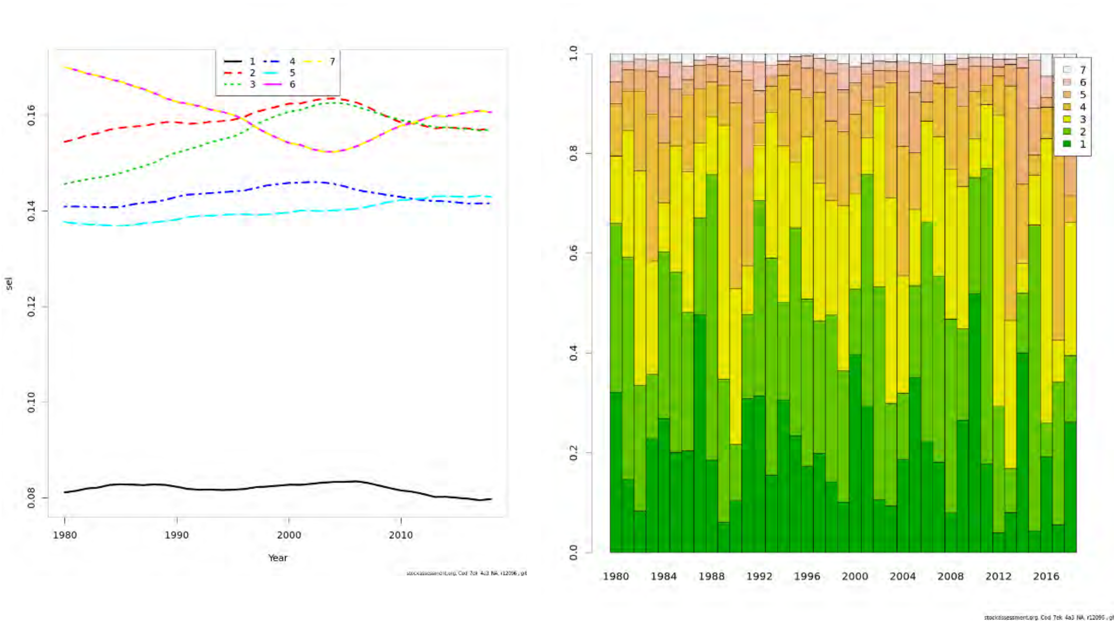

Figure 13. Results of the new accepted SAM assessment (data up to 2018). Selection pattern at age. Left panel: F divided by F_{bar}. Right panel: Biomass-at-age.

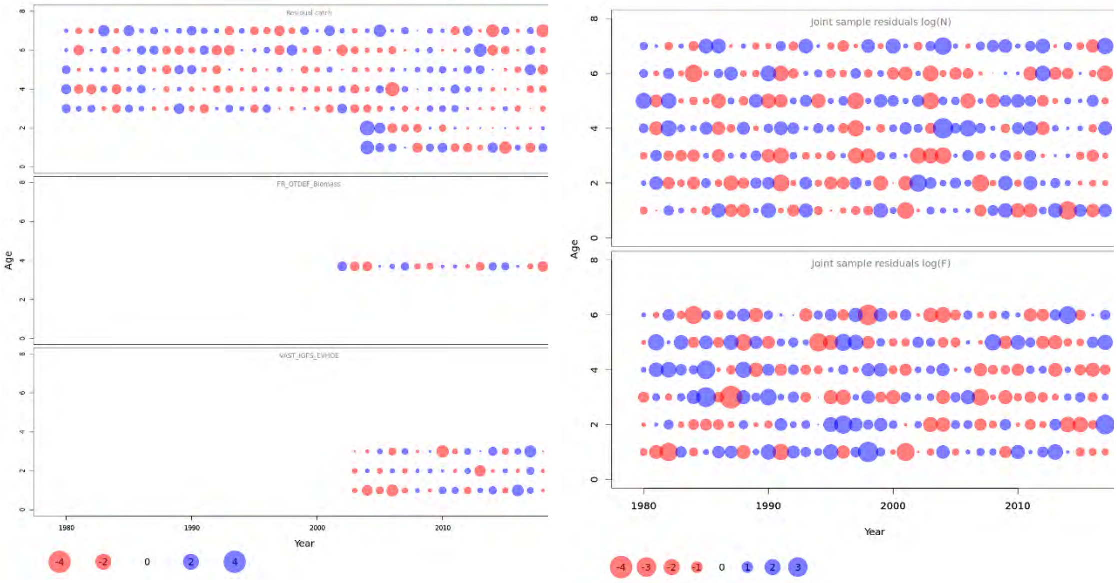

Figure 14. Results of the new accepted SAM assessment (data up to 2018). Left panel: Standardized one-observation-ahead residuals. Right panel: Process residuals - Standardized single-joint-sample residuals of process increments.

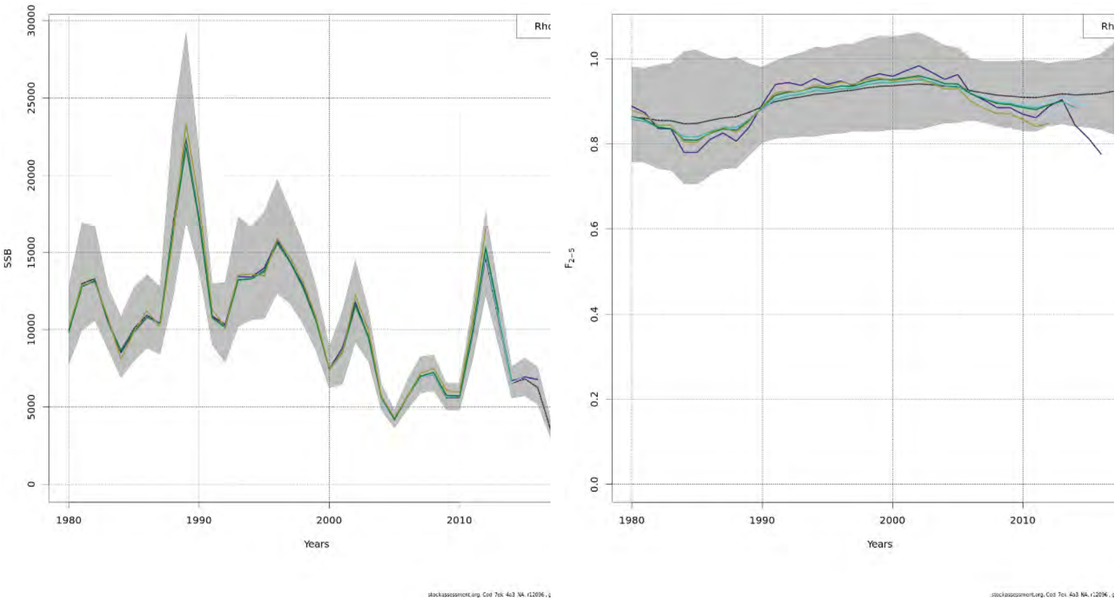

Figure 15. Results of the new accepted SAM assessment (data up to 2018) .Left panel: Retrospective of SSB, Mohns Rho of 13%. Right panel: Retrospective of F_{bar}, Mohns Rho of -7%.

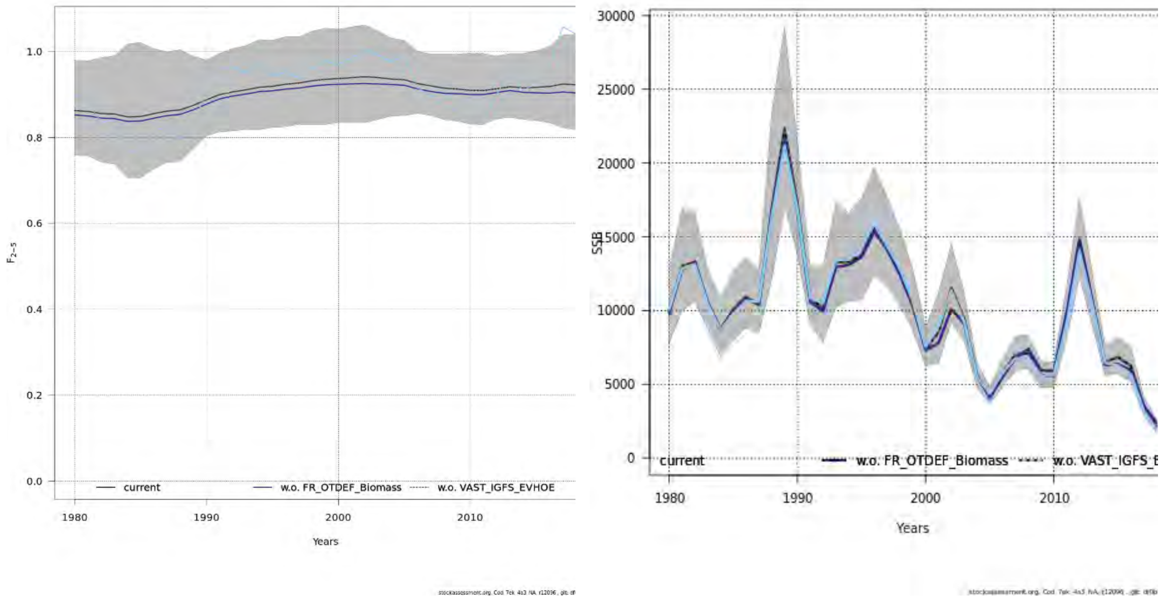

Figure 16. Results of the new accepted SAM assessment (data up to 2018). Leave one out runs.

Figure 17. Comparison of the median of SAM accepted assessment (with data up to 2018) and XSA 2019 assessment.

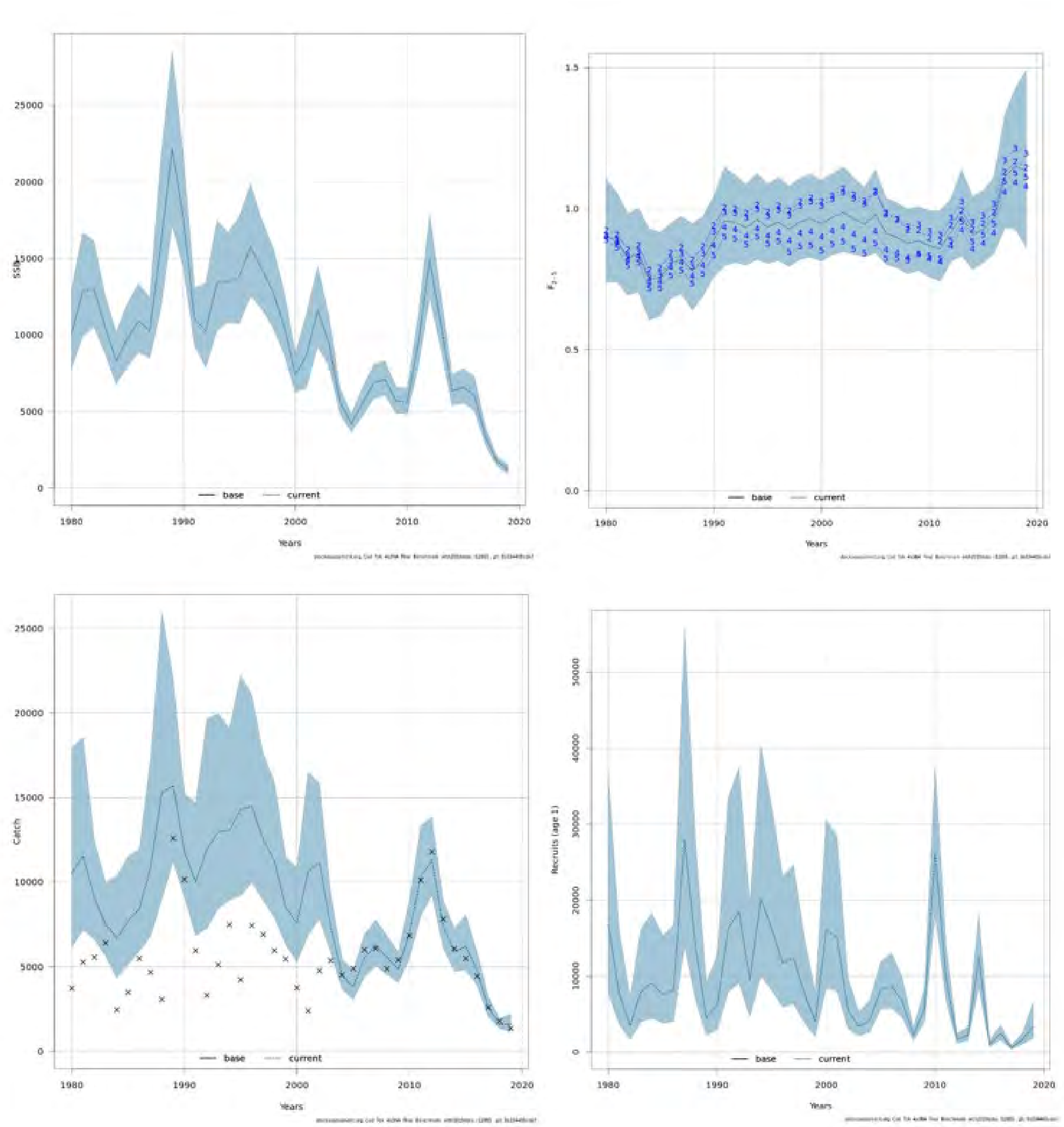

Figure 18. Results of the new accepted SAM assessment (data up to 2019). Solid line represents median and blues polygons the 95% confidence intervals. A) SSB, b) F_{bar}, c) Catch and d) Recruitment.

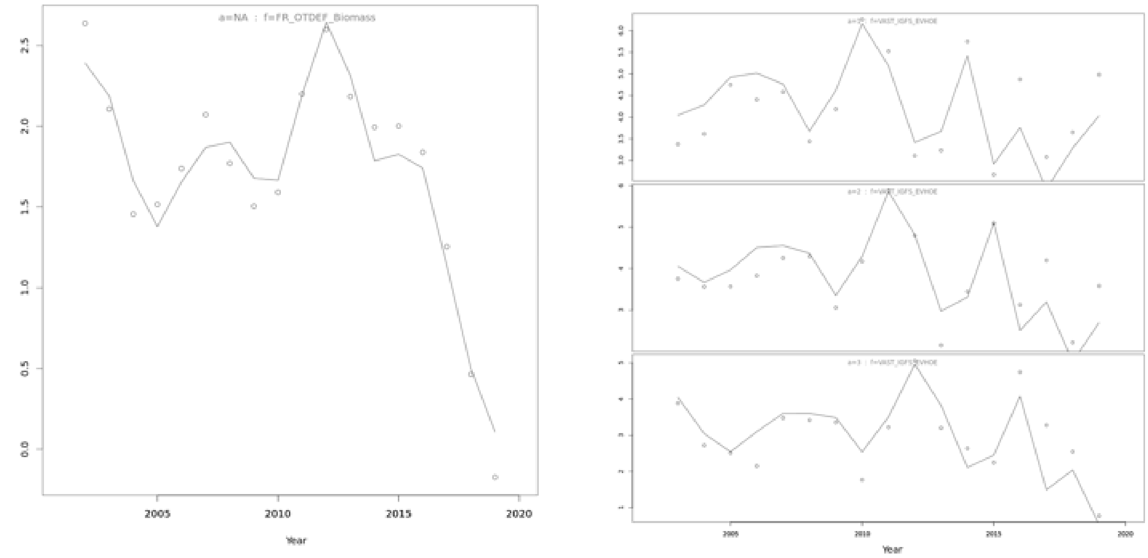

Figure 18. Results of the new accepted SAM assessment (data up to 2019). Fits to data. Left panel: French commercial tuning fleet and right panel: Survey index.

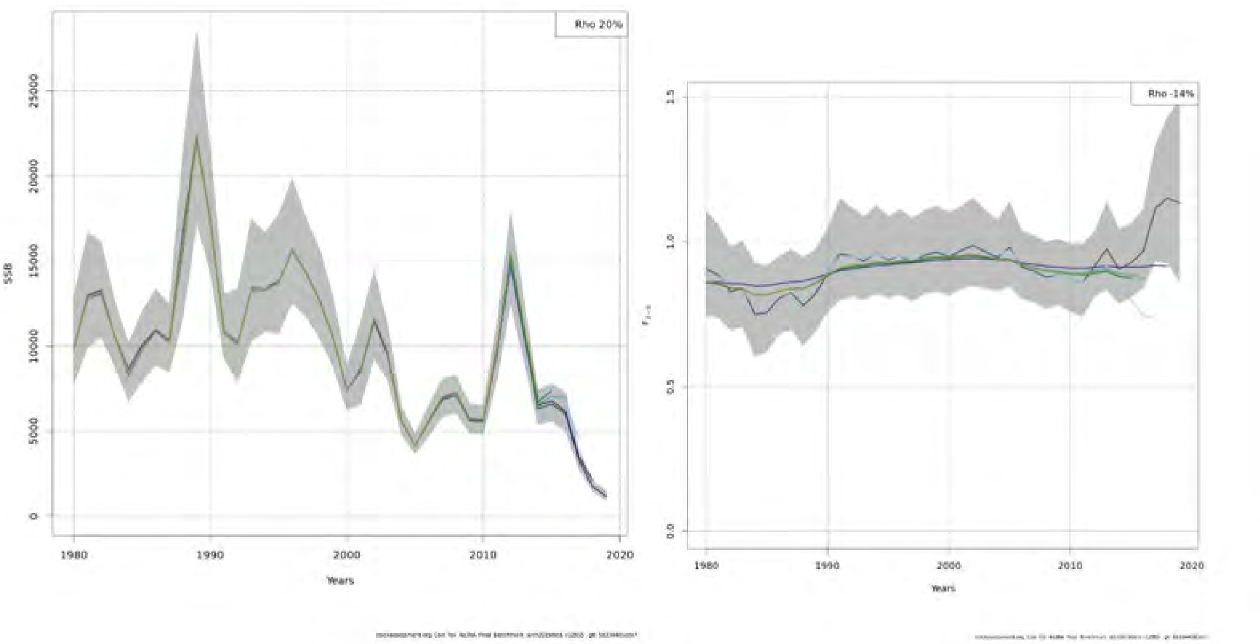

Figure 20. Results of the new accepted SAM assessment (data up to 2019) .Left panel: Retrospective of SSB, Mohns Rho of 20%. Right panel: Retrospective of F_{bar}, Mohns Rho of -14%.

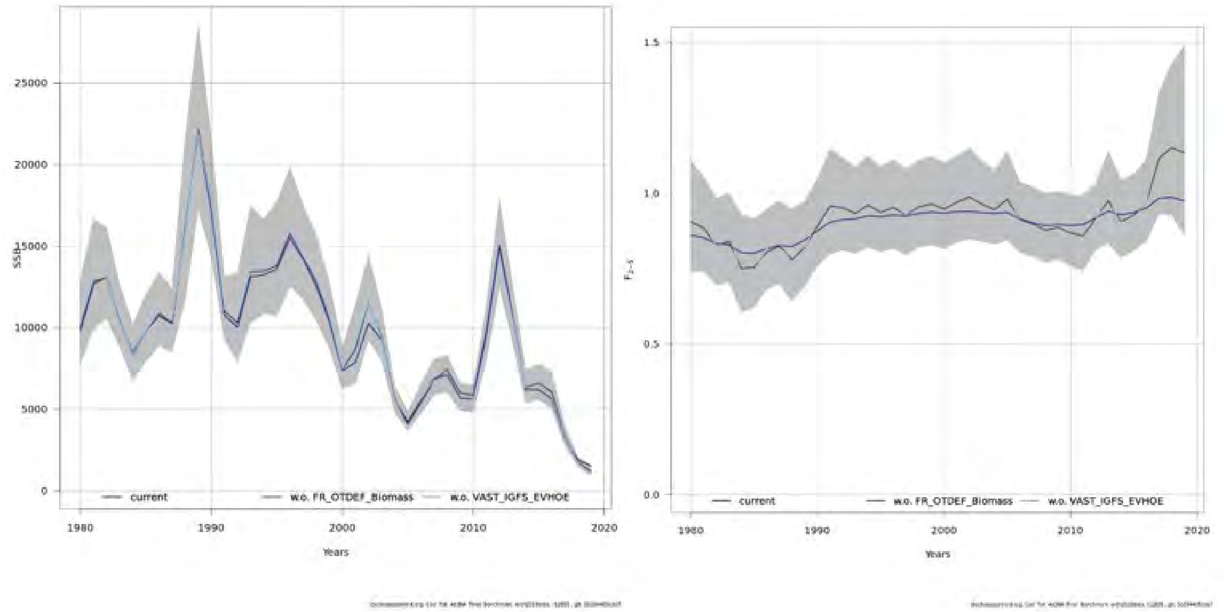

Figure 21. Results of the new accepted SAM assessment (data up to 2019) .Leave one out runs.

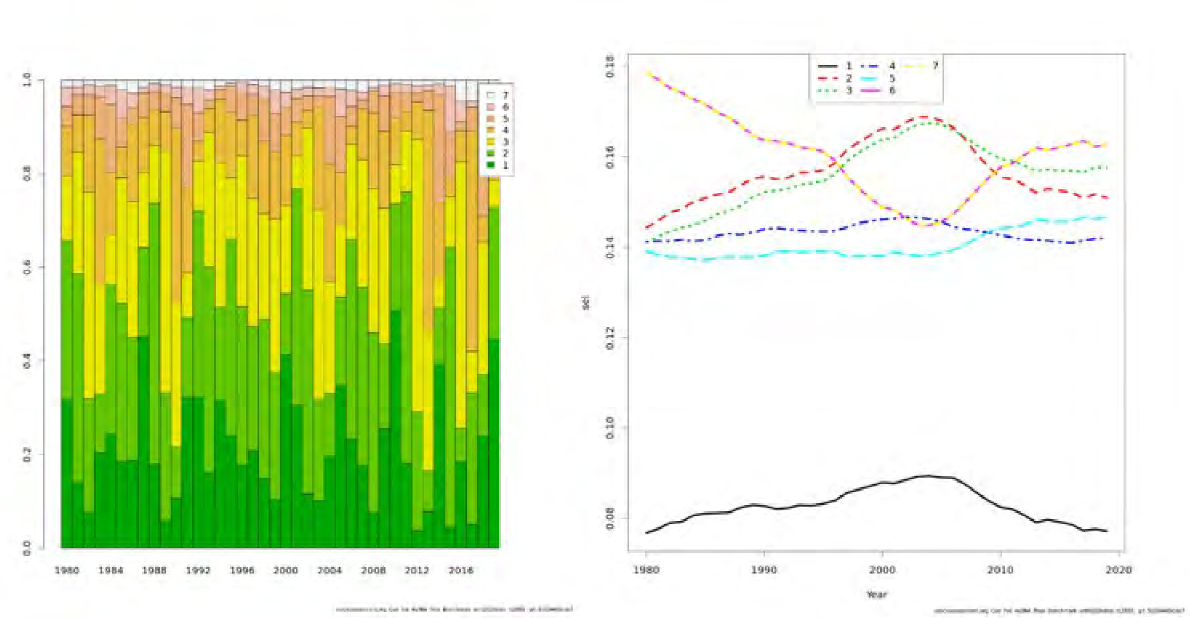

Figure 22. Results of the new accepted SAM assessment (data up to 2019). Selection pattern-at-age. Left panel: F divided by F_{bar}. Right panel: Biomass-at-age.

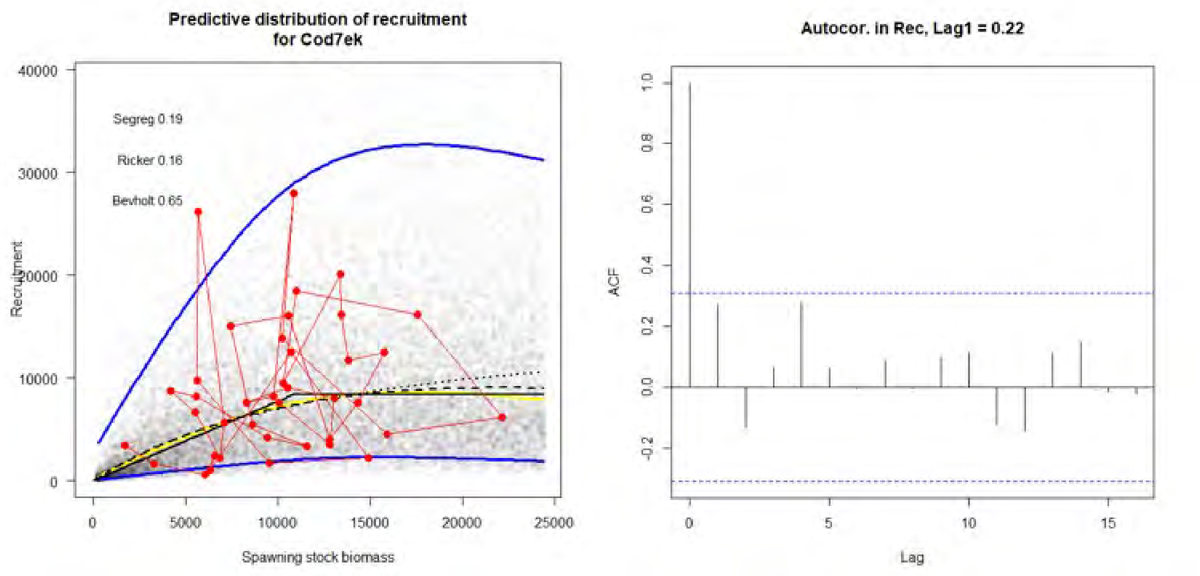

Figure 23. Stock–recruitment relationship for Celtic sea Cod.

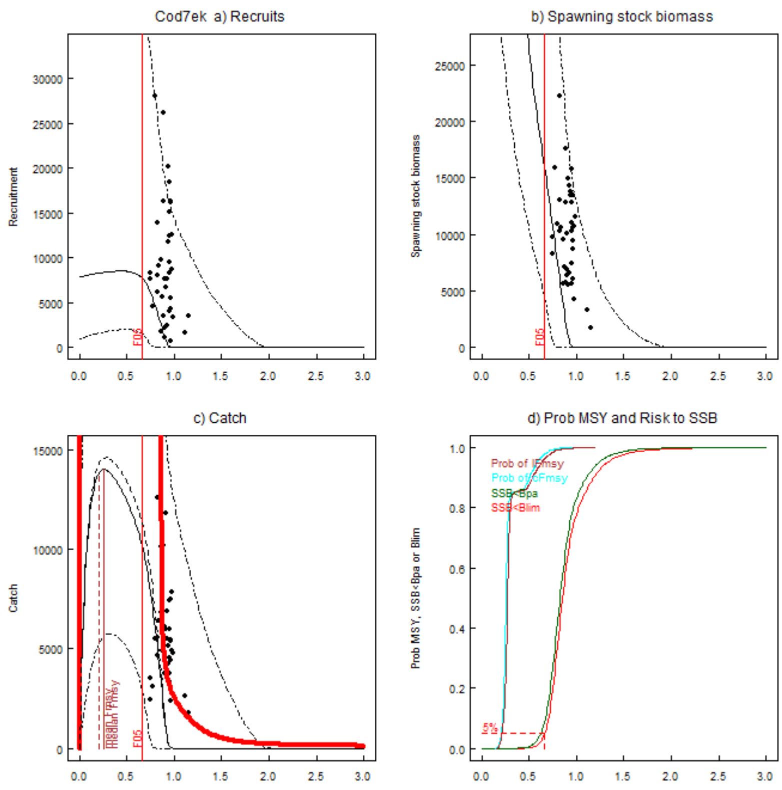

Figure 24. Overall stock 4 panel plot without MSY $B_{trigger}$.

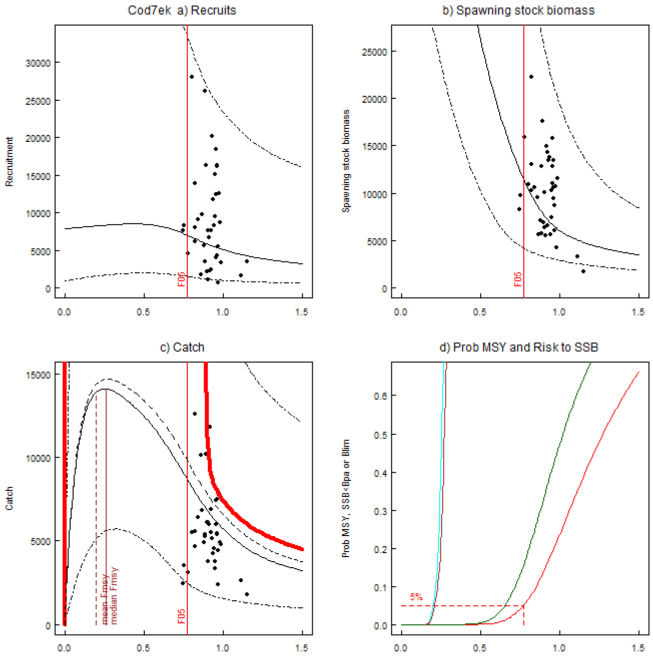

Figure 25. Overall stock 4 panel plot with MSY $B_{trigger}$.

Table 1. Mohns Rho indices calculated for each of the six XSA run using five years retro.

Mohns rho	Fbar	SSB
WGCSE2019 XSA	-0.38	0.48
XSAnewdata 2 indices	-0.29	0.27
XSAnewdata old survey only	-0.19	0.22
XSAnewdata commercial tuning only	-0.28	0.23
XSAnewdata new VAST survey only	-0.12	0.21
XSAnewdata VAST + commercial	-0.3	0.24

Table 2. Estimated recruitment, spawning–stock biomass (SSB), and average fishing mortality (with data up to 2018).

Year	R(age 1)	Low	High	SSB	Low	High	F_{bar} (2–5)	Low	High	TSB	Low	High
1980	16882	8223	34660	10003	7783	12855	0.863	0.759	0.981	19469	13686	27696
1981	8162	4019	16575	12984	9958	16931	0.861	0.757	0.978	20583	14887	28457
1982	3890	1902	7956	13302	10603	16689	0.856	0.742	0.986	17254	13541	21985
1983	9349	4568	19136	10584	8766	12780	0.855	0.738	0.990	15190	11990	19244
1984	10991	5312	22738	8652	6897	10853	0.848	0.706	1.018	15156	10979	20922
1985	8882	4372	18045	10067	7959	12733	0.849	0.705	1.021	16362	12042	22230
1986	9295	4594	18808	10941	8827	13561	0.856	0.727	1.007	16868	12883	22086
1987	31549	15760	63155	10375	8411	12797	0.861	0.742	0.999	24494	16736	35849
1988	15448	7777	30683	16820	12093	23395	0.864	0.743	1.005	30937	21076	45411
1989	4694	2399	9184	22329	17050	29243	0.875	0.774	0.989	28912	21932	38115
1990	5858	3036	11302	17234	13833	21472	0.888	0.804	0.981	20951	16923	25938
1991	14887	7757	28573	10838	9038	12997	0.900	0.813	0.996	17855	13778	23138
1992	17281	9012	33138	10155	7904	13048	0.906	0.815	1.008	20381	14612	28427
1993	8942	4587	17430	13287	10197	17314	0.911	0.818	1.014	21290	15770	28743
1994	18866	9817	36258	13305	10640	16637	0.917	0.818	1.028	22845	17311	30149
1995	15382	8052	29382	13733	10706	17616	0.919	0.823	1.026	24305	17849	33096
1996	11240	5884	21470	15609	12359	19712	0.924	0.825	1.035	24011	18381	31367
1997	11672	6089	22375	14367	11677	17678	0.927	0.830	1.034	21767	17010	27853
1998	7041	3670	13506	12679	10339	15549	0.932	0.829	1.048	18415	14386	23571
1999	3802	1982	7294	10503	8617	12802	0.936	0.830	1.054	13917	11186	17315
2000	14998	7983	28178	7428	6218	8875	0.937	0.834	1.052	14019	10524	18675
2001	13766	7403	25597	8512	6461	11216	0.939	0.834	1.058	17424	12670	23962

Year	R(age 1)	Low	High	SSB	Low	High	F_{bar} (2–5)	Low	High	TSB	Low	High
2002	4893	2786	8593	11541	9187	14499	0.941	0.834	1.062	17154	13319	22094
2003	3044	1913	4843	9461	7955	11250	0.939	0.842	1.048	12078	10148	14374
2004	3972	2495	6323	5556	4777	6461	0.936	0.849	1.032	7552	6469	8817
2005	8283	5641	12161	4188	3648	4808	0.934	0.851	1.026	7562	6364	8985
2006	8493	5569	12953	5724	4842	6766	0.926	0.856	1.001	10202	8416	12367
2007	6944	4661	10343	6992	5917	8263	0.920	0.851	0.995	11135	9305	13325
2008	2270	1532	3365	7114	6055	8358	0.915	0.842	0.995	9865	8328	11687
2009	5912	4017	8700	5597	4796	6532	0.913	0.838	0.994	8881	7538	10462
2010	27613	18973	40188	5608	4802	6550	0.910	0.831	0.996	15220	12137	19086
2011	9797	6661	14410	9686	8043	11664	0.909	0.830	0.996	17897	14650	21865
2012	1764	1195	2604	14719	12259	17672	0.913	0.843	0.990	18321	15401	21795
2013	2249	1513	3341	10597	8957	12537	0.918	0.847	0.996	12343	10592	14384
2014	13302	9002	19658	6522	5588	7613	0.916	0.842	0.996	12066	10012	14542
2015	1039	699	1547	6829	5714	8162	0.917	0.839	1.002	10231	8283	12636
2016	2634	1745	3975	6257	5166	7578	0.919	0.834	1.012	8491	7108	10143
2017	720	457	1135	3513	2945	4191	0.924	0.823	1.039	4353	3677	5153
2018	2231	1192	4174	2119	1714	2618	0.923	0.818	1.041	3216	2520	4104

Table 3. Estimated fishing mortality-at-age (with data up to 2018).

Year Age	1	2	3	4	5	6	7
1980	0.484	0.921	0.868	0.840	0.821	1.014	1.014
1981	0.484	0.921	0.868	0.837	0.816	1.007	1.007
1982	0.483	0.919	0.865	0.831	0.809	0.995	0.995
1983	0.483	0.919	0.865	0.829	0.807	0.990	0.990
1984	0.482	0.915	0.859	0.820	0.798	0.976	0.976
1985	0.482	0.917	0.861	0.820	0.797	0.973	0.973
1986	0.484	0.923	0.870	0.827	0.802	0.973	0.973
1987	0.486	0.927	0.878	0.833	0.808	0.973	0.973
1988	0.487	0.930	0.883	0.834	0.809	0.968	0.968
1989	0.490	0.940	0.897	0.844	0.818	0.970	0.970
1990	0.494	0.951	0.913	0.858	0.829	0.977	0.977
1991	0.497	0.960	0.927	0.870	0.842	0.985	0.985
1992	0.498	0.965	0.936	0.875	0.847	0.987	0.987
1993	0.500	0.970	0.944	0.879	0.850	0.986	0.986
1994	0.502	0.976	0.952	0.884	0.855	0.988	0.988
1995	0.502	0.978	0.956	0.886	0.857	0.985	0.985
1996	0.504	0.984	0.965	0.889	0.859	0.980	0.980
1997	0.506	0.989	0.972	0.891	0.856	0.969	0.969
1998	0.508	0.994	0.981	0.896	0.859	0.963	0.963
1999	0.509	0.998	0.987	0.898	0.860	0.957	0.957
2000	0.510	1.000	0.990	0.898	0.860	0.950	0.950
2001	0.510	1.001	0.993	0.900	0.864	0.948	0.948
2002	0.511	1.005	0.998	0.900	0.863	0.943	0.943
2003	0.511	1.004	0.998	0.896	0.860	0.936	0.936
2004	0.510	1.001	0.995	0.891	0.857	0.932	0.932
2005	0.510	0.998	0.994	0.888	0.858	0.934	0.934
2006	0.507	0.988	0.983	0.877	0.853	0.932	0.932
2007	0.503	0.980	0.976	0.872	0.853	0.936	0.936

Year Age	1	2	3	4	5	6	7
2008	0.499	0.970	0.969	0.868	0.854	0.940	0.940
2009	0.496	0.963	0.964	0.866	0.858	0.948	0.948
2010	0.493	0.957	0.960	0.863	0.859	0.953	0.953
2011	0.491	0.957	0.959	0.861	0.860	0.957	0.957
2012	0.491	0.960	0.961	0.865	0.867	0.969	0.969
2013	0.491	0.963	0.964	0.870	0.876	0.979	0.979
2014	0.490	0.961	0.961	0.867	0.873	0.975	0.975
2015	0.490	0.963	0.962	0.868	0.875	0.980	0.980
2016	0.490	0.965	0.964	0.869	0.877	0.985	0.985
2017	0.491	0.970	0.969	0.875	0.885	0.995	0.995
2018	0.492	0.970	0.968	0.873	0.881	0.990	0.990

Table 4. Estimated stock numbers-at-age (with data up to 2018).

Year Age	1	2	3	4	5	6	7
1980	16882	4646	667	297	90	73	22
1981	8162	6445	1330	234	96	31	24
1982	3890	3049	1885	400	79	35	14
1983	9349	1384	875	650	140	29	15
1984	10991	3570	378	262	215	49	12
1985	8882	4160	1050	138	97	80	21
1986	9295	3296	1209	373	57	41	31
1987	31549	3349	935	382	124	24	23
1988	15448	12465	919	308	116	44	15
1989	4694	5835	3747	337	117	41	19
1990	5858	1669	1662	1129	142	42	21
1991	14887	2120	444	493	347	60	21
1992	17281	5621	571	132	142	105	26
1993	8942	6518	1575	164	44	44	36
1994	18866	3150	1819	467	54	15	24
1995	15382	7123	818	511	149	19	11
1996	11240	5657	1981	273	155	52	8
1997	11672	4070	1526	575	104	47	15
1998	7041	4335	1077	424	188	44	18
1999	3802	2577	1172	299	125	65	21
2000	14998	1304	685	322	94	41	27
2001	13766	5705	325	189	101	33	25
2002	4893	5154	1574	99	60	29	18
2003	3044	1749	1263	404	31	20	15
2004	3972	1199	441	322	122	11	12
2005	8283	1683	285	142	98	41	9
2006	8493	2963	472	61	46	32	16
2007	6944	2860	794	147	20	16	17

Year Age	1	2	3	4	5	6	7
2008	2270	2362	736	225	51	7	11
2009	5912	848	654	221	75	18	6
2010	27613	2221	241	193	79	24	8
2011	9797	10292	660	87	65	28	9
2012	1764	3593	2937	208	34	23	13
2013	2249	613	979	846	72	14	11
2014	13302	820	175	284	278	22	6
2015	1039	5219	236	51	93	85	10
2016	2634	378	1335	75	17	31	29
2017	720	931	111	329	29	6	18
2018	2231	267	234	30	89	9	6

Table 5. Table of model parameters (with data up to 2018).

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-6.969	0.055	0.001	0.001	0.001
logFpar_1	-3.348	0.153	0.035	0.026	0.048
logFpar_2	-2.387	0.146	0.092	0.069	0.123
logFpar_3	-2.240	0.144	0.106	0.080	0.142
logSdLogFsta_0	-3.590	0.973	0.028	0.004	0.193
logSdLogN_0	0.002	0.136	1.002	0.764	1.314
logSdLogN_1	-1.749	0.294	0.174	0.097	0.313
logSdLogObs_0	-0.758	0.233	0.469	0.294	0.747
logSdLogObs_1	-0.946	0.235	0.388	0.242	0.622
logSdLogObs_2	-1.333	0.119	0.264	0.208	0.335
logSdLogObs_3	-1.821	0.229	0.162	0.102	0.256
logSdLogObs_4	-0.643	0.153	0.526	0.387	0.713
transfIRARdist_0	-0.605	0.523	0.546	0.192	1.554
itrans_rho_0	0.734	1.001	2.084	0.282	15.421

Table 6. Estimated recruitment, spawning–stock biomass (SSB), and average fishing mortality (with data up to 2019).

Year	R(age 1)	Low	High	SSB	Low	High	Fbar(2-5)	Low	High	TSB	Low	High
1980	16777	7755	36298	10072	7827	12960	0.906	0.742	1.106	19520	13218	28827
1981	7627	3658	15904	12842	9895	16665	0.885	0.741	1.057	20178	14473	28133
1982	3514	1697	7276	13051	10551	16143	0.826	0.695	0.983	16729	13270	21091
1983	8027	3964	16255	10544	8804	12628	0.840	0.705	1.001	14598	11716	18190
1984	9096	4514	18330	8306	6783	10171	0.750	0.606	0.928	13806	10271	18558
1985	7638	3809	15315	9780	7933	12058	0.754	0.621	0.916	15273	11573	20155
1986	8236	4053	16738	10887	8882	13345	0.804	0.682	0.948	16228	12583	20930
1987	27946	13971	55900	10277	8489	12443	0.824	0.698	0.974	22888	15816	33122
1988	13890	6931	27839	15904	11724	21573	0.779	0.641	0.947	28624	19771	41442
1989	4528	2233	9184	22169	17221	28539	0.820	0.691	0.974	28453	21900	36966
1990	6165	2985	12731	17586	14342	21564	0.891	0.760	1.045	21415	17391	26371
1991	16212	7862	33429	11012	9271	13080	0.957	0.798	1.148	18590	13761	25114
1992	18451	9108	37379	10284	7908	13374	0.952	0.811	1.118	21123	14455	30868
1993	9502	4624	19527	13417	10300	17478	0.933	0.800	1.087	21762	15746	30078
1994	20127	10057	40281	13451	10847	16679	0.961	0.821	1.125	23558	17339	32008
1995	16210	8145	32258	13803	10738	17742	0.936	0.806	1.088	24807	17767	34638
1996	11735	5943	23171	15768	12536	19834	0.953	0.817	1.111	24471	18426	32499
1997	12465	6317	24598	14335	11728	17522	0.927	0.795	1.080	22061	16970	28680
1998	7643	3881	15053	12844	10488	15729	0.954	0.821	1.109	18928	14554	24616
1999	4043	2067	7906	10607	8755	12850	0.964	0.829	1.123	14194	11332	17779
2000	16116	8498	30564	7421	6255	8804	0.947	0.815	1.101	14450	10638	19628
2001	15077	8017	28356	8655	6566	11408	0.970	0.837	1.123	18174	12947	25512
2002	5514	3128	9719	11585	9265	14486	0.987	0.848	1.150	17568	13537	22801
2003	3373	2136	5325	9462	7981	11217	0.964	0.839	1.108	12283	10301	14647
2004	4243	2650	6795	5591	4833	6467	0.945	0.830	1.076	7707	6598	9002
2005	8211	5688	11854	4212	3670	4834	0.980	0.844	1.138	7584	6398	8991
2006	8709	5809	13055	5552	4721	6531	0.912	0.803	1.037	9974	8276	12020
2007	6669	4549	9776	6878	5853	8082	0.899	0.791	1.021	10937	9185	13024

Year	R(age 1)	Low	High	SSB	Low	High	Fbar(2-5)	Low	High	TSB	Low	High
2008	2206	1519	3203	7095	6068	8297	0.877	0.770	0.999	9791	8314	11529
2009	5670	3923	8195	5684	4889	6608	0.887	0.781	1.006	8862	7579	10361
2010	26155	18247	37491	5613	4843	6505	0.868	0.759	0.993	14720	11874	18249
2011	9787	6784	14117	9527	7984	11369	0.858	0.743	0.992	17550	14487	21261
2012	1709	1179	2477	14921	12487	17830	0.917	0.812	1.035	18547	15647	21983
2013	2244	1536	3278	10725	9106	12632	0.975	0.834	1.139	12473	10736	14490
2014	12516	8631	18151	6329	5401	7416	0.906	0.786	1.044	11572	9633	13901
2015	1037	712	1511	6594	5582	7789	0.927	0.809	1.063	9814	8078	11924
2016	2436	1665	3564	6049	5030	7273	0.967	0.841	1.112	8148	6887	9640
2017	625	418	935	3311	2786	3934	1.115	0.932	1.334	4071	3447	4807
2018	1640	1081	2487	1748	1483	2060	1.151	0.927	1.429	2571	2174	3040
2019	3422	1791	6536	1181	906	1540	1.134	0.863	1.491	2809	1917	4118

Table 7. Estimated fishing mortality-at-age (with data up to 2019).

Year Age	1	2	3	4	5	6	7
1980	0.492	0.924	0.904	0.904	0.890	1.144	1.144
1981	0.484	0.908	0.887	0.881	0.863	1.104	1.104
1982	0.458	0.856	0.832	0.819	0.799	1.016	1.016
1983	0.466	0.871	0.847	0.832	0.809	1.023	1.023
1984	0.422	0.784	0.758	0.739	0.718	0.903	0.903
1985	0.425	0.791	0.765	0.742	0.719	0.900	0.900
1986	0.451	0.843	0.818	0.792	0.764	0.944	0.944
1987	0.462	0.863	0.840	0.812	0.783	0.957	0.957
1988	0.440	0.821	0.797	0.763	0.736	0.892	0.892
1989	0.464	0.867	0.844	0.800	0.770	0.921	0.921
1990	0.500	0.940	0.920	0.870	0.835	0.989	0.989
1991	0.532	1.005	0.988	0.935	0.901	1.059	1.059
1992	0.530	1.000	0.985	0.927	0.896	1.050	1.050
1993	0.522	0.984	0.968	0.904	0.874	1.020	1.020
1994	0.537	1.014	0.999	0.930	0.901	1.048	1.048
1995	0.525	0.990	0.974	0.905	0.877	1.015	1.015
1996	0.536	1.012	0.997	0.916	0.887	1.015	1.015
1997	0.527	0.994	0.978	0.888	0.848	0.957	0.957
1998	0.543	1.026	1.011	0.913	0.867	0.961	0.961
1999	0.550	1.040	1.026	0.920	0.871	0.952	0.952
2000	0.543	1.026	1.011	0.901	0.852	0.918	0.918
2001	0.553	1.047	1.035	0.923	0.875	0.935	0.935
2002	0.565	1.070	1.059	0.936	0.884	0.934	0.934
2003	0.555	1.049	1.039	0.911	0.858	0.901	0.901
2004	0.545	1.028	1.019	0.891	0.843	0.882	0.882
2005	0.564	1.063	1.058	0.921	0.878	0.921	0.921
2006	0.527	0.986	0.983	0.856	0.825	0.873	0.873
2007	0.514	0.962	0.964	0.845	0.825	0.879	0.879

Year Age	1	2	3	4	5	6	7
2008	0.494	0.925	0.937	0.828	0.818	0.880	0.880
2009	0.492	0.924	0.943	0.840	0.840	0.911	0.911
2010	0.476	0.897	0.920	0.824	0.832	0.910	0.910
2011	0.469	0.887	0.909	0.812	0.825	0.906	0.906
2012	0.495	0.942	0.969	0.869	0.888	0.983	0.983
2013	0.517	0.993	1.026	0.926	0.955	1.059	1.059
2014	0.484	0.928	0.954	0.858	0.884	0.979	0.979
2015	0.493	0.949	0.977	0.878	0.907	1.009	1.009
2016	0.511	0.988	1.019	0.915	0.946	1.057	1.057
2017	0.579	1.130	1.172	1.060	1.098	1.225	1.225
2018	0.598	1.168	1.214	1.093	1.127	1.250	1.250
2019	0.587	1.147	1.198	1.079	1.113	1.236	1.236

Table 8. Estimated stock numbers-at-age(with data up to 2019).

Year Age	1	2	3	4	5	6	7
1980	16777	4673	676	301	90	73	21
1981	7627	6345	1334	231	93	29	22
1982	3514	2847	1877	398	77	33	12
1983	8027	1292	870	658	141	29	14
1984	9096	3109	373	264	216	50	12
1985	7638	3642	1039	144	102	84	22
1986	8236	3005	1196	388	61	45	34
1987	27946	3085	924	389	130	26	25
1988	13890	11215	908	310	119	46	16
1989	4528	5478	3729	349	122	44	21
1990	6165	1663	1673	1161	147	44	23
1991	16212	2227	450	495	352	60	21
1992	18451	5895	576	129	138	103	24
1993	9502	6717	1593	162	42	42	34
1994	20127	3293	1842	466	53	15	23
1995	16210	7310	828	503	146	18	10
1996	11735	5827	2002	272	153	50	8
1997	12465	4120	1527	569	102	46	15
1998	7643	4523	1086	424	188	44	18
1999	4043	2701	1183	296	124	65	21
2000	16116	1341	689	317	92	41	27
2001	15077	5891	328	188	99	33	25
2002	5514	5382	1543	97	59	29	19
2003	3373	1874	1265	391	30	19	15
2004	4243	1250	455	318	119	11	12
2005	8211	1739	285	142	97	41	9
2006	8709	2802	467	60	46	31	17
2007	6669	2868	761	146	20	16	18

Year Age	1	2	3	4	5	6	7
2008	2206	2313	744	222	51	7	11
2009	5670	835	666	227	76	19	7
2010	26155	2097	253	197	81	25	8
2011	9787	9904	657	90	67	29	10
2012	1709	3659	2962	213	36	23	14
2013	2244	610	1002	852	73	14	11
2014	12516	803	169	277	269	21	6
2015	1037	4889	243	50	92	83	9
2016	2436	380	1281	75	16	30	27
2017	625	854	110	310	28	6	17
2018	1640	209	198	25	73	8	5
2019	3422	525	43	43	7	18	3

Table 9. Table of model parameters (with data up to 2019).

Parameter name	par	sd(par)	exp(par)	Low	High
logFpar_0	-6.967	0.053	0.001	0.001	0.001
logFpar_1	-3.176	0.159	0.042	0.030	0.057
logFpar_2	-2.304	0.154	0.100	0.073	0.136
logFpar_3	-1.979	0.154	0.138	0.102	0.188
logSdLogFsta_0	-2.448	0.485	0.086	0.033	0.228
logSdLogN_0	-0.023	0.132	0.977	0.751	1.272
logSdLogN_1	-1.853	0.288	0.157	0.088	0.279
logSdLogObs_0	-0.746	0.229	0.474	0.300	0.750
logSdLogObs_1	-1.044	0.249	0.352	0.214	0.579
logSdLogObs_2	-1.402	0.136	0.246	0.188	0.323
logSdLogObs_3	-1.754	0.225	0.173	0.110	0.271
logSdLogObs_4	-0.529	0.161	0.589	0.427	0.812
transfIRARdist_0	-1.072	0.493	0.342	0.128	0.918
itrans_rho_0	1.706	0.609	5.509	1.629	18.629

Table 10. Biological Reference Point Estimates from the various assumption tested with Eqsim.

Reference point	Current	SR Type 1	SR Type 2	SR type 5	SR Type 5	SR Type 5	SR Type 5	SR Type 5	SR Type 5 (final)	SR Type 5	SR Type 5
Blim	7300	5600	10600	2200	4200	4200	4200	4200	4200	4200	4200
Bpa	10300	6700	14700	2600	5800	5800	5800	5800	5800	5800	5800
Flim	0.80	1.05	0.82	1.7	1.22	0.97	1.12	1.14	1.13	1.15	0.9
Fpa	0.58	0.96	0.59	1.55	0.88	0.70	0.81	0.82	0.81	0.83	0.57
Fmsy	0.35	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
MSYBtrigger	10300	6700	14700	2600	5800	5800	5800	5800	5800	5800	5800
Settings											
WAA/Selectivity period	5	5	5	5	5	5	3	5	5	10	5
Sigma F	0.2	0.06	0.2	0.06	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sigma SSB	0.2	0.11	0.2	0.11	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Time series of R	1980-2018	1980-2018	1980-2018	1980-2018	1980-2018	2000-2018	1980-2018	1980-2018	1980-2019	1980-2018	2000-2018
Basis for Blim	Bloss = 1976	Blim = 2010	Seg regr point	Bloss = 2018	Bloss = 2005	Bloss = 2005	Bloss = 2005	Bloss = 2005	Bloss = 2005	Bloss = 2005	Bloss = 2005
Autocorr in Recruitment ?	False	False	False	False	False	False	True	True	True	True	True

3.4 References

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Appendix 1: R Script to derive reference points estimates

```
##~------------------------------------------------------------------------
# Code to take the SAM assessment results from stockassessment.org (new TMB fits),
# and run ICES standard EqSim reference point analyses
# D.C.M.Miller
#
# Celtic sea cod version : Lionel Pawlowski
##~------------------------------------------------------------------------

rm(list=ls())
## Create matrix for reference points
refPts <- matrix(NA,nrow=1,ncol=9, dimnames=list("value",c("MSYBtrigger","5thPerc_SSBmsy","Bpa","Blim","Fpa","Flim", "Fp05","Fmsy_unconstr","Fmsy"))) # "Fmsy_unconstr" is the Fmsy value without any precautionary considerations (i.e. ignore 5% P(SSB<Blim))
# Note: stores teh 'uncontrained Fmsy as well (i.e. without PA considerations)



##~------------------------------------------------------------------------
##        SECTION WHERE CHANGES NEED TO BE MADE
##~------------------------------------------------------------------------

path <- "c:\\repointCOD\\"   # folder were the code is and where results will be saved (in a subfolder)
runName <- "Final_Blim5600_5yrs_sigma0.2_autoT_w2019" # (no spaces) Results will be saved in a subfolder with this name (so make it descriptive)## Save plots?
savePlots <- T

stockName <- "Cod7ek"                                   # Used only in plots (i.e. titles) and when saving data (i.e. file names)
SAOAssessment <- "Cod_7ek_4a3NA_Final_Benchmark_with2019data"   # = stock name in stockassesssment.org

user <- 3                         # User 3 = Guest (ALWAYS GETS THE LATEST COMMITTED VERSION); User 2 = Anders
ages <- 1:7
years <- 1980:2019
assYear <-2020
meanFages <- c(2:5)
sigmaF <- 0.2                     # Gets from last year estimated in the assessment (SAM), unless this is specified as a value i.e. !is.na()
sigmaSSB <- 0.2                   # Gets from last year estimated in the assessment (SAM), unless this is specified as a value i.e. !is.na()
refPts[,"Blim"]  <- 4200          # Insert value for Blim, code below will calculate Bpa and MSY Btrigger

# Which years (SSB years, not recruitment years) to exclude from the SRR fits
#rmSRRYrs <- c(1980:1999)                          # leave as 'c()' if the full time-series is to be used (default)
rmSRRYrs <- c()

# Autocorrelation in recruitment?
```

```
rhoRec <- T                              # default=F

## Weight-at-age and selectivity
numAvgYrsB <- 5                          # Number of recent years to use for WAA
bioConst   <- TRUE                         # Constant/average WAA (TRUE) or resampling from the
years specified (FALSE)
numAvgYrsS <- 5                          # Number of recent years to use for selectivity
selConst   <- TRUE                      # Constant/average selectivity (TRUE) or resampling from
the years specified (FALSE)

## Forecast error (see Guidance document for details on calculation of these values)
# F
cvF  <- 0.212                            # Default = 0.212
phiF <-        0.423                           # Default = 0.423
# SSB
cvSSB <- 0                               # Default = 0
phiSSB <- 0                              # Default = 0


# 5th percentile of SSB in the final year of the assessment
SSB05<-0                                # used in MSY Btrigger calculation. If set at 0, ignored





##~-----------------------------------------------------------------------------
## Simulation settings
# Number of sims
noSims <- 1001                              # Choose a suitable number, final run should use at
least 1000, test runs coudl be done with less to save time

# SR models to use
appModels <- c("Segreg","Ricker","Bevholt")   # SRR models to use

# If using FLStock object:
useFLStock <- F
# .rdata file with FLSTOCK object should be in the directory 'path' (specified above)
if (useFLStock) {
  load(paste(path,"FLStock_object.rdata")) #change name to match .rdata file with the FLStock object
  stk <- stock   # assign the FLStock object in the .rdata file to 'stk
}


##~-----------------------------------------------------------------------------
##        NO CHANGES NEED TO BE MADE BELOW THIS POINT
##~-----------------------------------------------------------------------------
```

```
##~-------------------------------------------------------------------------
## Set working directory
setwd(path)
# create subfolder
shell(paste("md", runName, sep=" "))
setwd(paste(path,runName,"/",sep=""))

# Load libraries
#require(devtools)
#devtools::install_github("fishfollower/SAM/stockassessment")  # run this once if stoassessment has not been installed before
library(stockassessment)
#install_github("ices-tools-prod/msy") # run this once if msy has not been installed before
library(msy)
require(FLCore)

##~-------------------------------------------------------------------------
if(!useFLStock) {
## Get fit from stockassessment.org
url <- paste("https://www.stockassessment.org/datadisk/stockassessment/userdirs/user",user,"/",SAOAs-sessment,"/run/", sep="")
download.file(paste(url,"model.RData",sep=""), "model.RData")
load("model.RData") # loads 'fit' to the workspace (last baserun conducted on stockassessment.org)

# Check model fit
if (savePlots) x11()
plot(fit)
if (savePlots) savePlot(paste("01_",stockName,"_Assessment.png"),type="png")
if (savePlots) dev.off()
## Stock-recruitment plots
df <- data.frame(summary(fit))
ds <- dim(df)
rec <- df$R.age.1.[2:ds[1]]/1000
ssb <- df$SSB[1:(ds[1]-1)]/1000
yr  <- rownames(df)[1:(ds[1]-1)]

if (savePlots) x11()
plot(ssb,rec,type='l',ylim=c(0,1.1*max(rec)),xlim=c(0,1.1*max(ssb)),main=stock-Name,xlab="SSB",ylab="Recruits at age 1",cex.lab=1.5); text(ssb,rec,yr,cex=.8)
if (savePlots) savePlot(paste("02_",stockName,"_SRR.png"),type="png")
if (savePlots) dev.off()
if (savePlots) x11()
plot(yr,log(rec/ssb),type='b',main=stockName,xlab="Year",ylab="ln(Recruits/SSB) ",cex.lab=1.5)
if (savePlots) savePlot(paste("03_",stockName,"_SPR.png"),type="png")
if (savePlots) dev.off()

## Get sigmaSSB and sigmaF from the assessment fit
if (is.na(sigmaSSB)) {
  idx <- names(fit$sdrep$value) == "logssb"
  sigmaSSB <- fit$sdrep$sd[idx][fit$data$years==max(years)] # Use last year in status table
  #sigmaSSB <- fit$sdrep$sd[idx][fit$data$years==(max(years)-1)]
```

```
}
if (is.na(sigmaF)) {
  idx <- names(fit$sdrep$value) == "logfbar"
  #sigmaF <- fit$sdrep$sd[idx][fit$data$years==max(years)]
  sigmaF <- fit$sdrep$sd[idx][fit$data$years==(max(years)-1)]  # Use last year in status table
}

##~--------------------------------------------------------------------------------
## Create FLStock object  (Note: if the assessment has been done outside of stockassessment.org, the
code can be adapted here to simply read in the stock object with final assessment results)
flq <- FLQuant(NA, dimnames = list(age = ages, year = years), quant='age')
stk <- FLStock(stock.n = flq,
               name = stockName,
               desc = "FLStock_from_SAM")
units(stk)[1:17]    <- as.list(c(rep(c("tonnes","thousands","kg"),4), rep("NA",2),"f",rep("NA",2)))
# Mean F range
range(stk)[c("minfbar","maxfbar")]    <- c(min(meanFages), max(meanFages))
# Last age a plusgroup
stk  <- setPlusGroup(stk,stk@range["max"])

### Read raw data from stockassessment.org
url <- paste("https://www.stockassessment.org/datadisk/stockassessment/userdirs/user",user,"/",SAOAs-
sessment,"/data/", sep="")
filestoget <- c("cn.dat", "cw.dat", "dw.dat", "lf.dat", "lw.dat",
                "mo.dat", "nm.dat", "pf.dat", "pm.dat", "sw.dat",
                "survey.dat")
d <- lapply(filestoget, function(f)download.file(paste(url,f,sep=""), f))

# add catches
#catch.n(stk)[,ac(years[1]:(max(years)-1))] <- landings.n(stk)[,ac(years[1]:(max(years)-1))] <- tmp-
Cat; rm(tmpCat)
tmpCat <- t(read.ices("cn.dat"))
tmpLF <- t(read.ices("lf.dat"))
dms <- list(intersect(ac(ages),dimnames(tmpCat)[[1]]),intersect(years,dimnames(tmpCat)[[2]]))
catch.n(stk)[dms[[1]],dms[[2]]] <- tmpCat[dms[[1]],dms[[2]]]
catch.n(stk)[is.na(catch.n(stk))] <- 0
landings.n(stk)[dms[[1]],dms[[2]]] <- tmpCat[dms[[1]],dms[[2]]] * tmpLF[dms[[1]],dms[[2]]]
landings.n(stk)[is.na(landings.n(stk))] <- 0
discards.n(stk)[] <- catch.n(stk) - landings.n(stk)
rm(tmpCat, dms)

#catch.wt(stk)[,ac(years[1]:(max(years)-1))] <- t(read.ices("cw.dat"))[-1,]
tmpCwt <- t(read.ices("cw.dat"))
dms <- list(intersect(ac(ages),dimnames(tmpCwt)[[1]]),intersect(years,dimnames(tmpCwt)[[2]]))
catch.wt(stk)[dms[[1]],dms[[2]]] <- tmpCwt[dms[[1]],dms[[2]]]; rm(tmpCwt,dms)
catch.wt(stk)[is.na(catch.wt(stk))] <- 0.001  # Replace NA weights with something low
catch.wt(stk)[catch.wt(stk)==0] <- 0.001  # Replace 0 weights with something low

tmpLwt <- t(read.ices("lw.dat"))
dms <- list(intersect(ac(ages),dimnames(tmpLwt)[[1]]),intersect(years,dimnames(tmpLwt)[[2]]))
landings.wt(stk)[dms[[1]],dms[[2]]] <- tmpLwt[dms[[1]],dms[[2]]]; rm(tmpLwt,dms)
```

```
landings.wt(stk)[is.na(landings.wt(stk))] <- 0.001  # Replace NA weights with something low
landings.wt(stk)[landings.wt(stk)==0] <- 0.001  # Replace 0 weights with something low

tmpDwt <- t(read.ices("cw.dat"))
dms <- list(intersect(ac(ages),dimnames(tmpDwt)[[1]]),intersect(years,dimnames(tmpDwt)[[2]]))
discards.wt(stk)[dms[[1]],dms[[2]]] <- tmpDwt[dms[[1]],dms[[2]]]; rm(tmpDwt,dms)
discards.wt(stk)[is.na(discards.wt(stk))] <- 0.001  # Replace NA weights with something low
discards.wt(stk)[discards.wt(stk)==0] <- 0.001  # Replace 0 weights with something low

discards(stk) <- computeDiscards(stk)
landings(stk) <- computeLandings(stk)
catch(stk) <- computeCatch(stk)



# add bio
tmp <- t(read.ices("mo.dat")); dms <- list(intersect(ac(ages),dimnames(tmp)[[1]]),inter-
sect(years,dimnames(tmp)[[2]]))
mat(stk)[dms[[1]],dms[[2]]] <- tmp[dms[[1]],dms[[2]]]; rm(tmp,dms)
tmp <- t(read.ices("nm.dat")); dms <- list(intersect(ac(ages),dimnames(tmp)[[1]]),inter-
sect(years,dimnames(tmp)[[2]]))
m(stk)[dms[[1]],dms[[2]]] <- tmp[dms[[1]],dms[[2]]]; rm(tmp,dms)
tmp <- t(read.ices("pf.dat")); dms <- list(intersect(ac(ages),dimnames(tmp)[[1]]),inter-
sect(years,dimnames(tmp)[[2]]))
harvest.spwn(stk)[dms[[1]],dms[[2]]] <- tmp[dms[[1]],dms[[2]]]; rm(tmp,dms)
tmp <- t(read.ices("pm.dat")); dms <- list(intersect(ac(ages),dimnames(tmp)[[1]]),inter-
sect(years,dimnames(tmp)[[2]]))
m.spwn(stk)[dms[[1]],dms[[2]]] <- tmp[dms[[1]],dms[[2]]]; rm(tmp,dms)

# Update stock and fisheries from SAM fit
stock.n(stk)[] <- exp(fit$pl$logN)
tmp <- t(read.ices("sw.dat")); dms <- list(intersect(ac(ages),dimnames(tmp)[[1]]),inter-
sect(years,dimnames(tmp)[[2]]))
stock.wt(stk)[dms[[1]],dms[[2]]] <- tmp[dms[[1]],dms[[2]]]; rm(tmp,dms)
stock.wt(stk)[is.na(stock.wt(stk))] <- 0.001  # Replace NA weights with something low
stock.wt(stk)[stock.wt(stk)==0] <- 0.001  # Replace 0 weights with something low
stock(stk)[] <- computeStock(stk)
# harvest is unique to the set cod (i.e. depends on config)
# check conf. file for which F states are estimated
Fstates <- fit$conf$keyLogFsta[1,]
Fstates_start <- which(Fstates==0)
Fstates_end   <- which(Fstates==max(Fstates))
harvest(stk)[Fstates_start:min(Fstates_end),] <- exp(fit$pl$logF)
harvest(stk)[Fstates_end[-1],] <- harvest(stk)[Fstates_end[1],]
harvest(stk)[Fstates==-1,] <- 0


###
landings.n(stk)<-catch.n(stk)
landings(stk)<-catch(stk)

} #end of !useFLStock loop
```

```
# ## Selectivity curves
# if (savePlots) x11()
# meanF <- apply(harvest(stk)[meanFages,],2, "mean")
# sel <- sweep(harvest(stk),2,meanF,"/")
#  plot(ages,sel[,ac(max(years)-1)],  type="l",  ylim=c(0,max(sel)),  xlab="Age",  ylab="Selectivity", main="Selectivity")
# for (i in ac(1997:2015)) lines(ages,sel[,i], col=i)
# lines(ages,apply(sel[,ac(2014:2016)],1,mean), col=1, lwd=5)
# lines(ages,apply(sel[,ac(2012:2016)],1,mean), col=2, lwd=5)
# lines(ages,apply(sel[,ac(2007:2016)],1,mean), col=3, lwd=5)
# lines(ages,apply(sel[,ac(1997:2016)],1,mean), col=4, lwd=5)
# legend("topleft", legend=c("Mean last 3yrs","Mean last 5yrs","Mean last 10yrs","Mean last 20yrs"), lwd=5, col=1:4, bty="n")
# #legend("bottomright", legend=c(1997:2016), lwd=1, col=1:20, bty="n")
# if (savePlots) savePlot(paste("00_",stockName,"_Selectivity.png"),type="png")
# if (savePlots) dev.off()
#
# ## Weight-at-age
# if (savePlots) x11()
#  plot(ages,stock.wt(stk)[,ac(max(years)-1)],  type="l",  ylim=c(0,max(stock.wt(stk))),  xlab="Age", ylab="Weight (kg)", main="Weight-at-age")
# for (i in ac(1997:2015)) lines(ages,stock.wt(stk)[,i], col=i)
# lines(ages,apply(stock.wt(stk)[,ac(2014:2016)],1,mean), col=1, lwd=5)
# lines(ages,apply(stock.wt(stk)[,ac(2012:2016)],1,mean), col=2, lwd=5)
# lines(ages,apply(stock.wt(stk)[,ac(2007:2016)],1,mean), col=3, lwd=5)
# lines(ages,apply(stock.wt(stk)[,ac(1997:2016)],1,mean), col=4, lwd=5)
# legend("topleft", legend=c("Mean last 3yrs","Mean last 5yrs","Mean last 10yrs","Mean last 20yrs"), lwd=5, col=1:4, bty="n")
# #legend("bottomright", legend=c(1997:2016), lwd=1, col=1:20, bty="n")
# if (savePlots) savePlot(paste("00_",stockName,"_WAA.png"),type="png")
# if (savePlots) dev.off()


# year range
minYear <- range(stk)["minyear"]; maxYear <- range(stk)["maxyear"]


### Trim off last year of the stock object (only if incomplete data for last assessment year)
# origStk <- stk
# stk <- window(stk, start=minYear, end=(maxYear-1))


###-------------------------------------------------------------------------------
### Set SRR Models for the simulations
#Models: "segreg","ricker", "bevholt"; or specials: "SegregBlim/Bloss" (breakpt. Blim/Bloss)


## SRR years
# Which years (SSB years) to exclude from the SRR fits
# Keep all except last 2 (poorly estimated rec/selec)
rmSRRYrs <- union(rmSRRYrs, c(maxYear-1,maxYear))  # This removes last two years
srYears <- setdiff(c(minYear:(maxYear-1)),rmSRRYrs)
```

```
## determine segreg model with Blim breakpoint and (roughly) geomean rec above this
SegregBlim  <- function(ab, ssb) log(ifelse(ssb >= refPts[,"Blim"], ab$a * refPts[,"Blim"], ab$a *
ssb))

## determine segreg model with Bloss breakpoint and (roughly) geomean rec above this
SegregBloss  <- function(ab, ssb) log(ifelse(ssb >= min(ssb(stk)), ab$a * min(ssb(stk)), ab$a * ssb))


###~~~~~~~~~~~~~
## autocorrelation
ACFrec <- acf(rec(stk)[,ac(srYears)])
acfRecLag1 <- round(ACFrec$acf[,,][2],2)
if (savePlots) x11()
acf(rec(stk), plot=T, main=paste("Autocor. in Rec, Lag1 =",acfRecLag1,sep=" "))
if (savePlots) savePlot(paste("04_",stockName,"_SRautocor.png"),type="png")
if (savePlots) dev.off()


# Set a max for AC?

###-----------------------------------------------------------------------------
## Fit SRRs
FIT_segregBlim <- eqsr_fit(stk,nsamp=noSims, models = "SegregBlim", remove.years=rmSRRYrs)
#FIT_segregBloss <- eqsr_fit(stk,nsamp=noSims, models = "SegregBloss", remove.years=rmSRRYrs)
FIT_segreg <- eqsr_fit(stk,nsamp=noSims, models = "Segreg", remove.years=rmSRRYrs)
#FIT_segregAR1 <- eqsr_fit(stk,nsamp=noSims, models = "segregAR1", remove.years=rmSRRYrs)
FIT_All <- eqsr_fit(stk,nsamp=noSims, models = appModels, remove.years=rmSRRYrs)

# save model proportions and parameters:
write.csv(FIT_segregBlim$sr.det, paste(stockName,"_FIT_segregBlim_SRpars.csv",sep=""))
#write.csv(FIT_segregBloss$sr.det, paste(stockName,"_FIT_segregBloss_SRpars.csv",sep=""))
write.csv(FIT_segreg$sr.det, paste(stockName,"_FIT_segreg_SRpars.csv",sep=""))
write.csv(FIT_All$sr.det, paste(stockName,"_FIT_All_SRpars.csv",sep=""))

# Plot raw SRR results
if (savePlots) x11()
eqsr_plot(FIT_segreg,n=2e4)
if (savePlots) savePlot(paste("05ai_",stockName,"_segreg.png"),type="png")
if (savePlots) dev.off()

if (savePlots) x11()
eqsr_plot(FIT_All,n=2e4)
if (savePlots) savePlot(paste("05b_",stockName,"_SRRall.png"),type="png")
if (savePlots) dev.off()


###-----------------------------------------------------------------------------
## Run simulations
###-----------------------------------------------------------------------------
```

```
###-----------------------------------------------------------------------------
## Calculate Bpa based on sigmaSSB
refPts[,"Bpa"]  <- refPts[,"Blim"]*exp(sigmaSSB*1.645) # Used as Btrigger

###-----------------------------------------------------------------------------
## Simuation 1 - get Flim
# Flim is derived from Blim by simulating the stock with segmented regression S-R function with the point of inflection at Blim
# Flim = the F that, in equilibrium, gives a 50% probability of SSB > Blim.
# Note this simulation should be conducted with:
#  fixed F (i.e. without inclusion of a Btrigger)
#  without inclusion of assessment/advice errors.

SIM_segregBlim <- eqsim_run(FIT_segregBlim,  bio.years = c(maxYear-numAvgYrsB, maxYear-1), bio.const = TRUE,
                            sel.years = c(maxYear-numAvgYrsS, maxYear-1), sel.const = TRUE,
                            Fcv=0, Fphi=0, SSBcv=0,
                            rhologRec=rhoRec,
                            Btrigger = 0, Blim=refPts[,"Blim"],Bpa=refPts[,"Bpa"],
                            Nrun=200, Fscan = seq(0,2.0,by=0.01),verbose=T)

# save MSY and lim values
tmp1 <- t(SIM_segregBlim$Refs2)
write.csv(tmp1, paste("EqSim_",stockName,"_SegregBlim_eqRes.csv",sep=""))
refPts[,"Flim"] <- tmp1["F50","catF"]

# Fpa is derived from Flim in the reverse of the way Bpa is derived from Blim. i.e.:
tmpFpa <- refPts[,"Flim"] * exp(-sigmaF * 1.645)
if (tmpFpa<0.2) refPts[,"Fpa"] <- round(tmpFpa , 3) else refPts[,"Fpa"] <- round(tmpFpa , 2)
if  (refPts[,"Flim"]<0.2)  refPts[,"Flim"]  <-  round(refPts[,"Flim"],3)  else  refPts[,"Flim"]  <- round(refPts[,"Flim"],2)

###-----------------------------------------------------------------------------
## Simuation 2a - get initial Fmsy
# FMSY should initially be calculated based on:
#     a constant F evaluation
#     with the inclusion of stochasticity in population and exploitation
#     as well as assessment/advice error.
#     Appropriate SRRs should be specified (here using all 3)

SIM_All_noTrig <- eqsim_run(FIT_All,  bio.years = c(maxYear-numAvgYrsB, maxYear-1), bio.const = FALSE,
                            sel.years = c(maxYear-numAvgYrsS, maxYear-1), sel.const = FALSE,
                            Fcv=cvF, Fphi=phiF, SSBcv=cvSSB,
                            rhologRec=rhoRec,
                            Btrigger = 0, Blim=refPts[,"Blim"],Bpa=refPts[,"Bpa"],
                            Nrun=200, Fscan = seq(0,3.0,by=0.01),verbose=T)

# save MSY and lim values
tmp2 <- t(SIM_All_noTrig$Refs2)
write.csv(tmp2, paste("EqSim_",stockName,"_AllnoTrig_eqRes.csv",sep=""))
Fmsy_tmp <- tmp2["medianMSY","lanF"]
```

```
# save Equilibrium plots
if (savePlots) x11()
eqsim_plot(SIM_All_noTrig,catch=TRUE)
if (savePlots) savePlot(paste("06_",stockName,"_AllnoTrig_eqMSYplots.png"),type="png")
if (savePlots) dev.off()

# To ensure consistency between the precautionary and MSY frameworks, FMSY is not allowed to be above Fpa
refPts[,"Fmsy_unconstr"] <- Fmsy_tmp
if (Fmsy_tmp > refPts[,"Fpa"]) {
  print("WHOAAA, Fmsy > Fpa!")
  refPts[,"Fmsy"] <- refPts[,"Fpa"]
} else {
  refPts[,"Fmsy"] <- Fmsy_tmp
}


###-----------------------------------------------------------------------------
## MSY Btrigger
data.05<-SIM_segregBlim$rbp
x.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$Ftarget
b.05 <- data.05[data.05$variable == "Spawning stock biomass", ]$p05
plot(b.05~x.05, ylab="SSB", xlab="F")
b.lm <- loess(b.05 ~ x.05)
refPts[,"5thPerc_SSBmsy"] <- predict(b.lm, refPts[,"Fmsy"])
# check if F<Fmsy last 5 years
if (sum(as.numeric(fbar(stk)[,ac((maxYear-4):maxYear)])<=refPts[,"Fmsy"])<3) {
  refPts[,"MSYBtrigger"]  <- refPts[,"Bpa"]
} else {
# Check if Bmsy_05>Bpa
  refPts[,"MSYBtrigger"] <- ifelse(refPts[,"5thPerc_SSBmsy"]>refPts[,"Bpa"],refPts[,"5thPerc_SSBmsy"],refPts[,"Bpa"])
# Check if Bmsy_05 > SSBcur_05
  refPts[,"MSYBtrigger"] <-ifelse(refPts[,"5thPerc_SSBmsy"] > SSB05,max(refPts[,"Bpa"],SSB05),refPts[,"5thPerc_SSBmsy"])
  }


###-----------------------------------------------------------------------------
## Simuation 2b - get final Fmsy
# MSY Btrigger should be selected to safeguard against an undesirable or unexpected low SSB when fishing at FMSY
# The ICES MSY AR should be evaluated to check that the FMSY and MSY Btrigger combination adheres to precautionary considerations:
#       in the long term, P(SSB<Blim)<5%
# The evaluation must include:
#       realistic assessment/advice error
#       stochasticity in population biology and fishery exploitation.
#       Appropriate SRRs should be specified (here using all 3)

SIM_All_Trig <- eqsim_run(FIT_All,  bio.years = c(maxYear-numAvgYrsB, maxYear-1), bio.const = FALSE,
```

```
                          sel.years = c(maxYear-numAvgYrsS, maxYear-1), sel.const = FALSE,
                          Fcv=cvF, Fphi=phiF, SSBcv=cvSSB,
                          rhologRec=rhoRec,
                          Btrigger = refPts[,"MSYBtrigger"], Blim=refPts[,"Blim"],Bpa=refPts[,"Bpa"],
                          Nrun=200, Fscan = seq(0,1.5,by=0.01),verbose=T)

# save MSY and lim values
tmp3 <- t(SIM_All_Trig$Refs2)
write.csv(tmp3, paste("EqSim_",stockName,"_AllTrig_eqRes.csv",sep=""))
refPts[,"Fp05"] <- tmp3["F05","catF"]

# save Equilibrium plots
if (savePlots) x11()
eqsim_plot(SIM_All_Trig,catch=TRUE)
if (savePlots) savePlot(paste("07_",stockName,"_AllTrig_eqMSYplots.png"),type="png")
if (savePlots) dev.off()

# If the precautionary criterion (FMSY < Fp.05) evaluated is not met, then FMSY should be reduced to
Fp.05.
if (refPts[,"Fmsy"] > refPts[,"Fp05"]) {
  print("WHOAAA, Fmsy > Fp05!") # If Fmsy > Fp05, Fmsy = Fp05
  if (refPts[,"Fp05"]<0.2) refPts[,"Fmsy"] <- round(refPts[,"Fp05"],3) else refPts[,"Fmsy"] <-
round(refPts[,"Fp05"],2)
} else {
  if (refPts[,"Fmsy"]<0.2) refPts[,"Fmsy"] <- round(refPts[,"Fmsy"],3) else refPts[,"Fmsy"] <-
round(refPts[,"Fmsy"],2) # Otherwise keep value from constant F simulation (which has been checked
against Fpa)
}
if (refPts[,"Fp05"]<0.2) refPts[,"Fp05"] <- round(refPts[,"Fp05"],3) else refPts[,"Fp05"] <-
round(refPts[,"Fp05"],2)



###-------------------------------------------------------------------------------
## Save reference points
write.csv(refPts, paste(stockName,"_RefPts.csv",sep=""))

###-------------------------------------------------------------------------------
## Save run settings
SRused <- appModels[1]
if (length(appModels)>1) for (i in 2:length(appModels)) SRused <- paste(SRused,appModels[i],sep="_")
SRyears_min <- min(srYears); SRyears_max <- max(srYears)
setList <- c("stockName", "runName", "SAOAssessment", "sigmaF", "sigmaSSB", "noSims", "SRused",
"SRyears_min",
             "SRyears_max", "acfRecLag1","rhoRec", "numAvgYrsB", "numAvgYrsS", "cvF", "phiF", "cvSSB",
"phiSSB")
runSet <- matrix(NA,ncol=1, nrow=length(setList), dimnames=list(setList,c("Value")))
for (i in setList) runSet[which(setList==i),] <- eval(parse(text = i))

write.csv(runSet, paste(stockName,"_RunSettings.csv",sep=""))

###-------------------------------------------------------------------------------
```

```
## Save workspace
save.image(file=paste(stockName,"_",maxYear,"_EqSim_Workspace.Rdata",sep=""))
```

4 Haddock in divisions 7.b,c,e–k

The following report details the development of the stock assessment for Celtic Sea haddock (had.27.7b–k) undertaken during the Benchmark WKCELTIC. The age-structured assessment used between 2013 and 2019 to assess the state of the stock was put through the ICES benchmark process in 2012.

4.1 Stock assessment data

4.1.1 Catch-at-age data

Member States (MS) fishing the Celtic Sea haddock stock comprise primarily Belgium, France, Ireland and the UK. The ICES meeting WKCELTIC 1 reviewed each MS approach to processing catch and observer data in applying national catch-at-age raising, and recommended standard approaches be implemented. Following this meeting, MS were requested to review their data submissions and re-submit/ upload their data to the ICES InterCatch database.

Following national re-submission of catch-at-age data, all data were downloaded from InterCatch and processed jointly, through a standardised approach, across the time frame 2002 to 2019.

Almost all catch data submitted were classified by year (Figure 1), with sampling showing similar patterns across countries, years and ages (Figure 2).

The data processing approach applied the observer details of age–length information relative to sample numbers across catch relative to country, area, quarter and fleet hierarchically. Discards were estimated from landings where no direct observation was available through time-series of three raising factors, dependent upon the available catch detail and sample, at the resolution of:

i. Year, Country and Gear (Figure 3)
ii. Year and Gear (Figure 4)
iii. Year (Figure 5)

With gears set to: GNS_DEF, OTB_CRU, OTB_DEF, TBB_DEF and MIS_MIS.

During this processing certain catch gears and time frames were removed owing to their discarding approaches not being representative, these included:

- The OTB_DEF Spanish fleet 2002–2019
- The UK (England) "MIS-MIS" classification 2002–2019
- The UK (England) TBB_DEF fleet in 2002

This process was repeated in July 2020 following data updates.

The R-markdown report of this is available: aggregate_IC_data_had.27.7b–k_July_2020.Rmd.

Note that catch data used in all assessments runs from 1993, with only data from 2005 onwards updated following the review of the raising of data from 2003, where raising estimates between 2003 and 2004 showed inconsistencies with the empirical understanding of discarding practices over this time (Figures 1 to 4). The proportional discards of the 2020 updated catch data, applied in the final assessment are shown in Figure 7.

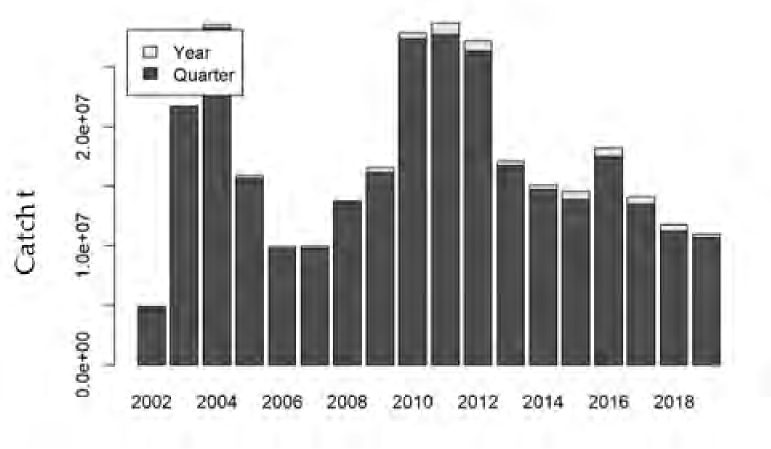


Figure 16. Annual catch time classification 2002 to 2019.

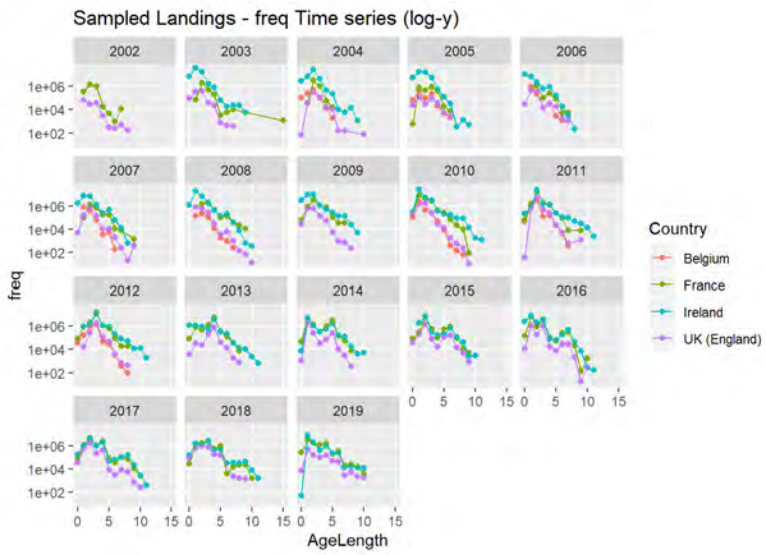


Figure 17. National sampling by age of landings 2003–2019 (log y-axis).

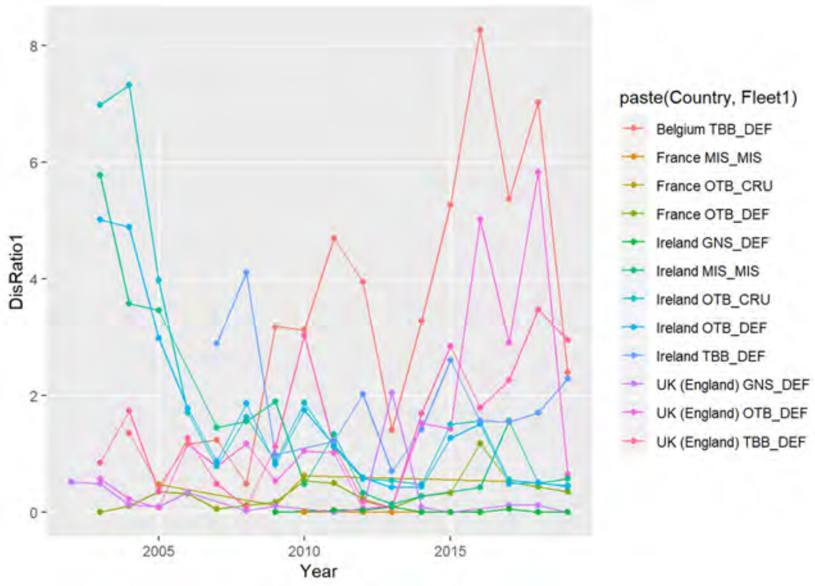


Figure 18. Discard raising ratios by Year, Country and Gear.

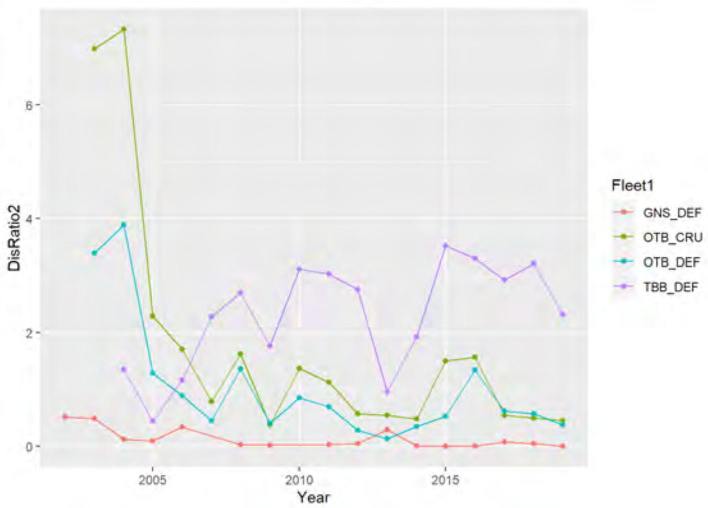


Figure 19. Discard raising ratios by Year and Gear.

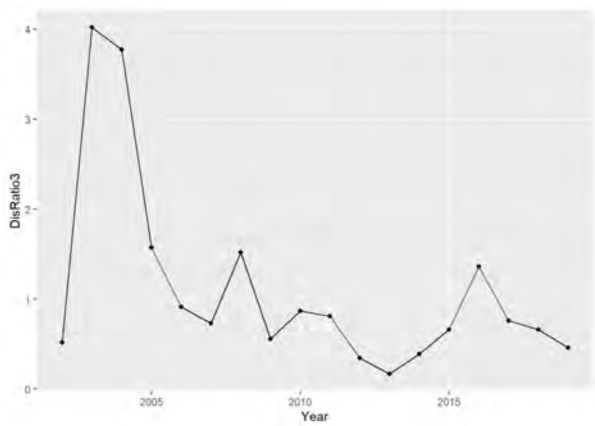


Figure 20. Discard raising ratios by Year.

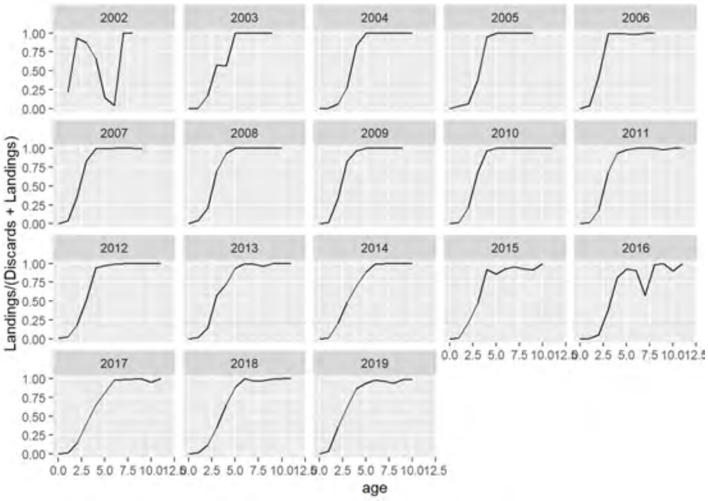


Figure 21. 2019 time-series of landings-at-age relative to catch (discards + landings).

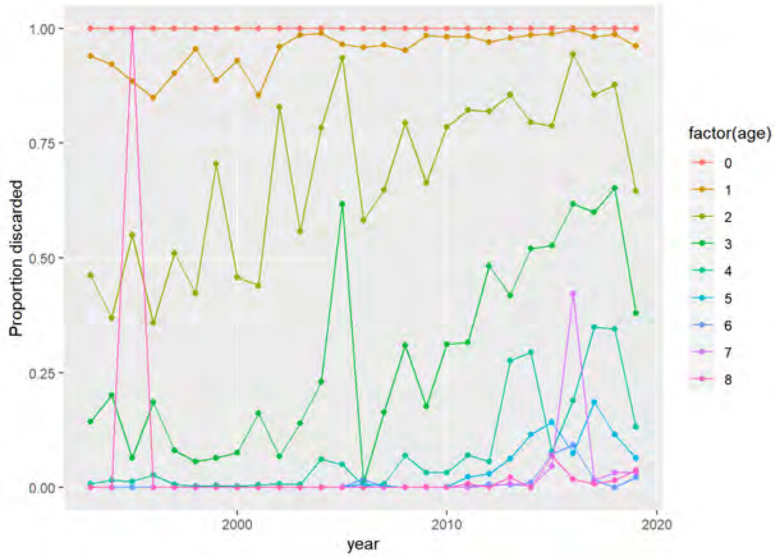


Figure 22. Assessment applied proportional discards by age time-series (post-2020 raising processing for years 2005 to 2019).

4.1.2 Tuning index data

The 2012 benchmarked assessment implemented two tuning indices to the assessment, a joint French-Irish survey indices and a commercial Irish fleet. These were available for application in the 2020 benchmark.

Tuning indices datasets available to the 2020 benchmark:

i. The joint French-Irish scientific survey undertaken in the last quarter of the year. The French-Irish survey index combined IGFS-WIBTS-Q4 and EVHOE-WIBTS-Q4, standardised to half hour fishing operations and ages 0 to 9 incorporated, from 2003 to 2018.

ii. The joint French-Irish scientific survey data were also available in a standardised format following the application of a Vector Autoregressive Spatio-Temporal (VAST) modelling approach, following Thornson (2019).

iii. The Irish commercial survey indices previously used, based on the Irish gadoid fleet on the south coast of the country. The commercial survey incorporated only fish aged 3 to 7 as discards were expected to be high below this age, and covering a restricted area off the south coast of Ireland over the years 1995 to 2018.

iv. A commercial survey indices based on the French gadoid fleet was proposed. Following WKCELTIC 1 a further French commercial tuning indices was developed and proposed for inclusion into the assessment. This covers 2004 to 2018 and ages 0 to 8, built from A GLMM with a Gaussian link function and following Zuur *et al.*, 2009 procedure (equ 1.)

WD-WKCELTIC - French commercial tuning fleets_Final_2020.pdf)

$$\log(CPUE_i) = \alpha_i + \beta 1_j * Year_{ij} + \beta 2_q Quarter_{iq} + \beta 3_a Area_{ia} + \beta 4 VslPwr_i + \beta 5_g Gear_{ig} + \beta 6_{jq} Year_{ij} * Quarter_{iq} + \beta 7_{ja} Year_{ij} * Area_{ia} + \beta 8_{aq} Area_{ia} * Quarter_{iq} + 1 \mid vslId_{ri} + \varepsilon_i \quad \text{equ 1}$$

The application of all three potential indices was reviewed through application in the 2012 ASAP assessment and proposed 2020 assessment.

4.1.3 Maturity-at-age estimates

Following review of data collected between 2004–2018 new maturity-at-age estimates were proposed (WD-2019 DC WKCELTIC Had.27.7e-k Maturity Ogives.docx). Maturity-at-age applied in the previously benchmarked assessment are given in Table 1.

Table 6. Maturity profiles applied in the 2012 assessment.

AGE	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
Maturity proportion	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

A number of options for applying updated maturity were reviewed, including maintaining the 2012 estimates, and introducing year specific estimates by age. It was decided to adopt a standard set of maturity at age proportions, as this was more likely to be reflective of the general age at maturity, and not depend upon year specific estimates which may lack accuracy owing to sample sizes and origins, and also remove the annual dependence of recalculating maturity for every annual assessment (Table 2).

Table 7. Maturity profiles applied in the 2020 assessment.

AGE	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
Maturity proportion	0.000	0.039	0.911	0.970	0.980	1.000	1.000	1.000	0.000

4.1.4 Natural Mortality

Natural mortality in the 2012 assessment were set for all years in the assessment (Table 3).

Table 8. Mortality profiles applied in the 2012 assessment.

AGE	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
Mortality	0.99	0.72	0.6	0.5	0.43	0.4	0.37	0.36	0.34

Revised natural mortality-at-age options were proposed (WDXX WDXX - Natural mortality in the Celtic sea gadoids.docx). Following review of available data from IGFS-WIBTS-Q4 and EVHOE-WIBTS-Q4 surveys, 2003 to 2018, estimates of mortality at age from growth parameters and assumption averages were applied through to Von Bertalanffy parameters 2003 to 2018:

$$k = 0.256; - Linf = 607mm; \; t_0 = -1.33.$$

These were applied through the Lorenzen and Gislason approached to estimate natural mortality (Table 4).

Table 9. Mortality profiles applied in the 2020 assessment.

AGE	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
Mortality Lorenzen	1.087	0.721	0.575	0.483	0.440	0.406	0.398	0.385	0.360
Mortality Gislason	1.087	0.544	0.372	0.279	0.239	0.209	0.203	0.190	0.169

Reviewing the Lorenzen and Gislason options it was decided to apply the updated Lorenzen estimated of natural mortality in the proposed 2020 assessment.

4.2 Assessment approaches

Several assessment tools/methods were considered for application and discussed. These primarily included the assessment tool adopted in 2012 "Age-Structured Assessment Program" (ASAP)' Assessment For All (a4a) and the state–space fish stock assessment (SAM) tool. A working version of the SAM assessment tool at www.stockassessment.org was developed.

The 2019–2020 revised data were assessed through the existing ASAP model framework, to investigate changes in the assessment resulting from data revisions, and changes.

4.2.1 ASAP tests

A range of different ASAP assessments were developed, with outputs compared against the 2019 assessment (Figure 8), taken as the "base" assessment.

ASAP variant assessments

With the catchability variable setting in ASAP allowed to be self-defining:	
	All with /¯¯ shaped catchability:
1. asap.2019	This is the original 2019 stock assessment as of WGCSC 2019
2. asap.2019.New.Biol	Original 2019 stock assessment as of WGCSC 2019 - WITH new Maturity and Natural Mortality of WKCELTIC
3. asap.1_Indicies	New catch-at-age data from WKCELTIC, with ONLY the survey indices as of WGCSE 2019
4. asap.2_Indicies	New catch-at-age data from WKCELTIC, with the survey indices and Irish Commercial Index (WGCSE 2019)
5. asap.3_Indicies	New catch-at-age data from WKCELTIC, with survey indices Irish and new French Commercial Index. Catchability as 2019 assessment selectivity block (Table 5). Outputs indicated that this model was not appropriate owing to flat fishing pressure estimates over the time-series, hence models 6 and 7
To enable inclusion of the French Commercial index:	
6. asap.3_Indicies_Better_index_selectivity_1	
	New catch-at-age data from WKCELTIC, with survey indices Irish AND new French Commercial Index
	/¯¯ shaped catchability:
	better indices catchability “1” selectivity block (Table 6)
7. asap.3_Indicies_Better_index_selectivity_2	
	New catch-at-age data from WKCELTIC, with survey indices Irish AND new French commercial Index
	/¯¯ shaped catchability:
	better indices catchability “2” selectivity block (Table 7)
To change catchability (q) for older age classes - two options:	
8. asap.3_Indicies_Better_index_selectivity_2_Catch_F_1	
	New catch-at-age data from WKCELTIC, with survey indices Irish AND new French commercial Index
	/¯`- shaped catchability v1
	better indices catchability “2”
9. asap.3_Indicies_Better_index_selectivity_2_Catch_F_2	
	New catch-at-age data from WKCELTIC, with survey indices Irish AND new French commercial Index
	/¯\ shaped catchability v2
	better indices catchability 2

The following series of plots and comparisons highlight the flowing points:

- The update of natural mortality and maturity data has a small effect on the assessment in recruitment between the late 1990s and late 2000s, while no substantial effect on SSB or fishing pressure (Figure 9).
- With the updated natural mortality and maturity estimates and running the assessment with only the scientific survey indices showed minor differences in recruitment, a switch of the mid assessment peaks in F (2002 and 2005) and a resulting small increase in the SSB estimates over the final seven years (Figure 10).
- A similar, but less dramatic effect was shown by running the assessment with new catch-at-age data and using both the scientific survey and the Irish commercial indices (Figure 11).
- The initial attempt to introduce the French commercial tuning indices employing the same selectivity blocks as applied to the Irish commercial tuning indices (Selectivity start age = 4, Selectivity end age = 8; parameter settings Table 5) did not achieve a useful indication of fishing pressure (Figure 12) with a model estimate being flat at around 0.5 over the full time-series.

Table 10. Selectivity block settings for commercial tuning indices assigned to both the Irish and French commercial fleets (Figure 12).

Age	1	2	3	4	5	6	7	8	9
Initial guess:	1	1	1	1	1	1	-1	-1	-1
Phase:	1	-1	-1	-1	-1	-1	-1	-1	-1
Lambda:	1	0	0	0	0	0	0	0	0
Coefficient of Variation:	0.0001	1	1	1	1	1	1	1	1

- This leads to a change in the selectivity blocks in ASAP, namely (Selectivity start age = 4, Selectivity end age = 8; parameter settings Table 6) did. This resulted in similar estimates in recruitment, with SSB reduced in the last five years of the time-series, and an F pattern following similar trends to the 2019 assessment, with reduced F over much of the last ten years (Figure 13). This resulted in a catchability mirroring that of the 2019 assessment, showing a sharp increase in younger fish (0 to 2) and flat from ages 3 to 8.

Table 11. Selectivity block settings for commercial tuning indices assigned to both the Irish and French commercial fleets (Figure 13).

Age	1	2	3	4	5	6	7	8	9
Initial guess:	-1	-1	-1	0.8	1	1	1	1	-2
Phase:	-1	-1	-1	1	1	1	1	1	-1
Lambda:	0	0	0	0	0	0	0	0	0
Coefficient of Variation:	1	1	1	1	1	1	1	1	1

- A further variant on the selectivity blocks to enable the introduction of the French commercial tuning indices (Selectivity start age = 4, Selectivity end age = 8; parameter settings Table 7) produced virtually identical patterns in recruitment, SSB and F patterns (Figure 14).

Table 12. Selectivity block settings for commercial tuning indices assigned to both the Irish and French commercial fleets (Figure 12).

Age	1	2	3	4	5	6	7	8	9
Initial guess:	-1	-1	-1	0.8	1	1	1	1	-1
Phase:	-1	-1	-1	1	1	1	1	1	-1
Lambda:	0	0	0	0	0	0	0	0	0
Coefficient of Variation:	1	1	1	1	1	1	1	1	1

- By fixing the catchability in ASAP to force it to reduce and flatten in ages 7, 8 and 9 (giving a /‾`- shaped catchability), following consideration that older fish would be less likely to be caught owing to maturity and improved swimming strength, a further fit was examined. This yielded similar patterns in recruitment, SSB and F seen in the proceeding model variants (Figure 15).
- This potential set up was further examined by reducing catchability again for 9 year old fish, giving a dome shaped catchability pattern (/‾\ ). This again resulted in virtually similar patterns in recruitment, SSB and F seen in the proceeding model variants (Figure 16).
- Following consideration of any benefit in the assessment structure of including the second French commercial tuning indices the model variants employing only the survey tuning index, and the survey and Irish commercial tuning index were compared (Figure 17), which showed similar patterns, with different peeks in F in 2003 and 2005 and similar 2018 F and SSB.
- These were compared directly against the 2019 ASAP assessment model (Figure 18) with recruitment and SSB showing similar patterns across the time-series with the three showing subtle differences in the F pattern while following similar trends and similar 2018 estimates.

Figure 19 compares three developmental ASAP model runs against the 2019 ASAP assessment. The tree include updated catch-at-age data, undated natural mortality and maturity estimates and a range of 1 to 3 survey, to commercial tuning indices. All four follow very similar patterns, with larges differences centring around the F pattern, especially the peaks in 2002 and 2005. Terminal F was estimated highest by the model with two indices, lowest with the model with three indices, with little difference between the 2019 assessment and the model with one indices. The inverse was seen in the terminal (2018) SSB estimates.

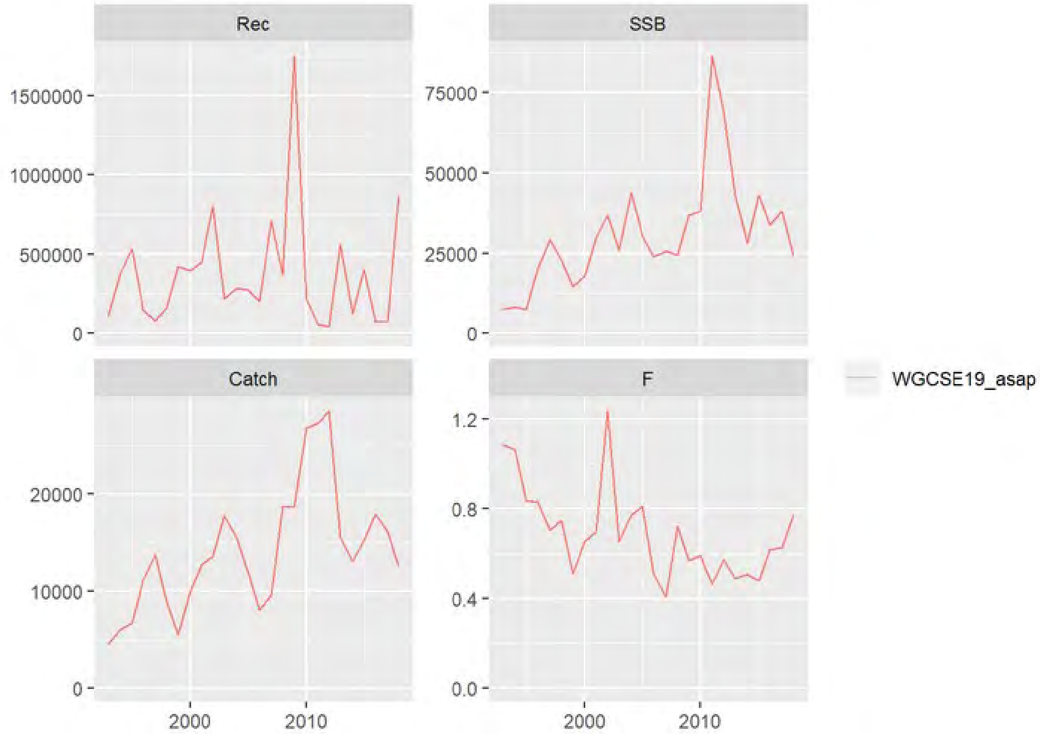


Figure 23. 2019 assessment.

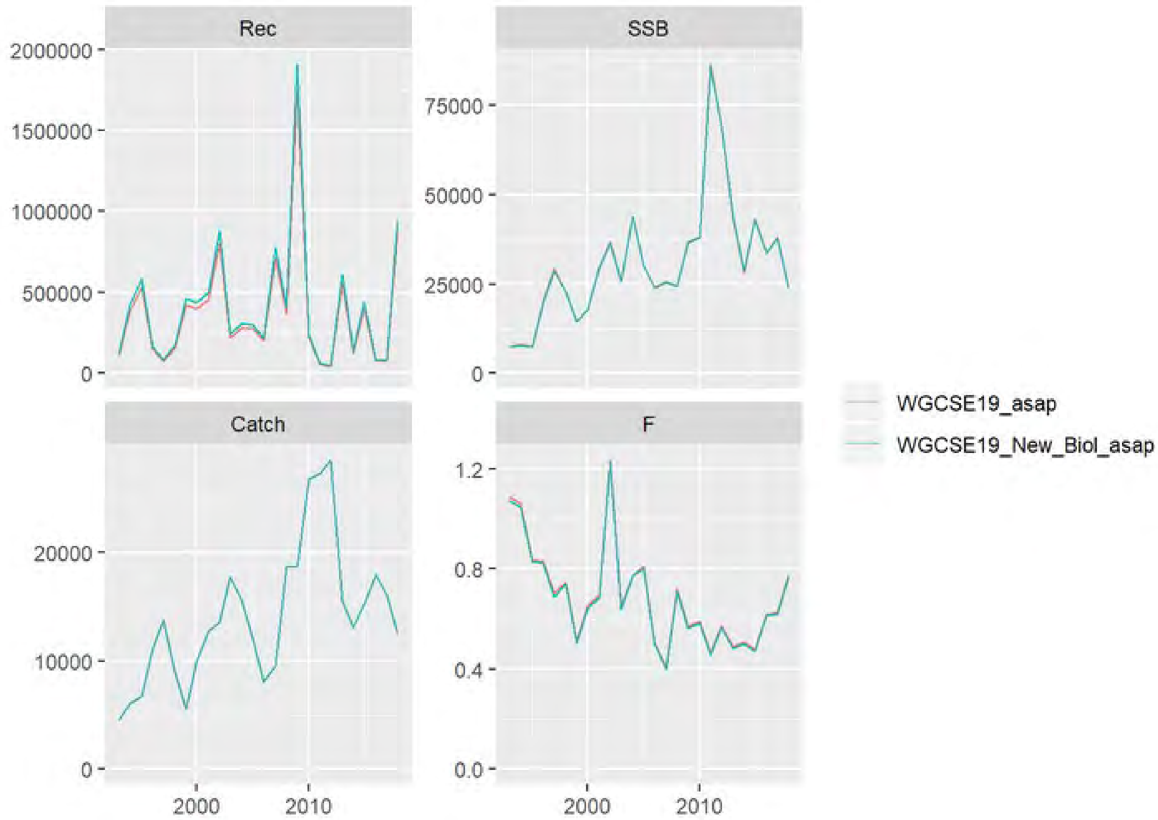


Figure 24. 2019 assessment vs 2019 assessment with updated Maturity and Natural Mortality.

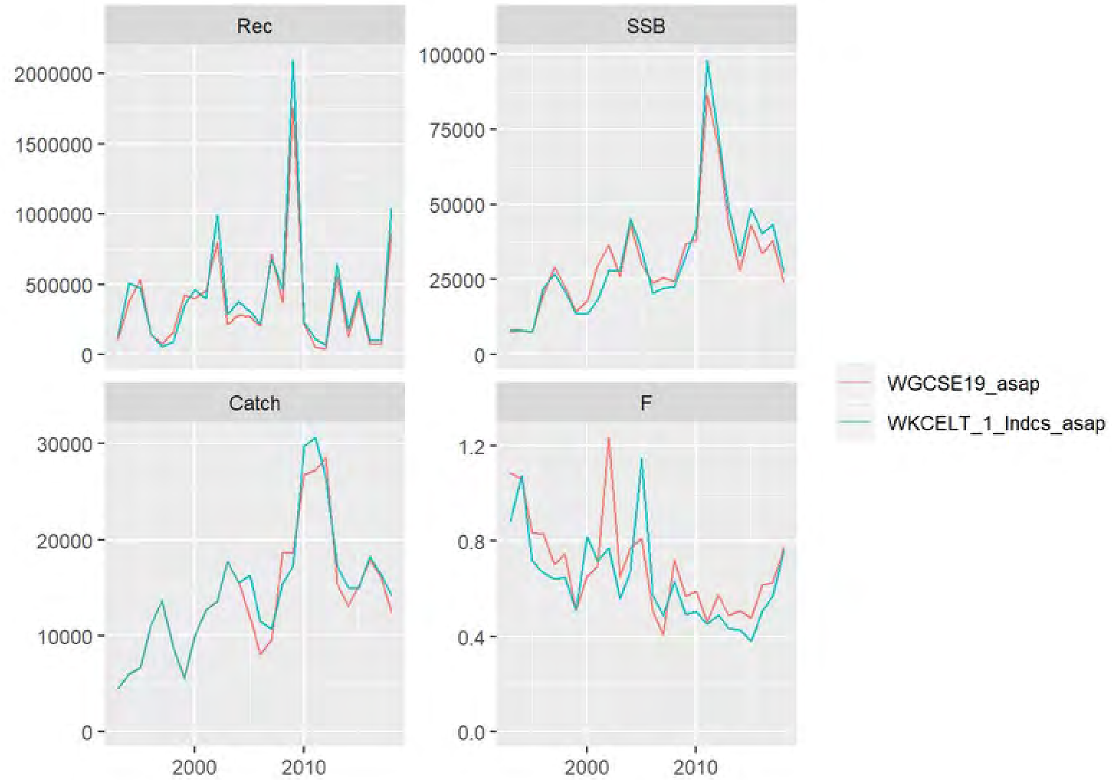


Figure 25. 2019 assessment vs new catch-at-age data from WKCELTIC, with only the survey indices as of WGCSE 2019.

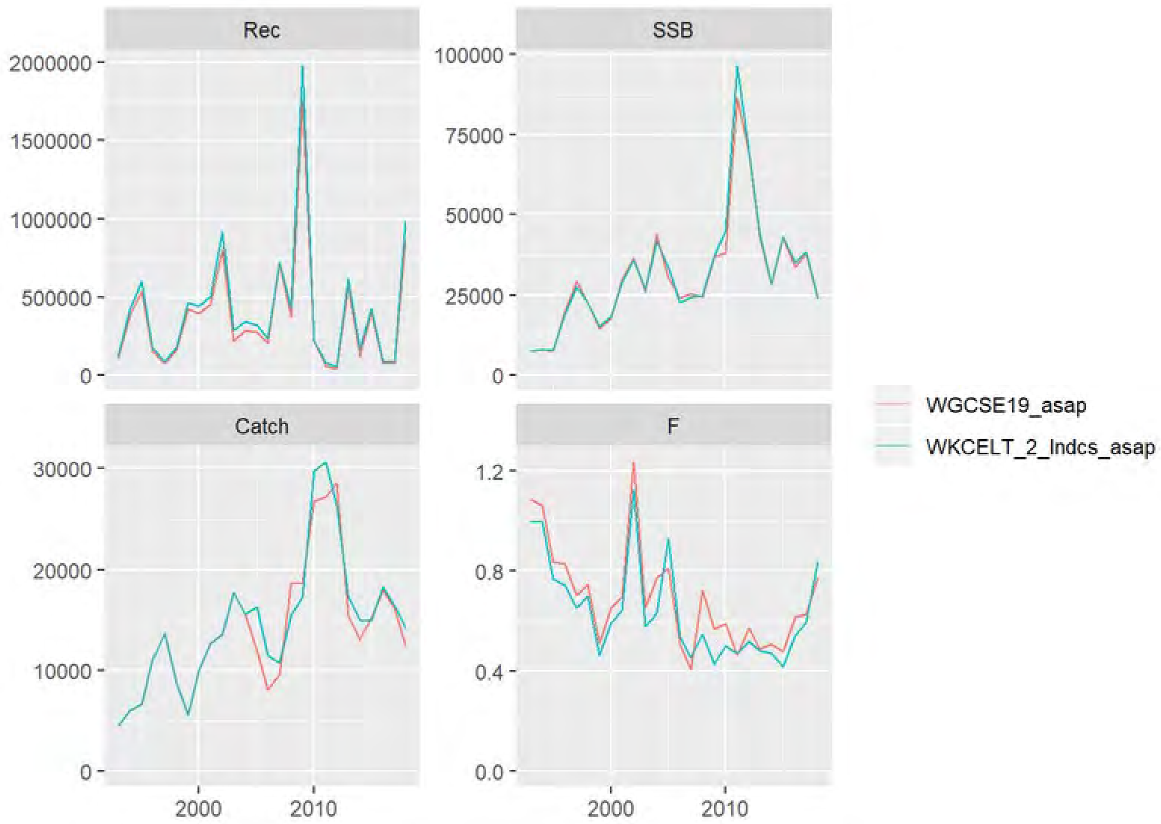


Figure 26. 2019 assessment vs new catch-at-age data from WKCELTIC, with the survey indices and Irish Commercial Index (WGCSE 2019).

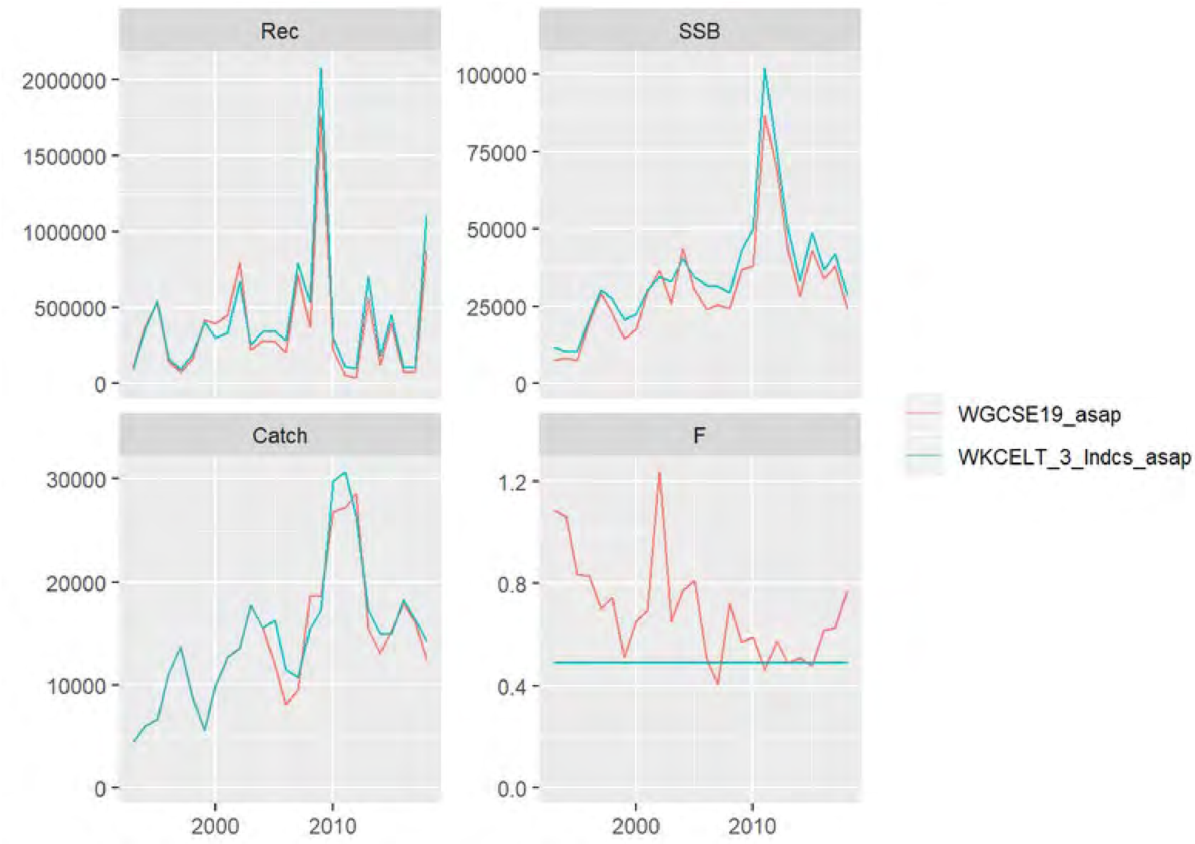


Figure 27. 2019 assessment vs new catch-at-age data from WKCELTIC, with survey indices Irish AND new French Commercial Index.

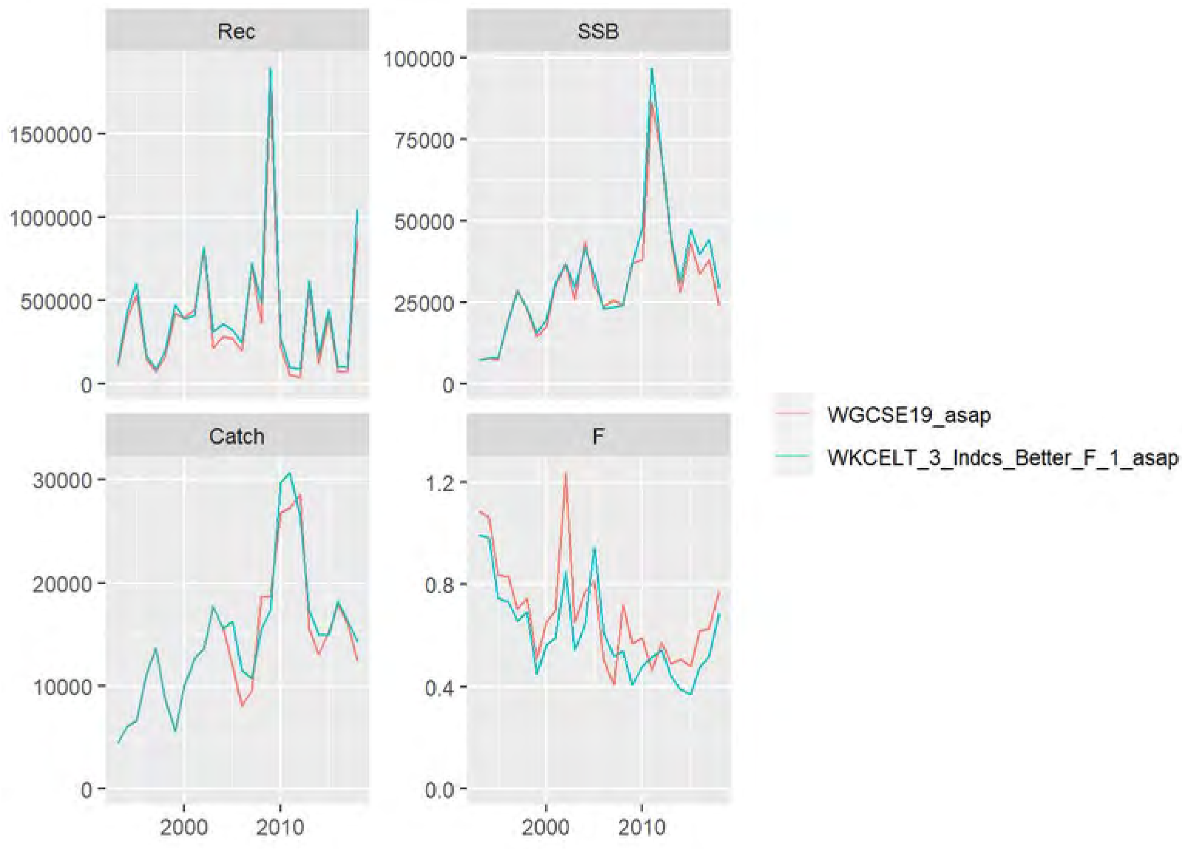


Figure 28. 2019 assessment vs new catch-at-age data from WKCELTIC, with survey indices Irish and new French commercial Index, /¯¯ shaped catchability - better indices catchability "1".

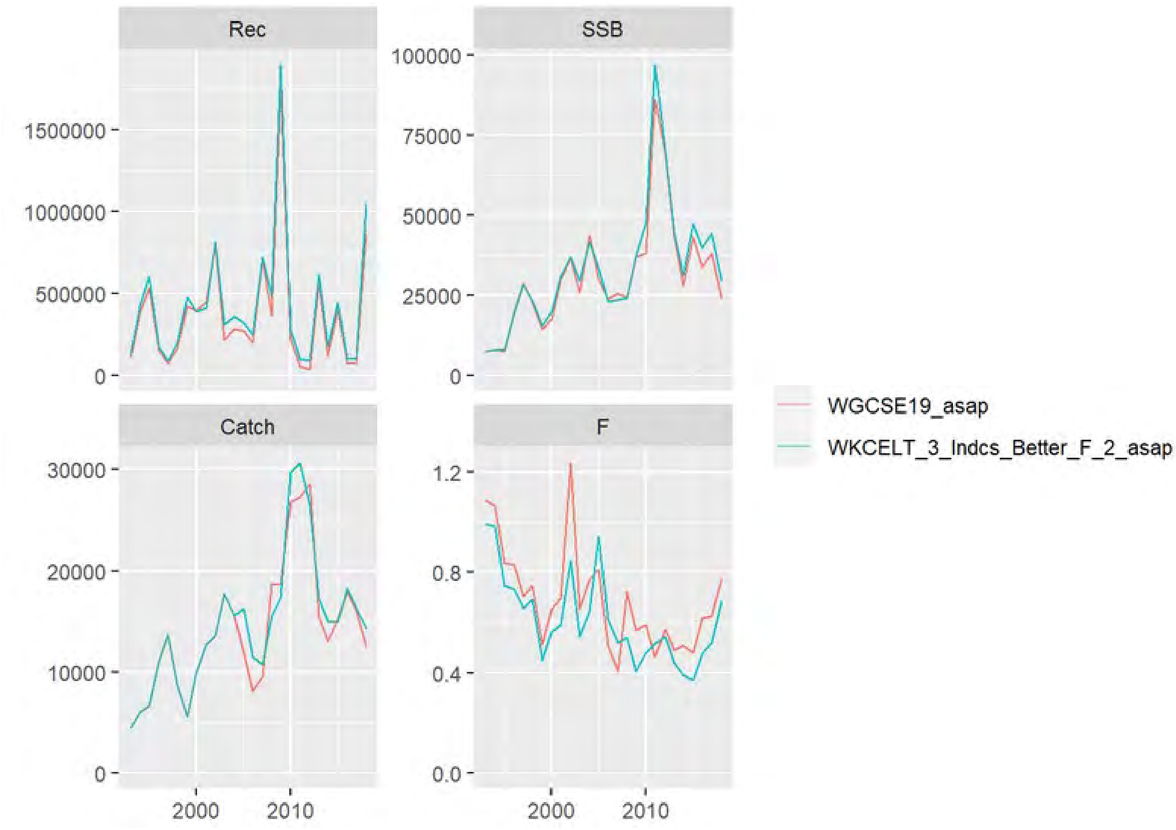


Figure 29. 2019 assessment vs. New catch-at-age data from WKCELTIC, with survey indices Irish AND new French Commercial Index, /¯¯ shaped catchability - better indices catchability "2".

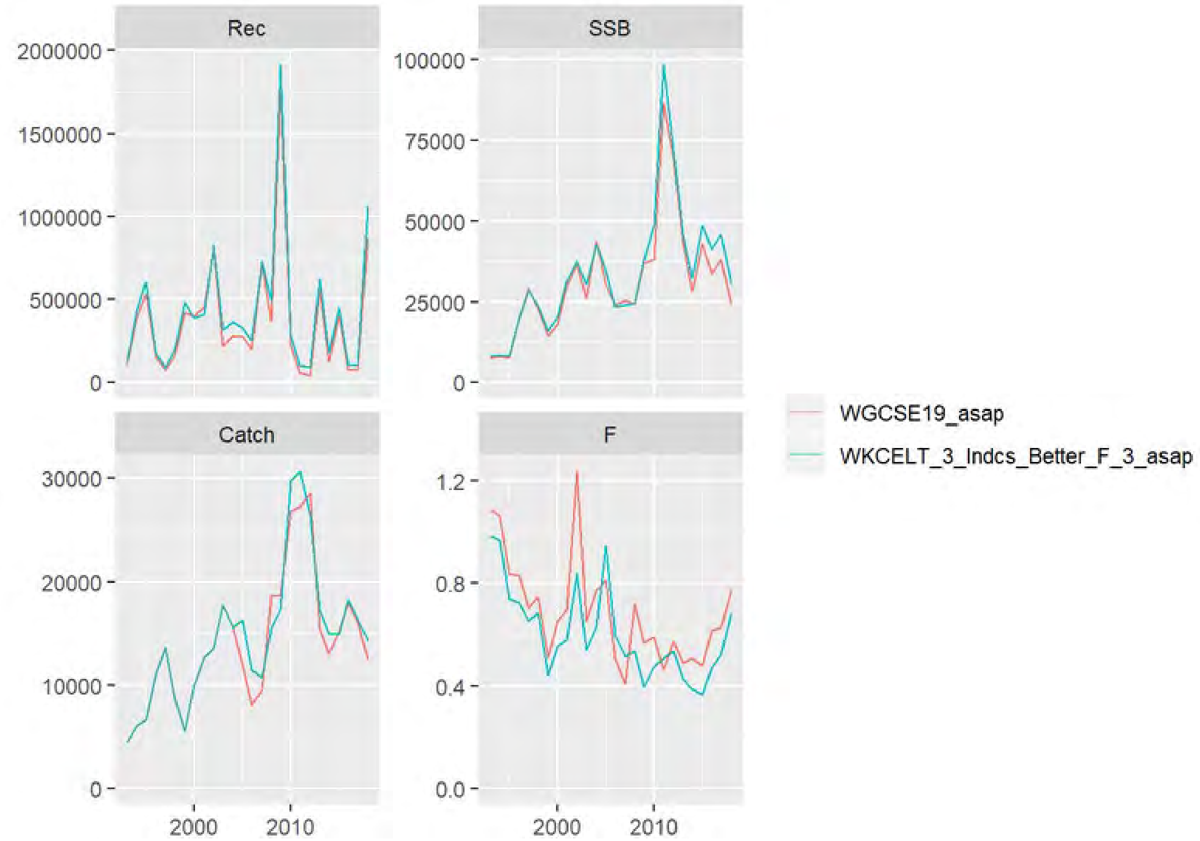


Figure 30. 2019 assessment vs new catch-at-age data from WKCELTIC, with survey indices Irish AND new French commercial Index, /‾`- shaped catchability v1 - better indices catchability "2".

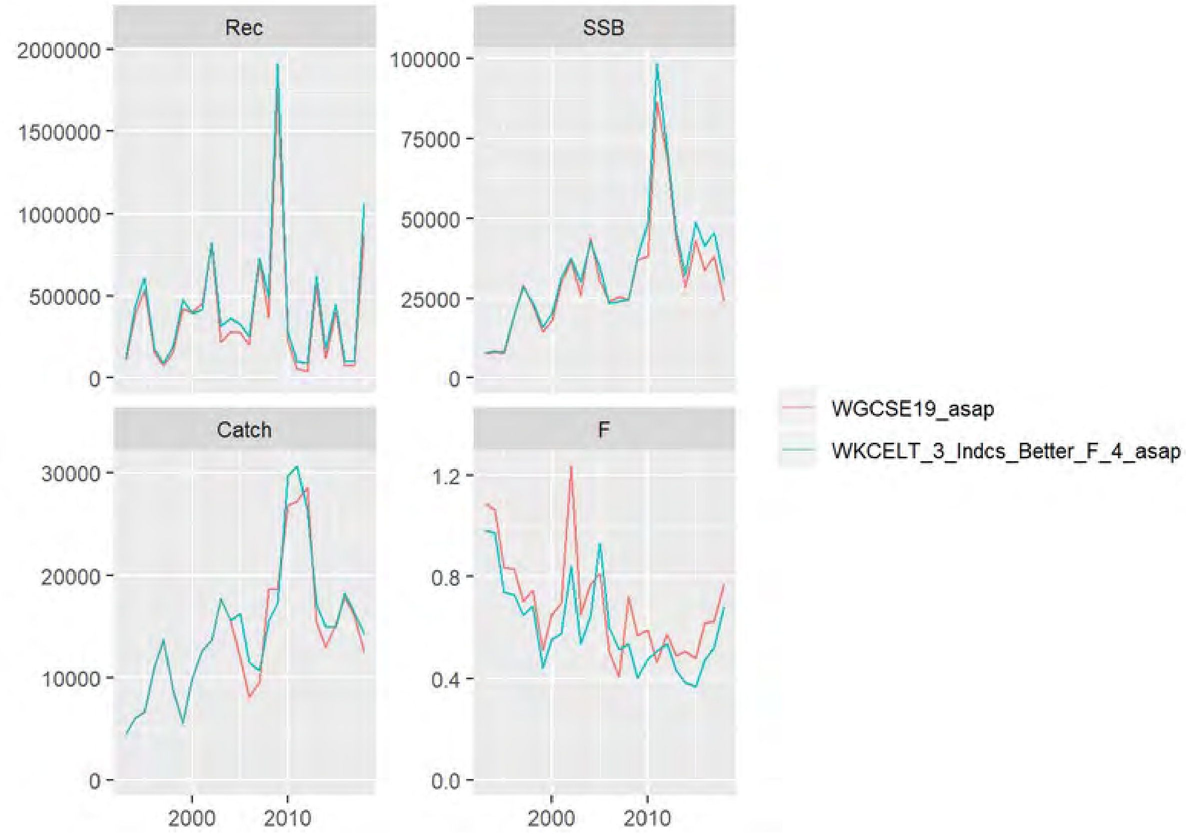


Figure 31. 2019 assessment vs new catch-at-age data from WKCELTIC, with survey indices Irish AND new French commercial Index, /¯\ shaped catchability v2 - better indices catchability "2".

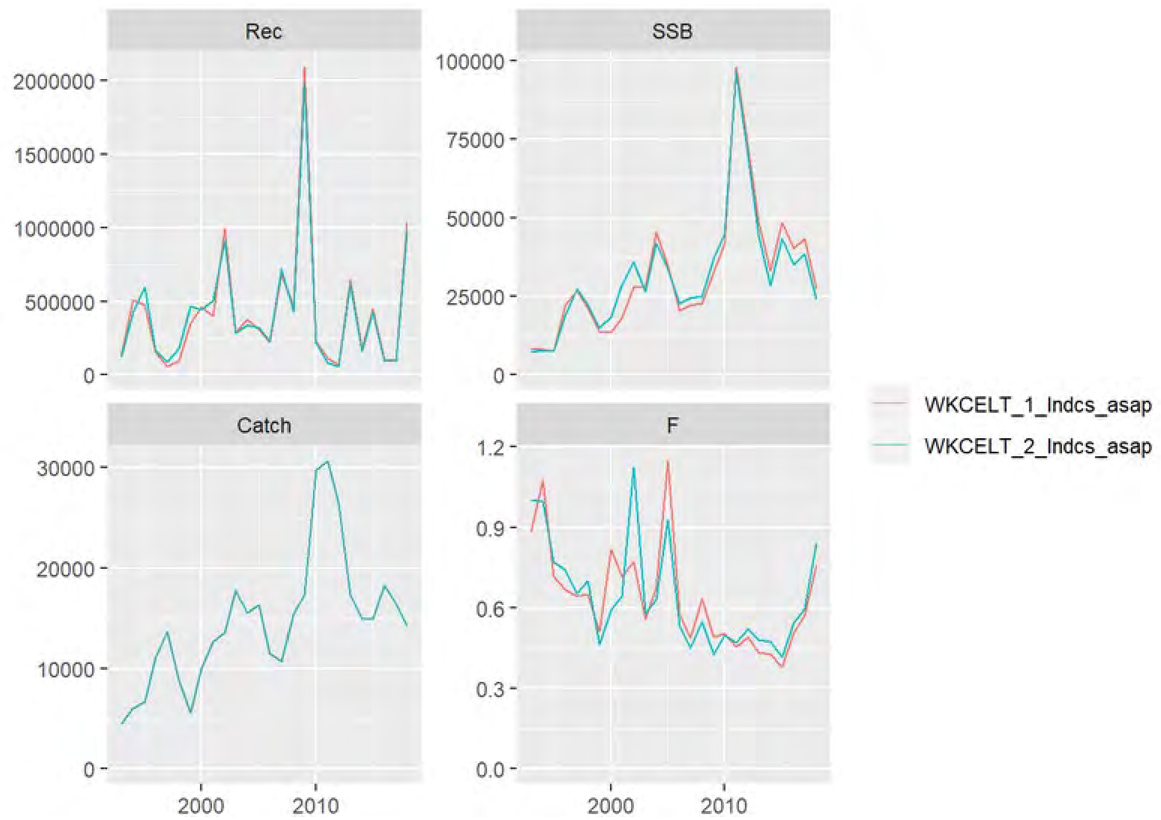


Figure 32. New catch-at-age data from WKCELTIC, with ONLY the survey indices as of WGCSE 2019 - New catch-at-age data from WKCELTIC, with the survey indices and Irish Commercial Index (WGCSE 2019).

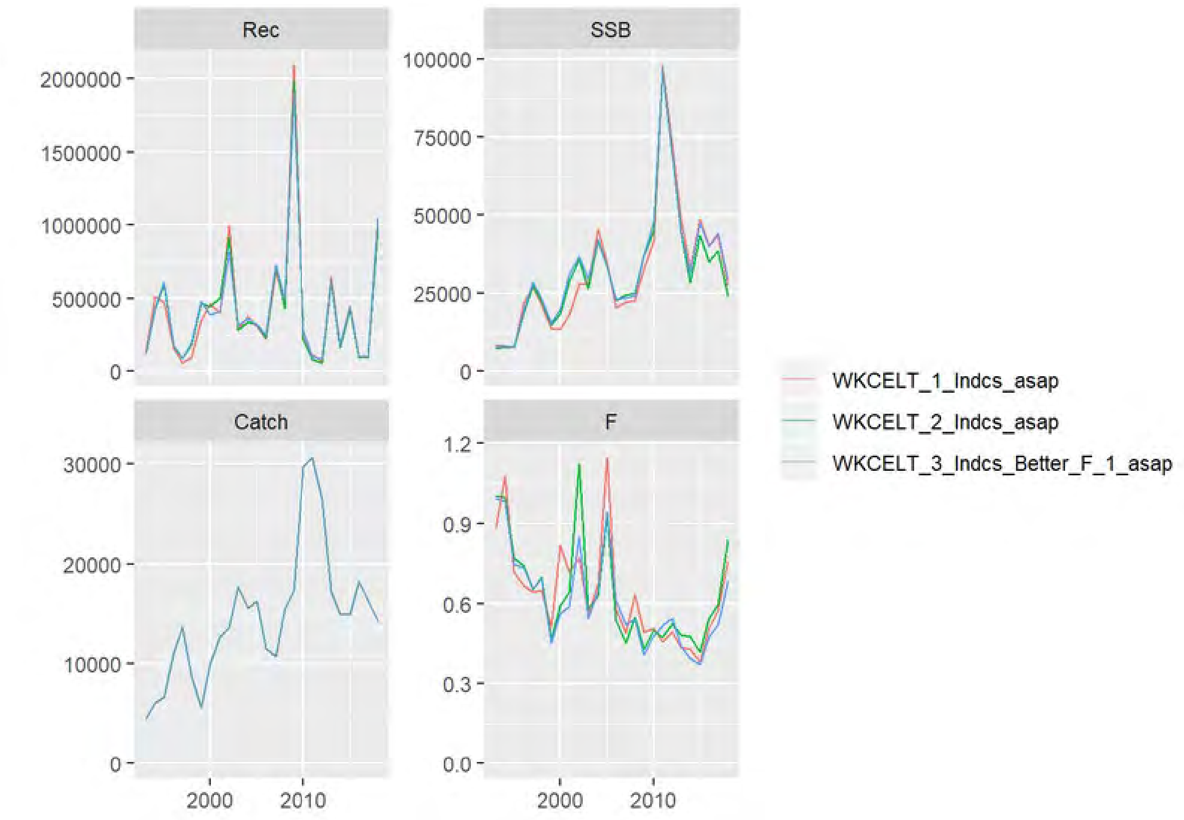


Figure 33. 2019 assessment vs. New catch-at-age data from WKCELTIC, with ONLY the survey index as of WGCSE 2019 - New catch-at-age data from WKCELTIC, with the survey index and Irish Commercial Index (WGCSE 2019).

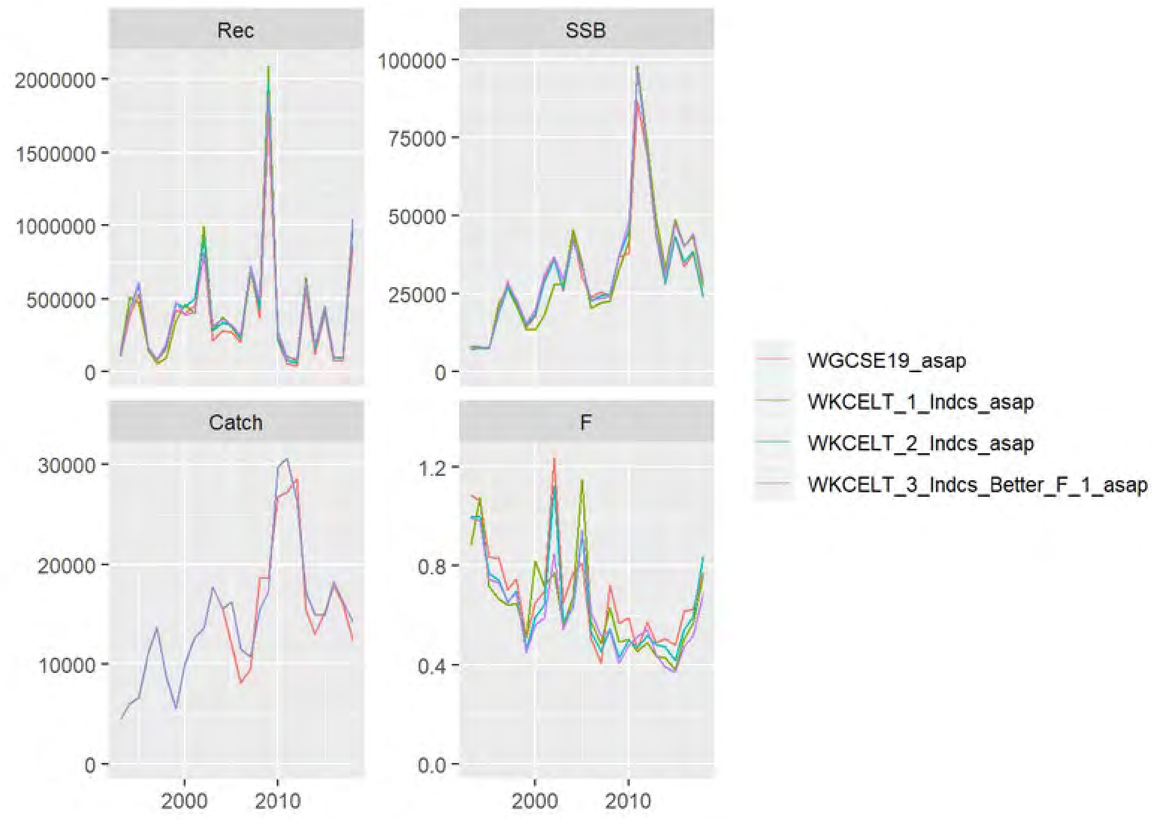


Figure 34. 2019 assessment vs new catch-at-age data from WKCELTIC, with ONLY the survey index as of WGCSE 2019 - New catch-at-age data from WKCELTIC, with the survey index and Irish Commercial Index (WGCSE 2019).

Table 13. Summary of Mohn's Rho retrospective indices.

Model	F	SSB	R
asap.2019	0.26	-0.120	0.0163
asap.2019.New.Biol	0.27	-0.123	0.0100
asap.1_Indicies	0.30	-0.094	-0.0105
asap.2_Indicies	0.33	-0.145	-0.0158
asap.3_Indicies	Na	Na	Na
asap.3_Indicies_Better_index_selectivity_1	0.26	-0.091	0.0039
asap.3_Indicies_Better_index_selectivity_2	0.26	-0.091	0.0039
asap.3_Indicies_Better_index_selectivity_2_Catch_F_1	0.28	-0.102	-0.00056
asap.3_Indicies_Better_index_selectivity_2_Catch_F_2	0.28	-0.101	-0.0002

4.2.2 SAM tests

The stock state–space assessment model (SAM) was implemented in a number of configurations to develop an understanding of how best to fit it to the data, given the nature of the data, its availability, and time-scales, and knowledge of the fishery. Review of the patterns in catch, SSB, F and recruitment estimates, diagnostics, residuals and retrospective patterns and simplicity of models were used to evaluate the fit of each model variant.

The SAM models were developed to mirror the test ASAP runs, to iteratively investigating the influence off each data change on the assessment. Note that catch data for all assessments runs from 1993, with only data from 2005 onwards updated.

SAM variant assessments

Model variant	
1	HAD7bk-Bench2020
	Initial model build, New catch-at-age data from WKCELTIC. Updated natural mortality and maturity estimates. Survey indices entered as 2019 assessment (averaged French – Irish 30 minute standardised), ages 0 to 8. Irish commercial index, ages 1 to 6. French commercial index, ages 0 to 6. F_{bar} set to ages 4 to 7
2	HAD7bk-Bench2020_2
	New catch-at-age data from WKCELTIC. Updated natural mortality and maturity estimates. Survey indices entered as 2019 assessment (averaged French – Irish 30 minute standardised), ages 0 to 8. F_{bar} set to ages 4 to 7
3	HAD7bk-Bench2020_2_VAST
	New catch-at-age data from WKCELTIC. Updated natural mortality and maturity estimates. Survey indices (VAST standardised survey data), ages 0 to 7. F_{bar} set to ages 4 to 7
4	HAD7bk-Bench2020_2_VAST_b
	New catch-at-age data from WKCELTIC. Updated natural mortality and maturity estimates. Survey indices (VAST standardised survey data), ages 0 to 7. Down weighted older catches to improve residuals. F_{bar} set to ages 4 to 7

Model variant	
5	HAD7bk-Bch_2020_2_VAST-new_f-bar37
	New catch-at-age data from WKCELTIC, Updated natural mortality and maturity estimates. Survey indices (VAST standardised survey data), Irish and new French commercial index. Down weighted older catches to improve residuals. F_{bar} set to ages 3 to 5
6	HAD7bk_2020_Survey_and_Irish_Com
	New catch-at-age data from WKCELTIC, Updated natural mortality and maturity estimates. Survey indices (VAST standardised survey data), Irish and new French commercial index. Irish commercial index, ages 1 to 8. Down weighted older catches to improve residuals. F_{bar} set to ages 4 to 7
7	HAD7bk_2020_Survey_and_two_Com_ind
	New catch-at-age data from WKCELTIC, Updated natural mortality and maturity estimates. Survey indices (VAST standardised survey data), Irish and new French commercial index. Irish commercial index, ages 1 to 6. French commercial index, ages 0 to 8. Down weighted older catches to improve residuals. F_{bar} set to ages 4 to 7
8	HAD7bk_2020_Benchmark_II
	New catch-at-age data from WKCELTIC, Updated natural mortality and maturity estimates. Survey indices – updated VAST standardised survey data, Irish and new French commercial index. Down weighted older catches to improve residuals. F_{bar} set to ages 2 to 5 following 2019 assessment assumptions.
9	JW_2019_assessment_Test_had27.7bk
	SAM rebuild of the 2019 ASAP assessment 2019 assessment catch-at-age data 2019 natural mortality and maturity estimates. Survey indices entered as 2019 assessment (averaged French – Irish 30 minute standardised), ages 0 to 8. Irish commercial index, ages 3 to 8.

Following July 2020 data updates, the SAM assessment was updated:

HAD7bk_2020_Assessment	AIC 682.59
HAD7bk_2020_Benchmark_II with updated data	
Updated July 2020 catch data (2005–2019)	
Updated VAST Survey indices ages 0 to 7 (2003–2019).	
Inclusion of updated reference points incorporating catch and survey data detailed above.	
Inclusion of forecast within SAM.	

SAM models were developed from the trials and comparisons exploring the impacts different datasets in ASAP. The initial SAM model structure included all available data (1 - HAD7bk-Bench2020). The second iteration (2 - HAD7bk-Bench2020_2) included only the scientific survey tuning indices, standardised to 30 minute tows.

A development of the survey indices applied in the benchmark meeting to the Celtic Sea whiting and cod assessments was also made available for the haddock assessment. A Vector Autoregressive Spatio-Temporal (VAST) modelling approach (Thornson, 2019; Section XX) was applied to the French and Irish quarter 4 survey time-series. This was applied in model 3 (HAD7bk-Bench2020_2_VAST) for comparison. This version was improved upon by down weighting older catches, which improved the residuals in the model and retrospective patterns.

Comparisons were made with the ASAP model by setting the average fishing mortality (F) age range to 3 to 5 year olds (5 - HAD7bk-Bch_2020_2_VAST-new_f-bar37) (Figure 20). To investigate the information input from the available commercial tuning indices model versions 6 and 7 (HAD7bk_2020_Survey_and_Irish_Com; HAD7bk_2020_Survey_and_two_Com_ind) were developed, including the Irish commercial tuning indices as applied in the ASAP model, and additionally the developed French commercial tuning indices (Figure 21). Following initial development a revised VAST survey indices dataset was provided which dealt with a minor inconsistency in its application (with one age class not converging). The improved VAST dataset was applied in model 8 (HAD7bk_2020_Benchmark_II; Figure 22). This version was viewed as the most appropriate for future application based on simplicity, residuals in the model and retrospective patterns, and set as the “base” run for graphing comparisons with other model versions.

Review of all model versions showed time-series patterns in SSB, F, recruitment and fitted catch estimates consistent with the perceived state of the stock.

To conclude the model development, a reconstruction of the ASAP 2019 assessment model was produced in SAM, as a means of considering difference in the most recent assessment from which catch advice was derived, and the proposed model structure. The reconstructed SAM version used the 2019 catch-at-age data, 30 minute standardised survey indices and natural mortality and maturity settings used in the 2019 ICES WGCSE assessment. The resulting model showed patterns SSB and recruitment, and catch estimates similar to the 2019 ASAP assessment. The pattern in F however differed markedly from the ASAP assessment pattern, and from the 2020 WKCELTIC SAM assessment. SSB also differed notably from the 2020 WKCELTIC SAM assessment (Figure 23).

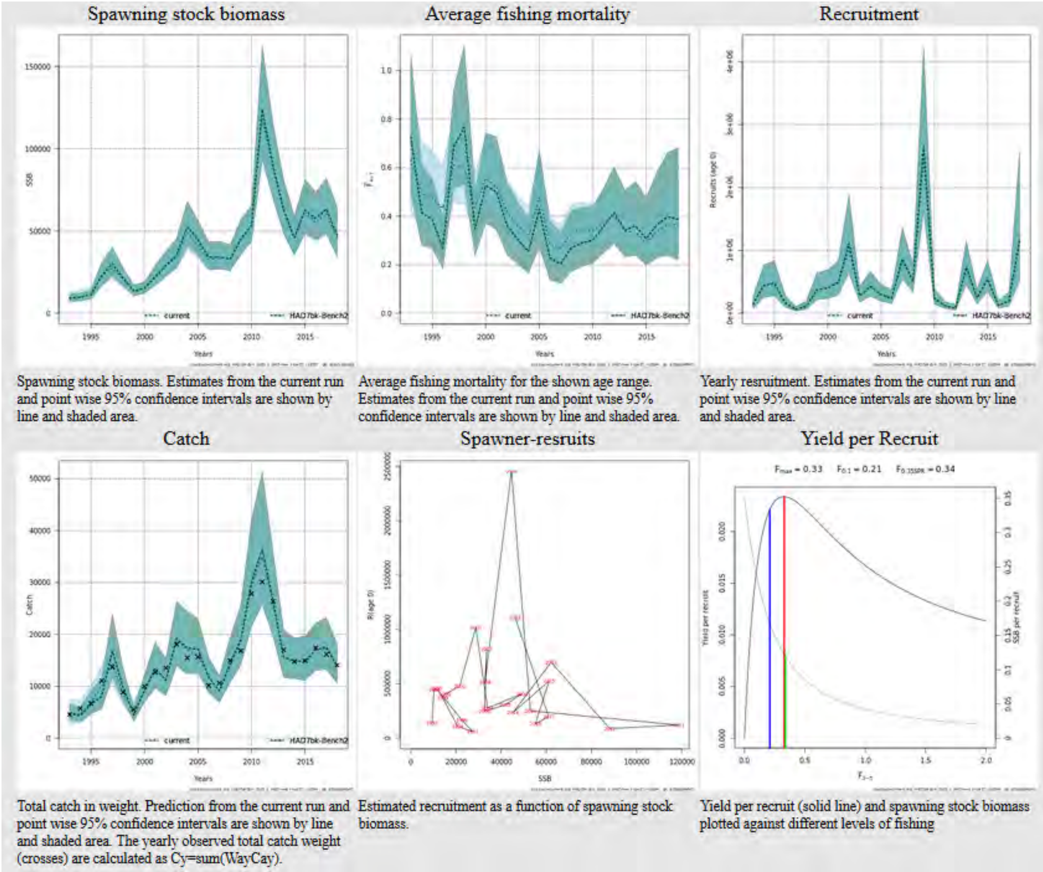


Figure 35. SAM model version 5. "HAD7bk-Bch_2020_2_VAST-new_f-bar37", with VAST survey indices and down weighted older catches.

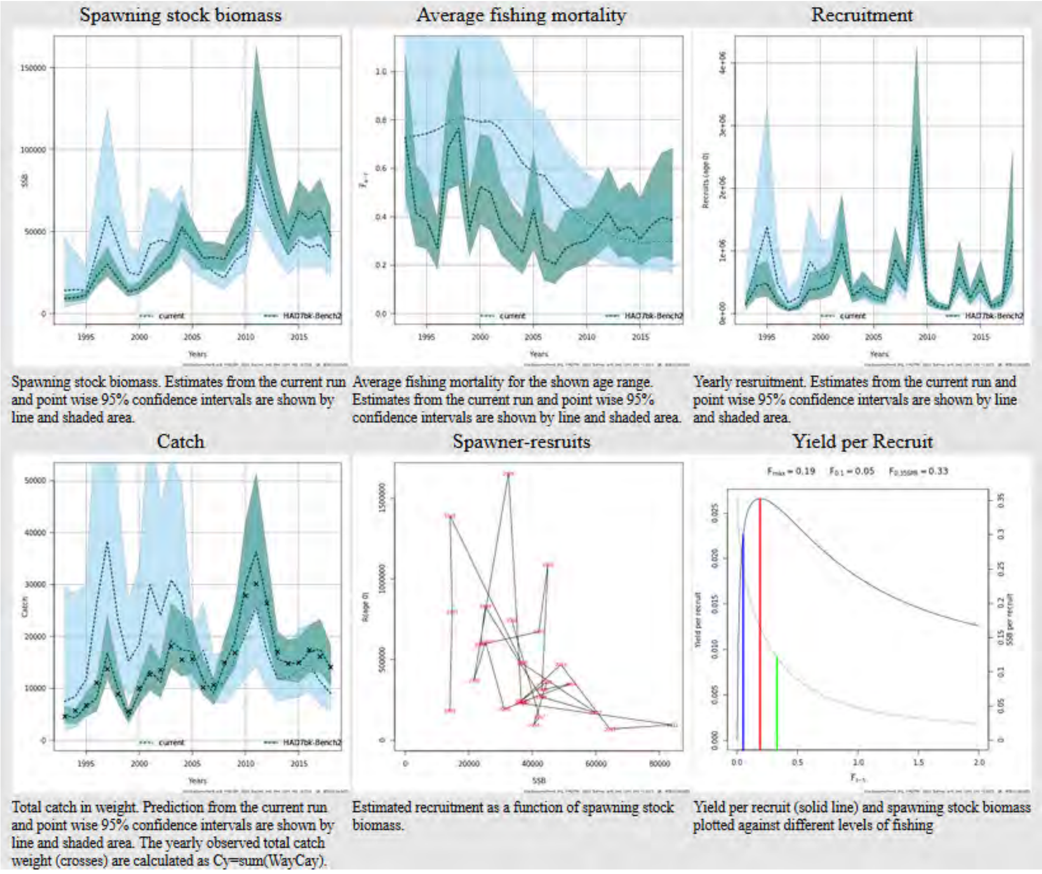


Figure 36. SAM model version 7 "HAD7bk_2020_Survey_and_two_Com_ind", incorporating the VAST standardised survey indices and two commercial tuning indices (Irish and French).

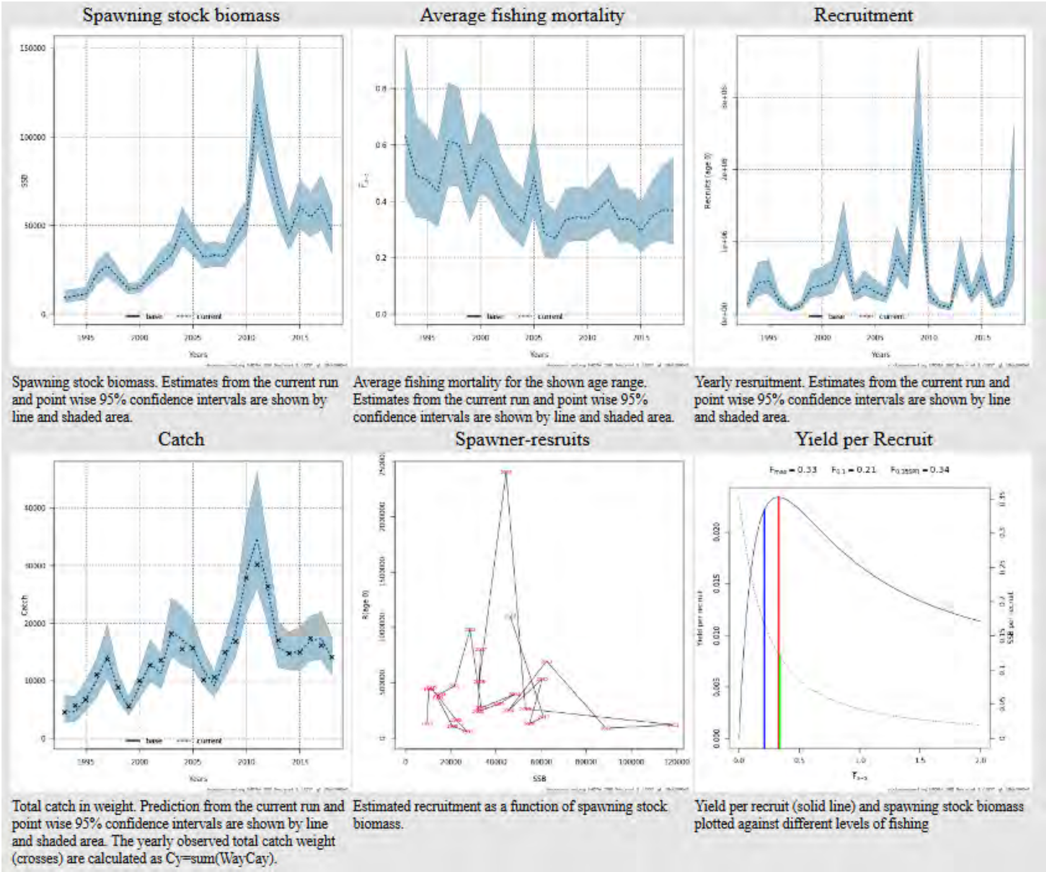


Figure 37. SAM model version 8. "HAD7bk_2020_Benchmark_II", incorporating updated VAST survey indices.

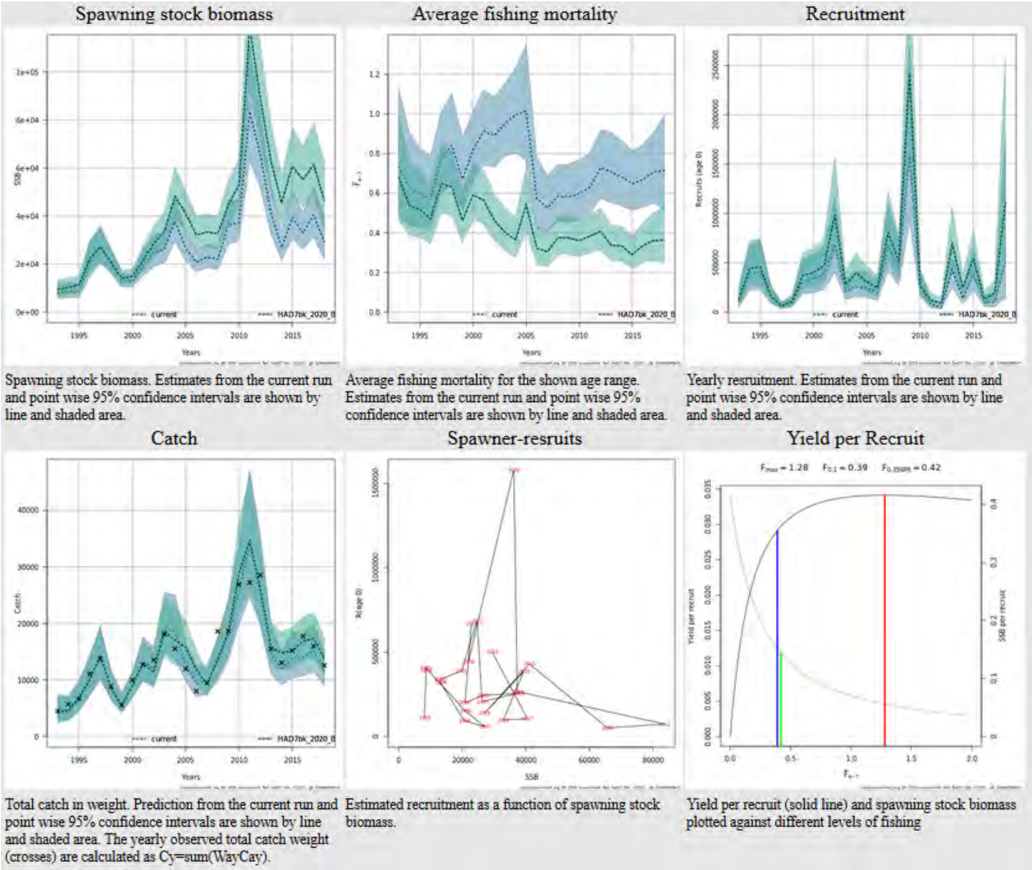


Figure 38. SAM model version 9. "JW_2019_assessment_Test_had27.7bk", rebuild of 2019 assessment.

4.2.3 Model comparisons

A series of comparisons were made between the last applied ASAP assessment model and developing SAM models. A comparison between the 2019 ASAP model and a SAM rebuild of it, using the same data and settings (Figure 24) shows the same patters in recruitment, catch and SSB with minor differences, for instance in slightly lower recruitment in the early time-series in the SAM model-2019 model. Catch in the two models follow the same trends, with a higher peak in 2011, while SSB estimate in 2002 was higher in the original ASAP model. Meanwhile patterns in fishing pressure of the two models followed the same general pattern, with the SAM model being generally smoother.

Figure 25 compares the 2019 ASAP assessment model with the final 2020 SAM model incorporating updated datasets. As with the previous comparison, the two models give similar estimates across recruitment, SSB and catch, with F showing generally similar trends for the middle section (1998–2015) of the time-series. The SAM 2020 model estimated lower F at the start (1993–1998) and the end (2015–2019) of the time-series. Comparing the 2019 SAM rebuild of the ASAP 2019 model with the 2020 SAM assessment model (Figure 26) shows the two have similar F patterns, with lower estimates in F resulting from the data in the 2020 model, though the change in the pattern is clearly a result to the transfer from ASAP to SAM. This is further evident when estimates of these three model are compared together (Figure 27) noting that the SAM 2020 assessment incorporates a final 2019 year.

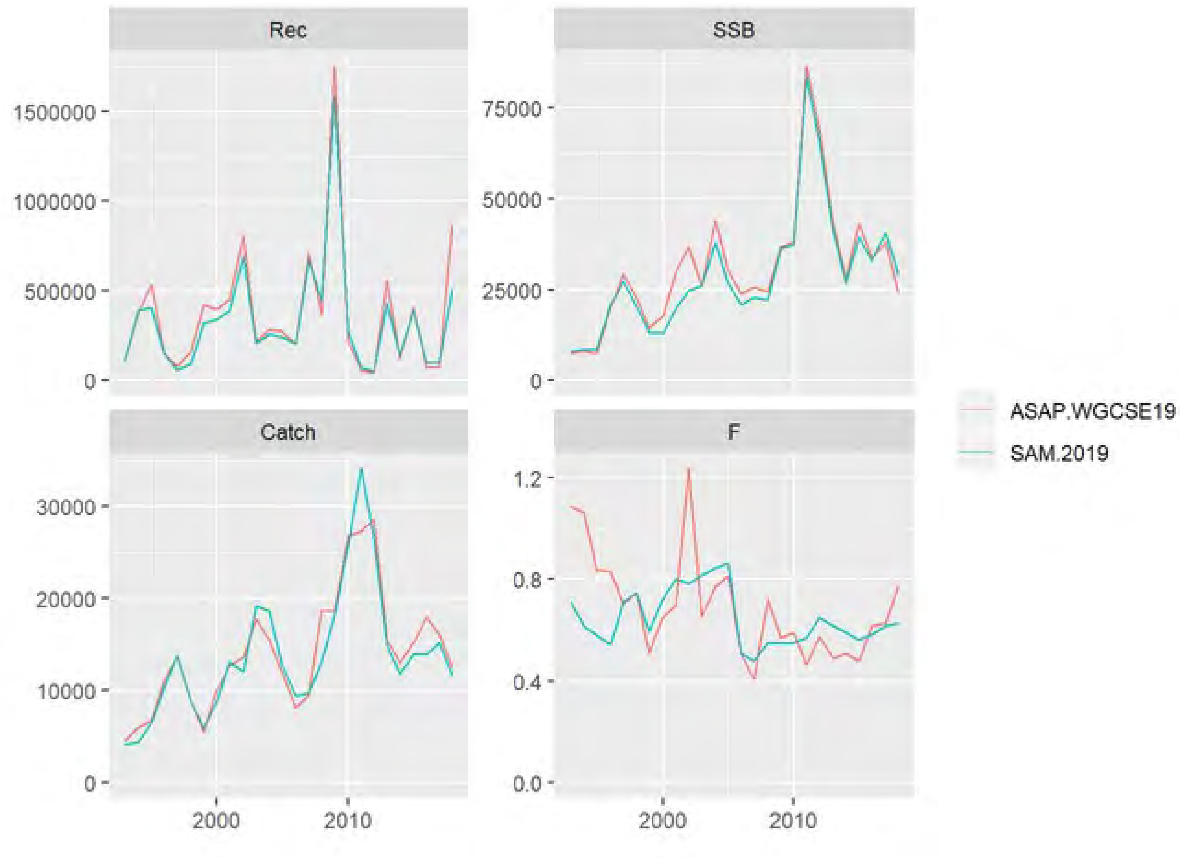


Figure 39. Comparison of the ASAP 2019 assessment model applied in ICES 2019, with a SAM rebuild of the model.

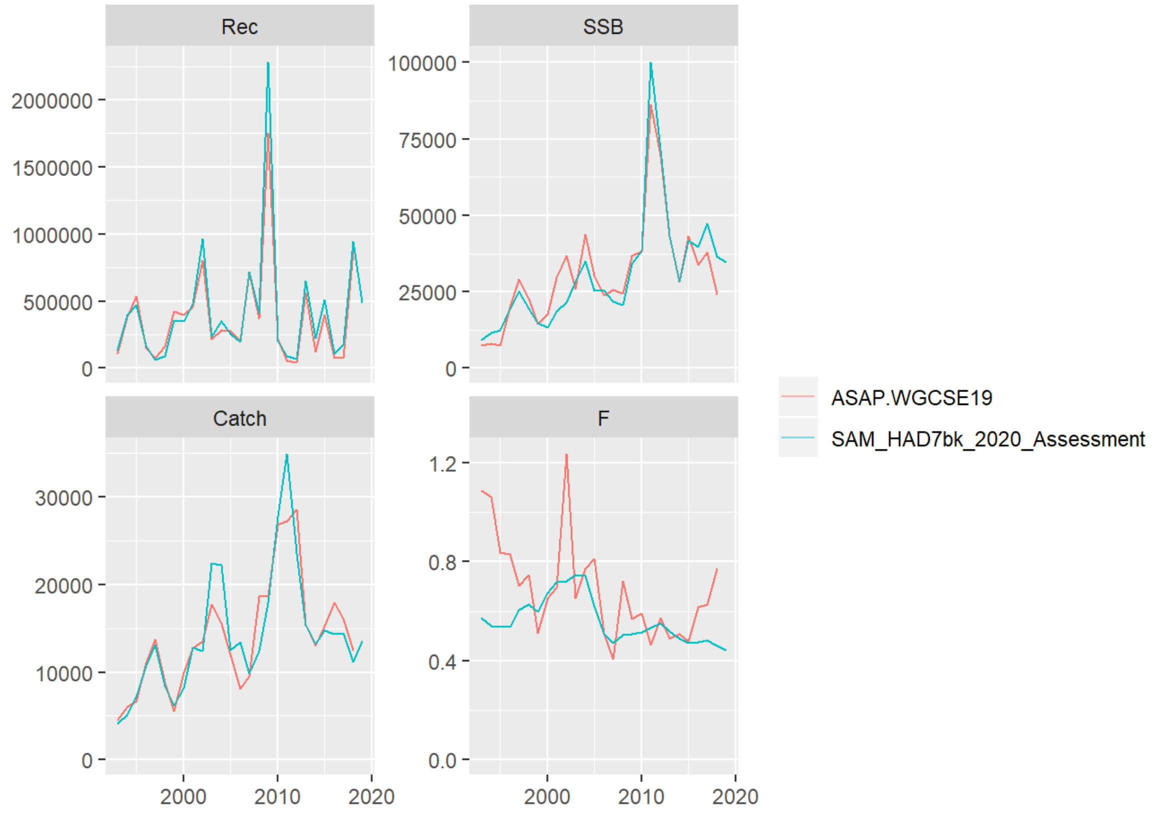


Figure 40. Comparison of the ASAP 2019 assessment model applied in ICES 2019, with the 2020 SAM model.

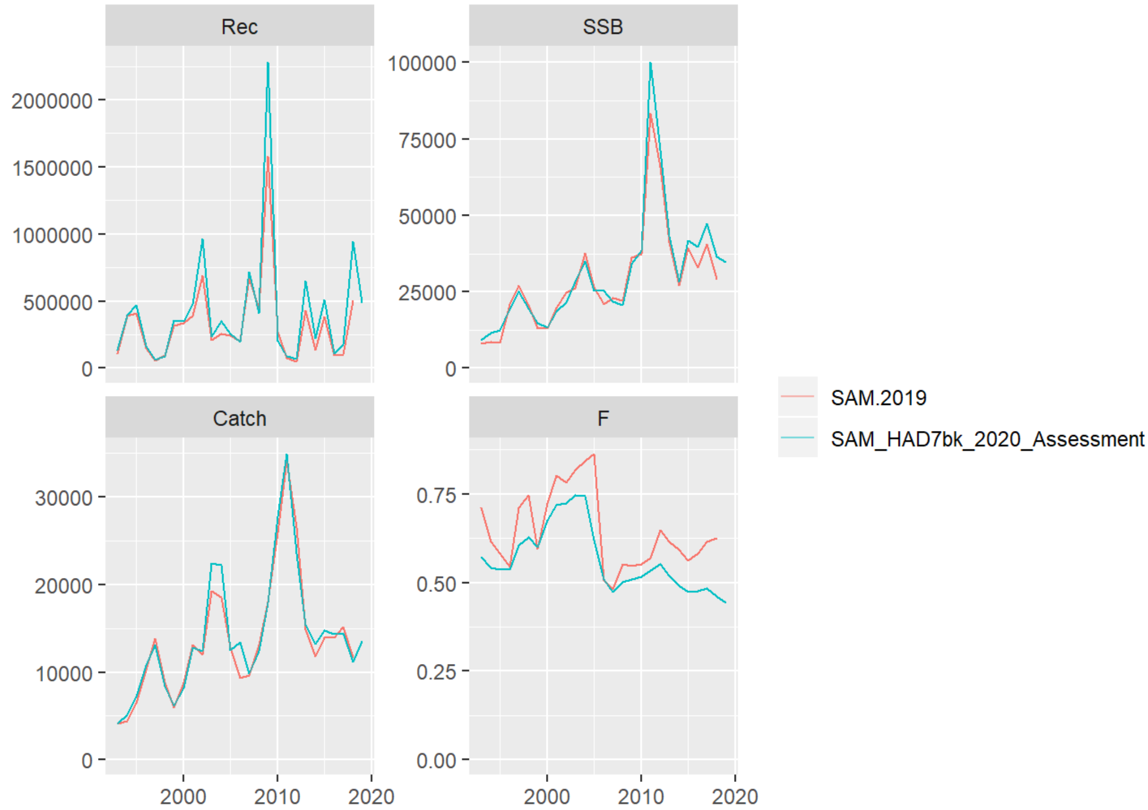


Figure 41. Comparison of the ASAP 2019 assessment model applied in ICES 2019, with the 2020 SAM model.

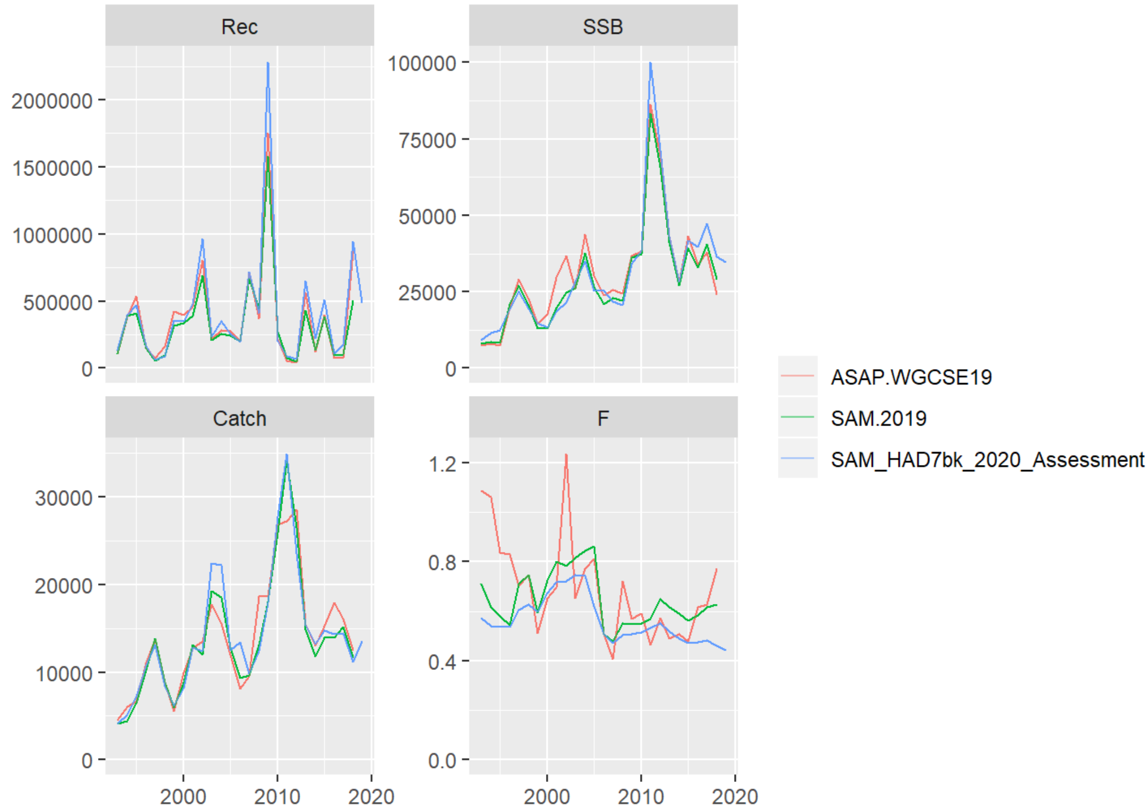


Figure 42. Comparison of the ASAP 2019 assessment model applied in ICES 2019, with the 2020 SAM model.

4.3 Reference points

Reference points were calculated with updated 2020 catch data resulting from the assessment in R using the SAM assessment "HAD7bk_2020_Assessment", with updated data prior to inclusion of the forecast. Reference points were calculated in the statistics package "R", employing the function "eqsim_run" in the R library "msy", which simulates the equilibrium results for a population forward in time given biological parameters, fishery parameters and advice parameters.

The Celtic sea haddock was taken as a Type 1 stock, a "Spasmodic stock with occasional large year classes". Following ICES guidelines, the base of estimating reference points, B_{lim} was based on the lowest SSB where large recruitment was observed (B_{loss}), where F has not been low throughout the observed history (ICES, 2017).

Following this, B_{lim} of 9227 t was based on the B_{loss} (excluding the terminal year of the assessment) which occurred in 1993 (Figure 28).

The assessment of reference points is available as R-markdown "had.27.7b-k_Ref-points_25-6-2020.html."

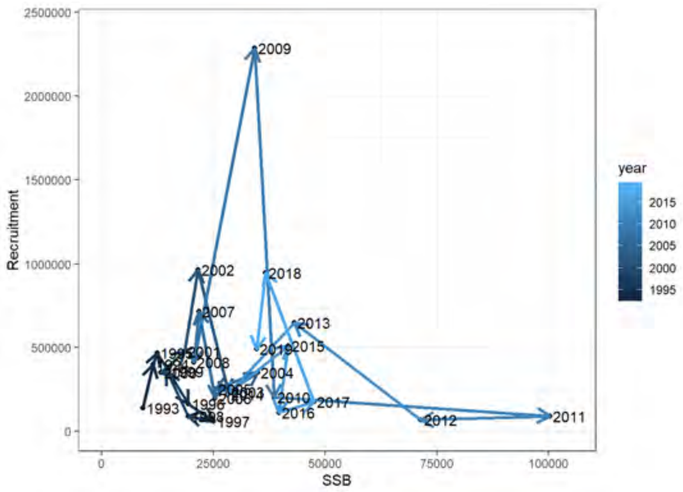


Figure 43. Stock–Recruitment time-series 1993 to 2019 of Celtic sea haddock resulting from SAM assessment.

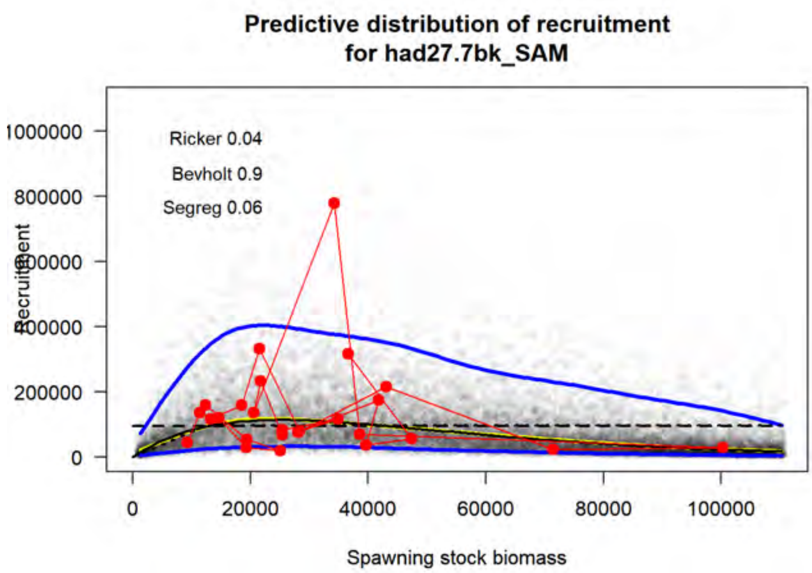


Figure 44. Stock–Recruitment time-series 1993 to 2019 of Celtic sea haddock resulting from SAM assessment showing best fit Ricker, Beverton–Holt and Segregated regression fits, and estimate fit points.

Table 14. Reference point estimates.

Framework	Reference Point	2020 value	2016 values*	Technical basis
MSY approach	MSY $B_{trigger}$	12 822 t	10 000 t	Tonnes; B_{pa}
	F_{MSY}	0.353	0.40	Median point estimates of (F_{05}) EqSim with combined SR.
Precautionary approach	B_{lim}	9227 t	6700 t	Tonnes; lowest observed SSB.
	B_{pa}	12 822 t	10 000 t	Tonnes; B_{lim} combined with the assessment error; $B_{lim} \times \exp(1.645 \times \sigma)$; $\sigma = 0.20$ (default setting)
	F_{lim}	1.40	1.41	F with 50% probability of SSB < B_{lim}.
	F_{pa}	1.01	0.89	F_{lim} combined with the assessment error; $F_{lim} \times \exp(-1.645 \times \sigma)$; $\sigma = 0.20$ (default setting).
EUMAP	MAP MSY $B_{trigger}$	12 822 t	10 000 t	Tonnes; MSY B_{pa}.
	MAP B_{lim}	9227 t	6700 t	Tonnes; lowest observed SSB.
	MAP F_{MSY}	0.353	0.40	F_{MSY}; Median point estimates of (F_{05}) EqSim with combined SR.
	F_{MSY} Lower	0.221	0.26	Median lower point estimates of (F_{05}) EqSim with combined SR. Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
	F_{MSY} Upper	0.521	0.60	Median upper point estimates of (F_{05}) EqSim with combined SR. Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.

*** ICES (2016).**

4.4 Assessment data and updates

Table **10** summarises the data proceeds and available to the 2020 benchmark for assessment of the Celtic Sea haddock stock (full model data configuration in the 2020 SAM assessment are detailed in Appendix 1).

Table 15. Summary of Celtic Sea haddock assessment changes adopted during WKCELTIC benchmark, February 2020.

Variable	2012 ASAP Assessment		2020 SAM Benchmarked assessment	
Catch data	InterCatch raised catch-at-age data, with discards from 2003 (and prior) estimated from Irish discard rates.		Catch-at-age data, raised following standardised raising procedure (external to InterCatch) following WKCELTIC data call. Data from 2005 onwards updated in assessment. Data prior to 2004 maintained as previous assessment.	
Maturity	Across all years:		Across all years:	
	Age 0	0.000	Age 0	0.000
	Age 1	0.000	Age 1	0.039
	Age 2	1.000	Age 2	0.911
	Age 3	1.000	Age 3	0.970
	Age 4	1.000	Age 4	0.980
	Age 5	1.000	Age 5	1.000
	Age 6	1.000	Age 6	1.000
	Age 7	1.000	Age 7	1.000
	Age 8	1.000	Age 8	1.000
Natural mortality	Across all years:		Across all years:	
	Age 0	0.990	Age 0	1.087
	Age 1	0.720	Age 1	0.721
	Age 2	0.600	Age 2	0.575
	Age 3	0.500	Age 3	0.483
	Age 4	0.430	Age 4	0.440
	Age 5	0.400	Age 5	0.406
	Age 6	0.370	Age 6	0.398
	Age 7	0.360	Age 7	0.385
	Age 8	0.340	Age 8	0.360
Model	ASAP 3 (September 2012)		SAM	
	(Age Structured Assessment Program) NOAA Toolbox		(State–space fish Stock Assessment)	
			Stockassessment.org	
	Catch data	Model	Catch data	Model
	Min age 1	Min age 0	Min age 1	Min age 0
	Max age 8	Max age 8	Max age 8	Max age 8

Variable	2012 ASAP Assessment	2020 SAM Benchmarked assessment
Indices	Two: Survey index (combined IGFS-WIBTS-Q4 and EVHOE-WIBTS-Q4) Irish commercial index (IRL_OTB_HAD) catches (age composition of landings and discards)	One: VAST standardised survey index (combined IGFS-WIBTS-Q4 and EVHOE-WIBTS-Q4) 2003 to 2019 Ages 0 to 7
Reference Points	Basis: Type 1 Spasmodic stock with occasional large year classes. B_{lim} based off B_{loss} , the lowest observed SSB showing a recovery – was set to 6700 t	Basis: Type 1 Spasmodic stock with occasional large year classes. B_{lim} based off B_{loss} , the lowest observed SSB showing a recovery – now set to 9227 t

4.5 2020 SAM Assessment and Forecast

4.5.1 Assessment

The final updated SAM assessment including forecasts and resulting catch options was prepared in www.stockassessment.org, and may be accessed at: HAD7bk_2020_Assessment. The data inputs to this and variables are detailed in Table 10, with the incorporated reference points listed in Table 9.

Previous comparisons with the proceeding assessment advice ASAP model, and other variants have detailed this model as appropriate for the basis of providing catch advice. Figure 30 shows recruitment, SSB, Catch and F estimates, with 95% confidence intervals, for the assessment model ("current") and the previous "benchmark" model with a developmental catch dataset, which differed by age classification rather than catch tonnage (labelled "HAD7bk-2020_benchmark"). The comparison shows similar estimates in catch and recruitment, with the 2020 Assessment model estimating a lower SSB since 2000, though following similar trend, and fishing pressure being higher especially over the period from the late 1990s to 20015. Note however, that the data used in the "HAD7bk-2020_benchmark" model are not considered current.

Estimated recruitment, spawning–stock biomass (SSB), and average fishing mortality of the 2020 SAM assessment model are detailed Table 13. For the 2020 SAM assessment model, Figure 31 shows yield and spawning–stock biomass, each per recruit, plotted against different levels of fishing, indicating $F_{max} = 0.33$, $F_{0.1} = 0.21$ and $F_{0.35SPR} = 0.38$.

The model estimates and fit to observed catch and survey datapoints (Figure 32) by age do show some discrepancies, most notably for the seven and eight year olds in catch data at in the early part of the time-series (1993–2003) however the majority of estimates are close to the observations.

Selection-at-age (Figure 33) of one year olds is low, as may be expected being smaller than most net mesh. Two to seven year olds showed variable selectivity, especially over the first half of the time-series, however from 2010 on selectivity is linear with age. Similarly biomass-at-age varied over the time-series, showing overlap across years, while showing greater proportions of the lower and middle age classes.

Residuals in the SAM assessment (Figure 34 and Figure 35) show no evident patterns.

Retrospective analysis of the assessment (Figure 36) details the Mohn's rho between most recent assessment with a year of data removed as 2% for recruitment, <0.5% for SSB and 6% for F. Recruitment patterns are barely discernible from one another, with all "peels" inside the 95% confidence intervals of the full dataseries. This is also the case for SSB, with the 2014 peel, and 2016 peels showing most deviation from others. For F peels do show some minor divergence from one another, mostly at junctures in the direction of the trend, most notably for 2002 going into 2004, following which F reduced. The peels for 2014 and 2016 show the largest divergence from the common trend, with the 2014 peel just breaking the 95% cl bound. In each case, there is no continual trend in one direction across peels.

Further, leave-one-out analytical figures are available in the assessment at www.stockassessment.org, named HAD7bk_2020_Assessment.

Table 14 and Table **15** show estimated fishing mortality and stock numbers-at-age.

4.5.2 Forecast

The SAM assessment, coupled with reference points detailed above, was applied in www.stockassessment.org to provide forecasts across a range of scenarios (Table 16), for years 2019 to 2022.

The forecast was calculated using assumptions for the interim year similar to those of the proceeding ASAP forecast (Table 11). Periods for estimates of these were retained, as this approach, the time periods and estimates are still considered to be the most appropriate.

Table 16. Haddock in divisions 7.b–k. Assumptions made for the interim year and in the forecast.

Variable	Value	Notes
$F_{ages\ 3\text{–}5}$ (2019)	0.406	Fsq = Fages 3–5 (2019).
SSB_{2020}	66 447	Tonnes; Short-term forecast.
R_{age} 0 (2019–2020)	351 066	Thousands; Median (1993–2019).
Catch (2020)	20 058	Tonnes; Short-term forecast.
Wanted catch (2020)	9149	Tonnes; Short-term forecast assuming 2019 discard pattern.
Unwanted catch (2020)	10 909	Tonnes; Short-term forecast assuming 2019 discard pattern.

From these, the 2021 estimates of Total catch, Projected landings (Wanted catch), Projected discards (Unwanted catch), F_{total}, $F_{Projected\ landings}$, $F_{Projected\ discards}$, and SSB for 2022 have been extracted in Table 12. Percentage changes in SSB and Advice are calculated relative to the advice provided in 2019, for SSB (2022 relative to SSB 2021; 71 323 tonnes) and for Advice (values for 2021 relative to the corresponding 2020 MAP advice of 16 671, 11 418 and 23 262 tonnes, respectively; other values are relative to F_{MSY}). This indicates an increase in EU MAP/ F_{MSY} advice of 10%. The changes in advice are the result of a combination of change to the estimated current state of the stock, a slight improvement in the SSB of the stock (Figure 25) and the slightly elevated reference points (Table **9**).

Table 17. Advice Forecast estimates (full estimates in Table 16).

Basis	Total catch (2021)	Projected landings (2021)	Projected discards (2021)	F_{total} (2021)	$F_{projected\ landings}$ (2021)	$F_{projected\ discards}$ (2021)	SSB (2022)	% SSB change *	% Advice change ^
ICES advice basis									
EU MAP^^: F_{MSY}	18382	9770	8612	0.35	0.25	0.107	70434	-1.25	10.0
F=MAP $F_{MSY\ lower}$	12128	6485	5643	0.22	0.15	0.07	77851	9.2	6.0
F=MAP $F_{MSY\ upper}$	25454	13418	12036	0.52	0.36	0.157	62142	-12.9	9.4
Other scenarios									
F = 0	0	0	0	0	0	0	92336	29.5	-100
F_{pa}	41510	21513	19997	1.01	0.71	0.31	44225	-38.0	149
F_{lim}	50744	25951	24793	1.40	0.98	0.42	34378	-51.8	204
$SSB_{2021} = B_{lim}$	78240	37584	40656	3.99	2.78	1.20	9259	-87.0	369
$SSB_{2021} = B_{pa}$= MSY $B_{trigger}$	73405	35759	37646	3.20	2.24	0.97	12859	-82.0	340
F = F_{2020}	20690	10980	9710	0.41	0.28	0.123	67674	-5.1	24.1

*** SSB 2022 relative to SSB 2021 (71 323 tonnes).**

^ Advice values for 2021 relative to the corresponding 2020 values (MAP advice of 16 671, 11 418 and 23 262 tonnes, respectively; other values are relative to F_{MSY}).

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

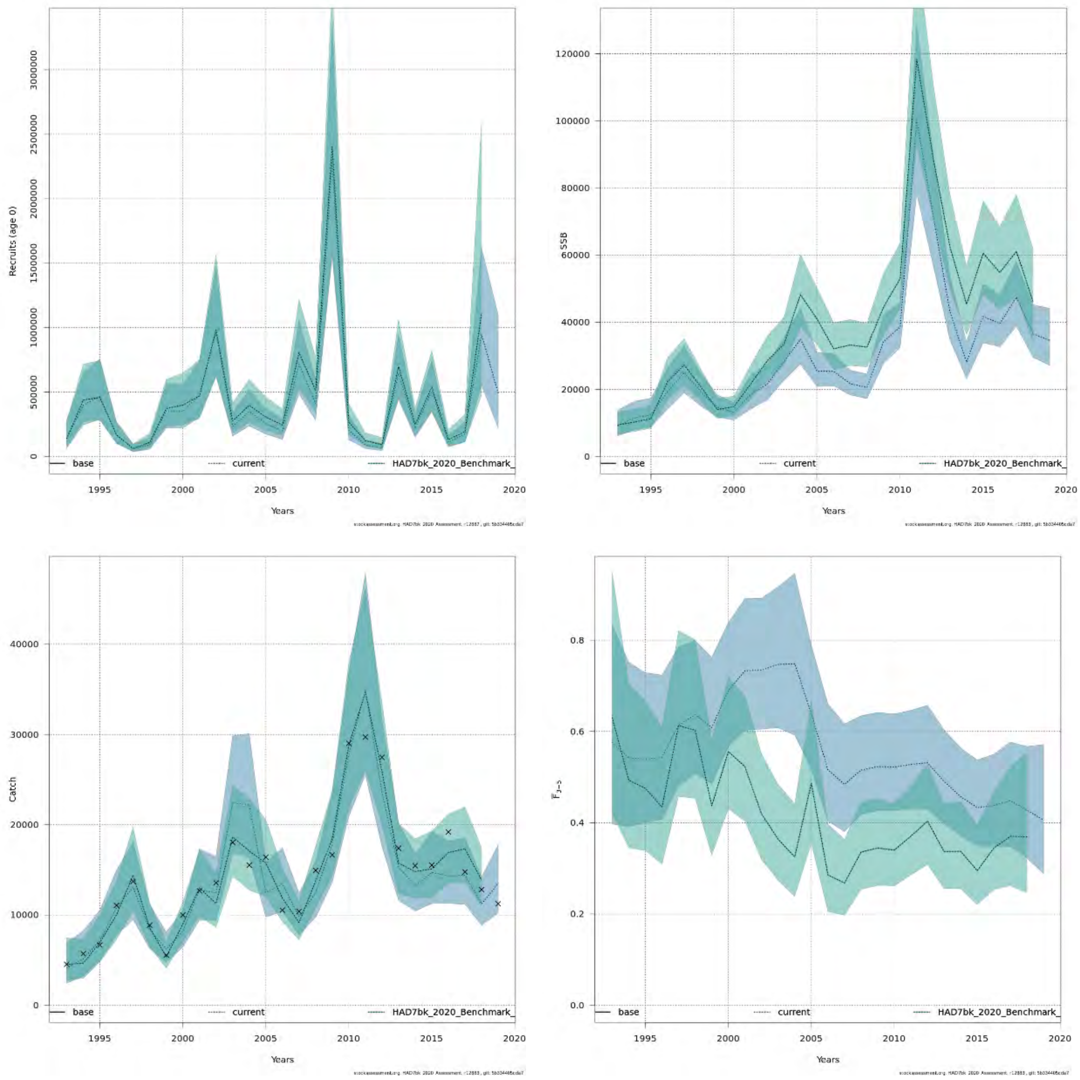


Figure 45. SAM assessment recruitment (at age 0) stock size (SSB, t), Fishing pressure (F3-5) catch (t). Prediction from the current run (2020 assessment model), with 95% confidence intervals around estimates. Points in the catch estimates figure, bottom right, are the observed annual catch.

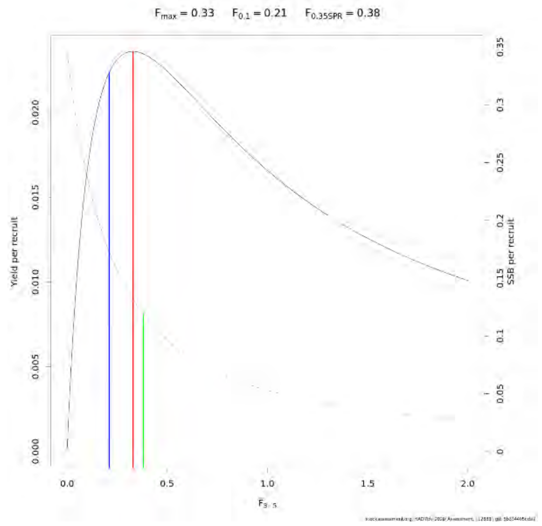


Figure 46. SAM assessment yield (solid line) and spawning–stock biomass per recruit plotted against different levels of fishing. Vertical lines represent biological reference points (blue: $F_{0.1}$, green: $F_{0.35SPR}$, and red: F_{max}).

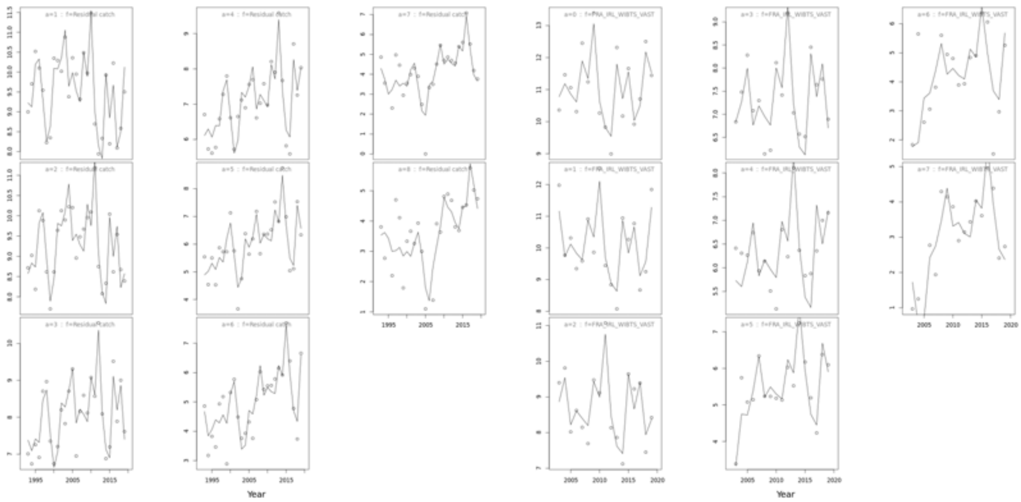


Figure 47. SAM assessment Fit to data; Predicted line and observed points for catch (left) and survey indices (right) (log scale).

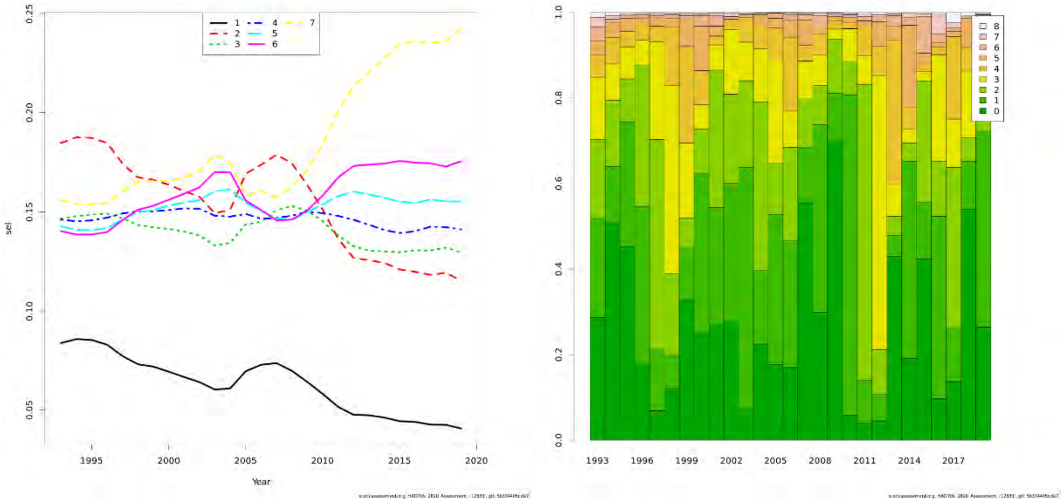


Figure 48. SAM assessment selection (F divided by F_{bar}; left) and Biomass-at-age (right)

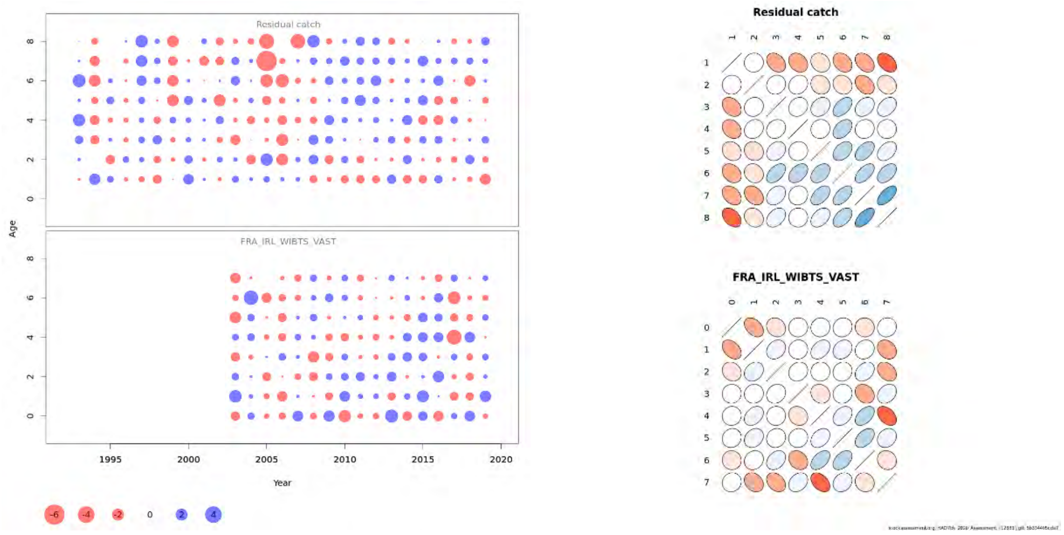


Figure 49. SAM assessment standardized one-observation-ahead residuals (left) and empirical correlations between ages in one-observation-ahead residuals (right) for catch (top) and survey indices (bottom).

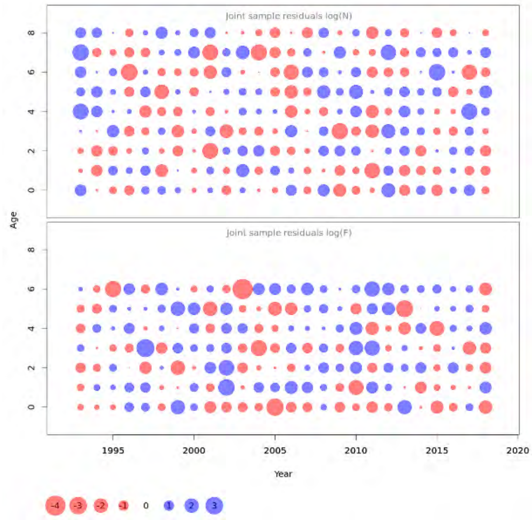


Figure 50. SAM assessment process residuals – standardized single-joint-sample residuals of process increments.

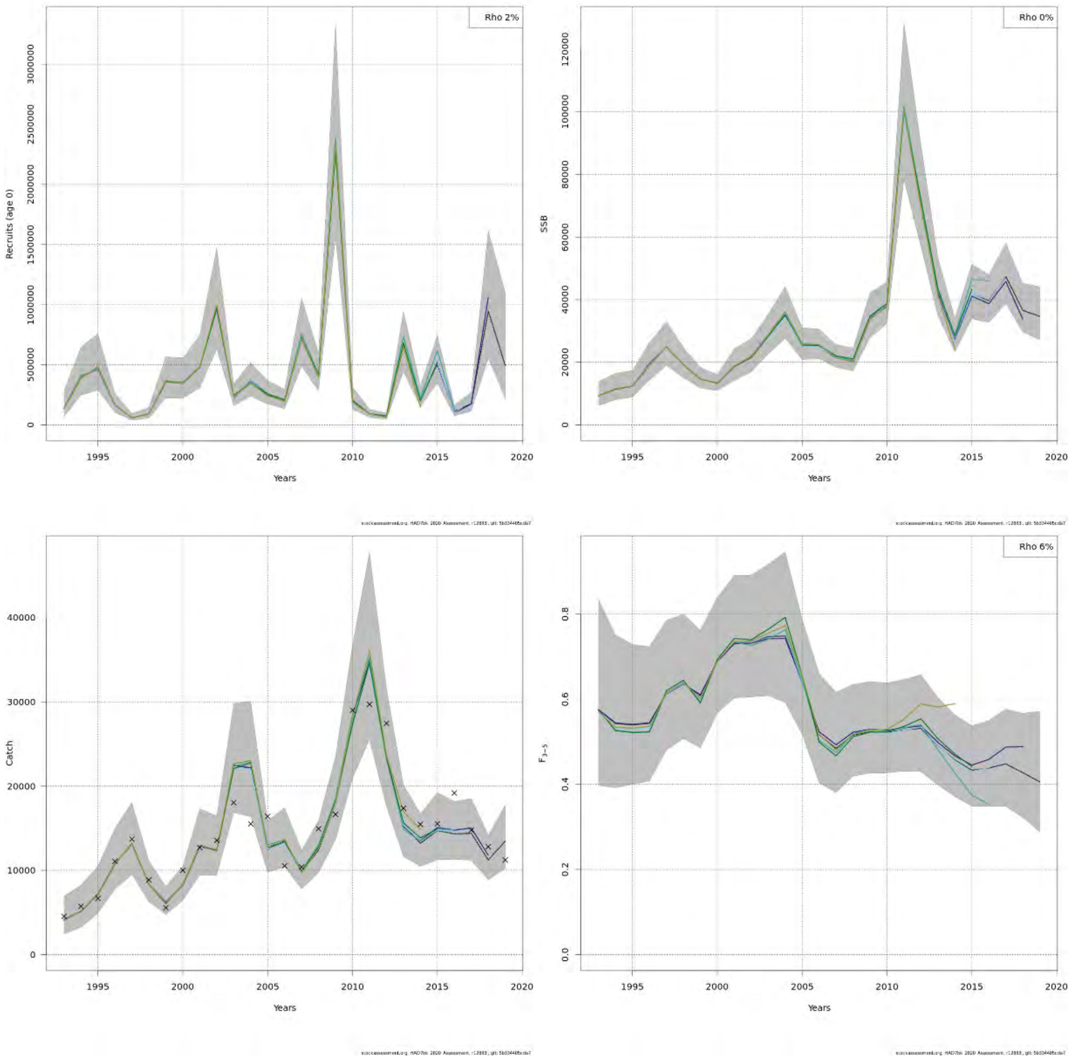


Figure 51. SAM assessment Retrospective SSB (top left), F (top right), Recruitment (bottom left) and Catch (bottom right) showing Mohn's rho.

Table 18. Estimated recruitment, spawning–stock biomass (SSB), and average fishing mortality.

Year	R(age 0)	Low	High	SSB	Low	High	F_{bar}(3–5)	Low	High	TSB	Low	High
1993	138345	67244	284625	9227	6164	13811	0.575	0.397	0.834	19749	13942	27976
1994	399725	246025	649446	11474	7981	16498	0.542	0.392	0.751	33040	24403	44735
1995	467464	288573	757253	12397	8840	17386	0.540	0.400	0.729	48638	37081	63796
1996	164566	102913	263153	19372	14217	26395	0.543	0.408	0.724	44445	35144	56209
1997	59414	37128	95079	25052	19040	32963	0.614	0.480	0.785	33778	26718	42702
1998	90819	56711	145438	19342	15073	24819	0.637	0.507	0.799	25055	20266	30975
1999	355678	223101	567038	14668	11751	18311	0.608	0.485	0.763	27192	22138	33400
2000	351066	220914	557897	13246	10906	16088	0.689	0.567	0.839	34940	28089	43461
2001	478013	306453	745616	18536	14130	24316	0.733	0.603	0.891	42508	34004	53139
2002	964657	629751	1477668	21591	16907	27572	0.734	0.605	0.892	55556	44751	68970
2003	233720	158479	344683	28331	22702	35356	0.747	0.608	0.917	78196	61784	98968
2004	351353	238746	517072	34893	27547	44198	0.748	0.592	0.946	61171	50576	73986
2005	254303	173861	371963	25454	20857	31063	0.639	0.518	0.789	54496	45660	65041
2006	198880	134290	294538	25375	21069	30560	0.516	0.403	0.660	48771	41300	57593
2007	715742	485286	1055639	21721	18351	25711	0.484	0.380	0.617	70929	56343	89291
2008	411306	282123	599640	20604	17252	24607	0.515	0.419	0.634	76880	62946	93899
2009	2283436	1558676	3345198	34259	27768	42267	0.523	0.426	0.642	189185	143328	249712
2010	203340	129987	318088	38596	32517	45813	0.522	0.427	0.638	181959	141049	234734
2011	90043	62113	130531	100253	78231	128473	0.528	0.431	0.646	125598	100650	156729
2012	68005	46251	99992	71377	56863	89595	0.531	0.430	0.657	82473	67010	101503
2013	647545	442510	947582	43110	34769	53452	0.490	0.398	0.604	84484	69022	103411
2014	220385	149029	325906	28142	23226	34097	0.457	0.371	0.563	78193	64811	94338
2015	509828	348175	746533	41749	33886	51436	0.433	0.349	0.538	98650	80515	120870
2016	111283	74238	166814	39627	32718	47993	0.438	0.349	0.550	83679	69332	100995
2017	176611	114812	271674	47446	38780	58048	0.448	0.348	0.577	67694	56426	81212
2018	946209	553266	1618231	36590	29591	45244	0.427	0.322	0.567	107011	78077	146668
2019	493214	221176	1099848	34642	27181	44151	0.406	0.288	0.572	121204	84971	172886

Table 19. Estimated fishing mortality-at-age.

Year Age	0	1	2	3	4	5	6	7	8
1993		0.332	0.733	0.582	0.579	0.566	0.556	0.618	0.618
1994		0.322	0.703	0.554	0.545	0.528	0.520	0.577	0.577
1995		0.318	0.697	0.553	0.542	0.524	0.516	0.572	0.572
1996		0.309	0.687	0.555	0.547	0.528	0.520	0.575	0.575
1997		0.322	0.727	0.611	0.622	0.609	0.607	0.668	0.668
1998		0.315	0.721	0.618	0.647	0.645	0.651	0.711	0.711
1999		0.296	0.684	0.586	0.619	0.621	0.630	0.682	0.682
2000		0.322	0.760	0.656	0.701	0.711	0.725	0.768	0.768
2001		0.328	0.790	0.690	0.747	0.762	0.784	0.824	0.824
2002		0.317	0.779	0.683	0.750	0.771	0.803	0.843	0.843
2003		0.306	0.757	0.675	0.751	0.815	0.863	0.907	0.907
2004		0.309	0.766	0.681	0.748	0.816	0.860	0.886	0.886
2005		0.298	0.725	0.615	0.638	0.663	0.667	0.678	0.678
2006		0.255	0.609	0.508	0.513	0.527	0.529	0.563	0.563
2007		0.241	0.584	0.493	0.480	0.480	0.476	0.514	0.514
2008		0.242	0.604	0.529	0.512	0.505	0.505	0.563	0.563
2009		0.224	0.569	0.524	0.523	0.522	0.525	0.595	0.595
2010		0.203	0.528	0.507	0.521	0.537	0.552	0.642	0.642
2011		0.184	0.487	0.492	0.528	0.563	0.596	0.716	0.716
2012		0.173	0.460	0.482	0.530	0.582	0.629	0.776	0.776
2013		0.161	0.427	0.444	0.488	0.539	0.591	0.749	0.749
2014		0.148	0.398	0.417	0.451	0.503	0.559	0.728	0.728
2015		0.136	0.370	0.397	0.427	0.475	0.538	0.719	0.719
2016		0.136	0.370	0.404	0.433	0.477	0.540	0.729	0.729
2017		0.134	0.370	0.409	0.446	0.489	0.546	0.737	0.737
2018		0.127	0.356	0.394	0.425	0.464	0.516	0.703	0.703
2019		0.116	0.330	0.371	0.403	0.444	0.502	0.693	0.693

Table 20. Estimated stock numbers-at-age.

Year Age	0	1	2	3	4	5	6	7	8
1993	138345	49488	13002	4488	1238	369	300	188	87
1994	399725	45995	17358	3489	1564	441	137	115	100
1995	467464	135687	15856	4814	1246	596	172	55	83
1996	164566	159179	47239	4369	1721	473	238	69	54
1997	59414	55315	58734	12747	1547	652	190	98	49
1998	90819	19673	19135	16675	4019	531	238	70	52
1999	355678	30232	6900	5251	5726	1282	182	83	41
2000	351066	121342	11096	1954	1853	2026	450	66	43
2001	478013	117633	42528	2904	624	608	653	143	35
2002	964657	160048	40381	10893	891	188	191	197	53
2003	233720	331692	58112	9845	3486	253	61	58	74
2004	351353	79881	114973	15182	3059	1041	69	17	36
2005	254303	116234	29577	29642	4650	887	271	17	14
2006	198880	83975	39395	7898	9581	1520	286	87	11
2007	715742	67523	31310	11813	3036	3748	587	115	35
2008	411306	233949	26033	9720	4375	1264	1547	246	65
2009	2283436	136202	86697	8015	3621	1693	545	637	119
2010	203340	779287	54034	27266	3035	1413	684	226	293
2011	90043	69378	304618	17499	9989	1265	558	268	197
2012	68005	30094	29992	102412	6602	3762	505	207	160
2013	647545	23336	12497	11940	38151	2527	1374	184	114
2014	220385	215663	9926	4550	5461	14793	1015	509	96
2015	509828	76092	89407	3767	1844	2538	5912	403	199
2016	111283	174220	33764	33911	1492	769	1134	2304	201
2017	176611	36993	71213	13407	13139	580	314	455	813
2018	946209	57565	16213	26987	5679	5320	226	124	421
2019	493214	317020	24411	6580	11231	2386	2217	92	192

Table 21. Forecast estimates.

Forecast table 1. MSY approach: F_MSY.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	0.353	0.211	0.581	351066	59414	2283438	71323	43395	118761	18382	10958	32754	0.246	0.146	0.408	0.107	0.065	0.173	9770	6113	16138	8612	4843	16616
2022	0.353	0.197	0.618	351066	59414	2283438	70434	37872	159516	18147	9872	39856	0.247	0.136	0.435	0.106	0.061	0.183	10971	6290	20733	7176	3582	19123

Forecast table 2. Precautionary approach: Fpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	1.01	0.603	1.662	351066	59414	2283438	71323	43395	118761	41510	25472	73168	0.705	0.419	1.169	0.305	0.184	0.493	21513	13880	34110	19997	11592	39058
2022	1.01	0.565	1.767	351066	59414	2283438	44225	19664	118843	26990	14349	68725	0.705	0.390	1.245	0.305	0.175	0.522	14137	7590	29293	12853	6759	39432

Forecast table 3. FMSY upper.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	0.521	0.311	0.857	351066	59414	2283438	71323	43395	118761	25454	15305	44906	0.364	0.216	0.603	0.157	0.095	0.254	13418	8494	21855	12036	6811	23047
2022	0.521	0.291	0.912	351066	59414	2283438	62142	32090	146978	22344	12330	50448	0.364	0.201	0.642	0.157	0.090	0.270	13023	7488	24813	9321	4842	25635

Forecast table 4. FMSY lower.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	0.221	0.132	0.364	351066	59414	2283438	71323	43395	118761	12128	7169	21765	0.154	0.092	0.256	0.067	0.040	0.108	6485	4016	10857	5643	3153	10913
2022	0.221	0.124	0.387	351066	59414	2283438	77851	43325	171483	13198	7069	28312	0.154	0.085	0.272	0.067	0.035	0.115	8175	4584	15620	5019	2485	12692

Forecast table 5. F = 0.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044.000	32224.000	0.283	0.184	0.440	0.123	0.082	0.183	9190.000	6348.000	13797.000	11084.000	6696.000	18427.000
2021	0	0	0	351066	59414	2283438	71323	43395	118761	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2022	0	0	0	351066	59414	2283438	92338	53707	193134	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Forecast table 6. Fpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	1.01	0.603	1.662	351066	59414	2283438	71323	43395	118761	41510	25472	73168	0.705	0.419	1.169	0.305	0.184	0.493	21513	13880	34110	19997	11592	39058
2022	1.01	0.565	1.767	351066	59414	2283438	44225	19664	118843	26990	14349	68725	0.705	0.390	1.245	0.305	0.175	0.522	14137	7590	29293	12853	6759	39432

Forecast table 7. F = Flim.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	1.4	0.838	2.304	351066	59414	2283438	71323	43395	118761	50744	31428	89223	0.977	0.580	1.620	0.423	0.256	0.684	25951	16867	40775	24793	14561	48444
2022	1.4	0.782	2.449	351066	59414	2283438	34378	13546	101384	27102	13338	74943	0.978	0.540	1.726	0.422	0.242	0.723	12838	6134	29164	14266	7204	45783

Forecast table 8. Fsq.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	0.408	0.242	0.668	351066	59414	2283438	71323	43395	118761	20690	12391	36764	0.283	0.168	0.470	0.123	0.074	0.198	10980	6904	18038	9710	5487	18726
2022	0.408	0.227	0.71	351066	59414	2283438	67674	35916	155623	19689	10793	43424	0.283	0.157	0.500	0.123	0.070	0.210	11764	6753	22242	7925	4038	21182

Forecast table 9. hit Blim.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44716	13669	10498	18083	0.332	0.236	0.465	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.266	0.623	351066	59414	2283438	66165	44270	103056	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	3.988	2.379	6.56	351066	59414	2283438	71323	43395	118761	78240	48166	147975	2.783	1.652	4.612	1.203	0.727	1.948	37584	24152	59156	40656	24014	88819
2022	2.9	1.628	5.099	351066	59414	2283438	9255	2291	42347	18060	5821	76849	2.023	1.130	3.579	0.877	0.498	1.520	4107	1217	15112	13953	4604	61737

Forecast table 10. hit Bpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44718	13669	10498	18083	0.332	0.236	0.469	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.268	0.623	351068	59414	2283438	66165	44270	103058	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	3.203	1.912	5.271	351068	59414	2283438	71323	43395	118761	73405	45361	135204	2.236	1.328	3.708	0.967	0.584	1.565	35759	23199	56159	37646	22166	79045
2022	2.085	1.171	3.664	351068	59414	2283438	12855	3531	53161	17855	6391	67797	1.455	0.812	2.571	0.630	0.359	1.093	5212	1699	16828	12643	4696	50965

Forecast table 11. hit MSY Btrigger.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.408	0.291	0.566	493368	222200	1083038	35227	27609	44718	13669	10498	18083	0.332	0.236	0.469	0.074	0.055	0.101	7955	6220	10175	5714	4278	7908
2020	0.408	0.268	0.623	351068	59414	2283438	66165	44270	103058	20274	13044	32224	0.283	0.184	0.440	0.123	0.082	0.183	9190	6348	13797	11084	6696	18427
2021	3.203	1.912	5.271	351068	59414	2283438	71323	43395	118761	73405	45361	135204	2.236	1.328	3.708	0.967	0.584	1.565	35759	23199	56159	37646	22166	79045
2022	2.085	1.171	3.664	351068	59414	2283438	12855	3531	53161	17855	6391	67797	1.455	0.812	2.571	0.630	0.359	1.093	5212	1699	16828	12643	4696	50965

4.6 References

ICES. 2019. ICES Advice 2019– had.27.7b – https://doi.org/10.17895/ices.advice.4785

ICES. 2016. Report of the Working Group for the Celtic Seas Ecoregion (WGCSE), 12–21 May 2015, ICES Headquarters, Copenhagen, Denmark. ICES CM 2015/ACOM:12. 1432 pp. http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2016/WGCSE/wgcse_2016.pdf

ICES. 2017. Advice Technical Guidelines. http://ices.dk/sites/pub/Publication%20Reports/Guidelines%20and%20Policies/12.04.03.01_Reference_points_for_category_1_and_2.pdf

Appendix 1

SAM assessment data model configuration in the 2020

```
# Configuration saved: Mon Feb 10 21:50:00 2020

# Where a matrix is specified rows corresponds to fleets and columns to ages.
# Same number indicates same parameter used
# Numbers (integers) starts from zero and must be consecutive

$minAge
# The minimium age class in the assessment
 0

$maxAge
# The maximum age class in the assessment
 8

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

$keyLogFsta
# Coupling of the fishing mortality states (normally only first row is used).
  -1   0   1   2   3   4   5   6   6
  -1  -1  -1  -1  -1  -1  -1  -1  -1

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

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

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

$keyVarF
# Coupling of process variance parameters for log(F)-process (normally only first row is
used)
   0   0   0   0   0   0   0   0   0
  -1  -1  -1  -1  -1  -1  -1  -1  -1

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

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

$keyVarObs
# Coupling of the variance parameters for the observations.
   0   0   0   0   0   0   0   0   0
   1   1   1   1   1   1   2   2  -1

$obsCorStruct
# Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstruc-
tured). | Possible values are: "ID" "AR" "US"
 "ID" "ID"

$keyCorObs
# Coupling of correlation parameters can only be specified if the AR(1) structure is
chosen above.
# NA's indicate where correlation parameters can be specified (-1 where they cannot).
#0-1 1-2 2-3 3-4 4-5 5-6 6-7 7-8
  NA  NA  NA  NA  NA  NA  NA  NA
  NA  NA  NA  NA  NA  NA  NA  -1

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

$noScaledYears
# Number of years where catch scaling is applied.
 0

$keyScaledYears
# A vector of the years where catch scaling is applied.


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

$fbarRange
# lowest and higest age included in Fbar
 3 5

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

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

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

```
 0

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

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

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

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

5 Whiting in divisions 7.b–ce–k

5.1 Stock ID

Whiting in the NE Atlantic extend from the Barents Sea and Iceland down to the southern Bay of Biscay. There are population genetics and tagging studies in the literature relating to stock structure and migrations, but the degree of separation between the Celtic Sea and surrounding stock(s) is not wholly conclusive.

This stock is managed by TAC covering 7.bk while the assessment area considered only 7.ek. The previous benchmark, WKCELT 2014, proposed inclusion of 7.bc within a 7.bk assessment and management area, but 7.d remains within the North Sea assessment area. Two ICES rectangles in the south of 27.7.a (33E2 and 33E3) are also included in 27.7.g. There was no agreed proposal from WKCELTIC 2020 to consolidate the TAC and assessment areas.

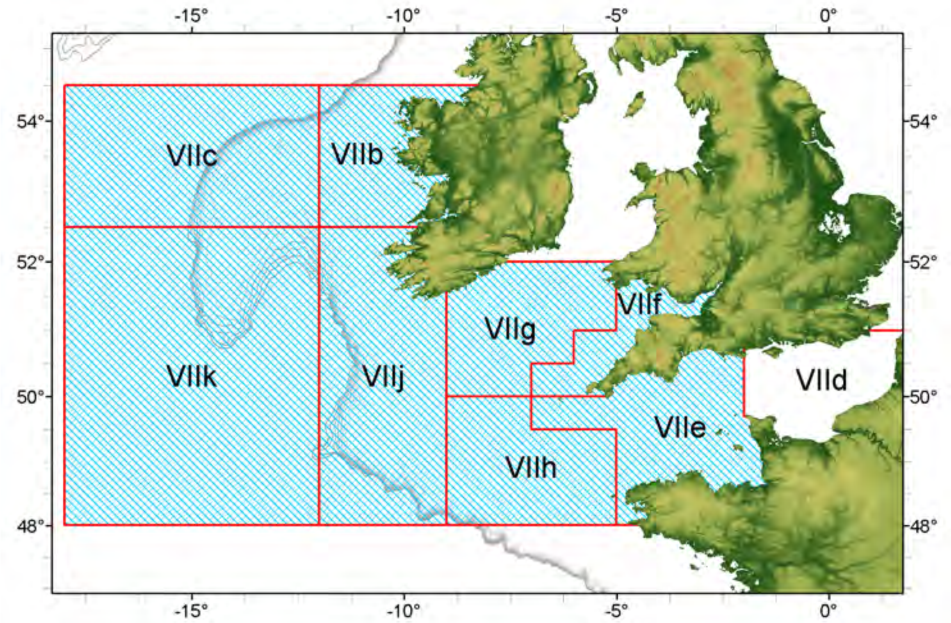


Figure 1. Whiting 27.7b–ce–k TAC Area 27.7b–k with assessment area highlight in blue.

5.2 Stock structure

A more detailed literature review was carried out and is available in WKCELT 2014 report in relation to whiting biology. In general however, egg and ichthyoplankton surveys indicate that whiting larvae are present at inshore sites throughout the Channel, Smalls, Saltees and Fastnet in the Celtic Sea as well as Stanton to the north. No whiting larvae were recorded on the Porcupine Bank or much beyond the 200m contour (Henderson and Holmes, 1989; Dransfeld *et al.*, 2004).

IBTS Q4 surveys show whiting juveniles in 7.bk predictably around the west and southwest coast of Ireland as well as the southern coast of Wales. Areas 7b,g and j in Q4 at least are all therefore important juvenile areas for whiting. By late summer 0-group fish settle out of the plankton,

overwinter in more coastal shallow habitat and have been closely associated with inshore abundance of *Crangon crangon* (Henderson and Holmes, 1989). The same authors found in late spring many of these 0-group juveniles in estuarine habitats moved offshore never to return, while in more open marine habitats they often spent a further year *in situ* before recruiting to the adult stock as 1-group fish. Adults are found in IBTS Q4 surveys around the Irish and UK coasts and throughout the Celtic Sea shelf area, but generally highest abundance is on the Smalls commercial fishing grounds in 7.g.

Compared to haddock there is generally a higher signal to noise ratio for whiting from the same surveys, particularly in the area of the English Channel, as well as higher variability in stock weights-at-age. This may suggest some stock mingling between the Celtic Sea, North Sea and/or Irish Sea in this area is a possibility. However, Pawson (1995) states there was "little indication of any migration" based on tagging of ~4000 individual in the western channel (1958–1960) with a return rate of 12–13% within three months.

A review by Reiss (Reiss *et al*., 2009) of genetic population studies suggest there is little evidence of heterogeneity within the NE Atlantic whiting stock including the northern North Sea. In contrast differentiation within the North Sea has been suggested as well some evidence for small scale population structure of whiting within the Irish Sea.

5.3 Fishery

Whiting in Divisions 7.bc and e–k are taken as a component of catches in mixed demersal trawl, and to a lesser extent, seine fisheries (Table 1). The main components of the gadoid mixed fishery being whiting, haddock and cod.

Table 1. Catch distribution by fleet in 2018 as estimated by ICES.[1]

Catch	Landings					Discards				
10 268 t	Otter trawls	Seine nets	Beam trawls	Mid-water	Other gears	Otter trawls	Seine nets	Beam trawls	Mid-water	Other gears
	78%	15%	2%	< 1%	5%	65%	< 1%	33%	< 1%	2%
	8773 t					1495 t				

Gadoid catches[2] in the Celtic Sea are generally located off the southeast coast of Ireland (Figure 1) in an area of high commercial activity for demersal trawlers known as the 'Smalls'. In terms of national participation in the fishery, Ireland and France are the major fleets (Table 2).

Table 2. Average official landings (t) and % of average annual landings by country for 2014–2018[1].

Belgium	France	Ireland	UK	Others	Total
153	5,156	6,387	796	47	2,508
1%	41%	51%	6%	1%	

[1] ICES Advice for Whiting 27.7b-ce-k http://ices.dk/sites/pub/Publication%20Reports/Advice/2019/2019/whg.27.7b-ce-k.pdf

[2] Gerritsen, H.D. and Kelly, E. 2019. Atlas of Commercial Fisheries around Ireland, third edition. Marine Institute, Ireland. ISBN 978-1-902895-64-2. 72 pp. (http://hdl.handle.net/10793/1432).

The Irish demersal trawl fleet tends to operate closer to the Irish coast on the Smalls, while the French OTB effort is more concentrated more centrally in the Celtic Sea and to the southwest.

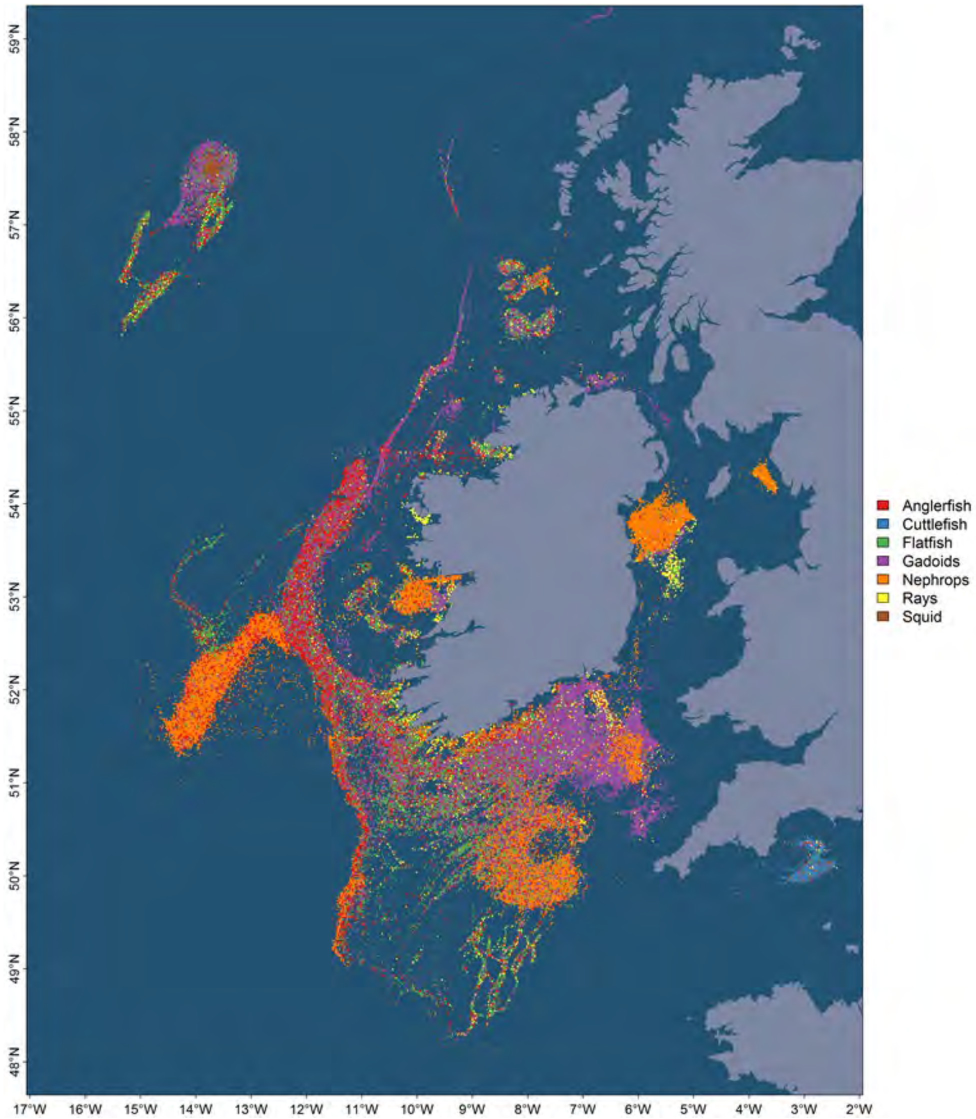


Figure 2. Species composition of demersal otter trawl vessels ≥12 m landing into Ireland in 2014–2018.

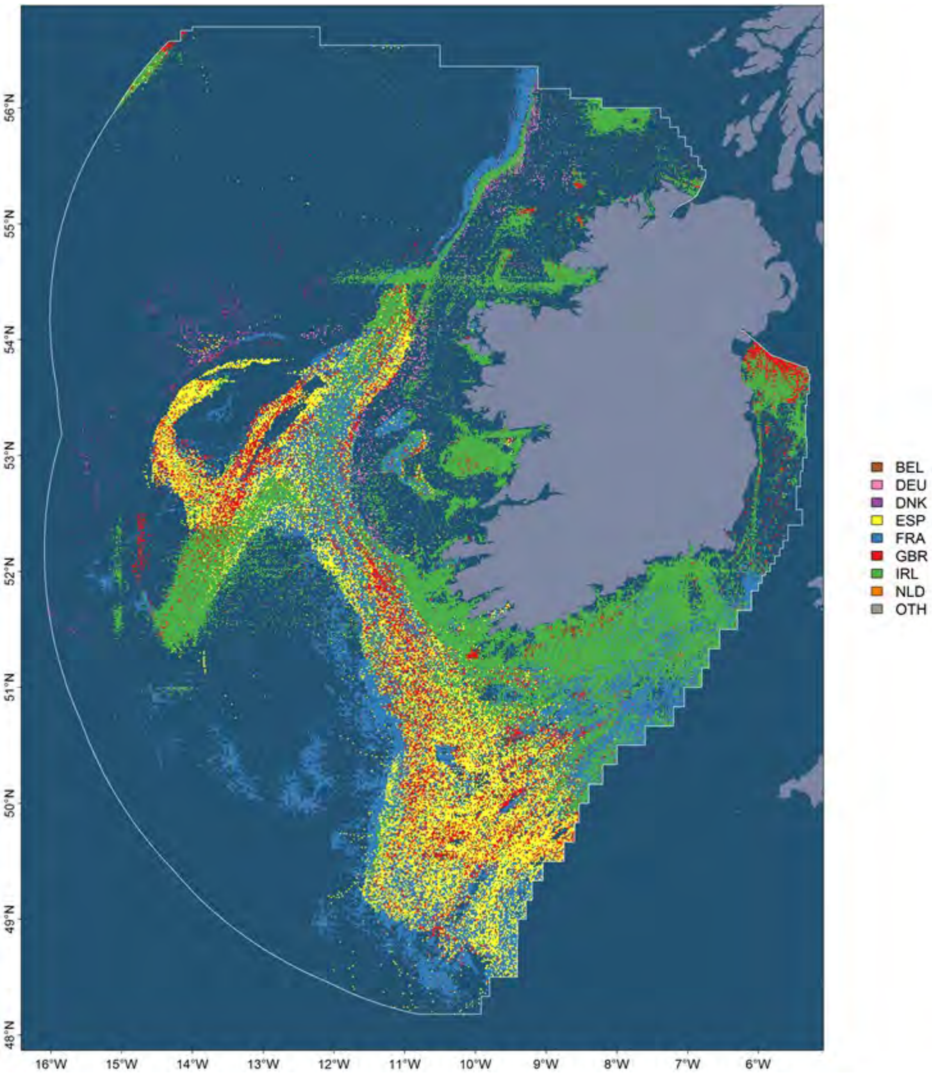


Figure 3. Distribution of international demersal otter trawl effort in the Irish EEZ by country in 2014–2018. French OTB effort can be seen concentrated more centrally in the Celtic Sea and to the southwest in comparison to the Irish fleet.

5.4 Issue list

A summary of the key issues around Celtic Sea whiting arising at successive WGCSE assessment meetings has been maintained and forms the basis of the key objectives for this benchmark meeting in relation to this stock.

Issue	Problem/Aim	Work needed / possible direction of solution	Data needed to be able to do this: are these available / where should these come from?	External expertise needed at benchmark
Tuning series	Streamline data compilation procedures for survey data. Mapping of survey indices by age show significant recruitment data available outside the current combined index area which could potentially be utilised to improve the 0-grp estimates.	Develop a standardised, reproducible method for combining the IGFS and EVHOE survey data for whiting. Produce a catch-at-age index with realistic measure of uncertainties.	All data is available in DATRAS	Experts on tuning indices
Catch-at-age data	Simplification of the complexity of métiers and the raising process in In-terCatch.	Review current sampling levels and adjust stratification accordingly. Test sensitivity of asssssment to alternative raising scenarios.	Ideally this would be based on either the RDB or RDB data submissions. r-scripts would be used to visualise and raise data.	Data submitters and stock co-ordinators.
Discards	Same as above.	Same as above	Same as above	Same as above
Biological Parameters	Review changes in mean weights and maturity	No major work required	Examine sensitivity of assessment and advice to possible changes	
Fisheries & ecosystem issues and data	Cod, haddock and whiting in the Celtic Sea should be benchmarked together in 2020. The aim of the benchmark is to examine mixed fisheries interaction for the three species together.	Linking with the issue above on the catch-at-age data develop a consistent approach for data compilation which satisfies the objectives of WGCSE and WGMIXFISH	Commercial catch and effort data for the métiers in the Celtic Sea.	Members of WGMIXFISH working on the Celtic Sea
Assessment method	Examine 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 propagate the main uncertainties into the forecasts and MSEs properly.	Trials have been carried out using A4A and SAM as alternatives to XSA for this stock. These should be developed further and evaluated using MSEs.	Standard assessment inputs	SAM expertise, A4A and ASAP.
Biological/ MSY Reference Points	The reference points would need to be updated to be consistent with the final assessment method. The main work here would be to test the performance of HCRs using the mixed fishery MSY ranges using MSEs.	A4A provides options to build full MSEs to test the assessment, forecasts and HCR performance under a range of scenarios.		Expertise in reference points estimation and evaluation.
Other				

5.5 Overview of data updates

5.5.1 Historical landings and discards

During the first preparatory data workshop, WKCELTIC I, it was agreed that an international data call would be issued to provide updated catch-at-age data from Member States targeting this stock. A general data handling approach was agreed and data submitted to InterCatch (IC) by France, Ireland, Belgium, UK, Spain and the Netherlands in advance of this Benchmark meeting.

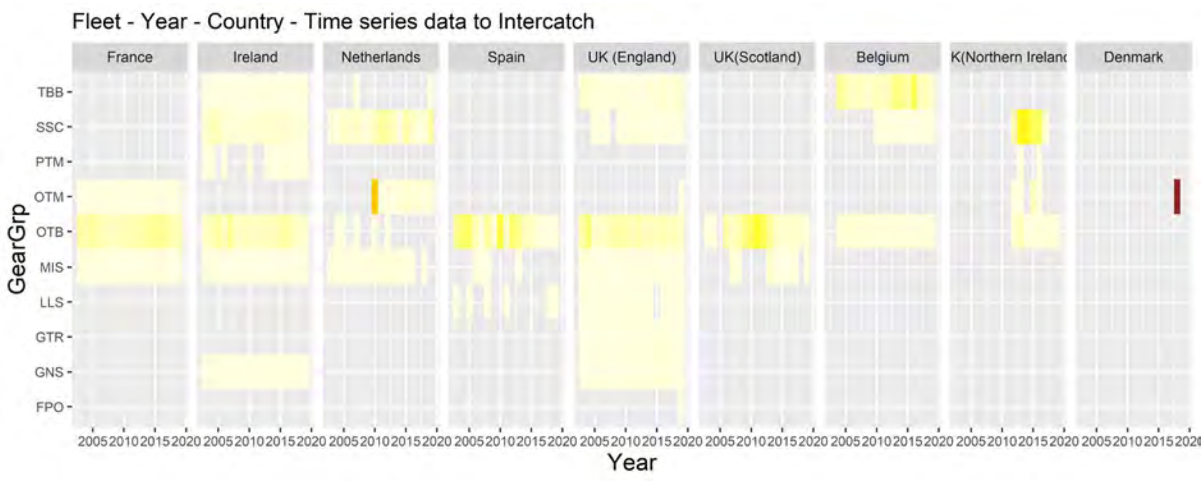


Figure 4. Overview of submission to InterCatch of international catch data by country in 2003–2019.

At the second data workshop, WKCELTIC II, a transparent and standardized approach to international catch data exploration and QC was taken across the three stocks in the form of a shared R markdown document[3] to be adapted for use across the three stocks. In so far as was possible, the allocation of sampling to un-sampled métiers was likewise standardized across stocks using the same R markdown template and editing only where necessary.

Raising of un-sampled catches to CNAA was implemented using a simple hierarchy for available samples where priority was given to the same:

i. Country & Season & Year
ii. Season & Year
iii. Year

With gears set to: GNS_DEF, OTB_CRU, OTB_DEF, TBB_DEF and MIS_MIS.

Discard raising was likewise implemented where samples were missing by estimating ratios at three levels:

i. Year, country and gear
ii. Year and gear
iii. Year

[3] https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/2014%20Meeting%20docs/02.%20Background%20documents/WHG/aggregate_IC_data_whg.27.7b-ce-k_Oct_2020.html

Overall the degree of sample allocation required was relatively small (Figure 5) in comparison to historic input data. As well as revising datasets, this was in part made possible by sharing age–length keys (ALKs) and length-weight (LW) parameters to allow improved sample estimation at the national level prior to submission to IC.

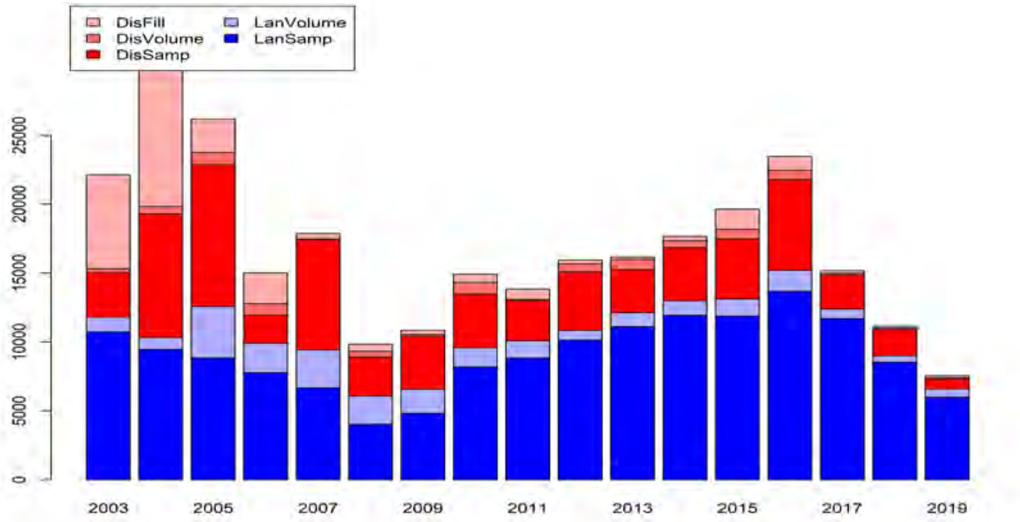


Figure 5. Overview of annual raising of landings and discards data (tonnes) in InterCatch by year in 2004–2018.

Some unusual trends in weight-at-age were observed (Figure 6.) with low numbers of older fish. The inflexion in French weight-at-age data was assumed within normal error. Both Belgium and the Netherlands catch whiting ostensibly from beam-trawl fleets in the central and eastern Celtic Sea. Therefore there may be a spatial and/or fleet selectivity influence here, but moderately small influence on overall stock weights (Figure 7.) and not considered a priority issue for the meeting.

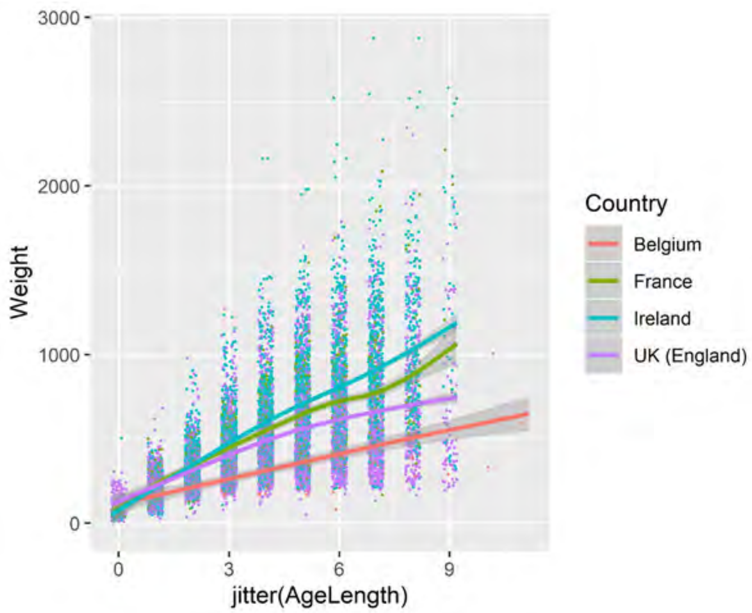


Figure 6. Weight-at-age in the IC catch data 2014–2018 m, by country.

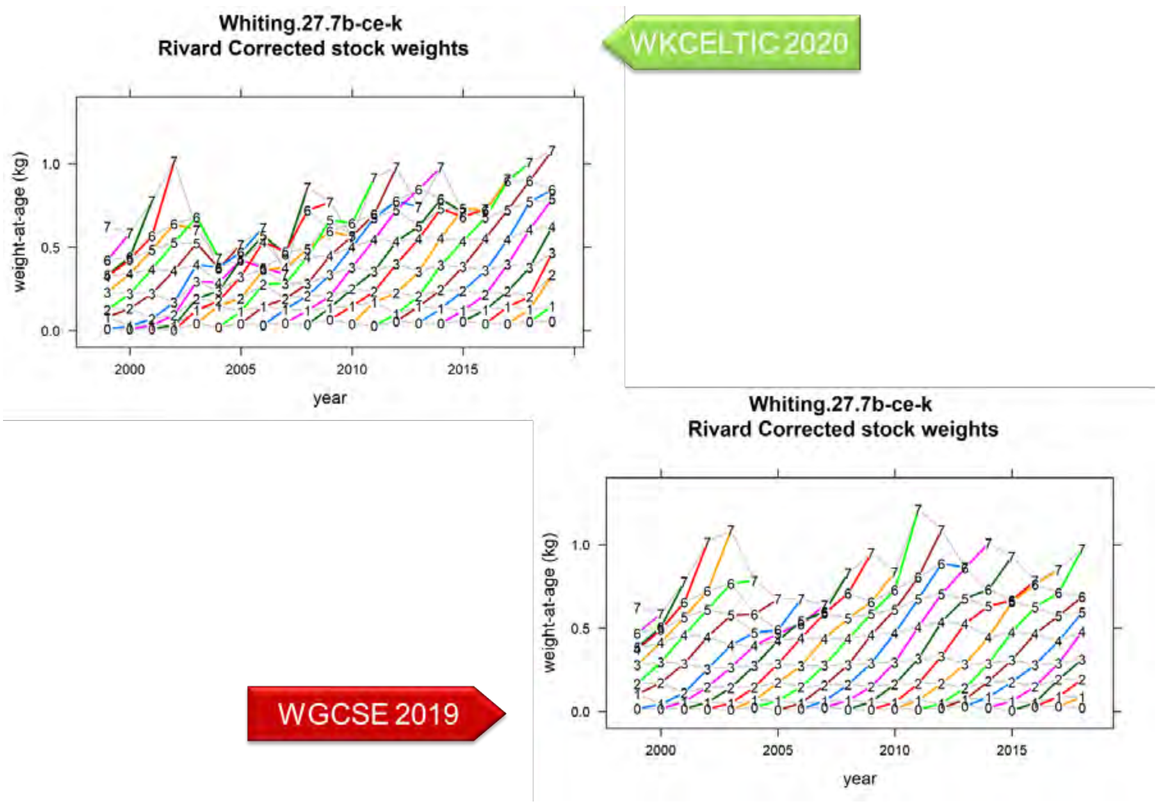


Figure 7. Comparison of Stock weights-at-age between historic and revised IC inputs.

Discards were first introduced into the Celtic Sea whiting assessment at the WKCELT2014 Benchmark. These were estimated at the time on data from a French as well as separate Irish OTB commercial tuning fleet submitted to the 2014 benchmark.

Post 2002 discard sampling for most countries within the EU Common Fisheries Policy (CFP) improved with the introduction of the Data Collection Regulation (DCR: 2002–2008) and associated funding. The DCR was then superseded by the Data Collection Framework (DCF: 2009–present). Despite improved sampling levels there was insufficient data to produce robust quarterly discards at age. Likewise applying an annual ALK was inappropriate given the fast growth rate of juvenile whiting. Therefore a knife-edge length split was used as a proxy for age.

The method of length split was applied to both the Irish and French datasets for input into the assessment. In order to extend the French time-series and take a slightly longer view in the assessment the French catch was estimated back to 1999 by proportion of landings to discards-at-age over the known time-series. The assumption of constant proportionality was discussed and seemed reasonable for this fleet and time period.

Therefore a degree of prediction was required for the historic discard estimates in particular. In contrast the discards-at-age data available to WKCELTIC2020 combines data and samples submitted from most countries and métiers. This is likely to account for some of the difference between historic and revised discard estimates (Figure 8.). In addition, Ireland had a highly restricted sampling program in 2006 in particular, which is also likely to have contributed to varying historic and revised estimates for that year in particular.

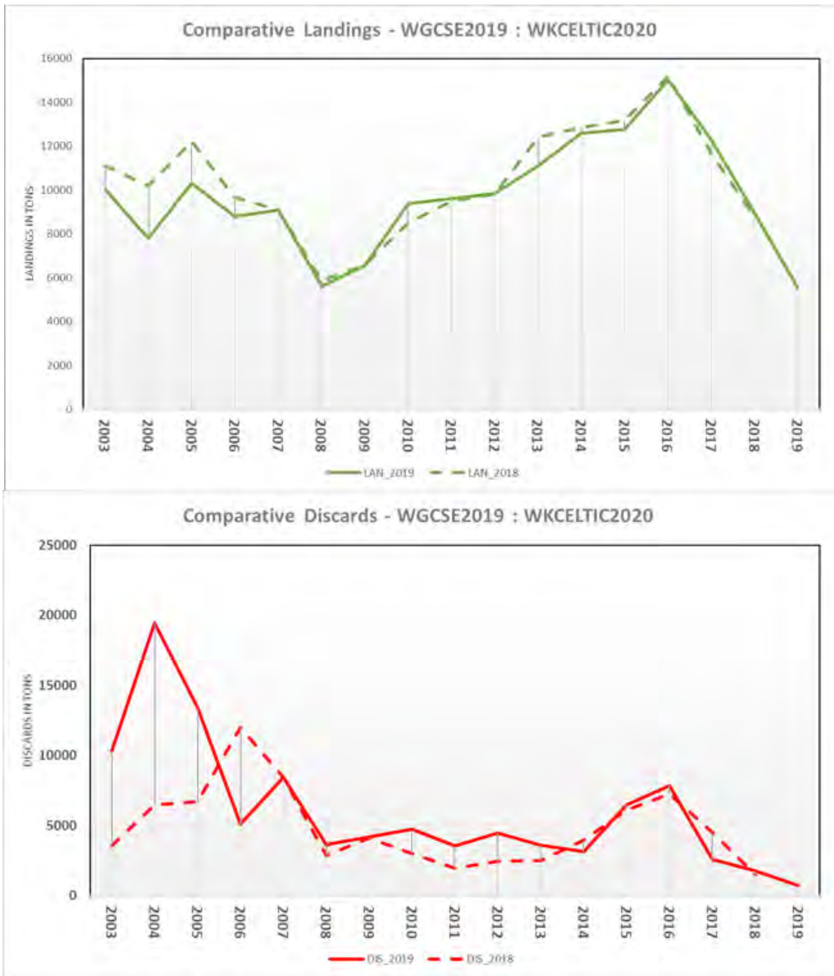
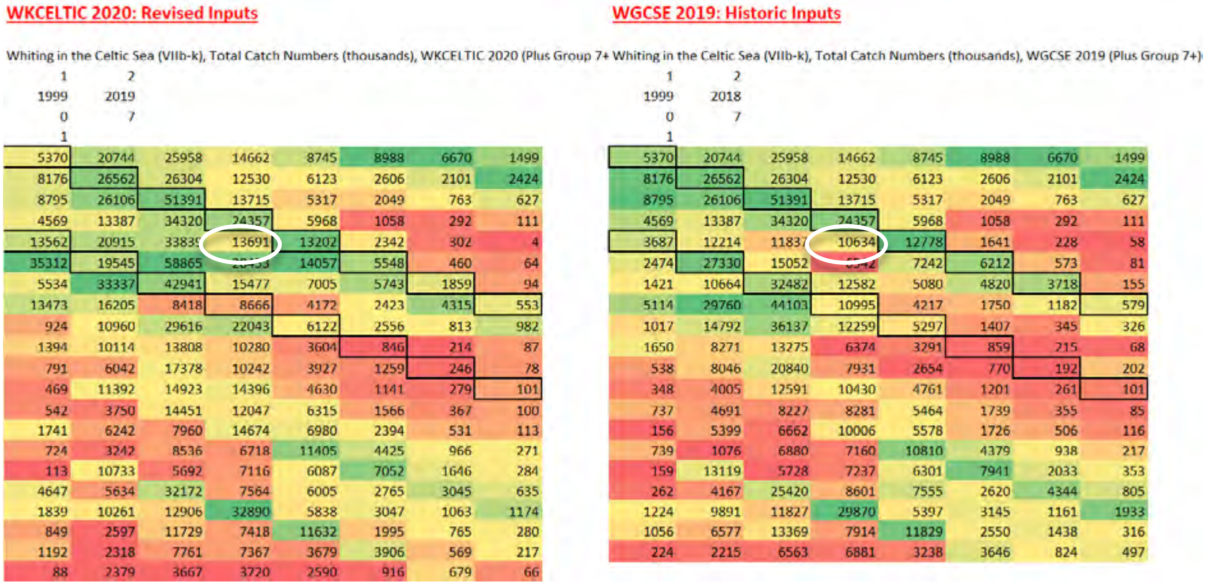


Figure 8. Comparison of InterCatch Landings and Discard inputs into the WGCSE2019 assessment (dashed lines) versus revised IC inputs (solid lines) available for WKCELTIC2020.

In terms of catch numbers-at-age the overall pattern between historic and revised IC data remain relatively constant (Figure 9). However, some notable differences have been highlighted such as

the increased 3 year old age group in 2004. A change in the French estimation of days at sea is one possibility.



WKCELTIC 2020: Revised Inputs

Whiting in the Celtic Sea (VIIb-k), Total Catch Numbers (thousands), WKCELTIC 2020 (Plus Group 7+

1	2						
1999	2019						
0	7						
1							
5370	20744	25958	14662	8745	8988	6670	1499
8176	26562	26304	12530	6123	2606	2101	2424
8795	26106	51391	13715	5317	2049	763	627
4569	13387	34320	24357	5968	1058	292	111
13562	20915	3383[illegible]	13691	13202	2342	302	4
35312	19545	58865	[illegible]	14057	5548	460	64
5534	33337	42941	15477	7005	5743	1859	94
13473	16205	8418	8666	4172	2423	4315	553
924	10960	29616	22043	6122	2556	813	982
1394	10114	13808	10280	3604	846	214	87
791	6042	17378	10242	3927	1259	246	78
469	11392	14923	14396	4630	1141	279	101
542	3750	14451	12047	6315	1566	367	100
1741	6242	7960	14674	6980	2394	531	113
724	3242	8536	6718	11405	4425	966	271
113	10733	5692	7116	6087	7052	1646	284
4647	5634	32172	7564	6005	2765	3045	635
1839	10261	12906	32890	5838	3047	1063	1174
849	2597	11729	7418	11632	1995	765	280
1192	2318	7761	7367	3679	3906	569	217
88	2379	3667	3720	2590	916	679	66

WGCSE 2019: Historic Inputs

Whiting in the Celtic Sea (VIIb-k), Total Catch Numbers (thousands), WGCSE 2019 (Plus Group 7+)

1	2						
1999	2018						
0	7						
1							
5370	20744	25958	14662	8745	8988	6670	1499
8176	26562	26304	12530	6123	2606	2101	2424
8795	26106	51391	13715	5317	2049	763	627
4569	13387	34320	24357	5968	1058	292	111
3687	12214	1183[illegible]	10634	12778	1641	228	58
2474	27330	15052	[illegible]	7242	6212	573	81
1421	10664	32482	12582	5080	4820	3718	155
5114	29760	44103	10995	4217	1750	1182	579
1017	14792	36137	12259	5297	1407	345	326
1650	8271	13275	6374	3291	859	215	68
538	8046	20840	7931	2654	770	192	202
348	4005	12591	10430	4761	1201	261	101
737	4691	8227	8281	5464	1739	355	85
156	5399	6662	10006	5578	1726	506	116
739	1076	6880	7160	10810	4379	938	217
159	13119	5728	7237	6301	7941	2033	353
262	4167	25420	8601	7555	2620	4344	805
1224	9891	11827	29870	5397	3145	1161	1933
1056	6577	13369	7914	11829	2550	1438	316
224	2215	6563	6881	3238	3646	824	497

Figure 9. Comparison of the historic and revised catch number-at-age used at WKCELTIC2020. The relatively strong 1999 and 2003 year classes have been highlighted for reference. Upward revision of 3 year olds in 2004 circled to highlight some differences, but overall pattern of revised data remains similar to historic inputs.

Finally, a summary of sampled and estimated length frequencies for landings and discards available in InterCatch for the meeting is presented in Figure 10. Moderately little estimation was required to raise national data to international catch-at-length.

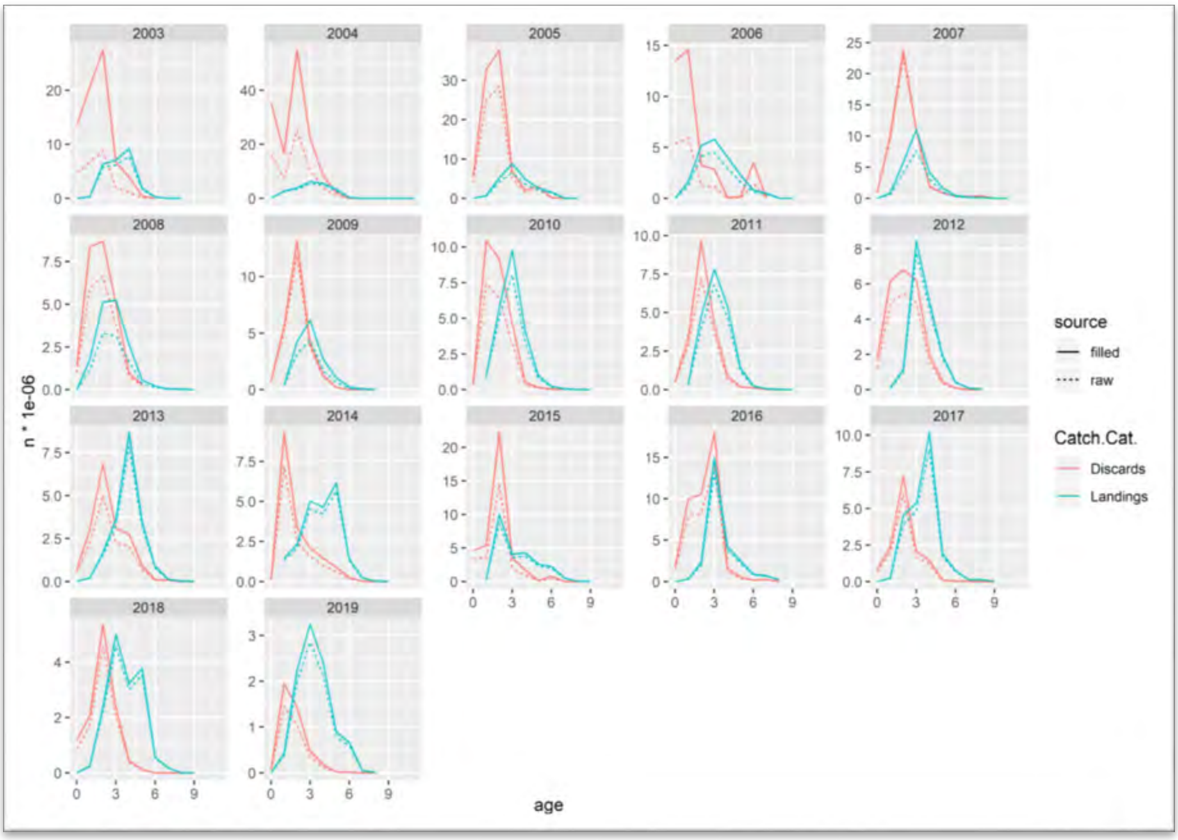


Figure 10. Comparison of the sampled and estimated (filled-in) catch number at length used at WKCELTIC2020.

5.5.2 Survey data

Since the last benchmark review, Celtic Sea whiting has included only a single tuning index in the assessment which is a combined Irish (IGFS) and French (EVHOE) survey index. These surveys are part of the IBTS Q4 survey effort coordinated by ICES and use similar methods and gear as well as overlapping in a spatial and temporal context (Figure 11).

A concern raised at the previous benchmark was that effort allocation/design of the two surveys differed to some degree and could lead to a bias. A simple approach was adopted at that time to using a grid to maximize the number of paired hauls between surveys over the area of interest. This in turn would help down weight any potential bias where a vessel having higher selectivity and number stations within a grid cell would only contribute to an average for that cell. Each cell only contributing a single value in the overall index rather than a proportionately high number of points from one survey going into an overall survey mean for example.

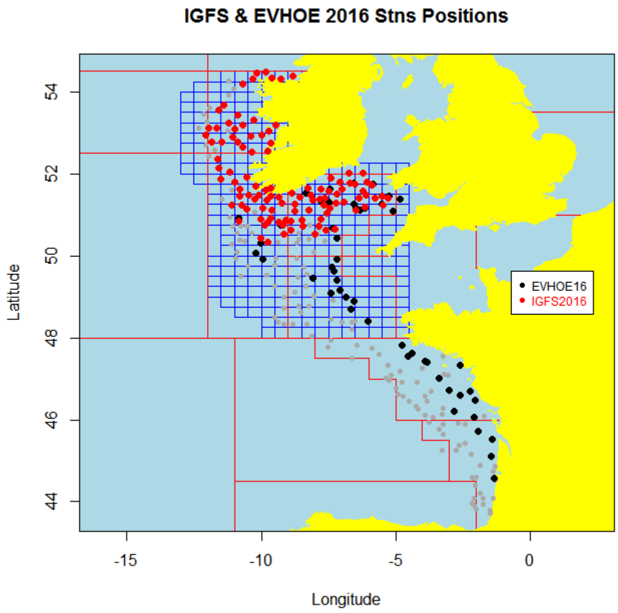


Figure 11. Map of spatial extent of survey stations for IGFS and EVHOE surveys. IGFS (red) and EVHOE (black) for 2016, with distribution for historic stations for other years in grey. Blue grid showing the area used for calculation of the combined tuning index.

While the approach aimed to minimize survey design differences, experience has highlighted the difficulty faced in the NE Atlantic area where there is minimal overlap in survey effort, in contrast to the North Sea. In both 2017 and 2019 for example, the French vessel was not available to undertake large parts of the survey. This left large gaps in the single tuning index going into the assessment and highlighted shortcomings where neither the index nor assessment method (XSA) routinely produce uncertainty estimates.

A data preparation workshop, Workshop on Evaluating Survey Information Celtic Sea Gadoids (WKESIG), was instigated to help identify and evaluate robust methods to estimate survey indices specifically for the WKCELTIC2020 benchmark (see WD and annex). Work has been ongoing since the workshop largely focused on the Spatio-Temporal approach and R library VAST[4].

Initially VAST was checked against the standard index calculation method for whiting being used for assessment currently, as well as a GAM model based approach (Berg *et al*., 2014[5]), each producing similar indices with the same input data. Secondly VAST was used to estimate the same indices when an entire survey was left out in successive years. The model performed well, however it was understandably poor in years where the index was significantly above or below average.

[4] https://github.com/James-Thorson-NOAA/VAST

[5] https://github.com/casperwberg/surveyIndex

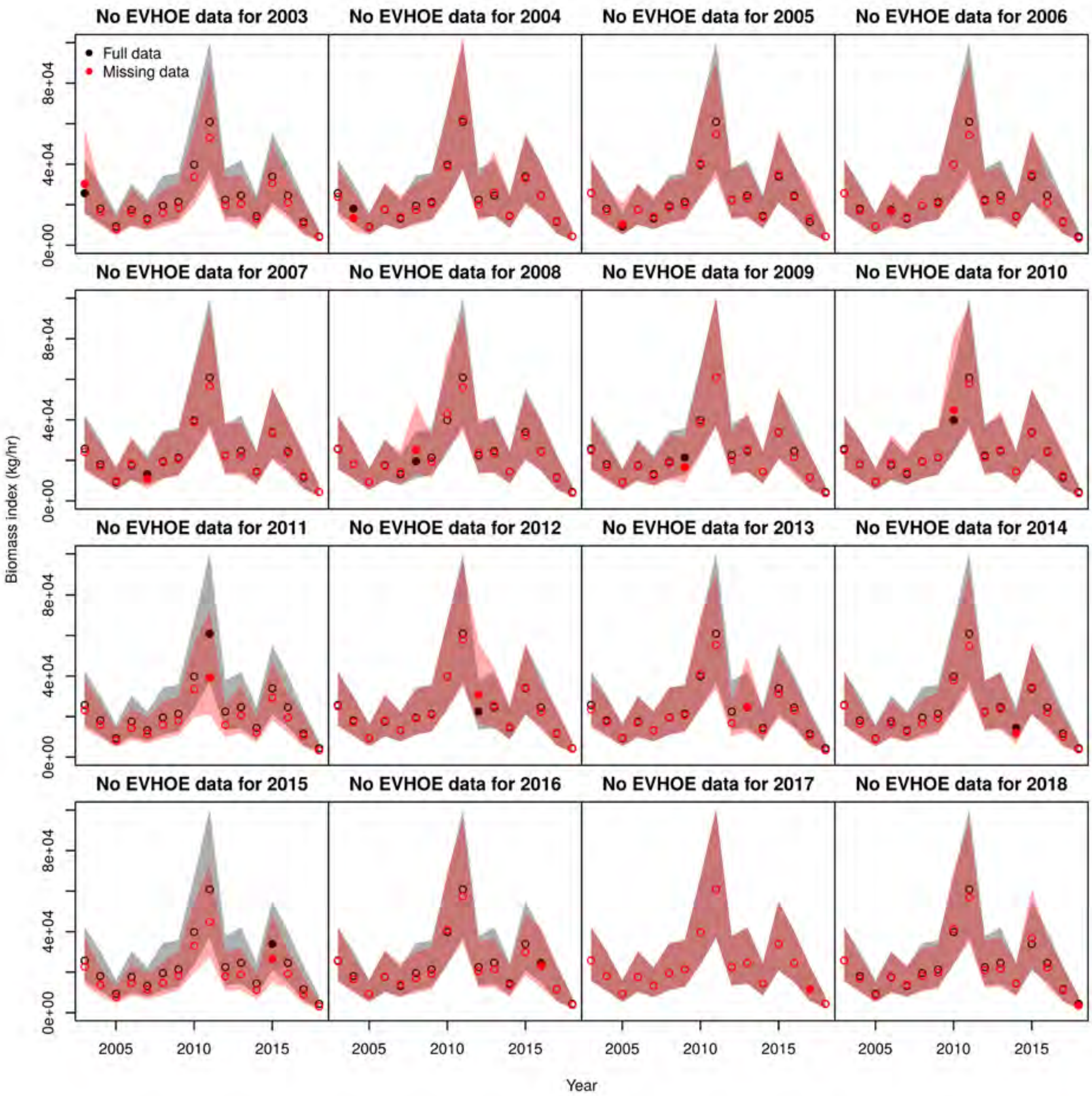


Figure 12. Whiting in area 7.b–k age 1: leave one year out differences. Full run is shown in black points and grey envelope, leave one year out run with red points and pink envelope. Specific year omitted is shown with closed points.

As well as evaluating model performance for quality assuring the survey index as far as possible where data may unavoidably be unavailable, the VAST model outputs were checked in terms of internal consistency. When compared against the standard grid index method, considerable gains can be seen particularly in younger ages with the modelled index (Figure 13).

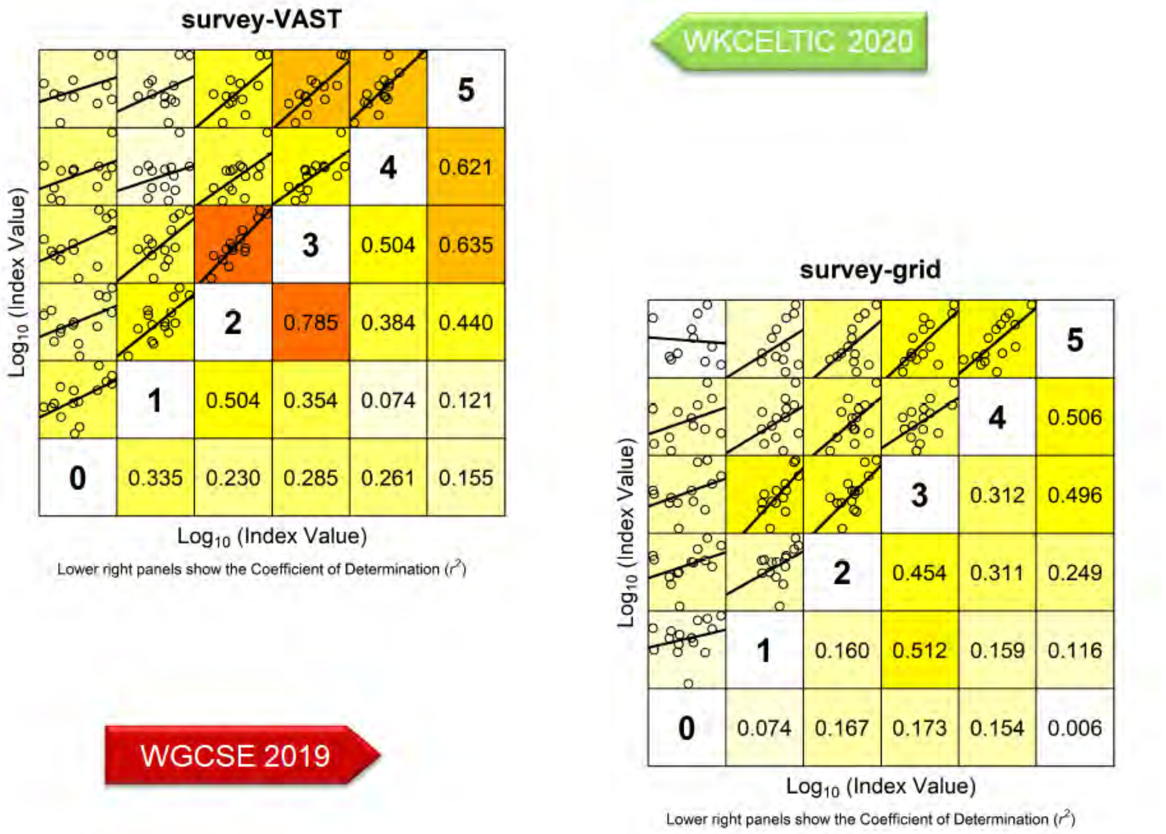


Figure 13. Summary of correlation between paired ages between proposed VAST modelled index (upper panel) and standard Grid Index approach (lower panel). Age groups are given on the diagonal so the correlation between log abundance of age 1 fish and age 2 fish the following year is 0.160 for the historic Grid approach. This increases substantially to 0.504 for example for the VAST index.

5.5.3 Commercial tuning data

An updated French commercial tuning fleet for whiting was made available. The Working Document Laviale *et al.*, 2019[6] details the issues raised by the old commercial tuning fleet and the work done to provide the updated French commercial tuning index. In summary, the list of species and the threshold used to select trips has been modified to better account for the fact that cod is no longer a target of these fisheries, but more a bycatch of whiting and haddock directed fisheries. Moreover, the commercial tuning now accounts for both landings and discards.

Comparison of runs were performed using SAM with or without the candidate French commercial tuning series. The final decision at WKCELTIC was to use the French commercial index as a biomass index, rather than numbers-at-age to avoid 'double dipping,' i.e. using some of the same age composition data in the catch and the index.

[6] https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/2014%20Meeting%20docs/04.%20Working%20documents/WD_03_WKCELTIC%20-%20French%20commercial%20tuning%20fleets_Final_2020.pdf

5.5.4 Natural Mortality

WKCELT2014 decided to change the assumed natural mortality from the fixed value of 0.2 for all ages to values depending on the mean weight-at-age according to the Lorenzen power function. These values were felt more realistic, and brought the practice for this stock in line with that for other gadoid stocks in the area.

As part of the WKCELTIC 2020, natural mortality estimates were revisited (see annex WD Pawlowski, 2019. Natural mortality in the Celtic sea gadoids). As more biological data have become available since the previous benchmark, the Lorenzen approach was applied directly on the mean weight-at-age data from EVHOE and IRGFS surveys. Values of M-at-age are quite similar to those estimated in 2014 up to age 3 for the Lorenzen approach. Results for an alternate approach, Gislason, as well as Lorenzen is presented in the table below (Table 3.) of M-at-age.

Table 3. Mortality estimates for ages 0 (M0) to age 7+ (M7+) from both Lorenzen and Gislason models.

	Method	M0	M1	M2	M3	M4	M5	M6	M7+
WKCELT2014	Reference Lorenzen	1.22	0.86	0.65	0.5	0.43	0.40	0.38	0.36
WKCELT2019 using mean W	Lorenzen	1.136	0.805	0.644	0.545	0.499	0.473	0.473	0.460
WKCELT2019 using mean L	Gislason	0.972	0.530	0.365	0.280	0.245	0.223	0.222	0.213

Whiting are considered a reasonably top predator and expected not to be very vulnerable to predation from a relatively young age due to fast growth. The Lorenzen method results in a relatively low M after age 1. However, this method does not account for other sources of mortality that may occur, like spawning or heat stress. The benchmark did not have sufficient time to investigate these issues, but the lack of older fish and the early maturation suggest that this stock may have a life-history strategy that is more consistent with a high natural mortality, as opposed to the slower-growing later-maturing stocks further north.

5.5.5 Maturity

A number of options for applying updated maturity were reviewed using updated data from 2004–2018[7]. Options included maintaining the 2012 estimates, and introducing year specific estimates by age. It was decided to adopt a revised fixed set of maturity-at-age proportions (Table 3) as this was more likely to be reflective of the general maturity-at-age, and not depend upon year specific estimates which may lack accuracy owing to sample sizes and origins. This also negates the annual dependence of recalculating maturity for every annual assessment.

[7] https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/2014%20Meeting%20docs/02.%20Background%20documents/2019%20DC%20WKCELTIC%20Cod.27.7.e-k%2C%20Had.27.7e-k%2C%20Whg.27.7b-k%20IE%202004-2019%20Maturity%20Ogives_updated.docx

Table 3. Revised maturity ogives for whiting available to WKCELTIC2020 as well as knife edged maturity ogive used in current WGCSE whg7bc–ek assessment.

whg-7b-k	Age:	0	1	2	3	4	5	6	7+
Sex:	F	0	0.29	0.96	0.98	0.99	1	1	1
	M	0	0.49	0.82	0.95	0.85	0.8	1	1
	All	0	0.61	0.94	0.97	0.97	0.95	1	1
	WGCSE	0	0	1	1	1	1	1	1

5.6 Exploratory Assessment runs

In order to keep track of changes a simple hierarchical approach was taken to exploratory assessment runs. Initially the existing XSA assessment method used at WGCSE was implemented to evaluate the revised input data in comparison to previous assessments. There was some significant scaling, but overall pattern remains as per recent assessments.

The next stage in the exploratory process addresses the agreed issue list and relates to finding a statistical assessment method to propagate uncertainties into the Forecasts and Management Strategy Evaluations. A number of options were discussed, but SAM was agreed as a reasonable next step given a key principal of the meeting being transparency and standardization across the three stocks, as well as the expertise available at the meeting.

5.6.1 XSA Exploratory Assessment runs

Settings were unchanged and implemented as per the current Stock Annex[8]:

Option	Setting
F_{BAR}	2–5
Weightings Required	F_{bar}
Ages Used	0–7+
First Age for Stock Size Indep. Catchability	0
Q plateau	5
Taper	No
F shrinkage SE	1.00
F shrinkage year range	5
F shrinkage age range	3
Fleet SE threshold	0.50
Prior weights	No

[8] https://community.ices.dk/ExpertGroups/StockAnnexes/Stock_Annexes/whg.27.7b-ce-k_SA.docx

5.6.1.1 XSA Run#1

Updated catch data were used with traditional grid based survey index calculation and inputs for mortality and maturity unchanged (Figure 14). The additional 2019 data year seems to continue the recent downward trend in SSB and upward trend in F, but the perception of the stock prior to 2019 is quite similar in both assessments.

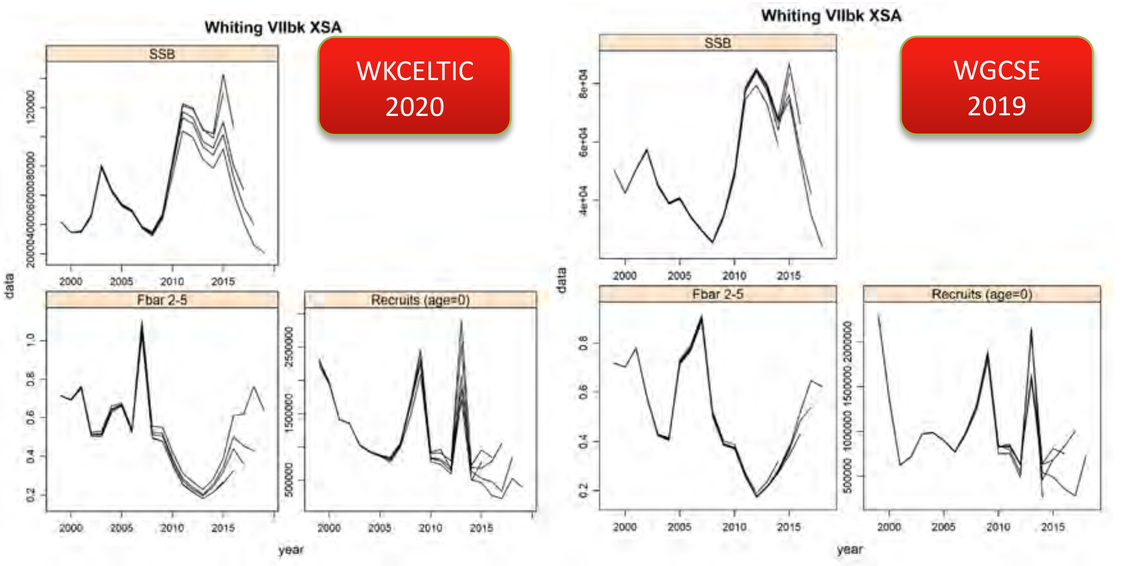


Figure 14. Retrospective plots from XSA assessment using revised catch data (1999–2019 catch data – left 3 panels) and previous WGCSE 2019 assessment output (1999–2018 catch data – right 3 panels).

5.6.1.2 XSA Run#2

The updated VAST survey index replaced the Grid index from Run#1 and is compared below (Figure 15). Some differences in Recruitment can be seen and internal consistency improves somewhat (Figure 16).

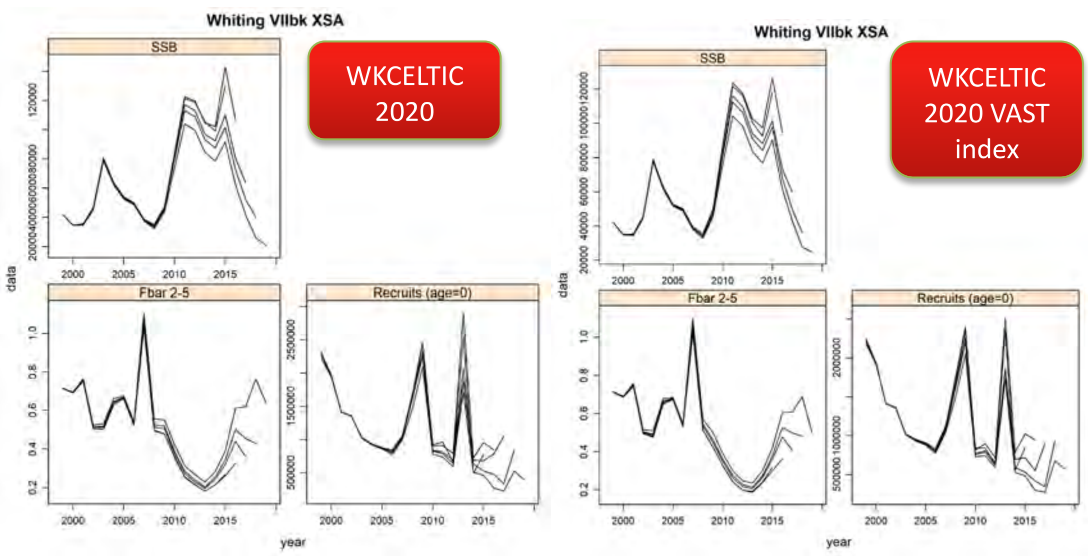


Figure 15. Retrospective plots from XSA assessment comparing Run#1 (left 3 panels) and Run#2 with revised VAST Survey Index (right 3 panels).

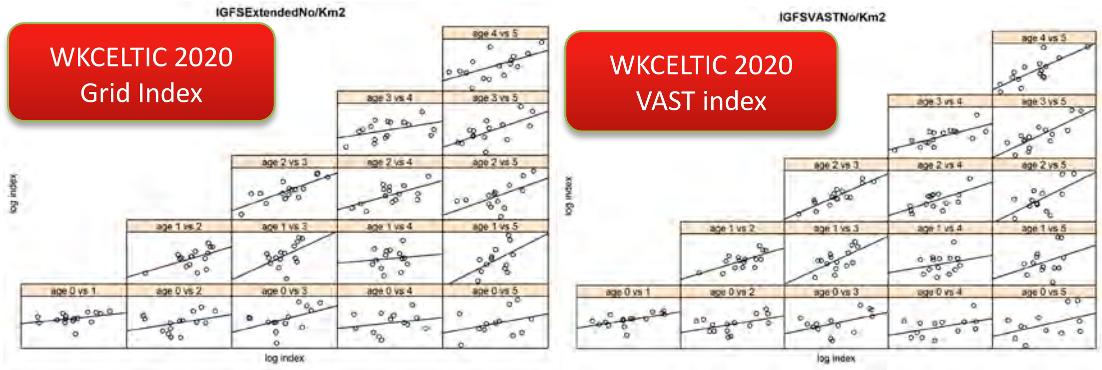


Figure 16. Scatterplots of Run#1 vs Run#2.

5.6.1.3 XSA Run#3

Updated catch data were used with the traditional grid based survey index and revised mortality inputs for mortality (Lorenzen and Gislason), maturity unchanged (Figure 17). Again the overall pattern remains largely constant, but with a slight increase in SSB for the revised Lorenzen estimates, but significant reduction for the Gislason approach. In addition, estimates of recruitment are significantly reduced and retrospective pattern in SSB has increased noise.

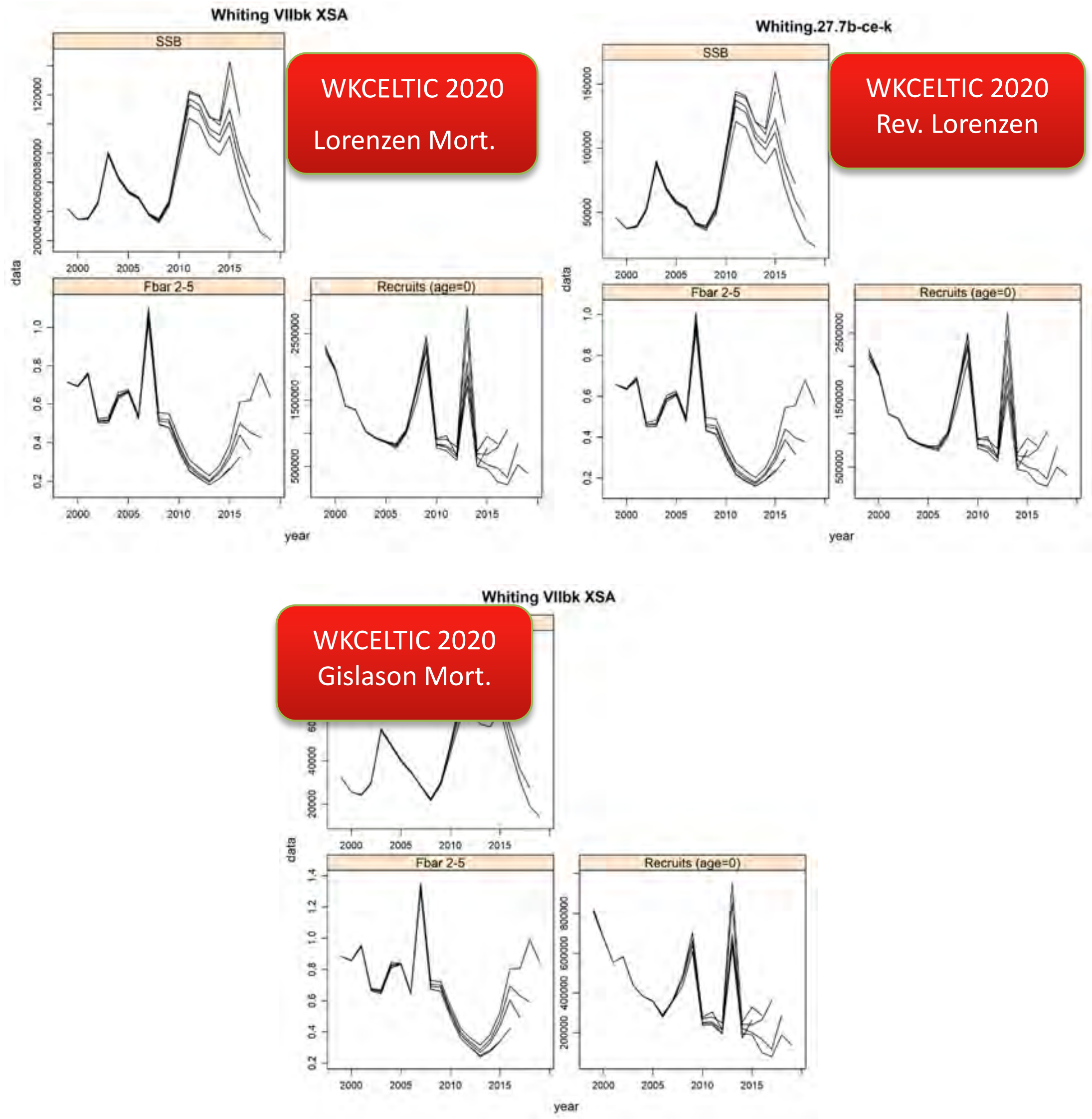


Figure 17. Retrospective plots from XSA assessment comparing Run#1 (left 3 panels) and Run#1 with revised VAST Survey Index (right 3 panels).

Overall the revised data did not significantly change the perception of the stock although SSB is revised significantly upwards from 80 Kt for the 2012 estimate to now 120 Kt for the same point. Other updated inputs for surveys, maturity and mortality had minimal influence other than a significant rescaling downwards again for the Gislason's mortality estimates. Here SSB returned to just under the previous 80 Kt value for 2012, but retrospective patterns were not seen to improve so it was agreed to opt for the Lorenzen approach to keep the three stocks in line where evidence did not convince the group otherwise.

5.6.2 SAM Exploratory Assessment runs

The same input files as used in the XSA runs (Lowestoft format) were uploaded to www.stock-assessment.org in order to configure and set up a base SAM run using the revised data.

5.6.2.1 SAM Run#1

A base run (whg.7b-ce-k_Run1) was set up with current WGCSE defaults: knife-edge maturity, existing Lorenzen mortality and Grid based survey index. Patterns looked similar to XSA runs, but 95% confidence intervals are now available for model estimates of SSB, F and Recruitment (Figure 18). Model fit to the catch data was a reasonable start, but fits to older ages in the survey index in particular show some strong residuals. Retrospective patterns were high and model optimization over subsequent runs looked at coupling between various parameters as we all as new the survey indices, mortality and maturity estimates.

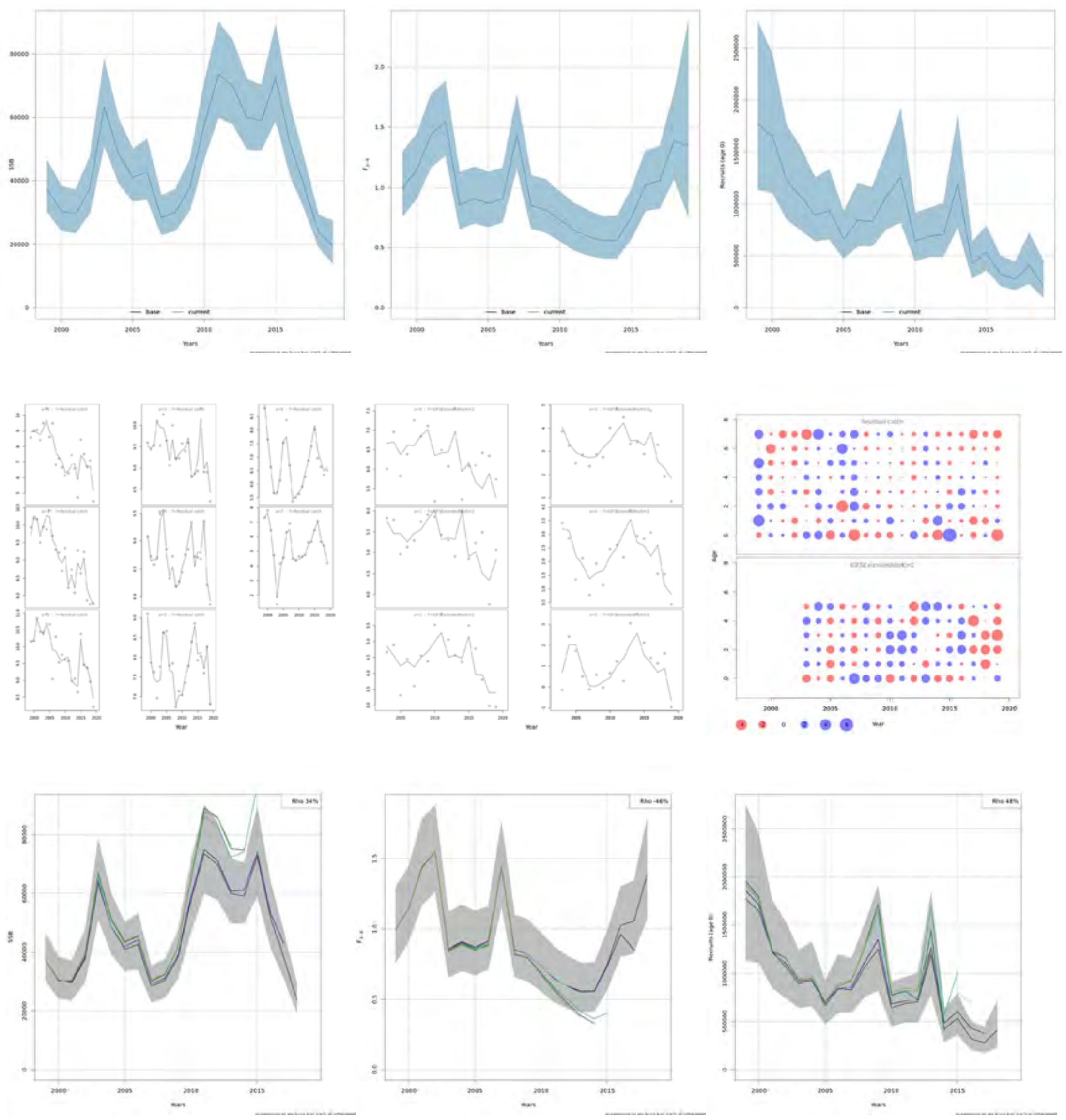


Figure 18. Diagnostic plots from SAM Run1. Estimates of SSB, F and Recruitment (top left, center and Right respectively). Model fit (solid line) to Catch Data (middle left), Survey Index (middle center) and bubble plots of the residuals (middle right). Retrospective plots of SSB, F and Recruitment (bottom left, center and right respectively) are high and show a marked jump post 2016.

5.6.2.2 SAM Run#2

Model optimization led to the penultimate run (whg.7b-ce-k_RevFRA_Aug2020_SurveyOnly) where a truncated VAST Survey Index (Ages 0-2yrs) was combined with the updated maturity and mortality estimates (Figure 19). Model fit and residual patterns are significantly improved with no strong trends in residuals and Mohn's Rho values all ≤17%.

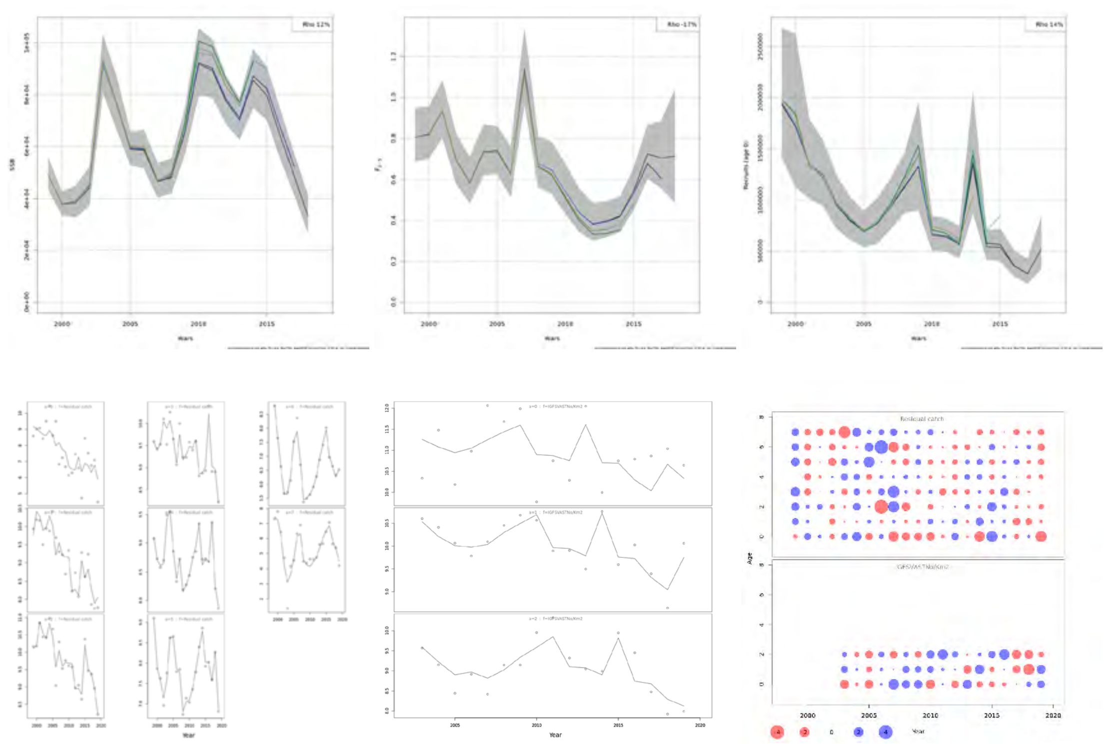


Figure 19. Diagnostic plots from SAM Run2. Retrospective plots of SSB, F and Recruitment (top left, center and Right respectively). Model fit (solid line) to Catch Data (bottom left), Survey Index (bottom center) and bubble plots of the residuals (bottom right). Retrospective plots of SSB, F and Recruitment still show a degree of shift post 2016, but less pronounced and within the confidence bounds.

5.6.2.3 SAM Run#3

The final run (whg.7b-ce-k_RevFRA_Aug2020) highlighted here is Run#2 with the inclusion of the proposed commercial tuning fleet from France (Figure 20). As mentioned earlier this was converted to a biomass index to avoid 'double dipping' where the catch and index data are not wholly independent.

Final model inputs and settings were:

- Full time-series of catch data(1999 to 2019, ages 0 to 7+)
- Model-filled discards for ages 5 – 7+ in 1999–2002
- VAST Model index for ages 0–2 from IGFS:EVHOE 2003–2019
- French Commercial biomass index in Kg/Hr for 2000–2019
- Fishing mortality states were bound for ages 6+
- Catchability for ages 1+ were bound for the survey index
- Default settings for remaining configuration
- Observation error on the first age in the survey was estimated separately from the older ages (i.e. ages 1–2 were bound).

While fit to the assessment model for the commercial index is not particularly good the improvement in Mohn's Rho values is significant with SSB and F now being ≤8%.

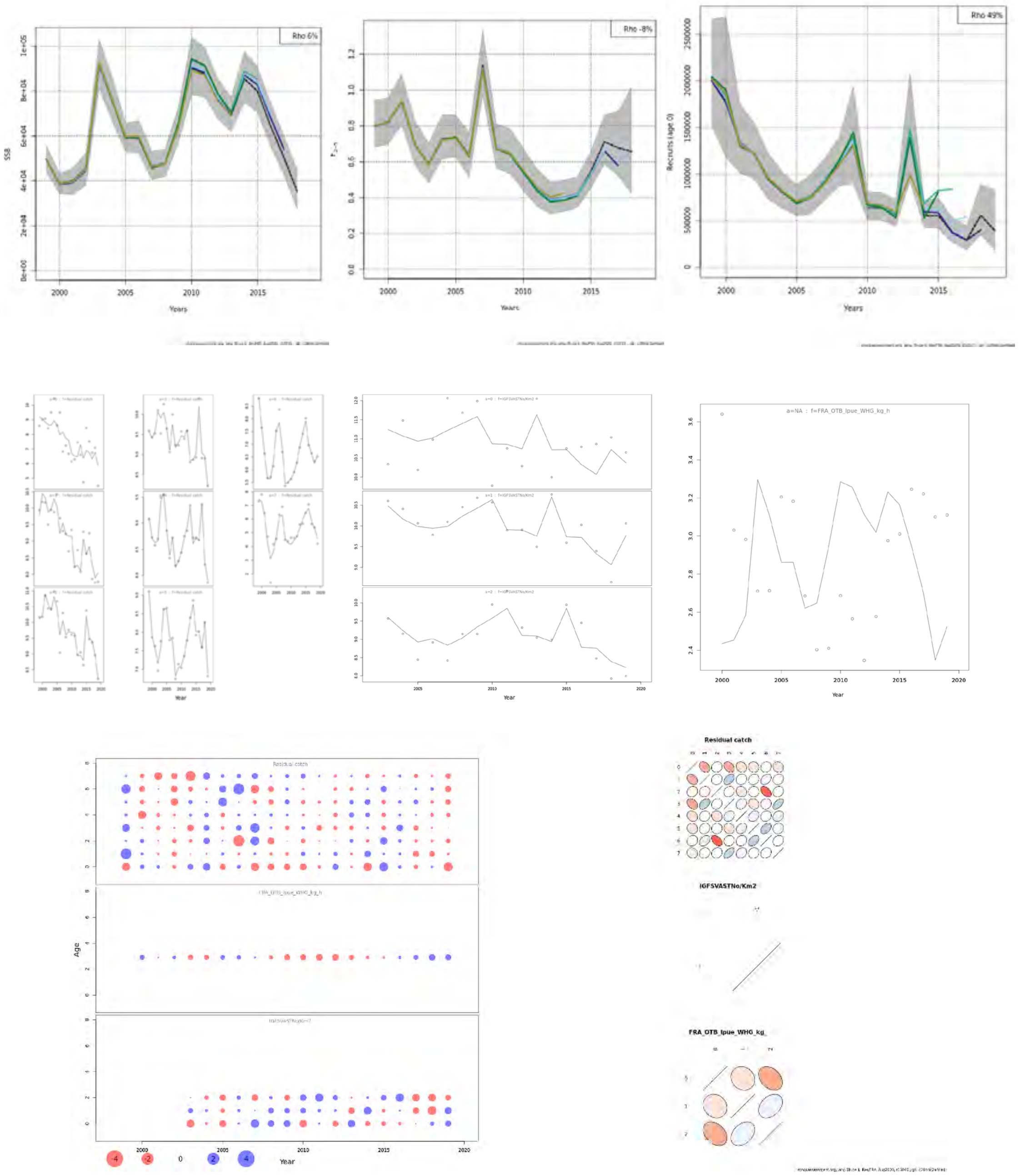


Figure 20. Diagnostic plots from SAM Run3. Retrospective plots of SSB, F and Recruitment (top left, center and Right respectively). Model fit (solid line) to Catch Data (middle left), Survey Index (middle center) and French commercial index (middle right). Bubble plots of the residuals over time (bottom left) and paired ages (bottom right). Retrospective plots of SSB, F and Recruitment show much less bias, although model fit to the commercial index is noisy.

5.6.2.4 SAM Final assessment Run#4

Following the final WebEx benchmark meeting two data input issues were identified and hence Run#3 was amended to address these.

Firstly, the catch weights were used for stock weights. The stock weights-at-age on January 1st are derived from the catch weights by the Rivard's method using the NOAA NFT Calculator (v2.1). Due to a copy and paste error, catch weights were used for stock weights in the exploratory runs above. This is often a small scaling issue, but can cause differences (Figure 21).

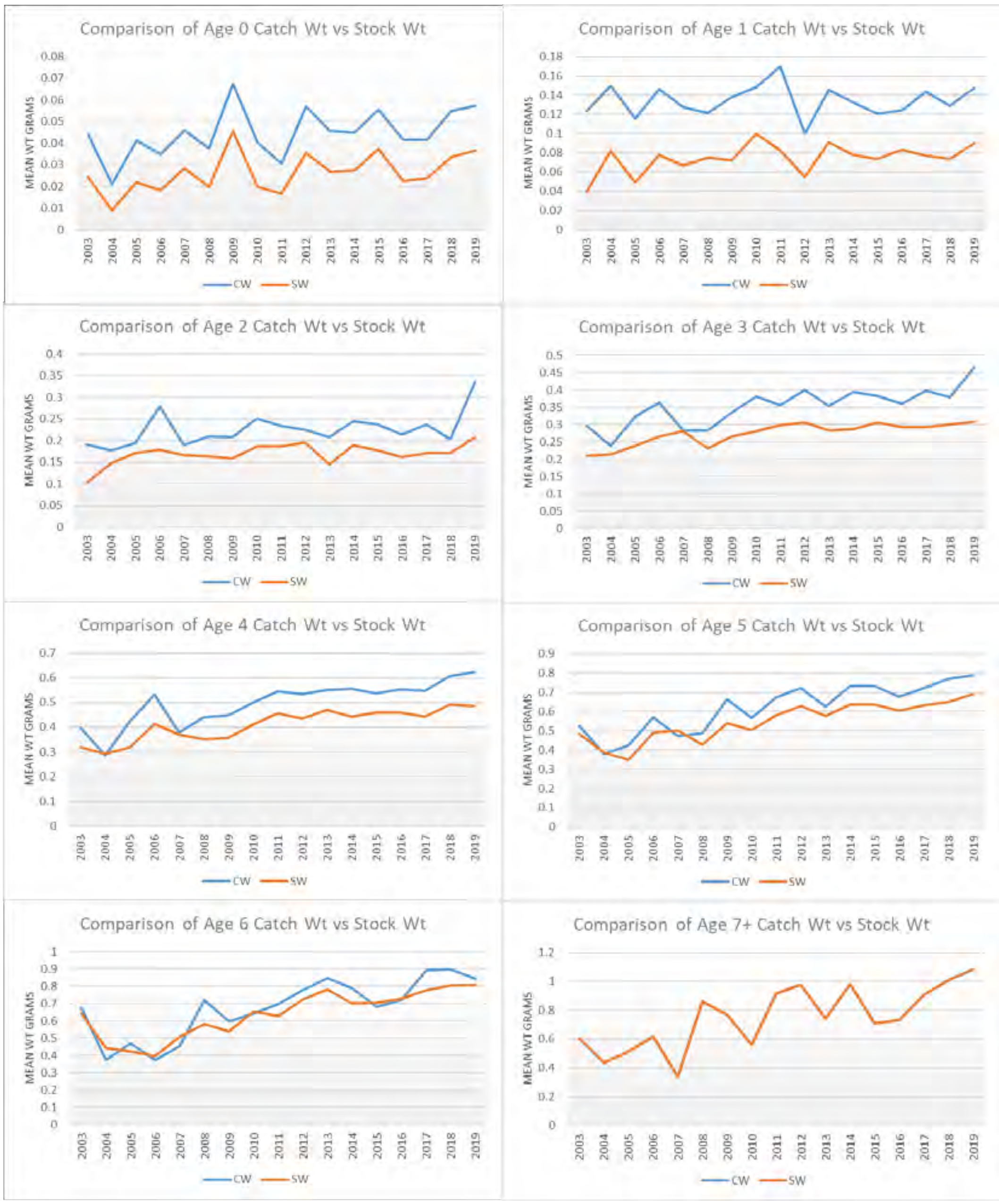


Figure 21. Comparison of annual mean catch weights over time versus stock weights (Rivard corrected catch weights) for age 0 to 7+ Celtic Sea whiting. For age 0–1 a simple scaling is apparent, for age 2 there is a more obvious influence in 2006 for example. Stock weights in the plus group superimpose. The peak in mean catch weight is clearly smoothed out by the stock weights correction.

The second amendment was to a file specific to the SAM stock assessment. The file for the Landings Fraction was wrongly understood to be in terms of biomass (Landings Kg/Catch Kg). This was clarified and amended to be in numbers (Landings no/Catch No). As can be seen in Figure 22, values in terms of biomass are not always associated with equally high or low numbers of individuals. Strong contrast between the sets of ratios doesn't seem apparent however.

Whiting VIIb-k, plusgroup, LANDINGS fraction (LNAA/CNAA for SAM test Run#4)

	0	1	2	3	4	5	6	7+
1999	0.000	0.190	0.391	0.859	0.983	1.000	1.000	1.000
2000	0.001	0.120	0.380	0.860	0.985	1.000	1.000	1.000
2001	0.000	0.011	0.229	0.848	0.988	1.000	1.000	1.000
2002	0.001	0.069	0.176	0.835	0.985	1.000	1.000	1.000
2003	0.000	0.013	0.188	0.515	0.699	0.808	0.919	1.000
2004	0.000	0.142	0.067	0.216	0.397	0.616	0.735	0.695
2005	0.000	0.021	0.121	0.571	0.697	0.465	0.872	0.910
2006	0.000	0.101	0.615	0.669	0.973	0.944	0.192	0.963
2007	0.011	0.076	0.195	0.501	0.683	0.661	0.586	0.267
2008	0.002	0.174	0.370	0.510	0.732	0.672	1.000	1.000
2009	0.000	0.062	0.244	0.599	0.680	0.834	0.969	0.877
2010	0.000	0.085	0.384	0.679	0.890	0.860	0.863	0.737
2011	0.000	0.100	0.333	0.648	0.860	0.891	0.687	0.793
2012	0.000	0.014	0.145	0.575	0.717	0.816	0.813	0.953
2013	0.010	0.067	0.197	0.541	0.758	0.787	0.895	0.644
2014	0.000	0.136	0.408	0.705	0.763	0.873	0.847	0.910
2015	0.000	0.044	0.312	0.538	0.713	0.941	0.740	0.968
2016	0.000	0.029	0.183	0.454	0.722	0.820	0.822	0.780
2017	0.000	0.088	0.386	0.724	0.874	0.952	0.976	0.938
2018	0.001	0.111	0.308	0.679	0.877	0.967	0.989	0.987
2019	0.004	0.180	0.610	0.872	0.931	0.975	0.974	0.989

Whiting VIIb-k, plusgroup, LANDINGS fraction (LWAA/CWAA for SAM)

	0	1	2	3	4	5	6	7+
1999	0.000	0.319	0.524	0.884	0.981	1.000	1.000	1.000
2000	0.002	0.431	0.557	0.902	0.985	1.000	1.000	1.000
2001	0.000	0.027	0.355	0.886	0.988	1.000	1.000	1.000
2002	0.004	0.157	0.263	0.870	0.987	1.000	1.000	1.000
2003	0.000	0.026	0.279	0.644	0.811	0.904	0.962	1.000
2004	0.000	0.240	0.121	0.309	0.522	0.697	0.822	0.798
2005	0.000	0.044	0.215	0.706	0.804	0.649	0.917	0.953
2006	0.000	0.176	0.714	0.771	0.981	0.953	0.276	0.975
2007	0.124	0.125	0.280	0.645	0.805	0.835	0.810	0.430
2008	0.010	0.317	0.493	0.643	0.859	0.853	1.000	1.000
2009	0.000	0.124	0.385	0.752	0.836	0.933	0.981	0.944
2010	0.000	0.166	0.519	0.769	0.921	0.924	0.946	0.867
2011	0.000	0.168	0.481	0.786	0.931	0.949	0.827	0.910
2012	0.000	0.031	0.234	0.721	0.840	0.907	0.928	0.970
2013	0.025	0.100	0.337	0.661	0.867	0.893	0.955	0.887
2014	0.000	0.241	0.524	0.814	0.863	0.938	0.933	0.972
2015	0.000	0.102	0.473	0.710	0.869	0.965	0.878	0.984
2016	0.000	0.059	0.335	0.666	0.864	0.917	0.905	0.884
2017	0.000	0.148	0.511	0.856	0.936	0.976	0.990	0.975
2018	0.005	0.219	0.516	0.827	0.940	0.975	0.988	0.985
2019	0.015	0.370	0.733	0.926	0.966	0.988	0.988	0.996

Figure 22. Heat maps of Landings/Catch-at-age in terms of numbers (left panel) and weight (right panel) for Celtic Sea whiting. Stronger red colour indicates below average values for that age group over the time-series. Conversely stronger green coloured cells indicate higher than av0erage for that age class.

While there was no error in the underlying data or work up, the wrong values were used in the Stock Weights and Landings Fraction input files and these have been amended. No changes to code or model assumptions were made and the final run presented here is a result of the correct values being moved to the two input files identified above.

The first step was to evaluate the impact of changing from estimating the landings fraction by weight to estimation by number (i.e. LNAA/CNAA). The previous Run#3 was cloned and set up as whg.7b-ce-k_RevFRA_Sept20_LanFractEdit and the LF.dat[9] file replaced with the corrected one. No other changes were made. Given catches remain unchanged, intuitively a change in the Landings:Catch ratio would not a affect the summary plots. Run#3 was plotted on top of the updated run and they completely superimpose as predicted across SSB, F and recruitment. (Figure 23).

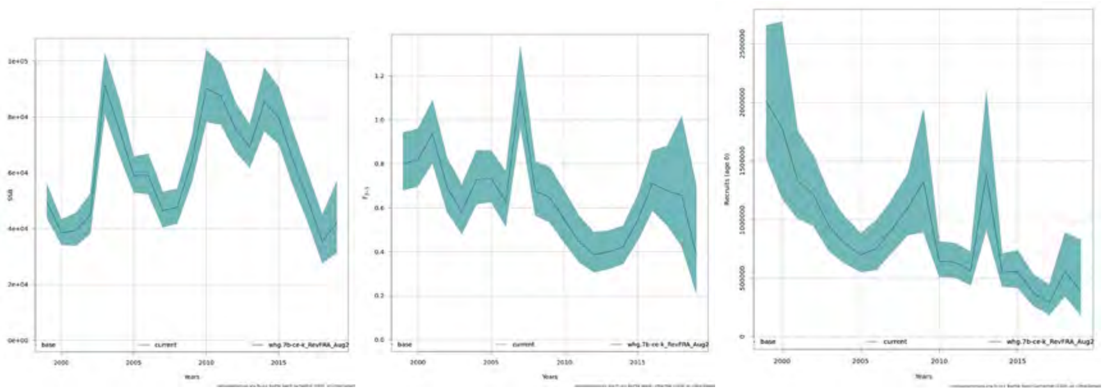


Figure 23. Stock summary plots for the original Run#3 superimposed on the updated run where landings fraction has been amended to LNAA/CNAA.

[9] https://www.stockassessment.org/results.php?token=3ddd571a673643dfa44bc9ca85db1000

Where we would expect to see changes will be in the proportions of landings vs discards and we can see that from the Forecast tables (Figure 24). The ICES Advice table is used here as an example, but the difference can clearly be seen in the estimates of discards from the assessment through to the forecast. Fewer discards are predicted when the catch is split by proportion in numbers than by weight.

Figure 24. Comparison of summary data for 2019–2022 for ICES Advice from Forecast table 12 in stockassessment.org where "_rev" indicates run with revised stock-weights file. Catches (top panel) remain unchanged, some increase in landings can be seen (middle panel), but discards show a clear reduction following a change from proportion by weight to number (lower panel).

5.6.2.5 SAM Run#4 – Final assessment run

The final run (whg.7b-ce-k_FRA_Sept20[10]) here is Run#3 with the amendments to the stock weights as well as landings fraction file discussed above.

[10] https://www.stockassessment.org/datadisk/stockassessment/userdirs/user231/whg.7b-ce-k_FRA_Sept20

Final model inputs and settings remain:

- Full time-series of catch data(1999 to 2019, ages 0 to 7+)
- Model-filled discards for ages 5–7+ in 1999–2002
- VAST Model index for ages 0–2 from IGFS:EVHOE 2003–2019
- French Commercial biomass index in Kg/Hr for 2000–2019
- Fishing mortality states were bound for ages 6+
- Catchability for ages 1+ were bound for the survey index
- Default settings for remaining configuration
- Observation error on the first age in the survey was estimated separately from the older ages (i.e. ages 1–2 were bound).

Given the nature of stock weights vs catch weights, as expected the impact on the assessment is to scale SSB downwards and this can be clearly seen in the plot of Run#4 (revised SSB) vs the previous Run#3 (Figure 25). No changes to fishing mortality or recruitment is visible and the two runs superimpose on each other, in part likely to the recruitment model in SAM being a random walk.

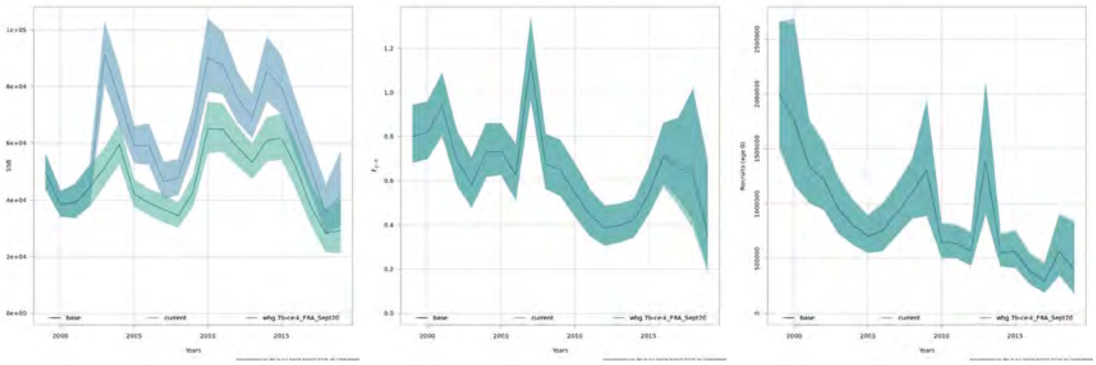


Figure 25. SAM assessment summary plots of SSB (left), Fbar2-5 (center) and recruitment at Age 0 (right). The effect of using stock weights versus mean catch weights-at-age can be seen in the downward scaling of SSB.

Model fit to the catch data between Run#3 and Run#4 is ostensibly identical (Figure 26).

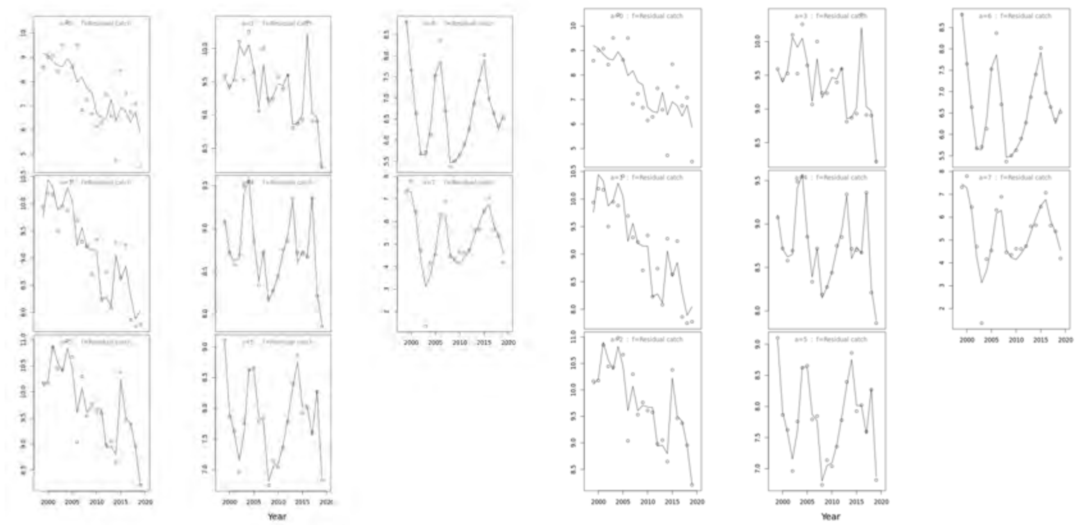


Fig 26. Fit to the catch at age data for SAM assessment Run#4 (left) and Run#3 (right).

Model fits to the IBTS Survey index and French commercial biomass index are also largely identical (Figure 27). Some slight deviation towards the end of the commercial time-series can be identified.

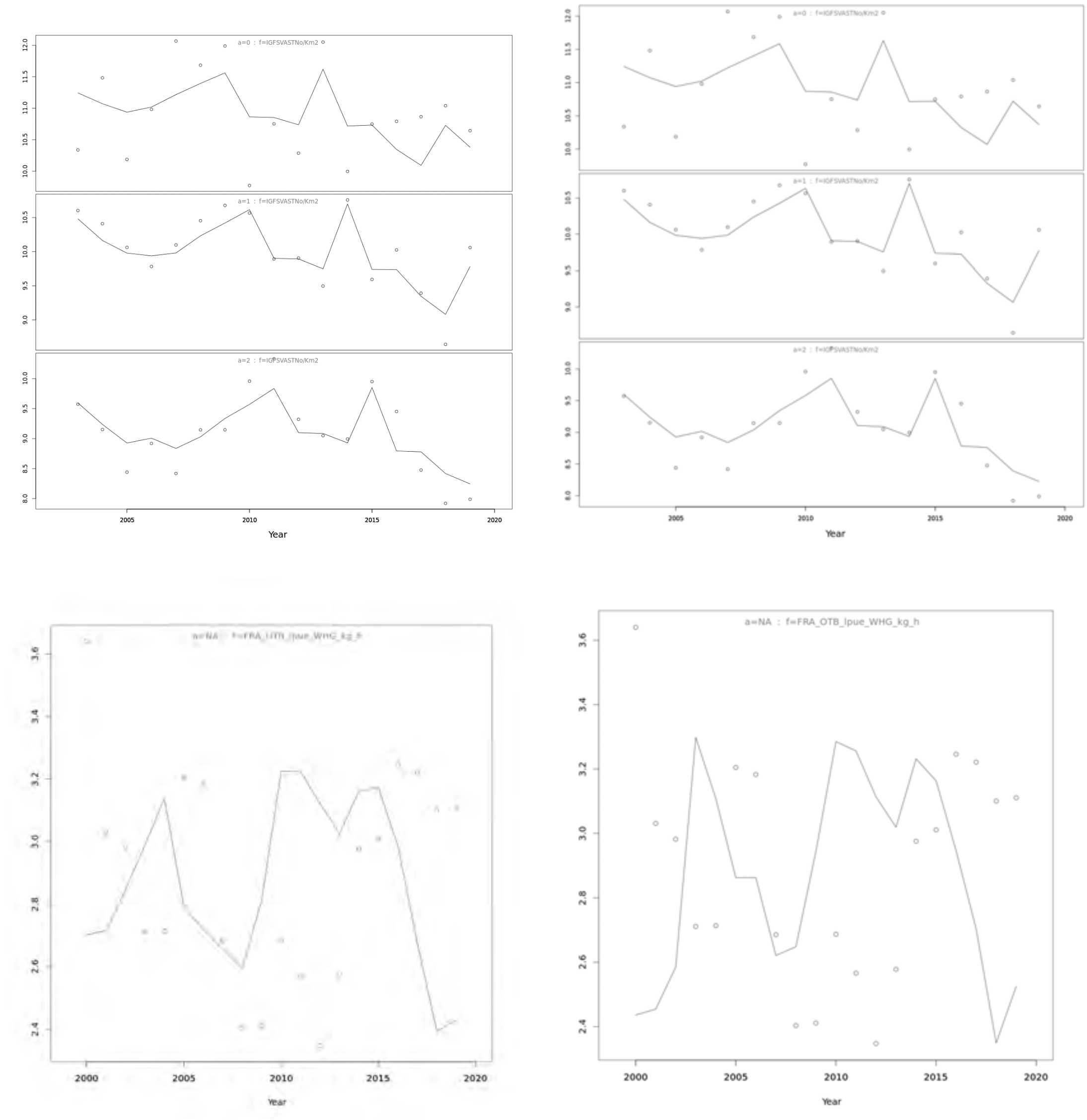


Figure 27. Fit to the survey catch-at-age data from VAST for SAM assessment Run#4 (top left) and Run#3 (top right). Model fits for commercial biomass index are given in lower left (Run#4) and lower right (Run#3).

Residual patterns show little difference if any (Figure 28).

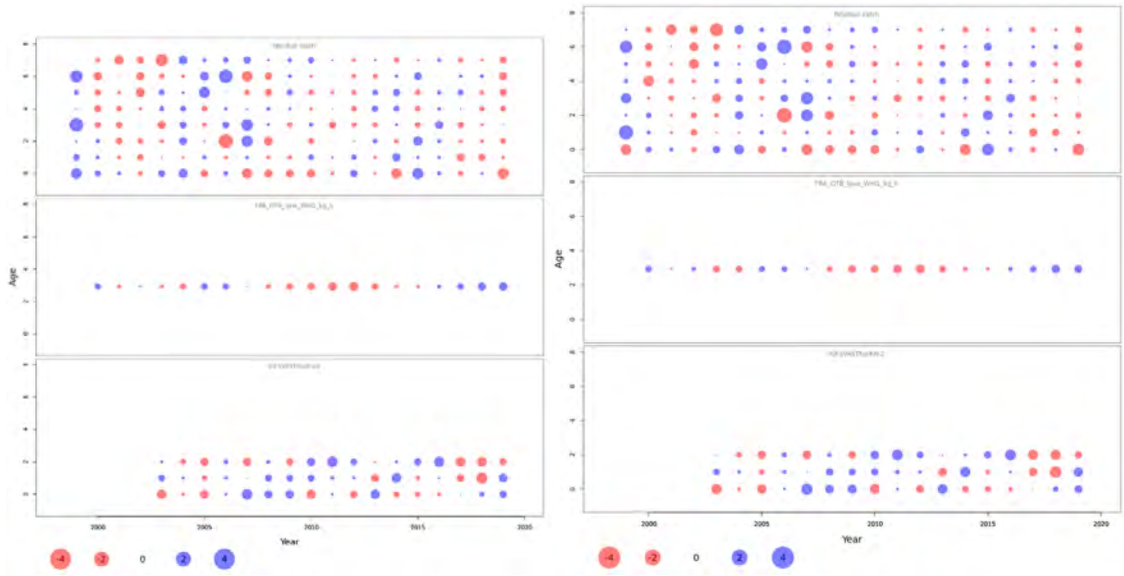


Figure 28. Residual patterns for Run#4 (left) and run#3 (right) show little difference.

Where a difference was noticeable was with retrospective patterns where the final peel for the SSB plot struggled to converge for the updated run#4. It did plot showing a 1% reduction in Mohn's rho over the previous Run#3, but given the error being indicated it was decided to revert to four peels instead of the default five (Figure 29). Both assessment runs were the carried out with four peels for direct comparison and while the Mohn's rho value did rise slightly for both, the latest run has still a lower value by 2%.

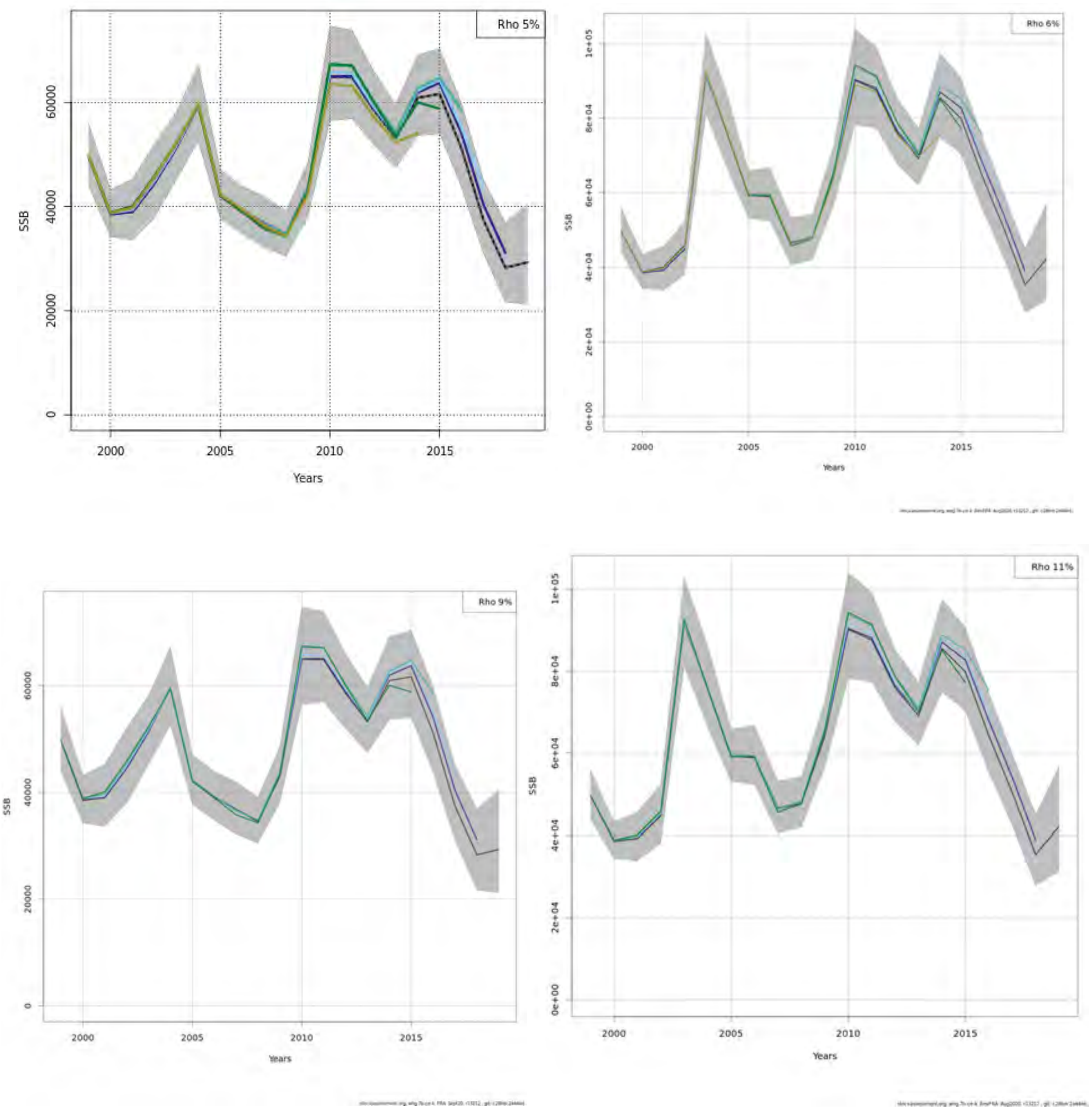


Figure 29. Retrospective runs for updated assessment run#4 (left two panels) against original assessment (right two panels). Comparison of 5 peels (top) and 4 peels (bottom) shows the run#4 assessment has lower bias in both scenarios.

Running retrospective runs for F with 4 peels versus 5 again increases the Mohn's rho value somewhat from 8% to 10% (Figure 30). Part of the issue is likely to be inclusion of a biomass index, but as more data are added the model in the next few years returning to the default five is unlikely to be problematic.

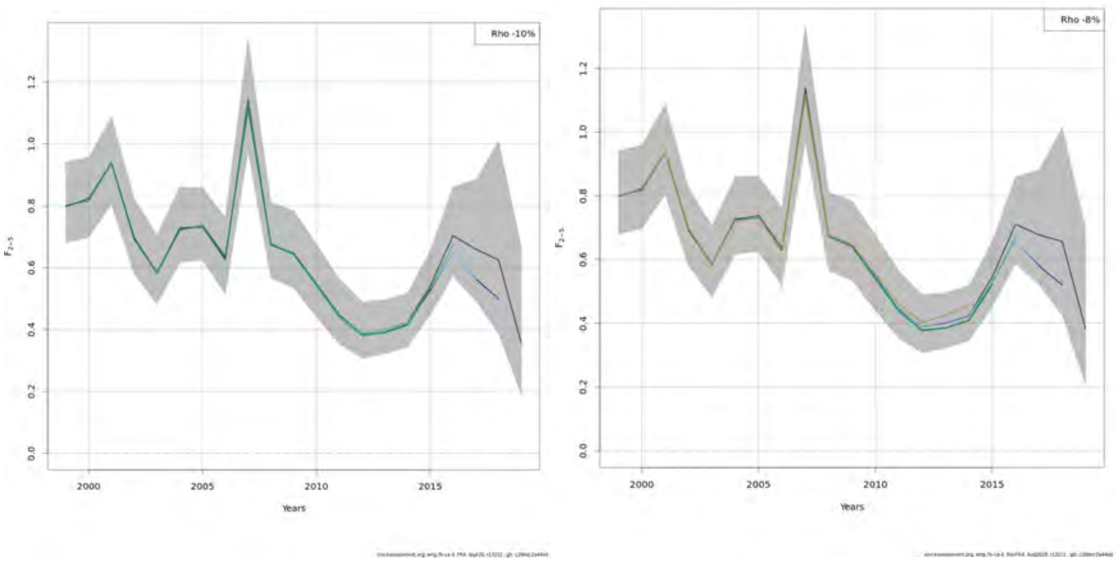


Figure 30. Retrospective patters for F_{bar} 2–5 for run#4 (left panel – 4 peels) and run#3 (right panel – 5 peels).

From the retrospective parameter plot (Figure 31), the survival variance parameter (logSdlogN1) approaches the zero limit in the early peels (but with huge variance). This happens sometimes for short time-series with SAM, but conversely the risk reduces as data are added. It is not in itself problematic, means that there are not enough data to disentangle changes in F from random survival perturbations.

It is possible to try and bound that parameter and circumvent the issue, but it is a temporary solution to what is unlikely to be a long-term issue. Mohn's rho and convergence are not directly linked unfortunately, it is the relatively short time-series currently combined with a quite flexible model that is the issue.

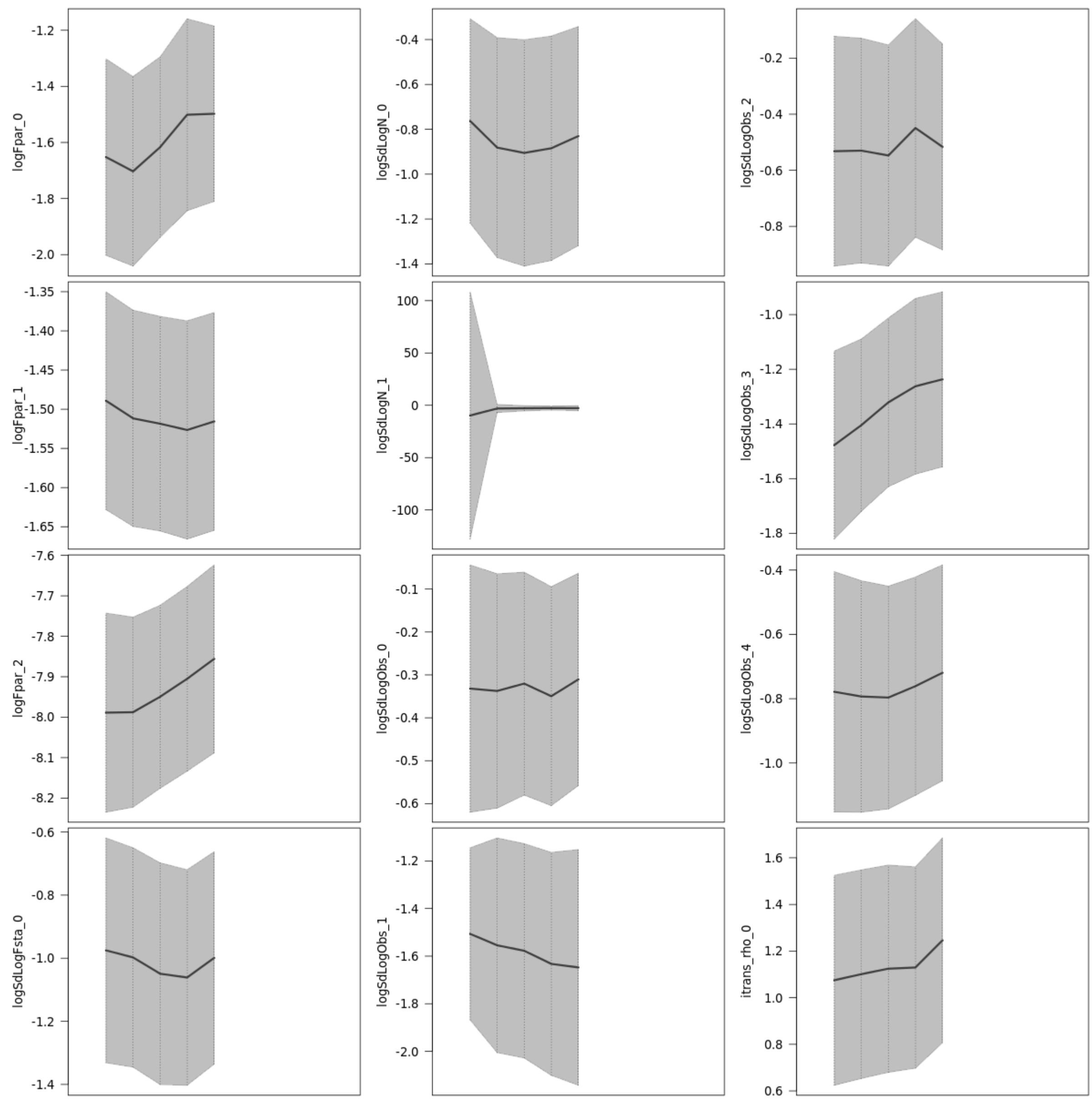


Figure 31. Plotted variance in the retrospective parameters.

5.7 Reference points

The reference points presented below were derived from final SAM run#4 (whg.7b-ce-k_RevFRA_Sept20[11]) and detailed in WD[12].

ICES guidelines define yield as catches above MCRS; however the current discard pattern includes a large amount of whiting above the minimum size. These discards are part of the potential yield for the purposes of MSY estimation and should therefore be included. Figure 32 shows the length-at-age for survey catches in the Celtic Sea. This provided the basis for estimated proportions at each age of the catch that would be below the minimum size (see WD[13]). Note that gear selectivity is not accounted for here and therefore the actual proportions are likely to be somewhat higher. These proportions are therefore considered precautionary.

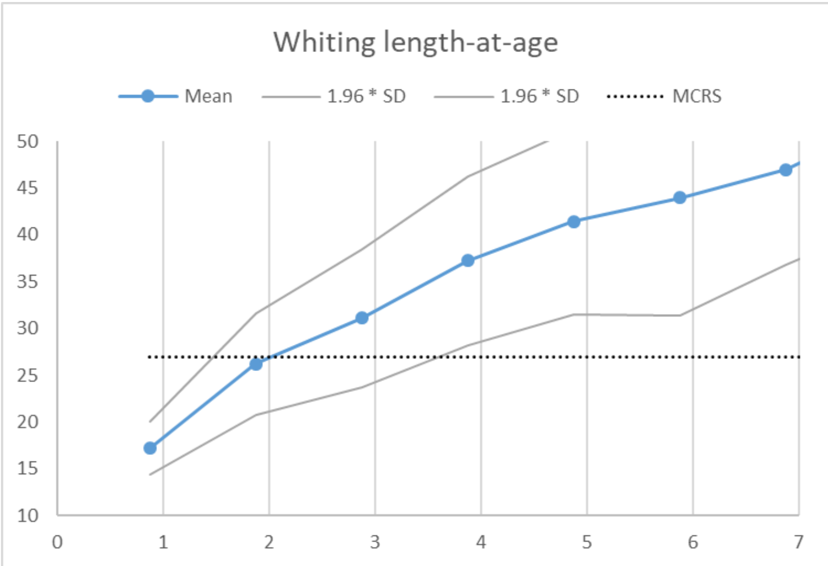


Figure 32. Mean length of whiting in the Celtic Sea from Q4 IBTS surveys. These data suggest that at age 0 all whiting are below MCRS; at age 1 around 85% are below MCRS and at age 2 around 25% are below MCRS, all older fish are above MCRS.

5.7.1 SBB and Recruitment summary

Interpreting the Stock–Recruit Relationship according to guidelines, Whiting 7bc–ek is proposed as Type 5: *A stock with clear plateau in the S–R relationship, where a wide range of F and SSB has been observed, but there is no evidence that recruitment has been impaired. For these stocks B_{loss} is identified as a candidate value of B_{lim}, below which the dynamics of the stock are unknown* (Figure 33).

[11] https://www.stockassessment.org/results.php?token=e191b1b78acded5c4e03dd2a2dc1d345

[12] https://www.stockassessment.org/results.php?token=e191b1b78acded5c4e03dd2a2dc1d345

[13] https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/2014%20Meeting%20docs/02.%20Background%20documents/WHG/WHGMSYfull_Final_Sept2020_DS_Fixed-Blim.html

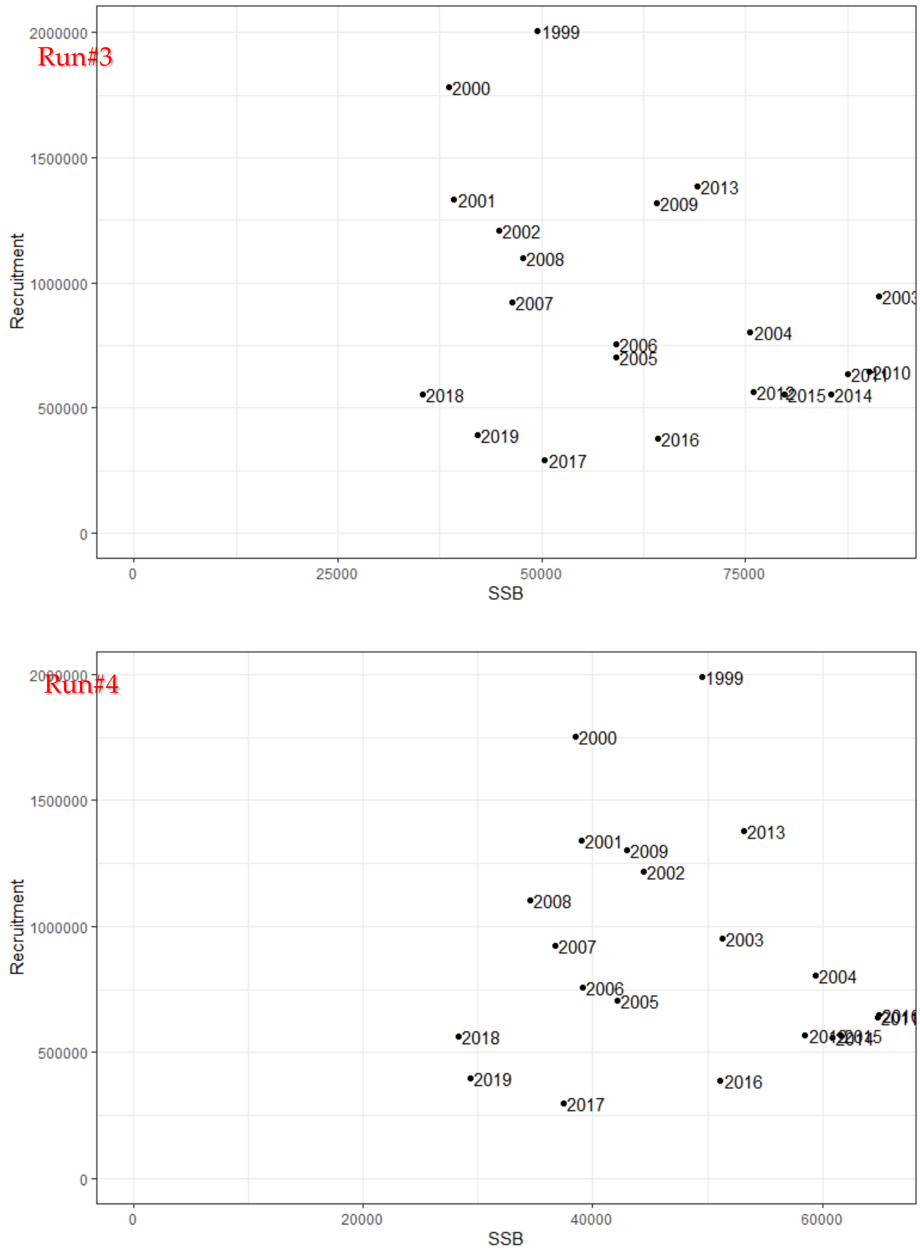


Figure 33. Stock–recruit pairs compared for the WHG7bc–ek assessment time series between benchmark Run#3 (top panel) and updated Run#4 (lower panel). Historically, moderate recruitment evident at all levels of SSB in the available time-series. However, 2013 is the most recent year in the upper half of the plot highlighting recruitment has been relatively under par during the period since then. Looking left to right however, we can see SSB appears to fluctuate on a much shorter time span.

Taking the Type 5 approach B_{lim} is taken as B_{loss} = 28 283 t being the minimum SSB in the time-series, excluding the most recent year (Table 5).

Table 4. Summary values for SSB and Recruitment.

SSB ref value	SSB Estimate
SSB ref value	SSB Estimate
Terminal SSB	29 290 t
Min observed	28 283 t
Max observed	64 934 t
50th Percentile	44 447 t
75th Percentile	58 529 t
Max observed	64 934 t

5.7.2 Uncertainty parameters

We now estimate B_{pa} as the SSB which will ensure a <5% chance of the true stock SSB going below our value for B_{lim}. We use the default value of sigma, the standard deviation of ln(SSB) at the start of the year following the terminal year of the assessment (sigma = 0.2). B_{pa} is then calculated from B_{lim} (Table 5).

Table 5. Summary of uncertainty parameters.

Refernce Point	Estimate
B_{lim}	28 283 t
B_{pa}	39 301 t

5.7.3 Estimating F_{MSY}

The base Eqsim run used the default ten year range for selection pattern and biological parameters. Uncertainties are taken from the previous section above. Fitting the three standard S–R models and letting the data decide on an average model, we see that Beverton–Holt gets a low weighting and converges on a very parameter (see Figure 34).

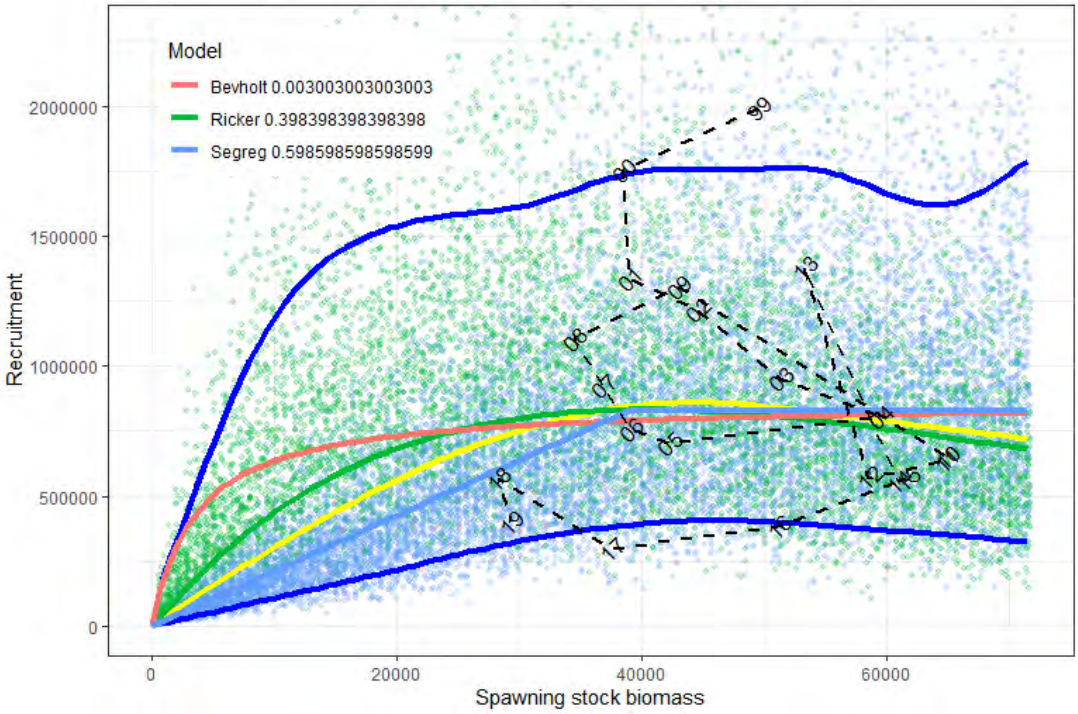


Figure 34. Stock–recruit relationship for the three default models (Ricker, Beverton–Holt and Segregated Regression).

Ricker gets a lot of weight but there is no evidence of impaired recruitment at high SSB so Ricker may not be an appropriate model. This leaves the segmented regression as a likely candidate S–R model (Figure 35). However, the Segreg breakpoint of 38 996 t reflects that much of the data driving the model are from earlier in the time-series where SSB would have oscillated around that level. B_{loss} of 28 283 t is more in line with the most recent assessments which, although noisy, indicate SSB is now below the current reference points so Setting the breakpoint to B_{loss} is the appropriate option.

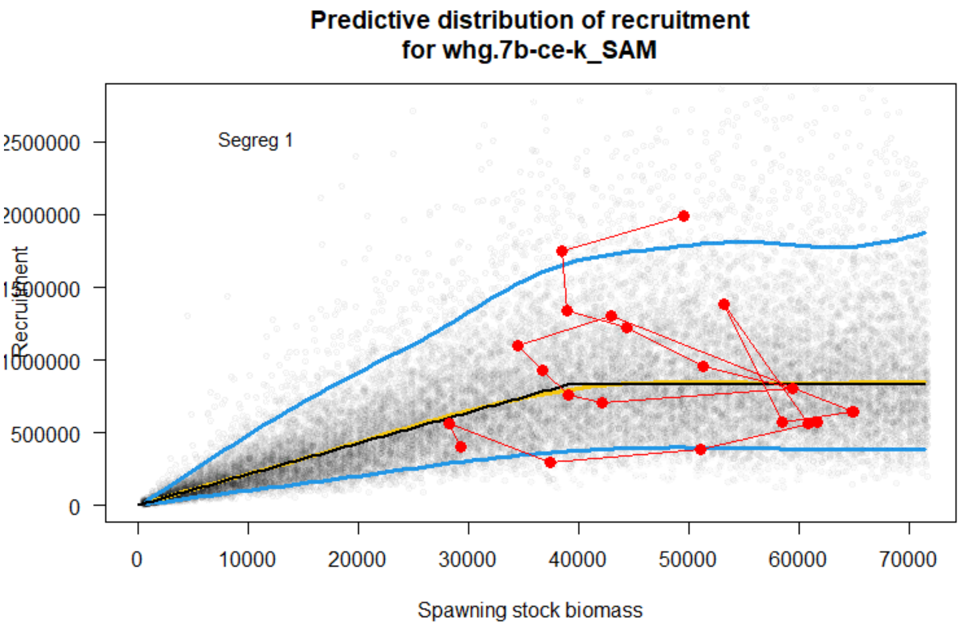


Figure 35. The segmented regression modelled stock–recruit relationship.

F_{MSY} is initially calculated as the F that maximizes median long-term yield in stochastic simulation under constant F exploitation (i.e. without MSY $B_{trigger}$). In Figure 36 we see that the median estimate of F_{MSY} is 0.995 which is expected to generate median catches of 16 225 t.

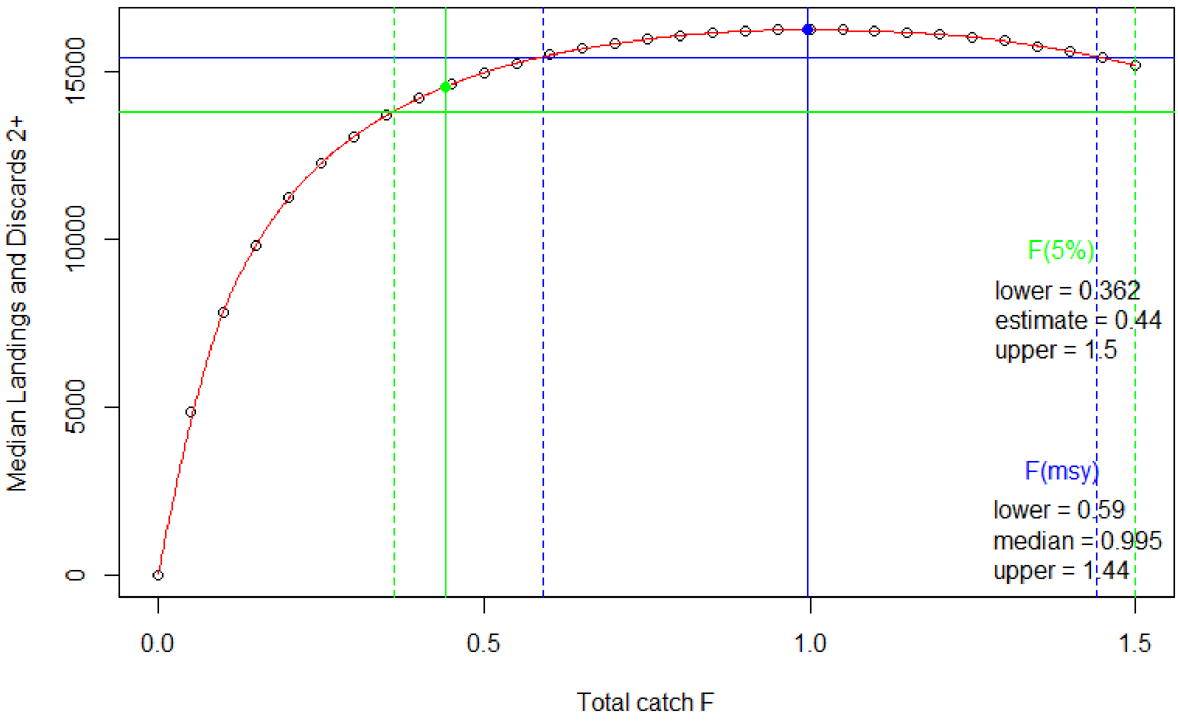


Figure 36. Yield curve and F_{MSY} upper and lower ranges (vertical blue lines) and F_{lim} upper and lower ranges (vertical green lines) for the segmented regression recruit model. F_{MSY} median point estimates and upper and lower bound are given. The value for median SSB corresponding to the lower and upper F_{MSY} bounds are also shown on the plot.

5.7.4 Estimating F_{lim} and F_{pa}

We also require F_{pa} which will replace F_{MSY} if more precautionary. Eqsim is run with no error ($B_{trigger}$ = 0, Fcv = 0 & Fphi = 0) to estimate F_{lim} with segmented regression with breakpoint at B_{lim}. Running the code with no error gives an estimate of F_{lim} = 0.994. Also, F_{pa} (0.715) is less than F_{MSY} (0.995) and therefore replaces F_{MSY}.

To calculate F_{lim} we use a loess smoother to predict the F that has a 50% probability of bringing the stock to B_{lim}. The sigma for the buffer is 0.2 default from guidelines. Running the code with no error gives an estimate of F_{lim} = 0.994.

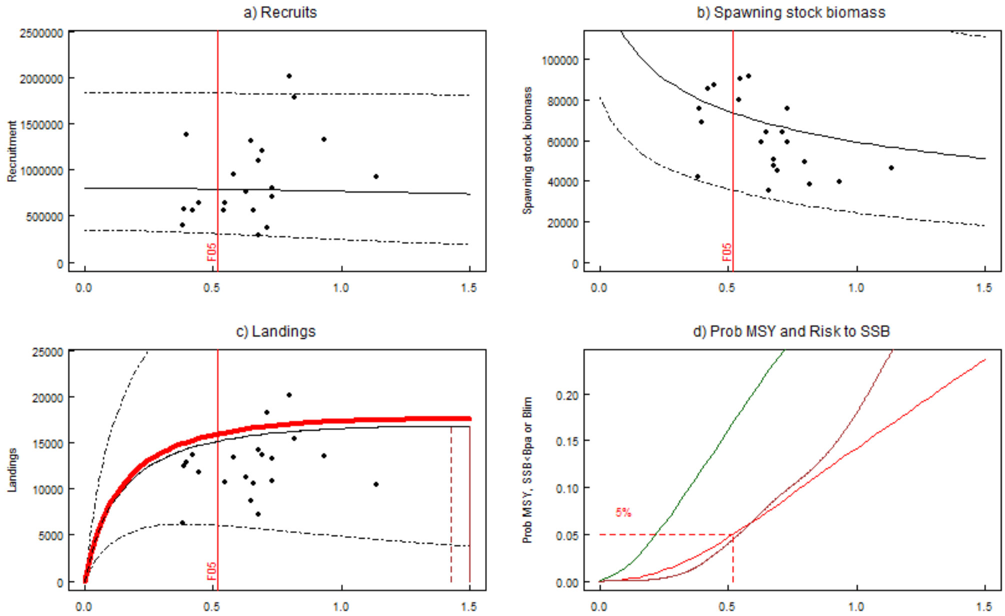
5.7.5 MSY $B_{trigger}$ without error

MSY $B_{trigger}$ is estimated as the 5th percentile of SSB when fished at F_{MSY}. This is calculated without assessment error, but includes noise in selectivity and population parameters. $B_{trigger}$ is estimated to be 10 726 t which is much lower than B_{pa}. Therefore $B_{trigger}$ will be changed to B_{pa} (39 301 t).

5.7.6 ICES Advice Rule – Assessment Error and $B_{trigger}$

The final step is to evaluate the ICES advice rule via stochastic simulation with these values of F_{MSY} and MSY $B_{trigger}$. If the F5% in this run is smaller than the candidate F_{MSY} then the candidate F_{MSY} is replaced by the F5% value. In this case F(5%) is 0.57 < F_{MSY}(1.5).

EqSim is run again, this time including the selected MSY $B_{trigger}$ value and error.



F_{MSY} is estimated as 0.534 F(5%), B_{lim} as 35 353 t and B_{pa} as 49 126 t. The full range of reference point values and their rationale are summarized in Table 6. In addition a run was performed to check sensitivity to a five year range (2015–2019) to estimate biological parameters and these are also included in the table[14]. The current model selection and settings seem relatively robust to the range used for estimation of biological parameters.

[14] https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/2014%20Meeting%20docs/02.%20Background%20documents/WHG/WHGMSYfull_Final_Aug2020_5yrBioSensitivity.html

Table 6. Summary reference points for Celtic Sea whiting.

Framework	Reference Point	Value	Rationale
MSY Approach	MSY Btrigger	39 301	Tonnes, Bpa
	Fmsy	0.57	Median point estimates of (F05) EqSim with segmented regression and fixed breakpoint (Blim).
	Blim	28 283	Bloss; lowest observed SSB (2018)
Precautionary Approach	Bpa	39 301	Blim combined with the assessment error; Blim × exp (1.645 × σ); σ = 0.20 (default setting)
	Flim	0.99	F with 50% probability of SSB less than Blim
	Fpa	0.57	The F that leads to SSB≥Blim with 95% probability
Management Plan*	FmsyLower	0.45	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
	FmsyUpper	0.57	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.

*** Proposed EU multiannual plan (MAP) for the Western Waters (EU, 2018[15]).**

5.7.7 Addendum

As a final consideration, the selected regression breakpoint of B_{lim} is from 2018 could be considered a relatively uncertain value. It might be more precautionary to consider an SSB value with higher certainty from earlier in the time-series. A further run for reference points with the two most recent years excluded from selection for B_{loss} was carried out. (Table 7).

[15] REGULATION (EU) 2019/472 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

Table 7.

Framework	Reference Point	Value	Rationale
MSY Approach	MSY Btrigger	47 963	Tonnes, Bpa
	Fmsy	0.4	Median point estimates of (F05) EqSim with segmented regression and fixed breakpoint (Blim).
	Blim	34 516	Bloss; lowest observed SSB (2008)
Precautionary Approach	Bpa	47 963	Blim combined with the assessment error; Blim × exp (1.645 × σ); σ = 0.20 (default setting)
	Flim	0.89	F with 50% probability of SSB less than Blim
	Fpa	0.64	The F that leads to SSB≥Blim with 95% probability
Management Plan*	FmsyLower	0.332	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
	FmsyUpper	0.4	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.

5.8 Short-term forecast

Using model outputs (Table 1–6), reference points above, 2020 TAC and F_{MSY} Catch Constraint, the short-term forecast was run and presented below (Forecast Table 1–10).

Forecast table 1. MSY approach: Fmsy.																								
Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.57	0.189	1.748	807039	299681	1991304	36141	22076	57180	10000	4896	19161	0.478	0.154	1.512	0.092	0.035	0.236	7609	3867	13796	2391	1029	5365
2022	0.57	0.158	2.103	807039	299681	1991304	44978	25115	74254	11848	5073	27158	0.478	0.129	1.805	0.092	0.029	0.298	8608	3900	17891	3240	1173	9267
Forecast table 10. hit MSY Btrigger.																								
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	1.212	0.401	3.718	807039	299681	1991304	36141	22076	57180	17152	9187	30426	1.016	0.327	3.215	0.196	0.074	0.503	12603	7131	20925	4549	2056	9501
2022	1.658	0.453	6.089	807039	299681	1991304	39284	20350	68057	20291	9839	43214	1.389	0.371	5.241	0.269	0.082	0.848	13106	6873	25561	7185	2966	17653

Forecast table 11. Take TAC in 2020, then Fmsy.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.651	0.267	1.631	807039	299681	1991304	31034	21034	45523	10863	6266	17938	0.546	0.218	1.41	0.105	0.049	0.221	8509	5012	13652	2354	1254	4286
2021	0.57	0.189	1.748	807039	299681	1991304	35063	21093	56037	9467	4667	18192	0.478	0.154	1.512	0.092	0.035	0.236	7120	3660	12933	2347	1007	5259
2022	0.57	0.158	2.103	807039	299681	1991304	44466	24730	73654	11596	4936	26798	0.478	0.129	1.805	0.092	0.029	0.298	8366	3775	17555	3230	1161	9243

Forecast table 12. ICES Advice Basis.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.524	0.174	1.608	807039	299681	1991304	36141	22076	57180	9356	4544	18079	0.439	0.141	1.39	0.085	0.033	0.218	7139	3592	13068	2217	952	5011
2022	0.57	0.158	2.103	807039	299681	1991304	45500	25582	74818	12104	5148	27684	0.478	0.129	1.805	0.092	0.029	0.298	8842	3976	18331	3262	1172	9353

Forecast table 13. ICES Advice lower.																								
Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.414	0.137	1.269	807039	299681	1991304	36141	22076	57180	7713	3672	15257	0.347	0.111	1.098	0.067	0.026	0.171	5925	2910	11172	1788	762	4085
2022	0.57	0.158	2.103	807039	299681	1991304	46856	26828	76323	12781	5350	29105	0.478	0.129	1.805	0.092	0.029	0.298	9449	4171	19568	3332	1179	9537

Forecast table 14. ICES Advice upper.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.524	0.174	1.608	807039	299681	1991304	36141	22076	57180	9356	4544	18079	0.439	0.141	1.39	0.085	0.033	0.218	7139	3592	13068	2217	952	5011
2022	0.57	0.158	2.103	807039	299681	1991304	45500	25582	74818	12104	5148	27684	0.478	0.129	1.805	0.092	0.029	0.298	8842	3976	18331	3262	1172	9353

Forecast table 2. Precautionary approach: Fpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.57	0.189	1.748	807039	299681	1991304	36141	22076	57180	10000	4896	19161	0.478	0.154	1.512	0.092	0.035	0.236	7609	3867	13796	2391	1029	5365
2022	0.57	0.158	2.103	807039	299681	1991304	44978	25115	74254	11848	5073	27158	0.478	0.129	1.805	0.092	0.029	0.298	8608	3900	17891	3240	1173	9267

Forecast table 3. FMSY upper.																								
Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.57	0.189	1.748	807039	299681	1991304	36141	22076	57180	10000	4896	19161	0.478	0.154	1.512	0.092	0.035	0.236	7609	3867	13796	2391	1029	5365
2022	0.57	0.158	2.103	807039	299681	1991304	44978	25115	74254	11848	5073	27158	0.478	0.129	1.805	0.092	0.029	0.298	8608	3900	17891	3240	1173	9267

Forecast table 4. FMSY lower.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.45	0.149	1.38	807039	299681	1991304	36141	22076	57180	8266	3961	16216	0.377	0.121	1.194	0.073	0.028	0.186	6335	3135	11822	1931	826	4394
2022	0.45	0.125	1.66	807039	299681	1991304	46402	26401	75802	10372	4257	24268	0.378	0.102	1.425	0.072	0.023	0.235	7694	3315	16388	2678	942	7880

Forecast table
5. F = 0.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0	0	0	807039	299681	1991304	36141	22076	57180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	807039	299681	1991304	53551	33349	83379	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Forecast table
6. Fpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.57	0.189	1.748	807039	299681	1991304	36141	22076	57180	10000	4896	19161	0.478	0.154	1.512	0.092	0.035	0.236	7609	3867	13796	2391	1029	5365
2022	0.57	0.158	2.103	807039	299681	1991304	44978	25115	74254	11848	5073	27158	0.478	0.129	1.805	0.092	0.029	0.298	8608	3900	17891	3240	1173	9267

Forecast table 7. Fsq.																							
Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	0.547	0.181	1.677	807039	299681	1991304	36141	22076	57180	9678	4718	18626	0.459	0.147	1.451	0.088	0.034	0.226	7374	3729	13446	2304	989	5180
2022	0.547	0.152	2.018	807039	299681	1991304	45239	25339	74554	11590	4925	26652	0.459	0.124	1.732	0.088	0.028	0.286	8455	3796	17623	3135	1129	9029

Forecast table 8. hit Blim.																							
Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	4.193	1.389	12.86	807039	299681	1991304	36141	22076	57180	32477	20088	54333	3.515	1.13	11.122	0.678	0.259	1.738	21598	13937	33073	10879	6151	21260
2022	4.314	1.179	16.206	759105	299681	1991304	28241	12714	53926	22722	10761	47540	3.612	0.959	13.918	0.702	0.22	2.288	11207	5229	23592	11515	5532	23948

Forecast table
9. hit Bpa.

Year	fbar:median	fbar:low	fbar:high	rec:median	rec:low	rec:high	ssb:median	ssb:low	ssb:high	catch:median	catch:low	catch:high	fbarL:median	fbarL:low	fbarL:high	fbarD:median	fbarD:low	fbarD:high	Land:median	Land:low	Land:high	Discard:median	Discard:low	Discard:high
2019	0.356	0.195	0.674	400557	192014	833340	29890	21808	41663	6532	5441	7819	0.32	0.172	0.619	0.036	0.023	0.055	5683	4752	6751	849	689	1068
2020	0.547	0.225	1.371	807039	299681	1991304	31034	21034	45523	9518	5405	15967	0.459	0.183	1.185	0.088	0.042	0.186	7488	4332	12235	2030	1073	3732
2021	1.212	0.401	3.718	807039	299681	1991304	36141	22076	57180	17152	9187	30426	1.016	0.327	3.215	0.196	0.074	0.503	12603	7131	20925	4549	2056	9501
2022	1.658	0.453	6.089	807039	299681	1991304	39284	20350	68057	20291	9839	43214	1.389	0.371	5.241	0.269	0.082	0.848	13106	6873	25561	7185	2966	17653

Annex 1: List of participants

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Annex 2: Stock Annexes

Stock ID	Stock name	Last up-dated	Link
cod.27.7e–k	Cod (*Gadus morhua*) in divisions 7.e–k (eastern English Channel and southern Celtic Seas)	November 2020	Celtic Sea cod
had.27.7b–k	Haddock (*Melanogrammus aeglefinus*) in Divisions 7.b–k (southern Celtic Seas and English Channel)	October 2020	Celtic Sea had-dock
whg.27.7.b–ce–k	Whiting (*Merlangius merlangus*) in divisions 7.b–c and 7.e–k (southern Celtic Seas and eastern English Channel)	September 2020	Celtic Sea whit-ing

Annex 3: Working documents

The following working documents are inserted in full in the pages below:

WD1: Historic discard estimates for Celtic Sea Cod. Hans Gerritsen, Marine Institute, Ireland.

WD2: Working document on a revision and proposal of French tuning fleets for the cod, whiting and haddock stock assessments. Gaël Lavialle, Lionel Pawlowski, Marianne Robert, Ifremer, France.

WD3: Working document on the updated French methodology used to produce landings and discards numbers- and weight-at-age data for the stock of cod 7e–k. Gaël Lavialle, Marianne Robert, Lionel Pawlowski. Ifremer, France.

Historic discard estimates for Celtic Sea Cod - WKCeltic 2020

Hans Gerritsen, Marine Institute, Ireland

21/01/2020

Abstract

Prior to 2004 only landings data are available for Celtic Sea Cod and it is unknown whether discard practices have changed over time. This document describes an approch to estimate the historic discard numbers-at-age.

Discarding in Celtic Sea cod is mainly confined to ages 1 and 2. For older ages, the catch numbers were assumed to be the same as the landings numbers. Discard estimates are available since 2004 and therefore catch numbers are known for all age classes in recent years. A seperable model was fitted (using the selection pattern for age 1 and 2 from the recent period) to estimate the catch numbers at ages 1 and 2 in the historic period. By substracting the observed landings numbers-at-age from the estimated catch numbers, the discards could be estimated for the period before 2004 (assuming the separable assumption is valid – i.e. selectivity is constant over time). There were no clear trends in the proportion of the catch-at-age that was discarded. Therefore it seems appropriate to simply apply the current discard rates to the historic data to estimate discard numbers before 2004.

Data

The historic dataset up to 2003 was combined with the updated dataset for the period 2004-18 that was produced at the WKCeltic data compilation workshop in 2019. Note that the historic landings weights-at-age were used as catch weights-at-age. (An alternative could be to use the stock weights). Also note that both the landings and discards numbers-at-age were SOP-corrected at the data compilation stage but not the catch-numbers-at age, leading to small inconsistencies in the dataset.

Figure 1 shows that during the period for which discard data are available, discarding mainly occured at ages 1 and 2 (catches of age 0 are negligable and discarding at ages 3 and older was rare).

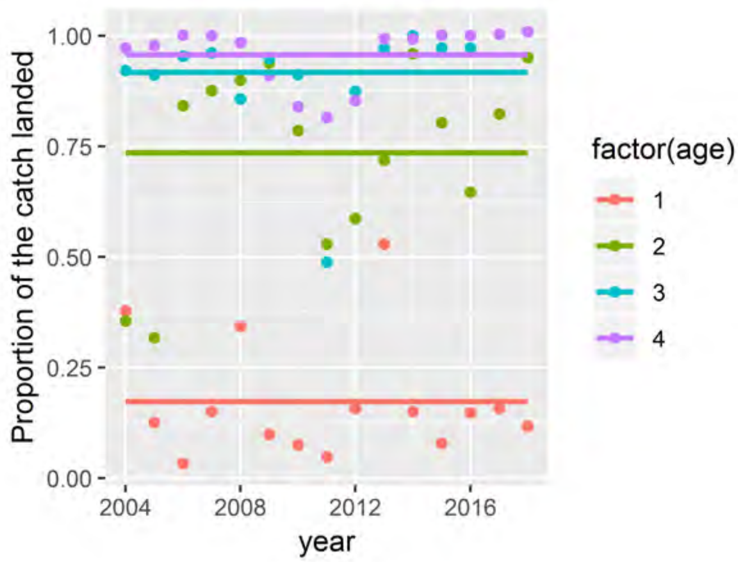


Figure 1: Proportion of the catch numbers-at-age that were landed

Back-filling discards

The discard practices before 2004 are unknown and may have changed over time (depending on TAC constraints, technical measures and market forces etc.). However, if the selection pattern can be assumed to be constant over time, it would be possible to determine a selection pattern for the recent period and apply this to the historic data to re-construct catch numbers-at-age based on this selection pattern.

In order to do this, a stock object was populated with historic catch numbers for ages 3+ only (ages 1 and 2 were set to NA; at older ages all catches were assumed to be landed). For the recent period (2004 onwards), catch numbers at all ages were included. A separable a4a model was fitted to these data using the tuning fleets proposed by the data compilation workshop. (See http://www.flr-project.org/FLa4a/ for details on the a4a model)

The model was set up as follows: the F model is flat-topped from age 3 onwards with ages 1 and 2 freely estimated. The year effect allows F to scale up and down but the selectivity is the same for all years (i.e. a separable model). The stock-recruit model is uninformative and the q models are flat for the survey (same selectivity for all ages) and the catchability of the commercial index is specified in the same way as the F model.

```
fmod <- ~factor(replace(age,age>3,3)) + factor(year)
srmod <- ~factor(year)
qmod <- list(~1,~factor(replace(age,age>3,3)))
fit1 <- sca(stock0,tun.sel,fmodel=fmod,qmodel=qmod,srmodel=srmod)
stock_a4a <- stock0+fit1
stock_a4a@name <- 'a4a'
```

The model appears to fit quite well. See appendix for model diagnostics. The model allows the catch numbers at ages 1 and 2 to be estimated for the period 1971-2003, discard numbers can then be estimated by subtracting the observed landings numbers from the modelled catch numbers for the full time series.

Figure 2 shows that there is no strong trend in the proportion discarded-at-age. There are some outliers at the start of the time-series and it may be best to truncate the earliest few years. From 1978 the results appear to be noisy but stable. With between 50 and 100% of the catch of 2-year-olds landed and 0-30% of 1-year-olds landed.

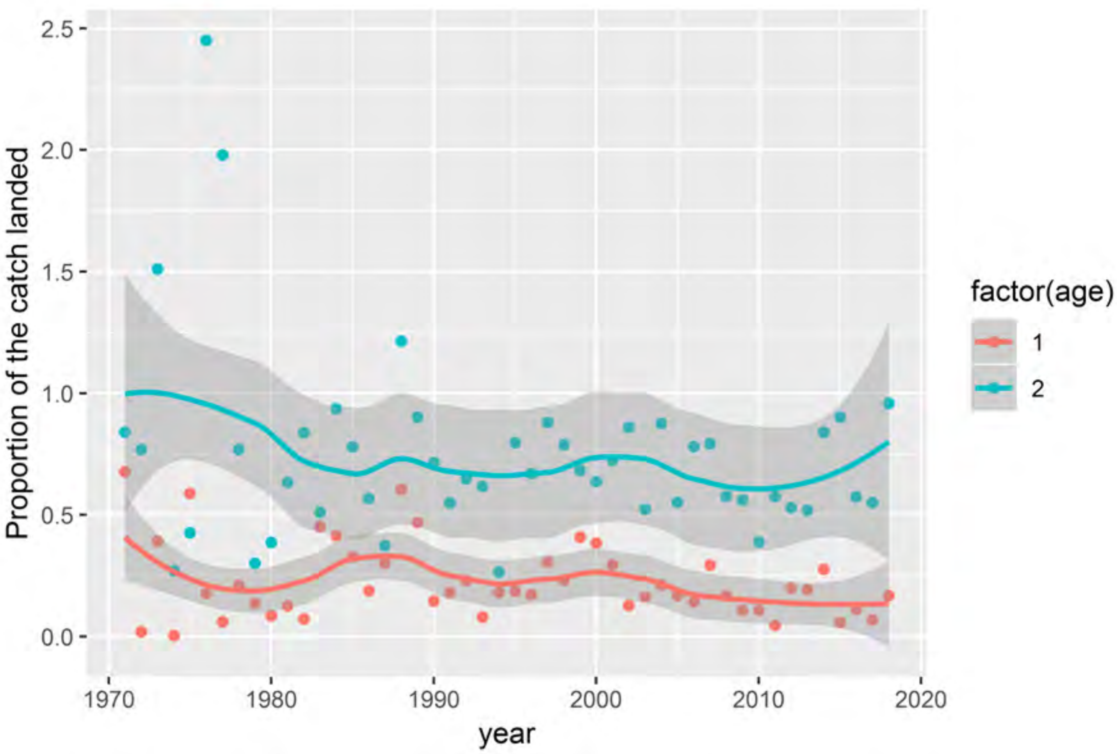


Figure 2: Modelled proportion of the catch that was landed

This analysis suggests that – if selectivity has been unchanged since 1971 – there does not appear to have been a strong trend in the discarding pattern over time. It might reasonable to assume that selectivity has actually been relatively stable as cod are fast growing and from the age of 2 they are pretty much fully selected, regardless of mesh size.

While it would be possible to use the seperable model to assess this stock, it may be better to only use this analysis to confirm that no major changes have taken place in the discard practices before 2003. Then the average discard proportions-at-age for the period 2004-2018 can be directly used to estimate the catches of the historic period. These proportions are (see Fig 1):

age	prop_land
1	0.1729330
2	0.7355398

Obviously, inflating the landings numbers (particularly of 1-year-olds) will increase the uncertainty around these numbers considerably, but there is likely to be enough contrast in the older ages to allow a model to accurately estimate fishing mortality.

Inflating the landings numbers using the proportions above to estimate the catch numbers for ages 1 and 2 in 1971 to 2003 results in the following catch-at-age matrix (for ages 1 to 10):

.

1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
4192	4	332	1	673	69	25	1139	438	609
627	774	1382	224	136	1456	416	676	357	7014
557	110	470	40	1070	61	236	129	263	387
96	205	60	118	83	107	87	116	68	175
35	260	74	38	105	11	82	20	601	52
17	35	17	214	20	22	2	34	26	55
5	11	6	24	20	12	2	6	24	14
29	5	4	4	12	5	5	46	5	0
1	1	6	14	1	1	10	5	2	0
0	0	0	0	0	0	0	2	1	0

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
315	76	1747	737	4198	651	2741	1830	666	489
3086	1157	529	1210	1693	1303	5470	5443	2639	846
811	5135	540	134	465	673	609	320	14358	1006
153	230	424	561	61	254	250	133	203	663
41	36	77	128	40	173	62	46	77	79
116	19	21	22	47	42	20	121	18	21
14	4	29	3	12	17	11	5	8	46
2	1	7	2	12	0	4	2	2	8
0	0	1	0	1	0	0	2	1	2
0	0	0	0	0	0	0	0	0	0

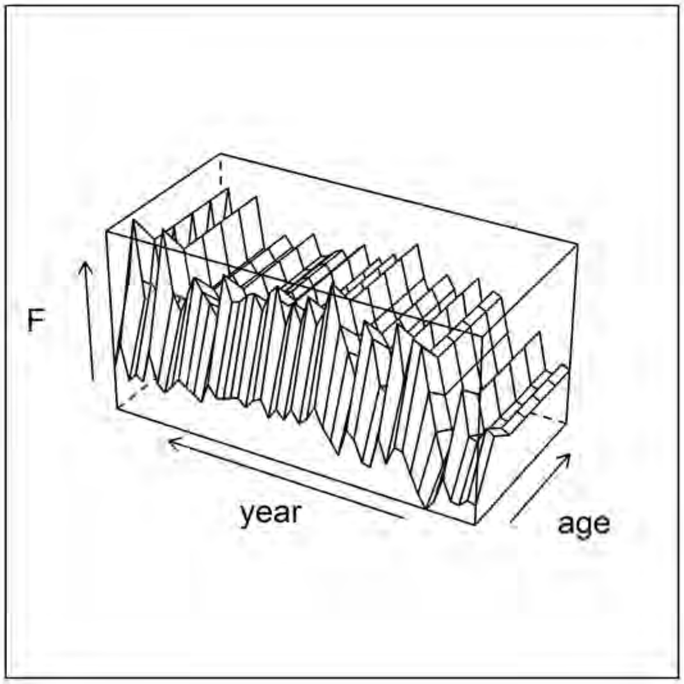
1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1377	8292	274	1340	823	617	1610	639	2868	1693
1034	3536	2371	4002	3320	2248	1870	2545	1551	464
229	329	928	1630	310	6933	951	641	756	419
1908	64	79	258	284	182	297	1469	158	169
276	70	139	27	73	95	48	135	59	254
48	53	26	10	75	43	22	36	36	23
11	16	14	11	3	3	35	6	9	12
3	6	2	6	3	1	0	2	29	2
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

2010	2011	2012	2013	2014	2015	2016	2017	2018
9794	2325	746	388	4708	242	624	159	902
618	4905	1860	383	415	2272	195	561	172
151	423	1757	581	83	137	707	57	137
107	49	117	516	132	26	33	166	14
46	34	18	55	149	47	7	24	38
14	13	14	16	8	37	17	5	5
4	4	10	7	2	7	16	14	2
1	0	1	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0

2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0	0	0	0	0	0	0	0

Appendix - model diagnostics

Below are some model diagnostics for the a4a model.



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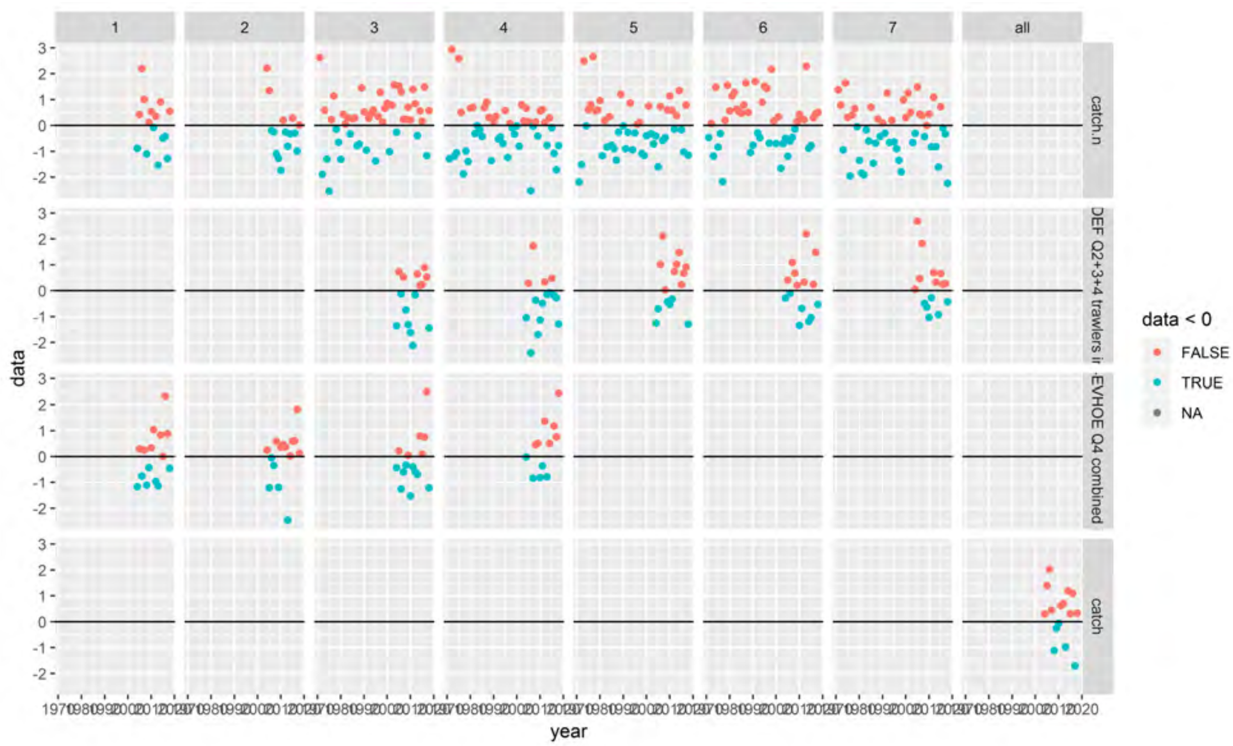


Figure 3: Residuals of the separable model. There are some large outliers in the catch numbers at ages 3, 4 and 5 at the start of the time series

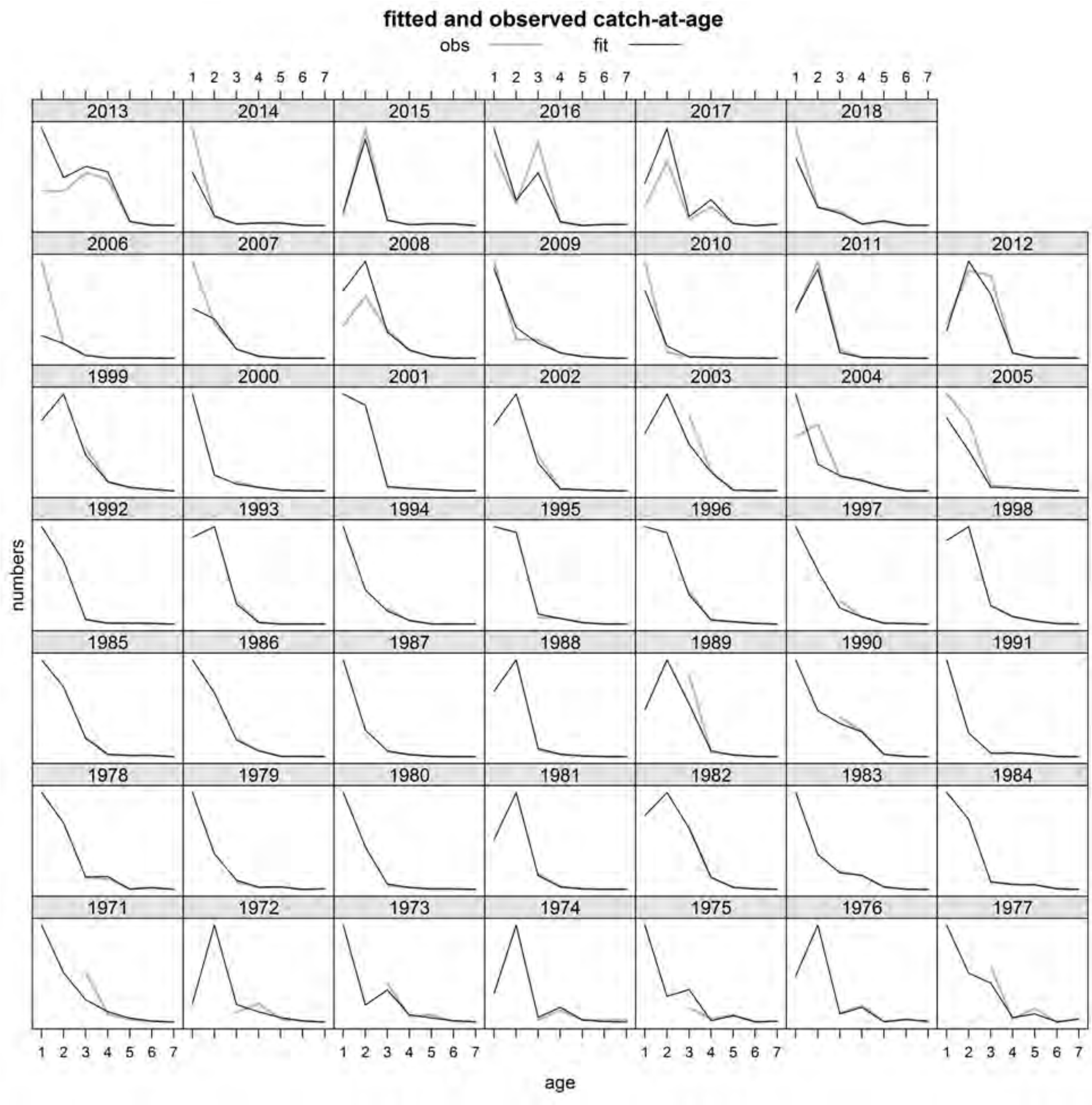


Figure 4: Observed and fitted catch numbers

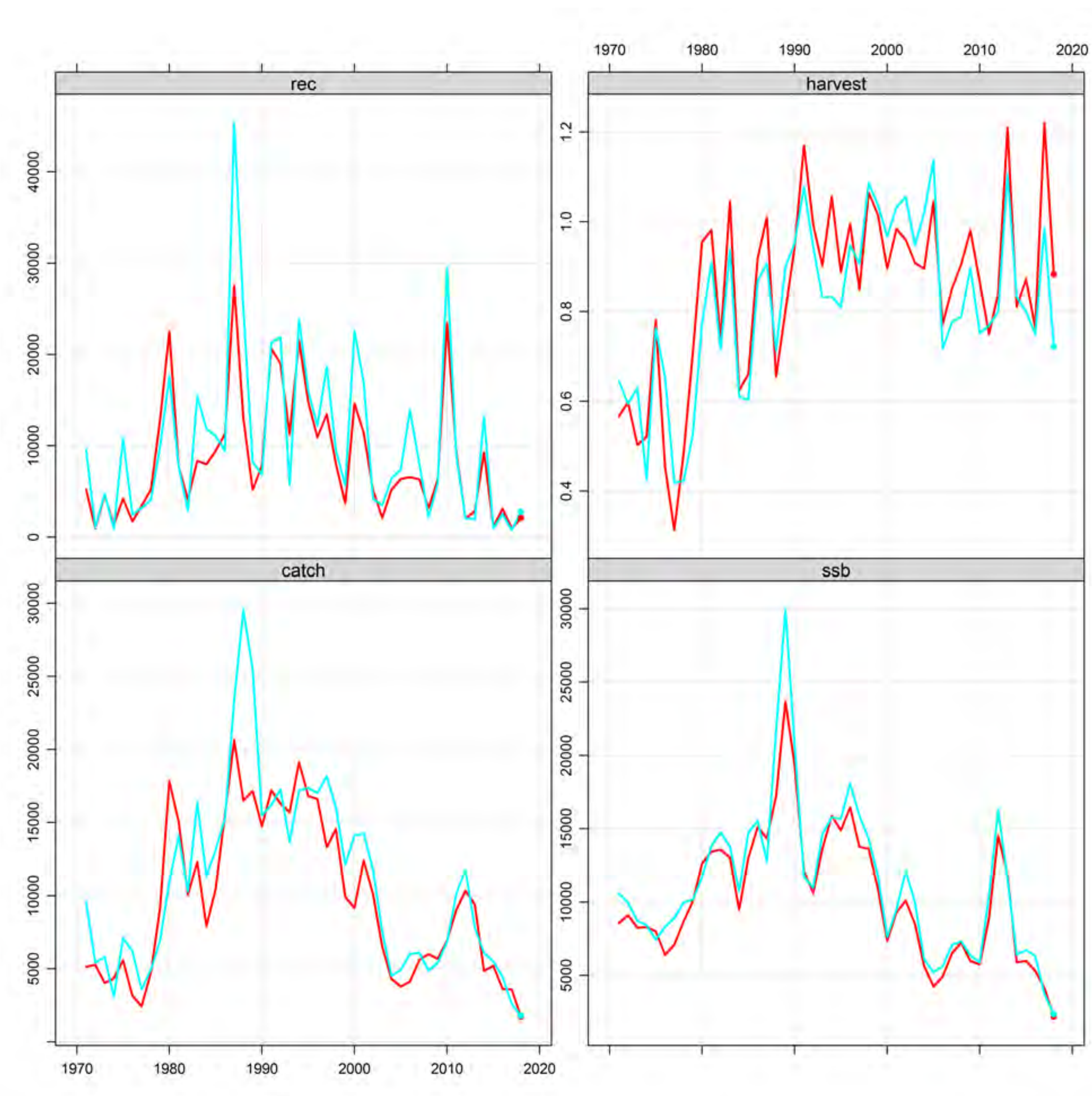


Figure 5: Comparison between the separable a4a model and an XSA model with the same settings as WGCSE2019

WKCELTIC – Benchmark on Celtic sea gadoids (cod 7e-k, haddock 7b-k, whiting 7b-k)

Working document on a revision and proposal of French tuning fleets for the cod, whiting and haddock stock assessments

IFREMER

January 2019

Gaël LAVIALLE, Lionel PAWLOWSKI, Marianne ROBERT

Summary

1. Introduction

This document summarizes the work undergone during the WKCELTIC 2019-2020 Benchmark on Gadoids Stocks to provide candidate commercial tuning indices for the Celtic sea cod, haddock and whiting stocks based on French data sets. The aim of this work was to revisit the current tuning fleet used for the cod assessment and proposed, if possible, candidate French commercial tuning fleet for whiting and haddock in the Celtic sea.

Data were available from two sources:

- The SACROIS algorithm developed by Ifremer and the French administration. SACROIS cross checks fishmarket sales, logbook and VMS data to produce a consolidated set of information at a disaggregated spatial (ICES statistical rectangle) and day scale.
- OBSVENTE/OBSMER which are respectively the fishmarket and observer at-sea sampling programs.

2. Cod 7e-k (+bc)

The French cod fishery is located in the north Celtic sea (7fg), spreading in 7h and 7e (Fig. 1). Cod is mainly captured with OTB and OTT gears targeting a lot of different species depending on the seasons and the areas (monkfish, megrim, rays, whiting, haddocks, squids, cuttlefish, etc.). The 7bc area is not yet included in the assessment but it accounts for a small part of the French landings.

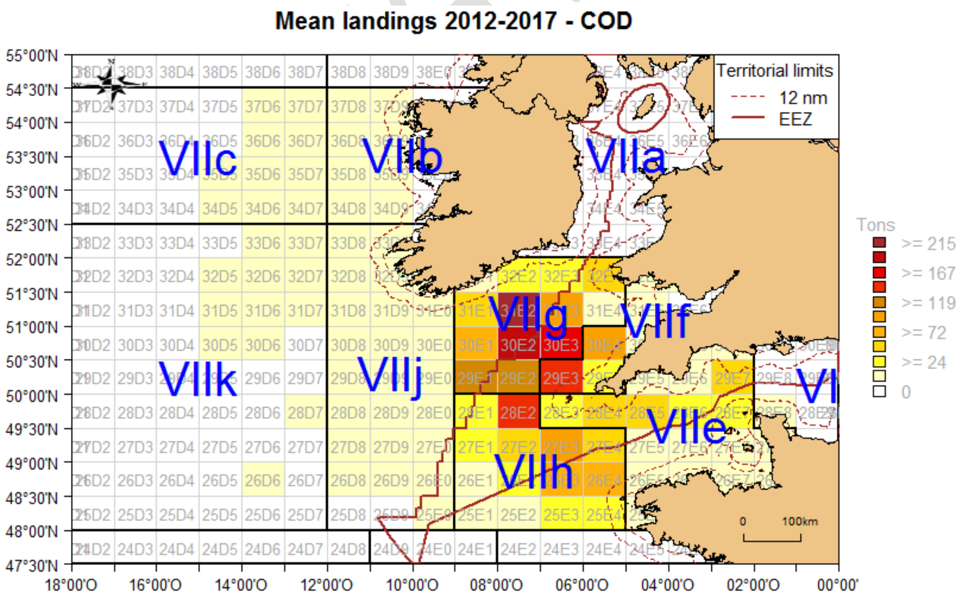


Fig. 1 : mean French landings of cod 7bc-ek over the 2012-2017 time series.

2.1. Current tuning fleet (since WKROUND 2012)

2.1.1. Selection criteria

The methodology used to define the fleet can be described as it follows (ALL_7bce_k_Q2Q4_2009):

a) Based on a defined set of 14 species association, fishing sequences during which cod has a high probability of being caught are identified from the following rule: at the quarter and ICES division level, if the landings composition of the landings from a vessel includes more or equal than 40% of the listed species[1] below, all its landings within the relevant ICES division and quarter are kept.

$$TH_{yqdv} = \frac{\sum_{s=1}^{S} LAN_{yqdvs}}{LAN_{yqdv}}$$

And:

$$\begin{cases} If\ TH_{yqdv} \geq 40\%\ then\ LAN\_tuning_{yqdv} = LAN_{yqdv} \\ LAN\_tuning_{yqdv} = 0\ otherwise \end{cases}$$

With: y = year; q = quarter; d = ICES division; v=vessel; s=species; species selected = 1…S; LAN = landings; LAN_tuning = landings of the tuning fleet; TH = threshold.

b) Effort calculation by quarter, ICES division and vessel level. In order to avoid fishing sequences which did not target the listed species, a spatial selection of the effort within each fishing trip has been made. More precisely, for each fishing trip included within the selection realized in a), all the effort made within a statistical rectangle with no landings recorded of the listed species was removed.

$$EFF\_tuning_{yqdv} = \sum_{t=1}^{T} \sum_{r=1}^{R} EFF\_tuning_{yqdvtr}$$

And: $$\begin{cases} If\ \sum_{s=1}^{S} LAN\_tuning_{yqdvstr} > 0\ then\ EFF\_tuning_{yqdvtr} = EFF_{yqdvtr} \\ EFF\_tuning_{yqdvtr} = 0\ otherwise \end{cases}$$

With t = fishing trip; r = statistical rectangle; EFF= fishing effort

The species list included 14 species : COD, HAD, WHG, POL, POK, BIB, LIN, BLI, FOR, GFB, MON, MNZ, LEZ, MEG and was defined during the 2012 benchmark. However, during the 2012 assessment working group the high recruitment in 2010 has induced a much higher number of vessels (than those considered as catching cod regularly) to be included in the tuning fleet between 2010 and 2012. A quick way to circumvent this problem during the 2012 assessment working group was to use the list of vessels identified in 2009 and use it onwards. As a consequence this frozen list of vessels resulted in a decreasing number of vessels being used since 2009 (because of various factors such as

[1] COD, HAD, WHG, POL, POK, BIB, LIN, BLI, FOR, GFB, MON, MNZ, LEZ, MEG

decommission, changing of activity...) while not taking into account new vessels which could have been selected using a threshold approach.

Due to the implementation of box closure in the Trevose area since 2005, the tuning fleet has only been defined for the three last quarters of the year. Indeed, during the first quarter of 2005, the rectangles 30E4, 31E4, and 32E3 (Fig. 2) were closed for fishing. Since 2006, the box is only closed in February and March each year.

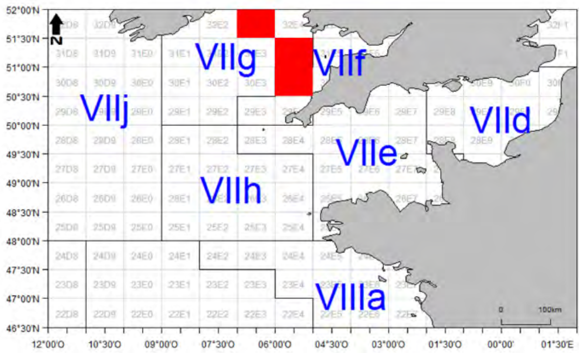


Fig. 2 : Trevose box (in red)

2.2. Limits of the current tuning fleet and proposals for a new one

Adding other species than cod to the selection process, given cod catches are part of a mixed fishery, allows the selected fishing effort to account for the real-zero catches. However, the large list of species allows some vessels which a very few catches of cod to be included in the tuning fleet. As a consequence, the landings by unit of effort can be underestimated. For example, the gillnetters targeting mainly monkfishes or pollack represent around 10% of the tuning fleet effort between 2000-2017 (Fig. 2) whereas they landed on average less than 2% of the fleet cod during the same period (Fig. 3). The Danish seine vessels can also been included in the tuning fleet whereas it is a recent métier which can induce a trend in catchability in the middle of the time series (2000-2017 for now). We decided to remove the vessels/gears whose the most part of the fishing effort has a little chance to induce some catches of cod (gillnets, .etc.) to keep only the OTT and OTB gears. It would allow to focus on the vessels targeting gadoids with an important part of their effort allocated to area and period corresponding to cod abundance.

The threshold and the list of species used to select the fishing sequences are the same whatever the gear, the period or the area. This approach assumes an homogeneous profile of catches over the stock area and period through the years. As a consequence, some vessels in some area, quarter and gear can be selected even if they have a low probability to catch and land cod. For instance, the selected gillnetters depend poorly of cod but strongly of monkfishes and pollack regardless of the area and the quarter. It means their fishing effort and its variations are driven by these species and not by cod. However, they are selected because monkfishes and pollack are included in the list. For the selected vessels within the fleet, the mean monkfishes landings share by gillnetter across all quarter and area is above 40% in every year, meaning this species is strongly implied in their selection. On the opposite,

OTB and OTT vessels are more dependent from cod even if it is a multispecific fishery with a lot of monkfishes, flatfishes and other gadoids. It seems that these gears are more likely to catch and land cod in association with their target species (especially gadoids) rather than the gillnetters.

We consider providing two tuning fleets. Based on recent works dealing with the multispecific features of the Celtic sea fisheries, we investigate the relevance of splitting the area in order to isolate a western Channel component. Indeed, Mateo et al., 2016 and Moore et al., 2018[2] identified several spatial clusters located within the Channel and the East of the Celtic Sea which have specific associations of landings (OTB working mostly with 80 mm codend (and 100 mm sometimes), targeting whiting, squids, cuttlefish, haddock and a lot of other species such as gurnard, pouting, etc.). This fleet may catch cod among its target species which are not the same compared to the otter trawlers in the Celtic sea (more monkfishes, megrim and gadoids). Knowing that, it could be relevant to set a specific threshold and list of species for the western Channel.

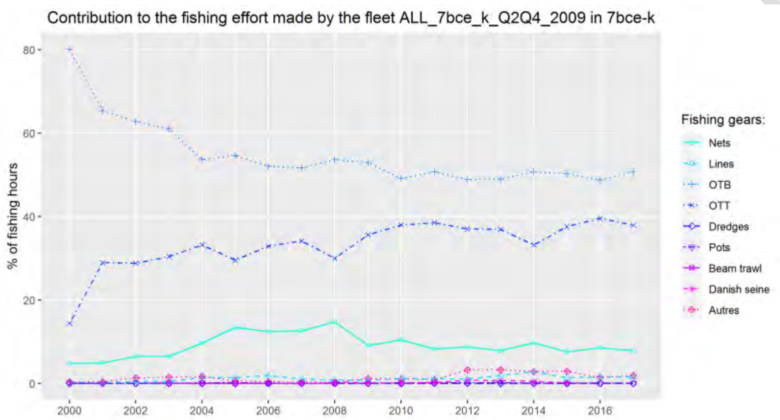


Fig. 3 : Contribution by fishing gear to the landings of cod of the ALL_7bce_k_Q2Q4_2009 fleet in 7bce-k over the 2000-2017 time series.

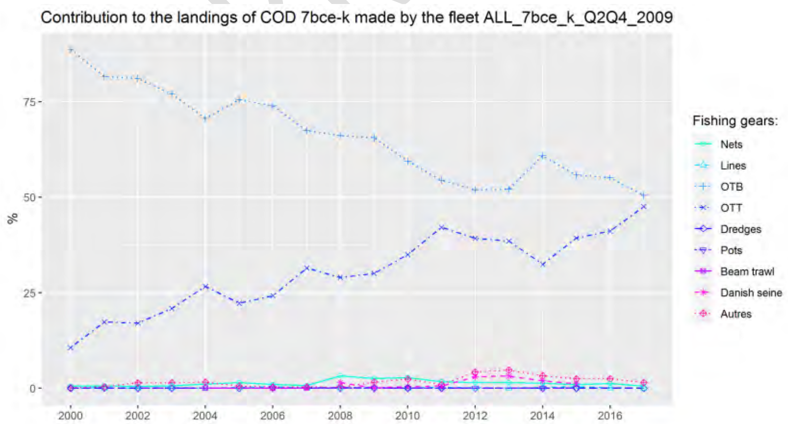


Fig. 4 : contribution by fishing gear to the fishing effort of the ALL_7bce_k_Q2Q4_2009 fleet in 7bce-k over the 2000-2017 time series.

2 Mateo, M., Pawlowski, L., and Robert, M. 2016 Highly mixed fisheries: fine-scale spatial patterns in retained catches of French fisheries in the Celtic Sea. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsw129.

It was also decided to exclude the inshore and coastal fishing effort from north Brittany (Fig. 5) which has no chance to catch cod. Therefore, only vessels longer than 12m were selected.

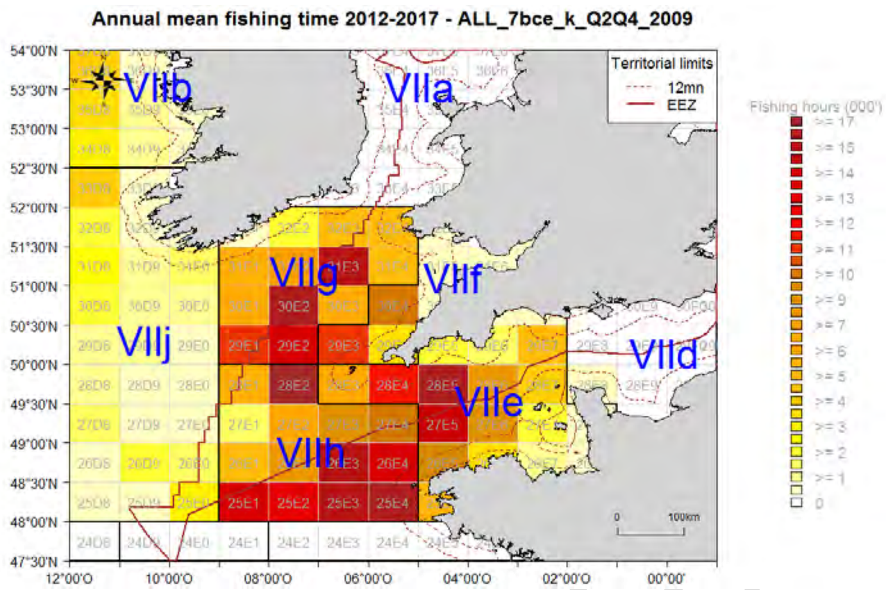


Fig. 5 : annual mean fishing time of the current French tuning fleet used for the cod 7e-k assessment over the 2012-2017 time series.

A two options approach was built:

Option 1: keeps one tuning fleet for the overall area (OTT/OTB > 12m) with one list of species and the associate threshold.

Option 2: splits the fleet of the option 1 in two fleets with their respective list of species and thresholds OTT/OTB 7f-k > 12m and OTB 7e> 12m. Species clusters and threshold analysis

Setting the list of species and the associated threshold is a critical step for the fleet definition process. The choice of the group of species used to calculate the threshold has to be composed of species associated with cod in order to keep as much as possible the fishing effort which has a high probability to generate catches of this species.

For each tuning fleet option, we define the most associated species in the landings by studying the correlations between species at the thinner scale available (day of fishing). Coefficient of correlation of spearman was calculated over all the day of fishing and over the time series (2000-2017). Species which has a coefficient of correlation with cod higher than 0.4 (this value is quite low because there is a lot of fishing sequences (more than 100,000) were kept. Among them, only target species (species which has a mean rank in the landings higher than 10 over the times series for the fleet considered) were selected in order to focus on the main drivers of the fishing effort. The selected species were sorted by decreasing order of correlation. Then, each time we add one more species to the threshold calculation, the effect on two indicators (for several level of threshold) was measured: i) The percentage of cod landed of the fleet after applying the threshold and the list of species tested (fleet landings with the subset / fleet landings with no subset * 100) ; and ii) The percentage of fishing effort

after applying the threshold and the list of species tested (fleet effort with the subset / fleet effort with no subset * 100).

2.2.1. Selected species by fleet

Species	ALL_7bce_k_Q2Q4_2009		OTT_OTB_7e_k_O12m		OTT_OTB_7f_k_O12m		OTB_7e_O12m	
	Correlation	Target ?	Correlation	Target ?	Correlation	Target ?	Correlation	Target ?
BIB	0.25	X	0.06	x	0.09		0.47	x
COD	-	X	-	x	-	x	-	x
CTC	-0.14	X	-0.23	x	-0.17	x	-0.06	x
GUR	0.22	X	-	x	-0.01	x	0.42	x
HAD	0.66	X	0.58	x	0.58	x	0.49	x
HKE	0.48	X	0.39	x	0.31	x	0.42	
JOD	0.5		0.31		0.21	x	0.49	x
LIN	0.51		0.42		0.38		0.47	
MEG	0.54	X	0.36	x	0.23	x	0.37	
MNZ	0.45	X	0.34	x	0.13	x	0.55	x
NEP	0.3		0.24		0.22		0.01	
POK	0.38		0.33		0.32		0.22	
POL	0.32		0.3		0.32		0.41	x
SKA	0.34	x	0.24	x	0.13	x	0.37	x
SQZ	0.15		-0.04		-0.03		0.32	x
WHG	0.57	x	0.45	x	0.49	x	0.44	x

Table 1 : Correlation coefficient (Spearman) with cod by species based on the overall days of fishing of each fleet over 2000-2017. The cross flags the species which belong to the 10 first species landed by the fleet on average over 2012-2017. In orange the species selected for each fleet.

The table 1 shows the correlation coefficient for each species either correlated or targeted by the fleets. The selected species for the threshold analysis are listed below:

Option 1 OTT_OTB_7e_k_O12m: COD, HAD, WHG

Option 2 OTT_OTB_7f_k_O12m: COD, HAD, WHG **and OTB_7e_O12m**: COD, MNZ, HAD, BIB, WHG, GUR, POL (the John Dory is excluded because it is a very specific and located fishery)

It is worth noting that whiting and haddock are well correlated in the landings with cod, notwithstanding the area. This observation confirmed the work done by Mateo & al, 2016 and Dolder & al, 2018[3].

2.2.1. Option 1 - one offshore otter trawl tuning fleet

The figure below presents the contribution to the cod landings and to the fishing effort of the OTT_OTB_7e_k_O12m fleet for each combination threshold/species cluster we tested.

[3] Dolder, P. J., Thorson, J. T. & Minto, C. Spatial separation of catches in highly mixed fisheries. *Scientific Reports* 8, (2018).

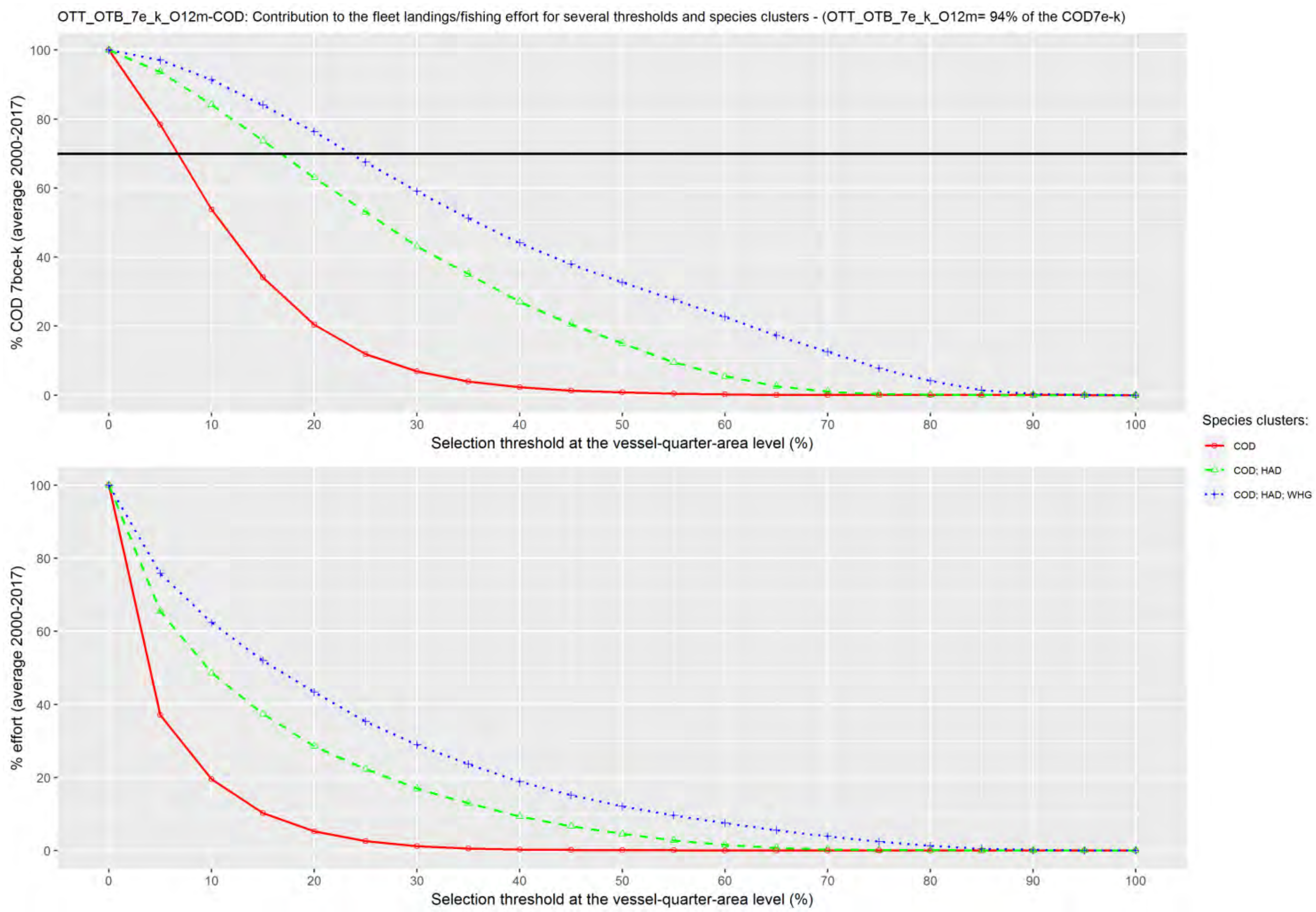


Fig. 6 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to cod the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 25% of COD/HAD/WHG landed represent 68% of the cod landed by the OTT_OTB_7e_k_O12m fleet and 35% of its fishing effort – Average over 2000-2017.

An arbitrary threshold was set to 70% of contribution to the cod landed by the fleet to achieve (black line on fig. 5). For the OTT_OTB_7e_k_O12m fleet which represents 94% of the cod 7e-k landings, the 70% threshold allow us to build a tuning fleet which account for 66% the stock landings (70%*94%). **We finally decided to keep cod, haddock and whiting as species list to define the threshold for this fleet, A 25% threshold will allow achieving the 70% contribution set above**.

2.2.2. Option 2 - Segmentation between western Channel and Celtic sea

2.2.2.1. OTB 7e > 12m

The high number of species well correlated with cod reflects many strategies taking place in the western Channel. However, the overall contribution of this fleet to the French landings of cod 7e-k is low (14% on average between 2000-2017). The good correlation with monkfish can be explained by the shallower waters of the western Channel (~80-150 meters). Figure 6 suggests a list of species made of COD/MNZ/HAD/BIB/WHG/GUR. However, we decided to narrow down **the list of species to COD/MNZ/HAD/BIB/WHG list. The threshold associated to this list to achieve the 70% of landings contribution is estimated at 35%.**

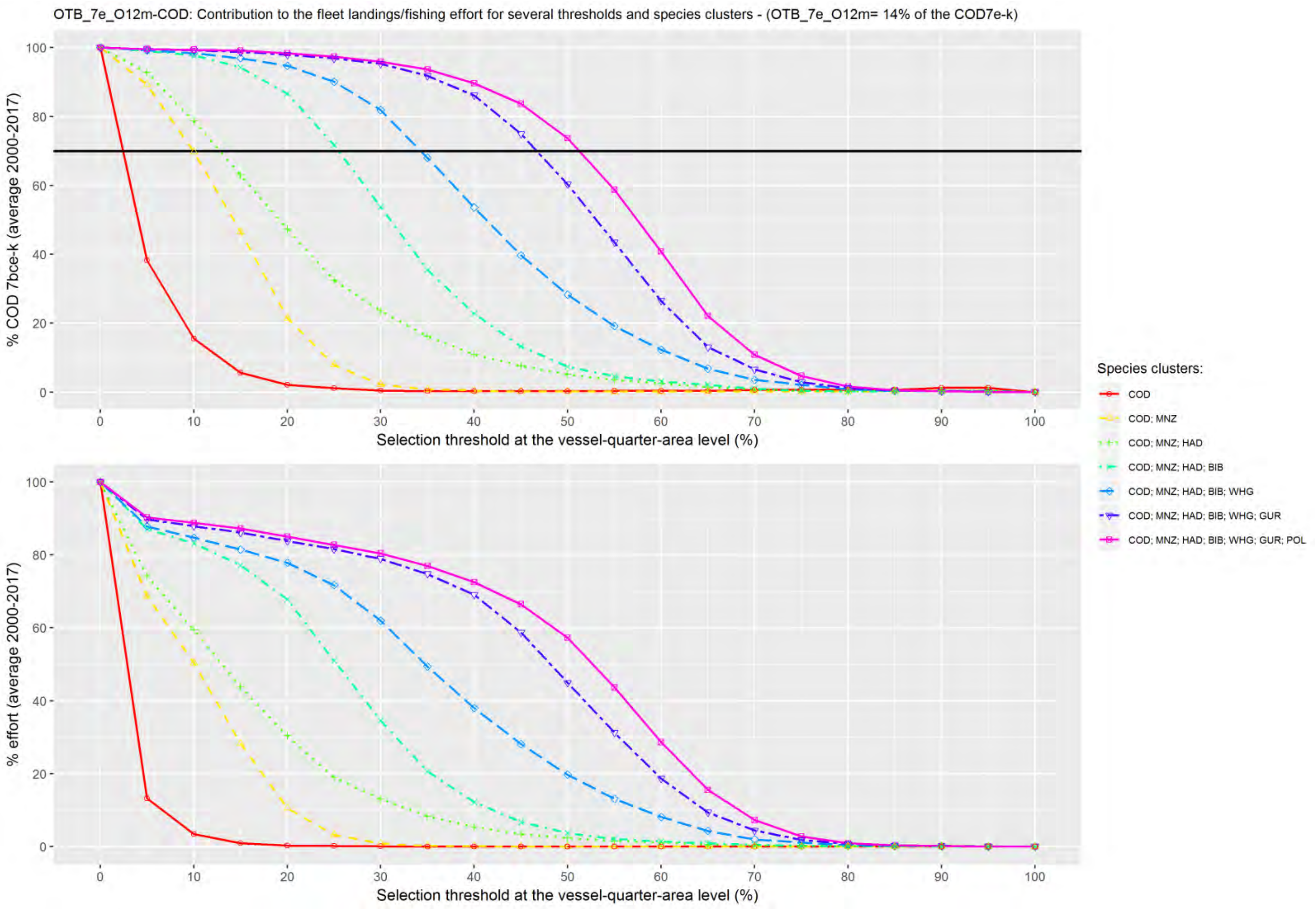


Fig. 7 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to cod the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 35% of COD/MNZ/HAD/BIB/WHG landed represent 68% of the cod landed by the OTB_7e_O12m fleet and 49% of its fishing effort – Average over 2000-2017.

2.2.2.2. OTT_OTB_7f-k_012m

Considering the similarity with the fleet from the option 1, the same thresold and list of species are selected (25% of COD/HAD/WHG).

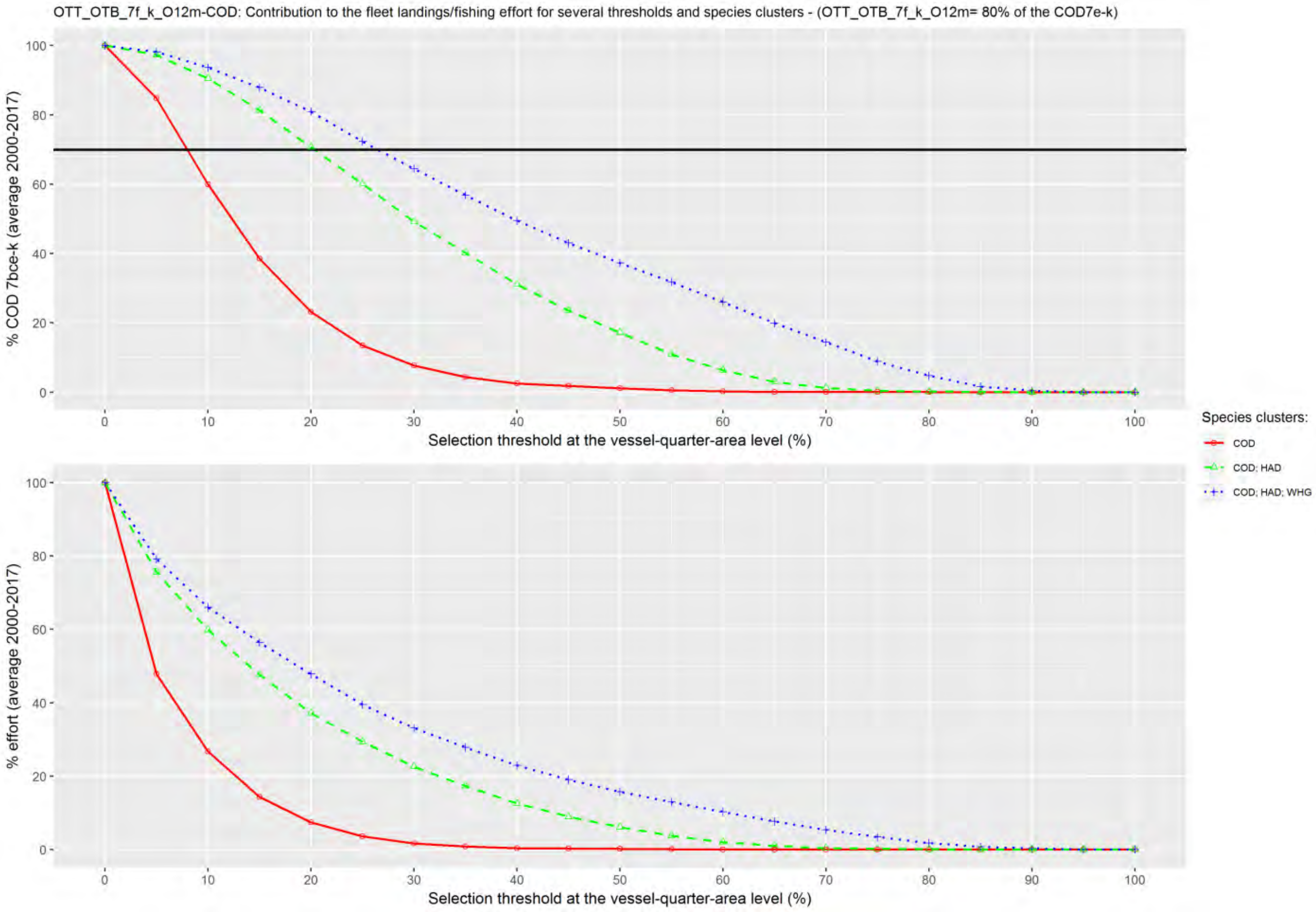


Fig. 8 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to cod the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 25% of COD/HAD/WHG landed represent 72% of the cod landed by the OTB_7f-k_O12m fleet and 40% of its fishing effort – Average over 2000-2017.

2.2.3. Summary

Table 2 : resume of the selected definition parameters of the French tuning fleets' options for the cod 7e-k.

Flottille	Option	Groupe d'espèces	Threshold	% French COD 7e-k	% COD fleet (A)	% fishing effort fleet (B)	A / B
OTB/OTT 7e-k > 12m	1	COD/HAD/WHG	25%	63%	68%	35%	1,9
OTB 7e > 12m	2	COD/MNZ/HAD/ BIB/WHG	35%	10%	68%	49%	1,4
OTB/OTT 7f-k > 12m		COD/HAD/WHG	25%	58%	72%	40%	1,8
ALL 7bce-k Q2Q4 2009	Current	COD/HAD/WHG/ POL/POK/BIB/LI N/BLI/FOR/GFB/ MNZ/MEG	40%	62%	92%	66%	1,4

2.3. LPUE of candidate tuning fleets

The variations of the number of vessels included into the tuning fleets can be considered as a proxy of the fleet stability (Fig. 9).

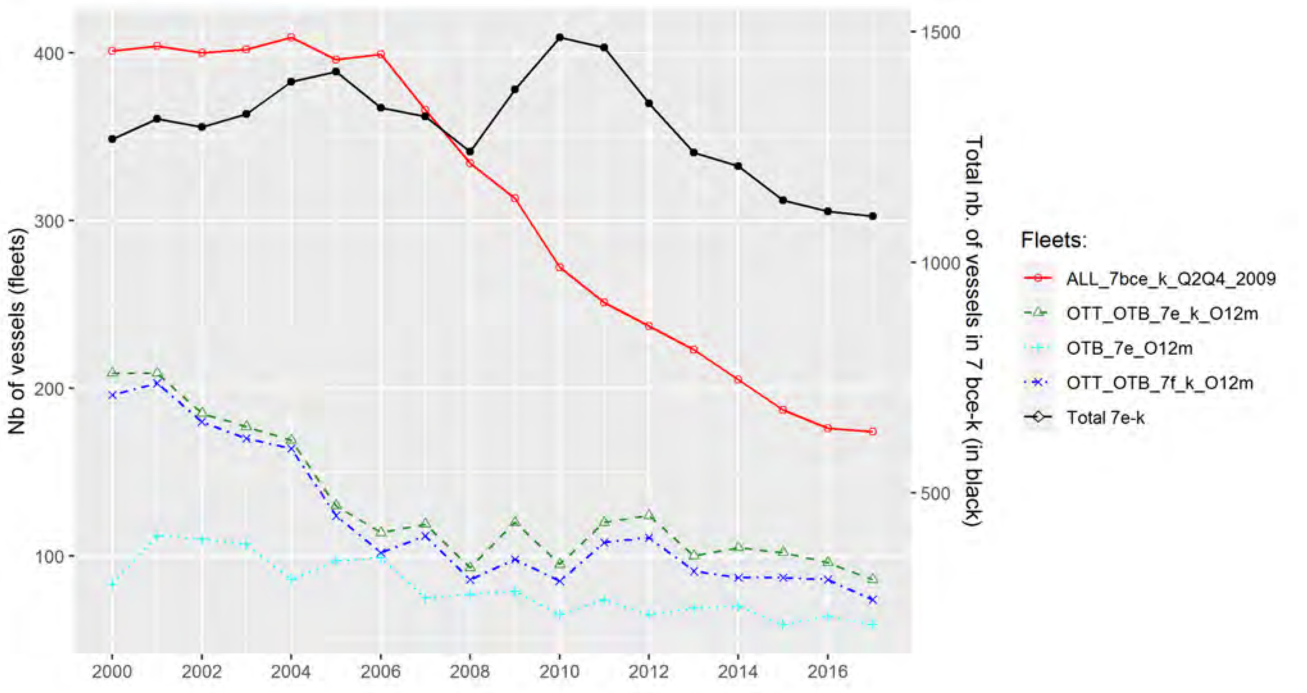


Fig. 9 : number of vessels for each tuning fleet built over the 2000-2017 period. The total number of vessels in the area is described by the black curve and the right axis.

The number of vessels of the current tuning fleet decreases due to the frozen list from 2009. The number of vessels of the three new proposed tuning fleets decreased in the beginning of the time series and since 2006 remain relatively stable across years except an increase in the Celtic sea during around 2011-2012, reflecting the period of strong recruitment of cod. At that time, some vessels might have caught more cod than usual (+ 30% of vessels included in the OTT_OTB_7e-k > 12m fleet between 2010 and 2012).

The time series of LPUE from the candidate tuning fleets were compared with the time series of biomass resulting from the latest assessment (figure 9). The Celtic fleet (dark blue) and the global otter trawler fleet (green) have higher LPUE than the current fleet which indicates that this new fleet targets cod more explicitly. Global shape is close to the current fleet but there are some differences in the variations amplitude along the time series (2006-2007; 2010-2012; 2015-2017). These two fleets reflect the fluctuation of the cod abundance, however the biomass estimate from XSA are partially derived from the current tuning fleet (circularity). In recent years, the Celtic sea fleet shows a slightly different pattern, with a smoother decreasing trend than for the other fleets. It does not seem to be related to management, as based on an industry feedback, the Celtic sea French vessels have not received more quota than the western Channel fleet. The LPUE of western Channel fleet (cyan, 10% of the French landings) does not properly reflect the fluctuations in abundance, as given by the current assessment. LPUE decreases in the beginning of the time series. Strong abundances of 2010-2012 were

not highlighted by these fleets. It shows a decreasing trend in recent year to reach very small values. It will produce a different signal that might be interesting to test with a XSA run.

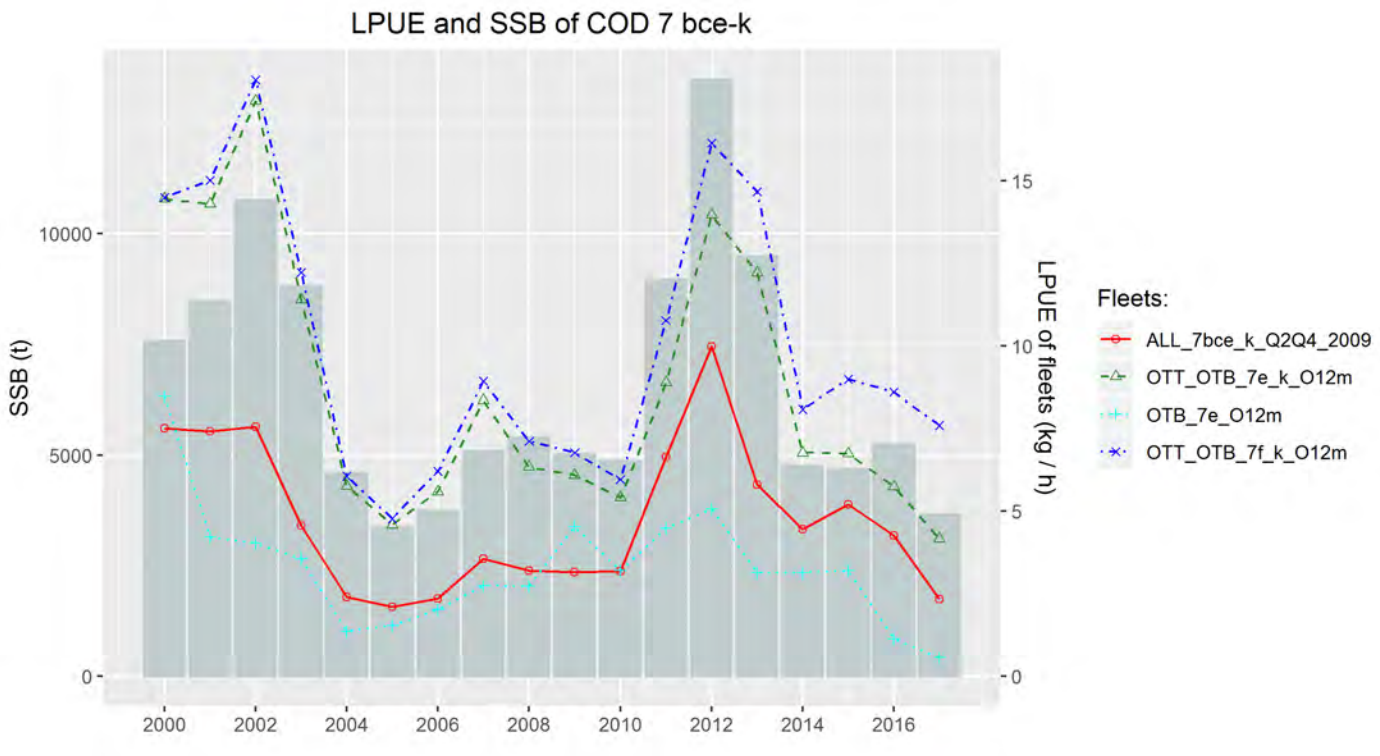


Fig. 10: LPUE of cod for the selected tuning fleets and SSB from the XSA assessment (ICES) over the 2000-2017 periods.

2.4. Raising length and age structure of candidate fleets

The final aim is to produce a time series of landings and discards at age for each tuning fleet based on the sampling data available. The discard data can only be provided by the at-sea sampling program.

The selection procedure of strata for which raising can be performed was based on the same threshold than for the total landings and discards data. Those threshold were agreed during the WKCELTIC-2020 (Working document on the updated French methodology used to produce landings and discards numbers and weight at-age data for the stock of cod 7e-k) and are presented below:

Estimator to raise	Catch category	Sampling	Number of trips	Number of fishing operations	Number of fish measured
Number at length	Discards	At-sea	2	5	20
Number at length	Landings	At-sea/market	2	-	100 (60 if the discard number at length is raised)

A first exploratory work on sample data on recent years shows some significant differences between the size structures of the catches, especially in western Channel with smaller fishes. However, the western Channel fleet is not sampled enough to produce a size structure of discards over the whole

time series even if its coverage has improved since 2014. Based on the work presented in this document, the western Channel fleet seems to be relevant but cannot be used currently. LPUE will need to be considered when the sampling level will be sufficient over a longer time period.

Table 3 shows the estimated quantities in tons per year and quarter for the two tuning fleets. Based on the low discards sampling data, we decided to raise the discards on an annual base. Missing annual discards estimates were fill in using the average of discard rate over the time series and age structure using the average of age distribution in weight over the time series.

The raised number of cod landed and discarded by the two French tuning fleets is presented in Figure 11. The sum of the two catch categories will provide the catch at age matrix of the commercial tuning fleet that can be used in the assessment. Figure 12 illustrates the raised landings and discards quantities by age, year and tuning fleet.

Table 3.a Tonnage of estimated landings and discards per year and quarter. Yellow cell indicates that no estimation can be performed due to too low number of sampling.

technical	catchCat	quarter	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
OTT_OTB_7bce_k_O12m	DIS	2													29	12		3	
		3				62	33			52	98	114			19		12		8
		4				50	28		18	57	42				5				
	LAN	2	1981	918	346	249	158	545	301	211	156	1051	1488	960	557	638	663	253	77
		3	1261	744	381	295	351	454	360	328	328	800	1334	604	447	665	378	152	61
		4	312	241	187	166	197	154	133	141	259	450	710	320	170	217	198	56	46
OTT_OTB_7bcf_k_O12m	DIS	2													26	12		3	
		3				61	31			30	139	85			16		10		8
		4				48	27		14	41	37				4				
	LAN	2	1922	864	332	241	151	524	269	154	141	909	1376	879	518	560	629	239	69
		3	1212	705	373	290	331	415	292	190	234	629	1208	563	338	488	344	143	54
		4	303	230	183	159	182	148	106	87	224	354	642	301	152	187	175	46	

Table 4.b Final tonnage of estimated per year and quarter for landings and per year for discards. Yellow cell indicates that no estimation can be performed due to too low number of sampling.

technical	catchCat	quarter	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
OTT_OTB_7bce_k_O12m	DIS	all			45	166	77		33	153	146	236	31	42	45	13	21	6	20
	LAN	2	1981	918	346	249	158	545	301	211	156	1051	1488	960	557	638	663	253	77
		3	1261	744	381	295	351	454	360	328	328	800	1334	604	447	665	378	152	61
		4	312	241	187	166	197	154	133	141	259	450	710	320	170	217	198	56	46
OTT_OTB_7bcf_k_O12m	DIS	all			44	162	72		28	102	159	193	29	41	39	12	17	6	19
	LAN	2	1922	864	332	241	151	524	269	154	141	909	1376	879	518	560	629	239	69
		3	1212	705	373	290	331	415	292	190	234	629	1208	563	338	488	344	143	54
		4	303	230	183	159	182	148	106	87	224	354	642	301	152	187	175	46	

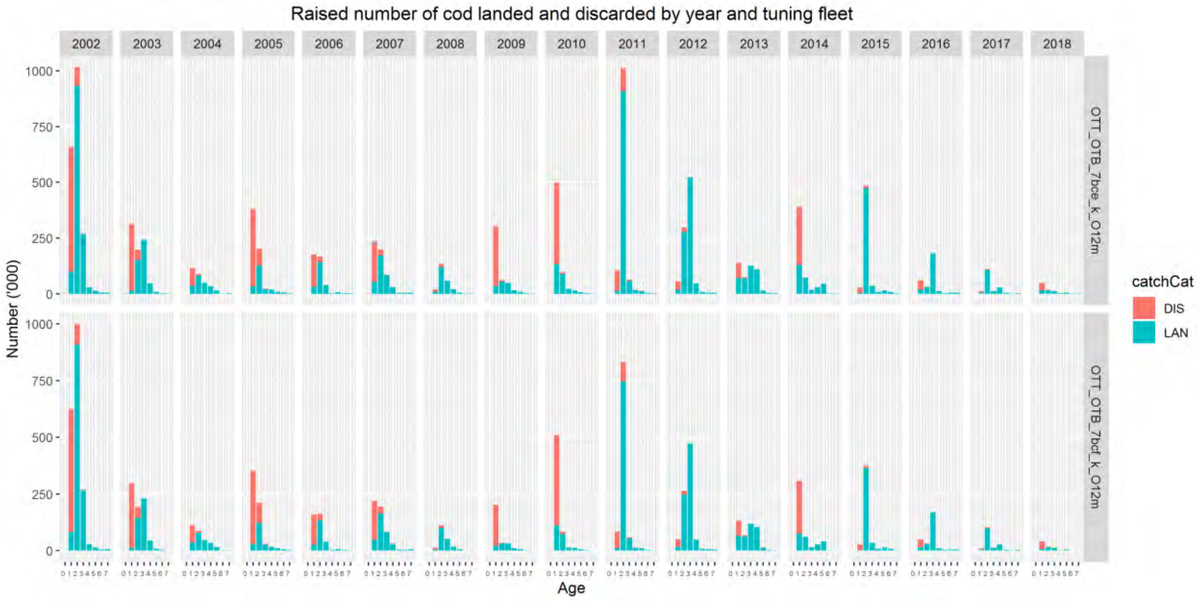


Figure 11. Raised number at age for landings and discards by year and tuning fleet.

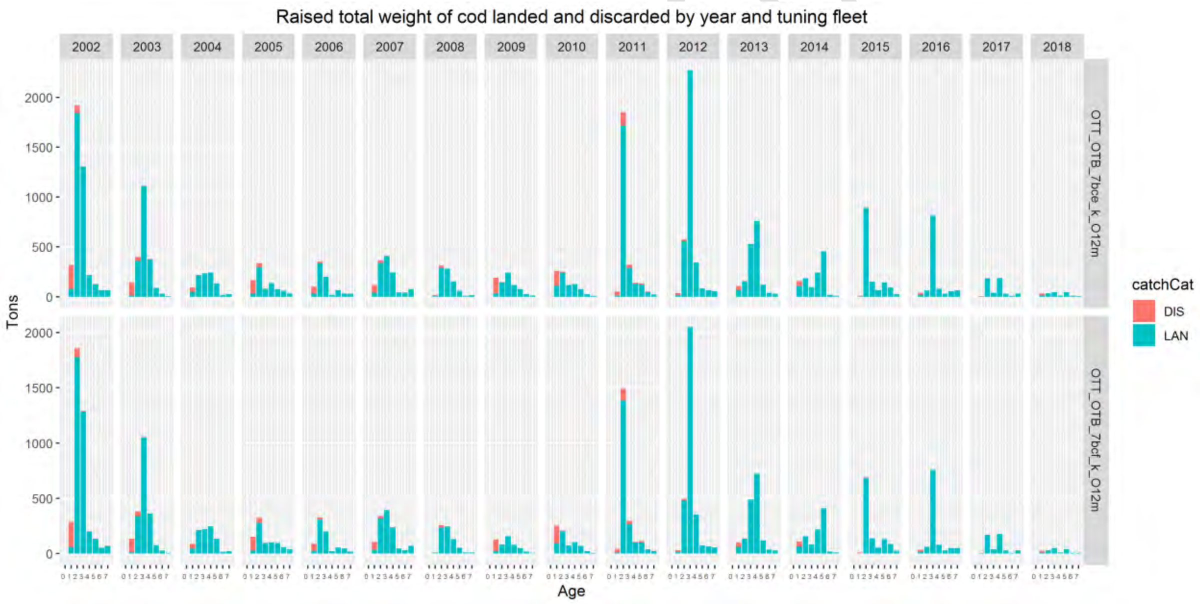
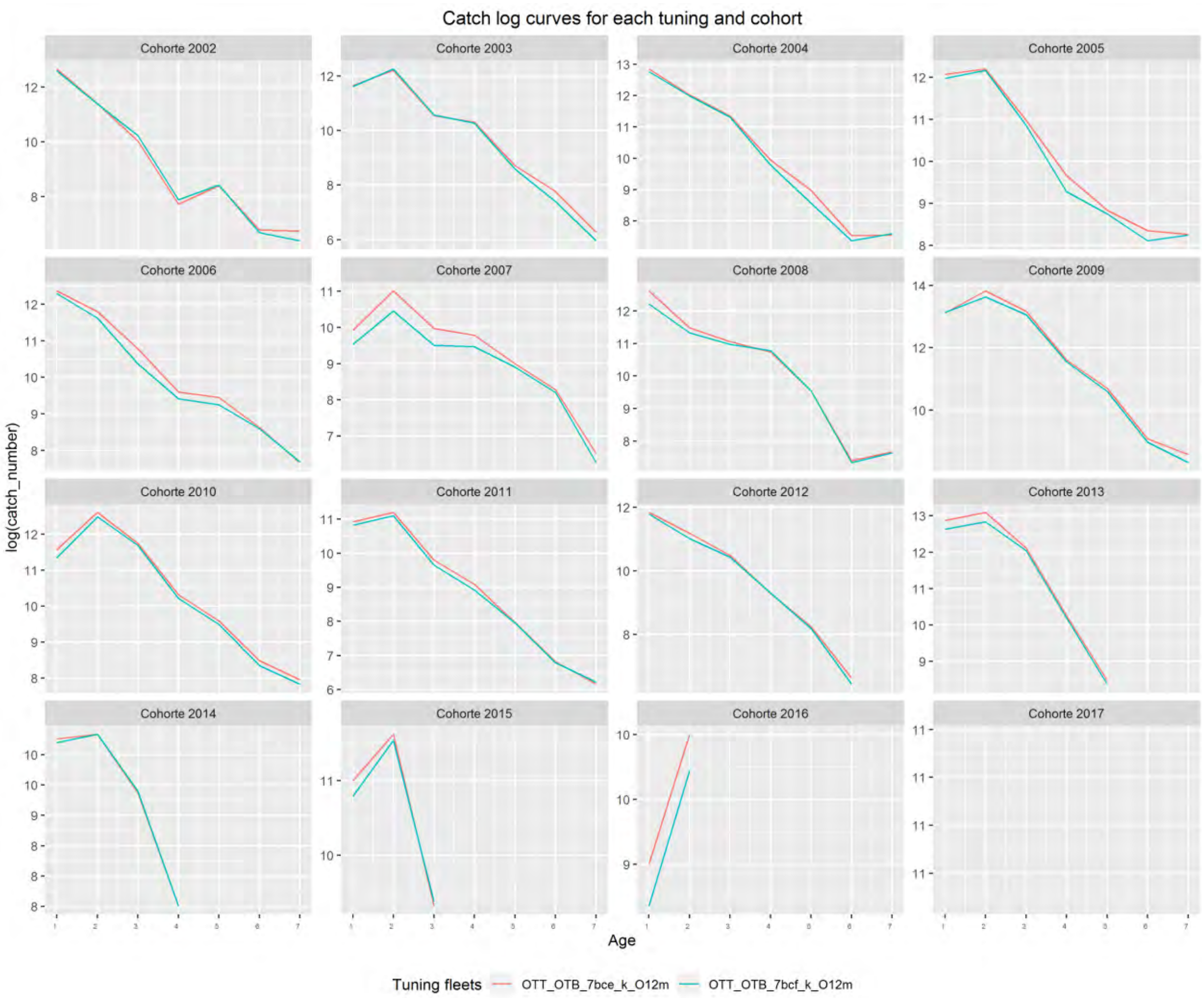


Figure 12. Raised landings and discards quantities by age, year and tuning fleet.

2.5. Cohort trackings



3. Whiting 7bce-k

The French fleet targeting whiting is essentially composed of OTB gears operating in the Western Channel and east Celtic sea with 80-99 mm and 100-119 mm mesh size in the codend. At the moment, there is no commercial tuning fleet for this stock (neither from France nor other countries). Nevertheless, the French otter trawler fleet represented 44% of the international landings in 2015 according to the 2017 ICES WGCSE report. In contrast to the Irish fleet, the French landings are mainly located in the western Channel (Fig. 13). The aim of this section was to explore a candidate French tuning fleet for whiting that can be tested during the benchmark.

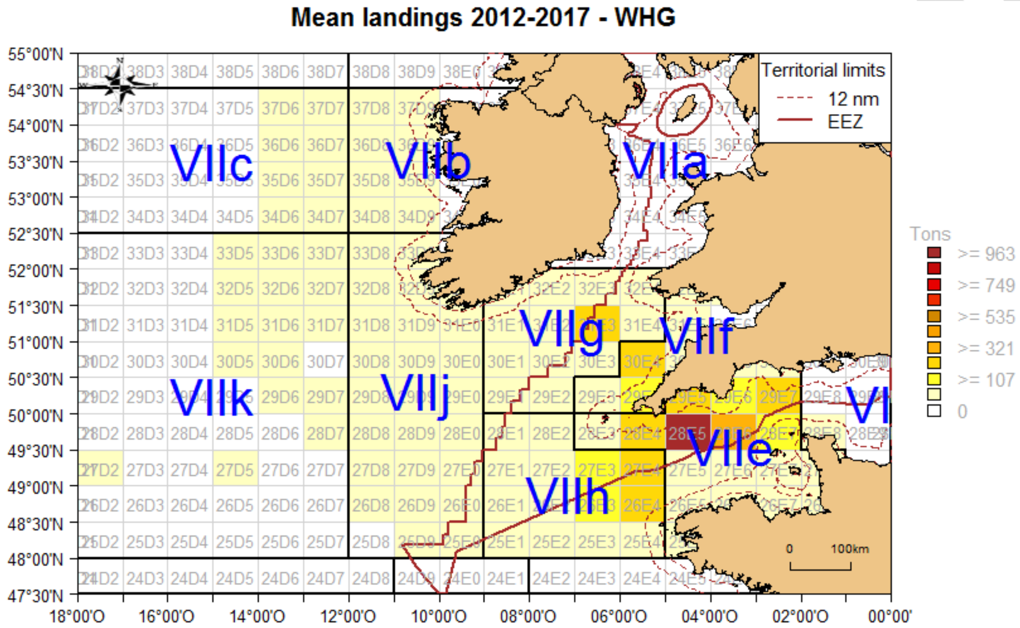


Fig. 13 : Mean French landings of whiting 7bce-k over the 2012-2017 time series.

3.1. Defining tuning fleet

Based on an exploratory analysis of commercial and sampling data and on some industry feedbacks, we considered the following information to build the segmentation process: i) The otter trawls (OTT/OTB) are the main contributors to the French whiting landings (and catches) in 7bce-k (94% on average over the 2012-2017 time series) ; ii) dominant mesh size are different between areas: 80-99 mm in western Channel and 100-119 mm in Celtic sea (Fig. 14) implying different selectivity pattern and length structure of the catches (REJEMCELEC, 2018 & Vogel et al, 2017[4]) and iii) The otter trawl fleet does not catch any whiting under 200 meters depth (Fig. 15).

[4] LAVIALLE Gaël, MORFIN Marie, SIMON Julien, MORANDEAU Fabien, VIMARD Mathieu, LARNAUD Pascal, 2018. Rapport d'étude final du projet REJEMCELEC. OP COBRENORD, Ifremer, Organisation des Pêcheurs Normands, 237p.

Vogel Camille, Kopp Dorothee, Morandeau Fabien, Morfin Marie, Mehault Sonia (2017). Improving gear selectivity of whiting (Merlangius merlangus) on board French demersal trawlers in the English Channel and North Sea. *Fisheries Research*, 193, 207-216

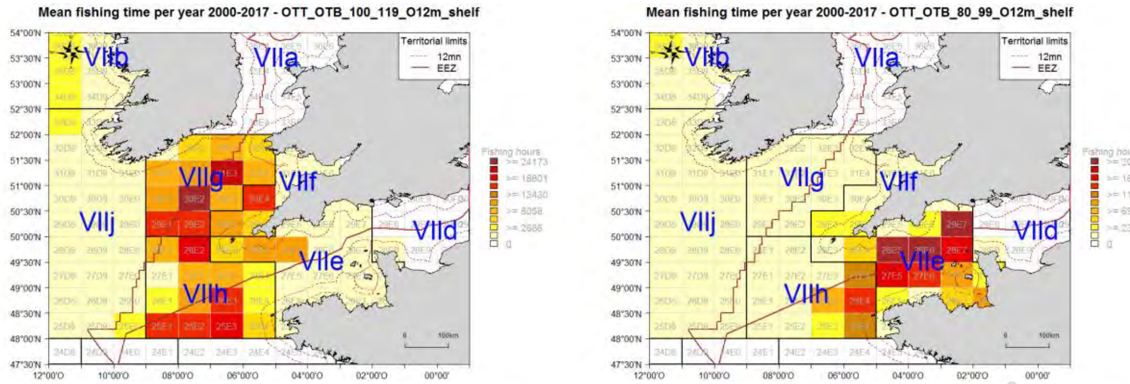


Fig. 14 : Left : annual mean fishing time of the French OTT_OTB with a 100-119 mm mesh size on the continental shelf over the 2012-2017 time series. Right: annual mean fishing time of the French OTT_OTB with an 80-99 mm mesh size on the continental shelf over the 2012-2017 time series.

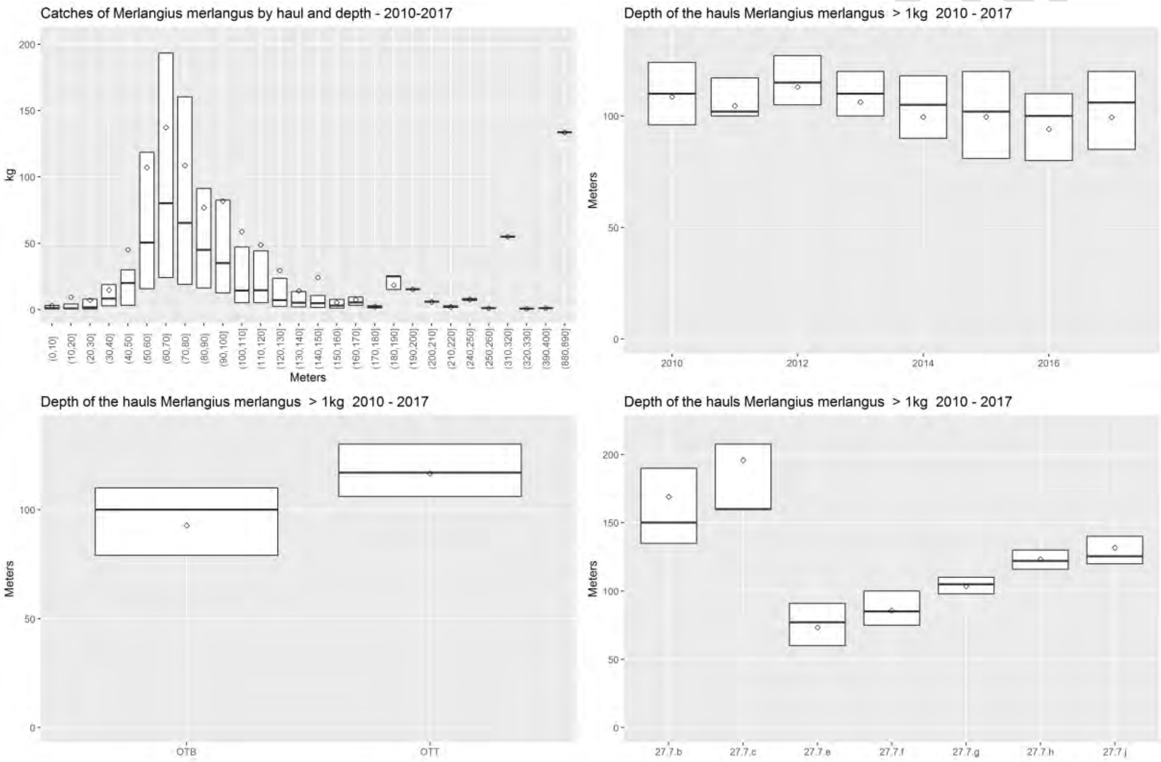


Fig. 15 : sampling data from the French sampling program for the OTB and OTT gears between 2010 and 2017. Distribution of the whiting catches by depth and distribution of the depth from the hauls with whiting by year, gear and area.

Based on this knowledge, two options were considered:

Option 1: produce the same overall fleet than the cod 7e-k (**OTT/OTB > 12 meters in 7bce-k**) but on the continental shelf (meaning a selection of each statistical rectangle with maximal depth less than 200m). It represents 94% of the French landings of whiting on average between 2012 and 2017.

Option 2: produce two tuning fleets, one **OTT/OTB > 12 meters with a 80-99 mm cod end** and a second one **OTT/OTB > 12 meters with a 100-119 mm cod end**, both operating on the continental shelf. They

represent respectively 36% and 59% of the French landings of whiting on average between 2012 and 2017 (But recently we observe an overthrow of this hierarchy).

3.2. Species clusters and threshold analysis

3.2.1. Selected species by fleet

Species	OTT_OTB_7bce_k_O12m_shelf		OTT_OTB_100_119_O12m_shelf		OTT_OTB_80_99_O12m_shelf	
	Correlation	Target ?	Correlation	Target ?	Correlation	Target ?
BIB	0.32	x	0.31		0.46	x
COD	0.43	x	0.48	x	0.39	
CTC	0.09	x	0.09	x	0.13	x
GUR	0.23	x	0.19		0.38	x
HAD	0.45	x	0.52	x	0.43	x
HKE	0.14	x	0.14	x	0.15	
JOD	0.2		0.15	x	0.27	
LIN	0.24		0.24		0.26	
MEG	0.02	x	-0.03	x	0.1	x
MNZ	0.11	x	0	x	0.27	x
POK	0.2		0.24		0.14	
POL	0.33		0.35		0.32	
SKA	0.19	x	0.16	x	0.24	x
SQZ	0.16		0.14		0.22	x

Table 5 : Correlation coefficient (Spearman) with whiting by species based on the overall days of fishing of each fleet over 2000-2017. The cross flags the species which belong to the 10 first species landed by the fleet on average over 2012-2017. In orange the species selected for each fleet.

Table 5 shows the correlation coefficient for each species either correlated with whiting or targeted by the tuning fleets. The selected species for the threshold analysis are listed below:

Option 1: OTT_OTB_7bce_k_O12m_shelf: WHG, HAD, COD

Option 2: OTT_OTB_100_119_O12m_shelf: WHG, HAD, COD **and OTT_OTB_80_99_O12m_shelf**: WHG, BIB, HAD, COD (we keep cod in order to be consistent with the other fleet and because it remains well correlated with whiting for this fleet).

3.2.2. Option 1 - one offshore otter trawl fleet on the continental shelf

The figure below presents the contribution to the whiting landings and to the fishing effort of the OTT_OTB_7bce_k_O12m_shelf fleet for each combination threshold/species cluster we tested.

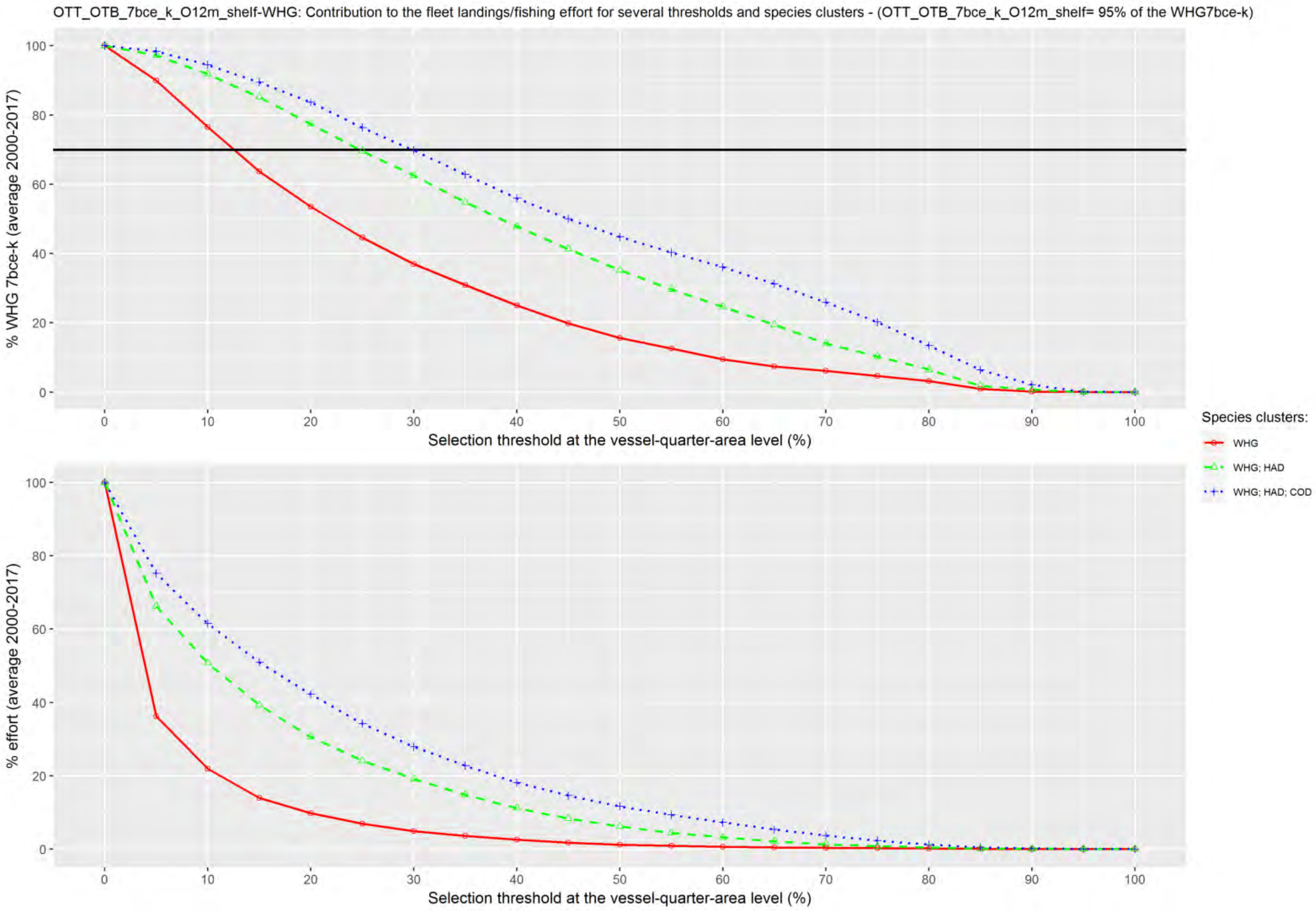


Fig. 16 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to whiting the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 30% of WHG/HAD/COD landed represent 70% of the whiting landed by the OTT_OTB_7bce_k_O12m_shelf fleet and 28% of its fishing effort – Average over 2000-2017.

In the same way than for cod 7e-k, an arbitrary threshold of 70% of contribution to the landed amount of whiting by the fleet was set (black line on Fig. 16). Since the three gadoids are well correlated and fished by the same vessels **the tuning fleet threshold can be defined by cod, haddock and whiting. A 30% threshold will allow achieving the 70% contribution set above**.

3.2.3. Option 2 - Segmentation between 80-99mm mesh size and 100-119mm mesh size.

3.2.3.1. OTT_OTB_100_119_O12m_shelf

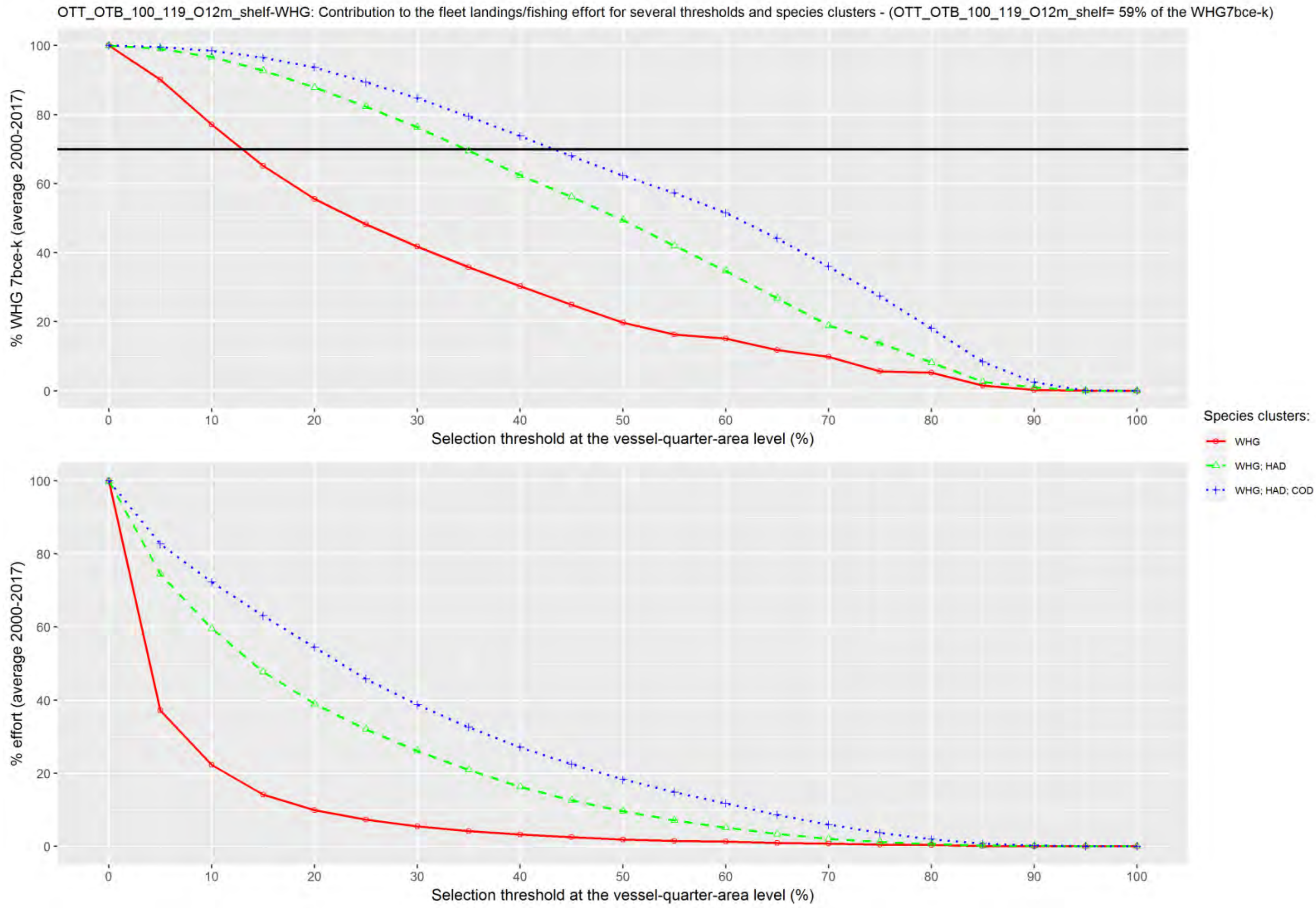


Fig. 17 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to whiting the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 45% of WHG/HAD/COD landed represent 68% of the whiting landed by the OTT_OTB_100_119_O12m_shelf fleet and 22% of its fishing effort – Average over 2000-2017.

The otter trawls operating with a 100-119 mm mesh have heterogeneous strategies regarding whiting. Indeed, the smooth decrease of the red curve on the first graphic indicates that there are some vessels specialized in whiting suggesting a high threshold has to be set to exclude the vessels which contribute the most to the landings of whiting into the fleet. **We propose to set the threshold at 45% with the three gadoids species which allow achieving about 70% of the whiting landed by this fleet.**

3.2.3.2. OTT_OTB_80_99_O12m_shelf

Based on the shape of the curves, **all the tested species (WHG/BIB/HAD/COD) are selected. We propose to set the threshold at 25% which allow achieving 75% of the whiting landed by this fleet.** The lower threshold might confirm that this fleet heavily targets whiting and pouting.

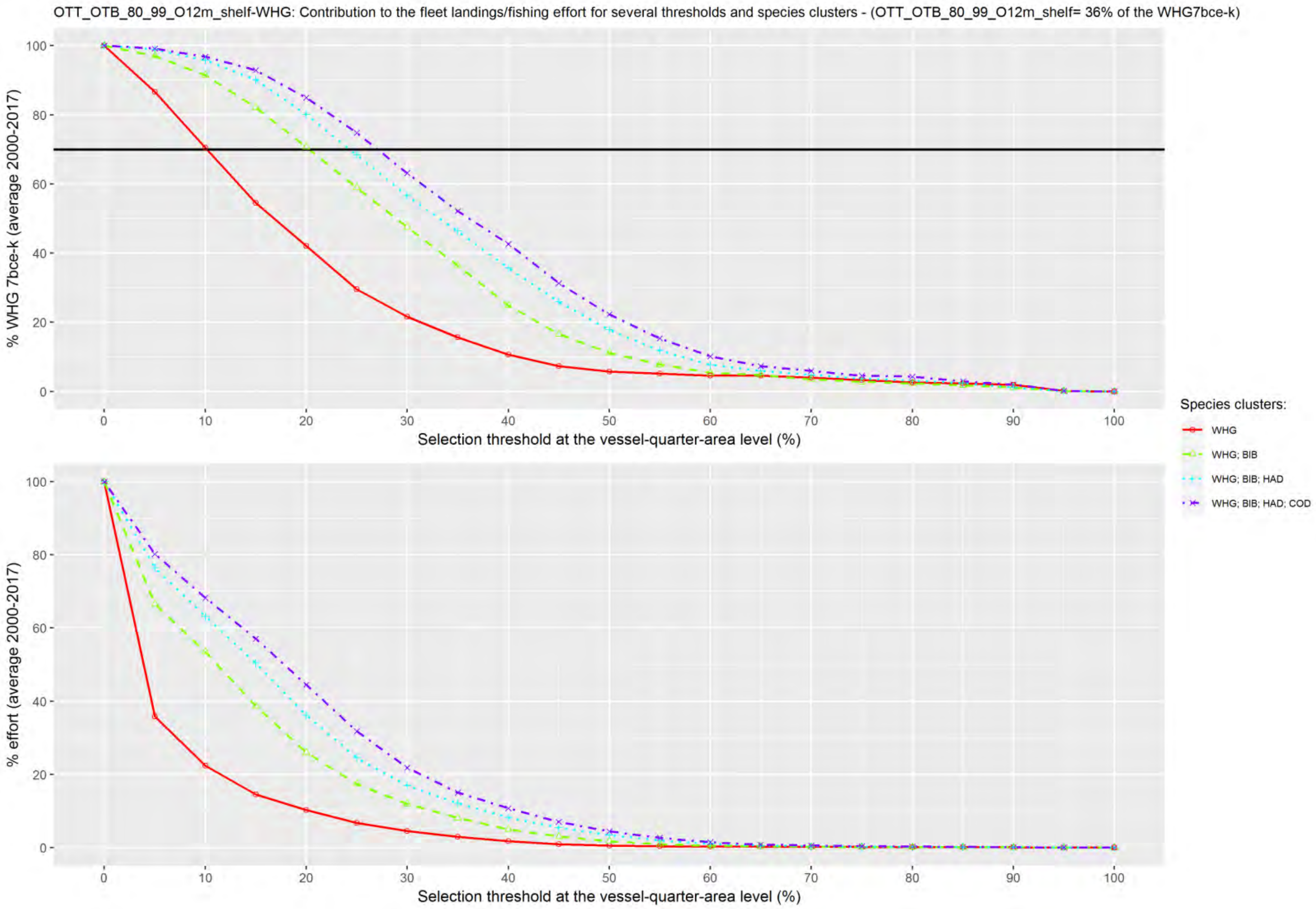


Fig. 18 : Contribution to the fleet landings/fishing effort for several thresholds and species clusters calculated as it is described in the 2.1. Each cluster has been made by adding sequentially to whiting the most correlated species - Example of reading: all the crosses vessel-quarter-area with more than 25% of WHG/BIB/HAD/COD landed represent 75% of the whiting landed by the OTT_OTB_80_99_O12m_shelf fleet and 32% of its fishing effort – Average over 2000-2017.

3.2.4. Summary

Flottille	Option	Groupe d'espèces	Threshold	% French WHG 7bce-k	% WHG fleet (A)	% fishing effort fleet (B)	A / B
OTB/OTT 7bce-k > 12m shelf	1	WHG/HAD/COD	30%	67%	70%	28%	2,5
OTT OTB 80-99 mm O12m shelf	2	WHG/BIB/HAD/ COD	25%	27%	75%	32%	2,3
OTT OTB 100-119 mm O12m shelf		WHG/HAD/COD	45%	40%	68%	22%	3,1

Table 6 : resume of the selected definition parameters of the French tuning fleets' options for the whiting 7bce-k.

With the two options, the contribution of the selected fleet to the French whiting landings is 67%. The ratio between landings and effort contribution is higher than for the cod tuning fleet because the whiting is more targeted by the fleets (i.e. vessels are more specialized).

3.3. LPUE of the Candidate tuning fleet

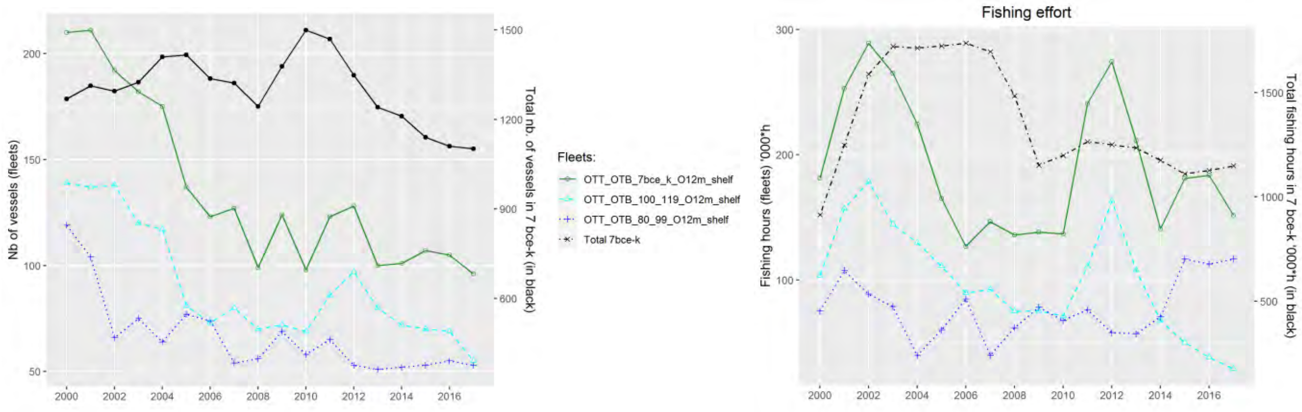


Fig. 19 : number of vessels (left) and fishing effort (right) for each tuning fleet built over the 2000-2017 period. The total number of vessels in the area is described by the black curve and the right axis.

The evolution of the number of vessels is quite similar to the case of the cod. The overall OTB/OTT fleet (green) shows a strong decreasing trend in the beginning of the time series and stabilized around 100 vessels in recent years. The 100 mm fleet (cyan) shows several strong variations between 2004-2005 (Trevose box ?) and 2010-2012 which seems to be linked with the cod stock dynamic more than the one related to whiting (Fig 20). Indeed, the proportion of cod in the 100 mm fleet landings increased by 9 points of percentage between 2010 and 2012. As a consequence, the number of vessels and the fishing effort (Fig. 19) of the fleet increased respectively by 27% and 130% on the same period due to the threshold selection procedure. Based on this knowledge, the 100mm fleet is not relevant to track whiting abundance.

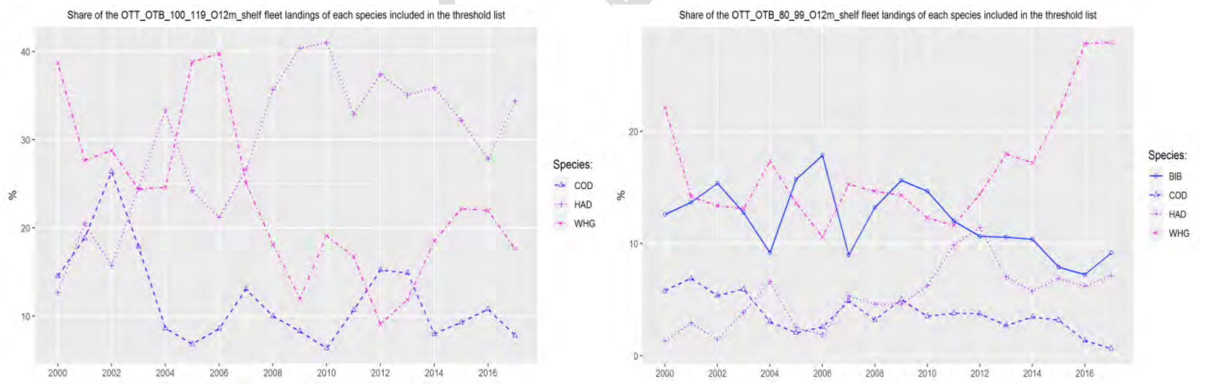


Fig 20 : proportion of each of the three gadoids used for the threshold calculation for the OTT OTB 100-119 mm > 12m fleet (left) and the OTT OTB 80-99 mm > 12m. Proportion of the total landings of the fleet over the 2000-2017 time series.

It seems pretty clear that the peaks of LPUE of the overall OTB/OTT fleet (green) and the 100 mm fleet (cyan) are linked with the variations of the number of vessels/fishing effort rather than with whiting abundance. It is difficult to identify if the constant progression of the LPUE of the 80 mm tuning fleet (dark blue) between 2011 and 2016 is related to an increase in abundance during this period or/and to a shift in fisherman strategies (proportion of whiting in landing strongly increased (Fig 20)).

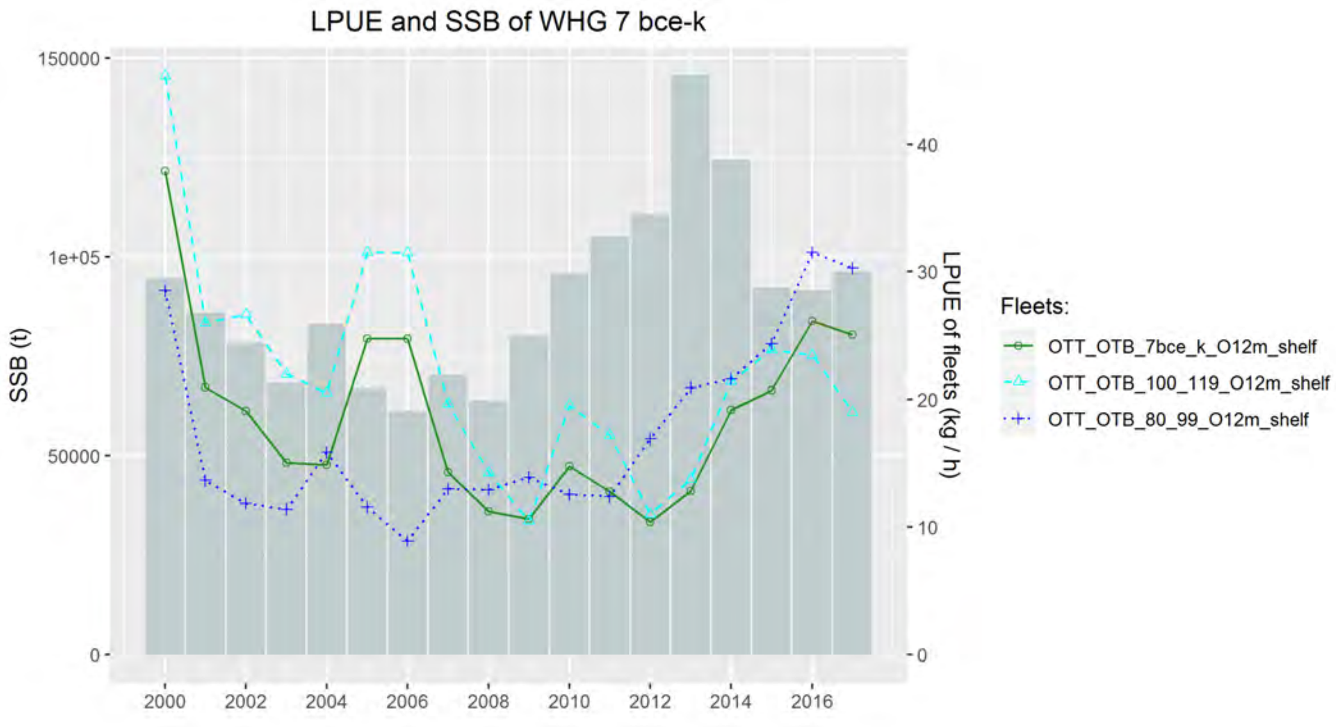


Fig. 21: LPUE of whiting for the selected tuning fleets and SSB from the XSA assessment (ICES) over the 2000-2017 periods.

3.4. Raising length and age structure of candidate fleets

The final aim of this process is to produce landings and discards at age for 80-99 mm fleet based on the sampling data available. Table 7 presents the summary of the French at-sea sampling data for each tuning fleet and year. Similarly to the cod 7e-k, the western Channel fleet (the 80 mm fleet operates mainly in 7e/7h) is poorly sampled over the whole time series. Based on the work presented in this document, the 80-99 mm fleet seems to be relevant but catch at age matrix cannot be provided due to lack of data.

Année	OTT_OTB_7bce_k_O12m_shelf	OTT_OTB_100_119_O12m_shelf	OTT_OTB_80_99_O12m_shelf
2004	4/28/504	2/7/101	1/1/3
2005	11/231/4478	6/132/1963	2/29/1281
2006	7/112/1135	5/93/1042	1/8/47
2007	1/19/568		
2008	10/204/2064	4/131/1182	
2009	24/214/3002	14/130/2144	4/24/377
2010	29/233/4624	16/124/2808	4/30/652
2011	18/116/3640	9/66/2996	4/9/76
2012	27/162/2724	14/105/2059	10/37/215
2013	19/163/2958	15/155/2932	2/2/6
2014	29/232/6022	20/161/4215	5/17/799
2015	42/356/8774	28/276/6209	11/68/2352
2016	42/358/8736	33/283/6731	9/59/1868
2017	31/329/7945	25/262/5663	6/54/2232

Table 7 : summary of the French at-sea program (OBSMER) for each tuning fleet proposed for the whiting 7b-k assessment. Reading: number of trip sampled/number of hauls sampled/number of fishes measured.

4. Haddock 7b-k

Ireland currently provides a tuning fleet for this stock which is based on the otter trawls LPUE from south Ireland. Several arguments push in favor of proposing a candidate French tuning fleet for haddock. The French otter trawler fleet (OTT/OTB) represented 58% of the international landings in 2016 according to the 2017 ICES WGCSE report and 96% of the French landings (SACROIS-logbooks/sales). During 2000-2018, a large part of the French fleet's strategies have changed in the Celtic sea, switching from a main OTB fishery targeting Nephrops and/or different white fish (especially cod) to an OTT fishery targeting monkfish, megrim, rays, and white fish as well. Over the last decade, haddock has replaced cod as the first white fish caught by these French vessels in weight and value.

As it is shown on the Fig. 22, the main vessels operated in all the east of the Celtic sea. Due to quota restriction, area closure and gear restriction (100/120 mm SMP), the fishery tended to go further south and east, to the 7e for OTB (less restrictions, whiting targeting instead of cod/haddock, etc.) and to the 7h for OTT (fishing ground for monkfish). Industry (Les Pêcheurs de Bretagne PO, 2018) suggests a spatial shift of the abundance with an increase of LPUE in the south of the 7h ICES division, notwithstanding the quota limitations. This pattern is supported by the survey data and increasing catches in the north of the Bay of Biscay in recent years.

Since 2012-2013 choke situations have led to increase discard practices and high grading. As a consequence, the small grade of haddock (~ < 40 cm) is not observed in the market data in recent year. In addition, according to the French industry, the vessels are avoiding fishing areas with small sized haddocks. Both statements impair the use of landings data for calculation of LPUE as proposed above for cod and whiting. We therefore proposed to use at-sea sampling data to derive standardized CPUE.

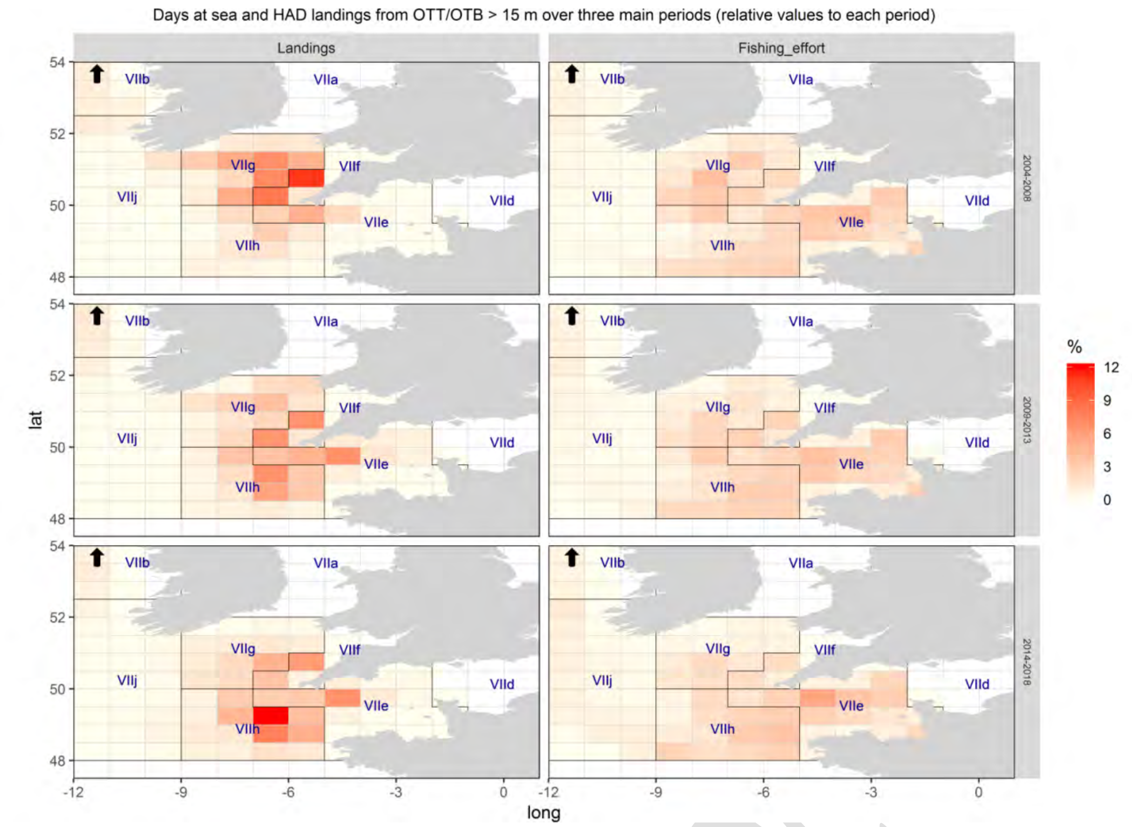


Fig. 22 : Days at sea and haddock landings from French OTT/OTB > 15 m vessels over three main periods: before quota restrictions and high recruit (2004-2009), during SSB transition due to high 2009 recruit (2009-2013), during quota restrictions (2014-2018).

4.1. Material and methods

The methodology proposed to build the tuning fleet follows four steps: i) Calculate CPUEs at the haul level from at sea sampling data (OBSMER); ii) Build a statistical model to extract the year effect from the variation of these CPUEs; iii) Calculate a standardised fishing effort based on the year effect; and iv) Standardised the tuning catch-at-age matrix by the standardised fishing effort.

4.1.1. Data subset

The at sea sampling data were subset to exclude the vessels and trips with no chance to catch haddock. The following criterions were used:

- Gears = OTT and OTB are the main gear used
- Areas = 27.7.bce-k, 7d excluded
- Vessel length >=15 meters. This excludes the coastal French fishery that does not catch haddock
- Quarter = 2,3,4.The first quarter was excluded as it was done for cod because of the Trevose box closure
- Trips with at least one catch of haddock sampled

4.1.2. Modeling

4.1.2.1. *Selection process of model*

A GLMM with a Gaussian link function was used. The selection process follows the Zuur & al, 2009 procedure which in a nutshell consist in:

1) Build a first model with all the plausible fixed effects (the "full model");
2) For each random effect, compare the AIC between the full model against the full model plus the random effect. Fit the model with REML method;
3) If the random effect improve the full model, keep it, otherwise use a GLM;
4) Study the residuals and check the normality hypothesis is not violated, if so change the link function (for instance) and redo the first steps;
5) Select the best fixed structure by removing one fixe variable at a time and look at the AIC delta (perform F test to compare). Use the classic Maximum Likelihood method (ML) to fit the models and keep only the variables with a significant difference of AIC.
6) Check the residuals;
7) Fit the final model with the REML method.

The lme4 R package was used to perform the GLMM fit (lmer function) and the nlme package to fit GLM with REML method (gls function).

4.1.3. Dataset summary

9 746 hauls belonging to 362 trips were selected over the 2004-2018 time series (no data available before).

Table 8 : at sea sampling dataset (OBSMER) summary after subset over the 2004-2018 time series.

Zero	Year	Nb. of trips sampled			Total	Nb. of hauls sampled			Total
		Quarter 2	Quarter 3	Quarter 4		Quarter 2	Quarter 3	Quarter 4	
CPUE>0	2004	-	2	3	5	-	35	29	64
	2005	1	5	7	13	9	152	135	296
	2006	1	5	4	10	44	128	68	240
	2007	-	4	4	8	-	44	44	88
	2008	2	3	10	15	86	82	208	376
	2009	12	12	7	31	288	420	194	902
	2010	12	21	13	46	365	682	414	1461
	2011	6	7	12	25	223	210	300	733
	2012	10	8	9	27	228	298	221	747
	2013	5	9	5	19	169	239	135	543
	2014	9	18	8	35	255	413	274	942
	2015	12	16	12	40	327	348	289	964
	2016	11	15	11	37	279	403	261	943
	2017	10	8	5	23	376	253	151	780
	2018	8	9	11	28	203	244	220	667
Total CPUE>0		99	142	121	362	2852	3951	2943	9746

4.2. Results

4.2.1. Selection of model

4.2.1.1. Random effects

Three random effects were tested:

1) The vessel effect to take into account the CPUE part of variance coming from the vessel (quota limitation, efficiency, etc.).
2) The year-area interaction to include the spatial changes of abundance and fishing effort allocation (Fig. 23). It was tested as a random effect in order to reduce the number of estimated parameters (Gruss & *al*, 2019). Some areas were grouped when there was a lack of data (27.7.bcjk and 27.7.f).
3) The year-quarter interaction for the same reasons as above (Fig. 24).

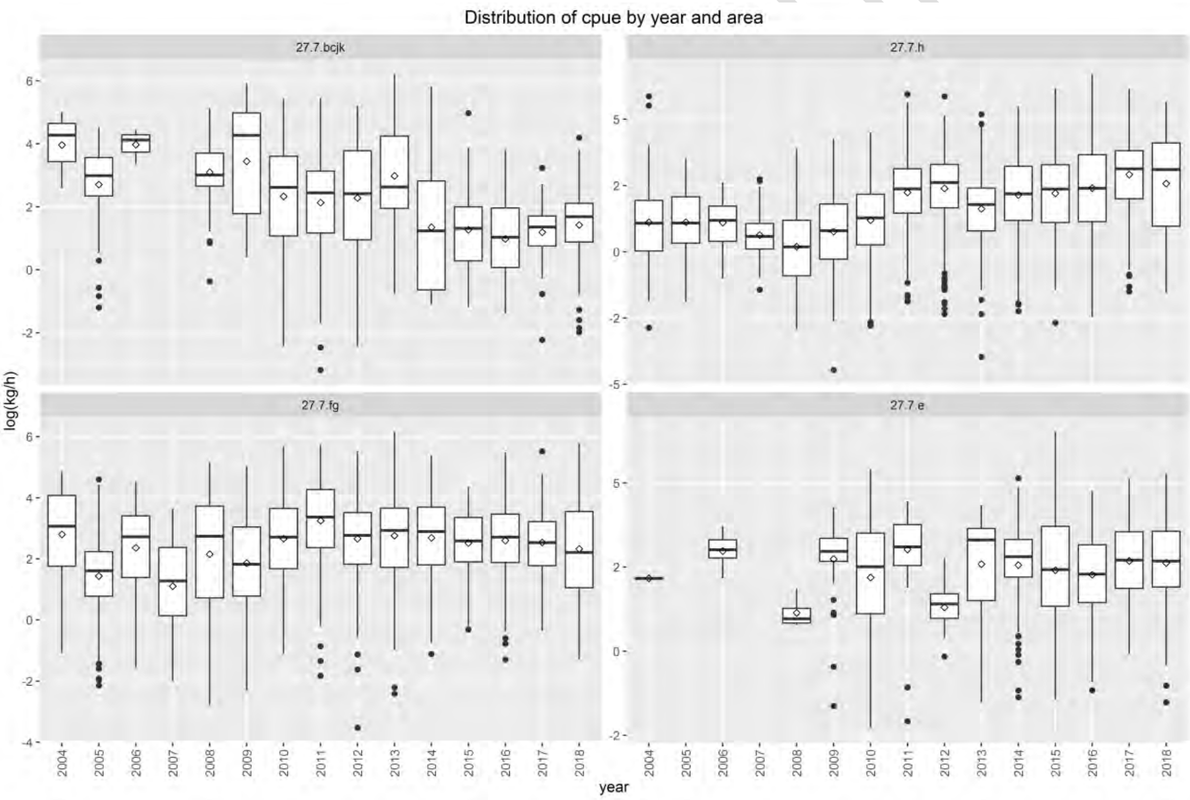


Fig. 23: distribution of log(CPUE) across year and areas.

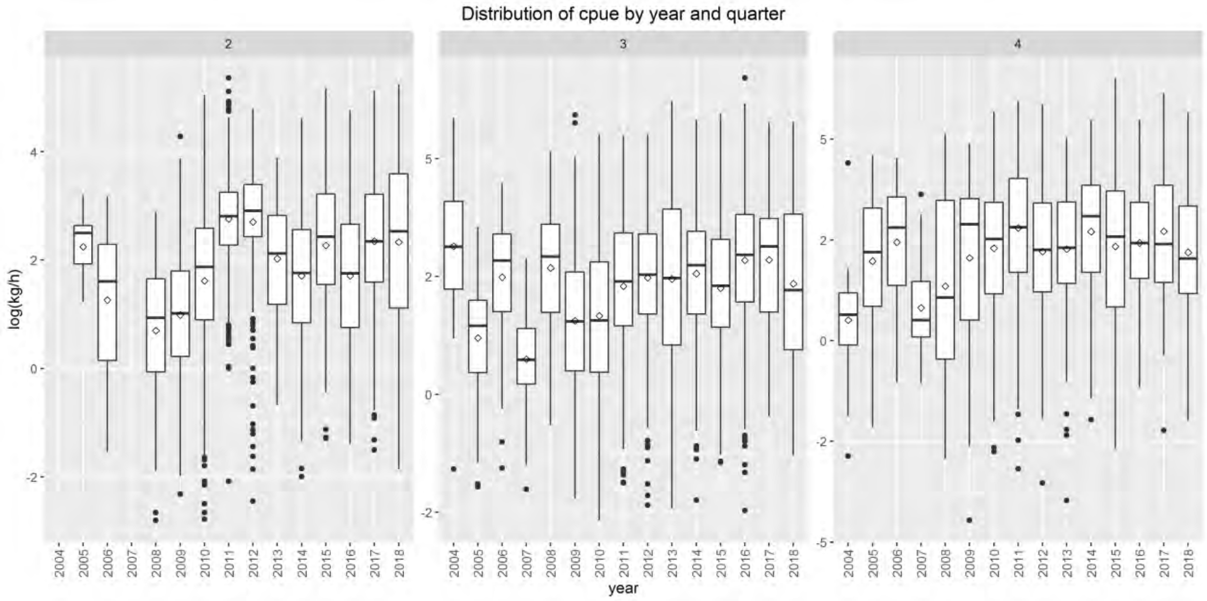


Fig. 24: Distribution of log(CPUE) across year and quarters.

Following the Zuur & al, 2009 procedure, the full model (eq. 1) was tested with each of the three random effects against its version without random effect.

$$\begin{aligned}\log(CPUE_i) = \; & \alpha_i + \beta1_j * Year_{ij} + \beta2_q Quarter_{iq} + \beta3_a Area_{ia} \\ & + \beta4 VslPwr_i + \beta5_g Gear_{ig} + \beta6_{jq} Year_{ij} * Quarter_{iq} \\ & + \beta7_{ja} Year_{ij} * Area_{ia} + \beta8_{aq} Area_{ia} * Quarter_{iq} \\ & + Random\_effect_{ri} + \varepsilon_i\end{aligned} \qquad \text{(eq. 1)}$$

It is worth noting that if an interaction was tested as random effect it was removed of the full model.

Table 9: AIC from the full models with and without random effect

Random_variable	full_model_AIC	with_random_AIC	%
vslId	34125.21	32328.72	-5.26%
year:area	34677.99	34167.06	-1.47%
year:quarter	34328.01	34118.24	-0.61%

As shown by the Table 9 the vessel effect (vslId variable) as random effect provides the lowest AIC compared to the full model without it. The year:area interaction improves also the full model when it is included as random effect but it provides a higher AIC than the one with the vessel effect. Therefore, the vessel ID is kept as a random effect in the model.

$$\begin{aligned}\log(CPUE_i) = \; & \alpha_i + \beta1_j * Year_{ij} + \beta2_q Quarter_{iq} + \beta3_a Area_{ia} \\ & + \beta4 VslPwr_i + \beta5_g Gear_{ig} + \beta6_{jq} Year_{ij} * Quarter_{iq} \\ & + \beta7_{ja} Year_{ij} * Area_{ia} + \beta8_{aq} Area_{ia} * Quarter_{iq} + 1|vslId_{ri} + \varepsilon_i\end{aligned} \qquad \text{(eq. 2)}$$

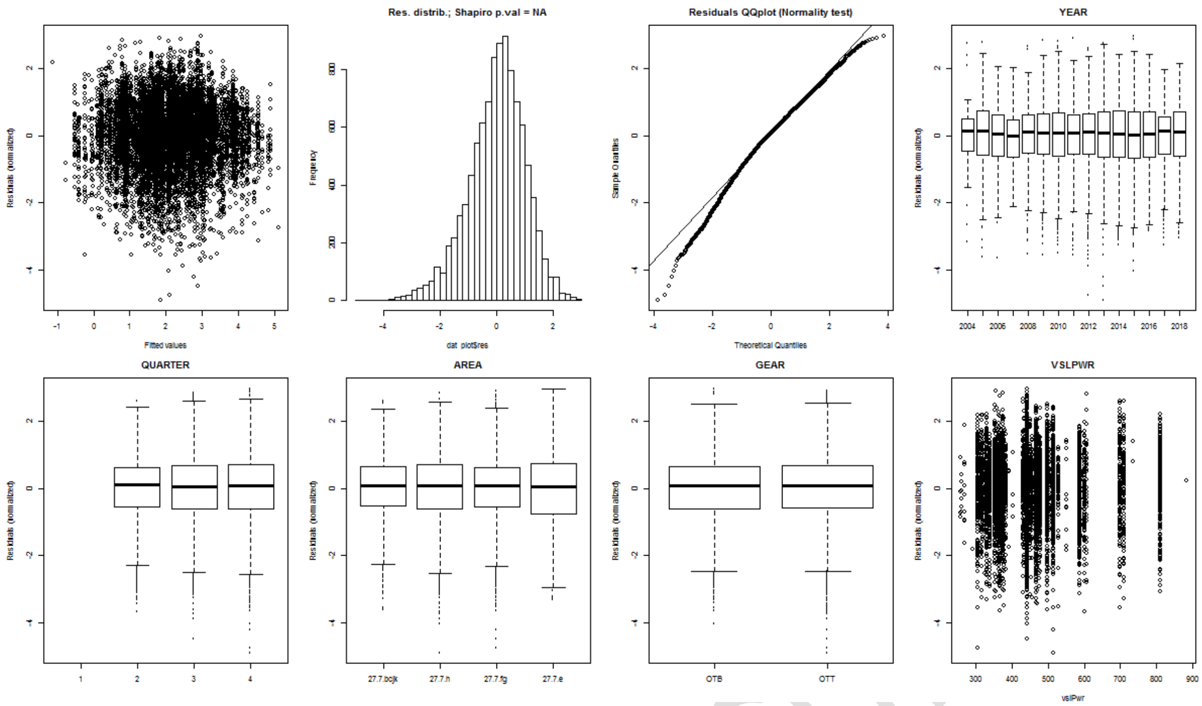


Fig. 25 : diagnostic of the residuals of the full model with a vessel random effect

Looking at the qqplot on the Fig. 25, the hypothesis of normality seems to be violated because of more residuals with negative values, result of a slight overestimation of the fitted data. However, considering the available time to this study and the small magnitude in qqplot deviation, the Gaussian hypothesis on the residuals function was kept and no link function was added.

4.2.1.2. *Fixed structure*

Each fixed variable of the full model (eq. 2) were successively removed in order to compare the AIC. The classic ML method was used to fit the models and the Chi-square test was performed to compare each model with the full one.

Table 10 : Chi-square test between each the full model and the full model with one variable removed.

Removed_variable	AIC	AIC_full_model	Chisq	Chi_Df	P_value
vslPwr	32144	32136	10	1	0.002
gear	32134	32136	0	1	0.990
area (and interactions with 'area')	32668	32136	628	48	0.000
quarter (and interactions with 'quarter')	32514	32136	446	34	0.000
area:quarter	32190	32136	66	6	0.000
year:quarter	32378	32136	294	26	0.000

year:area	32563	32136	505	39	0.000

As it shown by the Table 10 the gear variable does not improve the model fit and it has been removed. The final model selected is the following:

$$\log(CPUE_i) = \alpha_i + \beta1_j * Year_{ij} + \beta2_q Quarter_{iq} + \beta3_a Area_{ia} + \beta4 VslPwr_i + \beta6_{jq} Year_{ij} * Quarter_{iq} + \beta7_{ja} Year_{ij} * Area_{ia} + \beta8_{aq} Area_{ia} * Quarter_{iq} + 1|vslId_{ri} + \varepsilon_i \qquad \text{(eq. 3)}$$

4.2.1.3. Calculate the year effect

The year effect was extracted from the model with the R "margins" package. The 'margins' and 'dydx' functions were used to calculate a marginal effect in presence of interactions terms by estimating the derivate of the model of the variable of interest (here to derivate the log cpue from the year variable)[5].

The mean marginal effect of the year across areas and quarters shows a continuous strong increase from 2008 to 2012, matching with the high 2009 recruitment (Fig. 26). It follows with a decreasing trend except for the 2014 and 2017 years.

[5] https://cran.r-project.org/web/packages/margins/vignettes/TechnicalDetails.pdf

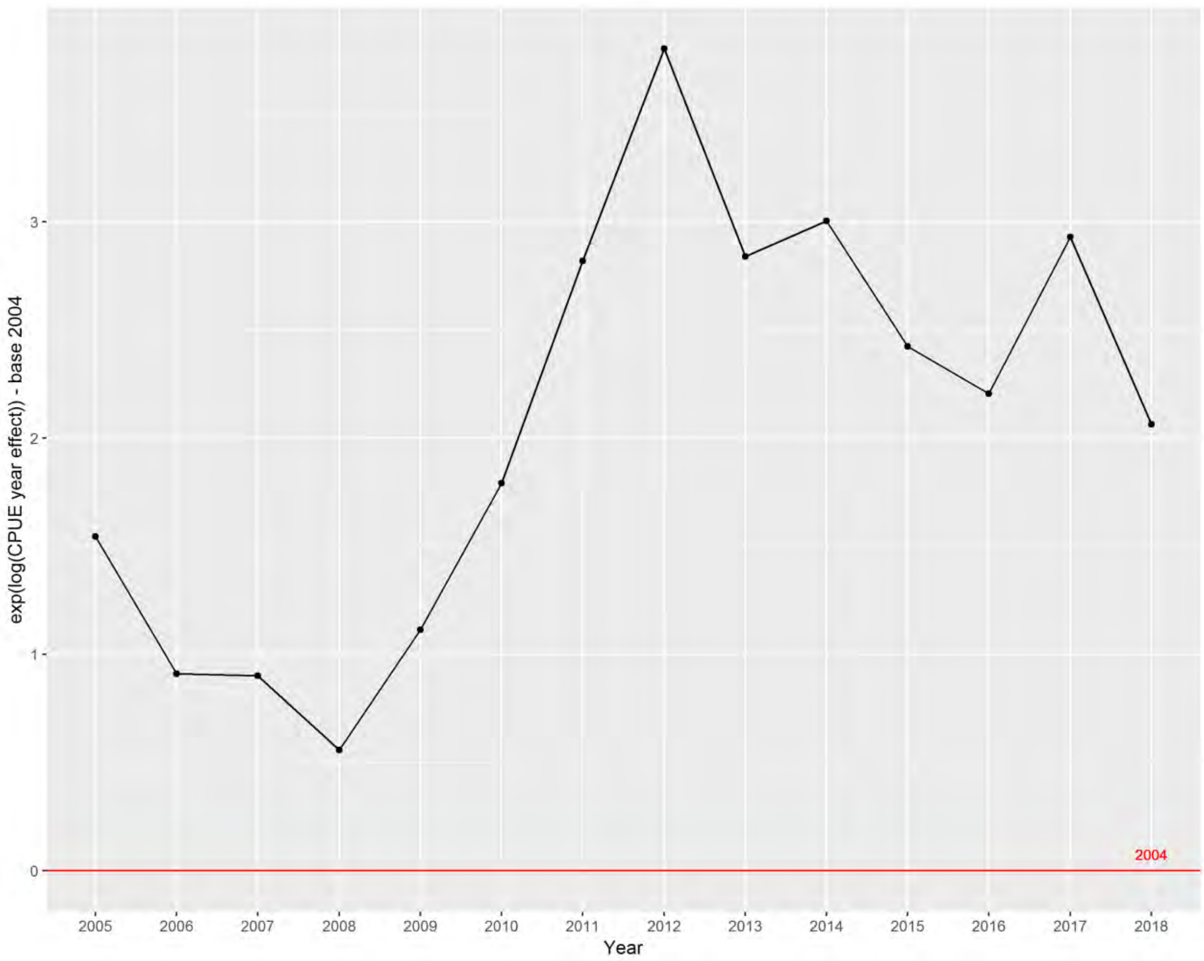


Fig. 26 : exponential of the mean marginal year effect on the log(CPUE) from the selected model relative to the 2004 year (kg/h).

The year effect is not the same across the areas. The 2008-2009 increasing trend seems to be highly influenced by the 27.7.e and 27.7h areas (except for 2012 in the 27.7.e) (Fig. 27). Due to the little amount of data in the 27.7.e, its trend have to be taken with precaution. In the same time, the CPUE index shows a decreasing trend in the 27.7.fg between 2014 and 2018 (mostly due to the 2014-2015 drop).

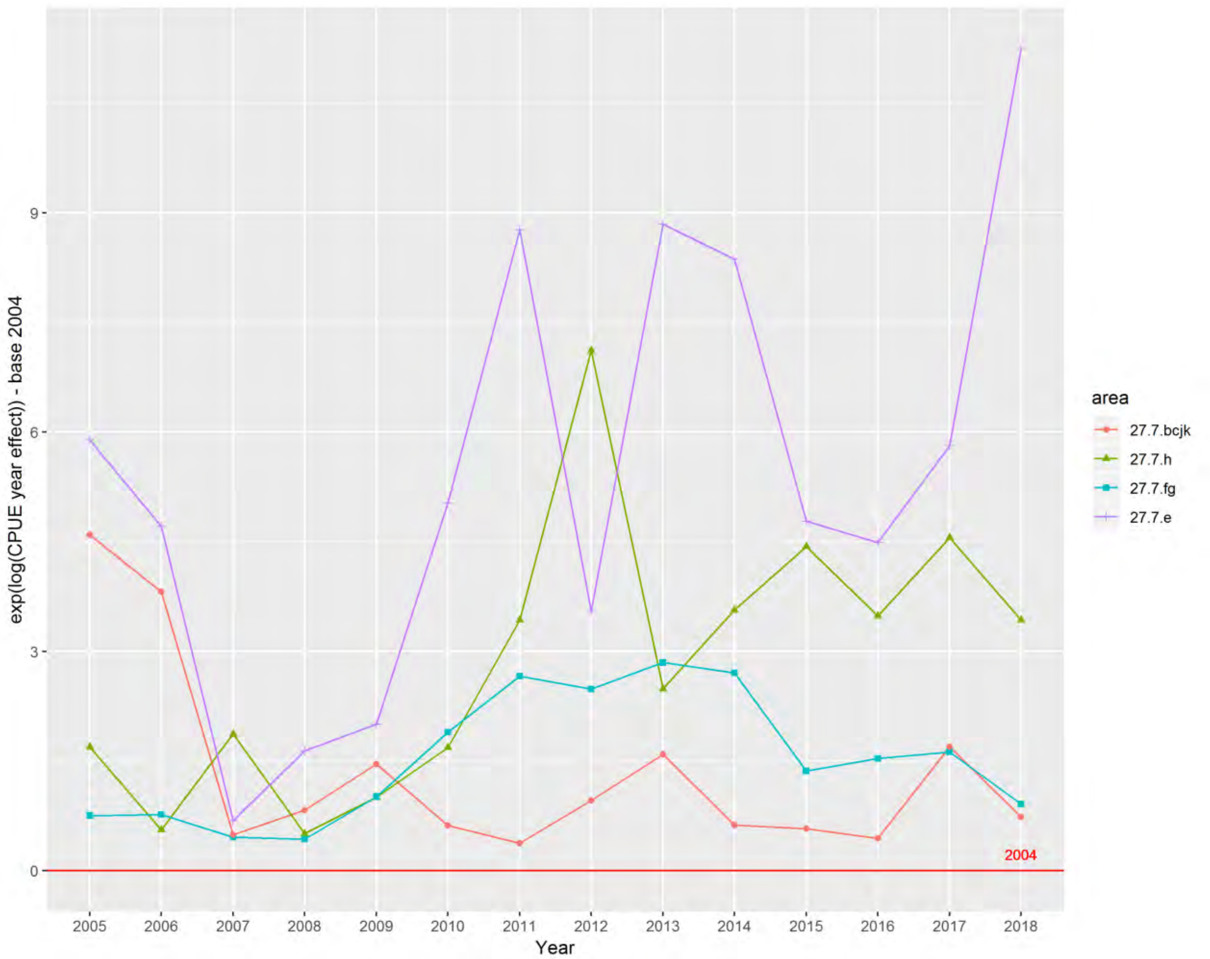


Fig. 27 : exponential of the mean marginal year-area effect on the log(CPUE) from the selected model relative to the 2004 year (kg/h).

4.2.2. Revision of the catch at age matrix

The method to calculate the catch-at-age matrix of the French haddock tuning fleet is based on Nimmegeers & al, 2019 (ICES Working Document for Sole 7fg assessment).

1) Select the OTT/OTB stratum from the raised catch number at age matrix data provided for the ICES datacall
2) Sum the catches over the quarters and Ices divisions to get a yearly catch number at age. If there is some missing quarter-Ices division level, raise at year level using by the landings in tons.
3) Calculate a standardized amount of fishing effort by dividing the catch in weight of the tuning fleet by the CPUE index.
4) Divide the numbers at age by the standardized amount of fishing effort to get a CPUE in numbers for each age and each year.

4.2.2.1. *Formulas*

Standardized effort

$$Std\_eff_y = \frac{\sum_{q=1}^{Q\_tot} \sum_{d=1}^{D\_tot} C\_tun_{yqd}}{CPUE\_index_y} \qquad \text{(eq. 5)}$$

With: CPUE_index the year effect index built in the previous part of this document

Final catch at age matrix for the French haddock tuning fleet

$$C\_nb\_tun\_std_{ya} = \frac{C\_nb\_tun_{ya}}{Std\_eff_y} \qquad \text{(eq. 6)}$$

With : C_nb_tun the catches of the OTT/OTB gears) submitted into InterCatch

4.2.2.2. *Standardised catch-at-age index*

Landings

Tableau 11. Standardised landings catch at age index

LAN	0	1	2	3	4	5	6	7	8
2004	0,0010	0,2257	0,2842	0,0811	0,0137	0,0490	0,0123	0,0006	
2005	0,0026	0,0879	0,1799	0,2675	0,0600	0,0636	0,0118	0,0198	0,0132
2006	0,0304	0,1857	0,2483	0,1217	0,0552	0,0151	0,0121	0,0037	0,0050
2007	0,0086	0,0075	0,2309	0,1329	0,0277	0,0226	0,0033	0,0062	0,0016
2008	0,0000	0,0956	0,0911	0,0975	0,0525	0,0117	0,0090	0,0059	0,0076
2009	0,0025	0,0797	0,2090	0,1435	0,0638	0,0125	0,0098	0,0043	0,0065
2010	0,0226	0,2657	0,4645	0,2656	0,0491	0,0258	0,0119	0,0106	0,0152
2011	0,0074	0,1684	0,7771	0,2715	0,1523	0,0374	0,0234	0,0132	0,0295
2012	0,0027	0,1809	0,5206	1,5330	0,3247	0,1291	0,0578	0,0245	0,0391
2013	0,0065	0,0749	0,2722	0,3600	0,6211	0,1006	0,0508	0,0141	0,0254
2014	0,0012	0,0602	0,2922	0,2608	0,3563	0,4527	0,0926	0,0651	0,0807
2015	0,0013	0,0573	1,0351	0,2464	0,0908	0,1644	0,1545	0,0370	0,0495
2016	0,0003	0,0318	0,1158	0,4724	0,1791	0,0916	0,0750	0,0416	0,0500
2017	0,0047	0,0474	0,4500	0,2386	0,5277	0,1408	0,0640	0,0619	0,0850
2018	0,0011	0,0197	0,1776	0,3306	0,1208	0,1340	0,0431	0,0250	0,0374

Discards

DIS	0	1	2	3	4	5	6	7	8
2004	0,500	1,494	0,137						
2005	1,208	2,432	0,672	0,131		0,004			
2006	0,987	1,102	0,230	0,012	0,004				
2008	0,613	0,990	0,181	0,031					
2009	0,207	1,273	0,964	0,050	0,003				
2010	1,519	2,929	0,596	0,092	0,006			0,000	
2011	0,564	3,749	2,599	0,339	0,003	0,000			
2012	0,205	2,215	2,380	2,627	0,054	0,036	0,005		
2013	0,737	1,363	0,959	0,332	0,583				
2014	1,319	5,720	0,468	0,061	0,059	0,099	0,000	0,000	0,000
2015	0,160	2,187	1,848	0,352	0,013	0,012	0,008		0,000
2016	0,775	2,148	0,690	0,654	0,098	0,017	0,008	0,003	0,001
2017	0,474	1,364	2,371	0,470	0,517	0,029	0,002	0,004	0,005
2018	0,361	1,653	0,993	0,514	0,048	0,026	0,000	0,001	0,001

Catch

Catch	0	1	2	3	4	5	6	7	8
2004	0.056	0.593	0.557	0.155	0.026	0.093	0.023	0.001	
2005	0.394	0.942	0.540	0.523	0.108	0.115	0.021	0.035	0.024
2006	0.403	0.637	0.390	0.154	0.069	0.019	0.015	0.005	0.006
2007	0.021	0.018	0.554	0.319	0.067	0.054	0.008	0.015	0.004
2008	0.155	0.395	0.184	0.155	0.079	0.018	0.014	0.009	0.012
2009	0.070	0.550	0.694	0.283	0.120	0.023	0.018	0.008	0.012
2010	0.748	1.715	0.853	0.369	0.063	0.032	0.015	0.013	0.019
2011	0.309	2.214	2.415	0.542	0.204	0.050	0.031	0.018	0.039
2012	0.028	0.512	0.999	2.423	0.453	0.182	0.080	0.034	0.054
2013	0.047	0.196	0.514	0.633	1.093	0.172	0.087	0.024	0.044
2014	0.269	1.235	0.471	0.348	0.471	0.604	0.119	0.084	0.104
2015	0.029	0.450	1.525	0.348	0.108	0.193	0.181	0.043	0.058
2016	0.473	1.336	0.514	0.778	0.204	0.084	0.065	0.035	0.041
2017	0.240	0.720	1.563	0.436	0.705	0.134	0.055	0.054	0.074
2018	0.178	0.832	0.688	0.628	0.161	0.165	0.049	0.029	0.043

Annex

WKCELTIC – Benchmark on Celtic sea gadoids (cod 7e-k, haddock 7b-k, whiting 7b-k)

Working document on the updated French methodology used to produce landings and discards numbers- and weight-at-age data for the stock of cod 7e-k

IFREMER

March 2019

Gaël LAVIALLE, Marianne ROBERT, Lionel PAWLOWSKI

Summary

1. Introduction

The methodology to produce national data up to date (2018) is documented in the WKCATCH templates completed by the members of the WKCELTIC group. These excel sheets describe the sampling design of each country and its raising procedure. The French one is presented in the section 2.(https://community.ices.dk/ExpertGroups/benchmarks/2019/wkceltic/_layouts/15/start.aspx#/2014%20Meeting%20docs/Forms/AllItems.aspx?RootFolder=%2FExpertGroups%2Fbenchmarks%2F2019%2Fwkceltic%2F2014%20Meeting%20docs%2F03%2E%20Report%202020&FolderCTID=0x012000565F2AD47EFA9043943C68C5D7EEE25D&View={A88BA838-1ACE-49AE-A19B-E9AFABF007DC})

The current document presents the analysis made during the benchmark WKCELTIC 2019-2020 to improve the methodology used to produce French data (landings and discards in tons, number at age/length and mean weight at age/length) for the historical time series back to 2003. This method will constitute the new reference in term of how the time series of data will be reproduced for the benchmark and how data will be processed in the future. This information is summarized in stock annex.

The main reviews of the methodology are:

- Documentation and harmonization of métiers labeling and clustering to ensure consistency throughout the time series and between countries.
    - The labels of metiers fit the ICES datacall format (Appendix 2)
    - Clusters of métier are documented and where possible being the same for all the countries
- Documentation and harmonization of the thresholds used to select strata (number of trips, hauls, fish measured, etc.).
- Biological parameters: a combined international biological dataset (Ireland, Belgium, England and France) was built and used.
    - ALK: probabilities matrix coming from a multinomial model are used instead of a multinomial filling of the empirical ALK
    - Weight-Length Relationship (WLR): a and b parameters fitted every years on the combined data set is used instead of fixed a and b parameter (Bellail, 2000).
- Documentation and harmonization of SOP procedure

2. Summary of the current raising procedure for cod 7e-k

Catch Category	Variable	Step_#	Step_description	Type	temporal*fleet*spatial aggregation	Type_of_calculation	Auxiliary_variable	Source_of_auxiliary_variable	Raising_factor_or_operation	Weighing	Type	Temporal*fleet*spatial_aggregation
PK	PK	PK	Describe the estimation step	Describe the core input data	describe the aggregation of the data	describe the type of calculation	describe the type of auxiliary variable (if any)	describe the source of auxiliary variable	describe the raising factor or operation	Were weights applied? If Yes describe	Describe the output data	Describe the aggregation of the data
Landings	Age comp landings	1 (at sea sampling)	Length sample --> haul	length composition of a 30 fish sample	Haul	Raised by landings	Landings (weight)	Observer data (own weight or report logbook from the fisherman)	(Weight landings haul / weight sampled) * number length i for each i	none	length composition in haul	Haul
Landings	Age comp landings	1bis (market sampling)	Length sample --> commercial grade	length composition of a sample	Trip-Commercial grade	Raised by landings	Landings (weight)	Sales note	(Weight landings commercial grade / weight sampled) * weight length i for each i	none	length composition in commercial grade	Trip-Commercial grade
Landings	Age comp landings	2	Raising factors check.	Quality check		Remove potential trips with wrong RF due to a break of the protocol most of the time. Expert decision						
Landings	Age comp landings	3 (at sea sampling)	haul --> trip	length composition of a 30 fish sample	Haul	Raised by number of hauls	Number of hauls	Observer data	(Nb of haul in trip / nb of hauls sampled) * mean number length i across sampled hauls for each i	none	length composition in trip	Trip
Landings	Age comp landings	3bis (market sampling)	Commercial grade --> Trip	length composition of a commercial grade	Trip-Commercial grade	sum across commercial grades			sum(raised number landed by commercial grade and length)	none	length composition in trip	Trip
Landings	Age comp landings	4	Check spatial representativeness of the sample in each quarter * fleet	Quality check								
Landings	Age comp landings	5	Trip --> strata (quarter * fleet)	length composition in trips	Trip	Raised by landings	Landings (weight)	logbooks + sales notes (SACROIS)	(Weight landings strata / total raised weight landings in trips) * mean number length i across trips for each i	none	length composition by strata (market + at sea)	quarter*fleet
Landings	Age comp landings	6	Length Frequency check	Quality check		Remove wrong lengths. Expert decision. Based on min and max reference lengths and an analysis of the trip including the outlier						
Landings	Age comp landings	7	Apply thresholds (>=90-100 fish measured per stratum, depending of the year)	Quality check		Apply thresholds (>=90-100 fish measured per stratum, depending of the year)						
Landings	Age comp landings	8	Check gaps in the age data (length class in the raised data missing in the CA)	Data estimation		Fit a multinomial model age ~ length by strata to estimate the probability of a fish to have each age given the missing class						
Landings	Age comp landings	9	Create virtual fish (between 5 and 10) in the CA for each missing length class and split them in age according to the estimated probability	Data estimation								
Landings	Age comp landings	10	Age correction in the CA: no age data available for discards unless during the EVOHE surveys (quarter 4) --> age 1 is often missing in the CA so the multinomial model does not fit this age and stick age 2 to length which are probably age 1	Hocus Pocus		Quarter 4: set all the length class <= 45 cm to age 1 in the CA; All quarters: set all the length class <= 35 cm to age 1 in the CA						
Landings	Age comp landings	11	ALK by quarter	length composition of stratum; age composition by length in a quarter	quarter*fleet	conversion length to age	ALK	Market sampling and survey	length * alk	none	length-age composition of a stratum	quarter*fleet
Landings	Age comp landings	12	Check Age Length relation	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	13	Mean weight at age	length-age composition by strata ; 2009 a&b parameters	quarter*fleet	calculation of mean weight at age		Market sampling and survey	sum(a&b * length * age)/nb of indiv.	none	mean weigth at age	quarter*fleet
Landings	Age comp landings	14	Check mean weight by age	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	15	Check age distribution	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	16	Check sop	age composition of strata	quarter*fleet	correction to number of individuals	weight-age relationship	sampling	numbers*weight@age	none	age composition of fleet (sop corrected)	quarter*fleet
Landings	Age comp landings	1	Length sample --> haul	length composition of a 30 fish sample	Haul	Raised by discards	Discards (weight)	Observer data	(Weight discards haul / weight sampled) * number length i for each i	none	length composition in haul	Haul
Landings	Age comp landings	2	Raising factors check.	Quality check		Remove potential trips with wrong RF due to a break of the protocol most of the time. Expert decision						
Landings	Age comp landings	3	haul --> trip	length composition of a 30 fish sample	Haul	Raised by number of hauls	Number of hauls	Observer data	(Nb of haul in trip / nb of hauls sampled) * mean number length i across sampled hauls for each i	none	length composition in trip	Trip
Landings	Age comp landings	4	Check spatial representativeness of the sample in each quarter * fleet	Quality check								
Landings	Age comp landings	5	Trip --> strata (quarter * fleet)	length composition in trips	Trip	Raised by landings	Landings (weight)	logbooks + sales notes (SACROIS)	(Weight landings strata / total raised weight landings in trips) * mean number length i across trips for each i	none	length composition by strata	quarter*fleet
Landings	Age comp landings	6	Length Frequency check	Quality check		Remove wrong lengths. Expert decision. Based on min and max reference lengths and an analysis of the trip including the outlier						
Landings	Age comp landings	7	Apply thresholds (>=90-100 fish measured per stratum, depending of the year)	Quality check		Apply thresholds (>=90-100 fish measured per stratum, depending of the year)						
Landings	Age comp landings	8	Check gaps in the age data (length class in the raised data missing in the CA)	Data estimation		Fit a multinomial model age ~ length by strata to estimate the probability of a fish to have each age given the missing class						
Landings	Age comp landings	9	Create virtual fish (between 5 and 10) in the CA for each missing length class and split them in age according to the estimated probability	Data estimation								
Landings	Age comp landings	10	Age correction in the CA: no age data available for discards unless during the EVOHE surveys (quarter 4) --> age 1 is often missing in the CA so the multinomial model does not fit this age and stick age 2 to length which are probably age 1	Hocus Pocus		Quarter 4: set all the length class <= 45 cm to age 1 in the CA; All quarters: set all the length class <= 35 cm to age 1 in the CA						
Landings	Age comp landings	11	ALK by quarter	length composition of stratum; age composition by length in a quarter	quarter*fleet	conversion length to age	ALK	Market sampling and survey	length * alk	none	length-age composition of a stratum	quarter*fleet
Landings	Age comp landings	12	Check Age Length relation	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	13	Mean weight at age	length-age composition by strata ; 2009 a&b parameters	quarter*fleet	calculation of mean weight at age		Market sampling and survey	sum(a&b * length * age)/nb of indiv.	none	mean weigth at age	quarter*fleet
Landings	Age comp landings	14	Check mean weight by age	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	15	Check age distribution	Quality check		remove or correct outliers. Expert decision						
Landings	Age comp landings	16	Check sop	age composition of strata	quarter*fleet	correction to number of individuals	weight-age relationship	sampling	numbers*weight@age	none	age composition of fleet (sop corrected)	quarter*fleet

3. Metiers definition and clustering

3.1. Current métier definition

Each country groups or splits their national metiers (DCF category 5 or 6) into the ICES metiers to be uploaded into Intercatch. At the end of the process, the stock coordinator does not know if an ICES métier represents a comparable fishing activity between countries. Moreover, the clusters of métiers can change one year to another and may not follow ICES métier labels as specified in Appendix 2, which brings bias in the year-to-year comparisons.

3.2. Updated French métier definition and international repository proposal

The new flow chart of metier definition at the French level can be summarized by the following steps:

1) The first step corrects some obvious mistakes and mismatches in the DCF national focatEU6 variable to produce a "Validated foCatEu6 " variable at the French level(see table below).
2) The second step translates the DCF labels into ICES labels (provide in the appendix 2 of the ICES data call) to document a common labeling between countries.
3) The third step allows to group comparable ICES metiers (in terms of fishing activities and catches) at the national level in order to increase sample size and improve raising process and estimates.

The final repository proposed for France over the time series is presented below:

<table>
<tr><th>Final cluster of metiers</th><th>Ices label</th><th>Validated DCF foCatEu6 (FRA)</th><th>DCF foCatEu6 (FRA)</th></tr>
<tr><td rowspan="17">GNS_DEF_120-219_0_0_all</td><td rowspan="6">GNS_CRU_0_0_0_all</td><td rowspan="5">GNS_CRU_100_119_0</td><td>GNS_CRU_0_0_0</td></tr>
<tr><td>GNS_CRU_10_30_0</td></tr>
<tr><td>GNS_CRU_100_119_0</td></tr>
<tr><td>GNS_CRU_50_70_0</td></tr>
<tr><td>GNS_CRU_90_99_0</td></tr>
<tr><td>GNS_CRU_120_219_0</td><td>GNS_CRU_120_219_0</td></tr>
<tr><td rowspan="11">GNS_DEF_100-119_0_0_all</td><td rowspan="11">GNS_DEF_100_119_0</td><td>GNC_DEF_0_0_0</td></tr>
<tr><td>GND_DEF_0_0_0</td></tr>
<tr><td>GND_DEF_10_30_0</td></tr>
<tr><td>GND_DEF_100_119_0</td></tr>
<tr><td>GND_DEF_50_70_0</td></tr>
<tr><td>GND_DEF_90_99_0</td></tr>
<tr><td>GND_LPF_100_119_0</td></tr>
<tr><td>GND_SPF_100_119_0</td></tr>
<tr><td>GNS_DEF_>=3_0</td></tr>
<tr><td>GNS_DEF_>=75_0</td></tr>
<tr><td>GNS_DEF_0_0_0</td></tr>
</table>

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			GNS_DEF_10_30_0
			GNS_DEF_100_119_0
			GNS_DEF_50_70_0
			GNS_DEF_90_99_0
			GNS_LPF_100_119_0
			GNS_SPF_100_119_0
	GNS_DEF_120-219_0_0_all	GNS_DEF_120_219_0	GND_DEF_120_219_0
			GND_LPF_120_219_0
			GNS_DEF_120_219_0
			GNS_LPF_120_219_0
			GNS_SPF_120_219_0
	GTR_CRU_0_0_0_all	GTR_CRU_120_219_0	GTR_CRU_120_219_0
	MIS_MIS_0_0_0_HC	GTR_DEF_100_119_0	GTN_DEF_0_0_0
			GTN_DEF_10_30_0
			GTN_DEF_100_119_0
			GTN_DEF_50_70_0
			GTN_DEF_90_99_0
			GTR_CEP_100_119_0
			GTR_DEF_0_0_0
			GTR_DEF_10_30_0
			GTR_DEF_100_119_0
			GTR_DEF_50_70_0
			GTR_DEF_90_99_0
	GTR_DEF_120-219_0_0_all	GTR_DEF_120_219_0	GTN_DEF_120_219_0
			GTR_CEP_120_219_0
			GTR_DEF_120_219_0
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	GNS_DEF_>=220_0_0_all	GNS_DEF_>=220_0	GND_DEF_>=220_0
			GNS_DEF_>=220_0
			GNS_SPF_>=220_0
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		GTR_CRU_100_119_0	GTR_CRU_0_0_0
			GTR_CRU_10_30_0
			GTR_CRU_100_119_0
			GTR_CRU_50_70_0
			GTR_CRU_90_99_0
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			GTR_CEP_>=220_0
			GTR_DEF_>=220_0
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			OTB_CRU_0_0_0,OTT_CRU_0_0_0
			OTB_CRU_0_16_0

			OTB_CRU_100_119_0
			OTB_CRU_16_31_0
			OTB_CRU_32_69_0
			OTB_CRU_70_99_0
		OTT_CRU_100_119_0	OTT_CRU_>=120_0
			OTT_CRU_0_0_0
			OTT_CRU_0_0_0,OTB_CRU_0_0_0
			OTT_CRU_0_16_0
			OTT_CRU_100_119_0
			OTT_CRU_16_31_0
			OTT_CRU_32_69_0
			OTT_CRU_70_99_0
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			OTB_DEF_0_0_0
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			OTB_DEF_0_0_0,OTT_CRU_0_0_0
			OTB_DEF_0_0_0,OTT_DEF_0_0_0
			OTB_DEF_100_119_0
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			OTB_DWS_>=120_0
			OTB_DWS_100_119_0
			OTB_SPF_>=120_0
			OTB_SPF_0_0_0
			OTB_SPF_100_119_0
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			OTT_DEF_0_0_0
			OTT_DEF_0_0_0,OTB_DEF_0_0_0
			OTT_DEF_0_0_0,OTT_CRU_0_0_0
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			OTT_DWS_100_119_0
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			OTB_DEF_>=55_0
			OTB_DEF_>=70_0
			OTB_DEF_0_16_0
			OTB_DEF_16_31_0
			OTB_DEF_32_69_0
			OTB_DEF_70_99_0
			OTB_DWS_32_69_0
			OTB_DWS_70_99_0

			OTB_SPF_0_16_0
			OTB_SPF_16_31_0
			OTB_SPF_32_69_0
			OTB_SPF_70_99_0
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			OTT_DEF_16_31_0
			OTT_DEF_32_69_0
			OTT_DEF_70_99_0
			OTT_DWS_32_69_0
			OTT_DWS_70_99_0
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			OTB_MOL_>=120_0
			OTB_MOL_100_119_0
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			OTT_CEP_0_0_0
			OTT_CEP_100_119_0
			OTT_MOL_100_119_0
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			OTB_CEP_16_31_0
			OTB_CEP_32_69_0
			OTB_CEP_70_99_0
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			OTB_MOL_0_0_0
			OTB_MOL_0_16_0
			OTB_MOL_16_31_0
			OTB_MOL_32_69_0
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			OTT_CEP_32_69_0
			OTT_CEP_70_99_0
			OTT_MOL_70_99_0
SSC_DEF_100-119_0_0_all	MIS_MIS_0_0_0_HC	SDN_CEP_100_119_0	SDN_CEP_100_119_0
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			SDN_CEP_70_99_0
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			SDN_DEF_0_0_0
			SDN_DEF_100_119_0
	SSC_DEF_70-99_0_0_all	SDN_DEF_70_99_0	SDN_DEF_0_16_0
			SDN_DEF_32_69_0
			SDN_DEF_70_99_0
TBB_DEF_70-99_0_0_all	MIS_MIS_0_0_0_HC	TBB_CEP_70_99_0	TBB_MOL_32_69_0

			TBB_MOL_70_99_0
	TBB_DEF_70-99_0_0_all	TBB_DEF_70_99_0	TBB_DEF_0_0_0
			TBB_DEF_0_16_0
			TBB_DEF_16_31_0
			TBB_DEF_32_69_0
			TBB_DEF_70_99_0

4. Thresholds

The first step of the raising procedure consists in selecting the strata used to raise and estimate the following statistics:

1) The total discard weights by stratum;
2) The landings at length and then at age (in numbers and weight);
3) The discards at length and then at age (in numbers and weight).

Historically, French selection procedure of strata was based on number of fish measured. Some modifications have been made to these threshold to increase consistency between countries and obtain a more accurate and complete estimation. The new thresholds are presented below:

Estimator to raise	Catch category	Sampling	Number of trips	Number of fishing operations	Number of fish measured
Total weight	Discards	At-sea	2	5	-
Number at length	Discards	At-sea	2	5	20
Number at length	Landings	At-sea/market	2	-	100 (60 if the discard number at length is raised)

The low threshold on discarded fish can be justified by the fact there is usually a low discard rate for a given species (around 10%) and a low stock abundance in recent years.

There is no threshold on the fishing operation for the landings at length because the market sampling is designed at the trip level (one fishing operation corresponds to one trip in the market sampling data base). In order to avoid as much as possible a strata selected for the discards but not for the landings, it was decided to decrease the landings threshold when the discards are raised.

5. Biological parameters

5.1. ALK estimation

5.1.1. Current French methodology

The French biological data come from the market sampling and the EVHOE survey (fourth quarter). French discards are not aged and no individual weights are recorded (except during the survey). This results very few age-length relationship for the youngest fish causing issues in multinomial modeling.

The current French methodology to estimate the ALK implements the following steps:

1) Merge the raised at length dataset from commercial sampling (market and at sea) with the biological dataset in order to identify the length classes present in the first and missing in the second (ALK gaps). These gaps have to be filled in.
2) Fit a multinomial model by quarter to estimate the probability of one fish to have each age conditional to a given length class.
3) For each missing length class, generate virtual fish and distribute them according to the probabilities estimated in 2).
4) Correct age of young fish. Attribute age 1 to all the fish under 35 cm and under 45 cm in the fourth quarter. Without this expertise, the multinomial model might attribute age 2 to length classes of age 1 or even 0 because no fish of age 1 was observed on the biological sampling (no aging of discards).
5) Calculate a new ALK with the biological dataset including virtual fish and apply it to the number at length to get number at age.

5.1.2. New data and methodology proposal

Based on the first meeting of the benchmark (February 2019), an exchange of biological datasets at the COST format (CA) was made between countries. The pooled dataset is particularly valuable for France because:

1) Irish, UK and Belgium provide an age sampling on discards which adds a lot of young fish to the dataset;
2) The binding dataset strengthens the oldest fish estimation by adding new length-age combination;
3) The Irish and Belgium sampling programs provide individual weights on a quarterly basis which allow updating each year the mean weight-at-age or weight-length or the relationships.

Looking at the Fig. 1, the added value of data sharing is obvious, especially on the youngest and oldest fish, avoiding to artificially allocating age 1 to fish smaller than 35 cm.

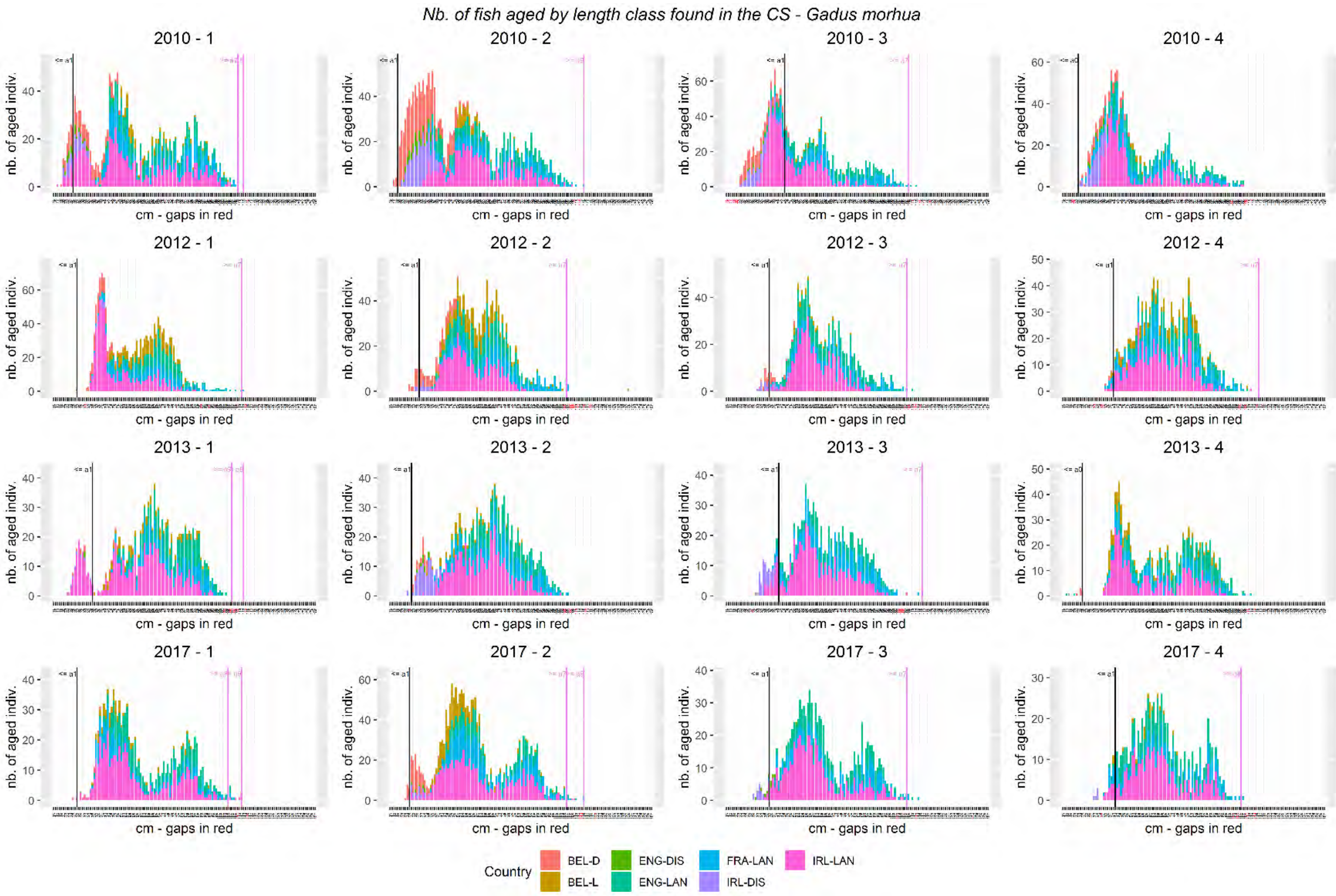

Fig. 1 : nb of fish sampled (age and length) in the combined CA (2010, 2012, 2013, 2017). In red on the x-axis the missing length classes from the CA but needed by commercial raising.

Based on scripts exchange and discussion, the procedure developed by Belgium was considered more appropriated and more robust to age reading errors of the otoliths. The probabilities provided by the multinomial model will be used as an ALK to translate the number at length in age. As a consequence, it is no more needed to create virtual fish and the model will smooth the probabilities distribution to avoid outliers to distort the ALK (Figure 2).

The comparison between the old and the new ALK were made for four year (2010 for the high recruitment, 2012 for the high abundance, 2013 because there is some SOP matters and 2017 because it is the most recent year, Figure 3).

Fig. 2: comparison between the old method with the French CA dataset and the new method with the combined CA dataset (2010, 2012, 2013, 2017). In red the multinomial probabilities and in black the empirical proportions from the French CA after multinomial filling.

We can see that the new dataset allows to estimate length-age relationship for the youngest fish (age 0-1) especially when there is a high recruitment. The estimates at age 1 of the empirical proportions from French CA after multinomial filling are consistent with the multinomial probabilities calculated on the combined data set, however the later distributes more the fish between ages for a given length. Higher differences are observed between the two approaches for the oldest ages (e.g. age 6 in 2017-2 or age 5 2017-1/4).

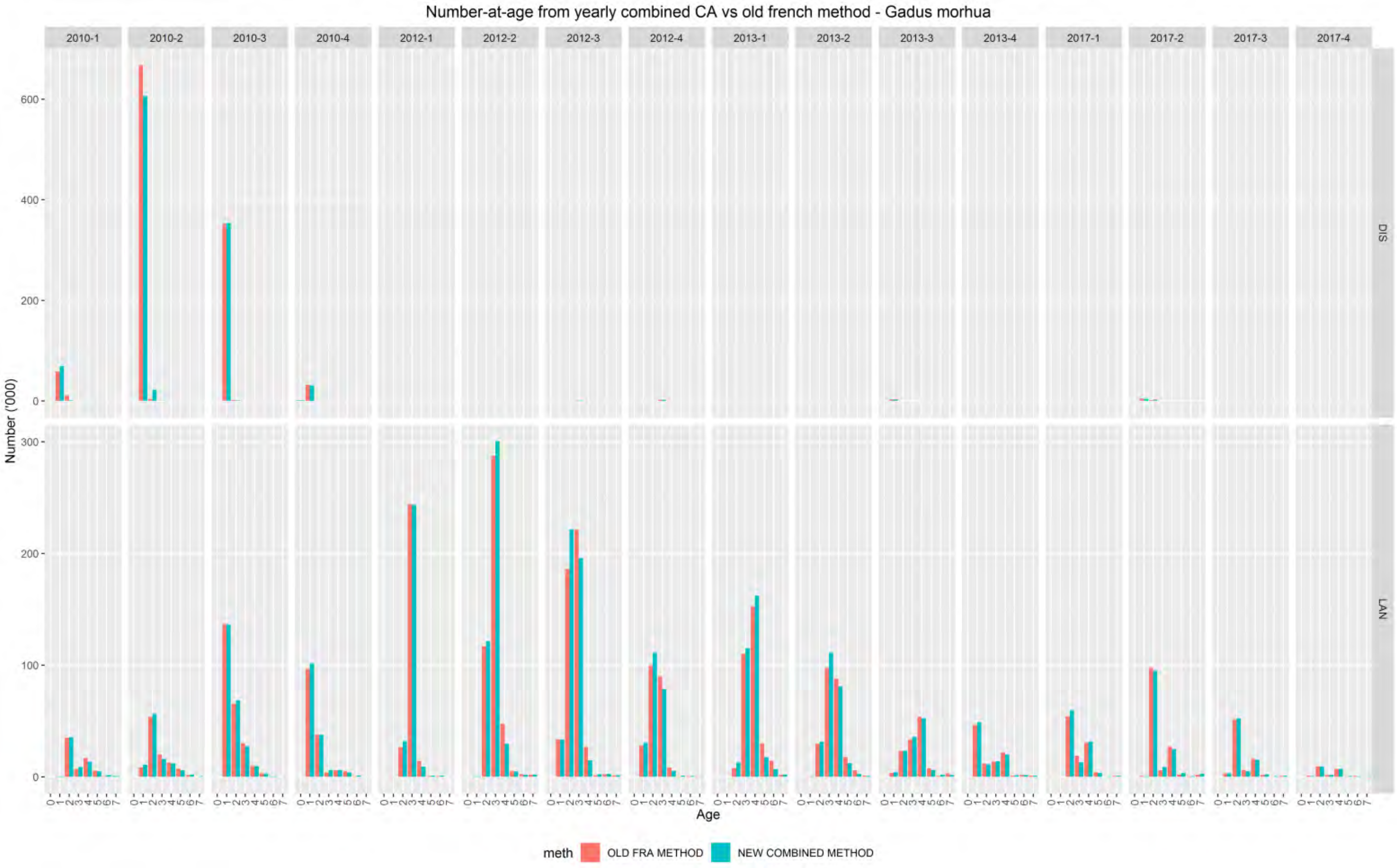

Fig. 3 : comparison of the raise at age results in numbers between the new method with the combined CA and the old French one with the French CA.

After applying the two ALKs to the length structure, we can see some slight differences which are difficult to explain since it depends on the stock dynamics and the biological samples. The new ALK seems to generate more fish at the youngest ages for the landings, especially during the strong year abundance (2012). That might be explained by the fact that the multinomial model is smoother than the empirical ALK and distribute the fish along a wider range of lengths.

5.2. Mean weight-at-age

The new combined CA allows fitting a weight-length relationship (WLR) on a yearly basis instead on using a fixed relationship (estimated in 2000, 2009, 2018 - Table 1).

Table 1 : French WLR updated every nine years

Year	Quarter	a	b	area
2000	1	0,00001729	2,90408	7ek
2000	2	0,00001828	2,8893	7ek
2000	3	0,001848	2,88864	7ek
2000	4	0,00001061	3,02811	7ek
2009	1	0,00001631	2,90408	7ek
2009	2	0,00001725	2,8893	7ek
2009	3	0,00001744	2,88864	7ek
2009	4	0,00001001	3,02811	7ek
2018	1	0,00001305	2,9561	7ek
2018	2	0,00001226	2,9703	7ek
2018	3	0,00001009	3,0154	7ek
2018	4	0,00000935	3,0373	7ek

The methodology to get the weight from the length has changed but it remains the same to get the weight at age from the weight at length. It can be resumed by the two following steps:

1) Translate the number at length in weight with the WLR for each length observed and raised for each stratum (métier-quarter);
2) For each stratum, calculate the mean weight at age by summing the weight at length and the number at length and dividing the first by the second. This method allows taking into account the differences of length structure at age between strata.

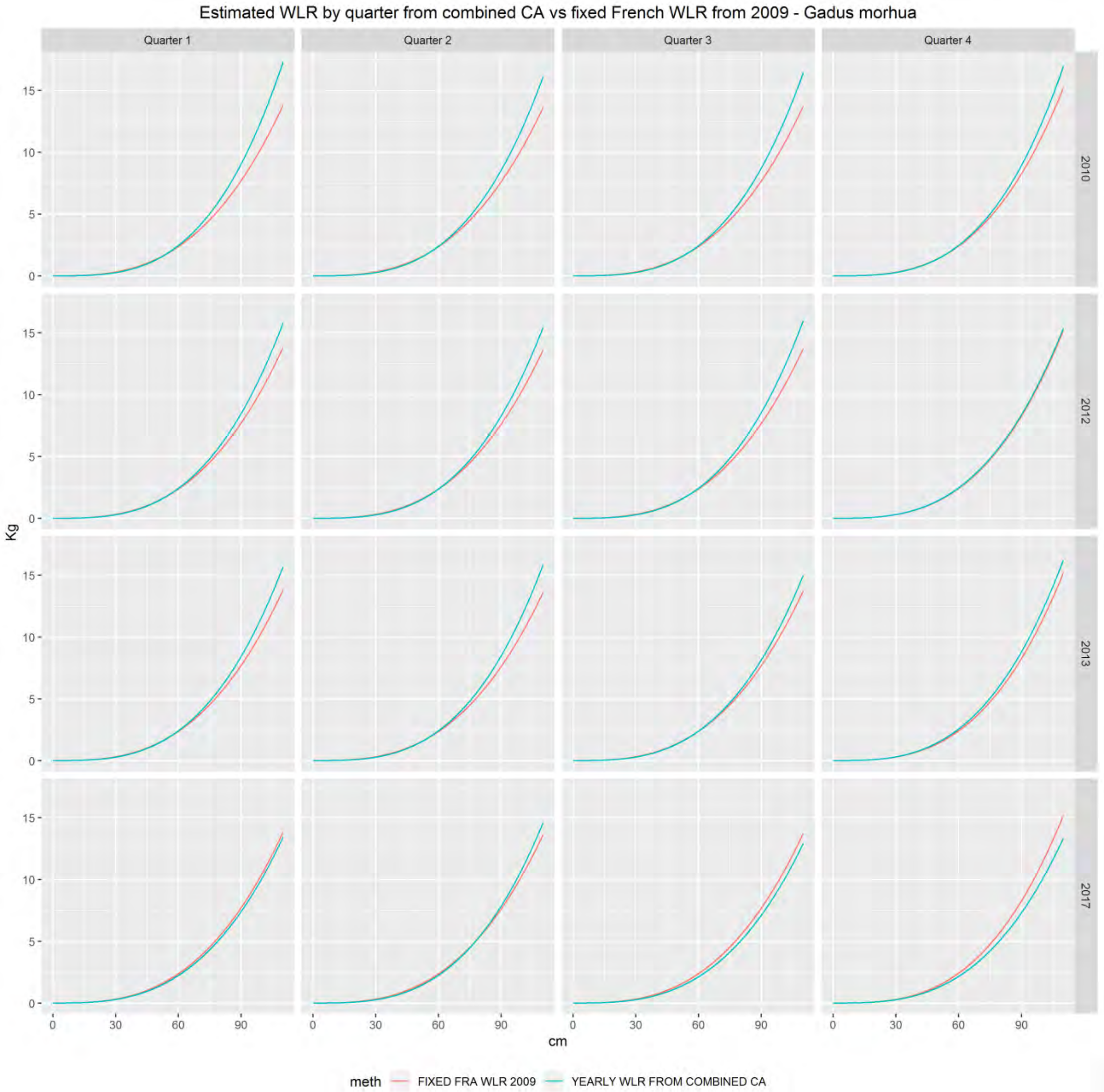

Fig. 4 : comparison of the old French WLR and the new one during 2010-2013 and 2017.

As we see on the Fig. 4 the new WLR seems to provide a higher weight at length between 2010 and 2013. The differences between the curves increase with length. However, for 2017 it seems to be the opposite, especially for the four quarter.

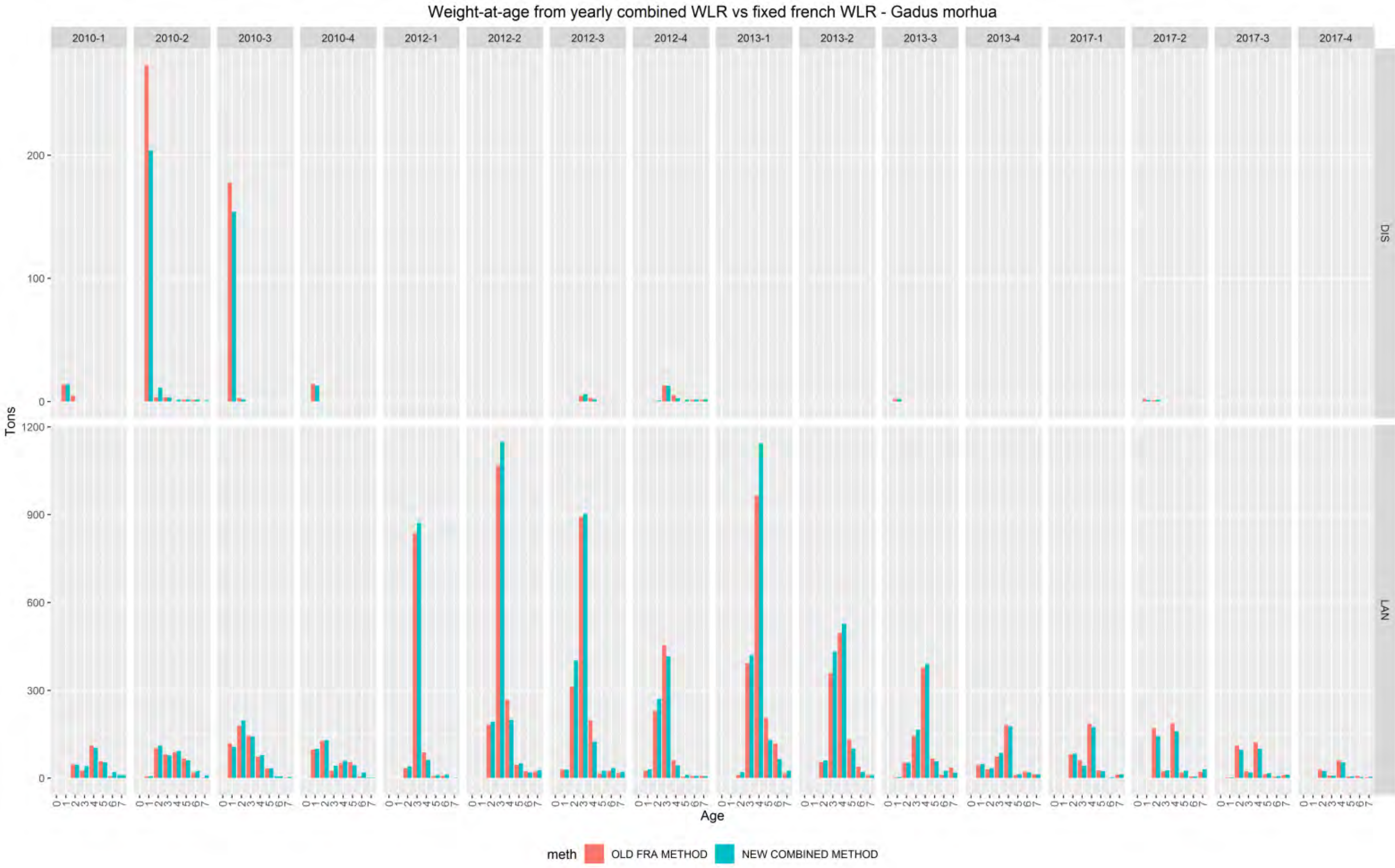

Fig. 5 : comparison of the raise at age results in total weight between the new method with the combined CA and the old French one with the French CA.

The differences between the two methods seem to be driven by the differences observed on the numbers (Fig. 3). Moreover the main differences between the WLR (Fig. 4) accentuate the higher total weight-at-age provide by the new method for the age 1-2 in the landings during 2010-2013. However, despite the greater WLR of the new method for the old and middle ages, the old method continues to provide a higher amount of landings for these ages.

6. SOP

The sum of the product (SOP) is calculated for each strata to quality check and consistency. No correction is applied if the SOP ranges between 0.8 and 1.2, corresponding to the InterCatch thresholds.

When a SOP is estimated outside this range, raw data and process are scrutinized. Eventually, SOP are corrected to 1 by adjusting the numbers.