# ICES WKWIDE REPORT 2017

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# Report of the Benchmark Workshop on Widely Distributed Stocks (WKWIDE)

30 January–3 February 2017

Copenhagen, Denmark

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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## Executive summary

The benchmark workshop on widely distributed stocks (WKWIDE) was held in ICES headquarters in Copenhagen from the 30th January to the 3rd February, 2017. The benchmark process started in November 2016 with a data compilation meeting, also held at ICES. Three stocks were benchmarked: Northeast Atlantic Mackerel, Western Horse Mackerel and North Sea Horse Mackerel.

**NEA Mackerel**

During the annual WGWIDE meeting in 2013, the statistical catch–at–age assessment method (ICA) was abandoned as the NEA Mackerel assessment model, due in large part to sensitivity to uncertainty in the reported historical catch. It was no longer considered to give a reliable estimate of the development of the stock and advice for 2014 was provided on the basis of a data limited approach.

During the 2014 benchmark exercise, an implementation of the state-space assessment model (SAM) was proposed as the assessment method. SAM is more flexible than ICA and was configured to include additional input datasets and to down-weight the influence of the catch-at-age data during the historical period. The additional data included a density-at-age index from a swept area survey (IESSNS) in northern waters, a recruitment index derived from observations of catch rates on groundfish surveys (IBTS) and tagging data which was particularly informative for the period prior to 2000 (when the catch data is considered unreliable).

Subsequently, annual catch advice for years 2015–2017 was given based on the MSY approach with stock status as per the SAM model output, configured as agreed at the 2014 benchmark. The MSY reference points were determined during an evaluation of a long–term management plan in 2015.

During the 2017 benchmark exercise a number of updates were made to the input data and the SAM model configuration. Data from the swept area survey is now considered as an abundance–at–age rather than a density–at–age. This change is facilitated by the extended time–series and 2 years when coverage was considered to be poor (2007 and 2011) can now be excluded from the time–series. This also permits additional data to be included in the index and the range of ages to be expanded from 6–11 to 3–11. Model diagnostics suggest no deterioration in model performance when these revised data are used.

Model settings were updated to account for a year effect observed in the IESSNS (by assuming that all the errors in a single year are correlated). This update improved the assessment model diagnostics. Model diagnostics for runs which decoupled the observations variance for the youngest fish which may not be fully selected by the survey were inconclusive and require further investigation.

In 2011 much of the methodology used on the tagging programme was changed and the data from the new RFID programme was not used during the 2014 benchmark exercise. However, this time–series is now more mature and has been included in the 2017 benchmark. The assessment model diagnostics indicate that separate survival and overdispersion parameters are required for each of the tagging time–series although the higher post-tagging mortality associated with the RFID remains to be fully explained. While there are indications of variations in post tagging survival between tag screening locations (i.e. processing factories), model performance deteriorates and there is insufficient data at this time to investigate further.

The triennial egg survey dataset was revised and quality checked and includes the preliminary 2016 data point. Additional years are available for the recruitment index. Outstanding issues were identified and should be addressed prior to the WGWIDE meeting in 2017. No updates to historical catch or discard data were submitted.

The stock reference points were revised following ICES standard guidelines. Those reference points determined directly from the assessment output ($B_{lim}$, $B_{pa}$ and MSY $B_{trigger}$) were revised. Although candidate values for the remaining points ($F_{lim}$, $F_{pa}$ and $F_{MSY}$) were available from the *eqSim* results, it was decided to wait until completion of the scheduled management plan evaluation before proposing new values. No update to the short–term forecast settings was implemented by the benchmark.

SAM updates were incorporated including using the TMB library which gives a performance improvement. Diagnostics were improved over 2014 and improved residual calculations were implemented.

A review of the information available on stock structure, with emphasis on the North Sea stock component concluded that abundances in the North Sea when the Western component is not present remain relatively low and, should these mackerel form a distinct spawning component, it would be sensible to continue with the current protection measures.

**Western Horse Mackerel**

A new assessment model based on an implementation of the integrated Stock Synthesis (SS3) assessment model is proposed by WKWIDE as the basis for the assessment of Western Horse Mackerel. The existing (SAD) model which was developed specifically for this stock suffers from a lack of fishery-independent data and the flexibility to incorporate additional data. Such flexibility is offered by SS3 and enables the use of two additional indices: a recruitment index derived from groundfish surveys and an acoustic index. The SS3 implementation also makes use of length composition and conditional age–at–length data from the acoustic survey and commercial catch sampling. Assumptions regarding selectivity were also limiting for a stock and fishery that has depended largely upon sporadic large year classes.

Commercial catch sampling data was reviewed and reworked to extend the plus group from 11+ to 15+, as large year classes can readily be tracked up to this age. The catch data was split on the evidence of differences in the length-frequency distributions between a southern (ICES division 8) fleet and a northern fleet. However, an implementation of SS3 with this 2 fleet structure was limited in its ability to fit the length and age composition data from the southern fleet and will required further investigation. Thus, a single fleet is considered for the final SS3 assessment model.

Acoustic estimates of biomass and length composition data from the Spanish PELACUS survey were included in the assessment and result in increased stability. Equivalent data from the French PELGAS (Bay of Biscay) acoustic survey resulted in a marked deterioration in model performance and it was not considered for the final assessment. In future, these data sources will be developed further and perhaps merged into a single index.

Comparisons with the previous model were complicated by the fact that the SS3 model can use the additional data whereas SAD is limited to only the egg survey data, and is sensitive to the exclusion of the first two data points, as has been used for the final SS3 assessment. Estimates of recruitment are similar as is the overall trend in stock development. The SS3 assessment indicates that the most recent SSB (2015) is the lowest in the time–series.

Due to time constraints, the reference points were considered by correspondence after the meeting. Following ICES guidelines, updated values for both precautionary and MSY reference points were calculated.

**North Sea Horse Mackerel**

A number of modelling approaches were considered for the development of an index of stock abundance for North Sea Horse Mackerel, using combined CPUE data from two surveys; the North Sea IBTS and the Channel Groundfish Survey.

A hurdle model which fits separate GLMs to the positive catch rates and the presence/absence data was found to be most appropriate for data which is characteristically zero-inflated and over-dispersed. A fishable biomass index (based on survey catches over 20cm) and a juvenile (under 20cm) index were calculated. Individual surveys were weighted to account for differences in spatial coverage and gear configurations.

# 1 Introduction

This report details the outcomes of the benchmark exercise established by ACOM to consider the assessment (input data and methodology), short–term forecast procedures and reference points for three stocks that fall under the remit of the assessment expert group WGWIDE.

The stocks benchmarked were

- Mackerel (*Scomber scombrus*) in subareas 1-7 and 14, and in divisions 8.a-e and 9.a (Northeast Atlantic), herein referred to as NEA Mackerel.
- Horse mackerel (*Trachurus trachurus*) in subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a-c, and 7.e-k (Northeast Atlantic), herein referred to as Western Horse Mackerel.
- Horse mackerel (*Trachurus trachurus*) in divisions 3.a, 4.b-c, and 7.d (Skagerrak and Kattegat, southern and central North Sea, eastern English Channel), herein referred to as North Sea Horse Mackerel.

The process was facilitated by three scientists from outside the ICES community, one of whom acted as external chair and the others as assessment experts. They were involved throughout the benchmark exercise and provided comment and input during the discussions.

Jonathan Deroba, NOAA, US (External chair)

Teresa A'mar, NOAA, US (External expert)

Paul Fernandes, University of Aberdeen, Scotland (External expert)

During the WGWIDE meeting in 2016, issue lists for each stock were compiled. The lists outlined a range of issues that the expert group felt should be addressed and they formed the basis for the work carried out by this benchmark.

A data coordination workshop was held at ICES, Copenhagen from 15–18th November 2016. It was attended by 16 scientists and considered the items on the issue lists in detail, in particular the various assessment input datasets. Initial results were presented and discussed and further work required in order for the data to be considered for inclusion in the assessment was identified. This work continued by correspondence with progress discussed at 2 WebEx meetings (21st December 2016 and 18th January 2017). Prior to the final plenary meeting, working documents were produced and uploaded to the meeting Sharepoint site. The final plenary meeting was held at ICES, Copenhagen from 30th January to 3rd February 2017 and was attended by 36 participants, including representatives from industry and managers. During the first part of the meeting, the various input data series were presented in plenary for consideration for inclusion within the assessments. Once the inputs were agreed, the stock assessments were developed and discussed in an iterative manner. A number of modifications to the model assumptions associated with the various input data series within the assessment were also explored. Due to a lack of time, the ToRs regarding the short–term forecast and reference points were addressed by correspondence and a final WebEx, held on 3rd March 2017.

# 2 External Experts Comments

**General Comments**

- The benchmark was conducted in good spirits and, in general, most attendees participated in a constructive manner. There were occasional disagreements, however, which generally only surfaced when the results of assessments were presented, reinforcing the chairman's view that such presentations can be counterproductive when evaluating the quality of an assessment.
- Much of the modelling work fell on four individuals which, at best, is rather unfair, at worst, it creates potential for individual error particularly after long hours of work. A better distribution of effort amongst the group, particularly amongst those with significant interests in the fishery would be worth pursuing although quite how this might be done is not clear to reviewers. This responsibility falls on the individual nation laboratories to provide adequate resources for the benchmark: given the value of the fisheries concerned this should not be too onerous a request.
- The general process of data preparation and assessment model development is in need of revision and needs to be timelier. Much of the data was not finalized when the meeting began, and several hours of the first day were lost to subgroups finalizing data that ideally would be done weeks in advance. Handing data to assessment scientists at the beginning of the benchmark week does not provide enough time for assessment model development and review. Such a hurried process is prone to mistakes, and in this case led to confusion from some participants about modelling decisions and structures, and insufficient time to develop reference points within the course of the benchmark week.
- Several working documents were not available until the Friday before the Benchmark meeting, and this was insufficient time for review.
- Several participants expressed confusion as to some of the underlying structures and methods of the SAM model. While expertise in the SAM model has improved since previous benchmarks (e.g., WKPELA 2014), greater understanding is still needed. As the SAM model has been used in this region for well over 5 years, has been used for NEA mackerel since 2014, and has been described in the peer reviewed literature, we encourage individuals to take it upon themselves to improve their knowledge of SAM. ICES should also facilitate the broader understanding of SAM as resources allow.
- It would be helpful if updated model specification documents (with equations) for SAM were provided, given that the MAC stock annex references Nielsen and Berg (2014) and subsequently SAM has both been converted from ADMB to TMB and extended to include tagging data. Work should continue on validating the changes to SAM, and providing quantitative metrics for model comparison and model fit diagnostics.
- There is a wider issue of assessment model evaluation which needs to be addressed, particularly in the light of so many untrained observers attending. Despite requests from the chairman, it was often difficult to avoid presenting results from the assessments (e.g., biomass and fishing mortality time–series) either before or along with an evaluation of model diagnostics.

Observers would often concentrate more on the different model outcomes rather than any improvement of fit and this, allied to a lack of understanding described above, caused some difficulties. ICES should consider a set of standard diagnostic features that should be considered to assess model performance. Examples include standardized residual plots, model minimization and fit criteria (log likelihoods, AIC) and standardized retrospective plots.

- Stock Synthesis was used to assess Western HOM. Several stocks within ICES are now assessed using Stock Synthesis, and similar to the SAM model, ICES should likely invest in some education if the Stock Synthesis model continues to grow in usage in the region (e.g., Rick Methot commonly does educational seminars on the use of Stock Synthesis), as well as standardized methods for model development and presenting results (e.g., use of the R package r4ss).
- In many previous benchmarks, several models would have been evaluated to determine which might fit the data better and deal with any particular issue, but that was not the case in this benchmark. A model ensemble which draws the same conclusions is always a more powerful demonstration of the underlying dynamics, even if the final model run that is chosen defers to the default model. This may not always be feasible given the staff resources available, but for high profile stocks like mackerel, ensuring adequate expertise to either understand the current model adequately or provide alternative model formulations would be worthwhile.
- As in WKPELA 2014, details of input data were inconsistently presented between the stocks. We painstakingly reviewed details of every possible input data stream for NEA mackerel, while other stocks were not given adequate time. We suggest greater standardization of how data are presented or an explicit acknowledgement that one assessment has generally well established inputs that may not need such extensive review.
- We recommend that retrospective patterns be presented on a relative scale (i.e., centred on zero, relative to the base run with the full time–series of data) to make comparisons easier and more general among assessment model runs and frameworks.
- Some data sources and model results were presented without an indication of error or uncertainty. It would be helpful if a measure of uncertainty were included with tables and figures, e.g., CVs for survey indices.
- Data development and storage is being done by individuals in an ad hoc way. This practice is mistake prone, lacks transparency, and makes calculations difficult to reproduce. ICES should continue work to standardize data collection, storage of data and model runs (e.g., input files, output files, executables), and calculation of assessment inputs.

**NEA Mackerel**

- Work should continue to resolve the differences in trend among the different survey indices. Work to understand the relative contribution of various stock components and migration rates would be particularly helpful. Given the likely sensitivity of the assessment model to the inclusion or exclusion of each of the surveys, and the politically tense atmosphere that surrounds mackerel, work on this topic should be a continued priority.

- The issue of survey containment in the mackerel egg survey needs careful scrutiny (see for example, results from Period 6 2016). The data seem to have long range autocorrelation and so there may be redundancy in the high intensity sampling currently taking place. Survey stratification may help alleviate the problem of containment: including a "core" stratum, which is often evident, has been considered but not implemented. Beyond the core, stations could be sampled, *e.g.* 60 miles apart, to cover adequate ground and avoid any containment issues. We note that WGMEGS is considering these points and encourage further work on survey design.
- Since WKPELA 2014, the IESSNS survey has improved in standardization of methodologies and stock area coverage. This work should continue and all the surveys should strive to settle on long–term methodologies to ensure a useful standardized index in the future.
- Work should continue on recommendations for which years to include when using the egg survey data, given that the in-year results are often revised.
- The results of the IESSNS survey should not be reported in absolute terms, or should be presented with strong caveats about interpretation. The estimates in absolute terms are likely to be biased (upwards, potentially by a factor of 2) due to the use of wing swept area in the estimation of fish density. Mackerel are likely to be herded by the boat, the doors, and the net, and although an appropriate factor may be difficult to determine, the use of door spread, which represents the larger area sampled would provide a more conservative estimate. This point is all the more compelling, given that the catchability of the survey from the assessment is 2, and the wing spread is half the door spread (i.e. if door spread was used, the survey estimate would be half of what it is, and the catchability would be 1). The reporting of the survey estimate in such absolute terms causes ambiguity and degrades the assessment: stakeholders often pin their beliefs on the survey's higher abundance estimate and inappropriately discredit the mathematical model/assessment.
- Work should continue on considering age and time-varying natural mortality (M). Independent (survey) estimates of total mortality (Z) may help to limit potential candidate M's: Z should be available from e.g. the IESSNS.
- Experimental work to explain potential differences in survival or other factors between the steel tags and RFID tags should be conducted. Other explorations might include sustained detectability of RFID tags that have been at sea for multiple years, whether tagged fish are randomly mixed, and explorations into the accuracy of recent catch.
- More work is required to solve the issue of correlated errors leading to residual patterns in the SAM model. Although a solution to this was found late in the benchmark week, some participants were dissatisfied with the proposed solution, although this may have been due to a lack of understanding and relates to points made above in relation to model evaluation.
- Given the limited resources there was no time to investigate the impact of misreported catches in the light of the new information available (extended survey data) These should be examined again in the future as the model

outputs now do not hindcast any misreported catch in the period 1992-2007, which is contrary to what is reported in the literature[1].

**Western HOM**

- In future applications of the IBTS survey into Stock Synthesis, age and length composition data should be incorporated directly into the assessment model, instead of developing a juvenile and adult indices based on an ad hoc length cut-off.
- More participants should be trained in stock synthesis to improve resilience in the group and widen understanding.
- When moving between assessment platforms, as in moving from SAD to Stock Synthesis in this case, changes should be made in relatively small incremental steps to build a "bridge" between the assessment platforms. This bridge will allow a greater understanding of differences and similarities that result from transitioning between frameworks.
- Incorporation of additional acoustic survey data (to include estimates of abundance–at–age and length) should be pursued, particularly from the PELGAS surveys. Small adaptations to the survey should be considered to allow for horse mackerel to be contained more effectively.
- An attempt to account for spatial variation in length composition was made by creating two fleets (i.e., a fleets as areas approach). In the future, an explicit two area model should be attempted to more accurately reflect the dynamics and allow for a better understanding by participants.
- Work should continue on developing the catch time–series, as a low level of discards was observed/reported but there is considerable uncertainty.

**North Sea HOM**

- Data seems available (e.g., indices, age composition) to attempt a full age or length based assessment model, and this should be tried in the future. Alternatively, a survey based model (e.g. SURBA) could be used to make the most of the age information and smooth out year effects. Several alternative approaches should be considered.
- A range of explanatory variables that might cause changes in the CGFS and IBTS indices that are unrelated to abundance should be explored, and this could be done within the current standardization modelling framework.
- Work should continue on development of a commercial CPUE index, and this work should look to incorporate the effect of moon phase and other environmental covariates on catchability and catch rates. However, it should be noted that a CPUE index is a measure of fish density in the area where fishing takes place and is not always a reflection on stock abundance. A large area with low fish densities, potentially unprofitable for fisheries, may have more fish than a small area with high fish densities (where fishing takes place). CPUE is a proxy for density not abundance, so CPUE can only be

1 Simmonds, E. J., Portilla, E., Skagen, D., Beare, D., and Reid, D. G. 2010. Investigating agreement between different data sources using Bayesian state-space models: an application to estimating NE Atlantic mackerel catch and stock abundance. ICES Journal of Marine Science, 67: 1138-1153.

indicative of abundance when it adequately represents the population, i.e. through an effective survey design. Fishing activities are not designed for such purposes.

- Work should continue on validating the index model, and providing measures of uncertainty and quantitative metrics for model comparison.

**Reference Points**

As in WKPELA 2014, reference points were often estimated using stock–recruit models fit external to the assessment model, which treats model estimates as data and the uncertainty related to using model estimates as data was ignored. Furthermore, the stock–recruit models often made assumptions that were inconsistent with assumptions related to recruitment estimates in the assessment model. For example, SAM assumed a random walk in recruitment, but this temporal correlation was later ignored in fitting stock–recruit curves. Claims that the NEA mackerel recruitment estimates appeared temporally independent are incorrect because the recruitments were generated with a random walk, which is by definition correlated. The consequence is likely biased parameter estimates and biased reference points. Attempts should be made in the future to estimate stock–recruit parameters internal to the assessment model (SAM and SS are both capable of this already) or properly account for the uncertainty and autocorrelated nature of stock and recruitment estimates. See:

Mark Dickey-Collas, Mark R. Payne, Verena M. Trenkel, Richard D.M. Nash; Hazard warning: model misuse ahead. ICES J Mar Sci 2014; 71 (8): 2300-2306. Doi: 10.1093/icesjms/fst215

M. Dickey-Collas, N. T. Hintzen, R. D. M. Nash, P-J. Schön, M. R. Payne; Quirky patterns in time–series of estimates of recruitment could be artefacts. *ICES J Mar Sci* 2015; 72 (1): 111-116. doi: 10.1093/icesjms/fsu022

Elizabeth N. Brooks and Jonathan J. Deroba; When "data" are not data: the pitfalls of post hoc analyses that use stock assessment model output. Canadian Journal of Fisheries and Aquatic Sciences, 2015, 72(4): 634-641, 10.1139/cjfas-2014-0231

Eric Loken and Andrew Gelman; Measurement error and replication crisis: the assumption that measurement error always reduces effect sizes is false. Science, 2017, 355: 584-585.

- Formal guidance and rationale should be developed by ICES in regards to when, how, and justifications for changing reference points. The current process is ad hoc.

# 3 Northeast Atlantic Mackerel

## 3.1 Issue List

A list detailing the issues that WGWIDE considered should be addressed by the benchmark assessment was compiled during WGWIDE 2016 and used to plan the programme of work for WKWIDE. The list is given below:

| STOCK | NEA MACKEREL | |
|---|---|---|
| Stock Coordinator | Afra Egan | afra.egan@marine.ie |
| Stock Assessor | Thomas Brunel | thomas.brunel@wur.nl |
| Data Contact | Afra Egan | afra.egan@marine.ie |

| ISSUE | PROBLEM OR AIM | WORK NEEDED/ POSSIBLE SOLUTION | DATA REQUIREMENT (SOURCE) | REQUIRED EXPERTISE/ CONTACT |
|---|---|---|---|---|
| Input Data- Landings | Update of time–series | Request updates to historic time–series | National data submitters | Afra Egan |
| Input Data- Discards | Update of time–series | Request updates to historic time–series | National data submitters | Afra Egan |
| Input Data- Length Frequency | Update protocol for length measurement | Request updates to historic time–series, length measurement protocols | National data submitters | Afra Egan, Teunis Jansen |
| Input Data- Maturity | WGBIOP concerns over maturity scales. Update to methodology | Revision of the methodology for calculation of the ogive | | Thomas Brunel |
| Input Data-Natural Mortality | Review available information | | Tagging Data, previous methodology, Relation with age – similar species/stocks | Steve Mackinson (multispecies models), Claus Reedtz Sparrevohn (tagging) |
| Input Data-Weights | Considered at WKPELA 2014. | No planned revisions to methodology. | | |
| Tuning Series- Recruitment Index | Further refinement of recruitment index | Include some North Sea stations. Investigate/correct for the effects of varying length measurement protocols | DATRAS, National data submitters | Teunis Jansen |
| Tuning Series – Egg Survey | Review of survey coverage for 2016. Updated survey time–series. | 2016 will not be finalised until April 2017. Distribution of percentiles of egg counts (50/90). Review of revisions between preliminary and final estimates. | | Finlay Burns, Brendan O'Hea, Gersom Costas |
| Tuning Series – Egg Survey | Review possibilities for additional sampling on existing survey programmes in relation to the monitoring of egg counts in years between scheduled egg surveys. | Investigate and draft appropriate recommendations. | | WGMEGS |

| | | | | |
|---|---|---|---|---|
| Tuning Series – IESSNS | 1-Consider the appropriateness of individual surveys for inclusion within the index (e.g. 2007)<br>2-Examine the feasibility of extending the number of ages included in the final index<br>3-Consider alternative metrics for the index such as absolute number or de-trended data?<br>4-StoX index calculation/ survey stratification | Produce analysis/maps to show that the survey adequately covers the ages proposed for inclusion.<br>Plot/calculate density and abundance index for core area based on centre of gravity (with a fixed radius) in the Norwegian Sea across ages 2-11.<br>Summary plot for the distribution changes (vector plot).<br>Density/abundance index based on alternative stratification schemes.<br>Comparing the model goodness of fit and the sensitivity of the output for a range of exploratory assessment runs with different configurations for the incorporation of the IESSNS survey. | | Leif Nottestad<br>Jan Arge Jacobsen<br>Gudmundur Oskarsson<br>S. Jónsson<br>Kjell Utne<br>Teunis Jansen<br>Anna Olafsdottir |
| Tuning Series – Tagging | Incorporate the RFID tagging time–series as an index within the SAM assessment. Investigate potential anomalies in the tagging estimates of stock size. | Incorporate the new tagging data time–series in the assessment as a separate time–series (i.e. with survival and variance parameters different from the old tag data time–series). Sensitivity analysis to investigate potential differences between screening locations. | Biological sampling data from 2014 onwards from Scotland. An updated tagging/recovery data time–series should be provided by IMR (Norway) | Scientists involved in the Norwegian tagging program (Aril Slotte, IMR, Norway). Steve (Scottish data) Anna O. (Icelandic Data) SAM model developer for technical support (Anders Nielsen, DTU-Aqua, Denmark). |
| Stock – components | Review available information on the relative size of the individual stock components. Relate the components with TAC split and biology differences and interactions | | | Martin Pastoors, Finlay Burns |

| | | | | |
|---|---|---|---|---|
| Stock – components | Uncertainty regarding the existence of a distinct North Sea component. Are the current protection measures in place for this component appropriate. | 1a) Is there a need for protection measures for the North Sea component?<br><br>1b) Is it possible to split catches in the North Sea into different components? | | 1a) Martin Pastoors/ Teunis Jansen<br>1b) Martin Pastoors/ Teunis Jansen/Afra Egan |
| Assessment Method – Improvement of the SAM model settings | There are indications that the parameters configuration used for the SAM model should be revised. For instance, the assumption of a unique observation variance for all ages for the catch data does not seem appropriate (by the look of the residuals). In addition, a modification of the 2014 benchmark settings has already been made by WGWIDE (replacing the random walk on the recruits by a stock-recruitment model). A full investigation of the parameters configuration is required to identify an optimal configuration.<br><br>Investigate whether the index from the survey carried out in year Y be first used in the assessment in year Y, or in year Y+1 when other data (*e.g.* catches) for year Y are also available? | 1-Conduct a series of exploratory runs with different parameter configurations and identify an optimal configuration based on goodness of fit and assessment stability criteria.<br><br>2-Look in to the year effects, within SAM model<br><br>3- Evaluate the patterns of processing errors and the consequences of it in the model. | No specific data requirements | Thomas Brunel<br>Teunis Jansen<br>Ander Neilsen |
| Assessment Method – Uncertainty on input | Include uncertainty on inputs | Incorporate age-segregated precision estimates on all tuning series and catch data used as input data | | Thomas Brunel<br>Anders Neilsen<br>Andrew Campbell |

| | | | | |
|---|---|---|---|---|
| Biological Reference Points | Investigate reference points under benchmarked assessment outcomes | Run long–term (stochastic) equilibrium simulations using the R *eqSim* package | | Andrew Campbell, Thomas Brunel, David Millar, Kjell Utne |
| Research and Review | Mackerel box/ nursery area information | | | Martin Pastoors |
| Research and Review | Distribution of mackerel in the North Sea during summer. Estimates by Year.<br>Hydrographic conditions in the northern North Sea – location of thermocline, fronts, mixed areas. | | HERAS, commercial catch (bycatch of mackerel in the herring fishery).<br>Other sources of hydrographic data? | Jeroen, Sasha,<br>Martin Pastoors,<br>Andrew Campbell |
| Research and Review | Investigation into the catchability at age of the IESSNS swept area survey in relation to environmental conditions. | | | Teunis Jansen |

## 3.2 Input Data Updates

### 3.2.1 Egg Survey

The NEA mackerel egg survey (MEGS) has been running triennially since 1977 and since 1992 has incorporated both the southern and western components of the NEA mackerel stock. The MEGS survey utilizes an adaptive survey methodology in the Northeast Atlantic that currently ranges from Iceland and the Faroe Islands down as far south as Cadiz and provides a total annual egg production estimate (TAEP) for both components using the most recently spawned stage 1 mackerel eggs. The TAEP is then converted after incorporating the relative realized fecundity estimate (RRF) into a spawning-stock biomass estimate (SSB). It is the only fishery–independent SSB estimate currently utilised in the mackerel assessment and in addition also provides a TAEP index for western horse mackerel. A comprehensive description of the methodologies utilized during the collection and subsequent analyses of the MEGS data can be found in the manual for the mackerel and horse mackerel egg surveys (ICES, 2014b).

Ahead of the NEA mackerel benchmark in 2017 the two main areas of concern surrounding the MEGS survey were the survey boundary issues that were raised subsequent to the presentation of the preliminary 2016 egg survey results at WGWIDE in 2016 (ICES, 2016) and the progress of the new total annual egg production (TAEP) estimation script that had been developed after the previous mackerel benchmark in 2014 (ICES, 2014a).

**Review/Update of 2016 MEGS Survey Results**

A presentation was delivered to DCWKWIDE in November 2016 (Annex 3, this report) which provided an updated revised estimate of the 2016 TAEP/SSB estimates. An error was detected within the Faroese data that had the net effect of overestimating (by around 50%) mackerel egg abundance for these stations. This affected all samples found along the Northern boundary during survey periods 5 and 6 and once corrected, reduced the majority of egg counts on these boundary stations to single figures thus providing a harder survey boundary. A series of maps presenting mackerel spawning distribution over the last 7 MEGS surveys was presented at the workshop. The distribution of survey rectangles representing 90% of the total spawning demonstrated the large changes which have taken place in spawning behaviour over the period 2001-2016. The rectangles accounting for 50% of the total spawning were also presented and both highlight the change in the location of the core spawning area over the same period with the data appearing to show spawning activity moving northwards and increasingly away from the shelf edge and over deeper water.

Also covered were the challenges the MEGS survey faced in 2016 and specifically its reduced geographical coverage, due to extension of the spawning season and reduced number of participating institutes, when compared to 2010 and 2013. Proposals for future work ahead of the next MEGS survey in 2019 including a potential additional egg survey were also presented. For further details, see the working document of Burns *et al.*, 2016.

**Improvements since WKPELA 2014**

WGMEGS presented a working document (Costas *et al.*, 2017) to the benchmark reviewing the work undertaken on the survey dataset together with the progress made in developing the new egg abundance estimation script since the previous benchmark meeting in 2014 (ICES, 2014a). A final set of revised TAEP and SSB indices for NEA mackerel were also delivered within this working document. See table 3.2.1 for reported SSB estimates. A detailed explanation of the bugs detected within the previous versions of the script and the results of comparative checks that were undertaken to quality check the final version of the script and SSB calculations are given in the working document.

**Table 3.2.1. Reported estimates of NEA mackerel SSB from egg survey 1992 – 2016.**

| MACKEREL SSB (T) | COMPONENT | 1992 | 1995 | 1998 | 2001 | 2004 | 2007 | 2010 | 2013 | 2016[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| Pre-2014 (Lockwood equation, Mendiola equation for 2013 survey) | Southern | - | 3.09*e5 | 8.00*e5 | 3.70*e5 | 2.80*e5 | 7.01*e5 | 8.58*e5 | 1.28*e6 | - |
| | Western | 2.93*e6 | 2.47*e6 | 2.95*e6 | 2.53*e6 | 2.47*e6 | 2.95*e6 | 3.43*e6 | 4.29*e6 | - |
| | Combined | 2.93*e6 | 2.78*e6 | 3.75*e6 | 2.90*e6 | 2.75*e6 | 3.65*e6 | 4.29*e6 | 5.57*e6 | - |
| WGWIDE 2014 (Mendiola equation) | Southern | 5.54*e5 | 4.51*e5 | 1.04*e6 | 4.73*e5 | 3.63*e5 | 7.50*e5 | 9.45*e5 | 1.21*e6 | - |
| | Western | 3.35*e6 | 3.39*e6 | 3.38*e6 | 2.80*e6 | 2.80*e6 | 3.22*e6 | 3.89*e6 | 3.82*e6 | - |
| | Combined | 3.90*e6 | 3.84*e6 | 4.42*e6 | 3.27*e6 | 3.17*e6 | 3.97*e6 | 4.84*e6 | 5.03*e6 | - |
| WGWIDE 2015, 2016 (Mendiola equation) | Southern | 6.72*e5 | 6.01*e5 | 1.19*e6 | 4.79*e5 | 3.70*e5 | 9.45 *e5 | 1.15 *e6 | 1.39*e6 | 4.43*e5 |
| | Western | 4.26*e6 | 3.90*e6 | 3.56*e6 | 3.11*e6 | 3.11*e6 | 3.48 *e6 | 4.29 *e6 | 4.24*e6 | 3.54*e6 |
| | Combined | 4.94*e6 | 4.51*e6 | 4.74*e6 | 3.58*e6 | 3.48*e6 | 4.43 *e6 | 5.44 *e6 | 5.63*e6 | 3.99*e6 |
| WKWIDE 2017 (Mendiola equation) | Southern | 5.07*e5 | 3.70*e5 | 8.83*e5 | 4.17*e5 | 3.09*e5 | 7.45 *e5 | 9.26 *e5 | 9.04*e5 | 4.27*e5 |
| | Western | 3.37*e6 | 3.40*e6 | 3.32*e6 | 2.82*e6 | 2.80*e6 | 3.23 *e6 | 3.88 *e6 | 3.93*e6 | 2.94*e6 |
| | Combined | 3.87*e6 | 3.77*e6 | 4.20*e6 | 3.23*e6 | 3.11*e6 | 3.98 *e6 | 4.81 *e6 | 4.83*e6 | 3.37*e6 |

1. Preliminary values.

WGMEGS was also asked to comment on the impact of WGWIDE using initial fecundity calculations in survey year versus final calculations in the year post survey. While the difference between initial and final estimates could be as high as 17% it was found that, due to the weighting of the survey in the assessment model, the impact of this difference was minimal in terms of the model output. It was therefore agreed that WGMEGS would continue to present preliminary SSB results for NEA mackerel to WGWIDE within the survey year.

### 3.2.2 Evaluation of the International Ecosystem Summer Survey in Nordic Seas (IESSNS) from 2007 to 2016

The IESSNS provides an age-disaggregated index of mackerel. It is the only annual fishery independent tuning series used in the mackerel assessment (ICES, 2014a). IESSNS is a swept-area surface trawl survey targeting the Northeast Atlantic mackerel stock as they feed in the Nordic seas during summer (Nøttestad *et al.*, 2016). The IESSNS was first executed in 2007, and annually since 2010. In 2016, four nations and five vessels participated in the survey covering approximately 3 million km$^2$. Trawl design, its operation, and sampling protocol are standardized between vessels and nations (ICES, 2013a). For details see the working document to WKWIDE of Olafsdottir *et al.*, 2017.

The IESSNS index was included in the assessment at the benchmark on NEA mackerel in February 2014 (ICES, 2014a). Since then three additional survey points have been collected. We argue that the additional survey points warrant revision of the method used to establish the tuning series used in the assessment. On basis of various analyses, the conclusion is that the IESSNS tuning series should be utilized in the mackerel assessment model as following:

a) Stratified approach using the StoX software to calculate mackerel age-segregated index and coefficient of variation (Salthaug *et al.*, 2017),
b) an annual swept-area age-structured abundance index,
c) for age 2 to age 11,
d) exclude years 2007 and 2011,
e) expand coverage to include the area from 60 °N northwards (east of longitude -2 W) (see Nøttestad *et al.*, 2016).

The WKWIDE 2017 meeting accepted the five above advices without any changes. However, during the assessment model evaluation it became evident that age 2 needed to be eliminated from the IESSNS index series as correlation structure was added to the IESSNS data to reduce bias due to year effects. The correlation structure could not be added to the dataset with age 2 included. Furthermore, during the model fitting process catchabilities were separated for all ages except age 10 and age 11, catchability of age 3 was decoupled from other ages, and observation variances for age 3 was decoupled from age range 4 to 11. For technical details of the model fitting see section 3.3. Scientists attending the benchmark did not agree whether catchabilities should be separated for all ages in the IESSNS surveys. Several participants asked for more time to study these technical model details in collaboration with statistical scientists at their institutes before making a final decision. The benchmark reviewers decided not to postpone the decision and decided to include separated catchabilities for all age groups, except age 10 and 11, from the ISSSNS in the assessment model.

**Table 3.2.2 IESSNS estimated mackerel abundance (thousands), calculated using StoX, for ages (3-11) and years (2010, 2012-2016) included in the final version of the assessment model.**

| YEAR | AGE 3 | AGE 4 | AGE 5 | AGE 6 | AGE 7 | AGE 8 | AGE 9 | AGE 10 | AGE 11 |
|---|---|---|---|---|---|---|---|---|---|
| **2010** | 1617005 | 4035646 | 3059146 | 1591100 | 691936 | 413253 | 198106 | 65803 | 24747 |
| **2012** | 1283247 | 2383260 | 2164365 | 2850847 | 1783942 | 740361 | 299490 | 149282 | 84344 |
| **2013** | 9201746 | 2456618 | 3073772 | 3218990 | 2540444 | 1087937 | 377406 | 144695 | 146826 |
| **2014** | 7034162 | 4896456 | 2659443 | 2630617 | 2768227 | 1910160 | 849010 | 379745 | 95304 |
| **2015** | 2539963 | 6409324 | 4802298 | 1795564 | 1628872 | 1254859 | 727691 | 270562 | 72410 |
| **2016** | 1374705 | 2635033 | 5243607 | 4368491 | 1893026 | 1658839 | 1107866 | 754993 | 450100 |

### 3.2.3Tagging

#### Steel-tags time-series

The Institute of Marine Research (IMR) in Bergen conducted tagging experiments with internal steel tags on mackerel from 1968 onwards, both in the North Sea and to the west of Ireland during the spawning season May–June. These tags were recaptured at metal detector/deflector gate systems installed at plants processing mackerel for human consumption. This system demanded a lot of manual work, paying for external personnel to stay at the plants during processing. Among the typical 50 fish deflected, the hired personal had to find the tagged fish with a hand-hold detector and send the fish to IMR for analysis. Here the age of the fish, and hence age at release was read by age readers among other biological information, to estimate number recaptured by year class. Numbers released by year class and screened by year class was estimated by length measurements of each tagged fish and length measurements of fish screened in combination with representative biological samples with aging (Age–length keys).

The information from mackerel tagged west of Ireland with was included in the mackerel assessment after the benchmark process in 2014 (ICES, 2014a), based on recaptures up to 2006 and from releases from 1977 to 2004. The actual format of the tagging data used in the assessment is as numbers tagged of a year class in a specific year, the numbers recovered of this year class from that release year in all successive years, as well as the numbers screened by year class in all years.

The assessment model SAM was developed to incorporate this tag data format, where tag recoveries for each year (recaptures from same year as tagging excluded) and each age class from age 2+ were modeled based on the number of fish screened in the processing factories, the amount of fish tagged in the previous years, and the corresponding abundances-at-age estimated by the model, conditional to a post-release survival rate (time invariant and for all ages) estimated by the model. Given the nature of this data (count data with over-dispersion) a negative binomial error model was used.

Incorporation of the tagging data to the assessment proved to be very influential for the historic SSB levels of the stock. The model without tagging data estimated a completely flat SSB until the mid-2000s, whereas the inclusion showed and decreasing SSB from about 4 million t in the early 1980s to levels about 2 million t in the period 1995–2000.

### RFID-tags time-series

In the present WKWIDE benchmark a new time–series of tag-recapture data using radio-frequency identification (RFID) technology, was accepted for use the future assessments (Slotte and Hjartakker 2017). RFID is a technology that uses radio waves to transfer data from an electronic tag, called an RFID tag, through an antenna-reader system to identify and tracking the object. The RFID tagging project on NEA mackerel was started in 2011 by IMR in Norway, with the objective to make the whole process of tag-recapture more automatic and effective then the steel tag technology, resulting in an improved tag-recapture data to use in the assessment.

It was decided to use the RFID time–series in future assessments of NEA mackerel. The time–series was in the same format and used in the SAM model in the same manner as the steel-tag time–series. However, there are a few clear differences between the steel tag time–series and RFID time–series that needs to be mentioned:

- Unlike the steel tagged fish RFID tagged fish are never removed from production, data is automatically updated in a database in Bergen whenever a tagged fish is recaptured at a factory, with information linked to all data recorded at time of release.
- All RFID tagged mackerel are linked to the age length key (ALK) at time of release, thus a recaptured fish has a distribution of ages between 0 and 1, summing up to 1 tag, compared with the steel tag data where one recapture was aged read to one specific age group. This means that numbers recaptured of a year class from a specific release year and recapture year will be in decimals for the RFID data compared to whole numbers for the steel-tags.
- The biomass, catch area and seasons screened for tags has increased heavily with the introduction of RFID, leading to more recaptures to work with. Now around 300,000 t is screened annually, whereas the biomass screened for steel tags were about 10 times lower around 30,000 t annually. The reason behind the increase is that more factories are having RFID antenna systems installed, given that it does not need much maintenance and works automatically. The RFID-tagged mackerel are currently recaptured at 16 European factories processing mackerel for human consumption. The project started with RFID antenna reader systems connected to conveyor belt systems at 8 Norwegian factories in 2012. Now there are 5 operational systems at 4 factories in UK (Denholm has 2 RFID systems), 3 in Iceland, and 1 at the Faroes. In addition, more systems are also bought by Denmark (1) and Ireland (3), which up to now has been non-operational.
- Analyses were presented at the benchmark indicating that we have differences in recapture rates within same year classes between factories, and to some extent between countries. The SAM model was tested using factory specific estimations of post-release survival rates (estimated by the model), with similar indications of factory differences. Still it was decided that is was better to merge data from all factories and treat the data as one data set as with the steel tag time–series to not over complicate the parameterization of the model. It was also anticipated that in future screenings of tagged fish each factory or country would contribute similarly from year to year, and that this effect would probably be of minor significance to the assessment. However, it is something that needs to be followed up in the future, as the reasons behind the factory or country differences are not clear.

- The SAM model estimations indicate significant differences in post-release survival rates between the steel tag time–series (estimated to be around 40%) and the RFID-time–series (estimated to be around 10%). The reason behind the much lower survival rates in the steel tag time–series is not conclusive; it may be linked to actual differences in mortality linked to the operations during the catch and tagging process, shedding processes or the efficiency during screening at the factories. The most likely explanation is that a change in the fishing process. The steel tagged fish were caught with manual jigging, and carefully unhooked and release into tanks, then tagging and direct release to the sea on the fishing side of vessel. The RFID tagged fish is caught with use of automatic tagging machines, being more effective and fishing a little deeper, yet likely leading to more rough handling of the mackerel during the hauling and leading into open pipes onboard prior to careful unhooking and release into tanks. Also RFID tagged fish is released through pipes on the opposite side from where fishing. The idea is that although the tagging mortality may have increased, at least the 4 machines fishing are doing the same thing within and between surveys, which was not the case with individual persons manually fishing the mackerel. So hopefully the variation between surveys has deceased.

The RFID data appears as a positive contribution to the SAM assessment and will hopefully create some more stability in an assessment with conflicting time–series. Given that this project has developed from pure Norwegian in the two first years 2011–2012 to an international one with RFID system in factories in more countries, the possibility of creating errors in the data or adding uncertainty has increased. The future quality of the RFID-time–series for use in the NEA mackerel stock assessment clearly relies on work from each country's research institutes, fisheries authorities or the industry it selves to provide additional data for the RFID data base about accurate biomass of catches screened through the RFID systems, position of catch (ICES rectangle), mean weight in catch etc. Regular representative biological sampling of the catches landed at these factories with aging is also needed for the data base. Altogether, these data are essential for the estimation of numbers screened per year class, which is an important input to the tag data-table currently used in the SAM-assessment for steel tags. It is expected that responsible persons in each country having RFID-systems contribute with all these necessary data, quality checked, on an annual basis for future assessments in WGWIDE.

### 3.2.4Recruitment Index

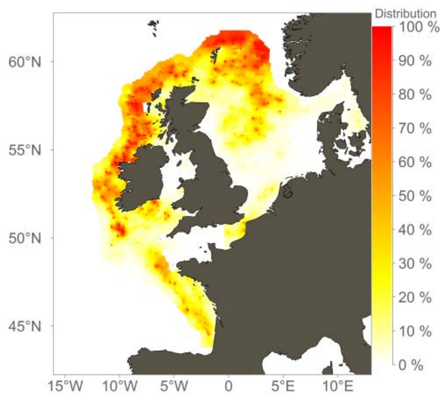
**The Data and the Model**

An index of survivors in the first autumn-winter (recruitment index) was derived from a geostatistical model fitted to catch data from bottom trawl surveys conducted during autumn and winter. A complete description of the data and model can be found in Jansen *et al*. (2015) and the stock annex.

Data was compiled from bottom trawl surveys conducted between October and March from 1998—2016. Surveys conducted on the European shelf in the first and fourth quarters are collectively known as the International Bottom Trawl Survey (IBTS). All surveys sample the fish community on the continental shelf and upper shelf slope. IBTS Q4 covers the shelf from Spain to Scotland, excluding the North Sea, while IBTS Q1 covers the shelf waters from north of Ireland, around Scotland, and into the North Sea.

Trawl operations during the IBTS have largely been standardized through the relevant ICES working group (ICES, 2013b). Furthermore, the effects of variation in wing-spread and trawl speed were included in the model (Jansen *et al*., 2015). Trawling speed was generally 3.5—4.0 knots, and trawl gear is also standardized and collectively known as the Grande Ouverture Verticale (GOV) trawl. Some countries use modified trawl gear to suit the particular conditions in the respective survey areas, although this was not expected to change catchability significantly. However, in other cases, the trawl design deviated more significantly from the standard GOV type, namely the Spanish BAKA trawl, the French GOV trawl, and the Irish mini-GOV trawl. The BAKA trawl had a vertical opening of only 2.1—2.2 m and was towed at only 3 knots. This was considered substantially less suitable for catching juvenile mackerel and, therefore, was excluded from the analysis. The French GOV trawl was rigged without a kite and typically had a reduced vertical opening, which may have reduced the catchability of pelagic species like mackerel. Catchability was assumed to equal the catchability of the standard GOV trawl because testing has shown that the recruitment index was not very sensitive to this assumption (Jansen *et al*., 2015). Finally, the Irish mini-GOV trawl, used during 1998—2002, was a GOV trawl in reduced dimensions.

A geostatistical log-Gaussian Cox process model (LGC) with spatiotemporal correlations was used to estimate the catch rates of mackerel recruits through space and time. The modelled average recruitment index (squared CPUE) surface was mapped in Figure 3.2.4.1. The time–series of spatially integrated recruitment index values was used in the benchmark assessment as a relative abundance index of mackerel at age 0 (recruits) – see Figure 3.2.4.2.



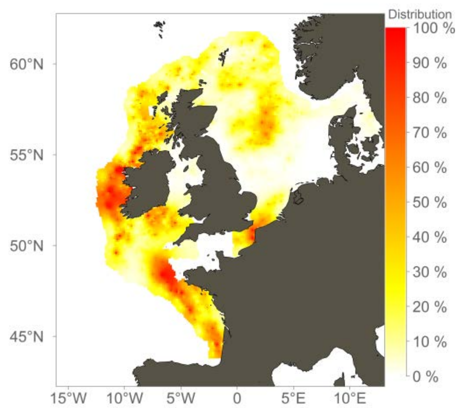




**Figure 3.2.4.1. Distributions of modelled squared catch rates of mackerel at approximately 3-9 months of age in first and fourth quarter demersal trawl surveys. Left) average rates for cohorts from 1998-2015, and Right) 2015 cohort. See Jansen *et al.* (2015) for details.**

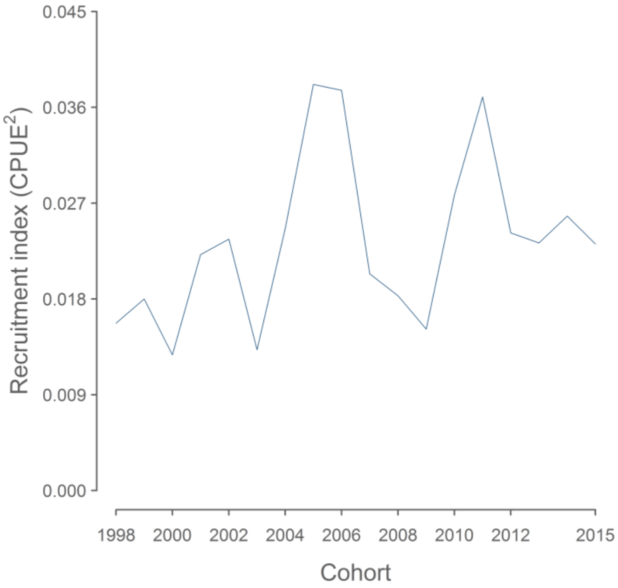



**Figure 3.2.4.2. IBTS recruitment index derived from spatially integrated square root transformed mean CPUE estimates. See Jansen et al. (2015) for details.**

**Survey Coverage**

The survey has insufficient spatial coverage in some areas, namely: (i) Since 2011, the English survey (covering the Irish sea and the central-eastern part of the Celtic sea including the area around Cornwall) has been discontinued, (ii) the Scottish survey has not consistently covered the area around Donegal Bay, (iii) the southern Norwegian Sea is known to be an important nursery area during summer (see IESSNS) and the IBTS observed high catch rates at the north-eastern edge of the survey area (towards the Norwegian trench) in winter. It is therefore possible that recruits are present further North along the shelf edge of Norway. It is therefore recommended that the Norwegian shelf is surveyed using IBTS-standards in January further north of the Norwegian trench.

**Catchability**

A study of the vertical distribution of juvenile mackerel during winter and its availability to the GOV-trawl was performed in 2014 (Jansen *et al.*, 2015). However, the study area may or may not be representative for the entire survey area. Furthermore, vessel and gear avoidance behaviour has not been studied. This could be done using multi-frequency echosounder and multi-beam sonar recordings, as well as underwater cameras. WKWIDE recommends that such studies are initiated.

**Data Quality**

Two sources of errors in the current input dataset were detected during preparations for the benchmark:

1 ) Data from 2015 and 2016 from the Scottish survey was revised, affecting the estimation of the catch rate of recruits from the 2015 year-class. This should be included in the next revision of the age–0 time–series.

2 ) The ICES DATRAS mackerel data product "CPUE by age and haul" was found to be missing up to 63% of the annual NS-IBTS Q1 hauls uploaded to

DATRAS, affecting primarily 2010, 2011, 2012 and 2015. This error was corrected by database administrators during the benchmark meeting. However, there was insufficient time to revise the index for the assessment.

In addition, the following potential sources of uncertainty were identified:

1 ) It has been found that national institutes providing mackerel data from first- and fourth-quarter demersal surveys do not measure the lengths of mackerel consistently. This leads to significant errors when combining age–length and catch–at–length data from multiple institutes. A conversion key has been provided (Hansen *et al.*, 2017) and WKWIDE recommends that length-conversions are implemented in DATRAS to provide a homogeneous data set for the recruitment model.

2 ) Mackerel samples collected on the EVHOE fourth quarter survey are not aged. The current practice of applying age-length keys from Ireland and Scotland to catches in the more southern EVHOE survey is not ideal, because the mackerel growth during the first year is related to latitude (Jansen *et al.*, 2013). WKWIDE therefore recommends that the Spanish age–length keys from the Bay of Biscay are considered for historic data and that Ifremer (France) initiate aging of mackerel starting from autumn/winter 2017.

Given the above issues, WKWIDE recommends a revision of the recruitment index in time for the assessment to be conducted at WGWIDE 2017. This revision should include a reconsideration of the *haul duration* parameter that was removed from the model during WGWIDE 2016 (ICES, 2016).

Finally, for quality assurance purposes, WKWIDE recommends that the input data from Ireland are uploaded to DATRAS before WGWIDE 2017.

For the benchmark assessment WKWIDE used the time–series from WGWIDE 2016 (Figure 3.2.4.2).

### 3.2.5Maturity Ogive

A working document proposing a revision of the calculation method for the maturity ogive for the western component was presented during WKWIDE (Brunel, 2017). It is showed that the proportion of mature individuals per age–class varied depending on the geographic origin of the samples. For instance, age 2 fish sampled in the English Channel were in average 40% mature. Fish of the same age sampled in the Celtic Sea and Bay of Biscay were 60% mature, while age 2 fish from the West of Ireland were 80% mature. It was assumed that young fish would leave nursery areas when becoming mature and move to the spawning ground, which would explain this geographical pattern.

The geographical origin of the samples used to compute the maturity ogives (biological sampling from catches taken in Q1-2) has changed over time. There is therefore a risk, if geographic differences in the proportion mature are not taken into account that part of the variation in the maturity ogive is accounted for by changes in sample origin.

The proposed approach computes the maturity ogive for the western component by calculating a separate maturity ogive for each of 5 geographical zones (see table below), and taking the average of these ogives, weighted by their respective area geographic area.

| GEOGRAPHICAL AREAS USED FOR WEIGHTING THE MATURITY OGIVE FOR THE WESTERN COMPONENT | ICES SUBDIVISIONS | WEIGHT |
|---|---|---|
| Bay of Biscay | 8.ab | 7.3% |
| Eastern Celtic Sea | 7.a,e-h | 20.7% |
| West Ireland | 7.b,c,j,k | 26.7% |
| West Scotland | 6.ab | 42% |
| English Channel | 7.d | 2.9% |

### 3.2.6Natural Mortality

Since the early 1980s, natural mortality (M) for mackerel (and horse mackerel) has been fixed within the assessment model at 0.15, for all ages and all assessment years. This value was calculated based on estimates of total mortality derived from tagging data combined with catch data (Hamre 1978, Anon 1978, Hamre 1980). The first mackerel working group report where this value was given was 1983 (ICES, 1984).

The benchmark was presented with a working document (Mackinson *et al.*, 2017) to consider whether natural mortality should be allowed to vary with age and time, because it is known that

i ) M changes over time due to changes in abundance of predators, feeding conditions, disease etc. (Siegfried and Sanso, 2013)

ii ) M is much higher in small/younger age classes and also for very old fish approaching maximum age. (Chen and Watanabe 1989; Jennings *et al*. 2001, Brodziak *et al*. 2011, Siegfried and Sanso 2013).

Drawing from information from multispecies models parameterised for the North Sea, and empirical models, the working document concluded that there was insufficient evidence to support time varying M, but a sensitivity test should be conducted to evaluate how options for age dependent M affects model performance. Three options were compared with a baseline fixed M=0.15, (Figure 3.2.6.1).

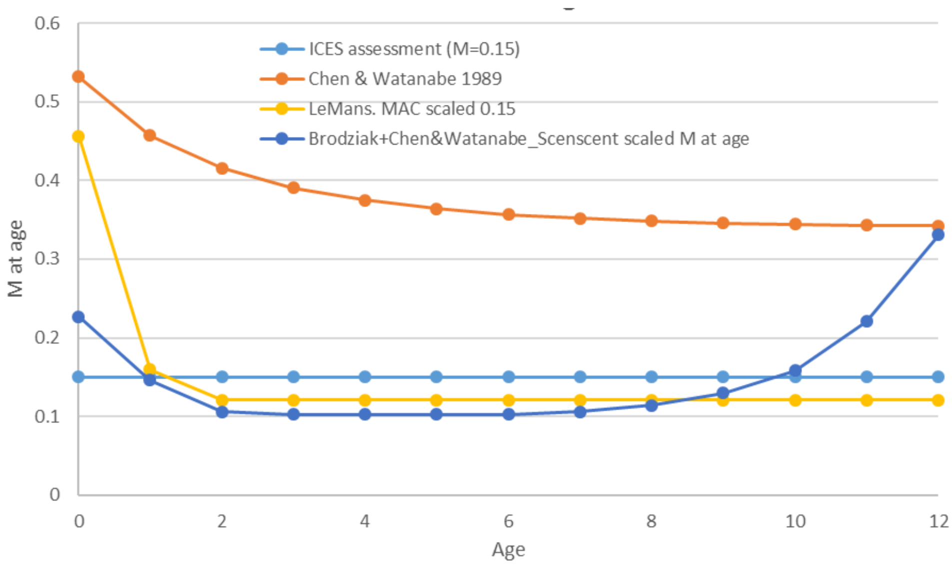



**Figure 3.2.6.1. Mackerel natural mortality (M)–at–age options for sensitivity testing. The *Brodziak + Chen & Watanabe_Scenecent* option is based on formulation from Robin Boyd (pers. comm). The *LeMans* option is based upon the output of LeMans model (Robert Thorpe, pers. comm). See Mackinson *et al.*, 2017 for details.**

## 3.3 Stock assessment

### 3.3.1SAM Model Developments

The basic state-space assessment model (SAM) is described in Neilsen & Berg (2014). The model has been further developed and adapted for the Mackerel stock. These extensions are described here. Furthermore, the model has been re-implemented to obtain faster computation time. It was validated at the working group meeting that the old and new implementation gave exactly the same result.

**Ignoring catches prior to the year 2000.**

The working group requested that the catches–at–age prior to the year 2000 should be ignored by the model. This was implemented by assigning the catch–at–age observations before 2000 a huge fixed variance. A variance of 10 was used for the logarithm of the catches, which corresponds to a coefficient of variation of more than 300%. The effect of this is that the catches before 2000 are down weighted and efficiently ignored in the model fitting procedure.

**Using an index of SSB.**

It was requested by the working group that a yearly index of SSB could be used to inform the model. The index was calculated as a relative index and the model was extended with the observation model:

$$\log(ssb_y) \sim N(\log(q_{ssb} \cdot \widehat{ssb_y}), \sigma_{ssb}^2)$$

where $\widehat{ssb_y}$ is the model predicted spawning stock biomass, $q_{ssb}$ is the catchability parameter, $\sigma_{ssb}$ is the standard deviation parameter, and $ssb_y$ is the observed SSB index.

**Using tagging data.**

It was requested by the working group that a tagging study should be used to inform the model.

The expected number of tags returned $r_{a,y}^{(i,j)}$ at the $i'th$ recapture event from the $j'th$ release is:

$$\mu_{a,y}^{(i,j)} = p_{surv} n_{scan}^{(i)} \frac{R^{(j)}}{N^{(j)}}$$

Here $N^{(j)}$ is the number in the cohort at release time, $R^{(j)}$ is the number of tagged individuals released into the cohort at the $j'th$ release event, and $n_{scan}^{(i)}$ is the number scanned at the $i'th$ recapture event.

To allow for overdispersion the observed number returned is assumed to follow a negative binomial distribution, such that the negative log-likelihood contribution becomes:

$$-\sum_{i,j} \log(f\left(r_{a,y}^{(i,j)}, \mu_{a,y}^{(i,j)}, \emptyset\right))$$

Where $f(x,\mu,\emptyset)$ is the pdf of the negative binomial distribution with mean value $\mu$ and overdispersion parameter $\emptyset$.

As a further extension the implementation allows for separate survival $p_{surv}$ and overdispersion $\emptyset$ parameters for different groups of tagging observations.

**Covariance structure for the swept area survey.**

The working group noticed a yearly pattern in the residuals for the swept area survey. This year effect is an indication that the observed indices for each age group are not independent within a given year. This was built into the model by considering the vector if indices in a year $I_y=(I_{a=3,y},\ldots,I_{a=11,y})$ to follow a multivariate normal distribution with a covariance structure, instead of assuming the indices-at-age to be independent. The observation model becomes:

$$\log(I_y) \sim N(\log(\widehat{I_y}), \Sigma)$$

where $\Sigma$ is the covariance matrix, and $\widehat{I_y}$ is the vector of the usual model predicted indices-at-age. Different covariance structures were tested. The working group decided to use an AR(1) covariance structure across ages, which adds only one model parameter $-1 < \rho < 1$, and express the correlation between two ages groups as $corr(\log(I_{a,y}), \log(I_{\tilde{a},y})) = \rho^{|a-\tilde{a}|}$.

**Residual computation.**

The residual calculation procedure in the state-space assessment model (SAM) has been changed. This was done because the standard practice of calculating the residuals (as 'observed' minus 'predicted' divided by an estimate of the standard deviation) is strictly only valid for models with purely independent observations. It is not valid for state-space models, where an underlying unobserved process is introducing a correlation structure in the (marginal) distribution of the observations. It is also not valid if the observations are directly assumed to be correlated (e.g. multivariate normal, or multinomial for age compositions). The problem is that the resulting residuals will not become independent.

To get independent residuals the so-called 'one-observation-ahead' are computed. The residual for the *n'th* observation is computed by using the first *n-1* observations to predict the *n'th*. Details can be found in Thygesen *et al.* (2017), which is currently under revision.

### 3.3.2 Base case run and approach adopted

During WKWIDE, all exploratory runs were based on the data used at the latest working group meeting (ICES, 2016). This assessment used catch-at-age data from 1980 until 2015 for ages 0 to 12 (plus group). The survey indices for the base case run were:

- Triennial egg survey SSB index covering years 1992 to 2016 (with the preliminary 2016 estimate revised shortly after the 2016 working group).
- The IBTS recruitment index from the 2016 working group covering the period 1980-2015.
- The IESSNS index expressed as a density for the years 2007 and 2010-2016. This index was corrected in January 2017 (hence different from the one used at WGWIDE 2016).

In addition, tagging/recapture data (steel tags) from release year 1980 to recapture year 2006 were also used in the model, as in WGWIDE 2016.

During the benchmark meeting, the effect of the change or addition of different data sources was investigated. Those changes were done one step at a time and a consistent set of diagnostics was used to assess the differences between each exploratory run and the base case assessment. Once a decision was made on a given data source, the base case run was updated on the basis of the decision. The exploratory assessments were judged on the basis of statistical and goodness of fit criteria, rather than on the resulting stock trends. The main criteria used were:

- Model log likelihood comparison (and ratio test) and AIC comparison when the models were fitted on the same data
- Model parameter estimates
- One Step Ahead (OSA) residual plots
- Assessment uncertainty as estimated by the SAM model. The joint uncertainty of the recent SSB and Fbar estimates were investigated based on the "ellipse" plots. The standard deviations of the parameter estimates were also compared.
- Retrospective analyses were also used, even though their usefulness in representing the instability of the assessment was limited due to the short length of some of the time–series (new IESSNS, RFID tag/recaptures).

### 3.3.3 Revision of the IESSNS index

The proposal for modifying the IESSNS index involved two changes compared to the index previously used:

1 ) moving from a density index to an abundance index

2 ) removing the years 2007 and 2011 for which survey coverage was limited. In addition, one of the tasks on the issue list for the benchmark was to investigate whether the estimates from the IESSNS for ages 2 to 5 could be used in the assessment.

#### 3.3.3.1 Abundance estimate versus density estimate

Data and model configuration

The assessment model was first fitted using the IESSNS index expressed as abundance and compared to the base case. This run was made to assess the effect of changing from density to abundance, and the same years and age classes as the original IESSNS index were used (age 6-11 and years 2007, 2010-2016).

Results

The model using the IESSNS expressed as abundance was poorer than the base case in many aspects. The observation variances increased for the egg survey SSB index and for the IESSNS index, indicating that the model had less trust in both surveys. Many parameter estimates had larger standard deviations (larger uncertainty). The uncertainty on final SSB and Fbar estimates (2014 and 2015) also increased dramatically. The retrospective plot also deteriorated.

#### 3.3.3.2 Removing the year 2007 and 2011

Data and model configuration

The assessment model was then fitted using the IESSNS index expressed as abundance excluding the year 2007 and 2011 and compared to the base case. The new proposed index is shorter than the previous one (maximum 5 successive year instead of 7, figure 3.3.3.1). The variation of the abundances at age are in general quite similar to the previous index.

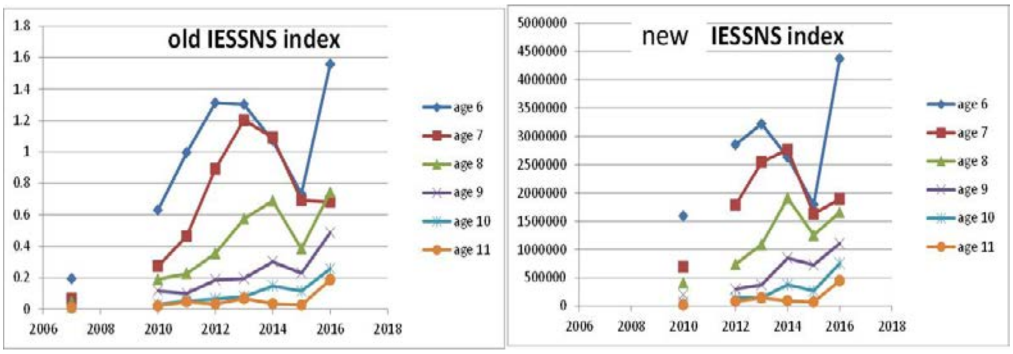



**Figure 3.3.3.1: Comparison of the old IESSNS index (left) and the new proposed index (right).**

Results

The model using the proposed new IESSNS index showed some small improvement compared to the base case run. The run based on the new index had a lower observation variance for the 3 survey indices while the observation variance for the catches slightly increased (figure 3.3.3.2). This indicates that the model considered that all surveys had a lesser variability (though the improvement was large only for the IESSNS index) and therefore a higher weight in the assessment. Other model parameters were very similar except the catchability of the IESSNS changed as a result of the change of unit of the index. This catchability is estimated at a value of almost 2, concretely meaning that the assessment considers that the survey index is twice larger than the model estimate.

The values of the standard deviation of the parameter estimates (not shown) were only marginally different between the 2 models, with slightly less uncertainty on the estimates of the observation variance for the catches and of the egg survey catchability, but slightly higher uncertainty for the process variances and for the observation variance for the IESSNS. There was a small improvement in the overall model uncertainty on the final SSB and Fbar (figure 3.3.3.3).

There was a slightly larger revision of the SSB for the retrospective run with 3 years of data removed for the model with the new IESSNS, and larger revisions in Fbar for the model with the old IESSNS index, but overall retrospective plots for both model runs did not show major differences (figure 3.3.3.4).

The residuals for the catch-at-age, the recapture of tags and the recruitment index for the 2 models were very similar (figure 3.3.3.5 and 3.3.3.6). The residuals for the IESSNS for the model using the new index showed some strong year effects (negative residuals for 2010, and then alternation of positive/negative/positive residuals for 2014-15-16. Year effects were also present in the residuals in the model using the old IESSNS index.

The historical stock development estimated by the models were quite similar, except for a higher estimated Fbar over the recent years for the run using the new index (figure 3.3.3.7)

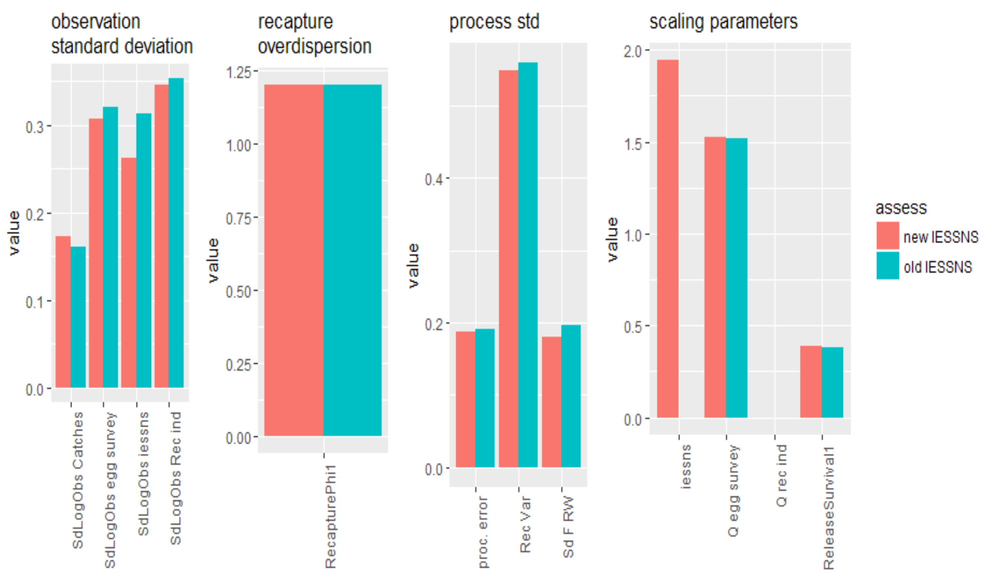



**Figure 3.3.3.2: Model parameter estimates for the base case run (old IESSNS) and the run using the proposed changes in the index (new IESSNS).**

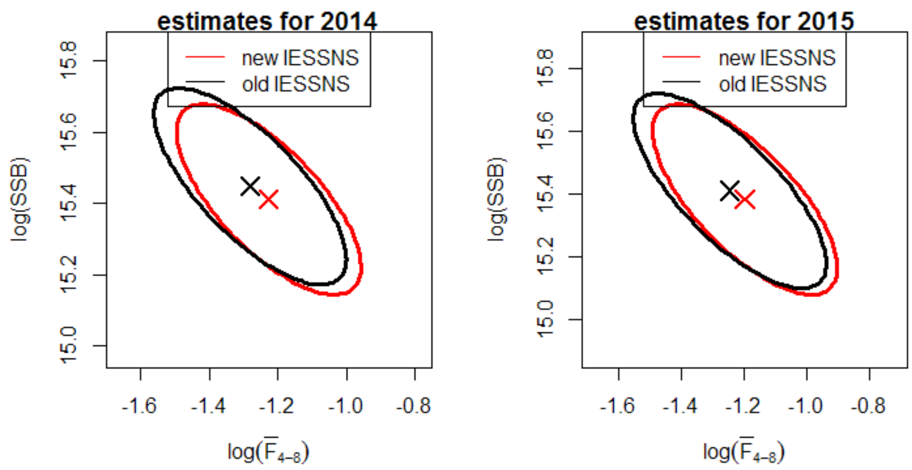



**Figure 3.3.3.3: Joint distribution of the (log) estimates of SSB and Fbar for the last 2 years in the assessment (the crosses depict the point estimate and the ellipse represents the 95% confidence bounds).**

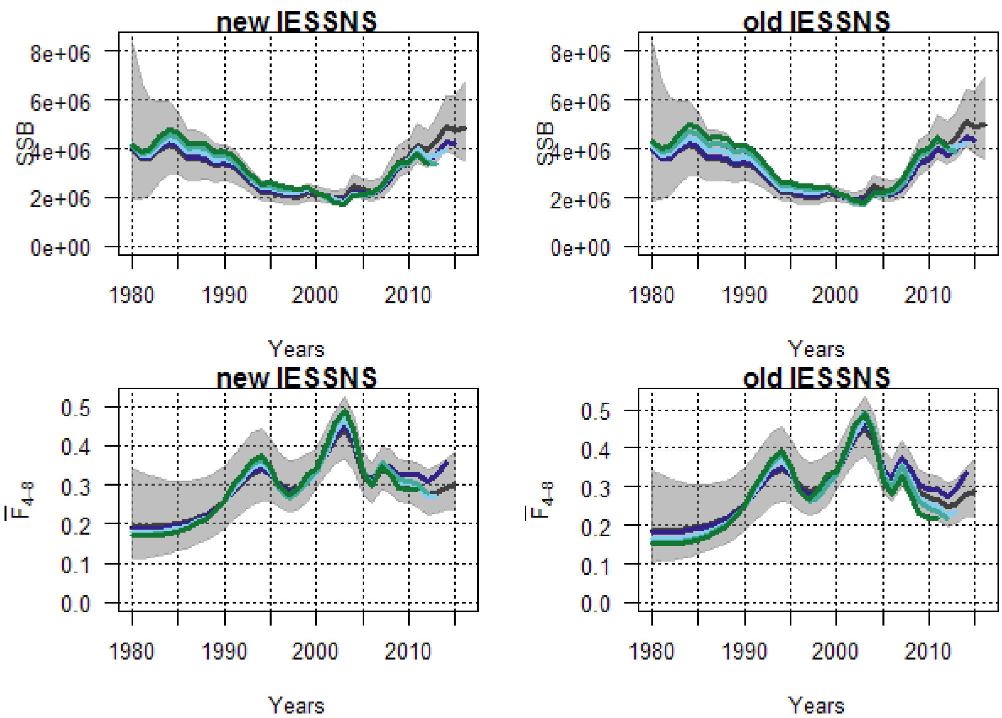



**Figure 3.3.3.4: Retrospective analysis for the assessment run with the new (left panels) and with the old (right panels) IESSNS index**

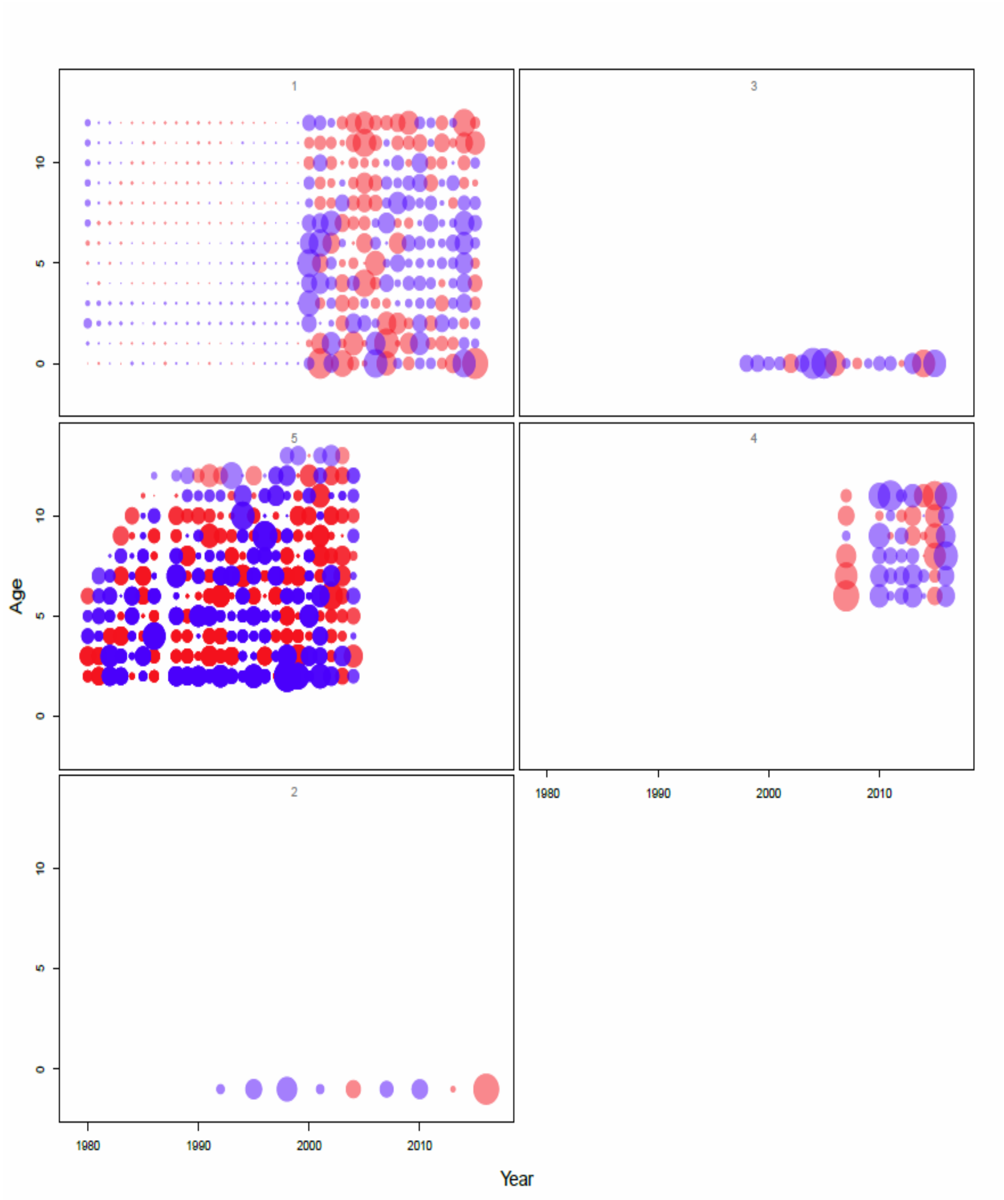



**Figure 3.3.3.5: Residuals for the model fit fitted using the old IESSNS index (1: catch-at-age, 2: egg survey SSB index, 3: recruitment index, 4: IESSNS, 5: recaptures of tags). Red represents negative residuals, and blue represents positive residuals.**

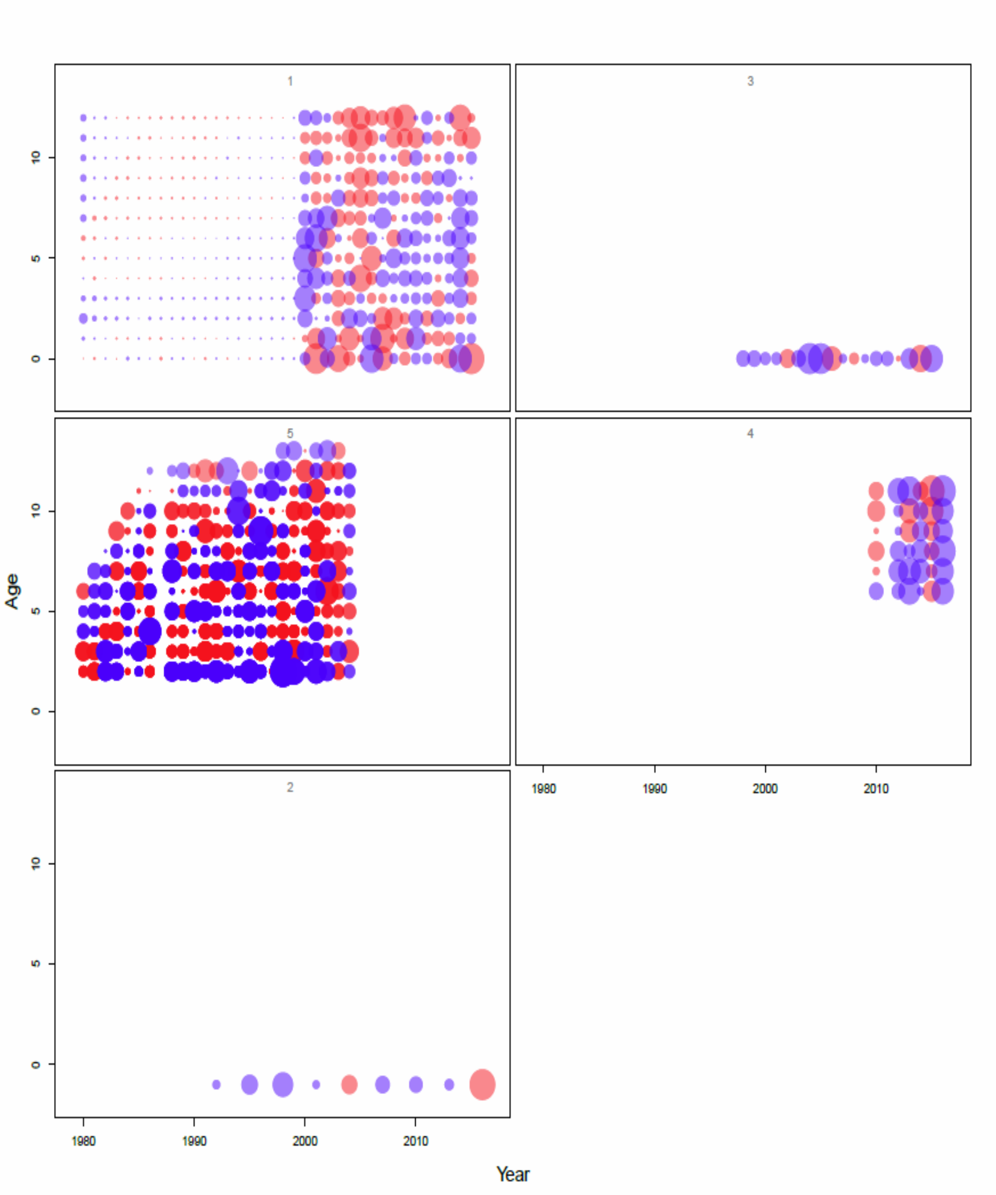



**Figure 3.3.3.6: Residuals for the model fit fitted using the new IESSNS index (1: catch-at-age, 2: egg survey SSB index, 3: recruitment index, 4: IESSNS, 5: recaptures of tags). Red represents negative residuals, and blue represents positive residuals.**

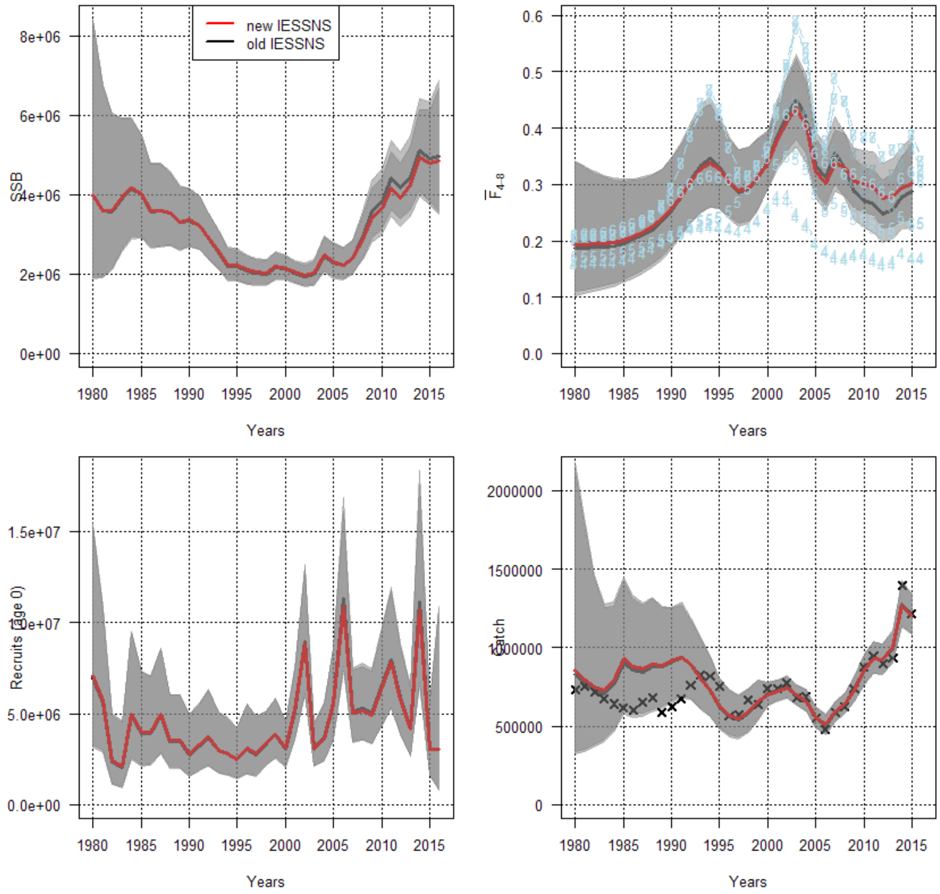



**Figure 3.3.3.7: Estimated stock development from the model fitted using the old and the new IESSNS index.**

### 3.3.3.3Incorporation of ages 2 to 5

Data and model configuration

The additional age classes were included in the model (figure 3.3.3.8). In the base case assessment, a single catchability parameter is estimated for all ages (6–11) for the IESSNS. This configuration was chosen because of the limitations of the previous optimization algorithm (ADMB) which experienced convergence problems for this assessment when too many parameters were estimated by age–group (ICES, 2014a). Given the improved model performance with the new TMB optimizer, a larger number of parameters can be estimated without convergence issues. As a basis for comparison, the base case model was run with the same data, but estimating one catchability per age-class for the new IESSNS. Then, the model was run incorporating also the age-classes 2 to 5, estimating one catchability per age and two observation variances, one for ages 2–3, which are assumed to have a higher variability (see section 3.3.6) and one for ages 4–11.

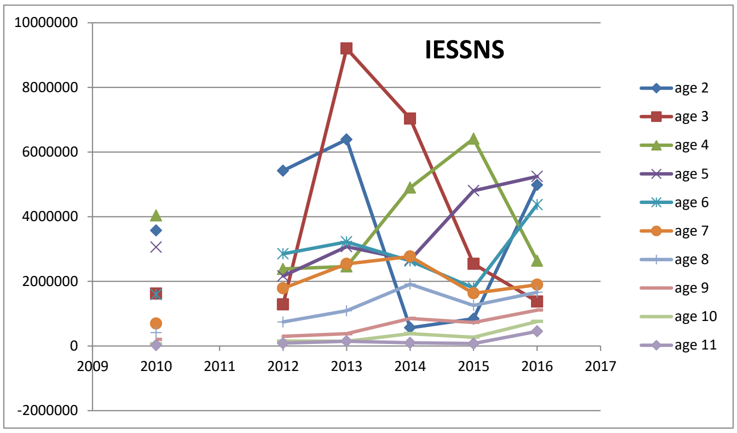



**Figure 3.3.3.8: IESSNS index for ages 2 to 11.**

Results

Estimating a separate catchability for each age–group instead of a single parameter for ages 6–11 in the IESSNS had little effect on the estimated stock trend (figure 3.3.3.9). The estimated catchabilities for age 6 to 11 all have similar values, on average close to the catchability estimated when the ages are grouped (figure 3.3.3.10).

The model incorporating the IESSNS indices for ages 2 to 5 estimated a higher SSB for the last 3 years, and a slightly lower Fbar (figure 3.3.3.9). Further investigation of the age composition of the SSB in this model showed that this increase was mostly due to higher estimates for the abundance of ages 4 and 5.

Model parameters were in general similar for the assessments using ages 6-11 and 2-11 with separate catchability at age (figure 3.3.3.10). The observation variance for ages 2 and 3 was estimated to be high (0.6) indicating that these observations had a low contribution to the model fit. Observation variance for the older ages in the IESSNS was slightly lower than for the model fitted without ages 2 to 5. The observation variance for the egg survey increased also slightly. The estimated catchabilities for the IESSNS increased gradually from 0.5 at age 2 to above 2 for age 7, and decreased moderately for older ages. This pattern conforms to the observation that younger age–classes are present only in a portion of the area covered by the survey, which produces an underestimated. Other parameters show no difference.

The model including ages 2 to 5 had slightly better defined parameters (figure 3.3.3.11), especially process and observation variances. The precision on recent SSB and Fbar were also slightly improved (especially for SSB, figure 3.3.3.12).

The retrospective plots for the assessments using ages 2–11 and 6–11 with multiple catchability were very similar (not shown).

The residuals for most data sources were very similar between the two assessments (and similar to figure 3.3.3.13). The only difference was found for the residuals for the IESSNS due to the addition of the younger ages. The year effects are still visible, even though the negative residuals for the year 2015 are observed only for the older fish.

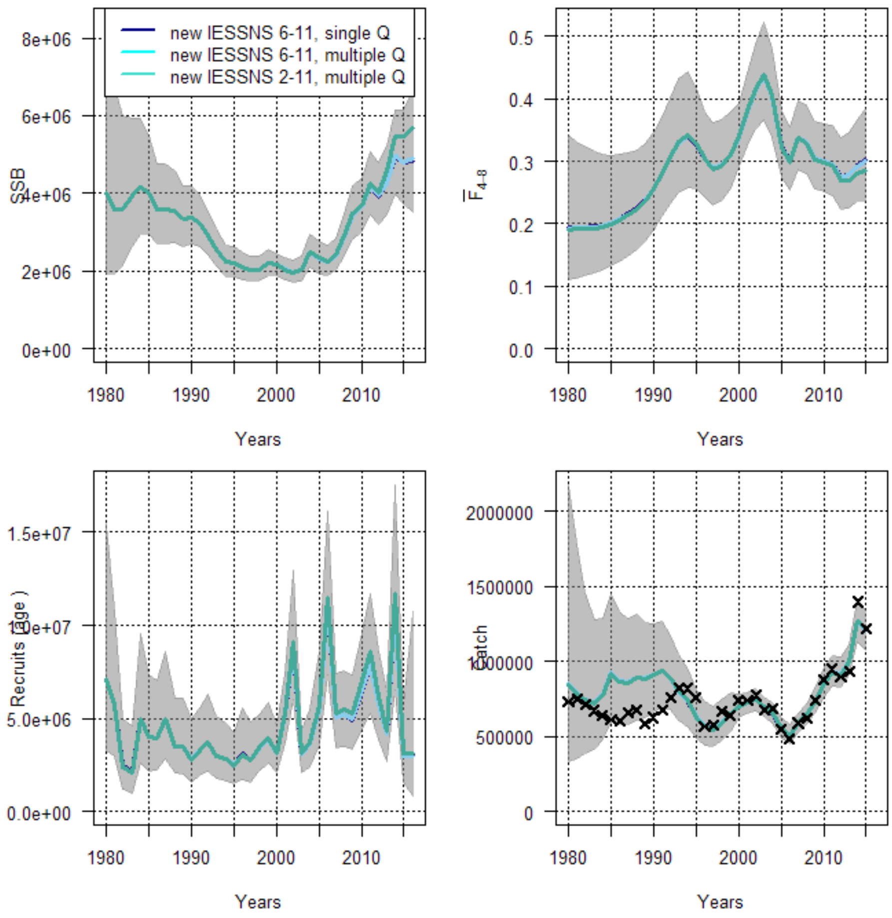



**Figure 3.3.3.9: Estimated stock development from the models fitted using the new IESSNS index for age 6–11 using a single catchability, using an age varying catchability, and using the IESSNS 2-11 with age varying catchability**

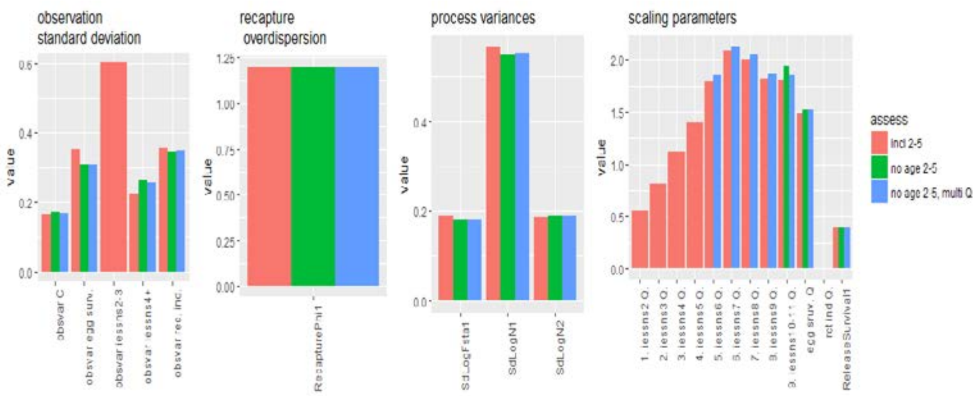



**Figure 3.3.3.10: Parameter estimates for the 3 SAM runs (models fitted using the new IESSNS index for age 6–11 using a single catchability, using an age varying catchability, and using the IESSNS 2-11 with age varying catchability)**

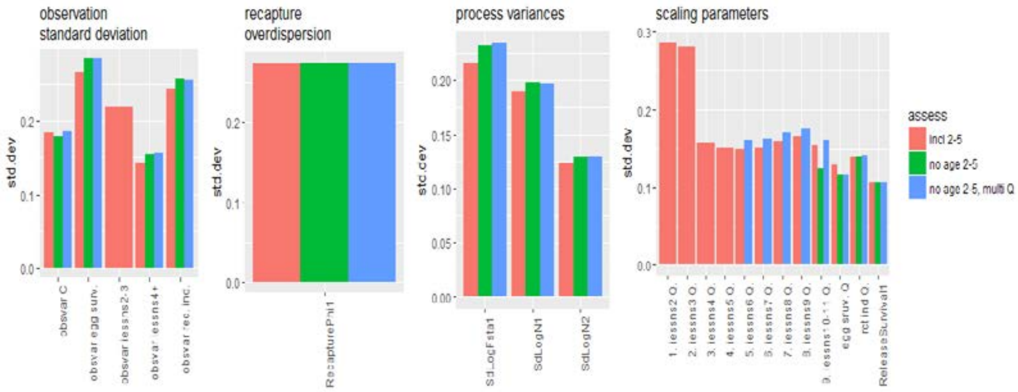



**Figure 3.3.3.11: Standard deviation of the parameter for the 3 SAM runs (models fitted using the new IESSNS index for age 6–11 using a single catchability, using an age varying catchability, and using the IESSNS 2-11 with age varying catchability)**

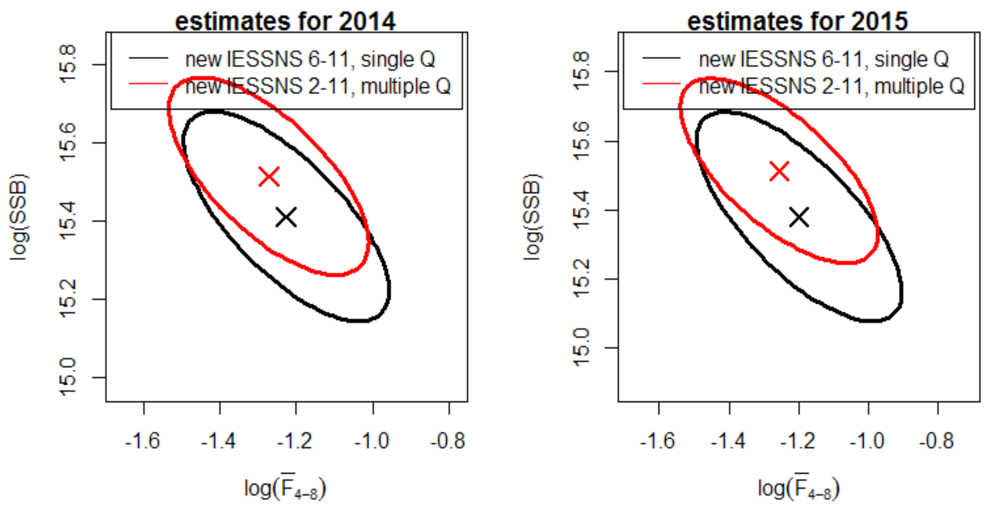



**Figure 3.3.3.12: Joint distribution of the (log) estimates of SSB and Fbar for the last 2 years in the assessment using age 6–11 and the assessment using ages 2–11 from the IESSNS with age varying catchabilities (the crosses depict the point estimate and the ellipse represents the 95% confidence bound).**

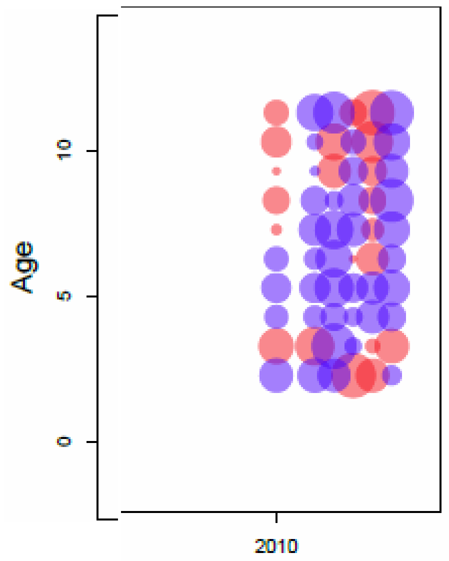



**Figure 3.3.3.13: OSA residuals for the IESSNS ages 2 to 11.**

### 3.3.3.4Conclusions

The use of an abundance index for the IESSNS instead of density index in itself does not seem to affect the model substantially. The main changes observed were a higher weight given to surveys in general, and a minor increase in parameter uncertainty. The proposal to use from now on an abundance index can therefore be accepted, as this calculation method appears to be more appropriate for this survey (see section 3.2.2).

However, the results of these exploratory runs clearly show that if the abundance index is used, the years 2007 and 2011 should be removed. This result was not surprising, as the proposal to move to an abundance index for the IESSNS was combined with the removal of the year 2007 and 2011 for which the lack of geographical coverage of the survey introduced a bias in the index.

In addition, the previously identified issue regarding the year effect remains when this new index is used.

The incorporation of additional age–groups did not result in any problem in the model either. There was even an improvement in the precision of the parameter estimates. These age groups seem to bring new information on the recent abundance of younger age classes, which results in a slightly different perception of the stock in the recent years (higher abundances for age 4 and 5).

Additional sensitivity tests showed that ages 2 and 3 had virtually no influence on the assessment output. It was however decided to keep them in the model as their inclusion did not result in any problem in the model, and they were appropriately handled by the model (they received a low weight (high observation standard deviation)).

### 3.3.4 Incorporation of the RFID tag/recapture data

#### 3.3.4.1 Incorporation of the RFID tags using the same parameters as for the steel tags or a separate set of parameters

Data and configuration

The RFID tag/recapture data available for the benchmark covered the period 2011 (tagging year) to 2016 (recapture) year. The recapture of fish occurring in the same year as their release were not included in the dataset, as the tagged fish may not have remained in the water long enough to have complete mixing with the rest of the population. The youngest age at release was 2 years, and data from fish tagged at an older age than 11 (last age group before the plus group in the model) were not used, as the expected recapture from the model cannot be calculated.

The base case run used is the model using the IESSNS index for ages 2 to 11 with an age varying catchability. A first run incorporating the RFID tags was made assuming that the model parameters (post release survival and recapture overdispersion) for the new tags were the same as for the historical tag dataset. A second run was made estimating separate sets of parameters for each tagging time–series.

Results

The model assuming a single survival rate and overdispersion was clearly not appropriate, estimating unrealistic SSB and Fbar values (figure 3.3.4.1). The post-release survival rate estimated, mostly representative of the steel tags which represent the bulk of the data, appears to be too high for the RFID tags and the model can only deal with the lower recaptured numbers in this dataset by estimating large stock abundance for the corresponding cohorts.

Using a separate set of parameters for the RFID tags significantly improved the model (the log likelihood increased from -2729 to -2681 for 2 additional parameters, $p<0.001$). The estimated stock development was similar to the model not including the RFID tags, except for the last 3 years for which a lower SSB was estimated.

The parameter estimates were in general similar to the model not using the RFID tags (figure 3.3.4.2). The estimated post release survival rate for the RFID tags was estimated to be much lower than for the steel tags (0.39 for the steel tags and 0.08 for the RFID tags). The overdispersion for the recapture of the RFID tags was estimated to be larger than for the steel tags.

The inclusion of the RFID tags did not affect substantially parameter uncertainty (figure 3.3.4.3), but improved the joint uncertainty on the recent SSB and Fbar estimates (figure 3.3.4.4).

The retrospective analysis also showed signs of improvement when the RFID tags are used, especially for the SSB (figure 3.3.4.5).

Finally, inspection of the residuals for the tag recaptures (figure 3.3.4.6) did not show any sign of model misspecification. The only minor concern was for fish released at age 2 for which the predominance of positive residuals suggested that the post-release mortality for those fish may have been lower than for other ages (more tags return than expected). This minor problem can be addressed by estimating a separate set of parameters for fish released at age 2, but this option was not tested during the meeting due to lack of time.

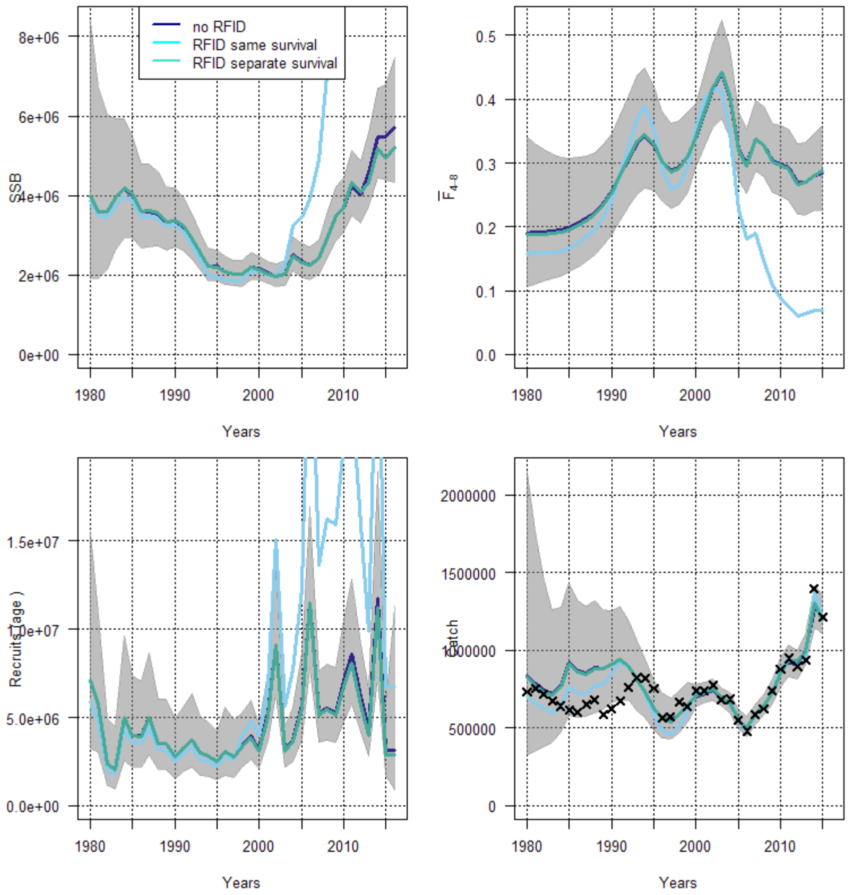



**Figure 3.3.4.1: Estimated stock development from the models not using the RFID tags and the models using the RFID tags with a unique set of parameters for all tags, or with separate parameters for both tag types.**


**Figure 3.3.4.2: Parameter estimates for the model runs not using the RFID tags and using the RFID tags with a separate set of parameters.**

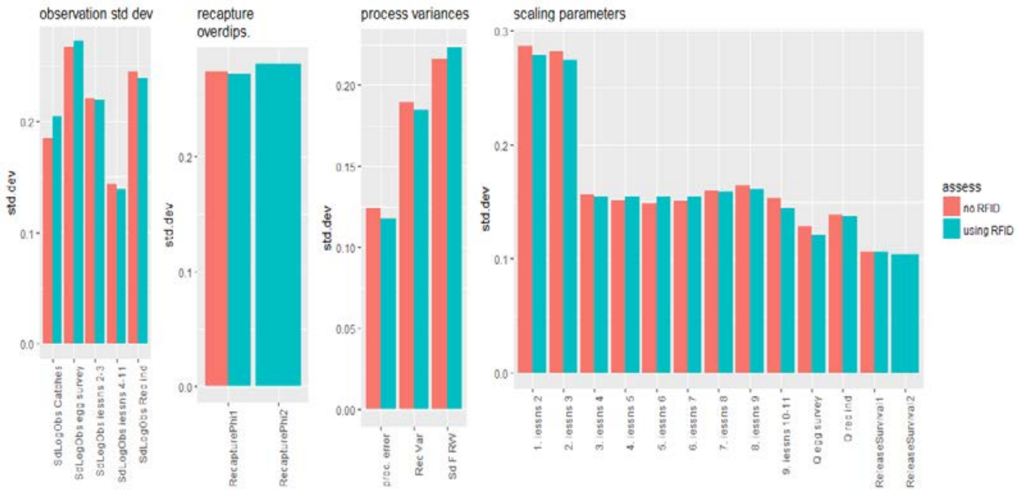



**Figure 3.3.4.3: Standard deviation of the parameters for the model runs not using the RFID tags and using the RFID tags with a separate set of parameters.**

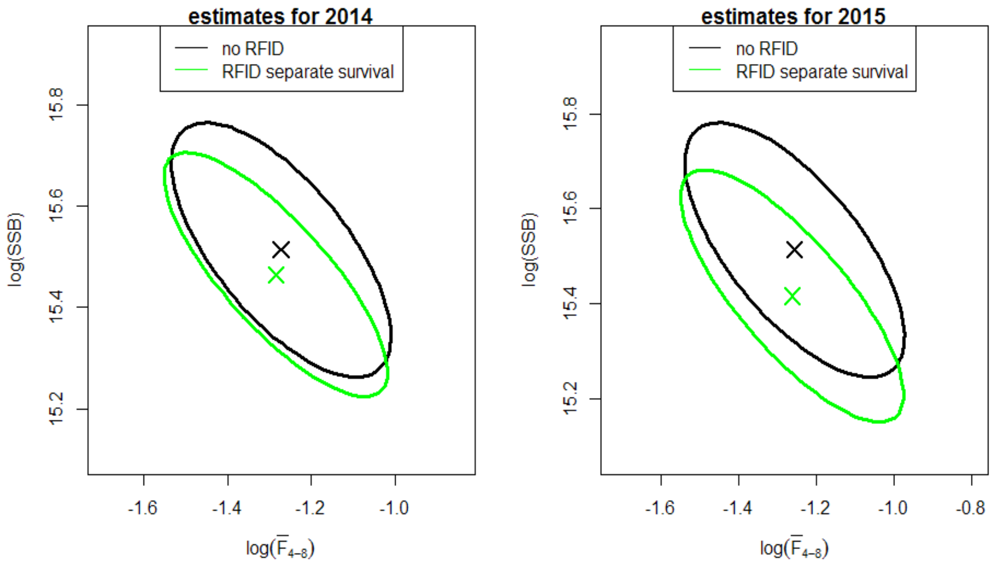



**Figure 3.3.4.4: Joint distribution of the (log) estimates of SSB and Fbar for the last 2 years in the assessments with and without the RFID tags.**

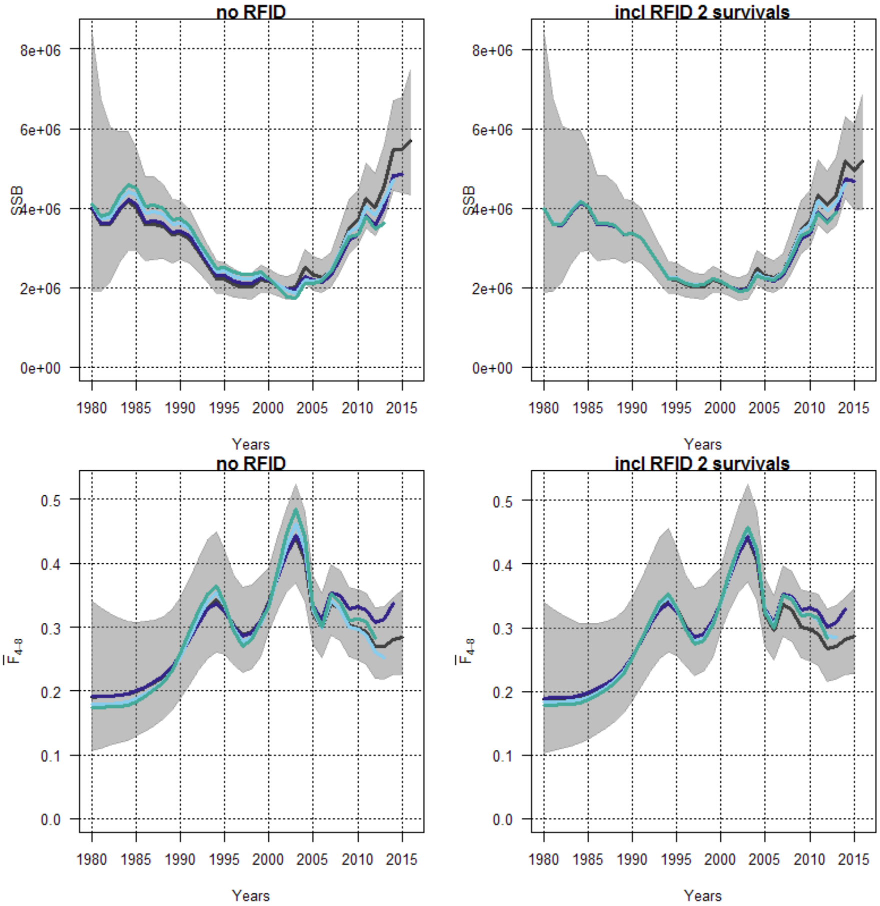



**Figure 3.3.4.5: Comparison of the retrospective plots for the assessments with and without the RFID tags.**

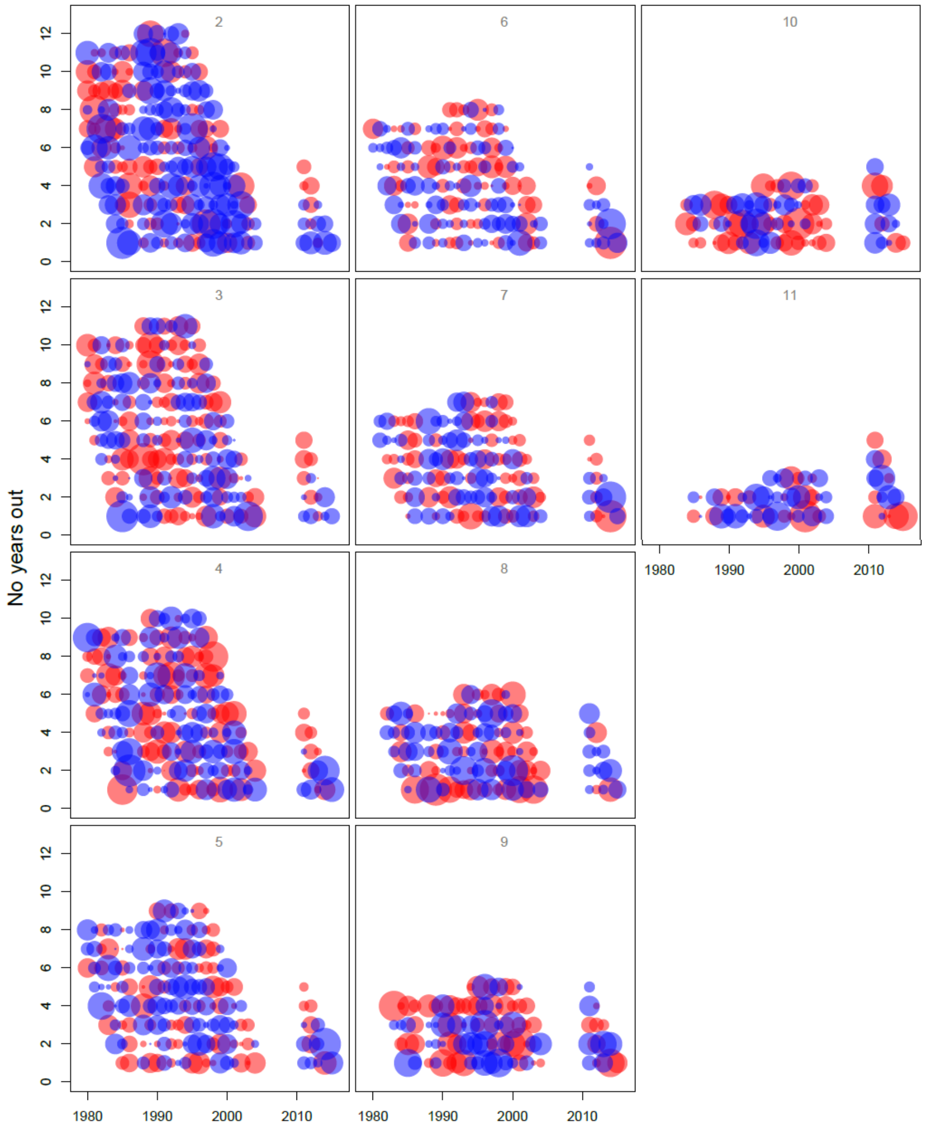



**Figure 3.3.4.6: OSA residuals for the tags recaptures in the model using the RFID tags with separate parameters.**

### 3.3.4.2 Estimating a Factory Effect

<u>Data and configuration</u>

Exploratory analyses of the RFID tag data presented at the meeting indicated that the stock abundances estimated directly from the tag data using the Petersen estimate from different fish processing factories showed systematic differences. A series of potential explanations were proposed to explain those differences (e.g. differences in tag detection efficiency potentially linked to noise interference, differences in the way the volumes of fish scanned are estimated). From a model perspective, these different effects would all be confounded with the parameter post-release survival (which actually reflects survival itself, plus all other factors having a systematic effect on the numbers recaptured).

In an attempt to account for these potential factory effects, the model was fitted using a separate survival rate for each factory. Exploratory runs that also estimated separate overdispersion parameters for each factory were found to be over-parameterized and therefore, a single overdispersion parameter was used for the recaptures from all factory for the RFID tags.

Results

The model incorporating an estimated factory effect estimates substantially lower SSB and higher F in the recent years (not shown). The uncertainty on the recent SSB and Fbar also increased substantially. The estimated effects (survival rates) were significantly different (figure 3.3.4.7). Factories with higher survival rates (*i.e.* more tag returns compared to the others) were in Iceland (IC01 and 02), Scotland (GB01 and 04) and Norway (NO05). Conversely, some factories had a lower associated survival rate (GB03, NO01 and 03).

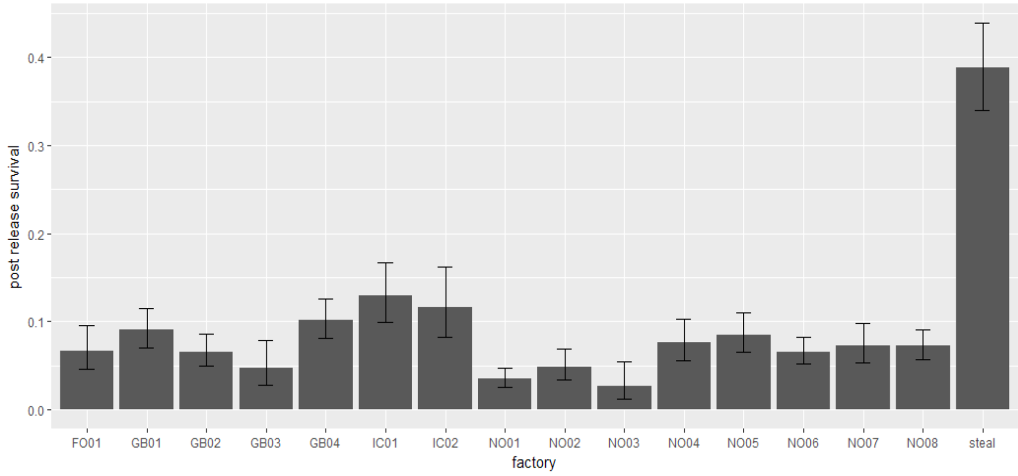



**Figure 3.3.4.7: Estimated post-release survival rate for the SAM run specifying factory effects.**

### 3.3.4.3Conclusions

This series of exploratory runs have shown that the model could deal appropriately with the new RFID tagging data when both types of tagging data are treated as separate time–series (i.e. a set of parameters for each data–series). There is no deterioration of model fit to the other sources of data, and residuals are acceptable. The inclusion of the RFID tags modifies the perception of the stock in the recent years, and improves slightly the model in several aspects (i.e. precision of estimates, retrospective pattern).

While the data and the model suggest that tag recapture data are affected by factory effects, the model estimating a survival rate per factory was not considered as a preferred option as it had larger uncertainty on recent SSB and Fbar estimates and showed signed of instability (convergence warning). In addition, the RFID tagging/recapture program is relatively recent and still in development with the number of factories scanning the catch changing in the recent years. Improvements are being made in the factories to improve the scanning efficiency, implying potential future changes in factory effects. Therefore, in addition to the identified model issues, it was felt that there was insufficient RFID data to accurately estimate the differences between factories, and that the configuration with factory effect should be re-evaluated during the next benchmark.

### 3.3.5 Observation error correlation structure

Rationale for the implementation of an observation error correlation

In the case of the mackerel assessment, strong year effects are present in the IESSNS index (see residual plots - figure 3.3.3.13). A year effect indicates that all observations from a same year have a similar deviation from their modelled value, which implies they are correlated between age-groups. The default model in SAM assumes that each observation is independent from the other. Fitting a model assuming independent observations while these are in reality correlated in statistically incorrect, and can result in bias in estimated parameters and statistical tests. Another possible effect of assuming observation independent is an inappropriately (high) weighting given to the correlated data, as the information given by one observation is already partially contained in other observations, since those are correlated.

A recent development of the SAM model (Berg & Nielsen, 2016) allows for the specification of an error structure for the observations. This new feature was implemented to appropriately better handle data sources which are inherently correlated. The default model therefore appears to be inappropriate and alternative runs with correlated errors for the IESSNS were investigated.

Trial run

Based on the model using the IESSNS index for age 2 to 11 and the RFID tags, a first exploratory run was conducted specifying unstructured correlation for the IESSNS, in which one correlation (i.e. one parameter) is estimated for each pair of age-group from the IESSNS (45 additional parameters in total). This model was poorly defined with high standard deviations for all the error correlations and for the observation variance for the catches. The observation variance for the IESSNS increased substantially while the observation variance for the egg survey decreased. The observation variance for the catches became very small, corresponding to a nearly perfect fit to the catches. This model configuration was therefore discarded. However, the error correlation estimated by this model showed that a positive correlation is expected between all age groups in the IESSNS, except age 2 which was negatively correlated to all other ages.

Final run

Based on the above observation, the model was re-fitted using an autoregressive (AR) autocorrelation structure for the observation for ages 3–11, and excluding the IESSNS data for age 2. The AR correlation structure estimates a single parameter, and results in the single correlation between neighboring age-groups, a single correlation between age–groups 2 years apart etc. A test run was made without correlated error and excluding the age 2 index from the IESSNS. This run showed virtually no difference with the run incorporating the age 2.

Comparing the likelihoods of the models with and without correlation structure (log likelihood increasing from -2647.95 to -2636.92 for one additional parameter) shows that the assumption of independent observation errors for the IESSNS index is rejected (p= 2.665629e-06). The estimated AR error correlation matrix (figure 3.3.5.1) shows a correlation of 0.80 between adjacent age-classes, decreasing to 0.64 between age-classes 2 years apart, and further decreasing thereafter.

The model incorporating correlated error gives a lower weight (higher observation variance) to the IESSNS survey (figure 3.3.5.2) and the egg survey has a lower observation variance.

Uncertainty (standard deviation) on the estimated parameters increased for the model with correlated observation error, especially for the observation variance and the catchability of the IESSNS (figure 3.3.5.3). The uncertainty on the recent estimates of SSB and Fbar was also larger for the model with correlated errors (figure 3.3.5.4).

The figure 3.3.5.6 shows a comparison of the residuals for the IESSNS from the model with and without correlated error structure. Although still present to some extent in the residuals for the model with correlated errors, the year effect pattern for the IESSNS was greatly reduced.

As a result of the lower weight of the IESSNS (which pulls the estimated SSB up in the recent years, see section 3.3.5.7) and higher weight of the egg survey (pulling the assessment down in the recent years), the model run using AR correlated error structure estimates a lower stock size in the recent years

Conclusion

Trial runs using auto-correlated observation errors of the IESSNS show that the data are not independent, and that using a model assuming independence would be statistically wrong. The risk in using a model for which the condition of independence is violated is to have biased parameter estimates and incorrect confidence bounds.

The assessment accounting for correlation between age groups in the IESSNS index has larger confidence bounds than the assessment without correlation structure. This should however not be taken as sign that this is a poorer assessment. Berg & Nielsen (2016) have shown that the uncertainty on the most recent stock estimates in the SAM model with correlated observations tended to be larger than for model assuming independent observations. However, one can argue that, uncertainty estimates from a model assuming independent observations are biased (i.e. over-optimistic) if observations are indeed correlated and that the uncertainty estimates from the model with auto-correlated errors are more reliable. In addition, uncertainty on prediction is lower for models with correlated observation.

By taking into account correlations in the IESSNS index, the weight of this index in the model with correlation becomes lower, which better reflects the true amount of information contained in this survey.

Since the IESSNS and the egg survey give contradictory information on the stock trend for the last three years, the decreasing weight of the IESSNS mechanistically results in an increasing weight of the egg survey, which is in turn reflected in the assessment output in lower recent estimated of SSB.

The model with AR correlation structure was accepted as the final WKWIDE 2017 assessment.

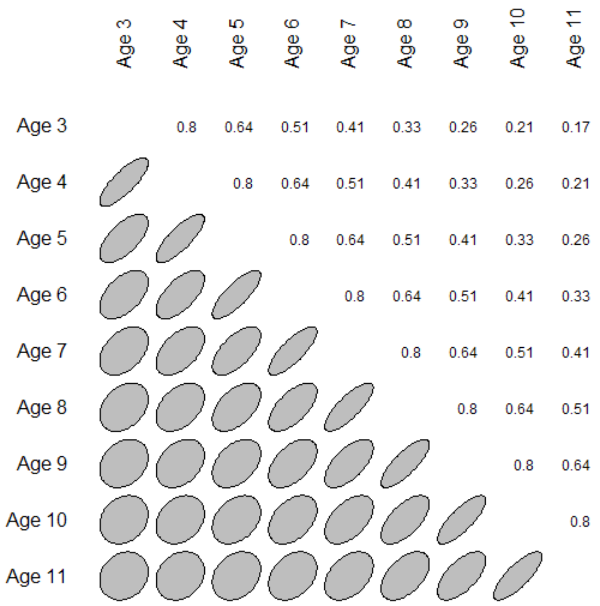



**Figure 3.3.5.1: Estimated AR correlation structure for the observation errors in the IESSNS survey.**

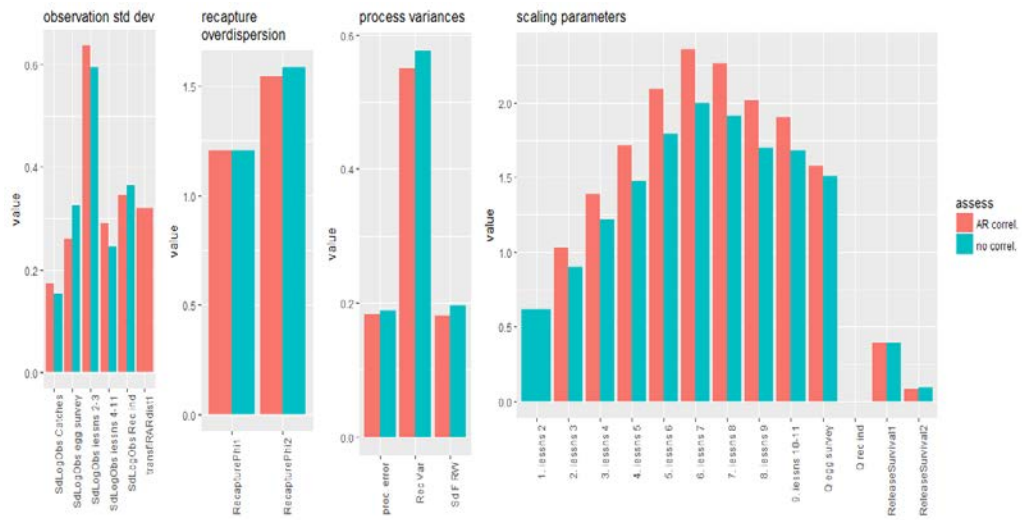



**Figure 3.3.5.2: Parameter estimates for the model with and without correlated observation errors for the IESSNS survey**

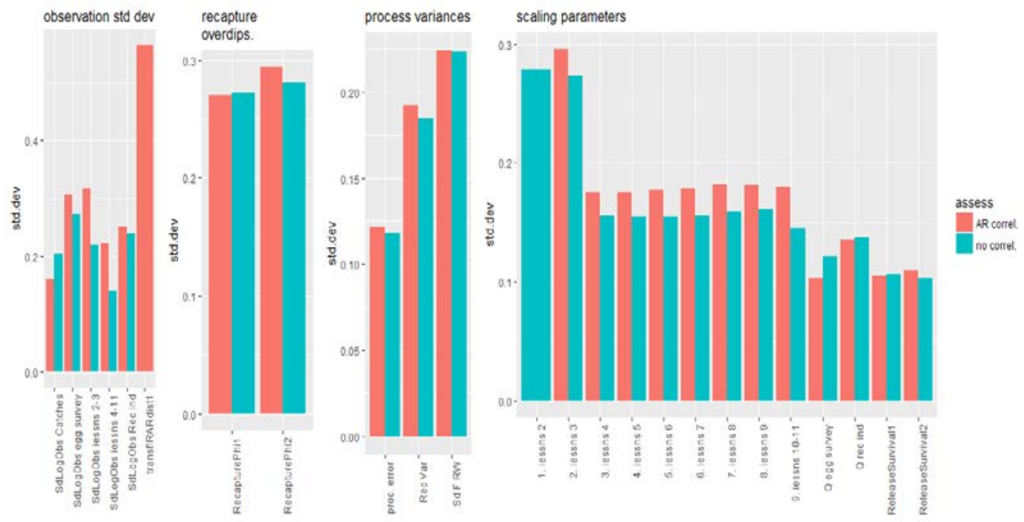



**Figure 3.3.5.3: Standard deviation of the parameters for the model with and without correlated observation errors for the IESSNS survey.**

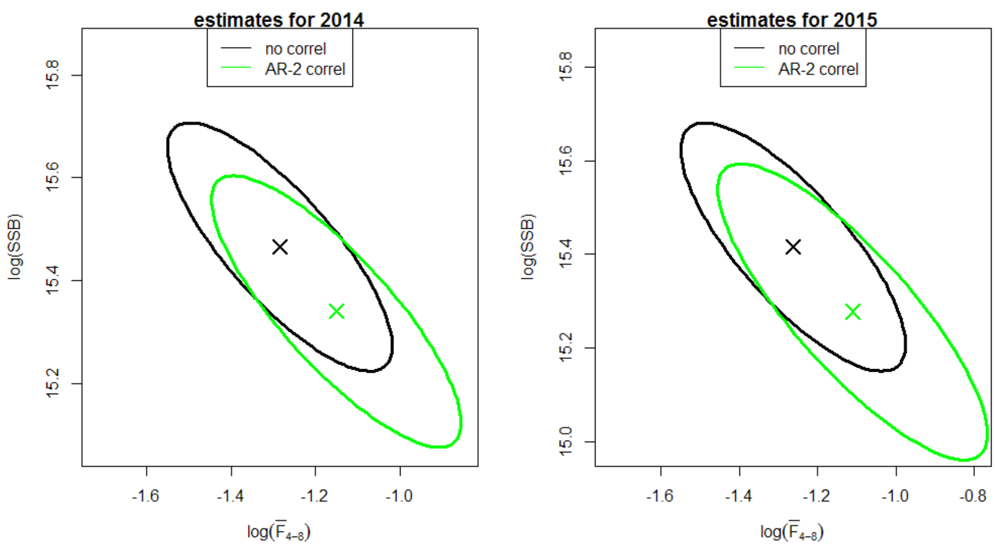



**Figure 3.3.5.4: Joint distribution of the (log) estimates of SSB and Fbar for the last 2 years in the assessments with and without correlated observation errors for the IESSNS survey.**

| No correlation structure | AR correlation structure |
| --- | --- |

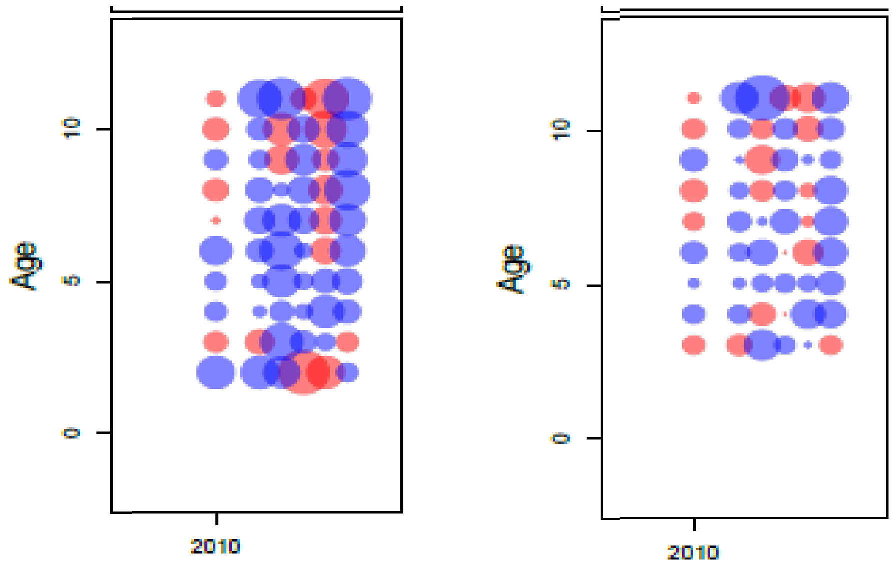



**Figure 3.3.5.5: Residual to the IESSNS survey for the model with and without error correlation structure.**

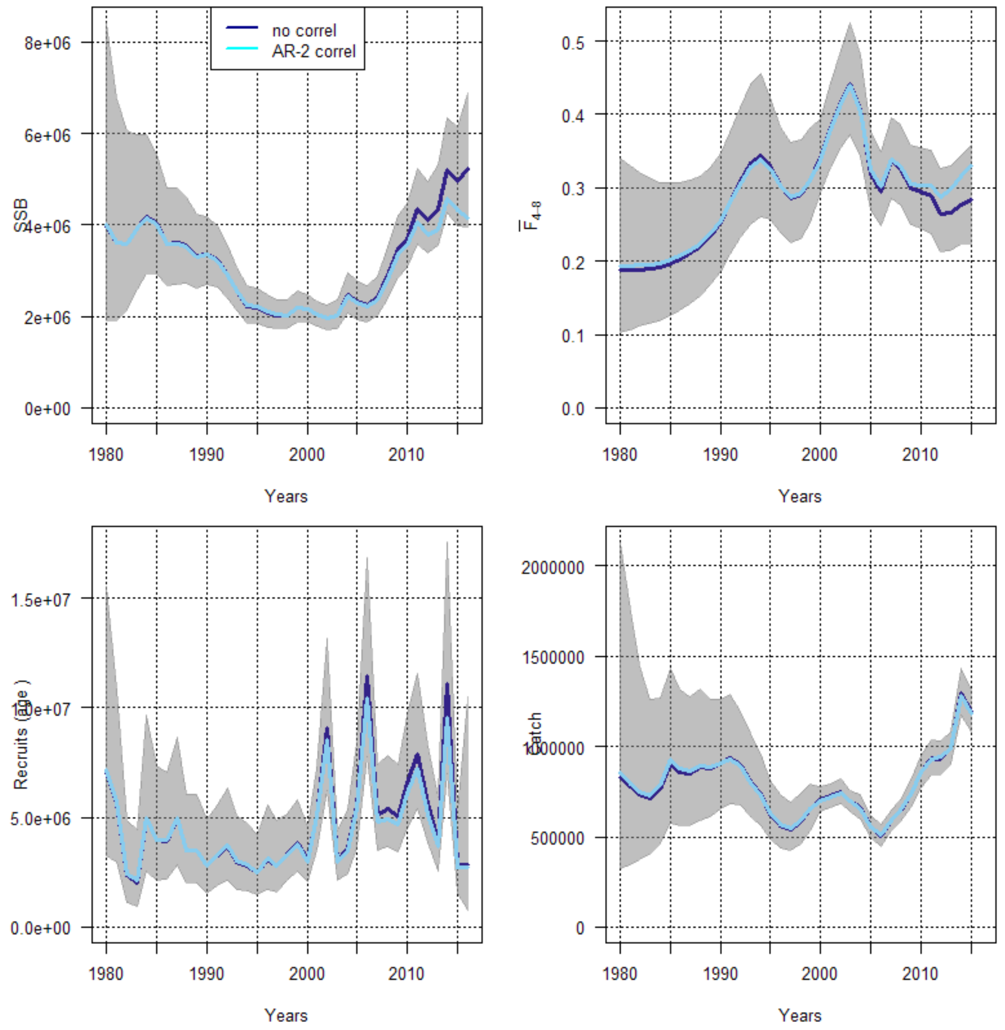



**Figure 3.3.5.6: Comparison of the model output with and without correlated observation errors for the IESSNS.**

### 3.3.6Decoupling catches observation variances

The assumption of a unique observation variance for all ages of the catch data appears inappropriate. This was indicated by the large residuals for the 0 and 1 year olds that are not targeted by the fishery and may have affected by highly variable unaccounted mortality in the catch process. To investigate how this might be accounted for within the assessment, the observation variance of 0–1 year olds was decoupled from the remaining age groups in SAM.

Compared with the base run (without the correlation structure), this led to a reduction of AIC from 5320 to 5245 and an increase in log likelihood from -2637 to -2598. This was a significantly better model fit to the data ($p<0.001$). The same was found when comparing with the base run with the IESSNS observation error correlation structure (see section 3.3.5).

Compared to the base run, the observation variance for the commercial catch was, as expected, found to be higher for the 0–1 year olds and lower for the older age groups. The other notable difference was that the observation variance decreased substantially for the recruitment index (IBTS survey 0-group index). Parameter estimates are given in Figure 3.3.6.1 and residual plots in Figure 3.3.6.2. The effect of this model improvement on SSB and F was minor, but the effect on the recruitment estimates was large as it followed the recruitment index closely (Figure 3.3.6.3).

The group regarded the tight fit to the recruitment index as unrealistic and chose to retain the current model structure because there was insufficient time to continue with this analysis. WKWIDE recommends that this work is prioritized during the next benchmark, because the problem with juvenile catches remained unsolved.

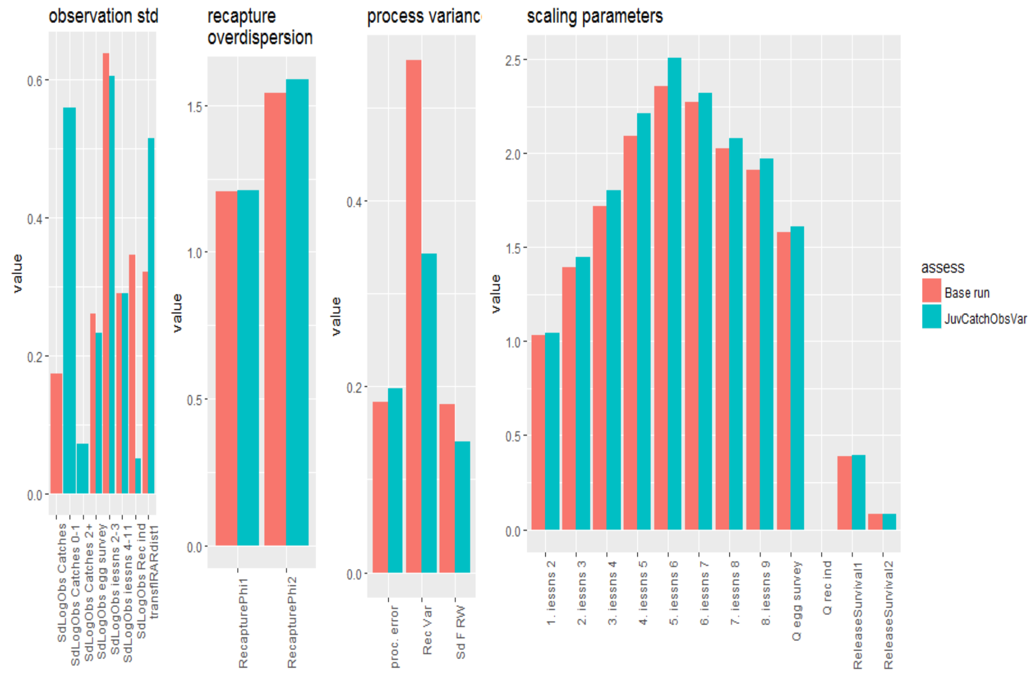



**Figure 3.3.6.1: Parameter estimates for the model with and without decoupling of the juvenile observation variance.**

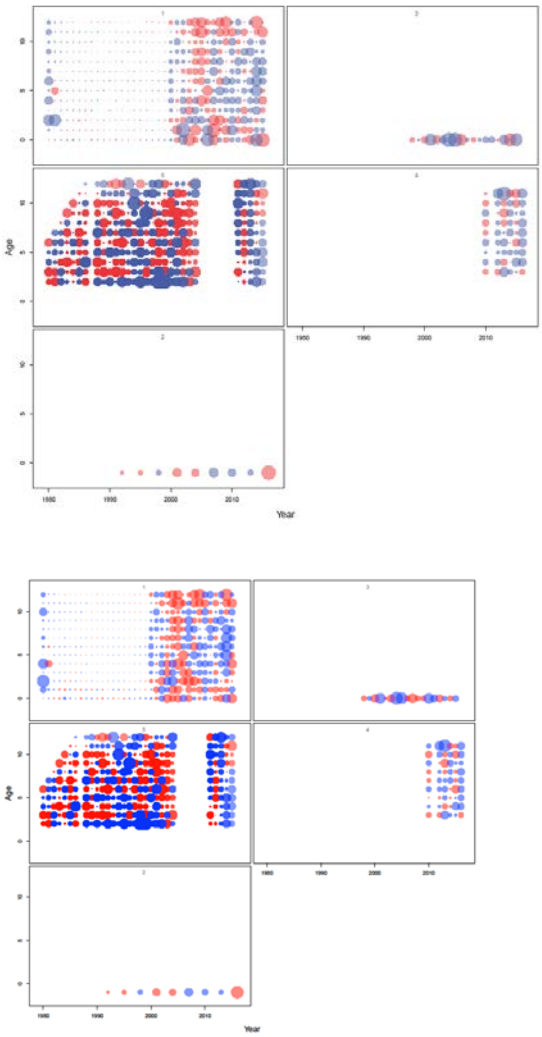



**Figure 3.3.6.2: Above: Residuals of the base run (without the IESSNS error correlation structure). Below: Residuals for the model with decoupled observation variance.**

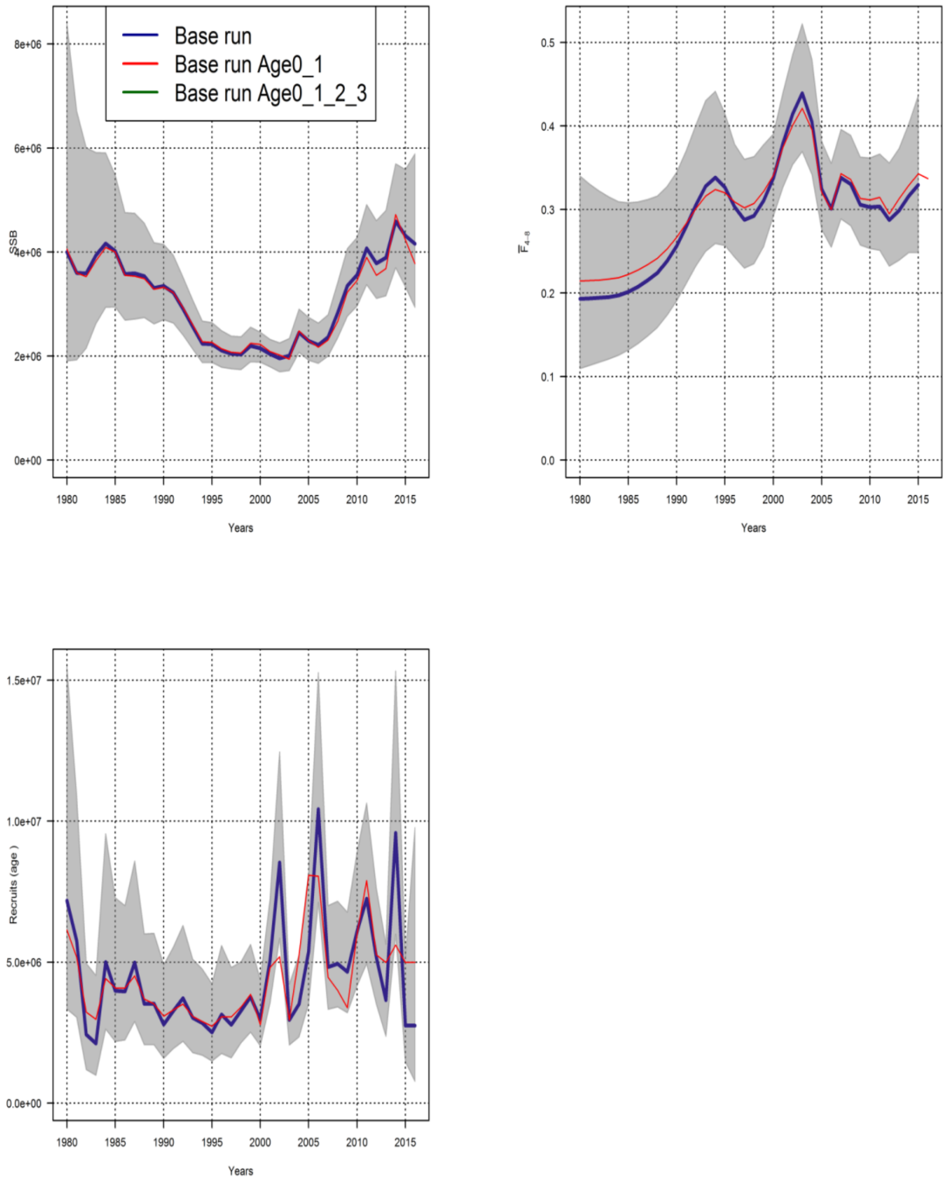



**Figure 3.3.6.3: Comparison of the model output with and without decoupled observation variance for juvenile catches.**

## 3.3.7Sensitivity tests

### 3.3.7.1.1 Use of in-year Survey Indices

Data and model configuration

In order to test the sensitivity of the assessment output to the use of in-year indices (as is currently the practice), the assessment data and configuration accepted as the final WKWIDE assessment (see Section 3.3.8) was taken as the base case. For the alternative case, an assessment was run using the same input data and configuration (with the exception of the survey and tagging data), for which the in-year indices were excluded.

It should be acknowledged that the revision of the most recent egg survey index value (typically available the year after the survey has been completed) due to changes in fecundity has not been evaluated. This was not possible due to the various revisions of the historical series which prevents calculating historical preliminary index values.

Results

The assessment model output when in-year indices are excluded was very similar to the base case. The historical stock development shows small differences in SSB and Fbar, with lower abundances and higher fishing mortalities when deleting the in-year index relative to the base case (Figure 3.3.7.1.1.1). The uncertainty both in SSB and F estimates is very similar for both cases (Figure 3.3.7.1.1.2).

The diagnostics for the model omitting the in-year indices showed some small improvement compared to the base case run. Observation variances for the catches were unchanged, but for the assessment without in-year indices, the fit to the egg survey was substantially better (Figure 3.3.7.1.1.3). In this case, observation variances improved (i.e. decreased) and the catchability increases, mainly for the egg survey, but also for the IESSNS and the recruitment index, although only slightly i.e. the model gives higher weight to the surveys (mainly to the egg survey). However, the egg survey variance improvement is due to the 2016 conflict among surveys, so there is no real improvement that can be attributed to this alternative treatment of in-year indices. The remaining model parameters were very similar for both assessments. The parameter standard deviation estimates (Figure 3.3.7.1.1.4) were in general less uncertain for the scaling parameters when omitting the in-year indices.

Regarding the retrospective patterns, there was no improvement, as a large revision of the SSB and Fbar is observed in both cases. For the base case this revision appeared in the retrospective run with 2 years of data removed, whereas when removing the in-year index this revision arose in the retrospective run with one year removed. As when not considering the in-year index the year effect of the egg survey did not disappear, it was just translated one year forward (Figure 3.3.7.1.1.5).

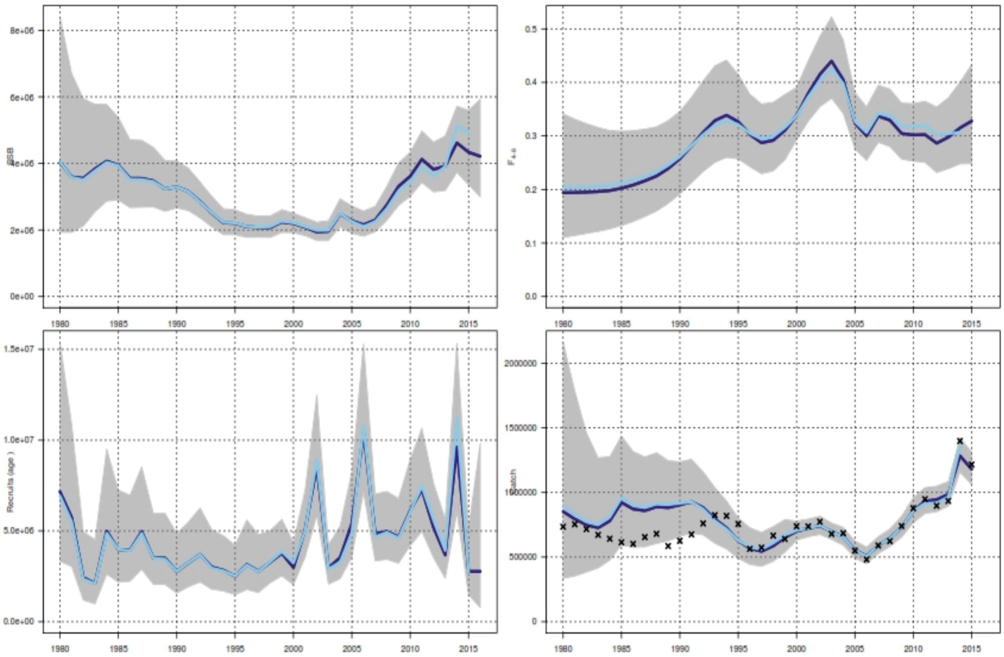



**Figure 3.3.7.1.1.1: Summary of stock assessment, comparison between final WKWIDE accepted assessment (dark blue with confidence interval as shaded grey area) with the alternative case in which in-year indices are omitted (light blue). From left to right and top to bottom: SSB (in tonnes), F (Fbar for ages 4-8), recruits (millions) and catches (in tonnes).**

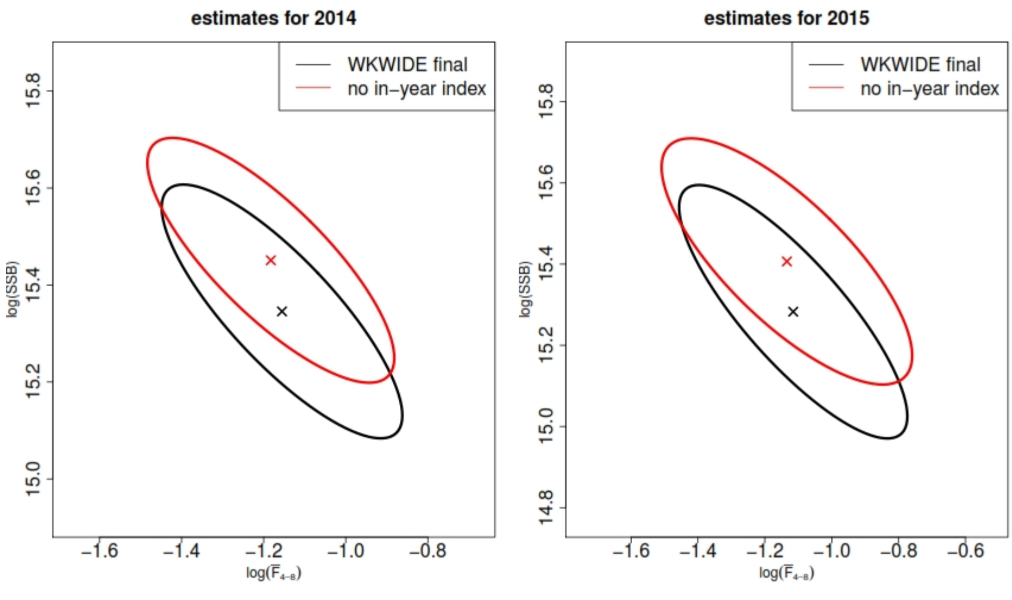



**Figure 3.3.7.1.2.2. Joint distribution of the (log) estimates of SSB and Fbar for the last year in the assessment for the final WKWIDE accepted assessment (black) and for the alternative case in which in-year indices are omitted (red). The point depicts the point estimate and the ellipsis represents the probability intervals at different confidence levels.**

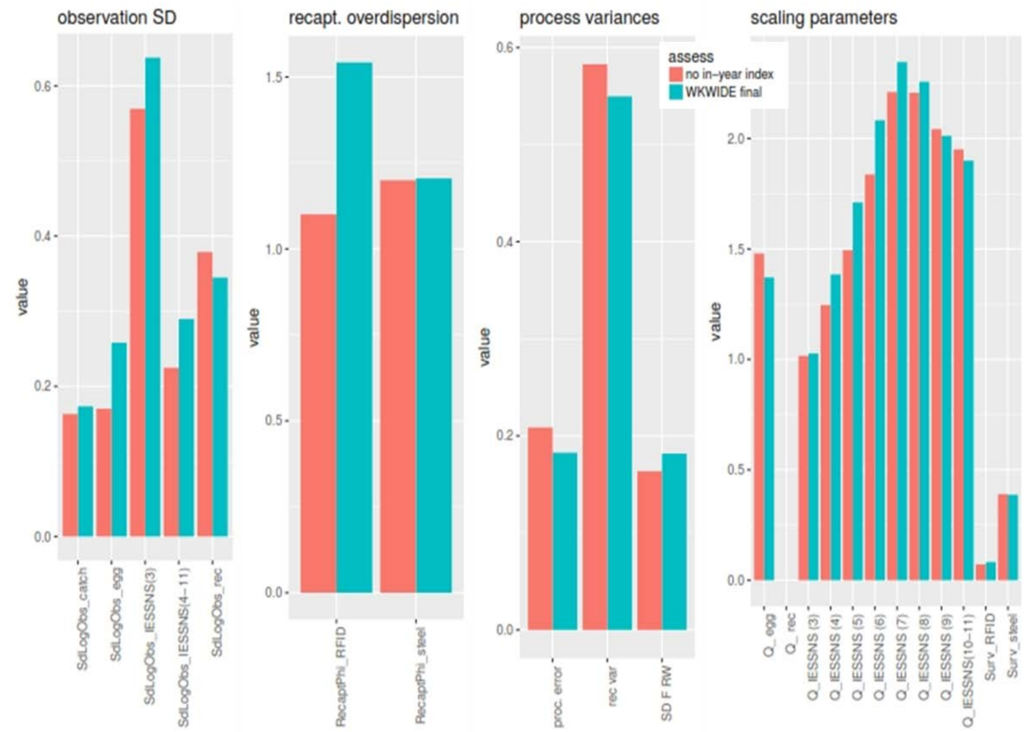



**Figure 3.3.7.1.1.3. Parameter estimates for two alternative SAM runs: the final accepted WKWIDE assessment (red) and the alternative case in which in-year indices are omitted (green). From left to right: i) observation standard deviation for the catches and the different surveys; ii) recapture over-dispersion for the tagging; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

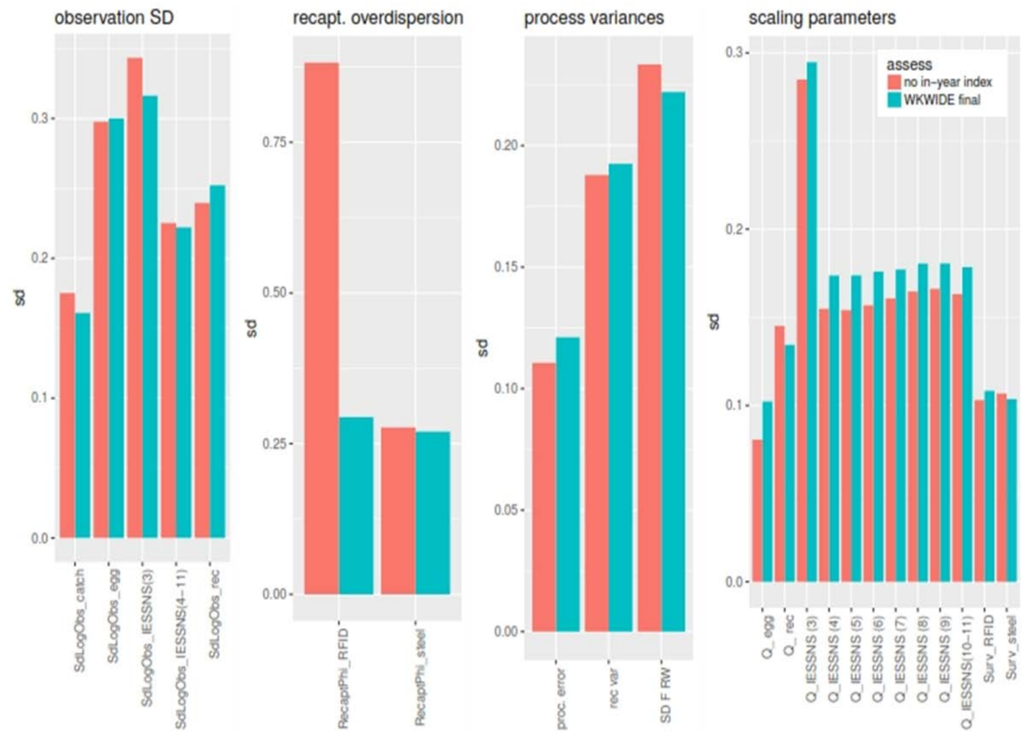



**Figure 3.3.7.1.1.4. Standard deviation of the model parameter estimates for two alternative SAM runs: the final WKWIDE accepted assessment (red), and the alternative case in which in-year indices are omitted (green). From left to right: i) observation standard deviation for the catches and the different surveys; ii) recapture overdispersion for the tagging; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

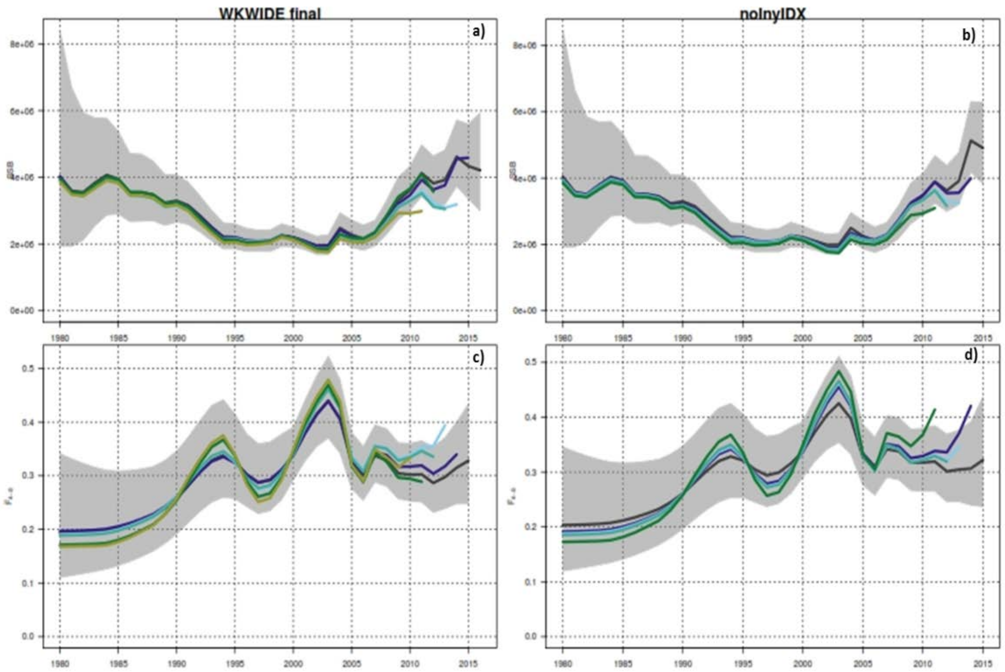



**Figure 3.3.7.1.2.5. Retrospective analysis of SSB (in tonnes) (a & b) and F (Fbar for ages 4-8) (c & d) for two alternative SAM runs: the final WKWIDE accepted assessment (a & c) and the alternative case in which in-year indices are omitted (b & d). The 95% confidence interval is shown for the final accepted assessment.**

Conclusions

Given the above, there is no marked improvement when in-year surveys are not used, as the observed year effect is just postponed one year. Additionally, there is no real improvement on the survey indices' observation variances. Moreover, when the in-year information is not used, there is a need for additional assumptions for the assessment year, (in this case, 2016), which contributes to the overall assessment uncertainty.

##### 3.3.7.1.2 Leave one out

Data and model configuration

In order to test the sensitivity to the exclusion of particular indices the final WKWIDE assessment data and configuration (see Section 3.3.8) was taken as the base case. For the alternative cases, the model was fit using the same data and configuration, but omitting one index each time.

Results

Both the run omitting the recruitment index and the one omitting the tagging information encountered convergence issues and were considered invalid. Therefore, only sensitivity to the omission of the egg survey index or the IESSNS index was tested.

The historical stock development estimated by the model is very similar for the initial years, but marked differences appear mainly in the last 7 years (Figure 3.3.7.1.2.1). The assessed stock trends show more marked differences in SSB and Fbar when omitting the egg survey index (with higher abundances and lower fishing mortalities) and when omitting the IESSNS index (with lower abundances and higher fishing mortalities). This is mainly due to the contrasting trends in these indices in 2016. The uncertainty both in SSB and F estimates is very similar for all three cases (Figure 3.3.7.1.2.2).

Regarding model parameter estimates, there was no clear improvement for any of the cases (Figure 3.3.7.1.2.3). Firstly, when omitting one of the indices (egg survey or IESSNS), all the observation variances decreased except the one for the recruitment index. Moreover, when omitting one of the two indices, the observation variance of the other sharply decreased, these differences were bigger when the egg survey was not used. Secondly, process variances increased for the recruitment variance only when egg survey was omitted, whereas standard deviation of the F random walk increased in both cases, but more when egg survey was omitted. Finally, survey catchabilities decreased, except the one for the egg survey. Estimates of over dispersion of the tag recaptures and the estimated post tagging survival rates both slightly changed for all the tested alternatives.

The standard deviations of the parameter estimates (Figure 3.3.7.1.2.4) were markedly lower when using all the available indices.

Regarding the retrospective patterns (Figure 3.3.7.1.2.5), more marked patterns appeared when not excluding the egg survey, which was due to the year effect of including a new egg survey estimate. Additionally, in the retrospective run with 5 years of data removed, if not omitting the IESSNS survey index, SSB values got out of the confidence interval. On the contrary, when omitting it, the F values got out of the confidence interval.

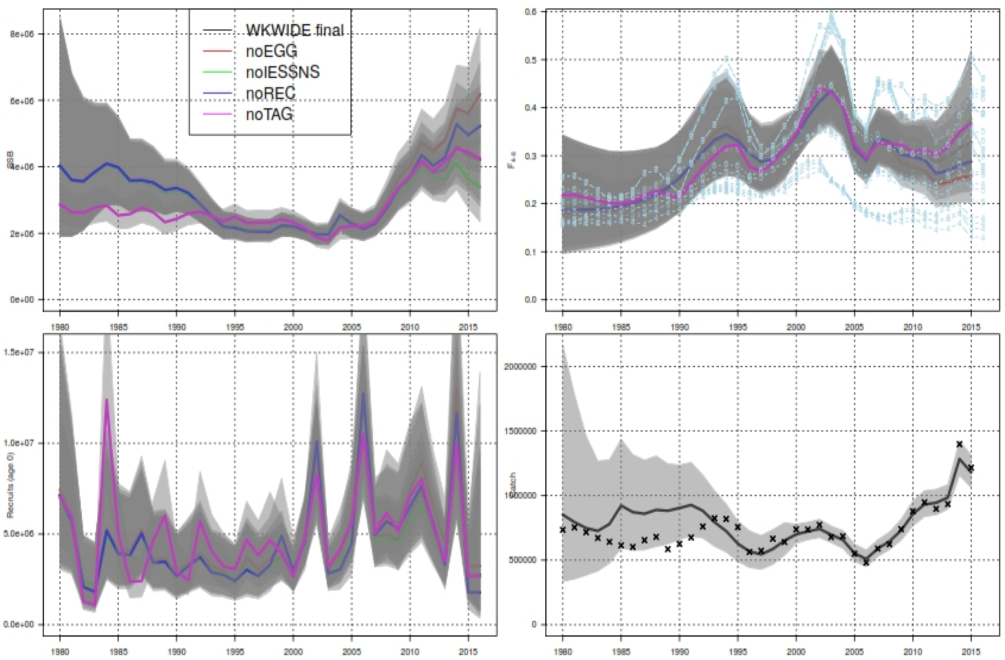



**Figure 3.3.7.1.2.1. Summary of stock assessment, comparison between final accepted assessment (black with confidence interval as dashed grey area) with the alternative cases taking indices out one by one: without egg survey index (red), without IESSNS index (green), without IBTS recruitment index (blue) and without tagging information (pink). From left to right and top to bottom: SSB (in tonnes), F (Fbar for ages 4-8), recruits (millions) and catches (in tonnes) over the years.**

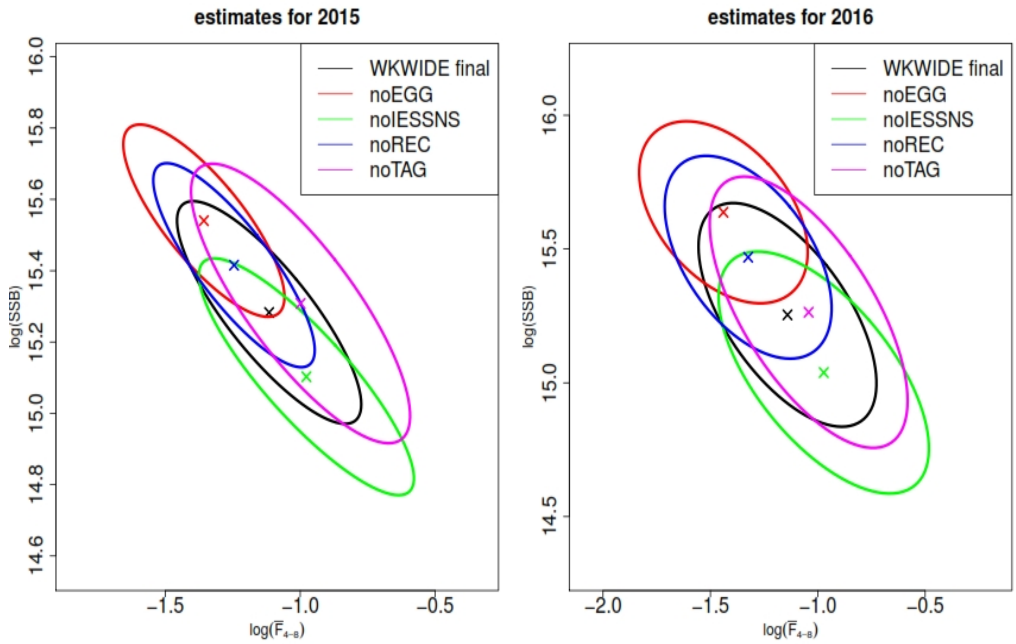



**Figure 3.3.7.1.2.2. Joint distribution of the (log) estimates of SSB and Fbar for the last two years in the assessment, for final accepted assessment (black) and the alternative cases taking indices out one by one: without egg survey index (red), without IESSNS index (green), without IBTS recruitment index (blue) and without tagging information (pink). The point depicts the point estimate and the ellipsis represents the probability intervals at different confidence levels.**

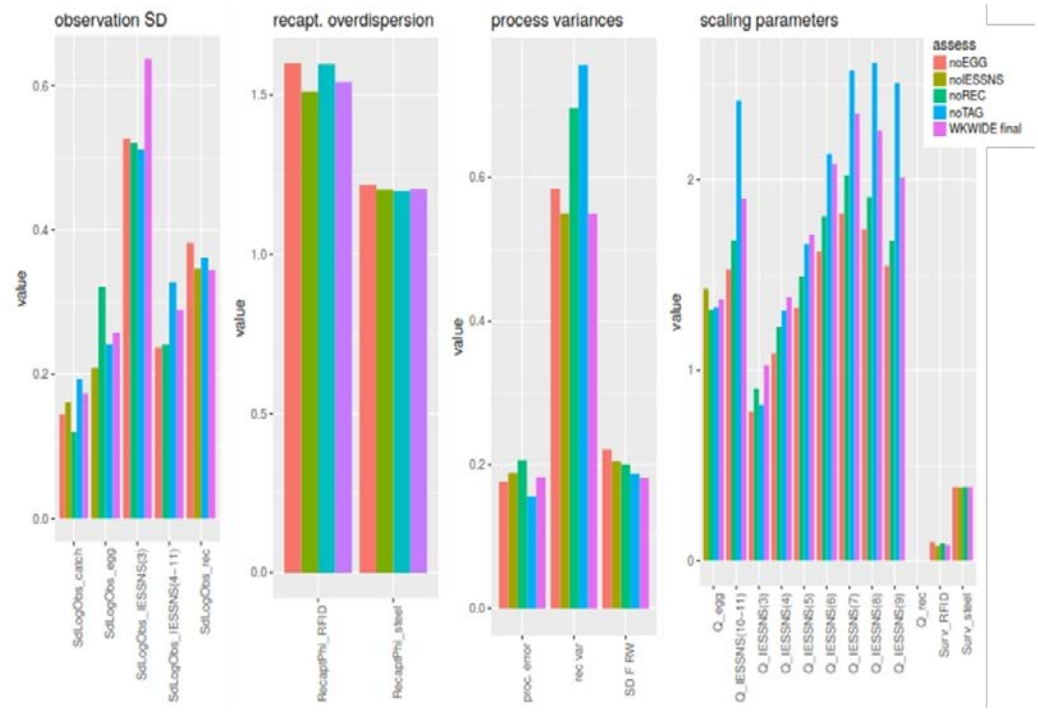



**Figure 3.3.7.1.2.3. Parameter estimates for alternative SAM runs: final accepted assessment (pink) and the alternative cases taking indices out one by one: without egg survey index (red), without IESSNS index (brown), without IBTS recruitment index (green) and without tagging information (blue). From left to right: i) observation standard deviation for the catches and the different surveys; ii) recapture overdispersion for the tagging; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

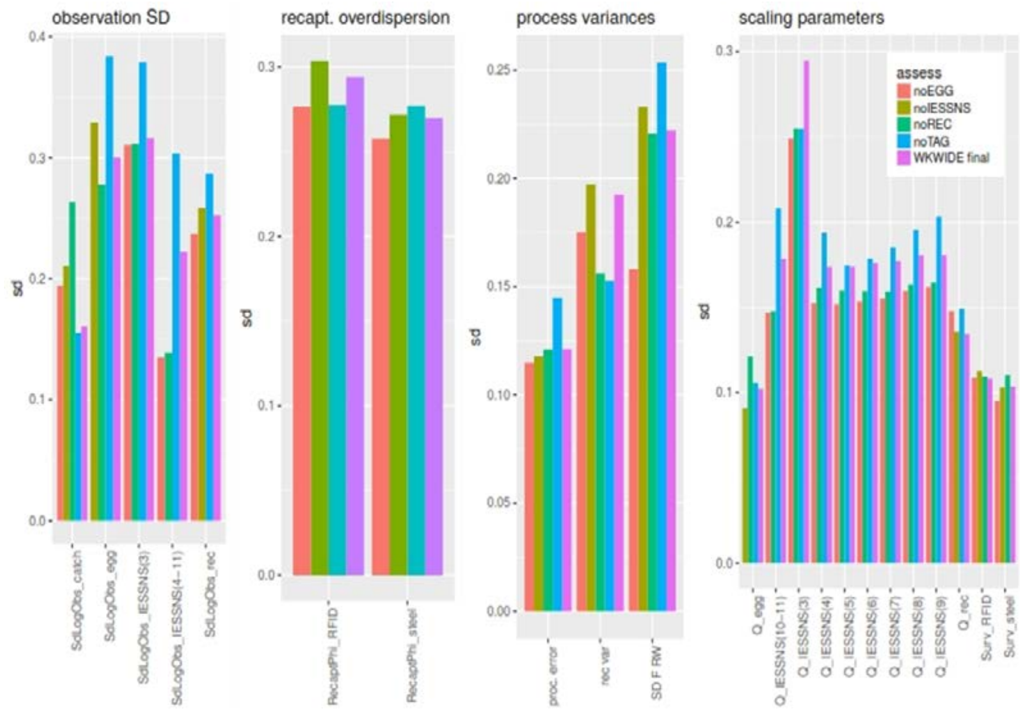



**Figure 3.3.7.1.2.4. Standard deviation of the model parameter estimates for alternative SAM runs: final accepted assessment (pink) and the alternative cases taking indices out one by one: without egg survey index (red), without IESSNS index (brown), without IBTS recruitment index (green) and without tagging information (blue). From left to right: i) observation standard deviation for the catches and the surveys; ii) tagging recapture overdispersion; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

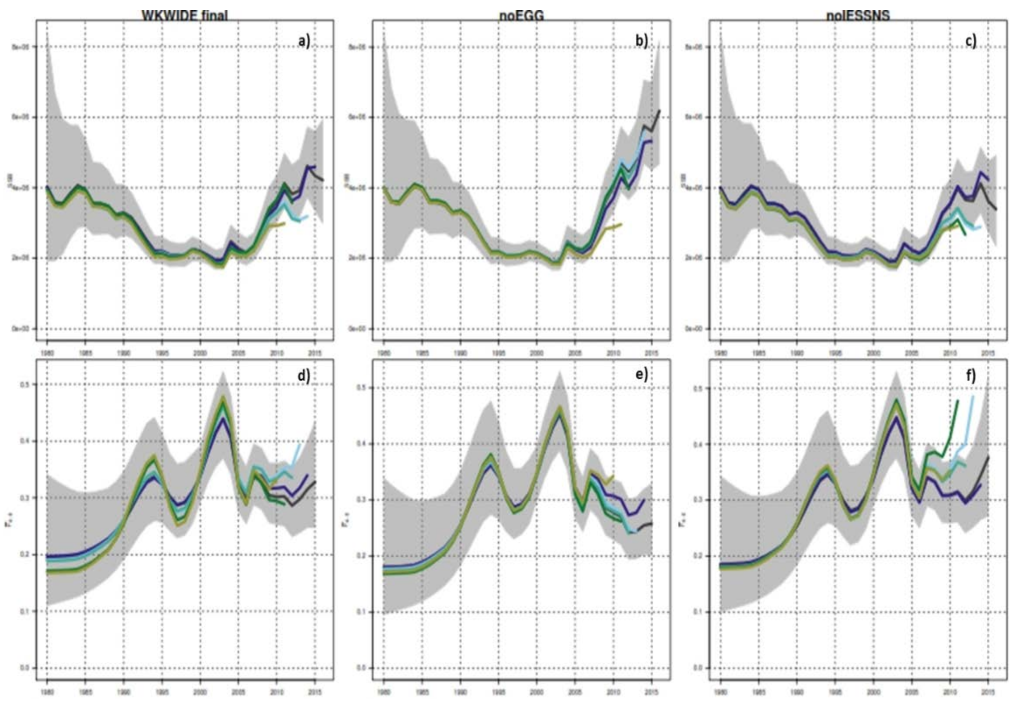



**Figure 3.3.7.1.2.5. Retrospective analysis of SSB (in tonnes) (a-c) and F (Fbar for ages 4-8) (d-f) for alternative SAM runs: final WKWIDE accepted assessment (a & d) and the alternative cases excluding individual indices: without egg survey index (b & e) and without IESSNS index (c & f). The 95% confidence interval is shown for the final accepted assessment.**

Conclusions

Despite the fact the assessment is quite sensitive to omitting one or other of these surveys; they are important sources of information.

#### 3.3.7.1.3 Sensitivity to revisions in the egg survey

Data and model configuration

Given that the annual update assessment in the year of an egg survey is run with provisional survey estimates (the fecundity is finalised in the following year), the sensitivity of the assessment to this revision was investigated.

In order to test the sensitivity of the assessment output to the revision of the fecundity parameter, the final WKWIDE assessment data and configuration (see Section 3.3.8) was taken as the base case. For the alternative case, the model was fit using the same data and configuration, except for the egg survey data, where two alternative values have been set for the 2016 index value (Table 3.3.7.1.3.1 and Figure 3.3.7.1.3.1), derived from an assumed 20% variation relative to the provisional fecundity value.

**Table 3.3.7.1.3.1. Alternative egg survey index values for 2016, assuming a 20% variation of the fecundity value.**

| | Fecundity (n/g) | Western Comp. | Southern comp. | SSB | diff. |
|---|---|---|---|---|---|
| SSB (provisional fecundity) ) | 1138 | 2938.9 | 427.2 | 3366.1 | |
| SSB (20% reduction in fecundity) | 910.4 | 3673.6 | 534.1 | 4207.7 | 0.25 |
| SSB (20% increase in fecundity) | 1365.6 | 2449.1 | 356.0 | 2805.1 | -0.17 |

The 20% variation is considered adequate, due to the fact that the mean fecundity revision has ranged between 1% and 17%, since 1995. The maximum historical revision occurred in 1995 and 2013.

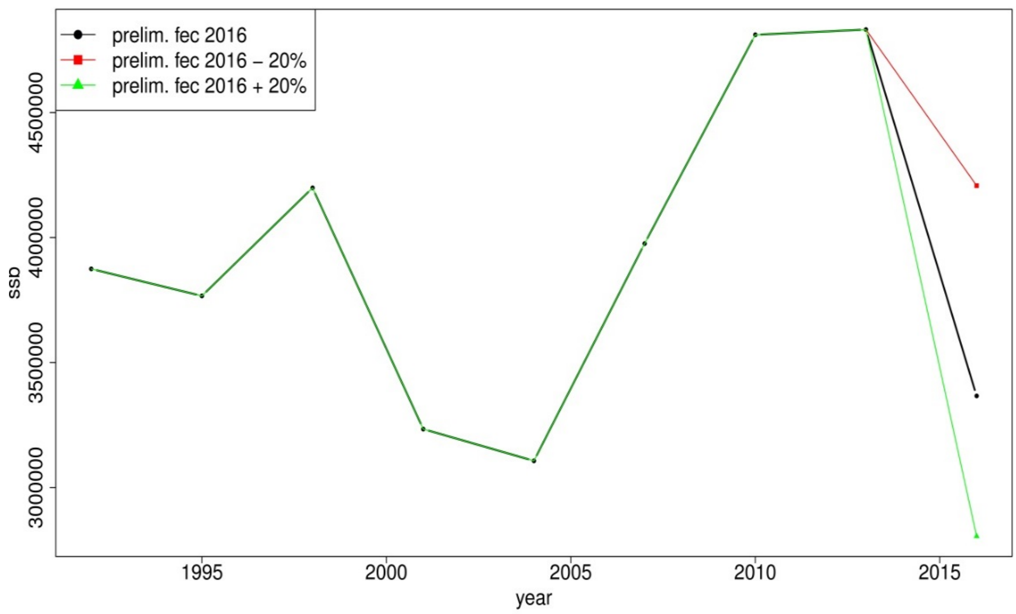



**Figure 3.3.7.1.3.1: Egg survey index time–series. Values in 2016 correspond to the SSB estimate using: i) preliminary fecundity (black); ii) a fecundity 20% smaller than the preliminary one (red); and iii) a fecundity 20% higher than the preliminary one (green).**

Results

Figure 3.3.7.1.3.2 shows the historical stock development estimated by the model for the three alternative assessments carried out. The assessed stock trends show very small differences in SSB and $F_{bar}$, with slightly lower abundances and higher fishing mortalities when revising the fecundity 20% downwards relative to the base case and the contrary when revising it a 20% upwards. The uncertainty in SSB and F estimates was very similar for all the three cases (Figure 3.3.7.1.3.3).

Regarding model parameter estimates, when the final fecundity parameter was reduced, the model showed some small improvement. Except for the egg survey, the observation variances for the catches and the rest of the surveys barely changed. The fit to the egg survey was slightly better (Figure 3.3.7.1.3.4), as observation variances improved (*i.e.* decreased) and the catchability increased. Additionally, the catchability for all the surveys increased as the fecundity decreased. Both, the estimates of over dispersion of the tag recaptures and the estimated post tagging survival rates were very similar independently to the fecundity estimate used.

The value of the standard deviation of the parameter estimates (Figure 3.3.7.1.3.5) were only marginally different between the three models, with slightly less uncertainty on the estimates of the observation variance for the egg survey catchability and uncertainty for the process variances when fecundity parameter was higher, but slightly higher uncertainty for the scaling parameter of the egg survey.

Regarding the retrospective patterns, they were very similar and largely independent of the fecundity estimate (Figure 3.3.7.1.3.6).

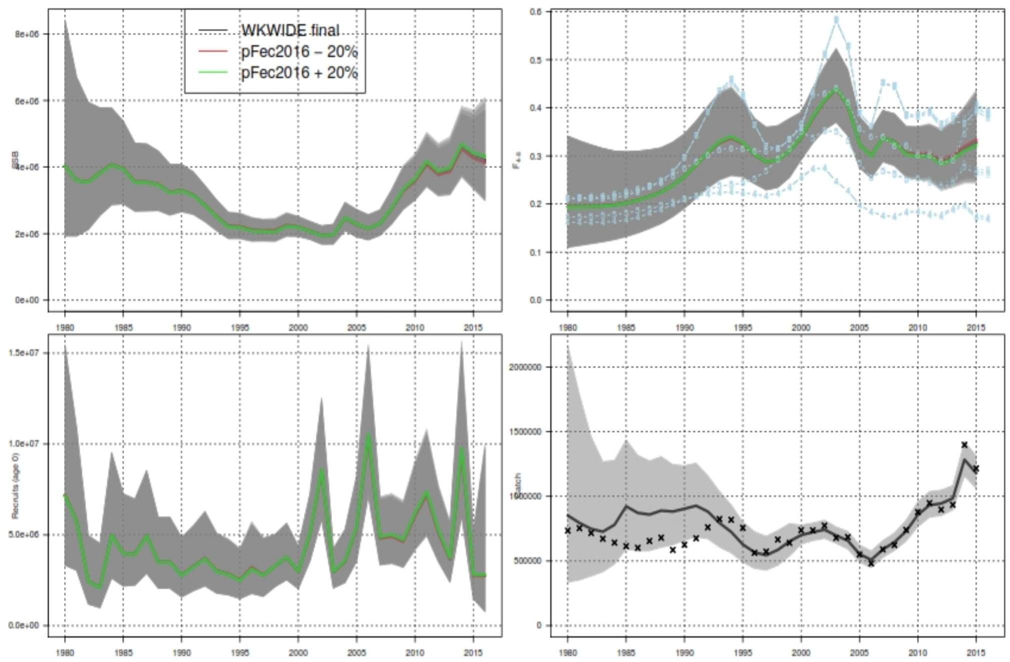



**Figure 3.3.7.1.3.2. Summary of stock assessment, comparison between final WKWIDE accepted assessment (black with confidence interval as dashed grey area) with the alternative cases in which the egg survey index is recalculated based on a revision of the fecundity 20% downwards (red) or 20% upwards (green). From left to right and top to bottom: SSB (in tonnes), F (Fbar for ages 4-8), recruits (millions) and catches (in tonnes) over the years.**

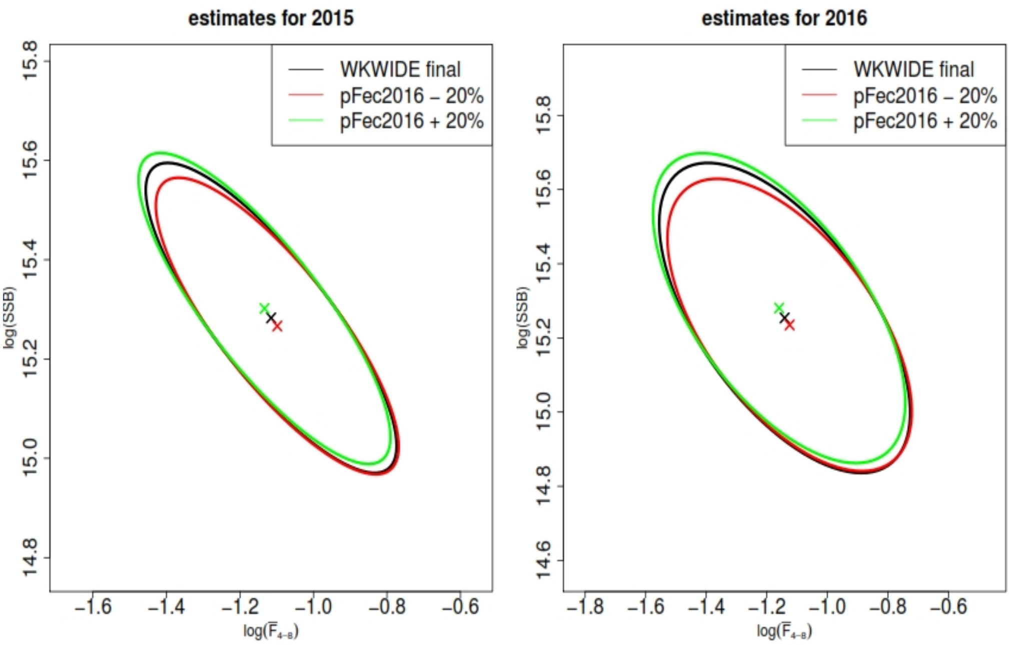



**Figure 3.3.7.1.3.3. Joint distribution of the (log) estimates of SSB and Fbar for the last two years in the assessment, for final WKWIDE accepted assessment (black) and the alternative cases in which the egg survey index is recalculated based on a revision of the fecundity: 20% downwards (red) and 20% upwards (green). The point depicts the point estimate and the ellipsis represents the probability intervals at different confidence levels.**

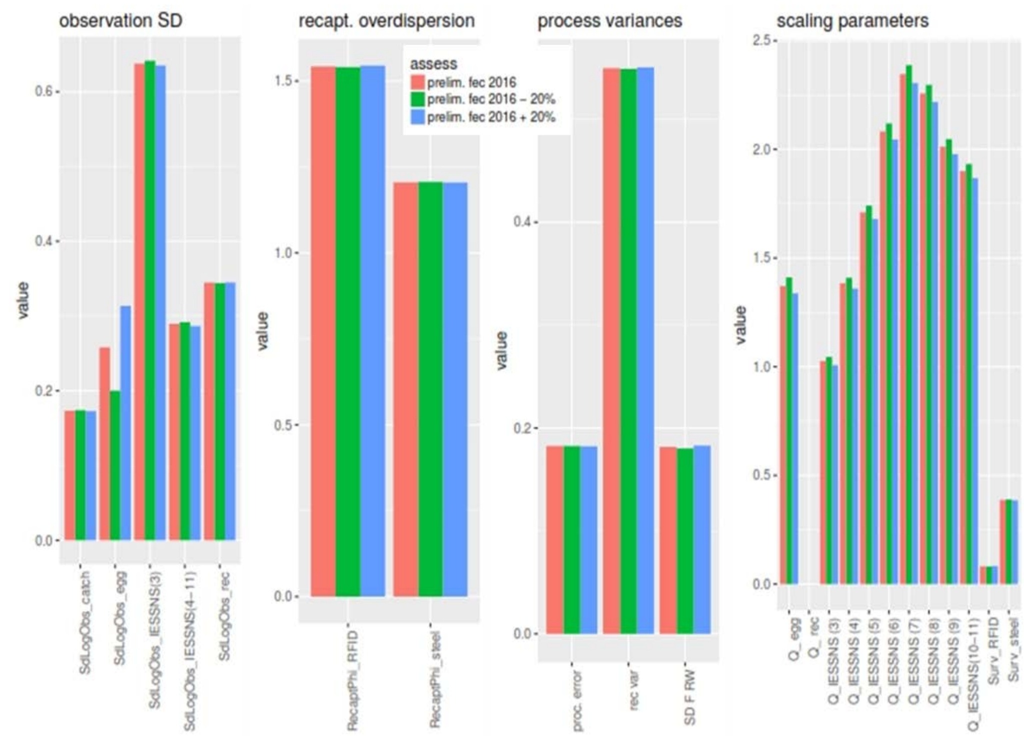



**Figure 3.3.7.1.3.4. Parameter estimates for three alternative SAM runs: final accepted assessment (red) and the alternative cases in which the egg survey index is recalculated based on a revision of the fecundity: 20% downwards (green) and 20% upwards (blue). From left to right: i) observation standard deviation for the catches and the different surveys; ii) recapture overdispersion for the tagging; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

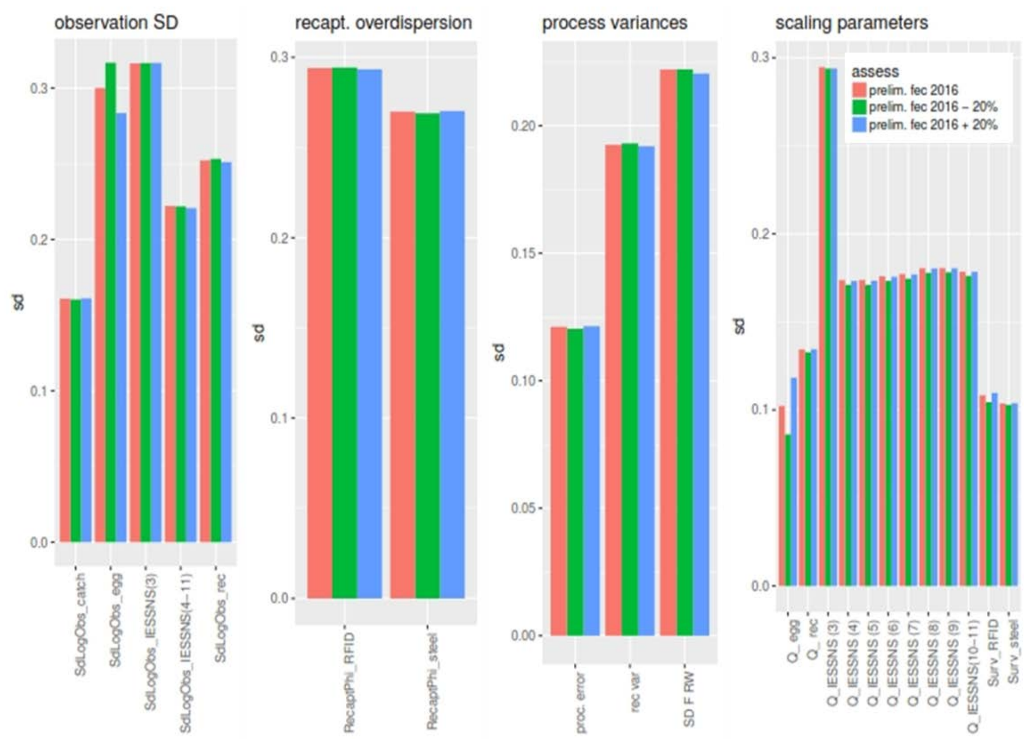



**Figure 3.3.7.1.3.5. Standard deviation of the model parameter estimates for three alternative SAM runs: final accepted assessment (red) and the alternative cases in which the egg survey index is recalculated based on a revision of the fecundity: 20% down (green) and 20% up (blue). From left to right: i) observation standard deviation for the catches and the different surveys; ii) recapture overdispersion for the tagging; iii) process variances: process error, recruitment variance and standard deviation for the F random walk; and iv) scaling parameters: catchability for the different surveys and tagging survival rate.**

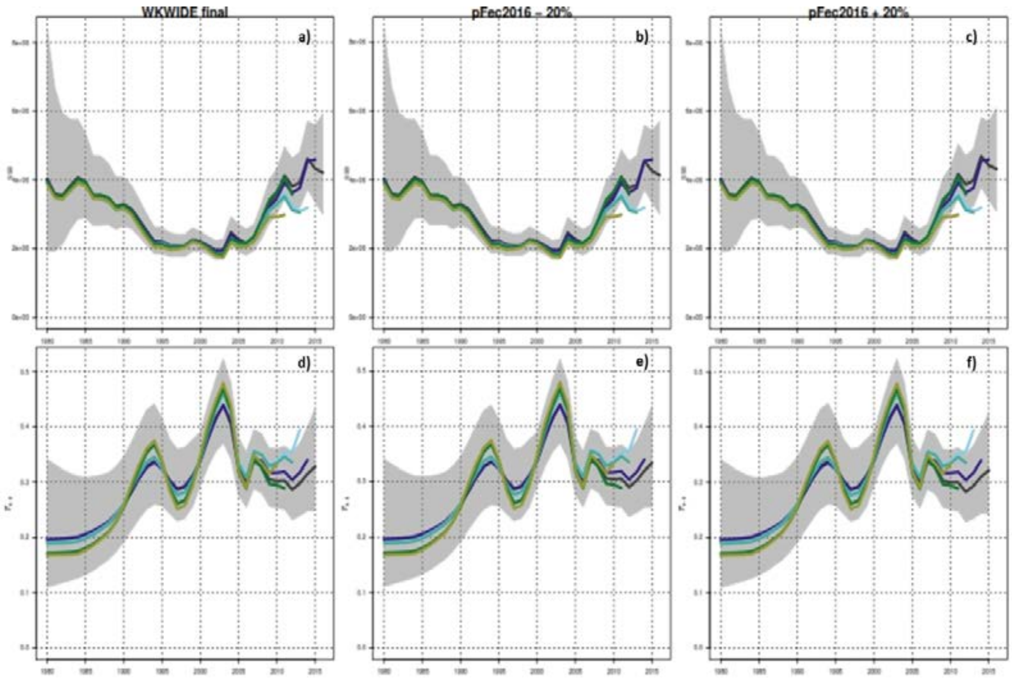



**Figure 3.3.7.1.3.6. Retrospective analysis of SSB (in tonnes) (a-c) and F (Fbar for ages 4-8) (d-f) for three alternative SAM runs: final WKWIDE accepted assessment (a & d) and the alternative cases in which the egg survey index is recalculated based on a revision of the fecundity: 20% downwards (b & e) and 20% upwards (c & f). The 95% confidence interval is shown for the final accepted assessment.**

Conclusions

A revision of the fecundity index, no bigger than 20%, has a negligible effect on the assessment. Historically, fecundity revisions have been lower than 20% (maximum historical revision has been of 17% relative to the initial value).

#### 3.3.7.1.4 Natural mortality

The model fit results for the various natural mortality scenarios outlined in section 3.2.6 are given in the table below

| Model | AIC | LogLik |
|---|---|---|
| Base run | 5355 | -2654 |
| Chen & Watanabe, 1989 | 5418 | -2686 |
| LeMans. scaled 0.15 | 5350 | -2652 |
| Brodziak + Chen & Watanabe_Scenecent, scaled M at age | 5334 | -2644 |

The sensitivity test showed that the U-shaped natural mortality-at-age pattern provided a slightly better model fit than the baseline. In plenary discussion, it was considered that formulations tested were not sufficiently defensible to warrant a change to the current approach at the present time. However, the results indicate that it would be worthwhile to consider the issue again, with attention to more detailed parameterisations and justification for alternative M-at-age options.

#### 3.3.7.1.5 Maturity ogive

In order to investigate the importance of the choices made for the calculation method of the maturity ogive for the western component, the sensitivity of the assessment to the maturity ogive was investigated. The base case run used was the model used during WGWIDE 2016. A trial run was made using a constant maturity ogive (computed by taking the average over time of the time varying maturity ogive used in the assessment.

A comparison of the two runs shows that using a fixed maturity ogive did not change the perception of the historical development of SSB in the SAM assessment (figure 3.3.7.1)

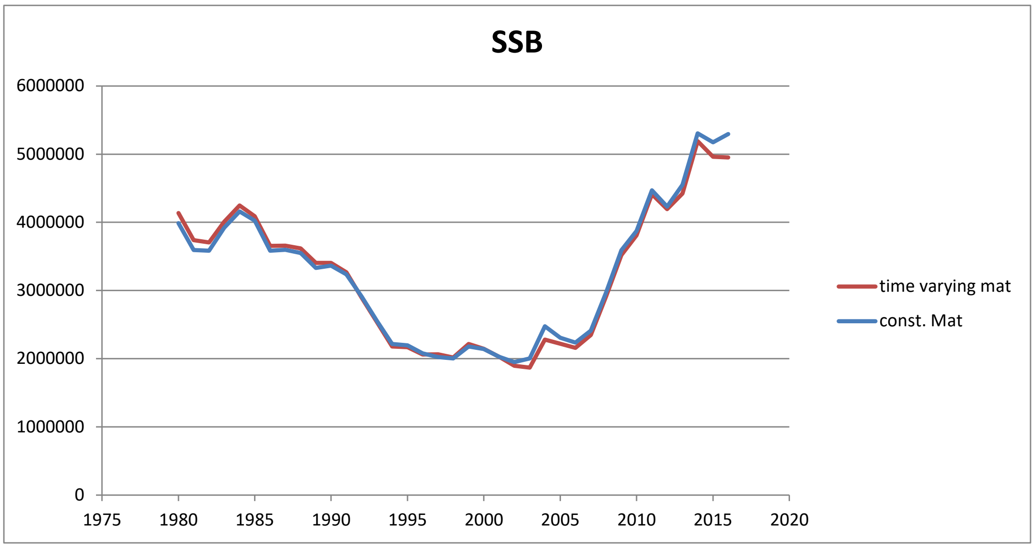



**Figure 3.3.7.1: Comparison of the SSB estimates using a time varying and a constant maturity ogive.**

### 3.3.8Final assessment

During the 2017 WKWIDE benchmark a number of changes have been explored, discussed and accepted for the NEA mackerel assessment. The final accepted assessment now uses the IESSNS index expressed in abundance, for the ages 3 to 11, with an age-varying estimated catchability, and a separate observation variance for age 3 and for ages 4 and older. The updated assessment also uses the new RFID tag/recapture data, parameterized with a survival rate and overdispersion parameters estimated separately from the historical steel tag data. Finally, the model also uses an AR error structure for the observation from the IESSNS. No other change to the data used or the model configuration was made compared to the previous assessment. A detailed list of the input data and the SAM configuration is given in table 3.3.8.1 below.

The 2017 WKWIDE assessment gives the perception of a stock with SSB varying from 1.94 Mt in 2002 and 4.63 Mt in 2014, and fishing mortality ranging from 0.19 at the start of the time–series to 0.44 in 2003 (figure 3.3.8.1. and table 3.3.8.2). The historical development of the stock estimated by the new assessment is broadly similar to the perception from the previous assessment. The new assessment gives however a lower perception of SSB over the last decade (-8% on average and up to -13% for the 2013 and 2015 estimates) and a higher perception of Fbar (8% on average and up to -17% for the 2013 estimate).

The figure 3.3.8.2 shows the impact of the successive changes made to the assessment during WKWIDE 2017. The change in the IESSNS index (change to abundance index and excluding 2007 and 2011) did not result in substantial change in the perception of the stock. The inclusion of age 3 to 5 caused an upward revision of the stock (due to a higher perceived abundance of age 5 fish) in the recent years, and the opposite change in Fbar. The inclusion of the RFID tags brought the SSB back down, close to the base case assessment. Finally, introducing the auto-correlated error structure caused a downward change in SSB (and opposite for Fbar). However, all these successive runs are within the confidence bounds of both the previous and the new accepted assessments

**Table 3.3.8.1: Final WKWIDE 2017 SAM assessment input data and parameter settings**

INPUT DATA TYPES AND CHARACTERISTICS:

| NAME | YEAR RANGE | AGE RANGE | VARIABLE FROM YEAR TO YEAR | REVISED DURING WKWIDE 2017 |
|---|---|---|---|---|
| Catch in tonnes | 1980 –2015 | | Yes | No |
| Catch-at-age in numbers | 1980 –2015 | 0–12+ | Yes | No |
| Weight-at-age in the commercial catch | 1980 –2015 | 0–12+ | Yes | No |
| Weight-at-age of the spawning stock at spawning time. | 1980 –2016 | 0–12+ | Yes | No |
| Proportion of natural mortality before spawning | 1980 –2016 | 0–12+ | Yes | No |
| Proportion of fishing mortality before spawning | 1980 –2016 | 0–12+ | Yes | No |
| Proportion mature-at-age | 1980 –2016 | 0–12+ | Yes | Yes |
| Natural mortality | 1980 –2016 | 0–12+ | No, fixed at 0.15 | No |

**Tuning data:**

| TYPE | NAME | YEAR RANGE | AGE RANGE |
|---|---|---|---|
| Survey (SSB) | ICES Triennial Mackerel and Horse Mackerel Egg Survey | 1992, 1995, 1998, 2001, 2004, 2007, 2010, 2013,2016. | Not applicable (gives SSB) |
| Survey (abundance index) | IBTS Recruitment index (log transformed) | 1998–2015 | Age 0 |

| | | | |
|---|---|---|---|
| Survey (abundance index) | International Ecosystem Summer Survey in the Nordic Seas (IESSNS) | 2010, 2012–2016 | Ages 3–11 |
| Tagging/recapture | Norwegian tagging program | Steal tags : 1980 (release year)-2006 (recapture years)<br>RFID tags : 2011 (release year) 2016 (recapture year) | Ages 2 and older (age at release) |

**SAM parameter configuration :**

| Setting | Value | Description |
|---|---|---|
| Coupling of fishing mortality states | 1/2/3/4/5/6/7/8/8/8/8/8/8 | Different F states for ages 0 to 6, one same F state for ages 7 and older |
| Correlated random walks for the fishing mortalities | 0 | F random walk of different ages are independent |
| Coupling of catchability parameters | 0/0/0/0/0/0/0/0/0/0/0/0/0<br>1/0/0/0/0/0/0/0/0/0/0/0/0<br>2/0/0/0/0/0/0/0/0/0/0/0/0<br>0/0/0/3/4/5/6/7/8/9/10/10/0 | No catchability parameter for the catches<br>One catchability parameter estimated for the egg<br>One catchability parameter estimated for the recruitment index<br>One catchability parameter for each age group estimated for the IESSNS (age 3 to11) |
| Power law model | 0 | No power law model used for any of the surveys |
| Coupling of fishing mortality random walk variances | 1/1/1/1/1/1/1/1/1/1/1/1/1 | Same variance used for the F random walk of all ages |
| Coupling of log abundance random walk variances | 1/2/2/2/2/2/2/2/2/2/2/2/2 | Same variance used for the log abundance random walk of all ages except for the recruits (age 0) |
| Coupling of the observation variances | 1/1/1/1/1/1/1/1/1/1/1/1/1 | Same observation variance for all ages in the catches |

| | | |
|---|---|---|
| | 0/0/0/0/0/0/0/0/0/0/0/0/0<br>2/0/0/0/0/0/0/0/0/0/0/0/0<br>0/0/0/3/4/4/4/4/4/4/4/4/0 | One observation variance for the egg survey<br>One observation variance for the recruitment index<br>One observation variance for the IESSNS (all ages) |
| Stock recruitment model | 0 | No stock-recruiment model |
| Correlation structure | "ID", "ID", "ID", "AR" | Auto-regressive correlation structure for the IESSNS index, independent observations assumed for the other data sources |

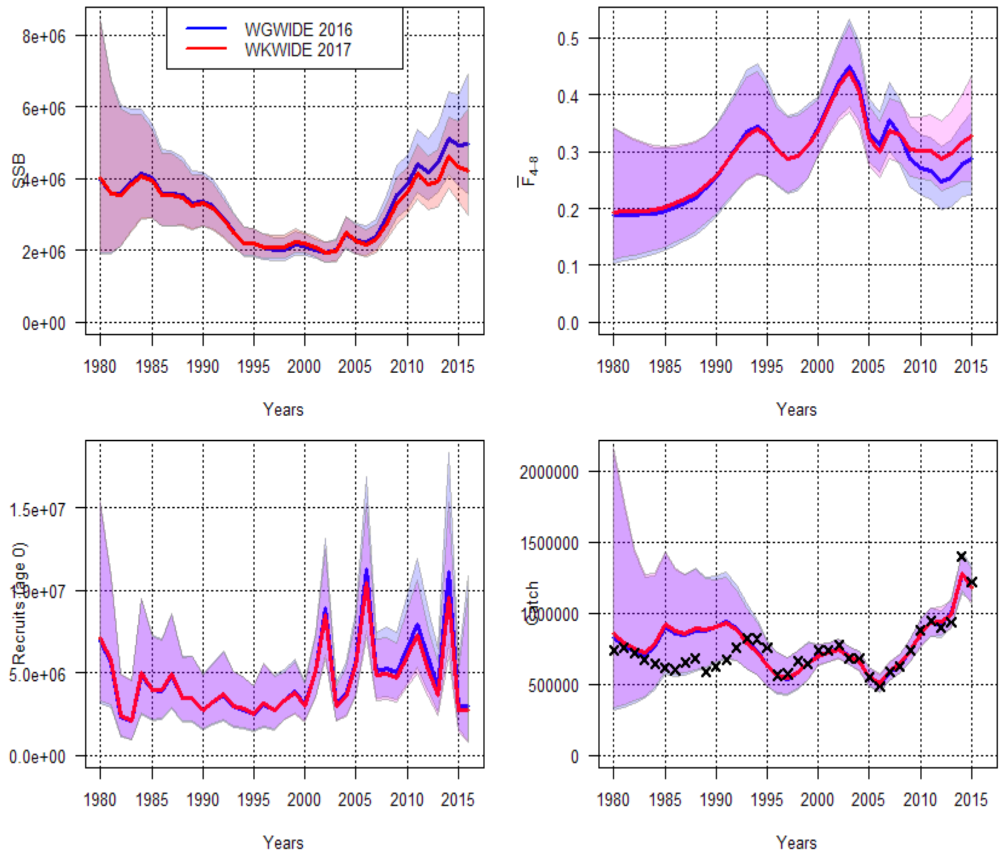



**Figure 3.3.8.1: Comparison of the final 2017 WKWIDE mackerel assessment (red) with the previous assessment of January 2017 (correction of the 2016 WGWIDE assessment), (blue).**

**Table 3.3.8.2: WKWIDE 2017 final assessment summary.**

| Year | SSB | Low | Hig | R(age 0) | Low | High | Fbar(4–8) | Low | Hig |
|---|---|---|---|---|---|---|---|---|---|
| 1980 | 4029077 | 1930585 | 8408574 | 7165018 | 3331449 | 15409958 | 0.19 | 0.11 | 0.34 |
| 1981 | 3595005 | 1928780 | 6700638 | 5744464 | 3037583 | 10863530 | 0.19 | 0.11 | 0.33 |
| 1982 | 3552767 | 2122416 | 5947067 | 2426976 | 1188988 | 4953971 | 0.19 | 0.12 | 0.32 |
| 1983 | 3836576 | 2547393 | 5778188 | 2111903 | 986827 | 4519671 | 0.2 | 0.12 | 0.32 |
| 1984 | 4069321 | 2868334 | 5773168 | 4992468 | 2619797 | 9513997 | 0.2 | 0.13 | 0.31 |
| 1985 | 3946986 | 2896598 | 5378275 | 3972511 | 2177456 | 7247377 | 0.2 | 0.13 | 0.31 |
| 1986 | 3551325 | 2674313 | 4715943 | 3944179 | 2233046 | 6966513 | 0.21 | 0.14 | 0.31 |
| 1987 | 3549281 | 2683249 | 4694829 | 4962750 | 2885009 | 8536848 | 0.22 | 0.15 | 0.31 |
| 1988 | 3475060 | 2694393 | 4481914 | 3502680 | 2058958 | 5958727 | 0.22 | 0.16 | 0.32 |
| 1989 | 3234066 | 2559507 | 4086404 | 3501682 | 2055227 | 5966142 | 0.24 | 0.17 | 0.33 |
| 1990 | 3297007 | 2662172 | 4083227 | 2767808 | 1577986 | 4854774 | 0.26 | 0.19 | 0.35 |
| 1991 | 3156088 | 2582179 | 3857552 | 3249640 | 1923092 | 5491241 | 0.28 | 0.21 | 0.37 |
| 1992 | 2852053 | 2361759 | 3444131 | 3702351 | 2188240 | 6264120 | 0.31 | 0.23 | 0.4 |
| 1993 | 2510596 | 2092526 | 3012193 | 3012363 | 1789206 | 5071709 | 0.33 | 0.25 | 0.43 |
| 1994 | 2212480 | 1854984 | 2638873 | 2831666 | 1692670 | 4737091 | 0.34 | 0.26 | 0.44 |
| 1995 | 2199208 | 1856433 | 2605275 | 2506002 | 1489807 | 4215341 | 0.33 | 0.26 | 0.41 |
| 1996 | 2095942 | 1776567 | 2472731 | 3148481 | 1770216 | 5599845 | 0.3 | 0.24 | 0.38 |
| 1997 | 2075486 | 1782621 | 2416465 | 2781526 | 1611027 | 4802456 | 0.29 | 0.23 | 0.36 |
| 1998 | 2071994 | 1774730 | 2419050 | 3277674 | 2142167 | 5015083 | 0.29 | 0.23 | 0.36 |
| 1999 | 2240974 | 1925870 | 2607634 | 3774200 | 2527839 | 5635083 | 0.31 | 0.26 | 0.38 |
| 2000 | 2193404 | 1918015 | 2508332 | 2983546 | 2033567 | 4377305 | 0.34 | 0.29 | 0.39 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | 2079865 | 1827513 | 2367063 | 5079769 | 3555804 | 7256883 | 0.38 | 0.33 | 0.44 |
| 2002 | 1940247 | 1685516 | 2233475 | 8553727 | 5863726 | 12477774 | 0.42 | 0.35 | 0.49 |
| 2003 | 1961717 | 1686183 | 2282276 | 2960989 | 2070882 | 4233682 | 0.44 | 0.37 | 0.52 |
| 2004 | 2478447 | 2092192 | 2936013 | 3536488 | 2368189 | 5281143 | 0.4 | 0.34 | 0.48 |
| 2005 | 2275442 | 1901569 | 2722825 | 5412355 | 3556357 | 8236965 | 0.32 | 0.28 | 0.38 |
| 2006 | 2156612 | 1811444 | 2567551 | 10466079 | 7154570 | 15310327 | 0.3 | 0.25 | 0.35 |
| 2007 | 2297339 | 1947397 | 2710164 | 4850701 | 3348945 | 7025884 | 0.34 | 0.29 | 0.39 |
| 2008 | 2753234 | 2289158 | 3311391 | 4965030 | 3434945 | 7176686 | 0.33 | 0.28 | 0.39 |
| 2009 | 3311072 | 2734688 | 4008938 | 4676267 | 3222564 | 6785739 | 0.3 | 0.26 | 0.36 |
| 2010 | 3613888 | 3011283 | 4337083 | 6119266 | 4193547 | 8929295 | 0.3 | 0.25 | 0.36 |
| 2011 | 4126722 | 3423994 | 4973675 | 7282772 | 4974443 | 10662252 | 0.3 | 0.25 | 0.36 |
| 2012 | 3820397 | 3145817 | 4639633 | 5190618 | 3527840 | 7637114 | 0.29 | 0.23 | 0.35 |
| 2013 | 3921030 | 3186813 | 4824404 | 3676104 | 2391238 | 5651357 | 0.3 | 0.24 | 0.37 |
| 2014 | 4618125 | 3728981 | 5719279 | 9619478 | 6030607 | 15344121 | 0.31 | 0.25 | 0.4 |
| 2015 | 4337417 | 3360749 | 5597914 | 2771955 | 1482582 | 5182672 | 0.33 | 0.25 | 0.43 |
| 2016 | 4213683 | 2994568 | 5929112 | | | | 0.32 | 0.23 | 0.45 |

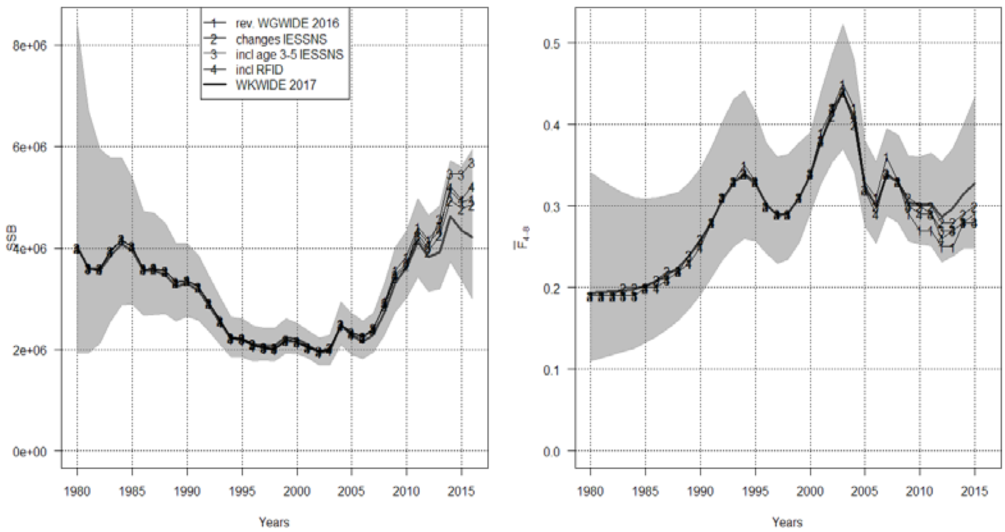



**Figure 3.3.8.2: Cumulative effect on estimated SSB and Fbar of the assessment updates implemented during the WKWIDE 2017 benchmark exercise.**

### 3.3.9Short-term Projections

The method used to carry out short–term projection has not been revisited and remains unchanged from previous benchmark.

### 3.3.10Reference points

#### 3.3.10.1Introduction

The reference points previously evaluated for NEA mackerel are given in Table 3.3.10.1. These were reviewed or defined during the previous benchmark (ICES 2014a) and at the management plan evaluation in 2014 (ICES 2014c). The reference points were reviewed again during WKWIDE 2017, following the latest ICES Advice technical guidelines on reference point estimation for category 1 and 2 stocks (http://ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/12.04.03.01_Reference_points_for_category_1_and_2.pdf).

#### 3.3.10.2Precautionary reference points

**$B_{lim}$** – there is no evidence of significant reduction in recruitment at low SSB within the time–series (fig. 3.3.10.1) hence the previous basis for $B_{lim}$ is retained. $B_{lim}$ is taken as $B_{loss}$, the lowest estimate of spawning stock biomass from the revised assessment. This was estimated to have occurred in 2002 with $B_{loss}$ = 1 940 000t.

**$B_{pa}$** – the ICES basis for advice requires that the assessment uncertainty in the estimate of spawning stock biomass is taken into consideration. This leads to a precautionary reference point $B_{pa}$, which is a biomass reference point designed to avoid reaching Blim. Consequently, Bpa was calculated from

$$B_{pa} = B_{lim} * \exp(1.645\sigma_{SSB})$$

Where $\sigma_{SSB}$ (0.17) was taken as the uncertainty in the SAM estimate of the (log) spawning stock biomass in the most recent assessment year (2016). This results in a $B_{pa}$ value of 2 570 000t.

**$F_{lim}$** – $F_{lim}$ is derived from $B_{lim}$ and is determined as the fishing mortality that, on average would bring the stock biomass to $B_{lim}$. The value for $F_{lim}$ is derived from long–term simulations as the F that, in stochastic equilibrium will result in the median SSB equal to $B_{lim}$. The value estimated at the benchmark workshop was 0.35 (see below for further details on the benchmark conclusions).

**$F_{pa}$** – the value of the estimated fishing mortality which ensures that the true F has a less than 5% probability of being above the reference point $F_{lim}$. $F_{pa}$ is calculated from

$$F_{pa} = F_{lim} * \exp(-1.645\sigma_{Fbar})$$

where $\sigma_{Fbar}$ (=0.17) is the standard deviation of the estimate of ln(Fbar) in the terminal year of the assessment. This leads to an estimate for $F_{pa}$ of 0.26.

#### 3.3.10.3Long–term stochastic simulations for the estimation of MSY

The ICES MSY framework specifies a target fishing mortality ($F_{MSY}$) which, over the long–term maximizes yield and a spawning biomass (MSY $B_{trigger}$), below which fishing mortality is reduced proportionately, relative to $F_{MSY}$ (the ICES MSY advice rule). The ICES basis for advice notes that, in general, $F_{MSY}$ should be lower than $F_{pa}$ while MSY $B_{trigger}$ should be equal to or higher than $B_{pa}$. The value of $F_{MSY}$ should be checked using stochastic simulation to ensure that, by taking consideration of uncertainties, the probability of equilibrium SSB falling below $B_{lim}$ is less than 5% (ICES 2014d).

In the absence of well-defined parametric model fits a stochastic evaluation using equilibrium stochastic simulations (ICES 2014d) was carried out, using the "msy" R package provided by ICES.

##### 3.3.10.3.1 Configuration of the simulations

<u>Definition of the stock recruitment model</u>

Due to the lack of reliable catch information before 2000, the stock assessment has a large uncertainty in the earlier years. Model precision improves considerably for the estimates after the early 1990s, due to the increasing number of data sources used in the assessment. As it was done for the previous evaluation of the NEA mackerel reference points, only the stock recruitment pairs since 1990 were used as a basis to estimate the stock-recruitment model for the simulations. The latest recruitment estimate (2015) was also considered too uncertain and excluded from the time–series.

The standard ICES tool uses a non-parametric bootstrap procedure to approximate the joint distribution of the S-R model parameters and the probability of different stock-recruitment functional forms. An initial run of the S-R estimation software function indicated a very low weight for the "Ricker" function (0.3%). For the estimation of the final model, only the "Beverton and Holt" and the "Segmented Regression" functions were considered.

This model, retained for the stochastic simulations, has a 21% probability for the "Segmented Regression" and a 79% probability for the "Beverton and Holt" model (figure 3.3.10.1). Note that the two largest observed recruitments (2002 and 2006) are outside of the 90% envelope of the predicted values based on the estimated stock-recruitment model.

EqSim Simulation Setup

The default setting for the biological vectors (weights–at–age, proportion mature at age, proportion of natural and fishing mortality occurring before spawning) is a 10 year window in which values for the simulation period are taken by resampling. In the case of the NEA mackerel, most of the biological input data show a clear trend over the last decade. According to ICES guidelines, the simulations should represent the current productivity state of the stock, and make no inference on the direction of future changes. Based on this, the mean values for the biological vectors used in the previous management plan evaluation were based on the average of the last 3 observed years. Since the simulation tool from the ICES "msy" R package simulates by resampling (i.e. not by drawing from a statistical distribution as done for the most recent management plan evaluation), it was decided to use the last 5 years of observations in order to have sufficient data for resampling. In order to examine the sensitivity of the reference points estimates to this configuration, simulations were run also using the default 10-year window and results were compared. Since no obvious pattern was observed in the selection pattern of the fishery, the default 10 year window was used for this parameter.

Estimating the imprecision in the advice year proved difficult for the NEA mackerel stock. The appropriate method involves conducting a retrospective evaluation of the accuracy of the short-term forecast run using the true (observed) catch as conditioning for the intermediate year, and comparing the forecasted SSB and Fbar to the values in the corresponding year estimated by the most recent assessment (taken as baseline). However, in the case of NEA mackerel, these errors on the advice year SSB and Fbar can be calculated only for 3 (advice) years (2014, 2015 and 2016), which is insufficient for accurate estimation of the standard deviation and autocorrelation. For years prior to 2014, the basis for the advice was differed (based on the old ICA assessment using only catches and the egg survey) and thus cannot be included in the calculation. Standard deviation and autocorrelation for the SSB and Fbar in the advice year were taken from the previous management plan evaluation work although, it was acknowledged that, since the assessment model changed during the benchmark, it could be expected that those values may have also changed.

The simulations were based on 1000 replicates of the stock, used the values of $B_{lim}$ and $B_{pa}$ defined above, and considered MSY $B_{trigger}$ = Bpa (see rationale below).

The detail of the configuration of the simulation is given in the table below.

```
SIMBtrig <- eqsim_run(FIT,
bio.years = c(2011, 2015),
bio.const = FALSE,
sel.years = c(2006, 2015),
sel.const = FALSE,
Fscan = seq(0.01,0.8 , len = 80),
Fcv = 0.35, Fphi = 0.61,
SSBcv = 0.31
rhologRec = F,
Blim=1940000, Bpa=2570000
Btrigger = 2570000
Nrun = 1000,
process.error = TRUE,
verbose = TRUE )
```

#### 3.310.3.2 Simulation output and FMSY estimation

Simulations were first run assuming zero assessment error and without implementing the ICES MSY advice rule (i.e. setting MSY $B_{trigger}$ = 0 in the simulations) in order to estimate $F_{lim}$. The F value for which the median of the SSB across replicates was equal to $B_{lim}$ was 0.35. This candidate value for $F_{lim}$ is very close to the current value (0.36).

Additional simulations were then run including estimates of assessment error, but still without the ICES MSY advice rule. The median of the yield across iterations reached a maximum for a F value of 0.156 (figures 3.3.10.2-3). This F value appeared to be precautionary as it was lower than $F_{.05}$ (=0.209), the fishing mortality above which the probability of SSB falling below $B_{lim}$ is larger than 5%. Based on these simulations, the lower SSB value (5% quantile for the distribution across iterations) observed when fishing constantly at the candidate $F_{MSY}$ value of 0.16 was 2 751 337 tonnes. This value was a candidate value for MSY Btrigger. Following ICES guidelines, however, implies than MSY Btrigger should be set equal to $B_{pa}$ in the case of the NEA mackerel, for which fishing mortality over the last 5 years was higher than $F_{MSY}$.

Following ICES guidelines, simulations were run again implementing assessment errors and the ICES MSY advice rule using an MSY $B_{trigger}$ = $B_{pa}$ (2.57 Mt) to check if the candidate $F_{MSY}$ (0.16) is still found to be precautionary, which was the case.

Finally, an additional simulation run was made to test the sensitivity to the choice of a 5 year or 10 year window for the biological vectors. Using the last 10 years, the estimated $F_{MSY}$ was 0.161 (figure 3.3.10.4), a 3% difference with the value obtained using the 5 year window.

#### 3.3.10.4 Conclusions

The benchmark considered revising the full suite of reference points based upon the analysis described above. It was felt however, that, given that an evaluation of a long–term management strategy will be conducted in the near future, it would be appropriate to consider the results of this evaluation before proposing revisions to reference points based upon long–term simulations. Since the evaluation is concerned only with mackerel, it is possible that this will be a more suitable approach than the generic *EqSim* tool. The current reference points were determined by a similar exercise in 2015. Updated values for reference points that can be determined directly from the assessment output ($B_{lim}$, $B_{pa}$ and MSY $B_{trigger}$ in this case) are proposed by the benchmark. The updates are given in table 3.3.10.2.

**Table 3.3.10.1: Current NEA mackerel reference points**

| Framework | Reference point | Value | Technical basis | Source |
|---|---|---|---|---|
| MSY approach | MSY Btrigger | 3 million t | Bpa | ICES (2015) |
| | FMSY | 0.22 | Stochastic simulation. | ICES (2015) |
| Precautionary approach | Blim | 1.84 million t | Bloss in 2002 from 2014 benchmark assessment. | |
| | Bpa | 3 million t | exp(1.654 × $\sigma$) × Blim, $\sigma$ = 0.30. | ICES (2015) |
| | Flim | 0.36 | The F that on average leads to Blim. | ICES (2015) |
| | Fpa | 0.25 | The F that on average leads to Bpa. | ICES (2015) |

**Table 3.3.10.2: Proposed revisions of the NEA mackerel reference points after the 2017 benchmark.**

| Framework | Reference point | Value | Technical basis | Source |
|---|---|---|---|---|
| MSY approach | MSY Btrigger | 2.57 million t | Bpa | ICES (2017) |
| | FMSY | 0.22 | Stochastic simulation. | To be re-estimated at the next management plan evaluation |
| Precautionary approach | Blim | 1.94 million t | Bloss in 2002 from 2014 benchmark assessment. | ICES (2017) |
| | Bpa | 2.57 million t | exp(1.654 × $\sigma$) × Blim, $\sigma$ = 0.17. | ICES (2017) |
| | Flim | 0.36 | The F that on average leads to Blim. | To be re-estimated at the next management plan evaluation |
| | Fpa | 0.25 | The F that on average leads to Bpa. | To be re-estimated at the next management plan evaluation |

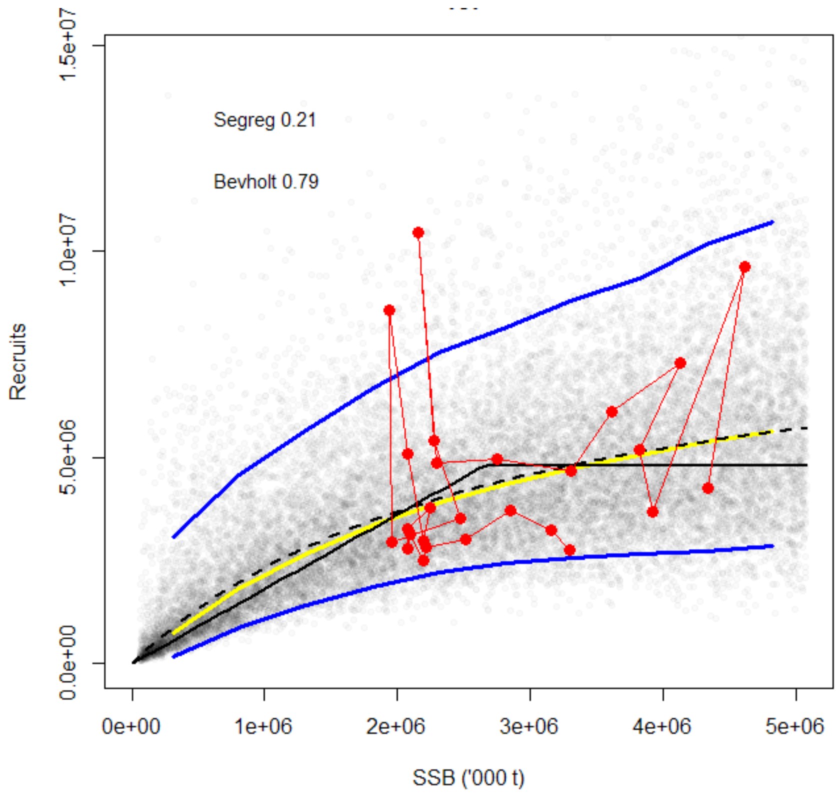



**Figure 3.3.10.1: NEA mackerel stock-recruitment models used for the stochastic simulations. SAM estimates of the stock-recruitment pairs used for model fitting are depicted in red (1990-2014). Black lines show the average Segmented Regression (solid) and Beverton and Holt (dashed) models. The grey dots represent simulated values, the yellow line represents the median and the blue lines the 5% and 95% percentiles for the simulated values.**

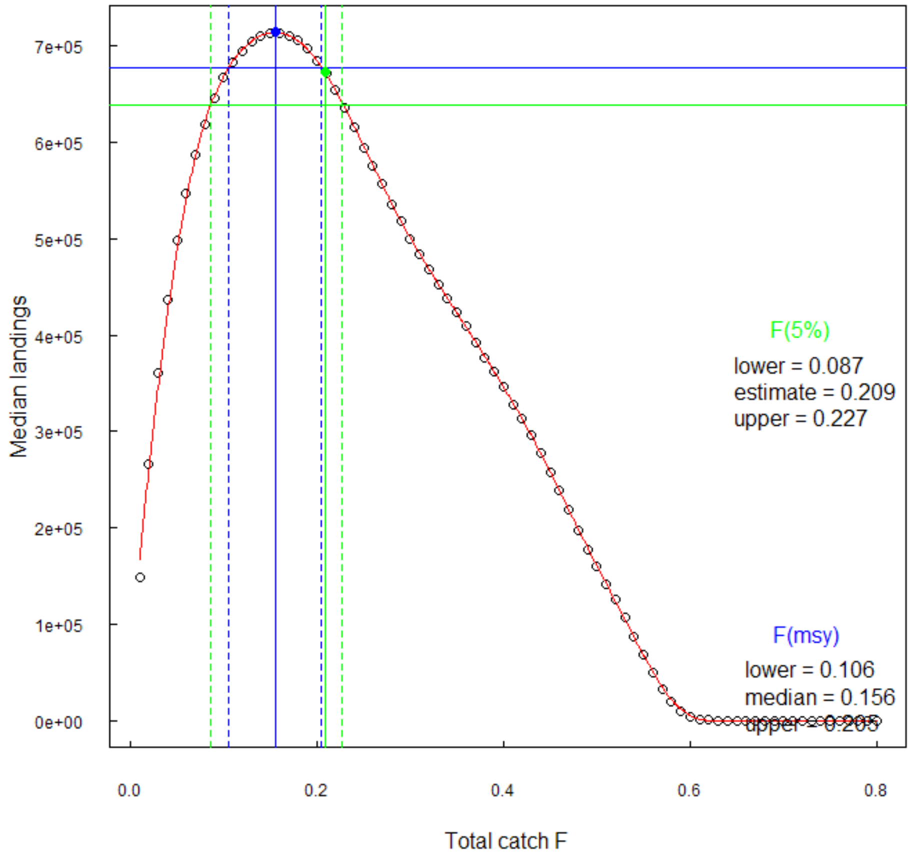



**Figure 3.3.10.2: Median (1000 iterations) for the mean yield at stochastic equilibrium as a function of the fishing mortality applied. The blue vertical line corresponds to $F_{MSY}$ (with the dashed lines representing the $F_{MSY}$ range limits). Green vertical lines represent the fishing mortality at which p(SSB<$B_{lim}$)>5%. Simulations run without ICES MSY advice rule.**

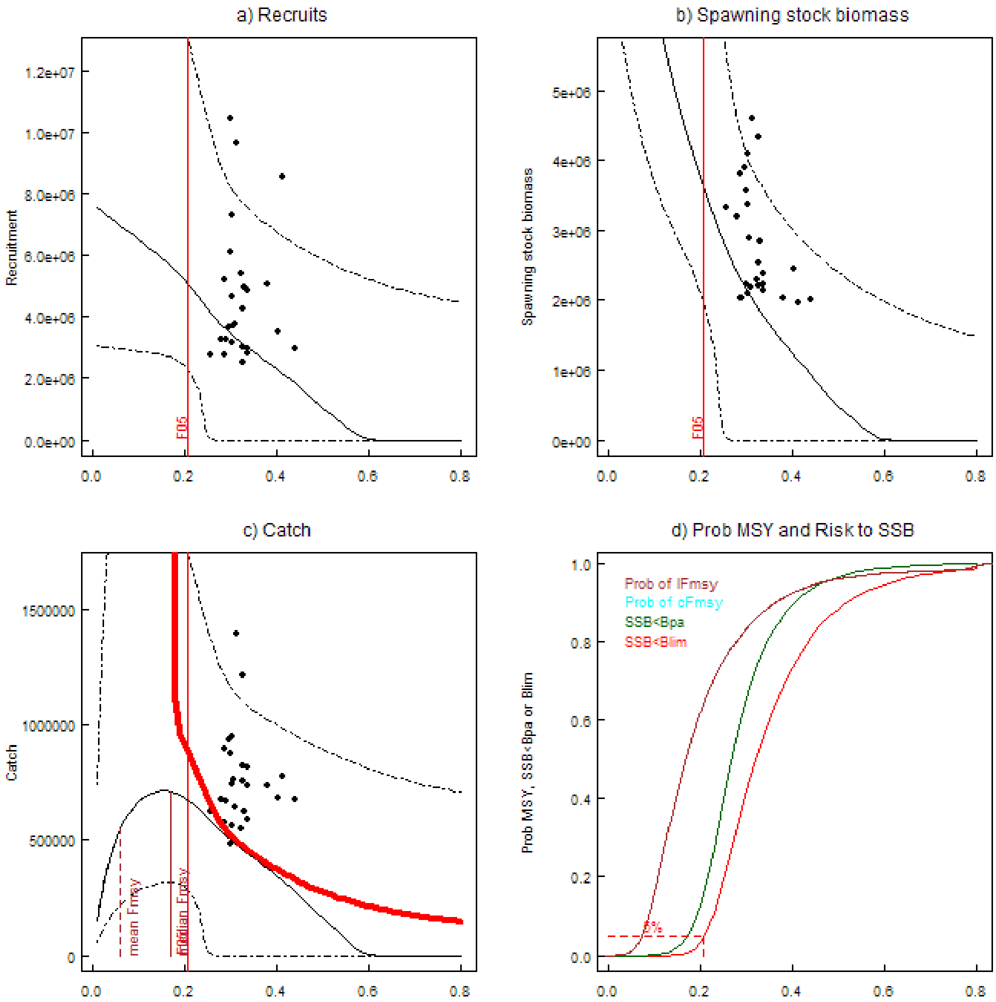



**Figure 3.3.10.3: Simulated recruitment, SSB, yield and p(SSB<$B_{lim}$) as a function of the fishing mortality in the long–term simulations. a, b and c): solid line represents the median value (1000 iterations), dashed lines represent 5% and 95% percentiles of the distribution, historical estimates are depicted by the black dots.**

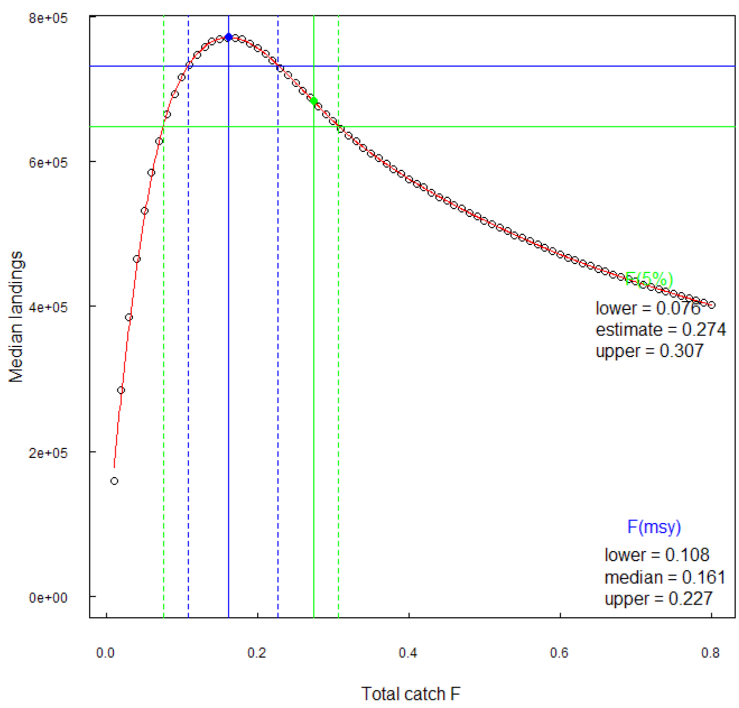



**Figure 3.3.10.4: $F_{MSY}$ estimation for the sensitivity run with a 10 year window used for the biological vectors.**

## 3.4 Stock Structure

The Atlantic mackerel in the Northeast Atlantic is traditionally characterised as three distinct 'components': the southern component, the western component and the North Sea component. The basis for the components is derived from tagging experiments (ICES, 1974), however, the methods normally used to identify stocks or components (e.g. ectoparasite infections, blood phenotypes, otolith shapes and genetics) have not been able to demonstrate significant differences between animals from different components. The mackerel in the Northeast Atlantic appears on one hand to mix extensively whilst, on the other hand, exhibit some tendency for homing (Jansen *et al.* 2013, Jansen and Gislason, 2013). Consequently, it cannot be considered either a panmictic population, nor a population that is composed of isolated components (Jansen and Gislason 2013). Instead of dividing the NEA mackerel into three distinct components, Jansen and Gislason suggested the concept of a 'dynamic cline' (i.e. a continuum with gradients) could provide a more appropriate description. The dynamic cline can respond both to the changes in hydrography and mackerel behaviour (Jansen and Gislason 2013).

### 3.4.1 The North Sea Mackerel Stock Component

The WKWIDE benchmark workshop was requested to address the following ToR regarding the North Sea spawning component of mackerel:

*Taking into account the current knowledge on stock identity, structure and migration, review the appropriateness of the ICES advice to continue with the existing measures (spatio-temporal closures and minimum landing size) to protect the North Sea spawning component*

History

ICES has continuously recommended conservation measures for the North Sea component of the Northeast Atlantic mackerel stock since the mid-1970s (e.g. ICES 1974, ICES 1981). The measures advised by ICES to protect the North Sea spawning component aim to promote the conditions that make a recovery of this component possible.

Mackerel were known to be abundant in the North Sea in the 1950s and early 1960s and catches in those years were between 50 and 100 thousand tonnes (Figure 3.4.1.1) (Lockwood 1988, Jansen 2014). In the late 1960s, catches rapidly increased due to the development of new sonar and power block techniques and the realization that this was effectively a very large resource (Hamre 1980). This led to unparalleled catches of 900 000 tons in 1967 (Hamre 1978), which consisted to a large extent of juveniles landed for reduction purposes (Revheim and Hamre 1968, Hamre 1970). These high landings were followed by a collapse in the fisheries in the 1970s and the general understanding that the high fishing mortality had caused the collapse of the North Sea mackerel stock. This resulted in the introduction of protection mechanisms in the form of quotas and the setting of a minimum landing size (MLS). The basic assumption was that the North Sea mackerel stock would recover if the fishery could be minimized. However, despite measures to protect the 'North Sea component', mackerel spawning in the North Sea has never recovered to pre-collapse levels (Jansen 2014, ICES 2016). Later, the mackerel fishery in the northern North Sea was permitted to increase substantially during the late autumn and winter. This was allowed because tagging studies showed that most of these mackerel were spawning further south-west (Uriarte et al., 2001), and were considered to belong to the so-called Western and Southern components.

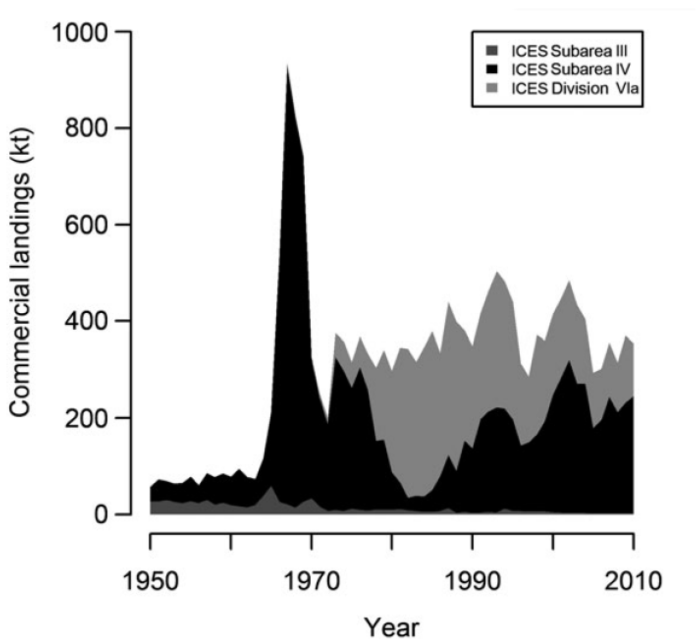



**Figure 3.4.1.1: Commercial landings of mackerel in the North Sea (ICES Subarea 4), Kattegat–Skagerrak (Subarea 3), and West of Scotland (Division 6.a). Data from 1945–1949 from Postuma (1972). Data from 1950–2010 from Lassen *et al.* (2012). (Figure 2 from Jansen (2014)).**

<u>Catches in the North Sea</u>

ICES cannot split the reported mackerel catches into components because there is no clear distinction between components upon which a split could be determined. Mackerel with a preference for spawning in the north-east including the North Sea (despite that they may originate from and sometimes spawn elsewhere) cannot presently be identified morphometrically or genetically (Jansen and Gislason 2013). Separation based on time and area of the catch is not a precise way of splitting mackerel with different spawning preferences, because of the mixing and migration dynamics including inter-annual (and possibly seasonal) variation of the spawning location, combined with the post-spawning immigration of mackerel from the south-west (where spawning ends earlier than in the North Sea).

<u>Indices of Abundance</u>

The only surveys that provide information on the trends in abundance of mackerel with a tendency to spawn in the north-east are the Mackerel Egg Survey in the North Sea and the Continuous Plankton Recorder (CPR) surveys. Other surveys of mackerel in the North Sea, such as the IBTS survey, reflect a mixture of mackerel with an unknown and variable proportion of mackerel with a tendency to spawn in the north-east.

*Egg surveys*

Egg surveys for mackerel in the North Sea have been carried out since the early 1970s (Iversen 1981, ICES 2016). Currently, the egg survey in the North Sea is carried out every third year (in the year after the egg survey west of the British Isles and in the Bay of Biscay). The egg survey is mainly used to estimate the relative size of the three spawning components under the assumption that the egg abundance in the North Sea can be directly compared to the egg abundances in the western and southern areas the year before.

*CPR data*

Jansen and Kristensen *et al.* 2012 published an analysis utilizing the CPR data for the mackerel in the North Sea (Jansen, Kristensen *et al.* 2012a). This provides a unique and long time–series of the development of mackerel eggs in the area, which they compared to other indices of abundance. The analysis clearly demonstrates the lower abundance of mackerel in the North Sea after the 1950s and 1960s.

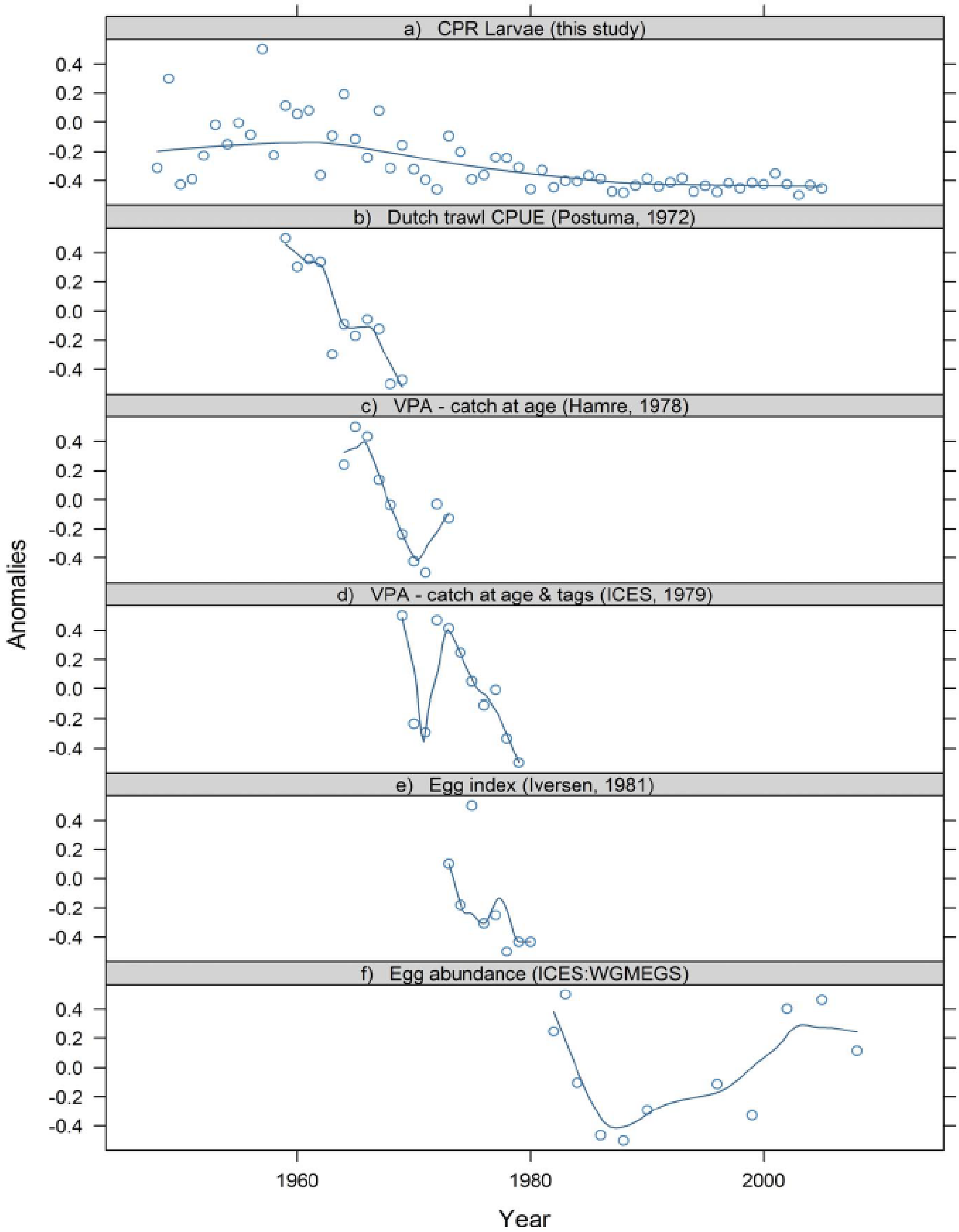



**Figure 3.4.1.2 Long–term mackerel trends in the North Sea from different sources. Loess smoothed line with span=0.5. From (Jansen, Kristensen *et al.* 2012a).**

*IBTS survey*

Mackerel is frequently caught in the IBTS surveys that are carried out in the North Sea in quarters 1 and 3. However, this mackerel consists of a variable mixture of mackerel with various spawning preferences. As no method is currently available for the splitting of the survey samples, is currently not informative with regard to the individual components. An estimate of recruits based on the IBTS Q1 survey is used in the assessment because acoustic investigations has indicated that the juvenile mackerel is close to the bottom at this time of the year. This is not the case for mackerel in Q3 (van der Kooij *et al.* 2016).

Management Measures

The recommended closure of Division 4.a for fishing during the first half of the year is based on the perception that the western mackerel enter the North Sea in July/August, and remain there until December before migrating to their spawning areas. Updated observations from the late 1990s suggested that this return migration actually started in mid- to late February (Jansen *et al*. 2012b). This was believed to result in large-scale misreporting from the northern part of the North Sea (Division 4.a) to Division 6.a. The presence of mackerel in the northern North Sea in late autumn and winter are affected by the relatively warm shelf edge current and temperature fluctuations within the current (Jansen *et al*. 2012b).

Recent EU TAC regulations have permitted some small quotas in 3.a and 4.b,c. In the same regulation it is also stated that within the limits of the quota for the western component (6, 7, 8.a,b,d,e, 5b (EU), 2a (non EU), 12, 14), a certain quantity of this stock may be caught in 4.a but only during the periods 1 January to 15 February and 1 September to 31 December. Up to 2010, 30% of the Western mackerel TAC (MAC/2CX14-) could be taken in 4.a. From 2010 onwards, this percentage has been set at 40%.

The minimum landing size for mackerel is currently set at 30 cm for the North Sea and 20 cm in the western area. The historical basis for the setting of minimum landing sizes detailed in a working document to WGWIDE in 2015 (Pastoors 2015). The MLS of 30 cm in the North Sea was originally introduced by Norway in 1971 and was intended to protect the very strong 1969 year class from exploitation in the industrial fishery. The 30 cm became the norm for the North Sea MLS on the basis of productivity assumptions. The MLS for mackerel in western waters was set at 20 cm in 1992. Unfortunately, the underpinning of that regulation (*i.e.* the European Commission proposal) is no longer available on any of the archives, so that the arguments used as a basis for its introduction cannot be reviewed. However, ICES recommended in the early 1990s that, because of mixing of juvenile and adult mackerel on western waters fishing grounds, the adoption of a 30 cm minimum landing size for mackerel was not desirable as it could lead to increased discarding (ICES 1990a) (ICES 1991).

With the introduction of the landing obligation in EU fisheries, the discussion on the basis and the application of the minimum landing size of mackerel in the North Sea has reappeared. This is because a substantial part of the catch of NEA mackerel is taken in ICES division 4.a during the period October until mid-February. Unfortunately, there is limited understanding on the effectiveness of minimum landing sizes in achieving certain conservation benefits (STECF 2015). Therefore, changes in minimum landing sizes are difficult to argue and in most cases the MLS agreed in the past are continued into the future, including the mismatch between the MLS for mackerel in the North Sea and in the western waters.

Collapse or pseudo-collapse?

The hypothesis that North Sea mackerel is an isolated stock or a distinct component of a larger Northeast Atlantic mackerel stock has been widespread for half a century. The collapse of the mackerel in the North Sea in the 1970s has been well documented. However, the lack of recovery despite the management measures that have been taken, gives rise to doubts of this hypothesis. The PhD thesis of Jansen (2012) contains many of the elements and analyses that are challenging the hypothesis of the North Sea mackerel as an isolated component. Based on a number of alternative approaches, it is shown that the collapse of mackerel in the North Sea was most likely driven by very high catches and associated fishing mortality in the late 1960s. However, the lack of recovery of mackerel in the North Sea was probably associated with unfavourable environmental conditions, particularly reduced temperatures (unfavourable for spawning), lower zooplankton availability in the North Sea and increased wind-stress induced turbulence. These unfavourable environmental conditions probably led the mackerel to spawn in western waters instead of in the North Sea. On a population level, the reduced abundance of mackerel in the North Sea is not an indicator of a local stock collapse, but rather a southwest shift in the spawning distribution of mackerel in combination with a reduction in that portion of the population cline with an affinity for spawning in the north-eastern part of the spawning area, including the North Sea. While the temperature has increased, preferred food (such as Calanus finmarchicus) has remained at a low level. No indication of irreversible genetic or behavioural losses caused by the events was found (Jansen, 2014).

Conclusions

- Northeast Atlantic mackerel should be considered as a single population (stock) with individuals that show stronger or weaker affinity for spawning in certain parts of the spawning area. Management should ensure that fisheries do not decrease genetic and behavioural diversity, since this could reduce future production. Protection of mackerel that tend to spawn in the north-eastern parts of the spawning area is therefore still advisable to some extent.
- The decline in mackerel in the North Sea in the 1970s was likely due to high fishing mortality from fisheries in the late 1960s and early 1970s.
- The lack of rebuilding of spawning in the North Sea seems related to two environmental factors that have remained unfavourable: (i) zooplankton concentration, and (ii) wind-induced turbulence.
- The catch of mackerel in area 4.a between September and February consists of an unknown mixture of mackerel that has spawned in the North Sea and mackerel that has spawned in the western waters.
- The minimum landing size of 30 cm in the North Sea is based on the historical concern with catches of juvenile mackerel for reduction purposes in the early 1970s. It is not known what the rationale has been for the establishment of the minimum landings size of 20 cm in the western areas, although it is most likely based on fishery selectivity arguments. Under the new EU landing obligation, the minimum landing size of 30 cm in the North Sea is leading to a potential waste of valuable resources (because fish under the minimum landing size needs to be landed but cannot be used for human consumption).

### 3.4.2Mackerel Distribution in the Autumn in the Mackerel Box

The mackerel box is an area with fishing restrictions around the Cornish Peninsula of the UK established in 1981 to protect juvenile mackerel over the winter months

Since its introduction, no consistent fisheries independent survey effort has been conducted in the Mackerel box. However, since 2012 the multi-disciplinary PELTIC ecosystem survey has been conducted in the Celtic Sea and English Channel, covering much of the Mackerel box area. The results from the survey suggest that the Mackerel box continues to be important for mackerel and that it is an important nursery ground, with the majority of fish sampled of age 0 (van der Kooij and Silva, 2017).

# 4 Horse Mackerel

## 4.1 Issue List

A list detailing the issues that WGWIDE considered should be addressed by the benchmark assessment of both horse mackerel stocks was compiled during WGWIDE 2016 and used to plan the programme of work for WKWIDE. The lists are given below:

| Stock | Western Horse Mackerel | |
|---|---|---|
| Stock Coordinator | Gersom Costas | gersom.costas@vi.ieo.es |
| Stock Assessor | Piera Carpi | piera.carpi@cefas.co.uk |
| Data Contact | Gersom Costas | gersom.costas@vi.ieo.es |

| Stock | North Sea Horse Mackerel | |
|---|---|---|
| Stock Coordinator | Gersom Costas | gersom.costas@vi.ieo.es |
| Stock Assessor | Alfonso Pérez Rodríguez | alfonso.perezrodriguez@wur.nl |
| Data Contact | Gersom Costas | gersom.costas@vi.ieo.es |

**Western Horse Mackerel**

| Issue | Problem or Aim | work needed/ possible Solution | data requirement (source) | required expertise/ contact |
|---|---|---|---|---|
| Assessment - Input Data | Assumed value of 0.15 for M | Value of 0.15 should be investigated. For different sizes. Multispecies models, other HOM stocks, predator abundances. | | Lisa Readdy, Piera Carpi, Steve Mackinson. |
| | Egg production during early years (1983, 1989) does not include southern part of the stock | Review availability of information and estimate egg production in southern part for these years – none available | WGMEGS | Finlay Burns, Cindy van Damme |
| | Realised fecundity - Prior based in *Abaunza et al., 2003* | Review literature, update estimates | WGMEGS | Cindy van Damme, Gersom Costas |
| | Mean Weight-at-age in the stock: there are not samples available for younger ages in area VIIj Quarter 1,2 | Explore another source of information in order to estimate mean weight-at-age for stock. | | Andrew Campbell, Jens Ulleweit |
| | Limited acoustic survey information | Review other surveys (HERAS, PELGAS, BWAS) – sampling | | Pablo Carrera, Andrew Campbell, Erwan Duhamel |
| | Investigate incorporating egg count index within SS. | | | Modellers |
| | Catch at age/LF data by division since 2000 | | | Gersom Costas |
| | Effective sample size for SS input data | Summary of sampling intensity. | | Piera Carpi, Gersom Costas |
| Tuning series | Lack of fishery dependant  and independent information | Exploration of additional fishery dependent and independent time–series to base an abundance index on. | DATRAS, National laboratories, Industry data | |
| Discards | Discard information is incomplete | All fleets where discarding is thought to be occurring should be sampled for discard. | Data should be supplied to the coordinator accompanied by | |

| | | | | |
|---|---|---|---|---|
| | | | documentation describing the sampling protocol. | |
| Assessment method | Suitability of SADVF model for provision of annual advice. | Stock Synthesis model to be investigated. Review history of advice | | |
| Biological Reference Points | Evaluate biomass- and fishing mortality reference points | Evaluation of the work already completed by WKMSYREF3 and industry (Pelagic AC). Evaluate possibility of estimation within stock assessment model. Use of standard tools. | | |
| Stock ID | Uncertainty on the links with the North Sea stock | Review previous work and set directions for future analysis. Contrast index development work in NS and WHM stocks. | | |

**North Sea Horse Mackerel**

| Issue | Problem or Aim | work needed/ possible Solution | data requirement (source) | required expertise/ contact |
|---|---|---|---|---|
| Discards | Discard information is incomplete | All fleets where discarding is thought to be occurring should be sampled for discard. | Data should be supplied to the coordinator accompanied by documentation describing the sampling protocol. | National laboratories, Gersom Costas |
| | Change in the spatial coverage CGFS survey | Evaluate the effect of this change in the index of abundance by length | National laboratories | FR-CGFS Survey coordinator, Alfonso Pérez Rodríguez |
| | Investigate utility of groundfish surveys (individually or in combination) as indicators of recruitment/ adult stock | Data analysis, apply alternative modelling approaches (as with Western Horse Mackerel investigations) | DATRAS | Alfonso Pérez Rodríguez |

| | | | | |
|---|---|---|---|---|
| | Investigate industry data as a potential indicator of recruitment/ adult stock | Data analysis, modelling (as above) | Industry supplied data | Martin Pastoors, Inge van dep Knapp, Teunis Jansen |
| Stock Assessment | No current accepted stock assessment | Investigation of alternatives e.g. length based model, DLS approach | Catch at length – National laboratories, WKLIFE | Piera Carpi, Alfonso, David Millar |
| Biological information | No information about maturity state at age and length. | Explore available sources of information in order to estimated maturity ogives by age and length. Sampling of maturity state during international and national surveys | Data should be supplied to the coordinator accompanied by documentation describing the sampling protocol. | National laboratories |
| Stock ID | Uncertainty on the links with the Western stock | Review previous work and set directions for future analysis | | Martin Pastoors, José de Oliveira, Edward Farrell, Neil Campbell |

## 4.2 Catch Quality/Discards

In preparation for WKWIDE 2017, the available information on catch and sampling data for Horse Mackerel was reviewed (Costas, 2017).

ICES considers the horse mackerel in the north east Atlantic as separated into three stocks: the North Sea, the Southern and the Western stocks (ICES, 1990b), see section 4.3, this report. The currently understood distribution of the three stocks is based on the results of the HOMSIR project (ICES, 2004). Based on spatial and temporal distribution of the horse mackerel fishery catches of horse mackerel were allocated to the three stocks as follows:

- Western stock: catches from ICES divisions 3.a and 4.a in the 3rd and 4th quarters. All catches from ICES divisions 2.a, 5.b, 6.a, 7.a–c,e–k and 8.a-e.
- North Sea stock: catches from ICES divisions 3.a and 4.a in the 1st and 2nd quarters: All catches from ICES divisions 4.b,c and 7.d.
- Southern stock: All catches from ICES division 9.a.

Catch statistics for this review were available in a number of formats. The main data source came from former data coordinators of horse mackerel stocks which provided the old electronic archives available.

Although the catch statistics for horse mackerel in ICES are generally considered to be reliable it has to be considered that for some of the historical data, there is a certain amount of confusion and possible error in these statistics when there were uncertainties associated with the spatial distribution limits for the three horse mackerel stocks.

The available catch data time–series for horse mackerel was categorized in three blocks depending on data quality:

- Good quality: available as the original electronic files that were provided by national laboratories. These files include details of catches, landings, discards (although likely incomplete) and sampled catch by year, division, quarter and country. In preparation for this benchmark this information has been uploaded into InterCatch. These files cover the period from 1997 to 2015 although 1997 - 1999 have not yet been uploaded into InterCatch.
- Medium quality: electronic files containing aggregated information by year, division and quarter. These cover the period from 1991 to 1996.
- Low quality: no electronic archives available. This information in only available from previous reports with data available from 1982 to 1990.

This benchmark study has reviewed catch data for the Western horse mackerel stock only.

In relation to the WHOM catches, the main mismatches between the originally reported and the newly estimated catches were found in years 1990, 1991, 2001 and 2009. Some of the causes of these mismatches are: in some years the WG assigned catches from the North Sea stock to the WHOM, in some years all catch data were not included in the report perhaps due to late availability of some data, in some years were reported only the official catch instead of WG catches (Figure 4.2.1, Table 4.2.1).

The catch–at–age matrix for the data that has been reviewed to date is given in the Table 4.2.2. Figures 4.2.2-4 show reviewed and reported catch at age data along entire temporal series. Main mismatches were found in years 1991, 1995, 2000-2003 and 2009-2011 with the main cause of these mismatches are caused for assigning some catches from North Sea to WHOM stock, not include all catch data for WHOM, …

During the WKWIDE meeting it was noted that some discard data (2012-2014) had not been upload into InterCatch. These discards represent less than 1% of total catch but were not implemented for the WKWIDE due to time limitations. The final catch data will be amended for the next WGWIDE in 2017.

In relation to discarding, information suggests that discard rates for the directed fishery are low with the majority of discards from non–directed demersal fisheries. The available estimates of discards are based on information provided by only a few countries and the total discards are considered to be underestimated. Only in the most recent years have the majority of countries involved in the fishery submitted discard information. The overall underestimate of the discard rate is variable over the time–series.

During preparations for the benchmark, national data submitters were asked to submit all available information on discarding of horse mackerel. The majority of national submitters responded to the request and indicated that discarding of horse mackerel was at low levels with the majority from the demersal mixed fisheries although there is high uncertainty in discard estimates due to low levels of sampling.

**Table 4.2.1: Total catch for Western Horse Mackerel, 1982-2015. Reported and WKWIDE revised catch data.**

| Year | Reported | WKWIDE2017 Revision | Year | REPORTED | WKWIDE2017 REVISION |
|---|---|---|---|---|---|
| 1982 | 61197 | 61197 | 1999 | 298076 | 299092 |
| 1983 | 90442 | 90442 | 2000 | 196911 | 202732 |
| 1984 | 96744 | 96744 | 2001 | 212090 | 229081 |
| 1985 | 103843 | 103843 | 2002 | 194292 | 196120 |
| 1986 | 145999 | 145999 | 2003 | 190183 | 191856 |
| 1987 | 187338 | 187338 | 2004 | 157627 | 159742 |
| 1988 | 214729 | 214729 | 2005 | 181994 | 182001 |
| 1989 | 296037 | 296037 | 2006 | 155094 | 155827 |
| 1990 | 398645 | 374230 | 2007 | 123408 | 123356 |
| 1991 | 357288 | 287338 | 2008 | 139741 | 143349 |
| 1992 | 394793 | 395005 | 2009 | 176918 | 183782 |
| 1993 | 458628 | 453234 | 2010 | 205268 | 203112 |
| 1994 | 413022 | 410411 | 2011 | 199593 | 193698 |
| 1995 | 538131 | 540529 | 2012 | 173142 | 169859 |
| 1996 | 420942 | 420739 | 2013 | 165085 | 165258 |
| 1997 | 471700 | 468615 | 2014 | 137333 | 136360 |
| 1998 | 326443 | 328384 | 2015 | 98419 | 98419 |

**Table 4.2.2: Total catch number at age for Western Horse Mackerel, 1982-2015. Reviewed catch-at-age data.**

| YEAR | A0 | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A13 | A14 | A15+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 0 | 3713 | 11515 | 13197 | 11741 | 8848 | 1651 | 414 | 1651 | 6582 | 18483 | 28679 | 19431 | 8210 | 21072 | 134743 |
| 1983 | 0 | 7903 | 53508 | 15345 | 44539 | 52673 | 17923 | 3291 | 5505 | 3385 | 17017 | 23902 | 38352 | 46482 | 2269 | 32900 |
| 1984 | 0 | 0 | 36294 | 149798 | 22350 | 38244 | 34020 | 14756 | 4101 | 0 | 638 | 1757 | 5080 | 50894 | 241360 | 4439 |
| 1985 | 0 | 1633 | 4463 | 41822 | 100376 | 12644 | 16172 | 6200 | 9224 | 339 | 849 | 3723 | 1250 | 34814 | 4901 | 602992 |
| 1986 | 0 | 0 | 676208 | 8727 | 65147 | 109747 | 25712 | 21179 | 15271 | 3115 | 1030 | 855 | 291 | 51530 | 0 | 1548 |
| 1987 | 0 | 99 | 2950 | 891660 | 2061 | 41564 | 90814 | 11740 | 9549 | 19363 | 8917 | 1398 | 201 | 32899 | 493 | 0 |
| 1988 | 876 | 27369 | 4402 | 18968 | 941725 | 12115 | 39913 | 67869 | 9739 | 16326 | 17304 | 5179 | 4892 | 32396 | 6112 | 2099 |
| 1989 | 0 | 0 | 18282 | 5308 | 14500 | 1276731 | 12046 | 59357 | 83125 | 13905 | 24195 | 13731 | 8987 | 18133 | 0 | 20766 |
| 1990 | 0 | 20406 | 61442 | 33298 | 10549 | 20607 | 1384850 | 37011 | 70512 | 101945 | 14987 | 34687 | 18077 | 56599 | 45036 | 138929 |
| 1991 | 20176 | 24021 | 159643 | 97147 | 49515 | 21713 | 17148 | 1028419 | 20309 | 12161 | 43665 | 8141 | 7053 | 25553 | 56066 | 17977 |
| 1992 | 14888 | 229694 | 56280 | 255874 | 126816 | 48711 | 18992 | 23447 | 1099780 | 13409 | 23002 | 65250 | 11967 | 33246 | 36332 | 80550 |
| 1993 | 46 | 131108 | 62342 | 105760 | 325674 | 141148 | 68418 | 55289 | 30689 | 1075607 | 11373 | 24018 | 68137 | 32140 | 109807 | 16738 |
| 1994 | 3686 | 60759 | 53056 | 44520 | 38769 | 221863 | 106390 | 40988 | 43083 | 22380 | 918512 | 10143 | 14599 | 36635 | 911713 | 115729 |
| 1995 | 2702 | 233030 | 269658 | 74592 | 114649 | 36076 | 228687 | 113304 | 96624 | 59874 | 63187 | 951901 | 39278 | 148243 | 646753 | 526053 |
| 1996 | 10729 | 19774 | 189273 | 87562 | 52050 | 55914 | 53835 | 57361 | 56962 | 91690 | 67114 | 56012 | 349086 | 165611 | 659641 | 864188 |
| 1997 | 4860 | 110451 | 408648 | 256563 | 141168 | 143166 | 143770 | 123043 | 133165 | 96059 | 176730 | 98196 | 51674 | 283111 | 471611 | 732959 |
| 1998 | 744 | 91505 | 359590 | 217571 | 153136 | 119309 | 77494 | 67072 | 50108 | 58791 | 30535 | 65839 | 57583 | 141362 | 184443 | 488661 |
| 1999 | 14822 | 97561 | 265820 | 254516 | 212217 | 187196 | 147271 | 77622 | 35582 | 22909 | 34440 | 29743 | 41830 | 122176 | 83715 | 176919 |
| 2000 | 565 | 66210 | 14594 | 17509 | 18642 | 18585 | 10031 | 73174 | 130897 | 64801 | 119297 | 232346 | 202175 | 165745 | 109218 | 54365 |
| 2001 | 60561 | 93125 | 38576 | 22749 | 17102 | 14092 | 18857 | 64868 | 204360 | 166641 | 113659 | 120410 | 141419 | 259974 | 218002 | 110319 |
| 2002 | 14044 | 505717 | 46167 | 29692 | 25333 | 11305 | 12753 | 72682 | 122603 | 158114 | 123258 | 66640 | 68890 | 95052 | 132743 | 87285 |
| 2003 | 1913 | 323194 | 57089 | 31748 | 27158 | 8832 | 7683 | 40641 | 509889 | 141442 | 148989 | 89122 | 59047 | 48582 | 52305 | 102089 |
| 2004 | 22237 | 159011 | 54542 | 33298 | 12581 | 13407 | 4305 | 21278 | 116055 | 486195 | 81099 | 98855 | 69441 | 48969 | 32589 | 51953 |
| 2005 | 1305 | 74538 | 27019 | 42746 | 23677 | 6849 | 7491 | 18626 | 171420 | 310767 | 540649 | 69957 | 74746 | 61889 | 44443 | 22726 |
| 2006 | 1905 | 53322 | 11828 | 17073 | 32025 | 12877 | 7464 | 24645 | 58091 | 75505 | 91274 | 482229 | 57377 | 37222 | 41970 | 16865 |
| 2007 | 5121 | 32399 | 8728 | 7015 | 8462 | 14021 | 7618 | 18335 | 38598 | 40530 | 61938 | 112724 | 347284 | 48160 | 29112 | 21504 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | 30155 | 78121 | 25172 | 14466 | 12787 | 9269 | 13194 | 24124 | 24456 | 53525 | 57125 | 84358 | 54701 | 297879 | 49889 | 36692 |
| 2009 | 47421 | 86053 | 42063 | 30583 | 21230 | 8266 | 6811 | 39752 | 31431 | 56816 | 40104 | 36174 | 62700 | 57683 | 273217 | 68318 |
| 2010 | 4331 | 68198 | 70041 | 34486 | 24421 | 14887 | 14942 | 44201 | 122386 | 69381 | 29371 | 30496 | 51312 | 110033 | 73973 | 285281 |
| 2011 | 1136 | 17035 | 239472 | 88764 | 29187 | 17731 | 9783 | 35379 | 61864 | 106032 | 51259 | 35380 | 38626 | 59428 | 59031 | 61017 |
| 2012 | 5350 | 48100 | 41255 | 162118 | 50523 | 24043 | 11621 | 30567 | 42653 | 64221 | 171284 | 56012 | 37917 | 28132 | 25608 | 45490 |
| 2013 | 94165 | 138663 | 31217 | 20836 | 106242 | 21316 | 16279 | 24536 | 34651 | 34171 | 76847 | 248958 | 67370 | 25070 | 18447 | 20746 |
| 2014 | 19215 | 26080 | 23876 | 23654 | 24509 | 57284 | 25197 | 23878 | 83034 | 34591 | 28200 | 62102 | 152650 | 56679 | 21786 | 16441 |
| 2015 | 85629 | 108174 | 10883 | 12584 | 11794 | 7272 | 48586 | 15935 | 25416 | 51631 | 31604 | 24613 | 46201 | 118679 | 27331 | 12698 |

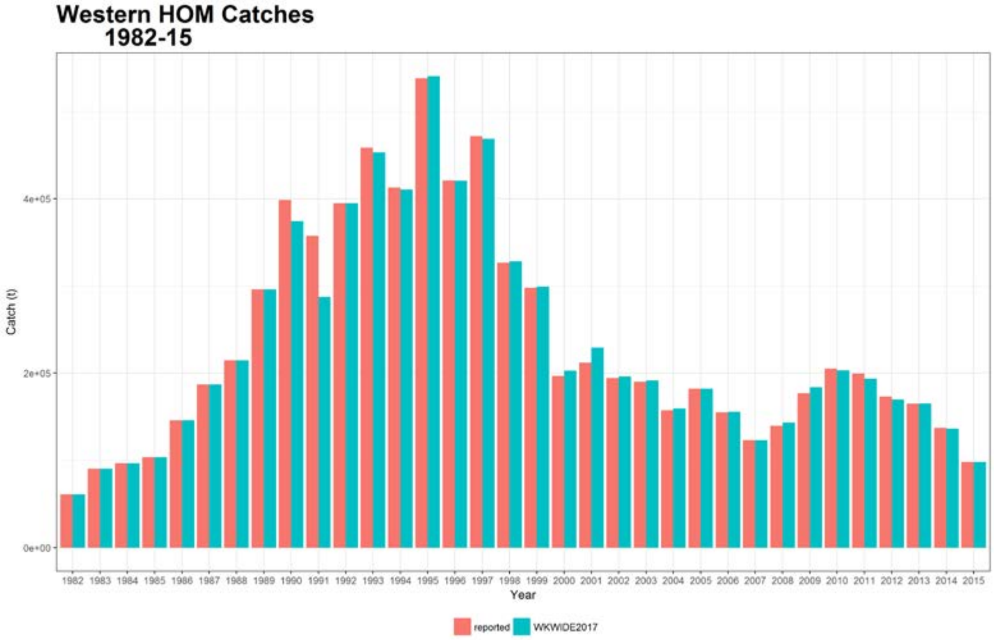



**Figure 4.2.1. Total catch for Western Horse Mackerel, 1982-2015. Reported and WKWIDE 2017 reviewed catch data.**

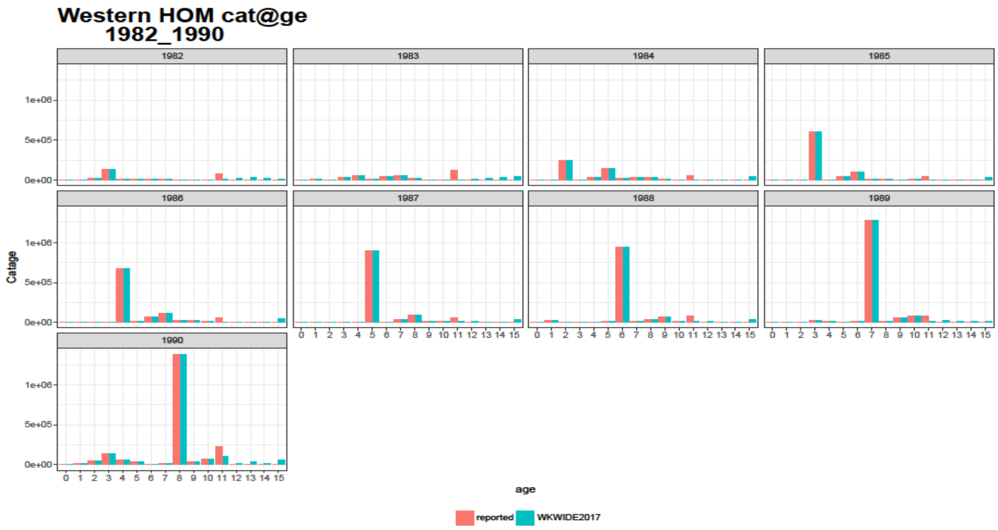



**Figure 4.2.2: Catch-at-age for Western Horse Mackerel, 1982-1990. Reviewed (WKWIDE 2017) and reported catch at age data.**

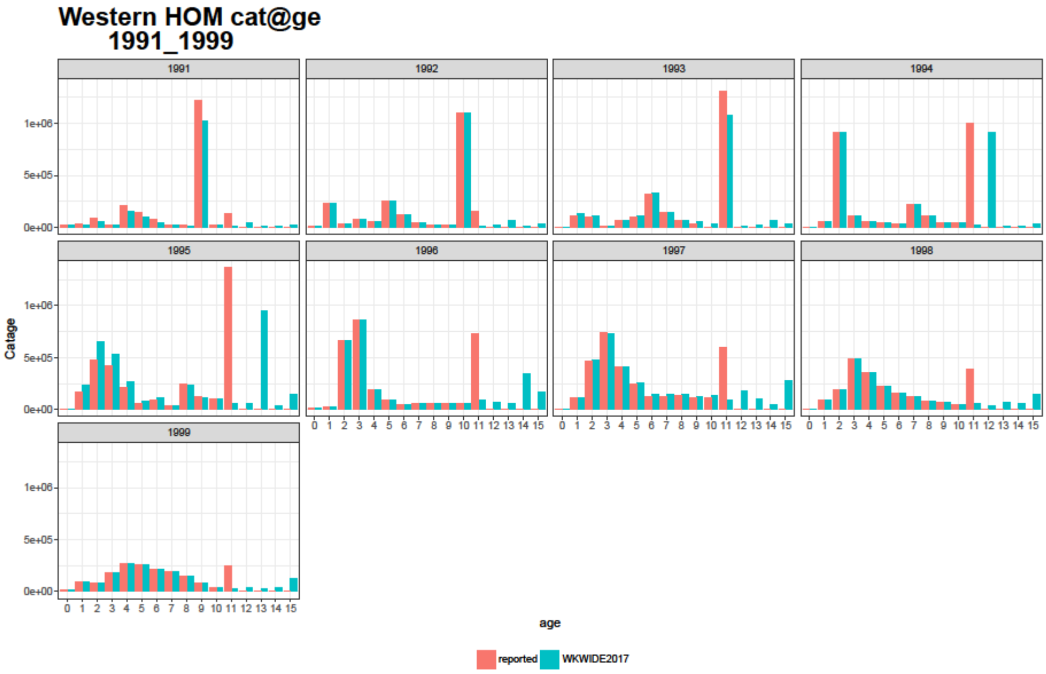



Figure 4.2.3: Catch-at-age for Western Horse Mackerel, 1991-1999. Reviewed (WKWIDE 2017) and reported catch at age data.


Figure 4.2.4: Catch at age for Western Horse Mackerel, 2000-2015. Reviewed (WKWIDE2017) and reported catch at age data.

## 4.3 Stock Structure

Prior to 2004 horse mackerel stocks in the ICES area were defined mainly according to the identification of spawning areas based on egg distribution, resulting in: a "western stock" (northeast continental shelf of Europe, from France to Norway); a "North Sea stock" (North Sea area) and a "southern stock" (Atlantic waters of the Iberian Peninsula). However, there is no recognizable boundary in the distribution of eggs between the putative western and southern horse mackerel stocks (ICES, 1999a). The few publications on horse mackerel stock structure in the ICES area either cover only a small part of the species' distribution areas, or the information is so specific that it is not possible to delineate sub-populations. Nefedov *et al.* (1978) analysed muscle esterase allotypes and found differences between horse mackerel in the North Sea and those to the west of the British Isles. Borges *et al.* (1993), using plasma transferrin phenotypes, did not find any difference in samples collected throughout the Northeast Atlantic distribution area. Abaunza *et al.* (1995) used anisakid infestation levels as biological tags and found significant differences between the Cantabrian Sea and Galician waters, two areas that were considered to belong to the southern stock. An analysis of morphological variation by Murta (2000) found similarities between horse mackerel from the Portuguese and the North African Atlantic coasts, casting doubt on the southern boundary of the southern stock. Finally, Karaiskou *et al.* (2004), using mitochondrial DNA, confirmed the lack of genetic differentiation in horse mackerel throughout its distribution area.

The stock structure of horse mackerel in the north Atlantic and Mediterranean Sea was most recently investigated by the HOMSIR project, (QLK5-CT1999-01438). This multidisciplinary project attempted to apply a range of genetic, morphometric and parasitological techniques to the same fish in order to allow cross-validation of results.

Samples of 50 spawning horse mackerel were collected at 20 sites across the north Atlantic and Mediterranean Sea (Fig. 4.3.1), where possible in both 2000 and 2001. Further samples of non-spawning fish were collected on an opportunistic basis.

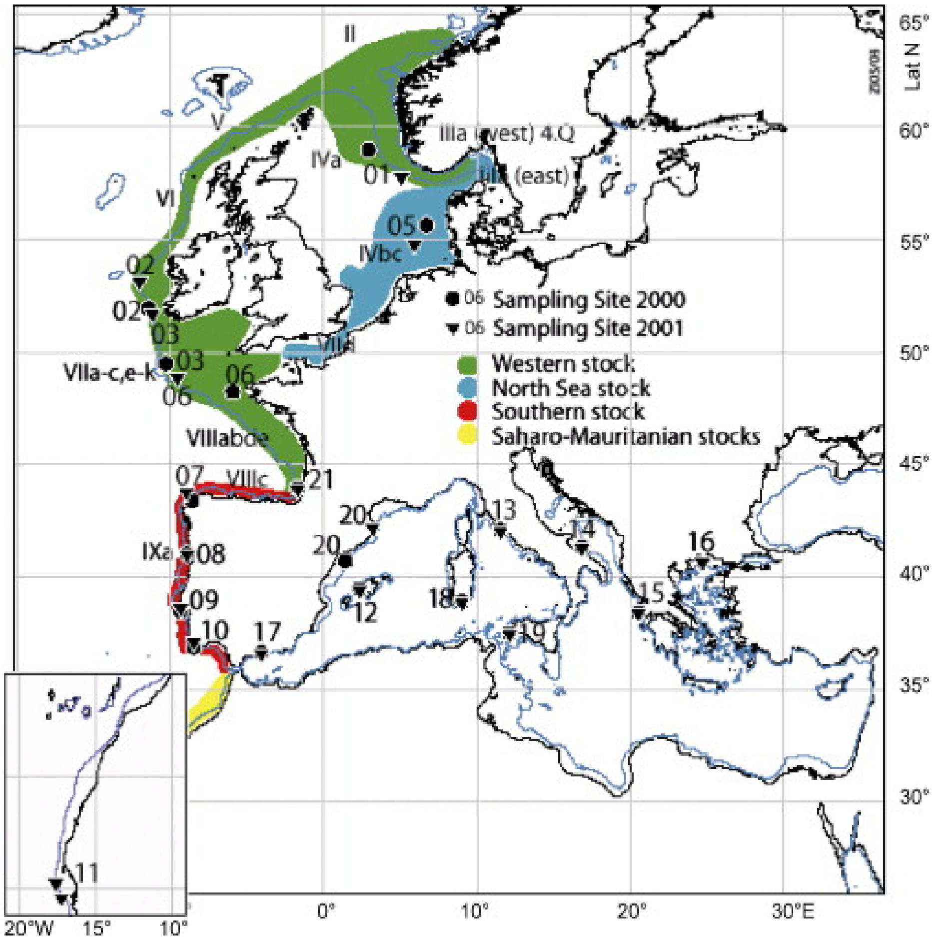



**Figure 4.3.1: Location of sampling sites in the HOMSIR project.**

Results from genetic studies were variable, with three of the four techniques applied - allozyme electrophoresis, mtDNA and msDNA – finding no significant variation between samples from the extreme ranges of the study area. Single strand conformation polymorphism was the sole genetic technique to find significant differences to populations.

Parasitological studies revealed significant structuring of populations, with characteristic parasite faunas representative of western, North Sea and southern stocks (MacKenzie *et al.* 2008). North Sea horse mackerel showed particular characteristics that differentiated it from adjacent Atlantic areas. Parasite analysis of horse mackerel by age class showed that samples from area 5 had a much higher mean abundance of the nematode Hysterothylacium aduncum and lighter infections of Anisakis spp. (fig. 4.3.2) than those observed in the adjacent areas 1, 2, 3, 6 and 21 (MacKenzie, 2002; MacKenzie *et al.*, 2008). Some individuals were distinguished from all other fish in the same sample by their markedly different patterns of nematode infection: three fish with heavy infections of Anisakis spp. in sampling area 5, one with heavy infection of H. aduncum in area 1, one with heavy infection of H. aduncum in area 2 and two with heavy infection of H. aduncum in area 3. This suggested limited mixing between the North Sea and adjacent areas (MacKenzie *et al.*, 2008). The analysis of body morphometrics supported the separation between fish from area 5 (North Sea) and those from the other sampling sites of the Atlantic Ocean (Murta *et al.*, 2008).

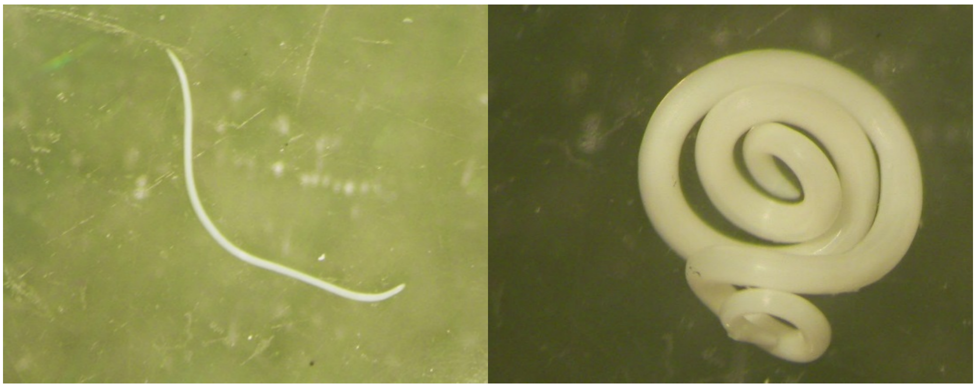


**Figure 4.3.2:** ***Hysterothylacium aducum*, (left) and *Anisakis* spp. (right).**

Sample 01, collected in Div. 4.a, was a non-spawning sample, collected from the Norwegian fishery in August. Fish from this area were classified as belonging to the Western stock by parasitic indicator species, parasite genetics, otolith and body morphometry, and SSCP. The discovery of parasite species characteristic of fish from the coast of North Africa suggests fish caught in this area may be highly migratory.

Evidence from parasitological tags for a strong boundary at the southern extent of the western stock was less conclusive. The results of cluster analysis on body morphometric data, however, revealed three well differentiated groups in the Atlantic Ocean: the West Iberian Atlantic coast (Portuguese coast = areas 8, 9 and 10); the Bay of Biscay and western Ireland (2, 7 and 21) and the North Sea (5) (Murta et al., 2008). These results were also confirmed by discriminant analysis, which showed that only 3% of individuals were misclassified between the adjacent locations 8 (north Portugal) and 7 (north Galicia). Discriminant analysis of the otolith shape data (Stransky *et al.*, 2008) supported the separation of the Portuguese coast (areas 8, 9 and 10) from the more northerly Atlantic areas (areas 1, 2, 3, 5, 7 and 21), though higher misclassification rates (up to 21%) were observed. As a consequence of this finding, the area over which the western stock was assessed was revised to include the Galician coast (ICES Div. 8.c). Little work on stock identity has been carried out subsequent to the HOMSIR project, and therefore some questions remain unanswered. Of most relevance to the western stock is the degree of mixing taking place in the English Channel. Currently the stocks are divided at the 7.d – e line, however the appropriateness of this is unknown. Data from parasite indicators suggested approximately 4% of fish in the North Sea could be migrants from the western stock, however there were no indications of movement in the opposite direction.

## 4.4 Utility of Industry Derived Data

Introduction

Data collection from commercial fisheries is traditionally carried out by research institutes who will take regular samples of catches in the fish auctions or using scientific observers at sea. Although the information thus collected is appropriate for most stock assessment approaches, the level of sampling is often too low to get meaningful information on catch compositions and catch rates small temporal and spatial scale.

The Pelagic Freezer-trawler Association (PFA) represents freezer trawlers in five European countries that predominantly fish for small pelagics in the Northeast Atlantic but also off West Africa and in the South Pacific. The association initiated a research programme in 2015-2018 to further develop and utilize ongoing (self-) sampling activities on board of commercial vessels. One of the elements of the research programme is to digitize and collate historical catch by haul information from the vessels. In preparation for the benchmark of mackerel and horse mackerel, these historical catch records have been digitized and initial analyses have been carried out.

Aim

The intention of this work was to focus the analysis on the development of additional indicators for horse mackerel, because the assessments of the two horse mackerel stocks (western horse mackerel and North Sea horse mackerel) are both based on relatively few abundance indicators.

Data Available

Haul by haul information was available from 6 pelagic freezer-trawlers covering different year ranges and also fishing in different areas (table 1). The raw data were read from Excel spreadsheets (in different formats) and converted to RData objects which were then 'sanitized' by making sure that the information collected under the different variables was consistent and in the same units. An important element in the conversion process, was that the descriptions of the species compositions in the catch per haul (example: "mk 30% jax"), were converted into separate entries by species (example: "mac: 70%, hom: 30%).

To achieve the aim mentioned above, the information was split into a number of ICES areas: North Sea, Eastern Channel (7d), Western Channel (7e) and Western area (remainder of area 7 and area 6).

**Table 4.4.1: Overview of catch period and properties of the 6 vessels based on historical trawl lists.**

| Vessel | Active Period | Number of HOM trips* | average number hauls including HOM per trip | average catch HOM per haul (tonnes) | total catch HOM (tonnes) | average CPUE (tonne/hr) |
|---|---|---|---|---|---|---|
| 1 | 2007–2016 | 48 | 20 | 32.5 | 31,602 | 10.7 |
| 2 | 2003–2014 | 29 | 23 | 23.1 | 55.784 | 26.5 |
| 3 | 2006–2015 | 93 | 28 | 56.7 | 49,362 | 28.0 |
| 4 | 1998–2015 | 54 | 26 | 79.6 | 90,651 | 19.1 |
| 5 | 1998–2013 | 204 | 12 | 50.0 | 97,789 | 24.6 |
| 6 | 2000–2014 | 37 | 10 | 58.8 | 19,350 | 7.8 |

* HOM trips were defined as trips in which at least 5% of the catch consisted of horse mackerel.

Catches by species and area for the four main target species (HER, HOM, MAC, WHB) are shown in figure 4.4.1 and indicate that horse mackerel has mostly been caught in the Channel area and in the Western area.

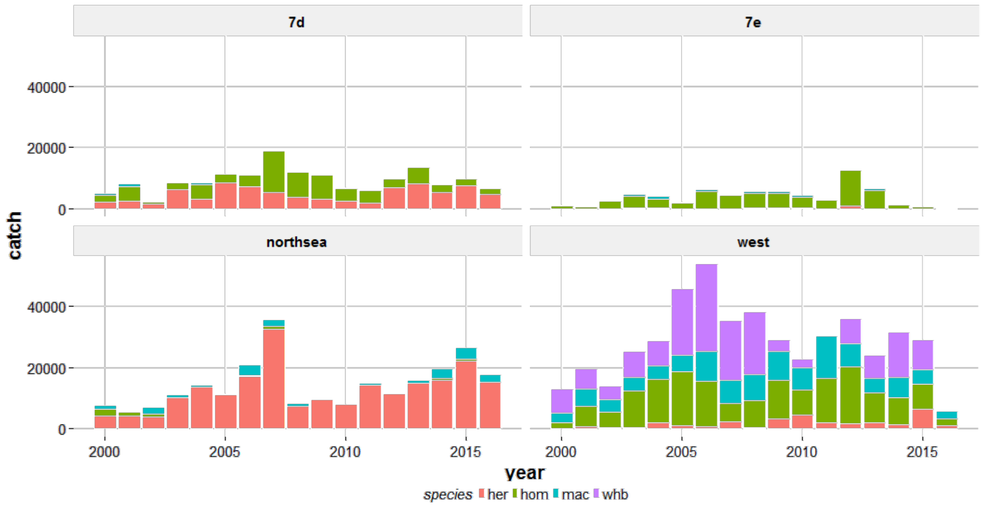



**Figure 4.4.1: Catch by species and year as derived from the historical trawl lists (tonnes).**

Total catch of horse mackerel by area and year (figure 4.4.2) shows that most of the catches were taken in the Western area. It should be noted that some of the differences will be due to different number of vessels fishing in the area and having kept trawl list information.

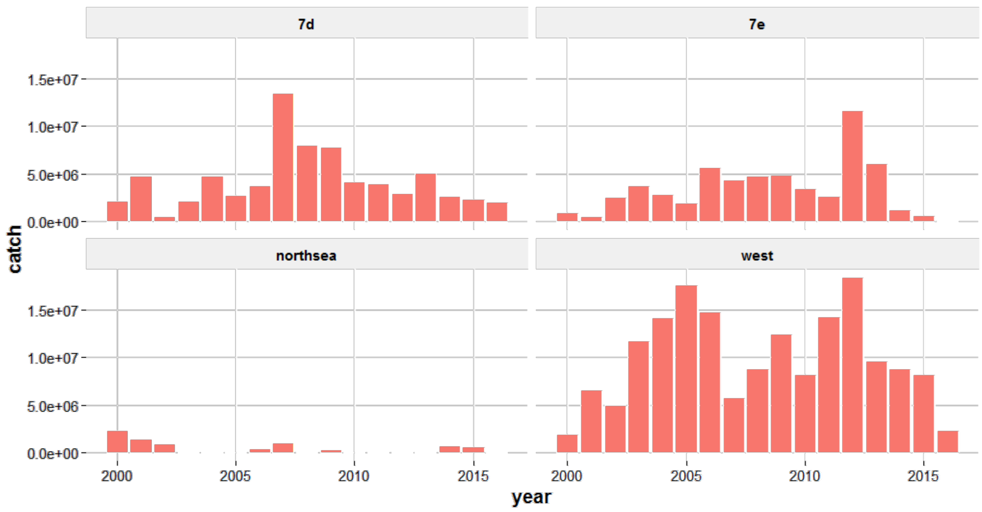



**Figure 4.4.2: Total catch of horse mackerel by area and year as derived from historical trawl lists (tonnes).**

Analyses

To prepare for the analyses, catches were separated into zero and non-zero catches (of horse mackerel, Figure 4.4.3).

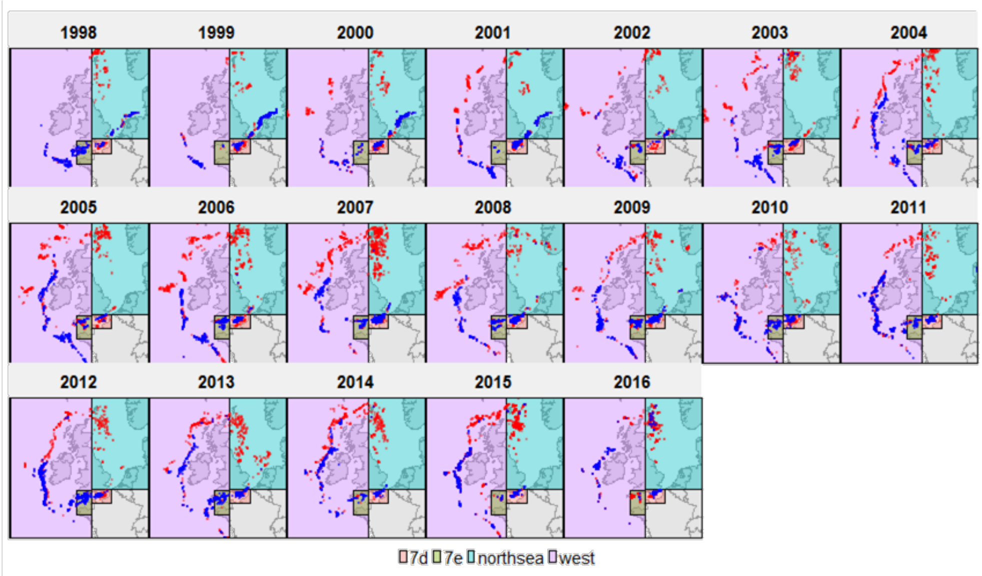



**Figure 4.4.3: Classification of horse mackerel catches by year in four strata. Red points indicate zero catch, blue points indicate non-zero catches.**

However, when trying to apply the two-stage models like Delta Log-normal and Hurdle models, but also in the more advanced Bayesian GLM model and the Log Gaussian-Cox model, it was found that the definition of horse mackerel trips turned out to be problematic. Initially only trips with at least 5% horse mackerel in the catch were included as horse mackerel trips. Later, all trips were included in the analysis and the zero catch of horse mackerel in some of these trips were simply interpreted as absence of horse mackerel. But due to the different number of trips targeting different species, the two stage models gave unrealistic results for the probability of encountering horse mackerel. For example, in a year with relatively more intense herring fishery, the number of zero hauls of horse mackerel would increase.

This means that the analysis could not be carried out as intended during the benchmark. It is recognized, however, that the information does hold promise for future applications, as a minimum as a reality check on the survey results, but also by filling in on areas where no surveys are available (e.g. 7.e).

Conclusions

Catch by haul data from a number of pelagic freezer-trawlers were collated and converted into catches by species and haul and the associated fishery and environmental variables. This also lead to a time–series of horse mackerel CPUE in the fishery.

Initial analyses were undertaken to model the CPUE as two stage processes (Delta Log-normal, Hurdle), a Bayesian two stage GLM model and a Log Gaussian-Cox model. However, final results were not presented because it was found that the definition of horse mackerel trips was not sufficiently worked out to allow the application of these models.

In principle, this type of information is very new to the assessments of pelagic species like horse mackerel. However, it is acknowledged that if modelled appropriately and taking into account the technological developments in the fishery, it could provide valuable additional information especially for relatively data-poor species like horse mackerel.

# 5 Western Horse Mackerel

## 5.1 Input Data

### 5.1.1Egg Survey

The international egg surveys for both mackerel and horse mackerel (MEGS) have been running triennially since 1986 and since 1992 have been covering the southern distribution of these species in the Northeast Atlantic (ICES Sub-area 8 and division 9.a). The MEGS survey utilizes an adaptive survey methodology in the Northeast Atlantic that currently ranges from Iceland and the Faroe Islands down to Cape Finisterre and provides a total annual egg production estimate (TAEP) for the Western horse mackerel using the most recently spawned stage 1 horse mackerel eggs. A comprehensive description of the methodologies utilized during the collection and subsequent analyses of the MEGS data can be found in the manual for the mackerel and horse mackerel egg surveys (ICES, 2014b).

As a consequence of the revision of the mackerel and horse mackerel historical egg survey database carried out by WGMEGS in 2014 (2014 ICES), preliminary results of the TAEP (Total Annual Egg Production) of the whole time–series for Western horse mackerel using this reviewed historical database were presented to WGWIDE in 2015 (ICES, 2015a). Revised estimates including 2016 egg survey was presented to WGWIDE in 2016 (ICES, 2016). It should be noted that the egg production time–series in the assessment of Western horse mackerel included years 1983 and 1989. These years are no longer considered appropriate as the egg surveys did not cover the southern part of the Western horse mackerel stock (division 8.c).
The updated time–series for Western horse mackerel is given below in Table 5.1.1.1.

**Table 5.1.1.1. Time–series of Western horse mackerel egg production estimates.**

| YEAR | STOCK | EGG_PROD. | SE |
|---|---|---|---|
| 1992 | Western | 2.09*e15 | 3.01*e14 |
| 1995 | Western | 1.34*e15 | 1.02*e15 |
| 1998 | Western | 1.24*e15 | 5.70*e14 |
| 2001 | Western | 8.64*e14 | 2.75*e14 |
| 2004 | Western | 8.84*e14 | 2.85*e14 |
| 2007 | Western | 1.65*e15 | 9.96*e14 |
| 2010 | Western | 1.03*e15 | 3.86*e14 |
| 2013 | Western | 3.66*e14 | 1.25*e14 |
| 2016 | Western | 3.31E+14 | 1.19E+14 |

### 5.1.2Recruitment Index

Introduction

The current SAD (separable ADAPT) assessment for Western Horse Mackerel suffers from a lack of fishery-independent information with only the triennial international mackerel and horse mackerel egg survey providing an index of production in the form of an egg count. This contributes to an uncertain assessment that has been prone to substantial revision in the perception of the development of the stock in years when new egg survey data points become available.

The stock and fishery have been dominated by the contribution from single, large year classes such as 1982 and 2001. In some years, more than half the total catch in number has been accounted for by a single year class. These large year classes are rare and infrequent and not thought to be related to the standing stock size, more likely the success of an individual year class is due to environmental conditions. While widespread, the main fishery takes place in western waters, away from the juvenile areas in the Bay of Biscay and outer Channel. An index of recruitment would be a valuable piece of information for the assessment given the low representation of juveniles in the catch data.

Data Analysis and Selection

Aside from the egg survey, no dedicated survey data is available for this stock. However, the bottom trawl surveys that constitute the IBTS cover much of the currently understood distribution of Western horse mackerel which, although considered as a pelagic species is known to favour the seabed and is readily available to the GOV trawl gear used on the IBTS. An initial scoping exercise shows that horse mackerel is present in, on average over 75% of groundfish tows.

A number of approaches for the calculation of an index of juvenile abundance based on catch rates observed on IBTS surveys conducted by Ireland, France and Scotland covering the main distribution (Bay of Biscay, Celtic Sea, West of Ireland and West of Scotland) have been investigated (Campbell, 2017).

| Survey | Country, ICES Areas | Quarter | Vessel |
|---|---|---|---|
| EVHOE | France, 8.a-d, 7.f-j | 4 | Thalassa |
| IGFS | Ireland, 6.a, 7.bcgjk | 4 | Celtic Explorer |
| SWC | Scotland, 6.a, 7.b | 1,4 | Scotia |

There are additional surveys within the IBTS, such as those carried out by Spain on the Porcupine Bank and the Spanish North Coast. These have not been considered for the time-being due to gear incompatibility and concerns over variable catchability. This was also the reason for excluding 2001 and 2002 from the analysis as the Irish survey was less extensive and carried out by a smaller vessel using a gear of reduced dimensions. Thus, the final dataset used consisted of a total of 5,347 hauls from 2003 to 2015. On average, there were over 400 hauls were recorded each year.

IBTS survey protocols stipulate that the entire catch is sampled. While only the Irish survey carried out ageing, all surveys record length frequency information for each haul. Annual composite horse mackerel LFs for the IGFS, EVHOE and SWC surveys are shown in figure 5.1.2.1.

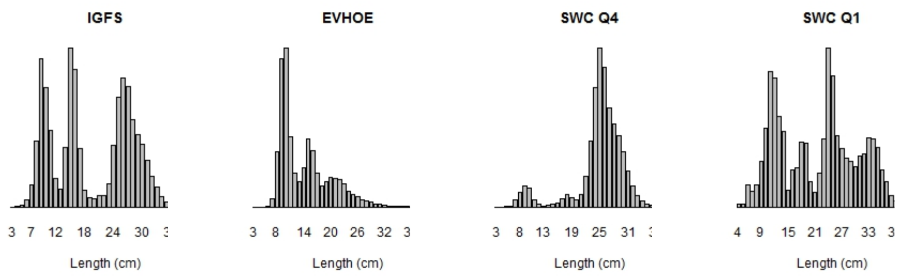



**Figure 5.1.2.1: Composite length frequency data for horse mackerel catches on the IGFS (Irish), EVHOE (French) and SWC (Scottish Q4 and Q1) IBTS surveys.**

There is a distinct mode associated with juveniles (age 0) and often also for age 1. The length-frequency information from each annual survey was examined and the location of a knife edge selection for separation of juveniles from older fish was determined.

Using the vessel speed and gear parameters recorded during each tow, a swept area (*SW*) is calculated:

$$SW\ [m^2] = 0.5144 * GS[knots] * WS[m] * Dur[minutes] * 60$$

Where *GS* is the ground speed, *WS* is the wing spread and *Dur* is the haul duration. This measure of effort incorporates both the duration of the haul and the gear parameters. Should the gear parameters not be available, either an average of the values recorded during other tows from the same survey and year is used or an average for the entire time–series for that survey is calculated (for some surveys, this information was not collected in certain years). Using the length cutoff value, total catch in number at length and the swept area, a juvenile catch rate for each haul can be calculated. Figure shows the catch rates for 2008 (left) and 2011. Commercial catch sampling indicates that 2008 is the largest recent year class. Initial indications from the same data point to 2001 being a weak year class.

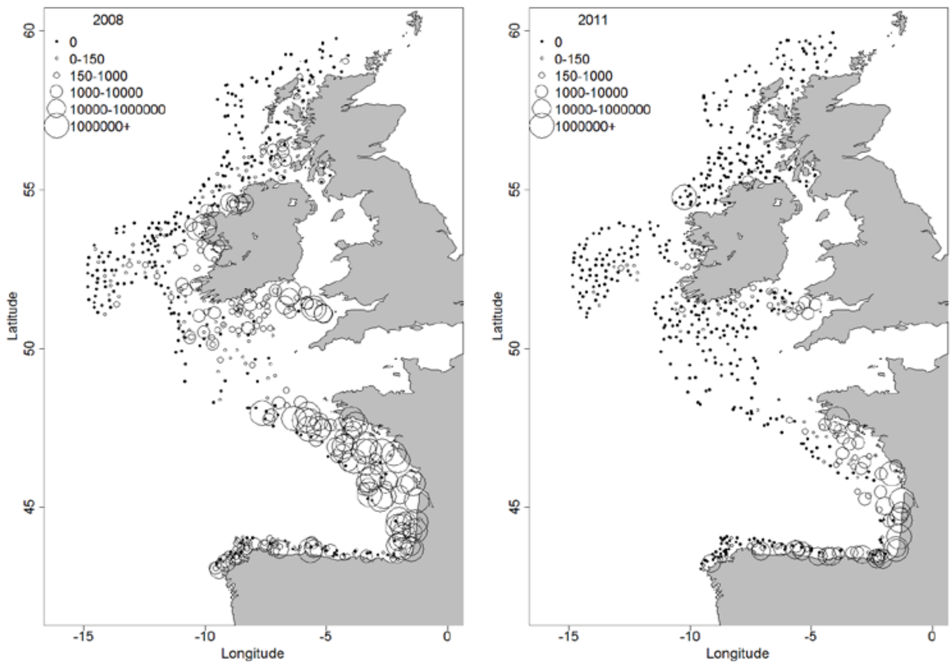



**Figure 5.1.2.2: IBTS catch rates (numbers per swept square nautical mile) of juvenile horse mackerel in 2008 and 2001**

The resulting catch rates display characteristic zero-inflation and over-dispersion (variance>>mean), which is to be expected with the patch distribution associated with a schooling fish such as horse mackerel. Rates are highest and most consistent in the Bay of Biscay region, the traditional juvenile area for horse mackerel.

There exists significant spatial and temporal overlap between the surveys *i.e.* the Irish (IGFS) and Scottish (SWC) quarter 4 surveys conducted in the south of ICES division 6.a and the Irish (IGFS) and French (EVHOE) quarter 4 surveys conducted in the Celtic Sea in ICES divisions 7.g and 7.j. A comparison of the non-zero catch rates for horse mackerel encountered on the Celtic Sea surveys shows good agreement (figure 5.1.2.3).

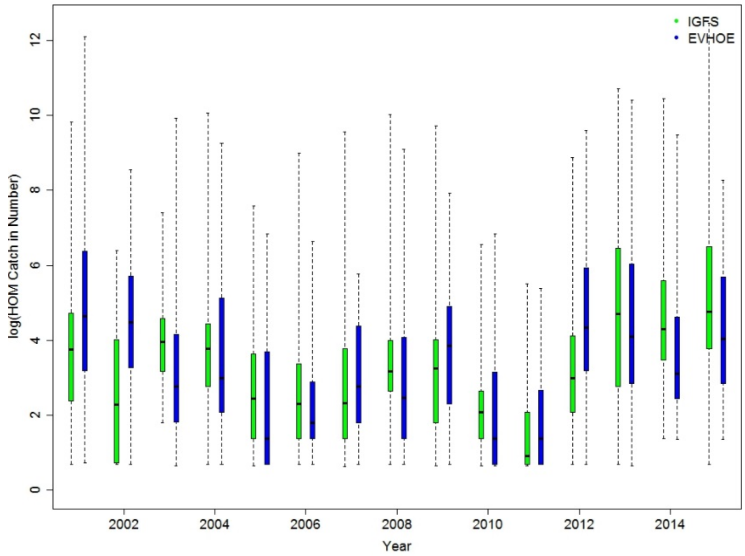



**Figure 5.1.2.3: Comparison of the non-zero catch rates of horse mackerel for the IGFS (green) and EVHOE (blue) surveys in the area of overlap in the Celtic Sea. Note the difference in 2001 and 2002 when the Irish survey was conducted using a smaller gear and vessel. These years have been excluded from the analysis.**

In order to ensure adequate coverage and an appropriate distribution of sampling effort, individual surveys stratify survey effort with strata design typically centered around a latitude range (or a proxy such as ICES subarea) and depth. However, not all surveys considered here define their strata on the same rationale or have used the same design throughout the time–series and thus it is necessary to formulate a stratification scheme that can be considered appropriate and is suitable for the analysis of the complete dataset.

It is considered that within each stratum there exists a homogeneous population and stratum boundaries are defined consistent with this assumption. A number of strata are defined based upon area and depth and the observed catch rates. The strata are shown in figure 5.1.2.4.

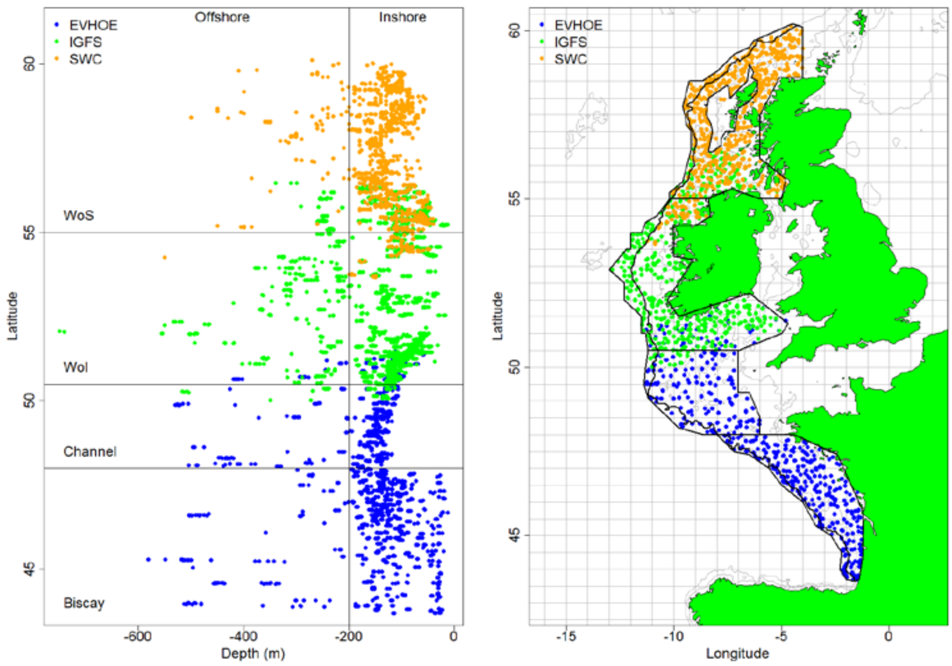



**Figure 5.1.2.4: Stratification scheme for the French (EVHOE), Irish (IGFS) and Scottish (SWC) surveys.**

<u>Modelling of the Catch Rate</u>

A number of GLM modelling approaches exists for the analysis of catch rate from simple Poisson regression, quasi-Poisson regression, zero-inflated models (typically assuming either a Poisson on Negative binomial distribution) and delta (aka hurdle) models. Delta models consider the probability of obtaining a zero catch and the catch rate when catch is non-zero separately (Steffánson, 1996). The probability of detection can be influenced by the abundance of a species and can also be used to account for over-dispersed data which contain a large proportion of zeros due to the inherent nature of the species under consideration *e.g.* a schooling fish.

Since each model involves fundamentally different source data (binary for the detection, always positive and over-dispersed for the second), the approach involves fitting two separate GLMs to the data:

- A binomial (logistic) regression for presence/absence where the log odds of the binary outcome are modelled as a linear combination of predictor variables.
- A GLM for the non-zero catch rate values. A variety of distributions have been used in similar analyses of count or catch rate data. The most commonly selected is the log-normal with the gamma, Poisson and negative binomial also considered.

Since an indicator of year class strength (of which the catch rate of juveniles is assumed to be a proxy) is the primary focus of this analysis, the year class is a necessary explanatory variable for inclusion in the GLM, regardless of the statistical significance. However, there are other candidate explanatory variables including those related to

- Haul position (latitude, longitude)
- Haul depth
- Haul time (month, day, season, day/night)
- Vessel characteristics (length, breadth, power)
- Gear (gear type, wingspread)
- Tow (tow duration, towing speed)
- Environmental factors (wind speed, oceanographic conditions)

For the data under consideration, several of these variables will be confounded *e.g.* vessel and latitude, haul longitude and haul depth, and it is not likely to be instructive to include both within the analysis. Others are either unlikely to be significant explanatory variables either due to survey design (*i.e.* all hauls within the same quarter, all hauls conducted during daylight hours, standardised gears and towing protocols) or a lack of information (wind speed, tidal conditions).

In addition to the year effect, this study considers primarily depth and spatial factors. These are encapsulated within the stratification scheme outlined above.

A binomial regression was carried out for a number of nested models using R's glm() function (with default logit link function). The output in terms of the explanatory variables and independent terms is given below

Binomial regression fit details

| Model | Terms | Residual Deviance | AIC | DF | Deviance Explained | p-value (additional term) |
|---|---|---|---|---|---|---|
| 1 | NULL | 7385 | 7387 | 5346 | - | |
| 2 | YC | 7042 | 7068 | 5334 (-12) | 5% | <0.001 |
| 3 | YC + Stratum | 5205 | 5245 | 5327 (-7) | 30% | <0.001 |
| 4 | YC + Stratum + YC*Stratum | 4911 | 5119 | 5243 | 33% | <0.001 |
| 5 | YC + Stratum + HaulDuration | 5201 | 5249 | 5323 | 30% | 0.31 |
| 6 | YC + Stratum + TowSpeed | 5196 | 5248 | 5317 | 30% | 0.31 |
| 7 | YC + Stratum + WingSpread | 5204 | 5246 | 5322 | 30% | 0.04 |
| 8 | All | 4899 | 5116 | 5238 | 34% | - |

The inclusion of Stratum and Year Class as explanatory variables is significant (although year class only explains 5% of the deviance in the null model) as is their interaction term (model 4). However, the inclusion of haul duration, tow speed does not explain a statistically significant proportion of the observed variance.

Considering only hauls with non-zero juvenile catch rates, a second GLM is fit with either a gamma or a Lognormal distribution. The Lognormal fits for positive catch rates are summarised below and show that the same terms are significant as for the logistic model.

Lognormal regression fit details (for positive catch rates)

| Model | Terms | Residual Deviance | AIC | DF | Deviance Explained | p-value (additional term) |
|---|---|---|---|---|---|---|
| 1 | NULL | 18891 | 12 077 | 2479 | - | |
| 2 | YC | 18449 | 12 043 | 2467 (-12) | 2% | <0.001 |
| 3 | YC + Stratum | 12 153 | 11 022 | 2460 (-7) | 36% | <0.001 |
| 4 | YC + Stratum + YC*Stratum | 11 221 | 10 952 | 2396 (-64) | 41% | <0.001 |
| 5 | YC + Stratum + HaulDuration | 12 116 | 11 020 | 2457 (-3) | 36% | 0.05 |
| 6 | YC + Stratum + TowSpeed | 12 119 | 11 020 | 2452 (-8) | 36% | 0.6 |
| 7 | YC + Stratum + WingSpread | 11 855 | 10 968 | 2456 (-4) | 37% | <0.001 |
| 8 | All | 10 889 | 10 896 | 2381 | 42% | - |

A juvenile abundance index can be formulated as the product of the appropriate logistic and log-normal models.

A possible limitation to this approach is that the presence of juveniles and the positive catch rates are separate models and, should there exist a correlation between the two, this will not be accounted for.

Thorson and Ward (2013) developed a Bayesian Delta-GLMM that can be configured to include interactions between stratum and year and permits this interaction to be correlated between the presence/absence and positive models. The code is freely available (from https://r-forge.r-project.org/scm/?group id =1316) and was applied to the WHM catch rate data.

As with the Delta-Lognormal described above, the overall model consists of 2 sub-models. The probability of catch rate being non-zero is approximated by a logistic regression model. The probability density for catch rate given a non-zero can be approximated by either a gamma or lognormal distribution. For consistency, the lognormal approach is adopted here.

Stratum-year interactions are treated as random effects with the random effect for the presence/absence sub-model (ω) correlated with the random effect for positive catch rates ($\gamma$)

$$p(\omega_{j,k}^{(sy)}, \gamma_{j,k}^{(sy)} | \Sigma_{sy}) = MVN(0, \Sigma_{sy})$$

Where MVN(μ,Σ) is a multivariate normal density function and $\Sigma_{sy}$ is the covariance among stratum-year random effects within a given stratum-year combination:

$$\Sigma_{sy} = \begin{bmatrix} \sigma_{\omega}^2 & \rho_{sy}\sigma_{\omega}\sigma_{\gamma} \\ \rho_{sy}\sigma_{\omega}\sigma_{\gamma} & \sigma_{\gamma}^2 \end{bmatrix}$$

Simpler models (i.e. those with uncorrelated effects) involve the estimation of fewer parameters.

A Bayesian framework is employed; priors are as described in Thorsen and Ward (2013). MCMC methods are used to sample from the posterior distributions from the JAGS packages which is accessed through R via the R2jags package. A number of diagnostic outputs are generated by the software to examine the model convergence. As in the original model runs, 3 chains were used, each with 70 000 samples. The first 50 000 samples are discarded and the remaining 20 000 were thinned to obtain approximately 4000 independent samples. Plots of the sampling chains and the first order autocorrelation for all model parameters were examined for evidence of non-convergence.

Four separate model runs were conducted corresponding to the possible stratum-year interaction configurations. It was not possible to calculate an index for the model with fixed stratum-year effects as there are particular combinations of stratum and year where no juveniles were encountered which was the case in several years for some of the offshore (deeper) strata.

Model results indicate that there is a positive correlation between the random stratum-year effects of the presence/absence and positive catch rate models although the distribution is no wholly positive. The correlation could be due to random changes in the spatial distribution of juveniles among years leading to increased or decreased abundance in particular stratum and year combinations, in turn leading to an increased or decreased probability of detection and subsequent catch rates.

An index of abundance can be derived by multiplying the posterior distributions for the probability of a non-zero catch and the probability density of catch when non-zero and taking the sum weighted by stratum area. Identical strata to those described earlier were used here. The index from the Bayesian approach is contrasted to that from the GLM model in figure 5.1.2.5.

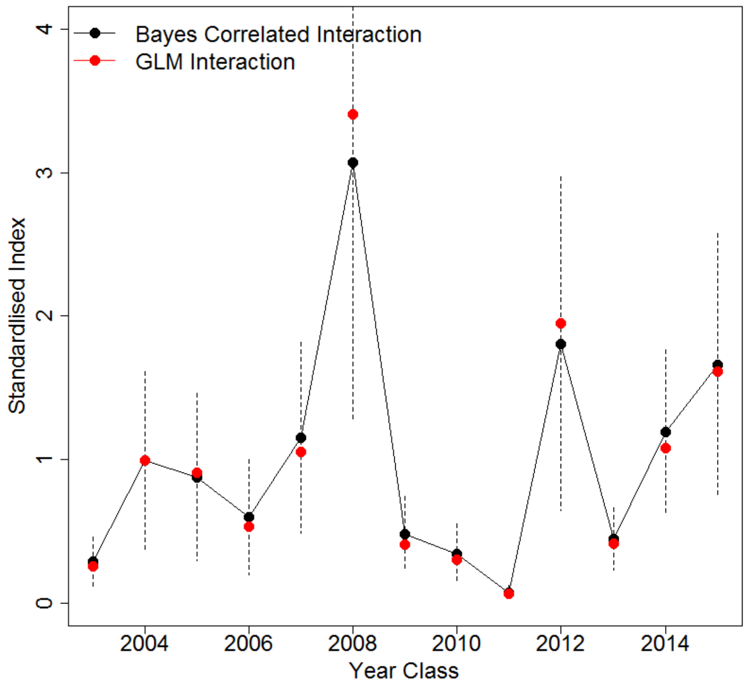



**Figure 5.1.2.5: Standardised index of juvenile catch rate from the Bayesian GLMM including a correlated interaction term (black) and the Delta-Lognormal GLM with an interaction (red).**

The index proposed for the assessment is that available from the Bayesian model. Although both approaches produce similar output, CVs are also available from the Bayesian-GLMM model.

### 5.1.3Acoustic Surveys

Two acoustic surveys are available for the southern part of its distribution, *i.e.* along the French coast of the Bay of Biscay (PELGAS) and along the Northern coast of Spain (PELACUS). Both surveys provide estimates of horse mackerel abundance in the area and are described below. A third survey, the PELTIC acoustic survey, carried out in the Western English Channel, Isles of Scilly and the Bristol Channel, is temporally out of sync compared to the spawning season of the stock, and therefore is not considered as an appropriate indicator of stock abundance in the area.

PELGAS

Acoustic data are collected along systematic parallel transects perpendicular to the French coast (Figure 5.1.3.1) from the Northern French coast to Spain, over a linear total distance of about 6 500 nautical miles (NM, 1 NM = 1 852 m). The transects are uniformly spaced every 12 nautical miles (22 km). The survey design allows for the coverage of the whole Biscay continental shelf (about 23 000 $NM^2$), from 25 m depth to the shelf break (200 m depth). The nominal sailing speed is 10 knots; the speed being reduced to 2 knots on average during fishing operations (Doray *et al.*, 2014). The main target species for the survey are anchovy and sardine, which are abundant in the area and constitute one of the main fisheries in the Bay of Biscay. horse mackerel is well represented in the catch at the time of the survey as in the spring spawning adults are present in the Southern area. However, due to the limited area investigated compared to the distribution of the species and the restricted time period, a high degrees of variability is expected both in terms of abundance/biomass estimates as well as concerning the spectra of the length observed.

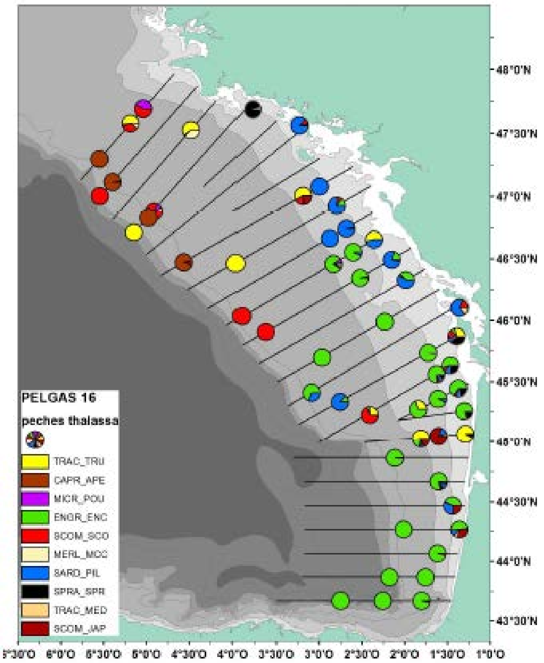



**Figure 5.1.3.1: PELGAS 2016 conducted by *R.V. Thalassa* – Survey transects, haul locations and species composition.**

The time–series provided for the index of abundance goes from 2000 to 2015. Since 2013, horse mackerel shows a small but consistent increase in biomass, after several years of low levels (figure 5.1.3.2).

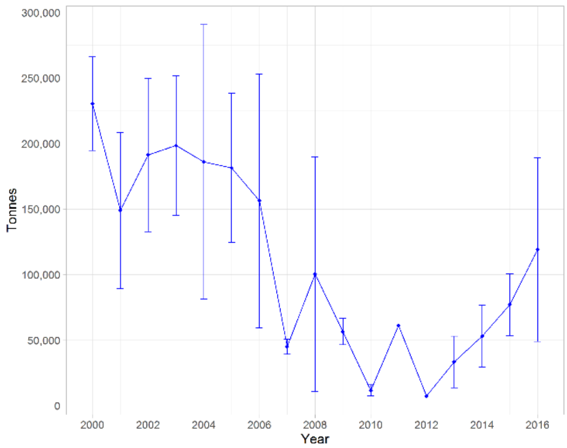



**Figure 5.1.3.2: PELGAS – Estimate of horse mackerel biomass estimate and associated CV from acoustic registrations.**

Length-frequency distribution (LFD) for horse mackerel has been provided for the years 2012, 2014 and 2015 for ICES area 8.ab only. The LFD are noisy, however two modes in the length frequency distribution indicate that both juveniles and adults are available to the survey in different years (figures 5.1.3.3 and 5.1.3.4).

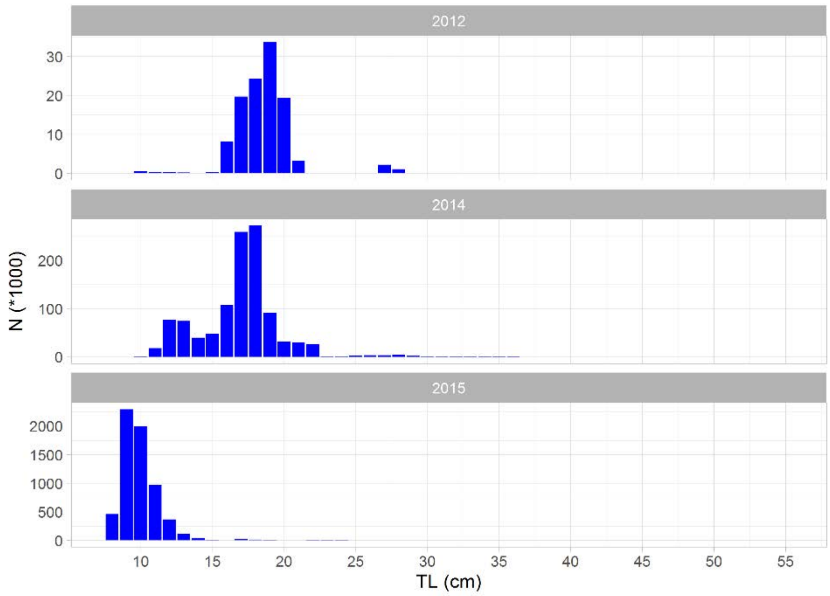



**Figure 5.1.3.3: PELGAS – LFD for horse mackerel for 2012, 2014 and 2015 in ICES division 8.ab.**

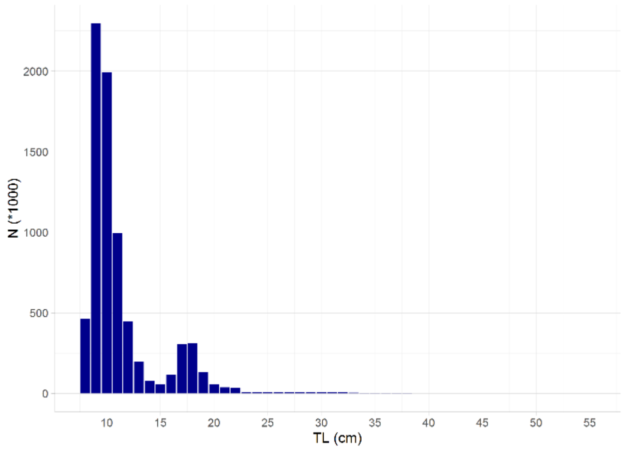



**Figure 5.1.3.4: PELGAS – Aggregated LFD for horse mackerel for 2012, 2014 and 2015 in ICES division 8.ab**

<u>PELACUS</u>

PELACUS 0315 is the latest of the long-time–series (started in 1984) of spring acoustic surveys carried out by the Instituto Español de Oceanografía to monitor pelagic fishery resources in the north and northwest shelf of the Iberian Peninsula (ICES divisions 9.a – South Galicia and 8.c – Cantabrian Sea). Since 2013, the survey is carried out in the R/V Miguel Oliver (ICES 2015a). The survey is coordinated with those undertaken by Ifremer in the Bay of Biscay (ICES Divisions 8.a and b) and IPMA on the Portuguese shelf (9.a including the Gulf of Cadiz).

In addition to acoustic (18, 38, 70, 120, 200 kHz) recording, several samplers are also used to characterise the pelagic ecosystem. Among them, a Continuous Underway Fish Egg Sampler (CUFES), used to delimit the potential spawning area of sardine, anchovy, mackerel and horse mackerel.

Prior to 2013, the PELCUS survey was conducted by the French vessel, R/V Thalassa. An inter-calibration exercise was carried out in 2014 which made comparisons of both fishing performance (length distributions and species proportions) and acoustic registrations. Intra-ship variability was of the same order as inter-ship variability (ICES 2015d).

The survey sampling design consists of a grid with systematic parallel transects equally separated by 8 nm and perpendicular to the coastline with random start, covering the continental shelf from 30 to 1000 m depth and from Portuguese-Spanish border to the Spanish-French border. Acoustic echotraces were recorded during day time together with egg samples; CTD casts and plankton and water samples were taken during night time over the same grid in alternating transects. Pelagic trawling was carried out opportunistically to provide samples for the ground-truthing of the acoustic data.

Two different pelagic gears were used, depending of the depth of the area. Hauls were mainly performed in depths between 36 m and 554 m, with an average duration of 39 minutes (and usually with a minimum duration of 20 minutes).

Biomass estimation is done for on each survey stratum using the arithmetic mean of the backscattering energy attributed to each fish species and the surface expressed in square nautical miles and summed over the whole area (figure 5.1.3.5).

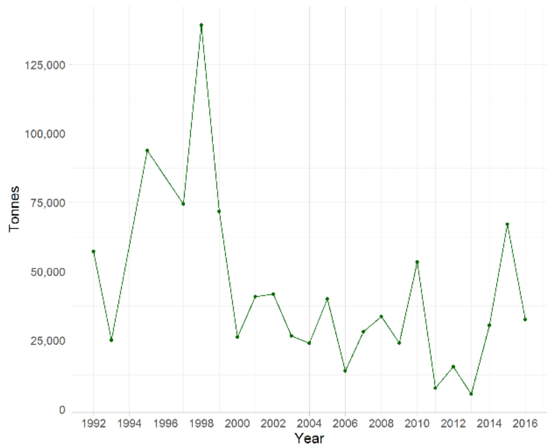



**Figure 5.1.3.5: Horse mackerel biomass estimates from PELACUS acoustic survey.**

Fish were sampled for length and weight. The length frequency distributions are shown in figure 5.1.3.6. and 5.1.3.7. Both adults and juveniles are caught in the area.

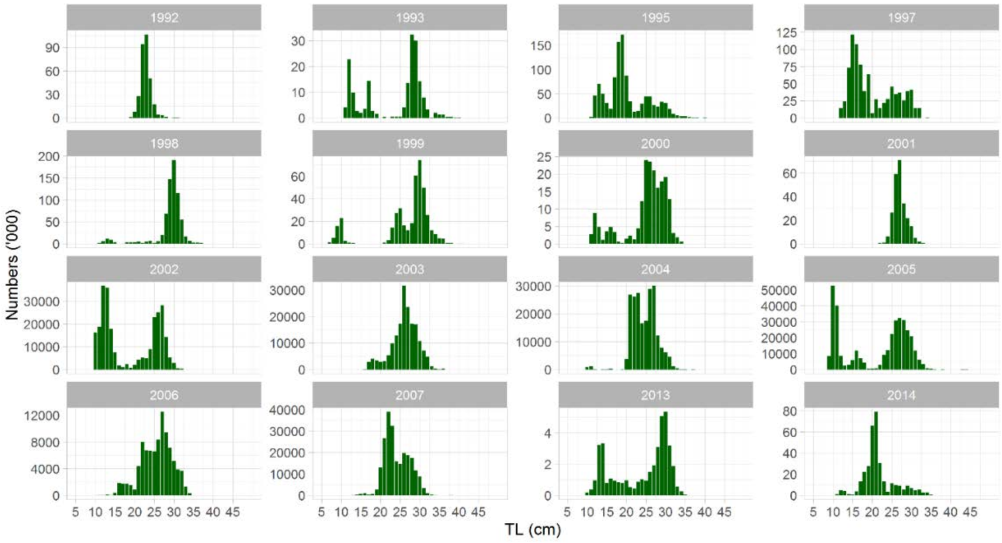



**Figure 5.1.3.6: PELACUS – LFD for horse mackerel, 1992-1993, 1995, 1997-2007, 2013-2014**

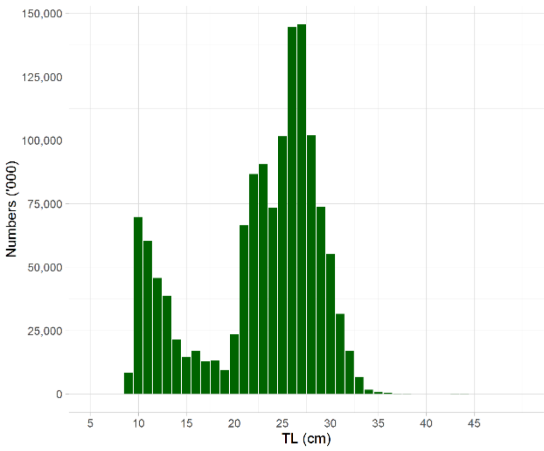



**Figure 5.1.3.7: PELACUS – aggregated LFD for horse mackerel, 1992-1993, 1995, 1997-2007, 2013-2014.**

## 5.2 Stock Assessment

The final assessment selected by the benchmark is an implementation of the Stock Synthesis (SS) assessment model (Methot, 1990), version 3.24U (Methot, 2011).

The Stock Synthesis assessment model makes use of the ADMB modelling architecture (Fournier *et al.*, 2012) and it was chosen primarily for its highly flexible statistical model framework allowing the building of simple to complex models using a mix of data compositions available. Among other features, Stock Synthesis has the ability to handle spatial and seasonal structure in population and fishing dynamics, is flexible in the parameterization of life history characteristics, allows for mirroring of parameters such as selectivity among fishing fleets (which will aid design of the various model configurations), and can fit to size composition in addition to age structure and abundance indices. Technical details of SS were described by Methot (2005, 2007).

Base Case Assessment

A mixed age–length model was fitted in SS as the base case. Two scenarios have been tested: a one-fleet and a two-fleet (northern and southern) model, which allows more flexibility in modelling the differences in selectivity.

The data included in the base case assessment (both fleet scenarios) is summarised in the table below:

<table>
<tr><th rowspan="2">Data</th><th rowspan="2">Type</th><th colspan="2">1 fleet set up</th><th colspan="2">2 fleets set up</th></tr>
<tr><th>Fleet</th><th>Period</th><th>Fleet</th><th>Period</th></tr>
<tr><td rowspan="2">Total landings</td><td>Biomass</td><td rowspan="2">Overall</td><td rowspan="2">1982–2015</td><td>Northern fleet</td><td>1982–2015</td></tr>
<tr><td>Biomass</td><td>Southern fleet</td><td>1982–2015</td></tr>
<tr><td rowspan="4">Indices of biomass / abundance</td><td>Numbers of recruits</td><td>IBTS</td><td>2003–2015</td><td>IBTS</td><td>2003–2015</td></tr>
<tr><td>Numbers of eggs</td><td>Egg survey</td><td>1992–2015</td><td>Egg survey</td><td>1992–2015</td></tr>
<tr><td>Biomass</td><td>PELGAS</td><td>2000–2015</td><td>PELGAS</td><td>2000–2015</td></tr>
<tr><td>Biomass</td><td>PELACUS</td><td>1992–1993,<br>1995,<br>1997–2015</td><td>PELACUS</td><td>1992–1993,<br>1995,<br>1997–2015</td></tr>
<tr><td rowspan="4">Length composition data</td><td rowspan="4">Numbers at length</td><td rowspan="2">Overall</td><td rowspan="2">2000–2014</td><td>Northern fleet</td><td>2000–2015</td></tr>
<tr><td>Southern fleet</td><td>1994–2014</td></tr>
<tr><td>PELGAS</td><td>2012,<br>2014–2015</td><td>PELGAS</td><td>2012,<br>2014–2015</td></tr>
<tr><td>PELACUS</td><td>1992–1993,<br>1995,<br>1997–2007,<br>2013–2015</td><td>PELACUS</td><td>1992–1993,<br>1995,<br>1997–2007,<br>2013–2015</td></tr>
<tr><td rowspan="3">Age composition data</td><td rowspan="2">Numbers at age</td><td rowspan="2">Overall</td><td rowspan="2">1982–2015*</td><td>Northern fleet</td><td>1982–2015*</td></tr>
<tr><td>Southern fleet</td><td>1982–2015</td></tr>
<tr><td>Conditional Age at length</td><td>Overall</td><td>2003–2015</td><td>Northern fleet</td><td>2003–2015</td></tr>
</table>

* When both conditional age at length and numbers at age (*i.e.* northern fleet from 2003 to 2015) were available, only conditional age at length were used to fit the model to avoid redundancy in the data. However, numbers at age have been left in as "ghost" fleet, data that do not enter in the overall likelihood computation, but whose fitting is still shown.

Annual data (i.e. landings, survey indices, age frequency and length frequency) is used in both models, with one area spatial structure (the two-fleets set up model was an attempt to represent different areas through the use of different selectivity pattern). Sexes were used combined.

With respect to the previous (SAD) assessment model, the SS implementation features

- An increased plus-group (from 11+ to 15+)
- An investigation of a two fleet versus a single fleet model.
- The use of a double-normal selectivity functional form for the length-data from the commercial catch sampling.
- The inclusion of new survey indices.

Changes to the Plus Group

The catch at age composition data for Western Horse Mackerel are characterized by infrequent strong year classes that persist in the catch-at-age matrix well after reaching age 11, creating large plus group catches that last for several years. As part of this exercise, the plus group was increased to 15+. It was not possible to extend it further due to limitations in the data available. This change reduced the overall relative size of the plus group catches (Figure 5.2.1).

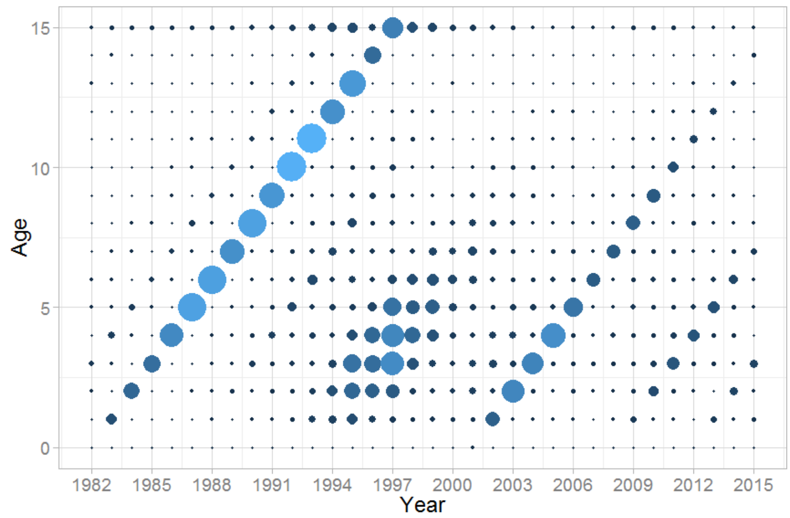



**Figure 5.2.1: Catch-at-age matrix, expressed as numbers (thousands). The area of bubbles is proportional to the catch number.**

Sample Size

The sample sizes used in SS were derived from the sample coverage reported by WGWIDE in 2015 (ICES, 2015c). The total number of samples (rescaled by dividing by 10, since high numbers become meaningless in SS) was used as sample size for the length composition of the catch. The percentage of catch covered (rescaled by dividing by 10) was used as sample size for the catch at age matrix. The numbers of fish read for each age class, rescaled for the percentage of catch covered in order to maintain the relative weight of each age at length class and at the same time avoiding the overall sample size of the age length keys to be huge, were used as sample size for the conditional age at length. In the absence of information, an arbitrary value of 10 was assigned to the length composition data available from the survey.

Selectivity Pattern

An empirical analysis of the fishery length and age composition shows that the landings-at-length/age for the Northern and Southern fleets combined, cover the whole range of length from about 12 cm.

Therefore, when the one fleet model was tested, the overall fleet was set up as double normal, forcing the selectivity to be asymptotic. The tendency of this pattern to deviate from an asymptotic shape was tested leaving the model free to estimate the parameter for the selectivity in the final part of the curve: despite this, the curve still tended to an asymptote. However, to avoid unexpected behaviour with the inclusion of new data, it was decided to keep it fixed.

A simple logistic was also considered but behaved poorly compared to the double normal.

The selectivity at length of the two acoustic surveys was also set to a double normal. The selectivity for the PELGAS survey was modelled to have a narrow dome-width, while a wider dome-width was attempted for the selectivity of the PELACUS acoustic survey. Different selectivities for the two surveys is expected in light of the fact that the French PELGAS survey is able to fish more inshore compared to the Spanish PELACUS survey, mainly due to the nature itself of the coast (which is rocky – and therefore less accessible- on the Spanish coast).

The egg survey and the IBTS indices were assigned the special selectivity option available in SS for (respectively) an SSB index (in which the survey abundance is expected to be equal to the spawning stock biomass given the population fecundity), and a recruitment index, in which the survey is expected to equal age 0 recruitment.

Model Development – from SAD to a 2 Fleet Stock Synthesis Model

The consideration of an alternative assessment model during the benchmark assessment exercise for Western Horse Mackerel is due to limitations intrinsic to the model itself that have become apparent in recent years. The current SAD model was developed specifically for the Western Horse mackerel stock given the limited fishery independent data available and the recruitment characteristics of the stock. The SAD model explicitly accounts for potential fecundity as a function of fish weight to allow the use of the triennial egg survey abundance index (at the time the only index available). The SAD implementation also accounts for the development of a targeted fishery on the strong 1982 year-class. However, the reliance of this assessment on only a single fishery independent index with a new data point available every 3 years resulted in significant assessment revision each time a new data point became available. In addition, gradual changes in selectivity are observed over time as fishers primarily target the proportion of the stock which comprises the large year classes. The SAD model includes an assumption of separability (and therefore constant selectivity) for a minimum of 6 years. SAD is also limited in its capability for incorporating recently available additional potential tuning indices.

For these reasons, the choice was made to move towards an integrated analysis model. These models provide a tool to estimate fish abundance, recruitment and fishing mortality from different kinds of data, including both length and age composition, and incomplete time–series (Methot 1990, 2000). Stock Synthesis (SS) is such a method also offering the possibility to consider several fleets, to have time varying parameters for selectivity, to include the egg survey as an index of spawning stock biomass and allowing the model to estimate fecundity parameters. SS is a methodology that is widely used on the Pacific coast of the USA, and has been successfully applied in ICES for some of its stocks. It has a well-documented manual, a well-established community and strong support from the developers themselves. It was therefore a natural choice.

Due to different pattern in selectivity between the northern and the southern fleets, the initial development of SS saw the inclusion of

- two fleets: a northern fleet covering the whole distributional area of the stock except for division 8, and a southern fleet covering division 8
- 4 indices of abundance: the triennial egg survey, the recruitment index from the IBTS survey and two acoustic surveys
- free parameters (slope and intercept) for the estimation of fecundity.

The selectivity was modelled by length for all the fleets. From an analysis of the length frequency distribution it seemed appropriate to have an asymptotic selectivity for the Northern fleet while having a bi-modal selectivity for the southern fleet, with a higher peak for the smaller fish and a lower peak for the bigger fish (mainly due to the lower availability of the older specimens in the area). The northern fleet was therefore modelled with a double normal selection pattern, having the curve forced to an asymptotic shape, while the southern has been modelled as a cubic spline with 5 knots, fixing the position of the knots and the value of the second knot (peak in selectivity), and having 6 parameters estimated. Other options have been tested for the selectivity of the southern fleet, namely a random walk selectivity pattern and a double normal with a decreasing selectivity for bigger/older specimen, but the performances of both were poor.

The model was able to fit adequately the length frequency distribution of both the northern and the southern fleet, although fits were poor when the pattern of the southern fleet followed a clear bimodal distribution. Additionally, the was not able to appropriately fit to the age composition data for the southern fleet (fig 5.2.2). This was particularly evident for the 2001-year class, which is not found in the southern catch at age matrix after age 6. Also, for the first part of the time–series the model is expecting big year classes to enter the catches. This may be caused by the left skewed selectivity curve and by the fact that for the more recent years the number of young in the catches is much higher, implying either a change in the availability of horse mackerel in the area or some changes in the fleet. Both these highlighted issues require further investigation.

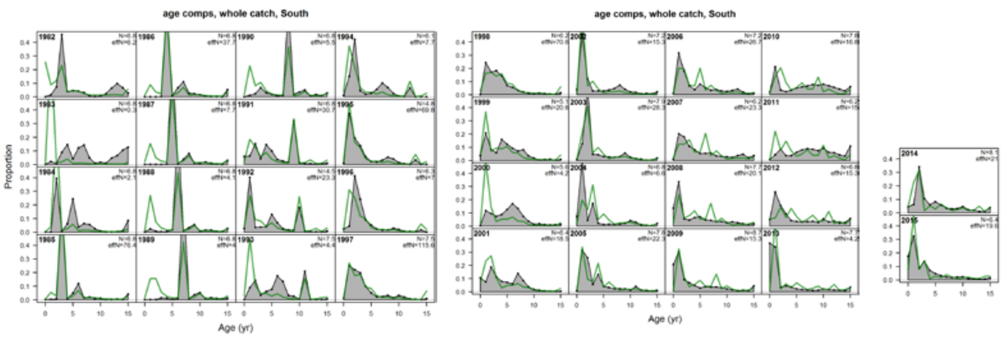



**Figure 5.2.2: Fitting to the age comp of the southern fleet in the two-fleets model set up from 1982–2015.**

From a 2-Fleet to a Single Fleet Setup

From the two-fleets set up base run several model variations were attempted. However, difficulties remained regarding the fit of the southern fleet for both the length and age composition data. It was therefore decided to move to a one-fleet model set up, and eventually consider a time varying selectivity curve if needed.

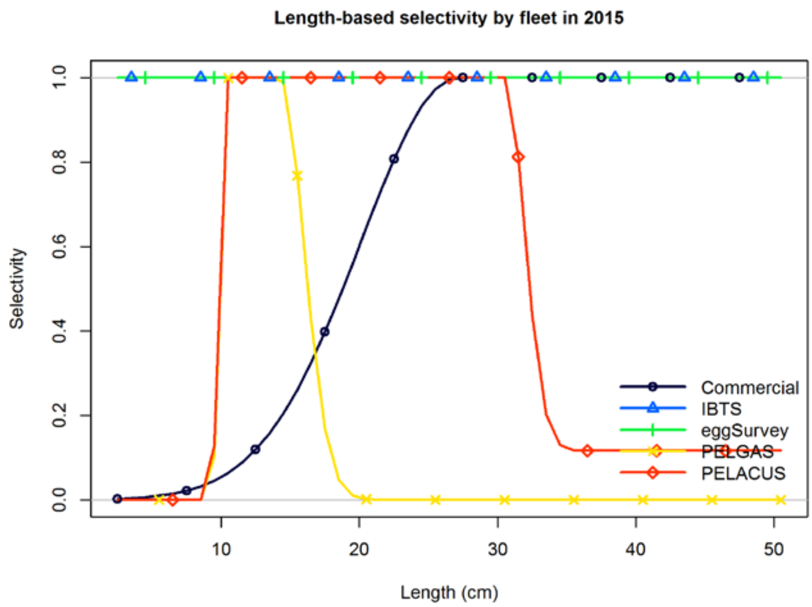



**Figure 5.2.3. Selectivity pattern for the one-fleet model set up for the commercial fleet and the 4 indices.**

The one-fleet model set up incorporated a double normal selectivity forced to an asymptote for the bigger/older fish (figure 5.2.3). The selectivity for the two acoustic surveys was also set to a double normal, with the range of lengths targeted being much narrower for the PELGAS survey and wider for the PELACUS survey.

The pooling of the length and age data for the two fleets and forcing an asymptotic selectivity on the oldest age improved the model fit to the age composition data. It was considered unnecessary to implement a time varying selectivity.

Estimation of Fecundity Parameters

An attempt to estimate the fecundity parameters (*a* and *b*, respectively intercept and slope of the fecundity curve) inside the model to account for the biology of the species was made. However, the information provided so far are insufficient for the model to properly estimate those: the slope was hitting the lower bound at zero, and the intercept was just increasing to high values, without affecting anything else except increasing the catchability of the survey itself and improve the fitting. *a* and *b* were then fixed to respectively 1 and 0 to interpret the 2 egg parameters as linear eggs/kg on body weight (eggs equivalent to SSB).

Sensitivity To Ageing Error

From the outcome of two previous ICES workshops (ICES, 1999b; ICES, 2015b) on age reading on horse mackerel, it is evident that the ageing of this species is particularly difficult, and the ageing error associated can be significant. Initially, the standard deviation as reported in the 2015 report was used as a smoothed curve with a flat top from age 12 onward (fig 5.2.4). However, the high standard deviation for all ages was causing problems to the fitting. It was therefore attempted to use the SD presented in the 1999 report (fig 5.2.4), which has lower values and shows a more reasonable, increasing pattern with a flat top from age 12.

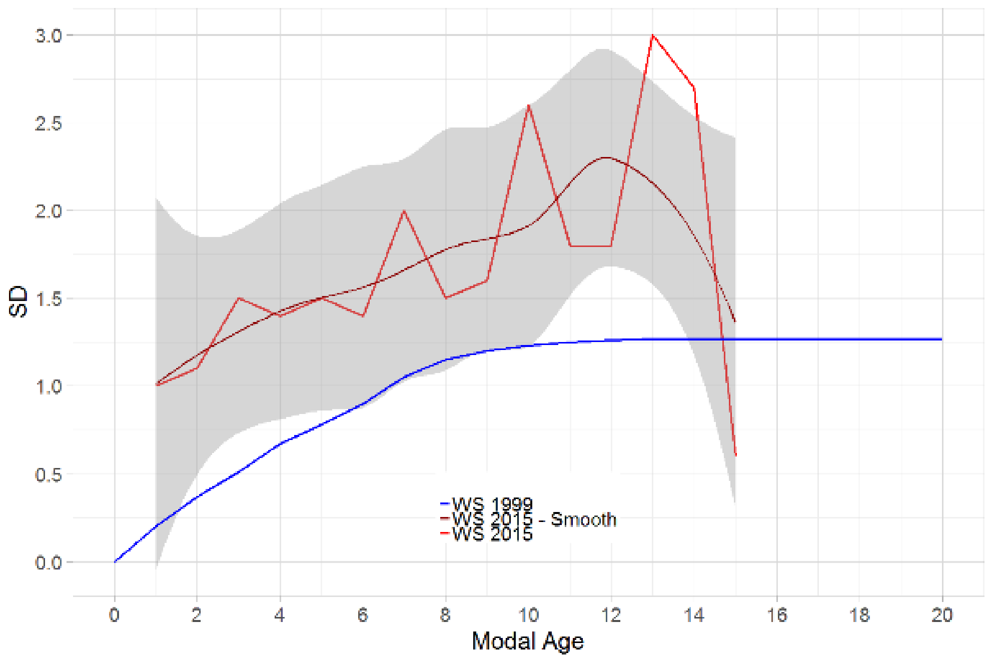



**Figure 5.2.4: Precision in age reading by modal age group expressed as Standard Deviation from the 1999 workshop (blue line) and the 2015 workshop (red line). The smoother used in the assessment is shown as well.**

Several settings were tested, mainly related to the selectivity pattern and the sample weighting, in order to improve the model fitting. However, the large ageing error prevented the model from properly fitting any of the age composition data, including the strong 1982 and 2001 year classes, worsening with time as the cohorts grew old (fig 5.2.5).

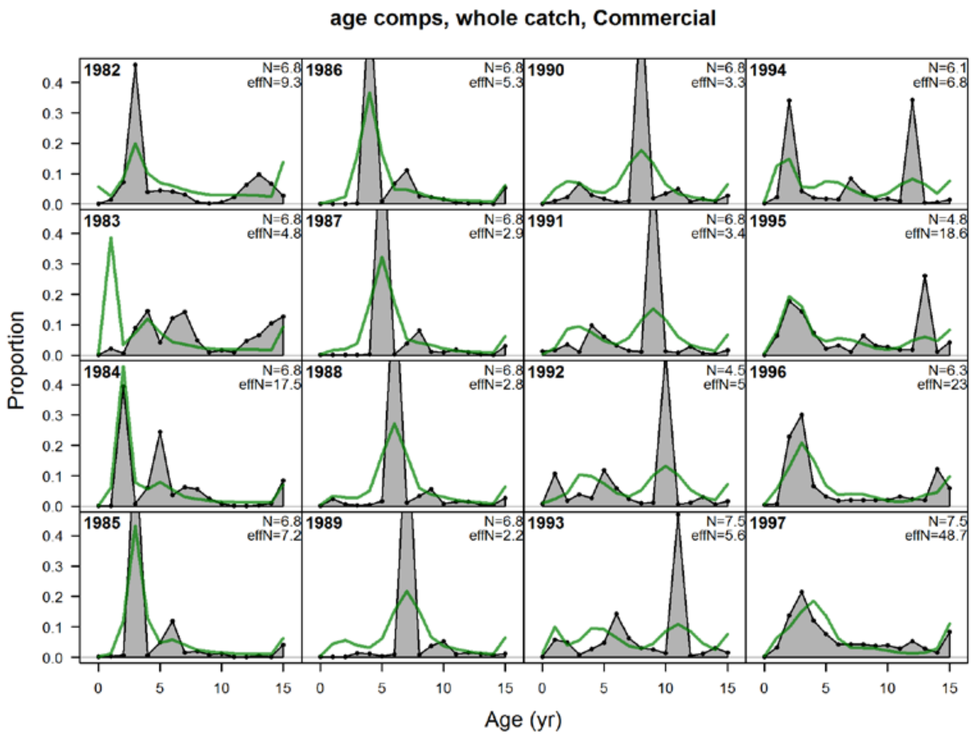



**Figure 5.2.5: Model fits to the age composition of the commercial fleet for the model with ageing error as reported in ICES CM 1999/G:16.**

The working group is aware that this issue requires a resolution and that for horse mackerel it is important to take into account the imprecision related to the ageing of the fish. However, additional investigation is required before this can be incorporate it into the assessment model, and therefore was agreed by the benchmark group to remove the effects of ageing error from the assessment until such investigations can be carried out.

<u>Sensitivity To Survey Indices</u>

To investigate the sensitivity to and contribution of the survey indices to the model fit, indices were progressively removed from the base run, starting with the relatively noisy acoustic indices that cover only part of the stock distribution and have the poorest fits.

When the acoustic indices were removed from the model, the double normal selectivity used for the commercial fleet altered shape and the peak moved towards much smaller fish. This also changed the overall perception of the stock, resulting in significantly higher biomasses and lower fishing mortalities (figure 5.2.6). To verify that the change in stock perception was a result of the (unrealistic) selectivity pattern, the double normal shape of the commercial fleet was replaced with a simple logistic: both the selection pattern and the model estimated returned similar to what estimated from the base case run.

The inclusion of the PELACUS acoustic index, compared to the run when only IBTS and egg survey are used, lowers the biomass estimation in the recent period, and seems to improve the fit to the egg survey in the most recent year. The estimated recruitment is relatively stable between runs with an increase since 2011.

The likelihood relative to the age composition was used to compare the performance of each model (table 5.2.1): the likelihood when removing the PELGAS changes significantly. On the other hand, removing PELACUS and subsequently the IBTS index improved the likelihood only slightly.

When the egg survey only was used in the model, the fitting to the age comp improved even more, however:

- The fitting of the IBTS is rather good;
- The inclusion of annual surveys (a recruitment index and a biomass index) will provide some extra information for the years in between two subsequent egg surveys.
- Improvements of the data quality of the acoustic survey are foreseen and might be available soon.

In light of that, WKWIDE decided to keep both IBTS and PELACUS in the final model.

**Table 5.2.1: Likelihood components for the catch and age composition for runs comparing indices.**

| Surveys Included | Catch Likelihood | Age comp Likelihood |
|---|---|---|
| Base Run (Egg, IBTS, PELGAS and PELACUS) | 1.05E-14 | 125 |
| Egg, IBTS, PELACUS | 3.38E-15 | 105 |
| Egg, IBTS, PELGAS | 7.95E-15 | 131 |
| Egg, IBTS | 1.37E-15 | 103 |
| Egg | 1.05E-15 | 101 |

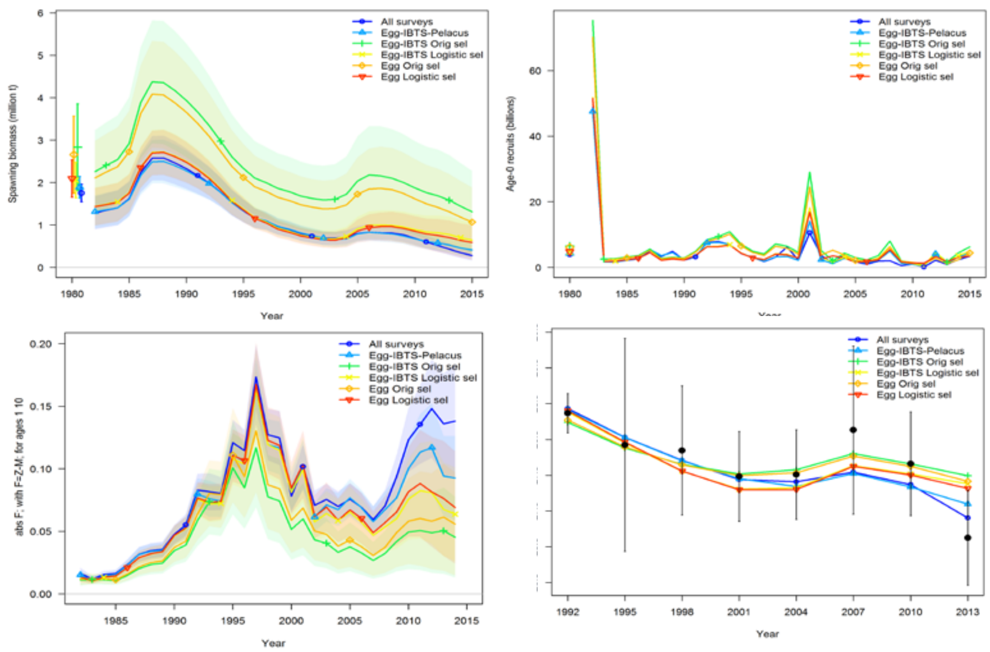



**Figure 5.2.6: Run comparison for SSB (top left), recruitment (top right), F(1-10) (bottom left) and fit to the egg survey index (bottom right). For the runs including the IBTS survey and the egg survey only, results are shown for both the double normal and the logistic selectivity.**

## Data Reweighting

Data weighting can have a large impact on stock assessment results and its influence largely depends on existing conflict between data. In theory, any reasonable data weighting method should produce similar results if the model is correctly specified. A comparison between the two weighting methodologies proposed for SS has been carried out, comparing the output using the McAllister and Iannelli (1997) *vs* the Francis (2011) method. Both the methods have been proved to perform well and no general consensus on using one or the other exists. Comparisons here show little difference between the schemes and the McAllister and Iannelli (1997) method was selected. This iterative reweighting approach uses the multinomial likelihood to make the effective sample size consistent with the residual variance of the fit.

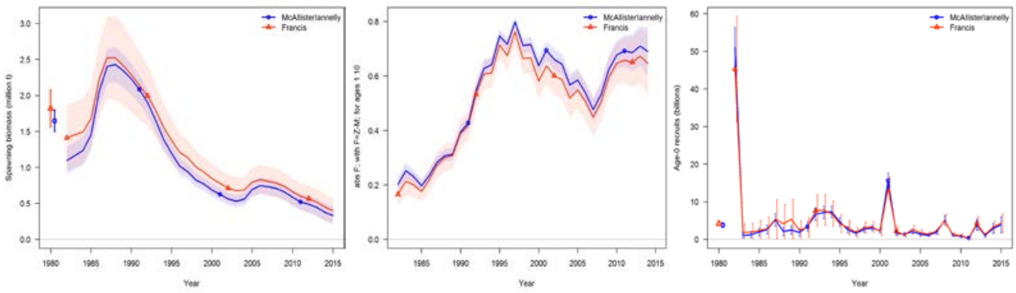



**Figure 5.2.7: Comparison of the McAllister/Iannelli and Francis data weighting methods; SSB (left), F (middle) and Recruitment (right).**

Sensitivity to choice of Stock-Recruit Steepness

The influence of the steepness of the stock-recruitment relationship was investigated using the final run as the baseline. Runs were carried out for steepness values from 0.2 to 0.99. The total of negative log likelihood was compiled for the range of values, and tended to be lowest at steepness values approaching unity.

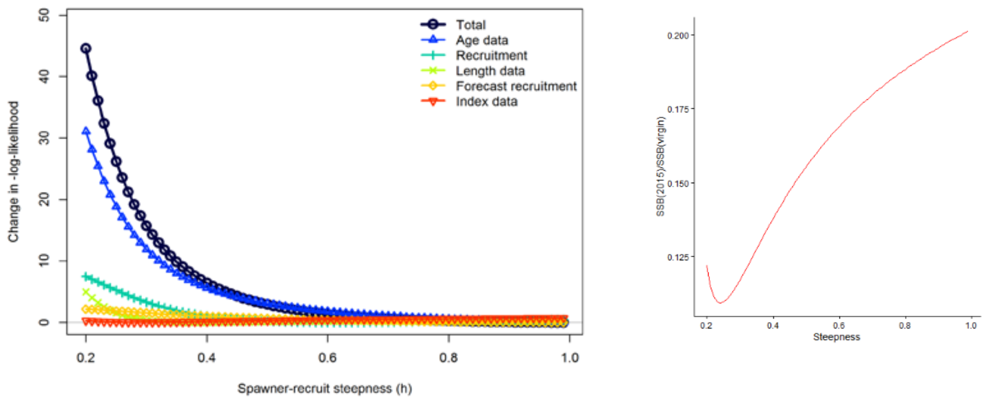



**Figure 5.2.8: Total negative log likelihood from variants of final run with different fixed input values of stock–recruit steepness; (right): relationship between SSB depletion in 2015 and input values of steepness.**

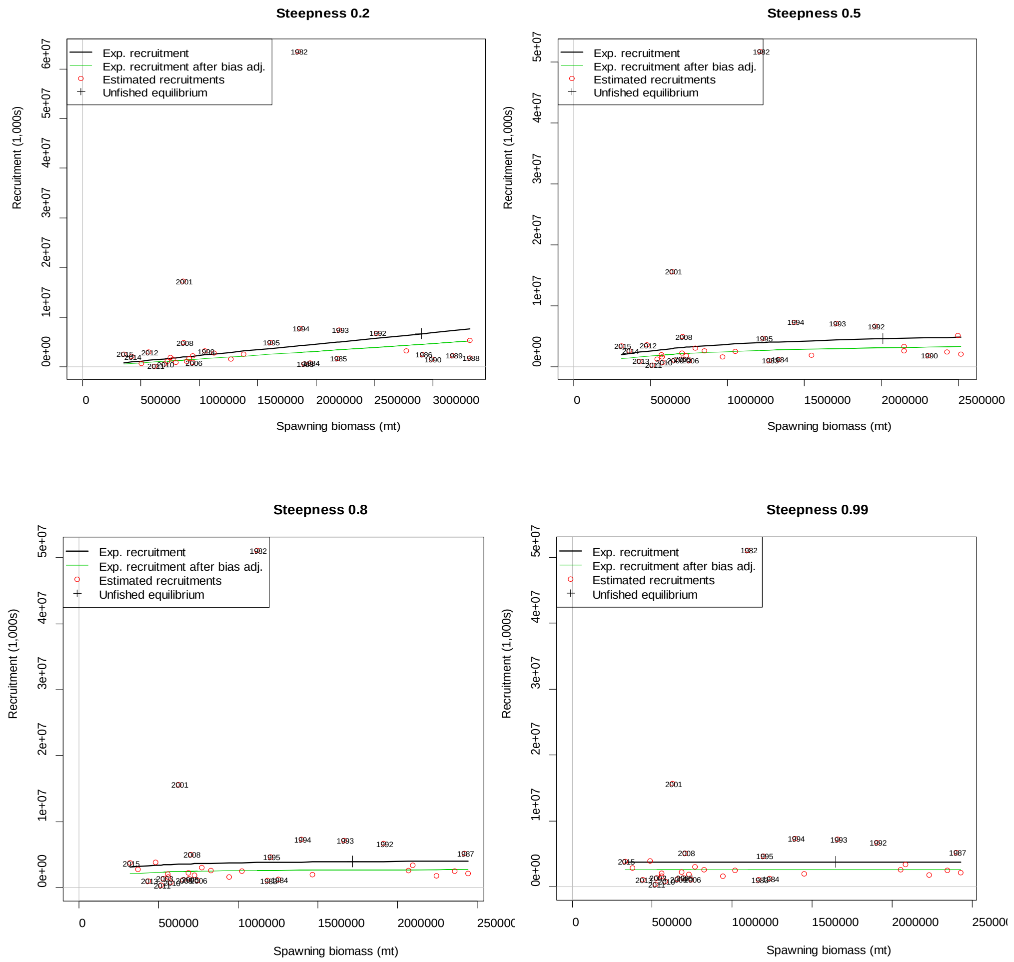



**Figure 5.2.9: Stock–recruit estimates from final run variants with steepness values fixed at 0.2, 0.5, 0.8 and 0.99.**

There is no clear stock-recruitment relationship in western horse mackerel therefore the value of steepness equal to 0.99 seems the most plausible one, and it's confirmed by the fact that the likelihood reaches its minimum with high value of steepness. Recruitment can vary widely, and the highest peaks have been generated by intermediate-low spawning stock biomasses.

Comparison with the Previous Assessment

Results from the final SS model (i.e. including the Egg, IBTS and PELACUS indices – labelled SS_Final) and a run using only the egg survey index data were compared with the SAD assessment. For both SS and SAD, a sensitivity on the inclusion and exclusion of 1983-1989 egg survey data was performed. In the case of the SAD assessment, the removal of the old surveys (1983 and 1989) results in a significantly different stock development, with SSB estimation and F that are respectively much lower and much higher than the original assessment (figure 5.2.10). This is unsurprising considering the limited information available. The influence of the 1983 and 1989 egg-survey data-points is much reduced for SS, and in particular it gets lower when more data are used (run including only egg survey as tuning index *vs* final run including also IBTS and PELACUS acoustic survey) (fig 5.2.10).

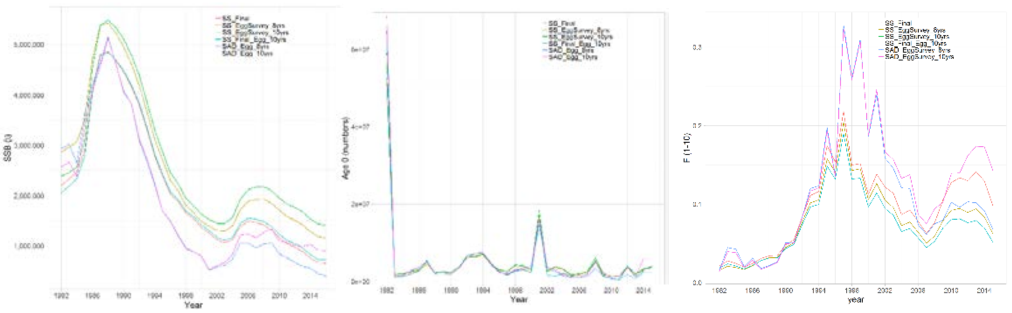


**Figure 5.2.10: Run comparison for SSB (left), recruitment (middle) and Fbar (1-10) (right) for the SAD models vs the SS model including and excluding the egg survey data point for 1983 and 1989.**

Jitter Analysis

An analysis was run using the jitter function within SS3 which added 10% variation to the 71 model parameters estimated. This was to check whether the model would be able to converge and provide similar results for each run with similar negative log likelihood values. 25 runs were carried out on the final run. All of the 25 runs were able to converge, 15 of those converged at the same point, giving the same negative log likelihood values, 3 converged with a difference in likelihood of 1, one run converged with a gradient of 3, while four of the runs converged with warnings and very different values. The results are almost identical for all the runs with the exception of the results from the run that converged at a very different likelihood value.

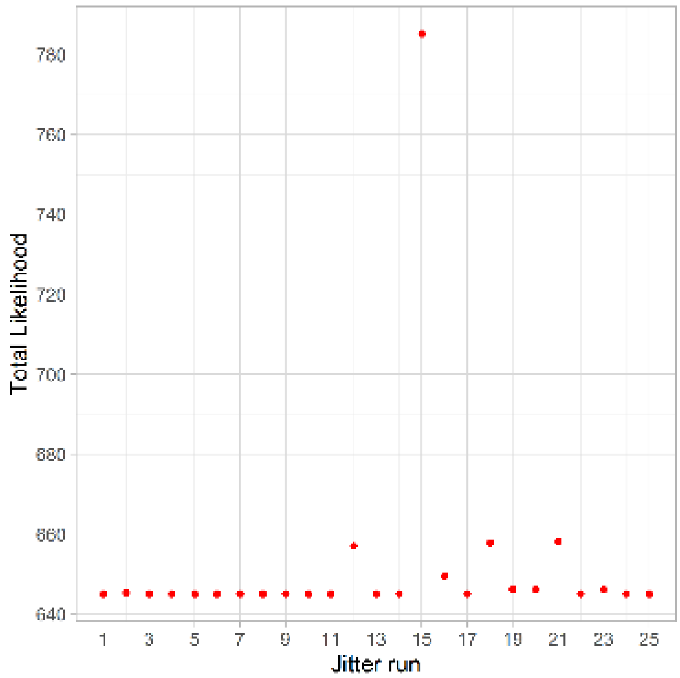



**Figure 5.2.11: Total likelihood comparison for the jitter analysis on the final run.**

Conclusions of the Model Development Process

The final (SS) model considered by the working group as suitable for future update assessment, differs significantly from the (SAD) model previously used for the assessment of this stock.

Exploratory runs indicate that the information available and the initial two-fleet model settings did not allow to distinguish between the Northern fleet and the Southern one: despite a clear, different pattern in the selectivity of the two fleets, the model was not able to fit the data properly. The simpler one fleet model on the other hand was easier to set up and fit the data quite well.

The extension of the catch at age matrix from 11 plus to 15 plus was needed since the strong, sporadic year classes that characterize the stock tended to accumulate in the plus group: this was likely to be the cause of the year trend in the residuals of the plus group estimation in SAD model.

The inclusion of length data and age-at-length data, which allowed the estimation of the growth parameters inside the model itself, is a novelty compared to the previously used SAD model.

The egg survey data was utilised as an index of spawning stock biomass within the assessment. However, due to the fact that western horse mackerel is an indeterminate spawner, and that some data on the potential fecundity of the species are available, it would be useful to investigate alternative approaches for including this information (for example constructing a matrix of empirical age-fecundity and body weight-at-age from the egg-survey and including it in the weight-at-age file). An attempt to estimate fecundity parameters was not successful. As currently configured, the model has insufficient information to estimate these parameters.

The inclusion of additional tuning indices helps with model stability. For example, when the sensitivity of SS to the inclusion/exclusion of the first two data-points of the egg survey was tested, the output was much more stable when the IBTS survey and the acoustic survey were included, compared to when the egg survey only was used. This addressed a key concern of WGWIDE- that the only survey data in the assessment was from a triennial egg survey.

WKWIDE discussed at length the potential use of the PELACUS acoustic survey index in the assessment, since the fitting to both the total index and the length composition is poor. From a statistical point of view, there is limited benefit in excluding it. However, its inclusion improves the fitting to the egg survey index, since they both provide the same indication on the stock for 2013, so it seemed reasonable to keep it in the final assessment. It is likely that the acoustic data from PELACUS and PELGAS will be revised in future, and possibly combined into a single index of abundance.

The current assessment does not include discards, for which information are poor and sporadic. It should be noted however that, for the limited information available, discard rates are low.

The additional data sources and new assessment model adopted by WKWIDE has little impact on estimates of recruitment compared to the past assessment. There is however, a change in perception of development of biomass, in particular for the more recent periods. SSB is estimated as being currently the lowest of the entire time–series and the biomass estimation for 2001 is much higher than the one estimated from the SAD model. The values for F are slightly higher in the most recent years but are lower in the nineties than the estimates reported from the SAD assessment.

The overall picture from the current assessment is a stock which is in a poor, constantly declining since 2006 such that the 2015 SSB is the historic low. Estimates of recruitment indicate an increase in recent years although overall can be considered low.

WKWIDE considers the final run presented here to be a more robust representation of stock development than the model proposed by WGWIDE 2016, but cautions that there are a number of uncertainties regarding i) the quality of the acoustic survey, ii) natural mortality estimates which have been kept equal to the value used in the past, but may need revision; iii) the selectivity patterns for the acoustic surveys and the difference in selectivity pattern between the northern and the southern fleet; iv) effects of ageing error.

WKWIDE concluded that the new assessment contains valuable information on fishing mortality rates and on the stock development.

Final Model Diagnostics

The model run considered by WKWIDE as suitable for future update assessments by ICES differs in several important respects from the model used previously by WGWIDE. The changes include:

- Extension of the catch at age matrix from 11 plus to 15 plus.
- Inclusion in the assessment model of 2 additional indices, namely a recruitment index and an acoustic index.
- The use of length composition data and conditional age at length in the assessment model to help the estimation of the growth parameters.

Exploratory runs indicated that the inclusion of the acoustic surveys tends to lower the estimates of biomass and increase fishing mortality in the recent years compared to runs using only the egg survey or the egg survey and IBTS survey as indices of SSB.

The data incorporated in the assessment are represented graphically in Figure 5.2.12. The fleet landings are also shown. A range of model outputs are shown in Figures 5.2.13 to 5.2.24. Standard summary tables, and tables of output stock numbers and commercial fishery F are given in Table 5.2.3. Note that three out of 6 parameters for the selectivity of the commercial fleet are estimated in the final run: parameter 5 (representing the selectivity at first bin) is fixed at -999, which implies the small fish selectivity being derived from parameter 3; parameter 4 and 6, that determine the selectivity on the bigger fish, are fixed to force the selectivity to an asymptote. The parameter correlation matrix was examined to see if any selectivity parameters in particular were correlated. No strong correlations were evident. The likelihoods and their component values for the final run are given in Table 5.2.2. The length composition data carry 51% of the total of the negative log likelihood (main contribution is from the PELACUS acoustic survey), while the fishery age composition contributes with 43%.

The retrospective analysis was carried out for five years. There is evidence of a retrospective bias (figure 5.2.22) for the F from a 2 year retro (Mohn's Rho=|0.24|). This is due to the fact that in 2013 a new data point for the egg survey become available. Also, 2013 corresponds to the lowest value of the PELACUS survey. The retrospective pattern for recruitment and SSB is good, even though the Mohn's Rho for recruitment is slightly higher than the |0.2| reference criteria provided by ICES in relation to the frequency of assessment (Mohn's rho = |0.21|). The value for SSB is equal to |0.16|, therefore below the reference criteria.

**Table 5.2.2: Likelihood components for the final assessment.**

| | Likelihood | % |
|---|---|---|
| TOTAL | 646.2160 | |
| Catch | 0.0000 | 1.5E-15 |
| Equil_catch | 0.0118 | 0.002 |
| Survey | 13.3520 | 2.066 |
| Length_comp | 332.9250 | 51.519 |
| Age_comp | 281.6120 | 43.579 |
| Recruitment | 18.1973 | 2.816 |
| Forecast_Recruitment | 0.1163 | 0.018 |
| Parm_priors | 0.0000 | 0.000 |
| Parm_softbounds | 0.0010 | 0.000 |
| Parm_devs | 0.0000 | 0.000 |
| Crash_Pen | 0.0000 | 0.000 |

**Table 5.2.3: Summary table of the results from the final assessment model.**

| | SSB | Rec | Fbar(1-10) |
|---|---|---|---|
| 1982 | 2193534 | 51045200 | 0.01995 |
| 1983 | 2329654 | 1062746 | 0.026278 |
| 1984 | 2466254 | 1232436 | 0.023507 |
| 1985 | 2899493 | 1965198 | 0.019391 |
| 1986 | 4103527 | 2620180 | 0.02398 |
| 1987 | 4804238 | 5204280 | 0.030513 |
| 1988 | 4859157 | 2108860 | 0.034064 |
| 1989 | 4688926 | 2479740 | 0.034806 |
| 1990 | 4461943 | 1832826 | 0.048507 |
| 1991 | 4166714 | 3381020 | 0.054889 |
| 1992 | 3806417 | 6686540 | 0.084161 |
| 1993 | 3313213 | 7170080 | 0.112029 |
| 1994 | 2784051 | 7341160 | 0.117704 |
| 1995 | 2391205 | 4670480 | 0.177111 |
| 1996 | 2034659 | 2513120 | 0.156609 |
| 1997 | 1881119 | 1612412 | 0.223558 |
| 1998 | 1648929 | 2626260 | 0.153783 |
| 1999 | 1537742 | 3046660 | 0.156157 |
| 2000 | 1370913 | 2251460 | 0.116213 |
| 2001 | 1251850 | 15632440 | 0.143271 |
| 2002 | 1120655 | 1640886 | 0.126361 |
| 2003 | 1060736 | 1379286 | 0.118345 |
| 2004 | 1119085 | 2058900 | 0.090243 |
| 2005 | 1388600 | 1341724 | 0.096364 |
| 2006 | 1491716 | 1088614 | 0.08143 |
| 2007 | 1461581 | 1907176 | 0.065574 |
| 2008 | 1413353 | 5089560 | 0.079831 |
| 2009 | 1313488 | 1153150 | 0.110438 |
| 2010 | 1165289 | 818520 | 0.134515 |

| | | | |
|---|---|---|---|
| 2011 | 1040618 | 364272 | 0.14203 |
| 2012 | 976290.1 | 3895520 | 0.139123 |
| 2013 | 885736.3 | 1033972 | 0.152474 |
| 2014 | 755505.6 | 2882740 | 0.141031 |
| 2015 | 661917 | 3859300 | 0.107796 |

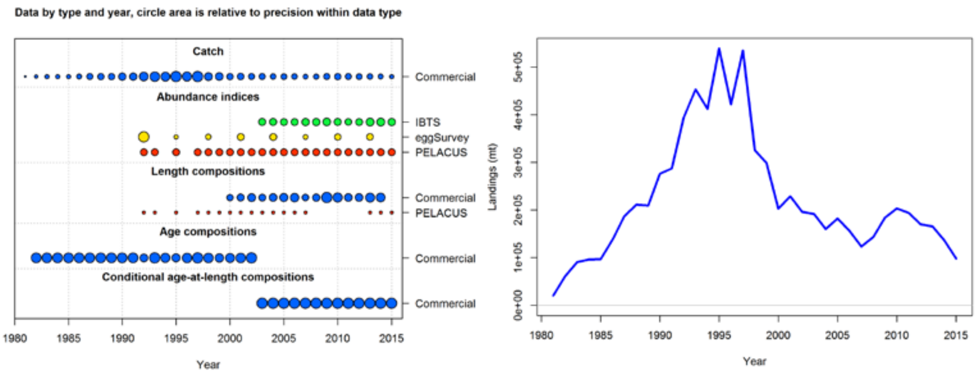



**Figure 5.2.12: Datasets used in the final western horse mackerel assessment (left) and total landings (right).**

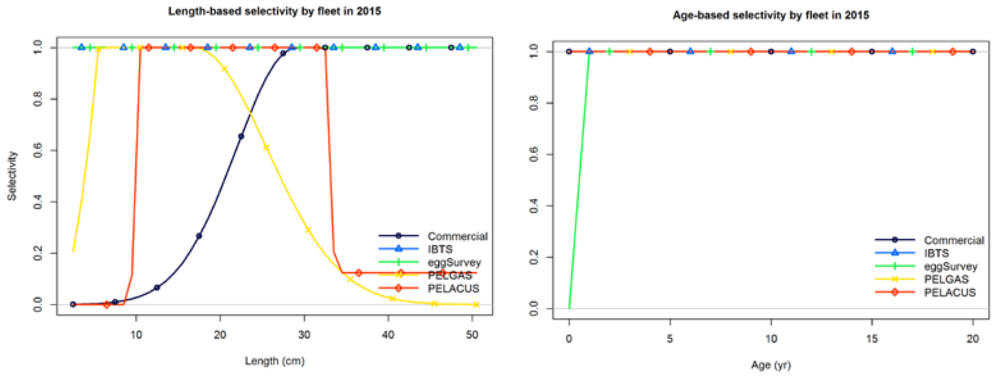



**Figure 5.2.13: Final horse mackerel assessment. Fitted length based and age based selectivity curves**

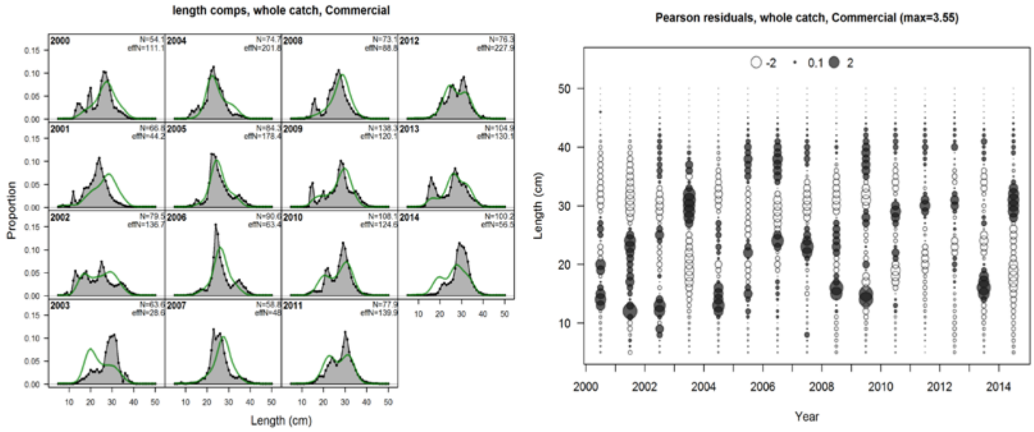



**Figure 5.2.14: Final western horse mackerel assessment. Fit to the commercial length composition data**

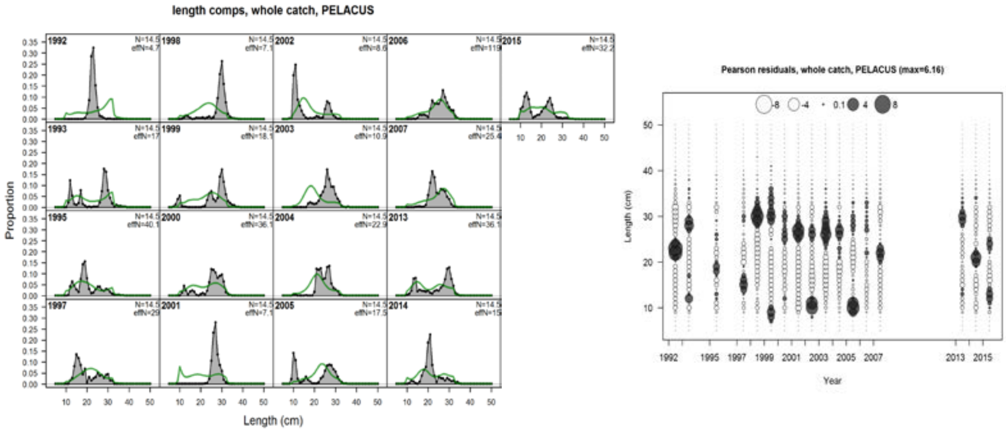



**Figure 5.2.15: Final western horse mackerel assessment. Fit to PELACUS acoustic survey length composition**

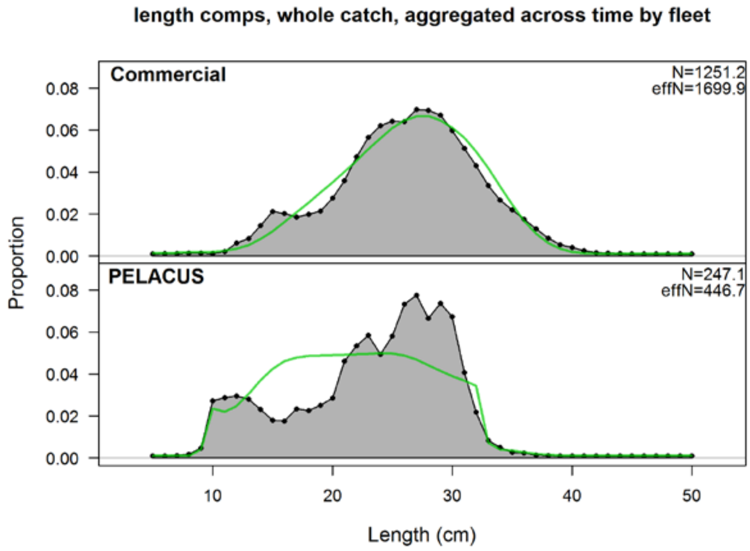



**Figure 5.2.16: Final western horse mackerel assessment. Fit to commercial and acoustic length composition aggregated across time**

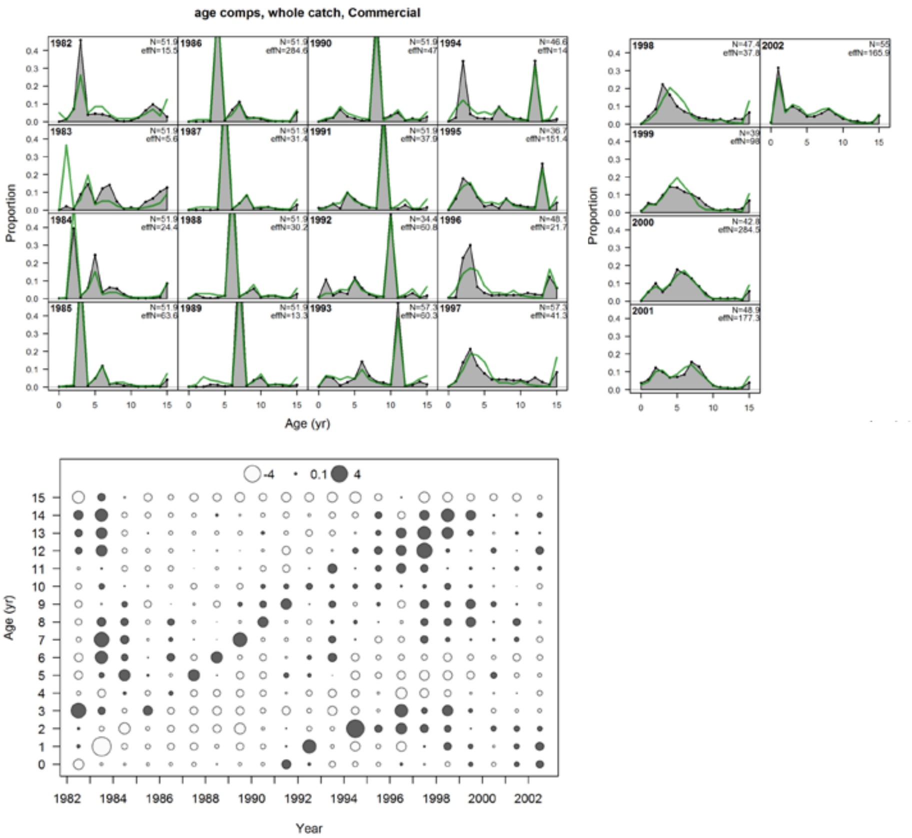



**Figure 5.2.17: Final western horse mackerel assessment. Fit to age composition data for the commercial fleet**

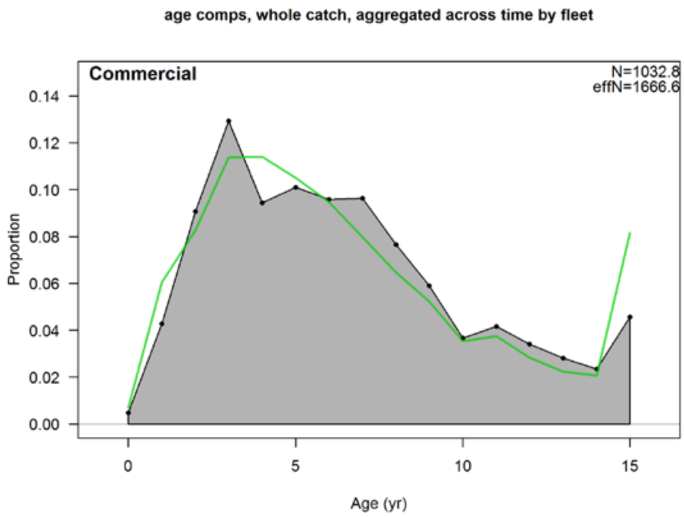



**Figure 5.2.18: Final western horse mackerel assessment. Fit to commercial fleet age compositions, aggregated across time**

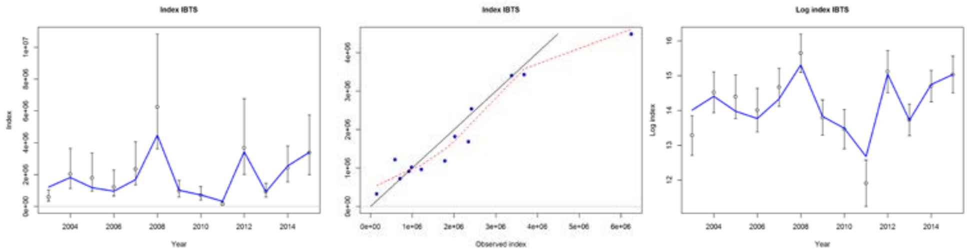



**Figure 5.2.19: Final western horse mackerel assessment. Fit to IBTS recruitment index (natural and logarithmic scales), accounting for length-based selectivity.**

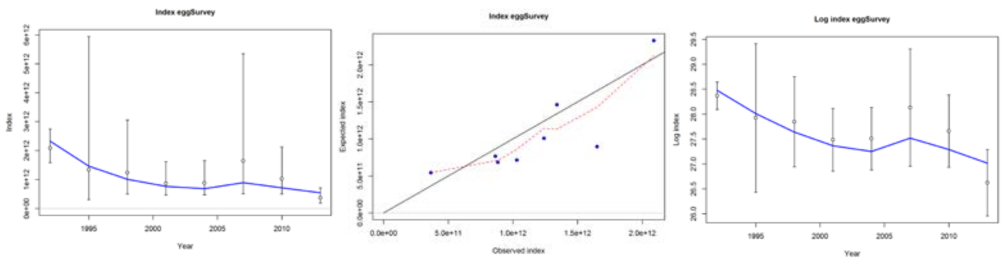



**Figure 5.2.20: Final western horse mackerel assessment. Fit to Egg survey SSB index (natural and logarithmic scales), accounting for length-based selectivity**

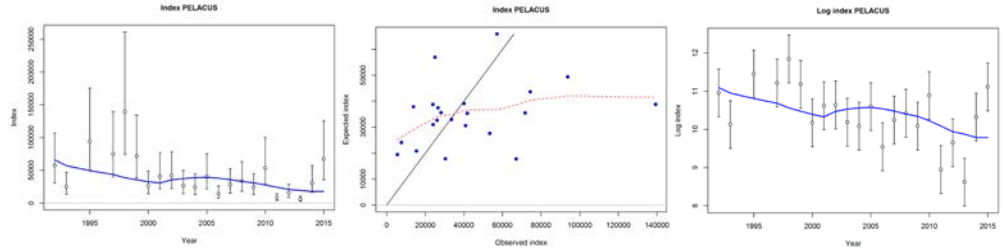



**Figure 5.2.21: Final western horse mackerel assessment. Fit to PELACUS acoustic survey total biomass index (natural and logarithmic scales), accounting for length-based selectivity.**

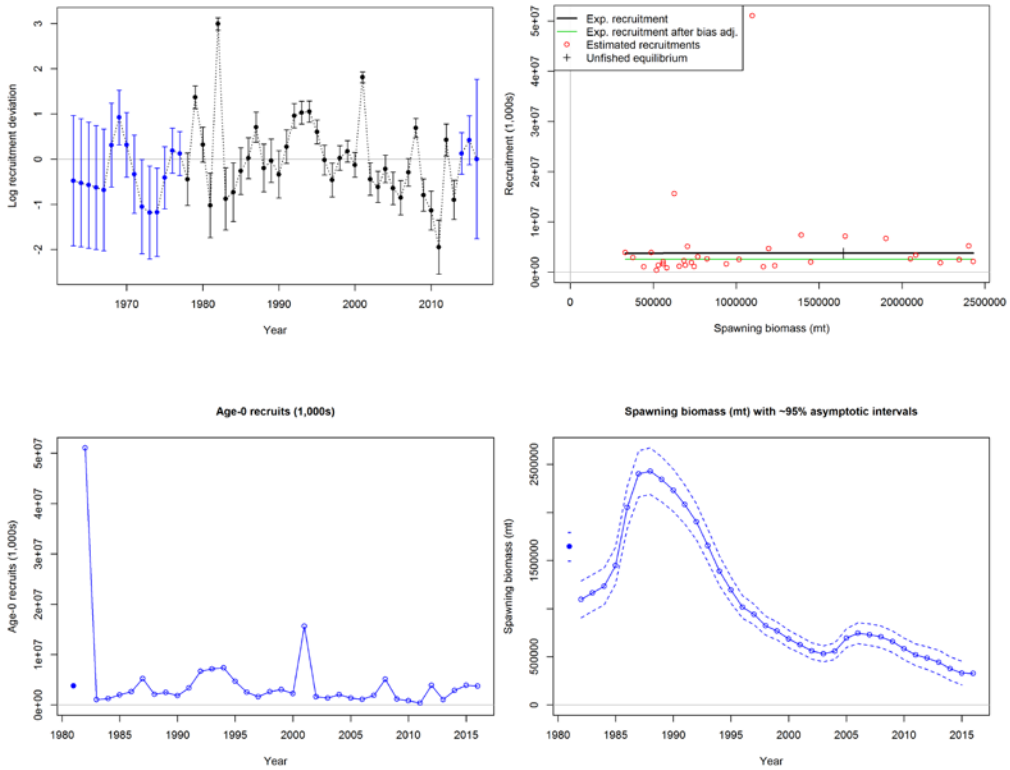



**Figure 5.2.22: Final western horse mackerel assessment. Top left: time–series of log recruit deviations. Top right: stock–recruit scatter (model is fitted assuming Beverton–Holt stock–recruit model and steepness = 0.99). Bottom left: recruitment time–series, bottom-right; SSB series (female only, based on 50:50 sex ratio-at-age) with 95% asymptotic intervals.**

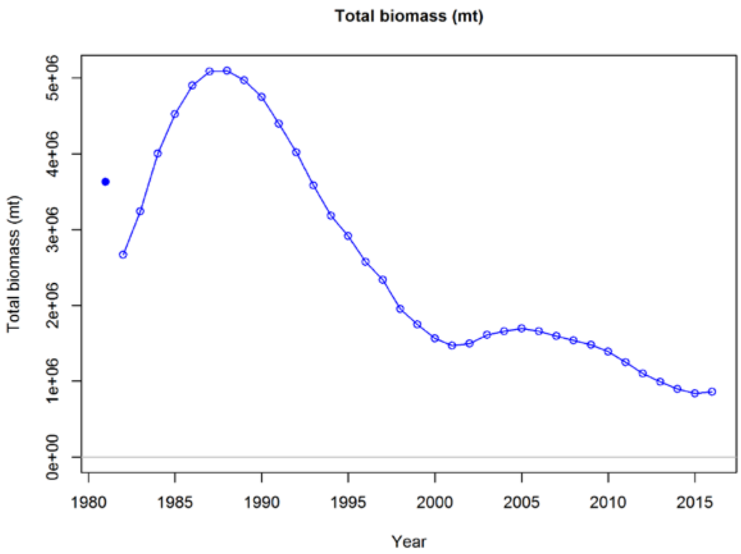



**Figure 5.2.23: Final western horse mackerel assessment. Total biomass time–series.**

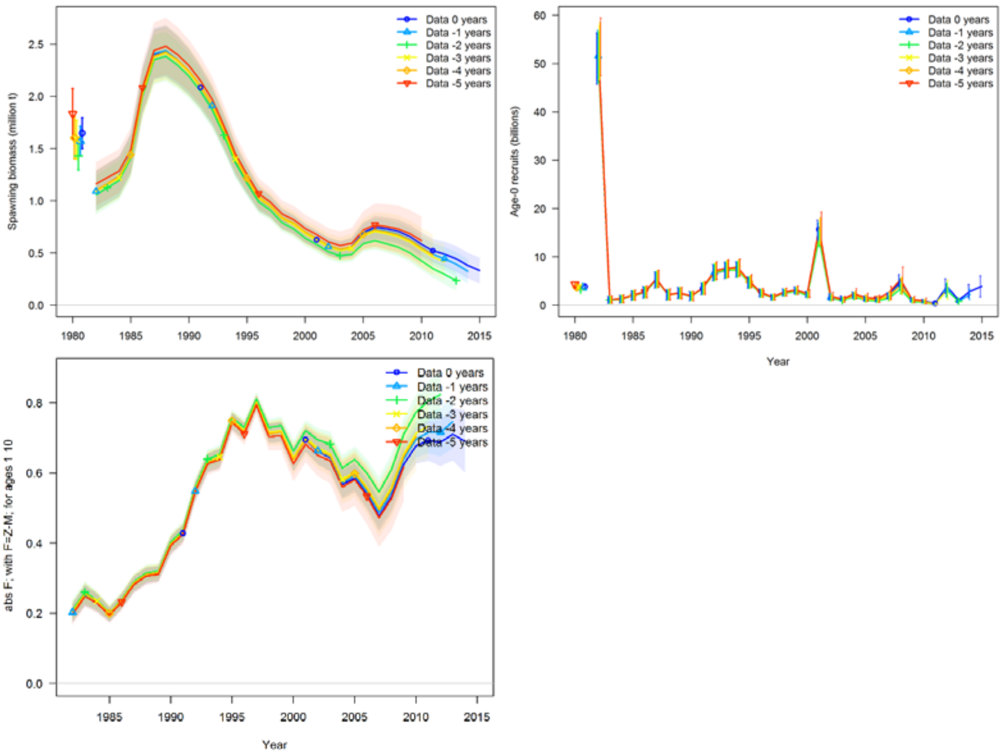



**Figure 5.2.24: Final western horse mackerel assessment. 5 years retrospective analy-sis for SSB (top left), recruitment (top right) and F(1–10) (bottom left)**

**Western Horse Mackerel revised stock assessment inputs and model structure/ parameters**

The structure and input data/ parameters of the western horse mackerel revised SS model are summarized below:
Model structure

- Temporal unit: annual based data (landings, survey indices, age–frequency and length–frequency);
- Spatial structure: single area;
- Sex: Both sexes combined.

*Fleet definition*
1 fleet defined: all countries and all gears combined.

*Landed catches*
Annual landings in tonnes from 1982 to final year for the fleet from ICES Subdivisions 2a, 4a, 3a, 5b, 6a, 7a-c, 7e-i, 8.

*Abundance indices*
Triennial egg survey from 1992 to 2013. Input CV for survey provided by year.
Bottom trawl survey for the whole area, recruitment index from 2003 to 2015. Standardized through log-Gaussian Cox model. CV from model by year.
PELACUS acoustic survey, 1992-2015, sub-division 8c. Length composition data from 1992 to 2007 and from 2013 till 2015. CV = second highest CV from the PELGAS survey.

*Fishery landings age composition data: commercial fleet*
Age bins: 0 to 14 with a plus group for ages 15 and over. Age compositions for the commercial fleet expressed as fleet-raised numbers-at-age for the years 1982 to 2002, and as conditional age at length for the years 2003 to present.

*Length composition data: commercial fleet*
The length bin was set from 5 to 50 cm by 1 cm intervals. Length compositions for the commercial fishing fleets were used from 2000 to present.

*Model assumptions and parameters*

Table 5.2.4 summarises key model assumptions and parameters. Other parameter values and input data characteristics are defined in the SS control file WHOM.ctl, the forecast file Forecast.SS and the data file WHOM.dat as used by WKWIDE 2017.

**Table 5.2.4: Key model assumptions and parameters from the western horse mackerel final run**

| Characteristic settings | |
|---|---|
| Starting year | 1982 |
| Ending year | 2015 |
| Equilibrium catch for starting year | 20,000 |
| Number of areas | 1 |
| Number of seasons | 1 |
| Number of fishing fleets | 1 |
| Number of surveys | 3 surveys: Egg survey; IBTS, PELACUS acoustic. |
| Individual growth | von Bertalanffy, parameters estimated.<br>Initial values (same for both sexes):<br>L_at_Amin_GP_1 = 5<br>Linf = 40<br>k = 0.205 |
| Number of active parameters | 71 |
| *Population characteristics* | |
| Maximum age | 20 |
| Genders | 1 |
| Population length bins | 2–50, 1 cm bins |
| Ages for summary total biomass | 0–20 |
| *Data characteristics* | |
| Data length bins (for length structured fleets) | 5–50, 1 cm bins |
| Data age bins (for age structured fleets) | 0–15+ |
| Minimum age for growth model | 1.2 |
| Maximum age for growth model | Linf |
| Maturity | Age Logistic 2-parameters fixed – females; A50 = 3.5 yr, slope = -2. |
| *Fishery characteristics* | |
| Fishery timing | -1 (whole year) |
| Fishing mortality method | Hybrid |
| Maximum F | 3 |
| Fleet 1: commercial fleet | Double normal, length-based |
| *Survey characteristics* | |
| IBTS timing (yr) | 0.91 |
| Egg survey timing (yr) | 0.33 |
| PELACUS survey timing (yr) | 0.34 |
| Catchabilities (all surveys) | Analytical solution |
| Fleet 2: IBTS survey | Recruitment selectivity |
| Fleet 3: Egg survey | SSB selectivity |
| Fleet 4: PELACUS | Double normal, length based |
| *Fixed biological characteristics* | |
| Natural mortality | 0.15 |
| Beverton–Holt steepness | 0.999 |
| Recruitment variability (σR) | 0.9 |
| Weight–length coefficient | 0.00000585 |
| Weight–length exponent | 3.087 |

Assessment Procedure

The model run with the executable file SS3.exe in the same folder as the following files:

WHOM.ctl (SS3 configuration file),
WHOM.dat (SS3 data inputs)
Starter.SS (SS3 startup file)
Forecast.SS (SS3 forecast file)

Results are output in the same folder (key results file is "results.sso"). Plots can be generated using r4ss after calling library(r4ss), using the following code (adjusted with correct path name):

finalRun <- SS_output(dir="BASE_RUN /",covar=T, verbose=F, forecast=TRUE)

SS_plots(out_BR, uncertainty=T, png=T)

Retrospective analysis is done with the output files from the base run in the same folder as the file retro.bat. For five retrospectives, six Starter.ss files are included. The base file Starter.SS includes the following code nine lines from the bottom:

-5 # retrospective year relative to end year (e.g. -4)

The five retrospective Starter files use the name convention Starter-5; Starter-4; Starter-3; Starter-2; Starter-1, amending the command -5 # retrospective year relative to end year (e.g. -4) to reflect the year peel stated in the file name. A piece of code "Retro-Plots_R4SS" is available to plot the retrospectives.

When the end year for the Stock Synthesis run is specified as the last year with fishery data, the Report.sso file contains estimates of biomass and numbers only to the start of the final year with data, and Zs only to the year before the final one. A work-around to get biomass and numbers for survivors at the end of the last year with data, and Zs for the final year with data, the end year can be specified as the year after the last with data. F values, as used by ICES, are not generated automatically by Stock Synthesis but can be computed from the Zs after subtracting M.

Future Considerations for Assessment Development

- Several issues were identified during WKWIDE as requiring further investigation. In particular: Inclusion of weight at age from egg survey data.
- Inclusion of additional length frequency distributions from the acoustic survey.
- Investigation on the effects of and sensitivity to ageing error;
- Incorporation of the fecundity data within the assessment.
- Consideration of the assumptions regarding natural mortality.

## 5.3 Short-term Projections

Due to the time required to configure Stock Synthesis to mirror the ICES procedures for short-term forecasts, it was decided not to try to develop a forecast procedure within Stock Synthesis. This loses the ability to provide MCMC confidence intervals around the assessment and forecasted variables, and the forecasts are entirely deterministic. Forecasts were instead carried out using the 'fwd()' method in FLR (Flash R add-on package). Previously, the short-term forecast for western horse mackerel was conducted with the ICES standard software MFDP (Multi Fleet Deterministic Projection) version 1a: the results from both software were compared and, being very similar, it was decided to proceed with the FLR approach. The overall settings are the same used in the MFDP software and are summarized below (for details refer to the stock annex). Management options involving biological reference points (BRPs) were tested.

*Input*

Table 5.3.1. lists the input data for the short–term predictions. Weight at age in the stock and weight at age in the catch are the average of the 2013 to 2015. Selection (exploitation pattern) is based on F in 2015 from the most recent assessment and is the average of ages 1 to 10. Natural mortality is assumed to be 0.15 across all ages. The proportion mature for this stock has a logistic form with fully mature individuals at age 4 and values are copied from the assessment input. As with last year, the expected landings for the intermediate year were set to the level that corresponds to the 2016 TAC in EU waters, 124 403 t. Note that -despite the plus group in the catch being equal to 15+- the true population in SS model is set to arrive up to age 20 (as from literature) and is therefore estimated accordingl

**Table 5.3.1. Short–term prediction: input data.**

| 2016–2018 | Stock abundance | Natural mortality | Maturity Ogive | Prop of F before spawning | Prop of M before spawning | Weight in the stock | Exploitation pattern | Weight in the catch |
|---|---|---|---|---|---|---|---|---|
| 0 | 2329148 | 0.15 | 0.00 | 0.45 | 0.45 | 0.0004 | 0.0024 | 0.0079 |
| 1 | | 0.15 | 0.00 | 0.45 | 0.45 | 0.0143 | 0.0314 | 0.0382 |
| 2 | | 0.15 | 0.05 | 0.45 | 0.45 | 0.0396 | 0.0665 | 0.0631 |
| 3 | | 0.15 | 0.27 | 0.45 | 0.45 | 0.0663 | 0.1052 | 0.0909 |
| 4 | | 0.15 | 0.73 | 0.45 | 0.45 | 0.0963 | 0.1372 | 0.1197 |
| 5 | | 0.15 | 0.95 | 0.45 | 0.45 | 0.1274 | 0.1584 | 0.1484 |
| 6 | | 0.15 | 0.99 | 0.45 | 0.45 | 0.1580 | 0.1702 | 0.1762 |
| 7 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.1869 | 0.1760 | 0.2025 |
| 8 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.2135 | 0.1785 | 0.2269 |
| 9 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.2374 | 0.1797 | 0.2490 |
| 10 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.2587 | 0.1801 | 0.2686 |
| 11 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.2772 | 0.1804 | 0.2858 |
| 12 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.2933 | 0.1805 | 0.3006 |
| 13 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3072 | 0.1805 | 0.3134 |
| 14 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3190 | 0.1806 | 0.3243 |
| 15 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3291 | 0.1806 | 0.3336 |
| 16 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3376 | 0.1806 | 0.3414 |
| 17 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3448 | 0.1806 | 0.3480 |
| 18 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3508 | 0.1806 | 0.3535 |
| 19 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3559 | 0.1806 | 0.3582 |
| 20 | | 0.15 | 1.00 | 0.45 | 0.45 | 0.3646 | 0.1806 | 0.3660 |

*Output*

A range of predicted catch and SSB options from the short–term forecast are presented in Table 5.3.2. FMSY scenario and Fcurrent are shown at the bottom.

**Table 5.3.2. Short–term prediction; single area management option table. Catch constraint 124 403 t in 2016 (EU TAC).**

| F factor | Fbar | Catch 2015 | Catch 2016 | Catch 2017 | Catch 2018 | SSB 2017 | SSB 2018 | Change SSB 2017–2018(%) | Change Catch 2015–2017(%) |
|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.000 | 98419 | 124403 | 0 | 0 | 592550 | 699135 | 15.25 | -100.00 |
| 0.1 | 0.011 | 98419 | 124403 | 10708 | 12349 | 588973 | 686405 | 14.19 | -89.12 |
| 0.2 | 0.022 | 98419 | 124403 | 21293 | 24291 | 585416 | 673908 | 13.13 | -78.37 |
| 0.3 | 0.033 | 98419 | 124403 | 31755 | 35837 | 581880 | 661642 | 12.06 | -67.74 |
| 0.4 | 0.044 | 98419 | 124403 | 42096 | 46998 | 578365 | 649600 | 10.97 | -57.23 |
| 0.5 | 0.055 | 98419 | 124403 | 52318 | 57786 | 574870 | 637780 | 9.86 | -46.84 |
| 0.6 | 0.067 | 98419 | 124403 | 62423 | 68210 | 571395 | 626176 | 8.75 | -36.57 |
| 0.7 | 0.078 | 98419 | 124403 | 72411 | 78282 | 567941 | 614786 | 7.62 | -26.43 |
| 0.8 | 0.089 | 98419 | 124403 | 82284 | 88011 | 564506 | 603604 | 6.48 | -16.39 |
| 0.9 | 0.100 | 98419 | 124403 | 92043 | 97406 | 561091 | 592627 | 5.32 | -6.48 |
| 1.1 | 0.122 | 98419 | 124403 | 111228 | 115235 | 554321 | 571273 | 2.97 | 13.01 |
| 1.2 | 0.134 | 98419 | 124403 | 120655 | 123687 | 550966 | 560888 | 1.77 | 22.59 |
| 1.3 | 0.145 | 98419 | 124403 | 129975 | 131842 | 547629 | 550694 | 0.56 | 32.06 |
| 1.4 | 0.156 | 98419 | 124403 | 139188 | 139708 | 544312 | 540685 | -0.67 | 41.42 |
| 1.5 | 0.167 | 98419 | 124403 | 148295 | 147295 | 541014 | 530860 | -1.91 | 50.68 |
| 1.6 | 0.178 | 98419 | 124403 | 157299 | 154609 | 537735 | 521215 | -3.17 | 59.83 |
| 1.7 | 0.190 | 98419 | 124403 | 166200 | 161659 | 534476 | 511745 | -4.44 | 68.87 |
| 1.8 | 0.201 | 98419 | 124403 | 175000 | 168452 | 531235 | 502449 | -5.73 | 77.81 |
| 1.9 | 0.212 | 98419 | 124403 | 183699 | 174996 | 528012 | 493322 | -7.03 | 86.65 |
| 2.0 | 0.224 | 98419 | 124403 | 192300 | 181297 | 524809 | 484362 | -8.35 | 95.39 |
| **1.0** | **0.108** | 98419 | 124403 | 98808 | 103790 | 558712.9 | 585063.2 | 4.50 | 0.40 |
| **1.2** | **0.130** | **98419** | **124403** | **118026** | **121351** | **551903** | **563777** | **2.11** | **19.92** |

## 5.4 Reference Points

The calculation of reference points for western horse mackerel has proved difficult in the past due in the main to an uncertain assessment and with the characterisation of the stock-recruit relationship within a simulation. Prior to this benchmark, only MSY reference points were defined with MSY Btrigger based on Bloss and FMSY on a yield per recruit analysis. Following ICES guidelines, the benchmark proposed a full suite of points the basis (Carpi, 2017) for which is outlined below.

#### 5.4.1.1 Precautionary reference points

**$B_{lim}$** – there is no evidence of significant reduction in recruitment at low SSB within the time–series hence $B_{lim}$ is taken as $B_{loss}$, the lowest estimate of spawning stock biomass from the revised assessment. This was estimated to have occurred in 2015 with $B_{loss}$ = 661917 t.

**$B_{pa}$** – the ICES basis for advice requires that the assessment uncertainty in the estimate of spawning stock biomass is taken into consideration. This leads to a precautionary reference point $B_{pa}$, which is a biomass reference point designed to avoid reaching Blim. Consequently, Bpa was calculated from

$$B_{pa} = B_{lim} * \exp(1.645\sigma_{SSB})$$

Where $\sigma_{SSB}$ (0.19456) was taken as the uncertainty in the assessment SS estimate of the (log) spawning stock biomass in the most recent assessment year (2015). This results in a $B_{pa}$ value of 911587 t.

**$F_{lim}$** – $F_{lim}$ is derived from $B_{lim}$ and is determined as the fishing mortality that, on average would bring the stock biomass to $B_{lim}$. The value for $F_{lim}$ is derived from long–term simulations as the F that, in stochastic equilibrium will result in the median SSB equal to $B_{lim}$. The value estimated at the benchmark workshop was 0.151 (see below for further details).

**$F_{pa}$** – the value of the estimated fishing mortality which ensures that the true F has a less than 5% probability of being above the reference point $F_{lim}$. Since the F estimated by SS is different from the Fbar ICES uses to describe the exploitation of the stock, it was not possible yet to derive an estimate of the uncertainty. Hence $F_{pa}$ is calculated from

$$F_{pa} = F_{lim}/1.4$$

This leads to an estimate for $F_{pa}$ of 0.108.

#### 5.4.1.2 Long-term stochastic simulations for the estimation of MSY

The ICES MSY framework specifies a target fishing mortality ($F_{MSY}$) which, over the long–term maximizes yield and a spawning biomass (MSY $B_{trigger}$), below which fishing mortality is reduced proportionately, relative to $F_{MSY}$ (the ICES MSY advice rule). The ICES basis for advice notes that, in general, $F_{MSY}$ should be lower than $F_{pa}$ while MSY $B_{trigger}$ should be equal to or higher than $B_{pa}$. The value of $F_{MSY}$ should be checked using stochastic simulation to ensure that, by taking consideration of uncertainties, the probability of equilibrium SSB falling below $B_{lim}$ is less than 5%.

In the absence of well-defined parametric model fits a stochastic evaluation using equilibrium stochastic simulations (ICES 2014d) was carried out, using the "msy" R package provided by ICES.

##### 5.4.1.2.1 Configuration of the simulations

Definition of the stock recruitment model

There is no clear evidence of stock recruitment relationship for western horse mackerel, hence it has been considered as a type 5 in ICES guidelines. A segmented regression S-R was used excluding the 1982 year class and setting the breakpoint at Blim (figure 5.4.1).

EqSim Simulation Setup

Biological parameters (mean weights at age, maturity and natural mortality) and exploitation pattern were as in the last 10 years (2006–2015) of the stock assessment. Assessment and advice error for the estimation of the MSY reference points were fixed as the default value used during the WKMSYREF4 (Fcv=0.212; Fphi =0.433, estimated as the median of 5 stocks).

The simulations were based on 500 replicates of the stock, used the values of $B_{lim}$ and $B_{pa}$ defined above, and considered MSY $B_{trigger}$ = Bpa (see rationale below).

The detail of the configuration of the simulation is given in the table below.

| DATA AND PARAMETERS | SETTING | COMMENTS |
|---|---|---|
| SSB-Rec data | Full time–series (1982–2015) | |
| Exclusion of extreme value | 1 run with 1982, 1 run without | |
| Mean weights, maturity and natural mortal | 2006–2015 | |
| Exploitation pattern | 2006–2015 | |
| Assessment error in the advisory year. CV of F | 0.212 | Default value from WKMSYR |
| Autocorrelation in assessment error in the advisory year | 0.423 | Default value from WKMSYR |

#### 5.4.1.2.2 Simulation output and FMSY estimation

Simulations were first run assuming zero assessment error and without implementing the ICES MSY advice rule (*i.e.* setting MSY $B_{trigger}$ = 0 in the simulations) in order to estimate $F_{lim}$. The F value for which the median of the SSB across replicates was equal to $B_{lim}$ was 0.151.

Additional simulations were then run including estimates of assessment error, but still without the ICES MSY advice rule. The median of the yield across iterations reached a maximum for a F value of 0.12 (figures 5.4.2-3). This F value was higher than Fpa and therefore lowered to Fpa (0.107). Based on these simulations, the lower SSB value (5% quantile for the distribution across iterations) observed when fishing constantly at the candidate $F_{MSY}$ value of 0.107 was 624 098 tonnes. This value was a candidate value for MSY Btrigger. Following ICES guidelines, however, implies than MSY Btrigger should be set equal to $B_{pa}$ in the case of the WHOM, since this value is lower than Bpa.

Following ICES guidelines, simulations were run again implementing assessment errors and the ICES MSY advice rule using an MSY $B_{trigger}$ = $B_{pa}$ (911 588 t) to check if the candidate $F_{MSY}$ (0.107) is still found to be precautionary, which was the case.

The final reference points are summarised in the table below:

| | FLIM | FPA | FMSY | FP05 | BTRIGGER |
|---|---|---|---|---|---|
| Segmented S-R | 0.1510 | 0.1079 | 0.1079 | 0.1203 | 911 588 |

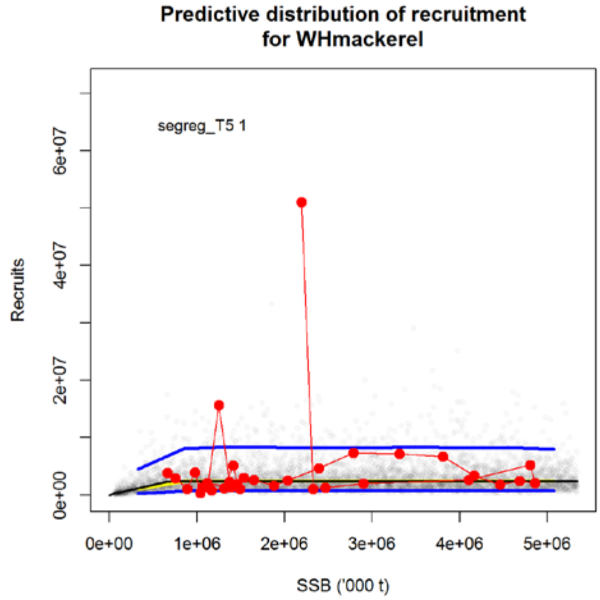



**Figure 5.4.1: *EqSim* SR analysis excluding 1982.**

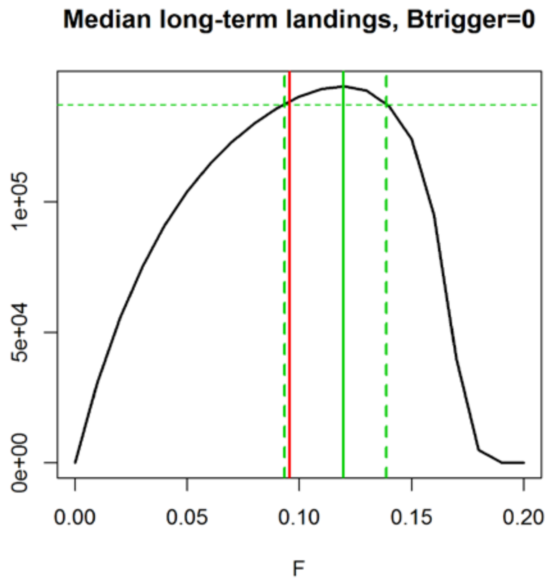



**Figure 5.4.2: Median (500 iterations) for the mean yield at stochastic equilibrium as a function of the fishing mortality applied. The green vertical line corresponds to $F_{MSY}$ (with the dashed lines representing the $F_{MSY}$ range limits). Red vertical line represents the fishing mortality at which p(SSB<$B_{lim}$)>5%. Simulations run without ICES MSY advice rule.**

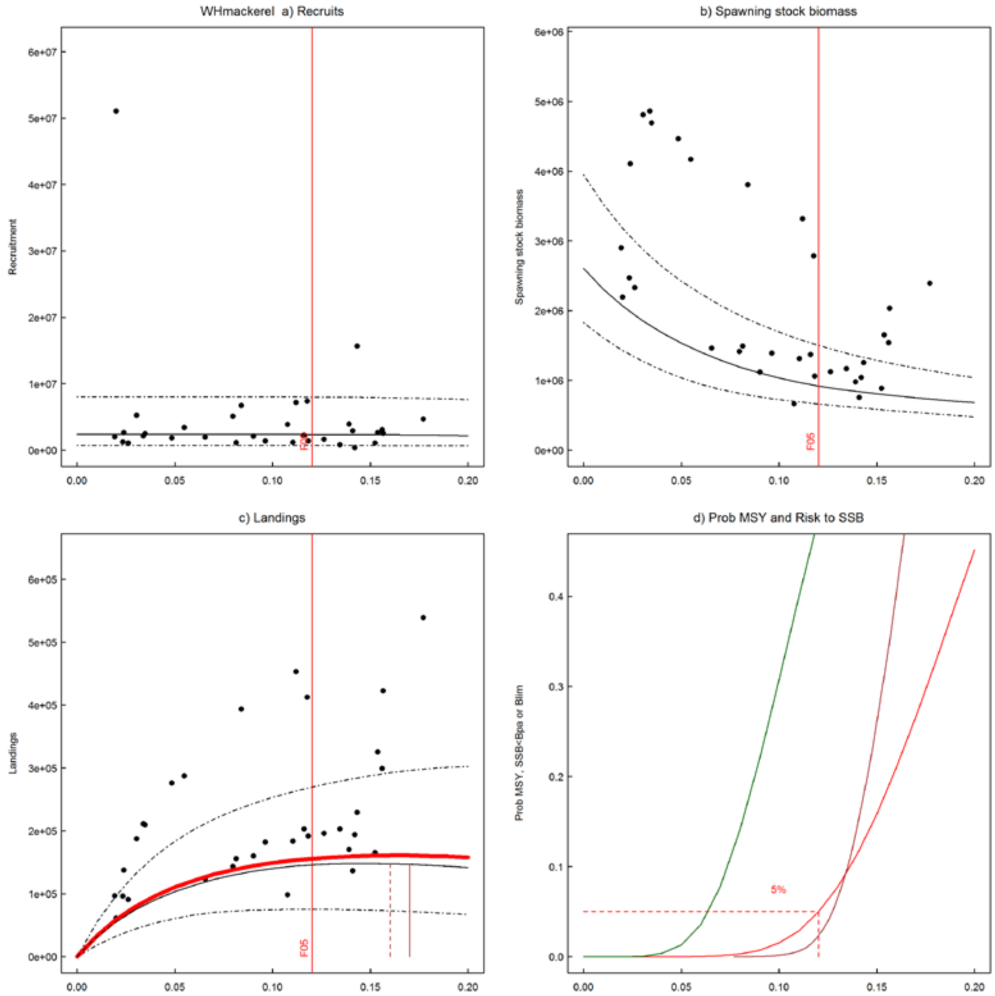



**Figure 5.4.3:** ***EqSim*** **summary plot for Western horse mackerel (without $B_{trigger}$). Panels' a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<Blim (red), SSB<Bpa (green) and the cumulative distribution of FMSY based on yield as landings (brown).**

# 6 North Sea Horse Mackerel

## 6.1 Changes in the spatial coverage of the CGFS

The main sources of information to evaluate trends in the state of the North Sea Horse Mackerel (NSHM) are the North Sea International Bottom Trawl Survey (IBTS) and Channel Ground Fish Survey (CGFS). The IBTS is conducted during the third quarter of the year and covers ICES divisions 4.b and 4.c, while the CGFS is carried out in the fourth quarter and covers division 7.d. The annual proportion of the total catch of NSHM taken from 7.d has increased since the early 1990s, while catches from 4.b and 4.c have reduced significantly (ICES, 2016). Accordingly, the importance of the CGFS in evaluating the state of the NSHM stock has increased.

With the intention of increasing the area covered by the CGFS and expanding it towards western areas beyond 7.d, the *R/V Gwen Drez* was replaced in 2015 by the larger *R/V Thalassa.* Thalassa also uses a larger Great Overture GOV trawl with a higher vertical net opening (~4.4m now versus ~3.3m). In 2014, a calibration exercise was conducted (Auber *et al.*, 2015), and conversion factors were estimated for all the main commercial species, including horse mackerel for which it showed that the catchability of the new R/V is 10.363 times higher. No significant differences were observed in the size distribution of the catches of horse mackerel between vessels (Figure 6.1.1).

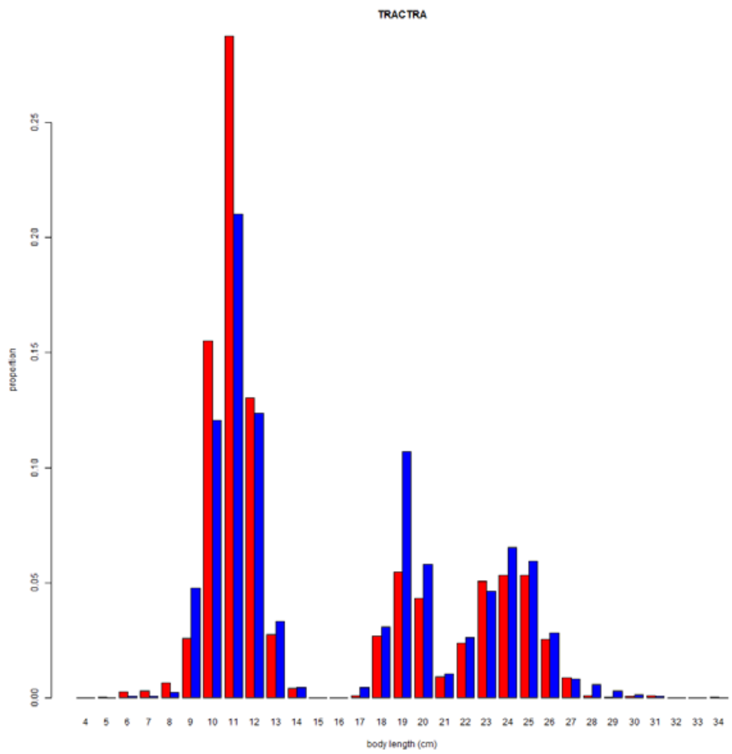



**Figure 6.1.1.- Size distribution of horse mackerel catch from comparative tows conducted during the 2014 calibration exercise for the *RV Gwen Drez* (red) and *RV Thalassa* (blue).**

Associated with this change of vessel is a slight variation in the spatial distribution of the survey. The fishing sets in the North-eastern part of the sampling area (ICES Statistical Rectangles 33F1 and 33F2) have been removed from the sampling programme (Figure 6.1.2). In addition, due to the larger size of the *RV Thalassa*, it is not possible to conduct the hauls in the mouth of the Seine river. Regarding the western side of the surveyed area, due to the rough and hard bottom, some stations where trawl damage was frequent have been removed, although the spatial coverage has not been reduced. In fact, it is planned to extend the CGFS survey to the Western English Channel (between 6°W and 2°W) from 2018 onwards.

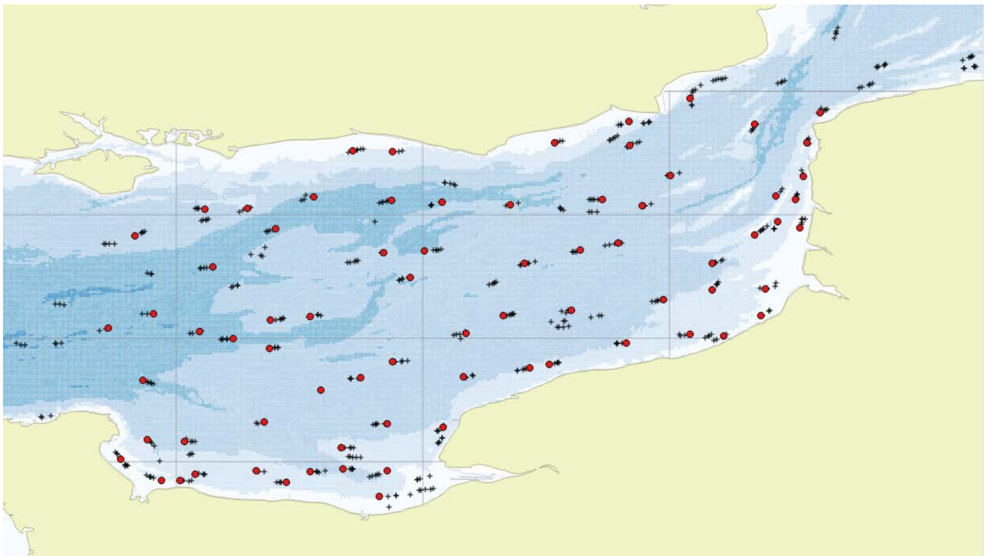


**Figure 6.1.2.- Sampling location for the *RV Thalassa* in 2015 (red dots) and sampling location over the period 2009-2013 for the *RV Gwen* Drez (black crosses). Fishing trawls in ICES statistical rectangles 33F1 and 33F2 in the North eastern area of the sampling distribution (large black ellipse) and the mouth of the Seine river (small black ellipse) have been removed from the sampling protocol.**

Due to the increased relevance of the CGFS survey in the context of increased commercial catch in 7.d, any possible effect of the reduction in the number of hauls in the perception of the state of the stock needs to be assessed. To do so, the survey index was estimated using the Delta Log-Normal (DLN) method, employed for the assessment of the NSHM (ICES, 2016). The DLN index was estimated both with and without the sampling stations in statistical rectangles 33F1 and 33F2, as well as the hauls in the Seine river mouth. The 95% confidence intervals for both survey index time–series were calculated by bootstrapping the original data and re-estimating the survey index. The results showed that differences in the survey index with and without those fishing sets, both for the juvenile (<20 cm) and exploitable (>20 cm) sub-stocks, were minor and not significant with both time–series being contained within the confidence interval of the other (Figure 6.1.3).

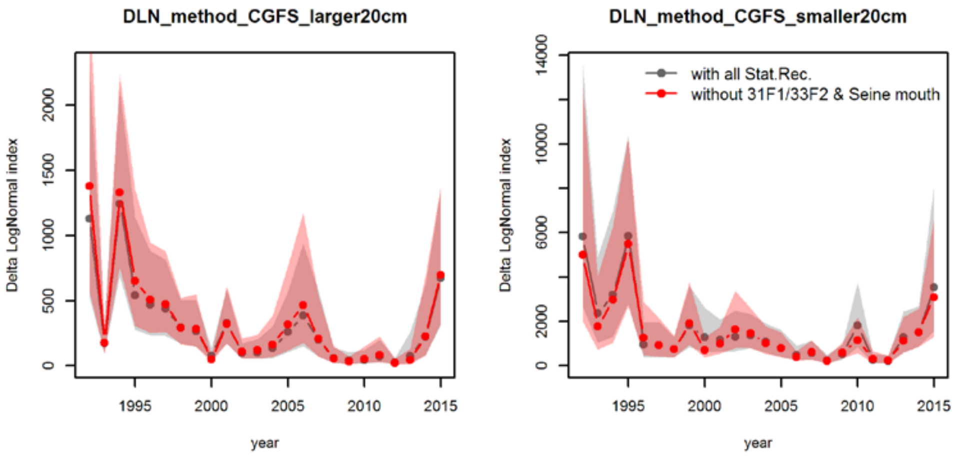



**Figure 6.1.3.- Survey index time–series estimated using the DLN method for both juveniles (<20cm) and exploitable (>20cm) NSHM. The grey line shows the survey index with all the hauls, while the red line shows the survey index without the hauls in ICES statistical rectangles 31F1 and 31F2, as well as those hauls in the Seine river mouth. The 95% confidence intervals are depicted in the same colour as the corresponding time–series**

## 6.2 Stock Index Development

Since 2014, the assessment of the state of the NSHM stock has been based on separate estimates of survey indices with the information from the CGFS in the division 7.d, and the IBTS in 4.b and 4.c. However, the indices from both surveys are very uncertain and individual years are not considered to be indicative of trends. For this reason, the NSHM is currently classified as a category 5 stock (stocks for which only landings data are available (ICES, 2016)). In accordance with this classification, the survey indices are only used as informative for overall trends, and not used directly for advice. During the benchmark, a modelling exercise was carried out to determine the possibility of using the survey data more comprehensively (i.e. directly as a basis for advice). In this section of the report the rationale, results and selection of an alternative annual CPUE survey index using the CGFS and IBTS databases are presented.

Data selection and exploration

The 20 cm fish length was considered as the cut off length to split the NSHM stock into a "juvenile" sub-stock (<20 cm) and an "exploitable" sub-stock (>20 cm), in line with the approach followed since 2014 for this stock (ICES, 2014e). Despite the fact that no significant differences are apparent in the DLN survey index (see section 6.1), the hauls in statistical rectangles 31F1 and 31F2 and the mouth of the Seine river were removed from the analysis to ensure consistency in the survey effort over time.

Based on the current spatial-temporal division of the North East Atlantic horse mackerel stocks (Abaunza *et al.*, 2008), catches in ICES divisions 3.a and 4.a during the 3rd and 4th quarters of the year are considered to be from the western horse mackerel stock (WHM). Since the North Sea IBTS data considered in this study are collected annually during Q3, hauls conducted in divisions 3.a and 4.a were excluded from the NSHM analysis and modelling dataset. The catch in numbers per haul were standardized for all hauls to a 60 minute duration. Hence the Catch Per Unit Effort (CPUE) of NSHM was estimated as the catch in numbers divided by 60. Although most hauls lasted approximately 30 minutes some fishing hauls were much shorter or longer and hauls with duration below 15 min. or above 45 min. were disregarded from the analysis. The catch values in the CGFS were standardized over the entire period using the conversion factor 10.363 estimated for the proportion of catches of *RV Thalassa* in relation to those of the *RV Gwen Drez*.

In both the CGFS and the IBTS surveys, the deepest hauls were in waters of less than 90m. The CPUE distribution by depth indicates that in the IBTS in divisions 4.b and 4.c the highest catches were recorded from hauls conducted between 15 and 45 m, while in the CGFS this range was wider, with high number of hauls with presence of NSHM in the deeper areas (Figure 6.2.1). In both surveys catches from hauls in less than 50 m were in general higher than in deeper waters. This may suggest the 50 m depth as a limiting value to split the North Sea-English Channel into two depth ranges above (shallow stratum) and below 50 m (deep stratum). However, the number of hauls in the deep stratum was low in both surveys. More importantly, the number of hauls with presence of NSHM in the deep stratum was zero in IBTS in several years (table 6.2.1). Based in this exploration, the stratification by depth was considered unnecessary, and even inadvisable in terms of sampling size by strata.

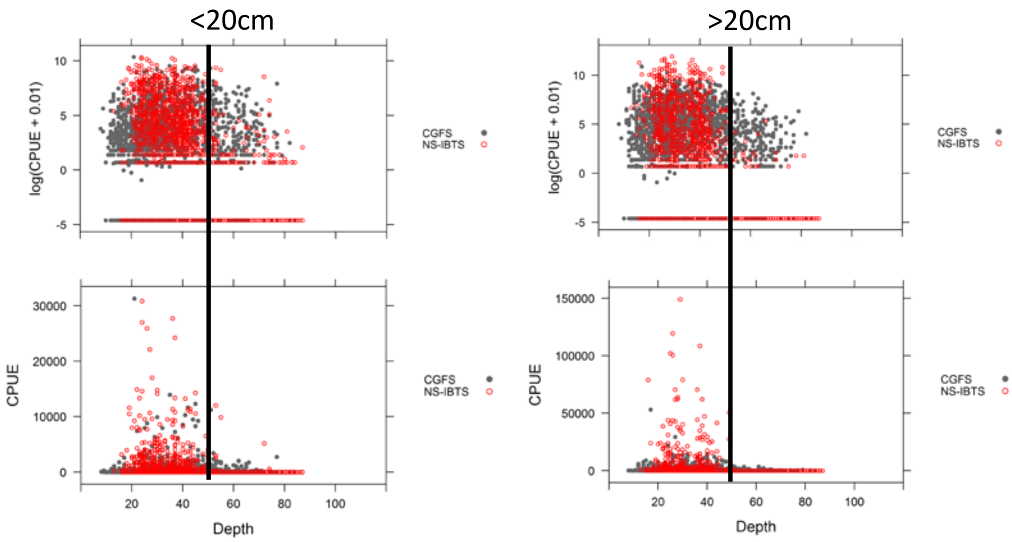



**Figure 6.2.1.- Depth distribution of CPUE (number/hour) and log(CPUE) in the CGFS (grey) and IBTS (red) over the period 1992-2015 for the juvenile (<20 cm) and exploitable (>20 cm) sub-stocks.**

The range of latitude/longitude of both surveys is different, with only a relatively low overlap in longitudes from 0 to 2 (Figure 6.2.2). Due to the expected influence of these differences in the CPUE of NSHM, this factor was considered as relevant for consideration as an explanatory variable within the modelling exercise.

**Table 6.2.1.- Number of hauls by year and survey with presence/absence of NSHM within the shallow and deep strata (defined by the 50 m depth limit).**

| | Deep | | | | Shallow | | | |
|---|---|---|---|---|---|---|---|---|
| | CGFS | | NS-IBTS | | CGFS | | NS-IBTS | |
| Year | absence | presence | absence | presence | absence | presence | absence | presence |
| 1992 | 0 | 5 | 21 | 0 | 1 | 44 | 7 | 55 |
| 1993 | 0 | 8 | 17 | 0 | 1 | 47 | 9 | 56 |
| 1994 | 0 | 20 | 12 | 2 | 1 | 46 | 7 | 40 |
| 1995 | 3 | 11 | 12 | 2 | 1 | 52 | 5 | 21 |
| 1996 | 0 | 0 | 13 | 1 | 4 | 30 | 11 | 30 |
| 1997 | 0 | 12 | 15 | 3 | 3 | 45 | 2 | 37 |
| 1998 | 0 | 5 | 19 | 1 | 2 | 53 | 9 | 44 |
| 1999 | 2 | 16 | 29 | 6 | 1 | 57 | 12 | 60 |
| 2000 | 4 | 6 | 22 | 0 | 1 | 59 | 12 | 21 |
| 2001 | 0 | 12 | 31 | 0 | 3 | 72 | 13 | 26 |
| 2002 | 0 | 6 | 28 | 2 | 2 | 73 | 16 | 50 |
| 2003 | 1 | 9 | 25 | 7 | 1 | 73 | 16 | 59 |
| 2004 | 0 | 8 | 26 | 5 | 4 | 67 | 16 | 44 |
| 2005 | 2 | 13 | 32 | 0 | 6 | 63 | 27 | 37 |
| 2006 | 2 | 13 | 34 | 1 | 6 | 65 | 26 | 35 |
| 2007 | 2 | 13 | 26 | 2 | 8 | 62 | 32 | 38 |
| 2008 | 4 | 16 | 25 | 0 | 9 | 59 | 37 | 47 |
| 2009 | 1 | 18 | 29 | 1 | 6 | 67 | 28 | 34 |
| 2010 | 2 | 15 | 26 | 0 | 7 | 63 | 30 | 30 |
| 2011 | 1 | 18 | 28 | 0 | 14 | 56 | 41 | 25 |
| 2012 | 1 | 13 | 25 | 0 | 8 | 52 | 51 | 12 |
| 2013 | 0 | 10 | 32 | 2 | 11 | 62 | 41 | 13 |
| 2014 | 1 | 15 | 25 | 1 | 7 | 69 | 36 | 36 |
| 2015 | 1 | 14 | 23 | 1 | 4 | 56 | 51 | 26 |

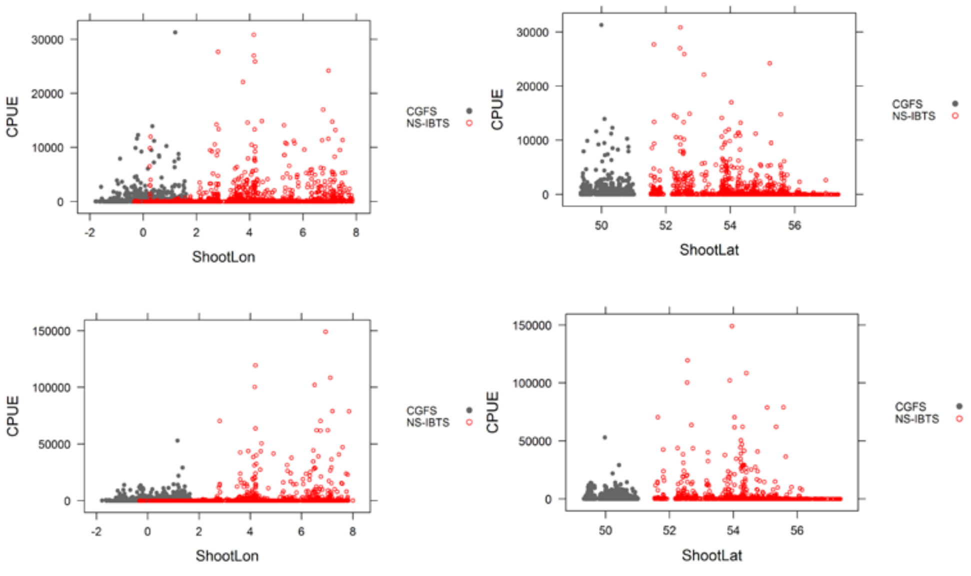



**Figure 6.2.2.- CPUE (number/hour) as a function of haul shoot longitude and latitude in the juvenile (<20cm; lower panels) and exploitable (>20cm upper panels).**

Index modelling

The CPUE (number/hour) was modelled separately for the juvenile and exploitable stocks as a function of:

Year: a factor (with 24 levels), to account for all the latent processes affecting the CPUE each year, such as recruitment, natural mortality, vertical distribution, *etc.*

Survey: a factor (with 2 levels), to account for all the variables associated with each survey, such as the difference in latitude and longitude likely to affect several oceanographic variables influencing on the NSHM abundance and distribution, but also other latent factors determining differences in the catchability between the CGFS and the IBTS.

In order to assess the amount of dispersion in the data that is not accounted by the model, a dispersion statistic was estimated as:

$$dispersion\ statistic = \frac{\chi^2}{residual\ degrees\ of\ freedom}$$

Where $\chi^2$ is the sum of the squared Pearson residuals. It is considered that a dispersion statistic higher than 1 is indicative of overdispersion in the data not accounted by the model.

GLM Poisson

The first option was fitting a GLM with a Poisson distribution, with variance $var(Y_i)$ equal to the mean $\mu$. A logarithmic link function was applied to relate the *CPUE* with the explanatory variables *Year* and *Survey*.

$$\log(CPUE_i) = Intercept + Year_i + Survey_i$$

Where *i* relates to each haul conducted over the study period 1992-2015.

Models with all possible combinations of explanatory variables and interactions were fitted. The model with the lowest AIC included both Year and Survey and an interaction term. The estimated dispersion in the best GLM Poisson model was 3082 and 7046 for the juvenile and exploitable sub-stocks respectively, which is a strong indication that the Poisson distribution cannot account for the high dispersion in the CPUE data per year and survey.

GLM negative binomial

As an alternative approach to account for over-dispersed data, the GLM with a negative binomial distribution was fitted. The difference in relation to the GLM-Poisson is an additional parameter $\theta$ which provides extra flexibility to model the variance of the distribution:

$$var(Y_i) = \mu\ x\ \frac{\mu^2}{\theta}.$$

The link function in the GLM-negative binomial is also logarithmic.

As with the GLM-Poisson, the full model with Year, Survey and interactions produced the lowest AIC. The log-likelihood ratio test indicated that this model explained better the data than simpler models although the dispersion parameter was still greater than unity (3.4 both in the juvenile and exploitable sub-stocks). However, the most important drawback of this GLM-negative binomial model was that, like the GLM Poisson, it was not able to account for the very high proportion of zero CPUE values observed in both surveys every year(especially in the IBTS) (Figure 6.2.3).

In order to account for the zero inflation nature of the data, the zero inflated and hurdle models were tested.

*Zero inflated & hurdle (zero altered) models*

Zero inflated and hurdle (aka zero altered) models, are a combination of two GLM sub-models, one with a Bernoulli distribution to account for the absence/presence of individuals in samples (zero CPUE values) and a second sub-model with a Poisson, negative binomial or other distribution to fit the relation of the response and explanatory variables in those non-zero samples (those hauls where the NSHM was caught).

The difference between the zero inflated and the hurdle models is the way the zero samples are treated. In the zero inflated models the zeros are assumed to be the result of two possible reasons: i) false zeros, corresponding to sampling errors (such as sampling in inappropriate areas, *i.e.* outside the distribution area of the species, or using an inappropriate technique) and ii) real zeros, corresponding to sampling in low abundance areas. In hurdle models all zero values are assumed to be a true absence of individuals, and no error in sampling design or any other source of false zeros is assumed.

The probability of a zero CPUE in hurdle models (a false zero in zero inflated models) was modelled by a logistic regression with a GLM-binomial distribution model:

$$logit(\pi_i) = Intercept_{zero} + Year_{i,zero} + Survey_{i,zero}$$

Where $\pi_i$ is the mean probability of having a CPUE zero as a function Year and Survey.

The expected CPUE of NSHM, conditional to not having a zero in hurdle models (not having a false zero in zero inflated models) was modelled with a GLM-negative binomial distribution model. The Poisson distribution was disregarded at this stage due to the lack of capacity to account for the overdispersion in the data as discussed in the previous section. Hence, the count sub-model took the form:

$$\log(CPUE_i) = Intercept_{count} + Year_{i,count} + Survey_{i,count}$$

In hurdle models the GLM-negative binomial explaining the count data is zero truncated, while in the zero inflated models it is not, and also explains the “real” zeros.

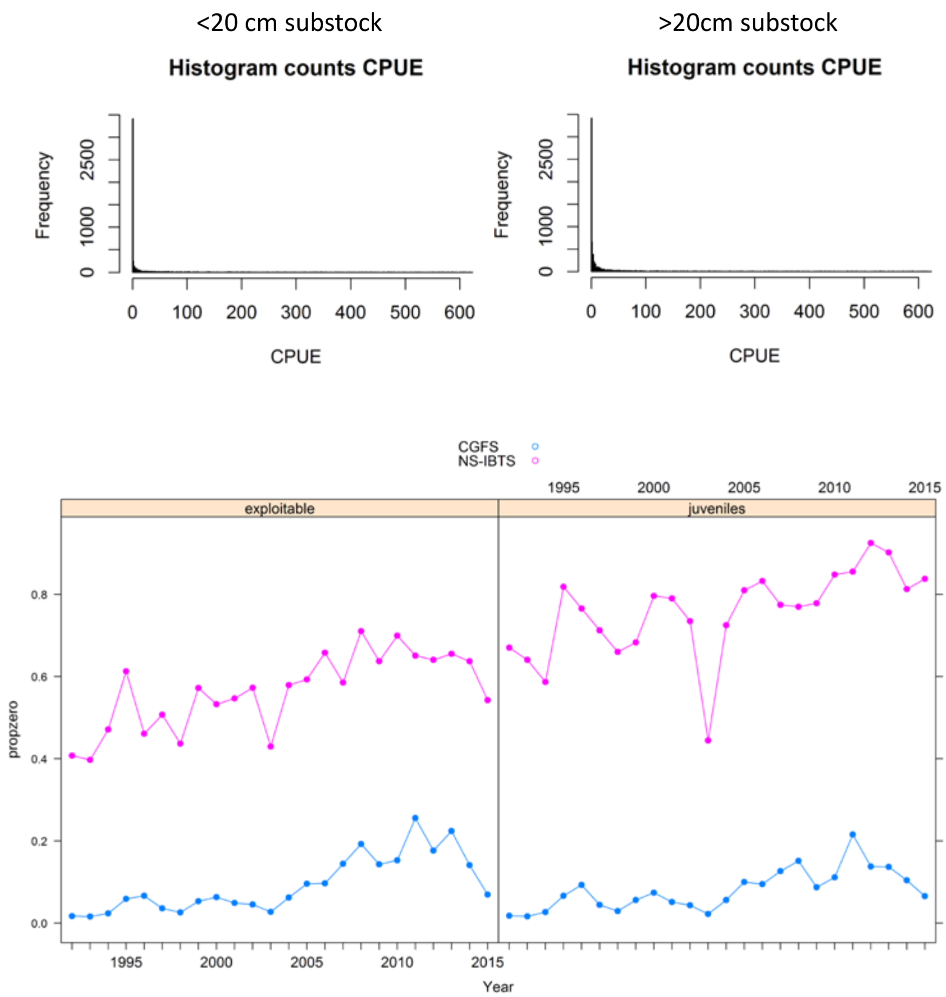



**Figure 6.2.3.- Frequency of the different CPUE values over the period 1992-2015 (upper panel). Proportion of hauls with zero CPUE in relation to the total number of hauls per year and survey (pink dotted line: IBTS; blue dotted line: CGFS).**

The analysis of the output of model fit showed that both model types (zero inflated and hurdle models), produced very similar results. However, the dispersion statistic was higher in the zero inflated models. This difference in the capacity to explain dispersion in the data is related with the way the zero values are interpreted (true/false versus all-true zeros). The fact that the hurdle models had a lower dispersion statistic (1.3 versus 3.4 in the best model) suggests that the observed zeros are likely real zeros. Due to the capacity of fitting better the zero values and accounting for overdispersion in the data, the hurdle models were finally selected to fit the relation of NSHM CPUE with *Year* and *Survey* factors.

The hurdle model with *Year* and *Survey* as explanatory factors (including the interaction) in the *count model* (GLM-negative binomial), and Year and Survey without the interaction in the *zero model* (GLM-binomial) was the model with the lowest Akaike Information Criteria AIC (table 6.2.2; Figure 6.2.4). Although not very pronounced, models including an interaction between Year and Survey in the zero sub-model always resulted in a higher AIC than the comparable model without this interaction. Removing the Survey term from the zero model leads to a much higher AIC value (figure 6.2.4). This is in agreement with the relatively parallel curves shown in figure 6.2.3 for the proportion of null hauls (no NSHM in the catch), *i.e.*, no interaction of year-survey, but a very different proportion between surveys (outstanding survey effect in the presence/absence proportion).

The log-likelihood ratio test indicated significant improvement in the fit of the hurdle model number 2 in comparison with all the other models (p-value<0.0001), with the exception of model number 1, for which this test indicated that an increase in complexity did not improve significantly the explained variance. This result is in line with the obtained AIC. In addition, the evidence ratios ER estimated as shown in Snipes & Taylor (2013) support the model 2 (with *Year* and *Survey* as explanatory factors including the interaction in the *count model* (GLM-negative binomial), and Year and Survey without the interaction in the *zero model* (GLM-binomial)) as the best model in an information criteria sense. The ER was higher than 7 when comparing this model with all the remaining models of simple structure, which as exposed by Anderson and Burnham (2002), is a level of difference in AIC enough to support the structure of this model as the most appropriate to predict the NSHM survey CPUE index.

**Table 6.2.2.- Akaike Information Criteria (AIC) obtained for each possible models result of combining the explanatory factors Year and Survey. The lowest AIC was obtained for the model 2, including Year and Survey in both submodels, the count and zero submodels, which are separated in this table by a vertical bar.**

| MODEL | <20CM SUBSTOCK | >20CM SUBSTOCK |
|---|---|---|
| 1.- Year x Survey ǀ Year x Survey | 40165 | 39389 |
| 2.- Year x Survey ǀ Year + Survey | 40144 | 39358 |
| 3.- Year x Survey ǀ Year | 41282 | 40129 |
| 4.- Year x Survey ǀ Survey | 40344 | 39676 |
| 5.- Year + Survey ǀ Year x Survey | 40197 | 39444 |
| 6.- Year + Survey ǀ Year + Survey | 40176 | 39413 |
| 7.- Year + Survey ǀ Year | 41315 | 40184 |
| 8.- Year + Survey ǀ Survey | 40376 | 39731 |
| 9.- Year ǀ Year x Survey | 40354 | 39556 |
| 10.- Year ǀ Year + Survey | 40333 | 39525 |
| 11.- Year ǀ Year | 41471 | 40295 |
| 12.- Year ǀ Survey | 40533 | 39843 |
| 13.- Survey ǀ Year x Survey | 40319 | 39537 |
| 14.- Survey ǀ Year + Survey | 40298 | 39506 |
| 15.- Survey ǀ Year | 41437 | 40277 |
| 16.- Survey ǀ Survey | 40498 | 39824 |

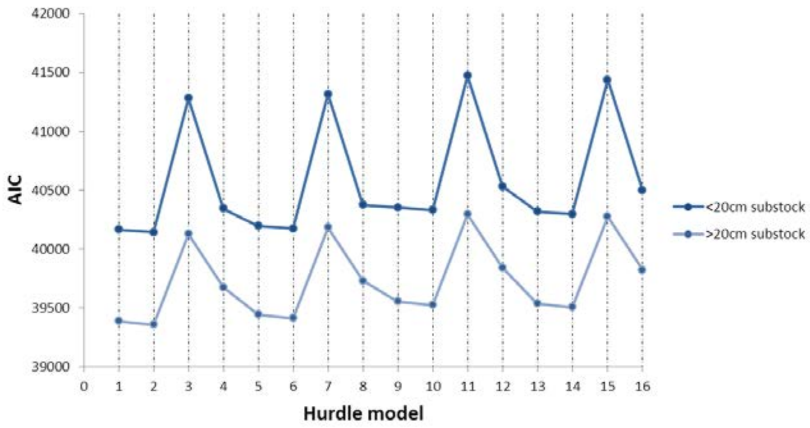



**Figure 6.2.4.- AIC for each of the fitted hurdle models. Numbers in the horizontal axis correspond to number coding each one of the models shown in table 6.2.2.**

Mean annual survey index

The mean annual survey index was estimated as the average value of the CPUE predictions per haul (CGFS and IBTS hauls) made by the model in each year.

However, the English channel (surveyed by the CGFS) represents only 14% of the total NSHM distribution area, while the north sea (surveyed by the IBTS) covers the 86%. In addition, the wingspread of the gear used in the CGFS from 1992 to 2014 was on average, 52.6% of that in the gear used in the IBTS. In order to account for these differences, a joint weighting factor was estimated, resulting in 0.24 for the CGFS and 0.76 for the IBTS. These weighting factors were applied to the predicted CPUE per haul for each of the surveys. Finally, an average value was estimated, resulting in the mean annual survey index.

Confidence interval

The confidence interval around the weighted mean predicted values was estimated by bootstrapping the residuals of the selected hurdle model, adding them to the original vector of CPUEs, re-fitting the model and producing new estimates of CPUE each time. The process was repeated 999 times. The 95% confidence interval was estimated with the range of values between 2.5 and 97.5 quantiles. The mean predicted values and the confidence interval for the selected model (weighted as explained in the previous section), both for the juvenile and exploitable sub-stocks are presented in figure 6.2.5.

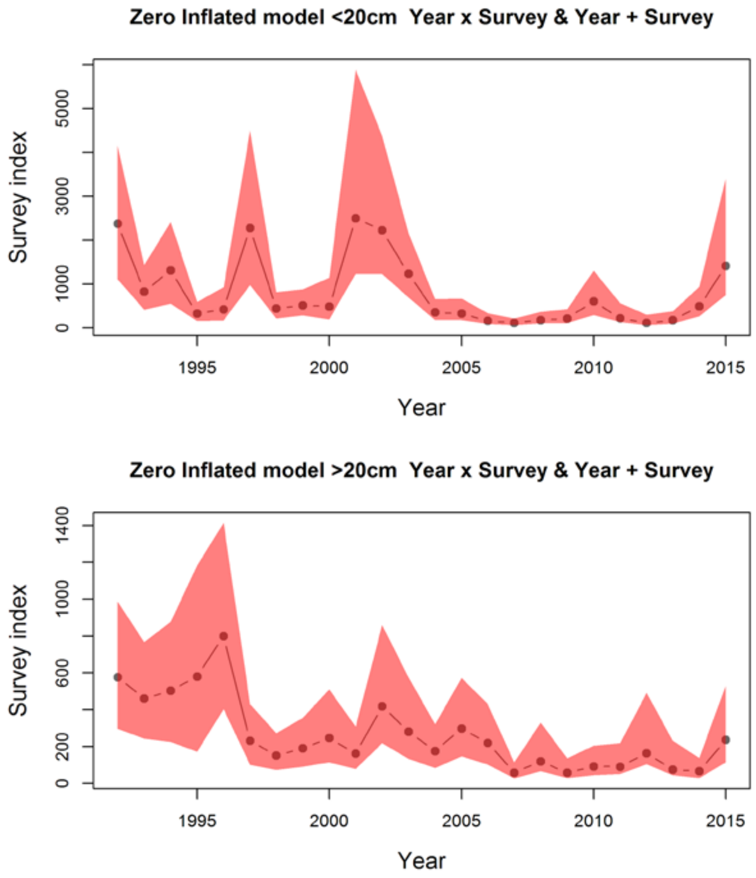



**Figure 6.2.5.- Predicted average CPUE value using the selected hurdle model CPUE ~ year * survey | year + survey for the juvenile (<20cm length; upper panel) and the exploitable (>20cm; lower panel) sub-stocks. The pink area represents the 95% confidence interval obtained from the range of predicted values from a bootstrap resampling and re-fitting process.**

Increase of survey index in 2015

In the last year of the time–series there is a marked increase in the average CPUE survey index. This increase is coincident with the change of vessel in the CGFS. At the time of the WKWIDE meeting the review of the calibration exercise conducted by IFREMER was still not concluded. Due to the large difference in catchability of horse mackerel between the *RV Gwen Drez* and the *RV Thalassa* (estimated conversion factor 10.363), there are concerns that the increase in 2015 has been produced by the difference in catchability rather than by a real increase in the NSHM stock abundance.

However, the exploration of the predicted average annual CPUE index separated per survey using the hurdle model 2 showed that the increase in the overall survey index in 2015 was not due to the increase in the estimated CGFS index, but the increment in the IBTS index (Figure 6.2.6). In addition, the study of the size distribution of catches both in the IBTS and CGFS surveys from years 2013-2015 indicates the existence of good recruitments in 2013-2014 in the English Channel (figure 6.2.7) and good recruitment in 2014 in the North Sea (figure 6.2.8). This above average successful cohorts can be tracked in the size distribution of both surveys in 2015.

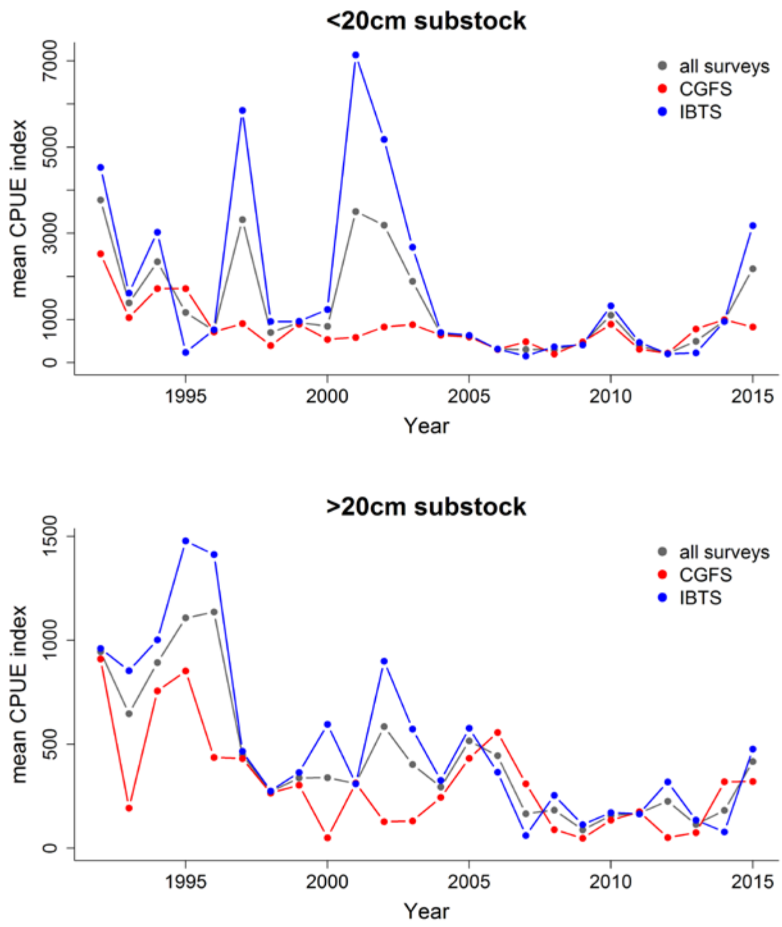



**Figure 6.2.6.- Predicted annual CPUE index using the selected hurdle model (model number 2 in table 6.2.2) for the CGFS and IBTS separately, as well as the combined index (same than presented in Figure 6.2.5).**

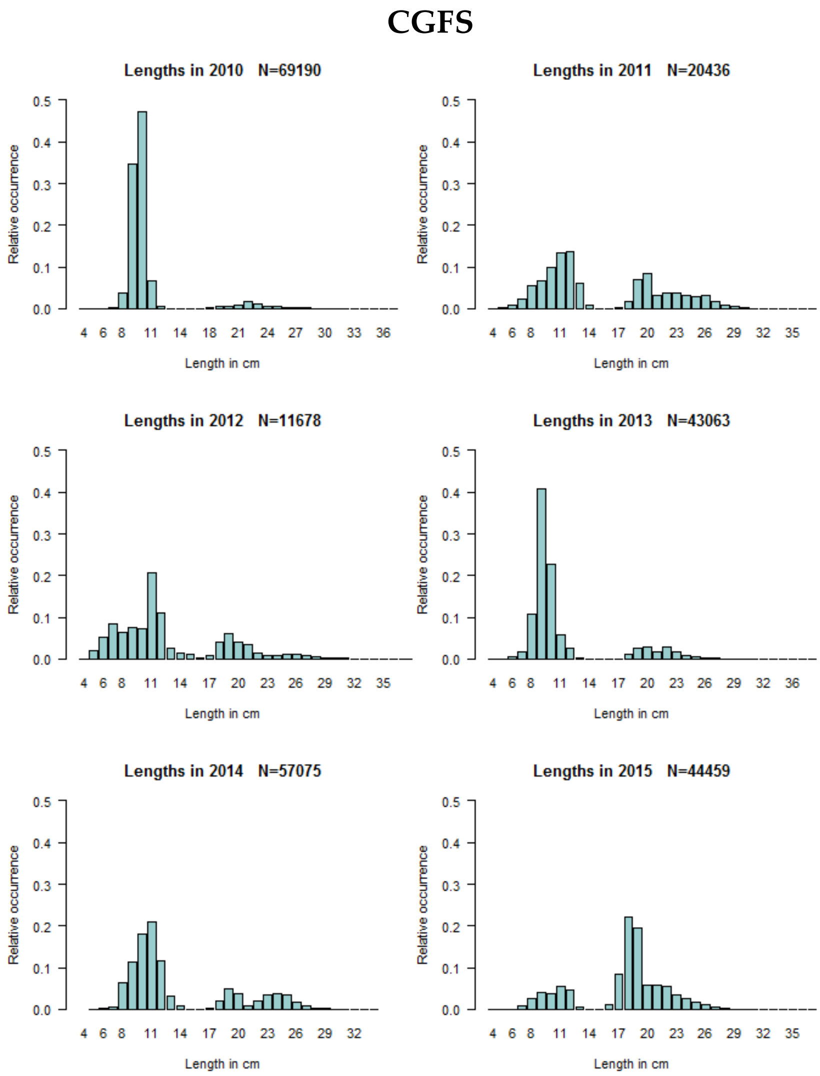



**Figure 6.2.7.- Size distribution of total catches (in numbers) each year during the CGFS in the English channel.**

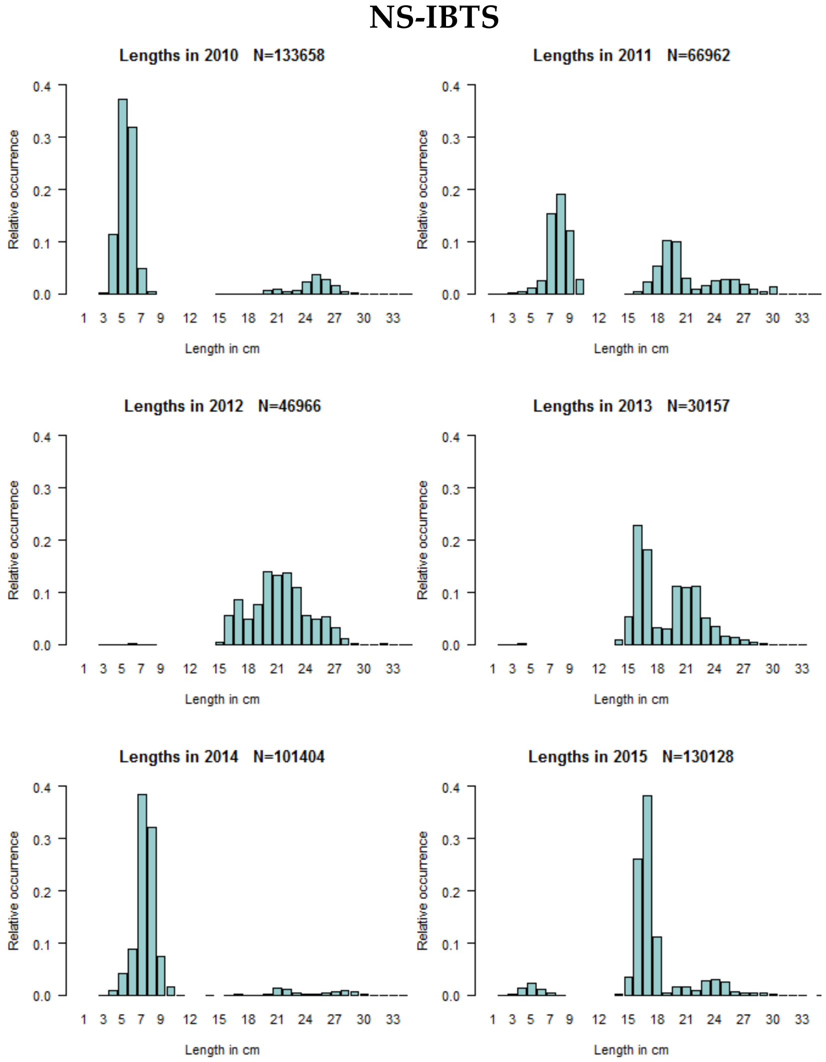



**Figure 6.2.8.- Size distribution of total catches (in numbers) each year during the IBTS in the North Sea.**

<u>Conclusions</u>

Based on capacity to model the overdispersion and the high proportion of zero values in the survey catch data the hurdle models are the best option of all the model alternatives tested.

The log-likelihood ratio test, the AIC and the evidence ratio supported the hurdle model with *Year* and *Survey* as explanatory factors (including an interaction between the two) in the *count model* (GLM-negative binomial), and Year and Survey without the interaction in the *zero model* (GLM-binomial) as a suitable model to synthesise the information from both the GCFS and IBTS and predict the average annual CPUE index per haul as an indicator of trends in stock abundance over the period 1992-2015, both for the juvenile (<20cm) and exploitable (>20cm) sub-stocks.

The exploration of the size distribution of catches in both the CGFS and the IBTS, as well as the predicted survey index for individual surveys lead to the conclusion that the increase in the index observed in 2015 is likely due to the increase in abundance as result of the apparently good recruitment events in 2013 and 2014.

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## Annex 2:WKWIDE Terms of Reference

2016/2/ACOM37 A **Benchmark of Widely Distributed Stocks** (WKWIDE), chaired by External Chair Jon Deroba*, US and ICES Chair Andrew Campbell*, Ireland, and attended by two invited external experts, Teresa Amar, US and Paul Fernandes, UK will be established and meet for a three-day data evaluation meeting at ICES HQ 15–18, November 2016 and at ICES Headquarters for a Benchmark meeting, 30 January – 3 February 2017 to:

a ) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short–term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:

  i ) Stock identity and migration issues;

  ii ) Life-history data;

  iii ) Fishery-dependent and fishery-independent data;

  iv ) Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook

b) Agree and document the preferred method for evaluating stock status and (where applicable) short–term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology

c ) If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

d ) Re-examine and update if appropriate necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

e ) Develop recommendations for future work to improve the assessment and data collection and processing;

f ) Produce working documents following the DEWK to be reviewed during the Benchmark meeting at least 7 days prior to the meeting

g ) Taking into account the current knowledge on stock identity, structure and migration, review the appropriateness of the ICES advice to continue with the existing measures (spatio-temporal closures and minimum landing size) to protect the North Sea spawning component;

h ) Stakeholders are invited to participate in the benchmark work and to contribute data (including data from non-traditional sources) and to contribute with relevant data and information. As part of the data compilation work consider the quality of data including discard and estimates of misreporting of landings. Stock identity issues of horse mackerel should be linked with the stocks being benchmarked in WKPELA, if possible addressed before the DEWK.

i )

| Stocks | Stock leader |
|---|---|
| Mackerel (*Scomber scombrus*) in Subareas 1-7 and 14 and Division 8a-e, 9a (Northeast Atlantic) | |
| Horse mackerel (*Trachurus trachurus*) in Subarea 8 and Divisions 2a, 4a, 5b, 6a, 7a–c, e–k (Northeast Atlantic) | |
| Horse mackerel (*Trachurus trachurus*) in Divisions 3a, 4b, c, and 7d (Skagerrak and Kattegat, Southern and Central North Sea, Eastern English Channel) | |

The Benchmark Workshop will report by 31 March 2017 for the attention of ACOM.

## Annex 3:DCWKWIDE Report

**Introduction**

The data coordination workshop in preparation for the benchmark assessments of NEA Mackerel, Western Horse Mackerel and North Sea Horse Mackerel met at ICES Headquarters, Copenhagen from 15-18th November 2016. The meeting was attended by 16 scientists.

Meeting documentation can be found on the WKWIDE Sharepoint website.

**NEA Mackerel** (IssueList, Stock Annex ,Latest Advice)

Stock coordinator: Afra Egan, Ireland (afra.egan@marine.ie)

Stock Assessor: Thomas Brunel, Netherlands (thomas.brunel@wur.nl)

Catch and Sampling Data, Maturity and Natural Mortality

Minor updates to catch data have been supplied to the stock coordinator. No revisions to discard estimates or information from recreational fisheries have been submitted. The impact of these revisions on the associated stock assessment inputs will be minor.

Length-frequency information for 2013-15 by quarter and ICES subarea was also requested and has been submitted by some countries. This data is not a requirement for the current assessment model and will be analysed when a more complete dataset has been received.

A working document was submitted on the calculation of the maturity ogive. It is proposed to take the geographic origin of the sample into account when calculating the overall maturity ogive as the distribution of samples may vary from year to year. It was proposed to give equal weight to samples from 5 different geographic regions. The group felt that this may give undue influence to samples from areas which are associated with low abundance. The following alternative weighting schemes were proposed

- Egg abundance in each of the areas
- Catch from each area

No decision was reached on this issue - further discussions will take place via email/WebEx.

WKPELA 2014 recommended that the assumption of a natural mortality of 0.15 for all years and all ages should be investigated. An updated tagging data series is now available and will be analysed. An alternative source of information is output from multispecies models. A presentation of output from the *Ecosim with Ecopath* and *Le Mans* models indicates a rise in natural/predation mortality in recent years although the absolute value is uncertain. Multispecies models rely on (often limited) predation studies to implement species interactions. Model output is not age/length disaggregated for mackerel (a constant mortality at all ages/lengths is likely to be unreasonable). Also, because these models are run for the North Sea region they make an assumption regarding the proportion of the mackerel stock present in the North Sea.

International Ecosystem Survey in the Nordic Seas (IESSNS)

Survey Design

The background to and history of the IESSNS survey was presented which detailed the changes in gear design and coverage since first survey in 2007. 8 surveys have been completed (2007, 2010-2016). Since 2012 the survey has operated in largely an identical manner.

Coverage

Over the survey time–series, coverage has varied due to several factors including the availability of vessels, weather and stock distribution. None of the surveys cover the southern boundary of the stock distribution and it is recognised that there is a portion of the stock in the Northern North Sea and to the West of Scotland that is not covered. The 2013 survey had extended coverage, south of 60°N to investigate the distribution in the Northern North Sea. This data was discussed at WKPELA in 2014 and compared with acoustically recorded data on the HERAS and IBTS surveys.

Coverage to the west and north is better, in particular for 2014-2016. With the exception of 2011 when coverage was much reduced, relatively small densities were recorded on the outer trawl stations from 2007 onwards.

At the previous benchmark, it was decided that data in the North Sea and west of the British Isles south of 62°N should be excluded from the index. It was suggested at this meeting that this be changed to exclude data south of 60°N in this area. Since 2010 the survey has generally extended as far south as 60°N. In 2007, the southern-most stations were at approximately 62°N.

Index Basis and Calculation

Alternative stratification schemes for the survey were proposed. However, they were not consistently presented and while the group was satisfied that the scheme proposed for the last 2 years was appropriate, it would be helpful if the complete survey time–series was worked up based on a consistent stratification scheme. A comparison with the original scheme (statistical rectangle level) was also sought.

The proposal to adopt the StoX software as the basis for survey estimates was considered appropriate.

There was a proposal to extend the number of age classes in the survey from the current 6-11 to include younger ages also. These ages make up to majority of the commercial catch and survey observations. Maps were presented showing the spatial distribution of ages 1-4 in years 2013-2016. The indication is that at from age 2 the ages are distributed throughout the survey area and it is likely that the index can be extended to include these ages. Additional years and ages should be provided and at a finer spatial scale *i.e.* at haul level, not aggregated to strata.

Another proposal for this survey is to use an index based on abundance rather than density. The density index was considered appropriate at the previous benchmark to account for the variable survey coverage. Given the improved coverage in recent years and the potential to exclude particular years from the survey index, it was felt that the use of abundances rather than densities is a possibility. Index time–series on both bases should be produced until a concrete decision is reached.

As an alternative or a complement to the index based on the entire survey area, the possibility of using a core area was discussed. An aged based index for a core area defined by the location of the centre of gravity will be calculated, for comparison with that based on the entire area.

The distribution (vertical and horizontal) of mackerel outside the IESSNS survey area was also discussed. Indications at the previous benchmark were that this biomass had been increasing in the most recent years. An update to this time–series will be requested. The assessment model estimates a catchability in recognition that the IESSNS does not cover the entire stock.

Information on the hydrography in this area will be compiled in order to ascertain the potential suitability of the region for an extension of these survey techniques.

Catchability of Mackerel in the IESSNS

Initial research on the possible effects of the environment (principally thermocline depth) on the catchability of mackerel on the IESSNS survey was presented. Analysis of the IESSNS age-specific residuals from the assessment indicates a relationship with thermocline depth (or the depth of the 7 degree isotherm) as determined from CTD data. Additional analysis is required and it is unlikely that this will be sufficiently complete for inclusion in the benchmark assessment.

IBTS Recruitment Index

Work on the recruitment index to be carried out prior to the benchmark exercise includes

- The addition of some trawl stations in the North Sea previously missing from the calculation
- An investigation into the effect of varying measurement techniques for mackerel length. A table will initially be circulated to countries supplying data to determine which measurement is taken. Should a length conversion be necessary, this can be achieved using data collected on recent IBTS surveys.

Egg Survey

An update to the preliminary 2016 egg survey TAEP and SSB estimate was presented.

This update incorporates revised estimates from those presented at WGWIDE (and used in the 2016 assessment) due to correction of an error in the Faroese survey data. The correction affects 86 stations in total and results in a reduction in the estimate of the number of stage 1 eggs/m$^2$/day in periods 5 and 6. The overall effect is an 8% reduction in the combined TAEP estimate (and a 38% decrease on the 2013 value) and a 9% decrease in the SSB estimate (a 33% decrease on the 2013 estimate). The 2016 estimate remains preliminary until April 2017 when WGMEGS will complete the analysis.

Distribution maps of the affected periods showing first the erroneous, and then the corrected stage 1 egg counts were presented for comparison. Although the zero line was not reached in either period, the majority of non-zero counts on the northern boundary were reduced to single figures. It is accepted, however that several stations with higher counts remain on the boundaries elsewhere, notably on the western boundary around Hatton Bank and also along the shelf edge on the northeast corner.

The distribution of survey rectangles from which 90% of the total spawning was recorded show the large change in spawning distribution over the period 2001-2016. The rectangles accounting for 50% of the total spawning were also presented and show the change in the location of the core spawning area.

There was discussion about the challenges faced during the MEGS survey in 2016 and specifically its reduced geographical coverage when compared to that in 2010 and 2013. Several issues were highlighted as being contributory factors and these are reported within the submitted working document that accompanies the presentation made to DCWKWIDE.

There was a discussion on additional survey work that could be undertaken before the next scheduled egg survey in 2019 to investigate the northerly extent of the distribution although at present it is unclear how these surveys can be realised. In addition, several alternative sources were discussed that could also potentially provide additional information within this northern boundary region in the years prior to the 2019 MEGS survey.

An R script which is being developed as part of the process to migrate from the original FORTRAN code base is being finalised. A complete time–series will be delivered for use by the benchmark by the end of the year.

A working document providing a fuller account of the issues discussed in the presentation is located on the DCWKWIDE sharepoint.

RFID Tagging Programme

An update on the RFID mackerel tagging programme was presented. RFID tags have been released annually since 2011. Since the previous benchmark when this data was first considered for inclusion in the assessment, additional years of data are available and there has been a considerable increase in the proportion of the total catch screened, due mainly to the installation of additional screening equipment in Scottish, Icelandic and Faroese factories.

The only physical measurement taken of a tagged fish during tagging and recapture is a length measurement during tagging. In the interests of keeping handling and possible damage to a minimum, the fish is measured with a splayed tail and the observer estimates the total fish length which is input to an age length key to estimate the age of the specimen. There are indications that this technique for measuring length may introduce a bias into subsequent estimates of age. This will be further analysed prior to the benchmark.

A comparison of stock numbers at age estimated from releases in 2011, 2012, 2013 and 2014 shows a currently unexplained and unrealistically large reduction between the estimates based on 2012 and those from 2013. The following are possible reasons which will be investigated

- A change to the tag and/or release methodology/personnel
- A change in the spatial profile of the screened catches with later years screening more catch from Icelandic waters and west of the British Isles. Should the mixing of tagged fish depend upon migration routes then this may result in a different recapture rate, not necessarily related to stock abundance.
- An issue with a particular screening facility.

In addition, a complete set of biological sample data is lacking for some screening locations. This data is particularly important as it is necessary to have accurate information regarding the number of fish screen by year class. Efforts are being made to ensure this data is made available.

**Western Horse Mackerel** (Issue List, Stock Annex, Latest Advice)

Stock coordinator: Gersom Costas, Ireland (gersom.costas@vi.ieo.es)

Stock Assessor: Piera Carpi, England (piera.carpi@cefas.co.uk)

Catch and Discard Sampling

The catch and sampling dataset was presented. The available data starts in 1982 although electronic archives are only available from 2000 to the present. As a part of this exercise, data from 2000 onward has been uploaded to InterCatch. The majority of national data submitters have responded to the data call although several were still checking data at the time of the meeting. Others confirmed that no revisions are required or supplied minor corrections. No response was received from the French data submitter who was subsequently contacted and has indicated that data will be supplied during December.

The updated distribution of catch and sampling levels by division, quarter and country was presented.

Juvenile Index

A proposal to develop a juvenile index based on IBTS catch rates was presented. The available data was described and several alternative modelling approaches were developed. It was found this it is necessary to explicitly account for the high proportion of zero tows, overdispersion in the data and spatial and temporal correlations within the model framework.

Application of a spatial model (log Gaussian cox process model) is promising with good agreement between modelled catch rates of juvenile horse mackerel and the relative size of year classes as predicted by the current, age based assessment. Additional work was identified in terms of the procedure for the calculation of an appropriate index from the posterior model predictions.

Industry Data

As a part of ongoing catch sampling, Dutch freezer vessels routinely self-sample their catch recording characteristics such as length, weight, fat, row, stomach contents. Photographic records are also kept and skippers log books record details of individual hauls that are not included in routine logbook records.

This data was summarised and presented and is part of an ongoing project to enhance knowledge of  the stock structure of horse mackerel (Western and North Sea) through genetic, chemical and vessel analysis. The data is also being analysed in terms of providing an indicator of stock abundance. A method for the identification of a horse mackerel fishing trip has been identified and a dataset of catch rates has been compiled. Modelling work will continue to investigate the potential of this data as a stock indicator.

Assessment Development

The current SAD assessment model for Western Horse Mackerel suffers from a lack of fishery independent data (an egg survey data point every 3 years which has resulted in large retrospective adjustments), only incorporates a single fleet, makes the assumption of constant selectivity in the most recent years and would require significant development if additional data sources were to be considered. For this reason, it is proposed to consider an alternative - the Stock Synthesis model. A presentation was made outlining the initial approach which currently includes the following data as input

- Catch at age data
- Acoustic estimates of the (largely juvenile) population in the Bay of Biscay
- Length composition data
- Age at length
- Mean length at age

Additional data sources that may be incorporated include additional acoustic survey data, effective sample size, extension of the plus group beyond 11+, multiple fleets, the egg survey time–series, and index of recruitment from the IBTS. At present, the data is split into two separate fleets, one from the Northern fishery where adult horse mackerel make up the majority of the catch and a second Southern fleet, targeting mainly juveniles (Spanish data). The number and makeup of each of the fleets will be reviewed as the development work continues.

**North Sea Horse Mackerel** (Issue List, Latest Advice)

Stock coordinator: Gersom Costas, Ireland (gersom.costas@vi.ieo.es)

Stock Assessor: Alfonso Pérez Rodríguez, Netherlands (alfonso.perezrodriguez@wur.nl)

Catch and Discard Sampling

The catch and sampling data was presented. The available data starts in 1982 although electronic archives are only available from 2001 to the present. As a part of this exercise, data from 2001 onward has been uploaded to InterCatch. The majority of national data submitters have responded to the data call. Several were still checking data at the time of the meeting. Others confirmed that no revisions are required or supplied minor corrections. No response was received from the French data submitter who was subsequently contacted and has indicated that data will be supplied during December. This is particularly important as France previously supplied estimates of discards for 2015. Estimates from earlier years covered by the French discard sampling programme are believed to exist and should be incorporated into the dataset.

The updated distribution of catch and sampling levels by division, quarter and country was presented.

Assessment

The work proposed by the stock assessor (who was unable to attend the data compilation meeting) was presented. The proposed work plan includes

- Investigation of alternative modelling approaches (GLM, Delta-LogNormal) for the 2 surveys currently used as indicators for this stock (The Q3 IBTS survey in the North Sea and the Q4 French Channel survey)
- Investigation industry data as an indicator of stock status or recruitment
- Develop alternative DLS methods based on catch information as explored at WKLIFE

**Meeting Participants**

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