INTERBENCHMARK PROTOCOL ON REFERENCE POINTS FOR WESTERN HORSE MACKEREL (*Trachurus trachurus*) IN SUBAREA 8 AND DIVISIONS 2.A, 4.A, 5.B, 6.A, 7.A-C,E-K (THE NORTHEAST ATLANTIC (IBPWHM)

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Contents

i Executive summary

The focus of this process was to review and update, if appropriate the stock MSY and PA reference points. In addition, alternative assessment models were considered, with emphasis on reducing the retrospective bias characteristic of the current assessment.

The current reference points for Western Horse Mackerel were determined during the 2017 assessment benchmark exercise during which an implementation of the SS3 assessment model was adopted. Based upon the output of the new assessment, stochastic simulations were conducted to derive MSY reference points. The precautionary biomass limit reference point was set to the lowest observed biomass, given no clear indication of impaired recruitment at any observed biomass above this.

Subsequent update assessments in 2017 and 2018 led to revision in the absolute value and timing of the assessment B_{loss}. Deriving annual catch advice from the most recent assessment output and reference points determined at the benchmark gave rise to annual changes in catch advice at odds with the most recent information on stock development. It is therefore considered that the reference points as estimated in 2017 are no longer suitable and require revision.

An extensive range of stochastic simulations using the ICES EqSim software were conducted to explore a number of scenarios with regard to the stock-recruit relationship, the basis for precautionary biomass limits, the time period for the underlying source data and the associated assessment model run. The consideration of each of the three SS3 model runs (the benchmark run and subsequent update assessments) allows the robustness of the reference point values potential future assessment retrospective bias to be determined.

As with previous exercises exploring the parameterisation of the stock and recruit relationship for the purposes of simulation, no clear functional relationship is evident. A mixed model approach is also inappropriate as the proportions of individual models are variable when individual assessments, time periods and the influence of individual data points are explored. The IBP concluded that the most appropriate formulation is a segmented regression. However, exploration of fits of this model to the underlying stock and recruit datasets indicated that the breakpoint is poorly defined and is particularly sensitive to individual data points. It was considered that a segmented regression, with a breakpoint constrained at the associated B_{lim} value is most appropriate for the parameterisation of recruitment in a long term simulation of this stock. This conclusion is in agreement with that from the previous benchmark study.

The stock assessment is based on data available from 1982. The recruitment estimate from the first year is over 20 times the mean of the time series and is 3 times the size of the next largest (in 2001). Western horse mackerel is relatively long lived and the 1982 year-class dominated both the stock and fishery for more than a decade. There is no indication of a likely driver for this extraordinary year class (including stock size) and no comparable year class has emerged since. The analyses considered 3 different time periods; all years, excluding 1982 and from 1995 on with 1995 selected as a cut-off as it corresponds to the year when the contribution of the 1982 year-class to the spawning stock biomass falls below that of the maximum contribution from the next largest year class (2001). During the period when the 1982 year-class was prevalent, SSB rose significantly before returning to levels similar to that in 1982. The IBP selected the time period from 1995 on as a basis for the final reference point estimates as it is considered to be a more appropriate basis for modelling of future recruitment.

Several alternative bases for a B_{lim} value were considered, corresponding to a number of the stock types as detailed in the ICES guidelines. B_{lim} values corresponding to B_{loss} and SSB in each of 2001 (the lowest biomass leading to a high recruitment) and 2003 (the lowest biomass from the stable

part of the assessment output) were considered. These points were also considered as proxies for B_{pa}, with the corresponding $B_{lim} = B_{pa}/1.4$. The IBP determined that the B_{loss} is an inappropriate basis for B_{lim}, due to the retrospective revision issue. SSB 2001 is also not considered as it is related to a particular recruitment event and there is weak support for a relationship between stock and recruitment. SSB in 2003 is adopted as a proxy for B_{pa} on the basis that fishing mortality has been relatively low for the data period (mean ~0.11, natural mortality = 0.15), and there is no indication of reduced recruitment below the associated B_{lim}, despite a continuing decline in SSB.

Sensitivity analyses indicated the results are insensitive to plausible alternatives to the EqSim default settings with regard to recruitment autocorrelation, trimming of extreme high recruitment values and the data period for the biological and fishery selection vectors. The assessment error/advice parameters calculated on the basis of the most recent assessment and historical assessment and forecasts are similar to the default EqSim values with both leading to similar estimates of FMSY.

The updated reference point values are given below:

Framework	Reference Point	Value	Basis
MSY Approach	$MSYB_{trigger}$	1,168,272 t	Stochastic Simulation
	F_{MSY}	0.074	Stochastic Simulation
Precautionary Approach	B_{lim}	834,480 t	$B_{pa}/1.4$
	B_{pa}	1,168,272 t	SSB_{2003}
	F_{lim}	0.103	Stochastic Simulation
	F_{pa}	0.074	$F_{lim}/1.4$

Under ToRc, an exploratory SAM assessment was configured based on a subset of the input data used by the current Stock Synthesis assessment model (excluding length frequency information from the commercial catch and the acoustic survey). Updates to the default SAM configuration were implemented to reduced large retrospectives in both F and SSB and large uncertainty in the estimates. A fixed selectivity pattern was adopted as with free selection at age, the model tended to over-fit to the only age-specific input data – the catch at age, leading to the large retrospectives. The final exploratory model fit shoes similar trends in F and SSB to the stock synthesis results albeit at different levels.

ii Expert group information

Expert group name	Inter-benchmark Protocol on Reference Points for Western Horse Mackerel (*Trachurus trachurus*) in Subarea 8 and Divisions 2.a, 4.a, 5.b, 6.a, 7.a-c,e-k (the northeast Atlantic) (IBPWHM)
Expert group cycle	Annual
Year cycle started	2019
Reporting year in cycle	1/1
Chair(s)	Andrew Campbell, Ireland
Meeting venue(s) and dates	27 June 2019, by correspondence, 9 participants
	8 August 2019, by correspondence, 9 participants

1 Introduction

ACOM recommended that the Western Horse Mackerel stock should undergo an interbenchmark assessment, in order to

a) Review the basis of reference points and investigate the possibility of relative reference points;
b) Update, if appropriate, MSY and PA reference points;
c) Explore alternative assessment models for comparison with the current model, with particular emphasis on reducing retrospective bias.

2 The 2017 Benchmark, 2017 and 2018 Update Assessments

The stock assessment of Western Horse Mackerel was benchmarked at WKWIDE in early 2017 (ICES, 2017a). A new assessment model based on an implementation of the integrated Stock Synthesis model (SS3) was adopted, replacing the incumbent SAD (Separable ADAPT) model which had been developed specifically for this stock.

SS3 was considered a more appropriate model for this stock because it offers increased flexibility over the SAD model in terms of incorporating fishery independent data. At the benchmark, it was configured to fit to additional indices in the form of a recruitment index derived from groundfish surveys and estimates of biomass and length composition data from an acoustic survey. Prior to this, the fishery independent dataset comprised a 3-yearly estimate of egg production from the International Mackerel and Horse Mackerel Egg Survey (MEGS), leading to substantial revisions in the perception of the stock whenever a new egg survey estimate became available. Assumptions regarding selectivity were also limiting for a stock characterised by sporadic large year classes.

The SS3 implementation resulted in an updated perception of the stock development, particularly in the most recent period. The SS3 terminal year SSB considered to be the lowest in the time series. Biomass estimates in previous years were revised upwards such that the stock is considered to have been in decline for several years and at a historic low.

Utilising the *EqSim* software, part of the ICES MSY R package (https://github.com/ices-tools-prod/msy) and informed by ICES technical guidance (ICES, 2017b), the following updated values for both precautionary and MSY reference points were adopted by the benchmark:

Table 1: Western Horse Mackerel reference points, estimated at WKWIDE 2017 (ICES, 2017a).

Framework	Reference Point	Value	Basis
MSY Approach	$MSYB_{trigger}$	911,587 t	Stochastic Simulation
	F_{MSY}	0.108	Stochastic Simulation
Precautionary Approach	B_{lim}	661,917 t	B_{loss} (2015)
	B_{pa}	911,587 t	B_{lim} x exp(1.645 x σ)
	F_{lim}	0.151	Stochastic Simulation
	F_{pa}	0.108	F_{lim}/1.4

There is no evidence of a significant reduction in recruitment at the lowest observed SSBs and so the B_{loss} value was considered an appropriate proxy for B_{lim}. B_{loss} was estimated to have occurred in 2015, the terminal assessment year. B_{pa} was calculated directly from B_{lim}, incorporating the uncertainty in the assessment estimate of SSB.

The F_{lim} value was derived from B_{lim} using the *EqSim* package to perform a stochastic simulation to determine the fishing mortality that would lead to a stock with a 0.5 probability of being above (or below) B_{lim}. A factor of 1.4 was applied to F_{lim} to determine F_{pa} since it was not possible to obtain an estimate of the uncertainty in fishing mortality from the assessment.

A number of potential scenarios related to parameterisation of the stock-recruit relationship and choice of B_{lim} (and consequently B_{pa} and F_{P05}) were investigated by the benchmark. The western horse mackerel stock and fishery is characterised by spasmodic high recruitments, in particular that in 1982 making a determination of stock productivity for the purposes of long term simulation particularly challenging. In the absence of a clear functional relationship between stock levels and recruitments, the benchmark concluded on a segmented regression model, fit to assessment output with the exception of the most recent (poorly estimated) and the large 1982 recruitment data point. The *EqSim* simulations parameterised with this stock-recruit relationship resulted in an estimated F_{MSY} value of 0.108 and an MSYBtrigger value equivalent to B_{pa} (in line with ICES guidelines when a stock has not been fished at F_{MSY} in the most recent 5 year period)

The first catch advice provided for Western Horse Mackerel based on the updated SS3 assessment was for 2018 and was published in late 2017, following an update assessment conducted at WGWIDE in 2017 (ICES, 2017c). This update applied the assessment method as parameterised by the benchmark settings but incorporating an additional year (2016) of commercial catch and fishery independent data. Unfortunately, the assessment again exhibited a degree of retrospective bias with a sensitivity analysis indicating highly influential 2016 commercial catch length-frequency information. A further, smaller revision occurred in 2018 when the 2017 catch and sampling information was included. SSB and fishing mortality estimates from each of these assessments are shown below:

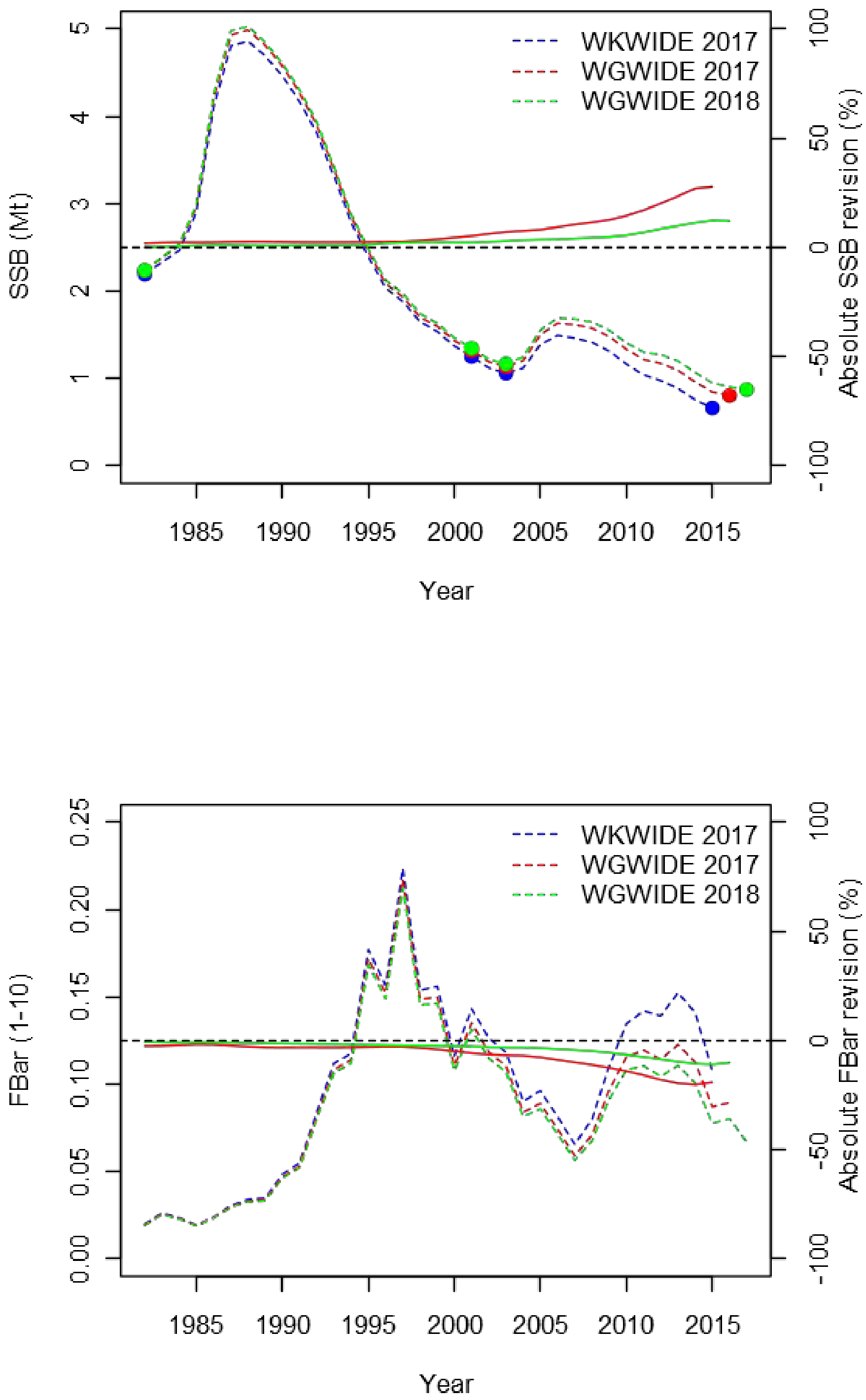


Figure 1 – SSB (upper) and Fbar (lower) estimates from the 2017 benchmark assessment (WKWIDE 2017) and subsequent working group annual update assessments in 2017 (WGWIDE 2017) and 2018 (WGWIDE 2018). Solid lines indicate the absolute percentage revision from the previous assessment

The ICES MSY catch advice based on the WKWIDE 2017 reference points and update assessments is summarised below.

Table 2: WHM MSY advice for 2018, 2019

Assessment (y)	Catch Advice (y+1)	F_{MSY}	MSY $B_{trigger}$	SSB_{Jan1} (y +1) (from STF)	Advised F
WGWIDE 2017	117,070 t (+69%)	0.108	911,587 t	818,082 t	0.097 (0.108 * 818082/911587)
WGWIDE 2018	145 237 t (+24%)	0.108	911,587 t	941,821 t	0.108 (SSB_{Jan1} > MSY $B_{trigger}$)

In applying the ICES MSY advice rule, the upward revision of SSB in the 2017 and 2018 assessment estimates resulted in a significant annual increase in catch advice. However, each of the assessments conducted in 2017 and 2018 indicated that SSB in the terminal assessment year is the historic low.

The F_{MSY} and MSY $B_{trigger}$ values estimated during the benchmark were based on the assumption that the lowest observed biomass (B_{loss}) was an appropriate proxy for B_{lim}. Both the MSY reference points are influenced by the choice of B_{lim} as B_{pa} is considered a proxy for MSY $B_{trigger}$ and F_{MSY} is ultimately restricted by precautionary considerations (F_{P05}). Since the B_{loss} estimate from the benchmark assessment corresponds to the terminal assessment year (2015), estimates have been substantially revised by the subsequent assessments, such that the reference points can no longer be considered appropriate for the provision of catch advice.

3 PA, MSY Reference Point Estimation (ToR a,b)

3.1 General Approach

As described above, when used in conjunction with an assessment that displays a significant degree of retrospective bias with respect to estimates of SSB, the reference points estimated during the benchmark exercise in 2017 lead to changes in catch advice at odds with the perceived stock trends and information from stakeholders and as such, they are considered unsuitable for the provision of catch advice and determination of stock status.

The primary aim of this interbenchmark exercise is therefore to estimate updated precautionary and MSY reference points, with consideration of both absolute and relative values.

Following on from a number of workshops during the early 2000s ICES published guidance for the estimation of precautionary reference points in the report of the Study Group on Precautionary Reference Points for Advice on Fishery Management (ICES, 2003). Reference points in support of MSY based management were developed during the WKMSYREF series of workshops between 2014 and 2016 (ICES, 2014a, 2015, 2016). In 2017 (ICES, 2017a), ICES published technical guidelines (ICES, 2017b) encapsulating the results of the PA and MSY workshops and suggesting approaches for the calculation of reference points for category 1 and 2 stocks. Where practicable, this exercise has adopted the approach recommended in the guidelines.

The determination of reference points has proved problematic in the past with several alternative approaches considered and refined as the stock assessment methodology has developed. The assessment output suggests that this stock does not correspond to any one of the stock-type characterisations detailed in the guidelines. Consequently, several alternative scenarios are considered with the final values selected on the basis of

- Likely robustness to assessment retrospective bias
- Compatibility with information on current stock status and historical stock development (plausibility)
- Likely impact on near-future catch advice

In line with the suggested approach and the 2017 benchmark, this exercise considers the following

- The identification of appropriate datasets (year ranges) upon which to base the analysis
- Identification of stock type(s) on the basis of the stock-recruit relationship and historical stock development
- Estimation of limit reference points and subsequent calculation of the precautionary limits
- Long term (*EqSim)* stochastic simulations to determine MSY reference points including stochasticity in recruitment, biology, fishery selection and assessment and advice error

3.2 Biomass limit & precautionary reference points B_{lim}/B_{pa}

The B_{lim} reference point is the single-most important point as the remaining precautionary reference points are estimated from this. Conceptually, it is a biomass limit below which a stock is considered to have reduced reproductive capacity. The source of data for its determination is therefore the time series of SSB and recruitment estimates from the most recent assessment. ICES guidelines suggest that the full time-series should be considered unless there is strong evidence to suggest otherwise and that poorly estimated values should be excluded.

3.3 Stock-Recruit Investigations

The WHM stock-recruit time series is dominated by the extraordinarily large year class of 1982. 1982 is the first year of data available to the assessment and remains by a significant margin, the largest recruitment event observed (~52 billions), over 20 times the geometric mean (~2.5 billions). The 2001 recruitment (~17 billions) has also traditionally been considered to be a recruitment spike although it is approximately 1/3 of the 1982 value.

The most recent assessment of Western Horse Mackerel was conducted during 2018 (ICES, 2018). A summary of the stock development is shown in figure 2.

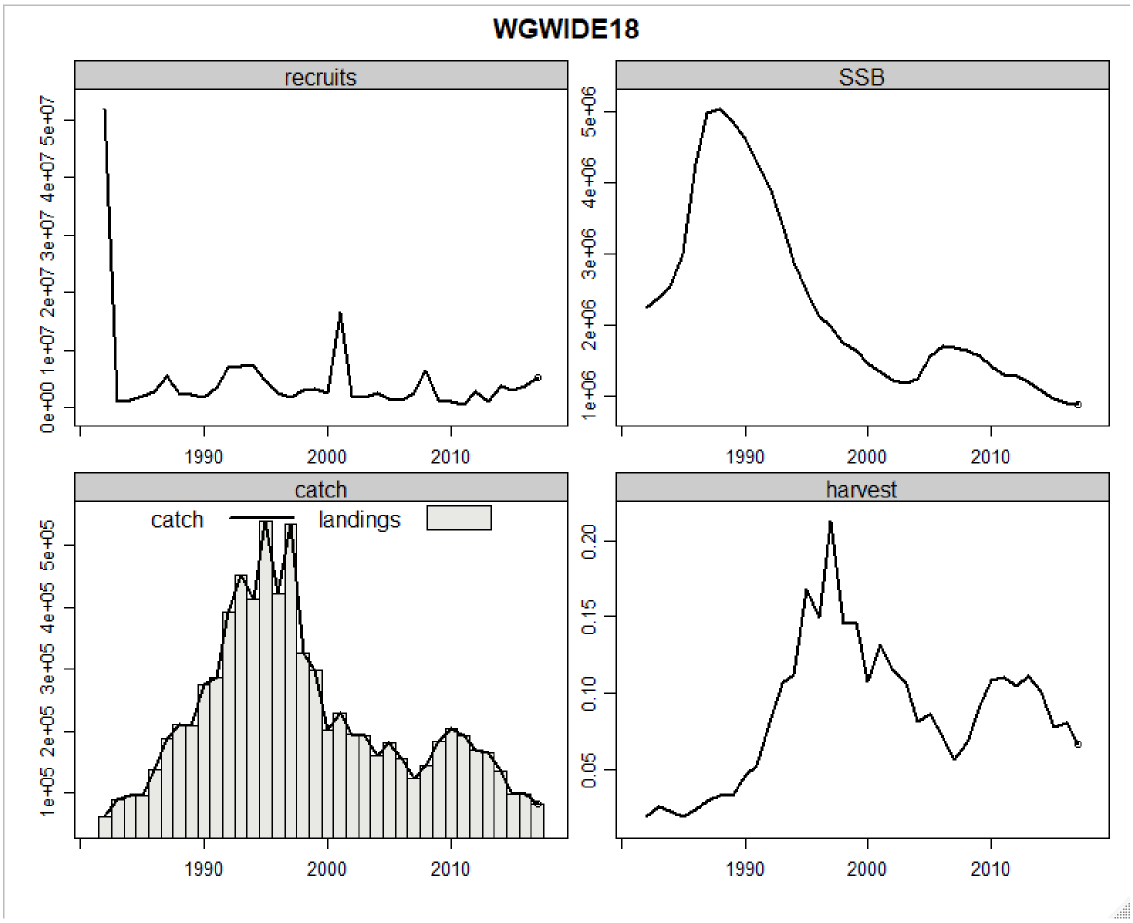
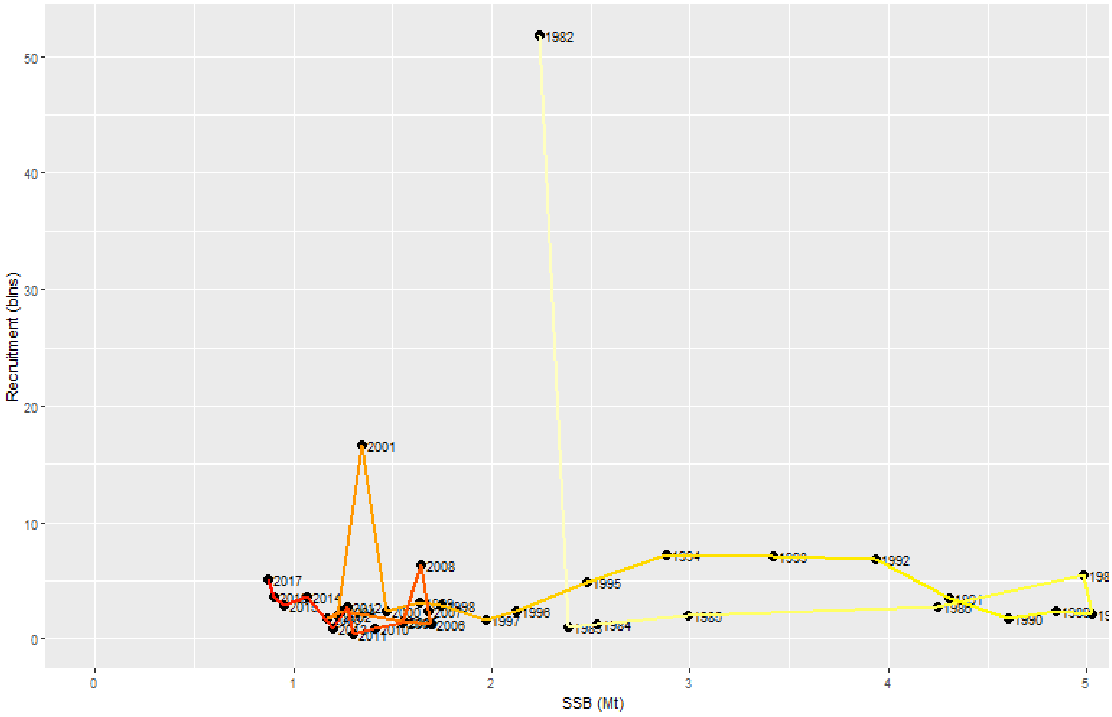


Figure 2: WGWIDE 2018 Western Horse Mackerel assessment summary.

Stock recruit pairs from the 2018 assessment are shown in figure 3 for (a) all data points, (b) excluding 1982.

(a) all years



(b) excluding 1982

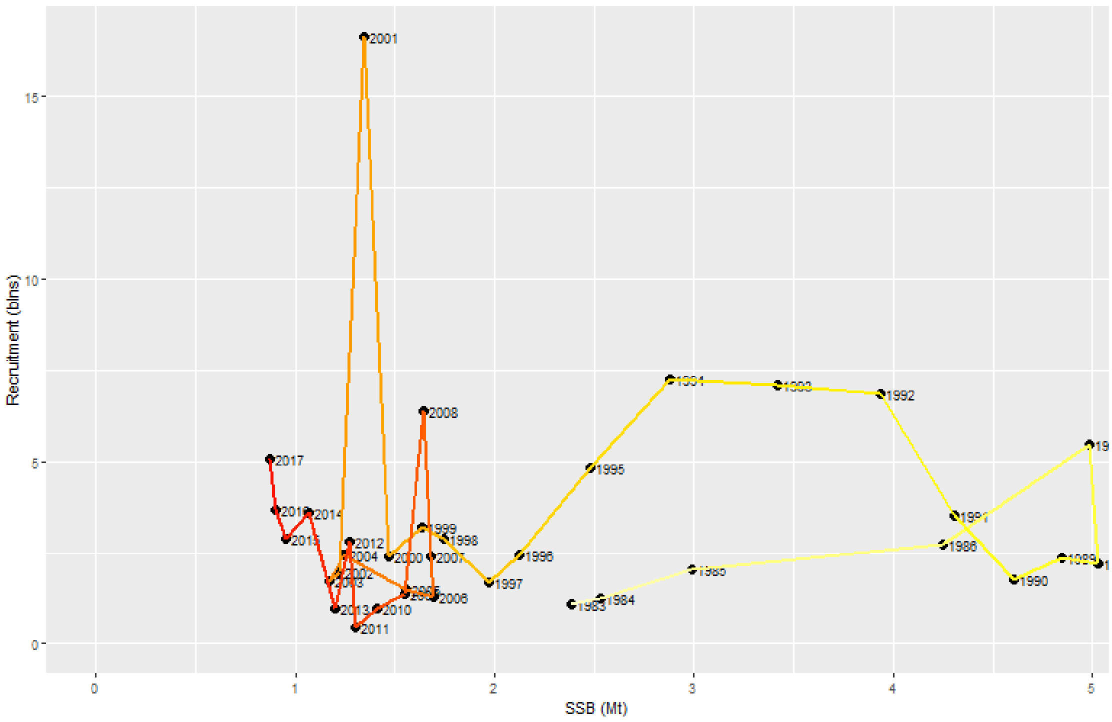


Figure 3: SSB-Recruit pairs from WGWIDE 2018 Western Horse Mackerel update assessment.

An extensive study of the S-R relationship was undertaken in 2014 during the evaluation of a management strategy (ICES, 2014b) and for the estimation of F_{MSY} ranges (ICES, 2015). During this exercise, the *plotMSY* software (ICES, 2013) was used to fit three stock-recruit curves to stock-recruit pairs (excluding the 1982 and 2001 recruitment spikes). The software allocated weights of 46% for Beverton-Holt, 32% to Ricker and 22% to Segmented Regression 22%.

With recruitment parameterised using this mixed-model approach, the MSE simulations indicated a low tolerance to fishing and an estimate of F_{MSY} yielded a very low value (~0.05). Only in the presence of spikes in recruitment (simulated separately on the basis of 1 spike in recruitment every 19 years and with equal probability of a recruitment of the order of the 1982 or 2001 estimate) could moderate levels of fishing pressure be sustained. Further investigations indicated the high uncertainty associated with the estimation of the stock-recruit parameters resulted in a significant number of implausible stock-recruit functional shapes with low F_{crash} values, leading to high risk and prolonged recovery times for some model iterations.

During subsequent investigations, the stock-recruit model was simplified to a constrained hockey stick model, in recognition of no clear biological evidence base for either of the alternatives (Ricker and Beverton-Holt) and the high parameter uncertainty for these models. Given no evidence of reduced recruitment below any observed biomass, it was considered appropriate to use the lowest observed biomass as a constrained breakpoint below which recruitment reduces linearly to zero at zero stock size and geometric mean recruitment used as an estimate when above this biomass.

During the 2017 benchmark (ICES, 2017a), it was again concluded that, given the lack of a clear functional form for the stock-recruitment relationship, for the purposes of simulation, the segmented regression model with a breakpoint at B_{lim} was adopted. The following decisions were made

- The 1982 SSB/Recruitment data point should be excluded from the analysis. 1982 was an exceptionally large year class. No comparable data has been observed since and the magnitude of the strongest year classes since is much reduced. The contribution to the SRR fit of this single data point is significant and should be ignored.
- There is no stock-recruit relationship. SRR is thus characterised by a segmented regression with a breakpoint set at B_{lim} (or B_{loss}, whichever is higher *i.e.* the breakpoint should not be lower than the minimum observed SSB).

With the exception of the most recent years, the time series of recruitment estimates are little changed between recent assessments. The most recent data indicates increased recruitment (albeit uncertainty is still relatively high) since 2013, even though biomass is at a historic low. Although the retrospective revision of SSB and fishing mortality evident in the assessment would suggest that the stock-recruit relationship may be altered between assessments there is little clear evidence of a strong relationship between SSB and recruitment in the most recent assessment.

As with the *plotMSY* software, *EqSim* provides a function to fit a number of stock-recruit models. This is achieved by bootstrapping the SSB-recruitment pairs, fitting each of the Ricker, Beverton-Holt and segmented regression models and assigning an overall proportion to each based on model averaging. The results can then be used to approximate recruitment in a long term simulation for the determination of reference points

A fit of all 3 models to each of the benchmark, and 2017 and 2018 update assessments (ignoring the highly uncertain terminal year SSB/R data pair) is shown below in figure 4.

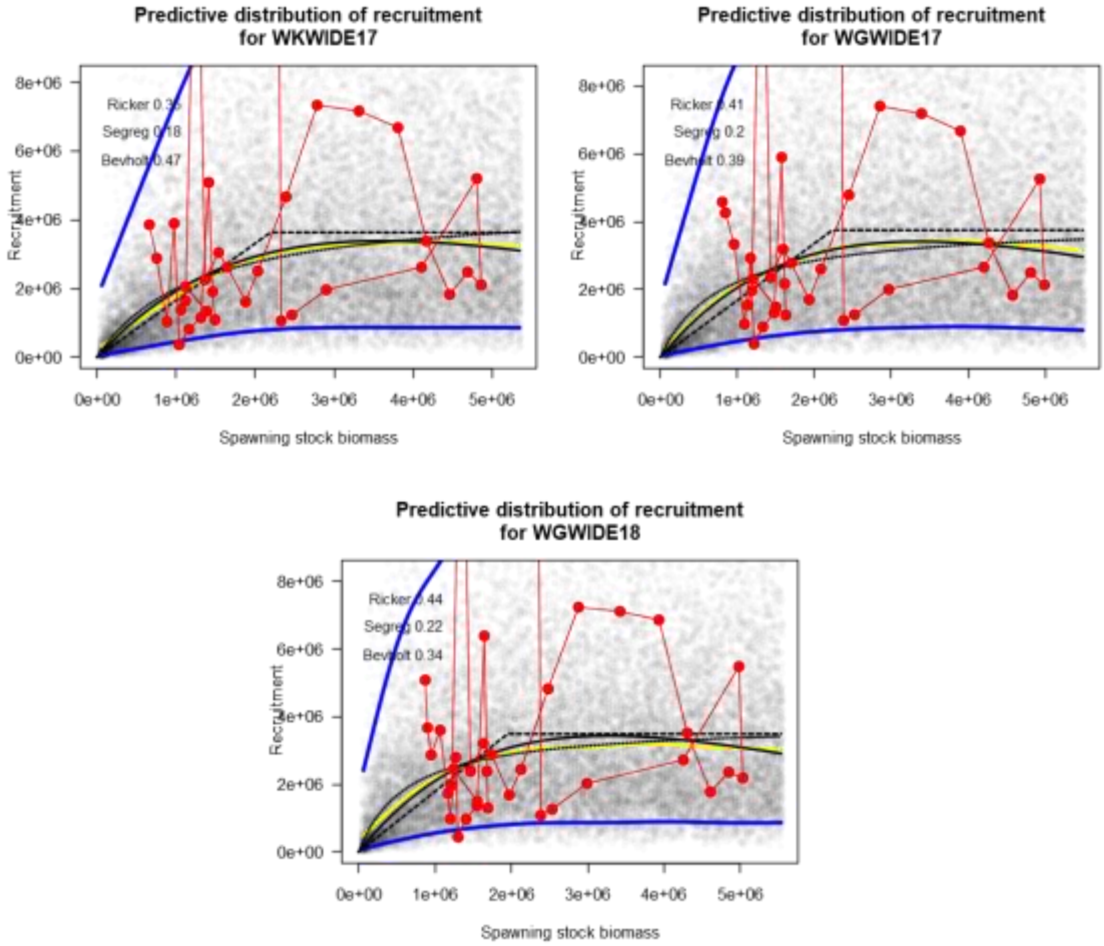


Figure 4: ***EqSim*** **fits of 3 SRRs to each of the three assessments (ignoring the terminal year estimate)**

The proportions assigned to each SRR model are given in table 3 and figure 5. The sensitivity to recruitment spikes in 1982 and 2001 is explored by omitting either or both of these years from the data.

Table 3: SRR proportions as determined by ***EqSim*** **(terminal year ignored)**

Assessment	1982?	2001?	Ricker	Beverton-Holt	Segmented Regression
WK'17	Y	Y	36%	47%	18%
	N	Y	61%	25%	14%
	Y	N	36%	50%	13%
	N	N	62%	26%	12%
WG'17	Y	Y	41%	39%	20%
	N	Y	62%	26%	11%
	Y	N	39%	46%	15%
	N	N	66%	25%	8%
WG'18	Y	Y	44%	34%	22%

Assessment	1982?	2001?	Ricker	Beverton-Holt	Segmented Regression
	N	Y	61%	25%	14%
	Y	N	46%	41%	13%
	N	N	62%	26%	12%

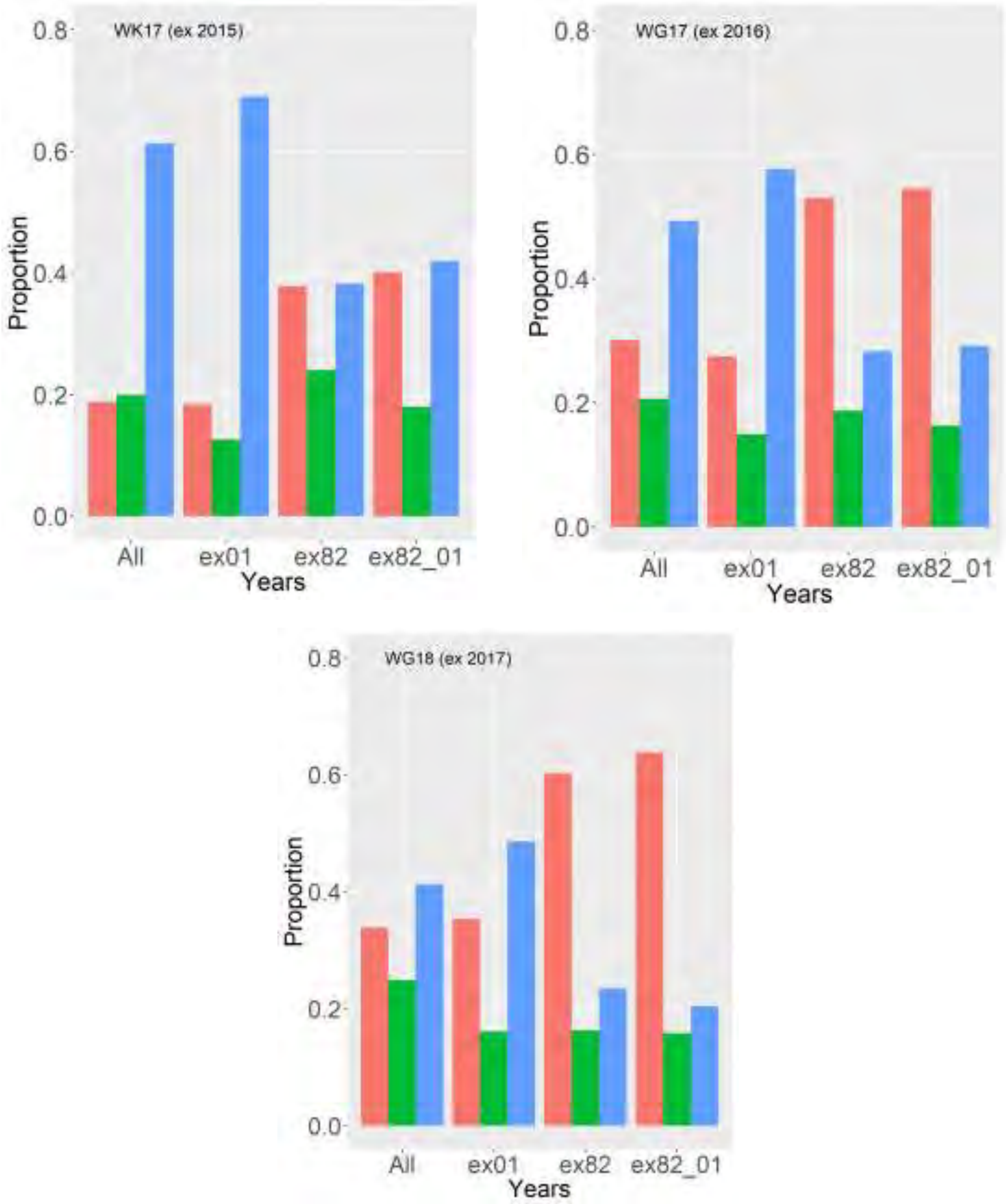


Figure 5: ***EqSim*** **SRR model proportions (Ricker – red, Beverton-Holt – blue and Unconstrained Segmented Regression – green) for each assessment (terminal year Recruitment/SSB data point ignored).**

There are significant differences both between assessments and within an assessment year due to the strong influence of the high recruitment values (particularly 2001).

In terms of the most recent assessment (WG18) which includes some relatively high recruitments at the lowest observed biomasses, there is an increased proportion of Ricker models that provide the best fit to resampled data, primarily at the expense of the Beverton-Holt formulation. Inclusion of the 1982 data point has a significant effect on the overall fit, increasing further the proportion of Ricker models as the very high recruitment at a SSB in the middle of the observed range favours a fit to this functional form. Inclusion of the second recruitment spike (in 2001) in the dataset has a minor influence compared to that from 1982.

The individual Ricker, Beverton-Holt and Segmented Regression fits for the WGWIDE 2018 dataset including/excluding 1982 are shown in figures 6 and 7:

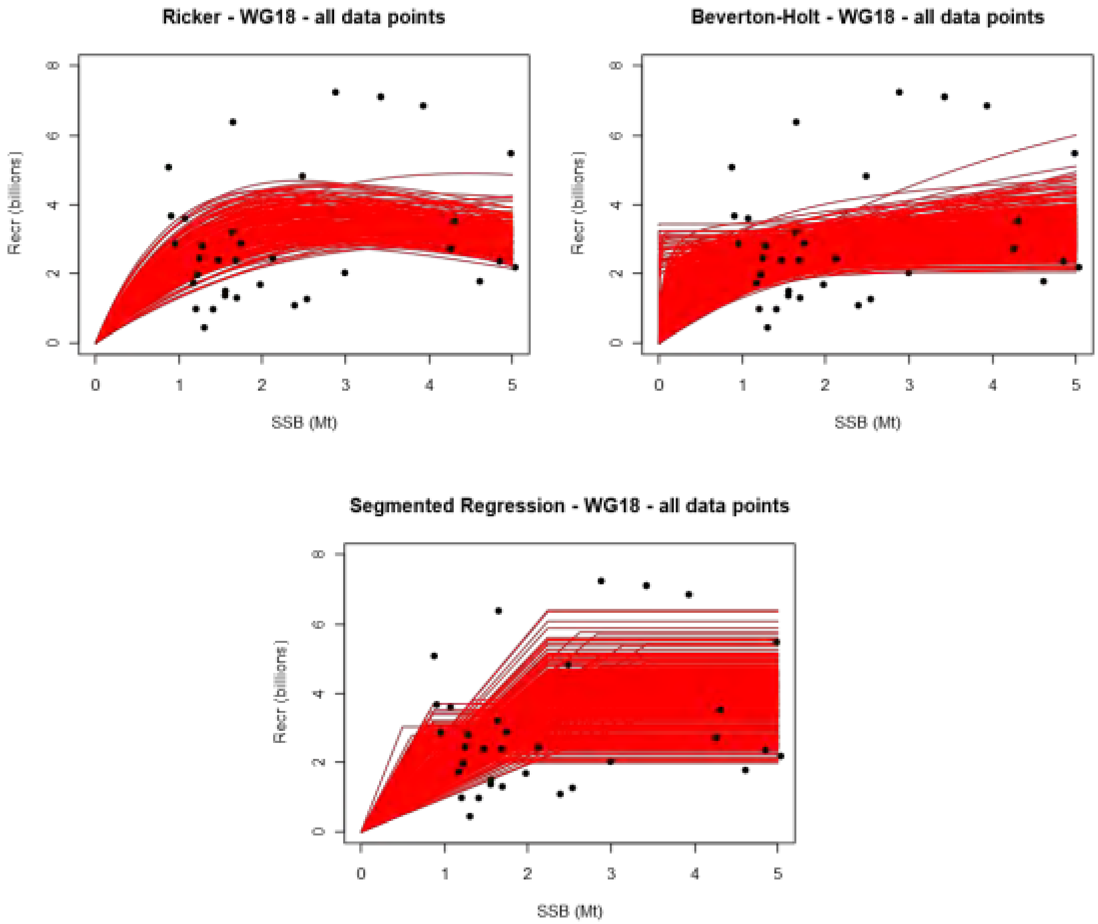


Figure 6: Stock-Recruit fits based on WG18, all data points

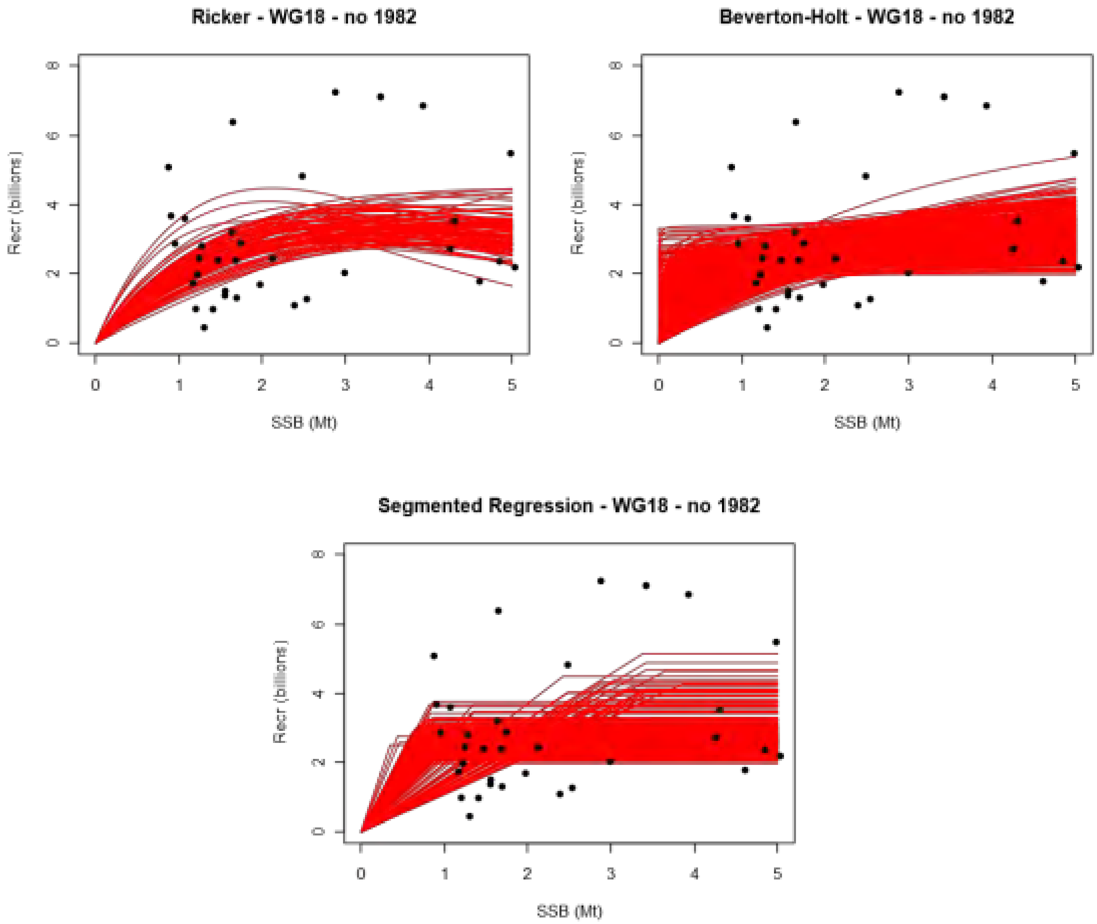


Figure 7: Stock-Recruit fits based on WG18, excluding 1982

Excluding the 1982 data point has a significant effect on the proportions assigned to each functional form. In both cases, there are a number of implausible Beverton-Holt fits with significant recruitment predicted a very low SSB. A wide range of breakpoints result for the segmented regression fits from lower than the minimum observed SSB to almost 4Mt.

As with previous exercises during the MSE evaluation in 2014/15 and the benchmark in 2017, there is no clear evidence of a relationship between SSB and recruitment. The most appropriate formulation is the simple segmented regression (or hockey stick) model. It assumes no relationship between SSB and recruitment above a particular (breakpoint) biomass with a linearly decreasing recruitment at lower biomasses towards the only true point i.e. zero recruitment at zero biomass.

Fitting an unconstrained segmented regression to the full dataset for each of the assessments estimates the (deterministic) breakpoint at approximately 2Mt, well above the B_{loss}. However, this breakpoint estimation is sensitive to the inclusion of the 1982 data point such that excluding this value leads to a breakpoint at B_{loss} for the WGWIDE 2018 assessment. Figure 8 shows the segmented regression fit for the 2018 assessment including 1982 (left) and without this data point (right)

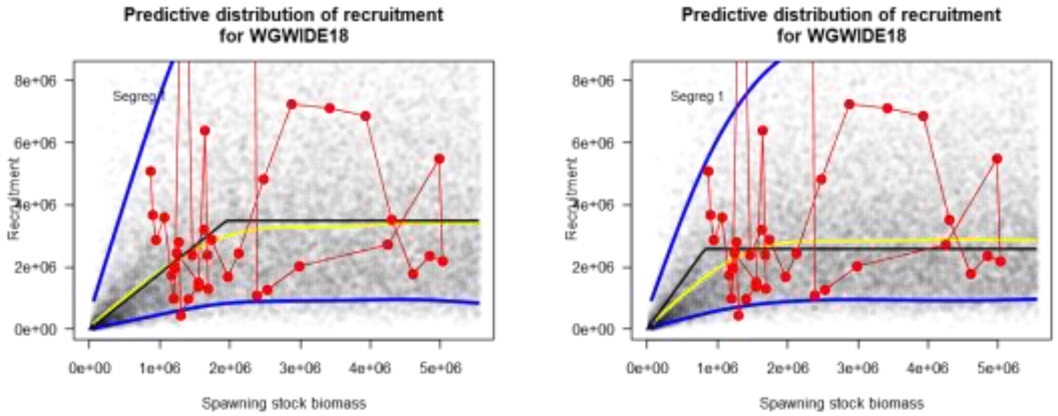


Figure 8: Segmented regression fit to 2018 assessment with (left) and without (right) the 1982 data point.

The breakpoint of the segmented regression is synonymous with the B_{lim} reference point as, below this SSB, recruitment is considered to be impaired. A value of 2Mt would imply that the stock has been below B_{lim} for the most recent 20 years and above for the earlier period. Whilst there are a number of low recruitments during the recent past, there are also several high values, including 2001 and no indication of a reduction in recruitment,

We consider the segmented regression as the most appropriate stock-recruit formulation for the purposes of a long term simulation. Since the breakpoint for an unconstrained fit is poorly defined, the breakpoint is constrained at B_{lim} or B_{loss} (in event that $B_{loss} < B_{lim}$) as it would not be precautionary to consider a breakpoint below the lowest observed biomass. This is the same conclusion that was reached during the 2017 benchmark evaluation.

To determine the candidate value for B_{lim}, ICES describes a number of stock types, based on the S-R relationship and the history of the stock development. The features noted above mean that this stock can potentially be considered to fit under a number of stock categories:

- Type 1 – spasmodic stocks with occasional large year classes where B_{lim} can be based on the lowest SSB where large recruitment is observed, unless F has been low throughout the observed history, in which case the lowest SSB can potentially be considered a proxy for B_{pa}. The most recent assessment indicates that fishing mortality has been relatively low, only exceeding 0.15 once (in 1997).
- Type 5 – stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment. In such cases B_{lim} could be based on B_{loss}. This was the selection of the 2017 benchmark evaluation.
- Type 6 – stocks with narrow dynamic range of SSB and showing no evidence of past or present impaired recruitment. In this instance, no B_{lim} is directly available although B_{loss} could be considered a candidate for B_{pa}, if historical fishing mortality is low.

The full time series of stock and recruit data would suggest that type 6 is not an appropriate characterisation of the stock as the biomass has varied from 1Mt to 5Mt. However, the period of high biomass occurred during the late 1980s/early 1990s and was due in the main to the exceptional 1982 year-class. The relative importance of the 1982 year-class on the estimated SSB over time is illustrated in figure 9 which shows the proportion of the total SSB that is due to individual year classes for the period of the assessment output.

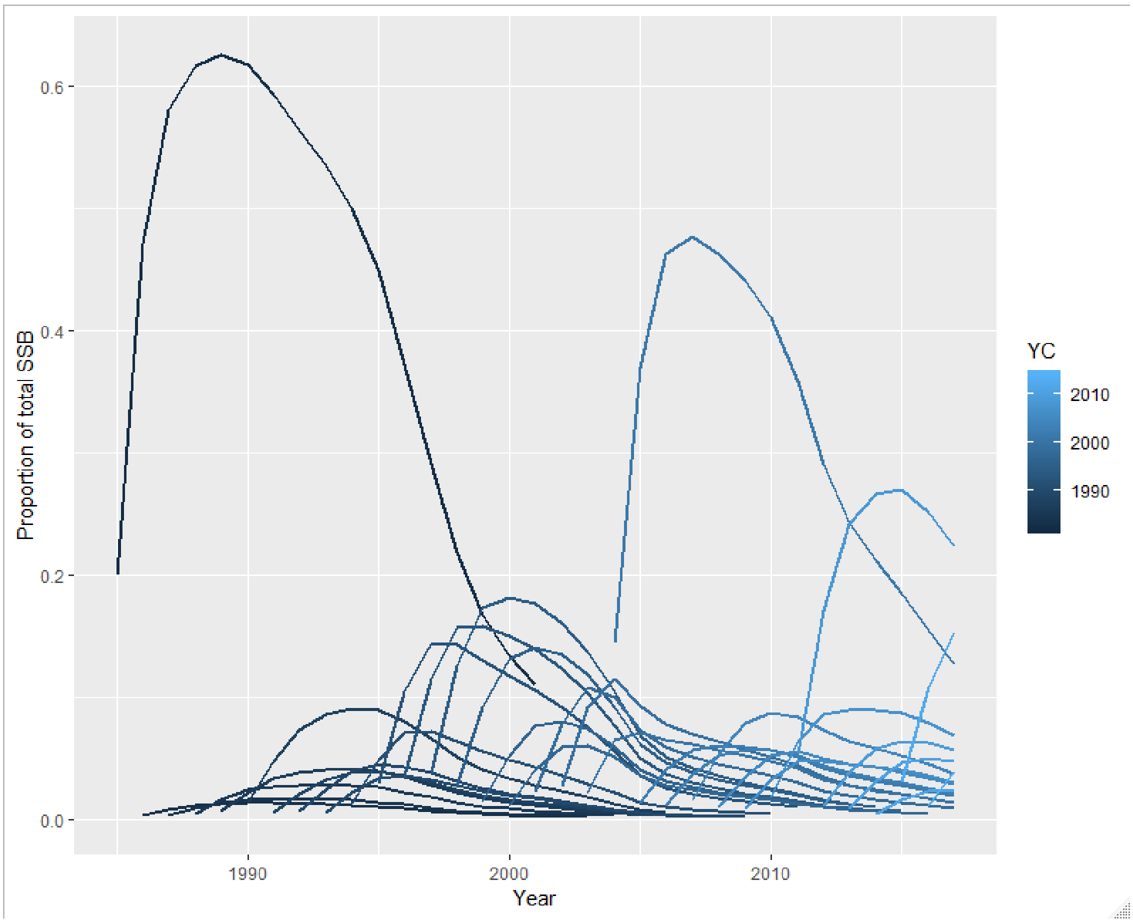


Figure 9: Proportion of total SSB from each year class, as estimated by the WGWIDE 2018 assessment.

The 1982 year-class dominates the overall SSB estimate for several years during the early part of the time series. When fully mature (at age 3) it initially accounts for 20% of the total SSB (in 1985). However, weak recruitment in the following years means that this year class contributes over 60% of the SSB for several years. This period of relatively high SSB is therefore due to the presence of a single recruitment event. It is therefore appropriate to consider a scenario that excluding this period during which the stock biomass range is limited. Post 1995, the contribution of the 1982 year-class to the standing stock is equivalent to or lower than the maximum contribution from the next largest (2001) year class. When considering data from 1995 onwards, the SSB ranges from the current low value to just over 2Mt with an average fishing mortality of 0.11.

3.4 Baseline Simulation Scenarios

A suite of baseline scenarios has been defined based upon combinations of potential B_{lim} values, assessment data periods and stock-recruit model formulations.

The following are considered as potential proxies for B_{lim} or B_{pa}

1. SSB_{2001} – the lowest SSB giving rise to a high recruitment
2. SSB_{2003} – the lowest SSB from the stable part of the assessment output *i.e.* the period not subject to significant retrospective revision.
3. B_{loss} – the lowest observed biomass (as WKWIDE 2017)

In situations that the reference SSB is considered as B_{pa}, the appropriate B_{lim} value is calculated as B_{pa} /1.4. This differs from the approach taken at WKWIDE 2017 where the assessment uncertainty in ln(SSB) was used to derive the precautionary point from the limit point. For this exercise, it is considered that the 1.4 factor is more appropriate as it assumes a greater uncertainty than that estimated by the assessment, which is considered to be an under-estimate.

3 alternatives are considered for the data period:

1. The full time series, excluding the most recent year
2. As (1) but excluding the 1982 estimates
3. As (1) but excluding all estimates prior to 1995

An *EqSim* analysis is run for each combination of B_{lim} and data period with the segmented regression stock recruit model, constrained at B_{lim}, or B_{loss} in the event B_{loss} is greater than the assumed B_{lim} value. To investigate the sensitivity of individual scenario results to potential ongoing retrospective bias each analyses was run based on estimates from each of the available SS3 assessment datasets *i.e.* the benchmark assessment from early 2017 which contained data up to and including 2015 (WK'17), the update assessment with data up to 2016 conducted at WGWIDE in late 2017 (WG'17) and the most recent update assessment in 2018 (WG'18) which contains catch and sampling data up to and including 2017.

The range of scenarios tested on each assessment dataset are described in table 4

Table 4: *EqSim* analysis baseline scenarios

Scenario	B_{lim} basis	Data	SRR
1.1	SSB_{2001}	All	SR breakpoint @ B_{lim}
1.2		All, ex 1982	
1.3		1995-	
2.1	$B_{pa}/1.4$; $B_{pa}=B_{loss}$	All	SR breakpoint @ B_{pa}
2.2		All, ex 1982	
2.3		1995-	
3.1	B_{loss}	All	SR breakpoint @ B_{lim}
3.2		All, ex 1982	
3.3		1995-	
4.1	$B_{pa}/1.4$; $B_{pa} = SSB_{2001}$	All	SR breakpoint @ B_{lim}
4.2		All, ex 1982	
4.3		1995-	
5.1	$B_{pa}/1.4$; $B_{pa} = SSB_{2003}$	All	SR breakpoint @ B_{lim}
5.2		All, ex 1982	
5.3		1995-	
6.1	SSB_{2003}	All	SR breakpoint @ B_{lim}
6.2		All, ex 1982	
6.3		1995-	

The process for the determination of the full suite of reference points using the *EqSim* R packages if described in detail in the ICES technical guidelines and summarised below:

1. B_{lim} and B_{pa} are set according to the scenario settings *i.e.* based on SSB_{2001}, SSB_{2003} or B_{loss} with $B_{lim} = B_{pa}$ /1.4 or $B_{pa} = 1.4*B_{lim}$
2. 1000 segmented regression models are fit to bootstrapped stock-recruit pairs with the breakpoint constrained at B_{lim} or $B_{loss,}$ if $B_{lim}<B_{loss}$.
3. Using *EqSim*, conduct a stochastic simulation (stochastic recruitment, biology and fishery selection) to determine the fishing mortality that, on average, leads to a 50% probability that SSB is below the scenario B_{lim}. This fishing mortality is the F_{lim}.
4. Calculate the precautionary fishing mortality reference point (F_{pa}) as F_{lim}/1.4.
5. Using *EqSim*, run a second stochastic simulation, this time also including error on assessment/advice to identify a candidate value for F_{MSY}. See below for an explanation of the calculation of the assessment and advice error.
6. If the value of F_{MSY} in (5) exceeds the F_{pa} value calculated in (4), reduce it to this value as the F_{MSY} is not permitted to be greater than F_{pa} under precautionary considerations.
7. Identify an appropriate MSY $B_{trigger}$, the biomass selected to safeguard against low SSB when fishing at F_{MSY}. This is defined as the 5^{th} percentile on the distribution of SSB when fishing at F_{MSY}. Given the lack of available data for fishing at F_{MSY}, MSY $B_{trigger}$ is set to B_{pa} for each scenario considered.
8. Evaluate if the advice rule and proposed F_{MSY} is precautionary (P(SSB)<B_{lim} is below 5%) by conducting an additional stochastic simulation that incorporates all of the stochastic elements above and the ICES MSY advice rule (*i.e.* linear reduction in target F when below MSY $B_{trigger}$). If the precautionary limit is exceeded, reduce F_{MSY} to F_{P05}, the fishing mortality corresponding to a risk to B_{lim} of 5%.

Both absolute and relative reference point values were calculated for each scenario considered. Absolute values are available directly from the EqSim output as described above. Relative values correspond to the absolute estimates divided by the arithmetic mean of the appropriate (SSB or F_{bar}) time series.

The catch advice provided for Western Horse Mackerel for 2018 and 2017 was derived from the SS3 assessment benchmarked in 2017 and using the reference point values outlined in table 1 with advice based on applying the ICES MSY rule. Thus, if SSB on Jan 1 of the advice year was predicted to be above MSY $B_{trigger}$, a catch consistent with a fishing mortality equivalent to the F_{MSY} estimate was given. In the event SSB was below MSY $B_{trigger}$, the target fishing mortality was linearly scaled down (such that F=0 at SSB=0).

To illustrate the changes associated with the updated reference points as proposed by this exercise the 2017 and 2018 advice has been recalculated under the condition that

1. The absolute reference points had been evaluated in 2017 under the scenario settings explored as part of this IBP.
2. The absolute reference points had been annually updated on the basis of the most recently available assessment at the time but using consistent *EqSim* settings.
3. Relative reference points had been evaluated in 2017 under the scenario settings explored as part of this IBP and subsequently used to scale the F_{MSY} and MSY $B_{trigger}$ values used for the provision of advice from the update assessments in 2017 and 2018.

This exercise involves re-running the short term forecast conducted at WGWIDE in 2018 as the intermediate year (2018) catch will have differed under each scenario examined. During this process it was assumed that the advised catch (rounded to the nearest 1kt) for 2018 was taken in full.

Assessment/Advice Error

EqSim is a software designed specifically for conducting long term stochastic simulation. It does not perform a stock assessment and forecast as part of the simulation, rather it adopts the "short-cut" approach. To account for errors in the stock assessment and advice process, *EqSim* provides for a two parameter error function which is applied directly to the target fishing mortality. The parameter values for the error function are determined from an analysis of the most recent assessment output and the short term forecast details contained in the annual advice sheets. The assessment provides the most estimates of the realised catch and fishing mortality (F_{yr}). The advice sheets are used to estimate the fishing mortality (F_{ya}) that would have been advised to obtain the estimated catch (linearly interpolating between two appropriate catch options in the event the actual catch is not available on the advice sheet). The deviation in year y are then calculated as $\ln(F_{yr}/F_{ya})$, the standard deviation σ_m of the log deviations gives the marginal distribution. The conditional standard deviation σ_c is calculated as $\sigma_m = \sqrt{1-\emptyset^2}$ where ϕ is the autocorrelation of the AR(1) process. σ_c and ϕ are the input parameters to *EqSim* (Fcv and Fphi).

An analysis of the most recent assessment output and advised fishing mortalities from the historical advice sheets, available since 2011, yields values of 0.2 for Fcv and 0.4 for Fphi. In the absence of an estimate of Fcv and Fphi, *EqSim* assumes default values of 0.212 and 0.423 respectively

3.5 Sensitivity Simulations

The baseline simulation scenarios described above cover a number of alternative assumptions with regard to the most influential aspects of the analysis i.e. the parameterisation of the stock-recruit relationship, the choice of the biomass limit point and the source of the data underpinning the analysis (assessment and time period).

There are a number of additional parameterisations required in order to most appropriately implement stochasticity in the long term simulations. Previous exercises have indicated that these may also be important but, in order to restrict the overall number of simulations to be conducted, these settings are investigated through running targeted sensitivity analyses *i.e.* exploring individual parameter settings for a limited number of baseline scenarios. Table 5 details the *EqSim* settings for the baseline runs and the sensitivity analyses.

Table 5: *EqSim* settings

Data and Parameters	Baseline Setting	Sensitivity Run Setting
SSB-Recruitment data	Subcase 1:1982 → (Y_{term}-1) Subcase 2:1983 → (Y_{term}-1) Subcase 3:1995 → (Y_{term}-1)	NA
SR Model	Segmented regression with breakpoint @ B_{lim} or B_{loss}	NA
Assessment/Advice error and autocorrelation (F_{cv}, F_{phi})	Calculated values (0.2, 0.4)	NA
Recruitment autocorrelation	FALSE	TRUE
Mean weights, maturity and natural mortality.	Random selection (bio.const = FALSE) from last 10 years (default *EqSim* setting)	Last 3 years

Data and Parameters	Baseline Setting	Sensitivity Run Setting
Exploitation pattern	Random selection (sel.const = FALSE) from last 10 years (default *EqSim* setting)	Last 3 years
Trimming of extreme recruitments	(-3,3) (default *EqSim* setting)	(-3,1.5)

4 Results

4.1 Baseline Scenarios

The full set of results for all scenarios are presented in tabular form in appendix 1. The fishing mortality reference point estimates for each of the baseline scenarios using the longest data time-series (baseline scenarios $x.1$ in table 4) are summarised in figure 10.

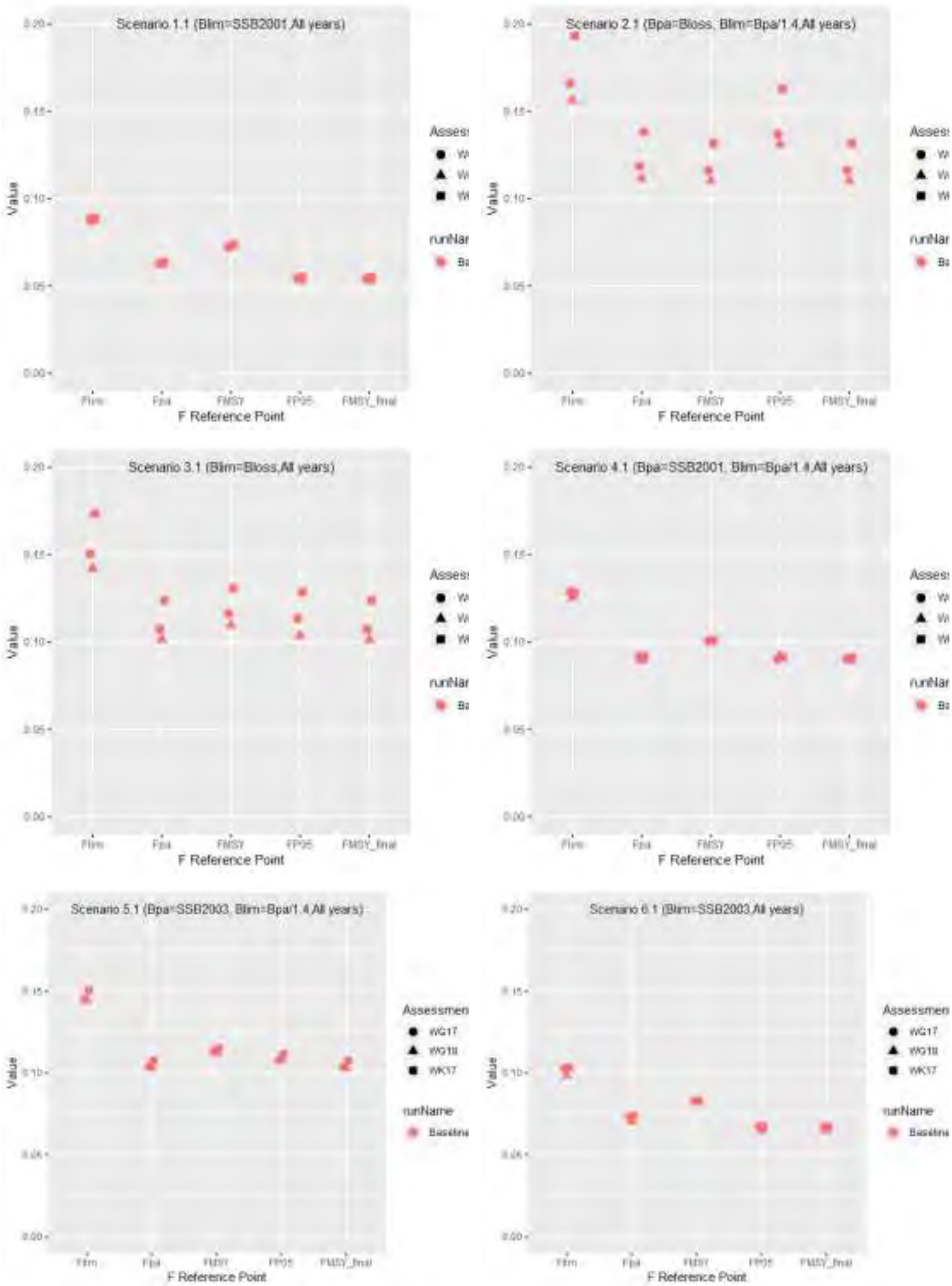


Figure 10: Fishing mortality reference point estimates using SSB-Recruitment data from 1982 onwards (excluding the terminal year) for each SS3 assessment.

Equivalent results for simulations excluding the 1982 data pair (scenarios x.2) are shown in figure 11:

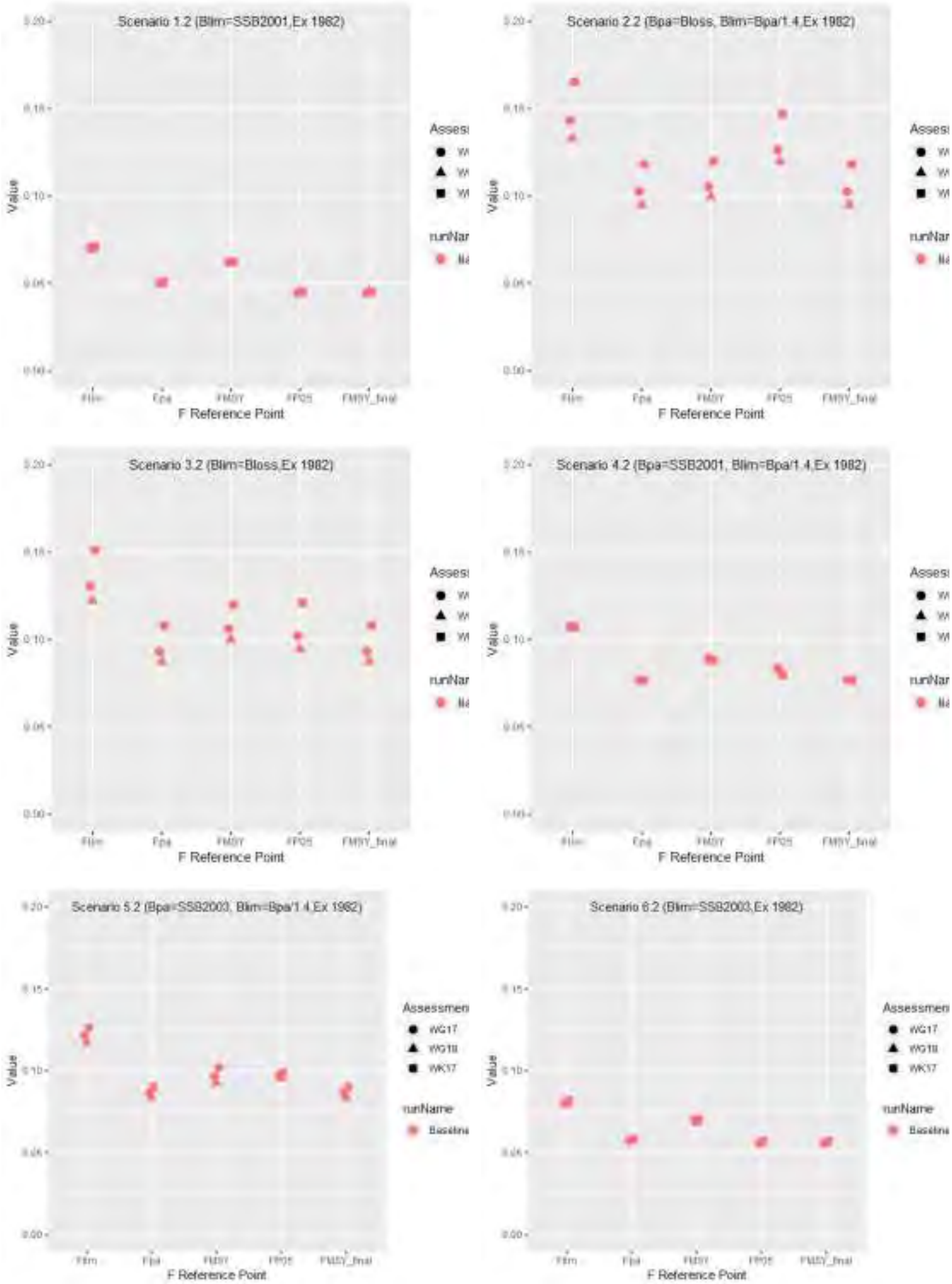


Figure 11: Fishing mortality reference point estimates excluding 1982 data point. Scenario 3.2 settings correspond to those selected by the 2017 benchmark (*i.e.* B_{lim} = B_{loss}, segmented regression SRR using the full time series but excluding 1982 with a breakpoint at B_{lim}, biology and selectivity based upon the most recent 10 years). The red squares correspond the estimates based on the 2017 benchmark assessment output. The circle (update assessment in 2017) and triangle (update assessment in 2018) depict the estimates based upon the output from subsequent assessments. With the exception of a minor difference in B_{pa} (and subsequently MSY $B_{trigger}$ – assumed to be an error in the benchmark code), this analysis leads to the same reference point values when the analysis is based on the WK17 assessment. F_{MSY} is estimated to be 0.108 (limited by F_{pa}) in both exercises.

The third alternative time series consists of stock-recruit pair estimates from 1995 onwards (scenarios x.3). Reference points estimated on the basis of this, shorter time series are shown in figure 12.

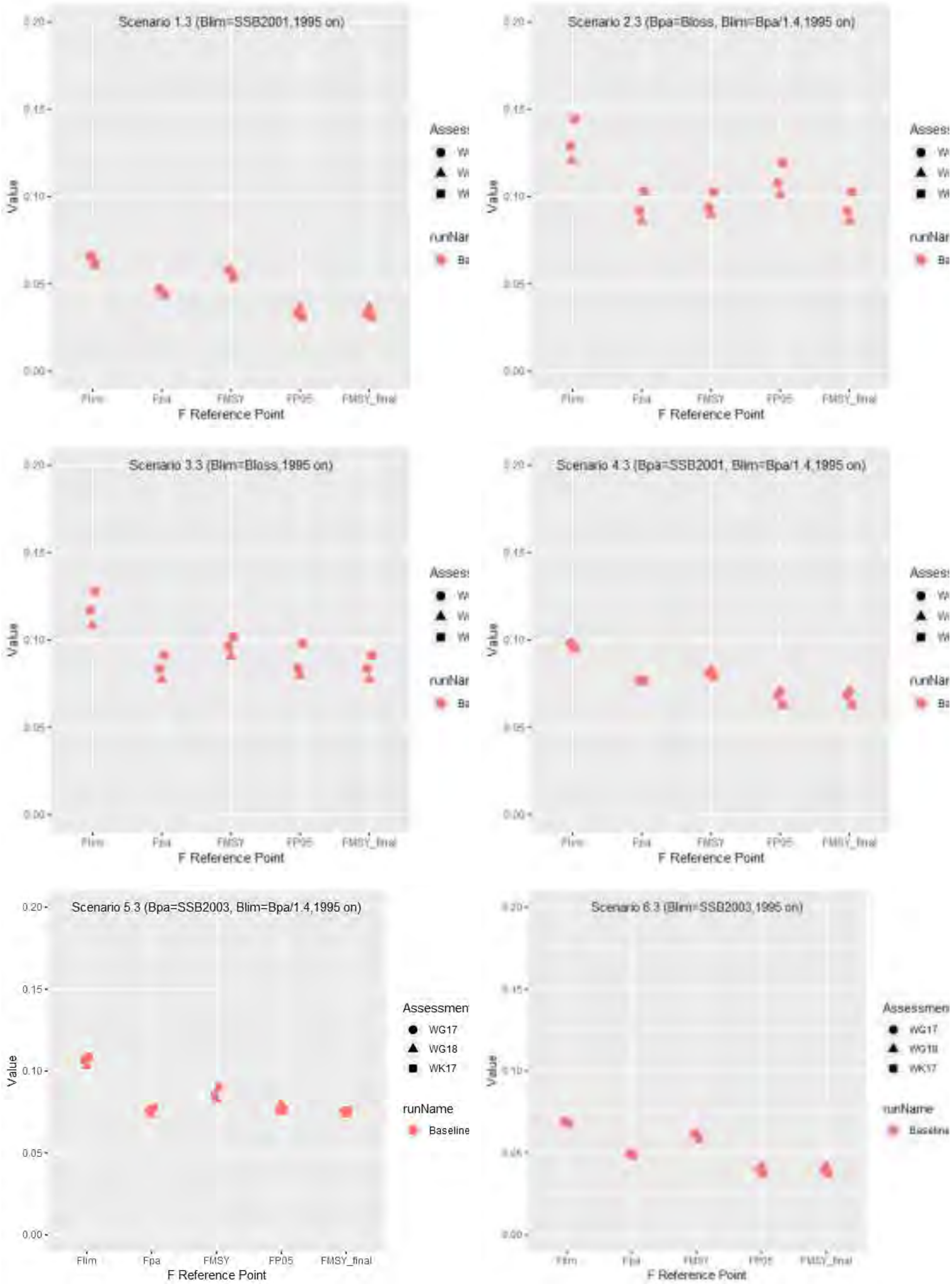


Figure 12: Fishing mortality reference point estimates for SSB-Recruit data from 1995 onwards.

Comparing figures 10-12, estimates of F_{MSY} are highest for the dataset including the 1982 data-point and lowest when based on the contemporary data only (1995 on). Stock productivity as characterised by the SRR fit is reduced when the high 1982 data point is excluded and further reduced when the period of high SSB in the mid-late 1980s and early 1990s is excluded when fitting the stock-recruit model.

For scenarios with a biomass limit (B_{lim} or B_{pa}) is based on the lowest observed biomass (scenarios 2 and 3) annual re-evaluation of the reference point values (using the same basis and assumptions) based on output from the most recent assessment leads to significant downward revisions in the estimates of F_{MSY}. The largest revision occurs between the 2017 benchmark and 2017 working group assessments, consistent with the assessment revision in SSB and Fbar (see figure 1). B_{loss} is revised up significantly by each assessment and subsequently MSY $B_{trigger}$ estimate also increases as they are derived from B_{pa} and ultimately B_{lim}. This is particularly acute since B_{loss} corresponds to the terminal assessment year in each case and is thus subject to the greatest retrospective revision. In the case that annually updated reference points been used for the provision of MSY-based advice then the catch advice would have been lower than that issued. For each scenario tested, advice for 2019 represents an increase over that for 2018.

Scenario 2 is similar to scenario 3 in that B_{lim} is based upon B_{loss} which, as discussed, results in substantial annual revision in reference point estimates as B_{loss} is revised. However, scenario 2 considers that B_{loss} is a proxy for B_{pa} rather than B_{lim}, with B_{lim} calculated as $B_{pa}/1.4$. This would imply a B_{lim} value lower than any historically observed SSB and represents the least precautionary scenario considered.

Scenarios 1 and 4 explore outcomes when B_{lim} is based on the SSB in 2001, the lowest SSB that resulted in high recruitment. For scenario 1 B_{lim} is set equal to SSB_{2001} whereas scenario 4 considers this SSB a precautionary limit, the consequence of which is a lower B_{lim} for scenario 4. Since the basis for B_{lim} is a historic SSB, this value is subject to reduced revision by subsequent assessments (1.25Mt for WK'17, 1.32Mt (+6%) for WG'17 and 1.3Mt for WG'18), leading to more stable reference point estimates for subsequent assessments. Analyses based on the complete time series with the exception of 1982 result (scenarios 1.2 and 4.2) lead to a consistent F_{MSY} estimate. When based on recent data only, revisions are evident, although reduced from those for scenarios 2 and 3.

Scenarios 5 and 6 assume SSB in 2003 as a basis for B_{lim} directly (scenario 6) or B_{pa} (scenario 5). This is the lowest SSB from the stable part of the assessment output and has been subject to minor revision by the subsequent assessments (1.06Mt for WK17, 1.14Mt (+8%) for WG17 and 1.17Mt (+3%) from the most recent assessment in 2018). Revisions are slightly higher than those with B_{lim} based on the 2001 SSB estimate.

A summary of the F_{MSY} estimates is given in tables 6a and 6b.

Table 6a: F_{MSY} estimates (scenarios 1-4). The WG18 percentage figure indicates the change in estimated value between the benchmark assessment and the most recent update assessment.

Ass	Scenario							
	2.2 B_{pa} =B_{loss}	3.2 B_{lim} = B_{loss}	2.3 B_{pa}=B_{loss}	3.3 B_{lim} = B_{loss}	1.2 B_{lim} = SSB_{2001}	4.2 B_{pa} = SSB_{2001}	1.3 B_{lim} = SSB_{2001}	4.3 B_{pa} = SSB_{2001}
	Full time series (ex 1982)		1995 on		Full time series (ex 1982)		1995 on	
WK17	0.116	0.106	0.100	0.089	0.042	0.074	0.022	0.056
WG17	0.099	0.092	0.089	0.079	0.040	0.074	0.030	0.061
WG18	0.093 (-20%)	0.085 (-20%)	0.083 (-17%)	0.074 (-17%)	0.044 (+4%)	0.074 (-)	0.029 (+32%)	0.064 (+14%)

Table 5b: F_{MSY} estimates (scenarios 5 and 6)

Ass	Scenario			
	6.2 B_{lim} = SSB_{2003}	5.2 B_{pa} = SSB_{2003}	6.3 B_{lim} = SSB_{2003}	5.3 B_{pa} = SSB_{2003}
	Full time series (ex 1982)		1995 on	
WK17	0.057	0.090	0.037	0.075
WG17	0.056	0.087	0.040	0.076
WG18	0.056 (-2%)	0.084 (-7%)	0.042 (+14%)	0.074 (-1%)

The retrospective pattern in the assessment of western horse mackerel leads to significant revision to estimates of SSB and FBar, particularly in the most recent years, when SSB is at a historic time series low, rendering reference points derived on the basis of a B_{lim} related to B_{loss} likely unsuitable for the provision of advice. An alternative approach in this situation would be to consider the assessment results as indicative of trends and not reliable in absolute terms (ICES stock category 2). In this case assessment output is scaled by the time series average and presented in relative terms. Relative reference points are used during the evaluation of stock status and the provision of advice. For each of the scenarios tested here, relative values have also been calculated. The absolute values derived from the EqSim analysis in each case are divided by the mean SSB/FBar from the assessment output for the appropriate time period.

Estimates of relative reference points for each scenario are summarised in tables 7a and 7b.

Table 6a: F_{MSY} estimates, scenarios 1-4 (relative)

Assessment	Scenario							
	2.2 $B_{pa} = B_{loss}$	3.2 $B_{lim} = B_{loss}$	2.3 $B_{pa} = B_{loss}$	3.3 $B_{lim} = B_{loss}$	1.2 $B_{lim} = SSB_{2001}$	4.2 $B_{pa} = SSB_{2001}$	1.3 $B_{lim} = SSB_{2001}$	4.3 $B_{pa} = SSB_{2001}$
	Full time series (ex 1982)		1995 on		Full time series (ex 1982)		1995 on	
WK'17	1.158	1.059	0.768	0.685	0.416	0.734	0.171	0.434
WG'17	1.075	0.991	0.760	0.675	0.433	0.804	0.255	0.523
WG'18	1.049 (-9%)	0.954 (-10%)	0.756 (-1%)	0.673 (-2%)	0.495 (+20%)	0.840 (+14%)	0.266 (+50%)	0.576 (+33%)

Table 6b: F_{MSY} estimates, scenarios 5 and 6 (relative)

Assessment				
	6.2 $B_{lim} = SSB_{2003}$	5.2 $B_{pa} = SSB_{2003}$	6.3 $B_{lim} = SSB_{2003}$	5.3 $B_{pa} = SSB_{2003}$
	Full time series (ex 1982)		1995 on	
WK'17	0.571	0.900	0.286	0.580
WG'17	0.603	0.937	0.342	0.647
WG'18	0.633 (+11%)	0.943 (+4%)	0.381 (+33%)	0.668 (+15%)

Relative reference points can be considered for use in the provision of advice when the absolute estimates of SSB and FBar from the assessment are not considered reliable, yet the trends are. It is instead assumed that biological reference points remain unchanged in relative terms from year to year. The potential utility using relative reference points for Western Horse Mackerel can therefore be assessed by comparing relative values updated by subsequent assessments.

Table 6 indicates that, in contrast to the absolute reference point values, relative values exhibit greater stability when B_{lim} is based upon B_{loss}, particularly when based upon data from 1995 onwards. The relative values that are prone to revision are likely because of inconsistent trends between subsequent assessments. For the period 2006 (peak SSB) to 2015, the trend in reduction in SSB is reduced from 92kt yr^{-1} for the benchmark assessment to 82kt yr^{-1} for the 2018 update assessment.

A summary of the B_{lim} estimates for each scenario is given in table 7

B_{lim} estimates (SSB2019 = 941,821 t – WGWIDE2018)

Table 7: B_{lim} estimates in tonnes.

Ass.	Scenario					
	1.x $B_{lim} = SSB_{2001}$	2.x $B_{lim} = B_{pa}/1.4$ $B_{pa} = B_{loss}$	3.x $B_{lim} = B_{loss}$	4.x $B_{lim} = B_{pa}/1.4$ $B_{pa} = SSB_{2001}$	5.x $B_{lim} = B_{pa}/1.4$ $B_{pa} = SSB_{2003}$	6.x $B_{lim} = SSB_{2003}$

WK17	1,251,849	472,798	661,917	894,178	757,668	1,060,736
WG17	1,317,591	575,158	805,221	941,137	810,968	1,135,355
WG18	1,346,656	622,865	872,011	961,817	834,480	1,168,272

The following general conclusions can be reached

- Inclusion of the 1982 data point leads to higher stock productivity and increased F_{MSY} estimates. Given the period of time elapsed since this event, the magnitude or the associated recruitment estimate and the lack of a testable hypothesis of the driving process(es), it is considered precautionary to exclude this data point from further analysis.
- B_{loss} is an inappropriate basis for B_{lim} due to the retrospective revision of SSB and fishing mortality in recent years when the stock is estimated to be at B_{loss}
- Basing B_{lim} /B_{pa} on the SSB from a stable period of the assessment leads to stable estimates of F_{MSY}.
- Using the SSB in 2001 or 2003 directly as an estimate for B_{lim} leads to very low values of F_{MSY}. When used as a proxy for B_{pa}, higher F_{MSY} is estimated. All estimates are lower than the estimate from WKWIDE 17.
- Increased stability in the estimate of F_{MSY} is evident with longer time series of input data.

4.2 Sensitivity Scenarios

A number of simulations were conducted for a subset of the baseline scenarios (absolute estimates from scenarios 4.2 and 4.3 and relative estimates from scenario 3.3) to investigate the sensitivity of the estimates to a number of *EqSim* settings for a range of assumptions.

Table 8: Baseline scenarios used for sensitivity testing.

Scenario	RP Type	Base data	B_{lim}
3.3	Relative	1995 onwards	B_{loss}
4.2	Absolute	1993 onwards	$SSB_{2001}/1.4$
4.3	Absolute	1995 onwards	$SSB_{2001}/1.4$

The results of each sensitivity test are described below.

Recruitment Autocorrelation

The estimation and inclusion of autocorrelation in recruitment is not included in the baseline simulations. The results of simulations with it included are compared with the baseline results in figure 13

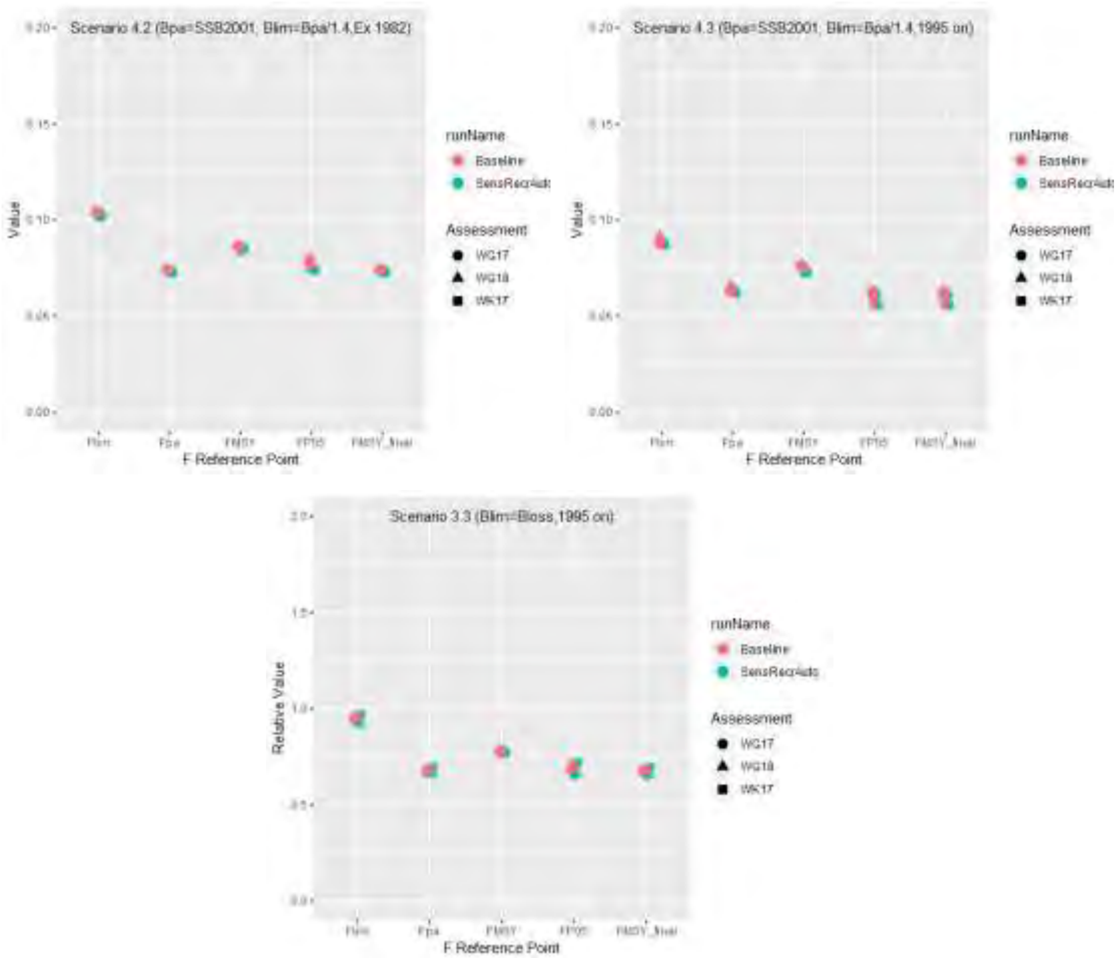


Figure 13: F reference point estimates for the baseline runs for scenarios 4.2 and 4.3 (absolute values) and 3.3 (relative values) (shown in red) and runs with recruitment autocorrelation included (blue).

The inclusion of recruitment autocorrelation has a negligible effect on the estimates of F_{MSY}. There are minor differences with the baseline results for analyses based on data including the early period (*i.e.* pre 1995) during which there are short periods during which recruitment estimates are relatively stable (1988–1990 and 1992–1994).

Selection of Assessment Years for Biological Data

The baseline simulations have been conducted using the last 10 years of biological data. The weights in the catch at age are shown in figure 14. While there is evidence of an increase in weight for older fish in the most recent years' fluctuations are generally without trend over the last decade for the most populous age classes. Maturity at age in the assessment is considered to be constant over time.

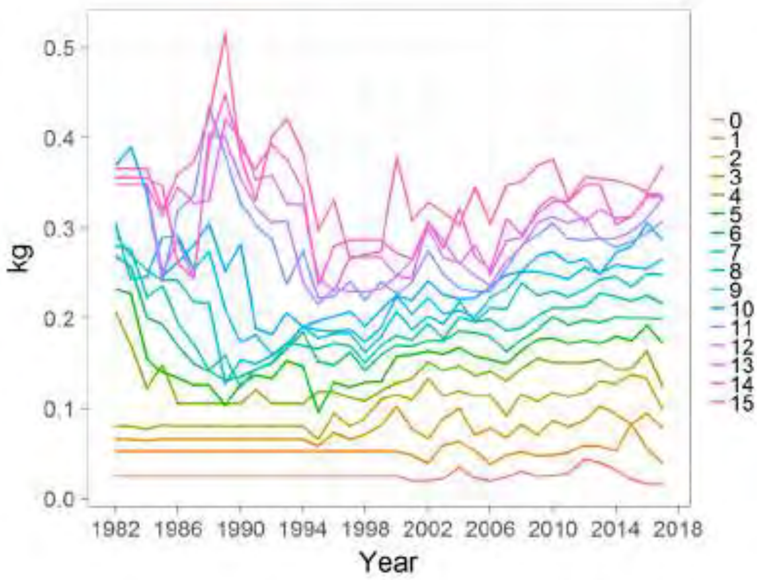


Figure 14. Catch weight at age, Western Horse Mackerel

A sensitivity run was carried our reducing the biological sampling years to the most recent 3 years. A comparison of the reference point estimates with those from the baseline runs is shown in figure 15.

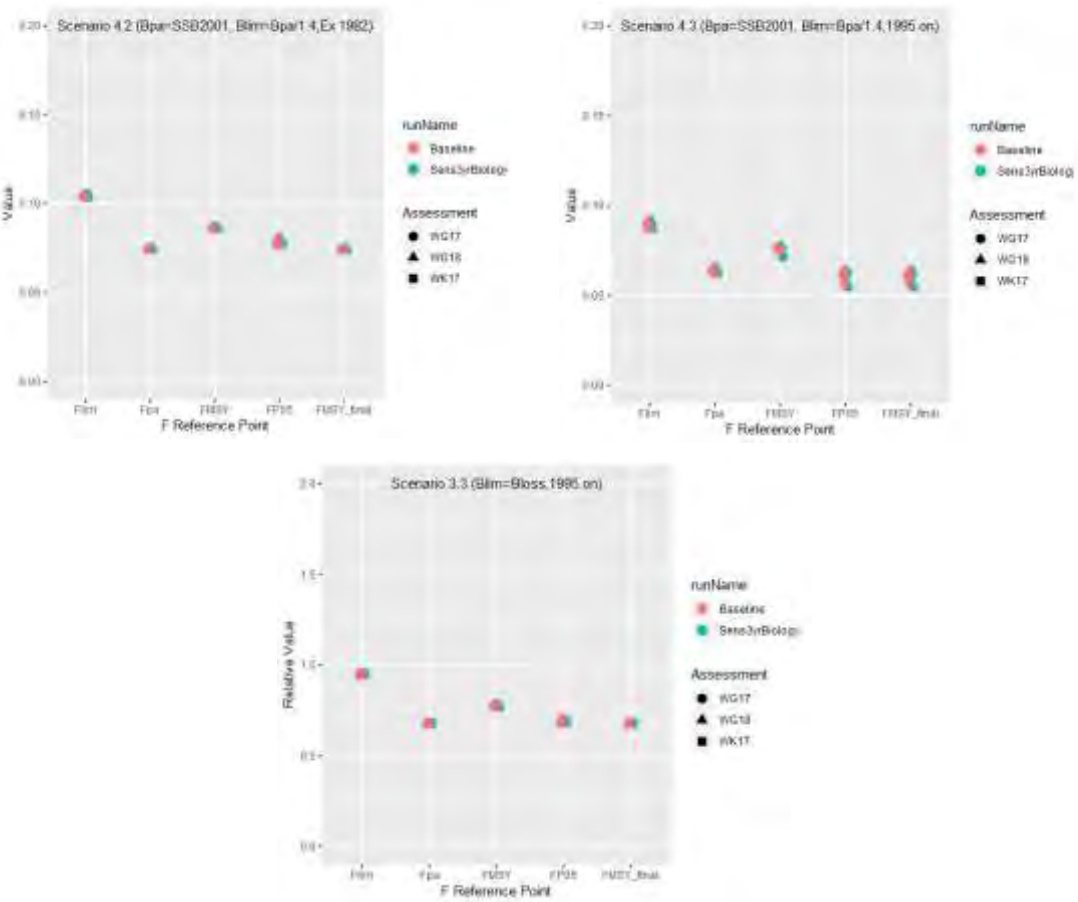


Figure 15: F reference point estimates for the baseline runs for scenarios 4.2 and 4.3 (absolute values) and 3.3 (relative values) (shown in red) and runs with a reduction in the number of years of biological data from the last 10 to the most recent 3 (blue).

Selection of Assessment Years for Fishing Pattern

The baseline simulations have been conducted randomly drawing a selection pattern from the final 10 years of assessment output. An analysis of the fishery data supplied to the working group indicates that, even though catches have been reducing in recent years, the geographical distribution of the catch has been relatively stable over this period (figure 16)

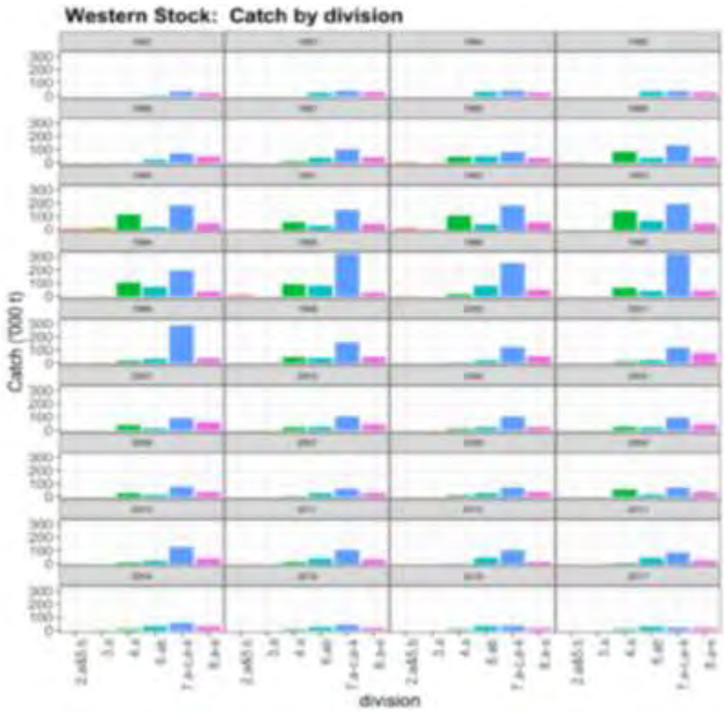


Figure 16: Commercial catch of Western Horse Mackerel by ICES division 1982–2017.

Given the tendency for once off large recruitments, the catch at age profile shows considerable variation over time. Figure 16 is a bubble plot of the catch at age for the full time series.

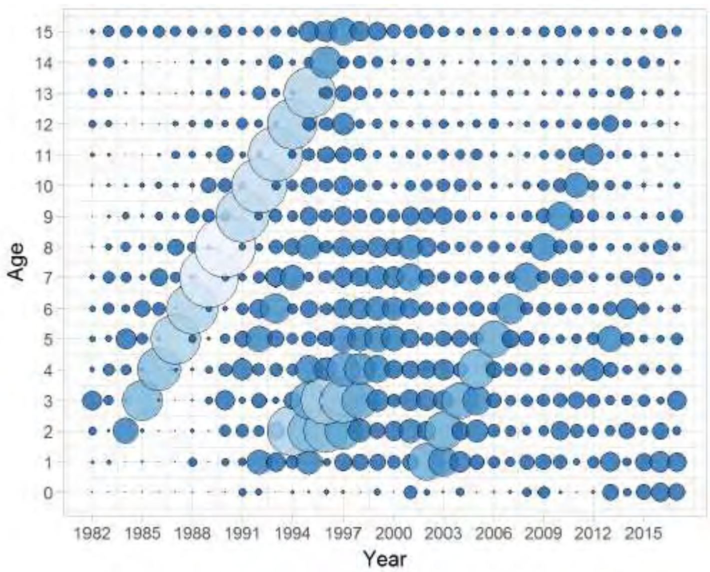


Figure 17: Western Horse Mackerel, catch at age

The progression of the large year classes through the stock is evident. Considering the most recent period, there is evidence of a shift towards increased proportions of younger fish as stronger recruitments have entered the fishery. For this reason, a sensitivity run has been conducted on a reduced selection period the include only the most recent 3 years. A comparison with the baseline is shown in figure 18.

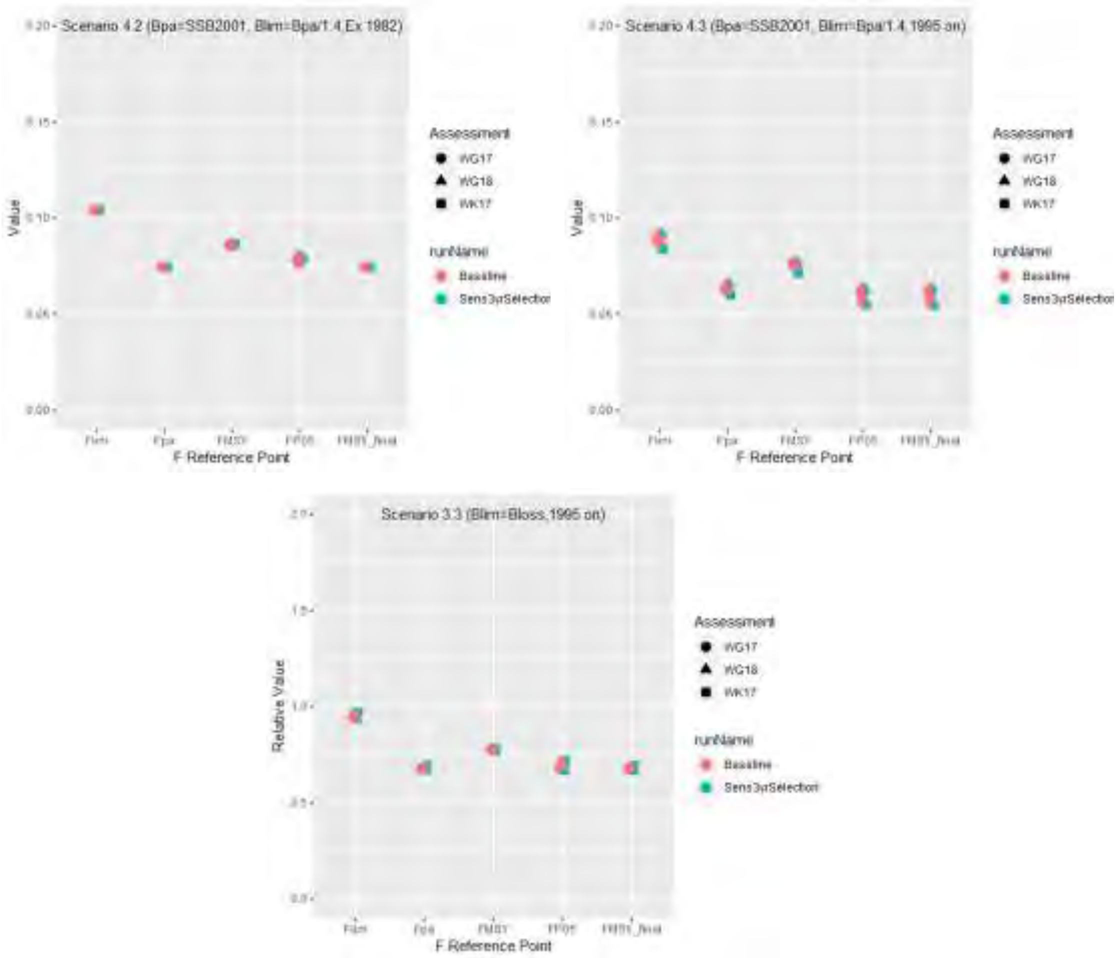


Figure 18: F reference point estimates for the baseline runs for scenarios 4.2 and 4.3 (absolute values) and 3.3 (relative values) (shown in red) and runs with a reduction in the number of years of fishery selection from the last 10 to the most recent 3 (blue).

Trimming of Extreme Recruitment Values

EqSim generates stochastic recruitments for the functional form specified. It has been shown that there is little evidence for the existence of a relationship between SSB and recruitment with high cvs associated with SRR model parameters. By default, EqSim trims the most extreme stochastic recruitment values. Figure 19 depicts the segmented regression fit for scenario 4.3. A number of very high stochastic recruitments can be seen, exceeding the highest observed (2001).

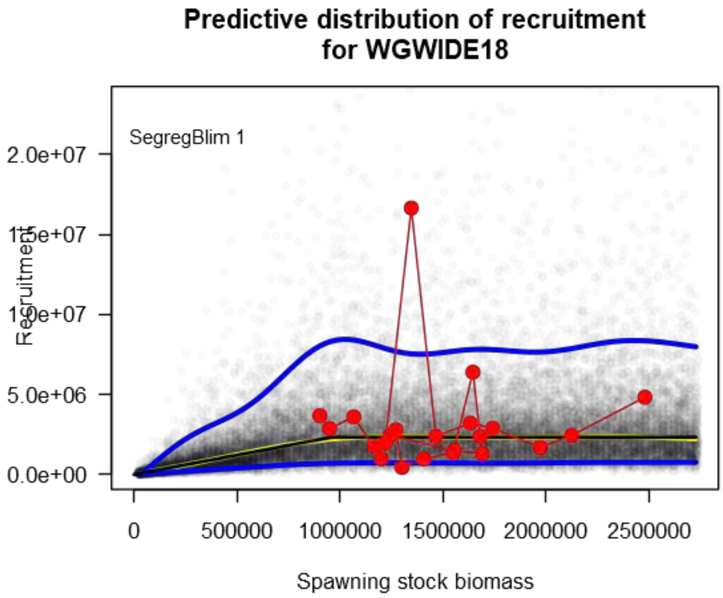


Figure 19 – stock-recruitment fit for scenario 4.3

To investigate the likely impact of these high draws on the estimated reference points, the trimming for large values was made more restrictive and reduced from 3 to 1.5. A comparison of the baseline results with those for the reduced trimming limit are shown in figure 20.

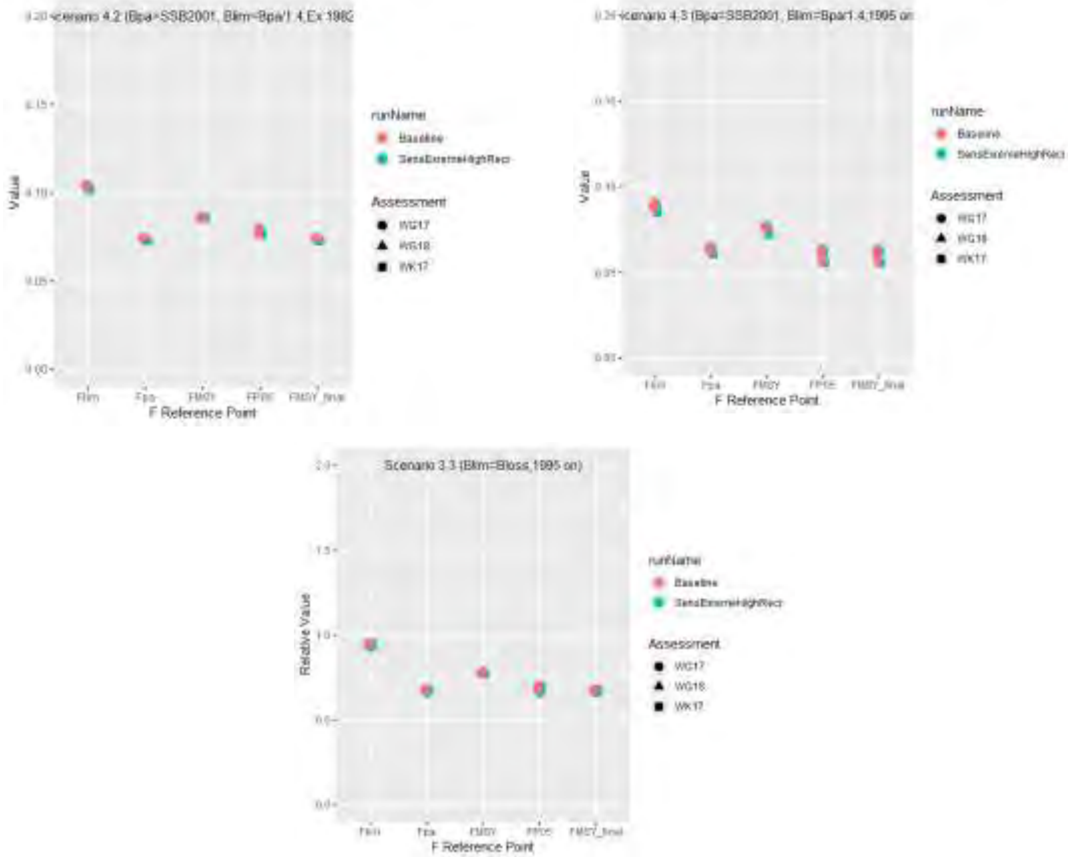


Figure 20: F reference point estimates for the baseline runs for scenarios 4.2 and 4.3 (absolute values) and 3.3 (relative values) (shown in red) and runs with a reduction in the trimming level for high recruitments (blue).

A comparison of observed recruitments and those drawn using the EqSim recruitment fit (An ECDF comparing observed recruitments from the most recent assessment (excluding 1982) with those predicted by the EqSim software for a segmented regression model with a breakpoint constrained at B_{lim} is shown in figure 21.

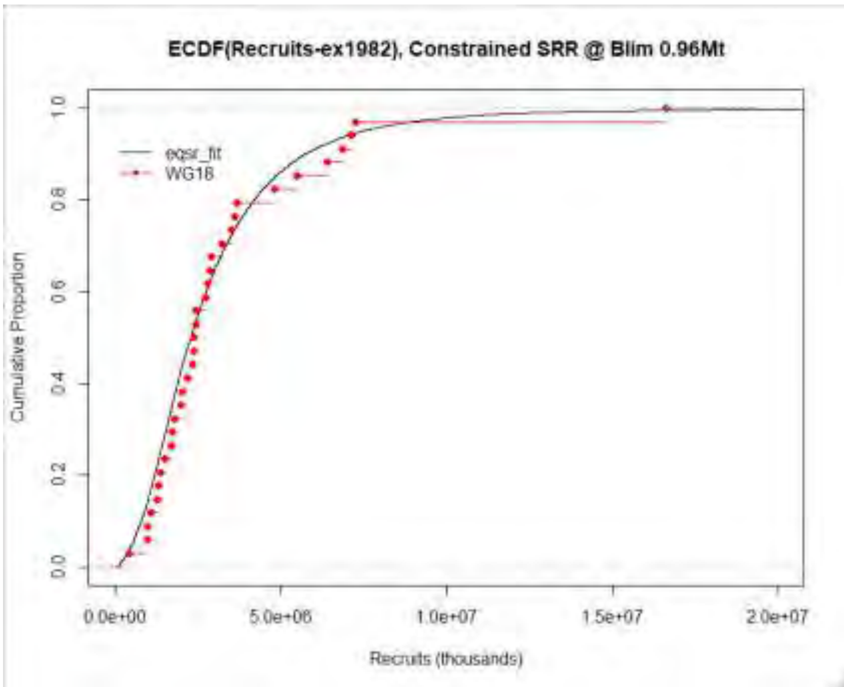


Figure 21: ECDF of observed (WG18, ex 1982) and *EqSim* modelled recruits (constrained segmented regression at B_{lim} = SSB_{2001}/1.4)

4.3 Conclusions

An analysis of the stock-recruit dataset indicates that, as found previously, there is no evident functional relationship between SSB and recruitment. Based on a bootstrap of the data, proportions of each of the Ricker, Beverton-Holt and unconstrained Segmented Regression models are variable between the 3 most recent assessments and also sensitive to the inclusion/exclusion of individual data points, in particular those associated with high recruitments. In this case, the segmented regression model is considered the most appropriate SRR formulation. The breakpoint for the segmented regression is also poorly defined. While numerical fits suggest a breakpoint either at B_{loss} (<1Mt) or approximately 2Mt, there is no evidence of systematic recruitment impairment below 2Mt with a wide range of recruitment values at stock sizes below 2Mt.

The final choice of SRR is a constrained segmented regression with a breakpoint at B_{lim}, the biomass reference point below which recruitment is considered to be impaired. For scenarios tested where the B_{lim} is considered to be below B_{loss}, the segmented regression changepoint is set at B_{loss} to be precautionary.

A B_{lim} reference point based on B_{loss} leads to significant revision in estimates between assessments due to the retrospective issue. This could be dealt with by undertaking an annual evaluation of the reference points as part of the annual update assessment and advice process. However, this approach carries the risk that, should the stock continue to decline and B_{lim} is annually updated to the new B_{loss} estimate that insufficiently robust management action will be taken (as the stock will be considered to be at B_{lim}) to prevent further decline.

The use of relative reference points was also investigated, However, the analysis implies these are also subject to annual revision, primarily because relative reference points are designed for the situation where the trends are consistent between assessments although absolute levels may not be. In this case, the trend is also modified annually i.e. the rate of reduction of SSB in recent years is falling with subsequent assessments. Additionally, the assessment would have to be moved to category 2 and this is not a decision within the remit of this exercise.

An alternative basis for B_{lim} is another SSB from a stable part of the time series such as SSB_{2001} which is the lowest SSB that gave rise to a large year class or SSB_{2003}, the B_{loss} from the stable part of the time series

Basing B_{lim} directly on either of these leads to very low estimates of F_{MSY} (0.03-0.05) and implies that the stock is currently below B_{lim}. An alternative is to propose that either of these values could be a proxy for B_{pa} on the basis that lower biomasses have been observed in the following years without a reduction in recruitment and the fishing mortality has been relatively low over the period of the assessment (above 0.15 in 1997 only). An estimate of B_{lim} is then available from $B_{pa}/1.4$ (in the absence of a robust estimate of uncertainty in SSB from the assessment). This leads to F_{MSY} values of the order of 0.06-0.08.

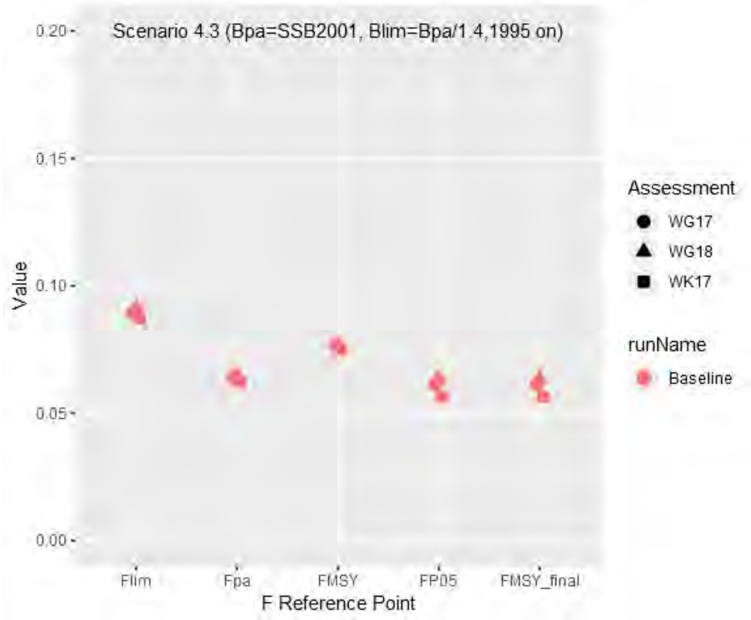
In terms of the data period upon which the SRR and stochastic simulations are parameterised, it is considered appropriate to exclude the 1982 data point, as in previous evaluations. This exercise proposes a further restricting on the time period to 1995 onwards to remove much of the effect of the 1982 recruitment on SSB estimates, leaving 2 scenarios for consideration (4.3 in which $B_{pa} = SSB_{2001}$ and 5.3 with $B_{pa} = SSB_{2003}$). The results of each of these are summarised below:

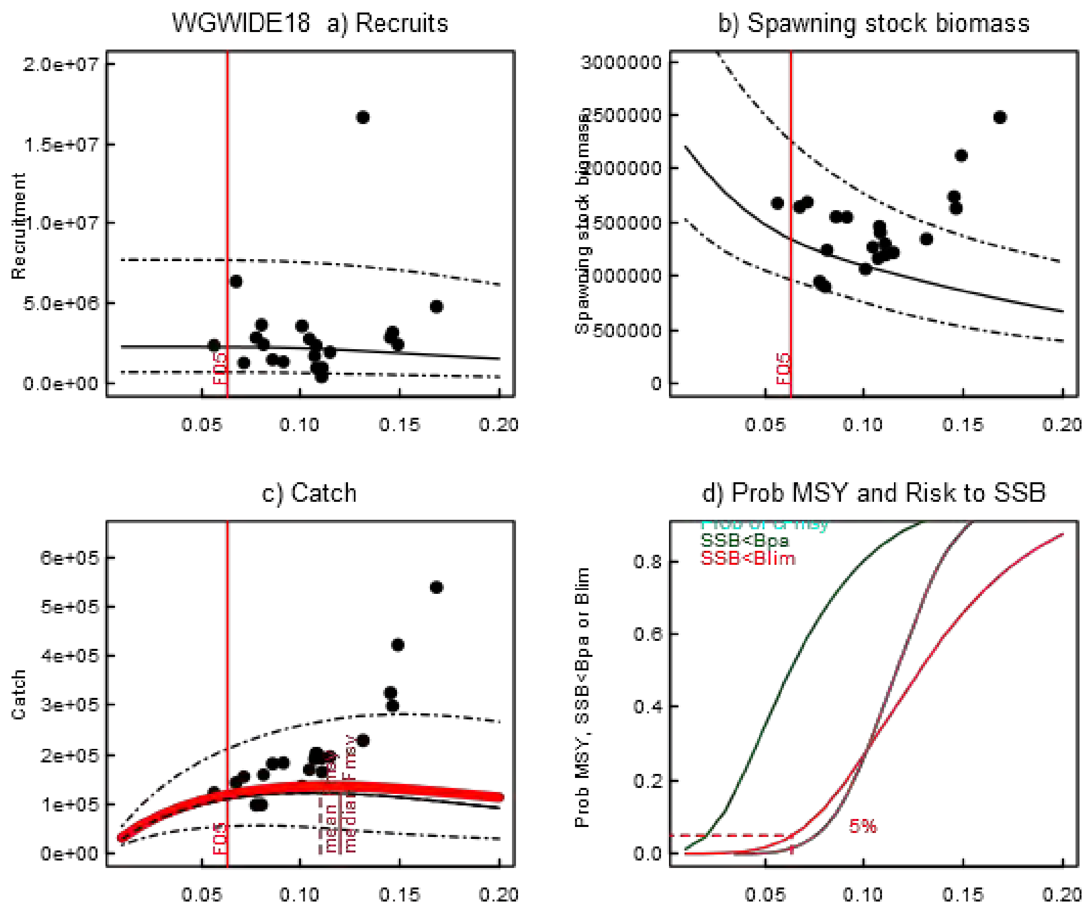
Scenario 4.3

$B_{lim} = SSB_{2001}/1.4$. 2001 is the year associated with the lowest SSB leading to a high recruitment and as such, SSB_{2001} can be considered a proxy for B_{lim}, or, in this case B_{pa} since there is no evidence of a reduction in recruitment at any observed SSB and fishing mortality has been relatively low throughout over the exploitation history. SRR data here is from 1995 onwards. This excludes not only the 1982 recruitment estimate but also a number of years during which the highest SSB values were observed, due in large part to the high 1982 recruitment. Post 1995, the contribution to the total SSB from the 1982 year-class was equivalent or lower than the maximum contribution from the 2001 year-class (~50% in 2007).

RP	WK'17	WG'17	WG'18
B_{lim}	894,178 t	941,137 t	961,897 t
B_{pa}	1,251,849 t	1,317,591 t	1,346,656 t
F_{lim}	0.087	0.089	0.092
F_{pa}	0.062	0.064	0.065
Initial F_{MSY}	0.075	0.077	0.077
MSY $B_{trigger}$	1,251,849 t	1,317,591 t	1,346,656 t
F_{P05}	0.056	0.061	0.064
Final F_{MSY}	0.056	0.061	0.064
WKWIDE17 RP Based Advice			
Fishing Mortality		0.037	0.045

RP	WK'17	WG'17	WG'18
$F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		F_{MSY} (0.056) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,251,849)	F_{MSY} (0.056) x SSB_{Jan1} (1,001,972) /$MSYB_{trigger}$ (1,251,849)
Catch		46 kt	83 kt
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.038 F_{MSY} (0.061) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,317,591)	0.048 F_{MSY} (0.064) x SSB_{Jan1} (1,000,236) /$MSYB_{trigger}$ (1,346,656)
Catch		48 kt	71 kt





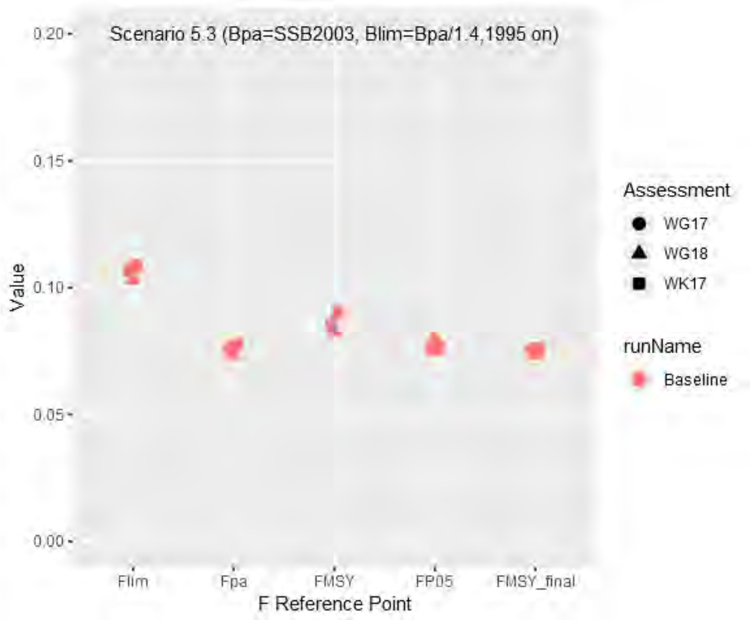
Estimates for this scenario are somewhat less stable than the equivalent scenario for the longer time series. This is because the recent period is subject to greater annual retrospective revision than the earlier years. Estimates of F_{MSY} are unchanged to the second decimal place (0.06) across all 3 assessments. The final F_{MSY} is limited by the F_{P05} value although it is similar to F_{pa}. Catches at F_{P05} are of the order of 100kt, similar to the current level and also those from the start of the time series, two periods that are not overly influenced by a large recruitment event. The current SSB (~900kt) is slightly below the B_{lim} from the WG18 assessment and significantly below the MSY $B_{trigger}$ (1.35Mt).

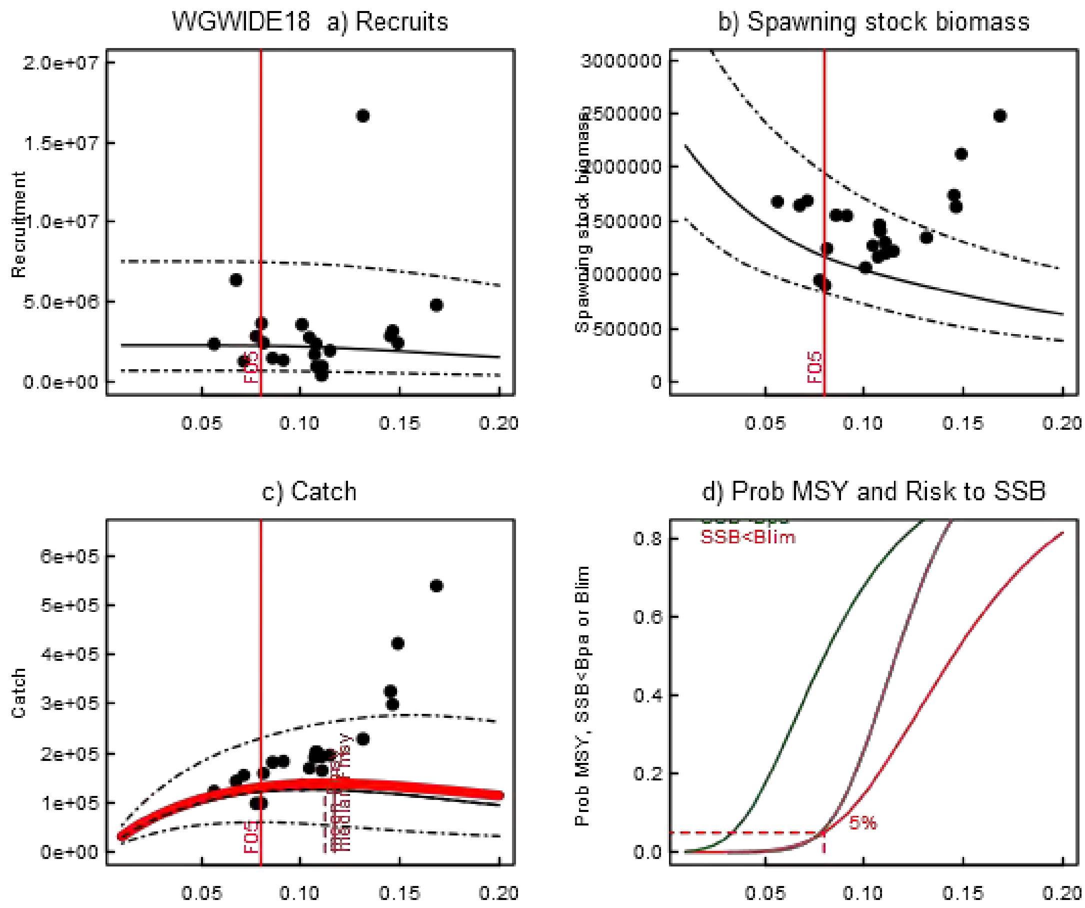
Scenario 5.3

B_{pa} = SSB_{2003} & B_{lim} = B_{pa}/1.4. SSB_{2003} is the minimum observed SSB from the stable part of the assessment output. It is greater than B_{loss}. No reduction in recruitment has been observed for the biomasses lower than this and so it is proposed as a B_{pa} point with B_{lim} = B_{pa} /1.4.

RP	WK'17	WG'17	WG'18
B_{lim}	757,668 t	810,968 t	834,480 t
B_{pa}	1,060,736 t	1,135,355 t	1,168,272 t
F_{lim}	0.107	0.106	0.103
F_{pa}	0.076	0.076	0.074
Initial F_{MSY}	0.087	0.086	0.083

RP	WK'17	WG'17	WG'18
MSY $B_{trigger}$	1,060,736 t	1,135,355 t	1,168,272 t
F_{P05}	0.075	0.076	0.079
Final F_{MSY}	0.075	0.076	0.074
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.058 F_{MSY} (0.075) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,060,736)	0.069 F_{MSY} (0.075) x SSB_{Jan1} (979,424) /$MSYB_{trigger}$ (1,060,736)
Catch		72 kt	98 kt (+36%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.055 F_{MSY} (0.076) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,135,355)	0.063 F_{MSY} (0.074) x SSB_{Jan1} (982,890) /$MSYB_{trigger}$ (1,168,272)
Catch		68 kt	90 kt (+32%)





Both of these scenarios lead to similar values of F_{MSY}. Given the lack of a functional relationship between stock and recruitment and no evident mechanism for the occurrence of strong year classes, it is not considered appropriate to select the 2001 biomass as a basis for B_{pa} /B_{lim} on the basis that it is associated with a strong recruitment event, rather the B_{loss} from the stable part of the assessment output (2003) is adopted as the most appropriate available B_{pa} value. The final set of reference points are given in table 9.

Framework	Reference Point	Value	Basis
MSY Approach	$MSYB_{trigger}$	1,168,272 t	Stochastic Simulation
	F_{MSY}	0.074	Stochastic Simulation
Precautionary Approach	B_{lim}	834,480 t	B_{pa}/1.4
	B_{pa}	1,168,272 t	SSB_{2003}
	F_{lim}	0.103	Stochastic Simulation
	F_{pa}	0.074	F_{lim}/1.4

Table 9: Revised Western Horse Mackerel reference points.

5 Exploration of an alternative assessment model (ToR c)

Since the benchmark in 2017 (ICES, 2017a), the Western horse mackerel assessment has been carried out using the Stock Synthesis method. This method allows for the incorporation of length frequency information and the dynamic estimation of growth. The Stock Synthesis assessment of western horse mackerel utilizes the length distributions of the commercial catch and from the samples obtained during the PELACUS survey, while the other information is provided as biomass (total catch, egg survey) or age specific data (recruitment index). The SS assessments that have been carried out since the benchmark in 2017 have generally shown narrow confidence intervals, yet the annual revisions in estimated stock size and fishing mortality between subsequent assessments has been substantial. These retrospective revisions are not well understood. In addition, there has been some concern about the complex nature of the input data to the Stock Synthesis method and the ability to adequately quality control the input data and model performance.

As part of the Interbenchmark of Western horse mackerel, it was agreed to explore the possibility of an alternative assessment approach to Stock Synthesis. The intention was to test methods that are more familiar to members of the WGWIDE assessment group. It was decided to use the SAM model as the alternative approach because it is already being used for mackerel and blue whiting and because it will allow for an evaluation of harvest control rules in a similar manner as is currently being applied for Western Baltic Spring Spawning herring.

The exploratory SAM assessment (https://www.stockassessment.org/setStock.php?stock=WHOM3) was initiated with the same input data as was used for the Stock Synthesis assessment of WGWIDE 2018 (ICES, 2018) with the exception of the length frequency data, which was not used. The PELACUS survey data was therefore only used as an index of biomass within SAM. When using the default SAM configuration, the assessment output displayed a strong retrospective pattern and very large uncertainty in both F and SSB. A process of fine-tuning the assessment lead to the binding of the observation variances for certain variables and the application of a fixed selectivity pattern (correlation coefficient ϱ=1 in the F random process, see Nielsen and Berg 2014) that was originally allowed to change by year (Fig. 1) (https://github.com/martinpastoors/wgwide/blob/master/R/HOM%20optimization_SAM.R).). The only aged-structured observation available for this stock is for the commercial catch. As a result, the model has a tendency to over-fit these observations, notably for the older ages. This induced important variations in fishing selectivity over time that seemed inconsistent and led to very large retrospective patterns in both SSB and F. Fixing the fishing selectivity over time resulted in a significant improvement in these retrospective patterns for only a slightly larger AIC (1217.453 vs. 1212.974 with variable relative fishing mortality). The final exploratory assessment from this exercise was selected on the basis of the trade-off between a low AIC and reduced retrospective pattern (Figures 2-5). A comparison between SS and SAM (Figure 6) indicates that the overall patterns in F, SSB and recruitment are similar although the levels appear to be somewhat different.

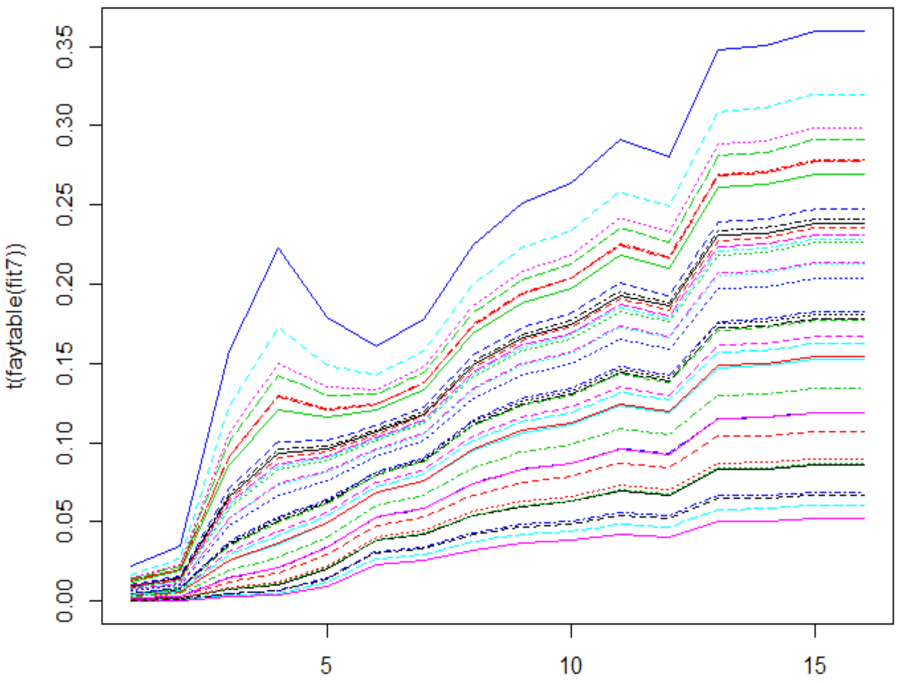


Figure 1: Western horse mackerel SAM assessment: fishing mortality at age for all years. Note that the level of F changes but not the selectivity (shape of the curve).

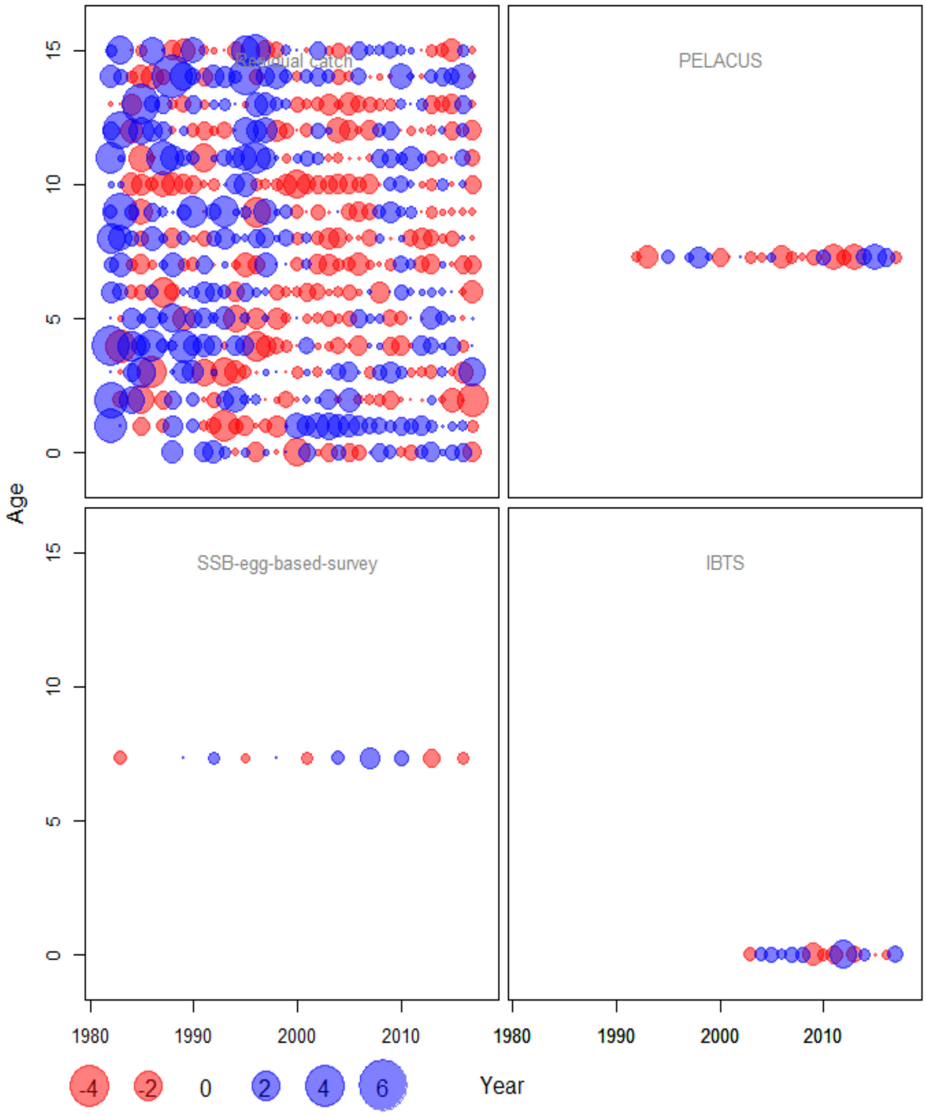


Figure 2: Western horse mackerel SAM assessment: residual patterns

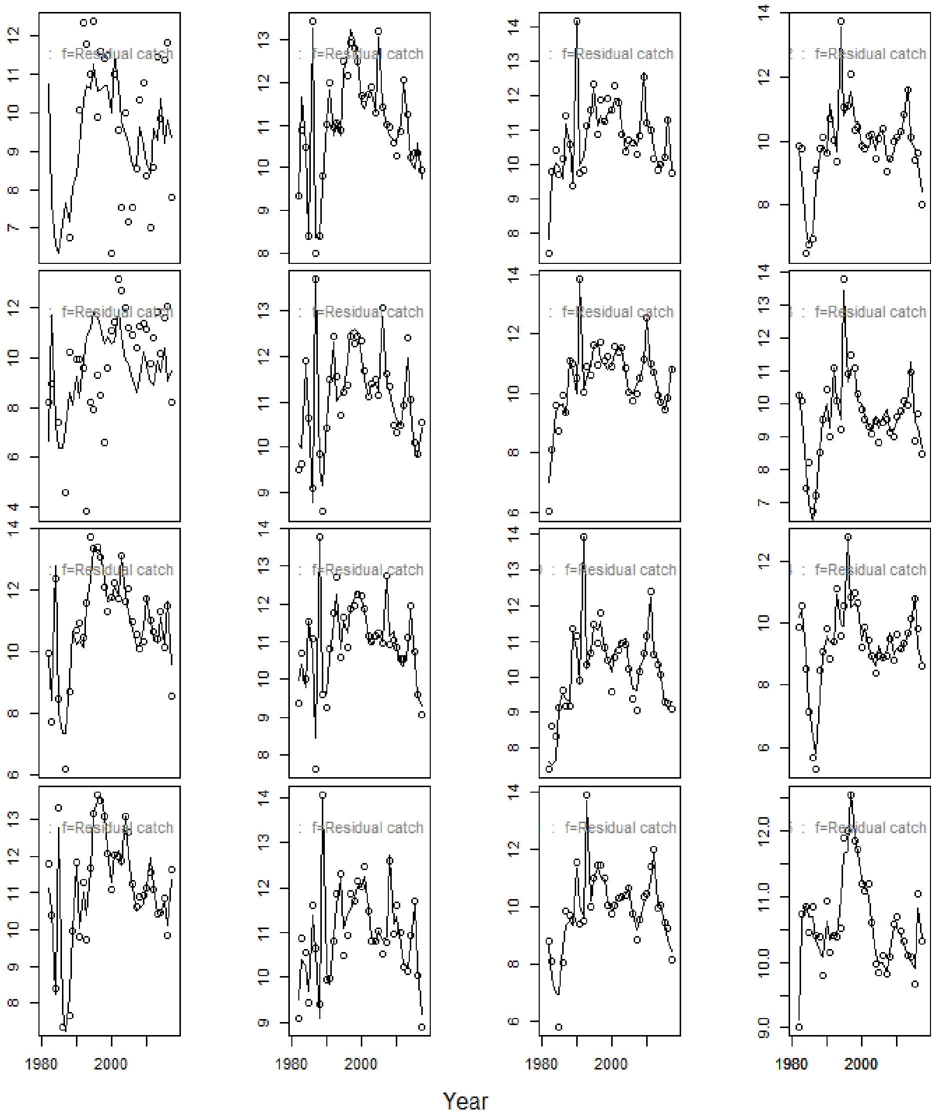


Figure 3: Western horse mackerel SAM assessment: observations and predicted values for catch at age

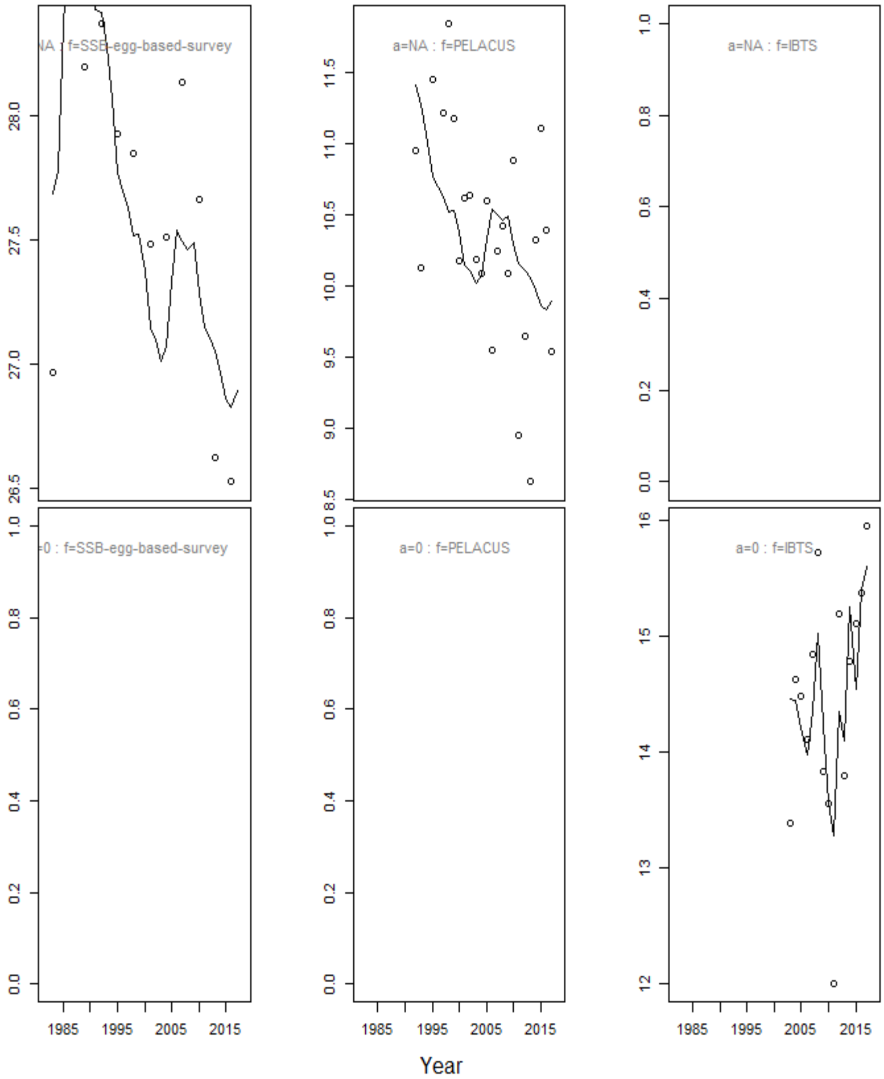


Figure 4: Western horse mackerel SAM assessment: observations and predicted values for surveys

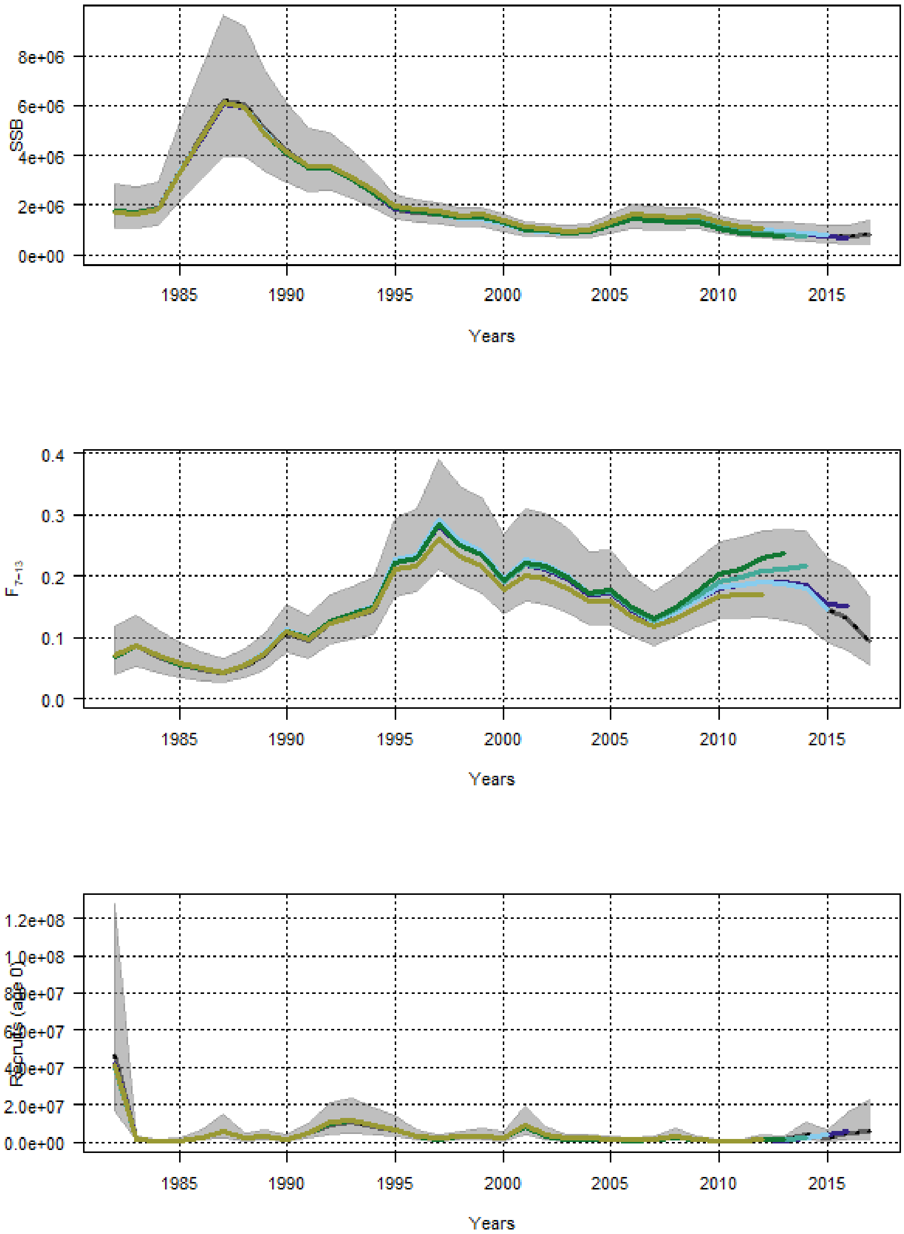


Figure 5: Western horse mackerel SAM assessment: retrospective analysis with peel of 5 years

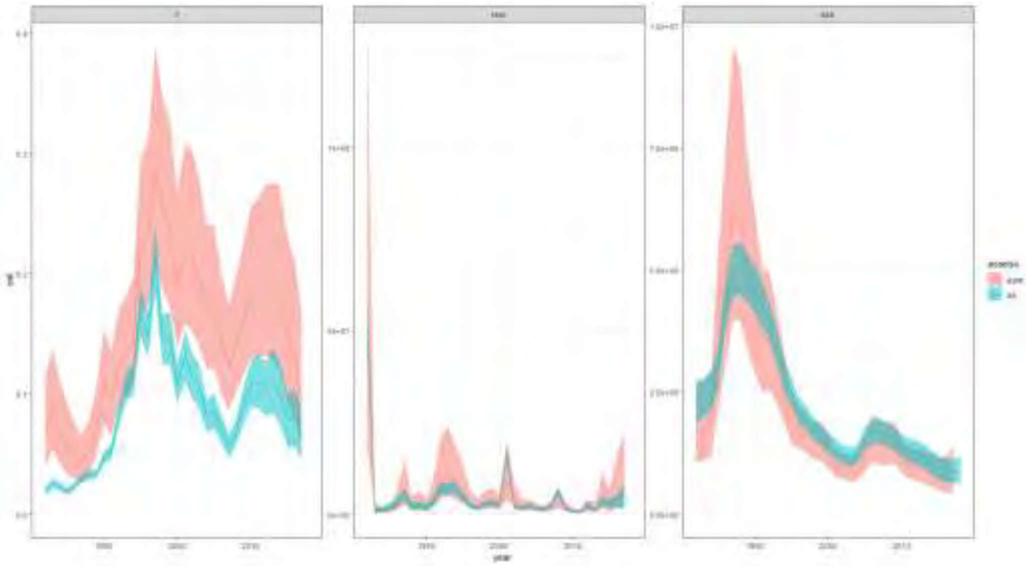


Figure 6: Western horse mackerel. Comparison of the 2018 Stock Synthesis assessment (blue) and the exploratory SAM assessment (pink)

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Annex 1: List of participants

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Annex 2: Reviewers' comments

Review of the Interbenchmark Protocol on reference points for Western horse mackerel (T*rachurus trachurus*) in subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a-c,e-k (the Northeast Atlantic) (IBPWHM)

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Thorough analyses have been conducted exploring the sensitivity of the reference points to different data choices. It is, no doubt, a complicated case for setting reference points. It is evident from the analyses that thorough consideration has been given to the specifics of the stock dynamics as well as the assessment issues (i.e. retrospective bias).

I support the decision to move away from setting biomass reference points based on very last years in the time series, which would always be shakier, compared to the historical part. I also follow the logic behind defining the 2003 SSB as Bpa rather than Blim. If the resulting Blim would get considerably below any observed SSB value, this would be a concern. However, this does not seem to be the case here (based on visual inspection).

An issue where am somewhat lacking clear strong argumentation is concerning excluding the SR time series prior to 1995. Especially, as the report states that longer time series resulted in more stable estimates of FMSY (end of chapter 4.1).Thus, the final choice of nevertheless excluding the historical part is in contradiction with this result. Also, longer time series with more contrast in the data would generally be useful for identifying any possible S-R relationship.

The report says that the years prior to 1995 are excluded due to high influence of the extraordinary 1982 recruitment estimate on SSB. I agree that the 1982 data point is appropriate to exclude. However, the report is lacking further elaboration why the information on recruitment levels that the SSB in 1983-1994 has produced is considered not relevant to use. In other words, why the fact that the SSB in these years is influenced by this one year-class makes it inappropriate to consider the subsequent recruitments that this SSB has produced. The fact that SSB is dominated by a single year-class in itself is hard to consider as a strong argument against using the corresponding recruitments. There are other cases where SSB is dominated by single year-classes (for example, the western Baltic cod in recent years).

I am not necessarily opposing the decision made by the group to omit the data prior to 1995. There a probably extensive discussions and reasoning behind, which are not well explained in this report. I am just suggesting that this should be clearer explained somewhere, as it makes some difference for FMSY. If the high biomasses observed prior to 1995 are considered unrealistic to ever reach again with "normal" recruitments, even when fishing at FMSY, this would be a valid argument not to consider the recruitments that such SSB levels have produced. Maybe this is what was actually thought, so it is just a matter of explaining it clearly.

I consider the proposed reference points appropriate for providing management advice for the stock.

Concerning future work, due to the specific characteristics of the stock with occasional high recruitment events that have significant impacts on reference points, these may need to be revisited again, when a new outstanding recruitment event will occur. Furthermore, if the issue with retrospective bias is still present in the assessment, this may need further efforts. Although the present revised reference points are not very sensitive to this issue, the stock status in relation to reference points would still be uncertain, especially when the stock estimates are in the vicinity of Blim/Bpa.

Annex 3: Tables of Results

Scenario 1.x (B_{lim}=SSB_{2001})

Absolute Values

Scenario 1.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.1.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	1,251,849 t	1,317,591 t	1,346,656 t
B_{pa}	1,722,457 t	1,812,913 t	1,852,905 t
F_{lim}	0.084	0.084	0.084
F_{pa}	0.060	0.060	0.060
Initial F_{MSY}	0.071	0.070	0.071
MSY $B_{trigger}$	1,722,457 t	1,812,913 t	1,852,905 t
F_{P05}	0.050	0.050	0.051
Final F_{MSY}	0.050	0.050	0.051
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.023 $\left(0.050 * \frac{818,082}{1,722,457}\right)$	0.026 $\left(0.050 * \frac{904,098}{1,722,457}\right)$
Catch		29 kt	39 kt (+34%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.023 $\left(0.050 * \frac{818,082}{1,812,913}\right)$	0.025 $\left(0.051 * \frac{904,098}{1,852,905}\right)$
Catch		29 kt	38 kt (+31%)

Scenario 1.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.1.2.a

RP	WK‘17	WG‘17	WG‘18
B_{lim}	1,251,849 t	1,317,591 t	1,346,656 t
B_{pa}	1,722,457 t	1,812,913 t	1,852,905 t
F_{lim}	0.067	0.066	0.065
F_{pa}	0.048	0.047	0.047
Initial F_{MSY}	0.058	0.057	0.058
MSY $B_{trigger}$	1,722,457 t	1,812,913 t	1,852,905 t
F_{P05}	0.042	0.040	0.044
Final F_{MSY}	0.042	0.040	0.044
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.020 $\left(0.042 * \frac{818{,}082}{1{,}722{,}457}\right)$	0.025 $\left(0.042 * \frac{1{,}020{,}214}{1{,}722{,}457}\right)$
Catch		25 kt	37 kt (+48%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.018 $\left(0.040 * \frac{818{,}082}{1{,}812{,}913}\right)$	0.024 $\left(0.044 * \frac{1{,}021{,}952}{1{,}852{,}905}\right)$
Catch		23 kt	36 kt (+57%)

Scenario 1.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.1.3.a

RP	WK'17	WG'17	WG'18
B_{lim}	1,251,849 t	1,317,591 t	1,346,656 t
B_{pa}	1,722,457 t	1,812,913 t	1,852,905 t
F_{lim}	0.054	0.059	0.059
F_{pa}	0.038	0.042	0.042
Initial F_{MSY}	0.048	0.053	0.052
MSY $B_{trigger}$	1,722,457 t	1,812,913 t	1,852,905 t
F_{P05}	0.022	0.030	0.029
Final F_{MSY}	0.022	0.030	0.029
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.010 $\left(0.022 * \frac{818,082}{1,722,457}\right)$	0.013 $\left(0.022 * \frac{1,031,519}{1,722,457}\right)$
Catch		12 kt	20 kt (+67%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.014 $\left(0.030 * \frac{818,082}{1,812,913}\right)$	0.016 $\left(0.029 * \frac{1,026,300}{1,852,905}\right)$
Catch		18 kt	25 kt (+38%)

Relative Values

Scenario 1.2 (Full time series ex 1982)

Table A.1.2.r

RP	WK17	WG17	WG18
B_{lim}	0.556	0.570	0.581
B_{pa}	0.766	0.785	0.800
F_{lim}	0.665	0.709	0.736
F_{pa}	0.475	0.506	0.526
Initial F_{MSY}	0.582	0.620	0.649
MSY $B_{trigger}$	0.766	0.785	0.800
F_{P05}	0.416	0.433	0.495
Final F_{MSY}	0.416	0.433	0.495
Mean SSB	2,201,415 t	2,265,624 t	2,274,957 t
Mean FBar	0.098	0.090	0.086
MSY $B_{trigger}$	1,722,457 t	1,735,468 t (0.766*2,265,624)	1,742,617 (0.766*2,274,957)
F_{MSY}	0.042	0.037 (0.416*0.090)	0.036 (0.416*0.086)
F Advice		0.017 F_{MSY} (0.037) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,735,468)	0.021 F_{MSY} (0.036) x SSB_{Jan1} (1,023,691) /$MSYB_{trigger}$ (1,742,957) (2018 catch = 21 kt)
Catch Advice		21 kt	32 kt (+52%)
Original Advice		117 kt	145 kt (+24%)

Scenario 1.3 (1995 on)

Table A.1.3.r

RP	WK17	WG17	WG18
B_{lim}	0.917	0.908	0.908
B_{pa}	1.261	1.249	1.249
F_{lim}	0.411	0.507	0.534
F_{pa}	0.294	0.362	0.381
Initial F_{MSY}	0.372	0.452	0.475
MSY $B_{trigger}$	1.261	1.249	1.249
F_{P05}	0.171	0.255	0.266
Final F_{MSY}	0.171	0.255	0.266
Mean SSB	1,331,952 t	1,421,582 t	1,456,360 t
Mean FBar	0.129	0.116	0.109
MSY $B_{trigger}$	1,722,457 t	1,792,615 t (1.261*1,421,582)	1,836,470 t (1.261*1,456,360)
F_{MSY}	0.022	0.020 (0.171*0.116)	0.019 (0.171*0.109)
F Advice		0.009 F_{MSY} (0.020) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,792,615)	0.011 F_{MSY} (0.019) x SSB_{Jan1} (1,031,519) /$MSYB_{trigger}$ (1,836,470) (2018 catch = 12kt)
Catch Advice		12 kt	16 kt (+33%)
Original Advice		117 kt	145 kt (+24%)

Scenario 2.x (B_{lim}= B_{pa}/1.4, B_{pa} = B_{loss})

Absolute Values

Scenario 2.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.2.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	472,798 t	575,158 t	622,865 t
B_{pa}	661,917 t	805,221 t	872,011 t
F_{lim}	0.191	0.164	0.153
F_{pa}	0.136	0.117	0.109
Initial F_{MSY}	0.131	0.113	0.109
MSY $B_{trigger}$	661,917 t	805,221 t	872,011 t
F_{P05}	0.159	0.136	0.128
Final F_{MSY}	0.131	0.113	0.109
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.131 (SSB_{2018}>MSY $B_{trigger}$)	0.131 (SSB_{2019}>MSY $B_{trigger}$)
Catch		156 kt	169 kt (+8%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.113 (SSB_{2018}>MSY $B_{trigger}$)	0.109 (SSB_{2019}>MSY $B_{trigger}$)
Catch		135 kt	144 kt (+6%)

Scenario 2.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.2.2.a

RP	WK'17	WG'17	WG'18
B_{lim}	472,798 t	575,158 t	622,865 t
B_{pa}	661,917 t	805,221 t	872,011 t
F_{lim}	0.163	0.139	0.130
F_{pa}	0.116	0.099	0.093
Initial F_{MSY}	0.120	0.102	0.096
MSY $B_{trigger}$	661,917 t	805,221 t	872,011 t
F_{P05}	0.148	0.124	0.113
Final F_{MSY}	0.116	0.099	0.093
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.116 (SSB_{2018}>MSY $B_{trigger}$)	0.116 (SSB_{2019}>MSY $B_{trigger}$)
Catch		139 kt	153 kt (+10%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.099 (SSB_{2018}>MSY $B_{trigger}$)	0.093 (SSB_{2019}>MSY $B_{trigger}$)
Catch		120 kt	126 kt (+5%)

Scenario 2.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.2.3.a

RP	WK‘17	WG‘17	WG‘18
B_{lim}	472,798 t	575,158 t	622,865 t
B_{pa}	661,917 t	805,221 t	872,011 t
F_{lim}	0.140	0.125	0.117
F_{pa}	0.100	0.089	0.083
Initial F_{MSY}	0.101	0.091	0.087
MSY $B_{trigger}$	661,917 t	805,221 t	872,011 t
F_{P05}	0.116	0.101	0.096
Final F_{MSY}	0.100	0.089	0.083
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.100 (SSB_{2018}>MSY $B_{trigger}$)	0.100 (SSB_{2019}>MSY $B_{trigger}$)
Catch		121 kt	134 kt (+11%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.089 (SSB_{2018}>MSY $B_{trigger}$)	0.083 (SSB_{2019}>MSY $B_{trigger}$)
Catch		107 kt	114 kt (+7%)

Relative Values

Scenario 2.2 (Full time series ex 1982)

Table A.2.2.r

RP	WK17	WG17	WG18
B_{lim}	0.210	0.249	0.269
B_{pa}	0.294	0.348	0.376
F_{lim}	1.622	1.504	1.469
F_{pa}	1.158	1.075	1.049
Initial F_{MSY}	1.194	1.103	1.079
MSY $B_{trigger}$	0.294	0.348	0.376
F_{P05}	1.470	1.340	1.278
Final F_{MSY}	1.158	1.075	1.049
Mean SSB	2,201,415 t	2,265,624 t	2,274,957 t
Mean FBar	0.098	0.090	0.086
MSY $B_{trigger}$	661,917 t	666,093 t (0.294*2,265,624)	668,837 t (0.294*2,274,957)
F_{MSY}	0.116	0.104 (1.158*0.090)	0.100 (1.158*0.086)
F Advice		0.104 (SSB_{2018}>MSY $B_{trigger}$)	0.100 (SSB_{2019}>MSY $B_{trigger}$)
Catch Advice		125 kt	134 kt (+7%)
Original Advice		117 kt	145 kt (+24%)

Scenario 2.3 (1995 on)

Table A.2.3.r

RP	WK17	WG17	WG18
B_{lim}	0.346	0.396	0.420
B_{pa}	0.485	0.555	0.588
F_{lim}	1.076	1.064	1.058
F_{pa}	0.768	0.760	0.756
Initial F_{MSY}	0.772	0.780	0.786
MSY $B_{trigger}$	0.485	0.555	0.588
F_{P05}	0.888	0.862	0.873
Final F_{MSY}	0.768	0.760	0.756
Mean SSB	1,331,952 t	1,421,582 t	1,456,360 t
Mean FBar	0.129	0.116	0.109
MSY $B_{trigger}$	661,917 t	689,467 t (0.485*1,421,582)	706,335 t (0.485*1,456,360)
F_{MSY}	0.100	0.089 (0.768*0.116)	0.084 (0.768*0.109)
F Advice		0.089 (SSB_{2018}>MSY $B_{trigger}$)	0.084 (SSB_{2019}>MSY $B_{trigger}$)
Catch Advice		107 kt	116 kt (+8%)
Original Advice		117 kt	145 kt (+24%)

Scenario 3.x (B_{lim}=B_{loss})

Absolute Values

Scenario 3.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.3.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	661,917 t	805,221 t	872,011 t
B_{pa}	910,752 t	1,107,928 t	1,199,827 t
F_{lim}	0.173	0.149	0.140
F_{pa}	0.123	0.107	0.100
Initial F_{MSY}	0.130	0.116	0.108
MSY $B_{trigger}$	910,752 t	1,107,928 t	1,199,827 t
F_{P05}	0.128	0.107	0.099
Final F_{MSY}	0.123	0.107	0.099
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.110 $\left(0.123 * \frac{818{,}082}{910{,}752}\right)$	0.123 (SSB_{Jan1}>MSY $B_{trigger}$)
Catch		132 kt	162 kt (+23%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.079 $\left(0.107 * \frac{818{,}082}{1{,}107{,}928}\right)$	0.079 $\left(0.099 * \frac{958{,}648}{1{,}199{,}827}\right)$
Catch		96 kt	110 kt (+15%)

Scenario 3.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.3.2.a

RP	WK'17	WG'17	WG'18
B_{lim}	661,917 t	805,221 t	872,011 t
B_{pa}	910,752 t	1,107,928 t	1,199,827 t
F_{lim}	0.149	0.128	0.118
F_{pa}	0.106	0.092	0.085
Initial F_{MSY}	0.117	0.104	0.097
MSY $B_{trigger}$	910,752 t	1,107,928 t	1,199,827 t
F_{P05}	0.118	0.098	0.093
Final F_{MSY}	0.106	0.092	0.085
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.095 $\left(0.106 * \frac{818,082}{910,752}\right)$	0.106 (SSB_{Jan1}>MSY $B_{trigger}$)
Catch		115 kt	142 kt (+23%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.068 $\left(0.092 * \frac{818,082}{1,107,928}\right)$	0.069 $\left(0.085 * \frac{969,897}{1,199,827}\right)$
Catch		83 kt	97 kt (+17%)

Scenario 3.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.3.3.a

RP	WKWIDE '17	WGWIDE '17	WGWIDE '18
B_{lim}	661,917 t	805,221 t	872,011 t
B_{pa}	910,752 t	1,107,928 t	1,199,827 t
F_{lim}	0.125	0.111	0.104
F_{pa}	0.089	0.079	0.074
Initial F_{MSY}	0.101	0.091	0.086
MSY $B_{trigger}$	910,752 t	1,107,928 t	1,199,827 t
F_{P05}	0.092	0.080	0.076
Final F_{MSY}	0.089	0.079	0.074
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.080 $\left(0.089 * \frac{818{,}082}{910{,}752}\right)$	0.089 (SSB_{Jan1}>MSY $B_{trigger}$)
Catch		98 kt	123 kt (+26%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.058 $\left(0.079 * \frac{818{,}082}{1{,}107{,}928}\right)$	0.060 $\left(0.074 * \frac{979{,}424}{1{,}199{,}827}\right)$
Catch		72 kt	86 kt (+19%)

Relative Values

Scenario 3.2 (Full time series ex 1982)

Table A.3.2.r

RP	WK17	WG17	WG18
B_{lim}	0.294	0.348	0.376
B_{pa}	0.405	0.479	0.518
F_{lim}	1.483	1.388	1.336
F_{pa}	1.059	0.991	0.954
Initial F_{MSY}	1.162	1.124	1.094
MSY $B_{trigger}$	0.405	0.479	0.518
F_{P05}	1.179	1.064	1.047
Final F_{MSY}	1.059	0.991	0.954
Mean SSB	2,201,415 t	2,265,624 t	2,274,957 t
Mean FBar	0.098	0.090	0.086
MSY $B_{trigger}$	910,752 t	917,578 t (0.405*2,265,624)	921,358 (0.405*2,274,957)
F_{MSY}	0.106	0.095 (1.059*0.090)	0.091 (1.059*0.086)
F Advice		0.085 F_{MSY} (0.095) x SSB_{Jan1} (818,082) /MSY$B_{trigger}$ (917,758)	0.091 SSB_{Jan1} (952,596) > MSY $B_{trigger}$ (921,358) (2018 catch = 103kt)
Catch Advice		103 kt	125 kt (+21%)
Original Advice		117 kt	145 kt (+24%)

Scenario 3.3 (1995 on)

Table A.3.3.r

RP	WK17	WG17	WG18
B_{lim}	0.485	0.555	0.588
B_{pa}	0.667	0.764	0.809
F_{lim}	0.958	0.945	0.942
F_{pa}	0.685	0.675	0.673
Initial F_{MSY}	0.773	0.775	0.779
MSY $B_{trigger}$	0.667	0.764	0.809
F_{P05}	0.707	0.682	0.689
Final F_{MSY}	0.685	0.675	0.673
Mean SSB	1,331,952 t	1,421,582 t	1,456,360 t
Mean FBar	0.129	0.116	0.109
MSY $B_{trigger}$	910,752 t	948,195 t (0.667*1,421,582)	971,392 t (0.667*1,456,360)
F_{MSY}	0.089	0.080 (0.685*0.116)	0.074 (0.685*0.109)
F Advice		0.069 F_{MSY} (0.080) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (948,195)	0.074 F_{MSY} (0.074) x SSB_{Jan1} (969,031) /$MSYB_{trigger}$ (971,392) (2018 catch = 86kt)
Catch Advice		84 kt	103 kt (+23%)
Original Advice		117 kt	145 kt (+24%)

Scenario 4.x (B_{lim}= B_{pa}/1.4, B_{pa} = SSB_{2001})

Absolute Values

Scenario 4.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.4.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	894,178 t	941,137 t	961,897 t
B_{pa}	1,251,849 t	1,317,591 t	1,346,656 t
F_{lim}	0.126	0.126	0.123
F_{pa}	0.090	0.090	0.088
Initial F_{MSY}	0.099	0.099	0.097
MSY $B_{trigger}$	1,251,849 t	1,317,591 t	1,346,656 t
F_{P05}	0.088	0.089	0.087
Final F_{MSY}	0.088	0.089	0.087
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.058 F_{MSY} (0.088) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,251,849)	0.069 F_{MSY} (0.088) x SSB_{Jan1} (979,424) /$MSYB_{trigger}$ (1,251,849)
Catch		72 kt	98 kt (+36%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.055 F_{MSY} (0.089) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,317,591)	0.063 F_{MSY} (0.087) x SSB_{Jan1} (982,890) /$MSYB_{trigger}$ (1,346,656)
Catch		68 kt	90 kt (+32%)

Scenario 4.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.4.2.a

RP	WK'17	WG'17	WG'18
B_{lim}	894,178 t	941,137 t	961,897 t
B_{pa}	1,251,849 t	1,317,591 t	1,346,656 t
F_{lim}	0.104	0.104	0.104
F_{pa}	0.074	0.074	0.074
Initial F_{MSY}	0.086	0.086	0.087
MSY $B_{trigger}$	1,251,849 t	1,317,591 t	1,346,656 t
F_{P05}	0.077	0.078	0.081
Final F_{MSY}	0.074	0.074	0.074
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.048 F_{MSY} (0.074) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,251,849)	0.059 F_{MSY} (0.074) x SSB_{Jan1} (989,826) /$MSYB_{trigger}$ (1,251,849)
Catch		60 kt	85 kt (+42%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.046 F_{MSY} (0.074) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,317,591)	0.055 F_{MSY} (0.074) x SSB_{Jan1} (992,428) /$MSYB_{trigger}$ (1,346,656)
Catch		57 kt	80 kt (+40%)

Scenario 4.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.4.3.a

RP	WK'17	WG'17	WG'18
B_{lim}	894,178 t	941,137 t	961,897 t
B_{pa}	1,251,849 t	1,317,591 t	1,346,656 t
F_{lim}	0.087	0.089	0.092
F_{pa}	0.062	0.064	0.065
Initial F_{MSY}	0.075	0.077	0.077
MSY $B_{trigger}$	1,251,849 t	1,317,591 t	1,346,656 t
F_{P05}	0.056	0.061	0.064
Final F_{MSY}	0.056	0.061	0.064
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.037 F_{MSY} (0.056) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,251,849)	0.045 F_{MSY} (0.056) x SSB_{Jan1} (1,001,972) /$MSYB_{trigger}$ (1,251,849)
Catch		46 kt	67 kt (+46%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.038 F_{MSY} (0.061) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,317,591)	0.048 F_{MSY} (0.064) x SSB_{Jan1} (1,001,104) /$MSYB_{trigger}$ (1,346,656)
Catch		47 kt	71 kt (+51%)

Relative Values

Scenario 4.2 (Full time series ex 1982)

Table A.4.2.r

RP	WK17	WG17	WG18
B_{lim}	0.397	0.407	0.415
B_{pa}	0.556	0.570	0.581
F_{lim}	1.033	1.126	1.177
F_{pa}	0.738	0.804	0.840
Initial F_{MSY}	0.851	0.933	0.978
MSY $B_{trigger}$	0.556	0.570	0.581
F_{P05}	0.762	0.841	0.909
Final F_{MSY}	0.738	0.804	0.840
Mean SSB	2,201,415 t	2,265,624 t	2,274,957 t
Mean FBar	0.098	0.090	0.086
MSY $B_{trigger}$	1,251,849 t	1,259,686 t (0.556*2,265,624)	1,264,876 t (0.556*2,274,957)
F_{MSY}	0.074	0.066 (0.738*0.090)	0.063 (0.738*0.086)
F Advice		0.043 F_{MSY} (0.066) x SSB_{Jan1} (818,082) /MSY$B_{trigger}$ (1,259,686)	0.050 F_{MSY} (0.063) x SSB_{Jan1} (995,897) /MSY$B_{trigger}$ (1,264,876)
Catch Advice		53 kt	73 kt (+38%)
Original Advice		117 kt	145 kt (+24%)

Scenario 4.3 (1995 on)

Table A.4.3.r

RP	WK17	WG17	WG18
B_{lim}	0.655	0.649	0.649
B_{pa}	0.917	0.908	0.908
F_{lim}	0.670	0.763	0.829
F_{pa}	0.479	0.545	0.592
Initial F_{MSY}	0.576	0.654	0.699
MSY $B_{trigger}$	0.917	0.908	0.908
F_{P05}	0.434	0.523	0.576
Final F_{MSY}	0.434	0.523	0.576
Mean SSB	1,331,952 t	1,421,582 t	1,456,360 t
Mean FBar	0.129	0.116	0.109
MSY $B_{trigger}$	1,251,849 t	1,303,590 t (0.917*1,421,582)	1,335,482 t (0.917*1,456,360)
F_{MSY}	0.056	0.050 (0.434*0.116)	0.047 (0.434*0.109)
F Advice		0.031 F_{MSY} (0.050) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,303,590)	0.035 F_{MSY} (0.047) x SSB_{Jan1} (1,008,049) /$MSYB_{trigger}$ (1,335,482)
Catch Advice		39 kt	52 kt (+33%)
Original Advice		117 kt	145 kt (+24%)

Scenario 5.x (B_{lim}= B_{pa}/1.4, B_{pa} = SSB_{2003})

Absolute Values

Scenario 5.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.5.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	757,668 t	810,968 t	834,480 t
B_{pa}	1,060,736 t	1,135,355 t	1,168,272 t
F_{lim}	0.15	0.145	0.144
F_{pa}	0.107	0.104	0.103
Initial F_{MSY}	0.115	0.113	0.112
MSY $B_{trigger}$	1,060,736 t	1,135,355 t	1,168,272 t
F_{P05}	0.112	0.108	0.109
Final F_{MSY}	0.107	0.104	0.103
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.083 F_{MSY} (0.107) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,060,736)	0.096 F_{MSY} (0.107) x SSB_{Jan1} (954,325) /$MSYB_{trigger}$ (1,060,736)
Catch		101 kt	132 kt (+31%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.075 F_{MSY} (0.104) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,135,355)	0.084 F_{MSY} (0.103) x SSB_{Jan1} (962,109) /$MSYB_{trigger}$ (1,168,272)
Catch		92 kt	117 kt (+27%)

Scenario 5.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.5.2.a

RP	WK'17	WG'17	WG'18
B_{lim}	757,668 t	810,968 t	834,480 t
B_{pa}	1,060,736 t	1,135,355 t	1,168,272 t
F_{lim}	0.127	0.121	0.117
F_{pa}	0.090	0.087	0.084
Initial F_{MSY}	0.103	0.097	0.093
MSY $B_{trigger}$	1,060,736 t	1,135,355 t	1,168,272 t
F_{P05}	0.101	0.097	0.096
Final F_{MSY}	0.090	0.087	0.084
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.069 F_{MSY} (0.090) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,060,736)	0.082 F_{MSY} (0.090) x SSB_{Jan1} (969,032) /$MSYB_{trigger}$ (1,060,736)
Catch		84 kt	115 kt (+37%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.063 F_{MSY} (0.087) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,135,355)	0.070 F_{MSY} (0.084) x SSB_{Jan1} (974,227) /$MSYB_{trigger}$ (1,168,272)
Catch		78 kt	99 kt (+27%)

Scenario 5.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.5.3.a

RP	WK'17	WG'17	WG'18
B_{lim}	757,668 t	810,968 t	834,480 t
B_{pa}	1,060,736 t	1,135,355 t	1,168,272 t
F_{lim}	0.107	0.106	0.103
F_{pa}	0.076	0.076	0.074
Initial F_{MSY}	0.087	0.086	0.083
MSY $B_{trigger}$	1,060,736 t	1,135,355 t	1,168,272 t
F_{P05}	0.075	0.076	0.079
Final F_{MSY}	0.075	0.076	0.074
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.058 F_{MSY} (0.075) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,060,736)	0.069 F_{MSY} (0.075) x SSB_{Jan1} (979,424) /$MSYB_{trigger}$ (1,060,736)
Catch		72 kt	98 kt (+36%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.055 F_{MSY} (0.076) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,135,355)	0.063 F_{MSY} (0.074) x SSB_{Jan1} (982,890) /$MSYB_{trigger}$ (1,168,272)
Catch		68 kt	90 kt (+32%)

Scenario 6.x (B_{lim} = SSB_{2003})

Absolute Values

Scenario 6.1 (Full time series)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.6.1.a

RP	WK'17	WG'17	WG'18
B_{lim}	1,060,736 t	1,135,355 t	1,168,272 t
B_{pa}	1,485,030 t	1,589,497 t	1,635,581 t
F_{lim}	0.103	0.103	0.098
F_{pa}	0.074	0.073	0.07
Initial F_{MSY}	0.083	0.083	0.082
MSY $B_{trigger}$	1,485,030 t	1,589,497 t	1,635,581 t
F_{P05}	0.067	0.067	0.065
Final F_{MSY}	0.067	0.067	0.065
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.037 F_{MSY} (0.067) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,485,030)	0.045 F_{MSY} (0.067) x SSB_{Jan1} (1,001,972) /$MSYB_{trigger}$ (1,485,030)
Catch		46 kt	66 kt (+43%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.034 F_{MSY} (0.067) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,589,497)	0.040 F_{MSY} (0.065) x SSB_{Jan1} (1,005,444) /$MSYB_{trigger}$ (1,635,581)
Catch		42 kt	59 kt (+40%)

Scenario 6.2 (Full time series ex 1982)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.6.2.a

RP	WK‘17	WG‘17	WG‘18
B_{lim}	1,060,736 t	1,135,355 t	1,168,272 t
B_{pa}	1,485,030 t	1,589,497 t	1,635,581 t
F_{lim}	0.082	0.080	0.080
F_{pa}	0.059	0.057	0.057
Initial F_{MSY}	0.071	0.070	0.068
MSY $B_{trigger}$	1,485,030 t	1,589,497 t	1,635,581 t
F_{P05}	0.057	0.056	0.056
Final F_{MSY}	0.057	0.056	0.056
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.031 F_{MSY} (0.057) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,485,030)	0.039 F_{MSY} (0.057) x SSB_{Jan1} (1,008,049) /$MSYB_{trigger}$ (1,485,030)
Catch		39 kt	59 kt (+51%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.029 F_{MSY} (0.056) x SSB_{Jan1} (818,082) /$MSYB_{trigger}$ (1,589,497)	0.035 F_{MSY} (0.056) x SSB_{Jan1} (1,010,655) /$MSYB_{trigger}$ (1,635,581)
Catch		36 kt	53 kt (+47%)

Scenario 6.3 (1995 on)

Absolute RP estimates based on benchmark assessment (WK17) and updated based on subsequent assessments (WG17 and WG18).

Table A.6.3.a

RP	WK'17	WG'17	WG'18
B_{lim}	1,060,736 t	1,135,355 t	1,168,272 t
B_{pa}	1,485,030 t	1,589,497 t	1,635,581 t
F_{lim}	0.068	0.069	0.068
F_{pa}	0.048	0.050	0.049
Initial F_{MSY}	0.058	0.062	0.062
MSY $B_{trigger}$	1,485,030 t	1,589,497 t	1,635,581 t
F_{P05}	0.037	0.040	0.042
Final F_{MSY}	0.037	0.040	0.042
WKWIDE17 RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.020 F_{MSY} (0.037) x SSB_{Jan1} (818,082) /MSY$B_{trigger}$ (1,485,030)	0.025 F_{MSY} (0.037) x SSB_{Jan1} (1,020,213) /MSY$B_{trigger}$ (1,485,030)
Catch		25 kt	38 kt (+52%)
Annually updated RP Based Advice			
Fishing Mortality $F_{MSY} * \frac{SSB_{Jan1}}{MSYB_{trigger}}$		0.020 F_{MSY} (0.040) x SSB_{Jan1} (818,082) /MSY$B_{trigger}$ (1,589,497)	0.026 F_{MSY} (0.042) x SSB_{Jan1} (1,020,213) /MSY$B_{trigger}$ (1,635,581)
Catch		25 kt	39 kt (+56%)

Annex 4: Resolutions

IBPWHM – Inter-Benchmark Protocol on reference points for Western Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a–c,e–k (the Northeast Atlantic)

2018/2/FRG44 An Inter-Benchmark Protocol on reference points for Western Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a-c,e-k (the Northeast Atlantic), chaired by Andrew Campbell, Ireland, will be established and work by correspondence to:

a) Review the basis of reference points and investigate the possibility of relative reference points;
b) Update, if appropriate, MSY and PA reference points;
c) Explore alternative assessment models for comparison with the current model, with a particular emphasis on reducing retrospective bias.

Stocks	Stock leader	Stock assessor
Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a-c,e-k (the Northeast Atlantic)	Jens Ulleweit	Lisa Readdy

The Inter-Benchmark Workshop will report by 15 July 2019 for the attention of ACOM.