WORKSHOP FOR HARVEST CONTROL COMPONENT OF LONG-TERM MANAGEMENT PLAN FOR ROCKALL HADDOCK (WKROCKMSE)

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i Executive summary

The meeting continued the benchmark of Rockall haddock (*Melanogrammus aeglefinus*) started at WKROCK in 2019. The workshop was tasked with calculating the reference points, evaluating the proposed NEAFC management plan special request, and providing the 2020 Advice for Rockall haddock. The workshop addressed all three Terms of Reference.

The assumptions for the reference points was revised and the reference points were updated, with F_{MSY} = 0.168, B_{lim} = 2474 t, and B_{pa} = MSY $B_{trigger}$ = 3711 t (where B_{pa} = 1.5 * B_{lim}). The forecast settings for producing annual advice was updated for the Stock Annex. Most importantly, catch in the intermediate year is constrained by the sum of expected landings from the Russian Federation and UK and Ireland quota (the previous assumption was based on status quo F). The management strategy evaluation concluded that the harvest control rules proposed for the stock are considered precautionary in the short, medium, and long term in the base and many robustness scenarios.

ii Expert group information

Expert group name	NEAFC Request for harvest control component of long-term MP for Rockall haddock (WKROCKMSE)
Expert group cycle	NA
Year cycle started	2019
Reporting year in cycle	1/1
Chair(s)	Quang Huynh, Canada
Meeting venue and dates	20–23 August 2019, Copenhagen, Denmark (seven participants

1 Introduction

2018/2/FRSG24 **NEAFC Request for harvest control component of long-term MP for Rockall haddock** (WKROCKMSE), chaired by Quang Huynh from Canada and attended by two invited external experts, Daniel Ricard from Canada (via WebEx) and Alfonso Perez Rodriguez from Norway, will meet for a four day workshop starting on the 20th August 2019 to:

a) Conduct an MSE for use in the ICES advice in 2019;
b) Re-examine and update, if appropriate, MSY and PA reference points according to ICES guidelines (see Technical document on reference points); and,
c) Update assessment and draft new advice for 2020.

Stocks	Stock assessor	Stock Coordinator
Rockall haddock Haddock (*Melanogrammus aeglefinus*) in Division 6.b (Rockall)	Vladimir Khlivnoy	Helen Dobby

The Workshop will report by 23 September 2019 for the attention of ACOM.

2 Reference points for Rockall Haddock 6.b

2.1 Background

The current, pre-2019, reference points (see below) were derived at WKMSYREF4 based on the stock assessment conducted in 2015 and followed the general guidance on deriving reference points at that time. The stock was benchmarked early in 2019 (WKROCK, ICES 2019) but during that meeting there was insufficient time to re-evaluate the MSY reference points and therefore this process has been conducted as part of the MSE meeting.

Reference Point	Value	Technical Basis
FMSY	0.20	F that provides maximum yield (Based on simulation, EqSim)
MSY Btrig-ger	10 200 t	Bpa
FMSY lower	0.13	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
FMSY upper	0.20	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY.
Blim	6800 t	Bloss from which the stock has increased (SSB in 2014 as estimated in 2019)
BPA	10 200 t	Blim x 1.5. This is considered to be the minimum SSB required to obtain a high probability (95%) of maintaining SSB above Blim, taking into account the uncertainty of the assessment
Flim	0.69	Based on simulation using segmented regression with Blim as the breakpoint (EqSim): F such that 50% probability of SSB < Blim
FPA	0.46	Flim/1.5

2.2 Input data and parameters

The first step in defining reference points is to agree the data to be used in the calculations.

2.2.1 Recruitment time period

The results from the latest stock assessment (ICES, 2019) are shown in Figure 2.1. Although there is a period of very low recruitment between 2007 and 2012, the WK agreed that there was no clear evidence of a regime change based on the recruitment per SSB (Figure 2.2) and therefore the full time-series of stock and recruit pairs was used in the estimation of biomass and F reference points (both PA and MSY). The full time-series of recruitment shows significant autocorrelation (Figure 2.3) and therefore the option to account for this feature in the estimation of the reference points was included in the EqSim analysis.

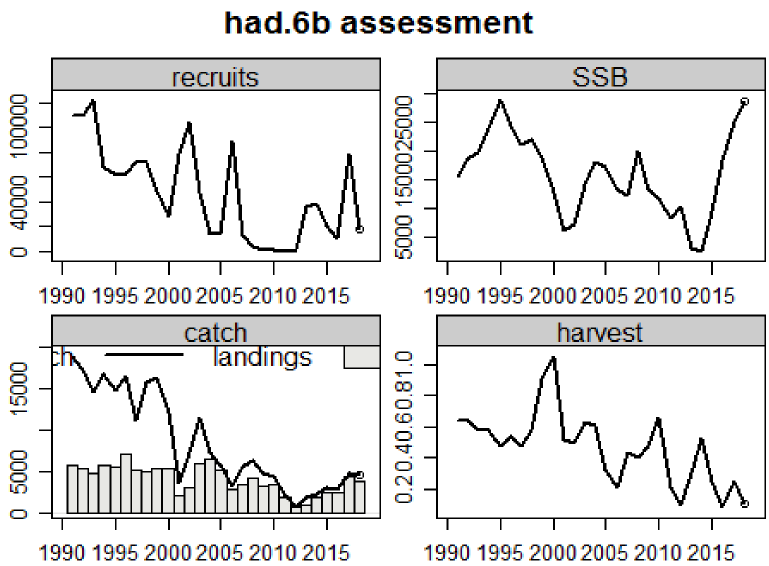

Figure 2.1. Haddock in Division 6.b. Stock assessment summary.

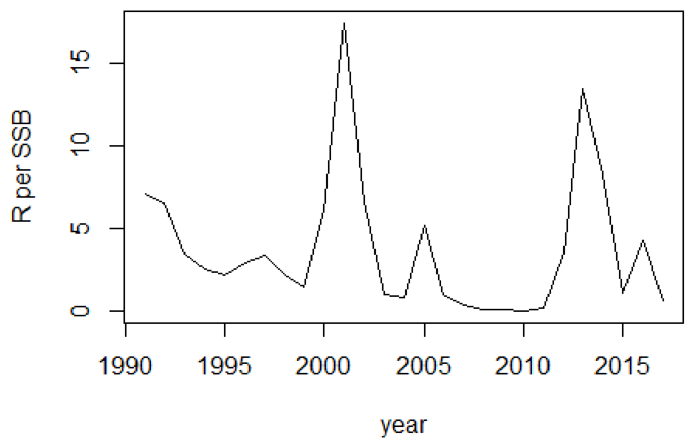

Figure 2.2. Haddock in Division 6.b. Recruitment per SSB.

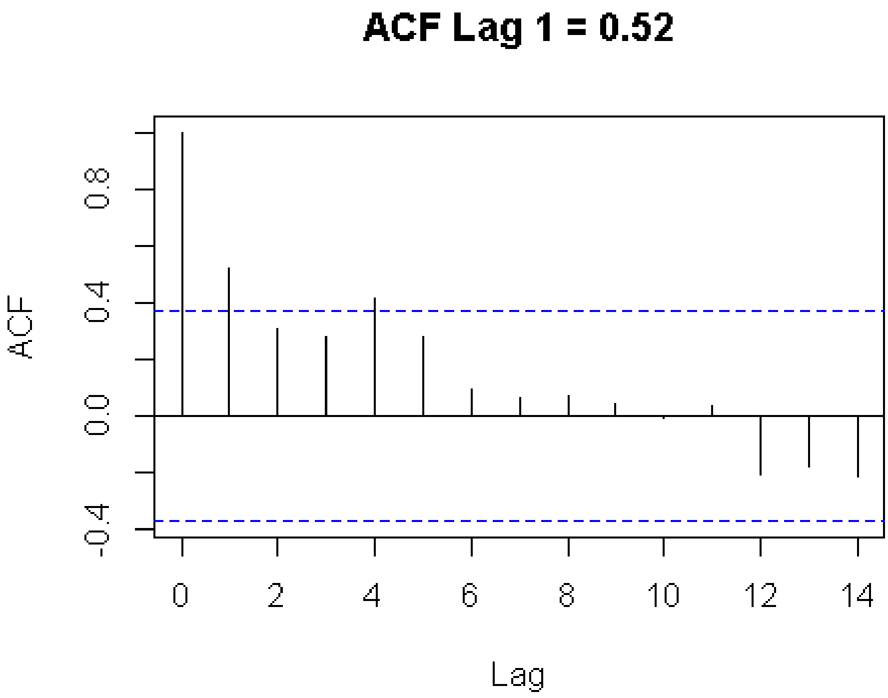

Figure 2.3. Haddock in Division 6.b. Recruitment temporal autocorrelation.

2.2.2 Biological and fishery Parameters

Eqsim provides MSY reference points based on the equilibrium distribution of stochastic projections. Stochasticity is included in biological and fishery parameters by resampling at random from the recent stock assessment data. The mean weights-at-age in the stock, catch and landings are shown below (Figures 2.4 and 2.5). Mean weights show an increasing trend in the latter half of the time-series as well as increased uncertainty (except for the stock weights which are smoothed), the latter potentially due to a combination of low sampling levels and weak (or almost absent) year classes. The increases in mean weights-at-age may be attributed to density-dependent effects as observed in other haddock stocks (with weak cohorts growing more quickly). However, it seems likely that other factors (e.g. environmental or fishery effects) have also contributed to this increase as it appears that some of the increases in the older age classes appear sooner than the increases in younger classes. For that reason the workshop considered that the biological parameters should be resampled from the most recent ten-year period as at least in the medium term, these are considered to be most representative of the stock (see WD2 for a sensitivity analysis).

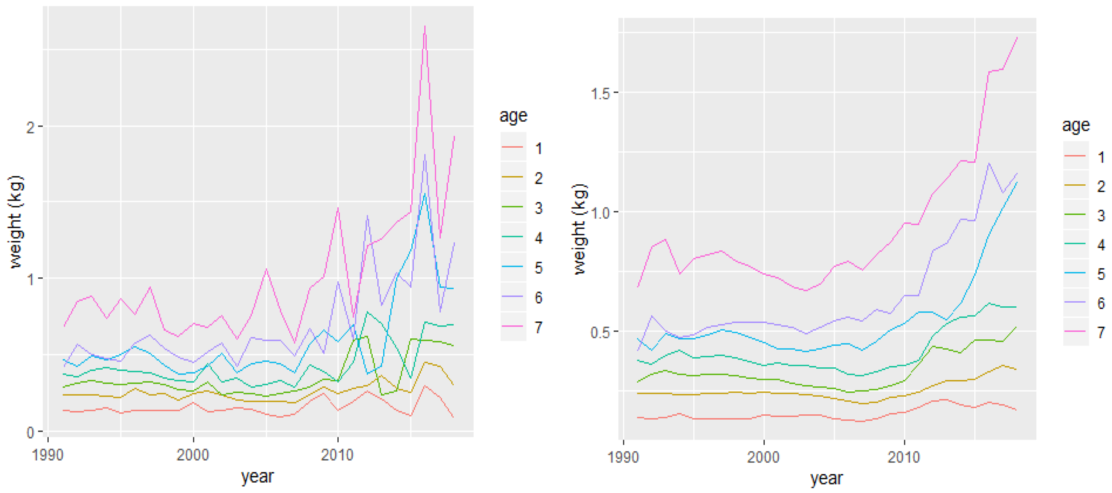

Figure 2.4. Haddock in Division 6.b. Mean weights-at-age in the catch (left) and stock (right). Note the two figures have different y-axis scales.

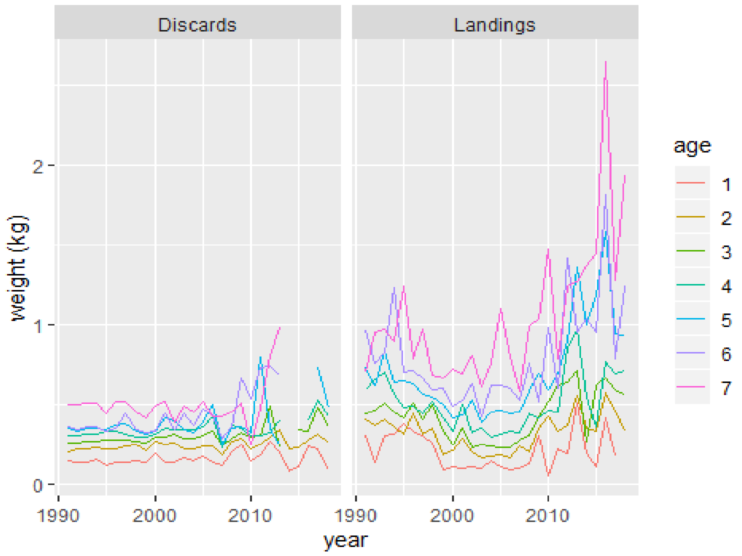

Figure 2.5. Haddock in Division 6.b. Mean weights-at-age in the discards and landings.

Fishing mortality-at-age as estimated by the assessment model is shown in Figure 2.6. The estimates are very noisy with selectivity sometimes estimated as flat-topped, sometimes dome-shaped and sometimes increasing with age. However, there do not appear to be systematic changes over time and therefore the EqSim uses the default setting and randomly samples from the most recent ten years in the simulations.

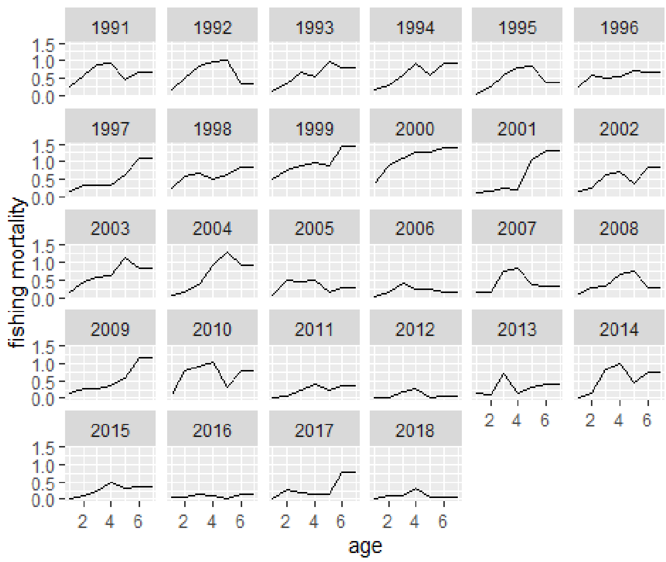

Figure 2.6. Haddock in Division 6.b. Fishing mortality-at-age.

2.2.3 Yield

In deriving F_{MSY}, a decision has to be taken about the definition of yield – ICES defines this as catch above MCRS. In the baseline model run, landings are taken to be an approximation of above MCRS catch, based on discard rates resampled from the most recent ten years which show high discarding (on average) at ages 1 and 2, lower discard rates at ages 3 to 5 and very low discard rates at age 6 and above. This decision was made on the basis that a proportion of the Scottish catches aged 3 to 5 are typically below MCRS (although this clearly varies with growth rate of particular cohorts).

Age	1	2	3	4	5	6	7+
10 year average discard rate	0.83	0.66	0.3	0.2	0.19	0.05	0.02

2.3 Defining PA reference points

The current B_{lim} is 6800 tonnes and was defined on the basis of the B_{loss} from which the stock has increased (SSB in 2001 as estimated in the 2015 assessment). According to the current ICES guidelines, defining B_{lim} requires identifying the stock type (ICES, 2017a). Using the full time-series of stock and recruit pairs, this stock would be characterised as Type 5: a stock with no evidence of impaired recruitment or with no clear relationship between stock and recruitment. In such cases the ICES guidance suggests B_{lim} is set at B_{loss}. The new B_{loss} is SSB in 2014 (2474 t) and this is much lower than the breakpoint estimated by fitting a segmented regression to the stock and recruitment data (see WD2) although the stochastic distribution of the estimated breakpoint suggests this value to be very poorly estimated (95% CI: 2051 t–83 651 t).

Other haddock stocks (Northern Shelf and Irish Sea haddock) are often classified as Type 1: spasmodic stocks, with occasional large year classes, and in such cases B_{lim} is based on the lowest SSB where large recruitment occurred. The workshop considered this classification and agreed that although R per SSB could potentially be classed as spasmodic (Figure 2.2), this did not fulfil the criteria to be classed as a Type 1 stock according to the ICES guidelines.

WKMSYREF4 (ICES, 2016) considered that the stock assessment of Rockall haddock was likely to be more uncertain than for other stocks (given the uncertainty of much of the commercial input data, due to low levels of sampling). Because of this, it was agreed that B_{pa} should be defined as 1.5 x B_{lim} or B_{lim} x exp(1.645sigma) where sigma=0.25 rather than sigma=0.2 as more typically used by ICES. This WK had no reason to deviate from the approach adopted by WKMSYREF4 which resulted in B_{pa}=3712 t.

F_{lim} estimation was performed using Eqsim (without assessment/advice error) to derive the F that has 50% probability of SSB falling below B_{lim} (1.06) using a segmented regression stock–recruitment relationship with the breakpoint fixed at B_{lim}. F_{pa} was calculated from F_{lim} using the value of sigma=0.25 for consistency with the biomass reference point calculations and results in a value of 0.71.

2.4 Calculating F_{MSY}

F_{MSY} calculations require the use of a stock–recruitment relationship. In situations where the stock–recruitment relationship is uncertain, the ICES guidance suggests using the model averaging approach but also suggests using a segmented regression with breakpoint fixed at the lowest observed SSB for Type 5 stocks. We follow the latter approach and use a segmented regression with breakpoint fixed at B_{lim}.

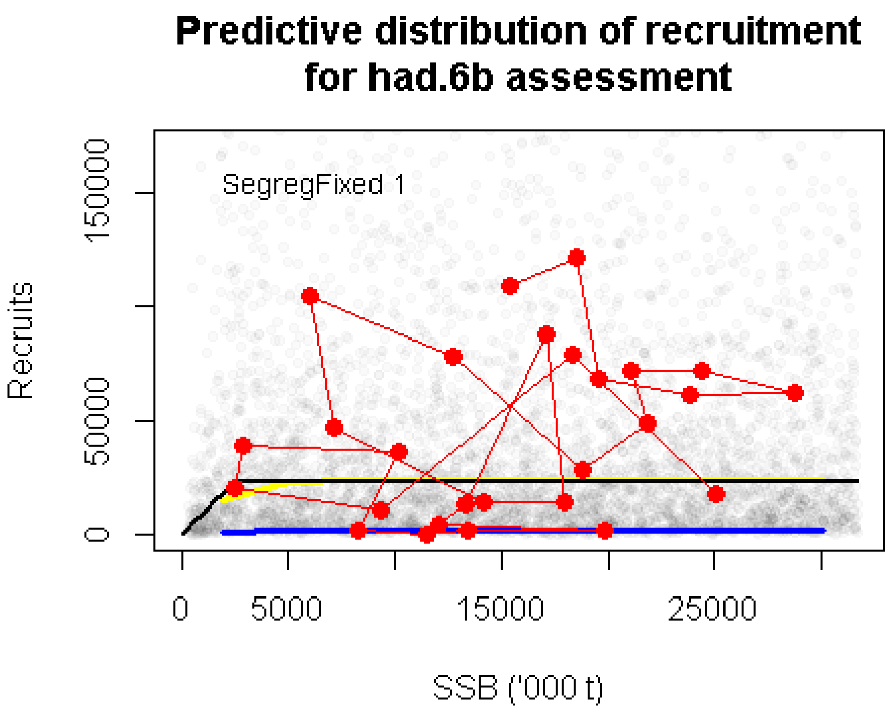

Figure 2.7. Haddock in Division 6.b. Stock–recruitment data (red points) with fitted relationship using segmented regression with fixed breakpoint (solid black line). Blue lines are 5th and 95th percentiles. Yellow line: 50th percentile.

F_{MSY} is initially calculated by running EqSim with assessment/advice error, but without application of the ICES advice rule (MSY $B_{trigger}$). To include assessment and advice error, the values Fcv=0.212 and Fphi=0.423 (default values suggested by WKMSYREF4 (ICES, 2016)) were used. The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.168 (Figure 2.8). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.268 and the lower bound 0.105. Note that the associated SSB is above the historically observed values, although recruitment and landings are within the range of historical values (See WD 2).

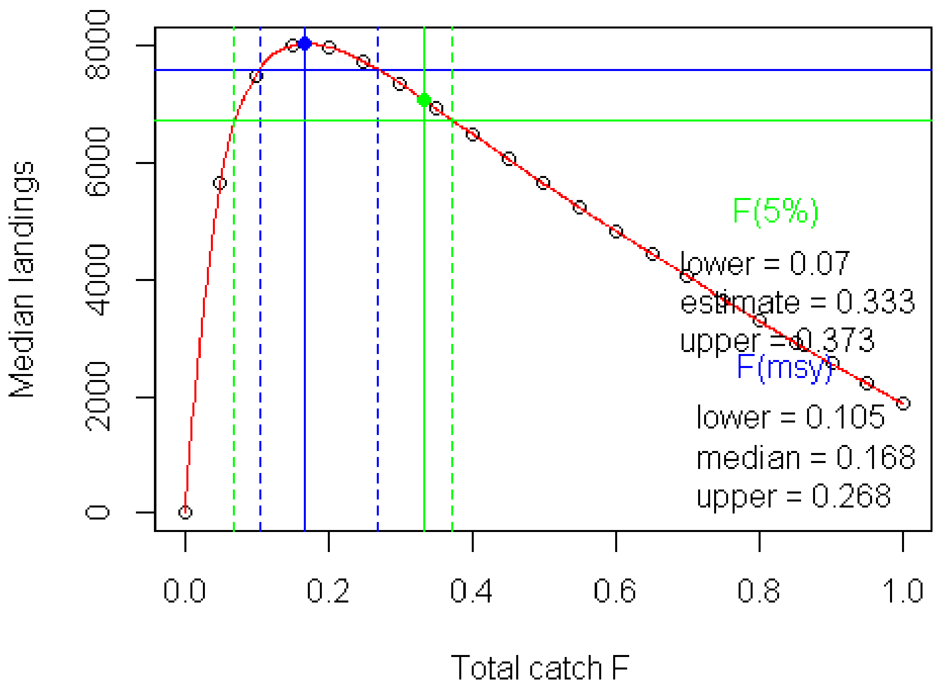

Figure 2.8. Haddock in Division 6.b. Median yield curve with estimated reference points for fixed F. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{p.05}$ estimate (solid line) and range at 95% of yield at $F_{p.05}$ (dotted line).

The next step is to set MSY $B_{trigger}$. According to ICES guidelines MSY $B_{trigger}$ is set equal to B_{pa} unless the stock has been fished below F_{MSY} for the last five years. The ICES MSY advice rule is then evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having a less than 5% annual probability of SSB <B_{lim} in the long term. (The evaluation includes assessment/advice error). The $F_{p.05}$ is calculated as 0.41 (Figure 2.9) which is greater than the F_{MSY} (and F_{MSY} upper) without the advice rule and therefore the F_{MSY} reference points are not limited by $F_{p.05}$.

Further outputs from the final EqSim runs including sensitivity testing to the input parameter assumptions can be found in WD 2.

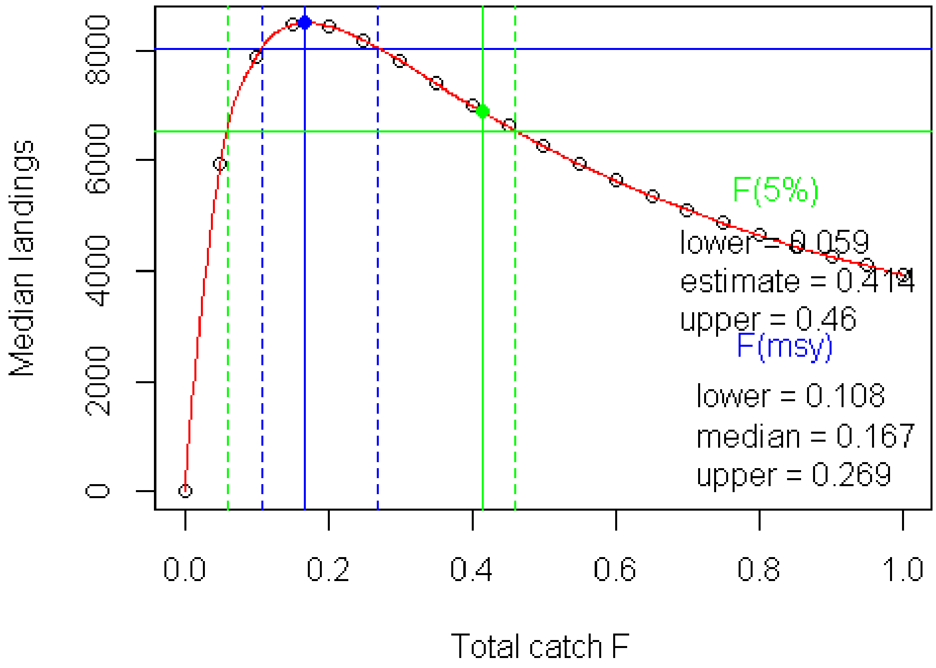

Figure 2.9. Haddock in Division 6.b. Median yield curve with estimated reference points when applying the ICES advice rule with $B_{trigger}$=3712 tonnes. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{p.05}$ estimate (solid line) and range at 95% of yield at $F_{p.05}$ (dotted line).

2.5 Proposed final reference points

The final proposed reference points are shown below. The B_{lim} estimate has decreased substantially since it was last estimated at WKMSYREF4. This is due to the fact that the stock has recovered from a very low biomass to very high levels since then (the method for defining B_{lim} has not changed). The very low B_{lim} therefore results in a high F_{lim} and F_{pa} which is significantly higher than for Northern Shelf or Irish Sea haddock and more in line with Celtic Sea haddock.

Table 2.1. Haddock in Division 6.b. Final proposed reference points (previous values in brackets).

Reference Point	Value (previous value in brackets)	Technical Basis
F_{MSY}	0.168 (0.2)	F that provides maximum yield (calculated from EqSim using Segmented regression relationships including full time-series of stock–recruit data and recruitment autocorrelation)
MSY $B_{trigger}$	3712 t (10 200 t)	B_{pa}
B_{lim}	2474 t (6800 t)	B_{loss} from which the stock has increased (SSB in 2014 as estimated in 2019)
B_{pa}	3712 t (10 200 t)	B_{lim} x 1.5
F_{lim}	1.06 (0.69)	Based on simulation using segmented regression with B_{lim} as the breakpoint (EqSim): F such that 50% probability of SSB <B_{lim}
F_{pa}	0.71 (0.46)	F_{lim}/1.5
F_{MSY} lower (without ICES AR)	0.105 (0.13)	F at 95% MSY (below F_{MSY})
F_{MSY} upper (without ICES AR)	0.27 (0.2)	F at 95 % MSY (above F_{MSY})
$F_{p.05}$ (with ICES AR)	0.41 (0.2)	F that gives a 5% probability of SSB <B_{lim} when the ICES advice rule is applied

3 Management strategy evaluation of Rockall haddock 6.b

3.1 Methods used for the Management strategy evaluation

The MSE was carried out using two methods:

- method uses FLR and the stock–recruitment relationship which was modelled as a Beverton–Holt relationship;
- method uses approach that the recruitment was randomly resampled from the actual historical recruitment estimates same as in the previous MSE ICES evaluation (ICES, 2013a).

3.2 FLR–based management strategy evaluation for Rockall haddock

3.2.1 Conditioning of operating model

MSE was performed on the basis of the ICES stock assessment 2019, applying an XSA assessment model as a full approach in the management procedure (MP). The baseline operating model (OM) is set up using the historic time-series of the XSA assessment with catch data and biological data from 1991–2018 as input. The catch data include ages 1 up to plus group 7. In the historic time-series, raw catch weights-at-age are used as input, and a 5-year moving average of catch weights is used as stock weights. All individuals across years reach full maturity-at-age 3, natural mortality is constant at 0.2 across ages and years. Mean fishing mortality (F_{bar}) is calculated for ages 2–5.

In the historical period, biological parameters and selectivity are assumed constant across replicates. Catches are deterministic. The projection period starts in year 2019 and lasts for 25 years. The MSE is run with 1000 iterations.

3.2.1.1 Recruitment

There does not appear to be a significant SSB–recruitment relationship for this stock. The relationship was modelled as a Beverton–Holt (BH) relationship using estimates of the full time-series of historical data since 1991 (Figure 3.1). Two alternative SSB–recruitment relationships, Ricker and a segmented regression, are presented for comparison (Figure 3.2). Applying the Beverton–Holt relationship, residuals are lower than for Ricker relationship, and the BH relationship is more plausible with regard to the absence of a clear reduction in recruitment at low SSB. The smoother Beverton–Holt relationship is used in the MSEs rather than a segmented regression with abrupt breakpoint (Figure 3.3). The historical assessment gives SSB in tonnes and recruitment in numbers (thousands).

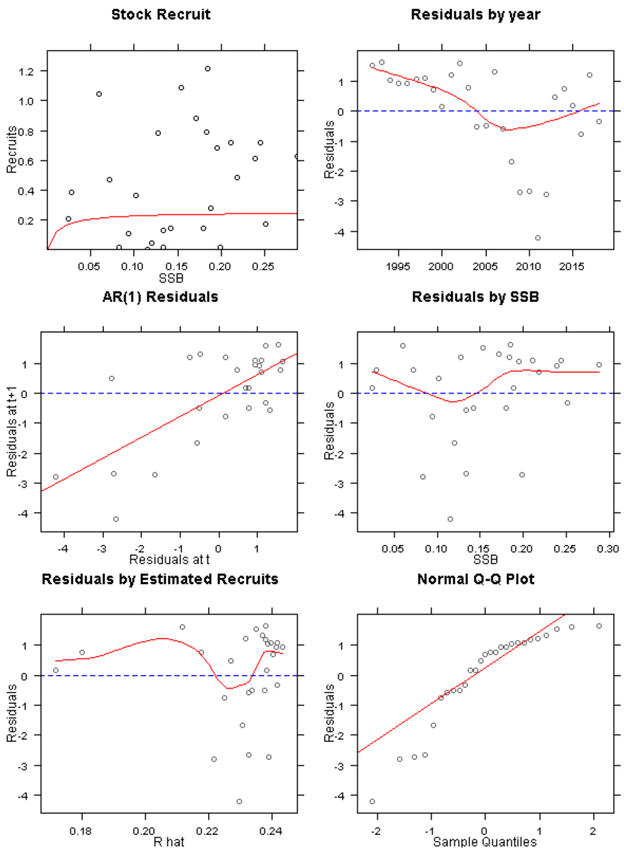

Figure 3.1. Rockall haddock in 6b. SSB–R relationship estimation (SSB and recruitment divided by 100 000), Beverton–Holt, used in the MSE.

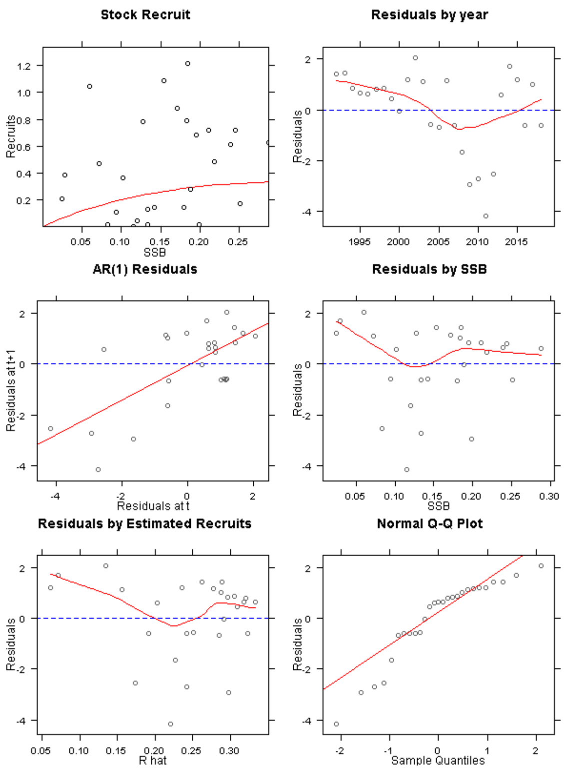

Figure 3.2. Rockall haddock in 6b. SSB–Recruitment relationship estimation (SSB and recruitment divided by 100 000), Ricker for comparison.

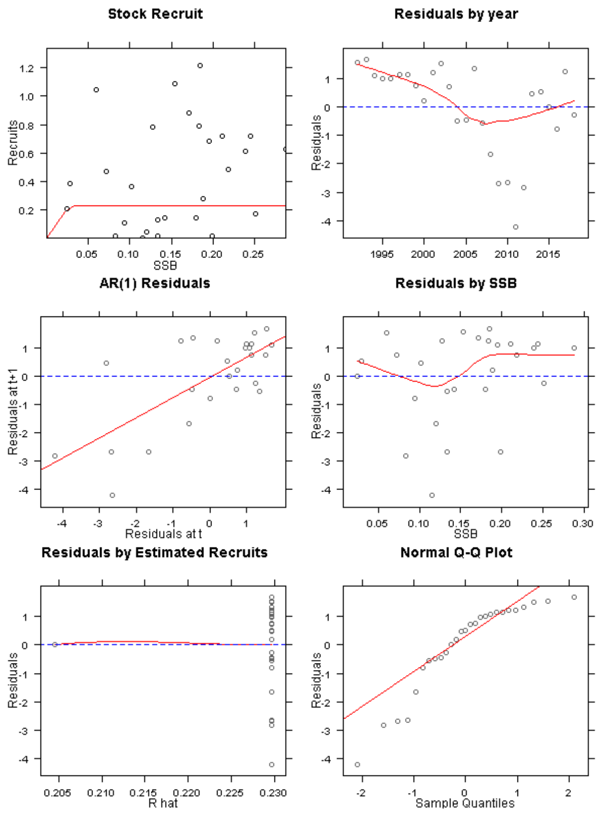

Figure 3.3. Rockall haddock in 6b. SSB–Recruitment relationship estimation (SSB and recruitment divided by 100 000), segmented regression for comparison.

The historic time-series of recruitment exhibits significant autocorrelation in lag 1 (Figure 3.4). Recruitment (with bias correction) and autocorrelation in lag 1in the projection period is given by (Thorson et al., 2014; Wiedenmann et al., 2015):

$$\mathrm{R}_{y+1} = \frac{a\mathrm{SSB}_{\mathrm{y}}}{\mathrm{b} + \mathrm{SSB}_{\mathrm{y}}} \mathrm{e}^{\left(\varepsilon_{y+1} - \frac{\sigma_{\mathrm{R}}^2}{2}\right)}$$

$$\varepsilon_{y+1} = \rho\varepsilon_y + \sqrt{1-\rho^2}\delta_{y+1}$$

where $\delta_y \sim N(0, \sigma_{\mathrm{R}}^2)$ with $\sigma_R = 0.45$, a and b the estimated parameters (Beverton–Holt relationship, Figure 3.1), ρ the estimated autocorrelation parameter at lag 1. In comparison, a lower alternative value of $\sigma_R = 0.3$ (as used in previous MSE in ICES, 2012) is not sufficient to represent observed residuals in recruitment (Figure 3.5). A value of $\sigma_R = 0.45$ ensures enough variability representing a medium level of recruitment residuals. Even though maximum values of the early historic time-series are hit only occasionally, the recent values are well covered. This appears appropriate, considering the decline in residuals in recent years. However, the lower residuals are not covered sufficiently, which are dealt with under alternative operating model with scenarios of lower recruitment level.

The parameters for the SSB–recruitment relationship were estimated and are assumed to be the same for all replicates.

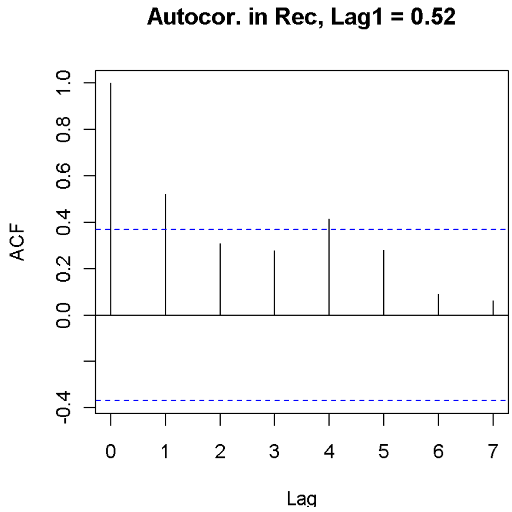

Figure 3.4. Rockall haddock in 6b. Autocorrelation in recruitment, significant at lag=1, with ρ=0.52.

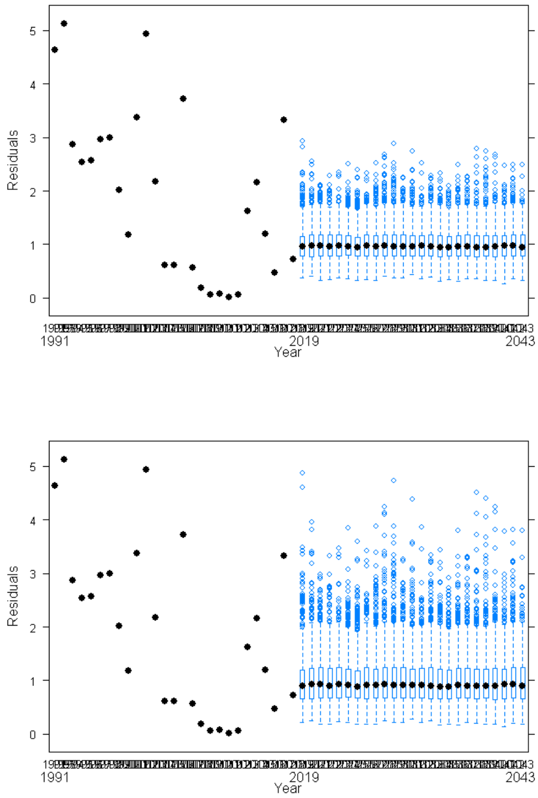

Figure 3.5. Rockall haddock in 6b. Historic recruitment residuals vs simulated residuals, left: $\sigma_R = 0.3$, right: $\sigma_R = 0.45$ (box-whisker plots on 1000 replicates, median in black).

Mean weights-at-age, natural mortality, selectivity

In the projection period, it is assumed that catch and stock weights-at-age are sampled from the recent ten years of historical data following EqSim assumptions (Figures 3.6–3.7). As in the assessment, historical stock weights-at-age are the smoothed 5-year average of catch weights-at-age. Selectivities for the projection period are sampled from estimated fishing mortalities of the recent ten years of historical data (Figure 3.8). Maturity is constant in time with full maturity from age 3 in both the historic and projected time period. Natural mortality is constant across ages and years at 0.2 in both the historic and projected time period. The proportion of F and M occurring before spawning is set to 0 throughout, with SSB being calculated in the beginning of the year.

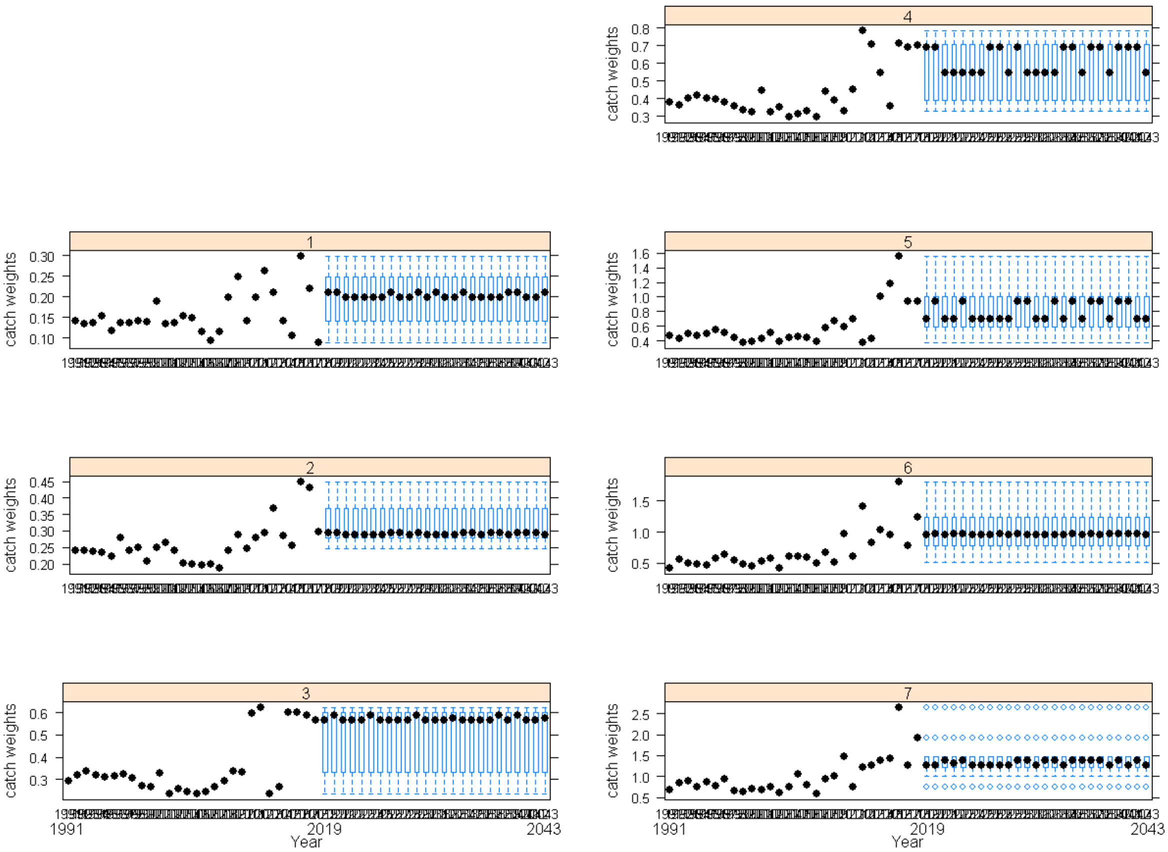

Figure 3.6. Rockall haddock in 6b. Raw catch weights-at-age in the historical period and sampled from the recent ten years in the projection period (box-whisker plots on 1000 replicates, medians in black).

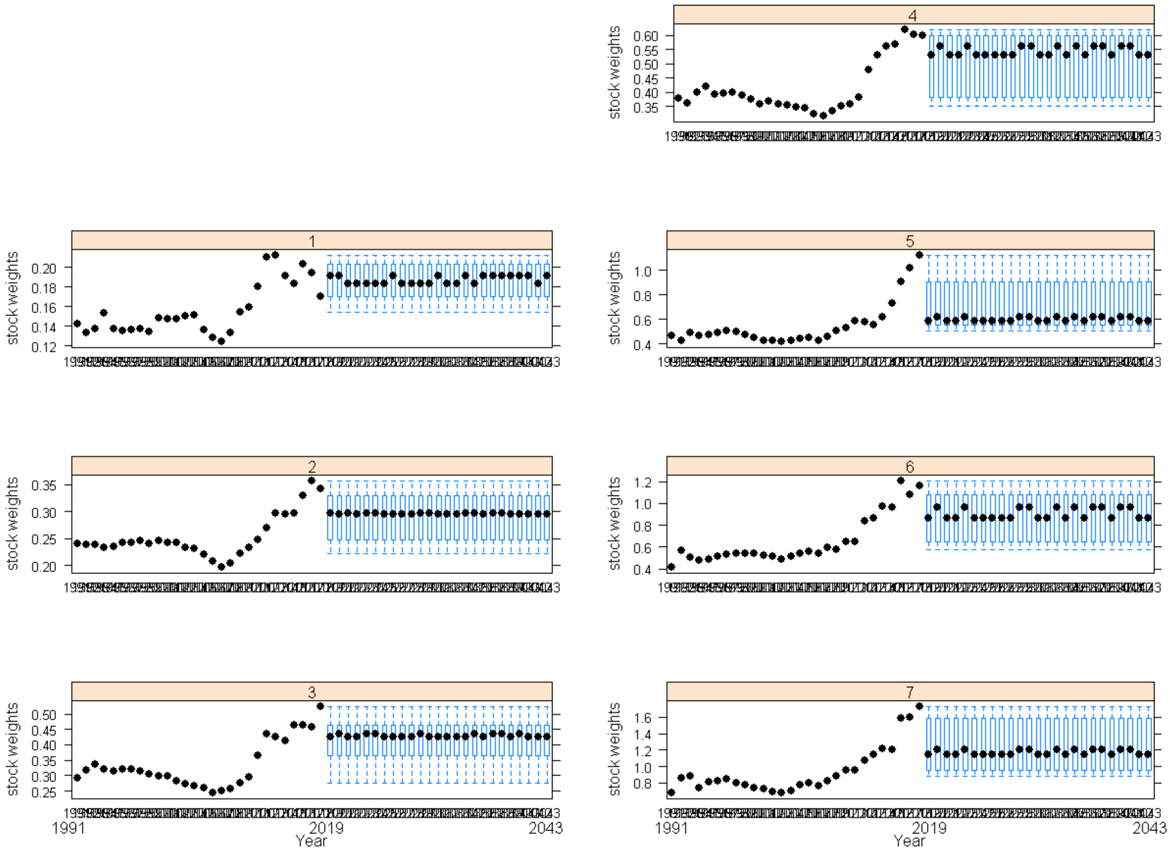

Figure 3.7. Rockall haddock in 6b. Stock weights-at-age in the historical period and sampled from the recent ten years in the projection period (box-whisker plots on 1000 replicates, medians in black).

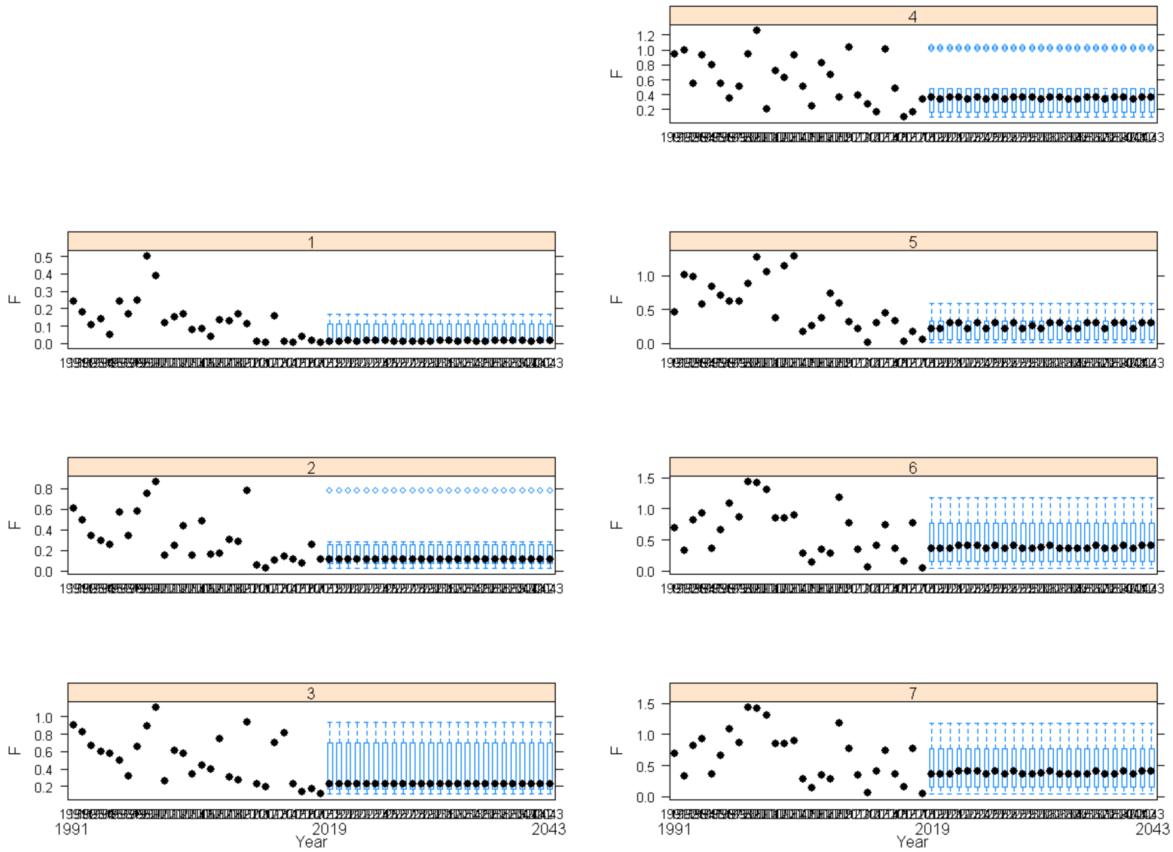

Figure 3.8. Rockall haddock in 6b. Fishing mortality-at-age in the historic times, and projection period sampled from the recent ten years (box-whisker plots on 1000 replicates, medians in black).

Survey index and observation error

The actual ICES assessment for Rockall haddock uses indices from a research-vessel survey (Scottish Q3 groundfish survey), conducted since 1991 for ages 0 to 6.

A survey index was produced for the historical period for ages 1 to 6 (Figure 3.9). Survey indices are based on stock numbers-at-age with independently varying lognormal error and constant variance (sigma=0.3). As assessment model and OM is based on ages 1 to 7+, the generated survey index excludes age 0.

A stochastic survey index for the historical period, $I_{a,y,k}$ for age a and year y in the kth iteration, is generated using estimated stock numbers and independent lognormal error:

$$I_{a,y,k} = N_{a,y} e^{\varepsilon_I - \frac{\sigma^2}{2}}$$

Where $\varepsilon_I \sim N(0, \sigma_I^2)$ and standard deviation $\sigma_i = 0.3$, which assumes constant survey catchability. Similarly for the projection period, survey deviates are produced using the same error structure and stock numbers-at-ages 1 to 6 (Figure 3.10).

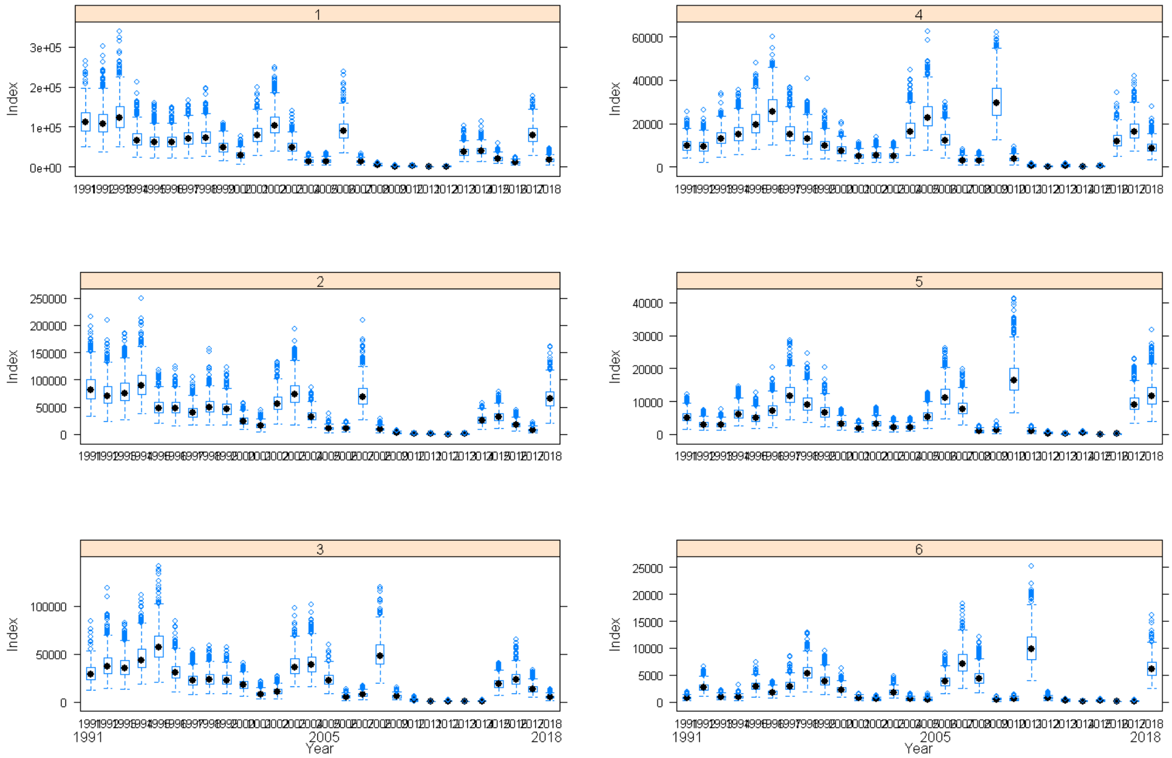

Figure 3.9. Rockall haddock in 6b. Simulated indices for the historical period (box-whisker plots on 1000 replicates, medians in black).

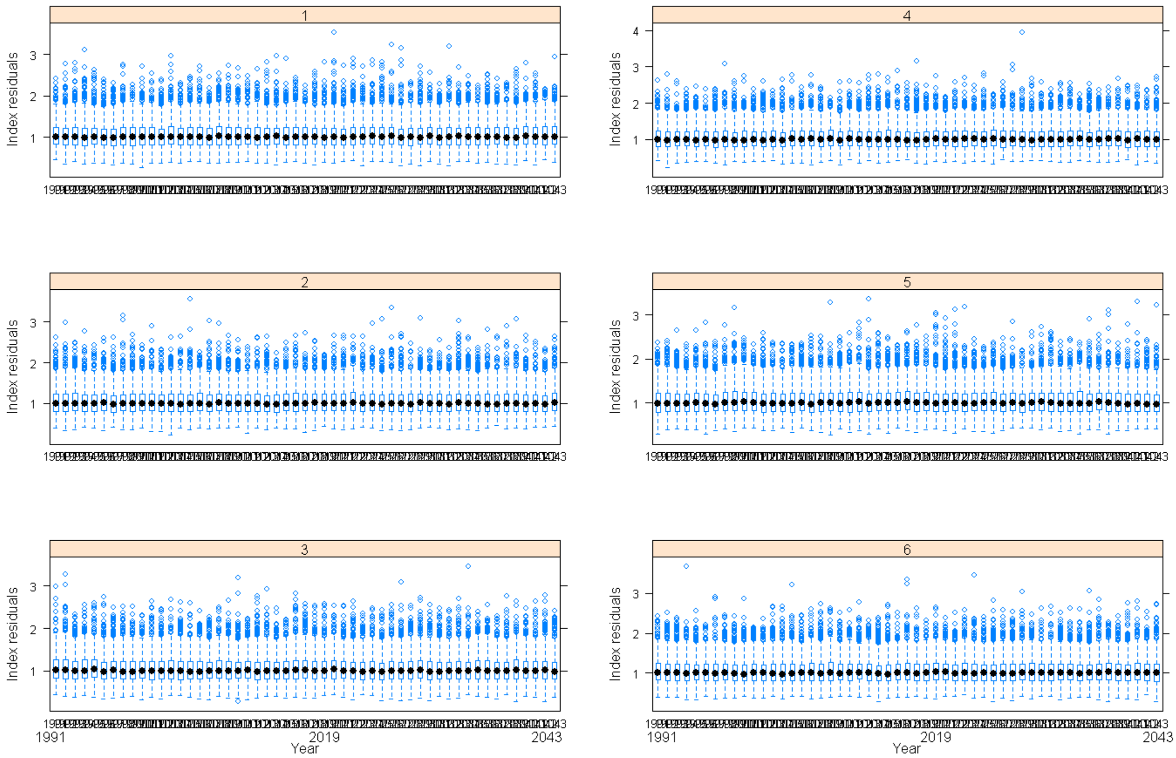

Figure 3.10. Rockall haddock in 6b. Survey deviates for the entire time-series (box-whisker plots on 1000 replicates, medians in black).

3.2.2 Alternative operating models OM1-8

The baseline OM (OM0) was the accepted benchmark assessment, coupled with a period of medium level recruitment, weights-at-age sampled from the recent historical ten years, knife-edge maturity-at-age 3, natural mortality M=0.2 for all ages and years in OM and MP, and without implementation error in the projection period.

Alternative operating models were created to test whether Harvest control rules (HCRs) are robust to assumptions of recruitment level, natural mortality, weights-at-age and implementation error (Table 3.1).

Table 3.1. Rockall haddock in 6b. Alternative OMs for robustness tests.

Alternative OM	Difference to baseline OM0 projection period
OM1	Low recruitment level
OM2	Misspecification of M (OM: M=0.3 , MP: M=0.2)
OM3	Misspecification of maturity (OM: knife-edge age 2, MP: knife-edge age 3)
OM4	Misspecification of M (OM: M=0.1, MP: M=0.2)
OM5	Weights-at-age sampled from the recent 20 years
OM6	Weights-at-age sampled from the recent 20 years + Misspecification of M (OM: M=0.3, MP: M=0.2) + Low recruitment level
OM7	Implementation error
OM8	Very low recruitment level

OM 1 and OM 8: Recruitment level

The baseline OM includes recruitment at a medium level. We assume a more pessimistic recruitment scenario in two of the alternative operating models; OM1 represents low level of recruitment; OM 8 represents very low level of recruitment in the projection period (Figure 3.11). OM1 and OM8 are run with the MSE to test the robustness of the recruitment assumption in the projection period. The parameters estimated for the baseline OM (OM0, Section 3.2.1) were adapted in a stepwise manner to create these two alternative scenarios of lower recruitment level. The value of σ_R to create residuals is assumed to be 0.45 as in the baseline OM.

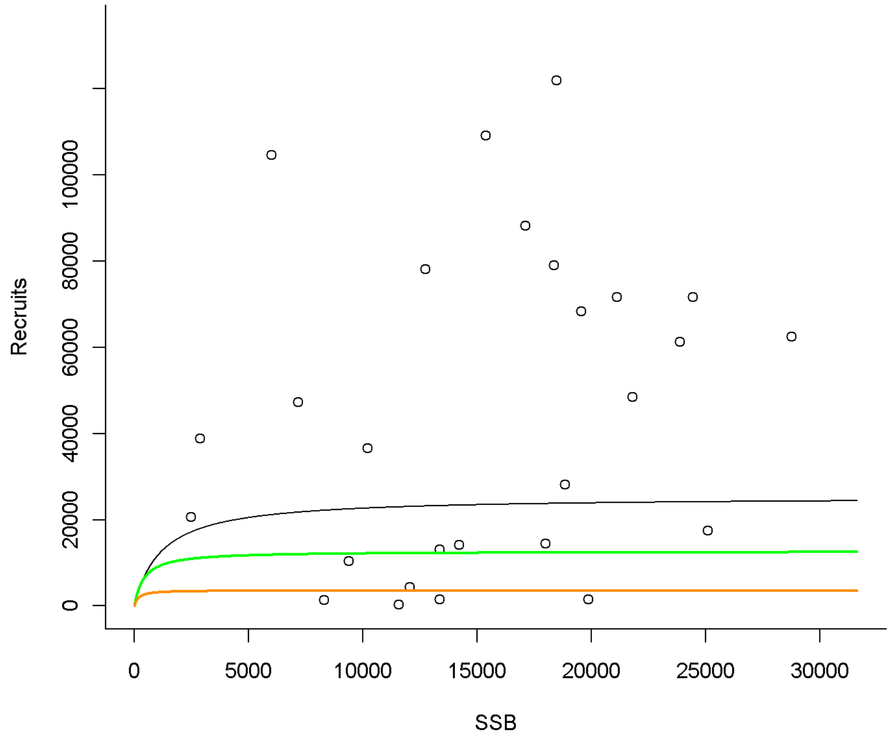

Figure 3.11. Rockall haddock in 6b. Alternative recruitment scenarios of Beverton–Holt relationship, in black estimated relationship from historic data (since 1991), in green (OM1) and orange (OM8) alternative scenario with reduced recruitment level. Recruitment in thousands, SSB in tonnes.

OM 2 and OM 4: Natural mortality

Natural mortality on the stock in the projection years could change unnoticed. While reference points and MP stay the same, alternative values of natural mortality of M=0.3 (OM2) or M=0.1 (OM4) are used for the stock dynamics in the projection period. This can be caused in reality not only by changes in predation mortality but any environmental change or stressor affecting the survival of fish.

OM 3: Maturity

Maturity in the stock is highly uncertain. In the baseline OM, it is assumed constant full maturity occurs at ages 3 and older, while individuals aged 1–2 are immature. However, it other haddock stocks earlier maturation has been observed in recent years (Filina *et al.*, (2009); Hunter *et al.* (2015)). Potential changes in the maturation probability in the stock in the projection years could occur without being immediately detected. While reference points and MP stay the same, an alternative maturity ogive (knife-edged maturity-at-age 2), is used for the stock (OM3) in the projection period.

OM 5: Catch weights and stock weights sampled from recent 20 years

Catch weights-at-age have increased in recent historical period. With high recruitment and stock size, a reduction in weights-at-age could occur in the projection period. Instead of sampling the recent ten years, in an alternative operating model weights-at-age are sampled from the recent 20 years. This allows for a stronger immediate reduction in weights-at-age in the projection period in both OM5 and respective MP (Figure 3.12–3.13).

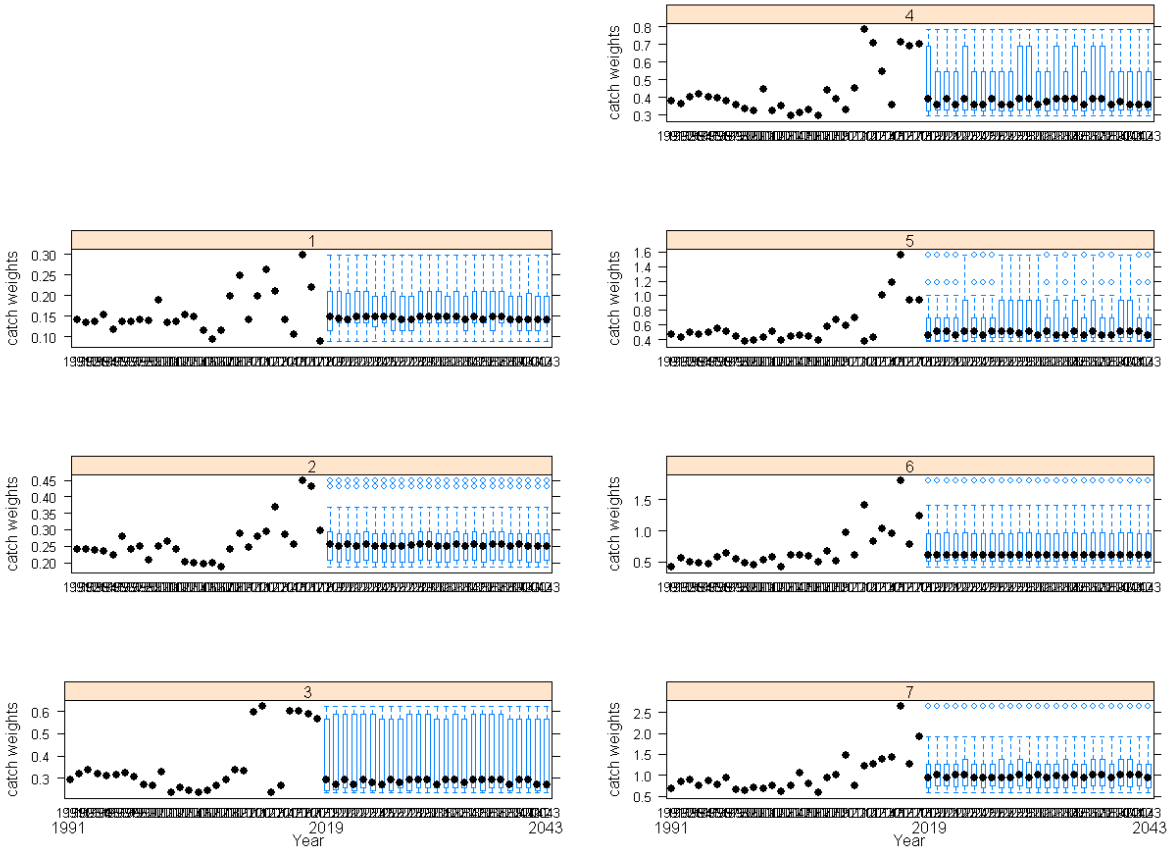

Figure 3.12. Rockall haddock in 6b. Catch weights-at-age in the historical period and sampled from the recent 20 years in the projection period (box-whisker plots on 1000 replicates, medians in black).

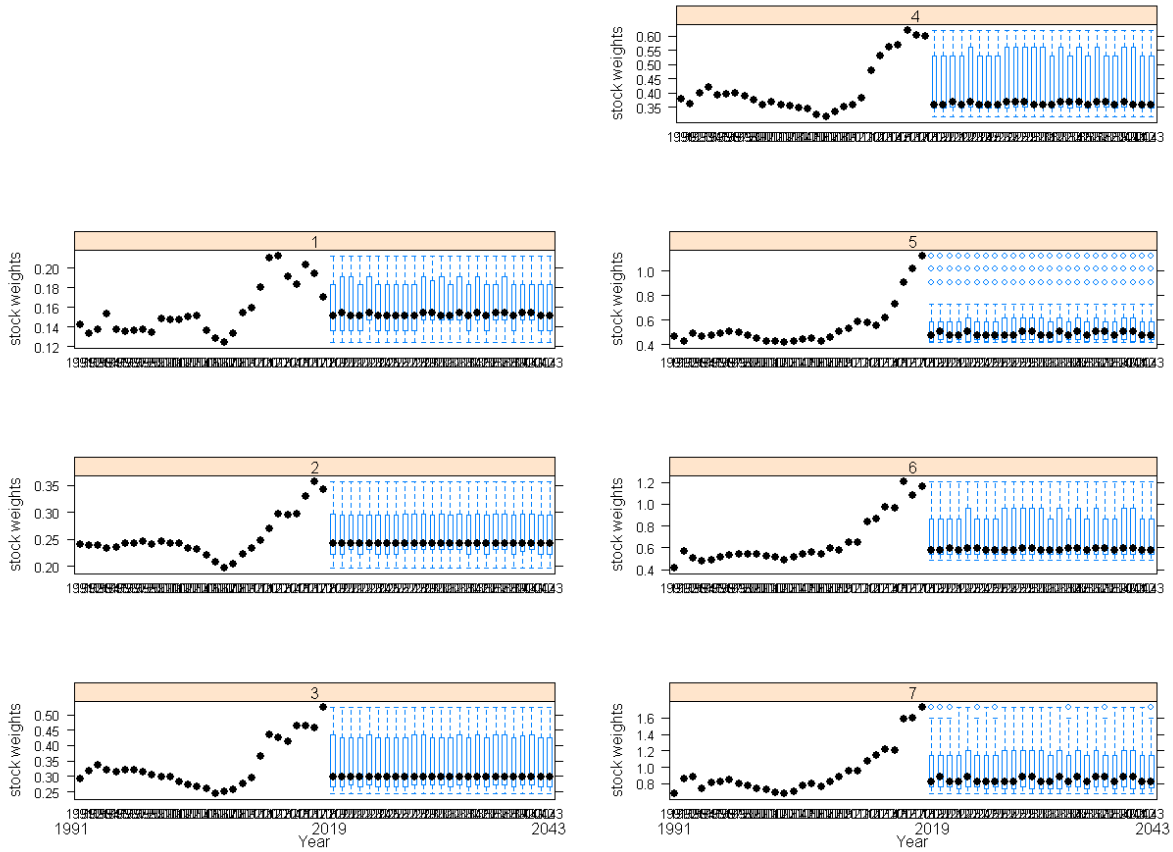

Figure 13.3. Rockall haddock in 6b. Stock weights-at-age in the historical period and sampled from the recent 20 years in the projection period (box-whisker plots on 1000 replicates, medians in black).

OM 6: Combine OM1, OM 2, OM5

An alternative operating model is run comparing performance of management options with reduced recruitment level (low level), higher natural mortality in the stock (M=0.3 in OM) and weights-at-age sampled from the recent 20 years. Here it is assumed that changes in growth (lower weights-at-age) will coincide with higher natural mortality and lower recruitment in the projection period.

OM 7: Implementation error

In reality the TAC may not be fully used, or catches can be higher than the TAC due to discards despite the landing obligation. To test for the robustness of HCRs to implementation error in catches, variability around the TAC is implemented in OM7 as a multiplicative lognormal error $\varepsilon_{Imp} \sim N(0, \sigma^2_{\text{Imp}})$ with $\sigma_{Imp} = 0.1$ on the TAC derived in the management procedure (Figure 3.14).

$$TAC_{Imp} = TACe^{\varepsilon_{Imp}}$$

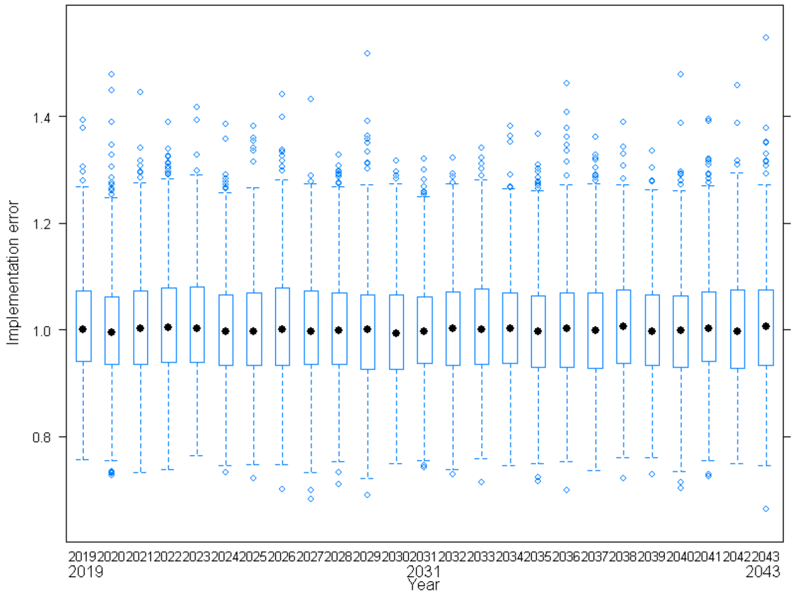

Figure 3.14. Rockall haddock in 6b. Multiplicative implementation error for the projection period.

3.2.3 Management procedure

The management procedure (MP) includes a full assessment using XSA based on total catches with the same settings as in the ICES assessment, biological data, and the simulated survey index (Section 4.1.3) and a short-term forecast. In the MP forecast, recruitment (age 1) for the intermediate, TAC year, and TAC year+1 are assumed to be the 25th percentile rank of the entire recruitment time-series since 1991, set for each iteration separately. In the actual ICES assessment, instead an RCT3 prediction (based on age 0 survey index) is used for the intermediate year and the 25th percentile rank of the historical recruitment series (since 1991). As the age 0 group is not available from the operating model in the MSE projection, the 25th rank percentile is used in the intermediate year MP forecast. In the forecast, averages of the most recent three years of biological parameters (stock weights-at-age, natural mortality, proportion mature at-age, and proportion of F and M occurring before spawning) and fishing selectivity were used. Due to a recent outlier in raw catch weights-at-age, a five-year average is used for catch weights-at-age in the forecast.

In 2019 (intermediate year), fishing mortality is set to result in the TAC set by ICES (10 469 t). In the following projection years, fishing mortality is set to the respective TAC determined in the MP. Following the NEAFC request, F_{target} in the TAC year is set to F_{MSY} and a TAC constraint is applied only if $SSB_{target}>B_{trigger}$. Two TAC constraint options (a, b, Annex 2) were tested.

The $B_{trigger}$ rule ($B_{trigger}=B_{pa}$) is applied only if $B_{lim}<SSB_{target}<B_{pa}$, where SSB_{target} is the SSB at the end of the TAC year (SSB in TAC year+1):

$$F_{target} = F_{MSY} - \left[(F_{MSY} - F_{low})\left(B_{pa} - SSB_{Ftarget}\right)/(B_{pa} - B_{lim})\right],$$

where F_{low} is 0.1 or 0.05 or 0. The equation can be re-arranged such that the slope of the relationship is defined by:

$F = a * SSB_{target} + b$,

where $a = \frac{(F_{MSY}-F_{low})}{B_{pa}-B_{lim}}$ and $b = F_{MSY} - a * B_{pa}$.

If SSB_{target} is forecasted to be below B_{lim}, fishing mortality in the TAC year is set to F_{low}. The Harvest control rules (HCRs) are summarized in Figure 3.15. A total of six management options are tested using MSE (combinations of F_{low} and TAC constraint rules in the NEAFC request):

HCR	Flow	TAC constraint rule
1a	0	a
1b	0	b
2a	0.05	a
2b	0.05	b
3a	0.1	a
3b	0.1	b

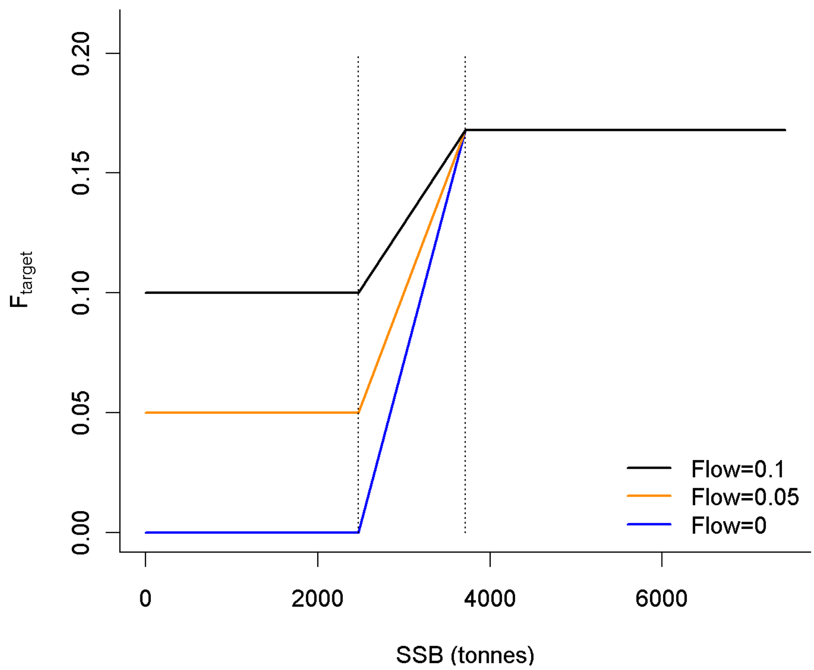

Figure 3.15. Rockall haddock in 6b. Harvest control rules with F_{low} of 0 (1, blue), 0.05 (2, orange) and 0.1 (3, black), with F_{MSY}=0.167 and $B_{trigger}$=B_{pa}= 3712 t, B_{lim}= 2474 t (dotted).

3.2.4 Performance Statistics

To compare the performance of HCR options, performance indicators are calculated. These include median catch, median SSB, interannual catch variability (IAV), and risk of falling below B_{lim} across 1000 iterations. The risk is calculated either as Risk 1 (the mean annual probability to fall below the SSB threshold across years of a predefined period) or Risk 3 (the maximum annual probability to fall below the SSB threshold across years of a predefined period). These indicators are given for projection results in the short-term (1–5 years), medium-term (6–10 years) and long-term (11–20 years).

3.2.5 Results

Baseline OM (OM0)

In the baseline OM0, median MP and OM results show good agreement (Figure 3.16). Also for an individual iteration, MP and OM show good agreement despite observation error on the survey index (Figure 3.17). Simulated SSB and recruitment pairs in the projection period (OM0, HCR 1a) show medium level recruitment as compared to the historic estimates (Figure 3.18).

Risks are below 5% for all six tested HCRs in short-, medium- and long-term. Risks are lower for constraint rule (a). Interannual catch variability is generally higher for the constraint rule (a) (Figures 3.19–3.20). As the TAC change is more flexible in constraint rule (a), a faster reduction in TAC is possible from one year to the next, leading to slightly lower risk to fall below B_{lim} (Table 3.2). The constraint rule (a) leads to higher SSB, lower realized F_{bar} and lower catches in the short term but slightly lower SSB in the long term than rule (b) (Table 3.3). In the baseline OM0, the value of F_{low} does not affect the results much, which indicates that SSB is generally estimated to be above B_{lim} and MSY $B_{trigger}$ in the MP.

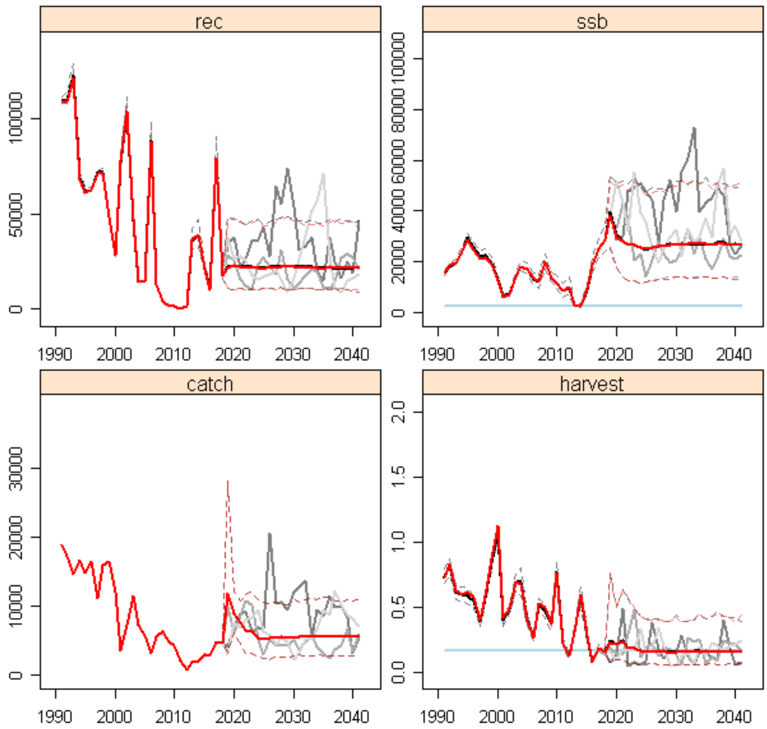

Figure 3.16. Rockall haddock in 6b. Results OM0 HCR 1a (F_{low}=0, TAC constraint rule a), with recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5), OM in red (grey: single iterations OM), MP in black. Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

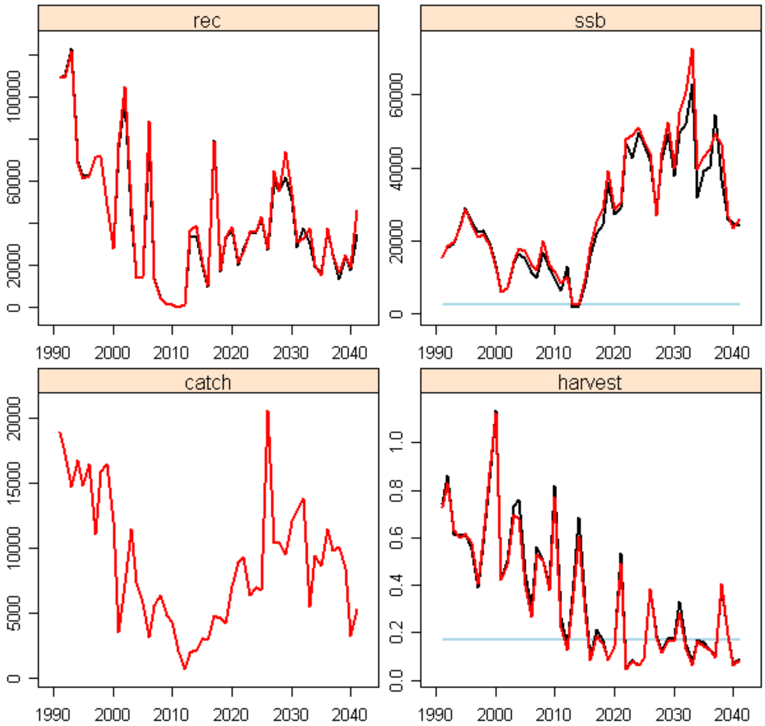

Figure 3.17. Rockall haddock in 6b. Compare a single iteration OM0 HCR 1a (F_{low}=0, TAC constraint rule a), OM in red, MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). F_{MSY} and B_{lim} in blue.

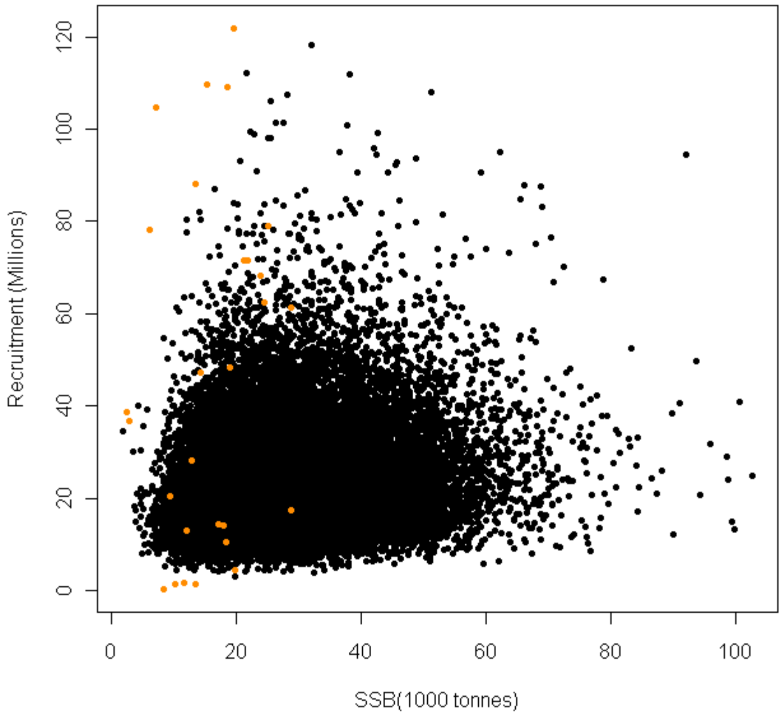

Figure 3.18. Rockall haddock in 6b. Historic SSB recruitment pairs (orange) simulated SSB-recruitment pairs (black, OM0 HCR 1a).

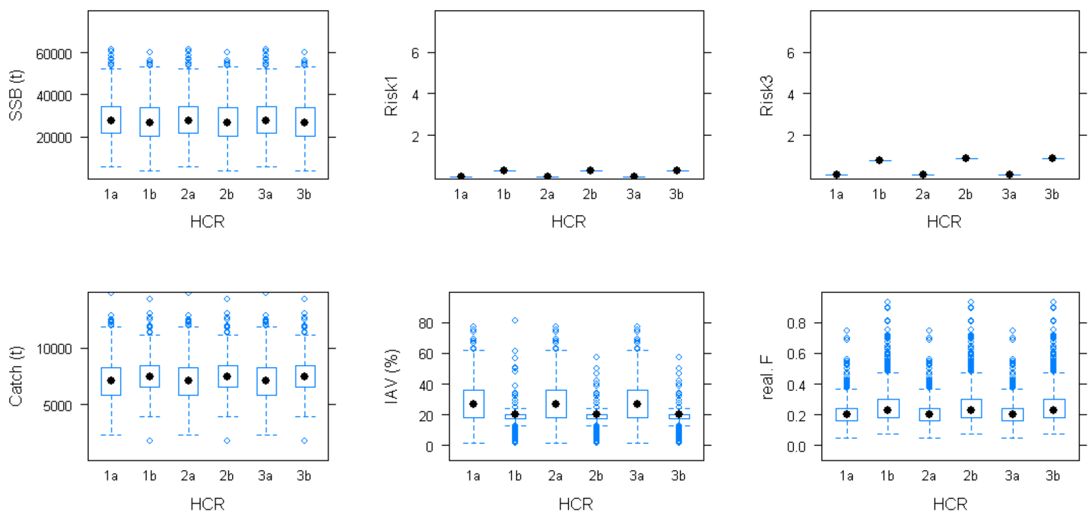

Figure 3.19. Rockall haddock in 6b. Results OM0, short-term (year 1–5). HCR 1: Flow=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b. Median values in black.

Table 3.2. Rockall haddock in 6b. Results median values OM0 in the short term (year 1–5). IAV interannual catch variability. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	SSB(t)	Catch (t)	IAV (%)	Risk3 (%)	Risk1 (%)	Real.Fbar
1a	27736	7054	27	0.1	0.02	0.198
1b	26700	7434	20	0.8	0.3	0.231
2a	27736	7054	27	0.1	0.02	0.198
2b	26700	7434	20	0.9	0.32	0.231
3a	27736	7054	27	0.1	0.02	0.198
3b	26700	7434	20	0.9	0.32	0.231

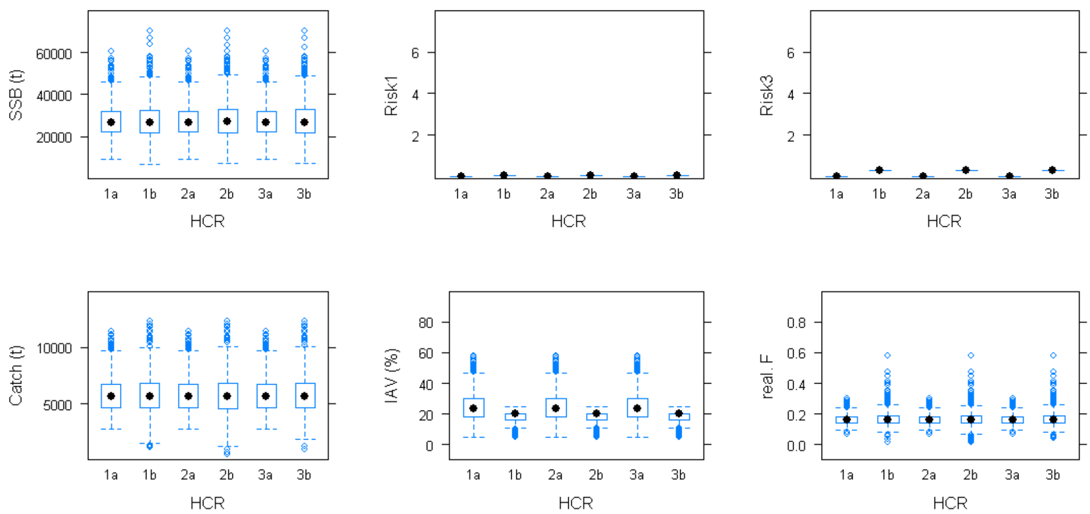

Figure 3.19. Rockall haddock in 6b. Results OM0, long-term (year 11–20), Black median values of SSB, Catch, IAV (interannual catch variability), realized F_{bar} (ages 2–5). HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

Table 3.3. Rockall haddock in 6b. Results median values OM0 in the long-term (year 11–20). IAV interannual catch variability. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	SSB(t)	Catch (t)	IAV (%)	Risk3 (%)	Risk1 (%)	Real.Fbar
1a	26750	5631	24	0	0	0.161
1b	26876	5635	20	0.3	0.06	0.1625
2a	26750	5631	24	0	0	0.161
2b	27038	5615	20	0.3	0.06	0.162
3a	26750	5631	24	0	0	0.161
3b	26898	5631	20	0.3	0.06	0.1625

Summary: Alternative OM results long-term

In the baseline OM (OM0), all six tested management options can be considered precautionary in the short, medium and long term. While the value of F_{low} has little effect on the performance of the HCRs, the TAC constraint rule (a) shows lower risks but higher interannual catch variability in the long term. Long-term median catches are similar across options.

All HCRs are precautionary in the short, medium and long term under the baseline OM0 and the alternative OMs OM3, OM4 and OM7 (Table 3.8–3.10).

HCRs with constraint rule (a) are also precautionary in the short, medium and long term under OM1, OM2 and OM5 (Table 3.8–3.10). In contrast, under alternative OM1, HCRs with constraint rule (b) are not precautionary in the short term. In OM2 (M=0.3) and OM5 (lower catch weights), constraint rule (b) is not precautionary in the short and medium term.

In OM6, combining low recruitment level with low weights-at-age and misspecification of natural mortality (M=0.3), all HCRs are not precautionary in the short and medium term. However in the long term, HCRs with rule (a) are precautionary while rule (b) is not precautionary. In all time periods, HCRs using TAC constraint rule (a) show lower risks (Table 3.8–3.10).

In OM8 (very low recruitment) all HCRs are not precautionary, with risks above 5% in the medium as well as long term. In the short term, HCRs with rule (a) are precautionary while rule (b) is not. HCRs using constraint rule (a) show lower risk in the short, medium and long term. In the long term, HCRs with F_{low}=0 show lower risk, with rule (1a) and (1b) performing similarly in terms of risk (Tables 3.8–3.10).

Long-term median SSB and catches are compared among HCRs in Tables 3.4 and 3.5, respectively. Median SSB in the long term was highest for HCR 2b across most alternative operating models (except OM8: HCR 1b). Median catches in the long term are highest in HCRs with constraint rule (a), except in OM0 and OM4 where rule (b) showed highest median catches.

When considering alternative OMs, rule (a) performs better in terms of risk in the short, medium and long term than rule (b) (Table 3.6-3.8). HCRs with constraint rule (a) are precautionary in most alternative OMs, except in OM6 and OM8. While the value of Flow has a small impact in most alternative OMs, low values of F_{low} (F_{low}=0) are preferable in terms of risks when recruitment level is very low (OM8) or in case of combined effects of low, recruitment, lower weights-at-age and overestimation of natural mortality (OM6). HCR 1a performs generally better in terms of risk than other control rules, while HCR 3b performs worst. More detailed results and plots for alternative OMs can be found in Annex 4, Working document WD1.

Table 3.4. Rockall haddock in 6b. Long-term SSB (t, year 11–20). Largest median SSB shaded. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	26750	13372	13882	32498	60052	19312	7007	26700	4270
1b	26876	13474	14048	32837	61475	20271	7833	26872	5249
2a	26750	13372	13882	32498	60052	19312	6997	26700	4062
2b	27038	13801	14252	32927	61642	20900	8223	27199	4538
3a	26750	13372	13882	32498	60052	19312	6997	26700	3971
3b	26898	13422	13965	32835	61642	20469	7633	26984	4094

Table 3.5. Rockall haddock in 6b. Long-term median catch (t, year 11–20). Largest median catch shaded. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	5631	2904	3644	5682	9593	4119	1873	5551	840
1b	5635	2769	3487	5682	9817	3918	1674	5548	630
2a	5631	2904	3644	5682	9593	4119	1874	5551	849
2b	5615	2763	3464	5669	9817	3789	1697	5531	777
3a	5631	2904	3644	5682	9593	4119	1874	5551	846
3b	5631	2776	3497	5676	9817	3885	1780	5547	792

Table 3.6. Rockall haddock in 6b. Short-term risk (year 1–5), risk 3 (maximum annual probability SSB<B_{lim}) in %. Above 5% shaded. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	0.1	0.7	1.1	0	0	1.9	5.5	0	4.2
1b	0.8	5.3	5.6	0.1	0.2	7.8	26.8	0.8	21.9
2a	0.1	0.7	1.1	0	0	1.9	5.5	0	4.2
2b	0.9	5.3	5.6	0.1	0.2	8.2	27.1	0.8	23
3a	0.1	0.7	1.1	0	0	1.9	5.5	0	4.3
3b	0.9	5.4	5.6	0.1	0.2	8.3	27.7	0.8	23.7

Table 3.7. Rockall haddock in 6b. Medium-term risk (year 6–10), risk 3 (maximum annual probability SSB<B_{lim}) in %. Above 5% shaded. HCR1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	0	0.6	0.6	0	0	1.1	7.4	0	7.8
1b	0.4	4.6	7.2	0.1	0	6.2	34.2	0.8	28.3
2a	0	0.6	0.6	0	0	1.1	7.4	0	8.6
2b	0.4	4.8	7.2	0.1	0	6.7	34.6	0.8	29.8
3a	0	0.6	0.6	0	0	1.1	7.4	0	9.8
3b	0.4	4.9	7.2	0.1	0	7	35.9	0.9	32.8

Table 3.8. Rockall haddock in 6b. Long-term risk (year 11–20), risk 3 (maximum annual probability SSB<B_{lim}) in %. Above 5% shaded. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	0	0.1	0.2	0	0	0.2	2.2	0	8.3
1b	0.3	1.4	1.8	0.1	0.1	0.7	6.5	0.2	8.2
2a	0	0.1	0.2	0	0	0.2	2.2	0	10.7
2b	0.3	1.4	1.9	0.1	0.1	0.7	6.6	0.2	11.6
3a	0	0.1	0.2	0	0	0.2	2.2	0	13
3b	0.3	1.6	2	0.1	0.1	0.7	7.4	0.3	17.7

Table 3.9. Rockall haddock in 6b. Long-term risk (year 11–20), risk 1 (mean annual probability SSB<B_{lim}) in %. Above 5% shaded. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	0	0.01	0.07	0	0	0.07	1.36	0	7.44
1b	0.06	0.42	0.66	0.01	0.01	0.35	2.12	0.11	4.75
2a	0	0.01	0.07	0	0	0.07	1.37	0	9.51
2b	0.06	0.41	0.7	0.01	0.01	0.34	2.17	0.11	7.27
3a	0	0.01	0.07	0	0	0.07	1.39	0	11.56
3b	0.06	0.44	0.75	0.01	0.01	0.33	2.51	0.12	11.54

Table 3.10. Rockall haddock in 6b. Long-term results (year 11–20), interannual catch variability (absolute value). HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	24	23	23	24	26	25	23	27	37
1b	20	20	20	20	20	20	21	18	25
2a	24	23	23	24	26	25	23	27	30
2b	20	20	20	20	20	20	23	18	25
3a	24	23	23	24	26	25	23	27	26
3b	20	20	20	20	20	20	20	18	24

Table 3.11. Rockall haddock in 6b. Long-term results (year 11–20), median realized F_{bar}. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1, with TAC constraint rule a or b.

HCR	OM0	OM1	OM2	OM3	OM4	OM5	OM6	OM7	OM8
1a	0.161	0.167	0.199	0.161	0.121	0.168	0.204	0.16	0.144
1b	0.1625	0.161	0.194	0.162	0.12	0.157	0.175	0.16	0.0915
2a	0.161	0.167	0.199	0.161	0.121	0.168	0.204	0.16	0.151
2b	0.162	0.159	0.193	0.162	0.12	0.154	0.164	0.16	0.125
3a	0.161	0.167	0.199	0.161	0.121	0.168	0.204	0.16	0.16
3b	0.1625	0.162	0.195	0.162	0.12	0.156	0.181	0.16	0.141

3.2.6 References

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3.3 Management strategy evaluation for Rockall haddock using randomly resampled recruitment from the actual historical estimates

3.3.1 Methodology

Evaluation of management strategy was based on the method presented to ACOM in 2011 (Khlivnoy, 2011) and in the reports of WKROCKHAD 2012 (ICES, 2012) and of WKROCKHAD 2013 (ICES, 2013).

In 2013, the simulations were carried out using the Excel spreadsheet and exploratory runs on the basis of that method were also made in the R. The use of the two programs was due to the need to thoroughly check of the results of simulation. The runs of the two programs gave similar results. In 2019, the simulations were carried out using the R.

The HCR was evaluated using the simulation model for the population.

The model had the following features:

- used in the model were the functions VPA (Baranov equation, Popes approximation, etc.).
- the simulations were carried out taking into account errors and fluctuation of recruitment.
- the model took into account the assessment errors related to errors in the results of survey, in data on the average weight of haddock in stock, etc.

The proposed harvest control rules were evaluated with the following objectives:

a) to include uncertainty in the model;
b) to analyse the stock state with different levels of recruitment;
c) to estimate the correspondence between catches and TAC in the presence and in the absence of discards in the fishing practice;
d) to elaborate F rules;
e) to estimate the reduction in F when SSB<B_{pa};
f) to estimate the probability of SSB<B_{pa};
g) to estimate the probability of SSB<B_{lim}; and
h) to define the limit on year–to–year variation in catches, etc.

3.3.2 Input data

The input data for the simulations are similar to those used for the Rockall Haddock assessment in WGCSE and the report of WKROCKHAD 2012. The selected population model was as follows:

- Recruitment: age 1.
- Plus group: 7+.
- F_{bar}: 2–5.
- Maturation knife-edged at-age 3.
- • Natural mortality-at-age: 0.2.

- For long-term forecasting discards and landings, the proportion of discards/landings-at-age in 2009–2018 was used.
- For long-term simulations mean values for the period 2009–2018 were used for fishing mortality, stock and catch weights.

Start Year for runs: 2019

3.3.3 Recruitment

Same as in 2012 (ICES, 2012) and 2013 (ICES, 2013a) no significant relationship between spawning biomass and the recruitment was found (Figures 3.3.1–3.3.3). The strong year classes were observed in years with high level of SSB and in years with very low SSB. In the years when biomass is at high levels, poor year classes are often observed. So in 2001, when the stock was low, one of the most abundant year classes appeared.

There are factors that have a stronger impact on the numbers of recruitment than the SSB. The main impact on the recruitment are environmental factors. There is a well-expressed relationship between the number of *Euphausiacea* and haddock recruitment at Rockall (Figure 3.3.4).

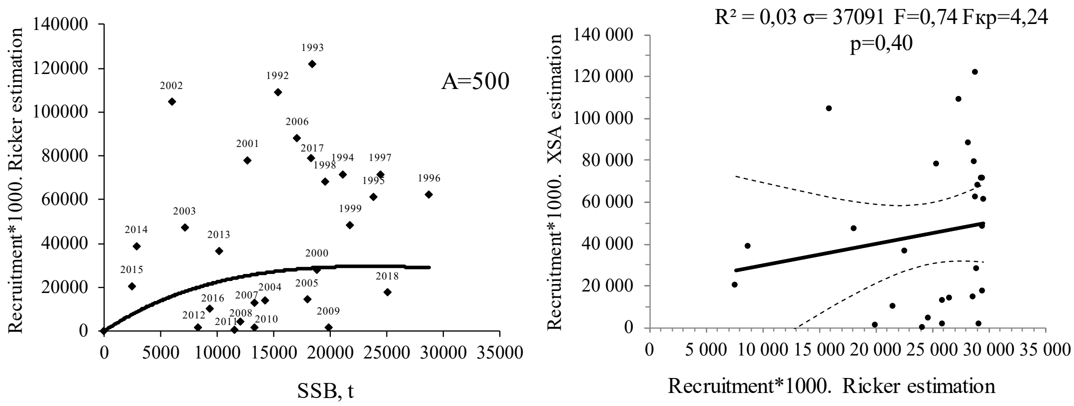

Figure 3.3.1. Stock–recruitment relationship estimated by Ricker model and comparison with the XSA assessment of recruitment.

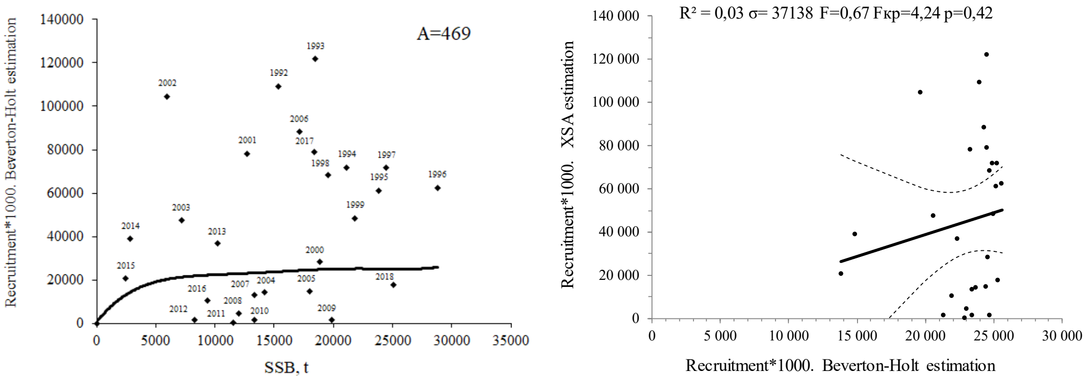

Figure 3.3.2. Stock–recruitment relationship estimated by Beverton–Holt model and comparison with the XSA assessment of recruitment.

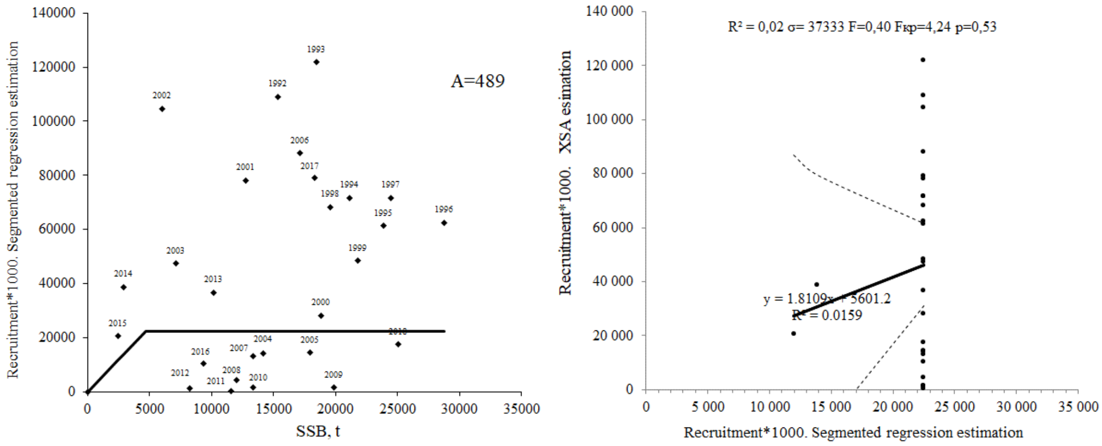

Figure 3.3.3. Stock–recruitment relationship estimated by segmented regression model and comparison with the XSA assessment of recruitment.

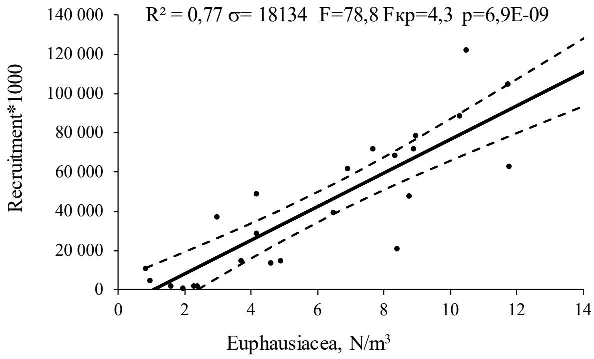

Figure 3.3.4. The relationship between haddock recruitment at Rockall and *Euphausiacea* in May–October in the year of 0-group generation and April–July next year in squares B5 and B6. Data on *Euphausiacea* from SAHFOS (DOI, 10.7487/2017.51.1.1035) available until 2016.

There are periods with low recruitments (2004–2012) and periods with high recruitment (1991–2003). In 2004–2012 the SSB increased and has been higher than B_{pa} but the recruitment was very poor. Only one strong year class 2005 was observed. In 2007–2012 recruitments were extremely low. (ICES, 2012; ICES, 2013). (Figures 3.3.5).

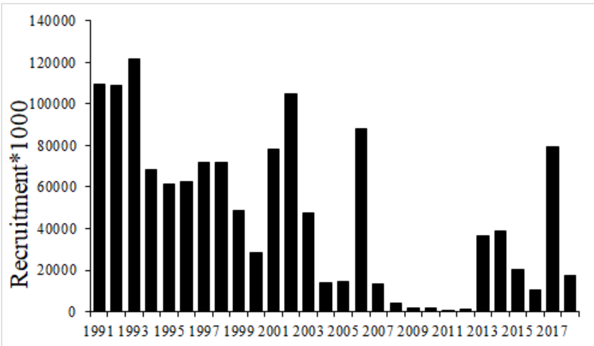

Figure 3.3.5. Recruitment of Rockall haddock in 1991–2018.

In the absence of a significant relationship between spawning biomass and recruitment, historically observed recruitment patterns were used. The recruitment for the simulations was modelled using an approach that randomly resampled from the actual historical recruitment estimates.

3.3.4 Assessment errors

The assessment errors related to errors in the results of survey, in data on the average weight of haddock in stock, etc. were taken into account in the simulation. Those interannual assessment errors were measured and realised in model by retrospective analysis of assessment. There are the year–to–year variations of TSB and recruitment obtained from the results of stock assessment. The errors show how TSB changed in the year Y by the results of stock assessment in the year Y compared to the previous stock assessment. The assessment errors for the simulations were modelled using the method of random numbers with historical errors.

Taking into account the assessment errors, TSB was calculated according to the following function (1):

$$TSB = TSBa * \varepsilon\ TSB, \qquad (1)$$

where TSB is the total biomass recalculated with assessment errors; the TSBa is biomass by the results calculated in year Y according to the VPA functions;

ε TSB are the interannual assessment errors of TSB.

Taking into account the assessment errors, the recruitment was calculated according to the following function (2):

$$R=Ra*\varepsilon R, \qquad (2)$$

where R is the recruitment recalculated with assessment errors; the Ra is biomass by the results calculated in year Y according to the VPA functions; ε R are the interannual assessment errors of recruitment.

The errors ware modelled using an approach that randomly resampled from the retrospective estimates.

3.3.5 Model settings

For all runs, 300 iterations for 27 years (2019–2045) were made. The analysis covered the period 2021–2045.

Table 3.3.1. The simulations were made for the four scenarios.

The scenarios with were used for the simulations. Recruitment-level	Fishery with or without discards
1. Long-term Recruitment pattern (1991–2018)	a. Discards and quotas set on the level of total catch *
	b. No discards or the ICES method 2009–2016**
2. Recent Recruitment pattern (2004–2018)	a. Discards and quotas set on the level of total catch *
	b. No discards or the ICES method 2009–2016**
3. Low Recruitment pattern (2004–2012)	a. Discards and quotas set on the level of total catch *
	b. No discards or the ICES method 2009–2016**
4. The extremely low recruitment pattern (2008–2012)	a. Discards and quotas set on the level of total catch *
	b. No discards or the ICES method 2009–2016**

***the total quotas set at the TAC level but TAC includes landings and discards.**

****the total quotas set at the landing (a human consumption) level. If there are no discards the landings will be equal to the yield and TAC.**

3.3.6 Results

Scenarios with the option 3a of proposed harvest control component of the management plan:

*"The Parties agree that the TAC that results from the application of the fishing mortality referred to in paragraph 2 will be adjusted according to either of the following rules:a. TACy = TACf + 0.2 * (TACy-1 =–TACf) where TACy is the TAC that is to be set by the management plan, TACy-1 is the TAC that was fixed the previous year and TACf is the TAC resulting from the provisions in paragraphs 1 and 2."*

The analysis was carried out for all possible combinations of the three factors: recruitment, TAC constraint and discards. All that factors have effects on risk. The implementation of a TAC constraint has the effect on risk. The risk percentages are provided in Tables 3.3.2, 3.3.3 and 3.3.4.

Results of simulations show that with the proposed HCR and the option 3 a (TACy = TACf + 0.2 * (TACy-1–TACf)), there will be a minimal probability of SSB falling below B_{lim}. That probability is very low in the case if recruitment will be same as in whole historical observed period (1991–2018), in recent period (2004–2018) and in the period with low recruitment (2004–2012) when only one strong year class was observed.

The new reference points have much smaller values than the previous ones on based on minimal observed level of SSB. Historically the SSB was above new B_{lim}. Simulations showed that recently high level of stock would maintain the SSB an above-average level (Figures 3.3.6–3.3.17). Therefore, the probability of a reduction in biomass is lower than B_{lim}, set at the minimum observed level is extremely small.

If the recruitment is at a whole historically observed pattern level, as in 1991–2018, the SSB will be above B_{pa} and options 4 and of proposed management plans (F_{MSY}–[(F_{MSY}-F_{low}) × (B_{pa}–$SSBF_{tar}$) / (B_{pa}–B_{lim})], where F_{low} = 0.1 or 0.05 or 0 for the SSB below B_{pa} will not works. Results of simulations is same different F_{low}. In that case there is impact of discards on the SSB and other population values (Table 3.3.2, Figures 3.3.6–3.3.9).

In the presence of discards for recent and low recruitment pattern, the probability of the stock falling below B_{lim} could be higher. However and in that case the probability will not exceed the five percent level (Table 3.3.2, Figures 3.3.6–3.3.17).

Scenarios with the option 3b of proposed harvest control component of the management plan

"*b. Where the rules in paragraph 2 would lead to a TAC, which deviates by more than 20% below or 25% above the TAC of the preceding year (TACy-1), the Parties shall fix a TAC that is respectively no more than 20% less or 25% more than the TAC of the preceding year*".

Results of simulations show that with the proposed HCR and the option 3 b (20%/25% interannual deviations of TAC) probability of SSB falling below B_{lim} is higher compare options 3a. The Rockall Haddock is characterised by sharp fluctuations in biomass. If biomass is rapidly reduced, the reduction of the TAC will be limited to 20% interval. This will result in high levels of TAC and F at low biomass. It increases the probability of the SSB falling below B_{lim}.

If the recruitment is at a whole historically observed pattern level, as in 1991–2018, the probability of the stock falling below B_{lim} is low (0.6%). In the presence of discards and if quotas will set on the level corresponded to total forecasted catch the probability of the stock falling below B_{lim} could be in 13–15 times higher compare fishery without discards or when the quota will be set on the level of forecasted landings. The probability of the stock falling below B_{lim} could be 8.0% for F_{low}=0 and 9.1% for F_{low}=0.1 (Table 3.3.2, Figures 3.3.18–3.3.21).

If the recruitment is at a Recent Recruitment pattern level, as in 2004–2018, the probability of SSB falling below B_{lim} will be 2.6%–2.8% for fishery without discards and 11.18%–14.21% for fishery with discards (Table 3.3.3).

If recruitment will be same as in the period with low recruitment (2004–2012) when only one strong year class was observed the probability will be 4.74%–6.4% without discards when the quota will be set on the level of forecasted landings. In the presence of discards the probability of the stock falling below B_{lim} could be in more than three times is higher compare fishery without discards or when the quota will be set on the level of forecasted landings (Table 3.3.3, Figures 3.3.22–3.3.25).

Scenarios with extremely low recruitment

In 2008–2012 very low recruitment of Rockall, haddock without any strong year classes was observed. If the recruitment are extremely low, same as observed in 2008–2012 for a long time the probability of SSB falling below B_{lim} will be higher. Maximal values of probability will be for fishery with discards when applied the option 3b of proposed harvest control component of the management plan (Table 3.3.4, Figures 3.3.26–3.3.27).

3.3.7 Conclusion

Results of simulations show that with the proposed HCR and the option 3 a (TACy = TACf + 0.2* (TACy-1–TACf)), probability of SSB falling below B_{lim} is very low are considered to be in accordance with precautionary approach as risk for SSB to be below B_{lim} when the HCR is used is less than 5%.

When the option 3 b (20%/25% inter annual deviations of TAC) are applied probability of SSB falling below B_{lim} is higher compare to options 3a. This is because when the biomass is rapidly reduced as it is typical for Rockall haddock, the reduction of the TAC will be limited to 20% interval. It give high levels of TAC and F at low SSB.

In the presence of discards and if quotas will set on the level corresponded to total forecasted catch the probability of the stock falling below B_{lim} could be in 3–15 times higher compare fishery without discards or when the quota will be set on the level of forecasted landings.

In case of a low recruitment similar to that observed in 2008–2012, the risk of SSB falling below B_{lim} would be considerably higher.

Table 3.3.2. Summary of probability SSB <B_{lim} for new proposal plan with option 3a of proposed harvest control component of the management plan (TACy = TACf + 0.2 * (TACy-1–TACf)).

Recruitment level	Fishery with or without discards	The probability SSB<B_{lim}, %		
		Flow=0	Flow=0.05	Flow=0.1
Recruitment pattern 1991–2011	a. Discards and quotas set on the level of total catch *	0	0	0
	b. No discards or the ICES method 2009-2016**	0	0	0
Recent recruitment pattern 2004–2018	a. Discards and quotas set on the level of total catch *	0.01	0.04	0.1
	b. No discards or the ICES method 2009-2016**	0	0	0
Low recruitment pattern 2004–2012	a. Discards and quotas set on the level of total catch *	0.04	0.68	2.14
	b. No discards or the ICES method 2009-2016**	0	0.22	0.71

***the total quotas set at the TAC level but TAC includes landings and discards.**

****the total quotas set at the landing (a human consumption) level. If there are no discards the landings will be equal to the yield and TAC.**

Table 3.3.3. Summary of probability SSB <B_{lim} for new proposal plan with option 3a of proposed harvest control component of the management plan (a TAC that is respectively no more than 20% less or 25% more than the TAC of the preceding year).

Recruitment level	Fishery with or without discards	The probability SSB<Blim, %		
		Flow=0	Flow=0.05	Flow=0.1
Recruitment pattern 1991–2011	a. Discards and quotas set on the level of total catch *	8.0	8.6	9.1
	b. No discards or the ICES method 2009-2016**	0.6	0.6	0.6
Recent recruitment pattern 2004–2018	a. Discards and quotas set on the level of total catch *	11.18	12.58	14.21
	b. No discards or the ICES method 2009-2016**	2.35	2.46	2,61
Low recruitment pattern 2004–2012	a. Discards and quotas set on the level of total catch *	13.32	16.5	20.47
	b. No discards or the ICES method 2009-2016**	4.74	5.36	6.4

***the total quotas set at the TAC level but TAC includes landings and discards.**

****the total quotas set at the landing (a human consumption) level. If there are no discards the landings will be equal to the yield and TAC.**

Table 3.3.4. Summary of probability SSB <B_{lim} for new proposal plan for the extremely low recruitment pattern same as 2008–2012.

Recruitment level	Fishery with or without discards	The probability SSB<Blim, %		
		Flow=0	Flow=0.05	Flow=0.1
Option 3 a of HCR (TACy = TACf + 0.2 * (TACy-1–TACf))				
Recruitment pattern 2008–2012	a. Discards and quotas set on the level of total catch *	1.71	20.49	49.83
	b. No discards or the ICES method 2009-2016**	1.07	13.35	34.92
Option 3 b of HCR (TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year)				
Recent recruitment pattern 2008–2012	a. Discards and quotas set on the level of total catch *	17.29	39.69	69.01
	b. No discards or the ICES method 2009-2016**	13.04	27.25	49.32

***the total quotas set at the TAC level but TAC includes landings and discards.**

****the total quotas set at the landing (a human consumption) level. If there are no discards the landings will be equal to the yield and TAC.**

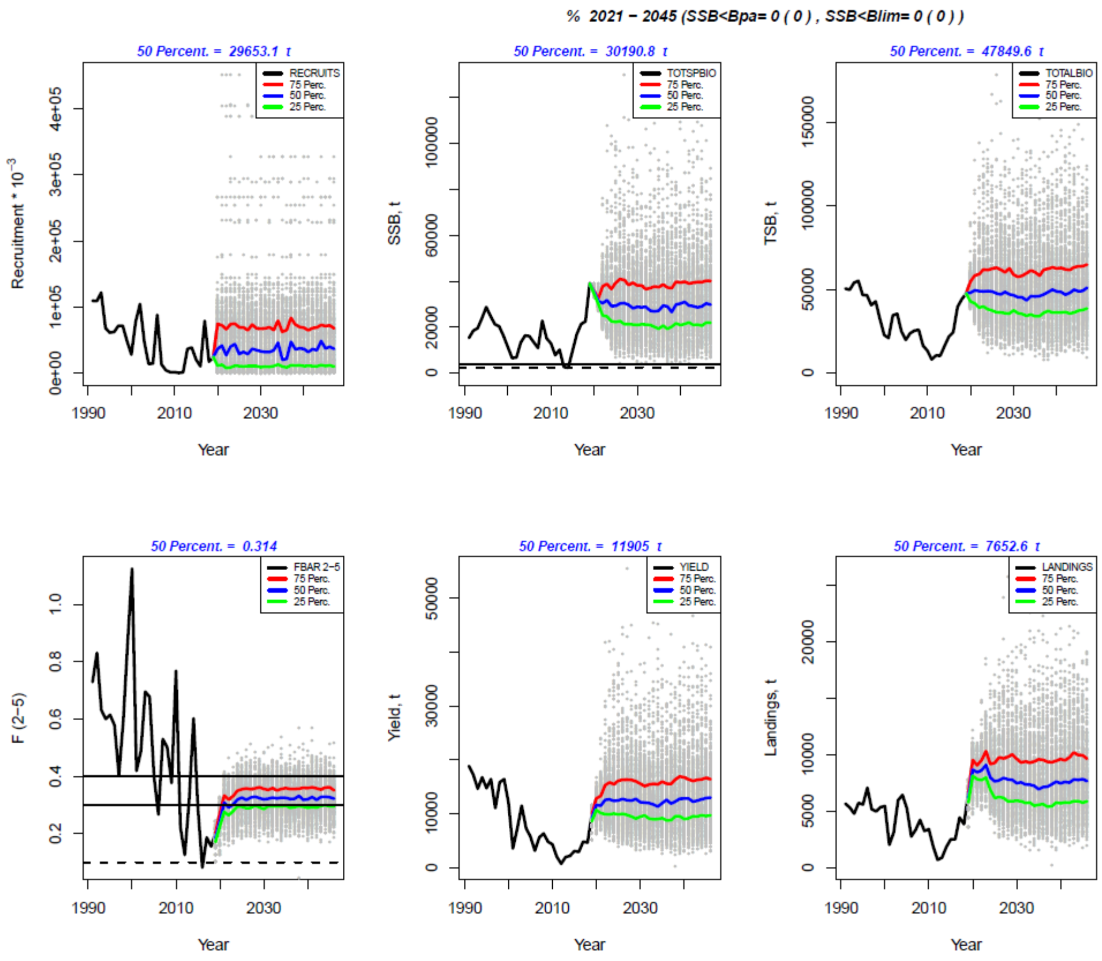

Figure 3.3.6. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Long-term recruitment (1991–2018). There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

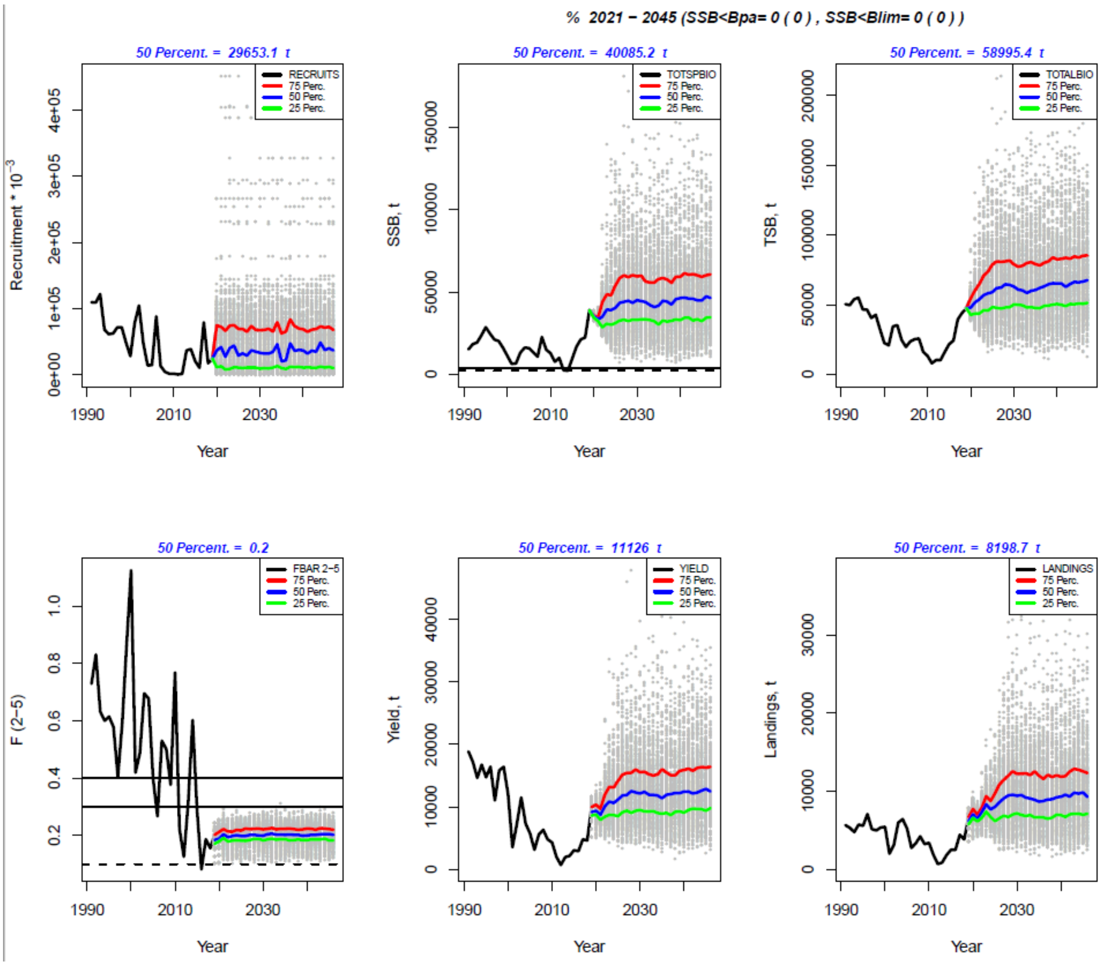

Figure 3.3.7. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Long-term recruitment (1991–2018), no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

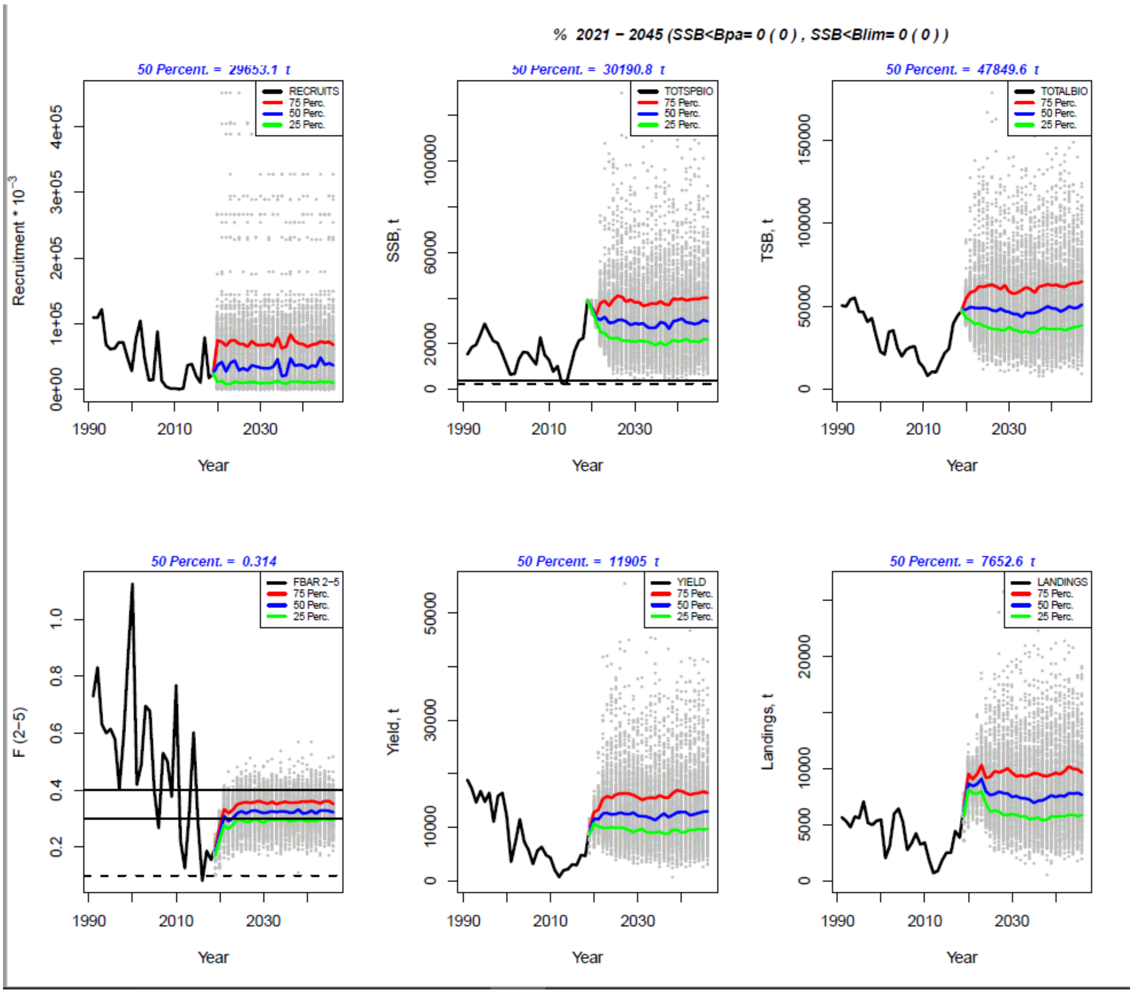

Figure 3.3.8. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Long-term recruitment (1991–2018). There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

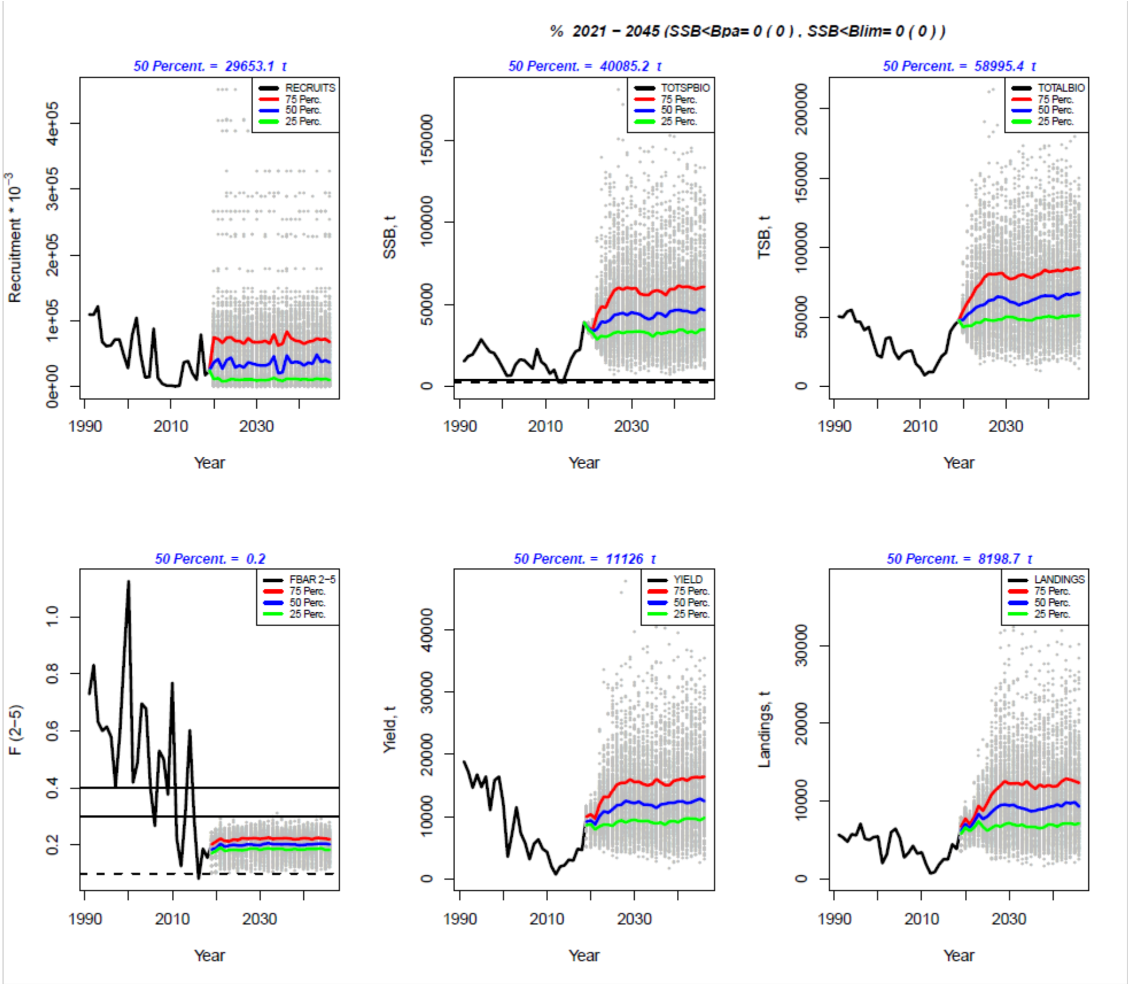

Figure 3.3.9. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Long-term recruitment (1991–2018), no discards or the total quotas set at the landing used by ICES in 2009–2016. Flow=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

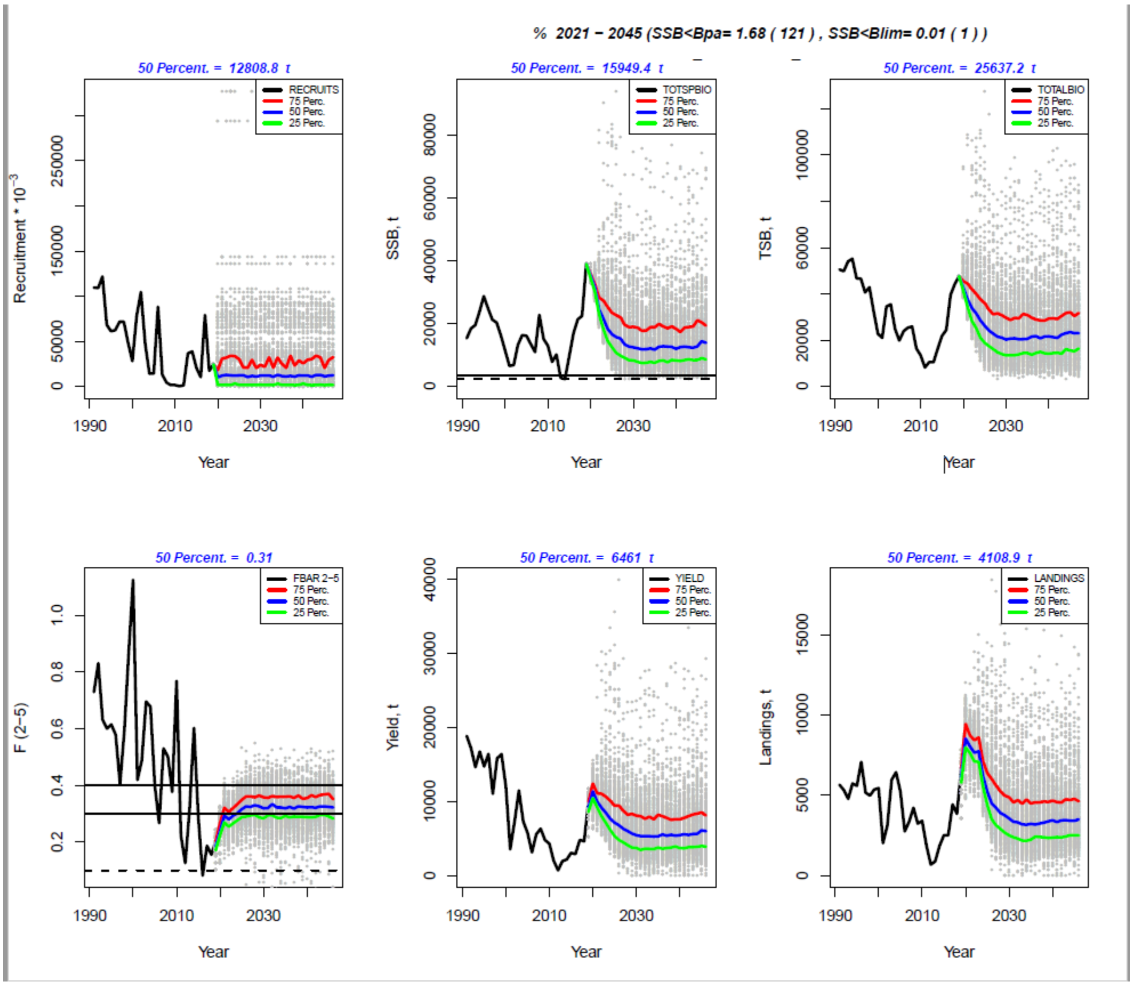

Figure 3.3.10. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

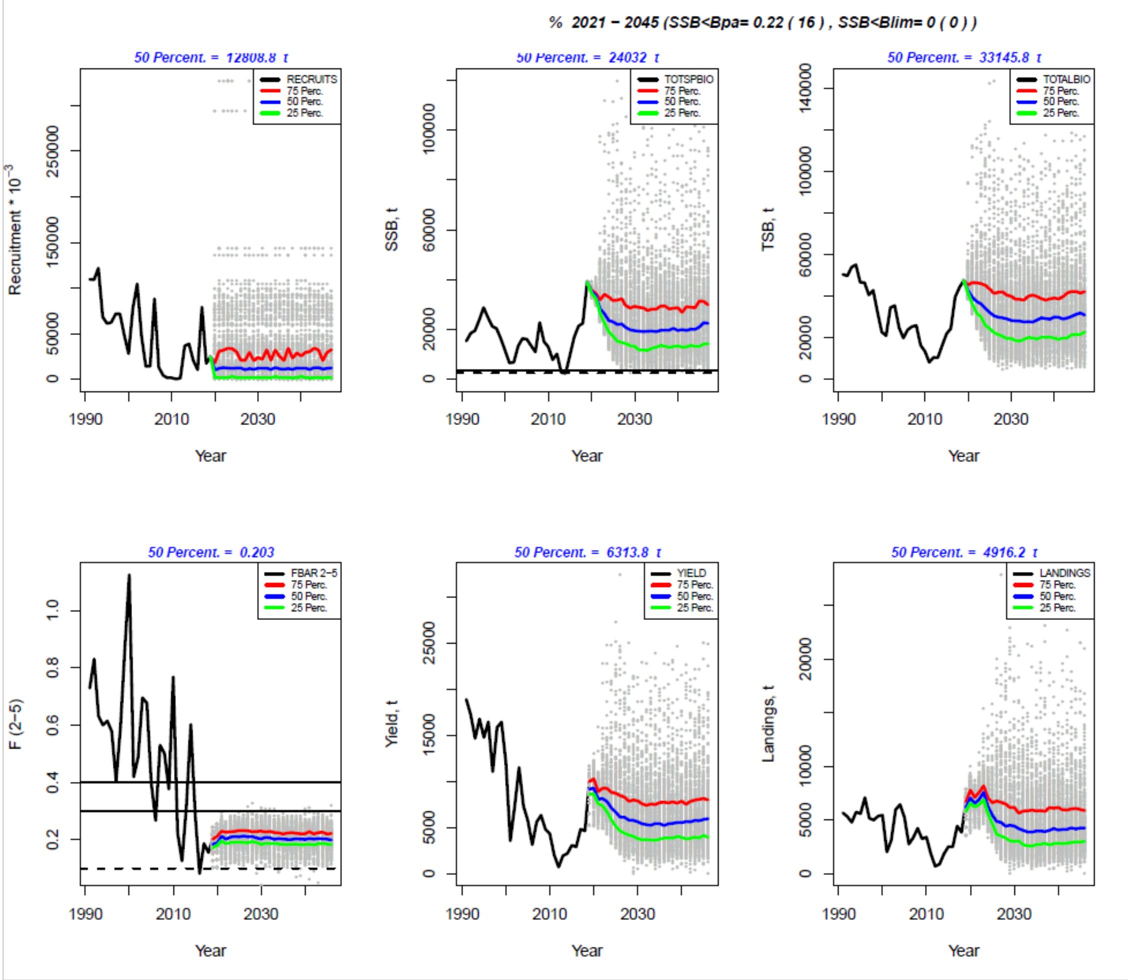

Figure 3.3.11. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern, no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

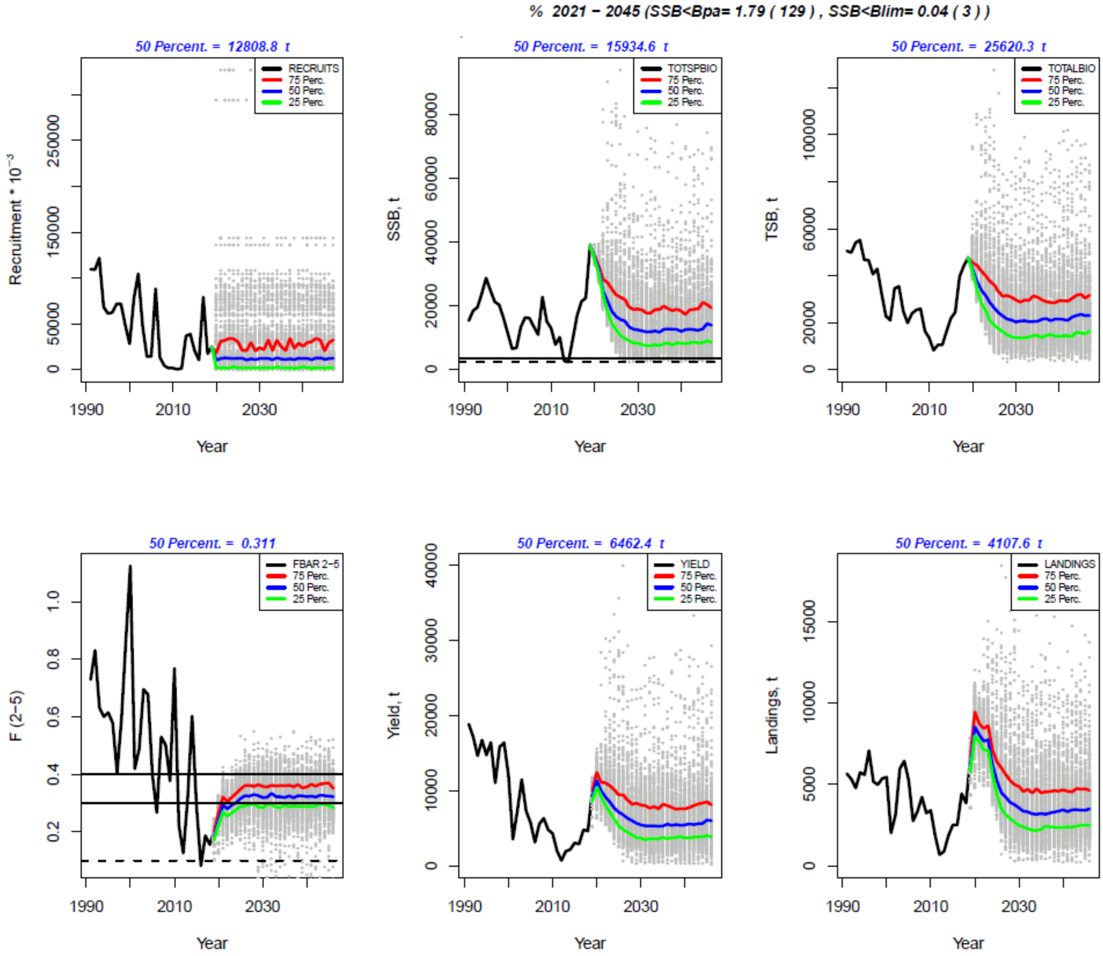

Figure 3.3.12. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.05. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

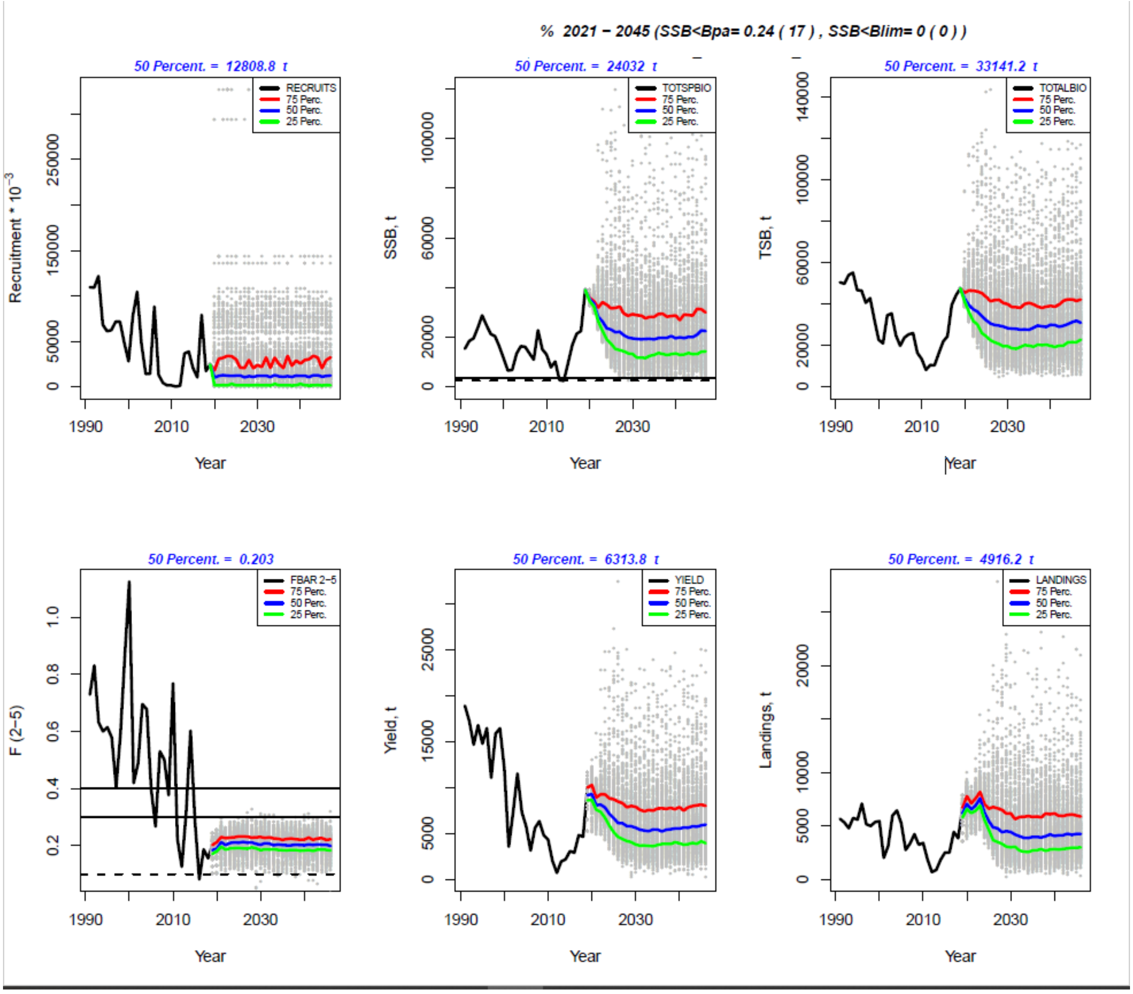

Figure 3.3.13. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern, no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.05. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

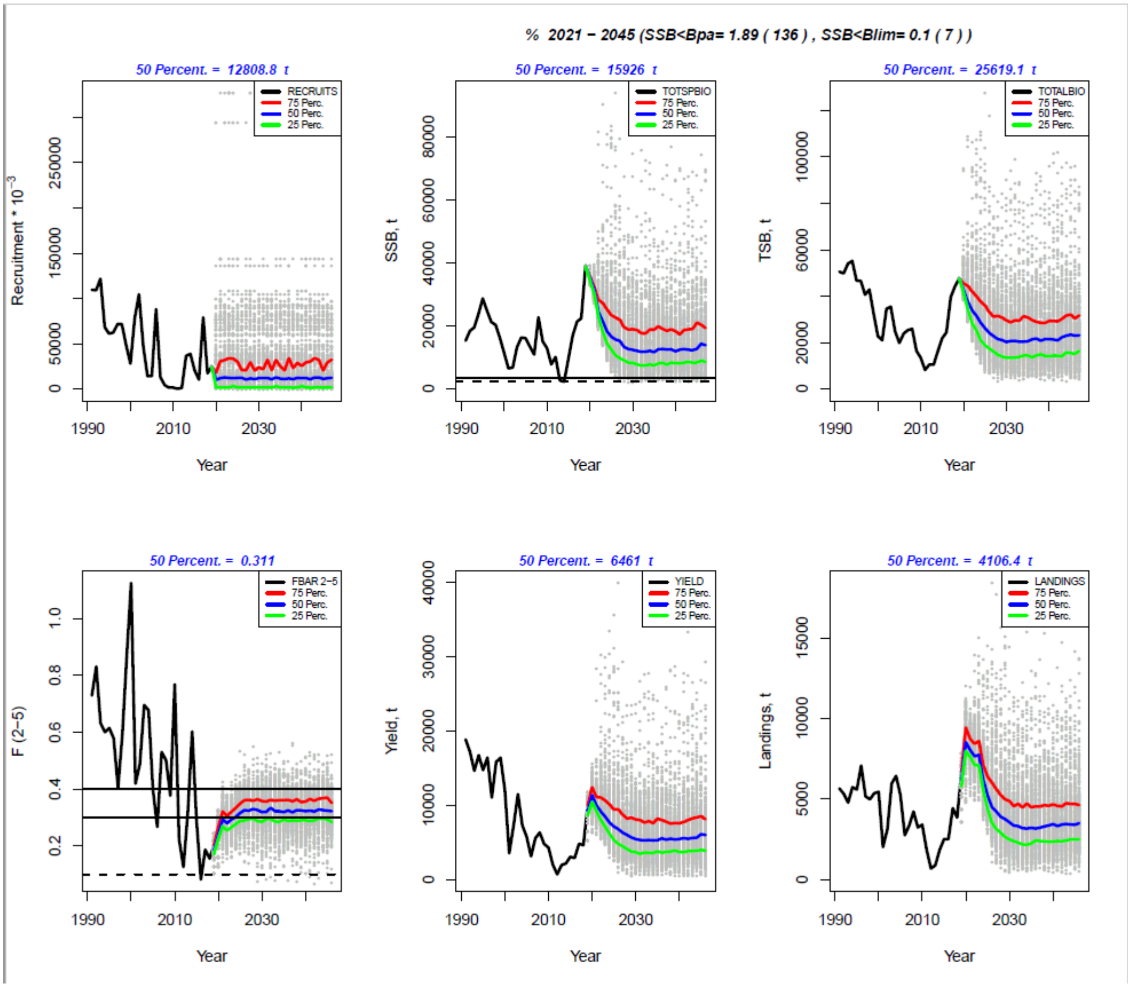

Figure 3.3.14. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.05. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

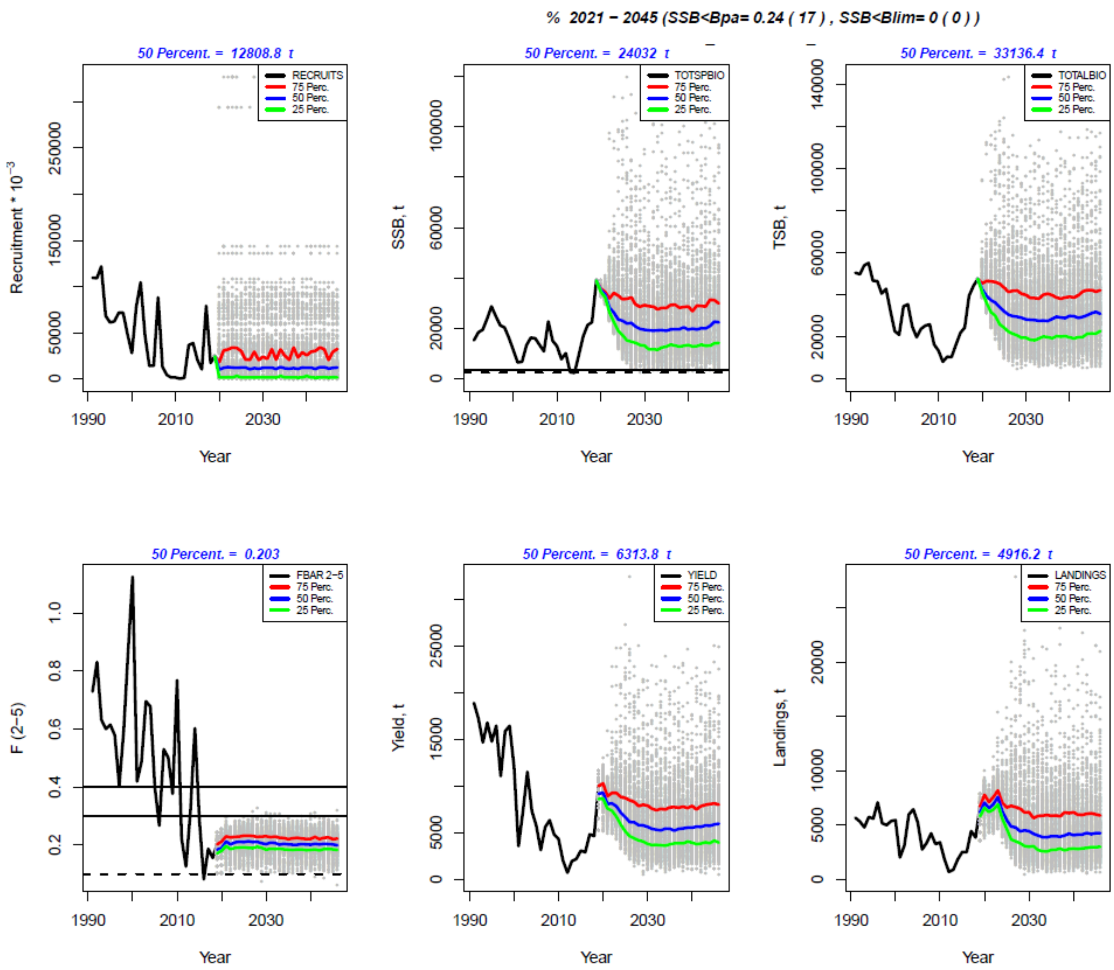

Figure 3.3.15. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Recent recruitment (2004–2018) pattern, no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

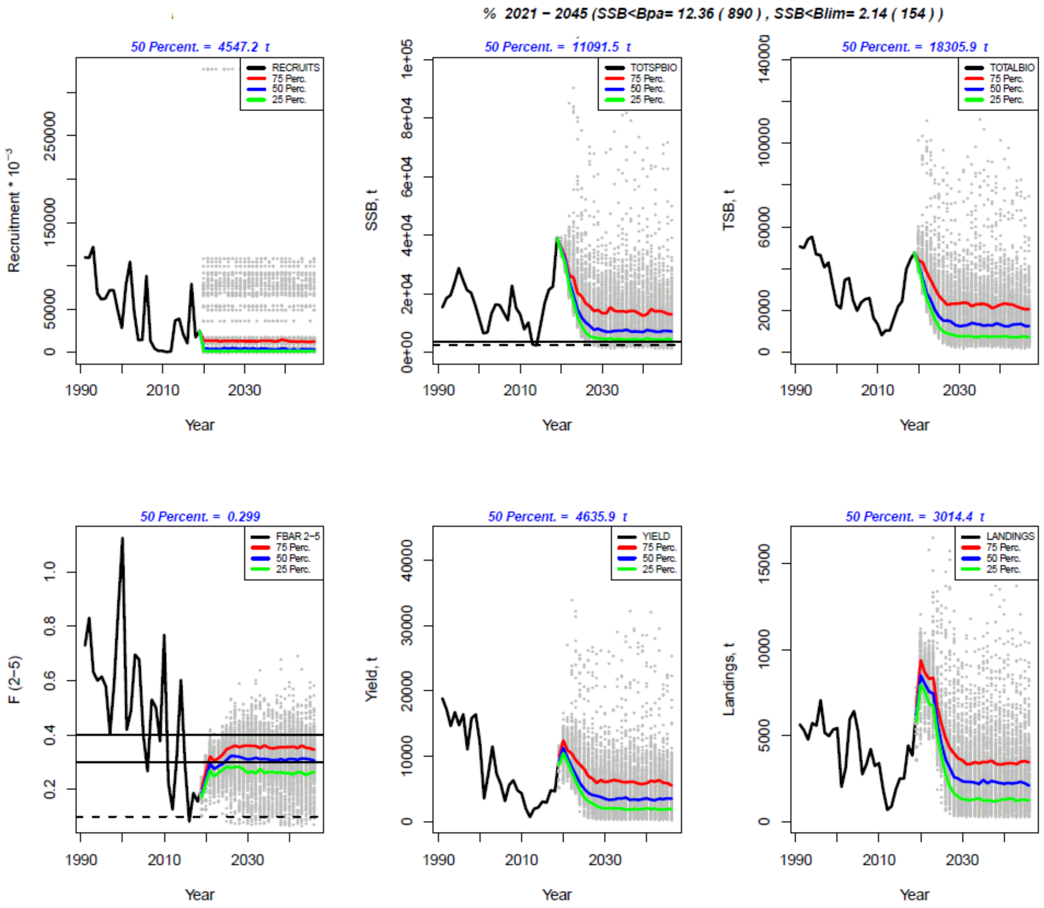

Figure 3.3.16. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Low recruitment as in 2004–2012. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

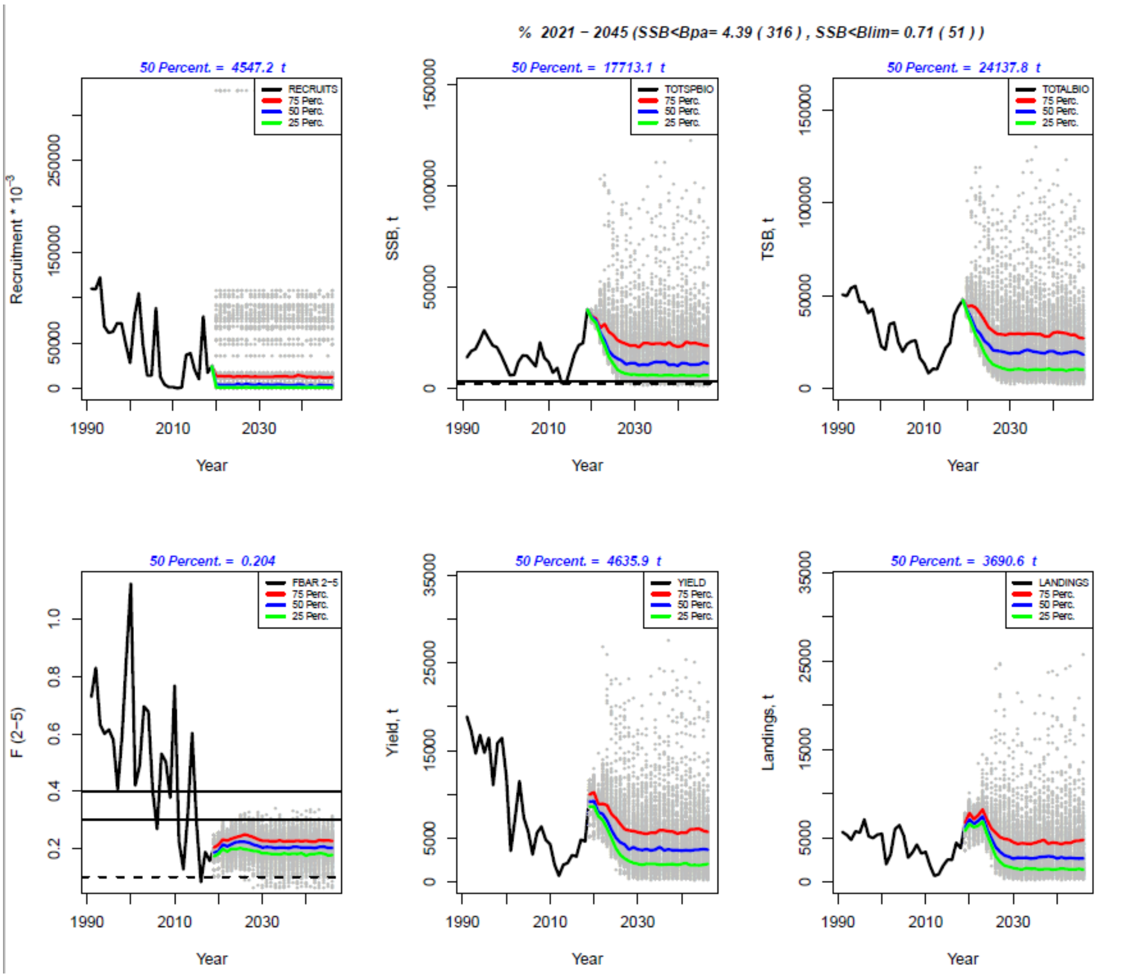

Figure 3.3.17. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Low recruitment as in 2004–2012, no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

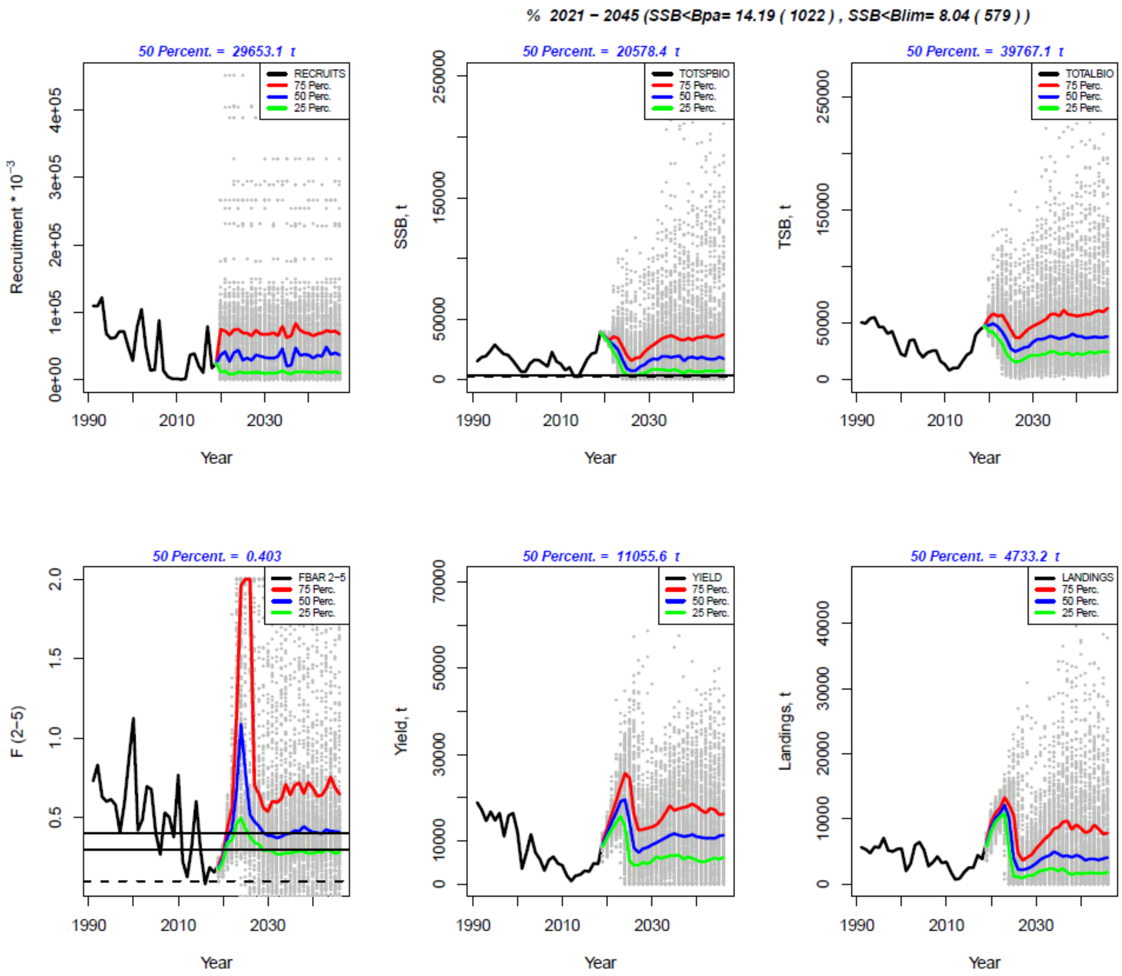

Figure 3.3.18. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Long-term recruitment as in 1991–2018. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

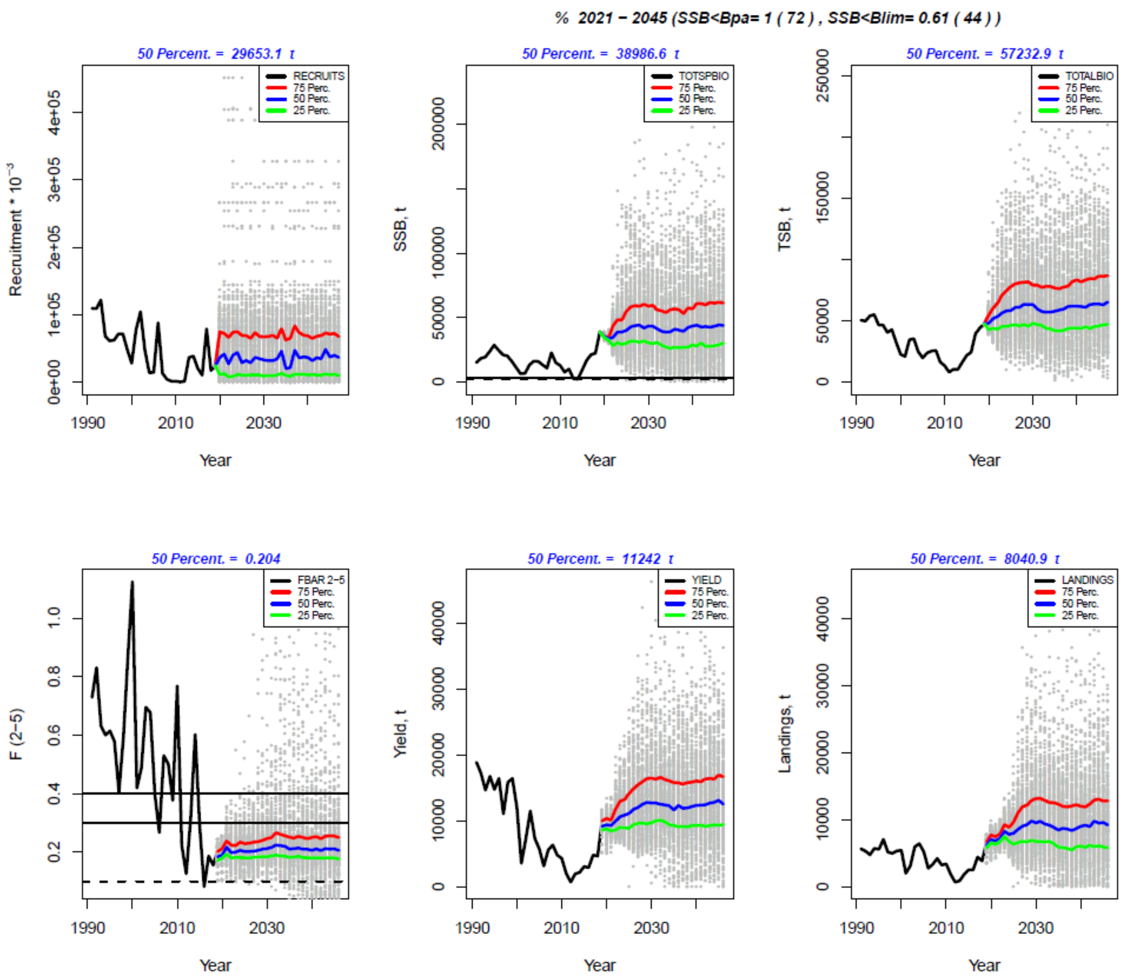

Figure 3.3.19. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Long-term recruitment as in 1991–2018. No discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

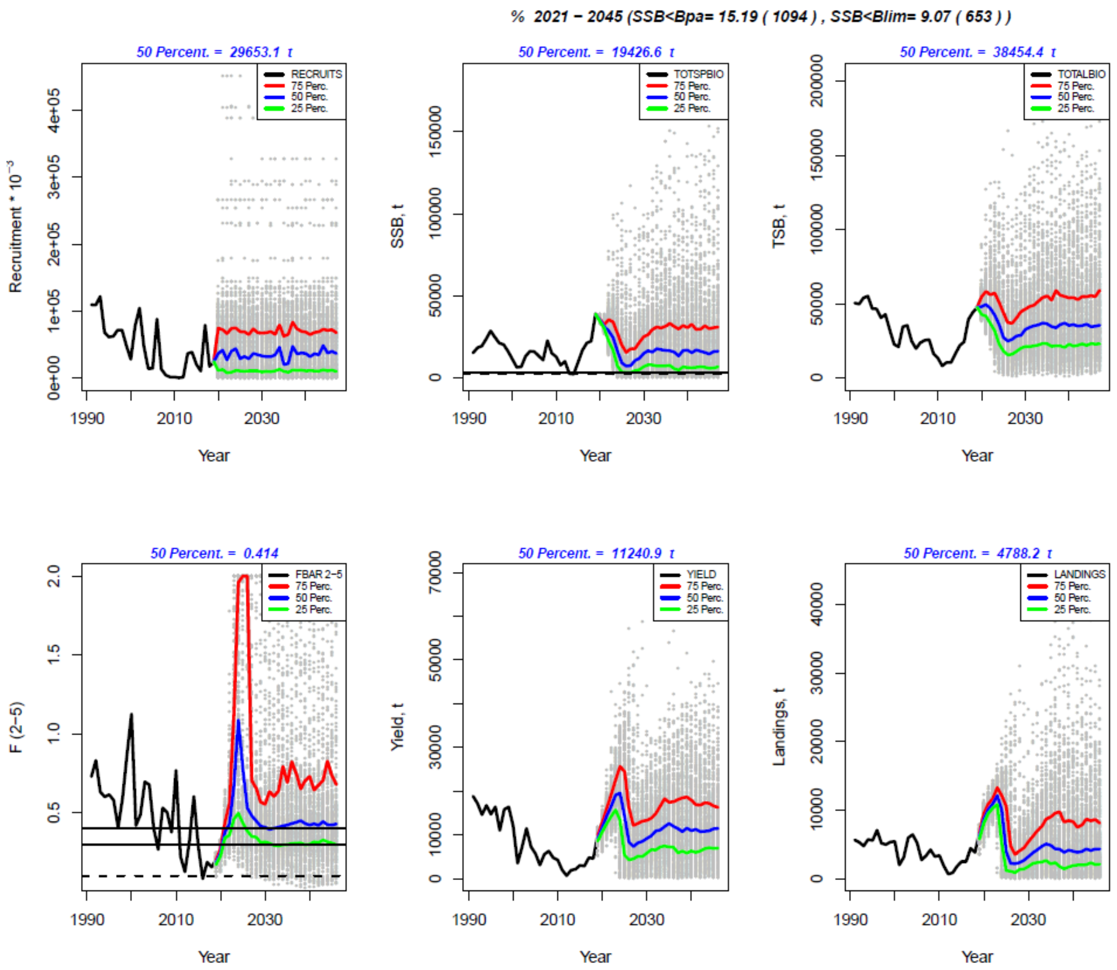

Figure 3.3.20. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Long-term recruitment as in 1991–2018. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

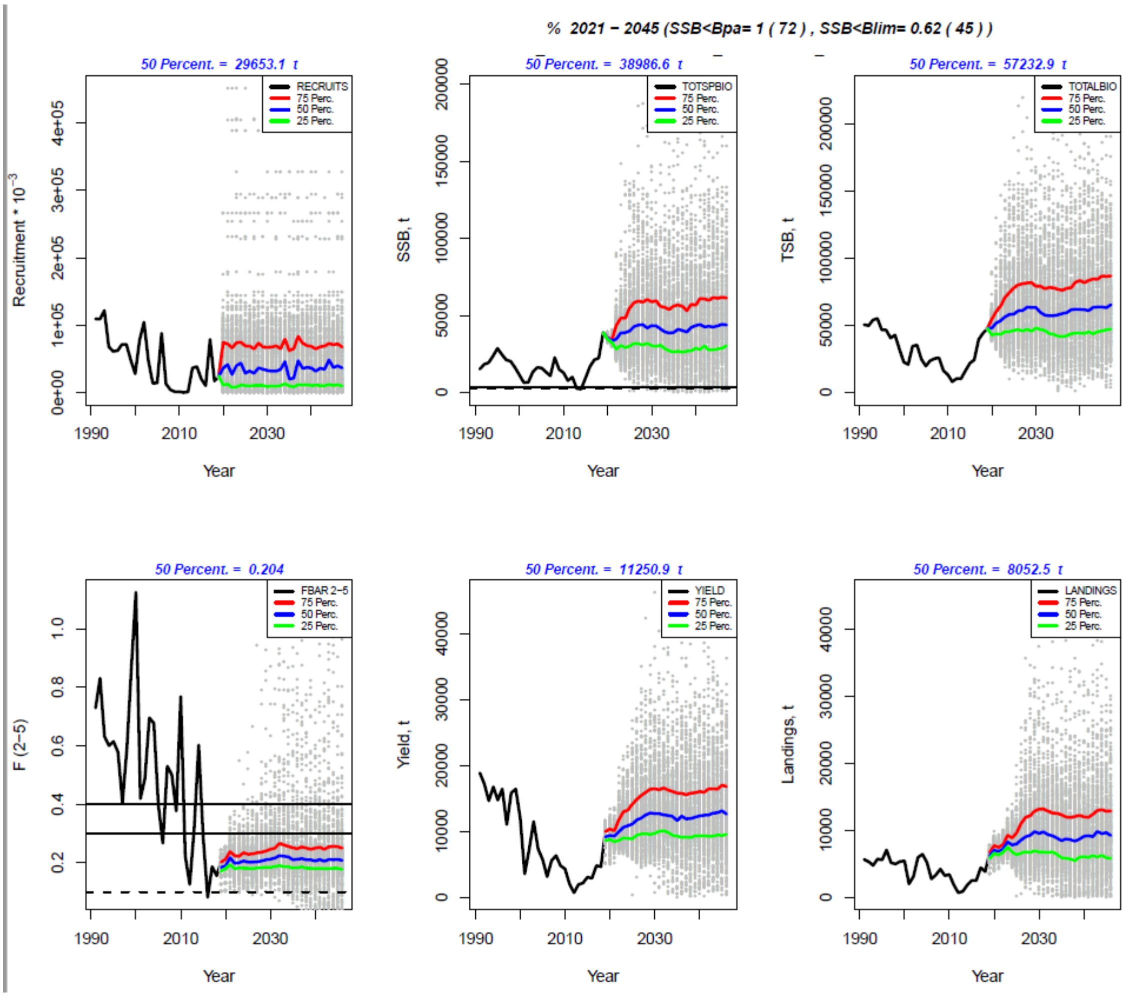

Figure 3.3.21. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Long-term recruitment as in 1991–2018. No discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

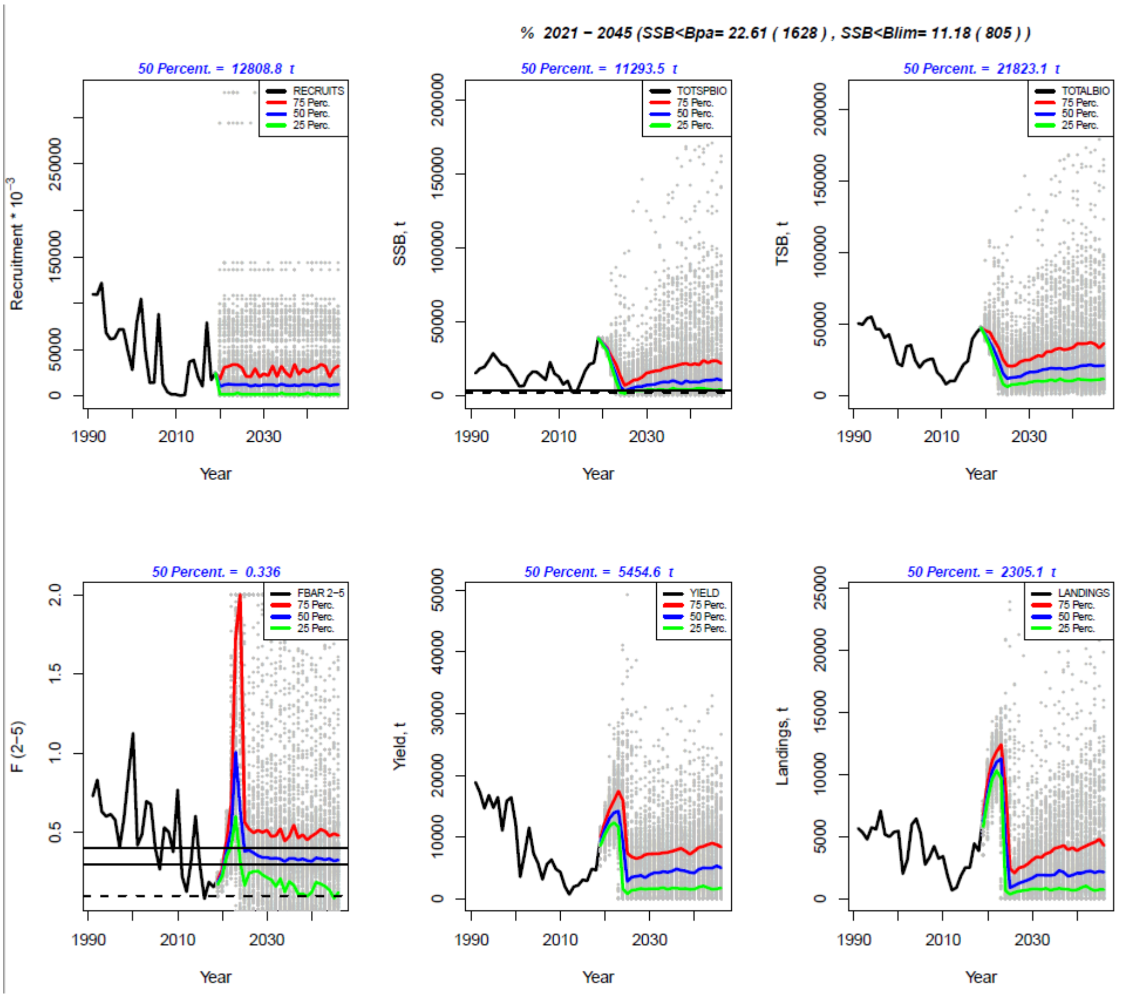

Figure 3.3.22. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Low recruitment as in 2004–2012. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

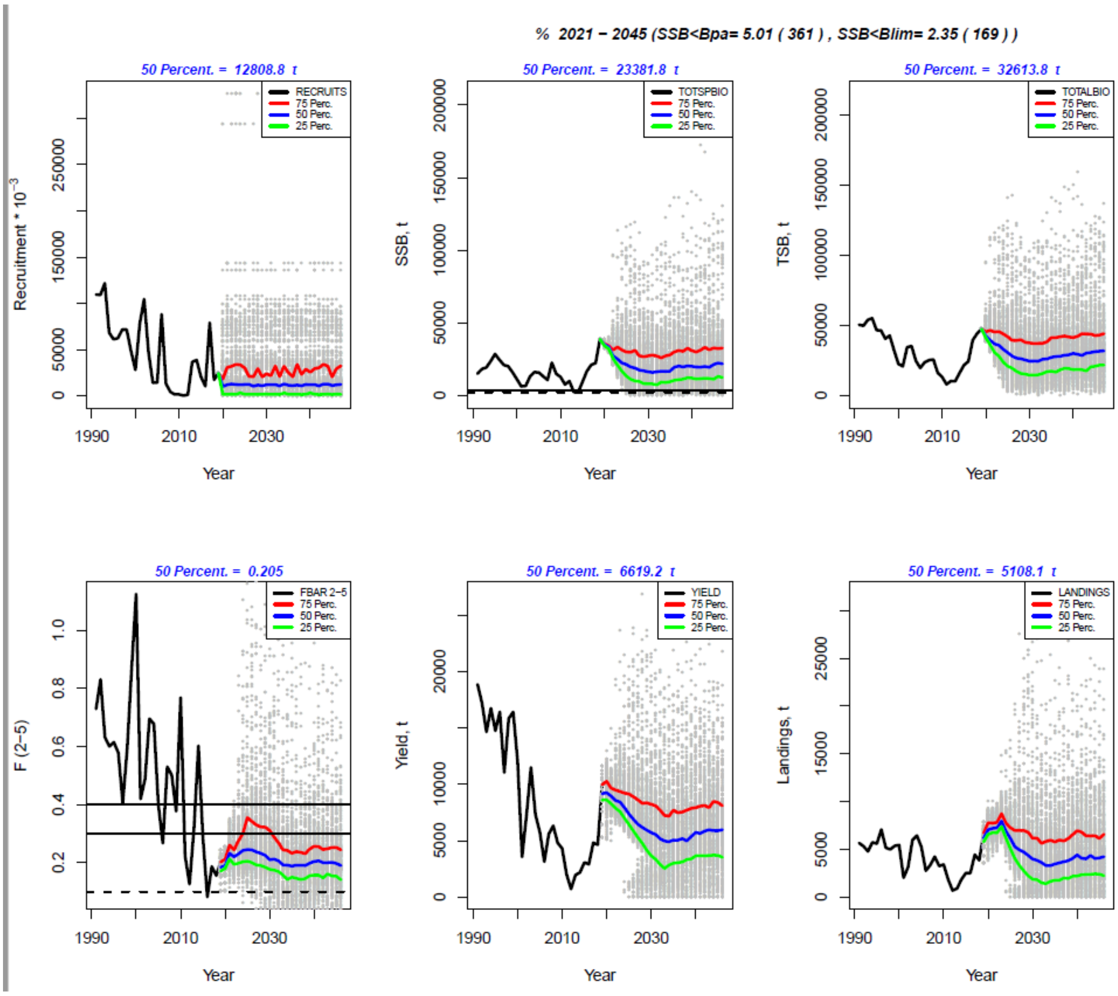

Figure 3.3.23. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Low recruitment as in 2004–2012. No discards or the total quotas set at the landing used by ICES in 2009-2016. F_{low}=0.0. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

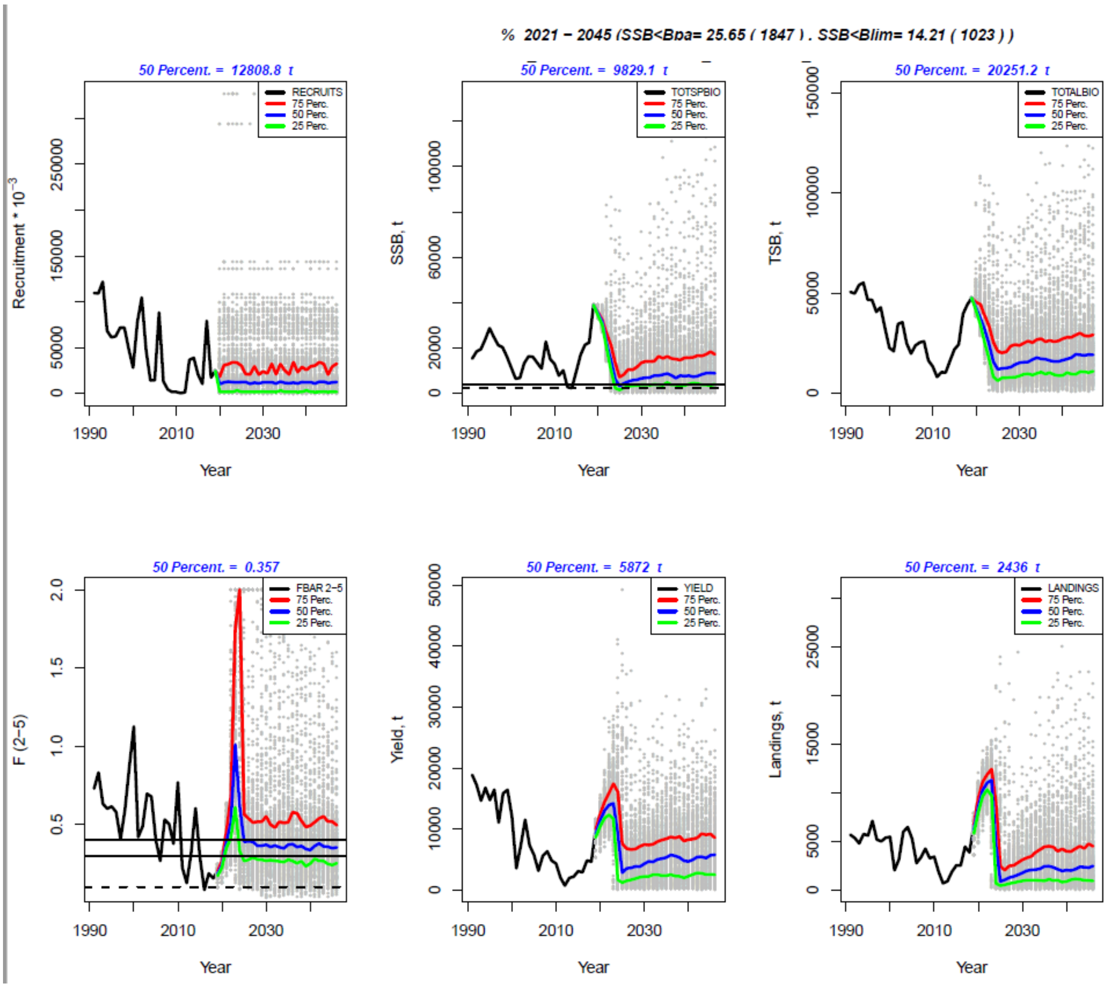

Figure 3.3.24. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Low recruitment as in 2004–2012. There are discards and the total quotas set at the TAC level that includes landings and discards. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0).

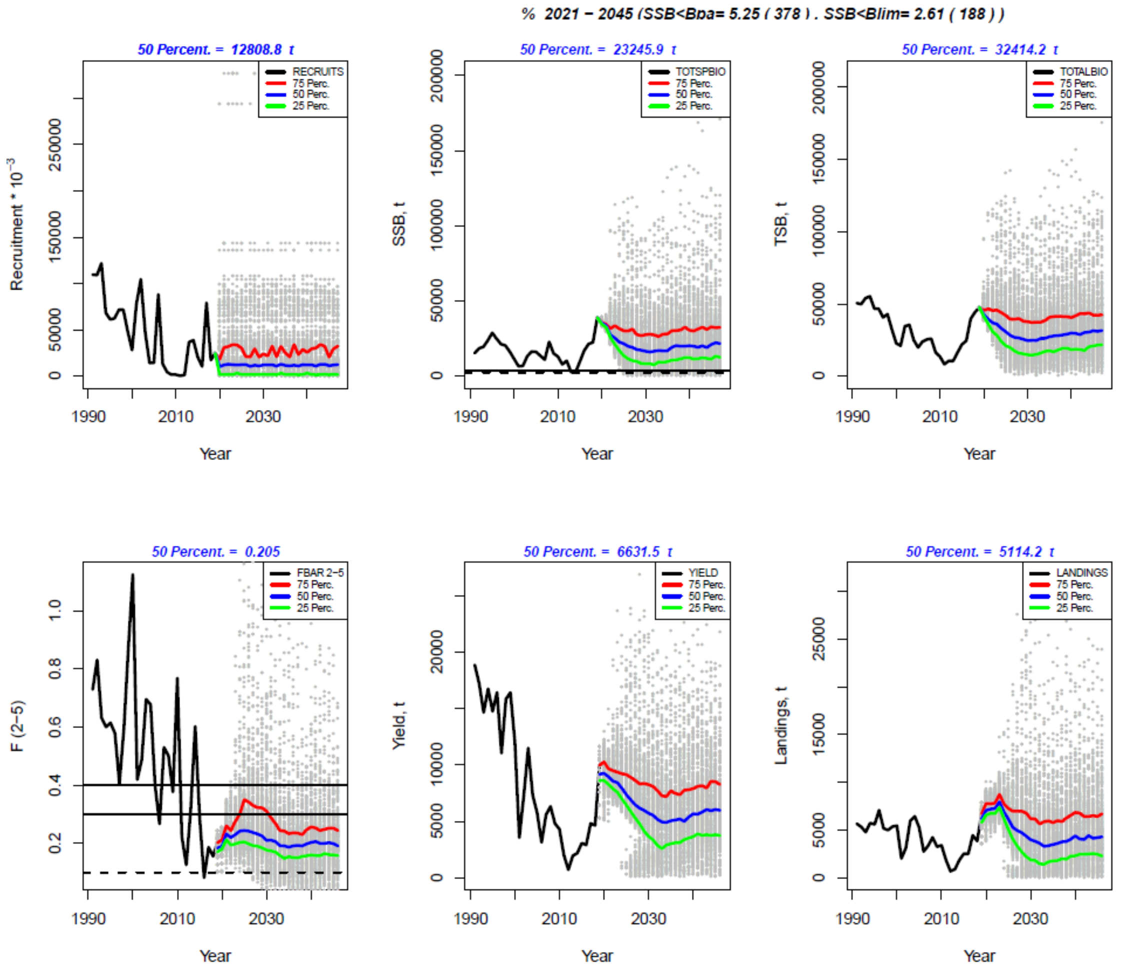

Figure 3.3.25. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Low recruitment as in 2004–2012. No discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.1. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

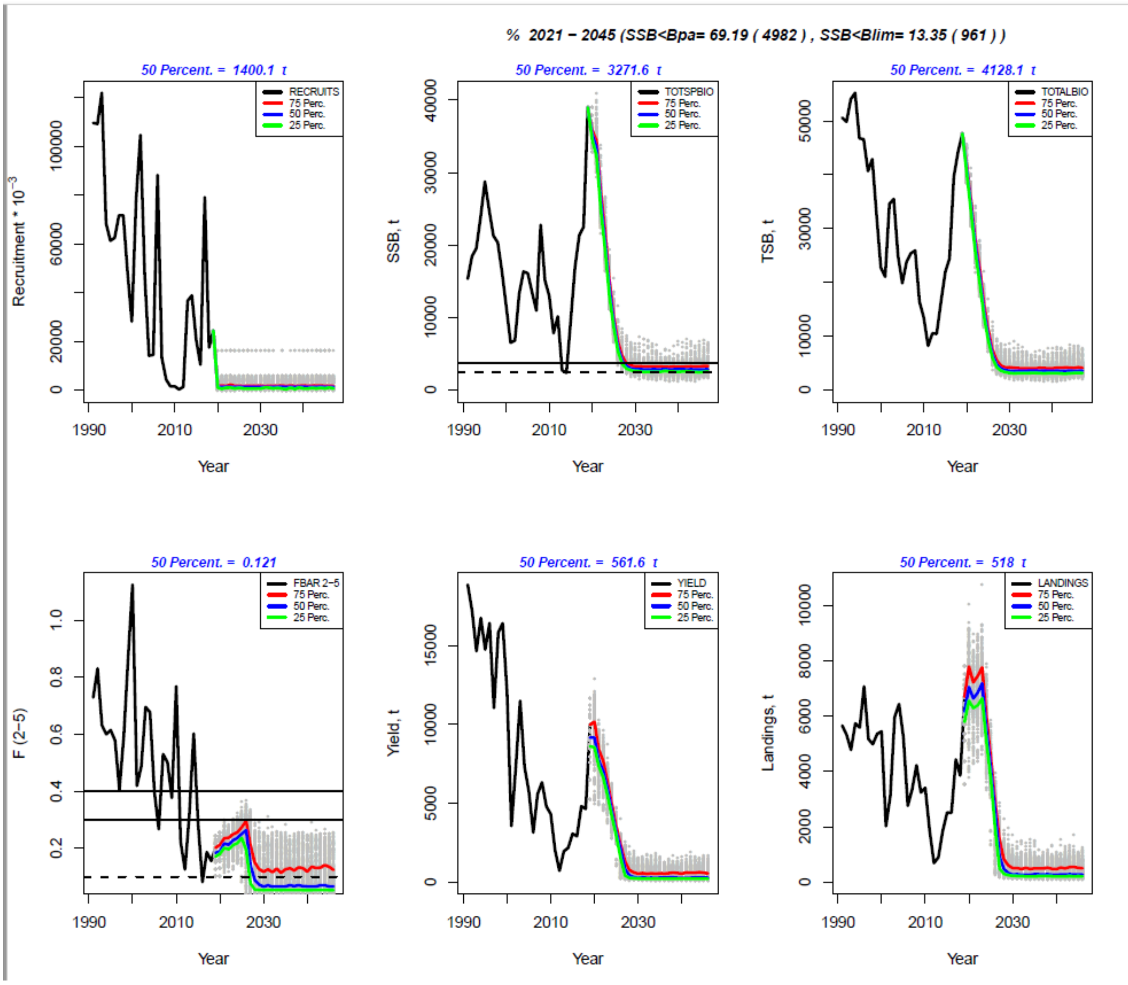

Figure 3.3.26. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3a of management plan: TACy = TACf + 0.2 * (TACy-1–TACf). Extremely low recruitment as in 2008–2012, no discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.05. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

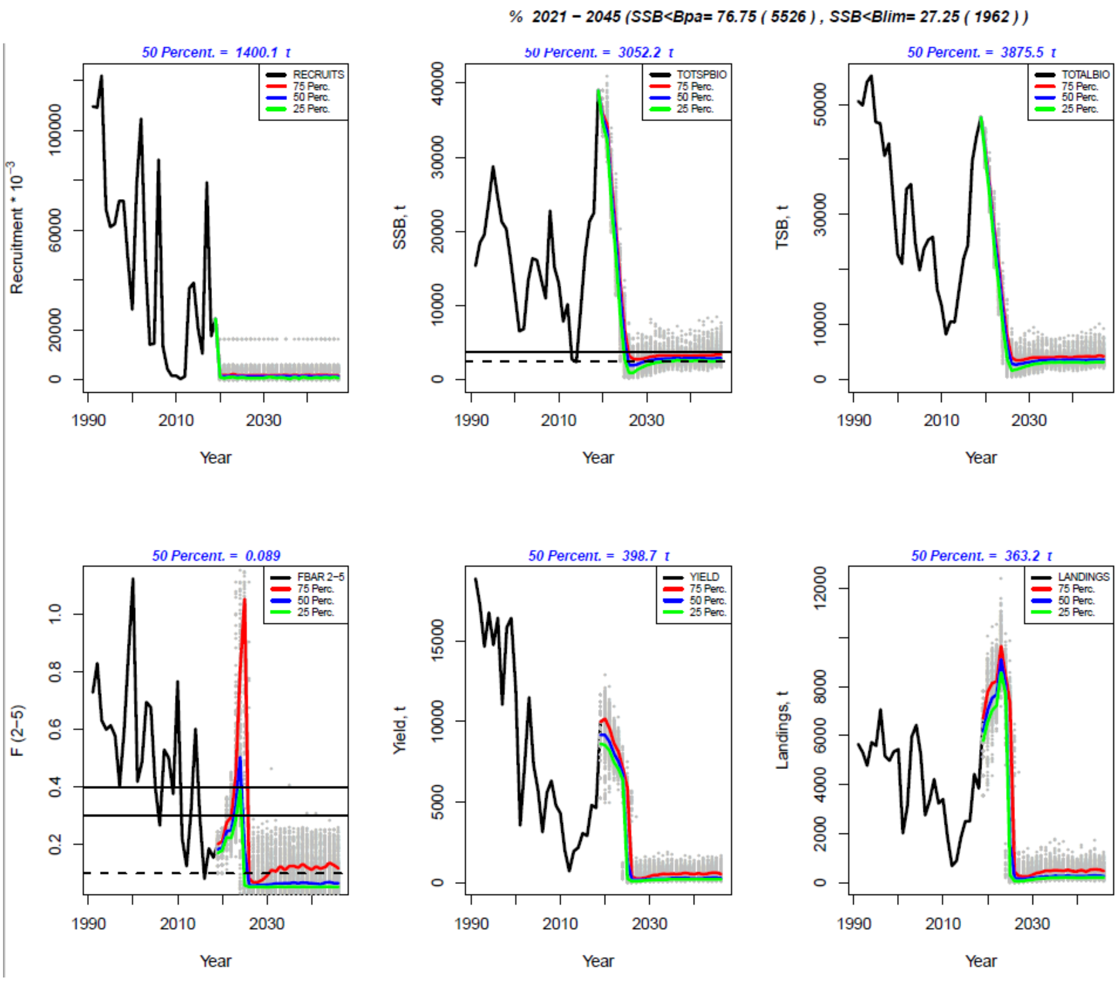

Figure 3.3.27. Summary plots of population values from the 300 simulation iterations run of the Rockall haddock. Option 3b of management plan: TAC is respectively no more than 20% less or 25% more than the TAC of the preceding year. Extremely low recruitment as in 2004–2008. No discards or the total quotas set at the landing used by ICES in 2009–2016. F_{low}=0.05. The solid colour lines indicate 25th, 50th and 75th percentiles. The thin solid black horizontal lines show B_{pa}/B_{MSY} and for comparison F_{pa} =0.4, F_{MSY}=0.3 for 2013. The horizontal dashed lines show B_{lim} and F_{MSY}=0.168 (F scale start not 0). The landings present for the method of setting a human consumption of TAC. If there are not discards, the landings will be equal to the yield and TAC.

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Annex 1: List of participants

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Alfonso Perez, Invited Expert	Institute of Marine Research	Norway	alfonso.perez.rodriguez@hi.no
Daniel Ricard, Invited Expert by correspondence	Fisheries and Oceans Canada, Moncton	Canada	daniel.ricard@dfo-mpo.gc.ca

Annex 2: NEAFC Request

Background

NEAFC requests ICES to evaluate the following proposal for the harvest control component of a long-term management plan for Rockall haddock (HAD.27.6.b) and in particular to consider whether the plan is consistent with the precautionary approach and will provide for the sustainable harvesting of the stock. If the plan fails to be precautionary, ICES will also be asked to suggest possible options to bring the plan aligned with the precautionary approach.

Other supplementary information to assist the interpretation of the request:

Previous work: EU-Russia Workshops over several years (~2001–2012)

Relevant documents:

European Commission and Russian Federation. 2009. Report of the European Community - Russian Federation Scientific Expert Working Group on Rockall Haddock. Moscow, Russia (8–11 April 2008 and 9–11 September 2009); Edinburgh, Scotland (4–6 February 2009).

Needle, C.L. and Mosqueira, I. 2011. An Evaluation of a Proposed Management Plan for Haddock in Division VIb (Rockall). Working Document to the ICES Advisory Committee.

Request

NEAFC proposal for harvest control component of a long-term management plan for haddock at Rockall.

In the following, the TACs refer to total catches, not just landings.

1. Every effort shall be made to maintain a level of Spawning–Stock Biomass (SSB) greater than B_{pa} and a minimum level of SSB greater than B_{lim}. $SSBF_{tar}$ denotes the SSB at the end of the year in which the TAC is applied, assuming $F_{tar}= F_{MSY}$ during that year. No iterative process is involved anywhere in the calculations in paragraphs 2–5.
2. For [20XX] and subsequent years the Parties agreed to set a TAC to be consistent with a fishing mortality rate of no more than F_{MSY} (as estimated by ICES) for appropriate age groups, when the SSB in the end of the year in which the TAC is applied ($SSBF_{tar}$) is estimated above B_{pa}.
3. The Parties agree that the TAC that results from the application of the fishing mortality referred to in paragraph 2 will be adjusted according to either of the following rules:
   a) TACy = TACf + 0.2 * (TACy-1–TACf)

where TACy is the TAC that is to be set by the management plan, TACy-1 is the TAC that was fixed the previous year and TACf is the TAC resulting from the provisions in paragraphs 1 and 2.

Or

   b) Where the rules in paragraph 2 would lead to a TAC, which deviates by more than 20% below or 25% above the TAC of the preceding year (TACy-1), the Parties shall fix a TAC that is respectively no more than 20% less or 25% more than the TAC of the preceding year.
4. Where $SSBF_{tar}$ is estimated to be below B_{pa} but above B_{lim}, the TAC shall not exceed a level, which will result in a fishing mortality rate equal to

$F_{MSY} - [(F_{MSY} - F_{low}) \times (B_{pa} - SSBF_{tar}) / (B_{pa} - B_{lim})]$, where $F_{low} = 0.1$ or 0.05 or 0.

This consideration overrides paragraph 3.

5. Where $SSBF_{tar}$ is estimated to be below B_{lim} the TAC shall be set at a level corresponding to a total fishing mortality rate of no more than $F_{low} = 0.1$ or 0.05 or 0.

This consideration overrides paragraph 3.

6. The Parties shall review and if deemed necessary, revise this long-term management plan at the latest in [20XX] on the basis of, inter alia, the ICES benchmark report. If the Parties receive new and relevant information, an earlier review of the management plan will be considered.

Intended use of the request output

The long-term management strategy evaluations will inform the management of haddock at the Rockall area.

Annex 3: MSE summary sheet

Condensed MSE guidelines	
Operating Model	
Biology and Fishery Model (Base Case)	
Basis for the Base Case	The Base Case corresponds to the ICES stock assessment agreed in a benchmark 2019.
Recruitment	A Beverton–Holt spawning–stock recruitment relationship is fitted to historical data (since 1991). Residuals are generated using multiplicative lognormal error with autocorrelation (AR(1), following EqSim settings).
Growth	Resampled weights-at-age from the recent ten years of historical data (2009–2018). No density-dependence included (following EqSim settings). Resampling is done by selecting a year at random and taking respective catch weights and stock weights-at-age for this year.
Natural mortality	Constant natural mortality across ages and years (M=0.2).
Maturity	Knife-edged maturity ogive (age 3), constant across years.
Fishery selectivity	Resampled F at age from the recent ten years of historical data (2009–2018, following EqSim settings).
Initial stock numbers	Initial numbers from the stock assessment agreed by ICES for the stock. XSA does not provide uncertainty estimates. Uncertainty in the historical period was included by generating survey indices from estimated stock numbers and a multiplicative lognormal error.
Technical interactions (mixed fisheries)	No technical interactions were included.
Biological interactions	No biological interactions were included.
Biology and Fishery Model (alternative dynamics)	
Alternative biology and fishery scenarios	Alternative operating models were used: OM1 Low recruitment level OM2 Misspecification of M (OM: M=0.3 , MP: M=0.2) OM3 Misspecification of maturity (OM: knife-edge age 2, MP: knife-edge age 3) OM4 Misspecification of M (OM: M=0.1, MP: M=0.2) OM5 Weights-at-age sampled from the recent 20 years OM6 Weights-at-age sampled from the recent 20 years + Misspecification of M (OM: M=0.3, MP: M=0.2)

	+ Low recruitment level OM7 Implementation error OM8 Very low recruitment level
Observation Model	
Simulation of input data for a stock assessment or for direct use in a harvest rule (e.g. for survey-based harvest rule)	This MSE is following a full approach (with XSA assessment and forecast in the MSE). Observation data for the harvest rule was generated from the operating model. Catches were deterministic, survey indices were generated from stock numbers-at-age with a multiplicative lognormal observation error. Input to assessment: Catches-at-age, survey index, biological parameters
Implementation Model	
Implementation error	Implementation error not included in the base case. Implementation error included in an alternative operating model (OM7) as a robustness test.
Management Procedure	
Estimation Model	
If a full assessment is conducted in the MSE loop	The estimation model (XSA) in the management procedure is the same as in the assessment conducted to provide ICES advice.
If a shortcut approach (instead of a full assessment) is used in the MSE loop	Not applicable.
Harvest rules requiring a stock assessment followed by a short-term forecast	Assessment followed by a short-term forecast. Recent three-year average of selectivities, stock weights-at-age, biological parameters and recent five-year average of catch weights-at-age were used in the forecast. Recruitment in forecast years is the 25th percentile rank of the historical recruitment series (since 1991). The MSE forecast procedure is the same as the ICES forecast except that the ICES forecast makes use of RCT3 estimate of recruitment (using age 0 survey index) in the intermediate year. Age 0 is not available from the OM, therefore the 25th percentile rank was used instead in the intermediate year of the MSE forecast.
Decision Model (Harvest rule)	
Harvest rule design	The NEAFC request asks to evaluate six specific management strategies (three HCRs and TAC constraint options; see Annex 2). The three harvest control rules define an F dependent on SSB at the end of the TAC year, with a constant F (= F_{target}) when SSB is at or above $B_{trigger}$, and an initial linear reduction in F when SSB is below $B_{trigger}$. The harvest control rule slopes differ depending on the value of Flow (three options). If SSB is below B_{lim}, F is set to the respective F_{low}.

Harvest rules that include stabilizers	The fishing mortality is adjusted according to either of two TAC constraint rules (a, b; see Annex 2). Constraint rule a) TACy = TACf + 0.2 * (TACy-1–TACf) and constraint rule b) asymmetric TAC constraint (-20%, +25%) are applied only if SSB at the end of the TAC year is above $B_{trigger}$. Combining the HCR and TAC constraints options results in a total of six management options tested in the MSE.
Duration of decisions	TAC set annually
Conditions for reevaluating the MSE in the future	Three main situations may be identified: • If the performance of the stock assessment used to apply the harvest rule (for model-based harvest rules) or the quality of the data used in the harvest rule (for empirical harvest rules) deteriorate substantially relative to what was assumed in the MSE • If the observed conditions of the stock and/or fishery depart considerably from what was assumed in the MSE. In particular, if the recruitment in future years is considerably lower than assumed in the base case for long periods of time.
Running the MSE simulation	
Number of iterations (independent replicates simulated in the MSE)	1000 iterations
Projection time (number of future years included in the MSE)	25 years
Reporting outputs	Summary projections for recruitment, SSB, catch and realized F. Comparison of management strategies against performance statistics for the base case OM. Robustness tests of management strategies against the alternative operating models (OM1–OM8).
Validation checks (for different components of MSE simulation)	XSA assessment does not provide uncertainty estimates on assessment results. Generated recruitment residuals were compared and adapted to historical estimates. Simulated recruitment generation checked against historical recruitments. Summary projections indicated no obvious breaks between past and future dynamics, and included worm plots of selected replicates. Alternative operating models were developed to check a number of assumptions on MSE components.
Reference points	
Reference points used in the MSE	The reference points used in the management procedure are the reference points used by the ICES assessment (according to the most recent benchmark for the stock). The reference points are the same in the operating model and management procedure (i.e. the same B_{lim} is used in both cases).

Performance statistics and precautionary criterion	
Performance statistics	Short-term, medium-term, and long-term performance statistics typically relate to the following: • Catch • Probability of SSB falling below B_{lim} • SSB • Interannual catch variability • Realised ("real") F We define short-, medium- and long-term as years 1–5, 6–10 and 11–20 respectively in the projection period.
Risk type****	Prob3 (Risk3), Prob1 (Risk1)
Precautionary criterion	Prob3 ≤5% over all years included in the management strategy (short and long terms) is the ICES criterion for considering a management strategy as precautionary.
Experiences and comments	
Use of ICES guidelines for MSE (WKGMSE2 2019)	The guidelines are intended to guide the decisions based on best practice throughout the evaluation.

****** Risk types (for a period of ny years):**

Prob1 = average probability that SSB is below B_{lim}, where the average is taken across the ny years.

Prob2 = probability that SSB is below B_{lim} at least once during the ny years.

Prob3 = maximum probability that SSB is below B_{lim}, where the maximum of the annual probabilities is taken over the ny years.

Annex 4: External Reviewers' report

External Reviewers:

- Quang Huynh
- Alfonso Perez
- Daniel Ricard, attending by correspondence

Introduction

The reviewers were tasked with evaluating (1) calculation of the reference points associated with the benchmark assessment; (2) evaluation of the management advice to respond to the NEAFC Special Request; and (3) the forecast settings used to provide the Advice for Rockall haddock in 2020.

Similar to what happened at the WKROCK benchmark meeting, much of the technical work for WKROCKMSE needed to be done during the meeting. This constrained the discussions that could take place during the meeting but was necessary to ensure that the assumptions used were the same, for example, identical stock–recruitment relationships for the reference point calculation and MSE were used. The reviewers contributed to the discussion for the decisions needed to start and refine the technical work, but it was not possible to comprehensively review all the results of the MSE, including the base and alternative scenarios, during the meeting due to the runtime needed to complete the simulations.

Reference points

The estimation of the reference points for Rockall haddock in Division 6.b was made using the stochastic equilibrium software EqSim and following the ICES guidelines for the estimation of Precautionary Approach and MSY reference points. Haddock (*Melanogrammus aeglefinus*) in Division 6.b (Rockall) had gone through a benchmark in April 2019. The main questions raised by the reviewers during the benchmark were related with the procedure used to generate the catch-at-age data (how the raising of discards was done), the variability in mean weight-at-age, and some other aspects of the biology and ecology of the stock.

Regarding the definition of Precautionary reference points, there was a long discussion about the type of ICES stock with respect to the relationship between SSB and recruitment (ICES, 2017). It was difficult to find a type that closely matches the pattern observed in the Rockall Haddock SSB-Recruitment data. Despite some evidence (visually) of increased recruitment at higher values of SSB (albeit with very high variability), it was agreed both by reviewers and workshop participants that the stock type 5 was the best option of those indicated in the ICES guidelines: "*Stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent S–R signal*)", for the purposes of defining B_{lim}.

Supporting this decision is the fact that the stock has recover from the lowest SSB values of 2012–2014, which suggest that recruitment had not been impaired. However, it was highlighted that the extreme importance of this decision in terms of the definition of precautionary reference points. In the type 5 stock, the $B_{lim} = B_{loss}$, the lowest SSB observed in the time-series that allowed the recovery of the stock. For the Rockall haddock, the B_{loss} is the SSB estimated in 2014. This involves a reduction in B_{loss} from the previous value, 6800 tons, to 2474 tons. Due to the lack of estimates of variance on SSB, B_{pa} was set to 1.5 B_{lim} (3464 tons). This is slightly more precautious than the default value of 1.4 B_{lim} that is commonly used.

In following the ICES guidelines for the determination of the precautionary reference points, there was concern that the stock type selected generated a very low B_{lim}. The fact is that it was not only the recruitment event of 2014 that improved the status of the stock, but also the recruitment events of 2012 and 2013.

Current ICES practice allows for revision of reference points in an inter-benchmark setting, if needed. Thus, the reviewers agreed that the current classification of type 5 stock–recruit relationship for Rockall haddock is appropriate based on the benchmark assessment, while allowing for re-evaluation in the near future as needed.

EqSim was used in the estimation of the remaining reference points (F_{lim}, F_{pa}, F_{MSY}, and $MSYB_{trigger}$). After some discussion, it was agreed using a hockey stick SSB–Recruitment relationship, with the breakpoint being the agreed B_{lim}. There were relevant discussions during the workshop for the definition of the main parameters defining the biological and fisheries development in the long-term simulations.

- Weight-at-age: There were doubts about the range of years of the historic period that should be used to produce the mean weight-at-age in the simulations with EqSim. Initially a range of 20 years was used. However, it was concluded by reviewers and workshop participants that this long range of years would produce a low mean weight-at-age (median of 1000 iterations), close to the lower values of weight-at-age observed during $^2/_3$ of the historic period. Since it can be expected that the mean weight-at-age in the near future will more likely be close to the values observed in the recent period, a 10-year window was decided instead. There was also an extensive discussion to decide if using the raw mean weight-at-age sampled from the commercial catches or using the weight-at-age result of the 5-year moving average. It was agreed using the 5-year moving average since this was the agreement achieved during the Benchmark meeting on April 2019 to do the assessment for this stock.
- Discard rate at age: Despite the fact that there is a ban for discards within the EU, it is believed that there is still a relatively high percentage of discards at different ages for this stock. It is expected that this rate is related with the length of the individuals caught. For this reason, it may be expected that during the last years of the historic period, discards have been lower than before 2005, when the mean weight-at-age (and expected length) was lower. EqSim does not allow coupled and correlated resampling of discard rates and mean weight-at-age. For this reason, there are possibilities of obtaining the discard cases that are thought to be unlikely, i.e. high discard rate in years where mean weight-at-age is high, and low discard rate when the mean weight is low. This is an aspect that should be solved in the future for EqSim simulations. Despite being aware of this limitation, it was agreed using the mean discard rate at age of the last ten years in the historic period in the EqSim simulations.
- The definition of yield as the catch of individuals larger than 30 cm was considered adequate by the reviewers. This criterion is intended to find the fishing mortality rate that maximizes yield in the non-discarded range of the stock.
- The fishing pattern (selectivity) applied every year in the EqSim simulations was assigned using the default option: randomly resampling from the last ten years of the historic period in the last approved assessment. During the meeting, it was highlighted by the reviewers that the fishing pattern has been very variable in the last ten years. However, it was concluded that this may also represent the reality in the coming years.
- Regarding the SSB–Recruitment used in the simulations, one of the characteristics of stocks of type 5 in relation to the SSB–Recruitment relationship is that a clear relationship does not exist. Accordingly, a hockey stick relation was used to model the SSB–Recruitment, and it was agreed using the estimated B_{lim} as the breakpoint. Autocorrelation in

recruitment has been observed for this stock. Thus, autocorrelation was also modelled in EqSim and used in the prediction of annual recruitment over the simulating period.

Management strategy evaluation

The management strategy evaluation (MSE) was used to address the NEAFC Special Request, which proposed a management plan and requested advice from ICES whether it was precautionary. The historical dynamics of the operating model (OM) was conditioned on the XSA assessment, which follows standard ICES practice. Risk calculations follow guidelines evaluated at WKGMSE2. In particular, Type 3 risk was used to classify whether a harvest control rule was precautionary or not.

For the 25-year projection period, the base OM re-sampled fishery selectivity and growth from the most recent ten years of the assessment. Future recruitment (stochastic) was based on a stock–recruit relationship obtained using historical spawning biomass and recruitment from the entire time-series of the assessment. The reviewers agree with these decisions because these parameter values were likely to reflect the stock in the near future (the next 1–5 years). These assumptions were aligned with the reference point calculations. When needed, new information from the next benchmark would be used to update the operating model and re-evaluate the management plan. Thus, the reviewers believed that the decisions for these settings were appropriate for the current evaluation.

Alternative OM scenarios were also developed to evaluate whether the management plan would be precautionary if future conditions in the projection period were to be more pessimistic compared to conditions assumed in the benchmark assessment, for example, lower recruitment, i.e. a lower asymptote of the stock–recruitment relationship, or an increase in natural mortality.

The core work for the MSE was done in FLR with 1000 simulations. Some additional testing was performed using the same settings as those used in the 2013 evaluation of the management plan, with few simulations (n = 100) (ICES, 2013).

Preliminary results presented during the meeting showed that the candidate harvest control rules were precautionary for the base and most alternative OM scenarios. Most notably, the additional testing evaluated a scenario where future recruitment was very low, by re-sampling recruitment values observed from 2004–2012). This additional testing was useful to highlight the point that any conclusion regarding the harvest control rule is dependent on the operating model conditioning.

During the meeting, the reviewers agreed with the general conclusion based on the results available: that the candidate harvest control rules are precautionary, but that further evaluation will be needed if very low recruitment levels similar to those from 2004–2012 are observed.

Forecast for the 2020 Advice

For the forecast, the reviewers agreed with the decisions that growth, selectivity, and discards would be similar to recent values, e.g. most recent three-year average, assumed or estimated in the benchmark assessment.

Since Rockall haddock is a quota-based fishery with landings dominated by three countries (UK, Ireland, and Russia), the reviewers agree with the decision to updated the intermediate year catch to be constrained by the UK and Ireland TAC and expected Russian catch.

The RCT3 model is used to predict the age-1 recruitment in the intermediate year from historical age-0 surveys and predicted age-1 recruits from the XSA assessment, while the 25th percentile of historical recruitment is used for subsequent years. These values are used in near-term stock projections for the Advice sheet. There was lengthy discussion regarding three outlier survey values observed from the RCT3 model, and whether they should be removed from the analysis since the CVs in those years were notably high (around 0.7). Doing so (removing the values) drastically improves model fit, and predicts moderately higher recruitment in the intermediate year. The expert group preferred to use inverse-variance weighting in the model, but this feature was not possible in the current software. Due to time limitations, this issue could not be resolved during the meeting. The reviewers agreed with the decision to leave the outliers in the model, but that the decision could be re-evaluated in the working group in the future.

Further recommendations

The review could have been more streamlined if the computer code for the MSE, however preliminary, were made available to the reviewers in a platform such as TAF. The reviewers are familiar with MSE software, and availability of the computer code would have increased the delivery of information from the experts to reviewers and relieved the time needed for discussion and preparation of PowerPoint slides. Currently, ICES does not have a platform for MSE as it currently does for benchmark assessments.

Robustness scenarios for the MSE was used to evaluate pessimistic, but plausible, future conditions for the stock, e.g. increase in M, high discards, or low recruitment. Notably, there were major uncertainties with the XSA assessment model, with uncertainty in discard, M, and maturity estimates. The alternative scenarios did not evaluate scenarios in which the historical dynamics were incorrectly specified in the assessment model in the first place, e.g. the true M in the historical and future periods is higher or lower than the 0.2 value used in the assessment.

Such an analysis evaluates whether the management plan is robust to incorrect assumptions of the assessment model, which would highlight the research priorities for the next benchmark. While impactful, such work is currently generally beyond the scope of ICES evaluation of management plans (ICES, 2019). The terms of reference of this meeting did not call for an evaluation of robustness. A future ICES workshop could be held to explore and demonstrate the benefits of this more strategic use of MSE.

References

ICES. 2013. Report of the Second Workshop to evaluate the EU-Russian proposal for the harvest control component of the management plan for Rockall haddock, 4–6 June 2013, ICES HQ, Copenhagen, Denmark. ICES CM 2013/ACOM 67. 58 pp.

ICES. 2017. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice Technical Guidelines 12.4.3.1. DOI: 10.17895/ices.pub.3036.

ICES. 2019. Workshop on Guidelines for Management Strategy Evaluations (WKGMSE2). ICES Scientific Reports. 1:33. 162 pp. DOI: 10.178975/ices.pub.5331.

Annex 5: Working documents

WD 1 Alternative OMs

A1.1 OM 1 low recruitment, OM 8 very low recruitment

With low recruitment level in the projection period (OM1), the risk to fall below B_{lim} is slightly higher than in the baseline OM, in particular in the short and medium term. However, for constraint rule (a) risks remain below 5% in the low recruitment scenario in the short, medium and long term (OM1, Figure A1.2, Figure A1.3). Management options with constraint rule (b) are precautionary in the medium and long term, but not in the short term. Constraint rule (a) (0.2 rule) shows lower risks than rule (b). In the short term, rule (a) shows lower median catch and higher SSB (Figure A1.2). In the long term, rule (a) leads to slightly lower median SSB and slightly higher catches and lower risk than rule b. Recruitment level is lower than in baseline OM0 as illustrated in Figures A1.1 and A1.4.

At very low recruitment level (OM8), risks of the stock being below B_{lim} in the projection period are high in the short, medium and long term (Figure A1.6, Figure A1.7), with Risk3 being above 5% in the medium and long term for all HCRs (Figure A1.7). Only in the short term, Risk3 for HCRs with constraint rule (a) remain below 5%, while constrain rule (b) is not precautionary with Risk3 above 5%. In this recruitment scenario, risks are lowest for management options with F_{low}=0 (HCR 1a, b). Risks are highest using a value of F_{low}=0.1 and with constraint rule b. In the short term, rule (a) leads to higher median catches and SSB than rule (b). In the long term, median SSB is lower and catches are higher for rule (a).

Simulated recruitment in OM8 is extremely low, without any sporadic recruitment peaks, close to the level observed in 2007–2012 (Figure A1.8).

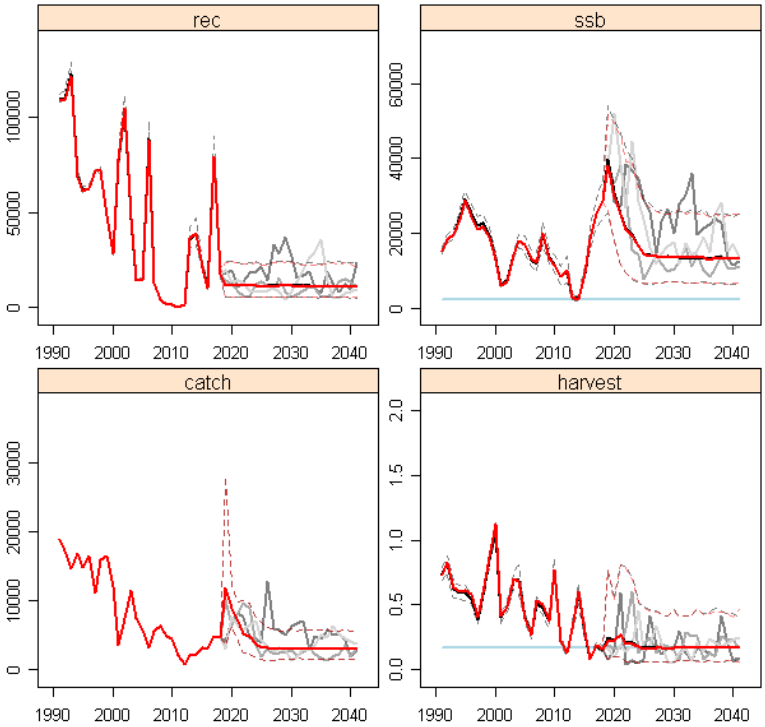

Figure A1.1. Rockall haddock in 6b. Results OM1 HCR 1a (F_{low}=0, TAC constraint rule a), OM in red (grey individual iterations), MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

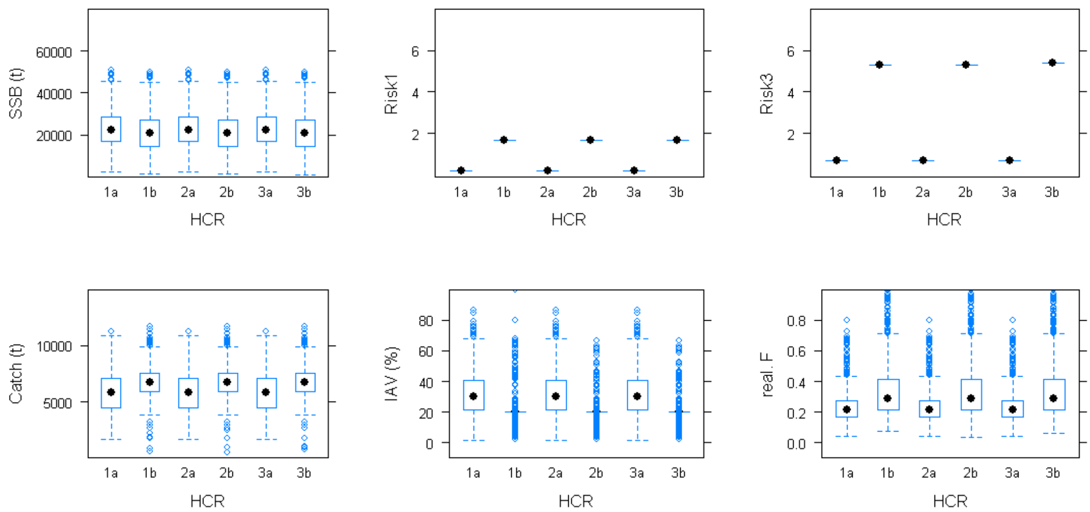

Figure A1.2. Rockall haddock in 6b. Results OM1, short-term (1–5 years), median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

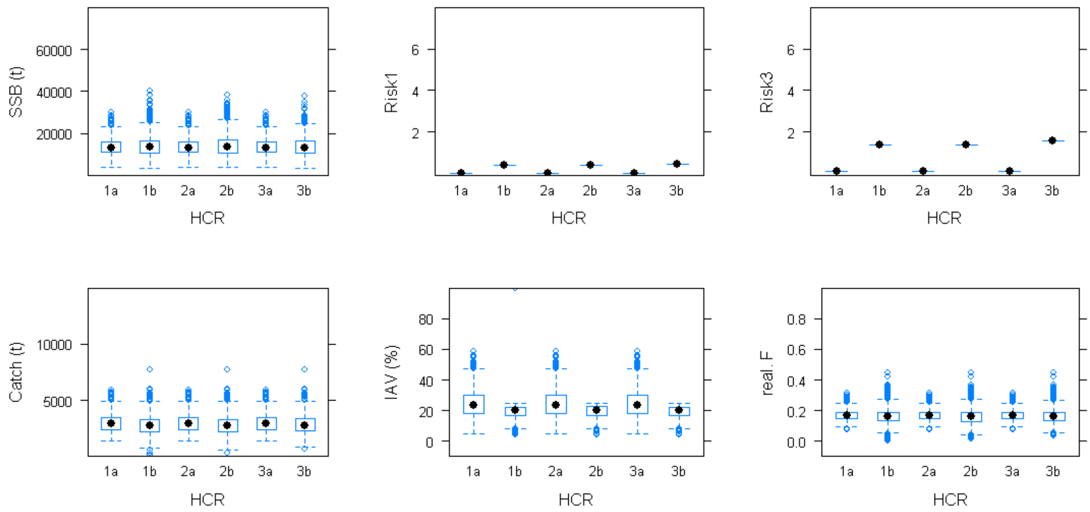

Figure A1.3. Rockall haddock in 6b. Results OM1, long-term (11–20 years), median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

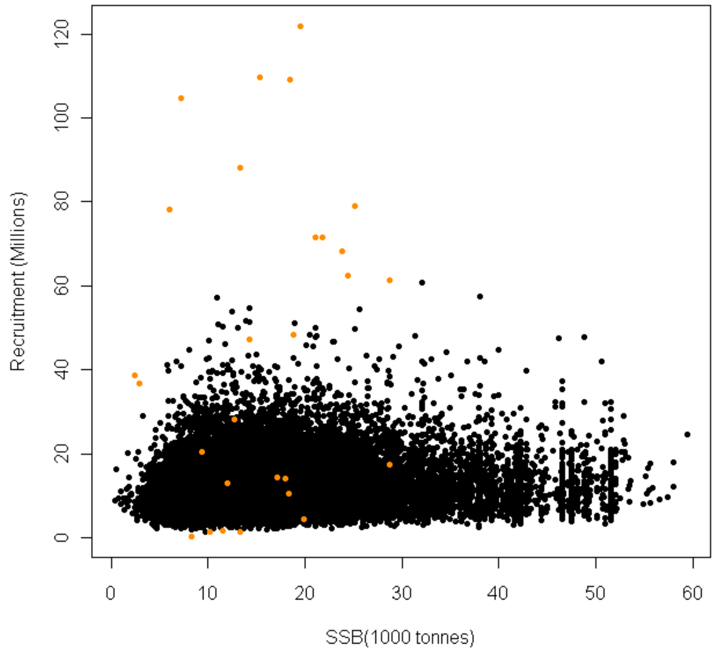

Figure A1.4. Rockall haddock in 6b. SSB recruitment pairs from historical assessment (orange) and simulated SSB recruitment pairs from OM1 HCR1a.

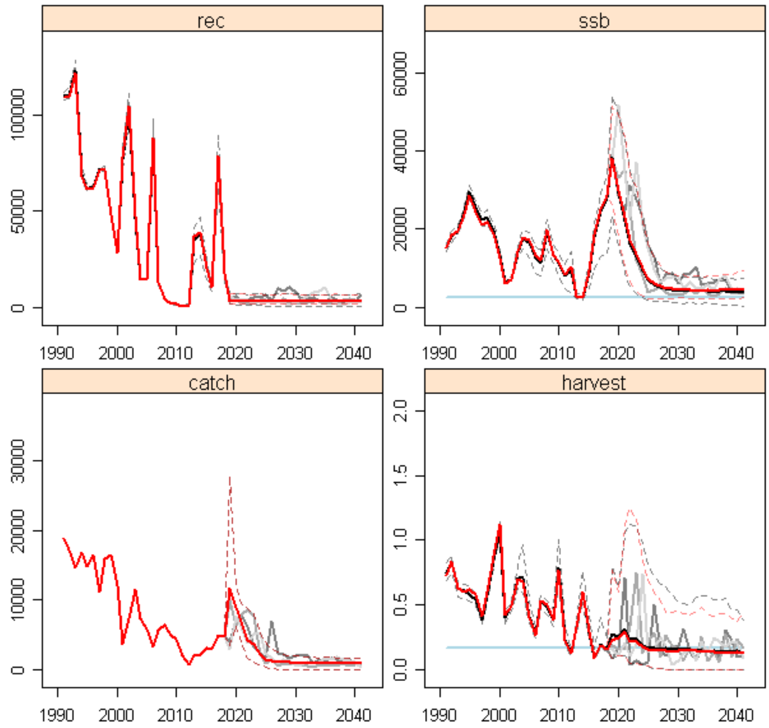

Figure A1.5. Rockall haddock in 6b. Results for OM8 HCR 1a (F_{low}=0, TAC constraint rule a), OM in red (grey individual iterations), MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

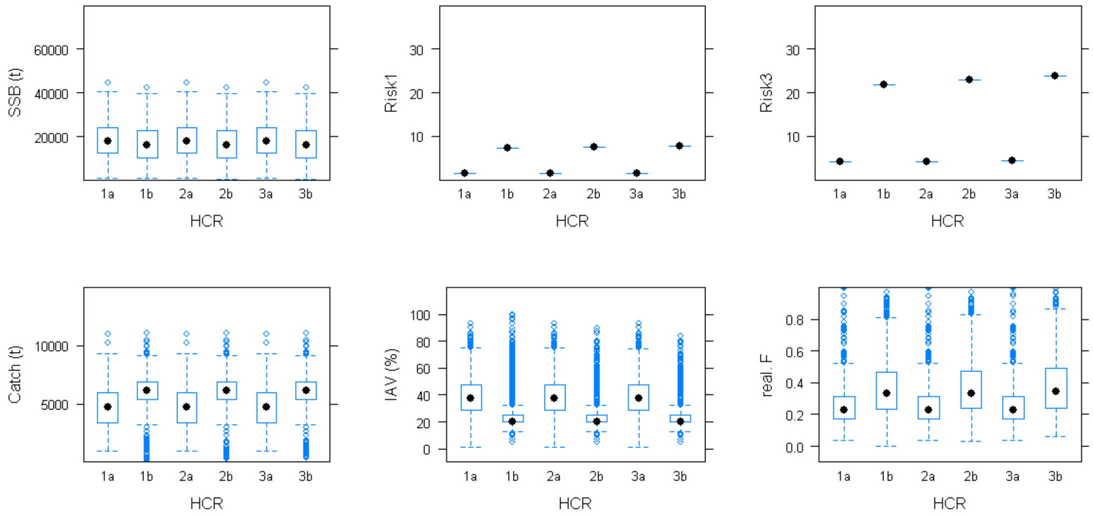

Figure A1.6. Rockall haddock in 6b. Results OM8, very low recruitment, in the short term (year 1–5), median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

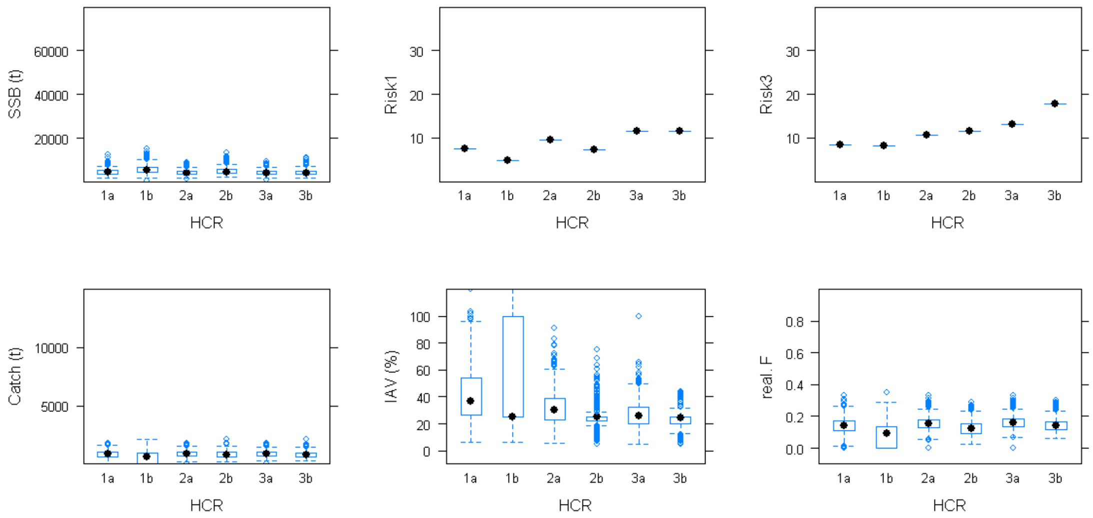

Figure A1.7. Rockall haddock in 6b. Results OM8, very low recruitment, in the long term (11–20), median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

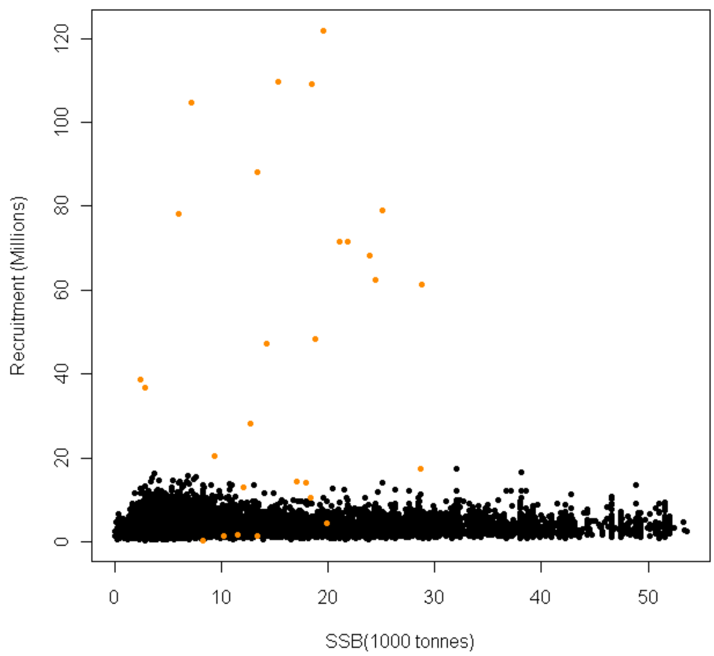

Figure A1.8. Rockall haddock in 6b. SSB recruitment pairs from historical assessment (orange) and simulated SSB recruitment pairs from OM1 HCR1a.

A1.2 OM 2 and OM4 Regime shift in natural mortality (M=0.3 and M=0.1)

In alternative operating model OM2, natural mortality in the OM (stock, M=0.3) differs from the assumed value in the MP (M=0.2) in the projection period. The MP is underestimating recruitment (and slightly underestimating the SSB) relative to the OM (Figure A1.9-A1.10). The higher survival of recruits assumed in the MP, leads to lower estimated recruitment and SSB estimates necessary to explain the "observed" catch and survey index in the projection period. Risks remain below 5% in the short, medium and long term for HCRs with rule (a) (Figures A1.11, A1.13). In the short and medium term, Risk3 is above 5% for HCRs with TAC constraint rule b (Figure A1.12). Performance of HCRs is similar for different values of F_{low}.

In the alternative OM4, natural mortality in the projection period is lower in the OM (M=0.1) than in the MP (M=0.2). The MP overestimates recruitment and also SSB relative to the OM (Figures A1.14, A1.15). The lower survival assumed in the MP leads to higher estimated recruitment necessary to explain the "observed" catches and survey indices in the projection period. Risks are below 5% in the short, medium and long term (Figure A1.16, see Section 4.5.2). The lower natural mortality in OM4 (M=0.1 rather than 0.2 or 0.3) in the projection period leads to higher overall SSB in comparison to OM0 and OM2, thereby reducing the risk for the stock to fall below biomass thresholds. The risk to fall below biomass threshold is lower when natural mortality is overestimated (OM4) rather than underestimated (OM2) in the MP.

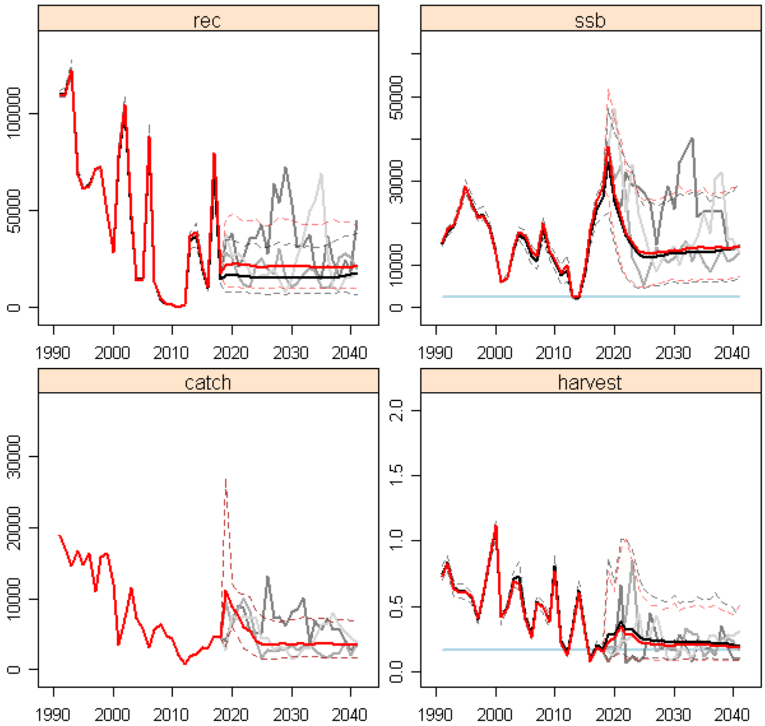

Figure A1.9. Rockall haddock in 6b. Results OM2 (M=0.3), HCR 1a (F_{low}=0, TAC constraint rule a); OM in red (individual iterations in grey), MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

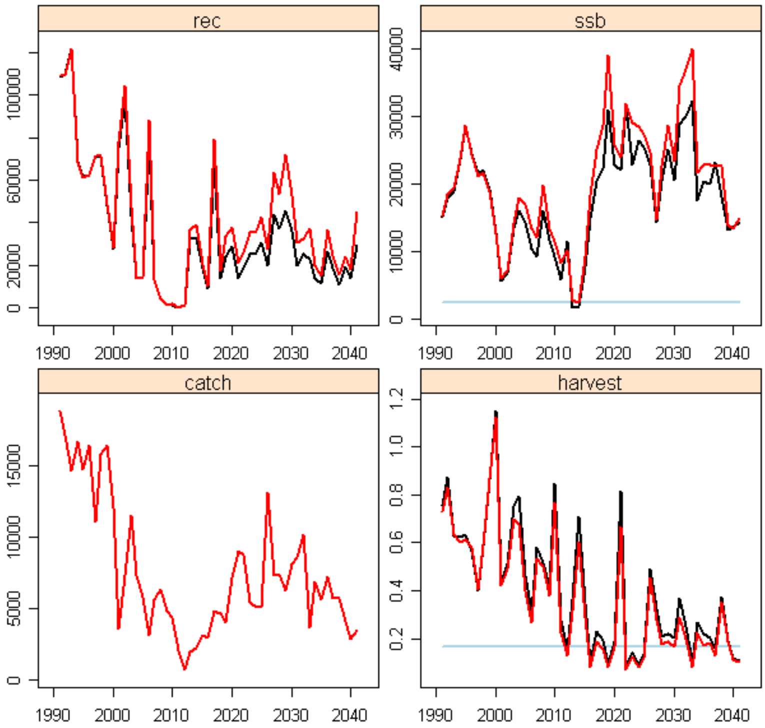

Figure A1.10. Rockall haddock in 6b. Results OM2 (M=0.3) HCR 1a (Flow=0, TAC constraint rule a); individual iteration, OM in red, MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). F_{MSY} and B_{lim} in blue.

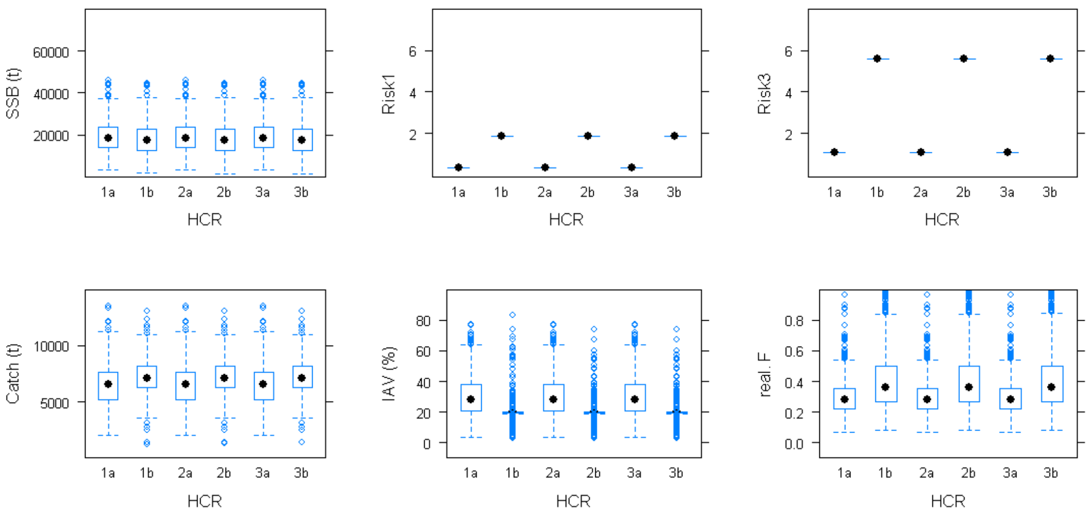

Figure A1.11. Rockall haddock in 6b. Performance statistics in short term (1–5 years) OM2 (M=0.3). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

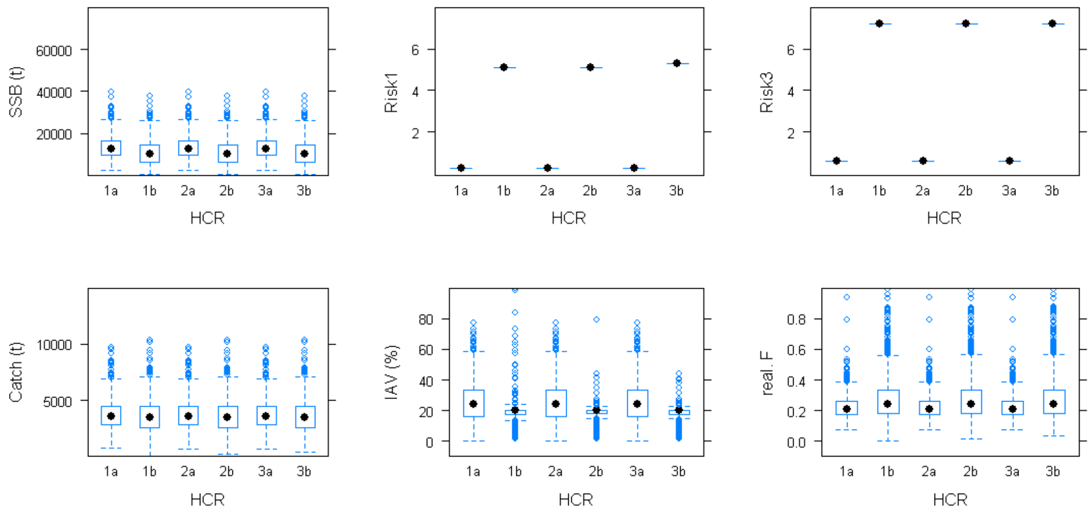

Figure A1.12. Rockall haddock in 6b. Performance statistics in medium term (6–10 years) OM2 (M=0.3). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

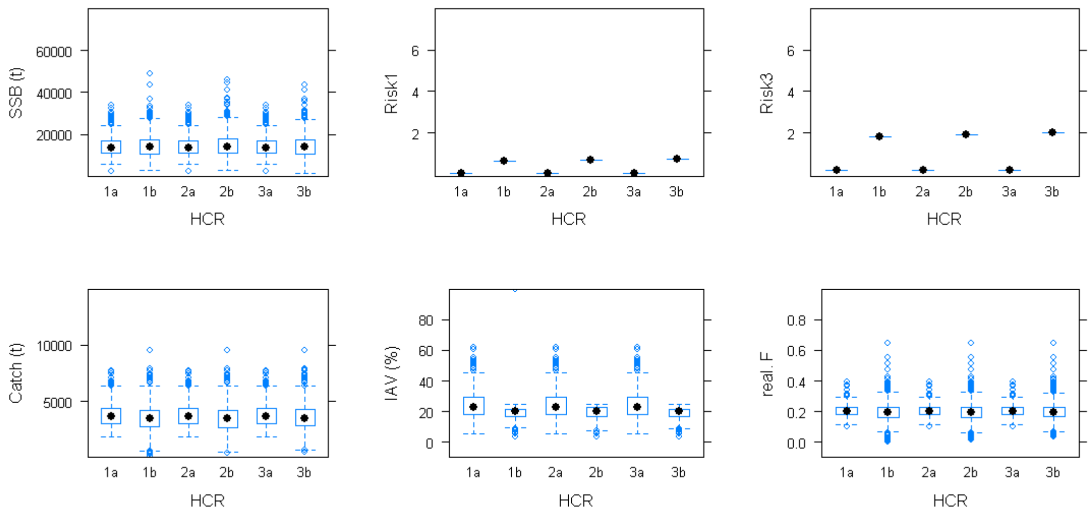

Figure A1.13. Rockall haddock in 6b. Performance statistics in long term (11–20 years) OM2 (M=0.3). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

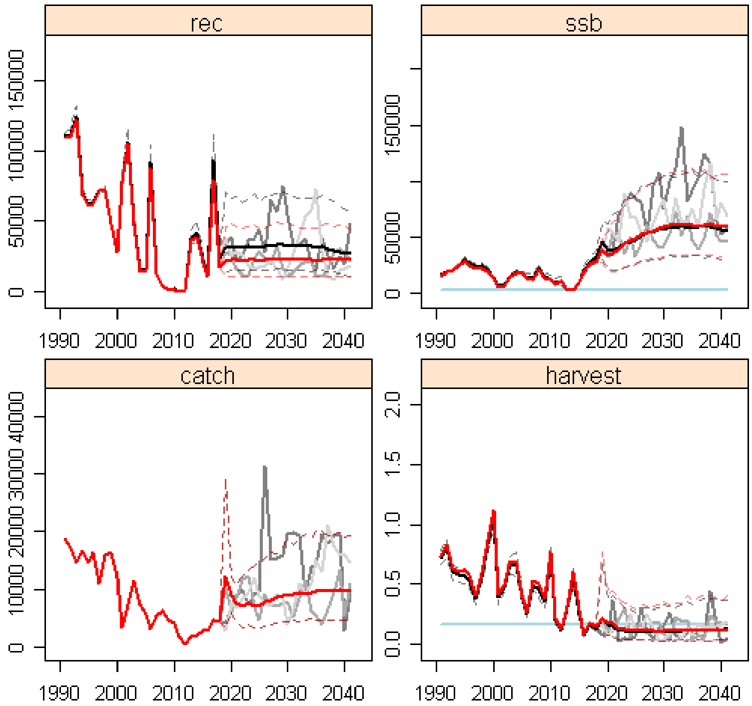

Figure A1.14. Rockall haddock in 6b. Results OM4 (M=0.1) HCR 1a (F_{low}=0, TAC constraint rule a), OM in red (individual iterations in grey), MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

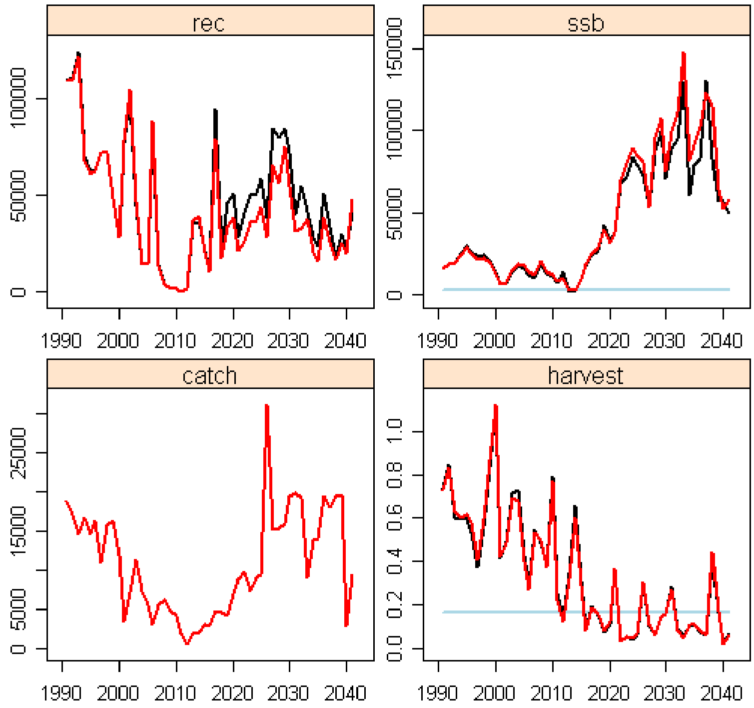

Figure A1.15. Rockall haddock in 6b. Results OM4 (M=0.1) HCR 1a (F_{low}=0, TAC constraint rule a), OM in red (individual iterations in grey), MP in black. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). F_{MSY} and B_{lim} in blue.

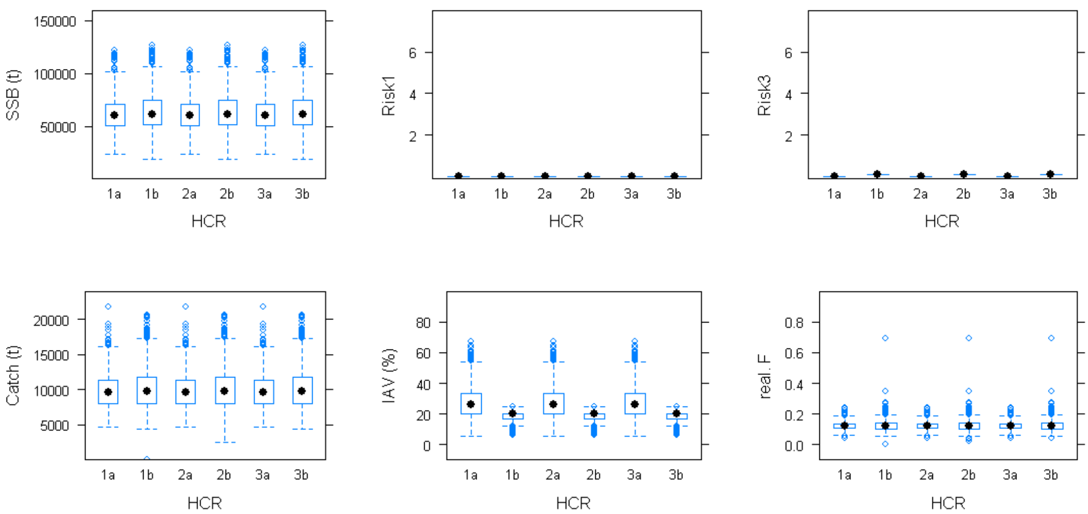

Figure A1.16. Rockall haddock in 6b. Performance statistics in long term (11–20 years), OM 4 (M=0.1). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

A1.3 OM 3 Regime shift maturity (knife-edged from age 2)

In alternative operating model OM3, the maturity ogive in the OM (knife-edge age 2) differs from the assumed values in the MP (knife-edge age 3) in the projection period. The MP is underestimating SSB relative to the OM, because a larger number of individuals are included in the SSB of the stock (OM3) (Figure A1.17, A1.18). Risks remain below 5% in the short, medium and long term (Figure A1.19). Performance of HCRs is similar for different values of Flow. TAC constraint rule (a) leads to higher median SSB and lower catches in the short term, but lower median SSB and slightly lower catches in the long-term than rule (b).

Risks OM3 are lower than in the baseline OM0, since the change of the maturity ogive in the OM leads to larger SSB relative to the same B_{lim} reference point. Fishing mortality is estimated correctly (MP similar to OM), because the stock dynamics are not influenced by the change in the maturity ogive with the SSB–recruitment relationship being relatively constant across wide range of SSB values. Both SSB and fishing mortality in the MP are consistently calculated for the same age range, 3–7+ and 2–5 respectively, across historic and projection period.

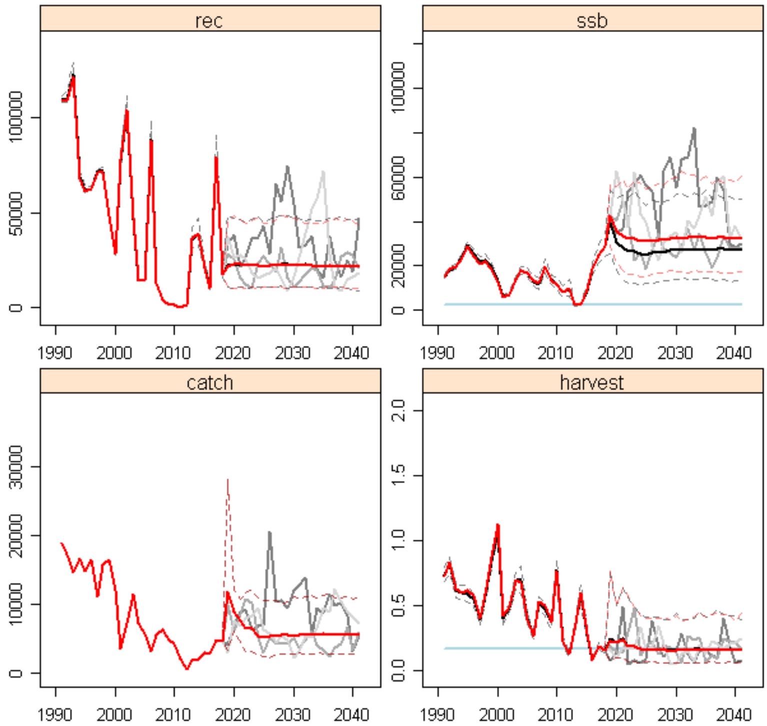

Figure A1.17. Rockall haddock in 6b. Results, OM3 (maturity ogive knife-edged age 2) HCR 1a (F_{low}=0, TAC constraint rule a). MP in black, OM in red. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

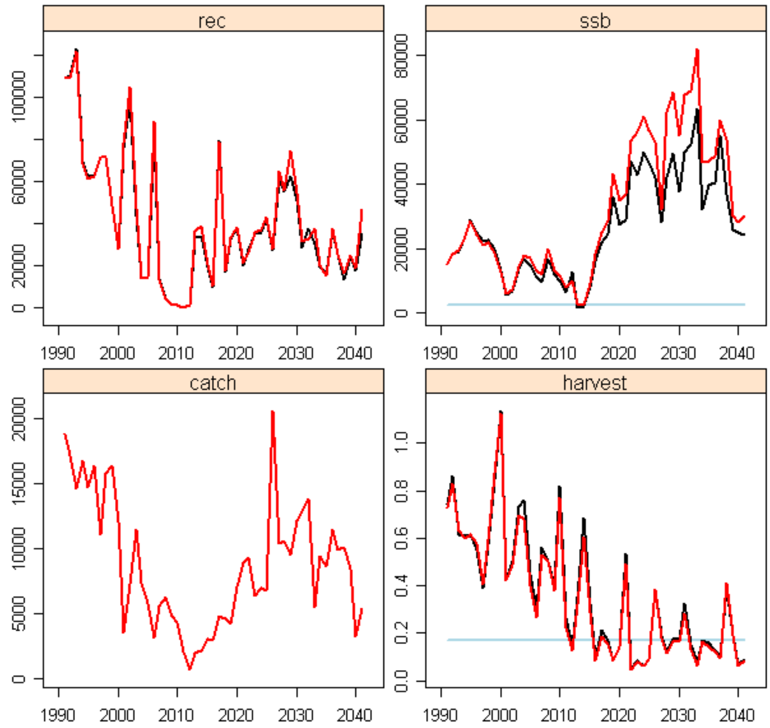

Figure A1.18. Rockall haddock in 6b. Results, OM3 HCR 1a (F_{low}=0, TAC constraint rule a), iteration 1. Maturity ogive knife-edged age 2 in OM in projection period. MP in black, OM in red. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). FMSY and B_{lim} in blue.

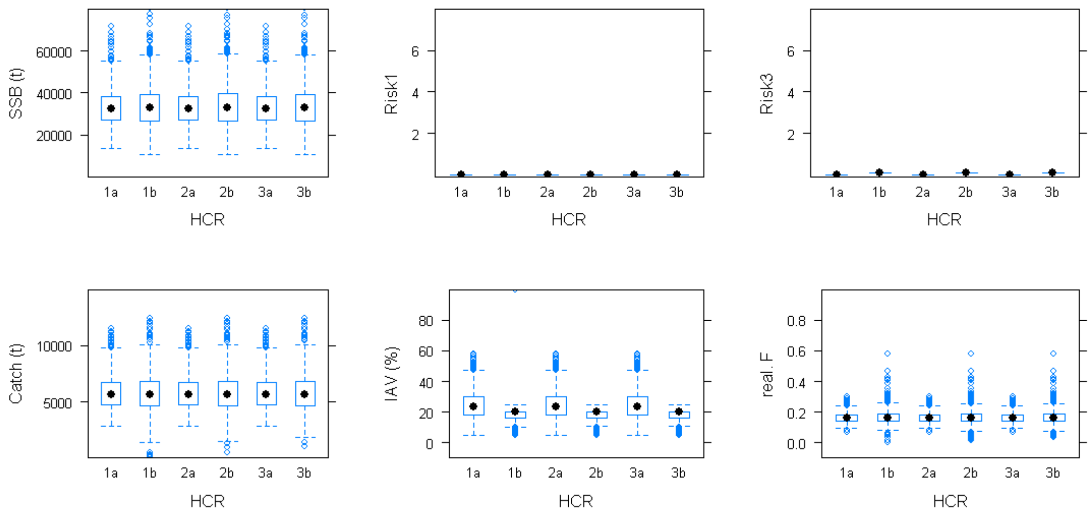

Figure A1.19. Rockall haddock in 6b. Performance statistics in long term (11–20 years), OM3. Maturity ogive knife-edged age 2 in OM in projection period. Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

A1.4 OM 5 Weights sampled from period of recent 20 years

In alternative operating model OM5, weights-at-age in the projection period are sampled from the recent 20 historical years instead of recent ten years. Due to the increase of weights-at-age over time in the historic period, catch weights-at-age are lower in OM5 than in the baseline OM0. Weights-at-age are identical in the OM and MP, median results of OM and MP overlap in the projection period (Figures A1.20, A1.21). Risks remain below 5% in the long term for all HCR options (Figures A1.22, A1.23). Risks are higher for management options with constraint rule (b). In the short and medium term Risk3 for TAC constraint rule (b) is above 5% for all values of F_{low}. Risks are higher than in the baseline OM0, since lower weights-at-age lead to lower SSB values for the same number of individuals. In the short term rule (a) leads to higher median SSB and lower catches, while in the long term rule (a) leads to lower median SSB and higher catchers than rule (b).

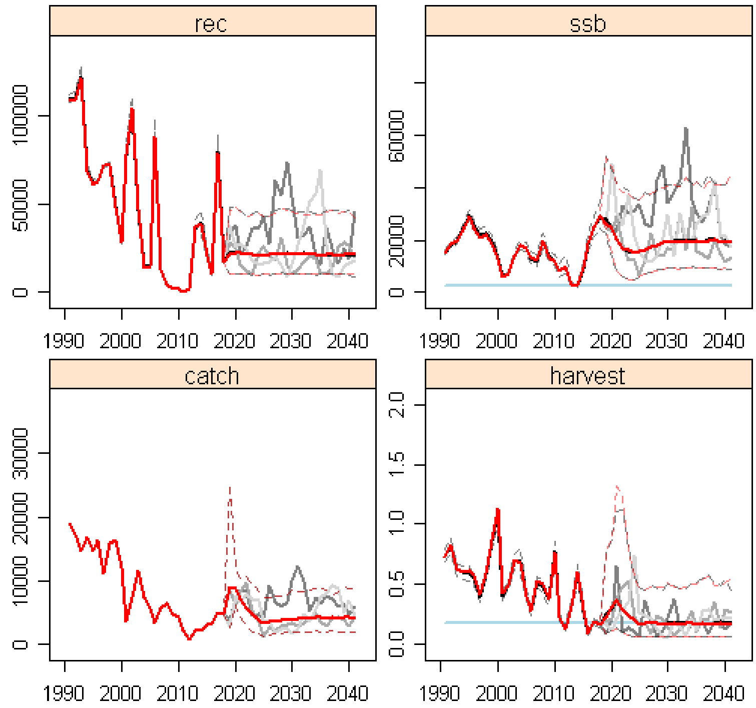

Figure A1.20. Rockall haddock in 6b. Results, OM5, HCR 1a (F_{low}=0, TAC constraint rule a). MP in black, OM in red. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

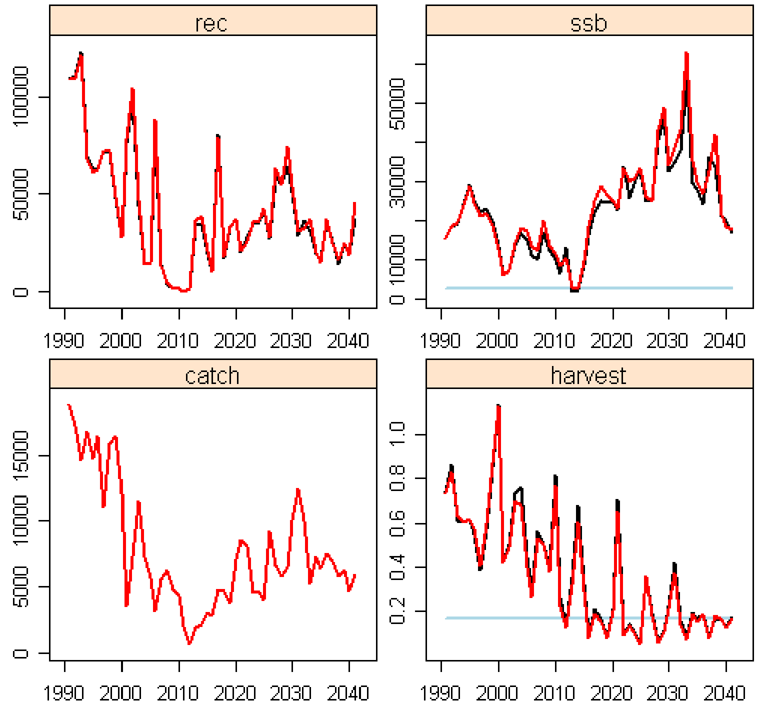

Figure A1.21. Rockall haddock in 6b. Results, OM5, HCR 1a (F_{low}=0, TAC constraint rule a). MP in black, OM in red. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). F_{MSY} and B_{lim} in blue.

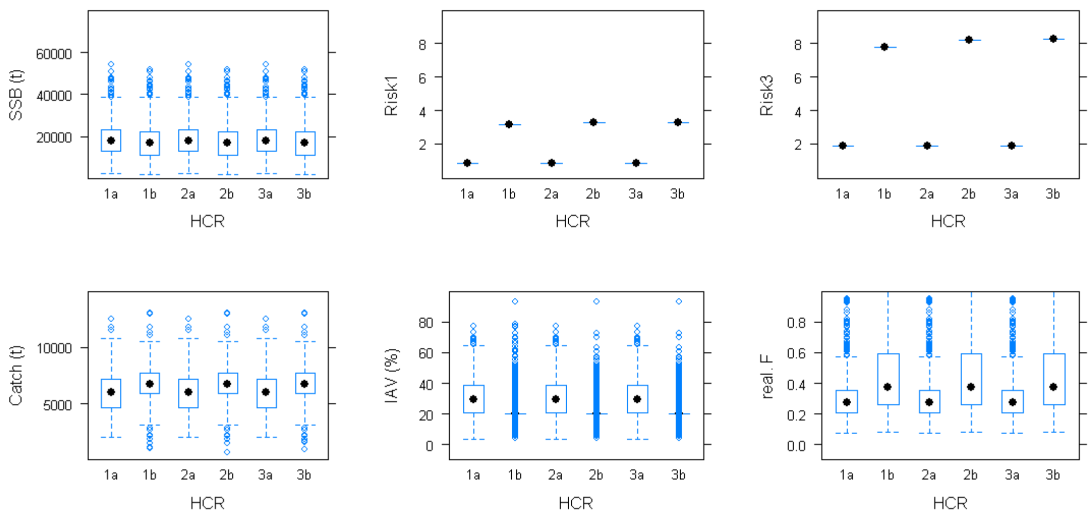

Figure A1.22. Rockall haddock in 6b. Performance statistics in short term (1–5 years), OM5. Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

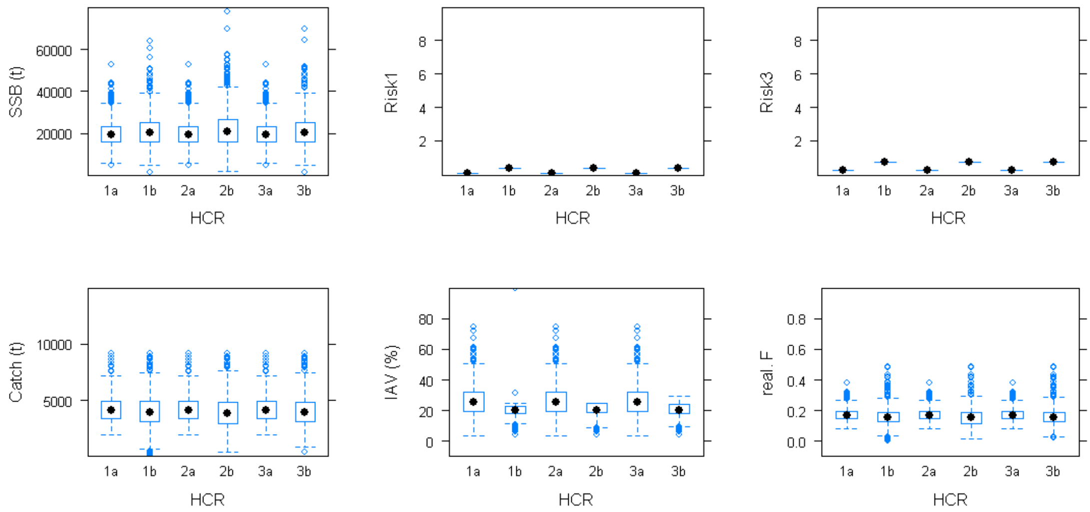

Figure A1.23. Rockall haddock in 6b. Performance statistics in long term (11–20 years), OM5. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

A1.5 OM 6 Combine OM 1, OM 2, OM5

In alternative operating model OM6, in the projection period weights-at-age are sampled from the recent 20 historical years, recruitment is at low level and natural mortality in the OM is 0.3. Weights-at-age are assumed to be the same in the OM and MP assessment. MP slightly underestimates recruitment and overestimates fishing mortality as observed in OM2, due to lower natural mortality assumed in the MP (Figures A1.24, A1.25). Risks are above 5% for all HCRs in the short and medium term (Figure A1.26). In the long term, only for constraint rule (b) Risk3 is above 5% (Figure A1.27). Risks are lower for constraint rule (a) than for rule (b). In the short term, for rule (a) median SSB is higher and catches lower, while in the long term median SSB is lower and catches are higher than for rule (b).

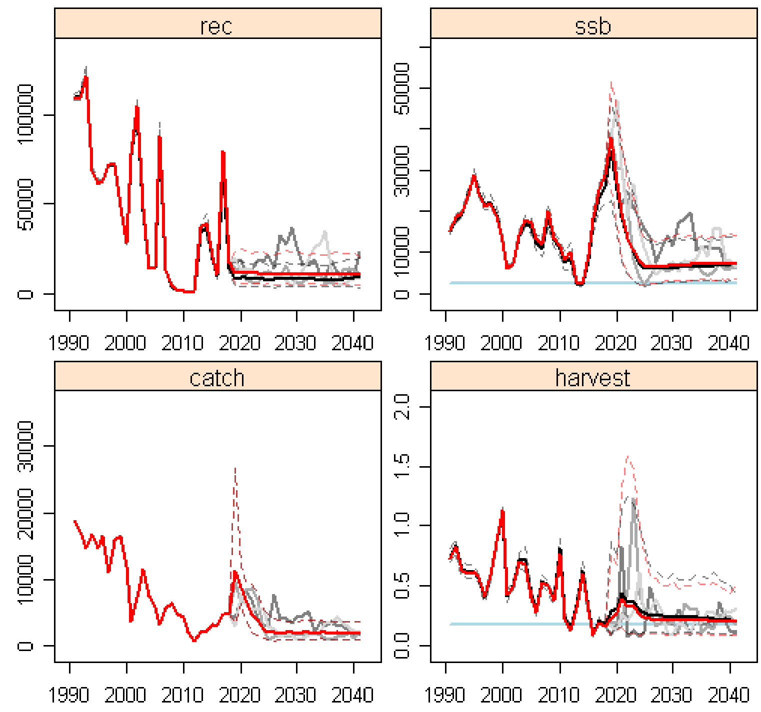

Figure A1.24. Rockall haddock in 6b. Results for OM6 HCR1a (F_{low}=0, TAC constraint rule a), with recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). OM in red (grey: single iterations OM), MP in black. Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

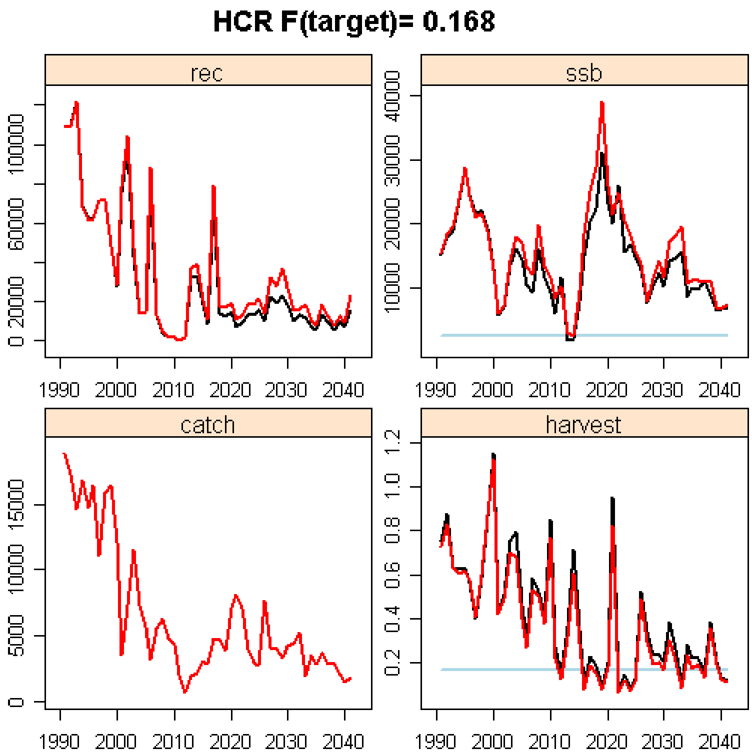

Figure A1.25. Rockall haddock in 6b. Results, OM6, HCR 1a (F_{low}=0, TAC constraint rule a). MP in black, OM in red. Results as recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). F_{MSY} and B_{lim} in blue.

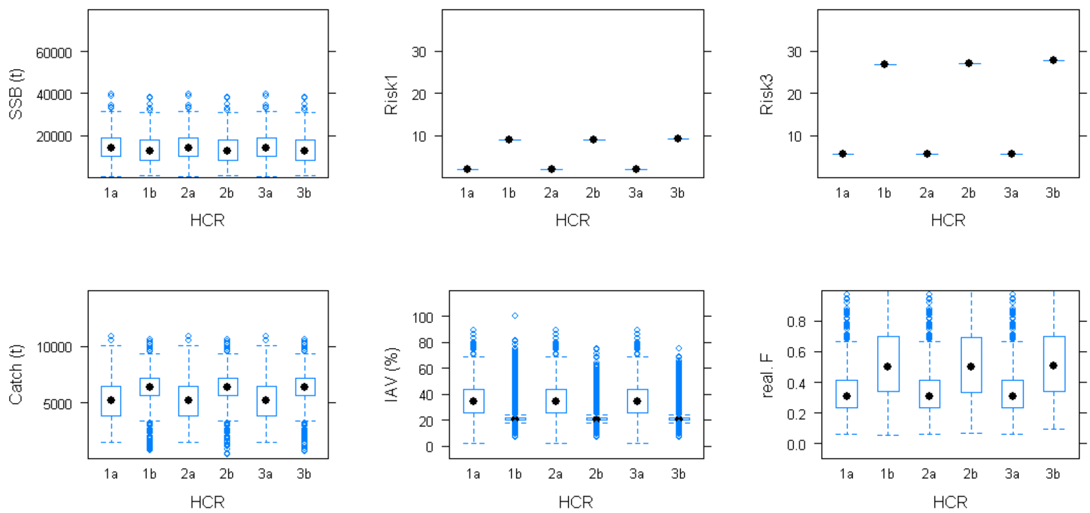

Figure A1.26. Results OM6, short term (year 1–5). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

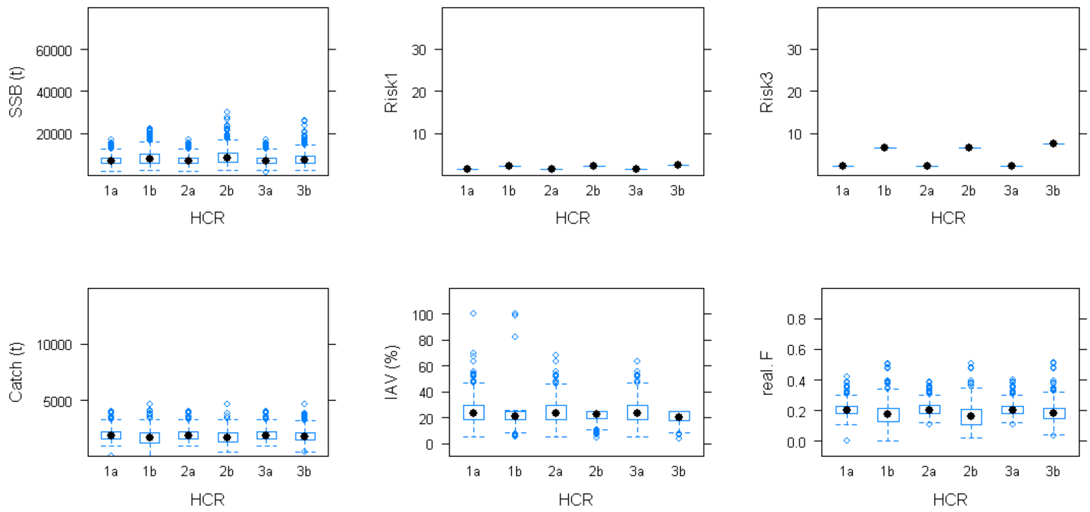

Figure A1.27. Results OM6, long term (year 11–20). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

A1.6 OM 7 Implementation error (10% variability in TAC)

Alternative operating model OM7 differs from the baseline OM0 only in the implementation error on TAC. MP and OM agree in the results (Figure A1.28). With implementation error (OM7) risks are below 5% in the short, medium and long term (Figure A1.29–A1.30). Performance of HCRs in terms of risk is slightly better for constraint rule (a) and low impact of the value of F_{low}. In the short term, for rule (a) median SSB is higher and catches lower, while in the long term median SSB is lower and catches are slightly higher as compared to rule (b). Risks are low and comparable to the baseline OM0 scenario, with Risk3 being slightly higher in the medium term and Risk1 being higher in the long term in OM7.

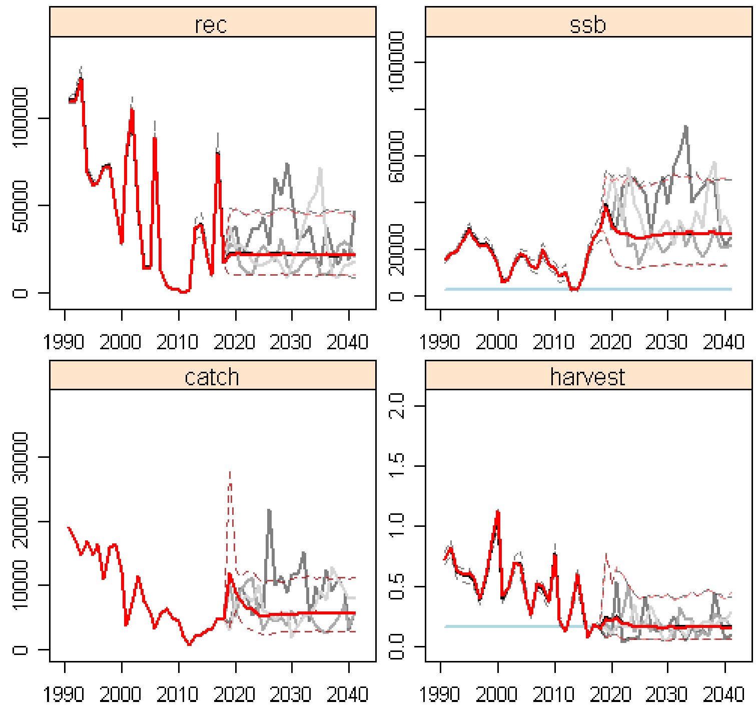

Figure A1.28. Rockall haddock in 6b. Results OM7 HCR 1a (F_{low}=0, TAC constraint rule a), with recruitment (thousands), SSB (t), catch (t), harvest rate expressed as fishing mortality F_{bar} (age 2–5). OM in red (grey: single iterations OM), MP in black. Plotted are medians (solid, OM: red, MP: black) and 95%, 5% percentiles of 1000 iterations (dashed). F_{MSY} and B_{lim} in blue.

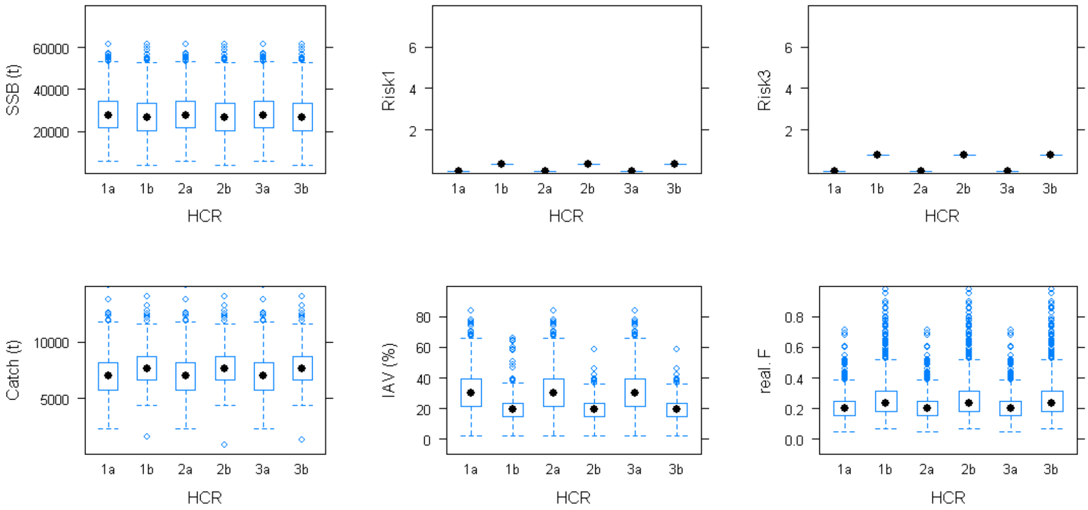

Figure A1.29. Rockall haddock in 6b. Results OM7, short term (year 1–5). Median values in black. HCR 1: F_{low}=0, 2: F_{low}=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

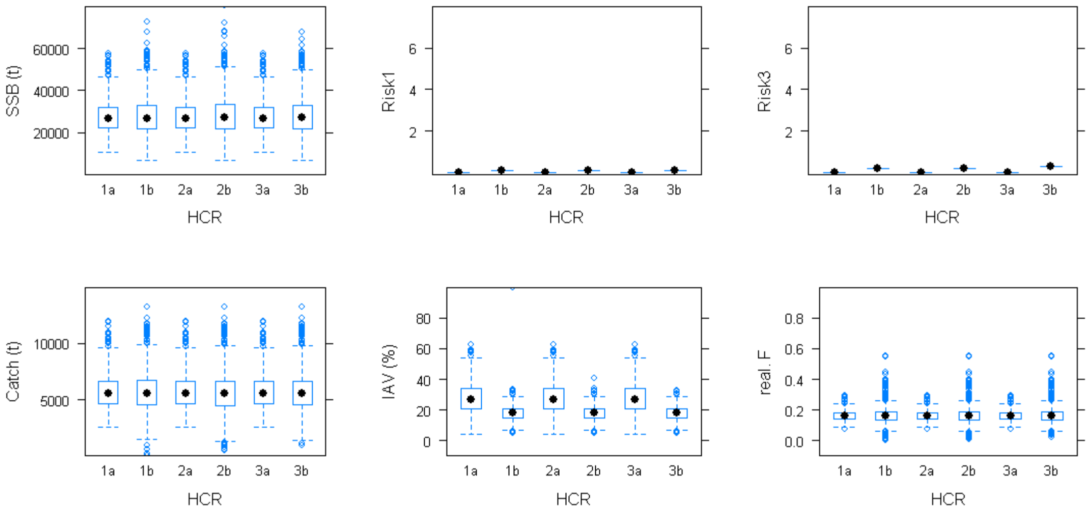

Figure A1.30. Rockall haddock in 6b. Results OM7, long term (year 11–20). Median values in black. HCR 1: F_{low}=0, 2: Flow=0.05, 3: F_{low}=0.1. TAC constraint option a or b.

WD 2 Haddock in 6b: Reference Points - WKROCKMSE

Helen Dobby

Executive

The WD is an extensive document which contains all the EqSim R code, figures and many of the tables for estimating PA and MSY reference points. The main assumptions and results are summarized here:

- Yield is assumed equal to landings (with discard rate resampled from recent ten year average);
- Fishery selectivity resampled from the last ten years (default assumption);
- Mean weights resampled from ten years;
- Full recruitment time-series and including autocorrelation;
- Type 5 stock => $B_{lim} = B_{loss}$;
- Default assessment/advice error;
- $B_{trigger}=B_{pa}$.

PA reference point	Value	Basis
B_{lim}	2474 t	B_{loss} from which the stock has increased (2014 SSB from 2019 assessment).
B_{pa}	3712 t	B_{lim} x 1.5
F_{lim}	1.06	F that has 50 % probability of SSB falling below B_{lim} (Derived using EqSim analysis with the full time-series of stock and recruit pairs and a segmented regression with breakpoint fixed at B_{lim} including autocorrelation).
F_{pa}	0.71	F_{lim}/1.5

MSY Reference point	F_{MSY} (no AR)	F_{MSY} lower (no AR)	F_{MSY} upper (no AR)	$F_{p.05}$ (with AR)
Fixed segreg	0.168	0.105	0.27	0.41

Sensitivity

Bio parameters year range

Estimated F_{MSY} varies between about 0.18 and 0.16 as a moving time window of years (ten years) is used for the bio data (higher for earlier years).

Fishery parameters year range

Estimated F_{MSY} varies between about 0.18 and 0.13 as a moving time window of years (ten years) is used for the fishery data (lowest in the early years).

Yield assumption

Approximating yield by landings based on discards resampled from the most recent five years (instead of ten) i.e. virtually all age 3+ catch are assumed >MCRS results in an increase in the estimate of F_{MSY} to 0.21.

Stock–recruitment relationship

Stock–Recruitment Relationship	F_{MSY} (no AR)	F_{MSY} lower (no AR)	F_{MSY} upper (no AR)
Segreg with estimated breakpt	0.125	0.085	0.182
Ricker	0.193	0.141	0.25
Beverton–Holt	0.155	0.101	0.21

Introduction

This is an R markdown type document which uses the EqSim package to explore potential MSY reference points for Rockall haddock based on the output of the XSA stock assessment agreed at WKROCK, including catch and survey data to 2018.

Eqsim (stochastic equilibrium reference point software) provides MSY reference points based on the equilibrium distribution of stochastic projections. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age, maturities, and selectivity) are resampled at random from the last few years of the assessment (although there may be no variability of these values). Recruitments are resampled from their predictive distribution, which is based on parametric models fitted to the full time-series provided. The software also allows the incorporation of assessment/advice error. Random deviations from S–R are the same for each target F. Uncertainty in the stock–recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland *et al*., 1997) although often the S–R is taken to be just a single one function (most commonly segmented regression). A $B_{trigger}$ can optionally be specified; in such cases F is reduced when the stock biomass is below $B_{trigger}$ (although results are still main F target i.e. the value of F intended to be applied when stock biomass is above $B_{trigger}$).

The reference points which were agreed at WKMSYREF4 (ICES, 2015) are shown below:

	value
B_{lim}	6800.00
B_{pa}	10200.00
$B_{trigger}$	10200.00
F_{lim}	0.69
F_{pa}	0.46
F_{MSY}	0.20

In the model runs presented here, we follow the ICES technical guidelines (ICES, 2017a) for deriving reference points for category 1 stocks and make use of the data/results from the WGCSE 2019 assessment. Stock weights are assumed to be a five-year running average of the catch weights (as agreed at WKROCK, 2019).

The assessment summary is shown below (Figure 1). Following a period of very low recruitment between 2006 and 2012, the SSB has recovered to a high level and fishing mortality has declined substantially.

The plot of stock and recruit pairs (Figure 2) shows limited evidence of a stock–recruitment relationship with moderate recruitment occurring at very low SSB (2013 and 2014 year classes) and very poor recruitment from moderate SSB (2007–2011).

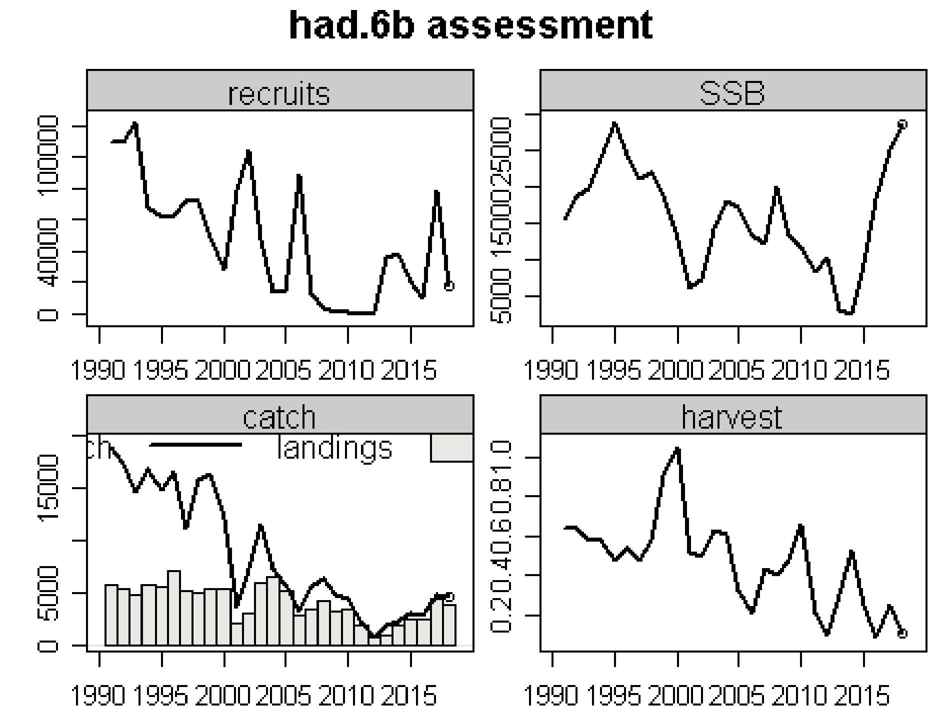

Figure 1. Had.6b. Stock assessment summary.

Figure 2. Had.6b. Stock–recruit relationship with points labelled by year class (or SSB year).

Biological Parameters

In recent years, the raw mean weights-at-age in the landings (and catch) (Figures 3 and 5) are very noisy (most likely due to low sampling levels) and for this reason, it was agreed at WKROCK to use a smoothed catch weight for the stock weights (five-year running average). The smoothed mean weights-at-age in the stock used in the analysis presented here, are shown in Figure 4.

There has also been an increasing trend in mean weights, particularly at older ages. The WKROCK MSE meeting agreed that a ten-year window sampling for mean weights was likely to be most appropriate given there appears to have been increases in mean weight over time which may partly be related to cohort effects and potentially other environmental (or fishery) effects. The default ten-year sampling window is used with a check of the sensitivity of the results to this assumption is also carried out (see Sensitivity section).

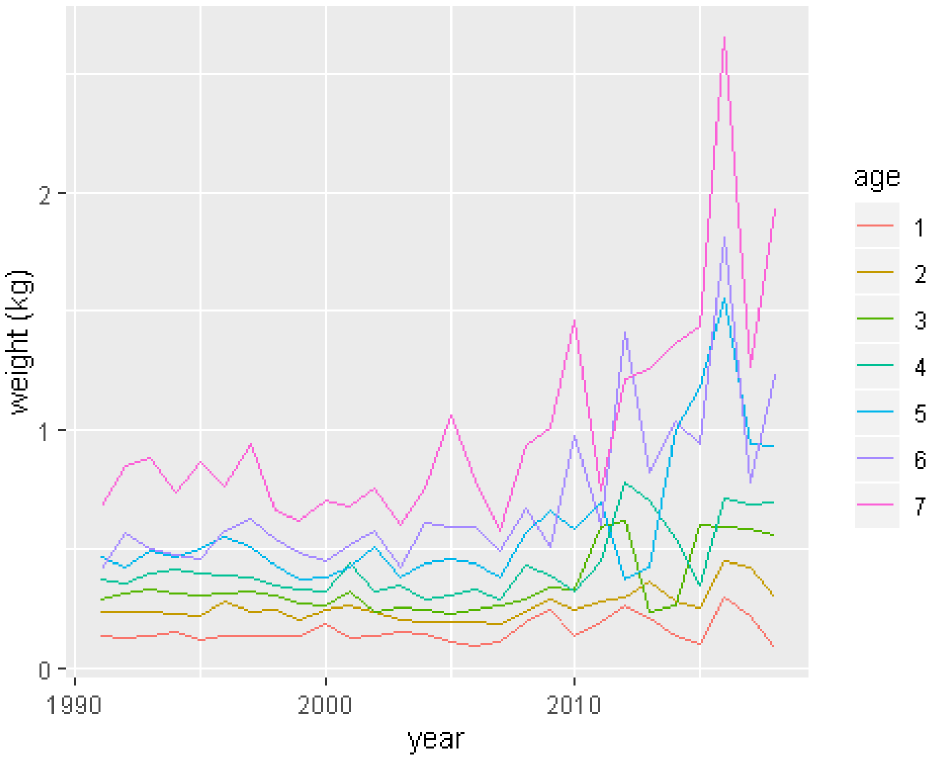

Figure 3. Had.6b. Mean weights-at-age in the catch.

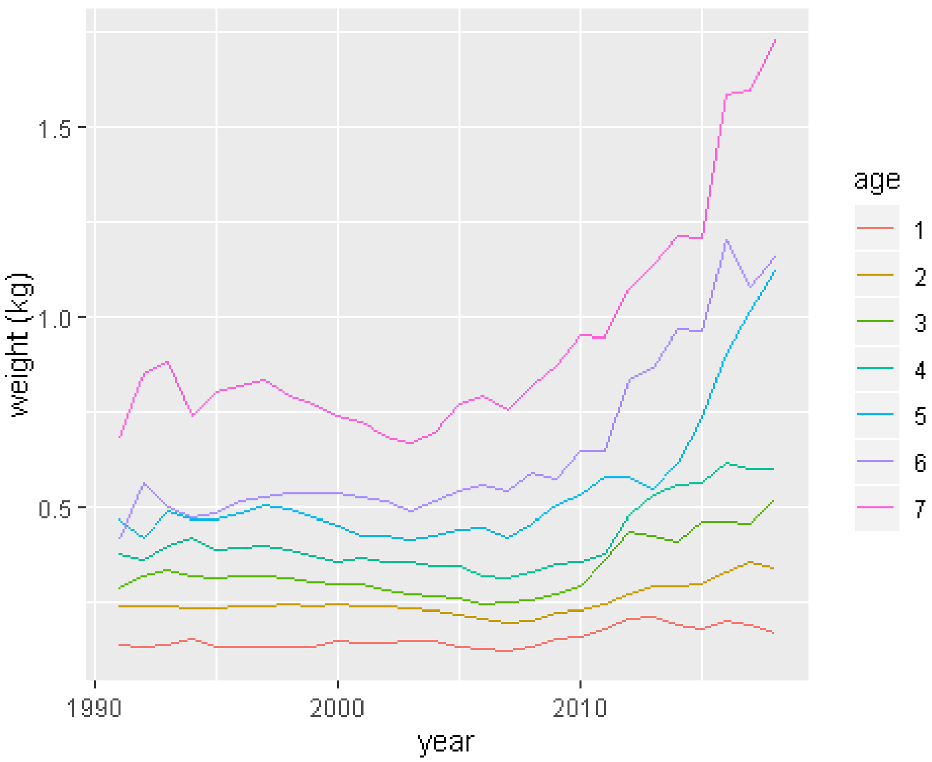

Figure 4. Had.6b. Mean weights-at-age in the stock.

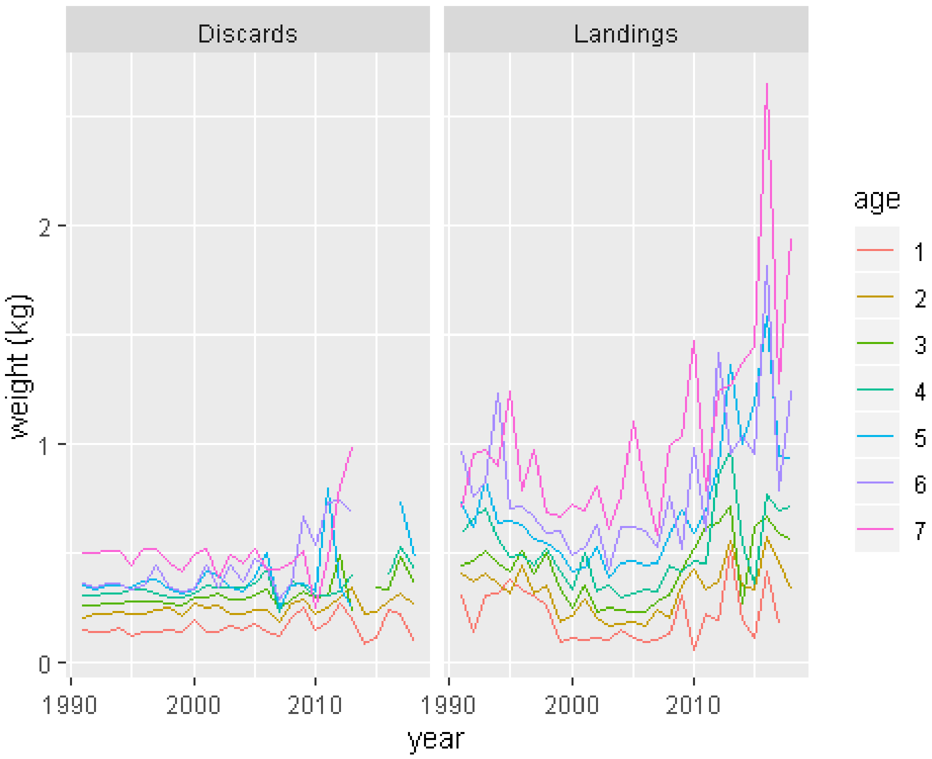

Figure 5. Had.6b. Mean weights-at-age in the discards and landings.

Fishery Parameters

There is substantial variability in the fishery selection pattern, but no obvious systematic changes. Therefore, the default ten-year window is used for resampling within EqSim.

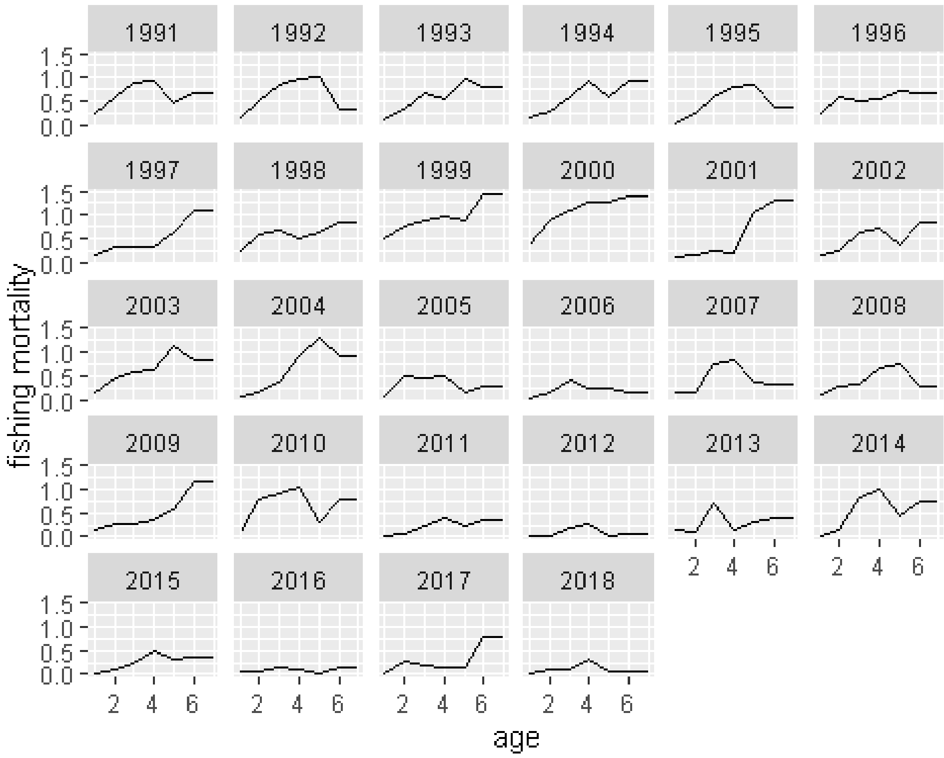

Figure 6. Had.6b. Changes in selection pattern over time.

Defining yield

In deriving FMSY, a decision has to be taken about the definition of yield; ICES defines this as catch above MCRS. In the baseline model run, landings are taken to be an approximation of above MCRS catch, based on discard rates resampled from the most recent ten years which show high discarding (on average) at ages 1 and 2, lower discard rates at ages 3 to 5 and very low discard rates at age 6 and above. (The estimated discard rate averaged over a ten-year period is shown below). This decision was made on the basis that a proportion of the Scottish catches aged 3 to 5 are typically below MCRS (although this clearly varies with growth rate of particular cohorts). A sensitivity analysis is conducted (see later in the document) in which the stock object is manipulated such that discards are resampled from the recent five years (with resulting landings assumed to be above MCRS catch).

```
b.yr <-10
f.yr <-10

stk <-stk.out
disc.rate <-stk.out@discards.n/stk.out@catch.n
disc.rat <-as.numeric(yearMeans(window(disc.rate,start=2009,end=2018)))
print(round(disc.rat,2))

## [1] 0.83 0.66 0.30 0.20 0.19 0.05 0.02

disc.rat <-as.numeric(yearMeans(window(disc.rate,start=2014,end=2018)))
print(round(disc.rat,2))

## [1] 0.80 0.46 0.05 0.03 0.00 0.00 0.00
```

Deriving PA reference points

Defining B_{lim}

The first step is to define B_{lim}, the biomass limit below which a stock is considered to have reduced reproductive capacity.

Some cod stocks (North Sea and Irish Sea) make use of a truncated time-series of stock and recruit pairs in the derivation of reference points based on possible changes in reproductive potential, possibly related to environmental factors. For Rockall haddock, there was a period of very low recruitment from 2007 to 2012, but there is no suggestion from the plot of recruitment per SSB (below) that there has been a systematic persistent change in stock productivity. Therefore, for the baseline model run we use the full time-series of stock and recruitment data.

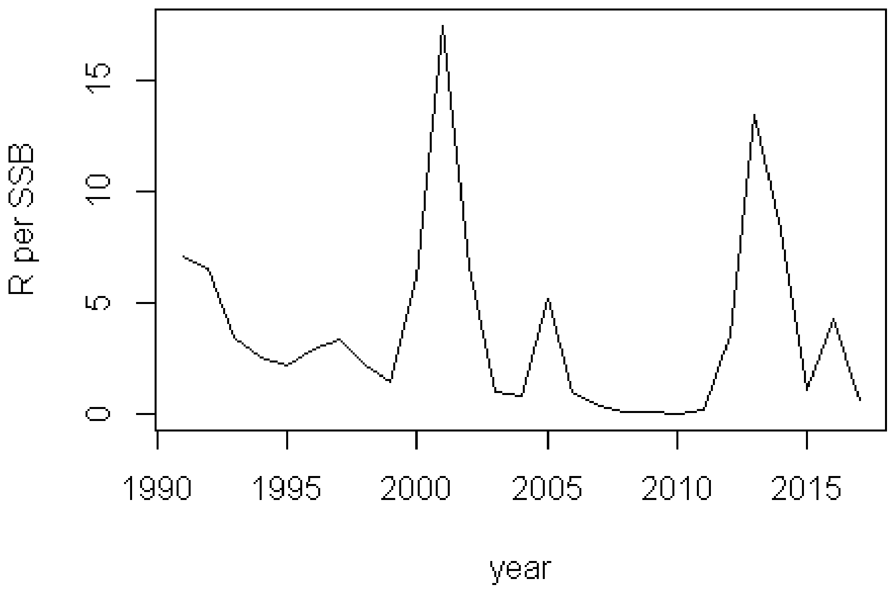

Figure 7. Had.6b. Recruitment per SSB over time.

The current B_{lim} is 6800 tonnes and was defined on the basis of the B_{loss} from which the stock has increased (SSB in 2001 as estimated in the 2015 assessment). According to the current ICES guidelines, defining B_{lim} requires identifying the stock type (ICES, 2017a). Using the full time-series, this stock would be characterised as Type 5: a stock with no evidence of impaired recruitment or with no clear relationship between stock and recruitment. In such cases, the ICES guidance suggests B_{lim} is set at B_{loss}. The new B_{loss} is SSB in 2014 and this is much lower than the breakpoint estimated by fitting a segmented regression to the stock and recruitment data (see below) and much lower than the currently used B_{lim}.

Note that other haddock stocks are often classified as Type 1: spasmodic stocks; stocks with occasional large year classes (Northern Shelf and Irish Sea haddock). In such cases, B_{lim} is based on the lowest SSB where large recruitment is observed. Classifying Rockall haddock in such a way could lead to a B_{lim} = SSB in 2001 and would hence be more in line with the current value.

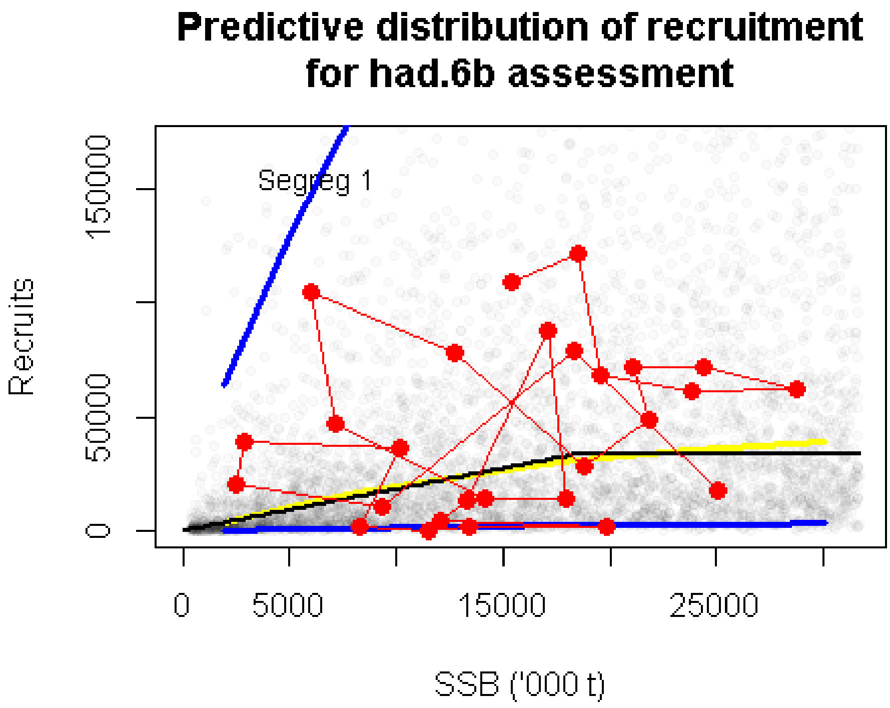

Figure 8. Had.6b. Stock–recruitment plot with fitted segmented regression.

```
blim <-min(ssb(stk))
```

At WKMSYREF4, it was concluded that this assessment was more uncertain than other stock assessments and therefore B_{pa} was evaluated as 1.5 x B_{lim}. The same approach is used here.

```
print(blim)

## [1] 2474.434

print(bpa)

## [1] 3711.652
```

Deriving F_{lim} and F_{pa}

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

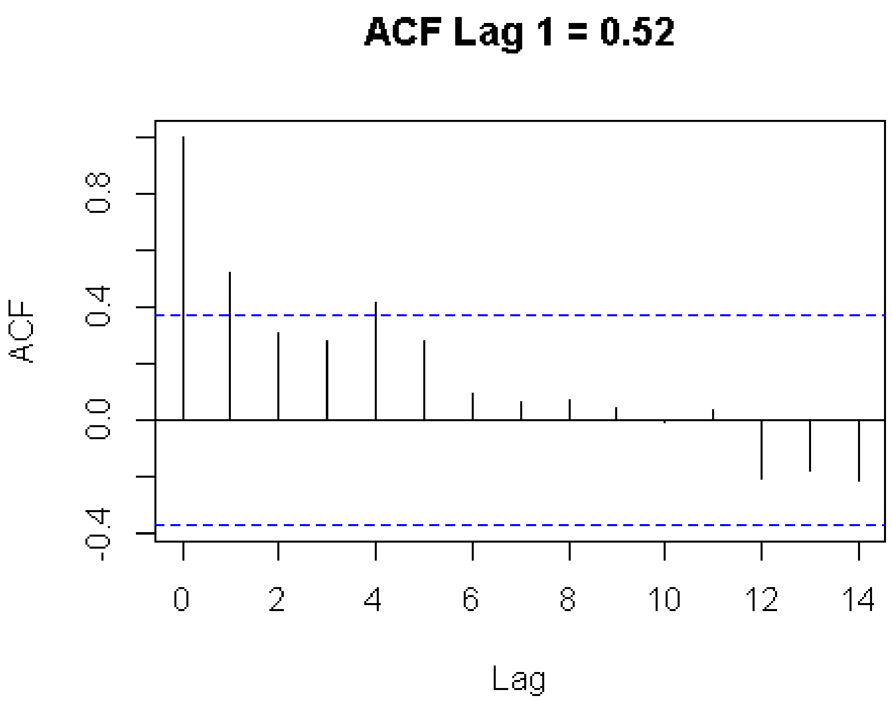

Figure 9. Had.6b. Recruitment autocorelation.

Using the full time-series of recruitment gives significant autocorrelation at lag 1 and lag 4 and therefore this feature is included in the eqsim simulations.

The use of a very low B_{lim} results in a very high estimate of F_{lim}, substantially higher than for Irish Sea or Northern Shelf haddock, but lower than Celtic Sea haddock.

```
B <-blim
SegregFixed <- function (ab, ssb) {
  log(ifelse (ssb>=B, ab$a*B, ab$a*ssb))
}

had.indat <-list(data=stk,
             bio.yrs=c(max.yr-b.yr+1,max.yr),
             sel.yrs=c(max.yr-f.yr+1,max.yr),
             Fscan=seq(0,2.0,by=0.05),
             Fcv=0,
             Fphi=0,
             Blim=blim,
             Bpa=bpa,
             Btrigger = 0,
             extreme.trim=c(0.05,0.95),
             rhologRec=TRUE
             )

had.res <-within(had.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= "SegregFixed")
  sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
```

```
        Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
        Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
        rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.flim.all.rec.rdata",sep="")))
```

Table 1. Had.6b. Summary of eqsim run without assessment/advice error, to determine F_{lim} using segmented regression with B_{lim} as breakpoint and full recruitment time-series.

	catF	lanF	catch	landings	catB	lanB
F05	0.350	NA	9779	NA	20 845	NA
F10	0.466	NA	8995	NA	14 452	NA
F50	1.062	NA	3890	NA	2485	NA
medianMSY	NA	0.162	NA	8717	NA	43 563
meanMSY	0.300	0.200	10 065	8411	24 831	37 367
Medlower	NA	0.118	NA	8073	NA	58 218
Meanlower	NA	0.148	NA	16 408	NA	NA
Medupper	NA	0.266	NA	8042	NA	27 985
Meanupper	NA	0.347	NA	16 388	NA	NA

Table 2. Had.6b. Summary of F reference points.

F_{lim}	F_{pa}
1.062	0.708

Calculating F_{MSY}

F_{MSY} is initially calculated by running EqSim with assessment/advice error, but without application of the ICES advice rule (MSY $B_{trigger}$). To include assessment and advice error, the values F_{cv}=0.212 and F_{phi}=0.423 which are the default values suggested by WKMSYREF4 (ICES, 2015) were used.

The ICES guidance notes that while the segmented regression stock–recruitment may be required to provide the best estimate of a change point for B_{lim}, other stock–recruitment functions may better characterise the whole stock dynamics, and hence should be used in the calculation of F_{MSY}. For this stock all S–R relationships give a very poor fit to the data, we calculate the F_{MSY} reference points using the segmented regression with breakpoint fixed at B_{lim}. Figure 11 shows the model averaged fit of the Beverton–Holt, Ricker and segmented regression (fitted) relationships for comparison.

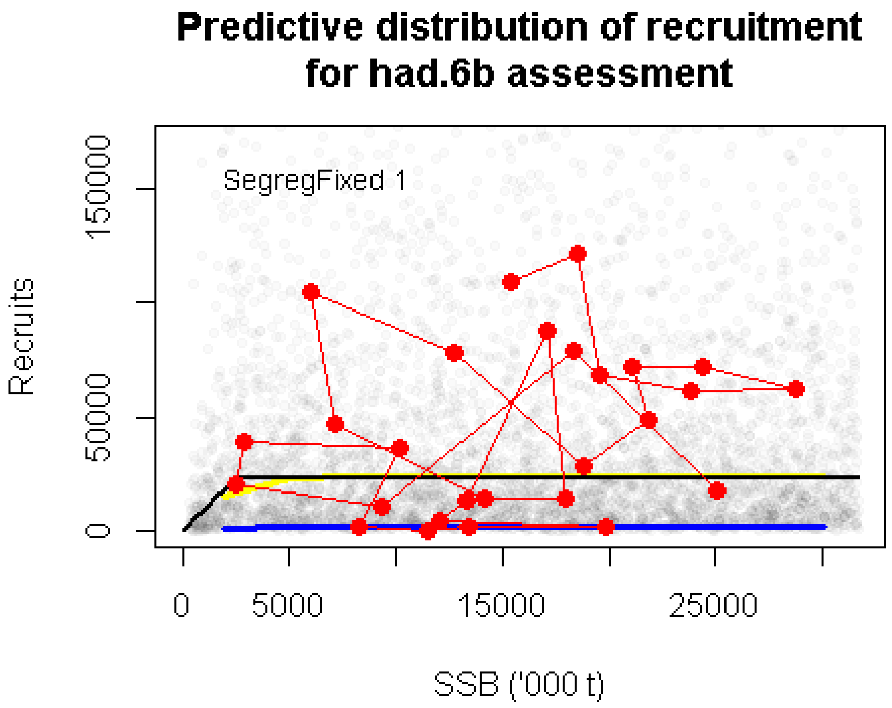

Figure 10. Had.6b. Stock–recruitment relationship; segmented regression with fixed breakpoint.

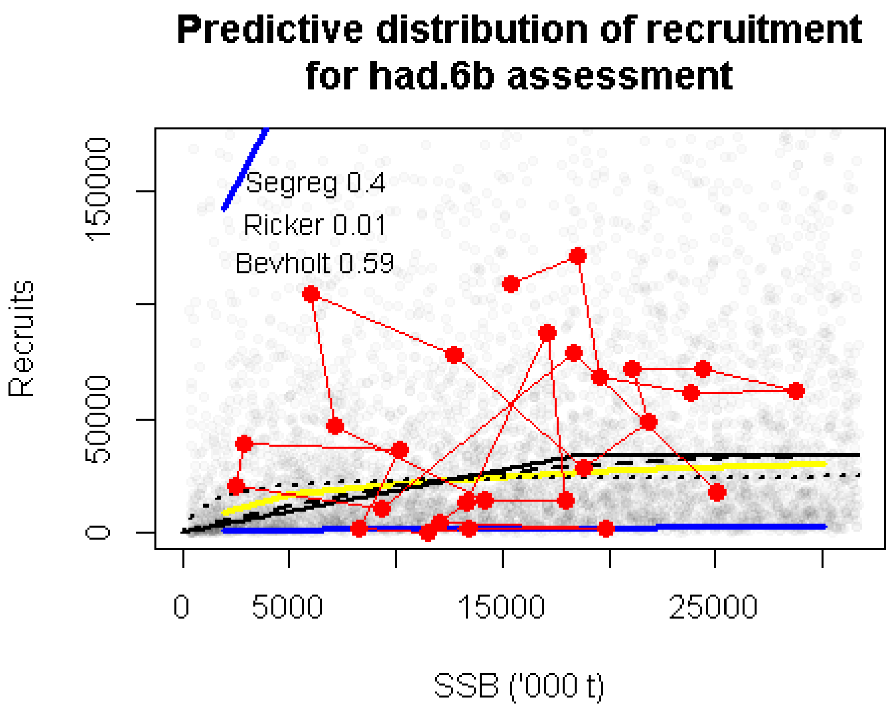

Figure 11. Had.6b. Stock–recruitment relationship; model averaged.

Fixed segreg and no advice rule (AR)

The first run includes assessment and advice error, but not $B_{trigger}$.

```
B <-blim
SegregFixed <- function (ab, ssb) {
 log(ifelse (ssb>=B, ab$a*B, ab$a*ssb))
}
had.indat <-list(data=stk,
            bio.yrs=c(max.yr-b.yr+1,max.yr),
            sel.yrs=c(max.yr-f.yr+1,max.yr),
            Fscan=seq(0,1.0,by=0.05),
            Fcv=0.212,
            Fphi=0.423,
            Blim=blim,
            Bpa=bpa,
            Btrigger = 0,
            extreme.trim=c(0.05,0.95),
            rhologRec=TRUE
            )

had.res <-within(had.indat,
{
 fit <-eqsr_fit(stk,nsamp=1000,models= c("SegregFixed"))
 sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
            Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
            Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
            extreme.trim=extreme.trim,
            verbose=FALSE,
            rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.fmsy.no.ar.segregfix.rdata",sep="")))
```

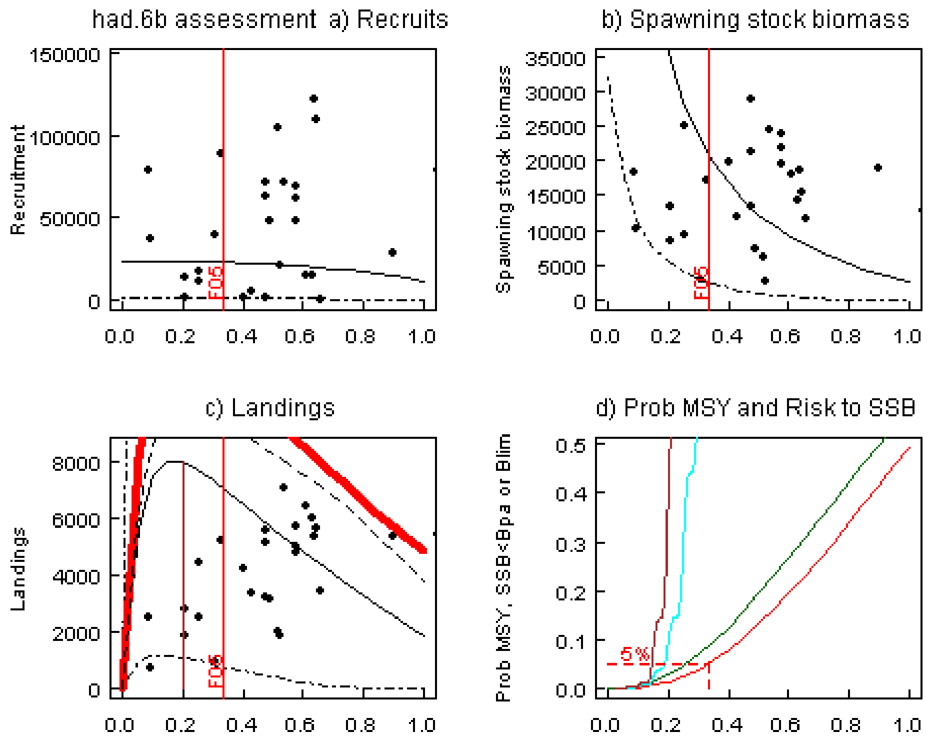

Figure 12. Had.6b. Eqsim summary plot. Panels a–c: historic values (dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa} (green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

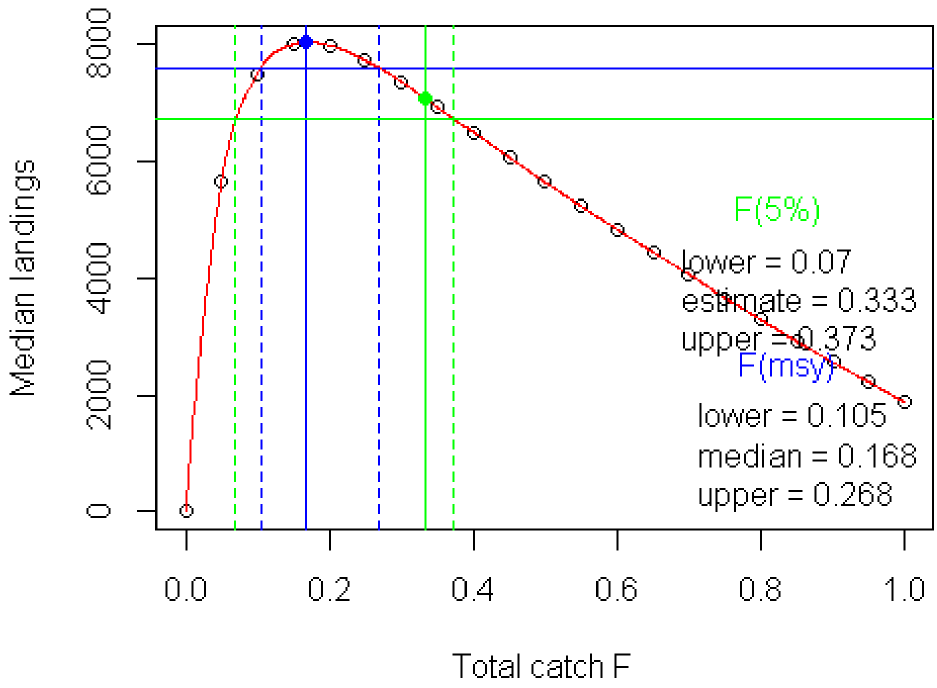

Figure 13. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

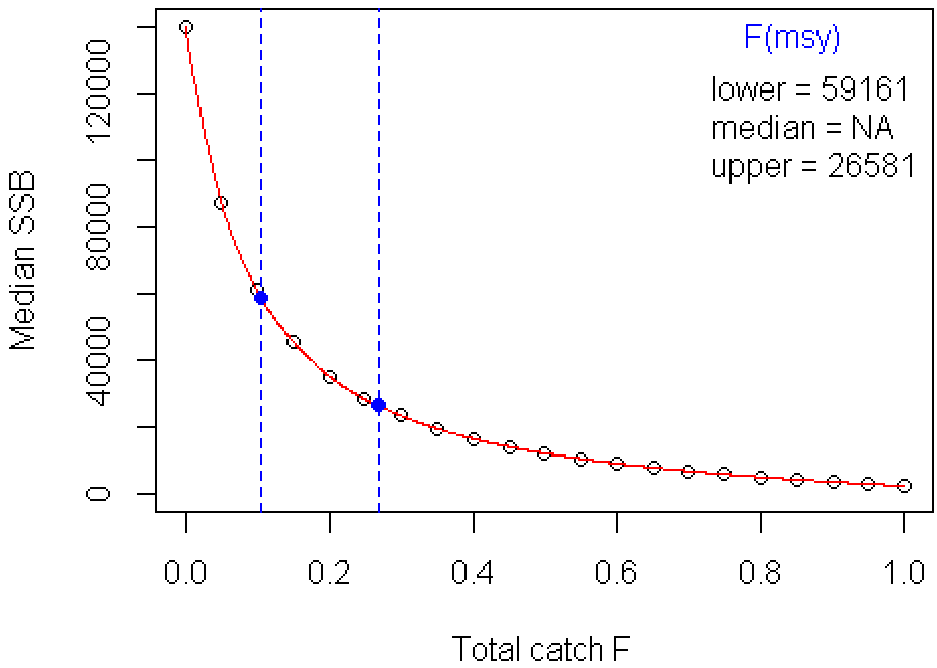

Figure 14. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F_{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.17. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.27 and the lower bound 0.11. Note that the associated SSB is above the historically observed values (Figure 1).

Fixed segreg with advice rule

The next step is to set MSY $B_{trigger}$. According to ICES guidelines, MSY $B_{trigger}$ is set equal to B_{pa} unless the stock has been fished below F_{MSY} for the last five years (which is not the case for Rockall haddock). The ICES MSY advice rule is then evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination fulfils the precautionary criterion of having a less than 5% annual probability of SSB $<B_{lim}$ in the long term. (The evaluation includes assessment/advice error).

```
B <-blim
SegregFixed <- function (ab, ssb) {
 log(ifelse (ssb>=B, ab$a*B, ab$a*ssb))
}
had.indat <-list(data=stk,
          bio.yrs=c(max.yr-b.yr+1,max.yr),
          sel.yrs=c(max.yr-f.yr+1,max.yr),
          Fscan=seq(0,1.0,by=0.05),
          Fcv=0.212,
          Fphi=0.423,
          Blim=blim,
          Bpa=bpa,
          Btrigger = bpa,
          extreme.trim=c(0.05,0.95),
          rhologRec=TRUE
          )

had.res <-within(had.indat,
{
 fit <-eqsr_fit(stk,nsamp=1000,models= c("SegregFixed"))
 sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
           Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
           Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
           extreme.trim=extreme.trim,
           verbose=FALSE,
           rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.fmsy.with.ar.segregfix.rdata",sep="")))
```

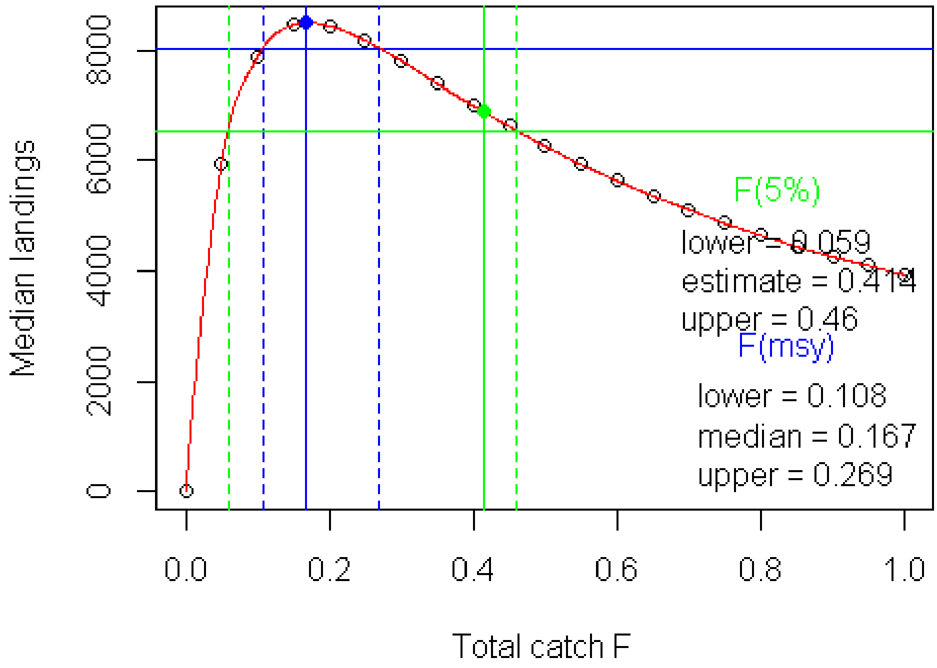

Figure 15. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

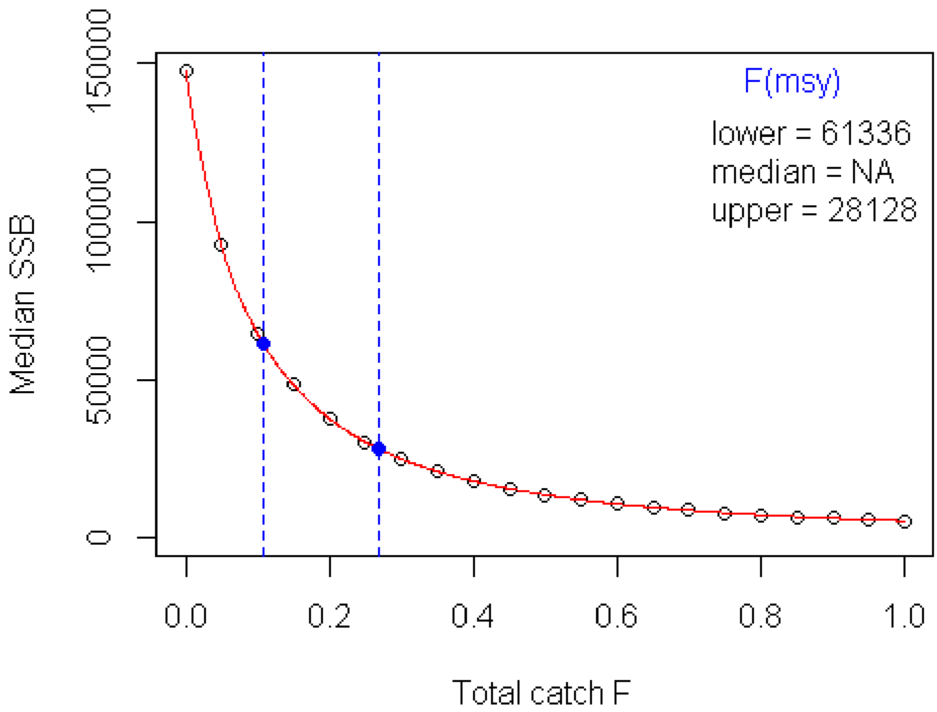

Figure 16. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F^{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

Table 3. Had.6b. Summary of Eqsim run including assessment/advice error and the ICES MSY advice rule.

	catF	lanF	catch	landings	catB	lanB
F05	0.414	NA	9571	NA	17 373	NA
F10	0.577	NA	8775	NA	11 471	NA
F50	NA	NA	NA	NA	NA	NA
medianMSY	NA	0.167	NA	8509	NA	44 301
meanMSY	0.250	0.200	10 329	8436	30 387	37 862
Medlower	NA	0.108	NA	8061	NA	61 336
Meanlower	NA	0.119	NA	12 110	NA	NA
Medupper	NA	0.269	NA	8048	NA	28 128
Meanupper	NA	0.307	NA	12 095	NA	NA

The $F_{p.05}$ (the F at which there is a 5% probability of falling below B_{lim}) is calculated as 0.414 which greater than the F_{MSY} (and $F_{MSY\ upper}$) without the advice rule and therefore the F_{MSY} reference points are not limited by $F_{p.05}$.

Sensitivity testing

We consider the sensitivity of the estimated F_{MSY} reference points to the stock–recruitment relationship used in the EqSim analysis, the year ranges used to resample the fishery and biological parameters and how yield (catch >MCRS) is approximated.

Estimated segreg and no advice rule (AR)

```
had.indat <-list(data=stk,
         bio.yrs=c(max.yr-b.yr+1,max.yr),
         sel.yrs=c(max.yr-f.yr+1,max.yr),
         Fscan=seq(0,1.0,by=0.05),
         Fcv=0.212,
         Fphi=0.423,
         Blim=blim,
         Bpa=bpa,
         Btrigger = 0,
         extreme.trim=c(0.05,0.95),
         rhologRec=TRUE
         )

had.res <-within(had.indat,
{
 fit <-eqsr_fit(stk,nsamp=1000,models= c("Segreg"))
 sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
          Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
          Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
```

```
            extreme.trim=extreme.trim,
            verbose=FALSE,
            rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.fmsy.no.ar.segregest.rdata",sep="")))
```

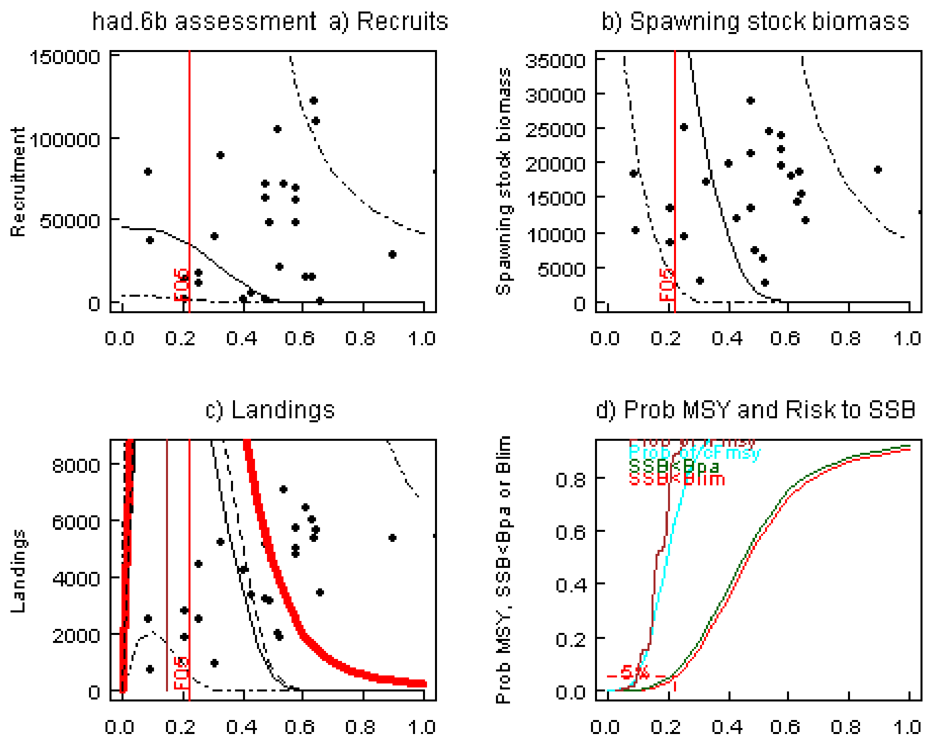

Figure 17. Had.6b. Eqsim summary plot. Panels a–c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa} (green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

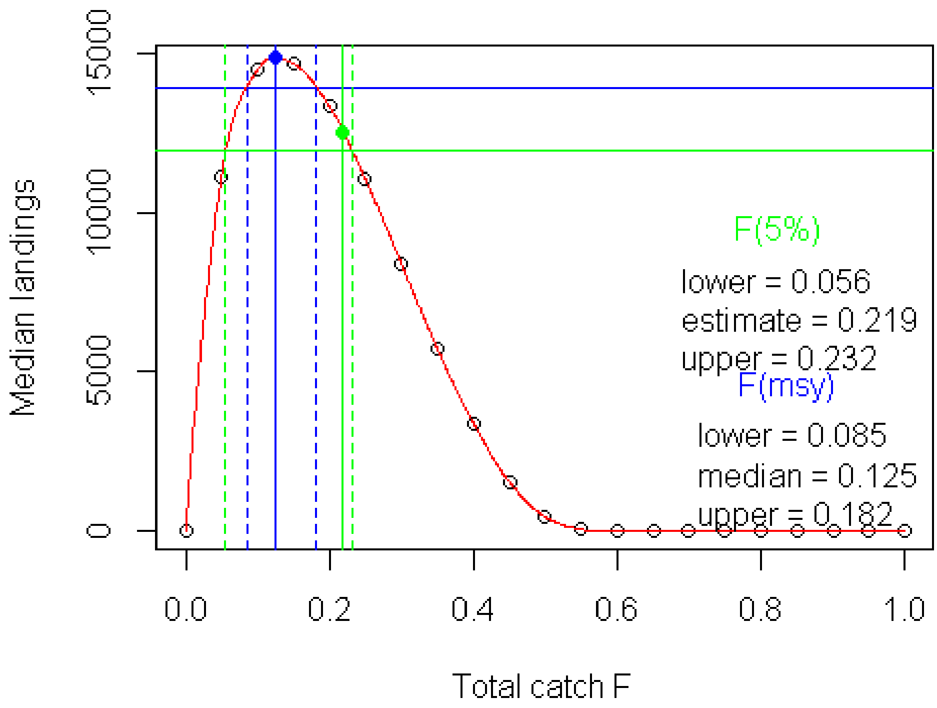

Figure 18. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

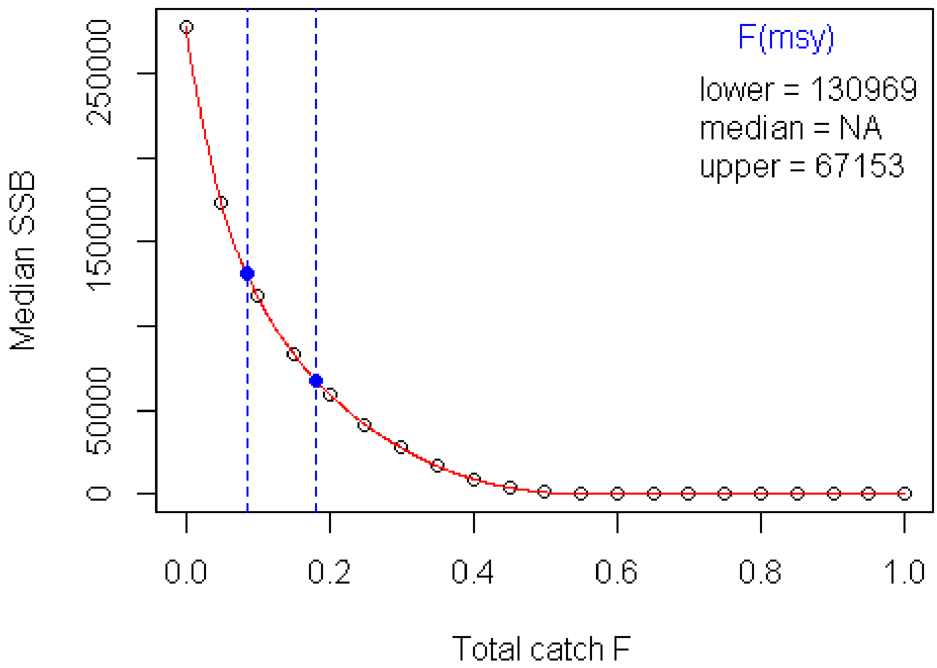

Figure 19. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F_{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.13. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.18 and the lower bound 0.09. Note that the associated SSB is above the historically observed values (Figure 1).

Ricker and no advice rule (AR)

```
had.indat <-list(data=stk,
          bio.yrs=c(max.yr-b.yr+1,max.yr),
          sel.yrs=c(max.yr-f.yr+1,max.yr),
          Fscan=seq(0,1.0,by=0.05),
          Fcv=0.212,
          Fphi=0.423,
          Blim=blim,
          Bpa=bpa,
          Btrigger = 0,
          extreme.trim=c(0.05,0.95),
          rhologRec=TRUE
          )

had.res <-within(had.indat,
{
 fit <-eqsr_fit(stk,nsamp=1000,models= c("Ricker"))
 sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
          Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
          Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
          extreme.trim=extreme.trim,
          verbose=FALSE,
          rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.fmsy.no.ar.segregrick.rdata",sep="")))
```

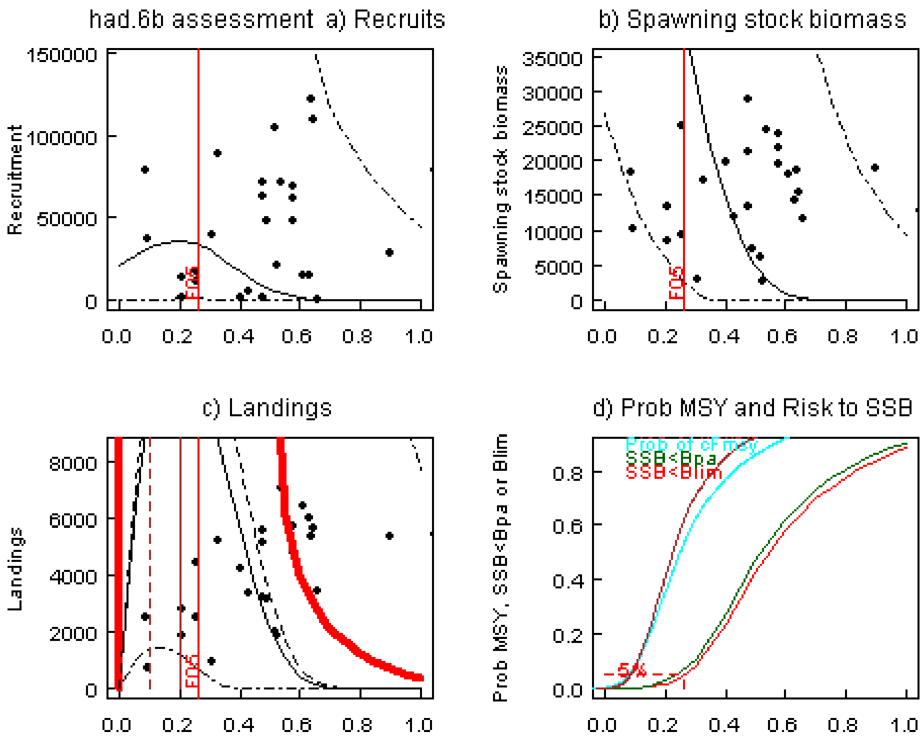

Figure 20. Had.6b. Eqsim summary plot. Panels a–c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa} (green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

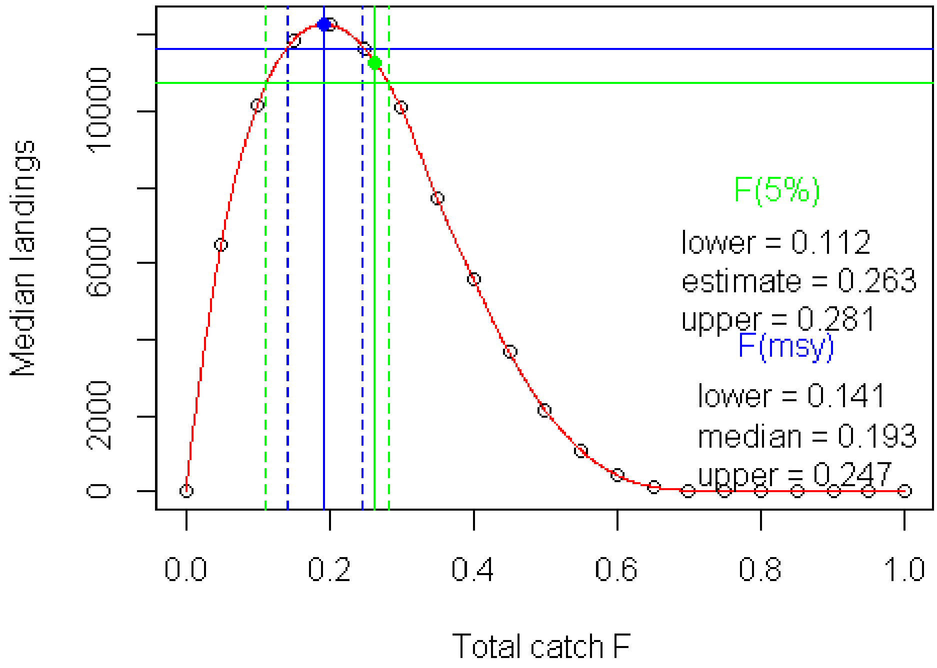

Figure 21. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

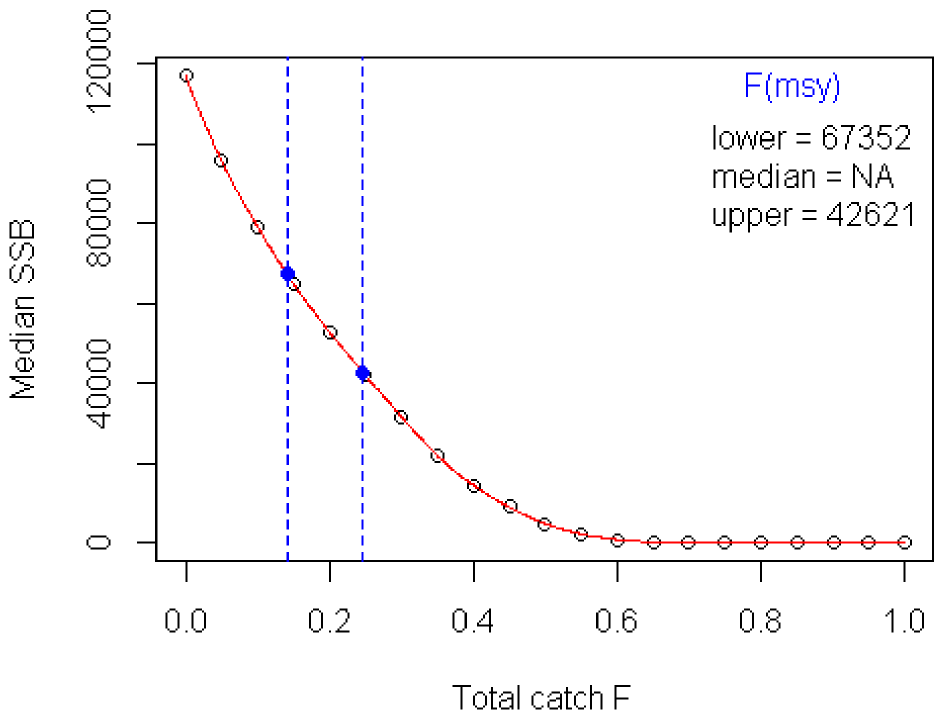

Figure 22. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F_{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.19. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.25 and the lower bound 0.14. Note that the associated SSB is above the historically observed values (Figure 1).

Beverton–Holt and no advice rule (AR)

```
had.indat <-list(data=stk,
         bio.yrs=c(max.yr-b.yr+1,max.yr),
         sel.yrs=c(max.yr-f.yr+1,max.yr),
         Fscan=seq(0,1.0,by=0.05),
         Fcv=0.212,
         Fphi=0.423,
         Blim=blim,
         Bpa=bpa,
         Btrigger = 0,
         extreme.trim=c(0.05,0.95),
         rhologRec=TRUE
         )

had.res <-within(had.indat,
{
 fit <-eqsr_fit(stk,nsamp=1000,models= c("Bevholt"))
 sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
          Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
          Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
          extreme.trim=extreme.trim,
          verbose=FALSE,
          rhologRec=rhologRec)
})
save(had.res,file=file.path(paste("eqsim.fmsy.no.ar.segregbh.rdata",sep="")))
```

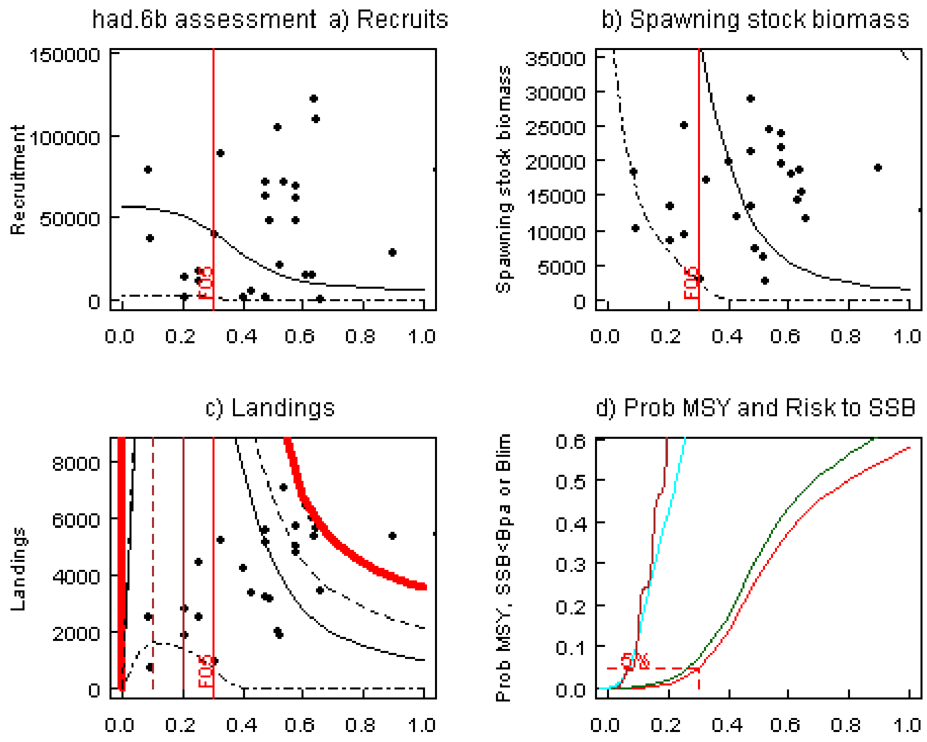

Figure 23. Had.6b. Eqsim summary plot. Panels a–c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa} (green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

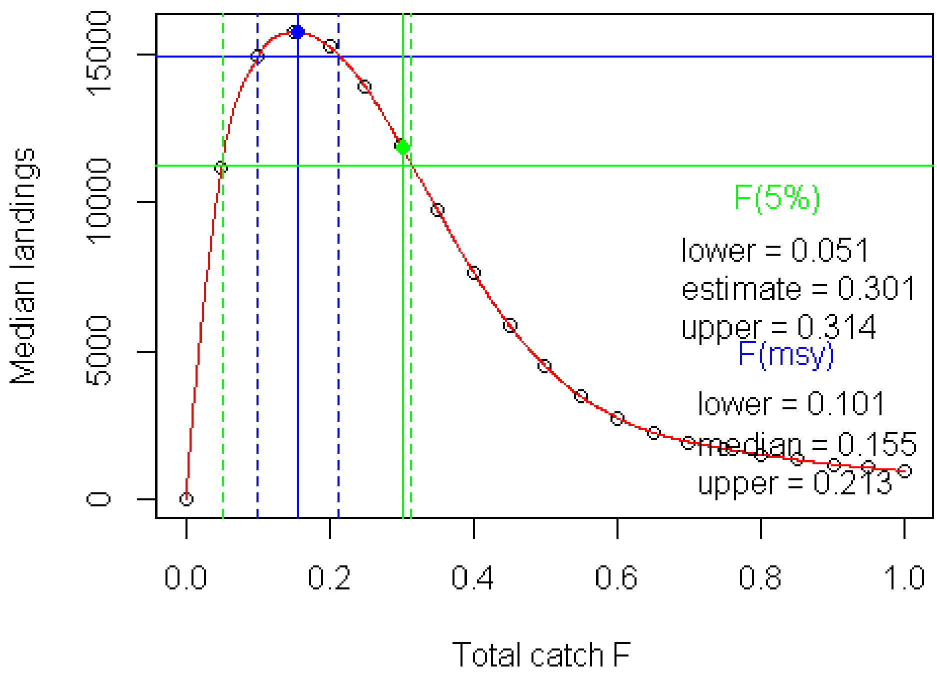

Figure 24. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

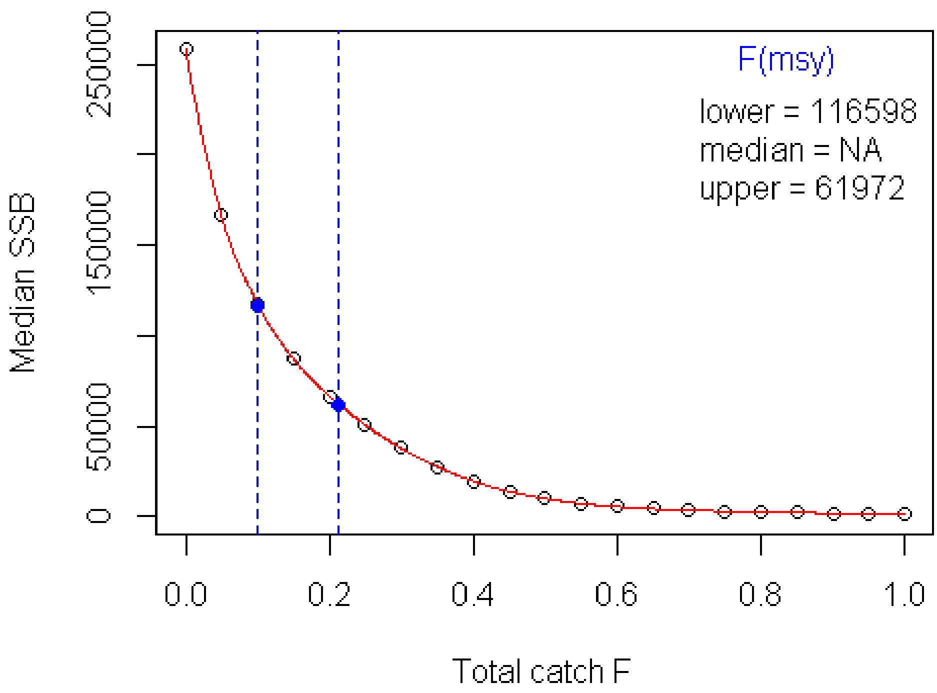

Figure 25. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F_{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.16. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.21 and the lower bound 0.1. Note that the associated SSB is above the historically observed values (Figure 1).

Biological parameters year range

We next consider the sensitivity of the F_{MSY} reference points to the range of years in the biological input parameters by calculating F_{MSY} (and its range) with a moving window of ten-year blocks of data.

```
bio.yrs<-c(2008,2017)
sel.yrs<-c(max.yr-f.yr+1,max.yr)
Fscan<-seq(0,1.0,by=0.05)
Fcv<-0.212
Fphi<-0.423
Blim<-blim
Bpa<-bpa
Btrigger <- 0
extreme.trim<-c(0.05,0.95)

fit <-eqsr_fit(stk,nsamp=1000,models= "SegregFixed")
out <-NULL

for(y in 1991:2009){
 cat(y,'\n')
```

```
 bio.yrs[1] <- y
 bio.yrs[2] <-y+9
 #  setup$sel.years <- c(y-4,y)
 sim <- eqsim_run(fit, bio.years = bio.yrs, bio.const = FALSE,
             sel.years = sel.yrs, sel.const = FALSE, Fscan = Fscan,
             Fcv = Fcv, Fphi = Fphi, Blim = Blim, Bpa = Bpa,
             Btrigger = 0, verbose = FALSE,extreme.trim = c(0.05,0.95),
             rhologRec=TRUE)

 out0 <- data.frame(y,
              Fmsy05 = sim$Refs2[2,6],
              Fmsy95 = sim$Refs2[2,8],
              FmsyMed = sim$Refs2[2,4]
 )
 out <- rbind(out,out0)
}##################################END

save(out,file=file.path(paste("fmsy.bio.sensitivity.rdata",sep="")))
```

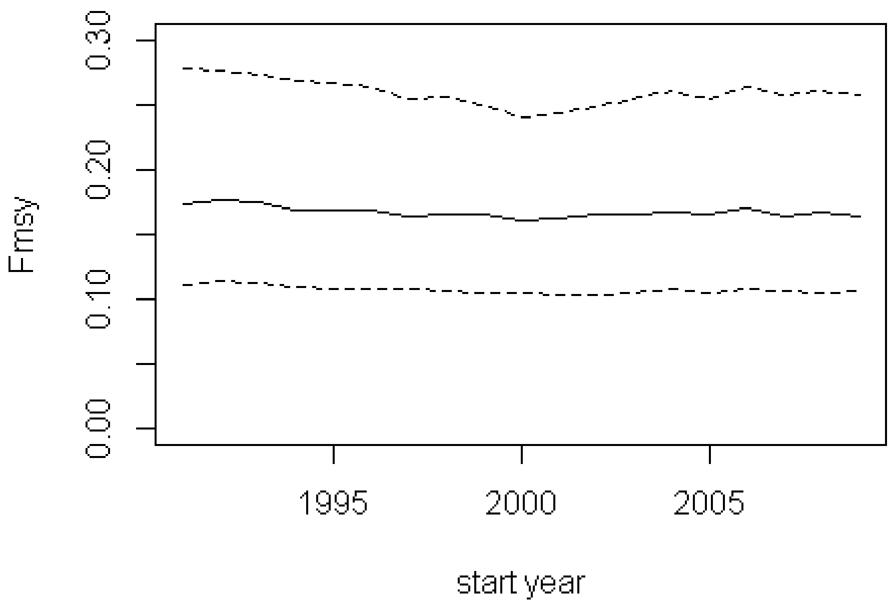

Figure 25. Had.6b. Variability in estimates of F_{MSY} (solid line) and $F_{MSYupper}$ and lower with different ten-year windows of biological parameter sampling (labelled by start year of window).

Fishery parameters year range

We next consider the sensitivity of the F_{MSY} reference points to the range of years in the fishery input parameters by calculating F_{MSY} (and its range) with a moving window of ten-year blocks of data.

```
bio.yrs<-c(max.yr-b.yr+1,max.yr)
sel.yrs<-c(max.yr-f.yr+1,max.yr)
Fscan<-seq(0,1.0,by=0.05)
Fcv<-0.212
Fphi<-0.423
Blim<-blim
Bpa<-bpa
Btrigger <- 0
extreme.trim<-c(0.05,0.95)

fit <-eqsr_fit(stk,nsamp=1000,models= "SegregFixed")
out <-NULL

for(y in 1991:2009){
 cat(y,'\n')
 sel.yrs[1] <- y
 sel.yrs[2] <-y+9
 #  setup$sel.years <- c(y-4,y)
 sim <- eqsim_run(fit, bio.years = bio.yrs, bio.const = FALSE,
          sel.years = sel.yrs, sel.const = FALSE, Fscan = Fscan,
          Fcv = Fcv, Fphi = Fphi, Blim = Blim, Bpa = Bpa,
          Btrigger = 0, verbose = FALSE,extreme.trim = c(0.05,0.95),
          rhologRec=TRUE)

 out0 <- data.frame(y,
           Fmsy05 = sim$Refs2[2,6],
           Fmsy95 = sim$Refs2[2,8],
           FmsyMed = sim$Refs2[2,4]
 )
 out <- rbind(out,out0)
}################################END

save(out,file=file.path(paste("fmsy.fish.sensitivity.rdata",sep="")))
```

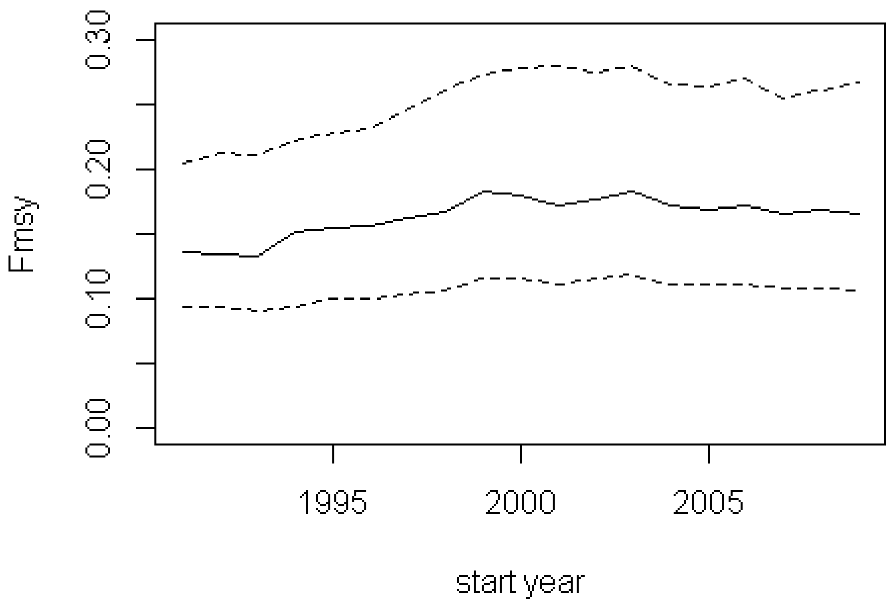

Figure 25. Had.6b. Variability in estimates of F_{MSY} (solid line) and $F_{MSYupper}$ and lower with different ten-year windows of fishery parameter sampling (labelled by start year of window).

Definition of yield

Finally, we explore the sensitivity of the estimate of F_{MSY} to the assumption about the definition of above MCRS yield. Here we resample the discard rates from the most recent five years while resampling the selectivity from ten years. This is done by overwriting landings and discards from 2009 to 2013 with values derived from the total catch multiplied by discard rates from 2014 to 2018.

```
stk <-stk.out

disc.rate <-stk.out@discards.n/stk.out@catch.n


stk@discards.n[,19:23] <-stk.out@catch.n[,19:23]*disc.rate[,24:28]
stk@landings.n[,19:23] <-stk.out@catch.n[,19:23]*(1-disc.rate[,24:28])

disc.rate <-stk@discards.n/stk@catch.n

disc.rat <-as.numeric(yearMeans(window(disc.rate,start=2009,end=2018)))
print(disc.rat)

## [1] 0.7956934555 0.4578332167 0.0516172156 0.0341746426 0.0002068313
## [6] 0.0003873874 0.0000000000

had.indat <-list(data=stk,
            bio.yrs=c(max.yr-b.yr+1,max.yr),
```

```
            sel.yrs=c(max.yr-f.yr+1,max.yr),
            Fscan=seq(0,1.0,by=0.05),
            Fcv=0.212,
            Fphi=0.423,
            Blim=blim,
            Bpa=bpa,
            Btrigger = 0,
            extreme.trim=c(0.05,0.95),
            rhologRec=TRUE
)

had.res <-within(had.indat,
            {
             fit <-eqsr_fit(data,nsamp=1000,models= "SegregFixed")
             sim <-eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                        Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                        Blim=Blim, Bpa=Bpa, Btrigger=Btrigger,
                        verbose=FALSE,
                        rhologRec=rhologRec)
            })
```

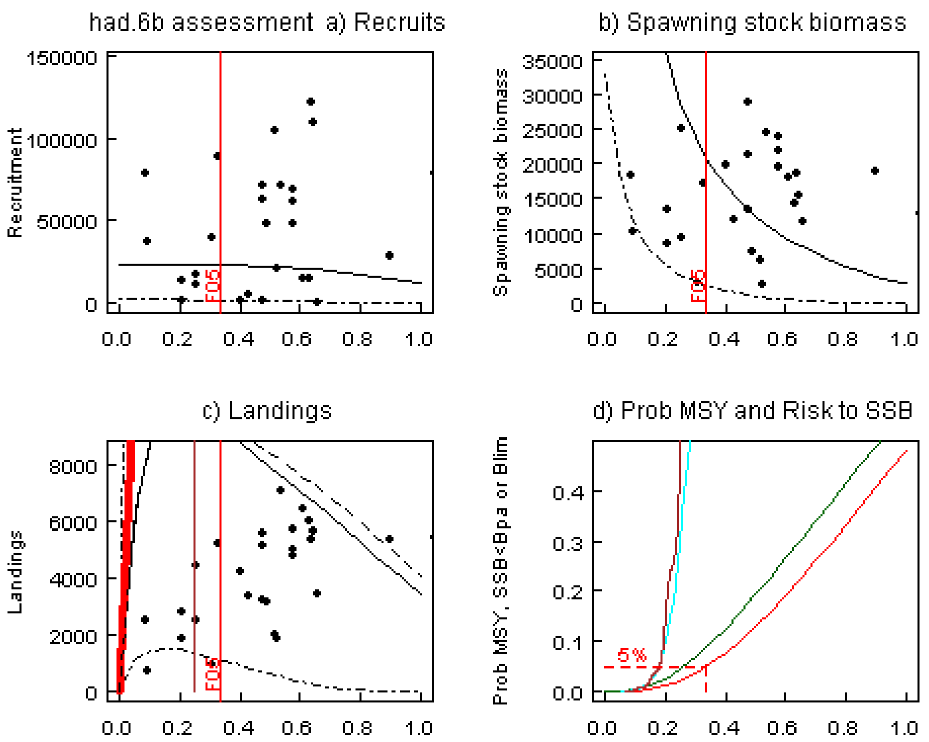

Figure 26. Had.6b. Eqsim summary plot. Panels a–c: historic values(dots), median (solid black) and 90% intervals (dotted) for recruitment, SSB and yield for exploitation at fixed values of F. Panel c also shows mean yield (red). Panel d shows the probability of SSB less than B_{lim} (red), less than B_{pa} (green) and the cumulative distribution of F_{MSY} based on > MCRS yield (brown) and catch (cyan).

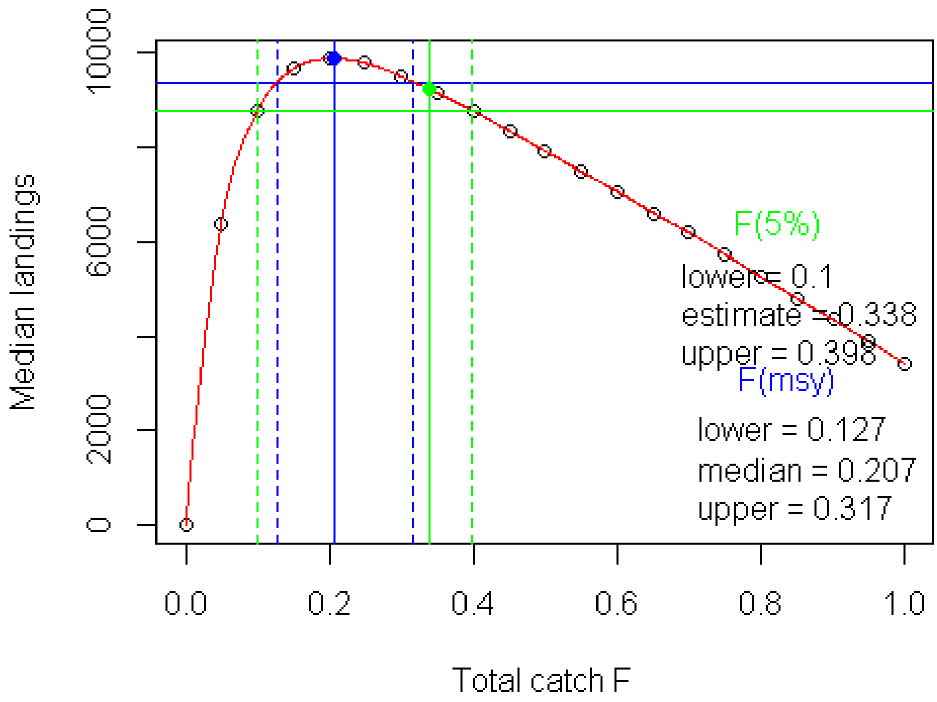

Figure 27. Had.6b. Yield (>MCRS) with median F_{MSY} (and 5th and 95th percentiles), blue vertical lines.

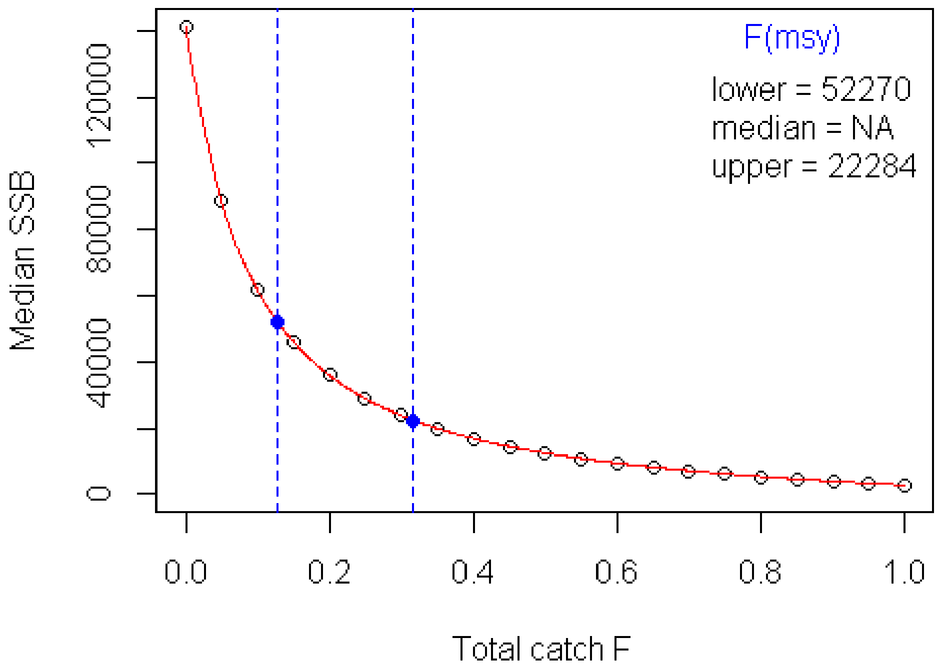

Figure 28. Had.6b. Median SSB curve over a range of target F values. Blue line corresponds to F_{MSY} range (Note that the 'NA' at median F_{MSY} is a persistent feature of EqSim).

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.21. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was 0.32 and the lower bound 0.13. Note that the associated SSB is above the historically observed values (Figure 1).

Annex 6: Stock Annex

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

Stock ID	Stock name	Last updated	Link
had.27.6b	Haddock in Division 6.b	May 2019	Rockall haddock