ICES WKMSYREF4 REPORT 2015

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Report of the Workshop to consider F_{MSY} ranges for stocks in ICES categories 1 and 2 in Western Waters (WKMSYREF4)

13–16 October 2015

Brest, France

ICES
International Council for the Exploration of the Sea
CIEM
Conseil International pour l'Exploration de la Mer

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Executive Summary

The report is based on work conducted in a workshop that was held in Brest, France on 13–16 October 2015, and describes the preparatory work in response to the EC long-term management plans for western EU waters (ICES Subareas V to X). Specifically Art. 10 of Regulation (EU) No 1380/2013 on the Common Fisheries Policy, which requires a multiannual plan including quantifiable target. In this context ICES was requested to provide plausible values around F_{MSY} for some stocks inhabiting western EU waters. Estimates of reference points B_{lim}, B_{pa}, F_{lim} and F_{pa} are provided for the stocks considered, and the F_{MSY} ranges [F_{lower}, F_{upper}] are estimated by ICES to be precautionary, and deliver no more than 5% reduction in long-term yield compared with MSY.

The report provides information on the following stocks:

Black-bellied anglerfish *(Lophius budegassa)* in Divisions VIIIc and IXa

White-bellied anglerfish *(Lophius piscatorius)* in Divisions VIIIc and IXa

Blue ling *(Molva dypterygia)* in Subdivision Vb, and Subareas VI and VII

Cod (*Gadus morhua*) in Divisions VIIe-k (Celtic Sea cod), Division VIIa (Irish Se and Division VIa (West of Scotland)

Sea bass (*Dicentrarchus labrax*) in Divisions IVbc, VIIa, and VIId–h (Irish Sea, Celtic Sea, English Channel, and southern North Sea)

Greenland halibut in Subareas V, VI, XII and XIV

Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb,c,e-k and Division VIb (Rockall)

Hake (*Merluccius merluccius*) in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock) and in Division VIIIc and IXa (Southern stock)

Megrim (*Lepidorhombus spp*) in Divisions IVa and VIa

Four-spot megrim *(Lepidorhombus boscii*) in Divisions VIIIc and IXa

Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa

Plaice (*Pleuronectes platessa*) in Division VIIe (Western Channel)

Sole (*Solea solea*) in Divisions VIIIa,b (Bay of Biscay), Divisions VIIf,g (Celtic Sea, Division VIIe (Western Channel)and Division VIIa (Irish Sea)

Whiting (*Merlangius merlangus*) in Division VIIe-k, Division VIIa (Irish Sea) and Division VIa (West of Scotland)

Nephrops in Division VIa (North Minch, FU 11), Division VIa (South Minch, FU 12), Division VIa (Firth of Clyde + Sound of Jura, FU 13, Division VIIa (Irish Sea East, FU 14), Division VIIa (Irish Sea West, FU 15), Division VIIb,c,j,k (Porcupine Bank, FU 16), Division VIIb (Aran Grounds, FU 17), Division VIIa,g,j (Southeast and West of IRL, FU 19)and the Smalls (FU 22)

For stocks where ICES advice is given based on the MSY approach, ICES has developed an advice rule (AR) based on the F_{MSY} fishing mortality reference point, that provides the exploitation rate to give catch advice, and a biomass reference point MSY $B_{trigger}$ which is used to linearly reduce F if the biomass in the TAC year is predicted to be lower than this reference value (ICES, 2015). The ICES MSY AR is evaluated to check

that the F_{MSY} and MSY $B_{trigger}$ combination results in maximum long-term yield subject to precautionary considerations. The report provides ranges for both with and without the AR.

1 Opening of the meeting

The ICES Workshop to estimate F_{MSY} ranges and precautionary reference points for Western Waters stocks with category 1 assessments was held at Ifremer, Brest, France 13–16 October 2015. The workshop was convened in response to a request from the European Commission for advice on potential intervals above and below F_{MSY}. The list of participants and contact details are given in Annex 1. The chairs, John Simmonds (ICES), and Michel Bertignac (France) welcomed the participants and highlighted the variety of ToRs. The draft agenda was presented and Terms of Reference for the meeting (see Section 2) were discussed. The Agenda was agreed and responsibility for individual tasks distributed among individuals.

2 Terms of Reference

The specific ToRs for the workshop were

2015/2/ACOM:58 The Workshop to develop F_{MSY} ranges and precautionary reference points for selected stocks in ICES categories 1 and 2 in Western Waters (see detailed list of stocks below) (WKMSYREF4), co-chaired by John Simonds, UK, and Michel Bertignac, France, will meet at Ifremer, in Plouzane, France 13–16 October, 2015 to establish F_{MSY} ranges for these stocks that are compatible with obtaining no less than 95% of the estimated maximum sustainable yield and which are considered precautionary in implementation. This is the fourth workshop in a series of workshops developing principals and methods for estimating F_{MSY} ranges. The specific ToRs for this workshop are:

1) Collate necessary data and information for the stocks listed below prior to the workshop.
2) Using ICES agreed procedures estimate precautionary reference points, F_{pa} and B_{pa}, for the stocks listed below. If other stocks during the 2015 advisory process are "upgraded" to category 1 or 2, they should also be considered;
3) Estimate values of F_{MSY} and MSY $B_{trigger}$ and F_{MSY} ranges for each of the stocks listed below such that management following advice based on these F_{MSY} ranges will be precautionary and yield are no less than 95% of F_{MSY} For stocks where an appropriate MSE methodology has already been developed, with careful consideration of the uncertainties involved for the stock, the MSE software should be the preferred one to be used for the calculation of reference points. For stocks where such an MSE does not exist, or is not suitable, use the methods agreed at WKMSYREF3 for age-based assessments and develop comparable methods for length-based assessments.
4) Update if necessary additional guidelines and where appropriate indicate suitable software for the estimation of F_{MSY} ranges for category 1 stocks with length based assessments.

WKMSYREF4 will report to ACOM no later than 6 November 2015.

Background

The Commission is preparing long-term management plans for western EU waters (ICES Subareas V–X). According to Art. 10 of Regulation (EU) No 1380/2013 of the Common Fisheries Policy a multiannual plan shall include quantifiable targets, a time frame to reach the targets and safeguards to ensure that the quantifiable targets are met.

ICES is requested to provide plausible values around F_{MSY} (range for F_{MSY}) for the stocks (see list below) inhabiting western EU waters (including those straddling western EU waters and adjacent waters).

The plausible values around F_{MSY} should be based on the stock biology, fishery characteristics and environmental conditions.

ICES is also requested to advise on safeguard values, i.e. reference points that are associated to stock situations to avoid, such as stock sizes below which there is a known risk of very slow or no recovery.

Data availability

Before September 17th, data for all relevant stocks should be uploaded in a ready-to-use format to the ICES SharePoint. Responsible persons are appointed once participation is confirmed.

ICES is requested to provide plausible values around F_{MSY} (range for F_{MSY}) for the following stocks inhabiting western EU waters (including those straddling western EU waters and adjacent waters).

Stocks to be considered by the workshop:

Black-bellied anglerfish (*Lophius budegassa*) in Divisions VIIIc and IXa

White-bellied anglerfish (*Lophius piscatorius*) in Divisions VIIIc and IXa

Blue ling (*Molva dypterygia*) in Subdivision Vb, and Subareas VI and VII

Cod (*Gadus morhua*) in Divisions VIIe–k (Celtic Sea cod)

Cod (*Gadus morhua*) in Division VIIa (Irish Sea)

Cod (*Gadus morhua*) in Division VIa (West of Scotland)

European sea bass (*Dicentrarchus labrax*) in Divisions IVbc, VIIa, and VIId–h (Irish Sea, Celtic Sea, English Channel, and southern North Sea)

Greenland halibut in Subareas V, VI, XII and XIV

Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb,c,e–k

Haddock (*Melanogrammus aeglefinus)* in Division VIb (Rockall)

Hake (*Merluccius merluccius*) in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d (Northern stock)

Hake (*Merluccius merluccius*) in Division VIIIc and IXa (Southern stock)

Megrim (*Lepidorhombus spp*.) in Divisions IVa and VIa

Four-spot megrim (*Lepidorhombus boscii*) in Divisions VIIIc and IXa

Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa

Nephrops in Division VIa (North Minch, FU 11)

Nephrops in Division VIa (South Minch, FU 12)

Nephrops in Division VIa (Firth of Clyde + Sound of Jura, FU 13)

Nephrops in Division VIIa (Irish Sea East, FU 14)

Nephrops in Division VIIa (Irish Sea West, FU 15)

Nephrops in Division VIIb,c,j,k (Porcupine Bank, FU 16)

Nephrops in Division VIIb (Aran Grounds, FU 17)

Nephrops in Division VIIa,g,j (Southeast and West of IRL, FU 19)

Nephrops in the Smalls (FU 22)

Plaice in Division VIIe (Western Channel)

Sole (*Solea solea*) in Divisions VIIIa,b (Bay of Biscay)

Sole (*Solea solea*) in Divisions VIIf, g (Celtic Sea)

Sole (*Solea solea*) in Division VIIe (Western Channel)

Sole (*Solea solea*) in Division VIIa (Irish Sea)

Whiting (*Merlangius merlangus*) in Division VIIe-k

Whiting (*Merlangius merlangus*) in Division VIa (West of Scotland)

3 Overall approach and changes from MSYREF3

3.1 Precautionary criteria

The workshop included the requirement to evaluate limit and precautionary reference points in spawning–stock biomass (SSB), i.e. B_{lim} and B_{pa}, and fishing mortality (F), i.e. F_{lim} and F_{pa}. For finfish stocks with age based assessments the WG generally followed the basis of these reference points from the draft ACOM document. In this context, for many of the stocks the time-series of stock and recruitment data were evaluated and B_{loss} was used for either B_{lim} or B_{pa}, depending on the range of SSB/F that had been explored historically, if this was limited, F generally low and biomass range small B_{loss} would be used as B_{pa} (e.g. Bay of Biscay sole), otherwise if F had been higher and biomass range included a wider range B_{loss} is taken as B_{lim}. This approach was modified slightly to exclude those SSBs where low recruitment was observed at the lowest observed SSB, and in these cases B_{lim} or B_{pa} was based on an SSB value where 'above average' recruitment had been observed. Cases where B_{loss} was taken as B_{PA} then B_{lim} was derived as B_{lim}=B_{pa}/1.4 rather than calculating B_{lim} first and deriving B_{pa} from B_{lim}, which would be the default approach. In this case the B_{lim} is effectively a proxy value that is useful (and necessary) for evaluation rather than a fully estimated value. In rare cases the WK used fitted S-R relationships based on segmented regression, this was rare because in many cases the fitted breakpoint was poorly determined high in the data cloud and dependent on a few points, for example Western Channel sole has a few low recruitments at the start of the time-series that give a relatively high breakpoint compared with other sole stocks (see section on Western Channel Sole for a discussion on this issue). F_{lim} was calculated from B_{lim} using simulated recruitment based on S-R with breakpoint at B_{loss}, or the fitted S–R relationship used for MSY evaluations.

3.2 F_{MSY} range definitions

The range of fishing mortalities compatible with an MSY approach to fishing were defined as the range of fishing mortalities leading to no less than 95% of MSY and which were precautionary in the sense that the probability of SSB falling below B_{lim} in a year in long-term simulations with fixed F was ≤5%. The ranges were produced by first estimating MSY and F_{MSY} without an MSY $B_{trigger}$ but including advice error in the evaluation. For many cases a standard value of advice error was applied (F_{cv}=0.233, F_{phi}=0.423) this was based on median values of CV and autocorrelation in advice error from WKMSYREF4. The ranges were produced by first estimating ranges of fishing mortalities leading to no less than 95% of MSY (F_{MSY} lower and F_{MSY} upper) without F_{MSY} $B_{trigger}$ but including advice error. This range was then compared with the estimated $F_{p.05}$ (value of F corresponding to 5% probability of SSB< B_{lim}). Where the estimated F_{MSY} upper exceeded the estimated $F_{P.05}$, F_{MSY} upper was specified as $F_{p.05}$. This reduction to $F_{P.05}$ was carried out for two option for, with or without the ICES AR. If F_{MSY} > $F_{p.05}$ **without** AR, F_{upper} is set F_{upper} = $F_{p.05}$ only if F was meant to be used **without** AR. If F_{MSY} > $F_{p.05}$ **with** AR, F_{upper} is set F_{upper} = $F_{p.05}$ (with AR) only if F_{upper} was meant to be used **with** AR. However, in its annual catch advice ICES uses the AR and, therefore, F_{MSY} is capped by $F_{p.05}$ **with** AR rather than by $F_{p.05}$**without** AR. Where the estimated F_{MSY} exceeded the estimated $F_{p.05}$, F_{MSY} and F_{MSY} upper were both specified as $F_{p.05}$and F_{MSY} lower redefined as the lower fishing mortality providing 95% of the yield at $F_{p.05}$ ($F_{p.05lower}$). In all cases for age based assessment, B_{lim} was defined and $F_{p.05}$ could be estimated. In the case of surplus production model (Chapter 6) and where F_{MSY} proxies were used (Sea bass Chapter 5.3 and *Nephrops* Chapter 7) the upper bound of the F_{MSY} range was set to F_{MSY} as there was no evidence to suggest that higher fishing mortalities were precautionary. This was due to the absence of a numerical simulation analysis to evaluate long-term probabilities of being below B_{lim} for these stocks.

The range was thus defined as:

Case	F_{MSY} range		
$F_{MSYupper} < F_{p.05}5$	$F_{MSYlower}$	-	$F_{MSYupper}$
$F_{MSY} < F_{p.05} < F_{MSYupper}$	$F_{MSYlower}$ r	-	$F_{p.05}$
$F_{p.05} < F_{MSY}$	$F_{p.05lower}$	-	$F_{p.05}$
$F_{p.05}$ cannot be defined	$F_{MSYlower}$	-	F_{MSY}

In the results ranges are given both based on fixed fishing mortalities at all levels of F and based on F estimated by implementing the ICES F_{MSY} Advice Rule (AR where F decreases linearly to zero as SSB/MSY $B_{trigger}$ declines to zero). If such an AR is in use, the estimated $F_{p.05}$ is higher, which may allow a slightly higher average yield in cases where $F_{MSY} > F_{p.05}$. In practice the higher yield will only occur when SSB is high as F will be reduced when SSB is low. On average SSB will be lower if Fs above the fixed $F_{p.05}$ are included in the range.

4 Estimation methods available to estimate F_{MSY} and F_{MSY} ranges

4.1 Eqsim

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). Often the SR is taken to be just a single one function (see below). WKMSYREF4 used mostly only segmented regression S-R functions in order to be compatible with the precautionary considerations. So the multiple mosel feature is optional and the Eqsim can also be run with a single SR relationship). A $B_{trigger}$ can optionally be specified; if a $B_{trigger}$ is used, then F is reduced when the stock biomass is below $B_{trigger}$. When a $B_{trigger}$ is used, the results are still presented by main F target (i.e. the value of F intended to be applied when stock biomass is above $B_{trigger}$).

https://github.com/wgmg/msy

The main function calls provide for fitting of stock recruit relationships and equilibrium simulation:

Stock–recruit fitting:

```
FIT <- eqsr_fit(stock,
                nsamp = 1000,
                models = c("Ricker", "Segreg"))
```

Where stk is an FLR stock object giving SSB and recruitment; nsamp is the number of stock recruit draws to determine the median and 90% intervals simulated; models provides for 3 standard models, though alternative equations can also be fitted. The models are weighted by the method based on Buckland.

```
SIM <- Eqsim_run(FIT,
                 bio.years = c(2004:2013),
                 sel.years = c(2004:2013),
                 Fcv=0.24,
                 Fphi=0.42,
                 Blim=106000,
                 Bpa=200000,
                 Fscan = seq(0,1.2,len=40),
                 verbose=FALSE)
```

The fitted S-R object (FIT) is then combined with biological parameters drawn randomly (bio.const=FALSE) or as an average from a recent period (bio.years typically 10 years 2004–2013). Similarly selection in the fishery is drawn randomly (sel.const=FALSE) or as an average from a recent period (sel.years e.g. 10 years 2004–2013).

4.1.1 Stochasticity implemented in Eqsim

The report of the Workshop on Guidelines for Management Strategy Evaluations (WKGMSE) held at ICES in 2013 (ICES 2013c) discussed different sources of error, and identified biological process error (recruitment variability, growth and natural mortality etc.) measurement error (assessment error) and advice error (the additional error in the management process from a short-term forecast following the estimation of the state of the stock). ICES does not include implementation error if managers were to set TACs outside the advice. Generally it is preferred that assessments are run within the MSE evaluation, however, practically this is not possible for this situation, where many stocks are to be considered together and Eqsim does not provide this possibility. The ICES guidance report also describes 'short cut approach' (Section 4.4.3 ICES 2013). This approach note the importance of taking into account the additional error introduced by the short-term forecast. Estimation error in Eqsim (F_{CV} and F_{phi}), provides for a two parameter error function which is applied directly on the target F. The controlling parameters are the conditional standard deviation in the log domain and the autocorrelation described as an AR (1) process. In this case the requirement is to include all the errors in setting a catch that are the responsibility of the advisory process. So including errors in estimation of the stock, the short-term forecast and if necessary the estimation of catch. Here we exclude the elements of implementation error associated with choosing a TAC and the control and enforcement aspects of ensuring a catch.

The information used by the workshop to evaluate appropriate parameters for this are obtained by the following procedure:

The estimated realized catch and F (F_{yr}) for the previous ten years (or more) are taken from the most recent assessment. The annual ICES advice sheets issued in y-1 are consulted to estimate the F in year y that would have been advised to obtain the estimated catch. Where the appropriate catch is not available in the catch option table linear interpolation is used to estimate the F in year y. The deviation in year y is calculated as $\log_e (F_{yr}/F_{ya})$, the standard deviation σ_m of the log deviations gives the marginal distribution. The conditional standard deviation σ_c is calculated as $\sigma_m \sqrt{(1-\phi^2)}$, where ϕ is the autocorrelation of the AR (1) process. Then σ_c ϕ are input parameters for Eqsim.

The results for σ_c ϕ for the five stocks for which the evaluations were completed in WKMSYREF3 are shown in the text table below, the median of these was used in WKMSYREF4 as default values.

	HER 437D	SOL VIID	SAITHE III,IV, VI	SOL IV	PLE IV	MEDIAN
sigma	0.286	0.233	0.269	0.222	0.227	0.233
F_{cv}	0.192	0.214	0.244	0.226	0.189	0.212
Phi	0.741	0.402	0.423	0.240	0.551	0.423

B_{lim} and B_{pa} are given as input parameters for the plots.

The range of F_{target} values and the steps to scan over (F_{scan}) can be set evenly or may be varied to give more detail in regions where this is required by providing a suitable sequence. The ICES MSY HCR is based on $F=F_{target}$ above a biomass ($B_{trigger}$) and $F_{target} = F_{target}$ *SSB/ $B_{trigger}$ below $B_{trigger}$. If the HCR is implemented the plots are given against the target Fs without indicating the reduction in F due to reduced biomass below $B_{trigger}$.

The number of populations simulated is given by Nrun; the stochastic variability of recruitment may be omitted (process.error = FALSE); when used the stochastically drawn individual deviations to simulate recruitment may be limited (recruitment.trim = c (3,-3)) where the limit is expressed in standard deviations. In addition to the underlying variability of recruitment autocorrelation may be optionally included (rhologRec=TRUE). This facility was not included at WKMSYREF3 and in most cases has not been applied except where it was considered important, (e.g. Rockall haddock and Bay of Biscay sole).

The following issues were identified as requiring attention at WKMSYREF3 and have all been dealt with:

1) Recruitment deviations one set over iterations and Fs
2) MSY interval code added in as call or as standard within the routine
3) Autocorrelation in recruitment.
4) Trimming issues were encountered and need fixing.
5) Problems with fitting segreg in some cases.

4.2 PlotMSY

PlotMSY (equilibrium approach with variance) is intended to provide robust estimation of deterministic MSY estimates (i.e. without future process error) that could be applied easily and widely. It fits three stock–recruit functions, namely the Ricker, Beverton–Holt, and a smooth Hockey-stick (Mesnil and Rochet, 2010), to estimate MSY quantities. Uncertainty in MSY estimates is characterized by MCMC sampling of the joint pdf of the stock–recruit parameters and sampling from the distributions of other productivity parameters (i.e. natural mortality, weights-at-age, maturities, and selectivity). Stock–recruit model uncertainty is taken into account by model averaging of the three functions. A more detailed description of the method, including examples and guidelines for use is given in Annex 7 of ICES WGMG report (ICES 2013b).

4.3 Method used for Northern hake and White Anglerfish

A method was developed for the calculation of reference points for the stocks of northern hake (hke-nrtn) and white anglerfish in Divisions VIIIc and IXa (anp-8c9a).

These two stocks are assessed with SS3 using length data and without any age data. The population dynamics model used in their assessments is similar for both stocks and code was developed for use for both stocks. The population dynamics in the assessment model uses quarterly time-steps; recruitment (at age 0) comes in at the start of several quarters during the year and growth follows a von Bertalanffy curve with dispersion around it. Catches are taken by several fleets, with fleet-specific selection-at-length and retention-at-length. Recruitment is modelled as a set of deviations around a Beverton–Holt function with steepness of 0.999; therefore, for all practical purposes, recruitment in the assessment model is estimated as free parameters without a stock–recruitment relationship.

The R and WinBUGS scripts developed for the calculation of reference points are available on the software folder of the WKMSYREF4 SharePoint. The process used for the calculation of reference points parallels the process used in Eqsim and is briefly described in the sequel.

It is possible to fit Beverton–Holt, Ricker and Hockey-Stick stock–recruitment functions to the (SSB, Rec) pairs estimated from the stock assessment. This was implemented in a Bayesian context, calling WinBUGS from R and using relatively uninformative (i.e. fairly diffuse) priors. Posterior model probabilities can also be calculated for each of the three stock–recruitment models.

After fitting the stock–recruitment models, a long-term stochastic projection can be performed based on the quarterly step population dynamics and length-based selection and retention used in the SS3 assessments. Recruitment is stochastically drawn on a quarterly basis (for the quarters assumed to have recruitment) and growth is according to the von Bertalanffy based models used in the SS3 assessments. Fishery parameters are randomly drawn from a selected number of recent years. Errors in the assessment/advice are incorporated as in Eqsim (i.e. ln (F_realized/F_intended) is assumed to follow a 0-mean AR (1) process with variance and autocorrelation entered as inputs).

The procedure to calculate reference points from the results of the stochastic simulation is the same as used in Eqsim and, therefore, there is no need to describe it specifically in this section.

4.4 Method used for Southern hake

Southern hake is assessed with GADGET, an age-length based method. The population dynamics in the assessment model uses quarterly time-steps; recruitment (at age 0) comes in at the end of first and second quarter with equal proportions. Growth follows a von Bertalanffy curve with dispersion around it. M is set to 0.4 for all ages and quarters. Maturity at length is year specific and is not incorporated in the model fit but after the fit to estimate yearly SSB. This means that Southern hake recruitment is estimated by GADGET independently of the SSB. Landings and discards are modelled with different selection at length.

All analyses were conducted with ad-hoc software developed in R-3.2.1. The software consists of 3 main blocks:

1) A deterministic yield-per-recruit (YPR) and stock per recruit (SPR) length based analysis as described in ICES (2010), annex 3.
2) A Bayesian stock–recruitment analysis for 3 models (Beverton–Holt, Ricker and hockey stick) implemented in OpenBUGS-3.2.3 (Thomas *et al*., 2006) with the R2OpenBUGS-3.2.3 R library (Sturtz *et al*., 2005). Priors are non-informative.
3) A stochastic link between SPR and the stock–recruitment parameters providing the distribution for the different equilibrium reference points, as described in Cerviño et al. (2013).
4) The main routine R code is as follows:

```
-> source("main.r")
```

The main.r file requires the following information:

- Basic hake data (biology and exploitation patern) in "./data/gadgetR.RData" produced with the script ./data/gadgetData/out/gadget2R.r".
- Per-recruit data from "./data/perRec.RData" file estimated with "./analisis/perRec.r".
- SR models in "../data/bugOutRk.RData; bugOutBh.RData and bugOutHs.RData " files produced with "./analisis/sr/rickerFit.r; bevholtFit.r and hockstickFit.r".
- stochastic MSY ref points in "./data/srBrp.RData" file estimated with "./analisis/msyStochRefPts.r"
- All outputs are saved in ./plots folder

5 MSY interval analysis by stock: Stocks with age based assessments

5.1 White anglerfish (*Lophius piscatorius*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)

5.1.1 Current reference points

Table 5.1.1 Summary table of current stock reference points

	VALUE	TECHNICAL BASIS
Current B_{lim}	Not defined	
Current B_{pa}	Not defined	
Current F_{lim}	Not defined	
Current F_{pa}	Not defined	
Current F_{MSY}	0.19	Proxy based on F0.1 (length 30–130 cm) (ICES, 2012)
Current MSY $B_{trigger}$	Not defined	

5.1.2 Source of data

All data used in the MSY interval analysis were taken from the latest ICES assessment for southern white anglerfish, given in the WGBIE 2015 report (ICES, 2015).

5.1.3 Methods used

All analyses were conducted with the method developed *ad hoc* for northern hake and southern white anglerfish stock (see methods Section 4.4).

5.1.4 Settings

Table 5.1.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Year classes 1980–2014	
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	No	
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2005–2014	
Assessment error in the advisory year. CV of F	0.233	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

5.1.5 Results

5.1.5.1 Stock-recruitment relation

The full available time-series of recruitment was used to fit stock recruitment models. The stock recruitment fit, using the three models (Ricker, Beverton–Holt and Hockey-stick) weighted by the Bayesian model, available in the *ad hoc* method employed, resulted in very low weight to the Ricker model (11%). The Beverton–Holt and Hockey-stick models obtained 54% and 35% respectively. Because the S–R data do not show a clear pattern, and following the procedures presented above for these situations, it was decided to use the Hockey-stick model (Figure 5.1.1).

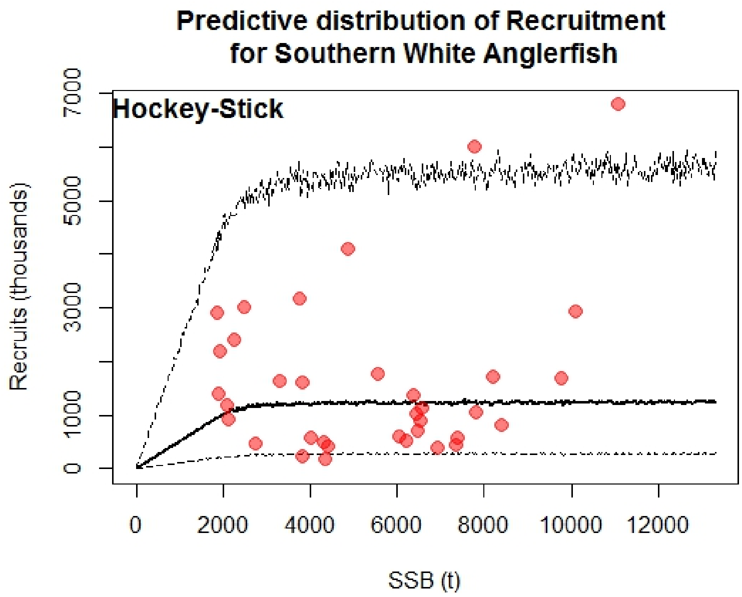


Figure 5.1.1 Assumed stock recruitment relationship for southern white anglerfish based on Hockey-stick model. The median and 90% intervals (in black) and S-R pairs by year (red).

5.1.5.2 Yield and SSB

For the base run, yield does not include discards, with F_{MSY} being taken as the peak of the median landings yield curve (Figure 5.1.2). The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.1.5.3 Reference Points analysis

B_{lim} was set at 1 865 t, the lowest value of the SSB time-series (B_{loss}) estimated in 1994 (Table 5.1.2). The B_{pa} was derived from B_{lim} estimate at 2 592 t.

The median F_{MSY}, estimated by applying a fixed F harvest strategy was estimated at 0.31 (Figure 5.1.3). The upper bound of the F_{MSY} range giving at least 95% of maximum yield was estimated at 0.41 and the lower bound was estimated at 0.18. $F_{P.05}$ was estimated at 0.46 higher than F_{MSY} upper bound and therefore fishing at the F_{MSY} upper bound is considered precautionary. The median of the SSB estimates at F_{MSY} was estimated at 9 829 t, lower than the maximum historical SSB of 11 092 t.

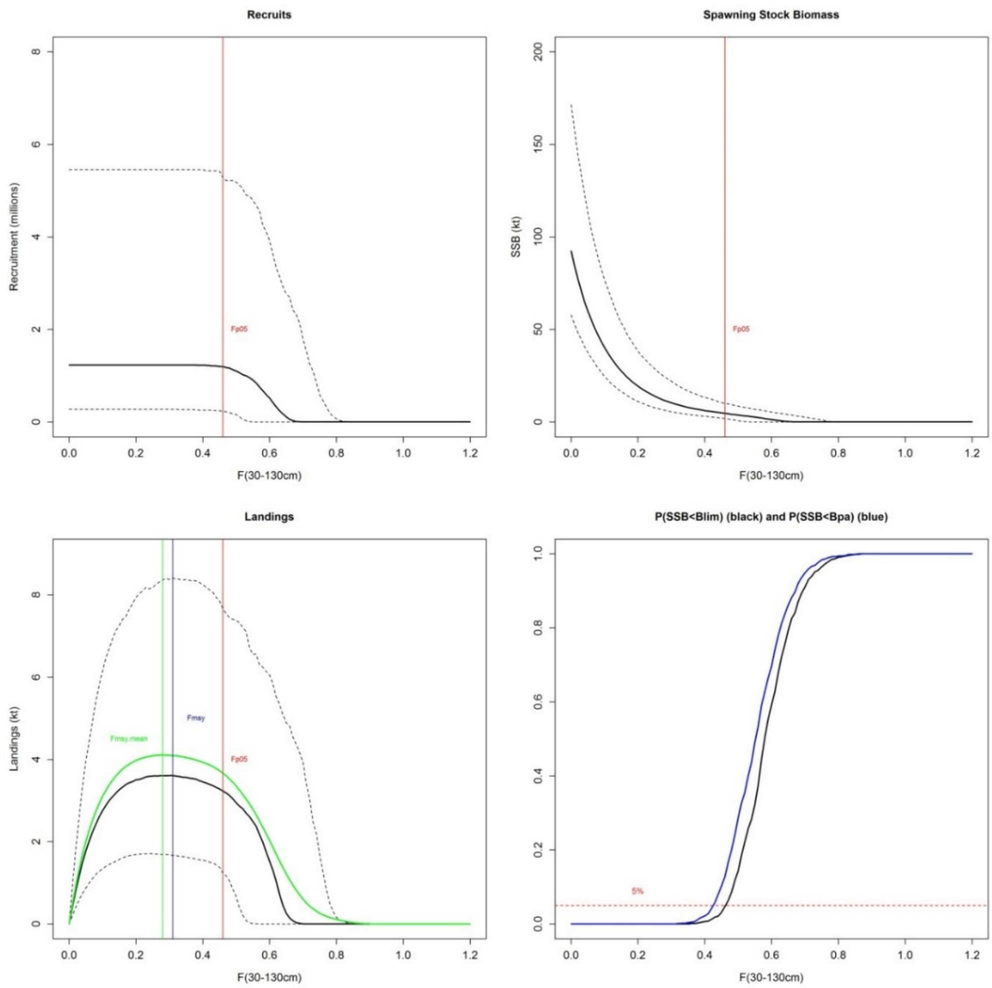


Figure 5.1.2. Results of applying the Hockey-stick assumption for recruitment for southern white anglerfish. Median (solid black) and 90% intervals (dotted black) for recruitment (up-left), SSB (up-right) and landings (bottom-left) for exploitation at fixed values of F. Panel bottom-right also shows mean landings (green solid line). Probability of SSB<B_{lim} (black) and SSB<B_{pa} (blue) are also represented (bottom-right).

A run with no error in the advice was carried out to estimate MSY $B_{trigger}$ and F_{lim}. MSY $B_{trigger}$ was estimated at 5 755 t and F_{lim} at 0.60 (Table 5.1.3).

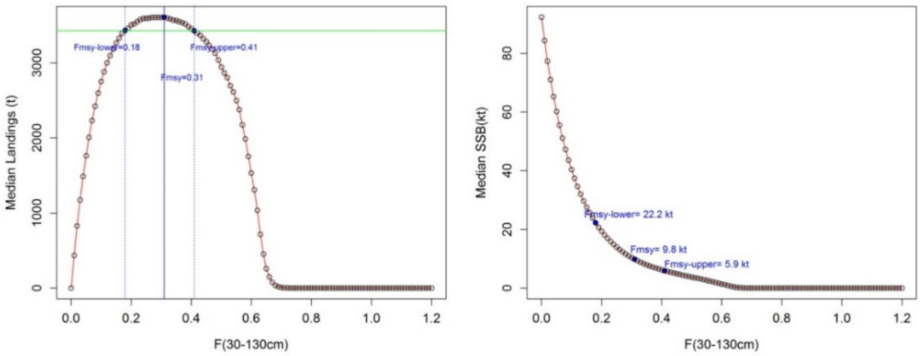


Figure 5.1.3. Southern white anglerfish with fixed F exploitation. Median landings yield curve with estimated reference points (left) and median SSB with estimated reference points (right).

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 5 755 t, median F_{MSY} was estimated at 0.32 with lower bound of the range at 0.18 and upper bound at 0.47. The $F_{P.05}$ increased to 1.09.

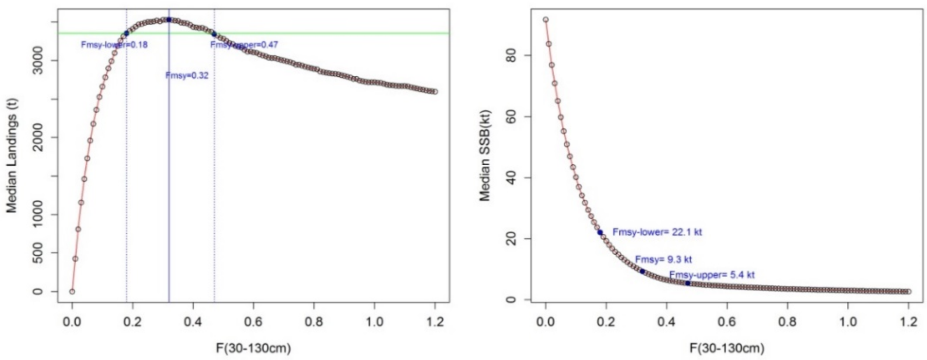


Figure 5.1.4. Southern white anglerfish when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 5 755 t. Median landings yield curve with estimated reference points (left) and median SSB with estimated reference points (right).

5.1.6 Proposed reference points

Table 5.1.3 Summary table of proposed stock reference points.

STOCK		
PA Reference points	Value	Rational
B_{lim}	1 900 t	B_{loss} (1994)
B_{pa}	2 600 t	B_{lim}*exp (1.645* σ) σ = 0.2
F_{lim}	0.60	Based on segmented regression simulation of recruitment with B_{lim} as the breakpoint.
F_{pa}	0.43	F_{lim}*exp (-σ *1.645) σ = 0.2
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.31	
F_{MSY} lower without $B_{trigger}$	0.18	
F_{MSY} upper without $B_{trigger}$	0.41	
MSY $B_{trigger}$	5 755 t	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.46	
F_{MSY} upper precautionary without $B_{trigger}$	0.41	
$F_{P.05}$ (5% risk to Blim with Btrigger, Bpa)	1.09, 0.53	
F_{MSY} with $B_{trigger}$, B_{pa}	0.32, 0.28	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.18, 0.18	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.47, 0.41	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.47, 0.41	
MSY	3 608 t	
Median SSB at F_{MSY}	9 829 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	5 909 t	
Median SSB upper (median at F_{MSY} lower)	22 253 t	

5.1.7 Discussion / Sensitivity.

No sensitivity analysis was carried out for this stock.

The obtained value of F_{MSY} at 0.31 is significantly higher than the value of $F_{0.1}$ (0.19) defined as proxy of F_{MSY} for southern white anglerfish stock in the WGHMM2012. The assumption of a Hockey-stick model to estimate the F_{MSY}, with the implication of no relationship between stock size and recruitment above breakpoint, could explain this increase in the F_{MSY} value.

5.2 Blue ling (*Molva dypterygia*) in Division Vb and Subareas VI and VII

5.2.1 Current reference points

Table 5.2.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	None	
Current B_{pa}	None	
Current F_{lim}	None	
Current F_{pa}	None	
Current F_{MSY}	0.07	F50% SPR from deterministic YPR assuming M=0.11
	0.11 to 0.15	Calculated from YPR at equilibrium using natural mortality from 0.1 to 0.13
Current MSY $B_{trigger}$	None	

5.2.2 Source of data

Data used in the MSY interval analysis were taken from the stock assessment with SRA (Stock Reduction Analysis) made at ICES WGDEEP 2015. SRA is basically an aged-structured production model, assuming a Beverton–Holt stock–recruitment relationship with steepness=0.75 the model is fitted to the time-series of landings since the onset of the fishery in 1966 and to three time-series of biomass indices. These data are from the latest assessment from WGDEEP (ICES 2015).

5.2.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

A number of options were tested, using either the segmented regression with breakpoint at 54000 t or the Beverton–Holt stock–recruitment, assuming or not assessment error and autocorrelation in the advisory year and setting or not MSY $B_{trigger}$. Three MSY $B_{trigger}$ value were used: $B_{trigger}$=B_{lim}=B_{loss}, $B_{trigger}$=1.4xBlim, $B_{trigger}$=5%BMSY.

The settings below and the results are shown for the two stock recruitment relationships.

5.2.4 Settings

Table 5.2.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full series 1966–2014	The assessment model estimates the exploitable and spawning biomass, which are the same for this stock as immature juvenile are negligible in the catch. No observed time-series of recruitment is used, the recruitment used as input are those derived from the Beverton–Holt recruitment function assumed in the model
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	No	Standard (-3,+3 Standard deviations) trimming makes no change, recruitment values are within 3 sd.
Mean weights and proportion mature; natural mortality	2005–2014	No annual mean weights. The same mean weights are assumed throughout the time-series. These are based upon the length-weight relationship and the estimated length-at-age from age estimations of catch in 2009-2013. The proportion of mature in the exploitable stock and the catch is 100% (blue ling immigrate to the fishing ground at maturity) Natural mortality is based upon the 2015 stock assessment. The M=0.11 used is also similar to the M=0.1 assumed for the Icelandic stock (BLI-5a14).
Exploitation pattern	2005–2014	Only mature fish are caught. Assumed knife edge selection at age 8. Immature fish not available to the fishery. No change of exploitation pattern expected
Assessment error in the advisory year. CV of F	0.233	Default value calculated from 5 stocks in WKMSYref3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYref3

No stock–recruitment relationship for the stock. Assessment to the stock historical trajectory (1966–2014) is carried with a Stock Reduction Analysis (SRA). This model is basically an aged-structured production model, assuming a Beverton–Holt stock–recruitment relationship with steepness=0.75.

5.2.5 Results

5.2.5.1 Stock recruitment relation

The Beverton–Holt stock recruitment relationship fits better the data than the segmented regression with breakpoint at 54000 t, simply because it is an assumption in the assessment (Figure 5.2.1).

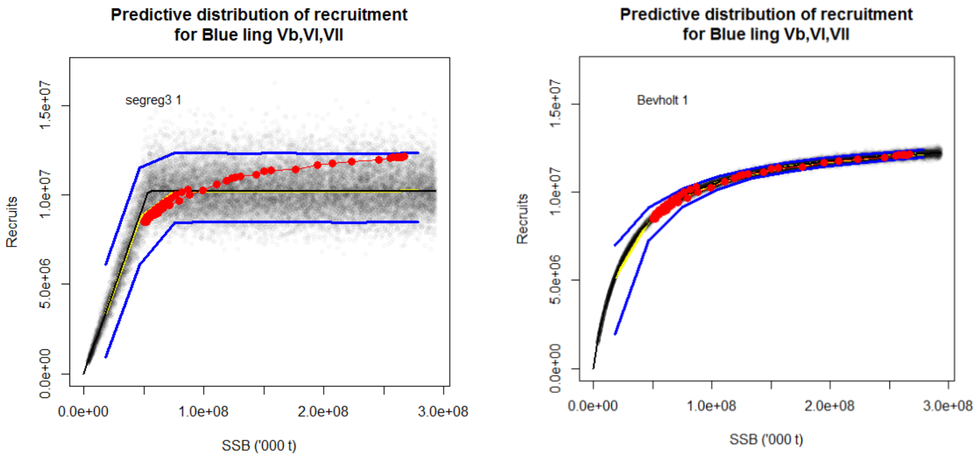


Figure 5.2.1 Stock recruitment relationship used in Eqsim, showing stock recruitment pairs from the age-structured production model (so the absence of variability). Left: segmented regression with breakpoint at 54000 t; Right Beverton–Holt model, which perfect fit comes from the use of this model in the assessment.

5.2.5.2 Yield and SSB

Yield is taken as landings with no discards. Discards of blue ling are not know to occur and on-board observed show a negligible level of discards (<<1%). The F_{MSY} range is calculated as F values corresponding to median yield that is 95% of the peak of the median yield curve.

5.2.5.3 Eqsim analysis

Include a) overall stock 4 panel plot without MSY $B_{trigger}$, b) yield and SSB plots, with (and c) if interesting without) MSY $B_{trigger}$.

The stock data shows the SBB (Figure 5.2.2, top right) from the onset of the fishery in 1966 starting from slightly more 250 000 t (units on the plot are kg), decreasing to 54 000 t in 2001 and increasing thereafter. The recruitment (top left) follows a similar pattern, with a much smaller relative variation owing to the Beverton–Holt stock–recruitment relationship. Catch (bottom left) increasing to high levels, about ten time current levels in the 1970s and gradually decreased thereafter. Catch levels have been constrained by TACs since 2003. The fishing mortality increased up to 0.25 and has been driven down by management during the past decade (bottom right).

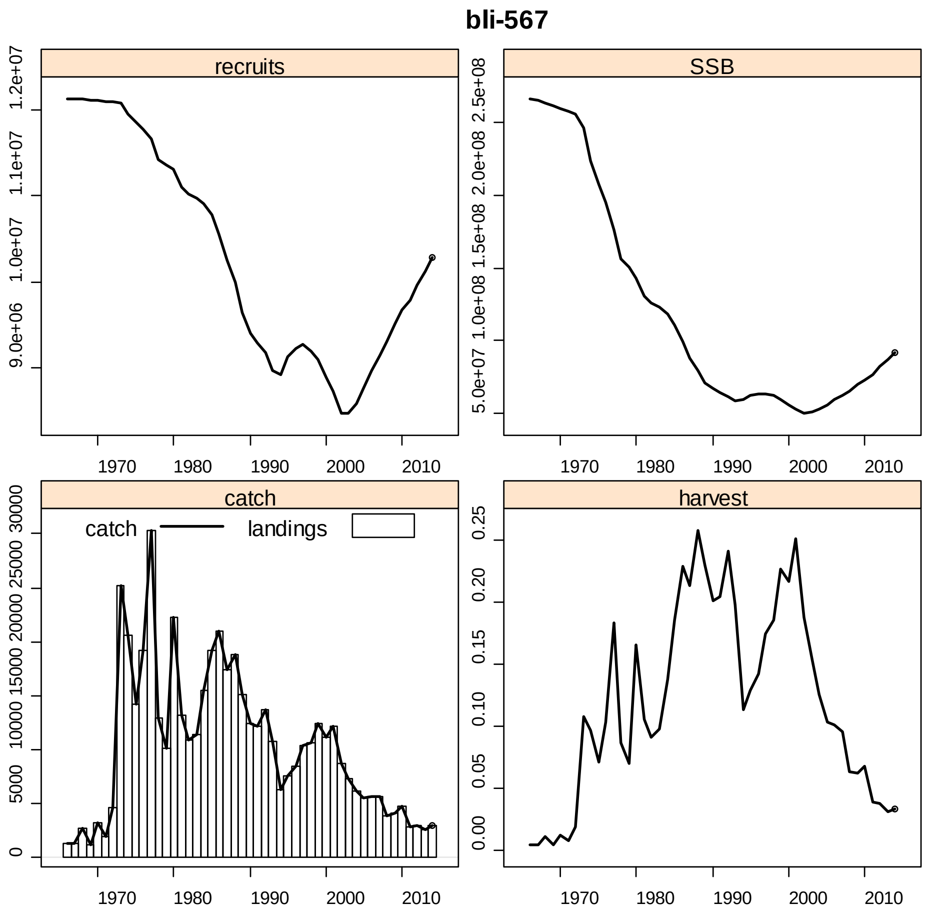


Figure 5.2.2 Blue ling in Vb, V and VII. Stock summary

The results with advice error

5.2.6 Proposed reference points

Reference points were calculated based on the segmented regression and the Beverton–Holt stock recruitment models.

The former has the advantage to do minimal assumptions for the stock–recruitment relationship, the latter is consistent with the assessment model. Assessment error and autocorrelation were set at default values and, when used, $B_{trigger}$ was set to B_{lim}=B_{loss}=54000 t. Results with the segmented regression and no $B_{trigger}$ are shown in Figure 5.2.3 and 5.3.4. Results with the Beverton–Holt model are shown in figure 5.2.5 and 5.2.6 Simulations with no error and/or no $B_{trigger}$ returned (not shown) returned higher F_{MSY} levels. With the segmented regression with breakpoint at 54000 t an F_{MSY} of 0.17 is obtained. This seems a high value, well above M=0.11. The F_{MSY}=0.12 obtained with the Beverton–Holt stock–recruitment, which seems more in line with the rules of thumb F_{MSY}≈M or F_{MSY} ≈0.8 M (e.g. MacCall, 2009). Reference points were then taken from this model.

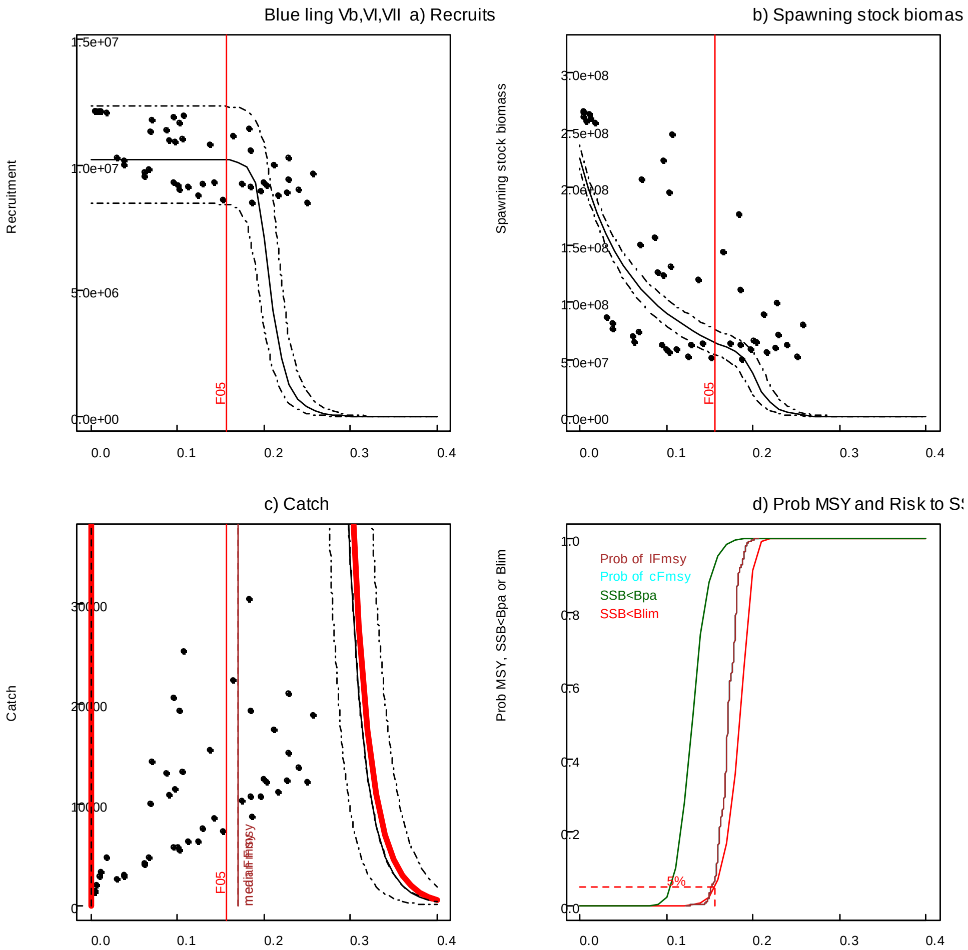


Figure 5.2.3 Eqsim results of simulations for blue ling Vb, VI and VII assuming a segmented regression with breakpoint at 54000 t stick stock–recruitment relationship. Assessment error and autocorrelation set at default levels, no $B_{trigger}$.

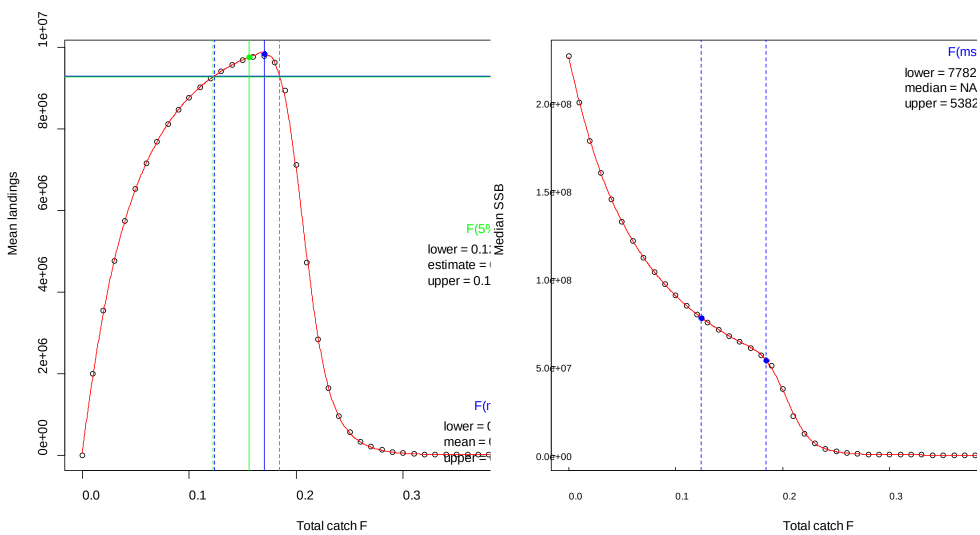


Figure 5.2.4. Eqsim results of simulations for blue ling Vb, VI and VII assuming a segmented regression with breakpoint at 54000 t stock–recruitment relationship. Assessment error and autocorrelation set at default levels, no $B_{trigger}$. Left: yield, right SSB

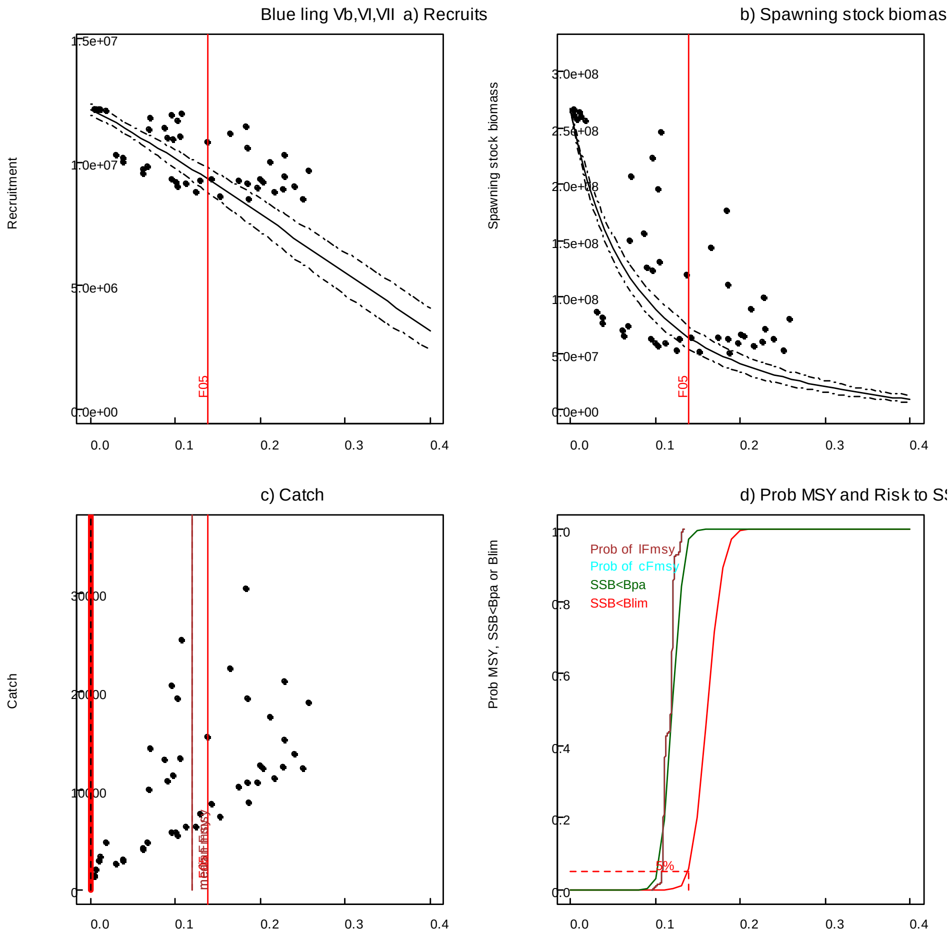


Figure 5.2.5 Eqsim results of simulations for blue ling Vb, VI and VII assuming a Beverton–Holt stick stock–recruitment relationship. Assessment error and autocorrelation set at default levels, no $B_{trigger}$.

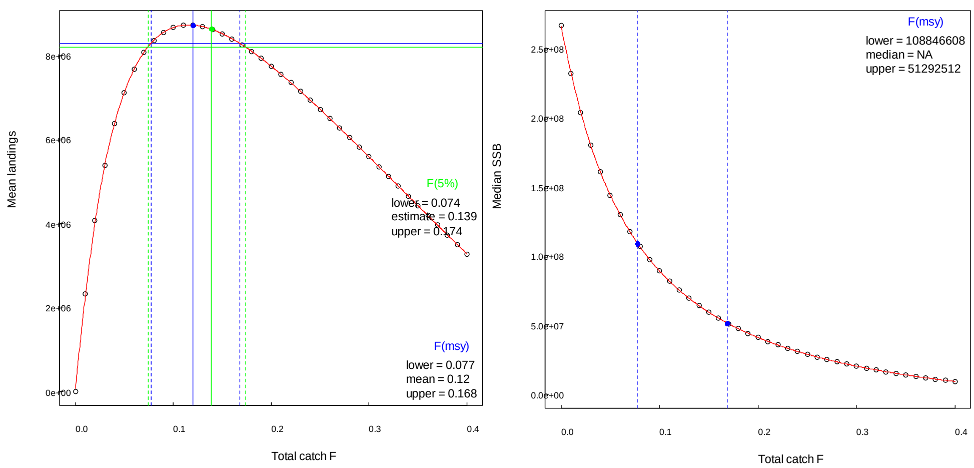


Figure 5.2.6. Eqsim results of simulations for blue ling Vb, VI and VII assuming a Beverton–Holt stick stock–recruitment relationship. Assessment error and autocorrelation set at default levels, no $B_{trigger}$. Left: yield, right SSB

The analysis was continued using only the Beverton–Holt stock–recruitment relationship. Figure 5.2.7 shows the simulations with $B_{trigger}$=Loss=54 000 t.

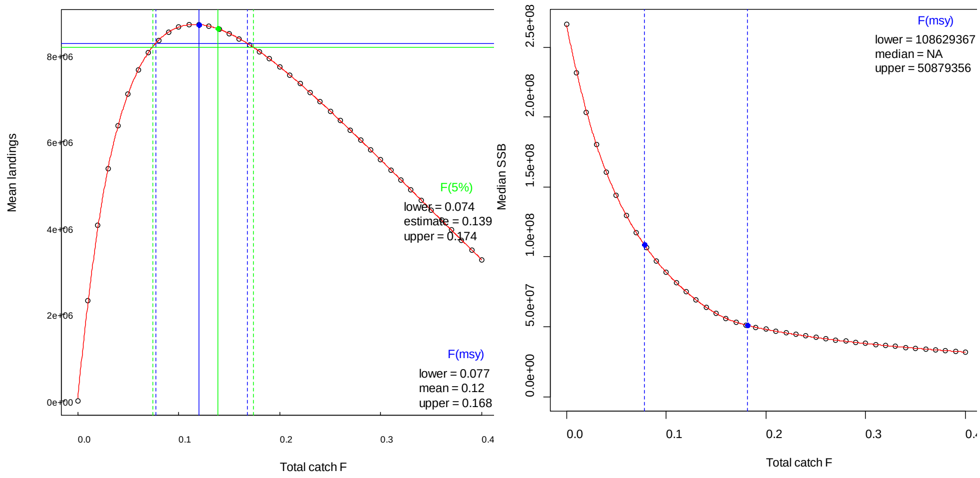


Figure 5.2.7 E Eqsim results of simulations for blue ling Vb, VI and VII assuming a Beverton–Holt stick stock–recruitment relationship. Assessment error and autocorrelation set at default levels, $B_{trigger}$ set at B_{lim}=B_{loss}=54 000 t. Left: yield, right SSB

Table 5.2.3 Summary table of proposed stock reference points for method Eqsim. The 3 values of some F reference point are with $B_{trigger}$=5%BMSY, $B_{trigger}$=B_{lim} and $B_{trigger}$=B_{pa}, in this order

STOCK		
PA Reference points	Value	Rational
B_{lim}	54 000 t	B_{loss},
B_{pa}	75 000 t	1.4*B_{lim}
F_{lim}	0.17	Based on simulated SSB to B_{lim}
F_{pa}	0.12	F_{lim} *exp(-1.645*0.2)
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.12	
F_{MSY} lower without $B_{trigger}$	0.08	
F_{MSY} upper without $B_{trigger}$	0.17	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.14	
F_{MSY} upper precautionary without $B_{trigger}$	NA	
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$)	0.14, 0.14, 0.18	
F_{MSY} with $B_{trigger}$	0.12, 0.12, 0.12	
F_{MSY} lower with $B_{trigger}$	0.08, 0.08, 0.08	
F_{MSY} upper with $B_{trigger}$	0.17, 0.18, 0.25	
F_{MSY} upper precautionary with $B_{trigger}$	NA	
MSY	8500	
Median SSB at F_{MSY}	75000	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	51000	
Median SSB upper (median at F_{MSY} lower)	107000	

5.2.7 Discussion / Sensitivity.

The variability of the stock dynamics is not fully captured in this analysis, because the modelling approach does not allow for significant variability of recruitment. In these circumstances a MSY $B_{trigger}$ based on 5% of BMSY is not meaningful and is not recommended

The current F at 0.03–0.04 is well below any reference F_{MSY}. This is the result of ten years of management that reduced TACs according to non-quantitative advices that the stock was depleted. These data-limited assessments were right as the stock was below SSB_{MSY} at the time. This management induced a rebuilding trajectory for the stock. The management at MSY now implies F to be increased to a level of twice recent levels. This increase is expected to be gradual as TACs should not change by more than 20% at each revision. Therefore, it seems most appropriate to use ' F_{MSY} lower with $B_{trigger}$ as an interim F_{MSY} reference point for management purpose. This would allow, increasing the catch and continuing the rebuilding of the stock biomass, while getting more years in the assessment. Noteworthy, a Multiyear Catch Curve (MYCC, a type of statistical catch-at-age) model is also used for assessment in addition to the SRA. Note that the current F estimated by the MYCC is also 0.03–0.04. With an increasing number of years with age composition data the output of the MYCC will provide stock–recruitment data.

5.3 Seabass (*Dicentrarchus labrax*) in Divisions IVb and c, VIIa, and VIId–h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)

5.3.1 Current reference points

Table 5.3.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	5250t	Lowest observed spawning-stock biomass (ICES, 2014)
Current B_{pa}	$B_{lim} \times \exp(1.645 \times \sigma)$.	
Current F_{lim}	Not defined.	
Current F_{pa}	Not defined.	
Current F_{MSY}	0.13	Proxy based on F35% SPR (Ices, 2014)
Current MSY $B_{trigger}$	8000t	B_{pa} (ICES, 2015)

5.3.2 Source of data

Data used in the MSY interval analysis were taken from an analysis of the SS3 output last run from WGCSE, 2015 created during ICES WKREFMSY4, and from Yield-per-recruit Curve calculated at WGCSE 2014. Data represent the latest assessment input and output data from WGCSE (ICES 2015X).

5.3.3 Methods used

MSY Plots has been tested. Data available do not allow to use Eqsim.

The main routine R code is as follows*:

```
senfile = ".\\Data\\BASS.sen"
titlename = "BSS47"
fpa = NA
flim = NA
bpa = 8000
blim = 5250
index = NA
pfpm = c(0,0)
nits = 1000
nhair = 100
varybiodata = TRUE
srweights <- c(NA,NA,NA)
trimming  <- NA
source("plotMSY.r")
stock = plotMSY(senfile, index, pfpm, srweights, nits, nhair, varybio-
data, titlename, fpa, flim, bpa, blim, silent=TRUE, onlyYPR=FALSE)
```

**NB: See plotymsy.r and documentation for more details of how to use the program*

5.3.4 Results

5.3.4.1 Stock recruitment relation

Results of MSY Plots are given below (Figure 5.3.1)

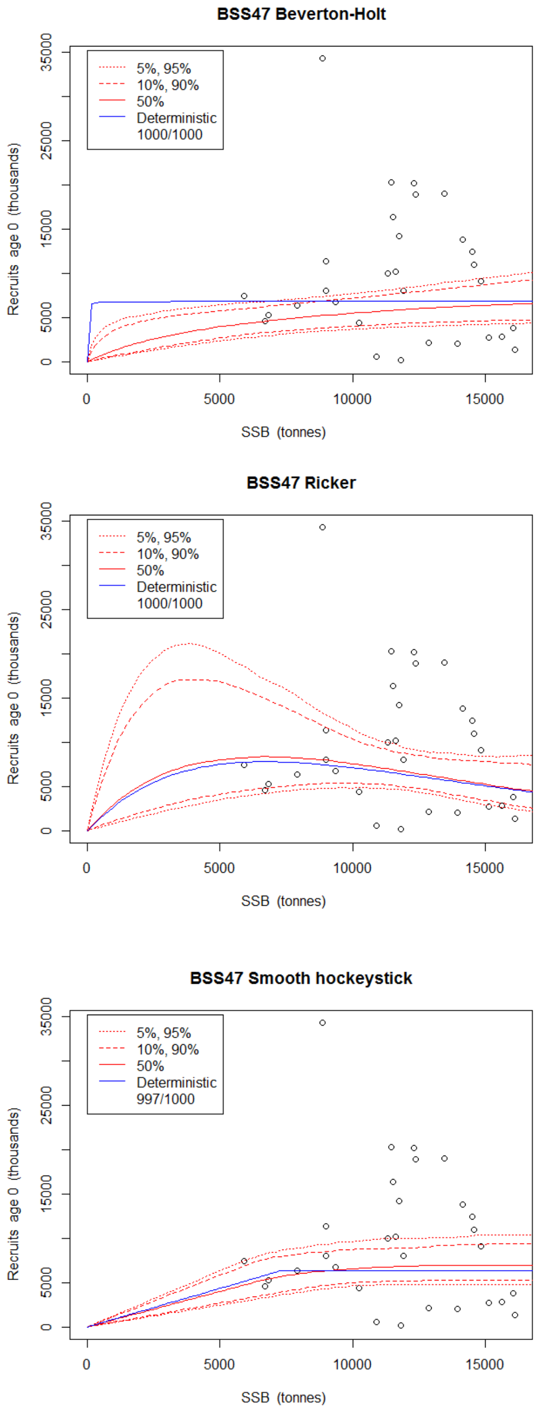
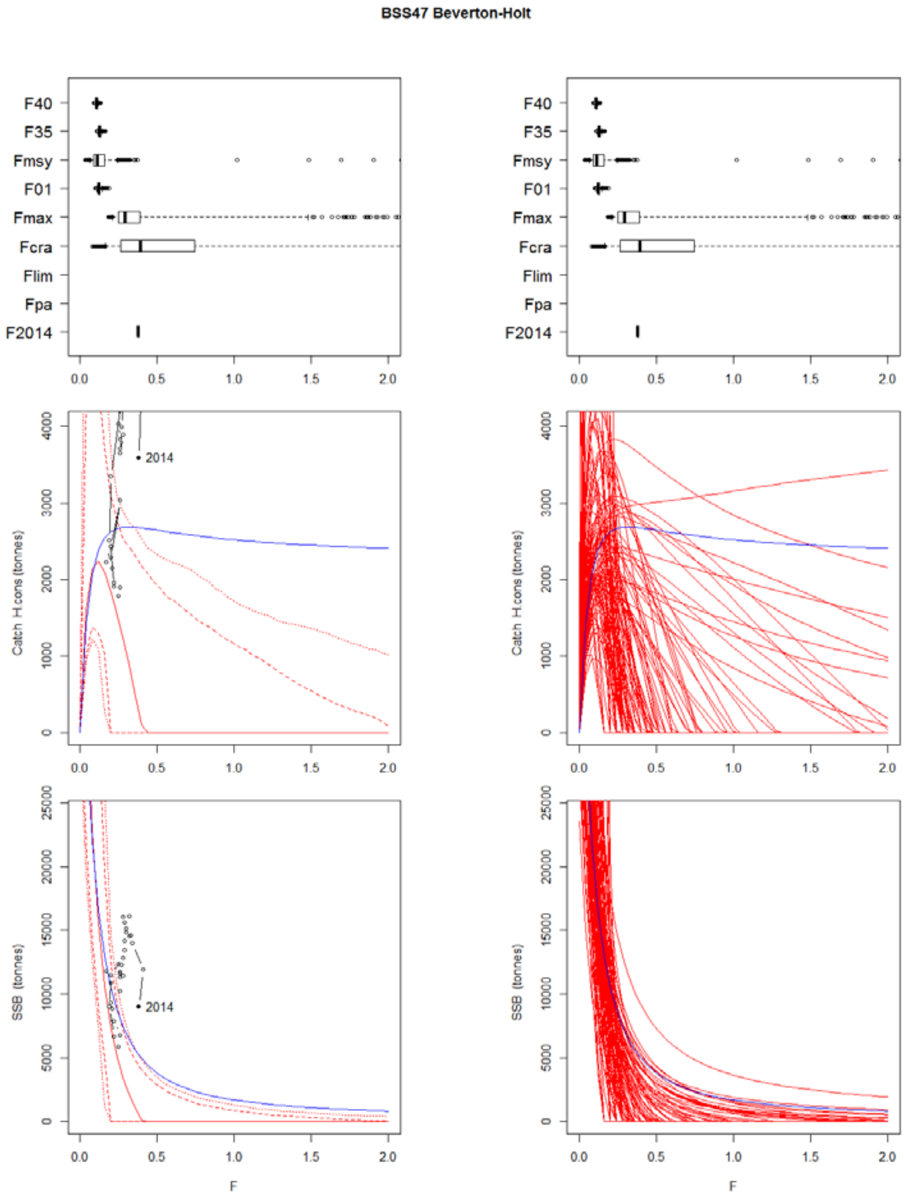
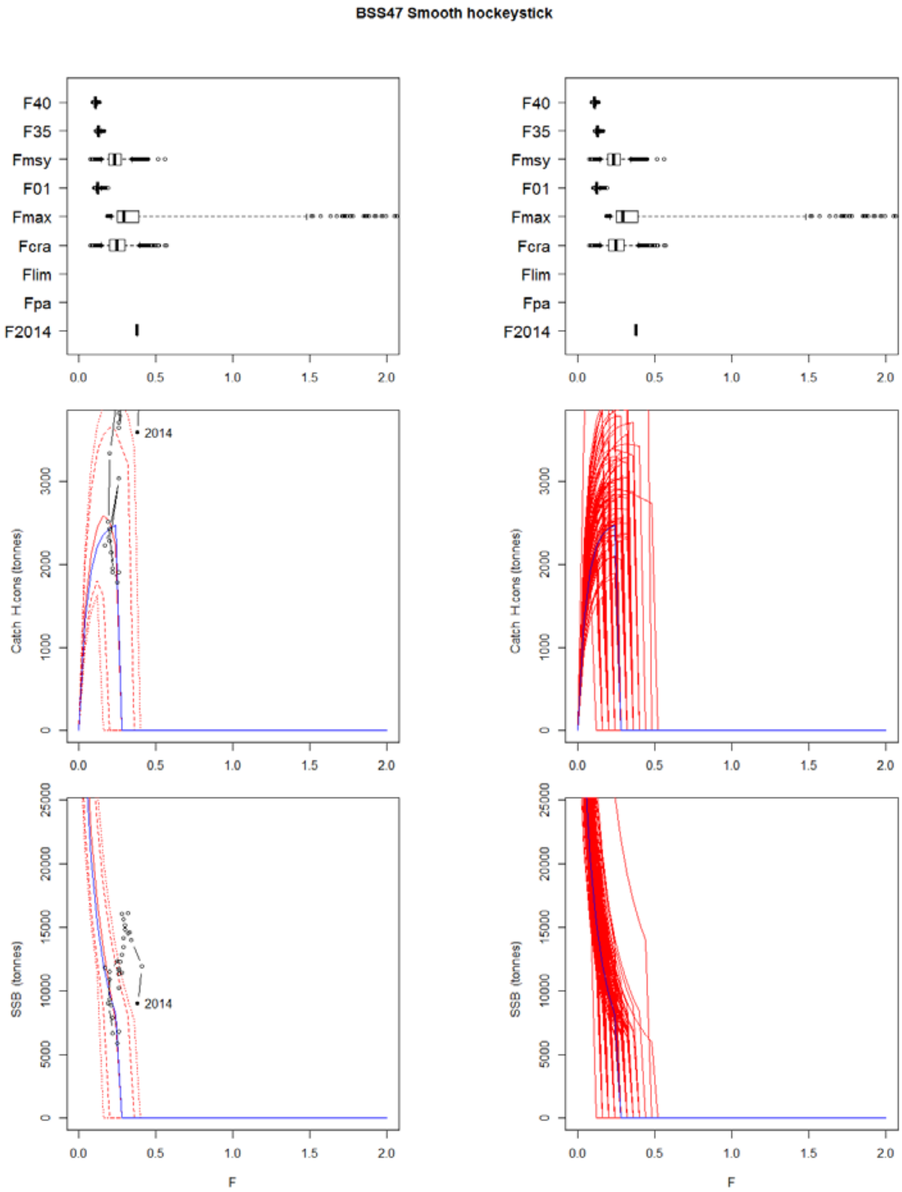
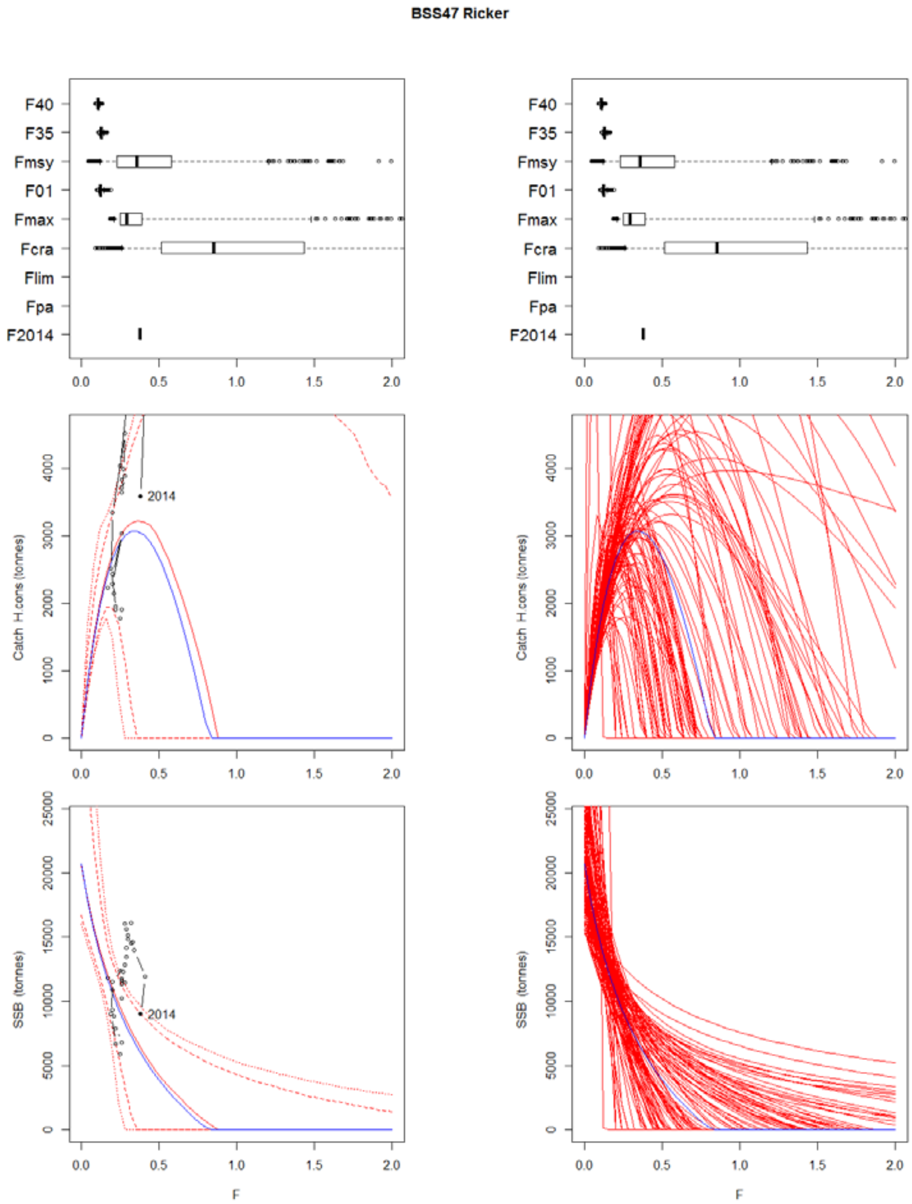


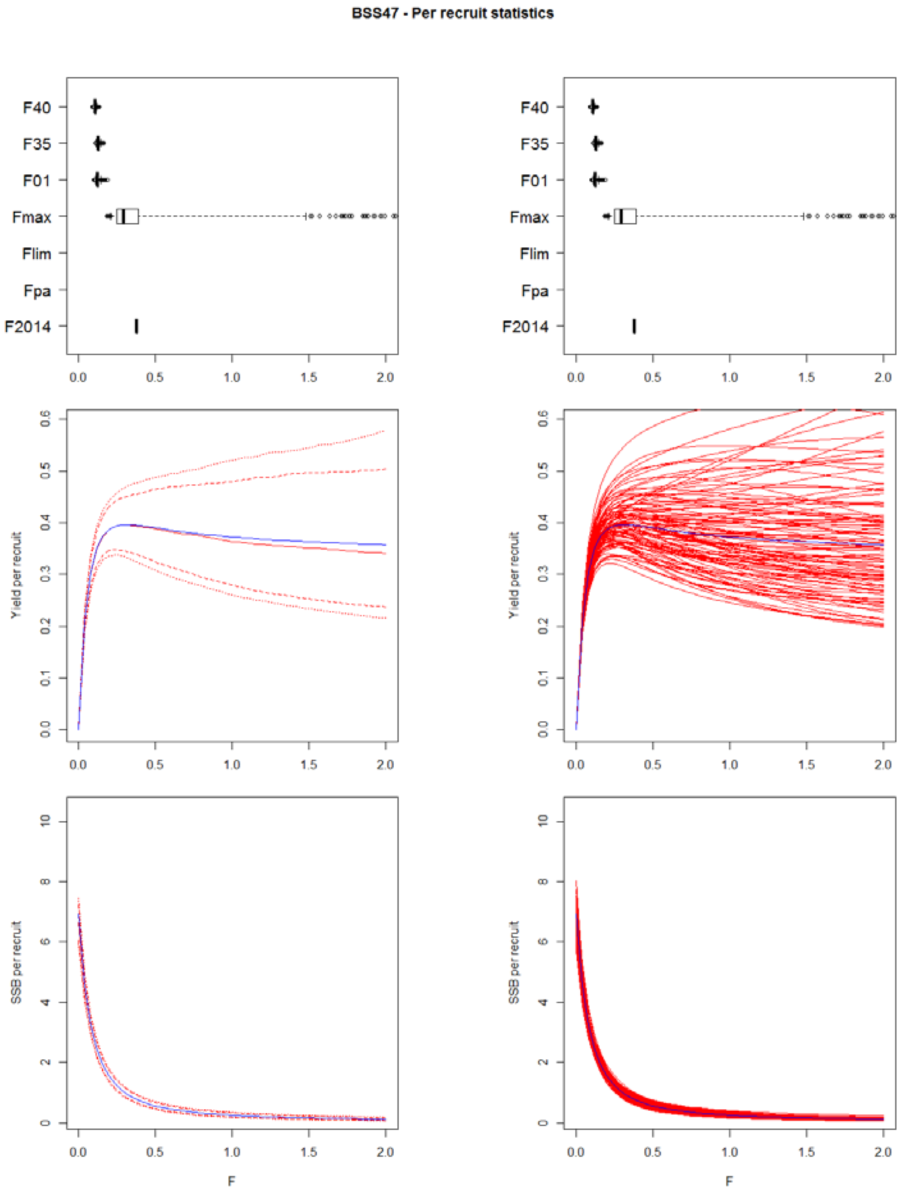
Figure 5.3.1: results of the MSY Plots Model on stock recruitment.



BSS47 Beverton-Holt
F40
F35
Fmsy
F01
Fmax
Fcra
Flim
Fpa
F2014
Catch H.cons (tonnes)
2014
SSB (tonnes)
F


BSS47 Smooth hockeystick
F40
F35
Fmsy
F01
Fmax
Fcra
Flim
Fpa
F2014
2014
Catch H.cons (tonnes)
SSB (tonnes)
F


BSS47 Ricker
F40
F35
Fmsy
F01
Fmax
Fcra
Flim
Fpa
F2014
Catch H.cons (tonnes)
SSB (tonnes)
2014
F



MSY plot doesn't include the necessary uncertainties to calculate reference points: F_{MSY} Plot cannot answer to the TOR's of the WKREFMSY4. It has been decided to use the Yield-per-recruit to give a confident interval for F. The Yield-per-recruit curve (source: WGCSE 2014) has been used in order to calculate the F_{inf}. F_{inf} corresponds to the 95% Y/R of F35%spr. Results are presented on figure 5.3.2.

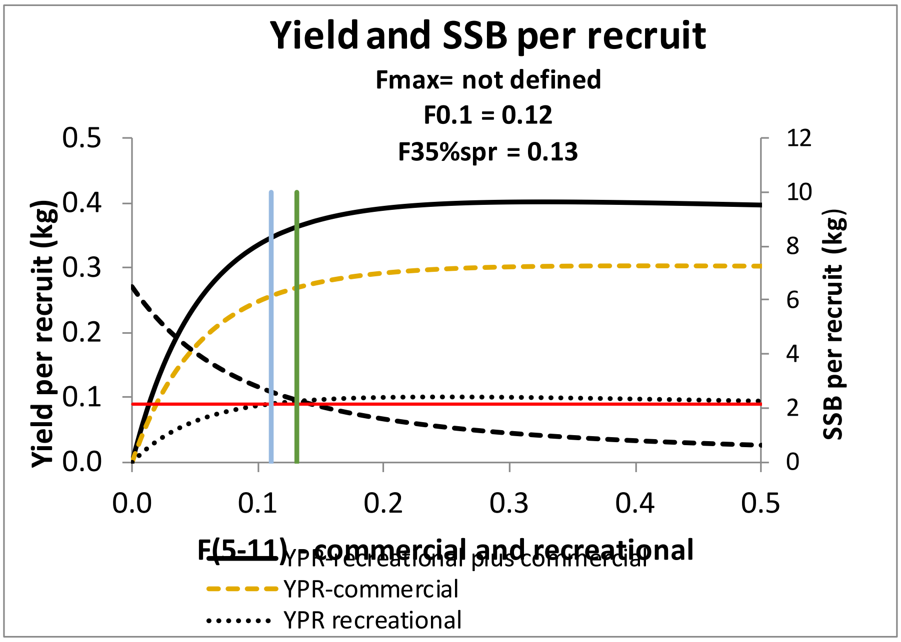


Figure 5.3.2: Yield and SSB per recruit, and confidence interval on F.

F35%spr=0.131

F_{inf}95%=0.11

5.3.5 Discussion / Sensitivity.

As the Stock Synthesis 3 model for Seabass as configured does not produce a stock object needed for input to the EQSIM model, it would need to create a file with the necessary input, based on the 2015 WGCSE final run. Some of the uncertainties in estimates are not given explicitly in the SS3 output. A suitable file could not be created for the group in the time available, but if ICES agrees the inter-Benchmark for early next year, this work could probably be explored.

The seabass selectivities are currently estimated using age based data for UK fleets and length-based data for France. That is why an inter-Benchmark is proposed in the first months of 2016 to evaluate the utility of French age data that became available this year, so that we can move to a fully age based model next year. There is the added complication of the ad-hoc way recreational F is estimated based on only one year of recreational survey data, and then added to the M-at-age vector under the crude assumption that this recreational F is constant over time the same way we assume that M is constant. This would ideally be built into the assessment code so that model estimates of recreational catches relative to the survey estimate are included in the likelihoods and the uncertainties around use of the data in the assessment is properly reflected. This is not available for WKREFMSY4. Finally, the use of the stock recruit data to estimate F_{MSY} is going to be limited as all our implementations have wanted to converge to a SR steepness of 1.0. Fixing at lower values forces apparent curvature in the S/R data (you get the steepness you put in) but leads to worsening likelihoods, and we fix it at 1.0. That is why we use the F35%spr approach, and this is largely driven by the choice of M. A reduction in assumed M from 0.2–0.15 after the last benchmark reduced the F35%spr from 0.18–0.13.

5.4 Cod (*Gadus morhua*) in Divisions VIIe–k (Eastern English Channel and Southern Celtic Seas)

5.4.1 Current reference points

Table 5.4.1 Summary table of current stock reference points. The current references points were estimates during the WGCSE 2015 (Details are given in WD MSY reference points for Cod in VIIek).

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	7300 t	SSB in 1976 (former Bloss calculated and agreed in 2012).
Current B_{pa}	10300 t	$B_{PA}=B_{lim}*1.4$. Default proxy in the absence of specific quantification of assessment uncertainty.
Current F_{lim}	0.78	F with 50% probability of SSB<B_{lim}
Current F_{pa}	0.56	$F_{pa}=F_{lim}/1.4$. Default proxy in the absence of specific quantification of assessment uncertainty.
Current F_{MSY}	0.32	
Current MSY $B_{trigger}$	10300 t	B_{pa}

5.4.2 Source of data

Data used in the analysis were taken from the FLStock object created during ICES WGCSE 2015. Data represent the latest assessment input and output data (ICES 2015, WGSCE report).

5.4.3 Methods used

All analyses were conducted with R (3.1.2, 64 bits) using Eqsim package (https://github.com/wgmg/msy)

```
load('xsa.stock.Rdata')     #Available     on     WGCSE     sharepoint
/Data/cod7ek/reference point
### function that fits segmented regression with a breakpoint at Blim
Blim=7300
segreg3  <- function(ab, ssb) log(ifelse(ssb >= Blim, ab$a * Blim, ab$a
* ssb))
# FMSY and FMSY ranges estimates
##########################
codsetup <- list(data = xsa.stock,
                 bio.years = c(1990, 2014),
                 bio.const = FALSE,
                 sel.years = c(2000, 2014),
                 sel.const = FALSE,
                 Fscan = seq(0,1.5,by=0.01),
                 Fcv = 0.2, Fphi = 0.3,
                 Blim = 7300,
                 Bpa = 10300,
                 extreme.trim=c(0.05,0.95),
                 verbose = TRUE)
cod_res_all <- within(codsetup,
                  {
                           fit <- eqsr_fit(data, nsamp = 1000, models =
c("segreg3"))
                           sim <- Eqsim_run(fit, bio.years = bio.years,
bio.const = bio.const,
                                            sel.years    =    sel.years,
sel.const = sel.const, Fscan = Fscan,
```

```
                                           Fcv = Fcv, Fphi = Fphi, Blim
= Blim, Bpa = Bpa,
                                           extreme.trim     =     ex-
treme.trim)
                        })
cod_res_all$sim$Refs
cod_res_all$sim$Refs2
Eqsim_plot_range(cod_res_all$sim, type="mean")
Eqsim_plot_range(cod_res_all$sim, type="median")
Eqsim_plot_range(cod_res_all$sim, type="ssb")
eqsr_plot(cod_res_all$fit,ggPlot=FALSE)
Eqsim_plot(cod_res_all$sim, catch = FALSE)
# MSY Btrigger estimates
###########################
codsetup_MSYBTRIGGER <- list(data = xsa.stock,
                             bio.years = c(1990, 2014),
                             bio.const = FALSE,
                             sel.years = c(2000, 2014),
                             sel.const = FALSE,
                             Fscan = seq(0,1.5,by=0.01),
                             Fcv = 0, Fphi = 0,
                             Blim = 7300,
                             Bpa = 10300,
                             extreme.trim=c(0.05,0.95),
                             verbose = TRUE)
cod_res_all_B <- within(codsetup_MSYBTRIGGER,
                        {
                          fit <- eqsr_fit(data, nsamp = 1000, models =
c("segreg3"))
                          sim <- Eqsim_run(fit, bio.years = bio.years,
bio.const = bio.const,
                                           sel.years    =    sel.years,
sel.const = sel.const, Fscan = Fscan,
                                           Fcv = Fcv, Fphi = Fphi, Blim
= Blim, Bpa = Bpa,
                                           extreme.trim     =     ex-
treme.trim)
                        })
cod_res_all_B$sim$Refs
Eqsim_plot_range(cod_res_all_B$sim, type="mean")
Eqsim_plot_range(cod_res_all_B$sim, type="median")
Eqsim_plot_range(cod_res_all_B$sim, type="ssb")
eqsr_plot(cod_res_all_B$fit,ggPlot=FALSE)
Eqsim_plot(cod_res_all_B$sim, catch = FALSE)
# Additional settings to fill table 5.4.4
      # Bpa= 10300 , btrigger=10300 , Fcv=0.2 and Fph=0.3
      # Bpa= 10300 , btrigger= 14466 , Fcv=0.2 and Fph=0.3
```

5.4.4 Settings

Table 5.4.1 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full time-series 1971–2014	Strong recruitments are observed at both low medium and high SSB value. Recruitment is is environmentally driven (period of poor recruitment and periodic picks of strong recruitment). No indication of density-dependent growth in the stock; high biomass is not linked to low weight. No obvious issues with very high biomass.
Exclusion of extreme values (option extreme.trim)	0.05–0.95	
Trimming of R values		
Mean weights and proportion mature; natural mortality	1990–2014	The first 20 years of the time-series were removed from the analysis because fixed mean weights were used for the first decade followed by a period with a declining trend in mean weights.
Exploitation pattern	2010–2014	A long time-series was chosen instead of a 10 or 5 year period to down weight the influence of changes in selection patterns resulting from the very weak year class of 2008 followed by a very strong year class in 2009
Assessment error in the advisory year. CV of F	0.2	Assumed in line with similar assessments in the North Sea.
Autocorrelation in assessment error in the advisory year	0.3	Assumed in line with similar assessments in the North Sea.

5.4.5 Results

5.4.5.1 Stock recruitment relation

The stock recruitment relationship used is a segmental regression with fixed breakpoints (Figure 5.4.1).

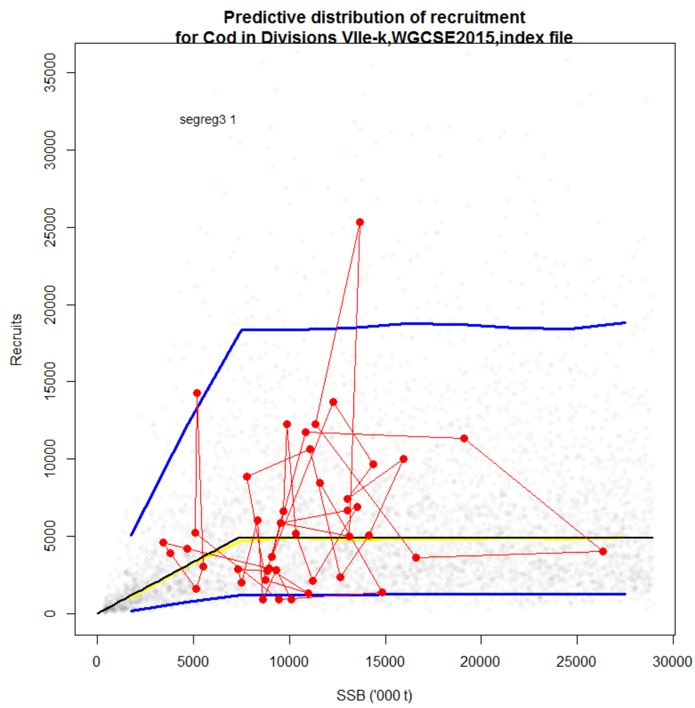


Figure 5.4.1. Stock recruitment relationship for Celtic sea Cod with fitted segmented regression (Fixed breakpoint at 7300t=B_{lim}).

The S–R graphic indicates the Celtic sea cod shows no obvious S–R relationship (Figure 5.14), mainly because the recruitment is erratic (period of low recruitment with occasional high picks) and suspected to be environmentally driven (WGCSE 2015). This stocks show a strong recruit-stock relationship. The highest 1986 year-class results in the four highest SSB observations. There is no evidence of reduced reproductive capacity at any of the observed SSB level. High recruitments are observed at low, medium and high SSB.

Segmented regression is considered to be more appropriate. Breakpoint was estimated around 13000t which was considered to be inappropriate, too high compared to the S-R dynamic. As such a fixed breakpoint at B_{lim} (7300) was used.

5.4.5.2 Yield and SSB

For the base run, yield includes landings (because discards are not included in the assessment), with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.4.5.3 Eqsim analysis

Definition of F_{MSY} and F_{MSY} ranges

F_{MSY} median point estimates is 0.35 (0.353). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated to 0.55(0.553) and the lower bound at 0.23(0.225) (Figure 5.4.2). $F_{p.05}$ was estimated 0.55 and therefore the upper bound don't need to be restricted because of precautionary limits.

During WGCSE 2015 retrospective estimates of F_{MSY} (using segmented regression) were obtained by repeating the analysis after iteratively removing the most recent year from the dataset (See WD MSY reference points for Cod VIIek, WGCSE 2015). The analysis indicates that the F_{MSY} estimate is quite stable over time.

F_{lim} (e.g. F50: F with 50% probability of SSB<B_{lim}) estimates is 0.80 (Table 5.4.2). F_{pa} was calculated at 0.58 using the formula F_{lim} exp (-1.645σ), with σ of 0.2

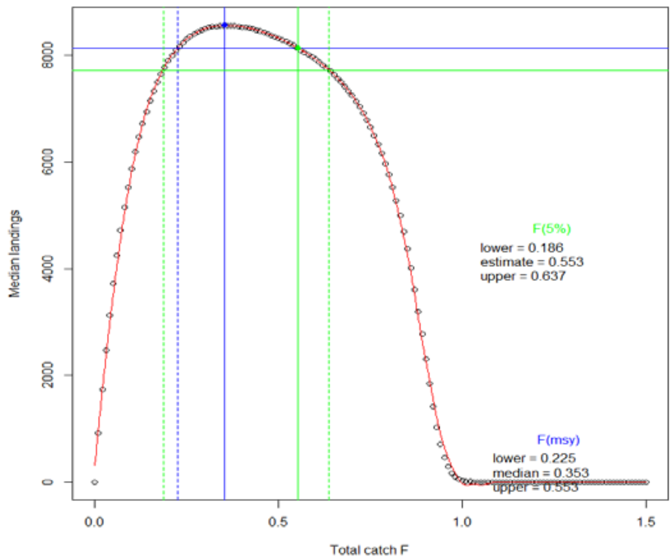


Figure 5.4.2 Yield curve and F_{MSY} upper and lower ranges (vertical blue lines) and F_{lim} upper and lower ranges (vertical green lines) for the segmented regression with fixed breakpoint. F_{MSY} median point estimates and upper and lower bound are given (bottom right).

Table 5.4.2. Output table for Eqsim analysis for the segmented regression with a fixed breakpoint at 7300t (F_{cv}=0.3, F_{ph}=0.3).

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.55	0.60	0.80	NA	0.37	NA	NA	NA	NA
lanF	NA	NA	NA	0.35	0.37	0.23	0.23	0.56	0.58
catch	8212	7973	5896	NA	8601	NA	NA	NA	NA
landings	NA	NA	NA	8606	8601	8185	8720	8179	8721
catB	15466	13496	7304	NA	24640	NA	NA	NA	NA
lanB	NA	NA	NA	26366	24640	39344	NA	15108	NA

The overall stock 4 panel plot without MSY $B_{trigger}$ are illustrated in Figure 5.4.3.

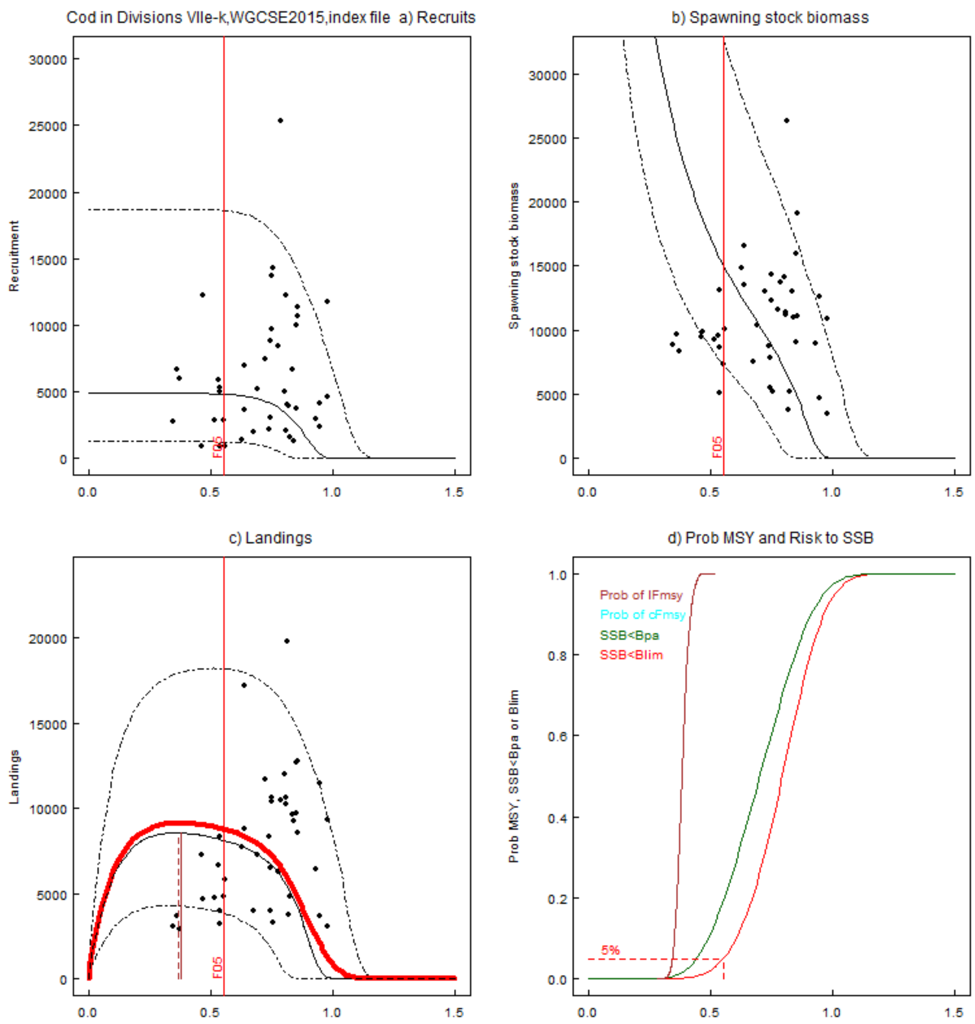


Figure 5.4.3 Overall stock 4 panel plot without MSY $B_{trigger}$.

Definition of MSY $B_{trigger}$

Table 5.4.3 Output table for Eqsim analysis for the segmented regression with a fixed breakpoint at 7300t (F_{cv}=0 and F_{ph}=0).

	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.58	0.63	0.82	NA	0.38	NA	NA	NA	NA
lanF	NA	NA	NA	0.35	0.38	0.23	0.23	0.56	0.59
catch	8192	7962	6031	NA	8688	NA	NA	NA	NA
landings	NA	NA	NA	8699	8688	8262	8689	8262	8694
catB	14466	12831	7300	NA	24158	NA	NA	NA	NA
lanB	NA	NA	NA	26391	24158	39671	NA	15079	NA

The estimation of $MSYB_{trigger}$ was performed by setting the assessment error (F_{cv}) and the autocorrelation in the assessment (F_{ph}) to zero. $MSYB_{trigger}$ (5% on distribution of SSB at F= F_{MSY}) was estimated for the segmented regression model with fixed breakpoint at 14 466 t (Table 5.4.3).

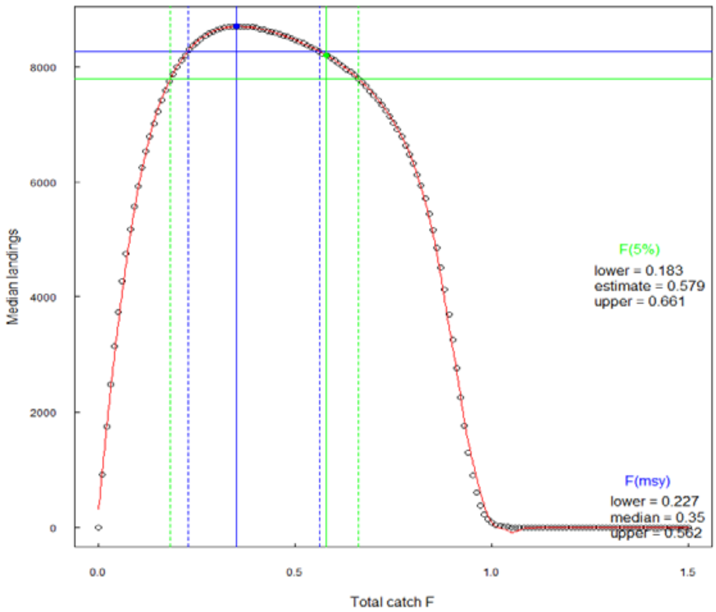
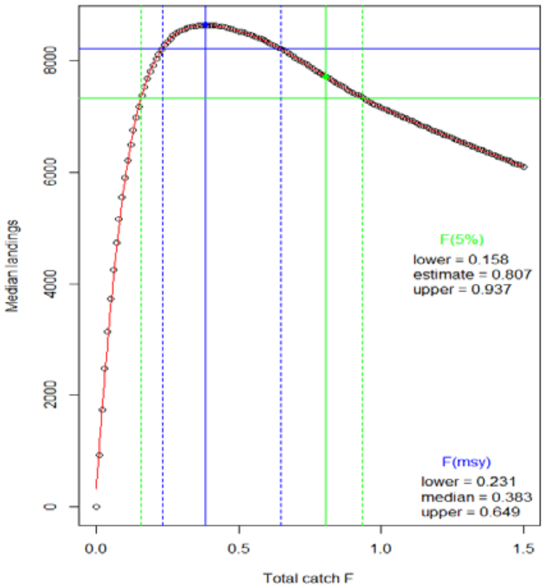


Figure 5.5.4 Yield curve and F_{MSY} with $MSYB_{trigger}$.

Analysis with $B_{trigger}$ set at B_{pa} or $MSYB_{trigger}$



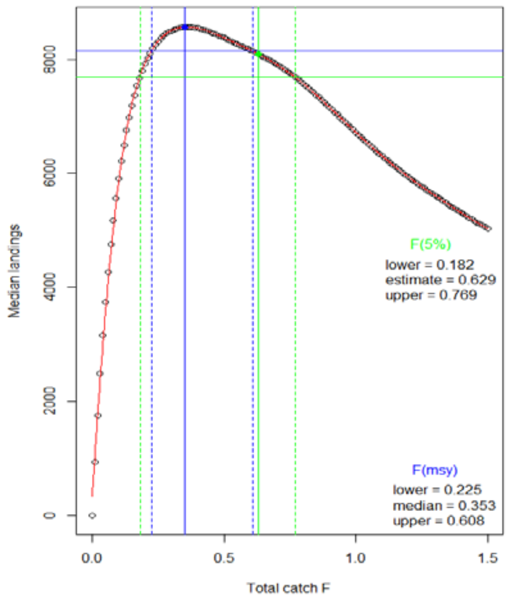


Figure 5.4.6 Left: Yield curve and F_{MSY} with $B_{trigger}$ equal to $MSYB_{trigger}$. Right Yield curve and F_{MSY} with $B_{trigger}$ equal to B_{pa}.

5.4.6 Proposed reference points

Table 5.4.4 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	7300 t	B_{lim}= B76
B_{pa}	10300 t	B_{pa}=B_{lim}*1.4. Biomass above this value affords a high probability of maintaining SSB above B_{lim}, taking into account the variability of the stock dynamics and the uncertainty in assessment.
F_{lim}	0.80	F with 50% probability of SBB <B_{lim} (see Table 5.11)
F_{pa}	0.58	F_{pa}= F_{lim}/1.4. Default proxy in the absence of specific quantification of assessment uncertainty
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.35	
F_{MSY} lower without $B_{trigger}$	0.23	
F_{MSY} upper without $B_{trigger}$	0.55	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.55	
F_{MSY} upper precautionary without $B_{trigger}$	0.55	
MSY $B_{trigger}$	14466t	
F_{MSY} with $B_{trigger}$, B_{pa}	0.23, 0.23	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.38, 0.35	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.65, 0.61	
FP.05 (5% risk to B_{lim} with $B_{trigger}$, B_{pa})	0.81, 0.63	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.65, 0.61	
MSY	8606	
Median SSB at F_{MSY}	26366	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	15108	
Median SSB upper (median at F_{MSY} lower)	39344	

5.4.7 Discussion / Sensitivity.

It is difficult to estimate B_{lim} because it is no clear that low SSB reduces the reproductive capacity of the stock. However, a number of consecutive years of low recruitment quickly lead to low SSB. Good recruitments are observed for all SSB and are capable of rapidly rebuild the stock.

B_{lim} is set at B_{76}, which do not correspond to B_{loss}. B_{loss} is B_{2005} = 3436 t, however around 2005-2010 SSB estimates are considered to be biased by important misreporting resulting of restricted TAC. WGCSE and WKREF4 concluded that the previous B_{lim} (B_{76}) remain appropriate to this stock. Additionally, B_{lim} is assumed to have little influence of the MSY estimate given the dynamic of this stock.

$MSYB_{trigger}$ estimate from Eqsim appears unrealistically high compared with the time-series of observed SSB. Biomass values higher that 15 000t have only been observed after the 1986 year class which was several times higher than GM. Removing this extreme points from the analysis would led to lower $F_{P.05}$ (F corresponding to 5% probability of SSB<B_{lim}) than when the occasional very high recruitments is included. Maintaining the B_{pa} of 10300 t as $MSYB_{trigger}$ for this stock was considered more appropriate by the working group.

Given that almost all values of F_{MSY} suggested are lower than almost all historic F, it is not surprising that SSB at F_{MSY} is relatively high in historic context (value never observed). Given the dynamic of this stock characterized by periods of sequential low recruitment and unpredictable strong recruitments, it is difficult to characterized both $MSYB_{trigger}$ and BMSY using the current tools available. More work is needed to better estimate this quantities.

Discards are not included in the assessment. Therefore F_{MSY} estimate may be overestimated. Celtic sea cod is a fast growing species that reach the MSL of 35 cm in one or two years. Indeed, discards are mainly composed on age 1 fish, except when highgrading occurs due to quota restriction. Sensitivity analysis to F_{MSY} estimate when increasing F at age 1 was performed during WGCSE 2015 (see WD MSY reference point for Cod VIIek). WKMSYREF4 decided to select the F_{MSY} estimates given by the segmented regression with fixed breakpoint et B_{lim} and advices to revised reference points when discards will be included in the assessment instead of using *ad hoc* way to incorporate discards in the present reference points analysis.

5.5 Cod (*Gadus morhua*) in Division VIIa (Irish Sea)

5.5.1 Current reference points

Table 5.5.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	6000 t.	$B_{lim} = B_{loss}$. The lowest observed SSB*
Current B_{pa}	10 000 t.	$B_{pa} = M_{BAL}$. This level affords a high probability of maintaining the SSB above B_{lim}. Below this value the probability of below average recruitment increases.*
Current F_{lim}	1.0	$F_{lim} = F_{med}$*
Current F_{pa}	0.72	$F_{pa} = F_{med}$*0.72. This F is considered to have a high probability of avoiding Flim*
Current F_{MSY}	0.25–0.54	Provisional proxy based on stochastic simulations, assuming Ricker, Beverton–Holt and hockey stick stock–recruitment relationship (WGCSE 2010).
Current $MSYB_{trigger}$	10 000 t.	Default to value of B_{pa}*

*Unchanged since 1998

5.5.2 Source of data

Data used in the MSY interval analysis were taken from Celtic Seas WG created during ICES WGCSE 2015. Data represent the latest assessment input and output data from 2015 WG (ICES 2015).

5.5.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
Bpa= 6000
Blim=10000
BpFix  <- function(ab, ssb) log(ifelse(ssb >= BP, ab$a * BP, ab$a *
ssb))
FIT <- eqsr_fit(stock, nsamp = 1000, models = "BpFix")
eqsr_plot(FIT,n=2e4)
SIM <- Eqsim_run(FIT,
                 bio.years = c(2005:2014),
                 sel.years = c(2005:2014),
                 Fcv=0.233,
                 Fphi=0.423,
                 Blim=6000,
                 Bpa=10000,
                 Btrigger=10000,
                 Fscan = seq(0,1.6,len=61),
                 verbose=FALSE)
```

5.5.4 Settings

Table 5.5.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1968–2014)	
Exclusion of extreme values (option extreme.trim)	Yes	5th and 95th percentiles
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	Inspected and no trend in last 10 years observed
Exploitation pattern	2005–2014	Inspected and no trend in last 10 years observed
Assessment error in the advisory year. CV of F	0.233	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

5.5.5 Results

5.5.5.1 Stock recruitment relation

Combined Beverton–Holt, Ricker and hockey stick recruitment models were examined. The fitted hockey stock contributed greater that 99% of the model weights. A hockey stick with unrestricted fit was compared to a hockey stick model with a fixed breakpoint at current B_{lim} (Figure 5.5.1). It was proposed that given the low biomass condition of the stock, below $B_{lim,}$ and without a recent recruitment recovery signal there was little support to re-estimate the current biomass reference points. Further the observed disparate clusters of low and high stock–recruitment pairs are potentially an artefact of the assessment models estimation, and scaling, of catch in the recent part of the time-series. (ICES2014) (WGCSE2014). The unrestricted fit, with a breakpoint at 11490t was used in further simulations of reference points from the current assessment data.

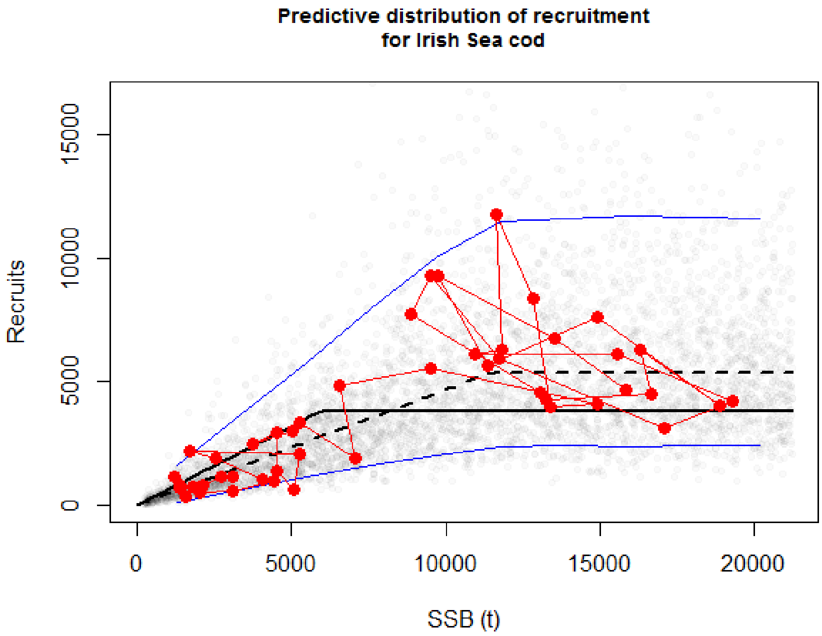


Figure 5.5.2 Two hockey stick stock–recruitment relationships used in Eqsim showing stock–recruit pairs, model (black) with 90% intervals (blue). The solid line shows a hockey stick fitted with breakpoint at the current B_{lim} (6000t) and the broken lined the unrestricted Eqsim fitted hockey stick, with breakpoint 11490t.

5.5.5.2 Yield and SSB

Yield is taken as landings with no discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.5.5.3 Eqsim analysis

The stock data are given in Figure 5.5.2, the results for a run without advice error included is illustrated in Figure 5.5.3 for both yield and SSB.

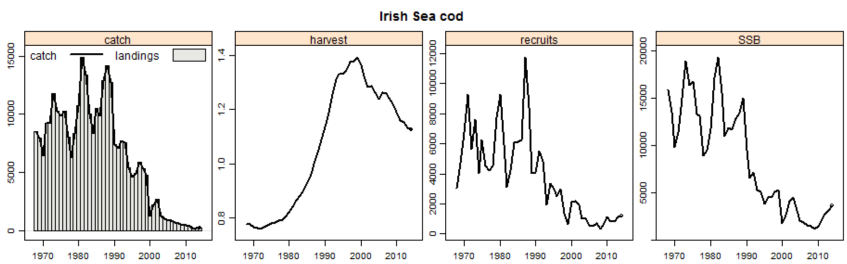


Figure 5.5.3 Sole in the Irish Sea

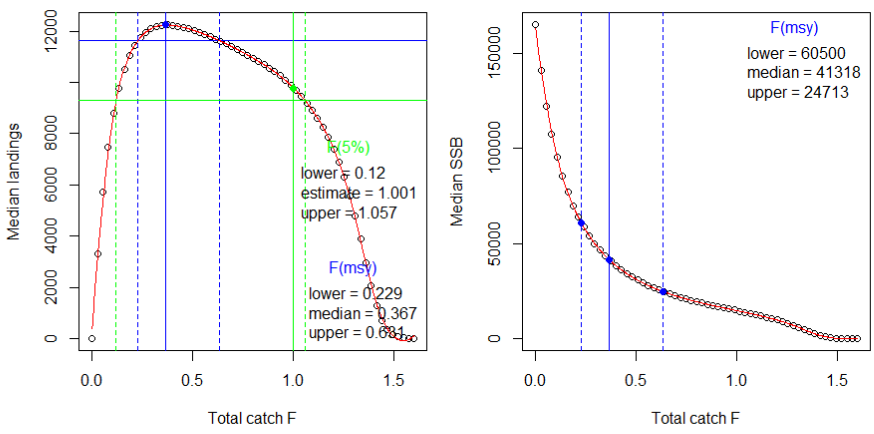


Figure 5.5.4 Results of simulations for Irish Sea cod

5.5.6 Proposed reference points

Table 5.5.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	6000	The lowest observed SSB as estimated in previous assessment.*
B_{pa}	10 000	MBAL; This level affords a high probability of maintaining the SSB above Blim. Below this value the probability of below average recruitment increases.*
F_{lim}	1.33	Based on simulated recruitment to median biomass = B_{lim}
F_{pa}	0.96	F_{lim} * exp(-1.645 * 0.2)
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.37	
F_{MSY} lower without $B_{trigger}$	0.23	
F_{MSY} upper without $B_{trigger}$	0.63	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	1.00	
F_{MSY} upper precautionary without $B_{trigger}$	1.06	
MSY $B_{trigger}$	26 569	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	1.31, 1.01	
F_{MSY} with $B_{trigger}$, B_{pa}	0.41, 0.37	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.23, 0.23	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.73, 0.63	
F_{MSY} upper precautionary with $B_{trigger}$	NA	

MSY	12 234
Median SSB at F_{MSY}	40 866
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	24 343
Median SSB upper (median at F_{MSY} lower)	60 826

*Exceeds maximum observed Spawning-stock biomass.

5.5.7 Discussion

The stock is at a low level and mean recruitment has been seen to be reduced at current biomass. Simulations were conducted with a hockey stick stock–recruit function that followed the mean of the recruitment data. An alternative hockey stick recruitment model with a fixed breakpoint, fixed at current $B_{lim,}$ did not change $F_{MSY,}$ but did correspond to lower estimates F_{lim} and F_{pa}. This also suggested a higher stock resilience than shown in the data with low recruitment values, close to the origin, below the predicted relationship. However, a high degree of uncertainty in the fishing mortalities from the current stock assessment model provides low confidence in the derived stock parameters. With the current perceived low stock biomass and without a recent recruitment recovery signal there was limited evidence to support a review of the current biomass reference points. Similar F_{MSY} range where derived as previously estimated (ICES2010x WGCSE). The upper biomass reference points and $MSYB_{trigger}$ (26569t) exceed values previously observed biomass for the stock. These biomass values are considered to be unrealistic target reference points for the stock.

5.6 Cod (*Gadus morhua*) in VIa (West of Scotland)

5.6.1 Current reference points

Table 5.6.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	14000 t	B_{lim} = Bl_{oss}, the lowest observed spawning stock estimted in previous assessments
Current B_{pa}	22000 t	Considered to be the minimum SSB required to ensure a high probability of maintaining SSB above Blim, taking into account the uncertainty of assessments. This also corresponds to the lowest range of SSB during the earlier, more productive historical period.
Current F_{lim}	0.8	Fishing mortalities above this have historically led to stock decline.
Current F_{pa}	0.6	This F is considered to have a high probability avoiding F_{lim}.
Current F_{MSY}	0.19	Provisional proxy by analogy with N Sea cod.
Current $MSYB_{trigger}$	22000 t	B_{pa}

5.6.2 Source of data

The results from the TSA stock assessment conducted at ICES WGCSE 2015 were used to create an FLStock object which was used in the MSY interval analysis. Data represent the latest assessment input and output data (ICES 2015).

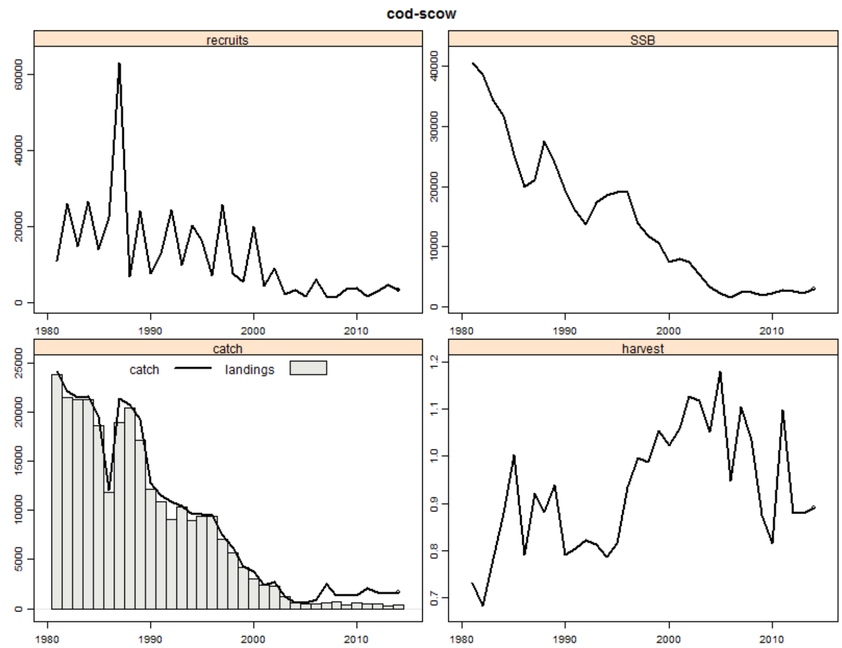


Figure 5.6.1 West of Scotland cod stock summary used as the basis for the MSY interval evaluation.

5.6.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
cod.indat <-list(data=cod6a,
                 bio.yrs <-c(2010,2014),
                 sel.yrs <-c(2005,2014),
                 Fscan <-seq(0,1.5,by=0.05),
                 Fcv=err.cv, # or 0
                 Fphi=err.phi, # or 0
                 Blim=14000,
                 Bpa=20000,
                 Btrigger = 0 # or 65073 or Bpa
                 )
cod.res <-within(cod.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models= c("Ricker", "Bevholt", "Seg-
reg"))
  sim <-Eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger)
})
```

5.6.4 Settings

Table 5.6.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries	
Exclusion of extreme values (option extreme.trim)	Not used	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2010–2014	
Exploitation pattern	2005–2014	
Assessment error in the advisory year. CV of F	0.212	Reasonable default value agreed at this WK
Autocorrelation in assessment error in the advisory year	0.423	Reasonable default value agreed at this WK

5.6.5 Results

5.6.5.1 Stock recruitment relation

The full available time-series of data were used to fit stock recruitment models. Given the lack of evidence supporting a specific stock recruit model, the Eqsim analysis uses the three models (Ricker, Beverton–Holt, and segmented regression) weighted by the default 'Buckland' method. Using this approach, predicted average recruitment values at F_{MSY} are within the bounds of historically observed recruitment values.

During the process of agreeing on appropriate stock recruitment models, the PA reference points were also reconsidered. B_{lim} was maintained as 14000 t although the basis is now considered to be the B_{loss} from which the stock has increased (SSB in 1992). A B_{lim} based on a low biomass from which a high recruitment has been observed was also considered, but the value of SSB where this occurs is less clear. The uncertainty in final year estimates of biomass from the TSA assessment ranges from 15–20 % (CV) in the most recent assessments and therefore the standard multiplier of 1.4 was used to derive a B_{PA} (1.4 x 14000 = 20000 t).

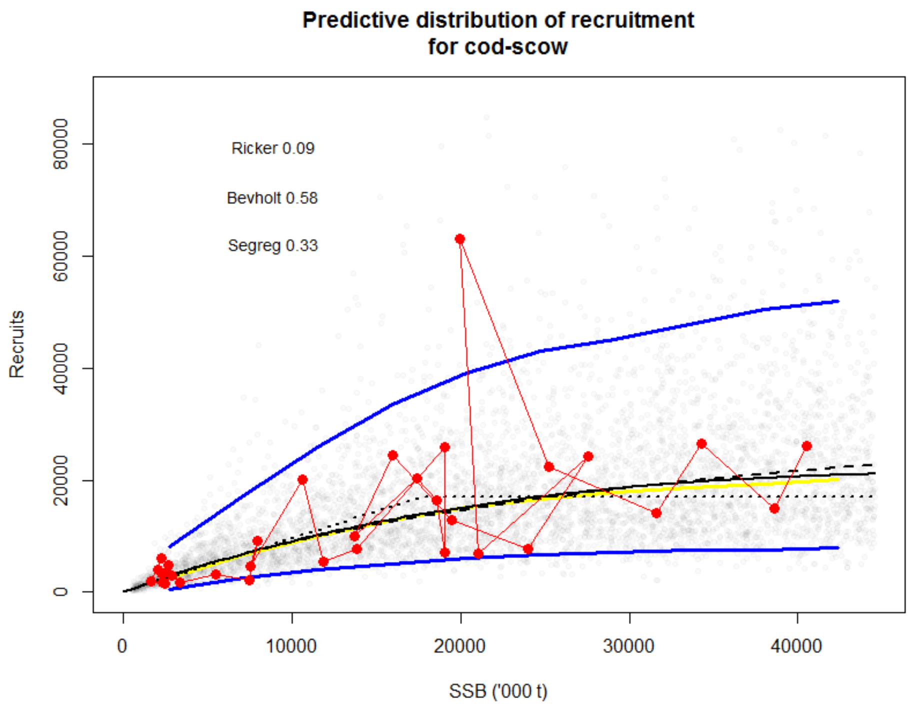


Figure 5.6.2. Eqsim summary of recruitment models using the default "Buckland" method (Ricker, Beverton and Holt and segmented regression)

5.6.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.6.5.3 Eqsim analysis

The base run largely uses default settings for the input parameters with the exception of the biological parameters. There is evidence of a persistent downward trend in the mean stock/catch weights at age (Figure 5.6.8) and hence a shorter period (last 5 years, 2010–2014) is used as input data for the biological parameters. Selection pattern shows no obvious trends over time and therefore the default 10 year range of data are used.

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.17 (Figure 5.6.4) with median landings of 13597 t. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.25 and the lower bound was estimated at 0.11. $F_{P.05}$ was estimated at 0.54 which is well above the estimate of upper bound on F_{MSY} implying that fishing at this upper bound is precautionary. The median of the SSB estimates at F_{MSY} was 112050 t (Figure 5.6.5). Note that this value is well above the maximum historical observed SSB of 40536 t.

A run with no error in the advice was carried out to estimate MSY $B_{trigger}$ using the 5[th] percentile of the distribution of SSB when fishing at F_{MSY}. MSY $B_{trigger}$ was estimated at 65073 t which is well above the maximum historical observed SSB of 40536 t.

An Eqsim run (no error and no $B_{trigger}$) using a segmented regression recruitment model with breakpoint fixed at B_{lim} was carried out to determine F_{lim}, the equilibrium F that gives a 50% probability of SSB>B_{lim}. This was estimated as 0.82. This results in F_{pa} = 0.59 (F_{lim}/1.4).

Figures 5.6.6 and 5.6.7 show the Eqsim results with simulations incorporating MSY $B_{trigger}$ = 65073 t.

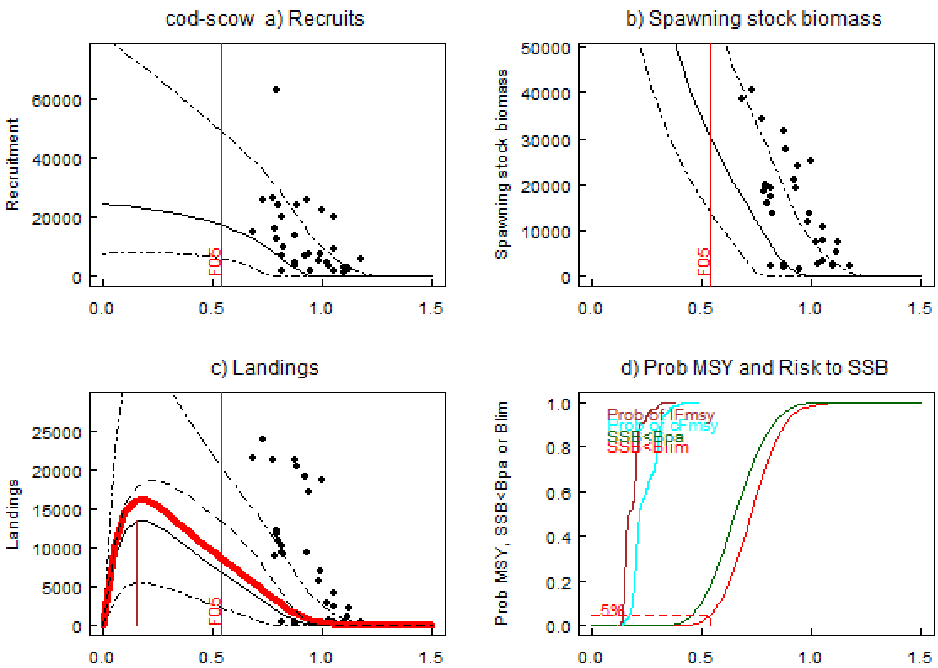


Figure 5.6.3. Eqsim summary plot for West of Scotland cod (without $B_{trigger}$). Panels' a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

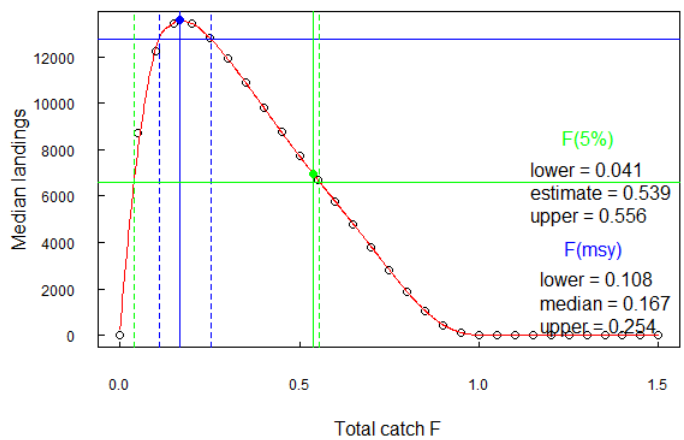


Figure 5.6.4 West of Scotland cod median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

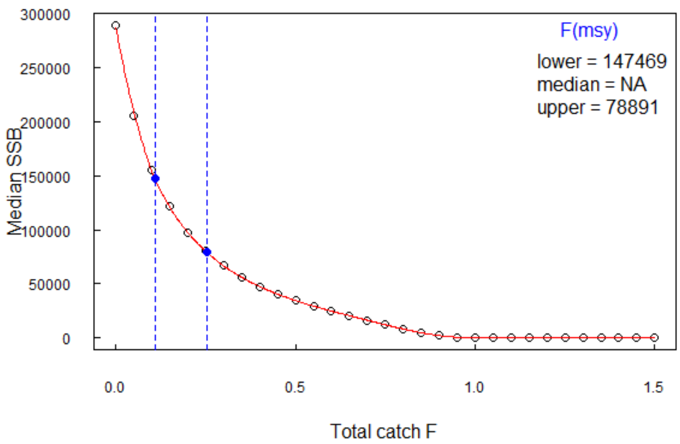


Figure 5.6.5 West of Scotland cod median SSB curve over a range of target F values (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

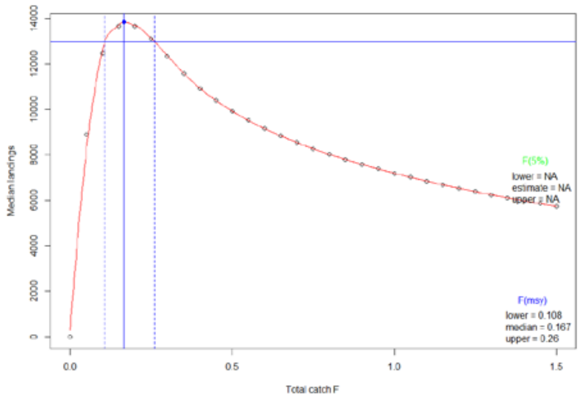


Figure 5.6.6 West of Scotland cod median landings yield curve with estimated reference points (MSY $B_{trigger}$=65073t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

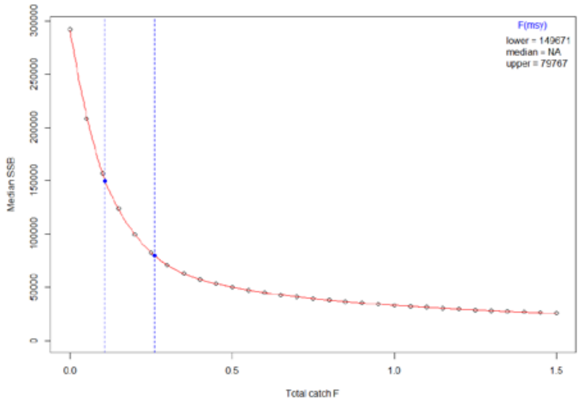


Figure 5.6.7 West of Scotland cod median SSB curve over a range of target F values (MSY $B_{trigger}$=65073 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.6.6 Proposed reference points

Table 6.1.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	14000 t	B_{loss} from which the stock has increased (SSB in 1992 as estimated in 2015)
B_{pa}	20000 t	1.4 x B_{lim}
F_{lim}	0.82	Based on segmented regression simulation of recruitment with B_{lim} as the breakpoint
F_{pa}	0.59	B_{lim}/1.4
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.17	
F_{MSY} lower without $B_{trigger}$	0.11	
F_{MSY} upper without $B_{trigger}$	0.25	
MSY $B_{trigger}$	65073 t	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.54	
F_{MSY} upper precautionary without $B_{trigger}$	0.25	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	NA, 0.65	
F_{MSY} with $B_{trigger}$, B_{pa}	0.17, 0.17	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.11, 0.11	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.26, 0.25	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.26, 0.25	
MSY	13597 t	
Median SSB at F_{MSY}	112050 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	78891 t	
Median SSB upper (median at F_{MSY} lower)	147469 t	

5.6.7 Discussion / Sensitivity.

Although the overall selection pattern does not appeared to have changed significantly over time (Figure 5.6.9), the proportion of the catch which is landed has changed (Figure 5.6.1) and this is likely to have an effect on the estimates of F_{MSY}. To explore the sensitivity, Eqsim was run using 5 year blocks of selectivity data starting with 1995-1999 and finishing with 2010–2014. The effect on the estimate of F_{MSY} is shown in Figure 5.6.10. The estimate varies between 0.23 and 0.16 depending on the year range chosen (bio year range remained constant) with a decrease in the estimate at around the time the discard proportion increased.

A final Eqsim run was conducted which used the default 10 year range for the selectivity data, but the proportion discarded at age was set at the long-term average over the years before the TAC restricted the landings. (1981-2000). (Results in a discard ogive of c (0.56, 0.04, 0, 0, 0, 0, 0) over ages 1–7+). To do this, the FLStock object was modified so that:

```
disc.rate <-cod6a@discards.n/cod6a@catch.n
disc.rat                                   <-as.numeric(yearMeans(win-
dow(disc.rate,start=1981,end=2000)))
cod6a.alt <-cod6a
cod6a.alt@discards.n <-cod6a@catch.n*disc.rat
cod6a.alt@landings.n <-cod6a@catch.n*(1-disc.rat)
```

The Eqsim output is shown below in Figures 5.6.11–5.6.13. The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.22 (Figure 5.6.12) with median landings of 20882 t. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.34 and the lower bound was estimated at 0.15. $F_{P.05}$ was estimated at 0.54 which is well above the estimate of upper bound on F_{MSY} implying that fishing at this upper bound is precautionary. The median of the SSB estimates at F_{MSY} was 89396 t. Note that this value is well above the maximum historical observed SSB of 40536 t.

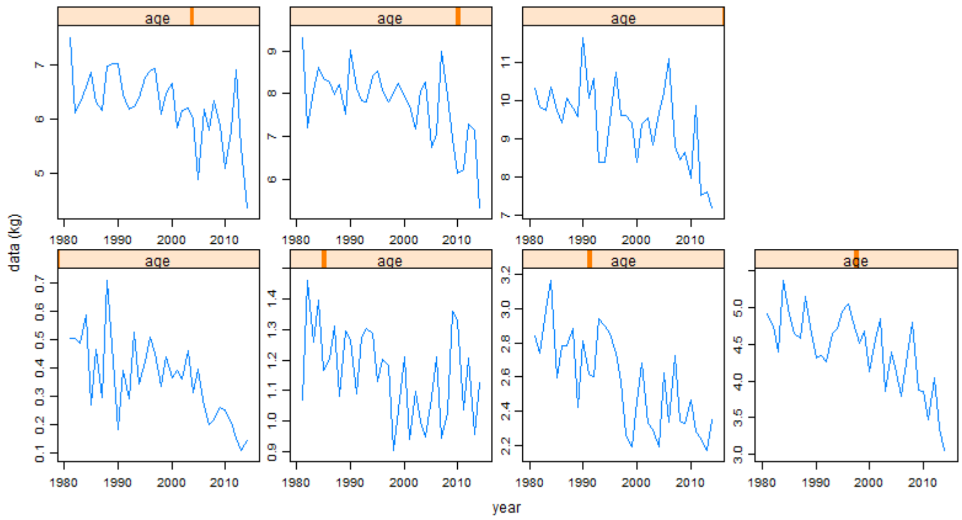


Figure 5.6.8 West of Scotland cod. Mean stock/catch weight at age.

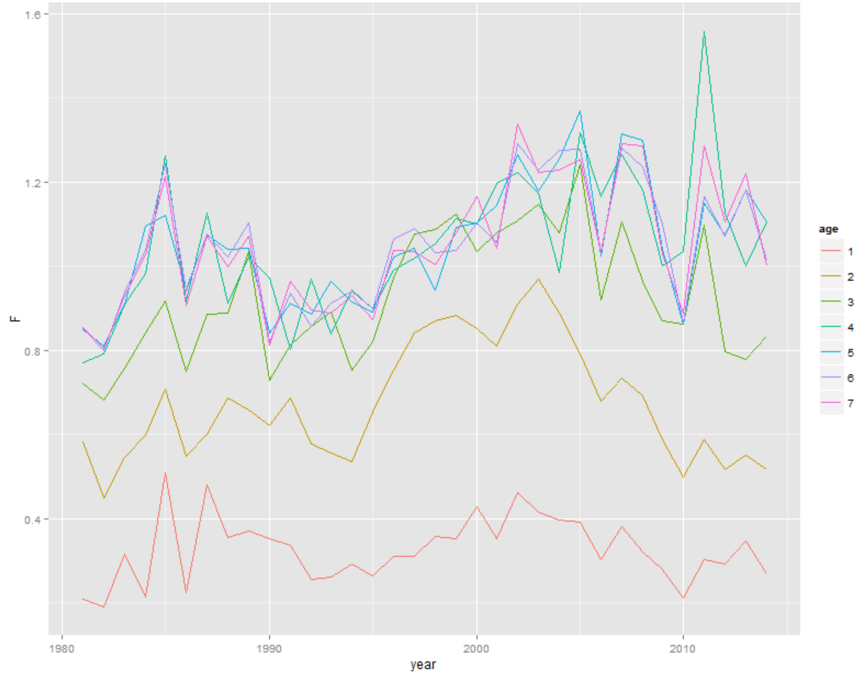


Figure 5.6.9 West of Scotland cod. Fishing mortality-at-age.

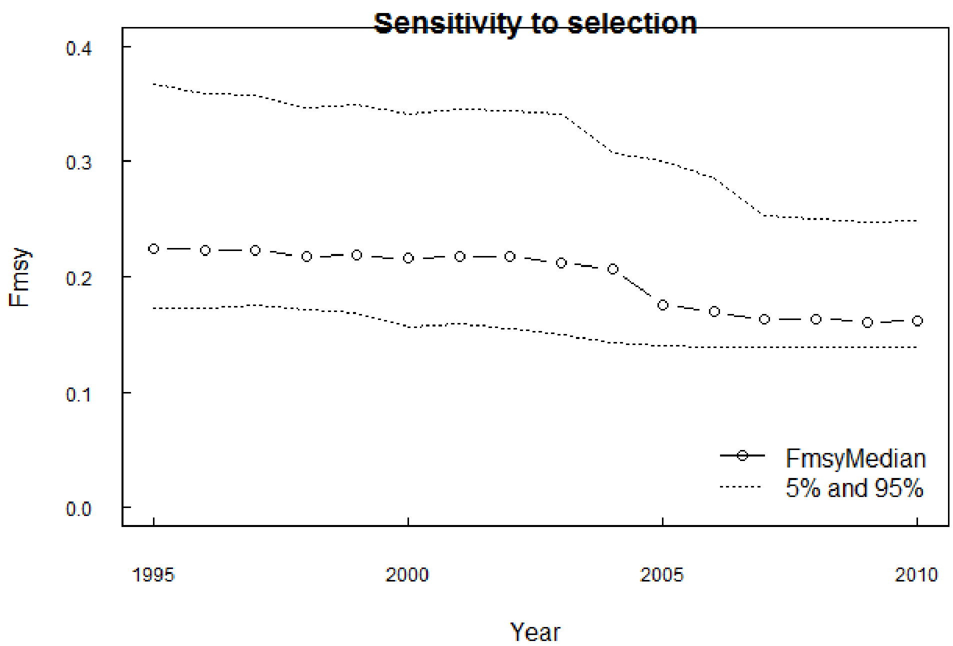


Figure 5.6.10. West of Scotland cod. Sensitivity of F_{MSY} estimate to year range of selectivity data. (Year label is 1st year of a 5 year range).

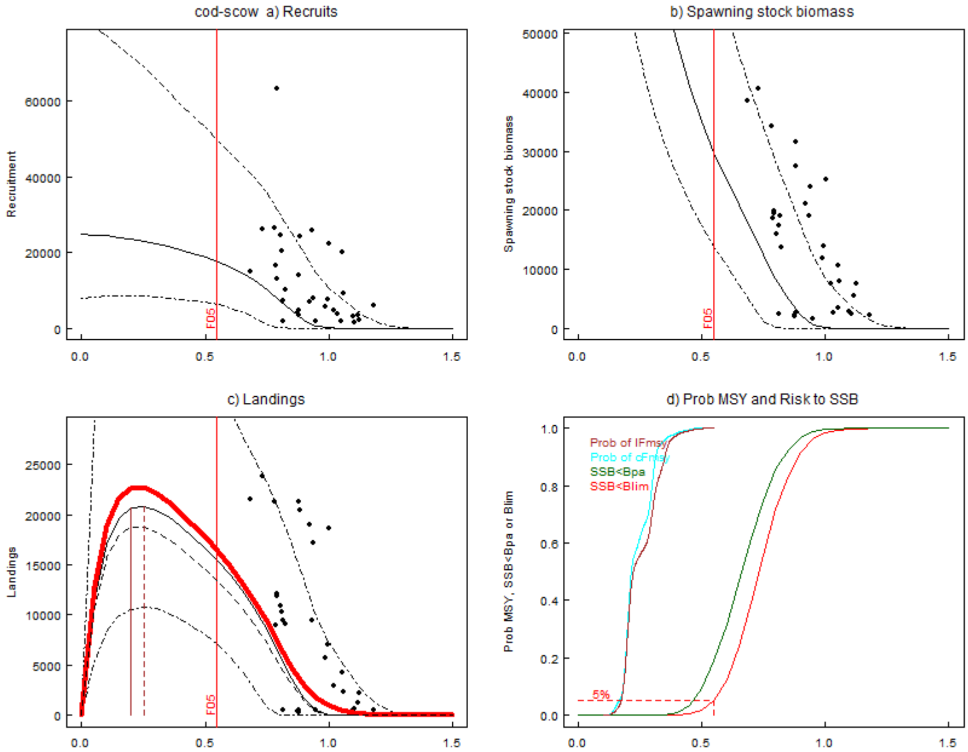


Figure 5.6.11. Eqsim summary plot for West of Scotland cod (alternative discard rate, without $B_{trigger}$). Panels' a–c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

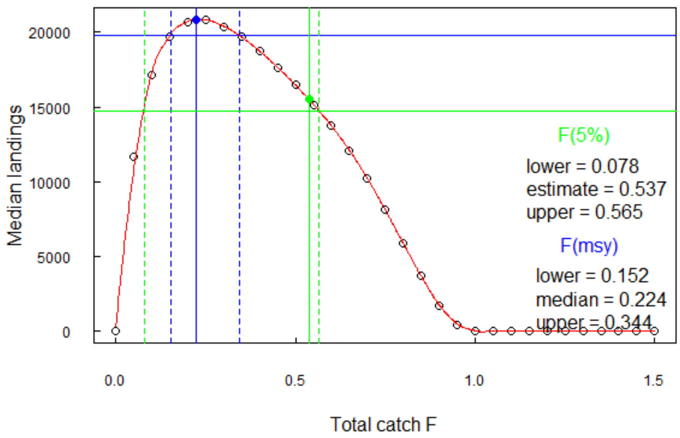


Figure 5.6.12. West of Scotland cod median landings yield curve with estimated reference points (alternative discard rate, without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

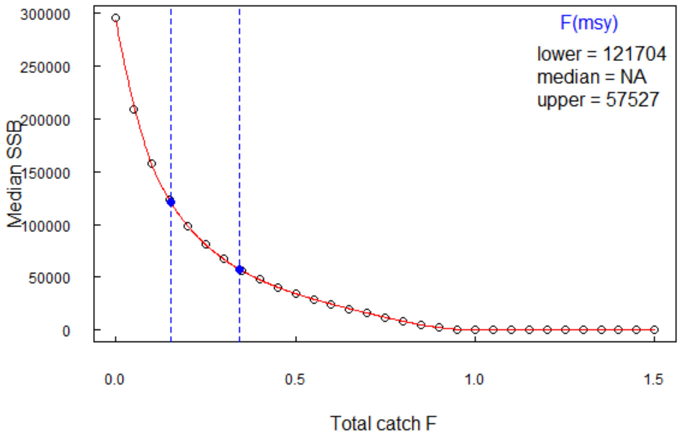


Figure 5.6.13. West of Scotland cod median SSB curve over a range of target F values (alternative discard pattern, without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.7 Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb–k (Southern Celtic Seas and English Channel)

The values used in the MSY analysis were taken from ICES WGCSE 2015 based on the latest assessment input and output data from the 2015 WG (ICES 2015) and are summarized below (Table 5.7.1)

5.7.1 Proposed reference points

Table 5.7.1 Summary table of proposed stock reference points from WGCSE 2015

STOCK		
PA Reference points	Value	Rational
B_{lim}	6,700	B_{loss}
B_{pa}	10,000	B_{lim} combined with the assessment error; $B_{lim} \times \exp(1.645 \times \sigma)$, $\sigma = 0.26$
F_{lim}	1.41	F with 50% probability of SSB< B_{lim}
F_{pa}	0.89	F_{lim} combined with the assessment error; $F_{lim} \times \exp(-1.645 \times \sigma)$, $\sigma = 0.28$
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.40	
F_{MSY} lower without $B_{trigger}$	0.26	
F_{MSY} upper without $B_{trigger}$	0.60	
MSY $B_{trigger}$	10,000	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.74	
F_{MSY} upper precautionary without $B_{trigger}$	0.39	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	0.84	
F_{MSY} with $B_{trigger}$, B_{pa}	0.40	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.26	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.60	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.60	
MSY	0.40	
Median SSB at F_{MSY}	38.6kt	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	60.3kt	
Median SSB upper (median at F_{MSY} lower)	29.0kt	

5.8 Haddock (*Melanogrammus aeglefinus*) in Division VIb (Rockall)

5.8.1 Current reference points

Table 5.8.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	6000 t	B_{lim}=B_{loss}, the lowest observed spawning stock estimated in previous assessments.
Current B_{pa}	9000 t	B_{pa}=B_{lim} × 1.5. This is considered to be the minimum SSB required to obtain a high probability of maintaining SSB above Blim, taking into account the uncertainty of assessments.
Current F_{lim}	Not defined.	Not defined due to uninformative stock recruitment data.
Current F_{pa}	0.4	This F is adopted by analogy with other haddock stocks as the F that provides a small probability that SSB will fall below B_{PA} in the long term.
Current F_{MSY}	9000 t	B_{pa}.
Current $MSYB_{trigger}$	0.2	Based on stochastic simulations (ICES, 2013).

5.8.2 Source of data

Data used in the MSY interval analysis were taken from the XSA assessment created during ICES WGNSSK 2014. Data represent the latest assessment input and output data from WGCSE (ICES 2015).

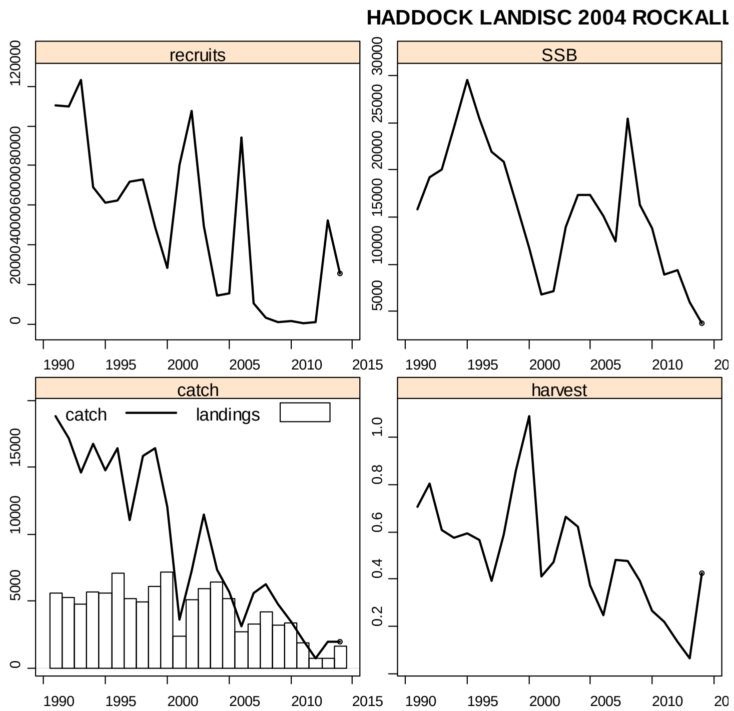


Figure 5.8.1 Rockall haddock stock used as the basis of evaluation.

5.8.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
BP= 6778
segreg3  <- function(ab, ssb) log(ifelse(ssb >= BP, ab$a * BP, ab$a *
ssb))
# breakpoint forced through Blim
FIT <- eqsr_fit(window(stock), nsamp = 1000, models = "segreg3")
SIM <- Eqsim_run(FIT,
                 bio.years = c(2005,2014),
                 sel.years = c(2005,2014),
                 Fcv=0.212,  # or 0
                 Fphi=0.423, # or 0
                 Blim=6778,
                 Bpa=10167,
                 Fscan = seq(0,0.6,len=61),
                 Btrigger = 10855, #  or 0 or Bpa
                 rhologRec=FALSE,
                 verbose=FALSE)
```

To represent the recent period with the poor recruitment the recruitment was restricted to the period 2004 to 2013,

5.8.4 Settings

Table 5.8.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1991–2013)	Recruitment was tested with 10 most recent years 2004-2013
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2005–2014	
Assessment error in the advisory year. CV of F	0.233	Taken from WKMSWREF4 estimates of 5 stocks
Autocorrelation in assessment error in the advisory year	0.423	Taken from WKMSWREF4 estimates of 5 stocks

The growth and selection were examined for recent trend. Both show a great deal of variability and some cohort effects, the last 10 years appear to be comparatively consistent and values were drawn from the last 10 year. The influence of the 10 year choice was evaluated through retrospective analysis (see Sensitivity evaluation below).

5.8.5 Results

5.8.5.1 Stock recruitment relation

Fitted S–R relationships give a poor representation of the observations, the segmented regression fits with a breakpoint well above B_{lim}, with very poor model fit, with substantial trends in residuals after 2005 and overdispersion of values, questioning the validity of the fit. The autocorrelation (Figure 5.8.2 mid left) shows correlation of about

0.75, which is substantial. The main evaluation was carried out with S-R based on segmented regression with the breakpoint at the newly proposed B_{lim} (Figure 5.8.3) using the fitted value of process variability. Recent recruitment over the last ten years has been particularly poor (Figure 1), to test for the implications of this a further run was made using S–R for just the ten most recent values (Figure 5.8.4). The consequences of the recruitment assumptions are discussed further in the sensitivity tests below.

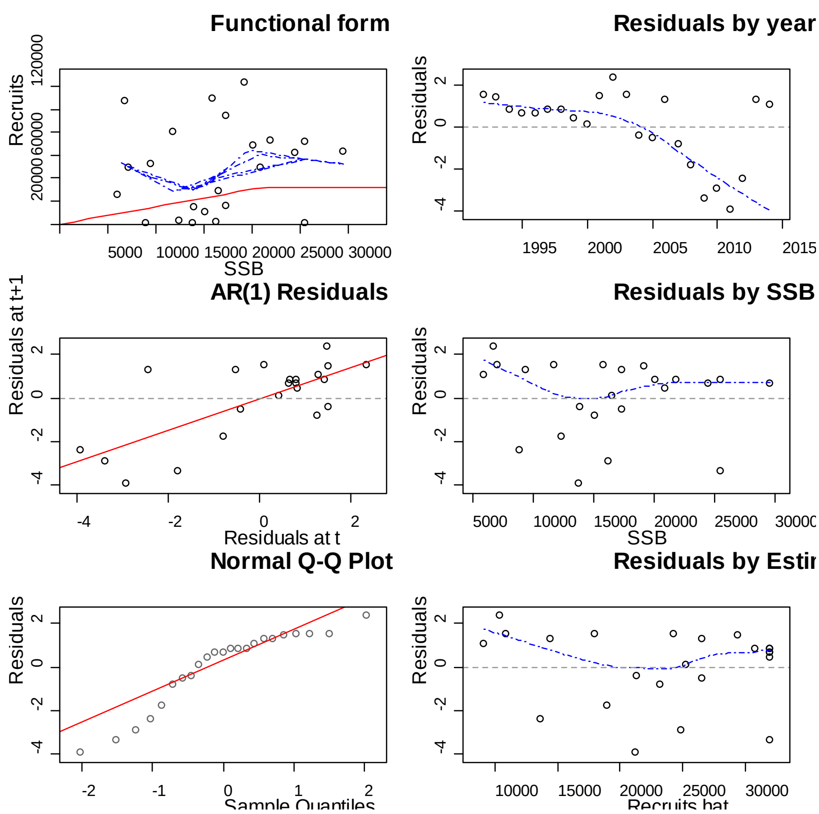


Figure 5.8.2 example of fit in segmented regression showing poor residual patterns. Note also high autocorrelation AR (1).

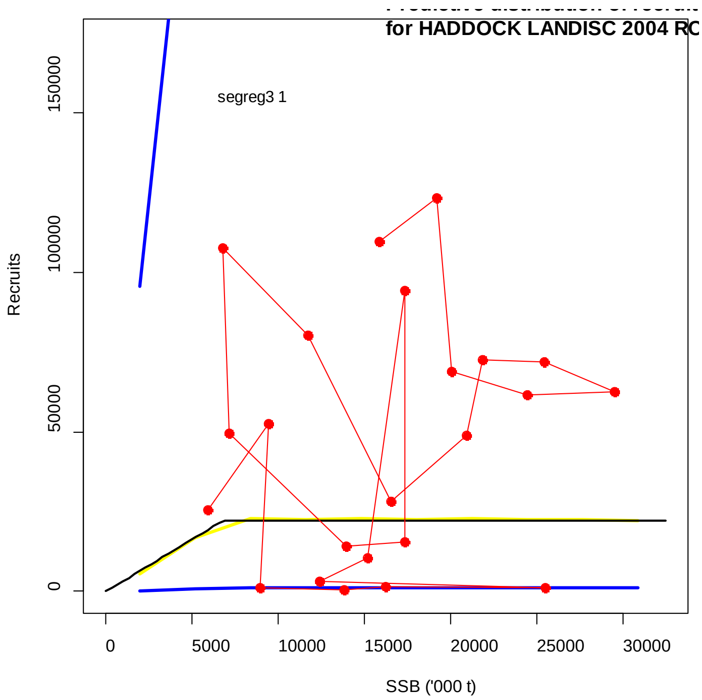


Figure 5.8.3 S–R function used to carry out the evaluation (black) based segmented regression forced through B_{lim} and fitted to data, intervals on simulated values (blue).

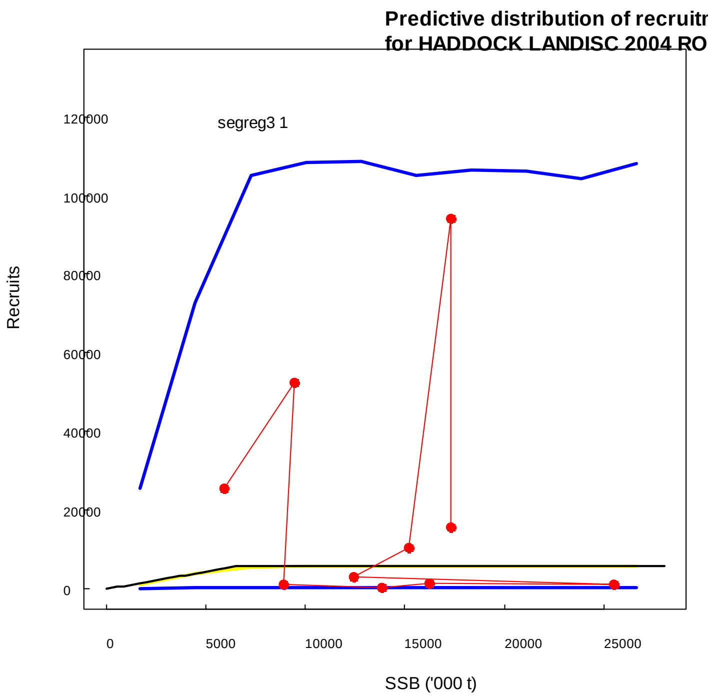


Figure 5.8.4 S–R function used to carry out the evaluation with recent low recruitment (red) based segmented regression (black) forced through B_{lim} and fitted to data, intervals on simulated values (blue).

5.8.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve, because recent discard rates are low (Figure 5.8.1) this choice is examined through retrospective analysis. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.8.5.3 Eqsim analysis

Include the overall stock dynamics based on the full time-series of recruitment at a range of constant F exploitation are summarized in Figure 5.8.5 which shows a) simulated and historic recruitment, b) SSB in equilibrium, c) catch and d) the cumulative probability of F_{MSY} based on catch or landings and the probability of SSB<B_{pa} and B_{lim}. The F ranges are based on less than 5% reduction in yield (Figure 5.8.6). F_{MSY} is evaluated to be 0.20 for the full series.

The simulation based on data for recent low recruitment (years 2004–2013) time-series showed that the initial values of the referents points do not change much. For low recruitment F_{MSY} is evaluated to be 0.20 (Figure 5.8.7). However, the low recruitment gave no precautionary Fs with or without the inclusion of MSY $B_{trigger}$=B_{pa} (Figure 5.8.7). The yield and SSB assuming the low recruitment are shown in Figure 5.8.8.

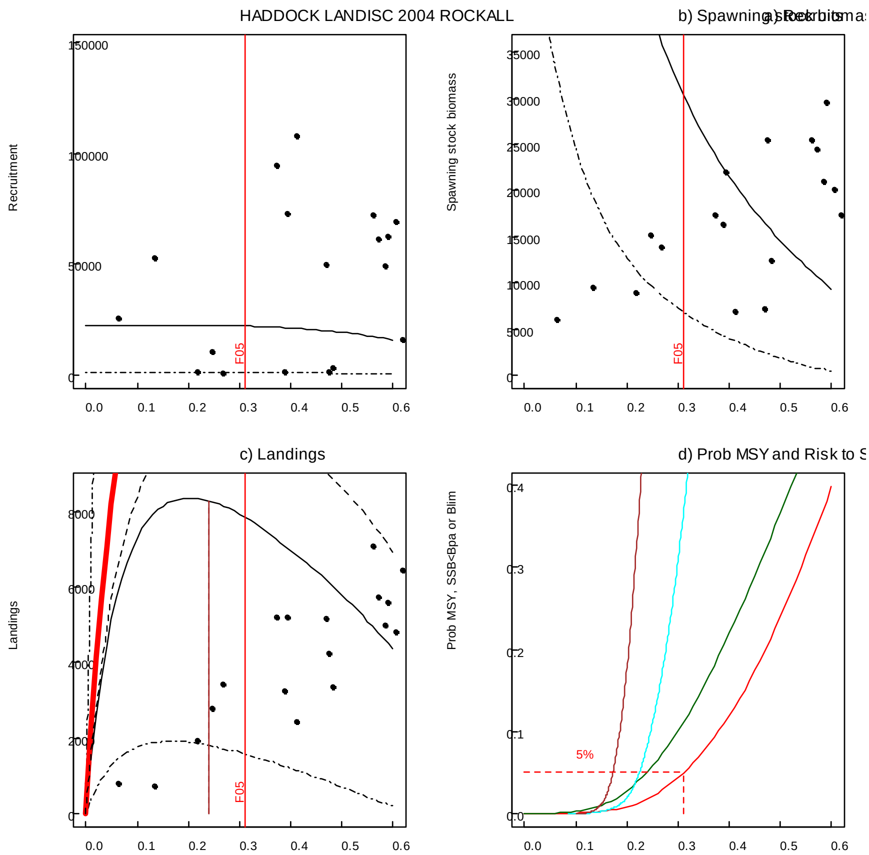
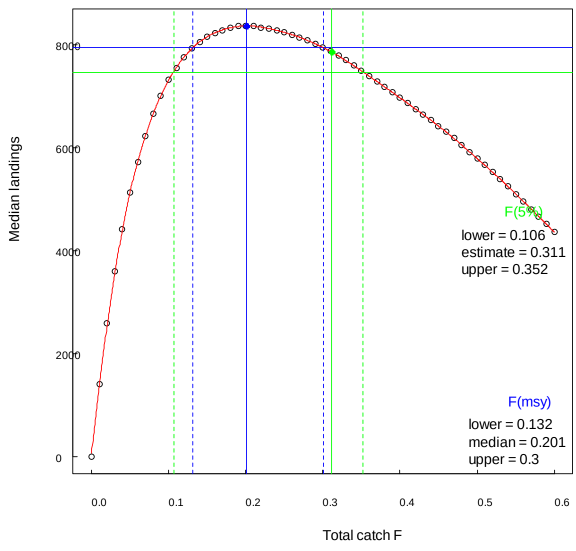


Figure 5.8.5 Summary of MSY evaluations using full time-series of recruitment.



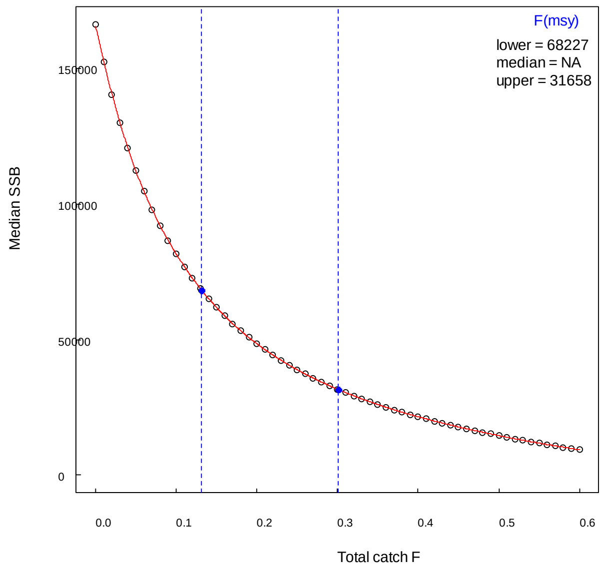


Figure 5.8.6 (Top) Catch at a fixed F with advice error and setting $B_{trigger}$ =B_{pa}, MSY ranges based on 95% of yield at MSY, (Bottom) SSB at fixed F. Using reduced series of recruitment

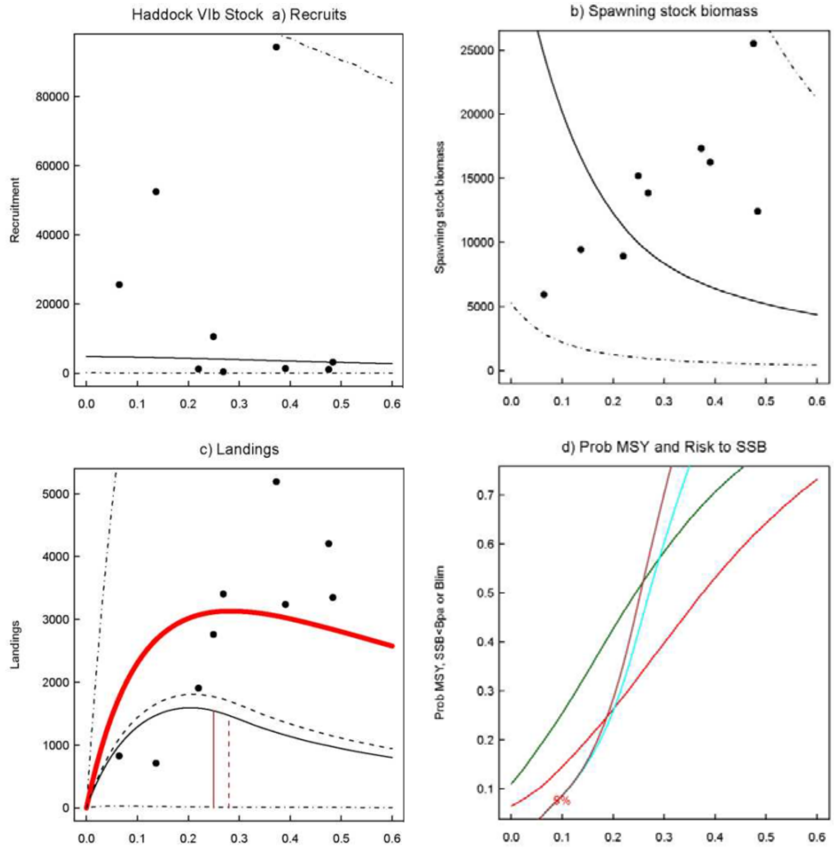


Figure 5.8.7 Summary of MSY evaluations using full reduced series of recruitment. F_{MSY} is similar to full time-series at just under 0.20, however, no fs are precautionary.

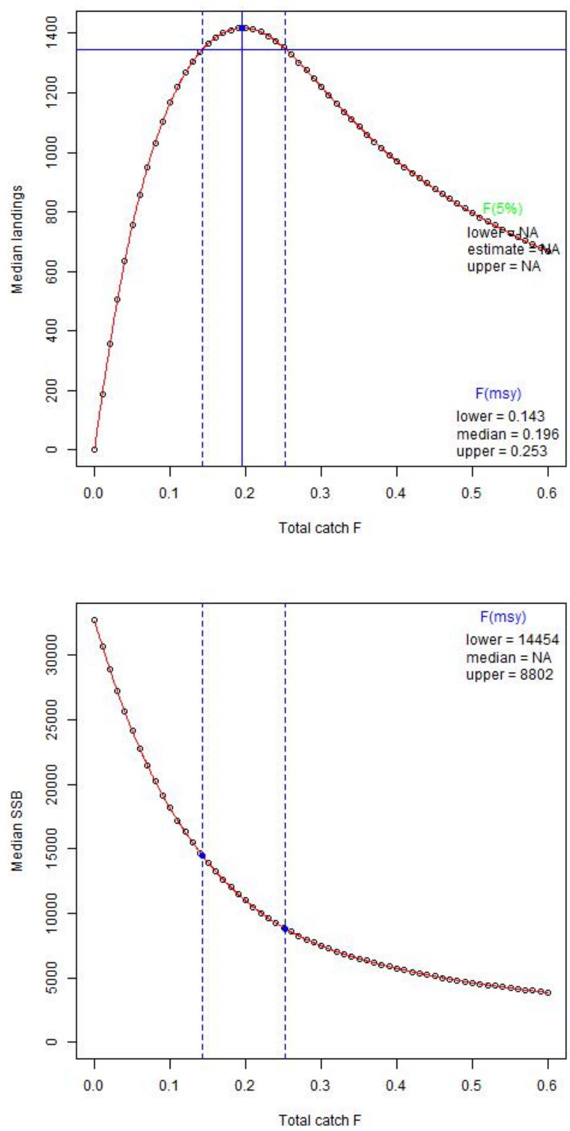


Figure 5.8.8 Catch at a fixed F with advice error and setting $B_{trigger}$ =B_{pa}, MSY ranges based on 95% of yield at MSY recent for recent period with low recruitment, F_{MSY} = 0.20, however, no Fs are precautionary with or without MSY $B_{trigger}$=B_{pa}.

Table 5.8.3 Summary table stock reference points for method Eqsim for the reduced time recruitment period (2004–2013) with the poor recruitment

STOCK	
MSY Reference point	Value
F_{MSY} without $B_{trigger}$	0.20
F_{MSY} lower without $B_{trigger}$	0.14
F_{MSY} upper without $B_{trigger}$	0.26
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	No values of F were precautionary
F_{MSY} upper precautionary without $B_{trigger}$	No values of F were precautionary
MSY $B_{trigger}$	10167
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	No values of F were precautionary
F_{MSY} with $B_{trigger}$, B_{pa}	0.19, 0.20
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.14, 0.15
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.25, 0.26
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	No values of F were precautionary,
MSY	1382

5.8.6 Proposed reference points

Table 5.8.4 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	6800	B_{loss} (2001) estimated in 2015
B_{pa}	10200	B_{lim}*1.5
F_{lim}	0.69	Based on segmented regression simulation of recruitmemt with B_{lim} as the breakpoint
F_{pa}	0.46	F_{lim}/1.5
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.20	
F_{MSY} lower without $B_{trigger}$	0.13	
F_{MSY} upper without $B_{trigger}$	0.30	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.31	
F_{MSY} upper precautionary without $B_{trigger}$	0.30	
MSY $B_{trigger}$	13690	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	0.39, 0.39	
F_{MSY} with $B_{trigger}$, B_{PA} , B_{pa}	0.20, 0.28	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.13, 0.18	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.30, 0.39	
F_{MSY} upper precautionary with $B_{trigger}$	0.38,0.38	
MSY	8.357	
Median SSB at F_{MSY}	48330	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	68227	
Median SSB upper (median at F_{MSY} lower)	31658	

5.8.7 Discussion / Sensitivity.

Two retrospective runs were carried out, a) a moving window with ten years data terminating at the year shown, and b) a truncated window running from 2005 to the terminating year shown. Two sensitivity analyses based on different recruitment options were tested. The reduced recent recruitment calculated from the last ten years of estimated recruits and the inclusion of autocorrelation in recruitment at lag of one year =0.75. This high level of autocorrelation is due to the low recruitment in recent years compared to relatively high recruitment in the early part of the time-series. The high autocorrelation gave only precautionary Fs at F=0.14 with the inclusion of $B_{trigger} = B_{pa}$. The low recruitment gave no precautionary Fs.

In 2013 ICES advised "that when SSB is greater than B_{PA} a maximum F value of 0.2 would be required for the HCR to be consistent with the precautionary approach even under a low recruitment regime. In the HCR that was found to be precautionary, the SSB value used in paragraph 4 is calculated directly applying F = 0.2 during the TAC year, without performing any iterative steps." Taken with the MSE evaluation these results strongly suggest that due to considerable uncertainty in recruitment safe exploitation cannot expected above F=0.2. If the last ten years recruitment was to continue indefinitely reference points would need to be redefined.

The evaluation carried out here suggest that the situation has not changed substantially from when the MSE was evaluated and in conclusion it is considered that given the uncertainty in recent stock dynamics the ICES advice from 2013 should be maintained and F_{upper} should be set equal to F_{MSY} and the extensive MSE evaluation that require F below 0.20 should take precedence over the small number of options evaluated here.

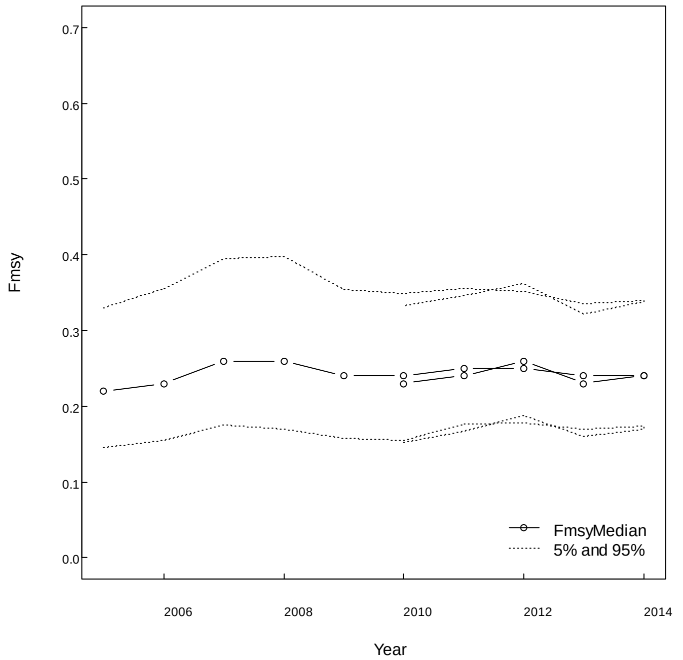


Figure 5.8.7 Two retrospective runs based on 2015 assessment; The run from 2005–2014, based on a moving window with ten years terminating at the year shown, and the run from 2010–2015 based on a truncated window 2005 to terminating year shown. Greater instability is due to years prior to 2005.

5.9 Hake (*Merluccius merluccius*) in Subareas IV, VI, and VII and Divisions IIIa, VIIIa, b, d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)

5.9.1 Current reference points

Table 5.9.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	33 000	Analysis of historical evolution of the stock (ICES, 2014)
Current B_{pa}	46 200	$B_{lim}*e^{0.2*1.645}$ (ICES, 2014)
Current F_{lim}	Not available	
Current F_{pa}	Not available	
Current F_{MSY}	0.28	F_{max} of expected yield
Current MSY $B_{trigger}$	46 200	F_{pa}

5.9.2 Source of data

Data used in the MSY interval analysis were taken from SS3 output files created during ICES WGBIE 2015. Data represent the latest SS3 assessment input and output data from WGBIE (ICES 2015).

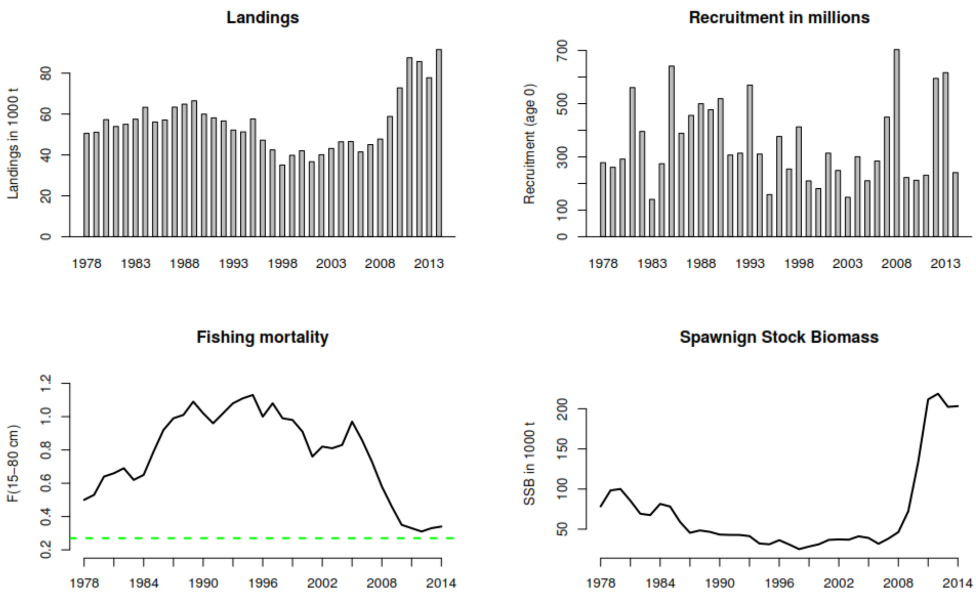


Figure 5.9.1 Summary indicators of Northern Hake stock used as the basis for the evaluations.

5.9.3 Methods used

All analyses were conducted using the method described in section 4.4.

5.9.4 Settings

Table 5.9.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1978–2014)	
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	No	
Mean weights and proportion mature; natural mortality	These parameters are constant in SS·, the same values used.	
Exploitation pattern	2005–2014	
Assessment error in the advisory year. CV of F	0.212	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

5.9.5 Results

5.9.5.1 Stock recruitment relation

First, a mixture of Beverton–Holt, Hockey Stick and Ricker stock recruitment models was fitted to observed stock–recruitment data using a Bayesian model. The breakpoint in the Hockey stick model was constrained to be above the lowest observed SSB. The same prior probability (1/3) was assigned to each of the three SR functions (Beverton–Holt, Hockey Stick and Ricker) and the parameters (9 parameters, i.e. 3 per SR model type) as well as the posterior probabilities of the three SR models were estimated. In the MCMC chain, the sampler moved from model to model depending on the updated posterior probabilities of each of the three SR models, which depended on the goodness of the fit of the SR models to the SR data. The resulting posterior probabilities were 0.8 for Hockey Stick, 0.17 for Beverton–Holt and 0.03 for Ricker.

As the weight given to Hockey Stick was very high, for simplicity, it was decided to use Hockery Stick relationship with conduct the analysis. The red points in the figures below represent the observed stock–recruitment pairs. The lines in the left hand side plot represent the stock–recruitment curve estimated in each of the model replicates. The right hand side figure shows the predictive intervals which takes into account departures of observed recruitment from fitted curves. The median breakpoint in the Hockey Stick model was around 48 000 tonnes.

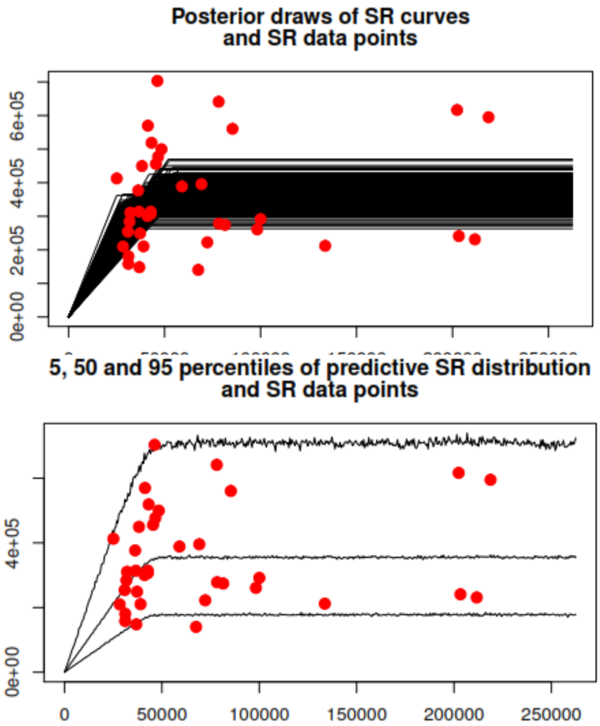


Figure 5.9.2 in the left panel stock recruitment model curves fitted in each model replicate. In the right panel the predictive intervals of recruitment.

5.9.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.9.5.3 Analysis

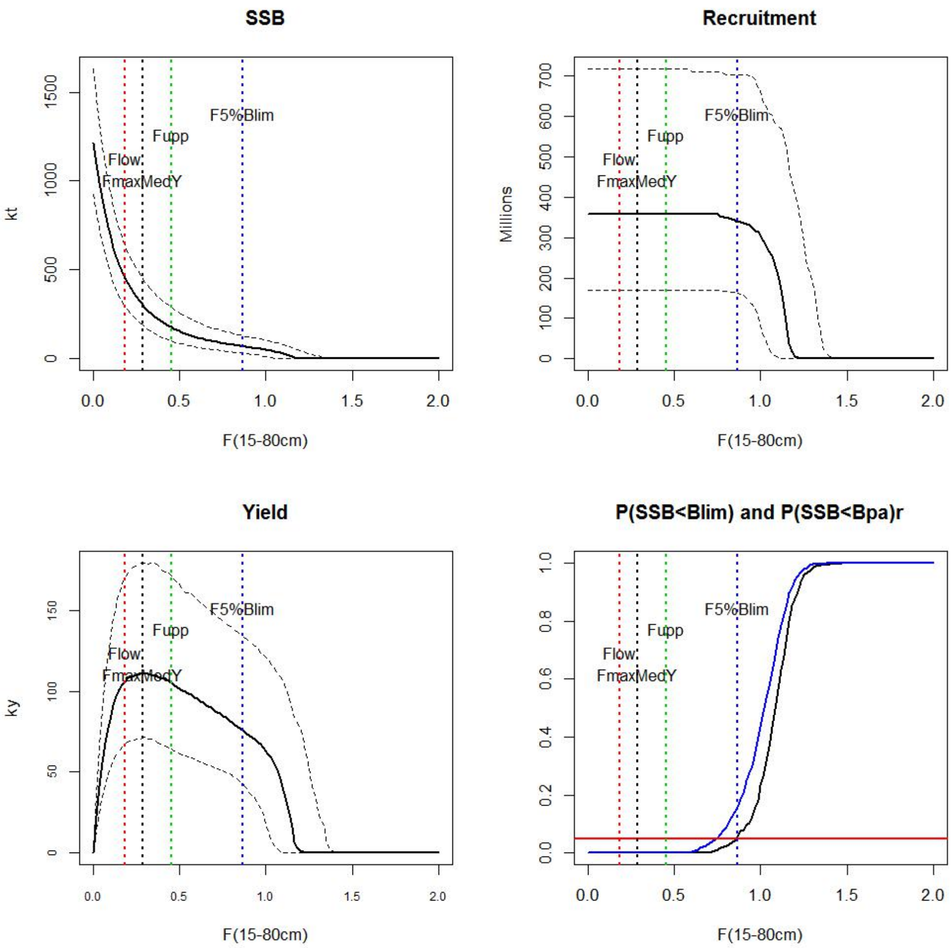


Figure 5.9.3 SSB, Recruitment, Yield and $p(SSB<B_{lim})$, $p(SSB<B_{pa})$ vs. Fbar. The solid line in the first three plots correspond to the median and the dashed lines with the 5% and 95% quantiles. The solid black line in bottom-right panel correspond to $p(SSB<B_{lim})$ and the blue one with $p(SSB<B_{pa})$. The vertical lines correspond to lower limit of fishing mortality range (red), F_{max} of Median Yield curve (black), upper limit of fishing mortality range (blue) and the fishing mortality which results in a 5% probability of being below B_{lim}.

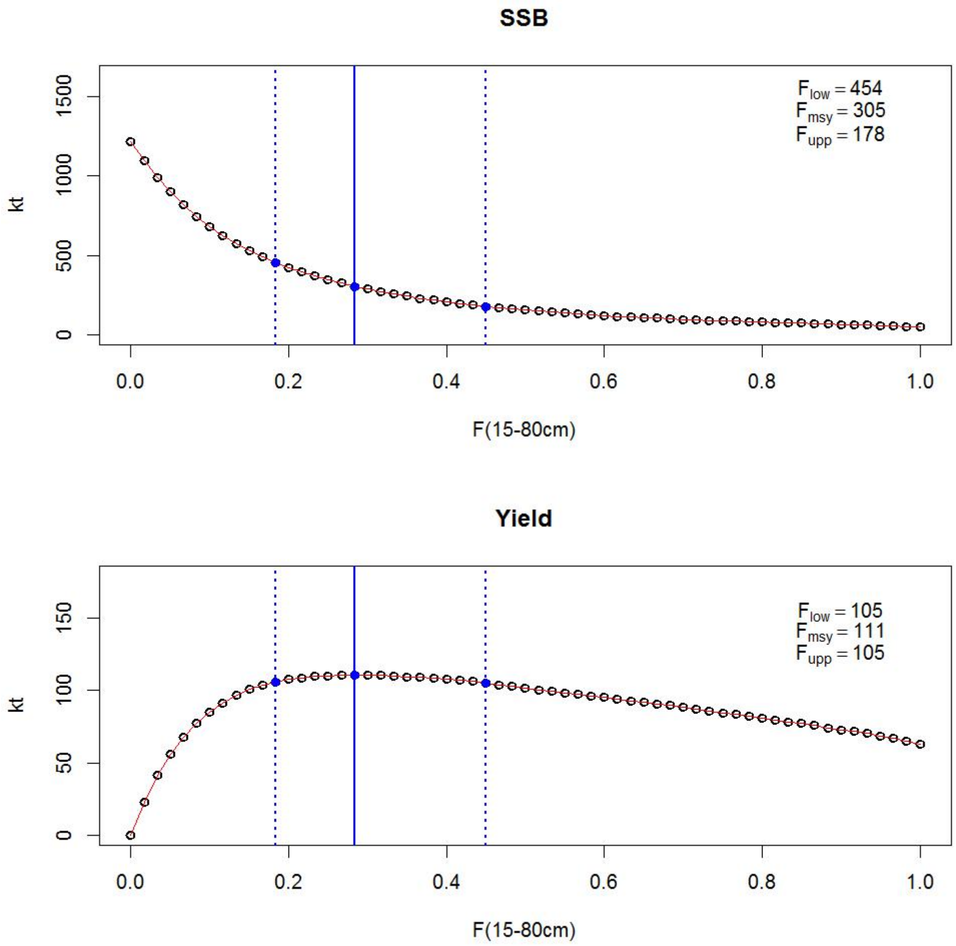


Figure 5.9.4 Median SSB (top) and landings yield (bottom) curve with estimated reference points for Northern stock of Hake with fixed F exploitation. Vertical solid line correspond to the median and dotted ones with the upper and lower limits of the fishing mortality ranges.

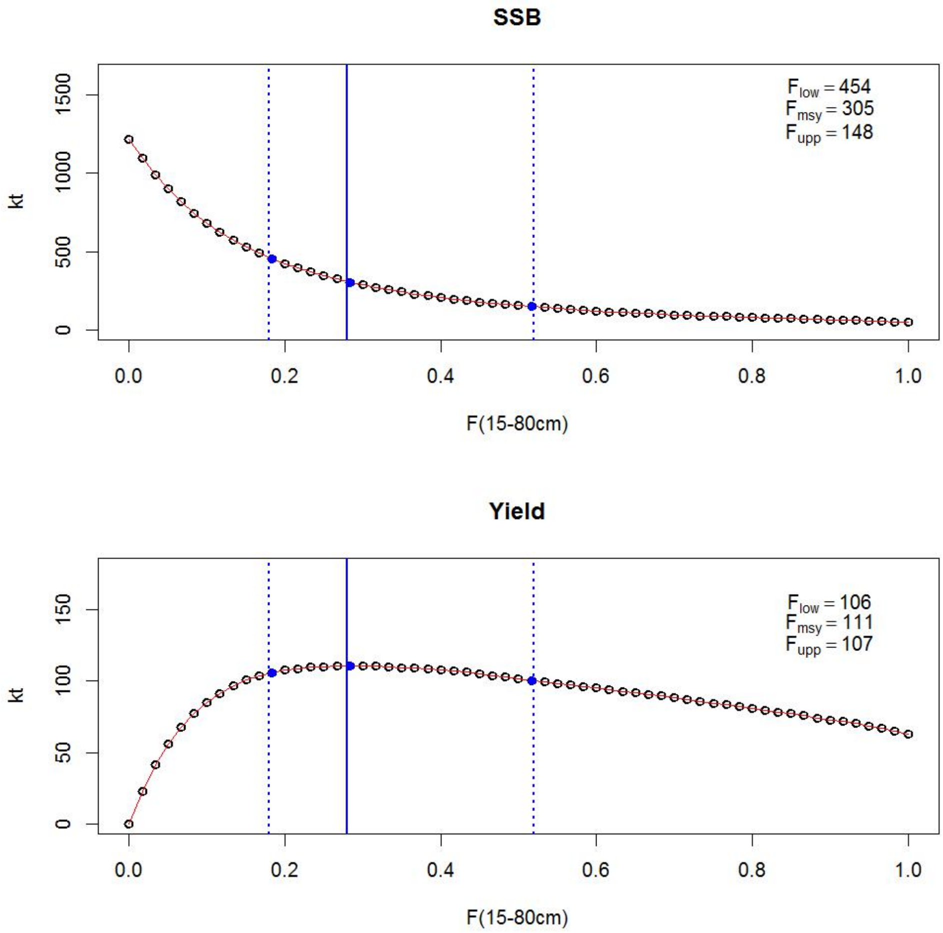


Figure 5.9.5 Median SSB (top) and landings yield (bottom) curve with estimated reference points for Northern stock of Hake with fixed F exploitation when applying the ICES MSY harvest control rule with $B_{trigger}$ at 222 607 t. Vertical solid line correspond to the median and dotted ones with the upper and lower limits of the fishing mortality ranges.

5.9.6 Proposed reference points

Table 5.9.3 Summary table of proposed stock reference points for method

STOCK		
PA Reference points	Value	Rational
B_{lim}	32 000	Low biomass followed by recovery SSB_{2006}
B_{pa}	45 000	$B_{lim}*e^{0.2*1.645}$ (ICES, 2014)
F_{lim}	0.87	
F_{pa}	0.62	$F_{lim}/1.4$
F_{MSY} without $B_{trigger}$	0.28	
F_{MSY} lower without $B_{trigger}$	0.18	
F_{MSY} upper without $B_{trigger}$	0.45	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.87	
F_{MSY} upper precautionary without $B_{trigger}$	0.45	
MSY $B_{trigger}$	222 607 t	

$F_{P.05}$ (5% risk to Blim with $B_{trigger}$)	> 3
F_{MSY} with $B_{trigger}$	0.28
F_{MSY} lower with $B_{trigger}$	0.18
F_{MSY} upper with $B_{trigger}$	0.52
F_{MSY} upper precautionary with $B_{trigger}$	0.52
MSY	111 000 t
Median SSB at F_{MSY}	305 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	178 000 t
Median SSB upper (median at F_{MSY} lower)	454 000 t

5.9.7 Discussion / Sensitivity.

No sensitivity analysis was carried out.

5.10 Hake (*Merluccius merluccius*) in Divisions VIIIc and IXa (Southern stock) (Cantabrian Sea, Atlantic Iberian Waters)

5.10.1 Current reference points

Table 5.10.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	9000	A biomass that produces a recruitment that is at or above average
Current B_{pa}	-	
Current F_{lim}	-	
Current F_{pa}	-	
Current F_{MSY}	0.24	F max
Current $MSYB_{trigger}$	-	

5.10.2 Source of data

Data used in the MSY interval analysis were taken from southern hake stock assessment created during 2015. Data represent the latest assessment input and output data from WGBIE (ICES 2015).

5.10.3 Methods used

This stock is assessed with GADGET, an age-length based method (see Section 4.4).

All analyses were conducted with ad-hoc software developed in R-3.2.1 using a deterministic yield-per-recruit (YPR) and stock per recruit (SPR) length based analysis, a Bayesian stock–recruitment analysis for 3 models (Beverton–Holt, Ricker and hockey stick), and a stochastic link between SPR and the stock–recruitment parameters providing the distribution for the different equilibrium reference points, as described in Cerviño et al. (2013).

5.10.4 Settings

Table 5.10.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (year classes 1982–14)	Large SSB figures at the beginning of the time-series are uncertain given the lack of large fish calibration data to fit the assessment model.
Maturity	2012–2014	There has been a reduction in length of first maturity affecting recent years
Exploitation pattern	2012–2014	Recent changes on regulations has driven the fishery towards higher discarding rate in recent years.
Other biological data (growth, M, length-weight relationship)	Historical mean	These data are assumed as constant over the time-series and are kept this way in this simulation

5.10.5 Results

5.10.5.1 Stock recruitment relation

3 SR relationships were explored with Bayesian models (see Figure 5.10.1): Ricker, Beverton–Holt and hockey stick. Any of these fits were considered superior to the others to represent the Southern hake dynamics in this MSY analysis. It was also explored a combination of this three models as an alternative. This approach is considered preliminary since the Bayesian weighting procedure could not be implemented with the same model settings (some uninformative priors). The combined model catches some interesting features from different models such us a steeper slope at origin (compared with Beverton–Holt) or a reduced recruitment at higher SSB. However further work is needed to improve the weighting procedure.

The hook stick model was finally selected given the good definition of the breaking point for the B_{lim} estimation and subsequent reference points (B_{pa}, F_{lim} and F_{pa}). Hockey stick model has a constant recruitment after the breakpoint being a neutral option compared to Beverton–Holt (where recruitment slightly increases after breakpoint) or Ricker (where recruitment decreases after the breakpoint).

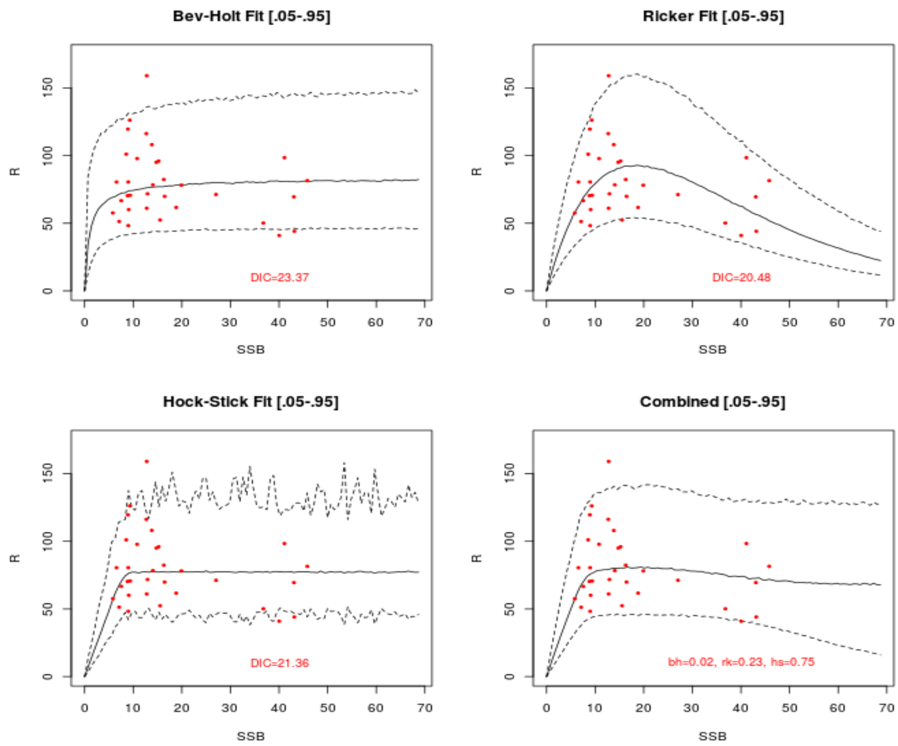


Figure 5.10.1. Stock recruitment Bayesian models with Median, and predictive percentiles (0.05–0.95)

5.10.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve (Figure 5.10.2). The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

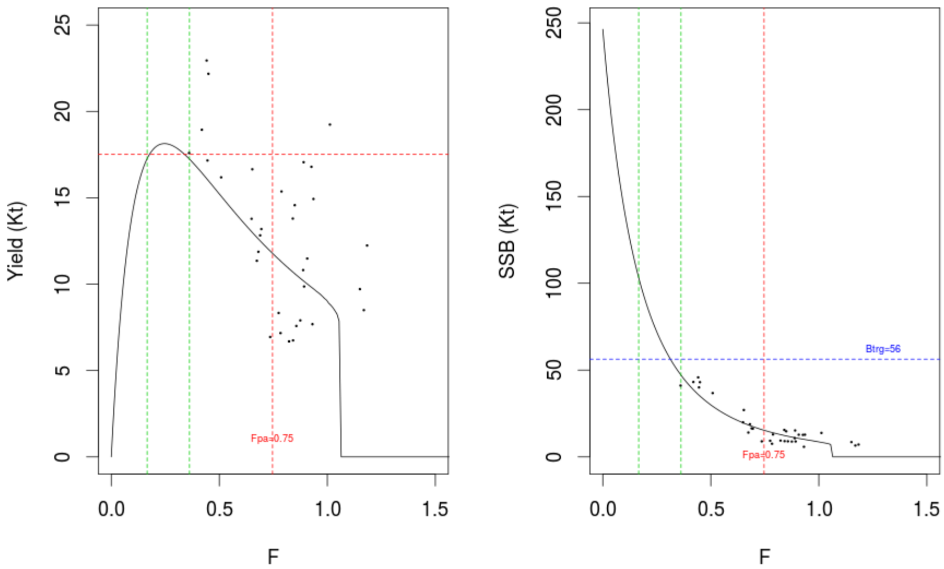


Figure 5.10.2 F vs. median equilibrium Yield (left) and Fvs.median equilibrium SSB (right). Green lines represent the F ranges (lower and upper) at yield equal to 95% of maximum yield.

Estimated ranges [0.17–0.36] are presented in both plots (green dashed lines). Left plot shows a clear separation between F_{pa} (0.75) and the upper bound of F_{MSY} (0.36) suggesting that this bound could be precautionary. On the other plot (in the right) we can see $B_{trigger}$ (dashed blue line), that is the 5% lower percentile of B_{MSY}. $B_{trigger}$ crosses the equilibrium SSB line (continues black line) at F figures below F upper. The corresponding F that drives the stock in equilibrium to $B_{trigger}$ is $FB_{trigger}$ = 0.31 (below F_{up}= 0.36). This suggests the upper F limit would be result in reduced F if the 5% BMSY value is used for the ICES MSY approach. However we have to take in consideration that this analysis was performed considering only the uncertainty in S-R relationship, ignoring other sources of uncertainty coming from the biology side such us growth, maturity or M and coming from the fishery such us F level or exploitation pattern. Under these circumstances $B_{trigger}$ has to be considered an upper figure of true $B_{trigger}$. Furthermore $B_{trigger}$ (56 Kt) is well above the maximum estimated historic SSB that is 45 Kt in 1983. For these two reason the constraint imposed by $B_{trigger}$ to the upper bound of F_{MSY} should be considered with caution.

5.10.6 Proposed reference points

Table 5.10.3 Summary table of proposed stock reference points

STOCK SOUTHERN HAKE		
PA Reference points	Value	Rational
B_{lim}	7 956	Hockey stick breakpoint
B_{pa}	11 133	B_{lim} * 1.4
F_{lim}	1.045	F corresponding to the slope of the hockey stick SSB-Rec relationship
F_{pa}	0.746	F_{lim} / 1.4

MSY Reference points	
F_{MSY}	0.245
F_{MSY} lower	0.166
F_{MSY} upper	0.362
5% on B_{MSY} ($B_{trigger}$)	56 275
F to give $B_{trigger}$	0.311
B_{MSY}	73 330
MSY	18 139
Median SSB lower precautionary (median at F_{MSY} upper)	47 475
Median SSB upper (median at F_{MSY} lower)	104 349

5.10.7 Discussion / Sensitivity.

Hake is a quite cannibal species which implies that Ricker dynamics can suit their stock–recruitment relationship. For this stock the Ricker fit is dominated by 3 dots, all of them corresponding to the beginning of the time-series (years 1985–87), with a higher uncertainty in the SSB figures. Ricker fit was disregarded because of this uncertainty. However it was also explored the combination of different S-R relationships in the same MSY analysis. This analysis is quite preliminary since S-R model structure and Bayesian priors had to be modified to sample Bayesian posteriors on model weights (i.e. the weight that is given to each of the model). Furthermore the combined analysis, with a 23% of Ricker, 75% of Hockey stick and 2% of Beverton–Holt did not change F_{MSY} figures compared with hockey stick model alone. For this reason the combined model was also disregarded. Further work is needed to allow a combined estimation that is still considered promising.

Classing F_{upper} as precautionary?

To class w F_{upper} as precautionary there should less than 5% probability of SSB<B_{lim} when the stock is exploited at F=F_{upper}. B_{lim} was estimated as the median of the posterior breakpoint in the Bayesian hockey-stick relationship (7.95 Kt). The 5% upper limit of this distribution is 9.97 Kt, however this posterior only considers the variability the S-R relationship without other considerations (i.e. no errors in M, growth, maturity or F). In this situation is not possible to make a complete analysis of the probability of being below B_{lim}. However there are two reasons to support that F_{uppper} is precautionary:

1) There is a substantial difference between F_{upper} (0.362) and F_{pa} (0.746). Given the separation between these two Fs it is expected that fishing at F_{upper}, the probability of being below B_{lim} is negligible, and clearly lower than 5%.

2) Northern hake has a similar dynamic with similar biology, exploitation pattern and F reference points (F_{MSY}=0.27, F_{upper}=0.38, F_{pa}=0.62). Since fishing Northern hake at F=0.87 gives a 5% probability of being above B_{lim} (considering B trigger gives even higher $F_{p0.5}$ figures). It seems reasonable to think that fishing Southern hake at F_{upper}=0.36 is also precautionary.

5.11 Four-spot megrim (*Lepidorhombus boscii*) in Divisions VIIIc and IXa (Bay of Biscay South, Atlantic Iberian Waters East)

5.11.1 Current reference points

Table 5.11.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	3300 t	B_{loss} (WKSOUTH, ICES 2014)
Current B_{pa}	4600 t	1.4*B_{lim} (WKSOUTH, ICES 2014)
Current F_{lim}	Not defined	
Current F_{pa}	Not defined	
Current F_{MSY}	0.17	F_{max} (WKSOUTH, ICES 2014)
Current $MSYB_{trigger}$	4600 t	B_{pa} (WKSOUTH, ICES 2014)

5.11.2 Source of data

Data represent the latest XSA assessment input and output data from ICES WGBIE 2015 (ICES 2015).

5.11.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
segreg3 <- function(ab, ssb) log(ifelse(ssb >= 3300, ab$a * 3300, ab$a
* ssb))
FIT <- eqsr_fit(megw,nsamp=2000,remove.years=c(2014),models = c("seg-
reg3"))
eqsr_plot(FIT, n=
2e4)
Fscan <- c(seq(0,0.4,by=0.01), seq(0.42,0.8,by=0.02))
SIM<- Eqsim_run(FIT, bio.years = c(2005, 2014), bio.const=FALSE,
sel.years=c(2005,2014), sel.const=FALSE, Fscan = Fscan, length(Fscan),
Fcv=0.212, Fphi=0.423, Blim=blim, BPA=BPA)
```

5.11.4 Settings

Table 5.11.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1986–2014)	2014 values excluded from the analysis because WGBIE did not trust in this value and it was replaced by a geometric mean in the short-term projections
Exclusion of extreme values (option extreme.trim)	Yes	
rimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2005–2014	

Assessment error in the advisory year. CV of F	0.212	Taken from WKMSWREF4 estimates of 5 stocks
Autocorrelation in assessment error in the advisory year	0.423	Taken from WKMSWREF4 estimates of 5 stocks

5.11.5 Results

5.11.5.1 Stock recruitment relation

The stock recruitment fit using the three models (Ricker, BandH and segmented regression) weighted by the default "Buckland" method available in Eqsim. The stock–recruit relationship was fit initially using three models (Ricker, segmented regression and Beverton–Holt). The values obtained from the assessment do not show any clear stock–recruitment signal to allow a clear estimation of a stock–recruitment curve. The time-series is relatively short and there are no data sufficiently close to the origin to allow an understanding of what may happen at lower stock biomasses. Segmented regression is considered to be more appropriate in cases with S-R relationships with no clearly maxima defined. Breakpoint was fixed in B_{lim} (Figure 5.11.1).

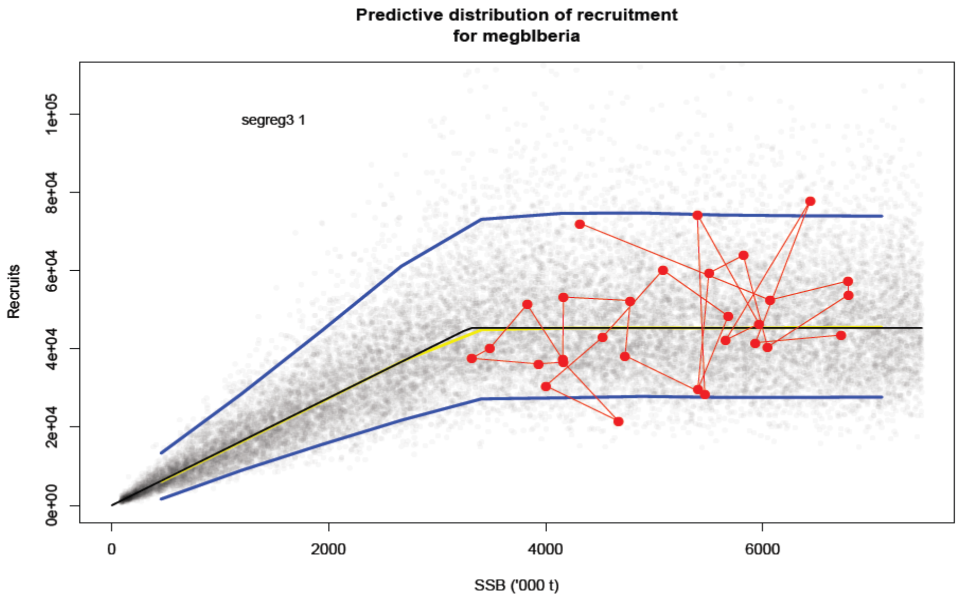


Figure 5.11.1. Stock–recruitment model using a segmented regression with the breakpoint fixed in Blim (3300 t)

5.11.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.11.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.19 (Figure 5.11.2) with median landings of 1372 t. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.29 and the lower bound was estimated at 0.12. $F_{P.05}$ was estimated at 0.40 which is above the estimate of upper bound on F_{MSY} implying that fishing at this upper bound is precautionary

(Figure 5.11.3). The median of the SSB estimates at F_{MSY} was 8725 t (Figure 5.11.4). This value is above the maximum historical observed SSB of 6790 t.

A run with no error in the advice was carried out to estimate MSY $B_{trigger}$ and F_{lim}. MSY $B_{trigger}$ was estimated at 6975 t, which is above the maximum historical value, and Flim at 0.57. This results in F_{pa} = 0.41.

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 6975 t median F_{MSY} was estimated higher at 0.24 with a lower bound of the range at 0.16 and an upper bound at 0.34 (Figure 5.11.5). The $F_{P.05}$ increased to 0.58. The median of the SSB estimates at F_{MSY} was 12068 t which is above historical observed values (Figure 5.11.6).

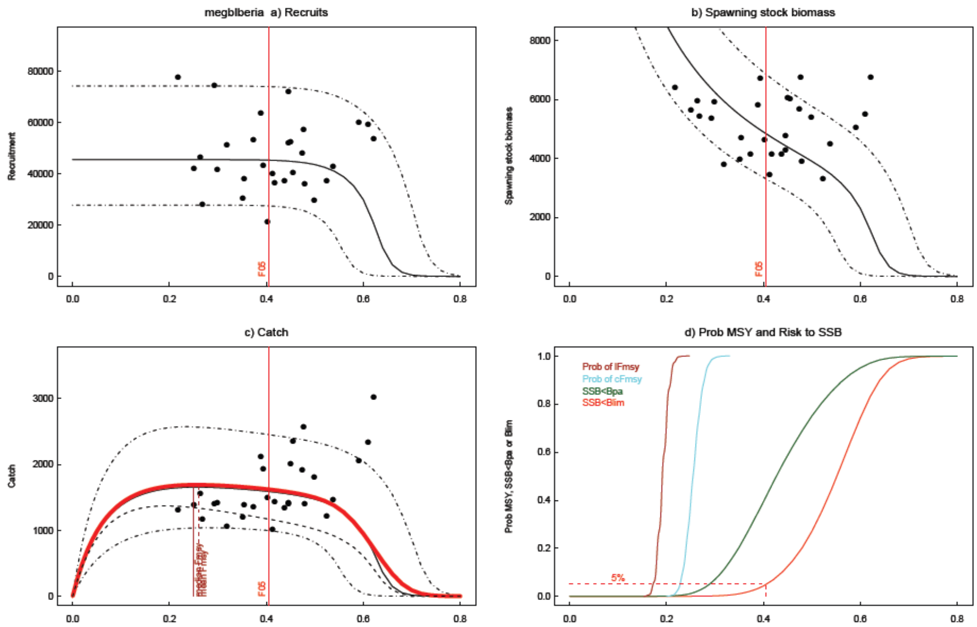


Figure 5.11.2. Eqsim summary plot for four-spot megrim in VIIIc and IXa (without $B_{trigger}$). Panels' a–c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

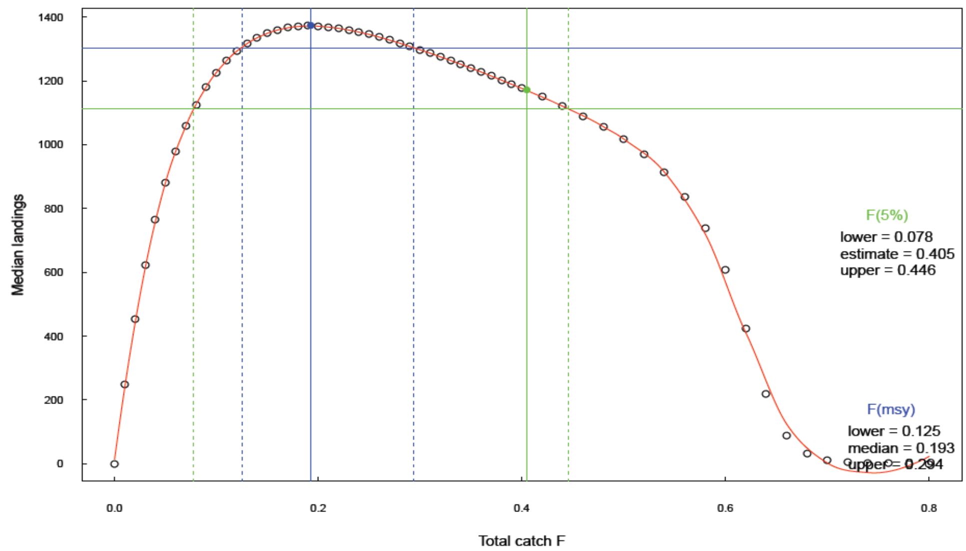


Figure 5.11.3. Four-spot megrim in VIIIc and IXa median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

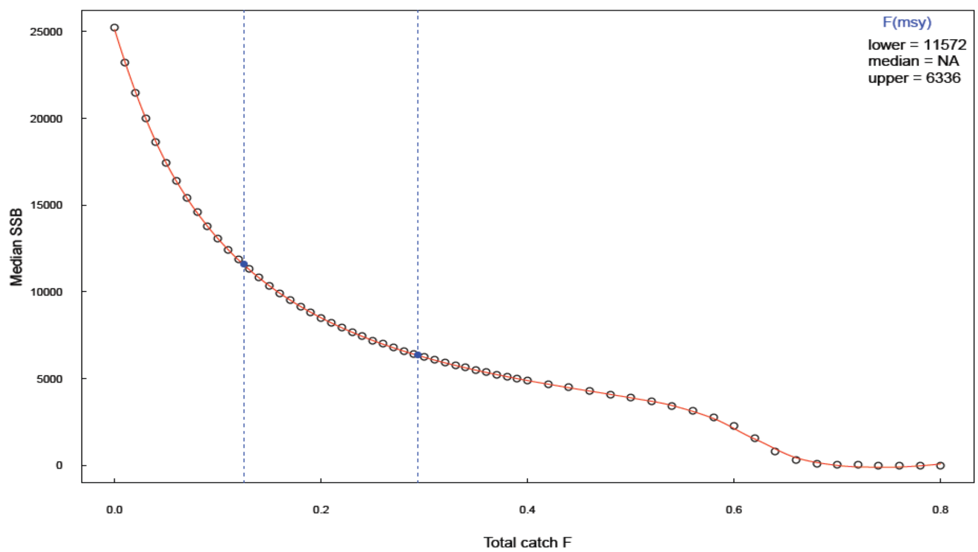


Figure 5.11.4. Four-spot megrim in VIIIc and IXa median SSB curve over a range of target F values (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

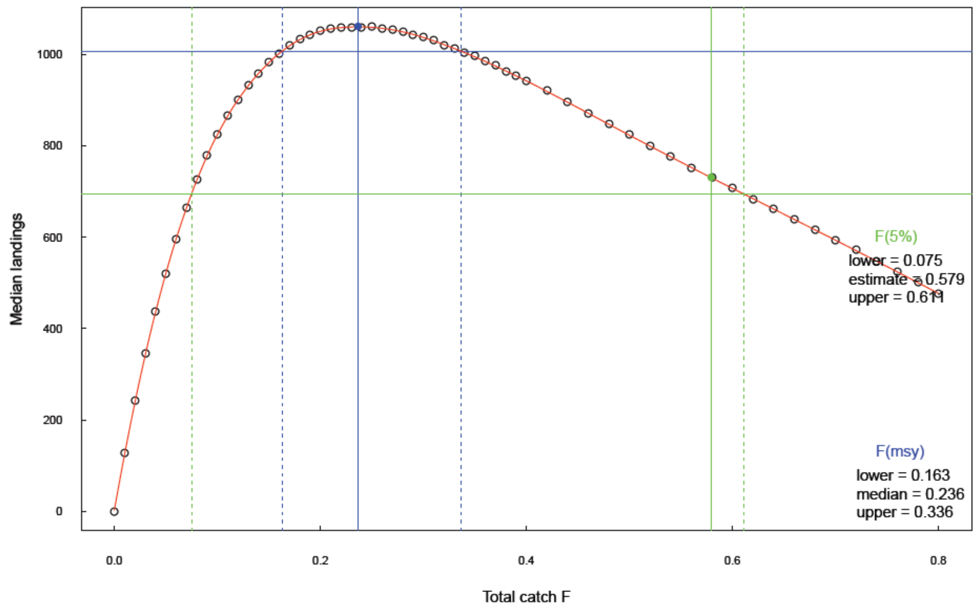


Figure 5.11.5. Four-spot megrim in VIIIc and IXa median landings yield curve with estimated reference points (MSY $B_{trigger}$=6975 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

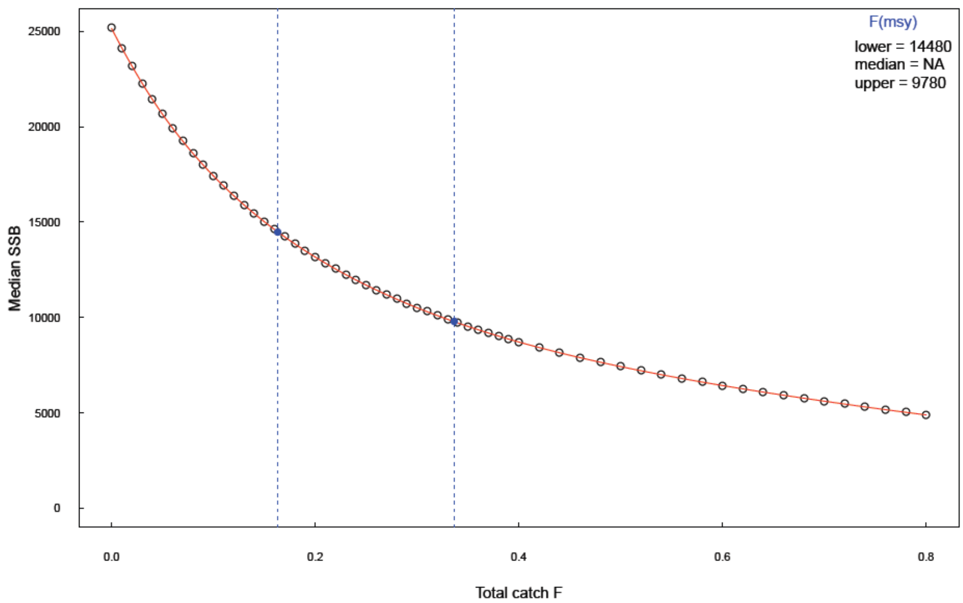


Figure 5.11.6. Four-spot megrim in VIIIc and IXa median SSB curve over a range of target F values (MSY $B_{trigger}$=6975 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.11.6 Proposed reference points

Table 5.11.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	3300 t	B_{loss} estimated in 2015
B_{pa}	4600 t	B_{lim}*1.4
F_{lim}	0.57	Based on segmented regression simulation of recruitment with Blim as the breakpoint and no error
F_{pa}	0.41	$F_{pa} = F_{lim} \times \exp(-\sigma \times 1.645)$ σ=0.2
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.19	
F_{MSY} lower without $B_{trigger}$	0.12	
F_{MSY} upper without $B_{trigger}$	0.29	
MSY $B_{trigger}$	6975 t	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.40	
F_{MSY} upper precautionary without $B_{trigger}$	0.29	
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$, B_{pa})	0.58, 0.58	
F_{MSY} with $B_{trigger}$, B_{pa}	0.24, 0.23	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.16, 0.16	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.34, 0.33	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.34, 0.33	
MSY	1060 t	
Median SSB at F_{MSY}	12068 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	9780 t	
Median SSB upper (median at F_{MSY} lower)	14480 t	

5.11.7 Discussion / Sensitivity.

A previous exploratory run of Eqsim was carried out using a combination of the 3 stocks-recruitment models weighted by the default method available in Eqsim. Due to the fact that a clear S-R relationship was not found, it was decided to use only a segmented regression with breakpoint at B_{lim}. The obtained value of F_{MSY} (0.19) does not differ very much from the value of F_{max} (0.17) defined as F_{MSY} in the Benchmark WKSOUTH in 2014.

5.12 Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)

5.12.1 Current reference points

Table 5.12.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current B_{lim}	650 t	B_{loss} (WKSOUTH, ICES 2014)
Current B_{pa}	910 t	1.4*B_{lim} (WKSOUTH, ICES 2014)
Current F_{lim}	Not defined	
Current F_{pa}	Not defined	
Current F_{MSY}	0.17	F_{max} (WKSOUTH, ICES 2014)
Current MSYBtrigger	910 t	B_{pa} (WKSOUTH, ICES 2014)

5.12.2 Source of data

Data represent the latest XSA assessment input and output data from ICES WGBIE 2015 (ICES 2015).

5.12.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
segreg3 <- function(ab, ssb) log(ifelse(ssb >= 700, ab$a * 700, ab$a *
ssb))
FIT <- eqsr_fit(megw,nsamp=2000,remove.years=c(2014),models = c("seg-
reg3"))
eqsr_plot(FIT, n=2e4)
Fscan <- seq(0, 0.8, len = 40)
SIM<- Eqsim_run(FIT, bio.years = c(2005, 2014), bio.const=FALSE,
sel.years=c(2005,2014), sel.const=FALSE, Fscan = Fscan, length(Fscan),
Fcv=0.212, Fphi=0.423, Blim=blim, Bpa=bpa)
```

5.12.4 Settings

Table 5.12.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	Full dataseries (years classes 1986–2014)	2014 values excluded from the analysis because WGBIE did not trust in this value and it was replaced by a geometric mean in the short-term projections
Exclusion of extreme values (option extreme.trim)	Yes	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2005–2014	

Assessment error in the advisory year. CV of F	0.212	Taken from WKMSWREF4 estimates of 5 stocks
Autocorrelation in assessment error in the advisory year	0.423	Taken from WKMSWREF4 estimates of 5 stocks

5.12.5 Results

5.12.5.1 Stock recruitment relation

The stock recruitment fit using the three models (Ricker, BandH and segmented regression) weighted by the default "Buckland" method available in Eqsim. The stock–recruit relationship was fit initially using three models (Ricker, segmented regression and Beverton–Holt). The values obtained from the assessment do not show any clear stock–recruitment signal to allow a clear estimation of a stock–recruitment curve. The time-series is relatively short and there are no data sufficiently close to the origin to allow an understanding of what may happen at lower stock biomasses. Segmented regression is considered to be more appropriate in cases with S-R relationships with no clearly maxima defined. Breakpoint was fixed in B_{lim} (Figure 5.12.1).

B_{lim} was chosen as the lowest value of the SSB time-series (B_{loss}). Due to a data revision carried out in 2015, B_{loss} is now a bit higher from that used during the Benchmark in 2014 to define B_{lim}. A B_{lim} based in this new B_{loss} (700 t) was considered more convenient.

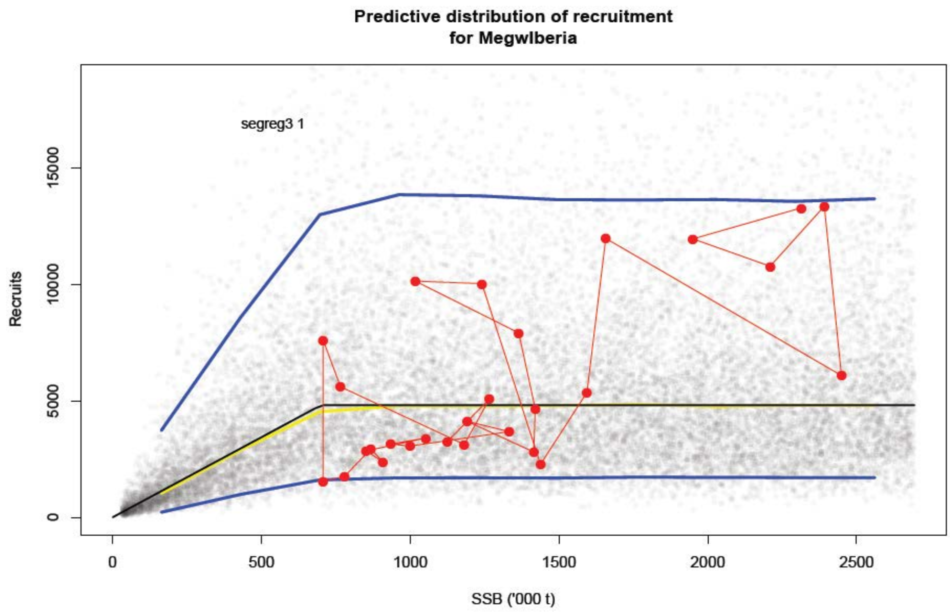


Figure 5.12.1. Stock–recruitment model using a segmented regression with the breakpoint fixed in Blim (700 t)

5.12.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.12.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.19 (Figure 5.12.2) with median landings of 336 t. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.29 and the lower bound was estimated at 0.12. $F_{P.05}$ was estimated at 0.24 which is below the estimate of upper bound on F_{MSY} implying that fishing at this upper bound needs to be restricted because of precautionary limits (Figure 5.12.3). The median of the SSB estimates at F_{MSY} was 1782 t (Figure 5.12.4). This value is below the maximum historical observed SSB of 2249 t.

A run with no error in the advice was carried out to estimate MSY $B_{trigger}$ and Flim. MSY $B_{trigger}$ was estimated at 1347 t, which is below the maximum historical value, and F_{lim} at 0.45. This results in F_{pa} = 0.32.

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 1347 t median F_{MSY} was estimated higher at 0.25 with a lower bound of the range at 0.17 and an upper bound at 0.34 (Figure 5.12.5). The $F_{P.05}$ increased to 0.40. The median of the SSB estimates at F_{MSY} was 2429 t which is above historical observed values (Figure 5.12.6).

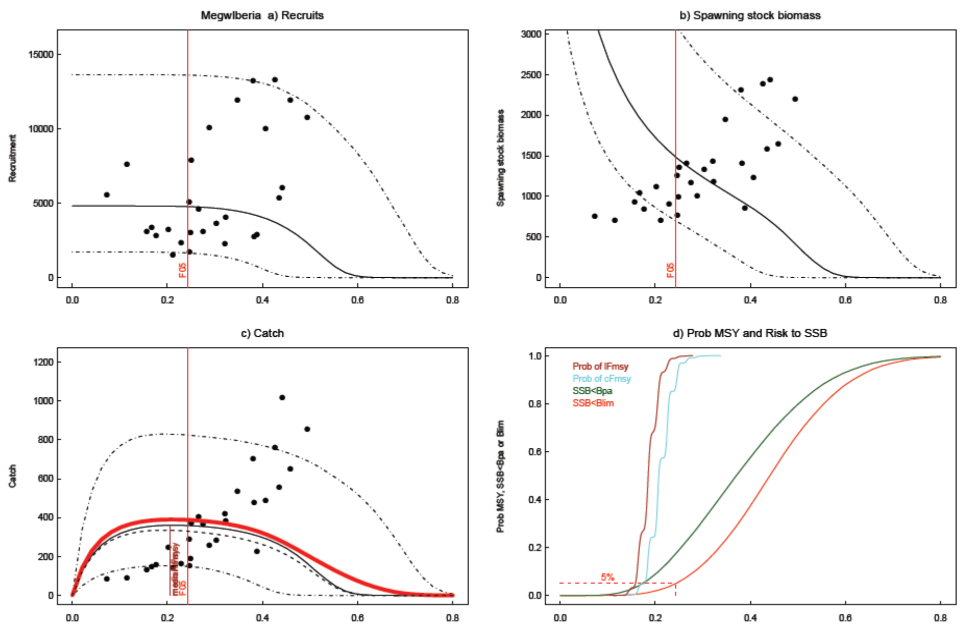


Figure 5.12.2. Eqsim summary plot for megrim in VIIIc and IXa (without $B_{trigger}$). Panels' a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

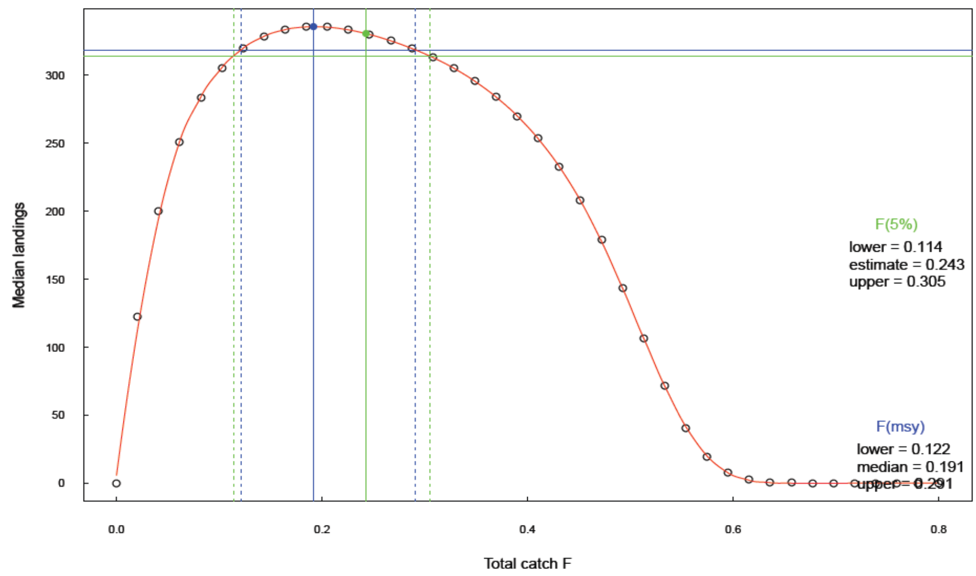


Figure 5.12.3. Megrim in VIIIc and IXa median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

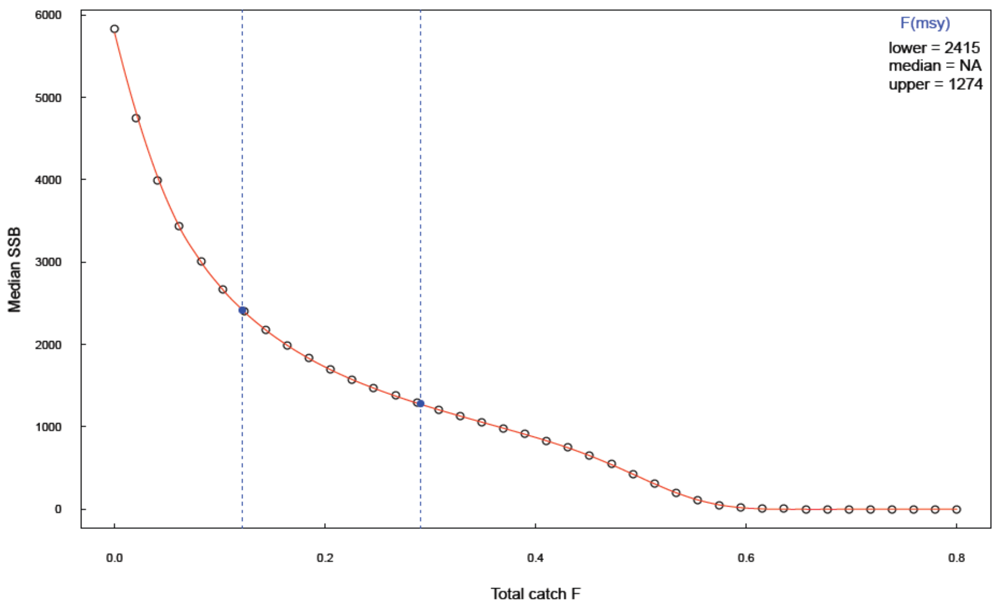


Figure 5.12.4. Megrim in VIIIc and IXa median SSB curve over a range of target F values (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

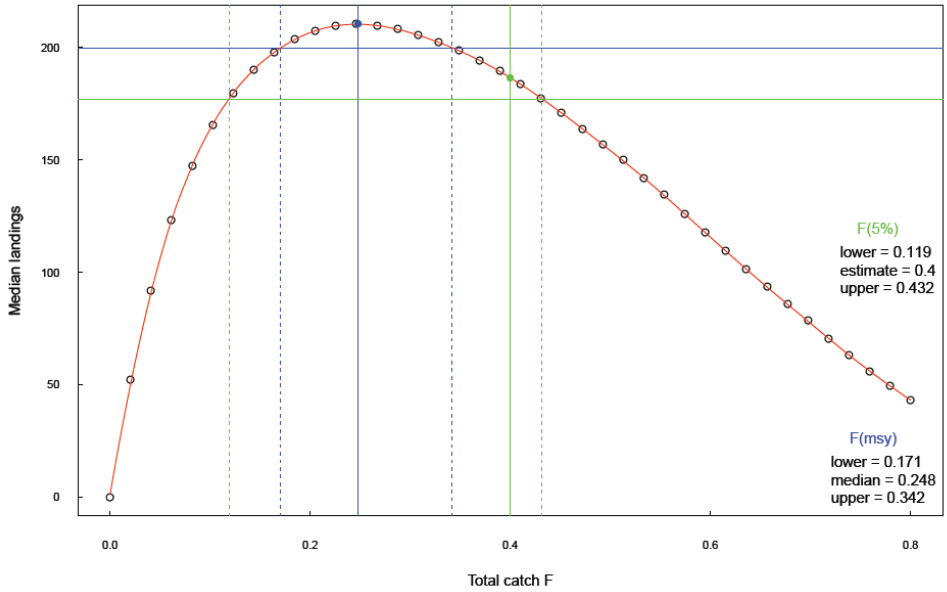


Figure 5.12.5. Megrim in VIIIc and IXa median landings yield curve with estimated reference points (MSY $B_{trigger}$=1347 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

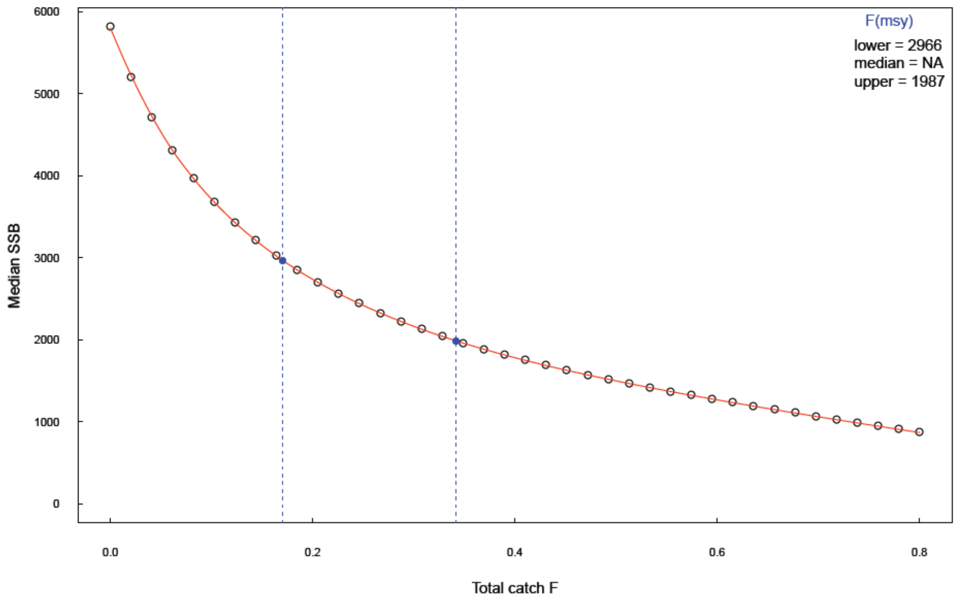


Figure 5.12.6. Megrim in VIIIc and IXa median SSB curve over a range of target F values (MSY $B_{trigger}$=1347 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.12.6 Proposed reference points

Table 5.12.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	700 t	B_{loss} estimated in 2015
B_{pa}	980 t	B_{lim}*1.4
F_{lim}	0.45	Based on segmented regression simulation of recruitment with Blim as the breakpointand no error
F_{pa}	0.32	$F_{pa} = F_{lim} \times \exp(-\sigma \times 1.645)$ σ=0.2
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.19	
F_{MSY} lower without $B_{trigger}$	0.12	
F_{MSY} upper without $B_{trigger}$	0.29	
MSY $B_{trigger}$	1347 t	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.24	
F_{MSY} upper precautionary without $B_{trigger}$	0.24	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	0.40, 0.40	
F_{MSY} with $B_{trigger}$, B_{pa}	0.25, 0.25	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.17, 0.17	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.34, 0.34	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.34, 0.34	
MSY	210 t	
Median SSB at F_{MSY}	2429 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	1987 t	
Median SSB upper (median at F_{MSY} lower)	2966 t	

5.12.7 Discussion / Sensitivity.

A previous exploratory run of Eqsim was carried out using a combination of the 3 stocks-recruitment models weighted by the default method available in Eqsim. Due to the fact that a clear S-R relationship was not found, it was decided to use only a segmented regression with breakpoint at B_{lim}. The obtained value of F_{MSY} (0.19) does not differ very much from the value of F_{max} (0.17) defined as F_{MSY} in the Benchmark WKSOUTH in 2014.

5.13 Plaice (*Pleuronectes platessa*) in Division VIIe (Western English Channel)

5.13.1 Current reference points

Table 5.13.1. Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	Not defined	
Current B_{pa}	Not defined	
Current F_{lim}	Not defined	
Current F_{pa}	Not defined	
Current F_{MSY}	0.24	F_{MAX} (2012). This value is stock specific.
Current $MSYB_{trigger}$	1650 t	Preliminary based on lowest SSB (in converged part of XSA) from which the stock recovered.

5.13.2 Source of data

Data used in the MSY interval analysis were taken from the FLStock object created during ICES IBPWCFlat2 2015. Data represent the latest assessment input and output data.

5.13.3 Methods used

All analyses were conducted with Eqsim. The main routine R code is as follows:-

```
blim <- round(min(ssb(stk.new)))
bpa <- round(blim*1.4)
segreg3  <- function(ab, ssb) log(ifelse(ssb >= blim, ab$a * blim, ab$a*
ssb))
FIT <- eqsr_fit(stk.new, nsamp = 5000, models = "segreg3")
SIM  <-  Eqsim_run(FIT,  bio.years=c(2005,  2014),  bio.const=FALSE,
sel.years=c(2005,2014),   sel.const=FALSE,   Fscan=seq(0,1.2,len=61),
Fcv=0.212, Fphi=0.423, Blim=blim, Bpa=bpa)
```

5.13.4 Settings

Table 5.13.2. Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1980–2014)	
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	Inspected and no trend in last 10 years observed
Exploitation pattern	2005–2014	Inspected and no trend in last 10 years observed

Assessment error in the advisory year. CV of F	0.212	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

New biomass reference points were defined and used within Eqsim. B_{lim} was set to B_{loss} and B_{PA} was calculated as B_{lim}*1.4, giving a B_{lim} of 1 745 t and a B_{pa} of 2 443 t.

5.13.5 Results

5.13.5.1 Stock recruitment relation

It was decided to base the analysis on a segmented regression only. The stock displays no stock and recruitment relationship with some of the highest levels of recruitment coming from the lowest levels of SSB. A segmented regression was assumed with breakpoint at B_{loss}, below which the dynamics of the stock are unknown (Figure 5.13.1): this implies no relationship between SSB and recruitment within the range of observed SSBs.

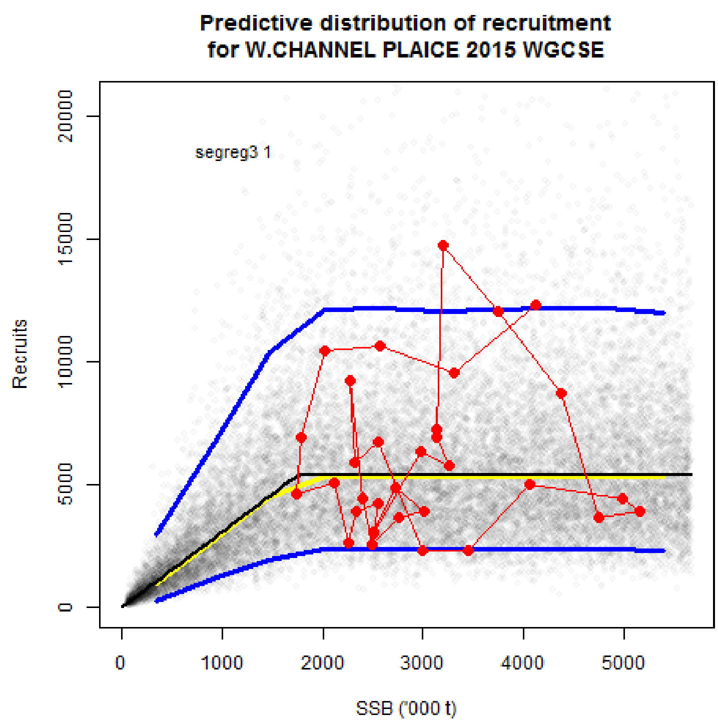


Figure 5.13.1. Stock recruitment relationship for plaice in Division VIIe.

5.13.5.2 Yield and SSB

F_{MSY} was taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve. F_{P05} is the F value associated with a 95% probability of SSB remaining above B_{lim}.

5.13.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.24 (Figure 5.13.3). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.47 and the lower bound at 0.14. F_{P05} was estimated at 0.59 and therefore the upper bound of the F_{MSY} range does not need to be restricted because of precautionary limits. The median of the SSB estimates at F_{MSY} was 7 403 t which is well above historically observed values (Figure 5.13.4).

A run with no error in the advice was carried out to estimate MSY $B_{trigger}$ and F_{lim}. MSY $B_{trigger}$ was estimated at 5 355 t and F_{lim} at 0.88.

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 5 355 t median F_{MSY} was estimated higher at 0.27 with a lower bound of the range at 0.14 and an upper bound at 0.51 (Figure 5.13.5). F_{P05} was not estimated as the probability of SSB remaining above B_{lim} does not fall below 95% over the range of Fs examined. The median of the SSB estimates at F_{MSY} was 6 736 t which is also outside historically observed values (Figure 5.13.6).

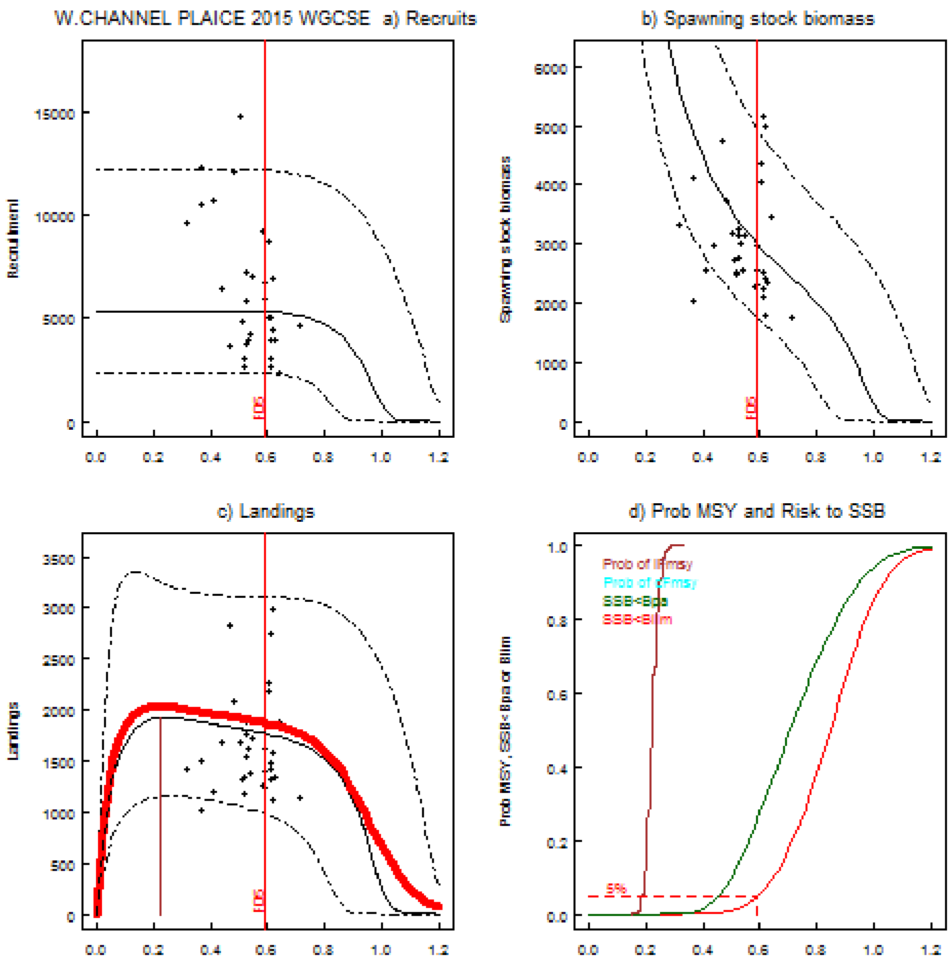


Figure 5.13.2. Eqsim summary plot for plaice in Division VIIe without MSY $B_{trigger}$.

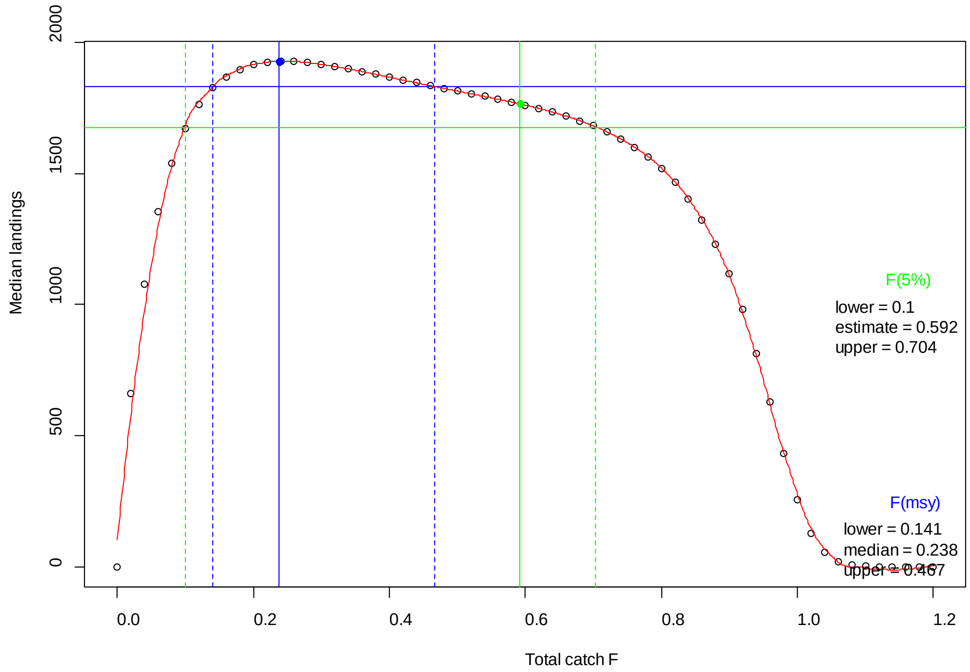


Figure 5.13.3 Median landings yield curve with estimated reference points for plaice in Division VIIe with fixed F exploitation.

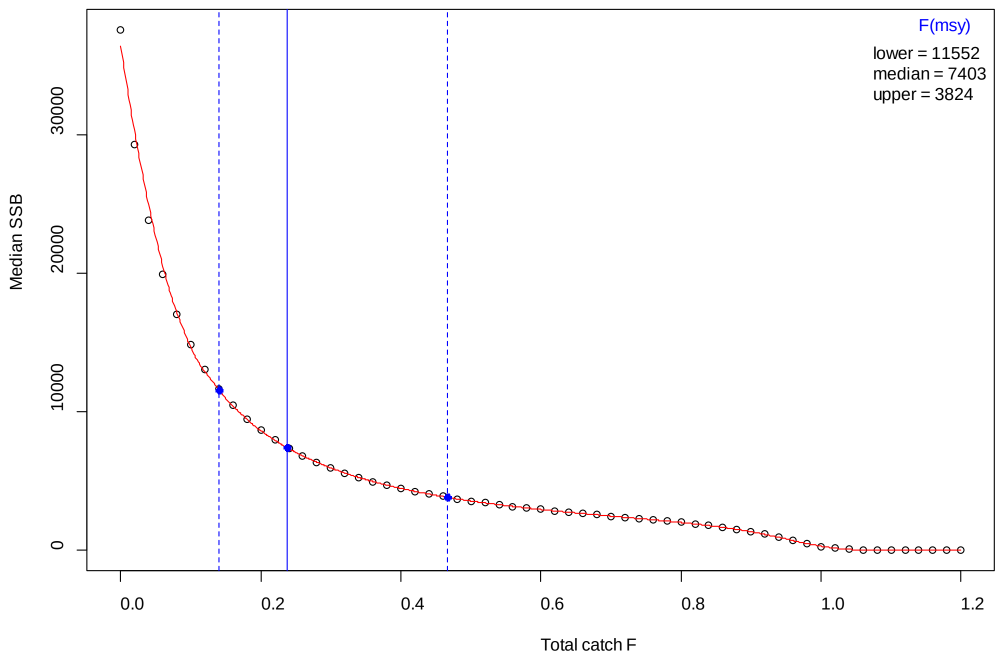


Figure 5.13.4. Median SSB for plaice in Division VIIe with fixed F exploitation.

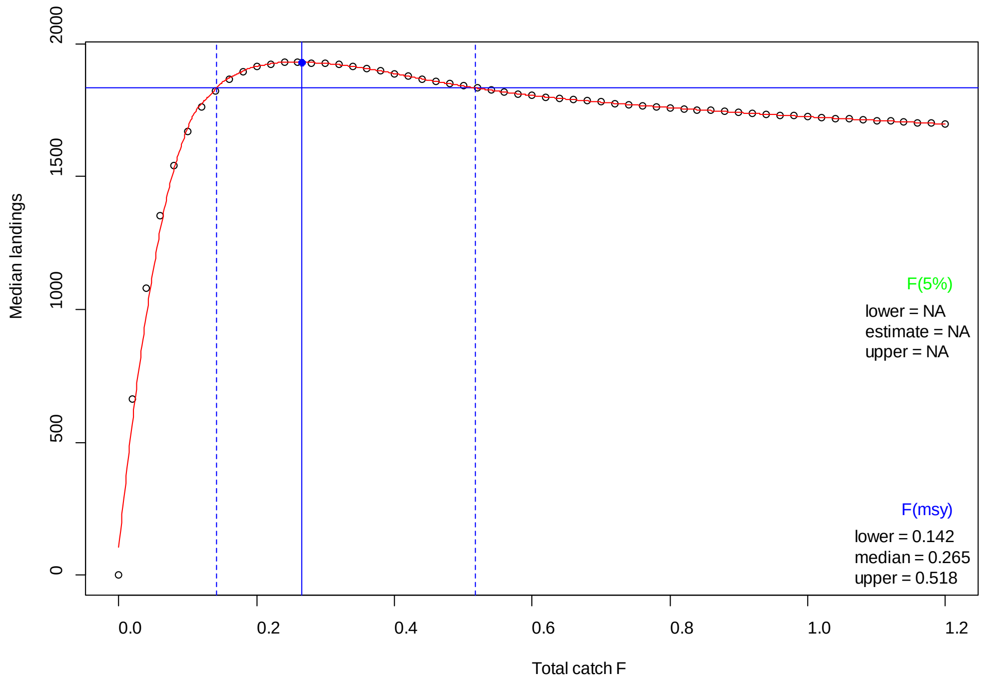


Figure 5.13.5. Median landings yield curve with estimated reference points for plaice in Division VIIe when applying the ICES MSY harvest control rule with $B_{trigger}$ at 5 355 t.

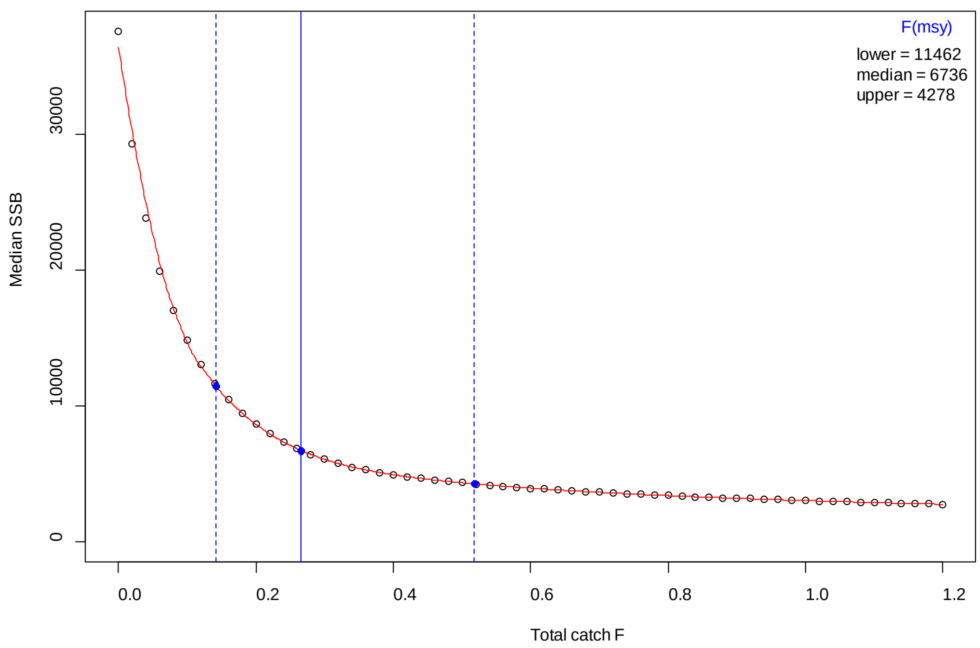


Figure 5.13.6. Median SSB for plaice in Division VIIe when applying the ICES MSY harvest control rule with $B_{trigger}$ at 5 355 t.

5.13.6 Proposed reference points

Table 5.13.3. Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	1 700 t	B_{loss}
B_{pa}	2 400 t	$1.4*B_{lim}$
F_{lim}	0.88	Based on segmented regression simulation of recruitment without error
F_{pa}	0.63	$F_{lim}*\exp(-1.645*\sigma)$; $\sigma=0.2$
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.24	
F_{MSY} lower without $B_{trigger}$	0.14	
F_{MSY} upper without $B_{trigger}$	0.47	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.59	
F_{MSY} upper precautionary without $B_{trigger}$	0.70	
MSY $B_{trigger}$	5 355 t	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	NA, 0.69	
F_{MSY} with $B_{trigger}$, B_{pa}	0.27, 0.24	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.14, 0.14	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.52, 0.48	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	NA, 0.88	
MSY	1 927 t	
Median SSB at F_{MSY}	7 403 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	3 824 t	
Median SSB upper (median at F_{MSY} lower)	11 552 t	

5.13.7 Discussion / Sensitivity.

During ICES IBPWCFlat2 2015 an exploratory run of Eqsim was carried out using an automatic weighting of all three stock–recruit models (Ricker, segmented regression and Beverton–Holt) resulting in an F_{MSY} of 0.35. Given the lack of any apparent stock–recruit relationship and no evidence that recruitment has been impaired the decision was made at WKMSYREF4 to use only a segmented regression with breakpoint at B_{loss}, below which the dynamics of the stock are unknown. This results in an F_{MSY} of 0.24 which is consistent with the value of F_{MAX} 2012 used previously.

5.14 Sole (*Solea solea*) in division VIII a and b (Bay of Biscay)

5.14.1 Current reference points

Table 5.14.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	Not defined	
Current B_{pa}	13000 t	The probability of reduced recruitment increases when SSB is below 13 000 t, based on the historical development of the stock.
Current F_{lim}	0.58	Based on the historical response of the stock.
Current F_{pa}	0.42	F_{lim} x exp(-σ x 1.645)
Current F_{MSY}	0.26	Fmax (as estimated by WGHMM 2010) because no stock–recruitment relationship, limited variations of recruitment, Fishing mortality pattern known with a low uncertainty
Current $MSYB_{trigger}$	13000 t	B_{pa} (provisional estimate)

5.14.2 Source of data

The Bay of Biscay sole is a category 1 stock with age based assessment (XSA). Data used in the analysis were taken from the FLStock object created during ICES WGBIE 2015. Data represent the latest assessment input and output data (ICES 2015, WGBIE).

5.14.3 Methods used

All analyses were conducted with EQSIM in R. The main routine R code is as follows:

```
segreg3 <- function(ab, ssb) log(ifelse(ssb >= Bpa, ab$a * Bpa, ab$a * ssb))
FIT <- eqsr_fit(sol, nsamp=2000, model="segreg3", method="Buckland", id.sr=NULL, remove.years=NULL, delta=1.3, nburn=10000)
SIM <- Eqsim_run(FIT, Fscan=seq(0, 1, len = 20), verbose=FALSE, extreme.trim=c(0.05, 0.95), bio.years=c(2005, 2014), sel.years=c(2005, 2014), bio.const=FALSE, sel.const=FALSE, Fcv=0.17, Fphi=0.64, Blim=7600, Bpa=10600, Btrigger=0, rhologRec=TRUE, recruitment.trim=c(3,-3), Nrun=200, process.error=TRUE)

For the retrospective:
out <- NULL
for(y in 2008:2014){
  cat(y,'\n')
  bio.years <- c(y-9,y)
  sel.years <- c(y-9,y)
    SIM_S <- Eqsim_run(FIT_S, Fscan=Fscan, verbose=verbose, extreme.trim=extreme.trim, bio.years=bio.years, sel.years=sel.years, bio.const=bio.const, sel.const=sel.const, Fcv=Fcv, Fphi=Fphi, Blim=Blim, Bpa=Bpa, Btrigger=Btrigger, rhologRec=rhologRec, recruitment.trim=recruitment.trim, Nrun=Nrun, process.error=process.error)
  out0 <- data.frame(y, Fmsy05 = SIM_S$Refs2[2,6], Fmsy95 = SIM_S$Refs2[2,8], FmsyMed = SIM_S$Refs2[2,4], FmsyMean = SIM_S$Refs2[2,5])

  out <- rbind(out,out0)}
```

5.14.4 Settings

Table 5.14.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	Full dataseries (years classes 1984–2014)	
Exclusion of extreme values (option extreme.trim)	Yes	(0.05 ; 0.95) default
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	Default
Exploitation pattern	2005–2014	A 10 years period was chosen to down weight the influence of changes in selection patterns resulting from the last 4 years (figure 5.14.1).
Assessment error in the advisory year. CV of F	0.17	Estimated from ICES advice 2002 to 2014 (table 5.14.3)
Autocorrelation in assessment error in the advisory year	0.64	Estimated from ICES advice 2002 to 2014 (table 5.14.3)

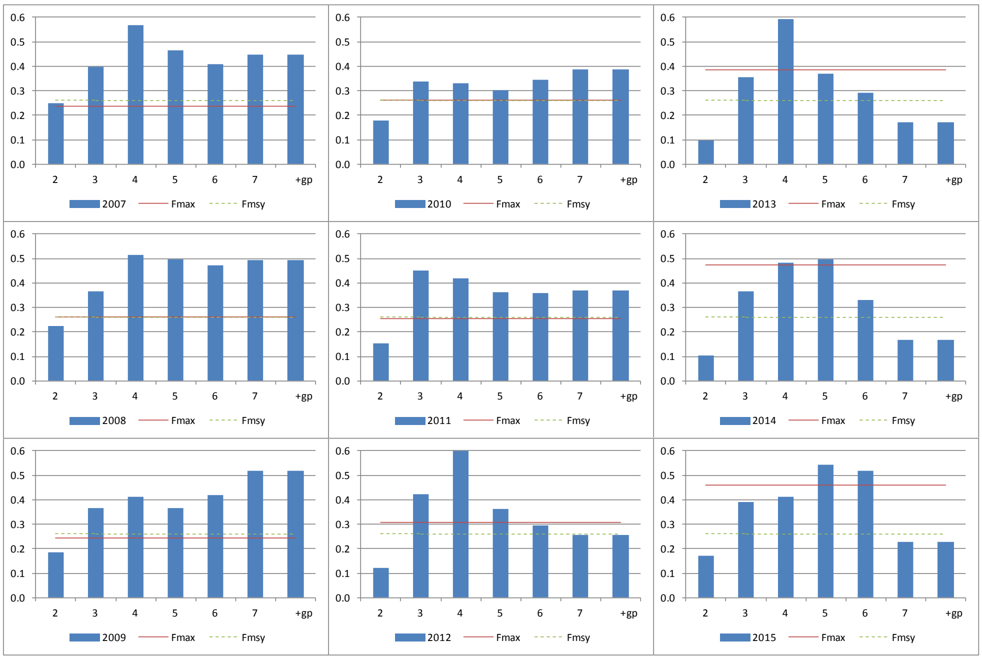


Figure 5.14.1: Evolution of the selection pattern (2007–2014) and the F_{max} (red line)

Table 5.14.3: Calculation of CV and autocorrelation between F Assessed and F Set for the assessments 2002-2014 for Sole VIIIab.

YEAR	F ASSESS	F SET	LN(FASS)	LN(FSET)	DEVIATIONS
2002	0.83	0.90	-0.186	-0.105	-0.081
2003	0.49	0.77	-0.722	-0.259	-0.463
2004	0.37	0.44	-1.000	-0.827	-0.172
2005	0.46	0.47	-0.775	-0.760	-0.015
2006	0.43	0.42	-0.836	-0.868	0.032
2007	0.45	0.36	-0.810	-1.013	0.204
2008	0.48	0.43	-0.739	-0.845	0.106
2009	0.44	0.33	-0.810	-1.097	0.287
2010	0.40	0.30	-0.923	-1.188	0.266
2011	0.38	0.35	-0.958	-1.037	0.079
2012	0.45	0.38	-0.801	-0.972	0.171
2013	0.47	0.39	-0.753	-0.936	0.183
2014	0.48	0.35	-0.734	-1.055	0.321

STD DEVIATIONS	0.22
F_{cv}	0.17
Phi	0.64

5.14.5 Results

5.14.5.1 Stock recruitment relation

The Bay of Biscay sole has a stock recruitment relationship with very little dependence of R or SSB (figure 5.14.2).

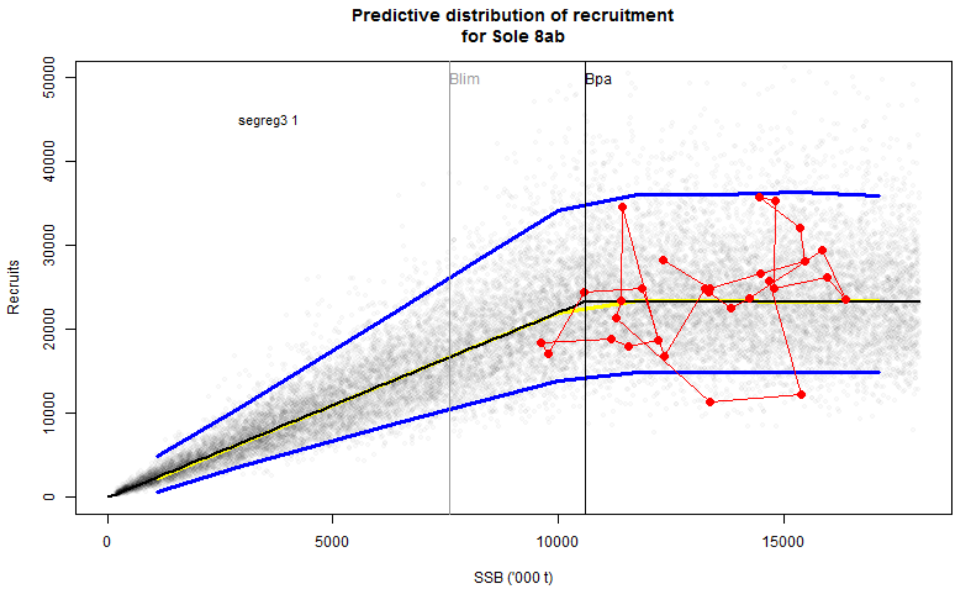


Figure 5.14.2: Stock recruitment relationship for the Bay of Biscay sole (vertical grey line is the B_{lim} and vertical black line is B_{pa}).

The WKMSYREF3 (2014) recommends that in such cases, when the mean recruitment is more or less stable at the observed SSB, appropriate model they should be a hockey stick relationships with the lowest observed SSB as the forced breakpoint. In this case where just two below average recruitments were observed at the lowest biomass and B_{pa} was set at an SSB just above this SSB and it was decided to base the analysis on a segmented regression only with the breakpoint set at B_{pa}.

For this stock, the group decides to define the B_{pa} as the lowest value of the observed series where good recruitment was observed and biomass had shown a positive response (10600 t). Then a proxy for B_{lim} was estimated with the equation [$B_{pa} = B_{lim}$ x exp (σ x 1.645)] at 7600 t. The breakpoint was decided to B_{pa} (10600 t).

5.14.5.2 Yield and SSB

For the base run, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.14.5.3 Eqsim analysis

a) Segmented regression method, full SR time-series, without $B_{trigger}$

This first run, using the segmented regression as the only SR method gives a F_{MSY} at 0.33. The F (5%) estimate (0.48) is closed to the F (0.47) estimated for 2015 during the WGBIE (2015).

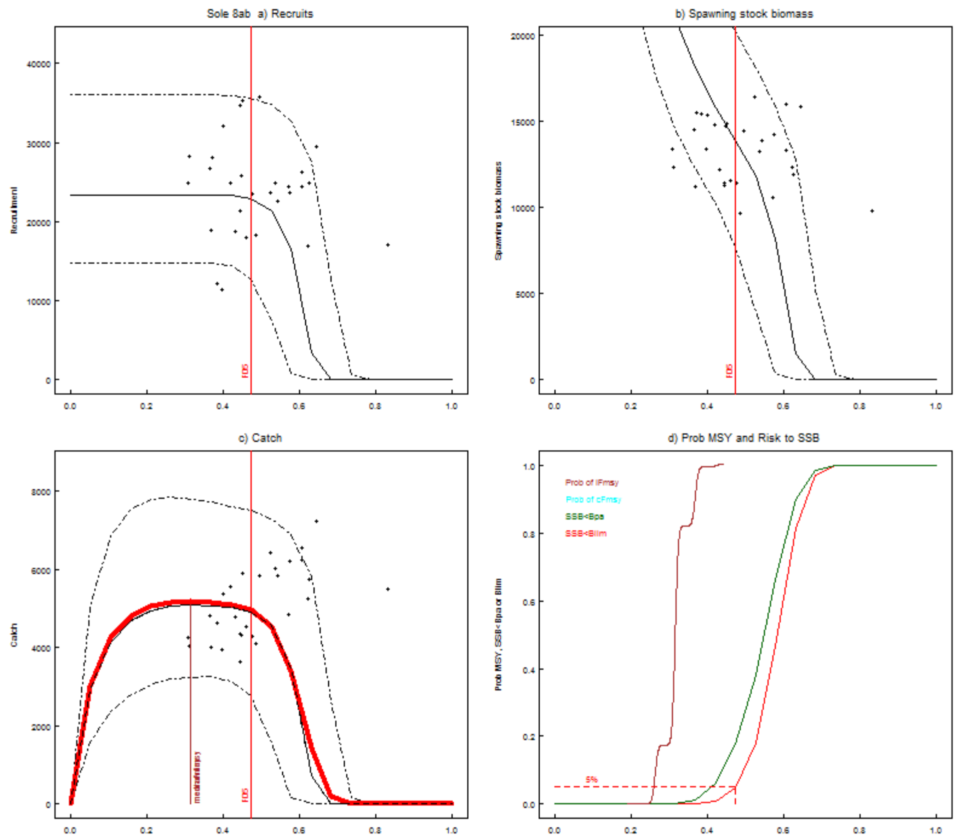


Figure 5.14.3: Eqsim summary plot for Sole VIIIab without $B_{trigger}$. Panels a to c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown).

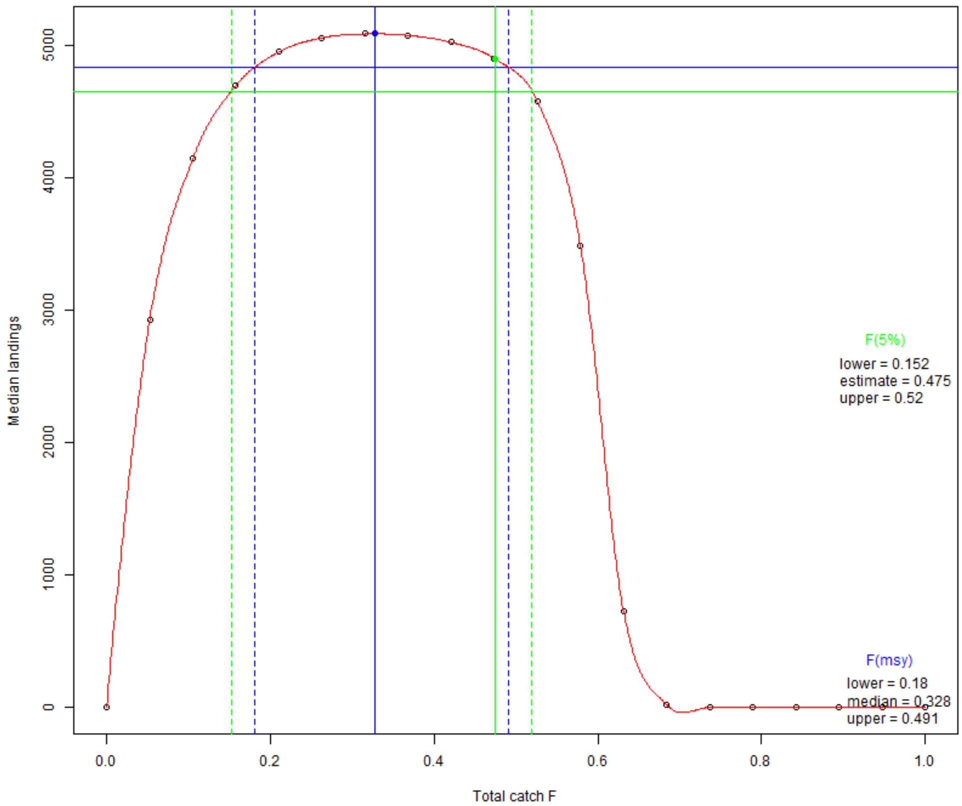
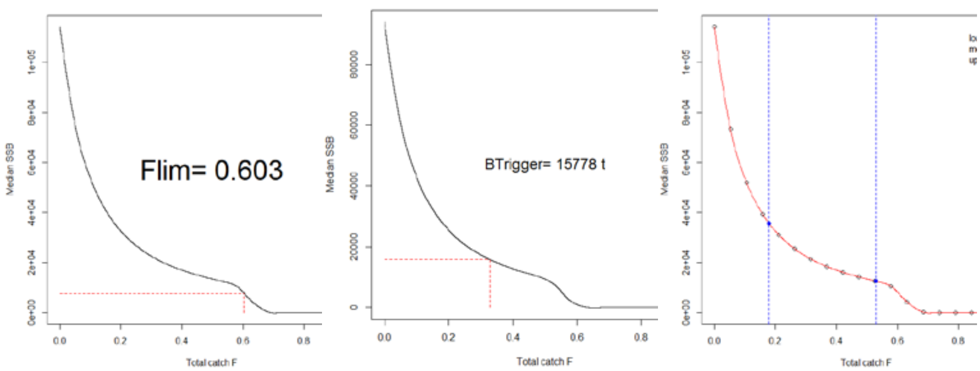


Figure 5.14.4: Eqsim median landings yield curve with estimated reference points without $B_{trigger}$. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F (5%) estimate (solid) and range at 95% of yield implied by F (5%) (Dotted) for sole VIII ab.

Running the code with no error gives an estimate of F_{lim} = 0.6 and MSY $B_{trigger}$ at 15800 t with a F_{MSY} at 0.33.



b) Segmented regression method, full SR time-series, with $B_{trigger}$

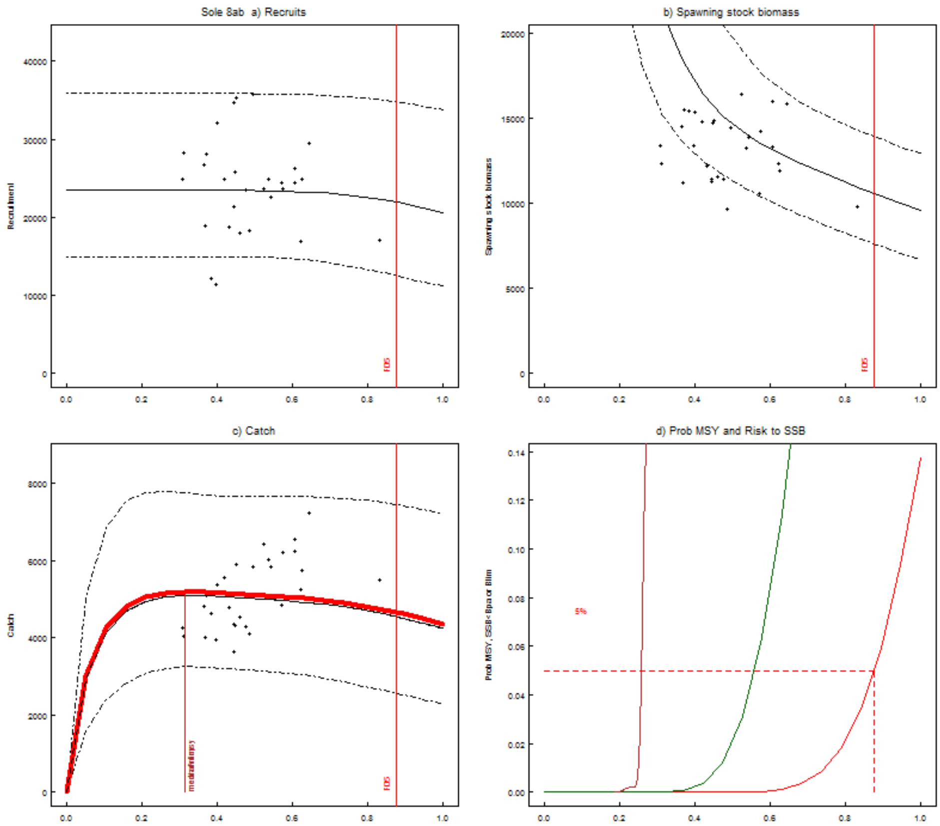


Figure 5.14.5: Eqsim summary plot for Sole VIIIab with $B_{trigger}$. Panels a to c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown).

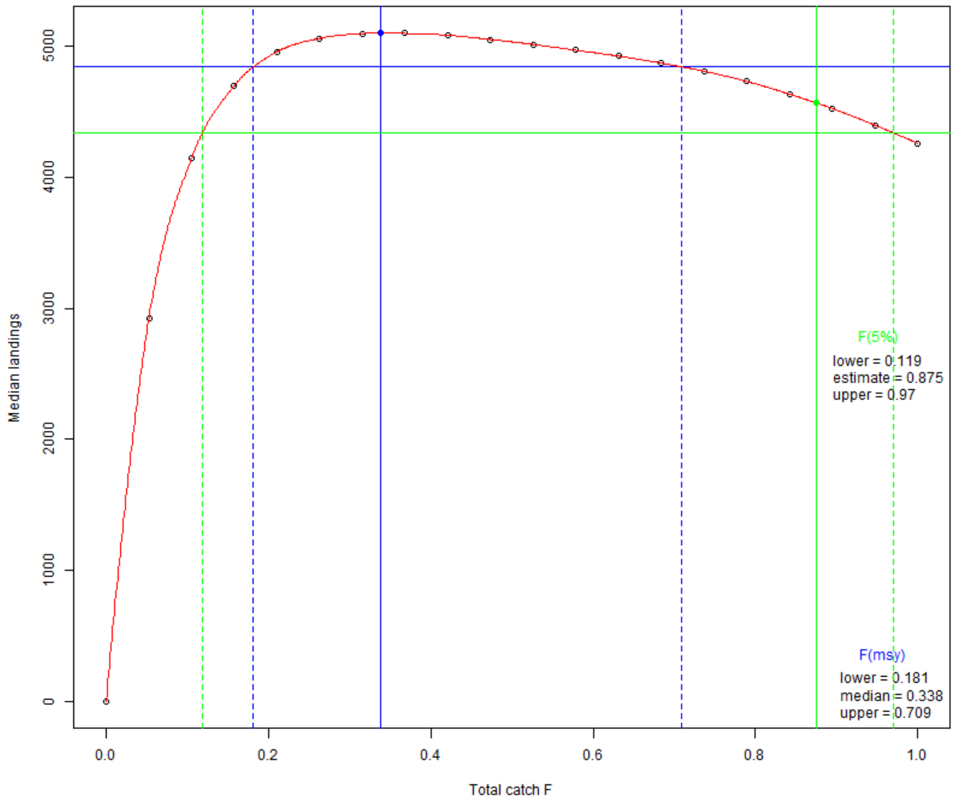


Figure 5.14.6: Eqsim median landings yield curve with estimated reference points with $B_{trigger}$. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F (5%) estimate (solid) and range at 95% of yield implied by F (5%) (Dotted) for sole VIII ab.

5.14.6 Proposed reference points

Table 5.14.4 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	7600	$B_{lim} = B_{pa} / \exp(\sigma \times 1.645)$ (proxy)
B_{pa}	10600	lowest SSB with good recruitment and increase of SSB
F_{lim}	0.6	In equilibrium gives a 50% probability of SSB>B_{lim}
F_{pa}	0.43	$F_{pa} = F_{lim} \times \exp(-\sigma \times 1.645)$
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.33	
F_{MSY} lower without $B_{trigger}$	0.18	
F_{MSY} upper without $B_{trigger}$	0.49	
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	0.48	
F_{MSY} upper precautionary without $B_{trigger}$	0.52	
MSY $B_{trigger}$	15800 t	
$F_{P.05}$ (5% risk to B_{lim} with $B_{trigger}$, B_{pa})	0.88, 0.59	

F_{MSY} with $B_{trigger}$, B_{pa}	0.34, 0.33
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.18, 0.18
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.71, 0.55
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.97, 0.65
MSY	5094 t
Median SSB at F_{MSY}	19826 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	12071 t
Median SSB upper (median at F_{MSY} lower)	34787 t

5.14.7 Discussion / Sensitivity.

Exploratory runs were done using only the segmented regression weighted by the default "Buckland" method with breakpoint at B_{PA}. The calculation of F_{MSY} with or without $B_{trigger}$ gives similar values. The F_{MSY} with $B_{trigger}$ is set at 0.34 and at 0.33 with $B_{trigger}$ = 0 or B_{pa}.

The retrospective analysis (Figure 5.14.7) shows that after stability for the F_{MSY} until 2011, he is increasing. This shows that it is sensitive to changes that have been observed in the selection pattern in recent years.

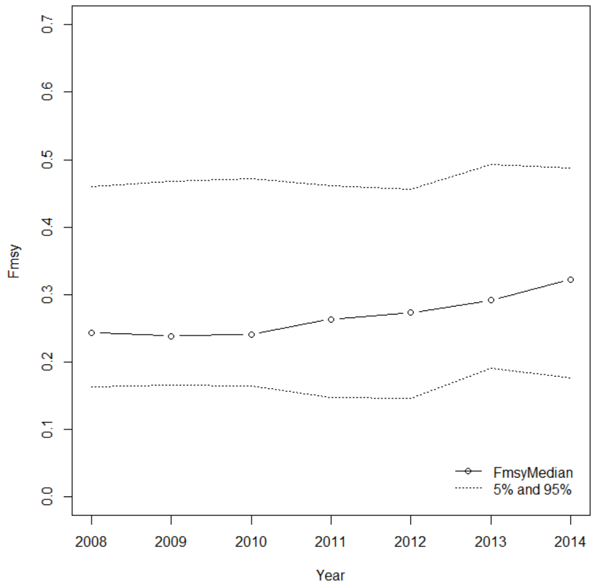


Figure 5.14.7: Retrospective analysis (F_{MSY} Median)

5.15 Sole (*Solea solea*) in Divisions VIIf,g (Bristol Channel, Celtic Sea)

5.15.1 Current reference points

Table 5.15.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	Not defined	
Current B_{pa}	2200t	There is no evidence of reduced recruitment at the lowest biomass observed and B_{PA} can therefore be set equal to the lowest observed SSB
Current F_{lim}	0.52	F_{lim}: F_{loss}
Current F_{pa}	0.37	This F is considered to have a high probability of avoiding Flim and maintaining SSB above B_{PA} for ten years, taking into account the uncertainty of assessments. Fpa: Flim × 0.72 implies a less than 5% probability that (SSBMT< B_{PA}).
Current F_{MSY}	0.31	Provisional proxy based on stochastic simulations.
Current $MSYB_{trigger}$	2200 t	B_{pa}

5.15.2 Source of data

Data used in the MSY interval analysis were taken from an FLStock object created during ICES WGCSE 2015. Data represent the latest assessment input and output data (ICES 2015).

5.15.3 Methods used

All analyses were conducted with Eqsim.

The main code is as follows:

```
segreg3  <- function(ab, ssb) log(ifelse(ssb >= 1700, ab$a * 1700, ab$a
* ssb))
FIT_S <- eqsr_fit(sol, nsamp=2000, model ="segreg3")
eqsr_plot(FIT_S, n=2e4)
SIM_S <- Eqsim_run(FIT_S,  Fscan= seq(0, 1, len = 20), verbose=FALSE,
bio.years= c(2005,   2014), sel.years= c(2005,   2014), Fcv=0.212,
Fphi=0.423,  Blim=1700,  Bpa=2380,  Nrun=150,  Btrigger=0,  rhologRec
=FALSE)
```

5.15.4 Settings

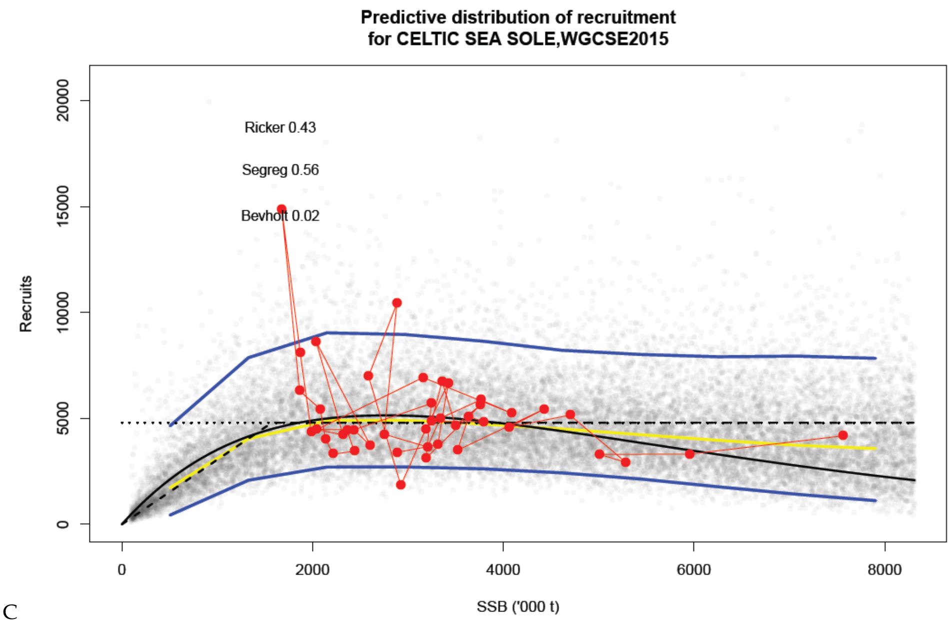
Table 5.15.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1971–2014)	
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2005–2014	
Assessment error in the advisory year. CV of F	0.212	Sensible default value
Autocorrelation in assessment error in the advisory year	0.423	Sensible default value

5.15.5 Results

5.15.5.1 Stock recruitment relation

The full available time-series of recruitment was used to fit stock recruitment models. The stock recruitment fit, using the three models (Ricker, Beverton–Holt and segmented regression) resulted in very low weight to the Beverton–Holt model. The Ricker and segmented regression models obtained 43% and 56% respectively (Figure 5.15.1). Considering that there was no particular biological reason to support a Ricker stock assessment model, the workshop decided to use a more conservative approach and to base the analysis on a segmented regression only with a breakpoint set at B_{lim} of 1700t (Figure 5.15.2). B_{lim} was chosen as the lowest value of the SSB time-series (B_{loss}).



C

Figure 5.15.1. Eqsim summary of recruitment models using the default "Buckland" method (Ricker, Beverton–Holt and segmented regression)

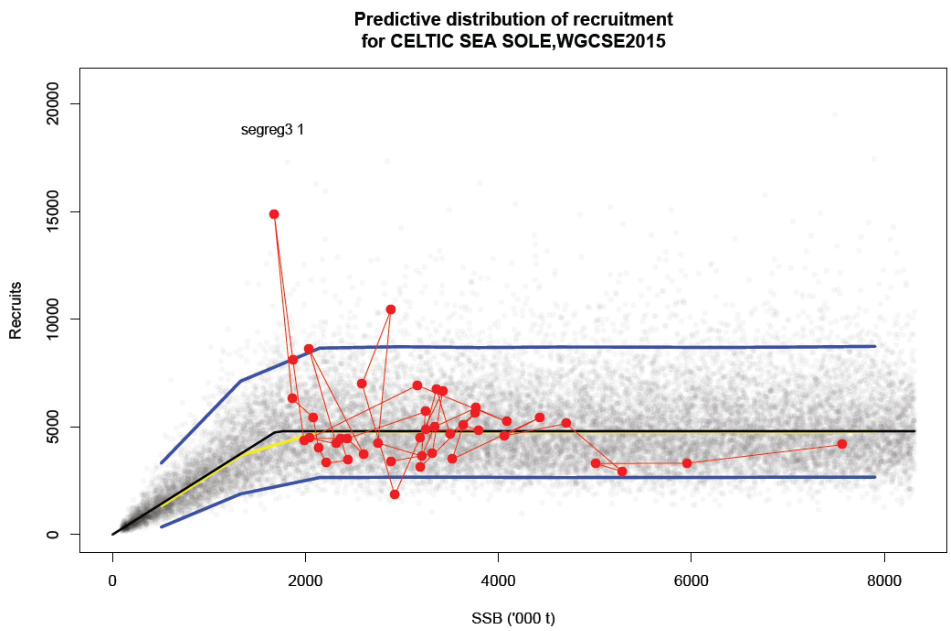


Figure 5.15.2. Eqsim summary of recruitment models using a segmented regression with the breakpoint set at a SSB of 1700t

5.15.5.2 Yield and SSB

For the base run, yield excludes discards as they are considered negligible (Catch = Landing), with F_{MSY} taken as the peak of the median catch yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.15.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.27 (Figure 5.15.4). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.42 and the lower bound was estimated at 0.15. $F_{P.05}$ was estimated at 0.36 and therefore the upper bound should be restricted to that value for precautionary reasons. The median of the SSB estimates at F_{MSY} was 3361t.

A run with no error in the advice was carried out to estimate $MSYB_{trigger}$ and F_{lim}. $MSYB_{trigger}$ was estimated at 2683t and F_{lim} at 0.48.

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 2683t, median F_{MSY} was estimated at 0.28 with lower bound of the range at 0.16 and an upper bound at 0.58. The $F_{P.05}$ increased to 0.49

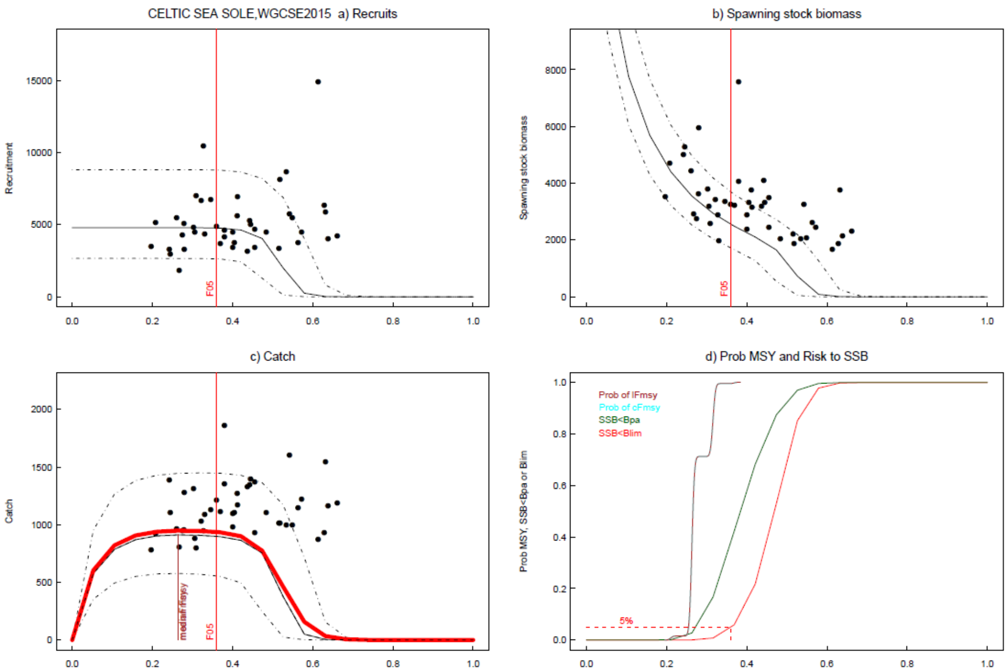


Figure 5.15.3. Eqsim summary plot for Bristol Channel and Celtic Sea sole (no trim, no $B_{trigger}$). Panels a–c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

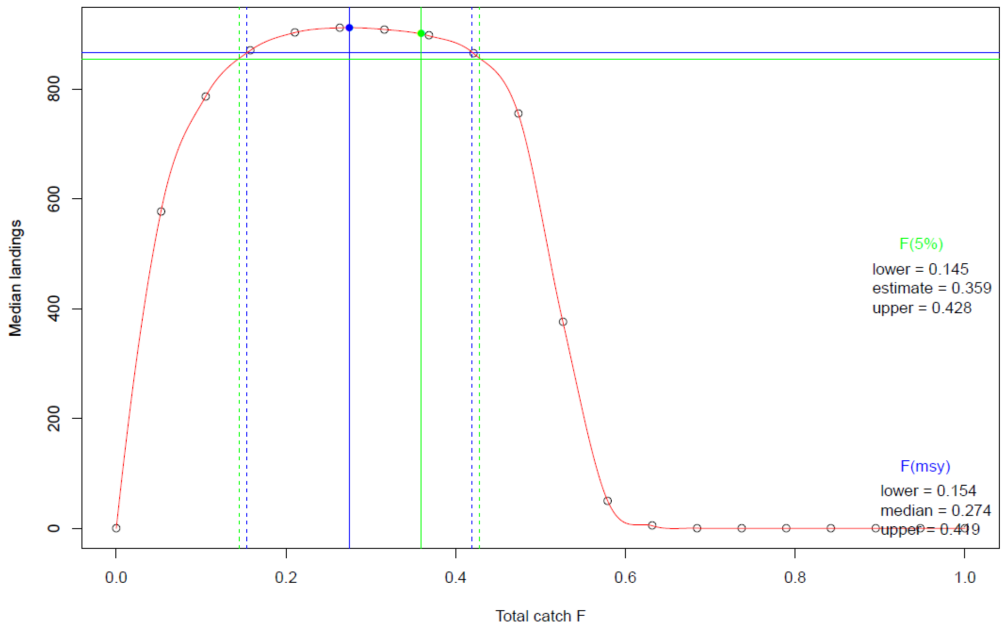


Figure 5.15.4 Bristol Channel and Celtic Sea sole median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

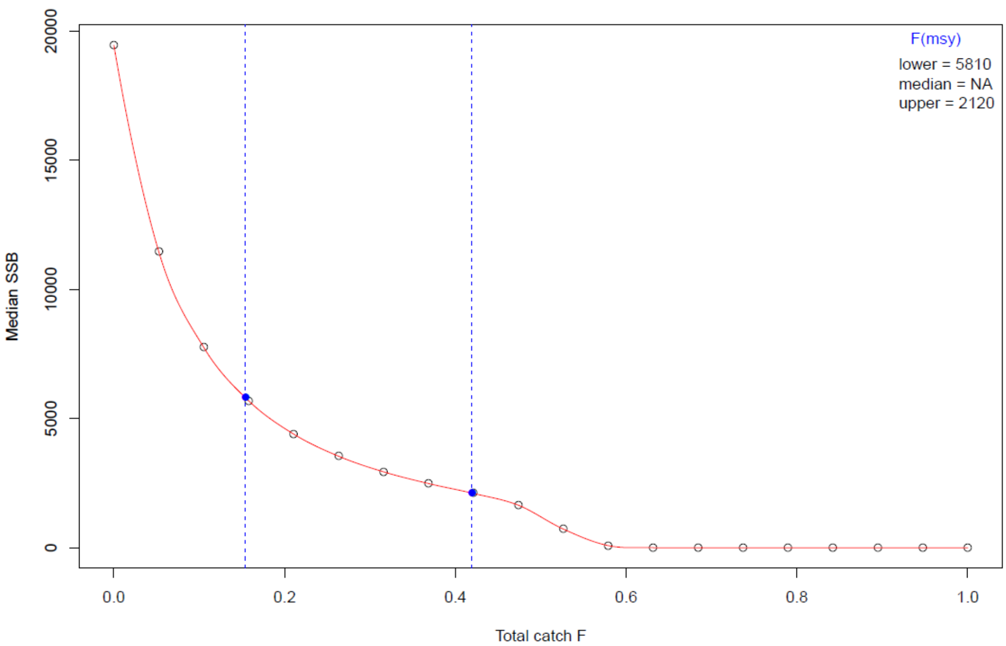


Figure 5.15.5 Median SSB for Northern Shelf haddock over a range of target F values (without MSY $B_{trigger}$). Blue lines show location of F (MSY) (solid) with 95% yield range (dotted).

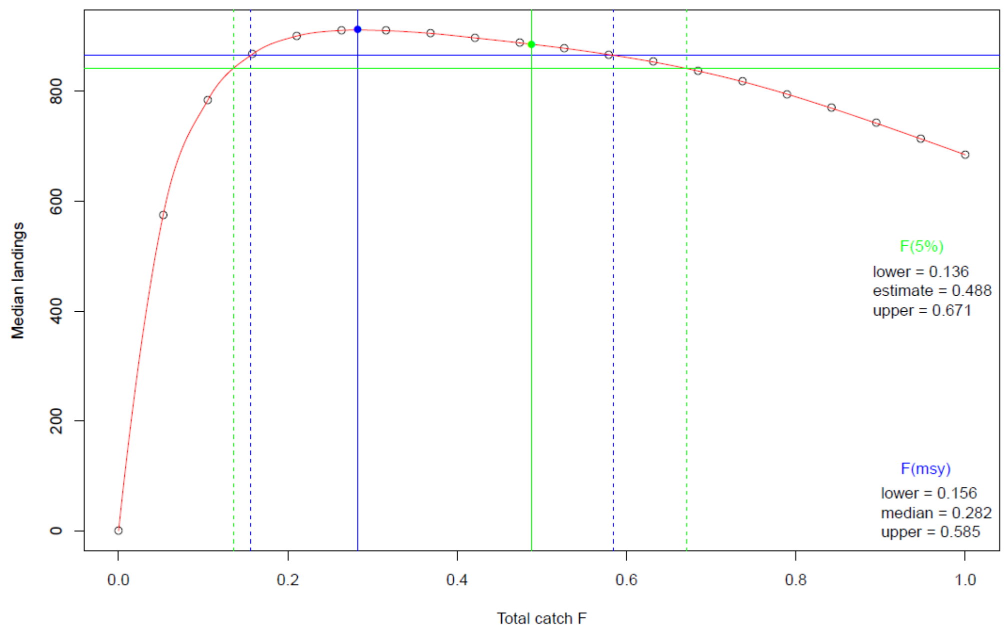


Figure 5.15.6 Bristol Channel and Celtic Sea sole median landings yield curve with estimated reference points (with MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

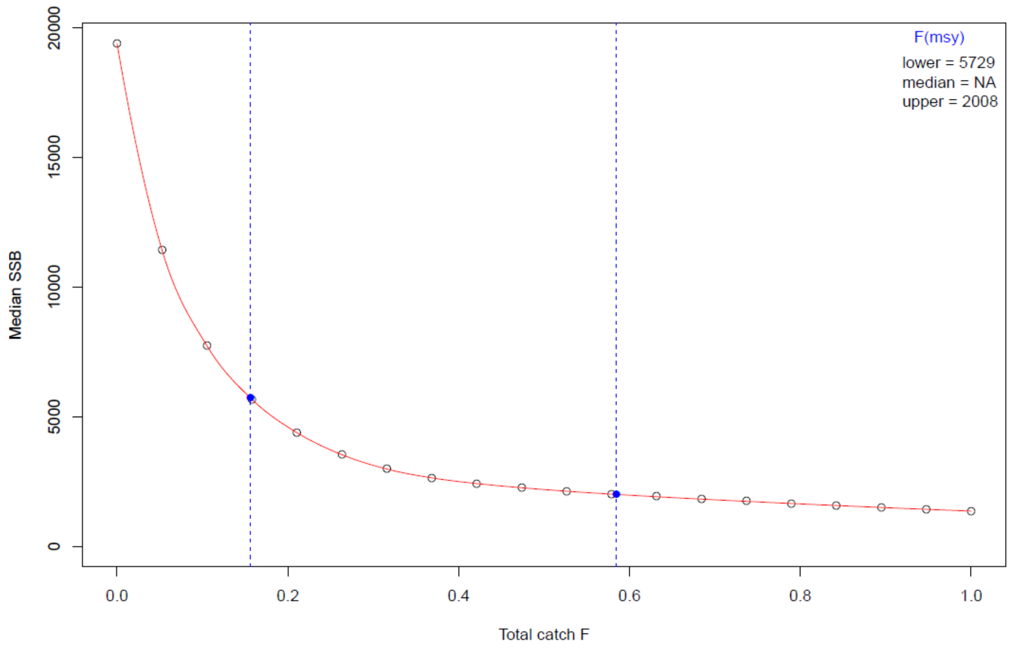


Figure 5.15.7 Median SSB for Northern Shelf haddock over a range of target F values (with MSY $B_{trigger}$). Blue lines show location of F (MSY) (solid) with 95% yield range (dotted).

5.15.6 Proposed reference points

Table 5.15.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	1700t	Bl_{oss} estimated in 2015
B_{pa}	2380t	B_{lim}*1.4
F_{lim}	0.48	Based on segmented regression simulation of recruitment with Blim as the breakpoint
F_{pa}	0.34	F_{lim}/1.4
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.27	
F_{MSY} lower without $B_{trigger}$	0.15	
F_{MSY} upper without $B_{trigger}$	0.42	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.36	
F_{MSY} upper precautionary without $B_{trigger}$	0.36	
$MSYB_{trigger}$	2683t	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{PA})	0.49,0.43	
F_{MSY} with $B_{trigger}$	0.28,0.28	
F_{MSY} lower with $B_{trigger}$	0.16,0.15	
F_{MSY} upper with $B_{trigger}$	0.58,0.54	
F_{MSY} upper precautionary with $B_{trigger}$	0.49,0.43	
MSY	906t	
Median SSB at F_{MSY}	3361t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	2114t	
Median SSB upper (median at F_{MSY} lower)	5770t	

5.15.7 Discussion / Sensitivity.

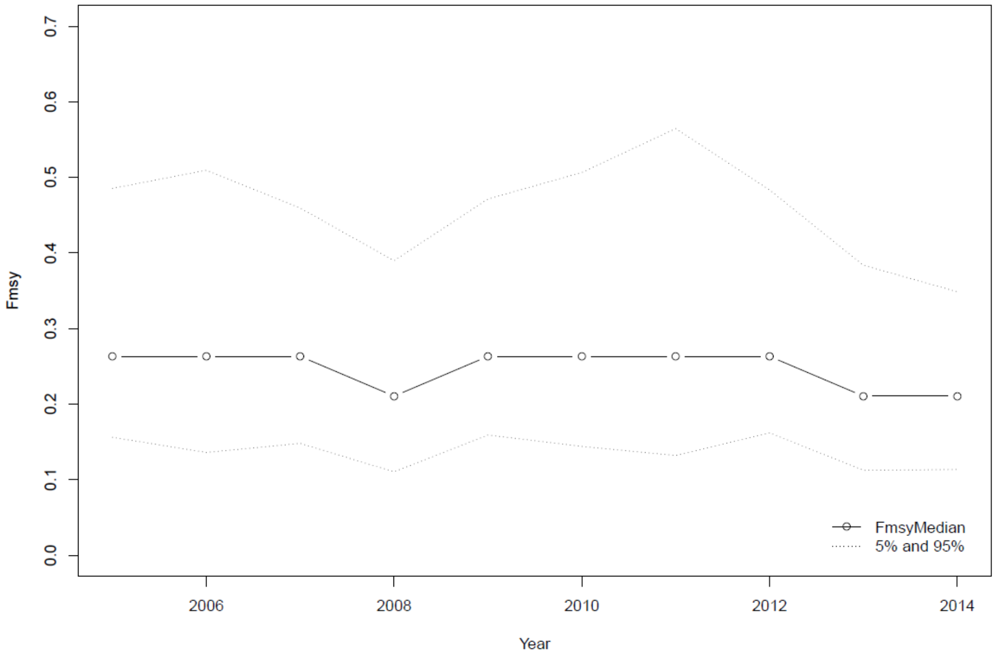


Figure 5.15.8. Retrospective estimates of F_{MSY}, the last year of the data were iteratively removed from the simulation. The solid line represents the F_{MSY} estimate based on the median yield, the dotted lines represent the 5th and 95th percentiles of F_{MSY} median.

The retrospective analysis carried out by removing the last year of the series using a moving window of ten years did not show any noticeable instability in the F_{MSY} estimates.

5.16 Sole (*Solea solea*) in Division VIIe (Western English Channel)

5.16.1 Current reference points

Table 5.16.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	1300 t	WKFRAME2 meta-analysis
Current B_{pa}	1800 t	WKFRAME2 meta-analysis
Current F_{lim}	Not defined	
Current F_{pa}	Not defined	
Current F_{MSY}	0.27	Based on long-term stochastic simulations
Current $MSYB_{trigger}$	2800 t	Based on the lower 95% confidence limit with exploitation at F = 0.27 from long-term stochastic simulations.

5.16.2 Source of data

Data used in the MSY interval analysis were taken from the FLStock object created during ICES IBPWCFlat2 2015. Data represent the latest assessment input and output data.

5.16.3 Methods used

All analyses were conducted with Eqsim. The main routine R code is as follows:-

```
segreg3  <- function(ab, ssb) log(ifelse(ssb >= bloss, ab$a * bloss,
ab$a* ssb))
FIT <- eqsr_fit(stk.new, nsamp = 2000, models = "segreg3")
SIM  <-  Eqsim_run(FIT,  bio.years=c(2005,  2014),  bio.const=FALSE,
sel.years=c(2005,2014),   sel.const=FALSE,   Fscan=seq(0,1.2,len=61),
Fcv=0.212, Fphi=0.423, Blim=blim, Bpa=bpa)
```

5.16.4 Settings

Table 5.16.2. Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1969–2014)	
Exclusion of extreme values (option extreme.trim)	No	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	Inspected and no trend in last 10 years observed
Exploitation pattern	2005–2014	Inspected and no trends in last 10 years observed
Assessment error in the advisory year. CV of F	0.212	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

New biomass reference points were defined and used within Eqsim. Given that the range of historic F is not sufficient to explore biomass fully, B_{PA} was set to the lowest SSB with recruitment above the plateau of the segmented regression (SSB in 1999) and B_{lim} was calculated as $B_{pa}/1.4$, giving a B_{lim} of 2 039 t and a B_{PA} of 2 855 t.

Assessment error (F_{cv}) and autocorrelation (F_{phi}) were estimated from ICES advice for the years 2005-2014, giving an F_{cv} of 0.106 and an F_{phi} of -0.190. However, because advised Fs could not be obtained for 2010 and 2012, few pairs were available to calculate autocorrelation. Also, advised F is consistently higher than realized F, introducing a bias over the period. For these reasons it was decided to use default, rather than calculated, values of assessment error and autocorrelation.

5.16.5 Results

5.16.5.1 Stock recruitment relation

The stock–recruit relationship was fit initially using three models (Ricker, segmented regression and Beverton–Holt). However, both the Ricker and Beverton–Holt curves increased without reaching plateau. In such cases, F_{MSY} tends to be estimated at very low values as it is assumed in predictions that recruitment is an ever increasing function of SSB. To avoid such unrealistic predictions it was decided to base the analysis on a segmented regression only.

During ICES IBPWCFlat2 (2015) a run of Eqsim was carried out using a fitted segmented regression (Figure 5.16.1 left). This stock–recruit relationship was driven by low recruitment in the early years of the time-series and estimated a breakpoint within the range of observed SSBs (3 466 t). WKMSYREF4 considered that recruitment was unlikely to be impaired within the range of biomasses observed and therefore assumed a segmented regression with breakpoint at B_{loss} (Figure 5.16.1 right). This stock–recruit relationship is compatible with the new B_{pa} (the lowest SSB with high recruitment), whereas using the stock–recruit function from ICES IBPWCFlat2 (2015) would imply a B_{PA} in the point cloud. Forcing the breakpoint of the segmented regression at B_{loss}, rather than B_{lim}, gives a more conservative stock–recruit function as B_{loss} takes a higher value of SSB.

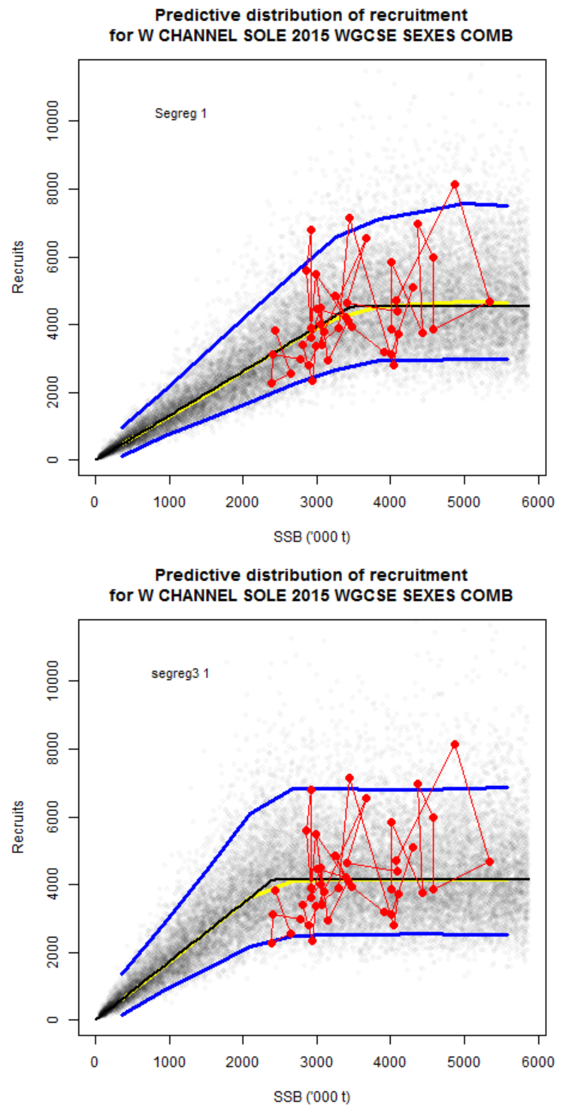


Figure 5.16.1. Stock recruitment relationships for sole in Division VIIe from ICES IBPWCFlat2 (left) and WKMSYREF4 (right).

5.16.5.2 Yield and SSB

F_{MSY} was taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve. F_{P05} is the F value associated with a 95% probability of SSB remaining above B_{lim}.

5.16.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.29 (Figure 5.16.3). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.34 and the lower bound at 0.16. F_{P05} was estimated at 0.32 and therefore the upper bound should be restricted to that value for precautionary reasons. The median of the SSB estimates at F_{MSY} was 3 356 t which is within the range of historically observed values (Figure 5.16.4).

Runs with no error in the advice were carried out to estimate $MSYB_{trigger}$ and F_{lim}. Additionally, to estimate F_{lim} the breakpoint of the segmented regression was set to B_{lim}. F_{lim} was estimated at 0.44 and $MSYB_{trigger}$ was estimated at 2 826 t, which was considered close enough to 2 855 t to be replaced by B_{pa}.

When applying the ICES MSY harvest control rule with $B_{trigger}$ at B_{PA} median F_{MSY} was estimated at 0.30 with a lower bound of the range at 0.16 and an upper bound at 0.43 (Figure 5.16.5). F_{P05} increased to 0.40. The median of the SSB estimates at F_{MSY} was 3 313 t (Figure 5.16.6).

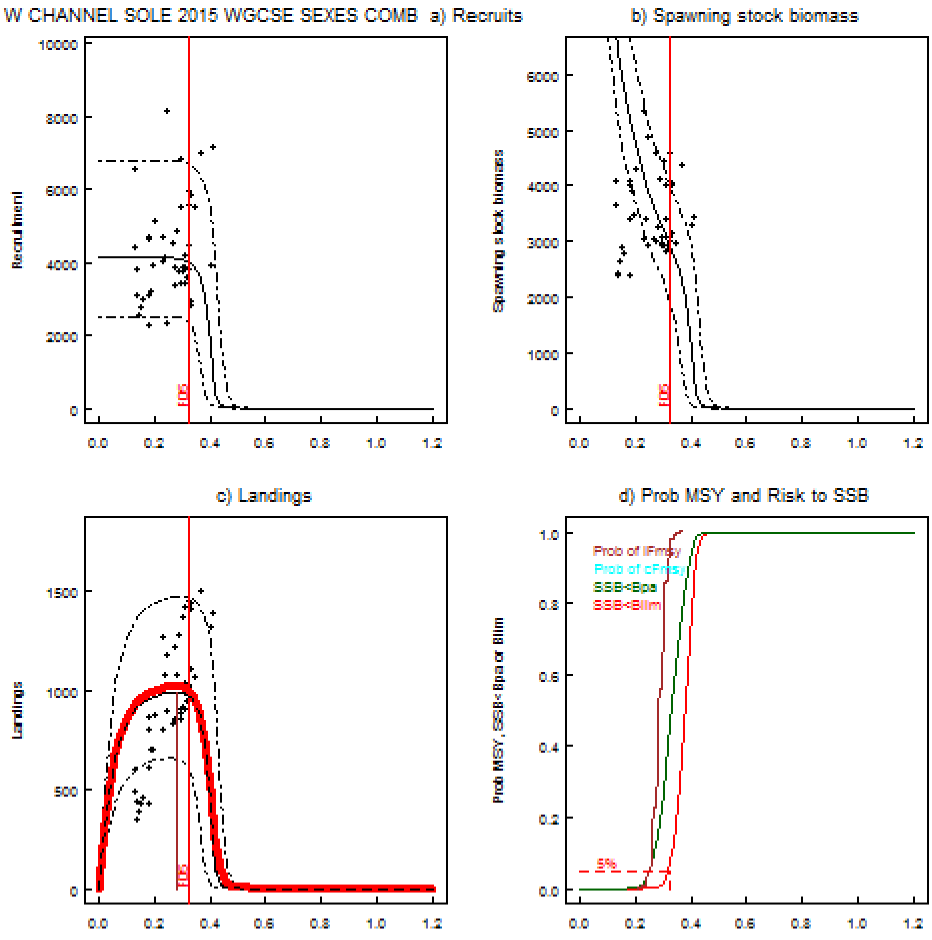


Figure 5.16.2. Eqsim summary plot for sole in Division VIIe without $MSYB_{trigger}$.

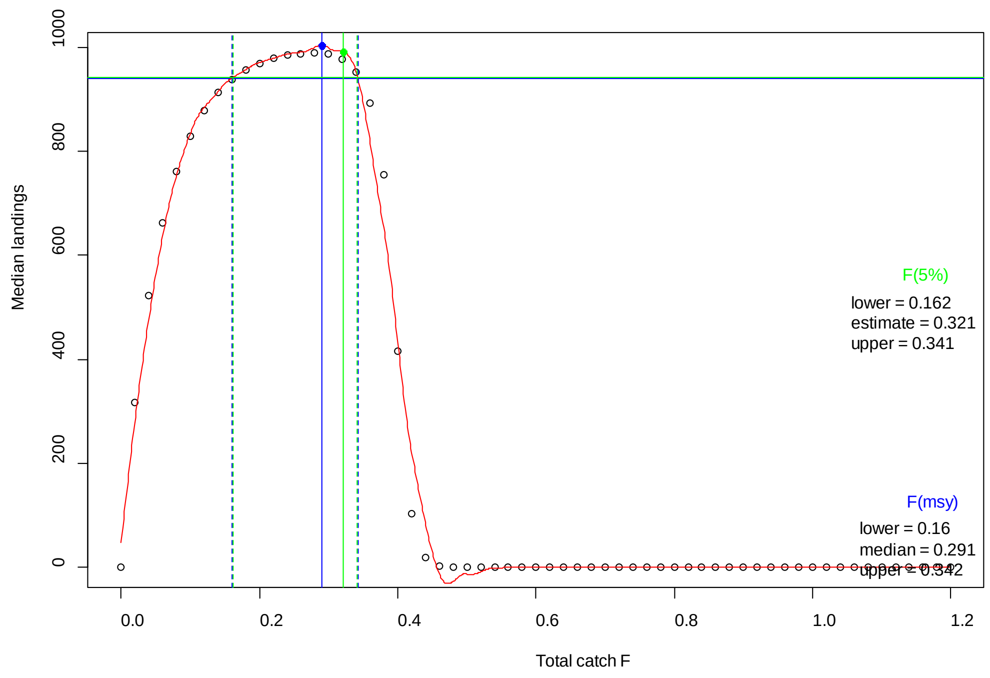


Figure 5.16.3. Median landings yield curve with estimated reference points for sole in Division VIIe with fixed F exploitation.

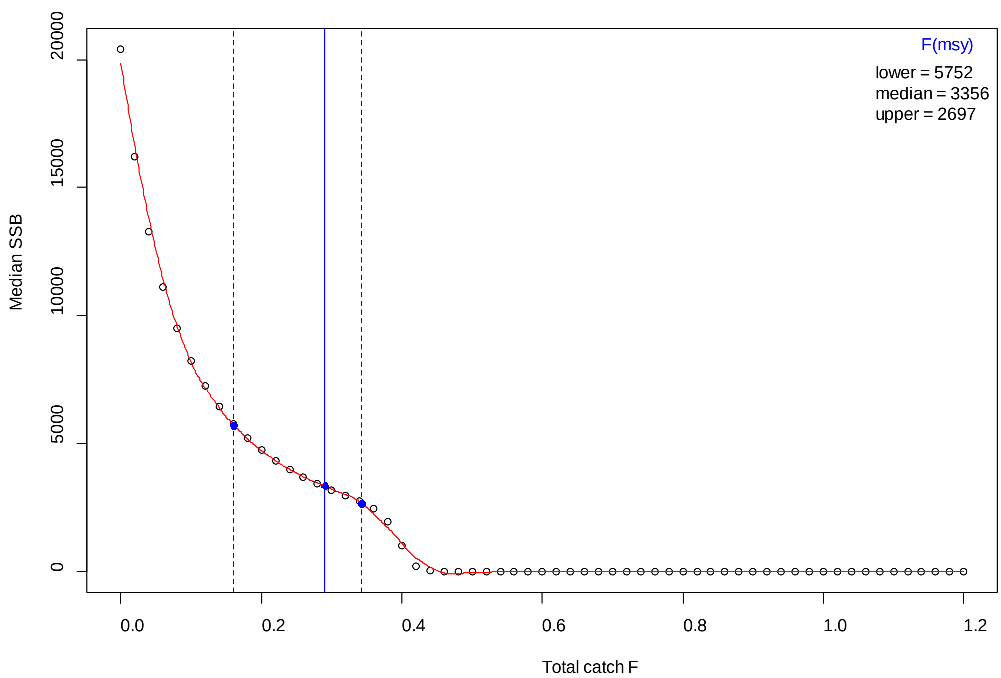


Figure 5.16.4. Median SSB for sole in Division VIIe with fixed F exploitation.

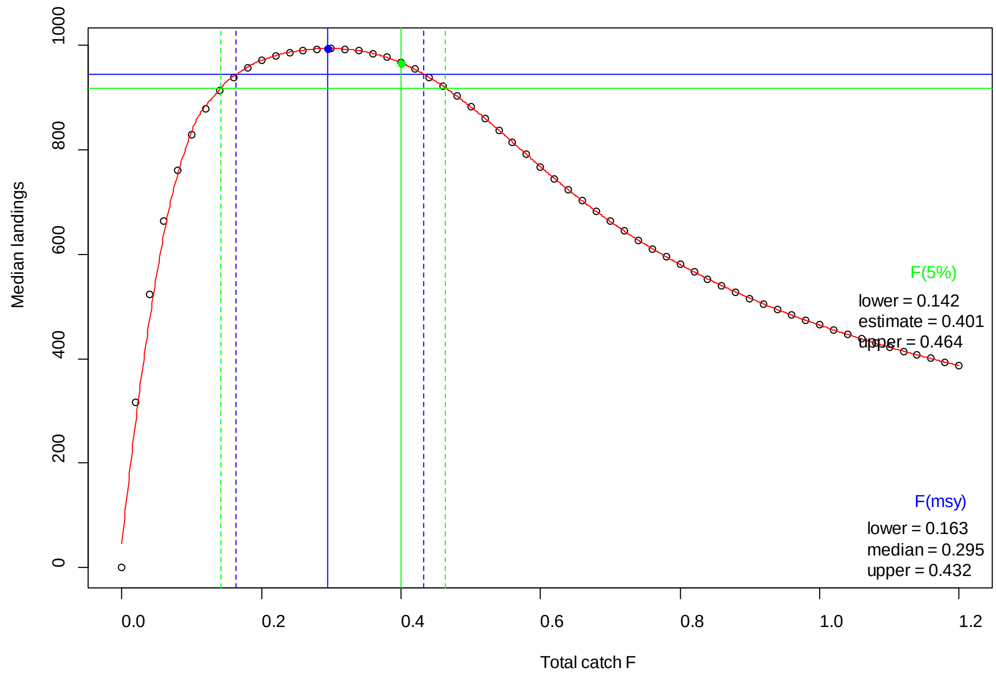


Figure 5.16.5. Median landings yield curve with estimated reference points for sole in Division VIIe when applying the ICES MSY harvest control rule with $B_{trigger}$ set to B_{pa} at 2 855 t.

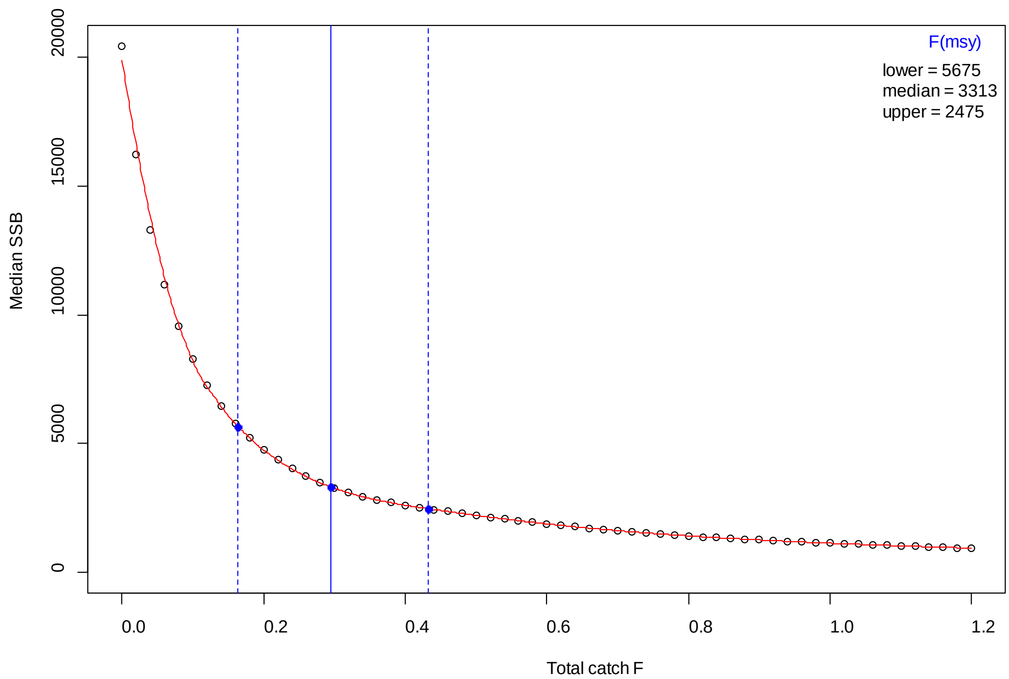


Figure 5.16.6. Median SSB for sole in Division VIIe when applying the ICES MSY harvest control rule with $B_{trigger}$ set to B_{pa} at 2 855 t.

5.16.6 Proposed reference points

Table 5.16.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	2 000 t	B_{pa}/1.4 (Proxy)
B_{paA}	2 900 t	B_{loss} (1999 yc). Lowest SSB with good recruitment.
F_{lim}	0.44	Based on segmented regression simulation of recruitment with Blim as the breakpoint and no error
F_{pa}	0.32	F_{lim}*exp(-1.645*σ); σ=0.2
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.29	
F_{MSY} lower without $B_{trigger}$	0.16	
F_{MSY} upper without $B_{trigger}$	0.34	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.32	
F_{MSY} upper precautionary without $B_{trigger}$	0.34	
MSY $B_{trigger}$	2 826 t	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	0.39, 0.40	
F_{MSY} with $B_{trigger}$, B_{pa}	0.29, 0.30	
F_{MSY} lower with $B_{trigger}$, B_{pa}	0.16, 0.16	
F_{MSY} upper with $B_{trigger}$, B_{pa}	0.43, 0.43	
F_{MSY} upper precautionary with $B_{trigger}$, B_{pa}	0.46, 0.46	
MSY	989 t	
Median SSB at F_{MSY}	3 356 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	2 697 t	
Median SSB upper (median at F_{MSY} lower)	5 752 t	

5.16.7 Discussion / Sensitivity.

During the recent benchmark (ICES IBPWCFlat2, 2015) runs of Eqsim estimated F_{MSY} at 0.21. These runs assumed a fitted segmented regression stock–recruit relationship with breakpoint estimated at 3 466 t. This relationship is driven by low recruitment in the early years of the time-series. If this was to be taken as the breakpoint this would imply that the stock was depleted at Fs of around 0.3 and require a higher B_{lim} (at 3 500t) and B_{pa}. WKMSYREF4 considers that recruitment is unlikely to be impaired within the range of observed biomasses. Given that the range of historic F is not sufficient to explore biomass fully, the precautionary approach takes B_{pa} as the lowest SSB with above average recruitment (2 039 t). The segmented regression with breakpoint at B_{loss} assumed during WKMSYREF4 is compatible with this value of B_{pa} and therefore more in accord with precautionary considerations. The IBPWCFla2 choice of both B_{lim} and B_{PA} below B_{loss} is less coherent

In order to consider if the approach was reasonable the slope of the WKMSYREF4 segmented regression was compared to those of other sole stocks to determine if assumptions about the resilience of Western Channel sole are precautionary. The assumed slope for Western Channel sole (1.73) is shallower than the slope for Bay of Biscay sole

(~2.25), and both of these stocks assume a shallower slope than a fitted segmented regression for North Sea sole (~4.28). To make this comparison accounting for differences in age of the recruitment gives a slope of 1.91 for Western Channel Sole and ~2.49 for Bay of Biscay sole. As the WKMSYREF4 slope for WC sole is shallower and therefore more precautionary than those of other sole stocks it does not seem likely that the benchmark stock–recruit function with an even shallower slope is more appropriate. Use of the WKMSYREF4 stock–recruit function leads to an F_{MSY} of 0.27.

The determination of F_{lim} requires Eqsim to be run excluding assessment error and with the breakpoint of the segmented regression at B_{lim} which, for sole in Division VIIe, is below the chosen breakpoint at B_{loss}. A sensitivity run of Eqsim without error and with the breakpoint of the segmented regression at B_{loss} (as in Figure 5.16.1) was performed, estimating both F_{lim} and F_{pa} slightly lower at 0.40 and 0.29 respectively.

A sensitivity run of Eqsim applying the ICES harvest control rule with MSY $B_{trigger}$ set to the 5th percentile of the distribution of SSB when fishing at F_{MSY} (excluding assessment error) was performed. The value of 5% B_{MSY} is very close to the value of B_{pa} (2 826 t and 2 855 t respectively) and therefore yields very similar results to the final run.

5.17 Sole (*Solea solea*) in Division VIIa (Irish Sea)

5.17.1 Current reference points

Table 5.17.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	2200 t.	$B_{lim} = B_{loss}$. The lowest observed spawning stock, followed by an increase in SSB.
Current B_{pa}	3100 t.	$B_{pa} \sim B_{lim} \times 1.4$. The minimum SSB required that ensures a high probability of maintaining SSB above its lowest observed value, taking into account the uncertainty of assessments.
Current F_{lim}	0.40	$F_{lim} = F_{loss}$. Although poorly defined, there is evidence that fishing mortality in excess of 0.4 has led to a general stock decline and is only sustainable during periods of above-average recruitment.
Current F_{pa}	0.30	This F is considered to have a high probability of avoiding F_{lim}.
Current F_{MSY}	0.16	Provisional proxy based on stochastic simulations, assuming a Ricker stock–recruitment relationship.
Current $MSYB_{trigger}$	3100 t.	Default to value of B_{pa}.

5.17.2 Source of data

Data used in the MSY interval analysis were taken from Celtic Seas WG created during ICES WGCSE 2015. Data represent the latest assessment input and output data from 2015 WG (ICES 2015).The stock is summarized in Figure 5.17.1

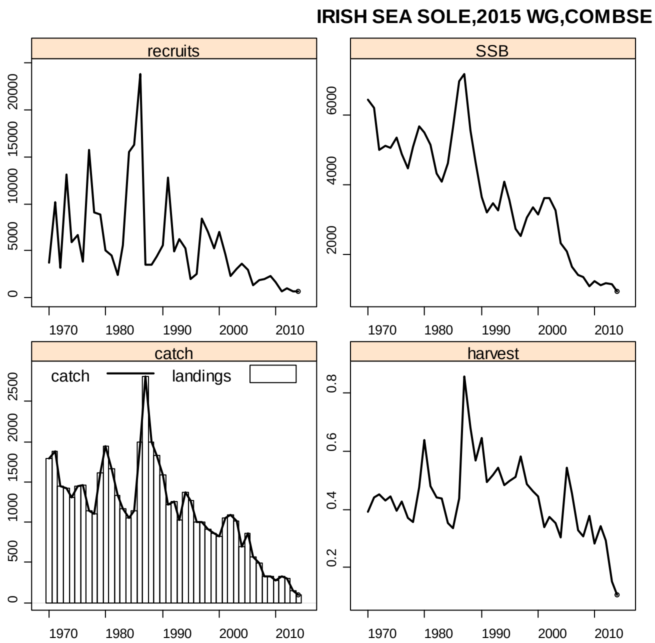


Figure 5.17.1 Irish Sea sole stock used as the basis for the evaluations.

5.17.3 Methods used

All analyses were conducted with EQSYM

The main routine R code is as follows:-

```
BP= 4612
Blim=2533
segreg3  <- function(ab, ssb) log(ifelse(ssb >= BP, ab$a * BP, ab$a *
ssb))
FIT <- eqsr_fit(stock, nsamp = 1000, models = "segreg3")
eqsr_plot(FIT,n=2e4)

SIM <- Eqsim_run(FIT,
                 bio.years = c(2005,2014),
                 sel.years = c(2005,2014),
                 Fcv=0.212,
                 Fphi=0.423,
                 Blim=2533,
                 Bpa=3546,
                 Btrigger=4287.712,
                 Fscan = seq(0,0.6,len=61),
                 verbose=FALSE)
```

5.17.4 Settings

Table 5.17.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	Full dataseries (years classes 1968–2012)	
Exclusion of extreme values (option extreme.trim)	No	Not needed for this stock and median value used for output
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	Inspected and no trend in last 10 years observed
Exploitation pattern	2005–2014	Inspected and no trend in last 10 years observed
Assessment error in the advisory year. CV of F	0.233	Default value calculated from 5 stocks in WKMSYREF3
Autocorrelation in assessment error in the advisory year	0.423	Default value calculated from 5 stocks in WKMSYREF3

5.17.5 Results

5.17.5.1 Stock recruitment relation

Combined models were examined, the Beverton–Holt and Ricker models fitted with rising lines throughout the datasets, in Eqsim the segreg fit also gave a rising line, in FLR the fit (Figure 5.17.1) gave a breakpoint at 4612 t. This was used in Eqsim (Figure 5.17.2) for modelling S–R.

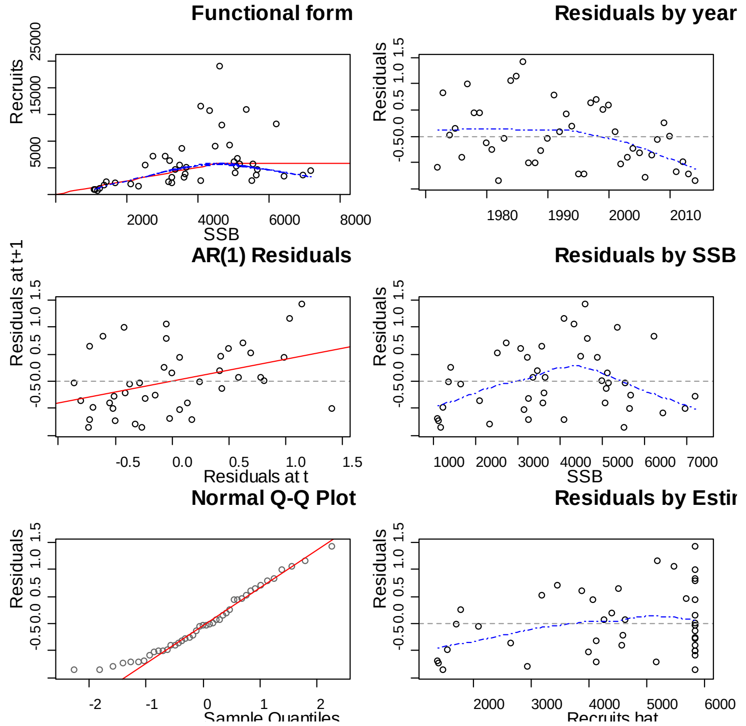


Figure 5.17.1 Fitted hockey stick S–R relationship

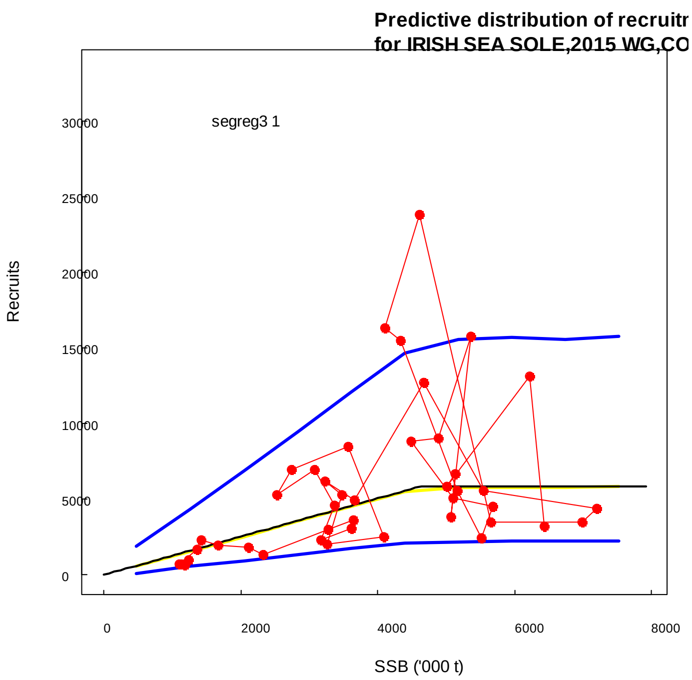


Figure 5.17.2 hockey stick S-R relationship used in Eqsim showing S–R pairs, model (black) and simulated values (yellow) with 90% intervals (blue)

5.17.5.2 Yield and SSB

For the base run, yield is based on landings with no discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.17.5.3 Eqsim analysis

The stock data are given in Figure 5.17.3, the results for a run with advice error included is illustrated in Figure 5.17.4 for both yield and SSB.

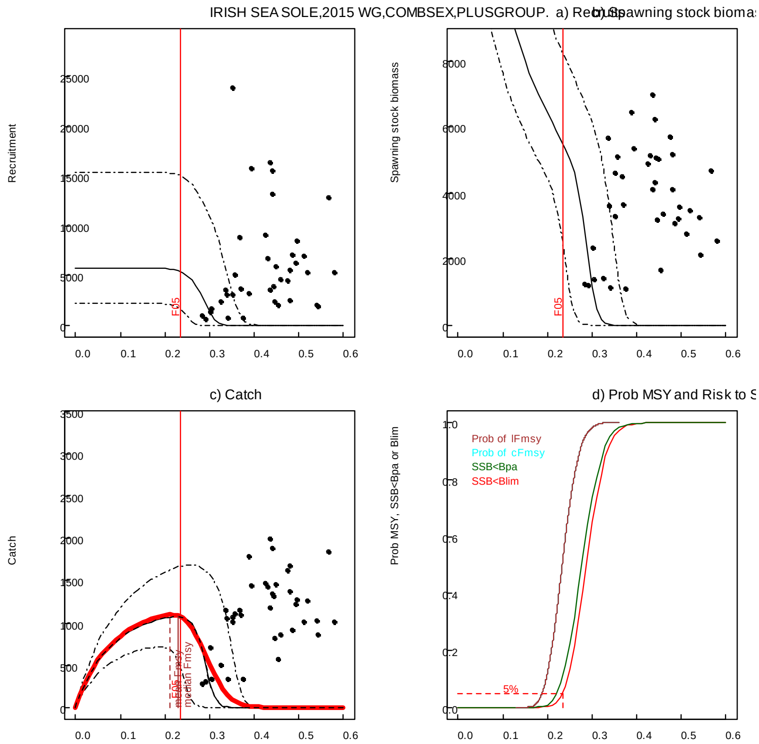


Figure 5.17.3 Summary of MSY evaluations, a) simulated and observed recruitment, b)simulated and observed biomass, c) simulated an observed catch and d) Cumulative probability of F_{MSY} and SSB< B_{lim} and B_{pa}. Note for this stocks F has been above equilibrium F for most of the time-series, (dots are to the right on each plot) leading to declining SSB.

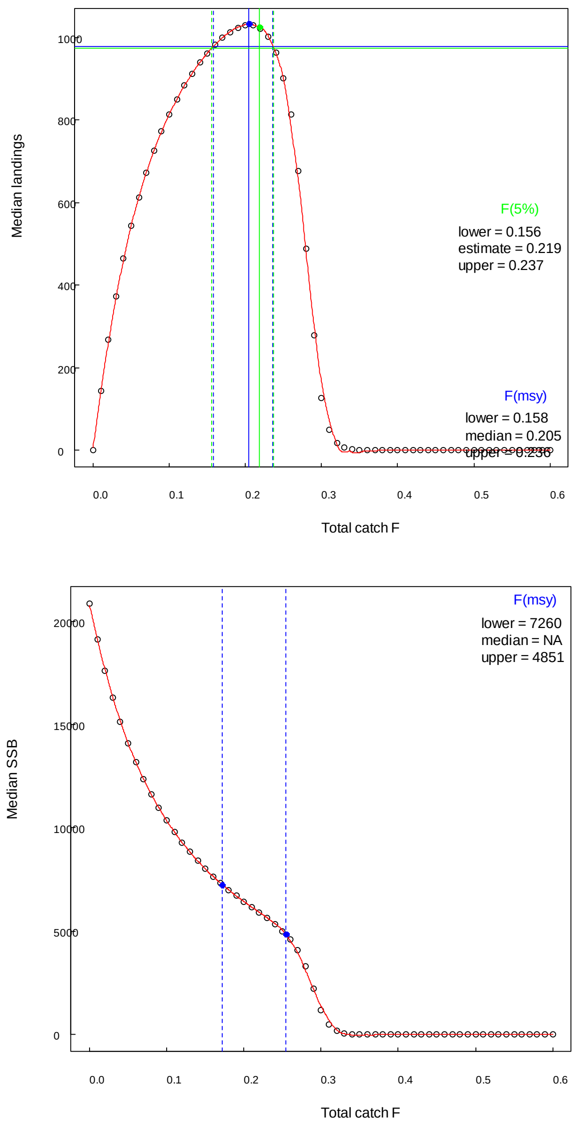


Figure 5.17.4 Results of simulations for Irish Sea sole

5.17.6 Proposed reference points

Lowest SSB with high R = Based on median SSB Flim from EQSIM (no error) 0.39 (10 year)

F_{pa}= 0.52/1.4 = 0.37

B_{pa} = 1.4*2533=

Table 5.17.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference point	Value	Rational
B_{lim}	2500	Lowest value with above average recruitment
B_{pa}	3500	B_{lim}*1.4
F_{lim}	0.29	Based on simulated recruitment to give median biomass = B_{lim}
F_{pa}	0.21	F_{lim}*1.4
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.20	
F_{MSY} lower without $B_{trigger}$	0.16	
F_{MSY} upper without $B_{trigger}$	0.24	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.22	
F_{MSY} upper precautionary without $B_{trigger}$	0.22	
MSY$B_{trigger}$	4141	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$, B_{pa})	0.29, 0.27	
F_{MSY} with $B_{trigger}$,B_{pa}	0.22, 0.22	
F_{MSY} lower with $B_{trigger}$,B_{pa}	0.16 , 0.16	
F_{MSY} upper with $B_{trigger}$,B_{pa}	0.27, 0.26	
F_{MSY} upper precautionary with $B_{trigger}$	0.24	
MSY	1126	
Median SSB at F_{MSY}	6190	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	7670	
Median SSB upper (median at F_{MSY} lower)	5167	

5.17.7 Discussion / Sensitivity.

Sensitivity of values, to other settings, retro analysis etc.

The stock is at a low level and mean recruitment has been seen to be reduced at current biomass, simulations were conducted with S-R function that followed the mean of the recruitment data, giving some reduction in recruitment at B_{lim}. Alternative recruitment models with the point of inflection at B_{lim} did not change F_{MSY}, but did give higher F_{lim} and F_{pa}, though such models suggested a higher stock resilience (steeper slope to the origin) than supported by the data. In this case all observed R values close to the origin were below the line. Such a model was not considered to represent the expected R al low biomass so was not used to give MSY or reference points.

The recent changes in selection and growth were relatively minor, with much greater trends observed earlier in the time-series. A retrospective analysis based on the last assessment shifting the endpoint back year by year gives stable values (Figure 5.17.6)

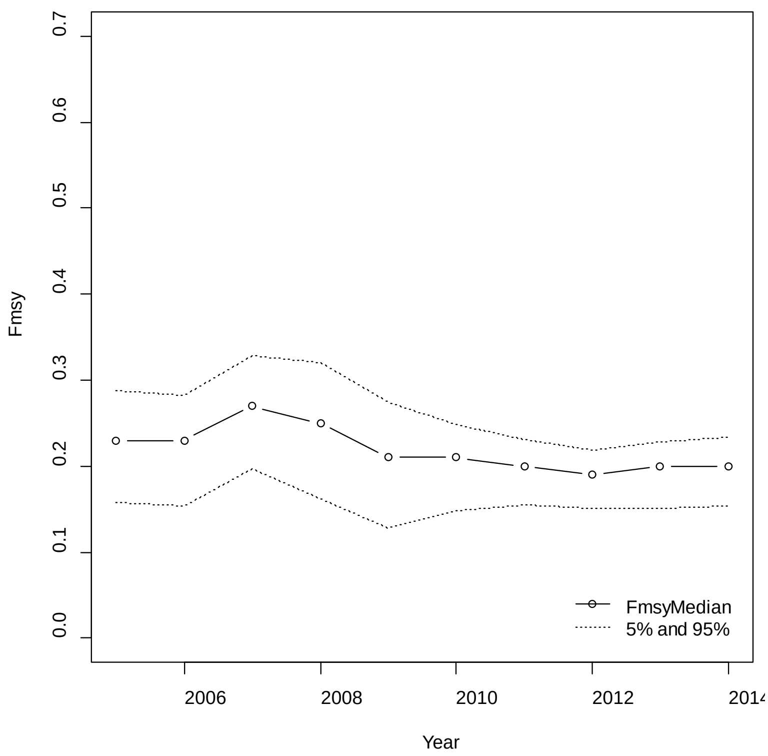


Figure 5.17.6 Retrospective analysis based on last assessment showing relatively stable estimates of F_{MSY} and F_{upper} and F_{lower}.

5.18 Whiting (*Merlangius merlangus*) in the Celtic Sea (Divisions VIIb,c,e–k)

5.18.1 Current reference points

The current reference points were estimate at WKCELT in 2014 using HCS.

Table 5.18.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current B_{lim}	25 000 t	B_{loss}, the lowest observed spawning-stock biomass.
Current B_{pa}	40 000 t	Lower bound of expected range at $F_{0.1}$.
Current F_{lim}	0.5	Increasing risk of reaching B_{lim}.
Current F_{pa}	Undefined	
Current F_{MSY}	0.32	$F_{0.1}$ as estimated using a stochastic equilibrium analysis on the full time-series.
Current $MSYB_{trigger}$	40 000 t	B_{pa}; Lower bound of expected range at $F_{0.1}$.

5.18.2 Source of data

Data used in the MSY interval analysis were taken from whg7bk_stock.Rdata created during ICES WGCSE 2014. Data represent the latest assessment input and output data from WGCSE (ICES 2015).

5.18.3 Methods used

All analyses were conducted with EQSIM

The main routine R code is as follows:-

```
setup <- list(data = stock,
bio.years = c(1999, 2014),
bio.const = FALSE,
sel.years = c(2012, 2014),
sel.const = FALSE,
Fscan = seq(0,1.5,by=0.05),
Fcv = 0.212, Fphi = 0.423,
Blim = 25000,
Btrigger = 28093.07,
Bpa = signif(25000.00 * exp(1.645 * 0.2) ,2),
extreme.trim=c(0.05,0.95))

SetBlim<-25000

FixedBlim<-function (ab, ssb)
{log(ifelse(ssb >= SetBlim, ab$a * SetBlim, ab$a * ssb))}

res <- within(setup,
{fit <- eqsr_fit(data, nsamp = 1000, models = "FixedBlim")
sim <- Eqsim_run(fit, bio.years = bio.years, bio.const = bio.const,
sel.years = sel.years, sel.const = sel.const, Fscan = Fscan,
Fcv = Fcv, Fphi = Fphi, Blim = Blim, Bpa = Bpa,
extreme.trim = extreme.trim, verbose = FALSE)})
```

Table 5.18.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries (years classes 1999–2014)	
Exclusion of extreme values (option extreme.trim)	Yes	extreme.trim=c(0.05,0.95)
Trimming of R values	No	-
Mean weights and proportion mature; natural mortality	1999–2014	Use the full time-series although there is a trend in the last decade
Exploitation pattern	2012–2014	Selection should have improved since 2012 with the introduction of various TCMs in the Celtic Sea.
Assessment error in the advisory year. CV of F	0.212	Sensible default value
Autocorrelation in assessment error in the advisory year	0.423	Sensible default value

5.18.4 Results

5.18.4.1 Stock recruitment relation

The stock–recruitment relationship for Celtic Sea whiting is shown below (Figure 5.18.1). There is no obvious relationship between stock size and recruitment despite a large range of stock size. In this scenario WKMSYREF4 concluded that a segmented regression was the most appropriate relationship with use with a breakpoint fixed at B_{lim} of 25,000 t.

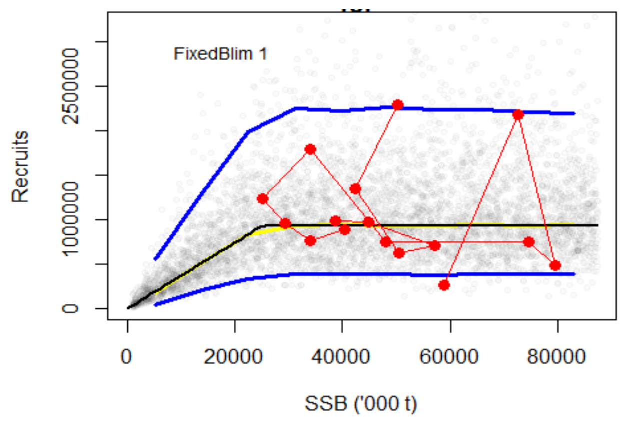


Figure 5.18.1. Celtic Sea whiting Eqsim summary of recruitment model using a segmented regression with the breakpoint set at a SSB of 25,000t

5.18.4.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.18.4.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.52 (Figure 5.15.4). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.83 and the lower bound was estimated at 0.32. $F_{P.05}$ was estimated at 0.58 and therefore the upper bound should be restricted to that value for precautionary reasons. The median of the SSB estimates at F_{MSY} was 46k t.

A run with no error in the advice was carried out to estimate $MSYB_{trigger}$ and F_{lim}. $MSYB_{trigger}$ was estimated at 28kt and F_{lim} at 1.12

When applying the ICES MSY harvest control rule with $B_{trigger}$ at 28kt, median F_{MSY} was estimated at 0.53 with lower bound of the range at 0.32 and an upper bound at 0.82. The $F_{P.05}$ remains unchanged at 0.58

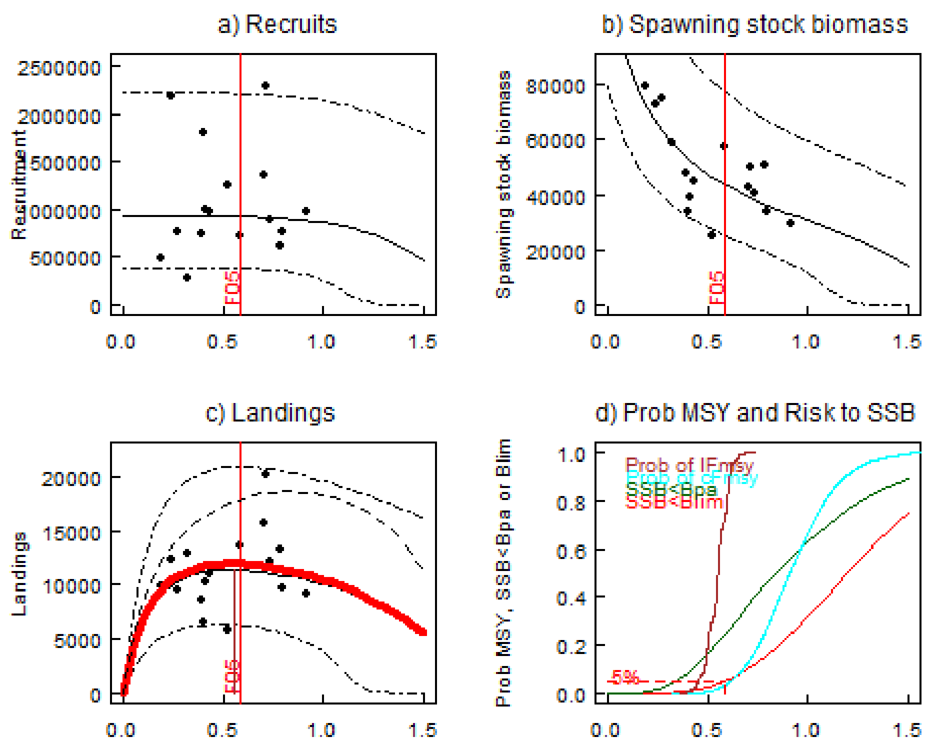


Figure 5.18.4. Eqsim summary plot for Celtic Sea whiting (without $B_{trigger}$). Panels a–c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

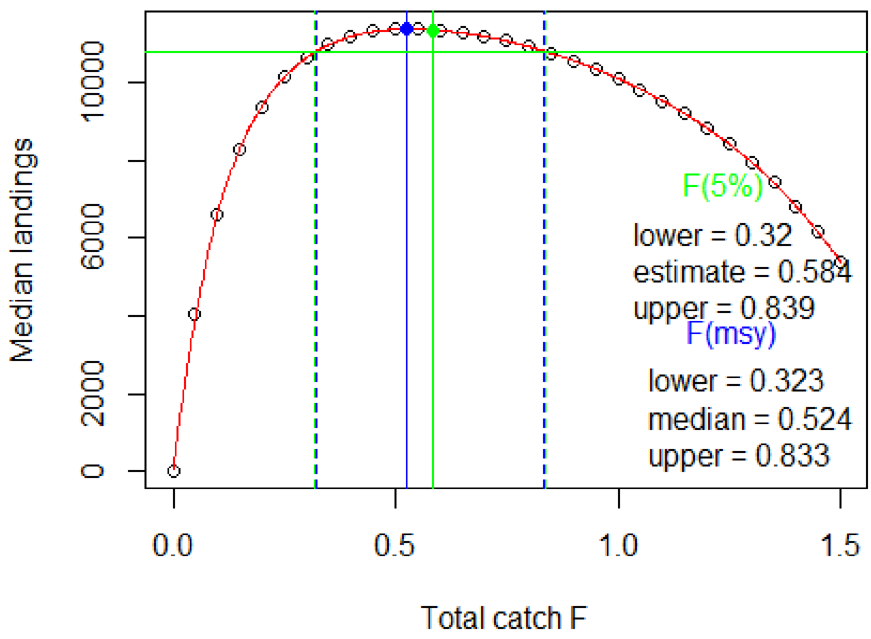


Figure 5.18.5 Celtic Sea whiting median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

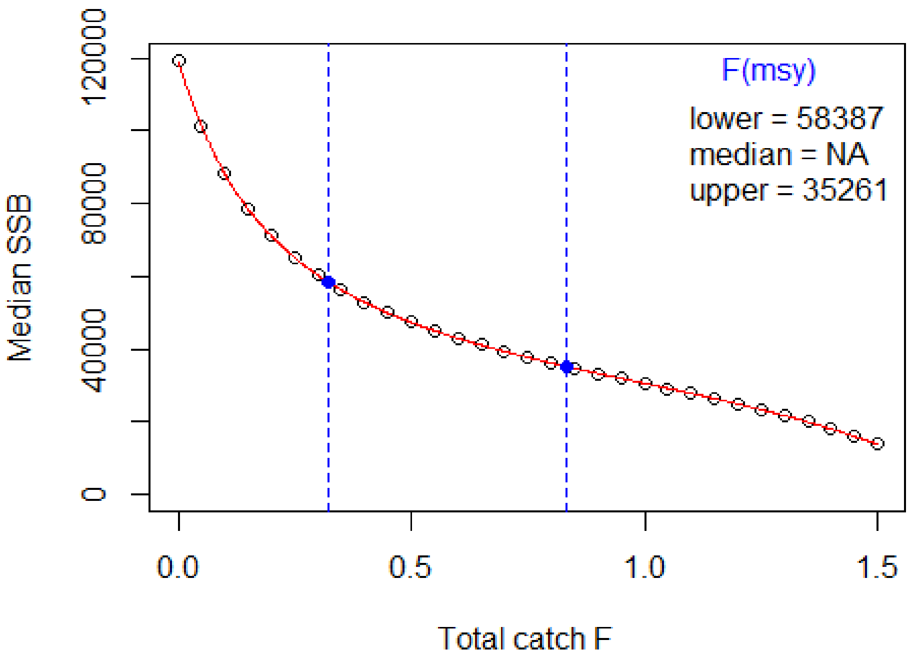


Figure 5.18.6 Celtic Sea whiting median SSB curve over a range of target F values (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

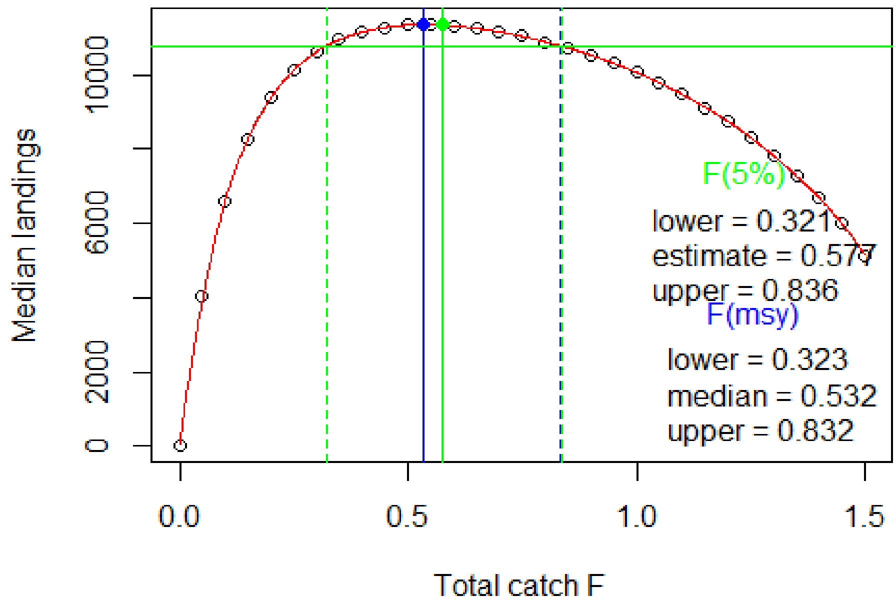


Figure 5.18.7 Celtic Sea whiting median landings yield curve with estimated reference points (MSY $B_{trigger}$=28kt). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

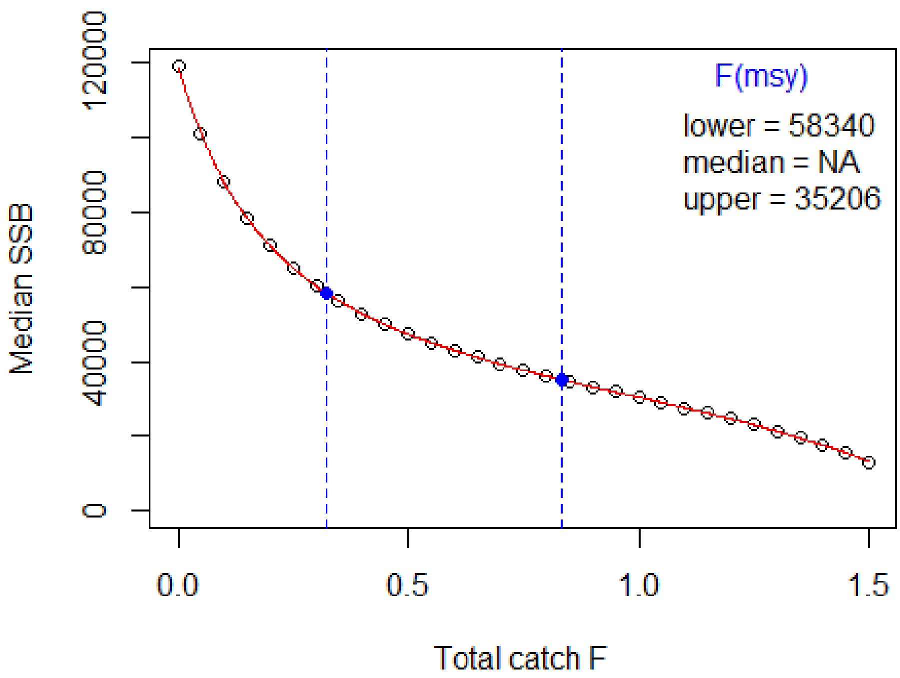


Figure 5.19.8 Celtic Sea whiting median SSB curve over a range of target F values (MSY $B_{trigger}$=28kt). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.18.5 Proposed reference points

Table 5.18.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	25kt	B_{loss}
B_{pa}	35kt	B_{lim} * 1.4
F_{lim}	1.12	Based on segmented regression simulation of recruitment with B_{lim} as the breakpoint
F_{pa}	0.8	F_{lim}/1.4
F_{MSY} without $B_{trigger}$	0.52	
F_{MSY} lower without $B_{trigger}$	0.32	
F_{MSY} upper without $B_{trigger}$	0.83	
MSY $B_{trigger}$	28kt	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.58	
F_{MSY} upper precautionary without $B_{trigger}$	0.58	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$)	0.58	
F_{MSY} with $B_{trigger}$	0.53	
F_{MSY} lower with $B_{trigger}$	0.32	
F_{MSY} upper with $B_{trigger}$	0.58	
F_{MSY} upper precautionary with $B_{trigger}$	0.58	
MSY	11.3kt landings	
Median SSB at F_{MSY}	45kt	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	58kt	
Median SSB upper (median at F_{MSY} lower)	35kt	

5.18.6 Discussion / Sensitivity.

In the Celtic Sea there have been several TCMs introduced and changes in mesh size for some fleets since 1999. SMPs were introduced in 2012 and augmented in 2014. A priori we should expect and improved selection pattern in recent years.

There have also been strong changes in mean weights-at-age over time for this stock. In the past decade there has been an increasing trend with a dip in 2014 Figure 5.18.9. These are probably linked to ecosystem factors such as prey abundance and changes in the spatio-temporal pattern of the fishery. It is probably wise to use the full time-series for the mean weight as these changes may not persist over time. Given the trends observed to date the stability of F_{MSY} should be monitored.

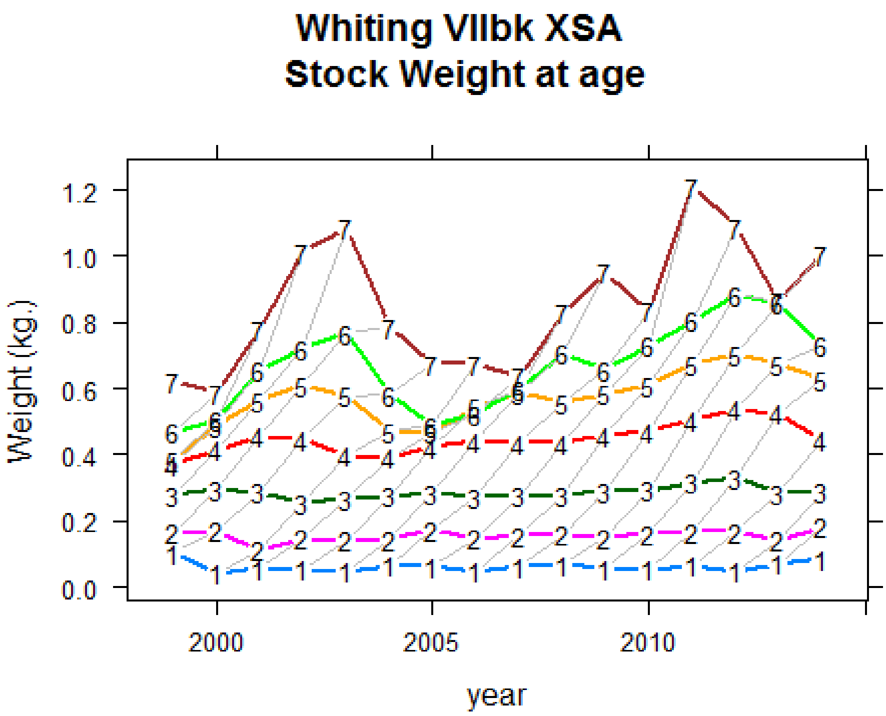


Figure 5.18.9 Celtic Sea whiting mean weights-at-age in the stock.

A sensitivity analysis was conducted which involved running Eqsim with a moving window of 3 year of selectivity data starting with 1999–2002 and finishing with 2010–2014 (bio data year range 1999–2014 as base run). The effect on the estimate of median F_{MSY} is shown in Figure 5.18.10. This shows and increasing trend in F_{MSY} estimates over time from below 0.4 to over 0.5 at the end if the series. This is as expected with improvements in selectivity in the fishery and increasing trends in mean weight. Given the trend and changes in selectivity in the fishery it is logical to use a recent selection pattern. Because the mean weight trend may revert back it is also logical to use the full time-series for the mean weights.

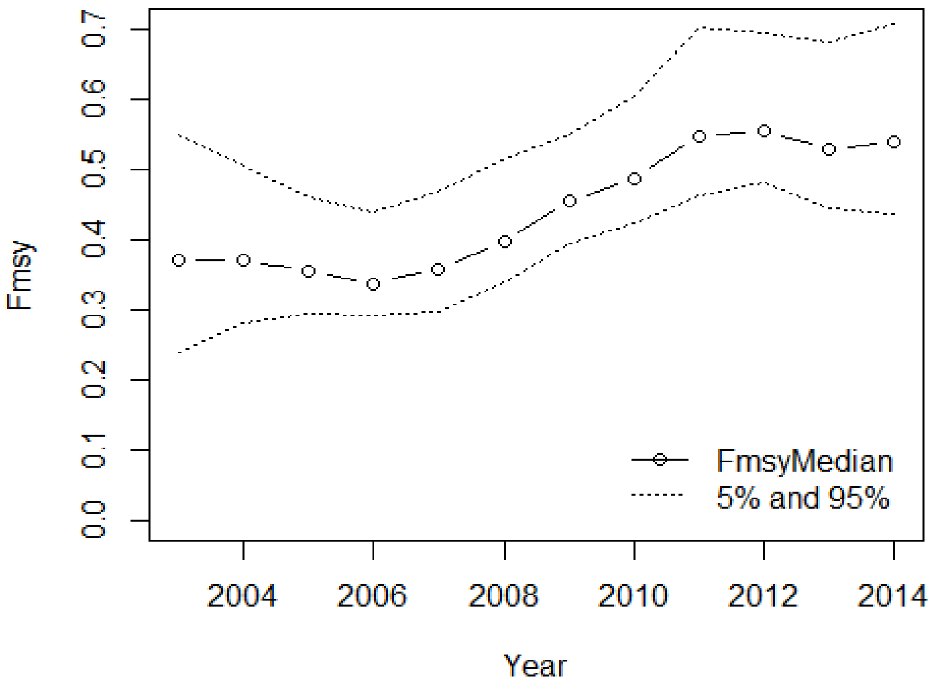


Figure 5.18.10 Celtic Sea whiting sensitivity of Median F_{MSY} estimate using a three year moving average for selectivity data.

5.19 Whiting (*Merlangius merlangus*) in VIa (West of Scotland)

5.19.1 Current reference points

Table 5.19.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current B_{lim}	28500 t	Breakpoint from the stock assessment (TSA) segmented regresstion stock recruitment relationship (IBP 2015)
Current B_{pa}	39900 t	1.4 x B_{lim}
Current F_{lim}	NA	
Current F_{pa}	NA	
Current F_{MSY}	NA	
Current $MSYB_{trigger}$	NA	

5.19.2 Source of data

The results from the TSA stock assessment conducted at ICES WGCSE 2015 were used to create an FLStock object which was used in the MSY interval analysis. Data represent the latest assessment input and output data (ICES 2015).

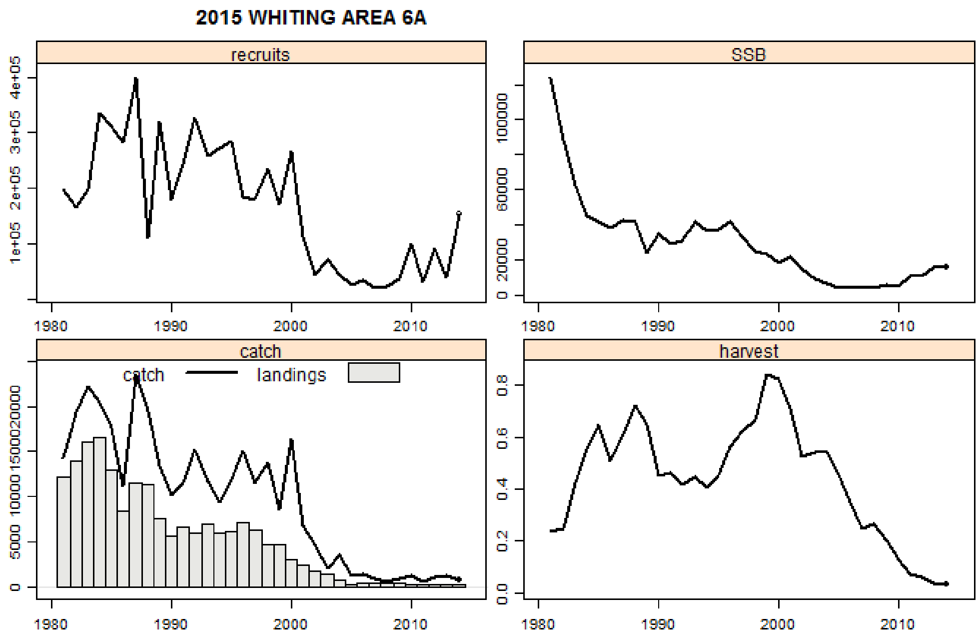


Figure 5.19.1 West of Scotland whiting stock summary used as the basis for the MSY interval evaluation.

5.19.3 Methods used

All analyses were conducted with Eqsim

The main routine R code is as follows:-

```
brk.pt <-28500
segreg3  <- function(ab, ssb){
  log(ifelse(ssb >= brk.pt, ab$a * brk.pt, ab$a * ssb))
}
whi.indat <-list(data=whg6a,
```

```
                bio.yrs <-c(2005,2014),
                sel.yrs <-c(2010,2014),
                Fscan <-seq(0,1.0,by=0.02),
                Fcv=err.cv, # or 0
                Fphi=err.phi, # or 0
                Blim=28500,
                Bpa=39900,
                Btrigger=0 # or 39900 (Bpa)
)

whi.res <-within(whi.indat,
{
  fit <-eqsr_fit(data,nsamp=1000,models="segreg3")
  sim <-Eqsim_run(fit,bio.years=bio.yrs,sel.years=sel.yrs,
                  Fscan = Fscan, Fcv = Fcv, Fphi = Fphi,
                  Blim=Blim, Bpa=Bpa, Btrigger=Btrigger)
})
```

5.19.4 Settings

Table 5.19.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full dataseries	
Exclusion of extreme values (option extreme.trim)	Not used	
Trimming of R values	Yes	-3,+3 Standard deviations
Mean weights and proportion mature; natural mortality	2005–2014	
Exploitation pattern	2010–2014	
Assessment error in the advisory year. CV of F	0.212	Reasonable default value agreed at this WK
Autocorrelation in assessment error in the advisory year	0.423	Reasonable default value agreed at this WK

5.19.5 Results

5.19.5.1 Stock recruitment relation

The full available time-series of data were used to fit stock recruitment models. Using the three models (Ricker, Beverton–Holt and segmented regression) in the stock recruitment fit results in very low weight to both the Ricker and the Beverton–Holt modes (Figure 5.19.2). The workshop decided to use the segmented regression model, consistent with that estimated from the TSA stock assessment, with a breakpoint set at B_{lim} of 28500 t (Figure 5.19.3).

The Workshop agreed that it was appropriate to retain B_{lim} and B_{pa} at the value agreed by the IBP in 2015.

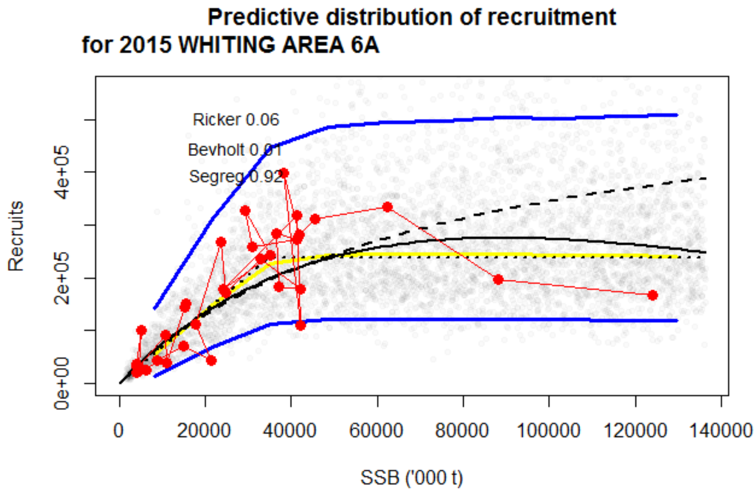


Figure 5.19.2. Eqsim summary of recruitment models using the default "Buckland" method (Ricker, Beverton–Holt and segmented regression)

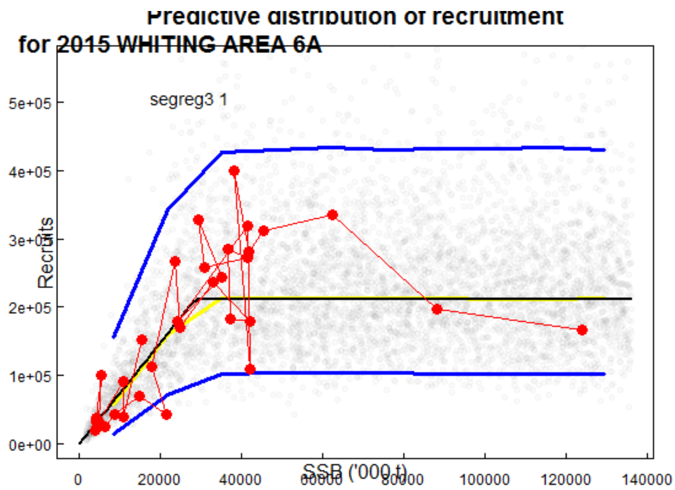


Figure 5.19.3. Eqsim summary of segmented regression fit with fixed breakpoint.

5.19.5.2 Yield and SSB

For the base run, yield includes discards, with F_{MSY} being taken as the peak of the median landings yield curve. The F_{MSY} range is calculated as those F values associated with median yield that is 95% of the peak of the median yield curve.

5.19.5.3 Eqsim analysis

The base run largely uses default settings for the input parameters with the exception of the selection parameters. Although there is some evidence of a persistent downward trend in mean weight in the youngest age class other ages appear to exhibit periodic variation in mean weight and some are highly variable in the most recent years (Figure 5.19.9). Therefore the standard ten year window is used as input for the mean stock/catch weights at age. The introduction of large square mesh panels in the TR2 fleet (since 2012) which has been responsible for a large proportion of whiting discards should have resulted in a change in selection pattern in recent years and therefore a shorter period is used for the selectivity pattern year window (last five years, 2010–

2014). (Note that the expected change in selectivity is not particularly apparent in the F at age pattern from the TSA stock assessment (Figure 5.19.10)

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was estimated at 0.19 (Figure 5.19.5) with median landings of 2852 t. The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.22 and the lower bound was estimated at 0.14. $F_{P.05}$ was estimated at 0.14 which is below the estimate of F_{MSY} implying that fishing at F_{MSY} is not consistent with the precautionary approach. The median of the SSB estimates at F_{MSY} was 36552 t.

A run with no error in the advice was carried out to estimate $MSYB_{trigger}$ using the fifth percentile of the distribution of SSB when fishing at F_{MSY}. The estimate of the fifth percentile of SSB is 22380 tonnes which is lower than the agreed B_{pa} (39900 t) and therefore, following the approach agreed at the workshop, $MSYB_{trigger}$ was set equal to B_{pa}.

The Eqsim run with no assessment error and no $B_{trigger}$ was also used to determine F_{lim}, the equilibrium F that gives a 50% probability of SSB>B_{lim}. This was estimated as 0.25. This results in F_{pa} = 0.18 (F_{lim}/1.4).

Figures 5.19.7 and 5.19.8 show the Eqsim results with simulations incorporating MSY $B_{trigger}$ = 39900 t.

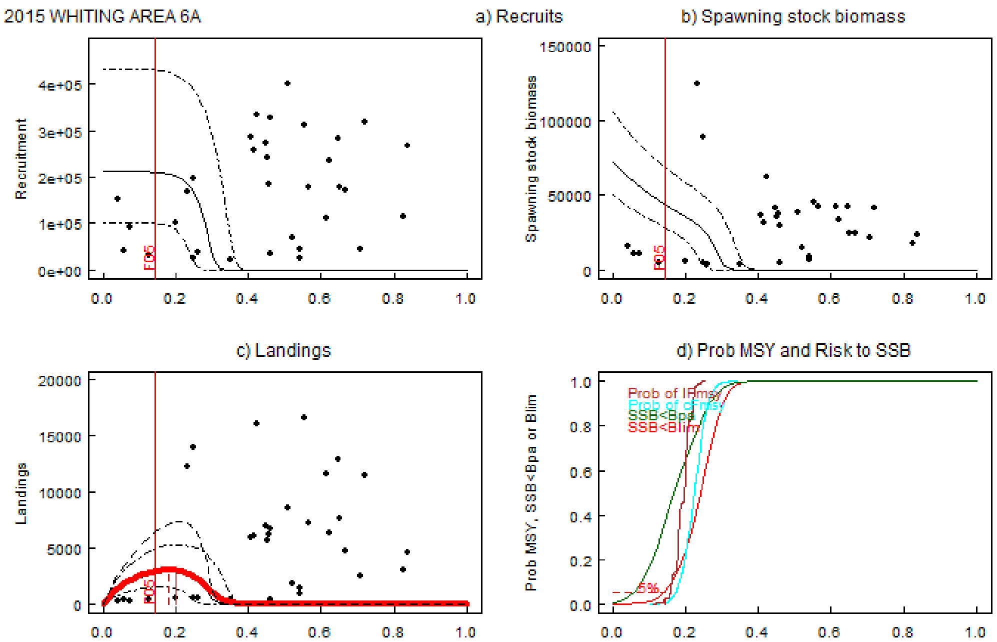


Figure 5.19.4. Eqsim summary plot for West of Scotland whiting (without $B_{trigger}$). Panels a–c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d shows the probability of SSB<B_{lim} (red), SSB<B_{pa} (green) and the cumulative distribution of F_{MSY} based on yield as landings (brown) and catch (cyan).

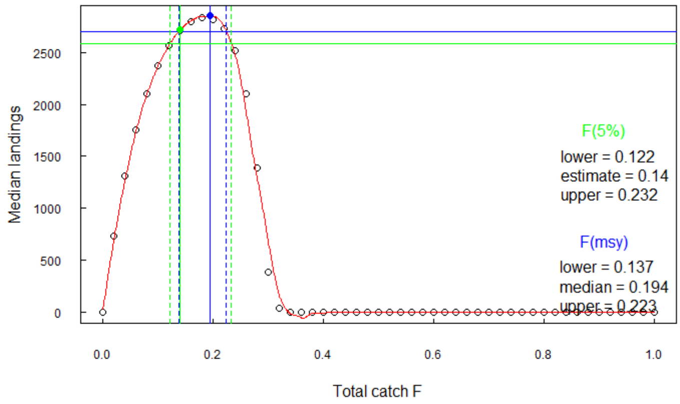


Figure 5.19.5 West of Scotland whiting median landings yield curve with estimated reference points (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted).

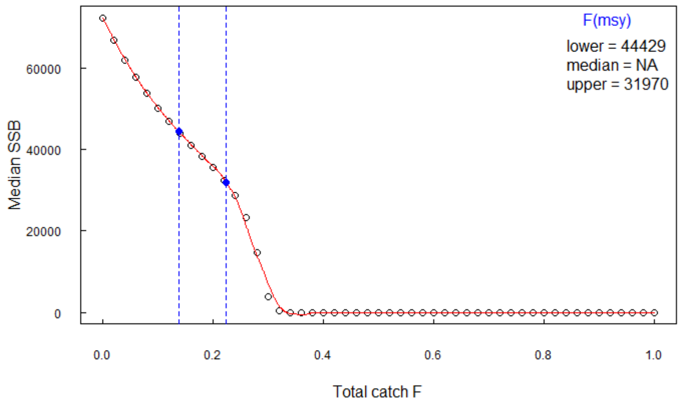


Figure 5.19.6 West of Scotland whiting median SSB curve over a range of target F values (without MSY $B_{trigger}$). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

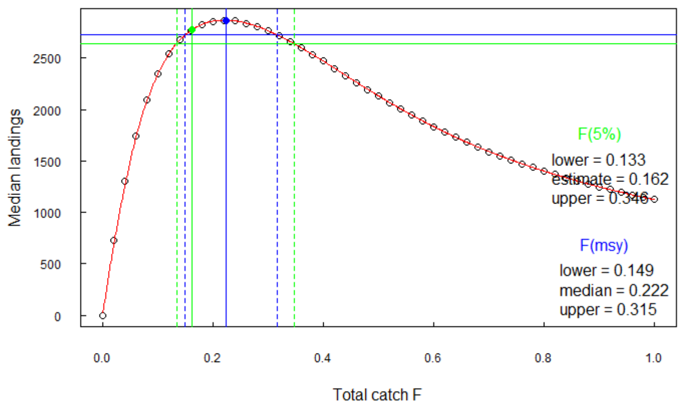


Figure 5.19.7 West of Scotland whiting median landings yield curve with estimated reference points (MSY $B_{trigger}$=39900 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: $F_{P.05}$ estimate (solid) and range at 95% of yield implied by $F_{P.05}$ (dotted)

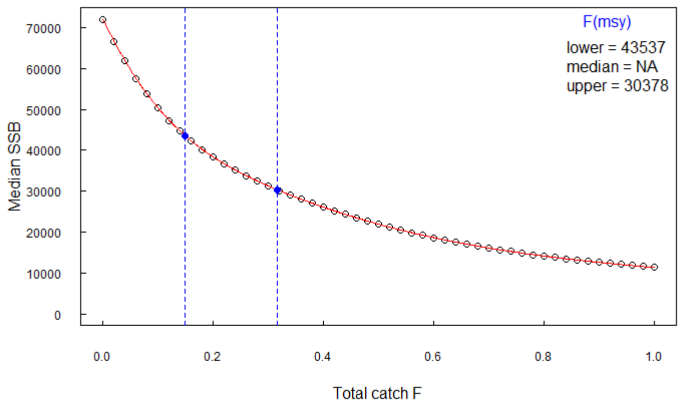


Figure 5.19.8 West of Scotland whiting median SSB curve over a range of target F values (MSY $B_{trigger}$=39900 t). Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted).

5.19.6 Proposed reference points

Table 5.19.3 Summary table of proposed stock reference points for method Eqsim

STOCK		
PA Reference points	Value	Rational
B_{lim}	28500 t	Breakpoint from the stock assessment (TSA) segmented regresstion stock recruitment relationship (IBP 2015)
B_{pa}	39900 t	1.4 x B_{lim}
F_{lim}	0.25	Based on segmented regression simulation of recruitment with Blim as the breakpoint
F_{pa}	0.18	B_{lim}/1.4
MSY Reference point	Value	
F_{MSY} without $B_{trigger}$	0.19	
F_{MSY} lower without $B_{trigger}$	0.14	
F_{MSY} upper without $B_{trigger}$	0.22	
MSY $B_{trigger}$	39900 t	
$F_{P.05}$ (5% risk to Blim without $B_{trigger}$)	0.14	
F_{MSY} upper precautionary without $B_{trigger}$	0.14	
$F_{P.05}$ (5% risk to Blim with $B_{trigger}$ (=B_{pa})	0.16	
F_{MSY} with $B_{trigger}$ (= B_{pa})	0.22	
F_{MSY} lower with $B_{trigger}$ (=B_{pa})	0.15	
F_{MSY} upper with $B_{trigger}$ (=B_{pa})	0.32	
F_{MSY} upper precautionary with $B_{trigger}$ (=B_{pa})	0.16	
MSY	2852 t	
Median SSB at F_{MSY}	36552 t	
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	31970 t	
Median SSB upper (median at F_{MSY} lower)	44429 t	

5.19.7 Discussion / Sensitivity.

Sensitivity analysis was conducted which involved running Eqsim with a moving window of 5 year of selectivity data starting with 1995–1999 and finishing with 2010–2014 (bio data year range 2005–2014 as base run). The effect on the estimate of F_{MSY} is shown in Figure 5.19.11. The estimate varies between 0.33 and 0.19 depending on the year range chosen. The estimate of $F_{P.05}$ was always below the estimated F_{MSY}.

West of Scotland whiting is similar to North Sea whiting in that the slope of the stock recruit curve is estimated to be very shallow at the origin which results in very low estimates of $F_{P.05}$ (typically used as an upper bound for F_{MSY})

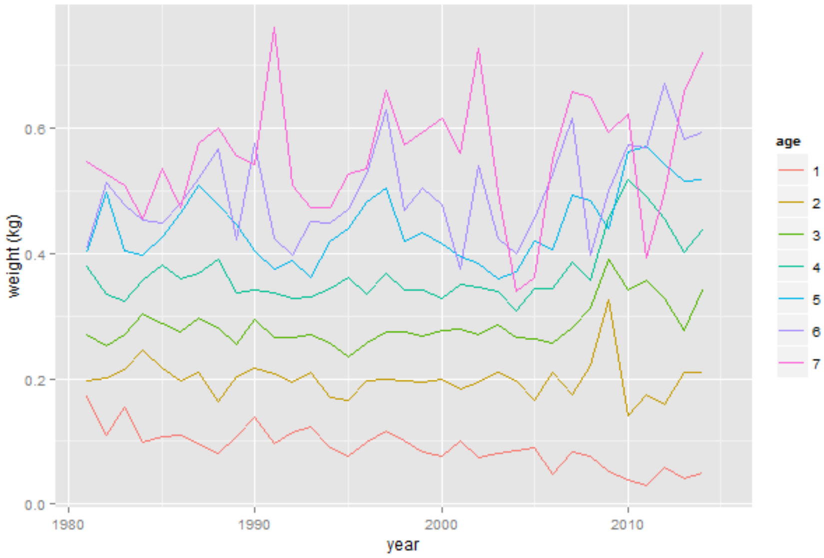


Figure 5.19.9 West of Scotland whiting. Mean stock/catch weight at age.

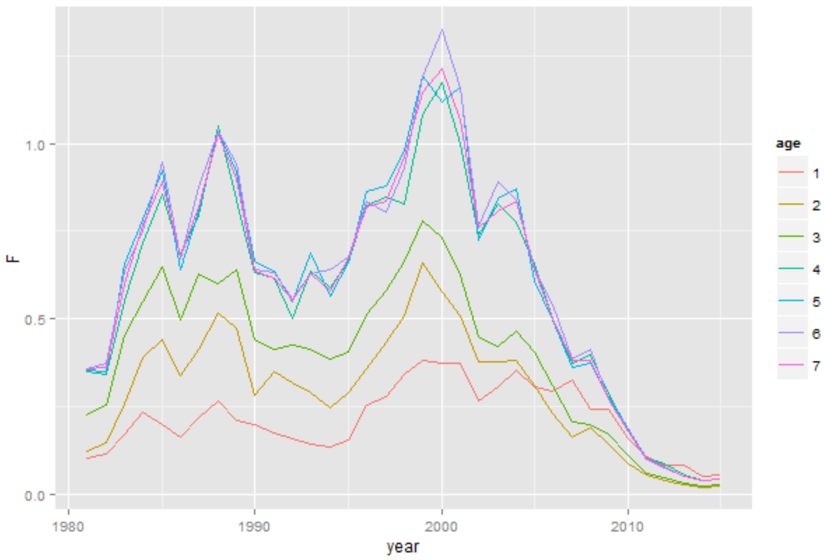


Figure 5.19.10 West of Scotland whiting. Fishing mortality-at-age.

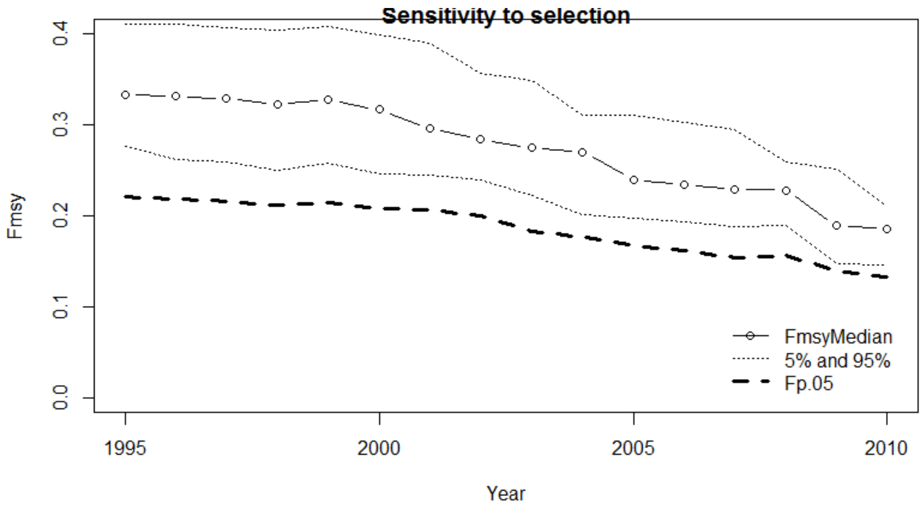


Figure 5.19.11. West of Scotland whiting. Sensitivity of F_{MSY} estimate to year range of selectivity data. (Year label is 1st year of a five year range).

6 Scheafer based Surplus production models.

Three of the stocks considered in WKMSYREF4 are assessed using surplus production models: black anglerfish in Divisions VIIIc and IXa (anb-8c9a) is assessed with the software ASPIC, whereas megrim in Divisions IVa and VIa (meg-4a6a) and Greenland halibut in Subareas V, VI, XII and XIV (ghl-grn) are assessed using a Bayesian surplus production model which includes process error; ICES (2012a, 2012b, 2013).

This section is to a large extent a repetition of Section 7 of the WKMSYREF3 report (ICES 2014), albeit with some adaptation. It should also be noted that equation (1), presented below, contained an error in the WKMSYREF3 report and the correct version of the equation is the one presented here.

The population biomass dynamics corresponding to the surplus production model are (in continuous time form):

$$\frac{dB_t}{dt} = r\,B_t\left(1-\frac{B_t}{K}\right) - B_tF_t \qquad (1)$$

ASPIC works by directly solving equation (1) for annual time-steps and considers deterministic population dynamics; Catch is obtained as the integral of B_tF_t during the course of a year.

The Bayesian surplus production model uses the following alternative discrete time implementation with process error:

$$B_j = \left\{B_{j-1} + r\,B_{j-1}\left(1-\frac{B_{j-1}}{K}\right) - C_{j-1}\right\} e^{u_j}, \text{ where } C_{j-1} = B_{j-1}\,F_{j-1}. \qquad (2)$$

In the discrete time implementation in equation (2),$B_j\,F_j, C_j$ denote stock biomass, fishing mortality and catch in year$j$, and u_j follows a Normal $(0,\sigma^2)$ distribution, independently from year to year. (Note: other alternative formulations of the equation for catch in (2) have also been used in the megrim assessment.)

6.1.1 Current reference points

Results from surplus production models are normally presented as time-series of F/F_{MSY} and B/B_{MSY}, where $F_{MSY} = r/2$ is the F at which deterministic equilibrium yield is maximized and $B_{MSY} = K/2$ is the corresponding deterministic equilibrium biomass. The deterministic calculations are presented later in this section.

The following reference points are currently available for the anglerfish, megrim and Greenland halibut stocks. Note that the value of F_{MSY} is updated at each new assessment and all other reference points are expressed relative to F_{MSY} or B_{MSY}.

REFERENCE POINT	VALUE
Current F_{MSY} (all 3 stocks)	$r/2$
Current $MSYB_{trigger}$ (all 3 stocks)	0.5 B_{MSY} (= 0.25 K)
Current B_{lim} (megrim and Greenland halibut)	0.3 B_{MSY} (= 0.15 K)
Current F_{lim} (Greenland halibut)	1.7 F_{MSY}

Some comments on these reference points follow:

- B_{lim}: For surplus production models B_{lim} cannot be set following the standard ICES approach, as the standard approach is based on examining historical stock–recruitment pairs and these surplus production models do not provide recruitment estimates. Common practice in ICES in the last few years has been to set B_{lim} for these models as the biomass corresponding to an equilibrium yield equal to MSY/2. Other approaches using the actual historic estimates of biomass and F may perhaps be possible and it could be worth exploring their potential merits, but this has not been considered to date.

- F_{lim}: The definition of F_{lim} follows ICES standard practice, in that F_{lim} corresponds to the F that drives the stock to B_{lim} (albeit it is based on a deterministic rather than a stochastic approach).
- F_{pa} and B_{PA}: So far no F_{pa} or B_{PA} reference points have been set for any of these stocks. The surplus production models implemented provide uncertainty intervals around the historic estimates of F/F_{MSY} and B/B_{MSY}; therefore, the probability of F exceeding F_{lim} or biomass being below B_{lim} in any assessment year can be directly calculated from the assessment output and it is not necessary to set F_{pa} or B_{pa}. There are likely advantages and disadvantages in using this approach relative to the ICES standard approach of setting F_{pa} and B_{PA} from lognormal distributions using the CV of the assessment estimates in the final assessment year; however, this was not considered during the WKMSYREF4 workshop and no changes to the approach currently used for surplus production models are proposed.

6.1.2 F_{MSY} ranges

To find a range of values of F consistent with equilibrium yield being at least 95% of the possible maximum and to evaluate the long-term probability that $B < B_{\text{lim}}$ for any given F, a stochastic simulation analysis could be undertaken, taking into account the population biomass dynamics implied by the surplus production model. This is described in Chapter 7 of the WKMSYREF3 report and is not repeated here, given that it was not implemented for any of the stocks included in WKMSYREF4. Such an analysis could be seen as a counterpart of what is currently done in Eqsim for age-based assessment models but developing it would require a significant amount of programming and further consideration of some aspects, which has not been done to date.

A simpler alternative that provides a first approximation is to consider deterministic equilibrium results, based on deterministic population dynamics and without inclusion of errors. Under these simplifying assumptions, the population dynamics model in (1) or (2) is in equilibrium when

$$r\,B\,\left(1-\frac{B}{K}\right)=B\,F \qquad (3)$$

Equation (3) leads to the following equilibrium biomass and catch as a function of F:

$$B=K\left(1-\frac{F}{r}\right) \qquad (4)$$

$$C=K\left(1-\frac{F}{r}\right)F \qquad (5)$$

It is clear from the above equations that maximum equilibrium catch is obtained at $F_{\text{MSY}}=r/2$. The catch and biomass associated with F_{MSY} are MSY = $Kr/4$ and $B_{\text{MSY}}=K/2$. This is also shown in Figure 6.1.

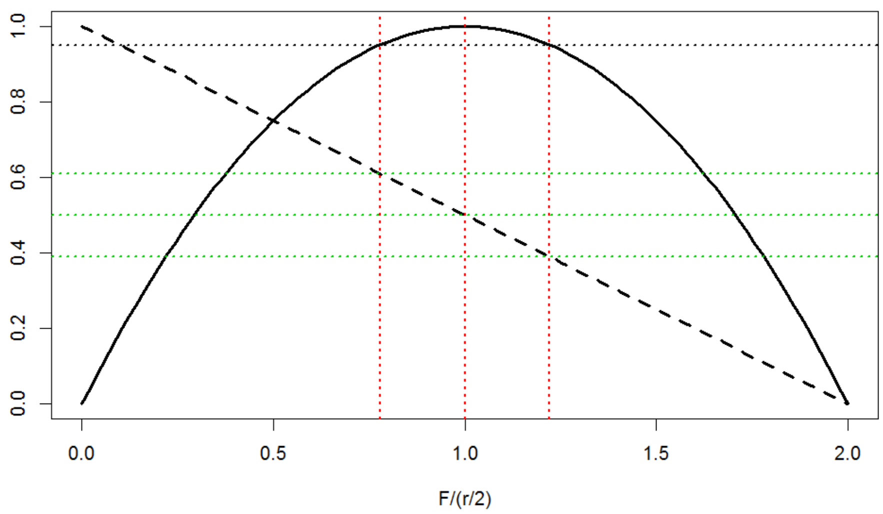


Figure 6.1: Equilibrium catch (solid black line) and biomass (dashed black line) as a function of $F/(r/2)$, based on a deterministic calculation. In the figure, both the equilibrium catch and biomass are scaled so that each has a maximum equal to 1. Maximum catch is obtained at $F_{MSY} = r/2$ (shown as the value 1 in the horizontal axis) and the corresponding biomass is $K/2$ (shown as the value 0.5 on the vertical axis). The dotted horizontal line at the top marks the range of values of F for which equilibrium catch is ≥ 0.95 MSY.

From equation (5) it is immediate that the range of Fs that give equilibrium catch ≥ 0.95 MSY is obtained by solving the following equation for F:

$$K\left(1-\frac{F}{r}\right)F = 0.95\,\frac{K\,r}{4}$$

which is equivalent to solving:

$$F^2 - r\,F + \frac{0.95}{4}\,r^2 = 0$$

There are 2 solutions to this equation:

$$F = \frac{r \pm \sqrt{r^2 - 0.95\,r^2}}{2} = \frac{r}{2}\left(1 \pm \sqrt{0.05}\right) = \mathrm{F_{MSY}}\,(1 \pm 0.22)$$

Therefore, the interval of values of F that give equilibrium catch ≥ 0.95 MSY is

($0.78\ \mathrm{F_{MSY}}$, $1.22\ \mathrm{F_{MSY}}$). This interval is shown with dotted vertical lines in Figure 6.1.

According to equation (4), the biomass associated with the F at the upper end of this interval (i.e. the biomass associated with F=1.22 $\mathrm{F_{MSY}} = 0.61\,r$) is $B = K\left(1-\frac{F}{r}\right) = 0.39\,K$ (lowest dotted horizontal line in Figure 6.1); this biomass value is above MSY $B_{trigger}$ ($0.25\,K$) and $B_{\lim}$ ($0.15\,K$).

However, this very simple deterministic calculation does not allow evaluating the long-term equilibrium probability that $B < B_{\lim}$. This has implications for how the upper end of the range for F is defined. In these circumstances, for precautionary considerations, the upper range of the proposed interval for F is not allowed to contain values larger than the point estimate of F_{MSY}; the proposed interval of Fs consistent with catch ≥ 0.95 MSY would therefore be.($0.78\ \mathrm{F_{MSY}}$, $\mathrm{F_{MSY}}$).

Stochastic evaluations similar to the Eqsim ideas outlined at the start of this document might lead to some modification of this interval, with potential extension to values of F above the point estimate of F_{MSY} if the evaluation shows that such values of F correspond to less than 5% long-term equilibrium probability of $B < B_{lim}$.

6.1.3 Proposed reference points for the stocks of black anglerfish (anb-8c9a), megrim (meg-4a6a) and Greenland halibut (ghl-grn)

Summary table of proposed stock reference points

STOCK	BLACK ANGLERFISH IN DIVISIONS VIIIC AND IXA MEGRIM IN DIVISIONS IVA AND VIA GREENLAND HALIBUT IN SUBAREAS V, VI, XII AND XIV
Reference point	Value
F_{MSY} without $B_{trigger}$	$\frac{r}{2}$
F_{MSY} lower without $B_{trigger}$	0.78 F_{MSY}
F_{MSY} upper without $B_{trigger}$	1.22 F_{MSY}
$F_{P.05}$ (5% risk to B_{lim} without $B_{trigger}$)	Not available, as reference points are derived from deterministic equilibrium calculation
F_{MSY} upper precautionary	F_{MSY} (because probability of biomass going below B_{lim} not evaluated)
Proposed F_{MSY} range	(0.78 F_{MSY}, F_{MSY})
MSY $B_{trigger}$	0.5 B_{MSY} (= 0.25 K)
B_{lim}	0.3 B_{MSY} (= 0.15 K)
F_{lim}	1.7 F_{MSY}
F_{pa}, B_{pa}	Not calculated. The probability of exceeding F_{lim} or being below B_{lim} in any assessment year can be directly calculated from the assessment output.

7 MSY interval analysis by stock: *Nephrops* stocks

The following Functional Units are considered for the ICES assessment and advice for *Nephrops* in Subarea VII and Division VIa. The functional units are shown in the following table:

Table 7.1. *Nephrops* functional units in Division VIa and Subarea VII and ICES advice basis

FU no.	Name	ICES advice basis
11	North Minch	MSY approach
12	South Minch	MSY approach
13	Clyde (Firth of Clyde and Sound of Jura)	MSY approach
14	Eastern Irish Sea	MSY approach
15	Western Irish Sea	MSY approach
16	Porcupine Bank	MSY approach
17	Aran Grounds	MSY approach
19	South and southwest Ireland	MSY approach
20-21	Labadie, Baltimore and Galley	PA/DL approach
22	Smalls Grounds	MSY approach

7.1 *Nephrops* Reference points by FU

The basis for the advice for all these FUs is the ICES MSY approach. This uses *Nephrops* abundance estimates in the FU (obtained from UWTV surveys), combined with exploitation rates considered likely to generate high long-term yield and low probability of stock overfishing. Given the lack of analytical assessments (and estimated stock–recruitment relationships), it is not possible to calculate F_{MSY} directly and per-recruit proxies have been proposed as F_{MSY} proxies. No precautionary reference points have been defined.

In many *Nephrops* stocks, there are substantial differences in relative exploitation rates between the sexes (due to differences in growth and behaviour). To account for this, the population model underpinning the per-recruit analysis is structured by sex, allowing for different fishery and biological parameters for males and females. The model is length-dependent, with length derived from a growth curve. The input parameters to the per-recruit model (fishery selection, female relative catchability and discard ogive) are derived from a length cohort analysis. So far, this analysis has been run with 'dead removals' length frequency data, i.e. ignoring the component of the discards which are assumed to survive. $F_{0.1}$, F_{max} and $F_{35\%SPR}$ are considered as potential F_{MSY} proxy reference points.

The appropriate F_{MSY} candidate has been selected for each functional unit independently, according to the perception of stock resilience, factors affecting recruitment, population density, knowledge of biological parameters, and the nature of the fishery (sporadic/new/stable); more conservative values have been chosen for stocks with perceived low resilience or limited fishery/biological information. Values for each of the candidate proxy reference points have been determined for males and females separately, and for the two sexes combined; normally the combined-sex value has been selected. A decision-making framework for the choice of F_{MSY} proxy reference points is available in the introduction to the *Nephrops* ICES advice sheets. The current F_{MSY} proxy reference points for *Nephrops* evaluated at WKMSYRef4 are given in Table 7.1.

Table 7.1 Current MSY reference points for *Nephrops* in Division VIa.

Stock	FU11 (West of Scotland, North Minch)	FU12 (West of Scotland, South Minch)	FU13 (Firth of Clyde)	FU13 (Sound of Jura)	FU14 (Irish Sea, East)	FU15 (Western Irish Sea)	FU16 (West and Southwest of Ireland, Porcupine Bank)	FU17 (Aran Grounds)	FU19 (Southwest Ireland	FU22 (Smalls)
Reference point										
Current F_{MSY}	10.9%	12.3%	16.4%	14.5%	11 %	17.1%	5 %	8.5%	8.1%	10.9%
Rationale F_{MSY}	$F_{35\%SPR}$ combined sexes	$F_{35\%SPR}$ combined sexes	F_{max} combined sexes	$F_{35\%SPR}$ combined sexes	$F_{0.1}$ combined sexes	F_{max} combined sexes	$F_{0.1}$ combined sexes	$F_{0.1}$ combined sexes	$F_{0.1}$ combined sexes	$F_{35\%SPR}$ combined sexes
Current MSY $B_{trigger}$ (millions)	541	1016	579	Not defined	350	3000	Not defined	540	Not defined	Not defined

7.2 Defining F_{MSY} ranges

Since the F_{MSY} proxy reference points are based on per-recruit analyses, it is considered appropriate to define F ranges consistent with MSY as the set of F values for which yield-per-recruit is at least 95% of the yield-per-recruit obtained at the F_{MSY} proxy reference point. However, when the F_{MSY} proxy is below F_{max}, this can lead to very high and unreasonable values of F (well above F_{max}) at the upper end; therefore, the largest possible F value considered for the range is the value above F_{max} that leads to yield-per-recruit equal to 95% of the maximum.

No precautionary reference points have been defined for *Nephrops* stocks. Whereas the F_{MSY} proxy reference points were chosen with the intent that they should lead to a low probability of stock overfishing, no formal evaluation of this (e.g. an evaluation of the long-term probability that $B<B_{lim}$, for a range of plausible B_{lim} values) has been conducted to date. This has implications for how the upper end of the range for F can be defined. In these circumstances, for precautionary considerations, the upper range of the proposed interval for F is not allowed to exceed the F_{MSY} proxy reference point (Table 7.2).

7.3 Defining MSY $B_{trigger}$

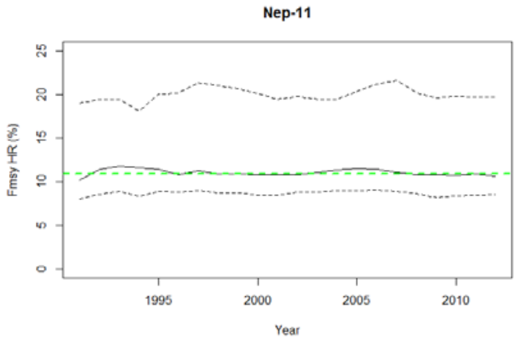
For FU 11, 12, 13FC, 14, 15 and 17 the MSY $B_{trigger}$s are based on the time-series of abundance indicators and as these have not been updated, no new proposals have been made for these values. For FU 19 and 22 which did not previously have MSY $B_{trigger}$ specified the time-series and range of indicator biomass is limited such that direct use of B_{loss} is considered too close to equilibrium biomass. The Workshop considered a lower bound based on precision of estimates, however, this leads to lower MSY $B_{trigger}$ for the FUs with greater uncertainty. A preliminary proposal was made to use the 5% interval on the probability distribution of indicator biomass assuming a normal distribution, which is analogous to the 5% on B_{MSY} proposed for finfish stocks assuming these *Nephrops* FU have been exploited at a rate close to near HR_{MSY}. The values for Nep-19 and Nep-22 are 434 and 987 respectively. These are considered somewhat *ad hoc*, however, it seems unlikely that a better approach can be found in the short term and it seems preferable to provide an MSY $B_{trigger}$ than to operate without one, so these are proposed as preliminary values that should be reviewed at future benchmarks. An MSY $B_{trigger}$ was not previously proposed for FU13 (SJ) as there were few points in the survey series (due to missing years). The survey series is now considered to be of sufficient length to allow the B_{loss} (abundance in 1995) to be proposed as the MSY $B_{trigger}$. This results in a value of 160 million. For FU16 the time-series of UWTV observations is too short and the densities observed are too low to be able to propose an MSY $B_{trigger}$ at this time.

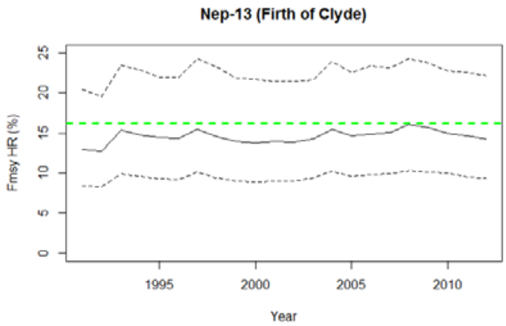
7.4 Sensitivity analysis and discussion

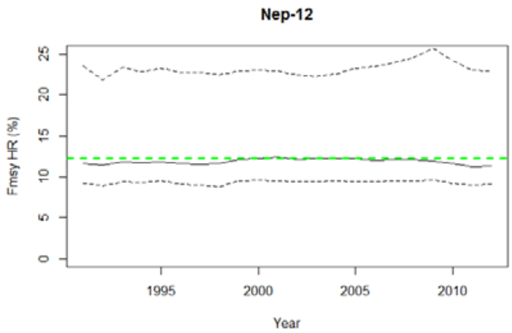
For each functional unit a sensitivity analysis was conducted in which a moving 3 year window was used to average the catch length frequency data which were used as input to the separable length cohort analysis. The parameters estimated from each LCA were then used as input to the per-recruit analysis and the F_{MSY} proxy harvest rate (and values at 95 % of YPR) were calculated. Figure 7.1 shows the results. The estimates for nep-11 and nep-12 are fairly stable over time although there is some suggestion of a reduction in nep-12 in recent years. For nep-15 the estimated harvest rate at F_{max} appear stable over time with a mean of 18.7 and standard deviation of .23. The highest estimated maximum sustainable harvest rates were observed in the early part of the time-series, declining gradually until the mid-2000's with an increase in most recent years. For nep-16 the $F_{0.1}$ has fluctuated a lot over the long time-series from 3.1–7.3 but there are known fluctuations in recruitment and changes in selection over time in the fishery that can explain this. The $F_{0.1}$ for this stock is low due to the high L50 in the fishery. For nep-17 the $F_{0.1}$ estimate is relatively stable over the short series and the mean of 8.5 is the same as was estimated by IBPNEPH (ICES, 2015).

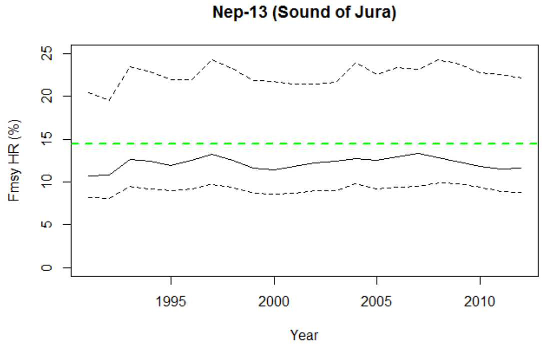
The estimates derived for the Nep-13 split as Firth of Clyde (FC) and Sound of Jura (SJ) are based on the combined length frequency data for these two subareas of FU13 combined (most of the samples are from the FC and there are insufficient samples to provide length frequencies for the SJ separately). The fishery in the SJ is perceived to be more sporadic than that in the FC and hence the basis for the reference points in the two subareas is different.

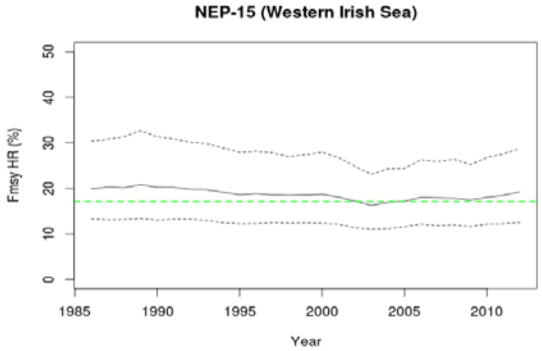
The time-series of estimated F_{MSY} harvest rates for FU13 are more variable than those for FU11 and FU12 and this appears to be due to substantial changes in parameter estimates in the separable LCA from one year to the next (although parameter estimates are still within reasonable bounds) which may be due particularly unusual annual length frequency distributions. The time-series becomes smoother if a five year window is used to average the landings and discard length frequency data as a single year's data becomes less influential and conversely, more noisy, if only a two year window is used. For FU13, estimates of F_{MSY} based on recent length frequency data are substantially lower than the currently used F_{MSY} values.

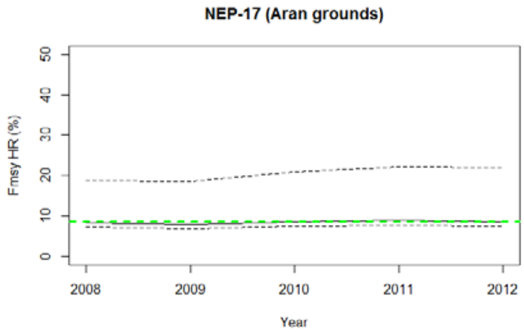

Nep-11
Fmsy HR (%)
Year


Nep-13 (Firth of Clyde)
Fmsy HR (%)
Year


Nep-12
Fmsy HR (%)
Year


Nep-13 (Sound of Jura)
Fmsy HR (%)
0
5
10
15
20
25
1995
2000
2005
2010
Year


NEP-15 (Western Irish Sea)
Fmsy HR (%)
0
10
20
30
40
50
1985
1990
1995
2000
2005
2010
Year


NEP-17 (Aran grounds)
Fmsy HR (%)
0
10
20
30
40
50
2008
2009
2010
2011
2012
Year

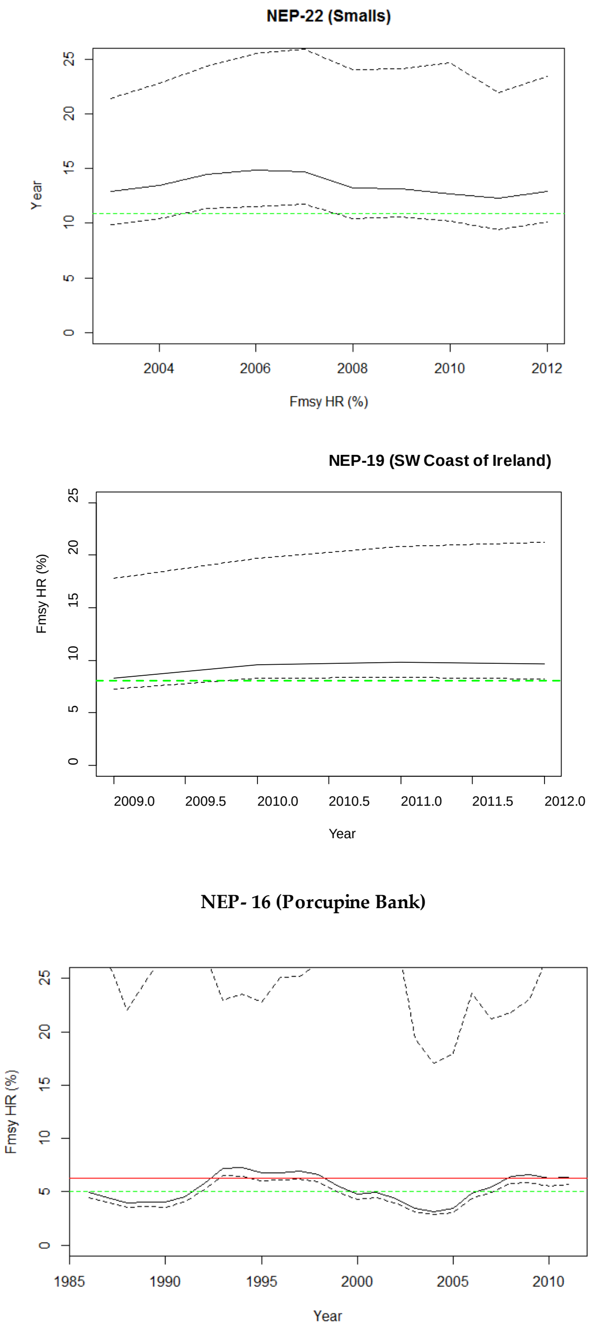


Figure 7.1. Results of sensitivity analysis in which a moving three year window of landings and discards length frequency data were used as input to the separable length cohort analysis. Solid line is the estimate of F_{MSY} harvest rate; green dashed line is current F_{MSY}; lower dashed line is harvest rate at 95 % of YPR at the F_{MSY} proxy and upper dashed line is harvest rate at 95 % of maximum YPR (at F above F_{max}).

In contrast to the approach taken for North Sea *Nephrops*, the F_{MSY} reference points for FU11, FU12, FU13, FU15, FU16, FU17, FU 22 and FU19 are updated on the basis of an average of estimated F_{MSY} proxy harvest rates over a period of years, this corresponds more closely to the methodology for finfish. In cases where there is a clear trend in the values a five year average was chosen. Similarly, the five year average of the F at 95 % of the YPR obtained at the F_{MSY} proxy reference point was proposed as the F_{MSY} lower bound and the five year average of the F above F_{max} that leads to

YPR of 95% of the maximum as the upper bound. Using an average value also has the advantage of reducing the effect of any unusually high or low estimates of the F_{MSY} proxy which occasionally appear.

Given the lack of precautionary reference points for *Nephrops* stocks (See 7.1.1), it was agreed at WKMSYREF3 that the upper range of the proposed interval for F is not allowed to exceed the F_{MSY} proxy reference point (Table 7.2). However, as suggestion has been made that given that the proposed F_{MSY} proxy reference point is taken as an average over five years' of estimates, the maximum of the five estimates can be assumed as an upper bound on F_{MSY} which is precautionary. However, this proposal uses elements of uncertainty to define the MSY HRs and this would not be in accord with the principles for defining MSY ranges based on yield and precautionary considerations that was used for the North Sea and Baltic. The Workshop has provided both precautionary and period maxima for F_{upper} in Table 7.2

Table 7.2. F_{MSY} ranges of functional Units

	FU 11	FU12	FU13 (FC)	FU13 (SJ)	FU14*	FU15	FU16	FU17	FU19	FU22
Mean F_{MSY} (5 yr)	10.8	11.7	15.1	12.0	-	18.2	6.2	8.5	9.3	12.8
Mean F_{MSY} (10 yr)	11.0	11.9	15.0	12.4	-	17.7	5.0	-	-	13.5
Mean F_{MSY} (all yrs)	11.1	11.9	14.6	12.2	11.0	18.7	5.3	8.5	9.3	13.5
Min F_{MSY} of series	10.2	11.2	12.7	10.7	-	16.2	3.1	8.0	8.3	12.3
Max F_{MSY} of series	11.8	12.4	16.2	13.4	-	20.8	7.3	8.9	9.8	14.8
Mean 95% low (5 yr)	8.4	9.3	9.9	9.4	-	12.4	5.6	7.4	8.0	10.2
Min 95 % lower (5 yr)	8.2	9.0	9.4	8.8	-	11.1	5.0	6.9	7.3	9.4
Mean 95% upper (5 yr)	19.8	24.1	23.1	23.1	-	27.9	24.0	20.5	19.1	24.0
Max 95 % upper (5 yr)	20.2	25.7	24.3	24.3	-	32.7	27.4	22.1	21.2	25.9
Max F_{MSY} (5 yr)	10.9	12.1	16.2	12.8	-	19.2	6.6	8.9	9.8	13.2
Proposed Reference Points										
MSY $B_{trigger}$ (millions)	541	1016	579	160	350	3000	Not Defined	540	434	987
New F_{MSY}	10.8	11.7	15.1	12.0	11.0	18.2	6.2	8.5	9.3	12.8
Basis	Calculated as previously, but estimates averaged over last 5 years.									
F_{MSY} lower	8.4	9.3	9.9	9.4	9.1	12.4	5.0	7.4	8.3	10.2
F_{MSY} upper (YPR)	19.8	24.1	23.1	23.1	25.3	27.9	24.0	20.5	19.1	24.0
F_{MSY} upper period max	10.9	12.1	16.2	12.8	-	19.2	6.6	8.9	9.8	13.2
F_{MSY} upper precautionary	10.8	11.7	15.1	12.0	11.0	18.2	6.2	8.5	9.3	12.8

**It is only possible to calculate the FMSY based on data for the last two years because sampling is insufficient prior to that.*

8 Summary of results

Three of the stocks considered in WKMSYREF4 are assessed using surplus production models: black anglerfish in Divisions VIIIc and IXa (anb-8c9a), megrim in Divisions IVa and VIa (meg-4a6a) and Greenland halibut in Subareas V, VI, XII and XIV (ghl-grn). The results for these stocks are all given in relative to the estimated model parameters, not as specific numerical values and are given in Section 6.1.3 for these stocks full stochastic evaluations are not available and thus F_{MSY} upper is limited to F_{MSY} .

The results for all the *Nephrops* stocks are given in Section 7 Table 7.2. For these stocks full stochastic evaluations are not available and thus F_{MSY} upper is limited to F_{MSY}.

For all the rest of the stocks a summary of the revised reference points for the stocks dealt with in Section 5 is given in Table 8.1. Where revisions have been made these are relatively minor, with most of the changes coming from changes in the F limits rather than biomass revisions.

For these stocks a summary of the F_{MSY} values and ranges is given in Table 8.2. The final four columns in this table are the basis for the answer to the special request, and are derived from the first six columns based on the method described in Section 4.

The effect on advice that would result from a change in MSY $B_{trigger}$ from current values, which is almost always B_{pa} to the ACOM proposed 5 percentile on the distribution of BMSY is shown in Table 8.3. The values shown in the two right-most columns of the table is the value of the factor potentially applicable to reduce F in case SSB2015<MSY$B_{trigger}$ for two options, a) setting the value of MSY$B_{trigger}$ to the current value =B_{pa} (second column from right) and b) setting MSY$B_{trigger}$ to the 5 percentile on the distribution of BMSY (right-most column). The factor is calculated when SSB2015 is below the trigger value. When SSB is above the trigger value, the ratio is set to 1 as would be done when applying the ICES MSY AR. To allow a comparison to be made between the proposed values and historic data the lowest and highest stock sizes are also included in the same Table. The relative positions of historic stock (Minimum and Maximum biomasses) B_{PA}, current SSB (2015), %5 on BMSY and BMSY is illustrated by stock in Figure 8.1.

The biggest influence of the proposed changes to MSY $B_{trigger}$ are for the three cod stocks where the multipliers on F_{MSY} would change (reduce) substantially. I.e. Celtic Sea cod (0.75/0.53), Irish Sea cod (0.36/0.14) and West of Scotland cod (0.15/0.04). All these cod stocks are currently below B_{pa} and only for the Celtic Sea would the immediate advice change, because the advice for the other two stocks is for minimum catch, but future advice for all three stocks would be different if the change to MSY$B_{trigger}$ in implemented immediately. There are also some stocks which are above B_{pa} in 2015 but would be below the 5% on BMSY, the changes for these stocks would be: a change to 0.91 and 0.34 for Northern and Southern hake, respectively, and to 0.76 for Bay of Biscay sole. This is a very big change for southern hake. For a few other stocks SSB in 2015 is close to 5% on BMSY and the changes are small in 2015 (<5%), but the change could increase if the stock does not continue to increase (or experiences some decrease) in biomass. Quite a few stocks are close to and could fall below 5% on BMSY in the near future. Management of the change to $B_{trigger}$ based on 5% of B_{MSY} is discussed further below.

For a few stocks the analyses require further consideration;

- For Western Channel sole the recent Inter-Benchmark advised a higher breakpoint on the S-R relationship and lower values of B_{pa} and B_{lim} than the ones chosen at WKMSYREF4. WKMSYREF4 has considered the benchmark proposals but has concluded that the PA and MSY points presented here provide a more coherent basis for reference points.

- For West of Scotland whiting the situation is similar to NS whiting with recent recruitment very low and no F_{upper}> F_{MSY} can be recommended.
- For Rockall haddock recent recruitment has been low for more than 10 years and it is proposed that the advice should be based on the ICES Management Plan evaluation carried out over 2011–2013
- For blue Ling the assessment model is based on an S-R assumption that does not give any variability of year-to-year recruitment, so the 5% on BMSY is not useful as an $MSYB_{trigger}$ and is not recommended.
- For southern hake it was not possible to carry out full stochastic evaluations, thus the probability of SSB<B_{lim} could not be directly estimated. The separation of the PA reference points from F ranges suggests that there are no precautionary issues for this stock. This was confirmed by comparing the F ranges for northern hake with southern hake which has similar dynamics and concluding it was safe to use the estimated F ranges for southern hake although the full tests had not been carried out.

Table 8.1 Revised PA reference points by stock, for details see Section 5.

STOCK	ORIGINAL PA REFERENCE POINTS				WKMSYREF4 PA POINTS			
	F_{lim}	F_{pa}	B_{lim}	B_{pa}	F_{lim}	F_{pa}	B_{lim}	B_{pa}
White anglerfish (*Lophius piscatorius*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlanic Iberian Waters)	not defined	not defined	not defined	not defined	0.60	0.43	1852	5592
Blue ling (*Molva dypterygia*) in Subareas VI-VII and Division Vb (Celtic Seas, English Channel and Faroes Grounds)	not defined	not defined	not defined	not defined	0.17	0.12	54000	75000
Seabass (*Dicentrarchus labrax*) in Divisions IVb and c, VIIa, and VIId–h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)	not defined	not defined	B_{loss} = 5250t	1.5*B_{lim}= 8000t	not defined	not defined	5300	8000
Cod (*Gadus morhua*) in Divisions VIIe–k (Eastern English Channel and Southern Celtic Seas)	F(p(SSB<B_{lim})=50%) = 0.78	F_{lim}/1.4 = 0.56	B_{loss} = 7300t	1.4*B_{lim}= 10300t	0.82	0.59	7300	10300
Cod (*Gadus morhua*) in Division VIIa (Irish Sea)	1.0 (F_{med})	0.72 (F_{med}*.72)	6000t (Blim = B_{loss}; 1998)	10000t (B_{pa} = MBAL)	1.33	0.96	6000	10000
Cod (*Gadus morhua*) in Division VIa (West of Scotland)	0.8 (F above lead to stock decline)	(high probability to avoid F_{lim}) = 0.6	B_{loss}= 14000t	22000t (Basis?)	0.82	0.59	14000	20000
Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb–k (Southern Celtic Seas and English Channel)	F(p(SSB<B_{lim})=50%) = 1.41	F_{lim}*exp(-1.645*.28) = 0.89	B_{loss}= 6700t	B_{lim}*exp(1.645*0.26) = 10000t	1.41	0.89	6700	10000
Haddock (*Melanogrammus aeglefinus*) in Division VIb (Rockall)	not defined	[Low prob. that SSB fall below B_{pa}] =	B_{loss} = 6000t	B_{lim}*1.5 = 9000t	0.62	0.41	6800	10200

		0.4						
Hake (*Merluccius merluccius*) in Subareas IV, VI, and VII and Divisions IIIa, VIIIa,b,d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)	not defined	not defined	33 000t	B_{lim}*1.4 = 46200t	0.87	F_{lim}/1.4=0.62	32000	45000
Hake (*Merluccius merluccius*) in Divisions VIIIc and IXa (Southern stock) (Cantabrian Sea, Atlanic Iberian Waters)	not defined	not defined	[SSB that produce R at or above average] = 9000t	not defined	1.05	0.75	8000	11100
Four-spot megrim (*Lepidorhombus boscii*) in Divisions VIIIc and IXa (Bay of Biscay South, Atlanic Iberian Waters East)	not defined	not defined	B_{loss}= 3300t	1.4*B_{lim}= 4600t	0.57	0.41	3300	4600
Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlanic Iberian Waters)	not defined	not defined	B_{loss}= 650t	1.4*B_{lim} = 910t	0.45	0.32	700	980
Plaice (*Pleuronectes platessa*) in Division VIIe (Western English Channel)	not defined	not defined	not defined	not defined	0.88	0.63	1700	2400
Sole (*Solea solea*) in Divisions VIIIa, b (Bay of Biscay North and Central)	[Historical response of the stock] = 0.58	[F_{lim}*.72] = 0.42	not defined	[prob of reduced R if SSB<B_{pa}] = 13000t	0.60	0.43	7600	10600
Sole (*Solea solea*) in Divisions VIIf,g (Bristol Channel, Celtic Sea)	F_{loss} = 0.52	[F_{lim}*.72] = 0.37	not defined	B_{loss} = 2200t	0.48	0.34	1700	2400
Sole (*Solea solea*) in Division VIIe (Western English Channel)	not defined	not defined	[WKFRAME2 analysis] = 1300t	[WKFRAME2 analysis] = 1800t	0.44	0.32	2000	2900
Sole (*Solea solea*) in Division VIIa (Irish Sea)	F_{loss} = 0.40	[high probability to avoid F_{lim}] = 0.30	B_{loss}= 2200t	1.4*B_{lim} = 3100t	0.29	0.21	2500	3500

Whiting (*Merlangius merlangus*) in Divisions VIIb,c,e–k (Southern Celtic seas and Eastern English Channel)	[increased risk of reaching B_{lim}] = 0.5	not defined	B_{loss} = 25000t	[low bound (95%??) of expected range at F_{MSY}] = 40000t	1.12	0.8	25000	35000
Whiting (M*erlangius merlangus*) in Division VIa (West of Scotland)	not defined	not defined	[breakpoint of Hockey-S S/R] = 28500t	B_{lim}*1.4 = 39900t	0.25	0.18	28500	39900

Table 8.2 Summary of F_{MSY} reference points, estimates of F_{lower} F_{MSY} and F_{upper} and $F_{P.05}$ calculated without a $B_{trigger}$ are given in columns 1–4. Columns 5 and 6 show the $F_{p.05}$ with MSY$B_{trigger}$ set to B_{pa} and to the 5 percentile of BMSY respectively, The final 4 columns give the F_{MSY} and F_{upper} values conditional on the use or not of the ICES advice rule with an MST $B_{trigger}$ based on B_{pa}.

FULL NAME	WITHOUT $B_{TRIGGER}$									
	F_{lower}	F_{MSY}	F_{uppper}	$F_{P0.5}$	$F_{P0.5}$ ($B_{trigger}$=B_{pa})	$F_{P0.5}$ ($B_{trigger}$=5%B_{MSY})	F_{MSY} (No AR)	F_{upper} (No AR)	F_{MSY} (Inc. AR)	F_{upper} (Inc. AR)
White anglerfish (*Lophius piscatorius*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)	0.18	0.31	0.41	0.46	0.53	1.09	0.31	0.41	0.31	0.41
Blue ling (*Molva dypterygia*) in Subareas VI-VII and Division Vb (Celtic Seas, English Channel and Faroes Grounds)	0.07	0.12	0.17	0.14	0.14	0.18	0.12	0.14	0.12	0.14
Seabass (*Dicentrarchus labrax*) in Divisions IVb and c, VIIa, and VIId–h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)	0.11	0.13	0.00				0.00	0.00	0.00	0.00
Cod (*Gadus morhua*) in Divisions VIIe–k (Eastern English Channel and Southern Celtic Seas)	0.23	0.36	0.56	0.58	0.63	0.63	0.36	0.56	0.36	0.56
Cod (*Gadus morhua*) in Division VIIa (Irish Sea)	0.23	0.37	0.63	1.00	1.01	>1.01	0.37	0.63	0.37	0.63
Cod (*Gadus morhua*) in Division VIa (West of Scotland)	0.11	0.17	0.25	0.54	0.65	>1.5	0.17	0.25	0.17	0.25
Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb–k (Southern Celtic Seas and English Channel)	0.26	0.40	0.60	0.74	0.74	0.74	0.40	0.60	0.40	0.60
Haddock (*Melanogrammus aeglefinus*) in Division VIb (Rockall)	0.18	0.27	0.38	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Hake (*Merluccius merluccius*) in Subareas IV, VI, and VII and Divisions IIIa, VIIIa,b,d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)	0.18	0.28	0.45	0.87	1.00	>3	0.28	0.45	0.28	0.45

Hake (*Merluccius merluccius*) in Divisions VIIIc and IXa (Southern stock) (Cantabrian Sea, Atlantic Iberian Waters)	0.17	0.25	0.36	0.00	0.88	<0.881	0.00	0.00	0.25	0.36
Four-spot megrim (*Lepidorhombus boscii*) in Divisions VIIIc and IXa (Bay of Biscay South, Atlantic Iberian Waters East)	0.12	0.19	0.29	0.40	0.58	0.58	0.19	0.29	0.19	0.29
Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)	0.12	0.19	0.29	0.24	0.40	0.40	0.19	0.24	0.19	0.29
Plaice (*Pleuronectes platessa*) in Division VIIe (Western English Channel)	0.14	0.24	0.47	0.59	0.69	NA	0.24	0.47	0.24	0.47
Sole (*Solea solea)* in Divisions VIIIa, b (Bay of Biscay North and Central)	0.18	0.33	0.49	0.48	0.59	0.88	0.33	0.48	0.33	0.49
Sole (Solea solea) in Divisions VIIf,g (Bristol Channel, Celtic Sea)	0.15	0.27	0.42	0.36	0.43	0.49	0.27	0.36	0.27	0.42
Sole (*Solea solea*) in Division VIIe (Western English Channel)	0.16	0.29	0.34	0.32	0.40	0.39	0.29	0.32	0.29	0.34
Sole (*Solea solea*) in Division VIIa (Irish Sea)	0.16	0.20	0.24	0.22	0.26	0.29	0.20	0.22	0.20	0.24
Whiting (*Merlangius merlangus*) in Divisions VIIb,c,e–k (Southern Celtic seas and Eastern English Channel)	0.32	0.52	0.83	0.58	0.58	0.58	0.52	0.58	0.52	0.58
Whiting (*Merlangius merlangus*) in Division VIa (West of Scotland)	0.14	0.19	0.22	0.14	0.16	0.00	0.14	0.14	0.16	0.16

Table 8.3. Summary of MSY$B_{trigger}$ with effect on advice shown as the Fmod1 the ratio of current $B_{trigger}$ to 2015 SSB (B2015/B_{pa}) and if 5% on BMSY is greater F_{Mod2} modification due to the 5% on B_{MSY} to 2015 SSB (B2015/B5%MSY), where SSB2015 is greater than the biomass modifier F mod1 or F mod2 are shown = 1.0. For comparison with history the lowest and highest stock sizes are also included in the table.

FULL NAME	SSB 2015	B_{pa}	50% B_{MSY}	5% BMSY	$B_{trigger}$	MIN SSB	MAX SSB	F MOD1 (B/B_{pa})	F MOD2 (B/5%B_{MSY})
White anglerfish (*Lophius piscatorius*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)	7546	2592	9829	5755	5755	1852	11092	1.00	1.00
Blue ling (*Molva dypterygia*) in Subareas VI-VII and Division Vb (Celtic Seas, English Channel and Faroes Grounds)	95000	75000	75000		75000	54000	275000	1.00	1.00
Seabass (*Dicentrarchus labrax*) in Divisions IVb and c, VIIa, and VIId–h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)	6925	8000			8000	5250	19242	0.87	0.87
Cod (*Gadus morhua*) in Divisions VIIe–k (Eastern English Channel and Southern Celtic Seas)	7676	10300	26366	14466	14466	3436	26324	0.75	0.53
Cod (*Gadus morhua*) in Division VIIa (Irish Sea)	3645	10000	40866	26569	26569	1194	19285	0.36	0.14
Cod (*Gadus morhua*) in Division VIa (West of Scotland)	2905	20000	112050	65073	65073	1646	40536	0.15	0.04
Haddock (*Melanogrammus aeglefinus*) in Divisions VIIb–k (Southern Celtic Seas and English Channel)	23212	10000	60000	21000	21000	7164	83210	1.00	1.00
Haddock (*Melanogrammus aeglefinus*) in Division VIb (Rockall)	13052	10167	48330	13690	13690	3762	29525	1.00	1.00
Hake (*Merluccius merluccius*) in Subareas IV, VI, and VII and Divisions IIIa, VIIIa,b,d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)	203296	45000	305000	222607	222607	25087	218747	1.00	0.91
Hake (*Merluccius merluccius*) in Divisions VIIIc and IXa (Southern stock) (Cantabrian Sea, Atlantic Iberian Waters)	18856	11133	73330	56275	56275	5812	45802	1.00	0.34
Four-spot megrim (*Lepidorhombus boscii*) in Divisions VIIIc and IXa (Bay of Biscay South, Atlantic Iberian Waters East)	6725	4600	12068	6975	6975	3316	6790	1.00	0.96
Megrim (*Lepidorhombus whiffiagonis*) in Divisions VIIIc and IXa (Cantabrian Sea, Atlantic Iberian Waters)	1311	980	2429	1347	1347	707	2249	1.00	0.97

Plaice (*Pleuronectes platessa*) in Division VIIe (Western English Channel)	6230	2443	7403	5355	5355	1745	6230	1.00	1.00
Sole (*Solea solea*) in Divisions VIIIa, b (Bay of Biscay North and Central)	12012	10600	19826	15800	15800	9627	16378	1.00	0.76
Sole (*Solea solea*) in Divisions VIIf,g (Bristol Channel, Celtic Sea)	2620	2380	3361	2683	2683	1677	7557	1.00	0.98
Sole (*Solea solea*) in Division VIIe (Western English Channel)	4515	2855	3356	2826	2855	2390	5338	1.00	1.00
Sole (*Solea solea*) in Division VIIa (Irish Sea)	942	3546	6190	4141	4141	942	7193	0.27	0.22
Whiting (*Merlangius merlangus*) in Divisions VIIb,c,e–k (Southern Celtic seas and Eastern English Channel)	58779	35000	45000	35000	35000	25265	79438	1.00	1.00
Whiting (*Merlangius merlangus*) in Division VIa (West of Scotland)	15355	39900	36552	22380	39900	3947	123916	0.38	0.38

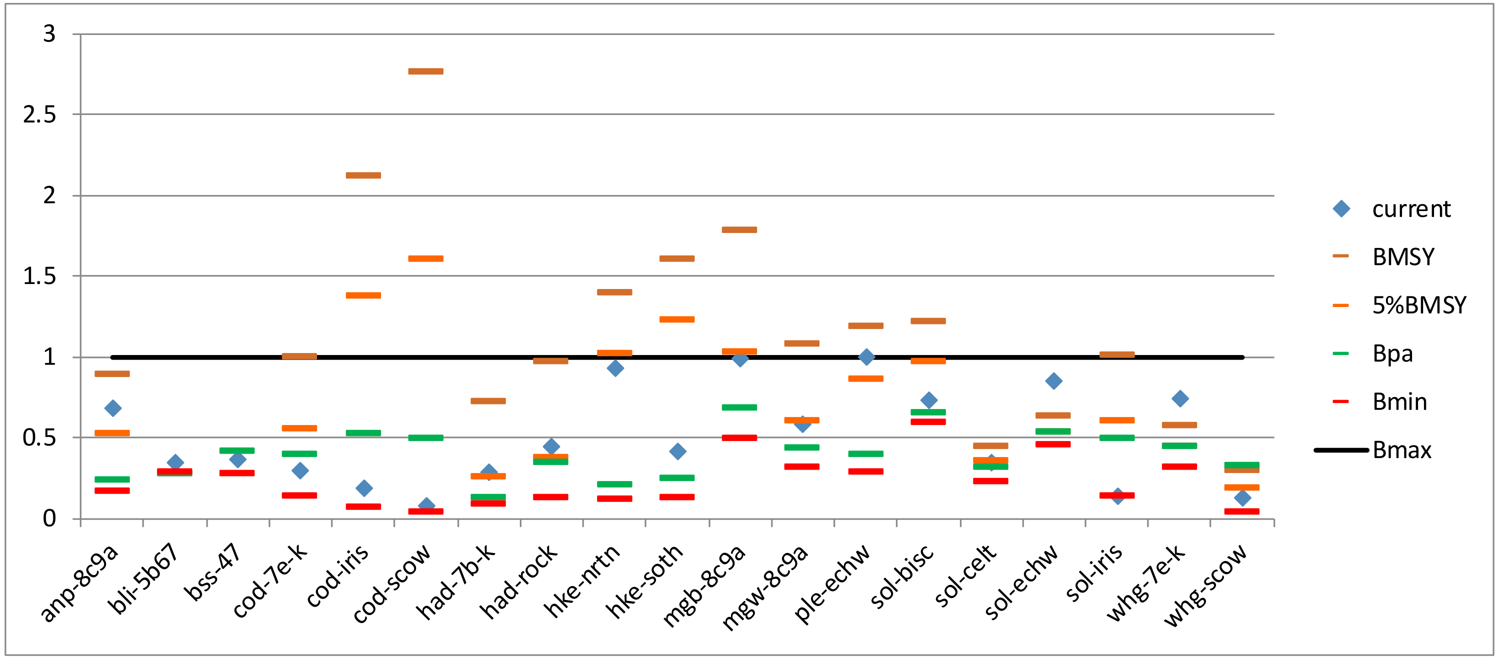


Figure 8.1 Comparison of historic, current and reference point biomasses. All biomasses are plotted relative to historic maximum biomass (1). Lower bound on historic biomass (red), current biomass (blue dot) are shown along with potential BMSY, B_{pa} and 5% on BMSY the current and potential $MSYB_{trigge}$. For some stocks $MSYB_{trigger}$ is well above historic biomass.

9 General guidance

9.1 Modifications suggested for estimation of Precautionary Reference points

In most cases the WKMSYREF4 followed the ACOM document, rather consistently. There is one exception however, when no previous B_{lim} was available and B_{loss} is not considered to be at B_{lim} because the range of F and SSB explored in history is not sufficient then B_{loss} has not always been set as B_{PA}. In a few cases where lowest biomass was characterized by low recruitment (below the mean of the series) the B_{pa} was set at the lowest biomass with an above average recruitment. It is proposed that the ACOM document is updated with this approach.

Setting B_{lim}

The breakpoint in the hockey stick has been rarely used to define B_{lim} by ICES (WKMSYREF3 and also this document). In many cases the fit is poor (e.g. Rockall haddock) and the breakpoint is not considered a good indication of a lower bound. Predominantly the lowest biomass with 'recovery' is taken as B_{lim}.

Calculating F_{lim}

F_{lim} is calculated as the F that would keep B at B_{lim} given the S-R function without including observation or implementation error. Mostly the breakpoint in the simulated R is fixed at B_{lim}. However, where recruitment below B_{lim} is observed, and the line to the origin from B_{lim} lies substantially above the observations of recruitment then a fitted S-R model should be used. See for example Section 5.17 sole in the Irish Sea. Setting the point of inflection at B_{lim} in such circumstances would imply a more resilient stock than the one implied by the observations.

When Bl_{oss} =B_{pa}, with breakpoint set to B_{pa}, F_{lim} is determined by stochastic simulation with breakpoint at B_{loss}. This provides a safe evaluation of F_{lim} in the absence of information, and is preferred to the assumption that indeed recruitment can be relied upon to be maintained at the mean level at unobserved biomasses.

When B_{loss} is above B_{lim} but below B_{pa}, then the breakpoint is not set at B_{lim}.

In some cases the breakpoint was set to B_{pa} (e.g. sol-bisc) where there is some indication of reduced recruitment below B_{pa}, similar to the argument above, otherwise F_{lim} is determined by stochastic simulation with breakpoint at B_{loss} (e.g. sol-echw).

For a number of stocks where F has been high, low recruitment at very low biomass can be observed. This is typical for a number of cod stocks (e.g. Irish Sea cod, Western Baltic cod, and North Sea cod). If the breakpoint in the regression has been judged to be appropriate (e.g. Baltic cod), then is used directly to evaluate F_{lim}. In some cases the breakpoint on the segmented regression it not used to define B_{lim}, but a low biomass giving good recruitment is taken as B_{lim}. In these circumstances F_{lim} should be based on a fitted relationship that follows the observations below B_{lim} to ensure the resilience of the stock is correctly reflected in the value of F_{lim}.

Surplus production models use a different approach. This should be included in the ACOM reference point document.

9.2 Modifications suggested for estimation of F_{MSY} ranges

In MSYREF4 the segmented regression S-R relationship was used extensively, this was chosen to remove the strong influence of either rising R with SSB implied by the

Berverton-Holt or falling R with SSB implied by the Ricker. In most cases it was thought to be better to impose independence of R on SSB at high biomass unless good biological reasons could be identified. In total in WKMSYREF4 the segmented regression was used more often rather than the combined SR.

Overall it is considered that the F_{MSY} and ranges defined here with $B_{trigger}$=B_{PA} are all consistent with the approach of WKMSYREF3.

9.3 Choice of MSYB$_{trigger}$

B_{MSY} is uncertain, not only because recruitment is variable, but because stock dynamics today may not match stock dynamics over the history used simulate the MSY evaluations. The current status of the stocks evaluated here is shown in Figure 9.1. As highlighted in Section 8 some stocks are far from BMSY and 5% on BMSY and if the 5% interval is imposed immediately will require substantial reduction in advised F. Imposing biomass limits based on percentiles of B_{MSY} directly may result in unachievable expectations, therefore a transition process from MSYB$_{trigger}$=B_{pa} is suggested. A number of options were considered, applying new MSYB$_{trigger}$s immediately, applying the new MSY $B_{trigger}$ as soon as the stock reaches this value, or giving a 'safe margin' to ensure a smooth relatively trouble free transition. The numerical basis of a margin is hard to quantify, but the use of the ICES precision margin of 1.4 used to define B_{pa} for many stocks ensures that changes are made only when there is a high probability of being above the current MSYB$_{trigger}$. Figure 9.1 shows the relative biomasses at which transition would commence for the stocks evaluated here. The suggested transition process is outlined below:

1) Starting point was MSYB$_{trigger}$=B_{pa}
2) Candidate MSYB$_{trigger}$=5th percentile of SSB distribution at F_{MSY} without $B_{trigger}$ or error in F.
3) The maximum of B_{pa} and any subsequently agreed MSYB$_{trigger}$ and the new candidate value, according to procedure in the reference point document.
4) Transition, take the minimum of the new candidate $B_{trigger}$ and average SSB of the last three years * 0.71 (with B_{pa} as the lower bound).
5) This means that for all stocks that are above B_{pa}, initially they are above $B_{trigger}$.
6) $B_{trigger}$ should be reviewed when F_{MSY} is reviewed, following item 3 above.
7) $B_{trigger}$ could be reduced below current $B_{trigger}$ in the following exceptional circumstances: (1) stock dynamics are considered to have changed substantially with reducing historic biomass, (2) an error in the assessment

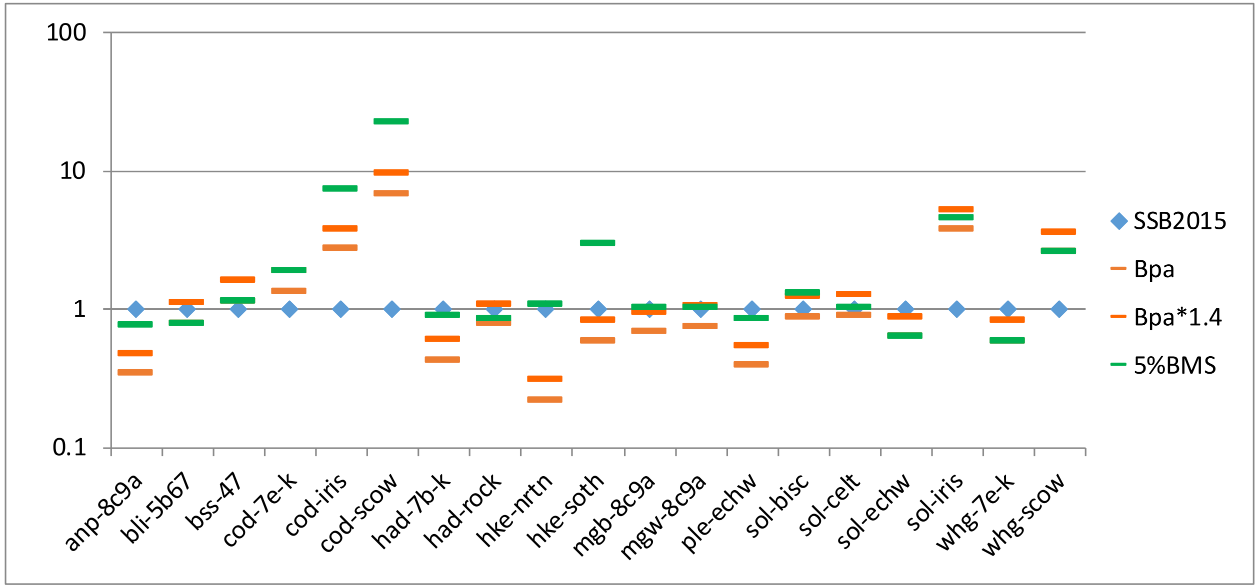


Figure 9.1 Potential biomass (relative to current biomass) when transition to new MSY $B_{trigger}$ would occur.

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Annex 2: MSY $B_{trigger}$ values for stocks in the Western Waters EU request

ICES has started a process to progressively update $MSYB_{trigger}$ values to ensure coherence with ICES MSY approach. When fishing at F_{MSY}, one would expect biomass to fluctuate within a range dependent upon the variation in recruitment and parameters such as growth, maturity and selectivity. ICES defines the $MSYB_{trigger}$ as the 5th percentile of the distribution of expected biomasses when fishing at F_{MSY}. The current $MSYB_{trigger}$ values are for most stocks not consistent with the definition, but instead based on B_{pa}. The process to update the $MSYB_{trigger}$ values follows the flowchart presented below. This was applied by correspondence, post-Advice Drafting Group meeting, to the Western Waters stocks in the EU special request for which it was possible to simulate the distribution of SSB when fishing at F_{MSY}.

In the process, the first thing is to check if the stock has been fished at or below $\mathbf{F_{MSY}}$ for 5 or more years (most recent years). Taking into account the new $\mathbf{F_{MSY}}$ values calculated by WKMSYREF4, the following stocks fulfilled this condition:

- White anglerfish (*Lophius piscatorius*) in 8c and 9a: For this stock, the 5th percentile of the distribution of SSB when fishing at F_{MSY} is 5755 t (see ICES, 2016), which is larger than B_{pa} (2592 t). For this stock, no $MSYB_{trigger}$ had been previously set. Additionally, SSB_{2015}=7546t (ICES, 2015). The 5th percentile of SSB_{2015} can be approximated by 7546/1.4=5390t. As the latter value is less than the 5th percentile of the equilibrium distribution of SSB when fishing **at** $\mathbf{F_{MSY}}$, this means that the latter value becomes $MSYB_{trigger}$; hence, with rounding, $MSYB_{trigger}$=5400t.
- Blue ling in 5b, 6 and 7: The WKMSYREF4 report (ICES, 2016) states that, the variability of the stock dynamics is not fully captured in this analysis, because the modelling approach does not allow for significant variability of recruitment. In these circumstances a MSY $B_{trigger}$ based on 5% of BMSY is not meaningful and is not recommended. Therefore, $MSYB_{trigger}$ was set at B_{pa}.
- Stocks of sole in 7e, whiting in 7b, c, e-k, and whiting in 6a, he 5th percentile of the distribution of SSB when fishing at F_{MSY} (ICES, 2016) is ≤ B_{pa} (ICES, 2016); hence, MSY $B_{trigger}$ = B_{pa}.
- Black-bellied anglerfish (*Lophius budegassa*) in 8c and 9a: As no stochastic evaluation is available, it was not possible to calculate the 5th percentile of the distribution of SSB when fishing at F_{MSY}**.** Therefore, the basis for $MSYB_{trigger}$ remained unchanged (50%B_{MSY}, where B_{MSY} is a model parameter in the surplus production model used for the assessment of this stock).

For all other stocks, $MSYB_{trigger}$ was set at B_{pa} when this reference point was defined. This excluded the two stocks assessed with surplus production models (Black-bellied anglerfish in 8c and 9a; and Greenland halibut in 5, 6, 12 and 14), as well as the *Nephrops* stocks. The $MSYB_{trigger}$ values for these stocks are explained in (ICES, 2016).

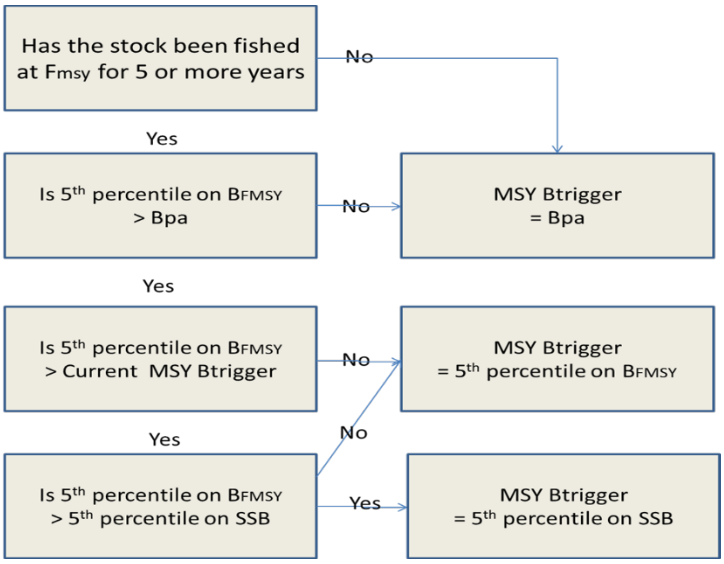

Figure 1. ICES determination decision tree for $MSYB_{trigger}$. Note the following: (1) BF_{MSY} denotes the expected equilibrium biomass when fishing at F_{MSY}; (2) SSB denotes the SSB in the last assessed year; (3) If the assessment does not have intervals on SSB, the commonly used (in ICES) CV of 20% giving 5th percentile at SSB/1.4 should be used; (4) MSYBtrigger is expected to be reduced by this process only if the new estimate of the 5th percentile of BF_{MSY} is lower than a previous estimate; and, (5) B_{pa}, $MSYB_{trigger}$, BFMSY are in units of SSB.

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Annex 3: Correction to Whiting (*Merlangius merlangus*) in Divisions 7b,c,e–k (Southern Celtic seas and Eastern English Channel)

ACOM Vice Chair: Carmen Fernandez

ICES Expert: Colm Lordan, Marine Institute, Ireland

Professional officer: Anne Cooper, ICES

Stock: Correction to Whiting (*Merlangius merlangus*) in Divisions 7b,c,e–k (Southern Celtic seas and Eastern English Channel) (reference ICES stock code whg-7bc, e-k)

During the preparation of the ACOM web-conference for advice approval, it was found that all runs conducted in the WKMSYREF4 workshop had inadvertently been done without MSY $B_{trigger}$ (i.e. with constant F exploitation instead of applying the ICES MSY AR). Therefore, one additional run was needed where the ICES MSY AR was applied, in order to get the correct value of $F_{p.05}$ and F_{upper} when the AR is applied.

The relevant stock scientist, together with WKMSYREF4 co-chair and ACOM vice-chair, produced a corrected run, with the consequence that the value of $F_{p.05}$ (and F_{upper}) increases from 0.58 (reported in Table 5.18.3 of the WKMSYREF4 report) to 0.67. This new run is presented here:

This is an R Markdown document to checks the MSY estimation procedure for Whiting (*Merlangius merlangus*) in Divisions 7b,c,e–k (Southern Celtic seas and Eastern English Channel).

```
library(FLCore)
library(msy)
library(dplyr)
source("C:/WKMSYREF4/eqsim_plot3.R")
load("C:/WKMSYREF4/whg7bk/whg7bk_stock.Rdata")
load("C:/WKMSYREF4/whg7bk/whg7bk_xsa.Rdata")
stock <- stock + xsa
```

The setup is the same as in WKMSYREF4: Full range of years for mean weights. Only the last three years for the selection pattern because recent selectivity improvements in the fishery are not likely to be reversed. The F_{cv} and F_{phi} settings were those agreed at WKMSYREF4 for stocks where these uncertainties cannot be estimated. The SR model was segmented regression with a breakpoint fixed at the B_{lim} of 25kt. In the new run here, $B_{trigger}$ was set at 35kt = B_{pa}.

```
stockSetup <- list(data = stock,
bio.years = c(1999, 2014),
bio.const = FALSE,
sel.years = c(2012, 2014),
sel.const = FALSE,
Fscan = seq(0,1.5,by=0.05),
Fcv = 0.212, Fphi = 0.423,
Blim = 25000,
Btrigger = 35000,
Bpa = signif(25000.00 * exp(1.645 * 0.2) ,2),
extreme.trim=c(0.05,0.95)
)

SetBlim<-25000

FixedBlim<-function (ab, ssb)
{log(ifelse(ssb >= SetBlim, ab$a * SetBlim, ab$a * ssb))}
```

The "do_the_whole_thing" function runs all the various runs specified by WKMSYREF4. Table 1 below gives the results from an implementation with the $MSYB_{trigger}$ of 35kt to simulate the ICES AR. All results presented labelled “without $B_{trigger}$” in the WKMSYREF4 report were done correctly and are not repeated here.

From Table 1, $F_{p.05}$ is 0.67. From Table 5.18.3 of the WKMSYREF4 report, F_{MSY}=0.52, and the range calculated without $B_{trigger}$ is 0.32 to 0.83. The $F_{p.05}$ value calculated here implies that, when the ICES AR is applied with $B_{trigger}$ = B_{pa}, F_{upper} is 0.67.

```
whg_res <- do_the_whole_thing(stockSetup)

knitr::kable(t(whg_res$sim_trigger$Refs2), digits=c(2,2,0,0,0,0))
```

Table 1. Whiting in 7bc,e-k Eqsim results with an MSY $B_{trigger}$ of 35kt.

	CATF	LANF	CATCH	LANDINGS	CATB	LANB
F_{05}	0.67	NA	18571	NA	41277	NA
F_{10}	0.83	NA	19079	NA	37220	NA
F_{50}	NA	NA	NA	NA	NA	NA
medianMSY	NA	0.57	NA	11500	NA	44920
meanMSY	1.05	0.55	19191	11494	33039	45613
Medlower	NA	0.33	NA	10924	NA	57668
Meanlower	NA	0.33	NA	11352	NA	NA
Medupper	NA	0.98	NA	10922	NA	34183
Meanupper	NA	0.97	NA	11347	NA	NA

```
knitr::kable(t(whg_res$sim_base$Refs2), digits=c(2,2,0,0,0,0))
```