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Report of the Joint ICES–MYFISH Workshop to consider the basis for FMSY ranges for all stocks (WKMSYREF3)

17–21 November 2014

Charlottenlund, Denmark

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CIEM Conseil International pour l'Exploration de la Mer

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Executive Summary

The **Joint ICES-MYFISH Workshop to consider the basis for FMSY ranges for all stocks** was held at DTU-Aqua, Charlottenlund, Denmark from 17—21 November 2014. The workshop was convened in response to a request from the European Commission for advice on potential intervals above and below F_{MSY}. The meeting was attended by 14 delegates from 8 countries and 3 representatives of 3 stakeholder organisations, and was chaired by John Simmonds (ICES) and Anna Rindorf (Denmark). The work conducted was centred around six Terms of Reference concerning methods for estimating F_{MSY} ranges, F_{MSY} ranges for North Sea demersal stocks, Baltic Sea stocks, anchovy in Subarea VIII and horse mackerel (Western stock) and guidelines for estimating F_{MSY} ranges for other stocks which are compatible with obtaining no less than 95% of the estimated maximum sustainable yield and which are considered precautionary in implementation.

The methodology used is based mostly on stochastic equilibrium yields that give 95% of yield at F_{MSY}. The approach was to use fixed F exploitation (without F reduced by the ICES HCR MSY $B_{trigger}$). The upper limit to F was constrained where necessary by precautionary criteria that there should be <5% probability SSB<B_{lim}.

For stocks assessed with surplus production models provisional intervals been calculated, but currently for the one stock concerned (megrim) it has not been possible to evaluate the precautionary considerations; therefore, the upper end of the MSY interval is limited to F_{MSY}.

For short lived stocks MSY intervals are based on escapement biomass targets and an interval at a lower exploitation rate that delivers 95% of MSY. No increase in exploitation is advised as escapement targets already include precautionary considerations.

MSY intervals are provided for category 1 stocks with age based assessment for the North Sea and Baltic regions. For only a few of these stocks were the upper ends of the F intervals within precautionary limits, and these were all species with L infinity > 60cm.

For stocks where precautionary reference points are not available, MSY intervals are limited to a maximum rate equal to F_{MSY}.

For stocks without MSY targets (category 3, 4, 5 and 6 stocks) it is not possible to provide MSY intervals.

1 Opening of the meeting

The **Joint ICES-MYFISH Workshop to consider the basis for FMSY ranges for all stocks** was held at DTU-Aqua, Charlottenlund, Denmark from 17—21 November 2014. 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 Anna Rindorf (Denmark) 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. A plan of action was adopted with individuals providing presentations on particular issues and allocated separate tasks to begin work on all ToRs.

2 Terms of Reference

The specific ToRs for the workshop was

a) Based on the stocks listed below collate necessary data and information for these stocks prior to the workshop.

b) Identify appropriate methods and criteria to determine 5 year F_{MSY} ranges which result in no less than 95% of the estimated maximum sustainable yield based on individual weight, maturity, natural mortality and selection for the most recent 10 year period and stock recruitment time ranges as defined in recent benchmarks.

c) Establish methods to where necessary modify upper limits to F_{MSY} ranges compatible with ensuring a <5% risk of the stock falling below B_{lim} not only in assessment years but also in forecast years under full MSEs

d) Estimate 5 year values of F_{MSY} and $MSYB_{trigger}$ 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 MSY.

e) Provide a draft advice on F_{MSY} and $MSYB_{trigger}$ and F_{MSY} ranges for each of the stocks listed below.

f) Establish guidelines and where appropriate indicate suitable software for the estimation of F_{MSY} ranges for category 1 stocks where full MSE analyses are not available.

WKMSYREF3 will report by 1 December 2014 for the attention of ACOM.

Bay of Biscay
Anchovy in Subarea VIII (Bay of Biscay)
Baltic Sea
Cod in Subdivisions 22–24 (Western Baltic Sea)
Cod in Subdivisions 25–32(Eastern Baltic Sea)
Herring in Division IIIa and Subdivisions 22–24 (Western Baltic spring spawners)
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)
Herring in Subdivision 28.1 (Gulf of Riga)
Herring in Subdivision 30 and 31 (Bothnian Sea)
Sprat in Subdivisions 22–32 (Baltic Sea)

North Sea
Cod in Subarea IV (North Sea) and Divisions VIId (Eastern Channel) and IIIa West (Skagerrak)
Haddock in Subarea IV and Divisions IIIa West and VIa (North Sea, Skagerrak, and West of Scotland)Nephrops in Division IIIa
Nephrops in Division IV (North Sea) if necessary by FU
Nephrops in Botney Gut – Silver Pit (FU 5)
Nephrops in Farn Deeps (FU 6)
Nephrops in Fladen Ground (FU 7)
Nephrops in Firth of Forth (FU 8)
Nephrops in Moray Firth (FU 9)
Nephrops in Noup (FU 10)
Nephrops in Norwegian Deeps (FU 32)
Nephrops off Horn's Reef (FU 33)
Nephrops in Devil's Hole (FU 34)
Plaice in Division IIIa West (Skagerrak)
Plaice in Subarea IV (North Sea)
Plaice in Division VIId (Eastern Channel)
Saithe in Subarea IV (North Sea) Division IIIa (Skagerrak) and Subarea VI (West of Scotland and Rockall)
Sole in Division IIIa and Subdivisions 22–24 (Skagerrak, Kattegat, and the Belts)
Sole in Subarea IV (North Sea)
Sole in Division VIId (Eastern Channel)
Whiting in Division IIIa (Skagerrak – Kattegat)
Whiting in Subarea IV (North Sea) and Division VIId (Eastern Channel)
Widely Distributed stocks
Horse mackerel (Trachurus trachurus) in Divisions IIa, IVa, Vb, VIa, VIIa-c, e-k, and Subarea VIII (Western stock)

3 Overall approach

The first part of the workshop was spent reviewing available methods and discussing conceptual issues which needed to be agreed before consistent estimates of F_{MSY} ranges could be produced. The general decisions on stock-recruitment relationships, input data and yield definition, implementation of stochasticity, definition of precautionary limits to fishing mortality, F_{MSY} range definitions and 'common sense' screening of results are noted below.

3.1 General decisions on stock-recruitment relationships, input data and yield definitions

3.1.1 Selection of S-R relationships

The stock recruitment relationship is crucial in the estimation of F_{MSY}, F_{MSY} ranges and the risk of falling below precautionary biomass reference points. Therefore, substantial effort in the workshop was dedicated to providing guidelines for best practice in the estimation of stock recruitment relationships. In the workshop, four different S-R relationships were used: Ricker, Beverton-Holt, Hockey Stick and Cadigan (Cadigan 2013). Others can potentially also be used if they are consistent with biological knowledge of the stock. The resulting guidelines are given in Table 3.1.

Table 3.1. Guidelines for best practice in the selection of stock recruitment relationships used for estimation of F_{MSY}

Issue	Recommended action
There is clear evidence that a specific S-R relationship is the correct model	In this case, the estimation of reference points should be based on the S-R relationship and no other S-R relationships should be included.
It is unclear which S-R relationship provides the best fit to data, e.g. when several models show similar fits to data	Use more than one S-R relationship of different shapes and weigh the results of simulations from the different options. Some problems were encountered in Eqsim with the automatic weighting procedures used to weigh the contribution of each relationship as the weight on one relationship may be substantially higher than on another without obvious reasons. The methodology uses the distribution of coefficients to weigh the different models and may be sensitive to particular formulation of the models, particularly if the model coefficients are correlated (e.g. Beverton/Holt). The comparison of the maximum likelihood models may not necessarily explain why this is happening. In this case, it may be a solution to use a hockey stick.
Individual points are highly influential in the S-R relationship	Examine the validity of the highly influential data points. If they are considered valid, then keep them in the analysis; the use of a hockey stick or the Cadigan method with bootstrap observations may provide a robust option incorperating the uncertainty associated with the function.

Prolonged shifts in recruitment success which are unrelated to SSB are suspected	Unless strong evidence exists that a consistent change has occurred, the full time series of stock and recruitment should be used. Be careful not to mistake periodicity in recruitment success induced by e.g. cyclic climate conditions for prolonged shifts. Serial autocorrelation in recruitment (or recruitment deviations from the model) may influence the results (See horse mackerel Section 6). In the future this should be taken into account but has not yet been implemented in any of the standard computational packages available to the workshop.
Constant recruitment at all values of SSB are estimated	Such relationships should not be included in the estimation. Where they appear to be an appropriate model they should be replaced by hockey stick relationships with the lowest observed SSB as the forced breakpoint.
Recruitment appears to increase with SSB for all values of SSB observed	In these 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. This seems highly unlikely. To avoid such unrealistic predictions, a hockey stick relationship can be used. The breakpoint of the hockeystick should be at the average of all observed SSBs, under the assumption that the asymptotic SSB does not correspond to impaired recruitment (which requires some expert judgment).
Recruitment appears to decrease with SSB for all values of SSB observed	This usually results in a Ricker curve or the Cadigan function fitting the points with the descending limb of the function. Hence, maximum recruitment is predicted to occur at unknown SSBs below the minimum observed. The interpretation that recruitment will increase at SSB values below the lowest observed seems highly risky. To avoid such predictions, a hockey stick relationship can be used. The breakpoint of the hockeystick should be at the lowest observed SSB.
Recruitment has occasional very high values	This type of S-R relationship is only incorporated in the method used for horse mackerel (Section 6.9). Removing the extreme points from the analysis for this stock led to lower suggested F_{MSY} and FP05 (F corresponding to 5% probability of SSB<B_{lim}) values than when the occasional high recruitments were included. As a minimum, it is recommended to investigate the sensitivity of the results to the occasional very high recruitments.
Predicted average recruitment at F_{MSY} is substantially higher than the maximum observed	Average recruitment at F_{MSY} which is greater than e.g. 150% of the maximum observed should be investigated thoroughly. Often, this results from estimating S-R functions using monotonically increasing observed S-R values. In this case, a hockey stick can be used (see explanation above).

3.1.2 Other input data

For the provision of MSY intervals valid for the next 5 years the input data for all other parameters than S-R relationships (weight at age in stock and catch, maturity, natural mortality and selection pattern) should as a default be derived from the latest 10 years of available data. When clearly documented persistent trends exist in a parameter, the period can be decreased to 3 to 5 years. Conversely, the period can be extended to longer periods if there is no evidence of temporal trends. If data on variability of e.g.

maturity is not included in the assessment but is available form other sources this can also be introduced, even if this variability has not been incorporated in the stock assessment. When introducing data from multiple separate analyses, care must be taken to ensure that multiple sources of variability are dealt with correctly and additional sources of variation take account of the presence of other changes in the simulations.

3.1.3 Yield definition

Three definitions of yield which can be used to estimate F_{MSY} were considered in the workshop: Landings, catch (landings+discards) and catch above minimum reference size (MRS) (landings+discards above minimum landing size or minimum conservation size). To maximize catch implies that it would be consistent with MSY to increase the proportion of the catch which is below MRS and hence seems undesirable. The workshop participants agreed that it would be preferable to maximise catch above MRS, but as data was not generally available at the meeting on the catch above MRS, WKMSYREF3 decided to use current landings as a basis for F_{MSY} estimation until data on catch above MRS is available. Although the procedure for estimating of F_{MSY} is based on maximisation of catch, the target F is the mean F on the population based on catch, and is not the partial F based on landings.

A test case of North Sea cod is included in section 6.1

The workshop participants agreed that the mean of the simulated predicted yield can have undesirable properties when yield distributions have highly skewed distributions (with high proportion of values in the tails of the distribution) or occasional very large values. The median is considered to often be more robust to these issues. In cases where the distribution of yields is unimodal and with short tails in the distribution the two values are generally similar. WKMSYREF3 agreed to use the median of the distribution of yield and recommends this for other cases. However, the mean can also be inspected. The choice of whether to use mean rather than median values should never be based on resulting estimates of F_{MSY}, only the distribution.

3.1.4 Default settings for S-R relationships, other input and yield definition used at the workshop

The workshop participants agreed to use all S-R data available unless other periods have been defined as appropriate at the latest benchmark for each given stock. Other periods were investigated in a few cases to investigate the potential influence of changing the S-R period used. We recommend future benchmarks and WGs review the time series choice of these stocks to ensure that the correct period is used. Similar investigations could be done in working groups, but truncated series of S-R pairs should not be used as a basis for advice unless there is strong evidence that there has been a consistent change in the S-R relationship. In selected cases, sensitivity analyses of the effect of individual years, of adding more years, of periodicity and highly skewed residual distributions on the S-R relationships were conducted and similar explorative investigations could be performed.

3.2 Implementation of stochasticity

There are several descriptions of how to implement stochasticity, process and estimation uncertainty and correlated errors (ICES 2013c, Kell *et al* 2005, Punt *et al* 2015). Variability in biological parameters such as growth, maturation and natural mortality can be included as random bootstrap approach or as parametric variability. As a minimum, realistic (estimated) uncertainties should be used when estimating recruitment from S-R relationships as this is usually the main source of variation. Inclusion of stochastic draws from inter-annual variability in recruitment is required for precautionary considerations. This can be either parametric or bootstrap of residuals but must include a functional form as discussed in the S-R section above. In the estimation of the probability of obtaining a stock size below B_{lim}, it is necessary to include realistic estimates of the implementation uncertainty (including the short term forecast), in particular when the F_{MSY} range is likely to result in biomasses approaching B_{lim}. This uncertainty can be estimated from a comparison of forecast F and resulting F taken from the most recent assessment. Only where it can be shown that MSY intervals are far from any precautionary considerations can stochastic issues of this kind be ignored. In general, the software used varied in the underlying assumptions about e.g. constraints to parameters. As a minimum, such underlying assumptions should be clearly specified.

Autocorrelation in e.g. recruitment can be included if shown to be important. Autocorrelation in recruitment has not yet been incorporated in the standard software available to the workshop and of the analyses performed at the workshop, only the MSE of horse mackerel included this type of autocorrelation.

3.3 Precautionary criteria

The criteria of precautionary limits to fishing mortality in an MSE were reviewed at the workshop and ICES agreed guidelines for MSE evaluation were used. The upper precautionary limit to fishing mortality, $F_{P.05}$, was defined as the fishing mortality resulting in a 5% probability of SSB falling below B_{lim} in a year in long term simulations with fixed F (i.e. without application of the ICES MSY HCR, which would reduce F below the MSY $B_{trigger}$ biomass).

Other precautionary limits to fishing mortality can be achieved by e.g. introducing HCRs where fishing mortality is reduced by some fraction at low stock sizes. Thus the target F in an HCR may be higher but in practice F is reduced in periods of lower biomass. The European Commission has indicated in its request to ICES that in the future HCRs would not form part of the basis for management plans being discussed with the European Parliament; as such, the MSY intervals would need to be precautionary in the absence of the ICES MSY HCR. Therefore the workshop participants felt that is was important that an initial advice on precautionary limits to F was valid in the simplest possible implementation (e.g. a fixed F at all SSB levels). Many HCR type rules can also added to evaluations and management and can be expected to give alternative estimates of F_{MSY} ranges and F_{MSY} if this is value is sensitive to precautionary considerations.

Precautionary limits to F are only defined when a B_{lim} has been agreed for the stock. However, stocks lacking B_{lim} reference points were encountered both among age based, length based and data limited assessments. In this case, a proxy for B_{lim} was derived as Bpa/1.4 for the stocks where B_{pa} was defined, MSY$B_{trigger}$/1.4 for the stocks where MSY$B_{trigger}$ was defined and B_{pa} was lacking, or as some other plausible value when both B_{pa} and MSY $B_{trigger}$ were lacking. The risk of falling below this proxy was examined and where this was higher than 5% at F_{MSY}, a comment was added to the advised range saying this should be checked against appropriate precautionary criteria. If the 5% limit to probability of SSB<B_{lim} (based on the proxy) was exceeded then MSY range was truncated to F_{MSY}.

3.4 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 the range of fishing mortalities leading to no less than 95% of MSY (F_{MSY}lower and F_{MSY}upper). 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 FP.05, F_{MSY}upper was specified as FP.05. Where the estimated F_{MSY} exceeded the estimated FP.05, F_{MSY} and F_{MSY}upper were both specified as FP.05 and F_{MSY}lower redefined as the lower fishing mortality providing 95% of the yield at FP.05 (FP.05lower). In some cases, mainly when no B_{lim} was defined or could be postulated, FP.05 could not be estimated. In this case, 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.

The range was thus defined as:

CASE	F_{MSY} RANGE		
F_{MSY} upper<FP.05	F_{MSY}lower	-	F_{MSY}upper
F_{MSY}<FP.05 <F_{MSY} upper	F_{MSY}lower	-	FP.05
FP.05 <F_{MSY}	FP.05lower	-	FP.05
FP.05 cannot be defined	F_{MSY}lower	-	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 MSY HCR (where F decreases linearly to zero with SSB from MSY $B_{trigger}$ to zero). If such an HCR is in use, the estimated FP.05 is higher, which may allow a slightly higher average yield in cases where F_{MSY}>FP.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_{p05} are included in the range.

3.5 'Common sense' screening of results

All results were screened in plenary at the workshop to ensure that results were judged to be plausible according to expert knowledge. Such screening should always occur to limit the risk of carrying estimation errors on to advisory groups.

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 re-sampled at random from the last few years of the assessment (although there may be no variability in these values). Recruitments are re-sampled from their predictive distribution which is based on parametric models fitted to the full timeseries 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). A $B_{trigger}$ can be specified, if used and F is reduced due to biomass. The results are still presented by main F target. The method is described in more detail in Annex 8 of ICES (2013b) and short manual is given in Annex 2 to this report and can be found at the following link.

https://github.com/einarhjorleifsson/msy/tree/master/inst/doc

The calls to the routines used and the meaning of the variables is given on https://github.com/einarhjorleifsson/msy/tree/master/man

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

Stock recruit fitting:

eqsr_fit <- function (stk, nsamp = 5000, models = c("ricker", "segreg", "bevholt"),

method = "Buckland", id.sr = NULL, remove.years = NULL, delta = 1.3,

nburn = 10000)

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 (see annex).

Eqsim_run <- function (fit, bio.years = c(2004, 2013), bio.const = FALSE, sel.years = c(2004, 2013), sel.const = FALSE, Fscan = seq(0,1.2, len = 61), Fcv = 0, Fphi = 0, B_{lim}, Bpa, recruitment.trim = c(3,

-3), $B_{trigger}$ = 0, Nrun = 200, process.error = TRUE,verbose = TRUE, extreme.trim=c(0,0))

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 eg. 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 implementation error (the additional error in the management process following the estimation of the state of the stock). 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 ICESc 2013). This approach note the importance of taking into account the additional error introduced by the short term forecast. Often the inclusion of the short term forecast is implied as of the assessment error, but not explicitly noted. Estimation error in Eqsim (Fcv and Fphi), provides for a two parameter error function which is applied directly on the target F. The controlling parameters are a 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 realised catch and F (F_{yr}) for the previous 10 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_{ya} 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_{ya} the deviation in year y d_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 approach used here attempts to include the errors in the ICES assessment and short term advisory process but does not include the differences introduced by the choice of TAC by managers or any implementation error due to control and enforcement.

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

The range of Ftarget values and the steps to scan over (Fscan) 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 based on F=F target above a biomass ($B_{trigger}$) and Ftarget=Ftarget*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 in 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.

The following issues have been identified as requiring attention:

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 encounterd and need fixing.
5. Problems with fitting segreg in some cases was found and may be fixed with use of continuous function.

4.2 Stockassessment.org

A new routine to calculate FMSY via the online interface to stockassessment (http://stockassessment.org) was presented at the meeting. The approach is an attempt to use the non-parametric stock---recruitment method outlined in Cadigan (2013).

4.2.1 Method

The method is: a) A sample of possible stock---recruitment functions for the stock is found from the historic SR time series via the non-parametric constrained spline method. b) The stock is simulated forward for each SR function with added process noise in the realized recruitment. c) For each simulation the yield is optimized w.r.t. to fishing mortality level to obtain a sample of F_{MSY}'s. d) The simulated distribution of F_{MSY} is used to draw inference about F_{MSY} (e.g. mode, mean, median, quantiles, ...).

4.2.2 Interface

Using this interface is fairly simple for a stock already defined on stockassessment.org. Log on and navigate to the `stock' named "MSYlink-calculator-v-0.1". Click on this stock. There is only a single data file called "nameStock.txt" and within that data file only a single string naming the stock. This name refers to the name of the stock on stockassessment.org, and is the name displayed on the front page e.g. "SISAM-PLAICE-sim". Finally press the "Go button" --- wait 5 minutes --- see the results. Some tuning options (no samples, no years, Fbar range, and so on can be found in the beginning of the file "plotscript.R".

If the stock has not already been defined on stockassessment.org the procedure requires a bit more. Log on and navigate to the `stock' named "MSY-calculator-v-0.1". Upload all the files normally needed to carry out an assessment and two additional files "n.dat" and "f.dat" containing estimates of numbers-at-age and fishing mortality at age respectively. These files can be added using the "data wizard", or by changing the example files already there. After the files are uploaded press the "Go button" --- wait 5 minutes --- see the results.

4.2.3 Code

All source files are online. Most are not used for this application and can be ignored. Two source files are important. The c++ file for calculating the constrained spline "rec.cpp", and the R script for simulating and plotting "plotscript.R". Both can be altered online if required.

4.3 Analytical approach to estimation of MSY Parameters, Horbowy and Luzenczyk.

A method for estimation of MSY reference points was developed by Horbowy and Luzeńczyk (2012). To test the method the operating models approach was applied and the sensitivity of F_{MSY} and other reference points to the range of available stock-recruitment data, recruitment variance, various steepness levels in the stock-recruitment models, misspecification of the stock-recruitment relationship, assessment variance and bias were inspected (Horbowy and Luzeńczyk, 2012).

The method combines stock-per-recruit (SPR) analysis with stock-recruitment (S-R) relationship. The equations for equilibrium yield and biomass have been developed and it may be easily shown, that for Beverton and Holt S-R relationship in the form

$$R = \frac{B}{a + bB}$$

the equilibrium yield, Y_{eq}, and biomass, B_{eq}, may be expressed as

$$Y_{eq}(F) = \frac{F(SPR(F) - a)}{b}$$

$$B_{eq}(F) = \frac{SPR(F) - a}{b}$$

where

R – recruitment,

B - spawning stock biomass,

F – fishing mortality,

a, b - S-R parameters.

For stock-recruitment relationship described by Ricker model

$$R = aBe^{-bB}$$

the equilibrium yield and biomass are

$$Y_{eq}(F) = \frac{F \ln(aSPR(F))}{b}$$

$$B_{eq}(F) = \frac{\ln(aSPR(F))}{b}$$

The F_{MSY} is obtained by maximizing the equilibrium yield function with respect to fishing mortality, and next the Y_{MSY} and B_{MSY} can be calculated. The example of shapes of equilibrium yield and biomass are shown in Figure 4.3.1. The SPR model may be both based on analytical formulae of Beverton and Holt with knife-edge selection and alternatively on the Thomson and Bell model.

The incorporation of stochasticity into the method is easy. The stock-recruitment data may be disturbed by random error, which may include both measurement (assessment) error and process error. Similarly, variables from SPR analysis (weight, selection, natural mortality, maturity -at-age) may be affected by random error. In such a way a number of replications of equilibrium yield and biomass curves and resulting F_{MSY} may be obtained. This allows for estimation of F_{MSY} and its distribution.

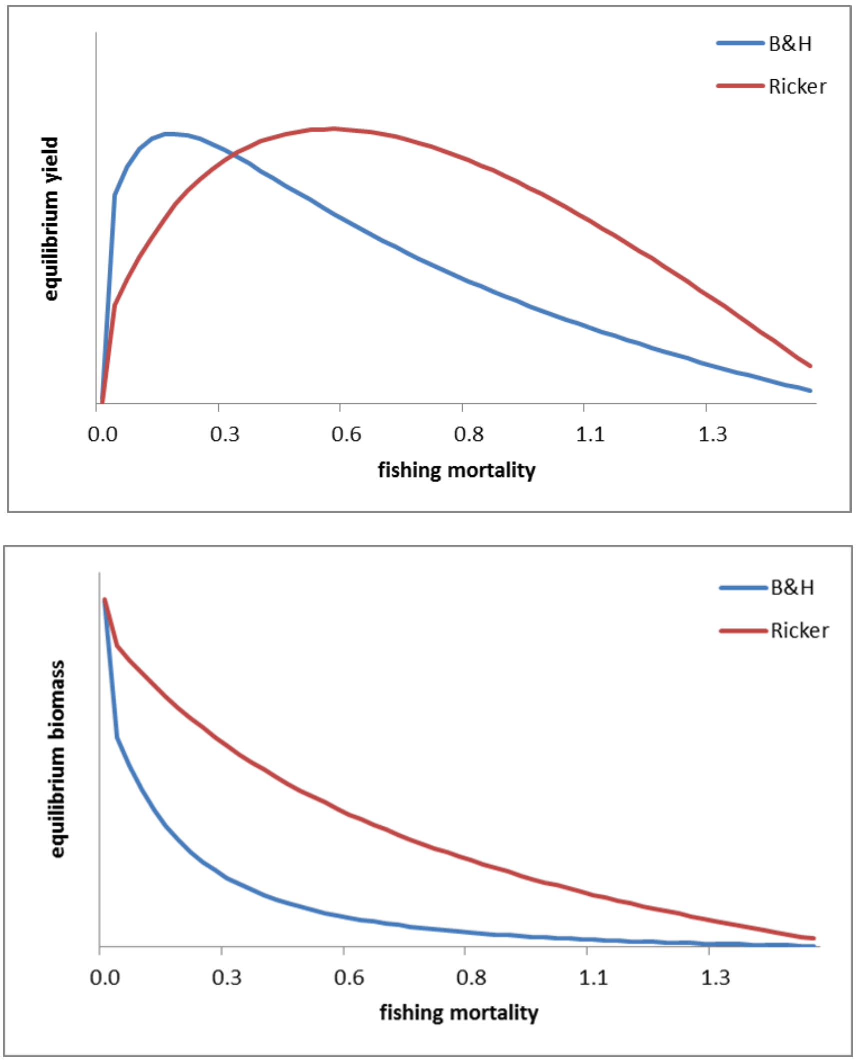

Fig. 4.3.1. Examples of equilibrium yield and biomass curves for Beverton and Holt and Ricker stock-recruitment relationships.

4.4 Plot$_{MSY}$

Plot$_{MSY}$ (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 characterised 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).

5 MSY interval analysis by stock: Short lived fish stocks

Short lived stocks are managed under ICES advice for the MSY approach through the Escapement Strategy (Gjøsæter et al. 2002; Nielsen et al. 2012; ICES 2014g). Under the escapement strategy, the stock is harvested in any individual year at a rate consistent with maintaining either a specific minimum spawning stock biomass or a achieving specified risk of falling below a specific stock biomass after the fishery has occurred. The strategy provides a higher long term average yield than methods such as the fixed F-strategies used when estimating F_{MSY}.

Escapement strategies are precautionary in implementation, though an upper cap on fishing mortalities is usually required (ICES 2014g), unless the approach uses a forward projection method fully incorporating the risk of SSB<B_{lim} at the end of the fishing season (ICES 2014d). By definition, the strategy corresponds to implementing the highest precautionary fishing mortality in any one year. Hence, implementing the equivalent of F_{MSY} ranges for short lived stocks can never result in advised fishing mortalities above those advised under the escapement strategy. A range of advised fishing mortalities can therefore be implemented by providing a lower limit to F consistent with 95% of the yield estimated from the escapement strategy. The actual value of this lower limit F will vary from year to year.

A fixed F strategy such as is used in the estimation of F_{MSY} or a harvest control rule as applied for the ICES implementation of MSY for long-lived species can also be used for short lived stocks. This will provide the opportunity to use the methods listed above to derive F_{MSY} ranges. However, in the available studies conducted to date, this has provided consistently lower yields. In most cases a single target F_{MSY} consistent with ensuring <5% probability of SSB<B_{lim} in all years would imply lower yields on average.

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

6.1 Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId

6.1.1 Current reference points

Table 6.1.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.19	Fmax 2010, within the range of fishing mortalities consistent with F_{MSY} (0.16–0.42).
Current B_{lim}	70 000 t	Bloss (~1995).
Current Bpa	150 000 t	B_{pa} = Previous MBAL and signs of impaired recruitment below 150 000 t.
Current $MSYB_{trigger}$	150 000 t	Default value B_{pa}

6.1.2 Source of data

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

6.1.3 Methods used

All analyses were conducted with Eqsim. The assessment error in the advisory year and the autocorrelation was derived from the results of a recent evaluation of HCRs (De Oliveira, 2013), including the HCR used in the current plan. The approach was to compare the intended target F (the F from application of the current plan HCR) with the realised F:

$$F^{i}_{rat,y} = F^{i}_{realised,y} / F^{i}_{HCR,y}$$

This is derived for each projection year y (2014-2032) and simulation i (100 in total). Then for each simulation i, the error parameters are estimated by calculating the standard deviation and serial correlation of the vector $\underline{F}^{i}_{rat}$ (each element representing a year), and taking the mean across simulations. The associated R code is as follows:

```
cv<-apply(frat,6,function (x) sd(c(x)))

rho<-apply(frat,6,function (x) acf(c(x))$acf[2])

meancv<-mean(cv)

meanrho<-mean(rho)
```

This leads for North Sea cod to a cv of 0.30 and a phi of 0.25.

6.1.4 Settings

Table 6.1.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series (years classes 1963-2012)	R per SSB shows so no signs of reduced productivity over time. However SSB and recruitment went down in parallel together with an increase e.g. of temperature. Observations of recruitment at higher SSB in the current climatic regime are needed to judge whether the currently observed low recruitment is caused by the low SSB or unfavourable environmental conditions. Only the segmented regression curve was used for the analysis.
Exclusion of extreme values (option extreme.trim)	No	
Mean weights and proportion mature; natural mortlaity	2009-2013	There is an increasing trend in mean weight at age over the last 10 years. There is also an increasing trend in predation mortality for age 3 cod in the years before 2009. Therefore a five year time period was chosen instead of a 10 year period.
Exploitation pattern	2009-2013	There is no change in exploitation pattern in the last 10 years. However, substantial unallocated removals have been estimated for the years 2004 and 2005 in the assessment. Therefore, a five year time period was chosen instead of a 10 year period.
Assessment error in the advisory year. CV of F	0.3	Estimated from recent MSE simulations
Autocorrelation in assessment error in the advisory year	0.25	Estimated from recent MSE simulations

6.1.5 Results

6.1.5.1 Stock recruitment relation

It was decided to base the analysis on a segmented regression only. The Ricker has its peak well outside the observed range of S–R pairs, with the Beverton-Holt function almost identical to the Ricker within this observed range, both fitting almost a straight line through the origin (Figure 6.1.1).

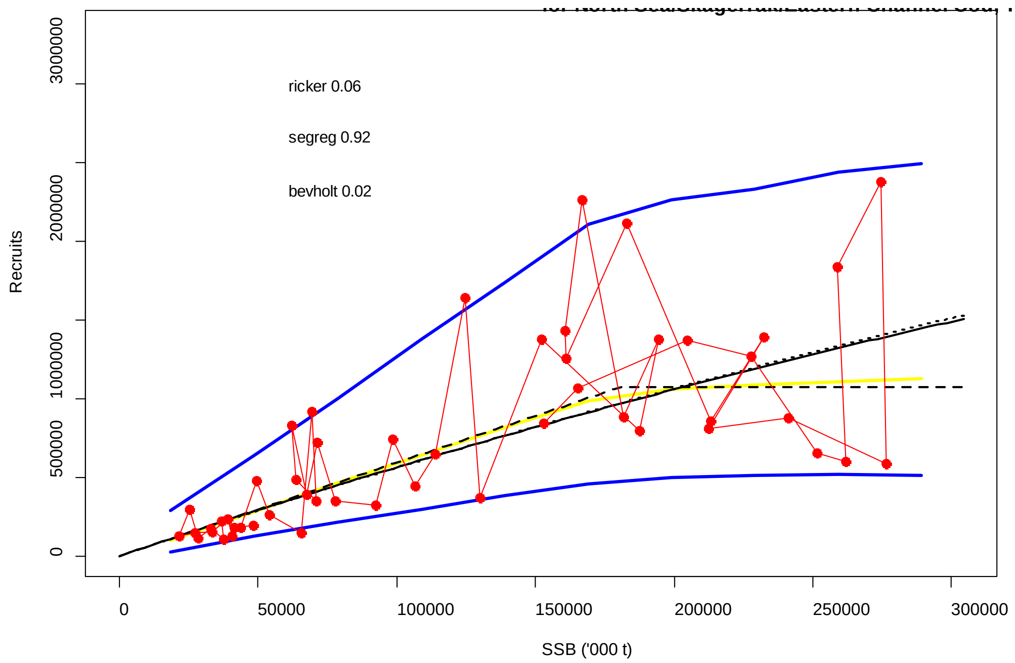

Figure 6.1.1. Stock recruitment relationships for cod and weighting for each SRR when all stock recruitment relationships would be used in the Eqsim analysis. Dotted black line: Beverton and Holt; solid black line: Ricker; dashed black line: Segmented Regression.

6.1.5.2 Yield and SSB

For the base run, yield excludes discards, with F_{MSY} being taken as the peak of the median 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 risk 1=5% (where risk 1 is as defined in ICES 2013c).

6.1.5.3 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.2 (Figure 6.1.2). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.33 and the lower bound at 0.13. $F_{P.05}$ was estimated at 0.7 and therefore the upper bound don't needs to be restricted because of precautionary limits. The median of the SSB estimates at F_{MSY} was 1 418 057 t and therefore well outside historically observed values (Figure 6.1.3).

When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 150 000 t, median F_{MSY} was also estimated at 0.2 with a lower bound of the range at 0.14 and an upper bound at 0.33 (Figure 6.1.4). The $F_{P.05}$ value increased to 1.06. The median of the SSB at F_{MSY} was also here well above observed historic values (Figure 6.1.5).

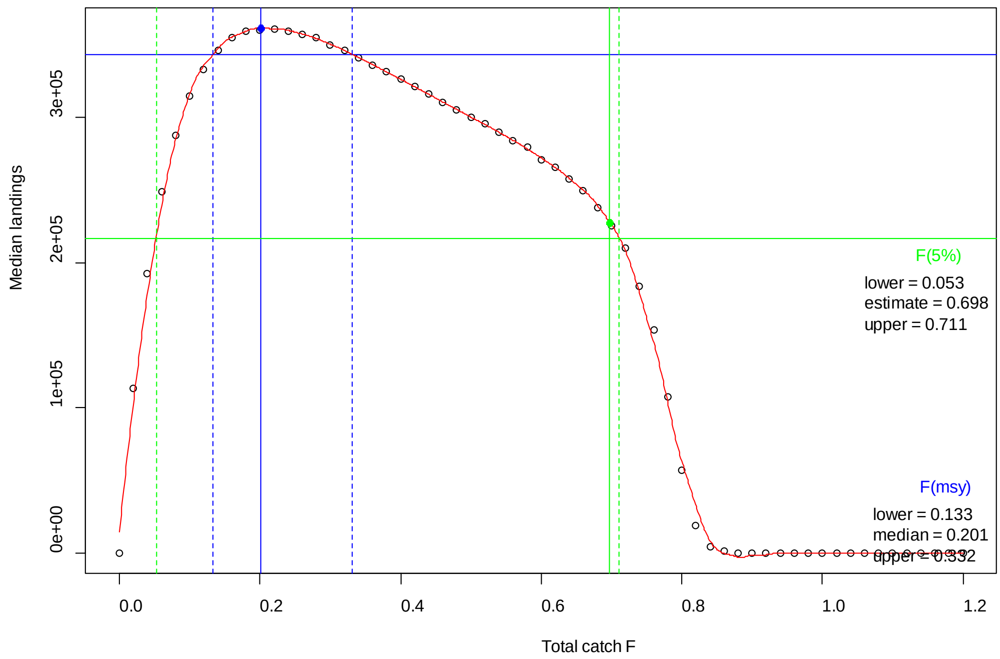

Figure 6.1.2. Cod, with fixed F exploitation. Left panel: Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

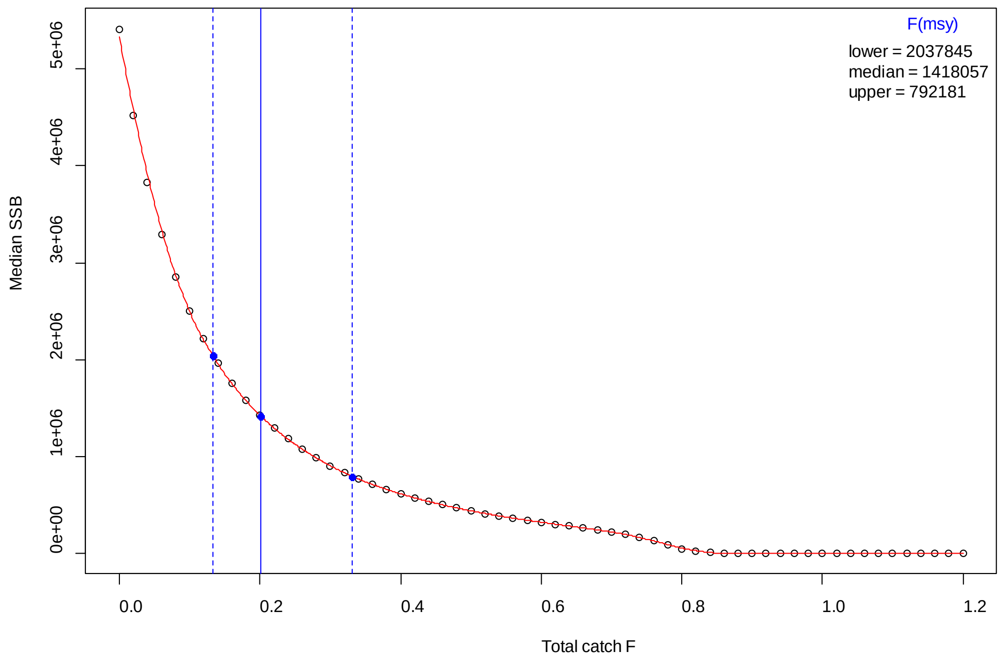

Figure 6.1.3. Cod (fixed F): median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

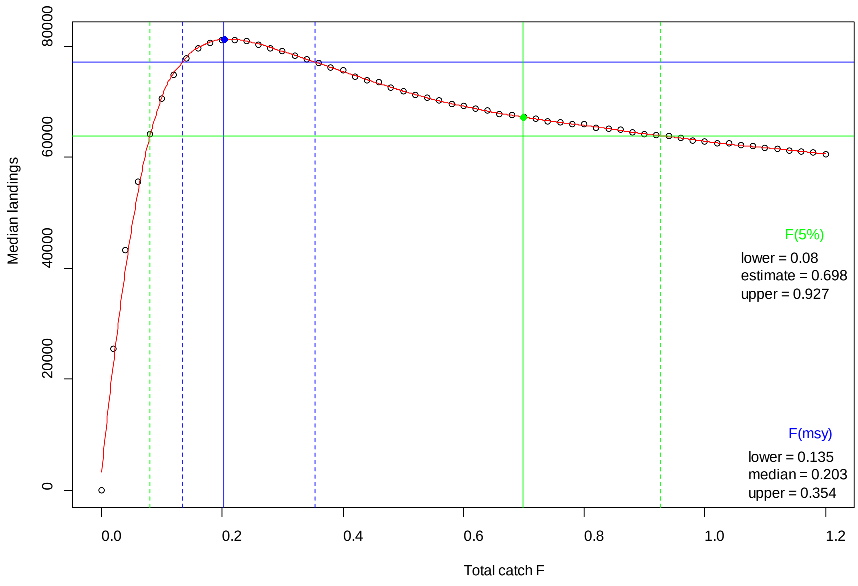

Figure 6.1.4. Cod when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 150000 tonnes. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

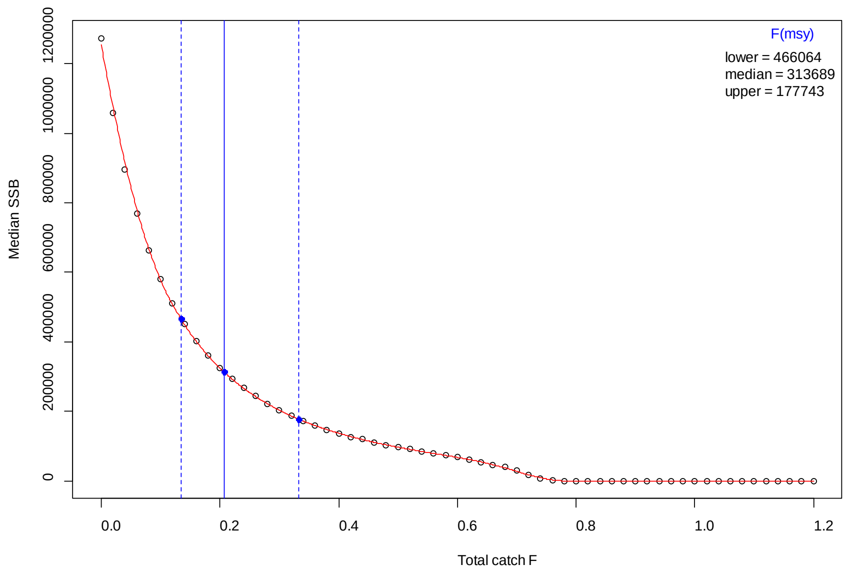

Figure 6.1.5. Cod when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 150 000 t. Median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

6.1.6 Proposed reference points

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

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.20
F_{MSY} lower without $B_{trigger}$	0.13
F_{MSY} upper without $B_{trigger}$	0.33
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.70
F_{MSY} upper precautionary without $B_{trigger}$	0.33
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	1.06
F_{MSY} with $B_{trigger}$	0.20
F_{MSY} lower with $B_{trigger}$	0.14
F_{MSY} upper with $B_{trigger}$	0.33
F_{MSY} upper precautionary with $B_{trigger}$	0.33
MSY	361 397 t
Median SSB at F_{MSY}	1 418 057 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	2 037 845 t
Median SSB upper (median at F_{MSY} lower)	792 181 t

6.1.7 Discussion / Sensitivity.

Two sensitivity analyses were carried out, one considering a truncated stock-recruit time series (to match the time period currently used for short-term forecasts, based on the 1997-2012 year classes), and the other assuming that all catches from age 3 onwards are landed (i.e. none are discarded), so that optimisation of yield will include all catches of age 3 and older, and only those landed at ages 1 and 2.

For the first sensitivity test, the F_{MSY} value (0.21) and range (0.14-0.33) were insensitive to truncating the stock-recruit time series to the currently observed low recruitment, and even though the F_{P05} value is reduced from 0.70 to 0.40, this would still not alter the upper bound of the F_{MSY} range. However, because of different S-R assumptions MSY yield and SSB values are affected (MSY reduced from ~360 000 tonnes to ~80 000 tonnes, and median SSB at F_{MSY} reduced from ~1.42 million tonnes to ~0.31 million tonnes).

For the second sensitivity test, the F_{MSY} value (0.22) and range (0.14-0.35) remained relatively insensitive to optimising yield when yield included fish discarded from ages 3 onwards. The F_{P05} value (0.7) did not change and the MSY yield and SSB values only changed slightly (~380 000 tonnes [4% change] and ~1.23 million tonnes [13% change]).

The $plot_{MSY}$ software was also run for comparison (although this software does not currently perform stochastic projections), and resulted in an F_{MSY} median estimate of 0.22 for the segmented regression stock-recruit function.

In conclusion the results presented are robust to current recruitment assumptions and discarding practices.

6.2 Cod in Subdivisions 22–24

6.2.1 Current reference points

Table 6.2.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current F_{MSY}	0.26	F_{MSY} from stochastic simulations (age range 3–5).
Current B_{lim}	26 000 t	Break point of the stock–recruitment relationship.
Current Bpa	36 400 t	1.4 × B_{lim}
Current $MSYB_{trigger}$	36 400 t	Bpa

6.2.2 Source of data

The analysis in this report uses the newest (1970-2013) assessment results from the 2014 SAM assessment (ICES 2014b).

6.2.3 Methods used.

Eqsim was used for this stock.

6.2.4 Settings

Table 6.2.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series	
Exclusion of extreme values (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Assessment error in the advisory year. CV of F	0.25	
Autocorrelation in assessment error in the advisory year	0.30	

The presently defined biomass reference points were used for precautionary considerations EqSim.

6.2.5 Results

6.2.5.1 Stock recruitment relation

The stock recruitment fit, using the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method available in EqSim, estimated a “straight line” for all models. Following the procedures presented above for situations with S-R relationships with poorly defined maxima a segmented regression model was used as the only stock recruitment model in the simulations with a breakpoint set arbitrarily at the average SSB (Figure 6.2.1).

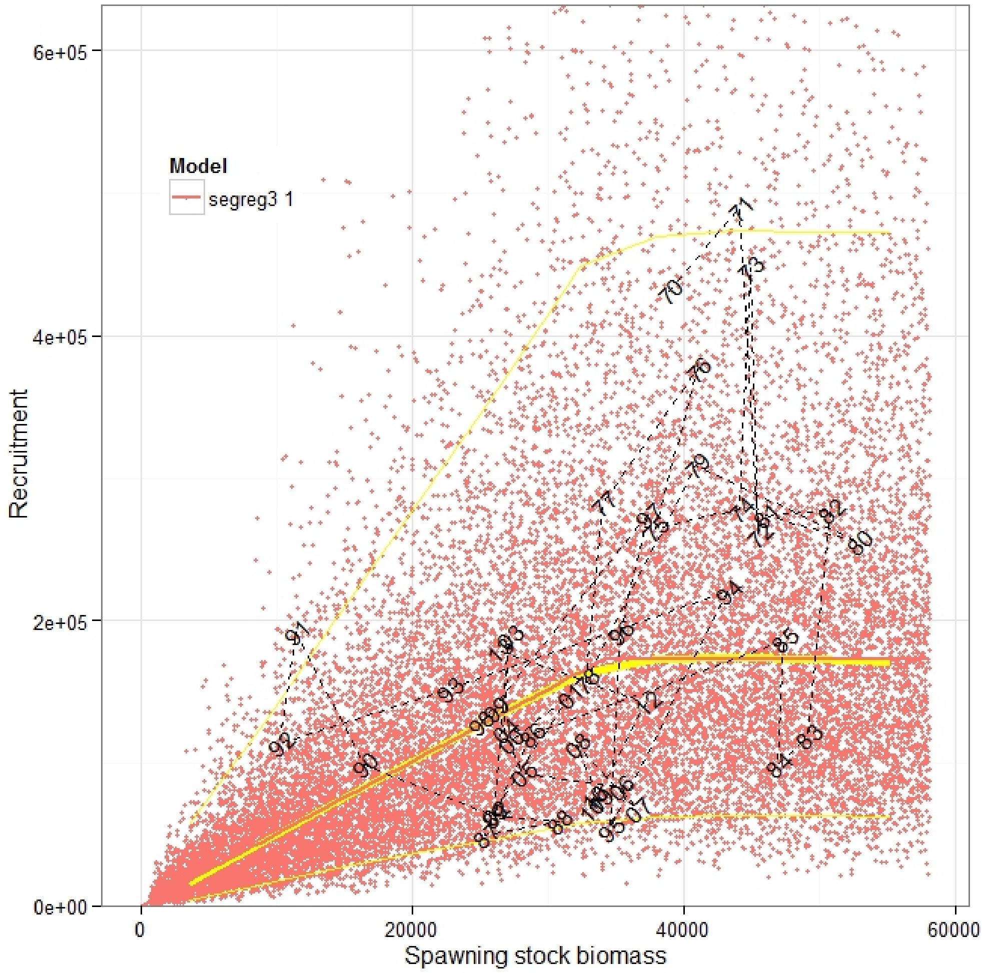

Figure 6.2.1. Assumed stock recruitment relationship for cod in Subdivisions 22-24 based on segmented regression with breakpoint at mean SSB for the time series of data. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

6.2.6 Proposed reference points

Results of Eqsim runs with and without $MSYB_{trigger}$ are shown in Figures 6.2.2 and 6.2.3 respectively. The reference points derived from these simulations are given in the Table 6.2.3 below.

Table 6.2.3 Summary table of proposed stock reference points

Stock	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.28
F_{MSY} lower without $B_{trigger}$	0.16
F_{MSY} upper without $B_{trigger}$	0.53
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	1.08
F_{MSY} upper precautionary without $B_{trigger}$	0.53
F_{MSY} with $B_{trigger}$	0.27
F_{MSY} lower with $B_{trigger}$	0.16
F_{MSY} upper with $B_{trigger}$	0.55

FP.05 (5% risk to B_{lim} with $B_{trigger}$)	1.07
F_{MSY} upper precautionary with $B_{trigger}$	0.55
MSY	56 500 t
Median SSB at F_{MSY}	206 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	113 000 t
Median SSB upper (median at F_{MSY} lower)	311 000 t

6.2.7 Discussion / Sensitivity.

Exploratory runs were done using the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method and using a segmented regression with breakpoint at B_{pa}. The results (data not shown) were rather similar to the final run.

The estimated B_{MSY} under the assumptions of S-R is much larger than the maximum observed SSB. For the time being, the working group considers the estimated F_{MSY} values to be appropriate. However, if the stock does grow to a level of SSB never observed before, the MSY reference points need to be re-estimated.

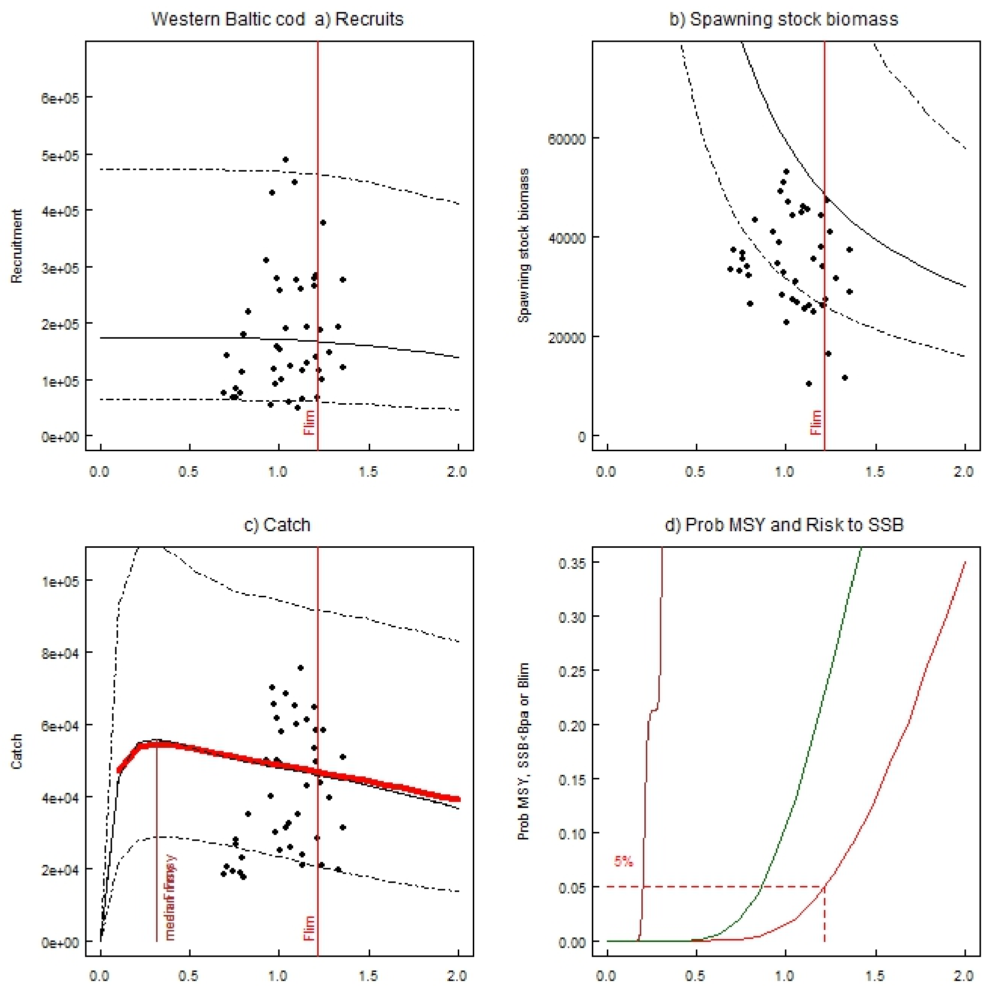

Figure 6.2.2. EquiSim results applying the Segmented regression assumption for recruitment for Cod in Subdivisions 22-24 with $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel 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).

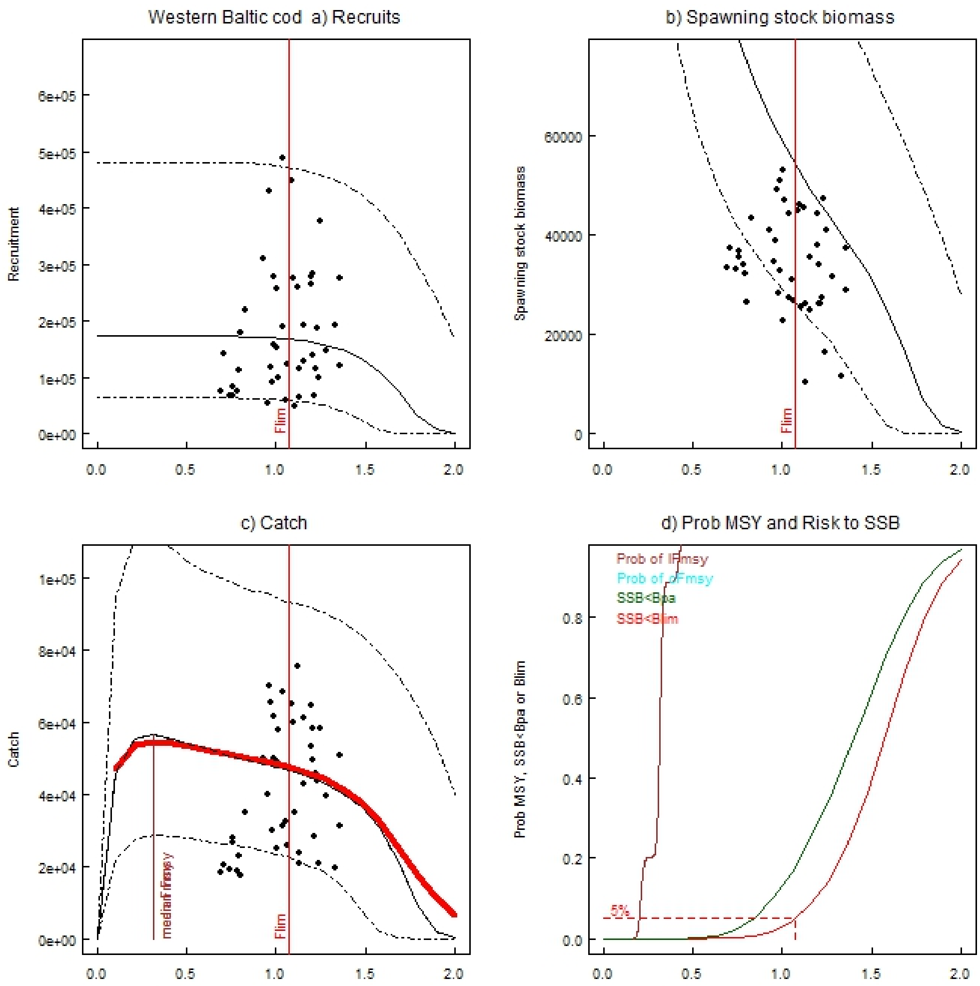

Figure 6.2.3. **EquiSim results applying the segmented regression assumption for recruitment for Cod in Subdivisions 22-24 without $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of 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).**

6.3 Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)

6.3.1 Source of data

ICES-WGNSSK (ICES 2014b).

6.3.2 Methods used

Eqsim with additional WKMSYREF3 code to produce median yield and F estimates (see Section 4.1).

6.3.3 Current reference points

Table 6.3.1 Summary table of current stock reference points (ICES 2014b):

Reference point	Value
Current FMSY	0.35
Current B_{lim}	63 000 t
Current Bpa	88 000 t
Current $MSYB_{trigger}$	88 000 t

6.3.4 Settings

6.3.4.1 Period used for S–R

The full available time period (1972-2014) was used for stock-recruit modelling. The first run used all three S-R models available in Eqsim (Ricker, Beverton-Holt and segmented regression): however, the Beverton-Holt model fit from this run proved to be a simple geometric mean until very close to the origin and it was disregarded for this reason. All subsequent runs used the Ricker and segmented regression models.

6.3.4.2 Advice error

Actual advice error could not be calculated, as Northern Shelf haddock is a new stock unit in 2014 and there is no corresponding history of assessment and landings. Default values were assumed: 0.25 (for error) and 0.3 (for autocorrelation).

6.3.4.3 Selectivity

The estimated F(MSY) for Northern Shelf haddock proved to be extremely sensitive to the year range assumed for both selectivity and biological parameters. ICES-WGNSSK (ICES 2014b) produced an estimate of around 0.35 using a 2008-2013 year range, while initial runs at WKMSYREF3 using a 2009-2014 year range produced estimates of around 0.5. The Workshop explored further the influence of the year range on F(MSY) estimates by estimating F(MSY) using 5-year blocks of sensitivity and biological parameters (starting from 2000-2004, up to 2009-2013). The results are presented in Figure 6.3.1, which shows a significant increase in estimated F(MSY) as more recent data are used. The estimate from a run using 10-years of data (2004-2013) smoothes out this variability, and is more consistent with previous F(MSY) estimates for this stock. The 10-year period was used for all subsequent analyses.

6.3.4.4 Annual biological parameters

See above.

6.3.5 Proposed reference points

The estimated yield curve for Northern Shelf haddock is quite flat, with a poorly-defined maximum (Figure 6.3.2). For this reason, F(MSY) estimates are not very precise, and there are relatively wide ranges when the 95% of maximum yield criterion is fulfilled.

Table 6.3.2 Summary table of proposed stock reference points for method Eqsim (medians based on landings):

STOCK	HADDOCK IN SUBAREA IV AND DIVISIONS IIIA AND VIA (NORTHERN SHELF)
Reference point	Value
F_{MSY} without $B_{trigger}$	0.372
F_{MSY} lower without $B_{trigger}$	0.248
F_{MSY} upper without $B_{trigger}$	0.523
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.512
F_{MSY} upper precautionary without trigger	0.512
F_{MSY} with $B_{trigger}$	0.380
F_{MSY} lower with $B_{trigger}$	0.248
F_{MSY} upper with $B_{trigger}$	0.560
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.546
F_{MSY} upper precautionary with $_{trigger}$	0.546
MSY	114 190 t
Median SSB at F_{MSY}	329 127 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	234 900 t
Median SSB upper (median at F_{MSY} lower)	454 416 t

6.3.6 Discussion / Sensitivity.

The F(MSY) estimate for Northern Shelf haddock is sensitive to the year range assumed for sensitivity and biological parameters (see Figure 6.3.1), but the use of a 10-year range appears to smooth out these fluctuations to provide a more robust estimate. This is also consistent with previous estimates (ICES 2014b).

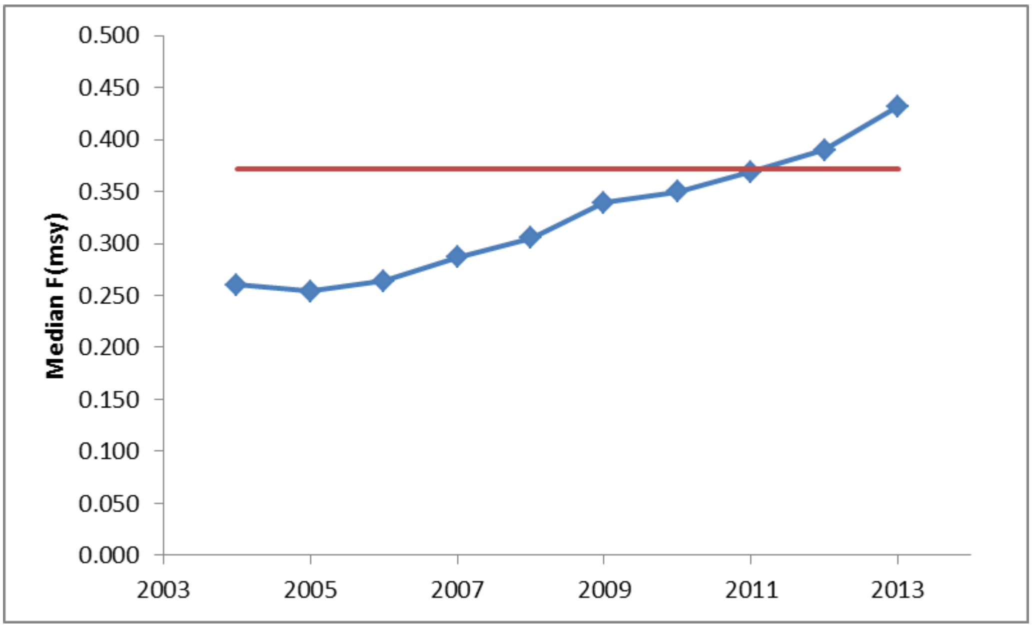

Figure 6.3.1. Comparison of final F(MSY) estimate using selectivity and biological data from 2004-2013 (red line) with estimates using data from 5-year periods (plotted here by the final year: so the estimate from the run using data from 2000-2004 is plotted here as 2004).

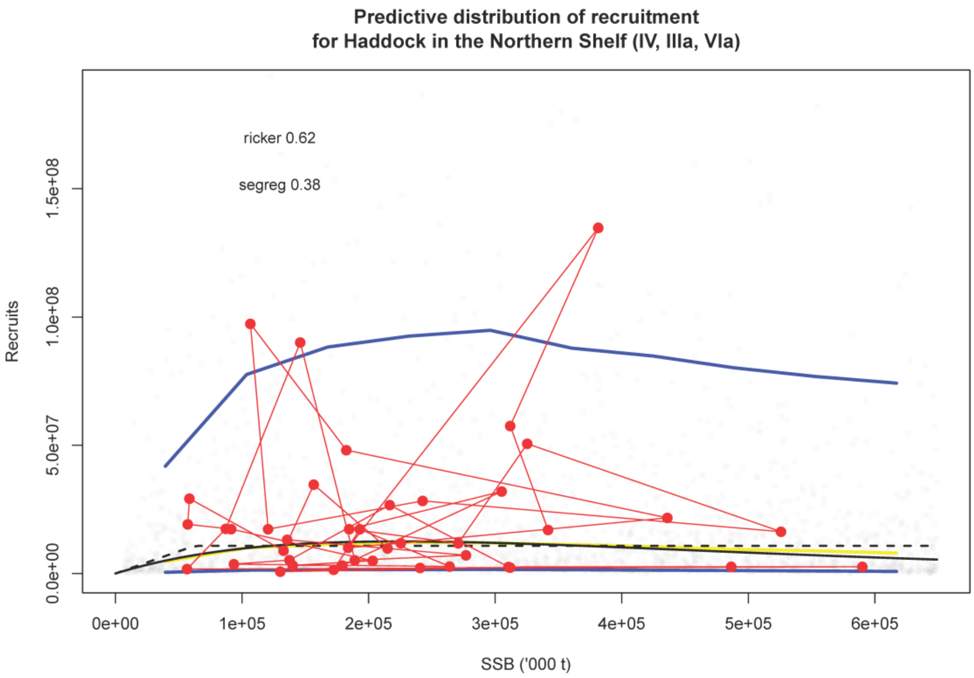

Figure 6.3.2. Summary of recruitment models (Ricker, segmented regression) for Northern Shelf haddock.

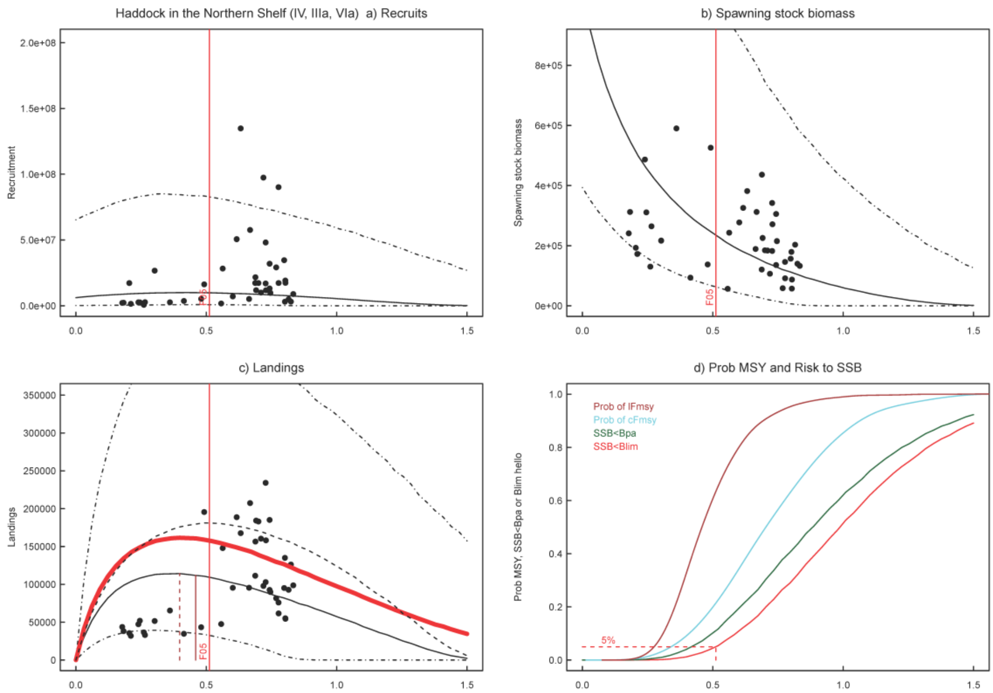

Figure 6.3.3. Eqsim summary plot for Northern Shelf haddock (no trim, no $B_{trigger}$). Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel 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).

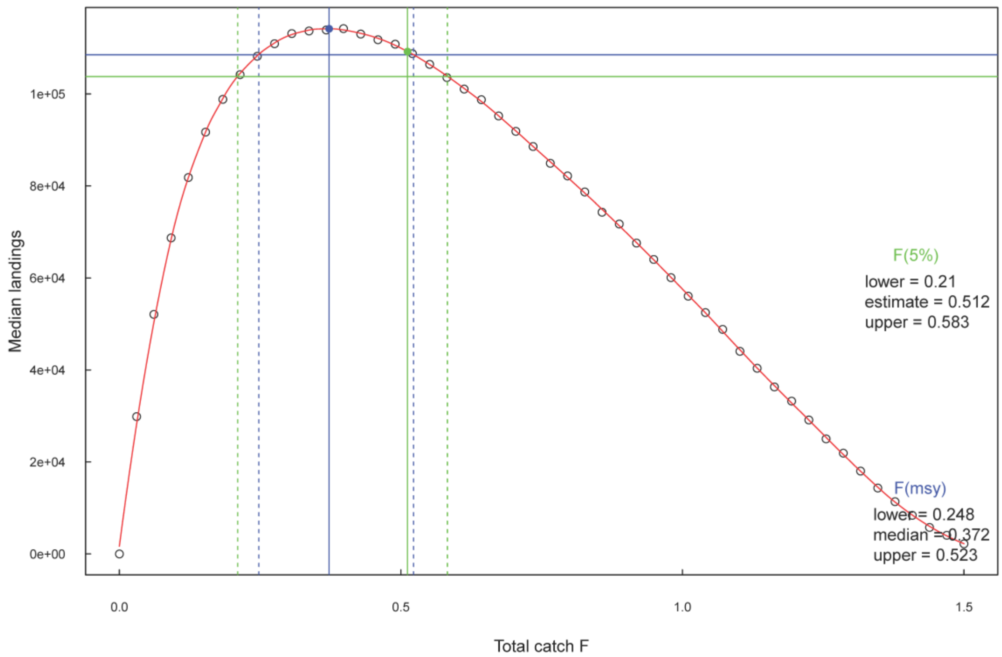

Figure 6.3.4. Median landings yield curve with estimated reference points. Blue lines: F($_{MSY}$) estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

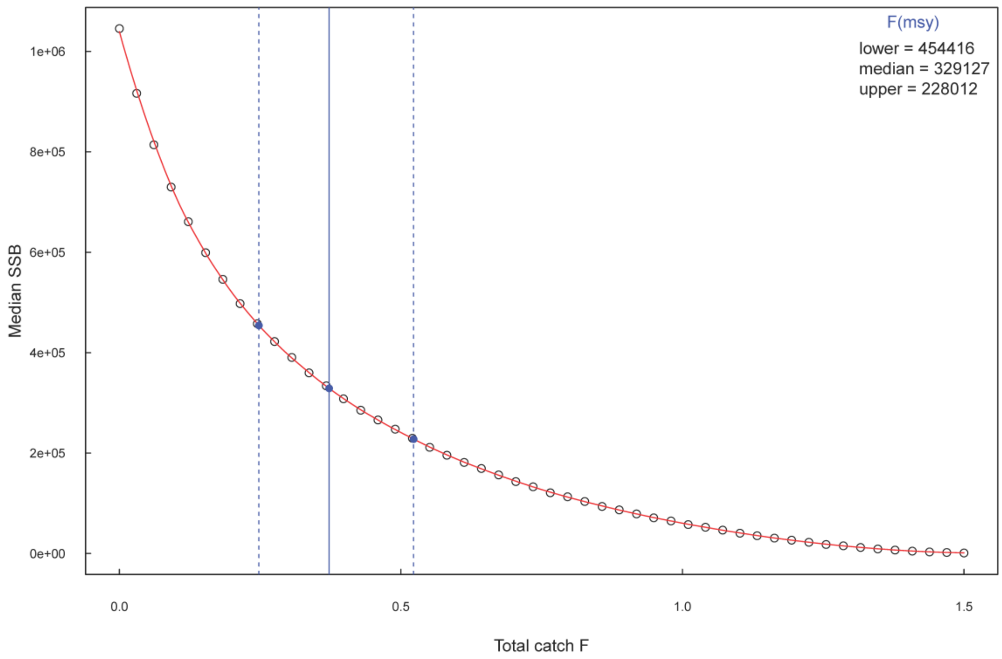

Figure 6.3.5. Median SSB for Northern Shelf haddock over a range of target F values. Blue lines show location of F(MSY) (solid) with 95% yield range (dotted).

6.4 Herring in Subdivision 30 (Bothnian Sea)

6.4.1 Current reference points

Table 6.4.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.15	Stochastic stock simulations with SOM
Current B_{lim}	Not defined	
Current Bpa	Not defined	
Current $MSYB_{trigger}$	316 000 t	2.5% percentile of B_{MSY} distribution

6.4.2 Source of data

The analysis in this report uses the newest (1973-2013) assessment results from the SAM assessment (ICES 2014f).

6.4.3 Methods used.

Eqsim was used for this stock.

6.4.4 Settings

Table 6.4.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	Full data series	
Exclusion of extreme values (option extreme.trim)	Not used	

Mean weights and proportion mature	2004-2013
Exploitation pattern	2004-2013
Assessment error in the advisory year. CV of F	0.25
Autocorrelation in assessment error in the advisory year	0.30

The presently defined biomass reference points were used for precautionary considerations in Eqsim.

6.4.5 Results

6.4.5.1 Stock recruitment relation

The stock recruitment fit using the three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method available in EquiSim gave a "straight" line for all models. Following the procedures presented above for situations with S-R relationships with poorly defined maxima a segmented regression model was used with a breakpoint set arbitrarily at the average observed SSB. B_{lim} was set at $B_{trigger}$ divided by 1.4.

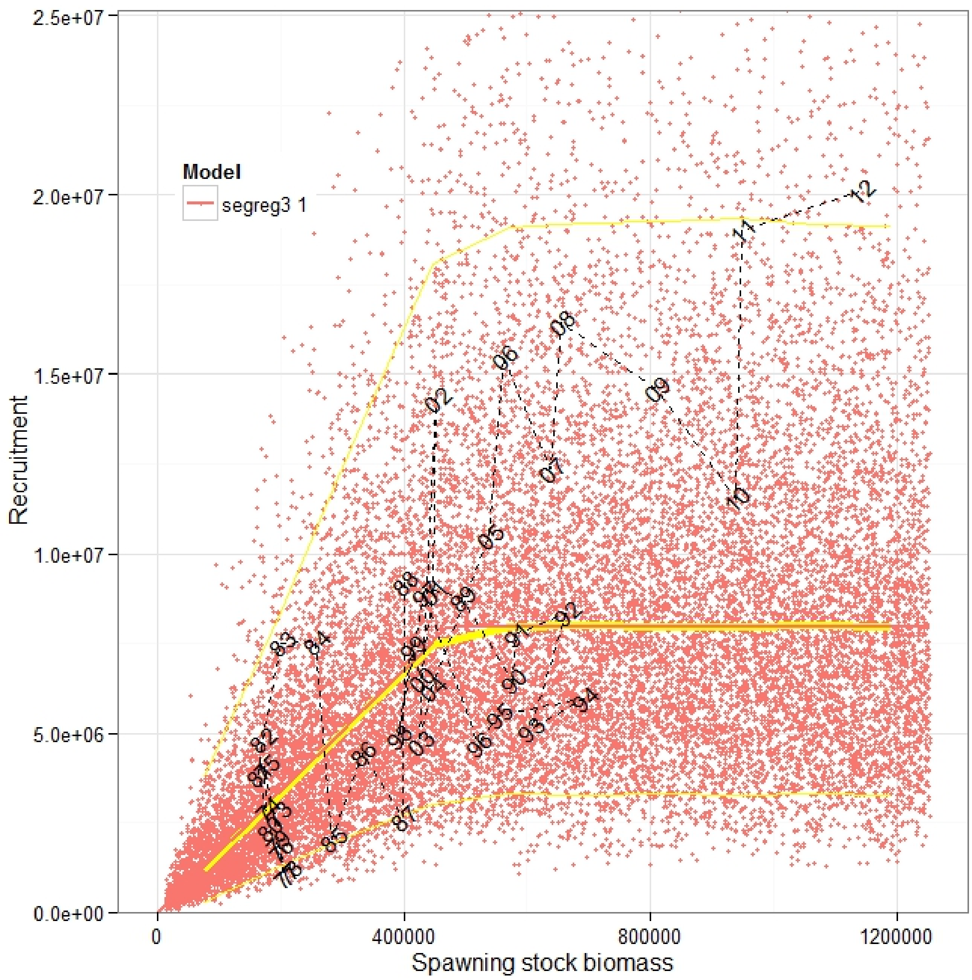

Figure 6.4.1. Stock recruitment relationship, Bothnian Sea herring, in subdivision area 30, based on segmented regression with breakpoint at mean SSB for the time series of data. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

6.4.6 Proposed reference points

Results of Eqsim runs with and without MSY$B_{trigger}$ are shown in Figures 6.4.2 and 6.4.3 respectively. The reference points derived from these simulations are given in Table 6.4.3 below.

Table 6.4.3 Summary table of proposed stock reference points

STOCK	
Reference point	Value
FMSY without $B_{trigger}$	0.12
FMSY lower without $B_{trigger}$	0.09
FMSY upper without $B_{trigger}$	0.13
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.12
FMSY upper precautionary without $B_{trigger}$	0.12
FMSY with $B_{trigger}$	0.12
FMSY lower with $B_{trigger}$	0.10
FMSY upper with $B_{trigger}$	0.15

FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.13
F_{MSY} upper precautionary with $B_{trigger}$	0.13
MSY	66 800 t
Median SSB at F_{MSY}	540 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	462 000 t
Median SSB upper (median at F_{MSY} lower)	626 000 t

6.4.7 Discussion / Sensitivity.

Sensitivity analyses were run with an alternative segmented regression fitted with a breakpoint set arbitrarily at $B_{trigger}$. The results were very similar to these of the final run and F_{MSY} was still limited by precautionary considerations (F_{lim}05% = 0.15 and 0.13, with and without $B_{trigger}$ respectively).

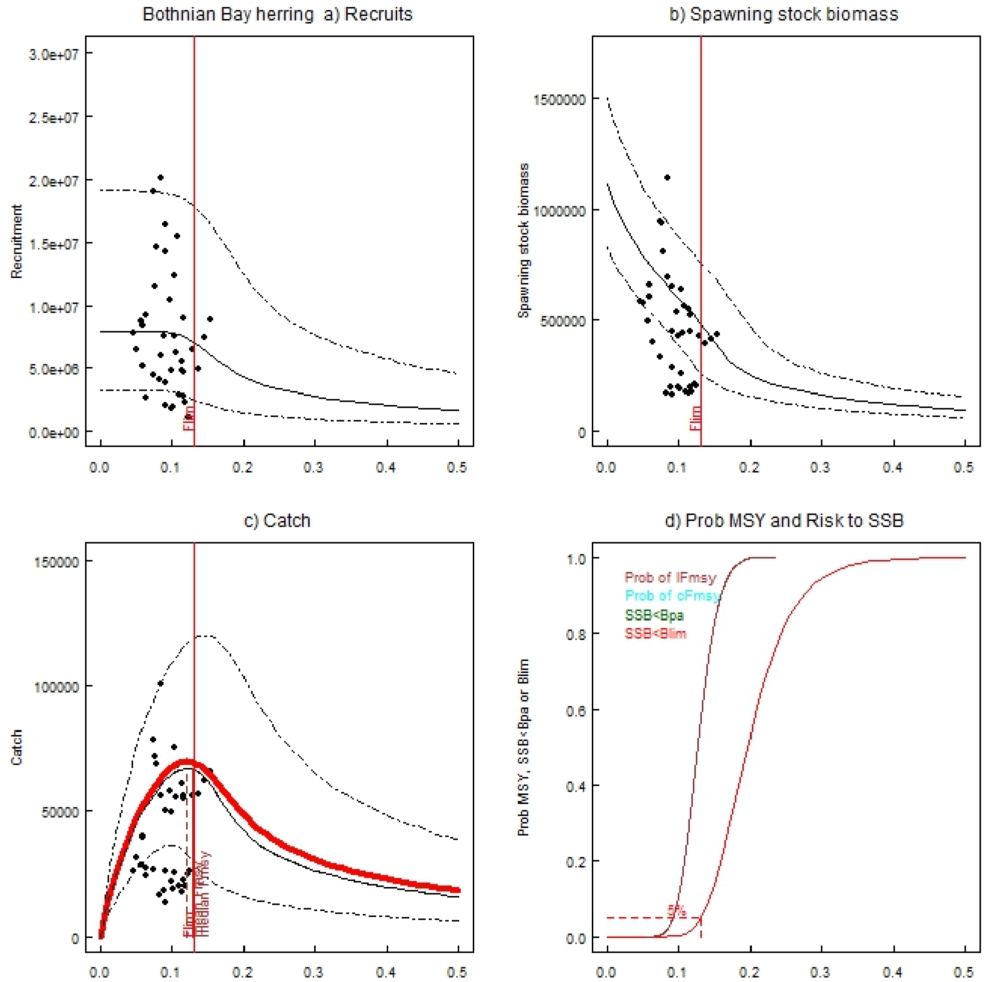

Figure 6.4.2. EquiSim results applying the standard regression method for Bothnian Sea herring in Subdivision 30 with $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also 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).

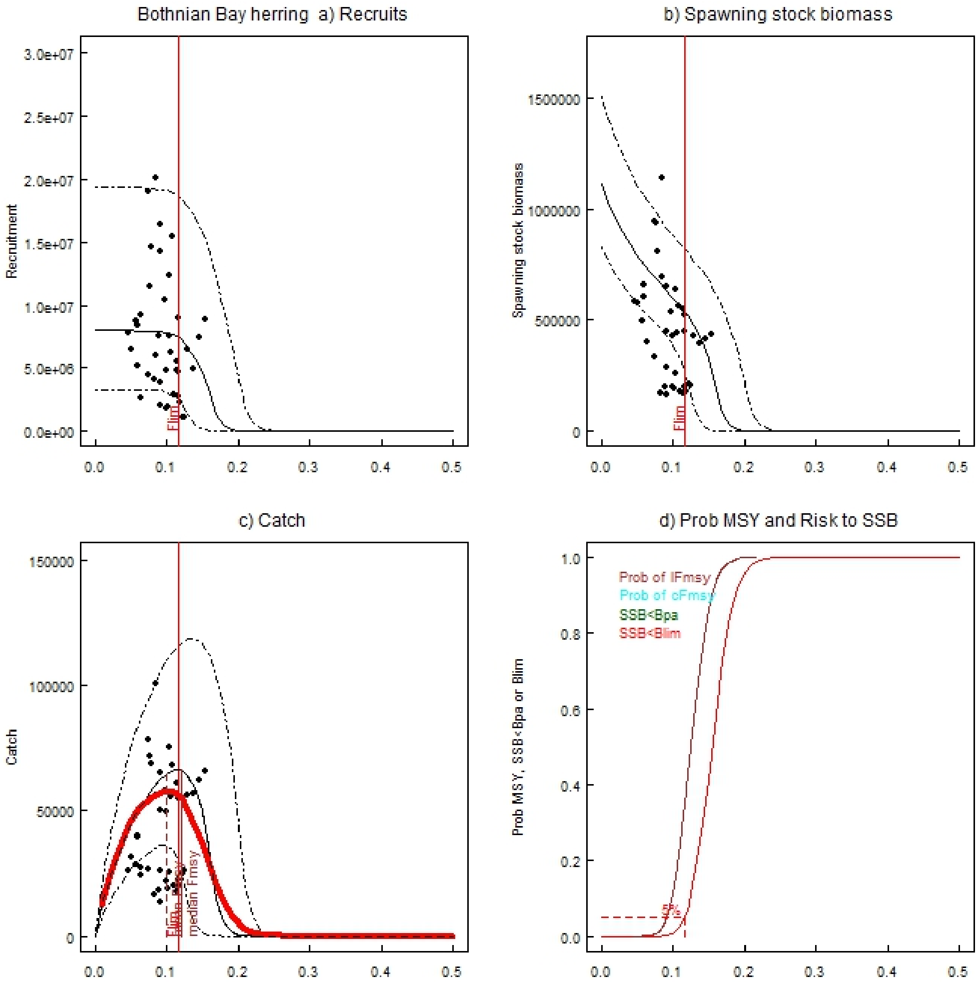

Figure 6.4.3. EquiSim results applying the standard regression method for Bothnian Sea herring in Subdivision 30 without $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c 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).

6.5 Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)

6.5.1 Current reference points

Table 6.5.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.26	Stochastic single species simulations, including S–R relationship
Current B_{lim}	430 000 t	Bloss
Current Bpa	600 000 t	B_{lim} × 1.4.
Current $MSYB_{trigger}$	600 000 t	Bpa

6.5.2 Source of data

The analysis in this report uses the newest (1974-2013) assessment results from the XSA assessment (ICES 2014f).

6.5.3 Methods used

Eqsim and Hobowy and Luzenczyk methods were both used, the results for point values can be compared, but only the Eqsim method provides the necessary precautionary considerations for setting the upper limits of the MSY interval.

6.5.4 Settings

Table 6.5.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	1974-2013	
Exclusion of extreme values (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Settings for EqSim Assessment error in the advisory year. CV of F	0.25	
Autocorrelation in assessment error in the advisory year	0.30	

The presently defined biomass reference points were used for Eqsim.

6.5.5 Results

6.5.5.1 Stock recruitment relation

The stock recruitment fit using the three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method available in Eqsim gave a “straight” line for the segmented regression. Thus, the segmented regression model was modelled setting a breakpoint at $B_{trigger}$.

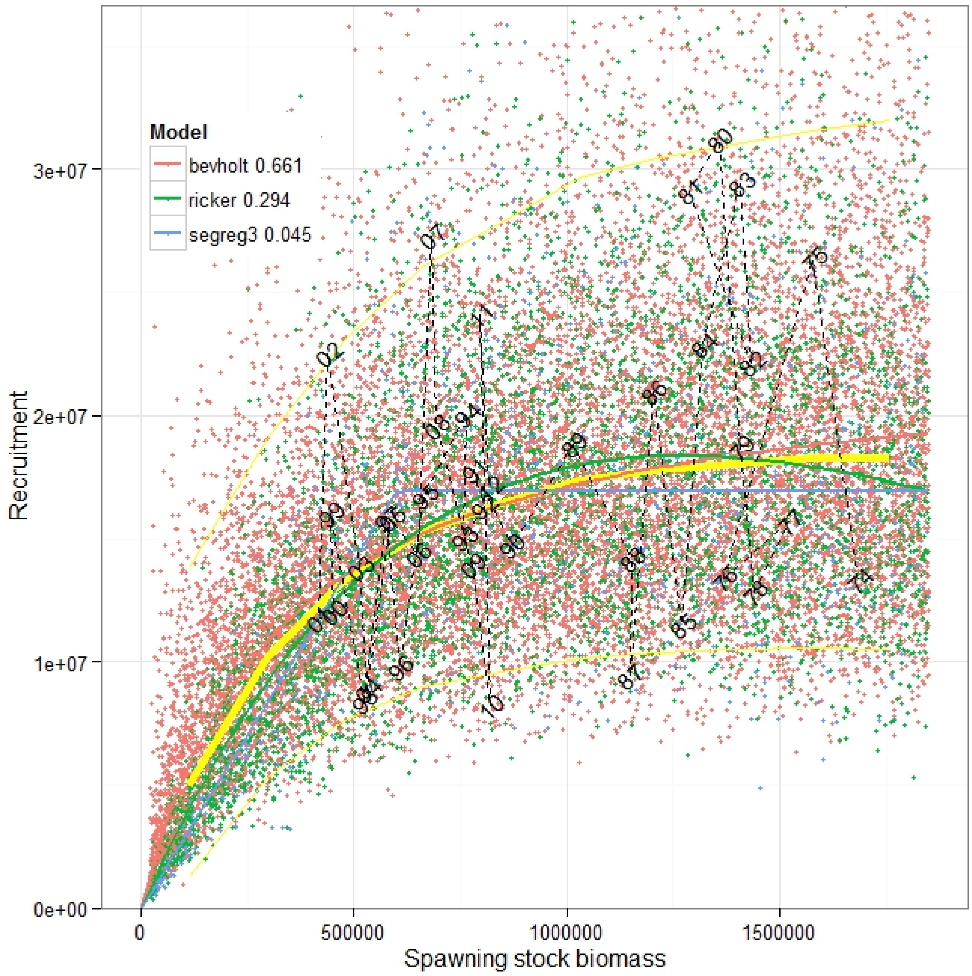

Figure 6.5.1. Stock recruitment relationship, Central Baltic herring subdivison 25–29 and 32 (excluding Gulf of Riga herring), based on segmented regression Beverton Holt and Ricker models. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

The stock recruitment relation used in the method developed by Hobowy and Luzenczyk were fit using two models (Ricker and B&H) weighted by inverse variance.

6.5.6 Proposed reference points

Results of Eqsim runs with and without $MSYB_{trigger}$ are shown in Figures 6.5.2 and 6.5.3, respectively. The reference points derived from these simulations are given in Table 6.5.3 below. The results from Hobowy and Luzenczyk are given in the further section to this table.

Table 6.5.3 Summary table of proposed stock reference points from Eqsim

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.23
F_{MSY} lower without $B_{trigger}$	0.16
F_{MSY} upper without $B_{trigger}$	0.31
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.22
F_{MSY} upper precautionary without $B_{trigger}$	0.22

F_{MSY} with $B_{trigger}$	0.24
F_{MSY} lower with $B_{trigger}$	0.17
F_{MSY} upper with $B_{trigger}$	0.39
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.28
F_{MSY} upper precautionary with $B_{trigger}$	0.28
MSY	141 000 t
Median SSB at F_{MSY}	651 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	485 000 t
Median SSB upper (median at F_{MSY} lower)	869 000 t

Table 6.5.4 Summary table of proposed stock reference points from method developed by Hobowy and Luzenczyk

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.29
F_{MSY} lower without $B_{trigger}$	0.20
F_{MSY} upper without $B_{trigger}$	0.40
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	NA
F_{MSY} upper precautionary without $B_{trigger}$	NA
F_{MSY} with $B_{trigger}$	NA
F_{MSY} lower with $B_{trigger}$	NA
F_{MSY} upper with $B_{trigger}$	NA
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	NA
F_{MSY} upper precautionary with $B_{trigger}$	NA
MSY	150 000 t
Median SSB at F_{MSY}	606 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	439 000 t
Median SSB upper (median at F_{MSY} lower)	796 000 t

6.5.7 Discussion / Sensitivity.

Sensitivity analyses were run using Ricker and Beverton & Holt models only. The results were very similar to these obtained with the final run and F_{MSY} was nevertheless limited by precautionary considerations (F_{lim}05% = 0.15 and 0.13, with and without $B_{trigger}$ respectively).

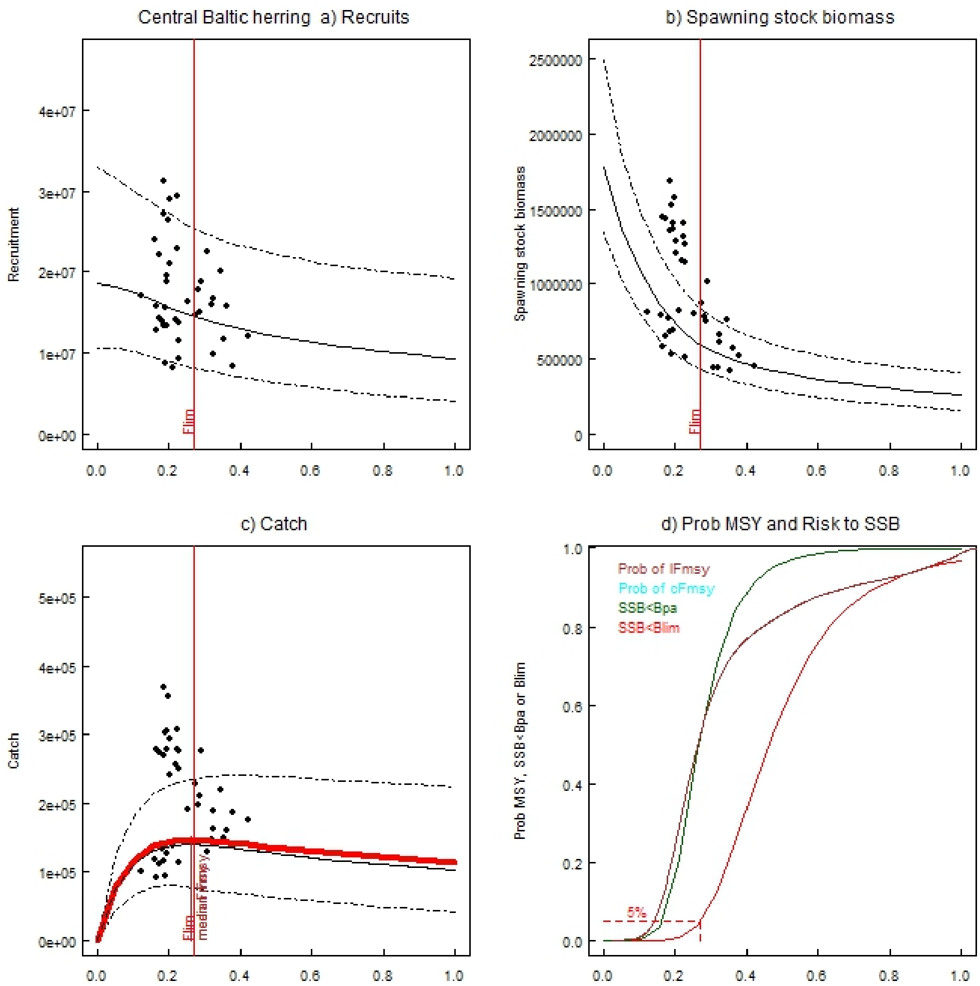

Figure 6.5.2. Eqsim results applying the standard regression method for Herring in Subdivisions 25–29 and 32 with $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows 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).

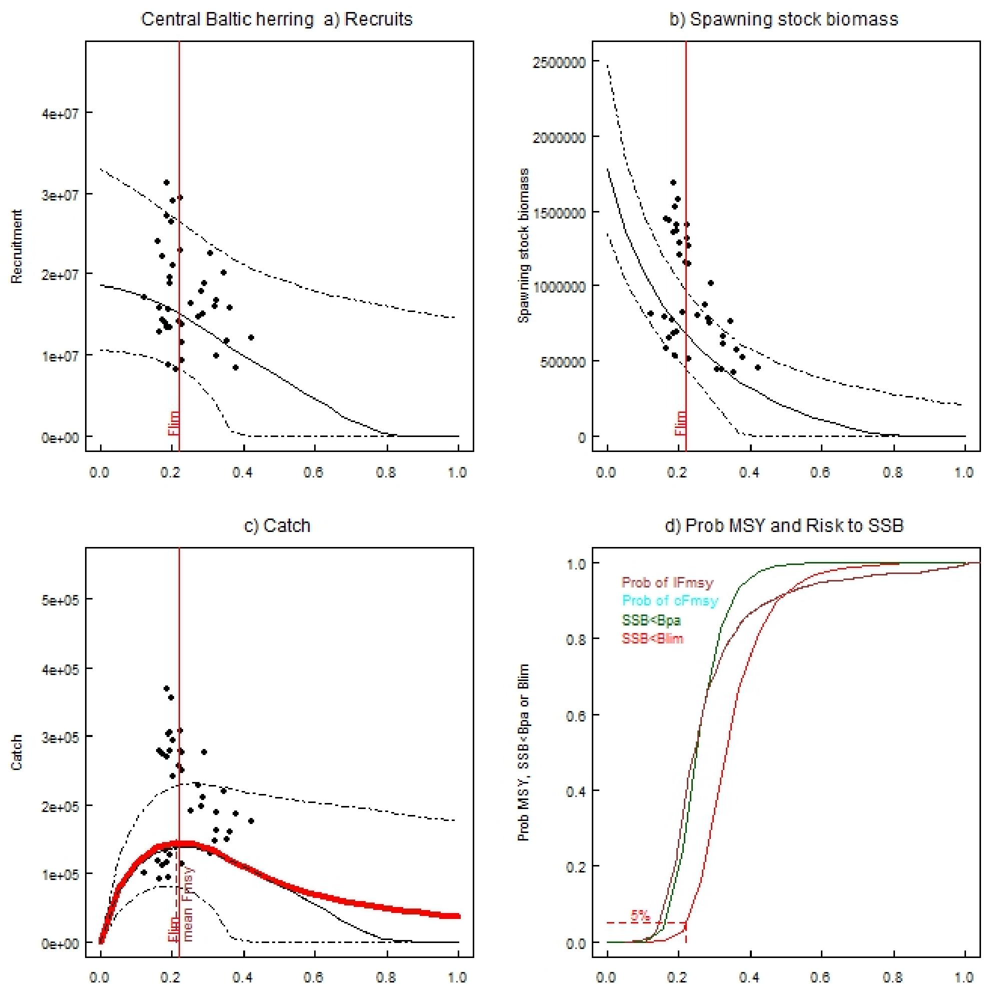

Figure 6.5.3. Eqsim results applying the standard regression method for Herring in Subdivisions 25–29 and 32 without $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also 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).

6.6 Herring in Subdivision 28.1 (Gulf of Riga)

6.6.1 Current reference points

Table 6.6.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.35	WKMAMPEL (ICES, 2009), based on stochastic simulations
Current B_{lim}	Not defined	
Current Bpa	Not defined	
Current $MSYB_{trigger}$	60 000 t	WKMAMPEL (ICES, 2009).

6.6.2 Source of data

The analysis in this report uses the newest (1977-2013) assessment results from the XSA assessment (ICES 2014f).

6.6.3 Methods used.

Eqsim was used for this stock.

6.6.4 Settings

Table 6.6.2 Model and data selection settings

Data and parameters	Setting	Comments
SSB-recruitment data	Full data series	
Exclusion of extreme values (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Assessment error in the advisory year. CV of F	0.25	
Autocorrelation in assessment error in the advisory year	0.30	

The presently defined biomass reference points were used for precautionary considerations in Eqsim.

6.6.5 Results

6.6.5.1 Stock recruitment relation

The stock recruitment fit, using the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method available in Eqsim, estimated a “straight line” for all models. Thus, a segmented regression model was used as the only stock recruitment model in the simulations with a breakpoint set arbitrarily at $B_{trigger}$ (Figure 6.6.1). A B_{lim} proxy was set at $B_{trigger}$ divided by 1.4.

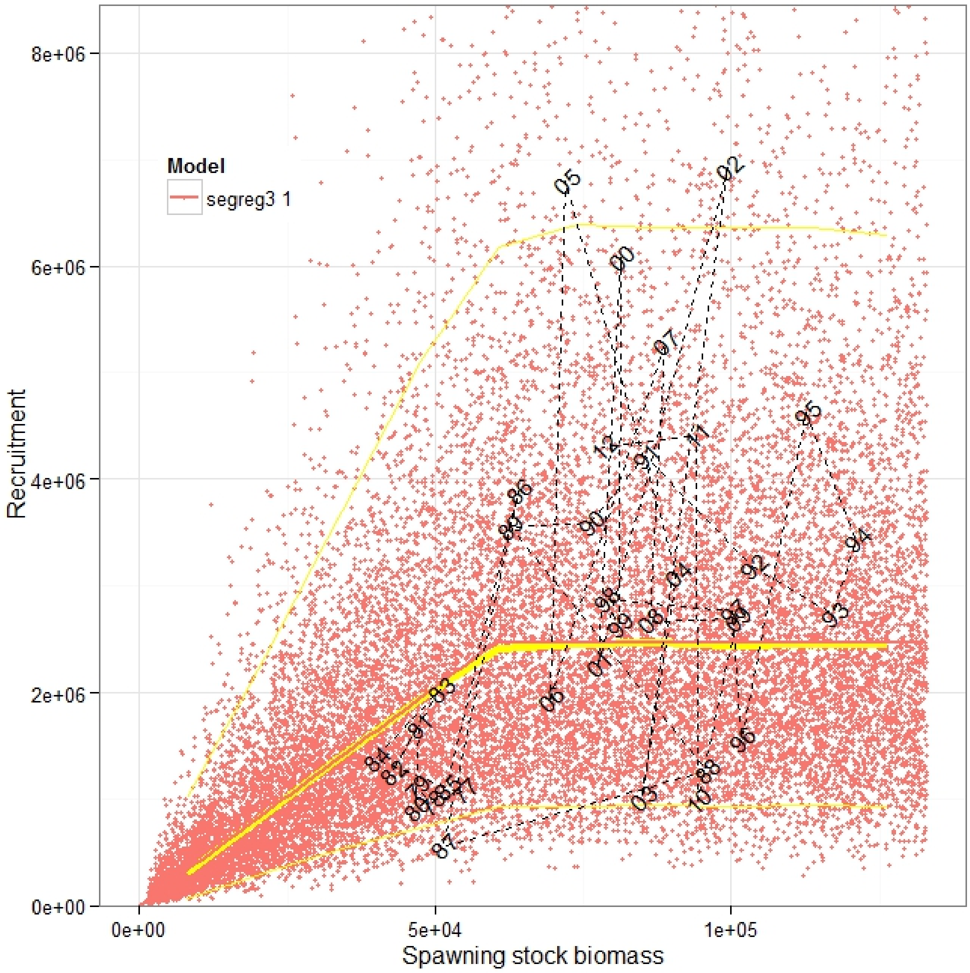

Figure 6.6.1. Stock recruitment relationship, Herring in Subdivision 28.1 (Gulf of Riga), based on segmented regression with breakpoint at $B_{trigger}$. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

6.6.6 Proposed reference points

Results of Eqsim runs with and without $MSYB_{trigger}$ are shown in Figures 6.6.2 and 6.6.3, respectively. The reference points derived from these simulations are given in Table 6.6.3 below.

Table 6.6.3 Summary table of proposed stock reference points

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.32
F_{MSY} lower without $B_{trigger}$	0.24
F_{MSY} upper without $B_{trigger}$	0.38
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.32
F_{MSY} upper precautionary without $B_{trigger}$	0.32
F_{MSY} with $B_{trigger}$	0.35
F_{MSY} lower with $B_{trigger}$	0.25
F_{MSY} upper with $B_{trigger}$	0.46

FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.38
F_{MSY} upper precautionary with $B_{trigger}$	0.38
MSY	24 200 t
Median SSB at F_{MSY}	84 700 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	68 000 t
Median SSB upper (median at F_{MSY} lower)	105 000 t

6.6.7 Discussion / Sensitivity.

Exploratory runs were also done using $B_{trigger}$ as Bim. The results were rather similar to the final run (data not shown).

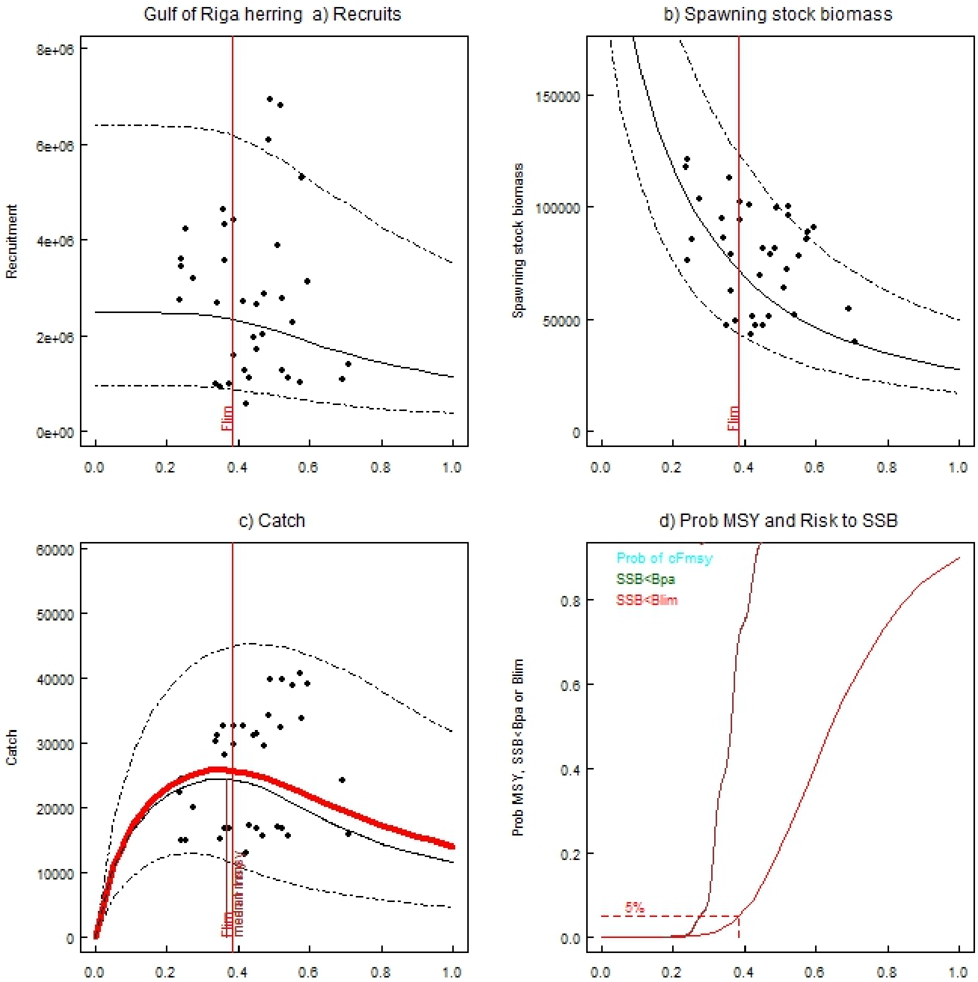

Figure 6.6.2. Eqsim results applying the Segmented regression method for Herring in Subdivision 28.1 (Gulf of Riga) with $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c 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).

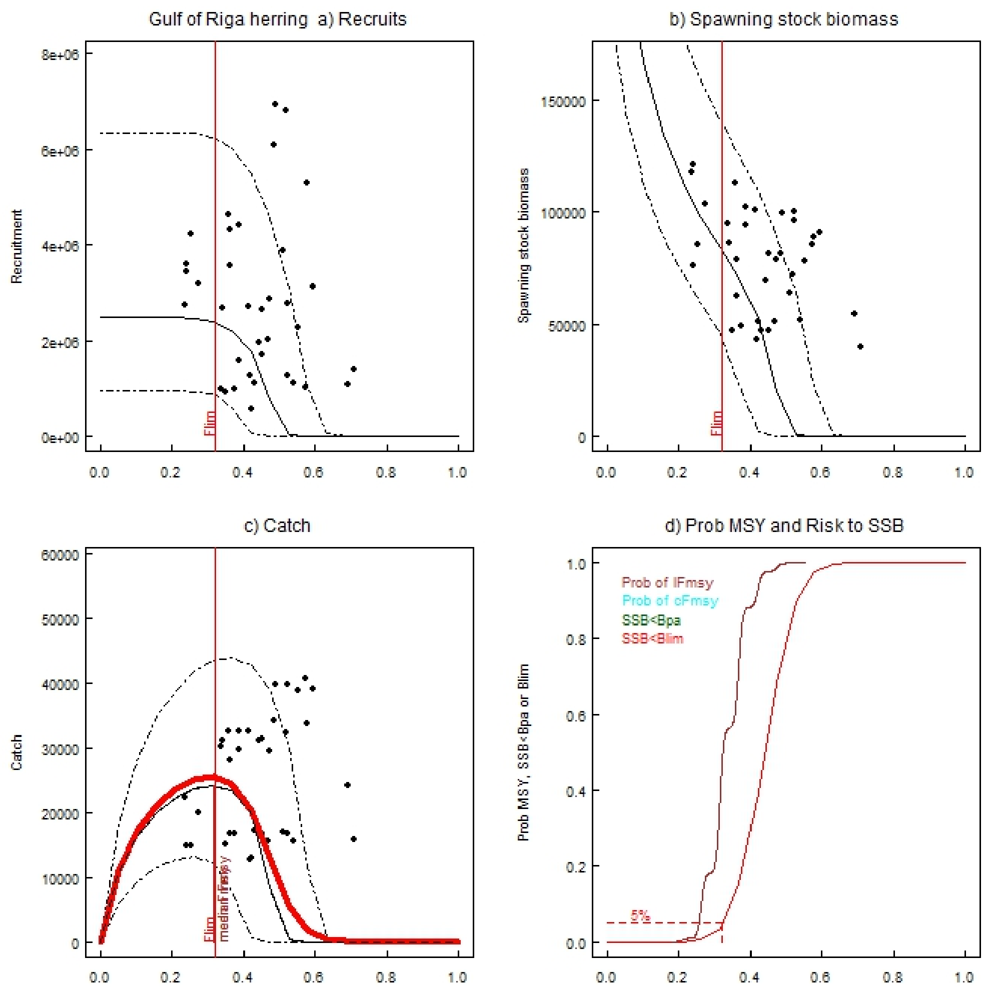

Figure 6.6.3. Eqsim results applying the Segmented regression method for Herring in Subdivision 28.1 (Gulf of Riga) without $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel 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).

6.7 Herring in Division IIIa and Subdivisions 22–24 (Western Baltic Spring Spawners)

6.7.1 Current reference points

Table 6.7.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.28	Based on randomized YPR analysis using plotMSY software, and a weighted average of F_{MSY} from (i) Beverton and Holt and (ii) Ricker stock–recruitment relationships.
Current B_{lim}	90 000 t	Chosen as Bloss based on lack of a well-defined recruitment slope at low SSB. Benchmark
Current Bpa	110 000 t	Upper 95% confidence limit of Blim using cv from the final-year SSB estimate in the assessment. Benchmark

Current $MSYB_{trigger}$	110 000 t	Tentatively chosen as Bpa, equal to the upper 95% confidence limit of B_{lim}. Benchmark

6.7.2 Source of data

The analysis in this report uses the newest (1991-2013) assessment results from the SAM assessment (ICES 2014e).

6.7.3 Methods used

Eqsim was used for this stock.

6.7.4 Settings

Table 6.7.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series	
Exclusion of extreme values (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Assessment error in the advisory year. CV of F	0.25	
Autocorrelation in assessment error in the advisory year	0.30	

The presently defined biomass reference points were used for Eqsim.

6.7.5 Results

6.7.5.1 Stock recruitment relation

The stock recruitment fit, using the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method. In the initial fit the method estimated a “straight line” through the origin for the segmented regression model. This was not considered correct and instead , the segmented regression was modelled independently with the FLR routine, which gave a breakpoint at around 149 000 t, this was then set in Eqsim and the three models refitted.

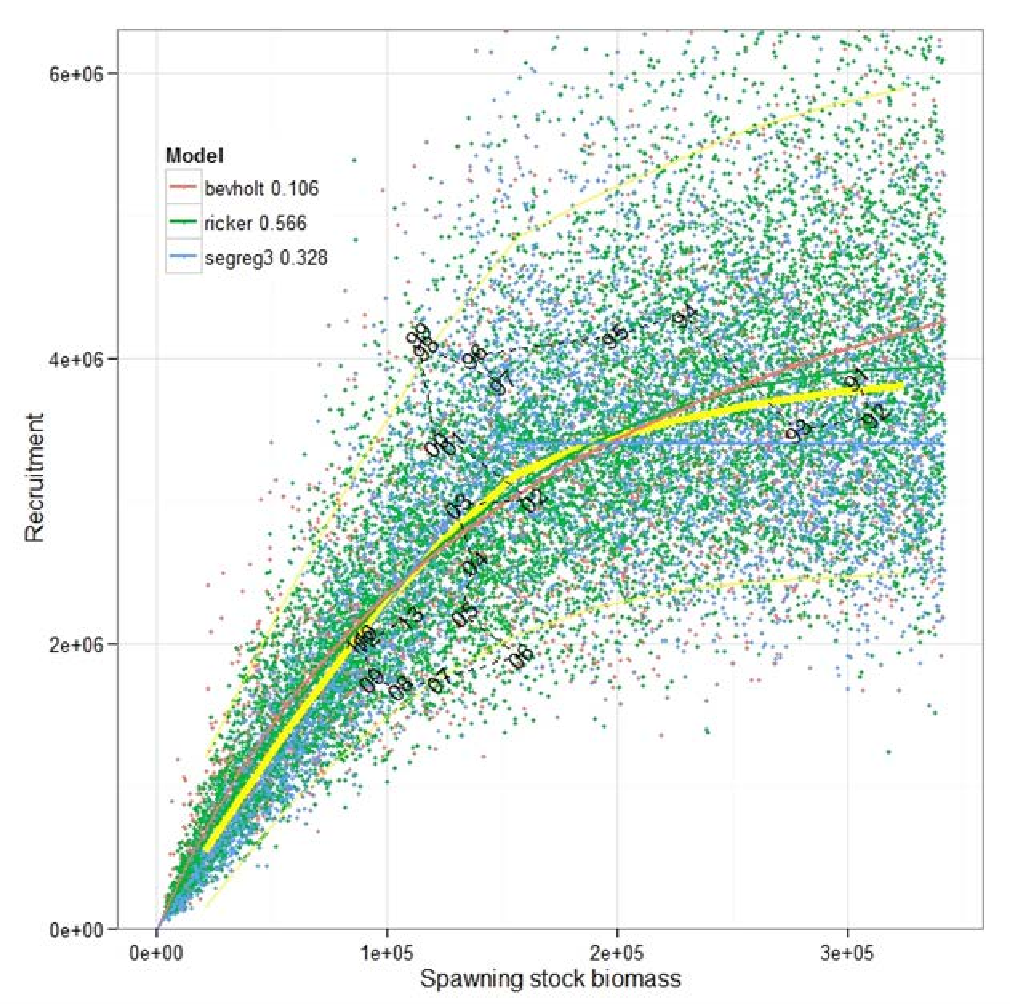

Figure 6.7.1. Stock recruitment relationships, Herring in Division IIIa and Subdivisions 22-24, based on segmented regression Beverton Holt and Ricker models. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

6.7.6 Proposed reference points

Results of Eqsim runs with and without $MSYB_{trigger}$ are shown in Figures 6.7.2 and 6.8.3 respectively. The reference points derived from these simulations are given in Table 6.7.3 below

Table 6.7.3 Summary table of proposed stock reference points

Stock	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.32
F_{MSY} lower without $B_{trigger}$	0.23
F_{MSY} upper without $B_{trigger}$	0.41
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.46
F_{MSY} upper precautionary without $B_{trigger}$	0.41
F_{MSY} with $B_{trigger}$	0.32
F_{MSY} lower with $B_{trigger}$	0.23
F_{MSY} upper with $B_{trigger}$	0.41

FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.52
F_{MSY} upper precautionary with $B_{trigger}$	0.41
MSY	106 000 t
Median SSB at F_{MSY}	288 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	208 000 t
Median SSB upper (median at F_{MSY} lower)	385 000 t

6.7.7 Discussion / Sensitivity.

Exploratory runs were also done using just the Beverton Holt model alone and compated with the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method. The results (data not shown) were rather similar to the final run based on the three models.

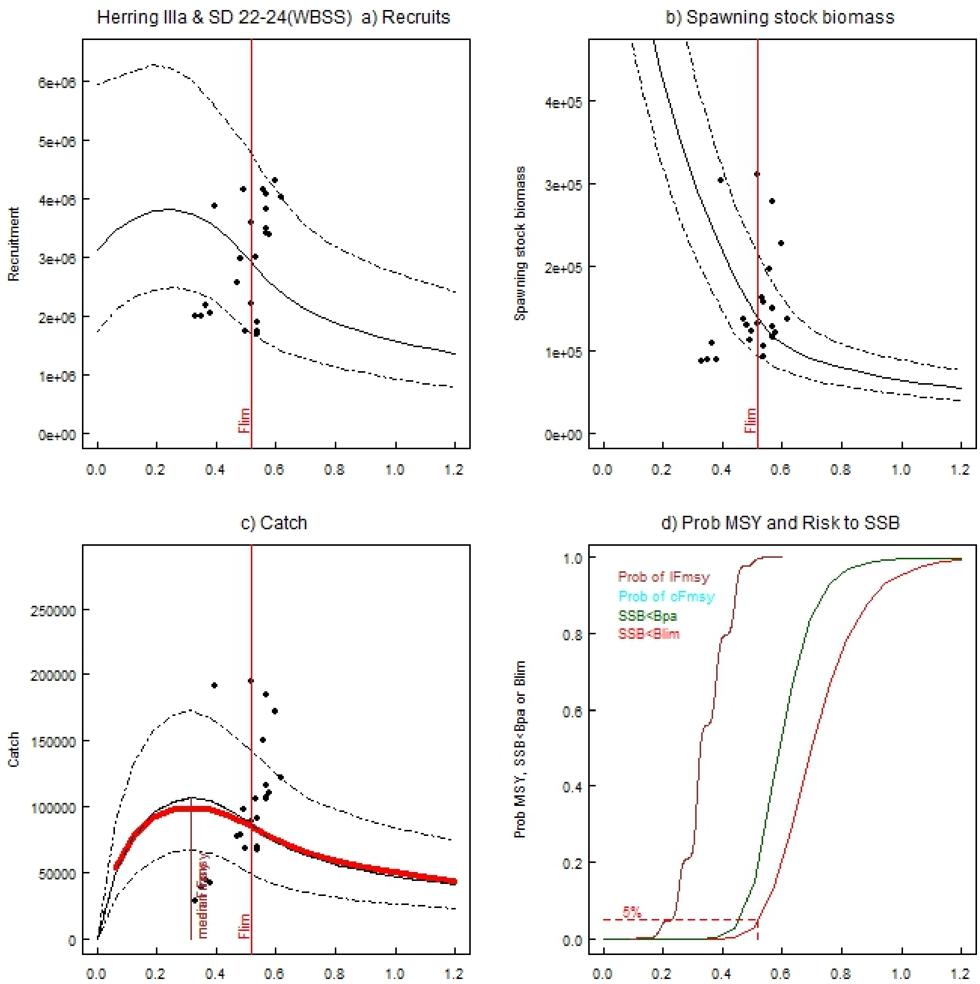

Figure 6.7.2. Eqsim results applying the Ricker, Beverton & Holt and the Segmented regression model for Herring in Division IIIa and Subdivisions 22-24 with $B_{trigger}$. The figure was run using the trimmer option to avoid unrealistic high values of catches. Panels a-c: historic values (dots) median (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).

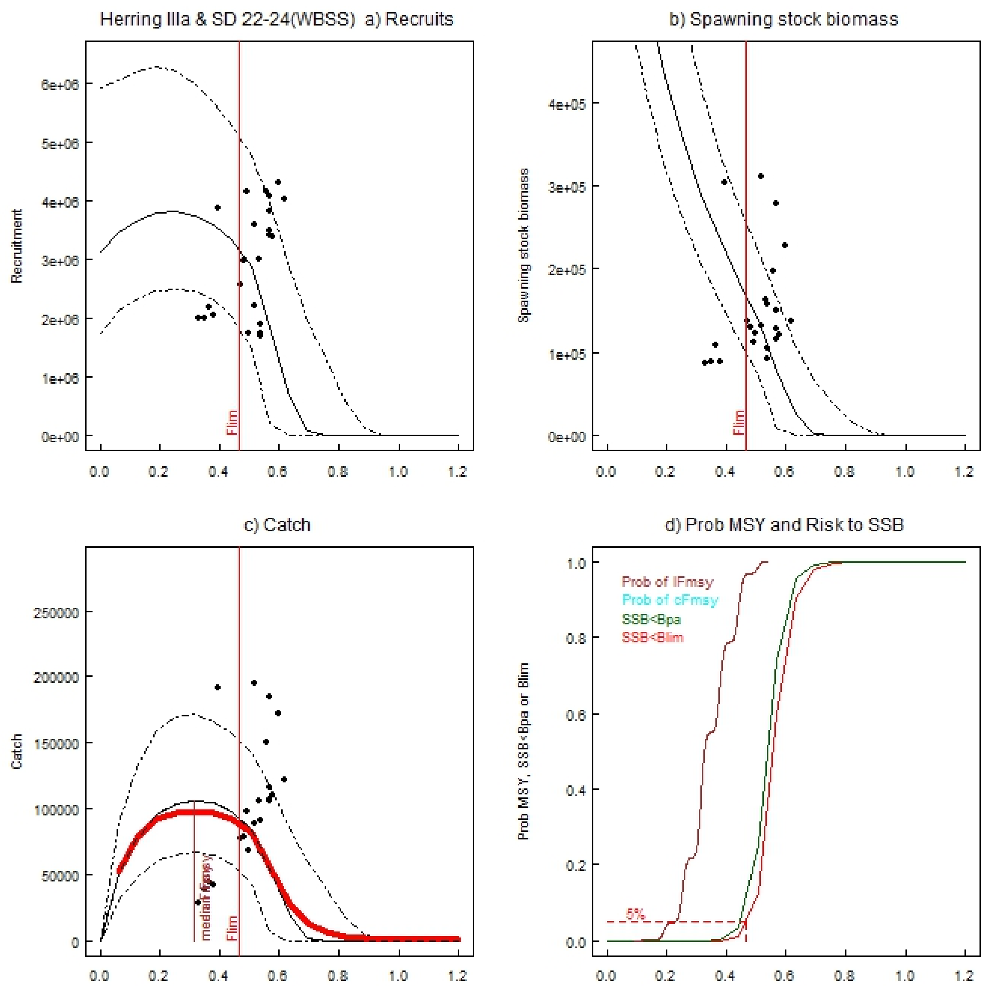

Figure 6.7.3. Eqsim results applying the Ricker, Beverton & Holt and the Segmented regression model for Herring in Division IIIa and Subdivisions 22-24 without $B_{trigger}$. The figure was run using the trimmer option to avoid unrealistic high values of catches. Panels a-c: historic values (dots) median (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).

6.8 North Sea herring

6.8.1 Current reference points

Table 6.8.1 Summary table of current stock reference points

Reference point	Value	Basis
Current F_{MSY}	0.27	Stochastic simulation based on Ricker and Beverton/Holt S-R relationships
Current B_{lim}	800 000 t	Defined in 1997/2003 at SSB<800 000 t reduced recruitment has been observed
Current Bpa	1 000 000 t	Based on <5% probability of SSB<B_{lim} with SAM model precision
Current $MSYB_{trigger}$	Not defined	

6.8.2 Source of data

The data for simulations are taken from the North Sea herring assessment documented in the report of ICES Herring Assessment WG march 2014 (ICES 2014e). The Assessment is illustrated in Figure 6.8.1

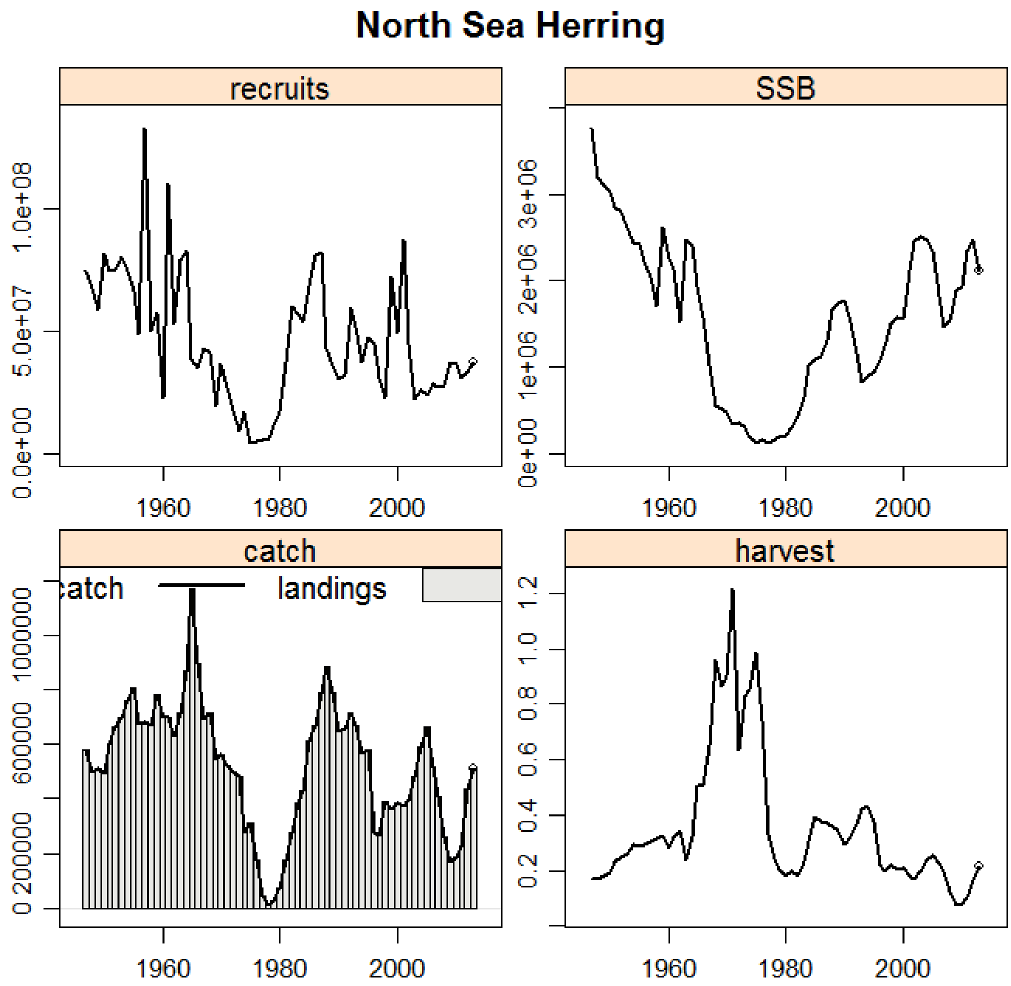

Figure 6.8.1 Stock of NS herring 1947 to 2013. Recruits, SSB, Catch/Landings and Fages 2-6

6.8.3 Methods used

The main simulation method was Eqsim.

6.8.4 Settings

The default settings were based on the last ten years of mean weights, maturities and natural mortalities at age.

Table 6.8.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series 1947-2013	With an option of recent low recruitment (2002 onwards) tested for sensitivity
Exclusion of extreme values for (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Assessment error in the advisory year. CV of F	0.192	Fcv based on ten years advice 2003 to 2012 and the 2014 assessment
Autocorrelation in assessment error in the advisory year	0.74	phi based on ten years advice 2003 to 2012 and the 2014 assessment

6.8.4.1 Period used for S-R

The initial S-R relationship was based on the full timeseries of stock recruit pairs from 1947 to 2012, omitting the last recruit values which are still estimated by only a few observations and are uncertain. Following the basis used by HAWG, Ricker and Beverton Holt S-R functional forms were used as the basis for recruitment. The choice of the period used for S-R has some influence on the results. NS herring recruitment prior to stock recovery in the 1980s appears to have been higher than in recent years. Since 2001 the recruitment has been low with no high values. The implications of recruitment options are discussed in the section on sensitivity.

6.8.4.2 Advice error

The error in the ICES advice was estimated by comparing the Fs in the ten years 2004 to 2013 estimated in the most recent years' assessment (ICES 2014e) with the F implied by the same catch given as forecast year by year in the ICES advice. Where the exact value is not available in the advice table the F is estimated by linear interpolation from the two closest options. For NS herring the industrial fisheries are included in the catch but do not directly influence the F2-6. The Standard Deviation and first order autocorrelation (AR1) of these deviations are use as input error values for Eqsim Fcv = 0.192 and Fphi = 0.74 (giving SD of 0.286)

Table 6.8.2 Estimation of error in the assessment.

Catch 2014 Assessment	F2-6 2014 Assessment	F2-6 STF given catch	Deviation (log (FA / FSTF)
587698	0.24	0.2	0.182322
663813	0.256	0.25	0.023717
514597	0.227	0.25	-0.09651
406482	0.196	0.31	-0.45846
257870	0.128	0.234	-0.60329
168443	0.076	0.14	-0.61091
187611	0.08	0.145	-0.59471
226478	0.104	0.133	-0.24596
434710	0.166	0.2	-0.18633
511416	0.214	0.23	-0.0721

6.8.5 Results

6.8.5.1 Stock recruitment relation

Results of the fitted S-R relationships for Ricker and Beverton Holt based on the full timeseries are given in Figure 6.8.2. Equilibrium simulations based on these S-R functions are illustrated in Figure 6.8.3.

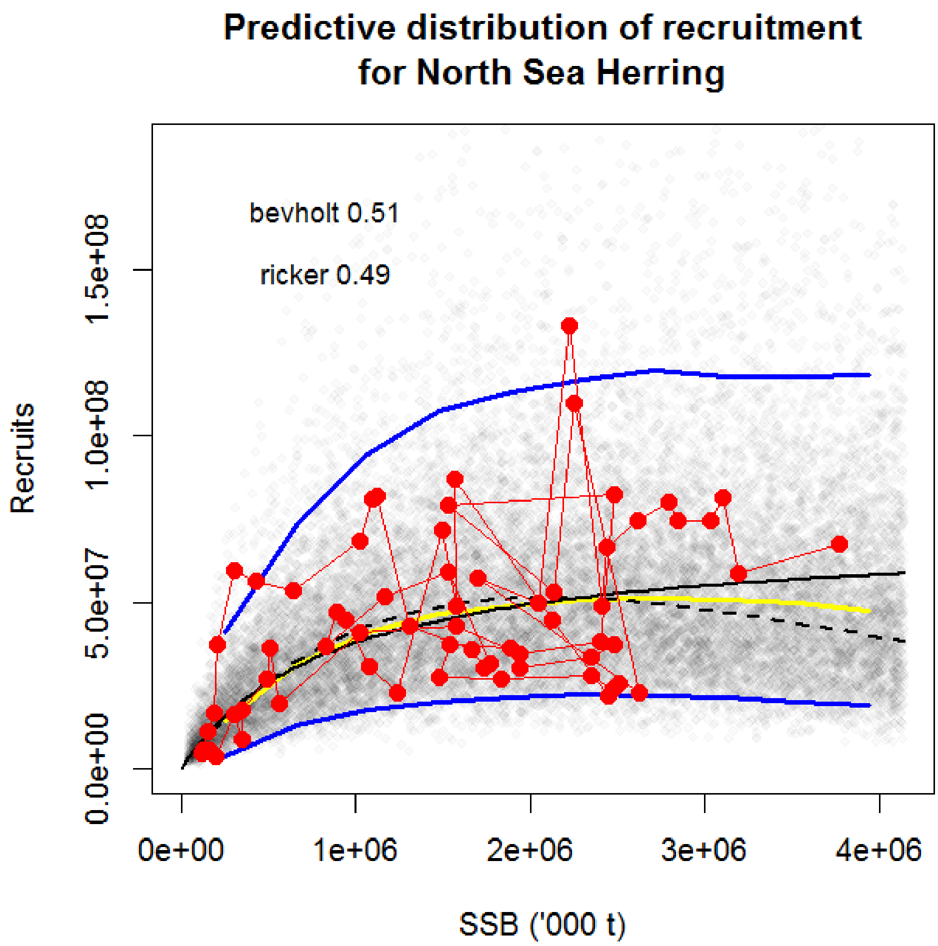

Figure 6.8.2 Fitted Stock recruit relationships and simulated recruitment based on Ricker and Beverton/Holt Stock recruit relationships with a weighting of 0.43 and 0.57 respectively. Black lines show maximum likelihood models of R verses SSB, yellow line shows the median recruitment based on weighed distribution of parametric models. Blue lines show 5 and 95% of simulated recruitment, red dots and red line historic sequence of recruitment.

6.8.6 Proposed reference points

The yield curve is slightly skewed left, with a clear peak (Figure 6.8.4).

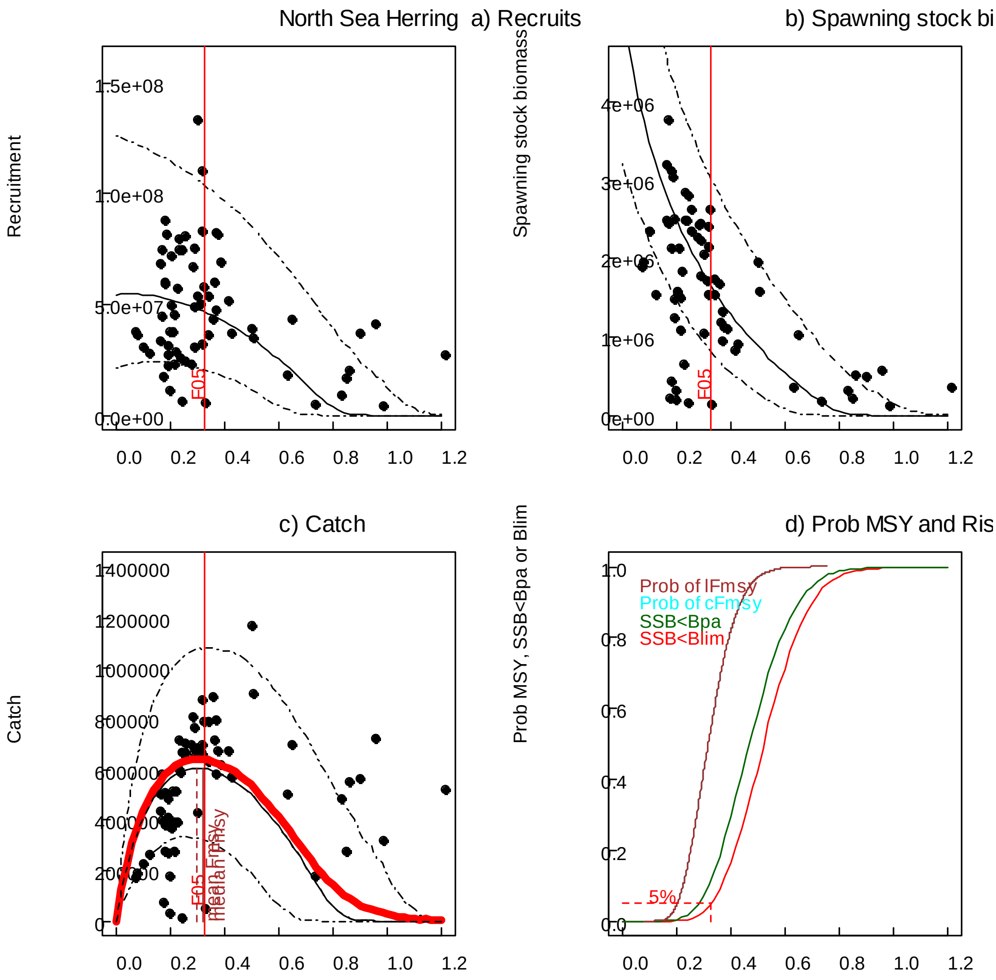

Figure 6.8.3 North Sea herring using S-R based on the full timeseries 1947 to 2012. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d 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).

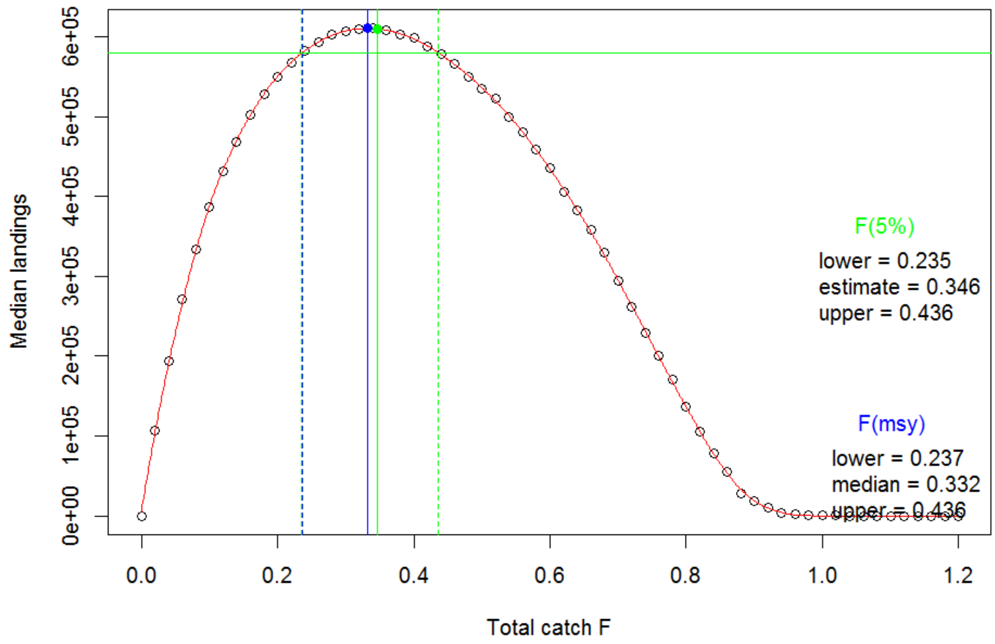

Figure 6.8.4 North Sea herring for full Series S-R data (1947 to 2012), with fixed F exploitation from $F_{2\text{-}6}$ 0 to 1.2. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted). Upper limit should be reduced for precautionary considerations.

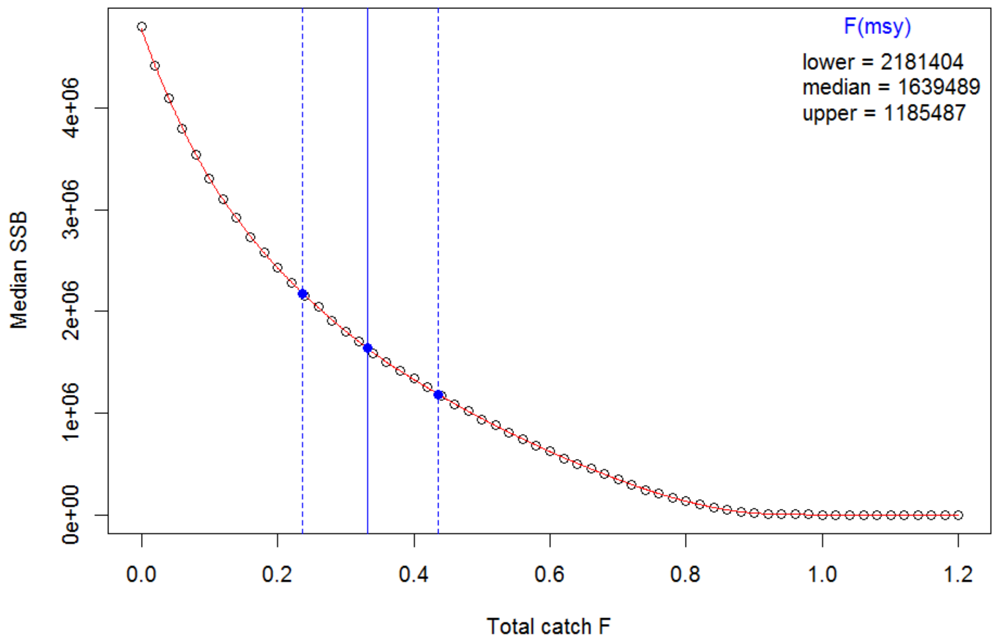

Figure 6.8.5. Median SSB for North Sea herring (assuming recruitment based on 1947-2012) over a range of target $F_{2\text{-}6}$ values. Blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

Table 6.8.3 Summary table of proposed stock reference points

STOCK	NS HERRING	
Reference point	Rec 1947-2012	Rec 2002-2012
F_{MSY} without $B_{trigger}$	0.332	0.345
F_{MSY} lower without $B_{trigger}$	0.236	0.253
F_{MSY} upper without $B_{trigger}$	0.436	0.438
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.346	0.248
F_{MSY} upper precautionary without $B_{trigger}$	0.346	0.248
F_{MSY} with $B_{trigger}$	0.348	0.407
F_{MSY} lower with $B_{trigger}$	0.240	0.280
F_{MSY} upper with $B_{trigger}$	0.507	0.633
FP.05 (5% risk to B_{lim} with $B_{trigger}$=1 000 kt)	0.381	0.287
F_{MSY} upper precautionary with $B_{trigger}$	0.381	0.287
MSY	611 000 t	349 000 t
Median SSB at F_{MSY}	1 639 000 t	1 272 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	1 563 000 t	1 272 000t
Median SSB upper (median at F_{MSY} lower)	2 181 000 t	

6.8.7 Discussion / Sensitivity.

The estimates F_{MSY} are sensitive to the S-R assumptions, particularly the period used to parameterised the Ricker and Beverton / Holt models. Recruitment since 2002 has been consistently lower than the expected value based on models that include the earlier period. The S-R model is difficult to fit to the most recent period however tests with Ricker and Beverton/Holt or Hockey Stick with a standardised breakpoint based on the full data series give similar MSY values estimates, however, in both these cases $F_{P.05}$ is reduced from 0.35 to 0.25 which is close to the lower bound of the MSY interval for the full recruitment period. Safe exploitation during periods of lower recruitment hence requires modification. This can be dealt with in a number of ways, including extended periods of low recruitment in the S-R model and modifying $F_{P.05}$ accordingly, which should give similar results to the models based on low recruitment, or inclusion of a biomass element in the F target rule. Without such a biomass rule the values suitable for the next 5 years need to account for this. The used of B_{pa} as the biomass $_{trigger}$ has been tested and this does not provide sufficient protection if the low recruitment situation continues.

6.9 Horse mackerel in Divisions IIa, IVa, Vb, VIa, VIIa-c, e-k, and VIIIa-e (Western stock)

6.9.1 Current reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current F_{MSY}	0.13	F0.1 from the yield-per-recruit (Section 5.7 in ICES, 2010).
Current B_{lim}	Not defined	
Current Bpa	Not defined	
Current $MSYB_{trigger}$	634 577 t	Bloss 2014 assessment; SSB in 2001.

6.9.2 Source of data

The data are from the latest ICES assessment for western horse mackerel, given in the 2014 WGWIDE report (ICES 2014h).

6.9.3 Methods used

Full MSE used as follows:

- Based on latest WGWIDE assessment (ICES 2014h)
- Create 1000 populations (var-cov matrix of estimable parameters used to derive this)
    - values created this way checked to see that they were consistent with point estimates and precision from original assessment
- For each population:
    - Fit S-R curve without the 1982 and 2001 spikes (type chosen according to weights allocated to stock-recruit fits using plotMSY with 5% trimming) to give stock recruit parameters (a_r, b_r), with associated variability and serial correlation (s_r, r_r)
    - Re-sample historic stock-recruit residuals with replacement and allocate to future years. For recruitment spikes, assume an average interval between spikes of 19 years (interval between 1982 and 2001 year-classes), and re-sample with replacement from the 1982 and 2001 residuals (calculated as the distance between these recruitment values and the fitted stock-recruit curve) to allocate when a spike is due in future
    - Apply catch and stock weights (sample vectors with replacement from 1998 onwards and allocated these to future years)
    - Apply separable period selection (last six years allocated to future years)
- Check that sensible modelled recruitment values are obtained (by comparing with historic recruitment for corresponding SSB values)
- Project populations for 200 years; take stats from last 50 years
- Add "assessment" error:

$$F_{\text{realised}} = F_{\text{intended}}\, e^{\varepsilon_y}, \quad \varepsilon_y = \rho\varepsilon_{y-1} + \sqrt{(1-\rho^2)}\,\eta$$

$$\eta \sim N(0;\sigma^2); \quad \sigma = 0.3; \quad \rho = 0.5$$

This approach is presented in the 2014 WGWIDE report, Section 5.7.2 (ICES 2014h). The SAD assessment used for western horse mackerel is described in De Oliveira et al. (2010). The current MSE approach is being developed in parallel between two labs using different modelling platforms for conducting the MSEs (both conditioned on the SAD assessment from WGWIDE, reported in ICES 2014h). Results for the two approaches are close, apart from minor differences in recruitment (a systematic bias is currently being investigated; results shown below are for the approach that is slightly more pessimistic on recruitment).

6.9.4 Settings

Table 6.9.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series (all years classes from 1983-2000 and 2002-2012 – the 1982 and 2001 year classes are exceptionally high, and are excluded from stock-recruit fits)	Recruitment spikes were handled separately to "normal" recruitment years (see section 6.9.3). Note 2012 is the final years for which the assessment provides an estimate of recruitment (age 0)
Mean weights and proportion mature	1998-2013	Sampled catch and stock weight vectors with replacement (agreed basis for MSE)
Exploitation pattern	2008-2013	Separable period in the assessment
Assessment error in the advisory year. CV of F	0.3	Sensible default values (since not enough advice years available for comparison)
Autocorrelation in assessment error in the advisory year	0.5	Sensible default values (since not enough advice years available for comparison)

6.9.5 Results

6.9.5.1 Stock recruitment relation

The plotMSY software (ICES 2013b) was used to fit three stock-recruit curves to stock-recruit pairs (excluding the 1982 and 2001 recruitment spikes), and these are shown in Figure 6.9.1. After applying a trimming of 5% to discard cases with extremely poor likelihood values, the software allocates a weight of 46% for Beverton-Holt, 32% to Ricker and 22% to the smooth Hockey-stick. These have been used in the MSE analysis, allocating stock-recruit types in these proportions to the 1000 populations (i.e. the first 460 are allocated a Beverton-Holt, the next 320 a Ricker, and the final 220 a smooth Hockey-stock).

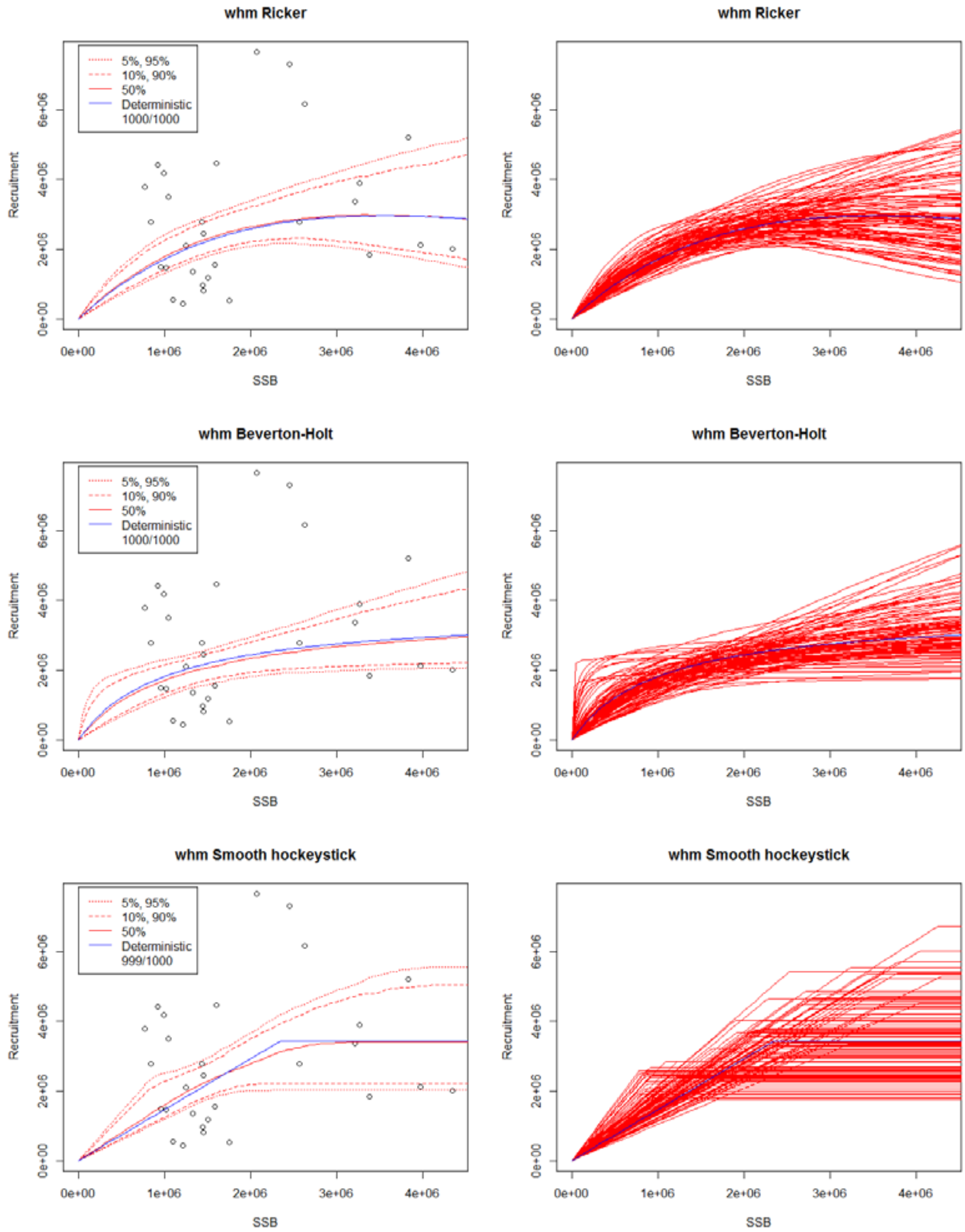

Figure 6.9.1. Western horse mackerel. Fits to three stock-recruit curves for stock-recruit pairs that exclude the 1982 and 2001 recruitment spikes, using plotMSY. This software allocated weights of 46% to Beverton-Holt, 32% to Ricker and 22% to Hockey-stick.

6.9.5.2 Yield and SSB curves

The MSE projects populations forward for 200 years, and calculates statistics for the final 50 years. These are given for yield (considered as catch for western horse mackerel) and SSB in Figure 6.9.2 (recruitment spikes and recruitment serial correlation included). Maximum median yield occurs at F_{MSY}=0.060, with the F values associated with 95% of maximum yield being 0.044 and 0.071 for the lower and upper values respectively. B_{lim} is not defined, but the workshop considered $MSYB_{trigger}/1.4$ = 453269 as a potential candidate. The F value associated with risk 1=5% of falling below this point is slightly less than F_{MSY} (F_{P05}=0.056). However, as $MSYB_{trigger}/1.4$ was considered a poor proxy for B_{lim}, F_{MSY}upper was determined as F_{MSY} (the default when B_{lim} is unknown) implying an F_{MSY} range of 0.044-0.060 for western horse mackerel.

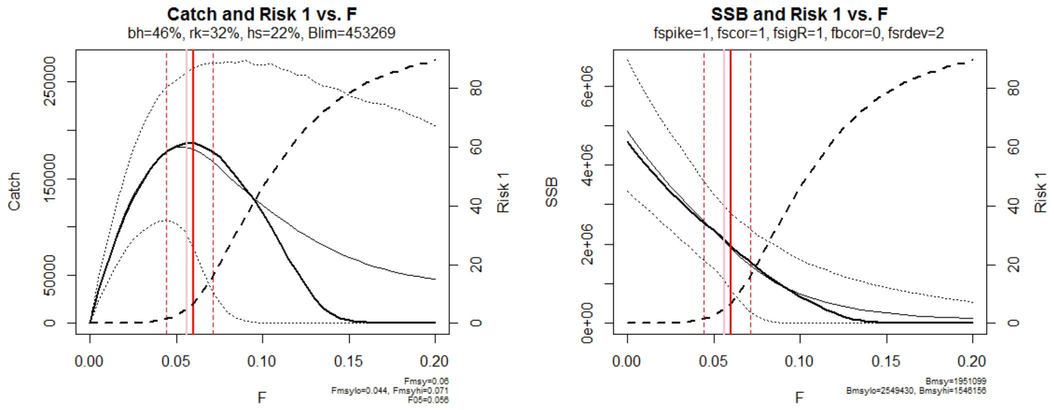

Figure 6.9.2. Western horse mackerel. Yield (left) and SSB (right) curves plotted against intended F in the case where both recruitment spikes and recruitment serial correlation is included. Medians are the solid bold black lines and means the solid light black lines; the 10th and 90th percentiles are the dotted black lines, while the hashed black line represents risk 1 as defined in ICES WKGMSE (ICES 2013c), and represented on the secondary y-axis. In the left plot, the solid red vertical line represents F_{MSY} (the peak of the median yield curve), and the hashed red vertical lines the F values associated with the median yield that is 95% of the peak; the solid pink vertical line represents the F_{P05}, the F value associated with a risk 1 value of 5%. These red vertical lines are repeated in the right plot.

6.9.6 Proposed reference points

Summary table of proposed stock reference points (Table 6.9.3) for the MSE approach described in Section 6.9.3.

Table 6.9.3 Summary table of Reference points

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.060
F_{MSY} lower without $B_{trigger}$	0.044
F_{MSY} upper without $B_{trigger}$	0.071
New FP.05 (5% risk to $B_{trigger}$/1.4 without $B_{trigger}$)	0.056*
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	Not calculated
F_{MSY} with $B_{trigger}$	Not calculated
F_{MSY} lower with $B_{trigger}$	Not calculated
F_{MSY} upper with $B_{trigger}$	Not calculated
F_{MSY} upper precautionary with note of whether conditional	0.060 (B_{lim} not defined for this stock)
MSY	187 096 t
Median SSB at F_{MSY}	1 951 099 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	1 546 156 t
Median SSB upper (median at F_{MSY} lower)	2 549 430 t

*Note that this is not an agreed B_{lim}, hence this value is not shown in later tables.

6.9.7 Discussion / Sensitivity.

Sensitivity was explored by considering (a) removing recruitment serial correlation, and (b) removing recruitment spikes (so that the S-R curves shown in Figure 6.9.1 are used on their own without additional recruitment spikes).

Ignoring recruitment serial correlation (as is currently done in the Eqsim software) leads to raised yields and SSB, but for horse mackerel did not change the F_{MSY} value (although the F_{MSY} upper range was shifted upwards). The most important effect was an improved risk 1 value for any given F, implying precautionary considerations are more likely to be modify F_{MSY} ranges when recruitment serial correlation is included.

When recruitment spikes are ignored for western horse mackerel, the stock appears hardly to be able to sustain any fishing pressure (Figure 6.9.3). Furthermore, even under no fishing, risk 1 is greater than 5%, bringing into question the B_{lim} proxy used to calculate risk 1, or the assumption that the stock does exhibit recruitment without spikes.

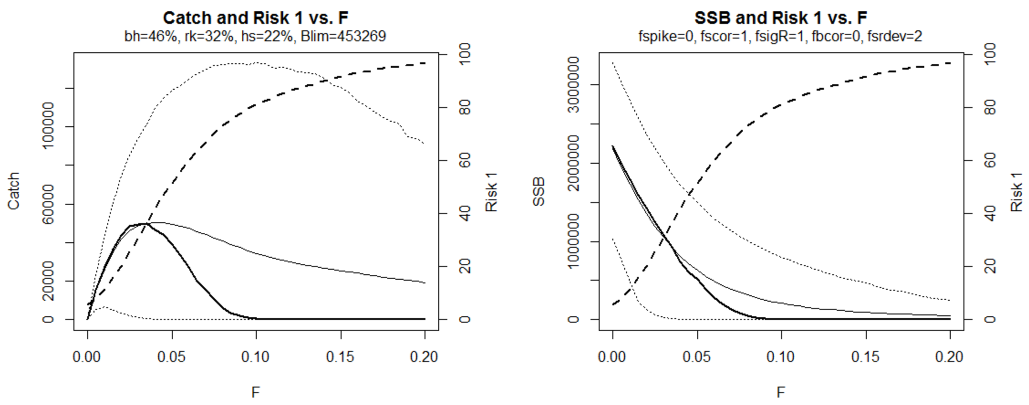

Figure 6.9.3. Western horse mackerel. Yield (left) and SSB (right) curves plotted against intended F for the case where recruitment spikes are ignored. See caption to Figure 6.9.2 for further information.

6.10 Plaice in Subarea IV (North Sea)

6.10.1 Current reference points

Table 6.10.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.25	Simulation studies and equilibrium analyses taking into account a number of possible stock–recruitment relationships (range of 0.2–0.3)), WGNSSK 2010.
Current B_{lim}	160 000 t	Bloss = 160 000 t, the lowest observed biomass in 1997 as assessed in 2004.
Current Bpa	230 000 t	$B_{lim} \times e1.645\sigma$, σ=0.20: approximately B_{lim}*1.4.
Current $MSYB_{trigger}$	230 000 t	Default to value of Bpa.

6.10.2 Source of data

All data used came from the WGNSSK 2014 final assessment (ICES, 2014b).

6.10.3 Methods used

The Eqsim and Cadigan (stockassessment.org) methods were applied. Bootstrapping was used in the stockassessment.org method. Runs with and without $MSYB_{trigger}$ were done for the Eqsim method, but this functionality is not included in the Cadigan method. In both methods the total (catch) F was optimised for maximum landings.

6.10.4 Settings

Table 6.10.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
Stock-recruit relationships	Ricker, Segmented regression and Beverton and Holt	All provide reasonable fits to the data.
SSB-recruitment data	Full data series excluding last 3 years (1957-2010)	Recent year class strength is informed by less data than earlier year classes so these estimates are considered less reliable. This assumption is used in the short term forecast for this stock (geometric mean recruitment excluding the last three years).
Exclusion of extreme values (option extreme.trim)	No exclusions	
Mean weights and proportion mature	2004-2013	No significant trends over the last ten years.
Exploitation pattern	2004-2013	No significant trends over the last ten years.
Assessment error in the advisory year. CV of F	0.189	Calculated according to Section 4.1
Autocorrelation in assessment error in the advisory year	0.551	Calculated according to Section 4.1

In order to estimate assessment uncertainty (CV and autocorrelation), advised and realised Fs for the observed catch for the last 9 years were compared (Table 6.10.3).

Table 6.10.3 pleIV_Error in advice

	F Assess	F set	ln(Fass)	ln(Fset)	Deviations
2005	0.54	0.4	-0.62	-0.92	0.30
2006	0.51	0.39	-0.67	-0.94	0.27
2007	0.52	0.33	-0.65	-1.11	0.45
2008	0.55	0.26	-0.60	-1.35	0.75
2009	0.35	0.24	-1.05	-1.43	0.38
2010	0.24	0.22	-1.43	-1.51	0.09
2011	0.24	0.21	-1.43	-1.56	0.13
2012	0.25	0.24	-1.39	-1.43	0.04
2013	0.23	0.21	-1.47	-1.56	0.09
			STD Deviations		0.227
				Fcv	0.189

	Phi	0.551

6.10.5 Results

6.10.5.1 Stock recruitment relation

The stock-recruit fits to for the two methods applied are shown in Figures 6.10.1 and 6.10.2. The SR scatter for North Sea plaice shows no clear patterns with both high and low recruitments found across the whole range of observed SSB. There is a single outlier (1985 year class) near the middle of the observed SSB range.

In the Eqsim method, the segmented regression failed to produce a reasonable fit to the data (constantly increasing slope to maximum observed SSB). Instead the segmented regression model was parameterised using FLRSR, with an estimated breakpoint at 339 000 t. This has a minimal impact on the model averaged fit since segmented regression only has 2% weighting compared to 82% for Beverton and Holt and 15% for Ricker.

The Cadigan non-parametric model fits to the data predominantly have Ricker-like curves. There are a few outlier fits that most likely result from a higher proportion of the bootstrapped values coming from the outlier SR point. In many cases the peak of the curve is either near the beginning or end of the observed SSB range, suggesting the model has difficulty defining the peak of the recruitment curve given the available data.

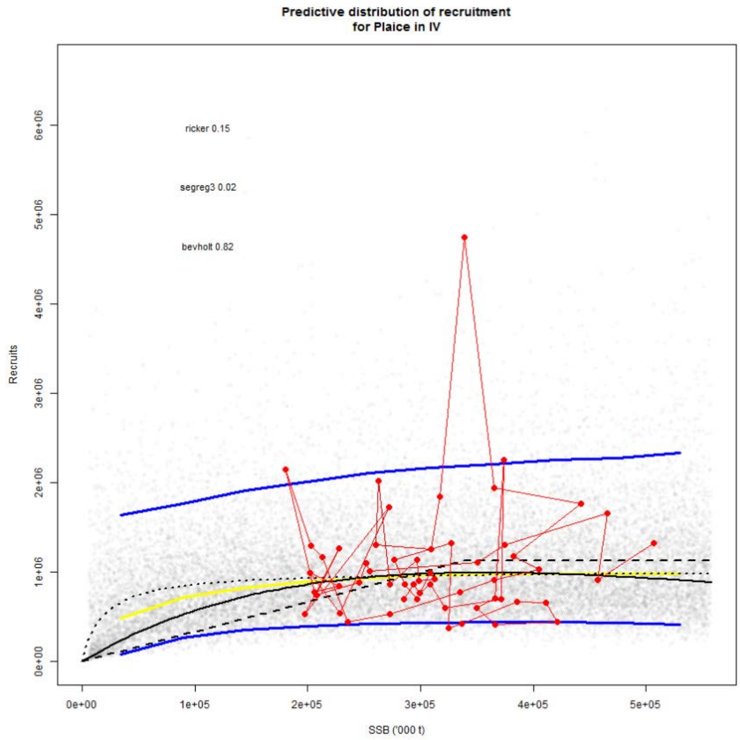

Figure 6.10.1. Eqsim.

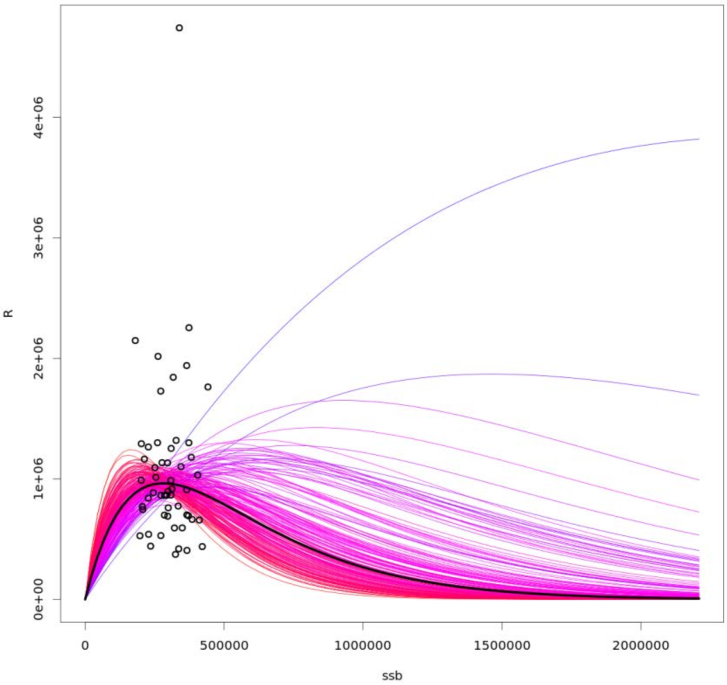

Figure 6.10.2. Cadigan.

6.10.6 Proposed reference points

The Eqsim method resulted in a well-defined dome shaped landing yield curve, slightly skewed to the left (Figure 6.10.3). The whole F_{MSY} range is lower than the F that leads to a 5% probability of SSB<B_{lim}. The reference point values for the Eqsim method are shown in Table 6.10.4.

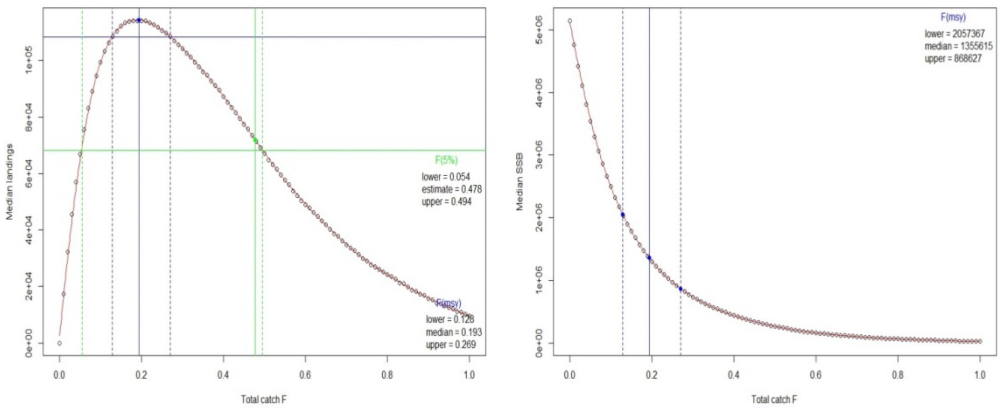

Figure 6.10.3. North Sea plaice, with fixed F exploitation from F = 0 to 1.0. Left panel: Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted). Right Panel: Median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

Table 6.10.4 Proposed Summary reference points (Eqsim)

STOCK	PLAICE IN SUBAREA IV (NORTH SEA)
Reference point	Value
F_{MSY} without $B_{trigger}$	0.19
F_{MSY} lower without $B_{trigger}$	0.13
F_{MSY} upper without $B_{trigger}$	0.27
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.48
F_{MSY} upper precautionary without $B_{trigger}$	0.27
F_{MSY} with $B_{trigger}$	0.19
F_{MSY} lower with $B_{trigger}$	0.13
F_{MSY} upper with $B_{trigger}$	0.27
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.56
F_{MSY} upper precautionary with $B_{trigger}$	0.27
MSY	114 413 t
Median SSB at F_{MSY}	1 355 615 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	868 627 t
Median SSB upper (median at F_{MSY} lower)	2 057 367 t

The Cadigan method resulted in more symmetrical dome shaped landing yield curve than the Eqsim method (Figure 6.10.2), shifted further to the right (higher F). This is not surprising given the more Ricker-like shape of the SRR curves and the rather strange fit of the Beverton and Holt in Eqsim, which seems to almost reach a saturation level at SSBs substantially lower than the lowest observed. The whole F_{MSY} range is lower than the F that leads to a 5% probability of SSB<B_{lim}. The reference point values for the Cadigan method are shown in Table 6.10.5.

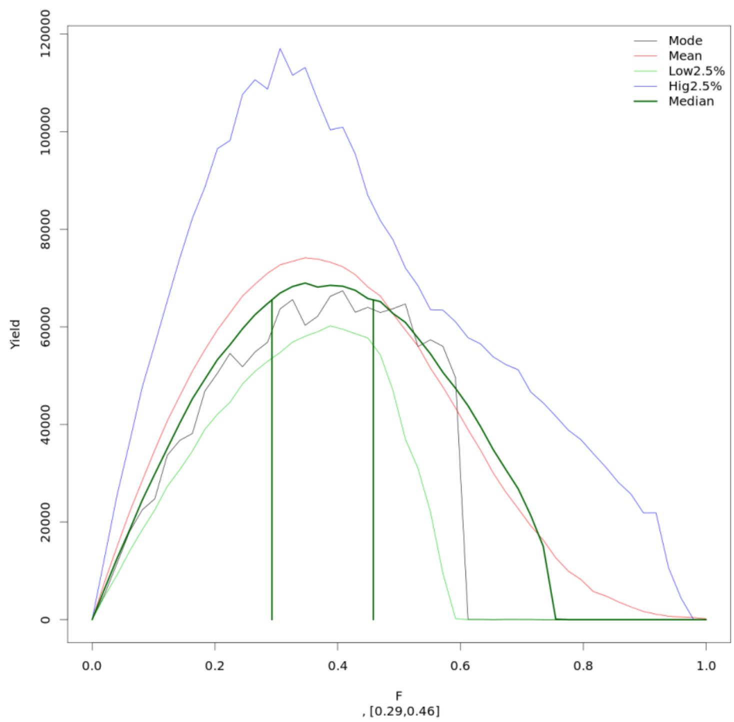

Figure 6.10.4.

Table 6.10.5. Results from the Cadigan method

STOCK	PLAICE IN SUBAREA IV (NORTH SEA)
Reference point	Value
F_{MSY} without $B_{trigger}$	0.37
F_{MSY} lower without $B_{trigger}$	0.29
F_{MSY} upper without $B_{trigger}$	0.46
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.53
F_{MSY} upper precautionary without $B_{trigger}$	0.46
F_{MSY} with $B_{trigger}$	N/A
F_{MSY} lower with $B_{trigger}$	N/A
F_{MSY} upper with $B_{trigger}$	N/A
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	N/A
MSY	73 521 t
Median SSB at F_{MSY}	466 248 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	376 084 t
Median SSB upper (median at F_{MSY} lower)	675 612 t

During WGNSSK 2014 the plotMSY software was used to estimate F_{MSY} values. Only Ricker and smooth hockeystick (segmented regression) fits were used (weighted 37% and 63%, respectively). The resultant median F_{MSY} estimate was 0.21. This lies near the middle of the Eqsim F_{MSY} range, but below the F_{MSY} range from the Cadigan method, presumably due to the inclusion of the hockey stick relationship in Eqsim.

6.10.7 Discussion / Sensitivity.

A sensitivity test was carried out using fewer years for average selectivity (5yrs vs 10yrs). This was done because there has been a significant shift in the gears used by the Dutch 80mm beamtrawl fleet in recent years. However, while this fleet is responsible for a significant proportion of the sole IV catches, it accounts for a substantially lower proportion of plaice IV catches. Hence, average selectivity over the last ten years for plaice is not notably different from average selectivity over the last 5 years. As a result the F_{MSY} range using a shorter selectivity period does not differ substantially from the range using the ten year selectivity period (0.13-0.28 (5yrs) vs 0.13-0.27 (10yrs)).

Another sensitivity test carried out was the exclusion of the first twenty yearclasses. These years have slightly lower than average recruitment leading to mostly negative residuals in the best stock recruitment fit. This also did not lead to a significantly different estimated F_{MSY} range (0.15 -0.29 (excluding early years) vs 0.13-0.27 (all years)). As there is no clear evidence to suggest that the plaice stock is currently in a different productivity regime, it was decided to proceed with the whole time series.

Ultimately the selection of the shape of the S-R relationship has a big effect on the resultant range of F_{MSY}.2 The two methods presented here result in very different F_{MSY} ranges, mainly due to the greater predicted reduction in recruitment at high SSB in the Cadigan method. The Cadigan method also results in an F_{MSY} range that is above the plotMSY point value estimate since the plotMSY method placed higher weighting on the segmented regression vs Ricker, leading to relatively less reduction in recruitment at higher SSB.

There is limited evidence for density dependent reduction in recruitment at high SSB for flatfish species. North Sea plaice is currently at the highest observed SSB, but there are no clear indications of reduced recruitment in recent years. In theory, the Cadigan non-parametric SR-relationship is a more objective way of allowing the data to determine the reduction in recruit per spawner with increasing biomass. However, in practice we have limited plaice data for the high SSB ranges associated with the equilibrium biomass along the F_{MSY} range. Therefore including a Beverton-Holt or segmented regression type curve (i.e. asymptotic maximum recruitment not declining with increasing SSB) is a possibility to control the expected recruitment at high, unobserved biomass. As the Eqsim method provides necessary estimates of precautionarity and includes implementation error, these values are given in the overall summary tables below (Section 10).

6.11 Plaice in Div. VIId

6.11.1 Source of data

All data used came from the WGNSSK 2014 final assessment (ICES, 2014b).

6.11.2 Methods used

Eqsim with additional WKMSYREF3 code to produce median yield and F estimates (see methods section 4.1)

6.11.3 Current reference points

Table 6.11.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.27	Proxy based on F_{MSY}, relative to the average time series in 2014. F_{MSY} Computed with Eqsim based on the current assessment and the Hockey stick relationship.
Current B_{lim}	Not defined	
Current Bpa	Not defined	
Current $MSYB_{trigger}$	Not defined	

6.11.4 Settings

Table 6.11.2 Model and data selection settings

Data and parameters	Setting	Comments
S/R - Relationship	Segmented regression	Breakpoint 3973 t
SSB-recruitment data	Year classes 1980-2013	
B_{lim} suggestion	3 973 t	Hovkey stick breakpoint
Exclusion of extreme values for (option extreme.trim)	No trimming	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	

Assessment error in the advisory year. CV of F	0.25
Autocorrelation in assessment error in the advisory year	0.30

6.11.5 Results

6.11.5.1 Stock recruitment relation

The full available time period (1980-2013) was used for stock-recruit modelling.

The stock recruitment fit, using the three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method, did not result in any weight to the Beverton & Holst model (flat line). The Ricker model and the segmented regression model obtained 33% and 67% of the weighting, respectively (Figure 6.11.1). The Workshop followed the more conservative approach taken by the WGNSSK (2014) to use the segmented regression model with a B_{lim} of 3973 t and a breaking point at 3973 t (Figure 6.11.2) for calculating F_{MSY} and F_{MSY} F-ranges.

The assessment error in the advisory year was set to 0.25 (Fcv) and the autocorrelation in assessment error in the advisory year was set to 0.30 (Fphi).

6.11.5.2 Eqsim scenarios

There were no extreme values excluded from the simulations (No Trim) and no $B_{trigger}$ was assumed. The year range assumed for both selectivity and biological parameters were set for 2004-2013 as no apparent trend were seen over this period for selectivity and stock/catch weights.

6.11.6 Proposed reference points

The segmented regression model with a B_{lim} of 3973 t and a breaking point at 3973 t was used (no trim, no $B_{trigger}$, not excluding years).The Eqsim summary plots for Plaice VIId are presented in Figure 6.11.3. The estimated yield curve for Plaice VIId is presented in Figure 6.11.4. Median SSB for Plaice VIId over a range of target F values are presented in Figure 6.11.5.

Table 6.11 3 Summary table of proposed stock reference points from Eqsim

STOCK – PLAICE VIID	
Reference point	Value
F_{MSY}	0.25
F_{MSY} lower	0.15
F_{MSY} upper	0.43
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.49
F_{MSY} upper precautionary with note of whether conditional	0.43
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	NA
MSY	5 102 t
Median SSB at F_{MSY}	18 452 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	8 887 t
Median SSB upper (median at F_{MSY} lower)	32 566 t

6.11.7 Discussion / Sensitivity.

Although the basic decisions and model settings at WKMSYREF3 are the same as proposed by WGNSSK in May 2014, a comparison with the F_{MSY} estimates provided at WGNSSK 2014 is not relevant as they have been calculated incorrectly at WGNSSK 2014 The revised values given here have been used to issue corrected advice for the stock.

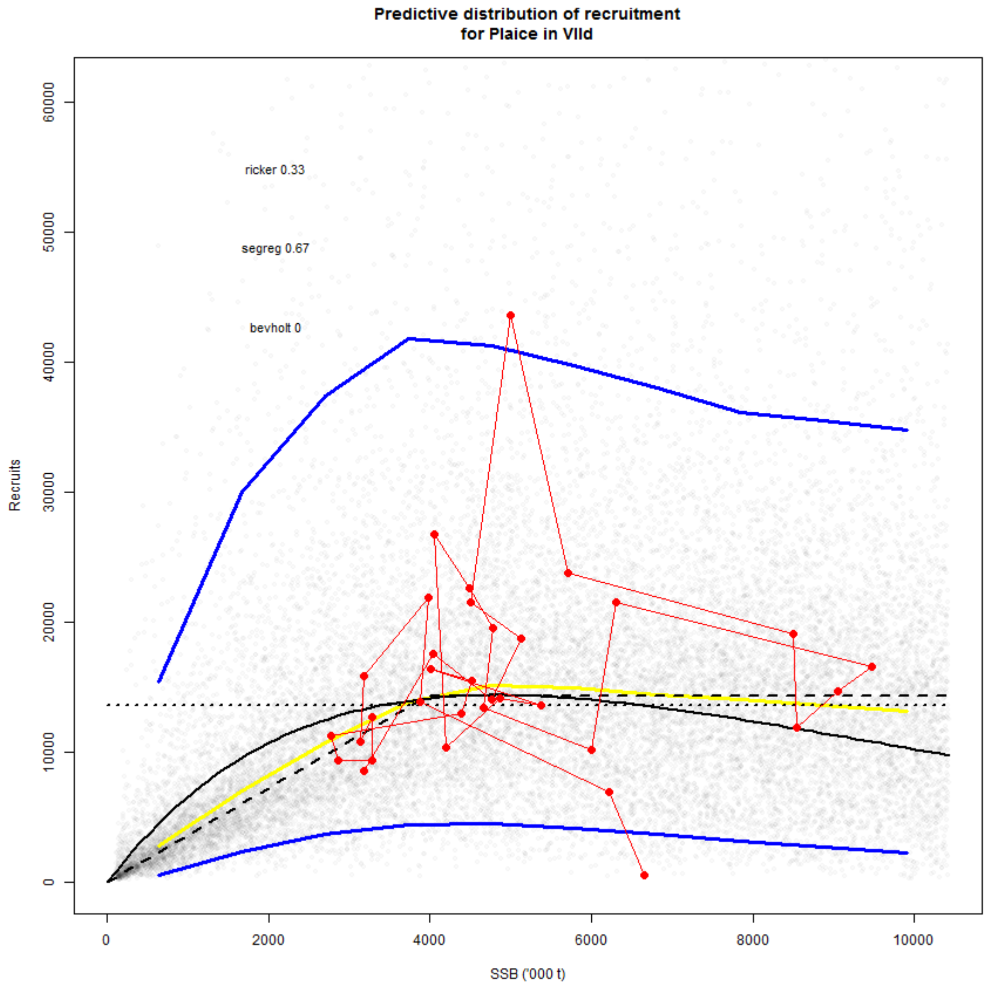

Figure 6.11.1. Eqsim summary of recruitment models using the default "Buckland" method (Ricker, Beverton & Holt) for Plaice VIId.

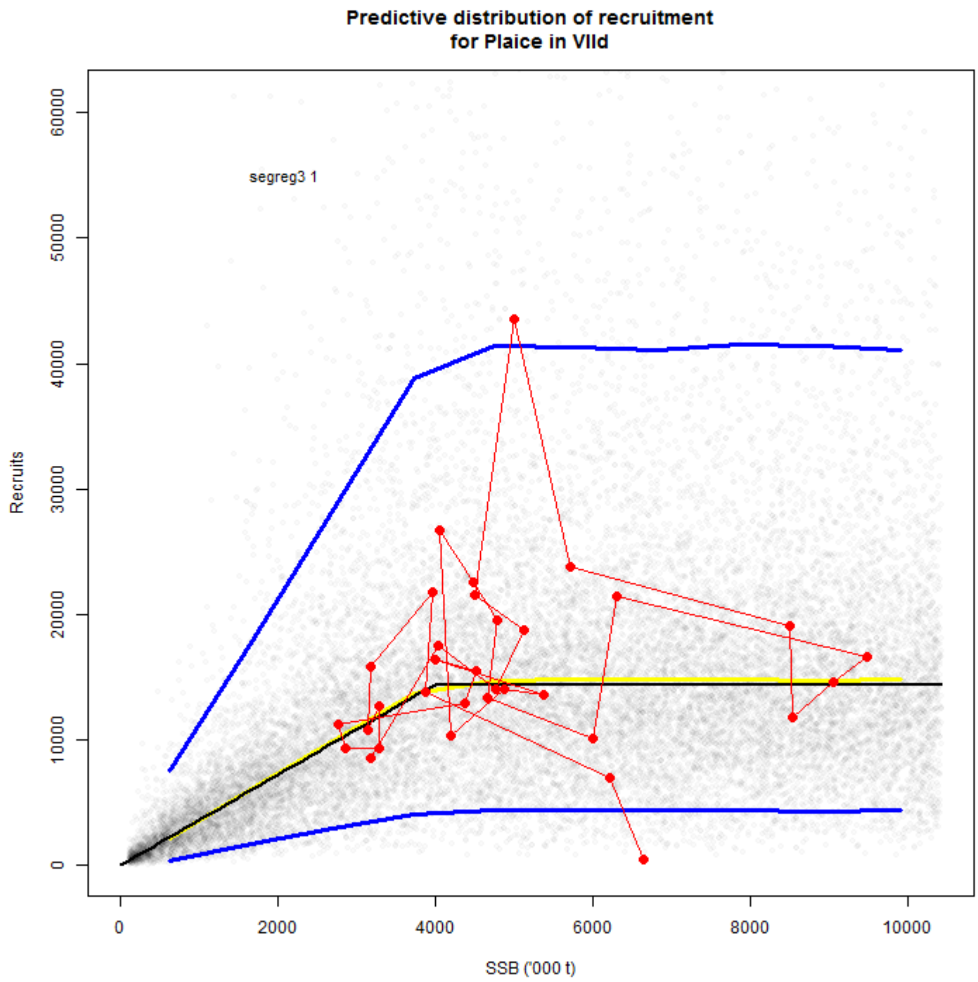

Figure 6.11.2. Eqsim summary of recruitment model (segmented regression) for Plaice VIId (used for analysis).

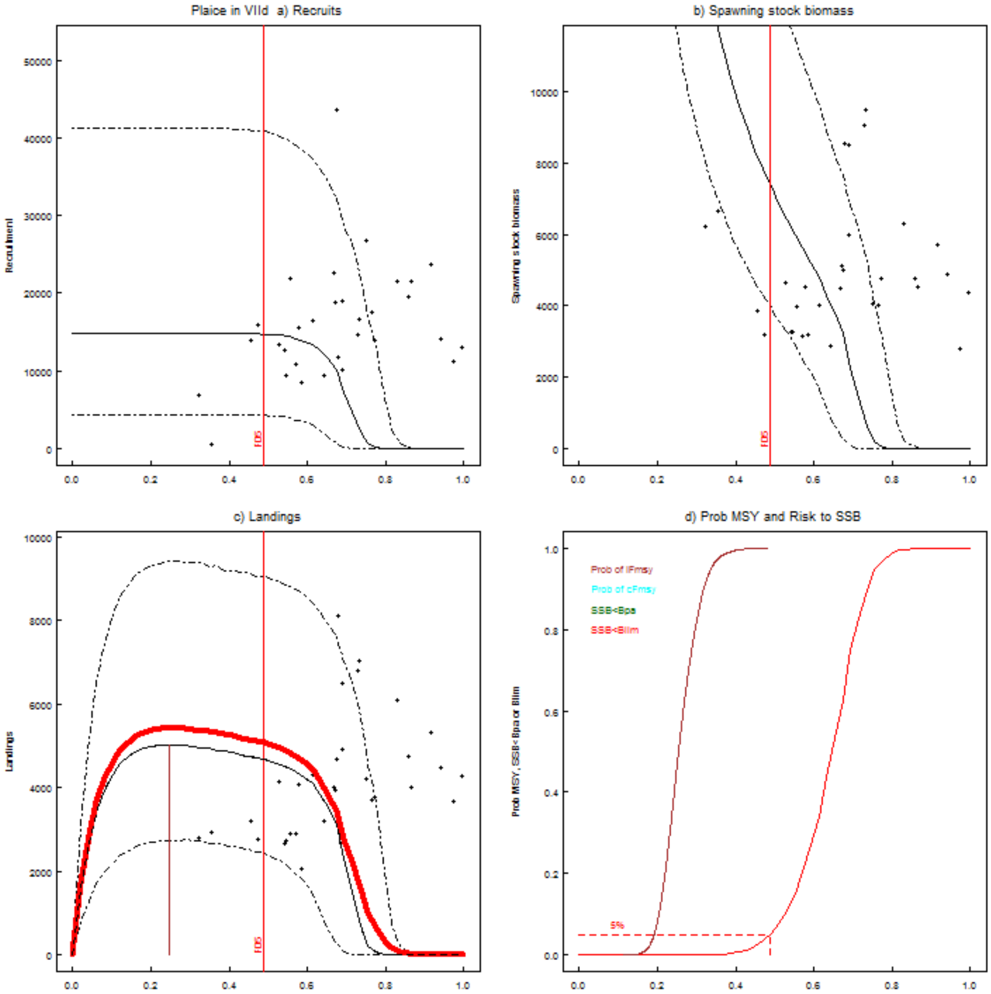

Figure 6.11.3. Eqsim summary plot for Plaice VIId (no trim, no $B_{trigger}$, no excluding years).

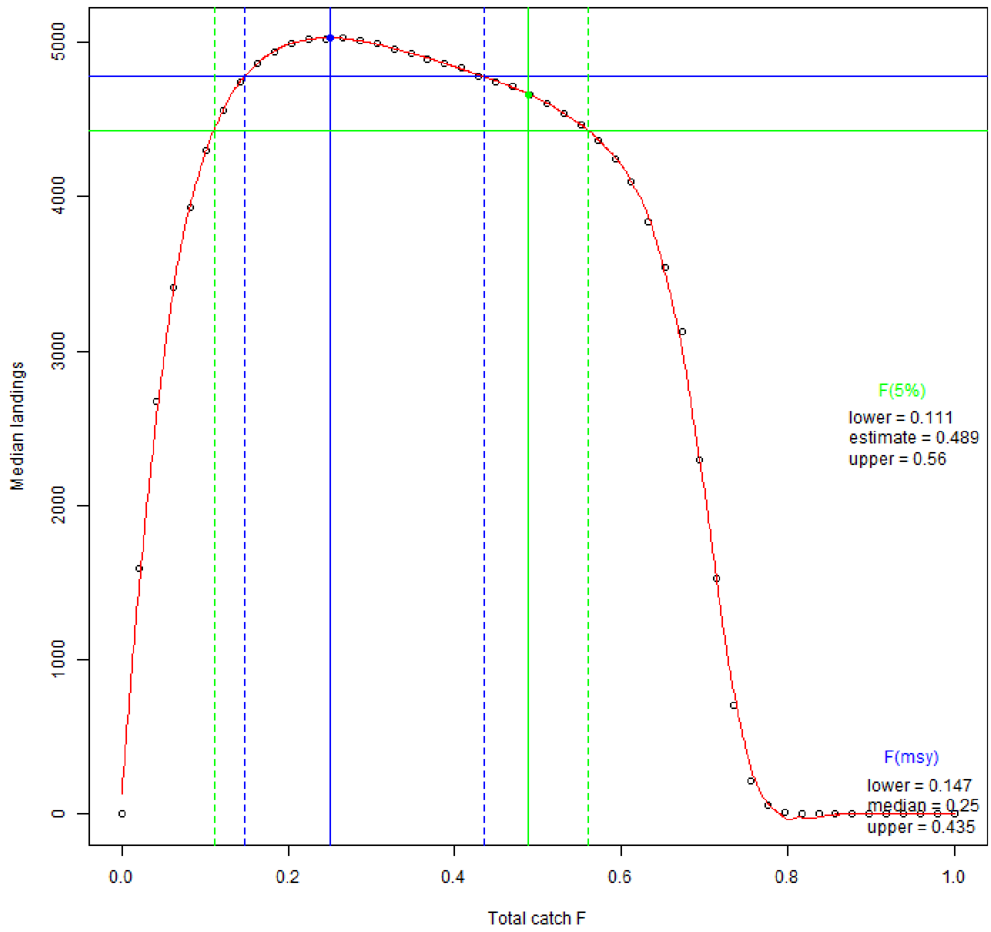

Figure 6.11.4. Plaice in Div. VIId Eqsim median landings yield curve with estimated reference points. Blue lines: F(MSY) estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted). The Total catch F is an F landings for ages 3-6.

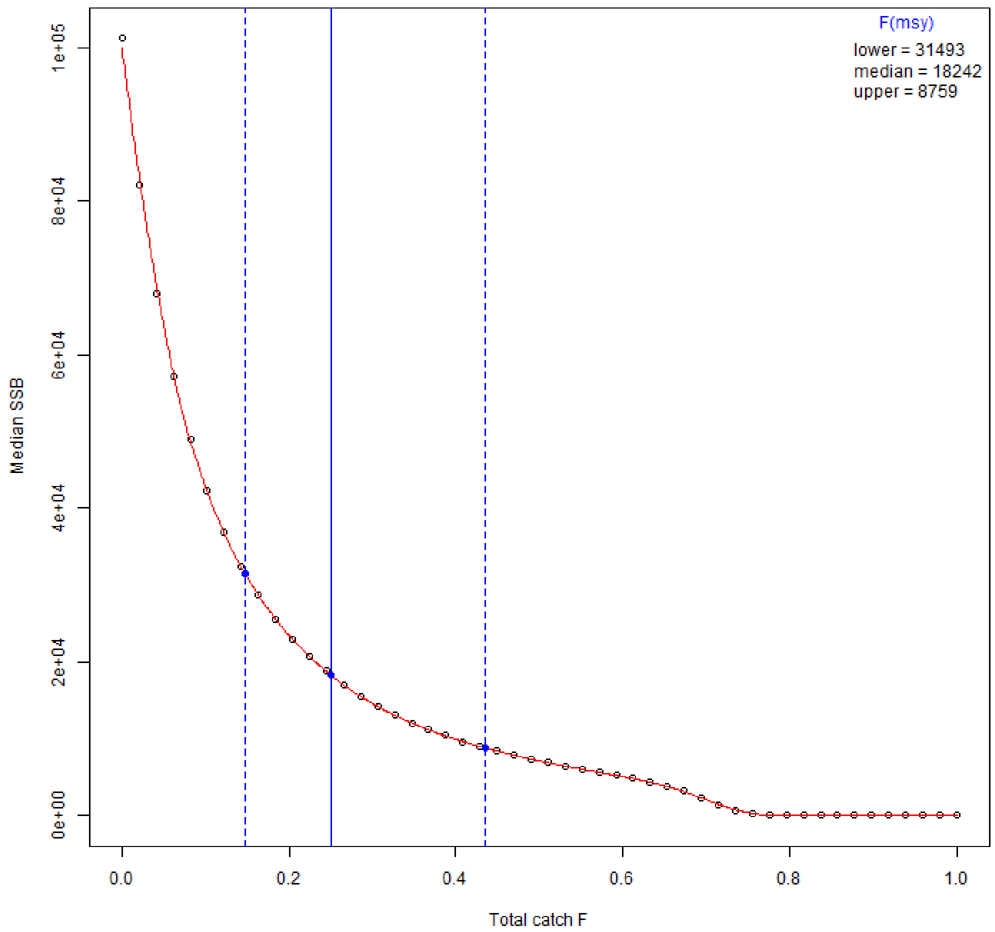

Figure 6.11.5. Plaice in Div. VIId Eqsim median SSB for Plaice VIId over a range of target F values. Blue lines show location of F(MSY) (solid) with 95% yield range (dotted). The Total catch F is an F landings for ages 3-6.

6.12 Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)

6.12.1 Current reference points

Table 6.12.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.3	Stochastic simulation using hockey-stick stock–recruitment.
Current B_{lim}	106 000 t	Bloss = 106 000 t (estimated in 1998).
Current Bpa	200 000 t	Affords a high probability of maintaining SSB above B_{lim}.
Current $MSYB_{trigger}$	200 000 t	Default value B_{pa}

6.12.2 Source of data

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

6.12.3 Methods used

All analyses were conducted with Eqsim. The Assessment error in the advisory year and the autocorrelation was derived by comparing F values from the latest assessment with forecasted F values in year -1 (Table 6.12.2):

Table 6.12.2 Assessment error in the advisory year and the autocorrelation derived by comparing F values from the latest assessment with forecasted F values in year -1

Year	F Assess	F set in forecast	ln(Fass)	ln(Fset)	Deviations		
2013	0.301	0.203	-1.20065	-1.59455	0.3939043		
2012	0.326	0.27	-1.12086	-1.30933	0.1884754		
2011	0.315	0.28	-1.15518	-1.27297	0.117783		
2010	0.319	0.29	-1.14256	-1.23787	0.0953102		
2009	0.413	0.25	-0.88431	-1.38629	0.5019867		
2008	0.358	0.22	-1.02722	-1.51413	0.4869054		
2007	0.256	0.21	-1.36258	-1.56065	0.1980699		
2006	0.269	0.36	-1.31304	-1.02165	-0.2913927	STD	0.26879
2005	0.252	0.32	-1.37833	-1.13943	-0.2388919	Fcv	0.243505
2004	0.193	0.16	-1.64507	-1.83258	0.1875164	Phi	0.423425

6.12.4 Settings

Table 6.12.3 Model and data selection settings

Data and parameters	Setting	Comments
Recruitment models chosen	Segmented regression and Ricker	Beverton-Holt SRR gave a straight horizontal line without a decrease near the origin what is not realistic
SSB-recruitment data	Full data series (year classes 1967 to 2010)	R per SSB shows signs of cyclic changes in productivity over time. Whether the current low productivity of the stock can be explained by cyclic changes or whether the stock is in a new productivity regime remains unclear (see also section sensitivity/discussion).
Exclusion of extreme values (option extreme.trim)	No	
Mean weights and proportion mature	Default (2004-2013)	During the last ten years mean weight at age was noisy without trend or declined and increased again in recent years for some ages.

Exploitation pattern	Default (2004-2013)	Exploitation pattern noisy without clear trends. Selectivity for age 4 increased in the last 2 years. Based on only 2 years it is not possible to judge whether this is a longer-lasting change in the fishery.
Assessment error in the advisory year. CV of F	0.24	Estimated by comparing F values from the latest assessment with forecasted F values in year -1
Autocorrelation in assessment error in the advisory year	0.42	Estimated by comparing F values from the latest assessment with forecasted F values in year -1

6.12.5 Results

6.12.5.1 Stock recruitment relation

The interval analysis was based on a segmented regression and the Ricker SRR (Figure 6.12.1). The Beverton-Holt SRR gave a straight horizontal line without a decrease in recruitment near the origin and was not considered realistic. The Ricker was included based on the general guideline that this type of SRR gets included in the analysis if the point of inflexion is inside the observed range of SSB and no objective criteria exists to completely ignore this type of SRR. The segmented regression got a weight of 87% and the Ricker SRR a weight of 13% in the analysis.

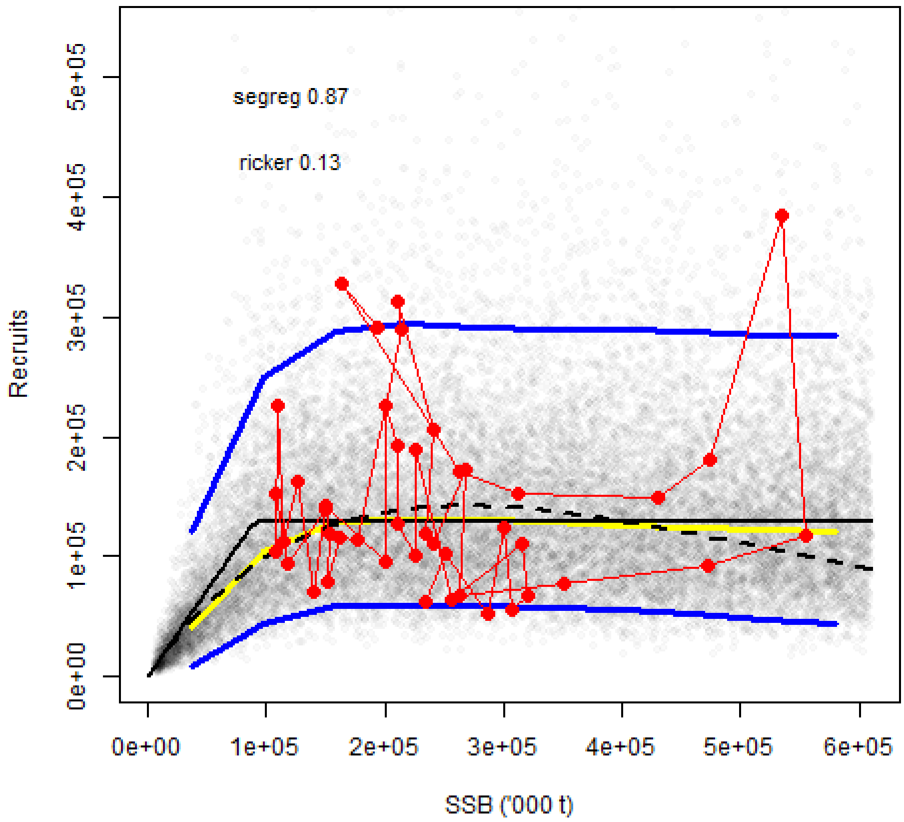

Figure 6.12.1: Stock recruitment relationships used in the interval analysis.

6.12.5.2 Eqsim analysis

The median F_{MSY} estimated by Eqsim applying a fixed F harvest strategy was 0.32 (Figure 6.12.2). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.43 and the lower bound at 0.20. Because $F_{P.05}$ was estimated at 0.39, the upper bound was restricted to 0.39 because of precautionary limits. The median of the SSB estimates at F_{MSY} was 259 062 t (Figure 6.12.3) and hence inside the range of observed SSBs in the last 10 years. Median SSB at the lower bound of the F_{MSY} range was 438 049 t and 200 400 t at the upper precautionary bound (F=0.39)

When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 200 000 t tonnes, median F_{MSY} increased to 0.37 with a lower bound of the range at 0.21 and an upper bound at 0.57 (Figure 6.12.4). The $F_{P.05}$ value also increased to 0.57 and therefore no restriction of the F_{MSY} range is needed in this case. Median SSB values are lower than under the constant F scenario because of the higher F_{MSY} values (Figure 6.12.5). Fishing with F= 0.57 above $B_{trigger}$ leads to an equilibrium SSB of 159 777 t which is below the current B_{pa}.

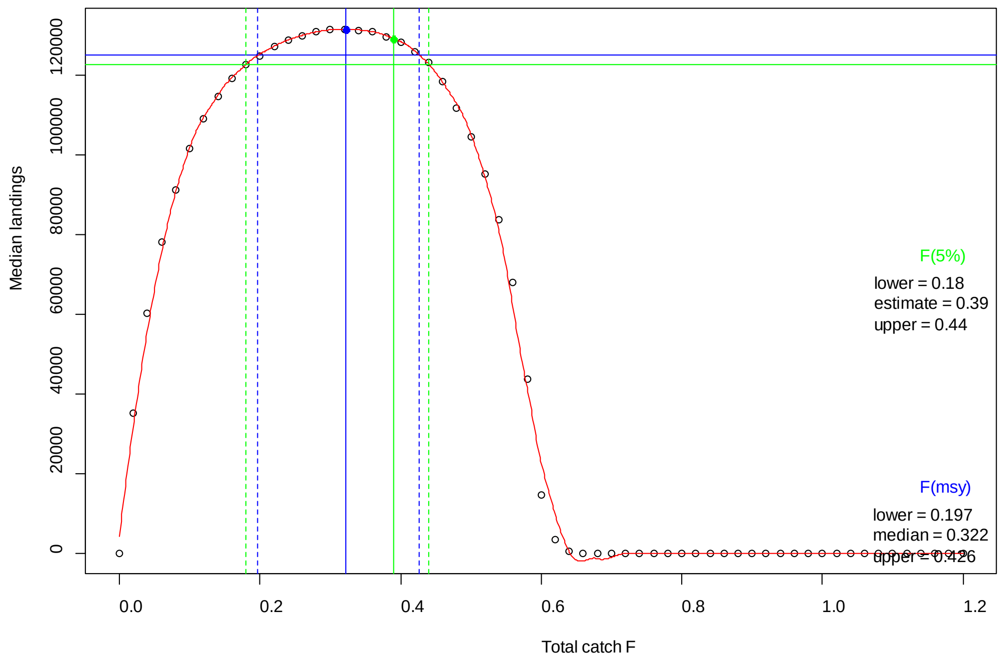

Figure 6.12.2: Saithe, with fixed F exploitation from F = 0 to 1.0. Left panel: Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

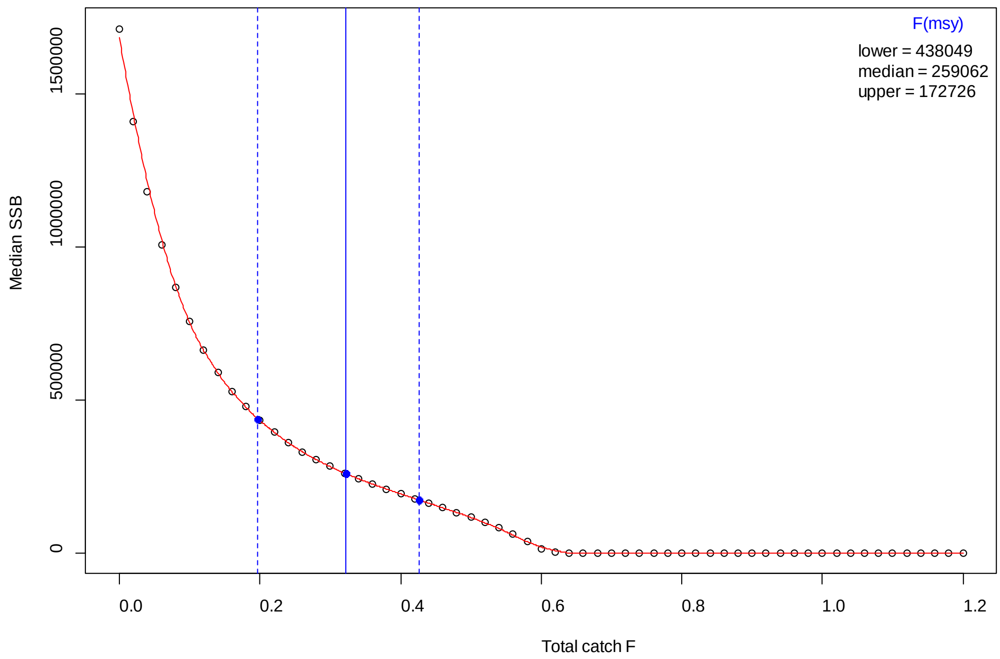

Figure 6.12.3: Saithe (fixed F exploitation): median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

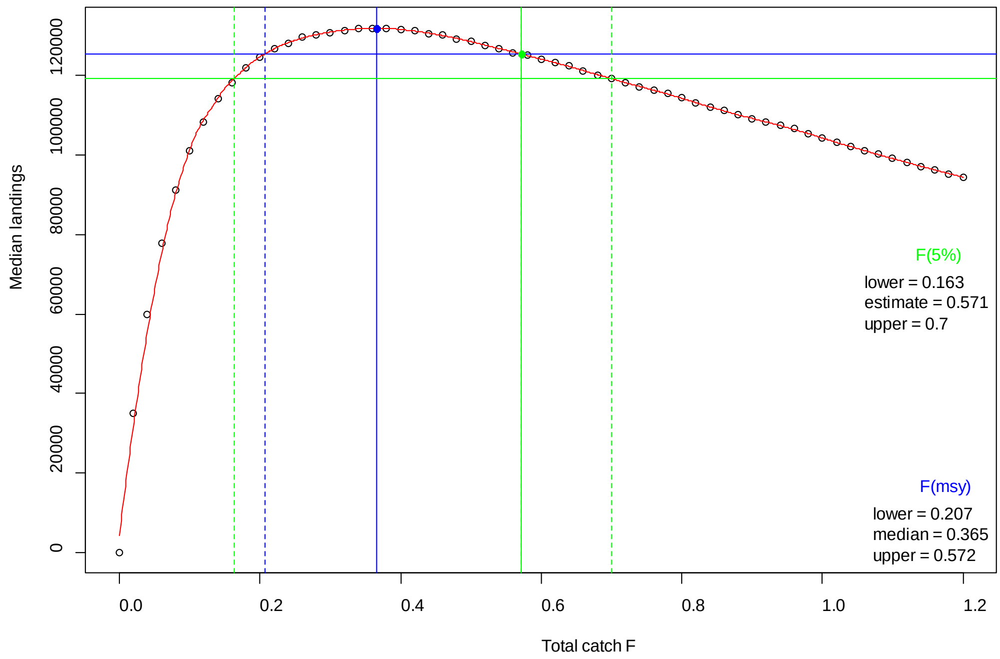

Figure 6.12.4: Saithe when applying the ICES MSY harvest control rule with a $B_{trigger}$ at 200000 tonnes. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

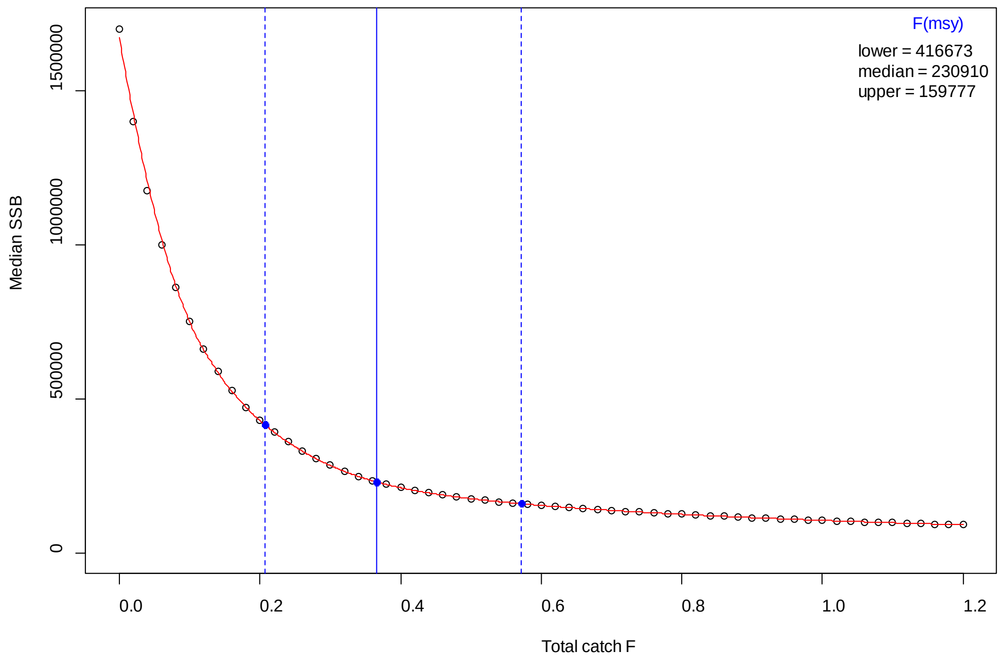

Figure 6.12.5: Saithe when applying the ICES MSY harvest control rule with $B_{trigger}$ at 200 000 t. Median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

6.12.6 Proposed reference points

Type of yield curve: Un-skewed maximum curve under fixed F harvest strategy, skewed to the right when applying the ICES MSY HCR.

Table 6.12.4 Summary table of proposed stock reference points from Eqsim

Stock Saithe in IV, IIIaN and VIa	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.32
F_{MSY} lower without $B_{trigger}$	0.20
F_{MSY} upper without $B_{trigger}$	0.43
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.39
F_{MSY} upper precautionary without $B_{trigger}$	0.39
F_{MSY} with $B_{trigger}$	0.37
F_{MSY} lower with $B_{trigger}$	0.21
F_{MSY} upper with $B_{trigger}$	0.57
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.57
F_{MSY} upper precautionary with $B_{trigger}$ at 200 000 t	0.57
MSY (no $B_{trigger}$)	128 899 t
Median SSB at F_{MSY} (no $B_{trigger}$)	259 062 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary; no $B_{trigger}$)	200 400 t
Median SSB upper (median at F_{MSY} lower; no $B_{trigger}$)	438 049 t

6.12.7 Discussion / Sensitivity.

6.12.7.1 Sensitivity towards assumptions on future recruitment

Recruitment per SSB shows signs of a cyclic trend over time. However, it is unclear whether the low productivity observed in recent years is part of cyclic changes or whether the stock has entered a new productivity regime (Figure 6.12.6). In order to test the effect of a pessimistic assumption on future recruitment, a segmented regression was fitted with a known breakpoint for the year classes 2003 to 2010 only (Figure 6.12.7). The breakpoint was assumed to be the same as the breakpoint observed in the segmented regression fitted to the full time series. The Eqsim analysis was carried out with the same setting as before apart from the SR-relationship.

In this pessimistic scenario the median F_{MSY} estimated by Eqsim when applying a fixed F harvest strategy was 0.29 (Figure 6.12.8). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.38 and the lower bound at 0.17. Because $F_{P.05}$ was estimated at 0.28, the upper bound needs to be restricted to 0.28 because of precautionary limits under a fixed F harvest strategy. It has to be noted that the median equilibrium SSB at F_{MSY} was 160 381 t and therefore below the current B_{pa} in this scenario.

When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 200 000 t (similar to the HCR currently used in the EU-Norway management plan), median F_{MSY} increased to 0.36 with a lower bound of the range at 0.19 and an upper bound at 0.92 (Figure 6.12.8). The $F_{P.05}$ value increased to 0.48. Therefore, fishing mortalities up to 0.48 can be regarded as precautionary even under this pessimistic scenario as long as a decrease in F when the stock falls below $B_{trigger}$ is ensured. Even with a harvest control rule, median equilibrium SSB is estimated below B_{pa} when fishing at the median F_{MSY} value.

6.12.7.2 Sensitivity towards the choice of the year range for biological parameters and exploitation pattern

Although there are no clear trends in exploitation pattern (Figure 6.12.9) and mean weight at age (Figure 6.12.10) over the last 10 years, a sensitivity analysis was run based on the full recruitment time series but with only the last 5 years as input for biological parameters and exploitation pattern instead of the default 10 years.

In this scenario the median F_{MSY} estimated by Eqsim when applying a fixed F harvest strategy was 0.33 and therefore very close to the estimate of the reference run (Figure 6.12.8). The upper bound of the F_{MSY} range giving at least 95% of the maximum yield was estimated at 0.44 and the lower bound at 0.19. Because $F_{P.05}$ was estimated at 0.41, the upper bound is restricted to 0.41 because of precautionary limits under this scenario.

When applying the ICES MSY harvest control rule with a $B_{trigger}$ at 200 000 t (similar to the HCR currently used in the EU-Norway management plan), median F_{MSY} increased to 0.38 with a lower bound of the range at 0.20 and an upper bound at 0.6 (Figure 6.12.8). The $F_{P.05}$ value increased to 0.62 and no restriction because of precautionary limits would be needed.

6.12.8 Conclusions

Especially the upper bound of a precautionary F range is sensitive towards the assumption on the future productivity of the stock. If it is assumed that stock productivity is low in the coming years, the precautionary upper bound of a possible F_{MSY} range needs to be adjusted downwards towards 0.28 if a fixed F harvest control rule is applied.

Under the ICES MSY HCR, F values up to 0.48 meet the criterion of a >95% probability to stay above B_{lim} even under a pessimistic assumption for future recruitment. It has to be noted that there is a high probability that the stock will fall below B_{pa} even when fished at relatively low fishing mortalities under a low productivity regime. The change in the year range for biological parameters and the exploitation pattern from 10 to 5 years had no large implications. Median F_{MSY} was estimated to be slightly higher as well as the upper bound. Overall, this analysis should be repeated if or when sufficient evidence for a regime shift in productivity, the exploitation pattern or mean weight at age is available.

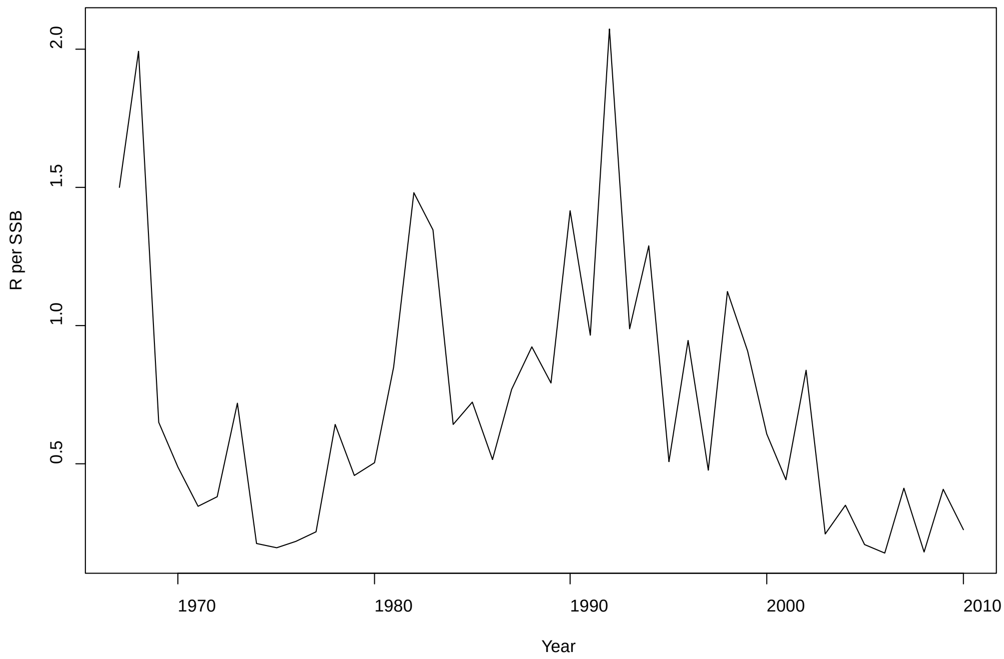

Figure 6.12.6. Recruitment divided by SSB over time.

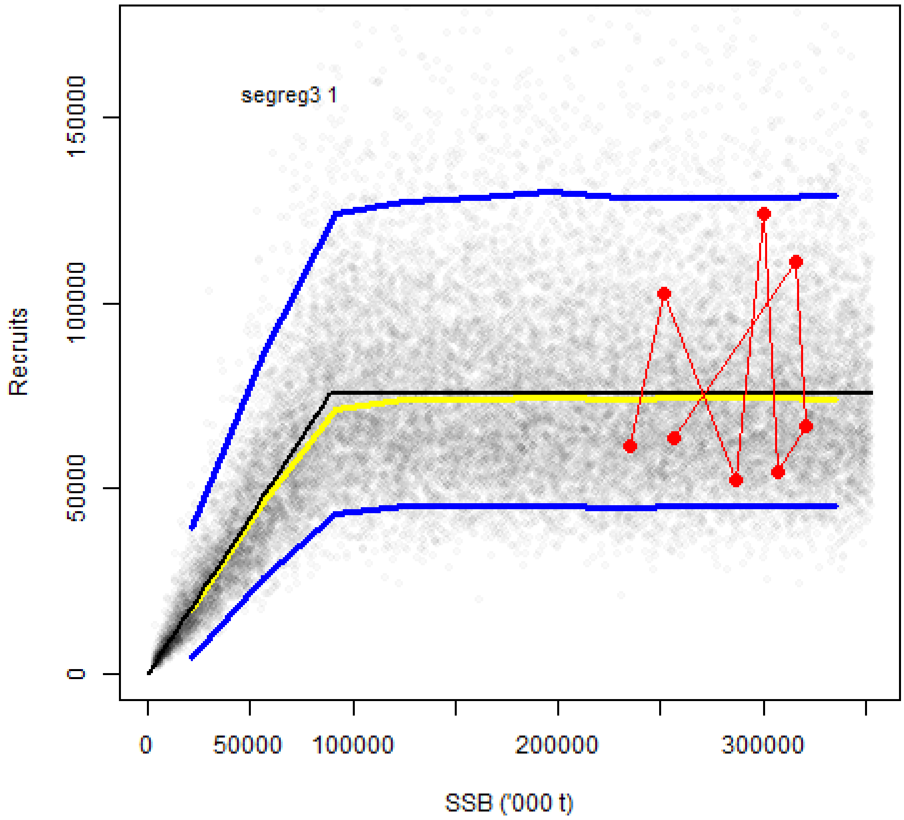

Figure 6.12.7. Stock recruitment relationship fitted for year classes 2003 to 2010 only.

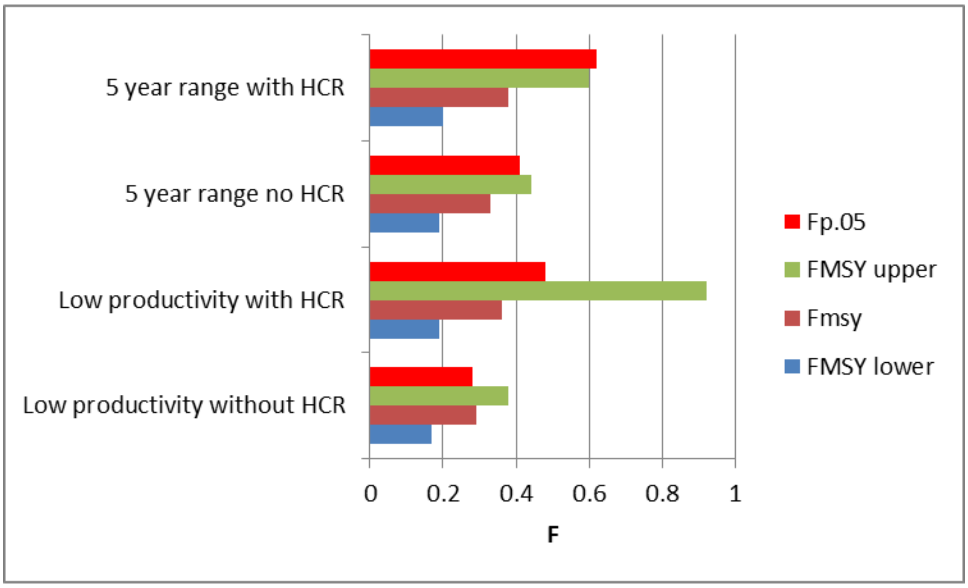

Figure 6.12.8. Results from the Eqsim analyses for the four sensitivity analyses carried out.

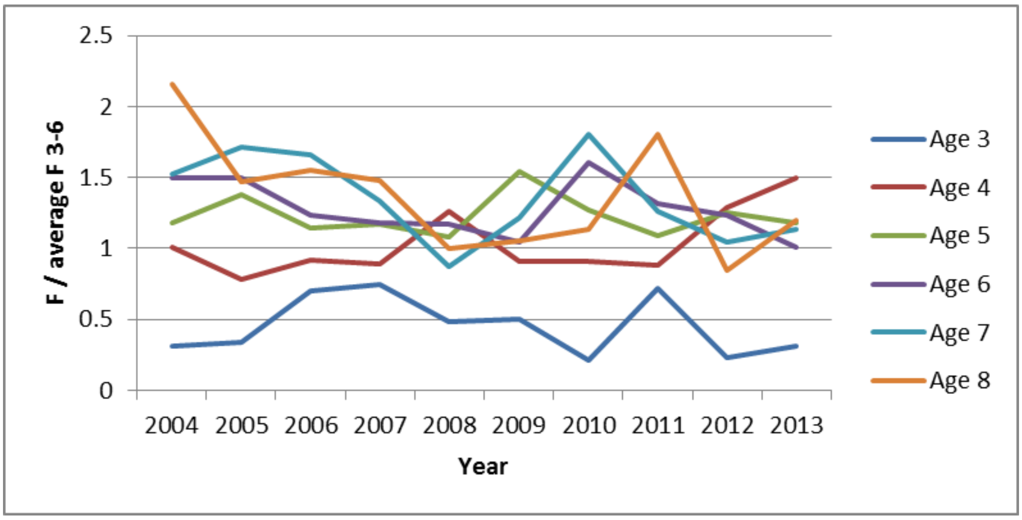

Figure 6.12.9. Exploitation pattern saithe in IV, IIIaN and VIa.

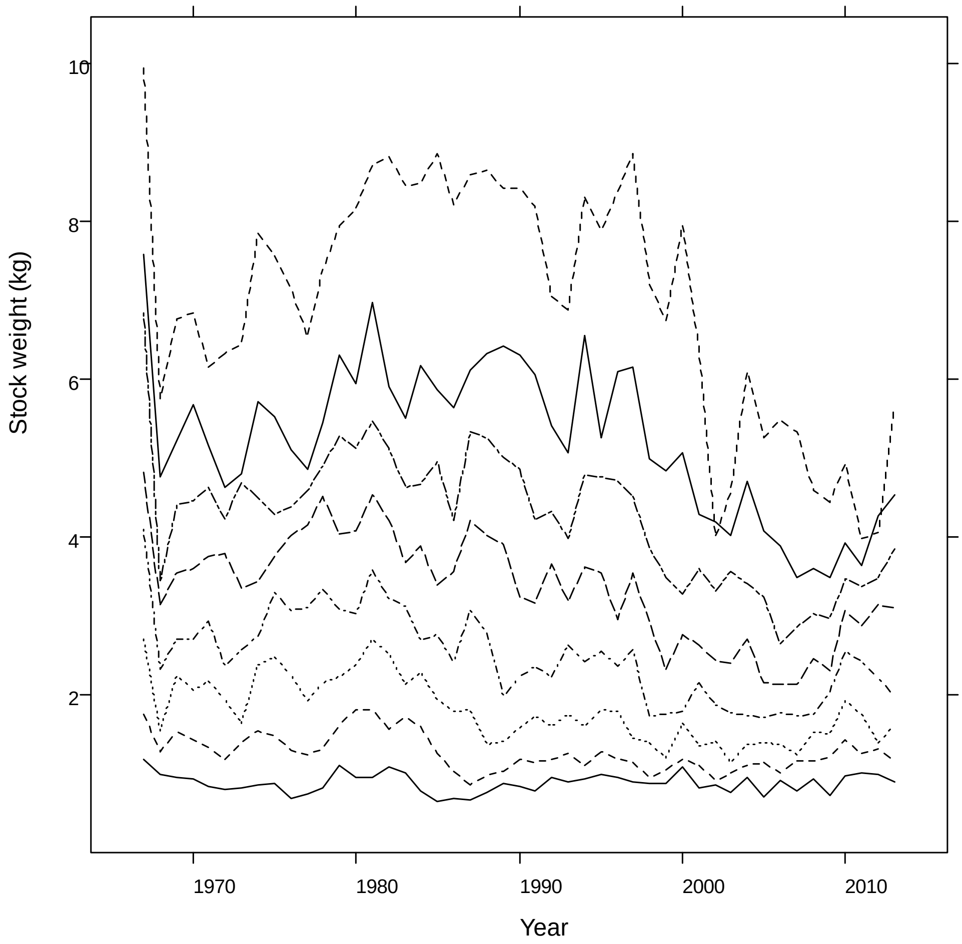

Figure 6.12.10. Weight at age in the stock (=weight at age in the catch) over time.

6.13 Sprat in Subdivisions 22–32 (Baltic Sea)

6.13.1 Current reference points

Table 6.13.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current F_{MSY}	0.29	Stochastic single species simulations, including S–R relationship
Current B_{lim}	410 000 t	S–R relationship (biomass which produces half of maximal recruitment in a B&H model).
Current Bpa	570 000 t	B_{lim} × 1.4.
Current $MSYB_{trigger}$	570 000 t	Bpa

6.13.2 Source of data

The analysis in this report uses the newest (1974-2013) assessment results from the XSA assessment (ICES 2014f).

6.13.3 Methods used

Eqsim and method developed by Hobowy and Luzenczyk were used for this stock.

6.13.4 Settings

Table 6.13.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	1974-2013	
Exclusion of extreme values (option extreme.trim)	Not used	
Mean weights and proportion mature	2004-2013	
Exploitation pattern	2004-2013	
Settings for EquiSim Assessment error in the advisory year. CV of F	0.25	
Autocorrelation in assessment error in the advisory year	0.30	

The presently defined biomass reference points were used for precautionary considerations in Eqsim.

6.13.5 Results

6.13.5.1 Stock recruitment relation

In the case of Eqsim, the stock recruitment data were fit using three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method available in Eqsim (Figure 6.13.1). The stock recruitment relation used in the method developed by Hobowy and Luzenczyk were fit using two models (Ricker and B&H) weighted by inverse variance.

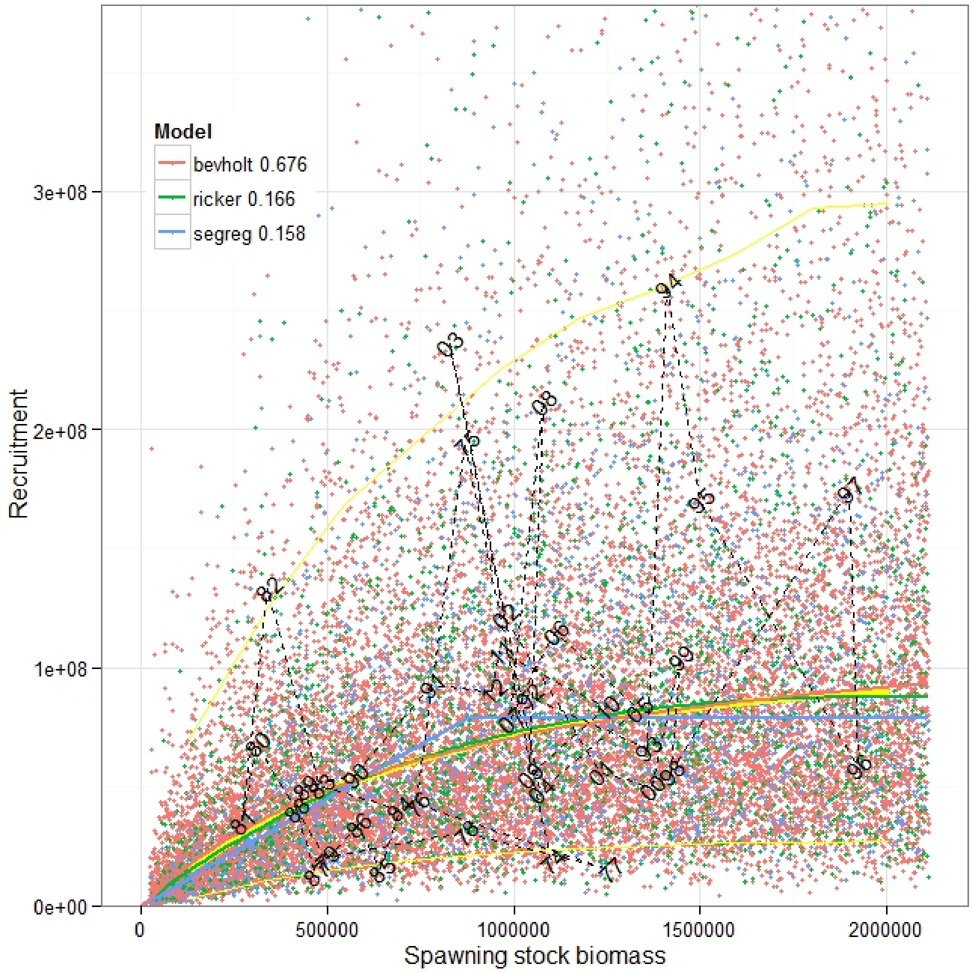

Figure 6.13.1. Stock recruitment relationship, Sprat in Subdivisions 22–32, based on segmented regression (blue) Beverton Holt (red) and Ricker (green) models. Simulated values (red dots) median (yellow line) and S-R pairs by year (numbers and black lines)

6.13.6 Proposed reference points

The results of Eqsim simulations run with and without $MSYB_{trigger}$ are shown in Figures 6.13.2 and 6.13.3 respectively. The reference points from the Eqsim and Hobowy and Luzenczyk analyses are given in the two text table below.

Table 6.13.3 Summary table of proposed stock reference points Eqsim

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.19
F_{MSY} lower without $B_{trigger}$	0.14
F_{MSY} upper without $B_{trigger}$	0.24
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.15
F_{MSY} upper precautionary without $B_{trigger}$	0.15
F_{MSY} with $B_{trigger}$	0.23
F_{MSY} lower with $B_{trigger}$	0.16
F_{MSY} upper with $B_{trigger}$	0.33

FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.19
F_{MSY} upper precautionary with $B_{trigger}$	0.19
MSY	184 000 t
Median SSB at F_{MSY}	921 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	711 000 t
Median SSB upper (median at F_{MSY} lower)	1 161 000 t

Table 6.13.4 Summary table of proposed stock reference points from method developed by Hobowy and Luzenczyk

STOCK	
Reference point	Value
F_{MSY} without $B_{trigger}$	0.26
F_{MSY} lower without $B_{trigger}$	0.19
F_{MSY} upper without $B_{trigger}$	0.34
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	NA
F_{MSY} upper precautionary without $B_{trigger}$	NA
F_{MSY} with $B_{trigger}$	NA
F_{MSY} lower with $B_{trigger}$	NA
F_{MSY} upper with $B_{trigger}$	NA
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	NA
F_{MSY} upper precautionary with $B_{trigger}$	NA
MSY	153 000 t
Median SSB at F_{MSY}	649 000 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	481 000 t
Median SSB upper (median at F_{MSY} lower)	831 000 t

6.13.7 Discussion / Sensitivity.

The reason for the lower F_{MSY} is linked to the shape of the SR curves, which present a rather low steepness for all models fitted. When assuming a regime shift in 1992 and running the model with a shorter time series, the model is not able to fit the Beverton and Holt model. Therefore, we fit the stock recruitment using only a Ricker and a segmented regression using only data from 1992 to 2013. The estimated values of MSY were still $_{lim}$ited by precautionary considerations (i.e. Fp05 = 0.27 and 0.21, with and without $B_{trigger}$, respectively). Thus, WGBFAS in the future should explore which is the appropriate length of the time series to be used in the simulations.

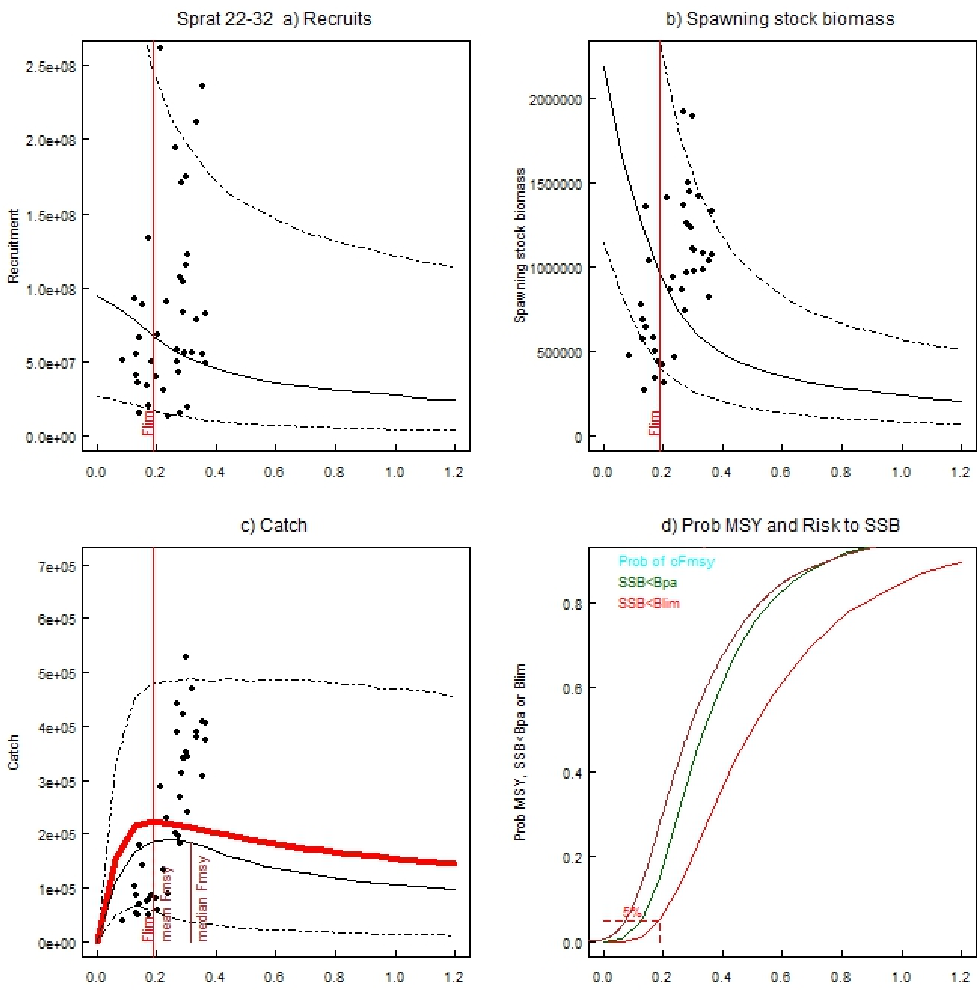

Figure 6.13.3. Eqsim results applying the standard regression method for Sprat in Subdivisions 22–32 with $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean 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).

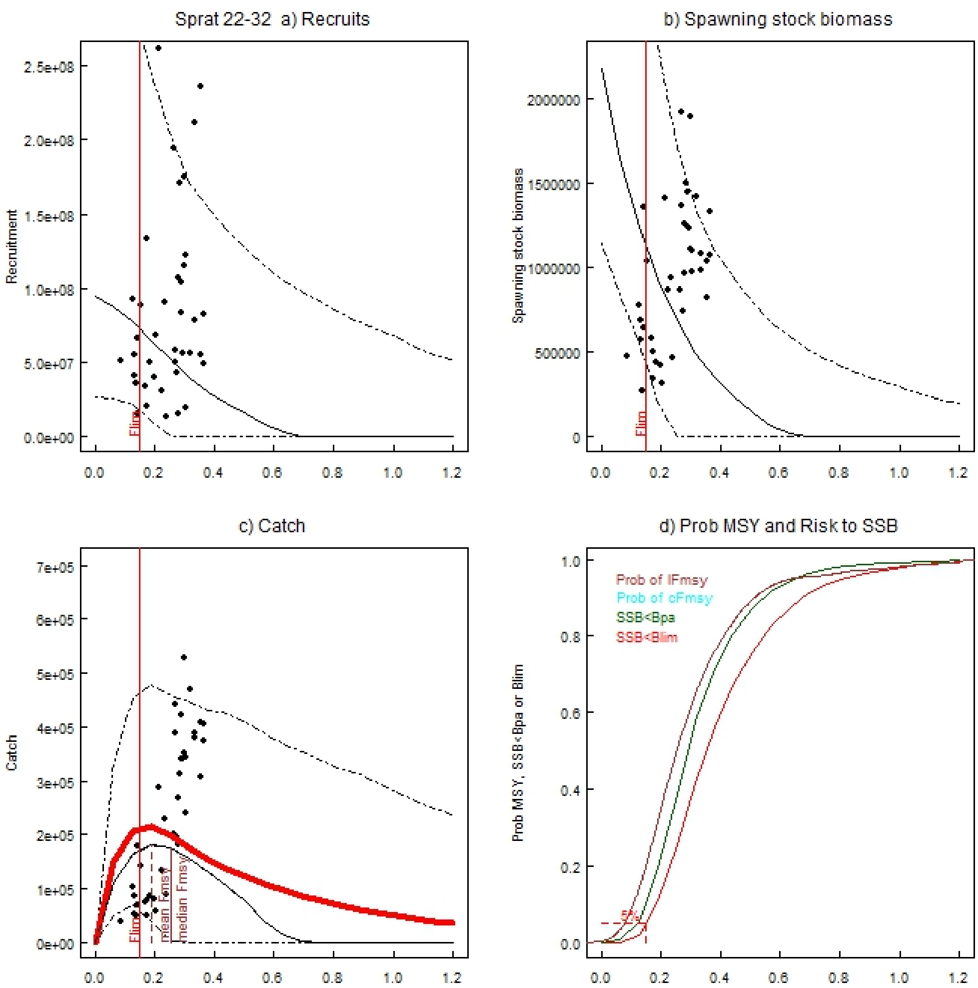

Figure 6.13.3. Eqsim results applying the standard regression method for Sprat in Subdivisions 22–32 without $B_{trigger}$. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows 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).

6.14 Sole in Div. IIIa and areas 22-24 (Kattegat sole)

6.14.1 Current reference points

Table 6.14.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.32	Equilibrium scenarios constrained by prob(SSB<B_{lim})<5% w. stochastic recruitment (ICES 2014g, ICES, 2014f).
Current B_{lim}	1 200 t	Bloss and segmented regression (ICES 2014g, ICES, 2014f).
Current Bpa	2 000 t	B_{lim}×e 1.645σ, σ=0.30 (ICES 2014g, ICES, 2014f).
Current $MSYB_{trigger}$	2 000 t	Lowest observed SSB, excluding low SSBs in 1984–1985.

6.14.2 Source of data

The sole IIIa stock was used a case study example for WKFMSYREF2 using the 1984-2012 assessment. The analysis in this report uses the newest (1984-2013) assessment results from the SAM assessment. In the WKFMSYREF2 analysis the age 8+ mean weights were substituted by the age 7 mean weight, to circumvent the observed lower mean weight for the plus group. The same adjustment of mean weights was done for this analysis.

6.14.3 Methods used

Two methods, Eqsim and Cadigan SR were used for this stock.

6.14.4 Settings Eqsim

Table 6.14.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
SSB-recruitment data	Full data series as default (1984-2013)	Based on WKMSYREF2 evaluation Additional analysis with a truncated time series 1992-2013 (generally lower recruitment)
Mean weights and proportion mature	2009-2013	
Exploitation pattern	2009-2013	Short period to reflect the most recent changes to SELTRA trawls.
Assessment error in the advisory year. CV of F	0.25	Based on WKMSYREF2 evaluation
Autocorrelation in assessment error in the advisory year	0.55	Based on WKMSYREF2 evaluation

6.14.5 Results Eqsim

6.14.5.1 Stock recruitment relation

The stock recruitment fit, using the three models (Ricker, B&H and segmented regression) weighted by the default “"Buckland" method, estimated the B&H as a horizontal “straight line”, so B&H was not considered further.

A fit with the Ricker and Segmented models (Figure 6.14.1) gives the highest weight to the Ricker model (73%). The mode of the Ricker fit is within the SSB observation. The inflection point for the segmented regression is estimated to value around B_{pa} (2000 t). For both methods, observed recruitment is generally higher than estimated values for the beginning (1984-1991) of the time series and below for later years.

To evaluate the effect of a possible shift in stock productivity the Eqsim analysis was also done on the basis of the truncated SR time series (Figure 6.14.2). The inflection point of the segmented regression is higher than estimated on the basis on the full time series.

A meta-analysis of recruitment for sole (Simmonds 2001) showed that the Ricker function makes in general a poor fit for sole stocks. Based on this, a fit with just the segmented regression model was also examined.

6.14.5.2 Eqsim scenarios

a) Ricker and Segmented regression method, full SR time series

Yield as function of F shows an almost constant yield in the F range of 0.2-0.6 (Figure 6.14.3) with maximum (mean) yield at F= 0.369. The median F_{MSY}=0.401 (not labelled correctly on the figure) is higher than the $F_{P.05}$ (=0.377), such that the precautionary F_{MSY} becomes 0.377 and the upper bound of the 95% range of F_{MSY} is bounded by $F_{P.05}$. The lower range is estimated to 0.292 (Figure 6.14.4). Other key output values can be found in Table 6.14..

b) Segmented regression method, full SR time series

Using the segmented regression as the only SR method gives a lower F_{MSY} (0.321) compared to the analysis including the Ricker method. In this analysis, F_{MSY} is lower than $F_{P.05}$ (0.354). The estimated F_{MSY} is identical to the analysis made during WKMSYREF2. See Figure 6.14.5, Figure 6.14.6 and Table 16.14.3 for detailed results.

c) Ricker and Segmented regression method, truncated SR time series

Excluding the first part of the SR time series (1984-1991) with a generally higher recruitment per spawner gives a stock recruitment relation mainly determined by the segmented regression method (91%, Figure 6.14.2) and an average reduction of the recruitment per spawner at around one third compared to the fit with the full time series. This lower stock productivity results in a lower F_{MSY} (0.222), which is slightly below the $F_{p0.05}$ (0.232). See Figure 6.14.7 and Figure 6.14.8 for details.

Table 6.14.3. Key results from Eqsim scenarios.

SOLE IIIA	RICER+SEGREG, FULL REC. TIME SERIES	SEGREG FULL REC. TIME SERIES	RICKER+SEGREG, TRUNCATED REC. TIME SERIES
Reference point			
F_{MSY} without $B_{trigger}$	0.401	0.321	0.222
F_{MSY} lower without $B_{trigger}$	0.295	0.227	0.174
F_{MSY} upper without $B_{trigger}$	0.622	0.401	0.263
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.377	0.354	0.232
F_{MSY} lower precautionary without $B_{trigger}$	0.292	0.227	0.174
F_{MSY} upper precautionary without $B_{trigger}$	0.377	0.354	0.232
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.545	0.498	0.338
MSY (at precautionary F_{MSY})	719 t	737 t	515 t
Median SSB at precautionary F_{MSY}	2 454 t	2 874 t	2 810 t

Median SSB lower precautionary (median at F_{MSY} upper precautionary)	2 454 t	2 634 t	2 692 t
Median SSB upper (median at F_{MSY} lower)	2 875 t	3 702 t	3 291 t

6.14.6 Methods used, Cadigan SR

6.14.6.1 Settings

The SAM assessment, without adjustment of mean weight at age was used for the Cadigan analysis. An average of the most recent 5 years data was used for mean weight at age and exploitation pattern. Preliminary analysis showed that the default bootstrap method gave some "outliers", probably due to the rather low number of observations in the SR time series. As an alternative, this analysis used the options where the SR parameters drawn from the estimated SR fit, using the variance, co-variance matrix.

6.14.6.2 Results

The Cadigan fit (Fig. 6.14.9) gives on average a Ricker like fit with mode within the centre of the SSB observations. The most likely F_{MSY} is estimated to 0.57 with a wide confidence interval (Fig. 6.14.10). The 95% interval of MSY is very wide (0.41-0.90) as presented in fig. 6.4.11. This range includes risk to B_{lim}>5% for F values above 0.58 (Fig. 6.14.12). This estimate should be taken as an upper limit as implementations uncertainty is not included.

6.14.7 Proposed reference points

WKMSYREF3 was not able to select one F_{MSY} value for management purposes. The choice of F_{MSY} depends very much on the length of time series of stock recruitment used in the analysis. Candidates for F_{MSY} are shown in the table below.

Table 6.14.4 Summary table of proposed reference points

SOLE IIIA	RICER+SEGREG, FULL REC. TIME SERIES	RICKER+SEGREG, TRUNCATED REC. TIME SERIES
Reference point		
F_{MSY} without $B_{trigger}$	0.401	0.222
F_{MSY} lower without $B_{trigger}$	0.295	0.174
F_{MSY} upper without $B_{trigger}$	0.622	0.263
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.377	0.232
F_{MSY} lower precautionary without $B_{trigger}$	0.292	0.174
F_{MSY} upper precautionary without $B_{trigger}$	0.377	0.232
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.545	0.338
MSY (at precautionary FMSY)	719 t	515 t
Median SSB at precautionary F_{MSY}	2 454 t	2 810 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	2 454 t	2 692 t
Median SSB upper (median at F_{MSY} lower)	2 875 t	3 291 t

6.14.8 Discussion / Sensitivity.

This analysis gives precautionary F_{MSY} in the range 0.22-0.38 for reasonable configurations of the Eqsim software. The Cadigan method provides a considerably higher F_{MSY} estimate (0.57) and a wider F_{MSY} range.

The final choice of F_{MSY} for management purposes is not trivial. If the apparent lower productivity of sole since 1992 is real, and is not a consequence of for example changes in stock area (inclusion of the SD 22-24) or lack of recruitment survey indices in the most recent years, the F_{MSY} is estimated to 0.22 while use of the full SR time series gives an F_{MSY} at 0.38. The 95% MSY range for the two estimates is not overlapping: the range is 0.292-0.377 for the full time series and 0.174-0.232 for the truncated time series. WKMSYREF3 recommends that WGNSSK examines which is the most appropriate time series to use for the S-R relationship and then uses the corresponding range of F_{MSY}.

The analysis made at the WKMSYREF2 by the stock assessor for this stock resulted in F_{MSY} at 0.32, which is the same as obtained here, using same settings but the 2014 assessment.

MSY (median) for the “low productivity” is estimated at 515 t which is lower than MSY (719-737 t) for the two “long term productivity” scenarios as expected. The B_{MSY} for the “low productivity” scenario (2810 t) is however close to B_{MSY} (2454-2874 t) for the other scenarios due to the much lower F_{MSY}.

Compared to the historical average values, historical F (0.42) was higher than the estimated F_{MSY} (0.22-0.38), yield (767 t) was higher than MSY (515-737 t) and SSB (2303 t) was lower than B_{MSY} (2454-2810 t). This comparison shows the estimated MSY and B_{MSY} is within the historical values and as such “likely”. It also shows that a high yield has been obtained with an F higher than the presented F_{MSY}. The most recent stock size is however close to a historic low which seems to be mainly due to reduced recruitment and less to F in the most recent years.

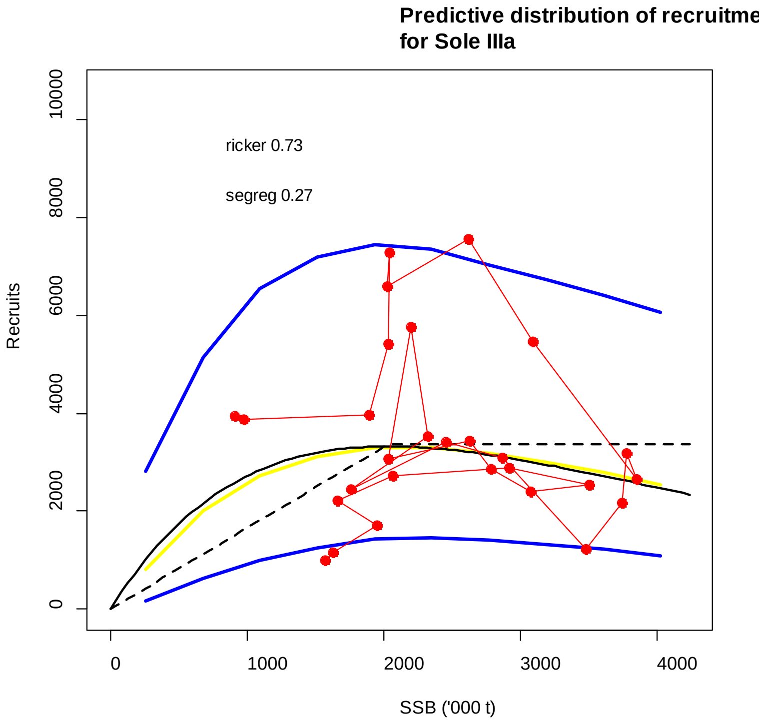

Figure 6.14.1. Eqsim results applying the Ricker and Segmented regression method for the full stock-recruitment time serie, Sole IIIa.

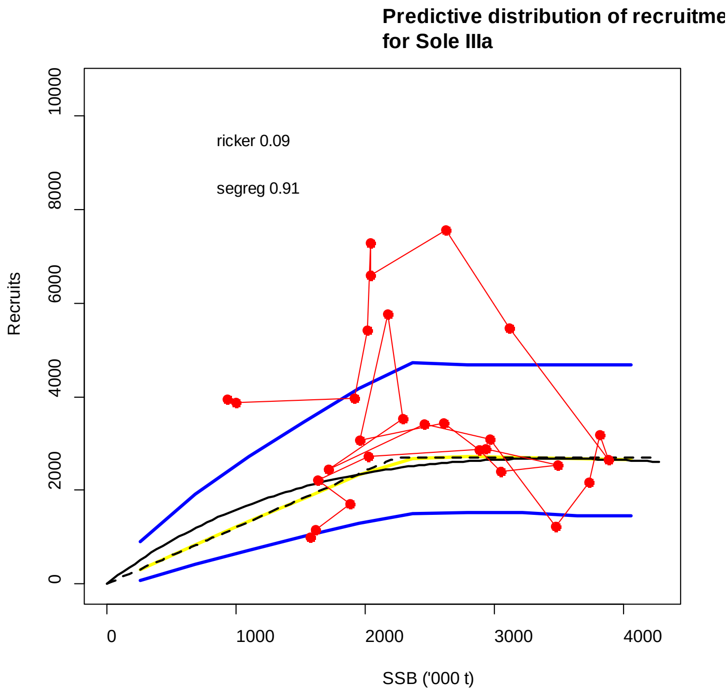

Figure 6.14.2. Eqsim results applying the Ricker and Segmented regression method for the truncated (1992-2014) stock-recruitment time series, Sole IIIa. (Please note that the red dots include the full time series).

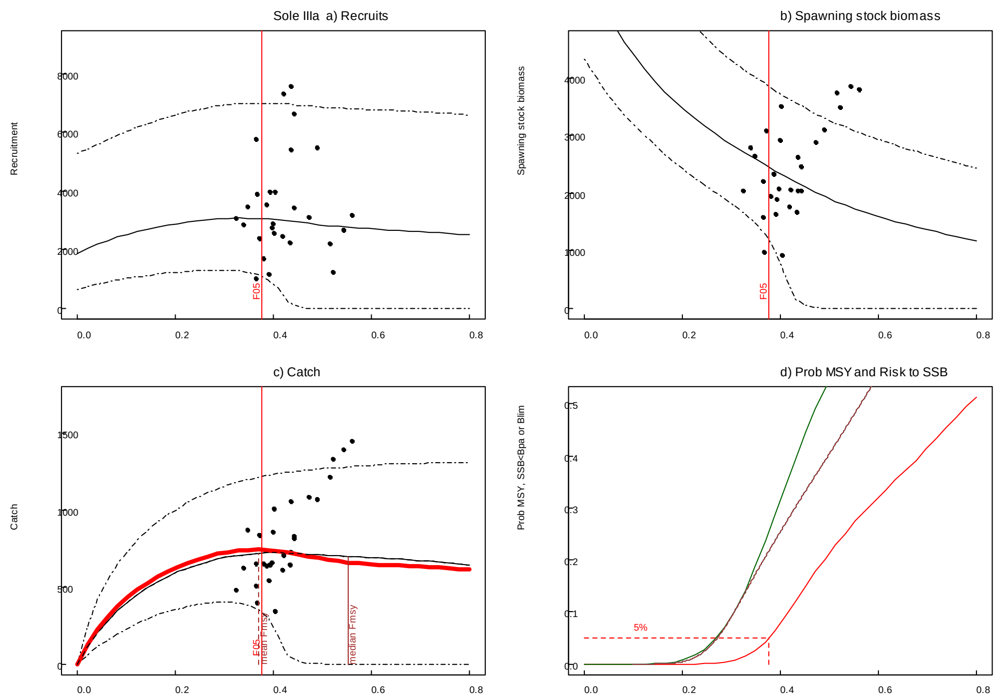

Figure 6.14.3. Sole IIIa. Eqsim results, full SR time series, method Ricker and segmented regression, Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid 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) (catch is the same).

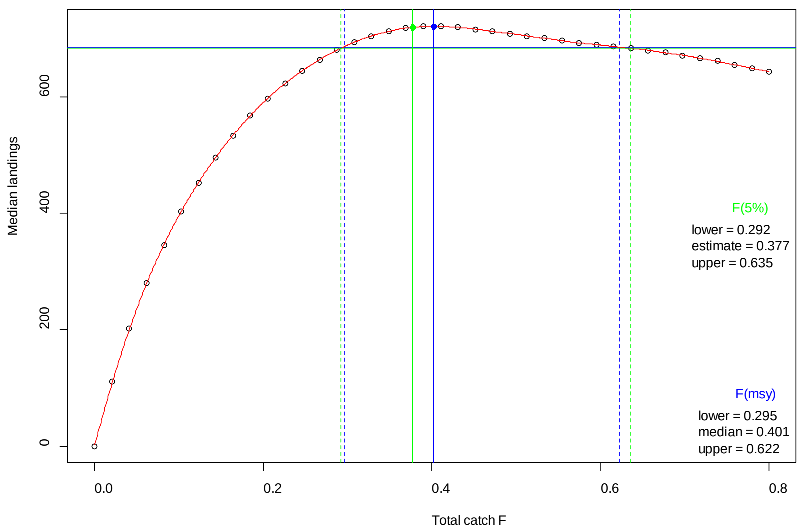

Figure 6.14.4. Sole IIIa based on full S-R timeseries, with fixed F exploitation from F = 0 to 0.8. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

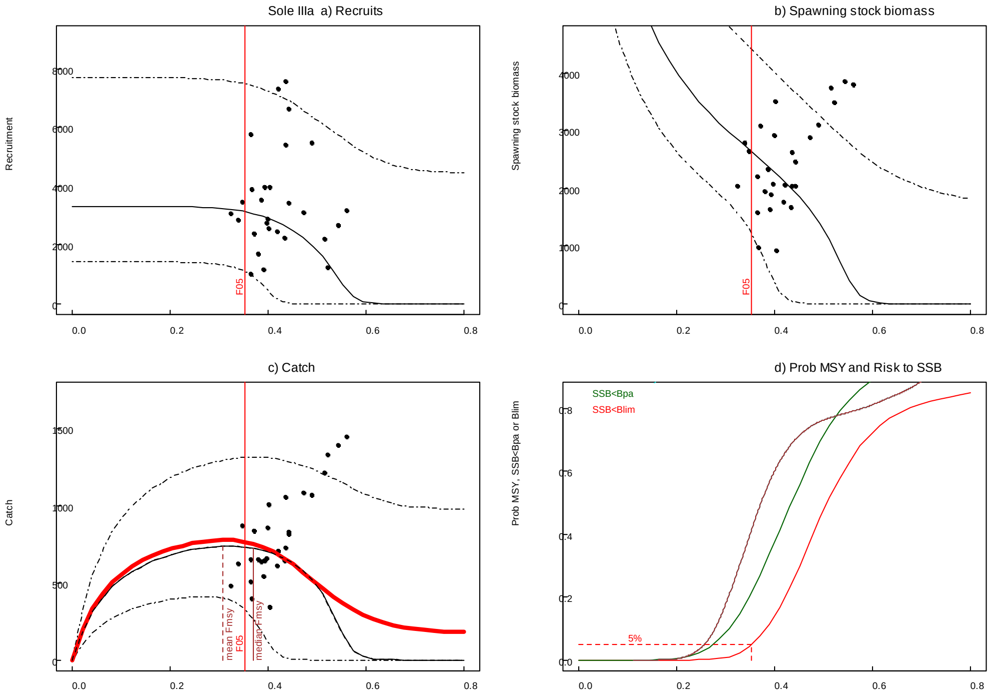

Figure 6.14.5. Eqsim results, full SR time series, segmented regression, Sole IIIa. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d 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) (catch is the same).

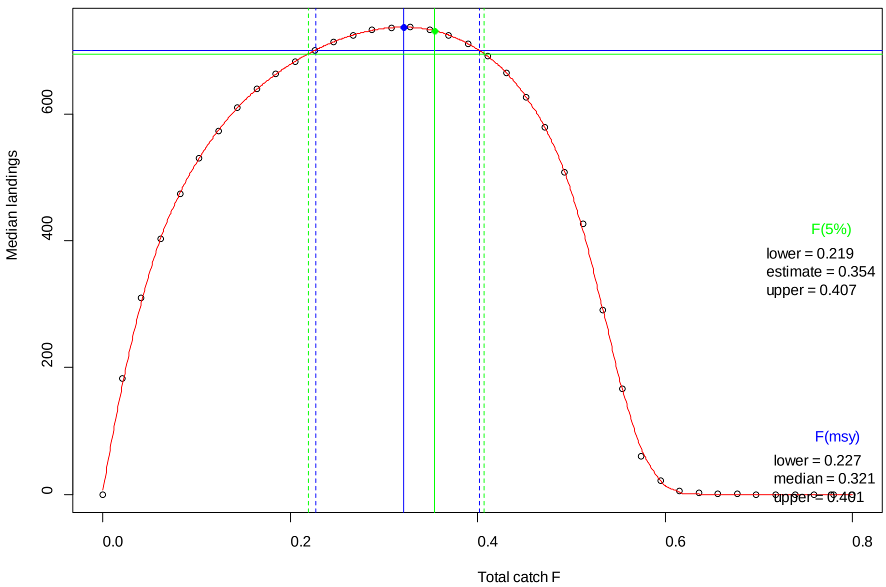

Figure 6.14.6. 95% range of MSY, full SR time series, segmented regression, Sole IIIa with fixed F exploitation from F = 0 to 0.8. Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

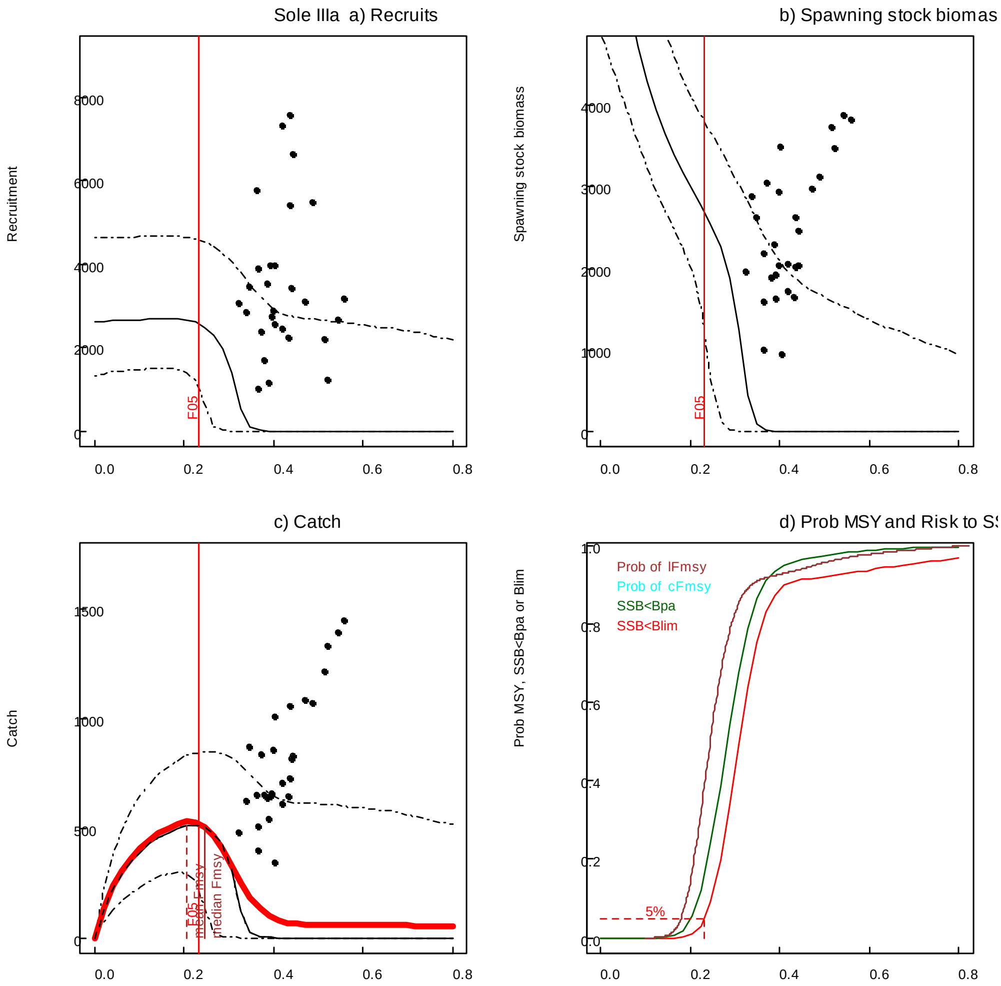

Figure 6.14.7. Eqsim results, truncated (1992-2003) SR time series, method Ricker and segmented regression, Sole IIIa. Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean 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) (catch is the same).

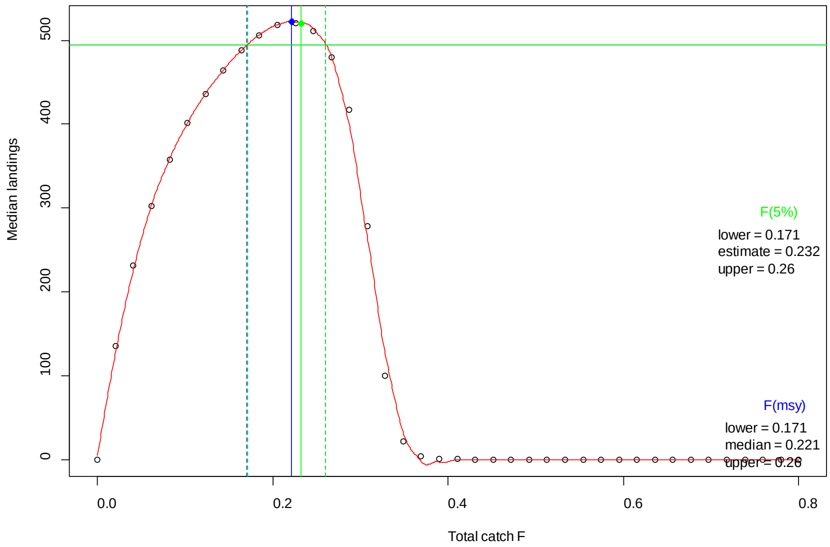

Figure 6.14.8. 95% range of MSY, full SR time series, method Ricker and segmented regression, Sole IIIa.

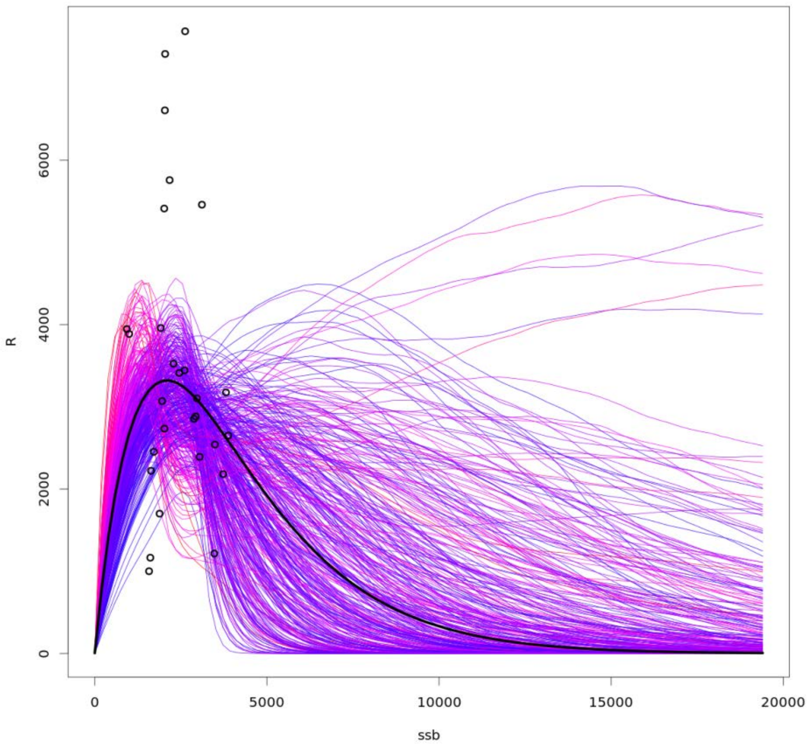

Figure 6.14.9. Stock recruitment relations according to the Cardigan method, Sole IIIa.

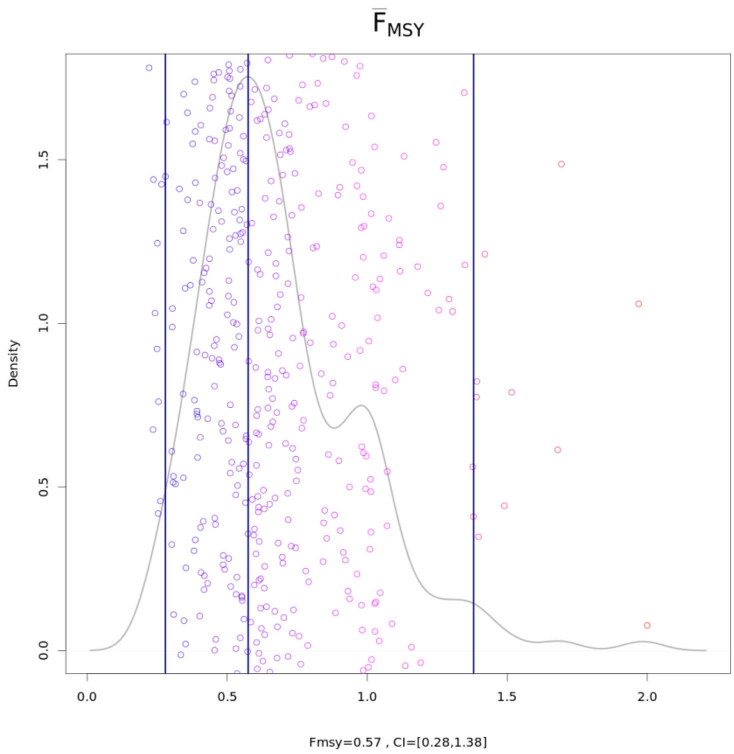

Figure 6.14.10. Distribution of F_{MSY} as estimated from the Cadigan method, Sole IIIa

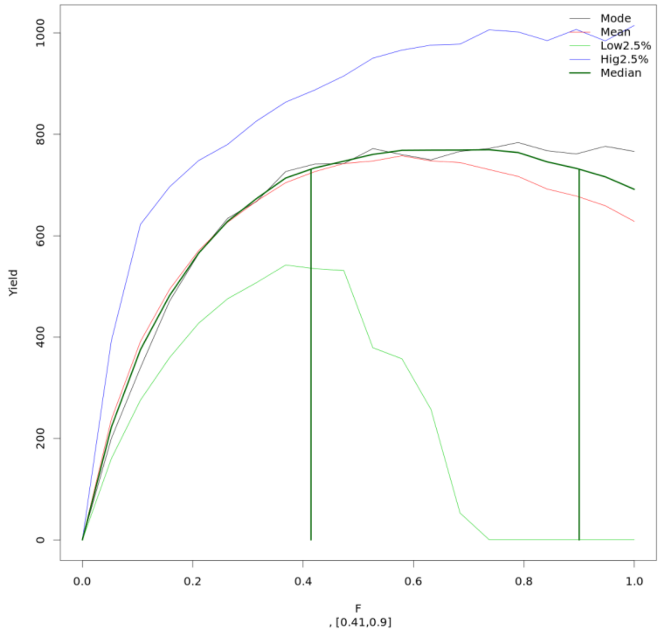

Figure 6.14.11. Estimate of range of F providing 95% of MSY as estimated from the Cadigan method, Sole IIIa.

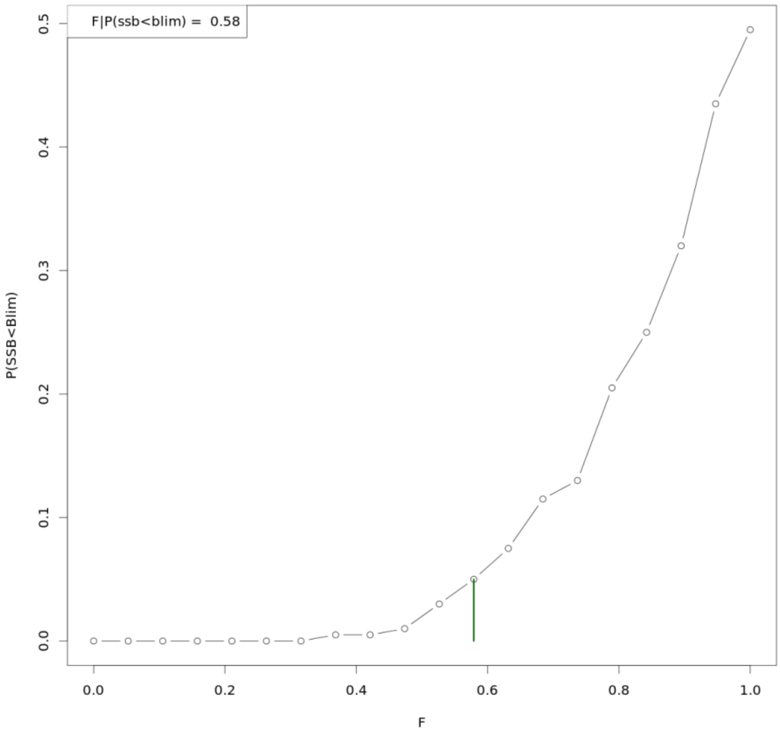

Figure 6.14.12. Probability of SSB below B_{lim} (1200 t) as function of F. The 5% probability is marked on the graph, Sole IIIa.

6.15 Sole in Subarea IV (North Sea)

6.15.1 Current reference points

Table 6.15.1 Summary table of current stock reference points

Reference point	Value	Technical basis
Current F_{MSY}	0.22	Median of stochastic MSY analysis assuming a Ricker stock–recruit relationship (range of 0.2–0.25), WGNSSK 2010.
Current B_{lim}	25 000 t	Bloss (WGNSSK 2011).
Current Bpa	35 000 t	B_{lim}×e1.645σ, σ=0.20: approximately B_{lim}*1.4.
Current $MSYB_{trigger}$	35 000 t	Default to value of Bpa.

6.15.2 Source of data

All data used came from the WGNSSK 2014 final assessment (ICES, 2014b).

6.15.3 Methods used

The Eqsim and Cadigan (stockassessment.org) methods were applied. Bootstrapping was used in the stockassessment.org method. Runs with and without $MSYB_{trigger}$ were done for the Eqsim method, but this functionality is not included in the Cadigan method. In both methods the total (catch) F was optimised for maximum landings.

6.15.4 Settings

Table 6.15.2 Model and data selection settings

Data and parameters	Setting	Comments
Stock-recruit relationships	Ricker and Segmented regression	Beverton and Holt failed to provide a reasonable fit to the data (equated to geometric mean recruitment at all SSB).
SSB-recruitment data	Full data series excluding last 3 years (1957-2010)	Recent year class strength is informed by less data than earlier year classes so these estimates are considered less reliable. This assumption is used in the short term forecast for this stock (geometric mean recruitment excluding the last three years).
Exclusion of extreme values (option extreme.trim)	No exclusions	
Mean weights and proportion mature	2004-2013 (Eqsim) 2009-2013 (Cadigan)	No significant trends over the last ten years. The Cadigan method only allows a single year range for weights and exploitation pattern, so it differs here to match the selectivity period.
Exploitation pattern	2009-2013	Recent shift from traditional beamtrawl to pulse trawl and sum wing gear with suspected different selectivity.

Assessment error in the advisory year. CV of F	0.23	Calculated according Section 4.1
Autocorrelation in assessment error in the advisory year	0.24	Calculated according to Section 4.1

In order to estimate assessment uncertainty (CV and autocorrelation), advised and realised Fs for the observed catch for the last 10 years were compared (Table 6.15.3).

Table 6.15.3 Error in advice

	F Assess	F set	ln(Fass)	ln(Fset)	Deviations
2004	0.4	0.519	-0.92	-0.66	-0.26
2005	0.36	0.58	-1.02	-0.55	-0.47
2006	0.32	0.471	-1.14	-0.75	-0.39
2007	0.5	0.473	-0.69	-0.75	0.06
2008	0.4	0.391	-0.92	-0.94	0.02
2009	0.42	0.398	-0.87	-0.92	0.05
2010	0.25	0.391	-1.39	-0.94	-0.45
2011	0.28	0.347	-1.27	-1.06	-0.21
2012	0.22	0.249	-1.51	-1.39	-0.12
2013	0.26	0.232	-1.35	-1.46	0.11
			STD Deviations		0.233
				Fcv	0.226
				Phi	0.240

6.15.5 Results

6.15.5.1 Stock recruitment relation

The stock-recruit fits to for the two methods applied are shown in Figures 6.15.1 and 6.15.2. The SR scatter for North Sea sole is clustered mainly in the 30-45 000 t SSB range. There is no clear patterns with both high (including a few spikes) and low recruitments found across the whole range of observed SSB. Above 100 000t SSB, there are two of the lowest observed recruitments (the 1961 and 1962 yearclasses) and the highest observed recruitment (1963 yearclass). In general, the observed recruitment above the most commonly observed SSB range tends to be below average.

In the Eqsim method, the segmented regression only has 27% of the weighting compared to 73% for Ricker.

The Cadigan non-parametric model fits to the data predominantly have Ricker-like curves. There are a few outlier fits that most likely result from a higher proportion of the bootstrapped values coming from the ‘spike’ recruitments. The peak of the curve in most cases is found within the range of observed SSBs.

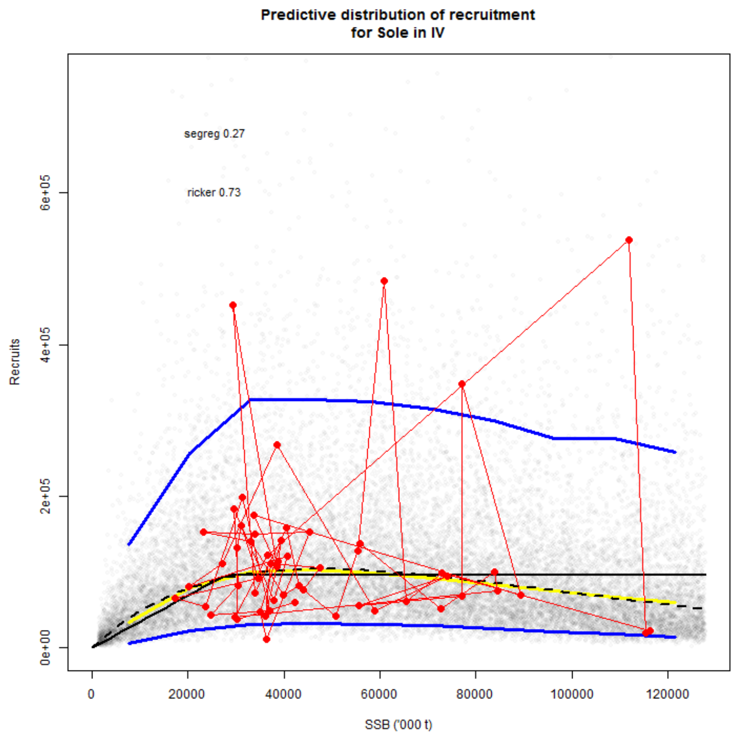

Figure 6.15.1. Stock recruit observations (red dots) and fitted relationships: Ricker (dashed) and segmented regression (solid). Simulated values , median (yellow) and 90% (blue) based on combined models in Eqsim.

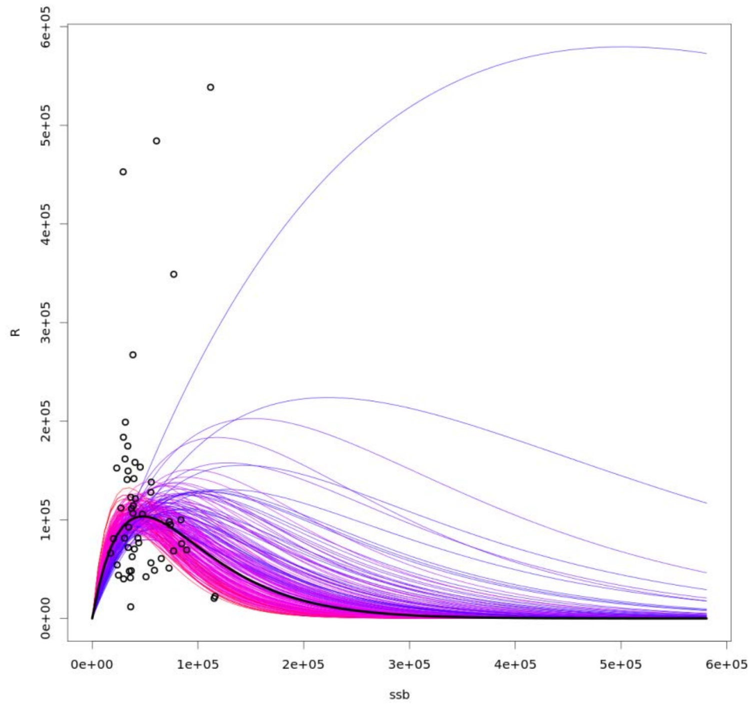

Figure 6.15.2. Cadigan.

6.15.6 Proposed reference points

The Eqsim method resulted in a well-defined dome shaped landing yield curve (Figure 6.15.3). The upper limit of the F_{MSY} range is greater than the F that leads to a 5% probability of SSB<B_{lim}, but the estimated F_{MSY} is below this. The reference point values for the Eqsim method are shown in Table 6.15.4. Results show a well-defined dome shaped yield (median landings) curve (Figure 6.15.3).

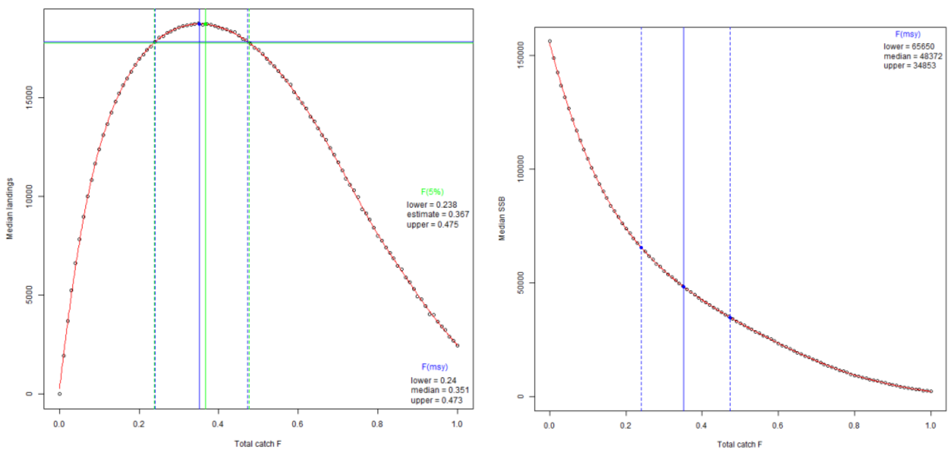

Figure 6.15.3 North Sea sole, with fixed F exploitation from F = 0 to 1.0. Left panel: Median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted). Right Panel: Median SSB blue lines show location of F_{MSY} (solid) with 95% yield range (dotted).

Table 6.15.4. Summary table of proposed stock reference points for method Eqsim

STOCK	SOLE IN SUBAREA IV (NORTH SEA)
Reference point	Value
F_{MSY} without $B_{trigger}$	0.35
F_{MSY} lower without $B_{trigger}$	0.24
F_{MSY} upper without $B_{trigger}$	0.47
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.37
F_{MSY} upper precautionary without $B_{trigger}$	0.37
F_{MSY} with $B_{trigger}$	0.38
F_{MSY} lower with $B_{trigger}$	0.25
F_{MSY} upper with $B_{trigger}$	0.56
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.41
F_{MSY} upper precautionary with $B_{trigger}$	0.41
MSY	18 748 t (landings)
Median SSB at F_{MSY}	48 372 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	34 853 t
Median SSB upper (median at F_{MSY} lower)	65 650 t

The Cadigan method resulted in a similar dome shaped landing yield curve to the Eqsim method (Figure 6.15.4). This is not surprising given the high weighting for the Ricker curve in the Eqsim method and the Ricker-like shape of the Cadigan SRR curves.

The F that leads to a 5% probability of SSB<B_{lim} is larger, presumably due to the lack of implementation error in the Cadigan implementation. The upper limit of F_{MSY} range is exactly at the F that leads to a 5% probability of SSB<B_{lim}, leading to a wider acceptable F_{MSY} range under this method. The reference point values for the Cadigan method are shown in Table 6.15.3.

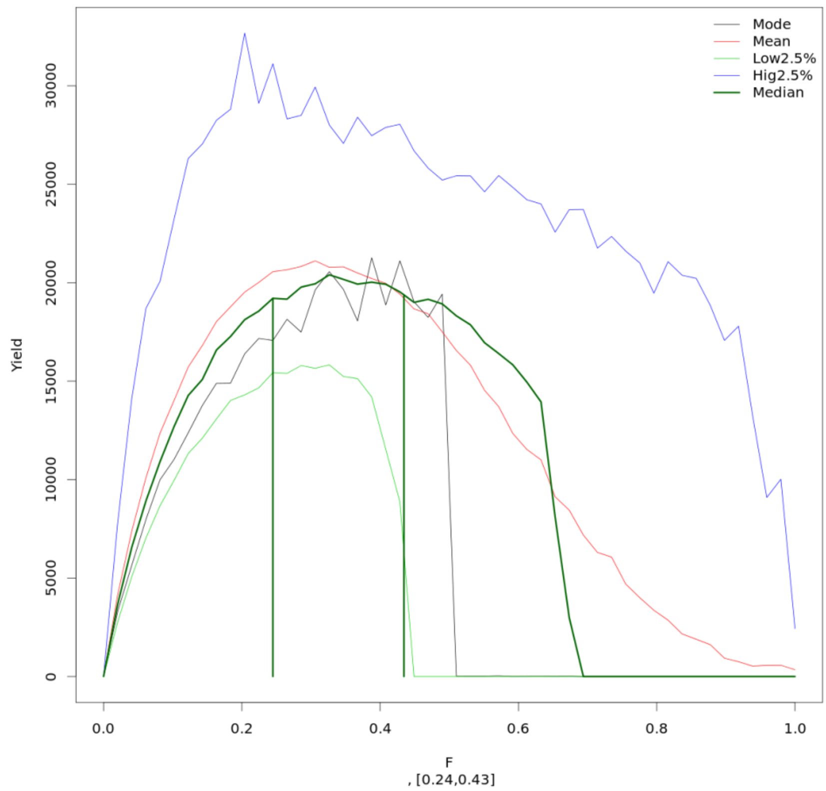

Figure 6.15.4. Yield curve based on Cadigan method.

Table 6.15.3.Results based on Cadigan method.

STOCK	SOLE IN SUBAREA IV (NORTH SEA)
Reference point	Value
F_{MSY} without $B_{trigger}$	0.34
F_{MSY} lower without $B_{trigger}$	0.24
F_{MSY} upper without $B_{trigger}$	0.43
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.43
F_{MSY} upper precautionary without $B_{trigger}$	0.43
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	N/A
F_{MSY} with $B_{trigger}$	N/A
F_{MSY} lower with $B_{trigger}$	N/A
F_{MSY} upper with $B_{trigger}$	N/A
MSY	20 734 t (landings)
Median SSB at F_{MSY}	53 449 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	41 002 t
Median SSB upper (median at F_{MSY} lower)	70 425 t

During WGNSSK 2014 the plotMSY software was used to estimate F_{MSY} values. Ricker, Beverton and Holt and smooth hockeystick (segmented regression) fits were used (weighted 40%, 22% and 38%, respectively). The resultant median F_{MSY} estimate was 0.33. This is very close to the F_{MSY} values estimated here. It lies in the upper part of the Eqsim F_{MSY} range, but near the middle of the F_{MSY} range from the Cadigan method.

6.15.7 Discussion / Sensitivity.

The presented analyses used the data currently available from WGNSSK 2014 (ICES 2014b). Sole IV is being benchmarked by ICES with the aim of providing a new assessment of the stock for the next WGNSSK meeting. One of the major changes will be the addition of discard data (previously assumed to be low and with no pattern). This will lead to different estimated catch selectivities in future that will likely impact on the estimated F_{MSY} range. The analyses above will be rerun following the benchmark.

A shorter time period (5yrs) was used for selectivity than for biological parameters (10yrs). There are no clear trends in weight at age over the last ten years, but there has been some significant changes to the gears used in the Dutch beam trawl fleet that takes >75% of the sole quota. These changes include a shift to pulse trawl gears and the increased use of sumwings. It is expected, though not fully quantified yet, that these gear changes will lead to changes in selectivity both through direct differences in the gear and changes in the speed and location of fishing with the new gears.

A sensitivity test was done excluding the 1961-1963 yearclasses (the only yearclasses arising from SSBs greater than 100 000 t). This was done to check the impact of excluding the two high SSB – low recruitment SR pairs on the weighting of the Ricker SRR in the Eqsim method. The natural mortality in 1963 is also set much higher (0.9) than in all other years (0.1) due to a particularly harsh winter, leading to some potential 'model artefacts' in the SSB and recruitment estimates for the 1963 yearclass. As expected, the Ricker received less weight with these yearclasses excluded, resulting in equal weighting for Ricker and segmented regression. This slightly lowered the F_{MSY} range (0.20 -0.35 (excluding 1961-193) vs 0.24-0.37 (all years)). As there is no clear reason to exclude these points, it was decided to proceed with the whole time series. At the benchmark the length of the time series used in the sole assessment could be reconsidered to exclude the early years.

The selection of stock recruitment function has a big effect on the lower limit of the F_{MSY} range. Though there is limited empirical evidence for density dependent reduction in recruitment at high SSB for flatfish species, the North Sea sole data does favour a Ricker fit over Beverton and Holt or segmented regression given the slightly lower recruitments at SSB >50 000 t and the two very low recruitments at the largest observed SSB. The objective Cadigan non-parametric SR allows the data to determine the reduction in recruit per spawner with increasing biomass and produces Ricker-like fits, similar to the averaged Eqsim S-R relationships. The equilibrium biomass along the F_{MSY} ranges of the two methods lies within the observed range of SSB from the sole assessment. Therefore either method could be seen as acceptable. However, as the Eqsim method provides estimates of precautionarity based on the includion implementation error, these values are given in the summary tables above.

6.16 Sole in Div. VIId

6.16.1 Current reference points

Table 6.16.1 Summary table of current stock reference points

REFERENCE POINT	VALUE	TECHNICAL BASIS
Current F_{MSY}	0.29	Stochastic simulations assuming a smooth hockey-stick relationship.
Current Blim	Not defined	Poor biological basis for definition.
Current Bpa	8 000 t	This is the lowest observed biomass at which there is no indication of impaired recruitment. Smoothed Bloss.
Current $MSYB_{trigger}$	8 000 t.	Bpa.

6.16.2 Source of data

ICES-WGNSSK (ICES 2014b).

6.16.3 Methods used

Eqsim with additional WKMSYREF3 code to produce median yield and F estimates (see section 4.1).

6.16.4 Settings

Table 6.16.2 Model and data selection settings

DATA AND PARAMETERS	SETTING	COMMENTS
S/R - Relationship	Segmented regression	Breakpoint 8000 t
SSB-recruitment data	Year classes 1986-2011	High uncertainty on age 1 and 2 estimates, therefore excluded 2012-2013
B_{lim}	7 200 t	
Exclusion of extreme values (option extreme.trim)	No trimming	
Mean weights and proportion mature	2003-2013	
Exploitation pattern	2003-2013	
Assessment error in the advisory year. CV of F	0.21	Based on last 12 years assessment (Between set F and realised F)
Autocorrelation in assessment error in the advisory year	0.40	Based on last 12 years assessment (Between set F and realised F)

6.16.5 Results

6.16.5.1 Stock recruitment relation

The full available time period (1982-2013) was used for stock-recruit modelling, excluding the last 2 years as the estimated recruitment of the last two years are highly uncertain (high SE's on the estimates).

The stock recruitment fit using the three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method, did not give any weight to the segmented regression model, apparently due to a problem with the estimation of the breakpoint in this software as the PLOTMSY model showed a much better fit of the s/r points to the segmented regression model (Figure 6.16.1) (WGNSSK 2014). The weightings by Eqsim of the Ricker and Beverton & Holt models with the default "Buckland" method are 81% and 16% respectively. The plot of the predicted recruitment (Figure 6.16.2) indicates an unrealistic high predicted recruitment for low biomasses where no historical observations are avialble. The resulting F_{MSY}, F_{MSY}lower and F_{MSY}upper estimates were estimated to be unprecautionary for this stock (Table 6.16.1).

At the ICES WKFRAME II workshop (ICES, 2012b), a Meta-analysis on 7 sole stocks was carried out, providing more coherent estimates of F_{MSY} reference points for these sole stocks. For sole VIId the estimated B_{lim} is 7200 t. It was decided to use the segmented regression model with a B_{lim} of 7200 t and a breaking point at 8000 t ($B_{trigger}$ – Bpa). Figure 3 shows the plot of the predicted recruitment. Specific cv values on log difference between the set F and the realised F (see section 4.1 for method) were estimated at the workshop. The estimated CV on the fishing mortality (Fcv) is 0.21 and the auto correlation value (Fphi) is 0.4 (Table 6.16.2).

6.16.5.2 Eqsim scenarios

Sensitivity analysis using the segmented regression model were carried out on the Exclusion of extreme values (Trim 0.10,0.90 /No Trim); the inclusion of a $B_{trigger}$; the exclusion of 2, 3 last years of the data and no exclusion of any years of data. All these analysis show very little difference to the final F_{MSY} and F_{MSY} ranges.

The year range assumed for both selectivity and biological parameters were set for 2003-2013 as no apparent trend were seen over this period for selectivity and stock/catch weights.

The results of the sensitivity analysis applying trimming, exclusion of years and including $B_{trigger}$ (8000 t) are presented in Table 6.16.3.

6.16.6 Proposed reference points

Table 6.16.3 summarises the proposed reference points based on results in Table 6.16.4

The segmented regression model with a B_{lim} of 7200 t and a breaking point at 8000 t ($B_{trigger}$ – Bpa) was used (no trim, no $B_{trigger}$, excluding 2012-2013) and the results are in table 6.16.5.

The Eqsim summary plots for Sole VIId are presented in Figure 6.16.4.

The estimated yield curve for Sole VIId is presented in Figure 6.16.5.

Median SSB for Sole VIId over a range of target F values are presented Figure 6.16.6.

Table 6.16.3 Summary table of proposed stock reference points for method Eqsim (medians based on landings):

STOCK – SOLE VIID	
Reference point	Value
F_{MSY}	0.30
F_{MSY} lower	0.16
F_{MSY} upper	0.43

New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.39
F_{MSY} upper precautionary without $B_{trigger}$	0.39
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	0.41
MSY	4327 t
Median SSB at F_{MSY}	15182 t
Median SSB lower precautionary (median at F_{MSY} upper precautionary)	26794 t
Median SSB upper (median at F_{MSY} lower)	11414 t

6.16.7 Discussion / Sensitivity.

During WGNSSK 2014 the plotMSY software was used to estimate F_{MSY} values. Initially using an automatic weighting Ricker, Beverton and Holt and smooth hockeystick (segmented regression) fits provided weightings of 32%, 29% and 39%, respectively. The resultant median F_{MSY} estimate was 0.34. The WGNSSK decided to use the smooth hockeystick (segmented regression) as the only recruitment model for this stock, also resulting in a median F_{MSY} of 0.34. This lies in the upper part of the Eqsim F_{MSY} range.

Table 6.16.1. Results of Eqsim weighted by the default "Buckland" method (Ricker & Beverton Holt regression models) for Sole VIId.

Auto S/R (Ricker & Beverton Holt)									
No Btrigger - Trim - No exclusion of years									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.34	0.40	0.68	NA	0.78	NA	NA	NA	NA
lanF	NA	NA	NA	0.92	0.78	0.62	0.49	1.28	1.20
catch	3805	4068	4713	NA	4795	NA	NA	NA	NA
landings	NA	NA	NA	4850	4795	4623	4440	4623	4438
catB	11761	10711	7192	NA	6361	NA	NA	NA	NA
lanB	NA	NA	NA	5364	6361	7798	NA	3551	NA

Table 6.16.4. Calculation of CV and autocorrelation between F Assessed and F Set for the assessments 2002-2013 for Sole VIId.

Year	F Assess	F set	ln(Fass)	ln(Fset)	Deviations
2002	0.378	0.35	-0.972861083	-1.049822124	0.076961041
2003	0.374	0.37	-0.983499482	-0.994252273	0.010752792
2004	0.403	0.31	-0.908818717	-1.171182982	0.262364264
2005	0.383	0.29	-0.95972029	-1.237874356	0.278154066
2006	0.436	0.33	-0.830113036	-1.108662625	0.278549589
2007	0.493	0.3	-0.707246105	-1.203972804	0.496726699
2008	0.426	0.25	-0.853315933	-1.386294361	0.532978428
2009	0.53	0.5	-0.634878272	-0.693147181	0.058268908
2010	0.489	0.6	-0.71539279	-0.510825624	-0.204567166
2011	0.415	0.33	-0.879476759	-1.108662625	0.229185866
2012	0.41	0.27	-0.891598119	-1.30933332	0.417735201
2013	0.474	0.27	-0.746547957	-1.30933332	0.562785363
	STD Deviations	0.23348901			
	Fcv	0.21			
	Phi	0.40			

Table 6.16.5. Results of Eqsim (Segmented regression model – B_{lim}=7200t – Breakpoint 8000t) sensitivity analysis for Sole VIId. The outlined results are the proposed F_{MSY} and F ranges.

Segmented regression									
No Btrigger - Trim - No exclusion of years									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.36	0.39	0.48	NA	0.27	NA	NA	NA	NA
lanF	NA	NA	NA	0.28	0.27	0.16	0.123	0.41	0.39
catch	4167	4105	3241	NA	4233	NA	NA	NA	NA
landings	NA	NA	NA	4233	4233	4027	3583	4028	3584
catB	12289	11180	7125	NA	16700	NA	NA	NA	NA
lanB	NA	NA	NA	15821	16700	26878	NA	10417	NA
No Btrigger - No trim - No exclusion of years									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.36	0.39	0.48	NA	0.29	NA	NA	NA	NA
lanF	NA	NA	NA	0.28	0.29	0.16	0.16	0.41	0.41
catch	4185	4100	3261	NA	4252	NA	NA	NA	NA
landings	NA	NA	NA	4254	4252	4046	4221	4046	4220
catB	12253	11138	7173	NA	15545	NA	NA	NA	NA
lanB	NA	NA	NA	16160	15545	27027	NA	10408	NA
No Btrigger - No trim - exclude 2011-2013									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.41	0.44	0.52	NA	0.31	NA	NA	NA	NA
lanF	NA	NA	NA	0.30	0.31	0.16	0.16	0.46	0.45
catch	4357	4293	3502	NA	4447	NA	NA	NA	NA
landings	NA	NA	NA	4450	4447	4228	4366	4231	4363
catB	11098	10354	7156	NA	15209	NA	NA	NA	NA
lanB	NA	NA	NA	15784	15209	27700	NA	9656	NA
No Btrigger - No trim - exclude 2012-2013									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.39	0.41	0.50	NA	0.29	NA	NA	NA	NA
lanF	NA	NA	NA	0.30	0.29	0.16	0.16	0.43	0.43
catch	4242	4179	3365	NA	4322	NA	NA	NA	NA
landings	NA	NA	NA	4327	4322	4116	4251	4115	4249
catB	11414	10663	7126	NA	15871	NA	NA	NA	NA
lanB	NA	NA	NA	15182	15871	26794	NA	10001	NA
With Btrigger - No trim - exclude 2012-2013									
	F05	F10	F50	medianMSY	meanMSY	Medlower	Meanlower	Medupper	Meanupper
catF	0.41	0.45	0.60	NA	0.31	NA	NA	NA	NA
lanF	NA	NA	NA	0.29	0.31	0.16	0.16	0.47	0.47
catch	4246	4187	3629	NA	4326	NA	NA	NA	NA
landings	NA	NA	NA	4326	4326	4114	4256	4113	4254
catB	10964	9973	7201	NA	14796	NA	NA	NA	NA
lanB	NA	NA	NA	15762	14796	26997	NA	9277	NA

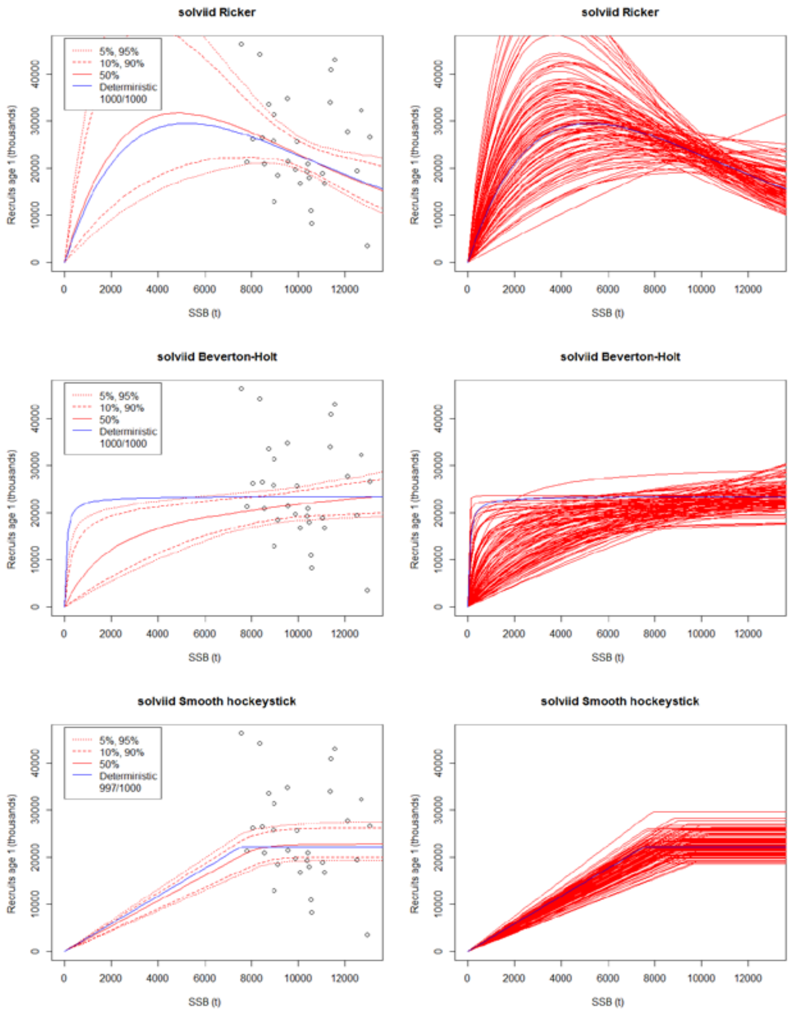

Figure 6.16.13. PLOTMSY results applying for Sole VIId (WGNSSK-2014).

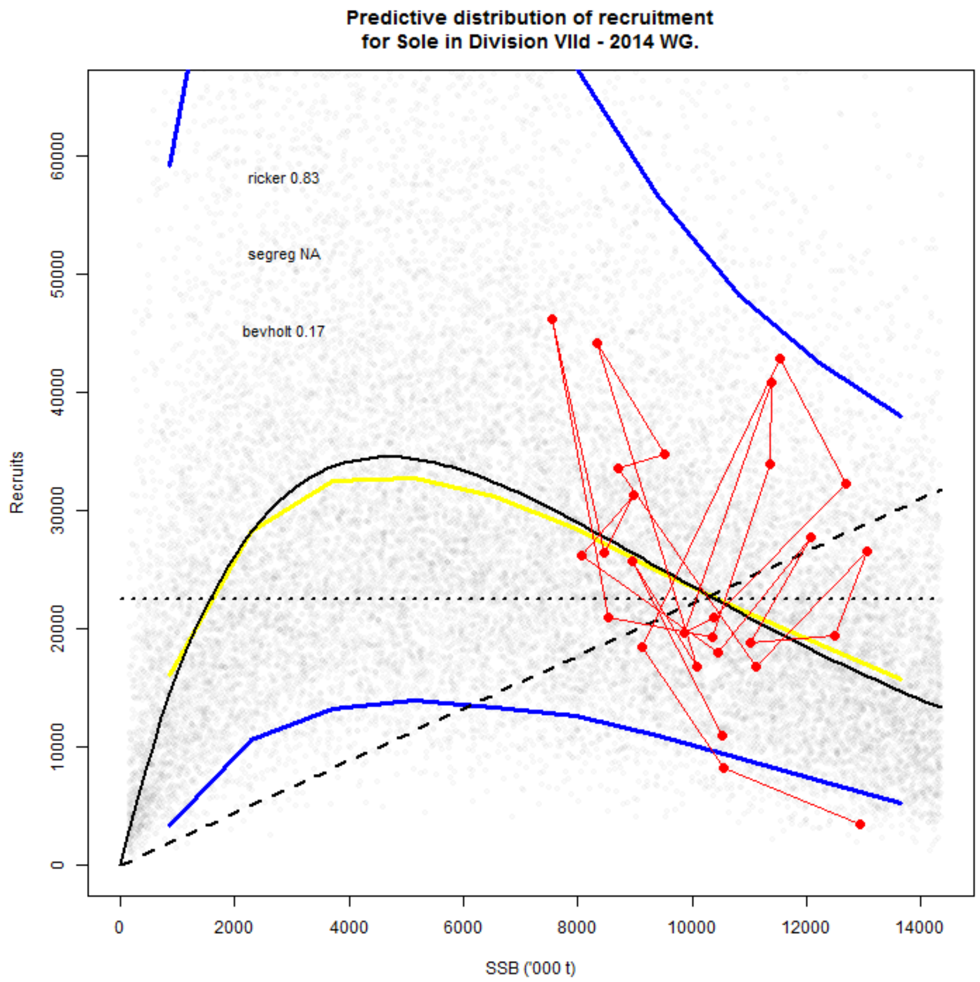

Figure 6.16.2. Eqsim summary of the recruitment models using the default "Buckland" method for Sole VIId. Stock recruit observations (red dots) and fitted relationships: Ricker (dashed) and segmented regression (solid). Simulated values , median (yellow) and 90% (blue) based on combined models in Eqsim.

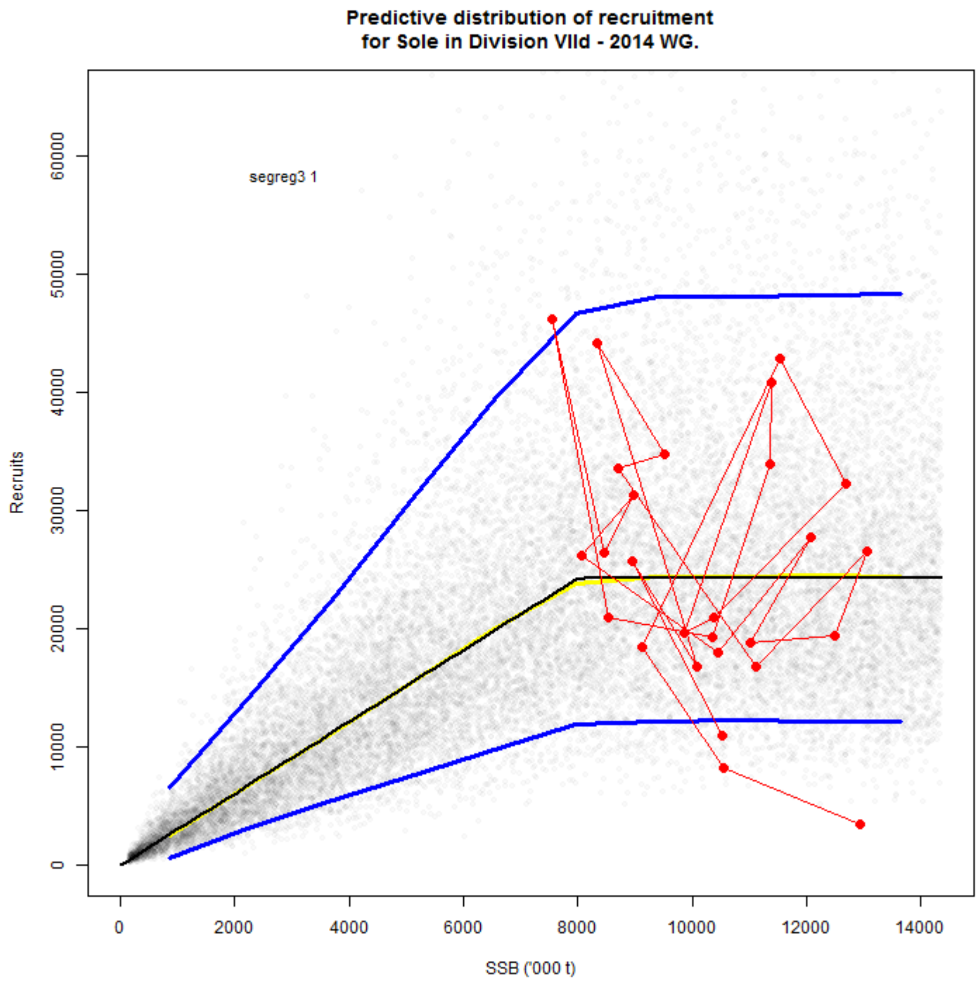

Figure 6.16.3. Eqsim summary of recruitment model (segmented regression) for Sole VIId (used for analysis). Stock recruit observations (red dots) segmented regression (solid black). Simulated values , median (yellow) and 90% (blue) .

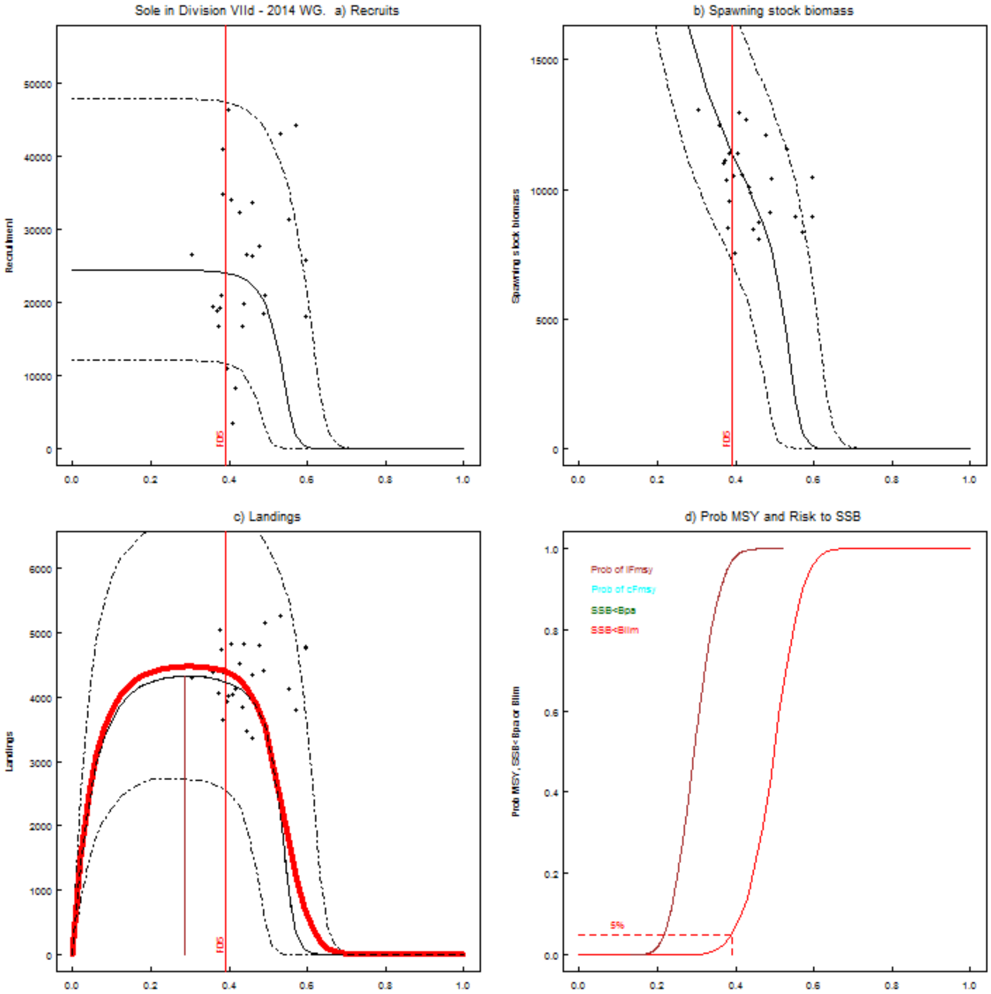

Figure 6.16.4. Eqsim summary plot for Sole VIId (no trim, no $B_{trigger}$, excluding 2012-2013). Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). 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).

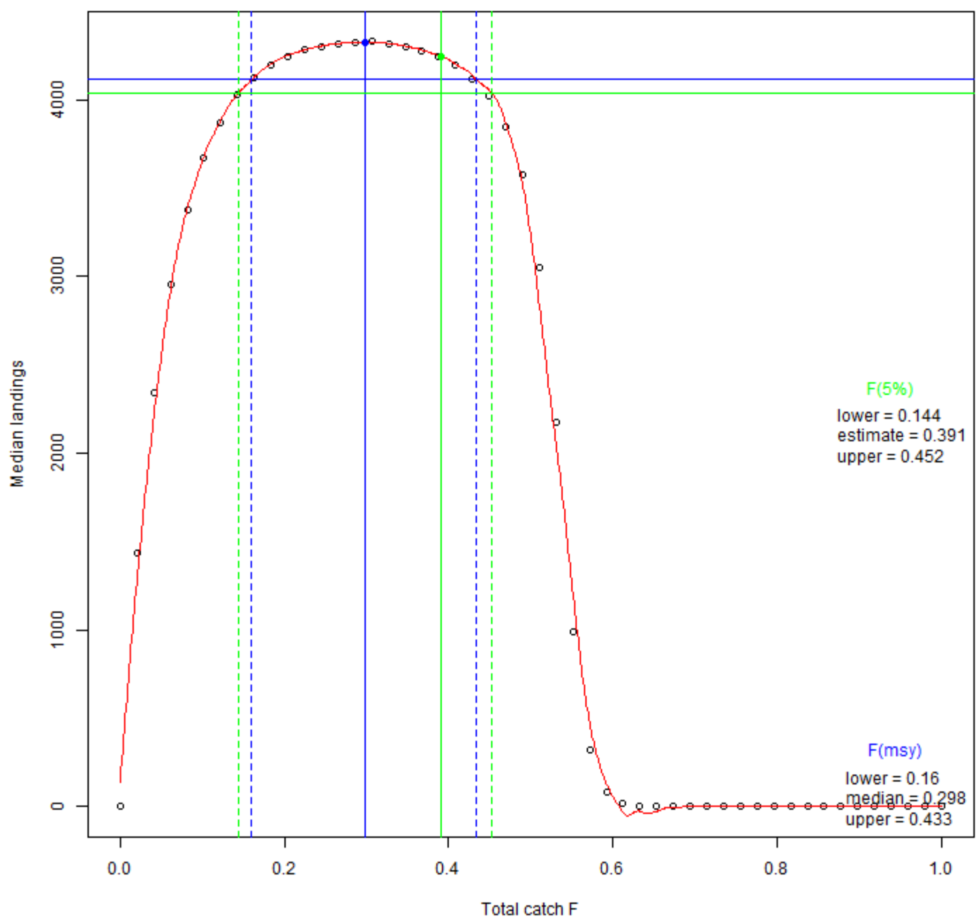

Figure 6.16.5. Eqsim median landings yield curve with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted). The Total catch F is an F landings for ages 3-6.

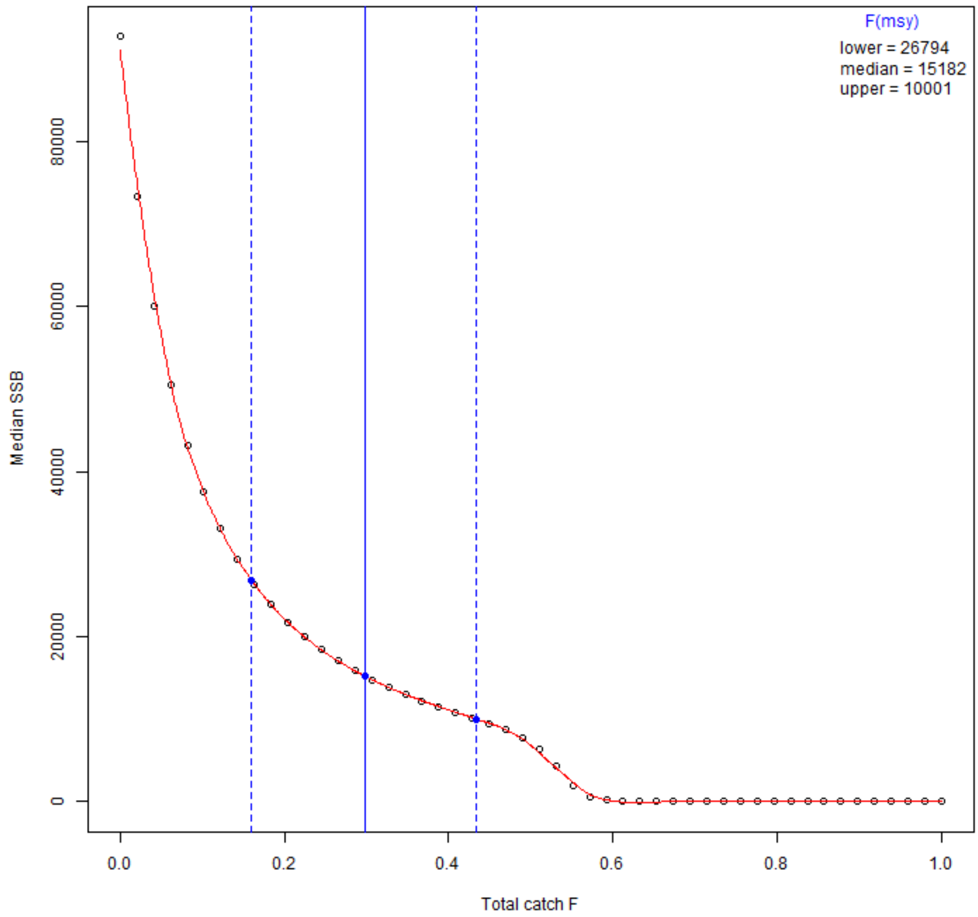

Figure 6.16.6. Eqsim median SSB for Sole VIId over a range of target F values. Blue lines show location of F(MSY) (solid) with 95% yield range (dotted). The Total catch F is an F landings for ages 3-6.

6.17 Whiting in Subarea IV and Division VIId

6.17.1 Source of data

ICES-WGNSSK (ICES 2014b).

6.17.2 Methods used

Eqsim with additional WKMSYREF3 code to produce median yield and F estimates.

6.17.3 Current reference points

Table 6.17.1 Summary table of current stock reference points

Reference point	Value
Current F_{MSY}	Undefined
Current B_{lim}	184 000 t (Bloss from ICES-WGNSSK (ICES 2014b)
Current Bpa	Undefined
Current $_{MSY}B_{trigger}$	Undefined

6.17.4 Settings

6.17.4.1 Period used for S–R

The full time period in the assessment (1990-2014) was used for stock-recruit modelling. Exploratory analysis showed that the segmented regression model fit was a simple straight line through the data with no changepoint, and this was deemed unsuitable for further consideration. The models used (Ricker, Beverton-Holt) are summarised in Figure 6.17.1.

6.17.4.2 Advice error

This was calculated as 0.24 with autocorrelation 0.6, from comparison of historical advice with current assessment (only possible for 2009 onwards as no TAC advice was given for previous years).

6.17.4.3 Selectivity

10 years (2004-2013).

6.17.4.4 Annual biological parameters

10 years (2004-2013).

6.17.5 Proposed reference points

The yield curve for North Sea whiting is skewed to the left, although it is still relatively flat (Figure 6.17.1).

6.17.2 Summary table of proposed stock reference points for method Eqsim:

STOCK	WHITING IN SUBAREA IV AND DIVISION VIID
Reference point	Value
F_{MSY}	0.209
F_{MSY} lower	0.144
F_{MSY} upper	0.336
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	0.074
F_{MSY} upper precautionary without $B_{trigger}$	0.074 (this study) or 0.15 (from MSE of long-term management plan, ICES 2013a)
FP.05 (5% risk to B_{lim} with $B_{trigger}$)	n/a (no $B_{trigger}$ value available)
F_{MSY} with $B_{trigger}$	n/a (no $B_{trigger}$ value available)
F_{MSY} lower with $B_{trigger}$	n/a (no $B_{trigger}$ value available)
F_{MSY} upper with $B_{trigger}$	n/a (no $B_{trigger}$ value available)
F_{MSY} upper precautionary with $B_{trigger}$	n/a (no $B_{trigger}$ value available)
MSY	21 775 t
Median SSB at F_{MSY}	315 000 t
Median SSB lower (median at F_{MSY} upper pr)	214 447 t
Median SSB precautionary (median at FP.05)	515502 t
Median SSB upper (median at F_{MSY} lower)	398 034 t

*An MSE conducted to evaluate the EU-Norway long-term management plan for whiting in the North Sea (ICES, 2013a) concluded that fishing at F=0.15 (with a 15% inter-annual TAC constraint) can be considered precautionary (5% long-term probability that SSB<B_{lim}) under the assumption that recruitment stays within a medium-low range. The difference found with the current Eqsim analysis is considered to be arising mainly because of different recruitment assumptions. The MSE evaluation in 2013 considered medium and low recruitment levels, with the same recruitment "regime" lasting for several years, in order to approximate the recruitment patterns observed for this whiting stock.

Note that most of the estimates are taken from a run with no trim applied in Eqsim. The summary Figures (Figures 6.17.2 to 6.17.4) include a 5% trim because infinite landings were possible without it, due to extreme S-R models. However, the median values from both runs are very similar and the principal conclusions are consistent between them.

6.17.6 Discussion / Sensitivity.

North Sea whiting has a very shallow stock-recruit curve at the origin, and hence a very low estimate of F(5%). If this is used as an upper constraint on F_{MSY}, then the fishing mortality assumed in advice will be very low indeed. The available median F_{MSY} estimates are not consistent with the conclusions from the earlier management plan evaluation (ICES-WGNSSK 2013). In this evaluation, recruitment was considered to have changed over time and with low and high recruitment regimes. The MSE carried out at WGNSSK concluded that F_{MSY} was 0.15. The analysis based on the MSE is more fully developed and it is considered that the value of F_{MSY} = 0.15 is more appropriate.

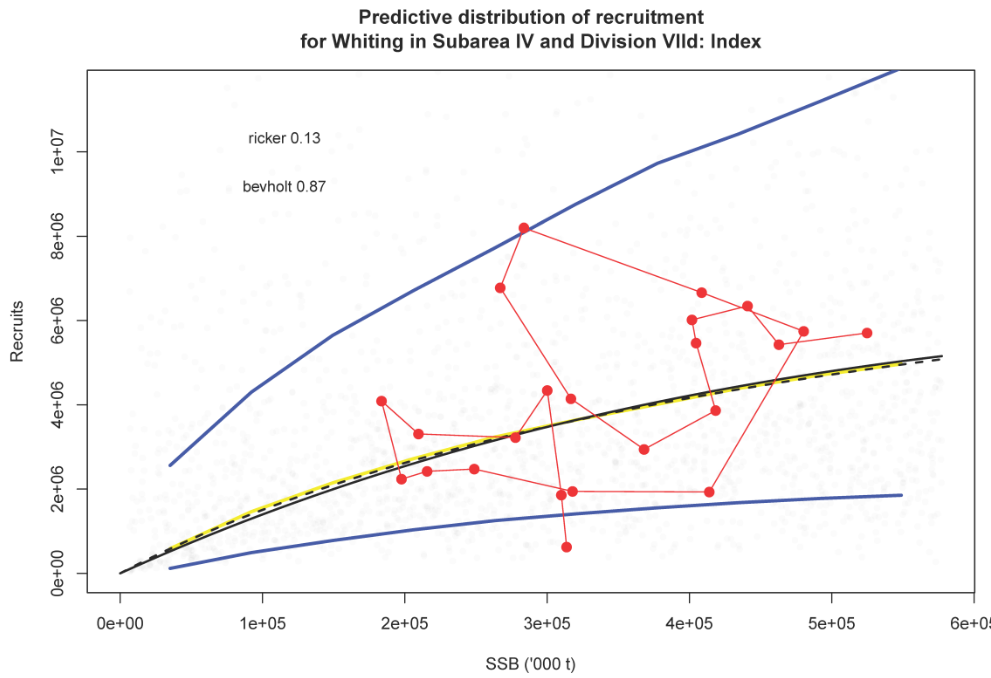

Figure 6.17.1. Summary of recruitment models (Ricker, Beverton-Holt) for North Sea whiting. Stock recruit observations (red dots) and fitted relationships: Ricker (dashed) and Beverton Holt (solid). Simulated values , median (yellow) and 90% (blue) based on combined models in Eqsim.

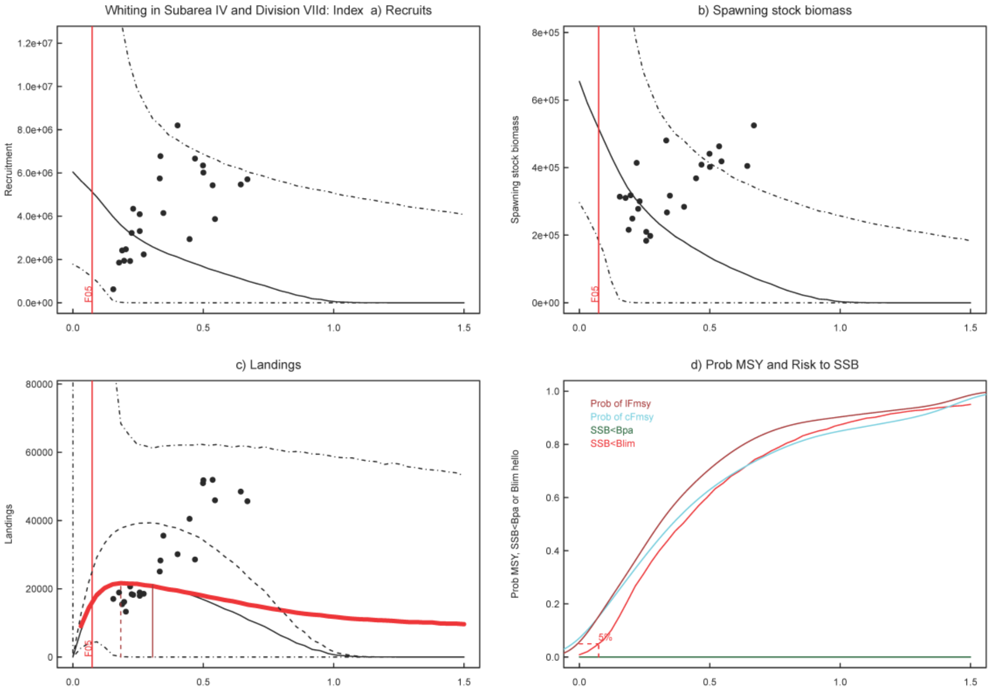

Figure 6.17.2. Eqsim summary plot for North Sea whiting (5% trim, no $B_{trigger}$). Panels a-c: historic values (dots) median (solid black) and 90% intervals (dotted black) recruitment, SSB and landings for exploitation at fixed values of F. Panel c also shows mean landings (red solid line). Panel d 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) or catch (cyan).

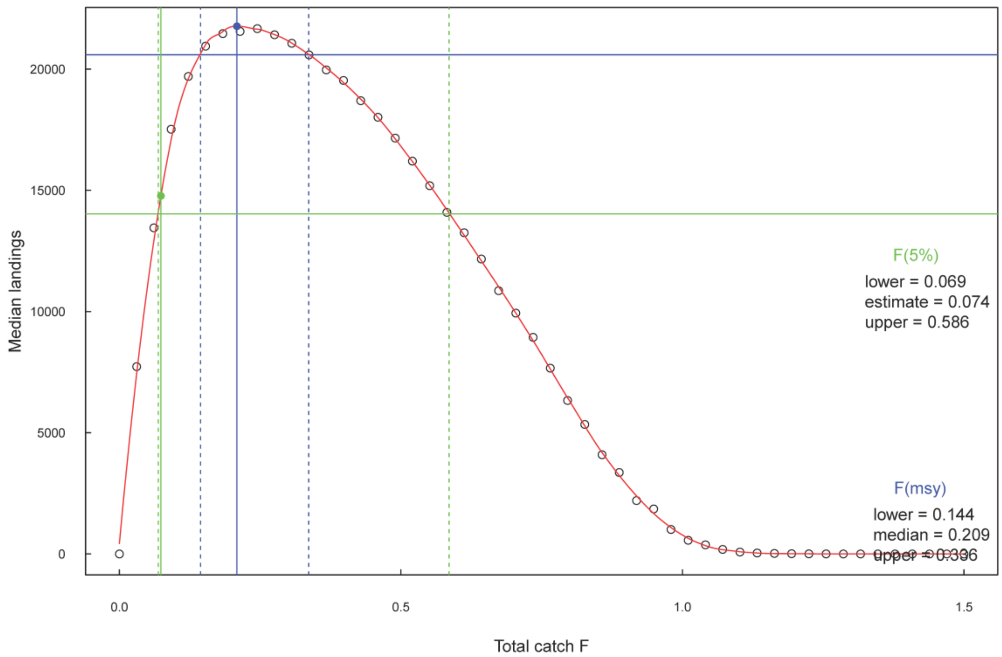

Figure 6.17.3. Median landings yield curve with estimated reference points (trimmed analysis). Blue lines: F($_{MSY}$) estimate (solid) and range at 95% of maximum yield (dotted). Green lines: F(5%) estimate (solid) and range at 95% of yield implied by F(5%) (dotted).

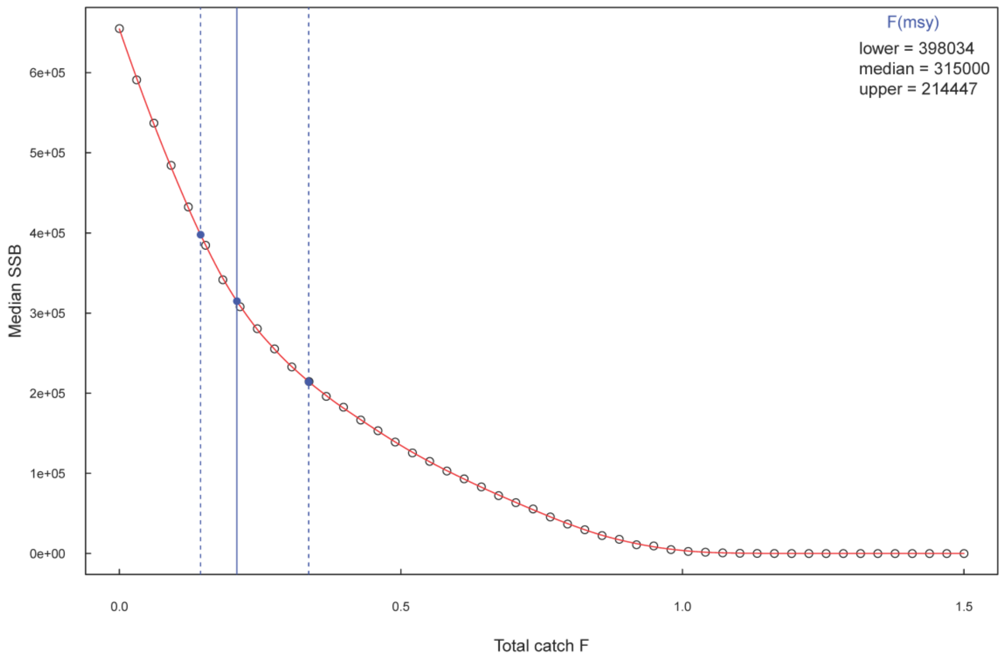

Figure 6.17.4. Median SSB for North Sea whiting over a range of target F values (trimmed analysis). Blue lines show location of F(MSY) (solid) with 95% yield range (dotted).

7 Megrim in Divisions IVa and VIa.

A surplus production model, including process error, is used for the assessment of this stock (fitted with Bayesian methods); ICES (2012a), ICES (2014c).

The population biomass dynamics corresponding to this model are (in continuous time form):

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

The following discrete time implementation of the model is used for the megrim assessment:

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

In this discrete time implementation, B_j, F_j, C_j denote stock biomass, fishing mortality and catch in year j, and u_j follows a Normal(0,σ^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)

For this stock, MSY B_{trigger} has been defined as $0.5\frac{K}{2} = 0.25\,K$ and B_{lim} has been defined as $0.3\frac{K}{2} = 0.15\,K$.

7.1.1 Current reference points

Table 7.1.1 Summary table of current stock reference points. Note that for megrim the numerical value of the reference points is updated at each assessment.

Reference point	Value
Current F_{MSY}	r/2
Current B_{lim}	$0.15\,K$
Current MSY $B_{trigger}$	$0.25\,K$

7.1.2 Suggested analysis based on a counterpart to the Eqsim software

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, an MSE-type analysis (similar to Eqsim) can be performed as follows:

In order to generate an equilibrium catch curve for different values of F, a vector Fscan would be created containing a range of values of F over which to scan. For each value of F in the vector Fscan, a long-term projection is run (say "Nrun" years into the future; e.g. Nrun=200). In each year j, the following population dynamics equation is applied:

$$B_j = \left\{B_{j-1} + r\,B_{j-1}\left(1 - \frac{B_{j-1}}{K}\right) - B_{j-1}F_{j-1}^{real}\right\} e^{u_j} \quad (3)$$

$$C_j = B_j\,F_j^{real} \quad (4)$$

where u_j follows a Normal(0,σ^2) distribution. This error can be independent from year to year or an autocorrelation can be introduced as appropriate for the stock (Walters et al 2008).

For each value of F in Fscan and future year j: "Niter" biomass and catch values are drawn from equations (3) and (4). "Niter" values for the parameters (r, K, σ^2) should be drawn from the posterior distribution corresponding to the Bayesian fit of the stock assessment model. The same Niter parameter values are used for all F values in Fscan and all future years j.

The values F_{j-1}^{real} and F_j^{real} in equations (3) are (4) should be either:

a) Identical to the value of F from Fscan. This corresponds to the case with no assessment/implementation error.

b) Obtained from the F in Fscan, applying an error to it (e.g. AR(1) error for log(F) as done in the Eqsim software). This corresponds to the case with assessment/implementation error.

c) There could also be a HCR that, for year j, decreases F linearly if $B_j < B_{trigger}$. This corresponds to testing a HCR instead of a flat F.

A number of years from the end of the "Nrun" simulation years (e.g. the last 50 years out of a total of 200 in the simulation) would be used to calculate the long-term equilibrium catch and the probability that $B < B_{\text{lim}}$ (as a function of the F values in Fscan).

For each value of F, the median equilibrium catch would be obtained; this would produce a single curve (median equilibrium catch) as a function of F. The range of values of F that lead to a median equilibrium catch ≥ 95% of the maximum of this curve is the range of values of F considered consistent with MSY. To stay within precautionary boundaries, it is additionally required that all values of F in the proposed range should correspond to less than 5% probability that $B < B_{\text{lim}}$, so any value of F that does not fulfil this property is left out of the proposed range.

This analysis would be the counterpart of what is currently done in Eqsim for age-based assessment models but would require some programming, which has not been conducted to date. The outputs would be calculated as for Eqsim.

7.1.3 A simple alternative based on a deterministic calculation

A simpler alternative that could provide a first approximation is not to consider the process error in equation (2), therefore treating the population dynamics as deterministic and additionally, not to consider assessment/implementation error (i.e. case a) above).

Under these simplifying assumptions, the population dynamics model in (2) [or (1)] is in equilibrium when

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

Solving equation (5) for biomass, leads to the following equilibrium biomass and catch (as a function of F):

$$B = K\,\left(1-\frac{F}{r}\right) \qquad (6)$$

$$C = K\,F\,\left(1-\frac{F}{r}\right) \qquad (7)$$

It is clear from the above equations that maximum equilibrium catch is obtained at $\text{F}_{\text{MSY}} = r/2$. The catch and biomass associated with F_{MSY} are MSY = $Kr/4$ and $\text{B}_{\text{MSY}} = K/2$. This is also shown in Figure 8.1.

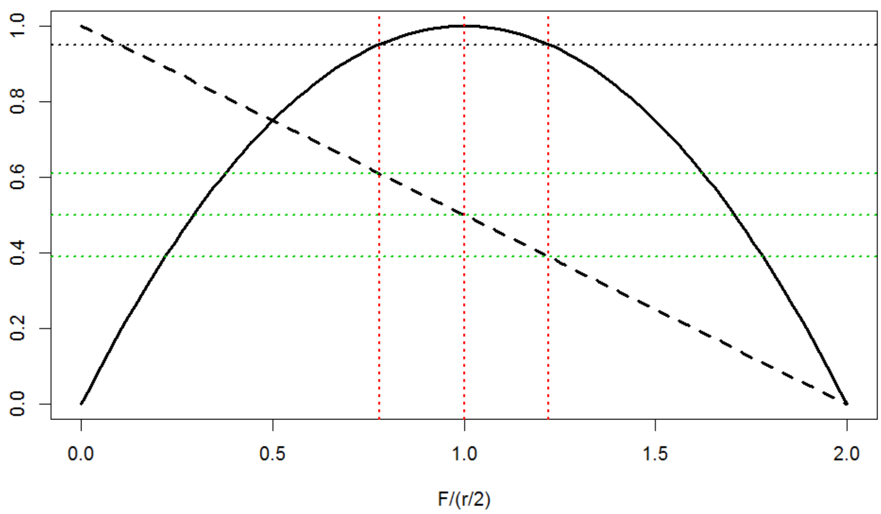

Figure 7.1: Equilibrium catch (solid black line) and biomass (dashed black line) as a function of $F/(r/2)$, based on a deterministic calculation. In the figure, both the equilibrium catch and biomass are scaled so that each has a maximum equal to 1. Maximum catch is obtained at $F_{MSY} = r/2$ (shown 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 ≥ MSY.

From equation (7) it is immediate that the range of Fs that give equilibrium catch ≥ 0.95 MSY is obtained by solving (for F):

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

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 7.1.

According to equation (6), 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 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 we define the upper end of the range for F. 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 $B < B_{lim}$.

7.1.4 Proposed reference points

Table 7.1.2 Summary table of proposed stock reference points

STOCK	MEGRIM IN DIVISIONS IVA AND VIA
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}
New FP.05 (5% risk to B_{lim} without $B_{trigger}$)	-
F_{MSY} upper precautionary	F_{MSY}

8 MSY interval analysis by stock: Nephrops stocks

The following Functional Units are considered for the ICES assessment and advice for *Nephrops* in Subarea IV and Division IIIa. The functional units are shown in the following Table and map (Figure. 8.1, Table 8.1).

Table 8.1. *Nephrops* functional units in Subarea IV and Division IIIa and ICES advice basis

FU no.	Name	ICES advice basis
3-4	Skagerrak-Kattegat	MSY approach
5	Botney Gut – Silver Pit	Data limited approach
6	Farn Deeps	MSY approach
7	Fladen Ground	MSY approach
8	Firth of Forth	MSY approach
9	Moray Firth	MSY approach
10	Noup	Data limited approach
32	Norwegian Deep	Data limited approach
33	Off Horn's Reef	Data limited approach
34	Devil's Hole	Data limited approach

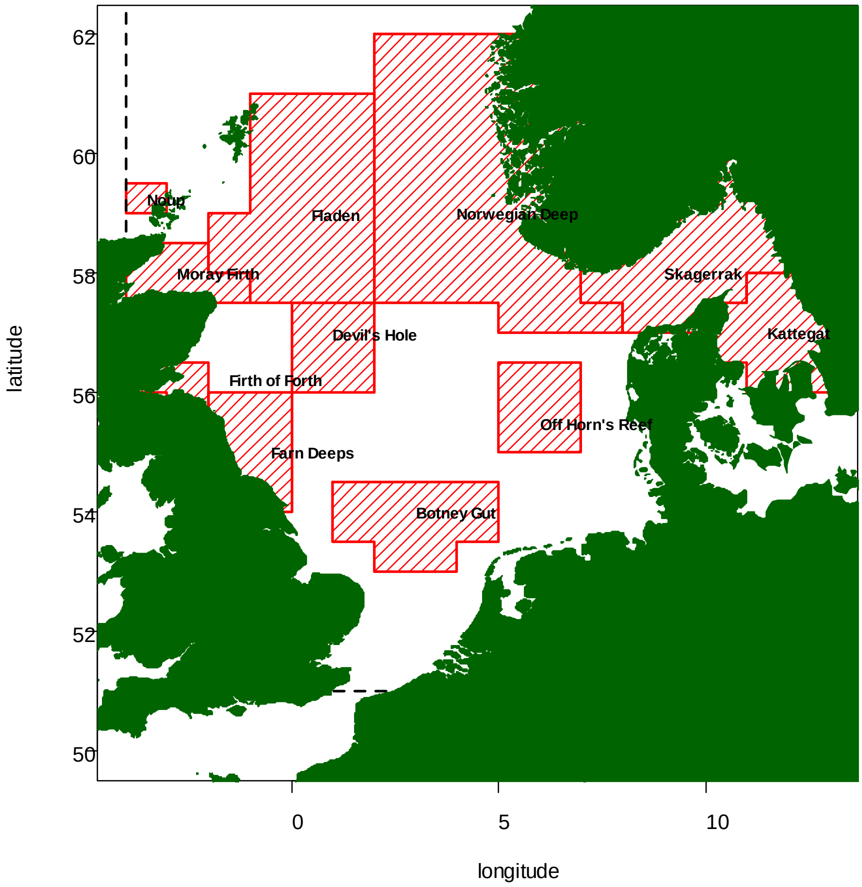

Figure 8.1 Geographical layout of Nephrops functional units in the North Sea, Skaggerak and Kattegat

8.1 Functional Units FU6 (Farn Deeps), FU7 (Fladen Ground), FU8 (Firth of Forth), FU9 (Moray Firth) and FU3-4 (Skagerrak-Kattegat).

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, but for FU6 the value corresponding to males was considered more suitable to try and protect against low numbers of male spawners observed in the past. A decision making framework for the choice of F_{MSY} proxy reference points is available in the introduction to the *Nephrops* ICES advice sheets.

8.1.1 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 that at F_{max}.

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 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 8.2).

Table 8.2. F_{MSY} ranges of functional Units FU6 (Farn Deeps), FU7 (Fladen Ground), FU8 (Firth of Forth), FU9 (Moray Firth) and FU3-4 (Skagerrak-Kattegat).

STOCK	FU6	FU7	FU8	FU9	FU3-4
Reference point					
Current F_{MSY}	8.1%	10.3%	16.3%	11.8%	7.9%
Rationale F_{MSY}	F35%SPR males	F0.1 combined sexes	Fmax combined sexes	F35%SPR combined sexes	Fmax combined sexes
Current MSY $B_{trigger}$ (millions)	858	2767	292	262	
New F_{MSY} = current F_{MSY}	8.1%	10.3%	16.3%	11.8%	7.9%
F_{MSY} lower	7%	8.8%	10.6%	9.1%	
F_{MSY} upper	17%	28%	25%	23%	
F_{MSY} upper precautionary	8.1%	10.3%	16.3%	11.8%	

8.2 Functional Units FU5 (Botney Gut – Silver Pit), FU10 (Noup), FU32 (Norwegian Deep), FU33 (Off Horn's Reef) and FU34 (Devil's Hole).

There are no abundance estimates for these functional units. The ICES advice follows the data-limited approach and no F_{MSY} proxy reference points are available for them. In order to give advice, ICES considers average catches or landings of the last ten years as the default option, after the following sensitivity check for precautionary considerations is made: A range of stock densities considered plausible (gathered through preliminary surveys or assumed based on neighbouring FUs) is considered, and the resulting harvest rates (for the average catches or landings of the last 10 years) are calculated. If all these plausible harvest rates are below the minimum F_{MSY} harvest rate calculated for the functional units in the North Sea (i.e. 8%, corresponding to FU6), this is considered a precautionary state and advice is given on the basis of the average catches or landings of the last 10 years. Where some of the plausible harvest rates resulting from this procedure are higher than 8%, additional precautionary reductions are considered and a lower catch advice is provided (in these cases, the average landings or catches of the last 3 years are typically examined as a potential alternative; 20% additional reductions (precautionary buffer) are incorporated if considered necessary).

It is important to note that the basis for advice for these stocks is the average catches or landings of some historic period (typically the last 10 years). The 8% acts as a hard limit, in the sense that the range of harvest rates considered plausible under the advice provided should, in all cases, be below 8%, but this limit does not drive the advice in any other way.

Given the above, it is not possible to provide F_{MSY} ranges for these stocks at this stage.

9 MSY interval analysis by stock: Data limited stocks

This section considers data-limited stocks for which the ICES advice for these stocks is based on the data-limited approach, except for *Nephrops*, which are considered in section 8.

9.1 Stocks in Category 3: Plaice in the Skagerrak and Anglerfish in Division IIIa and Subareas IV and VI.

For both these stocks, the advice is based on the so-called data-limited approach method 3.2.0. This means that the advice is based on recent catches, modified according to survey trends, and applying a ±20% cap to deal with uncertainty and an additional 20% reduction (precautionary buffer) if this is considered necessary. No reference points are defined for these stocks.

Given the above, it is not possible to provide F_{MSY} ranges for these stocks at this stage. However, the plaice stock will be benchmarked at the start of 2015 and changes may occur following this.

9.2 Stocks in Category 5: Whiting in Division IIIa.

For this stock, the advice is based on the so-called data-limited approach method 5.2.0. This means that the advice is based on recent catches (no survey trends are available). A 20% reduction over recent catches (precautionary buffer) was applied in the advice provided in 2012; the advice has not changed since that year. No reference points are defined for this stock.

Given the above, it is not possible to provide F_{MSY} ranges for this stock at this stage.

10 Summary of results

Table 10.1 shows the results for all stocks based on fixed F and Table 10.2 F based on a harvest control rule with $MSYB_{trigger}$. Ranges are given both based on fixed fishing mortalities at all levels of F and based on F estimated from a HCR where F decreases to zero for SSB going from $MSYB_{trigger}$ towards zero.

The use of $MSYB_{trigger}$ is a standard element in the ICES MSY approach. The effect of this is that target F is reduced linearly to zero at zero biomass. The intention of this is not to exploit the stock specifically at Fs that result in biomasses below the $MSYB_{trigger}$ but to guard against stock deletion at low biomass. If F_{p05} based on a fixed F is $>F_{MSY}$ then fishing with targets Fs above F_{MSY} will always result in less than maximum yield. If an HCR with reduced F is in use, on average even though the target F is > F_{p05} the realised F will be lower and the yield no greater. Only if F_{p05} is lower than F_{MSY} will the inclusion of the ICES MSY HCR deliver increased yield. The increased flexibility implied by an increased F in the interval above F_{MSY} if the ICES F_{MSY} HCR is implemented will only provide real increased F if SSB is high, as under other circumstances the annual advised F will be reduced by the HCR.

Table 10.3 shows the results for stocks based on fixed F exploitation modified by the a the precautionary considerations resulting from the inclusion of a harvest control rule with $MSYB_{trigger}$. Ranges are given both based on fixed fishing mortalities at all levels of F and based on F estimated from a HCR where F decreases to zero for SSB going from $MSYB_{trigger}$ towards zero. The procedure of selectiong F_{MSY} and MSY intervals limited by precautionary considerations is compatible with the procedures recommended in ICES (2014g) and used by ICES to estimate F_{MSY} throughout 2014.

Table 10.1 Estimates of F_{MSY}, $F_{MSYLower}$ $F_{MSYUpper}$ without implementation of ICES MSY HCR

STOCK	FP.05	F_{MSY}	F_{MSY}LOWER	F_{MSY}UPPER
Cod in Subdivisions 22-24	1.07	0.28	0.16	0.53
Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId	0.70	0.20	0.13	0.33
Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)	0.512	0.372	0.248	0.512
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	0.22	0.22	0.16	0.22
Herring in Subdivision 28.1 (Gulf of Riga)	-	0.32	0.24	0.32
Herring in Subdivision 30 (Bothnian Sea)	-	0.12	0.09	0.12
Herring in the North Sea Long timeseries (1947-2012)	0.35	0.33	0.24	0.35
Herring in the North Sea Short timeseries (2002-2012)	0.25	0.25	0.23	0.25
Herring in Division IIIa and Subdivisions 22-24 (Western Baltic Spring Spawners)	0.46	0.32	0.23	0.41

Horse mackerel in Divisions IIa, IVa, Vb, VIa, VIIa–c, e–k, and VIIIa–e (Western stock)	-	0.060	0.044	0.060
Plaice in Subarea IV (North Sea)	0.48	0.19	0.13	0.27
Plaice VIId	0.49	0.25	0.15	0.43
Saithe in IV, IIIaN and VIa	0.39	0.32	0.2	0.39
Sole in Div. IIIa and areas 22-24 (Kattegat sole) short time series (1992-2013)	0.232	0.222	0.174	0.232
Sole in Div. IIIa and areas 22-24 (Kattegat sole) long time series (1984-2013)	0.377	0.401	0.292	0.377
Sole in Subarea IV (North Sea)	0.37	0.35	0.24	0.37
Sole in Div. VIId	0.39	0.30	0.16	0.39
Sprat in Subdivisions 22–32 (Baltic Sea) (short time series)	-	0.26	0.19	0.34
Sprat in Subdivisions 22–32 (Baltic Sea) (long time series)	0.15	0.15	0.14	0.15
Whiting in Subarea IV and Division VIId	0.15	0.15	0.144	0.15
Nephrops FU6		8.1%	7%	8.1%
Nephrops FU7		10.3%	8.8%	10.3%
Nephrops FU8		16.3%	10.6%	16.3%
Nephrops FU9		11.8%	9.1%	11.8%
Megrim in Divisions IVa and VIa	-	$r/2$	0.78 F_{MSY} (= 0.39 r)	F_{MSY} (= $r/2$)

Table 10.2 Estimates of F_{MSY}, $F_{MSYLower}$ $F_{MSYUpper}$ with ICES MSY HCR using $MSYB_{trigger}$ shown.

STOCK	$MSYB_{TRIGGER}$	FP.05	F_{MSY}	F_{MSY}LOWER	F_{MSY}UPPER
Cod in Subdivisions 22-24	36400 t	1.08	0.27	0.16	0.55
Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId	150000 t	1.06	0.20	0.14	0.33
Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)	88000 t	0.546	0.380	0.248	0.546

Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	600000 t	0.28	0.24	0.17	0.28
Herring in Subdivision 28.1 (Gulf of Riga)	60000 t	-	0.35	0.25	0.35
Herring in Subdivision 30 (Bothnian Sea)	316000 t	-	0.12	0.10	0.12
Herring in the North Sea	1000000 t	0.381	0.348	0.240	0.381
Herring in Division IIIa and Subdivisions 22-24 (Western Baltic Spring Spawners)	110000 t	0.52	0.32	0.23	0.41
Plaice in Subarea IV (North Sea)	230000 t	0.48	0.19	0.13	0.27
Saithe in IV, IIIaN and VIa	200000 t	0.57	0.37	0.21	0.57
Sole in Div. IIIa and areas 22-24 (Kattegat sole) short time series (1992-2013)	2000 t	0.338			
Sole in Div. IIIa and areas 22-24 (Kattegat sole) long time series (1984-2013)	2000 t	0.545			
Sole in Subarea IV (North Sea)	35 000 t	0.41	0.38	0.25	0.41
Sole in Div. VIId	8000 t	0.41			
Sprat in Subdivisions 22–32 (Baltic Sea) (long time series)	570000 t	0.19	0.19	0.16	0.19

Table 10.3 Estimates of F_{MSY}, $F_{MSYLower}$ $F_{MSYUpper}$ modified by precautionary consideratons (Fp05hcr) due to inclusion of implementation of ICES MSY HCR

Stock	Fp05hcr	$MSYB_{trigger}$	F_{MSY}	F_{MSY} lower	F_{MSY} upper
Cod in Subdivisions 22-24	1.08	36400 t	0.28	0.16	0.53
Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId	1.06	150000 t	0.20	0.13	0.33
Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)	0.55	88000 t	0.37	0.25	0.51
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	0.28	600000 t	0.23	0.16	0.28
Herring in Subdivision 28.1 (Gulf of Riga)	0.38	60000 t	0.32	0.24	0.38
Herring in Subdivision 30 (Bothnian Sea)	0.13	316000 t	0.12	0.09	0.13
Herring in the North Sea Long timeseries (1947-2012	0.38	1000000 t	0.33	0.24	0.38
Herring in the North Sea Recent recruitment (2002-2012	0.29	1000000 t	0.29	0.25	0.29
Herring in Division IIIa and Subdivisions 22-24 (Western Baltic Spring Spawners)	0.52	110000 t	0.32	0.23	0.41
Horse mackerel in Divisions IIa, IVa, Vb, VIa, VIIa–c, e–k, and VIIIa–e (Western stock)					
Plaice in Subarea IV (North Sea)	0.48	230000 t	0.19	0.13	0.27
Plaice VIId					
Saithe in IV, IIIaN and VIa	0.57	200000 t	0.32	0.20	0.42
Sole in Div. IIIa and areas 22-24 (Kattegat sole) short time series (1992-2013)	0.34	2000 t	0.22	0.17	0.26
Sole in Div. IIIa and areas 22-24 (Kattegat sole) long time series (1984-2013)	0.55	2000 t	0.40	0.30	0.55
Sole in Subarea IV (North Sea)	0.41	35 000 t	0.35	0.24	0.41
Sole in Div. VIId	0.41	8000 t	0.30	0.16	0.41
Sprat in Subdivisions 22–32 (Baltic Sea) (short time series)					
Sprat in Subdivisions 22–32 (Baltic Sea) (long time series)	0.19	570000 t	0.19	0.14	0.19

In general, the results of the analyses highlighted the need to include precautionary considerations in the definition of F_{MSY} and therefore also the need to define precautionary biomass limits for all stocks (Fig 10.1.1). In an attempt to derived general guidelines, the median of the 18 estimated lower and upper limits to the range were estimated at 69% and 135% of F_{MSY}, respectively. Hence, the interval was slightly asymmetrical.

Investigating the meta-data, it appeared that species with a higher average length at old ages (Linf) tended to have values of FP05 that exceeded F_{MSY}upper, whereas species with a lower Linf tended to have values of FP05 which were equal to F_{MSY} (fig. 10.1.1). There were two extreme values of FP05 compared to F_{MSY}, that of western Baltic cod which was very high and that of North Sea whiting which was very low. Both FP05 rely heavily on the agreed value of B_{lim}, and hence any change to this parameter is likely to change the result, though not to the extent that the points for these stocks would fall into the estimated F_{MSY} range. For western Baltic cod the intervals specified are not thought to be sensitive to this issue.

Four other stocks are identified as particularly sensitive to the recruitment assumptions: Baltic sprat shows high recent recruitment supporting the current values but would not be precautionary if earlier Baltic regimes are considered; Saithe in III,IV and VI, sole in IIIa and NS herring show decreased recruitment success over time and it should be considered whether these are likely to persist and hence new estimates of F_{MSY} should be calculated. Of these four stocks, the change in herring and saithe recruitment was recent (app. 10 years) and the persistence of the change is still uncertain. WKMSYREF3 recommends continued monitoring of recruitment success together with an increased focus on the precauitonarity of management for these stocks and consideration of which intervals should be used for stocks that have 10 or more years of low recruitment.

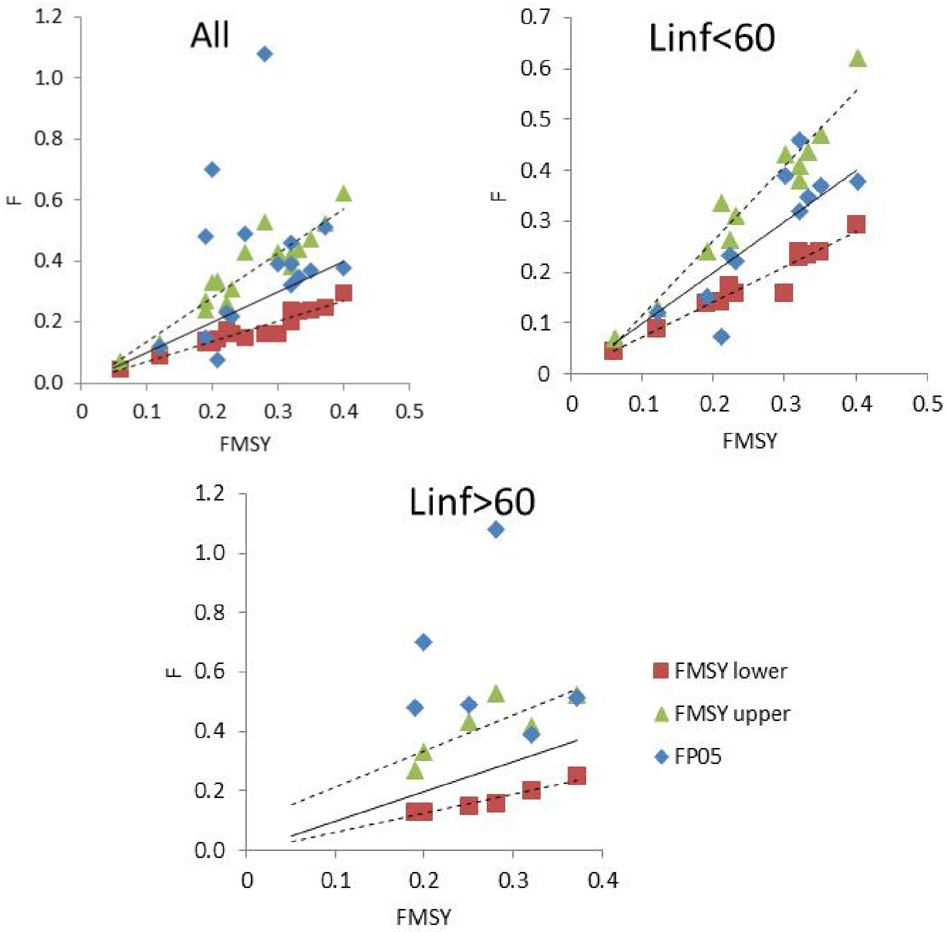

Fig. 10.1.1. F_{MSY}lower, F_{MSY}upper and FP.05 as a function of F_{MSY}. Solid line shows 1:1, hatched lines are regression lines of F_{MSY}lower and F_{MSY}upper. Top panel shows all values, bottom panels show values for small (Linf<60 cm) and large (Linf>60 cm) species.

11 General guidance in the estimation of F_{MSY} ranges

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 falling below B_{lim} in a year in long term simulations with fixed F was 5%. The recommended approach to defining F_{MSY}, F_{MSY} ranges and $F_{P.05}$ is described in detail in section 3. The group considered that these guidelines should be followed to define F_{MSY}, F_{MSY} ranges and $F_{P.05}$ and that these values should be updated at reasonable intervals. However, it was also clear to the group that it may not be possible for to perform the full analysis for all stocks right away. In these case, the recommendation is given in Table 11.1

Table 11.1 Guildines for establishing MSY ranges.

Status	Short term assumption	Long term action necessary
F_{MSY} and an estimate of FP05 based on fixed F are available and F_{MSY}upper<FP05	F_{MSY}lower= 0.69F_{MSY} F_{MSY}upper= 1.35F_{MSY}	Perform an estimation of the range according to guidelines in sec. 3 of this report
F_{MSY} and an estimate of FP05 based on fixed F are available and F_{MSY}<FP05<1.35F_{MSY}	F_{MSY}lower= 0.69F_{MSY} F_{MSY}upper= FP05	Perform an estimation of the range according to guidelines in sec. 3 of this report
F_{MSY} and an estimate of FP05 based on fixed F are available and F_{MSY}>FP05	F_{MSY}lower= 0.69FP05 F_{MSY}upper= FP05	Perform an estimation of the range according to guidelines in sec. 3 of this report
F_{MSY} based on fixed F is available but an estimate of FP05 is not available	F_{MSY}lower= 0.69F_{MSY} F_{MSY}upper= F_{MSY}	Perform an estimation of FP05 and F_{MSY} range according to guidelines in sec. 3 of this report

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Annex 1: List of participants

Name	Role
Coby Needle	participant
John Simmonds	Chair
Massimiliano Cardinale	participant
David Miller	participant
Alexander Kempf	participant
Willy Vanhee	participant
Anna Rindorf	Chair
Liane Veitch	participant
Anders Nielsen	participant
Anna Luzenczyk	participant
Henrik Sparholt	participant
Gustaf Almqvist	participant
Morten Vinther	participant
Carmen Fernandez	participant
José De Oliveira	participant
Lotte Worsøe Clausen	participant
Jurgen Batsleer	participant

Annex 2: Technical Minutes

The Technical Minutes contains two parts. One is the report of the external reviewers and the other is the analysis of *Nephrops* in FU 3-4, which time did not allow WKMSYREF3 to complete at the meeting.

RG/ADGFMSY, 16–19 March 2015

Review of the ***Report of the Joint ICES-MYFISH Workshop to consider the basis for FMSY ranges for all stocks (WKMSYREF3)*** ICES CM 2014/ACOM:64 REF. ACOM

Reviewers: Robin Cook (UK), Manuela Azevedo (PT)

General comments

The WKMSYREF3 report focusses on the Fmsy ranges for a number of stocks in the North Sea and Baltic Sea as requested by managers. The principal boundary placed on the range is that the "target" F should result in at least 95% of MSY. Additional constraints are set to reduce the risk of falling below Blim and F exceeding Flim ($FP_{.05}$, F corresponding to 5% probability of $SSB<B_{lim}$). Overall the analysis was thorough and well thought out. The proposed Fmsy ranges provide a sound basis for advice though it is necessary to take some care in the interpretation of the ranges. Also, the estimated MSY and B_{MSY} should regarded as theoretical values that may not be achieved in practice and should, therefore, be interpreted with caution.

In order to estimate MSY it is necessary to model the stock-recruitment relationship in as realistic way as possible and for most stocks this presents perhaps the greatest challenge. Three main methods are considered. These are Eqsim, stock assessment.org (SA) and an analytical method attributed to Horbowy and Luzenczyk (HL). All three methods have their strengths and weaknesses and all provide a satisfactory basis to derive MSY reference points. Eqsim was the standard method adopted by the group to provide the estimates of F_{MSY} ranges and the RG agree that this method came closest to modelling the required values. However, both SA and HL provide important alternative ways of estimating MSY with significantly different recruitment models. In fact, for some stocks more than one method was applied and this offers a very useful way of exploring structural uncertainty.

All the analyses are based on single species population dynamics and hence assume invariant biological parameters such as growth, maturity and non-fishing mortality. Multispecies models or full ecological models are likely to deviate significantly from these assumptions leading to very different estimates of MSY. This will matter mainly if managers expect to realise the yields or equilibrium biomass associated with the estimated MSY. In general one might expect both realised yield and biomass to be less than is estimated from MSY in single species models because of energy constraints in the system and dynamic predation mortalities. However, single species MSY does provide an adequate basis for the estimation of a moderate sustainable fishing mortality that will have a low probability of compromising long term yield. It is in this context that the Fmsy ranges in the report should be considered.

Eqsim: This method is perhaps the most comprehensive in dealing with the advice request taking in to account uncertainty in a variety of input values. The method fits up to three standard stock recruitment functions and weights the results according to a goodness of fit criterion. The method addresses the question "what target F will produce MSY within the designated boundary conditions?" rather than explicity estimating Fmsy analytically.

Stockassessment.org : This method models the stock-recruitment relationship using a non-parametric approach proposed by Cadigan (2013). In general the fitted functions showed strong overcompensation beyond the range of observed values which will tend to result in higher values of Fmsy and lower values of Bmsy than asymptotic stock-recruitment curves. The method was used in a small number of stocks but did not provide the basis for proposed Fmsy ranges.

Horbowy– Luzenczyk

This approach is closest to a conventional MSY calculation where closed form solutions to Fmsy and Bmsy are given for Beverton-Holt and Ricker models. Uncertainty in input values can be used to estimate uncertainty in MSY reference points. This method was used for some stocks in the Baltic but was not used for advice on Fmsy ranges.

The way the ToRs are framed means that the range of Fmsy is defined by the shape of the yield curve and hence the estimated ranges do not reflect full uncertainty in the estimates of Fmsy itself. In all the Eqsim outputs, for example, median values have been used to describe the yield curve so that the Fmsy range is conditioned on the shape of this curve. This is an important point because the choice of recruitment function can have a profound effect on the shape of the yield curve and this is of particular significance for the right hand (descending) limb of the curve which tends to be asymmetric. It can mean that 95%MSY can be achieved by over-exploiting the stock at comparatively large values of F. This can most obviously be seen for cod in 22-24 where the right hand side of the yield curve is quite flat (Fig 6.2.2) and gives an upper bound on Fmsy of 0.53, almost twice the Fmsy value of 0.28. Some thought needs to be given to this problem and in particular whether segmented regression, which is a major factor in this feature, is a useful way of describing recruitment when trying to estimate MSY values.

The high upper bound on Fmsy for some stocks will, of course, be associated with much lower equilibrium biomass. It is necessary to consider the risks to the stock associated with the upper bound of F_{MSY}, which is not dealt with explicitly in the current analysis.

Segmented Regression

Recruitment estimates are by nature highly variable making the identification of a suitable recruitment function difficult or impossible. In the analysis presented in the report a very simple segmented regression often forms the basis of the Fmsy calculation for a number of stocks. Some care is needed in the use of this function. The consequence of its use is that the yield curve derived from it is effectively yield per recruit scaled by mean recruitment up to the boundary of Fcrash. A question arises as to whether describing the population dynamics in terms of Fcrash and mean recruitment is adequate for generating plausible estimates of MSY. The particular issue is whether the dynamics outside the range of observed values is adequately captured by a linear descriptor. On the one hand, higher values of F will hit the Fcrash boundary and imply low stock resilience while low Fs will result in constant recruitment however large the SSB becomes. Neither of these characteristics is attractive biologically and there is a need to consider the sensitivity of the estimated MSY when the simulations (in Eqsim, for example) are run. While in the case of North Sea cod a truncated recruitment series is investigated as a sensitivity test, this demonstrates very little because with the segmented regression the only tangible change is a lower mean recruitment which simply rescales the same yield curve with little effect on Fmsy. Hence it cannot demonstrate any sensitivity to alternative assumptions about the recruitment function.

Stationarity in stochastic variables

Eqsim introduces variability in a number of biological parameters. The variability is typically assumed to be around a stationary mean. While such an approach does capture some natural variability, the use of median MSY values to define Fmsy largely loses the value of much of this variation. In practice, quantities such as growth and maturity, even natural mortality are likely to show trends, even over modest periods of time and may need to be modelled more explicitly. There are, for example, trends in natural mortality as estimated for North Sea stocks from MSVPA. This has potential relevance to the estimation of Fmsy.

Recommendations/Suggestions for future work

Some suggestions are provided for future work aiming at estimating F_{MSY} ranges that the group may want to consider:

- Exploring structural uncertainty in the S-R relationship: apply the several methods (Eqsim, SA, HL) to every stock. To some degree the model averaging performed by Eqsim hides the range of plausible model uncertainty. It is also suggested to use Eqsim with one recruitment model at a time before full model averaging is performed in order to demonstrate sensitivity to structural assumptions.
- Use of prior knowledge for S-R parameters: Each analysis presented in the report assumes that nothing is known about the stock recruitment function other than that which is contained in the stock data alone. Where few years of S-R data are available, or the observations appear uninformative, it is difficult to fit a functional form with any confidence. A possible way to improve the S-R modelling is to assume that at least within species/stock classes, information from one stock can provide some useful prior information for another. Meta-analyses have been done, for example, to estimate the slope at the origin for stocks worldwide (see Myers) and such analyses could be used to constrain or inform the estimation of stock-recruitment parameters for stocks with limited information. It could help especially in defining the left hand side of the stock-recruitment relationship where the segmented regression "Fcrash" assumption is speculative.
- North Sea whiting: Early stock assessments of whiting used data from 1963 onwards while more recent ICES assessments have used a truncated time series from 1990. As a result the stock-recruitment data available for the analysis are restricted to this more recent period with the consequence that it is harder to model the stock-recruitment function. For MSY calculations it is desirable to use a much recruitment data as possible and it would be useful to re-examine whether a more complete stock assessment could be done to assist in the MSY analysis. This issue may apply to other stocks.

Deriving F_{MSY} ranges for Nephrops in IIIa

Background

Within the ICES MSY framework, exploitation rates likely to generate high long-term yield (and low probability of stock overfishing) have been explored and proposed for each *Nephrops* functional unit (category 1 stocks only). Given the lack of an analytical assessment (& stock recruitment relationship), it is not possible to calculate F_{MSY} directly and hence per-recruit proxies for F_{MSY} have been calculated. 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 & biological parameters for males and females. The underlying model is an age-structured population model (i.e. equal intervals in time) but length dependent, with length derived from a growth curve. It operates at a fine temporal scale (monthly) such that it is essentially continuous in length. (This type of age-structured, length-dependent model formulation is the same as that used in the NOAA Toolbox length-based yield-per-recruit analysis).

The input parameters to the per-recruit modelling (fishery selection, female relative catchability and discard ogive) are derived from a length cohort analysis (LCA) in which males and females are modelled separately and the fishing mortality is assumed to be separable (into a logistic ogive and annual multiplier). The LCA uses fishery length frequency data which have been averaged over a number of years in order to reduce the effect of varying year class strength in the application of this model. So far, the LCA has been used with 'dead removals' length frequency data i.e. ignoring the component of the discards which are assumed to survive in the calculation of fishing selectivity and discard ogive.

The biological parameters (von Bertalanffy growth parameters, parameters in the length-weight relationship & natural mortality) are functional unit dependent and known with varying degrees of confidence.

$F_{0.1}$, F_{max} and $F_{35\%SpR}$ have been considered as potential F_{MSY} proxy reference points. Values for each of the candidate proxy reference points have been determined for males and females separately, and for the two sexes combined. 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) with more conservative values being chosen for stocks with perceived low resilience or limited fishery/biological information. A decision making framework is available in the introduction to the *Nephrops* advice sheets.

The full range of F_{MSY} proxy reference points for Nephrops in IIIa is given in Tables 1 (below). This table provides the harvest rate (total removals in number/total abundance in number), actual fishing mortality (for males & females separately) and spawner per recruit at each of the 9 potential F_{MSY} proxies. For IIIa Nephrops, these values were last updated at WGNSSK in 2011 and the per-recruit input parameters are derived from LCA based on data from 2008-2010. The shaded row shows the agreed F_{MSY} proxy values.

Table 1. Nephrops in IIIa. F_{MSY} proxy harvest rates and associated fishing mortality and spawning stock biomass per recruit as % of virgin (SPR).

		Fbar(20–40 mm)				SPR (%)		
		Fmult	M	F	HR (%)	M	F	T
F0.1	M	0.16	0.07	0.03	4.9	51.0	67.7	59.7
	F	0.28	0.12	0.05	7.6	36.1	53.7	45.3
	T	0.19	0.08	0.04	5.6	46.3	63.6	55.4
Fmax	M	0.24	0.11	0.04	6.8	40.1	57.7	49.3
	F	0.40	0.18	0.07	10.0	27.6	44.2	36.3
	T	0.29	0.13	0.05	7.9	35.2	52.8	44.4
F35%SpR	M	0.30	0.13	0.06	8.1	34.3	51.9	43.5
	F	0.58	0.26	0.11	12.9	20.3	34.7	27.8
	T	0.43	0.19	0.08	10.5	26.0	42.3	34.6

F_{MSY} ranges

The derivation of F_{MSY} proxy harvest rate ranges is based on fishing at rates which will provide a high % (90, 95, 98) total yield per recruit when compared to the actual yield per recruit obtained at each F_{MSY} proxy reference point.

The process for deriving the ranges for each of the 9 potential F_{MSY} proxies is described below:

1. Calculate the total (i.e. male + female) yield per recruit when fishing at each reference point, denoted $(Y_{total}/R)^{ref}$. (It is shown as a % of maximum total yield per recruit in the first column of each of the tables below).
2. Calculate mult x $(Y_{total}/R)^{ref}$ where mult is 90 %, 95 % or 98 %. (These values are shown as a % of max total yield per recruit in final 3 columns).
3. Find the two F-multipliers (one below Fmax & one above) which result in values of Y_{total}/R equal to those defined in the previous step. (Note, the calculation of the F-multipliers is not exact as Y_{total}/R is calculated at discrete values of F & the 'nearest' value is used).
4. Calculate the harvest rates equivalent to fishing at the values defined in 3).

Note: all calculations are based on **total** yield per recruit.

The estimated FMSY proxy ranges for IIIa Nephrops are given in the table below.

Table 2. IIIa *Nephrops* . Ranges of F_{MSY} proxy harvest rates equivalent to fishing at a rate which provides 0.9, 0.95 and 0.98 of the total yield per recruit obtained at each F_{MSY} proxy.

		% of max(Ytotal/R) at ref pt	Left hand side (HR %)			Right hand side (HR %)			% of max(Ytotal/R)		
			90	95	98	90	95	98	90	95	98
F0.1	M	90.1	3.8	4.3	4.6	13.3	12.6	12.0	81.1	85.6	88.3
	F	100.0	4.9	5.6	6.3	11.7	10.3	9.4	90.0	95.0	98.0
	T	94.8	4.3	4.9	5.4	12.6	11.7	11.0	85.3	90.0	92.9
Fmax	M	98.9	4.6	5.4	6.1	11.8	10.7	9.8	89.0	94.0	96.9
	F	96.4	4.3	5.1	5.6	12.3	11.3	10.5	86.8	91.6	94.5
	T	100.0	4.9	5.6	6.3	11.7	10.3	9.4	90.0	95.0	98.0
F35%SpR	M	100.0	4.9	5.6	6.3	11.7	10.3	9.4	90.0	95.0	98.0
	F	83.8	3.5	3.8	4.1	14.4	13.6	13.2	75.4	79.6	82.1
	T	94.6	4.3	4.9	5.4	12.6	11.7	11.0	85.2	89.9	92.7

Annex 3: Short manual Eqsim (pdf)

Using the msy package

John Simmond, Colin Millar and Einar Hjörleifsson

September 26, 2014

- R version 3.1.1 (2014-07-10), `x86_64-redhat-linux-gnu`
- Base packages: base, datasets, graphics, grDevices, grid, methods, stats, utils
- Other packages: dplyr 0.2.0.99, FLCore 2.5.20140919, ggplot2 1.0.0, gridExtra 0.9.1, knitr 1.6, lattice 0.20-15, lubridate 1.3.3, MASS 7.3-27, mgcv 1.8-3, msy 0.1.12, nlme 3.1-110, plyr 1.8.1, R2admb 0.7.10, RColorBrewer 1.0-5, reshape2 1.4, scales 0.2.3, scam 1.1-6, stringr 0.6.2, xtable 1.7-3
- Loaded via a namespace (and not attached): assertthat 0.1, colorspace 1.2-2, dichromat 2.0-0, digest 0.6.4, evaluate 0.5.3, formatR 0.10, gtable 0.1.2, labeling 0.2, Matrix 1.1-4, memoise 0.1, munsell 0.4.2, parallel 3.1.1, proto 0.3-10, Rcpp 0.11.2, stats4 3.1.1, tools 3.1.1

```
[1] "This document was created in knitr"
```

1 Preamble

This document is as much as the msy-package itself still in developement.
The origin of this package is from an intial coding by John Simmonds which was restructured by Colin Millar into an R-package with additional development, including coding the Buckland method. Einar Hjörleifsson compartmentalized the structure of the code as well as providing the output of the analysis in a more structured format.
At this moment there is no person responsible for the maintainance of the package, including the above mentioned names.

2 Installation

The developmental repository for the `msy` package is located on github at two locations:

- github.com/wgmg/msy: This version reflects to a large degree what was available and used at the WKMSYREF3 in January 2014.
- github.com/einarhjorleifsson/msy: This was forked from the wgmg site in September 2014. .... ST

The easiest way to install the `msy` package is to use the function `install_github` in the `devtools` package. The `Rtools.exe` software is needed for building packages under Microsoft Windows. Run the following lines to install the latest version of `msy`, any other packages that you require will automatically be downloaded from `CRAN`, the R package repository. All except for `FLCore` package, which is also installed from `github`.

```
library(devtools)
install_github("FLCore", "flr")
install_github("msy", "einarhjorleifsson", ref = "master")
```

The above is equivalent to `install.packages` and hence need only to be performed once. However, since the `msy` package is currently under development (including bug-fixing) one may expect more frequent code updating in the package than what one may be familiar with for packages on `CRAN`. Once the packages have been installed the library is simply loaded via the familiar:

```
library(msy)
```

Besides functions the package comes with the following data:

- codCS: `FLStock` object of the Celtic Sea cod
- codEB: `FLStock` object of the Eastern Baltic cod
- codIS: `FLStock` object of the Icelandic cod
- codNS: `FLStock` object of the North Sea cod
- codWB: `FLStock` object of the Western Baltic cod
- codWS: `FLStock` object of the West of Scotland cod
- saiFO: `FLStock` object of the Faroe saithe
- saiIS: `FLStock` object of the Icelandic saithe
- solKA: `FLStock` object of the Kattegat sole

These are all stored in the icesStocks list object.
The current version of the `msy` implements two methods that go under the working names EqSim and plotMSY. Only usage of functions for the EqSim approaches are described in the following sections.

3 EqSim

EqSim is a stochastic equilibrium software that may be used to explore MSY reference points. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age and maturities) as well as selection are re-sampled at random from user specified range of years from the assessment. Fixing these parameters to an average over specified years can also be set by the user. Recruitments are re-sampled from their predictive distribution. Uncertainty in the stock-recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland et al. 1997). In addition assessment errors can be emulated by applying a user-specified error (CV and autocorrelation) to the intended target fishing mortality.
The current version of EqSim only takes FLStock objects as inputs.

3.1 A quick start

In the following subsections we will simulate the north sea cod stock into the future under some basic assumptions. For the simulations we need to choose which years we will use to generate noise in the quantities: weight at age, maturity at age, natural mortality at age, and selection pattern. We also need to choose a set of Fbar values to simulate over in order estimate F reference points.
The eqsim approach consists of three components:

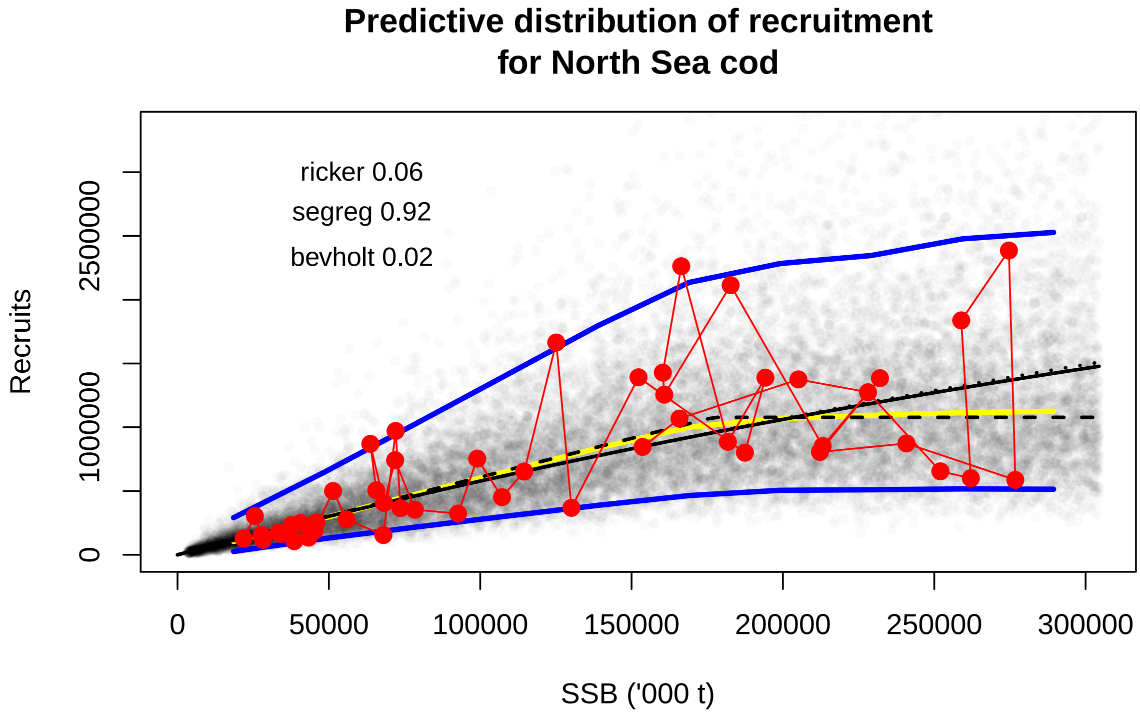
1. Estimate the stock recruitment relationship
2. Simulate a stock to equilibrium and continue simulating for some years
3. Calculate reference points from the simulated stock at equilibrium (last 50 years of the runs are used)

This can be done in one go with the following code:

```
FIT <- eqsr_fit(icesStocks$codNS,nsamp=1000)
SIM <- eqsim_run(FIT, Fcv=0.25, Fphi=0.30,
                 Blim=70000,Bpa=150000,
                 Fscan = seq(0,1.2,len=40),
                 verbose=FALSE,extreme.trim=c(0.05,0.95))
```

The stock recruitment function can be plotted by:

```
eqsr_plot(FIT,n=2e4)
```



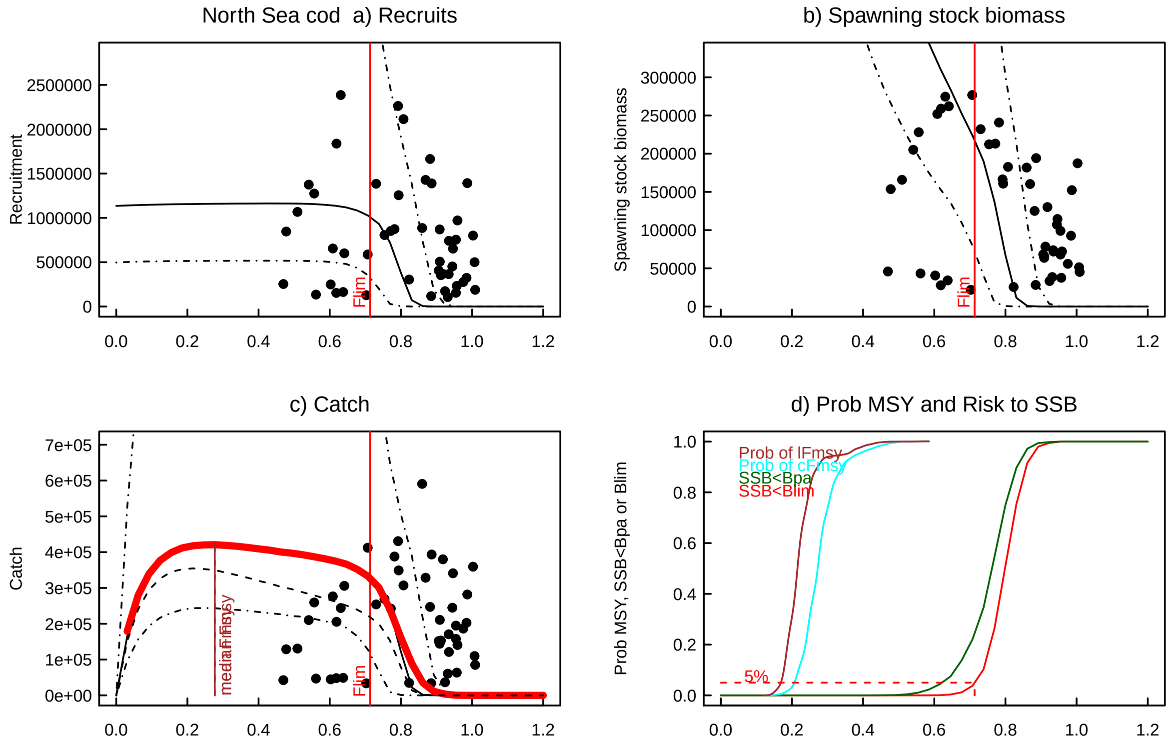
A summary of the key results can be obtained by:

```
xtable(SIM$Refs)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.71	0.74	0.80	0.28	0.28	0.77	0.86
lanF				0.22	0.22		
catch	322840.20	300902.00	127006.37	420750.12	420750.12	235248.73	1589.94
landings				354603.71	354603.71		
catB	217195.90	191398.01	70137.42	1035951.11	1035951.11	136913.27	779.78
lanB				1364156.27	1364156.27		

A summary plots conditioned on maximizing **catch** are obtained by:

```
eqsim_plot(SIM,catch=TRUE)
```



3.2 The recruitment model

Model fitting is done by maximum likelihood using the `nlminb` optimiser in R. By refitting to non-parametric bootstrap resamples of the stock and recruit pairs, samples from the approximate joint distribution of the model parameters can be made. This is done by invoking the `eqrs_fit` function. The function first sets up the stock and recruit pairs based on the information in the `FLStock` object and removes any incomplete pairs, before dispatching on the model fitting / averaging algorithm chosen. Currently only a bootstrap based model averaging method called smooth AIC is implemented fully. The details can be found in `eqrs_Buckland` function. The algorithm implemented is:

1. Take a resample with replacement from the stock and recruit pairs
2. Fit every stock-recruit model under consideration and store the AIC of each
3. Retain the parameter estimates from the best model
4. Repeat

This process provides a robust way to average over several models, as long as the bootstrap resampling procedure provides an adequate approximation to the empirical distribution of the stock and recruit pairs. The arguments to the fitting function are

```
args(eqsr_fit)

function (stk, nsamp = 5000, models = c("ricker", "segreg", "bevholt"),
    method = "Buckland", id.sr = NULL, remove.years = NULL, delta = 1.3,
    nburn = 10000)
NULL
```

Here:

- `stk` is an `FLStock` object

- `nsamp` is the number of simulations to run (often referred to as iterations)
- `models` is the models to average over (any of the combination of these can be supplied, including only a single model)
- `method` the method used (only Buckland as of now)
- `id.sr` placeholder if one wants to name the fit
- `remove.years` is used to remove years from the fit
- `delta` and `nburn` are related to an MCMC based fitting procedure (not implemented yet)

The results from the fitting process are returned to the user as a list:

```
str(FIT, 2, give.attr=FALSE)

## List of 6
##  $ sr.sto:'data.frame': 1000 obs. of  4 variables:
##   ..$ a    : num [1:1000] 6.58 5.71 5.17 5.92 6.06 ...
##   ..$ b    : num [1:1000] 1.79e+05 1.66e+05 1.79e+05 2.76e+05 4.44e-07 ...
##   ..$ cv   : num [1:1000] 0.48 0.449 0.443 0.411 0.434 ...
##   ..$ model: chr [1:1000] "segreg" "segreg" "segreg" "segreg" ...
##  $ sr.det:'data.frame': 3 obs. of  6 variables:
##   ..$ a    : num [1:3] 6.3 6.09 6.25
##   ..$ b    : num [1:3] 8.54e-07 1.77e+05 8.57e-07
##   ..$ cv   : num [1:3] 0.482 0.463 0.482
##   ..$ model: chr [1:3] "ricker" "segreg" "bevholt"
##   ..$ n    : int [1:3] 58 918 24
##   ..$ prop : num [1:3] 0.058 0.918 0.024
##  $ pRec  : num [1:1000, 1:49] 143712 124630 113032 129273 131144 ...
##  $ stk   :Formal class 'FLStock' [package "FLCore"] with 20 slots
##  $ rby   :'data.frame': 49 obs. of  6 variables:
##   ..$ year    : int [1:49] 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 ...
##   ..$ rec     : num [1:49] 845768 1067681 1375049 1274418 654744 ...
##   ..$ ssb     : num [1:49] 153638 165830 205112 228117 252019 ...
##   ..$ fbar    : num [1:49] 0.478 0.509 0.541 0.556 0.609 ...
##   ..$ landings: num [1:49] 109409 117035 167733 207369 235070 ...
##   ..$ catch   : num [1:49] 128686 130740 210237 259416 276387 ...
##  $ id.sr : chr "North Sea cod"
```

where

- `sr.sto` is the the (joint) stochastic distribution of the estimated model and parameters. The number of rows of the data frame is equivalent to the value supplied to `nsamp` in the `eqsr_fit` function.
- `sr.det` is the conventional determinimstic predictive estimate. The `n` indicates the number of times a particular function is drawn in the stochastic sample and the `prop` the proportion, given `nsamp`.
- `pRec` contains the fitted parameters to the observed data
- `stk` retains the original `FLStock` object passed to the function.
- `rby` (results by year) contains a summary of the ssb and rec data used in the fitting as well as other stock summary information used later down the line
- `id.rs` is the user specified id

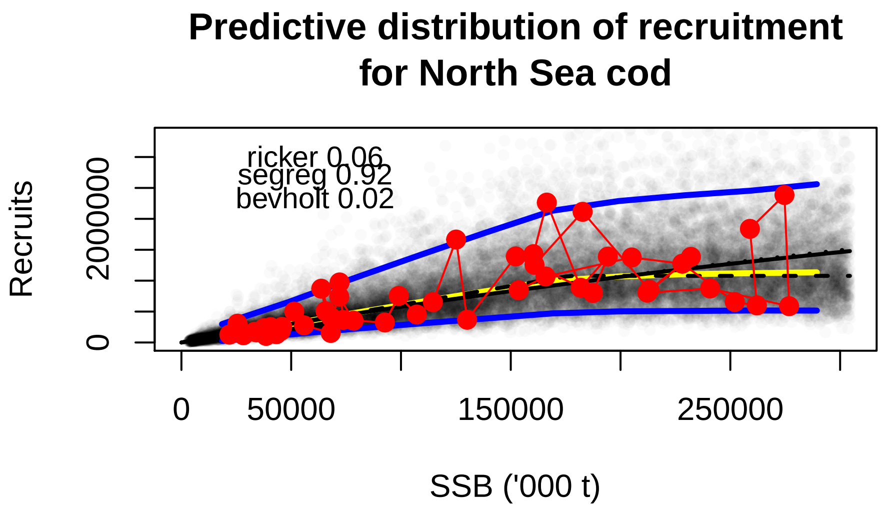
The contribution of each of the models can be obtained by printing out the `sr.det`:

```
xtable(FIT$sr.det,digits=c(0,2,-2,2,0,0,3))
```

	a	b	cv	model	n	prop
1	6.30	8.54E-07	0.48	ricker	58	0.058
2	6.09	1.77E+05	0.46	segreg	918	0.918
3	6.25	8.57E-07	0.48	bevholt	24	0.024

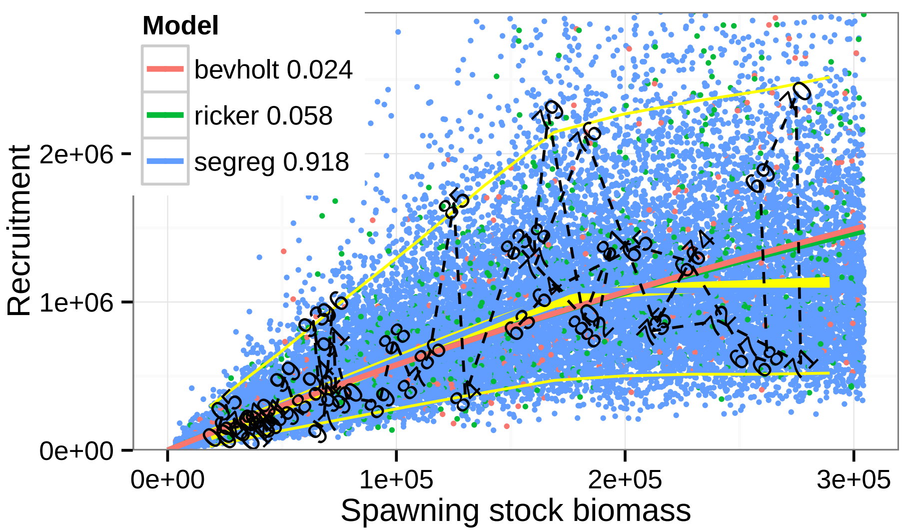
Here the a, b and cv are the estimated parameters from the deterministic fit for each model. The `n` and `prop` is a summary of the number and proportion that each model contributes to the final fit.
Again to obtain a plot one simply calls:

```
eqsr_plot(FIT,n=2e4)
```



The `n` supplied to the `eqsr_plot` stands here for the number of stochastic recruitment points desired to include in the plot. The various black dashed lines represent the best fit of the different recruitment models and the yellow and blue lines the median and 5% and 95% percentiles of the distributions of the stochastic recruits drawn from the models. The input data are represented by red points.
An alternative to the `base` plot is a `ggplot2` version (with too fancy colours :-):

```
eqsr_plot(FIT,n=2e4,ggPlot=TRUE)
```



Here the model fits are represented in different colours with the yellow lines indicating the 5%, 50% and 95% percentiles of the stochastic recruitment distribution. The input data are represented by text indicating year class. The weight of each model in the final stochastic recruitment draw is indicated as a proportion in the legends and by different colours for the stochastic draws.

3.3 The simulation

Simulating forward is done using the `eqsim_run` function. The function takes as input the output from the `eqsr_fit` function. Simulations are run independently for each sample from the distribution of model and parameters. This is done for a range of $F_{advisory}$ values. For example if we scanned over 10 values of $F_{advisory}$ and had taken 2000 samples from the stock-recruit relationship then 20000 simulations would be run in total. These simulations are run for 200 years (default, specified with `Nrun`), and the last 50 years are retained to calculate summaries, like the proportion of times the stock crashes at a given $F_{advisory}$. It is important to note that each simulation is conditioned on a single stock recruit relationship with fixed parameters and cv.

Error is introduced within the simulations by generating process error about the constant stock-recruit fit, and by using variation in maturity, natural mortality, weight at age and selection estimates. Note that if there is no variability in these quantities in the stock object then no variability will be taken in to the simulations. The user can also specify using average values for these parameters.

The arguments to the simulation function are:

```
args(eqsim_run)

## function (fit, bio.years = c(2008, 2012), bio.const = FALSE,
##     sel.years = c(2008, 2012), sel.const = FALSE, Fscan = seq(0,
##         1, len = 20), Fcv = 0, Fphi = 0, Blim, Bpa, recruitment.trim = c(3,
##         -3), Btrigger = 0, Nrun = 200, process.error = TRUE,
##     verbose = TRUE, extreme.trim)
## NULL
```

where:

- `fit` is the output list from `eqsr_fit`
- `bio.years` is the start and end year from which to generate noise in maturity, M and weights.
- `bio.const` is a flag indicating if the average maturity, M and weights over the specified years should be used (`TRUE`) or not (`FALSE`).
- `sel.years` is the start and end year from which to generated noise in the selection at age
- `sel.const` is a flag indicating if the average selection over the specified years should be used (`TRUE`) or not (`FALSE`).
- `Fscan` is the range of $F_{advisory}$ values to scan over
- `Btrigger` is the location of a modifier of a HCR upon which $F_{advisory}$ becomes linearily reduced. If `Btrigger` is 0 (default) this is equivalent to a constant F-rule.
- `Fcv` The assessment error in the advisory year.
- `Fphi` The autocorrelation in assessment error
- `Blim` B_{lim}
- `Bpa` B_{pa}
- `Nrun` is the number of years to simulate forward (fixed for now is that the last 50 years from those are used for summarising equilibrium conditions)
- `process.error` allows the simulations to be run using the predictive distribition of recruitment or the mean recruitment
- `verbose` controls if progress bar is displayed during the simulation
- `extreme.trim` A numerical vector of length 2 containing the lower and upper percentiles. If specified, recruitement values outside this range are trimmed (ignored).

The results from the simulation process are returned to the user as a list

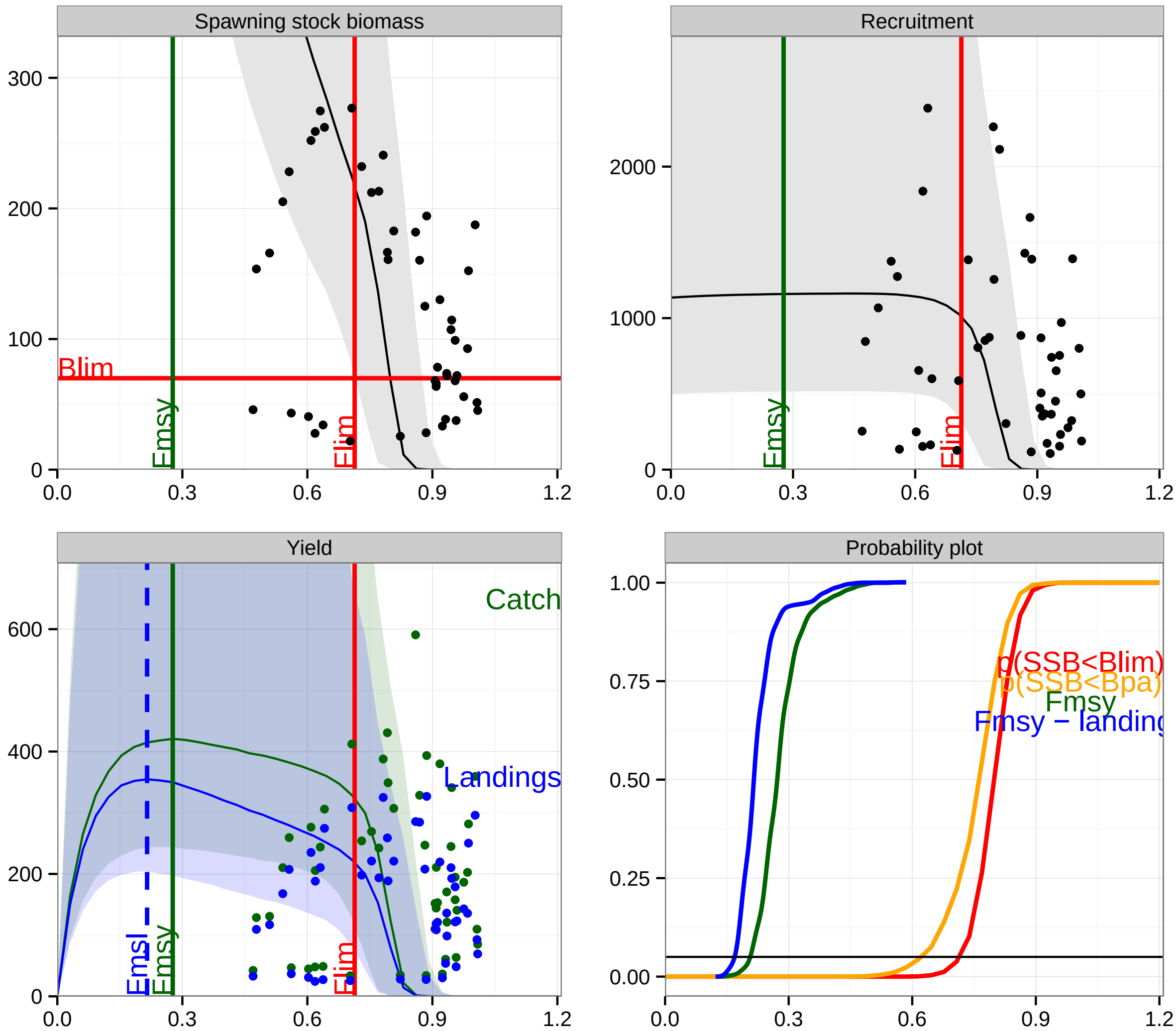
```
str(SIM, 2, give.attr = FALSE)

## List of 8
##  $ ibya    :List of 7
##   ..$ Mat  : num [1:7, 1:5] 0.01 0.05 0.23 0.62 0.86 1 1 0.01 0.05 0.23 ...
##   ..$ M    : num [1:7, 1:5] 1.039 0.696 0.487 0.232 0.2 ...
##   ..$ Fprop: Named num [1:7] 0 0 0 0 0 0 0
##   ..$ Mprop: Named num [1:7] 0 0 0 0 0 0 0
##   ..$ west : num [1:7, 1:5] 0.33 0.904 1.971 3.834 5.692 ...
##   ..$ weca : num [1:7, 1:5] 0.33 0.904 1.971 3.834 5.692 ...
##   ..$ sel  : num [1:7, 1:5] 0.246 0.795 1.087 1.118 1.142 ...
##  $ rby     :'data.frame': 49 obs. of  6 variables:
##   ..$ year    : int [1:49] 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 ...
##   ..$ rec     : num [1:49] 845768 1067681 1375049 1274418 654744 ...
##   ..$ ssb     : num [1:49] 153638 165830 205112 228117 252019 ...
##   ..$ fbar    : num [1:49] 0.478 0.509 0.541 0.556 0.609 ...
##   ..$ landings: num [1:49] 109409 117035 167733 207369 235070 ...
##   ..$ catch   : num [1:49] 128686 130740 210237 259416 276387 ...
##  $ rbp     :'data.frame': 160 obs. of  10 variables:
##   ..$ Ftarget : num [1:160] 0 0.0308 0.0615 0.0923 0.1231 ...
##   ..$ variable: chr [1:160] "Recruitment" "Recruitment" "Recruitment" "Recruitment" ...
##   ..$ p025    : num [1:160] 419839 428184 432069 435451 437914 ...
##   ..$ p05     : num [1:160] 496458 501939 506344 508486 510504 ...
##   ..$ p25     : num [1:160] 809012 812153 815043 817365 819201 ...
##   ..$ p50     : num [1:160] 1135311 1139997 1144264 1147753 1150500 ...
##   ..$ p75     : num [1:160] 1631315 1640186 1646286 1653743 1659540 ...
##   ..$ p95     : num [1:160] 3891780 4070696 4228494 4480689 4669759 ...
##   ..$ p975    : num [1:160] 25579487 26321607 26655710 28084605 29198515 ...
##   ..$ Mean    : num [1:160] NA NA NA NA NA NA NA NA NA NA ...
##  $ Blim    : num 70000
##  $ Bpa     : num 150000
##  $ Refs    : num [1:6, 1:7] 7.13e-01 NA 3.23e+05 NA 2.17e+05 ...
##  $ pProfile:'data.frame': 1104 obs. of  3 variables:
##   ..$ Ftarget : num [1:1104] 0.123 0.124 0.125 0.125 0.126 ...
##   ..$ value   : num [1:1104] 1.57e-06 3.60e-06 6.22e-06 9.55e-06 1.38e-05 ...
##   ..$ variable: chr [1:1104] "pFmsyCatch" "pFmsyCatch" "pFmsyCatch" "pFmsyCatch" ...
##  $ id.sim  : chr "North Sea cod"
```

where

- `ibya` (input by year and age) contains the biological and fisheries input data.
- `rby` (results by year) contains the stock summary data.
- `rbp` contains the 0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975 percentiles of the simulations of SSB, catch, landings and recruitment for each Fscan value.
- `Blim` B_{lim} input value
- `Bpa` B_{pa} input value
- `Refs` Calculated reference points
- `pProfile` The probability profiles for a given target F for B_{lim}, B_{pa} and F_{msy} (both for catch and landings).

```
eqsim_ggplot(SIM,1000)
```



4 plotMSY

Documentation is pending, further coding needed ...