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Report of the Workshop to consider reference points for all stocks (WKMSYREF2)

8–10 January 2014

ICES Headquarters, Copenhagen, Denmark

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International Council for the Exploration of the Sea
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Contents

Executive Summary

The Workshop to consider the basis for reference points for all stocks (WKMSYREF2) was co-chaired by John Simmonds, ICES, and Einar Hjörleifsson, Iceland at ICES Headquarters, 8–10 January 2014, The meeting had 17 participants from 10 ICES countries.

The workshop was convened in order to evaluate the basis for reference points for ICES fish stocks, and propose operational definitions. Including reference points within the ICES MSY framework (MSY $B_{trigger}$, F_{MSY}), and B_{lim} (acting as a constraint on MSY reference points, since <5% probability of B< B_{lim} must be ensured) and, where relevant, Bescapement.

The meeting was organised around the analysis of 7 stocks, in order to determine the basis for the approach and to test software and the utility of different aspects. The stocks chosen were cod stocks in North Sea, Irish Sea, West of Scotland and Celtic Sea, Faroe Saithe, Kattegat sole and North Sea sprat.

The report provides a description of a protocol for the estimation of F_{MSY} and $B_{trigger}$ in the context of B_{lim}. Details of aspects to be considered in the evaluation and sensitivity analysis are given. Sotware packages are recommended and a summary of the results of the analyses on the selected stocks presented. More detailed results are given an annexes. A discussion of intervals around F_{MSY} is provided.

The workshop has provided a basis for estimation of F_{MSY} and $B_{trigger}$ that conforms to ICES MSY framework and is compatible with the ICES precautionary approach and the definition of B_{lim}. F reference points (F_{lim} and F_{pa}) were not explicitly considered.

Potential F_{MSY} and $B_{trigger}$ values for Kattegat sole, Faroe saithe, NS sprat and the four cod stocks are proposed. Irish Sea and Celtic Sea cod have higher F_{MSY} than North Sea or West of Scotland cod. Only a limited evaluation was conducted but there are indications that the lower values for North Sea and West of Scotland may be due to the inclusion of discard data in the assessment and analysis. Thus F_{MSY} for Celtic Sea and Irish Sea cod may not fully reflect the current fisheries. It is possible that all these fisheries will change with the implementation of a landing obligation in 2016 onwards.

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2 Terms of Reference

2013/2/ACOM37 The **Workshop to consider the basis for reference points for all stocks** (WKMSYREF2), co-chaired by John Simmonds, ICES, and Einar Hjörleifsson, Iceland will meet at ICES Headquarters, 8–10 January 2014, for the stocks covered by the working groups HAWG, NWWG, NIPAG, WGWIDE, WGBFAS, WGNSSK, WGCSE, WGEF, WGDEEP, WGHMM, and WGANSA.

On the basis of work in WKMSYREF, WKLIFE3 and WKGMSE, and the overriding ICES precautionary criteria of $B< B_{lim}$ with a probability of <5%, evaluate the basis for reference points for fish stocks for which ICES is requested to provide advice and propose operational definitions. This relates to the reference points within the ICES MSY framework (MSY $B_{trigger}$, F_{MSY}), and B_{lim} (acting as a constraint on MSY reference points, since <5% probability of $B< B_{lim}$ must be ensured) and, where relevant, Bescapement. Consider the role of assessment error in selecting a target F and the utility of B_{pa} and F_{pa} as currently defined.

a. Using the following single stock examples taking into account current productivity states and recent fisheries refine the estimation and specification process and develop methods and clear guidance.

    i) Length based methods Northern hake, Southern hake

    ii) Age based methods North Sea cod, Kattegat cod, WoS cod, Irish Sea cod, Celtic Sea cod.

    iii) Short lived NS Sprat. (consider F and Bescapement approaches)

b. Consider any additional stocks that are identified as needing revision.

WKMSYREFII will report by 24 January 2014 for the attention of ACOM.

3 Introduction

The purpose of the ICES MSY approach is to provide simple harvest advice with the policy objective of Maximum Sustainable Yield. In this context sustainability is defined within an ICES precautionary approach. Exploitation (average long-term yield) is maximised under conditions of a fixed fishing mortality (or Harvest Rate). This results in the use of an ICES MSY HCR which consists of an appropriate fishing mortality rate that is followed as long as SSB is estimated to be above a biomass threshold ($B_{trigger}$). If SSB is less than $B_{trigger}$ the mortality rate is reduced towards zero based on the ratio of current SSB to $B_{trigger}$. It is acknowledged that such an approach may not give a maximum yield in the short term and in some cases may lead to small reductions in long term yield due to the characteristics of the fishery. More complex harvest regimes could be developed that are more responsive to episodic recruitment, or give more catch stability or higher economic yield. If such additional aspects are required a more complex approach would need to be tested under a Management Strategy Evaluation.

The workshop approached the ToRs by carrying out evaluations of four of the cod stocks (Celtic Sea, Irish Sea, West of Scotland and North Sea) and North Sea sprat identified in the ToRs. In addition five other stocks were considered, Faroe saithe, Kattegat sole, Barents Sea capelin, NEA cod and North Sea haddock. The work on each of these stocks is attached as annexes to the report and in summary below. The ToRs had requested evaluations of some stocks with length based assessments (Northern and Southern hake); however, due to shortage of resources work on these stocks was not carried out.

The report presents the basic principles of the ICES MSY approach and indicates the work required. Two software packages, PlotMSY and EqSim, were used extensively within the workshop and are identified as suitable for future evaluations.

4 Basis of the ICES MSY advice

4.1 Precautionary considerations

The ICES MSY Approach is considered to be within the ICES precautionary approach, conforming to the overriding criterion of an annual probability of >95% that SSB>B_{lim} in long term equilibrium. Checking for this aspect is part of the F_{MSY} evaluation process documented below.

4.2 Choice of metric for yield

In selecting F_{MSY} there is a need to define what constitutes Y or yield from the fishery. In the context of ICES advice the choice is between Y=landings or catch, though for fishing industry economic returns may be of greater utility. For some fisheries discarding is banned or is known to be negligible, in these cases landings and catches can be considered equal and the difference can be considered negligible (e.g. Eastern Baltic cod Figure 1 STECF, 2011). The presence of a significant discarded (or slippage or highgrading) component of catch in a fishery has two important influences on the selection of an appropriate F_{MSY} (e.g. North Sea plaice Figure 2, STECF 2010). Firstly in the definition of what constitutes the Yield in the context of MSY, and secondly the calculation of the F to give the maximum yield. F in this context should be total F, as used by ICES to provide advice. It is considered that the choice of Y as catches or landings is a matter for policy: if yield is considered to be that which is removed from the stock, F_{MSY} should be based on maximising catch; if yield is considered to be the utilised component from the stock, the amount contributing to economic or social benefit, then yield should be taken as landings and F_{MSY} calculated accordingly to maximise the landings. Generally, landings appear more applicable as they reflect the utilisation. Care should be taken to understand any discarding and to ensure that utilisable fish above minimum landing sizes is treated as utilised yield (in an MSY context) if it is being discarded just due to a shortage of quota. The basis of MSY may need reconsideration after the landing obligation comes into operation. It is too early to predict what will change under the landing obligation. In general it is considered that the best option is to make yield conform to the utilised part of the catch, which following the implementation of the landing obligation might be all sizes above the minimum conservation size (or minimum landing size). More complex exploitation criteria should be dealt with under a management plan evaluation.

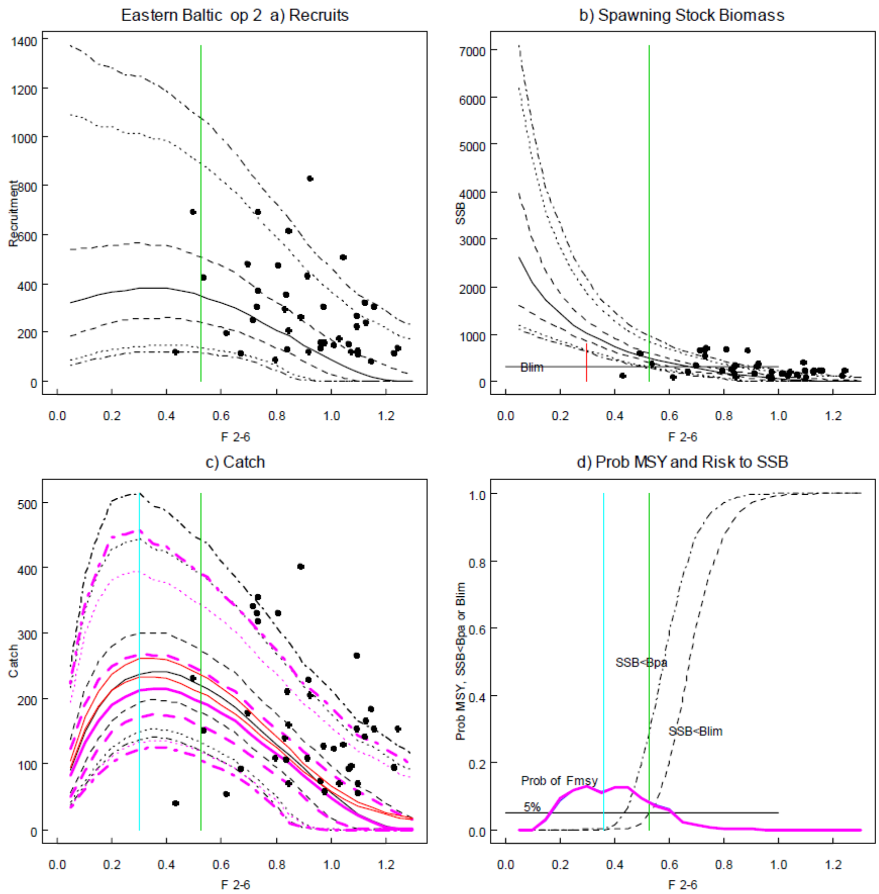

Figure 4.1 Equilibrium exploitation of Eastern Baltic cod (EB 2 – text table) against target F from F=0.05 to 1.3.Quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below B_{lim} and B_{pa}: black lines and 5% probability of SSB below B_{lim} green line in all panels. d) distribution of F for maximum catch, blue line, and maximum landings, pink line (in this case, the blue and pink lines overlap). F for maximum Landings: cyan line, based on 50% point on the distribution of F panel (d) and maximum mean Landings panel (c). The red line in panel b shows the current management plan or target F.

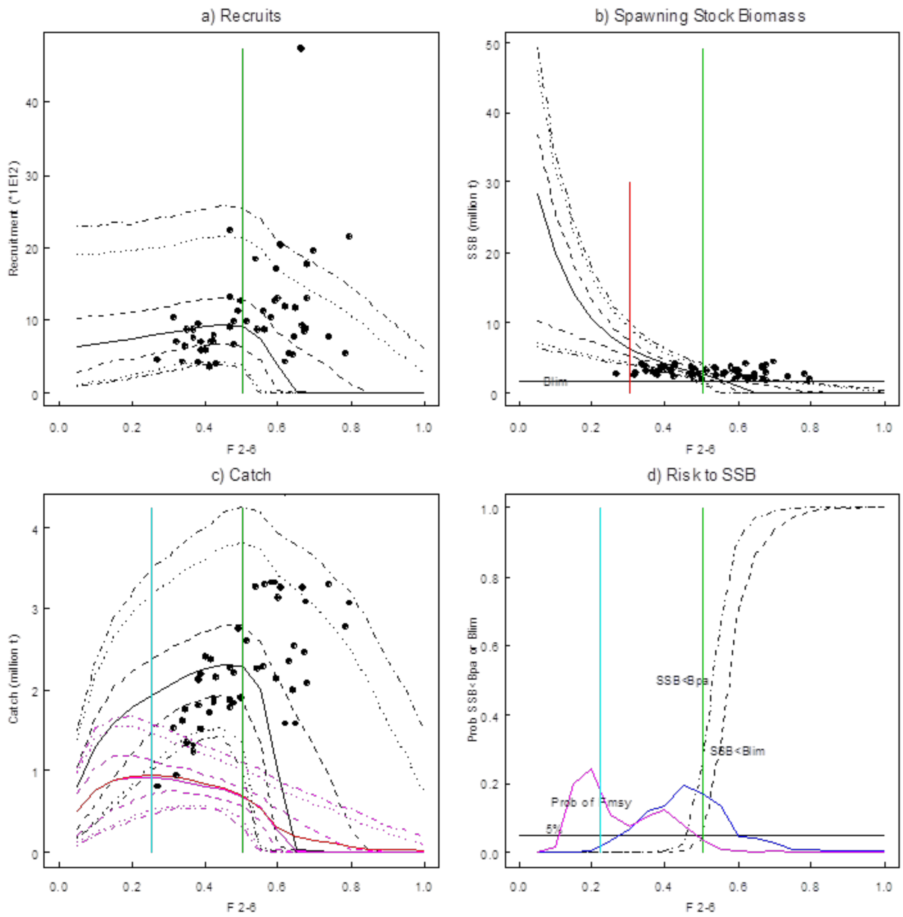

Figure 4.2 Equilibrium exploitation of NS plaice against target F from F=0.05 to 1.0.. Quantiles (0.025, 0.05, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below B_{lim} and B_{pa}: black lines and 5% probability of SSB below B_{lim} green line in all panels. d) distribution of F for maximum catch, blue line, and maximum landings, pink line. F for maximum Landings: cyan line, based on 50% point on the distribution of F panel (d) and maximum mean Landings panel (c). The red line in panel b shows the current management plan target F.

4.3 General procedure for obtaining ICES MSY HCR.

While F_{MSY} is generally considered as a property of the stock, the harvest rule that ICES uses to give MSY advice needs to be precautionary. Considerations provided here relate to medium and long lived species; short lives species with fisheries that are dominated by fisheries based on a different single yearclass each year are considered in section 5.6. In order to determine F_{MSY} and $B_{trigger}$ values that can be used in the ICES MSY Approach for advice the following procedure is suggested:

1) F_{MSY} would initially be calculated based on an evaluation without the inclusion of assessment/advice error. This is a constant F which should give maximum yield without biomass constraints (without $B_{trigger}$).

- Select $B_{trigger}$ (ICES MSY approach implies $B_{trigger}$ >= B_{pa}). Since MSY $B_{trigger}$ is intended to safeguard against an undesirable or unexpected low SSB when fishing at F_{MSY}, the trigger reference point should be based on the natural variation in SSB and the assessment uncertainty, and be located at a low percentile of the range of SSB expected when fishing at F_{MSY}. MSY $B_{trigger}$

should be equal to or higher than B_{pa}. This is appropriate since a precautionary approach is a necessary boundary to ensure sustainability, but not a sufficient condition for achieving the maximum sustainable yield implied by the MSY framework. In the case where a management plan has been evaluated as precautionary by ICES, then this $B_{trigger}$ could be used.

- The ICES MSY HCR should be evaluated to check that the F_{MSY} and $B_{trigger}$ combination results in maximum long term yield subject to precautionary considerations (in the long term, an annual probability <5% that SSB< B_{lim}). The evaluation must include realistic assessment/advice error and stochasticity in population and exploitation.
- If the precautionary criteria cannot be met then F_{MSY} should be reduced from the value calculated in point 1 above until the precautionary criteria are met. (in some circumstances it may be considered that it is preferable that, as well as adjusting F_{MSY}* (the initial F_{MSY} value calculated in point 1), $B_{trigger}$ may also be increased, though such an approach will increase variability in F due to greater dependence on SSB and will result in increased variability in catch relative to the same risk reduction obtained by reducing F_{MSY}).
- The final result of this process are values of F_{MSY} and $B_{trigger}$ that ICES will enter into advice sheet and use to formulate MSY advice and to evaluate the stock status in relation to MSY reference points.

Detail and items for consideration for this process are described below.

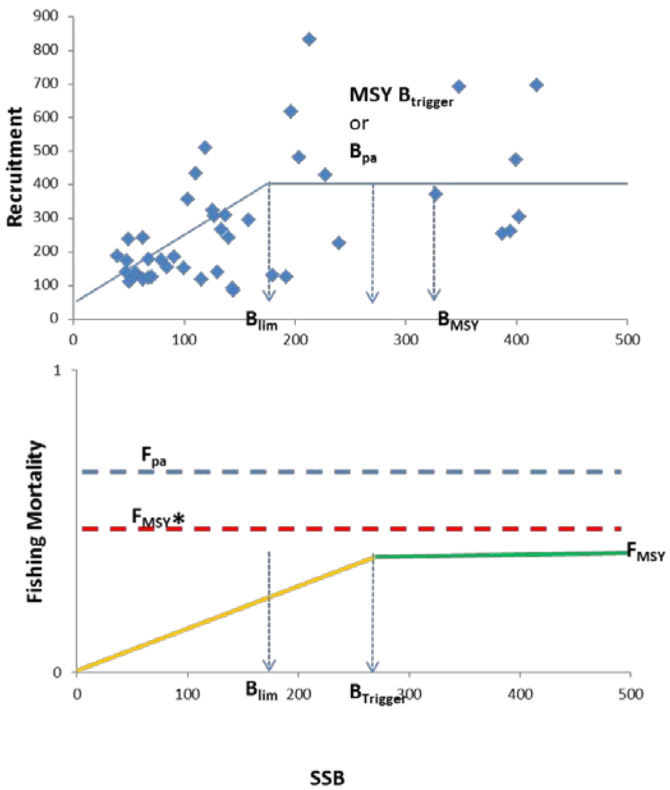

Figure 4.3 Relationship between ICES MSY HCR points and precautionary biomass and F reference points. B_{lim} and B_{pa} are the biomass precautionary reference points related to the risk of impaired reproductive capacity. Diamonds show the variable recruitment versus SSB that have been observed over the years. Recruitment can be seen to be generally lower below B_{lim}. F_{lim} (not shown) and F_{pa} are the fishing mortality precautionary reference points related to the exploitation that would bring the stock to reproductive capacity. F_{MSY}* is the initial estimate of F_{MSY} (calculated in point 1 of Section 4.3) which may lie anywhere though it is shown below F_{pa} in the graph. F_{MSY} may need to be lower than F_{MSY}* if the ICES MSY HCR based on the F_{MSY}* exploitation rate is not precautionary. $B_{trigger}$ (often equal to B_{pa}) is used as the parameter in the ICES MSY approach which triggers advice on a reduced fishing mortality relative to F_{MSY}. B_{MSY} is the long term average biomass expected if the stock is exploited at F_{MSY}.

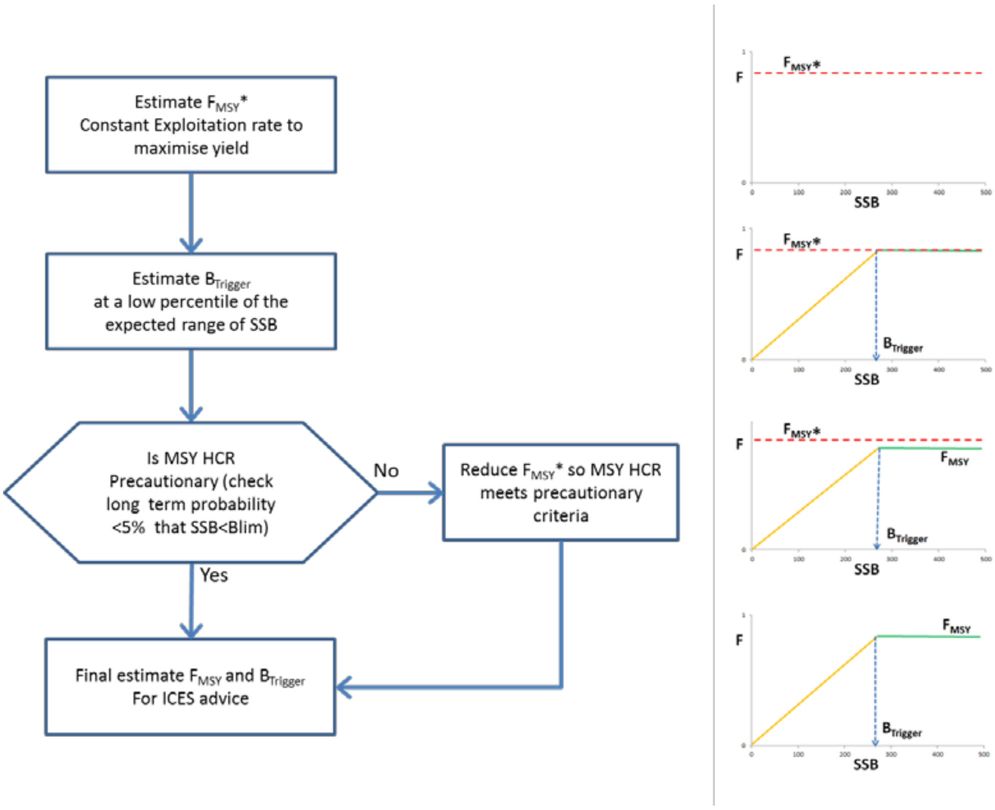

Figure 4.4 Decision Tree for estimation of F_{MSY} and $B_{trigger}$ as required for the ICES MSY HCR. (See points 1-5 in Section 4.3)

4.4 Detailed considerations in calculation of values for an ICES MSY HCR

Approaches and elements that are used to carry out point 3 (in Section 4.3) should include stochasticity, though point 1 (in Section 4.3) would preferably also be evaluated with stochasticity included. Evaluation of suitable F_{MSY} should include stochasticity in a number of parameters. Stochasticity in biological parameters such as M, Maturity, Weight should be included in all stages of the evaluation; typically a recent period should be chosen that reflects the current regime and variability. Stochasticity in selection should be included in all stages of the evaluation; typically a recent period should be chosen that reflects the current fishery and its variability. Where fixed selection patterns are fitted in the assessment, uncertainty in selection should be included based on the assessment information, for example CVs on the point estimates from the assessment or use catch residuals around the fitted selection. Inclusion of stochasticity in recruitment and the basis for mean recruitment (S-R relationship) needs to be considered. Some assessment models fit a S-R relationship as part of the assessment. Conceptually the use of this relationship with uncertainty in parameterisation would be the preferred option, provided the model chosen is considered valid. MSY evaluations require not just stochasticity but also assessment/advice error, so stochastic forward projections (without incorporating this error) will generally not capture sufficient variability. Two available approaches are PlotMSY and EqSim; both methods can include some stochasticity (details in Section 7) and can give initial values for F_{MSY}. Both methods assume that sets of S-R relationship can be fitted and combinations of models can be selected based on statistical criteria. Three relationships are provided (Beverton-Holt, Ricker, Hockey-Stick). If there are a priori biological reasons for choosing a S-R relationship generally this is preferable. In some cases the estimate of F_{MSY} is well away from the historic values; in this case S-R functions should be considered carefully. If the fits look reasonable and the extrapolation is not too great, then fitted results may be useful. If there is doubt about the utility of fitted Beverton-Holt or Ricker functions in particular, either or both of these could be excluded; using the Hockey stick implies no change in the dependence of recruitment at high biomass, this may be a more "neutral" assumption in the absence of other information. If the assessment provides meaningful stock recruitment relationship parameter estimates these could be used within the stochastic approach (EqSim) rather than refitting the model again. If it is considered that fitting S-R functions has no utility and even the use of hockey stick is not applicable, then proxies for F_{MSY} should be used.

For age based assessments sensitivity of F_{MSY} to the choice of plus group should be checked. If important changes in estimates of F_{MSY} depend on the choice of plus group this may be required. Other aspects may also change, such as density dependent growth and M; however, taking account of many of these aspects falls within the scope of an MSE rather than exploitation under constant F_{MSY}.

Overall if implementing F_{MSY} implies a major change of the state of the stock (if the SSB expected is well outside the historic values) the results of the evaluation may be expected to be valid for the current state and during the early stages of any transition, but may require checking again (in a benchmark) once the change of state in the stock has further advanced.

4.5 Proxies for F_{MSY}

It is common to use proxies for F_{MSY}, such as F_{max}, $F_{0.1}$, M, and $F_{20\text{-}40\%SPR}$ (see below). In this context F_{MSY} is used as a generic term for a robust estimate of a fishing mortality rate associated with high long-term yield. These proxies do not take into account the full range of stock dynamic directly but attempt to give good approximations to F_{MSY} where insufficient data is available to carry out a fuller evaluation. Conceptually these proxies have the following properties

F_{max}: The maximum yield point without accounting for the dependence of recruitment on SSB or its annual variability. Some stocks have a well defined F_{max} at low F that is a good approximation for F_{MSY}. For other stocks the peak is either poorly defined at high F or not defined at all and the value is unsuitable. F_{max} is sensitive to changes in the selection pattern / selectivity.

$F_{0.1}$: The point where the increase in yield with increasing F is 10% of the rate at very low (around zero) F. This point is often stable and well defined potentially giving a small reduction in yield relative to F_{MSY}, but may be quite close to F_{MSY} once dependence of recruitment on SSB and is annual variability is included. It is not necessarily suitable for stocks with higher natural mortality.

M: F_{MSY} taken equal to natural mortality (M). Most suited to stocks with high natural mortality

$F_{20\text{-}40\%SPR}$ The fishing mortality that reduces the life time reproductive output of a year class to 20–40% of the reproductive output without fishing. It is based on a study of a wide range of stock biology. It has characteristics similar to $F_{0.1}$ but it also depends on the maturity schedule and its relation to the fishery selectivity. It can be sensitive to assumptions of natural mortality as it depends on the unexploited biomass.

The workshop examined the utility of some of these proxies and made the following comments on considerations in their use in the ICES MSY HCR:

4.5.1 F_{MSY} proxies F35% and F40%

An F_{MSY} proxy reference point of $F_{X\%}$, the fishing mortality rate that reduces a recruit's lifetime reproductive output by X% relative to unexploited conditions, is commonly used when stock recruitment relationships cannot be reliably estimated. Choices of X in $F_{X\%}$ are often 35 or 40 based on the work of Clark (1991, 1993). In the first of these papers, Clark considered a range of demographic and selectivity parameters, together with a number of stock recruitment relationships, and based upon deterministic evaluations recommended $F_{35\%}$ as the proxy for F_{MSY}. In the second paper, Clark further introduced recruitment variability with natural logarithm of recruitment residuals having a standard deviation of 0.6, and based his recommendation to use $F_{40\%}$ rather than $F_{35\%}$ on the criterion of little chance in forward projections, under a constant F value, that spawning biomass would drop below 20% of its deterministic pristine level. Both $F_{35\%}$ and $F_{40\%}$ were found to be robust to uncertainty in values of life history parameters, although there was sensitivity to the form of the stock recruitment relationship (Beverton-Holt or Ricker) and the schedule of maturity at age relative to fishery selectivity. Subsequent analyses found that long-lived stocks with low resiliency (e.g., steepness <0.67) would require a higher SPR such as $F_{50\%}$ - $F_{60\%}$ or more (Clark, 2002).

4.5.2 Fmax and F0.1 proxies

If F_{max} is chosen as a proxy for F_{MSY} this choice requires a test for precautionary considerations (such as provided by EqSim, as noted above) to show that F_{MSY} is not too high. $F_{0.1}$ is generally expected to be precautionary; however, this may not always be the case. For example, $F_{0.1}$ has been observed to be give rather high probabilities of SSB< B_{lim} for some stocks with higher M such as Iberian Sardine (ref) so for such situations its use should be accompanied by a precautionary evaluation.

4.6 Specific consideration for short-lived stocks with population size estimates

For short-lived stocks managed by a target escapement strategy (e.g. capelin), constant F-based MSY reference points may not be relevant. Variable exploitation rates that maximise yield while protecting the stock through a biomass constraint have been developed (ICES 2013). This approach is based on evaluating how the maximum yield and the risk of stock depletion vary as a function of a biomass target escapement, in essentially the same way as one varies F for longer lived stocks.

For stocks that occasionally collapse naturally (eg capelin), SSB may be below B_{lim} in more than 5% of the years even with no fishing, so that the standard ICES biomass criteria of a probability of SSB < B_{lim} of <5% cannot be used directly. This precautionary aspect was discussed under ICES management strategy evaluation (ICES 2013b). In such a case, the harvesting strategy can be determined so that the difference in the proportion of years with SSB< B_{lim} between the years with harvest and the no fishing case is 'small'. Such an approach maximises yield while ensuring that the probability of SSB< B_{lim} is not increased significantly by allowing a fishery in some years.

The future size of a short-lived fish stock is very sensitive to recruitment because there are only a few age groups in the natural population. Incoming recruitment is often the main or only component of the fishable stock. In addition, care must be given to ensure a sufficient spawning-stock size as the future of the stock is highly dependent on annual recruitment (see above). For short-lived species, estimates or predictions of incoming recruitment are typically imprecise, as are the accompanying catch forecasts.

For most short-lived stocks, the ICES MSY approach is aimed at achieving a target escapement MSY $B_{escapement}$, the amount of biomass left to spawn (similar to the use of B_{pa} at spawning time in longer lived species; see Figure 4.3), which is robust against low SSB and recruitment failure and includes a biomass buffer to account for recruitment uncertainty. The yearly catch corresponds to the stock biomass in excess of the target escapement. No catch should be allowed unless this escapement can be achieved that year. (In such situations stable F strategy leads in general to lower yield so maximising yield required variable F)

For some short-lived species, assessments are so sensitive to incoming recruitment that the amount of biomass in excess of the target escapement cannot be reliably estimated until data obtained just prior to the fishery (or during the fishing year) have been analyzed. Therefore, an adaptive framework (ICES 2013) may be applied as follows :

1) Set a preliminary TAC that ensures a high likelihood of the target escapement being achieved or exceeded. This preliminary TAC is likely to be considerably below the final TAC (step 3).

2) Assess the stock just before or during the fishing year, typically based on a survey or an experimental fishery.

3) Adjust the TAC based on the assessment in step 2, ensuring that escapement is at, or above, the target.

The MSY $B_{escapement}$ should be set so there is sufficient biomass to provide a low risk of future recruitment being impaired, similar to the basis for estimating B_{pa} in a precautionary approach. In some cases the use of single value for B_{pa} similar to the approach for longer lived species can give rise to higher than acceptable probability of being below B_{lim} (see North Sea sprat section). If a pure escapement strategy is to be used, then the methodology should be similar to that used for Barents Sea capelin (Gjøsæter et al 2002, ICES 2013), where catch is chosen annually based on a specific analysis with the 5% criteria for SSB< B_{lim} directly, not on a deterministic projection to B_{pa} (note: When ICES gives advice under the Precautionary approach for longer lived species, if a stock is recovering from a biomass below B_{pa} ICES may modify the target F to achieve B_{pa} at the end of the TAC year; it is not explicitly stated but such and advice implies a 50% probability of SSB> B_{pa} which would be similar but not identical to the 5% criteria for SSB< B_{lim}).

For the situation where recruitment information is poor it may be necessary to apply a maximum F cap to ensure very high exploitation does not occur (see NS sprat section). Fisheries that catch short lived species only post first time spawning (eg. NS sprat) are more robust to errors than those that fish on pre-spawners (NS sandeel and capelin).

It is concluded that MSY for short lived species implies specific evaluations taking into account available data, the behaviour of the fishery and the stock biology.

5 Intervals on MSY

ICES gives advice based on a single value of F_{MSY}. In addition ICES provides stock status relative to the same value. An interval around F_{MSY} could be used in two ways, a) to indicate the precision of the estimate (see 5.1 below), or b) to define whether management is above, at or below F_{MSY} when giving information on stock status in the advice sheet (see 5.1 and 5.2 below).

5.1 Ranges based on precision of F_{MSY} estimate:

Ranges on the estimation of F_{MSY} are often difficult to define as the outcomes may depend strongly on the choices of analytical approach. It is noted that testing the ICES MSY HCR in a precautionary context does not use the information on the precision of the initial F_{MSY} estimate. In any case, the use of an estimate of the precision of F_{MSY} in management is not clear. If an interval around F_{MSY} based on the precision of the F_{MSY} estimate is used to define whether management is above, at or below F_{MSY}, there may be perverse incentives to obtain less precise estimates, therefore making it easier to be at F_{MSY} (within the interval) when knowledge is poorer. If such an interval is required this is best considered with managers and a fixed interval not related to the precision of the estimation process would not have these perverse properties.

5.2 Ranges based on high long-term yield:

It is possible to estimate the change in the long-term yield curve around the value of F_{MSY} (Figure 5.1). Though the mean long-term yields reduce as F moves away from F_{MSY}, they often do so over a fairly flat curve that may extend well above or below the value of F_{MSY}. All exploitation rates greater than F_{MSY} have higher risks to stock biomass and greater variability in yield than F_{MSY}. Exploitation rates lower than F_{MSY} have lower long-term yields, lower risk to stock biomass and have the potential to give lower variability in yield. In this context, the ICES HCR (F_{MSY} and $B_{trigger}$) forms a suitable upper bound of exploitation rates and a region below this could be selected based on achieving long-term high yield (not necessarily maximum yield). From the perspective of yield and yield stability there is a trade-off available at exploitation rates lower than F_{MSY}. ICES has provided evaluations of management plans which explore this region and indicate the available trade-offs. For simplicity, ICES could estimate the region within which long-term yield might be expected to be within, say, 95% of the maximum, indicating the range where flexible responses are possible and reduction in long-term yield would be small. Selection of suitable yield-based intervals is not a scientific decision, but rather the province of managers or stakeholders which science can inform. ICES could inform such a process by providing information on such aspects as risk-yield relationships such as those given in management plan evaluations.

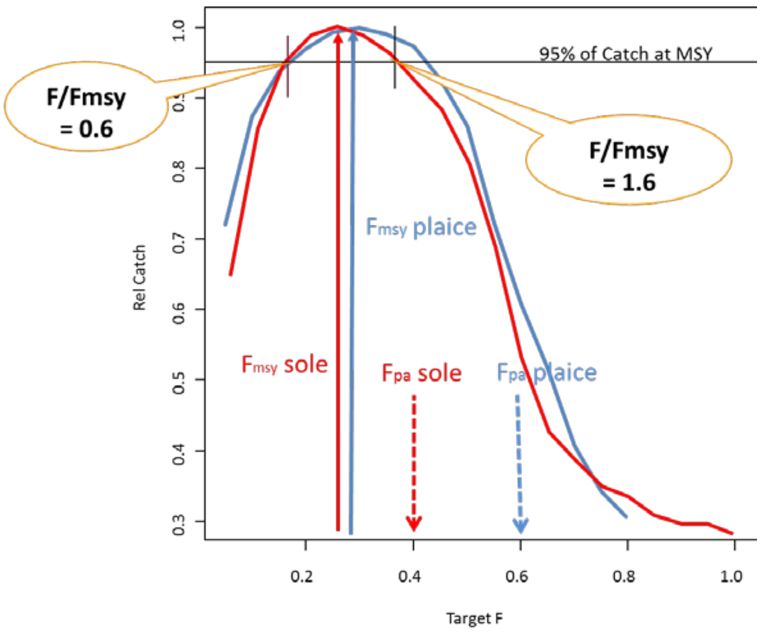

Figure 5.1. Example of a yield based interval around F_{MSY}. Yield of NS sole and NS plaice for a range of constant F exploitation from F=0 to F=1.0. Estimates of F_{MSY} and precautionary reference points F_{pa} for NS sole and NS plaice. Interval based on an arbitrarily selected >95% of maximum yield for both stocks occurs from F = $0.6F_{MSY}$ to F = $1.6F_{MSY}$ on sole. Information taken from STECF (2010)

In the context of mixed fisheries often different stocks are fished together at Fs that are at different distances from F_{MSY}. One could attempt to change these fisheries through, for example, gear or spatial measures to reconcile these differences. The interval discussed above could be used to allow some further 'space' within which to reconcile these differences while ensuring limited long-term loss in yield. This means aiming to reconcile the F's for the different stocks in the mixed fishery in the area below F_{MSY} (consistent with e.g. MSFD) with little loss in high long-term yield. The manner in which this 'space' is utilised is a management decision, however, science can inform. If for example the 'space' in the region below F_{MSY} proves insufficient and the Fs of some stocks in the mixed fishery are found to be below the lower limit of the interval, then managers may wish to seek some further flexibility above F_{MSY} so that the ensemble is 'at MSY', or just for the short term to give opportunities for change. In this case there would be a need to impose an overall constraint under the precautionary approach and F for each stock in the fishery would be constrained at the upper limit by the ICES precautionary criteria of SSB > B_{lim} with greater than 95% probability. In the case shown above there is more flexibility available for plaice than for sole because F_{pa} for plaice is higher than F_{pa} for sole. For some stocks F_{MSY} may already correspond to the precautionary criteria limit and increases in F above F_{MSY} in these cases would not be advised as precautionary by ICES. Developing such an approach would require a dialog amongst managers, stakeholders and scientists.

6 Software used

6.1 Differences in methodology between Eqsim and PlotMSY

PlotMSY (Method 1: equilibrium approach with variance) is intended to provide robust estimation of deterministic (i.e. no future process error) MSY estimates 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. ICES WGMG (2013), Annex 7 provides a more detailed description of the method, including examples and guidelines for use.

EqSim (Method 2: 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 3-5 years of the assessment (although there may be no variability in these values). Recruitments are re-sampled from their predictive distribution. The software also allows the incorporation of assessment/advice error. Uncertainty in the stock-recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland et al. 1997). The method is described in more detail in Annex 8 of ICES WGMG (2013).

6.2 Conclusions on Software

A number of conclusions have been drawn

Currently users are encouraged to use both software packages discussed here (PlotMSY and EqSim) and illustrated in the examples below. Generally PlotMSY is more mature but more limited in scope.

- Both packages are on GITHUB https://github.com/wgmg
- EQSIM needed a number of aspects to be completed before distribution these have been completed during the preparation of this report.
- Version numbers are needed and must be reported with use.
- A number of software points have been identified in EqSim that are required to be fixed, work on these have already commenced.

Priority 1

- Check use with R 3.0.0 64 bit it is noted that it works on R 3.0.2 on Windows version Home Premium 7 with pack 1. (Use R 3.0.2)
- Version numbers are needed and must be reported with use. (Included)
- Include landings option in EQSim and then EQPlot to use data (completed).
- Variability in a) weights/Mat M and b) Sel in different year ranges (completed).
- Residuals draws in recruitment to be same for each F for each population (completed).
- Make it easy to give proportions of models (included on S-R plot)

Priority 2

- Extraction of intervals on MSY / based on 95% interval on mean yield (values are available from the routines)

Priority 3

- Develop an data / parameter input not dependent on FLR (not done)

7 Worked examples

In order to help to define the approach given above and test the software available a number of specific examples were evaluated. Each evaluation is summarised below with more detailed information in annexes where these were provided.

7.1 Sprat in the North Sea

This stock is included as an example of an evaluation of a short lived species.

Six different management strategies were evaluated (a description of each strategy can be found in Annex I) based on a simulation model where fishing is applied to the "true" stock, whereas TACs were determined based on a "perceived" stock accounting for stock number estimation error (Fig. 7.1). The criteria of 95% probability of being above B_{lim}, was applied to identify the sustainable management strategies (more results graphs than presented here and a full description of the method can be found in Annex I).

Only strategies applying an F limit control rule were found to be sustainable. Neither the Escapement-strategy, where the spawning stock is fished down to B_{pa} every year, nor the F_{MSY}-strategy (F_{MSY}* see point 1 in Section 5.3) were sustainable (Fig. 7.1.1). In order to make the Escapement-strategy sustainable, it must be applied with a cap (an upper limit) on the fishing mortality (this strategy is here referred to as the Fcap-strategy) (Fig. 7.1.1). The F_{MSY} -strategy was simply not applicable to the sprat stock, as it was not possible to achieve a dome-shaped relationship between fishing mortality and total annual catch (Fig. 7.1.2). The sustainable strategies were the Fcap-strategy, the F-strategy (also known as the fixed F strategy), and the HCR-strategy (similar, although not identical, to the standard ICES MSY harvest control rule for medium and long lived species; see Annex I). Optimal control rules (or reference points if you like) for these strategies were F_{cap} ~ 1.2, F ~1.2, and F_{max} ~ 1.4. The HCR-strategy was slightly more robust toward situations where the biology assumed when optimizing the control rules (optimizing against the 95% probability of SSB> B_{lim} criteria) differed from the biology of the stock where the control rules were implemented. All three strategies were, however, most sensitive toward choice of stock-recruitment models and maturation age. Increasing fishing selectivity on young fish did not compromise sustainability for any of the strategies. All three strategies resulted in average annual catches around 160 and 165 thousand tons (Fig. 7.1.3). The Fcap-strategy and the F-strategy resulted in the same level of variance in annual catches, whereas the HCR-strategy resulted in closure of the fishery in 5% of all simulations (Fig. 7.1.4). Lastly, we also investigated an alternative escapement strategy where the spawning stock biomass is fished down to B_{lim} every year under the 95% probability of SSB > B_{lim} criterion. It turned out to be possible to approximate this strategy by identifying a $B_{escapement}$, which is higher than B_{pa}. This implementation of an escapement strategy resulted in marginally higher average annual catch compared to the Fcap-strategy and the F-strategy, but with closures of the fishery in a number of years (Fig. 7.1.5).

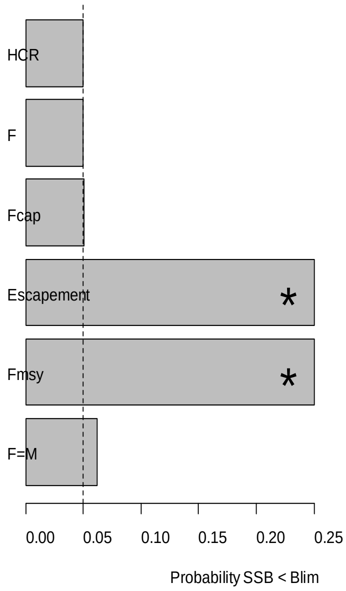

Figure 7.1.1. The probability that the spawning stock biomass will below B_{lim} calculated for six management strategies. Dashed line indicates the defined limit of sustainability. Stars indicate that the bars extent beyond the limit of the x-axis.

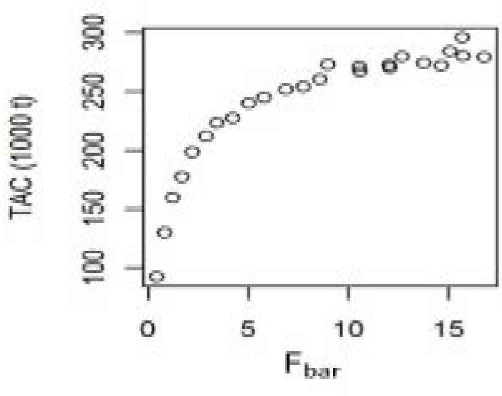

Figure 7.1.2. Illustrating the failed attempt to identify an F_{msy} reference point for the F_{MSY} -strategy within a sensible range of fishing mortalities.

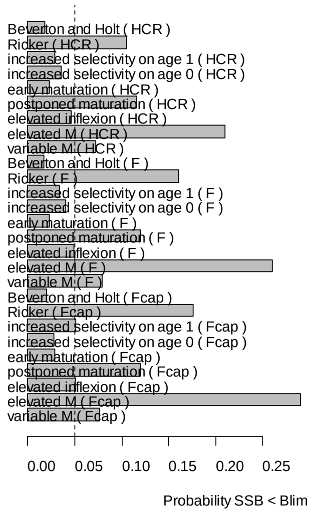

Figure 7.1.3. Robustness-test of the three sustainable management strategies.

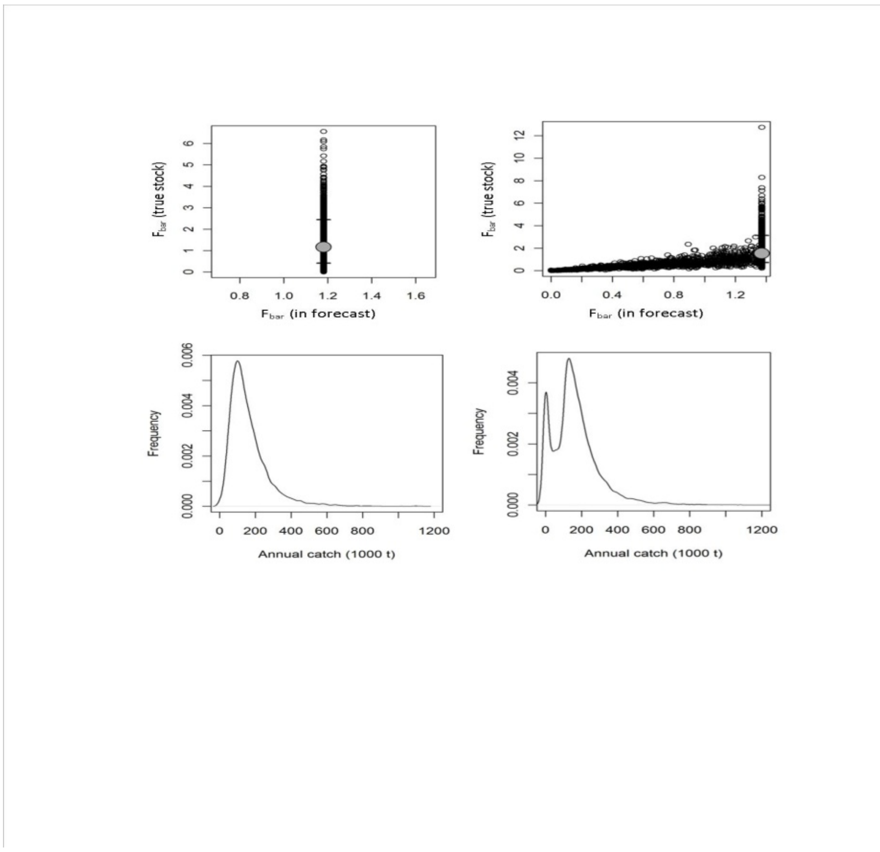

Figure 7.1.4. Variation in fishing mortalities and annual catches (left: Fcap-strategy and right: HCR-strategy). Upper: The fishing mortality expected based on the forecast (calculations made in the perceived stock) plotted against the realized fishing mortalities (calculations made in the True stock). Lower: probability distributions of annual catches or the TACs.

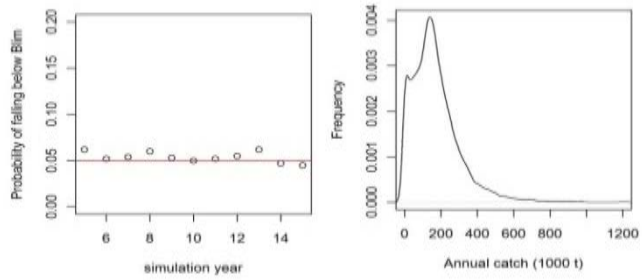

Figure 7.1.5. Investigation of an alternative escapement strategy where the spawning stock biomass is fished down to B_{lim} every year under the 95% probability of SSB > B_{lim} criterion. It turned out to be possible to approximate this strategy by identifying a $B_{escapement}$= 185000 (which is 43000 tons higher than B_{pa}) (left graph). This implementation of an escapement strategy resulted in marginally higher average annual catch compared to the Fcap-strategy and the F-strategy, but with closures of the fishery in a number of years (right graph).

7.2 Estimation of F_{MSY} reference points for four EU cod stocks

The two software packages PlotMSY and Eqsim (Section 7) were used to estimate F_{MSY} for four EU cod stocks; West of Scotland cod, Irish Sea cod, Celtic Sea cod and North Sea cod. To do this, the general principles as outlined in Section 5 of this report were followed. Results of the software packages were contrasted to each other. In addition, for North Sea cod different assumptions on productivity regimes and levels of natural mortality were tested. Detailed Eqsim results and code can be found in Annex II, PlotMSY results in Annex III.

7.2.1 Comparison of F_{MSY} across the four cod stocks and different methods

7.2.1.1 Estimation of F_{MSY}

For comparison F_{MSY} was estimated with PlotMSY and Eqsim without taking assessment and advice error into account and using a constant F (Eqsim scenario SIM_Berr in Annex II). All three stock recruitment relationships were included in the analysis and model averaging was applied. Biological and Fishery data were extracted for the most recent five years' data (2008-2012). For North Sea cod and West of Scotland cod, separate landings and discards data were available, and so separate runs were performed optimising landings and catch in turn. All F_{MSY} estimates presented here are median values.

For North Sea cod F_{MSY} is estimated to be 0.22 to optimise landings, and 0.28 to optimise catch in PlotMSY (Table 8.2.1). The majority of weight is given to the hockey-stick stock recruit function. The reason for the higher F when optimising catch is that a large proportion of young cod are discarded. When seeking to optimise landings, these young fish cannot be fished too intensively in order to allow them to reach a size where they will start contributing to landings, whereas when optimising catch, they are already contributing to the catch through discards and, given the high M at young ages, the optimal catch strategy is to apply higher fishing pressure and hence take more of the young fish. Similar results were also obtained with Eqsim for F_{MSY} optimising for catch (0.31) and optimising landings (0.23).

Like North Sea cod, West of Scotland cod also has a high proportion of discarding of young fish, and so PlotMSY estimates a large difference between the F_{MSY} estimated for maximising landings (0.18) and catch (0.28, Table 8.2.1). The data are not particularly informative about the best form of stock-recruit relationship to use, with weightings of 29%, 32% and 39% for the Ricker, Beverton-Holt and hockey-stick respectively. Eqsim estimates F_{MSY} at 0.31 optimsing catch and 0.19 optimising for landings. These values are very similar to the results from PlotMSY.

Estimates for Irish Sea cod indicate an estimate of F_{MSY} around 0.39, almost entirely derived from the fit of the hockey-stick stock recruitment form (given 87% weighting) in PlotMSY (Table 8.2.1). The F_{MSY} estimate from Eqsim is slightly higher (0.42). Why the F_{MSY} for Irish Sea cod is considerably higher compared to the other stocks needs further investigation. However, one explanation can be the absence of any discard data in the analysis for Irish Sea cod means that the extra yield at low F that is obtained for North Sea and West of Scotland cod is not observed in the analysis and the benefits of reduced F on the discard component are not made available for landings at older ages. If this lack of discard observations is replicated in the case of North Sea cod, by ignoring the discard component, it would lead to an estimate of F_{MSY} as 0.42 from PlotMSY, similar to the value estimated for Irish Sea cod.

F_{MSY} estimates for Celtic Sea cod are around 0.31 in PlotMSY (Table 8.2.1), based on a slight preference for the Beverton-Holt form (51%) over the Ricker and Hockey-stick (28% and 21% respectively). Eqsim estimates F_{MSY} at 0.35 and therefore above PlotMSY. This may be due to the shape of the S-R function around the maximum yield point, as the inclusion of stochastic recruitment and error may move the optimum point as the range of biomasses experienced are wider.

With Eqsim also runs were performed with no stochasticity in weight at age and selectivity for all stocks. Results can be found in Annex II.

7.2.1.2 Precautionary considerations

Based on the general principles for determining F_{MSY}, it was tested with Eqsim whether fishing at F_{MSY} leads to a less than five percent probability to fall below B_{lim} when applying the ICES MSY harvest control rule (Scenario SIM_Btri in Annex II, current $B_{trigger}$ values were used). To do this also assessment and advice error needs to be taken into account.

Assessment/advice error in the software package EqSim is characterised by two error parameters, a cv and serial correlation (rho), used to derive a time-series of realised F values given a time series of target F values supplied by, for example, the application of the ICES MSY rule.

For North Sea cod these error parameters were estimated 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:

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 (each element representing a year), and taking the mean across simulations. The associated R cod is as follows (note, x in the following is in FLQuant object; see Kell et al. 2007):

```
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 rho of 0.25. In the absence of information for the other three cod stocks, the default values were used (cv= 0.2, rho=0.3).

The fishing mortalities associated with a 5% probability for SSB to fall below B_{lim} (F5%, F_{lim} in Annex II) were estimated to be considerably higher than potential F_{MSY} candidates for North Sea cod, Irish Sea cod and Celtic Sea cod (Table 8.2.1). Therefore, a conflict with precautionary considerations seems to be unlikely. The F5% values are very high for North Sea and Irish Sea cod (>1) at first sight. However, the HCR applied leads to lower F values if the stock falls below $B_{trigger}$ (i.e. the ICES MSY HCR was tested, following from point 3 in Section 5.3). The F5% tabulated corresponds to the F applied above $B_{trigger}$, realized F may be considerably lower. For comparison runs were conducted with constant F instead of the HCR. In these runs F5% was lower especially for North Sea cod (0.7, Table 8.2.1). But it stays above 1 for Irish Sea cod . For West of Scotland and Celtic Sea cod the estimation of F5% was similar to NS cod at 073-0.77.

In Annex II also scenarios with assessment/advice error but with constant F can be found.

The version of PlotMSY available to the workshop was not able to test the 5% rule as outlined under the general principles (no HCR possible, F5% is not standard output). As an alternative, F5% is the level of constant F that causes the equilibrium SSB to be equal to B_{lim} in 5% of the iterations. The way F5% is derived by PlotMSY differs from that in EqSim because it does not include stochasticity in recruitment, it does not include assessment/advice error, and it is not subject to the ICES MSY rule (i.e. the level of F is not reduced below a $B_{trigger}$ level). Inclusion of the first two elements (stochasticity in recruitment and assessment/advice error) would tend to produce lower F5% values (because of the additional noise), but the third one (ICES MSY rule) higher F5% values (because of the additional protection below the $B_{trigger}$ point). As with EqSim, these values were estimated to be considerably higher than potential F_{MSY} candidates and are close to the Eqsim values when no HCR is applied. Tests based on F_{crash} (without assessment and advice error, no HCR) indicate that for Celtic Sea cod potential problems could arise (see Annex III).

7.2.2 Additional sensitivity analyses for North Sea cod

7.2.2.1 Sensitivity of F_{MSY} estimates towards different productivity regimes

The PA reference points for North Sea cod were estimated in 1995. B_{pa} was estimated at 150 kt with the justification that B_{pa} = Previous MBAL and signs of impaired recruitment below 150 000 t. B_{lim} was set at 70 kt equivalent to Bloss. A re-examination of the stock recruitment relations with an updated time series (1963-2012) reveals a clear sign of impaired recruitment below 150 kt as observed in 1995 (see Figure 8.2.1-2). Such observation will, according to the ICES guidelines for setting PA reference points, imply a B_{lim} at around 170 kt. However, a regime shift in the North Sea has occurred in the end of the 1980s (Reid et al. 2001, Beaugrand 2004) and the usage of

170 kt as B_{lim} may be misleading. The usage of a truncated time series from 1991 onwards was discussed to better reflect the current productivity regime and stock recruitment dynamics of North Sea cod.

To test the sensitivity of F_{MSY} towards assumptions on North Sea cod productivity regimes, alternative runs were performed in PlotMSY and Eqsim using the full stock-recruit time series (1963-2012) and a truncated time series (1991-2012), keeping the same values for the biological and fishery data (typical of 2008-2012). For the complete time series a break point around 170,000t is estimated for the Hockey stick in both approaches, whereas the truncated data only covers a period when SSB is below 80,000t, and so entirely on the ascending limb of the hockey-stick (Figures 8.2.1 -2). In PlotMSY a breakpoint below the highest observed SSB value is visible (note: the package constrains the breakpoint to be within the range of data), while Eqsim fits a breakpoint at the limit of the range of observed SSB (not visible in Figure 8.2.2). In neither case is the truncated distribution informative regarding a breakpoint or asymptote in mean recruitment at higher biomass. The hockey-stick stock-recruitment relationship is weighted most highly in PlotMSY when applying the complete SR time series whereas the truncated data lead to a near linear relationship that can be parameterised within each of the stock-recruit forms, and so the weightings are spread across the three models in both approaches (Table 8.2.2).

The truncated dataset gives only a slightly lower value of F_{MSY} in PlotMSY compared to the full dataset (NScodTruncpresent= 0.210 compared to NScodpresent = 0.218; Table 8.2.2), but yield (only landings were tested) estimated from the truncated series is around 45% of the yield estimated from the complete time series, and SSB around 42%. This result is the direct result of truncating the hockey stick function on the upper bound of the truncated data and is not informative. However the similarity in the F_{MSY} for both full and truncated implies that F_{MSY} for the current regime is not substantively changed by the recent S-R pairs.

Eqsim comes to similar results. F_{MSY} values are identical for both SR time series while yield and SSB is influenced to a larger extent (Table 8.2.3). The F where the probability to fall below B_{lim} reaches 5% (F_{MSY} harvest control rule applied + assessment/advice error) is lower in the truncated time series, but still far above potential F_{MSY} reference points. Thus these values of F_{MSY} appear to be very robust to precautionary considerations and no further modification would be required as described in section 5.3 above.

7.2.2.2 Multi species considerations for North Sea cod

In the current North Sea cod assessment variable M values from the multi species assessment model SMS are used. When using PlotMSY and EQsim only M values from the recent period 2008-2012 have been used because they are considered indicative of current conditions. However, multi species simulations have shown increasing cannibalism with an increasing cod stock (ICES WGSAM 2011). As the cod stock is predicted to increase substantially when fished at F_{MSY}, the currently low natural mortalities from 2008 to 2012 may not be applicable if the biomass increases as expected under the assumptions of the model used in the single species evaluations above. Another issue influencing predation mortalities of cod are current high seal populations in the North Sea compared to earlier time periods. It can be expected that these populations will stay at high levels. Therefore, three different natural mortality scenarios were investigated with PlotMSY: M typical of the most recent 5 years, M typical of 1963-1980 (period with a high cod stock), and a hybrid based on a hypothesis of cannibalism at 1963-1980 levels, but with higher seal mortality typical of the present (Table 7.2.4).

These different M vectors were used with both the complete and truncated stock-recruit data presented in above to estimate F_{MSY}. No assessment or advice error was taken into account and landings were optimized. The results for PlotMSY are shown in Table 7.2.2. With both stock-recruit time series, the present and hybrid scenarios give very similar F_{MSY} when optimizing landings (catch was not tested), only the historic scenario indicates a slightly lower value. Compared to the present scenario for both stock-recruitment time series, the historic scenario provides a ~10% smaller yield, and the yield in the hybrid scenario is ~50% smaller.

A similar sensitivity analysis was also carried out with Eqsim but only the present and hybrid scenario was tested. Also in Eqsim estimates of F_{MSY} are highly robust towards alternative M values and only SSB and yield become lower when higher M values are applied (Table 7.2.3). F5% is lowest when using the truncated SR time series combined with high M values. But F5% is still well above the median F_{MSY} candidates.

The robustness of F_{MSY} estimates towards changes in M is in contrast to multi species simulations carried out by WGSAM in 2012 to evaluate F_{MSY} in a multi species context. In these simulations F_{MSY} for North Sea cod was shifted towards higher values due to density dependent cannibalism rates. Next to this the WGSAM analysis has demonstrated that low F values for cod mean lower yield and higher probabilities to fall below B_{lim} for other species (e.g., whiting, haddock) and the cod stock should not be fished at too low F_{MSY} values. This shows that modelling predation processes explicitly can lead to a different perception on what is an optimal harvest strategy. For the future it may be beneficial to test density dependent mortality and growth directly in MSE simulations to test whether a dynamic inclusion of density dependent effect leads to different results.

7.2.3 Conclusions

The analyses on MSY carried out for the four cod stocks revealed that it is important to agree what exactly needs to be optimized. The basis for F_{MSY} depends to a large extent on the decision whether catch or landings should be the yield that is optimized. Indeed the decision may not just be between landings or discards but might be considered to consist of the utilizable part of the catch; that part above minimum landing size. The use of landings alone might institutionalize discarding above minimum landing size due to shortage of TAC. Thus the decision is not a pure scientific decision but should be discussed with stakeholders. With the anticipated ban in discarding practices, this may no longer be as important a consideration. In some cases the choice whether to use PlotMSY or Eqsim also influenced the F_{MSY} estimates, the differences were not as substantial as those coming from the other assumptions. Results from Eqsim indicate that there is no problem to stay above B_{lim} with more than 5% probability when applying F_{MSY}. For North Sea cod and Irish Sea cod F5% values seem to be high. However, it has to be taken into account that F is reduced when the stock falls below $B_{trigger}$ in the HCR applied to estimate F5%. When using a constant F instead of the HCR, F5% becomes lower and estimates are comparable to the ones from PlotMSY.

During the workshop it became obvious that the biomass reference points for North Sea cod are currently determined not following the standard ICES rules. The existence of different productivity regimes were discussed and the impact of using a truncated time series of stock recruitment observations was analysed. The choice whether to use a truncated time series from 1991 onwards or the complete time series had hardly any influence on the F_{MSY} estimates. F_{MSY} was also hardly influenced by using M values from different time periods. This contrasts with results from multi species simulations. Multi species considerations for North Sea cod also conclude that F_{MSY} for cod should not be too low because of negative effects on other stocks. Whether F_{MSY} should be chosen because of multi species considerations at the upper range of possible candidates needs to be discussed.

Table 7.2.1 F_{MSY} (median) and F5% estimates for the four cod stocks. In Eqsim (HCR) F5% tabulated corresponds to the F applied when SSB is above $B_{trigger}$. Realized F may be considerably lower. In PlotMSY and Eqsim (const. F) a constant F is applied over the full range of SSB values.

Cod stock	Catch or Landings	F_{MSY} PlotMSY	F_{MSY} Eqsim	F 5% plotMSY	F 5% Eqsim (HCR)	F5% Eqsim (const. F)
North Sea	Landings	0.22	0.23	0.64	1.05	0.7
North Sea	Catch	0.28	0.31	0.64	1.05	0.7
West of Scotland	Landings	0.18	0.19	0.50	?	?
West of Scotland	Catch	0.28	0.31	0.50	?	?
Irish Sea	Landings = Catch	0.39	0.42	1.04	1.37	1.05
Celtic Sea	Landings = Catch	0.31	0.35	0.41	0.61	0.54

Table 7.2.2. Sensitivity analyses for North Sea cod carried out with PlotMSY. Only landings were optimized.

Simulation	F	Yield	SSB	Ricker weighting	Beverton-Holt weighting	Hockeystick weighting
NScod present	0.218	360768	1360750	0.131	0.154	0.714
NScod historic	0.209	323774	1280580	0.131	0.154	0.714
NScod hybrid	0.222	186380	672074	0.131	0.154	0.714
NScodTrunc present	0.210	161140	568543	0.235	0.375	0.390
NScodTrunc historic	0.202	141599	551323	0.235	0.375	0.390
NScodtrunc hybrid	0.211	82172	302554	0.235	0.375	0.390

Table 7.2.3. Sensitivity analyses for North Sea cod carried out with Eqsim.

Scenario	Catch or Landings	F_{MSY} Eqsim	SSB	Yield	F5%
NScodpresent	Landings	0.23	1291630	356853	1.05
NScod hybrid	Landings	0.23	633931	176903	0.77
NScodTruncpresent	Landings	0.23	618556	170714	0.92
NScodTruncybrid	Landings	0.23	302353	84318	0.68
NScodpresent	Catch	0.31	925697	421395	1.05
NScod hybrid	Catch	0.35	387550	215237	0.77
NScodTruncpresent	Catch	0.31	440860	200888	0.92
NScodTruncybrid	Catch	0.31	215133	102594	0.68

Table 7.2.4 Alternative M scenarios

Age	Recent	Historic	Hybrid	CV (all)
1	1.04	1.26	1.45	0.1
2	0.70	0.82	1.02	0.1
3	0.49	0.27	0.48	0.1
4	0.23	0.20	0.23	0.1
5	0.20	0.20	0.20	0.1
6	0.20	0.20	0.20	0.1
7	0.20	0.20	0.20	0.1

Figures

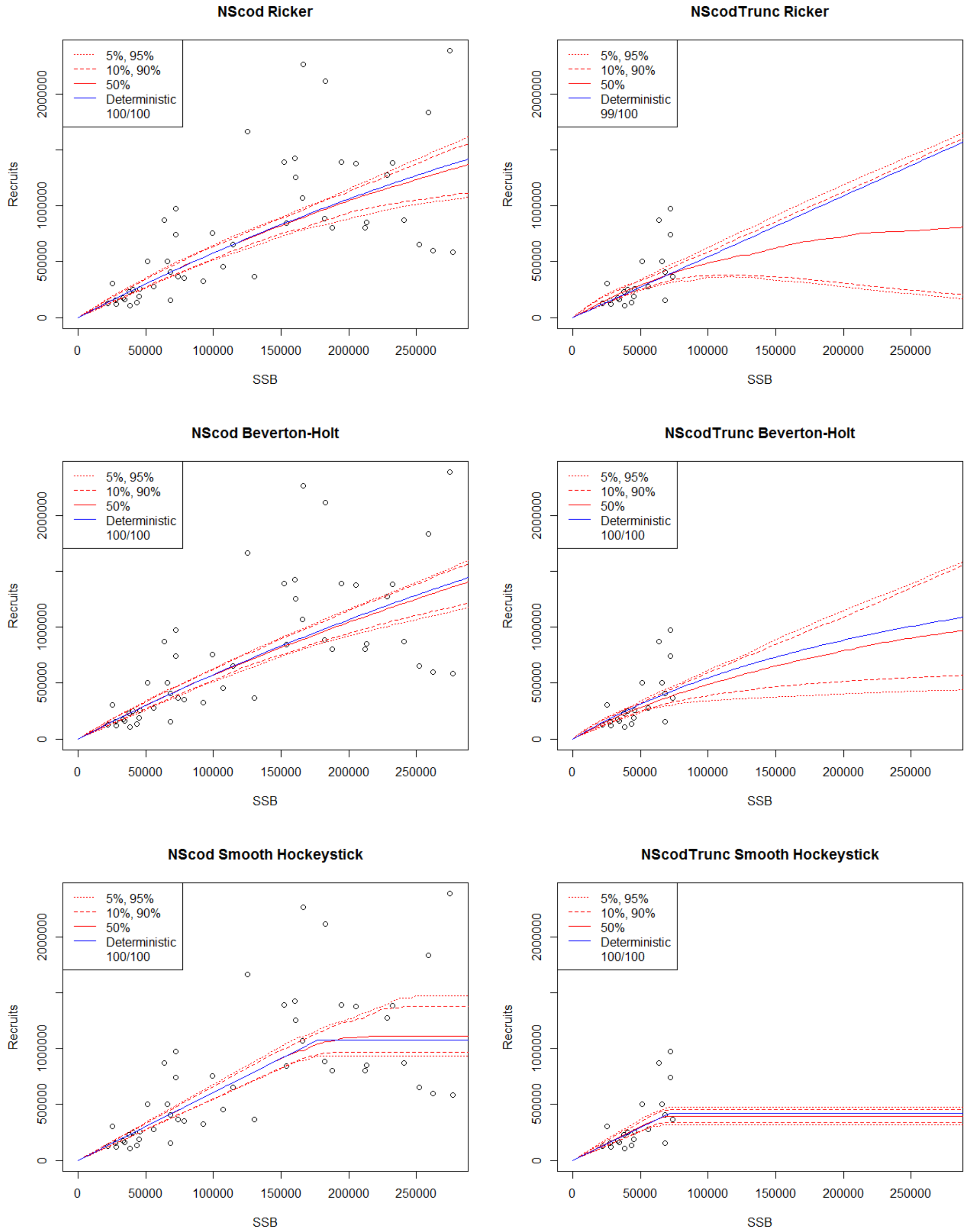

Figure 7.2.1: comparison of stock-recruit function fits to North Sea cod data with PlotMSY using the full time series (left) and a truncated series since 1991 (right)

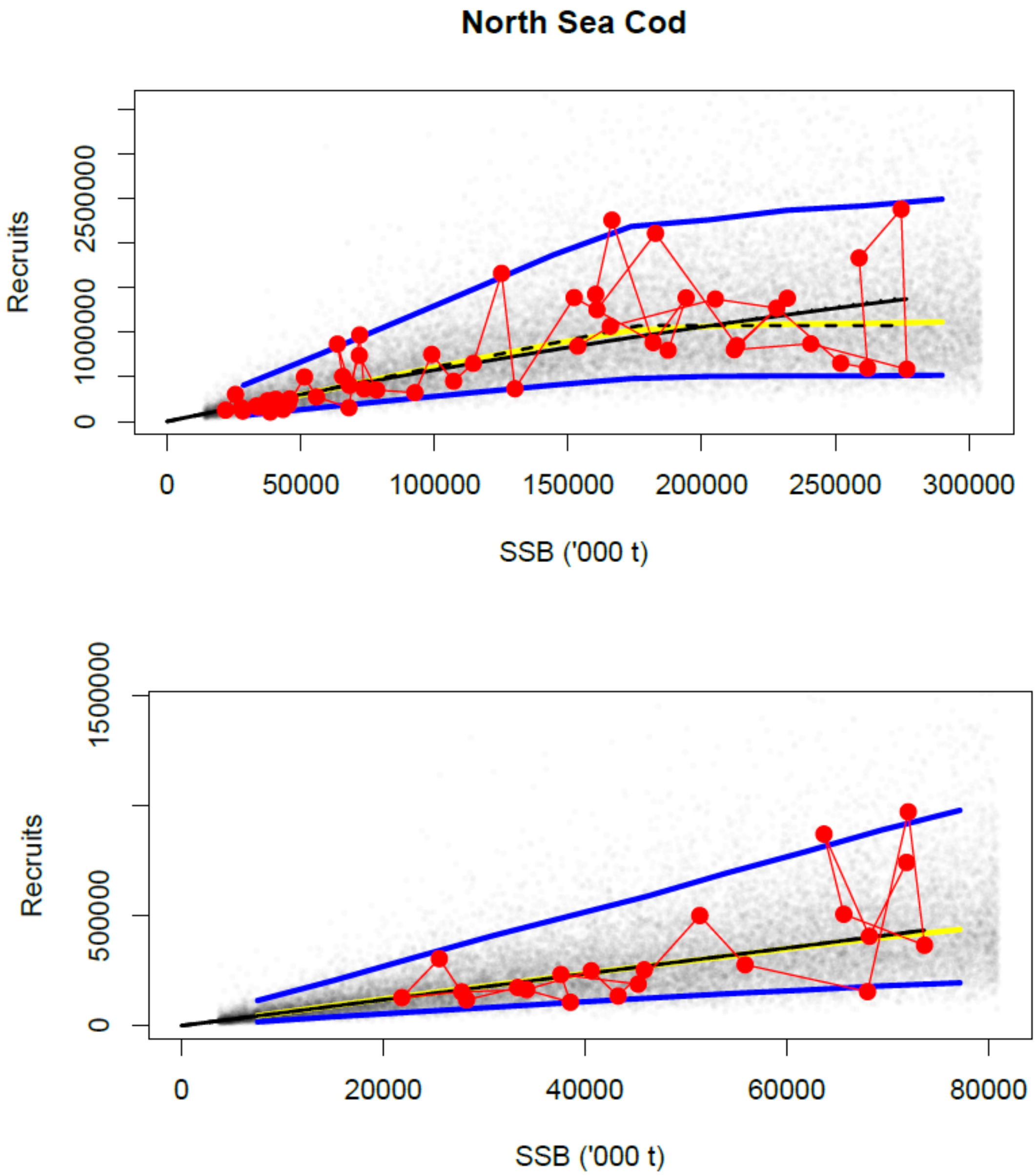

Figure 7.2.2: comparison of stock-recruit function fits to North Sea cod data with Eqsim using the full time series (top) and a truncated series since 1991 (bottom).

7.3 Faroe Saithe (ICES Vb) (See also Annex IV)

In 2011 stochastic simulations using MSE and including a HCR were performed to estimate potential F_{MSY} candidates conforming to the ICES MSY framework (ICES NWWG 2011, Section 6.4). A value of F_{MSY} =0.28 was estimated to provide maximum yield in the long term consistent with F_{pa}=0.28 (estimated Fmed in 1999)(Table 7.3.1)(ICES 2013 Advice sheet). $B_{trigger}$ was set to 55 000 t. which was also used as the breakpoint of the Hockey-Stick function with the recruitment above the breakpoint fitted to the historical stock-recruit pairs. The basis for B_{pa}= 55 000 t. was the historical lowest observed ssb (B_{loss}). F_{lim} and B_{lim} are not defined for faroe saithe.

Table 8.3.1. Faroe saithe. Reference points (Unchanged since 2011)

	Type	Value	Technical basis
MSY	MSY $B_{trigger}$	55 000 t.	Breakpoint in segmented regression.
Approach	F_{MSY}	0.28	Provisional stochastic simulations (performed in 2011).
	B_{lim}	Undefined.	
Precautionary	Bpa	55 000 t.	Bloss in 2011.
Approach	F_{lim}	Undefined.	
	F_{pa}	0.28	Consistent with 1999 estimate of Fmed.

F_{MSY}=0.28 was considered too precautionary given that the stock has never been below $B_{trigger}$(B_{pa}) at exploitation rates above F_{MSY} =0.28 since the early 1980's with no apparent depletion or impaired recruitment and therefore additional simulations were explored in 2012 (ICES NWWG 2012, Section 6.4) leading to a revised F_{MSY} =0.32 which was however not adopted by ICES (Figure 1)

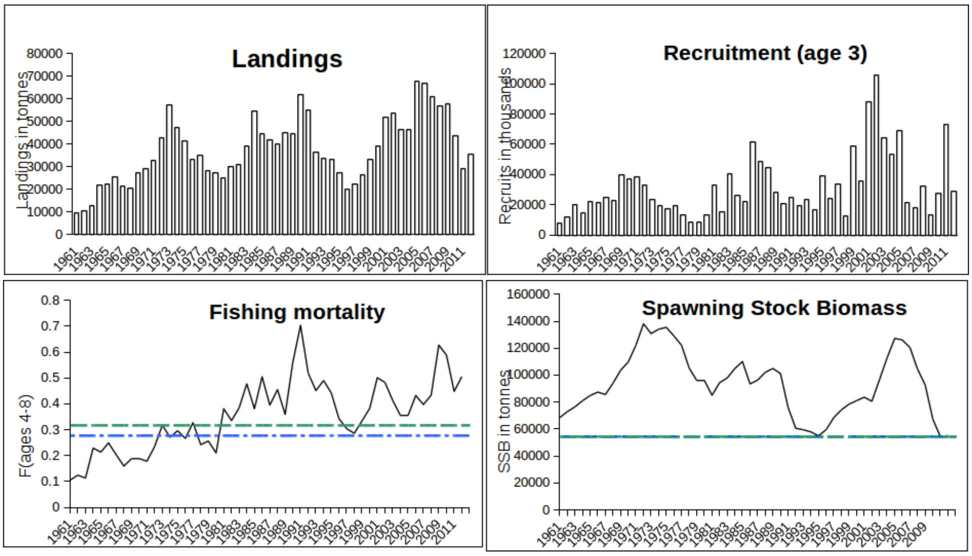

Figure 7.3. . Faroe saithe. Landings (tons), recruitment (thousand), average fishing mortality (F4-8) and spawning stock biomass (thousand). Blue stapled line is the current F_{MSY} =0.28. Green stapled line represents the alternative F_{MSY} =0.32.

At the WKMSYREF2 workshop the EqSim and plotMSY tools were used to explore the plausibility/consistency of the current F_{MSY}.

The EqSim framework fits three stock-recruit functions (Ricker, Beverton-Holt and Hockey-stick) on the bootstrap samples of the stock and recruit pairs from which approximate joint distributions of the model parameters can be made. The result of this is projected forward for a range of F's values and the last 50 years are retained to calculate summaries. Each simulation is run independently from the distribution of model and parameters. Error is introduced within the simulations by randomly generating process error about the constant stock-recruit fit, and by using historical variation in maturity, natural mortality, weight at age, etc.

PlotMSY fits three stock-recruit functions (Ricker, Beverton-Holt and smooth Hockey-stick). Although reference points are estimated for each of these functions individually, an option is provided to combine appropriate outputs from any number of these stock-recruit functions in order to derive integrated estimates for a given combination, where the default weighting is based on harmonic means of the likelihood of individual samples from the MCMC chains (PlotMSY Software manual).

PlotMSY puts all weight to the Ricker stock-rec function (99%)(best-fit of the three functions) giving a point estimate of F_{MSY} = 0.79 while the use of the equally-weighted option in the simulations estimates F_{MSY} =0.44. There is a high level of uncertainty in the estimates of F_{MSY} within the Ricker fits. The results of both options are very unrealistic, well above historical exploitation rates (F_{4-8}=0.35) and in the realm of EqSim F_{crash} estimates.

In this case the EqSim framework was considered superior to PlotMSY providing estimates of MSY reference values consistent with previous HCR simulation exercises (see above).

In the EqSim simulations the Hockey-Stick stock-recruit function were used assuming assessment and autocorrelation errors. Figures 8.3.2 and 8.4.3 illustrate the results of these simulations which suggest that candidates for F_{MSY} are F_{MSY} =0.34 (median yield) and F_{MSY} =0.30 (F that gives the maximum mean yield in the long term) lie above the current F_{MSY} = F_{pa} = 0.28 if autocorrelation and assessment errors are included in the simulation framework. If errors are ignored then estimates for F_{MSY} are predicted to F_{MSY} =0.38 (median yield), F_{MSY} =0.35 (maximum mean yield). A summary is given in Table 8.3.2.

Table 8.3.2. Faroe saithe. EqSim results.

	F	SSB	Catch	option
F_{lim}	0.34	87327.43	36479.80	ass. Error
F_{lim} 10	0.37	79116.87	35447.45	ass. Error
F_{lim} 50	0.46	38905.30	22023.28	ass. Error
MSY:median	0.34	88565.78	36665.24	ass. Error
Maxmeanland	0.30	101372.87	37109.88	ass. Error
FCrash5	0.41	63312.00	31637.31	ass. Error
FCrash50	0.52	855.73	550.19	ass. Error
F_{lim}	0.40	78435.72	38526.07	no ass. Err.
F_{lim} 10	0.42	73052.08	37660.27	no ass. Err.
F_{lim} 50	0.50	38910.57	24279.75	no ass. Err.
MSY:median	0.38	82329.53	38694.43	no ass. Err.
Maxmeanland	0.35	90688.34	39167.13	no ass. Err.
FCrash5	0.43	69750.99	37114.99	no ass. Err.
FCrash50	0.54	2847.53	1910.51	no ass. Err.

Other options were also explored within the EqSim framework combining the Ricker and segmented regression functions and ignoring errors all of which gave essentially unbounded yield for increasing fishing mortalities (figure not included).

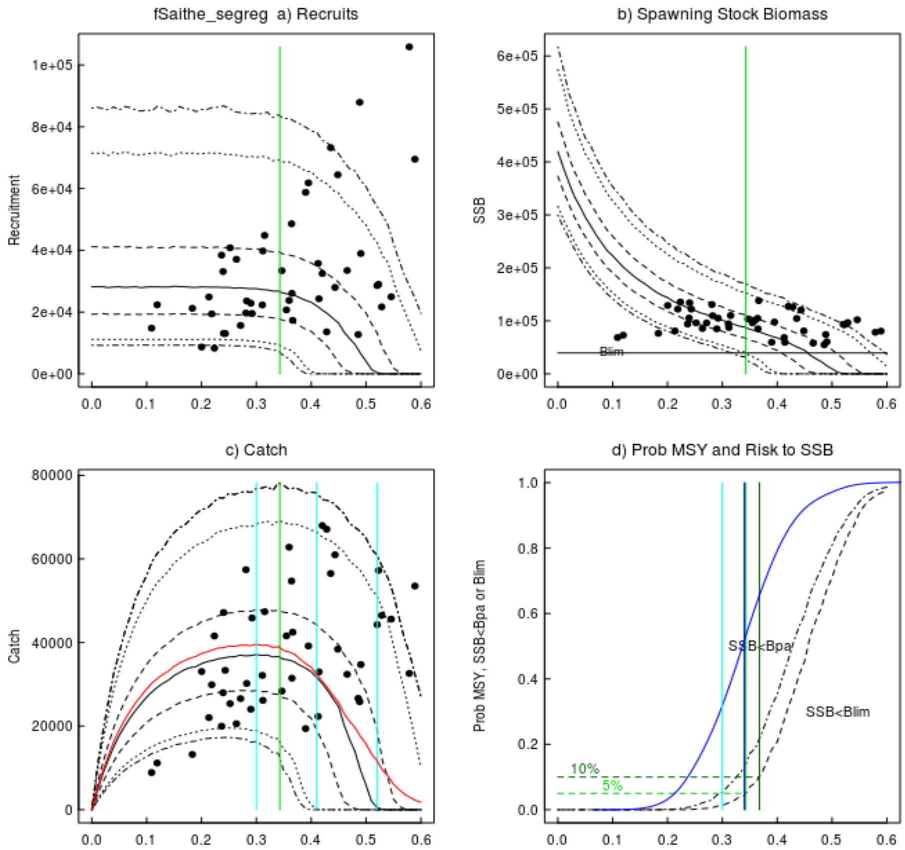

Figure 7.3.2. Faroe saithe. EqSim simulation outputs with assessment errors and Hockey-stick function. B_{lim} is undefined but was set as $B_{lim}=B_{pa}/1.4$ for the purpose of this analysis.

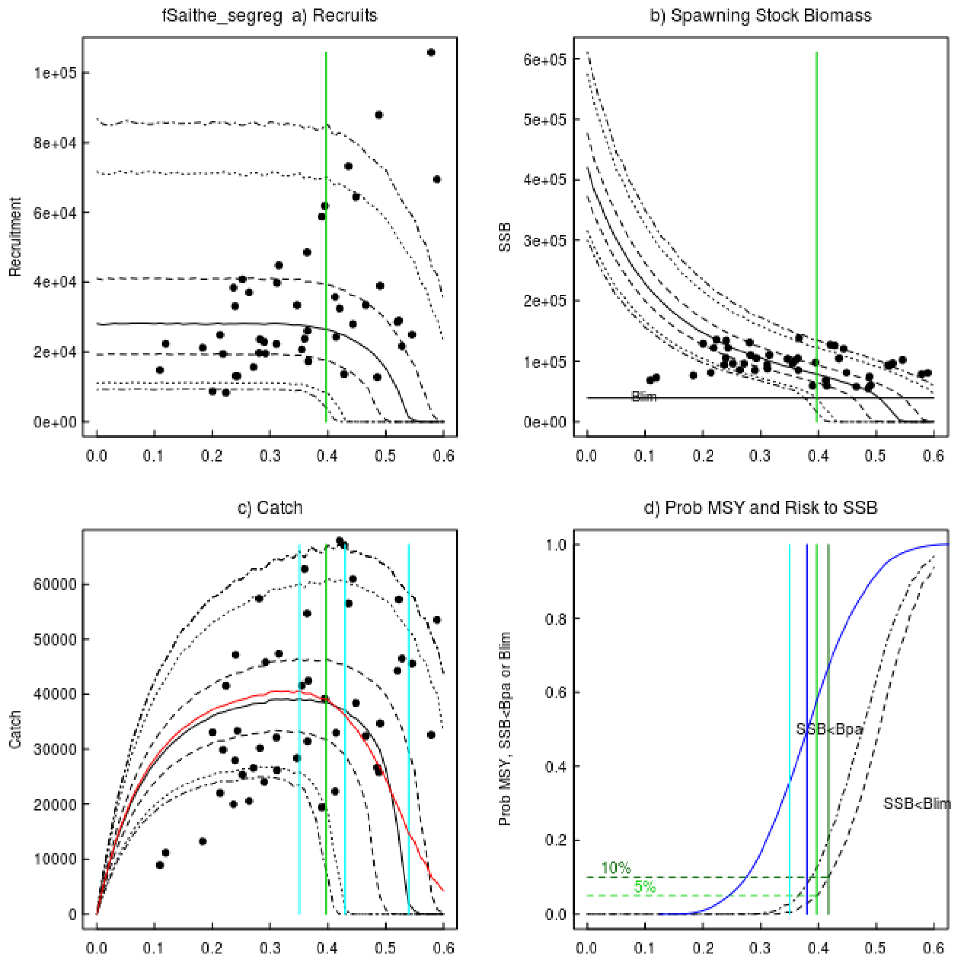

Figure 7.3.3. Faroe saithe. EqSim simulation outputs without assessment errors and Hockey-stick function.

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

7.4.1 Summary

At the last benchmark assessment of this stock at WKFLAT in 2010 F_{MSY} was estimated to 0.38 based on a low probability (20%) of being below an SSB of 2000 t (B_{pa}). Stock dynamics and productivity is poorly known below that biomass (only two observations of SSB's lower). The present ICES methodology of constraining F_{MSY} to the precautionary approach was not fully developed at that time and therefore this rationale was used as the most legitimate.

At WKFRAMEII in 2011 it appeared evident that the sole stock in Kattegat and Skagerrak was somewhat outstanding compared to other ICES sole stocks; F_{MSY} was estimated relatively high likely due to a low selectivity on the younger age groups and a decreasing weight on the older age groups. The decreasing weights were corrected for at the present analyses, and recent (2008-2012) mean weight at ages for age groups 2-6 and long term averages for the oldest age groups were therefore used for F_{MSY} evaluation.

In accordance with the breakpoint of segmented regression of SR, a B_{lim} candidate was estimated within the range 1000-1200 t (1000 t is Bloss). With the EqSim software the highest weighting was put on a Ricker stock-recruit relationship, and this model was therefore predominantly weighed in the equilibrium simulations. EqSim and PlotMSY gave equilibrium estimates of F_{MSY} (medians) of 0.53 and 0.47, respectively. However, the EqSim suggested that these estimates could be constrained by precautionary considerations (prob(SSB< B_{lim})<5%), which will restrict F_{MSY} to 0.36 with the weighted SR models. This analysis is conditional of a B_{lim} of 1200 t, assessment error of 0.3 and stochasticity in the input parameters. Assumptions of alternative B_{lim}, mean wgt-at-ages and assessment error had little impact of F_{MSY} estimation, but assumption on SR models did lower the PA constrained F_{MSY} estimate for the choice of segmented regression (F_{MSY} =0.32) as compared to the weighed combined model.

The previous F_{lim} was based on Fmed, which seemed unjustified with the present SR relation (observations only at right part of a ricker like SR relation). F_{pa} was then estimated to be consistent with F_{lim} (F_{lim} *e-1.645σ). Therefore, the previous estimated F_{pa} and F_{lim} are not considered appropriate anymore, and re-calculated to correspond to B_{lim} and B_{pa} by means of SR replacement lines. These estimates were considerably higher than the previous estimates, F_{pa} =0.49 and F_{lim} =0.92, as shown in the text table below. An F_{MSY} estimate that correspond to the estimation procedure for F_{pa} and F_{lim} (replacement lines) is a PA constrained F_{MSY} (0.32) based on a segmented regression.

Table 7.4.1 Sole in IIIa and 22-24. Reference points as previously adopted by ICES (upper) and as suggested by WKMSYREF2 (lower).

Reference point	Value	Basis
MSY $B_{trigger}$	2000 t	lowest observed SSB excluding 1984–1985 low SSB's (ICES, 2010).
B_{pa}	undefined	
B_{lim}	undefined	
F_{MSY}	0.38	Provisional value based on Stochastic simulations. F associated with highest yield and low prob. of SSB< $B_{trigger}$ (ICES, 2010).
F_{pa}	0.30	Consistent with F_{lim}
F_{lim}	0.47	F med analysis in 1998 excluding abnormal years around 1990
Reference point	**Value**	**Basis**
MSY $B_{trigger}$	2000 t	Previous B_{pa}
B_{pa}	2000 t	B_{lim} *$e^{1.645\sigma}$, σ=0.30
B_{lim}	1200 t	Candidate; based on B_{loss} and segmented regression (WKMSYREF2 2014)
F_{MSY}	0.32	Candidate; based on equilibrium scenarios constrained by prob(SSB< B_{lim})<5% w. stochastic recruitment (WKMSYREF2 2014)
F_{pa}	0.49	B_{pa} replacement line; Consistent with B_{pa} and F_{lim}
F_{lim}	0.92	F_{lim} replacement line; Consistent with B_{lim}

7.5 Haddock in Subarea IV (North Sea) and Division IIIaN (Skagerrak) (See also Annex V)

Haddock stocks in the North Sea and Skagerrak (Subarea IV and Division IIIaN) and to the West of Scotland (Division VIa) are due to undergo a benchmark process at the ICES Benchmark Workshop on Northern Haddock Stocks (WKHAD) during January and February 2014. Given this, WKMSYREF2 decided it would be opportune to produce exploratory estimates of F(msy) for the North Sea haddock stock in the first instance, using three approaches:

1) An *ad hoc* R script that was developed at the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak in 2010 to provide F(msy) estimates for North Sea haddock (see Section 13.7 in ICES-WGNSSK 2010);
2) The plotMSY code developed at Lowestoft (see Section XXXX); and
3) The eqSIM code currently under development by WKMSYREF2 members and others (see Section XXXX).

Details of the runs are given in Appendix IV.

The following table summarises the F(msy) 5%, median and 95% estimates produced by three methods used here. Apart from the eqSIM results (see Appendix IV), the estimates are quite similar and seem to be robust to the specific implementation used for estimation.

Method	F(msy) lower bound (5%)	F(msy) median	F(msy) upper bound (95%)
Ad hoc R script	0.222	0.370	0.570
plotMSY	0.319	0.359	0.406
eqSIM	n/a	1.00	na

However, none of the methods presented here are really yet in a suitable state for application during (for example) the forthcoming WKHAD benchmark meeting. The ad hoc R script is limited in that it can use only one stock-recruit model at a time, with no data-driven model selection. It has also only been used for a small number of stocks and has not been more widely tested, and there are no plans for further development. The plotMSY and eqSIM packages both require additional testing on different computer setups to ensure robustness, while in addition eqSIM can generate unrealistic results when confronted with very variable recruitment data. WKMSYREF2 recognises that these approaches are potentially extremely useful, and encourages further development on them. The identified problems in EqSim are expected to be dealt with in the near future which may solve some of the aspects such as the unrealistic results at high variability.

7.6 Northeast Arctic cod

Kovalev and Bogstad (2005) evaluated the MSY for Northeast Arctic cod. They used a biological model which included density-dependence as well as cannibalism. In their long-term stochastic simulations, the effect of including these processes in the model was explored, as well as the effect of changing the selection pattern. Fig. X illustrates some of the results. Although the yield curve is clearly affected by the model choice, it should be noted that in all cases, the yield curve is relatively flat for a range of Fs between 0.25 and 0.60. The current F_{MP} is 0.40, which is also the value presently used for F_{MSY}. The fishing mortality for this stock has been below 0.40 (in the range 0.23-0.35) since 2007. So far, the stock development at such low fishing mortalities seems to be in line with the simulation results obtained for such mortalities in Kovalev and Bogstad (2005). However, the age structure of this stock has not yet been completely restored, so in the next 3-4 years we will learn more about the stock dynamics in a situation with a considerable biomass of old and large fish.

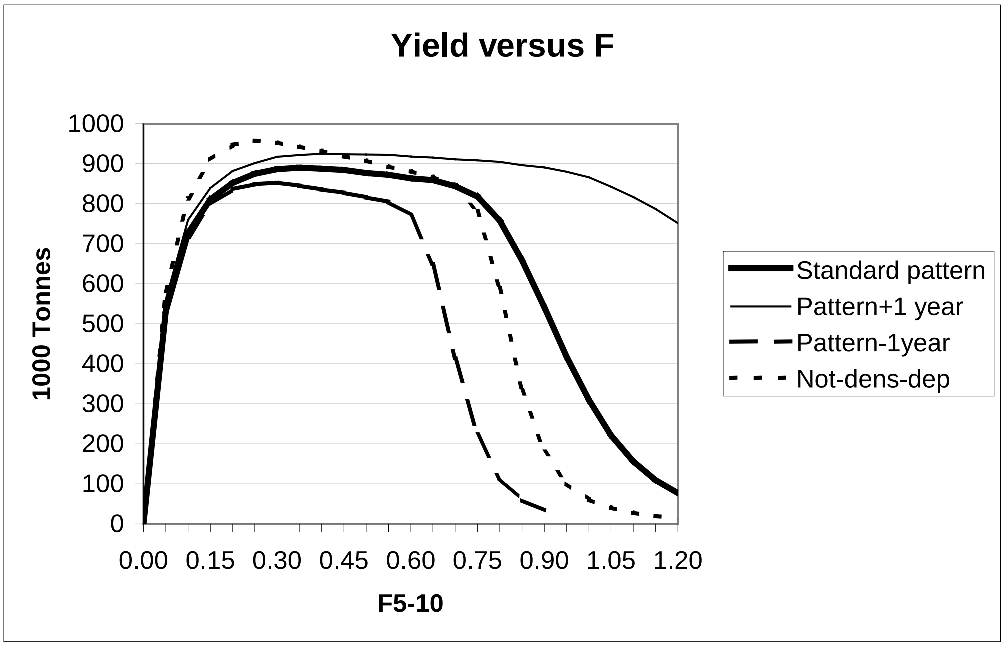

Fig. X. Average catch for 2026-2105 as a function of fishing mortality for different exploitation patterns and population models (Kovalev and Bogstad 2005).

Standard pattern: Recent (2002-2004) exploitation pattern

Pattern +1 year: Recent exploitation shifted 1 age group upwards

Pattern -1 year: Recent exploitation shifted 1 age group downwards

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Annex 1 An evaluation of six different management strategies applied to sprat in the North Sea, including a test of robustness toward assumptions made about biology of the stock and the selectivity in the fishery

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Results

Six different management strategies were evaluated (a description of each strategy can be found in Table 3) based on a simulation model where fishing is employed in the "true" stock, whereas TACs were determined in a "perceived" stock accounting for stock number estimation error (Figure A1.1). The criteria of 95% probability of being above B_{lim}, was applied to identify the sustainable management strategies. Only strategies applying a control rule were found to be sustainable. Hence, neither the Escapement-strategy, where the spawning stock is fished down to B_{pa} every year, nor the F_{MSY} -strategy were not sustainable (Figure A1.2). In order to make the Escapement-strategy sustainable a control rule must be applied on the fishing mortality (this strategy is here referred to as the Fcap-strategy) (Figure A1.3). The F_{MSY} -strategy was simply not applicable to the sprat stock, as it was not possible to achieve a dome-shaped relationship between fishing mortality and total annual catch (Figure A1.4). The sustainable strategies were the Fcap-strategy, the F-strategy (also known as the fixed F strategy), and the HCR-strategy (also known as the ICES harvest control rule strategy). Optimal control rules (or reference points if you like) for these strategies were F_{cap} ~ 1.2, F ~1.2, and F_{max} ~ 1.4. In contrast, the HCR-strategy was slightly more robust toward situations where the biology assumed when optimizing the control rules (optimizing against the 95% > B_{lim} criteria) differed from the biology of the stock where the control rules were implemented. All three strategies were, however, most sensitive toward choice of stock-recruitment models and maturation age. Increasing fishing selectivity on young fish did not compromise sustainability for any of the strategies. All three strategies resulted in average annual catches around 160 and 165 thousand tons (Figure A1.7). However, the Fcap-strategy and the F-strategy resulted in the same level of variance in annual catches, whereas the HCR-strategy resulted in closure of the fishery in 5% of all simulations (Figure A1.7). Effects on the stock demography differed only marginally between the three strategies and a comparison with a no-fishing scenario revealed that fishing the stock according to one of these strategies mainly affects the number of older fish in the stock, which already constitute a relatively small proportion of the entire stock due to a high natural mortality (Figure A1.2). Lastly, we also investigated an alternative escapement strategy where the spawning stock biomass is fished down to B_{lim} every year under the 95% > B_{lim} criteria. It turned out to be possible to approximate this strategy by identifying a B_{pa}*, which is higher than B_{pa}. This implementation of an escapement strategy resulted in marginally higher average annual catch compared to the Fcap-strategy and the F-strategy, but with closures of the fishery in a number of years (Figure A1.8).

Methods

The core model

The core of the simulation tool is an age and season resolved population model. The model keeps track of cohort development influenced by natural mortality (*M*) and fishing mortality (*F*). Stock numbers (*N*) is calculated for discrete age groups (a_0, a_1 … a_{max}) and updated at the beginning of each season (t_1, t_1 … t_{max}). The youngest age group is age-0 (a_0). a_0 in t_1 signifies the recruitment of young fish to the stock and is modeled as a function of spawning stock biomass (*S*). a_{max} is a plus-group and covers all age groups at or above the oldest age group for which accurate data is available. This population model was implemented and numerically solved in [R] (r-project.org) in the following way:

(1)

N_{a_i,t_i,y_i} is the stock number for any given age group, season, and simulation year. The onset of the simulation year may be different from the calendar year, since it starts at the time spawning. $N_{initiate}$ is a given set of initial stock numbers required to initiate the simulations. $f(S_{y_i})$ is a given stock-recruitment function (we return to the recruitment function later), where *S* in y_i is calculated as:

(2)

S is not calculated in y_1, since the recruitment in y_1 is given by $N_{initiate}$. P_{ai} is the proportion of a given age group that is mature and $W_{a_i,t_{max}}$ is the weight [g] of an average individual at the end of the simulation year.

Fishing mortality (*F*) and natural mortality (*M*) is act explicitly in each season and on each age group and removes individuals so that the stock number at the beginning of any season is equal to stock number at the beginning of the preceding season minus what has been removed by fishing and natural causes (mainly predation) during the course of the preceding season. Hence, *F* and *M* applied in the model are season and age resolved mortalities. It is assumed that *F* and *M* act in parallel throughout the course of a given season. This was realized using Pope´s approximation with one hundred sequential iteration cycles for each season and age group. *F* in model is composed of a prefactor (F_{mult}) and an exploitation pattern (*E*):

$$F_{a_i,t_i} = F_{mult} \times E_{a_i,t_i} \quad (3)$$

F_{mult} scales the overall fishing pressure up and down and is the same for all seasons and age groups, whereas E is given explicitly for each season and age group and describes the relative age selectivity of the fishery.

Annual fishing mortality and the annual natural mortality, the model also calculate the F_{bar} and M_{bar}, which we in the present study have chosen to define as the average of the annual mortality of age-1 and age-2, for example:

(4)

The catch [tons] of a given age group, in a given season and year is derived from the fishing mortality:

$$C_{a_i,t_i,y_i} = W_{a_i,t_i} \times N_{a_i,t_i,y_i} \times \left(1 - e^{-F_{a_i,t_i}}\right) \times 10^{-6} \tag{5}$$

To avoid the bias introduced by calculating the catch after natural mortality has taken its share (or before), we used Pope´s approximation with one hundred sequential iteration cycles for each season and age group. Total annual catch in a given year is the sum of all seasons and age groups.

The true stock-recruitment relationship is rarely known, and for both sandeel and sprat in the North Sea a so-called Hockey stick function is used to avoid making unsupported assumptions about the curvature of functions accounting for density dependence. However, in the present study we explored the robustness of different management strategies toward different types of stock-recruitment relationships:

Hockey stick: $$f(S_{y_i}) = \begin{cases} if\,(S_{y_i} > B_{pa}) \rightarrow hockey_{\max} \\ if\,(S_{y_i} < B_{pa}) \rightarrow \alpha_1 S_{y_i} + \beta_1 \end{cases} \tag{6}$$

Ricker: $$f(S_{y_i}) = \alpha_2 S_{y_i} \times e^{-\beta_2 S_{y_i}} \tag{7}$$

Beverton & Holt: $$f(S_{y_i}) = R_{\max} \frac{S_{y_i}}{S_{y_i} + \alpha_3 R_{\max}} \tag{8}$$

$Hockey_{max}$, α_1, β_1, α_2, α_3, β_2, and R_{max} are parameters shaping the stock recruitment relationships and was adopted from the hockey stick function used in the official 2013 stock assessment (ICES 2013a; ICES 2013). Remaining parameters (α_2, α_3, β_2, and R_{max}) were fitted based on the official recruitment and spawning stock biomass time series reported by ICES in 2013 (ICES 2013). Lastly, stochasticity was added to simulate environmental noise.

$$Stochastic\_recruitment = N_{a_0,t_1,y_i} = f(S_{y_i}) \times e^{\sigma_R \times NORM(0,1)} \tag{9}$$

σ_R was taken from the official stock assessment.

All model parameters and the information about the specific biology of the stock can be found in Table1 and 2.

Implementation and evaluation of management strategies

Each management strategy gives rise to a fishing mortality, which can be translated into a TAC (Total Allowable Catch) at the beginning of each simulation year when implemented into Eq. 5. In order to account for the fact that calculation of total allowable catch (TAC) is a forecast and therefore calculated based on incomplete information, the TAC is calculated based on the "perceived" stock numbers:

$$N^{*}_{a_i,t_1y_i} = NORM\left(N_{a_i,t_1,y_i}, \sigma_{N_{a_i}}\right) \qquad (10)$$

where the standard deviation (σ) represents the estimation uncertainty and is the coefficient of variation (CV) times the stock number. Coefficients of variation (CV) for each age group were taken from the official stock assessment (Table 1). Recruitment in the forecast (made in the "perceived" stock) was predicted directly from the stock recruitment relationship (Eq. 6) without adding environmental noise as in Eq. 9.

After having identified the TAC based on the "perceived" stock, we then fish the "true" stock with this TAC using Eq. 1. This, however, requires that we first identify the fishing mortality that gives rise to the removal of the TAC (the realized fishing mortality). Realized fishing mortality is found by identifying the F_{mult} that minimized the statement (total annual catch – TAC)^2, where the total annual catch is calculated by summing up Eq. 5 for all seasons and age groups. The minimization was carried out using the optimize-function in [R]. This step-wise procedure of implementing a given management strategy is summarized in Figure A1.1.

Evaluation of management strategies

Six different management strategies were evaluated for sprat and sandeel in the North Sea (see description of the six strategies in Table 3). Simulations of how the stocks fluctuate when managed according to a given management strategy was carried out for a period of 20 years, and the probability of falling below B_{lim} in the period between year 5 and year 20 was calculated repeating the simulation 500 times (assuming that by year five simulation results is no longer dependent of the initial conditions). The long term average yield (for the period between year 5 and year 20) was also calculated for each management strategy. Three out of the six strategies evaluated apply a control rule involving a reference point fishing mortality to constrain fishing mortality (see Table 3 for details), which is optimized in such a way that *S* fall below B_{lim} in ~5% of all simulated years by default (5% was defined as the critical level of whether or not a given strategy is sustainable). Identification of the optimal reference points was carried out visually on plots of the type shown in Figure A1.2. For these three management strategies we evaluated how robust each strategy was toward some of the default biological assumptions summarized in Table 1 and 2. This was done by testing what happened if the optimized control rules were to be applied in a situation where the default biological assumptions were changed. Table 4 contains an overview of the changes made to the default assumptions.

Table 1. Overview of parameter values used in the simulations. α_2, α_3, β_2, and R_{max} were fitted using the optimize function in [R]. All other parameters were adopted from the ICES stock assessment of North Sea sprat (ICES 2013).

Parameter	Description	Parameter Value
B_{lim}	reference point	90000 (t)
Bpa	reference point	142000 (t)

tmax	number of seasons	4
ɑmax	number of age classes	3
σR	sd on a log scale	0.65
CVN	assessment uncertainty (age 1 to age+)	0.48, 0.25, 0.26
hockeymax	upper plateu on the Hockey stick	200000
α1	Hockey stick slope	hockeymax/ B_{lim}
β1	Hockey stick intercept	0
α2	fitted parameter in Eq. XXX	1.716
α3	fitted parameter in Eq. XXX	0.37
β2	fitted parameter in Eq. XXX	2.31x10-6
Rmax	fitted parameter in Eq. XXX	397227

Table 2. Biological values specific for the North Sea sprat stock. All values were were adopted from the ICES stock assessment of North Sea sprat (ICES 2013).

	ɑ0	ɑ1	ɑ2	ɑ3
Stock numbers 2013 (Ny1,t1)	166239	25296	8333	1797
Exploitation pattern (Et1)	0.00	0.05	0.08	0.11
Exploitation pattern (Et2)	0.00	0.12	0.45	0.66
Exploitation pattern (Et3)	0.00	0.03	0.04	0.05
Exploitation pattern (Et4)	0.00	0.00	0.00	0.00
Weight in the catch (Wt1)	6.75	8.64	10.97	14.87
Weight in the catch (Wt2)	5.56	8.96	12.15	15.62
Weight in the catch (Wt3)	7.05	12.93	18.71	25.16
Weight in the catch (Wt4)	6.37	11.10	15.94	21.14
Proportion mature 2014 (P)	0.00	0.43	0.88	0.96
Natural mortality (Wt1)	0.27	0.56	0.45	0.13
Natural mortality (Wt2)	0.60	0.39	0.33	0.13
Natural mortality (Wt3)	0.27	0.26	0.22	0.22
Natural mortality (Wt4)	0.43	0.29	0.16	0.16

Table 3. Detailed descriptions of the six different management strategies evaluated

Fixed escapement strategy (Escapement-strategy): In this strategy the stock is fished down to Bpa every year after putting aside what is required to ecosystem services, here defined by the natural mortality. The TAC is determined each year by (i) identifying the fishing mortality that minimizes the statement $(Sy+1 – B_{pa})^2$ (ii) fish the "perceived" stock using this fishing mortality and (iii) derive the total annual catch by summing up Eq. 5 for all seasons and age groups.
Maximum sustainable yield (F_{MSY} -strategy): The stock is fished with a constant fishing mortality that maximizes the yield (F_{MSY}). F_{MSY} is found numerically by fishing the stock with different fishing mortalities and plotting these values against the average TAC (averaged over the period between year 5 and year 20).
Fishing mortality equal to natural mortality (F=M-strategy): The stock is fished with a fishing mortality that satisfies the statement Fbar = Mbar, where Mbar is calculated based on the natural mortalities assumed to apply for the stock (see Table 2).

Fixed fishing mortality (F-strategy): With this strategy the stock is fished with a fixed fishing mortality. This fishing mortality is defined as the maximum long term sustainable fishing mortality, and is optimized numerically by implementing a range of different fishing mortalities, where after the fishing mortality leading to a probability of 0.05 that S falls below B_{lim} is selected (see example in Figure A1.2).
Fixed escapement strategy with cap on fishing mortality (Fcap-strategy): This strategy is similar to the Escapement-strategy described above, except here the fishing mortality is constraint by Fcap, which represents a ceiling on the fishing mortality. This means that if the TAC that comes out of the Escapement-strategy corresponds to an Fbar (in the "perceived" stock) that exceeds Fcap, then the Escapement-strategy is disqualified and the TAC is instead determined by fishing the "perceived" stock with a fishing mortality corresponding to Fcap. Fcap is optimized numerically by implementing a range of different Fcap-values, where after the Fcap-value leading to a probability of 0.05 that S falls below B_{lim} is selected.
Harvest control rule (HCR-strategy): The stock is fished with a variable fishing mortality determined by a set of harvest control rules by evaluation S at the beginning of each year. When S < B_{lim} the fishing mortality should be zero. When S is between B_{lim} and B_{pa} the fishing mortality increase linearly from 0 to Fmax, and above B_{pa} the fishing mortality is fixed at Fmax. Fmax is optimized numerically by implementing a range of different Fmax-values, where after the Fmax-value where the probability of falling below B_{lim} is 0.05 is selected.

Table 4. Overview of changes made to the default model assumptions during the robustness-test of management strategies. Variability of natural mortality was calculated from the multispecies SMS output 2013, and was implemented by multiplying default M by a random value drawn from a normal distribution with a mean of 1 and the standard deviation given in this table.

Description	Change implemented
Variable natural mortality	0.16 (standard deviation)
High natural mortality	20% higher
Higher inflexion point	20% higher
Later maturation	20% fewer are mature at age 1 and 2
Earlier maturation	20% more are mature at age 1 and 2
Shifted from a Hockey stick to a Ricker	see Eq. 7
Shifted from a Beverton & Holt	see Eq. 8
Elevated exploitation of age 0	Same exploitation level as for age 1
Elevated exploitation of age 1	Same exploitation level as for age 2

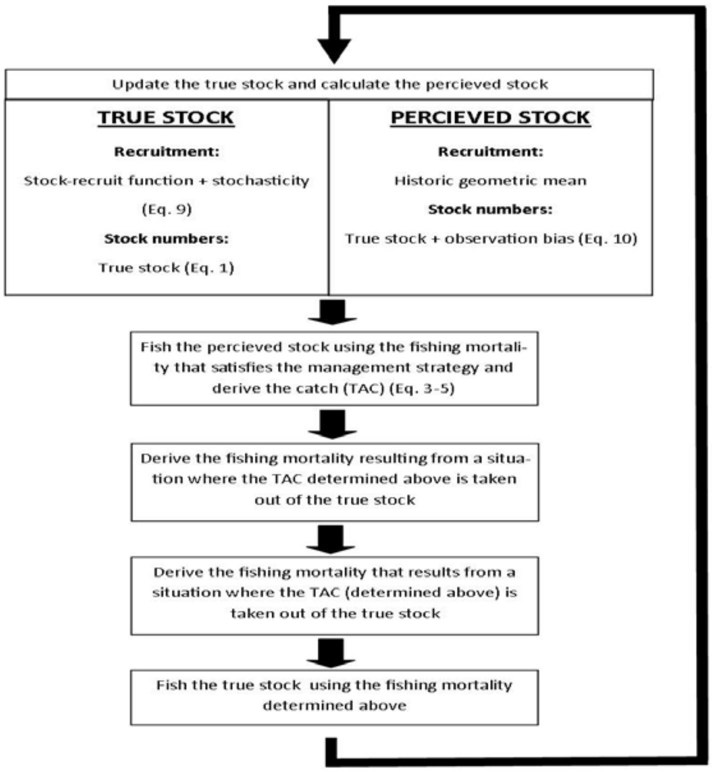


Figure A1.1. Flow diagram giving an overview of the step wise procedure in the simulations.

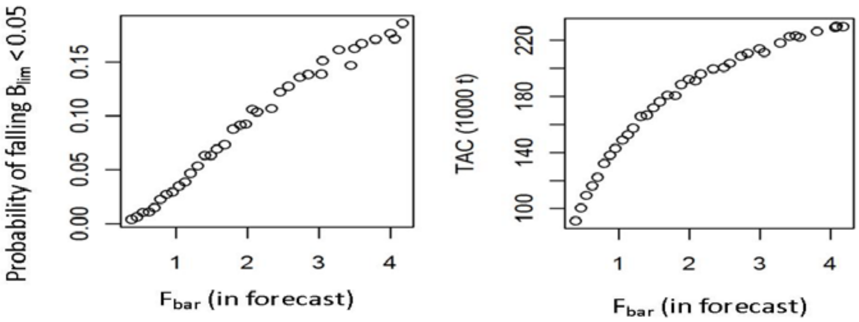


Figure A1.2. Example of how the optimal fishing mortality in the Fixed F-strategy is identified (left) and sensitivity of the TAC to small changes in the selected fishing mortality (right).

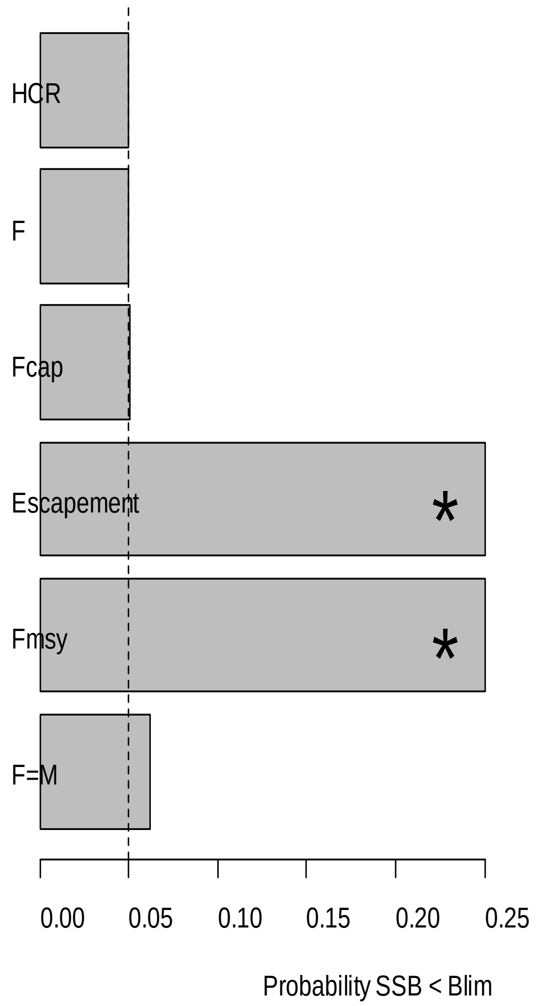


Figure A1.3. The probability that the spawning stock biomass will below B_{lim} in calculated for all six management strategies. Dashed line indicates the defined limit of sustainability. Starts indicates that the bars extent beyond the limit of the x-axis.

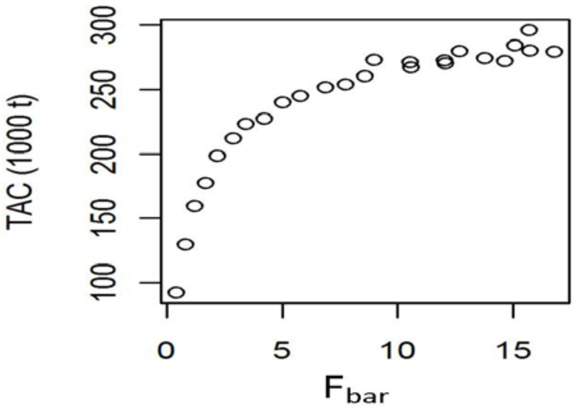


Figure A1.4. Illustrating the failed attempt to identify an F_{MSY} reference point for the F_{MSY} -strategy within a sensible range of fishing mortalities.

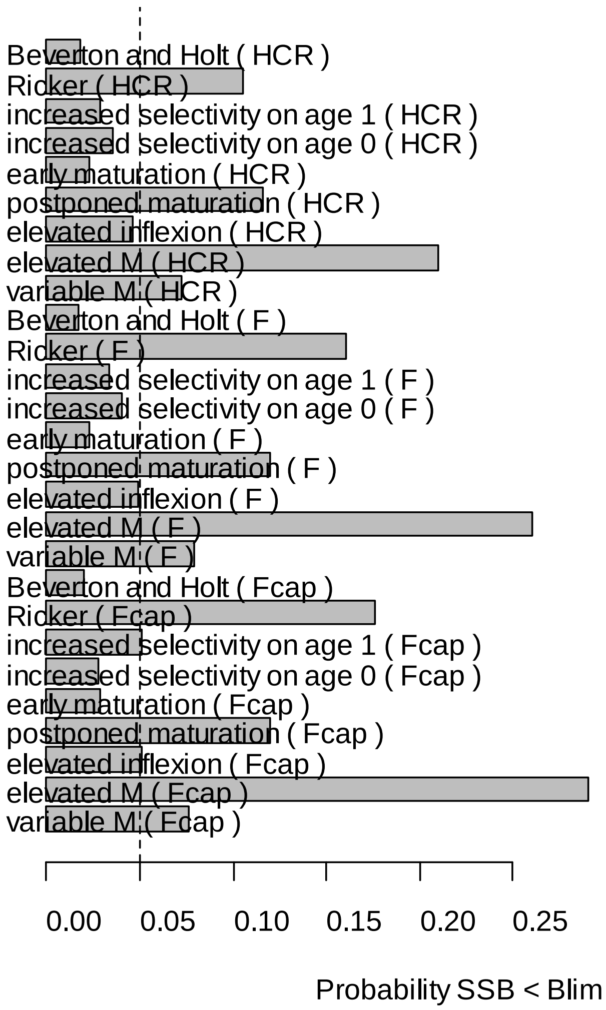


Figure A1.5. Robustness-test of three selected management strategies.

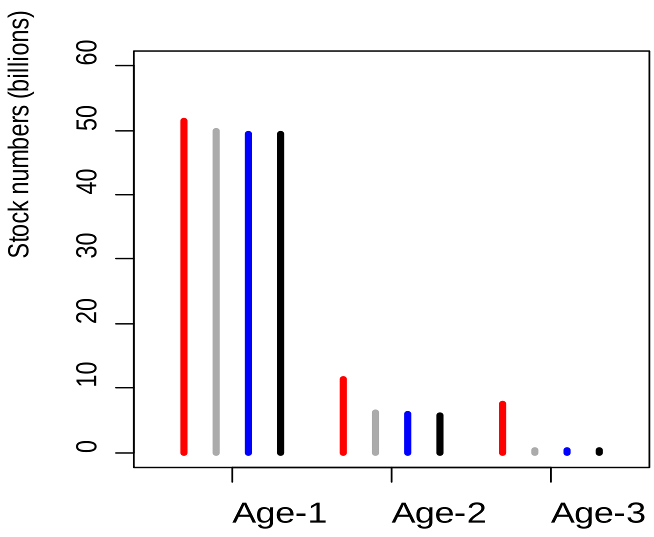


Figure A1.6. The average stock demographics under four different scenarios, no fishing (red), F-strategy (grey), Fcap-strategy (blue), HCR-strategy (black).

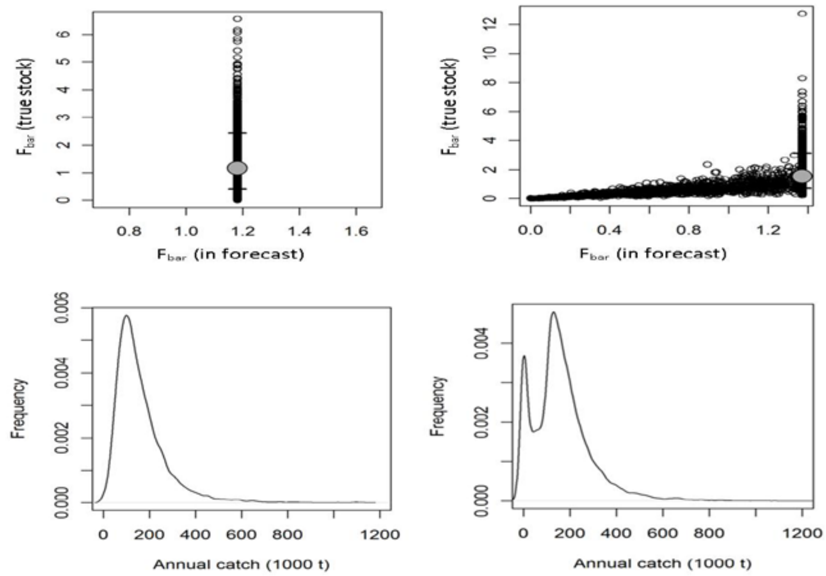


Figure A1.7. Variation in fishing mortalities and annual catches (left: Fcap-strategy and right: HCR-strategy). Upper: The fishing mortality expected based on the forecast (calculations made in the perceived stock) plotted against the realized fishing mortalities (calculations made in the True stock). Lower: probability distributions of annual catches or the TACs.

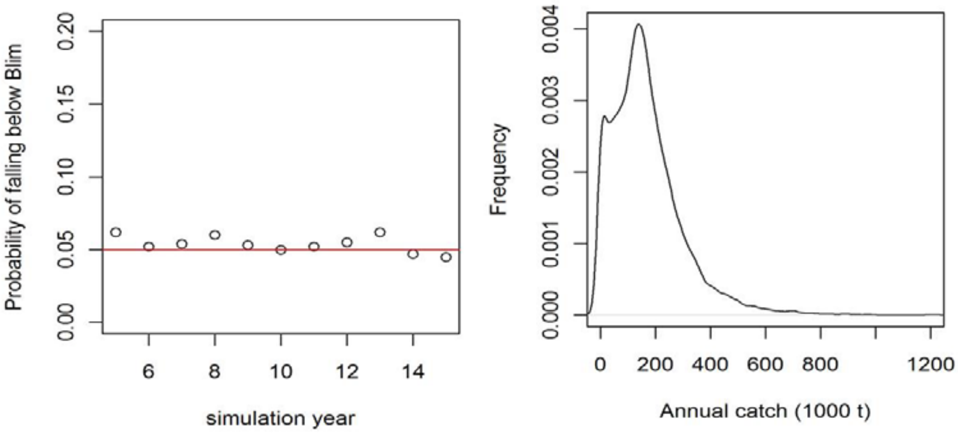


Figure A1.8. Investigation of an alternative escapement strategy where the spawning stock biomass is fished down to B_{lim} every year under the 95% > B_{lim} criteria. It turned out to be possible to approximate this strategy by identifying a B_{pa}* = 185000 (which is 43000 tons higher than B_{pa}) (left graph). This implementation of an escapement strategy resulted in marginally higher average annual catch compared to the Fcap-strategy and the F-strategy, but with closures of the fishery in a number of years (right graph).

Annex II Cod Stocks

After WKFMSYREF2: Compilation of code and results for some EUcods

Einar Hjörleifsson

February 23, 2014

```
toLatex(sessionInfo(), locale=FALSE)
```

- R version 3.0.2 (2013-09-25), `x86_64-redhat-linux-gnu`
- Base packages: base, datasets, graphics, grDevices, grid, methods, stats, utils
- Other packages: data.table 1.8.8, FLCore 2.5.20140123, ggplot2 0.9.3.1, gridExtra 0.9.1, knitr 1.2, lattice 0.20-15, lubridate 1.3.0, MASS 7.3-27, mgcv 1.7-27, msy 0.1.12, nlme 3.1-110, plyr 1.8, R2admb 0.7.10, RColorBrewer 1.0-5, reshape2 1.2.2, scales 0.2.3, scam 1.1-6, stringr 0.6.2, xtable 1.7-1
- Loaded via a namespace (and not attached): colorspace 1.2-2, dichromat 2.0-0, digest 0.6.3, evaluate 0.4.4, formatR 0.8, gtable 0.1.2, labeling 0.2, Matrix 1.0-12, munsell 0.4.2, proto 0.3-10, stats4 3.0.2, tools 3.0.2

```
print(paste('This document was created in knitr',now()))

[1] "This document was created in knitr 2014-02-23 11:35:29"
```

1 Preamble

This script documents some attempt in running the eqsim code that resides in the msy-package. Four cod stocks (North Sea, Celtic Sea, Irish Sea and West Coast of Scotland) are used as an example. The data for these stocks are included in the msy-package.

The scenarios run are somewhat fewer than those run during the WKMSYREF2 meeting and were based on an updated version of the msy-package. The objective was limited to looking at the feasibility of the eqsim approach and should in no sense constitute the definitive setup for any of the stocks.

2 A little function

Since a number of stocks are simulated in this document a little wrapper function is setup here, in order to make coding more efficient/reproducible across stocks:

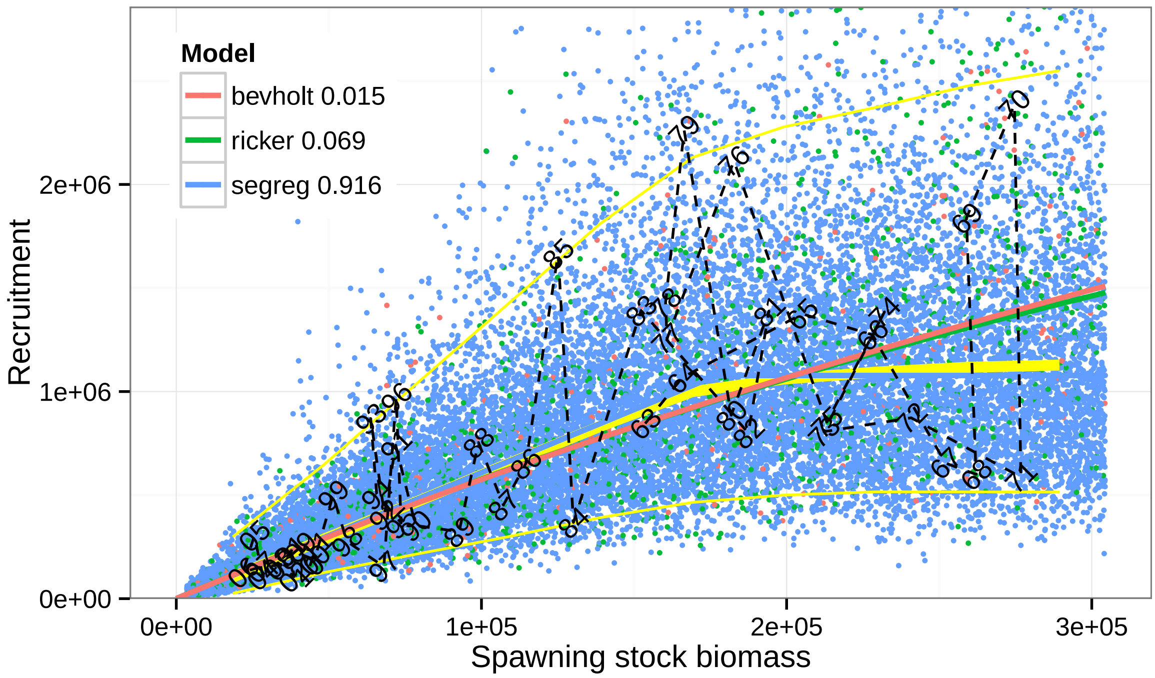
```
do_the_whole_thing <- function(stockSetup) {
  results <- within(stockSetup, {
  fit <- eqsr_fit(data, nsamp=1000)
  sim_noError <- eqsim_run(fit, Fscan=Fscan, verbose=verbose,
                           extreme.trim=extreme.trim,
                           bio.years=bio.years, sel.years=sel.years,
                           bio.const=TRUE, sel.const=TRUE,
                           Fcv=0, Fphi=0,
                           Blim=Blim, Bpa = Bpa)
  sim_ageError <- eqsim_run(fit, Fscan=Fscan, verbose=verbose,
                           extreme.trim=extreme.trim,
                           bio.years=bio.years, sel.years=sel.years,
                           bio.const=FALSE, sel.const=FALSE,
                           Fcv=0, Fphi=0,
                           Blim=Blim, Bpa = Bpa)
  sim_base <- eqsim_run(fit, Fscan=Fscan, verbose=verbose,
                           extreme.trim=extreme.trim,
                           bio.years=bio.years, sel.years=sel.years,
                           bio.const=FALSE, sel.const=FALSE,
                           Fcv=Fcv, Fphi=Fphi,
                           Blim=Blim, Bpa = Bpa)
  sim_trigger <- eqsim_run(fit, Fscan=Fscan, verbose=verbose,
                           extreme.trim=extreme.trim,
                           bio.years=bio.years, sel.years=sel.years,
                           bio.const=FALSE, sel.const=FALSE,
                           Fcv=Fcv, Fphi=Fphi,
                           Blim=Blim, Bpa = Bpa,
                           Btrigger=Btrigger)
  })
  return(results)
}
```

3 North Sea cod

```
codNS <- list(data = icesStocks$codNS,
              bio.years = c(2008, 2012),
              sel.years = c(2008, 2012),
              Fscan = seq(0, 1.5, len = 40),
              Blim = 70000,
              Bpa = 150000,
              Fcv = 0.25,
              Fphi = 0.30,
              Btrigger = 150000,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95))
res_codNS <- do_the_whole_thing(codNS)
```

The stock-recruitment fit:

```
eqsr_plot(res_codNS$fit,n=2e4,ggPlot=TRUE)
```



Deterministic fit and contribution of each stock recruitment model to the simulations:

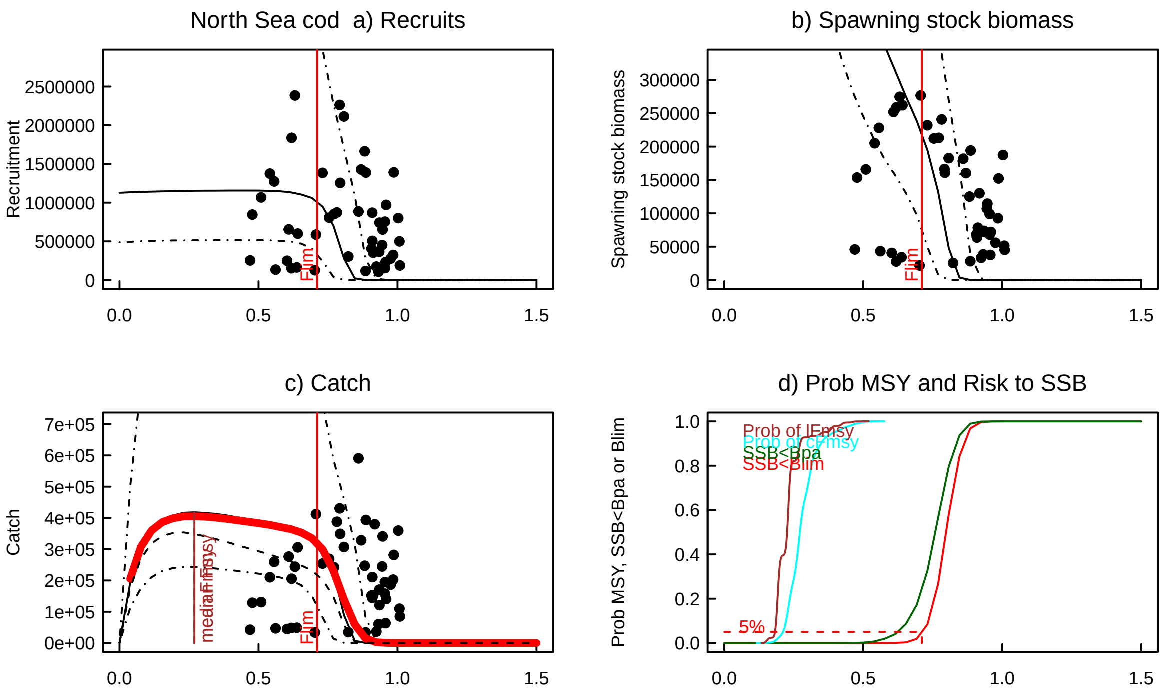
```
xtable(res_codNS$fit$sr.det,digits=c(0,2,-2,2,0,0,3))
```

	a	b	cv	model	n	prop
1	6.30	8.54E-07	0.48	ricker	69	0.069
2	6.09	1.77E+05	0.46	segreg	916	0.916
3	6.25	8.57E-07	0.48	bevholt	15	0.015

Summary plots

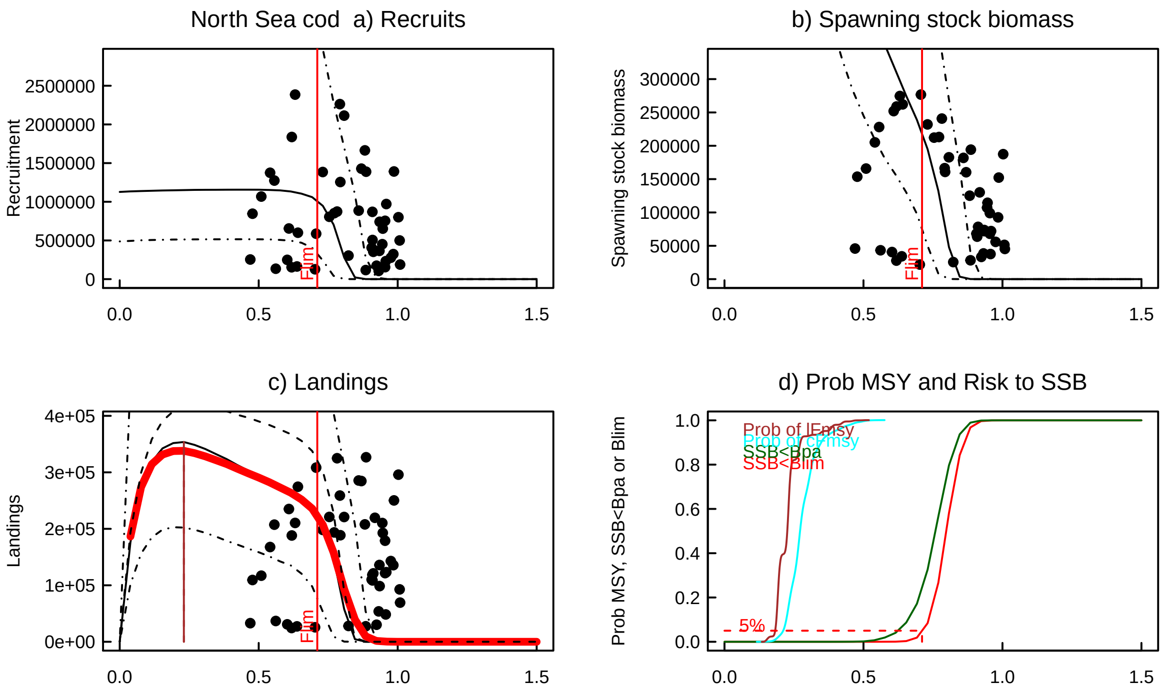
Optimization based on catch (using base case):

```
eqsim_plot(res_codNS$sim_base,catch=TRUE)
```



Optimization based on landings (using base case):

```
eqsim_plot(res_codNS$sim_base,catch=FALSE)
```



Summary tables

```
print(xtable(res_codNS$sim_noError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.77	0.78	0.83	0.27	0.27	0.81	0.88
lanF				0.23	0.23		
catch	323138.74	306956.59	129867.42	419729.55	419729.55	256390.62	1466.25
landings				350715.45	350715.45		
catB	194427.09	182094.79	71457.45	1082681.74	1082681.74	143558.81	706.17
lanB				1289603.03	1289603.03		

```
print(xtable(res_codNS$sim_ageError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.77	0.78	0.83	0.27	0.27	0.81	0.88
lanF				0.23	0.23		
catch	321776.25	305309.78	128629.97	420012.55	420012.55	255567.88	1436.09
landings				355926.85	355926.85		
catB	193623.68	181107.23	70847.60	1082948.41	1082948.41	143297.54	692.53
lanB				1290672.12	1290672.12		

```
print(xtable(res_codNS$sim_base$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.71	0.73	0.80	0.27	0.27	0.81	0.85
lanF				0.23	0.23		
catch	320745.18	295716.53	125142.53	418055.53	418055.53	88769.07	7118.61
landings				353710.41	353710.41		
catB	217787.33	189325.97	69755.58	1060096.49	1060096.49	47745.46	3631.19
lanB				1265049.42	1265049.42		

```
print(xtable(res_codNS$sim_trigger$Refs), floating=F)
```

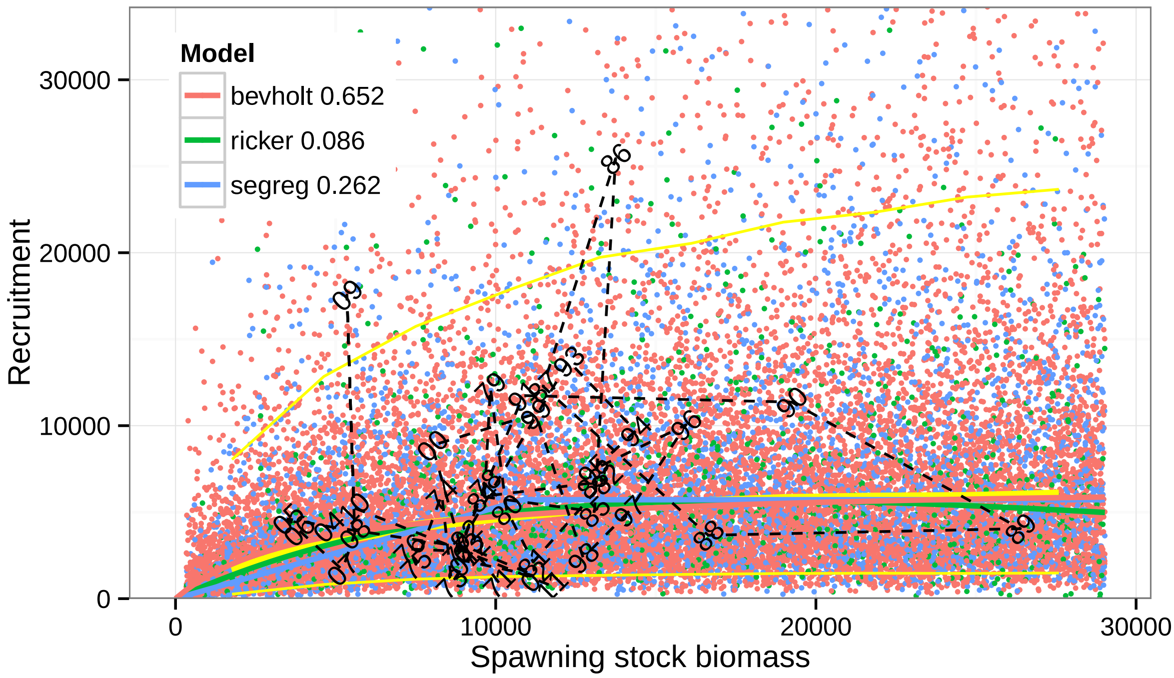
	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	1.13	1.24		0.27	0.27		
lanF				0.23	0.23		
catch	197155.02	177458.42		417665.39	417665.39		
landings				352765.69	352765.69		
catB	107498.13	97322.12		1060112.58	1060112.58		
lanB				1268275.02	1268275.02		

4 Celtic Sea cod

```
codCS <- list(data = icesStocks$codCS,
              bio.years = c(2008, 2012),
              sel.years = c(2008, 2012),
              Fscan = seq(0, 1.5, len = 40),
              Blim = 7300,
              Bpa = 10300,
              Fcv = 0.20,
              Fphi = 0.30,
              Btrigger = 10300,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95))
res_codCS <- do_the_whole_thing(codCS)
```

The stock-recruitment fit:

```
eqsr_plot(res_codCS$fit,n=2e4,ggPlot=TRUE)
```



Deterministic fit and contribution of each stock recruitment model to the simulations:

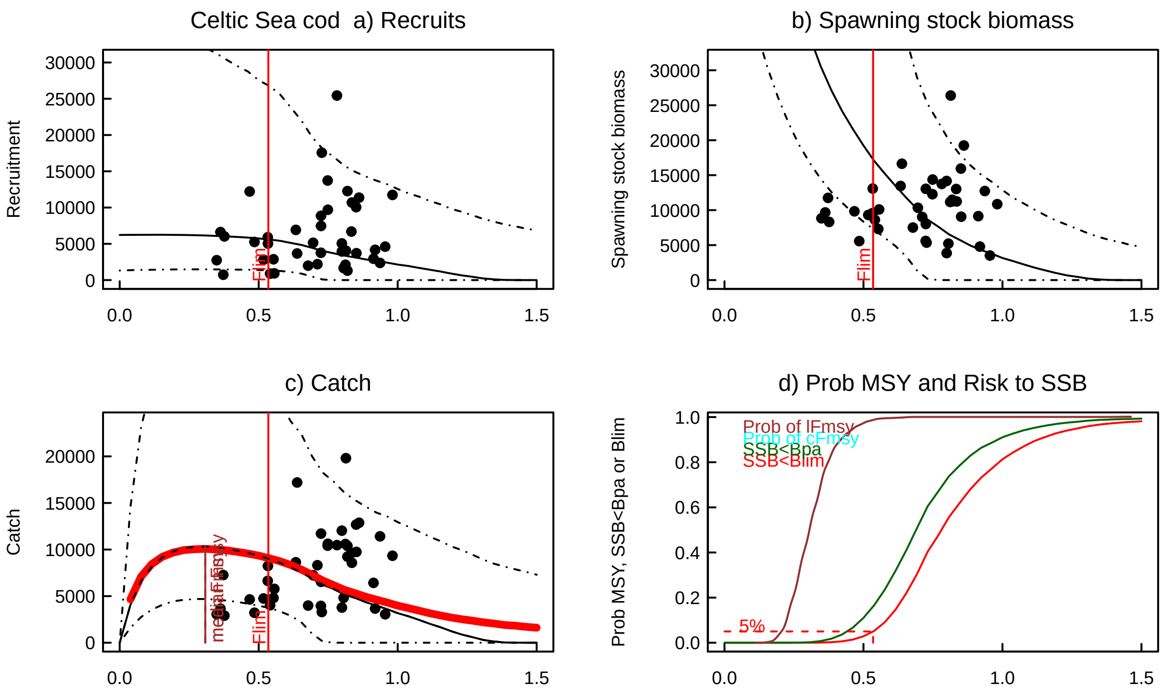
```
xtable(res_codCS$fit$sr.det,digits=c(0,2,-2,2,0,0,3))
```

	a	b	cv	model	n	prop
1	0.85	5.50E-05	0.81	ricker	86	0.086
2	0.53	1.09E+04	0.84	segreg	262	0.262
3	1.61	2.40E-04	0.81	bevholt	652	0.652

Summary plots

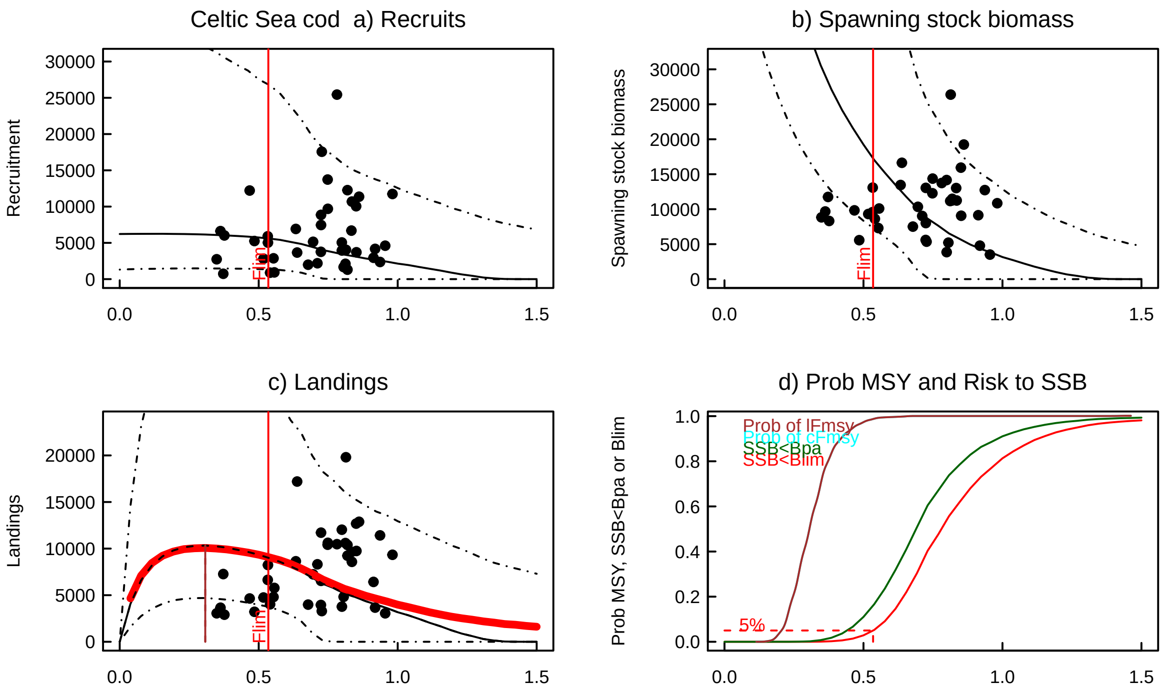
Optimization based on catch (using base case):

```
eqsim_plot(res_codCS$sim_base,catch=TRUE)
```



Optimization based on landings (using base case):

```
eqsim_plot(res_codCS$sim_base,catch=FALSE)
```



Summary tables

```r
print(xtable(res_codCS$sim_noError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.56	0.61	0.77	0.31	0.31	0.73	1.27
lanF				0.31	0.31		
catch	8943.59	8440.48	5937.33	10486.54	10486.54	6602.52	354.60
landings				10486.54	10486.54		
catB	15715.59	13613.29	7305.18	34650.91	34650.91	8658.66	241.47
lanB				34650.91	34650.91		

```r
print(xtable(res_codCS$sim_ageError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.56	0.61	0.80	0.31	0.31	0.77	1.31
lanF				0.31	0.31		
catch	8957.67	8427.42	5730.37	10469.05	10469.05	6092.14	474.89
landings				10469.05	10469.05		
catB	16365.29	14156.77	7311.80	35216.13	35216.13	8043.23	361.38
lanB				35216.13	35216.13		

```r
print(xtable(res_codCS$sim_base$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.53	0.58	0.78	0.31	0.31	0.73	1.31
lanF				0.31	0.31		
catch	9009.06	8493.76	5597.46	10326.21	10326.21	6221.72	298.27
landings				10326.21	10326.21		
catB	17260.60	14930.41	7306.35	34676.65	34676.65	8649.97	218.31
lanB				34676.65	34676.65		

```r
print(xtable(res_codCS$sim_trigger$Refs), floating=F)
```

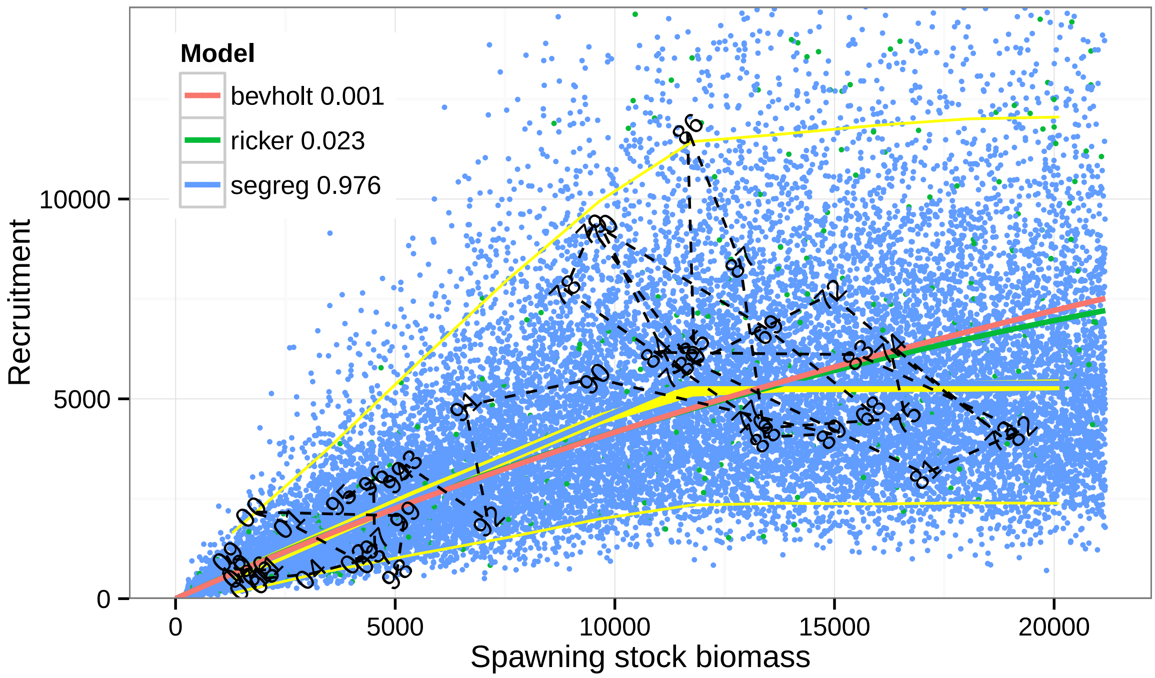
	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.62	0.69	1.09	0.31	0.31		
lanF				0.31	0.31		
catch	8483.51	7921.23	5679.86	10284.27	10284.27		
landings				10284.27	10284.27		
catB	14177.27	12003.40	7302.39	34505.78	34505.78		
lanB				34505.78	34505.78		

5 Irish Sea cod

```
codIS <- list(data = icesStocks$codIS,
              bio.years = c(2008, 2012),
              sel.years = c(2008, 2012),
              Fscan = seq(0, 1.5, len = 40),
              Blim = 6000,
              Bpa = 10000,
              Fcv = 0.20,
              Fphi = 0.30,
              Btrigger = 10000,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95))
res_codIS <- do_the_whole_thing(codIS)
```

The stock-recruitment fit:

```
eqsr_plot(res_codIS$fit,n=2e4,ggPlot=TRUE)
```



Deterministic fit and contribution of each stock recruitment model to the simulations:

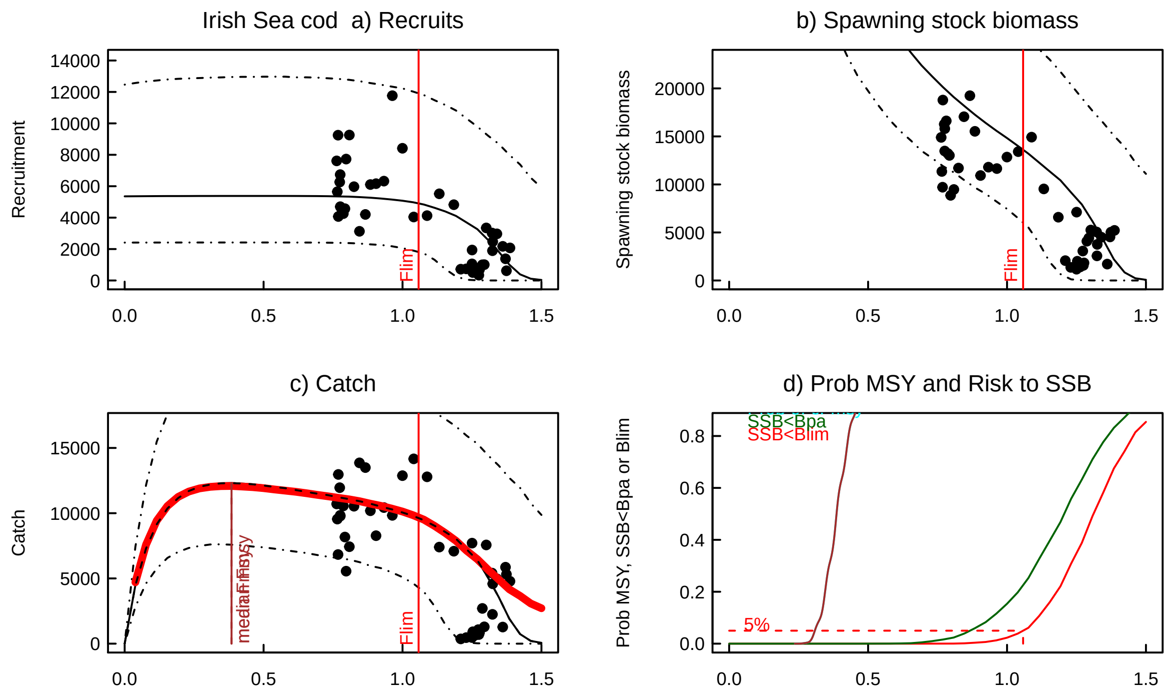
```
xtable(res_codIS$fit$sr.det,digits=c(0,2,-2,2,0,0,3))
```

	a	b	cv	model	n	prop
1	0.50	1.80E-05	0.52	ricker	23	0.023
2	0.47	1.16E+04	0.49	segreg	976	0.976
3	0.49	1.83E-05	0.52	bevholt	1	0.001

Summary plots

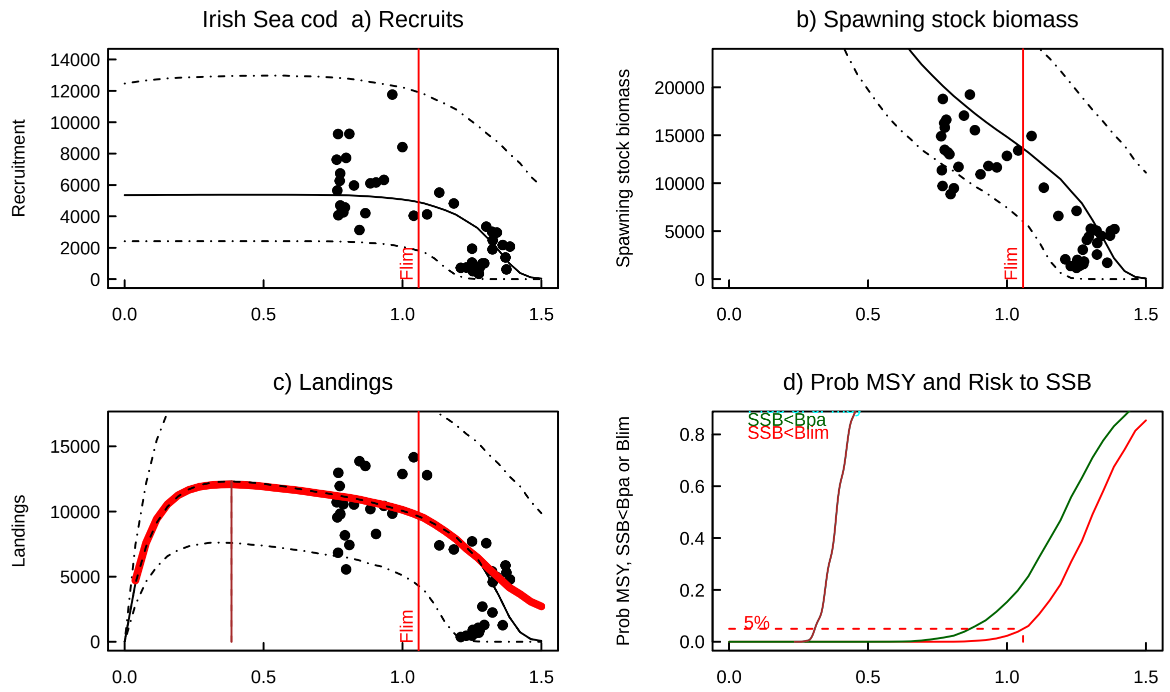
Optimization based on catch (using base case):

```
eqsim_plot(res_codIS$sim_base,catch=TRUE)
```



Optimization based on landings (using base case):

```
eqsim_plot(res_codIS$sim_base,catch=FALSE)
```



Summary tables

```
print(xtable(res_codIS$sim_noError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	1.11	1.16	1.34	0.38	0.35	1.23	1.46
lanF				0.38	0.35		
catch	9669.26	9230.45	5031.31	12436.49	12416.98	8199.81	346.99
landings				12436.49	12416.98		
catB	13134.37	12170.41	5976.47	39841.81	43709.62	10328.83	386.16
lanB				39841.81	43709.62		

```
print(xtable(res_codIS$sim_ageError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	1.11	1.16	1.35	0.38	0.35	1.23	1.46
lanF				0.38	0.35		
catch	9621.68	9138.02	5064.35	12465.12	12442.46	8146.95	456.67
landings				12465.12	12442.46		
catB	13067.45	12043.89	5999.31	39910.73	43832.82	10266.00	506.08
lanB				39910.73	43832.82		

```
print(xtable(res_codIS$sim_base$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	1.06	1.11	1.31	0.38	0.38	1.23	1.46
lanF				0.38	0.38		
catch	9622.47	9094.29	4922.44	12306.62	12306.62	7228.19	207.47
landings				12306.62	12306.62		
catB	13607.57	12411.47	5974.87	39453.55	39453.55	9154.40	230.77
lanB				39453.55	39453.55		

```
print(xtable(res_codIS$sim_trigger$Refs), floating=F)
```

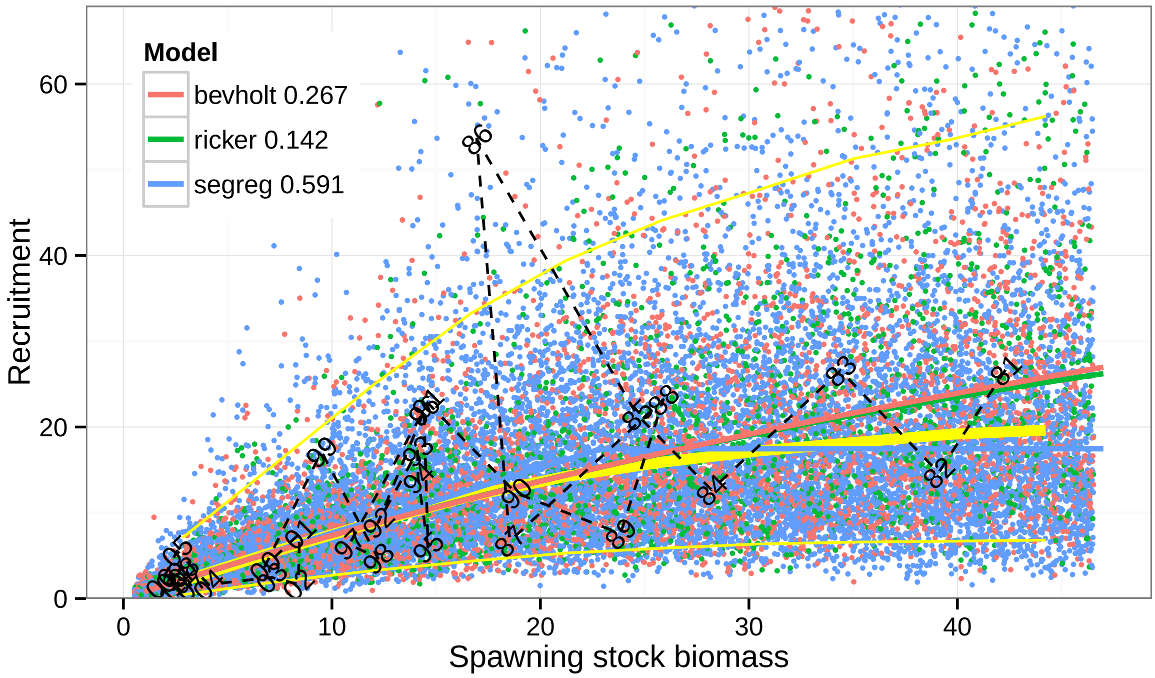
	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	1.38			0.38	0.35		
lanF				0.38	0.35		
catch	8368.81			12288.49	12268.22		
landings				12288.49	12268.22		
catB	10184.39			39317.10	43142.72		
lanB				39317.10	43142.72		

6 West Coast of Scotland cod

```
codWS <- list(data = icesStocks$codWS,
              bio.years = c(2008, 2012),
              sel.years = c(2008, 2012),
              Fscan = seq(0, 1.5, len = 40),
              Blim = 14,
              Bpa = 22,
              Fcv = 0.20,
              Fphi = 0.30,
              Btrigger = 22,
              verbose = FALSE,
              extreme.trim=c(0.05,0.95))
res_codWS <- do_the_whole_thing(codWS)
```

The stock-recruitment fit:

```
eqsr_plot(res_codWS$fit,n=2e4,ggPlot=TRUE)
```



Deterministic fit and contribution of each stock recruitment model to the simulations:

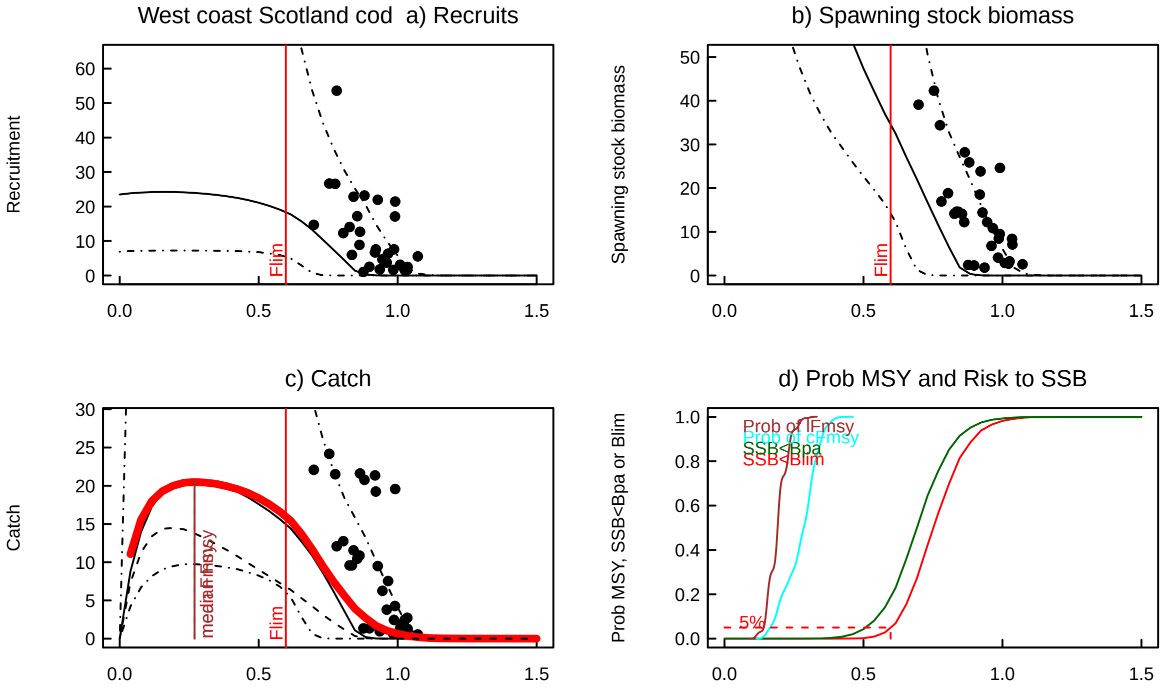
```
xtable(res_codWS$fit$sr.det,digits=c(0,2,-2,2,0,0,3))
```

	a	b	cv	model	n	prop
1	0.80	7.55E-03	0.62	ricker	142	0.142
2	0.76	2.29E+01	0.62	segreg	591	0.591
3	0.80	8.24E-03	0.62	bevholt	267	0.267

Summary plots

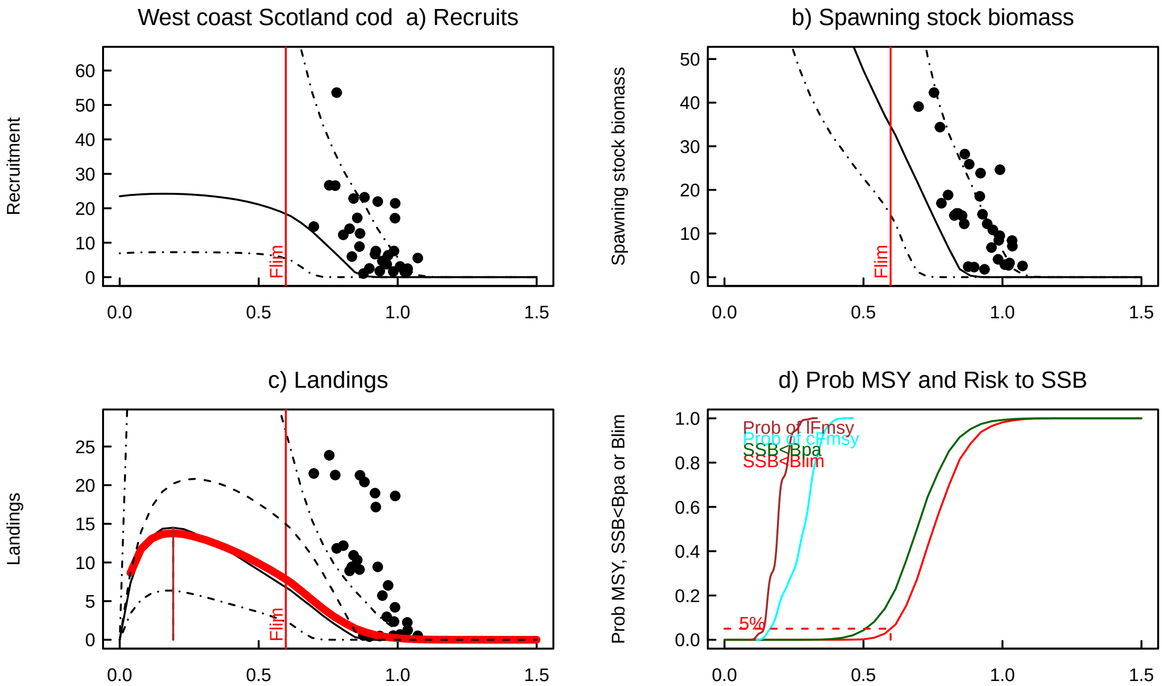
Optimization based on catch (using base case):

```
eqsim_plot(res_codWS$sim_base,catch=TRUE)
```



Optimization based on landings (using base case):

```
eqsim_plot(res_codWS$sim_base,catch=FALSE)
```



Summary tables

```
print(xtable(res_codWS$sim_noError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.62	0.65	0.77	0.31	0.27	0.73	0.88
lanF				0.19	0.19		
catch	14.86	13.71	7.56	20.78	20.92	10.13	0.45
landings				13.71	13.71		
catB	33.05	29.17	13.91	86.13	97.85	19.54	0.73
lanB				128.41	128.41		

```
print(xtable(res_codWS$sim_ageError$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.62	0.65	0.77	0.31	0.27	0.73	0.88
lanF				0.19	0.19		
catch	14.80	13.69	7.54	20.83	20.95	10.21	0.34
landings				14.57	14.57		
catB	32.94	29.21	13.93	86.40	97.97	19.82	0.54
lanB				128.61	128.61		

```
print(xtable(res_codWS$sim_base$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.60	0.63	0.75	0.27	0.27	0.73	0.88
lanF				0.19	0.19		
catch	14.95	13.78	7.30	20.81	20.81	8.61	0.20
landings				14.49	14.49		
catB	34.58	30.55	13.91	96.36	96.36	16.70	0.33
lanB				127.17	127.17		

```
print(xtable(res_codWS$sim_trigger$Refs), floating=F)
```

	Flim	Flim10	Flim50	medianMSY	meanMSY	FCrash05	FCrash50
catF	0.77	0.84	1.19	0.27	0.27		
lanF				0.19	0.19		
catch	11.70	10.49	7.50	20.97	20.97		
landings				14.54	14.54		
catB	22.34	19.81	14.00	96.62	96.62		
lanB				127.44	127.44		

Annex III – Results from plotMSY applied to cod data

The plotMSY software is described in detail in Annex 7 of WGMG 2013. For this workshop, sen and sum files were created from the FLStock object provided. The sum file contained only the data required by plotMSY, namely SSB, recruitment, yield and total Fbar. The sen files were created by extracting the most recent five years' data (2008-2012) and calculating the mean and cv. Where M had a CV smaller than 0.1, it was set to 0.1, and similarly for maturity between 0.05 and 0.95, CVs of less than 0.1 were replaced by 0.1. These data are shown in Table 1 and Table 2.

Initial Runs

Initial runs were performed for each of the four cod stocks available to the workshop. For two, North Sea and West of Scotland, separate landings and discards data were available, and so separate runs were performed optimising landings and catch in turn. These results are shown below in **Error! Reference source not found.**, where F5% is the level of F that causes the equilibrium SSB to be equal to B_{lim} in 5% of the iterations.

Table 1: Summary of F_{MSY} and F5% values for the European cod stocks

COD STOCK	CATCH OR LANDINGS	FMSY	F 5%
North Sea	Landings	0.22	0.64
North Sea	Catch	0.28	0.64
West of Scotland	Landings	0.18	0.50
West of Scotland	Catch	0.28	0.50
Irish Sea	Landings = Catch	0.39	1.04
Celtic Sea	Landings = Catch	0.31	0.41

For North Sea cod, shown in **Error! Reference source not found.** and **Error! Reference source not found.**, F_{MSY} is estimated to be 0.218 to optimise landings, and 0.276 to optimise catch. The reason for the higher F when optimising catch is that a large proportion of young cod are discarded. When seeking to optimise landings, these young fish cannot be fished too intensively in order to allow them to reach a size where they will start contributing to landings, whereas when optimising catch, they are already contributing to the catch through discards and, given the high M at young ages, the optimal catch strategy is to apply higher fishing pressure and hence take more of the young fish. Both these F_{MSY} values are well outside the corresponding confidence intervals for Fcrash, and below F5%. The majority of weight is given to the hockeystick stock recruit function.

Figure 3 and Figure 4 show the F_{MSY} estimates for West of Scotland cod. Like North Sea cod, this has a high proportion of discarding of young fish, and so a large difference between the F_{MSY} estimated for maximising landings (0.184) and catch (0.279). The data are not particularly informative about the best form of stock-recruit relationship to use, with weightings of 29%, 32% and 39% for the Ricker, Beverton-Holt and hockeystick respectively. These F_{MSY} estimates give a high probability of avoiding Fcrash, and F5% is well above the potential F_{MSY} values.

Estimates for Irish Sea cod are shown in Figure 5, indicating an estimate of F_{MSY} around 0.393, almost entirely derived from the fit of the hockeystick stock recruitment form (given 87% weighting).

Figure 6 shows F_{MSY} estimates for Celtic Sea cod of around 0.308, based on a slight preference for the Beverton-Holt form (51%) over the Ricker and Hockeystick (28% and 21% respectively). However, this value is very close to the lower fifth percentile of Fcrash, and may possibly lead to crashing the stock. An estimate of F_{MSY} that included the Harvest Control Rule would be required to investigate whether the proposed F_{MSY} value was consistent with the precautionary approach.

Sensitivity to Stock-Recruit data

Alternative runs (shown in Figure) were performed in plotMSY using the full stock-recruit time series (1963-2012) and a truncated time series (1991-2012), keeping the same values for the biological and fishery data (typical of 2008-2012). For the complete time series, the hockeystick stock-recruit is weighted most highly, and the data estimate a break point around 170,000t, whereas the truncated data only covers a period when SSB is below 80,000t, and so entirely on the ascending limb of the hockeystick. This near linear relationship can be parameterised within each of the stock-recruit forms, and so the weightings are spread across the three models. The truncated dataset gives a slightly lower value of F_{MSY} (0.210 compared to 0.218; **Error! Reference source not found.**), but yields estimated from the truncated series are less than 45% of the yield estimated from the complete time series.

Sensitivity to Mortality

Three different natural mortality scenarios were investigated, M typical of the most recent 5 years, M typical of 1963-1980 and a hybrid based on a hypothesis of cannibalism at 1963-1980, but with higher seal mortality typical of the present. The values are presented in **Error! Reference source not found.**.

Table 2: Alternative M scenarios

Age	Recent	Historic	Hybrid	CV (all)
1	1.04	1.26	1.45	0.1
2	0.70	0.82	1.02	0.1
3	0.49	0.27	0.48	0.1
4	0.23	0.20	0.23	0.1
5	0.20	0.20	0.20	0.1
6	0.20	0.20	0.20	0.1
7	0.20	0.20	0.20	0.1

These different M vectors were used with both the complete and truncated stock-recruit data presented in above to estimate F_{MSY}, and the results are shown in **Error! Reference source not found.**. With both stock-recruit periods, the present and hybrid scenarios give similar F_{MSY}, and the historic indicates a slightly lower value. Compared to the present scenario, the historic scenario provides a 10% smaller yield, and the hybrid 50% smaller.

Table 3: Estimated MSY quantities for alternative M scenarios and different stock-recruit periods.

Simulation	F	Yield	SSB	Ricker weighting	Beverton–Holt weighting	Hockeystick weighting
NScod present	0.218	360768	1360750	0.131	0.154	0.714
NScod historic	0.209	323774	1280580	0.131	0.154	0.714
NScod hybrid	0.222	186380	672074	0.131	0.154	0.714
NScodTrunc present	0.210	161140	568543	0.235	0.375	0.390
NScodTrunc historic	0.202	141599	551323	0.235	0.375	0.390
NScodtrunc hybrid	0.211	82172	302554	0.235	0.375	0.390

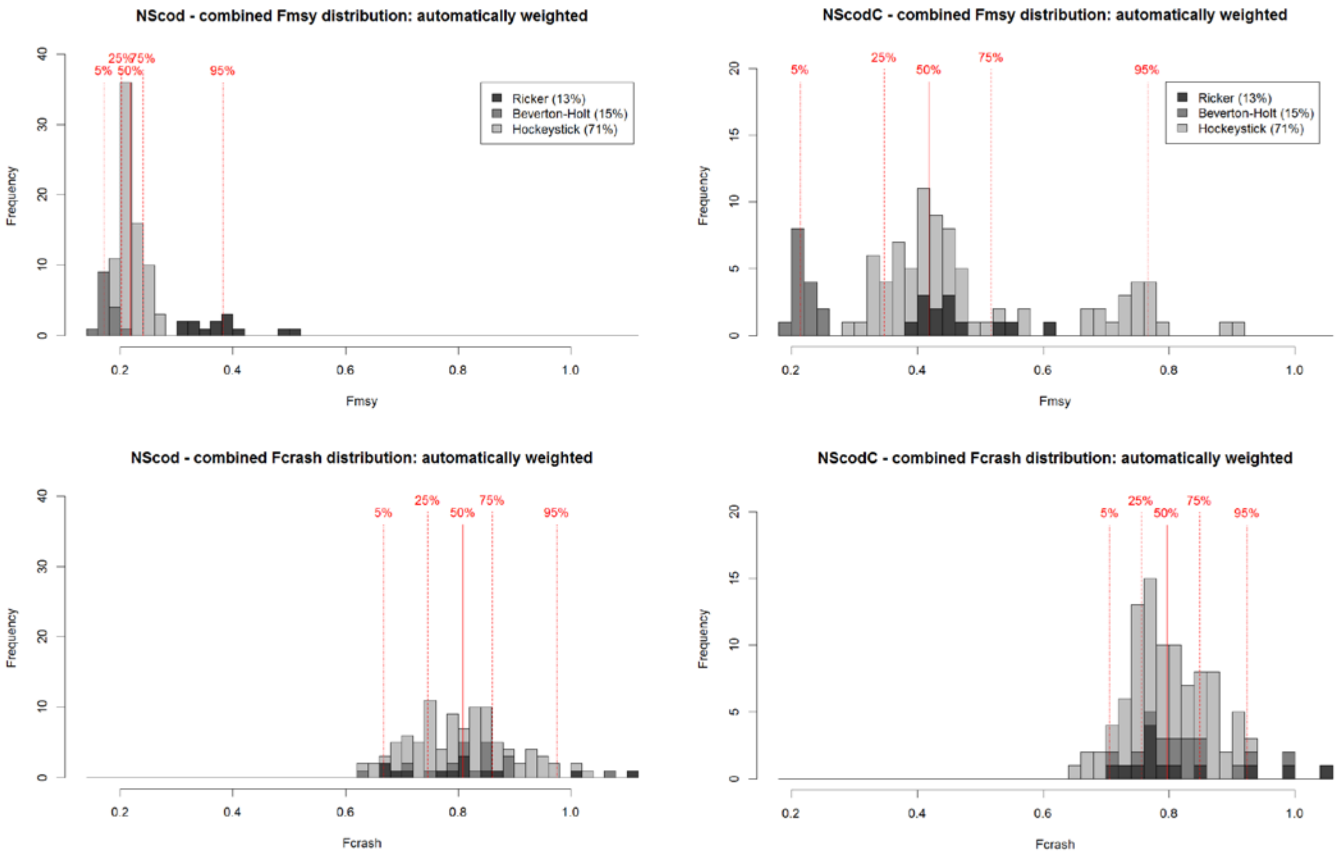
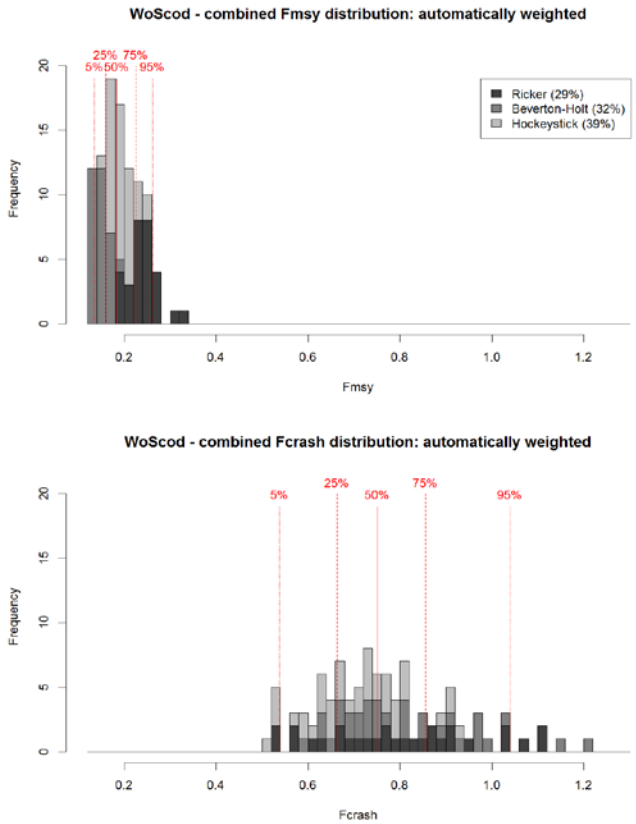


Figure 1: North sea cod F_{MSY} and Fcrash estimates based on optimising landings. Figure 2: North sea cod F_{MSY} and Fcrash estimates based on optimising catch



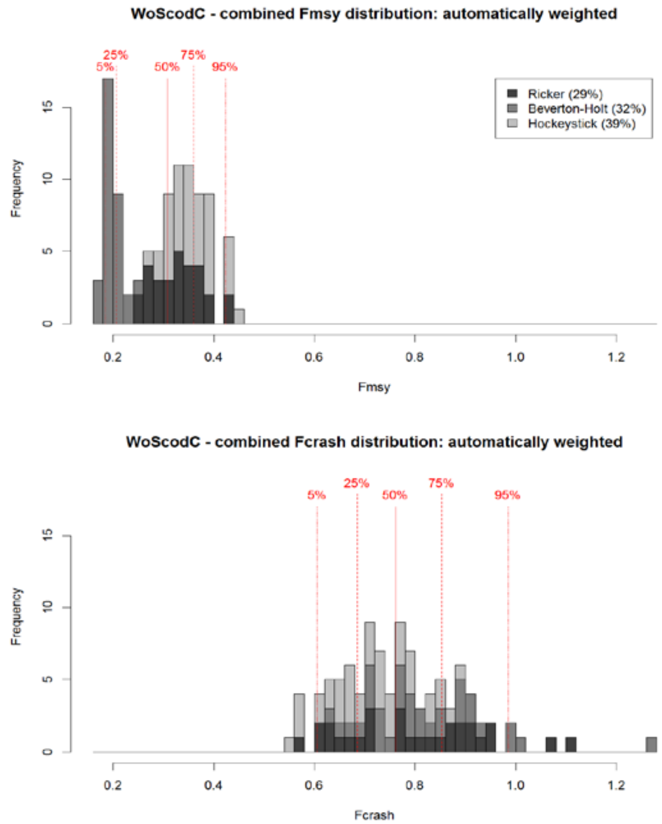
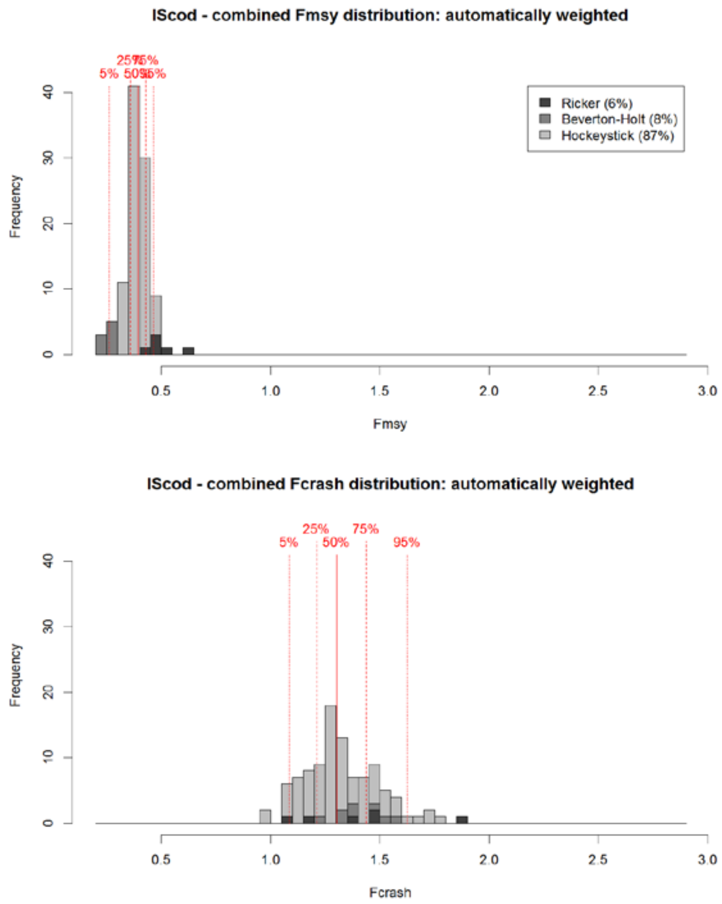


Figure 3: West of Scotland cod F_{MSY} and Fcrash estimates based on optimising landings Figure 4: West of Scotland cod Fms F_{MSY} y and Fcrash estimates based on optimising catch



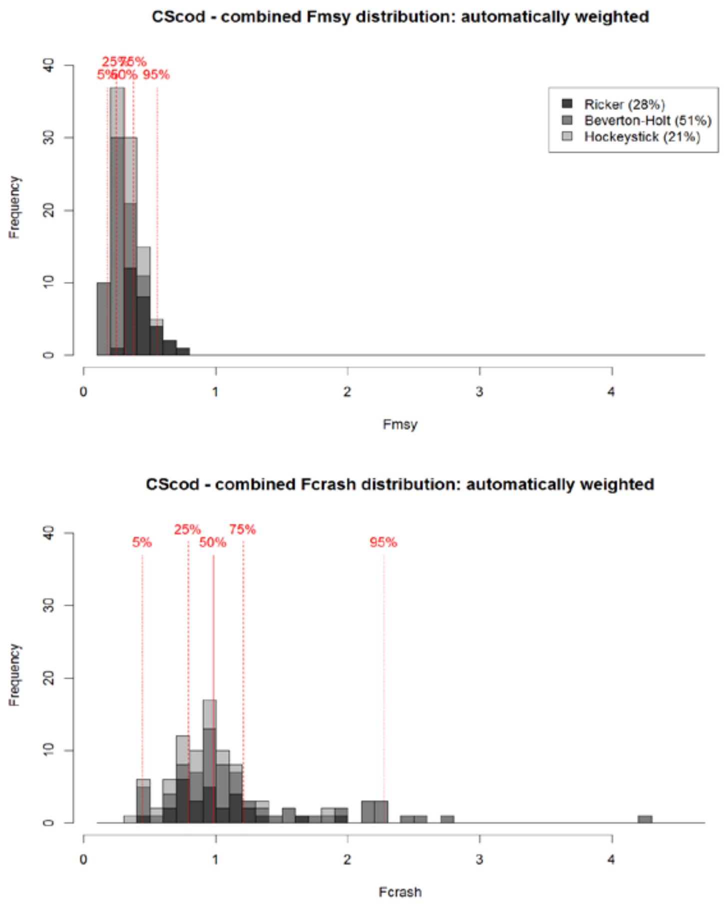


Figure 5: Irish Sea cod F_{MSY} and Fcrash estimates based on optimising landings/catch Figure 6: Celtic Sea cod F_{MSY} and Fcrash estimates based on optimising landings/catch

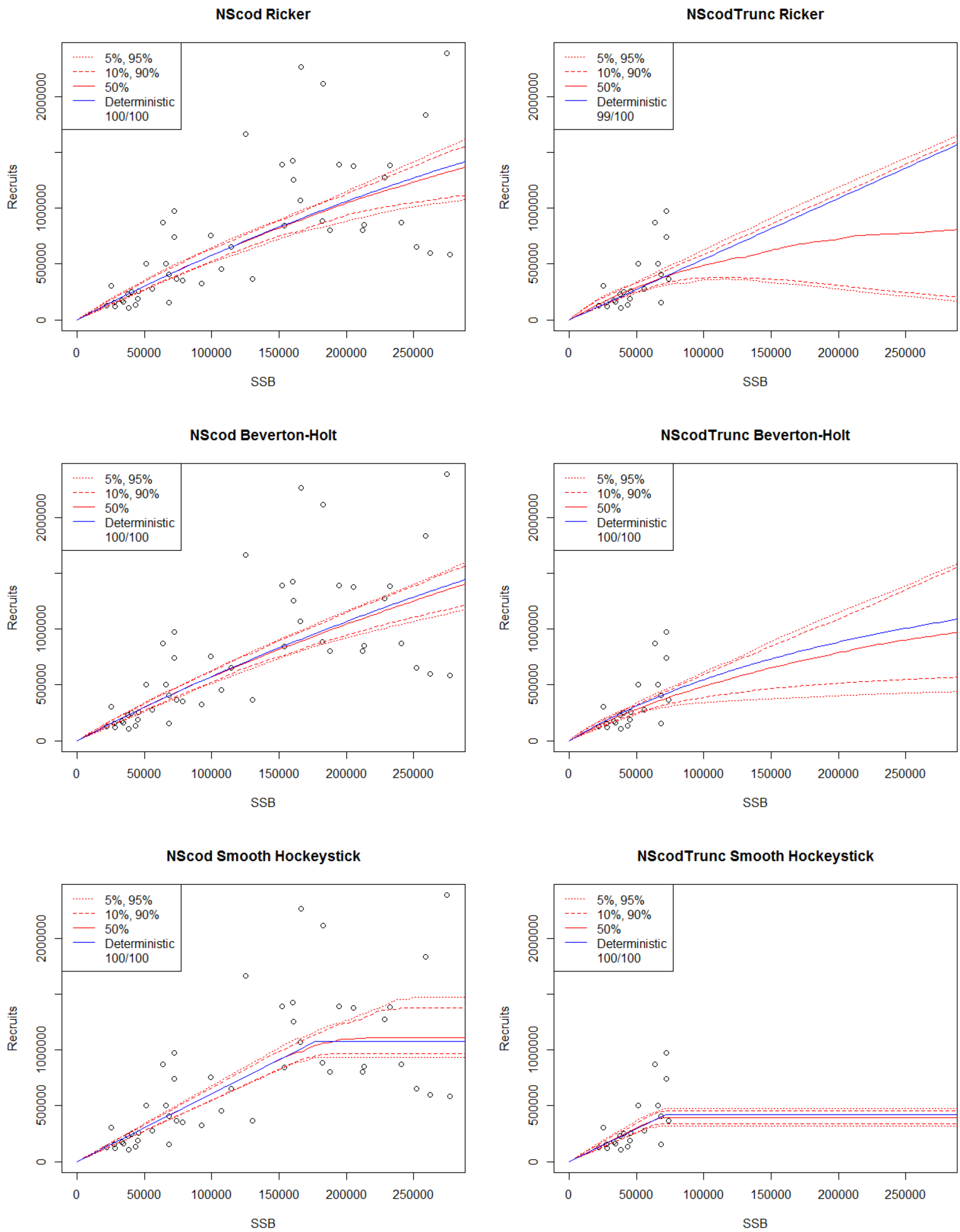


Figure 7: comparison of stock-recruit function fits to North Sea cod data using the full time series (left) and a truncated series since 1991 (right)

Table 1: Information about the cod stocks used in the sen files

Parameter	Age	Cscod		Iscod		NScod		WoScod	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
Landing Selectivity	1	0.340	1.502	0.076	0.020	0.022	0.626	0.001	1.319
Landing Selectivity	2	0.839	0.319	0.713	0.015	0.274	0.184	0.068	0.999
Landing Selectivity	3	0.956	0.135	1.190	0.004	0.731	0.269	0.222	0.884
Landing Selectivity	4	1.078	0.131	1.098	0.013	1.025	0.069	0.720	0.403
Landing Selectivity	5	1.127	0.281	0.941	0.028	1.124	0.024	1.067	0.069
Landing Selectivity	6	1.044	0.473	0.941	0.028	1.177	0.050	0.917	0.367
Landing Selectivity	7	1.044	0.473			1.179	0.042	1.122	0.031
Discard Selectivity	1	0.000	0.000	0.000	0.000	0.226	0.061	0.246	0.031
Discard Selectivity	2	0.000	0.000	0.000	0.000	0.520	0.101	0.648	0.102
Discard Selectivity	3	0.000	0.000	0.000	0.000	0.345	0.591	0.817	0.226
Discard Selectivity	4	0.000	0.000	0.000	0.000	0.104	0.625	0.427	0.692
Discard Selectivity	5	0.000	0.000	0.000	0.000	0.030	0.737	0.030	1.143
Discard Selectivity	6	0.000	0.000	0.000	0.000	0.037	1.078	0.195	1.852
Discard Selectivity	7	0.000	0.000			0.034	1.177	0.000	0.000
Landing weight	1	0.850	0.239	1.026	0.149	0.787	0.092	0.441	0.982
Landing weight	2	1.915	0.200	1.930	0.131	1.345	0.067	1.567	0.189
Landing weight	3	4.328	0.115	3.609	0.063	2.555	0.055	2.958	0.075
Landing weight	4	7.198	0.052	5.705	0.079	4.188	0.031	4.490	0.097
Landing weight	5	9.564	0.056	7.271	0.049	6.078	0.035	6.042	0.099
Landing weight	6	11.291	0.068	8.703	0.130	7.624	0.042	7.219	0.122
Landing weight	7	12.290	0.094			9.631	0.073	8.500	0.105
Discard weight	1	0.000	0.000	0.000	0.000	0.278	0.200	0.219	0.199
Discard weight	2	0.000	0.000	0.000	0.000	0.704	0.181	1.164	0.136
Discard weight	3	0.000	0.000	0.000	0.000	1.764	0.127	2.190	0.040
Discard weight	4	0.000	0.000	0.000	0.000	3.390	0.191	3.361	0.120
Discard weight	5	0.000	0.000	0.000	0.000	5.380	0.280	4.922	0.713
Discard weight	6	0.000	0.000	0.000	0.000	7.338	0.181	2.123	1.421
Discard weight	7	0.000	0.000			6.110	0.540	0.000	0.000
Stock weight	1	0.801	0.311	1.026	0.149	0.322	0.151	0.433	0.406
Stock weight	2	1.388	0.125	1.930	0.131	0.918	0.119	1.211	0.078
Stock weight	3	4.032	0.083	3.609	0.063	2.292	0.084	2.695	0.068
Stock weight	4	7.002	0.044	5.705	0.079	4.108	0.050	4.801	0.047
Stock weight	5	9.513	0.067	7.271	0.049	6.065	0.039	6.678	0.060
Stock weight	6	11.303	0.043	8.703	0.130	7.640	0.038	8.068	0.041
Stock weight	7	13.158	0.067			9.749	0.031	9.733	0.024
Natural mortality	1	0.512	0.100	0.200	0.100	1.038	0.100	0.530	0.100
Natural mortality	2	0.368	0.100	0.200	0.100	0.697	0.100	0.390	0.100
Natural mortality	3	0.304	0.100	0.200	0.100	0.489	0.100	0.310	0.100
Natural mortality	4	0.269	0.100	0.200	0.100	0.233	0.100	0.260	0.100
Natural mortality	5	0.247	0.100	0.200	0.100	0.200	0.100	0.240	0.100
Natural mortality	6	0.233	0.100	0.200	0.100	0.200	0.100	0.220	0.100
Natural mortality	7	0.222	0.100			0.200	0.100	0.210	0.100

Maturity	1	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000
Maturity	2	0.390	0.100	0.650	0.100	0.050	0.100	0.520	0.100
Maturity	3	0.870	0.100	1.000	0.000	0.230	0.100	0.860	0.100
Maturity	4	0.930	0.100	1.000	0.000	0.620	0.100	1.000	0.000
Maturity	5	1.000	0.000	1.000	0.000	0.860	0.100	1.000	0.000
Maturity	6	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Maturity	7	1.000	0.000			1.000	0.000	1.000	0.000

Table 2: Data used in Sum files for stock-recruit estimation. Data in grey removed for testing sensitivity of estimates to a truncated time series.

	CScod				Iscod			
Year	R	SSB	Yield	Fbar	R	SSB	Yield	Fbar
1963								
1964								
1965								
1966								
1967								
1968					3029	15804.918	9779.08	0.776
1969					4697	13478.485	9833.91	0.7756667
1970					6738	9710.1192	6831.03	0.768
1971	4774	10098.715	5778.402	0.55625	9247	11351.417	9548.44	0.7653333
1972	929	9311.6754	4750.18	0.51725	5649	14898.328	10709.47	0.763
1973	2810	8625.3853	4022.126	0.541	7612	18783.451	12968.41	0.769
1974	888	8316.911	2907.784	0.3765	4072	16270.556	11954.56	0.774
1975	6021	7509.3869	3988.659	0.67775	6264	16617.437	10650.04	0.7813333
1976	1986	7303.8342	4804.157	0.55325	4517	13214.45	10556.87	0.787
1977	2871	8834.0992	3057.916	0.34875	4256	13021.084	8172.73	0.7926667
1978	2738	9673.6533	3656.39	0.3625	4570	8863.0376	5555.84	0.797
1979	6619	9833.2277	4647.045	0.4675	7727	9474.3164	7430.21	0.8086667
1980	12215	10338.945	7241.092	0.69575	9257	11704.202	10533.75	0.8253333
1981	5145	11169.756	10594.713	0.812	5969	17050.252	13857.95	0.845
1982	2115	13456.764	8639.458	0.6335	3130	19240.468	13494.44	0.8663333
1983	6918	13021.238	9635.144	0.8335	4203	15527.82	10185.41	0.8843333
1984	6690	9573.678	6641.553	0.5325	6106	10927.777	8274.73	0.9046667
1985	5904	13085.526	8240.926	0.53325	6162	11797.813	10430.08	0.933
1986	5034	13744.073	10474.852	0.7815	6323	11651.307	9834.16	0.9633333
1987	25442	11480.704	10390.304	0.81925	11762	12849.914	12876.1	0.9996667
1988	12267	16635.081	17196.216	0.63825	8414	13413.208	14163.75	1.0403333
1989	3664	26385.09	19804.032	0.81375	4041	14923.186	12786.67	1.0883333
1990	4047	19243.164	12877.546	0.861	4127	9533.3304	7400.81	1.1323333
1991	11364	10854.252	9335.647	0.98125	5517	6586.7904	7085.56	1.1846667
1992	11740	9063.6454	9746.741	0.8515	4823	7115.7616	7704.22	1.2503333
1993	3705	12276.74	10416.037	0.748	1940	5252.56	7565.58	1.3013333

1994	13727	14371.652	10619.562	0.74875	3345	5049.456	5405.7	1.3223333
1995	9694	13048.112	11710.461	0.72425	3019	3757.7828	4586.68	1.3246667
1996	7462	15941.103	12680.948	0.8505	2471	4504.3466	4970.335	1.3396667
1997	10049	14167.819	12027.797	0.799	2969	4532.7406	5861.069	1.3706667
1998	5055	12731.273	11417.579	0.9365	1382	5031.7915	5315.978	1.374
1999	2366	11243.741	8579.842	0.83525	620	5216.9704	4782.65	1.3866667
2000	10689	8016.2811	6538.944	0.72425	2074	1706.2492	1273.548	1.3606667
2001	8860	9028.1431	8315.721	0.71125	2173	2564.593	2245.963	1.3236667
2002	2191	11251.681	9239.405	0.81925	1895	4087.15	2700.76	1.2873333
2003	1304	9139.675	6425.336	0.913	1000	4415.34	1290.8517	1.2943333
2004	2944	4785.933	3666.845	0.91875	1008	3064.95	1075.295	1.2726667
2005	4171	3510.2531	3055.962	0.955	619	2004.525	912.661	1.253
2006	4608	3858.0439	3773.931	0.79925	506	1829.692	838.354	1.277
2007	3951	5213.4933	4824.682	0.8055	692	1570.1375	698.461	1.2746667
2008	1665	5597.1501	3950.906	0.72375	339	1407.7065	661.9642	1.263
2009	3763	5353.9261	3295.714	0.727	644	1173.752	468.289	1.25
2010	17563	5570.5674	3217.931	0.48475	1057	1366.1475	464.537	1.2293333
2011	5252	11752.306	7266.665	0.3725	739	2066.401	365.3971	1.2096667
2012	738	20899.184	7676.156	0.421	720	2580.582	196.707	1.2116667

Cscod	**NScod**				**WoScod**			
Year	R	SSB	Yield	Fbar	R	SSB	Yield	Fbar
1963	462314	153637.64	128685.65	0.4776667				
1964	845768	165830.2	130740.04	0.5093333				
1965	1067681	205112.44	210237.44	0.541				
1966	1375049	228116.51	259416.02	0.5563333				
1967	1274418	252018.93	276386.51	0.6086667				
1968	654744	262090.32	305910.51	0.641				
1969	600189	258914.66	205510.03	0.619				
1970	1837653	274657.9	243866.77	0.631				
1971	2385693	276775.12	412263.7	0.7066667				
1972	587129	240800.87	387736.88	0.782				
1973	873270	212213.42	269138.55	0.754				
1974	806130	232062.88	253988.89	0.7303333				
1975	1384708	213153.8	242348.52	0.7716667				
1976	852561	182729.29	307102.44	0.8073333				
1977	2113805	160817.06	349037.65	0.7936667				
1978	1255444	160329.65	328584.55	0.8693333				
1979	1428306	166424.16	430687.95	0.792				
1980	2262543	181841.02	590678.16	0.8596667				
1981	885582	194208.37	393451.5	0.8863333	11.498	42.302735	24174.092	0.75375
1982	1388869	187441.51	359371.65	1.0026667	26.67	39.098659	22083.395	0.69825
1983	800507	152294.86	281696	0.9866667	14.68	34.38848	21507.541	0.77525

1984	1391649	130138.42	379974.04	0.918	26.574	28.202037	21609.901	0.8645
1985	368060	125125.38	247030.7	0.882	12.684	24.628097	19570.282	0.991
1986	1664441	114533.79	341046.57	0.9463333	21.43	16.943805	12086.232	0.7805
1987	652783	107195.88	244809.22	0.9446667	53.594	18.527736	21356.702	0.9185
1988	451802	99009.706	194798.48	0.9546667	6.685	25.889539	20777.527	0.8805
1989	753889	92681.298	202638.81	0.9843333	23.191	23.840132	19244.336	0.92125
1990	323515	78415.15	153020.84	0.9123333	7.566	18.834127	12747.363	0.80425
1991	353274	71894.763	121204.45	0.935	12.291	14.586014	11551.52	0.84125
1992	741181	68206.338	151755.07	0.9063333	22.837	12.217255	10868.061	0.8625
1993	405956	63699.814	144223.01	0.909	8.875	14.105477	10453.398	0.8545
1994	869784	65662.751	210754.53	0.9093333	17.203	14.134843	9579.894	0.827
1995	505852	73666.762	170581.2	0.9343333	14.06	14.609237	9583.319	0.83525
1996	365492	72051.227	140695.05	0.959	5.978	14.411145	9494.589	0.92825
1997	970921	68014.63	157765.7	0.9546667	21.951	10.83045	7535.861	0.9655
1998	154508	55876.296	186437.53	0.9753333	6.333	12.215622	6256.476	0.945
1999	276786	51383.297	109742.28	1.007	4.687	9.4970268	4270.28	0.99025
2000	499818	45274.8	85049.348	1.0086667	17.121	6.7823658	3794.413	0.9605
2001	188528	37606.083	63528.438	0.957	3.747	8.4498264	2449.011	0.98675
2002	232118	38558.256	60552.142	0.9316667	7.584	8.3824254	2726.204	1.0345
2003	106404	33330.64	36560.952	0.924	1.658	7.0994244	1271.043	1.03575
2004	173685	28259.394	33950.478	0.885	2.465	4.0834051	610.455	0.98425
2005	117243	25557.296	34810.095	0.823	1.628	2.5721123	551.86	1.07225
2006	304066	21842.726	33593.449	0.7026667	5.554	1.794694	965.044	0.9355
2007	127262	27779.908	48076.605	0.6183333	1.758	3.2391113	2475.265	1.0255
2008	153277	34214.849	48887.327	0.6376667	1.54	2.8632124	1378.6341	1.00875
2009	163571	40622.704	44824.185	0.6026667	3.103	2.3009789	1351.3418	0.898
2010	249197	43286.476	46897.459	0.5613333	2.524	2.4084691	1340.4426	0.87675
2011	134592	45879.148	42453.184	0.4696667	1.036	2.7106435	2127.0123	1.02175
2012	253723	54786.85	41490.455	0.3906667	2.198	2.0341687	1630.7297	0.91975

Annex VI. Sole in Div. IIIa and areas 22-24 (Kattegat Sole)

Background

At the last benchmark assessment of this stock at WKFLAT in 2010 F_{MSY} was estimated to 0.38 based on criteria of a low probability (20%) of being below an SSB of 2000 t (B_{pa}). B_{lim} is not known. The present ICES methodology of constraining F_{MSY} to the precautionary approach was not fully developed at that time and therefore this rationale was used as the most legitimate. With the development of the terminology of F_{MSY} and catch advice in relation to MSY and PA, it became evident that conceptually $F_{pa} > F_{MSY}$. For sole in IIIa and 22-24 F_{pa} was estimated to 0.30 while F_{MSY} was estimated to 0.38, and consequently F_{MSY} was constrained by F_{pa} for the catch advice for 2014. Present work at WKMSYREF2 therefore aimed to re-estimate F_{MSY} and other reference points for the sole stock in accordance with ICES terminology and using precautionary constraints of the MSY approach.

At WKFRAMEII in 2011 on implementing the MSY framework in the ICES advisory procedure a meta-analysis was conducted on the ICES sole stocks. It appeared evident that Kattegat sole was somewhat outstanding; due to a low selectivity on the younger age groups and a decreasing weight on the older age groups, F_{MSY} was estimated relatively high in order to exploit the young fish before growth ceases or mean weights in catches declines. The low selectivity on especially age groups 3-5 relative to other sole stocks is likely due to the fishing gear used for sole, trawl with mesh sizes of >90 mm and gillnets with 90-120 mm in combination with fishing in areas where adults predominates. The low mean weights for the older age groups, especially ages 7 to 9+ is less likely to explain; sex specific growth as usually seen in flatfish could have resulted in a higher exploitation of females and consequently left the stock with predominantly older males at the present low stock size, with lower mean weight at age than females. Another explanation for the decreasing weights for older age groups could be due to noise, either caused by the few individuals sampled in these age groups and/or due to ageing problems. The group decided to perceive the decreasing weights as noise and therefore attempts were made to estimate more realistic mean weights for the oldest age groups for use in the F_{MSY} calculations.

Data and methods

Data was available from the last sole update assessment (WGBFAS 2013) conducted as a SAM assessment (stockassessment.org). The software were EqSim and PlotMSY 4 run in an R environment under R version 3.0.0.

Mean weight at age for the older age groups were examined as this has been considered a major reason for estimating a relatively high F_{MSY}. For many of the recent years it is evident that the estimated mean weights are decreasing for the age groups 7, 8 and 9+ (Fig x.1) A simple average over the time series provide a fit that slightly resembles a Bertalanffy growth. As there do not seem any evident trends in weights for these older ages over the time series, such a mean is considered a valid estimate (Fig. x.2). For the present analyses are therefore used recent (2008-2012) mean weight at ages for age groups 2-6 and long term averages for the oldest age groups (Fig. x.2).

Stock recruitment relationships and biomass reference points

The WS-group questioned the first two estimates of SSB in the time series; these estimates are the lowest observed although year classes associated with this low spawning biomass are above long term average (Fig. x.3). Uncertainty associated to these two biomass estimates (1984 -85) is not outstanding and in addition the previous assessment model, XSA, gave similar SSB results. Catches in the years prior to the start of the assessment data (- 1984) are in the range 200-500 t, decreasing in the period 1977-83 and continuing being low 1984-85. Sole is known to be sensitive to cold temperatures and especially the winter 1984/85 was extremely cold and is likely to have caused a high mortality that resulted in lower biomasses for these years (Millner and Whiting, 1966). Since no TAC restrictions caused this decrease in catches, the low SSBs estimated for the years 1984-85 were decided to continue to be included in the data set for the assessment and analyses of reference points.

The tools PlotMSY and EqSim provide fits for the three SR models, Beverton-Holt, Ricker and Segmented regression (Hockey stick). The EqSim run provided a weighted combined relation that mostly followed a Ricker relation (Fig. X.4), while the PlotMSY run provided most weight to the Beverton-Holt relation (Fig XX.5). The breakpoint of the segmented regression that in some cases are used to define B_{lim} was approx. 1000 t for the PlotMSY, but about 2000 t for the EqSim. Excluding the 1984-85 yc observations as discussed above resulted in an estimated a breakpoint by the segmented regression at approx. 2000 t with the PlotMSY, while the segmented regression breakpoint was more or less unchanged with the EqSim tool. The fit of the remaining models (B-H and Ricker) did not change with the exclusion of the 1984-85 data.

B_{pa} was previously estimated at 2000 t and MSY $B_{trigger}$ is set equal to B_{pa}. B_{lim} has not been defined for the sole stock. In order to analyze an F_{MSY} candidate in relation to PA boundaries, i.e. prob(SSB< B_{lim}), a B_{lim} needs to be defined. Lowest observed SSB and breakpoints of segmented regressions are both approved ways of deriving B_{lim}. These approaches will result in B_{lim} of approx. 1000 t. WKFRAMEII (2011) estimated amongst others sole stocks, the Kattegat sole B_{lim} based on segmented regression which gave an estimate of 1200 t.

Assessment error for the SAM assessment is rather low, std dev is 0.24 on the terminal SSB estimate, and using this error in the standard formulae to derive B_{pa} from B_{lim} (B_{lim} *e $^{1.645\sigma}$) gives an B_{pa} of 1800 t. Considering the former B_{pa} defined in the neighborhood of this (2000t) , it is suggested to keep this estimate given the unusual low assessment error. B_{pa} is therefore suggested to be defined as previously at 2000 t.

For the simulations conducted to estimate F_{MSY} B_{lim} is therefore assumed in the range 1000-1200 t.

Equilibrium simulations and F_{MSY} evaluations

For the performance of equilibrium scenarios the data from previous approved assessment in 2013 was used with exception of mean weights, where weights for older ages were assumed constant equal to a long term average (see data and methods). Stochasticity on the last five years of population and exploitation parameters were used, and natural mortality and maturity was set constant as in the default assessment. Runs from EqSim and PlotMSY with these inputs are shown in Figs x.6 and x.7. For both approaches the simulations were conducted for best combined weighted SR relations as shown in figs x.4 and x.5.

The EqSim (Fig. x.6) estimated F_{MSY} (median) at 0.53 (indicated blue in Fig). From panel c in Fig x.6 it is obvious that no distinct maximum appears for catches with any target F and consequently F_{MSY} is estimated in the high end and where catches apparently have a poorly defined maximum. This is likely due to a poorly defined Fmax as illustrated in Fig x.8, as YR curve continue with high yields at high Fs with no distinct maximum in combination with the combined weighted SR relationship. PlotMSY provides F_{MSY} estimate at similar value, 0.47, and the estimated distribution is shown in Fig x.7.

Precautionary considerations of the F_{MSY} estimates i.e. annual probability <5% that SSB< B_{lim}, is provided in panel d of fig. x.6 with the 5% line. The F_{MSY} estimate that is constrained by this rule is considerably lower than the median F_{MSY}, and do therefore need to be adopted within the precautionary approach. This "5%F" equals 0.36 and is indicated as F_{lim} in panel a-c in Fig x.6. From the catch – F panel (c) it is obvious that lowering target F from the median value (0.53) to the 5%F (0.36) will not result in any significant losses in catch, but rather ensure higher probability of avoiding recruitment failure and crash of stock (panels a and b). The estimated 5%F (0.36) that is within the precautionary boundaries is suggested a candidate for F_{MSY} to be adopted for advisory purposes in accordance with the rules set up by WKMSYREF2.

Sensitivity of F_{MSY} estimates

The B_{lim} range 1000-1200 t were considered in the estimation procedure; median F_{MSY} did not change and 5%F changed only insignificantly between 0.36 and 0.38.

In order to test the sensitivity for the weighed combined SR models that mainly weighed the Ricker function (EqSim) a run with only segmented regression was conducted. As expected this model option lowered the estimated F_{MSY} and 5%F to 0.36 and 0.32 respectively. An assumption on a Ricker SR relation is consistent with assumptions for North Sea sole.

The equilibrium analyses showed that any target F within a range 0.26-0.36 did not result in any significant change in expected catch, but that exceeding 0.36 will be associated with an increased risk of lower catches. Assuming a segmented regression SR model (Fig x.10) will change the probability profile and the associated 5%F til 0.32. Given this SR model there will be a high risk of lower catches at higher fishing mortalities than 0.32.

Re-estimation of F_{pa} and F_{lim}

The present F_{lim} (0.47) is based on an F_{med} analysis in 1998 that excluded some high recruitment estimates around 1990. Though, the questioning of the recruitment estimates around 1990 has never been justified or detailed. F_{pa} was derived from F_{lim} by the formulae $F_{lim}*e^{-1.645\sigma}$ ~ 0.30. The F_{med} is basically an F corresponding to a SSB/R equal to the inverse of the 50% percentile of the observed R/SSB. The use of F_{med} as an F_{lim} candidate seem not appropriate in this case were the SR relation mostly consist of observations that constitute the right leg of a Ricker like SR model. In that case F_{med} is more likely an F_{pa} candidate. F_{med} analyses are now seldom used to calculate F reference points and it is therefore suggested to re-calculate estimates of F_{lim} and F_{pa} that are in accordance with the defined biomass reference points.

Using the replacement line for B_{lim} and B_{pa} will estimate the corresponding F_{lim} and F_{pa} at 0.92 and 0.49, respectively (Fig x.9). The calculated F_{MSY}'s (0.47-0.53) are in the range of the estimated F_{pa} at 0.49, and both can therefore serve as reference points used for catch advice. A F_{MSY} constrained by PA that is consistent with this estimation procedure (replacement lies) will be the F_{MSY} estimated based on the segmented regression. This PA constrained F_{MSY} (5%F) was estimated to 0.32.

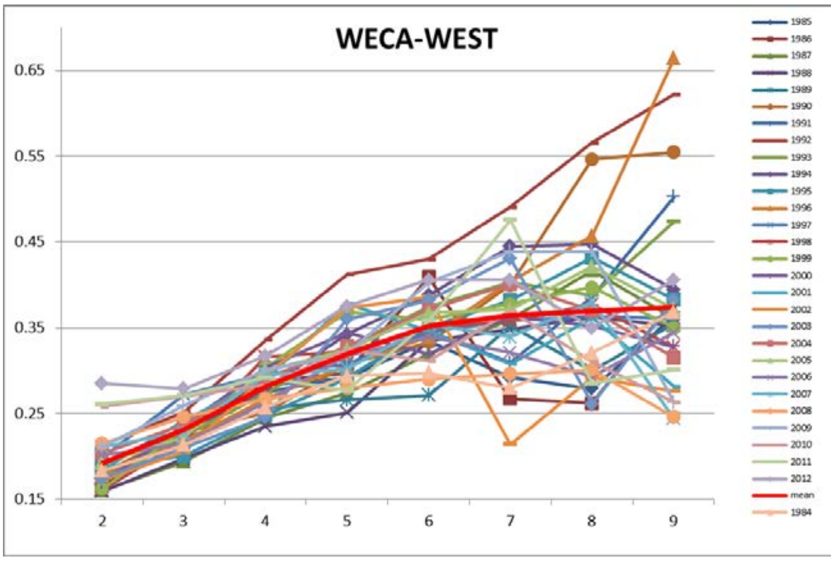


Figure A4.1. Mean weights at age for sole IIIa 22-24 for 1984-2012. Red bold line is mean for all years.

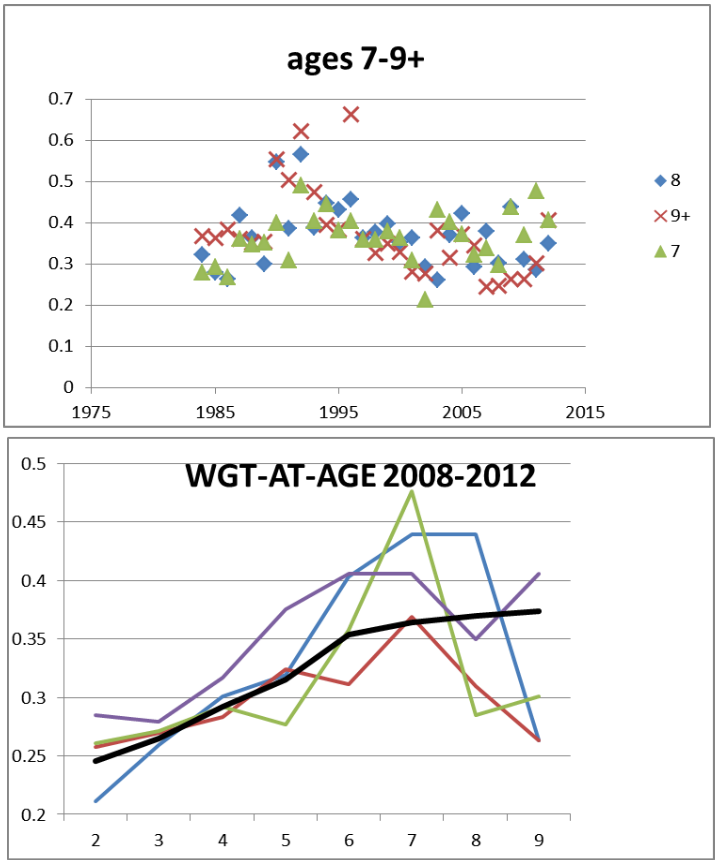


Figure A4.2 Upper panel: Mean wgts for ages 7,8 and 9+ in 1984-2012. Lower panel: Mean wgt-at-ages for 2008-12. Bold black curve is mean(2008-2012) for ages 2-6 and mean(1984-2012) for ages 7-9+.

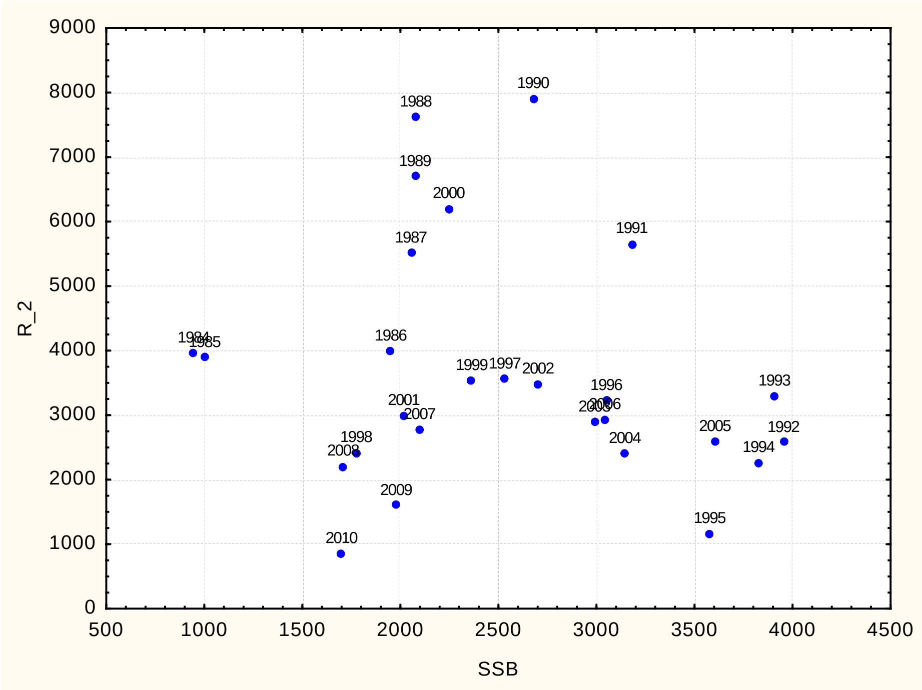


Figure A4.3 Sole in IIIa and 22-24. SSB – recruitment (age 2) plot. Year-classes are indicated.

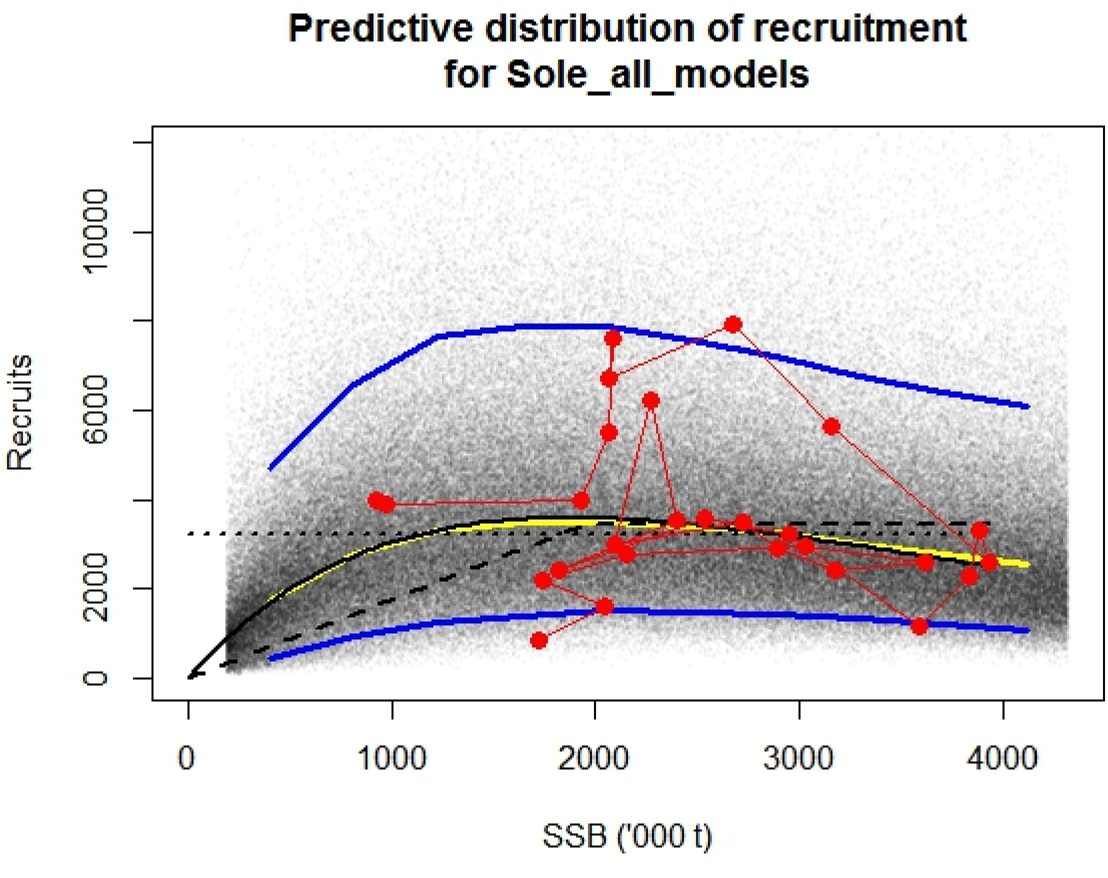


Figure A4.4 Stock – recruitment fit by the tool EqSim. Observations are red dots, dotted line is fitted Beverton-Holt model, dashed line is fitted segmented regression, black line is fitted Ricker curve and yellow line is combined weighted fit from stochastic simulations.

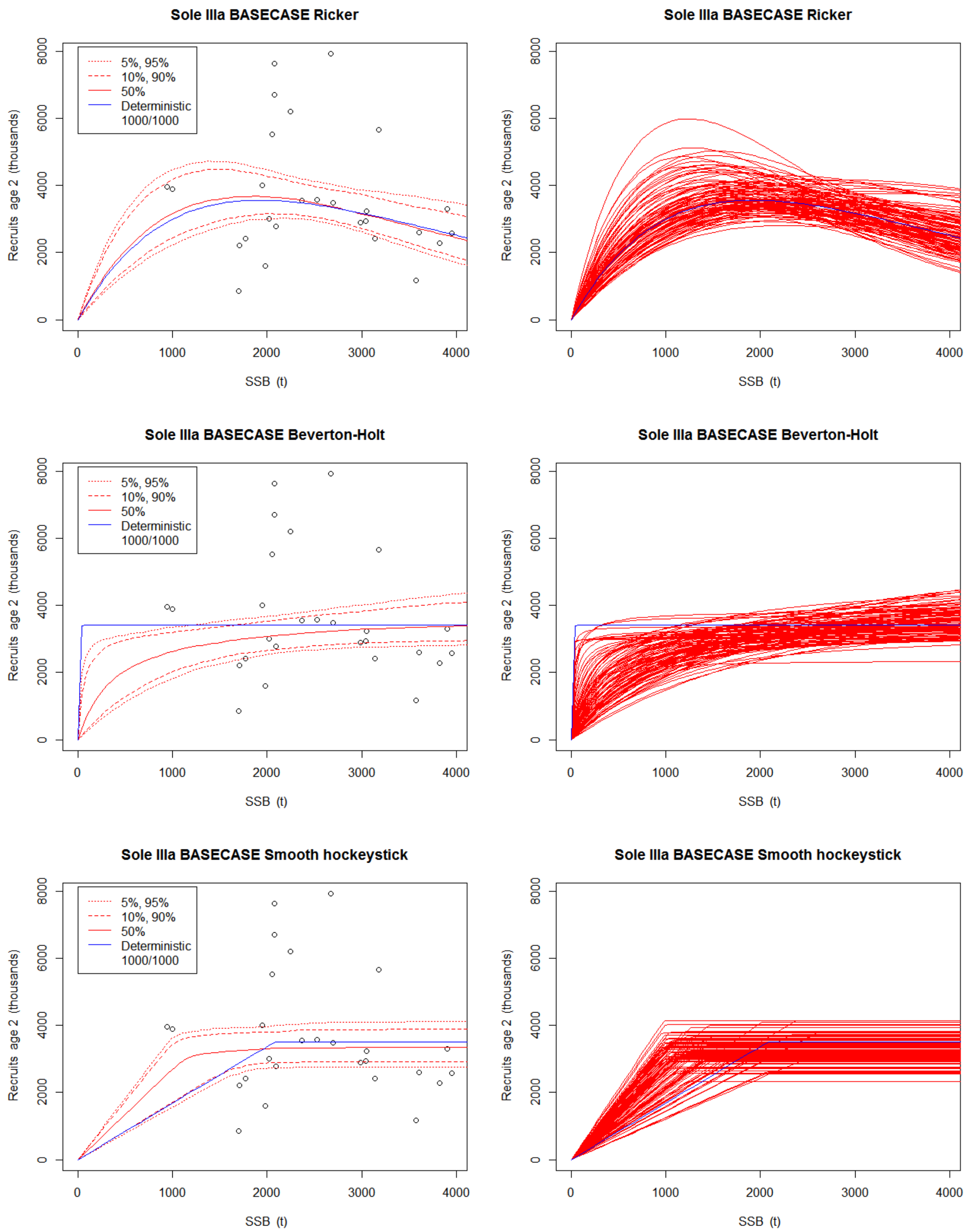


Figure A4.5 Stock-recruitment fit by PlotMSY tool for each of the models Ricker, Beverton-Holt and segmented regression.

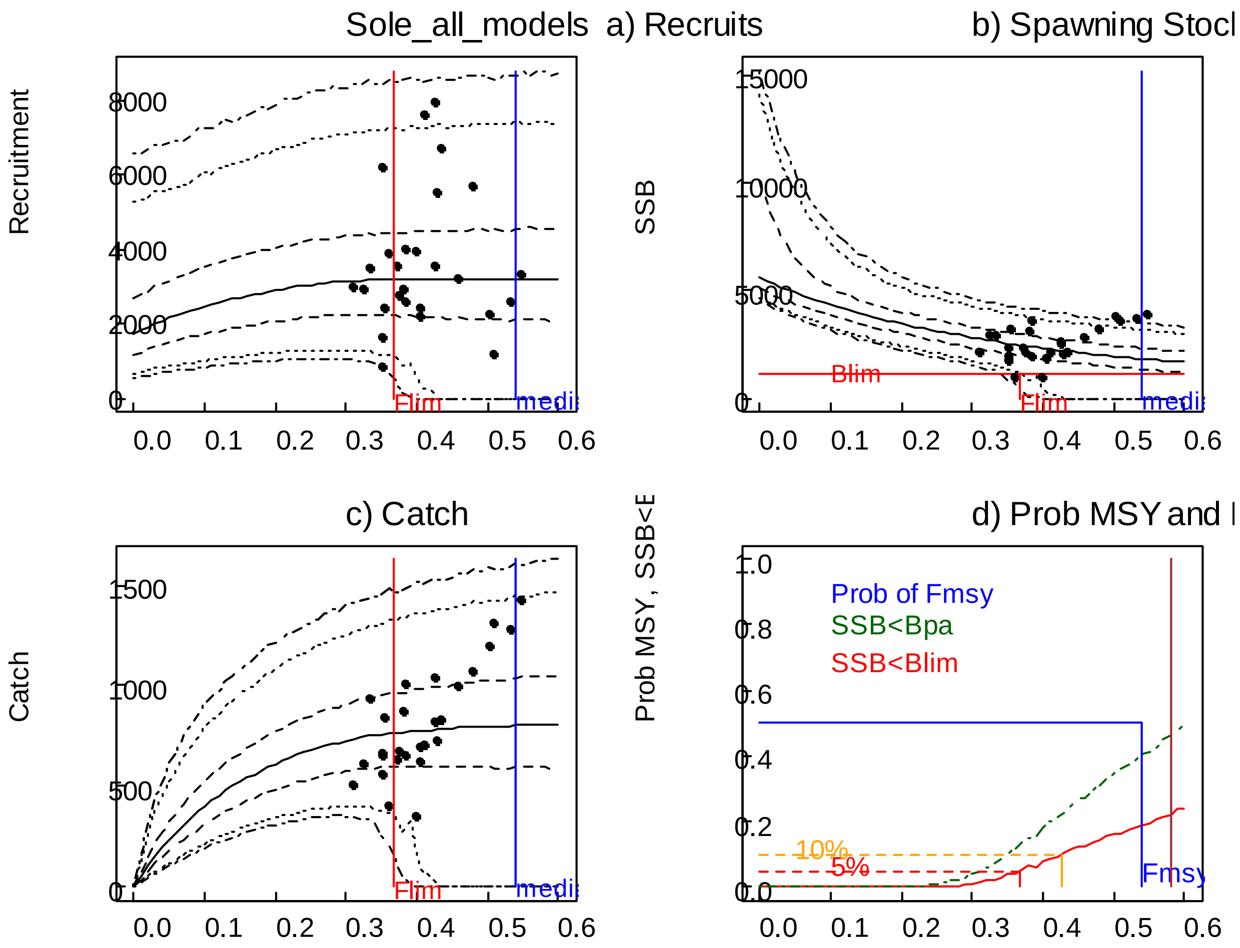


Figure A4.6. Output of equilibrium simulation from the EqSim tool.

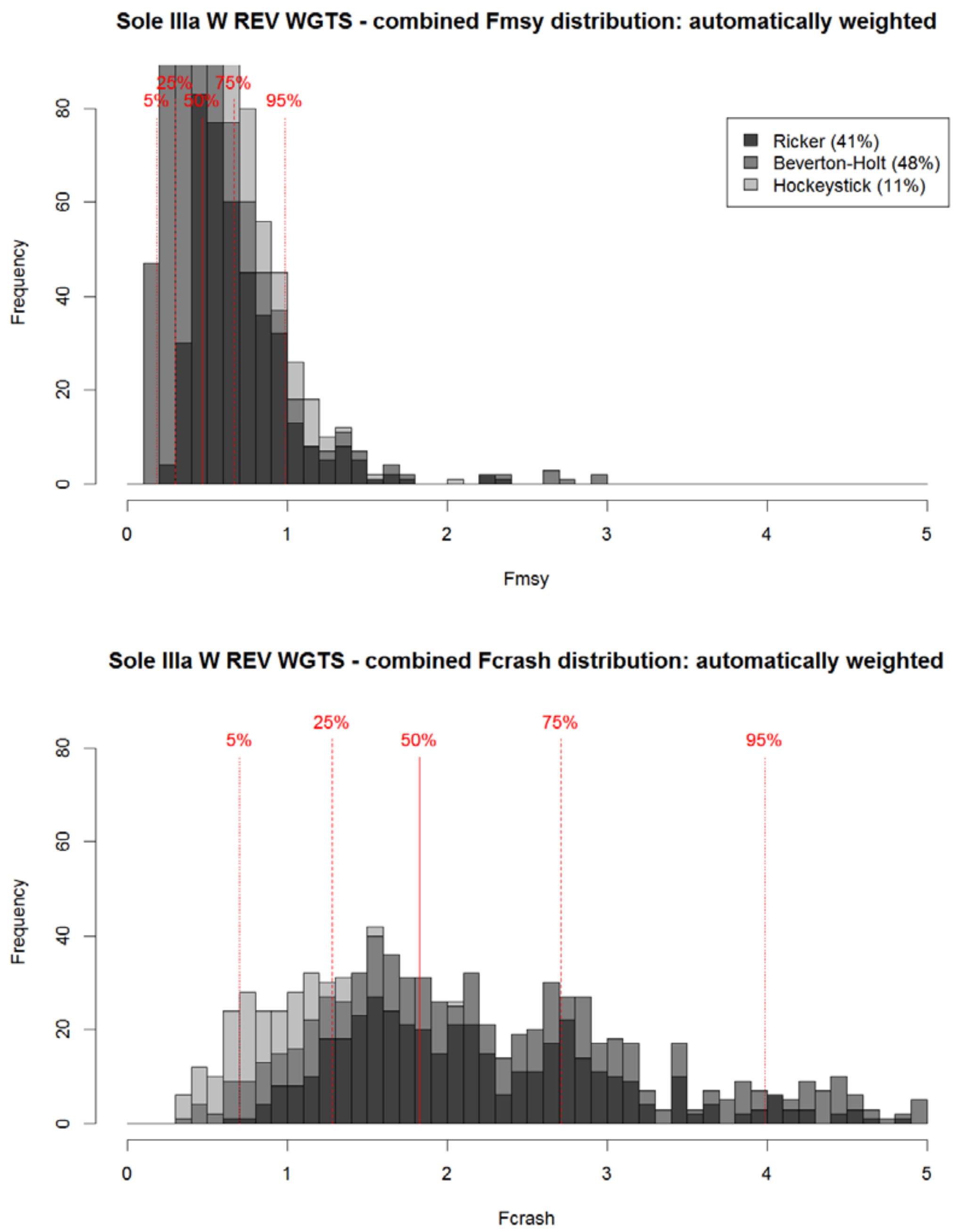


Figure A4.7. Output of equilibrium simulation from PlotMSY. Upper panel is F_{MSY} distribution with indication of SR relationship weighting. Lower panel is Fcrash distribution.

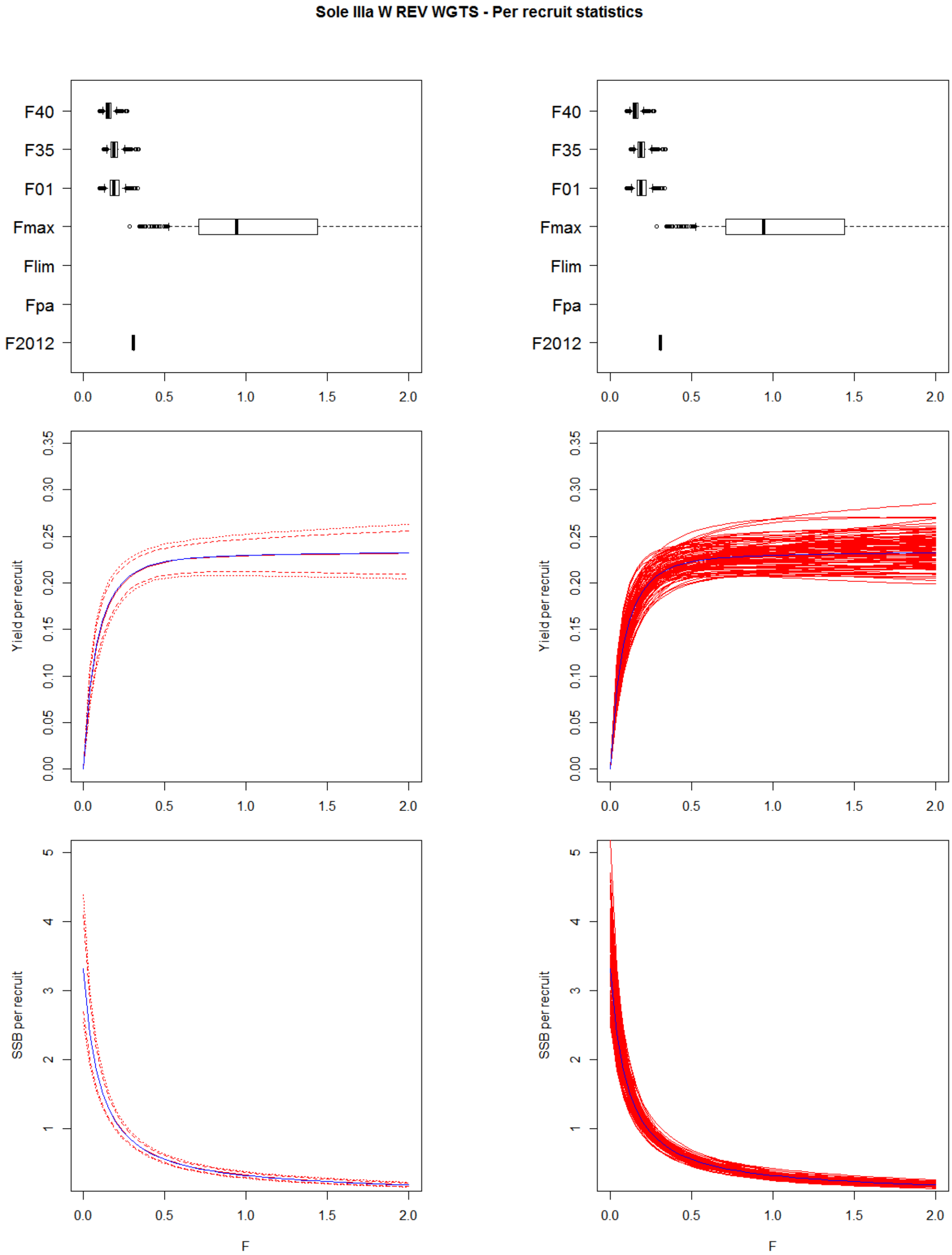


Figure A4.8. Yield per recruit and estimates of associated F reference points from PlotMSY.

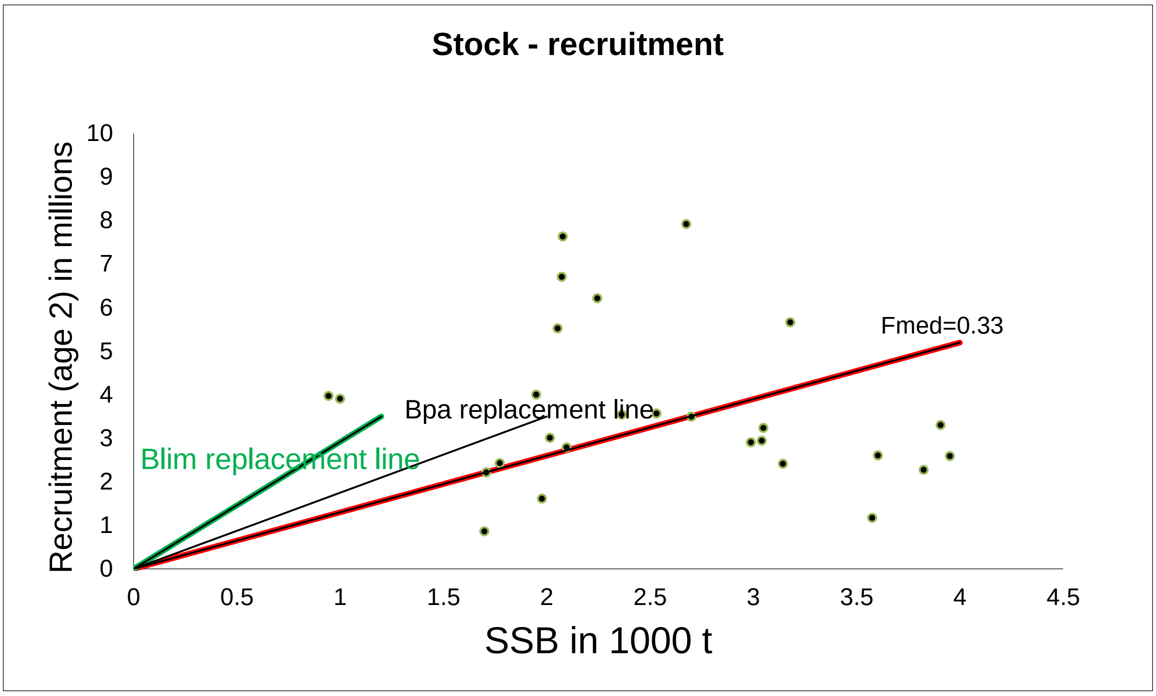


Figure A4.9. Sole in IIIa and 22-24. Fmed and replacement lines for B_{lim} (1200 t) and B_{pa} (2000t).

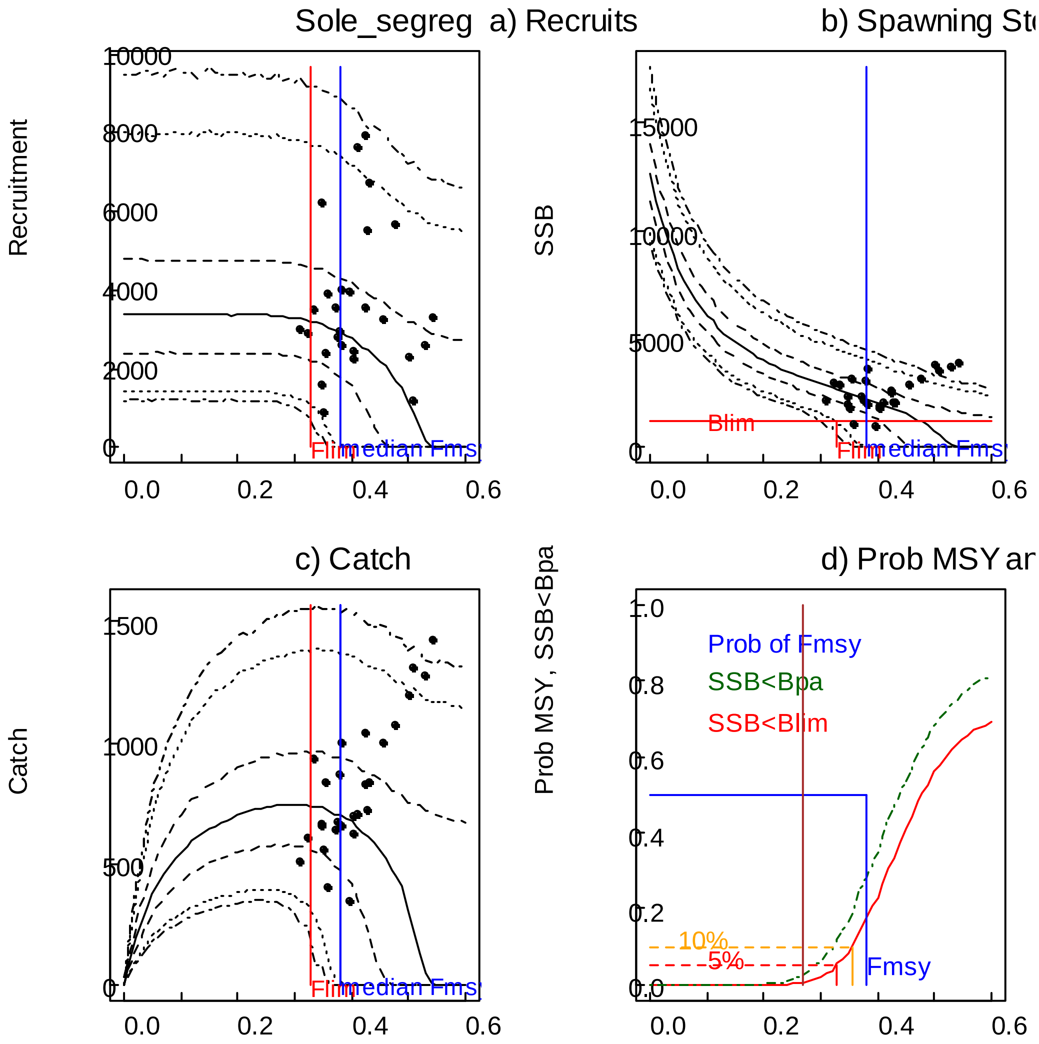


Fig A4.10 Output of equilibrium simulation from the EqSim tool assuming a segmented regression SR model.

Annex V Haddock in Subarea IV (North Sea) and Division IIIaN (Skagerrak)

Haddock stocks in the North Sea and Skagerrak (Subarea IV and Division IIIaN) and to the West of Scotland (Division VIa) are due to undergo a benchmark process at the ICES Benchmark Workshop on Northern Haddock Stocks (WKHAD) during January and February 2014. Given this, WKMSYREF2 decided it would be opportune to produce exploratory estimates of F(msy) for the North Sea haddock stock in the first instance, using three approaches:

1. An *ad hoc* R script that was developed at the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak in 2010 to provide F(msy) estimates for North Sea haddock (see Section 13.7 in ICES-WGNSSK 2010);
2. The plotMSY code developed at Lowestoft (see Section 7); and
3. The eqSIM code currently under development by WKMSYREF2 members and others (see Section 7).

ad hoc R script

Full details of the approach used in this script are given in ICES-WGNSSK (2010). The implementation considered here included only the Ricker stock-recruitment model, as there appeared to be fitting difficulties for both the Beverton-Holt and hockey stick (change point) model. No allowance was made for assessment or advice error, with stochasticity deriving only from bootstrap resamples of the fitted Ricker curve. The yield-per-recruit curve used total catch *F* and maximised landings yield, on the assumption that maximising discards would be inappropriate – this is the same approach that is used by ICES in formulating MSY-based advice. Input data were taken from the 2013 assessment (ICES-WGNSSK 2013).

Figure A4.1 shows the fitted Ricker stock-recruitment curve, along with resampled parameter values for the bootstrap process. Figure A4.2 gives the estimated landings yield-per-recruit (YPR) and SSB-per-recruit (SPR) curves, which are expressed as functions of total catch F. The YPR curve in particular is very flat, without a very clear maximum. Figure A4.3 summarises the F(msy) estimation for the best-fitting stock-recruit curve, showing landings and SSB against total catch F (and hence estimates for that stock-recruit curve of F(msy) and B(msy)). Finally, Figure A4.4 shows the results of retrospective analyses for F(msy), produced by incrementally removing the last year of the input data and re-estimating. F(msy) estimates have remained reasonably constant at just under 0.4, with 90% confidence limits of around 0.2 to around 0.55. The historical assessment estimates of F have fluctuated mostly in the lower reaches of this confidence interval, while estimates of F(0.1) (sometimes proposed as a proxy for F(msy)) are lower still.

plotMSY code

The plotMSY approach is described in detail elsewhere in this Report (see Section XXXX). It is based on the SUM and SEN files for North Sea haddock produced during the 2013 WGNSSK meeting (see ICES-WGNSSK 2013) which were the basis for the June and October 2013 advice. plotMSY could not be run successfully on the computer used for the *ad hoc* approach summarised above, and it would be helpful for future work (particularly WKHAD 2014) if such incompatibilities could be addressed.

Figure A4.5 gives the three fitted stock-recruit models for North Sea haddock, all of which are close to a simple geometric mean over most of the observed range. Figure A4.6 shows the weighted distribution of F(msy) and F(crash) estimates obtained using the three stock-recruit models: the stock-recruit data shows little evidence of reduced recruitment at high stock sizes, and the hockey-stick and Beverton-Holt models are given more weight that the Ricker model as a result. F(msy) estimates are relatively well-defined about a mean of 0.36, but F(crash) is highly uncertain, most probably due to uncertainty in the slope at the origin of any fitted stock-recruit curve (the stock-recruit relationship is very poorly defined for North Sea haddock . Finally, Figure A4.7 summarises the evaluation output for the smooth hockey-stick stock-recruit model.

eqSIM code

As for plotMSY, the eqSIM approach is described in detail elsewhere in this Report (see Section 7). It transpired that eqSIM could also not be run successfully on the computer used for the *ad hoc* approach summarised above, and it would be helpful if this were addressed.

The WKMSYREF2 meeting was the first time when eqSIM was applied to the North Sea haddock case. The method by which the available version of eqSIM determined the best estimate of F(msy) differed from the two approaches described above, in that it used the F relevant to the median of the maximum catches from each of the simulation runs, rather than the maximum of the median of the catches from all the simulation runs. This led to an unrealistically high estimate of F(msy): the code was not incorrect, but the methodology did not appear to be suitable for the extreme recruitment variability shown by North Sea haddock. The principal output is given in Figure A4.8 for completeness, but this issue will need to be addressed during further development.

Summary

The following table summarises the F(msy) 5%, median and 95% estimates produced by three methods used here. Apart from the eqSIM results, which are discussed above, the estimates are quite similar and seem to be robust to the specific implementation used for estimation.

Method	F(msy) lower bound (5%)	F(msy) median	F(msy) upper bound (95%)
Ad hoc R script	0.222	0.370	0.570
plotMSY	0.319	0.359	0.406
eqSIM	n/a	1.00	na

However, none of the methods presented here are really yet in a suitable state for application during (for example) the forthcoming WKHAD benchmark meeting. The ad hoc R script is limited in that it can use only one stock-recruit model at a time, with no data-driven model selection. It has also only been used for a small number of stocks and has not been more widely tested, and there are no plans for further development. The plotMSY and eqSIM packages both require additional testing on different computer setups to ensure robustness, The issues where EqSim can generate unrealistic results when confronted with very variable recruitment data have now been resolved. The difficulties with differing versions of R have not been experienced with other users. WKMSYREF2 recognises that these approaches are potentially extremely useful, and encourages further development on them. It is hoped that these changes resolve the issues mentioned here. Certainly more work is required for this stock.

References

ICES-WGNSSK (2010). Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 5 -11 May 2010, ICES Headquarters, Copenhagen. ICES CM 2010/ACOM:13. 1058 pp.

ICES-WGNSSK (2013). Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 24 - 30 April 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:13. 1435 pp.

Figures

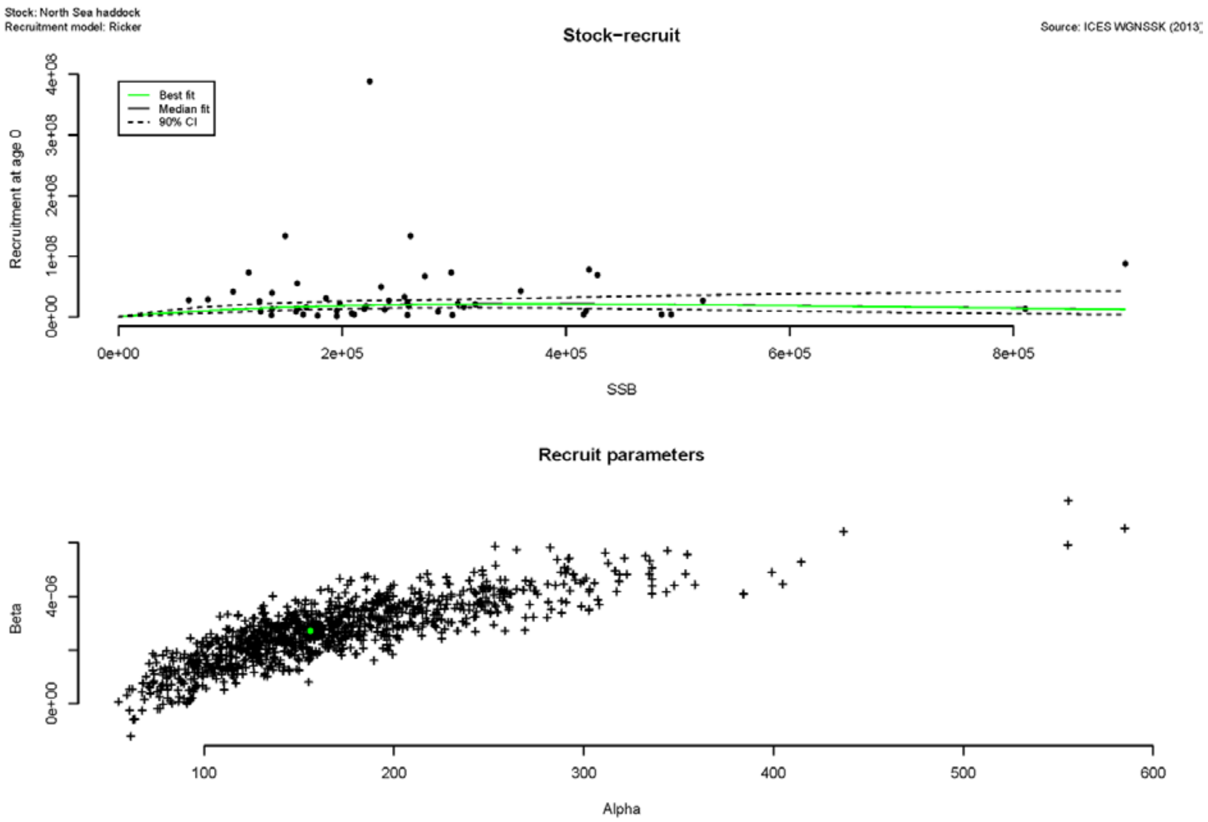


Figure A4.1. F(msy) evaluation for North Sea haddock using an ad hoc R script. Fitted Ricker stock-recruit curve (upper plot) and bootstrap resamples of Ricker model parameters (lower plot).

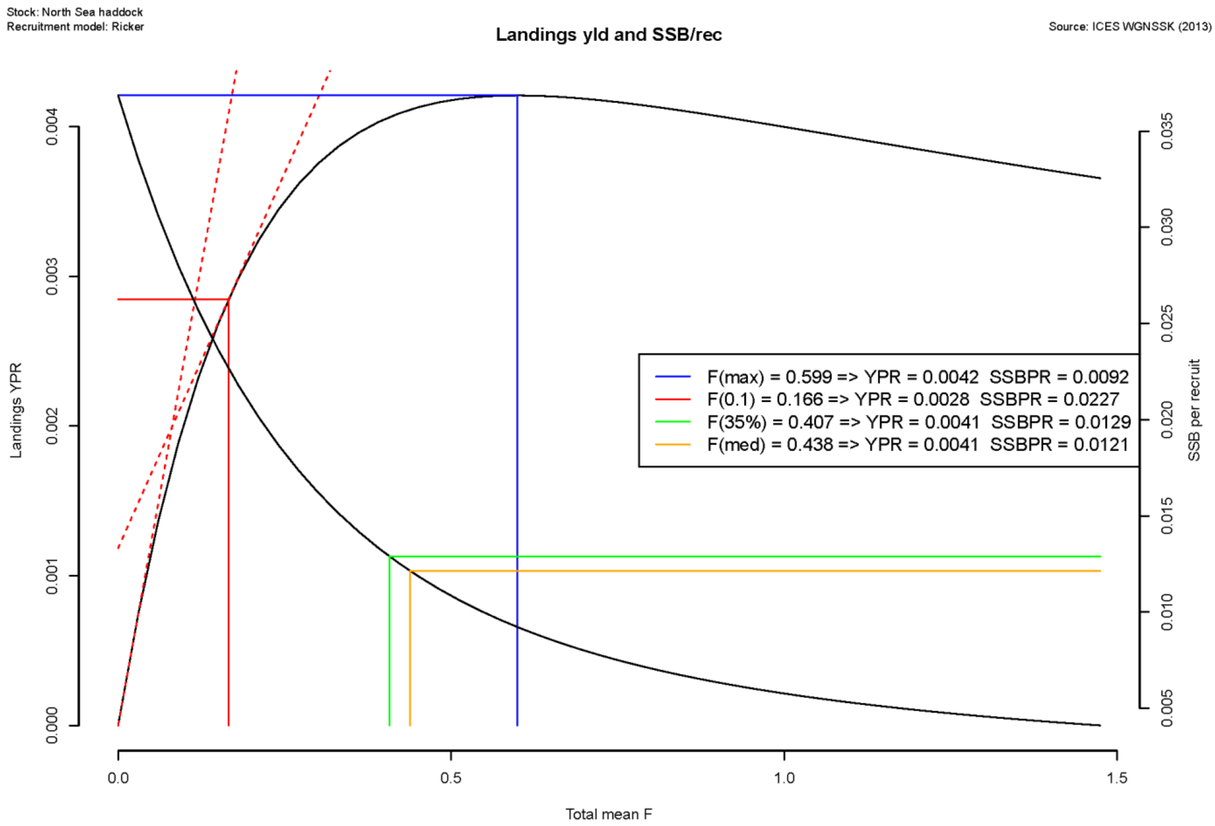


Figure A4.2. F(msy) evaluation for North Sea haddock using an ad hoc R script. Landings yield-per-recruit and SSB-per-recruit over values of total catch F from 0 to 1.5. Equilibrium-based F reference points are given in the legend, colour-coded with relevant lines on the plot.

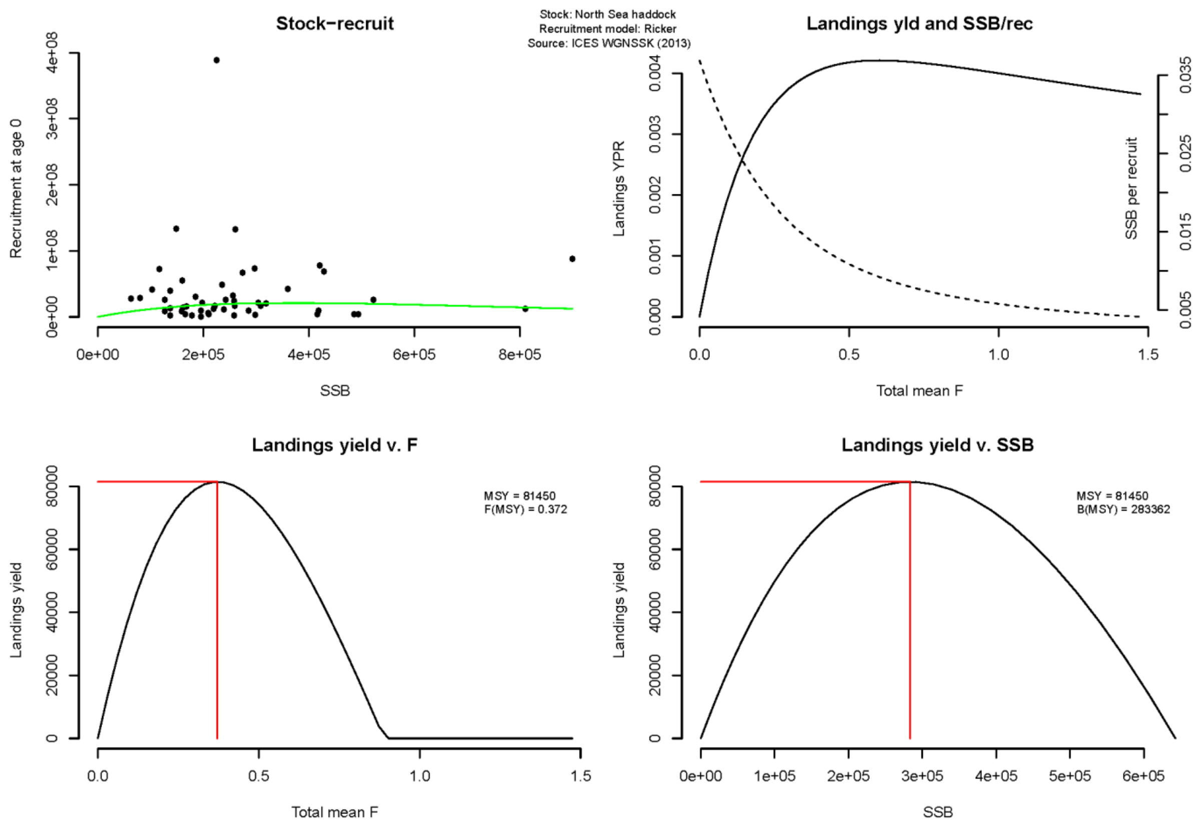


Figure A4.3. F(msy) evaluation for North Sea haddock using an ad hoc R script. Four-plot summary for the best-fitting Ricker stock-recruit model: stock-recruit model fit, yield-per-recruit and SSB-per-recruit, equilibrium landings yield against total catch F (showing F(msy) estimate), and equilibrium landings yield against SSB (showing B(msy) estimate).

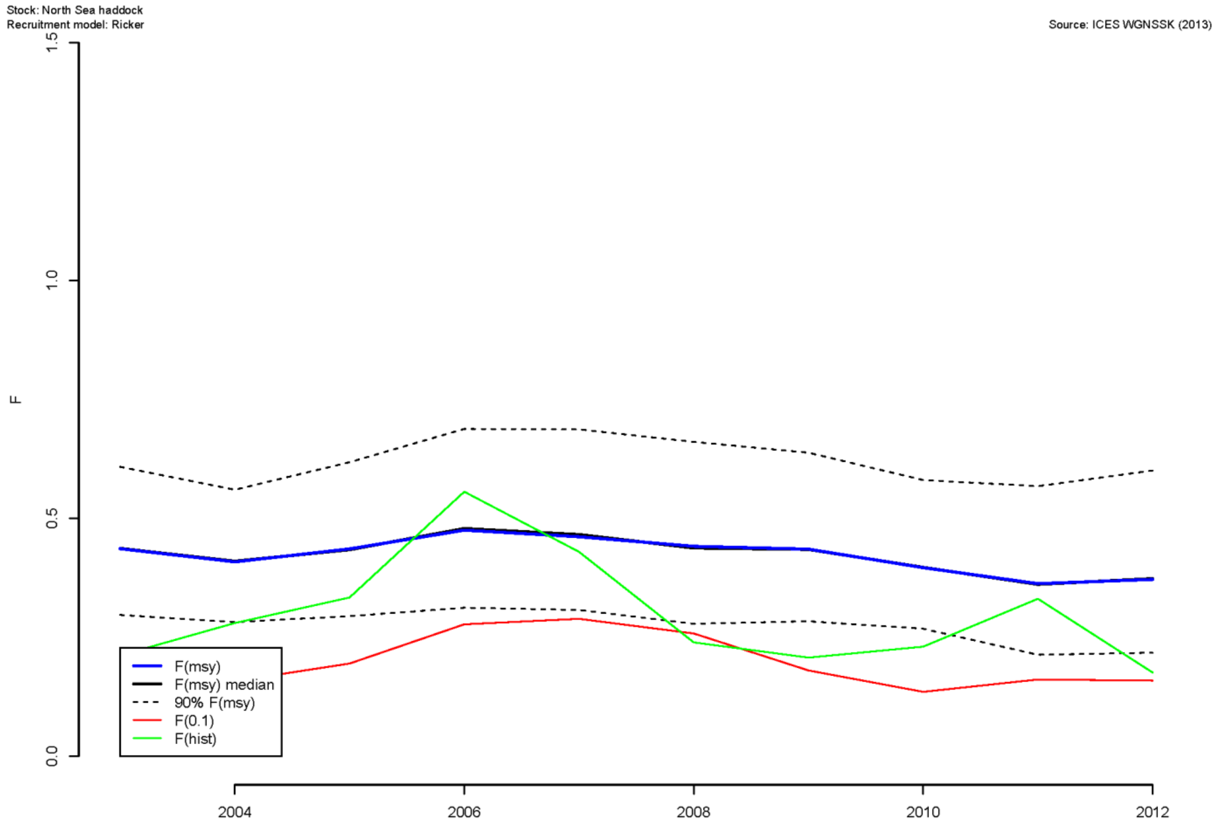


Figure A4.4. F(msy) evaluation for North Sea haddock using an ad hoc R script. Retrospective estimates of F(msy) (blue line), with 5%, 50% and 95% points (black lines), along F(0.1) estimates (red line) and the historical assessment estimates of F (green line).

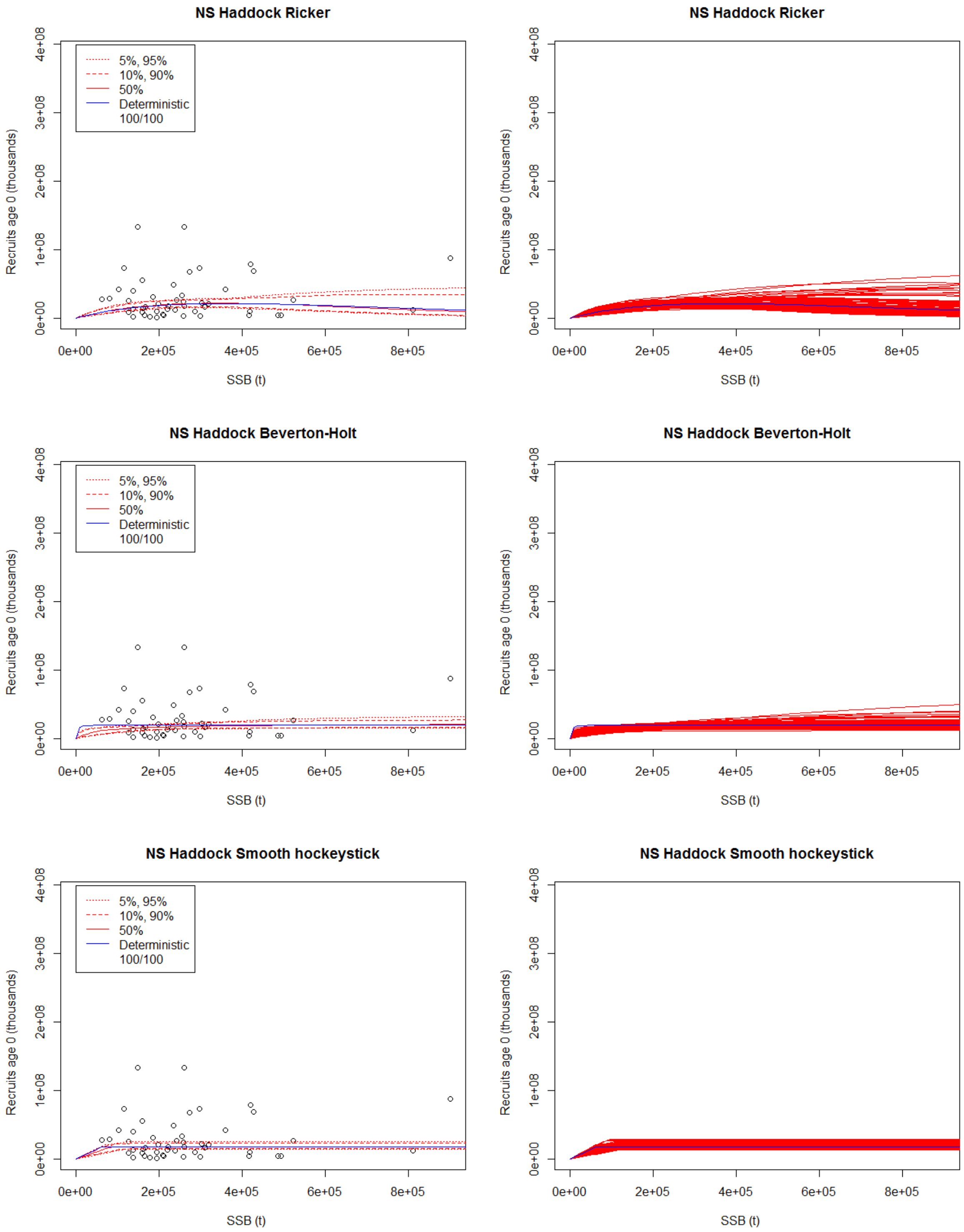


Figure A4.5. F(msy) evaluation for North Sea haddock using plotMSY. Stock-recruit model fits.

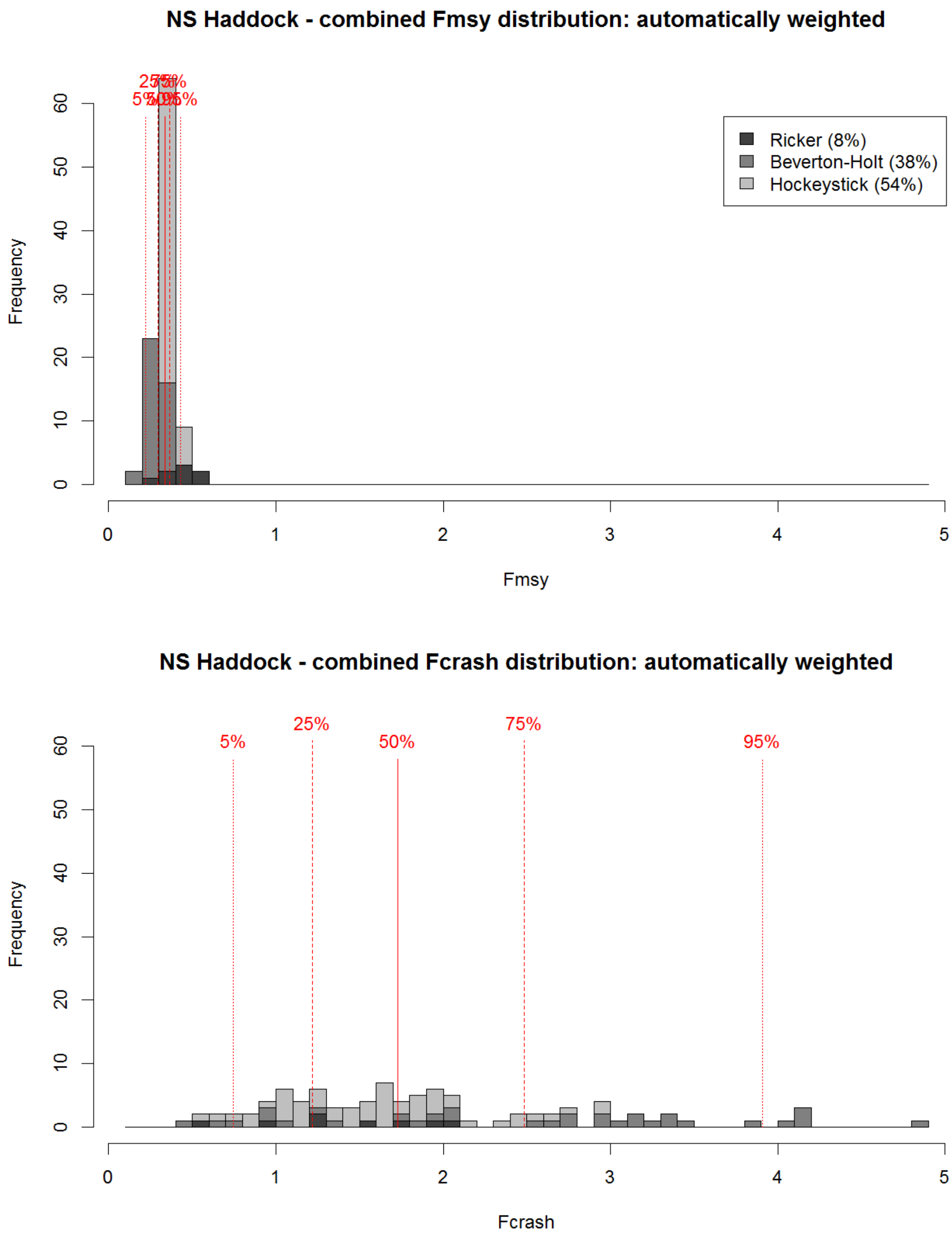


Figure A4.6. F(msy) evaluation for North Sea haddock using plotMSY. Distribution of fitted F(msy) (upper) and F(crash) (lower) estimates.

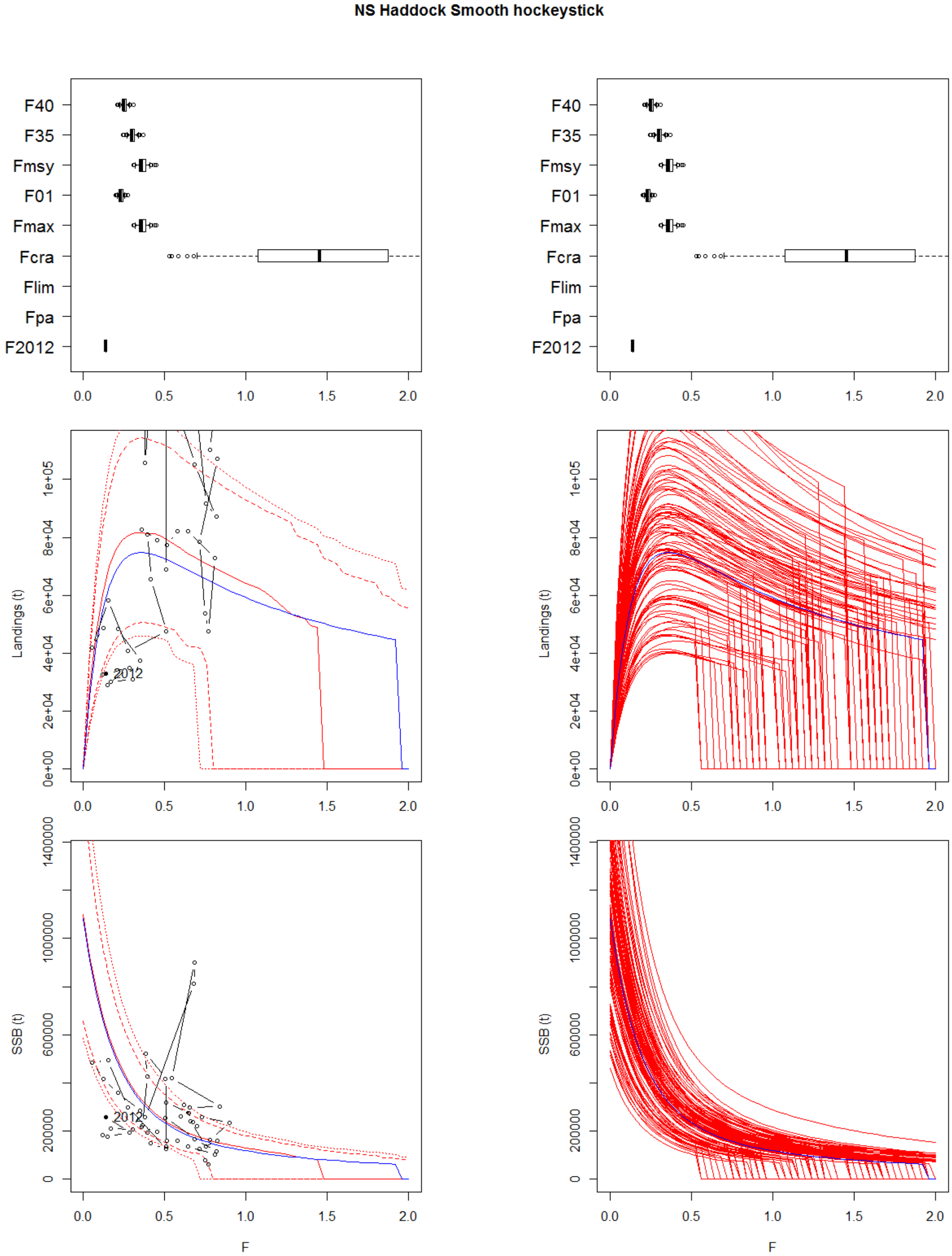


Figure A4.7. F(msy) evaluation for North Sea haddock using plotMSY. Evaluation summaries for the hockey-stick model.

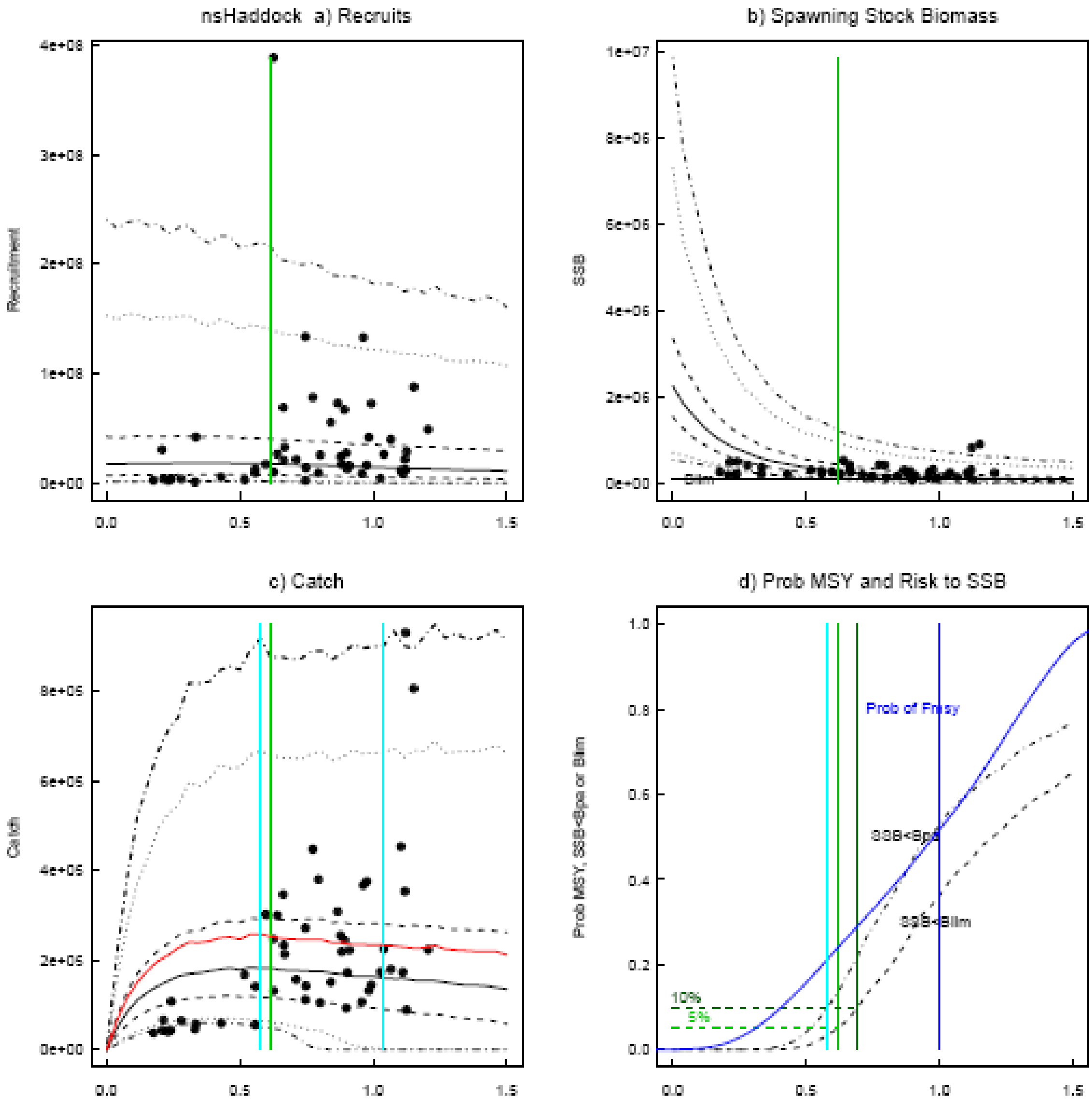


Figure A4.8. F(msy) evaluation summaries for North Sea haddock using eqSIM.