# WKFRAME-2 REPORT 2011

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# Report of the Workshop on Implementing the ICES Fmsy Framework (WKFRAME-2)

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*agreed management plan means endorsed by ICES and implemented by a competent authority

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## Executive summary

WKFRAME-2 met for 4 days in January to provide further technical guidelines to assist ICES expert groups in the implementation of the ICES MSY framework for advice which was introduced in 2010. The workshop was attended by scientists from the ICES community, stakeholders from the fishing industry and environmental interest groups. This year a particular focus of the group was trying to develop technical solutions to issues which proved problematic with the advice formulation in 2010. For this reason the meeting was overlapped with WGCHAIRS, which provided an important input to the first term of reference, "to evaluate the implementation of the advice and identify areas where further development is required". Apart from technical issues related to model fits of SRR, a major issue which arose last year was the confusion of what ICES was advising in relation to sustainable harvest rates, in situations either where stocks were reproductively impaired, or where there were technical differences between fishing at a defined $F_{msy}$ and according to an accepted management plan. The latter issue is now clarified and it is ICES policy to have a hierarchical approach to advice, where agreed management plans will be the primary consideration. In the situation where stocks are at risk of productivity impairment, the approach was to provide several options on the slope of the advised F rule where SSB is below $MSYB_{trigger}$. The decision on the implementation of any of these options is the responsibility of ACOM. WKFRAME suggests that adopting a singular approach will make it possible to give advice using the ICES MSY framework which is consistent with both the PA and MSY approaches. Several technical issues arose in 2010 also in regard to the calculation of advised exploitation under the transition schemes. The approach where SSB is above $MSYB_{trigger}$, is relatively straightforward, and there is a suggestion to calculate the transition from F2010 and follow 5 equal steps to the $F_{target}$. In the case where SSB is or falls below $MSYB_{trigger}$ during the transition, the situation is more complicated. To help clarify the options, WKFRAME has produced generic equations which cover the various options and suggests that ACOM choose one of these options with a caution against the mechanistic application of whatever rule is chosen. Most of these issues fall under the second ToR "on [the basis of issues arising in 2010] to further develop the MSY approach" and the details are provided in section 2 of the report. Finally there was a ToR to "further develop the MSY approach to be applied in cases where no analytical assessment is available". The first issue here was to address the semantic concern where the labelling of advice as maximum sustainable yield, when it was based on relatively imprecise determinations of whether overfishing (in relation to MSY) is occurring, caused problems. A suggested solution is to label this advice as sustainable yield advice. A clarification of the guidelines from WKFRAME I, with some references to appropriate methodologies is provided in section 4. In order to assist EG's to provide the basis for determinations required by the ADG's in drafting advice in situations where there is no forecast, a flow chart is provided.

# 1 Introduction

The first WKFRAME report (ICES 2010d) dealt with guidelines on robust approaches to estimating $F_{msy}$, and guidelines for the application of the ICES MSY framework (ICES 2010b) to stocks where there was no short term forecast. This report focuses on technical solutions to implementation issues which arose during the application of the framework to provide fisheries advice in 2010. Some of the issues arose due to confusion in the multiple aspects of advice, i.e. advice in relation to MSY advice in relation to PA, and advice in relation to management plans. In other cases controversy emerged in what are essentially policy decisions on transition options to bring fishing mortality in line with targets by 2015. The issue of confusion due to multiple aspects to the 2010 advice was echoed by consumers of the advice. In response ICES will introduce a hierarchy in the 2011 advice whereby in the situation where a long term agreed management plan[1] exists, this will have primacy for advice provision by ICES. Otherwise the advice will be given on the basis of the framework. The disconnect between the PA and the MSY approaches in the 2010 framework also caused confusion and controversy. This report deals with the issue by suggesting a unified approach to the provision of exploitation advice, bearing in mind that fish stocks need to have full reproductive potential in order to deliver maximum yields at $F_{msy}$. This logic is no different than that used to construct the ICES MSY framework, and any further developments proposed to the framework in this document are ultimately policy decisions to be made by ACOM. The logic for the approach taken in this report is outlined below (see also Section 3).

Stocks fished at $F_{msy}$ should fluctuate around a biomass which can provide maximum yield. In order to prevent against a condition of biomasses lower than this expected range, the ICES MSY framework uses the concept of a trigger point MSY$B_{trigge}$r (in much the same was as any HCR), which simply triggers action of reducing the exploitation from $F_{MSY}$ under the condition where the biomass moves out of the expected range. MSY$B_{trigger}$ is a biomass point which is expected with a low probability in a fully productive stock which is fished at $F_{msy}$. In 2011 for those stocks which ICES gives advice under management plans, it is anticipated that this will continue to be the basis for the advice. For those stocks exploited near $F_{msy}$, transition is expected to be relatively straightforward, and no additional considerations should be needed. In the case of some stocks for which ICES gives advice the exploitation is currently well above $F_{msy}$ and the biomass is at risk of, or is at a level, where recruitment impairment could be occurring. Under this condition a rebuilding is required before fishing at $F_{msy}$ can give maximum yield. Under the precautionary approach the condition of SSB>$B_{pa}$ is a requirement in order to ensure that there is a reduced risk of productivity impairment. In the case of stocks which are in this condition the biomass $B_{pa}$ can function as an operational point below which fishing mortality is reduced at some rate to allow rebuilding to a magnitude where there is a low risk that the stock cannot provide maximum yield under fishing at $F_{msy}$. The use of $B_{pa}$ in the ICES MSY framework in such a fashion is subtly different from its function in the PA, where fishing mortality is only adjusted such that there is a neutral risk of being below the point. Here $B_{pa}$ is simply being used as a trigger to reduce fishing mortality from $F_{msy}$ which is being applied as a target. The use of $B_{pa}$ as an operational trigger point was suggested in 2010, even though it was considered that ultimately MSY$B_{trigger}$ would correspond to a

1 agreed management plan means endorsed by ICES and implemented by a competent authority

lower percentile of the biomass distribution under the condition of fishing at $F_{msy}$. It is envisaged therefore that Bpa can act as a trigger point for stocks which require re-building. The rate of decrease of F below the point where recruitment is at risk of ($B_{pa}$) and becomes impaired ($B_{lim}$), is a matter of risk tolerance and choice on time taken for recovery. Under the PA approach ICES has previously stated that its advice is risk averse to $B_{lim}$ and in the circumstance where productivity maybe impaired, its advice is given to affect a safe and rapid recovery. The choice of the rate of decrease in F below the $MSYB_{trigger}$ should be consistent with this in order for a unified framework for advice under MSY and PA considerations to be appropriate.

The ToR's of WKFRAME II are given below and dealt with as follows: Section 2 of the report deals with ToR a, Section 3 deals with ToR b, and section 4 deals with ToR c

### WKFRAME II Terms of reference

a ) Evaluate the implementation of the MSY approach (reference points, framework and transition) in the 2010 ICES advice and specifically identifying such areas where further development is required

b ) On this basis, further develop the MSY approach including:

i. Improved guidelines for reference point setting including $F_{MSY}$, $B_{trigger}$ and $B_{lim}$ which might be a consideration at low stock size;

ii. Implementation guidelines for the MSY framework including greater specificity on how fishing mortality should change at low spawning biomasses;

iii. Put forward options for transition rules from 2011 onwards

c ) Further develop the MSY approach to be applied in situations where no analytical assessment is available.

Working documents presented at the meeting are included in Annex 3 at the end of this report.

# 2 Evaluation of the implementation of the MSY approach in the 2010 advice.

## 2.1 Overview of MSY reference points already defined

The relationships between F reference points from 2010 assessments were examined from data in "FishData 2010.xls"

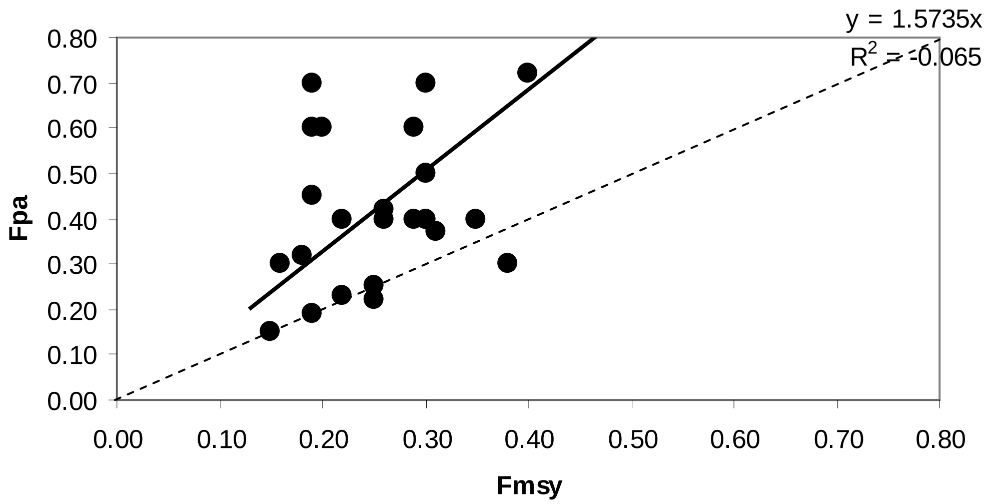



**Fig. 2.1.1 Scatter plot of $F_{pa}$ vs $F_{msy}$ estimates from the 2010 assessments.**

While the best fit to the scatter of $F_{pa}$ against $F_{msy}$ (Fig. 2.1.1) indicates that $F_{pa}$ is on average 1.6x $F_{msy}$, there are a number of stocks for which $F_{msy}$ is estimated to be equal to or higher than the estimated $F_{pa}$ (data points on or below the 1:1 line). These instances (sol-kask, her-irlw, her-noss, her-2532-gor, her47d3, her-noss, mac-nea) need to be investigated before the $F_{msy}$ points are confirmed as correct for use in the advice framework.

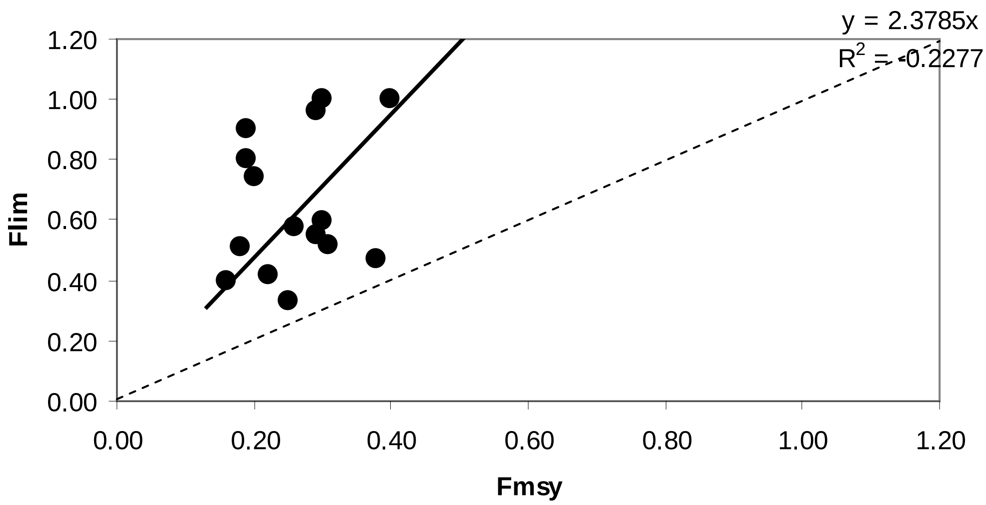



**Fig. 2.1.2. Scatter plot of $F_{lim}$ vs $F_{msy}$ estimates from the 2010 assessments.**

On average, $F_{lim}$ is about 2.4x $F_{msy}$ (Fig. 2.1.2) which suggests a reassuring distance between these two reference points for most stocks, although a couple of data points fall close to the 1:1 line suggesting potential problems (see bootstrap analysis below).

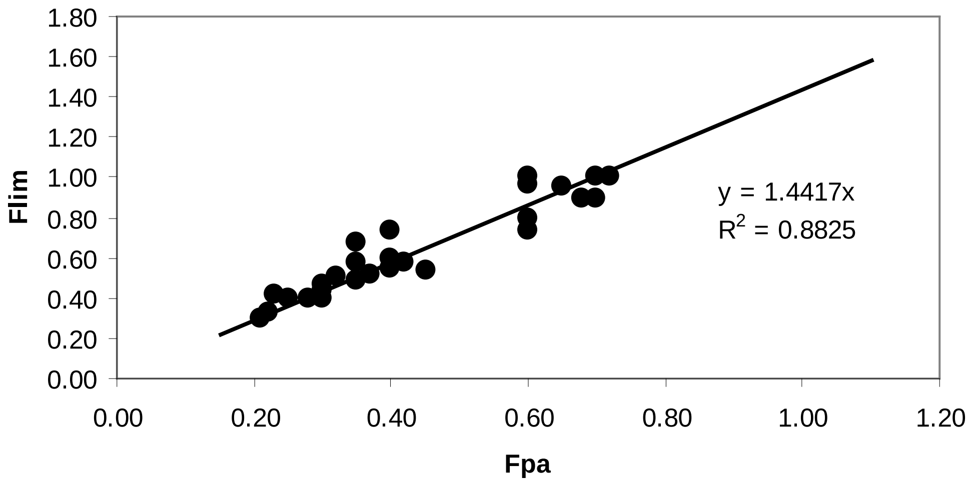



**Fig. 2.1.3. Scatter plot of Flim vs Fpa estimates from the 2010 assessments.**

Flim is about 1.4xFpa (Fig. 2.1.3) which is not surprising since this is the default factor used in computations for many ICES assessments.

The relationships between MSY reference points, when the S-R model is of the hockey-stick type, were examined in a non-parametric (model conditioned) bootstrap analyses in R by Mesnil (2011). A thousand S-R parameter pairs were generated from the baseline fit of S-R for Norwegian Spring Spawning Herring and North Sea Cod by bootstrapping, which is assumed to preserve the sign (if not the magnitude) of co-variance. Hockey-stick S-R models were fitted to each bootstrap S-R samples and fed to the MSY calculation routine, yielding distributions of MSY reference points. Results indicate that if Hockey-Stick is a valid representation of the actual S-R relationship (a big IF), $F_{msy}$ will most often be ≡ $F_{max}$, hence independent of the S-R parameterisation. In the case where the YPR curve peaks at very high F, $F_{msy}$ coincides with Fcrash (i.e. close to $F_{lim}$), and Bmsy coincides with the breakpoint in the Hockey Stick, i.e. $B_{lim}$ (see Figures of working document in Annex). This will create problems in applying the MSY framework for some stocks and suggests that mechanical application of default methods should be avoided.

## 2.2 A note on the implied function of MSYBtrigger

In the 2010 report WKFRAME discussed the role of $B_{trigger}$ and indicated it should be selected as a biomass that is encountered with low probability if $F_{msy}$ is implemented. It was stated that if the SSB is below this level it is (by definition) out of expected range, and thus a suitable trigger to initiate action. Also WKFRAME considered that although $B_{pa}$ is proposed as a default trigger biomass in the ICES MSY framework, it is not a logical candidate in the long term as it is derived from an error model basis around $B_{lim}$, whereas under MSY exploitation is should be a property of the expected distribution of SSB. Thus Btrigger in the longer term should form two roles, a trigger for management action, first a need to reduce catches because SSB is outside the expected range, but second it should also indicate a need to check that the basis for the stock dynamics is still valid. However, in practice by concentrating on SSB targets we should not neglect recruitment. In situations where a recruit index is available or the assessment gives a relatively reliable estimate of recruiting year classes, a series of unexpected recruitment may be the first indication that the biological assumptions may no longer be appropriate. Thus there may be good evidence for questioning the applicability of the assumed dynamics a few years before the SSB declines, this was the case for NS herring, where the dynamics observed from 83-2001 had been consistent but from 2002 an atypical sequence of low recruitment was observed. It was possible to observe that the dynamics were atypical two or three years before the biomass reached levels that were of concern. In the evaluations of NS plaice and sole multi-annual plans it was noted that a sequence of reduced recruitment would give a much more timely indication of impending problems than waiting for SSB to decline. EG should be encouraged to be aware of the assumptions underlying MSY exploitation for a stock and to look intelligently all indicators to confirm that the dynamic remain as expected. In such circumstances waiting for biomass alone to trigger a change in advice would not be making best use of available information.

## 2.3 Feedback from ICES EG's experiences in 2010

#### Arctic Fisheries Working Group (AFWG) Feedback

The AFWG stocks can for the purpose of calculating MSY reference points be divided into 4 groups:

1 ) Stocks for which there is an accepted analytical assessment and an agreed HCR: NEA cod, haddock, saithe

2 ) A short-lived stock with survey-based assessment and an agreed HCR, and for which a single-species MSY is meaningless since predation from cod and other predators is much larger than the fishery: Barents Sea capelin.

3 ) Stocks for which there are catch-at-age data and reasonable confidence in age readings, but no accepted assessment: Coastal cod, *S. marinus*, *S. mentella*

4 ) Stocks for which the age reading methodology is under revision (Age Reading Workshop to be held in 2011): Greenland halibut

For the stocks under 1), harvest control rules have been evaluated using long-term stochastic simulations based on biological models with density-dependent growth and maturation. There are agreed management plans based on these harvest control rules, and the target F in the harvest control rules are in the range of F values associated with high long-term yield. The biological models will be revised following benchmark evaluation of the respective stocks, and MSY calculations will then be updated accordingly. As for many other stocks, the yield curve is rather flat at the top, giving a wide range of F values which can be associated with high long-term yield. For NEA cod and haddock, the managers (Joint Norwegian-Russian Fisheries Commission) in 2010 agreed that the current HCRs should stay unchanged for 5 years and then be evaluated.

For Barents Sea capelin, the agreed HCR is that with 95% probability, at least 200 000 tonnes ($B_{lim}$) should be allowed to spawn. There is no $B_{pa}$ and no F-based reference points. MSY has been investigated by Tjelmeland (2005), using the multispecies model Bifrost. He found that the $B_{MSY}$ reference point of capelin depends markedly on the harvesting strategy chosen for Northeast Arctic cod and Norwegian Spring-Spawning herring, which both have strong biological interactions with capelin. Thus, calculating a single-species MSY for capelin is meaningless. The capelin MSY could be calculated given the agreed HCRs for cod and herring, and one could then investigate whether the MSY for capelin would change considerably if the harvesting strategies for cod and herring vary e.g. within the intervals corresponding to yields > 80% of the MSY for herring and cod.

For the stocks mentioned under 3 and 4, there are no F or SSB based harvest control rules, and better biological models are needed in order to calculate reference points.

WKFRAME comment: The approach taken by the AFWG is consistent with guidelines produced on the implementation of the MSY framework by ICES last year. The introduction of an hierarchical approach to advice, giving primacy to implemented management plans, should solve the issues in relation to category 1 stocks above. For category 4 stocks there is no immediate prospect of producing proxies for MSY reference points until the growth issues are sorted. For Category 3 stocks WKFRAME would suggest that progress could be made in identifying exploitation proxies (See WKFRAME I section 2.2)

#### North Western Working Group (NWWG) Feedback

During discussions in the group it was noted that simulations show that identifying a single $F_{MSY}$ value is almost an impossible task. Effectively one can only identify a range of fishing mortalities that all would conform to the MSY concept. Hence, the NWWG considers that the only appropriate method to evaluate the MSY principle is by evaluating catch rules in a stochastic simulation framework that takes into account both natural and assessment noise (as has been done e.g. for the Icelandic cod and saithe and to some extent the Icelandic haddock). The resulting fishing mortalities that lead to optimum yield obtained within such a framework are not analogous to the $F_{MSY}$ proxies obtained from applying the short-cut methods suggested e.g. in WKFRAME. On a similar note the current setup of the ICES advice summary sheet stock table can send out a wrong signal where when it states that the MSY reference points have not been defined but the stock is managed according to a HCR that has been evaluated to conform with the MSY-approach but that HCR does not have explicit $B_{trigger}$ and $F_{MSY}$ points as is the case for cod in Va.

WKFRAME comment: The introduction of an hierarchical approach to advice, giving primacy to implemented management plans, should solve the issues in relation to many of the stocks dealt with by the NWWG.

#### Working Group on Elasmobranch Fisheries (WGEF) Feedback

The Working Group on Elasmobranch Fishes attempted to apply the framework to each of its stocks. Certain issues arose with mixed species stocks, such as "Demersal Elasmobranchs in the Celtic Seas" where several species of ray are landed without species identification. Comparative species vulnerability was taken into account when formulating advice.

In addition there are certain species at low stock levels and with very low fecundity, where $F_{MSY}$ is not an achievable target in the short term. Such stocks include deepwater shark species.

In general, the *Guidelines for stocks where no analytical assessment is available*, were followed.

WKFRAME comment: The approach suggested this report is compatible with the WGEF decision to advise on Precautionary considerations where the stock productivity was impaired. This short term prioritization of the PA is rationalized in order to have any prospect of achieving MSY.

#### Herring Assessment Working Group (HAWG) Feedback.

In 2010, HAWG met before WKFRAME, however good progress was made in developing the new ICES FMSY framework. Medium term simulations were conducted using the HCS10 software. This is a medium term projection program designed for exploring harvest control rules, without doing a full assessment as part of the annual simulation loop. The program is a recently revised and updated version of the HCM/HCS software that has been used for evaluation of management plans in the past (mackerel, blue whiting and Celtic Sea herring). It has an age based population model in the background with stochastic recruitments but fixed weights and maturities, an 'observation' (assessment) model that produces a noisy basis for management decisions, a management rule module with various options, and an implementation module that translates management decisions into real removals, again with noise. Yield and biomass per recruit is calculated as a by-product. The program was run over 50 years with a range of fixed fishing mortalities as the management decision rule, with no modifications. The risk presented is the fraction of the iteration trajectories where the SSB is below $B_{lim}$ in year 50. Yield and biomass per recruit and $F_{0.1}$ are produced as a by-product.

The approach taken by HAWG was later incorporated in the work of WGFRAME. HAWG interpreted $F_{MSY}$ as a value of F that is expected to lead to a near maximum yield in the long term. For most stocks, there will be a lower bound where long term yield is lost because of low exploitation and an upper bound where there is an increasing risk of recruitment impairment. Within that range, there may sometimes be a distinct maximum, depending on selection at age, growth rate and natural mortality. The pattern may be modified if growth and maturity are density dependent, or if the natural mortality is sensitive to multispecies effects.

For most herring stocks, which typically are lightly exploited at small size and young age, there is no distinct maximum. Hence, the highest long term yield may be expected at a fishing mortality which is close to that leading to recruitment failure. The lower bound may be represented by $F_{0.1}$, but in some cases $F_{0.1}$ may be higher than the mortality leading to impaired recruitment. Hence, the most rational target fishing mortality may be one where the loss is small, and which is safely away from the region where the recruitment may be impaired.

Of the six stocks considered by HAWG, 2 have existing management plans, and 3 more had management plans under development. None of these plans is inconsistent with FMSY, though some do not have the same HCR as the generic ICES FMSY HCR.

HAWG outlined the region of fishing mortalities associated with a near maximum long term yield by calculating yield per recruit combined with a stock-recruit relationship. The effect of random variation in the recruitment in a stochastic equilibrium was evaluated, but not the uncertainties in assessment and implementation, nor variation in weights, maturity or selection.

Yield per recruit is sensitive to natural mortality, growth rate and selection at age, and assumes that all these are independent of F-level and stock size. This may not be true, and change in these factors may lead to a quite different perception of the shape and level of the yield per recruit curve, as well as the risk to stock collapse.

HAWG did not consider candidate values for a $B_{trigger}$ have in great detail. HAWG considered that there is a range of biologically appropriate biomass triggers are possible for each stock. The final choice will most likely be made based on management plan development. As such the trigger biomass has already been, or will be subject to evaluation by ICES. HAWG regards the development of management plans as the way forward to a rational utilisation of the resources, and is concerned that too strong an emphasis on specific values for $F_{MSY}$ or $B_{MSY}$ may hamper the development of good management plans.

**The table outlines some values of F and SSB that may be a guidance to setting $F_{MSY}$ and $B_{trigger}$. The suggested values are suggestions only. Biomasses are in thousands of tonnes.**

| | F range | | $F_{MSY}$ | $B_{trigger}$ | | Management plan | |
|---|---|---|---|---|---|---|---|
| **Stock** | **L** | **U** | **Suggested** | **10th %ile SSB at suggested $F_{MSY}$** | **Suggested** | **$B_{trigger}$** | **F** |
| North Sea herring | 0.15 | 0.25 | 0.25 (MP) | | MP | 800 to 1,500 | 0.25 (@ high SSB) |
| Western Baltic | 0.22 | 0.3 | 0.25 | 170 | UD* | | UD* |
| Via (North) | 0.17 | 0.35 | 0.25 (MP) | 85 | MP | 62.5 and 75 | 0.25 (@ high SSB) |
| Via (South) & VIIb,c** | 0.2 | 0.28 | 0.25? | 95 | UD** | | UD** |
| Celtic Sea | 0.18 | 0.3 | 0.25? | 50 | UD*** | | UD*** |
| Irish Sea | NA | NA | NA | NA | NA | NA | NA |

* As per simulation work in support of management plan development, underway in Jakfish Project.

** No analytical assessment available to estimate a TAC for a given F. Stock recruit information taken from converged VPA, as per simulation work conducted by Irish Marine Institute in 2010, in support of management plan development. Other inputs from sVPA using a terminal F of 0.5, considered the most informative exploratory assessment (Chapter 6).

*** As per simulation work conducted by Irish Marine Institute in 2010, in support of management plan development in conjunction with stakeholders' committee in Ireland.

MP: As per existing management plan

UD: Management plan under development

Setting a FMSY for a stock mixing with other stocks as the WBSS-NSAS complex in Division IIIa and adjacent areas proved rather difficult as reaching FMSY for all stocks involved in the mixing is impossible in practise. Thus for the WBSS, the WKWATSUP decided on a TAC setting procedure only acknowledging the weaker stock in the mix. Thus, the TAC should first be set for the WBSS according to the FMSY or FMSY transition framework for WBSS alone. If the NSAS is greatly impacted by management of the WBSS, this rule needs to be re-evaluated. Following this, the fraction taken in the Eastern part of the North Sea (parts of Sub Divisions IVb and IVaE) should be subtracted from the total TAC for the WBSS before sharing the TAC between Division IIIa and Subdivisions 22-24. Subsequently the best estimates of the proportions of the NSAS and WBSS in the catch by fleet should be used to calculate the combined catch options in compliance with the targeted catch for WBSS.

WKFRAME comment: The introduction of an hierarchical approach to advice, giving primacy to implemented management plans, should solve any issues in relation to advice provision where there is a management plan. The mixed fisheries issue in relation to the WBSS-NSAS complex is not solvable from a purely scientific perspective. The decision to provide TAC advice on the basis of not overexploiting the weakest stock (in the mixed fishery) is a policy decision, and it should remain transparent as such.

#### Working Group on Widely Distributed stocks (WGWIDE) feedback

WGWIDE 2010 was held over a shorter time than previous years and stock co-ordinators generally felt that the requirement to calculate new reference points (i.e. $F_{MSY}$ and $B_{trigger}$) posed a hindrance to the main purpose of assessing the stocks. There was uncertainty over what exactly $B_{trigger}$ was supposed to represent and how this should be determined. The ADMB plot MSY methodology was used for most of the stocks to examine potential $F_{MSY}$ values. Despite all stocks (with the exception of North Sea horse mackerel) being 'information-rich', there were still difficulties in establishing $F_{MSY}$ levels in the traditional equilibrium manner. This was mainly down to what were perceived as poor stock-recruit fits and uncertainty over the appropriate S-R functions. In addition numerous stocks had very flat-topped YPR curves on which Fmax (a fallback proxy for $F_{MSY}$) was poorly defined.

For NEA mackerel and blue whiting, both of which have recently had management strategies evaluated, the fallback position was put forward the simulation tested target F value as a candidate for sustainable management yielding high long term catches. For NSS herring, a simple stochastic simulation evaluation using a Beverton-Holt S-R function and measurement error was used to derive a safe, high yield F value which was proposed as $F_{MSY}$ for this stock. Stochastic yield per recruit analysis (using plotMSY) was used for western horse mackerel, where F0.1 was proposed as a $F_{MSY}$ proxy given the close proximity of Fmax to Fcrash. No values were proposed for North Sea horse mackerel (no assessment, only catch values). The integrity of this stock unit (whether it is a closed stock or not) most probably would prevent a viable $F_{MSY}$ value being determined.

There was substantial confusion over how the transition approach should be implemented, particularly in stocks where $B < B_{trigger}$ (i.e. blue whiting). There were also problems with the acceptability of advice arising from this transition scheme, particularly when there was a large discrepancy between PA approach/management plan and the MSY advice. The gradual step down towards $F_{MSY}$ may lead to advice that appears as unsustainable. This perception may be changed by presenting both what the advice would be purely according to $F_{MSY}$ as well as the intermediate $F_{MSY}$ transition advice.

The frequency of reference point revisions was raised as an issue during the ICES-Pelagic RAC meeting on the ecosystem approach to fisheries. Stakeholders expressed concern over the view that values proposed now are set in stone. They thought difficulty in revising values in the face of changes in stock productivity (e.g. regime shifts) or changes in the fishery was a cause for concern. It was felt that guidelines on when and how to revise $F_{MSY}$ reference points would be useful.

In Summary:

Stochastic simulation analyses were preferred to equilibrium analyses because of poorly defined stock-recruit relationships or flat-topped YPR curves.

The rationale for $B_{trigger}$ was ill-defined.

There were issues both in applying and the advice arising from the transition scheme.

WKFRAME comments: The issue of calculating reference points providing "a hindrance to the main purpose of assessing the stocks" could be helped if the ToR for EG related to *conducting the analysis required to provide an exploitation advice following ICES guidelines* rather than simply *update the assessment*. The introduction of an hierarchical approach to advice, giving primacy to implemented management plans, should solve any issues in relation to advice provision where there is a management plan. In relation to stakeholder feedback to WGWIDE on the frequency of reference point revision WKFRAME I suggested that $F_{msy}$ targets could be set provisionally and updated when more data and/or more complete analyses had been carried out, in this context $F_{msy}$ reference points could be annually updated until such time as these analyses are complete. With regard to the identification of regime shifts and how to advise when there are shifts in productivity, this issue is discussed in section 2.3.2 (below).

#### Working Group on North Sea and Skaggerrak (WGNSSK) Feedback

Four different approaches were developed by WGNSSK, largely developed around ICES WKFRAME and further used and developed during the WGNSSK meeting. The first three deal with stocks for which age-based information exist, and present many similarities in their standard combinations of YPR, SRR and SPR relationships. The fourth one is an approach specifically developed for Nephrops stocks ahead of the WG meeting. 1) A suite of programs (built in AD model builder) was successfully tested and used for a number of stocks during WGNSSK meeting, and served as the primary tool by the WGNSSK for providing final $F_{msy}$ estimates. 2) A number of R scripts using the FLR framework (www.flr-project.org) were developed ahead and during ICES WKFRAME 2010 (Case Studies 3 and 6). These scripts were later merged into a single generic R-FLR program (Finding $F_{msy}$ with FLR_v4.r), in order to explore and compare various methods for estimating $F_{msy}$ using a single FLStock object as input. An alternative R script was also developed around ICES WKFRAME 2010 (Case Study 5), using a analytical combination of fitted stock-recruit, yield-per-recruit and SSB-per-recruit curves. This script was used during WGNSSK for estimating $F_{msy}$ for the haddock stock, and is described in the corresponding section 13.7 in WGNSSK report. 4) The method developed for Nephrops is described under the WGCSE section below.

Summary: The MSY reference points estimates were found to be highly dependent of the underlying hypotheses. In a single-stock age-structured assessment context, the main problems encountered by the WGNSSK were:

- The usually very poor fit of the SRR estimates. In most cases, there is no evidence of any relationships;
- When this is the case, then different software (R/FLR versions, ADMB) may give very different parameters values, in particular for the break point in a Hockey-Stick relationship.
- Ricker-type SRR with a maximum estimated outside of the range of historical observations should not be used as a basis for analyses
- The number of years used for averaging the weight-at-age and selectivity-at-age values can play a major role. ICES WKFRAME (2010) recommended taking the longest time-span where no significant trends are observed; however, a number of software may take a three-years average as default value.
- Different values are usually obtained when estimating $F_{msy}$ using equilibrium equations (e.g. using the FLBRP package in FLR) or using stochastic projections

- Inclusion of multispecies considerations and density-dependent biological parameters can be an issue when considering that current parameters often correspond to periods of low abundance, and these may be quite inappropriate in future high abundance levels.

WKFRAME II comment: WGNSSK spent considerable time and effort exploring and developing methods and software to estimate $F_{msy}$ targets for the stocks covered by the WG. The problems encountered which are due to lack of correspondence between the data and assumed model, where they are not simply due to a short time series or lack of dynamic range, may simply be a property of the data and there is no analytical solution for that situation. In such situations expert judgment should be applied in order to determine the most appropriate outcome. Software defaulting to inappropriate time ranges is a technical issue which requires a technical fix of disabling automatic defaults and manually setting or hard coding the appropriate time range. Differences in $F_{msy}$ estimates between equilibrium and stochastic approaches can be expected. The best practice advocated by WKFRAME would be to use stochastic simulations; the approach is elaborated in Section 3.1. Dealing with density dependent biological parameters can be problematic, but a rational approach would be to use expert judgment and at least include as a source of uncertainty.

#### Working Group on Celtic Seas Ecosystem (WGCSE)/Working Group on Hake Monk and Megrim (WGHMM) Feedback

WGCSE used ADMB to explore the S-R, fishery selection, and growth potential data for fin-fish stock where assessment data were available. Based on an analysis of the uncertainty, the idea was that the most plausible S-R relationship would be used for the estimation of $F_{MSY}$. However in many cases more than one plausible S-R function existed and the $F_{MSY}$ estimates differed in the absolute values depending on the form of the S-R model used. Where this was the case WGCSE concluded that no definitive value of $F_{MSY}$ could be defined and the range was provided to the ADG.

For stocks with no assessment the Working Group performed qualitative evaluations and suggested, were possible, the current stock status in relation to $F_{MSY}$. Considerations were given to detail such as trends indicative of stock status, age structure, discard rates, status of other exploited stocks in a mixed fishery. Directional advice were proposed and major problems such as high discard rates were highlighted and possible management measures suggested to reduce discards with the presumption that it will increase future yield.

For *Nephrops* stocks, given the differences in fisheries and ecology it is inevitable that estimates of the exploitation rate leading to long-term MSY will vary between the FUs. Given this the approach taken by WGCSE depended on the data available. For those stocks with a TV survey, the Harvest Rates (removals divided by abundance as estimated by the TV survey) associated with fishing at $F_{0.1}$ and $F_{max}$ were estimated at the 2009 benchmark meeting WKNEPH. In response to the recommendations of WKFRAME, estimates of $F_{35\%SpR}$ and the corresponding Harvest Rate were also determined and these estimates typically lay between the estimates of $F_{0.1}$ and $F_{max}$. Suggestions for a TV-abundance based proxy for $B_{trigger}$ were made on the basis of the lowest observed TV-abundance (median survey value) *unless* the stock has shown signs of stress at a higher TV-abundance in which case this value was proposed $B_{trigger}$. The remaining challenge is determining which $F_{msy}$ proxy is appropriate for which stock and this becomes an exercise in expert judgment based upon knowledge of the fishery and the ecosystem. In order to assist communication of the expert judgement process the following bullet list is suggested as a standard checklist for describing the rationale behind the choice of a particular $F_{msy}$.

- Describe the absolute density. *Is it high (i.e. >1 per m²), medium (i.e. 1.0–0.2 per m²) or low (i.e. <0.2 per m²)*
- Variability in density. *Is there large interannual variability, spatial complexity?*
- Understanding of biological parameters. *Is the growth rate particularly fast or slow, high or low estimates of natural mortality?*
- Fishery timing and operation. *Is there a strong seasonal pattern leading to different exploitation rates on the sexes, does this pattern vary much between years?*
- Observed Harvest Rate or landings compared to stock status. *Is the harvest rate consistently around or above $F_{max}$? Have landings been stable? Have the indicators of stock status shown signs of difficulty?*

Accompanying this text should be a table listing the $F_{msy}$ proxies $F_{max}$, $F_{35\%SpR}$ and $F_{0.1}$ for males and females, the Harvest Rates they correspond to along with the implied %spawner-per-recruit for males and females.

Summary:

For stocks were a possible range of $F_{MSY}$ were proposed, a single value was put forward in the final advice even though the WGCSE proposed a range. There was no real consistency in the choice of $F_{MSY}$ across stocks within management areas and in some cases $F_{MSY}$ was set by analogy to other stocks of similar species.

Some issues arose from the implementation of the ICES transition scheme where stock biomass was below $B_{lim}$, but the MSY advice was for increased catch option above the current TAC. This was purely a function of the rigid implementation of the transition framework.

There are numerous stocks in the Celtic Sea ecoregion with no assessment and most of the issues and problems were associated with these stocks. The general approach for these stocks was to avoid generating rash $F_{MSY}$ values, but rather focus on providing directional advice, i.e., proposed management measures to get F closer to $F_{MSY}$ for stocks that are likely to exploited well above $F_{MSY}$. With the information available for these stocks it would be possible to generate specific $F_{MSY}$ targets, but with no estimate of current F the setting of quantitative advice remains problematic. Quantitative advice is relatively simple if the stock is exploited well above $F_{MSY}$, but advice for stocks that are exploited close to $F_{MSY}$ remains challenging.

WKFRAME comments: The approach taken by WGCSE and WGNSSK is consistent with guidelines suggested by WKFRAME I. Some issues surrounding model fits to SRR are touched on in this report (Section 2.1. & 3.1). Many of the problems relate to short time series and poor correspondence between the assumed model and the data. Where this problem may be due to limited data an alternative generic species approach outlined in this report section 2.3.1 (below) which could provide a way forward. The final problem raised by WGCSE is in relation to providing quantitative advice for stocks which may be exploited close to $F_{MSY}$, using the framework outlined in the introduction to the advice last year. This problem arises when the advice is only directional in relation to the catch on the basis of whether the stock is overexploited or not. The determination of whether the stock is over exploited or not determines the basis for the advice and this determination may rely on expert judgement to a greater or lesser extent. There are currently no guidelines to prescribe this expert judgement, and WGCSE indicate that they can foresee consistency problems arising where no guidelines exist. It may be that these difficulties relate to scientific argument and fishery specific issues, for which there will always have to be an accommodation in any rational basis for fisheries advice.

WGDEEP Feedback

WGDEEP had very little time to assimilate the guidance on the implementation of the ICES MSY concept from WKFRAME, however a number of recommended approaches for data-poor stock were explored, mainly using southern blue ling (Vb,VI and VII) as a case study. These were: Depletion corrected average catch ((MacCall, 2009); Catch curve analysis; and Productivity-susceptibility Analysis (PSA). Within the time constraints of the 2010 meeting, it was not possible to develop any of these approaches to the point where they could be used as a basis for advice but the Working Group recommended that further work on developing MSY reference points should be added to the ToR for 2011. Because MSY proxies could not be established for any stocks, draft advice for all stocks in 2010 was given relative to the precautionary framework as in previous years.

WKFRAME comment: The situation where there is no short term forecast arises frequently for the stocks covered by WGDEEP. In such cases making a determination of whether the stock is overfished or not and establishing the trend (if any) in abundance become the primary objective of the ICES MSY framework. Where size and growth data exist and there are informative abundance indices (i.e. standardised), the approach outlined by WKFRAME I and further elaborated here in Section 4 can be followed. This may involve some investigation (e.g. sensitivity analyses), but current and sustainable exploitation proxies can be derived easily to give a guidance for advice.

## 2.4 Summary of areas identified for further development

### 2.4.1 Sole meta analysis

Meta-analysis, applying generic methods within a species group, has benefits in terms of providing more stable estimates of $F_{MSY}$ reference points and estimates for individual stocks which by themselves may otherwise have insufficient data. Current ICES advice for seven sole stocks for which there is sufficient data gives $F_{msy}$ estimates which vary from 0.16 to 0.38, but these are specified for differing age ranges so are not directly comparable. $B_{pa}$ is estimated for six of these seven stocks but $B_{lim}$ is available for only two. Slope at the origin estimates for HS models for the seven stocks vary from 1.32, to 4.45 largely due to observed exploitation rates. An evaluation by Simmonds (2011) evaluates the use of a consistent framework to compare $F_{msy}$ targets and the sensitivity of long term yield to the choice of this value across these stocks.

Recruitment is modelled though stochastic multiple model based simulation for 1000 constructed "populations" for each stock by randomly sampling with replacement selection at age in the fishery, weights at age in the catch and weights at age in the stock for the period 2001-2009. S-R models were fitted in a Bayesian framework under the assumption that sole has generic exploitation form which can be scaled to the carrying capacity for each stock, but the resilience, or slope (R/SSB) to the origin, is consistent across stocks assuming each stock retains its own estimated or assumed growth and maturation. Three S-R models were applied, Hockey-stick, Ricker and Beverton-Holt with each model formulated so that the A parameter defined the slope to the origin which was assumed to be common for all stocks, whereas the B parameter related to density dependence was assumed to be independent.

The probability of each model type is selected for the set using the method described in Simmonds et al (2011).

Results show that changing from only HS to multiple models has a minor impact on the estimate of $F_{msy}$ or the F that maximizes mean catch, though the range of estimates is reduced. There is a small reduction in range through standardization of F bar over the same ages (3-8). A slightly larger reduction using mean selection at age in the fishery. The largest contribution comes from the different growth of the sole in different areas. In most cases if exploitation is at $F_{msy}$ there is less than 5% probability of SSB being less than Blim, except for NS sole. For NS sole measurement error will have some impact on the results whereas for other stocks the influence is limited.

The combined analysis (Table 2.4.1) shows that the range of F within which catch is within 5% of maximum catch is substantial. Only for Skagerrak-Kattegat sole is the target near the lower bound. For most stocks an F target (ages 3-8) of 0.25 is a good choice. The new $B_{lim}$ and $B_{pa}$ values are an important change, they are coherent with the simulations and contribute to the impression of safe exploitation. However they need to be considered carefully before acceptance, this further analysis would be most appropriately conducted by individuals familiar with the stocks. The higher exploitation rates for Irish Sea and Skagerrak are conditional on the growth and this need to be verified, particularly for Skagerrak-Kattegat.

**Table 2.4.1. Comparison of Median $F_{msy}$ estimates from the combined analysis in this study and those from ICES stock assessments.**

| Stock | Mean age | -5% Catch lower | F for Max Catch | Median Fmsy | -5% Catch upper | Ages for ICES Fmsy | ICES Fmsy 3-8 |
|---|---|---|---|---|---|---|---|
| BoB | 3-8 | 0.15 | 0.25 | 0.24 | 0.4 | 3-6 | 0.27 |
| CS | 3-8 | 0.15 | 0.25 | 0.22 | 0.35 | 4-8 | 0.31 |
| EC | 3-8 | 0.15 | 0.25 | 0.27 | 0.35 | 3-9 | 0.29 |
| IRS | 3-8 | 0.25 | 0.35 | 0.4 | 0.55 | 4-7 | 0.15 |
| NS | 3-8 | 0.2 | 0.25 | 0.35 | 0.4 | 2-6 | 0.24 |
| S-K | 3-8 | 0.35 | 0.4 | 0.43 | 0.65 | 4-8 | 0.36 |
| WC | 3-8 | 0.15 | 0.25 | 0.25 | 0.4 | 3-9 | 0.27 |

### 2.4.2 Detecting Regime shifts

#### Guidelines for determining ecosystem regime shifts

The issue of ecosystem regime shift (RS) will here only be considered in the context of S-R analysis within analysis of biological reference points for advice and management. Thus, changes in weight at age due to density dependence, accounted-for changes in natural mortality due to changes in predator stock biomass, etc., will not be considered.

Philosophically it might be fruitful to consider the following question: How can we sensibly identify ecosystem parameters of importance for a particular fish stock regarding RS, when we have no clue on which parameters that are influencing recruitment variability (except SSB) - are we introducing an inconsistency in our system by considering RS?

This issue of RS is related to the classic dilemma between having a long time series of data and a large dynamic range, versus considering a (fairly) constant ecosystem regime existing only for a shorter time. Due to the large variability of recruitment a time series of say 20 years is a short time series in the context of estimating S-R parameters.

Can individual years be regarded as a RS? Or is that better dealt with as noise? What about two years, three years etc? Is there a minimum length in terms of number of years for a regime?

It is important to realise that a regime shift does not have to be sudden, but can also be gradual.

It is also important to realise that the time series do not have to be continuous. If there is a temporal anomaly like the Gadoid Outburst for the North Sea, then it might or might not be appropriate to delete a time window and not all data points before the end of such an event.

RS can be a result of fisheries management, e.g. for the Baltic Sea the high F on cod has driven the stock to a low level and the sprat stock has increased simultaneously due to low predation from cod. Sprat in turn eat cod eggs and the cod S-R seems thus to be in a new Regime. Thus, theoretically fisheries management can in this case turn the regime back if wanted.

It is also worth considering that when a RS has been identified, is it then best to completely ignore data related to the anomaly period or can some useful information be extracted from e.g. the S-R prior to the RS?

RSs seem to influence the fishing mortality Reference Points (RP) more than the biomass RP:

a ) Baltic cod S-R breakpoint constant over time because it is mainly due to cannibalism, however at times of good environmental conditions with high cod egg survival, F can be increased and still keep the biomass above the breakpoint;

b ) Multispecies modelling results often have shown that allowing biomass to increase under good environmental conditions decreases the productivity of other species by predation;

c ) "*Pandalus* goes up when cod stocks go down" in 17 out of 18 ecosystems considered by Worm&Myers (2003);

d ) "*Nephrops* goes up when cod stocks go down" in the several *Nephrops* stocks in the greater North Sea area and the Irish Sea;

e ) Density dependent growth and reproductive output per individual fish (as illustrated by liver index) of Northeast Arctic cod.

f ) Food depletion of Baltic sprat and herring by high stocks biomasses, resulting in reduced growth.

WGIAB (ICES 2008a) and WKEFA (ICES 2007a) have given plenty of very useful points in relation to identifying RS and how to handle RS in scientific advice to management.

#### Notes from WKEFA Report (2007)

WKEFA considered how change due to environmental factors can be included directly in management advice. As ICES moves towards providing longer term advice in a rapidly changing environment there is a need to alter the way we consider the future and to provide advice that is both more robust and more adaptive to change. WKEFA attempted to formulate generic solutions to identify, develop and evaluate procedures for improving fisheries management strategies and advice by including environmental information. Two types of variability were defined, stochastic stability and regime shift. Stochastic stability treats the short term as variable around a stable point and regime shift as long term different centres of stability. Both need to be taken into account in developing scientific advice.

For stocks in a relatively healthy state the dominant characteristic for consideration in a management advice context is the carrying capacity (recruitment at medium to high biomass), reflecting available long term yield. For those in a depleted or recovery phase, the productivity (rate of increase in recruitment with biomass at low biomass) will be the dominant factor. The importance of understanding how the environment influences these two aspects therefore depends not just on the stock but also its state.

Medium-term simulations should include evaluations under different environmental regimes to determine robustness to different plausible possibilities, rather than expecting to optimise management under all conceivable options. It is unlikely that a single management strategy will be optimal under different regimes. On the basis of simulations WKEFA concluded that regime specific fishing mortality management strategies can be used as a tool for contending with decadal-scale climate or environmental variability. These management strategies outperformed constant fishing mortalities management strategies by providing a balance between benefits (high yield) and trade-offs (fishery closures).

Simulations suggest that fishing mortality based management strategies are more robust to regime shifts than biomass related management strategies (Kell *et al.* 2005), because regime changes often result in changes in carrying capacity leading to different equilibrium biomass. The necessary time frame to detect regime shifts in fish communities depends on the life history, the age of recruitment to the fishery and the exploitation rate (MacCall 2002; King and McFarlane 2006). Shorter lived species with low age of recruitment and high exploitation rates require rapid detection of change. Management for very short lived species normally involves rapid response to fluctuating recruitment, so such management regimes tend to have to respond to change quickly anyway, thus making them more adaptable under conditions of regime shift. If the management regime for short lived species is not robust, changes in regimes will make the situation even worse (Polovina 2005). In contrast long lived species exploited at a low rate and with older age of entry to the fishery allow for slower management response (King and McFarlane 2006).

#### Notes from WGIAB (2008)

WGIAB investigated 7 sub ecosystems of the Baltic, covering besides the Central Baltic Sea, the Gulf of Riga, the Gulf of Finland and the Bothnian Sea additionally the Sound, the Bothnian Bay and a coastal site of the Swedish coast. Future analyses of the Kattegat system are planned. Using multi-variate statistical analyses WGIAB demonstrated pronounced climate, fisheries and eutrophication related structural changes (i.e. regime shifts) in these regional Baltic ecosystems. About 30 different ecosystem parameters were analysed. The results showed that different selections of set of parameters gave wide variation in years of regime shifts and considering this large range of parameters were very important for determining reliable regime shifts.

**Changing state:**

In some cases environmental state changes are not directly reversible, although a change may cause a productivity change and may alter carrying capacity for a stock or stocks in a region, the reversal of that state change may not result in the subsequent reversal of the state of the stocks. The situation for managers is perhaps different when a shift is from a more favourable to less favourable regime, however there are also issues when the shift reverses. In the first case it is necessary to adapt to the lower productivity. However, in the reverse case it is important that management actions in the low productivity period do not prevent the reversal from occurring. For example it may be necessary to maintain sufficient stock size in a low regime to allow that stock to recover, once the more favourable regime occurs. Thus understanding the system response is critical to determining the safe exploitation under low productivity conditions.

### 2.4.3 The development of HCR's for generic species types

In 2008 an STECF working group (STECF 2008) tested the performance of some generic HCRs in a full MSE approach (De la Mare 1998, Punt and Donovan 2007) using FLR (Kell *et al*. 2007). Recently ICES (ICES 2010a) used the same simulation model and parameterization to test Annex IV HCRs (Anon 2010). The Operating Models were built based on two stocks with different life histories, Cod and Herring. For each of them two different stock recruitment relationships (SRR) and three different starting points were used. The SRRs had the same functional form for each stock, Ricker for Cod and Beverton and Holt for Herring, but they differed in their steepness. Steepness values of 0.75 and 0.9 were used to represent less productive and more productive stocks. The 3 starting points were relative to the exploitation level of the stocks, well managed stock ($F < F_{msy}$ & $SSB > B_{msy}$), stock experiencing overfishing ($F > F_{msy}$ & $SSB > B_{pa}$) and overfished stock ($F > F_{msy}$ & $SSB < B_{pa}$). The observation error model introduced error only in a simulated CPUE using a lognormal distribution with a CV of 30%. In some of the scenarios a retrospective bias was introduced in the CPUE. Regarding reference points, $F_{0.1}$ was used as $F_{msy}$ proxy and $F_{pa}$ was defined as $2 \times F_{0.1}$ for the cod-like stock and $3 \times F_{0.1}$ for herring-like stock. Different multipliers were used for the two stocks because in the case of the Ricker ("cod") stock recruitment relationship, the slope at the origin is less steep than for the Beverton and Holt ("herring") formulation, and so $F_{Crash}$ occurs at a lower level of fishing mortality. Then $B_{pa}$ was calculated as the SSB at $F_{pa}$.

In STECF work a model free HCR based on CPUE and 2 HCR based on VPA (XSA) results were used. Among VPA based HCRs one used $F_{0.1}$ as a target and the other the maximum between $F_{sq}$ and $F_{0.1}$. Besides both HCRs had common annual limitation in catch variation and more restrictive rules when the SSB fell below $B_{pa}$. The ICES work was focused in data-poor stocks and 4 different HCRs were tested. Two of them were fishing mortality based and used 3 years catch at age data to carry out a pseudo-cohort analysis and un-tuned VPA analysis. The other 2 were biomass based and used CPUE as a proxy of biomass; one used a step rule to set the TAC and the other a linear transition rule.

The STECF model free HCR was found to be dysfunctional. Its effect was to increase fishing mortality leading to an initial increase in yields but this was quickly followed by accelerated increases in fishing mortality, reductions in SSB, yield and eventual stock collapse. The use of a constant multiplier on fishing effort (and hence fishing mortality) was obviously not sufficiently adapted to changes in observed CPUE levels. Implementing a variable (delta E) to prevent run-away increases in fishing mortality may correct that failure and provide time for the CPUE to change and the HCR to adapt to changing conditions within the fishery.

The F-based rules in Annex IV applied to severely limited data conditions performed exceptionally poorly in terms achieving their intended target of $F_{msy}$. The biomass-based rule based on a step function, performed poorly because it responded to changes in total biomass when these changes were too small. A modification based on a linear transition rather than a step function, was more responsive to changes in total biomass and therefore performed better overall, in terms of achieving a stable SSB, when the biomass index was reliable in terms of trend. The objective of keeping SSB stable did not deal with the question of whether that SSB level was appropriate or will lead to optimal yields over time. Performance deteriorated for both biomass-based rules when retrospective bias was added to the survey.

The VPA based HCR which chose the maximum between $F_{sq}$ and $F_{0.1}$ often led to some rebuilding and recovery. However it often failed to improve situations where overfishing was occurring and even constituted a risk to well managed stocks. In these cases the rule either maintained fishing mortality at too high a level, preventing recovery, or it led to a gradual increase in fishing mortality leading to slow stock declines. The HCR could become stuck on relatively high fishing mortality rates that can harm or continue to harm stocks. This occurred because the $F_{sq}$ was often too high to be sustainable. Finally the $F_{0.1}$ based HCR maintained well-managed stocks and recovered stocks that had experienced overfishing or were being overfished. This recovery occurred even in the face of a retrospective bias, although the improvements and level of rebuilding were often reduced. This HCR would often lead to a reduction in yields for the first few years after the introduction of management. Performance in terms of the development in yield and stock biomass for overfished stocks was improved and the risk to well-managed stocks was reduced considerably.

There is probably much to be learned by exploring generic analyses of both species productivity (see Annex 3.1) and HCR's. In the former case (with careful circumspection) realistic target F's can be developed, where the individual stock data do not support such analyses, and in the latter case generic analyses can expose potential mismatches between the specifics of certain rule based approaches and the potential uncertainty and bias in the metrics of the stock response to the fishery. There is a further look at the development of HCR's for "data poor" species in section 4.3

# 3 Further developments of the ICES MSY approach

## 3.1 Choice of methodology to derive $F_{msy}$ values.

Advice should be prepared based on targets that are derived from various methodology. The following list forms a hierarchy of sources of estimates of suitable targets. WGs should select values that they consider are the most suitable for MSY exploitation and the following list provides guidance on which methods are expected to be preferred. Estimates derived from studies higher up the list are the preferred values.

i ) ICES endorsed multi-annual plan (not a target F but a complete plan in all its aspects)

ii ) Stochastic population model evaluation including errors (giving target F or agreed harvest rule)

Including assessment routines within a feedback framework with error

Feedback framework using an error model (without assessment)

Population model including varying biological parameters (annual or cohort effects) but excluding errors

Analytical yield per recruit and S-R relationship

Surplus production

iii ) Deterministic analysis

Yield per recruit combined with S-R function

Yield per recruit (assuming recruitment is independent of SSB)

All evaluations should include sensitivity analysis of (see WKFRAME I for further discussion):

Choice of S-R functional form

Growth and Maturation

Density dependence

Stability of fishery selection

Choice of period for S-R, growth maturation & fishery parameters

Where there is uncertainty in any aspect it is preferable to include this uncertainty in the analysis carried out, giving appropriate weight to differing possibilities with the objective of defining the ‘best’ target (or range of target exploitation). If natural mortality variability is included in the assessment then this should also be included in the evaluation, i.e. it is not considered appropriate to add variability in natural mortality as an additional source of variability to assessment with fixed Ms.

## 3.2 The use of calculated $F_{msy}$ values in formulating advice

The properties of targets derived by different methods can influence the formulation of the advice and the classification of the fishery/stock status. $F_{msy}$ derived from evaluations (category i evaluations in section 3.1) that include a range of error and variability are directly applicable as target Fs. While in general the inclusion of measurement and implementation error will mean that the deterministic $F_{msy}$ should be an upper bound for the target.

Model uncertainty (for example S-R 'density dependence', fishery selection) can bias targets in either direction.

In the absence of stochastic evaluations involving process and measurement error, this leads to three situations:

i ) If $F_{msy}$ is well below $F_{lim}$ such that the range of SSB anticipated is well above $B_{lim}$, but within or close to the historically observed range of SSB, the $F_{msy}$ target from the simpler analyses is expected to be generally appropriate as an exploitation target. Under condition (i) the $F_{msy}$ is an appropriate target.

ii ) If $F_{msy}$ is close to $F_{lim}$, such that the range of SSB is expected to include or come close to $B_{lim}$ (for example when a yield per recruit analysis gives a high or undefined $F_{max}$ and $F_{msy}$ is determined by the decline in recruitment at low biomass (ie. the breakpoint in a hockey-stick S-R function) then $F_{msy}$ derived from a simpler analysis is likely to be an over estimate of a suitable long term target F. Under condition (ii) (which is not uncommon for deterministic evaluations where YPR gives high or unresolved $F_{max}$ and $F_{msy}$ is estimated close $F_{crash}$) precautionary considerations need to taken into account in selecting a target. Under no circumstances should the $F_{target}$ be above $F_{pa}$. If $F_{msy}$ is below $F_{pa}$ it may be used as a provisional target however, efforts should be made to appropriately include measurement and implementation error. In the absence of $F_{pa}$ information a generic stock approach would be useful (see Section 2.4.1), or $F_{0.1}$, $F_{35\%SPR}$ $F_{40\%SPR}$ could be considered as a proxy for $F_{msy}$.

iii ) If the $F_{msy}$ is well below the F of the historic time-series which would lead to SSBs that are well above the historically observed SSB then the model uncertainty (eg S-R, density dependence) at this region may be unknown. Under condition (iii) a policy decision with policy makers is required to determine how quickly to change F.

If the WG is aware of IUU fishing and other implementation errors this should be taken into account in deriving the F and the TAC for the advice.

## 3.3 The choice of intervals around $F_{msy}$ (target F) and their use

Where management is based on a target value then a range of values are implied even when management is being carried fully in accordance with the plan. This aspect is correctly implied in the traffic light table section (see below) but requires a small amendment with the addition of X% to the upper and above and below target rows.

The WG should state if the realised F is within the expected range (+-X) for the management (plan) and classify the exploitation accordingly.

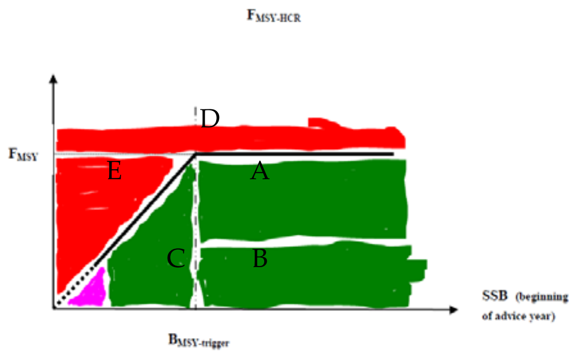
| | | | |
|---|---|---|---|
| **Management plan ($F_{target}$)** | F< F mgt target or<br>F< F mgt limit | ✔ | Below target<br>Below limit |
| | F within X% of target or within defined range | ✔ | At target or within target range |
| | F>F mgt target<br>F> F mgt limit | ✘ | Above target<br>Above limit |

Amended table would be:-

| | | | |
|---|---|---|---|
| **Management plan ($F_{target}$)** | F< F mgt target –X% or<br>F< F mgt limit | ✔ | Below target<br>Below limit |
| | F within X% of target or within defined range | ✔ | At target or within target range |
| | F>F mgt target +X%<br>F> F mgt limit | ✘ | Above target<br>Above limit |

A similar issue occurs with achieving MSY targets. Here the table is taken to reflect the biological state in the context of MSY exploitation. In this case there are a range of long term mean Fs over which yields are close to maximum yield thus if the management strategy is a target of to exploit 'at MSY' then appropriate F is within such an interval. The presence of this interval is not recognised within the table below.

| | | | |
|---|---|---|---|
| **MSY reference ($F_{MSY}$)** | A: F < $F_{MSY}$ and SSB > MSY $B_{trigger}$ | ✔ | Appropriate |
| | B: F <<< $F_{MSY}$ (~ 0) and SSB > MSY $B_{trigger}$ | ✔ | Below target |
| | C: F < $F_{MSYHCR}$ and SSB < MSY $B_{trigger}$ | ✔ | Appropriate |
| | D: F > $F_{MSY}$ | ✘ | Overfishing |
| | E: F > $F_{MSYHCR}$ and SSB < MSY $B_{trigger}$ | ✘ | Overfishing |
| | No reference point | ¿ | Undefined |
| | Stock status unknown | ? | Unknown |

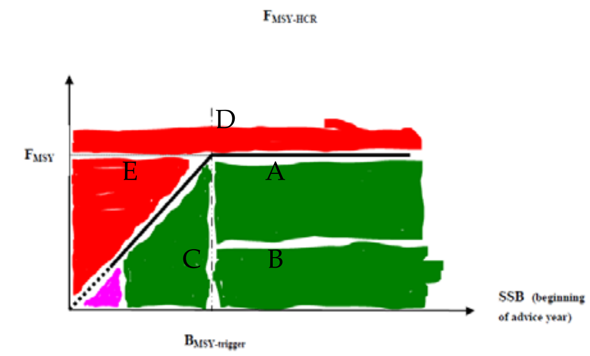



### The choice of intervals around $F_{msy}$ (target F) and their use

There are two ways in which intervals around $F_{msy}$ can be considered. First $F_{msy}$ is estimated with uncertainty and although it is possible to specify a target, that target has uncertainty, one concept of interval would be to use such an approach (see section 2.6 of WKFRAME I). Secondly there is an interval around $F_{msy}$ where long term exploitation implies only small reductions in long term yield, for operational purposes this second interval may be a much more appropriate measure of interval. For example for some sole stocks with $F_{msy}$=0.25 it is expected that if mean F is between 0.15 to 0.35 long term yields will be above 95% of yield at MSY (see Annex 3.1) thus if the management strategy is a target of to exploit 'at MSY' then an appropriate F is any F within such an interval. This gives an interval +-X around $F_{msy}$ that can be used to define that exploitation is 'appropriate' in the context of an $F_{msy}$ strategy. There is however a further use for such an interval, for example in the management of mixed fisheries. Such an interval could be used to specify a range of suitable Fs, compatible with the MSY strategy that would permit some reconciliation between F targets for fisheries on multiple stocks in a mixed fishery. While such an interval could clearly be abused for short term gain, use in a responsible manner would allow for a more relaxed approach to reconciling F targets in a mixed fishery.

To take account of the interval around $F_{msy}$ the following amendment would include this range of Fs that are delivering yields that are within 95% of MSY. Where $F_{msy}$ low and $F_{msy}$ high are the lower and upper long term mean F for yield at 95% of MSY (see Annex 3.1 for examples).

**MSY reference ($F_{MSY}$)**




| | | |
|---|---|---|
| A: $F_{msy}$ low < F < $F_{MSY}$ high and SSB > MSY $B_{trigger}$ | ✓ | Appropriate |
| B: F < $F_{MSY}$ low and SSB > MSY $B_{trigger}$ | ✓ | Below target |
| C: F < $F_{MSYHCR}$ and SSB < MSY $B_{trigger}$ | ✓ | Appropriate |
| D: F > $F_{MSY}$ high | ✗ | Overfishing |
| E: F > $F_{MSYHCR}$ and SSB < MSY $B_{trigger}$ | ✗ | Overfishing |
| No reference point | ¿ | Undefined |
| Stock status unknown | ? | Unknown |

These tables all seem to refer to the stock state or performance of management in the advice year. However, consideration of management plans or attainment of $F_{msy}$ is probably more informative as a mean over several years, for example the last 5 years. ACOM should consider whether it is better to specify this as a short or medium term evaluation. The opinion of WKFRAME is that a short term evaluation is responsive but possibly misleading and that a medium term evaluation is less responsive (i.e. more stable) but more informative.

## 3.4 Improved guidelines for setting $B_{lim}$

The guidelines for setting $B_{lim}$ as described in SGBRP 2003 are considered to be appropriate within the MSY framework. Additional data that have been obtained since they were last evaluated may warrant re-estimation of $B_{lim}$.

## 3.5 Modification of advice from $F_{msy}$ target advice due to stock status

When translating an assessment into advice, the following hierarchy applies:

1 ) If there is an ICES endorsed recovery or multi-annual plan this should be followed. Assuming that the plan is consistent with high long term yield.

2 ) If there is no ICES endorsed plan then the advice should depend on stock status based on SSB.

For all stocks the appropriate SSB is taken to be SSB in the TAC year.

### 3.5.1 If SSB is estimated to be above $MSYB_{trigger}$

Follow $F_{msy}$ framework

### 3.5.2 If SSB estimated below $MSYB_{trigger}$ and above $B_{lim}$.

If $F_{msy}$ has been set appropriately then continued exploitation at this constant F should provide optimal SSB and high long term yield. However, such an approach might be modified if $SSB<MSYB_{trigger}$. There are two possible objectives for reducing F from $F_{msy}$.

The original concept of the $MSYB_{trigger}$ was a biomass to trigger a cautious response (ICES 2010c) should the biomass move outside the range which would be expected under the condition of fishing at $F_{msy}$. Thus the trigger functions to take action because SSB is estimated to be no longer conforming to expectations which could be due to either intrinsic or extrinsic factors affecting the stock dynamics. For this case a reduction in F is triggered when SSB is less than a specified trigger value and this limit is chosen to meet the desired biomass criteria. Eg. $MSYB_{trigger}$ = B on 5% on the expect distribution of estimated SSB under exploitation at $F=F_{msy}$. The rate of reduction is hard to specify as the reason for the reduction may be diverse.

The original ICES MSY framework was also linked to the PA and productivity considerations, where the objective is to maintain biomass above the point at which recruitment is impaired (i.e. solely intrinsic). This is expected to be because the stock is depleted when the policy is implemented or due to a policy failure due to such things as measurement or implementation error or incorrect model formulation.

For this case the basis for the $MSYB_{trigger}$ could be $B_{pa}$, i.e. the point at which there is a 5% probability of being below $B_{lim}$ and thus might be an appropriate place to consider taking action to protect the stock from reduced recruitment. If F is reduced linearly from $F_{msy}$ at $SSB_{trigger}=B_{pa}$ to F=0 at SSB=0 then for most ICES stocks F will reduce by approximately 28% of $F_{msy}$ with the biomass at $B_{lim}$ (i.e. when SSB has 50% probability of being above or below $B_{lim}$). It might be considered that a 28% reduction insufficient. It may be considered applicable to follow the type of HCR defined for NS herring where the F is reduced to F=0.1 at $SSB=B_{lim}$. Or alternatively reduced F to $50\%F_{msy}$ by $SSB=B_{lim}$. In some cases these may not be very different, e.g. if $F_{msy}$ is close to 0.25.

It is considered that $B_{pa}$ would form the lower bound for $MSYB_{trigger}$ and the reduction specified where $B_{pa}=MSYB_{trigger}$ should always be greater than or equal to that implied when $MSYB_{trigger}$ is defined as some low percentile of the distribution of SSB when fishing at $F_{msy}$.

The current framework reduces F to 0.72* $F_{msy}$ at $B=B_{lim}$. If this is regarded as insufficient WKFRAME suggest three potential options:

1 ) Close the fishery at SSB=$B_{lim}$, WKFRAME consider this option to be inconsistent with best practice in HCR construction (ICES 2007b, 2008b) by introducing a discontinuity in the HCR and unnecessarily restrictive as $B_{lim}$ is the point at which recruitment begins to be impaired.

2 ) To deal with the discontinuity problem implement a very steep decline in F from F=$F_{msy}$ at $B_{pa}$ to F=0 at $B_{lim}$: again this is thought to restrictive because of the definition of $B_{lim}$.

3 ) A reduction from F=$F_{msy}$ at $MSYB_{trigger}$=$B_{pa}$ to F=$F_{msy}$/2 at $B_{lim}$, with further options below $B_{lim}$.

WKFRAME suggest that ACOM either continue with the current method, or select the third option with only one of the following suggestions which have progressively less reduction in F where SSB is below $B_{lim}$.

1 ) Closure of the fishery F=0 at B=$B_{lim}$. Again this is thought to be inconsistent with best practice in HCR construction (ICES 2007b 2008b) and unnecessarily restrictive as Blim is the point at which recruitment begins to be impaired. In addition it has the undesirable property of leading to a discontinuity in advice depending minor changes in the SSB.

2 ) Reduction of F from $F_{msy}$/2 at SSB=$B_{lim}$ to F=0 at SSB =2($B_{lim}$-$B_{pa}$). i.e. Continue the same rate of decline

3 ) Reduction of F from $F_{msy}$/2 at SSB=$B_{lim}$ to F=0 at SSB=0

4 ) Continue fishing at $F_{msy}$/2. However this does not provide the possibility to finally close the fishery should this be necessary.

These options are represented graphically in terms of F and yield below

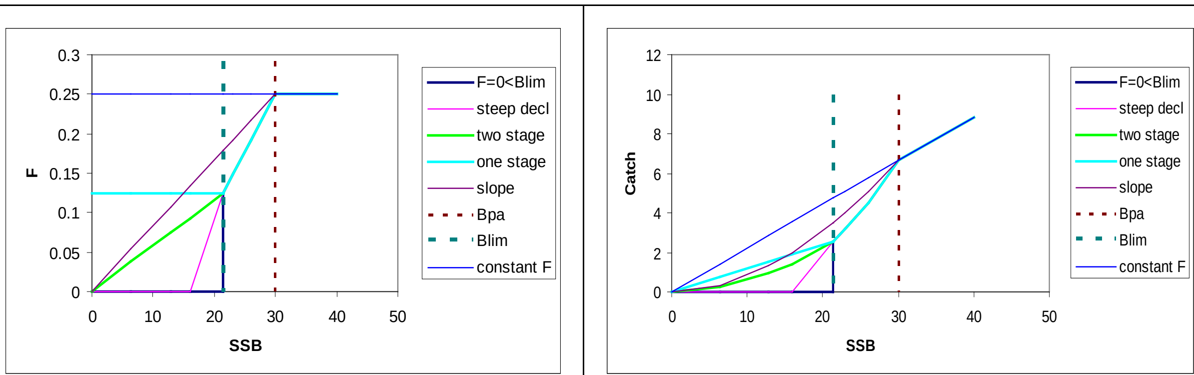



**Figure 3.5.2.1 Examples of F profiles and associated change in catch for continuation at 'constant F', the current 'slope' method and 4 more proposals with greater reduction in exploitation rate.**

### 3.5.3 Transitional $F_{targets}$ if SSB < $MSYB_{trigger}$

WKFRAME II suggest that where F is within the bounds of the target $F_{msy}$ (see section 3.3 above for more detail) then advice should not require a transition, so just advise at $F_{msy}$. Where F is above $F_{msy}$ and or SSB is below the trigger the advice should be according to the transition. Under these circumstances it may be confusing for clients to receive a separate advice corresponding to fishing at $F_{msy}$, though that could be certainly part of the catch options.

In those cases where current SSB is considered below $MSYB_{trigger}$ WKFRAME II revisited the issue of deriving transitional Fs. There are a number of different options how to derive the F targets for the transition period, but none of these result in a reduction of F in equal steps as the target is moving in these cases. However, the differences in F trajectory due to a moving target are small. WKFRAME notes that while managers requested a smooth transition (most likely) to avoid political problems with implementation; a smooth transition in yield does not necessarily translate into a reduction of F in equal steps.

There are a number of potential problems which are influenced by current conditions and subsequent changes in the stock. There needs to be an awareness of these.

The most important is for stocks where current F is much too high (either through failure to implement F advice, inappropriate advice or IUU fishing) and transition requires substantial change. In such cases equal decrements in F target are unlikely to change the fishery quickly enough and advice based on equal steps in F does not address the core issue. Where precautionary reference points exist these can be used to indicate the need to move quickly (see below), however, in some cases there are no PA points and the message to reduce quickly must be given by another mechanism. Failure to express this problem clearly just because of a mechanistic issue (the aim to follow defined rules even in extraordinary situations) would be unfortunate. One approach could be to 'borrow' a suitable Fpa from a similar but data rich stock. Such situations need to be given particular attention and WGs could be asked to suggest options and ACOM could then choose from amongst a set of supplied options.

For stocks which are known to have recently experienced low recruitment and catches are expected to decline in the future anyway, reducing F in equal steps will result in reduction of catch that is slower to start with and accelerating (because the biomass thus the F target both move downward).

For stocks which are known to have recently experienced large incoming recruitment it may be possible to maintain catches by reducing F more quickly, in such circumstances advice on F change for no increase in catch may be useful.

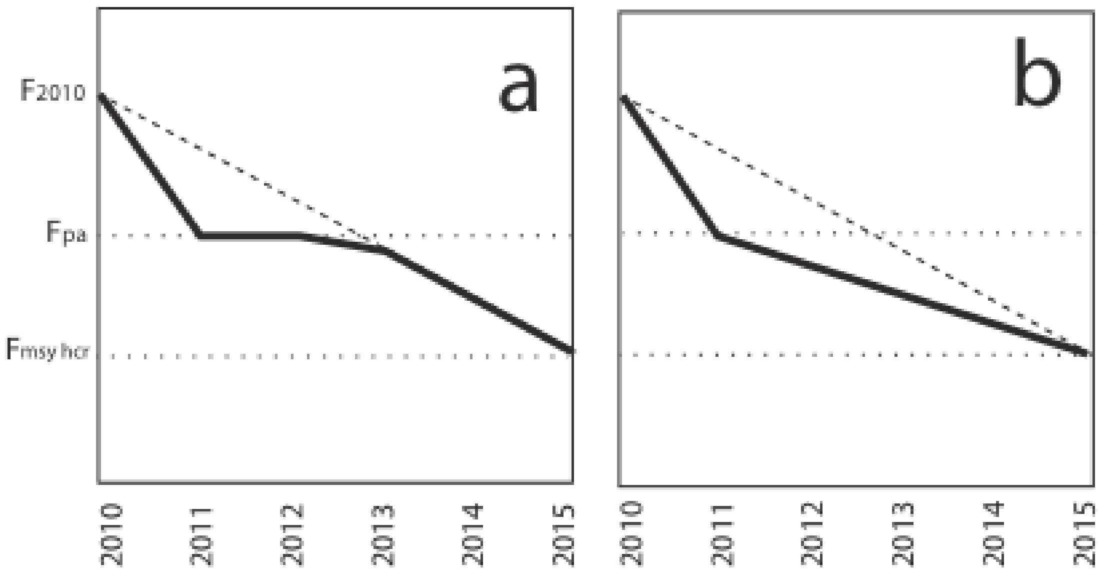
There are therefore a number of situations where the transition may work better if early changes are larger and almost no situations where slower reduction makes sense. This is in line with findings of the EU UNCOVER project that one element of a successful recovery plan should be a drastic reduction of F at the very beginning. This process really requires a dialog with managers.

**Transitional $F_{targets}$ if $F_{pa}$ takes precedence**

According to the ICES transition rule, any advice for an F in the transition phase is limited to $F_{pa}$. This of course only applies where $F_{pa}$ is defined. Where F remains above $F_{pa}$ in the second and subsequent years, there are again two options for the calculation of transitional Fs in years 2, 3 and 4:

a ) continue to advise for $F_{pa}$ – in this case Fs for the following years would be calculated on the basis of F2010 but limited by $F_{pa}$ where they are above $F_{pa}$. This would lead to a large reduction in the first year, an advice for a constant F for the next years and a bigger reduction in the latest years. This reduction in latest years would however not be bigger than if the rule were implemented without the $F_{pa}$ limitation.

b ) reduce F in 4 equal steps from $F_{pa}$ to $F_{msy}$ – in this case the biggest step is again in year 1 (reduction from $F_{sq}$ to $F_{pa}$), but if properly implemented the steps in the following years will be small.




WKFRAME suggests that ACOM should make a policy decision on which basis to apply the transition.

The following set of equations describe the different formulaic approaches, once ACOM has decided on what is appropriate all the unused equations should be deleted.

The calculation in year y of the target $F_{y+1}$ for the next year (y+1) based on N years transitions from the current estimate of $F_{s,y}$ in the start year $y_s$ (usually 2010) to a target $F_{msy}$ in 2015 is as follows:-

$$F_{y+1} = min( F_{s,y} - ( F_{s,y} - F_{msy,b} ) * ( y_{y+1} - y_s ) / N ; F_{pa} )$$

Where $F_{s,y}$ is the F in the start year (2010) as measured in the current assessment year y. This formula above gives F target to no greater than $F_{pa}$ from start year, Figure a. If the target is to decline from $F_{pa}$ in in subsequent years (Figure b) the formula is modified by substituting $F_{s,y+1} = F_{pa}$

$F_{msy,b}$ is the $F_{msy}$ target modified due to the state of the stock

The equations for different options are

For $B_{y+1}$>=$B_{trig}$ $F_{msy,b} = F_{msy}$

For $B_{y+1}$<$B_{trig}$

1) ACOM 2010 option $F_{msy,b} = F_{msy} B_{y+1} / B_{trig}$

2) Alternative options increasing in F reduction from 0.72*$F_{msy}$ at Blim to 0.5*$F_{msy}$ at $B_{lim}$ with a range of further options below $B_{lim}$.

when $B_{trig}$=$B_{pa}$ and $B_{pa}$> $B_{y+1}$>=$B_{lim}$

$$F_{msy,b} = F_{msy}(1-((B_{pa} - B_{y+1})/(B_{pa} - B_{\lim})/2))$$

With a number of Options for $B_{y+1}<B_{lim}$

2a) $F_{msy,b} = 0$

2b) $F_{msy,b} = \max(0, F_{msy}(1-((B_{pa}-B_{y+1})/(B_{pa}-B_{\lim})/2)))$

2c) $F_{msy,b} = (F_{msy}/2)*(B_{y+1}/B_{\lim})$

2d) $F_{msy,b} = F_{msy}/2$

# 4 Further develop the MSY approach to be applied in situations where no analytical assessment is available.

## 4.1 Updated guidelines for providing advice where there is no analytical assessment.

### 4.1.1 Stocks managed by a target escapement strategy

For short-lived stocks managed by a target escapement strategy (e.g. capelin), F-based reference points may not be relevant. However, one may investigate how the MSY and the risk of depletion of stock varies as a function of the target escapement, in essentially the same way as one varies F for other stocks. Thus most of the considerations about MSY made in Section 3 apply also to such stocks, but with $F_{MSY}$ replaced by $TE_{MSY}$ (target escapement MSY).

### 4.1.2 Other stocks where there is no accepted analytical assessment

The following text table prescribes the advice basis used in 2010 for stocks where there is no accepted analytical assessment.

| | No Overfishing | Overfishing or Unknown Exploitation Status |
|---|---|---|
| **Decreasing stock trend** | Reduce catch from recent level at rate of stock decrease | Reduce catch from recent level at rate greater than the rate of stock decrease |
| **Stable stock trend** | Maintain catch at recent level | Reduce catch from recent level |
| **Increasing stock trend** | Increase catch from recent level at rate of stock increase | Maintain catch at recent level |

This advice framework was considered in 2010 to be part of the ICES MSY framework. WKFRAME considers that in situations where no analytical assessment is available or for stocks with a poor data situation, calling this Maximum Sustainable Yield advice is potentially misleading. In these circumstances, the advised exploitation rates are compatible with sustainable exploitation (SE) and not a narrowly defined maximum sustainable yield. It is also important to stress that for these stocks, the approach is considered adaptive, where provisional targets are used and long term targets are periodically updated. As knowledge and data regarding stock dynamics improve advice may be possible using the ICES MSY HCR. For stocks falling under this approach, $F_{msy}$ proxies (e.g. $F_{01}$ ) should be defined and considered as a target.

WKFRAME distinguish two main groups of stocks (without analytical assessments or forecasts) which for which this approach would be suitable, i) stocks for which length or age data is not available and ii) stocks for which length or age data is available. Within each of these groups, WKFRAME has identified a number of potential scenarios and has suggested ways of delivering advice for such stocks. This scheme is summarised in the flowchart included in Figure 4.1.2.1.

The flowchart in Figure 4.1.2.1 includes the following main cases and should function as guidelines for setting advice where no analytical assessment is available or for stocks with limited data. **It is expected that expert judgment based on the stock biology and ecology is used alongside the information on the stock indicator trends.**

The cases identified are:

When length or age not available and:

1. When no commercial catch data are available
    a. Advice should be based on the species biology (productivity/susceptibility analysis).
2. When only trends in landings or catches are available
    a. Advice should be based on the analysis of the landings, ***if*** the landings are considered informative of stock trends e.g. are landings dependent on market conditions (if yes then trends may not reflect stock), is the time series long enough, etc. In these situations advice options are restricted to the right side of the advice table (i.e. because of unknown exploitation status)
3. When only ***standardised*** cpue from fisheries and/or cpue from survey is available
    a. Advice should be based on trend analysis, e.g. CUSUM with priority to long time series. Again in these situations advice options are restricted to the right side of the advice table (i.e. because of unknown exploitation status)
4. When the data time series of CPUE and catches are informative and cover an appropriate dynamic range, Biomass dynamic models can produce estimates current F and $F_{msy}$. In these cases you may be able to make a determination if the stock is overfished or not, and thus be able to follow the right hand side of the table for advice provision.

When length or age is available:

1. When population structure information (length or age) from catches (yearly catch at age) is available, then derive $F_{curr}$ via e.g. pseudocohort analysis and $F_{msy}$ proxies as e.g. $F_{01}$ via YPR, advice may refer to the left side of the advice table where appropriate. Direct proportionality between F and catches will have to be assumed. Another option is to produce a classic short term forecast using the results from the pseudocohort analysis and advice is given according to $F_{msy}$ proxies in the usual manner (reduce or increase catches to achieve $F_{msy}$).
2. When only survey based analysis is available then derive $F_{curr}$ using survey based methods (e.g. SURBA) and $F_{msy}$ proxies as e.g. $F_{01}$ via YPR, advice may refer to the left side of the advice table if appropriate. Again, direct proportionality between F and catches will be assumed.

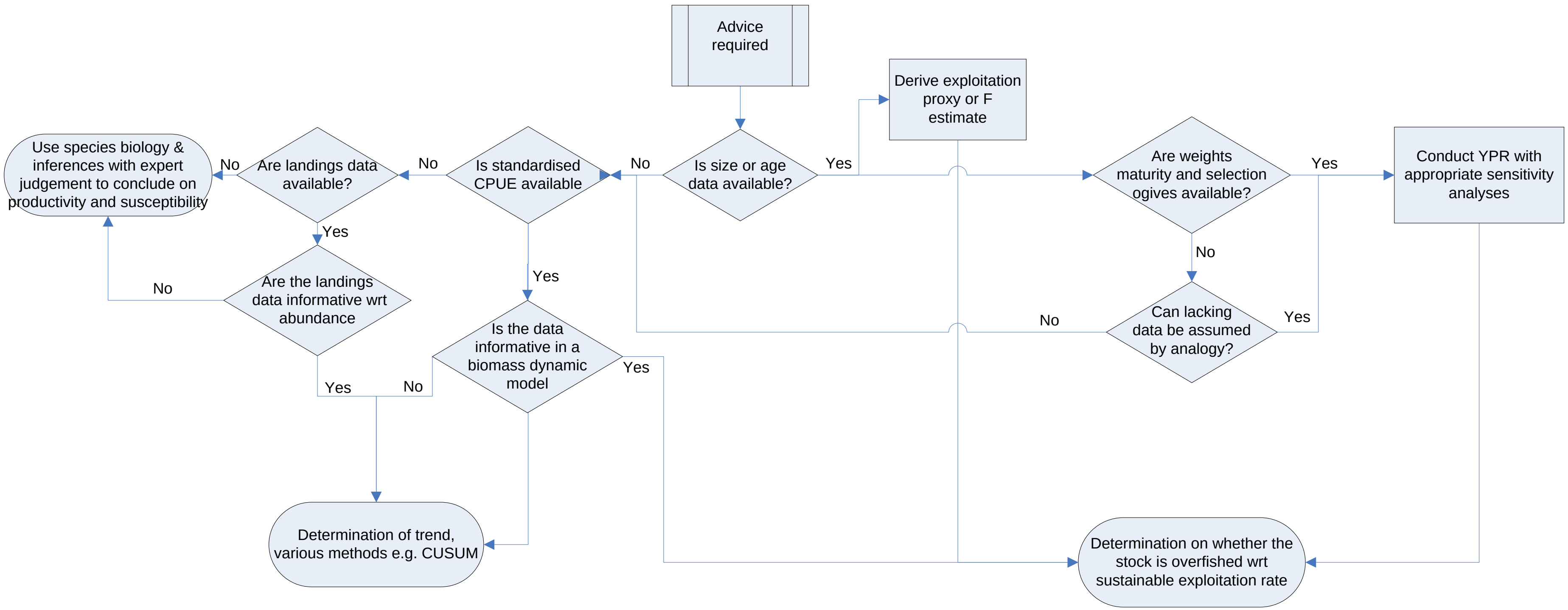
**Revised advice prescription table.**

| | **No Overfishing** | **Overfishing or Unknown Exploitation Status** |
|---|---|---|
| **Decreasing stock trend** | Reduce catch from recent level at rate of stock decrease | Reduce catch from recent level at rate greater than the rate of stock decrease |
| **Stable stock trend or no trend information** | Maintain catch at recent level | Reduce catch from recent level |
| **Increasing stock trend** | Increase catch from recent level at rate of stock increase | Maintain catch at recent level |

### 4.1.3 Limitations to the current approach

Using the table above (in conjunction with the flow chart Fig. 4.1.2.1) to give advice, still has problem of discontinuity, i.e. the establishment of whether overfishing is taking place determines how the index is interpreted. While this is perfectly rational it is technically an undesirable property of any advice/management action. The use of HCR's may be beneficial in this respect, and WKFRAME would encourage the development of HCR's for data limited situations, see further discussion in Section 4.3. In addition the above approach presumes a relationship between catch and F. In the short term this relationship may be perturbed by recruitment which deviates from the mean. Thus advice generated from the current ICES approach should be seen as directional and not sensitive to short term variability. Should there be a short term consideration which would significantly affect the annual advice, e.g. a large recruitment event, this should of course be taken into account and as suggested in section 3.5.3, the framework should not be applied mechanistically.

**Fig 4.1.2.1 flow chart of options for data limited stocks**



## 4.2 CUSUM a tool for detecting persistent deviations from a background mean

In the introduction to ICES advice, the decision table for “stocks without population estimates” presupposes that a determination is made of whether there is a trend in stock abundance. However, the issue of detecting a trend can be difficult in practice.

The EU project FISBOAT had the purpose of determining the status of fish stocks and marine ecosystems only on the basis of indicators from surveys. The indicators considered ranged from abundance indices, to length-based indicators (mean length and upper quantiles), through a variety of spatial indicators. Inevitably, the project had to confront the issue of detecting trends and/or change points in times series of observations. The approach chosen was to borrow methods from the field of statistical process control (SPC), which has been widely used in industrial contexts for decades and has solid statistical foundations. The specific methodology chosen involves control charts, simple graphic devices, and notably the decision-interval (or tabular) CUSUM control chart (Page, 1961; Hawkins & Olwell, 1998).

Briefly, the approach consists in first characterizing the mean and standard deviations of the process while it is functioning properly (“in-control state”). Then, all observations (past and incoming) are standardized to the in-control mean and SD. The next step is to recursively accumulate the positive and negative deviations exceeding some allowance $k$ separately in two CUSUM statistics. Finally the upper and lower CUSUM are plotted against the rank of observations. If a trend develops in the indicator, then one of the upper or lower CUSUM (depending on the sign of change) will start departing consistently from the baseline. At some point, an alarm will be triggered if the CUSUM plot crosses a decision limit $h$. This decision limit can be tuned to arrive at a desired compromise between the ability to detect worrisome changes quickly while avoiding false alarms, by looking up tables in textbooks or using some specialized software. Mesnil & Petitgas (2009) provide a simple introduction for the case of a single indicator. Petitgas (2009) extends the scheme for multiple indices, which can react differently or with different delays. A description with application to survey abundance indices can also be found in Section 5 of the 2008 ICES Methods Working Group (ICES 2008c), together with alternative methods from the fields of econometry or time series analysis.

The strong point of SPC methods is that they are well proven and statistically sound. However, this does not mean that the transfer from industrial settings to the field of fisheries is not without problems. In the first, place one has to determine a reference period when the system was deemed to perform properly, which involves expert judgment and/or collective decision. This is not easy in cases where observations are available only for periods that follow the start of degradation. Moreover, whereas the industrial production can count on thousands of data collected several times per hour, fishery survey data are typically few and far between (one value per year). Some characteristics of the data (non-normality, auto-correlation, in-control characterization estimated) are not necessarily an impediment to setting up a control chart, but they would typically increase the probability of false alarms compared to the values tabulated for the perfect case. Hence, the opinion of WKFRAME is that CUSUM charts are just one method among many, with the advantage of being sound, easy to use and available, but should not be viewed as THE magic recipe.

Incidentally, some participants in the FISBOAT projects later developed alternative methods for determining the existence of trends; see Trenkel & Rochet (2009 and 2010).

**In practice:**

The papers resulting from FISBOAT are published as a special issue (Volume 22, number 2) of the journal Aquatic Living Resources (http://www.alr-jounal.org/index.php?option=com_toc&url=/articles/alr/abs/2009/02/contents/contents.html). Open access versions of the paper by Mesnil & Petitgas, and by Petitgas are obtainable at addresses given in the reference list. Software for setting up and tuning a CUSUM control chart is available (zip file) in the form of rudimentary R scripts as online supplement to the Mesnil & Petitgas paper on the ALR website (and on WKFRAME SharePoint).

## 4.3 The development of HCR's for "data poor" stocks

The definition of "data poor" is not an exact one, for some stocks available data are scarce but informative while for others much data are available but the internal consistency in data is poor due to measurement noise or variable unreported mortality. Determining the utility and internal consistency of data may not be a trivial task, but proceeding with any analyses before making this determination, potentially undermines the credibility of any advice based on further analyses. Any of the analyses discussed below assumes that there is some internal consistency in the data and that the data points may be sparse.

Typically available data may include:

- Landings data
- Abundance indices, cpue or survey
- Recruitment indices
- Size distribution in the catches.

In addition data for species/stocks considered biologically similar might be available.

For many "data poor" stocks enough data is available to make some kind of HCR. The HCR will most likely be conservative to reflect uncertainty in knowledge about the stock. The approach should be more appropriate than classifying the stock in boxes, with separate action taken in each box; as this leads to discontinuity in the relationship between advice and abundance index.

### Feedback control

Feedback control is a large field in engineering and to some extent HCR's can be looked at as the controller in feedback control where the stock metric is the measuring device (algorithm). Managing fisheries however, has some intrinsic factors separating it from common feedback control systems.

Data points are collected slowly or approximately once per year.
The system is time varying and relatively few data points are collected while the system changes considerably.

- Errors with bias at various stages in the system (assessment, implementation)
- Delay in the measurement. Stock assessment converges in some years.
- One of the known facts from control theory is that an integrator is necessary in the control law if the goals of the HCR are to be reached and the integrator also helps if the dynamics in the system change, for example by change in M.

If target fishing mortality has been defined a candidate for harvest control rule could be

$$C_{y+1} = C_y - K_p(F - F_{ref}) - K_i \sum (F_y - F_{ref})$$

$$C_{y+1} = K_p(B_y - B_{ref}) - \max(0, K_i \sum (B_{ref} - B_y)) \quad 1)$$

Where $K_p$ and $K_i$ are the gains in the integral control. If a $B_{trigger}$ is available for the stock the rule might rather be changed to

$$F_{ref1y} = \min(F_{ref}, F_{ref} \frac{B_y}{B_{trigger}}) \quad 2a)$$

$$C_{y+1} = C_y - K_p(F - F_{ref1}) - K_i \sum (F_y - F_{ref1y}) \quad 2b)$$

Or even introduce an integral control if the biomass is below $B_{trigger}$

$$C_{y+1} = C_y - K_p(F - F_{ref}) - K_i \sum (F_y - F_{ref}) - K_{i2} \max(\sum (B_{trigger} - B_y), 0) \quad 3)$$

The problem with data poor stocks is that precise estimates of biomass or fishing mortality are not available and landings and unreported mortality may not be known with high precision. Therefore fishing mortality hast to be replaced by $\frac{C_y}{I_y}$ or $\log \frac{I_y}{I_{y-1}}$ (very noisy estimate of Z) and biomass estimates by $I_y$. Where CPUE from commercial fleets are used as an abundance index the **effort** derived could be used as proxy for fishing mortality (harvest ratio). The problem is deriving $F_{target}$ and $B_{trigger}$. Results from biomass models fitted to the data could potentially be used to guestimate $F_{target}$ and $B_{trigger}$ ($I_{trigger}$). Equation 1 can also be twisted a little so the goal is target biomass.

$$C_{y+1} = K_p(B_y - B_{ref}) - K_i \sum (B_y - B_{ref})) - K_{i2} \max(\sum (B_{trigger} - B_y), 0) \quad 4)$$

However ICES does not recommend managing to a biomass target, as natural fluctuations can lead to higher fishing mortality in periods of poor recruitment if the term $K_{i2}\max(\sum(B_{trigger}-B_y),0)$ was not included in the equation.

Still another form of equation deriving catches from survey indices is

$$C_{y+1}=C_y-K_p(I \quad -I_{y-1}) \quad 5)$$

However this form can be unstable and should be augmented by some biomass target to make it more stable.

#### Testing of HCR.

Testing of HCR for data poor stocks based directly on abundance indices is most easily done by generating data with the dynamics of the stock in question and linking that to an observation model giving the data that the HCR works on. The testing phase can be anything from relatively simple to very complex, including every imaginable uncertainty. One of the most important things to test against is trends in catchability in the surveys or fleet that the abundance indices originate from. As those are the only data on state of the stock detecting trends is close to impossible.

It must though be remembered not too make things too complicated if that is to delay action, rather put something in the HCR that makes it risk averse to driving the stock into recruitment impairment.

Most rules based directly on abundance indices might require a stabilizing mechanism to protect against abnormally high index values (abnormally low index values are less of a problem). Those “stabilizers” are often used in HCR based on “stock assessment” but the use of them there is questionable as stock assessment already acts a low pass filter.

**Summary**

Here some potential forms of HCR for data poor stocks have been introduced. The list is nowhere complete and some of the rules presented may be found unsuitable after testing. HCR’s can often be augmented by auxiliary information like mean size in landings, recruitment indices etc. But even in cases where data are very sparse using a simple robust HCR might be better than using decision table leading to discontinuity in the advice.

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## Annex 2: Agenda

**Agenda Monday February 10 1400-1800**

1. Introduction & Welcome
2. ToR's discussions
3. Round up from WG chairs on experience from 2010

**Agenda Tuesday February 11**

Morning

1. State of play from 2010 as per EG chairs (ToR A)
2. Heirarchy (ToR A)
3. F from framework when SSB is below Btrigger (ToR B)
4. Rationale for Btrigger (ToR)
5. Blim guidelines from SGBRP 2003. Henrisk WD, Benoits WD on fitting Hockeystick

Afternoon

6. Other issues how to select the time frame, guidelines on regime shift(ToR B)
7. Implementation plan options (not decisions) (ToR b iii)
8. a)F2011-Fmsy by 2015 b)F2012 – Fmsy by 2015 prescribe the equation when b is 4 steps and prescribe equation when b is the second of 5 steps Are there any pros and cons What should happen if F>>Fpa in 2009 and F still >>Fpa in 2010 ACOM decision
9. Stocks with no forecast (ToR C)
10. Text on a clarification of terms
11. Fisboat approach for statistical criteria for determining trends in indicators
12. Elaboration on generic stock simulation approach (hoksys indicator HCR) i.e in the technical evaluation of Annex IV rules, from Dankerts WD from WKFRAME I

**Agenda Wednesday & Thursday February 12-13**

Subgroup 1 Biscay room dealing with points 2-8

Subgroup 2 Kattegat room dealing with points 9-12

**Agenda Tuesday February 14 0930-1300**

1. Discussion on introduction items
2. Report text

# Annex 3: Working documents

### 3.1 Review of ICES sole stock MSY and reference points. E J Simmonds, Fish-Reg, JRC, Via E. Fermi, Ispra, VA, 21020, Italy.

## Summary

Meta-analyses, applying generic methods within a species group, have benefits in terms of providing more stable estimates of FMSY reference points and estimates for individual stocks which by themselves may otherwise have insufficient data. Current ICES advice for seven sole stocks for which there is sufficient data gives $F_{msy}$ estimates which vary from 0.16 to 0.38, but these are specified for differing age ranges so are not directly comparable. $B_{pa}$ is estimated for six of these seven stocks but $B_{lim}$ is available for only two. Slope at the origin estimates for HS models for the seven stocks vary from 1.32, to 4.45 largely due to observed exploitation rates. Here an evaluation using a consistent framework to compare $F_{msy}$ targets and the sensitivity of long term yield to the choice of this value across these stocks.

Recruitment is modelled though stochastic multiple model based simulation for 1000 constructed "populations" for each stock by randomly sampling with replacement selection at age in the fishery, weights at age in the catch and weights at age in the stock for the period 2001-2009. S-R models were fitted in a Bayesian framework under the assumption is that sole has generic exploitation form which can be scaled to the carrying capacity for each stock, but the resilience, or slope (R/SSB) to the origin, is consistent across stocks assuming each stock retains its own estimated or assumed growth and maturation. Three models S-R models were applied, Hockey-stick, Ricker and Beverton-Holt with each model formulated so that the A parameter defined the slope to the origin which was assumed to be common for all stocks, whereas the B parameter related to density dependence was assumed to be independent. The probability of each model type is selected for the set using the method described in Simmonds *et al* (2011).

Results show that changing from only HS to multiple models has a minor impact on the estimate of $F_{msy}$ or the F that maximizes mean catch, though the range of estimates is reduced. There is a small reduction in range through standardization of F bar over the same ages (3-8). A slightly larger reduction using mean selection at age in the fishery. The largest contribution comes from the different growth of the sole in different areas. In most cases if exploitation is at $F_{msy}$ there is less than 5% probability of SSB being less than $B_{lim}$, except for NS sole. For NS sole measurement error will have some impact on the results whereas for other stocks the influence is limited.

The combined analysis (Table x1) shows that the range of F within which catch is within 5% of maximum catch is substantial. Only for Skagerrak-Kattegat sole is the target near the lower bound. For most stocks an F target (ages 3-8) of 0.25 is a good choice. The new $B_{lim}$ and $B_{pa}$ values are an important change, they are coherent with the simulations contribute to the impression of safe exploitation. However they need to be considered carefully before acceptance, this further analysis would be most appropriately conducted by individuals familiar with the stocks. The higher exploitation rates for Irish Sea and Skagerrak are conditional on the growth and this need to be verified, particularly for Skagerrak-Kattegat.

## Introduction

Current parameters for the basis of ICES advice for sole stocks is summarized in Table 1. $F_{msy}$ is available for seven stocks and varies from 0.16 to 0.38 but is specified for differing age ranges. $B_{pa}$ is estimated for six of these seven stocks but $B_{lim}$ is available for only two. This evaluation uses a consistent framework to compare $F_{msy}$ targets and the sensitivity of long term yield to the choice of value. ICES advice on an eighth stock is limited as only landings are reported.

## Methods

Data is taken from ICES 2010 assessments of the sole (ICES 2010a) using SSB/R pairs from year available excluding any recent years where estimates are substituted by mean recruitment. The uncertainty in modeling is limited to match variability used in the assessment data.

Populations are parameterized as 1000 separate populations that includes:-

Selection at age in the fishery drawn at random 2004-2009 (Figure 1)

Weights at age in the catch drawn at random 2004-2009 (Figure 1)

Weights at age in the stock drawn at random 2004-2009

The random draws selects a year and draws all parameters from that year so correlation between weights etc. observed is maintained in the simulations, however, cohort effects are ignored. The following parameters are not varying in the assessment and the simulations do not include variability in the following:-

Annual variability in maturity

Annual variability in time of spawning

Annual variability in timing of fishery

Annual variability in natural mortality

## Recruitment simulation

Preliminary investigation of modeling suggested that fitting individual stock models implied very different stock dynamics (Table 2) slope at the origin for HS models vary from 1.32, to 4.45. The range is influenced greatly by the observed exploitation rates which differ among stocks limiting the range of observed biomass. In order to account for this a combined modeling approach was investigated.

Recruitment is modelled though stochastic multiple population model based simulation for the populations. Models are fitted in a Baysian framework. The underlying assumption is that sole has generic exploitation form which can be scaled to the carrying capacity for each stock, but the resilience, the slope (R/SSB) to the origin is consistent across stocks. Each stock retains its own estimated growth and maturation.

Three models are used are used

Hockey-stick model R = $\exp(A_h * B_{sh} * SSB + RND(\sigma))$ (SSB>B)
$\exp(A_h * SSB + RND(\sigma))$ (SSB<B)

Ricker model R = $\exp(A_r * SSB * \exp(-1/B_{sr} * SSB))$

Beverton Holt model R = $\exp(SSB/(A_b + B_{sb} * SSB))$

Where the A parameter which defines the slope to the origin is common across all the sole stocks but specific the model type, while B is independent for each model and stock. Where recruitment is modeled in the assessment at age 2 the slope is modified by natural mortality of 0.1 at age 1 making giving the three stocks with assessments starting at age to comparable to the others modeled from age 1.

The probability of each model type is selected for the set using the method described in Simmonds et al (2011).

## Population Simulation

The methods used conform to the methods described in ICES 2010b and matches the population dynamics fitted in the assessment. Simulation of exploitation is carried out at a range of constant F exploitation with selection at age as described above. The populations are taken to equilibrium by exploitation for 100 years and run a further 50 years to obtain equilibrium values for distribution of recruitment, SSB, catch and landings. The software has been validated against simulations for sole and plaice plans carried out at IMARES.

### Estimation of Fmsy

Two criteria are used to estimate $F_{msy}$: a) using the distribution of estimates of $F_{msy}$ by population to give a probability of $F_{msy}$ from which the median value is assumed to be the most unbiased point estimate. b) The maximum in the relationship between mean catch over F, this defines an integrated measure taking account of the sensitivity of mean yield with mean F the point value for $F_{msy}$ is the F giving the maximum mean catch.

### Estimation of Blim (and Bpa)

Following the methodology in the ICES PA from 2003 (ICES 2003) the median of the distribution of the breakpoints for the HS model fitted in the Bayesian framework is used to give estimates of $B_{lim}$ by stock. $B_{pa}$ is not required for this analysis but for comparison with previously estimated values of $B_{pa}$ are derived as $B_{lim}$*1.4.

### Inclusion of errors

In the exploitation target F will not be implemented accurately, due to noise in the data, retrospective bias in the assessment, implementation errors in the exploitation. All these contribute to a distribution of F around a target F. If there are know biases these can be removed as simple shift in target. Once biases are removed the error can be considered as a distribution and to set the impact of this the results are convolved with an error distribution in F.

## Results

### S-R modelling

Model parameter estimates and examples of simulate recruitment are illustrated in Figure 2-15. The joint posterior distributions of parameters A and B for each model are shown in the first figure for each stock. Note that the A parameter is common across stocks. The model fits shown in the second figure are compared with the observations in two ways, as 50 randomly selected models from the 1000 available from the MCMC and as quantiles of R against SSB (0.05,0.25,0.50,0.75 and 0.95). Also on these plots for comparison the maximum log likelihood model is also shown as a single line.

For both fits in the maximum log likelihood (using AICc) and Bayesian (using DIC) approaches the HS model has the best fit. Following the method of Simmonds et al 2011, the proportion of models (HS, RK and BH) for the set of sole stocks is 0.608, 0.046 0.346 respectively. Sensitivity to choice of a HS model or a combined model is reported below.

This process provides a basis for simulating recruitment that includes the uncertainty in S-R functional form, the parameters of the model but imposes a restriction that there is an underlying resilience to all of the sole stocks, through this is estimated with uncertainty.

#### PA Reference point estimation

As Blim values are available for only two stocks, these were estimated for all stock based on the B values of the HS S-R fits. The distribution of the parameters and the median estimates are shown in Figures 3-15 (odd numbers) and in Table 3. For comparison with ICES $B_{pa}$ values 1.4 * $B_{lim}$ values are also given in Table 3.

#### Equilibrium exploitation modelling

The results of equilibrium exploitation by stock are given in Figures 16-22 and estimated F values in Table 4. These plots show estimates of $F_{msy}$ based on the exploitation by the 1000 populations (Figure 23a) and F the catch against F (Figure 23b) allowing the estimate of F that maximizes mean catch to be estimated. The mean catch results also allow an estimate of the sensitivity of mean catch to the choice of F. The sensitivity of the two estimates of $F_{msy}$ to the underlying population parameters are illustrated in Figure 24. It can be seen that changing from only HS to multiple models has a minor impact on the estimate, though the range of estimates among sole populations is reduced, The is a small reduction in range through standardization of mean F over the same ages (3-8). A slightly larger reduction in range occurs when selection is substituted using mean selection at age from all of the fisheries. The largest change to estimated $F_{msy}$ comes moving to mean growth for sole in different areas. Thus growth is seen to be the dominant differentiating factor among the sole stocks.

Using the dependence of mean catch on the selected target F given in Figure 23, selecting the F for the maximum mean catch and the Fs that give catches of 95% of the maximum, the SSB at equilibrium exploitation can be compared with estimated $B_{lim}$ and $B_{pa}$ values (Figures 25-31). These show that in most cases if exploitation is at $F_{msy}$ there is less than 5% probability of SSB being less than $B_{lim}$, except for NS sole. For NS sole measurement error will have some impact on the results whereas for other stocks the influence is limited.

Most of the populations have very similar dynamics except for Irish Sea and Skagerrak-Kattegat sole. There is a difference in selection for Skagerrak-Kattegat sole due mostly to the assumptions of the new assessment model from 2011, though this has a minor impact. As mentioned above the major differences among stocks are cause by differences in growth at age. In most cases these seem to be well supported though for Skagerrak-Kattegat sole weights decline at the oldest true age and in the plus group. This is probably why the estimates of $F_{msy}$ are higher for this stock than others. These estimated mean weights may be correct and perhaps due to sexual dimorphism, suggesting that large females disappear from the older ages and only slower growing males survive. However, if this is the case, it is possible the mixed sex model used might not be suitable. The validity of these weight at age measures should be checked before the targets are adopted.

#### Ranges of Fmsy

Figure 23a illustrates the precision of estimates of $F_{msy}$, while Figure 23b shows the change in expected yield with target F. This latter consideration shows that fishing close to the target value will also give similar yields. Choosing an Arbitrary interval of F for yield>95% of max yield gives in exploitation interval compatible with high long term yield (Table 4). For operational purposes this interval may be of particular interest for example for some sole stocks with $F_{msy}$=0.25 it is expected that if mean F is between 0.15 to 0.35 long term yields will be above 95% of yield at MSY (Table 4) thus if the management strategy is a target of to exploit 'at MSY' then an appropriate F could be take to be within such an interval. This gives an interval ±X around $F_{msy}$ that can be used to define that exploitation is 'appropriate' in the context of an $F_{msy}$ strategy. There is however a further use for such an interval, for example in the management of mixed fisheries. Such an interval could be used to specify a range of suitable Fs, compatible with the MSY strategy that would permit some reconciliation between F targets for fisheries on multiple stocks in a mixed fishery. While such an interval could clearly be abused for short term gain, use in a responsible manner would allow for a more relaxed approach to reconciling F targets in a mixed fishery.

#### $F_{msy}$ in relation to stock collapse

Table 4 provides a variety of F measures associated with stock decline and stock crash. The mean F associated with stock decline as defined by 5% probability SSB<Blim varies from 0.36 for North Sea to 0.62 for Bay of Biscay. If $F_{lim}$ is defined at the F at which there is a 50% probability of the stock being at $B_{lim}$ (in accordance with ICES, 2003) this is between 20-50% higher than the F for the precautionary biomass criteria and quite comparable with 5% probability of stock crash.

#### Expected biomass in relation to $F_{msy}$

Figures 25 and 26 show the distribution of expected biomass at exploitation rates giving maximum mean catch and at 95% of maximum mean catch, in relation to the estimated $B_{lim}$ and $B_{pa}$ (Blim*1.4) implied by the composite S-R functions with growth, maturation and fishery selection defined separately by stock (from the last 6 years) (Fig 1).

For Bay of Biscay, Celtic Sea, Western Channel and Eastern Channel the equilibrium SSB is well clear of $B_{lim}$, over almost all the range for yield > 95 max yield. For these stocks estimation errors will negligible impact on exploitation if the stock is exploited close to or slightly below target. For Irish Sea, Kattegat and North Sea the range of expected biomasses is closer to $B_{lim}$ and both measurement/ implementation error and the target interval will influence the probability of being below $B_{lim}$.

#### Impact of errors

The targets for most populations are not particularly sensitive to error, though known biases should be removed. NS sole needs a small reduction in target F to deal with measurement error because the range of equilibrium SSB includes $B_{lim}$.

#### Sole stocks with limited data

The modeling approach gives a generic model for sole that can be used to answer additional questions that may be of relevance to ICES advice. The approach shows that for most stock a target F of 0.25 is applicable. However, there are differences associated with growth at older ages. Surprisingly the MSY targets were not heavily dependent on selection, which was seen to be estimated as very variable among years and stocks but with rather similar means across the seven stocks. Questions that could be asked and answered from generic sole model.

- With landings only data: what is the safe fixed TAC based on historic and MSY yields in generic sole stocks.
- With landings and growth: what is the optimal exploitation ratio between past and future landings; what is the safe fixed TAC based on historic and MSY yields in generic sole stocks.
- With landings at age: assuming generic selection what is current total mortality compared with an MSY target of Z=0.35. What is an optimal level of exploitation based of catch curves.

## Discussion

The purpose of this review was to highlight differences and to generate a model to help answer questions on other stocks. The analysis depends heavily on the assumption of a common slope to the origin at low stock size, readers can consider which approach is preferable

- the use of values slope from 1.3 to 4.5 implied by fitting models to individual stocks
- an adhoc approach of user defined models unsupported by data
- or a unified approach presented here with a common slope with uncertainty (5%-95% of 2.5 to 6.0)

Exploitation of sole stocks at F=0.25 is seem to be safe optimal target for four of the seven stocks. A slight reduction for NS sole is selected in the full MSE and supported by this analysis. The higher exploitation rates for Irish Sea and Skagerrak are conditional on the growth and this needs to be verified, particularly for Skagerrak-Kattegat.

The revision of $B_{lim}$ and $B_{pa}$ values are an important change, they are coherent with the simulations contribute to the impression of safe exploitation and need to be considered carefully before acceptance.

There is one considerable advantage, the production of a generic sole model is useful for giving advice in data poor situations. This study established a generic MSY target for sole and gives a framework to answer questions on safe exploitation for more poorly evaluated sole stocks.

## Conclusions

Table 4 shows that the range of F within which catch is within 5% of maximum catch is substantial, only for Skagerrak-Kattegat sole is the target near the lower bound. For most stocks an F target (ages 3-8) of 0.25 is a good choice. As the long term yields are not sensitive to small variation in target F this gives potential for more relaxed approach to target achievement.

**Table 1. ICES PA and MSY reference points for sole stocks**

| WG | Stock | Age R | Age F | Flim | Fpa | Blim | Bpa | FMSY | MSYBtrigger |
|---|---|---|---|---|---|---|---|---|---|
| wgbfas | sol-kask | 2 | 4-8 | 0.47 | 0.3 | | 2000 | 0.38 | 2000 |
| wgcse | sol-celt | 1 | 4-8 | 0.52 | 0.37 | | 2200 | 0.31 | 2200 |
| wgcse | sol-echw | 1 | 3-9 | 0 | 0 | | | 0.27 | 2800 |
| wgcse | sol-iris | 2 | 4-7 | 0.4 | 0.3 | 2200 | 3100 | 0.16 | 3100 |
| wghmm | sol-bisc | 2 | 3-6 | 0.58 | 0.42 | | 13000 | 0.26 | 13000 |
| wgnssk | sol-eche | 1 | 4-8 | 0.55 | 0.4 | | 8000 | 0.29 | 8000 |
| wgnssk | sol-nsea | 1 | 2-6 | 0 | 0.4 | 25000 | 35000 | 0.22 | 35000 |

**Table 2. S-R Aand B parameters of HS models fitted independently to SSB and R data by stock.**

| | Biscay | Celtic Sea | East Ch | West Ch | Irish Sea | Kat Skag | North Sea |
|---|---|---|---|---|---|---|---|
| A | 2.91 | 3.19 | 3.28 | 1.32 | 1.69 | 4.45 | 3.45 |
| B | 9.36 | 1.59 | 7.52 | 4.31 | 4.04 | 0.96 | 2.76 |

**Table 3. Comparison of ICES and common model derived limit and precautionary reference points**

| WG | Stock | Age R | ICES Blim | ICES Bpa | Est. Blim | Est.Blim *1.4 |
|---|---|---|---|---|---|---|
| wgbfas | sol-kask | 2 | | 2000 | 1200 | 1700 |
| wgcse | sol-celt | 1 | | 2200 | 1500 | 2000 |
| wgcse | sol-echw | 1 | | | 1300 | 1800 |
| wgcse | sol-iris | 2 | 2200 | 3100 | 1700 | 2300 |
| wghmm | sol-bisc | 2 | | 13000 | 7900 | 11100 |
| wgnssk | sol-eche | 1 | | 8000 | 7200 | 10000 |
| wgnssk | sol-nsea | 1 | 25000 | 35000 | 27200 | 38000 |

**Table 4. Comparison ICES Fmsy and common model derived Fmsy values including the interval on F for yield>95% maximum yield. Precautionary values are F for 5% of populations SSB<Blim, F for 50% populations <Blim which is equivalent to Flim and the F at which 5% of stocks crash.**

| Stock | Mean age | -5% Catch lower | F for Max Catch | Median Fmsy | -5% Catch upper | Ages for ICES $F_{msy}$ | ICES Fmsy 3-8 | F for 5% SSB $<B_{lim}$ | F for 50% SSB $<B_{lim}$ | F for 5% stock crash |
|---|---|---|---|---|---|---|---|---|---|---|
| BoB | 3-8 | 0.15 | 0.25 | 0.24 | 0.4 | 3-6 | 0.27 | 0.62 | 0.75 | 0.75 |
| CS | 3-8 | 0.15 | 0.25 | 0.22 | 0.35 | 4-8 | 0.31 | 0.42 | 0.53 | 0.55 |
| EC | 3-8 | 0.15 | 0.25 | 0.27 | 0.35 | 3-9 | 0.29 | 0.42 | 0.53 | 0.55 |
| IRS | 3-8 | 0.25 | 0.35 | 0.4 | 0.55 | 4-7 | 0.15 | 0.54 | 0.80 | 0.75 |
| NS | 3-8 | 0.2 | 0.25 | 0.35 | 0.4 | 2-6 | 0.24 | 0.36 | 0.56 | 0.60 |
| S-K | 3-8 | 0.35 | 0.4 | 0.43 | 0.65 | 4-8 | 0.36 | 0.56 | 0.82 | 0.90 |
| WC | 3-8 | 0.15 | 0.25 | 0.25 | 0.4 | 3-9 | 0.27 | 0.46 | 0.59 | 0.65 |

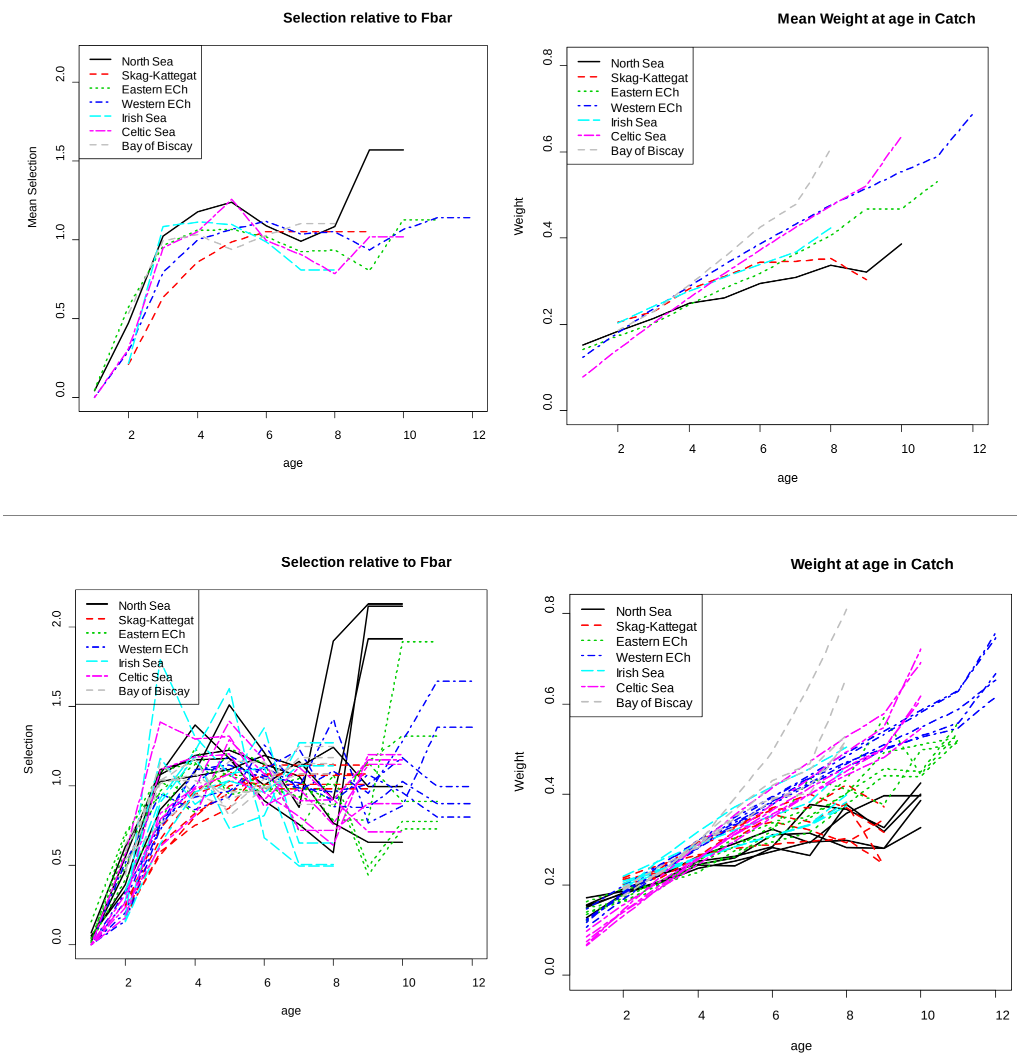


**Figure 1. Selection and catch weights at age by stock, mean by population and by population and year.**

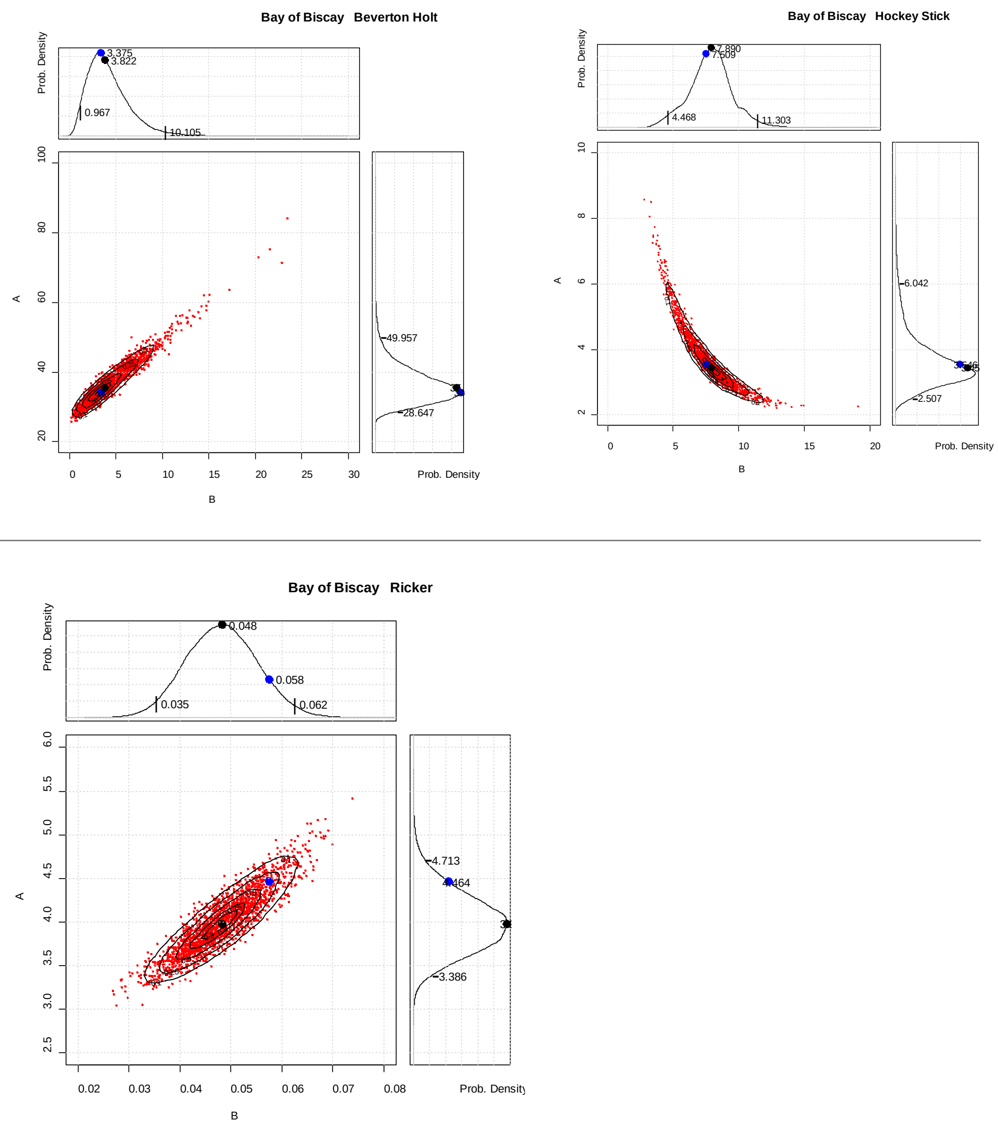


**Figure 2. Bay of Biscay Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

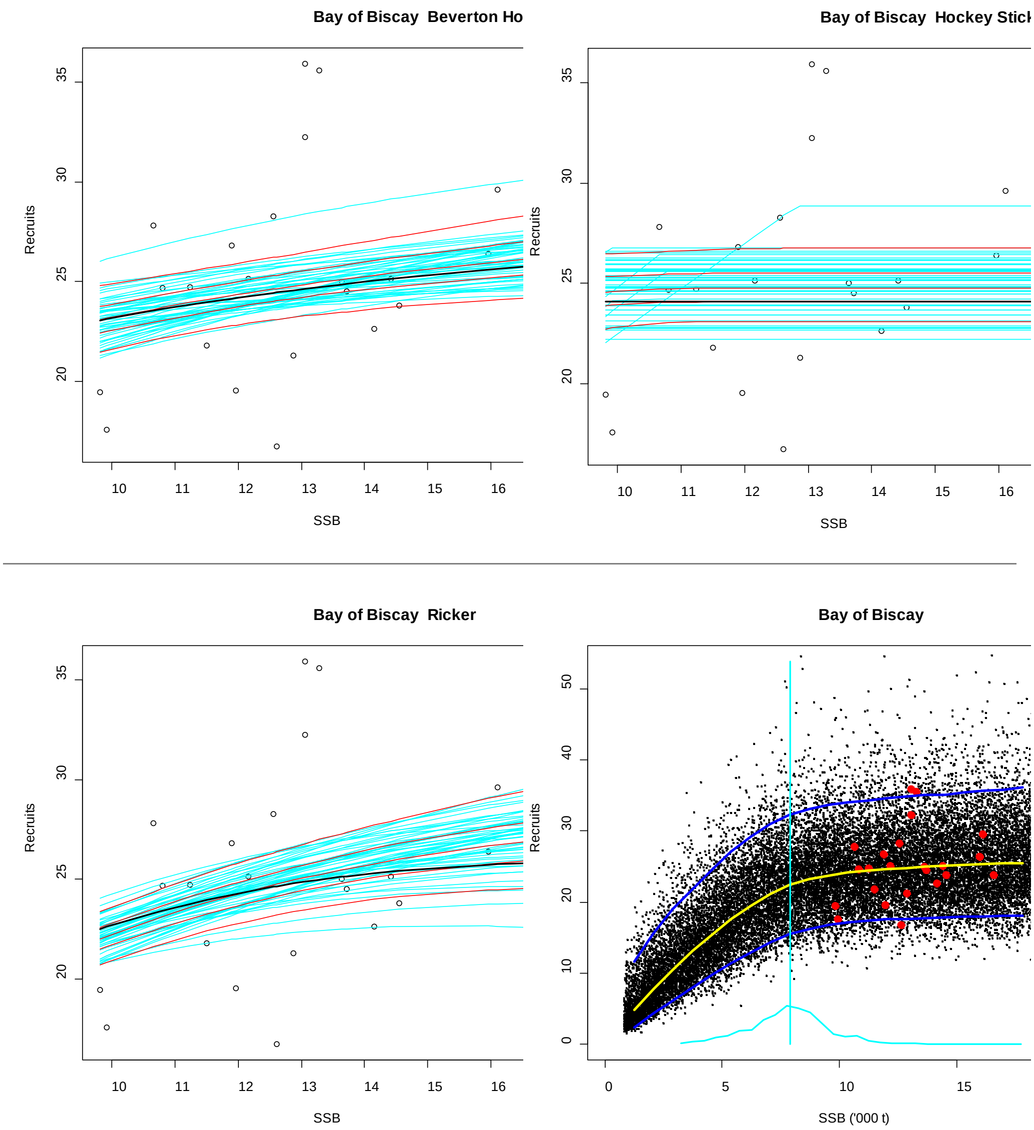


**Figure 3. Bay of Biscay S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

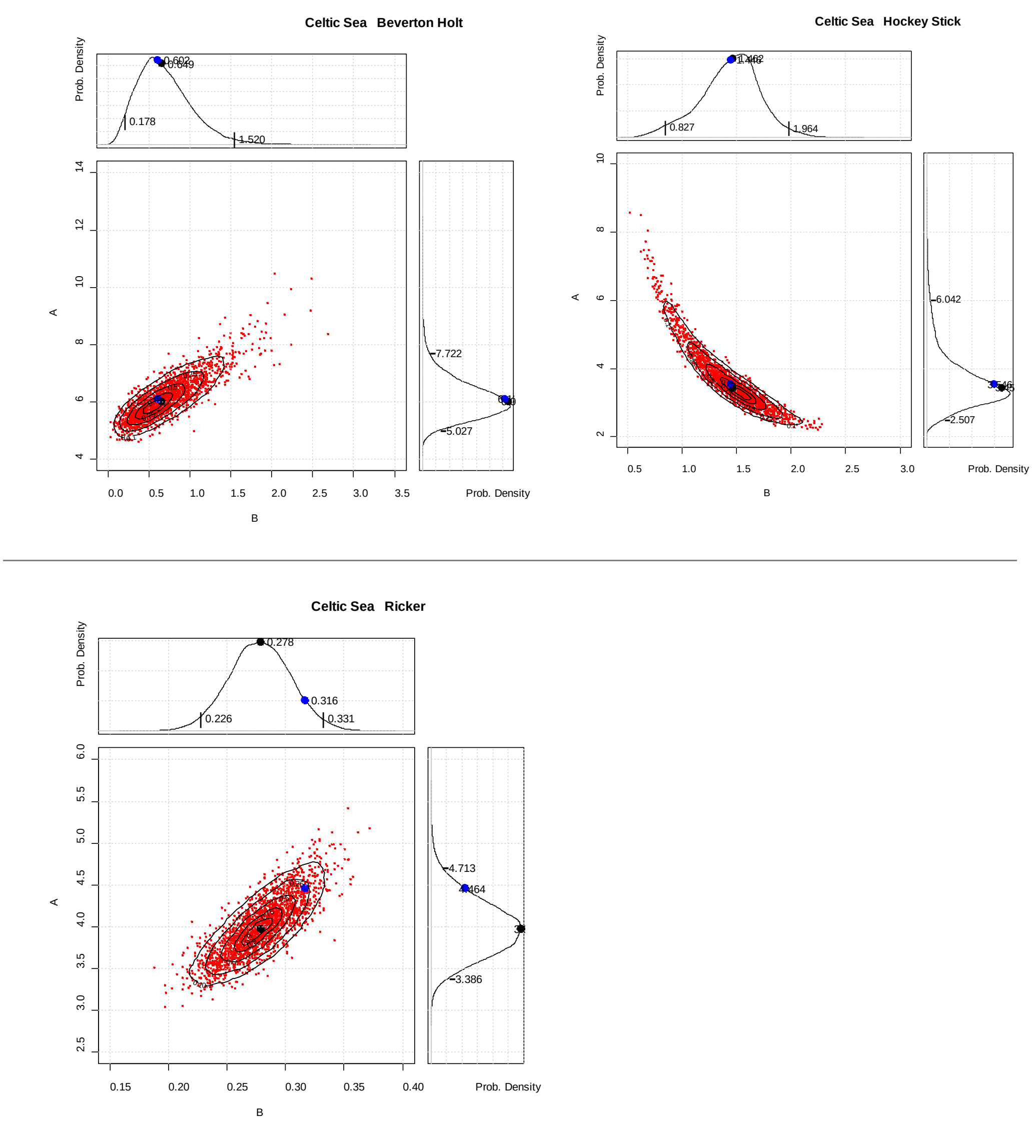


**Figure 4. Celtic Sea Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

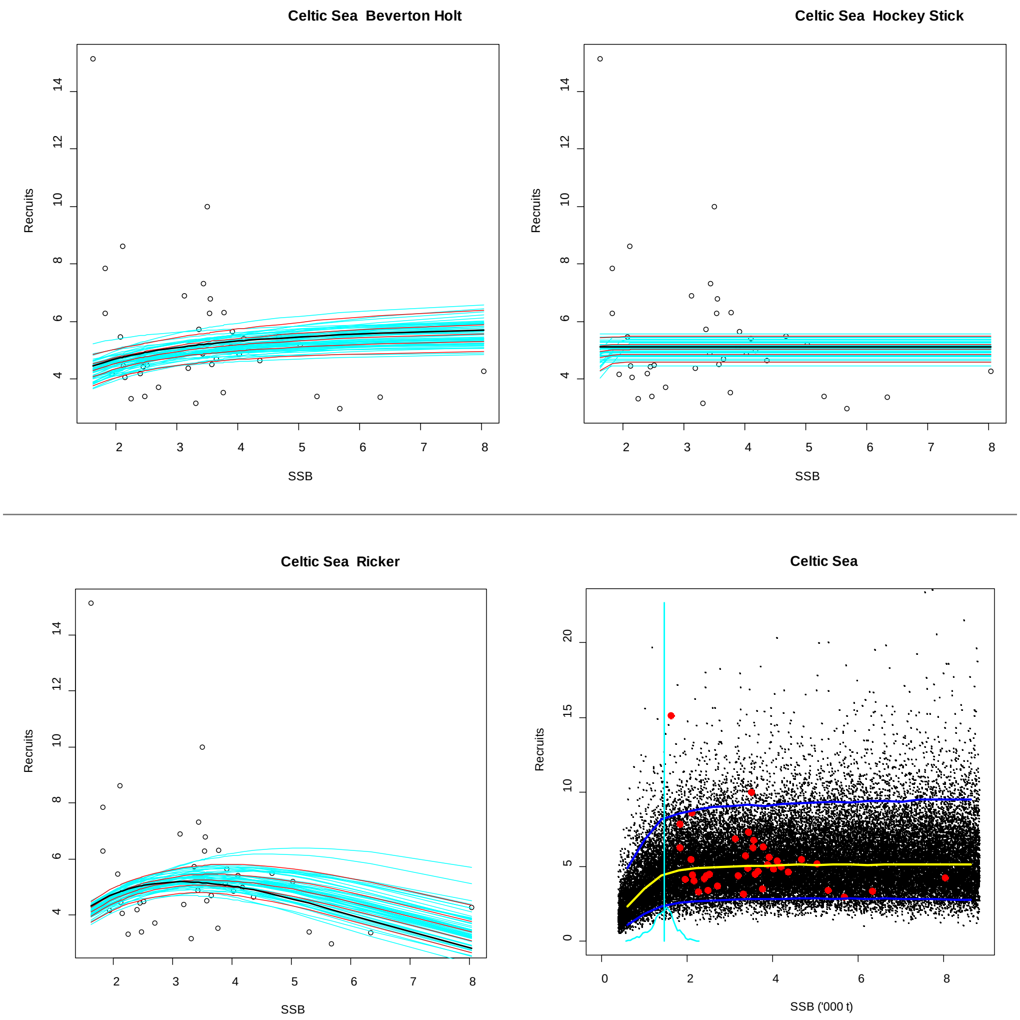


**Figure 5. Celtic Sea S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (•); simulated values using 35, 60,5 % of BH,HS,R models (•) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

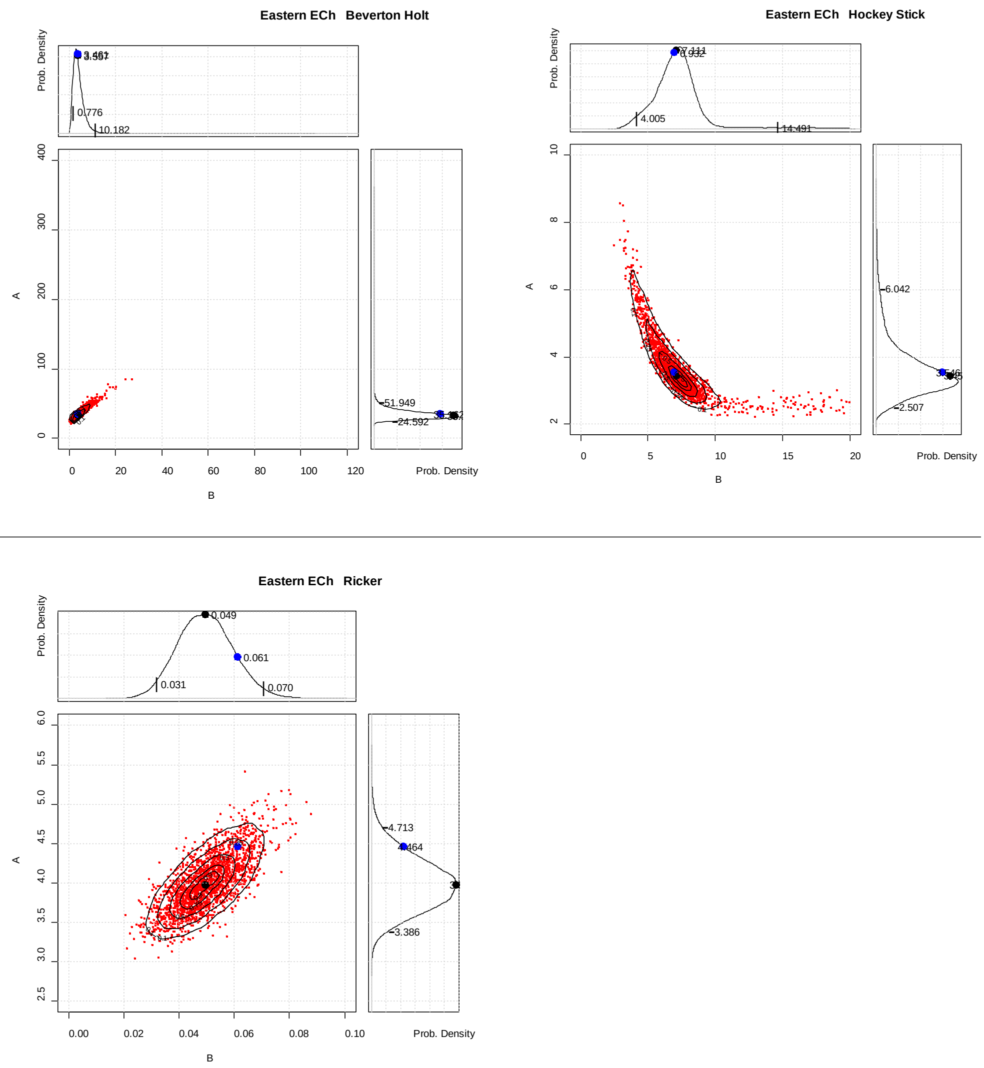


**Figure 6. Eastern English Channel Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

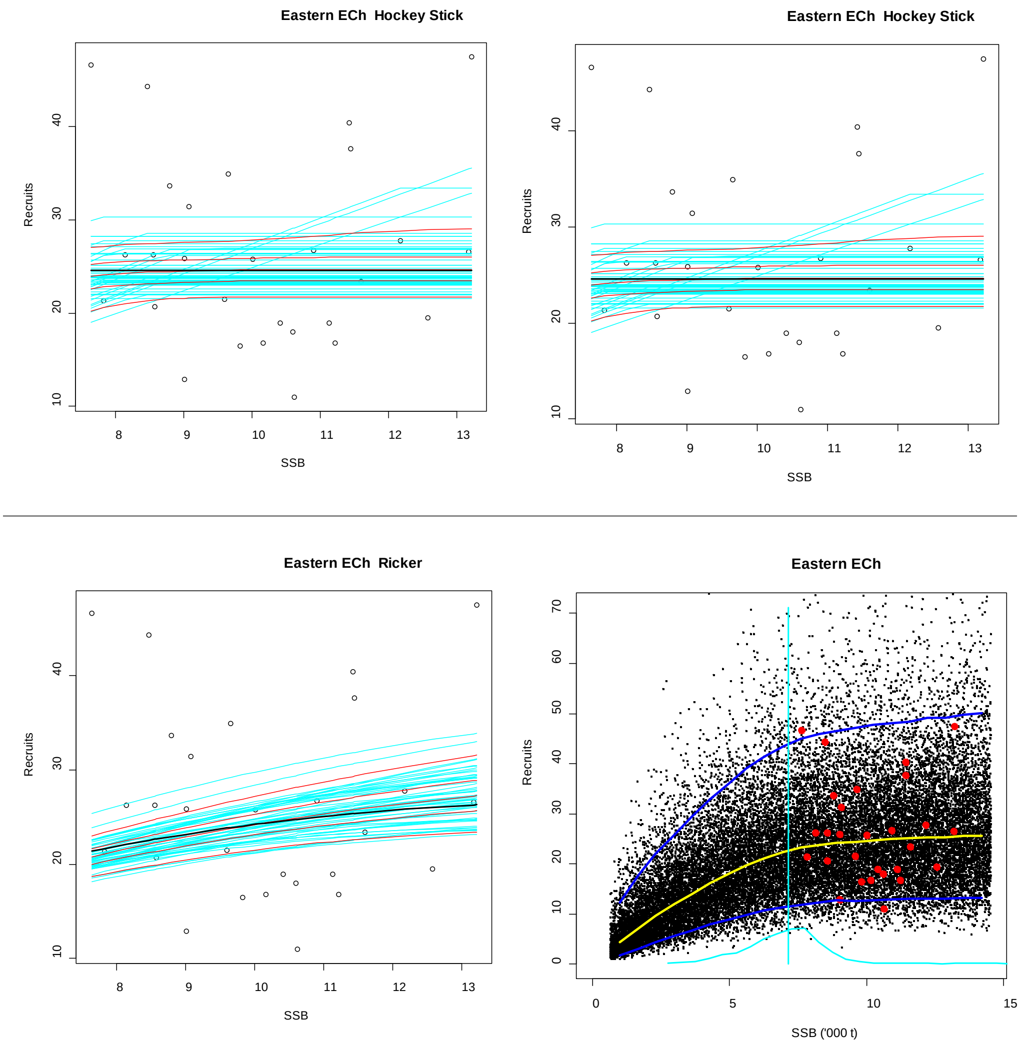


**Figure 7. Eastern English Channel S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

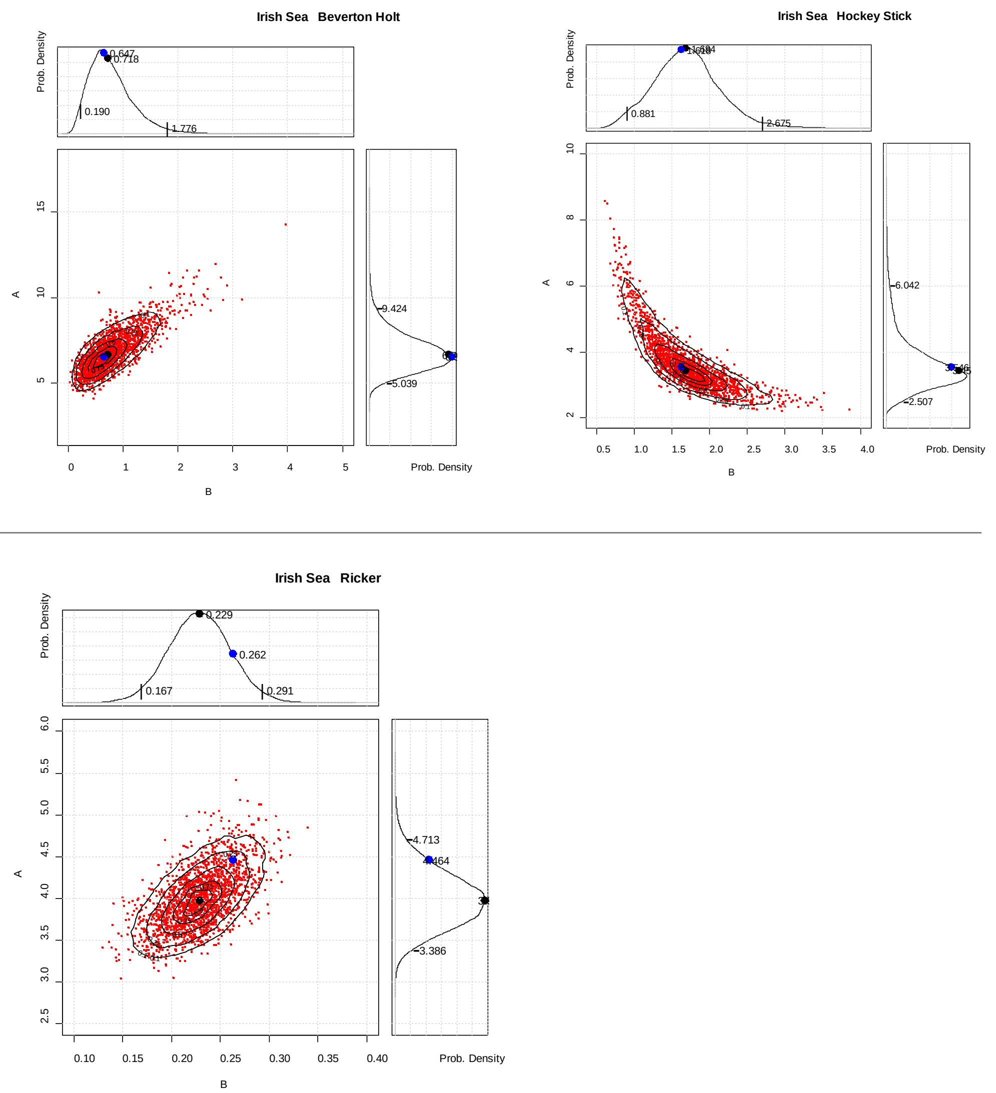


**Figure 8. Irish Sea Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

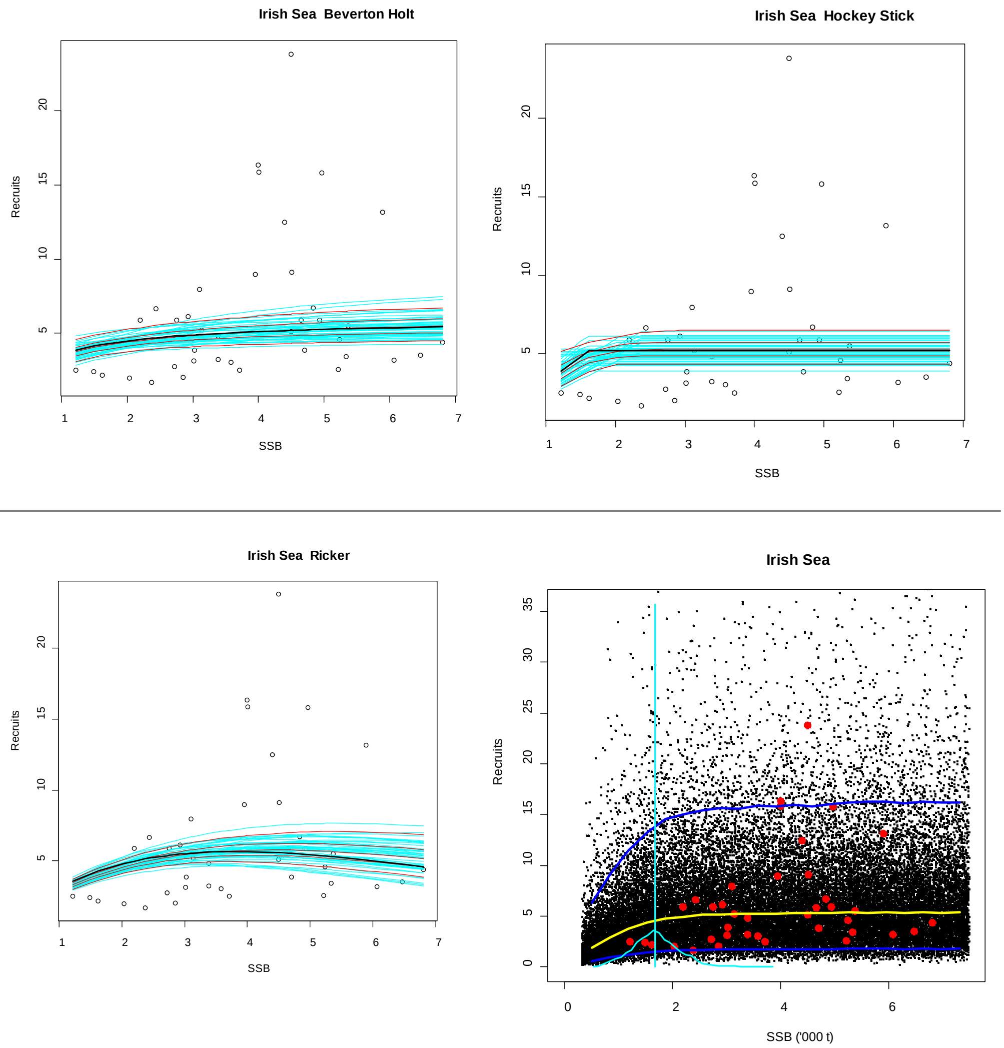


**Figure 9. Irish Sea S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

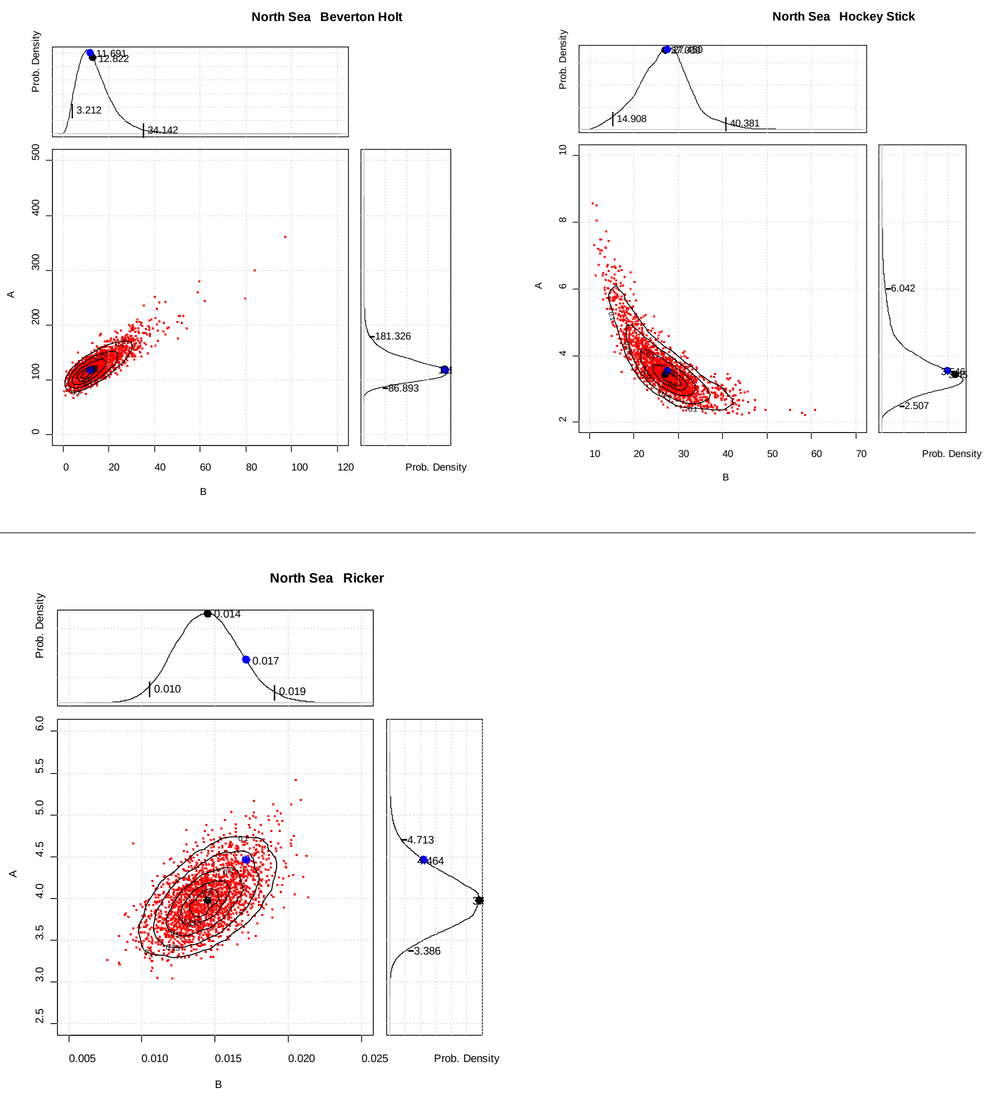


**Figure 10. North Sea Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

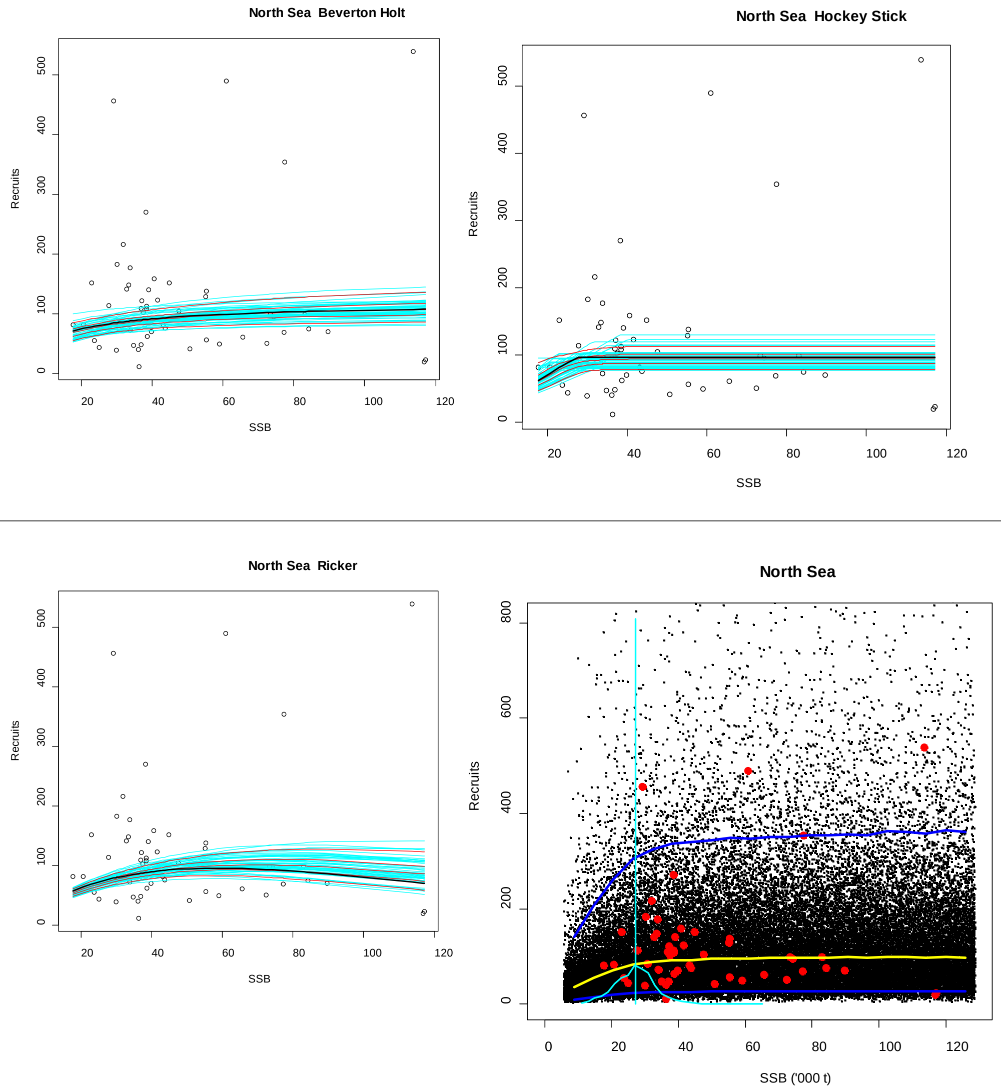


**Figure 11. North Sea S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

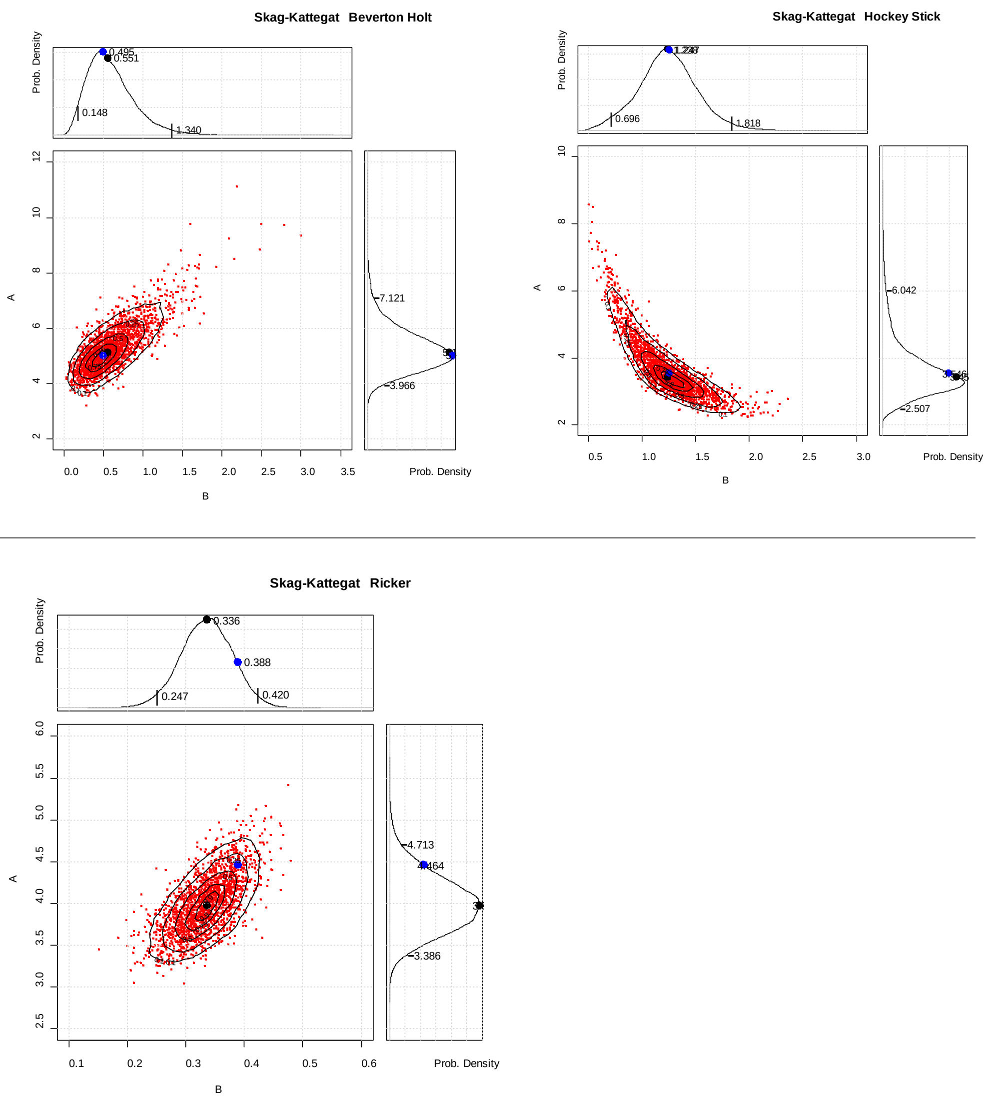


**Figure 12. Skagerrak-Kattegat Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

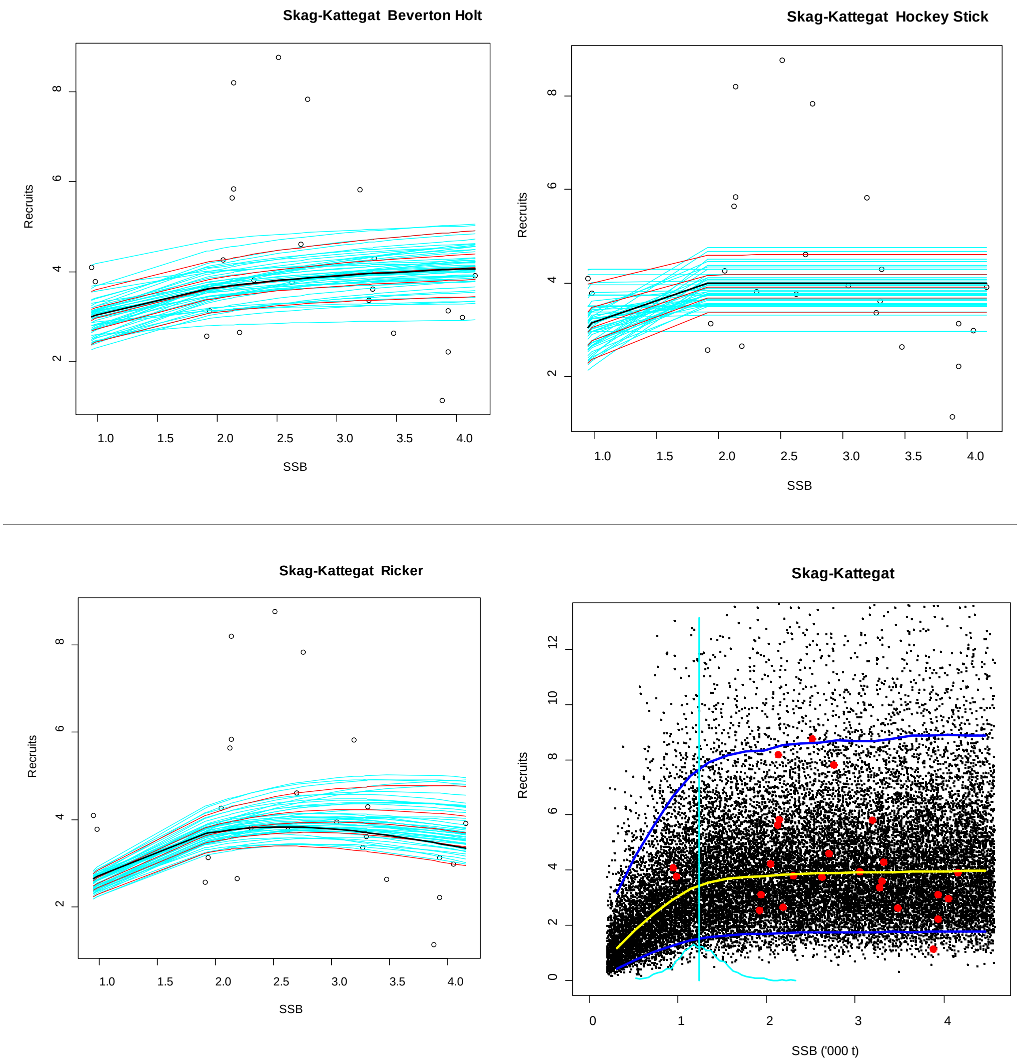


**Figure 13. Skagerrak-Kattegat S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue). Distribution of Blim from HS model and median value (Cyan)**

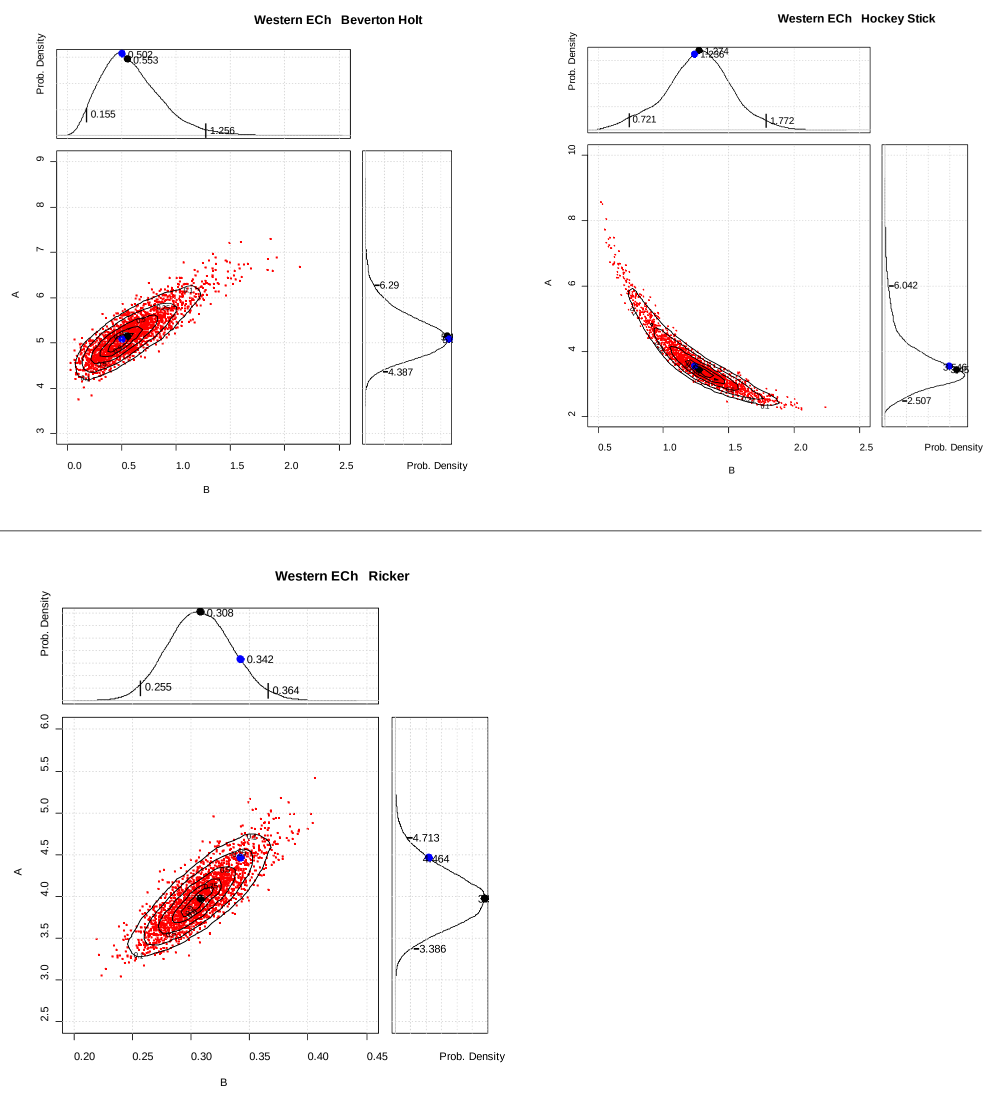


**Figure 14. Western English Channel Parameter values for S-R Bayesian fits for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships. Parameters A and B as defined in Table 2. black dots are median values for the fitted parameters and blue dots the parameters giving the maximum likelihood models.**

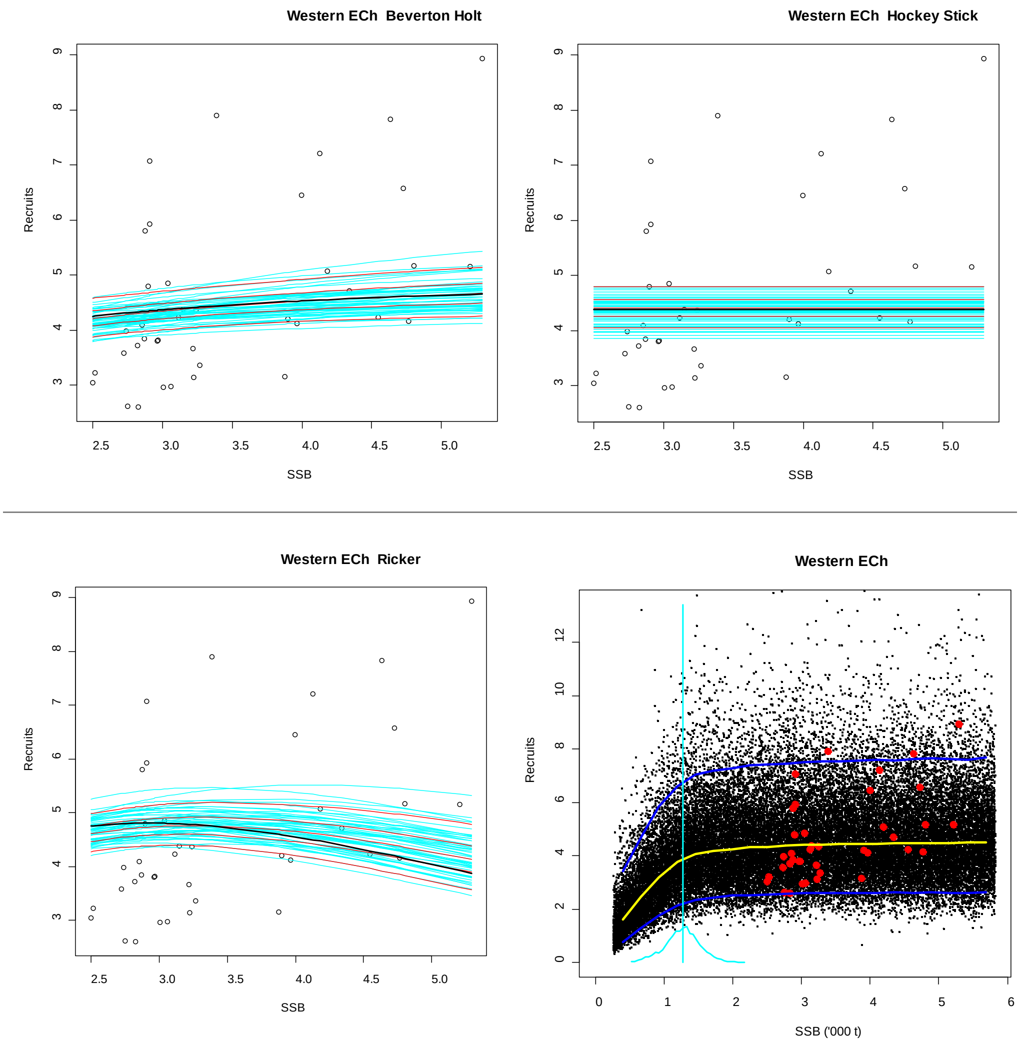


**Figure 15. Western English Channel S-R models with Bayesian fits and simulated values for a) Beverton Holt, b) Hockey stick and c) Ricker functional relationships individually and d) combined simulated values. Panels a,b,c) S-R observations from ICES assessments (o); 50 randomly selected models (cyan lines); Quantiles of modeled mean R at 5,25,50,75,95% ( red lines). For panel d) S-R observations from ICES assessments (●); simulated values using 35, 60,5 % of BH,HS,R models (●) median (yellow) and 5,95% (blue) .Distribution of Blim from HS model and median value (Cyan)**

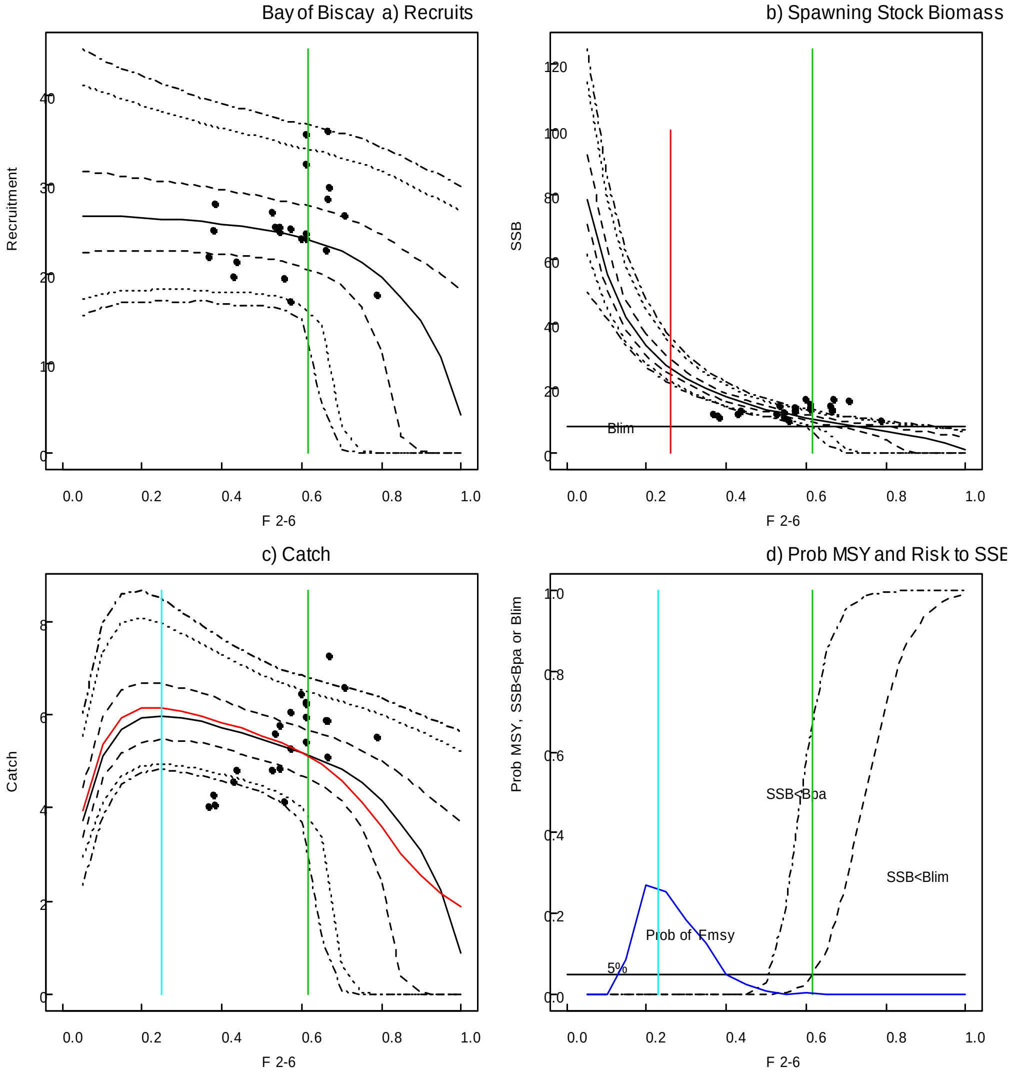


**Figure 16 Equilibrium exploitation of Bay of Biscay sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

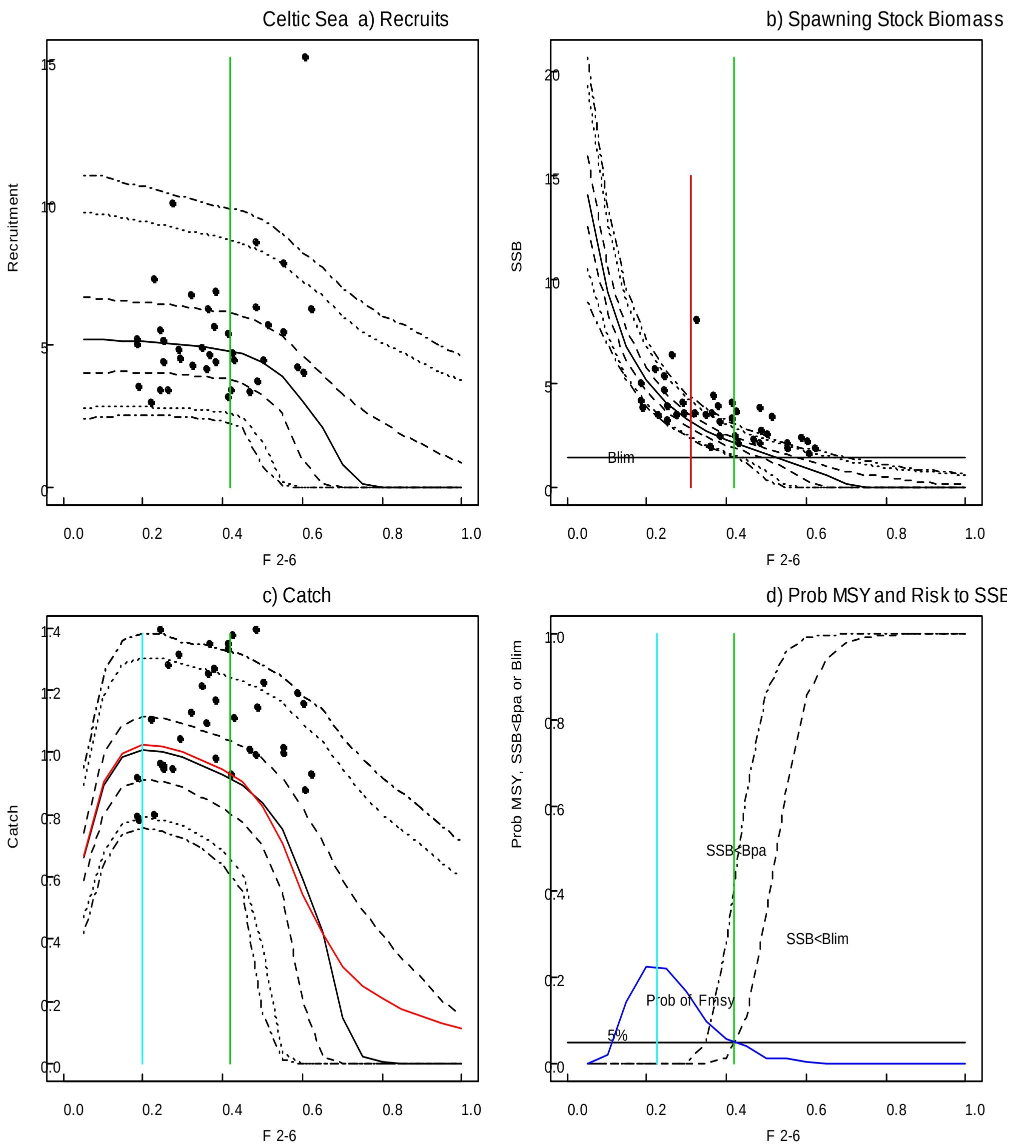


**Figure 17 Equilibrium exploitation of Celtic Sea sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

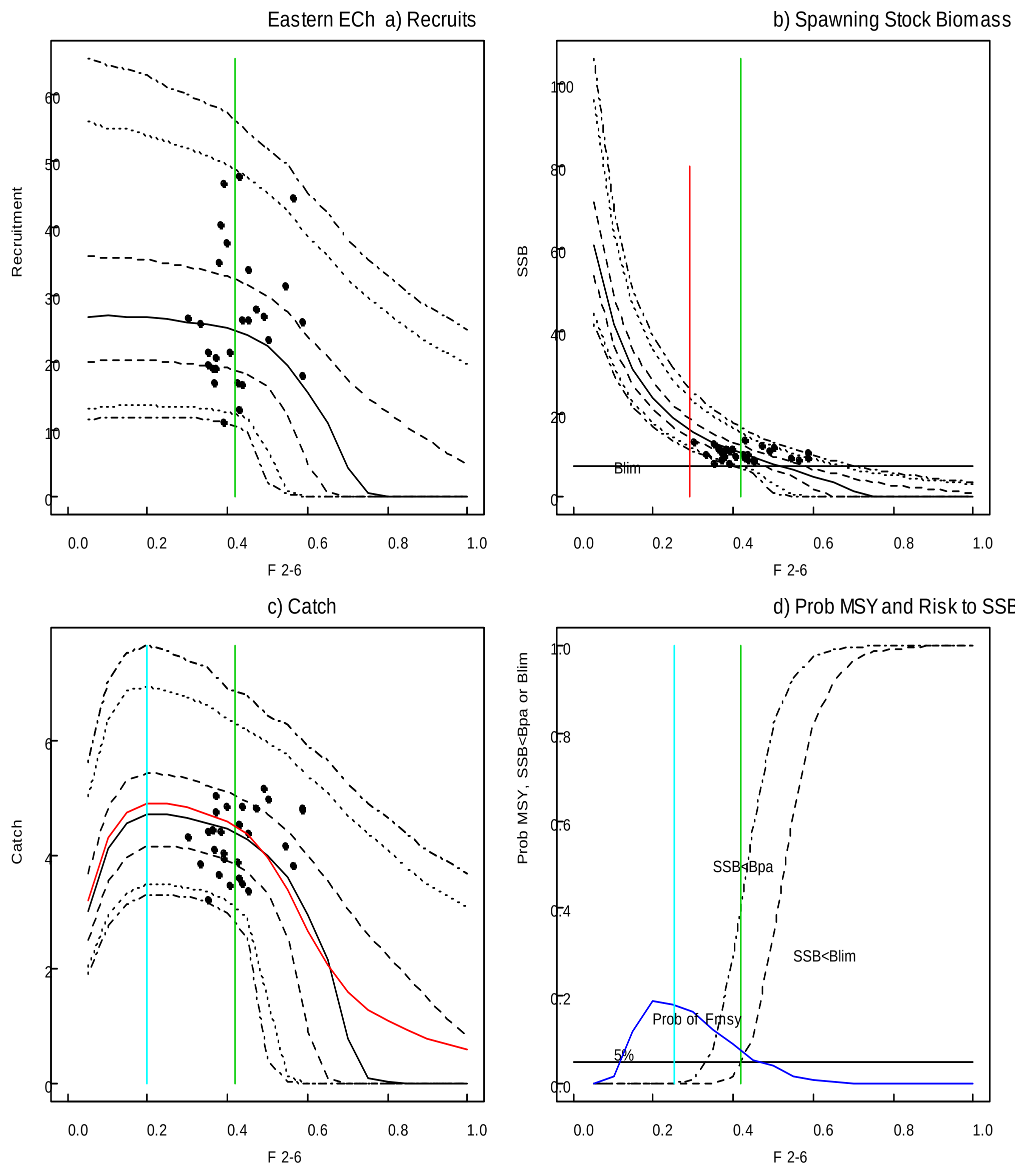


**Figure 18. Equilibrium exploitation of Eastern Channel sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

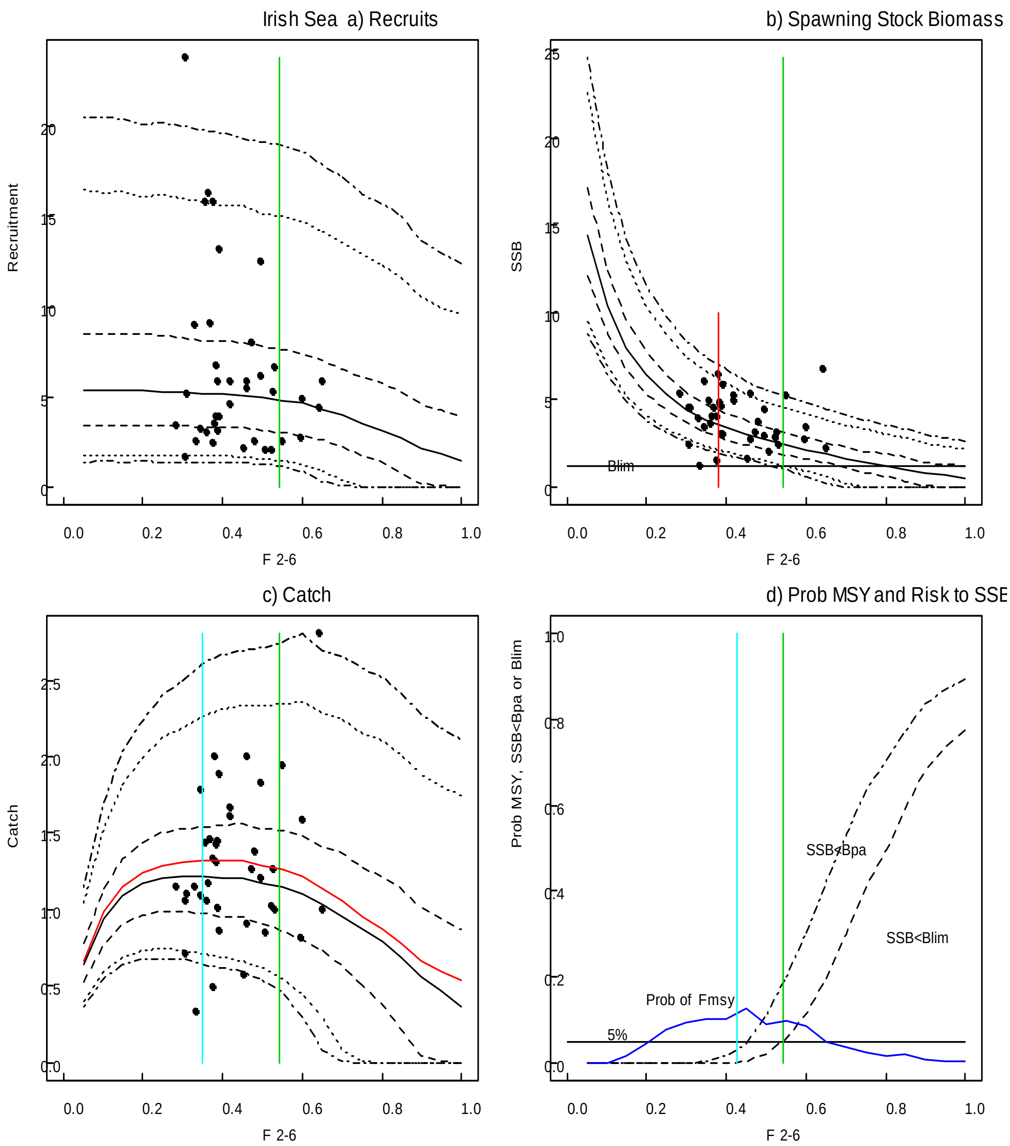


**Figure 19. Equilibrium exploitation of Irish Sea sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

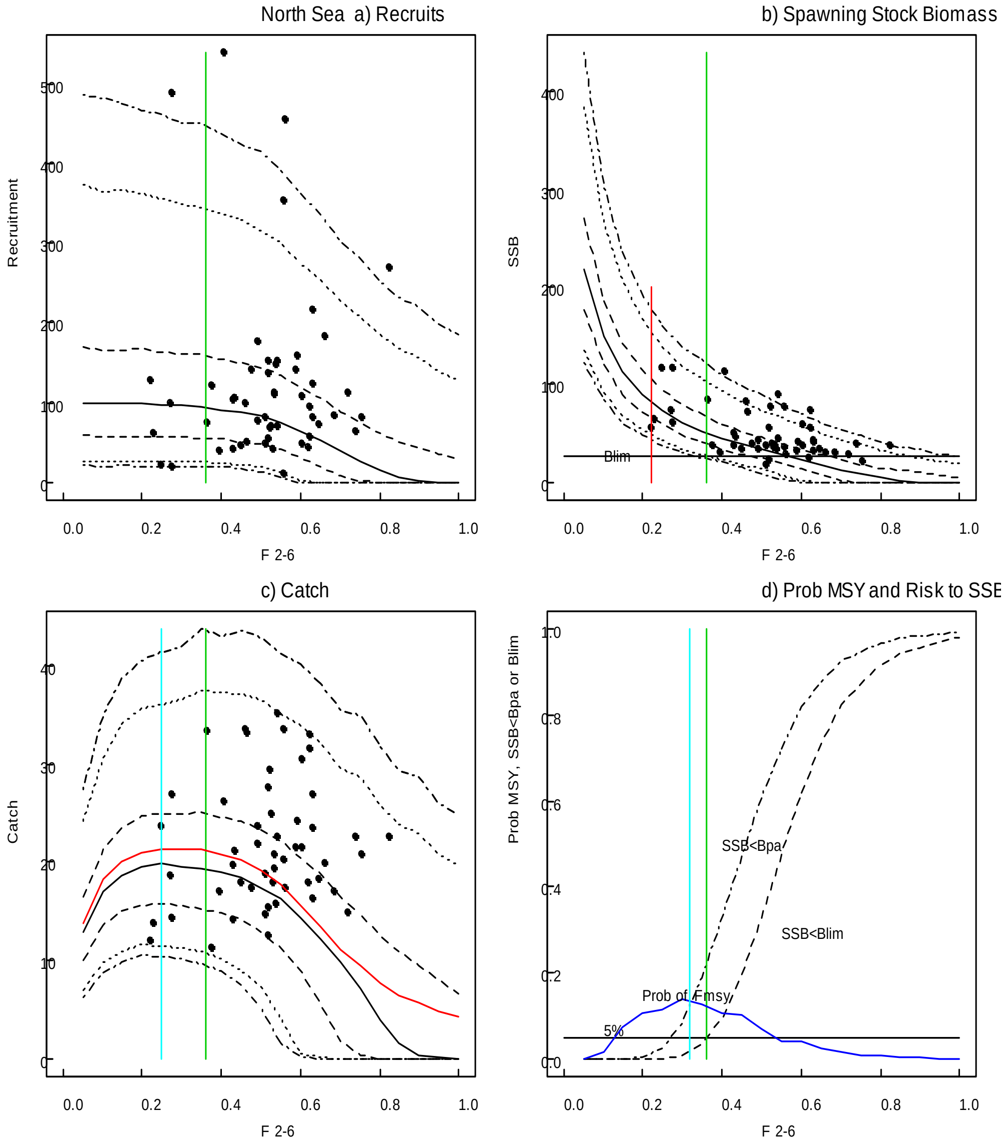


**Figure 20. Equilibrium exploitation of North Sea sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

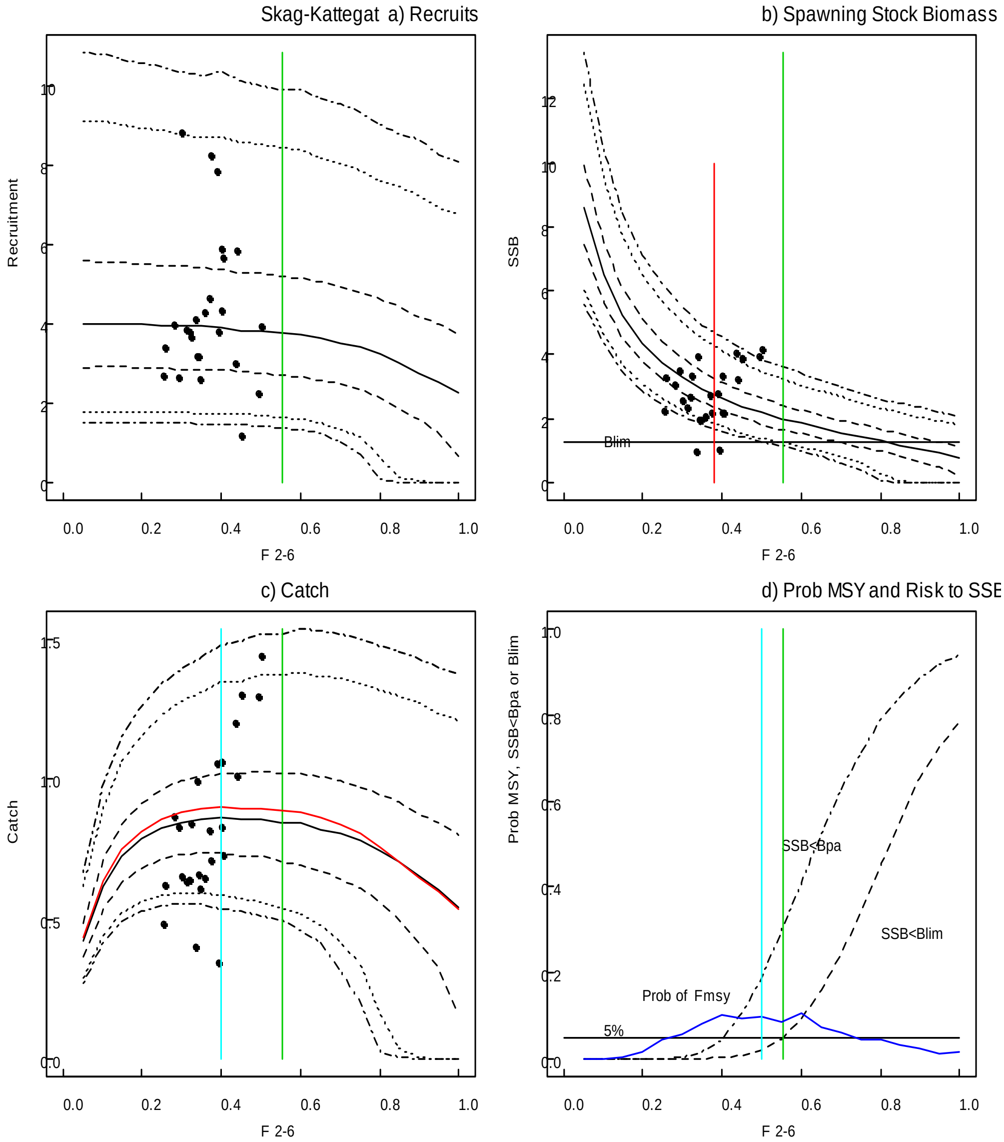


**Figure 21. Equilibrium exploitation of Skagerrak-Kattegat sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

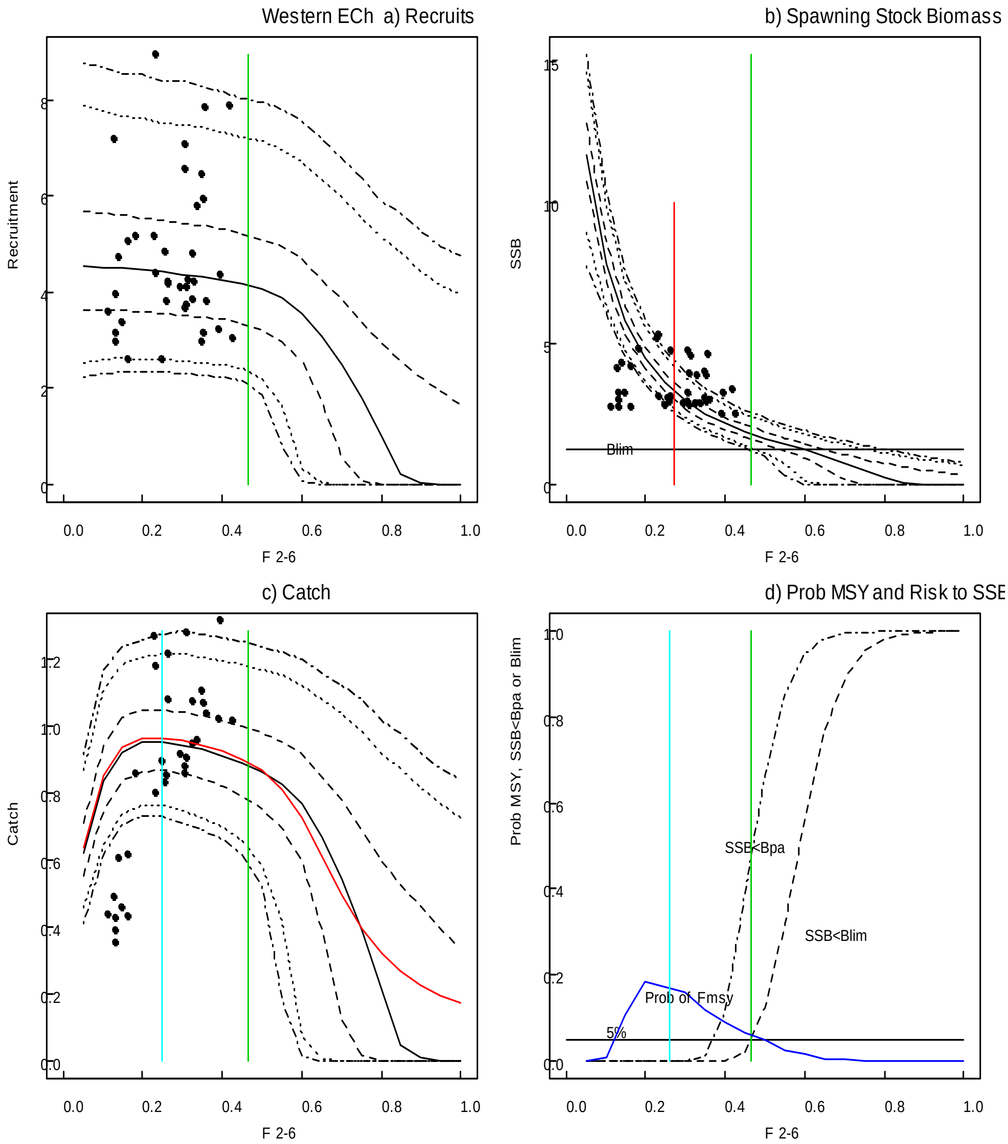


**Figure 22. Equilibrium exploitation of Western Channel Sea sole against target F from F=0.05 to 1.0.Quantiles (0.025, 0.5, 0.25, 0.5, 0.75, 0.95, 0.975) of simulated a) Recruits, b) SSB and c) Catch: black lines and Landings pink lines. Historic Recruits, SSB and Catch: black dots. c) mean landings: red line. d) probability of SSB below Blim and Bpa: black lines and 5% probability of SSB below Blim 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 or target F.**

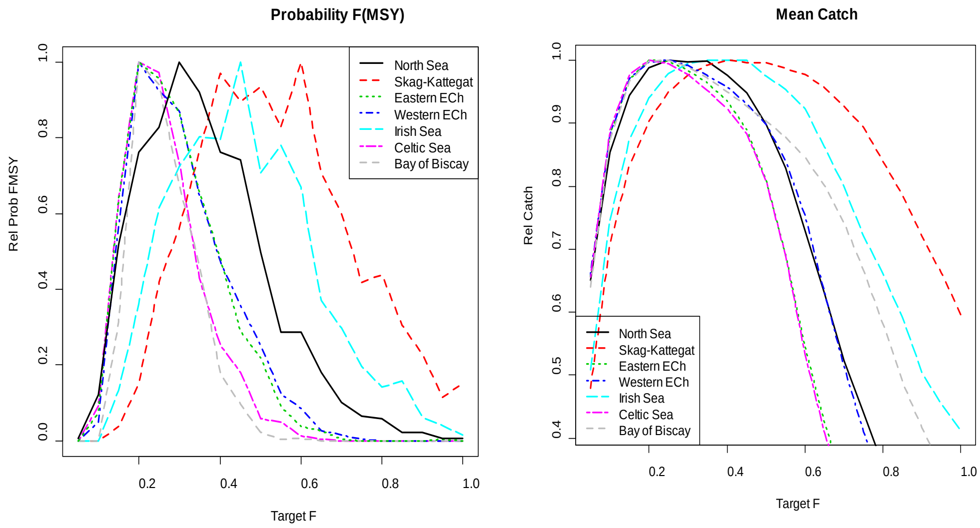


**Figure 23. Distribution of Fmsy by stock based on a) F for maximum yield from 1000 populations and b) maximum mean catch (landings) at equilibrium exploitation.**

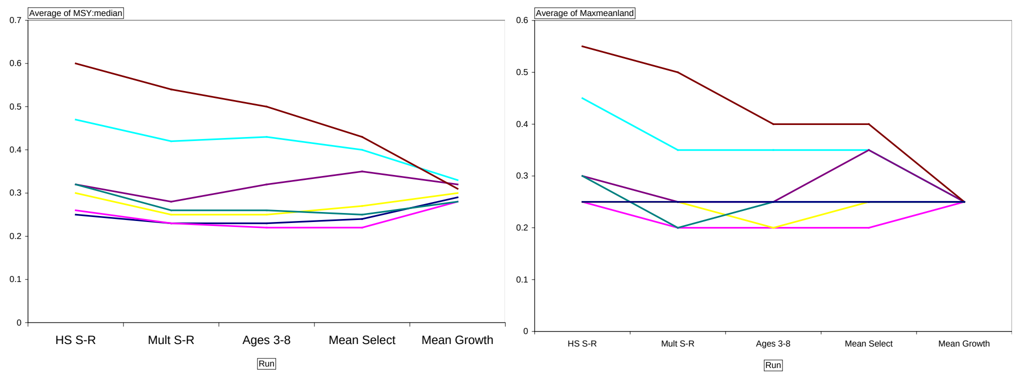


**Figure 24. Illustrating the source of differences in Fmsy across stocks: changes in Fmsy with parameters, a) Median F b) Max mean landings, for 1) HS model only, 2) HS/BH/RK models combined, 3) standardization of ages 3-8, 4) common average selection at age in the fishery, 5) common mean growth. The setting 3 is used for further evaluations.**

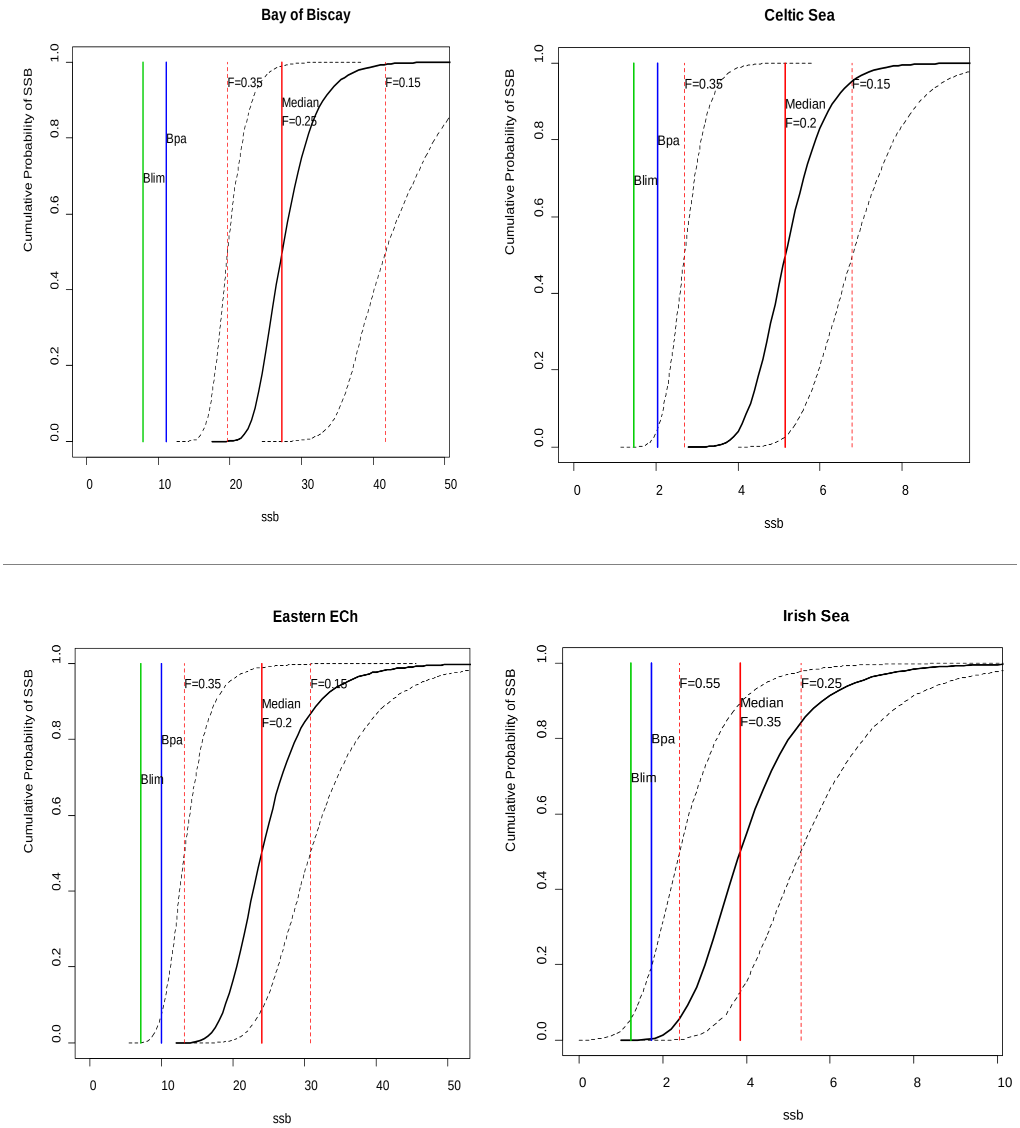


**Figure 25. Equilibrium exploitation of a) Bay of Biscay, b) Celtic Sea, c) Eastern Channel and d) Irish Sea sole. Distribution of SSB at fixed F equilibrium exploitation for maximum mean catch and at F that gives 95% of maximum mean catch, with estimated Blim and Bpa.**

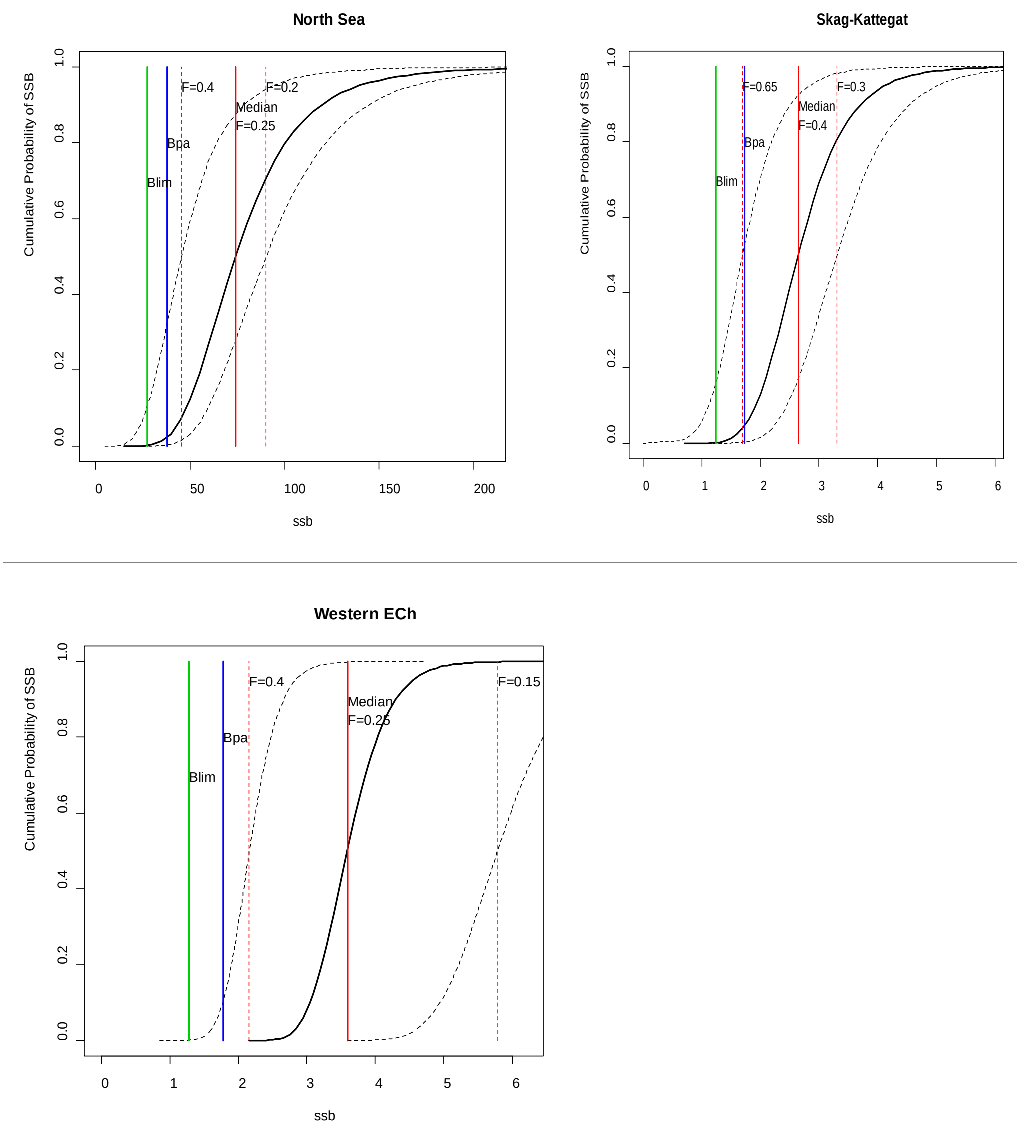


**Figure 26. Equilibrium exploitation of a) North Sea, b) Skagerrak-Kattegat and c) Western Channel sole. Distribution of SSB at fixed F equilibrium exploitation for maximum mean catch and at F that gives 95% of maximum mean catch, with estimated Blim and Bpa.**

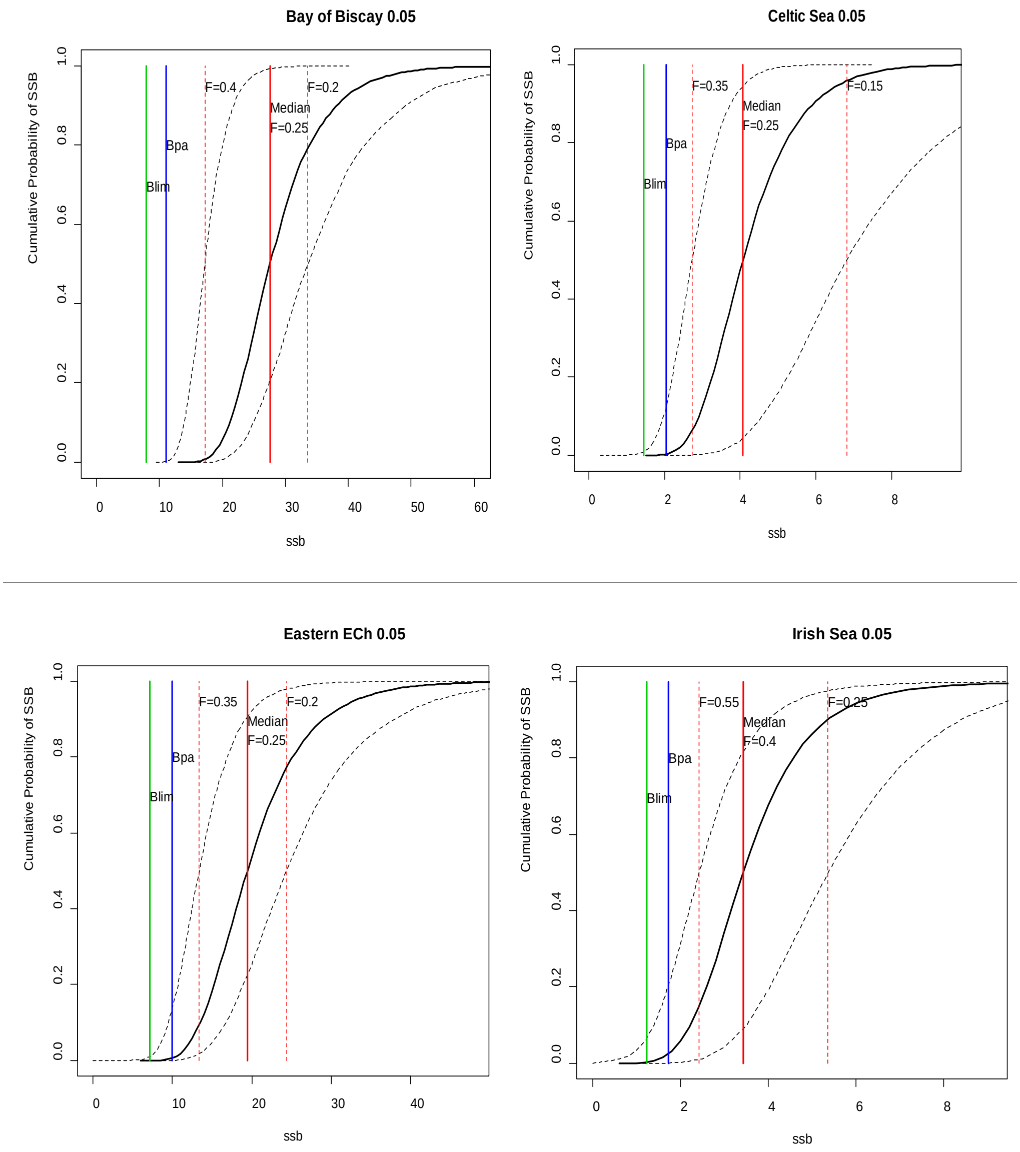


**Figure 27. Equilibrium exploitation with measurement or implementation error giving SD of 0.05 in long term F a) Bay of Biscay, b) Celtic Sea, c) Eastern Channel and d) Irish Sea sole. Distribution of SSB at fixed F equilibrium exploitation for maximum mean catch and at F that gives 95% of maximum mean catch, with estimated Blim and Bpa.**

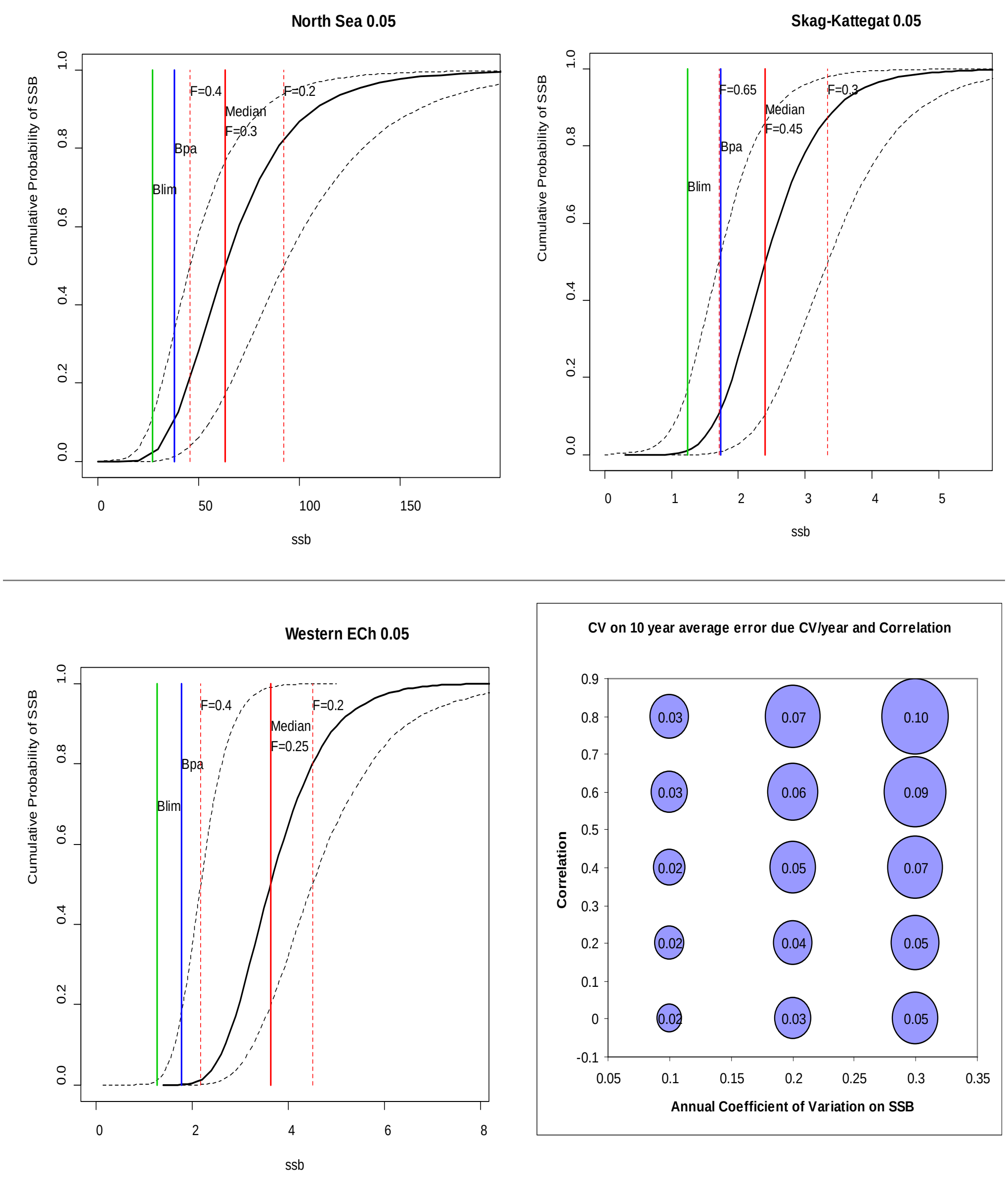


**Figure 28 Equilibrium exploitation with measurement or implementation error giving SD of 0.05 in long term F a) North Sea, b) Skagerrak-Kattegat and c) Western Channel sole. Distribution of SSB at fixed F equilibrium exploitation for maximum mean catch and at F that gives 95% of maximum mean catch, with estimated Blim and Bpa.**

**d) Relationship between long term deviation in F and CVs on annual values and correlation of errors among years. The error chosen for Figues 27 and 28 (0.05) is equivalent to 20% CV with correlation of 0.4**

## 3.2 Bootstrap Confidence Bounds for MSY Reference Points based on Hockey-Stick Stock-Recruit Models. Benoit Mesnil Ifremer, Département EMH, Nantes (France)

### 1. Introduction

As explained in WKFRAME 2010 (ICES, 2010b), the estimation of MSY-related reference points with dynamic-pool stock assessment models combines yield-per-recruit and SSB-per-recruit curves, and the "best fitting" stock-recruit relationship (S-RR). S-RR are generally very uncertain animals: many functional forms fit the data equally well (or badly), and with large residuals. By implication, the estimated reference points have wide confidence regions, and this is aggravated by additional uncertainty in the input data to per-recruit calculations (exploitation pattern, natural mortality M, maturity-at-age, weights-at-age). This is problematic when management decides to use MSY, Fmsy or Bmsy as targets, since the span of scientifically defensible options for choosing a specific value can be very wide. Moreover, in such situations, the range of Fmsy may overlap the range of risky fishing mortality such as Fcrash, and caution is warranted. As shown by Mesnil and Rochet (2010), a dangerous proximity between Fmsy and Fcrash is likely to take place when the S-RR is of the hockey-stick type, notably when the yield curve is flat-topped: a small addition to F may cause the production curve to fall more abruptly than with other S-RR. Hence, it is important to associate the estimates of MSY-related points with a quantification of their inherent variability.

In this short paper, only the effects due to the noise in the S-RR fit, when it is of the hockey-stick form, is considered (leaving aside errors in the per-recruit input data). In pages 52-53 of its report, WKFRAME 2010 suggests a procedure to estimate a confidence interval for Fmsy with a two-parameter S-RR. A bivariate normal distribution is generated using the variance-covariance matrix from the fit, and a large number of parameter pairs are sampled from this distribution. The calculation yielding the MSY reference points is replicated over the set of pairs, which results in a distribution of Fmsy etc. from which 90% confidence bounds can be produced. This procedure has the advantage of preserving the correlation between the S-RR parameters. However, the choice of a normal distribution has the disadvantage that a large fraction of negative, unfeasible parameters is generated; elimination of these values by hand results in badly distorted distributions, such that the confidence intervals are undesirably censored. Attempts to circumvent the problem through the generation of bivariate Gamma parameters (strictly defined on the positive axis) by means of the copula method proved frustrating (difficult to tune the shape and scale of the Gamma in order to mimic a plausible range of variation of the parameters). It was suggested that fitting the S-RR with Bayesian methods would naturally provide the joint posterior distribution, from which pairs of parameters could be sampled. Here, I took a simpler (and perhaps equivalent) approach using a non-parametric, model conditioned bootstrap.

### 2. Method

This study is restricted to the case of the Watts-Bacon continuous hockey-stick S-R model (Mesnil and Rochet, 2010). This has three parameters, but the general recommendation –which I followed – is to fix the curvature parameter at a small value (0.1 here), which leaves two free parameters. The procedure was implemented in simple R scripts, and the steps are as follows:

i ) Fit the hockey-stick model to stock-recruit data (typically read from VPA summaries) using any decent non-linear regression fitting algorithm; obtain the "base-case" parameters (half-slope of the ascending segment and SSB at breakpoint), the residuals at the ML solution, and the fitted recruitments at each observed SSB;

ii ) The non-parametric, model-based bootstrap consists in generating *N* replicates where randomly sampled residuals (with replacement) are added to the fitted recruitments in each year, and the S-RR is fitted again on these perturbed recruits against observed SSB. This was done with the R function *boot()* as explained in pp. 225-226 of Venables and Ripley (2002), yielding *N* (= 999) pairs of hockey-stick parameters ; note that this approach also preserves the sign (if not the magnitude) of possible correlation between S-RR parameters;

iii ) Feed the *N* pairs of bootstrap parameters into the routine producing the estimation of MSY, Fmsy, Bmsy etc., together with the standard input data for per-recruit calculations; this results in *N* estimations of MSY-related reference points;

iv ) Inspect and plot the distributions of the reference points.

## 3. Results

### 3.1. Example 1: North Sea cod

The stock and recruitment data (year-classes 1963-2006) were taken from the VPA summary of the 2009 assessment (ICES, 2009). The Watts-Bacon hockey-stick S-RR was fitted with a Marquardt algorithm in library *nls.lm*. Figure 1 shows the base-case fit along with a sample of 9 bootstrap replicates.

The table of input data for long-term predictions was taken from datasets available for trials at last years' WKFRAME meeting. The set considers fishing mortality and weights for the landings and for the discards; however, all estimates of MSY and Fmsy are based on maximisation of the landings component only. Moreover, the fishing mortalities at age of both components have been scaled, such that Fmsy and Fcrash are obtained as actual mean F's (ages 2-4), not as multipliers of the reference exploitation pattern. The distributions of MSY reference points resulting from bootstrapped S-RR parameters are shown in Figure 2.

Perhaps unexpectedly, the method indicates that Fmsy has remained strictly constant despite the large variation in the S-RR (Fig. 2.A). This can be explained easily. The recruitment R corresponding to MSY is obtained at the intersection of the S-RR with the replacement line associated with the fishing mortality maximising yield. When a hockey-stick is assumed, the replacement lines for F's maximising yield always cross the S-RR in the region where recruitment is flat. Hence, equilibrium yield is maximised as if R was constant; therefore, Fmsy ends up being equal to Fmax, the fishing mortality maximising yield per constant recruitment which, by definition, is unaffected by the specification of the S-RR or the variability of the parameters thereof. This feature happens with many stocks but is not a universal property, as seen with the next example. In this case, we can also see that Fmsy is safely distinct from Fcrash, as the respective distributions are broadly separated.

In contrast, estimates of MSY and Bmsy do have a huge variability in response to noise in the S-RR (Fig. 2.B-C). There are indeed clear outliers in these plots because of some extravagant S-RR from the bootstrap (Figure 1 shows that the residuals about the base-case fit can be large in some years). Although the inter-quartile range looks reasonable (410-517 kt for MSY, 2.0-2.5 Mt for Bmsy) eventually, the implication from this plot is that a policy based on a target fishing mortality near Fmsy would be less uncertain than one aiming at bringing the stock in the vicinity of Bmsy.

### 3.2. Example 2: Norwegian spring spawning herring

Critics often argue, rightly, that non-parametric, model-based bootstrap can be misleading when the pool of empirical residuals to draw from is small (i.e. the time series of stock and recruitment estimates is short). Although the length of data is decent for North Sea cod, it was tempting to try a longer time series; in ICES, the longest series available seems to be the one for Norwegian spring spawning herring (NSSH), currently assessed by WGWIDE (ICES, 2010a).

The stock and recruitment data for year-classes 1950-2007 were taken from the .sum file of the 2009 WG (dropping the last 2 values). Samples of Watts-Bacon HS fits are shown in Figure 3. Compared to cod (Figure 1) the S-R curves have a much steeper slope at the origin, but here again some historical recruitments are ways above the curve; hence, we can expect that the bootstrap will often pick up large residuals to add to the fitted values.

The input data for prediction were taken from Table 7.10.1.3 of the 2010 report. Since the exploitation pattern (average of the last 5 years) has not been scaled, the quantities labelled Fmsy and Fcrash are in effect multipliers to the reference F array. Note that this study differs from the WG assessment in important ways: I used the long series of S-R data whereas, for certainly good reasons, WGWIDE only chose a recent series since 1988; the WG considered additional noise in the input data, whereas I just consider the variability due to the S-RR; in addition, the WG considered various options for the maturity data. Hence, the results here are for illustration only, and should not be viewed as an update or an alternative to the ICES assessment, and still less as a contradiction.

The bootstrap distributions of the MSY reference points are displayed in Figure 4; these are based on 995 replicates because 4 were trapped for lack of converge. Compared to the previous example, panel A offers a very different perception of the effects of assuming a hockey-stick S-RR upon Fmsy. Not only Fmsy is not constant at Fmax but also, as noted by WGWIDE, the distribution of Fmsy is nearly identical to that of Fcrash. The process involved here seems to be that the search for Bmsy always converges at or very close to the value of the breakpoint S* of the hockey-stick (the ratio Bmsy/S* is 0.995-1.04 over all replicates). The true reason is that, as reported by WGWIDE, Fmax is poorly defined since the yield-per-recruit curve keeps increasing at Fs of 2 and above (see their Figure 7.8.2.ypr, p. 384 of the 2010 report); thus, the search for maximum yield is attracted in an area of high Fs where suddenly it crosses the boundary of the Fcrash domain. The only feasible maximum is then for an F just a small step below Fcrash, corresponding also to Bmsy in the vicinity of S*. In view of Figure 3 there are reasons to doubt that a hockey-stick S-RR is appropriate for this stock (WGWIDE also found a Beverton-Holt to be inadequate); supposing it was, there are indications that fishing at Fmsy would generally imply higher fishing mortality than the current one (inter-quartile range for the Fmsy factor is 0.93-1.51), but at the risk of excursions into the Fcrash region. This time, the distributions for MSY and Bmsy have a smaller number of extreme values and these reference points might be more robust bases for a management policy than Fmsy.

## 4. Discussion

It is well established that estimates of MSY-related reference points are strongly dependent on the specification of the stock-recruit relationship, which itself is highly uncertain for a large number of fish stocks. Where changes in productivity have occurred, owing to changes in ecosystems or climate, there is also the question of whether the S-RR parameters and the reference points should reflect only the current context rather than the full history. In any case, it is good practice to provide a quantification of the uncertainty in the reference points alongside the nominal values proposed to managers. One way of doing this is to consider parametric distributions for the input data. However, this can be fraught with difficulties: normal distributions return unwanted negative values, the log-normal can return extreme values from its long tail, bivariate gamma is hard to tune properly, etc. Apart from going fully Bayesian, one alternative is the non-parametric bootstrap, using residuals about the empirical data. This has the advantage of simplicity and speed (even with slow R); also, the range of variation of the input data is strongly driven by the signal in the observations, rather than being determined by a theoretical construct. The method is as well a natural way of caring for correlation among parameters (always negative with Watts-Bacon). However, the results are questionable when the number of residuals is small, i.e. the time series of S-R observations is "short".

As said, for a given stock, there are seldom strong justification to choose one among the several possible stock-recruit relationships. Nevertheless, it is very imprudent to assume that recruitment is independent of the stock size, notably in simulations where the latter can be strongly reduced. The hockey-stick is therefore often viewed as a cautious fall back option when some degree of S-RR is to be accounted for in simulation. There are, however, few studies of how the assumption of this specific S-RR affects the property of the MSY reference points based on it. For two cod examples, Mesnil and Rochet (2010) showed that Fmsy coincide with Fmax, and suggested that varying the S-RR parameters has negligible effects on the value of Fmsy; however, the evidence was weak as it was only based on a leave-one-out analysis resulting in small variations in the S-RR parameters and a handful of Fmsy estimates (whose differences proved to be within the tolerance set for the minimiser).

In this study, the North Sea cod example confirms these findings, with this time a large amplitude in the S-RR parameters. To the extent that one trusts the hockey-stick to be the pertinent S-RR, a practical implication is that Fmax can be confidently treated as a genuine Fmsy. This goes somewhat against the established thinking that Fmax is a risky proxy for Fmsy (Mace and Sissenwine, 1993; Quinn and Deriso, 1999; Punt and Smith, 2001); perhaps, it is the same arguments and analyses that support the treatment of Fmsy as a limit rather than as a target. In this example, it is shown that Fmax stays safely away from Fcrash, but this is not always the case; therefore, it is prudent to always produce a plot comparing the distribution of Fmsy and Fcrash.

The Norwegian spring spawning herring example provides a very different perspective on the properties of Fmsy when a hockey-stick is assumed. In this case, Fmsy varies over a broad range AND this range essentially coincides with that of Fcrash. WGWIDE 2010 came to the same conclusion although they used different data (recent S-R pairs) and a different approach (parametric, lognormal errors on input). As anticipated by Mesnil and Rochet (2010) in their conclusion, this configuration is to be expected in cases where the yield-per-recruit is flat-topped; automatically, the maximum yield can only be found for fishing mortalities just short of Fcrash, and the related implication is that Bmsy is close to the hockey-stick breakpoint S*. Perhaps, the review of experience by ICES WGs during 2010 at this years WKFRAME2 will indicate if this pattern occurs frequently or if (as I expect, given the poor exploitation patterns in many European fisheries) the pattern seen with North Sea cod is the standard. In the former case, it is still more imperative to produce a comparative plot of the distributions of Fmsy and Fcrash, suggested above as a regular diagnostic. A plot showing the ratio of Bmsy to the breakpoint S* in each bootstrap replicate would also be a useful diagnostic. For all cases resembling the NSSH pattern, it is clearly unwise to recommend a policy based on formally defined Fmsy. Fishing mortality levels producing high long term yield on a sustained basis should rather be explored through stochastic simulations to the extent, however, that these are not subject to the very same difficulties regarding the effects of the S-RR as we have seen in this example.

In conclusion, the choice of the stock-recruitment relationship is not neutral, particularly in the context of MSY reference points. The hockey-stick which is often viewed as a nice, unsophisticated and reasonable expedient may behave nastily in some circumstances.

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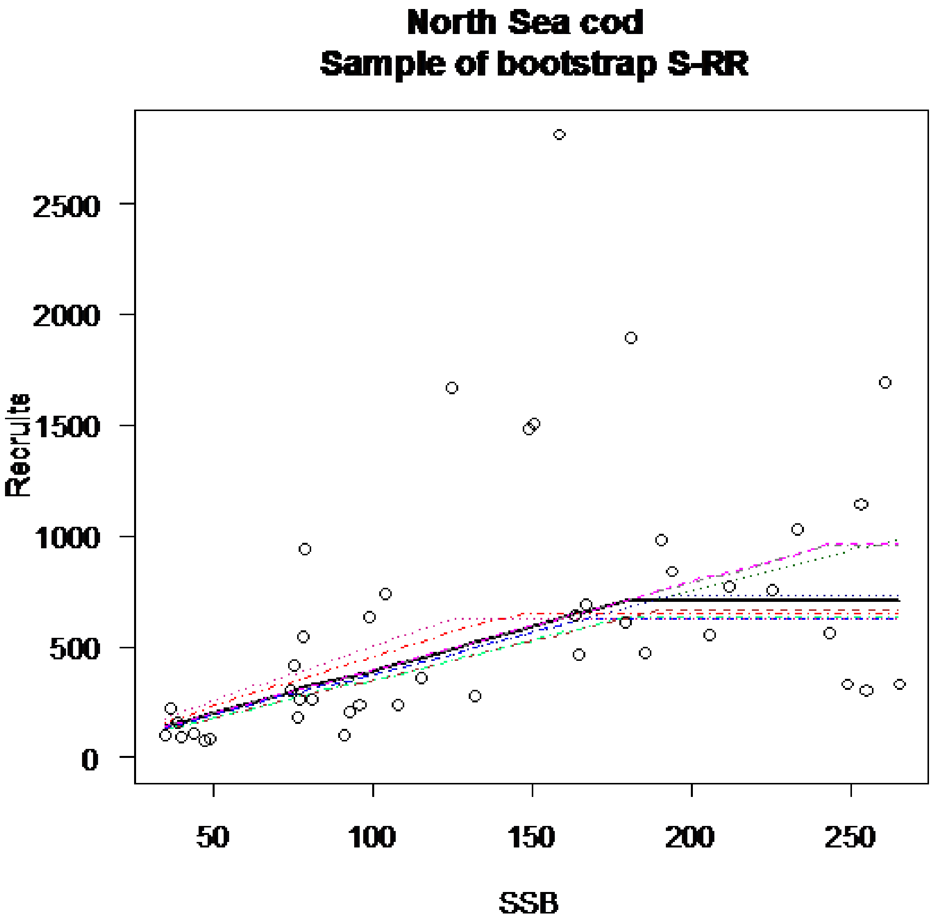


**Figure 1. North Sea cod. Base-case Watts-Bacon S-RR fit (black solid line) and a sample of bootstrap replicates. The open circles are the observed stock-recruits pairs**

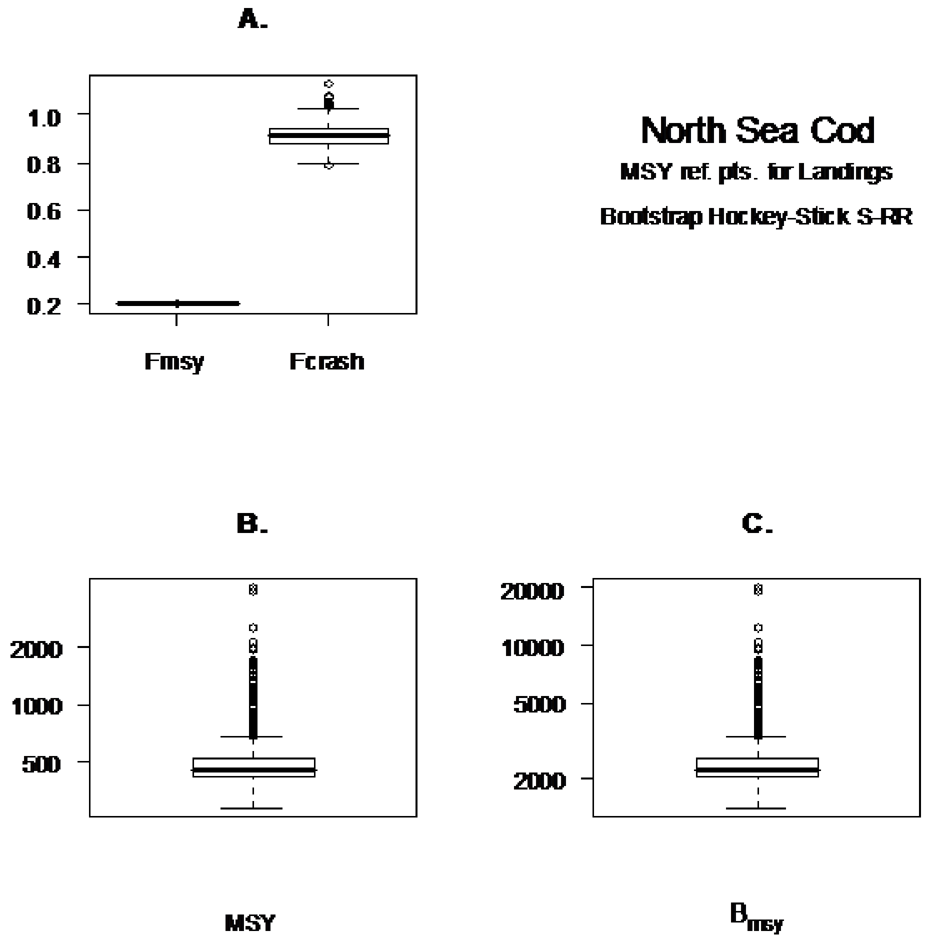


**Figure 2. North Sea cod. Bootstrap distributions of Fmsy and Fcrash (A; here these are actual F, not F factors), MSY (B) and Bmsy (C).**

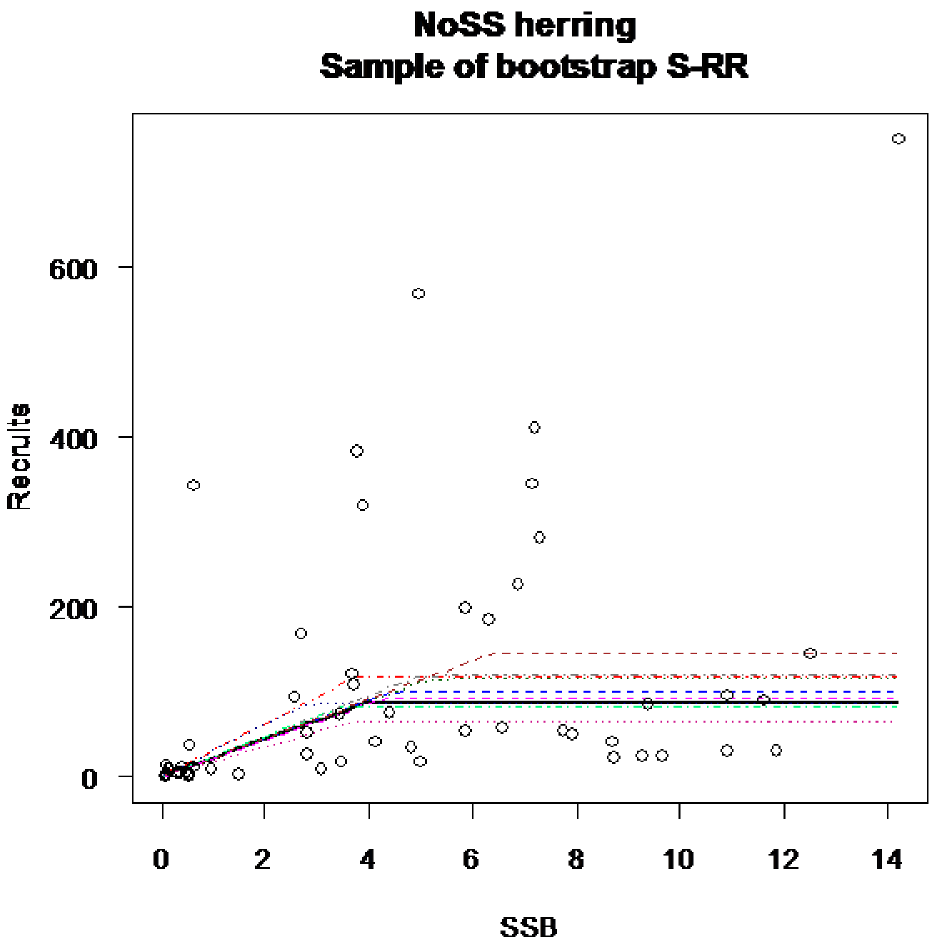


**Figure 3. Norwegian spring spawning herring. Base-case Watts-Bacon S-RR fit (black solid line) and a random sample of bootstrap replicates. Empirical data shown as open circles.**

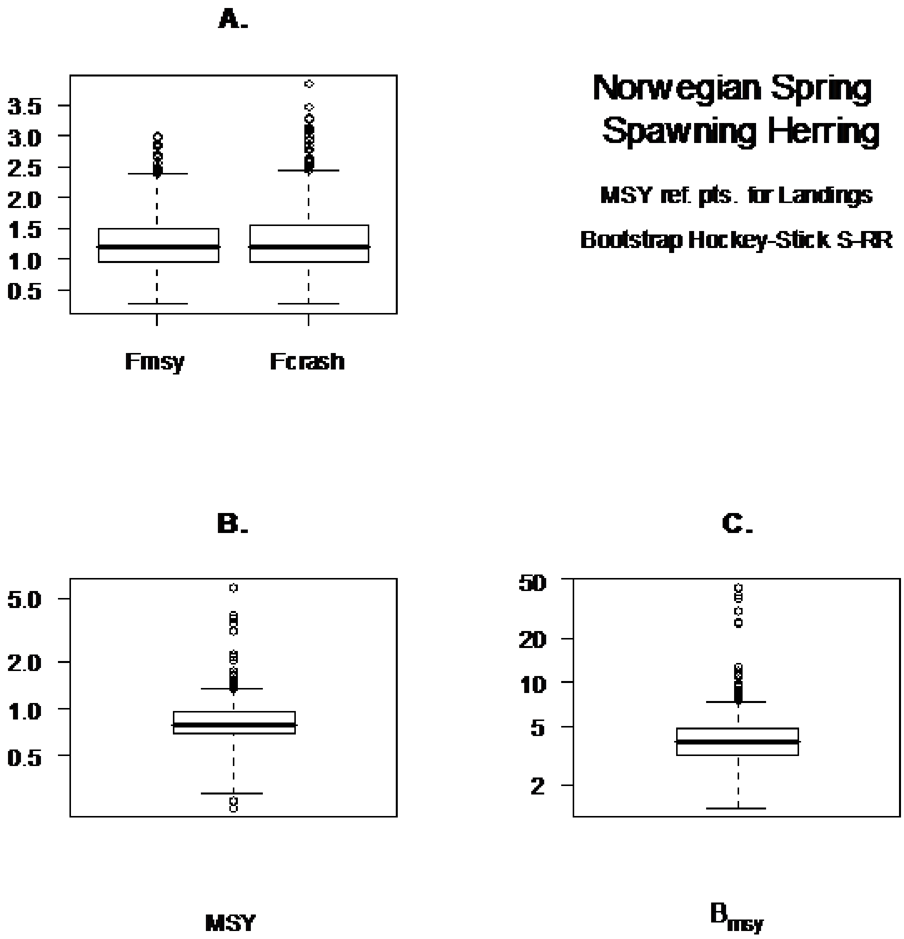


**Figure 4. Norwegian spring spawning herring. Bootstrap distributions of Fmsy and Fcrash (A; here these are F factors), MSY (B) and Bmsy (C).**

## 3.3 Revisiting $B_{lim}$ – using segmented regression in FLR. Henrik Sparholt

**Note that any comparisons with previously estimated $B_{lim}$ values need to use the same methodology, where the same methodology is not used then the direct comparison is not down to the new data alone.*

### Introduction

Most Blim values were set about 10 years ago. Therefore with 10 more data years in the S-R time series it might be worthwhile revisiting these estimates. Furthermore, time series which 10 years ago were considered too short for estimating Blim might now be long enough to do so. This document revisit Blim for 10 major ICES stocks using the FLSR function "segreg" for segmented regression. It also makes a small test of this FLSR function.

### Material

S-R time series were taken from ICES Advisory Report 2010 for the following stocks:

| Stock | Time series year range (year of spawning) |
|---|---|
| Cod in the North Sea | 1964-2008 |
| Cod in the Baltic SD 22-24 | 1971-2008 |
| Cod in the Baltic SD 25-32 | 1968-2008 |
| Cod in the Northeast Arctic | 1949-2008 |
| Haddock in the North Sea | 1963-2008 |
| Plaice in the North Sea | 1958-2008 |
| Sole in the North Sea | 1958-2008 |
| Mackerel in the Northeast Atlantic | 1980-2007 |
| Herring in the North Sea | 1961-2008 |
| Herring  Norwegian Spring Spawning | 1950-2008 |
| Sprat in the Baltic SD 22-32 | 1975-2008 |

The time series available generally include 2009 and 2010, but these data points are considered uncertain due to the convergence features of the assessment calculations. For mackerel even 2008 was rejected in the present analysis, because this assessment is particular uncertain in the terminal data years.

### Method

The segmented regression function "segreg" in FLSR was considered. It estimates the segmented regression curve, which gives the least sum of squared log residuals of the observed data. The "segreg" function assumes that the independent variable, S, is known without error. The code is given in Annex 1. The function can be found on the FLR homepage http://flr-project.org/.

A few simple tests were made of the ability of "segreg" to reproduce the break point on simulated S-R data. The data simulated assumed a basic model of S-R with a breakpoint at S=20, and a recruitment plateau at R = 20. Noise around this model were simulated based on log normal distributions and a CV = 0.1 for S (assumed to be mainly measurement error) and a CV = 0.5 for R (assumed to be mainly process error).

Each simulated data point was back transformed using the exponential function and bias corrected. The result of one simulation is given in figure 2.

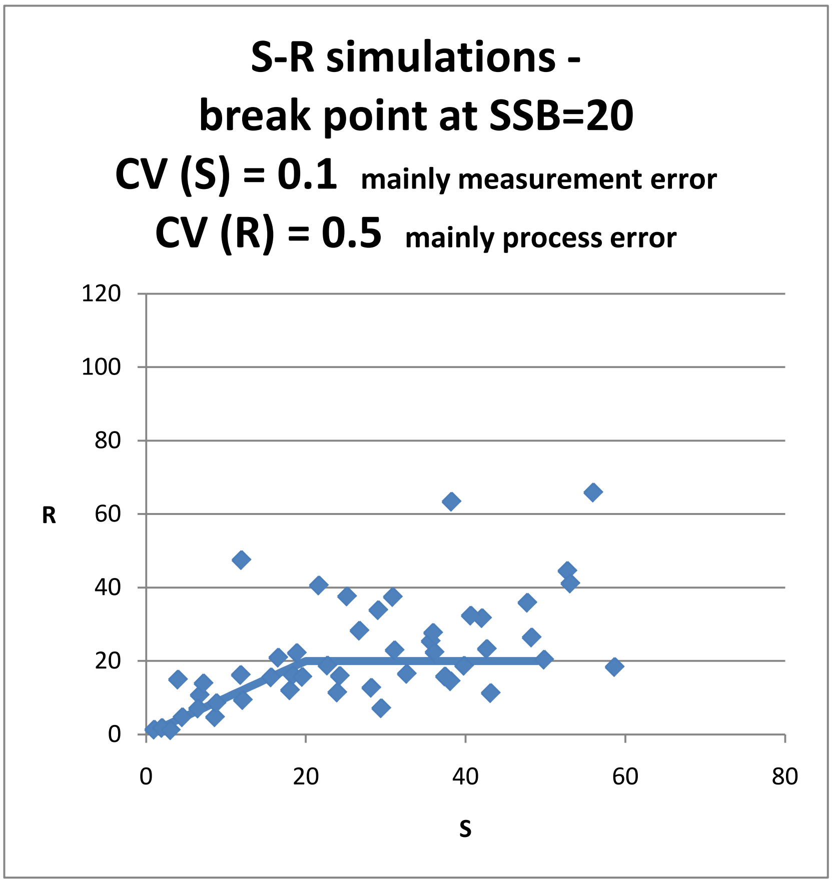


**Figure 1. Simulated S-R data based on a basic model with a breakpoint at S = 20 and a recruitment plateau at R = 20.**

The results of 10 test runs are given in table 1. It can be seen that it slightly overestimate the breakpoint which on average was 22.86 compared to the true value of 20, and the slope which on average was 1.18 compared to the true value of 1.00. However, the test runs were few and the deviations small. It can probably be questioned whether a bias correction in the simulate data are appropriate, but we did analyse that further. The assumption of “segreg” that the independent variable S is known without error could maybe play a role here as well.

**Table 1. Results of 10 test runs with the above simulated data and the use of FLSR "segreg" function.**

| | Breakpoint | Slope | Sigma |
|---|---|---|---|
| Test1 | 22.8 | 1.16 | 0.36 |
| Test2 | 26.6 | 1.06 | 0.26 |
| Test3 | 23.8 | 1.07 | 0.20 |
| Test4 | 13.6 | 1.58 | 0.34 |
| Test5 | 23.1 | 1.15 | 0.25 |
| Test6 | 25.7 | 1.07 | 0.16 |
| Test7 | 26.7 | 1.19 | 0.22 |
| Test8 | 22.0 | 1.10 | 0.28 |
| Test9 | 21.8 | 1.28 | 0.18 |
| Test10 | 22.5 | 1.11 | 0.17 |
| mean | 22.86 | 1.18 | 0.24 |
| True value | 20.00 | 1.00 | 0.25 |

In spite of the large variation in the simulated data the FLSR "segreg" function were able to give quite precise estimates in all the test runs. According to the FLR team (see http://flr-project.org/) no problems have been reported on the FLSR "segreg" function (personal communication).

The FLSR "segreg" function was therefore used on the 10 stocks analysed in this document. Input file format and R code used can be found in Annex 2.

In addition to the estimates of the slope, a, and the breakpoint, b, the program estimates a parameter Sigma which is $CV^2$. The recruitment plateau, the recruitment for S above the breakpoint, can be calculated as a*b. This gives the median R and in order to get the average R a bias correction is needed by multiplying a*b with exp(0.5*sigma).

Figure 2 and table 2 shows the results for North Sea herring. It can be seen that the breakpoint is at 831798 t of SSB, which is pretty close to the present Blim of 800000 t. The plot of residuals by year shows that there is a tendency that recruitment has been below the model in recent years. The 1 year autocorrelation plots shows that it is quite large. There is furthermore a tendency for positive residuals at low SSBs and low expected Rs and negative ones for high SSBs and high expected Rs. All in all, a bit worrying picture in terms of the model not being appropriate, that there might be several regime shifts (see e.g. Payne *et al*. 2009, Gröger *et al.* 2010, Dickey-Collas *et al.* 2011). This stocks has probably the worst diagnostics of all stocks and it is reassuring that it gives sensible results in spite of that.

**Table 2. Segmented regression results for North Sea herring.**

| | | |
|---|---|---|
| B --breakpoint | 831798 | tonnes |
| A --slope | 65.00697 | '000' per tonnes SSB |
| Sigma ~ $CV^2$ | 0.4527017 | |
| Recruitment plateau (A*B) | 54072668 | '000' |
| Recruitment plateau (A*B) biascorrected | 67807967 | '000' |

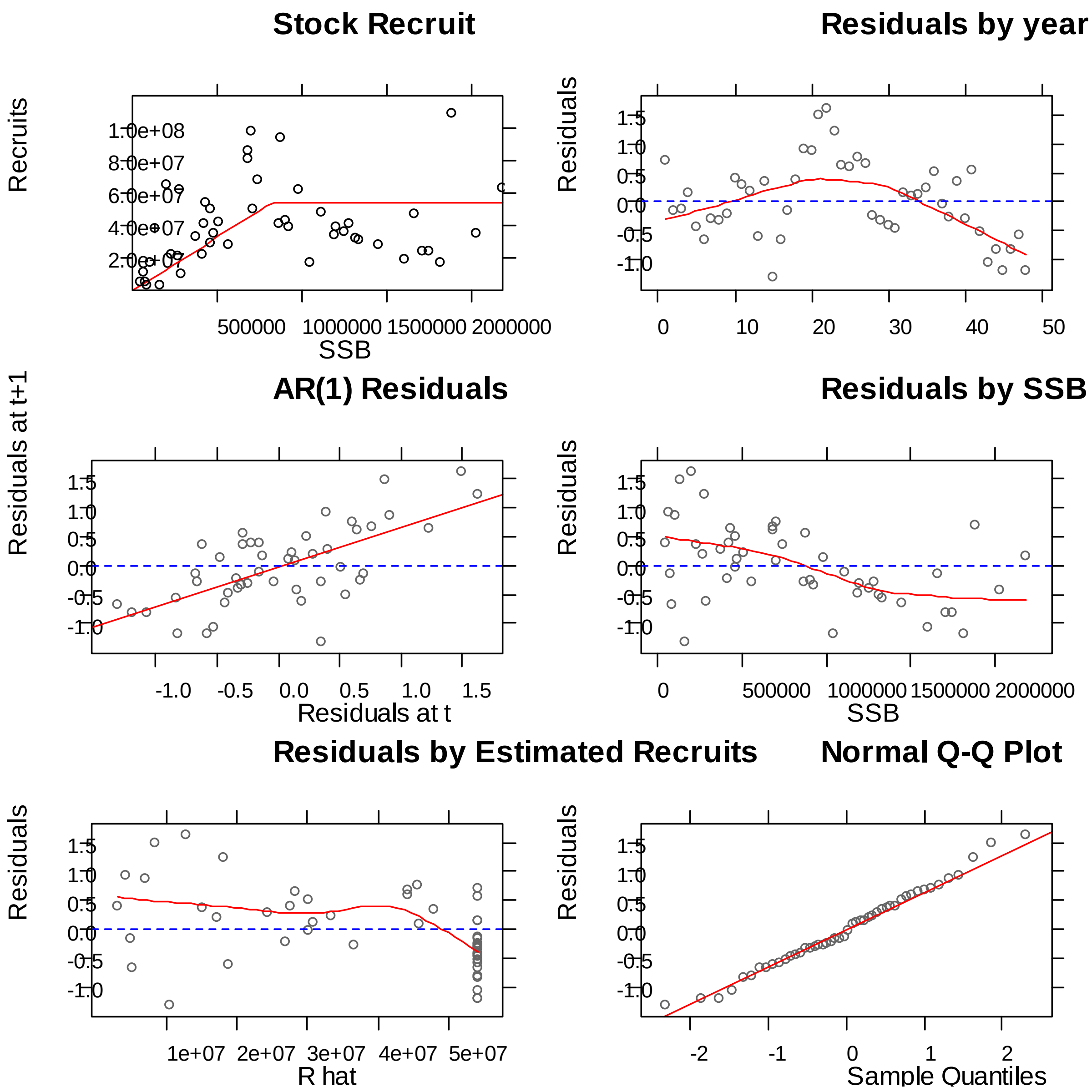


**Figure 2. Segmented regression results for North Sea herring.**

The new breakpoints estimated as described above, can be compared to the present $B_{lim}$ values. This has been done in Table 3. It can be seen that they are generally quite similar although all the new values are higher than the present $B_{lim}$ values. It can also been seen that sensible values have been found for the stocks which hitherto did not have a $B_{lim}$ defined.

**Table 3. The present $B_{lim}$ compared to the new break point estimates.**

| Stock | Present $B_{lim}$ '000't | New Breakpoint '000't |
|---|---|---|
| Cod in the North Sea | 70 | 136 |
| Cod in the Baltic SD 22-24 | Not defined | 32 |
| Cod in the Baltic SD 25-32 | undefined | 273 |
| Cod in the Northeast Arctic | 220 | 390 |
| Haddock in the North Sea | 100 | 105 |
| Plaice in the North Sea | 160 | 300 |
| Sole in the North Sea | 25 | 49 |
| Mackerel in the Northeast Atlantic | 1670 | 2269 |
| Herring in the North Sea | 800 | 832 |
| Herring Norwegian Spring Spawning | 2500 | 4238 |
| Sprat Baltic SD 22-32 | Not defined | 834 |

### Conclusion

There seems to be a possibility to improve the Blim estimates by the method outlined here for the stocks considered here and probably also for several other stocks. The general guidelines stated in ICES 2003 should then be followed based a.o. on inspection of the plots as presented in the present document.

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**Appendix 1. R code for the function segreg in FLSR (pers. communication Ernesto Jardim).**

```
> segreg
function ()
{
     logl <- function(a, b, sigma2, rec, ssb)
sum(dnorm(log(rec),
         log(FLQuant(ifelse(ssb <= b, a * ssb, a * b))),
sqrt(sigma2),
         TRUE), TRUE)
     model <- rec ~ FLQuant(ifelse(ssb <= b, a * ssb, a * b))
     initial <- structure(function(rec, ssb) {
         a <- mean(rec/ssb)
         b <- mean(ssb)
         sigma2 <- var(log(rec/ifelse(ssb <= b, a * ssb, a *
b)),
             y = NULL, na.rm = TRUE)
         return(list(a = a, b = b, sigma2 = sigma2))
     }, lower = rep(1e-04, 3), upper = rep(Inf, 3))
     return(list(logl = logl, model = model, initial = ini-
tial))
}
<environment: namespace:FLCore>
```

## Appendix 2. Input file format and R code used in the analysis in the present document.

```
Input files are two, one for R and one for S. They are simple
.txt files like the one shown below for North Sea herring SSB:
```

```
1882223
1658653
1114267
2185898
2028969
1447015
1279490
922768
412929
424352
374804
266152
288381
233492
162118
81865
78149
47923
65348
107676
131652
196399
279373
433963
680726
701031
681122
902635
1196740
1252458
1187888
982873
705749
475182
511922
463485
464038
562971
738121
866536
878518
1317450
1605297
1744930
1814302
1710000
1331695
1046787
```

The user has to make sure that the start and end of the file match the R file.

Start the R session by selecting R2.8.2. Set the working directory to where the input files are placed by e.g.:

>Setwd("D:\\SR") – but write it in R – problems with the " between Word and R.

Then install the relevant package from the internet by:

```
>install.packages(repos = "http://flr-project.org/R")


    library("FLCore")
```

This opens a dialog box where the FLCore package should be selected.

Now use these R codes:

```
rec <- FLQuant(quant="age",scan("herringNSeaR.txt"))
ssb <- FLQuant(quant="age",scan("herringNSeaS.txt"))
sr1 <- FLSR(rec=rec,ssb=ssb,model="segreg")
rec(sr1)
ssb(sr1)
sr1 <- sr(sr1)
plot(sr1)
params(sr1)
```

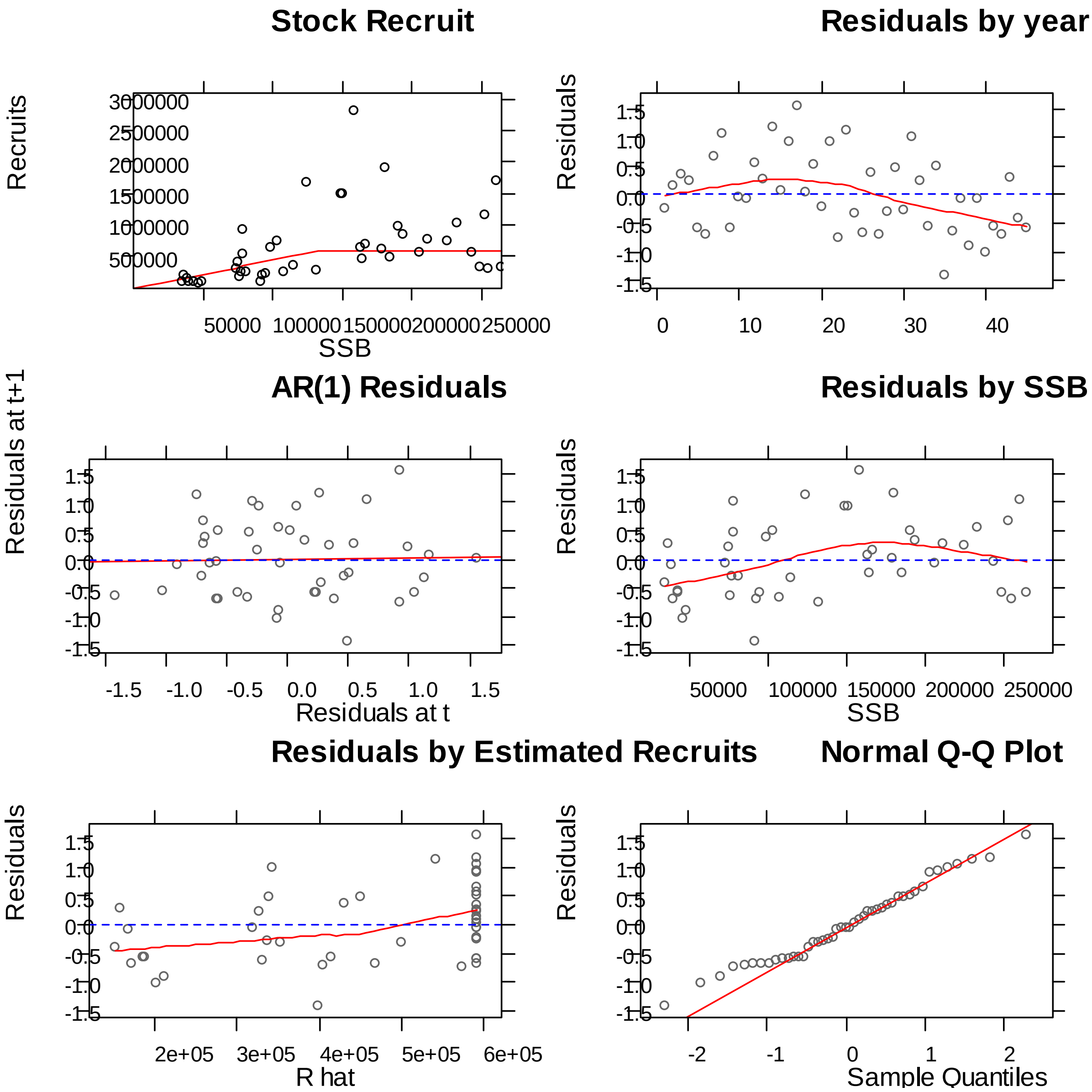
This will do what is needed. You will get estimates of the breakpoint, slope, and sigma as well as various plots.

## Appendix 3. Results by stock.

**----Cod NSea---**

Results

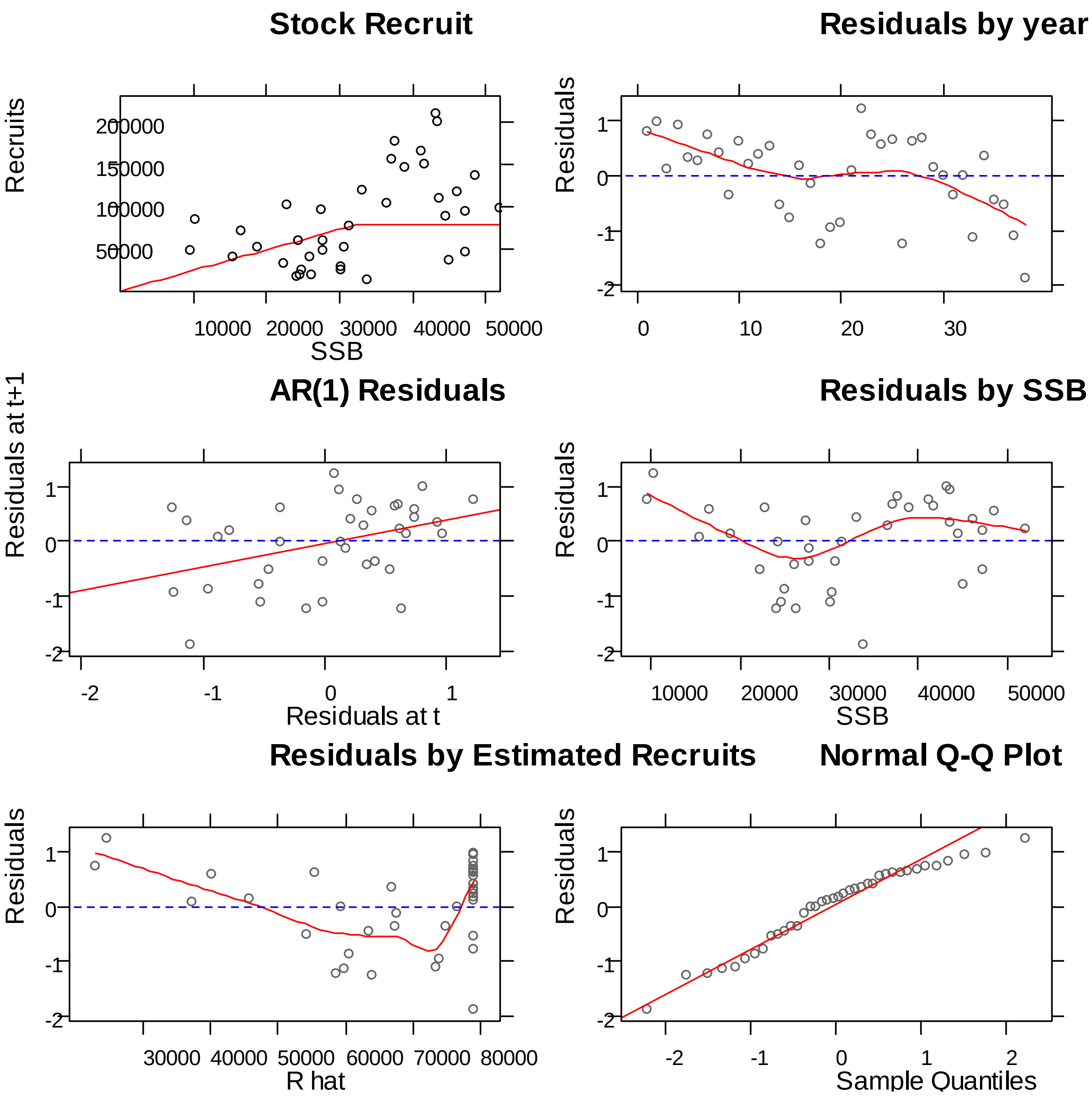
| | | |
|---|---|---|
| B --breakpoint | 135905 | tonnes |
| A --slope | 4.350424 | '000' per tonnes SSB |
| Sigma ~ CV² | 0.4418094 | |
| Recruitment plateau (A*B) | 591244 | '000' |
| Recruitment plateau (A*B) biascorrected | 737403 | '000' |



----Cod 2224 ---

Results

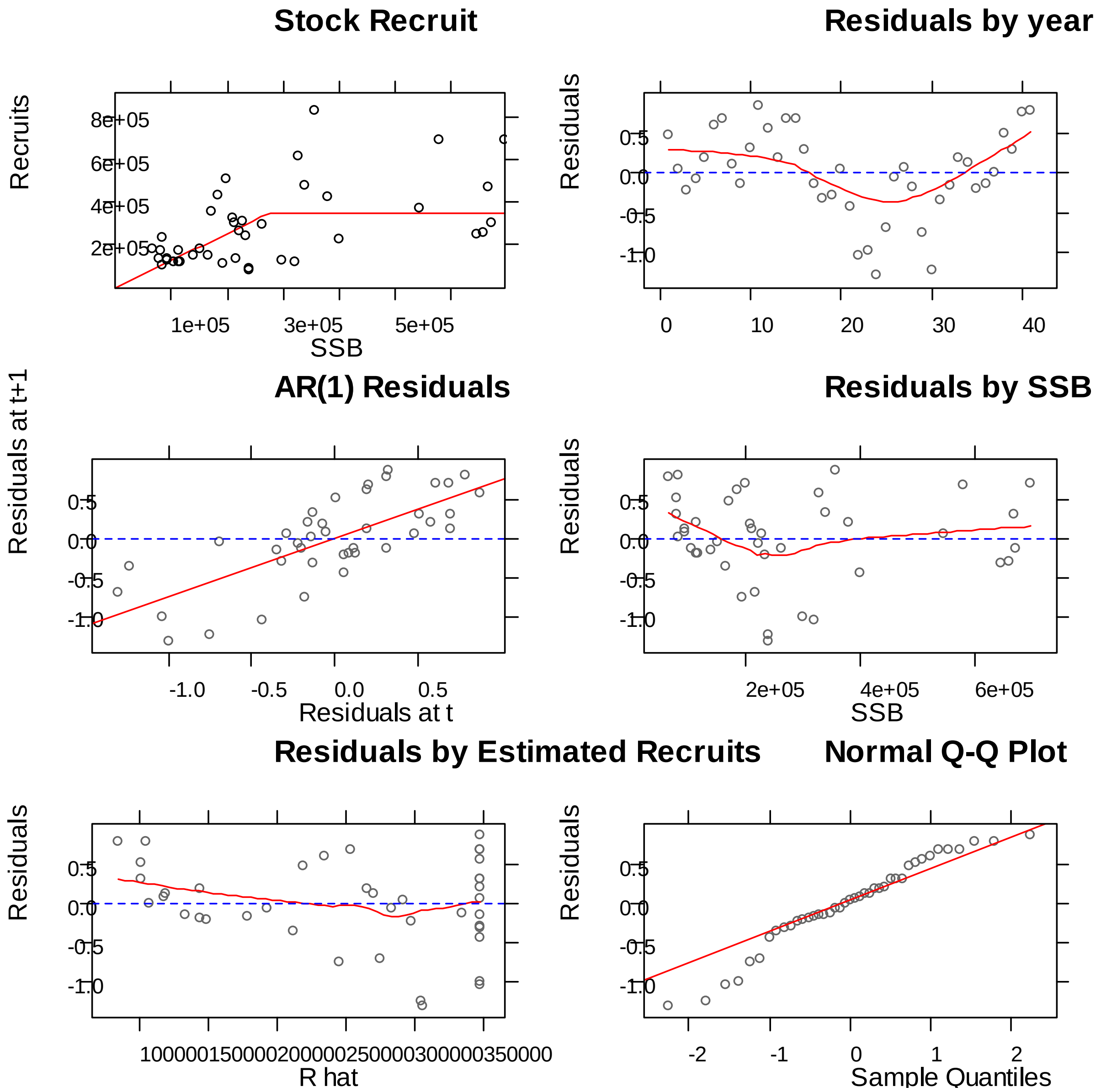
| | | |
|---|---|---|
| B --breakpoint | 32466 | tonnes |
| A --slope | 2.433162 | '000' per tonnes SSB |
| Sigma ~ CV² | 0.5398487 | |
| Recruitment plateau (A*B) | 78995 | '000' |
| Recruitment plateau (A*B) biascorrected | 103472.9 | '000' |



----Cod 2532 ---

Results

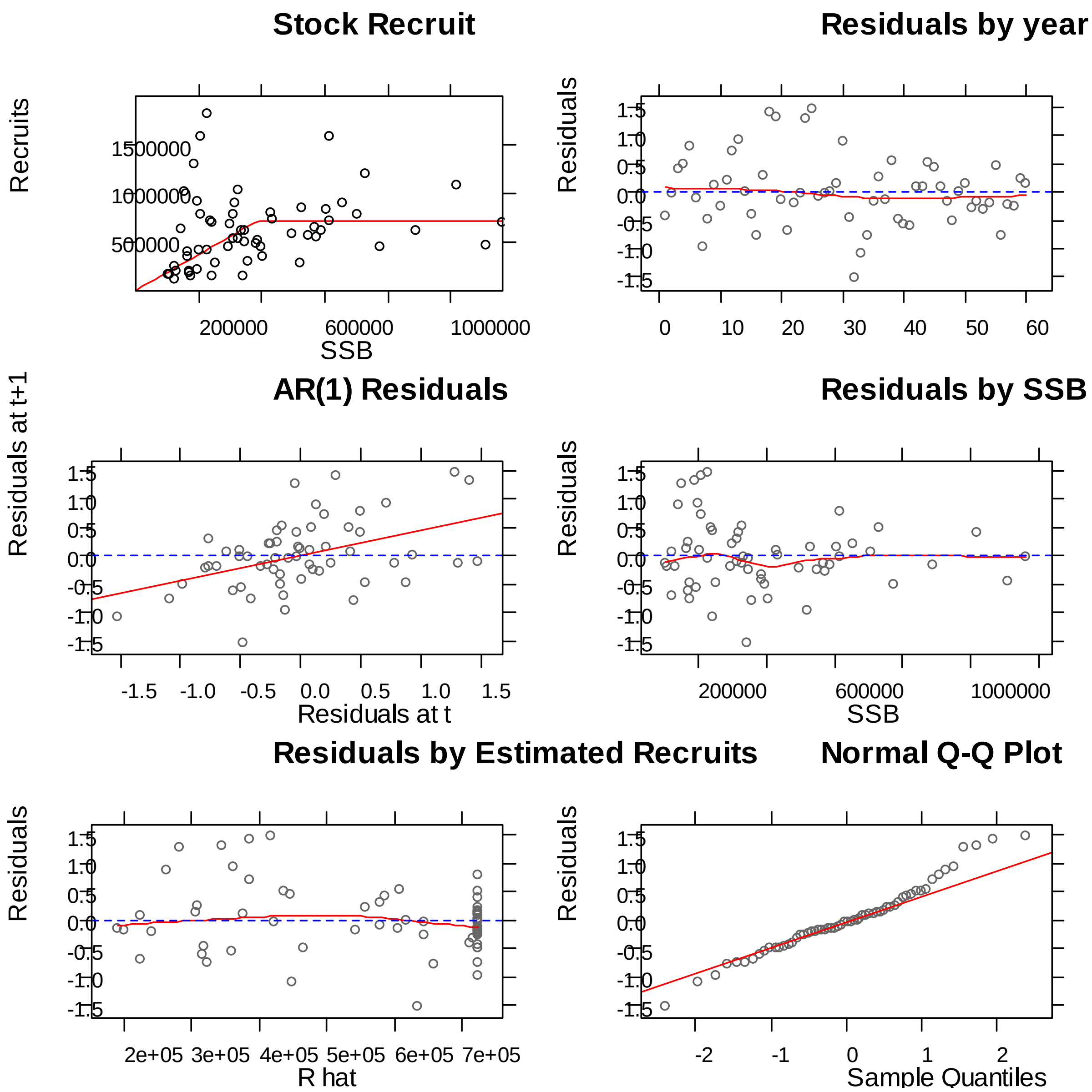
| | | |
|---|---|---|
| B --breakpoint | 272,675 | tonnes |
| A --slope | 1.272361 | '000' per tonnes SSB |
| Sigma ~ $CV^2$ | 0.2964 | |
| Recruitment plateau (A*B) | 346941 | '000' |
| Recruitment plateau (A*B) biascorrected | 402363 | '000' |



----Cod NEA---

Results

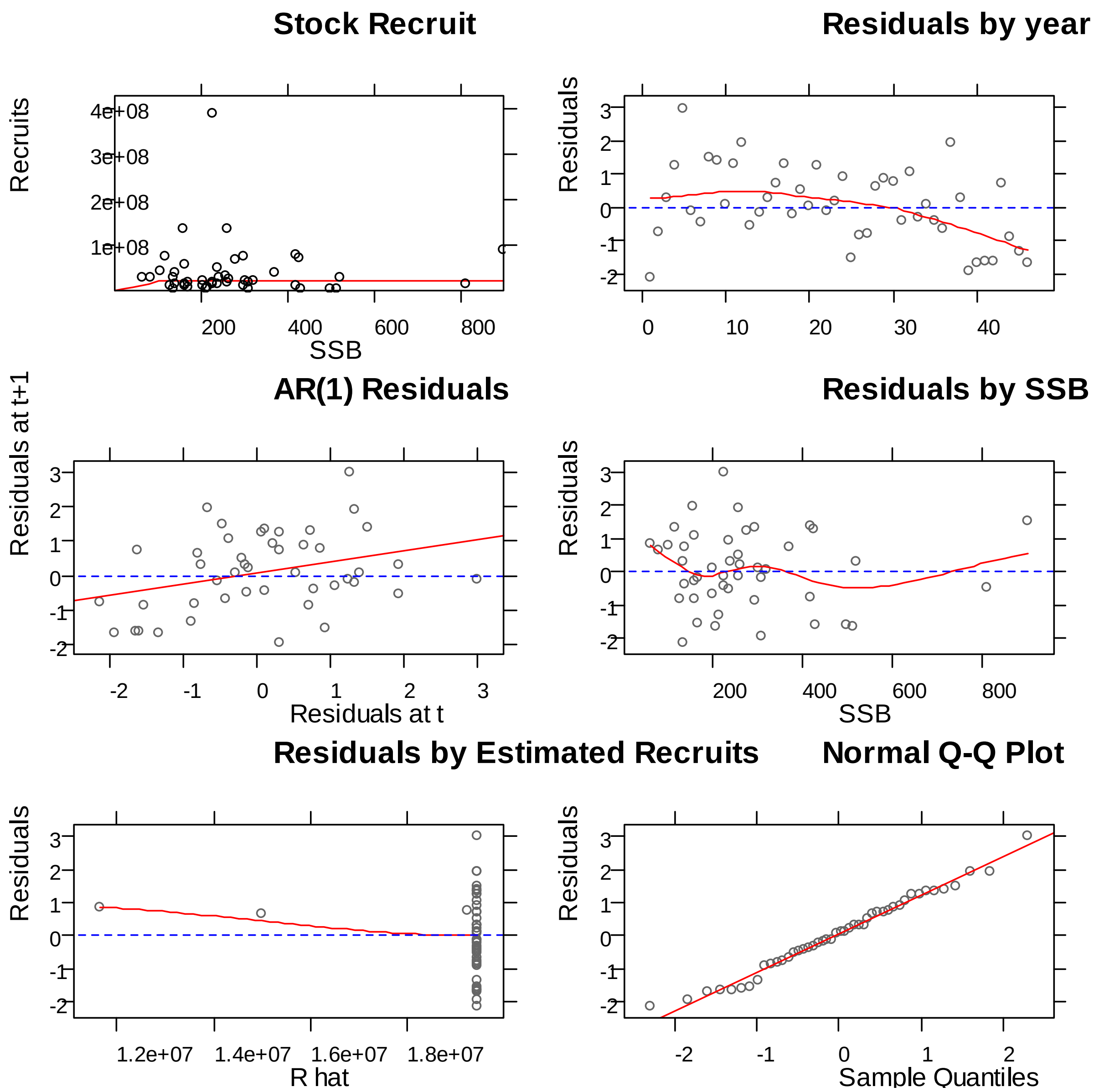
| | | |
|---|---|---|
| B --breakpoint | 389762 | tonnes |
| A --slope | 1.854207 | '000' per tonnes SSB |
| Sigma ~ $CV^2$ | 0.3549719 | |
| Recruitment plateau (A*B) | 722600 | '000' |
| Recruitment plateau (A*B) biascorrected | 863056 | '000' |



**---Haddock North Sea--**

Results

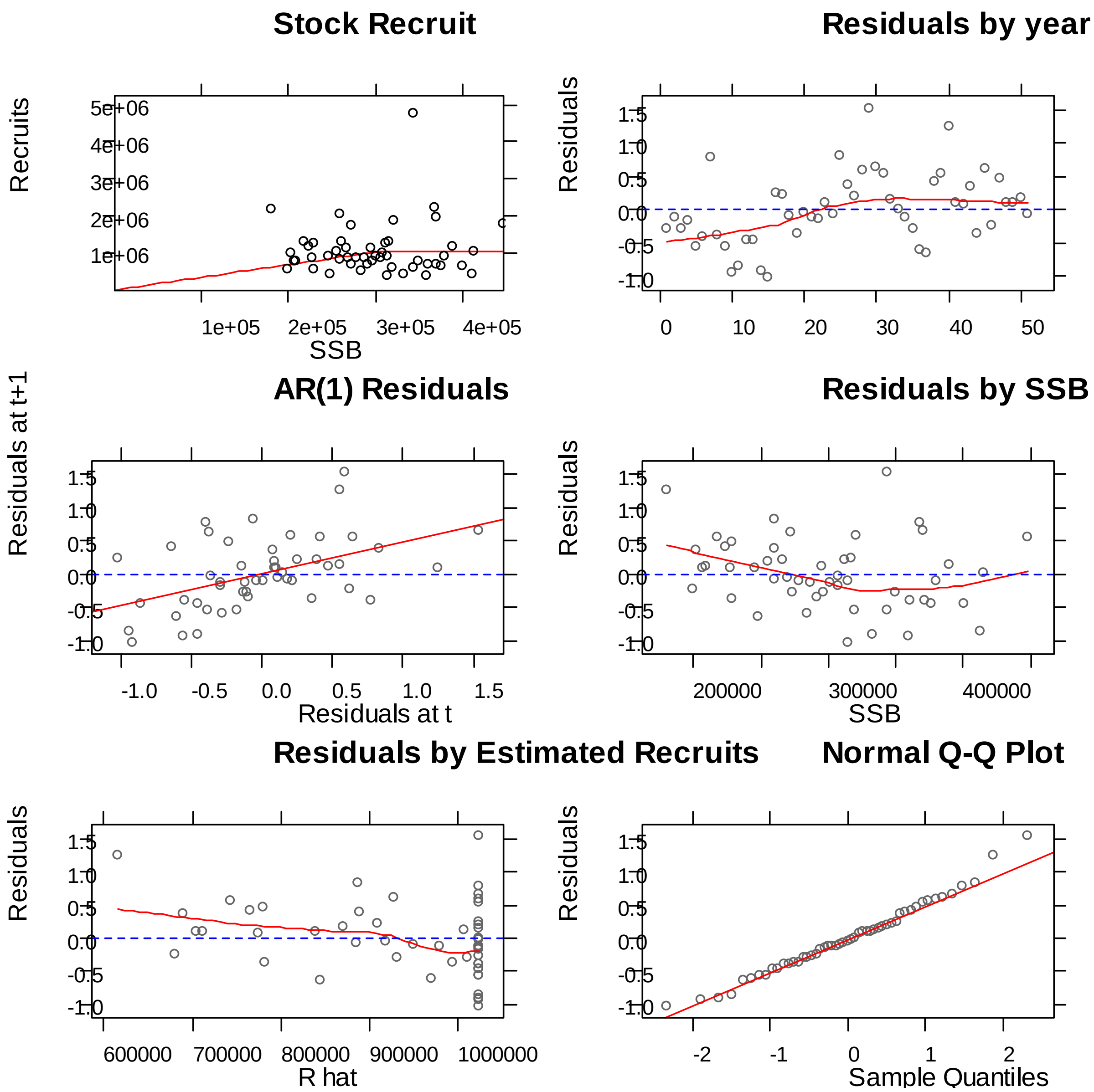
| | | |
|---|---|---|
| B --breakpoint | 105.0358 | tonnes |
| A --slope | 185066.1 | ‘000’ per tonnes SSB |
| Sigma ~ $CV^2$ | 1.302722 | |
| Recruitment plateau (A*B) | 19438566 | ‘000’ |
| Recruitment plateau (A*B) biascorrected | 37286078 | ‘000’ |



**----Plaice NSea---**

Results

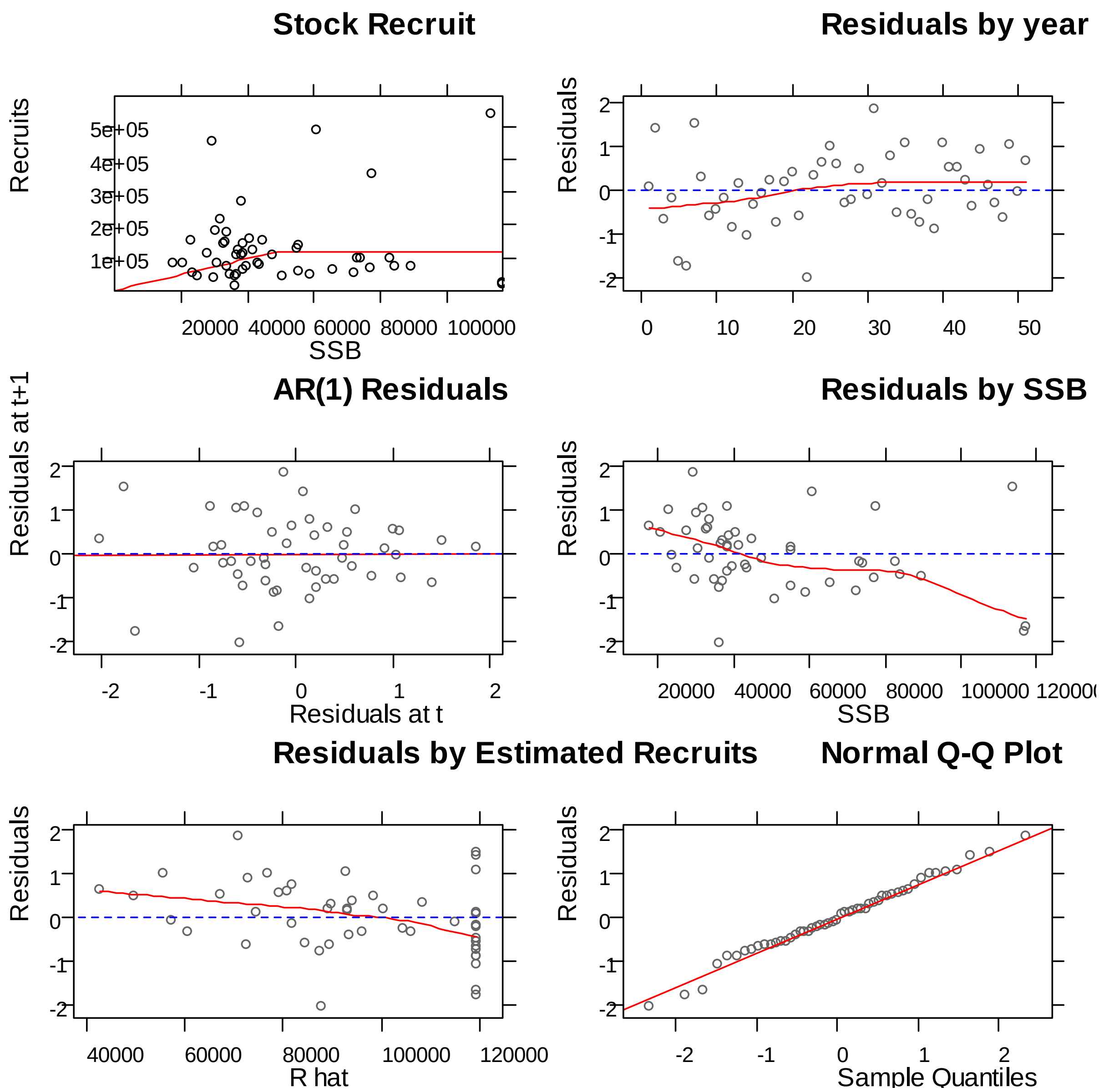
| | | |
|---|---|---|
| B --breakpoint | 300143 | tonnes |
| A --slope | 3.409036 | '000' per tonnes SSB |
| Sigma ~ CV² | 0.2787865 | |
| Recruitment plateau (A*B) | 1023198 | '000' |
| Recruitment plateau (A*B) biascorrected | 1176244 | '000' |



----Sole NSea---

Results

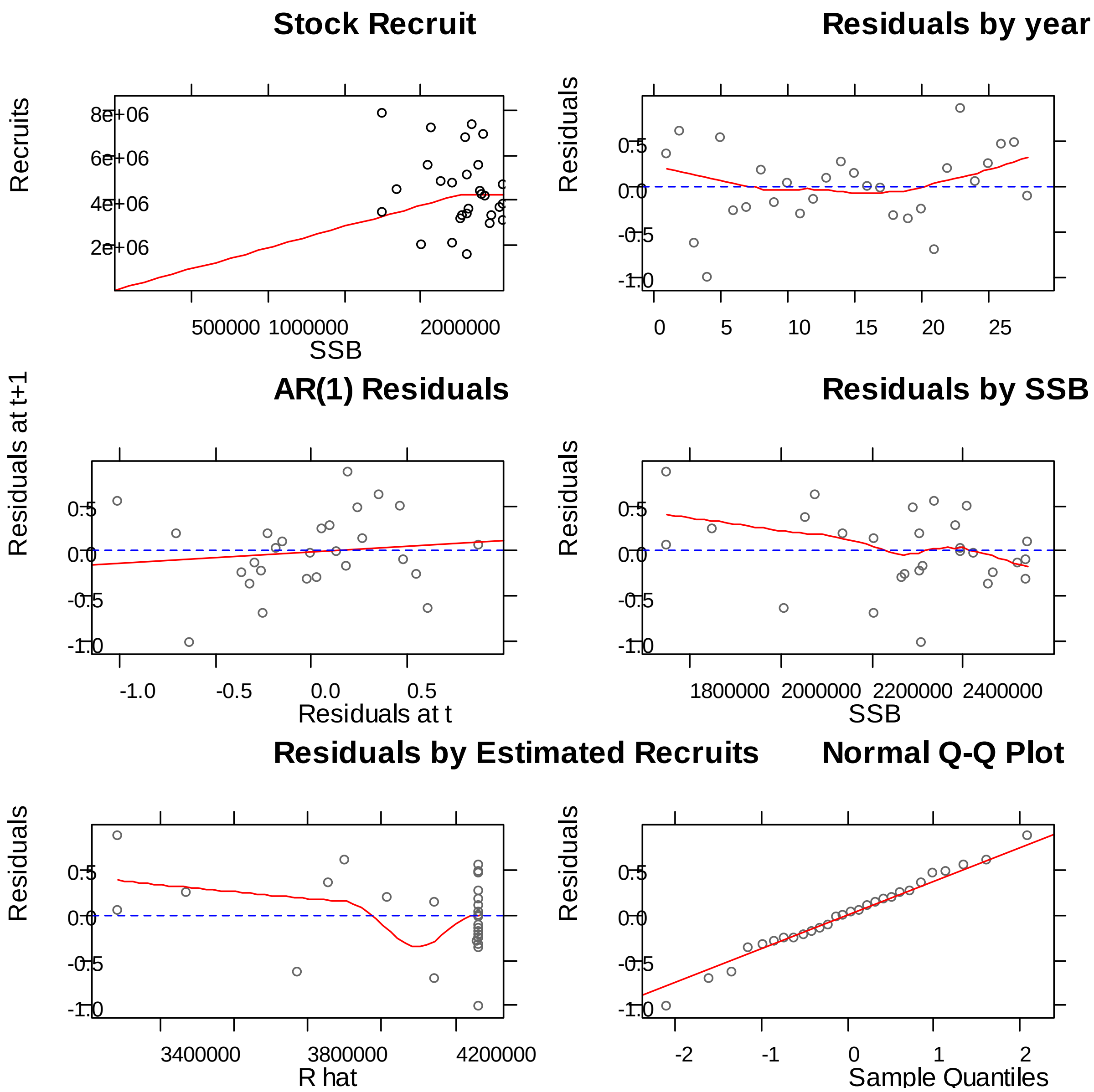
| | | |
|---|---|---|
| B --breakpoint | 49367 | tonnes |
| A --slope | 2.418962 | '000' per tonnes SSB |
| Sigma ~ CV² | 0.6395999 | |
| Recruitment plateau (A*B) | 119417 | '000' |
| Recruitment plateau (A*B) bias corrected | 164419 | '000' |



**----Mackerel NEA---**

Results

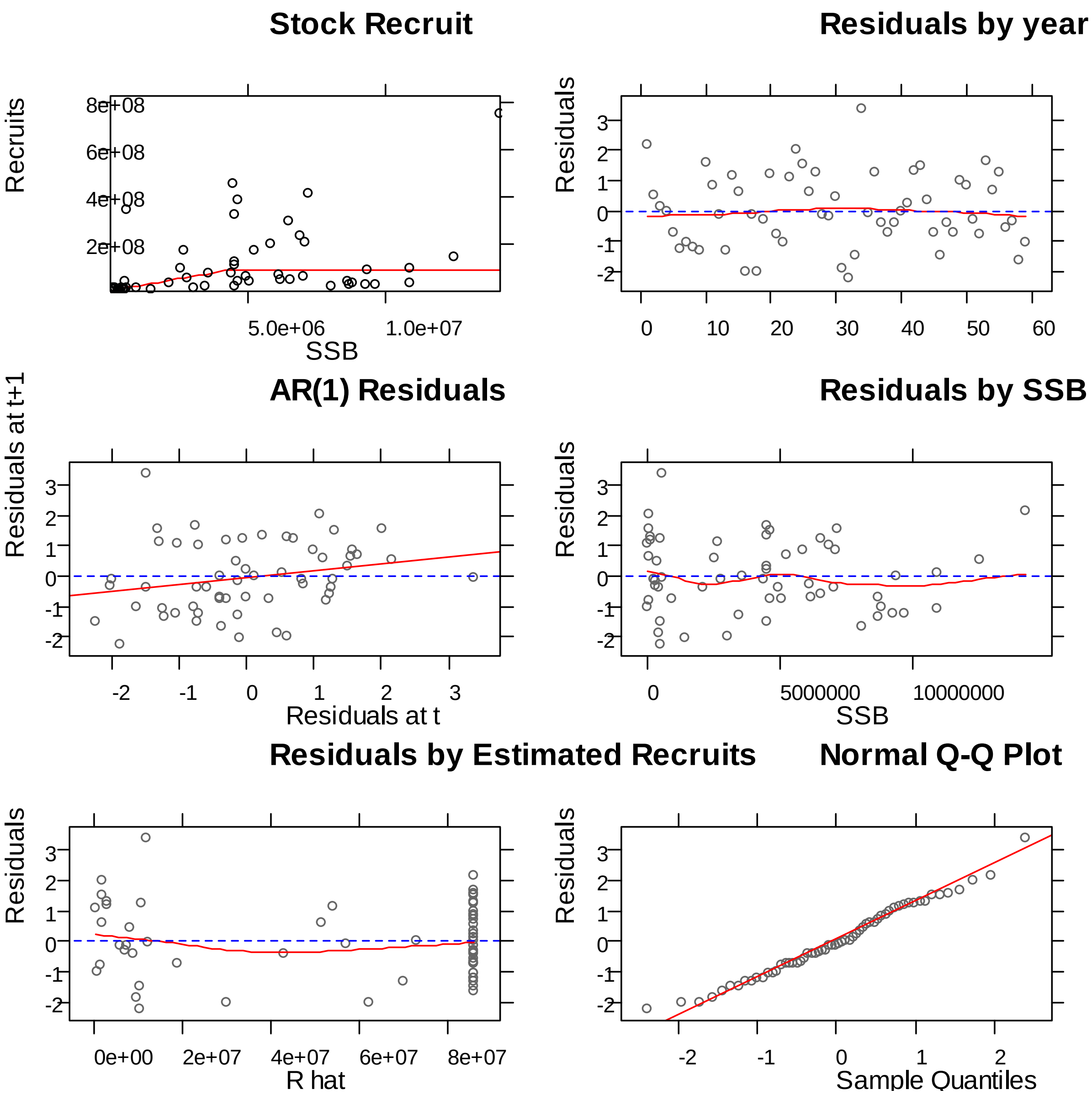
| | | |
|---|---|---|
| B --breakpoint | 2269000 | tonnes |
| A --slope | 1.87 | '000' per tonnes SSB |
| Sigma ~ $CV^2$ | 0.169 | |
| Recruitment plateau (A*B) | 4243030 | '000' |
| Recruitment plateau (A*B) biascorrected | 4617150 | '000' |



----Herring NSSP---

Results

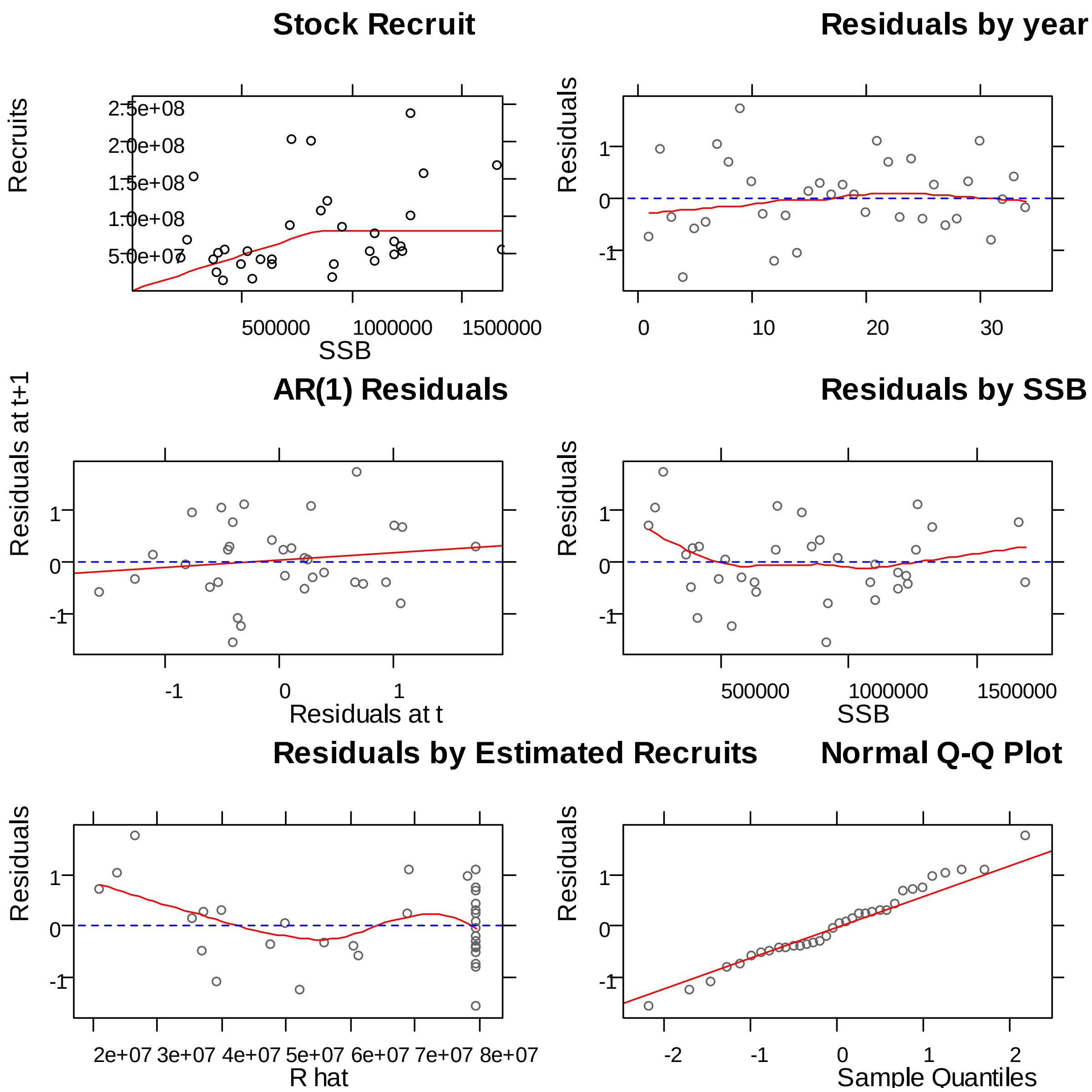
| | | |
|---|---|---|
| B --breakpoint | 4237949 | tonnes |
| A --slope | 20.32875 | '000' per tonnes SSB |
| Sigma ~ CV² | 1.39536 | |
| Recruitment plateau (A*B) | 8615221 | '000' |
| Recruitment plateau (A*B) biascorrected | 17308721 | '000' |



**----Sprat Baltic ---**

Results

| | | |
|---|---|---|
| B --breakpoint | 833882 | tonnes |
| A --slope | 95.53059 | '000' per tonnes SSB |
| Sigma ~ $CV^2$ | 0.5195542 | |
| Recruitment plateau (A*B) | 79661239 | '000' |
| Recruitment plateau (A*B) bias corrected | 103292032 | '000' |



## Annex 4: Recommendations

| Recommendation | For follow up by: |
|---|---|
| 1. That a single option for the MSY HCR below $MSYB_{trigger}$ is chosen from the set proposed by WKFRAME II | ACOM |
| 2. That a single option for the transition calculation is chosen from those proposed by WKFRAME II | ACOM |
| 3. That where a transition calculation is required, that the transition calculation is not applied mechanically | EG's ADG's |
| 4.That efforts are made to explore stock dynamics stochastically | EG's |
| 5.That the focus on producing advice for the MSY framework should not detract from helping develop management plans consistent with HLTY | ICES community |
| 6.That a greater effort is made to communicate ICES advice policy and basis to stakeholders as well as clients | ACOM, ICES secretariat |