Advisory Committee on Fishery Management ICES CM 2003/ACFM:09

REPORT OF THE

STUDY GROUP ON THE FURTHER DEVELOPMENT OF THE PRECAUTIONARY APPROACH TO FISHERY MANAGEMENT

ICES Headquarters
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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Participants

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1.2 Terms of Reference

Under the terms of Council Resolution 2ACFM17, the **Study Group on the Further Development of the Precautionary Approach to Fishery Management** [SGPA] (Co-chairs: C. Bannister, UK and M.Azevedo, Portugal) met at ICES Headquarters from 2-6 December 2002 to:

a) define the technical guidelines for the revision of reference point values for use by SGBRP and SGPRP;

b) specify the software to be used in the revision of reference values, and a format for the presentation of the relevant data and results

c) commence the development of a framework for specifying and monitoring rebuilding plans that take into account the status and dynamics of stocks, technical interactions, uncertainty, time period and risk, and the data required

1.3 Structure of the report

The rest of Section 1 is background information summarising:

- the precautionary approach background
- the implementation in ICES
- the sequence of PA Study Groups, leading to the reasons for the present Study Group
- summaries of the set of 17 Working Documents considered at this meeting.

Section 2 outlines a revised risk framework for calculating reference points taking assessment uncertainty into account.

Section 3 proposes the methodology for deriving the reference point values in the revised framework, and discusses those aspects that have been tested to date.

Section 4 provides a check list summarising the steps in Section 3

Section 5 discusses rebuilding plans

Annex 1 Summarises the basis of the existing ICES reference point values

Annexes 2 to 8 contain Working Documents 1 to 8

Annex 9 Technical annex containing text results for the segmented regression approach

Annex 10 Technical annex on estimating $\mathbf{F}_{pa}$ values that are risk averse to $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$

1.4 The Precautionary Approach Background

The principal international agreements specifying the introduction of the precautionary approach to fisheries are the FAO Code of Conduct for Responsible Fisheries (FAO, 1995b), and the UN Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Doulman, 1995). Their aim is to 'apply the precautionary approach to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment' and to 'avoid serious and irreversible harm to fisheries' by ensuring 'long term sustainability of fishery resources at levels which promote the objective of their optimum utilisation and maintain their availability for present and future generations'. The word 'serious' is most likely to apply to fisheries, and the word 'irreversible' to the effect of contaminants. Technical Guidance on the application of the Precautionary Approach in fisheries was provided by FAO 1995. In pursuit of these objectives, ICES has advised on the state of stocks relative to predefined limits that should be avoided to ensure that stocks remain within safe biological limits. The concept of safe limits is explicitly referred to in the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, but was in fact first introduced into ICES advice in 1981 and further developed in 1986 (Serchuk and Grainger, 1992).

1.5 The Precautionary Approach in ICES

The application of the Precautionary Approach in ICES was undertaken at two meetings of the ICES Study Group on the Precautionary Approach to Fisheries Management, the 1997 Study Group [SGPA 97, which reported as Anon 1997] and the 1998 Study Group [SGPA 98, which reported as Anon 1998].

SGPA 97 outlined the legal requirements, described how reference points should be defined and calculated, and proposed to maintain or restore stocks to within safe biological limits by using, respectively, pre-agreed harvest control rules or recovery plans (Anon 1997).

SGPA 98 estimated for as many stocks as possible the first set of reference point values, and these were adopted by ACFM in giving advice. In some cases these values have been amended, but the majority are still in use.

The status of the Precautionary Approach in ICES was subsequently reviewed and developed by the ICES Study Group on the Further Development of the Precautionary Approach to Fisheries Management, SGPA 01(which reported as Anon 2001) and SGPA 02a (which reported as Anon 2002), which led to the present Study Group meeting (SGPA 02b).

1.6 ICES reference points

Based on SGPA 97 and SGPA 98, the ICES approach is that for stocks and fisheries to be within safe biological limits, there should be a high probability that spawning stock biomass (SSB) is above a limit $\mathbf{B}_{lim}$ below which recruitment becomes impaired or the dynamics of the stock are unknown, and that fishing mortality is below a value $\mathbf{F}_{lim}$ that will drive the spawning stock to that biomass limit. The word 'impaired' is synonymous with the concept that on average recruitment becomes systematically reduced as biomass declines below a certain point due to the effect of fishing. Because of uncertainty in the annual estimation of F and SSB, ICES defines the more conservative operational reference points, $\mathbf{B}_{pa}$ (higher than $\mathbf{B}_{lim}$), and $\mathbf{F}_{pa}$ (lower than $\mathbf{F}_{lim}$), where the subscript $_{pa}$ stands for precautionary approach. When a stock is estimated to be at $\mathbf{B}_{pa}$ there should be a high probability that it will be above $\mathbf{B}_{lim}$ and similarly if F is estimated to be at $\mathbf{F}_{pa}$ there should be a low probability that F is higher than $\mathbf{F}_{lim}$. The reference values $\mathbf{B}_{lim}$ and $\mathbf{F}_{lim}$ are therefore estimated in order to arrive at $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$, the operational values that should have a high probability of ensuring that exploitation is sustainable based on the history of the fishery. Stocks that are both above $\mathbf{B}_{pa}$ and below $\mathbf{F}_{pa}$ are considered to be inside safe biological limits. Stocks that are both below $\mathbf{B}_{pa}$ and above $\mathbf{F}_{pa}$ are considered to be outside safe biological limits, and stocks that are above $\mathbf{B}_{pa}$ but also above $\mathbf{F}_{pa}$ are considered to be harvested outside safe biological limits. When a fishery is at or above $\mathbf{F}_{pa}$, ICES will advise that F should be reduced, and when a stock is estimated to be at or below $\mathbf{B}_{pa}$ ICES will advise that F should be reduced. When a stock is estimated to be above $\mathbf{B}_{pa}$, but is subject to an F that is at or higher than $\mathbf{F}_{pa}$, ICES will again advise that F should be reduced. **ICES intends that the reference points $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$ are boundaries to the safe limits domain, and not targets**.

ACFM previously defined and used the Minimum Biologically Acceptable Level (**MBAL**) of biomass for a number of stocks. **MBAL** was originally chosen as the SSB below which the probability of poor recruitment increased, and is therefore comparable to the current usage of $\mathbf{B}_{lim}$, but in some cases **MBAL** was more simply the biomass below which concerns were raised, and was therefore set as $\mathbf{B}_{pa}$, the level where management action to improve stock status should be taken. In some cases, where biomass estimates are not available, ICES uses the indices $\mathbf{U_{pa}}$ and $\mathbf{U_{lim}}$ based on LPUE (landings per unit effort) series, as biomass reference points.

Target reference points represent long term management objectives. Target reference points are constrained by the precautionary reference points, so that a target fishing mortality should be below $\mathbf{F}_{pa}$ and a target SSB should be above $\mathbf{B}_{pa}$. Target reference points have not yet been defined by clients of ICES advice nor used by ICES in the provision of advice.

1.7 Reviewing and developing ICES reference points

SGPA 01 reviewed the current status of the PA in ICES as follows (Anon 2001):

- the definition and status of the precautionary reference points used in ICES
- the computational basis of the current values (summarised in Annex 1 of the present report).
- compatibility between biomass and fishing mortality reference values, and with previous estimates of MBAL
- the issue of when reference point values should be changed, following changes to the assessment, or the exploitation pattern, or when new SSB values fall below previous values of $\mathbf{B}_{loss}$
- the character and structure of rebuilding plans
- the need to develop target reference points
- the problem of estimating MSY,
- the robustness of $F_{0.1}$ as a potential reference point based on SSB/R.

SGPA 02a then investigated the estimation of $\mathbf{B}_{lim}$, and further evaluated the topics of rebuilding plans and target reference points, as follows (Anon 2002):

- the estimation of reference points by exploratory visual analysis of stock-recruit plots
- statistically objective fitting of stock-recruit data by segmented regression in order to identify a change point, and hence determine $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$
- application of segmented regression to example stocks, including two data sets incorporating changing environmental regimes
- the effect of assessment model changes on the SSB trend in hake, raising the issue whether for management advice SSB should be scaled relative to a $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$ estimated for a particular year in the series, rather than as an absolute value
- further investigation of rebuilding plans, long term management objectives, harvest control rules, the estimation of MSY, and the robustness of SSB/R based on $\mathbf{F}_{0.1}$.

- the use of scenario models to investigate rebuilding plans, fishing mortality reference point estimation, structural uncertainty, and the utility of harvest control rules to reach long term targets

Based on the following factors, SGPA 02a concluded by recommending (see Section 8 of Anon 2002) that ICES should review the current reference point values:

i) some original reference point values do not appear to be in conformity with the precautionary approach definitions, e.g. some values of $\mathbf{B}_{pa}$ should more correctly have been designated as $\mathbf{B}_{lim}$.

ii) reference point values for several stocks, particularly those based on $\mathbf{B}_{loss}$, have been overtaken by subsequent changes…… e.g

- stock abundance has declined below $\mathbf{B}_{loss}$ without affecting recruitment
- changes to the assessment model structure have changed the output
- recruitment appears to have been affected by carrying capacity or some other key environmental parameter
- trends or fluctuations in weight and maturity at age, or age diversity of the spawning stock, may be causing trends in reproductive potential
- stocks have been affected by episodic large year-classes

iii) the point where recruitment becomes impaired should be validated by fitting a conventional stock-recruit curve, or fitting a segmented regression, which has been suggested as a promising tool for this purpose

iv) it should be considered whether the problem of assessment model structure uncertainty could be allowed for by using relative rather than absolute stock values

v) recent EU recovery plans have introduced technical measures to change the pattern of exploitation, thus changing the basis for reference point calculation

vi) despite the problems posed by multispecies interactions, there is scope for designating target reference points, such as $\mathbf{B}_{MSY}$, $\mathbf{F}_{MSY}$ and $\mathbf{F}_{0.1}$, to enable long term management objectives to be set, and move stocks away from cyclical fluctuations around $\mathbf{B}_{pa}$

v) there is a role for harvest control rules in the development of the precautionary approach. Rules are required for the management actions to be taken a) when stocks fall below $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$, or b) when recovery plans are required, or c) to reach target reference points. The development of target reference points and harvest control rules requires dialogue between ICES, managers, and stakeholders.

SGPA 02a recommended that the review should be undertaken by the ICES assessment working groups based on guidelines provided by SGPA and ACFM. It should also take into account any revisions of growth, maturity and condition data emerging from the Study Group on Growth, Maturity and Condition Indices in Stock Projections [SGGROMAT]. SGPA02a also recommended that candidate reference values and harvest control rules could be evaluated using a scenario modelling framework.

ICES agreed that the present meeting of SGPA should clarify procedures, technical guidelines, and the software to be used in the recalculation of reference points, prior to meetings of the Study Group on Biological Reference Points for Northeast Arctic Cod (SGBRP, 13-17 January 2003), and the Study Group on Precautionary Reference Points for Advice on Fishery Management (SGPRP, 24-26 February 2003), where the reference points themselves would be reviewed.

1.8 Working Documents

SGPA 02a proposed that the recalculation of reference points would use segmented regression to estimate $\mathbf{B}_{lim}$ from historical spawning stock-recruitment data. The methodology and examples of its application to a range of representative stocks were described in a series of working documents listed and summarised in Anon 2002. For continuity the following two key documents from Anon 2002 are included as WD1 and WD2 in Annex 2 of this report :

WD 1 (Annex 2a) O'Brien C.M. and D.L. Maxwell (2002a). Towards an operational implementation of the Precautionary Approach within ICES: biomass reference points. (Working Document 8 in Anon 2002).

WD2 (Annex 2b) O'Brien C.M. and D.L. Maxwell (2002b). A segmented regression approach to the Precautionary Approach: the case of Northeast Arctic Saithe (Subareas I and II). (Working Document 10 in Anon 2002).

At this meeting, the following new Working Documents were presented, of which Documents 3 to 8 have been included in Annexes 3 to 8.

WD 3 (Annex 3) Lassen, O'Brien, and Sparholt: DRAFT ICES' guidelines for calculating PA reference points for stocks with analytical assessments.

Proposes $\mathbf{B}_{lim}$ as the primary reference point, to be estimated as the change point in the stock-recruitment plot, and the estimation of $\mathbf{F}_{lim}$ from $\mathbf{B}_{lim}$ deterministically. Proposes to derive $\mathbf{F}_{pa}$ as the fishing mortality that ensures an agreed probability that SSB is above $\mathbf{B}_{lim}$, based on long term predictions incorporating uncertainty. Proposes to estimate $\mathbf{B}_{pa}$ as the 25% fractile of the distribution of SSB obtained in the long term at $\mathbf{F}_{pa}$. Also proposes procedures for short lived species, stocks with occasional strong year-classes, and stocks with limited data or limited dynamic range in SSB.

WD 4 (Annex 4) Jake Rice & Obai Mashal: Estimating Biomass Limit Reference Points For Canadian Cod with Non-Parametric Density Estimation methods.

Describes a method to use kernal estimation techniques to estimate limit and precautionary biomass reference points from a specified recruitment considered to represent 'impaired recruitment'. Once a low recruitment level has been specified, the method calculates the probability that for any given SSB, recruitment will fall below the specified value. Plotting how the probability of low recruitment varies with SSB allows the identification of an SSB value where the probability of a poorer recruitment either exceeds the acceptable level, or begins to increase markedly. The paper also illustrates methods for robust parameter estimation of the kernal bandwidth, and for sensitivity testing of the candidate SSB reference points relative to choices of unacceptably low recruitment.

WD 5 (Annex 5) Leire Ibaibarriaga, Enrique de Cárdenas & Lorenzo Motos: Testing stability of the segmented regression.

Examines the implementation of the segmented regression model to the data for NE Arctic saithe and cod and Northern Hake, to test if the change points are stable and robust to past (observed) and future variability of recruitment. Change points were estimated by a retrospective analysis, adding consecutively one year for the last ten years of the available S-R time series. Results suggest that the method can be very sensitive to the available data points and to variability in recruitment levels, suggesting that a thorough analysis of this kind should be made before adopting the change point as a proxy for a biomass reference point ($\mathbf{B}_{lim}$).

WD 6 (Annex 6) Enrique de Cárdenas, Carmela Porteiro and José Castro: More on the use of relative versus absolute PA reference points question.

For 15 stocks where $\mathbf{B}_{loss}$ was used to set $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$, the paper compared the trend in SSB derived in the last assessment year against that in the year when the PA points were chosen. In 7 cases $\mathbf{B}_{loss}$ from the most recent assessment is higher than the 1998 estimate, by 19% on average, and in 8 cases $\mathbf{B}_{loss}$ was lower than the 1998 estimate, by about 21% on average. The causes of the difference include in some cases changes in the catch at age or the biological data, and in the case of Northern hake the effect of a change in the plus group due to age determination problems, as described at SGPA 02a. Estimates of recruitment were less sensitive. The authors suggested that this problem should be resolved by setting reference points relative to the SSB in a particular year.

WD 7 (Annex 7) Dankert W. Skagen and Asgeir Aglen: Evaluating precautionary values of fishing mortalities using long term stochastic equilibrium distributions.

Proposes the use of long term equilibrium distributions as a tool to evaluate natural variations in SSB at a fixed F. Proposes quality criteria (reality checks) for the assumptions and parameters in the prediction model. Discusses the compatibility of Biomass and Fishing mortality reference points.

WD 8 (Annex 8) Azevedo & Jadim: "bhac" : an R package to compute %BPR and %SPR

Implements the calculation of $\mathbf{F}_{0.1}$ based on % BPR or %SPR in the language R

WD 9 Aglen A. and A. Ajiad**:** Fishing Mortality Reference Points of North-East Arctic Cod-the need for setting $\mathbf{F}_{lim}$ < $\mathbf{F}_{loss}$ when $\mathbf{B}_{lim}$ > $\mathbf{B}_{loss}$

Used PASoft to calculate F reference points for NE Arctic Cod and show their sensitivity to changes in biological parameters. Suggests candidate values for $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$.

WD 10 Yu. A. Kovalev: Revision of PA reference points for NEA cod.

Investigation of cod growth and maturation indicates two periods with considerable differences in cod biology. The first is from 1946 to 1981 when increasing trends in weights-at-age and a decreasing trend in age of 50 % maturity were observed. The second period is after 1981 when these parameters have varied without clear trends. Estimates of F reference points made using data for different periods change according to changes in the biological parameters of the cod population. Those estimated using data for the whole time series are considerably lower. It was shown that data for the period 1982-2000 shows more clear dependence of recruitment on SSB.

WD 11 Yu. A. Kovalev: Using data on NEA cod cannibalism in BRPs estimation.

Although the data on cod cannibalism can improve the assessment, there are several problems in using this information on cod abundance and natural mortality coefficients for different purposes. If the stock - recruitment relationship contains data for years where recruitment was estimated without using data on cod consumption there is an inconsistency in the recruitment time series. The presence or absence of cannibalism in the data also affects the relationship between stock-per-recruit and fishing mortality. These differences will affect the calculation of biological reference points.

WD 12 Kovalev and Tretyak: Changes in estimates of biological reference points for North-East Arctic cod related to changes of its population parameters

The sensitivity of $\mathbf{F}_{low}$, $\mathbf{F}_{med}$, $\mathbf{F}_{high}$, $\mathbf{F}_{loss}$, $F_{0,1}$ for NEA cod to changes in population parameters such as weight, maturity rate and natural mortality due to cannibalism was investigated. Reference points based on SPR equilibrium curve were considerably more sensitive. The sensitivity within this group increased for the points located to the right of the SPR curve. It seems the different biological parameters are markedly affected by density of the population. In general, a decrease in cod abundance leads to an increase in growth and maturation rate and a decrease in cannibalism. All of the changes in the population parameters caused increased estimates of the studied reference points. In 1984-1999, variability of the biological reference points estimated on the basis of data averaged by three successive years was considerable. Although cannibalism is mainly apparent at high biomass, its influence may affect the whole stock recruit curve and hence the estimation of reference points.

WD 13 Ajiad A. and A Aglen: Biomass Reference Points of Northeast Arctic Cod. An attempt to remove the temperature effect on recruitment.

The N E arctic cod recruitment time series was normalised by taking temperature into account, and the segmented regression used to calculate the change point for the full data series 1948 to 1998, and for the time period 1980-1998, using total spawning biomass and also female spawning biomass.

WD 14 Ajiad A. and A Aglen.: Female spawning biomass of North-East arctic cod used in a Ricker stock-recruitment analysis including temperature.

There have been marked trends in the proportion of females in the arctic cod stock, and in the 50% age of maturity. The historical time series has been reworked to take these changes into account in calculating total and female spawning biomass, and also to correct the recruitment data for the effects of temperature. Ricker stock-recruit curves were fitted to the total and female stock-recruit data with and without temperature correction for the total data series and the series split into data before and after 1980. The results compared the amount of variation in recruitment explained by the different models, and the spawning biomass producing peak recruitment.

WD 15 Rice, J: Why biomass reference points should not change with environment variability.

Addresses the consequence of using different biomass reference points for stocks that experience periods of high productivity followed by periods of low productivity. Changes in productivity could be due to either a decline in carrying capacity or reduced per capita productivity (increased mortality and or decreased fecundity). For both scenarios the only benefit was harvesting standing biomass when the productivity regime changed to correspond to a lower biomass reference point. The cost was foregone yield when the productivity changed to correspond to a higher biomass reference point but the stock was stuck at the lower biomass reference point. Simulation study showed that in the time course of even one full cycle of productivity regimes, costs greatly exceeded the benefits.

WD 16 Kell L T and P J Bromley: Implications for current management advice for North Sea Plaice: Part II. Increased biological realism in recruitment, growth, density dependent sexual maturation and the impact of sexual dimorphism and fishery discards.

Examines the effect of discarding, density dependence and changes in productivity on the assessment and management of the N Sea plaice

WD 17 Lassen and Sparholt: Guide to Recovery Plans.

Lists the features of a recovery plan

2 A RISK FRAMEWORK FOR CALCULATING REFERENCE POINTS

In applying the precautionary approach ICES emphasises the aim of preventing stocks from being seriously harmed due to recruitment overfishing. For the proposed recalculation of reference points, SGPA 02a therefore envisaged that the segmented regression method described in O'Brien and Maxwell (2002a and b) would be used wherever possible for estimating $\mathbf{B}_{\text{lim}}$ as the change point below which recruitment becomes impaired in a stock-recruitment scatter plot. $\mathbf{B}_{\text{lim}}$ would then be used as the basis for deriving $\mathbf{F}_{\text{lim}}$, $\mathbf{B}_{\text{pa}}$ and $\mathbf{F}_{\text{pa}}$. This approach, which relates primarily to stocks for which there are full analytical assessments, was amplified by Working Document 3, (Lassen, O'Brien, and Sparholt. DRAFT ICES guidelines for calculating PA reference points for stocks with analytical assessments) (Annex 3), which proposed.

a) to estimate $\mathbf{B}_{\text{lim}}$ as the change point in the stock-recruitment plot,

b) to estimate $\mathbf{F}_{\text{lim}}$ as the fishing mortality corresponding to $\mathbf{B}_{\text{lim}}$,

c) to estimate $\mathbf{F}_{\text{pa}}$ as the fishing mortality that ensures an agreed probability that SSB is above $\mathbf{B}_{\text{lim}}$, based on long term predictions incorporating uncertainty as estimated in the most recent assessment round,

d) to estimate $\mathbf{B}_{\text{pa}}$ as the 25% fractile of the distribution of SSB obtained in the long term at $\mathbf{F}_{\text{pa}}$.

WD 4 proposes an alternative approach for estimating $\mathbf{B}_{\text{lim}}$, however, using a non-parametric kernal method. WD 7 discusses the estimation of $\mathbf{F}_{\text{pa}}$ using long term equilibrium distributions, as well as the problem of obtaining compatibility between estimates of $\mathbf{F}_{\text{pa}}$ and $\mathbf{B}_{\text{pa}}$. The Study Group also discussed Sparholt and Bertelsen (2002), which indicates that the formulae previously used to define the relationship between the limit and precautionary reference points substantially underestimate the uncertainty of the assessments.

These working documents provoked extensive discussion of the management of risk in calculating reference points, and led to a more explicit framework for taking into account stochastic variability and assessment uncertainty. As a result it is proposed

- **to estimate B_{lim} on the basis of either the segmented regression method or the non-parametric kernel method**

- **to calculate F_{lim} from B_{lim} deterministically**

- **to calculate F_{pa} using a new methodology that accounts for assessment uncertainty by comparing intended F with realised F retrospectively, so that when F_{pa} is advised, there will be a low probability that realised F is above F_{lim},**

- **to calculate B_{pa} by comparing the yearly estimates of SSB with the realised SSB retrospectively, so that when observed SSB is at B_{pa}, there will be a low probability of SSB being below B_{lim}.**

The risk framework is described in Section 2.1 and the associated methodology is outlined in Section 3. The Study Group carried out further trials with the use of the segmented regression, but did not have time to test the implementation of the other methods, or evaluate whether they give suitable reference point values. The group was also unable to develop target reference points or harvest control rules. The task of further developing the precautionary approach in ICES is therefore not complete.

2.1 The risk management framework

The sources of uncertainty that affect the assessment of stocks, the estimation of reference points, and the provision of advice were described by Rosenberg and Restrepo (1995):

- *natural variation* in dynamic processes (e.g. recruitment, somatic growth, natural mortality), also termed process error
- *measurement error*, generated when collecting observations from a population
- *model error*, mis-specification of a model parameter (e.g. natural mortality), or the model structure
- *estimation error*, arises from any of the above errors and is the inaccuracy and imprecision in the parameters estimated by the model during the assessment process
- *implementation error*, arising because management actions are never implemented perfectly, whether because the management plan does not correspond to the advice fully, or because compliance with the intent of the management plan is imperfect

Natural variation: Even when the conditions that can be controlled by management action, i.e.F at age, are kept fixed, SSB and yearly catch will still vary, often considerably, because of year to year variation in recruitment, weight at age, maturity at age etc.

Measurement error, model error and estimation error: In practice it is not easy to quantify separately these sources of error, which all contribute to the divergence between the real values of stock abundance and mortality, and the estimates that are used to give management advice. The Study Group has therefore used a single term *assessment uncertainty* for their combined effect. Measurement error, model error and estimation error will contribute to assessment uncertainty in different ways. The formal statistical estimate of the uncertainty of parameter estimates provided by assessment models mainly represent estimation error, and will therefore generally underestimate the discrepancy. Uncertainty in the assessment often implies that there is a bias, such that stock abundance is systematically over-or under-estimated year after year. Several factors must contribute to this bias, including imperfect fisheries data, but although Working Groups constantly try to improve the precision of their assessments, it is not precautionary to assume that bias has been removed until this can be properly demonstrated.

Implementation error in the current year, in the form of 'black landings', or poor compliance with regulations, is not considered explicitly when setting reference points or giving advice on F and catches, because it occurs after the advice is provided. Past occurrence has, however, contributed to the measurement and estimation error in previous years, and is therefore captured in the assessment process.

Once $\mathbf{B}_{\text{lim}}$ has been calculated, the other reference points should be derived so as to take into account the sources of uncertainty in a systematic way based on the current perception of the history of the stock. Risk averseness should not be double counted. For example, if $\mathbf{B}_{\text{lim}}$ is chosen to imply a low probability that recruitment is impaired, it is proposed that $\mathbf{F}_{\text{lim}}$ should be kept risk neutral to $\mathbf{B}_{\text{lim}}$. It follows that if $\mathbf{F}_{\text{pa}}$ is then estimated to ensure that F remains below $\mathbf{F}_{\text{lim}}$, and if $\mathbf{B}_{\text{pa}}$ is estimated independently to ensure that SSB remains above $\mathbf{B}_{\text{lim}}$, then $\mathbf{F}_{\text{pa}}$ cannot ensure that there will be a low probability of SSB being below $\mathbf{B}_{\text{pa}}$ unless additional risk is taken into account. A revised framework for defining and linking reference points taking into account uncertainty is illustrated in Figure 1 and described in the rest of this section. The technical description of the proposed methodology for calculating the reference point values is given in section 3.

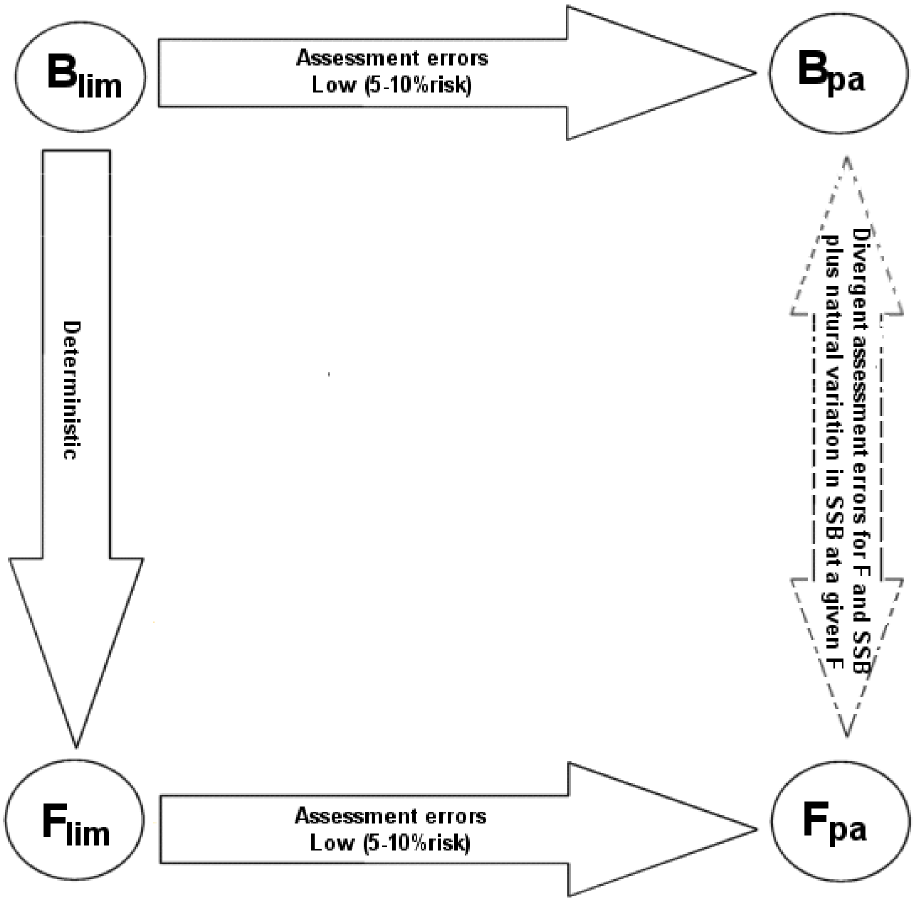

Figure 1 The links between reference points, and the related sources of uncertainty and risk.

2.2 $\mathbf{B}_{lim}$ and $\mathbf{F}_{lim}$

To prevent stocks being seriously harmed due to recruitment over-fishing, the revised reference point framework starts with stocks where there is a full analytical assessment, and a time series of SSB-R data that can be used to estimate $\mathbf{B}_{lim}$, the cornerstone reference point. $\mathbf{B}_{lim}$ has intrinsic biological meaning as the SSB below which there is a substantial increase in the probability of obtaining reduced (or 'impaired') recruitment. Such an estimate of $\mathbf{B}_{lim}$ should be risk averse, so that when the stock is at $\mathbf{B}_{lim}$ the probability that recruitment is substantially impaired is still small, but below $\mathbf{B}_{lim}$ that probability increases. The framework attempts to prevent impaired recruitment due to low SSB, so where stocks show a dome-shaped stock-recruitment diagram, i.e reduced recruitment at both low and high SSB, it is the left-hand part of the stock-recruitment curve that is being considered.

If the historic stock–recruit data indicate that the point of poor recruitment has not yet been reached, the lowest observed SSB ($\mathbf{B}_{loss}$) represents the lowest SSB for which information is available on the population dynamics of the stock. Bringing the stock to a lower SSB is therefore entering a domain with unknown risks, and on this reasoning $\mathbf{B}_{loss}$ can be used as a proxy for $\mathbf{B}_{lim}$. In a few cases, as when a stock has been lightly exploited and the stock-recruit data have limited dynamic range, it is not appropriate to use $\mathbf{B}_{loss}$ as $\mathbf{B}_{lim}$, but the lowest observed biomass can be proposed as a proxy for $\mathbf{B}_{pa}$.

One could consider setting $\mathbf{F}_{lim}$ on the basis of some a priori considerations about population biology, but it is proposed that in practice $\mathbf{F}_{lim}$ will be set on the basis of $\mathbf{B}_{lim,.}$. If $\mathbf{B}_{lim}$ has been chosen as the lowest biomass at which there is still a low risk of impaired recruitment, as here, then to avoid double counting of the risk, $\mathbf{F}_{lim}$ should be risk neutral to $\mathbf{B}_{lim}$ i.e $\mathbf{F}_{lim}$ should be the fishing mortality at which the deterministic equilibrium SSB is $\mathbf{B}_{lim}$.

2.3 $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$

$\mathbf{F_{lim}}$ and $\mathbf{B_{lim}}$ should be avoided with high probability. Because of uncertainty, ICES advises that F should not exceed a lower value, $\mathbf{F_{pa}}$, derived from $\mathbf{F_{lim,}}$ such that the fishing mortality actually realised by an advised catch corresponding to $\mathbf{F_{pa}}$ should have a very low probability of being above $\mathbf{F_{lim}}$. $\mathbf{F_{pa}}$ should therefore be estimated by a method that takes assessment uncertainty into account. Similarly, if $\mathbf{B_{pa}}$ is derived from $\mathbf{B_{lim}}$ taking assessment uncertainty into account, there should be a very low probability that a stock currently estimated to be at $\mathbf{B_{pa}}$ is actually at $\mathbf{B_{lim}}$. These derivations specifically exclude taking into account implementation error because at present this cannot be quantified.

2.4 The use of $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$ in giving advice

The operational reference points used in giving ICES advice are $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$. ICES advice seeks to control future F through a wide range of measures, e.g. TAC, effort constraints, close areas or closed seasons, etc.. If the estimated F exceeds $\mathbf{F_{pa}}$, ICES will advise that measures should be taken to reduce fishing mortality, and if the estimated SSB is below $\mathbf{B_{pa}}$, ICES will also advise measures to increase SSB. As derived here, $\mathbf{F_{pa}}$ will be calculated so that it should correspond to a low risk that F is above $\mathbf{F_{lim}}$, whilst $\mathbf{B_{pa}}$ should be calculated to correspond to a low risk that true SSB falls below $\mathbf{B_{lim}}$. Although both $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$ take into account assessment uncertainty, they do so independently, and because the uncertainties are not identical there can be no guarantee that when advice is given according to $\mathbf{F_{pa}}$, SSB will necessarily be at or above $\mathbf{B_{pa}}$ all of the time. (The absence of perfect correspondence between $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$ will arise because individual assessment inputs do not all affect F and SSB in identical ways, so that the distances $\mathbf{F_{pa}}$ - $\mathbf{F_{lim}}$ and $\mathbf{B_{pa}}$ - $\mathbf{B_{lim}}$ will not necessarily be the same, whilst SSB also varies due to natural causes.) This means that even if the stock is harvested at $\mathbf{F_{pa}}$, both the estimated and real SSB may still be below $\mathbf{B_{pa}}$ in some years, and the stock is therefore 'outside safe biological limits'. ICES will then advise a further reduction in fishing mortality to below $\mathbf{F_{pa}}$ if this is needed to keep the estimated SSB at or above $\mathbf{B_{pa}}$. Although one could envisage choosing an $\mathbf{F_{pa}}$ that has a lower probability of the stock being below $\mathbf{B_{pa}}$, this would result in advice that is more restrictive on harvests in the short term, even when SSB rises above $\mathbf{B_{pa}}$.

In this context, ICES should continue to emphasise that $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$ are intended to be <u>boundaries</u> (as clearly implied in the formal EU-Norway agreements) and <u>not targets</u>. ICES should advise that action is taken at $\mathbf{F_{pa}}$ in order to reduce F <u>below</u> $\mathbf{F_{pa}}$, or should advise that action is taken at $\mathbf{B_{pa}}$ in order to raise stock <u>above</u> $\mathbf{B_{pa}}$. It is not intended that stocks should be fished continually at $\mathbf{F_{pa}}$, or should remain continually at $\mathbf{B_{pa}}$.

3 RECALCULATING REFERENCE POINTS

Following SGPA 98, and Annex 1 of SGPA 01, ICES stocks with analytical assessments and a time series of paired SSB-R values can be grouped into categories as follows:

- Stocks with a wide dynamic range of SSB, and evidence that recruitment is or has been impaired. Identify the change point as an estimate of $\mathbf{B_{lim}}$
- Stocks with a wide dynamic range of SSB, but no evidence that recruitment is impaired. Identify $\mathbf{B_{loss}}$ as a candidate value of $\mathbf{B_{lim}}$, below which the dynamics of the stock are unknown
- Stocks where R increases as SSB decreases. Estimate $\mathbf{B_{loss}}$ as a candidate value of $\mathbf{B_{pa}}$
- Stocks with a narrow dynamic range of SSB. Estimate $\mathbf{B_{loss}}$ as a candidate value of $\mathbf{B_{pa}}$ (if no evidence of impairment in R) or $\mathbf{B_{lim}}$ (if there is evidence of impairment in R)

3.1 Estimating $\mathbf{B_{lim}}$ or $\mathbf{B_{loss}}$

The SSB-R plot should first be examined visually in order to

- classify the stock into one of the above categories,
- identify cases where SSB has declined below the previous estimate of $\mathbf{B_{loss}}$,
- identify cases where an estimate of $\mathbf{B_{lim}}$ or $\mathbf{B_{loss}}$ has been overtaken by a change in the SSB-R values due to a change in the structure of the assessment model, or a change in biological data.

The SSB below which R becomes impaired, or the recruitment dynamics are considered to be unknown, cannot necessarily be estimated by visual inspection of the data. For example, SGPA 02a analysed visually the SSB-R data for 66 ICES stocks and concluded that only 25 stocks showed a configuration where a possible point of impairment might be identifiable visually (those that conformed to Type 2 in Figure 3.1 of SGPA 02a). $\mathbf{B}_{lim}$ or $\mathbf{B}_{loss}$ must therefore be estimated using statistical methods. The two methods proposed here are the segmented regression method (O'Brien and Maxwell 2002 a and 200b, reproduced in Annex 2 as WD 1 and WD 2), or a non parametric method (Evans & Rice 1988; Rice and Mashal, WD 4).

3.1.1 Segmented regression

The segmented regression approach was previously proposed and tested for a number of stocks by SGPA 02a. The method assumes that recruitment is independent of SSB above some change point, below which recruitment declines linearly towards the origin at lower values of SSB. The segmented regression method identifies the value of SSB at this change point (**S***), which is therefore a candidate value for $\mathbf{B}_{lim}$. O'Brien and Maxwell (op cit) described statistical tests for the significance of the change point, as well as a log likelihood method for estimating confidence limits for the change point. The confidence interval around the change point is important for determining the actual value to be used as $\mathbf{B}_{lim}$. i.e $\mathbf{B}_{lim}$ should be at **S***(α), where α is chosen depending on an agreed risk strategy for $\mathbf{B}_{lim}$. In the revised risk framework, $\mathbf{B}_{lim}$ should be risk averse i.e. there should be a very low probability that at S* recruitment is actually impaired. Assessment scientists need to decide whether a point estimate of S* is sufficiently risk averse relative to natural variation, or a value of $\mathbf{B}_{lim}$ should be chosen at the top end of the range for α. Such a decision ideally requires examination of the probability distribution of **S***.

In SGPA 02a, it was suggested that a lower percentile of the confidence interval of S*, say 10%, could be used as $\mathbf{B}_{lim}$, and that an upper percentile, say 90%, could be used as $\mathbf{B}_{pa}$. This approach does not correspond to the revised framework, however, where it is proposed that the difference between $\mathbf{B}_{pa}$ and $\mathbf{B}_{lim}$ depends on assessment uncertainty, not simply the robustness of the statistical fit to the stock-recruit data.

- **Segmented regression versus other stock-recruit curves**

Segmented regression is being proposed here as a practical alternative to the traditional stock-recruit curves of Ricker or Beverton and Holt.

The Ricker curve implies that at very high stock size strong feedback mechanisms, resulting from cannibalism or the depletion of food resources, will reduce growth and fecundity, and thus cause recruitment to fall below the levels obtained at intermediate stock size. Although the Ricker S-R curve fits the data for some marine species and stocks quite well, there are numerous others where this is not the case, perhaps because stock sizes high enough to invoke the above feedback mechanisms are less commonly observed in exploited marine fish stocks. For Baltic cod, for example, it has been shown theoretically that cannibalism could result in significantly reduced R at spawning stock sizes above 1 million t, but actual SSB values larger than 700 000 t have not occurred during the period when stock size has been estimated (Sparholt 1995). Dome shaped S-R relationships are more frequent in fish stocks occupying bounded ecosystems (freshwater bodies or enclosed seas) where habitat limitation, resource depletion, or persistent cannibalism may be more likely. The stock-recruitment dynamics generated by a dome-shaped relationship may lead to stable oscillations: a large SSB will generate a low recruitment, and thence a reduction in SSB, leading in turn to a higher probability of a large recruitment that would give rise once more to a large SSB (Skagen & Aglen, WD #7).

It is likely that the Beverton and Holt model will be more suitable for S-R data with the dynamic range in SSB characteristic of many of the marine stocks that are managed and can be assessed. The B&H model implies that R increases asymptotically with increased SSB, the expected increase in recruitment becoming progressively smaller at moderate to high SSB. When there is a large noise to signal ratio in S-R data, then at intermediate to high SSB it becomes difficult to distinguish between the diminishing gain in R and a relationship where R becomes functionally independent of stock. A simple and parsimonious model such as the segmented regression (which assumes a "hockey stick" S-R relationship) may therefore become appropriate for identifying the value of SSB below which R becomes impaired and the stock becomes unable to produce maximum sustainable yield. The assumption that recruitment is reduced linearly with SSB below the change point implies that when simulating a stock with such dynamics, an F above that corresponding to the slope to the origin will lead to extinction. This should give a warning that the dynamics at such levels of F are unknown, although the distribution of, for example, SSB near $\mathbf{F}_{lim}$, will scarcely be realistic.

Unless the data cover the whole range from a very light exploitation to a severe recruitment failure, the parameters in any stock-recruitment model are likely to be highly correlated, and one should not extrapolate beyond the dynamical range of the historical data. If such extrapolation is done with the hockey-stick model, it is likely to serve warning by giving strange results.

- **The relationship with MSY**

The UN guidelines state that fisheries should be managed so that a stock is capable of producing maximum sustainable yield, and has only a low probability of falling below that level, taking uncertainty into account. Stock-recruitment relationships are therefore in principle very important for determining the stock size which meets these standards. In reality these relationships are often poorly determined by the available data and models, and there is still a very poor knowledge of the effect of multipsecies interactions. SGPA 01 and SGPA02a discussed many of the biological and statistical difficulties associated with deriving MSY from real data, but the present Study Group had no time to pursue this discussion further. From the viewpoint of the present framework, however, where the assumptions underlying the segmented regression are met, it is expected that above the change point recruitment will be on average as high as it can be. A stock that is kept above the change point will therefore be in the domain where it is potentially capable of producing the maximum sustainable yield.

3.1.2 Kernel methods

The segmented regression determines the SSB below which the expected recruitment ceases to be best estimated by the average recruitment at higher biomass. Although the expected recruitment below the change point is lower than above it, the initial difference in R when the stock first enters the domain of reduced recruitment may be very small, causing doubt as to whether the resulting recruitment actually constitutes "impaired productivity". In such circumstances it may be better to use a complementary procedure to estimate directly the probability of recruitment being impaired as a function of SSB, using a non-parametric method such as that described in WD 4 (Annex 4) by Rice and Mashal, based on Evans and Rice (1988) and Rice and Evans, (1988).

The kernel method uses a locally weighted smoother to estimate the probability density function of a recruitment as being either poor or poorer than some specified "poor" value, or as good or better than some specified "good" value. Evans and Rice use a Cauchy weighting for the S-R observations:

$\text{Weight}_{(i)} = 1 / [1 + (x_{(i)}/D)^2]$, where

$x_{(i)}$ is the distance of the SSB of the i_{th} observed stock-recruit pair from the SSB for which the pdf is being estimated, and

D is the bandwidth of the smoother, chosen by cross-validation to meet both a variance minimisation and an absence-of-bias criterion.

WD 4 uses MATLAB software, which allows other common weightings (negative exponential, normal) to be selected if preferred. Once the probability density function (pdf) of expected recruitment has been estimated for at least the range of SSB in the historic data series, the probability of recruitments at or below a specified poor value (or as good as or better than a specified good value) can be plotted directly. For a number of Canadian cod stocks examined in the WD, this probability was asymptotic as SSB declined from high values, then increased rapidly.The asymptotic probability of poor recruitment varied among stocks, with some stocks having a very low probability (<0.03) of poor recruitment at high SSB, and others having moderate probability (~0.2) of poor recruitment at the highest SSBs observed. Regardless of the asymptotic probability of poor recruitment, the inflection point in the probability plot was well determined in all cases, and was not highly sensitive to either the value of D or the exact recruitment selected as "poor". The inflection point is thus directly estimated as the SSB where the probability of poor recruitment begins to increase markedly (or the probability of good recruitment begins to decrease markedly), which is comparable to the ICES definition for "impaired recruitment".

Three advantages of the kernel method are that

a) it estimates directly the changing probability of impaired recruitment,

b) it makes no assumptions about the shape of the functional relationship between recruitment and SSB,

c) the estimate of the inflection point in the probability of poor recruitment is little affected by the occurrence of an occasional exceptionally strong recruitment, which can pose serious analytical problems for parametric methods.

The first two advantages may be helpful when the segmented regression method produces unstable estimates of the change point in sensitivity tests for particular data sets, or where the change point still appears to be associated with quite good recruitment. The third advantage is helpful when rare but exceptional year-classes are particularly important for stock dynamics, and in fact the kernel method can estimate how their probability changes with SBB, even if their probability is never high, provided that there is a sufficient number of such occurrences.. If the method indicates that their probability begins to decline below some SBB, such an SSB becomes an obvious candidate for a conservation reference point, viz, the SSB where the probability of strong recruitment essential for the stock begins to drop is a candidate for $\mathbf{B}_{\text{lim}}$.

Disadvantages of the kernel method are that

a) the value of poor (or good) recruitment must be specified outside the analytical framework. Several objective criteria could be proposed for selecting such a recruitment (the implied equilibrium biomass is below some level, or the expected yield-per-recruit cannot provide an adequate yield), but these criteria simply move the extra-framework decision to what equilibrium biomass or yield is unacceptable.

b) at the inflection point on the probability plot, the probability of poor recruitment is increasing, but could still be very low, if the asymptotic probability of poor recruitment at high SSB is also very low. Thus it may be necessary to specify some probability of poor recruitment that is unacceptable (the $\mathbf{B}_{\text{lim}}$), rather than just using the inflection point. Discussions of both of these points (what is a poor recruitment, and what probability of a poor recruitment is unacceptable) might be considered a healthy part of selecting precautionary reference points. All methods of estimating reference points, in fact, include decisions on both of these points, but the algorithms often simply make them for the user without informing the user of what values have been chosen.

c) kernel methods extrapolate poorly outside the range of historic stock-recruit data, without some additional and usually arbitrary assumptions. Since, however, ICES has already agreed that when historic S-R data do not describe the SSB where recruitment begins to be impaired, $\mathbf{B}_{\text{lim}}$ will be set to the lowest observed SSB, extrapolation below SSB is not necessary, and the kernel approach is particularly informative about whether the probability of impaired recruitment really has begun to change at the lowest observed SSB.

3.1.3 Comparing results by scenario modelling

The performance of segmented regression and the non-parametric estimator could be compared using a simulation framework applied to a range of stocks for a variety of assumptions in order to compare the performance and robustness of the two methods. The stocks should be chosen to represent a range of dynamics. SGPA hopes that such comparisons can be carried out intersessionally, based on the specification included in Annex 9b.

3.2 Deriving $\mathbf{F}_{\text{lim}}$ from $\mathbf{B}_{\text{lim}}$

It is proposed that $\mathbf{F}_{\text{lim}}$ is derived from $\mathbf{B}_{\text{lim}}$ as a deterministic equilibrium value, so that when the realised fishing mortality is $\mathbf{F}_{\text{lim}}$ there is an approximately 50% probability of the stock being at $\mathbf{B}_{\text{lim}}$. This risk neutral approach to estimating $\mathbf{F}_{\text{lim}}$ is proposed because the estimation of $\mathbf{B}_{\text{lim}}$ itself is intended to be risk averse. If $\mathbf{B}_{\text{lim}}$ is set such that the probability of obtaining a poorer recruitment does not increase until SSB is below $\mathbf{B}_{\text{lim}}$, then an $\mathbf{F}_{\text{lim}}$ that is equivalent on average to $\mathbf{B}_{\text{lim}}$ is equally risk averse relative to impaired recruitment. Consequently there is no need to be further risk averse about the estimation of $\mathbf{F}_{\text{lim}}$.

$\mathbf{F}_{\text{lim}}$ is estimated by obtaining a value for the expected recruitment at $\mathbf{B}_{\text{lim}}$, based either on the segmented regression, or the non-parametric method. The slope of the replacement line at $\mathbf{B}_{\text{lim}}$ is R/ $\mathbf{B}_{\text{lim}}$, and so the inverse, $\mathbf{B}_{\text{lim}}$ /R, will be equivalent to a particular fishing mortality on a curve of SSB/R against F. This F will be $\mathbf{F}_{\text{lim}}$.

Occasionally a large year class may occur in the vicinity of $\mathbf{B}_{\text{lim}}$. This may seem to exert undue leverage on the expected value of recruitment at $\mathbf{B}_{\text{lim}}$ derived from the parametric method, whereas in the non parametric method it will only affect the tail of the probability density function. Although it may be tempting to discount this year-class on the grounds that it may be the result of special environmental conditions, rather than being a function of SSB, there is usually no way of justifying this assumption in order to eliminate such a year-class from the R-SSB plot, and this may make the non-parametric method more suitable in these circumstances.

3.3 Deriving F_{pa} from F_{lim}

The aim of setting $\mathbf{F_{pa}}$ is that when $\mathbf{F_{pa}}$ is the intended or prescribed F in a TAC year, the forecast TAC should generate a realised F that has a very low probability of being above $\mathbf{F_{lim}}$. The 1998 calculations of $\mathbf{F_{pa}}$ allowed for uncertainty in the estimation of F by assuming a variance that was used to estimate $\mathbf{F_{pa}}$ as a fixed multiple of $\mathbf{F_{lim}}$. A comparable variance assumption was used to estimate $\mathbf{B_{pa}}$ from $\mathbf{B_{lim}}$. As discussed in WD 7, however, Sparholt and Bertelsen (2002) have since analysed the uncertainty in 33 ICES stocks for the period 1988-1999. They found that the multipliers used (1.41, 1.51, 1.64) generated on average a 30% chance that a stock at $\mathbf{B_{pa}}$ is below $\mathbf{B_{lim}}$, rather than the 5% desired, and that to achieve the 5% chance, a multiplier of 2.85 would be required.

The Study Group therefore proposes that an alternative method of allowing for assessment uncertainty is to calculate F_{pa} from F_{lim} using the observed difference between the intended F and the realised F for each individual stock. Realised F is estimated when the TAC prescribed by the intended F in the prediction year is applied to the 'true' stock size (obtained in retrospect by the most reliable recent assessment, the reference run, which should normally be the assessment whose SSB-R pairs are used to estimate B_{lim} and hence F_{lim}).

This approach allows for any causes of the difference between the intended and realised F due to assessment uncertainty as defined in Section 2.1, but not natural variation. Error in implementing F in the TAC year is not included, since what is used in the calculation of the realised F is the actual advised TAC The 'true' stock sizes calculated from the reference run could be affected in an unknown by catch reporting errors in the most recent years of the reference run, however.

3.3.1 Comparing intended and realised F using retrospective analysis

The proposed steps in the calculation of $\mathbf{F_{pa}}$ are as follows:

1) The reference data set comprises the stock numbers, mortalities, weights and maturities at age from the assessment whose SSB-R data are used to estimate $\mathbf{B_{lim}}$. The most recent years should be excluded if they produce instability in retrospective runs, therefore leaving a 'true' stock estimate from say year N-Y, where Y≥2, back to N-X, where N is the most recent year and X is the earliest terminal year for which there are sufficient data to perform a meaningful assessment

2) Estimate the relation between the intended F and the realised F, for as many of the TAC years prior to N-Y as are necessary, in the following way:

a) For each TAC year do an assessment with the data from N-X up to the terminal year, using where possible the current model formulation/conditioning. This requires a judgement whether the current model options are appropriate for previous years.

b) Make a short term forecast, using the weight, maturity, exploitation at age, and intermediate year assumptions that are standard for the stock.

c) The catch options table gives a range of intended F values, and the corresponding TAC values. Apply these catches to the "true" stock in the reference data set and derive the corresponding realised F as if a TAC had actually been taken. This gives pairs of intended and realised F for that TAC year.

d) Alternatively, use the catch options from existing assessment reports, assuming that this does not raise any data or model formulation issues.

3) At each intended F value there will therefore be a set of values for the realised F in each TAC year, i.e. a vector of the realised F at that intended F across years. Sort each vector into a cumulated distribution of realised F for each intended fishing mortality. It may be necessary to fit a probability distribution function to each vector to smooth the empirical distributions.

4) The range of intended F values will therefore give a set of probability distributions. Identify the highest intended F that still carries a low risk that the realised F is above $\mathbf{F_{lim}}$, and select this as the estimate of $\mathbf{F_{pa}}$.

This procedure requires a relatively long data series that allows a range of retrospective assessments to be carried out. Care is required if there are obvious time trends in the data, (e.g. if the probability profiles have clearly changed over time), particularly if some data series have ceased or new ones commenced. If the retrospective assessments are not possible, the first alternative is to use the catch option tables from historical assessments as noted above. If that is also impossible, e.g. because analytical assessments commenced only recently, the only option may be to make an educated guess about the relation between intended and realised fishing mortality, guided if possible by retrospective runs for only a few years back from the current assessment, or by analogy with similar stocks with similar fisheries.

3.4 Deriving $\mathbf{B}_{pa}$ from $\mathbf{B}_{lim}$

It is proposed to derive $\mathbf{B}_{pa}$ from $\mathbf{B}_{lim}$ in a similar manner to the above, using retrospective assessments and comparing the SSB in each assessment year with the 'true SSB' determined by the reference run, as follows.

1) Following the procedure in Section 3.3.1, estimate the SSB in the assessment year (SSB_{assm}) and compare it to the SSB_{true} estimated for that year by the reference assessment run. Over the range of terminal years, this will give a set of $\{SSB_{assm}, SSB_{true}\}$ pairs. (Note that the Study Group proposed to use the SSB in the assessment year because this is the SSB used by ACFM to compare with the reference points, but the forecast SSB at the start of the TAC year will relate more closely to the procedure for estimating the realised F in the TAC year).

2) Derive a ratio SSB_{assm}/SSB_{true} in an analogous way to the usual procedure for deriving $\mathbf{F}_{high}$ from a stock-recruit plot, by plotting the pairs of values of SSB_{assm} and SSB_{true}, with SSB_{true} as the independent variable. Draw a line through the origin so that α% of the points are above and (100-α) are below the line, where α is the acceptable risk. This may be 10% or less, depending on the availability of the data. If the number of pairs is small, the highest line passing through a point should probably be used, unless this is an obvious outlier.

3) The slope β of the line is the ratio between $\mathbf{B}_{pa}$ and $\mathbf{B}_{lim}$, thus $\mathbf{B}_{pa} = \beta * \mathbf{B}_{lim}$

3.5 The operational compatibility between fishing mortality and biomass reference points

The operational reference point $\mathbf{B}_{pa}$ is derived from $\mathbf{B}_{lim}$ in order to ensure that when a spawning stock is observed to be at $\mathbf{B}_{pa}$ there is a low probability that it is really at $\mathbf{B}_{lim}$. If SSB is at or below $\mathbf{B}_{pa}$, ICES should advise that F is reduced in order to increase SSB above $\mathbf{B}_{pa}$, (since ICES does not intend that $\mathbf{B}_{pa}$ is to be used as a target). Similarly, $\mathbf{F}_{pa}$ is derived from $\mathbf{F}_{lim}$ in order to ensure that when a stock is observed to be at $\mathbf{F}_{pa}$ there is a low probability that it is really above $\mathbf{F}_{lim}$. If F is at or above $\mathbf{F}_{pa}$, ICES should therefore advise that F is reduced below $\mathbf{F}_{pa}$ (since ICES does not intend that $\mathbf{F}_{pa}$ is to be used as a target). As explained in section 2.4, the assessment uncertainty taken into account by the independent calculations of $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$ is unlikely to be the same, so that when a stock is observed to be at $\mathbf{F}_{pa}$ this does not necessarily imply that SSB will be at $\mathbf{B}_{pa}$ all of the time. Therefore, when F is at $\mathbf{F}_{pa}$, but SSB is below $\mathbf{B}_{pa}$, ICES will also give advice to further reduce F. Although we do not expect that $\mathbf{F}_{pa}$ implies that equilibrium SSB is $\mathbf{B}_{pa}$, it will still be helpful to evaluate the performance of these reference points by monitoring the actual operational relationship between $\mathbf{F}_{pa}$, SSB, and $\mathbf{B}_{pa}$.

The Study Group discussed at some length the possibility of deriving directly a value of $\mathbf{F}_{pa}$ such that when the fishery is at $\mathbf{F}_{pa}$ there is a low probability that SSB is below $\mathbf{B}_{lim}$, or an $\mathbf{F}_{pa}$ that minimises directly the risk that when the fishery is at $\mathbf{F}_{pa}$, the SSB is below $\mathbf{B}_{pa}$. Such values for $\mathbf{F}_{pa}$ would combine the natural variation of SSB at a particular F with, in the former case, the assessment uncertainty on F, and in the second case, the assessment uncertainty on SSB. A proposed approach to calculating these distributions is suggested in Annex 10, but the Group was unable to evaluate this in detail and it is still at the developmental stage.

3.6 Evaluating the results for $\mathbf{B}_{lim}$, $\mathbf{F}_{lim}$, $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$

The methodologies proposed in this section seem intuitively sound, but they need to be tested in practice. The tests need to embrace the estimation aspect, but also the eventual outcomes using, say, a scenario modelling approach. The only tests that have been carried out to date are on the use of the segmented regression as described below.

3.6.1 Testing Segmented Regression

The estimation of $\mathbf{B}_{lim}$ from the change point of a stock-recruit curve using segmented regression has been reasonably well tested. SGPA 02a reviewed statistically objective fitting of stock-recruit data by segmented regression for the following stocks, as described in the numbered working documents of Anon 2002 listed below:

North east Arctic saithe	(SGPA 02a, WD 10)
Northern hake	(SGPA 02a, WD 11)*

North east Arctic cod	(SGPA 02a, WD 12)*
North Sea cod	(SGPA 02a, WD 13)*
West of Scotland cod	(SGPA 02a, WD 14)*
Irish Sea cod	(SGPA 02a, WD 15)*
Celtic Sea cod	(SGPA 02a, WD 16)
Skagerrak plaice	(SGPA 02a, WD 17)
North Sea herring	(SGPA 02a, WD 18)
Thames herring	(SGPA 02a, WD 19)
NE Atlantic mackerel	(SGPA 02a, WD 20)
Biscay anchovy, N Sea plaice & sole	(SGPA 02a, WD 21)

The present Study Group re-analysed the stocks marked with an asterisk using a version of the segmented regression re-written from the original S-plus code into the R language (Motos, pers comm). First, the 2001 assessment data used by O'Brien and Maxwell were tested, in order to verify that the same results were achieved with the recoded version of the programme. Virtually identical results were obtained by Study Group members with no previous experience of using this method.

The model was then fitted to the 2002 assessment data for the same species. Parameter values, including change point, slope at the origin and the recruitment plateau, were computed together with the F statistic and significance probability. Abstracts describing these tests are contained in Annex 9a.

SGPA02a stated that 'It is apparent from the WDs that the change point model can give a far more reasonable fit to stock-recruitment pairs at higher values of SSB than the WG S-R model'. However, beyond the significance of the fittings, reference point values must have other properties, including stability and robustness, in order to be considered a reliable basis for ICES advice on fisheries management. Sensitivity tests for the segmented regression fitting were already presented during SGPA02a, namely the variability observed by eliminating a single year-class in turn from the whole time series. A further way to test sensitivity of segmented regression fittings was presented at the present Study Group. WD 5 (Ibaibarriaga et al), investigated whether change points are stable and robust by retrospectively analysing model fittings to S-R data in the last 10 years i.e. estimating change points by adding one year for the last 10 years of the time-series of S&R available for each stock. The test could also be used to check future variability in recruitment by adding future observations for a range of plausible R&SSB realisations.

From the examples analysed it appears that the identification of a change point using the segmented regression is a suitable method when a long time series (>30 years) and a wide dynamic range of SSB are available. Shorter time series or narrow SSB ranges may lead to more unstable change points estimates.

Although the variability coming from uncertainty in the assessments has not been analysed systematically, it can be tested by comparing the change point fittings that result from consecutive assessment years. The examples analysed indicate that instability in the assessment is directly translated to instability in the change point estimates.

3.6.2 Reality checks

If there are large changes in the reference point values, this will affect current management decisions, so the new values will need to be justified to managers. The Study Group did not have time to discuss or develop specific 'reality' checks, but as a minimum the new values obtained should be checked visually by showing their location on the stock-recruit plots, by plotting the time trend in SSB with $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ marked (as in the ACFM report), and by plotting the time trend in F with $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$ marked (as in the ACFM report). This should indicate whether the new values have successfully removed any previous problem associated with $\mathbf{B}_{loss}$, or changes in the assessment outputs, and should identify whether the new values can sensibly be presented to managers. Longer term, the performance of these reference point values should be checked by scenario modelling.

4 GUIDELINES SUMMARY

An overview of the sequence of procedures is shown below:

- Tabulate the current (old) PA and Limit reference points and their basis, as well as other conventional reference points ($F_{0.1}$, $\mathbf{F}_{max}$.)

- Identify the assessment, R-SSB data set, and time period to be used in the recalculation

- Inspect the R-SSB data visually. Do the SSB data cover a wide dynamic range ? Do they contain exceptional year-classes ? Will the data be used to estimate $\mathbf{B}_{lim}$, or $\mathbf{B}_{loss}$, and is $\mathbf{B}_{loss}$ to be a proxy for $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$?

- Identify whether the current (old) reference points suffer from inconsistency, model structure, or regime issues, and identify what remedial action is needed. For example, has an old estimate of $\mathbf{B}_{loss}$ been overtaken by further decline in SSB, or has there been a material change in the R-SSB plot from the assessment due to changes in biological data or a change in the conditioning (formulation) of the assessment model?

- Estimation of $\mathbf{B}_{lim}$ or $\mathbf{B}_{loss}$

  - Segmented regression: estimate the change point S* and its confidence interval for the chosen set of R-SSB data. Examine the diagnostics for S* and decide if the fit is statistically robust. Specify what risk averse value of α is to be used in specifying $\mathbf{S^*}(\alpha)$, the proposed value of $\mathbf{B}_{lim}$ or $\mathbf{B}_{loss}$.

  - Kernel method: specify the reasons why this approach is chosen. Specify the value of recruitment to be used as ‘poor’, and the bandwidth of the smoother. Use the software to calculate the probability density function of expected poor recruitment at each SSB. Plot against SSB to identify the SSB below which recruitment becomes impaired, and hence identify $\mathbf{B}_{lim}$ or $\mathbf{B}_{loss}$.

- Estimate $\mathbf{F}_{lim}$ from $\mathbf{B}_{lim}$

  - Calculate R/SSB at $\mathbf{B}_{lim}$, the slope of the replacement line at $\mathbf{B}_{lim}$.

  - Invert to give SSB/R.

  - Use this SSB/R to derive $\mathbf{F}_{lim}$ from the curve of SSB/R against F.

- Estimate $\mathbf{F}_{pa}$ from $\mathbf{F}_{lim}$

  - Identify the most recent reliable assessment data set to be used as a reference data set (usually the one used to estimate $\mathbf{B}_{lim}$).

  - Note the year of the reference assessment, full documentation of the data sources, the assessment method, and the configuration used for the derivation of the new biological reference points.

  - Note the sensitivity of the reference assessment to assumptions (e.g. shrinkage, +group], and document and justify the exploitation pattern, weight and maturity at age for the reference assessment.

  - Use the reference data to carry out a set of retrospective assessments within the converged part of the assessment.

  - Tabulate and plot the distributions of realised F across assessment years generated by the TAC corresponding to each intended F.

  - Compare the distributions between intended F values and identify the highest intended F that still carries a low risk that the realised F is above $\mathbf{F}_{lim}$

- Estimate $\mathbf{B}_{pa}$ from $\mathbf{B}_{lim}$

  - Use the set of retrospective assessments to obtain the SSB in each assessment year and compare with the ‘true’ SSB estimated by the reference data set.

  - Plot the pairs of SSB_{assm} against SSB_{true}

  - Draw through the origin the line that leaves α% (where α is the acceptable risk) of the points above the line, whose slope is β in $\mathbf{B}_{pa} = \beta * \mathbf{B}_{lim}$.

- Results

  - Show the various working plots (segmented regression and diagnostics, kernel method plots of pdf R against SSB, plots of SSB/R, tables of intended and realised F, plots of SSB_{assm} and SSB_{true})

  - Reality check of new values:

    -show stock-recruit plot with new values of $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ marked

    -plot the time trend in SSB, with $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ marked (as ACFM)

    -plot the time trend in F, with $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$ marked (as ACFM)

  - Comparison with old values? Is there a need to change ?

  - Sensible and defendable to managers ?

  - Species/ area comparisons ?

  - Criteria for acceptance or rejection ?

5 REBUILDING PLANS

SGPA was asked to "commence the development of a framework for specifying and monitoring rebuilding plans that take into account the status and dynamics of stocks, technical interactions, uncertainty, time period and risk, and the data required."

A rebuilding plan can be defined as a set of multi-annual decisions aimed at improving the state of a depleted stock to reach an agreed target. It can be regarded as a special case of a harvest control rule (HCR) that is applied for a limited time horizon and typically uses a substantially lower fishing mortality than is normally advised, in order to achieve a specified goal. SGPA sees this topic within the broader context of the need for ICES to make progress in the area of multi-annual management plans and harvest control rules. The Group discussed issues related to the immediate context of rebuilding plans, but it also identified topics which it feels can only be addressed by establishing a dedicated ICES Working Group on Harvest Control Rule,which would also provide a natural home for the further development of rebuilding plans. The establishment of this working group is discussed in section 5.3.

On a semantic note, the terms "rebuilding plan" and "recovery plan" tend to be used interchangeably. The Group recommends that the term "rebuilding plan" is more appropriate because, although management can usually ensure some rebuilding of a stock by reducing fishing mortality, it cannot guarantee the production of future year classes sufficient to ensure actual recovery.

5.1 Rebuilding/recovery plan issues

When reviewing existing EU 'recovery plan' proposals, SGPA02a identified four generic components of a rebuilding plan :

1. A measure of the status of the stock with respect to biological reference points

2. A target recovery period

3. A target recovery trajectory for the interim stock status relative to the biological reference points

4. A transition from the recovery strategy to one that achieves long-term management objectives

5.1.1 Preliminary considerations

The status of the stock with respect to biological reference points will normally be measured by a routine stock assessment, and this will be used to identify why a rebuilding plan is needed, what the rebuilding target is to be, and how severe the management measures need to be. Implementation of the plan requires detailed discussion between scientists, managers and stakeholders on a range of issues: the target, the recovery period, the management measures to be adopted, their severity, the monitoring programme, and the criteria for removing the plan later. It should be recognised in advance that a rebuilding plan that requires substantial restrictions on fishing activity may well make it more difficult to sample and assess a stock, and hence to monitor progress towards recovery. This needs to be taken into account at the outset, by considering, for example,

- The possibility of assessing the stock using survey data only

- The need to collect data specific to each individual management measure, e.g. discard data for changes in gear selectivity, and data on the spatial distribution of catch and effort to monitor spatial closures

This would typically require increased coverage by scientific observers and enforcement agencies, and may therefore have manpower implications.

5.1.2 Rebuilding period

The target rebuilding period will depend both on stock related factors, and the type and effectiveness of the management measures implemented.

Relevant stock factors include the degree of depletion of the stock, the actual rebuilding target, and the productivity and biological characteristics of the stock that will determine the recovery rate e.g. growth, maturity, fecundity. Biological criteria that help in defining the rebuilding period and trajectory include,

- The age at 50% maturity

- Mean age of the spawning stock in an equilibrium population fished at $\mathbf{F}_{pa}$.

- The generation time of the stock (although this can be defined in several different ways e.g. Caswell, 1989; Goodyear, 1995).

Technical guidelines on the use of the Precautionary Approache in US fisheries (Restrepo *et al*, 1998) propose that the maximum rebuilding time should be linked to generation time in cases when rebuilding cannot be achieved in ten years. The guidelines note that "Linking the rebuilding period with generation time is important because it highlights the time span in the future during which recruitment will begin to depend primarily upon fish that have yet to be born, as opposed to spawners that already exist". This is particularly important in severely depleted stocks where the age structure is very narrow and largely comprises immature fish, because if rapid recovery is not instituted immediately, the known spawning stock will soon be depleted, and the major part of the rebuilding will depend on new year-classes not yet born. Whatever rebuilding period is chosen, it should be recognised that long term predictions about rebuilding based on the use of a stock-recruit relationship cannot be guaranteed. Management measures will aim to move the stock in the right direction but they cannot guarantee future good recruitment. Such considerations favour the early adoption of strict measures to ensure a rapid reduction in F on the current stock that is actually in the sea at the outset of the rebuilding period.

The likely effectiveness of the various management options will obviously affect recovery times. If a substantial reduction in fishing mortality is required over a sustained period, it is likely to be achieved more effectively through effort controls on all fisheries which catch fish from the relevant stock (including by-catch), rather than by TAC regulations. Although other possible measures include mesh changes and seasonal/area closures, it should be recognised that their effectiveness can be limited or nullified by, for example, failure to comply effectively with mesh changes, or by the reallocation of effort in response to closed areas. The Study Group feels that it is desirable to review practical experience with these approaches. There will hopefully be some progress in this direction during the Theme Session on Recovery Plans at the 2003 Annual Science Conference.

Although stock rebuilding is likely to be more rapid when restrictions on fishing mortality are severe, there are limits to what may be achievable. For example, although complete closure of a fishery may be justifiable biologically, this may not be acceptable for socio-economic reasons. Equally, that does not mean accepting alternative measures that are ineffective. There is clear need for dialogue with managers and other stakeholders on these issues.

5.1.3 The rebuilding trajectory

If the state of the stock, the recovery target, and the rebuilding period are all defined, the options for the trajectory are clearly rather limited. It is desirable, however, that a rebuilding plan produces a change in abundance or the other biological criteria that is measurable, taking into account the assessment and survey methodology available, so some iteration between the various components is therefore desirable. There is merit in attempting to achieve recovery in relatively large steps, in order to have a higher probability of the effect being detectable, although it may not be possible to do this on an annual basis in all cases. There is also merit in using a proposed trajectory as a measure of the performance of the rebuilding plan. This will allow managers some flexibility during the course of the rebuilding plan, e.g. to apply more or less severe measures if progress is behind or ahead of schedule. Such adaptability may be linked to the recruitment observed during the rebuilding period. For example, while a strategy that aims for a constant percentage increase in SSB may be desirable, in practice this will not be achievable in years when recruitment is poor, whereas in other years recruitment may be large enough to permit a larger increase in SSB.

5.1.4 Long term management objectives

It is highly desirable that managers see a rebuilding plan with its recovery target as an interim step towards achieving a longer term objective. This should be stated explicitly so that once "recovery" is achieved there will be a transition to a management plan aimed at achieving the long-term aims. This raises two separate questions; the need for long-term management objectives and the definition of what constitutes "recovery".

The existing ICES implementation of the Precautionary Approach is concerned only with avoiding recruitment overfishing, and reference points are defined only in relation to this objective. For most ICES stocks, no other management objectives are yet defined. For a stock subject to a rebuilding plan, however, it is important that management does not stop once the recovery target is achieved, otherwise it is highly likely that recovery will only be temporary, and that the stock will revert to its former state outside safe biological limits. One way of avoiding this is to establish long-term objectives and associated management plans while stocks are still in the rebuilding phase. Such considerations are not restricted solely to stocks subject to rebuilding plans, but apply equally well to other stocks.

On the definition of "recovery", the simplest case is to establish SSB above a reference level of biomass (e.g. $\mathbf{B}_{pa}$). In practice, it may also be desirable to specify as an additional criterion, that there are a number of different year-classes contributing to the spawning stock, and not just to one single large year-class. The presence of a number of different year-classes in the stock should help to ensure a higher probability of improved recruitment (e.g. Marteinsdottir and Thorarinsson, 1998), and avoid the SSB decreasing again once any single large year-class is fished-out.

5.2 "Collapse" in the fisheries context

The word 'collapse' is sometimes used to describe the state of fish stocks. Because stakeholders regard it as an emotive term, it is desirable to define what is meant if it is to be used in relation to a fish stock. Dictionary definitions of 'collapse' imply that a bad event is happening 'suddenly' over a short time scale. In the fisheries context, however, the element of suddenness is not appropriate, as most fish stocks decline gradually, rather than as a sudden event. For this reason the word 'collapse' may not be appropriate in describing the state of a fish stock.

Leaving aside this stricter definition, the word 'collapse' has been used in relation to, for example, the recent state of the North Sea cod stock, in order to imply depletion to a very low level where the risk to the stock is high. The connotation is that, as a result, recovery may occur only very slowly or not at all, even in the complete absence of any fishing mortality. Simply withdrawing the word 'collapse' from the fisheries vocabulary, whether for correctness or for appeasement of stakeholder views, should not be taken to imply that the concerns of scientists, or the responsibilities of managers, have been alleviated.

In any discussion related to stock depletion and recovery, it is instructive to refer to examples of stocks that have been severely depleted, and which may or may not have recovered subsequently. Examples are the cod in NAFO areas 2J3KL and 3NO, and the North Sea Mackerel, which were both severely depleted, and have subsequently remained at a very low level (as opposed to the North Sea herring, which reached a very low level but which recovered once the fishery was closed). In some cases, therefore, stocks can be depleted beyond the point from which they are able to recover in a foreseeable time span. Recovery can also be very slow, as in the case of the Norwegian spring-spawning herring stock, which took around 30 years to recover, whereas the North Sea herring stock recovered in around seven years. In some cases, if the stock is still producing year classes, albeit at a reduced level, a simple reduction in fishing mortality may be enough to permit a rapid recovery, as happened with the North East Arctic cod stock around 1990.

5.3 Proposal for a Working Group

SGPA proposes that to promote further work on the topics of harvest control rules (HCRs), fishery management plans and rebuilding plans, a specific working group is necessary. Such a working group should develop harvest-control rules and other aspects of multi-annual management. As a rebuilding plan is a special example of a harvest control rule, the working group could provide a natural home for work in relation to rebuilding plans. The initial topics of work for this group should include the following :

- Identify and review HCR types and their properties
- Identify candidate long-term management objectives
- Identify and review tools to evaluate HCRs and establish quality criteria and guidelines for them
- Consider the scope for developing a default HCR/Rebuilding rule.

On rebuilding plans, SGPA notes that there is scope for work on the following areas:

- Summarise the management tools available for use in the context of rebuilding plans, the practical experience of their use, and the data requirements for monitoring their effectiveness
- Consider what features of potential rebuilding plans are most likely to achieve measurable effects in a limited time scale.

While some stocks within the ICES area are subject to management plans including harvest control rules, progress in this area within the ICES context has generally been slow. In order to promote further progress on rebuilding plans and harvest control rules, it is proposed that a specific ICES Working Group is required. Client commissions have previously requested that ICES address this area, and the working group could draw on pre-existing work already commissioned by ICES clients. SGPA therefore concludes that there is considerable justification for the formation of a Working Group to develop Harvest Control Rules, Multiannual Management Plans and Rebuilding Plans. The proposal to establish a working group, rather than a study group, reflects the long-term, strategic need for this work.

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LIST OF ANNEXES

Annex 1 **The technical basis of the current ICES reference points**

Annex 2 **Working Document 1** (O'Brien and Maxwell, 2002a)

Working Document 2 (O'Brien and Maxwell, 2002b)

Annex 3 **Working Document 3**

Lassen, O'Brien, and Sparholt: DRAFT ICES' guidelines for calculating PA reference points for stocks with analytical assessments.

Annex 4 **Working Document 4**

Jake Rice & Obai Mashal: Estimating Biomass Limit Reference Points For Canadian Cod with Non-Parametric Density Estimation methods.

Annex 5 **Working Document 5**

Leire Ibaibarriaga, Enrique de Cárdenas & Lorenzo Motos: Testing stability of the segmented regression.

Annex 6 **Working Document 6**

Enrique de Cárdenas, Carmela Porteiro and José Castro: More on the use of relative versus absolute PA reference points question.

Annex 7 **Working Document 7**

Dankert W. Skagen and Asgeir Aglen: Evaluating precautionary values of fishing mortalities using long term stochastic equilibrium distributions.

Annex 8 **Working Document 8**

Azevedo & Jadim: "bhac" : an R package to compute %BPR and %SPR.

Annex 9 **Technical Annex** 9a Testing the segmented regression

9b Comparing results by scenario modelling

9c Testing the difference between two values of $\mathbf{B}_{lim}$

Annex 10 **Technical Annex** Proposed method for estimating an $\mathbf{F}_{pa}$ that is risk averse to $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$

ANNEX 1

Working Paper
ACFM May 2000

ICES Framework for the Implementation of the Precautionary Approach in Fisheries Management Advice

Precautionary Approach Reference Points
ACFM Practice 1998-1999

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Proposed Action: ACFM is invited to discuss this paper. The paper should serve as background for a discussion of the consistency in the ACFM advice and in discussions on laying down more precise and therefore more transparent advisory procedures.

1 ABSTRACT

This paper describes the Precautionary Approach Reference points used by ICES in formulating management advice on the exploitation of fish stocks. The paper summarises how ACFM operationally has defined the PA reference points and how the advice has been formulated based on these reference points. The paper only deals with those stocks for which an assessment is presented, about 35 % of all stock listed in the Annual ACFM report.

2 IMPLEMENTATION BY ACFM

The legal texts in the FAO Code of Conduct of Responsible Fisheries and in Annex II of the UN Agreement on Straddling and Highly Migratory Fish stocks was taken further within ICES and guidelines were formulated in:

Reports of the Study Group on Precautionary Approach to Fisheries Management (ICES CM 1997/Assess:7 and ICES CM 1998/ACFM:10);

The Introduction section of the ACFM Report 1999 (ICES Cooperative Research Report No. 236, 2000).

These guidelines are discussed in another paper presented to this meeting (ACFM May 2000) and in previous ICES reports are supplemented by a study of the practical use exercised at the ACFM meetings in October 1998, May 1999 and October 1999. This study is presented below.

ICES, in the ACFM report 1999, (CRR 236), proposed reference points for 63 stocks. This paper attempts to summarise the advisory practice now emerging.

Reference points used in this paper are those derived by ICES mostly based on considerations of the population dynamics of the stock.

Section 3 presents the references points including their numerical values that ICES proposed in 1999 together with the reasoning behind these reference points. Section 4 offers a list of reference points that has been proposed in various forums among which ICES has selected its four $\mathbf{F}_{\mathrm{lim}}$, $\mathbf{F}_{\mathrm{pa}}$,$\mathbf{B}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{pa}}$. This may serve as background in the discussions.

3 ACFM USE OF PA POINTS IN 1999

Tables A1 and A2 presented below are summaries based on the ACFM report for 1999, CRR No. 236.

Table A1 summarises the technical basis used by ACFM in 1999 when defining PA reference points. In total ACFM has defined PA points for 63 stocks or approximately half of the number of stock that are addressed in the ACFM report. The summary revealed:

$\mathbf{B}_{\mathrm{lim}}$ is in most cases on mainly $\mathbf{B}_{\mathrm{loss}}$ and only in two cases have it been based on $\mathbf{B}_{\mathrm{pa}}$.. Only in 6 cases were the basis S-R plots. $\mathbf{B}_{\mathrm{lim}}$ remained undefined for 11 stocks of the 63 stock where reference points have been defined.

$\mathbf{B}_{pa}$ was mainly based on $\mathbf{B}_{lim}$, but also $\mathbf{B}_{loss}$ was frequently used. S-R plots was used in 7 cases. $\mathbf{B}_{pa}$ remained undefined in 8 cases.

$\mathbf{F}_{lim}$ was based on $\mathbf{F}_{loss}$ in 21 cases. Only one other type of commonly used F reference points, namely F med was used and only in one case. $\mathbf{F}_{lim}$ remained undefined in 30 cases.

$\mathbf{F}_{pa}$ was based on $\mathbf{F}_{lim}$ in 15 cases. Not of F loss in any case. F med was used for 14 stocks and medium-term projections were used in 15 cases. Only one other type of commonly used F reference points, namely $\mathbf{F}_{0.1}$, was used. $\mathbf{F}_{pa}$ remained undefined in 13 cases.

Table A2 lists all PA reference points defined sorted by $\mathbf{B}_{lim}$, $\mathbf{B}_{pa}$, $\mathbf{F}_{lim}$, $\mathbf{F}_{pa}$ and within these groups sorted alphabetically. Heterogeneity in formulations and in philosophy is obvious. To what extent this heterogeneity reflects real differences in stock population dynamics or between-stock inconsistency in criteria for choosing reference points is not clear.

Table A1. Summary table of Precautionary Approach reference points as defined by ACFM 1999.

Reference point	Technical basis	**Number of stocks**
$\mathbf{B}_{lim}$	$\mathbf{B}_{pa}$	2
	$\mathbf{B}_{loss}$	36
	S-R plots	6
	MBAL	5
	Lowest that has produced outstanding y.c.	1
	20% of Umax	2
	Not defined	11
	Sum	63
$\mathbf{B}_{pa}$	$\mathbf{B}_{lim}$	28
	$\mathbf{B}_{loss}$	13
	S-R plots	7
	MBAL	6
	Lowest that has produced outstanding y.c.	1
	Not defined	8
	Sum	63
$\mathbf{F}_{lim}$	$\mathbf{F}_{loss}$	21
	$\mathbf{F}_{pa}$	3
	F that has let to stock decline	5
	$\mathbf{F}_{med}$	3
	$\mathbf{B}_{lim}$	1
	Not defined	30
	Sum	63
$\mathbf{F}_{pa}$	$\mathbf{F}_{lim}$	15
	$\mathbf{F}_{med}$	14
	Medium-term projections	16
	Historical experience	1
	By analogy to other stocks	2
	SSB/R in absence of fishing	1
	$\mathbf{F}_{0.1}$	1
	Not defined	13
	Sum	63

Table A2. PA reference points (sorted by type) as defined by ACFM in 1999.

PA point	Technical basis	Stock
$\mathbf{B}_{lim}$	0.71*$\mathbf{B}_{pa}$	Herring Gulf of Riga
$\mathbf{B}_{lim}$	0.72*$\mathbf{B}_{pa}$	Sole IIIa
$\mathbf{B}_{lim}$	400000t surviving for spawning	Capelin, Iceland
$\mathbf{B}_{lim}$	Agreed by managers	Plaice N.Sea
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	NEA cod
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	NEA saithe
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Whiting N.Sea
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Saithe N.Sea
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Sole N.Sea
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	N .pout N. Sea
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Plaice VIId
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Haddock VIa
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Haddock VIb
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Cod VIIa
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Whiting VIIa
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Sole VIIa
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Cod VIIe-k
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Whiting VIIe-k
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Plaice VIIf+g
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Plaice VIIe
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Sole VIIe
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Megrim VIIIc and IXa (L. boscii)
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Megrim VIIIc and IXa (L. whiffiagonis)
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Horse mackerel VIIIc+IXa
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Anchovy VIII
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Hake, Northern stock
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Cod Faroe Plateau
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Blue whiting
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Saithe Iceland
$\mathbf{B}_{lim}$	$\mathbf{B}_{loss}$	Greenland halibut V+XIV
$\mathbf{B}_{lim}$	Close' to lowest observed	Herring 25-29+32
$\mathbf{B}_{lim}$	From S-R plot. "Only poor R has been observed from 4 years of SSB < 50,000t and all moderate or large year classes have been produced at higher SSB."	NEA Haddock
$\mathbf{B}_{lim}$	ICES CM 1998/ACFM:10	Herring Icelandic
$\mathbf{B}_{lim}$	Increased risk of low R	Herring N.Sea
$\mathbf{B}_{lim}$	Lowest observed	Sandeel IV
$\mathbf{B}_{lim}$	Lowest observed	Cod Kattegat
$\mathbf{B}_{lim}$	Lowest observed	Herring Irish Sea
$\mathbf{B}_{lim}$	Lowest observed	Herring Celtic Sea
$\mathbf{B}_{lim}$	Lowest reliable estimated SSB	Herring VIa(N)+VIIb.c
$\mathbf{B}_{lim}$	Lowest SSB estimated in previous assessments	Whiting VIa
$\mathbf{B}_{lim}$	MBAL	Sprat 22-32
$\mathbf{B}_{lim}$	MBAL	Cod 22-24
$\mathbf{B}_{lim}$	MBAL	Haddock Faroe
$\mathbf{B}_{lim}$	MBAL	Herring Norwegian Spring Spawners
$\mathbf{B}_{lim}$	MBAL, R lower below this	Saithe Faroe
$\mathbf{B}_{lim}$	No biological basis fior defining $\mathbf{B}_{lim}$	Mackerel, combined stock
$\mathbf{B}_{lim}$	Not defined	Anglerfish IV and VI
$\mathbf{B}_{lim}$	Not defined	Haddock VIIa
$\mathbf{B}_{lim}$	Not defined	Sole VIIf+g
$\mathbf{B}_{lim}$	Not defined	Sole VIIIab
$\mathbf{B}_{lim}$	Not defined	Megrim VII and VIIIabde
$\mathbf{B}_{lim}$	Not defined	Anglerfish VIIb-k VIIIab

PA point	Technical basis	Stock
		(L. piscatorius)
$\mathbf{B}_{lim}$	Not defined	Anglerfish VIIb-k VIIIab (L. budegassa)
$\mathbf{B}_{lim}$	Not defined	Horse mackerel, western
$\mathbf{B}_{lim}$	Not defined. S-R data uninformative	Plaice VIIa
$\mathbf{B}_{lim}$	Poor biological basis for definition	Sole VIId
$\mathbf{B}_{lim}$	Rounded $\mathbf{B}_{loss}$	Cod N.Sea
$\mathbf{B}_{lim}$	Smooth $\mathbf{B}_{loss}$	Cod VIa
$\mathbf{B}_{lim}$	Smoothed $\mathbf{B}_{loss}$	Haddock N. Sea
$\mathbf{B}_{lim}$	SSB below which R is impaired	Cod 25-32
$\mathbf{B}_{lim}$	The lowest SSB that has produced an outstanding rich year class	Barents Sea capelin
$\mathbf{B}_{lim}$	Ulim 20% of highest survey index	S. marinus V,VI,XII +XIV
$\mathbf{B}_{lim}$	Ulim Umax/5	S. mentella Deep Sea V,VI+XIV
$\mathbf{B}_{pa}$	-	Capelin, Iceland
$\mathbf{B}_{pa}$	~1.4*$\mathbf{B}_{lim}$	Herring VIa(N)+VIIb.c
$\mathbf{B}_{pa}$	1.33*$\mathbf{B}_{lim}$	Herring 25-29+32
$\mathbf{B}_{pa}$	1.38*$\mathbf{B}_{lim}$	Sprat 22-32
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Haddock N. Sea
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Whiting N.Sea
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Sole N.Sea
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Sandeel IV
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Plaice VIId
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Whiting VIa
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Sole VIIa
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Whiting VIIe-k
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Sole VIIe
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Megrim VIIIc and IXa (L. boscii)
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{lim}$	Hake, Northern stock
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{loss}$	Haddock VIa
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{loss}$	Haddock VIb
$\mathbf{B}_{pa}$	1.4*$\mathbf{B}_{loss}$	Whiting VIIa
$\mathbf{B}_{pa}$	1.5*$\mathbf{B}_{loss}$	Horse mackerel VIIIc+IXa
$\mathbf{B}_{pa}$	1.51*$\mathbf{B}_{lim}$	Blue whiting
$\mathbf{B}_{pa}$	1.51*$\mathbf{B}_{lim}$	Herring Icelandic
$\mathbf{B}_{pa}$	1.6*$\mathbf{B}_{lim}$	Herring Irish Sea
$\mathbf{B}_{pa}$	1.63*$\mathbf{B}_{lim}$	Cod Kattegat
$\mathbf{B}_{pa}$	1.634*$\mathbf{B}_{lim}$	Herring N.Sea
$\mathbf{B}_{pa}$	1.64*$\mathbf{B}_{lim}$	Plaice VIIf+g
$\mathbf{B}_{pa}$	1.64*$\mathbf{B}_{lim}$	Megrim VIIIc and IXa (L. whiffiagonis)
$\mathbf{B}_{pa}$	1.64*$\mathbf{B}_{lim}$	Greenland halibut V+XIV
$\mathbf{B}_{pa}$	1.93*$\mathbf{B}_{lim}$	Cod Faroe Plateau
$\mathbf{B}_{pa}$	1.93*$\mathbf{B}_{lim}$	Herring Norwegian Spring Spawners
$\mathbf{B}_{pa}$	2 std above $\mathbf{B}_{lim}$	Saithe Faroe
$\mathbf{B}_{pa}$	2 std above $\mathbf{B}_{lim}$ but reduced based on S-R plot	Haddock Faroe
$\mathbf{B}_{pa}$	Agreed by managers	Plaice N.Sea
$\mathbf{B}_{pa}$	Below average R below 150000t	N .pout N. Sea
$\mathbf{B}_{pa}$	$\mathbf{B}_{lim}$*1.67	NEA Haddock
$\mathbf{B}_{pa}$	$\mathbf{B}_{lim}$+5%perc. of predicted SSB	Capelin Barents Sea
$\mathbf{B}_{pa}$	$\mathbf{B}_{loss}$	Plaice VIIa
$\mathbf{B}_{pa}$	$\mathbf{B}_{loss}$	Sole VIIf+g
$\mathbf{B}_{pa}$	$\mathbf{B}_{loss}$	Sole VIIIab
$\mathbf{B}_{pa}$	$\mathbf{B}_{loss}$	Megrim VII and VIIIabde

PA point	Technical basis	Stock
B_{pa}	B_{loss}	Anglerfish VIIb-k VIIIab (L. piscatorius)
B_{pa}	B_{loss}	Anglerfish VIIb-k VIIIab (L. budegassa)
B_{pa}	B_{loss}	Mackerel, combined stock
B_{pa}	Examined from S-R plot	NEA cod
B_{pa}	Examined from S-R plot	NEA saithe
B_{pa}	From S-R plot	Saithe N.Sea
B_{pa}	Historical development of stock	Cod VIIe-k
B_{pa}	MBAL	Plaice VIIe
B_{pa}	MBAL	Herring Gulf of Riga
B_{pa}	MBAL	Cod 25-32
B_{pa}	MBAL	Sole IIIa
B_{pa}	MBAL and signs of impaired R below it.	Cod N.Sea
B_{pa}	MBAL and signs of reduced R	Cod VIIa
B_{pa}	Not defined	Anglerfish IV and VI
B_{pa}	Not defined	Haddock VIIa
B_{pa}	Observed low SSB values in 1978-1993	Saithe Iceland
B_{pa}	Previously set at 25000t at which good R is probable. Reduced to 22000t due to an extended period of stock decline	Cod VIa
B_{pa}	Reduced prob.of low R	Herring Celtic Sea
B_{pa}	Set at 36000t, the SSB which allows the stock to remain above B_{lim} in the year following an event of a weak R	Anchovy VIII
B_{pa}	Set at 500000t, the egg survey estimate of SSB that produced the exceptionally strong 1982 y.c.	Horse mackerel, western
B_{pa}	Slightly above lowest observed	Pandalus IIIa
B_{pa}	Smooth B_{loss}	Sole VIId
B_{pa}	Smoothed B_{loss}	Plaice IIIa
B_{pa}	Upa =Umax/2	S. mentella Deep Sea V,VI+XIV
B_{pa}	Upa 60% of highest survey index	S. marinus V,VI,XII +XIV
B_{pa}	Withdrawn	Cod 22-24
F_{lim}	-	S. marinus V,VI,XII +XIV
F_{lim}	-	S. mentella Deep Sea V,VI+XIV
F_{lim}	-	Herring Icelandic
F_{lim}	-	Capelin, Iceland
F_{lim}	1.4*F_{pa} which has historically led to decline	Haddock N. Sea
F_{lim}	1.93*F_{pa}	Cod Faroe Plateau
F_{lim}	2 std over F_{pa}	Haddock Faroe
F_{lim}	Agreed by managers	Plaice N.Sea
F_{lim}	Based on historical response of the stock	Cod VIIe-k
F_{lim}	Consistent with B_{lim}	Saithe Faroe
F_{lim}	F above 0.8 had led o stock decline in early 1980s	Cod VIa
F_{lim}	F_{loss}	Cod N.Sea
F_{lim}	F_{loss}	Whiting N.Sea
F_{lim}	F_{loss}	Saithe N.Sea
F_{lim}	F_{loss}	Plaice VIId
F_{lim}	F_{loss}	Whiting VIIa
F_{lim}	F_{loss}	Sole VIIf+g
F_{lim}	F_{loss}	Sole VIIe
F_{lim}	F_{loss}	Megrim VII and VIIIabde
F_{lim}	F_{loss}	Anglerfish VIIb-k VIIIab (L. piscatorius)

PA point	Technical basis	Stock
F_{lim}	F_{loss}	Megrim VIIIc and IXa (L. boscii)
F_{lim}	F_{loss}	Horse mackerel VIIIc+IXa
F_{lim}	F_{loss}	Hake, Northern stock
F_{lim}	F_{loss}	Mackerel, combined stock
F_{lim}	F_{loss}	Herring 25-29+32
F_{lim}	F_{loss}	Herring Gulf of Riga
F_{lim}	F_{loss}	Herring VIa(N)+VIIb.c
F_{lim}	F_{loss}	Blue whiting
F_{lim}	F_{loss} and historical considerations	Sole VIIa
F_{lim}	F_{loss}. Analog to N.Sea sole	Sole VIId
F_{lim}	F_{med}	Cod VIIa
F_{lim}	F_{med}	Cod 25-32
F_{lim}	F_{med}, excl. abnormal yearsaround 1990	Sole IIIa
F_{lim}	Is 1.0 above which stock decline has been observed	Whiting VIa
F_{lim}	Median of F_{loss}	NEA cod
F_{lim}	Median of F_{loss}	NEA Haddock
F_{lim}	Median values of F_{loss}	NEA saithe
F_{lim}	None advised	N .pout N. Sea
F_{lim}	None advised	Sandeel IV
F_{lim}	Not considered relevant	Herring Norwegian Spring Spawners
F_{lim}	Not defined	Haddock VIa
F_{lim}	Not defined	Haddock VIb
F_{lim}	Not defined	Anglerfish IV and VI
F_{lim}	Not defined	Haddock VIIa
F_{lim}	Not defined	Plaice VIIa
F_{lim}	Not defined	Whiting VIIe-k
F_{lim}	Not defined	Plaice VIIf+g
F_{lim}	Not defined	Plaice VIIe
F_{lim}	Not defined	Sole VIIIab
F_{lim}	Not defined	Anglerfish VIIb-k VIIIab (L. budegassa)
F_{lim}	Not defined	Megrim VIIIc and IXa (L. whiffiagonis)
F_{lim}	Not defined	Anchovy VIII
F_{lim}	Not defined	Horse mackerel, western
F_{lim}	Not defined	Sprat 22-32
F_{lim}	Not defined	Cod 22-24
F_{lim}	Not defined	Herring N.Sea
F_{lim}	Not defined	Herring Irish Sea
F_{lim}	Not defined	Herring Celtic Sea
F_{lim}	Not defined	Capelin Barents Sea
F_{lim}	Not defined	Greenland halibut V+XIV
F_{lim}	Not yet defined	Saithe Iceland
F_{lim}	SSB has declined since early 1970s at F=1.0	Cod Kattegat
F_{lim}	Technical basis	Stock
F_{lim}	Undefined	Sole N.Sea
F_{pa}	-	S. marinus V,VI,XII +XIV
F_{pa}	-	S. mentella Deep Sea V,VI+XIV
F_{pa}	-	Capelin, Iceland
F_{pa}	0.3 considered to have a high prob. Of avoiding F_{lim}	Sole VIIa
F_{pa}	0.6 implies an Beq of 10600t and a rel. low prob. Of $B<B_{pa}$, and is within the range of historic Fs	Whiting VIIa

PA point	Technical basis	Stock
$\mathbf{F}_{pa}$	0.6*$\mathbf{F}_{lim}$	Whiting VIa
$\mathbf{F}_{pa}$	0.63*$\mathbf{F}_{lim}$ (also =$\mathbf{F}_{max}$ and $\mathbf{F}_{med}$)	Horse mackerel VIIIc+IXa
$\mathbf{F}_{pa}$	0.65*$\mathbf{F}_{lim}$, (also=$\mathbf{F}_{0.1}$)	Mackerel, combined stock
$\mathbf{F}_{pa}$	0.7*$\mathbf{F}_{lim}$	Whiting N.Sea
$\mathbf{F}_{pa}$	0.72*$\mathbf{F}_{lim}$	Cod VIIa
$\mathbf{F}_{pa}$	0.72*$\mathbf{F}_{lim}$	Anglerfish VIIb-k VIIIab (L. piscatorius)
$\mathbf{F}_{pa}$	0.72*$\mathbf{F}_{lim}$, implies a less than 10% prob. that SSBmt<$\mathbf{B}_{pa}$	Hake, Northern stock
$\mathbf{F}_{pa}$	0.72*$\mathbf{F}_{lim}$: implies a less than 10% prob. of SSBmt<$\mathbf{B}_{pa}$	Sole VIIe
$\mathbf{F}_{pa}$	0.72*$\mathbf{F}_{lim}$; implies a less than 5% prob. of SSBmt<$\mathbf{B}_{pa}$	Sole VIIf+g
$\mathbf{F}_{pa}$	0.8*$\mathbf{F}_{lim}$	Megrim VIIIc and IXa (L. boscii)
$\mathbf{F}_{pa}$	1.638*$\mathbf{F}_{lim}$	Cod Kattegat
$\mathbf{F}_{pa}$	35% of the unfished S/R. It is considered to be an approximation of $\mathbf{F}_{MSY}$	Anglerfish IV and VI
$\mathbf{F}_{pa}$	5% percentile of $\mathbf{F}_{med}$	Cod 25-32
$\mathbf{F}_{pa}$	5th % of $\mathbf{F}_{loss}$; SSB*>$\mathbf{B}_{pa}$ and prob. (SSBmt<$\mathbf{B}_{pa}$) 10%	Plaice VIId
$\mathbf{F}_{pa}$	5th perc. Of $\mathbf{F}_{loss}$ =0.49, F=0.4 implies an eq. SSB > $\mathbf{B}_{pa}$, and a less than 10% pro. That SSBMT<$\mathbf{B}_{pa}$	Sole N.Sea
$\mathbf{F}_{pa}$	5th perc. of $\mathbf{F}_{loss}$ which implies an eq. SSB>$\mathbf{B}_{pa}$ and a less than 10% prob. That SSBmt<$\mathbf{B}_{pa}$	Saithe N.Sea
$\mathbf{F}_{pa}$	5th perc. Of $\mathbf{F}_{loss}$, implies an eq. SSB > $\mathbf{B}_{pa}$ and a less than 10% pro. that SSBMT<$\mathbf{B}_{pa}$	Cod N.Sea
$\mathbf{F}_{pa}$	5th percentile of $\mathbf{F}_{loss}$=$\mathbf{F}_{lim}$*0.6	NEA cod
$\mathbf{F}_{pa}$	Adopted by analogy to other haddock stocks	Haddock VIb
$\mathbf{F}_{pa}$	Agreed by managers	Plaice N.Sea
$\mathbf{F}_{pa}$	Between $\mathbf{F}_{med}$ and 5th % of $\mathbf{F}_{loss}$; SSB>$\mathbf{B}_{pa}$ and prob. (SSB<$\mathbf{B}_{pa}$) 10%	Sole VIId
$\mathbf{F}_{pa}$	Close to $\mathbf{F}_{max}$ and $\mathbf{F}_{med}$	Cod Faroe Plateau
$\mathbf{F}_{pa}$	Consistent with $\mathbf{F}_{lim}$ and $\mathbf{F}_{med}$	Saithe Faroe
$\mathbf{F}_{pa}$	Consistent with longterm $\mathbf{B}_{pa}$	Cod VIa
$\mathbf{F}_{pa}$	F at which SSB/R is half what it would have been in the absence of fishing	Anchovy VIII
$\mathbf{F}_{pa}$	F sustained for 3 decades	Saithe Iceland
$\mathbf{F}_{pa}$	$\mathbf{F}_{0.1}$	Herring Icelandic
$\mathbf{F}_{pa}$	$\mathbf{F}_{lim}$*0.6	NEA saithe
$\mathbf{F}_{pa}$	Flpg, which implies an eq. SSB>$\mathbf{B}_{pa}$ and a less than 10% prob. that SSBmt<$\mathbf{B}_{pa}$	Haddock N. Sea
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	NEA Haddock
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Plaice IIIa
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Herring 25-29+32
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Sprat 22-32
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Herring Irish Sea
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Herring VIa(N)+VIIb.c
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Haddock Faroe
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Blue whiting
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$	Greenland halibut V+XIV
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$ consistent with proposed $\mathbf{B}_{pa}$	Anglerfish VIIb-k VIIIab (L. budegassa)
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$ implies a less than 5% prob. SSBmt<$\mathbf{B}_{pa}$	Plaice VIIf+g
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$ in a previous assessment and long-term consideration	Plaice VIIa
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$: less than 5% prob. (SSBmt<$\mathbf{B}_{pa}$)	Sole VIIIab
$\mathbf{F}_{pa}$	$\mathbf{F}_{med}$: less than 5% prob. (SSBmt<$\mathbf{B}_{pa}$)	Megrim VII and VIIIabde
$\mathbf{F}_{pa}$	From m-t projections	Herring Gulf of Riga

PA point	Technical basis	Stock
$\mathbf{F}_{pa}$	From simulations low risk of SSB<$\mathbf{B}_{pa}$	Herring N.Sea
$\mathbf{F}_{pa}$	ICES Study Group 1998	Herring Norwegian Spring Spawners
$\mathbf{F}_{pa}$	No defined	Herring Celtic Sea
$\mathbf{F}_{pa}$	No proposal	Megrim VIIIc and IXa (L. whiffiagonis)
$\mathbf{F}_{pa}$	None advised	N .pout N. Sea
$\mathbf{F}_{pa}$	None advised	Sandeel IV
$\mathbf{F}_{pa}$	Not defined	Horse mackerel, western
$\mathbf{F}_{pa}$	Not defined	Capelin Barents Sea
$\mathbf{F}_{pa}$	Not proposed	Whiting VIIe-k
$\mathbf{F}_{pa}$	Set at 0.5. Thid has a high prob of avoiding $\mathbf{B}_{pa}$ in the long-term	Haddock VIa
$\mathbf{F}_{pa}$	Set at an F which implies a less than 10% prob. of Bmt<$\mathbf{B}_{pa}$	Cod VIIe-k
$\mathbf{F}_{pa}$	Set by analogy with other hadock stocks.	Haddock VIIa
$\mathbf{F}_{pa}$	Set consistent with $\mathbf{F}_{lim}$	Sole IIIa
$\mathbf{F}_{pa}$	Set so that prob. (SSBmt<$\mathbf{B}_{pa}$) is low	Plaice VIIe
$\mathbf{F}_{pa}$	Technical basis	Stock
$\mathbf{F}_{pa}$	To be discussed with managers	Cod 22-24

4 SOME COMMONLY USED REFERENCE POINTS

(Extract from: Updated Draft Report of the ICES Study Group on the Precautionary Approach to Fisheries Management, ICES CM 1997/Assess:7)

RP	Definition	Data Required
$\mathbf{F}_{0.1}$	F at which the slope of the Y/R curve is 10% of its value near the origin	Weight at age, natural mortality, exploitation pattern
$\mathbf{F}_{max}$	F giving the maximum yield on a Y/R curve	Weight at age, natural mortality, exploitation pattern
$\mathbf{F}_{low}$	F corresponding to a SSB/R equal to the inverse of the 10% percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.
$\mathbf{F}_{med}$	F corresponding to a SSB/R equal to the inverse of the 50% percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.
$\mathbf{F}_{high}$	F corresponding to a SSB/R equal to the inverse of the 90% percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.
$\mathbf{F}_{MSY}$	F corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship or general production models
2/3 $\mathbf{F}_{MSY}$	2/3 of $\mathbf{F}_{MSY}$	as above
$F_{20\% SPR}$	F corresponding to a level of SSB/R which is 20% of the SSB/R obtained when F=0	Weight and maturity at age, natural mortality, exploitation pattern.
$\mathbf{F}_{crash}$	F corresponding to the higher intersection of the equilibrium yield with the F axis as estimated by a production model; could also be expressed as the tangent through the origin of a Stock-Recruitment relationship.	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship
F_{lpg}	F corresponding to a 10% probablity of giving a replacement line above G_{loss}	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship
$\mathbf{F}_{loss}$	F corresponding to a SSB/R equal to the inverse of R/SSB at the Lowest Observed Spawning Stock $\mathbf{B}_{loss}$	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship
F_{comfie}	F corresponding to the minimum of $\mathbf{F}_{med}$, $\mathbf{F}_{MSY}$ and $\mathbf{F}_{crash}$	
F >= M	Empirical (for top predators)	M and sustainable F:s for similar resources
F < M	As above (for small pelagic species)	M and sustainable F:s for similar resources
Z_{mbp}	Level of total mortality at which the maximum biological production is obtained from the stock	Annual data series of standard catch rate and total mortality
$\mathbf{B}_{MSY}$	biomass corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship or general production models
MBAL	A value of SSB below which the probability of reduced recruitment increases	Data series of spawning stock size and recruitment (not necessarily from an VPA)
$B_{50\% R}$	The level of spawning stock at which average recruitment is one half of the maximum of the underlying stock-recruitment relationship.	Stock recruitment relationship (not necessarily from an VPA)
$B_{90\% R, 90\% Surv}$	Level of spawning stock corresponding to the intersection of the 90th percentile of observed survival rate (R/S) and the 90th percentile of the recruitment observations	Data series of spawning stock size and recruitment
$B_{20\% B\text{-}virg}$	Level of spawning stock corresponding to a fraction (here 20%) of the unexploited biomass. Virgin biomass is estimated as the point where the replacement line for F=0 intersects the stock-recruitment relationship or as the biomass from a spawning stock per recruit curve when F=0 and average recruitment is assumed	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship
$\mathbf{B}_{loss}$	Lowest observed spawning stock size	Data series of spawning stock size

[1]Not all limit reference points are intrinsically equal, and their interpretation depends on the specifics of each particular case they are applied to. For example, $\mathbf{F}_{max}$ can in some cases be considered as a target, when it is well defined and corresponds to a sustainable fishing mortality, while it would be a limit when it is ill defined and/or corresponds to unsustainable fishing mortality. Similarly $\mathbf{F}_{MSY}$, that is suggested as a minimal international standard for a limit reference point in the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, could in some particular cases be considered a target. $\mathbf{F}_{crash}$ on the other hand is an extremely dangerous level of fishing mortality at which the probability of stock collapse is high. The probability of exceeding $\mathbf{F}_{crash}$ should therefore be very low.

ANNEX 2A

Working Document 1 Not to be cited without prior reference to the authors

ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management
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Towards an operational implementation of the Precautionary Approach within ICES – biomass reference points

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1 INTRODUCTION

The Precautionary Approach to fishery management provides the framework for the fishery management advice provided by the ICES Advisory Committee on Fishery Management [ACFM] (ICES, 2001). This states that reference points will be stated in terms of biomass and fishing mortality rate. The use of the two indicator scales is summarised in the following extract from the ACFM advice:

In order for stocks and fisheries exploiting them to be within safe biological limits, there should be a high probability that 1) the spawning stock biomass is above the threshold where recruitment is impaired, and 2) the fishing mortality is below that which will drive the spawning stock to the biomass threshold, which must be avoided. The biomass threshold is defined as $\mathbf{B}_{lim}$ ($_{lim}$ stands for limit) and the fishing mortality threshold as $\mathbf{F}_{lim}$.

It can be inferred from this extract that the ICES implementation of the Precautionary Approach is framed around a rather simple model of stock dynamics; i.e. that there is a specific value of spawning stock biomass below which recruitment is impaired, and that fishing mortality is the only external factor which influences the size of the spawning stock.

The ACFM advice continues further:

… although ICES sees its responsibility to identify limit reference points, it will suggest precautionary reference points for management use.

The simplicity of the ICES' approach inherently implies a correspondingly simple control rule for management action:

If **spawning stock biomass (SSB) < $\mathbf{B}_{lim}$**

then

Take Action

The implication that SSB is influenced only by fishing mortality is often not unreasonable for heavily-exploited stocks, with the proviso that fishing mortality is usually the only factor influencing SSB which fishery managers can seek to manage.

The ICES Study Group on the Incorporation of Process Information into Stock-Recruitment Models [SGPRISM] (ICES 2002b) noted that two Working Papers by O'Brien & Maxwell (namely, WD3 & WD4) provided an objective means of fitting a model which corresponds to the conceptual model behind the ICES implementation of the Precautionary Approach for biomass reference points. Furthermore, **SGPRISM proposed that the approach be investigated further with a view to addressing the ToR b) of the SGPA.**

The objective technique whereby biomass reference points might be developed is based upon a segmented (or piecewise linear) regression. This paper develops the technique further and accompanying papers present applications of the technique to a number of stocks within the ICES stock assessment area.

2 SEGMENTED REGRESSION

Piecewise linear regression involves fitting linear regression where the coefficients are allowed to change at given points. For one unknown changepoint, for any interval (X_0 , X_1) on the real interval, the problem is defined as,

$$\begin{aligned} f(x_i) &= \alpha_1 + \beta_1 x_i \qquad & X_0 \le x_i \le \delta, \\ &= \alpha_2 + \beta_2 x_i \qquad & \delta \le x_i \le X_1 \end{aligned}$$

(1)

For stock and recruitment data the model is simplified, it must pass through the origin ($\alpha_1 = 0$) and after the changepoint the line is horizontal ($\beta_2 = 0$).

Many different terms are used for models with changepoints; e.g. segmented regression, multiphase regression, changepoint regression (Quandt, 1958), piecewise regression and for the model above in particular; e.g. two-phase regression, split lines, hockey stick, broken stick.

Julious (2001) has recently published a paper including an algorithm, originally from Hudson (1966) for fitting the model with one unknown changepoint. Barrowman and Myers (2000) is a thorough investigation of applying such a model to spawner-recruitment curves but they do not consider the calculation of Precautionary Approach biomass reference points. They carry out model fitting by grid search (Lerman, 1980). Lerman notes a disadvantage of Hudson's method, if likelihood surfaces are required to study the relative plausibility of different parameter values then the surfaces have to be generated separately.

The algorithm in Julious (2001) has been implemented for the stock and recruitment case with $\alpha_1 = 0$, $\beta_2 = 0$ and log-normal errors. The model is

$$\begin{aligned} R_i &= \beta_1 S_i \, e^{\varepsilon_i} \qquad & 0 \le S_i \le \delta, \\ &= \alpha_2 e^{\varepsilon_i} \qquad & \delta \le S_i \end{aligned}$$

(2)

which on the natural logarithmic scale is:

$$\begin{aligned} \log R_i &= \log \beta_1 + \log S_i + \varepsilon_i \qquad & 0 \le S_i \le \delta, \\ &= \log \alpha_2 + \varepsilon_i \qquad & \delta \le S_i \end{aligned}$$

(3)

where ε_i are independent and identically distributed (iid) normal errors.

The correspondence between the notation in Julious (2001) and that used by Barrowman and Myers (2000) is as follows:

$\delta \equiv S^*$

$\beta_1 \equiv \alpha$

$\alpha_2 \equiv R^* = \alpha S^*$

(4)

An F-statistic can be derived (Worsley, 1983) that uses the ratio of the sum of squares between a one- and two-line model (H_0 versus H_1, respectively). If the changepoint has to be estimated, this test statistic does not have an exact F-distribution under the null hypothesis (Hinkley, 1988). However, a bootstrap distribution for the F-test can be derived and a P-value can thus be calculated. This has recently been programmed since the last ICES Working Group on Methods on Fish Stock Assessments [WGMG] (ICES 2002a).

The methodology in applying the bootstrap method to the changepoint problem is as follows:

Step 1: for a given set of data, obtain the best fitting change-point (two-line) model and one-line (mean) models and calculate the *F*-statistic.

Step 2: calculate the residuals for the two-line case.

Step 3: using the original spawning stock biomass (SSB) values, re-calculate the new recruitment values, by using the values from the best fitting one-line model and adding an error term, sampled with replacement from the set of residuals from the best fitting two-line model.

Step 4: to this new set of data, fit a two-line and a one-line model and calculate the *F*-statistic.

Step 5: repeat steps 3 and 4 a large number of times, each time using the one-line parameters and two-line residuals from the original data.

The ANOVA table comparing the RSS from fitting a changepoint model on the logarithmic scale to the residual sum of squares (RSS) from fitting an arithmetic mean on the logarithmic scale can be used to indicate the appropriateness of the changepoint model over the one-line (mean) model.

The parameters S*, α and R* given in equation (4) are not known exactly but must be estimated using an appropriate statistical procedure. Given suitable point estimates, confidence interval statements can be calculated.

If the null hypothesis is rejected then a $(1-\alpha)\%$ profile likelihood confidence interval for S* can be appropriately calculated using the expression:

maximum of log-likelihood – $\{ \chi^2_{1,(1-\alpha)} / 2 \}$

(Note that under certain conditions **only** the lower limit or upper limit will be available; the other limit being undefined - the coverage probability may be incorrect for such cases but further work is needed to either confirm or refute this assertion! This problem may be circumvented by using an alternative approach to producing confidence intervals based on the computationally intensive bootstrap method but this has not been investigated further. Such an approach would also allow concerns of bias in parameter estimates to be directly addressed.

For illustrative purposes, a $(1-\alpha)\%$ of 80% has been adopted in the applications presented (see Section 3 for details of the stocks considered) to derive the lower 10% limit denoted by S*(10) and the upper 90% limit denoted S*(90) of S*. In principle, there is nothing that implies a symmetric treatment of the $(1-\alpha)\%$ profile likelihood confidence interval for S*; i.e. a lower limit $S^*(\alpha_1)$ and an upper limit $S^*(1-\alpha_2)$ may be defined such that $(1-\alpha_1-\alpha_2)$ has the specified coverage probability of $(1-\alpha)$ but α_1 may be different from α_2. This argument is equally applicable for parametric S-R models for which estimates of the turning-point are derived with uncertainty (c.f. O'Brien, Maxwell, Roel & Basson 2002).

The choice of the appropriate level of acceptable risk in both the lower and upper tails of the empirical distribution of the SSB at which recruitment is impaired is a management decision. The approach presented here will enable that choice to be made in an objective way. The evaluation of candidate biomass reference points through the use of scenario modelling within a management procedure could be a requirement for the adoption of specific values in the future (c.f. Kell *et al*. 1999).

3 APPLICATIONS

The method developed in this paper has been applied to the stock-recruitment data of a number of stocks within the ICES stock assessment area. Specifically, the following stocks have been investigated:

North-east Arctic saithe (Subareas I and II) (O'Brien & Maxwell 2002a) northern hake (O'Brien & Maxwell 2002b)

plaice in Division IIIa (O'Brien & Maxwell 2002c)

North-east Atlantic mackerel (O'Brien & Maxwell 2002d)

cod in Division VIIa (O'Brien & Maxwell 2002e)

cod in Division VIIe-k (O'Brien & Maxwell 2002f)

cod in Division VIa (O'Brien & Maxwell 2002g)

cod in Subarea IV, Divisions IIIa and VIId (O'Brien & Maxwell 2002h)

North-east Arctic cod (Subareas I and II) (O'Brien & Maxwell 2002i)

herring in Subarea IV, Divisions IIIa and VIId (O'Brien, Maxwell & Roel 2002)

anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa) (O'Brien & Maxwell 2002j)

together with the Thames Estuary (or Blackwater) herring (O'Brien, Maxwell, Roel & Basson 2002).

The reader should consult each of the cited WPs for detailed results of applying the method of this paper to the respective S-R data. The results of applying the model in equation (2) are presented in a number of panels per stock within each of the WPs.

Panel A: an audit trail, ACFM summary and WG S-R model

Panel B: S-R data series and changepoint regression results

Panel C: a five-panel figure including a q-q normal plot with simulation envelope (Ripley, 1981; Atkinson, 1985). Estimation based upon approach of Hudson (1966).

panel 1: stock-recruitment pairs identified by year-classs; solid line is the changepoint model estimated; dotted lines are the changepoint models estimated by eliminating a single year-class in turn.

panel 2: changepoint versus year-class eliminated;

panel 3: slope at the origin and recruitment estimate above changepoint;

panel 4: standardised residuals versus covariate; and

panel 5: q-q plot with simulation envelope.

Panel D: a four-panel figure showing results from applying the bootstrap methodology.

panel 1: bootstrapped empirical distribution of the *F*-statistic (solid curve – bootstrap; dotted curve - *F*-distribution);

panel 2: histogram of bootstrapped estimates of S*;

panel 3: histogram of bootstrapped estimates of R*; and

panel 4: histogram of bootstrapped estimates of α.

Panel E: a four-panel figure. Estimation based upon approach of Lerman (1980).

panel 1: text;

panel 2: profile likelihood for slope at the origin;

panel 3: profile likelihood for changepoint (vertical line – approximate 80% likelihood ratio confidence interval for S*); and

panel 4: contour surface.

Panel F: a four-panel figure. Comparison to ICES WG fit.

panel 1: stock-recruitment pairs identified by year-classs; solid line is the changepoint model estimated; dotted line (if available) is the ICES WG stock-recruitment curve;

panel 2: standardised residuals versus year-class;

panel 3: fitted values versus time (solid line – changepoint; dotted line – WG); and

panel 4: difference in fitted values (ICES stock assessment WG minus changepoint).

4 FINAL COMMENTS

The consequence of incorporating the model given by equation (2) into medium-term stock projections has yet to be investigated.

It is apparent from the WPs that the changepoint model can give a far more reasonable fit to the stock-recruitment pairs at higher values of SSB than the WG S-R model – as in the case of North Sea cod (O'Brien & Maxwell 2002h).

4.1 Acknowledgements

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ANNEX 2B

Working Document 2. Not to be cited without prior reference to the authors

ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management
Lisbon, Portugal, 4-8 March 2002

A segmented regression approach to the Precautionary Approach – the case of North-east Arctic saithe (Subareas I and II)

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1 INTRODUCTION

This paper applies the method of O'Brien & Maxwell (2002) to the stock-recruitment data of North-east Arctic saithe (Subareas I and II). The reader should consult that WP for details of the method and the generic diagnostic plots that are generated.

2 OBSERVATIONS FOR NORTH-EAST ARCTIC SAITHE (SUBAREAS I AND II)

- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 155 398 tonnes
- 80% profile likelihood confidence interval is given by (111 425, 195 998) tonnes
- lower 10% limit of the profile likelihood confidence interval is ≈ 25% higher than the current $\mathbf{B}_{lim}$ of 89 000 tonnes; whereas the upper 90% limit is ≈ 30% higher than the current $\mathbf{B}_{pa}$ of 150 000 tonnes.

2.1 Acknowledgements

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2.2 References

O'Brien, C.M. and Maxwell, D.L. (2002). Towards an operational implementation of the Precautionary Approach within ICES – biomass reference points. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

Common name:	Saithe
Scientific name:	Pollachius virens
Organisation:	ICES
Area:	North-East Arctic; Subareas I and II
Stock units:	Tonnes
Recruit units:	Thousands at age 2
First year:	1960
Last year:	2001
Assessment model:	XSA.
Source:	ICES. 2001. Report of the Arctic Fisheries Working Group. ICES CM 2001/ACFM:19.
This file created:	D.Maxwell. 6/02/02.
Reference files:	Fishm$ on 'LOWNTH' :\ACFM\Acfm_final_2001\Acfm_may_2001\ Summary Reports\3.1\sai-arct.pdf Fishm$ on 'LOWNTH' :\Otherwgs\Afwg_2001\AFWG01-2.pdf

Precautionary Approach reference points (Established in 1998)
source: ICES CM 2001/ACFM:19.

ICES considers that:	**ICES proposes that:**
$\mathbf{B}_{lim}$ is 89 000 t, the lowest observed SSB in the 35-year time series	$\mathbf{B}_{pa}$ is set at 150 000 t, the SSB below which the probability of poor year classes increases
$\mathbf{F}_{lim}$ is 0.45, the fishing mortality associated with potential stock collapse	$\mathbf{F}_{pa}$ be set at 0.26. This value is considered to have a 95% probability of avoiding the $\mathbf{F}_{lim}$

Technical basis:

$\mathbf{B}_{lim} = \mathbf{B}_{loss}$	$\mathbf{B}_{pa}$ = examination of stock-recruit plot
$\mathbf{F}_{lim}$ = Median value of $\mathbf{F}_{loss}$	$\mathbf{F}_{pa} = \mathbf{F}_{lim} * 0.6$ from $\mathbf{F}_{pa} = \mathbf{F}_{lim}\, e^{-1.645\sigma}$ with $\sigma = 0.3$

3 WORKING GROUP RECRUITMENT MODELLING

Formulation	RCT3 for 1997 & 1998, GM for 1999 and subsequent year classes
Estimation method	
Assumed error structure	
Parameter estimates	1997 YC 219 million, 1998 YC 322 million, 1999- YC 210 million

Panel A

Working Group estimates of spawning-stock biomass (SSB) and recruitment at age 2 for Arctic Saithe, ICES Sub-areas I and II. SOP Corrected. Source: ICES CM 2001/ACFM:19.

Year-class	Parental SSB (tonnes)	Recruitment (thousands)	Year-class	Parental SSB (tonnes)	Recruitment (thousands)
1960	314777	355505	1980	138732	140068
1961	392583	121815	1981	142438	118912
1962	415700	368899	1982	121867	137543
1963	441021	210354	1983	167567	271686
1964	523587	241202	1984	151680	204400
1965	522884	191872	1985	121134	103478
1966	568765	367843	1986	89047	79261
1967	551179	347431	1987	90564	88859
1968	631001	379815	1988	124879	291666
1969	529248	219524	1989	138950	480544
1970	633034	278465	1990	124028	343495
1971	503856	117299	1991	111461	237615
1972	487481	206220	1992	107112	426830
1973	466089	373549	1993	129833	128661
1974	471317	305466	1994	222066	180151
1975	372735	178776	1995	280721	79070
1976	250577	283591	1996	319163	191980
1977	169207	167693	1997	356503	218731
1978	175906	356254	1998	409873	322000
1979	162681	152598			

Changepoint Regression Results

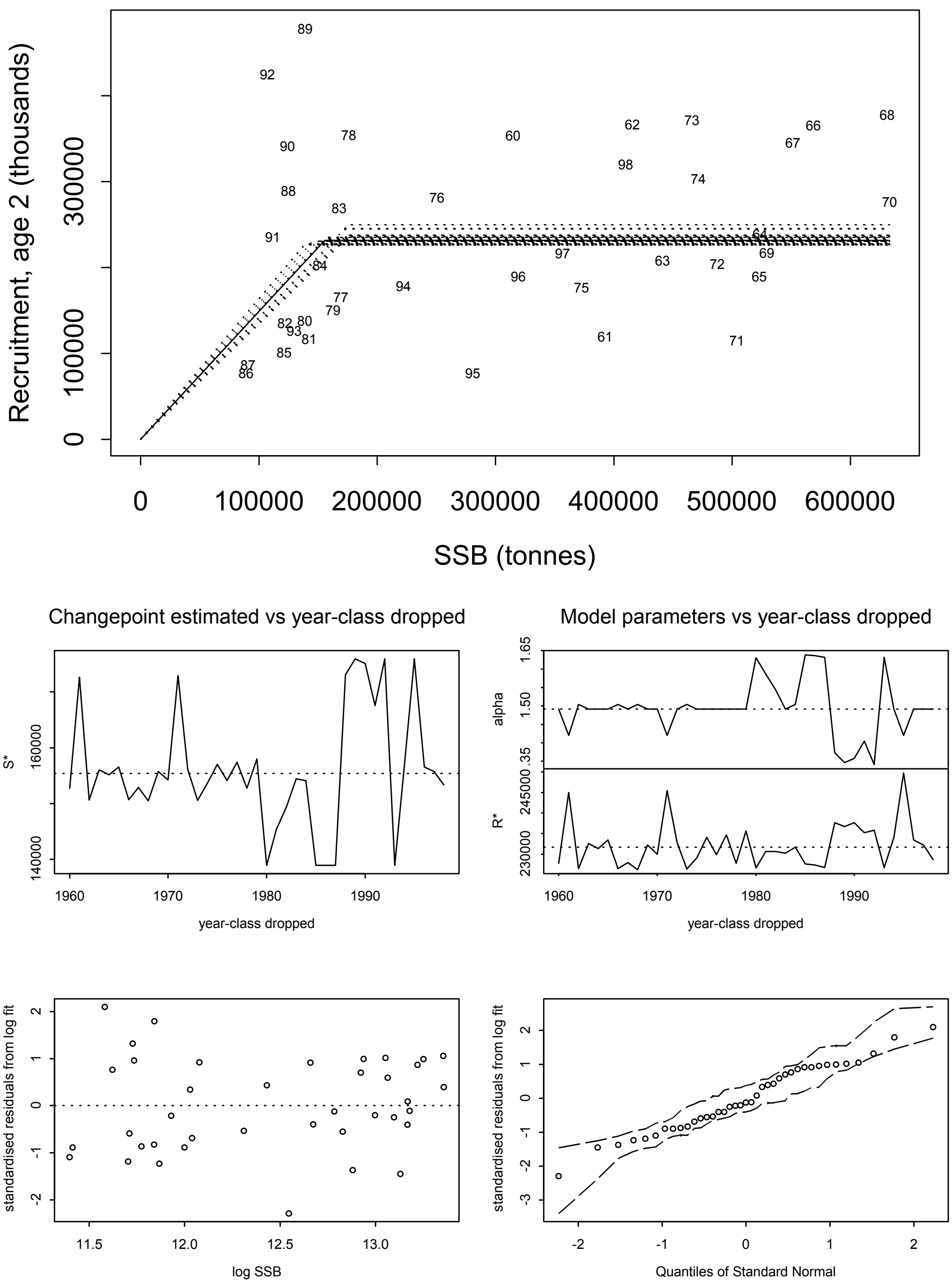
Saithe I & II

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
155398	1.491	231712		111425	155249	195998

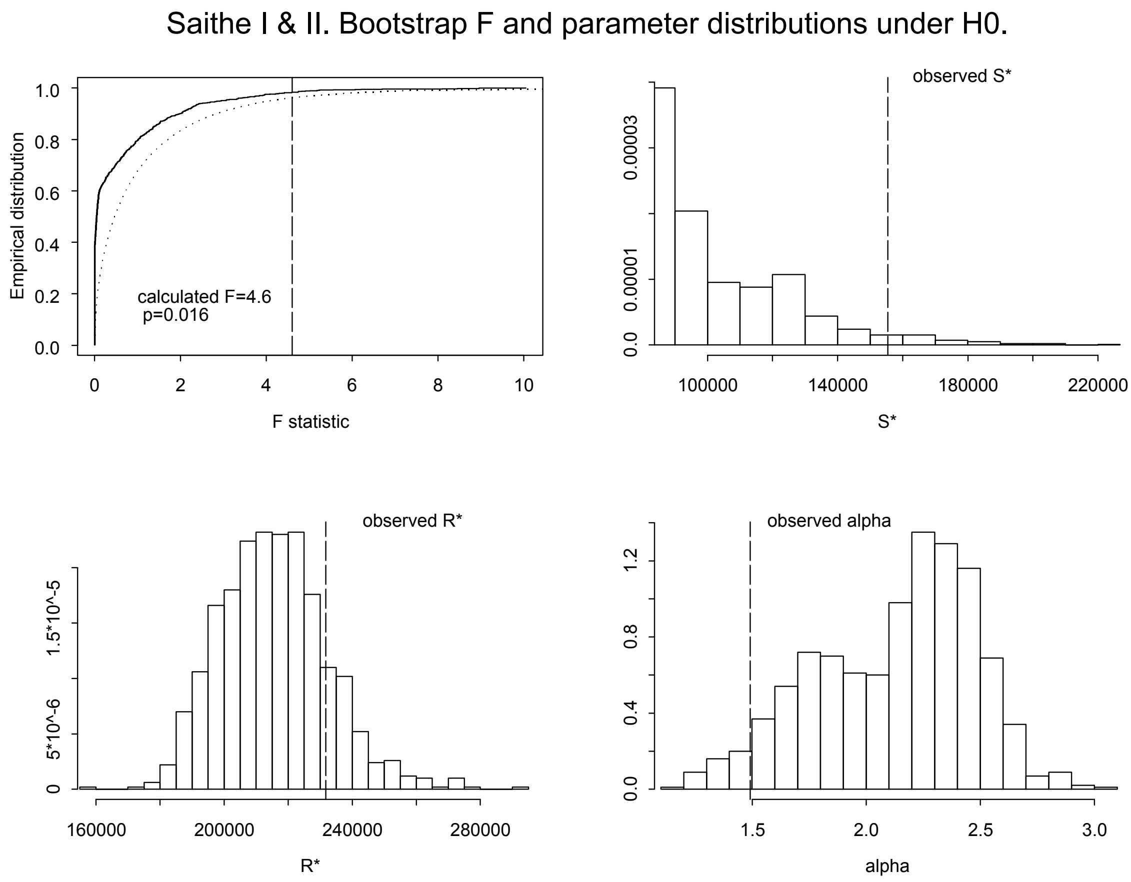
Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap**
mean	38	9.156				**p-value**
changepoint	37	8.145	1	1.012	4.60	0.016

Panel B

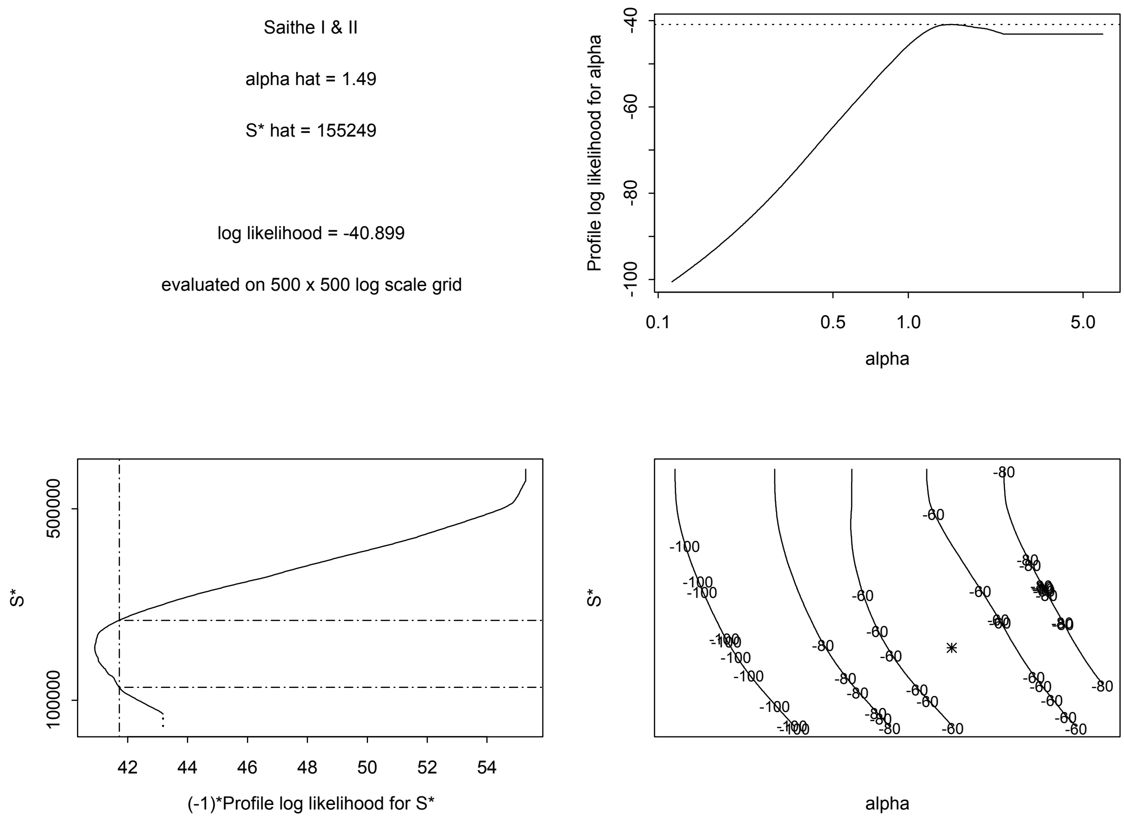
Saithe I & II



Panel C

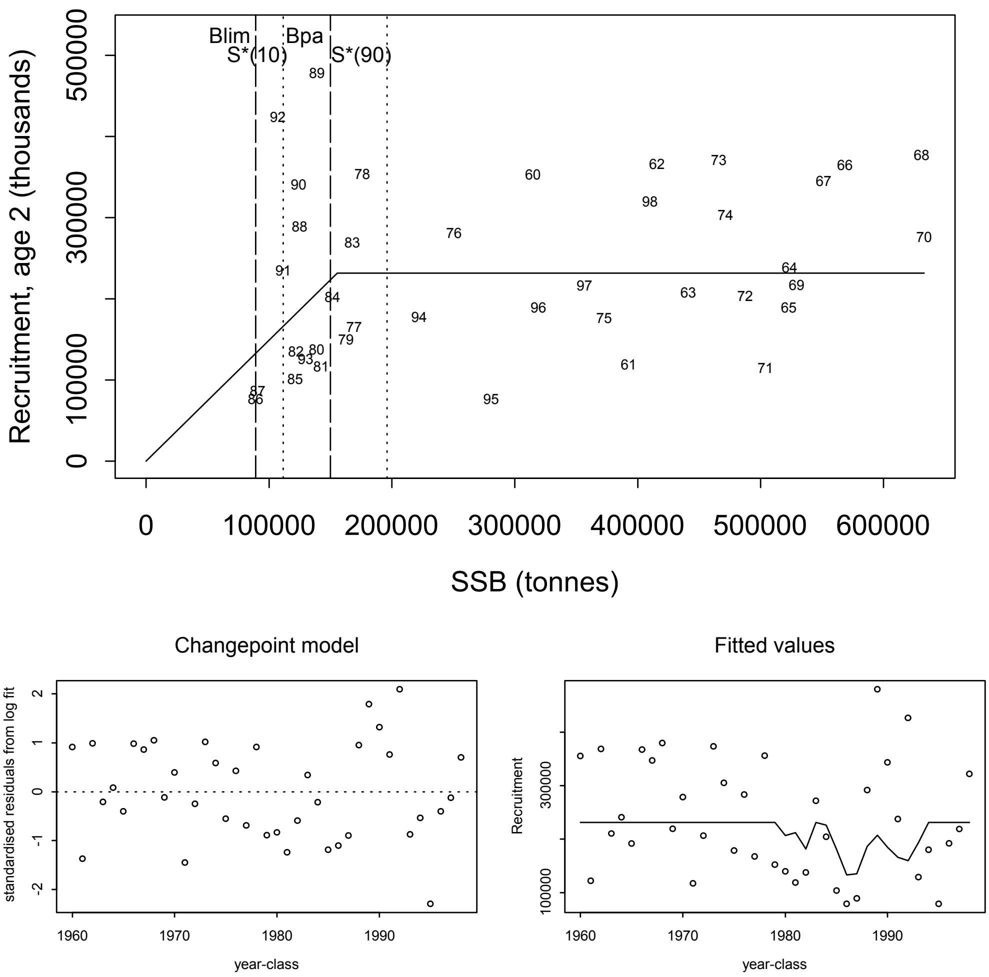

Saithe I & II. Bootstrap F and parameter distributions under H0.
Empirical distribution
calculated F=4.6
p=0.016
F statistic
observed S*
S*
observed R*
R*
observed alpha
alpha

Panel D


Saithe I & II
alpha hat = 1.49
S* hat = 155249
log likelihood = -40.899
evaluated on 500 x 500 log scale grid
Profile log likelihood for alpha
alpha
S*
(-1)*Profile log likelihood for S*
alpha

Panel E

Saithe I & II



Panel F

ANNEX 3

W Doc 3 / SGPA 02 b

DRAFT ICES' guidelines for calculating PA reference points for stocks with analytical assessments

By

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ABSTRACT

This paper describes the procedures used by ICES to calculate PA (Precautionary Approach) reference points for fish stocks with analytical assessments.

INTRODUCTION

The Precautionary Approach was introduced in UN resolutions in the mid 1990s. ICES established in 1998 a set of precautionary approach reference points for use in formulating advice on fishery management. These points were reviewed at the following ACFM meetings and some revisions were adopted. The reference points were set using the best assessment data then available, and ICES has decided that these reference point values will undergo a thorough review of all the current reference point values as described in three recommendations adopted in October 2002, see annex I.

The Precautionary reference point system includes four points called $\mathbf{B}_{\text{lim}}$, $\mathbf{B}_{\text{pa}}$, $\mathbf{F}_{\text{lim}}$ and $\mathbf{F}_{\text{pa}}$. $\mathbf{B}_{\text{lim}}$ and $\mathbf{B}_{\text{pa}}$ is measured in units of SSB at the time of spawning. The fishing mortality used in defining these reference points is measured as the arithmetic mean over a range of age groups. This range is specified in each case. In a few specific cases, e.g. Norwegian spring spawning herring, a weighted fishing mortality is used.

The prime objective in formulating the ICES advice is that the spawning stock biomass (SSB) should not fall below a minimum limit, described by the symbol $\mathbf{B}_{\text{lim}}$ (the biomass limit reference point). If the SSB is already below this value then the SBB should as soon as possible be increased. The value of $\mathbf{B}_{\text{lim}}$ is chosen such that below it, and mainly set by using historical data, there is a strong possibility that average recruitment will 'be impaired'. Alternatively, it may be set such that lower stock levels have not been observed before and therefore the behaviour of the stock at those lower levels is unknown. In other words, below $\mathbf{B}_{\text{lim}}$ there is a high, or unknown, risk that the stock could 'collapse'. The word 'collapse' does not mean that there is biological extinction, but it does mean that there is risk of a serious reduction in the productivity of the stock, and that the fishery could become unsustainable.

Similarly, ICES has advises that the fishing mortality rate should not be higher than an upper limit $\mathbf{F}_{\text{lim}}$ that will on average drive the stock to or below the biomass limit. $\mathbf{F}_{\text{lim}}$ should not be exceeded because above it, there is considered to be a serious risk that the stock will collapse, or that the behaviour of the stock is unknown.

Because of the uncertainty associated with the estimation of spawning biomass, or of fishing mortality rate, operational reference points are required to take account of this. To have a high probability for the spawning biomass to be above $\mathbf{B}_{\text{lim}}$, spawning biomass should in practice be kept above a higher level that allows for this variance in the estimates. ICES, therefore, creates a 'buffer zone' by setting a higher spawning biomass reference point $\mathbf{B}_{\text{pa}}$ (the biomass precautionary approach reference point). When the biomass falls to $\mathbf{B}_{\text{pa}}$, ICES advises that management action should be taken to increase stock again, so that the stock increases above $\mathbf{B}_{\text{lim}}$. The size of the buffer zone depends on the size of the uncertainty in the estimation and also on the acceptable risk that SSB falls below $\mathbf{B}_{\text{lim}}$.

Similarly, for the fishing mortality (F), it is necessary to establish a buffer zone below $\mathbf{F}_{\text{lim}}$. ICES therefore sets a precautionary approach reference point $\mathbf{F}_{\text{pa}}$ at a lower value of F. In order to be certain of being below $\mathbf{F}_{\text{lim}}$, a fishery should be below $\mathbf{F}_{\text{pa}}$. The size of the buffer zones depends on the size of the error and on the natural variation in the stock productivity. The fishing mortality $\mathbf{F}_{\text{pa}}$ should be set such that during a period of natural low productivity SSB would stay above $\mathbf{B}_{\text{lim}}$. In order to be certain of being below $\mathbf{F}_{\text{lim},}$ ICES will recommend on management actions which keeps F at or below $\mathbf{F}_{\text{pa}}$.

ICES uses these reference points in formulating its advice on fishery management, see Annex II.

The UN resolutions do not deal with buffer or threshold points, but with limit and target points. The $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$ although in the ICES definitions are buffer or threshold points they are meant by ICES to be lower respective upper boundaries for selecting target values by managers.

Each year there will be new sets of biomass, recruitment and fishing mortality values and therefore new SSB-R plots, new $\mathbf{F}_{med}$ values etc. However, in order to have some degree of stability in the reference points, these will only be updated every 3-5 years or if the new assessment and biological knowledge give significantly different values of the reference points. Changes in entire time series of maturity, natural mortality and weight at age will generally require new calculations of PA reference points. If these new reference points turn up to deviate more than to a marginally extent from the previous ones they should be adopted.

This paper provides guidelines for ICES' fish stock assessment working groups, ACFM, and others ICES' groups on the calculation of PA reference points. The paper gives particular emphasis to stocks for which an analytical assessment is available. The procedures given are based on the following work:

- the Report of the Study Group on Precautionary Approach to Fisheries Management (ICES CM 1997/Assess:7, and ICES CM 1998/ACFM:10, and ICES Study Group on Further Development of the Precautionary Approach to Fisheries Management, ICES CM 2001/ACFM:11, and ICES CM 2002/ACFM:10);

- the Introduction section of the ACFM Report 1999 (ICES Cooperative Research Report No. 236, 2000);

- the practical use as exercised at the ACFM meetings since October 1998.

PROCEDURE

The definition of the four reference points introduced in the section above assumes that information is available that allows the establishment of a SSB level ($\mathbf{B}_{lim}$) below which recruitment is impaired, i.e. that the medium term average recruitment is lower than has been observed at higher levels of SSB. Therefore, the definition requires implicitly that a Stock-Recruitment relationship exists and that there are observations available that shows where this lower limit of undisturbed recruitment occurs. Also, this concept is developed on the assumption that an assess and a projection procedure (e.g. an analytical assessment) is available and that this assessment includes an estimate of the precision of the assessment. The buffer considerations also require that a medium term projection model is available to enable the calculation of the buffer zones for F and SSB.

For short lived species such as sprat in the North Sea, capelin and anchovy, medium term projections are not possible. The ICES advisory procedure implied above is based on short term (1-2 years) projection and such projections are usually not possible for the short lived species.

However, there are numerous stocks for which no analytical assessment is available. Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks states: …"When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. Provisional reference points may be established by analogy to similar and better-known stocks…". Due to the limited amount of data for defining the Precautionary Approach reference points this means that a pragmatic approach and expert judgement often will be an important part of the process although ICES strives to be objective and consistent.

The following discussion on how to establish Precautionary reference points values is structured

	Short lived (1-2 years) species	**Long - lived (3+ years) species**
	M ~ 0.5 or larger, Possibly high mortality due to spawning	M~0.1 - 0.4, No spawning mortality
Short- and Medium term projections available	Section 3.1.1	Section 3.2.1
No projection available (Data Poor situations)	Section 3.1.2	Section 3.2.2.

Short-lived species

Assessment including a projection model is available

Short lived species • Capelin • Sprat in the Northeast Atlantic

Short-lived species can be split into those that die after spawning like capelin, salmon (marine phase) and maybe Norway pout and those that do not. This distinction has bearings on the projection model.

The advice for capelin catches in the Barents Sea and in Iceland is based on acoustic estimates of the stock biomass shortly before spawning. The approach is to let an amount of spawners survive the fishery to secure reproduction at a level, which is not impaired by a too low SSB. This minimum SSB serves as a $\mathbf{B}_{lim}$ value.

Because the uncertainty in the acoustic estimate is proportional to the estimated size of the stock, a fixed $\mathbf{B}_{pa}$ would not give the same probability in all years for maintaining SSB above $\mathbf{B}_{lim}$. Therefore, a fixed $\mathbf{B}_{pa}$ is not relevant for these stocks. Furthermore, $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$ is neither relevant because there is no point in having more spawners survive the fishery than needed to secure a non-impaired recruitment because most capelin die after spawning and these fish will thus be a lost for the fishery.

The advised TAC, using a 5% level for SSB dropping below $\mathbf{B}_{lim}$, is in each year calculated based on the estimated biomass together with the associated uncertainties. The simulations required for these calculations can be done using bootstrapping of the survey results (directly or of the residuals around means) or by fitting a parametric error distribution to the survey results. In each specific case the procedure used should be described.

For short-lived stocks, which do not die after spawning F reference points can be used in management in addition to SSB reference points. In principle these points can be set in a similar way as for long-lived stocks.

Data Poor situations

For a number of short lived species there are little data except landings. These cases are not dealt with in this round of revisions. ICES does not define Precautionary Reference points for these stocks.

Sprat in Div. IIIa Sprat in the southern North Sea

Long-lived species

Long lived species are fish with M (adult phase) in the range of 0.1-0.3 per year and without any appreciable mortality due to spawning

Long lived species with analytical assessments • Cod • Haddock • Saithe • Whiting • Plaice • Sole • Anglerfish • Megrim • Herring • Sand eel (North Sea) • Greenland Halibut

S-R relationship and Projection model available

There are three considerations that we need to specify

1. Defining a projection model. This involves as an integral part the definition of a stock-recruitment relationship

2. Estimation of the initial stock compositions and parameters (including uncertainties) in the projection model

3. Defining $\mathbf{B}_{lim}$

The simulations required calculating $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$ are based on the adopted procedure for making medium term projections:

- Stock-recruitment relationship including a model for variation around the mean relationship

$$R = f(SSB, \varepsilon)$$
$$\varepsilon : \text{Stochastic variable}$$

- If required stochastic noise on all components in the projection model (initial stocks size, mean weight at age, maturity ogive, etc)

- Acceptable Risk of SSB < $\mathbf{B}_{lim}$

Comments on the S-R Relationship

Reasons to split time series (or preferable conduct "remedial action" of the time series instead) could be changes over time in natural mortality, changes in regimes, [can we come up with more examples …?]

Due to VPA convergence problems it is recommended not to include the most recent (normally one to three) data points in the S-R analysis, if they are expected to be less precise than the rest of the points.

Proposed Procedure (Full Assessment)

1. Establish $\mathbf{B}_{lim}$

Plot the SSB-R relationship and judge the upper limit of SSB below which value Recruitment is impaired. Alternatively consider the lower limit of SSB for which Recruitment is not negatively affected. A segmented regression analysis (O'Brien and Maxwell, 2002) is a recommended tool to help deciding where the change-point is. This change-point will be the $\mathbf{B}_{lim}$.

In general, available time series of stock dynamic data, i.e. F (fishing mortality), SSB (spawning stocks biomass), and R (recruitment), are short and often with a limited dynamic range for analysis of S-R relationships, sustainable F etc., because there is only one point for each year covered by the analytical assessment. Furthermore, the variability of R for a given SSB is almost always so large that many observations are needed in order to establish the relationship between SSB and R. Therefore, it is recommended to use the entire time series unless there are very good reasons not to do so.

If there is no positive relationship between SSB and R then use the lowest observed SSB (converted as B_{loss}) as $\mathbf{B}_{lim}$. A segmented regression analysis will reveal whether there is a relationship or not.

$\mathbf{B}_{lim}$ will always be defined for stocks with an analytical assessment.

2. Establish $\mathbf{F}_{lim}$ $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$

$\mathbf{F}_{pa}$ is computed as the solution to

$$\max\left[F \middle| prob\left\{SSB < B_{\lim} \middle| F\right\} < \alpha\right]$$
$$\alpha = 0.05$$

taking into account natural, implementation and assessment variability.

$\mathbf{B}_{pa}$ is the lower fractile **(25%)** of the SSB distribution obtained in the long term under F_{pa}. B_{pa} is not the spawning stock biomass corresponding to F_{pa} in the mean.

$\mathbf{F}_{lim}$ is computed as the solution to

$$\max\left[F \middle| prob\left\{SSB < B_{\lim} \middle| F\right\} < \alpha\right]$$
$$\alpha = 0.05$$

A time trend in the SSB-R relationship, which gives a strong autocorrelation in the residuals of the SSB-R curve, is often used as an argument for including a regime shift in the analysis. However, such autocorrelation just mean that the normally unknown parameters, which cause the large fluctuations of R around the SSB-R curve, are not random from year to year. If the factors responsible for this can be identified and if they have statistically significant (exploratory regression analysis are not valid in this context) and important influence on R. then correct for the effect (central Baltic cod is an example of this where reproduction volume and sprat predation are important and significant factors in addition to SSB influencing recruitment and where the residuals around the model are not auto-correlated [Jarre et al. 200?]). However, most often the factors cannot be identified and in most cases the balance between having enough data vs. having possibly conflicting signals in the data seems to favour using the full time series. If the time series needs to be split into two (very rarely will there be data enough for three or more periods) and each period is analysed separately, then it will be case dependant whether to use the most recent, which might best represent the preset situation or the oldest period, where for instance misreporting and VPA convergence might be less of a problem. Maybe only one of the periods cover the SSB range where R is impaired and that period should then used.

Stocks with occasional very strong year classes

Haddock (Arctic, North Sea)
Horse mackerel (western)
Norwegian Spring Spawners

Some stocks show the occasional very strong year class. However, the time series are usually too sort to establish with any accuracy the frequency of such rare event. Table 1 lists such stocks for the ICES area, in total 7.

The segmented regression analysis works well on some of these stocks, but not all. For the three stocks: North Sea Sandeel, North Sea Haddock, and Western horse mackerel, where only a single year class is extreme, the large SSB figures in the time series might not be obtainable, without a new very strong year class.

Establishing biomass reference points for such stocks is often difficult. For several of these stocks their entire population dynamics depend crucially on that these strong year classes actually occur. The analysis should therefore focus on establishing the minimum SSB above which strong year classes have been observed. However, when simulating the corresponding $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$ these reference levels should be based on a S-R relationship based on data from periods where the very strong year class had no influence, i.e. before the year that produced the strong year class and period after starting from the year when the strong year class has little contribution to SSB.

Stocks with little dynamic range in SSB

Some stocks have little dynamic range in SSB, which makes it difficult to determine the SSB-R relationship and hence the biomass reference points. This is because, in reality, we have only one "point" to determine the SSB-R curve, namely a cloud of points in one particular spot on the SSB-R curve. Table 2 lists stocks for which the dynamic range of SSB is close to 2 or smaller, in total 11 stocks. Because according to the procedures above $\mathbf{B}_{lim}$ cannot be smaller than the smallest SSB observed, $\mathbf{B}_{pa}$, defined as 1.6 times $\mathbf{B}_{lim}$, may be higher than any SSB observed. At the moment this is the case for 5 of the 11 stocks, with the smallest dynamic range having its largest SSB being 1.46 its smallest SSB. The UN agreement states that the less knowledge available for a given stock, the more precautionary management should be. This indicates that ICES should aim for a $\mathbf{B}_{pa}$ slightly above the highest SSB observed in these five cases.

Horse mackerel (southern)
Sole (Irish Sea, Western Channel, Bay of Biscay)
Northern hake
NEA Mackerel (Western Mackerel)

Alternative Proposed Procedure (B_{loss})

Where a B_{lim} value cannot be defined because the S-R relationship is not showing such value a B_{loss} approach will be used. B_{pa} will then be set

$$B_{pa} = B_{loss}*1.6$$

according to Sparholt and Bertelsen (2002b).

However, this procedure may be refined by applying a stock specific factor to obtain $\mathbf{B_{pa}}$ corresponding to 25% confidence of being above $\mathbf{B_{lim}}$. This means that if an assessment is precise then a factor of less than 1.6 correspond to the 25% confidence level and if an assessment is imprecise then a factor of more than 1.6 correspond to it. It is recommended to try to estimate the relevant factor based on historical evidence like done by Sparholt and Bertelsen (2002b) and based on the current precision of the assessment for a given stock.

The stock specific factors should be derived based on the uncertainties in $\mathbf{B_{lim}}$ as estimated from the segmented regression analysis together with the uncertainty in the SSB, forecasted to survive the TAC year. Normally, however, the uncertainty of the $\mathbf{B_{lim}}$ is smaller than that of the forecasted SSB and the uncertainty of $\mathbf{B_{lim}}$ can sometimes be ignored. The uncertainty in the forecasted SSB can be obtained from simulations or for some stocks from Sparholt and Bertelsen (2002a), who analysed the actual uncertainty for 33 ICES stocks during the period 1988-1999. The previously used "magic numbers" (1.41, 1.51, and 1.64) which were supposed to represent the 5% risk of getting below $\mathbf{B_{lim}}$, given that SSB is estimated to be $\mathbf{B_{pa}}$, have shown too optimistic regarding precision. It seems rather to be representing on average 30% (Sparholt and Bertelsen 2002b). According to Sparholt and Bertelsen (2002b) the factor corresponding to 5% is on average 2.85. Using a factor of 2.85 will give very high $\mathbf{B_{pa}}$ values, which, if realised, are likely to result in strong density dependant effects on growth and predation mortality, reducing the potential yield from the stocks.

ICES need to deal with these cases individually. If the stock is exploited at a high fishing mortality above what seems reasonable based on other reference points, e.g. $\mathbf{F_{max}}$ and $\mathbf{F_{0.1}}$ or experience with similar stocks and if this has been the prevailing situation for most or all of the time series for which data are available then the stock should be considered as depleted and the SSB representing a stock that may not reproduce to its fullest potential. In this case a reasonable $\mathbf{B_{pa}}$ will need to be defined based on an $\mathbf{F_{pa}}$ consideration and is likely to be above the SSB forwhich ICES has experience with this stock. . If, on the other hand, the fishing mortality is low judged by conventional reference points and experience with similar stocks then this may actually be a stable stock for which the $\mathbf{B_{pa}}$ should be defined as the $\mathbf{B_{loss}}$ value.

CONCLUDING REMARKS

Use a reality check on the obtained PA reference points. If the stock has been able to stay above $\mathbf{B_{pa}}$ with an F higher than $\mathbf{F_{pa}}$ for the entire time period then there might reasons for adjusting the $\mathbf{F_{pa}}$ upwards, and vice versa if the stock now and then has been below $\mathbf{B_{pa}}$ with an F lower than $\mathbf{F_{pa}}$.

Compare the $\mathbf{F_{lim}}$ and $\mathbf{F_{pa}}$ with other stocks of similar species and explain differences. If this cannot be done consider adjusting $\mathbf{F_{lim}}$ and $\mathbf{F_{pa}}$ and correspondingly $\mathbf{B_{lim}}$ and $\mathbf{B_{pa}}$.

The PA ref. points are always quite uncertain and therefore it is recommended to round values to contain not more than 2 significant digits, i.e. if the calculated $\mathbf{B_{lim}}$ is 21 367 tonnes then round it to 21 000 tonnes.

Use your expert judgement to evaluate whether the calculated PA reference points make sense. If the new PA ref. points are very different from the old ones then be extra careful in the evaluation. If the new PA ref. points are only marginally different from previous values this should be marked and ICES will not propose to change the previously defined value.

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Sparholt, H, and Bertelsen, M. 2002a. Quality of ACFM advice: How good have forecasts been since 1988? Working Document for ICES Advisory Committee on Fisheries Management May 2002.

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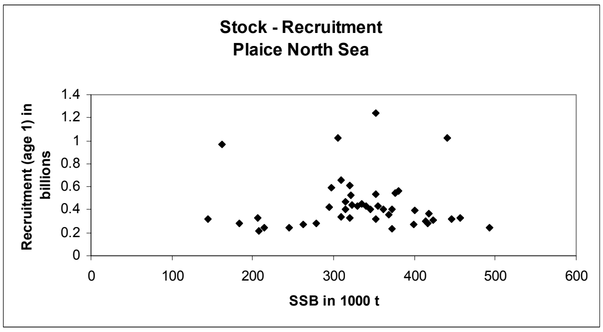
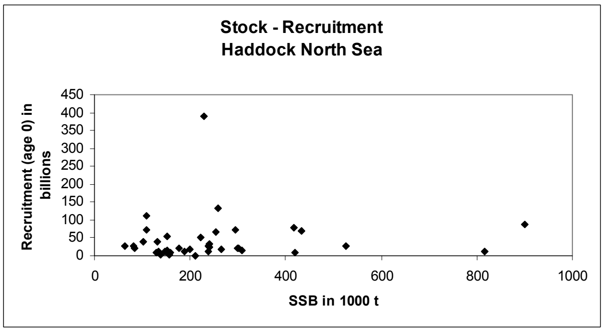
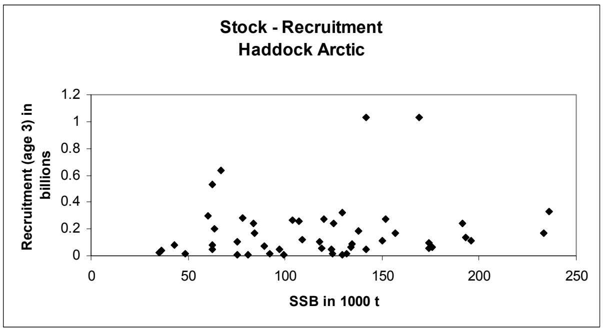
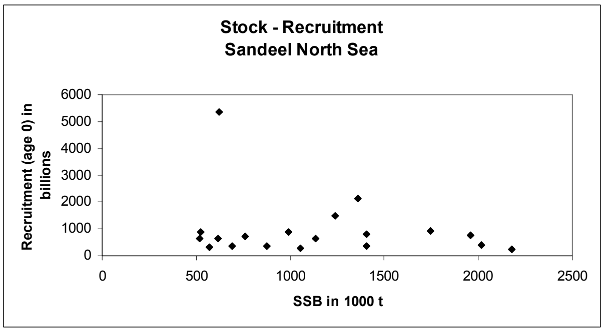
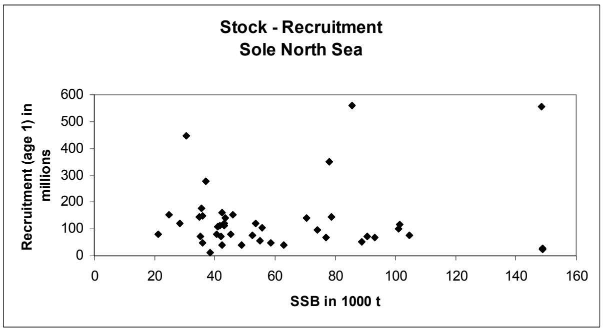
Table 1 Stocks with occasional very strong year classes.

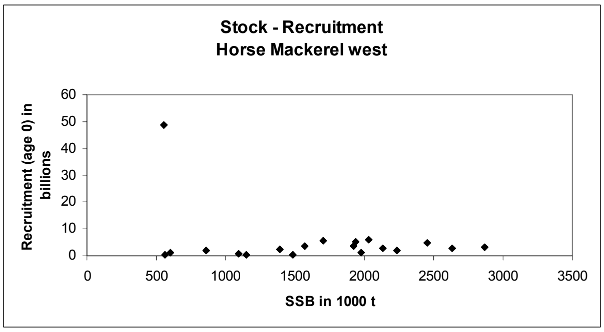












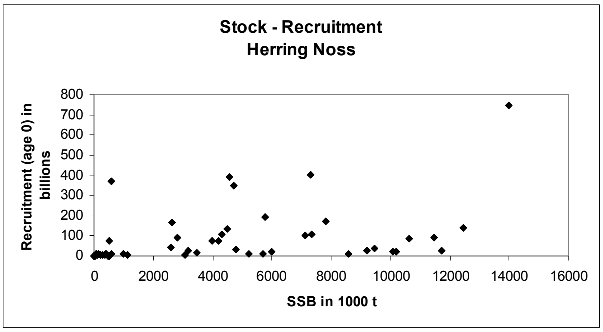
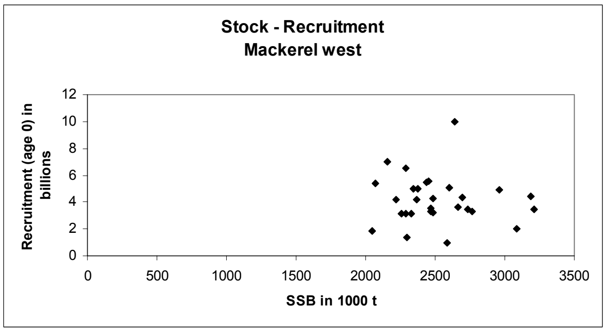
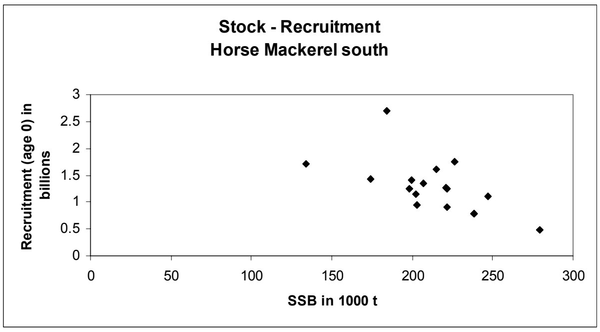
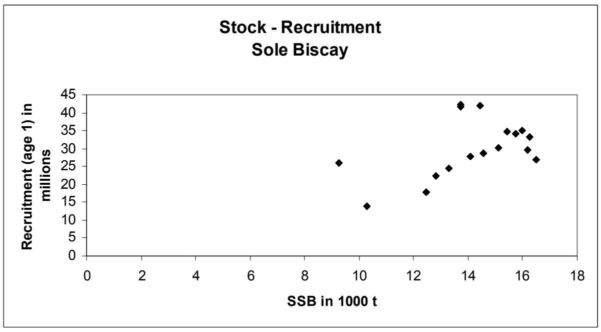
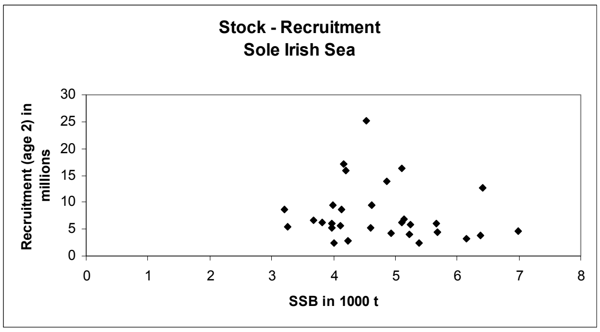


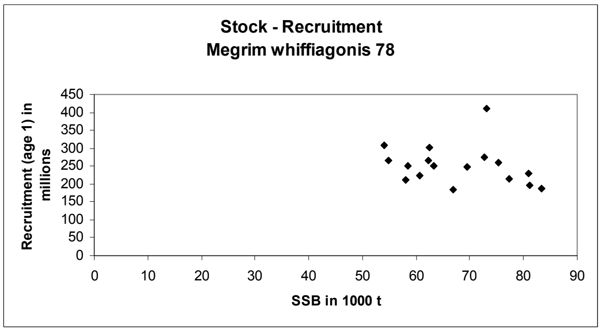
Table 2 Stocks with little dynamic range in SSB (close to or less than 2).

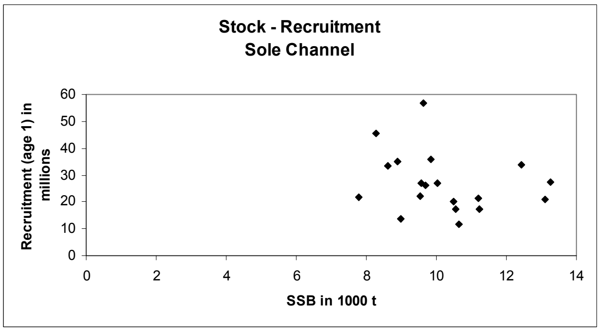


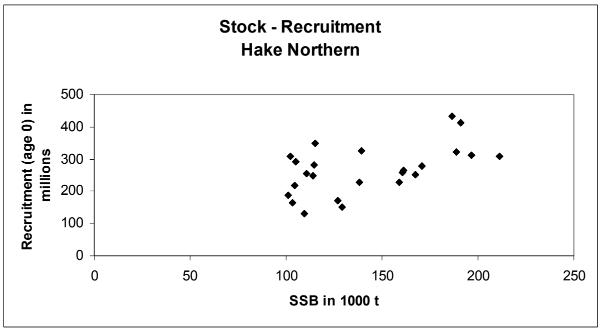


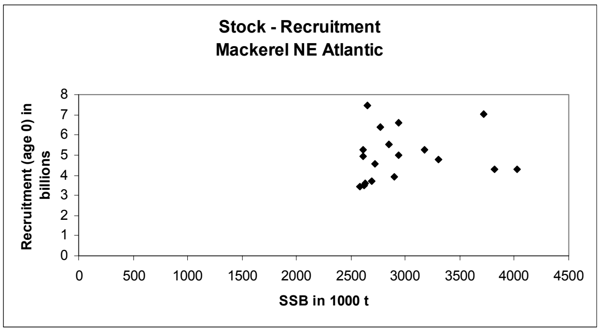


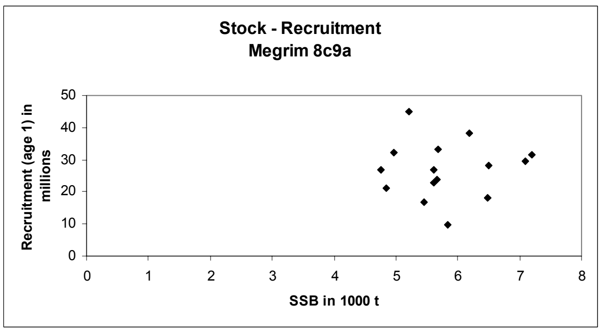












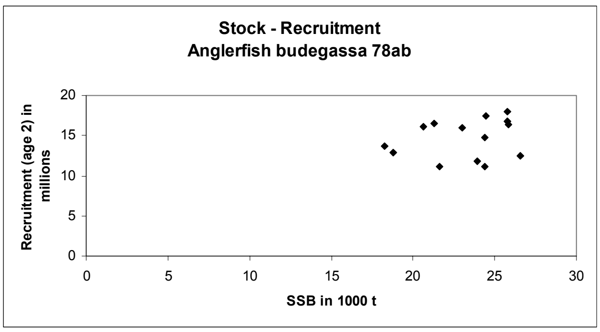
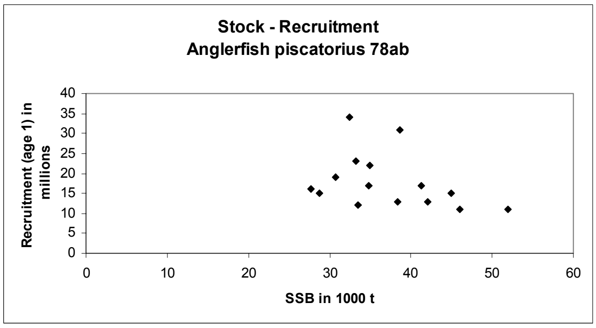


Table 2 Cont. Stocks with little dynamic range in SSB (close to or less than 2).



ANNEX I RECOMMENDATIONS FOR REVISION OF PRECAUTIONARY REFERENCE POINT VALUE

The **Study Group on the Further Development of the Precautionary Approach to Fishery management** [SGPA] (Co-chairs: C. Bannister, UK and M. Azevedo, Portugal) will meet 2-6 December 2002 at ICES HQ to:

a) complete the technical guidelines for revision of reference points developed by the Chairs of the SGPA and the ICES Secretariat.

A Study Group on biological reference points for Northeast Arctic cod (Chair: Yuri A. Kovalev, PINRO) will be established and will meet in Svanhovd, Norway from 13-17 January 2003 to:

a) determine the most appropriate time period for estimating biomass and fishing mortality reference points;

b) review the framework for calculating reference points established by SGPA in December 2003 and specify the technical basis for the reference point calculations;

c) propose reference points based on a) and b). In the event that agreement is not reached on points a) and b) different alternatives will be formulated and compared.

The Study Group will report on 24 January to the ad-hoc group on revision of reference points meeting in February 2003.

An ad-hoc **Group on Precautionary Reference Points for Advice on Fishery management** will meet at ICES Headquarters from 24-28 February 2003 (Chair: ACFM Chair, members Chairs of the following assessment Groups: HAWG, WGBFAS, AFWG, NWWG, WGNPWG, WGNSSK, WGHMM, WGNSDS, WGSSDS, WGMHSA and chair and co-chair of SGPA) to:

1) review the proposal prepared by the ICES Secretariat on Reference Points for the stocks dealt with by HAWG, WGBFAS, AFWG, NWWG, WGNPBW WGNSSK, WGHMM, WGNSDS, WGSSDS, WGMHSA. The proposal shall be built on the framework developed and agreed by SGPA in December and the outcome of the special meeting on NEA Cod reference points to be held in 13-17 January 2003;

2) propose revisions of the Reference points used by ACFM in formulating advice on fishery management for consideration by the assessment working groups and with a view for adoption and use by ACFM in its May and October 2003 meetings.

The Group will report by 5 March 2003 for the attention of ACFM.

ANNEX II FORM OF ICES ADVICE

Revision 3

1. ICES ADVICE

1.1 The Form of the ICES Advice

ICES recognises that "changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values" (FAO 1996). Therefore, ICES agrees that a precautionary approach should be applied to fishery management. Biological reference points, stated in terms of fishing mortality rates or biomass, are key concepts in implementing a precautionary approach. They should be regarded as signposts giving information of the status of the stock in relation to predefined limits (limit reference points) that should be avoided to ensure that stocks and their exploitation remain within safe biological limits.

The concept of safe biological limits was introduced in ICES advice in 1981 and further developed in 1986 (Serchuk and Grainger, 1992). The aim of keeping stocks within 'safe biological limits' was described in the UN Agreement on Straddling Fish Stocks and Highly Migratory Stocks: a stock should be kept at a sustainable level by keeping it above a minimum biomass benchmark, and by keeping the fishing mortality below a maximum fishing rate benchmark. In 1998, ICES introduced precautionary biological reference points as the basis for its advice.

ICES has agreed that the spawning biomass (SSB) should not fall below a minimum limit, described by the symbol $\mathbf{B}_{lim}$ (the biomass limit reference point) and set on the basis of historical data. The value of $\mathbf{B}_{lim}$ is chosen such that below it, there is a high risk that recruitment will 'be impaired' (seriously decline) and on average be significantly lower than at higher SSB. When information about the dependence of recruitment on SSB is absent or inconclusive, there will be a value of SSB, below which there is no historical record of recruitment. $\mathbf{B}_{lim}$ will then be set close to this value to minimize the risk of the stock entering an area where stock behaviour is unknown.

Below $\mathbf{B}_{lim}$ there is a higher risk that the stock could 'collapse'. The meaning of 'collapse' is not biological extinction, but that the stock has reached a level where it suffers from severely reduced productivity, and that a fishery therefore cannot be supported.

ICES has also agreed that the fishing mortality rate should not be higher than an upper limit $\mathbf{F}_{lim}$ that in the long term will drive the stock to the biomass limit.

Spawning biomass and fishing mortality can only be estimated with uncertainty. Therefore, operational reference points are required to take account of this. To be very certain that spawning biomass is above $\mathbf{B}_{lim}$, spawning biomass should in practice be kept above a higher level that allows for this uncertainty. Therefore, ICES creates a 'buffer zone' by setting a higher spawning biomass reference point $\mathbf{B}_{pa}$ (the biomass precautionary approach reference point). ICES has agreed that when the spawning biomass is estimated to be below $\mathbf{B}_{pa}$, management action should be taken to increase the stock to above $\mathbf{B}_{pa}$.

Similarly, to be very certain that fishing mortality is below $\mathbf{F}_{lim}$, fishing mortality should in practice be kept below a lower level $\mathbf{F}_{pa}$ that allows for this uncertainty. ICES has agreed that when fishing mortality is estimated to be above $\mathbf{F}_{pa}$, management action to reduce it to $\mathbf{F}_{pa}$ should be taken, even if the spawning biomass is above $\mathbf{B}_{pa}$.

ICES gives advice on many stocks for which there is no analytical assessment and accordingly no basis for setting reference points as described above. Also in these cases ICES uses a precautionary approach, but alternative models are applied, with reference points referring e.g. to catch per unit of effort instead of biomass.

The ICES advice is primarily risk-averse, i.e. it aims at reducing the risk of something undesirable happening to the stocks. Biological target reference points are listed and sometimes referred to, but because setting targets for fisheries management involves socio-economic considerations, they are not directly used in the advice. This means that even if the ICES advice is followed, exploitation of some stocks may be sub-optimal, i.e. the long-term yield is lower than it could be.

Managers are invited to develop management strategies. ICES will comment on these and consider if they are consistent with the precautionary approach. If they are, ICES will frame the advice to be consistent with the adopted management plan.

Framework for advice

When an assessment shows that the spawning biomass is below $\mathbf{B}_{pa}$ the stock is regarded by ICES as 'outside safe biological limits', regardless of the fishing mortality rate. Where this is the case ICES will advice to increase spawning biomass above $\mathbf{B}_{pa}$, and if appropriate, reduce fishing mortality to below $\mathbf{F}_{pa}$. If this cannot be achieved in the short-term, ICES will recommend that managers should develop a rebuilding plan specifying measures to increase SSB above $\mathbf{B}_{pa}$ in an appropriate time scale depending on the biological characteristics of the stock and other relevant factors.

When an assessment shows that the stock is above $\mathbf{B}_{pa}$ but that the fishing mortality is above $\mathbf{F}_{pa}$, the stock is 'harvested outside safe biological limits'. ICES will then recommend that the fishing mortality be reduced below $\mathbf{F}_{pa}$.

The current ICES reference points were set in 1998 using the stock and fishery data then available, as a provisional step in the implementation of the precautionary approach. In some cases, it has been necessary to change these reference point values as a result of changes in the data or the productivity of the stock, In order to to improve consistency with the framework described above. ICES will review all these points in 2003.

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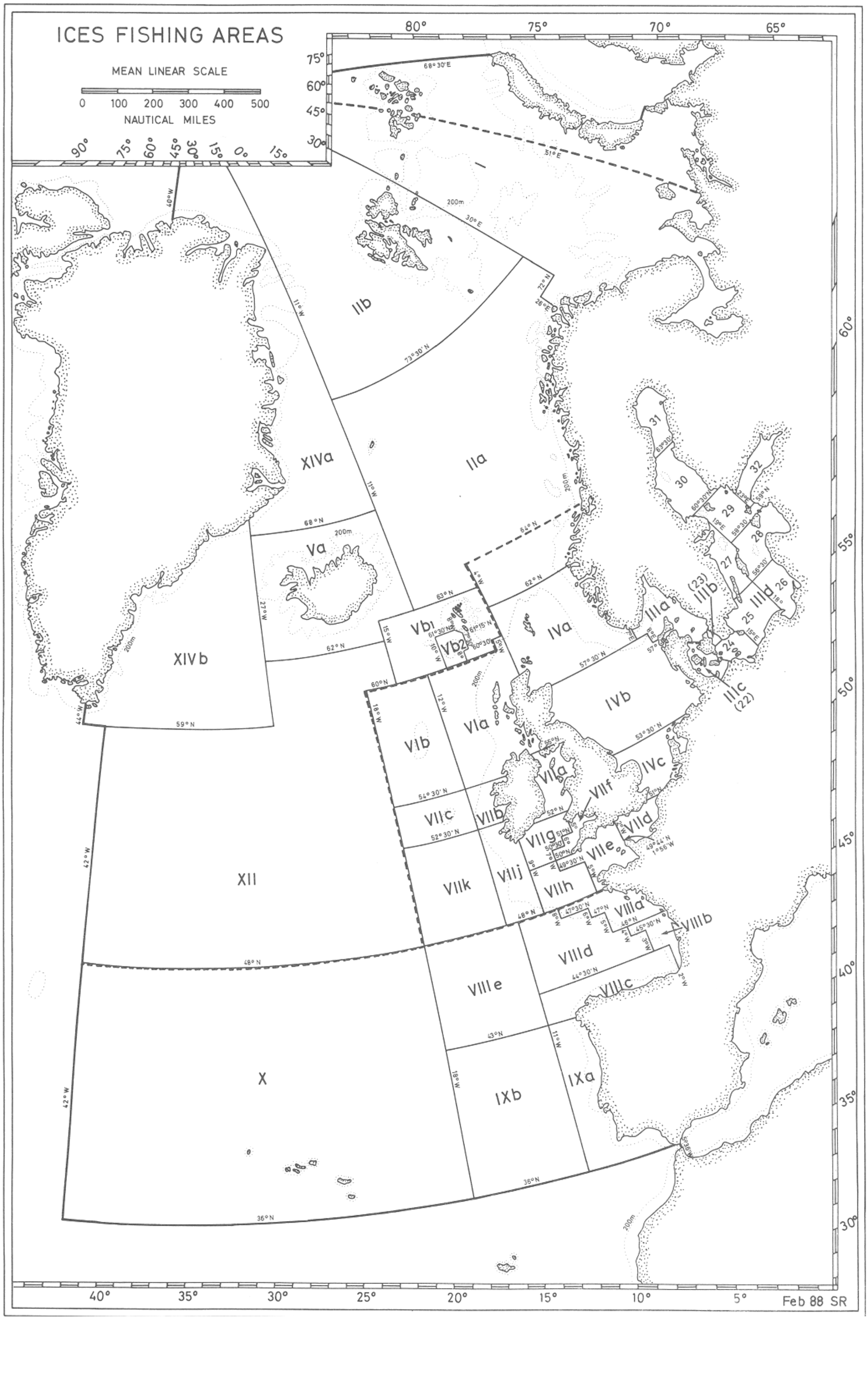
Serchuk, F M. and Grainger, J. R. 1992. Development of the basis and form of ICES Fisheries Management Advice; Historical background (1976–1990) and the new form of ACFM Advice (1991 - ?). ICES CM 1992/Assess:20.

Report of the 11th Dialogue Meeting Nantes January 1999, ICES Coop. Res. Rep. 228 (1999)

Report of the Follow-up meeting of the 11th Dialogue Meeting, February 2000.


ICES FISHING AREAS
MEAN LINEAR SCALE
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IIIc (22)
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ANNEX 4

Working Document 4 SGPA 02b

Estimating Biomass Limit Reference Points For Canadian Cod with Non-Parametric Density Estimation methods

Jake Rice – DFO / CSAS Canada
Obai Mashal – University of Ottawa, Ottawa, Ontario Canada

Limit Reference Points play an important role in ICES advice on status of fish stocks and sustainable harvesting options. Although recommendations on catch options are determined by risks of SSB falling below the Precautionary Reference Point ($\mathbf{B}_{pa}$), the position of $\mathbf{B}_{pa}$ is determined by the location of the Limit Reference Point ($\mathbf{B}_{lim}$), and whatever knowledge there is about uncertainty in the assessment. The location of $\mathbf{B}_{lim}$, in turn, is determined by the productivity characteristics of the stock. ICES has used several functional definitions of $\mathbf{B}_{lim,}$ even within the same year. In the current form of advice, ICES interprets $\mathbf{B}_{lim}$ as the SSB below which "productivity is impaired" (Text distributed 11/02). Past explanations have interpreted that impaired productivity may be the SSB below which either the probability of poor recruitment increases markedly, or the probability of good recruitment decreases markedly (ICES 2001). Biologically, this interpretation is consistent with the intent of conservation limits, to prevent "harm that is serious or impossible to reverse" (UNCED). It does not tell how the position should be determined, but it strongly suggests choice of $\mathbf{B}_{lim}$ should focus on estimating the rate of change in probabilities of poor and good recruitment.

There have been attempts to determine the position of $\mathbf{B}_{lim}$ using stock recruit relationship, but there are at least three problems with this approach. First, there are no discontinuities in parameterized stock-recruit relationships, so after parameters of the S-R relationship have been estimated, one is no closer to determining the location of $\mathbf{B}_{lim}$. Second the stock recruit data for many stocks do not fit a parameterized relationship well, so even areas of strong curvature are poorly determined. For some stocks the peak of the dome (Ricker) or asymptote (Beverton – Holt) are outside the range of S-R observations and although their values are readily estimates from S-R data, there is no biological justification for using the values in further analyses. Third, for most stocks there are few observations at high SSB, compared to the density of observations at intermediate and low SSB. Because parameterised S-R models are constrained to pass through the origin, the few observations of recruitments at high SSB have very high statistical leverage in the parameters of the equation, and observed recruitments at low SSB have particularly low leverage. This differential leverage is particular influential on estimates of the slope in the vicinity of the origin (α) (Rice NAFO workshop ms 1997). Estimating reference points which use these parameters (especially α) then place one in the logically untenable position of drawing conclusions about expected recruitment at low SSB from parameters primarily determined by recruitments observed at exceptionally high SSBs for the stock.

For these reasons, there have been attempts to use non-parametric methods to determine the appropriate value for $\mathbf{B}_{lim}$, such as B_{crash} and $\mathbf{B}_{loss}$. So far, however, these attempts still have not focused directly on the change in probability of poor (or good) recruitment as a function of SSB. The density estimation methods of Evans and Rice (1986) allow that question to be addressed directly. Those methods were used to determine the relationship specifically between the probability of poor recruitment and SSB for several Canadian cod stocks.

Methods

The core analysis was a kernel estimation technique, as described in Evans and Rice (1986) and Rice (1992). A brief summary of the methods is included here, but those references should be used for technical details. The cumulative probability density function (CPDF) of recruitment given a specific value for SSB is the smoothed stepwise pdf of the observed historic recruitments, with the step heights weighted by a Cauchy weight [1 / (1 + x/D)]. (Other weighting functions, including normal, reciprocol exponential, etc can be readily substituted readily, and make relatively little difference for most applications. We continue to use the Cauchy function because it is less prone than other methods to produce "bumpy" results when observations occur in clusters with gaps between them. [That is, there are several Rs observed in a narrow range of SSBs, then a wide stretch of SSB with no observations, and then several more observations.])

In the weighting function x is the distance of the SSB associated with each observed recruitment (each step) from the SSB for which the current CPDF is being estimated. D is the breadth of the influence function or "bandwidth"; when D is large relative to all x, then all steps are of nearly equal height. When D is small relative to some of the x's (the distance on the SSB axis from the SSB for which the CPDF is being calculated is > D for some stock-recruit pairs), then observations with small x (close to the "current" SSB) receive large weight (big steps in the CPDF) relative to observations with large x. For a variety of data sets with some relationship between a dependent and independent variable, but large noise, D's of between 1/6 and 1/10 of the range of observations on the independent variable (SSB axis) then to give reasonable performance. The more of the variance in the dependent variable accounted for by the independent variable, the smaller the value of the best D.

The best bandwidth is a compromise between over-smoothing and under-smoothing. Over-smoothing – using too wide a bandwidth – treats distant observations as more informative than they really are relative to local observations, and results in low rates of change in the dependent variable (expected R) as a function of the independent variable (SSB). Under-smoothing – using too narrow a bandwidth - gives influence only to observations at SSBs very close to the one for which the CPDF is being estimated, and results in very bumpy CPDFs and large changes in expected R for modest changes in SSB.

The best value of D is determined by cross-validation. Two statistics were used in the cross-validation step: an approximation to the variance and an approximation of a Chi-square statistic. The approximation to the variance was the sum (across all SSBs in the data set of stock-recruit pairs) of squared deviations of the observed recruitment from the median of the cross-validated CPDF at each SSB. This would be a true variance if the errors of the recruitment data were normally distributed, but that is rarely true. Minimising the variance approximation protects against over-smoothing.

A Kolmogorov-Smirnov (K-S) approximation was used as a test of under-smoothing, and gives information about the degree of bias in the full set of CPDFs. For a proper bandwidth that estimates local PDFs well, the observed R's should be a random sample from their individual PDFs, so the suite of probabilities associated with the full set of Rs should be uniform on (0, 1). The effect of under-smoothing is to make the CPDF overly steep in a narrow range of SSB, resulting an excess of observations near 0 or near 1 (depending on whether the CPDF is too steep above or below the observed R). The inverse of the probability associated with the maximum deviation of the actual distribution of probabilities associated with the observed Rs from the expected uniform distribution is the other criterion used to select the optimal D. This gives a big penalty to bandwidths that provide biased CPDFs over a substantial range of SSBs, but has little discriminating power for wide bandwidths.

Neither criterion is used as a formal statistical test, but to inform users about the distribution of observations in the family of CPDFs for each value of D. The optimal D had to satisfy the K-S criterion (not too low a probability), but once that condition was satisfied, selection was on the basis of minimum variance. This process for selecting D may see a bit *ad hoc*, but is actually more rigorous than for most common smoothing techniques such as Lowess smoothers. Commonly the weighting factor is simply set arbitrarily, often as a certain number of points closest to each observation receiving equal weight, and all other observations receiving zero weight.)

The analyses were performed using Matlab and a menu-driven program to conduct a series of step:
1) The User enter stock recruit data (designed for an Excel spreadsheet with S – R pairs).
2) Estimate the variance and K-S approximation for a range of D's from very small to much larger than the range of SSBs.
3) Plot the values of the variance and K-S probabilities as functions of SSB.
4) The User may examine the plots and select the best D value or the program will provide the minimum for each statistic, integrating a curve in the neighbourhood of the smallest observations, and propose a best D.
5) The User provides a value for a recruitment that is the boundary at and below which recruitments are considered poor, (This does not have to be a value from the historic series.), the SSB range of interest, and the number of points to be estimated within the range of the SSB.
6) Estimate the CPDF for the n points along the SSB axis, given the S-R observations and D.
7) Plot the probability of a recruitment at or below the "poor" recruitment (step 5), as a function of SSB

From the plot produced in 7, users have information on how the probability of poor recruitment varies with SSB. This information can be used directly in choices about limit reference points for SSB. The plot is, of course, specific to the input value for poor recruitment, and D. The sensitivity of the probability of poor recruitment as a function of SSB to different choices for D and what recruitment is "poor" can be explored by simply changing inputs at 5).

Being Objective

How to choose a "Poor" Recruitment

All methods for setting limit reference points require some quasi-arbitrary decision(s) at some point. For parameterised approaches, this is often cut-offs made in the continuous distributions estimated by the functional forms that are used. In this method the arbitrary step is the boundary for poor (or good) recruitment. Three options have been explored.

1. Ask the specialists on the stocks what is considered to be "poor" recruitment, or just look at the S-R data and pick the lowest quartile, or some natural discontinuity.
   For the Canadian cod stocks, choices of the assessment experts usually coincided with discontinuities in the historic S-R data, and often with temporal discontinues in recruitment time series as well. This approach has the disadvantage that experts might apply very different criteria in selecting what is "poor". It has the advantage of transparency and opportunity for inclusiveness of diverse expertise.
2. Using results of an (equilibrium-based) spawners-per-recruit analysis, choose the recruitment that, if experienced consistently, would produce an equilibrium biomass that just reached some specified (target) level.
   In this case, the arbitrary step is what boundary one sets on the specified "recovered" biomass desired for the stock. If there is wide consensus on historic periods when the stock was considered healthy (or at least "acceptable"), they would be the basis for the boundaries. This would link the Biomass Limit Reference Point to a biomass target explicitly, rather than hiding a target in the assumptions of the computations of the limits.
   A minor variant of this approach is to use desired yield rather than SSB as a basis for setting the "poor" recruitment level. This would be wise if there were harvest targets set for the stock. In

that case a yield-per recruit analyses would identify the minimum recruitment necessary to produce the desired yield.

Both of these alternatives (SSB or yield) require some assumption of total mortality, and therefore fishing mortality, in the analyses. The biomass formulation focuses directly on protecting some minimum spawning biomass from which recovery would be "rapid and secure", and would suggest that one should be looking at the minimum recruitment capable of providing the rebuild SSB assuming F=0. If one prefers a yield-based reference, then assuming F=0 is logically unsatisfying. By choosing a desired F, however, there would be a logical link between the F used in management and the Biomass Limit Reference Point.

It may sound circular to choose an SSB, a recruitment necessary to produce that SSB, and then the SSB necessary to produce that recruitment. However, the uncertainty in the S-R data and asymmetry in the CPDFs means that the non-parametric analysis will provide probabilistic information that will be important in selecting reference points.

3. Drawing from the positive performance of the BH50 and RK50 reference points (Myers et al 1994) use the recruitment which is 50% of the largest median recruitment possible to estimate from the S-R data. (This has to be done iteratively with the current program. For increasingly large trial values of R, estimate and plot CPDFs as a function of SSB. In just a few runs it is possible to identify the largest R for which *some* SSB has a CPDF that reaches 0.5 for that R. That is the largest possible R that has a median likelihood, given the historic data, just as the top of the Ricker dome is the largest possible recruitment that has a median (and mean) likelihood, given the historic data and assuming the Ricker functional relationship. Once the largest possible median R is estimated, the NP50 estimated by simply obtaining the probability plot in Step 7 for the recruitment that is 50% of that value. These steps could be automated readily, if desired.)

The Canadian meeting on reference points for cod stocks accepted the BH50 and RK50 as informative tools for estimating biomass limit reference points, as long as the peak (Ricker) or asympotote (BH) was well defined within the range of historic S-R data. Correspondingly the meeting preferred option 3, and used NP50 strategy to determine what was a poor recruitment (i.e 50% reduction in R from the best expected R was "impaired productivity").

How to choose Limit and Precautionary Reference Point?

Once one has a the plot of how the probability of poor recruitment varies with SSB, what probability should become the Precautionary Reference Point, and what value should be the Limit Reference Point? For stocks where recruitment does vary systematically with SSB, this method produces an asymptotic low probability of poor recruitment at moderate – high SSB. This asymptotic P may be quite different from 0, if recruitment failures occur occasionally, regardless of the size of the SSB. However, as one moves along the SSB axis towards lower values, inflection points are very commonly present. This is the SSB where the probability of poor recruitment begins to increase. If management should be risk averse relative production of impaired productivity, this is the SSB below which conservation actions should commence. Hence it is logically a suitable value for $\mathbf{B}_{pa}$. The uncertainty in the historic S-R relationship is captured in the CPDFs that provided the probability plot, but such a Precautionary Reference Point does not address bias in the annual point estimates of SSB.

An objective criterion for choosing the Limit Reference Point is less obvious. For options 2 and 3 above, however, selection of the value for poor recriutment is based on the development of SSB or expected R under average conditions. This would require that the Limit Reference Point should be the biomass where the probability of poor recruitment was 0.5. This can be read directly off the probability plot, and be taken as $\mathbf{B}_{lim}$.

It is worth noting that using this method there may be no SSB which results in the selected poor recruitment (or worse) having a probability >= 0.5. That is not a failure of the method, but an alert that the historic S-R data are uninformative about the SSB at which productivity is seriously impaired. As long as there is an inflection in the probability plot, however, the method will still produce a Precautionary Reference Point. It may even be the case that the asymptotic P of poor recruitment is close to 0.5, even at high SSB. This is important information for management. It makes clear that productivity is precarious at even high SSB, and management of such stock should be conservative.

Presentation of this method requires pointing out steps where some decisions have to be made. The analysis doesn't do everything for the User. I argue this is a virtue of the approach, and not a flaw. All other methods require the same decisions to be made. However they are frequently just hard-wired into the computations, and users don't even know that arbitrary decisions may have been made about what recruitment is low enough to be considered "impaired" and which probability of poor recruitment is unacceptably high. Forcing Users to make these choices explicitly increases transparency and clarity in the process of choosing limit reference points.

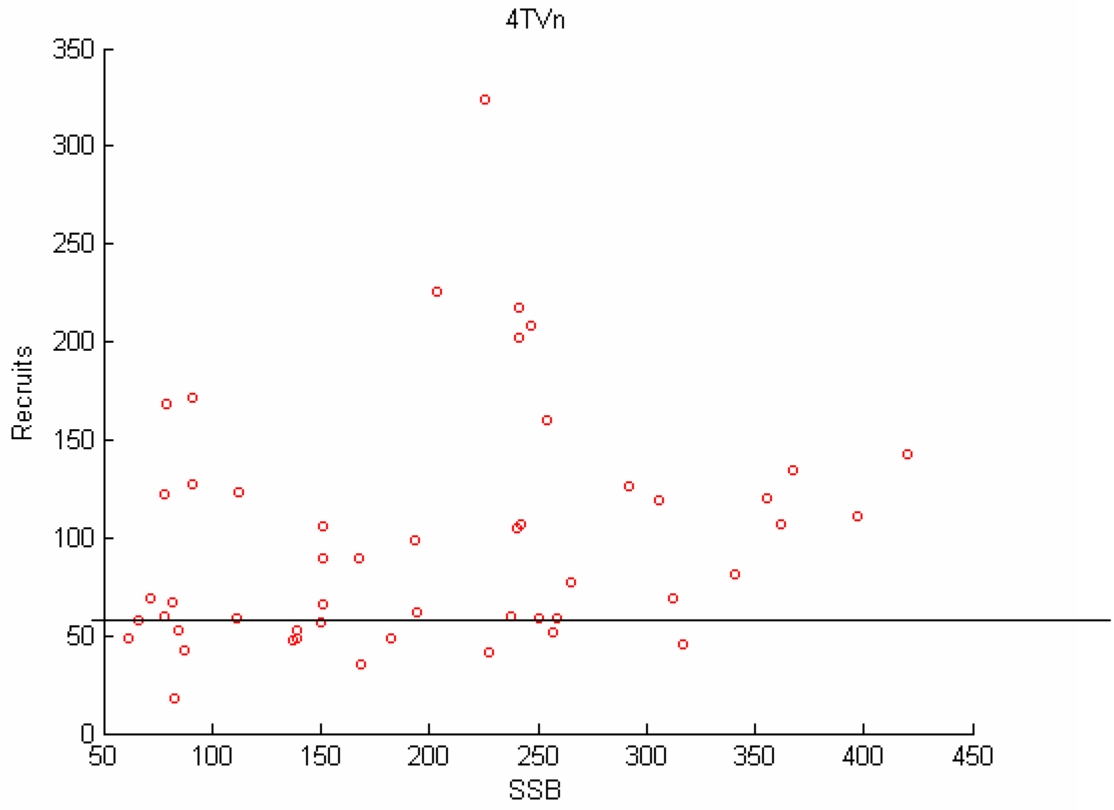
Examples

These methods were applied to several Canadian cod stocks. In all cases, the S-R data came from the most recent analytical assessment providing historic reconstructions of SSB and year-classes. For several stocks, sensitivity tests were made with different D's or with different choices of poor R.

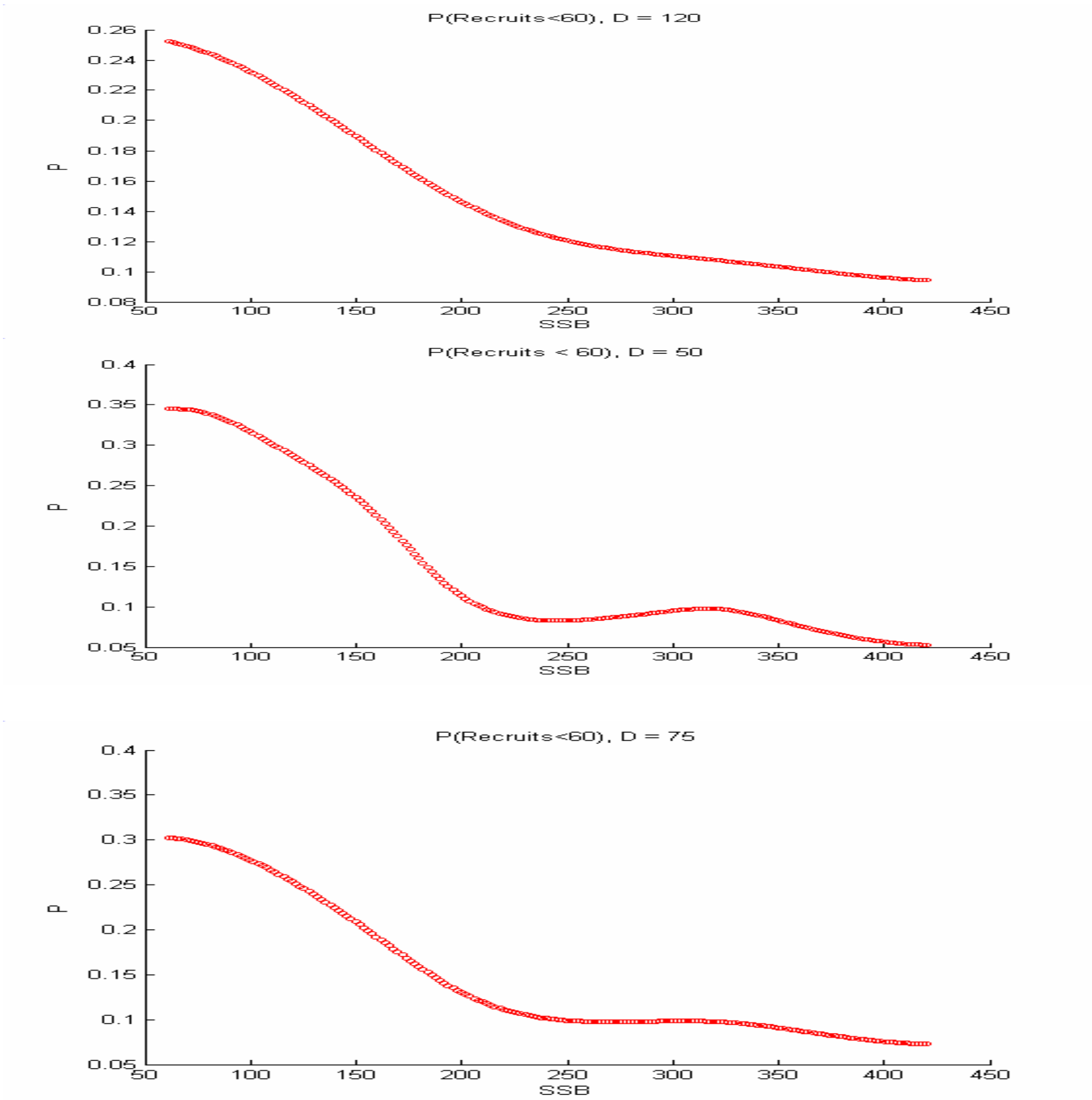
Evans and Rice 1986. Ices Journal of Marine Science.

Myers, R.A., Rosenberg, A.A., Mace, P.M., Barrowman, N. and Restrepo, V.R. 1994. In search of thresholds for recruitment overfishing. ICES J. Mar.Sci., 51:191-205.

Rice, J.C. 1992 Canadian Journal of Fisheries and Aquatic Sciences.

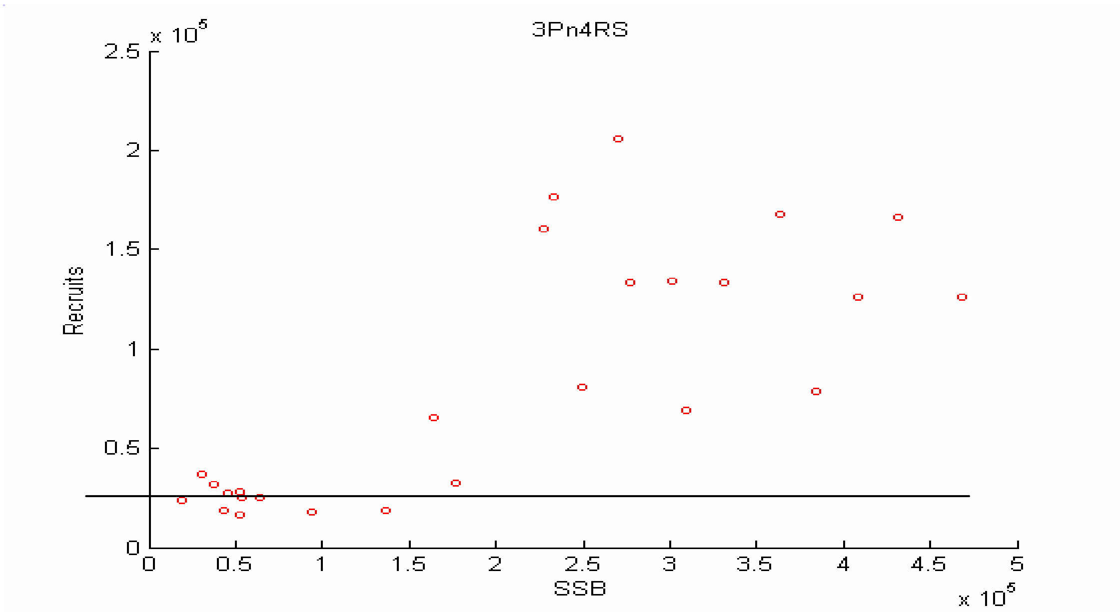


Scatterplot of stock and recruitment data for Southern Gulf Cod (4TVn), with “poor” value of 60 million recruits (from assessment scientist) designated

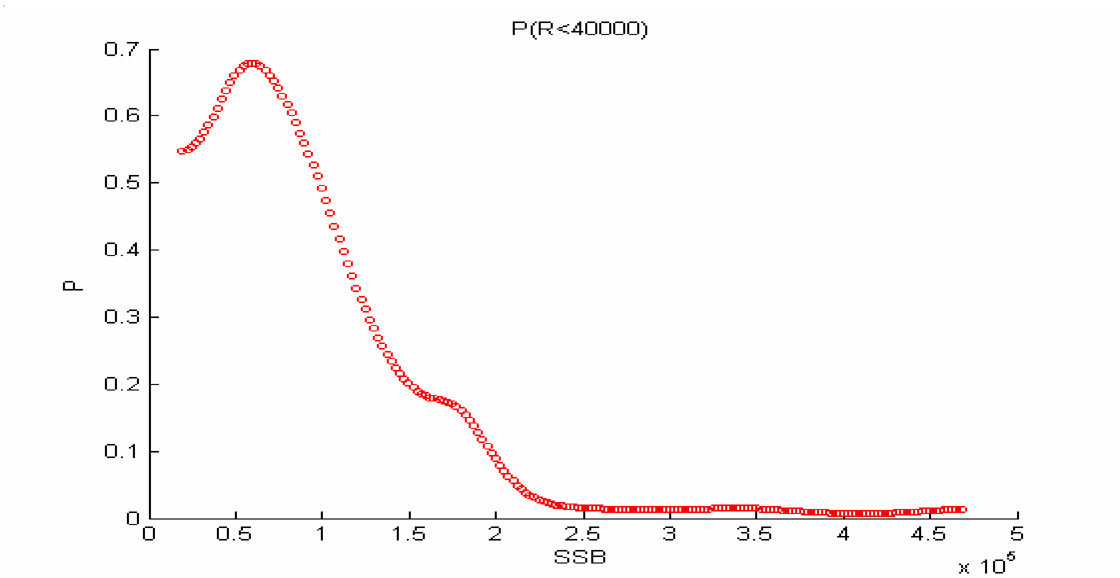


4 TVn analyses: Estimates of probability of “poor” recruitment for three difference values of D parameter. Parameterization step had suggested that D ~ 75 kt was optimal, but the optimum was not well defined. Note that even with SSB at 50 Kt, probability of poor recruitment was not > = 0.5.

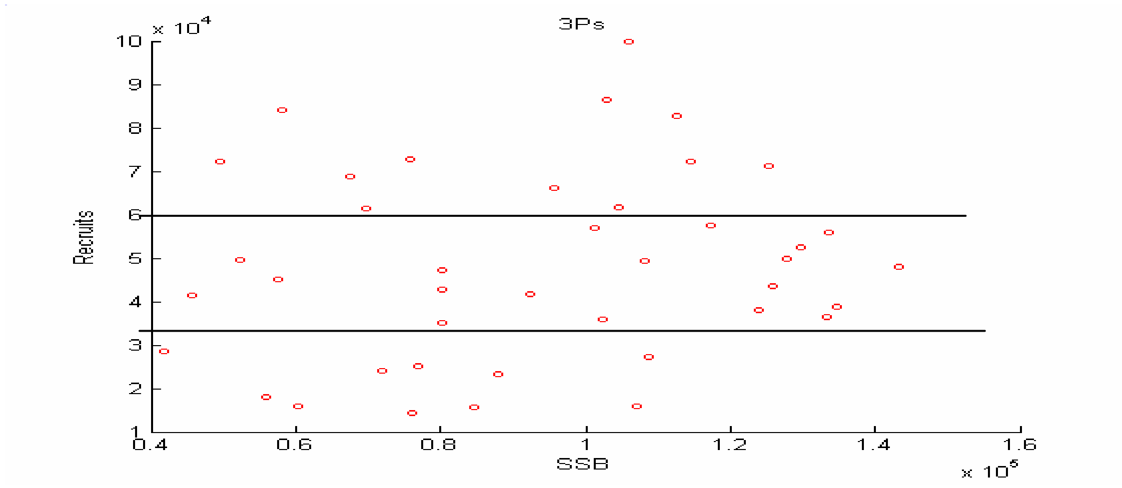
A – Stock - recruit data Stock for Cod in the northern Gulf of St. Lawrence (3Pn4RS).



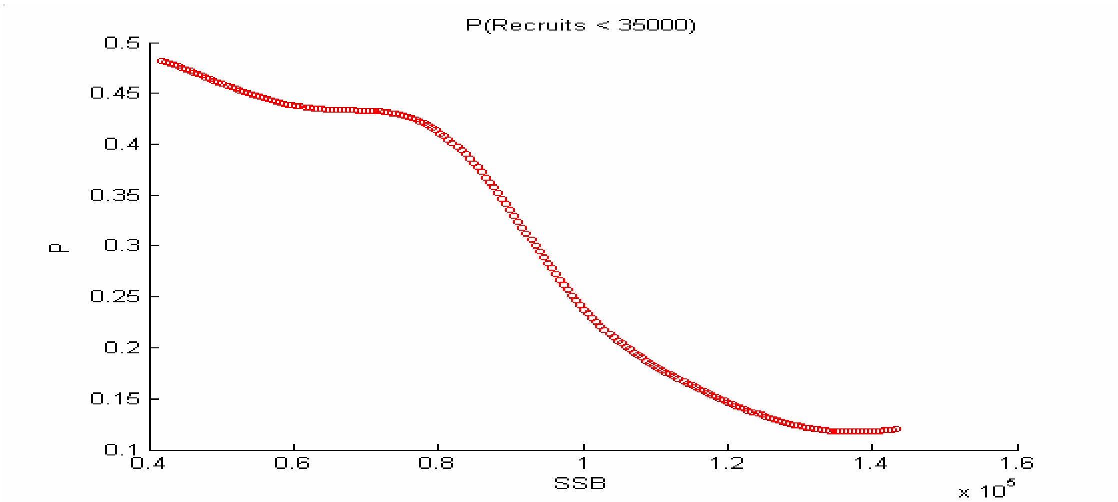
B. Probability plot for recruitment <= 40 million recriuts. Risk of poor recruitment begins to increase for SSB < 220 Kt, and exceeds 0.5 at 110 kt. The analysis of NP50 indicators R = 0.5 (max median R) ~ 75 million recruits, and SSB where this would be median R is ~ 180 kt.



S-R data for Cod on St. Pierre Bank (3Ps). Boundaries for poor and good R designated.



Analytical results indicate that risk of poor recruitment begins to increase for SSB < 120 kt. and approaches 0.5 for SSB < 80 Kt. Results also suggest that probability of GOOD recruitment peaks at ~ 120 kt, and falls off quickly thereafter.

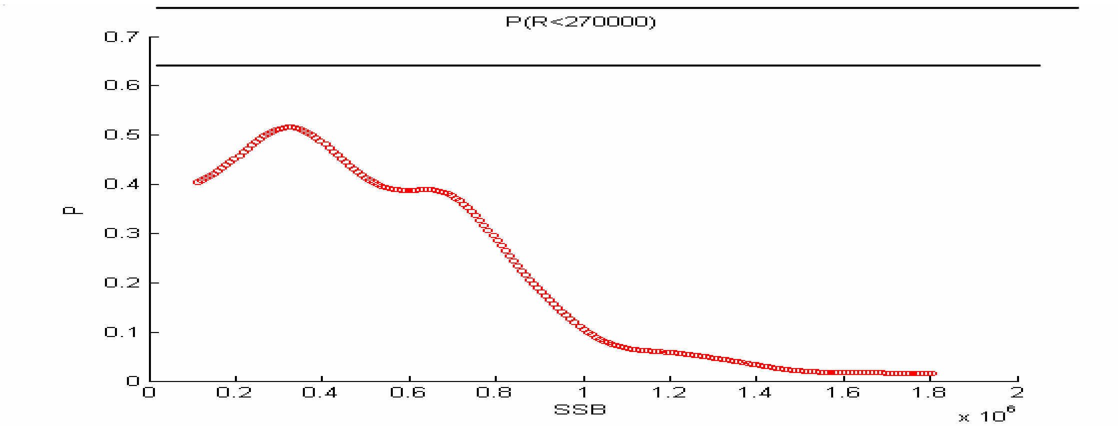


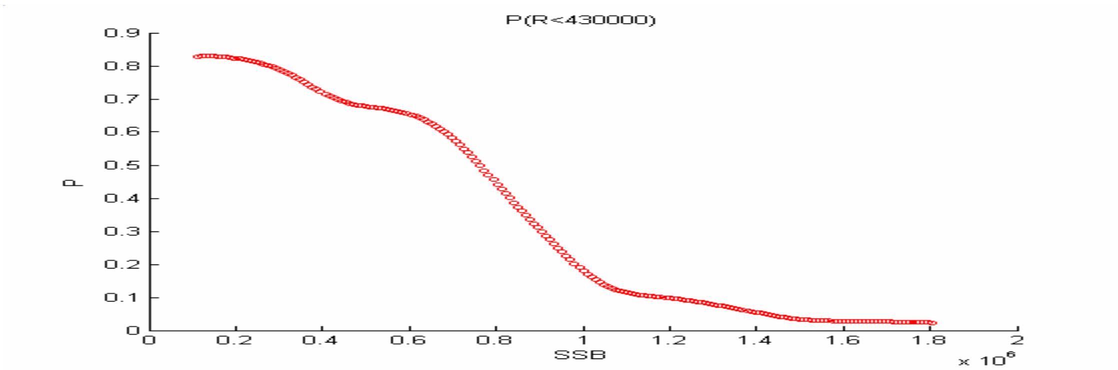
probability profile of good recruitment.

Stock recruit data for Northern Cod (2J3KL). Note that the recruiments are in 2 clusters.

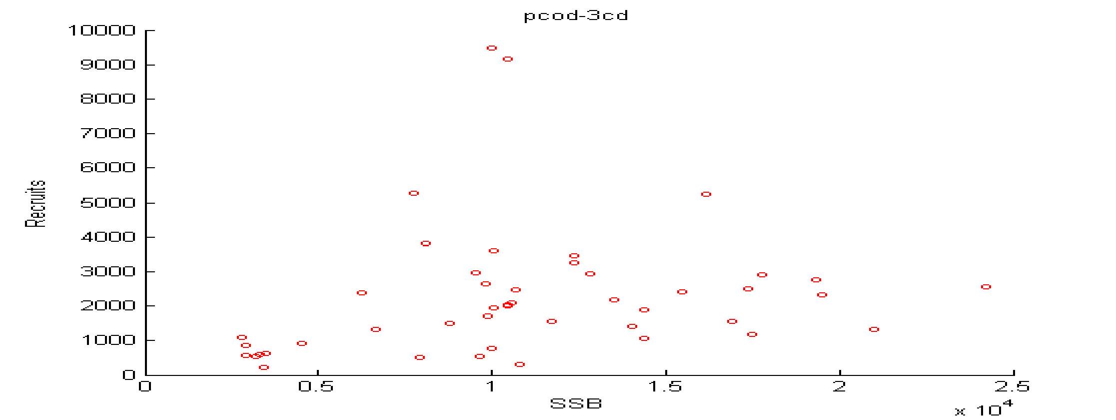
Hence the value of poor recruitment could be 450 million or ~ 300 million.

Depending on how much of the lower cluster was considered poor. However regardless of the choice of a poor recruitment, both probability plots suggest that a precautionary reference point would be about 1.1 mmt, and a limit at around 700,000 kt. Naturally the ABSOLUTE probability of exceeding the higher values for poor recruitment (430 million) is consistently higher than the absolute probability of recruitment exceeding 270 million, but the reference points are robust, given the data.

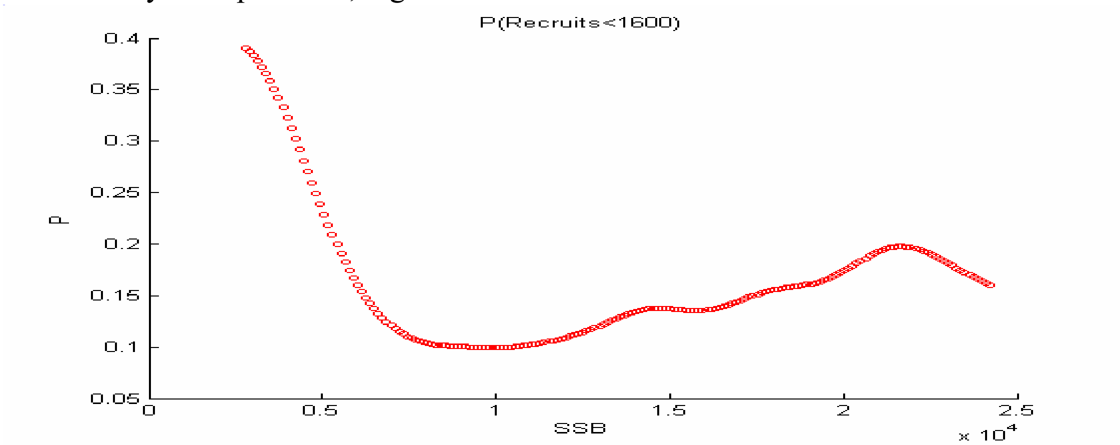




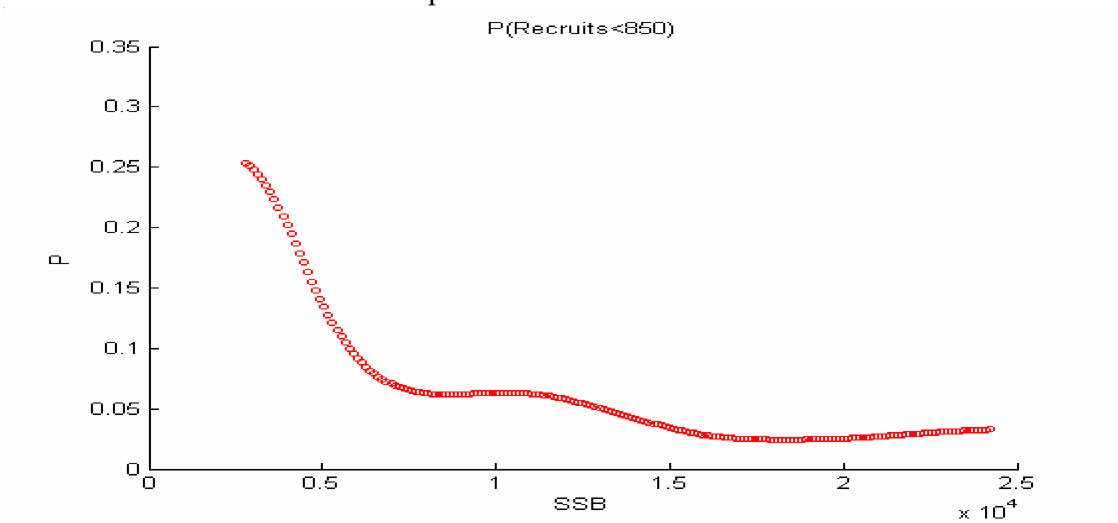
Stock and recruit data for Pacific cod in Moresby Gully and surrounding areas. Note the presence of two exceptional year-classes at intermediate SSBs. These values would have substantial impact on Ricker or BH – based reference points. However the probability profiles are only slightly



affected by their presence, regardless of where in the mess of low recruitments one decides to



determine that recruitment is poor.



Further Developments

1 – More Independent Factors affecting stock productivity
Since completing the work for the Canadian Gadoids Reference Point Workshop, there have been further developments with this approach. In discussions regarding 4TVn, the assessment biologists argued that mackerel and herring are severe predators on cod eggs and larvae, and this biomass of pelagic predators has been in a high and low regime during the decades covered by the SR data. They presented some published analyses indicating that in times of high pelagic predator biomass, SSB has little effect on cod recruitment, because survivorship from egg to recruit is kept low by predation. Only when pelagic predator biomass is low is it possible to see a positive relationship between SSB and R.

There is no logical need to constrain the non-parametric analyses to a single independent variable. Indeed these ancillary variables may be handled better with the nonparamtric methods than parametric ones, because with these methods it is not necessary to specify the shape and error structure of the functional relationship between the factor (predator biomass, water temperature, etc.). This may be a great virtue because with environmental & ecosystem factors affecting recruitment, not only are these functional forms rarely known, but they may not even be smooth and continuous.

The Matlab programs are designed to accept up to 30 variables for analyses, although it has not been tested with biological for more than 3. The menu drive protocol is the same as for just two dimensions, stock and recruit pairs, but it becomes more helpful to allow the program to find the best D and just output the marginals from the crossvalidation. Otherwise one falls into a time-consuming task of stratifying all but one independent variable to a narrow range of values, seeing the optimal D for the remaining one (say, choose a specific pelagic predator biomass, find the best D for SSB by crossvalidation. Then choose another value for perlagic biomass and repeat.

Results of the analysis are fully consistent with the explanation given by the biologists. There are clearly two regimes in the probability profile of recruitment as functions of SSB and pelagic biomass. P of poor R (Z axis – up and down) is high at high predator biomass (x axis – left to right), regardless of SSB (y axis – front to back), but some effect of SSB at low pelagic biomass (first following fig). This is particularly clear when the 3-D figure is rotated into 2 dimensions on the strong predator-biomass axis. In that figure (2nd following fig) the breadth of the spread of lines reflects the dependence of R on SSB, given each value of predator biomass. Clearly there are levels of predator biomass where SSB has little influence. The proper Biomass reference point for such stocks warrants discussion, but the discussion is well informed by the analyses.

Comparable analyses were done for water temperature and SSB for 3Ps, cod. In that case the influence of water temperature was quite modest, and only over part of the range of temperatures. There was an effect of SSB at essentially all temperatures, suggesting for this stock that the biomass reference point is the more dominant concern than temperature.

ANNEX 5

Working Document 5: Not to be cited without prior reference to the authors

ICES Study Group on the Precautionary Approach (SGPA'02b)
Copenhagen, 2-6 December 2002

Testing stability of the segmented regression

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Introduction

Based on SGPA'01 and SGPA'02a, ICES is currently developing a framework for verification or recalculation of reference point values. Among other actions, it is intended to recalculate new biomass reference point values using the method proposed in SGPA'02a.

In February 2002, SGPA'02a worked out statistically objective fitting of stock-recruit data by segmented regression in order to identify a change point with confidence interval, and hence determine $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ (O'Brien and Maxwell, 2002).

The approach is to fit a segmented regression to the current assessment data, identify the change point or $\mathbf{B}_{loss}$ and its confidence limits, and designate this as $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$ using the criteria below. Then calculate corresponding fishing mortality reference points.

According the proposal for designating $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ made in SGPA'01 (Anon, 2001), whenever a point of impairment is identified in an S&R plot (with wide dynamic range of SSB), that point will be designated as $\mathbf{B}_{lim}$. $\mathbf{B}_{pa}$ will then be estimated from $\mathbf{B}_{lim}$ according to the agreed risk criterion. Otherwise, if no impairment point can be identified, the $\mathbf{B}_{loss}$ criterion should be used.

The risk criterion for the difference between $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ could take into account, or be based upon, the confidence interval of the change point estimate (segmented regression). However, SGPA'01 advocated an appropriate dialogue with managers before decisions can be taken on this point.

The present meeting aims to prepare for the operational calculations of BRP in February 2003, based upon the framework discussed at SGPA'02a, since it was stated that 'It is apparent from the WPs that the changepoint model can give a far more reasonable fit to the stock-recruitment pairs at higher values of SSB than the WG S-R model'. However, beyond the goodness of fit, BRP must have other properties, including stability and robustness. The present paper presents several implementation of the segmented regression model to some case examples to find out whether change points are stable and robust both to past (observed) and future variability in recruitment.

O'Brien & Maxwell presented a sensitivity analysis based on changepoint models estimated by eliminating a single year-class in turn. The present paper tries to test the stability of changepoints by estimating them for the last 10 years of the time-series of S&R available for each stock. We hope that these results will bring light to the important issue of the stability of BRP as regards of reliability of ICES advice for fisheries management.

2. Methods

The method of O'Brien & Maxwell (WD8, ICES 2002) was used to estimate changepoints for some of the stocks covered by the same authors (WD 10 to 21).

- **North-east Arctic saithe (Subareas I and II)**
- **North-east Arctic cod (Subareas I and II)**
- **Northern hake**

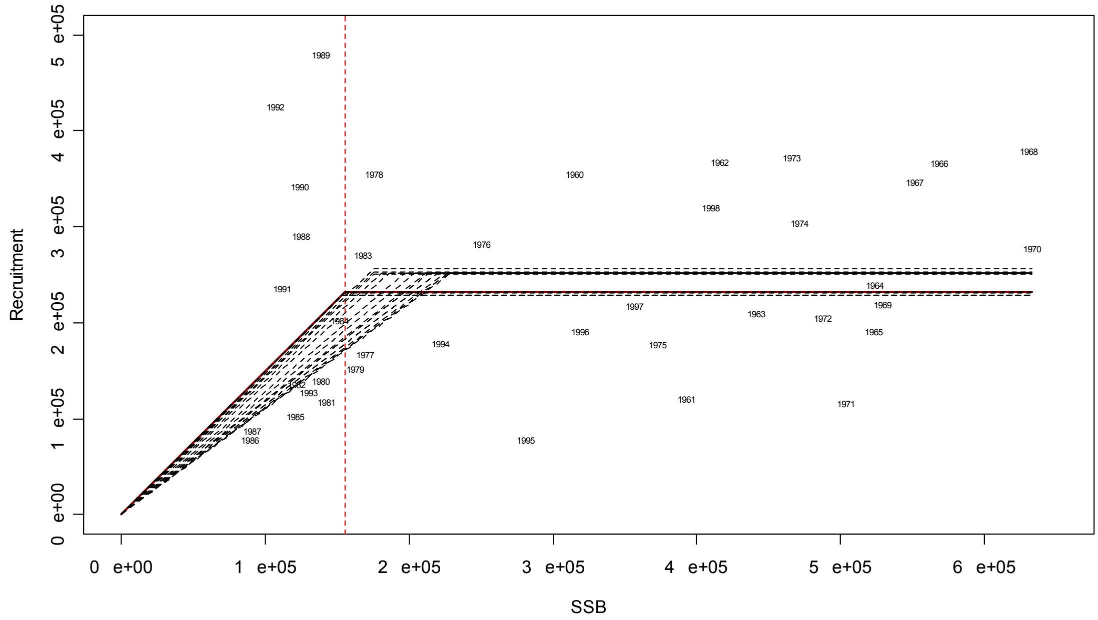
Results

For each population 4 plots are presented:

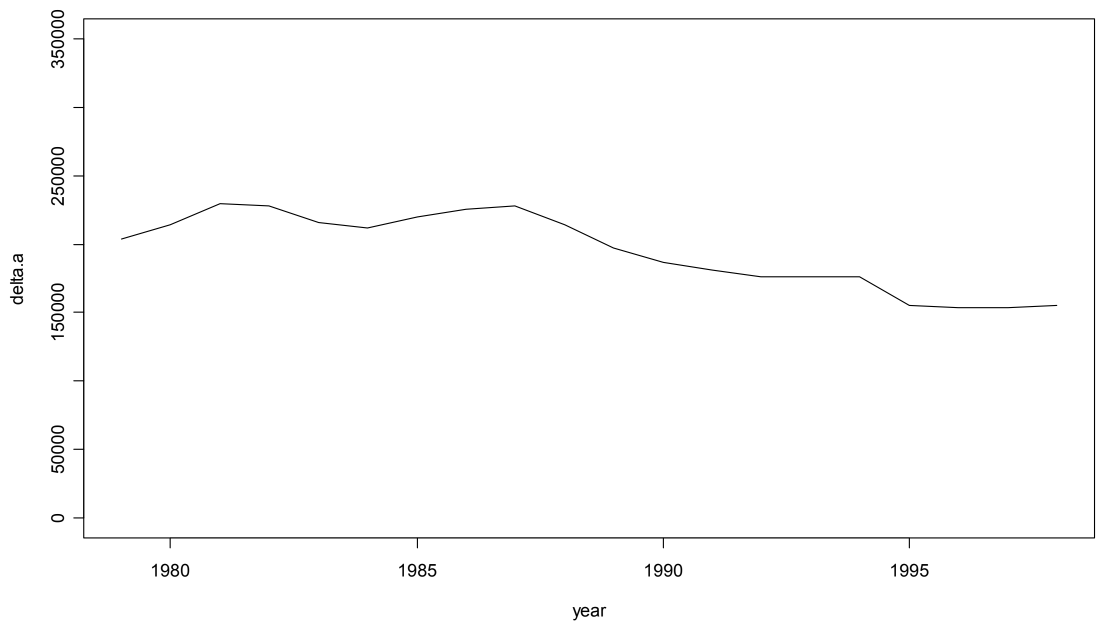
(A) stock-recruitment pairs identified by year-class; solid line is the changepoint model estimated; dotted lines are the changepoint models estimated by adding consecutively one year for the last years of the S&R time-series.
(B) changepoint versus added year-class;
(C) stock-recruitment pairs identified by year-classs; solid line is the changepoint model estimated; dotted lines are the changepoint models estimated by eliminating a single year-class in turn.
(D) changepoint versus year-class eliminated;

NEA Saithe (ICES I and II)

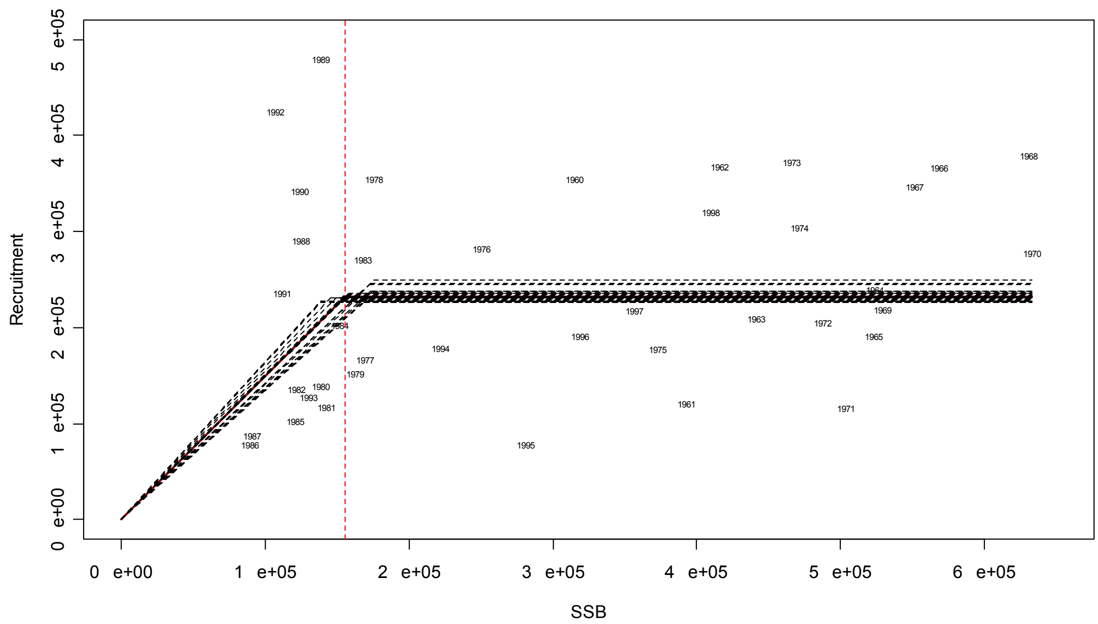
(A)



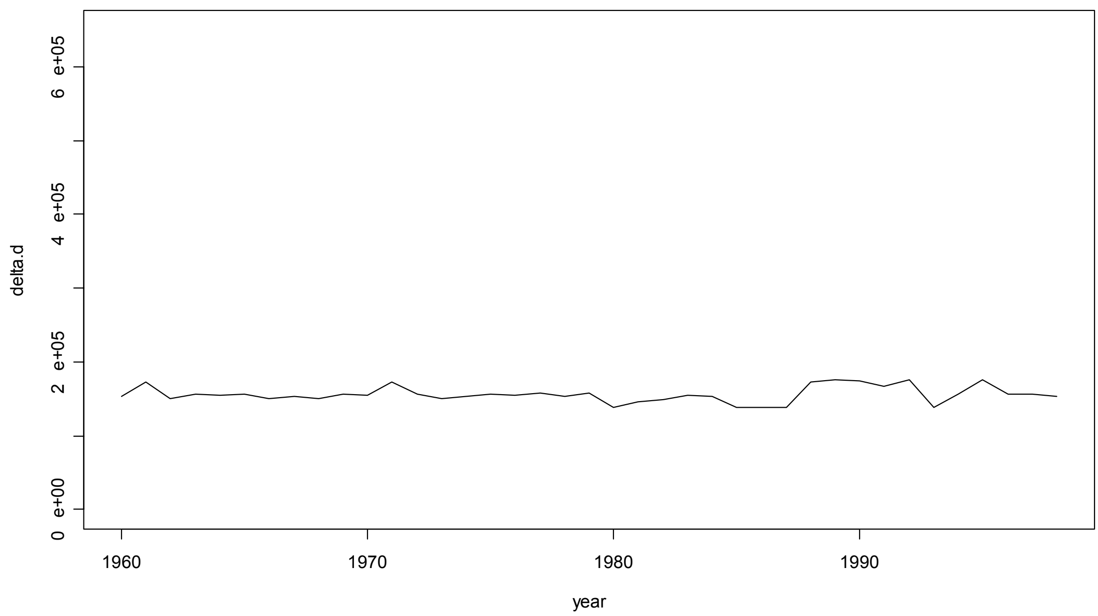
(B)



(C)

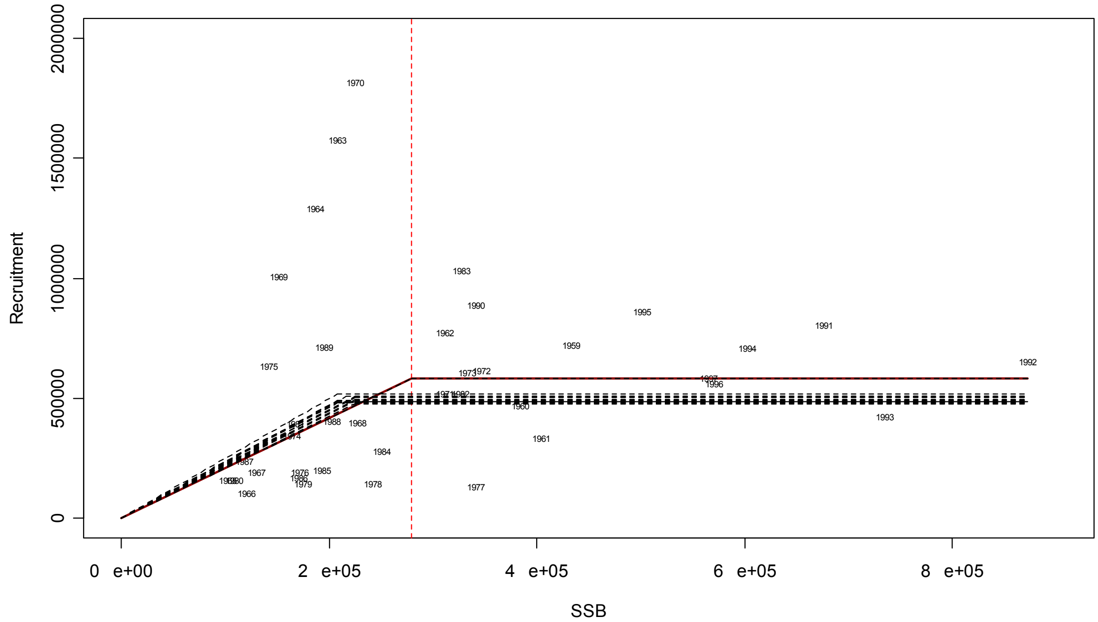

Recruitment
SSB
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
5 e+05
6 e+05

(D)

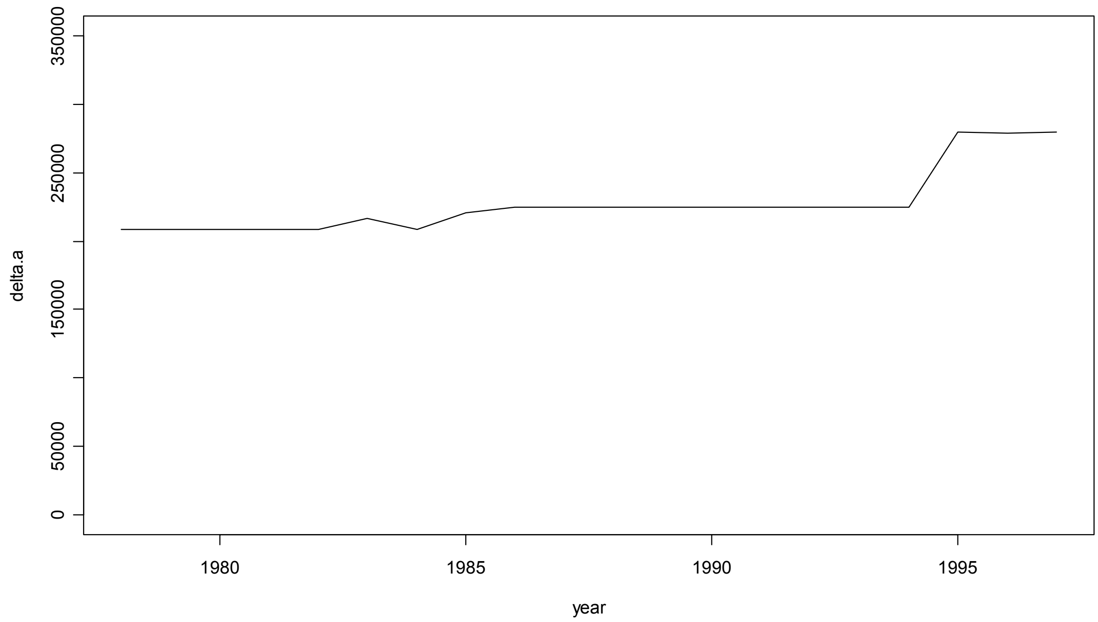

delta.d
year
0 e+00
2 e+05
4 e+05
6 e+05
1960
1970
1980
1990

NEA Cod (ICES I and II)

(A)

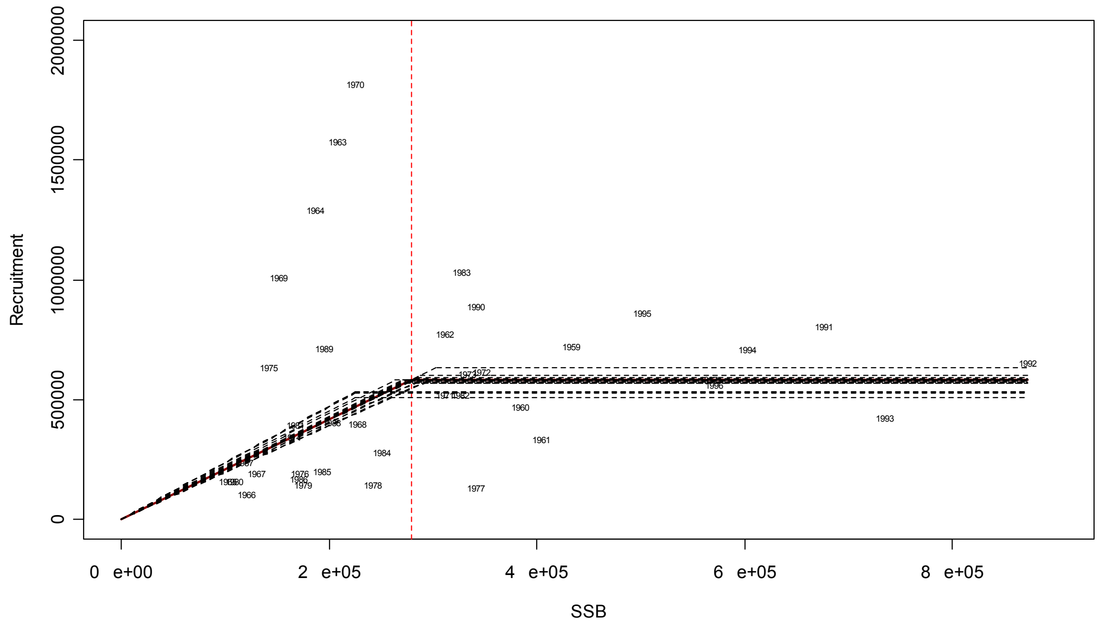


(B)



Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
224,500	273,300	278,200	272,500	282,000	304,000

(C)

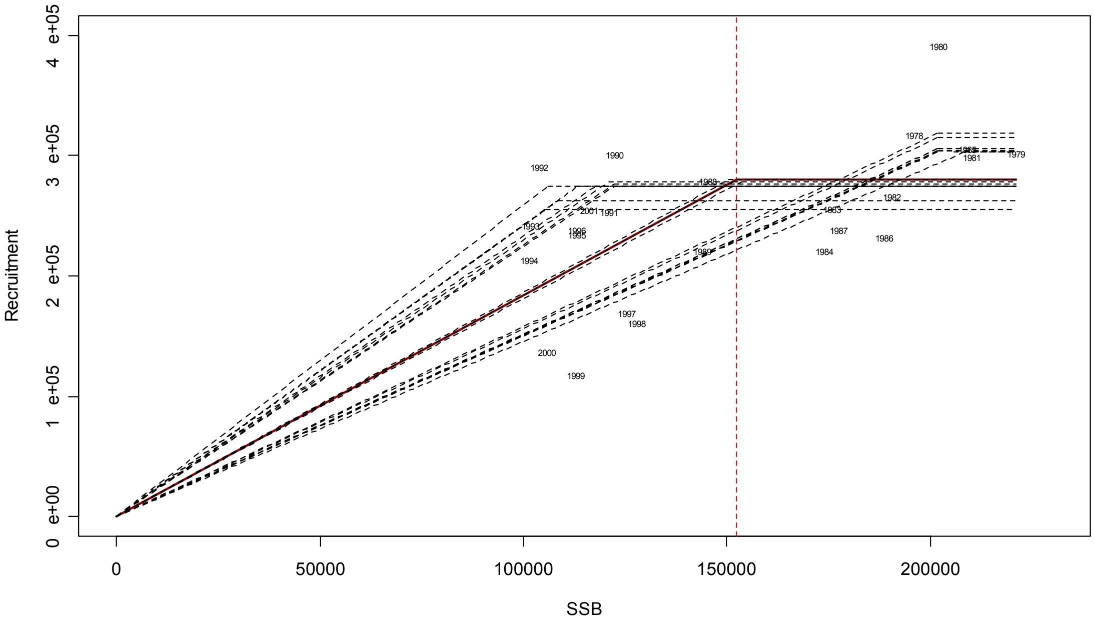


(D)

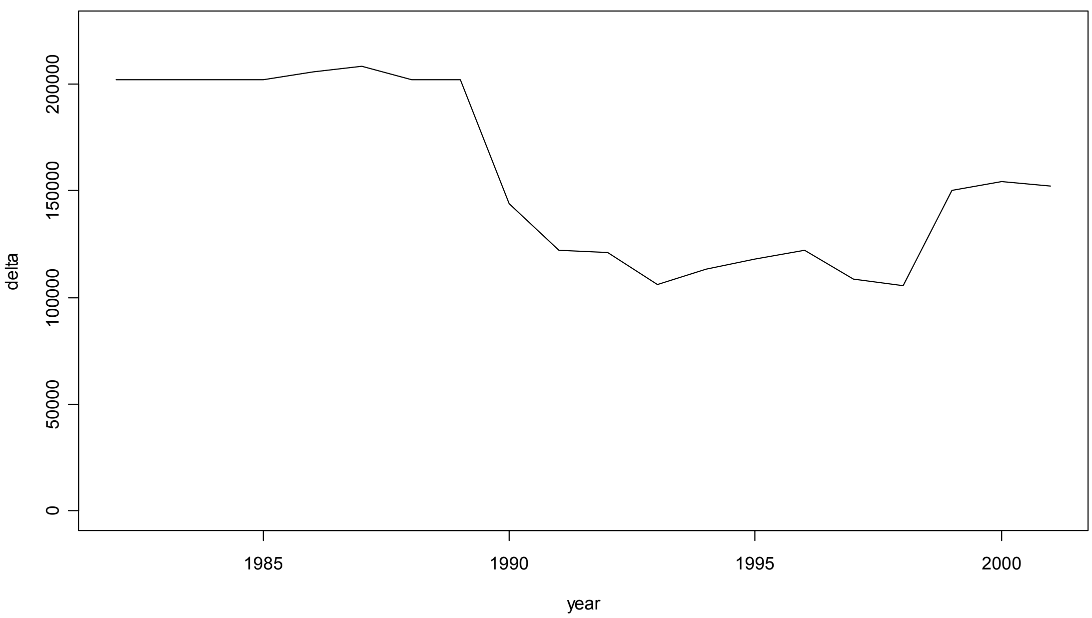
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
208,200	208,200	224,500	227,200	224,500	279,500

Northern hake

(A)

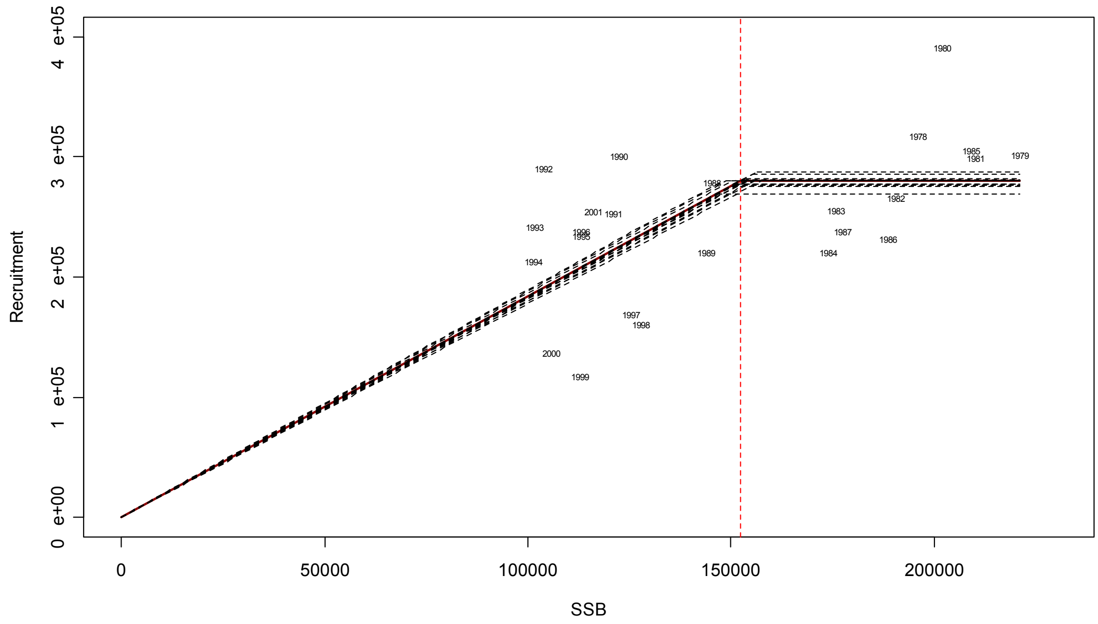


(B)



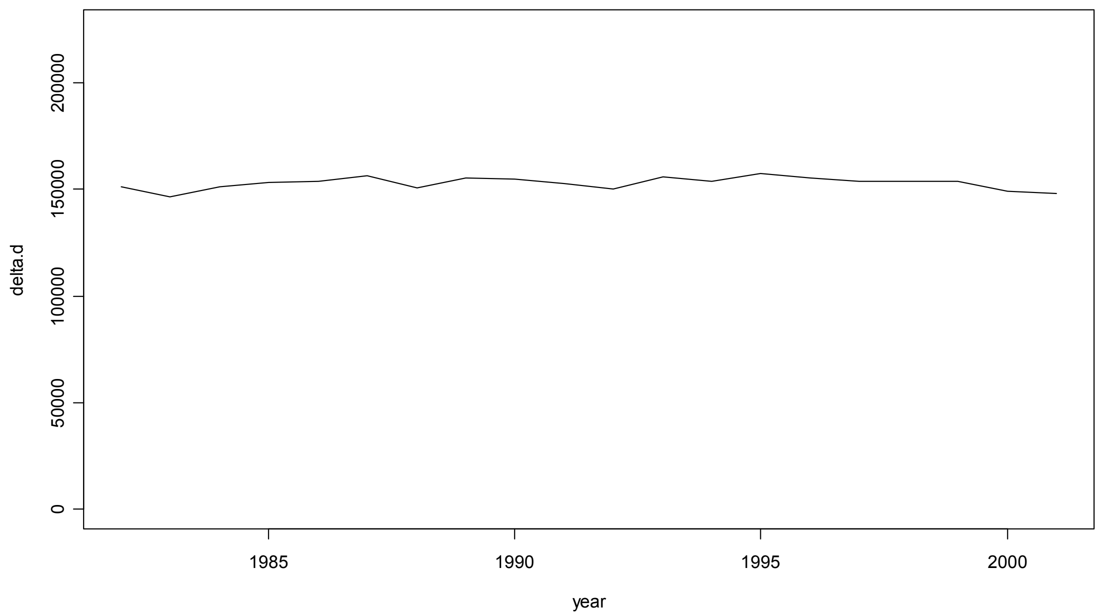
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
105600	120300	151300	157200	202000	208400

(C)



Recruitment
0 e+00
1 e+05
2 e+05
3 e+05
4 e+05
0
50000
100000
150000
200000
SSB
1980
1978
1985
1981
1979
1990
1992
1988
1982
2001
1991
1983
1993
1996
1995
1987
1986
1994
1989
1984
1997
1998
2000
1999

(D)



delta.d
0
50000
100000
150000
200000
1985
1990
1995
2000
year

Conclusions

Sensitivity of change-points to recruitment variability is clearly revealed when tracking its variation along the time series of the latest evaluation.

The analysis of sensitivity shown herein indicates that change-points estimated from segmented regression appears to be sensitive to variability in recruitment levels. Therefore, the values estimated using this method are prone to change in short time scales depending on recruitment variability. Although further analysis should be made, this feature puts problems to the use of this method. Clearly, a thorough analysis of the change point should be made before adopting it as a proxy for a biomass reference point ($\mathbf{B}_{\mathrm{lim}}$).

Acknowledgements

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Common name:	Hake
Scientific name:	Merluccius merluccius
Organisation:	ICES
Area:	Northern. Division IIIa, Sub-areas IV, VI and VII and Divisions VIIIa,b,d
Stock units:	Tonnes
Recruit units:	Thousands at age 0
First year:	1978
Last year:	2000
Assessment model:	XSA
Source:	ICES. 2002. Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks. ICES CM 2002/ACFM:05.
This file created:	D.Maxwell. 28/02/02.
Reference files:	Fishm$ on 'LOWNTH' :\ACFM\Acfm_final_2001\3.12\hke-nrth.pdf Fishm$ on 'LOWNTH' :\Soshwg\WGSSDS_2001\s5 Northern Hake.pdf

Precautionary Approach reference points (established in 1998)
source: ICES CM 2002/ACFM:05.

ICES considers that:	ICES proposes that:
$\mathbf{B}_{lim}$ is 120 000 t, the lowest observed biomass in the 1998 assessment.	$\mathbf{B}_{pa}$ be set at 165 000 t. Biomass above this affords a high probability of maintaining SSB above $\mathbf{B}_{lim}$, taking into account the uncertainty in assessments.
$\mathbf{F}_{lim}$ is 0.28, the fishing mortality above which stock dynamics are unknown.	$\mathbf{F}_{pa}$ be set at 0.20. This F is considered to have a high probability of avoiding $\mathbf{F}_{lim}$ and a 50% probability of maintaining SSB above $\mathbf{B}_{pa}$ in the next 10 years, taking into account the uncertainty in assessments.

Technical basis:

$\mathbf{B}_{lim} = \mathbf{B}_{loss}$	$\mathbf{B}_{pa} \sim \mathbf{B}_{lim}$ x 1.4
$\mathbf{F}_{lim} = \mathbf{F}_{loss}$	$\mathbf{F}_{pa} \sim \mathbf{F}_{lim}$ x 0.72, implies a less than 10% probability that ($\mathbf{SS}_{BMT} < \mathbf{B}_{pa}$).

Working Group recruitment modelling

Formulation	Ricker parametric model: $R_y = \alpha S_y \exp(-\beta S_y)$.
Estimation method	RECRUIT
Assumed error structure	Lognormal
Parameter estimates	For SSB in 000t and recruits in millions, α = 2.6596 (se 0.647); β = 0.0025 (se 0.0016)

<u>Panel A</u>

Working Group estimates of spawning-stock biomass (SSB) and recruitment at age 0 for Northern Hake. Source: ICES CM 2002/ACFM:05.

Year-class	Parental SSB (tonnes)	Recruitment (thousands)	Year-class	Parental SSB (tonnes)	Recruitment (thousands)
1978	188560	320545	1990	114935	348064
1979	211029	308935	1991	114561	281857
1980	190956	412843	1992	102411	308579
1981	196352	311002	1993	104828	291241
1982	170563	278806	1994	104342	218355
1983	161361	265870	1995	114214	247194
1984	159169	229743	1996	110536	254179
1985	186782	432966	1997	127192	170051
1986	167186	252835	1998	129045	149923
1987	160715	257781	1999	109303	131359
1988	139277	326059	2000	103394	164227
1989	137965	227306			

Changepoint Regression Results

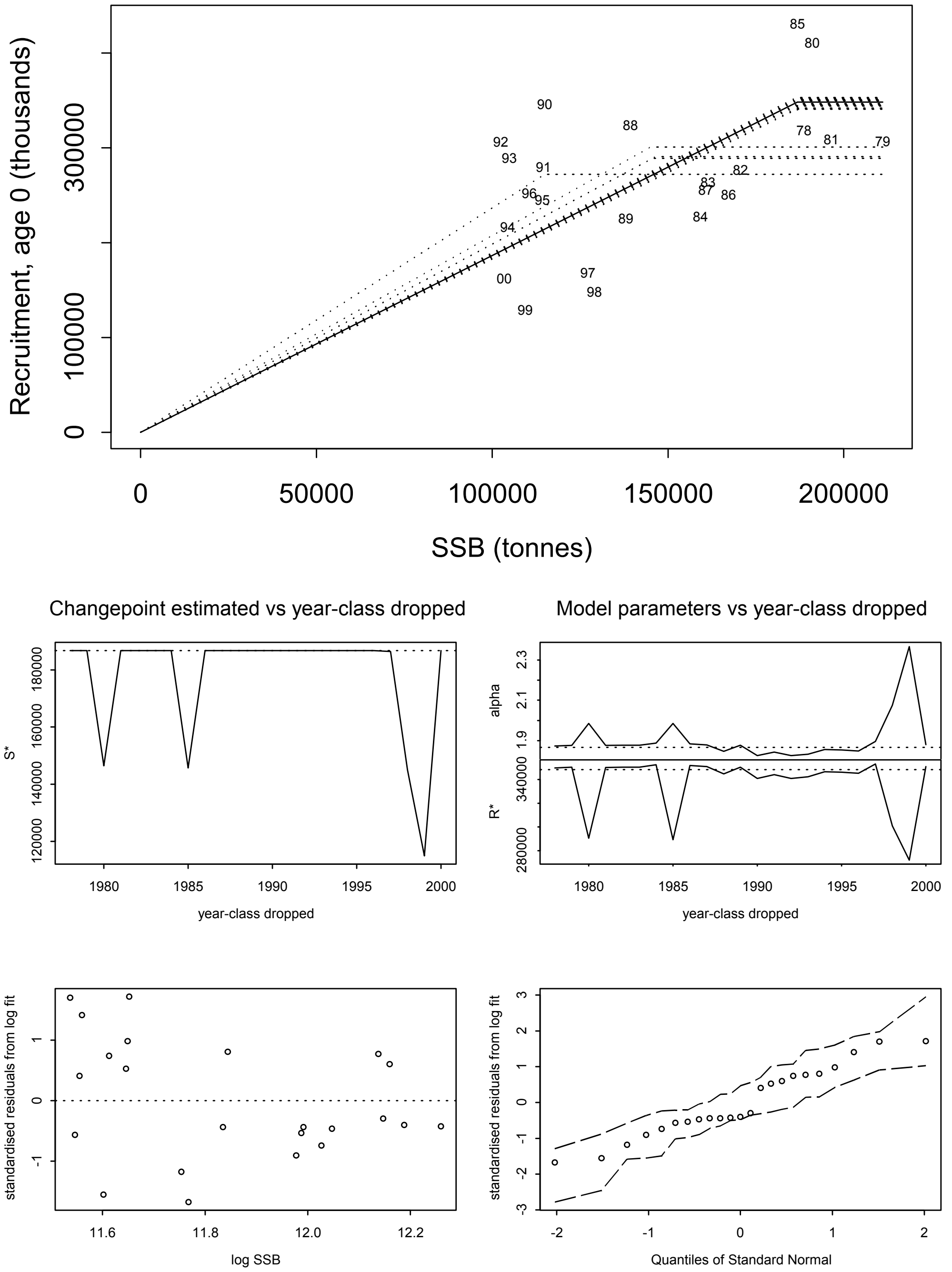
Northern Hake

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
186782	1.866	348485		136393	186767	not defined

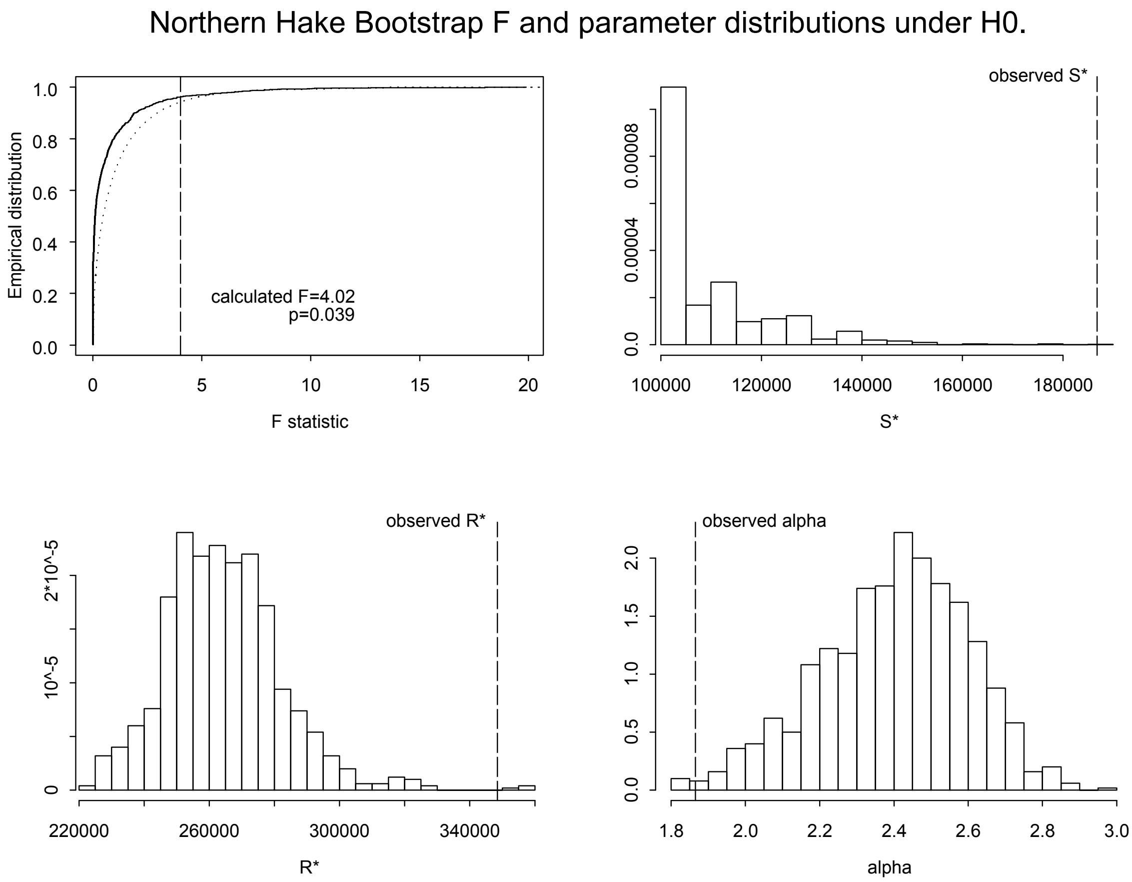
Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap**
mean	22	2.00				**p-value**
changepoint	21	1.68	1	0.321	4.02	0.039

Panel B

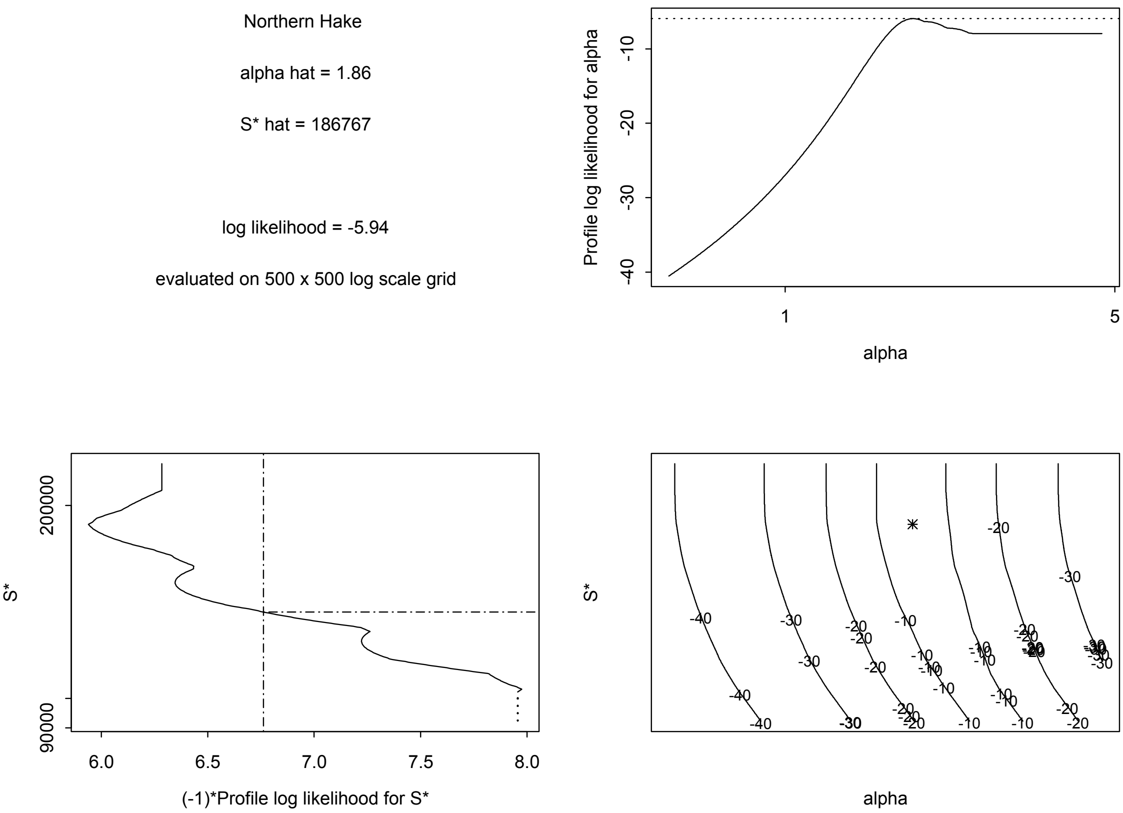
Northern Hake



Panel C

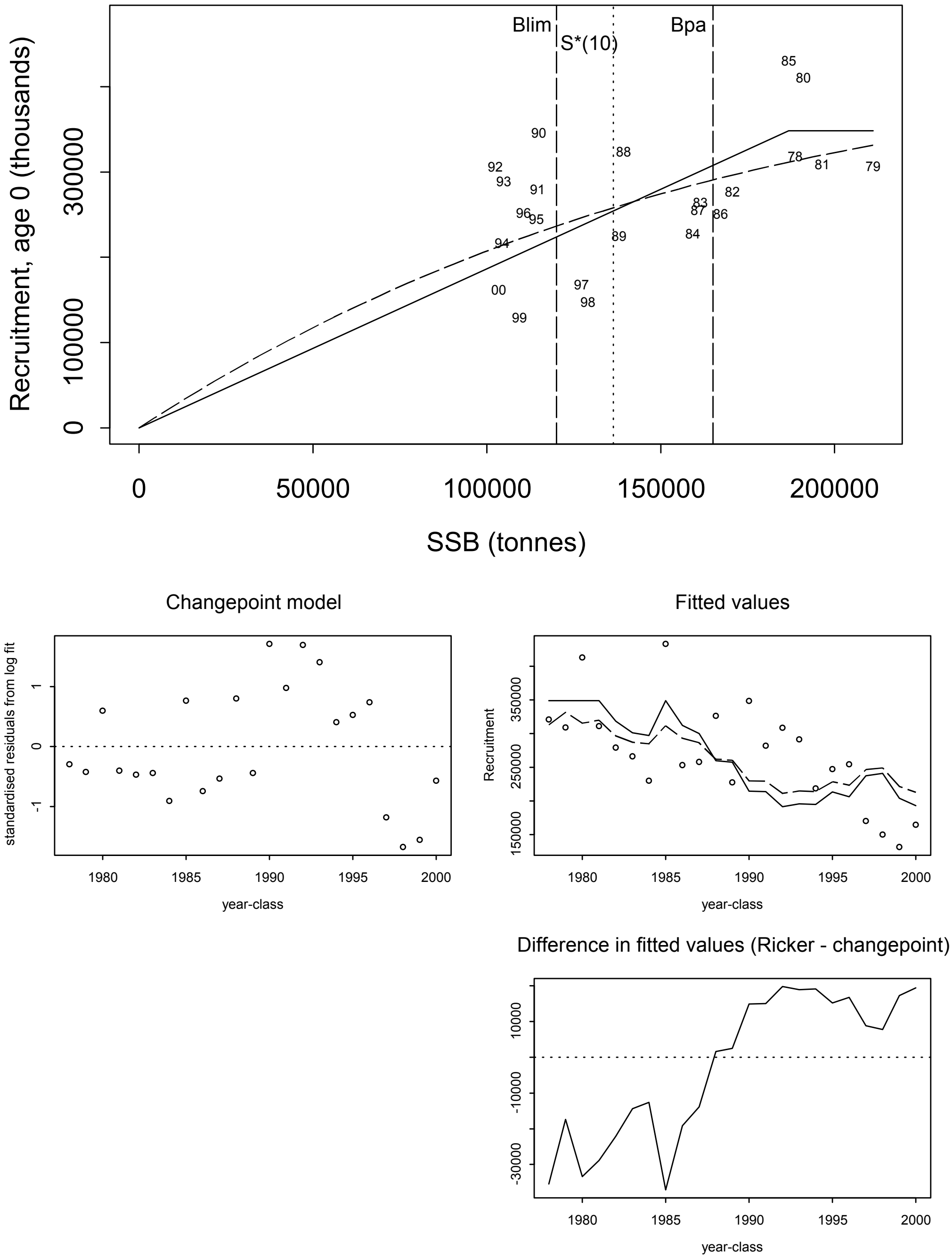

Northern Hake Bootstrap F and parameter distributions under H0.
Empirical distribution
1.0
0.8
0.6
0.4
0.2
0.0
calculated F=4.02
p=0.039
0
5
10
15
20
F statistic
observed S*
0.0
0.00004
0.00008
100000
120000
140000
160000
180000
S*
observed R*
0
10^-5
2*10^-5
220000
260000
300000
340000
R*
observed alpha
0.0
0.5
1.0
1.5
2.0
1.8
2.0
2.2
2.4
2.6
2.8
3.0
alpha

Panel D


Northern Hake
alpha hat = 1.86
S* hat = 186767
log likelihood = -5.94
evaluated on 500 x 500 log scale grid
Profile log likelihood for alpha
alpha
S*
(-1)*Profile log likelihood for S*
S*
alpha

Panel E

Northern Hake



Panel F

ANNEX 6

Working Document 6
More on the use of relative versus absolute PA reference points question.

by

Enrique de Cárdenas[1], Carmela Porteiro[2] and José Castro[3]

Working Paper for the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management; 2-6 December 2002; ICES, Copenhagen

Introduction

When PA biomass points are defined, for stocks in which analytical assessment is possible, last assessment is used to choose possible reference points. Currently, ICES fix these reference points in absolute values of SSB.

Every new assessment re-estimates the full series of abundance, then estimations of SSB could change respect to the assessment which was used as a base to obtain the reference points.

The October ACFM report shows 15 stocks where $\mathbf{B}_{loss}$ was used for set $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$, and the new values of SSB estimated in the last assessment by ICES WG and endorsed by ACFM are different to those estimated by the analysis used to choose the PA points.

Methodology and Results

Data and plots used in this document are included in ICES ACFM Report October 1998; 1999;2002 and ICES WGHMM Report, 2002.

Seven of these stocks show higher values of SSB in the last assessment (Case 1). The differences between the $\mathbf{B}_{loss}$ value between the two series, considering the same time period, fluctuated between 50% (Rockall haddock) and 5% (sole in VIIa) being about 19% on average. These stocks were the following: North Sea and Rockall haddock, VIIa and VIIe sole, North Sea sandeel, North Sea saithe, Cod in VIIe-k and anchovy in VIII. To Illustrate this problem, both SSB trends in 1999 (used to choose reference points) and 2002 assessments for Rockall haddock are represented (Fig.1).

The eight remaining stocks show the opposite effect: the new estimations of SSB in the time series are lower than that used to choose PA points (Case 2). In these cases the differences vary from a 42% in the case of Southern hake to a 6% in the case of white anglerfish in VII and VIII, been these differences about 21% on average. To illustrate this problem, both SSB trends in 1998 (used to choose reference points) and 2002 assessments for North Sea plaice are represented (Fig.2).

These changes in the estimations are apparent in stocks in which revisions in the database (catch matrix, maturity ogives, mean weight, etc.) occur. In this case the reference points should be recalculate after an important revision of the database for the stock and this would solve the problem.

However, these aforementioned changes are also present in stocks in which, because of problems in ageing old fishes, the plus group is defined at very early ages. As a result a large proportion of the spawning stock occurs in the plus group. In this case SSB estimations are more sensible to Fold, since reaching convergence will need a longer matrix. Thus, the estimations of SSB are rather sensible to the tuning process and small

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change (changes in F-shrinkage or inclusion of a particular fleet) could produce important effects, as Darby pointed out in last meeting (SGPA 2002a) for the case of Northern hake (see Fig. 3).

Nevertheless these problems do not affect (at least at the same level) the estimation of the recruitment since there are enough fishing mortality accumulated to reach convergence. To illustrate this point, similar figures for recruitment and for the same stocks are shown (Fig. 4 and 5).

Discussion

We may conclude that not only $\mathbf{B}_{loss}$ could be affected by this problem, but any other biomass PA points (like MBAL) selected with methods based on SSB-R relationships, both by visual examination of stock-recruit plots and by statistical objective fitting (segmented regression in the change point) (Fig. 6 and 7).

The use of absolute values for biomass PA points could lead us to problems in the formulation of advice. If we are in a case 2, our advice should be cautionary as the biomass PA points are estimated higher than they were actually. In contrast if we are in case 1 the stock could be in a risk situation not detected.

As it was noted in last SGPA meeting (ICES, 2002), a possible solution is to refer the biomass reference points to levels of biomass of a specific period. This period could be that in which $\mathbf{B}_{loss}$ is detected, or that in which the level of SSB is similar to MBAL, or also a particular value of SSB that we consider adequate to fix $\mathbf{B}_{lim}$ or $\mathbf{B}_{pa}$.

This solves the problem that we face now with several stocks, where if the criteria applied in the last assessment is the same than that used when PA points were chosen, these PA points are susceptible to change.

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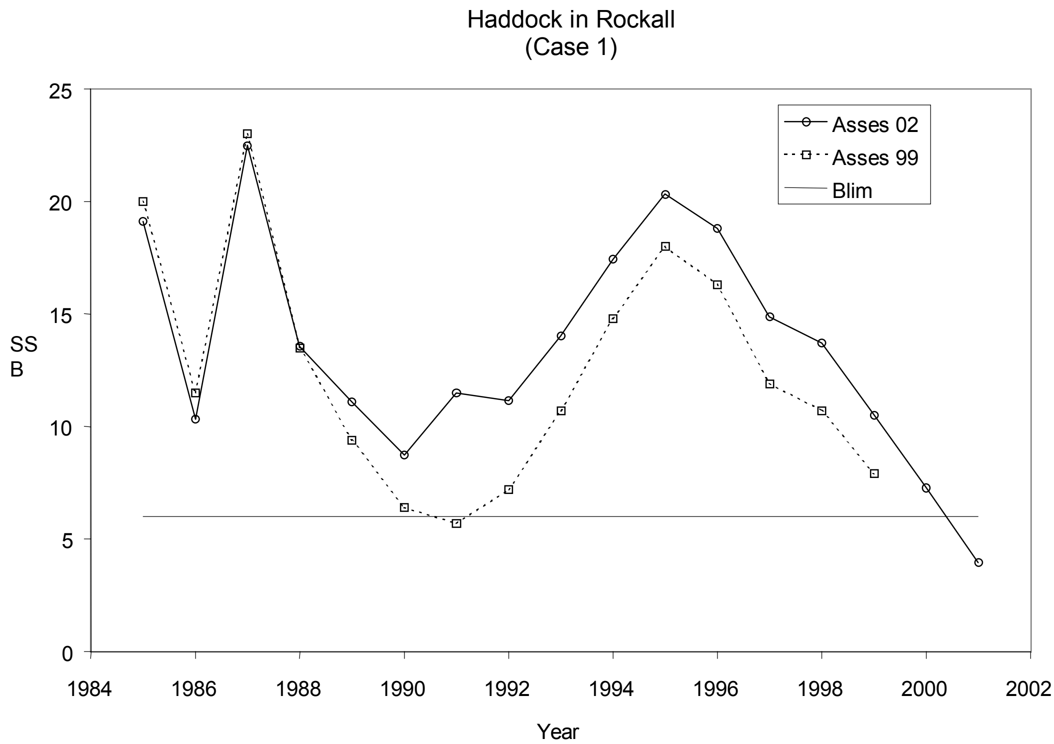

Fig. 1 *.- Estimated values for SSB in 1999 (dotted line) and in 2002 (solid line) VPAs, Rockall Haddock (ICES ACFM reports 1999; 2002).*

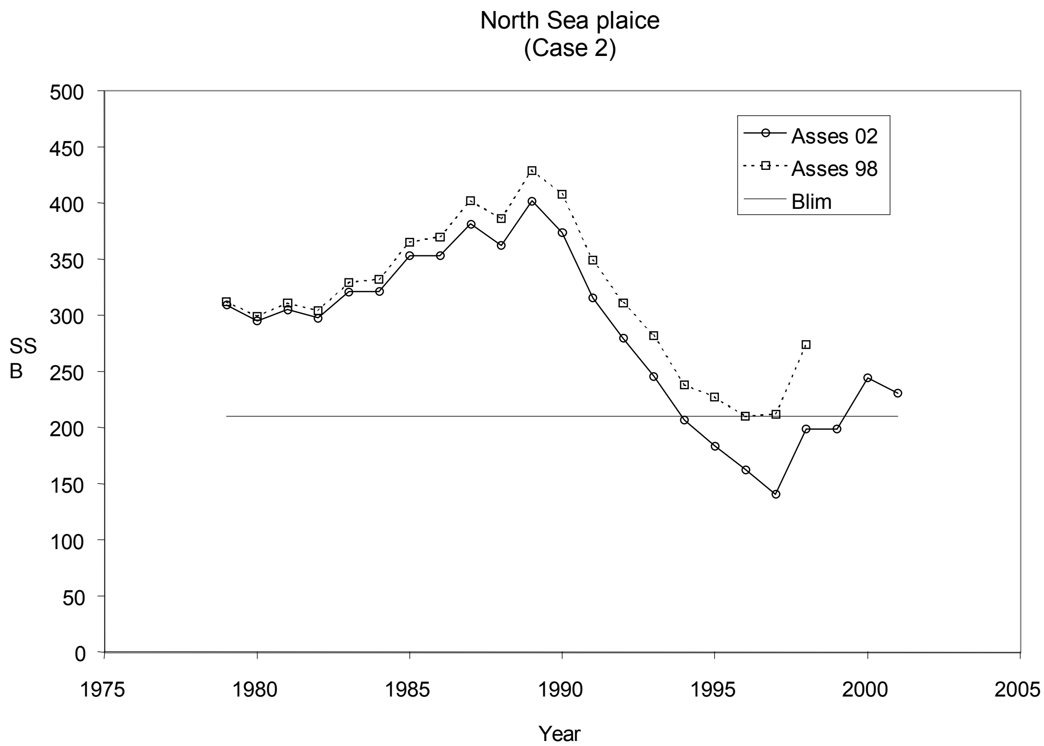

Fig. 2 *.- Estimated values for SSB in 1998 (dotted line) and in 2002 (solid line) VPAs North Sea plaice (ICES ACFM reports 1998; 2002).*

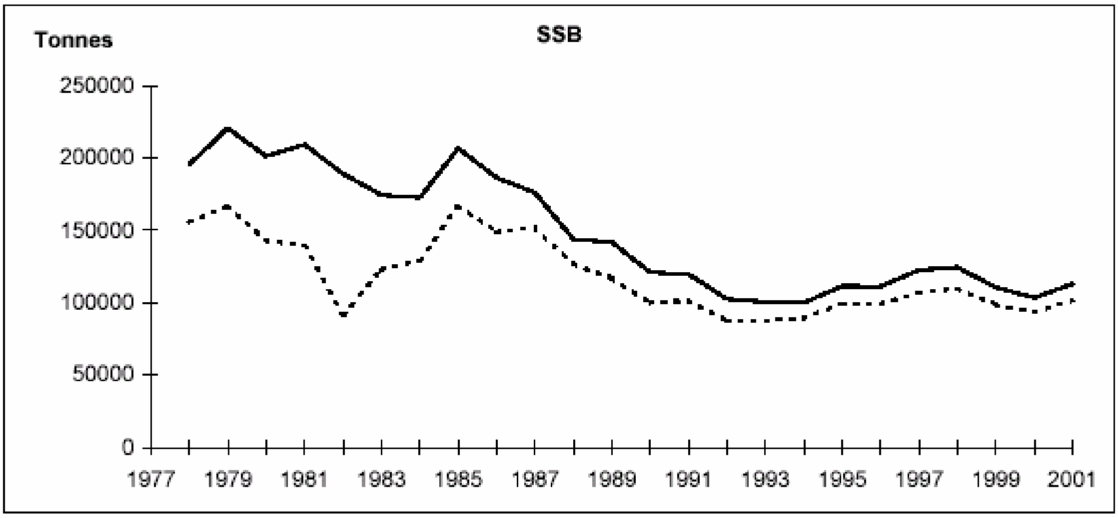

Fig.3.- *Northern hake assessment, with the same tuning ranges and XSA settings apart from the F-shrinkage period (the standard error of 1.0 for F-shrinkage was retained throughout the tuned period 1982-2002). Solid line: WG standard run. Dotted line: Year and Age shrinkage OFF (ICES WGHMM Report,2002).*

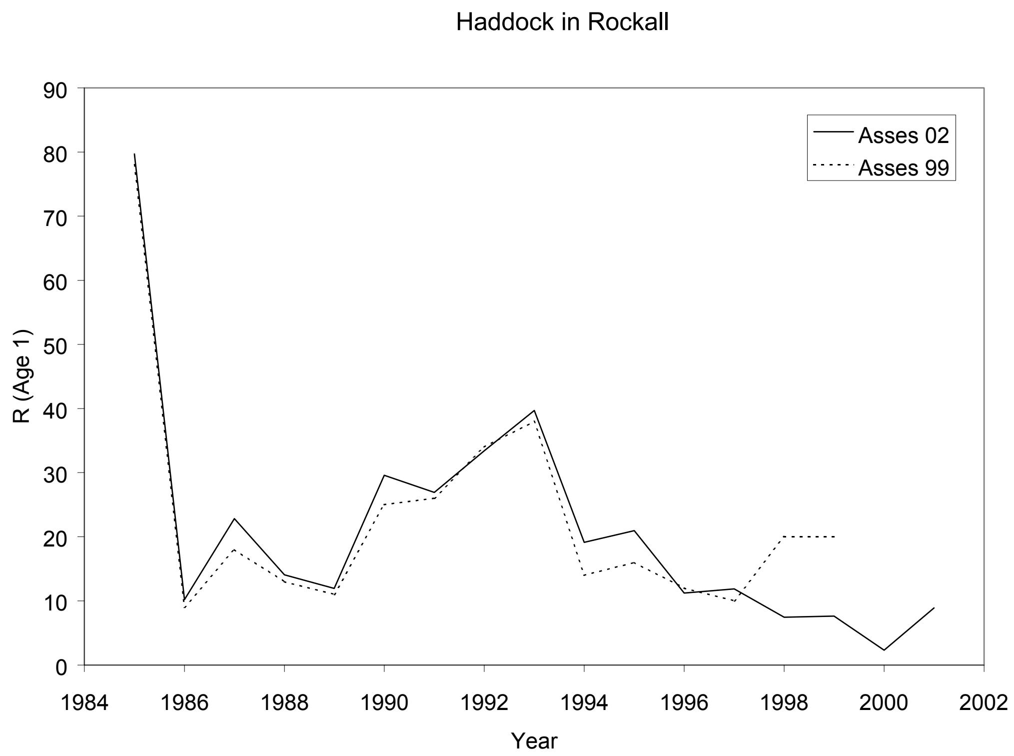

Fig. 4 *.- Estimated values for R, in 1999 (dotted line) and in 2002 (solid line) VPAs, Rockall Haddock (ICES ACFM reports 1999; 2002).*

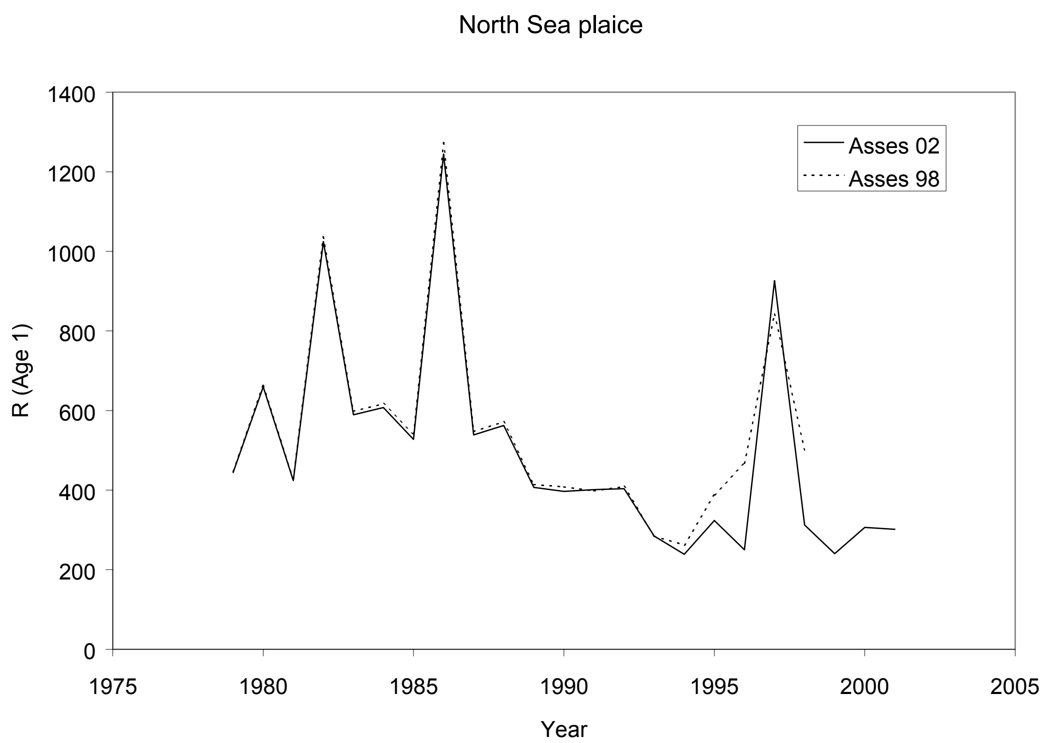

Fig. 5 *.- Estimated values for SSB in 1998 (dotted line) and in 2002 (solid line) VPAs North Sea plaice (ICES ACFM reports 1998; 2002).*

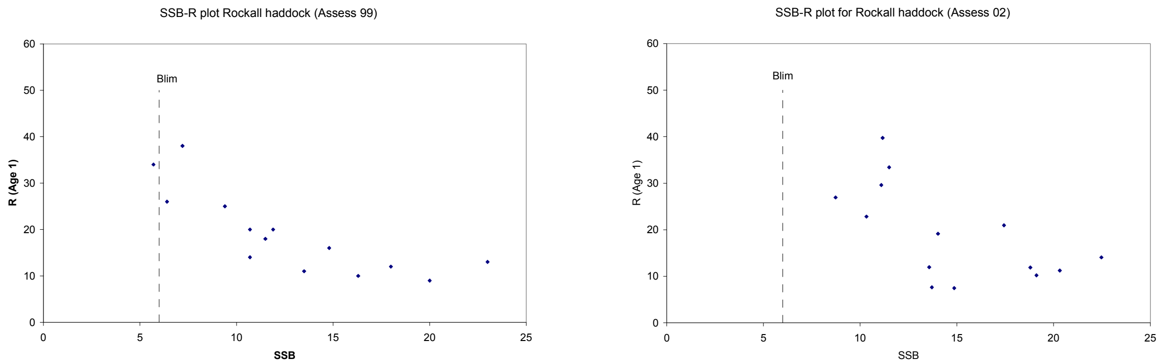

Fig. 6 *.- Stock-Recruitment plot for Rockall haddock, in 1999 and 2002 (ICES ACFM reports 1999; 2002).*

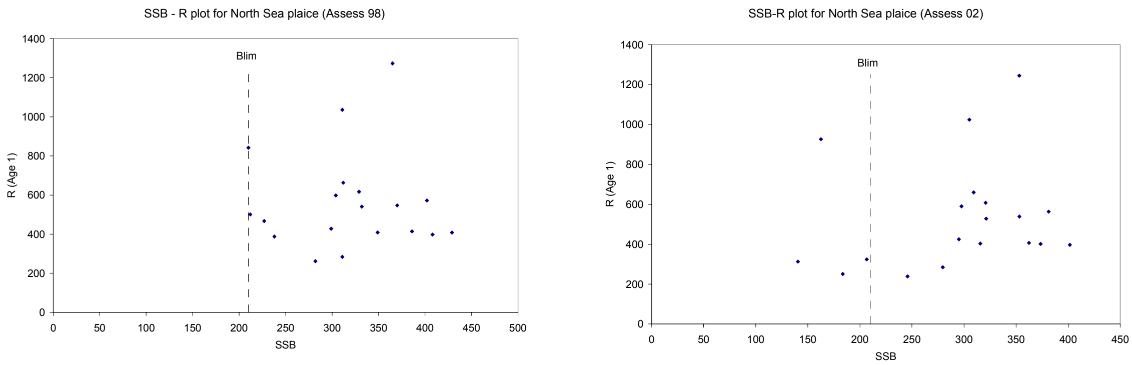

Fig. 7 *.- Stock-Recruitment plot for North Sea plaice, in 1999 and 2002 (ICES ACFM reports 1999; 2002).*

ANNEX 7

Evaluating precautionary values of fishing mortalities using long term stochastic equilibrium distributions.

Working Document 7: ICES SGPA, December 2002

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Introduction

The current ICES system of precautionary reference points considers reference points both for biomass and for fishing mortalities. For many stocks, F-reference points have been derived according to the deterministic equilibrium at a reference biomass, either F lim ~$\mathbf{F}_{loss}$ or $\mathbf{F}_{lim}$ ~$\mathbf{F}_{med}$. The first corresponds to an equilibrium at the lowest observed biomass, the other at somewhere near the historical median SSB. The replacement line at $\mathbf{F}_{crash}$, corresponding to an equilibrium at SSB=0, was discussed when the present reference points were decided, but has been used only exceptionally as $\mathbf{F}_{lim}$. Exploitation at $\mathbf{F}_{lim}$ as derived this way should give approximately 50% probability that the stock is below the reference value in the long run.

The $\mathbf{F}_{pa}$ is then set to give a safety margin for $\mathbf{F}_{lim}$, i.e. taking assessment uncertainty into account, the probability that the true F is at $\mathbf{F}_{lim}$ shall be small when the estimated F is at $\mathbf{F}_{pa}$. Likewise, $\mathbf{B}_{pa}$ is set to give a safety margin to $\mathbf{B}_{lim}$.

In practise, depending on the safety margins on F and SSB, defining F reference point this way implies that one will quite often experience that the stock is below $\mathbf{B}_{pa}$, i.e. 'outside safe limits' when the recommended $\mathbf{F}_{pa}$ is applied. In our view, such an advise is not good, neither for the rational exploitation of the stock, nor for the credibility of ICES.

We argue that in order to be precautionary, the recommended fishing mortality should ensure that:

- the management regime is risk adverse, in the sense that the probability of bringing the SSB to unacceptably low levels should be low.
- within the limitations set by the need to keep the risk low, the stock is harvested at a rate which gives a near maximal long term yield.

As a minimum requirement, one should control that the recommended $\mathbf{F}_{pa}$ implies a low probability of leading the SSB below $\mathbf{B}_{pa}$. To do so, the long term distribution of SSB at given values of realised F could be a useful tool.

The 'standard' reference points ($\mathbf{F}_{0.1}$, $\mathbf{F}_{med}$ etc.) only indirectly address these objectives. Thus, $\mathbf{F}_{0.1}$ represents a 'light' exploitation with only a moderate cost in terms of loss of long term yield. $\mathbf{F}_{med}$ was intended to prevent recruitment over-fishing, by ensuring that the recruitment is able to maintain SSB at historical levels. However, although it usually will imply a safe level of SSB, $\mathbf{F}_{0.1}$ does not account for the relation between stock and recruitment. Thus, if some SSB limit is set based on stock-recruit considerations, the risk of reaching this limit by applying $\mathbf{F}_{0.1}$ has to be evaluated separately. $\mathbf{F}_{med}$ was introduced to ensure a balance between SSB and recruitment, but this will be at historical levels and does not include considerations of the productivity of the stock.

In this Working Document, we discuss some technical and theoretical aspects of long term equilibrium distributions, and attempt to list some quality criteria or the stochastic terms that generate such distributions. In particular, we address problems with getting the distribution of the recruitment as a function of SSB in accordance with the historical experience.

Long term equilibrium distributions

The stochastic analogue to a deterministic equilibrium point is an equilibrium between stationary distributions. To each level of SSB there is – presumably – a distribution of recruitments, and to each recruitment level there is a distribution of SSBs. The distribution of SSB will generate a distribution of recruitments, and the distribution of recruitments will generate a distribution of SSBs. At the equilibrium, these distributions are stationary – the SSB distribution generates, through the recruitment distribution, an identical distribution of SSBs.

The variation in SSB at a given mortality is generated by variation in the recruitment, weight at age and maturity at age. Mathematically, the SSB is a weighted sum of previous recruitments, where the weighting is the weight at age, maturity at age and the reduction of the year class at each age due to mortality:

$$\text{SSB(year)} = \Sigma_{\text{ages}}\ \text{R(year-age)*W(age)*Prop.mature(age) * exp\{-Cumulated mortality(age)\}}$$

The distribution of SSB is the distribution of the product of the three stochastic terms R, W and Prop.mature, while the term due to mortality can be regarded as deterministic in this context. That means that we evaluate the risk associated with a certain true fishing mortality, assuming that the natural mortality is constant.

This approach differs somewhat from that used previously by the SGPA (ICES 1998, see also Cook 1998). This approach was to consider the replacement line at some critical point (e.g. at the lowest observed biomass) and the uncertainty of the estimate of the slope of the replacement line. Taking that uncertainty into account, a safety margin was obtained to the estimated slope, and that safety margin was included when deriving the recommended value of F from the slope of the replacement line.

The present approach is rather to consider the variation in SSB induced by the natural variations one has experienced historically in recruitment, growth and maturation. Underlying this approach is the view that the uncertainty in the stock-recruit data (except for the most recent years) is minor compared to the natural variation in the recruitment. Thus, we take the estimated variance of the residuals around the stock-recruit curve as an expression of natural variations, and keep that separate from assessment uncertainty. We then attempt to make sure that the ensuing residuals have the statistical properties that are assumed when generating random numbers in a stochastic prediction.

In the advisory process, there is in addition a need to account for discrepancies between intended fishing mortality and the realised fishing mortality. This is by definition the safety margin between $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$. Such considerations can be kept separate from the evaluation of the SSB at a given, realised fishing mortality.

Computation tools

There are several ways of finding the equilibrium distributions. One possibility is to run a stochastic projection with fixed fishing mortality very far into the future, until all effects of the initial stock abundance have subsided. Several medium term prediction programs have the option to do this. Alternatively, one may search iteratively for the equilibrium distributions, as it is done in the LTEQ software. The choice of software is mostly a practical question, although one should have a critical look at the criteria for equilibrium.

The stochastic elements that go into the calculation are the distribution assumed for recruitment at a given SSB, and the distributions of weight at age and maturity at age. In addition, natural mortality and selection at age are needed, usually as deterministic inputs.

The recruitment distribution is probably the most important in most cases, but the others should not be overlooked. The problem has two aspects, one is to get the distributions right in the first place, the other is to find software that allows for the kinds of distributions that are assumed. Some medium term prediction programs assume constant weights and maturities. This can be expected to lead to a too narrow distribution of the SSB, and thus underestimation of the risk associated with high fishing mortalities. Likewise, many programs assume that the recruitment variation is log-normal. Sometimes, other distributions may be more adequate.

Below, we discuss some quality criteria for each of these elements, illustrated with examples from some deliberately un-named stocks.

Stock recruitment function.

When drawing recruitments in a bootstrap routine, some relation of the following kind is applied:

$$R^* = R_0^*(SSB) + \varepsilon$$

where R^* can be the recruitment itself or a transform (very often the natural logarithm) of the recruitment, R_0 is the value of a deterministic stock-recruit function and ε is a random number drawn according to some parametric distribution (most commonly the normal distribution), or drawn randomly from the pool of historic residuals.

The most common relation probably is

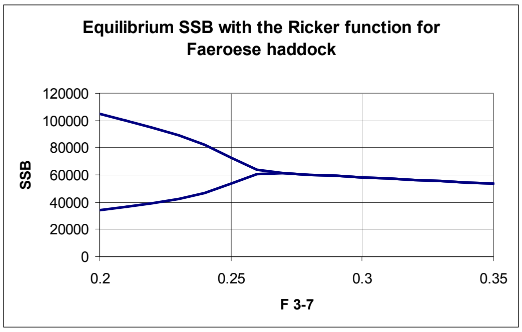
$$\log\{R\} = \log\{R_0(SSB)\} + \varepsilon$$

where ε is a normally distributed random number with mean = 0 and a given variance parameter σ.

The stock-recruit function R_0(SSB) should not be chosen *a priori*. Rather, one should search for a stock-recruit function that renders residuals with the right statistical properties, and just accept that no stock recruit function will be predictive in the sense that it can be extrapolated beyond the range of historical SSBs.

Some points on specific functions.

Functions (e.g. the Ricker function) that have a maximum at a finite SSB may be fully adequate if the recruitment really is reduced at high SSBs, but may also be misleading because they tend to place the maximum within the range where there are observations. If the stock has been consistently overexploited, this kind of function may suggest – for purely mathematical reasons - that the current exploitation is the one giving the best recruitment. Another problem is that the predicted recruitment at low SSB can be heavily influenced by data at high SSB, because the shape of the curve in both regions is determined by the same parameter. The third problem is that for SSB-R values corresponding to the right, downslope part of the function, the critical point is unstable. A high SSB will generate a low recruitment, which gives a low SSB. That low SSB in turn generates a higher recruitment, which gives the high SSB again. The Figure 1 below illustrates this for the Faeroese haddock (cfr. the worked examples below)



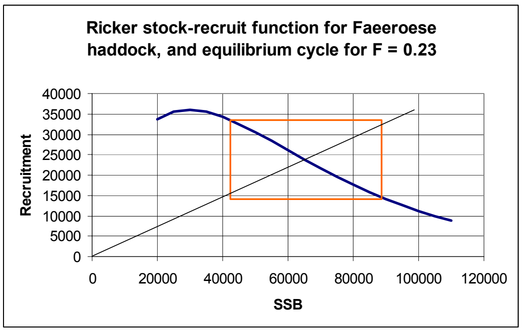


Figure 1.

In cases where there is no obvious trend in the recruitment, the 'Ockhams razor' is sometimes used as a conservative relation. Here, the recruitment is independent of SSB above some break-point, and declines linearly towards the origin at lower SSBs. This implies that F-values above the replacement line at the break-point will lead to extinction of the stock in the long term. With some recruitment variation included, the equilibrium distribution near the break-point will become strange. If the point is to evaluate risks near the break point, and the break point is the lowest observed SSB, it may be useful to use a somewhat lower break-point. If so, one should resist the temptation to draw conclusions about the behaviour of the stock at lower SSBs.

If there are no data to indicate the level of recruitment at high SSB, several of these functions, including the Beverton-Holt function will easily become an almost straight line through the origin. Around a fishing mortality corresponding to the slope of that line, the dynamics will change abruptly, and at lower fishing mortality, the equilibrium is very poorly defined.

Other stock-recruitment relations should be considered if the standard ones fail the quality tests outlined below. This also includes smoothers and kernel methods.

Quality criteria for stochastic stock-recruit functions

The usefulness of stochastic prediction models for evaluating both risks and outcome of future management actions depends critically on the assumptions about the statistical properties of the stochastic variables that go into the calculations. Both medium and long- term predictions have to some extent been discredited because the reality has been far outside the predicted range (Kens concerted action). Our view is that these problems to a large extent can be overcome by a critical control of the stochastic elements and their distributions. For the stock-recruit function, we suggest 3 criteria:

1. Independence between residuals and SSB
2. The probability coverage.
3. The recruitment estimates should be unbiased

1: The residuals around the stock-recruit function should be independent of the SSB

If the stock-recruit function is such that the residuals are dependent on the SSB, the recruitments will get a wrong distribution. For example, if most of the historic recruitments at low SSBs are negative, and residuals are drawn randomly independent of the SSB, the recruitments drawn at low SSBs will generally be higher than indicated by the historical experience. Then, apparently, bringing SSB down to that low level will not lead to impaired recruitment the way it has been seen in the past.

A necessary, but not sufficient condition for independence is that the correlation between the historic residuals and the SSB is 0. The correlation coefficient should be checked, and if it is far from 0, one should hesitate to use that stock-recruit function.

A further check is to fit a second order polynoma to the residuals. This curve should also be relatively flat. Figure 2 shows this for a rather well behaved stock-recruit function.

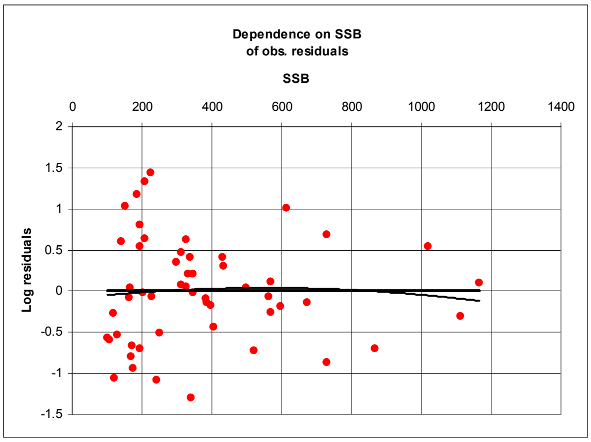


Figure 2. Residuals with linear and 2nd order trendlines. The correlation was forced to be 0

It may be considered to require that the correlation shall be 0 as a constraint when finding the parameters of the stock-recruit function. From a statistical point of view, this may not be quite good practise. A justification for doing so is that the parameters in a stock-recruit function will usually be quite correlated. Thus, this constraint may cost very little in terms of worsening the likelihood.

The figure 3 below illustrates this point. For the same stock as above, the Beverton- Holt parameter *b* (in the equation *R*=*a**SSB/[*b*+SSB]) was estimated for a range of values of the *a*-parameter, by minimising the sum of squares of the residuals. Above approximately *a*=650 000 almost equally good values of SSQ could be obtained by adjusting the *b*-parameter. Over this range, the correlation between SSB and residuals varies considerably, and the SSQ where the correlation is 0 is very similar to the minimum value. In such a case it should be acceptable to use zero correlation as a constraint.

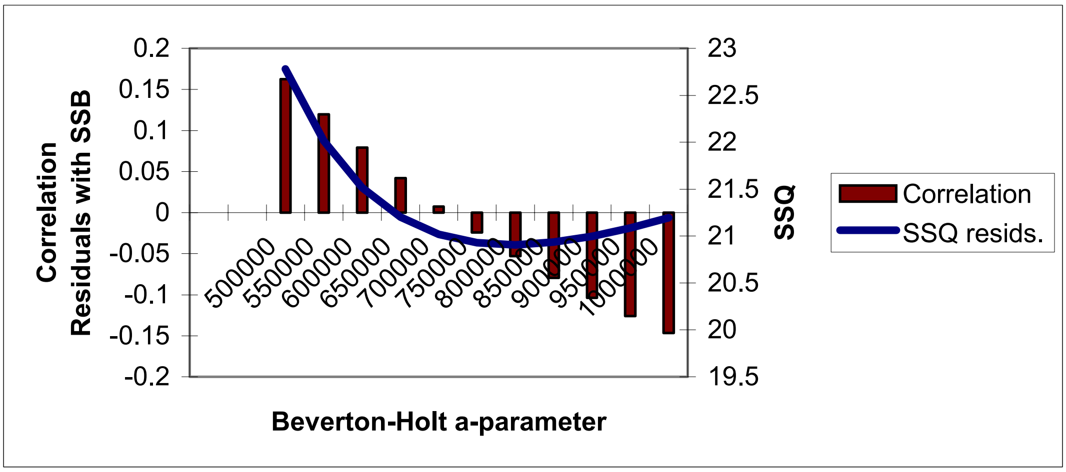


Figure 3. Correlation and likelihood profile.

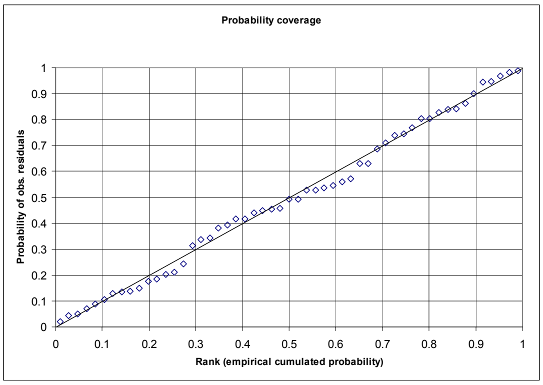
In cases where there is a strong correlation or a strong curvature in the second order line persists, one should look for a different stock-recruit function.

2: Probability coverage.

This is a control that the distribution assumed for the residuals is adequate. Assuming that each of the historic residuals is equally likely, the rank of each of them, divided by the number of observed residuals, gives the empirical cumulated probability of the historical residuals. On the other hand, according to the model that is assumed for the residuals in the prediction, there corresponds a cumulated probability for the value of each observed residual. Each of these model probabilities should be close to the empirical cumulated probability of the same historic residual.

The Kolmogorov goodness of fit test is based on this reasoning, and the Kolmogorov test statistic can be derived directly from the pairs of model and observed values. It may be even more illustrative to plot the model and observed probabilities as pairs. One may also convert the empirical cumulated probabilities to recruitments according to the assumed model, and compare with the historic recruitments. In both cases, the points should ideally all lie on the diagonal. This is shown in figures 4 and 5 below. In this case the fit seems to be rather satisfactory.

The Kolmogorov test statistic can be used to choose between alternative stock recruit functions and assumptions about distributions.



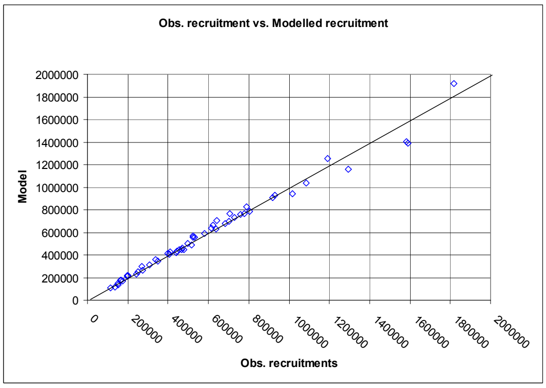
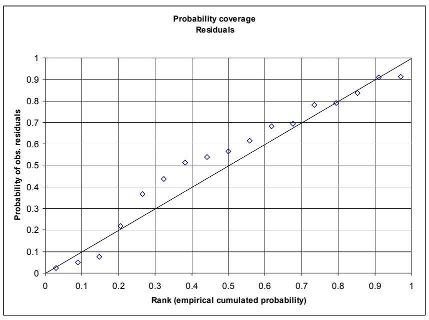
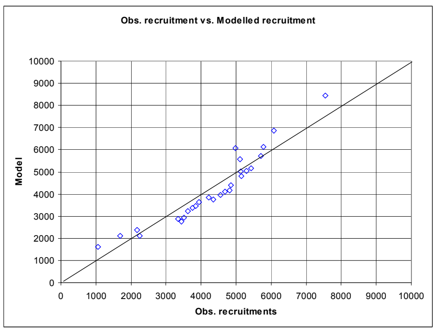


Figure 4 ***Figure 5***

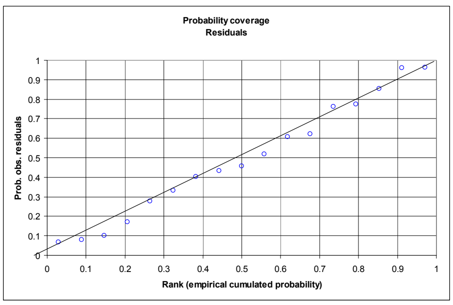
There may be cases where other distributions than the log-normal may be more adequate.
The example below is from a different stock where a normal distribution with constant coefficient of variation (Figures 8 and 9) seems to be more adequate than the log-normal distribution (Figures 6 and 7), although none of them are quite satisfactory.

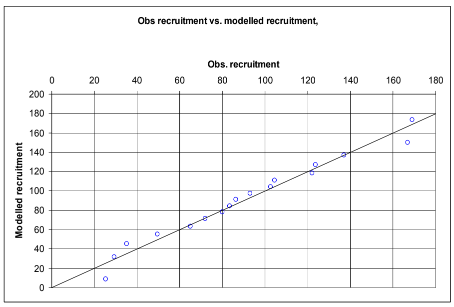




Log-normal distribution

Figure 6 ***Figure 7***





Normal distribution

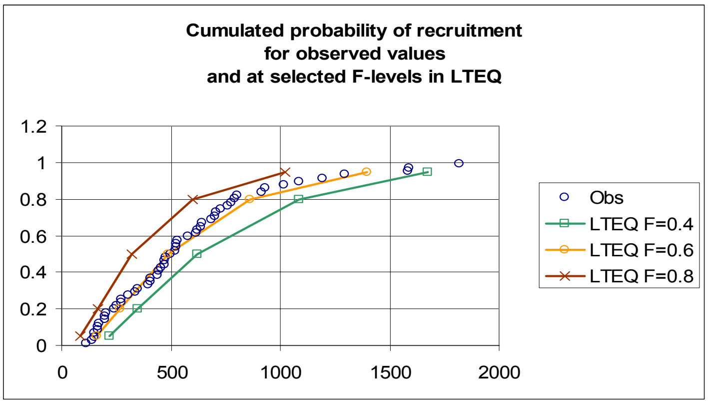
Figure 8 ***Figure 9***

Alternatively, instead of assuming a parametric distribution of the residuals, one may use the residuals themselves in a non-parametric bootstrap. The probability coverage should then be perfect, but it is still important that the residuals are uncorrelated to the SSB.

The final test in any case would be to take the distribution (or at least the standard percentiles) of recruitments from the long-term or medium term prediction and compare with the historic recruitments generated by similar levels of SSB.

The next figure (Figure 10) shows the a distribution of recruitments as obtained by long term equilibrium calculation with the LTEQ software.

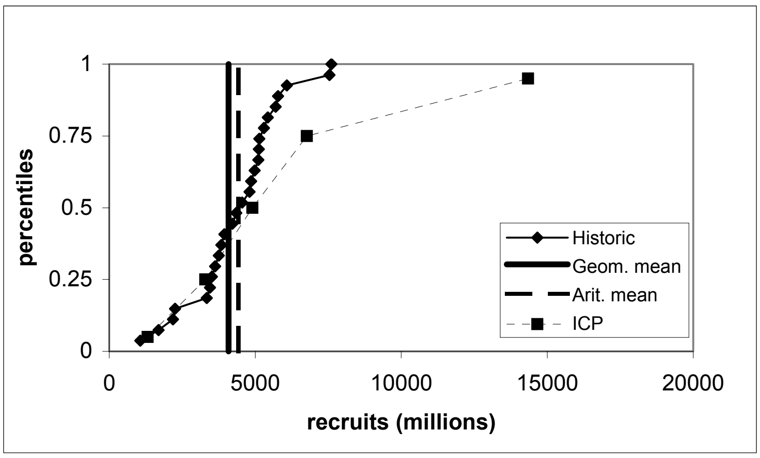
Figure 10



For this stock, F has fluctuated with a gradually increasing trend, from approximately 0.4 to approximately 0.9 in the period with historical data.

To give an example of the kind of problems that one may encounter, the figure 11 below is reproduced from the 2002 report of the ICES MHSA Working Group (Figure 2.12 in the report). It shows a comparison between the cumulated distribution of historic recruitments for NEA mackerel and the percentiles at 10 years ahead with a medium term prediction tool. There is no clear dependence of the recruitment on the SSB for this stock, so the distributions should be directly comparable. In this case, the prediction program generated large year classes far more often than experienced in the past and the WG decided not to present medium term predictions due to this problem.

Figure 11



3: Bias in recruitments.

A criterium for unbiasedness can be derived by comparing the modelled recruitments according to the empirical cumulated distribution discussed above, with the actually observed recruitments. The arithmetic mean of these two sets of recruitments should be equal, i.e. the sum of the differences between the pairs should be 0. This may be used as an additional constraint when finding the parameters of the stock-recruit function.

Software for finding a stock-recruit function.

The calculations above have been done on a spreadsheet, which is available from the author. The input data are stock and recruit pairs from an assessment. There are several choices of parametric stock recruit functions, which are used to compute residuals. There is one worksheet for assuming log-normal distribution of the residuals, and another for assuming a normal distribution with constant coefficient of variation (i.e. σ proportional to the model estimate of the recruitment). Furthermore, ranks and empirical cumulated probabilities are computed from the residuals, as well as the model recruitments corresponding to these cumulated probabilities. The Kolmogorov goodness-of-fit criterium is derived from these distributions. Finally, the sum of the differences between observed and modelled recruitments are computed. Graphs are provided for the quality checks outlined above, including probability coverages and correlations.

Parameter estimation is by minimising the sum of squares of the residuals (normalised in the case of normal distribution) using the SOLVER, and with optional constraints on the correlation between residuals and SSB, and on the sum of the difference between modelled and observed recruitments.

Weights and maturity at age

For many stocks both stock weights and proportion mature are just assumed constant, both in the historical time series and in forecasts. In such cases, the variation in SSB in predictions will be restricted to the effect of variation in recruitments, i.e. the calculated SSB will be a weighted sum of the stock numbers. Whether this is a better or worse proxy for the fecundity is probably still an open question. Thus, if these parameters are kept constant both in the historical record and in the prediction, the inferences that are drawn about feasible precautionary fishing mortalities may still make sense.

It is more problematic if the early part of the history has used constant weights and maturities, while measured values are used in the later part. The SSBs that generated the early historic recruitments may then be incompatible with predicted SSBs, where other standards for weight and maturity are applied. It is not clear how this problem is best handled. If the time series still is long enough, one may consider using only the recent part with variable weights and maturities, in particular if there is reason to suspect that the constant parameters applied are not representative for the population dynamics at the time.

When there are data for annual weights and maturities, these contribute to year to year variations in the SSB, and should obviously be taken into account in the prediction. There is no standard way of doing this. One way is to draw randomly from the pool of data. It may then be argued, however, that there are correlations between the weights at various ages, and between weights and maturity. A possible alternative is to draw years randomly and use the vectors of weights at age and maturities at age from that year. Another alternative is to apply some kind of growth model, and draw yearly parameters randomly. To my knowledge, these alternatives have not been systematically explored, and it is hard to tell the best way of getting the variation in SSB due to variation in weights and maturities best represented.

For many stocks, there is a more or less substantiated suspicion that the growth and maturity are density dependent. If possible, this should be taken into account when evaluating the effect on SSB and recruitment at fishing mortalities that are very different from the present. This is not an option in the standard software used in ICES, but should be relatively easy to implement.

In quite a number of cases, where the stock has been heavily exploited for decades or more, we have to admit that we cannot predict how the stock will behave at much lower mortalities. Reference points like $\mathbf{F}_{max}$, $\mathbf{F}_{MSY}$ and $\mathbf{F}_{0.1}$ will be far below the present exploitation level, and the calculated values may not be representative for the stock dynamics at such low mortalities. This should not be used as an excuse for maintaining a heavy exploitation, however, because there will be gains in terms of lower risk of recruitment failure anyway, even though it is less clear what the optimal exploitation level will be or how much the catches will improve.

Experience from worked examples

Below are some worked examples for a variety of stocks. They have been selected to illustrate a range of problems rather than to show ideal cases. The general experience from working with these data is that each stock has its peculiarities that require individual attention and sometimes a good deal of common sense. Thus, this is not a kind of work that is well suited for a more or less automated process.

Many of the problems seem to come from the sparse collection of historical stock-recruit pairs. One may suspect in some cases that there are cyclic variations in the recruitment that drives not only the time sequence of recruitments, but also the time sequence of SSBs. In such cases, other models for the relation between stock and recruitment than the simple stationary functions that are standard today may be needed. So far, tools for implementing such functions probably are not available.

Another common problem is that the signal in the stock – recruit data is too poor to estimate the parameters properly. Even with only two parameters, the model may be nearly over-parameterised, i.e. the parameters are closely correlated.

For some stocks, where the recruitment has been poor for several years, most of the points at low SSB are below the stock-recruit curve, indicating that in general, the model will be too optimistic at such SSBs. This may not be critical if the F-values that are considered do not lead to such low SSBs, but will be very misleading if the same stock-recruit relation is used to evaluate recovery plans.

Surprisingly often, a truncated normal distribution with constant c.v. seems to describe the recruitment variation better than the commonly used log-normal distribution. In particular, large year classes are encountered less often that a log-normal distribution would indicate.

Some stocks occasionally produce extreme year classes, which do not fit with a distribution that seems adequate for ordinary year classes. The solution to this problem is not obvious.

One alternative might be to first decide whether the year class shall be extreme or not according to one model, and then draw the actual value according to a standard stock recruit model.

Problems like these need to be solved, not only for the present purpose but even more for future evaluations of harvest control rules, which are critically dependent on reliable stochastic predictions. Nevertheless, we find the method promising for ensuring consistency between F and B reference points in many cases, but it is also clear that such methods can give very misleading results if the model is not properly conditioned, and that more work is needed on formulating functions and distributions describing the dynamics of the stocks.

A common experience is that once the risk of SSB being below some reference point starts to rise, it rises very sharply. That implies that the margin between a 5% risk and a 20% risk, say, is quite narrow. Thus, if one wants to have a low risk, one should stay safely away from the point where the risk starts to rise.

Worked examples

Data for selected stocks have been explored using the methods outlined above. To obtain the stock-recruit function, the spreadsheet described previously was used. Different kinds of stock-recruit functions were tried, with either normal or log-normal distribution function. The model formulation was chosen that gave the best probability coverage by inspection of the graphs comparing modelled and observed residuals and recruitments, the most straight second order polynoma fit to the residuals as function of SSB and the smallest Kolmogorov test statistic. Parameter estimation was done by minimising the sum of squares of the residuals (normalised by dividing by the expected value in the case of normal distribution), with the constraint that the average modelled recruitments according to the empirical cumulated distribution should equal the average of the observed recruitments. A constraint on the correlation between residuals and SSB was included if a feasible solution could be found.

Weights, maturities and natural mortality were taken from the assessment input data as used by the Working Group. A fixed selection at age in the fishery was assumed. The selection pattern used was taken from the input to the short term prediction by the WG.

Long term equilibria were calculated using the LTEQ software. This program searches iteratively for stationary distributions of SSB and recruitment. The idea is that, when there to each SSB value corresponds a stationary distribution of recruitments, and the SSB is a weighted sum of previous recruitments, a stationary distribution of SSB's should transform into a stationary distribution of recruitments and *vice versa*. Accordingly, the program just does a transform back and forth between the distribution of SSB's and the distribution of the recruitments until both distributions are stable.

The stochastic variables are

- Recruitments, according to a given stock recruitment function and a given distribution of the residuals.
- Weights and maturities at age, which are drawn randomly from historical values.

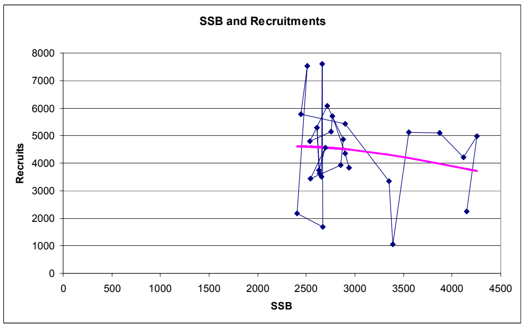
The weights and maturities at age are drawn from a collection of data for a range of years, by drawing a year and using the data from that year. The weights and maturities are not dependent on the current SSB, i.e. no density dependence is accounted for.

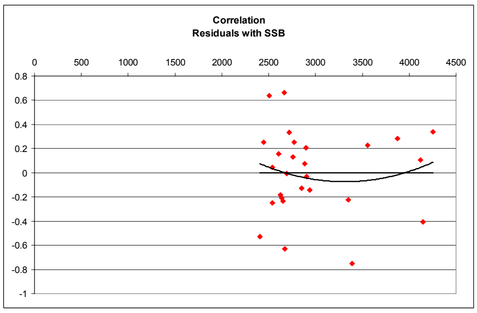
The results are presented as a set of graphs. These are:

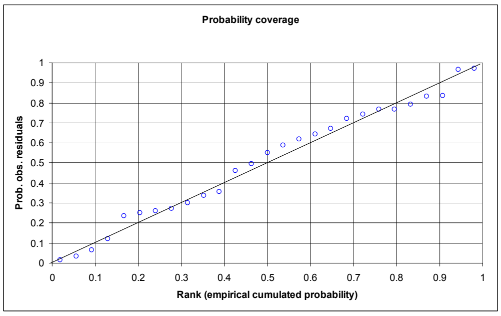
- The historical stock – recruit data and the assumed stock recruit relation.
- Residuals as function of SSB, with fitted first and second order polynomas.
- A comparison of residuals derived from the empirical cumulated distribution and the residuals from the observed data
- A similar comparison of recruitments corresponding to the derived residuals with the observed ones.
- Percentiles for SSB and catch as function of F
- Probability of being below reference biomass levels.
- Cumulated distribution of the historic recruitments together with cumulated probabilities of recruitments from LTEQ at selected levels of fishing mortality.

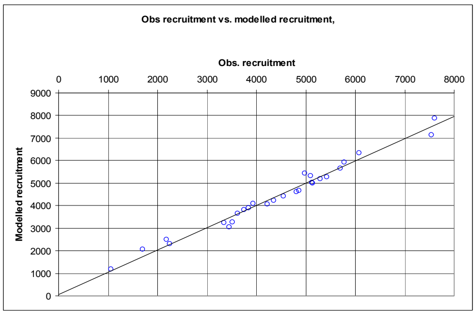
NEA mackerel.

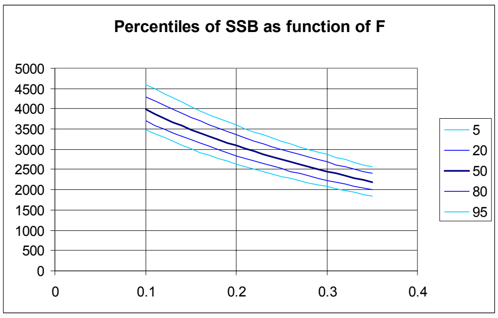
SR – data: From 2002 assessment, period 1972 – 1998
Function: Ricker
Distribution: Normal with constant CV. Lognormal gives much poorer probability coverage.
Conclusion: Current $\mathbf{B}_{pa}$ is 2300 thousand tonnes. $\mathbf{F}_{lim}$ is 0.26, $\mathbf{F}_{pa}$ is 0.17.
F at <0.23 gives minimal risk of passing $\mathbf{B}_{pa}$, and even at $\mathbf{F}_{lim}$, the risk is small. Agreed F is 0.15 – 0.20. Loss in yield compared to F=0.23 is 5 – 15 %
Should be satisfactory, but since the risk increases sharply once it starts rising, a slight downwards adjustment of $\mathbf{F}_{lim}$ could be considered.

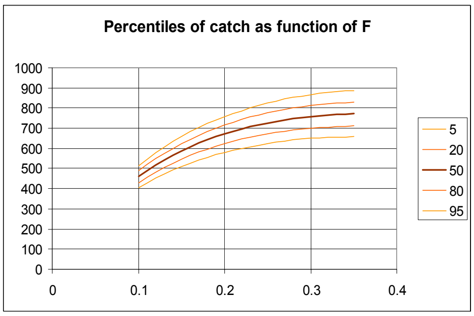


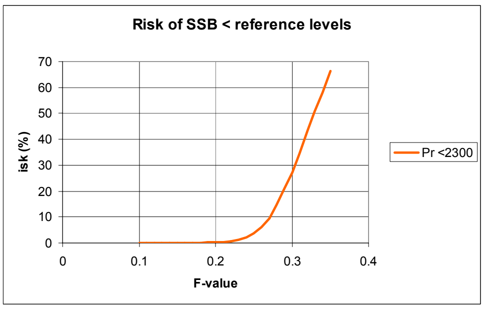


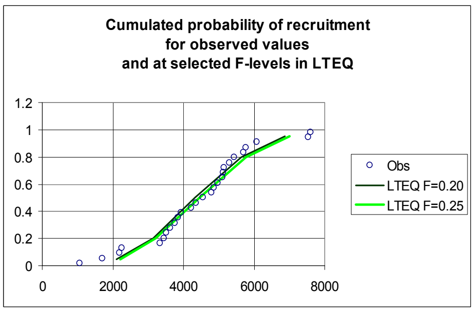




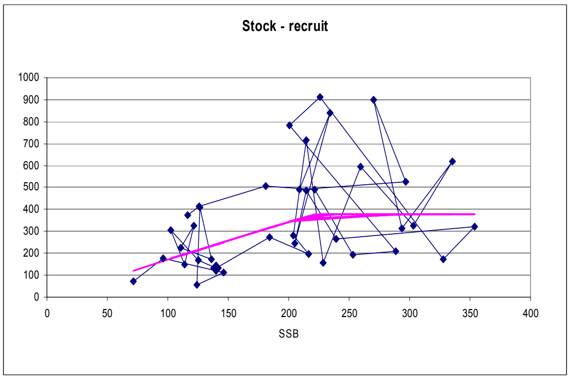


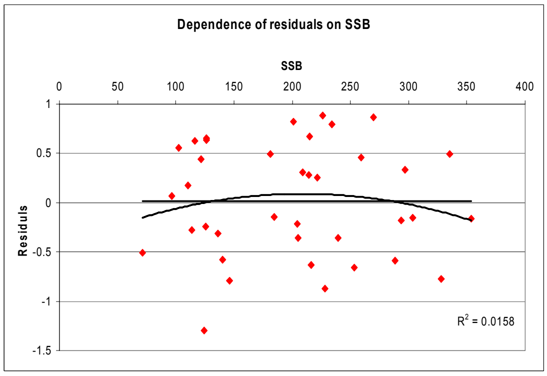


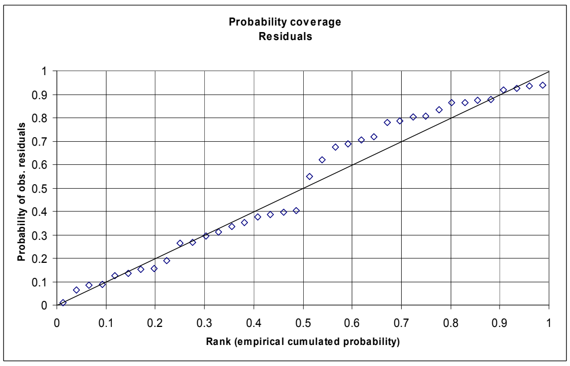


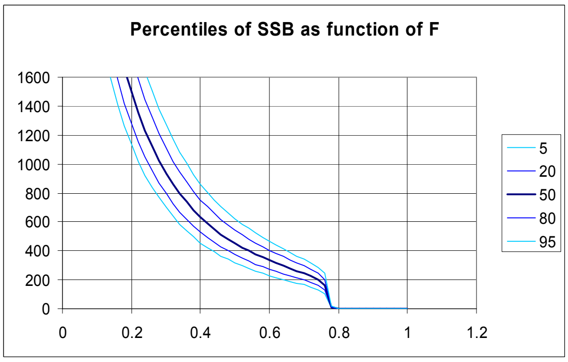


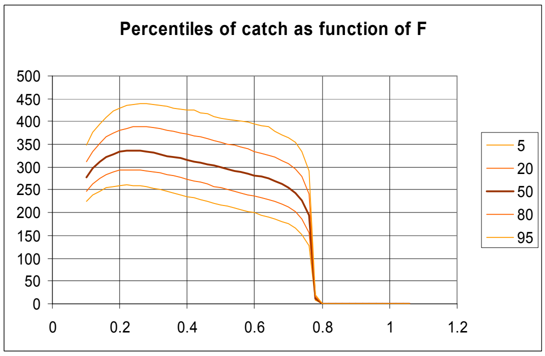
North Sea cod. (very sensitive to S/R function)
SR – data: From 2002 assessment, recruitment years 1964-2001
Function: Ockham, fitted breaking point at SSB=220.000 tonnes
Distribution: Lognormal.
Conclusion: Current $\mathbf{B}_{pa}$ is 150 thousand tonnes, $\mathbf{B}_{lim}$ is 70.000 tonnes. Current $\mathbf{F}_{lim}$ represents very high risk. Steep increase in risk at F>0.7. Low risk when "real" F <0.7. Buffer against F-bias requires lower F, which also increases yield.
Bev.Holt also gives rather steep risk in the same F-region, and gives higher R, SSB and yield at low Fs.

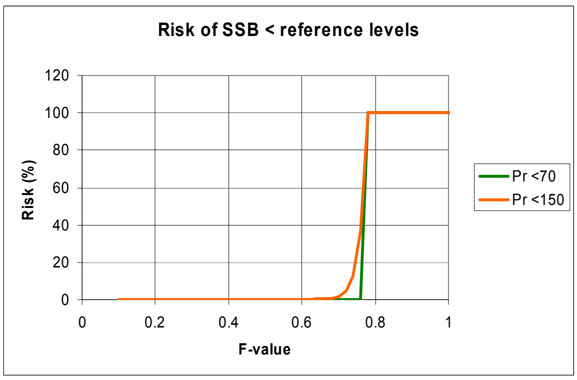


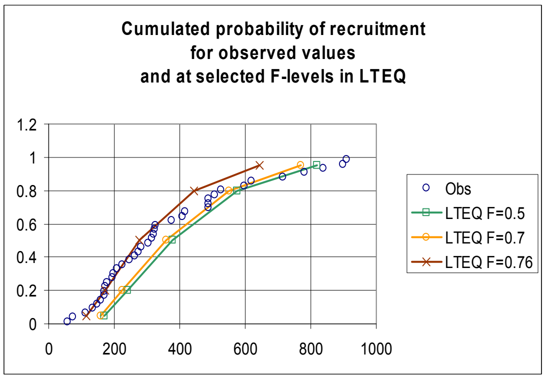






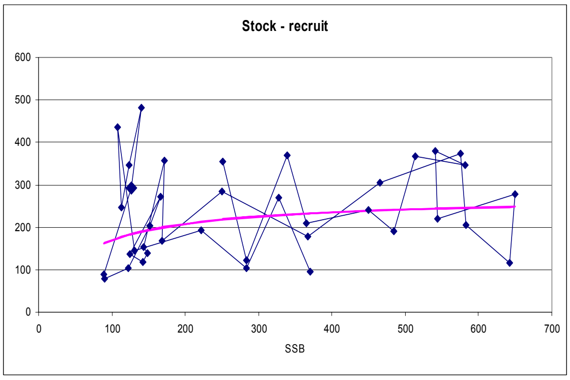


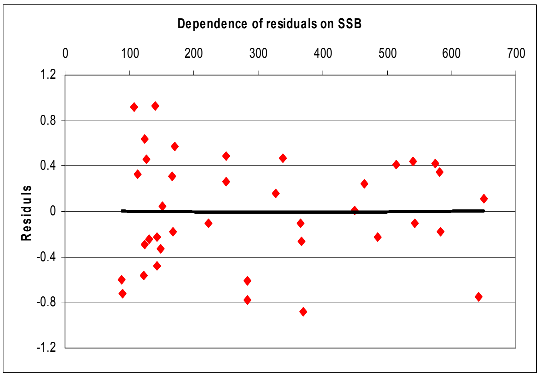


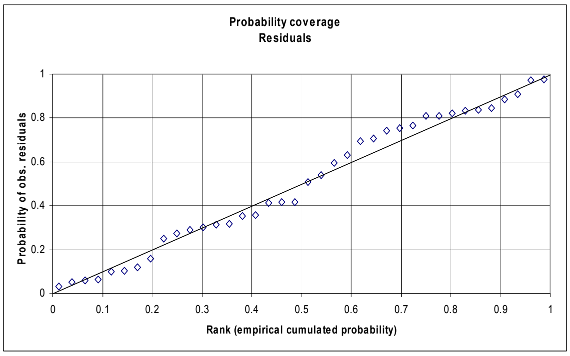


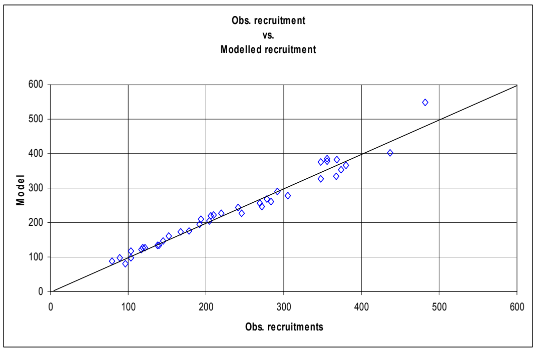
NEA saithe.

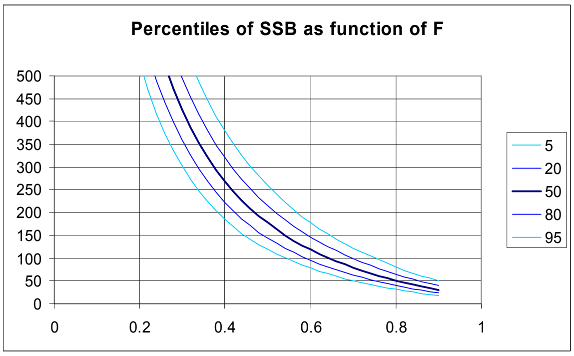
SR – data: From 2002 assessment, recruitment years 1962-1999
Function: Beverton and Holt
Distribution: Lognormal.
Conclusion: Current **B**$_{pa}$ is 150.000 tonnes, **B**$_{lim}$ is 89 thousand tonnes. Current **F**$_{lim}$(0.45) represents low risk to the stock.

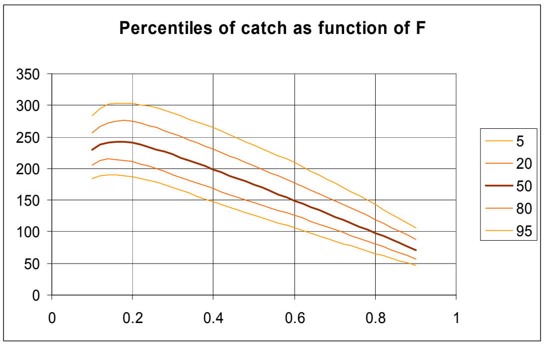


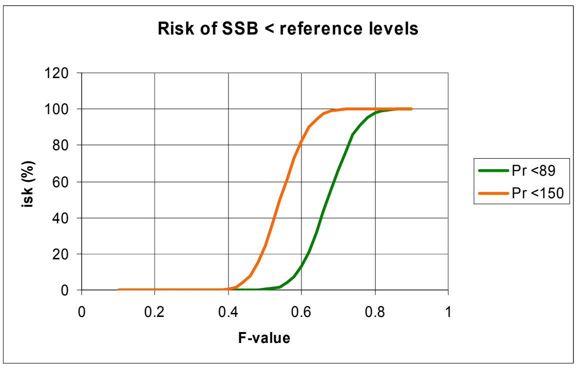


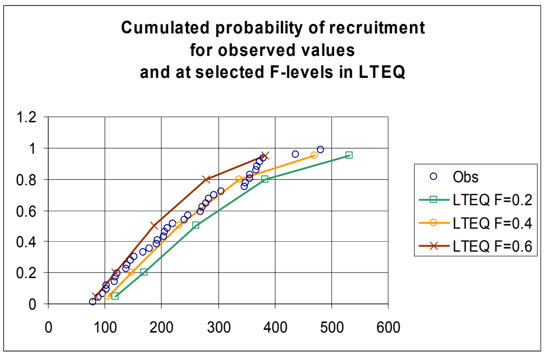






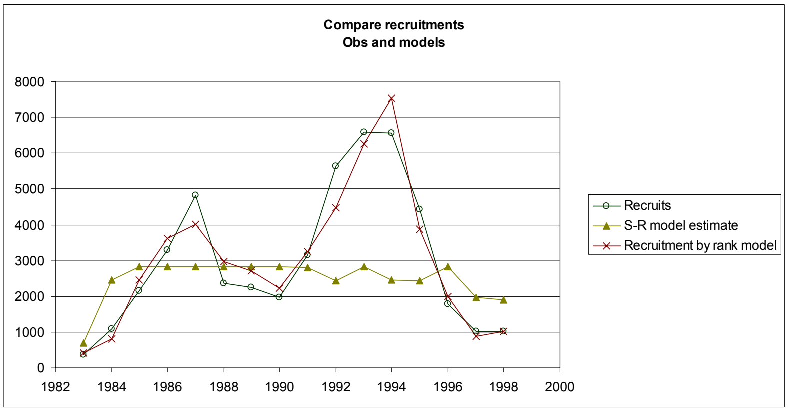


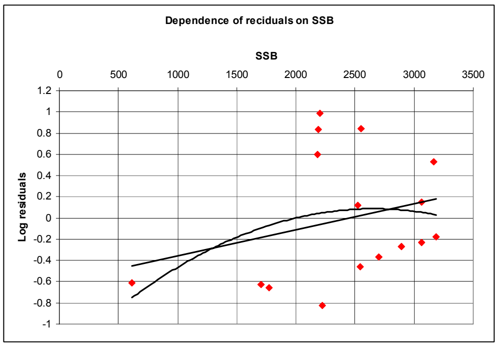


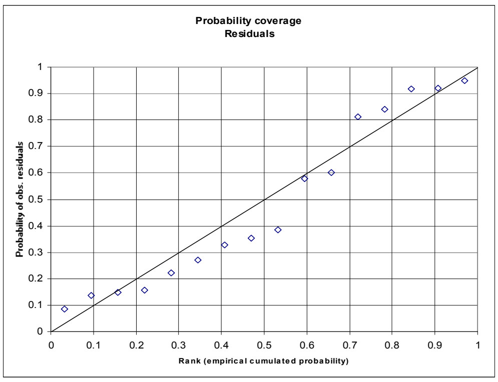


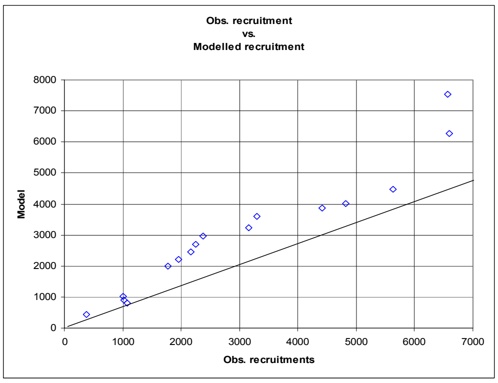
Western horse mackerel

SR – data: From 2002 assessment, recruitment years 1983-1998 (i.e. omitting the extreme 1982 year class)
Function: Ockham, no constraints on correlations.
Distribution: Lognormal
Conclusion: The upper figure indicates strong cyclic variations in the recruitment, while the SSB is dominated by the rise and fall of the extreme 1982 year class. Due to this, and the short time series, a stationary stock recruitment function does not seem to be adequate. The example shown here gives an optimal fit, but strong correlations, and the break-point in the Ockham function is very unstable. Hence, no attempt was made to estimate long- term equilibria.







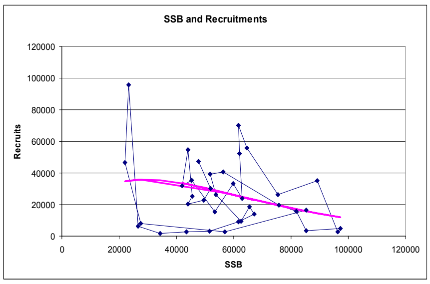


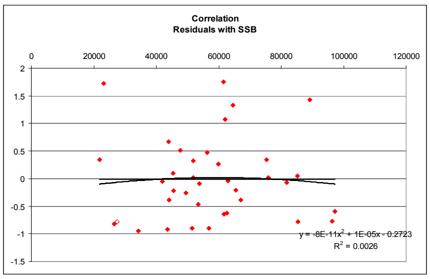
Faeroese haddock

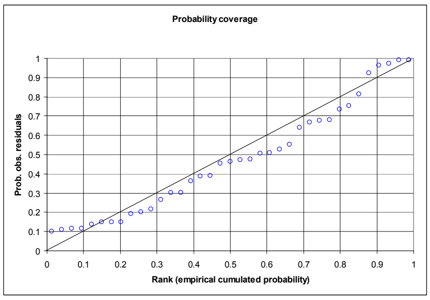
SR – data: From 2002 assessment, recruitment years 1963-1999
Function: Ockham, with beakpoint just below the lowest observed SSB
Distribution: Normal with constant CV, truncated at +- 1.5.

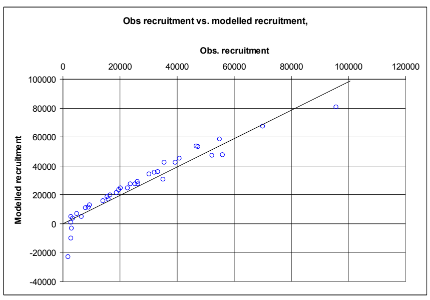
This stock has a few very large year-classes. However, excluding them does not improve the fit very much. The best fit is obtained with a Ricker function, although the evidence in the stock-recruit data that the recruitment is reduced at high SSB may not be quite convincing. The Ockham function with a break point just below the smallest observed SSB also gives a reasonably good fit, in particular if the strongest recruitments ise omitted, and will lead to a different perception of the stock dynamics. The correlation with SSB becomes –0.29 in this case, however. Assuming a normal distribution gives a much better probability coverage than with the log-normal distribution, as judged by the Kolmogorov test statistic and by inspection of the probability coverage graphs. As usual, the smallest residuals lead to negative values in this distribution, so that truncation is needed when using it in prediction. In the example, the ricker function with all data is used.

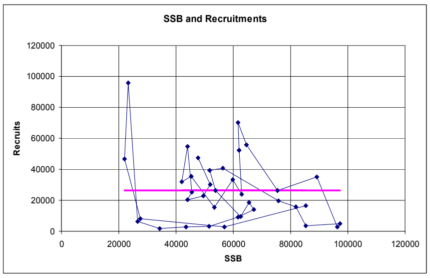
Quality graphs assuming normal distribution with constant CV, with the Ricker function (left) and the Ockham function (right)

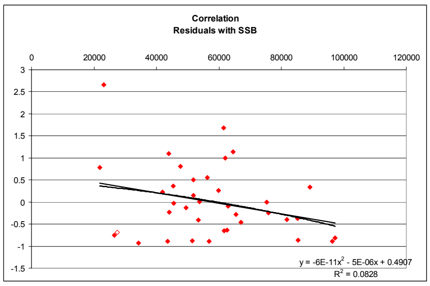


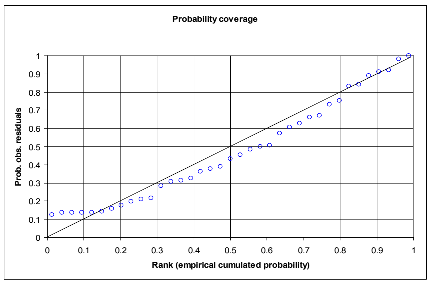


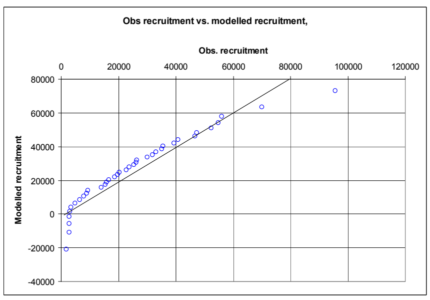




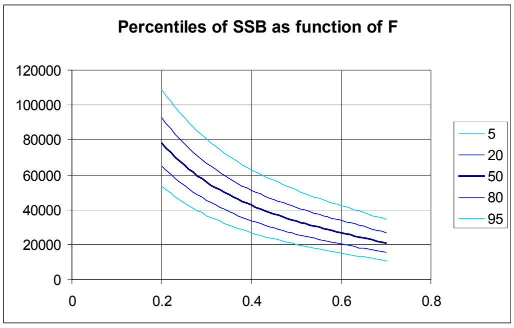


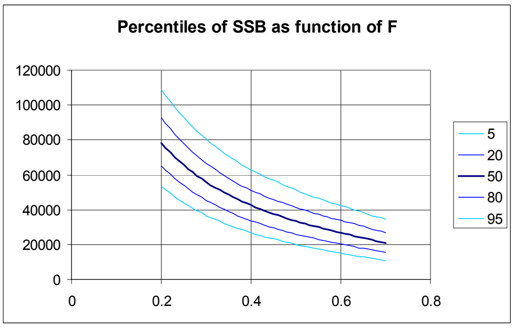


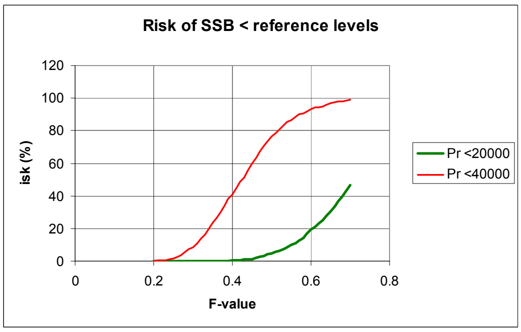


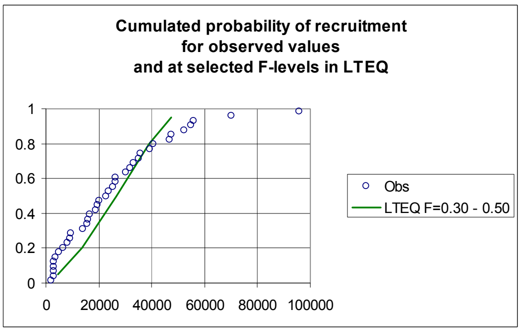


Using the Ricker function in LTEQ becomes problematic because the critical point is unstable for F-values below approximately 0.3 (see section on stock-recruit functions). The results below are with using the Ockham function. Clearly, the large year classes are not picked up properly, but the intermediate year-classes are generally overestimated. The results also indicate that without occasional large year classes, finding a $\mathbf{F}_{pa}$ that does not create problems with a $\mathbf{B}_{pa}$ with a sufficient safety margin to $\mathbf{B}_{lim}$ can be problematic for this stock. The current $\mathbf{B}_{lim}$ is 40000 tonnes and the $\mathbf{F}_{lim}$ is 0.4. Thus, there seems to be a quite large risk of falling below $\mathbf{B}_{lim}$ by fishing at $\mathbf{F}_{lim}$, while fishing at $\mathbf{F}_{pa}$ is borderline with respect to risk of $\mathbf{B}_{lim}$.









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ICES - Copenhage

"bhac"
An R package to compute %BPR and %SPR

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"bhac" is a package writen for R (http://www.r-projet.org) that implements the simple yield model of Beverton and Holt following the procedure described in Azevedo and Cadima (2002).

The following options are implemented in "bhac":

Option 1) For a given stock, characterized by M, K, c_m and exploitation pattern c: i) compute the %BPR and %SPR for long-term fishing mortality reference points; ii) determine biological reference points based on %BPR or %SPR criteria.

Option 2) Compute, for different stocks and exploitation patterns the %BPR and %SPR at a given fishing mortality reference point.

This paper presents the "bhac" reference manual that provides details on the implementation and sample sessions for each option. General guidelines on how to install R and "bhac" package are described below. A graphical component is under development and will take into account the suggestions made during this SGPA meeting.

R is an OpenSource project that implements the S language. As an OpenSource implementation, "bhac" is under the GNU Public License (http://www.gnu.org/licenses/gpl.html). The most important feature is that everyone can change the code and submitt the changes to the authors for updating the main code. All contributions will be considered and the authors will be added to the contributors list.

To install R:
Download it from the R home page (http://www.r-project.org), choose your platform (Linux, Windows, etc) and install it.

User's new to R should check the “An Introduction to R” manual, under the “help” menu. Also the R home page has a section on documentation where begginers can find several documents written in English, German, French and Spanish.

To install “bhac”:
i) Start R, go to “packages” menu, choose “Install package from local zip file”, browse and choose file bhac_#.#-#.zip, the last version.

ii) Before any analysis with “bhac” you have to load the package inside R, do:
> library(bhac)

If you want you can check the “bhac” help pages:

> help(package=”bhac”)

To read the package source:
i) Go to the directory where R is installed;
ii) Go to library / bhac / R
iii) Open the file “bhac” with any text editor

Package ‘bhac’

November 25, 2002

Version 0.5-2

Title Beverton and Holt yield simple model extended by Azevedo and Cadima

Author Ernesto Jardim <ernesto@ipimar.pt>, Manuela Azevedo <mazevedo@ipimar.pt>

Contributions Emygdio Cadima <cadima@netcabo.pt>

Maintainer Ernesto Jardim <ernesto@ipimar.pt>

Description Functions for fish stock assessment based on B&H simple yield model

Depends R (>= 1.5.0)

R topics documented:

`bhac` *%BPR and %SPR computation for given values of M, K, cm, c and x*

Description

For a given stock, characterized by `M`, `K`, `cm` and `c`: (i) compute the `%BPR` and `%SPR` for long-term fishing mortality reference points; (ii) determine biological reference points based on `%BPR` or `%SPR` criteria.

Usage

```
bhac(M, K, cm, c, x)
```

Arguments

`M`	natural mortality coefficient
`K`	growth coefficient of the Von Bertalanfy growth model
`cm`	maturity ogive - length of first maturity (l_m) as a percentage of assymptotic length ($L\infty$)
`c`	exploitation pattern - length of first capture (lc) as a percentage of assymptotic length ($L\infty$)
`x`	F index (scalar or vector). The rate of variation of the yield per recruit, expressed as a percentage of the rate when F=0. Used as target in the minimization process to estimate `Ex`.

$$x = \frac{\sum_{n=0}^{3} b_1(c,n) b_2(E,n)^2}{\sum_{n=0}^{3} b_1(c,n)}$$

where:

$$b_1(c,n) = U_n \frac{(1-c)^n}{M/K+n}$$

with

$$U_0 = 1; U_1 = -3; U_2 = 3; U_3 = -1$$

$$b_2(E,n) = \frac{(M/K+n)(1-E)}{M/K+n(1-E)}$$

Details

The yield simple model of Beverton and Holt (1966) characterizes the stocks with the parameter `M/K` and the exploitation with the parameters `c` for the exploitation pattern and `Ex` for the exploitation rate (`E=F/(F+M)`).

The longterm reference points, `Fmax`, `F0.1`, `F0.2`, or, in general terms `Fx`, are defined using the derivative, in order to `F`, of the yield per recruit function. Therefore, to simplify the calculation of `Fx`, Azevedo and Cadima (2002) have re-written the simple yield model of Beverton and Holt as a sum of products of two factors, one relating to the exploitation pattern, $b_1(c,n)$, and the other to the exploitation rate, $b_2(E,n)$. This allowed the extension of the model to include the biological parameter cm.

To analyse the conservative properties of `Fx`, exploitable total biomass and spawning biomass were calculated and expressed as the percentage of the respective unexploited biomasses, denoted by `%BPR` and `%SPR`. The `%SPR` calculation is possible due to the inclusion of `cm` on the Beverton & Holt model.

Value

A list with 9 components (scalars for bhac and vectors for bhac.xtab), the 5 parameters and

`Ex`	exploitation rate
`Fx`	long-term fishing mortality reference point

$$F_x = \frac{M E_x}{(1-E_x)}$$

`%BPR` percentage of exploitable biomass per recruit

$$\%BPR = \frac{\sum_{n=0}^{3} b_1(c,n) b_2(E,n)}{\sum_{n=0}^{3} b_1(c,n)}$$

`%SPR` percentage of exploitable spawning biomass per recruit

$$\%SPR = (\frac{1-cm}{1-c})^{\frac{Ex}{1-Ex}\frac{M}{K}} \frac{\sum_{n=0}^{3} b_1(cm,n) b_2(E,n)}{\sum_{n=0}^{3} b_1(cm,n)}$$

bhac returns `Fx`, `%BPR` and `%SPR` given input data on `M`, `K`, `cm`, `c`. If `x` is a vector a table will be returned with `Fx`, `%BPR` and `%SPR` for the set of `x` values.

Note

Note that when `x=0`, `F=Fmax`, when `x=0.1`, `F=F0.1`, etc.

Author(s)

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Manuela Azevedo ⟨mazevedo@ipimar.pt⟩

References

Beverton, R.J.H. and Holt, S.J. (1966) *Manual of methods for fish stock assessment.* Part 2. Tables of yield functions. FAO Fish. Tech. Paper 38 (Rev.1), 67p.

Azevedo, M. and Cadima, E.L. (2002) *Stock conservative properties of F0.1.* Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management. Lisbon, Portugal, 4-8 March 2002.

See Also

`optim`,`save.bhac`,`bhac.mk`

Examples

```
# You can check the arguments of this function:

args(bhac)

# or see the help page:

?bhac

# Example 1:
# Compute, for a given stock, the %BPR and %SPR for long-term fishing
# mortality reference points.
#
# The aim of this example is to compute %BPR and %SPR at the reference
# fishing mortalities Fmax, F0.1 and F0.2, for the southern black
# scabbardfish, Aphanopus carbo.
#
# The required input parameter values are (ICES, 2001):
# M = 0.27 y-1
```

```
# K = 0.2 y-1
# cm = 0.70 (103cm/147cm)
# c = 0.75 (110cm/147cm)
#
# To run this example you do:

x <- seq(0,0.2,0.1)
bsfx1 <- bhac(0.27, 0.2, 0.7, 0.75, x=x)

# Note that 0 index of F0 means F=Fmax.
# Note also that since for black scabbardfish cm < c the %SPR is the
# same as %BPR (see Azevedo and Cadima, 2002).
#
# Now we can save the bsfx1 object in an external file to be used by
# other software, like a spreadsheet:

save (bsfx1, file="filename.csv", sep=",")

# Notice that it is necessary to define the file (file="filename.csv") and
# the field separator ("sep=","). Other options are allowed, check
# ?save.bhac
#
# WARNING: R will not ask if you're giving the same name as other file,
# it will overwrite it !
#
# Example 2:
# Determine, for a given stock, biological reference points based on
# %BPR or %SPR criteria.
#
# Suppose now that one wants to determine for black scabbardfish the
# long-term fishing mortality Fx corresponding to a given %SPR, say 40%.
#
# Note the difference on the step of the seq function defining x, 0.01.

bsfx2 <- bhac(0.27,0.2, 0.7, 0.75, x=seq(0,0.2,0.01))

# The results show that for black scabbardfish the long-term fishing
# mortality reference point corresponding to the required 40% SPR is
# F0.15 and its value is 0.30.
```

---

bhac.mk	*%BPR and %SPR computation for given values of M/K, cm, c and x*

Description

Compute, for different stocks and exploitation patterns the %BPR and %SPR at a given fishing mortality reference point.

Usage

```
bhac.mk(MK, cm=seq(0,0.9,0.1), c=seq(0,0.9,0.1), x)
```

Arguments

MK	$\frac{M}{K}$, see bhac
cm	maturity ogive - length of first maturity (l_m) as a percentage of assymptotic length ($L\infty$)
c	exploitation pattern - length of first capture (lc) as a percentage of assymptotic length ($L\infty$)
x	F index (scalar or vector). The rate of variation of the yield per recruit, expressed as a percentage of the rate when F=0. Used as target in the minimization process to estimate Ex. see bhac

Details

bhac.mk returns a set of tables with %BPR and %SPR for several M/K, cm, c and x values. M/K defined by the function argument MK, is defined by the user as a scalar or vector. cm and c are defined by default as seq(0,0.9,0.1), which are sensible values for these parameters, but the user can define different values. Note, however, that the c and cm are values in the interval [0,1]. x is a scalar and must be selected by the user.

Value

A list with 8 components (vectors), the 4 parameters and

Ex	exploitation rate
Fx	long term fishing mortality reference point
%BPR	percentage of exploitable biomass per recruit
%SPR	percentage of exploitable spawning biomass per recruit

See bhac

Note

Note that when x=0, F=Fmax, when x=0.1, F=F0.1, etc.

Author(s)

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Manuela Azevedo ⟨mazevedo@ipimar.pt⟩

References

See bhac

See Also

optim,save.bhacmk,bhac

Examples

```
# You can check the arguments of this function:

args(bhac.mk)

# or see the help page:

?bhac.mk

# Example 1:
# For a given stock exploited at Fx, compute the %BPR and %SPR for
# different exploitation patterns c.
#
# Now suppose that by adopting the F0.15 reference point for black
# scabbardfish (e.g. the Fx determined in the example of bhac and
# corresponding to 40% SPR) one want to analyse the effect on %BPR
# and %SPR of different exploitation patterns, c.
#
# Note that for black scabbardfish, M=0.27, K=0.2 and cm=0.7. Therefore
# the input value for M/K is 1.35. Note also that x must be fixed at
# 0.15.

bsfmk1 <- bhac.mk(1.35, 0.7, c=seq(0,0.9,0.05), 0.15)

# The results show, for c ranging from 0 to 0.9 at step 0.05 (that
# includes the current exploitation pattern, c=0.75), the values of
# F0.15/M (column F/M) and the corresponding %BPR and %SPR. For
# instance for c=0.25, F0.15/M=0.49, %BPR=45 and %SPR=33.
#
# Saving is the same as before:

save(bsfmk1, file="filename.csv", sep=",")

# Example 2:
# Analyse the conservative properties, in terms of %BPR and %SPR,
# of long-term fishing reference points.
#
# In this example we select stocks characterized by M/K=1, cm and c
# from 0 to 0.9 and the fishing reference points F0.1 (x=0.1) and Fmax (x=0).
# 'bhac.mk' computes the correspondent %BPR and %SPR.

bsfmk.01 <- bhac.mk(1,x=0.1)

# Note that the results also indicate the expected increases in F0.1/M
# (F/M) with increasing c.

bsfmk.max <- bhac.mk(1,x=0)
```

---

print.bhac *bhac printing methods*

Description

Printing methods for bhac.

Warning

These are not suposed to be called directly by the user.

Author(s)

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`save.bhac` *bhac saving methods*

Description

Implements saving methods for bhac.

Usage

```
save(obj.x, file="file", sep=",")
save(obj.mk, file="file", sep=",")
```

Arguments

`obj.x`	A bhac object resulting from function `bhac`
`obj.mk`	A bhac object resulting from function `bhac.mk`
`file`	The name of the file to be passed to the write.table function.
`sep`	The field separator to be passed to the write.table function.

Author(s)

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See Also

`write.table`,`bhac`,`bhac.mk`

Index

Technical Annex 9 SGPA /02b

A. Testing the Segmented Regression

This annex summarises the results obtained when study group members used the 'R'software version of the segmented regression on the data for some key stocks and species.

Cod in the Irish Sea (Division VIIa)

Using Irish Sea cod data from the 2001assessmen, as adopted by O Brien and Maxwell at SGPA 02a, a segmented regression was applied (Fig 1), using "R" software and code from Motos (2002). The maximum likelihood estimate of the change point and other parameters was estimated using a Julious algorithm. The values obtained from this analysis were identical to those presented at SGPA 02a (Table 1). The SSQ surface showed a distinct minimum (Fig.2) and the breakpoint of the regression was estimated to be at 10,719t. Diagnostics from the analysis showed that the regression was highly significant (bootstrap P=0.0), although there was some deviation of residuals at extremes, from the expected distribution (Fig 3 and 4). Sensitivity analysis of the change point estimation showed some small sensitivity to the most recent years data but relative insensitivity to the removal of data from any other previous years.

The same analysis was conducted using the R-SSB data from the 2002 Irish Sea cod assessment (Fig 5). This time the maximum likelihood estimate of the breakpoint was estimated at 10,500t which is only 2% different. The regression was still highly significant (Bootstrap P=0.009). The SSQ surface again showed a distinct minimum (Fig. 6) and the distribution of the residuals was similar (Fig 7 & 8). Sensitivity analysis of the change point estimation showed significantly more sensitivity to the removal of any one year of data from any period of the time series, however, although the magnitude of the sensitivity was relatively small.

A cursory examination of the stock recruit data from both assessments show some differences in the estimation of the most recent years of the stock and recruit data pairs. Fig 9 shows that these changes to the data occur towards the lower end of the observed range of stock size and recuits. Such changes are likely to have an effect on the slope of any regression fitted from the origin, and thus the estimated change point. It appears that in this case, the algorithm used to calculate the maximum likelihood estimate of the breakpoint may be relatively sensitive, at least to the distribution of observations towards the lower end of the observed range.

Although this exercise has not been used to propose new $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ values, any estimation of these reference points from this type of analysis is likely to be significantly higher than those used a present. If $\mathbf{B}_{pa}$ is estimated to be risk averse with respect to $\mathbf{B}_{lim}$ it is likely to be significantly higher than the 10,000t which is currently used.

An empirical retrospective analysis was also carried out from the stock and recruit data sets produced by the last 5 Irish Sea cod assessments. Fig. 10 shows the maximum likelihood estimate of the change point from these data sets. With the exception of data from the 1997 WG these estimates are all within 5% of each other. The change point from the 1997 WG data is different to the rest. A brief examination shows that the SSB/R relationship changed significantly after 1997 (See Fig 11 vs Fig 12). This may have been due to a change in the maturity ogive by the 1998 WG (a doubling of the proportion mature at age 2 and an 18% increase in proportion mature at age 3). It is obvious (and somewhat reassuring) therefore that such a stock dynamic change results in a change in the estimation of the point below which recruitment becomes impaired.

Table 1 Comparison of maximum likelihood estimate of parameters of segmented regression on 2001 WG data for VIIa Cod

SGPA 2002(2) implemented in "R"				O' Brien & Maxwell SGPA 2002(1)			
beta1	alpha2	delta	SSQ	beta1	alpha2	delta	SSQ
0.6492552	6959.367	10719	10.37701	0.649	6959.4	10719	

Table 2 Maximum likelihood estimate of parameters of segmented regression on 2002 WG data for VIIa Cod

2002 WG data Cod VIIa			
beta1	alpha2	delta	SSQ
0.677873	7117.798	10500.19	9.710631

Table 3 Empirical retrospective comparison of maximum likelihood breakpoint estimate using Julious algorithm and the stock recruit pairs from the respective WG's

Data from WG year	Parameters from model fit using Julious algorithm				%difference from 2002 delta
Year	beta1	alpha2	delta	SSQ	
2002	0.677873	7117.798	10500	9.710631	0%
2001	0.6492552	6959.376	10719	10.37701	2%
2000	0.6225155	6785.419	10900	11.43043	4%
1999	0.6855851	7123.258	10390	7.75076	1%
1998	0.7012377	7124.618	10160	7.13700	3%
1997	0.8592365	7300.428	8496	7.299813	19%

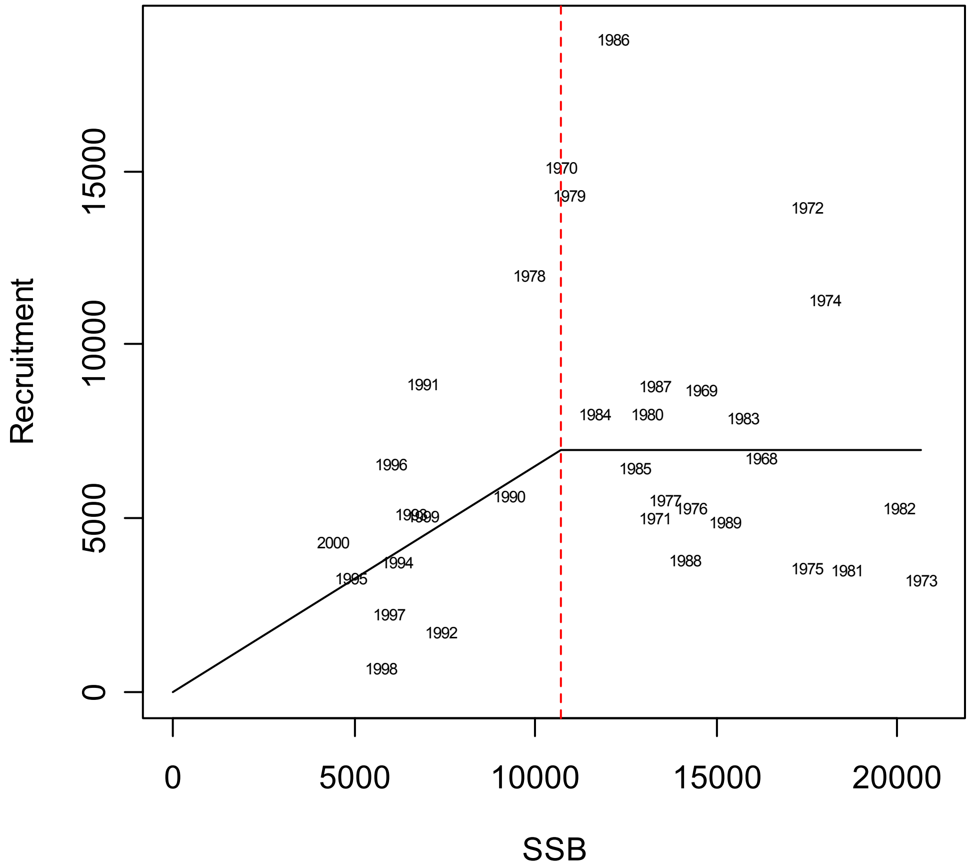


Fig 1 Segmented regression fit to stock and recruitment data for VIIa Cod using data from the 2001 WG

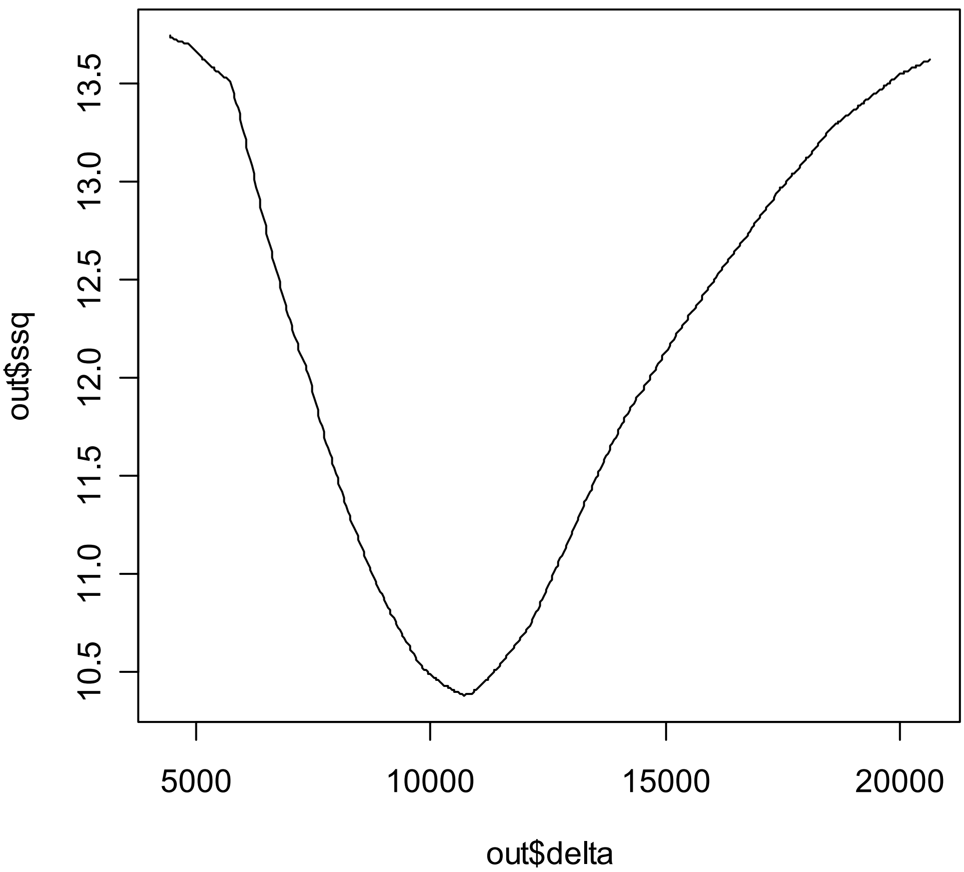


Fig 2 SSQ surface of the estimated breakpoint for Cod VIIa based on data from the 2001 WG

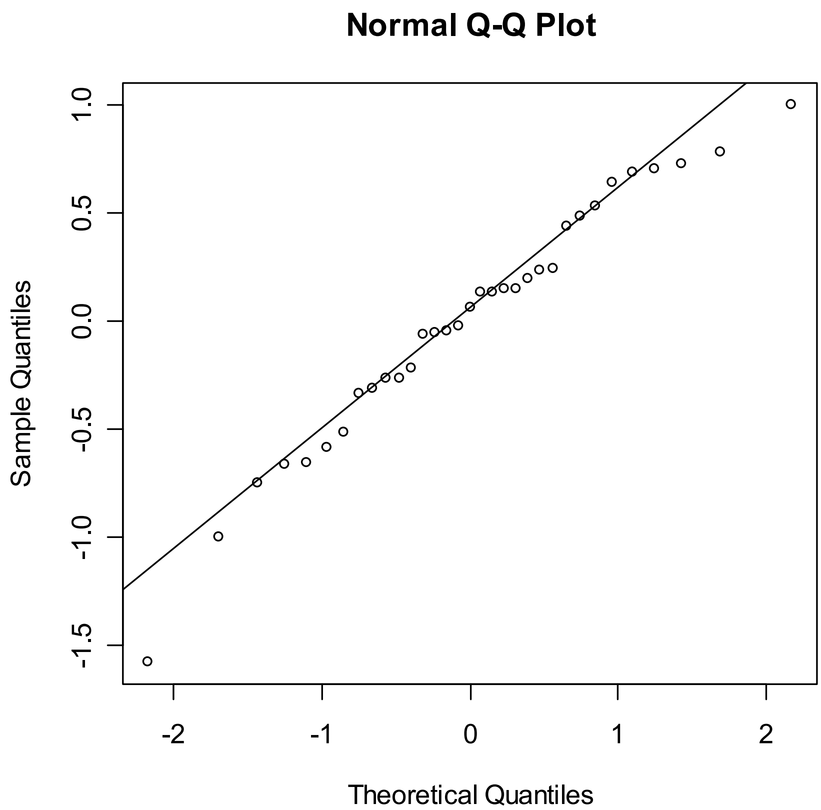


Fig 3 Normal probability plot of residuals Cod VIIa data from 2001 WG

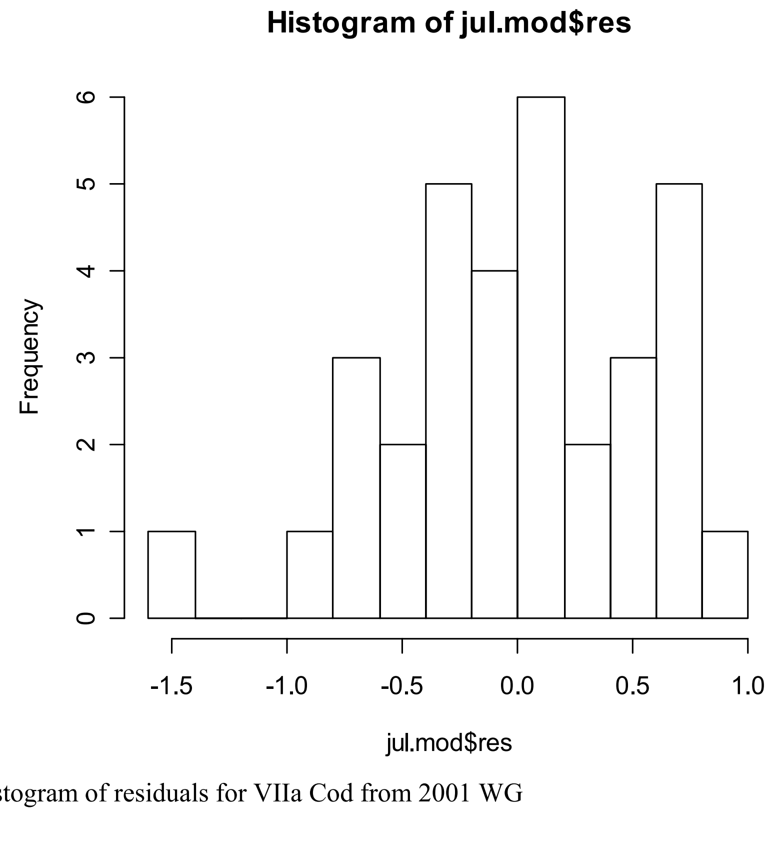


Fig.4 Histogram of residuals for VIIa Cod from 2001 WG

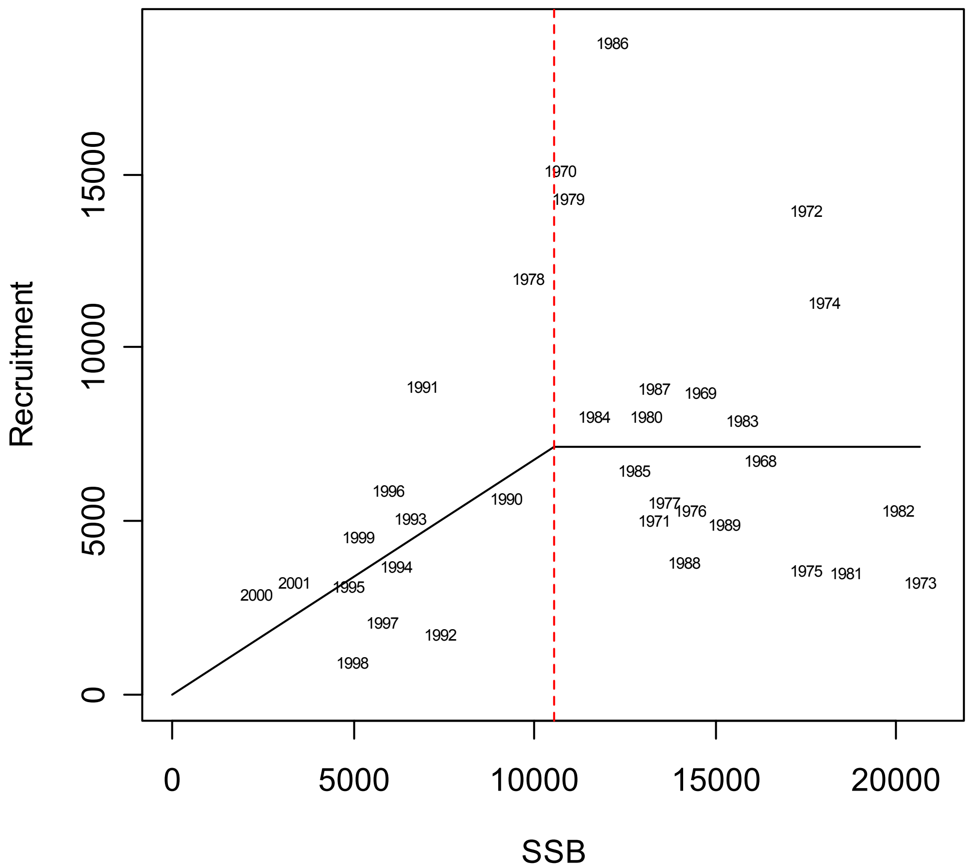


Fig 5 Segmented regression fit to stock and recruitment data for VIIa Cod using data from the 2002 WG

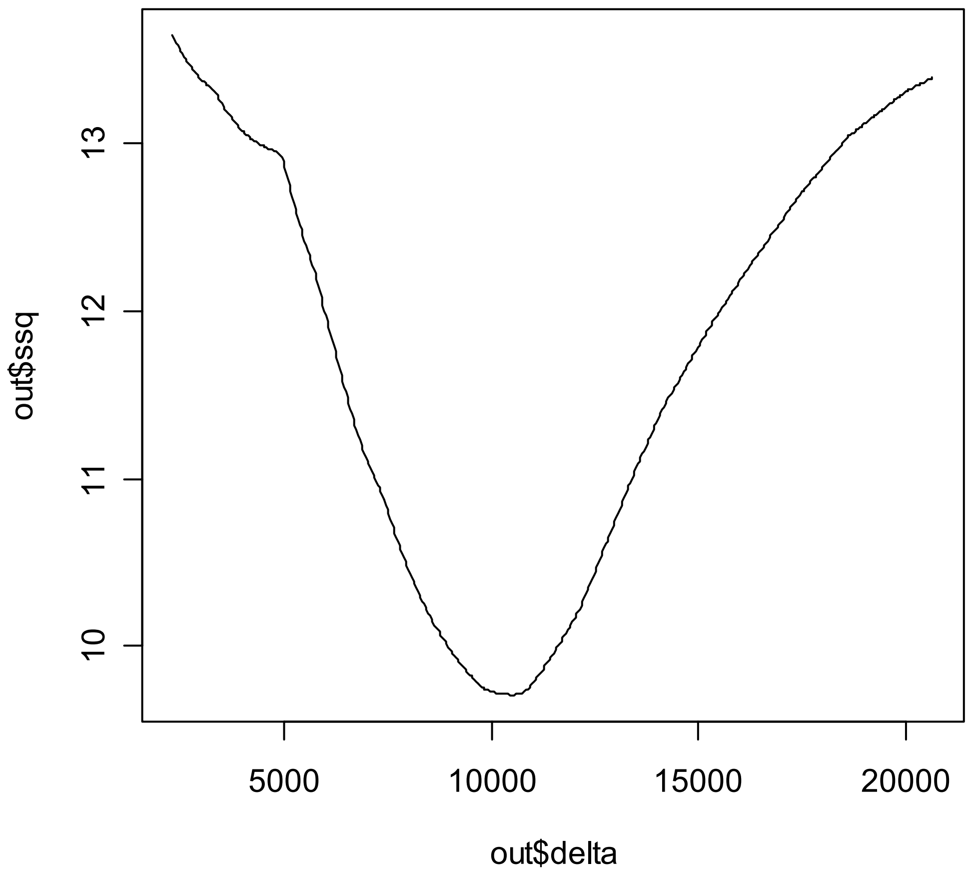


Fig 6 SSQ surface of the estimated breakpoint for Cod VIIa based on data from the 2002 WG

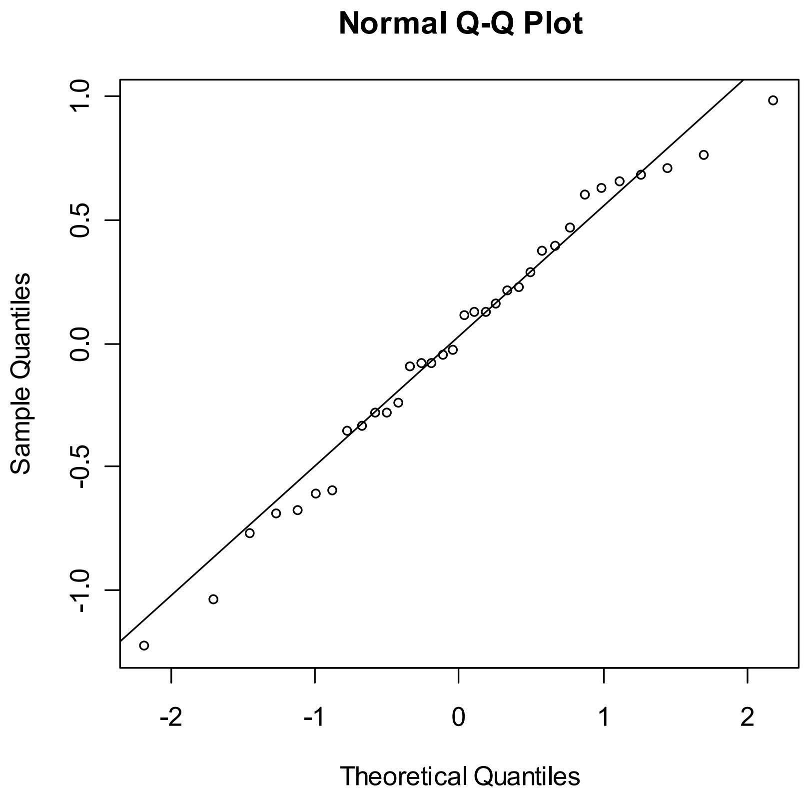


Fig 7 Normal probability plot of residuals Cod VIIa data from 2002 WG

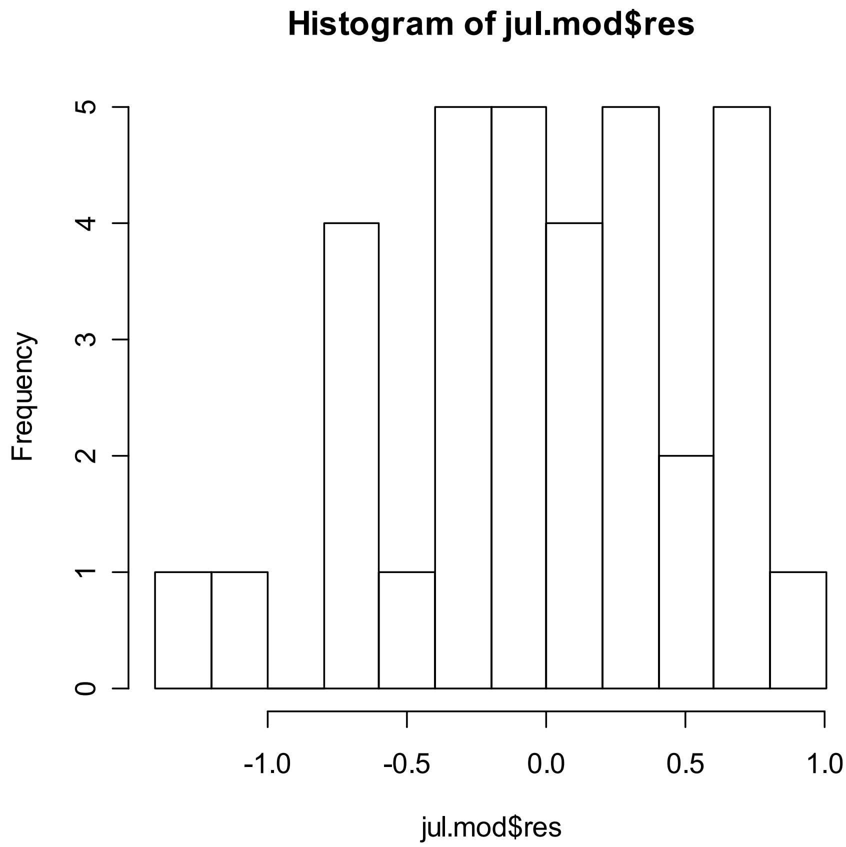


Fig.8 Histogram of residuals for VIIa Cod from 2002 WG

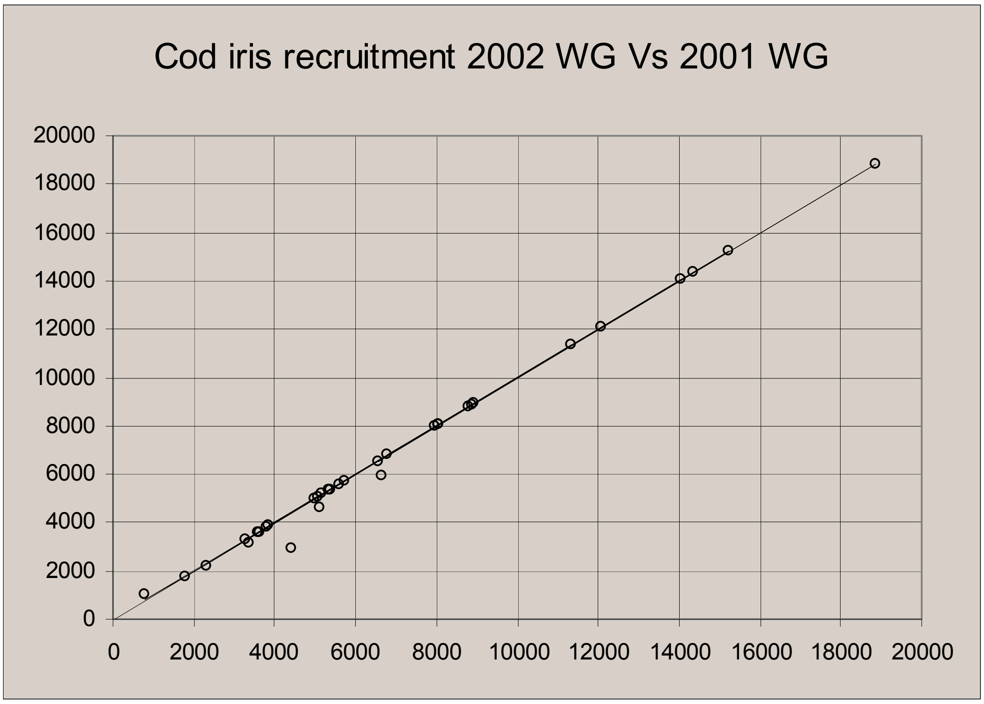


Fig.9 Plot of recruitment of VIIa Cod from the 2002 WG Vs the 2001 WG

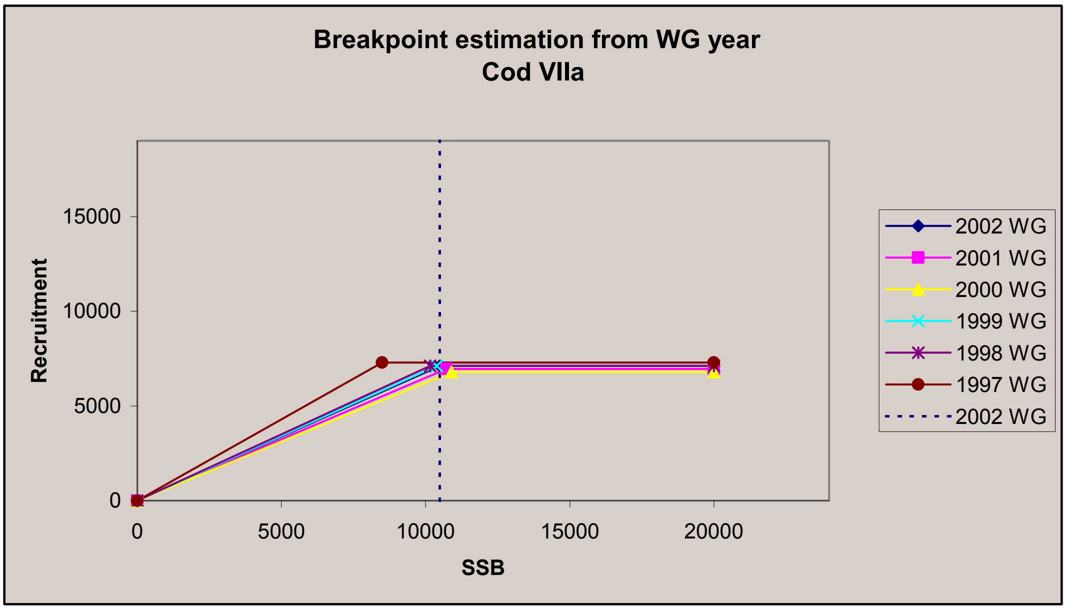


Fig. 10 Change in breakpoint estimate based on data from previous WG's. Data from the final two years of stock size and recruitment were not used from each WG .

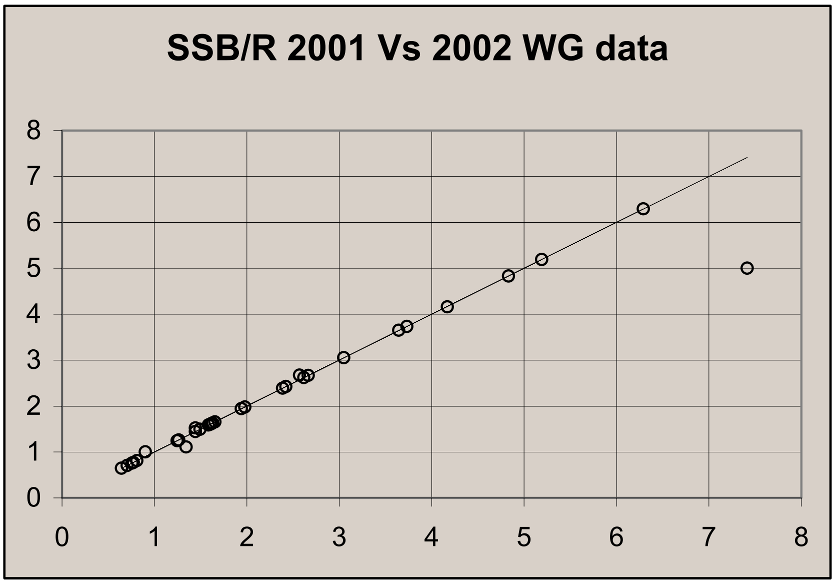


Fig. 11 Comparison of SSB/R between the 2001 and 2002 assessments, note the large outlier at the extreme due to the very low estimate of the 1998 year class from the 2001 assessment.

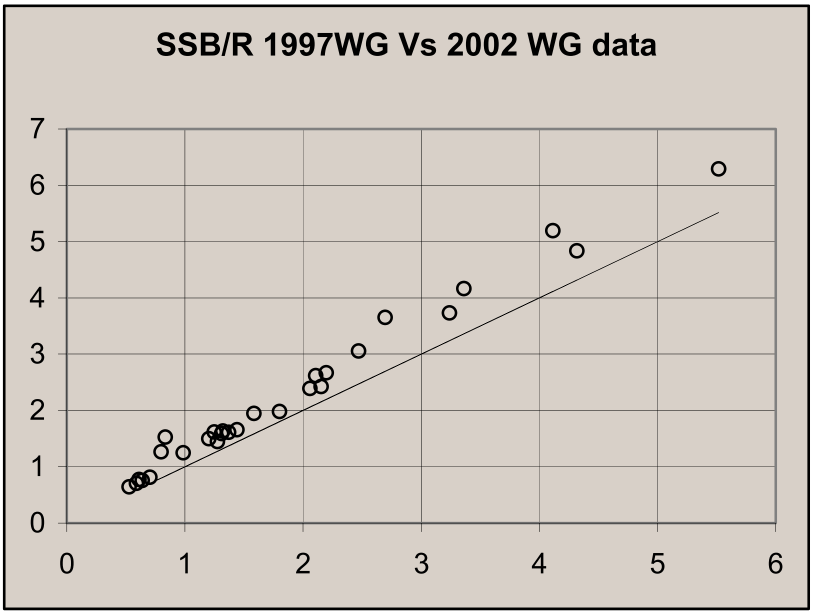


Fig. 12 SSB/R comparison between the 1997 WG and 2002 WG.

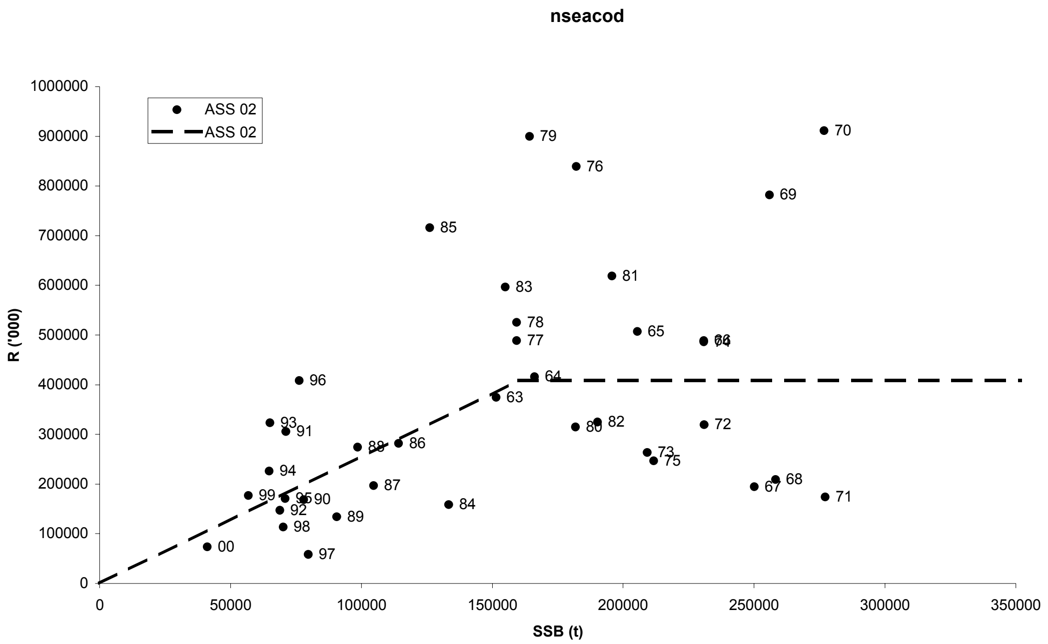
Cod in the North Sea (Division IV)

An exploratory segmented regression analyses was performed for North sea cod. First a run using the same input data as O'Brien and Maxwell (2002) (2001 assessment, 1963-000) was done, and the same results were obtained.

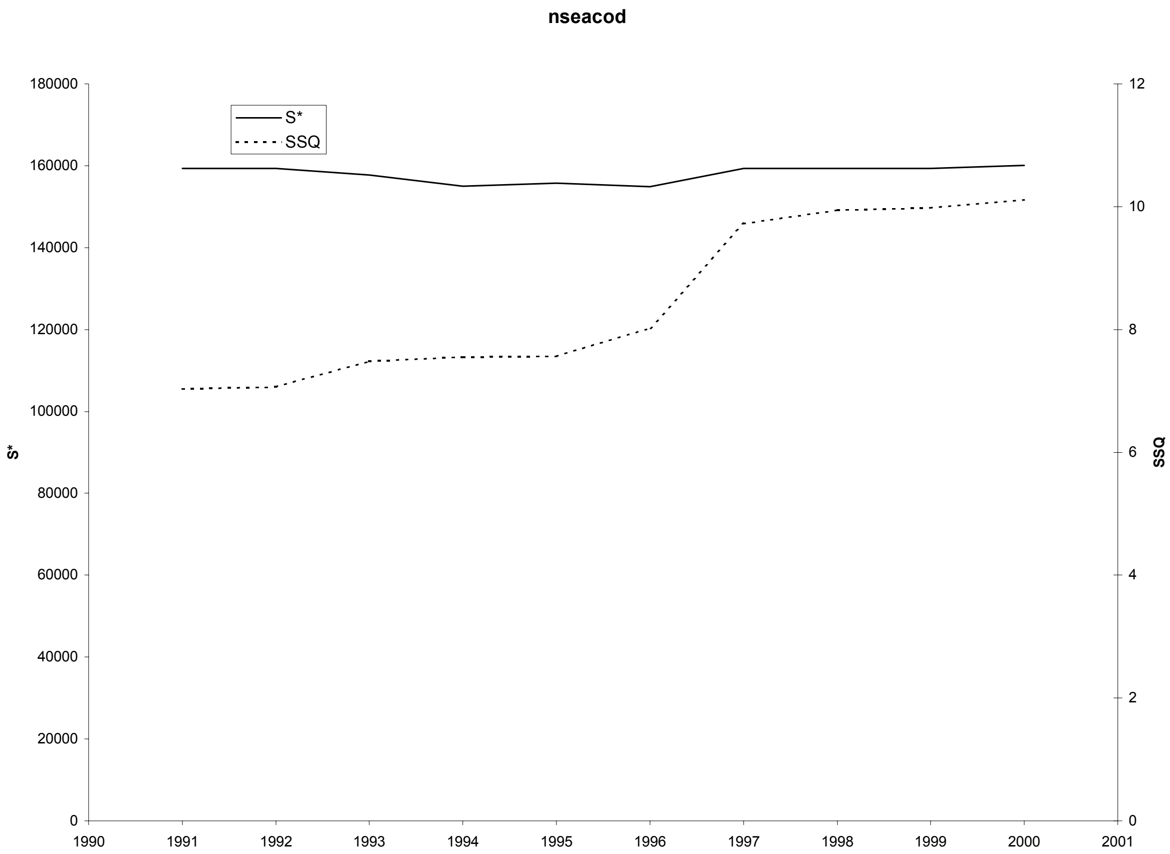
From algorithm in Julious (2001)		
S*	$\hat{\alpha}$	**R***
159349	2.62	417758

A new run were done using input data from the last assessment (double the reported landings. (ICES CM 2003/ACFM:02)..

	Julious algorithm					
Inputdata	**S***	**â**	**R***	SSQ	F-value	p-value
2002 Ass. 1963-2000 WC	**160048**	2.555	408863	10.11	23.76	<0.01



A change point can be identified at 160,048 t, with approximate 0.1 and 0.9 percentiles at 127,136.9 t and 198,593.4 t respectively.



Sensitivity analyses showed that the results are quite stable for the last 10 years, whereas the uncertainty of the fitting (ssq) jumped in 1997 to a higher level. (see figure above)

The influence of individual years is small, as tested by fitting the model to the whole data series dropping a year in turn.

Precautionary Approach reference points (unchanged since 1999)
source: ICES CM 2002/ACFM:01

ICES considers that:	ICES proposes that:
$\mathbf{B}_{lim}$ is 70 000 t, the lowest observed spawning stock biomass.	$\mathbf{B}_{pa}$ be set at 150 000 t. This is the previously agreed MBAL and affords a high probability of maintaining SSB above $\mathbf{B}_{lim}$, taking into account the uncertainty of assessments. Below this value the probability of below average recruitment increases.
$\mathbf{F}_{lim}$ is 0.86, the fishing mortality estimated to lead to potential stock collapse.	$\mathbf{F}_{pa}$ be set at 0.65. This F is considered to have a 95% probability of avoiding $\mathbf{F}_{lim}$, taking into account the uncertainty of assessments.

Technical basis:

$\mathbf{B}_{lim}$ = Rounded $\mathbf{B}_{loss}$ = 70 000 t.	$\mathbf{B}_{pa}$ = Previous MBAL and signs of impaired recruitment below: 150 000 t
$\mathbf{F}_{lim}$ = $\mathbf{F}_{loss}$ = 0.86	$\mathbf{F}_{pa}$ = Approx. 5th percentile of $\mathbf{F}_{loss}$; implies an equilibrium biomass >$\mathbf{B}_{pa}$ and a less than 10% probability that (SSBMT<$\mathbf{B}_{pa}$)

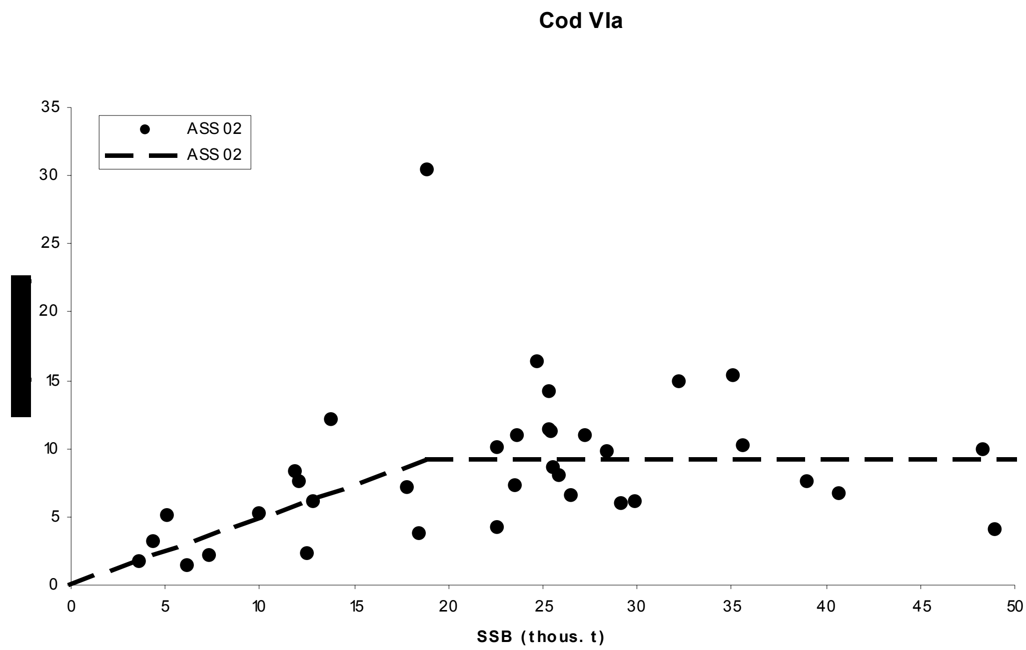
Cod at the West of Scotland (Division VIa)

The "R" software version of the segmented regression approach described in O'Brien & Maxwell (2001) was used to reproduce the SGPA 02a results using the same assessment data for VIa cod for the years 1966-1999. The approach was then repeated using the latest assessment data for the period 1967 to 2001.

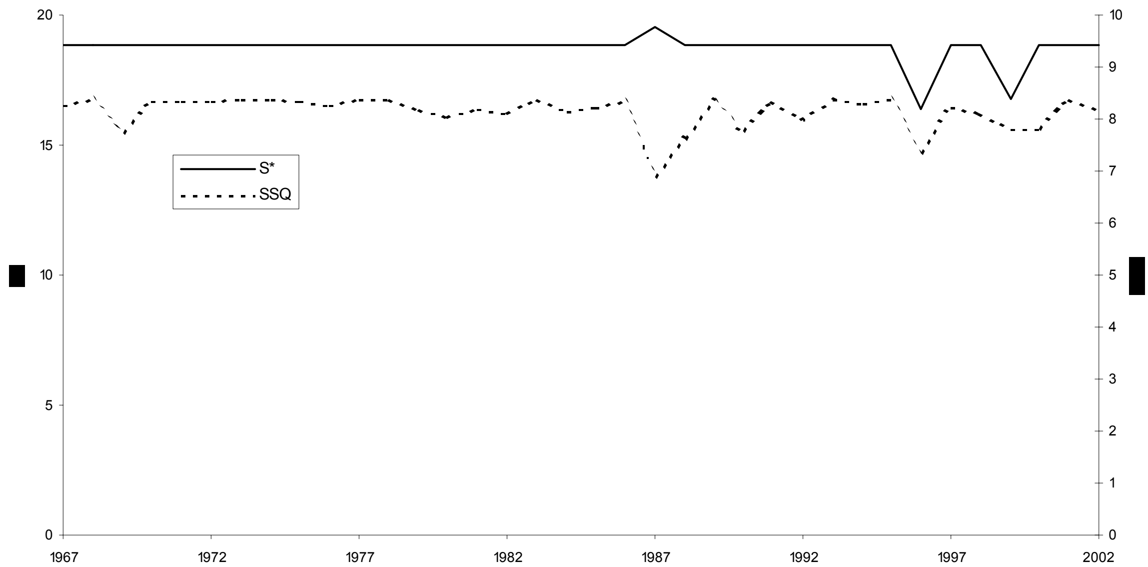
The first calculation obtained the same results as before, so that the second calculation could be carried out with confidence in the software. The following table summarises the two reuslts:

Cod VI a	From algorithm in Julious (2001)					
	$\hat{\alpha}$	R*	**S* = B**$_{lim}$	SSQ	F value	p-value
Ass. 2001	0.485	9.24	**19.04**	3.99	14.32	<0.001
Ass. 2002	0.486	9.16	**18.86**	6.80	27.57	<0.001

The segmented regression model fit to the 2002 assessment R-SSB data is plotted below. The estimated **B**$_{lim}$ values in both assessment years are each statistically significant. The estimated current **B**$_{lim}$ (= **S***) of assessment year 2002 appears to be 18.86k tonnes whereas that of assessment year 2001 is 19.04k tonnes. Thus, they differ only marginally from each other. The sensitivity plot of **S*** and SSQ against year (based on dropping out one year of data at a time) is generally stable over most of the range of years, with three larger peaks between 1987 and 2002.



Cod VIa



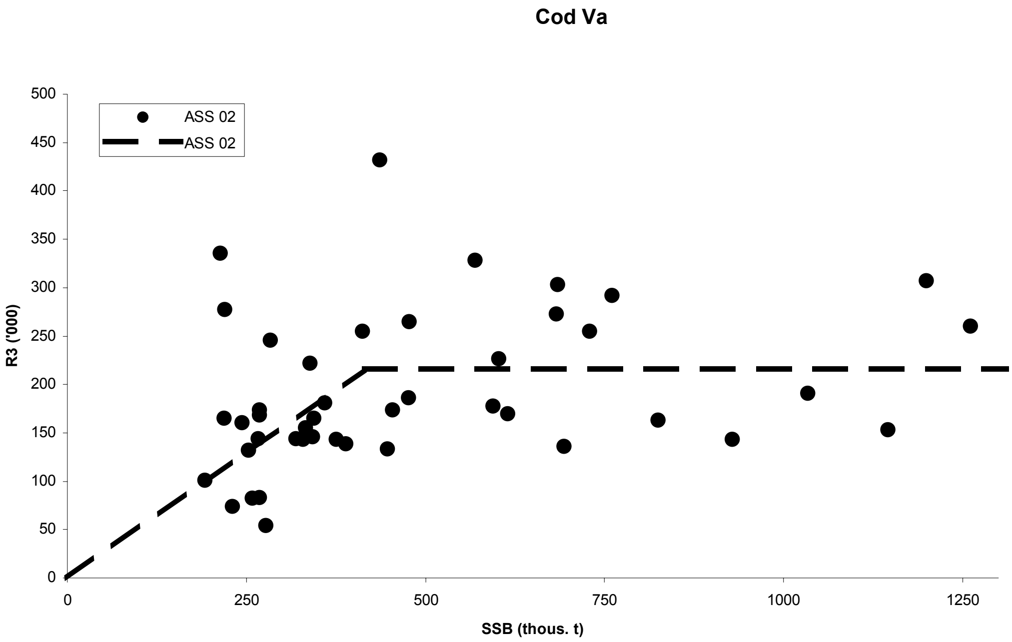
S*
SSQ
20
15
10
5
0
10
9
8
7
6
5
4
3
2
1
0
1967
1972
1977
1982
1987
1992
1997
2002

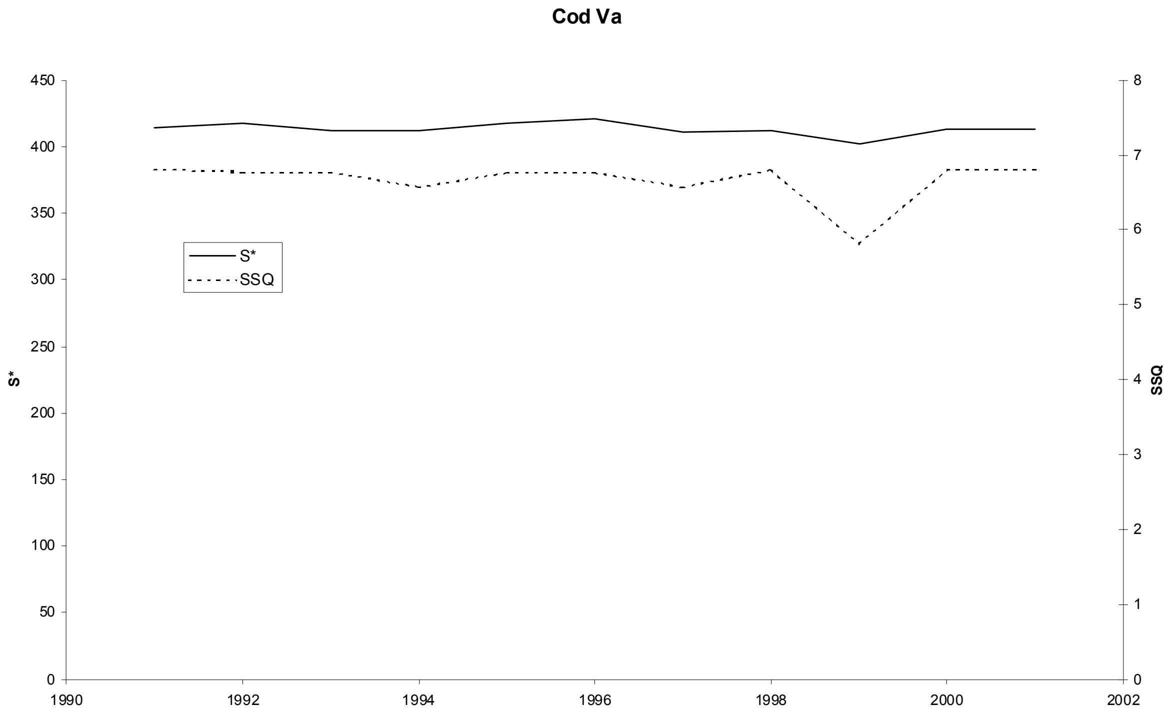
Cod at Iceland (Division Va)

The segmented regression approach was applied to Icelandic cod R-SSB data for the year-classes 1955 to 1998. The same procedure was also applied for a shorter time interval, i.e. for 1975-2001. The following table summarises the results for estimating $\mathbf{B}_{lim}$ as the point of the change point :

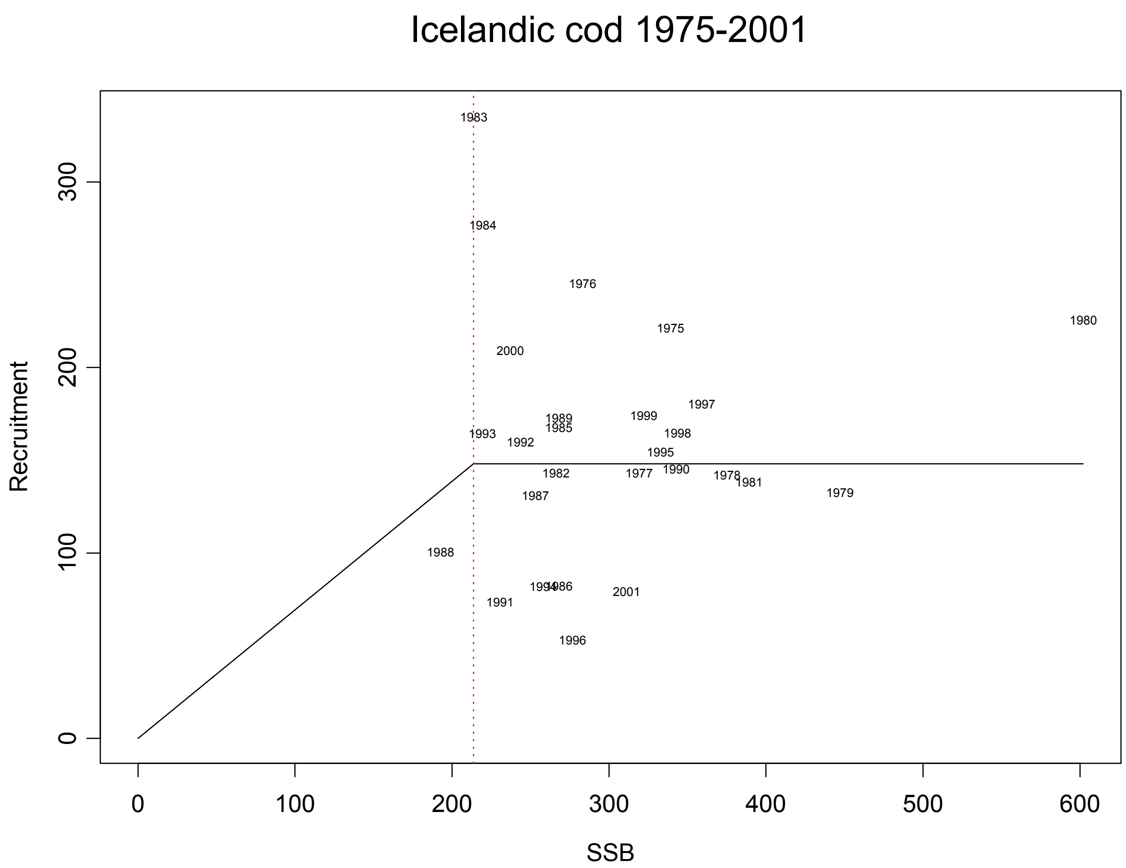
Icelandic cod	From algorithm in Julious (2001)					
	$\hat{\alpha}$	R*	**S* = $\mathbf{B}_{lim}$**	SSQ	F value	p-value
Ass. 2002 1955-1998	0.522	216381	**414234**	1.057	6.517	0.0144
Ass. 2002, 1975-2001	0.693	148092	**213799**	4.58		

The segmented regression model have been fitted to the scatter diagram of recruitment against SSB below. The table shows that the estimated $\mathbf{B}_{lim}$ value for the longer series (414234 tonnes) appears to be statistically significant at the 5% significance level but not at the 1% significance level. The Figures overleaf show the sensitivity analysis (leaving-out one year at a time), and the regression fitted to the 1975-2001 data, which show a much lower change point than the whole series. $\mathbf{B}_{lim}$ is therefore dependent on the time series used.





Cod Va
S*
SSQ
s*
ssq
450
400
350
300
250
200
150
100
50
0
8
7
6
5
4
3
2
1
0
1990
1992
1994
1996
1998
2000
2002



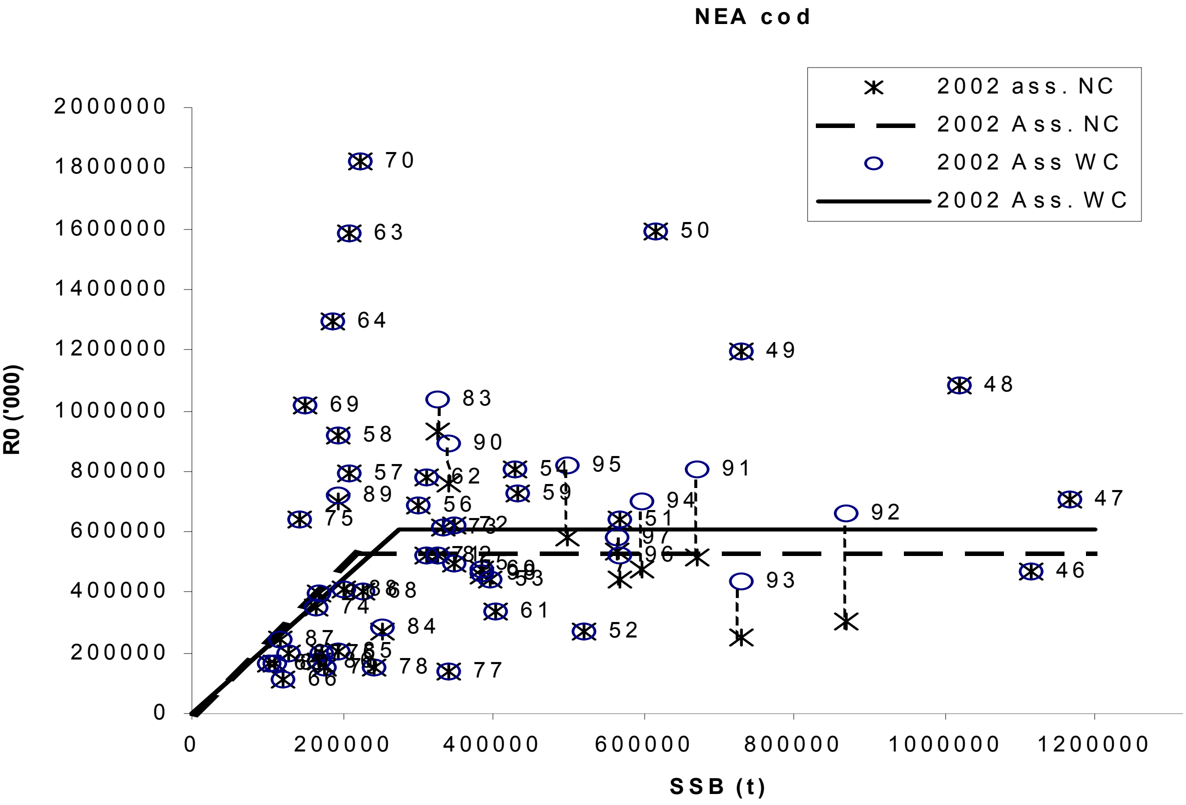
Icelandic cod 1975-2001
Recruitment
SSB
0
100
200
300
400
500
600
1983
1984
1976
1975
1980
2000
1997
1989
1985
1999
1993
1992
1998
1995
1990
1982
1977
1978
1981
1979
1987
1988
1986
2001
1991
1996

Northeast Arctic cod

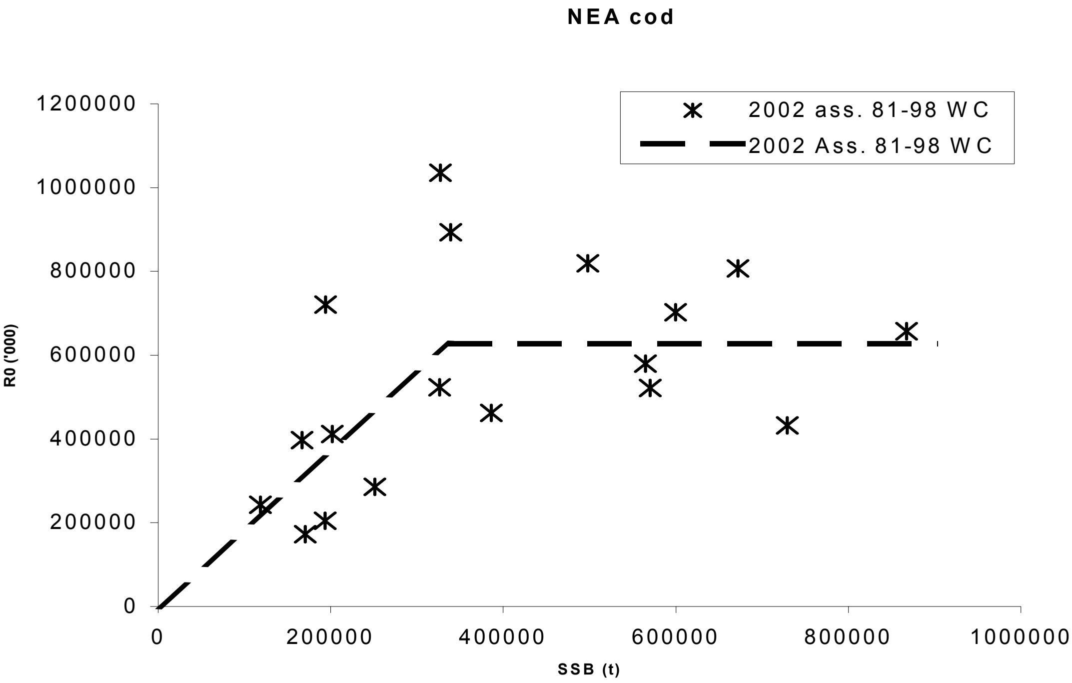
Exploratory segmented regression analyses were performed for Northeast Arctic cod. The first run used the same input data as O'Brien and Maxwell at SGPA 02a (i.e. 2001 assessment, 1946-1997, with cannibalism) and the same results were obtained.

New runs were performed using input data from the most recent assessment (ICES CM 2002/ACFM:18). First, SSB-R pairs from the converged part of the XSA time series (1946-1998), without and without cannibalism, were used. The segmented regression with cannibalism gave similar results to those obtained by O'Brien and Maxwell at SGPA 02a, but the run without cannibalism resulted in a somewhat lower change point because, when cannibalism is excluded from the XSA, the recruitment values for the SSB-R pairs are reduced, mainly at high SSB in the right hand part of the SSB-R plot, and the change point is shifted to the left.

	Julious algorithm					
Inputdata	**S***	**â**	**R***	SSQ	F-value	p-value
2001 Ass. 1946-1997 WC	278687	2.21	616621	19.3	14.74	>0.001
2002 Ass. 1946-1998 WC	274384	2.21	607322	19.3	14.60	>0.01
2002 Ass. 1946-1998 NC	224482	2.35	526716	19.8	11.92	>0.001
2002 Ass. 1981-1998 WC	339048	1.85	627143	2.3	15.25	>0.001



Then a run was performed with cannibalism included, but estricted to the part of the time series with stomach data (1981-1998). The resulting change point is higher than for the whole time series. The slope of the regression line is reduced and the change point is shifted to the right, indicating that recruitment starts becomes impaired at higher SSB-values than in the past.



Sensitivity analyses showed that, at least for the last five years, the results are quite stable for both time series.

Northern Hake

The analysis was done on the data from the May 2002 assessment and the results are compared with the output from the analysis on the 2001 assessment data presented at SGPA 02a (Lisbon, March 2002)

N. Hake	Julious					
	â	R*	S*	ssq	F value	p-value
Ass. 2001	1.866	348485	**186782**	1.68	4.02	0.039
Ass. 2002	1.836	279620	**152303**	1.41	4.98	0.040

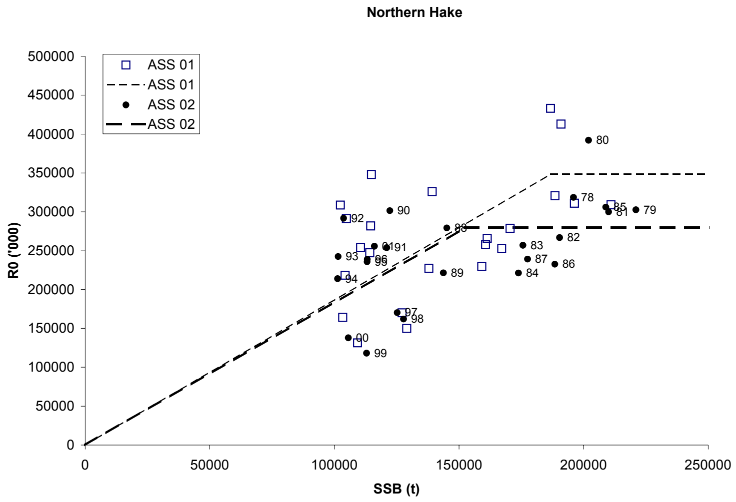
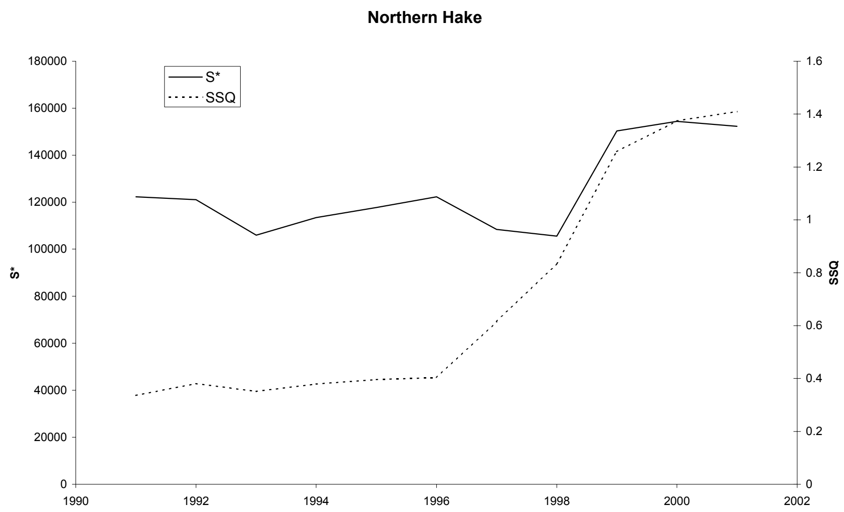


Fig .xx.1. Segmented resression fitted to N Hake data from WGSSDS 2001 and WGHMM 2002.

The change point (in SSB) has been revised downward by 18% from 187000t to 152000t as a consequence of the revised stock-recruitment data from the 2002 assessment relative to the 2001 assessment (fig. 1). The revision in the assessment's output is mainly due to change in the inputs (exclusion of age 0 in the catch matrix as they were very low in recent years and inclusion of a new tuning fleet).

The sensitivity analysis on the 2002 assessment data (Fig. xx.2) shows that the change point estimation is quite sensitive to the recent changes in the stock-recruitment data for the 4 recent and successive low recruitments (year-classes 1997 -2000). The SSQ residuals also increase significantly indicating poorer fit.



B. Comparing the segmented regression and the kernel method by scenario modelling

The performance of segmented regression and the non-parametric estimator could be compared using a simulation framework applied to a range of stocks for a variety of assumptions in order to compare the performance and robustness of the two methods. The stocks should be chosen to represent a range of dynamics. The following is a likely prescription for the simulation approach (Kell, pers comm).

The simulation framework consists of a population based upon the ICES working group "SEN" & "SUM" files. Natural mortality-, weights-, selection pattern- and maturity-at-age will come from the SEN files. The stock and recruitment relationship(s) will be a Beverton and Holt curve fitted to the Stock-Recruit pairs in the SUM files.

The population will consist of two parts, historical and future. The historical component will consist of 30 years, initially at equilibrium, where the trend in fishing mortality is the same as the mean fishing mortality in the SUM file. Three levels of fishing mortality should be simulated corresponding to a population at the end of the historical period below, at or above $\mathbf{B}_{pa}$. The future period will correspond to twenty years during which fishing mortality will be equal to $\mathbf{F}_{pa}$.

Uncertainty in the stock and recruitment relationship will be modelled by bootstrapping the residuals to the assumed stock and recruitment relationship. Uncertainty in the selection pattern will also be included and correspond to a log normal error with a 20% CV.

Time series of SSB and recruits for use by segmented regression and the non-parametric estimator will be derived using XSA fitted using the catch-at-age and a single index of CPUE covering the main ages in the stock. XSA will be fitted in each of the future years (i.e. 20 times) and $\mathbf{B}_{lim}$ estimated for the two methods.

Initially the simulation will only model process error (stock and recruitment and selection pattern) and estimation error (XSA). It will be assumed that management based upon fishing mortality can be implemented perfectly and that catch-at-age, natural mortality, weights and maturity-at-age are known without error (i.e. there will be no implementation or measurement error). Other forms of uncertainty could be explored, however.

The properties of using different parts of the time series, i.e. unconverged verses converged, could also be compared.

The estimates of $\mathbf{B}_{lim}$ obtained by the two methods can be compared to each other and to the stock recruitment relationship used in the simulated population. For example a meaningful statistic may be to derive from the stock recruitment relationship used in the simulated stock, the expected recruitment at $\mathbf{B}_{lim}$ as a percentage of recruitment at virgin biomass. The Study Group did not have time to discuss in detail this final evaluation procedure, or how to proceed further if the estimates from the two methods differ.

A key question is, even if the data are simulated and some stock-recruit relationship is structured in, at what point on the S-R function does recruitment become impaired? The suggestion to use some percentage of the recruitment expected at virgin biomass has precedents, e.g the recruitment that is 50% of the peak of a Ricker dome ('RK50'), or 50% of the Beverton-Holt asymptotic recruitment ('BH50') as reviewed by Rosenburg et al., but this is still an arbitrary choice. But if that recruitment is chosen as the criterion, then the non-parametric methods lose their subjective step, because what constitutes "impaired recruitment" then becomes specified (i. 'NP50'). In effect, therefore, there is no difference in objectivity between the parametric and the non-parametric methods, but the advantage of the latter is that it is more explicit that a choice is being made.

C. Comparing two differently derived $\mathbf{B}_{lim}$ values with each other

If testing the compatibility (or equivalence) of two $\mathbf{B}_{lim}$ values i.e. whether $\mathbf{B}_{lim}$ values derived by historical (or alternative) procedures differ from those derived by the segmented regression currently in use can be in principle done in two ways,

- either by carrying out a significance test (for instance, a parametric t and F test similar to a one-way ANOVA, respectively, or some non-parametric test)
- or by constructing a confidence interval around the estimated $\mathbf{B}_{lim}$ values to be compared (depending on the fact whether the associated variances exist).

In case using a parametric test method and if the variance of the alternative (or historical) $\mathbf{B}_{lim}$ value does not exist the estimated parameter $\mathbf{B}_{lim}$ of the segmented regression must be taken as central moment (together with its variance) in order to construct this test, assuming a (asymptotic) normal distribution of $\mathbf{B}_{lim}$ of the segmented regression. A generalization of this significance test allows for an inclusion of the variance of the alternative (or historical) $\mathbf{B}_{lim}$ value if this exist.

However, constructing confidence intervals around the two estimated $\mathbf{B}_{lim}$ values to be compared and inspecting whether the (one or vice versa the other) $\mathbf{B}_{lim}$ value falls into the (one or vice versa the other) interval leads to the same result but may be intuitively more informative for non-statisticians. Nevertheless, if the variance associated with the alternative (or historical) $\mathbf{B}_{lim}$ value does not exist (which may be the most frequent case) the $\mathbf{B}_{lim}$ value estimated from the segmented regression must be also taken here as central moment of the confidence interval (together with its variance) and the alternative (or historical) $\mathbf{B}_{lim}$ value must be considered to be constant.

Annex 10

Estimating an Fpa that is risk averse to B_{lim} and B_{pa}

This text describes a proposed methodology that still requires further discussion and evaluation.

a) The relationship between F_{pa} and B_{lim}

So far, $\mathbf{F_{pa}}$ has been derived so that when the fishery is estimated to be at $\mathbf{F_{pa}}$ there should be a low risk of the realised F being above $\mathbf{F_{lim}}$. If when advising $\mathbf{F_{pa}}$ it is desired that there should also be a low risk of SSB being below $\mathbf{B_{lim}}$ (the risk 'across the diagonal' in Figure 1) it is proposed (Skagen, pers comm) that two distributions should be combined, the distribution of realised F when $\mathbf{F_{pa}}$ is intended, and the natural variation of SSB at a realised F near $\mathbf{F_{lim}}$. It is therefore proposed that:

If Ps(SSB|F) is the probability distribution of SSB at a realised F (as computed by some long term equilibrium method – see below) and $Pf(F_{realised}|F_{intended})$ is the probability distribution of the realised F given the intended F (as estimated in section 3.5.1), then the probability distribution of SSB when intending to apply $\mathbf{F_{pa}}$ is the convolution of the conditional distributions:

$$P(SSB|F_{intended}) = \int_{AllFrealised} Ps(SSB|F_{realised})*Pf(F_{realised}|F_{intended})\, dF_{realised} \qquad (1)$$

If this results in an unacceptable probability that SSB is below $\mathbf{B_{lim}}$ because of a broad distribution of $P(SSB|F_{intended})$, it may be necessary to reduce Fpa until the probability that SSB is below $\mathbf{B_{lim}}$ becomes acceptable.

Ps(SSB|F), the distribution of true SSB at a given realised F, representing the natural variation in SSB, could be obtained as a long term equilibrium distribution. Several tools are available for obtaining such distributions, e.g. a forward stochastic projection, run forwards in time until all transients have subsided, or an iteration between distributions of recruitment and of SSB, as in the LTEQ programme. Such procedures should produce the same results. In all cases, it is essential to ensure that the distributions of the stochastic parameters are representative of reality. Quality checks e.g. of the probability coverage, should therefore be carried out as an integral part of the analysis and included in the documentation of the results. When projection methods are used, the time frame should be determined in each case by applying appropriate convergence criteria.

This proposal, and its underlying assumptions, have not yet been tested using real data, and one suggested criticism is that there are a number of parametric assumptions implicit in the above derivation that need to be tested carefully (Rice, pers comm).

b) The relationship between F_{pa} and B_{pa}

It is proposed (Skagen, pers comm) that if it is desired to have an $\mathbf{F_{pa}}$ that corresponds to a low probability of SSB being below $\mathbf{B_{pa}}$,(i.e $\mathbf{F_{pa}}$ is risk averse to $\mathbf{B_{pa}}$, which is already risk averse to $\mathbf{B_{lim}}$), then $\mathbf{F_{pa}}$ should be derived from the probability distribution of the yearly estimates of SSB conditional on the intended F when F is $\mathbf{F_{pa}}$. It is proposed that this probability, $P(SSB_{est}|F_{intended})$, is derived as follows:

1) $P(SSB_{est}|F_{intended})$ can be derived as a convolution of the distribution of $P(SSB_{true}|F_{intended})$, the true SSB conditional on the intended F, and the distribution of $P(SSB_{est}|SSB_{true})$, the estimated SSB conditional on the true SSB. This complexity accounts for several sources of uncertainty which cannot be estimated in a single step.

2)$P(SSB_{true}|F_{intended})$ can be obtained by applying equation 1 above.

3) The distribution $P(SSB_{est}|SSB_{true})$ can be constructed from the set of SSB_{est},SSB_{true} pairs described in Section 3.6 based on the same procedure as used for the intended and realised F in Section 3.5.1

4) The distribution of estimated SSB at candidate levels of Fpa is then the convolution of the distribution of the true SSB, and the distribution of estimated SSB when the true SSB is at Bpa, i.e:

$$P(SSB_{est}|F_{pa}) = \int_{All\ SSBtrue} P(SSB_{true}|F_{pa}) * P(SSB_{est}|SSB_{true})\, dSSB_{true} \qquad (3.2)$$

If the probability of estimated SSB being below $\mathbf{B_{pa}}$ is unacceptably high, lower values of $\mathbf{F_{pa}}$ may be required.

This proposal and its underlying assumptions have not been tested.

Targets and boundaries

It is likely that in order to be risk averse to $\mathbf{B_{lim}}$ and $\mathbf{B_{pa}}$, the two approaches outlined above will lead to a very conservative value for $\mathbf{F_{pa}}$. This stems from the incorporation of the additional risk, and the implied use of $\mathbf{F_{pa}}$ and $\mathbf{B_{pa}}$ as targets (whereas ICES intends that precautionary reference points should be used as boundaries, whereby, long term, F should be below $\mathbf{F_{pa}}$, and SSB above $\mathbf{B_{pa}}$).