Advisory Committee on Fishery Management

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Study Group on the Further Development of the Precautionary Approach to Fishery Management

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4–8 March 2002

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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Colin Bannister (Co-Chair)	UK (England & Wales)
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1.2 Terms of Reference

Under the terms of Council Resolution 2ACFM05, 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 IPIMAR in Lisbon, Portugal from 4-8 March 2002 to:

a) further develop the ICES strategy for providing advice on rebuilding plans taking into account

i) the problems of severity, time-scale, and uncertainty
ii) the need to describe the costs and benefits of rebuilding plans
iii) the need to monitor the trajectory of recovery and advice when rebuilding
iv) plans have reached their target

b) continue the development of the framework for formulating advice for

stocks under full analytical assessment,

i) where the reference points are based on F loss and B loss
ii) are based on historical evidence of reduced recruitment at low SSB levels

stocks with short life-spans supporting recruitment fisheries eg small pelagics
data poor situations eg deep water species

c) develop criteria for identifying stocks and assessments where it is meaningful to calculate $\mathbf{F}_{MSY}$ and $\mathbf{B}_{MSY}$

d) revise the description of the PA concepts introducing the ACFM report to make them more intelligible for non-fishery users
e) respond to any initiative from NAFO on the harmonisation of precautionary concepts and terminology

f) the Group shall report to ACFM at its may 2002 meeting.

The Scientific Justification for the Group was as follows:

'The work on developing the PA has continued within ACFM and ACFM has developed a practice. With the workload on ACFM it is unsatisfactory to continue to use this vehicle for development. It is desirable to open the discussion to involve also scientists outside ACFM.

ACFM adopted at its May 2001 meeting draft principles on which to formulate the ACFM advice. These principles include the use of rebuilding plans under certain conditions without this term being precisely defined. ACFM furthermore faced significant problems in formulating consistent advice for deep water species and for some other species for which data are either lacking or scarce. The SG should analyse these situations and propose to ACFM how a consistent policy might be formulated in these cases. MCAP found that there was a strong need for this group'

1.3 Working Documents

The following 25 Working Documents were prepared and presented at the Study Group. These are cited in the text of the report where relevant, and a number of key papers are included in the Annexes, as indicated in the relevant part of the text of the report. The Study Group agreed that all the working documents should be made available later in their entirety in an appropriate form such as a CD Rom.

WD1
Azevedo, M., Morgado, C. & Cardador, F.
Are there general patterns in SSB-R relations and F-SSB trajectories that can be used as guides for establishing PA reference points?

WD 2
William Silvert
Fuzzy Logic Modelling of Traffic Light Indicators

WD 3
Jakobsen,T and H Sparholt
Short-term forecast. Defining Status Quo F-the Status quo F versus TAC constraint. F advice versus SSB advice

WD 4.
Sparholt, H.
Quality of ACFM advice: How good have forecasts been since 1988?

WD 5
Ajiad, A. and T. Jakobsen
Incorporating Age Diversity Index and Temperature in the Stock- Recruitment Relationship of Northeast Arctic Cod

WD 6
Skagen, Dankert W.
Reference Points for Blue Whiting Revisited

WD 7
Cárdenas, E de
P A reference points for hake.

WD 8
O'Brien, C.M. and Maxwell, D.L.
Towards an operational implementation of the Precautionary Approach within ICES - biomass reference points

WD 9
O'Brien, C.M. and Smith, M.T.
A diagnostic for G_{loss}

WD 10
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic saithe (Sub areas I and II).

WD11
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of northern hake.

WD12
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic cod (Sub areas I and II).

WD13
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Sub area IV, Divisions IIIa and VIId.

WD14
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIa.

WD15
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIa.

WD16
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIe-k.

WD17
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of plaice in Division IIIa.

WD18
O'Brien, C.M., Maxwell, D.L. and Roel, B.A.
A segmented regression approach to the Precautionary Approach – the case of herring in Subarea IV, Divisions IIIa and VIId.

WD19
O'Brien, C.M., Maxwell, D.L., Roel,B.A. and Basson, M.
A segmented regression approach to the Precautionary Approach – the case of the Thames Estuary (or Blackwater) herring.

WD20
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Atlantic mackerel.

WD21
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the cases of anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa).

WD 22
Azevedo, M. & Cadima, E.
Stock conservation properties of $\mathbf{F}_{0.1}$

WD 23
Darby, C
Assessment model structural uncertainty in the estimation of Precautionary Reference Points.

WD 24
Brodie, W.
Development of a Precautionary Approach in the Northwest Atlantic Fisheries Orgnaisation (NAFO)

WD 25
Kell, L   Multi-annual TAC simulations

2 THE PRECAUTIONARY APPROACH IN ICES

2.1 Background

Since 1998, 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, explicitly referred to in the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, was first introduced into ICES advice in 1981 and further developed in 1986 (Serchuk and Grainger, 1992). The subsequent application of the Precautionary Approach in ICES is encompassed by the work of the three ICES Study Groups on the Precautionary Approach (Anon, 1997, 1998a and 2001a). The 1997 Study Group (Anon 1997) outlined the legal requirements, described how reference points should be defined and calculated, and proposed the use of pre-agreed harvest control rules and recovery plans to maintain or restore stocks within safe biological limits. The 1998 Study Group (Anon 1998a) estimated reference point values that were adopted by ACFM in giving advice (Anon 1999a), and that are generally still in use, although some reference values have since been recalculated by individual assessment working groups. The 2001 Study Group (Anon, 2001a) provided a general overview of the current status of the PA in ICES, and reviewed the technical basis for the points currently in use (Annex II of Anon, 2001a).

2.2 Conservation (limit and precautionary) reference points

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 $\mathbf{B}_{lim}$, where recruitment is 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. Because of the occurrence of error in the annual estimation of F and SSB, operational reference points are required to take account of such error. ICES therefore defined the more conservative reference points $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$ (the subscript $_{pa}$ stands for precautionary approach) as the operational thresholds. If a stock is estimated to be above $\mathbf{B}_{pa}$ there is a high probability that it will be above $\mathbf{B}_{lim}$ and similarly if F is estimated to be below $\mathbf{F}_{pa}$ there is a low probability that F is higher than $\mathbf{F}_{lim}$. The reference values $\mathbf{B}_{lim}$ and $\mathbf{F}_{lim}$ are used for calculation purposes in order to arrive at $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$, the operational values that should have a high probability of being sustainable based on the history of the fishery. Stocks above $\mathbf{B}_{pa}$ and below $\mathbf{F}_{pa}$ are considered to be inside safe biological limits. Stocks both below $\mathbf{B}_{pa}$ and above $\mathbf{F}_{pa}$ are considered to be outside safe biological limits, and stocks that are above $\mathbf{F}_{pa}$ but also above $\mathbf{B}_{pa}$ are considered to be harvested outside safe biological limits: in both cases action is required to bring them inside safe biological limits.

Previously, ACFM 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 impaired recruitment increased, and is therefore equivalent to $\mathbf{B}_{lim}$, but in some cases **MBAL** was more simply the biomass below which concerns were raised, and was therefore equivalent to $\mathbf{B}_{pa}$, the level where management action 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.

2.3 Target reference points

Target reference points represent long-term management objectives. Target reference points are constrained by the precautionary reference points. Therefore, a target fishing mortality should be below $\mathbf{F}_{pa}$ and a target SSB should be above $\mathbf{B}_{pa}$. As pointed out in Anon (2001a), target reference points have not so far been defined or used by ICES in the provision of advice.

3 STOCKS WITH ANALYTICAL ASSESSMENTS

The ICES definition of $\mathbf{B}_{\text{lim}}$ is the biomass below which recruitment becomes impaired, or where the dynamics of the stock become unknown. This implies a simple model of population dynamics in which recruitment is impaired at a particular threshold of SSB, and where fishing mortality is the only explicit factor that determines the size of the spawning stock, and that can be managed. In some stocks, where the stock-recruit data actually show a 'change point' where recruitment declines, the change point corresponds to the definition of $\mathbf{B}_{\text{lim}}$. In other cases, the stock-recruit data may not show clearly where recruitment becomes impaired. In these cases the 1998 Study Group used $\mathbf{B}_{\text{loss}}$, the lowest observed spawning biomass, as the estimate of $\mathbf{B}_{\text{lim}}$, for even if recruitment is not yet impaired, the dynamics of the stock are unknown below that point. The 2001 Study Group showed that 36 out of 63 estimates of $\mathbf{B}_{\text{lim}}$ were based on $\mathbf{B}_{\text{loss}}$ (Annex II of Anon, 2001a). In some stocks, however, the stock-recruit data show that R has been increasing with decreasing SSB, so $\mathbf{B}_{\text{loss}}$ was then used as an estimate of $\mathbf{B}_{\text{pa}}$. Where feasible, previous estimates of MBAL were adopted as either $\mathbf{B}_{\text{lim}}$, or $\mathbf{B}_{\text{pa}}$, as noted in Section 2.2.

To meet ToR b(i), Section 3 investigated further the identification of change points, as well as examples where there are inconsistencies between reference points, or where reference points may be affected by assessment model structure uncertainty, as follows.

3.1 Analysis of visual patterns in historical stock-recruit data

This section describes an approach in which historical data on **SSB**, **R** and **F** for 66 ICES stocks were examined to see whether conformity to the simple model of a threshold **SSB** (denoted here as **S***) and F, at which recruitment is impaired, could be determined by visual inspection. The visual analysis is described in detail in Working Document 1 (Azevedo *et al*. Are there general patterns in SSB-R relations and F-SSB trajectories that can be used as guides for establishing PA reference points ?), the text of which is included in Annex 1.

3.1.1 Patterns in R v SSB

Figure 3.1 illustrates general patterns, with some variants, derived from a visual interpretation of how recruitment is distributed at low and high levels of SSB.

Pattern 1:Low SSB produces a wide range of R (below and above median R):

1a) high SSB producing R below and above average
1b) high SSB producing R below average
1c) high SSB producing R above average.

Pattern 2:Low SSB produces only low R:

2a) median SSB produces R above average but high SSB produces R below average
2b) median to high SSB produce R below and above average
2c) median to high SSB produces R above average.

Pattern 3:Low SSB produces only high R:

3a) R decreases with increasing SSB.
3b) R is above and below average with increasing SSB.

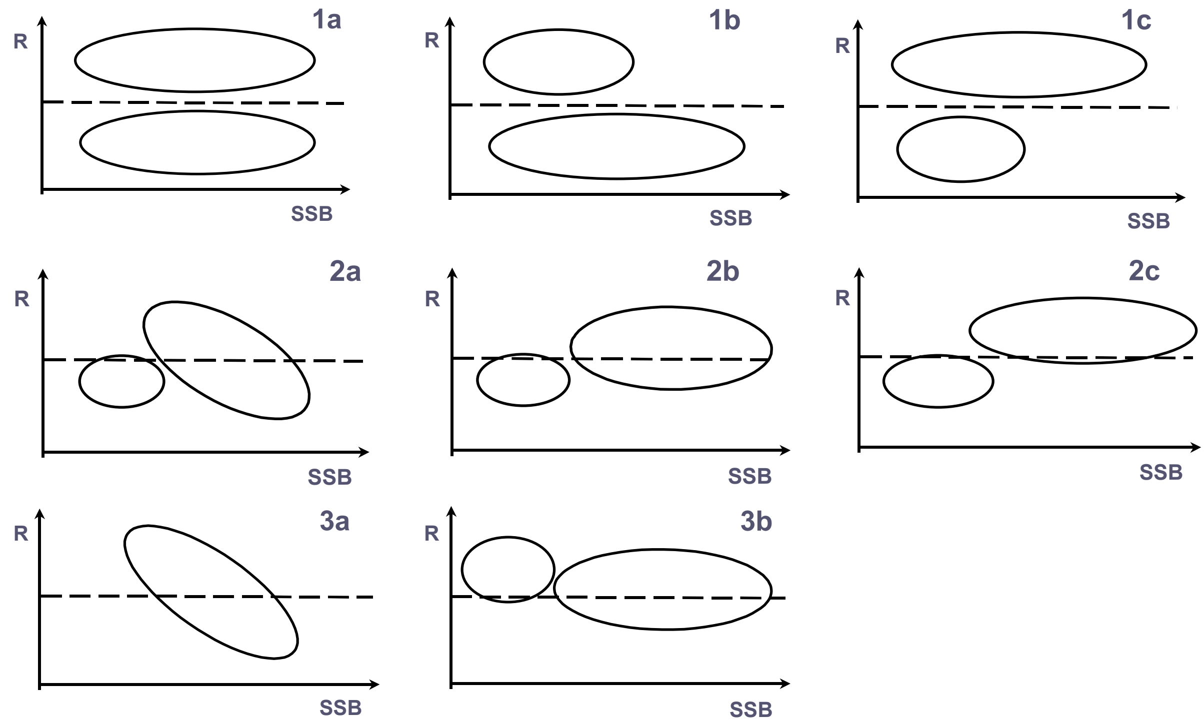


Figure 3.1 – Three patterns, with variants, in the relation between R and SSB, derived by visual inspection of stock-recruit data for 66 ICES stocks (Azevedo *et al* WD1). The dashed line represents the median value of recruitment.

Typical examples of stocks showing these patterns are illustrated in Figure 1 of Annex 1, and the distribution of stocks between patterns is listed in Table 2 of Annex 1. A majority of stocks (34, or 52%) show stock-recruit Pattern 1, of which most are Pattern 1a (23 stocks). Stocks showing Pattern 2 (25, or 38%) are distributed between Patterns 2a (8 stocks), 2b (11 stocks) and 2c (6 stocks). Only 7 stocks exhibited Pattern 3.

There was insufficient time for the Study Group to investigate rigorously whether stocks showing the same stock-recruit patterns share common demographic or environmental characteristics, or common rates of harvesting. Nevertheless, many pelagic species such as anchovy, sardine, blue whiting, mackerel, and several herring stocks all show SSB-R Pattern 1, although North Sea and Baltic herring show Pattern 2. Many of the gadoid stocks show Pattern 2, although some haddock stocks also show Patterns 1 and 3.

Based on historical recruitment at low SSB, only stocks with Pattern 2 permit visual identification of **S***, the SSB at which recruitment is impaired, estimated by dividing the R-SSB pairs into two distinguishable clusters (as for Irish Sea cod, for example, Figure 3.2). This approach gives rise to the set of **S***, or putative biomass reference values, listed in Table 2 of Annex 1, where they are compared against existing biomass reference values.

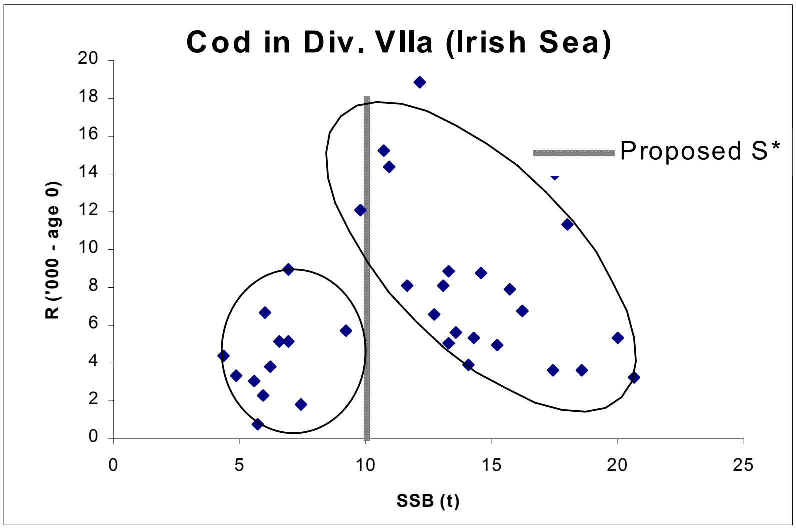


Figure 3.2 – Proposed identification of S* in Irish Sea cod, an example of stock-recruit Pattern 2.

3.1.2 Relationship between SSB and F

The benefit of identifying values of **S*** using stock-recruit patterns would be enhanced if it is also possible to identify a corresponding value of F from a relation between SSB and F. WD1 therefore inspected these relationships and identified three general patterns, again with some variants. During the meeting the working group analysed these patterns and adopted those described below.

Pattern 1: **SSB declining with increasing F**.

Pattern 2: **A wide SSB range at a narrow range of F**

Pattern 3: **SSB varying within a varying F range**

3a) SSB and F both vary widely
3b) SSB has a narrow range across a wide range of F

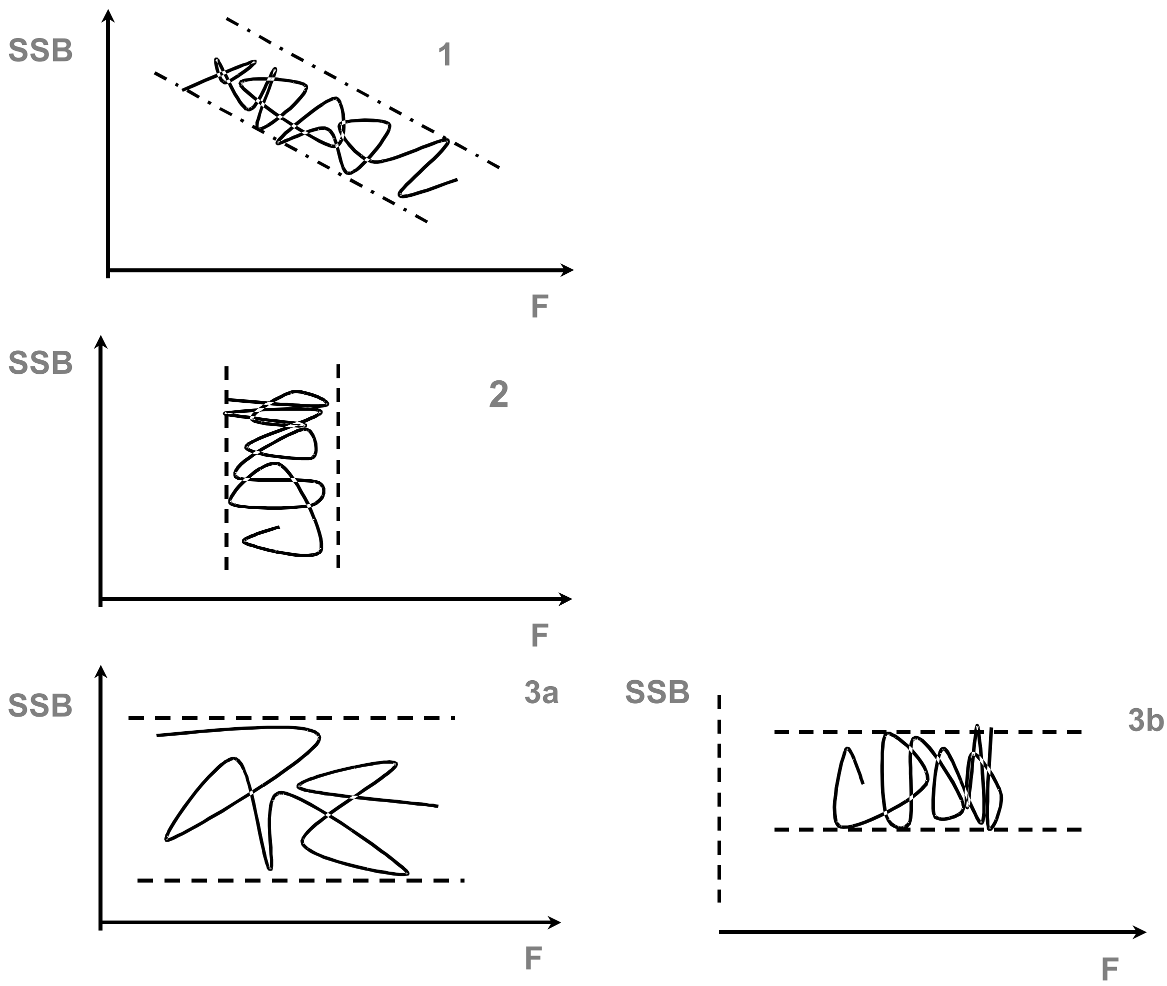
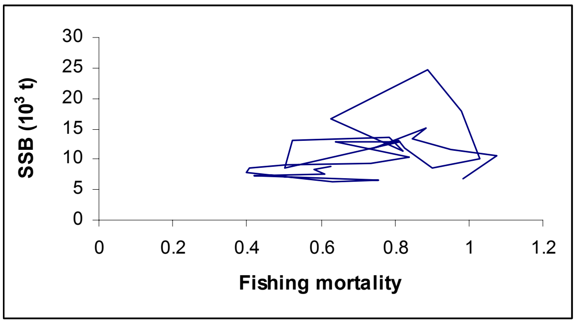


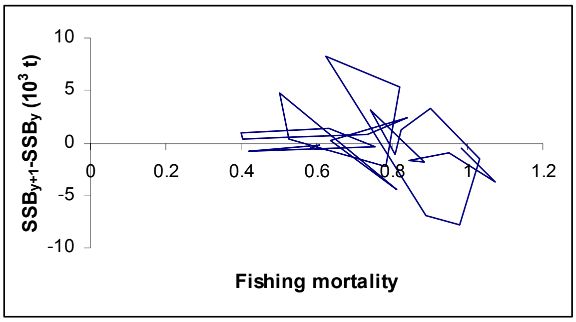
Figure 3.3 - Three patterns, with variants, in the relation between F and SSB, derived by visual inspection of data for 66 ICES stocks (adapted from Azevedo *et al* WD1).

Of the 65 stocks examined, a pattern of SSB on F could be identified in only 45 stocks. Only Pattern 1 illustrates a strong dependence of SSB on F, but this occurs in only 15 (33%) of the stocks. Pattern 2 (SSB varying widely across a narrow range of F) occurs in only 5 (11%) of the stocks, and the majority of stocks, 25 (56%), show Pattern 3, where SSB and F both vary but without showing a strong relationship. The data in these plots do not represent time-series. Figure 3.4 shows that the absence of a strong relationship between SSB and F occurs whether the relationship is expressed in absolute or relative terms.

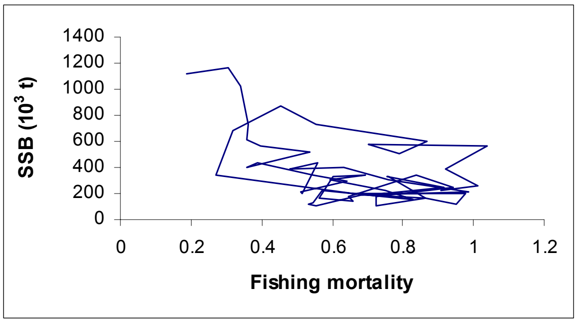
Absolute values **Annual changes**

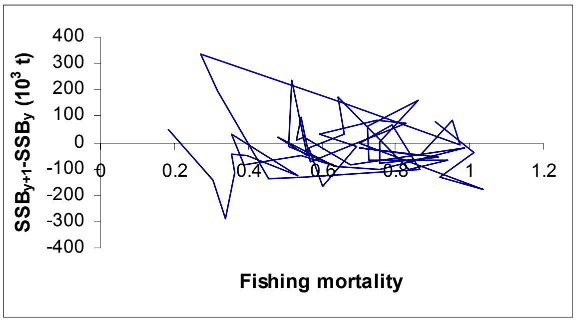
Cod VIIe-k



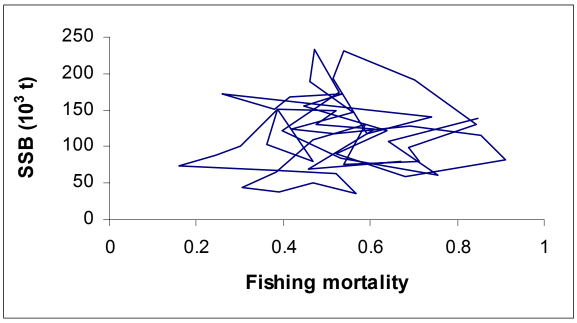


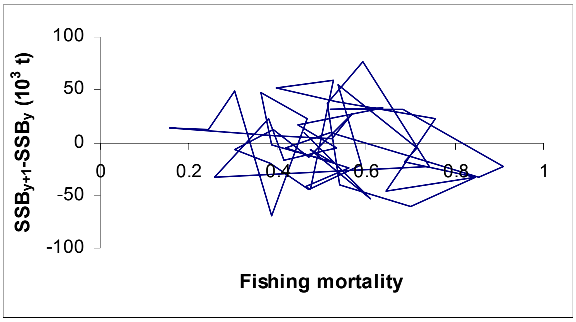
North East Arctic Cod



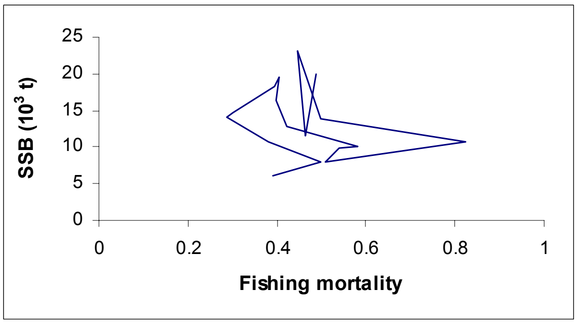


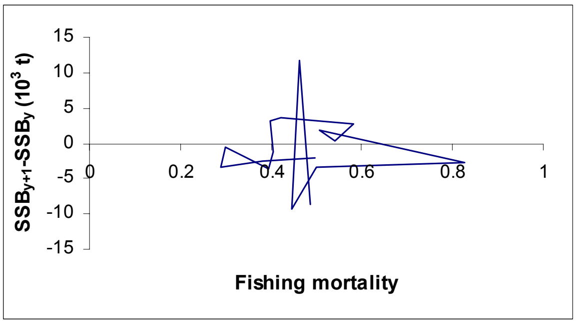
North East Arctic Haddock



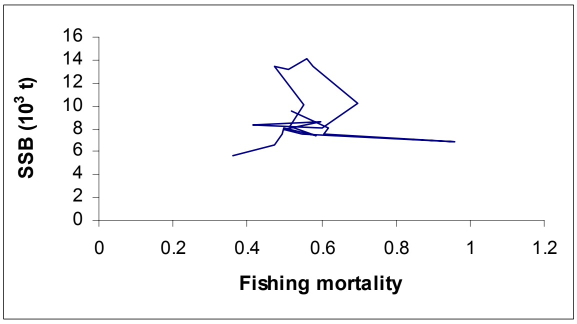


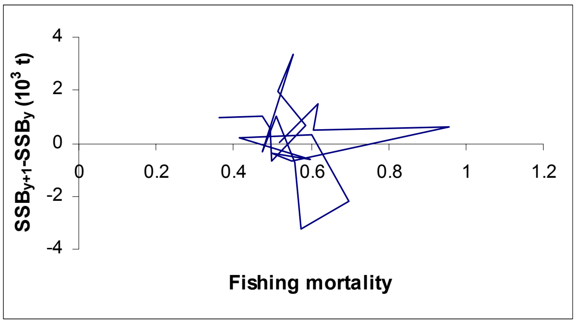
Rockall haddock (Div. VIb)





Plaice in Div VIId (Eastern Channel)





Cod in Subdivisions 25–32

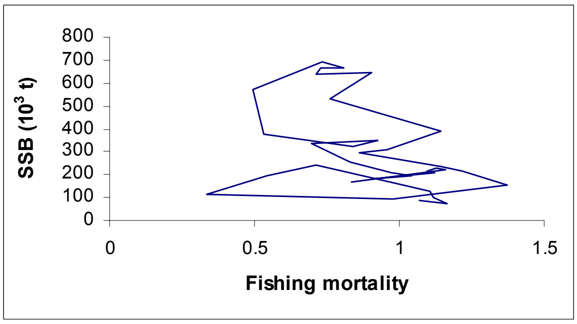


Figure 3.4 SSB v F, using absolute (left) and relative (right) values

Exploratory analysis suggests that relatively few biomass reference points can be estimated by visual interpretation of historical stock-recruit plots, and that relatively few stocks show a strong relationship between SSB and F. Only 7 stocks show the combination of R decreasing at low SSB, and SSB decreasing with increasing F (called Pairs 1, 2 in Working Document 1). These stocks are:

Cod (VIa)
Cod (VIIa)
Cod (IV, IIIa, VIId)
Herring (Subdivisions 25-29 etc)
Sole (VIIIa, b, d)
Whiting (VIa)
Whiting (VIIe-k)

It is concluded that values of $\mathbf{B}_{\text{lim}}$ and $\mathbf{F}_{\text{lim}}$ are not easily identifiable visually from stock-recruit data, and that the objective identification of a change point requires statistical methods, as described in the next section.

3.2 Identifying biomass reference points using segmented regression

This section illustrates a proposed objective statistical method for identifying **S***, the specific value of SSB below which recruitment is impaired. The method is the segmented regression approach of O'Brien and Maxwell, described in Working Document 8 (O'Brien and Maxwell, 2002. 'Towards an operational implementation of the Precautionary Approach within ICES – biomass reference points'.), which is contained in Annex 2. The method is a further development of an idea presented to the ICES Study Group on the Incorporation of Process Information into Stock-Recruitment Models (Anon 2002b) [SGPRISM]. Working Documents WD10-WD21 describe the application of the technique to a range of demersal and pelagic stocks assessed within the ICES stock assessment area.

Segmented (or piecewise linear) regression involves fitting linear regression where the coefficients are allowed to change at given points (Quandt, 1958). For one unknown change-point, for any interval (X_0 , X_1) on the real interval, the problem is defined as,

$$\begin{aligned} f(x_i) &= \alpha_1 + \beta_1 x_i & X_0 \le x_i \le \delta, \\ &= \alpha_2 + \beta_2 x_i & \delta \le x_i \le X_1 \end{aligned} \tag{1}$$

For stock and recruitment data the model is simplified so that it passes through the origin ($\alpha_1 = 0$) and is horizontal after the change-point ($\beta_2 = 0$). Julious (2001) presents an algorithm, originally from Hudson (1966), for fitting the model with one unknown change-point. This algorithm has been implemented for the stock and recruitment case with $\alpha_1 = 0$, $\beta_2 = 0$ and log-normal errors. Specifically, the model is

$$\begin{aligned} R_i &= \beta_1 S_i e^{\varepsilon_i} & 0 \le S_i \le \delta, \\ &= \alpha_2 e^{\varepsilon_i} & \delta \le S_i \end{aligned} \tag{2}$$

which on the natural logarithmic scale is:

$$\begin{aligned} \log R_i &= \log \beta_1 + \log S_i + \varepsilon_i \qquad 0 \le S_i \le \delta, \\ &= \log \alpha_2 + \varepsilon_i \qquad \delta \le S_i \end{aligned} \tag{3}$$

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

For the subsequent calculation of PA biomass reference points, it is simpler to consider the parameters S*, α and R* rather than the parameters in equation (3); i.e.

$$\begin{aligned} &\delta \equiv S^* \\ &\beta_1 \equiv \alpha \\ &\alpha_2 \equiv R^* = \alpha S^* \end{aligned} \tag{4}$$

Goodness-of-fit may be assessed with an *F*-statistic (Worsley, 1983) that uses the ratio of the sum of squares between a one- and two-line model (H_0 versus H_1, respectively). As the change-point 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. The details are presented in O'Brien and Maxwell (2002, WD8), reproduced in Annex 2 of this report.

Given suitable point estimates of the parameters **S***, α and **R***, confidence interval statements can be calculated. A (1-α)% profile likelihood confidence interval for **S*** can be calculated for appropriate values of α using the expression:

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

The applications presented in WD10-WD21 have adopted 80% for (1-α)%, the lower 10% limit denoted as S*(10), and the upper 90% limit denoted as S*(90), of **S***. The choice of 80% as a confidence interval for **S*** is merely illustrative and should not be treated as prescriptive. Similarly it is not obligatory to have a symmetric treatment of the (1-α)% profile likelihood confidence interval for **S***. The lower limit $S^*(\alpha_1)$ and the upper limit $S^*(1-\alpha_2)$ may be defined such that $(1-\alpha_1-\alpha_2)$ has the specified coverage probability of (1-α), but α_1 can be different from α_2 if desired. The choice of the appropriate level of acceptable risk in 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 segmented regression approach is an objective way of estimating the biomass **S*** at the change point, the SSB at which recruitment is impaired. Since the latter point is, in ICES terms, $\mathbf{B}_{\mathrm{lim}}$, a candidate value for $\mathbf{B}_{\mathrm{lim}}$ is either **S***, or, taking statistical uncertainty into account, $S^*(\alpha_1)$. Likewise, the upper bound $S^*(1-\alpha_2)$ is a candidate for $\mathbf{B}_{\mathrm{pa}}$, the biomass required to avoid $\mathbf{B}_{\mathrm{lim}}$ with high probability. Since neither of these estimates explicitly incorporates uncertainty in SSB and R due to the assessment process, their utility could be tested in the future using scenario modelling within a management procedure, as described by Kell *et al*. (1999a), and referred to previously in Section 3.

3.2.1 Examples of applying the segmented regression approach

As an example, the full results of applying the segmented regression approach to stock-recruit data for the case of Northeast Arctic saithe (O'Brien and Maxwell, WD 10) are reproduced in Annex 3. The principal results for all the stocks are reproduced in Annex 4, and summarised as follows:

WD 10
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic saithe (Subareas I and II).

$P < 0.016$
Current $\mathbf{B}_{\mathrm{lim}}$ = 89 kt and $\mathbf{B}_{\mathrm{pa}}$ = 150 kt
S*, at which recruitment is impaired, is 155 kt
S*(10) = 111kt, **S*(90)** = 196 kt

WD 11
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of northern hake.

$P < 0.039$
Current $\mathbf{B}_{lim}$ = 120 kt and $\mathbf{B}_{pa}$ = 165 kt
S*, at which recruitment is impaired, is 187 kt
S*(10) = 136kt**, S*(90) =** not defined

WD12
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic cod (Subareas I and II).

$P < 0.001$
Current $\mathbf{B}_{lim}$ = 112 kt and $\mathbf{B}_{pa}$ = 500 kt
S*, at which recruitment is impaired, is 280 kt
S*(10) = 206kt**, S*(90) =** 349 kt

WD13
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Subarea IV, Divisions IIIa and VIId.

$P<0.001$
Current $\mathbf{B}_{lim}$ = 70 kt and $\mathbf{B}_{pa}$ = 150 kt
S*, at which recruitment is impaired, is 159 kt
S*(10) = 131kt, **S*(90) =** 183 kt

WD14
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIa.

$P < 0.001$
Current $\mathbf{B}_{lim}$ = 14 kt and $\mathbf{B}_{pa}$ = 22 kt
S*, at which recruitment is impaired, is 19 kt
S*(10) = 14.7 kt**, S*(90) =** 24.3 kt

WD15
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIa.

$P < 0.003$
Current $\mathbf{B}_{lim}$ = 6 kt and $\mathbf{B}_{pa}$ = 10 kt
S*, at which recruitment is impaired, is 10.7 kt
S*(10) = 8.9 kt**, S*(90) =** 12.5 kt

WD16
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIe-k.

$P < 0.007$
Current $\mathbf{B}_{lim}$ = 5.4 kt and $\mathbf{B}_{pa}$ = 10 kt
S*, at which recruitment is impaired, is 13.5 kt
S*(10) = 10.99 kt**, S*(90**) **=** undefined

WD17
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of plaice in Division IIIa

$P = 1$ Not significant
Current $\mathbf{B}_{lim}$ undefined, $\mathbf{B}_{pa}$ = 24 kt
S*, at which recruitment is impaired, is < 23.2 kt

S*(10) undefined, **S*(90)** = 28.5 kt
WD18
O'Brien, C.M., Maxwell, D.L. and Roel, B.A.
A segmented regression approach to the Precautionary Approach – the case of herring in Subarea IV, Divisions IIIa and VIId.

$P < 0.001$
Current $\mathbf{B}_{lim}$ = 800 kt and $\mathbf{B}_{pa}$ = 1300 kt
S*, at which recruitment is impaired, is 512 kt
S*(10) = 407 kt, **S*(90)** = 647 kt

WD20
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the case of Northeast Atlantic mackerel.

P 0.065 Not significant
Current $\mathbf{B}_{lim}$ undefined, $\mathbf{B}_{pa}$ = 2300 kt
S*, at which recruitment is impaired, is 3722 kt
S*(10) = 2813kt, **S*(90)** = not defined

WD21
O'Brien, C.M. and Maxwell, D.L.
A segmented regression approach to the Precautionary Approach – the cases of anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa).

Results for these stocks are not significant.

3.2.2 Investigating G_{loss}

G_{loss}, the replacement line corresponding to the lowest observed spawning biomass, was proposed as a sustainability criterion (Cook, in Anon 1998a) on the basis that it is a minimal estimate of G_{crash}, the replacement line for the fishing mortality which results in stock collapse. Any fishing mortality that corresponds to a replacement line to the right of G_{loss} should be sustainable.

Working Document 9 (O'Brien and Smith) describes a diagnostic for G_{loss} (the smoothed estimate of recruitment at minimum SSB divided by minimum SSB). WD9 investigated the estimation of G_{loss} using a LOWESS smoothed stock-recruitment relationship with different spans for the LOWESS fit, applied to example data for N Sea cod, Northern hake and Thames herring.

There are conflicting objectives in choosing the span for the LOWESS smoother, which are dependent on the desired properties. Varying the span yields flexible smoothers but can produce unrealistic curves with multiple inflection points. Optimal choice of the smoothing parameter, as observed in simulations is by no means trivial. An Akaike information criterion was implemented to guide the choice of span to adopt in the calculation of the reference points G_{loss} and $\mathbf{F}_{loss}$.

The Study Group did not have time to consider this paper, but the results can be summarised as:

- a span of 1 is appropriate for North Sea cod,
- a span in the range (0.8, 1.0] is to be preferred for northern hake since the estimate of G_{loss} is little changed and these spans avoid multiple inflection points in the equilibrium calculations for the stock,
- a span of 0.5 is appropriate for Thames estuary herring but that the estimate of G_{loss} is little changed by a span in the range [0.5, 0.8] and the higher value might be more appropriate for the equilibrium calculations.

3.2.3 Comparing the results of segmented regression and visual analysis

For each pattern of historical stock-recruit data, one stock was selected in order to compare the estimate of **S*** obtained from visual analysis and by applying segmented regression.

Stock-recruit Pattern 1 does not easily allow the establishment of **S*** by visual inspection. For N E Arctic Saithe (Figure 3.5) showing Pattern 1c, for example, a visual estimate of **S*** would be placed above the higher limit of the low recruitment zone at about 550 kt, on the grounds that above this level recruitment is only above average, whereas below it recruitment could be high or low. The segmented regression, however, indicates a bound of SSB from 110 000 t to 195 000 t, corresponding to S*(10) and S*(90), representing candidate values of $\mathbf{B}_{\text{lim}}$ and $\mathbf{B}_{\text{pa}}$, respectively. The current values used by ACFM are $\mathbf{B}_{\text{lim}}$ of 89 000 t (the lowest observed SSB in the 35-year time-series) and $\mathbf{B}_{\text{pa}}$ of 150 000 t (allegedly the SSB below which the probability of poor year classes increases). The segmented regression results are more conservative, and suggest a visually justifiable estimate of S*(10)= $\mathbf{B}_{\text{loss}}$ = $\mathbf{B}_{\text{lim}}$.

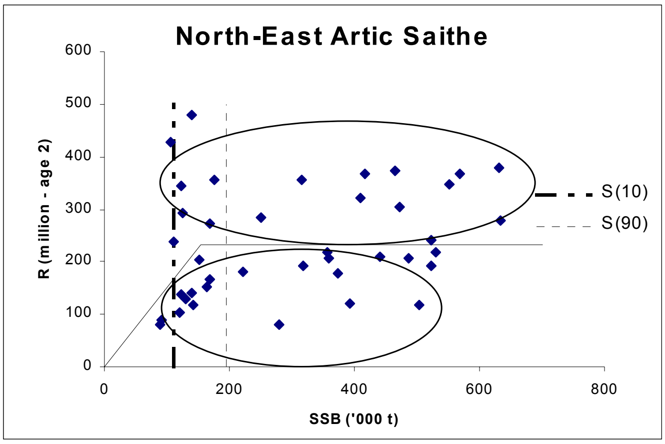


Figure 3.5 The stock-recruit plot for N E Arctic Saithe: visual pattern v. segmented regression

The Irish Sea Cod (Div VIIa) (Figure 3.6) shows a stock-recruit pattern of type 2a. An **S*** derived from the historical approach is about 10,000 t. This value is within the range of 9000 t to12500 t for S*(10) and S*(90), representing candidate values for $\mathbf{B}_{\text{lim}}$ and $\mathbf{B}_{\text{pa}}$ derived by segmented regression. The ACFM values are $\mathbf{B}_{\text{lim}}$ of 6 000 t (agreed by ACFM in 1998) and $\mathbf{B}_{\text{pa}}$ of 10000 t. *(This is the previously agreed MBAL and affords a high probability of maintaining the SSB above* $\boldsymbol{B}_{lim}$, *taking into account the uncertainty of assessments)*. As in the previous example, the segmented regression results are more conservative.

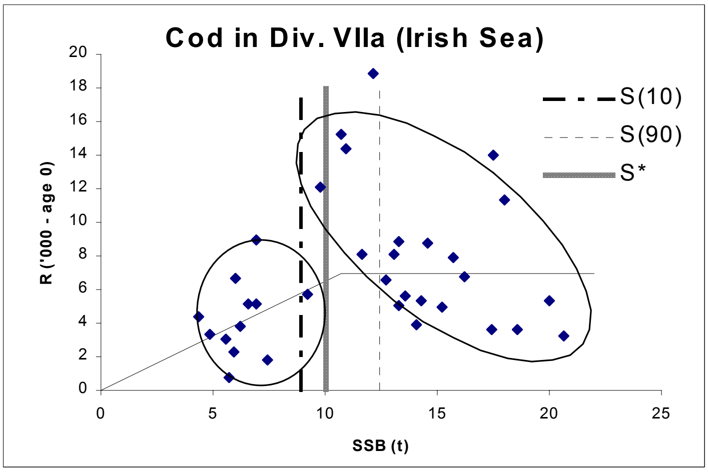


Figure 3.6 The stock-recruit plot for Irish Sea (VIIa) cod: visual pattern v. segmented regression

Plaice in IIIa was selected as the stock representing stock-recruit Pattern 3a (Figure 3.7). The visual approach suggests that S* could be in the SSB range of 28-40 kt. The segmented regression estimated a value of 28400 t for S*(90), a candidate value for $\mathbf{B}_{\text{pa}}$. A candidate value for $\mathbf{B}_{\text{lim}}$, S*(10), could not be identified unambiguously as S* occurs at $\mathbf{B}_{\text{loss}}$ and the profile likelihood surface is flat for all values of SSB below $\mathbf{B}_{\text{loss}}$.

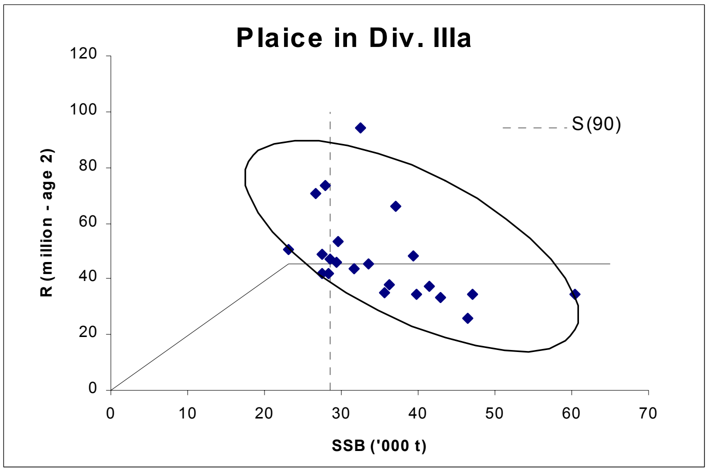


Figure 3.7 The stock-recruit plot for IIIa plaice: visual pattern v. segmented regression

To establish a proposal for F*, the fishing mortality corresponding to S*, stocks must have historical data with an F-SSB Pattern 1 and stock-recruit Pattern 2 (i.e the pair 1,2, such that $F>F_x$ / $SSB<SSB_y$ / $R<R_z$, and hence $F^*=F_x$ and $S^*=SSB_y$). Two examples of stocks with pattern (1, 2) similar to those illustrated in Figure 3.8 are cod in the Irish Sea and Sole in the Bay of Biscay.

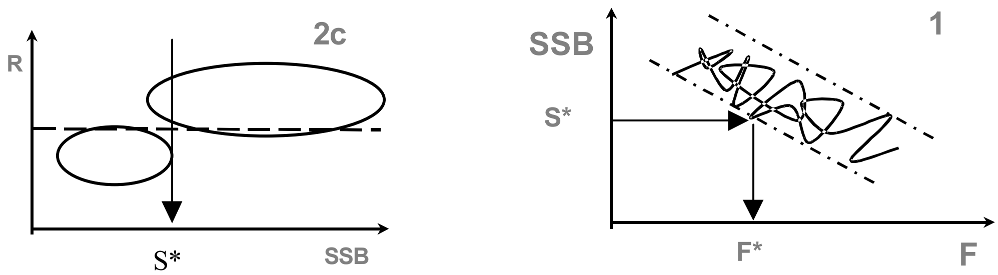


Figure 3. 8 Estimating $\mathbf{F}_{pa}$ based on historical evidence.

Since the model underlying the concept of fisheries management is that fishing depletes stocks, there *should be further reflection on the finding that apparently so few stocks show a clear-cut negative relationship between SSB and F.*

3.3 Inconsistencies between Reference points (Blue whiting)

Working Document 6 (Skagen: Reference points for Blue Whiting Revisited) presents a reappraisal of the reference points for blue whiting. These have been criticised for some years because of inconsistencies between $\mathbf{B}_{pa}$ and $\mathbf{F}_{pa}$. The paper is also an example of a generic problem: how to set meaningful reference points for stocks where the range of historically experienced SSB-values is narrow, and there is no experience of recruitment failure. Therefore the Study Group agreed to include the text of WD6 in full in this section of the report, within the following quotation marks:

'The present values of reference points for blue whiting and their technical basis are:

$\mathbf{B}_{lim}$: 1.5 mill tonnes; $\mathbf{B}_{loss}$
$\mathbf{B}_{pa}$: 2.25 mill. tonnes; $\mathbf{B}_{lim}$*1.5
$\mathbf{F}_{lim}$: 0.51; $\mathbf{F}_{loss}$
$\mathbf{F}_{pa}$: 0.32; $\mathbf{F}_{med}$.

The inconsistency problem is that fishing at $\mathbf{F}_{pa}$ implies a high probability of bringing the stock below $\mathbf{B}_{pa}$. The recent increase in the fishery has become a matter of concern, and work has been initiated by several coastal states to develop recovery plans. This adds to the need to revise the reference points, because of their role as targets for rebuilding and guidelines for future exploitation. In particular, one may question if the present $\mathbf{B}_{pa}$ is an adequate target for a rebuilding plan.

3.3.1 Background (Figures 3.9-3.11)

Recruitment dynamics

1. Within the range of historical observations, there is no trend in recruitment as a function of SSB. Thus, bringing the stock below $\mathbf{B}_{lim}$ implies 'unknown dynamics' in the ACFM terminology.
2. Historically, there have been strong year classes with 6-7 years intervals, and a sequence of 3-4 weak year classes in between.
3. The SSB has increased each time a strong year class entered the spawning stock, and decreased in the periods where the spawning stock was dominated by weak year classes. The SSB has been above the current $\mathbf{B}_{pa}$ only following strong year classes.
4. The $\mathbf{F}_{med}$ is intended to stabilise the SSB around the mean historical value. The $\mathbf{F}_{med}$ replacement line implies an SSB – recruitment ratio that, with geometric mean recruitment, is at equilibirum with an SSB about 1.9 mill tonnes, which is well below $\mathbf{B}_{pa}$.
5. In recent years, there has been an improvement of the recruitment. The 1995 year class was strong, which might be expected, but the 1996 year class was even far stronger, the 1997 year class was also strong, and there are indications of strong year classes both in 1999 and 2000. The strong year classes have been most prominent in the North and may have led to a more Northerly distribution of the stock as a whole. The reason for this is not known.

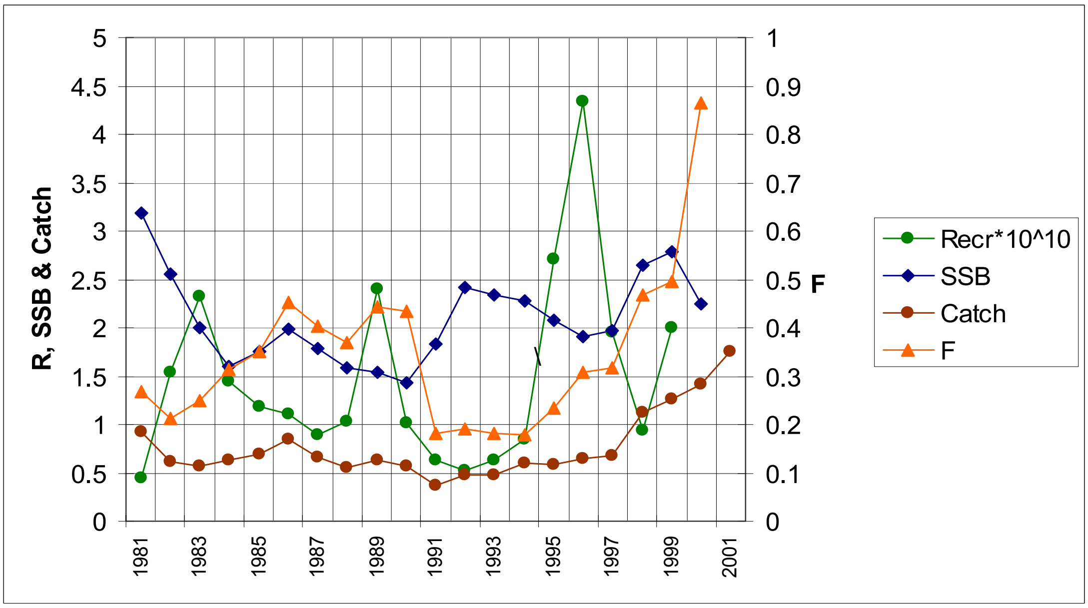


Figure 3.9 SSB (million tonnes), recruitment (*10^{10}), catch (million tonnes) and fishing mortality over the years

Figure 3.10 SSB and recruitment. Periods influenced by strong year classes are emphasised. The $\mathbf{F}_{med}$ replacement line and its equilibrium SSB at geometric mean recruitment (12.3 billion) are indicated.

Exploitation

1. Over the years, the fishing mortality has fluctuated between 0.2 and 0.45. It was reduced in 1991 because the stock was declining. The stock improved both because of this and because a new strong year class came in.
2. In recent years, there has been a dramatic increase in catches and in the fishing mortality.
3. The exploitation pattern has been relatively stable according to the last years assessment, with the major exploitation being on adults. The exploitation of juveniles has been modest, and caused by industrial fisheries in the North Sea and some traditional fisheries in the Southern part of the area.
4. In 2001, a large fishery developed in the Norwegian Sea in the summer, and there are indications that the proportion of juveniles was large in that fishery. Thus, it is likely that a new specific fishery for juveniles is developing.

Weight and maturity-at-age

1. The data indicate that the weight-at-age has fluctuated considerably over the years, with a peak in the mid 1990ies (Figure 3.11). The present weights-at-age are in the lower part of the historical range. The difference at the most central ages is approximately equivalent to one year's growth.

2. The maturity-at-age has not been estimated yearly. The assessment working group has used fixed values, and possible fluctuations are not known.

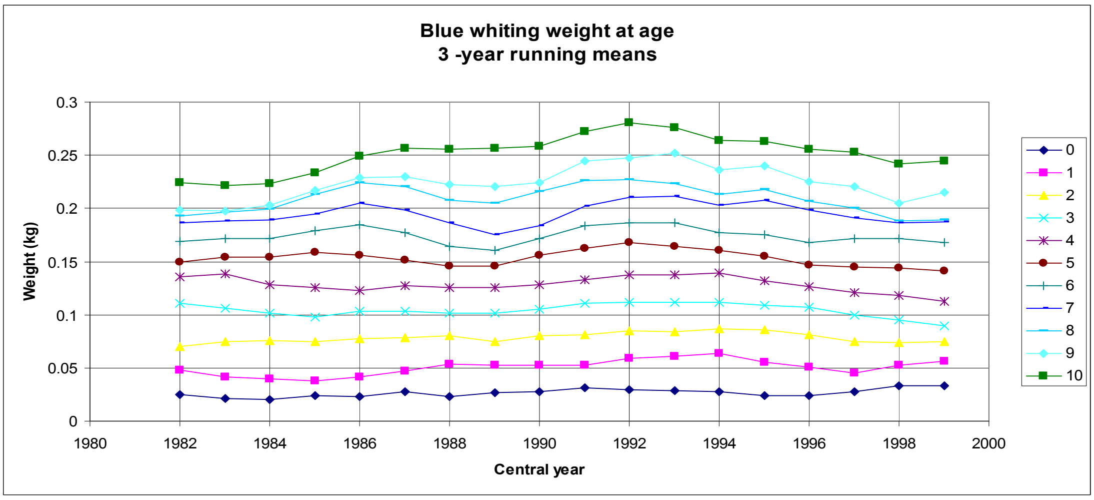


Figure 3.11 Running means (3 years) of weights-at-age. The same weights are used for the catch and in the stock.
Comments

It seems clear that SSB has been in the range between $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ in most of the historical years, and only climbed above $\mathbf{B}_{pa}$ after the occurrence of strong year classes. Except for the most recent period, the stock has mostly been moderately exploited, and there is no trend in the recruitment as function of SSB.

Thus, the safety margin built into the $\mathbf{B}_{pa}$ is so wide that the stock at moderate exploitation is dependent on well above average year classes to reach the present $\mathbf{B}_{pa}$. On the other hand, it may become very dangerous to assume that good recruitment will occur at lower SSB than hitherto encountered. Thus, any precautionary management should imply a low probability that SSB will fall below 1.5 million tonnes.

3.3.2 Long-term equilibria (Figures 3.12-3.14)

A set of long-term stochastic equilibria were computed to show the trade off between yearly catch and risk of SSB<$\mathbf{B}_{lim}$ for a range of fishing mortality. These calculations were made with the LTEQ software. This is a program that calculates the equilibrium between stationary distributions of SSB and recruitment. The recruitment was assumed to be log normally distributed, with σ = 0.485 (i.e. SD of the log-transformed numbers) and a geometric mean of 11915 millions, independent of SSB when SSB was above 1.0 million tonnes (which in practice always was the case). Weight and maturity were drawn from historical values, by drawing years randomly and use the data set for that year.

The s and the geometric mean are according to the assessed values of historical SSB and recruitment. Below 1.0 million tonnes, recruitment was assumed to decline linearily with SSB. The breakpoint at 1.0 million tonnes is arbitrary, but was chosen in order to avoid collapse of the stock at SSB immediately below the historical low and with a faint hope that the stock may be able to sustain such a low SSB.

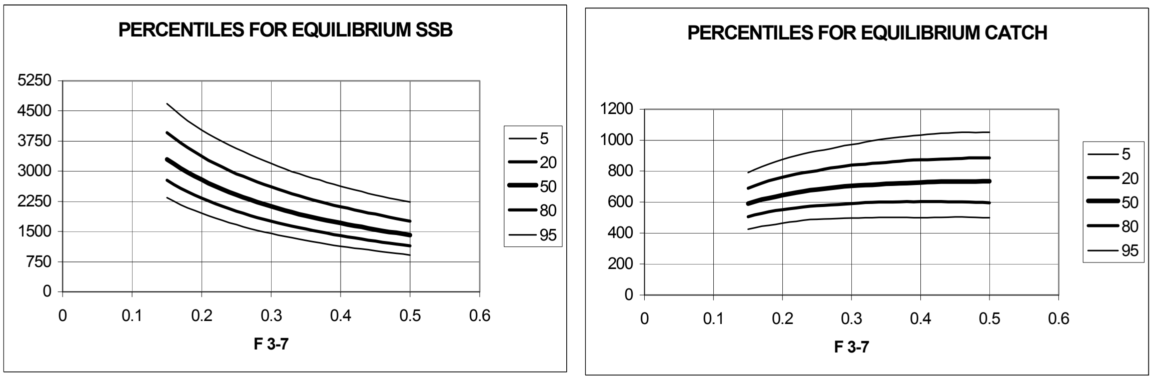


Figure 3.12 Percentiles for SSB and catch in long-term stochastic equilibrium, using the selection pattern for 2000 as assessed in 2001.

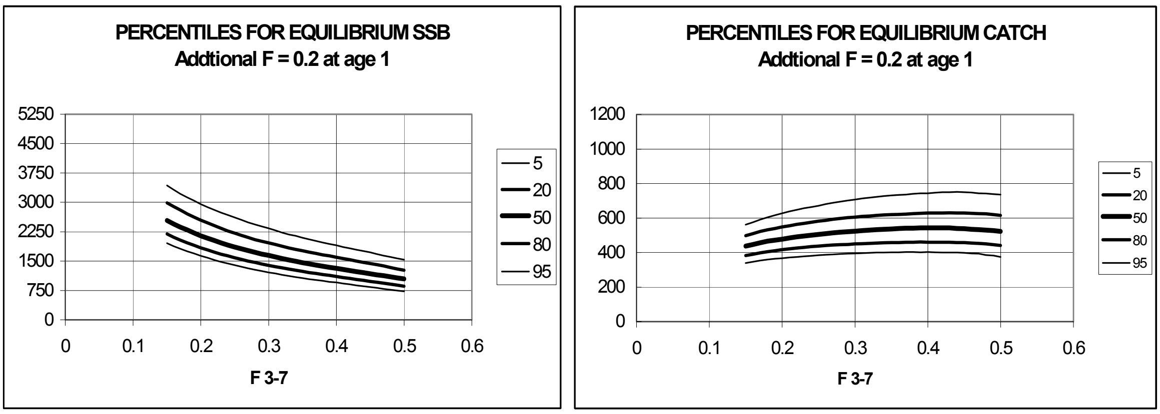


Figure 3.13 Percentiles for SSB and catch in long-term stochastic equilibrium, using the selection pattern for 2000 as assessed in 2001, but with a fixed additional fishing mortality of 0.2 on age 1. Mean recruitment is assumed to be independent of SSB at SSB>1.0 mill tonnes.

Another set of runs was made where there was assumed an additional mortality on age 1, to indicate the kind of loss that can be expected by a directed fishery for juveniles.

From these runs, it emerges that:

1. There is not much to gain by increasing the fishing mortality above approximately 0.3, and even at F=0.2, the expected loss in average long-term yield is only 10-12%.
2. The SSB curves are relatively flat as functions of F, which implies that the risk of having SSB<1.5 mill tonnes is very sensitive to the assumed average recruitment, or equivalently, to the exploitation of juveniles. Thus, reducing the input to the age 2 group, where part of the year class starts spawning, by 18%, corresponding to F at age 1 of 0.2, increases the computed risk considerably. The table below shows the probability that **SSB<1.5 mill tonnes** with and without an additional juvenile fishery, and Figure 4.3.6 shows the probability of SSB<1.5 mill tonnes without a juvenile fishery in some more detail.

F 3-7	Std. Selection	Add. F age 1 = 0.2
0.15	0.0	0.0
0.20	0.0	1.7
0.25	1.0	12.6
0.32	11.6	41.7

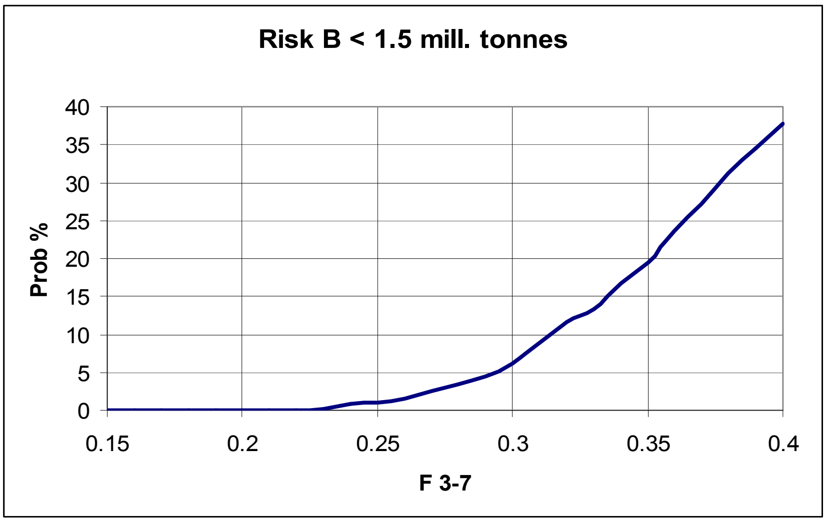


Figure 3.14 Risk of SSB<1.5 million tonnes with selection pattern as in 2000.

3. The probability that SSB will be below the present $\mathbf{B}_{pa}$ is high at the present $\mathbf{F}_{pa}$, consistent with the historical experience. This is shown in the next table, which shows the probability of **SSB<2.25 mill. tonnes**.

F 3-7	Std. Selection	Add. F age 1 = 0.2
0.15	2.4	25.7
0.20	21.4	58.7
0.25	48.8	81.7
0.32	77.9	95.5

3.3.3 Medium-term simulations (Figure 3.15)

Medium-term simulations were made to explore some possible alternatives to the present advisory framework. The simulations were done with the STPR software. This is a medium-term stochastic prediction programme that allows exploration of some harvest control rules.

Assumptions about recruitment, weights, maturities at age and selection were as for the LTEQ runs above, with no additional fishery on juveniles. An autoregressive model for the recruitments was assumed but this induced only minor fluctuations in the mean recruitments. Initial numbers (at the start of 2002) were taken from a bootstrap run by the AMCI assessment model. Bootstrap replicas of numbers at the start of 2001 from the assessment were projected forwards one year, assuming an ordinary catch of 1350 000 tonnes + a juvenile catch of 350 000 tonnes in 2001. The numbers estimated for the 2000 year class were raised so that their average became 12 billion at age 2, which is approximately the abundance of the strong 1995 year class at that stage. One thousand replicas were made in each run.

The harvest control rules explored included:

- A fixed fishing mortality at high SSB
- Below an 'action level' of SSB, the fishing mortality was reduced linearly with SSB, to reach F=0.05 at and below a $\mathbf{B}_{\mathrm{lim}}$ of 1.5 million tonnes.
- A maximum allowable catch of 1.2 million tonnes. Some alternative runs were made with 0.8 million tonnes instead of 1.2 million tonnes.
- Runs were made with and without a normally distributed error with C.V. = 30% in the stock estimates on which decisions about next years fishing mortality was made.

The performance of the simulated scenarios was evaluated according to the following criteria:

- Probability of SSB < 1.5 million tonnes in the true stock ***at least once*** in the 10 year simulation period.
- Probability that the decision would be taken to apply the fishing mortality valid for SSB < 1.5 million tonnes ***at least once*** in the 10 year simulation period. This probability deviates from the one above both because of error in the assessment, and because the decision rule applied in situations where a low F will bring the SSB above a limit, while a higher F will bring it below the limit, is to apply the lower F.
- The 50 percentile of SSB in year 10.
- The 50 percentile of the year to year variation of the catch in years 5 – 10, measured as the range of catches in the period divided by the mean, within each replica.
- The 50 percentile of the mean catch in years 1-10

The main results are shown in Figure 3.15 below.

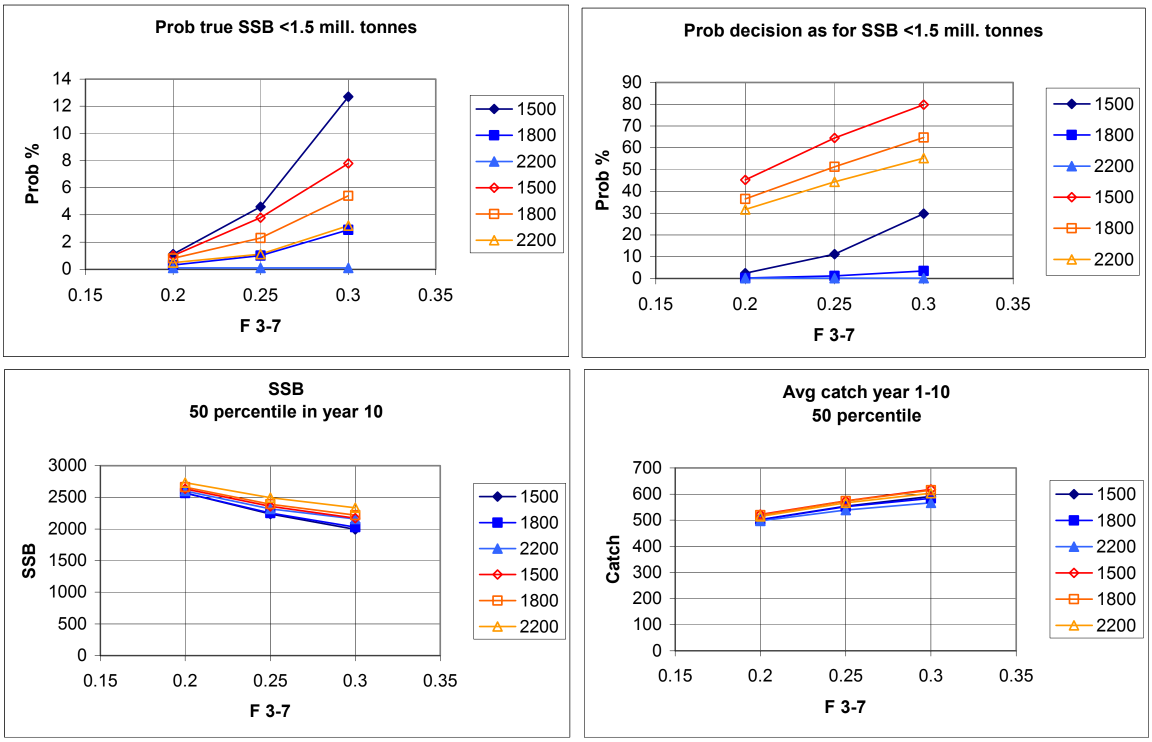


Figure 3.15 Results of medium-term simulations. Each curve represents one 'action level' for SSB. Filled symbols are assuming that future assessments are exact, open symbols are assuming errors in future assessments with a C.V of 30%.

The probabilities of SSB being below the limit is the probability that this will happen ***at least once*** in the 10 year simulation period.
Inferences:

- The risk of bringing SSB below the 1.5 million tonnes limit is quite sensitive to the fishing mortality, as expected. If there is error in the future assessment, the risk that SSB in reality is below the limit generally is higher, but not much. However, managers will far more often be led to act as if this were the case.
- Beginning to reduce the fishing mortality at some SSB level above 1.5 million tonnes has a substantial effect in reducing the risks.
- The long-term average catch increases somewhat with increasing fishing mortality, but the increase is modest, and is little influenced by the choice of 'action level'. Noisy assessments lead to a slightly higher average catch.
- In addition to what is shown in Figure 4.3.7 it was found that the year-to-year variation in the catches increased with increasing fishing mortality, and that it became much higher when noisy assessments were assumed.
- These simulations were made with an upper limit on the yearly catch of 1.2 million tonnes. This limit was rarely reached except in the cases with the highest fishing mortality and errors in the assessment, where it was reached with 3-5 % probability. With a lower limit of 800 000 tonnes, the limit was reached more often. This led to a slight reduction in the risk of reaching 1.5 million tonnes SSB, but led to a considerable reduction in the long-term yield.

3.3.4 Conclusions for blue whiting

1. One should still hesitate to allow SSB to fall below the $\mathbf{B}_{loss}$ of 1.5 million tonnes. A fishing mortality in the order of 0.25 could be appropriate as an $\mathbf{F}_{pa}$, provided that the exploitation of juveniles is kept low, and that the weights-at-age remain within the historical range. This would give an approximately 1 - 2% risk that SSB falls below $\mathbf{B}_{lim}$ in any year. The risk increases quite rapidly when F increases above this. The long-term average catch will be about 7% below the maximum catch achievable, but this maximum catch requires that the recruitment does not decline at low SSBs.
2. Even a moderate increase in the exploitation of juveniles will require a substantial reduction in adult F in order to keep the risk of dropping below 1.5 million tonnes at a low level. Fishery for juveniles should therefore be kept at a minimum.
3. The present $\mathbf{B}_{pa}$ which represents a safety margin to the limit SSB, but in practise serves as a target biomass, is not useful as a guidance for management.
4. This stock illustrates quite clearly the dilemma when there is no experience of recruitment failure, and the $\mathbf{B}_{loss}$ is the lower bound of a relatively narrow range of historical SSB values. If the uncertainty of the assessment is to be taken properly into account, this would lead to a $\mathbf{B}_{pa}$ which is difficult to reach even at a very moderate exploitation. Adopting such a $\mathbf{B}_{pa}$ would imply that the stock, even if exploited very moderately, would be outside safe biological limits most of the time, which is unnecessarily restrictive.
5. An alternative framework for advise, with emphasis on advising on fishing mortalities aiming at keeping the probability of SSB being above the historical low should be considered. In such a regime, it may be feasible to have an 'action level', below which the fishing mortality is reduced according to the SSB. An upper limit on the catch may be considered as an extra precaution, but does not seem to have any substantial beneficial effect.

Based on these considerations, the following advisory framework is suggested for the Blue whiting:

- Keep $\mathbf{B}_{lim}$ at 1.5 mill tonnes
- Let $\mathbf{B}_{pa}$ undefined.
- Define a ***precautionary management*** with

    a. An F target associated with low risk of reaching $\mathbf{B}_{lim}$ in the long-term (i.e. F in the order 0.25)
    b. A gradual reduction of F below some action level of SSB (SSB in the order of 2.0 million tonnes)
    c. A catch ceiling to protect against too high catches caused by an overly optimistic assessment in the order of 0.8 – 1.2 million tonnes may also be considered, but this measure may be relatively unimportant.
    d. A strong restriction on the F on juveniles, e.g. approximately F 0-1 = 0.03, which corresponds to F0-1 at the proposed F with the historical selection pattern.

- If an $\mathbf{F}_{lim}$ is needed, it may be in the order of 0.35, which according to the present calculations implies an approximately 20% probability of falling below $\mathbf{B}_{lim}$, and a 5 percentile for SSB about 1.3 mill. tonnes.

3.4 Reference points and structural model uncertainty (Northern hake)

The biomass reference points for Northern hake are $\mathbf{B}_{lim}$ =120 kt., estimated from $\mathbf{B}_{loss}$ in the 1998 assessment, and $\mathbf{B}_{pa}$ = 160 kt, estimated as $\mathbf{B}_{lim}$ * 1.4.. The hake stock is now subject to a rebuilding plan because in recent years SSB has been assessed as being below $\mathbf{B}_{lim}$, and recruitment has continued to decline. (Anon 2002a)

3.4.1 Analysis of the 2001 assessment data by segmented regression

The XSA configuration in the 2001 ICES assessment for northern hake gave rise to SSB values that are consistently about 20% below those estimated by the 1998 assessment. . These lower SSB values therefore fall more frequently below $\mathbf{B}_{lim}$. This is described in detail in Working Document 8 (Cárdenas: PA reference points for hake) which is contained in Annex 6.

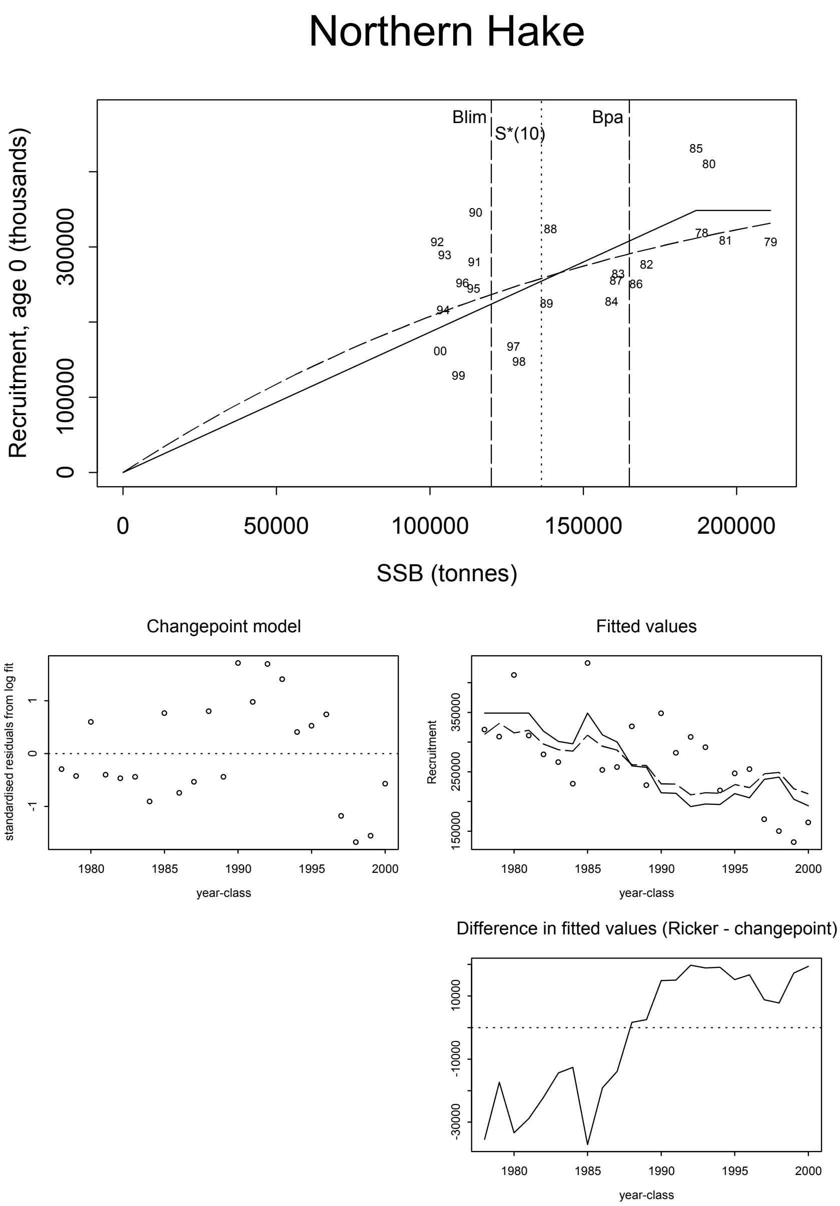


Figure 3.16 Segmented regression results for Northern Hake based on the data from the 2001 assessment.

Visual inspection of the 2001 stock-recruit plot raises the possibility that, on the basis of this particular assessment, hake recruitment could have been impaired as long ago as 1982. This possibility is supported by the results of the segmented regression analysis of O'Brien and Maxwell, described fully in Working Document 11, and summarised in Annex 4. For convenience the segmented regression fit is reproduced here as Figure 3.16. For the 2001 assessment results, the segmented regression estimate of S* is 187 kt, whilst S*(10), a likely candidate for $\mathbf{B}_{\text{lim}}$, is 136 kt. These estimates are both more conservative than the current reference points. This result is based on the full data set, including the estimated values for 1998 to 2000, which are in the unconverged part of the XSA output.

3.4.2 Assessment model structural uncertainty

The Study Group discussed the significance of changes in outputs resulting from changes in the configuration of an assessment, based on Working Document 23 (Darby; Assessment model structural uncertainty in the estimation of Precautionary Reference Points.) contained in Annex 7. Darby highlighted the effect of 'assessment model structure uncertainty' on the reference point estimates estimated for the Northern hake stock (Divisions IIIa, Subareas IV, VI, VII and VIIIa,b,d).

The framework of the Precautionary Approach outlined in Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks states that:

"Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality ***and major sources of uncertainty****."*

As outlined in the 2001 Study Group, ICES has acknowledged that it must:

"... explicitly consider and incorporate uncertainty about the state of stocks into management scenarios; explain clearly and usefully the implications of uncertainty to fisheries management agencies."

In general, ICES has interpreted uncertainty as the errors associated with estimates obtained from a single stock assessment model structure and reference point estimation method. In instances where multiple scenarios have been presented, based on alternative models, there is no formal procedure for quantifying the additional uncertainty and the "best available" has been taken to provide advice. Recent studies (Patterson et al. 2001, also described in Gavaris et. al. 2000) have shown that the choice of estimation method can have an appreciable impact on the perception of uncertainty and the risks associated with the consequences of fisheries management decisions.

It was shown that the XSA assessment model specified by the Southern Shelf Demersal Species Working Group is not a unique interpretation of the available assessment information but is one solution from a range of feasible solutions. A review of the model sensitivities and the underlying causes was presented.

The sensitivity of the trends in exploitation rate and biomass arises directly from the reduction in the age range of the assessment from a 10+ age group to 8+, based on the uncertainty of age determination in older hake. This has resulted in 30% of the mature catch in numbers being aggregated into the plus group and the oldest age and ~50% in the oldest two ages and the plus group. Due to poor VPA convergence at the oldest ages, VPA based assessment models fitted to data sets with significant numbers in the oldest age and plus group, are extremely sensitive to the method by which fishing mortality at the oldest age is estimated.

In recent years the WGSSDS has made substantial changes to the XSA model used to assess the Northern hake stock. As a result the assessment model structure may have become unstable due to the aggregation into fewer age groups.

The sensitivity of the estimated biomass and average fishing mortality trends to changes in the model assumptions was examined. It was shown that the hake assessment model has a range of what were considered to be equally valid solutions for biomass and fishing mortality, conditional on:

- the assumption of the shape of selection at the oldest ages;
- the time-series of catch per unit effort data used to calibrate the model;
- the inclusion or exclusion of ages for particular data sets;
- the data series themselves.

Each of the solutions generated a differing perception of the trends in the stock metrics with the majority being more pessimistic of the current state of the stock than the current Working Group analysis. Figure 3.17 shows the wide difference in stock trend resulting from differences in 'shrinkage', the weighting given to the assumption that the selection pattern is flat topped at the oldest age. The 2001 assessment used high shrinkage producing low SSB with a shallow trend, and a high F. Low shrinkage produced a lower F and a higher SSB, with a marked peak in 1985 followed by a much steeper decline. Comparable differences are generated by changing the time period and weighting applied to commercial catch per effort data used in tuning (Figure 3.18) or by selecting different national fleet data for tuning (Figure 3.19). The sensitivity in the XSA estimates was shown to be carried forward into uncertainty in the Precautionary Approach reference points for the stock (Figures 3.20 and 3.21).

In the case of the Northern hake, due to the current catch-at-age data structure, changes to the model structure have resulted in changes in the perception of risk that may have nothing to do with any real change in the state of a stock. Unless the structural uncertainty in the model can be resolved by the inclusion of additional information and new analysis, the interpretation of risk must be clearly linked to the XSA model assumptions and the alternative, more pessimistic alternatives considered.

These conclusions are consistent with the findings of Patterson *et al* (2001) who stated that:

"Many uncertainty estimates are predicated on a single structural population model which is accepted as the 'best' representation of reality. However, in some circumstances alternative representations of reality may be almost equally plausible (whether this is expressed as an expert opinion or as a likelihood function value) and the admission of such alternative representations as possibilities may greatly affect the perceived uncertainty. Conditioning of uncertainty estimates on a single structural model may result in such underestimation of uncertainty that for practical purposes the estimates of uncertainty in forecasts so generated bear little relation to the real likelihood of alternative eventual outcomes."

"The relative performance of different management options, and some parameters also will be more robust to structural uncertainty (for example, a parameter which is expressed in relative terms spawning biomass relative to virgin biomass is more robust than absolute measures of stock size). The importance of structural uncertainty will therefore depend on the parameters which are being used for management purposes."

The results for Northern Hake suggest that the changes in the inputs and outputs of the 2001 hake assessment may not be unique to hake, but are part of the wider problem of assessment model structure uncertainty. The Study Group concluded that the ICES Working Group on the Assessment of Southern Shelf Stocks of Hake Monk and Megrim [WGHMM] should examine in detail the sensitivity of the current management reference points to structural assumptions in the current assessment model. The review should include any additional information that can be provided on the dynamics of historic fishing effort directed towards the oldest ages and the application of alternative approaches.

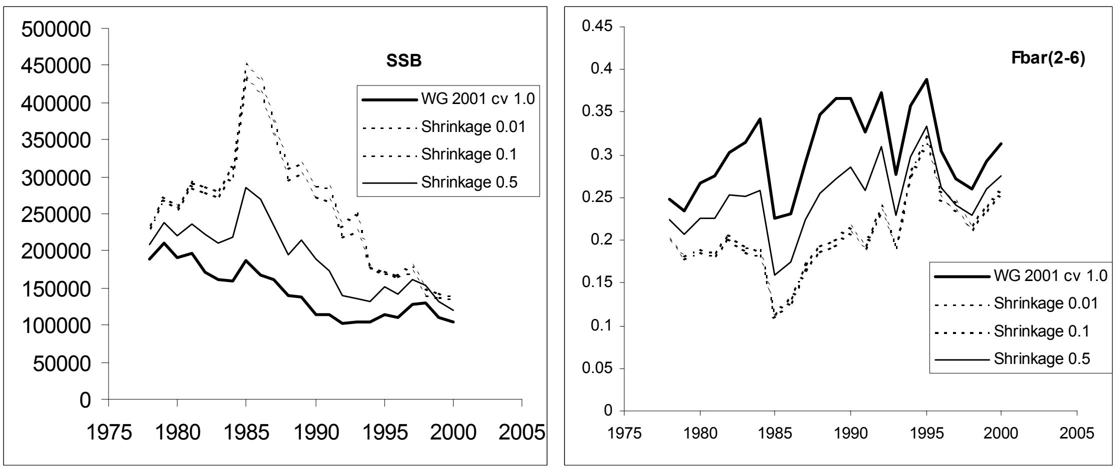


Figure 3.17 a, b. The time-series of spawning stock biomass and average fishing mortality as estimated within the XSA assessment fitted with increasing weight given to the assumption of a flat topped selection pattern at the oldest ages (lower cv = greater weight to constant selection).

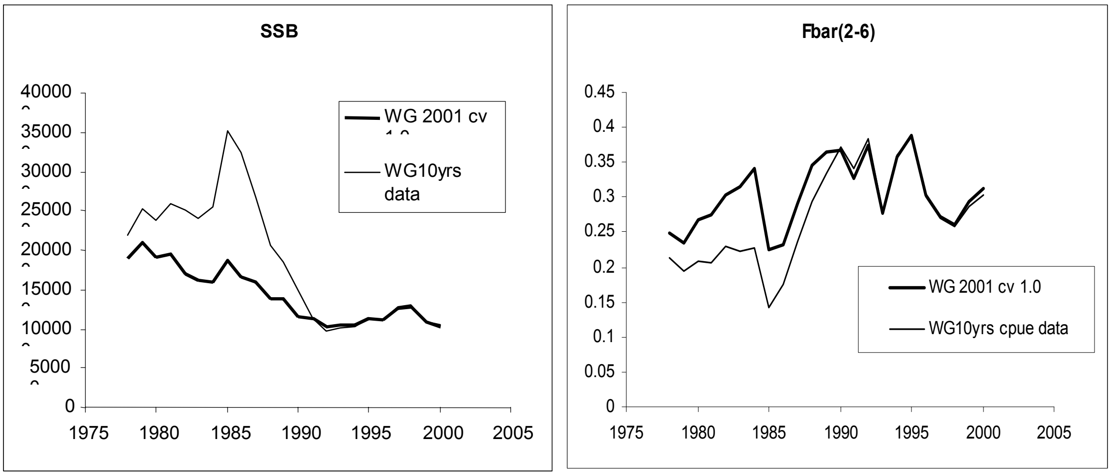


Figure 3.18 a & b. The time-series of spawning stock biomass and average fishing mortality as estimated within the XSA assessment fitted with a 20 year tri-cubic time-series weighting and no time-series weighting with CPUE calibration data for only the final 10 years.

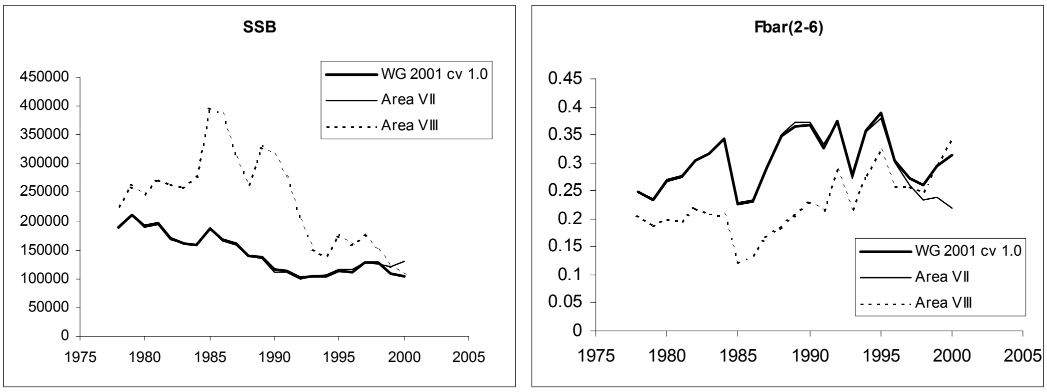


Figure 3.19 a & b. The time-series of Spawning stock biomass and average fishing mortality as estimated within the XSA assessment fitted independently to Subarea VII and Subarea VIII CPUE data series.

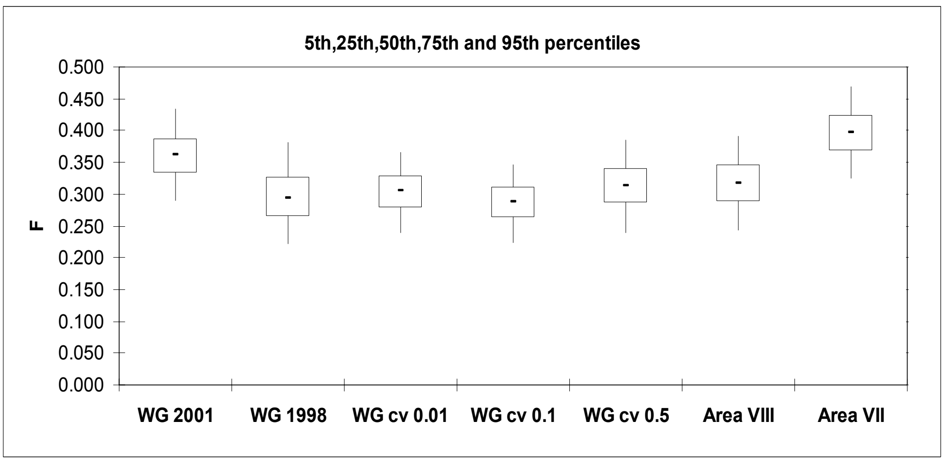
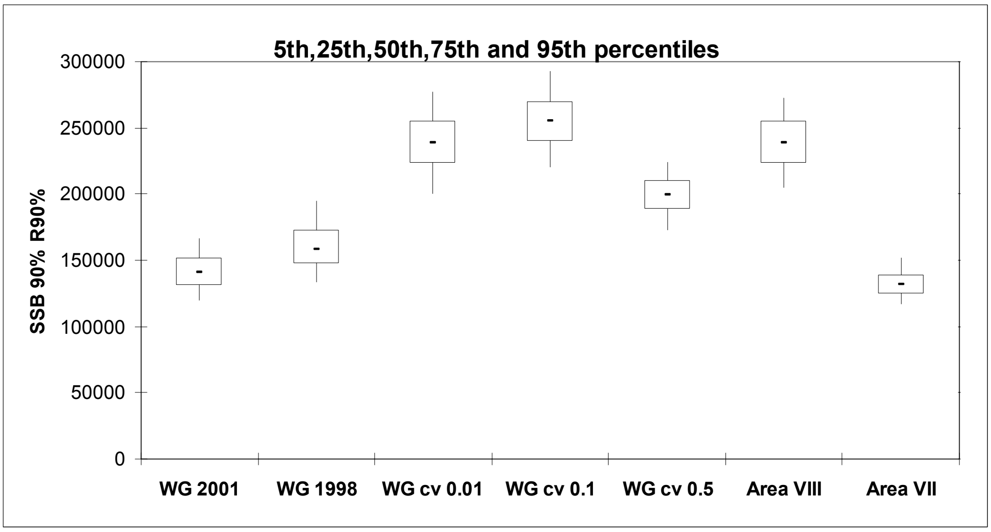


Figure 3.20 Estimates of $\mathbf{F}_{loss}$ derived from alternative XSA assessment model structures.

Legend: WG2001 – WGSSDS 2001. WG1998 – WGSSDS1998, the assessment used to estimate the current reference points. WG cvx.x – The SSDS 2001 XSA model structure with increasing weight given to the average selection pattern at age, lower CV's indicate more weight to the flat-topped selection pattern. Area VIII – an XSA assessment fitted to commercial data and survey information from ICES Division VIII. Area VII – an XSA assessment fitted to the commercial data from ICES Division VII.



Figures 3.21 Estimates of SSB corresponding to the intersection of the 90%ile of observed survival rate (R/SSB) and the 90%ile of the recruitment observations, derived from alternative XSA assessment model structures. Legend: WG2001 – WGSSDS 2001. WG1998 – WGSSDS1998, the assessment used to estimate the current reference points. WG cvx.x – The SSDS 2001 XSA model structure with increasing weight given to the average selection pattern at age, lower CV's indicate more weight to the flat-topped selection pattern Area VIII – an XSA assessment fitted to commercial data and survey information from ICES Division VIII. Area VII – an XSA assessment fitted to the commercial data from ICES Division VII.

3.4.3 Absolute versus relative values for reference points

For most ICES stocks the current SSB and F values are being compared against reference points derived from the 1998 assessment results. In addition to the effect of revisions in data on landings, weight-at-age or maturity-at-age, the structure of the recent assessments may differ from that used in 1998, and this may affect quite a number of ICES stocks. The previous section showed in detail how the output from the northern hake assessment has changed as a result of a change to the plus group following age determination problems with older hake. As a result the plus group is closer to the age of first maturity, and the estimation of SSB is sensitive to the fishing mortality on the oldest fish in the catch-at-age matrix, producing different historical values of SSB (Figure 3.22). Another example is that of haddock at Rockall (VIb) where $\mathbf{B}_{\mathrm{lim}}$ was estimated from a $\mathbf{B}_{\mathrm{loss}}$ of 6000t in the 1998 assessment, whereas in the 2001 assessment there were no historical SSB values below 7900t (Figure 3.23). Such a change makes it more difficult to determine the status of the stock relative to reference points.

As quoted above, Patterson et al (2001) commented that a parameterwhich is expressed in relative terms, is more robust than absolute measures of stock size. A solution to the problem of assessment model structure uncertainty may therefore be to compare SSB and F to reference points using relative values for particular years or periods of years (as suggested by Cárdenas, Working Document 7 in Annex 6), or relative to virgin biomass (the estimate of the latter can also vary from assessment to assessment). It is therefore suggested that SGPA and ACFM should consider further whether it is legitimate and robust to use relative rather than absolute values for reference points estimation and the evaluation of stock status.

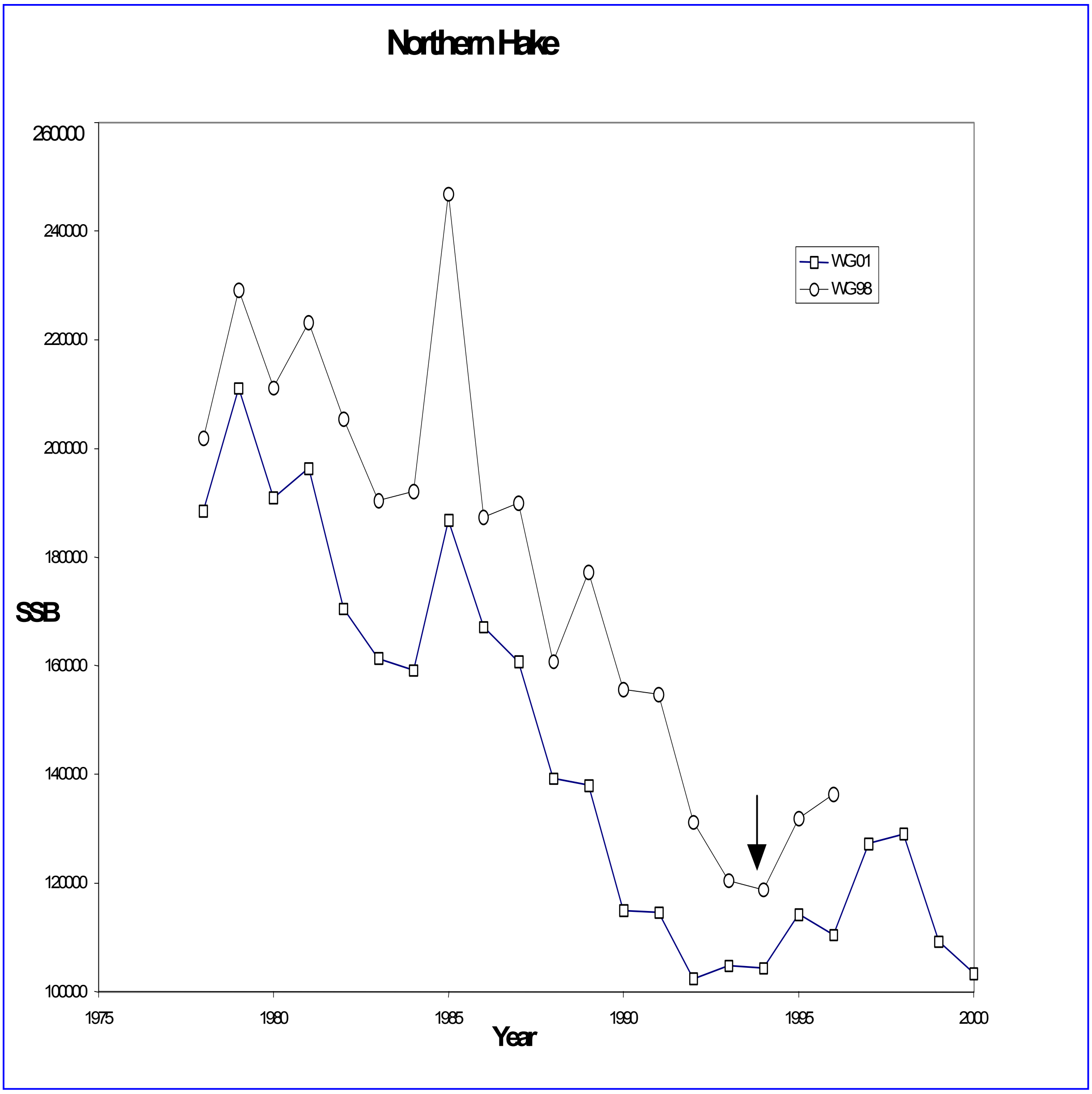


Figure 3.22. The trend in estimates of SSB for Northern Hake:
WG 98 =1998 assessment results, used to obtain PA reference points ($\mathbf{B}_{\mathrm{lim}}$ is indicated by the arrow). WG 01 = 2001 assessment

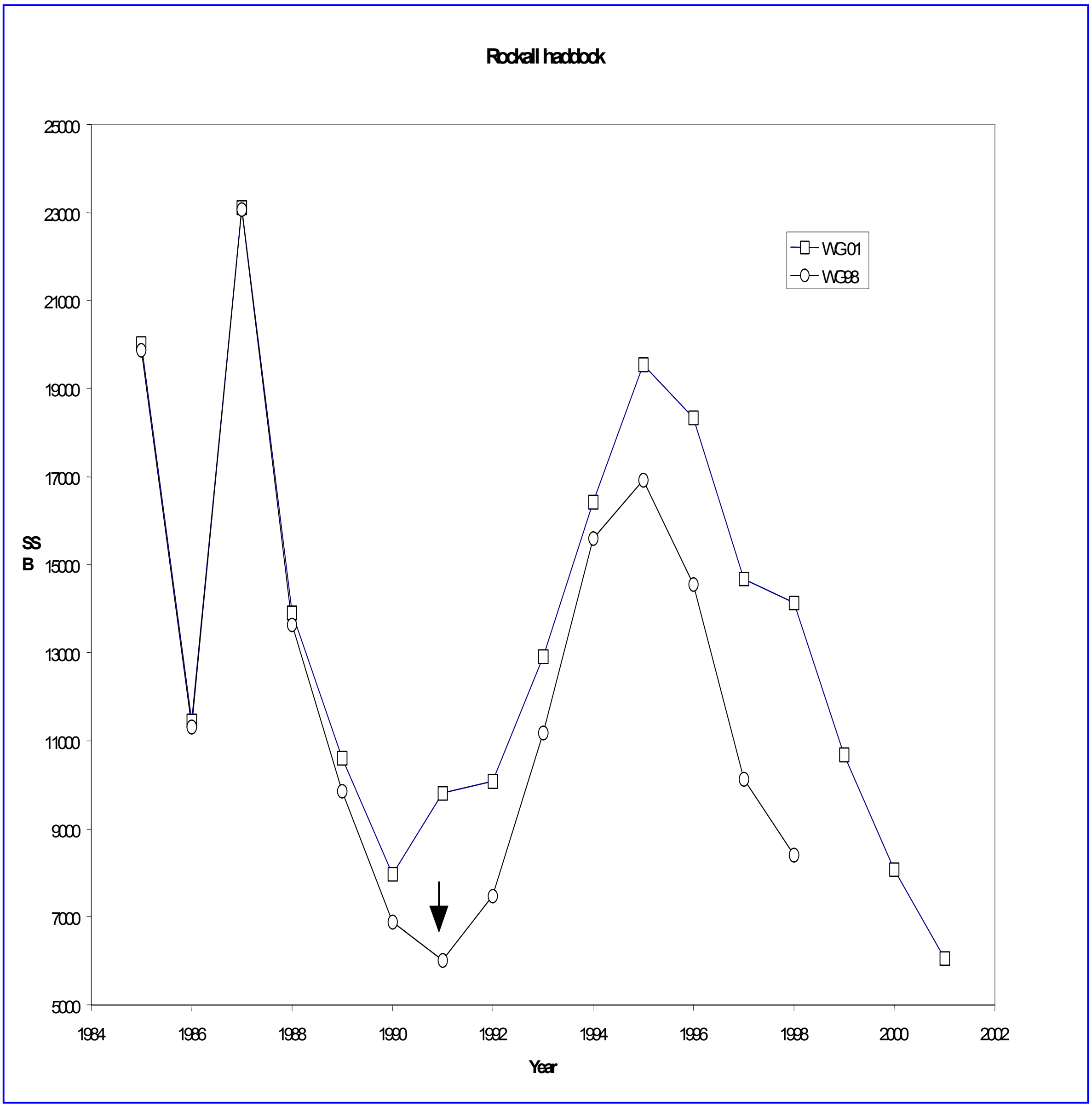


Figure 3.23. The trend in estimates of SSB for haddock at Rockall:
WG 98 =1998 assessment, used to obtain PA reference points ($\mathbf{B}_{lim}$ is indicated by the arrow). WG 01= 2001 assessment.

4 REFERENCE POINTS AND ENVIRONMENTAL EFFECTS

The examples of N E Arctic cod and Baltic Cod

ICES reference points have been estimated under the assumption that stock trends are determined mainly by fishing mortality and stochastic variation, and are not affected by factors such as inter-specific interactions, strong environmental interactions, or regime shifts. Because stock-recruit data contain a low signal to noise ratio, however, the true relationship between SSB and R is generally difficult to determine, and could easily be confounded by environmental factors. For species such as plaice and cod, for example, some North east Atlantic stocks show a significant inverse relationship between water temperature and recruitment (Fox et.al., 2000, O'Brien et.al, 2000) and therefore have the potential to be influenced by temperature trends linked to fluctuations in the North Atlantic oscillation, or to long-term climate change scenarios. Gadoid and flatfish stocks in the North Sea also show long-term changes in growth rate and maturity that are as yet not explained, but might result from food chain effects, or species interactions. For particular stocks such as the N E Arctic cod and the eastern Baltic cod it is suspected that the stocks have been affected by regime shifts, and it has been proposed that this should be taken into account in setting reference points (see below).

The analysis of environmental effects has been hampered by purely correlative studies that could generate a spurious correlation that is not enough on its own to justify further action. What is required in addition is a plausible hypothesis about the mechanism, and preferably enough supporting evidence to be confident that any detected relationship will persist in the future. These issues are best addressed by process studies aimed at identifying one or more likely mechanisms, and that provide information on how/where in a functional relationship the environmental factor should enter as a covariate (SGPRISM, 1999, 2001, 2002). Dividing a time-series into regimes makes the determination of the true stock-recruit relationship even more uncertain, suggesting that regime shifts should be really significant before such an approach is justified.

The Study Group could not investigate these aspects in depth, but it investigated the estimation of reference points for two stocks, North east Arctic cod and Baltic cod, where questions have been raised about the likely effect of environmental factors, and where some process information is available. In the North east Arctic, where water temperature during the 0-group feeding period may influence cod recruitment (Working Document 5, Ajiad, A. and T. Jakobsen, Incorporating Age Diversity Index and Temperature in the Stock- Recruitment Relationship of Northeast Arctic Cod), the level of cod recruitment appears to differ between the periods before and after 1970. In the Baltic, survival of cod eggs may be adversely affected in years when there is poor in$\mathbf{F}_{low}$ of saline and oxygen rich water from the North Sea, thus reducing the spawning volume, or in periods when predation by sprat is high, as has been the case in the 1990s. For these two stocks the Study Group reviewed the environmental background, and re-examined the stock-recruit data using segmented regression.

4.1 North east Arctic Cod

Several discussions have taken place about the possibility of changing the reference points for N E Arctic cod.

- In 2000 the Joint Russian-Norwegian Fisheries Commission asked ICES to review $\mathbf{B}_{pa}$, the former MBAL.

- In 2001 the Arctic Fisheries Working Group revised the historic data on maturity and weights-at-age, leading to lower SSB values for some years, and changing the historic stock-recruitment relationship (Anon 2001c [AFWG/ACFM:19]). The Arctic Working Group proposed a new value of $\mathbf{B}_{lim}$, corresponding to an SSB below which only poor year-classes have been produced. It also proposed a new safety margin between $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$, in response to a consistent overestimation of the stock over many years. It was proposed that $\mathbf{B}_{lim}$ should be 140,000 t, and that $\mathbf{B}_{pa}$ should be 378,000 t, based on $\mathbf{B}_{pa} = \mathbf{B}_{lim}\ e^{1.645\,\sigma} \times 1.4$, where 1.4 is a bias correction factor allowing for the difference between the converged and un-converged SSB values, and where σ , the fractional coefficient of variation of the assessment, is assumed to be 0.4.

- Scientific peer review of the 2001 assessment by Beckett and Serra (2001) noted that the R-SSB plot for the period after 1980 differed from the earlier period. The review commented that "it would seem questionable whether the full time-series of SSB values should be used, at least until more is known of the biological and physical processes". ACFM continued to use the current reference point values, however, pending clarification of how environmental factors affect recruitment, and whether the biological productivity of the stock has declined at low SSB.

- Recent findings on the effect of temperature and exploitation on the N E Arctic cod stock were described in Ajiad and Jakobsen (WD 5) and by Mehl (pers comm)

Ajiad and Jakobsen (WD 5) suggest that the time-series of age 3 recruits and SSB could be divided into two periods, 1946- 1970, and 1971- 1996 (their Figure 1). Average recruitment and SSB were higher in the first period (average of R= 759 million, and SSB= 419 000t) than in the second period (484 million and 339 000t respectively), when the average recruitment fell more than the average SSB, although by the 1990s recruitment was increasing again. The difficulty is to distinguish between the effects of exploitation and environmental factors. There is a progressive decrease in the age diversity index of the spawning stock throughout, and the second period includes a high rate of stock decline, but there was also an unusually sustained period of low temperature from 1977 to 1982, and two collapses of the Barents Sea capelin stock. Ajiad and Jakobsen show that temperature from the Kola section in the Barents Sea during the 0-group feeding period in the second half of the year is positively related to recruitment at age 3. A Ricker stock-recruit model incorporating temperature and age diversity gives a good fit to the recruitment data for 1971-1995, with 33% of the variance of recruitment explained by SSB, and 67% by temperature. Only 3% of the variance of R is explained by the diversity index which, paradoxically, is negatively correlated with recruitment. This is in contradiction to studies showing that stocks with a high age diversity give more recruits due to higher egg survival (Marshall, et al 1998, 1999). This analysis does not explain the underlying cause of the temperature effect, and the model fit may be caused by a good correlation between a few good year classes and higher temperatures in those years.

A new Masters thesis (Sigbjoern Mehl, pers. comm) has examined the effect of the North Atlantic Oscillation (NAO) on N E Arctic cod. The best correlation was obtained between the cod 0-group index and the NAO (2-year lag). It is suggested that a relevant biological factor may be changes to the relative number of old spawners and younger spawners. Relevant physical factors may be the great salinity anomaly in the 1970s, which was accompanied by cooling, and an eastward shift in the centre of low pressure in the period 1975 - 1979, increasing the number of storms in the following period. These factors will affect advection of copepod populations, and water turbulence, which could both affect the feeding of cod larvae. Other processes may be required to explain what happens between 0-group settlement and recruitment to the fishery at age 3 but there is a quite clear correlation between the NAO (3-year lag) and age 3 recruits (VPA) for the period 1975-1995. Before 1975 there was no such correlation. On this basis, the data should be partitioned between the periods 1946 to 1975, and 1976 to 1997.

4.1.1 Re-examining the stock-recruit relationship using segmented regression

Following the suggestion that important environmental changes in the mid-1970s may have influenced the recruitment pattern of fish stocks in the Barents Sea, Figure 4.1 shows a stock-recruitment plot for N E Arctic cod, with different symbols for the period before and after 1975. In the later period, recruitment has been lower and less variable than in the early period.

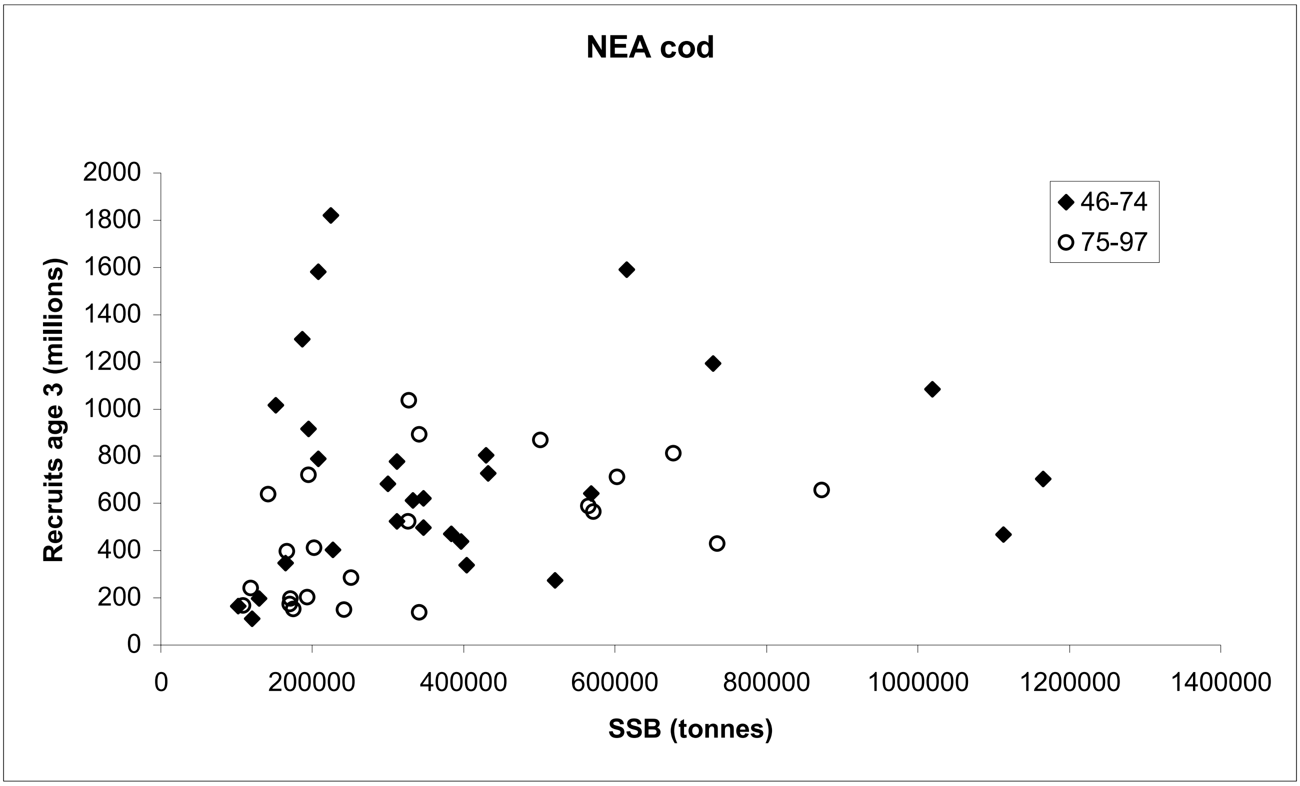


Figure 4.1 N E Arctic cod: Recruits at age 3 versus spawning stock biomass (SSB) for the periods 1946-74 and 1975-1997 (based on the ICES working group assessment in Anon 2001c)

The segmented regression approach was used to estimate S* (the SSB at the change point where recruitment decreases) for the whole data set, and for the two periods 1946-74 and 1975-1997. The segmented regression results are presented below in the format described in WD8, and the fitted regressions for the periods 1946-74, and 1975-1997, are shown in Figures 4.2 and 4.3 . No attempt was made to re-calculate fishing mortality reference points.

(i) complete time-series of R-SSB pairs

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
278687	2.21	616621		205762	280140	348858

(ii) time-series of R-SSB pairs prior to 1975

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
208207	3.13	652678		179350	209327	263124

(iii) time-series of R-SSB pairs from 1975

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
418420	1.54	646477		290470	419199	572514

The segmented regression estimates S* as 280 kt (205 kt –349 kt) for the entire data set, and 209 kt (179 kt- 263 kt) for the pre-1975 period. Figure 4.2 shows that these two change points are strongly influenced by the very high recruitment values emanating in 1963, 1964, 1969 and 1970 from an SSB in the region of 200 kt. For the period after 1975, visual exploration of the data would probably suggest a change point at around 300 kt, but the segmented regression (Figure 4.3) gives equal weighting to the wide range of recruitment occurring in 1977, 1983 and 1990 at an SSB of about 350 kt, and therefore locates S* at the much higher value of 419kt, albeit with a very wide confidence interval (290 kt -573 kt). This particular result could be considered somewhat controversial.

Taking S* as a prospective value for $\mathbf{B}_{\text{lim}}$, and S* (90) as a prospective value for $\mathbf{B}_{\text{pa}}$ (subject to managers views about α), the reference points estimated by segmented regression would be very different from the current values of $\mathbf{B}_{\text{lim}}$ (112 kt, based on $\mathbf{B}_{\text{loss}}$ in the 1997 assessment) and $\mathbf{B}_{\text{pa}}$ (500 kt, the former MBAL) in use since 1998, pending the revision of the data on stock weight and maturity. In each case $\mathbf{B}_{\text{lim}}$ would be more conservative than the present value (which was based on different criteria), but $\mathbf{B}_{\text{pa}}$ could be less or more conservative depending on whether the adopted value was for the whole data set or for the period after 1975.

This analysis was undertaken on an ‘if-then’ basis. If it is accepted that for environmental reasons the exploited life history should be broken down into pre- and post-1975 periods, and that the change points S* are best identified by segmented regression, then the results cited above could be proposed as new reference points. The justification for dividing the data into two periods remains a matter of opinion, however, since the environmental processes involved are still not fully explained, whilst the segmented regression result for the post-1975 period is very conservative. The Study Group was unable to take this analysis any further forward in the time available.

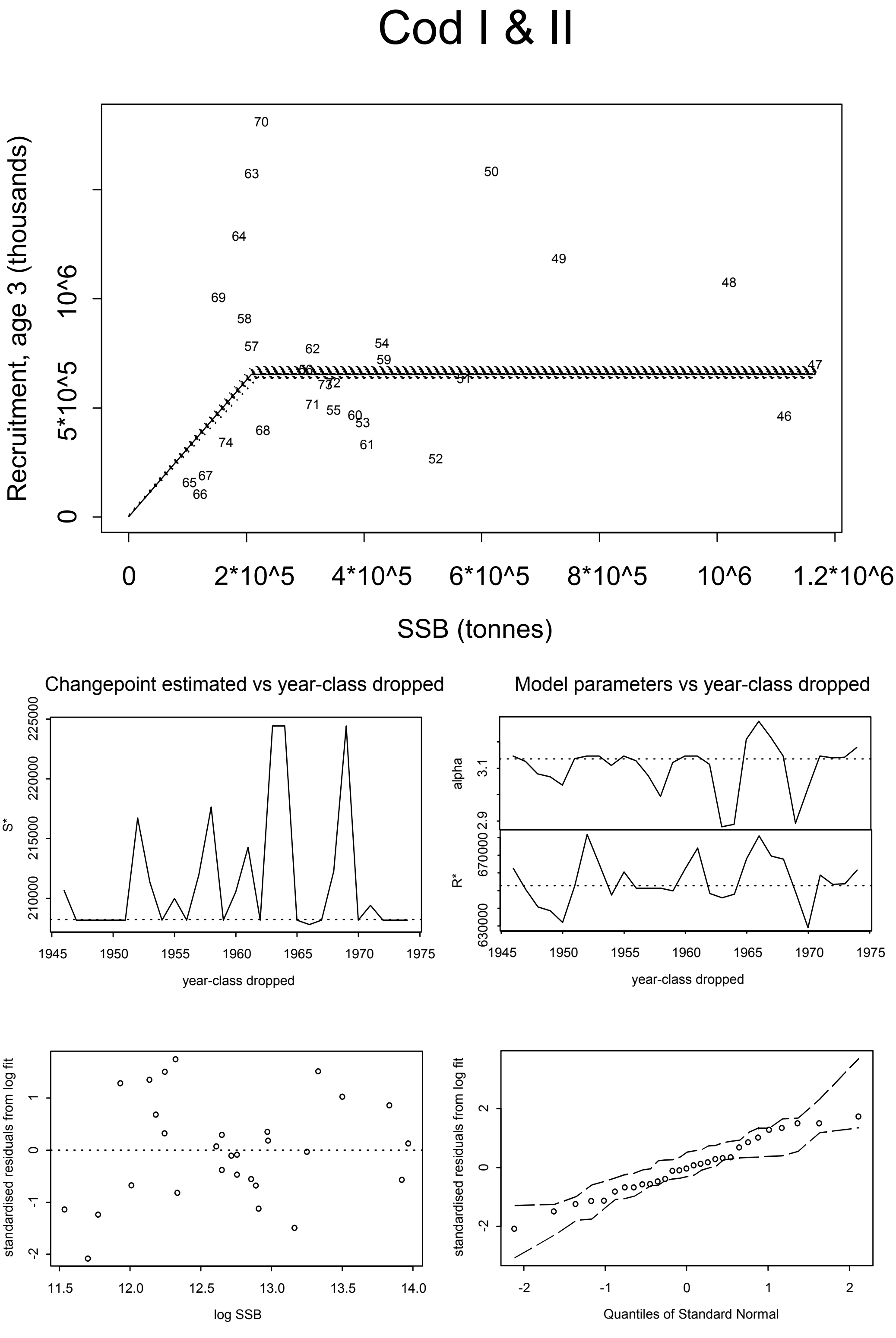


Figure 4.2 N E Arctic Cod: segmented regression fitted to R-SSB pairs prior to 1975

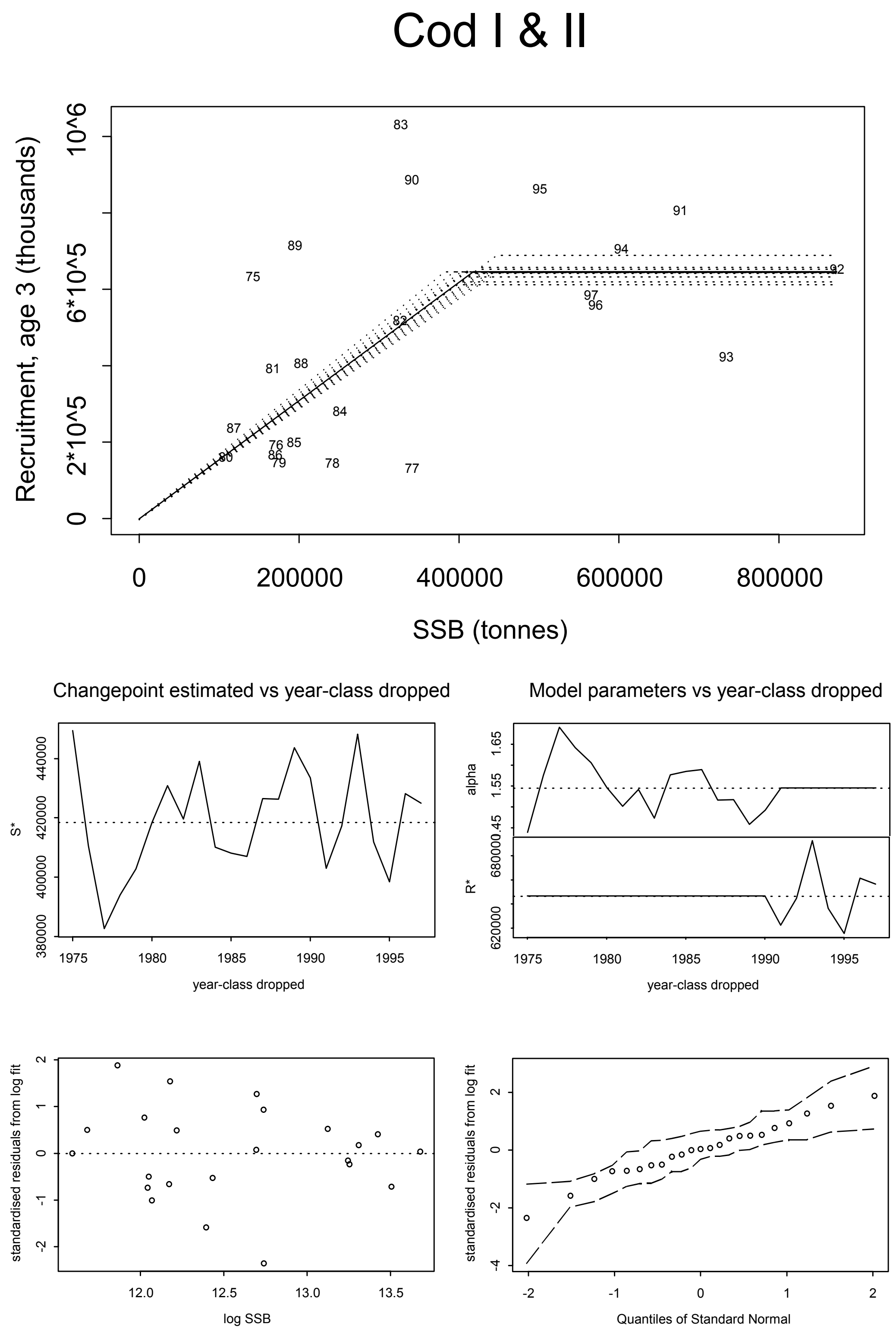


Figure 4.3 N E Arctic Cod: segmented regression fitted to R-SSB pairs after 1975

4.2 Baltic Cod

The relationship between spawning stock and recruitment for cod in the Eastern Baltic has been a fruitful area for research, including studies on environmental influences on recruitment. The most recent of these is summarised by Köster et al (2001a & b). Results show that the volume of water with sufficient salinity and oxygen for cod eggs to survive (the so-called “reproductive volume”) is an important influence on cod recruitment, and that it varies according to the strength and frequency of high-salinity inFlows of Atlantic water to the Eastern Baltic. Jarre-Teichman *et al*

(2000) noted an "observed shift in reproductive volume level" around 1980, since when reproductive volume and recruitment both appear to have been at lower levels than previously.

4.2.1 Current reference points for Eastern Baltic Cod

The basis for the existing reference points for the cod stock in Subdivisions 25-32 is given by the Study Group on Management Strategies for Baltic Fish Stocks (Anon, 1998c) (ICES CM 1998/ACFM:11). $\mathbf{B}_{pa}$ (240,000t) was based on the previous MBAL, although since MBAL is nominally the SSB where the ability of the stock to produce strong year classes is impaired, MBAL would normally be proposed as $\mathbf{B}_{lim}$. In this case, $\mathbf{B}_{lim}$ (160,000t) was obtained by dividing $\mathbf{B}_{pa}$ by $e^{1.645\sigma}$ (=1.5). The Baltic Study Group proposed an $\mathbf{B}_{pa}$ value of 0.65, corresponding to a 10% probability that SSB will be less then $\mathbf{B}_{lim}$ after 10 years in medium-term projections. Subsequently, the International Baltic Sea Fisheries Commission (IBSFC) adopted $\mathbf{F}_{lim}$ = 0.96, based on the $\mathbf{F}_{med}$ calculated in 1998, and $\mathbf{F}_{pa}$ = 0.6, based on the 5th percentile of $\mathbf{F}_{med}$. These reference points do not take into account environmental effects on the stock.

4.2.2 The need to review reference points for Eastern Baltic cod

There are several reasons why it may be appropriate to review Baltic cod reference points. Firstly, IBSFC has a commitment to review its reference points at three-year intervals, and a review will be required in 2003. Secondly, the EU project STORE, on stock and recruitment in Baltic cod and sprat (Schnack and Köster, 2001), is due to end in 2002, and includes a subtask to specify reference points based on the results. Thirdly, the estimated SSB for Eastern Baltic cod is currently well below the current $\mathbf{B}_{lim}$, and F is well above $\mathbf{F}_{lim}$, and ICES has therefore advised that the fishery should be closed during 2002 (Anon, 2002a). The Baltic Fishermen's Association, noting the importance of reproductive volume for Baltic cod recruitment, has responded that "The agreed value of $\mathbf{B}_{lim}$ for Eastern cod has not been adjusted in accordance with observed changes in stock dynamics and cannot be considered as relevant under present environmental conditions". Finally, IBSFC has introduced new fishing gear regulations for 2002, and has requested that ICES review reference points for Baltic cod taking these measures into account. There are therefore strong grounds for reviewing the reference points for this stock. The work in this section takes into account the results of research on the influence of environmental factors on cod recruitment, but does not consider the effect of the mesh changes.

4.2.3 Reviewing reference points in the light of process information

As a contribution to the review, the Study Group has considered the biomass reference points for Eastern Baltic cod in the light of the available process information on the effect of environmental factors on cod recruitment. One plausible interpretation of the recent history of the stock is that there has been a regime shift, and that the stock has entered a period of reduced productivity due to the reduced reproductive volume. Jarre-Teichman *et al* (2000) advocated fitting separate Ricker stock-recruit curves to two time-series covering year- classes up to 1980, and the year classes from 1982, (1981 being regarded as a transition year between the two states). If the assumption of a regime shift is correct, it would be appropriate to estimate reference points from the more recent stock-recruitment data corresponding to the assumed period of reduced productivity.

4.2.4 Exploring alternative reference points for Eastern Baltic cod

Alternatives to the current reference points of $\mathbf{B}_{lim}$ = 160 kt and $\mathbf{B}_{pa}$ of 240 kt were estimated by applying the segmented regression approach to the full data set, and to the separate sets for 1966-1980, and 1982-1998. The estimate values of the change point S* are shown below, and the fitted regressions are illustrated in Figures 4.4-4.6.

(i) complete time-series of R-SSB pairs, 1966-1998

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
352528	0.99	349648		301098	354922	505359

(ii) time-series of R-SSB pairs (1966-1980)

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
442117	1.48	653301		325620	441614	596761

(iii) time-series of R-SSB pairs (1982-1998)

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	R*		S*(10)	S*	S*(90)
139123	1.09	151599		not defined	138999	188845

Using the full time-series of stock-recruitment data for 1966 to 1998, the segmented regression (Figure 4.4) gives equal weight to the extreme recruitment values of 1976 and 1986, and estimates a change-point S* at around 355 kt (301-505kt). Since S*, or its lower limit S* (10), are the points where the segmented regression estimates that recruitment is impaired, they are candidates for a new $\mathbf{B}_{\mathrm{lim}}$ that is substantially higher than both the existing $\mathbf{B}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{pa}}$. The latter reference points are based on what appears to be an inappropriate use of the previous MBAL of 240 kt. which, according to the ICES definition, should have been defined as $\mathbf{B}_{\mathrm{lim}}$ and not as $\mathbf{B}_{\mathrm{pa}}$.

Using stock-recruit pairs up to and including the 1980 year-class, the change-point (Figure 4.5) is increased even further to around 442 kt (326-597kt), corresponding to the higher productivity regime assumed to apply in that period. This fit is driven by the recruitment observed at the two highest values of SSB in 1970 and 1980. If only the year classes from 1982 onwards are used, corresponding to the shift in reproductive volume identified by Jarre-Teichman *et al* (2000), the model fit is not significant with an irregular likelihood surface, and time-series trends in the residuals. Inspection of the plot (Figure 4.6) indicates that an alternative approach to this period might be to regard the years 1982 to1986 as a transition period, after which recruitment has been stable at a low level. There was insufficient time to pursue this approach further, but a visual inspection of Figure 4.6 suggests that the resulting estimate for $\mathbf{B}_{\mathrm{lim}}$ would be very similar to the current value. A decision about how or whether to change the reference points for Eastern Baltic cod therefore requires further investigation.

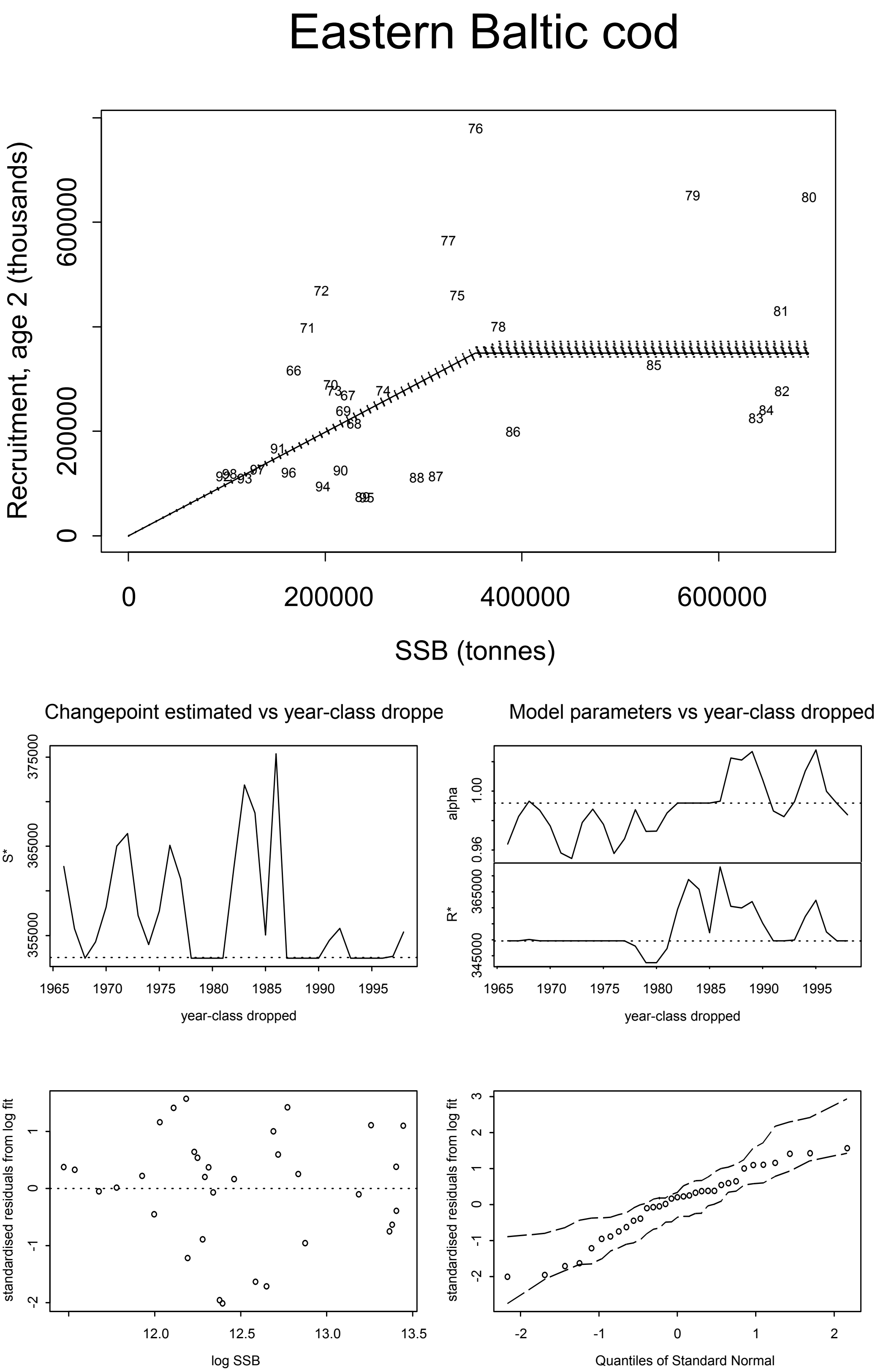


Figure 4.4 Eastern Baltic Cod: segmented regression fitted to all R-SSB pairs, 1966-1998

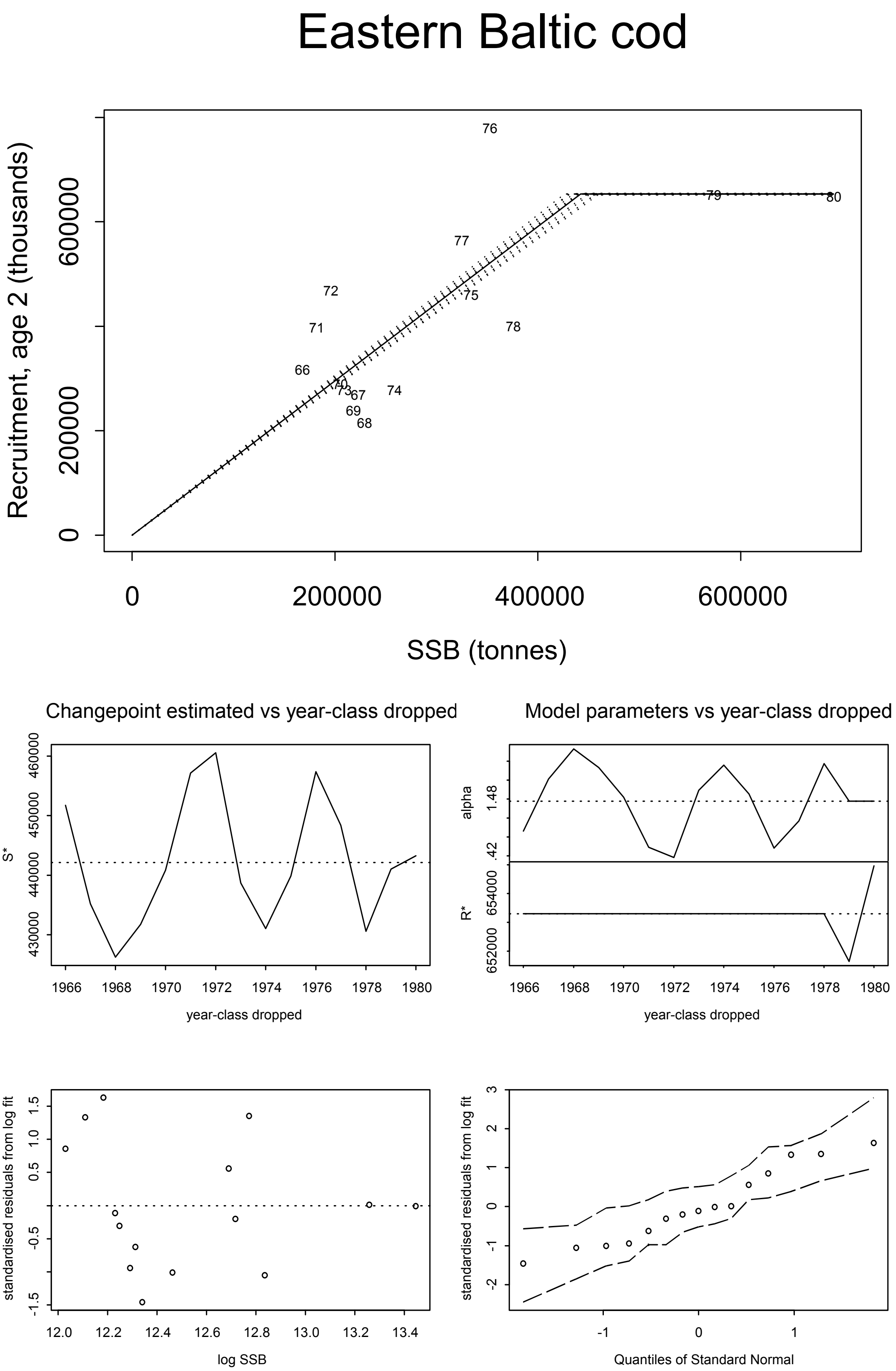


Figure 4.5 Eastern Baltic Cod: segmented regression fitted to R-SSB pairs for 1966-1980

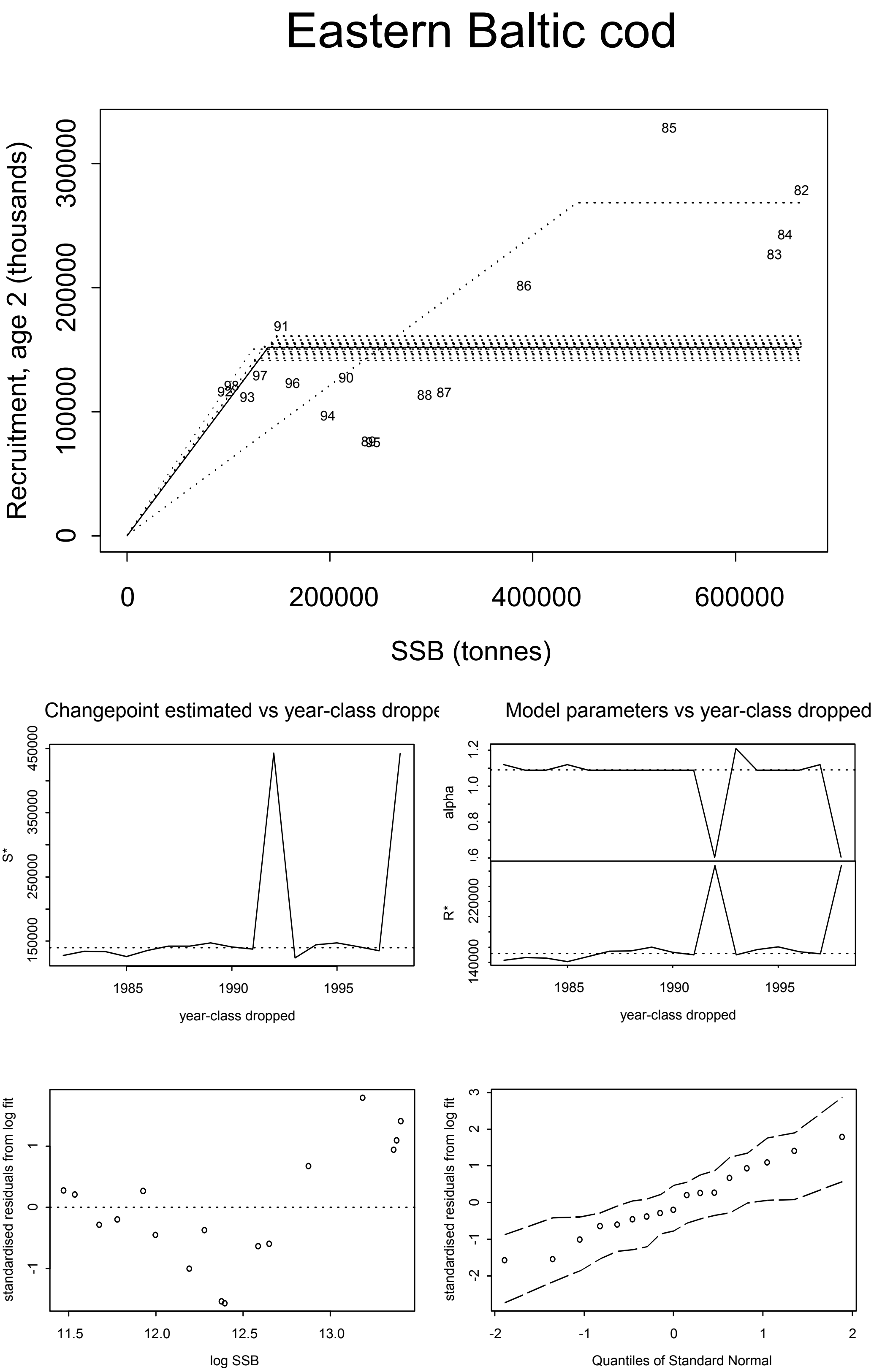


Figure 4.6 Eastern Baltic Cod: segmented regression fitted to R-SSB pairs from 1982

4.2.5 Concluding remarks for Baltic cod

The segmented regression analysis for this stock is exploratory, and incomplete, but it highlights that it may be an over-simplification to treat the post-1982 changes in the stock as a one-step regime shift accommodated by simply truncating the stock-recruitment time-series. To account for changes in stock productivity may require a more sophisticated approach, based on process information that achieves a more structured interpretation of the stock-recruit data. Simulation studies of the type performed by Basson (1999, 2000) may also be appropriate.

4.3 Concluding comments about the role of environmental variables

Improvements to the fit of a stock-recruitment model when an environmental factor is included may give rise to the suggestion that reference points should be changed. This is not a simple matter, however, because there is no longer a single S-R curve, but rather a surface comprising a different curve for each level or value of the environmental variable. Furthermore, as it will become more difficult to manage stocks whose reference points change from year to year, exactly how reference points should be adjusted still requires careful consideration. The two examples analysed above raise a number of points in relation to reference points for stocks where environmental effects may be having an important influence on recruitment:

- The identification of time periods corresponding to ‘regimes’ is not straightforward, and may be an over-simplification of the true environmental variation. Furthermore, a regime shift that occurs in one direction could presumably be reversed at some time in the future, but this may be very hard to identify or to predict.

- It is difficult to identify if and when ‘regime shifts’ have occurred. As a minimum, analysis should be based on detailed knowledge of how the environmental effect operates, and not just on a simple correlation. In ICES, some progress on the incorporation of process information on recruitment is being made by SGPRISM

- Changes to reference points annually or over longer but unpredictable time spans, could cause significant operational difficulties. It may therefore be more appropriate to place the emphasis on fishing mortality reference points, especially as it is fishing mortality that managers can influence, rather than the environment. Alternatively, biomass reference points should be set conservatively to ensure sustainable exploitation, even during periods when environmental conditions are unfavourable.

5 DEEP WATER SPECIES AND SMALL PEGALIC SPECIES

5.1 Deep water species

As discussed by the 2001 Study Group (Anon, 2001a), there is concern about the effect of exploitation on the largely unregulated deep water species because of their biological character (long-lived, slow-growing, and low reproductive potential) and the lack of suitable data for the calculation of standard reference points. The 2001 Study Group re-iterated the following reference point proposals made by SGDEEP (Anon, 2000c)

$$\mathbf{F}_{lim}=F35\%SPR; \quad \mathbf{F}_{pa} = M$$

$$\mathbf{U}_{\mathbf{lim}} = 0.2^* U_{max}; \quad \mathbf{U}_{\mathbf{pa}} = 0.5^* U_{max}, \text{ or } 0.3^*U_{max}$$

where U is an index of exploitable biomass. These empirical rules take no account of the biological diversity and stock structure of deep water species, however, or the different types and patterns of fishing among species, and among fishing areas within species.

Subsequently, ACFM (Anon, 2002a) provided advice on the vulnerability of deep water species to exploitation, using life history parameters to rank the species according to their productivity, on the grounds that

a) for a given fishing mortality stocks of lower productivity will decrease faster then more productive stocks
b) once depleted the more productive species will be able to rebuild more quickly.

Vulnerability may include many factors other than the species life history, including biological factors such as shoaling, migration, and habitat preferences, or fishery factors such as markets and fleet capacity. ACFM gave an overall average ranking based on individual rankings for longevity, growth rate, natural mortality, fecundity, and length at first maturity (Table 3.12.6.a.1 in Anon 2002a). It then proposed that effort should be reduced for a number of deep water species that are outside biological sage limits (Table 3.12.6.a.7in Anon 2002a).

In order to develop the life history ranking approach, this Study Group selected three species as examples characterized by their biology (coefficients of natural mortality and growth, length at first maturity and asymptotic or maximum length) and by the pattern of exploitation (length at first capture). Using the Beverton and Holt length based approach described previously (Azevedo and Cadima, 2001), these characteristics were used to compute long-term F reference points ($\mathbf{F}_{max}$, $F_{0.1}$, $F_{0.2}$, as ratios of M, and F=M) and the corresponding %BPR and % SPR.

The species selected were:

Orange Roughy *(Hoplostethus mediterraneus*)

This species has a spatially patchy distribution, with spawning aggregations located in ICES Subarea VI. A fishery targeting this species developed from 1991 onwards. After an initial peak, landings and fishing effort have quickly declined from an initial high level, consistent with a "mining" approach in which aggregations are located and then fished out sequentially.

Black Scabbardfish (*Aphanopus carbo*)

This is a widely distributed species and substantial catches are taken west of Scotland and the Rockall Trough, west of Ireland and the Western Approaches, off the Portuguese coast (ICES Subarea IX) and off Madeira. Two different fishing gears are used; bottom trawl at the Northern fishing areas and bottom long-lines in the southern areas. . It has been suggested that there is a single stock in ICES waters but available evidence is inconclusive.

Portuguese Dogfish (*Centroscymnus coelolepis*)

This species occupies a wide area of distribution. Portuguese dogfish is an ovoviviparous species, with 13 to 16 young per litter, and the gestation period is suspected to be higher than one year. Reproduction is therefore likely to be an important constraint on the resilience of these stocks to exploitation.

5.1.1 Reference point results

Table 5.1 summarises the F reference point results for these species. The %SPR corresponding to different reference point options can be compared with the proposed criteria of $\mathbf{F}_{lim}= F_{35\%SPR}$ and $\mathbf{F}_{pa}$=M. The results for $\mathbf{F}_{0.1}$, $F_{0.2}$, and F=M are clearly similar between species, but in the case of the northern Black Scabbard, however, the lower selectivity of the trawl fishery means that for F to be below $\mathbf{F}_{lim}$ it must be below M and below $F_{0.1}$ on the basis of the 35% SPR criterion. For the other species and fisheries F=M and $F_{0.2}$ will be above $\mathbf{F}_{lim}$. These results suggest that an approach based on length based methodology and life-history characteristics is a possible way of combining generality but also taking into account biological and fishery diversity, and the Study Group suggests that this approach should be developed further.

Table 5.1 Biological parameters, and %SPR and %BPR for various F reference points for Black Scabbard, Orange Roughy and Portuguese Dogfish.

Species	**Black scabbardfish**		**Orange Roughy**	**Portuguese dogfish**	
ICES area	**Southern**	**Northern**		**Southern**	**Northern**
	Longline	**Bottom trawl**		**Longline**	**Bottom trawl**
M ($year^{-1}$)	0.27	0.27	0.004	0.16	0.16
K ($year^{-1}$)	0.2	0.2	0.06	0.64	0.64
Lc (cm)	110	92	53	102	100
Lm (cm)	103	103	52	102	102
$\mathbf{L_{inf}}$ **(cm)**	147	147	77	137	137
Longevity	12	12	125	40	
M/K	1.4	1.4	0.1	0.3	0.3
c	0.7	0.6	0.7	0.7	0.7
$\mathbf{c_m}$	0.7	0.7	0.7	0.7	0.7
$\mathbf{F_{max}/M}$	12.3	5.0	4.46	3.67	3.67
%BPR	<5	9	14	15	15
%SPR	<1	2	14	15	15
$\mathbf{F_{0.1}/M}$	1.36	1.12	1.63	1.36	1.36
%BPR	34	35	34	35	35
%SPR	34	25	34	35	35
$\mathbf{F_{0.2}/M}$	0.84	0.72	1.03	0.88	0.88
%BPR	46	47	46	47	47
%SPR	46	38	46	47	47
$\mathbf{F_x/M=1}$	1	1	~ F0.2/M	1	1
%BPR	41	38		44	44
%SPR	41	28		44	44

Table 5.2 References sources

Species	**Black scabbardfish**		**Orange Roughy**	**Portuguese dogfish**	
ICES area	**Southern**	**Northern**		**Southern**	**Northern**
M	Estimated using Tanaka curve and assuming a longevity of 12 years		Annala and Sullivan, 1996 Tracy and Horn 1999	BASBLACK Pauly´s model (temp=5ºC)	
K	BASBLACK Project		Idem		
Lc (cm)	Visual inspection of Portuguese landings	Visual inspection of French landings	Visual inspection from Iceland landings	Visual inspection of Portuguese landings	Visual inspection of French landings
Lm (cm)	BASBLACK Project		Berrehar, DuBuit, Lorance unpublished	Girard and du Buit 1999 Girard 2000	
L_{inf} (cm)	BASBLACK Project		95% of Lmax from French catches	Carvalho, Quaresma and Figueiredo unpublished	
Longevity	BASBLACK Project		Annala and Sullivan, 1996 Tracy and Horn 1999	Carvalho, Quaresma and Figueiredo unpublished	

5.2 Short lived species

The Study Group listed the following characteristics of short lived species :

- life-span restricted to 4-6 years old.
- high level of natural mortality (mean around 1.0 or even greater) that can vary because a large proportion is caused by predation and environmental conditions that also vary
- recruitment is highly variable and the age at first capture is low, so that stock dynamics are characterised by large fluctuations
- fishing mortality is generally much smaller than natural mortality.

In the ICES area examples of short lived species of commercial interest are:

- capelin in the Barent Sea
- capelin around Iceland
- sandeel in the North Sea
- Norway pout in the North Sea
- sprat in the North Sea
- anchovy in the Bay of Biscay.

5.2.1 Precautionary Approach considerations

Owing to the high predation rate on these species it is important to either define an escapement biomass to secure food resources for predators or to include predator needs in assessments. This approach has been taken for the Barents Sea capelin, where yearly estimates of cod consumption are included in the assessment model, and for the Icelandic stock, where a constant escapement biomass is defined.

Owing to the variability of stocks, recruitment surveys are necessary for reliable catch predictions, and a low age at first capture implies that short-term predictions can only be given for the current year. Management therefore has to adopt a procedure for in-year advice. An example is the preliminary TAC for anchovy to be revised in the middle of the TAC year based on surveys in the spring.

5.2.2 Biological reference points

The exploitation of pelagic species should be undertaken with special care, keeping fishing mortality at a moderate level due to the risks of over fishing at low levels of biomass and taking into account that several of these stocks have collapsed (Ulltang 1980, Csirke 1988, Pitcher 1995). Mace and Sissenwine (1993) recommended that the higher the natural mortality, the larger should be the escapement percentage of spawning biomass per recruit in relation to the virgin state (the criterion of %SPR). They also indicated that small pelagic species could be poorly resistant to exploitation since for these species the %SPR corresponding to $\mathbf{F}_{med}$ can be as high as 40 to 60 %. Patterson (1992) suggest that a moderate and sustainable rate of exploitation could be F= 0.67 M. These reviews are based on knowledge of medium size species, rather than short lived species such as anchovy, but given current knowledge, they may be taken as a first approximation to sustainable levels of fishing mortality.

5.2.3 Fishing mortality reference points

Reference points based on the level of exploitation have been set for several pelagic species around the world. A recent report on the inclusion of environmental indices in the management of pelagic fish populations (Barange 2001),includes biological reference points for several small pelagic stocks, as follows:

- for Northern anchovy and Pacific sardine $\mathbf{F}_{MSY}$ is applied as a threshold or limit fishing mortality
- for Peruvian anchovy, Chilean (southern) anchovy and Chilean common sardine the target F is that maintaining 40% of the Biomass per year,
- for Chilean-Peruvian anchovy $\mathbf{F}_{lim}$ is the F that generates 40% of the Biomass per year, while F yielding 67% of Biomass is used as a target.
- for Pacific anchovy in Japanese waters, F30% SPR and 0.8*F30%SPR are used as limit and target reference points.

In general, therefore, a target F between F40% and F66% of SPR is frequently adopted for small pelagic or short living species.

5.2.4 Biomass reference points

Managing on the basis of F reference points ignores the risk that in small pelagic species catchability may increase at low levels of biomass, thus increasing the risk of stock collapse below certain threshold levels. To avoid this risk it may be advisable to adopt biomass reference points that can be managed by TAC. As with other species, there are examples of biomass reference points for small pelagic species based on $\mathbf{B}_{loss}$ or the SSB below which R is impaired (Anon 2001a).

Butterworth and Berg (1993) recommended SSB = 20% of Virgin Biomass as a minimum level for the South African anchovy. For Norwegian spring spawning herring $\mathbf{B}_{lim}$ is set at a threshold below which there is a high probability of impaired recruitment (Rottingen, 2000). In capelin stocks (Anon 2002a) and the Bay of Biscay anchovy (Anon 1998a and Anon 1998b), $\mathbf{B}_{lim}$ is set at the lowest SSB that resulted in outstanding year classes. Generally $\mathbf{B}_{pa}$ levels have been set in the standard way as $\mathbf{B}_{lim}$ exp(1.645*σ), with σ referring to the uncertainty in the biomass estimations (Anon 2001a)

5.2.5 Conclusions

In a new situation, it is suggested that an initial F target reference point for short lived species other than capelin or squid, should be 0.67M, as proposal by Patterson (1992), provided that M does not vary too much. An alternative is a target F between F40% and F66% of SPR based on other fisheries on short-lived species.

Limit biomass reference points could be set by analogy with other short-lived species, such as Barents Sea capelin, in which $\mathbf{B}_{lim}$ is estimated as the lowest SSB resulting in an outstanding year-class.

Regarding harvest control rules, difficulties in forecasting recruitment mean that close monitoring of the population by direct methods is required. If the fishery is to be regulated by TAC, a two-staged management strategy is required, involving a provisional annual TAC based on a provisional estimate of the incoming new recruitment, followed by a mid-year revision once a new survey estimate is available.

6 DEVELOPMENT OF THE PRECAUTIONARY FRAMEWORK

6.1 Background

6.1.1 Present ICES framework

In 1998 ICES introduced the Precautionary Approach (PA) in its annual advice on fishery management. The ICES interpretation of the PA is that its advice will ensure that the reproductive potential of stocks will not be affected by exploitation. ICES therefore introduced limit reference points for biomass and fishing mortality that have to be avoided at all times. The biomass limit reference point ($\mathbf{B}_{lim}$) is defined as the adult biomass in the stock below which it has been observed that recruitment is impaired, or below which the dynamics of the stock are unknown. For giving management advice an operational biomass reference point ($\mathbf{B}_{pa}$) has been introduced. $\mathbf{B}_{pa}$ is set so that if the estimated spawning biomass is above it, there is a very low probability that the stock is near $\mathbf{B}_{lim}$. $\mathbf{B}_{pa}$ therefore takes into account the accuracy of the assessment. Similarly, a limit fishing mortality reference point ($\mathbf{F}_{lim}$) has been defined as the fishing mortality associated with unknown population dynamics or stock collapse. The operational fishing mortality reference point used in giving management advice is $\mathbf{F}_{pa}$. $\mathbf{F}_{pa}$ is set as a safety margin to $\mathbf{F}_{lim}$ taking into account the accuracy of the assessment.

The ICES advice uses the PA reference points as trigger points for action. ICES advice on fishing mortality will never be higher than $\mathbf{F}_{pa}$. The advice is normally short-term advice based on a deterministic forecast. It is formulated according to guidelines referring to the state of the stock relative to PA reference points. If SSB is above $\mathbf{B}_{pa}$, the advice will normally be for a TAC corresponding to F less than $\mathbf{F}_{pa}$. If a stock declines below $\mathbf{B}_{pa}$, ICES will advise a reduction in fishing mortality that should bring the stock above $\mathbf{B}_{pa}$ 'as soon as possible'. If the stock is below $\mathbf{B}_{pa}$ and is not expected to recover to $\mathbf{B}_{pa}$ in the short-term, or if the stock has declined below $\mathbf{B}_{lim}$, ICES advises that a rebuilding plan should be implemented.

The reference points proposed by ICES have been formally accepted for the management of fish stocks shared by Norway and the EU, which have adopted the PA reference points in the management agreement for herring, cod, haddock, saithe and plaice in the North Sea, and mackerel in western waters.

6.1.2 Shortcomings with the ICES framework

When the PA was first introduced, ICES recognised that the advice would have to be further developed in the future. The present advice is based on single-species considerations only, whereas many species are caught in mixed or multispecies fisheries. Preferably the advice would have to be applied to fisheries, or a combination of species caught in the same fisheries, rather than to single-species. The precautionary approach would also have to be developed to take into account side effects of the fisheries or, in a wider sense, the ecosystem aspects of fisheries.

The ICES PA approach assumes that changes in recruitment are mainly driven by SSB and that reductions in biomass are due only to the effect of fisheries. In the real world, recruitment is dependent on short and long-term environmental variations, and on the effective fecundity of the spawning stock. SSB is used as a proxy for the effective fecundity but this does not take into account the dependence of fecundity on age composition, maternal nutritional status, and other factors that are known to influence fecundity. Maintaining a sufficient SSB is clearly imperative, but in the evaluation of the effect of management measures, such other factors may have a large impact.

The present implementation in management also has shortcomings. $\mathbf{F}_{pa}$ should be regarded as the upper bound of the fishing mortality that can be applied to a fishery in order to have a high probability of maintaining a sustainable resource. Similarly $\mathbf{B}_{pa}$ should be interpreted as the minimum required adult spawning biomass. These reference points are not intended as targets, but as thresholds. It is expected that fishery managers would have set targets beyond the reference points taking into account biological objectives, and others such as optimising catch/revenue or employment, or achieving political agreement. In practice the management system has not been able to agree such targets and the precautionary reference points are being used as a target. In the relevant cases (eg EU-Norway shared stocks), management has agreed to exploit stocks at $\mathbf{F}_{pa}$ and to start action if SSB decreases below $\mathbf{B}_{pa}$. By managing the stocks so close to the $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$ targets, however, there is a substantial probability that stocks will move above or below the target from year to year so that management action has to be taken frequently to change the stock trend.

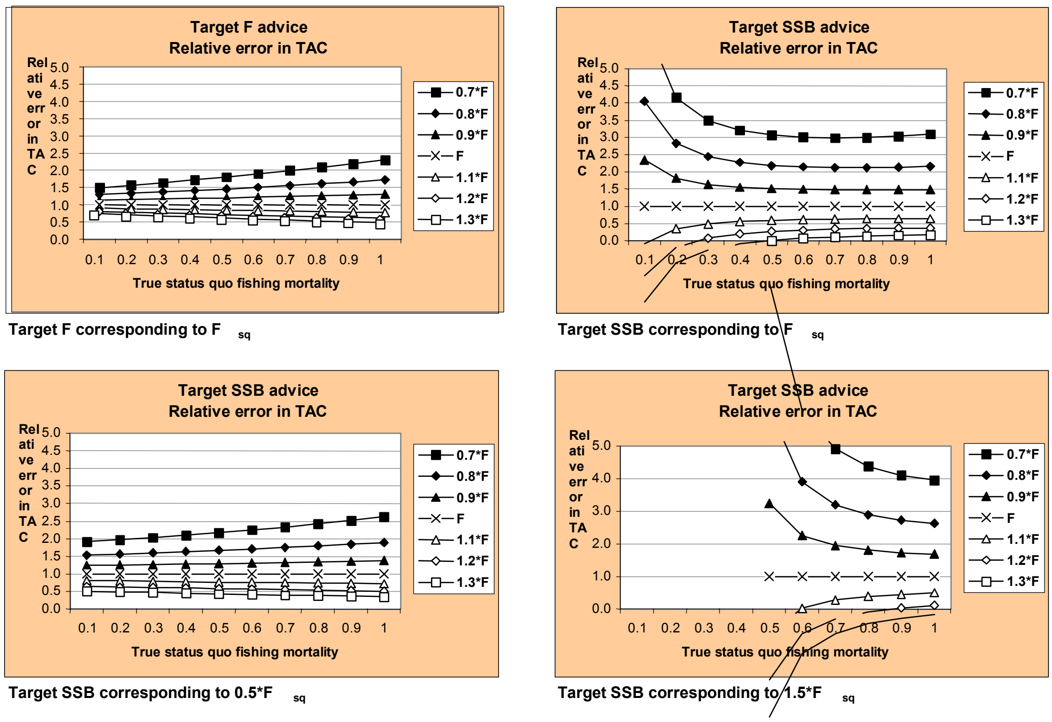
Since $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$ are derived independently, they are not always consistent with each other. Also, stocks with the same status relative to the reference points may not necessarily pose the same biological risks. For example, in some stocks, particularly those where no recruitment failure has been experienced in the past, normal recruitment may still be expected between $\mathbf{B}_{pa}$ and $\mathbf{B}_{lim}$. For other stocks, ICES has proposed $\mathbf{B}_{pa}$ at an SSB where recruitment starts to deteriorate (e.g. North Sea cod, where $\mathbf{B}_{pa}$, set at the previous MBAL, is the SSB that more properly conforms to the definition of $\mathbf{B}_{lim}$). Likewise, the reference F values represent a wide range of exploitation levels, to some extent depending on the historical exploitation of the stock.

ICES has defined $\mathbf{B}_{pa}$ as a safety margin to $\mathbf{B}_{lim}$, taking into account the uncertainty of the assessment. In principle, the better the assessment, the smaller could be the difference between $\mathbf{B}_{pa}$ and $\mathbf{B}_{lim}$. In practice $\mathbf{B}_{pa}$ has been also proposed and used as a trigger point for action when SSB declines below this reference point. This may not be appropriate, as it is arguable that a trigger point for action should also take into account such factors as the time needed to agree and implement actions, the feasible scale of the actions, and the natural dynamics of the stock. ICES may have to reconsider the use of $\mathbf{B}_{pa}$ as a trigger point for advising management action, when reference points are re-evaluated.

The question of error is not yet addressed fully. Error in a recommended TAC will depend on the error in the forecast, which in most cases will be heavily influenced by errors in the assessment. Examination of historical assessments has revealed that there have been substantial errors in the forecast of biomass (W. D 4. Sparholt: Quality of ACFM advice: How good have forecasts been since 1988 ? Appendix A of the 2001 Report of WGMG)) which suggests that the uncertainty assumed in setting PA reference points may be too small in some cases.

The calculations used to forecast catch and biomass reveal that TAC advice has a lower precision when it is based on achieving a level of SSB at $\mathbf{B}_{pa}$ than when the advice is based on F (WD3 Jakobsen and Sparholt , Annex 8 of this report). This is because errors in the assessment (VPA) gradually increase in the forecast period, and the SSB objective is one step later in the forecast than the F. Errors in the recruitment estimates will be brought forward in a similar way. The difference in TAC error depends on the fishing mortality, on the expected change in SSB, and on the importance of recruiting year classes in the forecast of catch and biomass. It is substantial in most cases, and can be very large (See Figure 6.1., from WD 3)

Figure 6.1 Error in TAC advice as function of error in assessment and level of true F, based on forecast of single cohort.



The legend in Figure 6.1 shows the relative error in F in the assessment.

6.1.3 The NAFO experience

6.1.3.1 Proposed NAFO PA framework

In 1997, the Scientific Council (SC) of NAFO proposed a framework (Figure 1), based on spawning biomass and fishing mortality, which outlined reference points for each measure (Serchuk et al. 1997), and proposed courses of management action for each of the main SSB-F zones in the framework. These pre-agreed management actions should be invoked when limit or target reference points are reached. Stock rebuilding and fishery reopening plans would be implemented when biological limit reference points are violated. Under the proposed framework, three types of reference points were proposed:

Type of reference point	**Fishing mortality-based**	**Biomass - based**
Stock specific biological limit ref.pts.	$\mathbf{F}_{\mathrm{lim}}$	$\mathbf{B}_{\mathrm{lim}}$
Uncertainty dependent buffer ref. pts.	$\mathbf{F}_{\mathbf{buf}}$	$\mathbf{B}_{\mathbf{buf}}$
Management target ref. pts.	$\mathbf{F}_{\mathbf{tr}}$	$\mathbf{B}_{\mathbf{tr}}$

The Scientific Council interpretated these reference points as follows:

$\mathbf{B}_{\mathrm{lim}}$: Level of SSB below which a stock should not be allowed to fall
$\mathbf{B}_{\mathbf{buf}}$: Level of SSB acting as a buffer to ensure high probability that $\mathbf{B}_{\mathrm{lim}}$ is not reached
$\mathbf{B}_{\mathbf{tr}}$: Target recovery level. For overfished stocks this is the total stock biomass that would produce MSY.

$\mathbf{F}_{\mathrm{lim}}$: F that should not be exceeded ($<= \mathbf{F}_{\mathrm{MSY}}$)
$\mathbf{F}_{\mathbf{buf}}$: Level of F acting as buffer to ensure high probability that $\mathbf{F}_{\mathrm{lim}}$ is not reached
$\mathbf{F}_{\mathbf{tr}}$: Target F, depending on management objectives, but <= $\mathbf{F}_{\mathbf{buf}}$.

Overall, the objectives of the PA proposed by SC were stated simply as:

1) Ensure that SSB is well above the buffer level, which by definition is above the biomass limit reference point.

2) Maintain fishing mortality such that, on average, it does not exceed $\mathbf{F}_{\mathbf{buf}}$, and which will allow the stock to increase towards $\mathbf{B}_{\mathbf{tr}}$ and ultimately be maintained at that level.

To aid in the development of a PA in NAFO, a Working Group on the Precautionary Approach was formed, comprised of managers from the Fisheries Commission, and scientists from the Scientific Council. The group has met on three occasions and some progress has been made in implementing a PA, for example in defining specific roles of scientists and managers in the process, and developing implementation plans for several stocks.

Implementing the proposed PA within NAFO

There are a number of reasons why the proposed PA framework has not been fully implemented within NAFO. One consideration is that the PA framework proposed by Scientific Council has never been formally endorsed by the Fisheries Commission. A contentious issue in the proposed PA framework is the statement that the level of $\mathbf{F}_{\mathrm{lim}}$ can be no higher than $\mathbf{F}_{\mathrm{MSY}}$, which is based on Scientific Council's interpretation of Paragraph 7 of Annex II of the UN Agreement. On one side were arguments that $\mathbf{F}_{\mathrm{MSY}}$ is an extremely difficult parameter to estimate reliably for some stocks, and that the clause in the UN agreement is not a compulsory one in any case. On the other hand were arguments that proxies for $\mathbf{F}_{\mathrm{MSY}}$ would be acceptable, and that promoting levels for $\mathbf{F}_{\mathrm{lim}}$ which are greater than $\mathbf{F}_{\mathrm{MSY}}$, in the context of collapsed stocks in the Northwest Atlantic, would not be consistent with conservation.

Another issue is harmonisation of concepts and terminology between various agency approaches. In February 2000, a meeting of the Working Group on Precautionary Approach Terminology, consisting of representatives of ICES, NAFO, ICCAT, and FAO, considered the various agency PA frameworks, and commented on similarities and differences in terminology, definition, concepts, and usage (ICES 2000b). This WG produced detailed comparisons of the ICES and NAFO approaches to the PA. Discussion on the possibility of common usage and concepts led the WG to conclude at that time, that " *… even if it were possible, it may be premature to recommend a common approach to the PA. In many cases, work on the PA is very much in the exploratory stage*".

Another difficulty within NAFO has been that SC has not yet defined a full suite of reference points, in accordance with the proposed PA framework, for any stock. Several stocks assessed within SC are considered to be "data moderate or data poor", and for the few of these with active fisheries, approaches such as production modelling (eg. ASPIC method for Division 3LNO yellowtail flounder), or the "traffic light" method (eg. Division 3M shrimp) have been employed. For yellowtail, reference points proposed by the SC include $\mathbf{F_{buf}}$ = 2/3 $\mathbf{F}_{MSY}$, and $\mathbf{B_{tr}}$=$\mathbf{B}_{MSY}$ (as a rebuilding target), but it has not been possible to propose a value for $\mathbf{B}_{lim}$ due to the lack of a stock-recruit relationship.

At present, many stocks assessed within SC are currently closed to fishing. For most of these, the scientific focus has generally been to define $\mathbf{B}_{lim}$, and the management focus has been on the strategies required to reach this benchmark (eg. ways to minimize by-catches). For some of these stocks, assessments based on sequential population analyses and stock - recruit relationships have resulted in some progress recently in defining reference points (eg. Division 3NO cod). For this stock and for Division 3LNO American plaice, there are indications that the stocks are currently in a period of much lower productivity compared to the 1960's and 1970's. This has presented an additional challenge in determining SSB-R relationships, reference points, and recruitment levels for medium-term forecasting.

6.1.3.2 Target reference points in the NAFO PA framework

Although target reference points are part of the proposed NAFO framework, SC noted that the biomass target is a proposed recovery level for overfished stocks. No other biomass targets, or fishing mortality targets, were proposed by SC, although the framework obviously requires a target F to be less than or equal to the buffer level. In discussions within the NAFO PA WG, it was agreed that selecting target reference points is the role of managers i.e. the Fisheries Commission of NAFO, although Scientific Council would provide advice on which SSB-F zone the stock was estimated to be occupying.

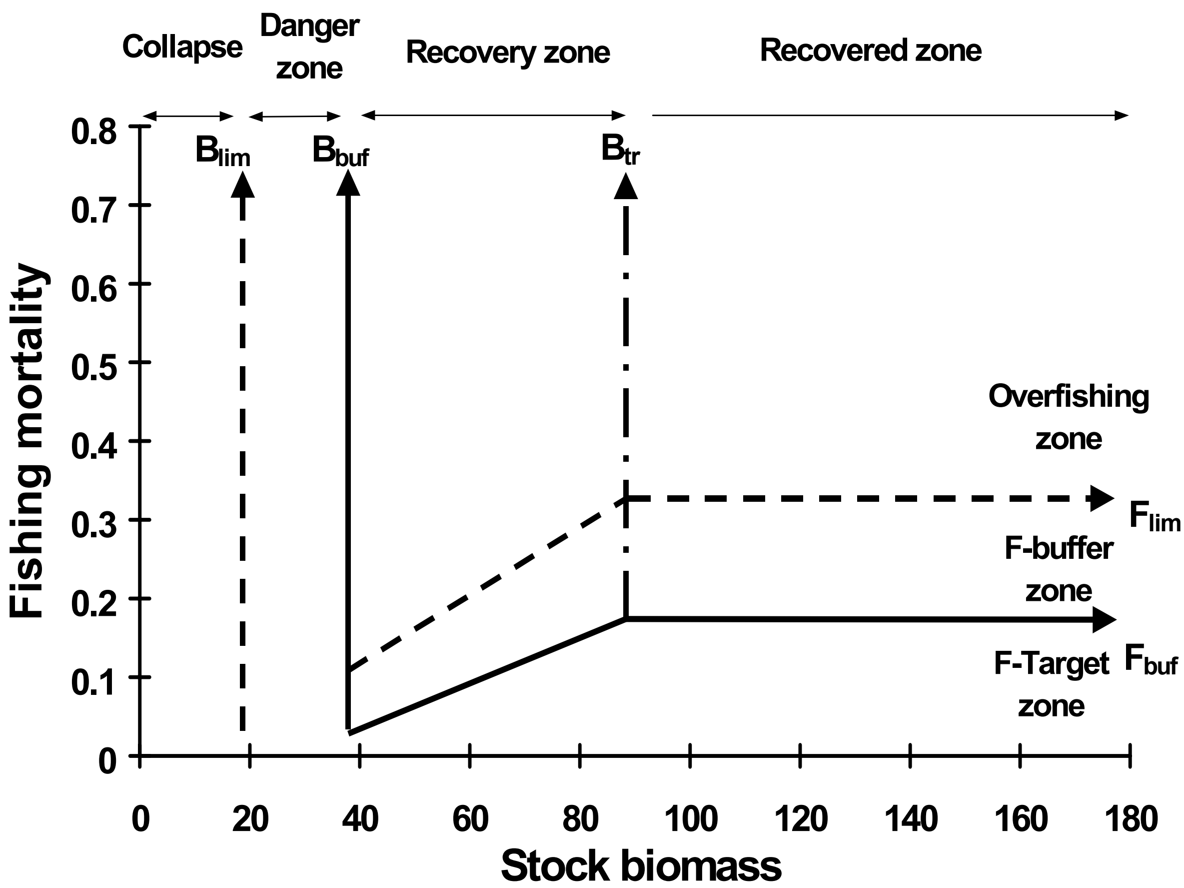


Figure 6.2 Framework for Precautionary Approach proposed by NAFO Scientific Council

6.2 Suggestions for improving the present ICES framework

6.2.1 Possible directions for the future

Improvements to the present framework can be made in several ways. Whilst the existing ICES definitions of $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ should be used operationally it was agreed that, following from Anon (2001a) and from Section 4 of this report, revision of the present precautionary reference point values is needed. This should take into account more realistic estimates of uncertainty in the assessments and observed variations and trends in biological parameters.

For a number of stocks with historically comparable dynamics, inconsistencies have been identified in the choice of reference points. These choices are not well explained. Since the biomass and fishing mortality reference points have been derived independently, the consistency between these reference points within the stocks should also be investigated (see Anon, 2001a).

It is also observed that safety margins and trigger points for management action need not be the same. Presently $\mathbf{B}_{pa}$ is used as both but the introduction of an additional trigger point should be considered.

However, even with the proposed improvements of the present system it would be difficult or impossible to address all shortcomings in the present framework, in particular to address the multispecies aspects and technical interactions of the fisheries as well as ecosystem issues.

Some of these shortcomings would be better addressed by shifting the emphasis from biomass to fishing mortality reference points. Below we discuss some possible directions for future development, such as a guideline for management, development of harvest control rules, and the introduction of target reference points.

In passing it should be noted that as the public and stakeholders make increasing use of documentation that is in the public domain via web sites, the language used to describe reference points and their application should be checked for clarity. An example from a recent ICES publication makes this point:

"$\mathbf{F}_{pa}$ = Approx. 5th percentile of $\mathbf{F}_{loss}$; implies an equilibrium biomass >$\mathbf{B}_{pa}$ and a less than 10% probability that (SSBMT<$\mathbf{B}_{pa}$)"

6.2.2 Biomass reference points versus fishing mortality reference points

Although both biomass and fishing mortality reference points are formally incorporated into the precautionary approach, biomass reference points seem to be preferred operationally by managers and laymen because they are easier to relate to and to understand. Although biomass reference points are required to classify the state of a stock and as trigger points for management action, they have several disadvantages if they are to be used as targets, and if ecosystem considerations are to be addressed. If fishing mortality reference points are used as the main tool, these disadvantages may be reduced.

Estimates of biomass are usually based on catch information but are extremely sensitive to the quality of catch data. In many cases catch data are incomplete and there is little or no information on the extent of unreported catches and discards. If discards or unreported catches are not included in the assessment, biomass will be underestimated. If these practices change, an additional error is introduced.

Where the main management objective is to maintain a target biomass, relatively large changes in fishing mortality and the corresponding TAC may be required each year. This is often undesirable when managers are striving to maintain stability in the catches.

Periods with different productivity and dynamics have also been observed for some stocks. This may have different causes and it is often not possible to distinguish between them. For instance recruitment may be reduced at low stock biomass, but there may also be indications that environmental factors could be responsible for the change in stock dynamics. Where a genuine 'regime shift' is occurring it could become very difficult to reach a target biomass. Finally, a biomass target alone does not address the additional need to maintain the age diversity of the stock.

Estimates of fishing mortality are in general more robust to misreporting because they are mainly based on the ratio of the numbers in a cohort. The numbers may be affected, but the ratio less so. A fishing mortality target would also be a more suitable instrument to achieve a wider age diversity the stock.

Again, while it may not be possible to achieve agreed biomass targets following a regime shift, fishing mortality reference points will in general be less sensitive to such shifts.

Finally, a fishing mortality target would be related more directly to the operational management objectives of controlling fishing effort and fleet capacity.

6.2.3 Harvest control rules

An extension of the fishing mortality reference concept is to design harvest control rules that can be simulated to estimate the risk that a stock reaches unwanted levels, taking into account several objectives. Such rules describe the permitted exploitation rate as a function of current biomass. TACs are derived from the F-value given by the rule and the estimate of the current stock abundance. These rules are conceptually different from rebuilding plans, and are mostly relevant for stocks that are not in a state of rebuilding.

There are many possible designs for such harvest control rules, which can to a large extent be adapted to particular management objectives and stock dynamics. A common basic framework is to define fishing mortality at 3 levels of SSB

a) below a low SSB value the fishery should be closed, or a low mortality caused by unavoidable by-catches assumed
b) at high SSB, a standard fishing mortality could apply
c) between these, the fishing mortality is reduced in proportion to SSB

This is the standard approach in the NAFO area and has also been proposed occasionally for stocks in the ICES area.

Such a rule has the advantage that fishing mortality is reduced when the stock becomes small, but small changes in stock abundance will only lead to small changes in mortality. The rule could contain constraints on the permitted year to year variation in catch, or have functional forms other than a straight line in the intermediate level, or set TACs for longer time periods than one year. If young and older fish are exploited by separate fleets, a harvest control rule could allow fishing mortality to be specified for these fisheries separately, and to account for the trade off between their fishing opportunities.

The limitations to the choice of rule are set by the risk of reaching the biomass selected as the limiting biomass. The risk should be properly evaluated by simulation, taking into account parameters such as the natural variations in recruitment, weight and maturity, or changes in the selection at age, as well as the uncertainty and possible bias in future assessments. The evaluation of risk should also consider the time lapse between the assessment of changes in stock abundance in the sea and the eventual implementation of the management measures. To be acceptable within the precautionary approach, the risk that the limit biomass is reached should be low, at least within the range of parameter variation observed historically.

There will always be a trade off between the operational level of fishing mortality at the upper level of SSB and the trigger point where the fishing mortality reduction commences. A high level of F will require a higher SSB trigger point and will lead to larger year to year variation in the TAC.

Generally, a harvest control rule will need some lower bound on the acceptable biomass that should be avoided with high probability, corresponding to $\mathbf{B}_{\mathrm{lim}}$ as used presently. $\mathbf{B}_{\mathrm{pa}}$ in the current use of the term will not be needed, because the design of the rule and the evaluation of the probability distributions for stock biomass should include the error that can be expected in the assessment. The new biomass reference point representing the trigger point for reducing the fishing mortality, is conceptually different from $\mathbf{B}_{\mathrm{pa}}$ and should be given a different name.

The fishing mortality adopted above the SSB trigger point will effectively serve as a target fishing mortality. It should take into account the considerations already noted for target reference points, such as trade offs between interest groups, concern for other stocks taken in mixed fisheries etc. Since the actual choice of fishing mortality at SSB above the trigger point SSB is conditional on the value chosen for the trigger point, a management regime aiming at a certain target F would have to be supplemented with a rule to reduce the fishing mortality at SSB below a trigger point, to give sufficient protection against reducing the stock to dangerous levels. This may make the current $\mathbf{F}_{\mathrm{pa}}$ redundant. It may be useful, however, to indicate an upper bound to the permissible F target, to prevent an increase in stock abundance from triggering a strong increase in fishing mortality that may be difficult to reverse.

Section 3.3, on the reference points for blue whiting, provides an example where a regime along these lines is suggested.

6.2.4 Candidate values for fishing mortality target reference points

In the 2001 Study Group, it was recognised that candidate target reference points would need to consider technical interactions, multispecies interactions, and socio-economic factors. It was also acknowledged that the selection of such reference points would require a substantial dialogue between ICES, managers, and stakeholders. Although these conditions are not yet met, candidate reference points could be evaluated based on their general properties and on assumed long-term objectives, such as maximising yield while keeping the stock in a condition that permits biomass to fluctuate naturally without the risk of a collapse.

If the long-term objectives include maximising the long-term yield, stabilising catches and a low risk of stock collapse, such fishing mortality targets as $\mathbf{F}_{MSY}$ or lower should be considered. $\mathbf{F}_{MSY}$ is often ill defined, however (Anon 2001a). Unfortunately, the Study Group did not have time to address Term of Reference c, to develop criteria for identifying stocks and assessments where it is meaningful to calculate $\mathbf{F}_{MSY}$ and $\mathbf{B}_{MSY.}$

Using $F_{0.1}$, which can generally be estimated more precisely as a proxy for $\mathbf{F}_{MSY}$, will usually imply an even lower risk than $\mathbf{F}_{MSY}$, and only a minor loss of long-term average yield. The use of $F_{0.1}$ as a reference point was further developed in Working Document 22 (Azevedo and Cadima: Stock conservation properties of $F_{0.1}$). However, for stocks that have long been exploited at a far higher mortality than the estimated $F_{0.1}$, a subsequent large reduction in mortality may lead to changes in growth, maturity and multispecies interactions. Nevertheless, to move towards long-term objectives, some reduction in fishing mortality from the current level must be undertaken, even though it is not possible to foresee the final optimal level. Therefore, such a management action should be taken at a slow pace, and with constant monitoring as the ecosystem evolves.

Finally, it is axiomatic that the development of target reference points and harvest control rules will require detailed consultation with managers and with stakeholders.

6.3 The precautionary approach in the framework of management

6.3.1 Biological sustainability and socio-economic consequences of management options

Fisheries management decisions in the ICES area are generally based on advice that is given principally on biological grounds, with little or no reference to socio-economic considerations or data. From a scientific viewpoint within ICES this is not surprising, since ICES has neither the mandate nor, currently, the expertise to bring socio-economic aspects into its advice. It also avoids the problem of attempting to establish trade-offs between objectives that are incompatible, such as maximising yield, maximising profit, or maximising employment. From time to time, however, managers and stakeholders have expressed the view that a purely biological perspective, with its emphasis on avoiding recruit failure through the rigid application of biological reference points, unduly restricts the choices or options that should otherwise be available to them. It is arguable that ICES advisors should at least recognise that because biologically-based advice inevitably has socio-economic implications, these economic consequences should be more widely considered. For example, an agreed fishing strategy that allows F to increase just because F is below $\mathbf{F}_{pa}$, may contribute, however unintentionally, to the maintenance of overcapacity. Equally, a recovery plan for one species in a mixed fishery may cause the adaptation of fishery behaviour to maintain economic viability, but at the expense of compliance with management rules for the other species. It is almost certain that as the role of stakeholders in the advisory process increases, concerns about the narrow basis of ICES advice will also increase.

Essentially ICES faces two opposing risks. On one hand, if it develops a wider basis for its advice, it could be accused of going beyond its mandate and its expertise. On the other hand, if it does not change, it can be accused of under-using available data and knowledge, and of reducing the efficiency and effectiveness of the fisheries management system. The Study Group therefore discussed whether it is possible for ICES to find a middle way, by making a careful distinction between different activities under the headings of diagnosis, prognosis, and advice.

Under diagnosis, ICES could use data and expertise to the full, in order to diagnose the ‘health of the stocks’ (e.g stock trends, reference points, risk of recruit failure), but also the ‘economic health of the fishery’ (e.g. ‘effort’, ‘capacity’, ‘catch per effort’ and ‘revenue per effort’). Information on the latter might begin to $\mathbf{F}_{low}$ naturally from greater stakeholder involvement.

Greater use could be made of the yield-per-recruit approach, used to illustrate the different biological and economic risks associated with the spectrum of exploitation between $\mathbf{F}_{MSY}$, $\mathbf{F}_{max}$, and $\mathbf{F}_{0.1}$, for example.

Under prognosis, ICES could maintain the current short-term forecast, catch option, and medium-term forecast scenarios, and couple these to explanations of longer term objectives in the $\mathbf{F}_{MSY}$-$F_{0.1}$ range that were more easily understandable to economists. This approach could also use yield-per-recruit, but with the proviso that it would be necessary to add caveats about the likely effects of density-dependence, and multispecies considerations at low effort levels. On the other hand, the likely fact that F could be reduced without serious risk of 'growth underfishing', is worth explaining to managers and stakeholders, even if it seems a trivial point to ICES scientists.

Under advice, ICES would retain its obligation to advise on the basis of the precautionary approach, but could perhaps be more sensitive to the desire of managers to understand the implications of all available options in the catch options table and the medium-term forecasts.

It is not ICES responsibility to *decide* that a smaller yield, and less jobs, are a reasonable price to pay for higher catch rates, less risk of recruit failure, and more resilience to year-class fluctuations. It is arguably ICES responsibility, however, to *explain* what these trade-offs are, and how they fit in with the current prognosis.

At the very least it would be healthy for ICES to debate the pros and cons of taking a wider view along these lines, in advance of the increased pressures from stakeholders as they become more involved in the advisory process and demand a more holistic view of fisheries management.

6.3.2 Single stock precautionary approach and multispecies fisheries management

Developing a precautionary framework limited to single stock considerations will not really contribute to better management if the reality of multispecies fisheries is not properly taken into account. ICES may not be in a position to provide advice encompass the full complexity of multispecies multi-fleet management. But it can contribute on at least two important issues, input management/overcapacity, and technical interactions.

6.4 Input based scientific advice

Among the arguments put forward in the past for maintaining overcapacity, is the fact that the diagnosis of overfishing did not cover all stocks. Some unregulated stocks could therefore still be fished. It is arguably therefore more important to make a first diagnosis for as large a number of stocks as possible, than to refine the precautionary approach for a very limited number of stocks.

It has been recognized that in many cases fishing mortality on a specific stock cannot be kept under control without effort limitations. But effort management must rely on the proper analysis, and ICES should undoubtedly be able to contribute more to these. If it cannot do so because the proper data are not made available, it must highlight this fact.

6.4.1 Technical interactions

Although such problems may be difficult to solve, they are sufficiently common and important to be given more attention within ICES. This can be illustrated by the example of a two species fishery, where ICES should contribute significantly to defining the management options, even if it cannot choose which trade off is 'best'.

For example, there may be a strong argument for reducing fishing mortality on stock 1, but no such recommendation for stock 2, yet there are strong technical interactions between them. Partners in the decision process may consider it unjustifiable to reduce global fishing mortality because of stock 2. But if fishing mortality on stock 2 can be reduced without a real risk of under-exploiting stock 2, the former argument can be discarded, provided that proper justification is included in the scientific advice. This reinforces the previous remark on the importance of having at least a basic assessment for as many stocks as possible.

In another example, one could consider a control diagram with fishing mortality for stock 1 on the x axis, and that for stock 2 on the y axis. Whenever ICES is in a position to define domains that can be achieved in practice because fishing fleets may modify their fishing practices (e.g. by changing the way they allocate their fishing effort in space and time, or by a gear change) such domains should brought to the attention of managers. This basic diagnosis could be improved by analysing the options for ensuring that the intended ratio of F values on both stocks will be achieved.

If ICES is not able to resolve the problems of technical interaction at present, it should undoubtedly attempt to develop this area of assessment and advice in the near future.

6.4.2 Ecosystem objectives

There was no extensive discussion of ecosystem objectives during the meeting, as the topic is extensively dealt with in other ICES fora. However, the following issues were identified that should be considered when integrating fisheries and ecosystem advice in the future.

In many cases, high rates of exploitation have reduced biomass considerably, thus reducing the age diversity of the stock, which has become dependent on incoming recruiting year classes. In an ecosystem context simply restoring spawning biomass above $\mathbf{B}_{pa}$ would not be sufficient. The objective should be to maintain a spawning stock the wider age diversity required to enable the stock to fulfil it full role in the ecosystem. As an example, older fish spawn in general earlier than the younger fish. A stock comprising younger and older fish would span a longer spawning season, and have a higher probability of producing a successful year class. The quality of eggs of older fish may also be better and therefore have a greater chance to develop successfully.

Heavy exploitation, which may result is a loss of specific components of the stock, could also reduce the genetic diversity of the population and therefore its ability to adapt to changes in the environment. An example of this may be the preponderance of slower growing fish in some heavily exploited stocks.

7 REBUILDING PLANS

'Depleted stocks require rebuilding in order to prevent irreversible long-term adverse effects on the stock and the ecosystems in which they function. Stock rebuilding requires criteria for determining conditions of stock depletion and stock recovery'.

(Anon, 1997, paragraph 3.6.2)

7.1 General considerations

The Study Group first considered what elements constitute generic features of rebuilding plans consistent with a precautionary approach. STECF concluded (Anon 2002d) that rebuilding plans require four components:

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

The SG recommends that ICES adopts these four components as the basis of any rebuilding plan. In addition, there is a need to consider the operational utility of such plans and to ensure that progress towards targets is evaluated. The precautionary approach counsels that rebuilding action be undertaken as soon as possible.

A rebuilding plan is a special form of harvest control rule. It involves a strategy for increasing the stock size to some predefined target level within a specified period of time by selecting a fishing mortality rate or equivalent catches, an exploitation pattern, and/or other ad-hoc measures. Plans should include quantifiable milestones to measure progress toward recovery during the implementation period. The precise value of the target recovery period will depend on biological characteristics such as generation time, as discussed by the 2001 Study Group. The recovery trajectory will depend on the status of the stock compared to the reference points, the severity of the plan in relation to the desired recovery period, and may also be influenced by the productivity of the stock and the carrying capacity of the environment.

In existing or proposed plans, $\mathbf{B}_{pa}$ serves as a provisional target, but $\mathbf{F}_{pa}$ may also be an integral part. Reference points may be revised before a stock has reached the target. Such changes may not necessarily be in one particular direction, however, so that the impact on a rebuilding plan could take different forms in different cases. It should therefore be considered whether to postpone the use of revised values in ICES advice until a rebuilding plan has achieved its initial goal, and until there has been a dialogue with managers about when revised reference points should formally be introduced into ICES advice.

ICES has recognised that harvest control rules need to be established for a range of stocks (Anon, 2002c) and that attention should be paid to defining management measures. The Study Group proposes that where a complete evaluation of a plan has not been carried out, or where data are sparse, a set of default measures and decision algorithms could be established. This will require discussion and agreement with stakeholders, and was not attempted during the meeting.

7.2 EU rebuilding plans for cod and hake

The Study Group examined the current EC recovery plan proposals for rebuilding 4 cod stocks and 1 hake stock within EU waters. Table 6.1 lists the stocks and their relevant statistics. Background and source material for this section comprised the Norway-EU agreement, an STECF report (Anon 2002d) and an EU consultation document outlining the proposed EU Council Regulation to establish measures for the recovery of cod and hake stocks.

EU recovery plans are a response to ICES advice that there should be a safe and rapid recovery of the relevant. The EU proposal is to establish a recovery programme that rebuilds the tonnage of mature fish to a target level equal to or greater than that specified for each stock. The target values equate to the $\mathbf{B}_{pa}$ for each stock although explicit reference to the targets as $\mathbf{B}_{pa}$ is not made in the proposal. Key elements are:

i) SSB should increase by 30% (cod) and 15% (hake) per year

ii) TAC variability should not to be greater than +/- 50 %

iii) the TAC should not generate a value of F greater than that specified for each stock (the values specified coincide with $\mathbf{F}_{pa}$, but the term $\mathbf{F}_{pa}$ is not explicitly mentioned)

iv) The target SSB should be reached for 2 consecutive years before recovery plan status is removed.

The EU has requested an ICES view of the plans. The Study Group therefore carried out a qualitative audit of the proposals. It also discussed the developing use of a quantitative simulation framework that could evaluate the suitability of different recovery strategies taking into account various sources of uncertainty, and different assumptions about model structure and the effectiveness of management measures in the real world.

7.2.1 The qualitative audit

The Study Group reviewed the EU proposals in the light of the four STECF criteria.

(1) A measure of stock status

The status of the recovery stocks has been measured against the current ICES reference point values using the ICES assessment output (Anon, 2002a), as shown by the **SSB** and $\mathbf{B}_{lim}$ values in Table 7.1. It is traditionally assumed that this diagnosis is affected only by the uncertainty associated with assessment data (landings, catch-at-age, weight-at-age), and the determination of reference points within a single assessment model structure. However, Patterson et al (2001), and Section 3.4 of the present report, describe the issue of assessment model structure uncertainty. For Northern hake, Section 3.4 showed that the final assessment configuration adopted by a working group is only one of a number of possibilities. Each outcome provides a different perception of the risk to the stock associated with the consequences of fisheries management decisions, and without additional information there is no objective way of choosing between them. Where such multiple scenarios based on alternative models are equally valid, there is no formal procedure for quantifying the additional uncertainty and including it within the specification of the recovery plan.

Table 7.1 SSB, biomass reference points, and recovery parameters for five EU stocks

Stock	**SSB $_{2002}$ if F $_{2001}$= F_{sq} t**	$\mathbf{B}_{lim}$	**SSB as % $\mathbf{B}_{lim}$**	**Target biomass (=$\mathbf{B}_{pa}$)**	**SSB as % $\mathbf{B}_{pa}$**	**Implied recovery time**	**Generation time (years)**
Northern hake	98	120	82	165	59	4	10.3
Irish sea cod	5.8	6	97	10	58	2 - 3	8.6
W Scotland cod	5.7	14	41	22	26	5-6	7.7
North Sea cod	55	70	79	150	37	4	9.3
Kattegat cod	5.2	6.4	81	10.5	50	3	9.2

(2) The target recovery period

The target recovery period does not appear to be stated explicitly in the plans, but it can be inferred indirectly from the starting SSB, and the target increases in SSB specified for each species. A per annum increase in SSB of 15% for hake and 30% for cod produces an implied recovery time shorter than the calculated generation time, and in that sense could be deemed as compatible with the precautionary approach, but only if the assumptions about recruitment are fulfilled. Whether recovery is actually achievable on this scale in practice depends on the effectiveness of the management measures that are taken, and on the recruitment that actually materialises. For hake (maturing at 5 years) this may be less critical, but for cod (maturing at 2-4 years) the rate of SSB increase could be more variable. The use of a single biomass criterion for recovery also ignores the differences in biology between cod stocks, and the different level of these stocks relative to their reference points.

(3) The recovery trajectory

The recovery plan trajectory specifies a 15 % SSB increase per annum for hake and 30% increase per annum for cod. The proposal does not explain the basis for this choice, or link it specifically to any biological analysis of the severity of the problem. The current plan stipulates that the recovery target has to be achieved for 2 consecutive years. It does not discuss how to distinguish between transient or equilibrium states, or the uncertainty of abundance estimation, or the fact that assessments are working in arrears.

(4) The long-term management objective

$\mathbf{B}_{pa}$ is being used as the target in each plan, and no other explicit management objective has been proposed. A long-term objective beyond $\mathbf{B}_{pa}$ deserves serious consideration, however, in order to move stocks away from $\mathbf{B}_{pa}$, and prevent them from switching recovery procedures off and on in response to short-term stock fluctuations around $\mathbf{B}_{pa}$. The present measures may therefore be acceptable as a first step but the SG suggests that a long-term management strategy should already be under discussion as part of the recovery plan, especially given the 'cost' of engagement with managers and stakeholders.

Although these stocks are below $\mathbf{B}_{lim}$ and are well below $\mathbf{B}_{pa}$, the risk of actual collapse is difficult to define. There is an obvious fear that further years of poor productivity and recruitment could be fatal, yet some stocks have been at or close to their current level for ten years (eg, N Sea cod). In addition to biomass, however, a long-term objective should give serious consideration to the age diversity of the stock, which in most cases is seriously diminished, with possible consequences for reproductive health. Although one or two good year-classes might result in a reasonably rapid attainment of $\mathbf{B}_{pa}$, the biological requirement to increase age diversity and optimise reproductive potential might take much longer. Although age structure aspects are not included in a precautionary approach based solely on biomass reference point criteria, they are more implicit if management is based on fishing mortality criteria. The most effective long-term target may therefore be to reduce F to at least $\mathbf{F}_{pa}$, or less, in order to stabilise SSB above $\mathbf{B}_{pa}$ and also improve age diversity. The question of long-term objectives and target reference points is considered in more detail in Section 6.

It is questionable whether sufficient attention has been paid to the issue of carrying capacity. The assumption is that environmental conditions and other constraints will not limit the attainment of the proposed targets. A recent analysis of historical data back to the XVIIth century has shown that the East Atlantic and Mediterranean bluefin tuna displayed significant long-term fluctuations in abundance (Ravier and Fromentin 2001). Such results indicate that carrying capacity could strongly vary over time, and that a single long-term biological reference point may not be appropriate. The effect of periodic environmental fluctuations on the abundance of cod stocks in the N E Arctic and the Eastern Baltic has already been discussed in Section 4. Long-term fluctuations in abundance have been also documented in several important stocks of cod and herring.

7.2.2 Progress towards implementation

Progress towards implementation has already commenced through the TACs agreed for 2002. Using the ACFM catch-option tables, the Study Group therefore compared this 2002 TAC to the landing required to achieve the first annual increment in SSB during 2002, on the basis of the current assessment data, and assuming no other changes. The conclusions are that in the case of North Sea Cod, the agreed TAC matches what is required to implement the first year SSB target. In Irish Sea and West of Scotland Cod, the agreed TAC is lower than required by the plan, potentially leading to a quicker recovery than that required by the SSB target. For Kattegat Cod and Northern Hake the 2002 TACs will only promote an SSB increase of 15% for cod (instead of 30%) and 9% for hake (instead of 15% required). The basis for these conclusions is as follows:

<u>The North Sea Cod example</u>

In the 2001 assessment, SSB (2002) is estimated as 55kt, compared to $\mathbf{B}_{pa}$ of 150kt.

In round figures the required 30% increase in SSB (kt) per year is:

2002	55
2003	72
2004	94
2005	122
2006	158

SSB should reach B_{pa} in 2006. From the ACFM catch option table for 2002, landings of no more than 58kt would be required to achieve SSB of 72kt in 2003.The agreed 2002 TAC is 58kt (including 1.6kt for the VIId component of the stock), which is consistent with the SSB objective.

7.2.3 The Irish Sea Cod example

SSB (2002) is 5.8kt, compared to B_{pa} of 10kt.The required 30% increase in SSB (kt) per year is

2002	5.8
2003	7.5
2004	9.8
2005	12.7

SSB should reach B_{pa} in 2004-2005. From the ACFM catch option table, landings of no more 4.0kt are required to achieve SSB at 7.5kt in 2003. The agreed 2002 TAC is 3.2kt, which should allow SSB to recover much more quickly than required by the recovery plan. SSB would then be close to B_{pa} in 2003.

7.2.4 The West of Scotland Cod example

SSB (2002) is 5.7kt, compared to B_{pa} of 22kt. The required 30% increase in SSB per year is:

2002	5.7
2003	7.4
2004	9.6
2005	12.5
2006	16.3
2007	21.2
2008	27.5

This stock is so low that SSB is unlikely to reach B_{pa} until 2007-2008. From the ACFM catch option table, landings of no more than 4.3kt would be required to achieve SSB at 7.4kt in 2003. The agreed 2002TAC is 3.9kt (0.7kt for the VIb component of the TAC excluded), which should allow SSB to recover slightly more quickly than required by the rebuilding plan.

7.2.5 The Kattegat Cod example

SSB (2002) is 5.2kt, compared to B_{pa} of 10.5kt. The required 30% increase in SSB per year is:

2002	5.2
2003	6.8
2004	8.8
2005	11.4

SSB should reach B_{pa} in 2004-2005. From the ACFM catch option table, landings of no more than 2.2kt would be required to achieve SSB at 6.8kt in 2003. The agreed 2002TAC is 2.8kt, which would allow SSB to recover by only 15%.

7.2.6 The Northern Hake example

The required SSB in 2002-2006 depends on the assumption for F in 2001 for which ACFM considered two scenarios, F (status quo), or F (TAC constraint). The 15% increase in SSB would require F to be reduced by 50%in both cases, but with the TAC constraint, the recovery period would be shortened, since SSB would reach B_{pa} (165kt) in 2005, instead of 2006.

	($\mathbf{F_{sq}}$)	(TAC constraint)
2002	98	115
2003	113	132
2004	130	152
2005	149	175
2006	171	

From the ACFM catch option tables, landings of 20kt are required to achieve SSB (2003) of 113kt or 132kt respectively. The agreed 2002TAC of 26kt corresponds to SSB (2003) of 107kt and 126kt respectively, an increase of no more than 9%.

These scenarios do not take into account the following factors:

a) sources of assessment uncertainty that affect the current estimate of stock status, or stock status in the future as the recovery plan proceeds. If the stock is, for example, overestimated, the resulting TAC could lead to an increase in effort as catchers seek to achieve their quotas, and this could alter or even halt the trajectory of the recovery.

b) the effect of technical conservation measures that are also being negotiated as part of the recovery plan package

c) technical interactions that could cause rebuilding plans to deviate from the desired trajectory through adjustments in species targetting, leading to unpredicted by-catches of the recovery plan species.

d) the effect of compensatory fishing behaviour such as mis-reporting, or the adoption of technological improvements to counteract perceived restrictions arising from a recovery plan. Although compliance is a tendentious area that is difficult to address, it is relevant to assess what level of non-compliance would compromise the plan. The Study Group did not atempt to evaluate this but it should be included in the specification for an evaluation by simulation. There may well be a case for utilising ‘fuzzy’ information in obtaining a better understanding of compliance issues. EU projects which include the collection of information and views directly from fishermen, may provide guidance.

7.2.7 The evaluation of outcomes

Scientists and managers need to know how well stocks are progressing towards the recovery target, and when they actually reach the target. Providing such information to stakeholders also has potential benefits in the hope of ensuring their compliance and their sense of ownership of the process, irrespective of whether the stock trend is positive or negative.

In the short-term, ACFM will need to set terms of reference for working groups to assess if stock changes are in line with the expected stock recovery trajectories, and whether the exploitation pattern is responding to recent changes in mesh size and related technical measures such as closed areas. Comments on age diversity could be requested. The new assessments should take into account whether changes in fleet behaviour are likely to affect the tuning of the assessment, and will also need a clear evaluation of what choices to make regarding the ‘middle year’. Working groups will eventually have to judge whether stocks that have reached $\mathbf{B}_{pa}$ for two years really do qualify to be removed from the recovery plan.

7.3 Comprehensive evaluation by scenario modelling

It is suggested that the only way of achieving a comprehensive evaluation of recovery plans and their associated management measures is to carry out scenario modelling. A promising approach to such modelling is the simulation framework first developed to investigate the response of fishery systems to management (Kell *et al* 1999a, 1999b, in press, & pers comm.). The framework creates a ‘real’ population and management scenario, then models how well a working group observes that, by simulating the sampling, data collection, assessment and reference point estimation procedures.

Current advice is based on catch-at-age data and an assessment model that are assumed to be unbiased, and a management system that is assumed to be implemented perfectly. The robustness of the advice to the intrinsic properties of the natural system, and to our ability to understand and monitor the system, is generally ignored. The simulation approach therefore considers important parts of the whole fishery system and their interactions not currently considered by conventional stock assessments. These may include knowledge about the population dynamics and its ecosystem, data collection, stock assessment, stock predictions, management advice, and implementation of management regulations. In particular, the framework combines the interactions between all system to provide an integrated evaluation (Wilimovsky, 1985; De la Mare 1998; Holt 1998).

Classical sensitivity analysis only investigates errors in the parameters of the stock assessment model, but the simulation framework acknowledges the presence of the following sources of uncertainty (Restrepo and Rosenberg,1995):

- Process error due to natural variation in dynamic processes (e.g. recruitment, somatic growth, natural mortality)
- Measurement error (generated when collecting observations from a population)
- Estimation error that arises from trying to model the dynamic process (during the assessment process)
- Implementation error since management actions are never implemented perfectly.

Using a model that incorporates likely estimates of these errors, 'real' stock and fishery dynamics are represented as the true system, from which simulated data are sampled. These data are then used within an assessment procedure to assess the status of the stock. Depending on the perception of the stock, management controls are then applied to the fishery. Metrics based on biology (the probability of the stock being above some minimum biological threshold), economics (value of the fishery over time) and production (average annual variation in yields) can be collected and used to evaluate the performance of the candidate management strategies. Simulations are typically run as a series of experiments to investigate the performance of different management strategies under a range of assumptions about resource dynamics.

7.3.1 Example for North Sea cod

To illustrate the approach, the current ICES assessment data for N Sea cod were used to simulate a TAC regime aimed at generating a 30% increase in SSB per annum until SSB was perceived to have recovered above $\mathbf{B}_{pa}$. Once above $\mathbf{B}_{pa}$ the TAC was set to maintain F at $\mathbf{F}_{pa}$ of 0.65 . TACs were not allowed to change by more than 50% in any year.

In Figure 7.1 the first panel shows the number of times that the true population actually fell above or below $\mathbf{B}_{pa}$ (columns), and contrasts this with the perception delivered by the system of management and assessment (rows). The working group results are inside the box, and the true picture is outside the box. In this simulation, true SSB is greater than $\mathbf{B}_{pa}$ 60% of the time. The working group correctly estimates SSB > $\mathbf{B}_{pa}$ 57% of the time, (a success rate of 95%). True SSB is < $\mathbf{B}_{pa}$ 40% of the time but the working group only gets this right 28% of the time and falsely estimates that SSB > $\mathbf{B}_{pa}$ 12% of the time (i.e.12/40 = 30% false positive results). This means that overall, the working group predicts that SSB is greater than $\mathbf{B}_{pa}$ 69% of the time, compared to the true picture of 60%. The consequences for yields could also have been analysed

The next three panels in Figure 7.1 show how working group estimates of the yield-per-recruit reference points F20% SPR, F30% SPR, $F_{0.1}$, $\mathbf{F}_{max}$ compare with the values of $\mathbf{F}_{MSY}$, $\mathbf{B}_{MSY}$ and MSY taken from the true population. The yield-per-recruit F reference points are broadly similar but all underestimate $\mathbf{F}_{MSY}$. $\mathbf{B}_{MSY}$ is over estimated by all the reference points and the estimate of MSY is imprecise.

The penultimate panel shows the probability of SSB being greater than $\mathbf{B}_{pa}$, and the final panel considers the mean yield and the variation in yield (estimated as the annual average variation). These results are illustrative only and are intended to show the utility of the approach not to provide specific advice.

The choice of reference point could be further investigated by inclusion in a harvest control rule, allowing the interaction between estimation and management to be explored.

In Figure 7.2 a simple mis-reporting rule was investigated. If the TAC implied a reduction in yield then the actual yield was the average of the TAC and last year's yield, and the reported catch was equal to the TAC. The results are broadly similar, showing that the current working group results are robust to the assumed mis-reporting behaviour, although perhaps counter-intuitively mis-reporting results in actual yields being reduced.

In Figure 7.3 the working group was able to perform a perfect assessment and estimate the historic population matrix without error. The reason for the differences in the perception and the true state of the system is because of the methodology used in the short-term projection to estimate the current year stock status and set the TAC. This experimental treatment corresponds to the type of medium- or long-term projection often used to evaluate harvest control rules. Unsurprisingly the working group is better able to estimate whether SSB is below $\mathbf{B}_{pa}$. Estimates of the MSY proxies are also improved. Comparing yields across treatments it can be seen that having a perfect assessment increases the mean yield and reduces the average annual variation. This result is qualitatively different from the previous two examples, the perception of the dynamics of the system depending more on the effect of modelling the performance of the working group than the degree of mis-reporting.

The above results are purely illustrative and are not intended to provide specific advice, but they show how the simulation approach could be used to evaluate different management or recovery plan strategies, or how the attainment of the recovery objective depends on uncertainty in the data, the models, and compliance with management measures. Recently, such a study has been completed using this framework for flatfish stocks in the EU (Kell et al pers. comm.).

7.3.2 The presentation of results

There are two major concerns about how to present material of this kind. One is the sheer volume of involved, which is generally too great to summarise in data tables or even in graphs. The other is the varying reliability of the data, due to the many different types and degrees of uncertainty.

Fuzzy traffic lights have been suggested as a means of dealing with this issue. In terms of presentation, relevant variables are traditionally represented by coloured indicators of stock condition using the standard red-yellow-green representation of traffic lights. Fuzzy lights extend the traditional formalism using lights that are mixtures of these colours, such as a mixture of green and yellow for variables that are close to the bottom of the acceptable range. This representation makes it possible to present even the most complex data in a form that is easily understood. The traditional traffic light restriction to just three values – red, yellow or green – is clear but too crude for most purposes. The fuzzy approach gives better resolution with little loss of clarity.

In addition to presentational advantages, the fuzzy approach makes it much easier to include uncertain information. This is particularly important in developing rebuilding strategies, as information about stock dynamics along the recovery path is often unreliable or even missing altogether. The information may be of a vague nature; for example, conjectures about the spawning of older fish, but without hard fecundity data. This is difficult to develop in a quantitative model, but can be expressed in terms of fuzzy rules.

Fuzzy concepts could also be used to describe and modify recovery pathways as they develop. In the case of NW Atlantic cod, for example, it was clear that the stock was not rebuilding as quickly as planned (or hoped), and constant readjustments had to be made. Adaptive rebuilding processes are difficult to base on accurate quantitative information, since by the time that there is enough data to establish a clear pattern, it is becoming too late to use the information effectively. Qualitative patterns based on the fuzzy approach, however, could be a promising alternative way to use new information. The approach could also be used to define such fuzzy concepts as sustainability, or to ‘model’ if-then scenarios (e.g ‘ IF compliance is ‘poor’ THEN …….etc)

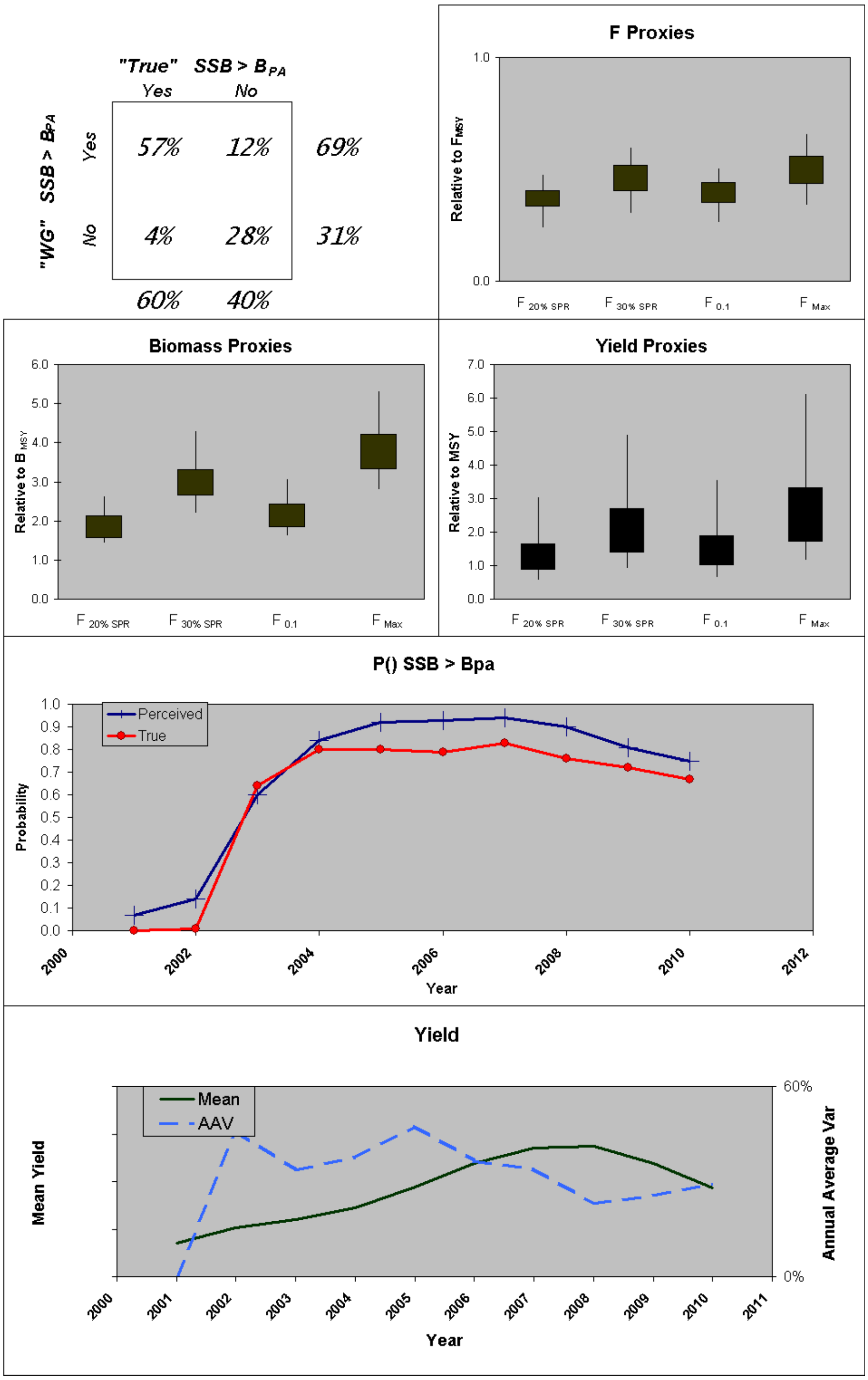


Figure 7.1. Summary of evaluation of recovery plan for a North Sea cod like stock. Box and whiskers show the 90th, 75th, 25th and 10th percentiles.

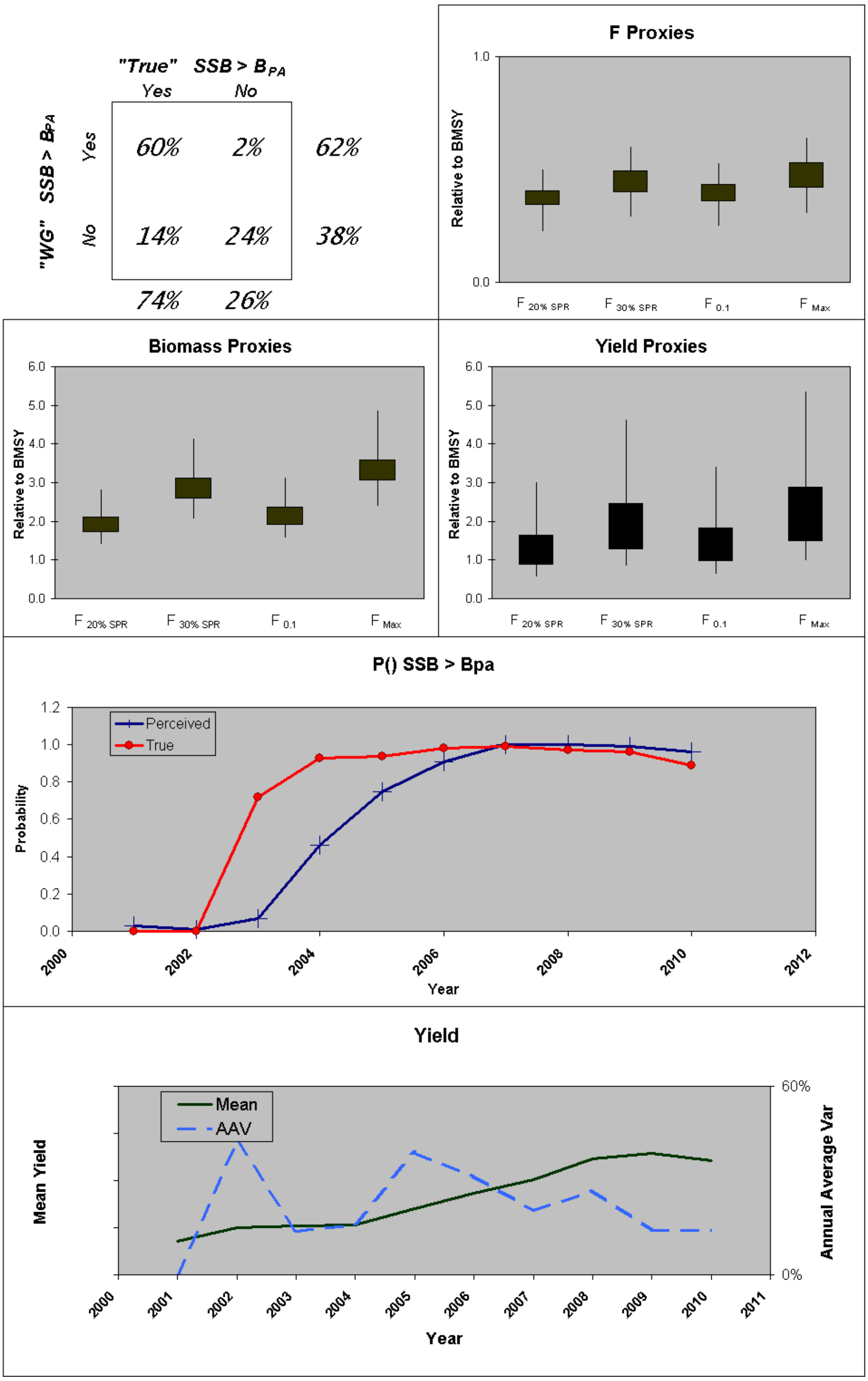


Figure 7.2. Summary of evaluation of recovery plan for a North Sea cod like stock, includes a simple mis-reporting rule. Box and whiskers show the 90th, 75th, 25th and 10th percentiles.

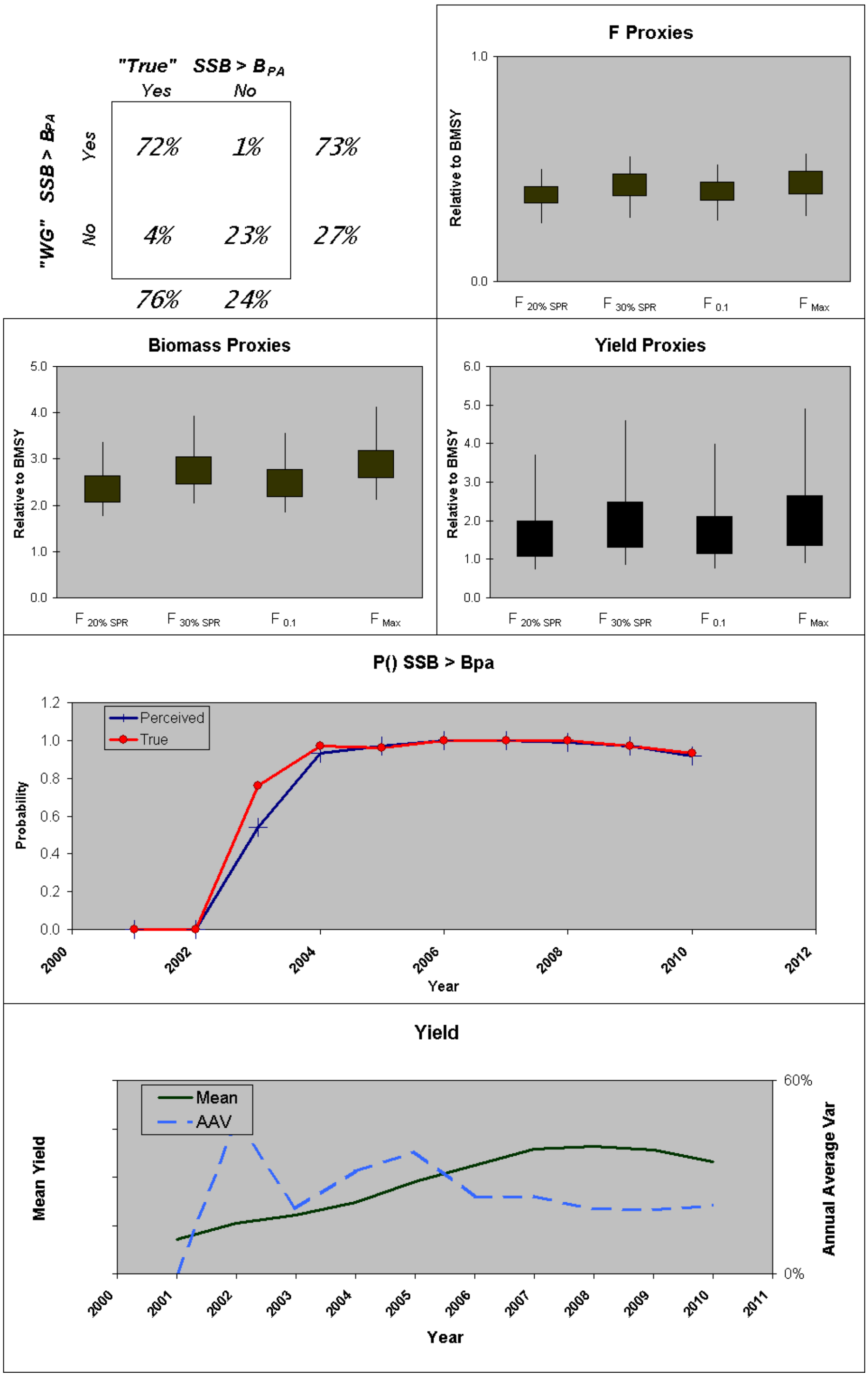


Figure 7.3. Summary of evaluation of recovery plan for a North Sea cod like stock: the working group are able to perform a perfect assessment (i.e. the true population matrix is know). Box and whiskers show the 90th, 75th, 25th and 10th percentiles.

8 RECOMMENDATIONS TO REVIEW REFERENCE POINTS

8.1 The evaluation and development of reference points

The precautionary approach reference points were established in 1998 using the best assessment data then available, and although it was envisaged that they would be re-evaluated after some time, no specific time was set for this to take place. The following factors now suggest that it is time to undertake a thorough review of all the current reference point values, and to augment them:

i) it appears that some original reference point values are not in conformity with the precautionary approach definitions, e.g. it would have been more correct if some previous $\mathbf{B}_{pa}$ values had been designated as $\mathbf{B}_{lim}$.

ii) the reference point values for several stocks, particularly those based on $\mathbf{B}_{loss}$, have been overtaken by various changes, as discussed in earlier sections of the present report e.g.,

- stock abundance has declined below $\mathbf{B}_{loss}$,
- a change in assessment output has occurred due to the choice of a different structure for the assessment model,
- trends in recruitment may be due to fluctuations in carrying capacity or some other key environmental parameter,
- account should be taken of trends or fluctuations in weight-at-age, maturity-at-age, and age diversity of the spawning stock, that may be causing trends in reproductive potential
- irregular changes to stocks dependent on episodic large year classes

iii) it is important to validate as objectively as possible the estimates of the change point where recruitment becomes impaired, whether 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 it is appropriate to overcome the problem of assessment model structure uncertainty by using relative rather than absolute values

v) the implementation of recovery plans for several EU stocks has led to the introduction of technical measures to change the pattern of exploitation, which will therefore change the basis for reference point calculation

vi) as part of the development of the precautionary approach in ICES, the Study Group has discussed the scope for designating target reference points, such as $\mathbf{B}_{MSY}$, $\mathbf{F}_{MSY}$ and $F_{0.1}$.Target reference points would enable long-term management objectives to be set, and although their precise estimation may be more difficult because of ecological factors such as multispecies interactions, their use would move stocks away from cyclical fluctuations around $\mathbf{B}_{pa}$. This would be particularly valuable at the end of the rebuilding trajectory of a stock recovery programme. The Study Group also discussed the idea of identifying trigger points, as described in Section 6.

vii) the Study Group has also discussed the role of 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. Attention is drawn to the scope for evaluating harvest control rule proposals using the scenario modelling approach described in Section 6. The development of target reference points and harvest control rules will require dialogue between ICES, managers, and stakeholders.

8.2 A review proposal

With the above points in mind the Study Group recommends that ICES commits itself to review and develop the PA reference values, and also consider the question raised in Section 3.4.3 concerning the use of relative or absolute values. The PA Study Group feels that in conjunction with ACFM it should provide guidelines as to how this review should be undertaken, but that the work itself should best be carried out by the ICES assessment working groups. It also notes that such a review will necessitate real dialogue with managers and stakeholders along the lines discussed frequently in the 2001 Study group report (Anon, 2001a). A possible timetable is suggested in Section 8.3, taking into account the following comments about other relevant activities in ICES.

In addition to the various estimation problems occasioned by parameter uncertainty and model structure, the estimation of biomass reference points is affected by trends in maturity, weight and condition. This was discussed recently by the ICES Study Group on Incorporation of Process Information into Stock Recruitment Models [SGPRISM] which recently proposed (Anon 2002b) that towards the end of 2002 a revision of growth data be undertaken by a dedicated Study Group on Growth, Maturity and Condition Indices in Stock Projections [SGGROMAT]. Participants at SGGROMAT will include process modellers, assessment scientists, and data collators in order to:

a) collate data on weights, maturity, condition, fecundity, and age-length and length-weight keys for stocks in the North Sea, Irish Sea, Northeast Arctic and Baltic Sea;
b) develop the implementation of growth, maturity and condition models for use in projections for those stocks for which data are available; and
c) agree an inter-sessional programme to apply the findings of the Study Group to areas not covered by the first term of reference.

It is intended that output from SGGROMAT will take the form of Working Papers to each assessment working group, proposing candidate growth/maturity projection models for application to stocks within their remit. SGGROMAT should precede the January 2003 meeting of ICES Working Group on Methods on Fish Stock Assessments [WGMG], which will review its report and recommend (or otherwise) its findings to assessment working groups meeting in 2003. Once the basic input data to the ICES VPA assessments have been revised, and stock assessments have been agreed, then an objective approach can be used to derive candidate biomass and fishing mortality reference points for stocks. The utility of the candidate reference points could be evaluated within the scenario modelling framework for the evaluation of harvest control rules.

8.3 An outline review timetable

1. In May 2002, ACFM should discuss and agree the review of current reference points, and the relevant timetable, and should discuss whether to develop target reference points, and harvest control rules, and over what time scale. Relevant recommendations should be drafted for discussion and approval at the 2002 ASC.
2. SGPA and the ICES Fisheries Secretary should work inter-sessionally this year to develop technical guidelines to be completed at a meeting of SGPA in February 2003. These guidelines should take into consideration the expected output from SGPRISM and SGGROMAT already described above.
3. Forward the guidelines to the assessment working groups in spring to carry out the review during spring and summer 2003
4. ACFM to review the resulting reference point proposals in October 2003. ACFM should also agree with management agencies the new **pa** values that will result in management action (The **limit** values are the prerogative of ICES). If the pa values are safety margins based on the quality of the assessment, ACFM will also be involved in deciding on the pa values.

5. Implementation in the assessments and advice for 2004

8.4 Guidelines

Clear guidance has to be provided on how the evaluation of the reference points should be carried out, based around the original guidance provided in the 1998 Study Group, but taking into account the preliminary reviews carried out by the 2001 Study Group, and the various examples and methods option discussed by the present Study Group. An initial framework is:

- Identify whether the existing reference points suffer from inconsistency, uncertainty, model structure, or regime issues, and identify what remedial action is needed
- Designate the stock according to its R-SSB pattern
- Fit a standard stock-recruit curve or segmented regression, whichever is appropriate, to estimate $\mathbf{B}_{\mathrm{lim}}$, and then estimate $\mathbf{B}_{\mathrm{pa}}$ in conjunction with the risk criteria agreed with ACFM and managers
- If neither is appropriate use other guidelines (to be specified) to obtain $\mathbf{B}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{pa}}$
- Define $\mathbf{F}_{\mathrm{pa}}$ and $\mathbf{F}_{\mathrm{lim}}$ to be consistent with the biomass points on the basis of medium-term projections
- If it has not been possible to define B reference points then try to define F reference points.
- Reality check for consistency with historical exploitation.
- Compare with yield-per-recruit reference points ($\mathbf{F}_{0.1}$, $\mathbf{F}_{\mathrm{max}}$, $\mathbf{F}_{\mathrm{MSY}}$)
- If agreed, develop target reference points and harvest control rules.
- Evaluation by scenario modelling

9 ICES ADVICE

ICES advice on the management of fish stocks is arrived at in three stages. In the first stage, an international working group of scientists assesses the state of the stock for the most recent year, and compares it with the precautionary reference points for that stock. This shows whether the stock is in a good or a poor state (‘inside or outside biological safe limits’). In the second stage, the working group forecasts the most likely stock and catch levels for the next TAC year, corresponding to a range of fishing rate options. This provides options from which a total allowable catch can be selected. Later, in the third stage, the Advisory Committee for Fishery Management evaluates the working group assessment and forecast, and then provides agreed advice on the most appropriate TAC or other management recommendation, consistent with the application of the Precautionary Approach. These stages are described below in more detail.

9.1 Assessment of the stocks, and catch forecasts

ICES assessment working groups usually meet annually to assess the state of stocks, and make a catch forecast. There are different regional working group, each carrying out assessments for the different species and stocks in particular areas, such as the Southern Shelf area, the Northern Shelf area, the North Sea and Skagerrak, and so on. The assessment is based on the data that the various national scientists bring to the working group and then combine for use in a calculation that involves using an agreed ‘assessment model’. The data are usually the most recent fishery landings (corrected for discarding, if possible) broken down into age groups, biological data on weight and maturity-at-age, data from research vessel surveys, and the landings per effort of commercial fishing fleets.

The landings at age data are combined for all countries and all areas of the stock. The assessment model uses these data to calculate the fishing rate (F). It then back-calculates to the number of fish that had to be in the sea to account for the combination of recorded landings and natural losses. Accurate landings data are therefore very important. The number in the stock is converted to weight (‘biomass’) and the fraction of this that is mature is the so-called ‘spawning stock biomass’(SSB).

The initial part of the assessment works ‘in arrears’. Thus, the assessment carried out in 2002 will only be able to include fisheries data up to the end of 2001, and it will estimate the population number and SSB at 1 January 2002. Starting with this population number, the 2002 working group will estimate how many fish are likely to be left in the sea at the end of the current year 2002, as a result of the current TAC, agreed last year. Since the working group is operating in mid-year, this requires a judgement about whether this years catch will be equal to the TAC, or not. The forecast will then predict one further year ahead, to calculate what options there are for the new TAC year, 2003. The options correspond to a range of possible fishing depletion rates. This forecast takes into account how many new young fish are expected to enter the stock this year and next year (the ‘recruitment’). The output from this part of the work is the basis of the ‘catch options table’ for the TAC year 2003.

In some assessments the catch options forecast is also carried on for several more years to predict the likely stock level after ten years (the ‘medium-term forecast’). This is simulated many times using sets of recruitment values selected from the past data, to estimate which yield and SSB values are most likely, taking into account the uncertainty of the future.

9.2 The Precautionary Approach

In line with the Precautionary Approach, scientists compare the most recent values of spawning biomass and fishing rate against benchmark values that have been calculated previously by analysing past data. The intention of the Precautionary Approach as implemented by ICES is to keep the stock at a safe and sustainable level by keeping it above the biomass benchmark, and keeping the fishing depletion rate below the fishing rate benchmark. This is described in more detail in Section 9.4.

9.3 The Advisory Committee on Fishery Management (ACFM)

The Advisory Committee on Fishery Management consists of designated scientists from all the member countries of ICES, who meet to review assessments and give advice twice a year, in May and October. The reports of the assessment working groups are presented at one or other of the ACFM meetings, and reviewed there by sub-groups of the ACFM members. ACFM then looks at the comparison between the current values of SSB and the biomass benchmark, and determines whether stocks can be diagnosed as ‘safe’ or ‘not safe’. This determines whether ICES should recommend that managers take action to improve the situation. When ACFM presents the catch options table, it shades those options where the fishing depletion rate is higher than the fishing rate benchmark, or the surviving biomass at the end of year 200x is lower than the biomass benchmark. These options are said to be ‘inconsistent with the precautionary approach’.

9.4 Benchmarks or biological reference points

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 depletion rate below a maximum fishing rate benchmark.

ICES has agreed that the spawning biomass should not fall below a minimum limit, described by the symbol $\mathbf{B}_{lim}$ (the biomass limit reference point), and set using historical data. The value of $\mathbf{B}_{lim}$ is chosen such that below it, there is a strong possibility that average recruitment (the number of new fish in the youngest age group each year) will ‘be impaired’ (i.e. will seriously decline). 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 $\mathbf{B}_{lim}$ there is a high, or higher, risk that the stock could ‘collapse’. The word ‘collapse’ does not mean that there is biological extinction, but it does mean that scientists expect there to be a serious reduction in the productivity of the stock, and that the fishery could become unsustainable.

ICES has similarly agreed that the fishing depletion rate should not be higher than an upper limit $\mathbf{F}_{lim}$ that will on average drive the stock to the biomass limit. $\mathbf{F}_{lim}$ 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.

In practice, scientists know that the information and the methods used to make stock assessments are imprecise. Because of the possibility of error in the estimation of spawning biomass, or of fishing depletion rate, 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 error. ICES therefore 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 biomass falls to $\mathbf{B}_{pa}$, management action should be taken to increase stock again, so that we can be sure that the stock has moved above $\mathbf{B}_{lim}$. The size of the buffer zone depends on the size of the error and also on how certain managers want to be that the stock is above $\mathbf{B}_{lim}$.

Similarly, for the depletion rate due to fishing, it is necessary to establish a buffer zone below $\mathbf{F}_{lim}$. ICES therefore sets a precautionary approach reference point $\mathbf{F}_{pa}$ at a lower value of F. In order to be certain of being below $\mathbf{F}_{lim}$, a fishery should be below $\mathbf{F}_{pa}$. The size of the buffer zones depends on the size of the error and also on how certain managers want to be that the stock is below $\mathbf{F}_{lim}$. ICES has agreed that in order to be certain of being below $\mathbf{F}_{lim}$ management action should be taken when the depletion rate due to fishing rises above $\mathbf{F}_{pa}$.

9.5 Framework for advice

When an assessment shows that spawning biomass is below $\mathbf{B}_{pa}$, the stock will be regarded by ICES as ‘depleted’, and a fishery where F is above $\mathbf{F}_{pa}$ will be regarded as ‘overfished’. These stocks are ‘outside safe biological limits’. Where this is the case ICES will consider that management is not precautionary, and that advice should be given to reduce the fishing depletion rate below $\mathbf{F}_{pa}$, and to increase spawning biomass above $\mathbf{B}_{pa}$. ICES will recommend that managers should develop a management plan or a rebuilding plan specifying measures to reduce F below $\mathbf{F}_{pa}$ and to increase SSB above $\mathbf{B}_{pa}$ in an appropriate (‘reasonable’) time scale depending on the biological character of the stock and other relevant factors.

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

Finally, when an assessment shows that the fishing rate is below $\mathbf{F}_{pa}$, but that the spawning biomass is below $\mathbf{B}_{pa}$ the stock is again outside safe biological limits and ICES will advise that the fishing depletion rate should be reduced.

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 may become necessary to change these reference point values as a result of changes in the data, or the productivity of the stock, and ICES will keep this problem under review.

10 REFERENCES

Annala J.H., & K.J. Sullivan. 1996. Report from the fishery assessment plenary, April-May 1996: stock assessments and yield estimates. NIWA, Wellington, 308 pp.

Anon. 1997. Report of the Study Group on the Precautionary Approach to Fisheries Management. Feb 1997. ICES CM 1997/Assess:7.

Anon.1998a. Report of the Study Group on the Precautionary Approach to Fisheries Management. Feb 1998. ICES CM 1998/ACFM:10.

Anon. 1998b. Report of the ICES Working Group on the Assessment of mackerel, horse mackerel, sardine and anchovy. (Copenhagen, 9-18 Sept.1997) ICES CM 1998/Asses: 6

Anon. 1998c. Report of the Study Group on Management Strategies for Baltic Fish Stocks. ICES CM 1998/ACFM:11

Anon. 1999a. Report of the ICES Advisory Committee on Fishery Management, 1998. ICES Cooperative Research Report No 229.

Anon. 1999b. Report of the Northern Pelagic and Blue Whiting Fisheries Working Group. ICES CM 1999/ACFM :28.

Anon. 2000a. Report of the ICES Advisory Committee on Fishery Management, 1999 . ICES Cooperative Research Report No 336.

Anon. 2000b. Report of the CWP Intersessional Meeting. Working Group on Precautionary Approach Terminology. ICES CM 2000/ACFM:17.

Anon. 2000c. Report of the Study Group on the Biology and Assessment of Deep-sea Fisheries Resources. ICES CM 2000/ACFM: 8.

Anon. 2000d. Report of the Study Group on Incorporation of Process Information into Stock-Recruitment Models, Lowestoft, UK, 23-26 November 1999. ICES CM 2000/C:01

Anon. 2001a. Study Group on the Further Development of the Precautionary Approach to Fisheries Management (Copenhagen, 2-5 April 2001) ICES CM 2001/ACFM11

Anon. 2001b. Report of the ICES Advisory Committee on Fishery Management, 2000. ICES Cooperative Research Report No 242

Anon. 2001c. Report of the Arctic Fisheries Working Group. ICES CM 2001/ACFM:19.

Anon. 2001d. Report of the Study Group on Incorporation of Process Information into Stock-Recruitment Models, Lowestoft, UK, 23-26 January 2001. ICES CM 2001/C:02

Anon 2001e. Report of the ICES Working Group on the Assessment of mackerel, horse mackerel, sardine and anchovy. (Copenhagen, 14-23 Sept.2000) ICES CM 2001/ACFM:06

Anon 2002a. Report of the ICES Advisory Committee on Fishery Management, 2001. ICES Cooperative Research Report No. 246.

Anon 2002b. Report of the Study Group on the Incorporation of Process Information into Stock-Recruitment Models, Lowestoft, UK, 14-18 January 2002. ICES CM 2002/C:01 Ref. D, WGRP.

Anon 2002c. Report of the Study Group on ACFM Working Procedures [SGWP]. Copenhagen, Feb 2002. ICES CM 2001: not yet coded

Anon 2002d. 13th Report of the Scientific, Technical, Economic and Scientific Committee. SEC (2002) 410. Brussels 12/4/2002.

Azevedo, M. and E. Cadima, 2001. $F_{0.1}$ and Precautionary Reference Points. Pers Comm. in Anon 2001a. Study Group on the further development of the precautionary approach to Fisheries Management (Copenhagen, 2-5 April 2001) ICES CM 2001/ACFM11

Barange, M. (Ed.) 2001: Report of the 1st meeting of the SPACC/IOC Study Group on "Use of environmental indices in the management of pelagic fish populations (3-5 Sept. 2001, Cape Town, South Africa). GLOBEC Special Contribution No 5, 122 pp.

Basson, M.,1999. The importance of environmental factors in the design of management procedures. *ICES J. Mar. Sci.* **56**, 933-942

Basson, M., 2000. Reference points and environmental factors: should they be linked? Presented at the symposium: *Targets, Reference Points and the Burden of Proof in Fishery Management* (31 October – 2 November 2000, MOTE Marine Laboratory, Sarasota, Florida) and submitted to *Bulletin of Marine Science*.

Beckett, J. S. and Serra, R. 2001. Scientific peer review of Northeast Arcic cod assessment. Internal report to ICES, 9 October 2001, Oslo, Norway.

Beverton, R.J.H. & 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.

Butterworth. D. S. and M. O. Bergh, 1993. The development of a management procedure for the South African anchovy resource. p.83-100. In S. J. Smith, J.J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Cochrane, K. L., Butterworth, D. S., De Oliveira, J. A. A. and Roel, B. A. 1998: Management procedures in a fishery based on highly variable stocks and with conflicting objectives: experiences in the South African pelagic fishery. Revs Fish Biol. Fish. 8: 177-214.

Csirke. J., 1988. Small shoaling pelagic fish stocks. p 271-302. In Fish Population Dynamics (Second Edition). (J.A. Gulland, editor) John Wiley & Sons Ltd. Chichester 1988, 422 pp.

De la Mare W.K. 1998. Tidier fisheries management requires a new MOP (management-oriented paradigm). Reviews of Fish Biology and Fisheries, 8: 349-356.

Fox, C.J., B.P.Planque, & C.D.Darby, 2000. Synchrony in the recruitment time-series of plaice (*Pleuronectes platessa* L) around the United Kingdom and the influence of sea temperautre. Journal of Sea Research 44, 159-168.

Gavaris, S., K.R. Patterson, C.D. Darby, P. Lewy, B. Mesnil, A.E. Punt, R.M. Cook, L.T. Kell, C.M. O'Brien, V.R. Restrepo, D.W. Skagen and G. Stefánsson (2000). Comparison of uncertainty estimates in the short-term using real data. ICES C.M. 2000/V:03

Girard, M., 2000. Distribution et reproduction de deux espèces de requins de grands fonds, les «sikis», Centrophorus squamosus et Centroscymnus coelolepis exploités dans l'Atlantique Nord-Est. Rennes: L'Ecole Nationale Superieure Agronomique de Rennes, These de Docteur, 214 pp.

Girard M., & M.-H. Du Buit., 1999. Reproductive biology of two deep-water sharks from the British Isles, Centroscymnus coelolepis and Centrophorus squamosus. Journal of the Marine Biological Association of the United Kingdom, 79, 923-931.

Hastie, T. and Tibshirani, R. (1990). Generalized Additive Models. Chapman and Hall, London.

Horn P. L., Tracey D. M., Clark M. R., 1998. Between area differences in age and length at first maturity of the orange roughy Hoplostethus atlanticus. Marine Biology, 132, 187-194.

Holt S. - 1998. Fifty years on. Reviews of Fish Biology and Fisheries, 8: 357-366.

Hinkley, D.V. (1988). Bootstrap methods. *Journal of the Royal Statistical Society, Series B*, **50**:321-337.

Hudson, D.J. (1966). Fitting segmented curves whose join points have to be estimated. *Journal of the American Statistical Association*, **61**: 1097-1129.

Jarre-Teichman A, Wieland,K., Mackenzie, B. Hinrichsen H-H, Pliksh, M and E. Aro, 2000. Stock-recruitment relationships for cod (*Gadus morhua,* L.) in the central Baltic Sea incorporating environmental variability. *Arch. Fish. Mar. Sci.* **48** (2) 97-123

Julious, S.A. (2001). Inference and estimation in a changepoint regression problem. *The Statistician*, **50**: 51-61.

Kell. L.T., C.M. O'Brien, M.T. Smith, T.K. Stokes, and B.D. Rackham. – 1999a. An evaluation of management procedures for implementing a precautionary approach in the ICES context for North Sea plaice Pleuronectes platessa L. "In Confronting Uncertainty in the Evaluation and Implementation of Fisheries-Management Systems. Payne, A.I.L. (Ed.). ICES Journal of Marine Science Vol. 56: 834-835

Kell, L.T., J.M. Fromentin, F. Gauthiez and V.R. Restrepo. – 1999b. A simulation framework to evaluate management strategies for Atlantic tunas: a preliminary example based on East Atlantic bluefin tuna. ICCAT working document. SCRS/99/11 2095 - 2116

Kell L.T., D.J. Die, V.R. Restrepo, J.M. Fromentin, V. Ortiz de Zarate and P. Pallares. (In press). An Evaluation Of Management Strategies For Atlantic Tuna Stocks. Scientifica Marina,

Kell, L.T, Smith M., Scott, R., Pastoors, M., Van Beek, F., Hammond, T.,and O'Brien-, C.. (pers comm) Analysis of possibilities of limiting the annual fluctuations in TACs EU Project Reference No FISH-2000-02-01

Köster, F.W., Mollmann, C., Neuenfeldt, S., St John, M.A., Plikshs, M. and R. Voss. 2001a. Developing Baltic cod recruitment models. I. Resolving spatial and temporal dynamics of spawning stock and recruitment for cod, herring, and sprat. *Can. J. Fish. and Aquat. Sci*., **58**, 1516-1533.

Köster, F.W, Hinrichsen, H.H., St John, M.A., Schnack, D., MacKenzie, B.R., Tomkiewicz, J. and M Plikshs.2001b. Developing Baltic cod recruitment models. II. Incorporation of environmental variability and species interaction. *Can. J. Fish. and Aquat. Sci*., **58**, 1534-1556.

Mace. P. M. and M.P. Sissenwine., 1993. How much Spawning per Recruit is Enough? p. 101-118. In S. J. Smith, J.J. Hunt and D. Rivard [ed.] Risk evaluation and viological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Marshall, C.T., Kjesbu, O.S., Yaragina, N.A., Solemdal, P., and O Ulltang, 1998. Is spawner biomass a sensitive measure of the reproduction and recruitment potential of Northeast Arctic cod ? Can. J.Fish. Aquat. Sci. 55: 1766-1783.

Marshall, C.T., Yaragina, N.A., Adlandsvik, B and A.V. Dolgov., 2000. Reconstructing the stock/recruit relationship for Northeast Arctic cod using a bionenergetic index of reproductive potential. Can. J. Fish. Aquat. Sci. 57: 2433-2442.

O'Brien, C.M., Fox, C.J., Planque, B. & J. Casey, 2000. Climate variability and North Sea cod. Nature, 404, 142

Patterson, K., 1992: Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish Biology and Fisheries, 2, 321-338 (1992).

Patterson K.R, R. M. Cook, C. D. Darby, S. Gavaris, L. T. Kell, P. Lewy, B. Mesnil, A. E. Punt, V. R. Restrepo, D. W. Skagen, and G. Stefánsson. (2001). Estimating Uncertainty in Fish Stock Assessment and Forecasting. Fish and Fisheries, (in press).

Pitcher, T. J., 1995 : The impact of pelagic fish behaviour on fisheries. Sci. Mar., 59 (3-4): 295-306.

Quandt, R.E. (1958). The estimation of the parameters of a linear regression system obeying two separate regimes. *Journal of the American Statistical Association*, **53**: 873-880.

Ravier C., & J-M. Fromentin, 2001. Long-term fluctuations in the Eastern Atlantic and Mediterranean bluefin tuna abundance. ICES Journal of Marine Science (in press)

Restrepo, V.R. and A.A. Rosenberg, 1995. Uncertainty and risk evaluation in stock assessment advice for U.S. marine fisheries. Canadian Journal of Fisheries and Aquatic Sciences 51:2715-2720.

Ripley, B.D. (1981). *Spatial Statistics*. New York: John Wiley and Sons.

Rottingen I. 2000: A review of the process leading to the establishment of limit and precautionary reference points for the stock of Norwegian-spring spawning herring. ICES CM 2000/X:08

Serchuk, F.M and J.R. Grainger, 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.

Serchuk, F., D. Rivard, J.Casey, and R.Mayo. 1997. Report of the ad hoc Working Group of the NAFO Scientific Council on the Precautionary Approach. NAFO SCS Doc. 97/12.

Schnack, D and F.W Köster 2001. Environmental and fisheries influences on fish stock recruitment in the Baltic Sea (STORE). Summary of results 1999-2000. ICES CM 2001/Mini Symp. U: 15

Tracey, D.M. and Horn, P.L., 1999. Background and review of ageing orange roughy (Hoplostethus atlanticus, Trichthyidae) from New Zealand and elsewhere. New Zealand Journal of Marine and freshwater Research 33: 67-86

Ulltang, O. 1980: Factors affecting the reaction of pelagic fish stocks to exploitation and requiring a new approach to assessment and management, Rapp. Procès-Verb. Réun. Cons. Int. Explor. Mer 177. 489-504.

Wilimovsky, N.J. - 1985. The need for formalization of decision algorithms and risk levels in fishery research and management. Canadian Journal of Fisheries and Aquatic Science, 42:258-262.

Worsley, K.J. (1983). Testing for a two-phase multiple regression. *Technometrics*, **25**:35-42.

ANNEX 1

Working Document 1.

Are there general patterns in SSB-R relations and F-SSB trajectories that can be used as guides for establishing PA reference points?

by

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BACKGROUND

The objective of this working document is to contribute to SGPA 2002 ToR b) i): continue the development of the framework for formulating advice for stocks under full analytical assessment, focusing on reference points based on $\mathbf{F}_{loss}$ and $\mathbf{B}_{loss}$ or on historical evidence of reduced recruitment at low SSB. As a first step data by stock published in the 2001 ACFM advice report (ICES, 2001) was gathered from all ICES stocks (except *Nephrops*) in order to be available for further analysis during the SGPA meeting.

A visual inspection of the historical SSB-R plots and F-SSB trajectory graphs were performed for 66 ICES stocks with full analytical assessment. This exploratory analysis has led to the establishment of general patterns in which most ICES stocks fit.

Some stocks were considered as typical of some of the patterns defined in this WD but the classification of some others can be subjective and this is pointed out. It is emphasised that there was no attempt to fit any theoretical SSB-R relationship. However this was already done for most stocks by the ICES assessment WGs. Also it should be beard in mind that these plots do not provide information on other factors such as multispecies and environmental effects, that may affect the recruitment.

The historical trends of SSB-R were analysed as a guide to the establishment of $\mathbf{B}_{pa}$. However, PA concepts are still under development and SGPA ToR d) will address the issue of revising their description. Therefore, only some examples of the establishment of $\mathbf{B}_{pa}$ reference points are provided based on historical evidence of reduced recruitment at low SSB.

Aiming to extract additional information regarding the historical stocks/species reaction to fishing pressure and resulting impact on recruitment links between SSB-R and F-SSB patterns were investigated. Some questions are addressed: which would be the advice for stocks showing a SSB decreasing trend with increasing F that also show low R at low SSB? How many stocks show this behaviour? Do they belong to the same species or fishing area?

Other common features between stocks/species were analysed, e.g., are occasional strong year-classes a common feature of some stocks or species? Does this feature suggest different productivity periods?

Patterns

SSB-R relation

General types with some variants have been defined based on recruitment (R) produced at low levels of spawning stock biomass (SSB) and the distribution of the majority of the points (SSB, R).

Pattern 1:

Low SSB produces a wide range of R (below and above average or median R):

1a) high SSB producing R below and above average
1b) high SSB producing R below average
1c) high SSB producing R above average.

Pattern 2:

Low SSB produces only low R:

2a) median SSB produces R above average but high SSB produces R below average
2b) median to high SSB produce R below and above average
2c) median to high SSB produces R above average.

Pattern 3:

Low SSB produces only high R:

3a) R decreases with increasing SSB.
3b) R is above and below average with increasing SSB.

Figure 1 shows the SSB-R patterns, with some ICES stocks selected as typical examples. Table 1 presents the stocks classification and Annex 1 shows all the SSB-R plots, including the indication of the pattern type and the basis for the establishment of current ACFM PA reference points.

All the stocks were classified, however in some cases the pattern was not easy to identify. The majority of the stocks (52%) shows a SSB-R pattern of type 1 and mostly variant 1a (23 stocks). Stocks categorised as pattern 2 (38%) are distributed in variants 2a (8 stocks), 2b (11 stocks) and 2c (6 stocks). Only 7 stocks showed to behave according to pattern 3.

Considering historical evidence of reduced recruitment at low SSB (ToR b) i) b), than only stocks showing pattern 2 (25 stocks) should be taken into account. For these stocks one could then propose that $\mathbf{B}_{pa}$ be set at approximately the SSB corresponding to the interception line that split the 2 different areas of points. To check if $\mathbf{B}_{pa}$ set with the proposed procedure is in agreement with the $\mathbf{B}_{pa}$ adopted by ACFM all the stocks included in pattern 2 were analysed (Table 2).

Following the current ICES procedure, $\mathbf{B}_{pa}$ for stocks classified in pattern 2 was set by ACFM 2001 based on:

(i) $\mathbf{B}_{loss}$* uncertainty factor (9 stocks);
(ii) MBAL (5 stocks) and
(iii) Historical evidence (7 stocks)

Although the technical basis was different between the ACFM and our approach the $\mathbf{B}_{pa}$ reference points are in agreement in two stocks when applying criteria (i) and in three stocks for criteria (ii). For the cases where the ACFM basis was the historical evidence the $\mathbf{B}_{pa}$ reference points are the same for three stocks (Cod in VIIe-k, Sole in Bay of Biscay and Sole Western Channel).

Table 2 shows that for Cod Kattegat, Cod in Subdivisions 22–24 and Whiting in Divisions VIIe-k, the $\mathbf{B}_{pa}$ proposed by ACFM are in a region that always produces low recruitment (Figure 2) and following our procedure $\mathbf{B}_{pa}$ should be higher.

Other patterns could also provide some references to the establishment of $\mathbf{B}_{pa}$ according to historical evidence:

- above a SSB level only low R are produced (patterns 1b, 2a and 3a);
- above a SSB level only high R are produced (pattern 1c);
- **below a SSB level only high R are produced (patterns 3a and 3b).**

How should one take into account these different behaviours?

For stocks with pattern 1c, should we set $\mathbf{B}_{pa}$ as the SSB above which only high R are produced?

For stocks with pattern 3a current ACFM practice is to set $\mathbf{B}_{pa}$=$\mathbf{B}_{loss}$, which is the case of the stocks of Megrim (VII, VIIIabd), Celtic Sea Sole and Plaice in Skagerrat and Kattegat. However given that at high SSB the R decreases, should one consider the $\mathbf{B}_{pa}$ as a SSB range?

For some stocks with pattern 1 ACFM set $\mathbf{B}_{pa}$=$\mathbf{B}_{loss}$, considering that at $\mathbf{B}_{loss}$ there is no evidence of reduced recruitment. However at pattern 1, low SSB produces a wide range of recruitment. If it is accepted that the stocks of Anglerfish (both species) in Divisions VIIb-k and VIIIabd, Sole in Eastern Channel fit into pattern 1 (a wide range of R for low SSBs) then the technical basis should be revised.

ACFM advises $\mathbf{B}_{pa}$=$\mathbf{B}_{loss}$ for Irish Sea Plaice arguing that at $\mathbf{B}_{loss}$ there is evidence of high recruitment. However, for SSB levels close to $\mathbf{B}_{loss}$ low R are observed, which is not supporting the ACFM technical basis.

F-SSB trajectory

Three general types with some variants were considered. Annex 2 shows all the F-SSB trajectories, including our pattern classification and the ACFM current basis for the establishment of PA reference points.

Pattern 1:

Declining SSB with increasing F.

Pattern 2:

F-SSB trajectory can be limited by narrow vertical or horizontal bands:

2a) F-SSB trajectory is limited within a narrow F range but within a wide SSB range
2b) F-SSB trajectory is performed within a wide F range but in a narrow SSB range.

Pattern 3:

Undefined or random.

Figure 3 shows the F-SSB patterns as well as some ICES stocks selected as typical examples. Table 3 presents the stocks classification.

Most of the stocks show a F-SSB pattern type 3 (42%). Stocks exhibiting clearly pattern 1 represent 27% and pattern 2 represent 24%.

The Norwegian spring-spawning herring (Annex 2) could not be included in the defined patterns.

It is evident that only pattern 1 indicates that SSB reacts to fishing pressure and according to our analysis most of the stocks show an undefined F-SSB trajectory. This feature may be the result of strong year classes, changes in the distribution area or environmental factors.

Link between F-SSB and SSB-R Patterns

For simplicity we have used pairs to indicate patterns (F-SSB, SSB-R).

In favour of establishing $\mathbf{F}_{pa}$=F_x and $\mathbf{B}_{pa}$=SSB_y would be the stocks represented by pairs (1,2) given that these stocks show a SSB decreasing trend when F increase and also low R at low SSB ($F>F_x$ / $SSB<SSB_y$ / $R<R_z$).

It is observed that only seven stocks are pairs (1,2):

- Cod (West of Scotland)
- Cod (Irish Sea)
- Cod (North Sea, Eastern Channel and Skagerrak)
- Herring (Subdivisions 25–29 including Gulf of Riga and 32)
- Sole (Bay of Biscay)
- Whiting (West of Scotland) and
- Whiting (Division VIIe-k).

An exercise using the historical evidence to estimate $\mathbf{F}_{pa}$ and $\mathbf{B}_{pa}$ values was done for Cod (West of Scotland) stock. For this stock at F≈0.7, SSB has been above 18000t, which is the SSB below which the recruitment has been always low. In this case it could be appropriate to consider F≈0.7 as candidate to $\mathbf{F}_{pa}$. However, if for instance, the stock productivity or the exploitation pattern has changed, then the $\mathbf{F}_{pa}$ based on historical evidence may not be adequate.

COMMON FEATURES BETWEEN STOCKS/SPECIES AND AREAS

It is interesting to notice that pelagic species as anchovy, herring, blue whiting, sardine, mackerel, etc. show SSB-R pattern 1, while most of the cod and whiting stocks follow pattern 2.

F-SSB trajectories for four Stocks of Herring (West of Scotland, Sub-Div 22-24 and Div IIIa (spring spawners), Sub-Div 31 (Bothian Sea) and Gulf of Riga) show pattern 1 indicating that SSB reacts to fishing pressure.

It is also interesting to refer that from the seven stocks categorised as pairs (1,2) three of them are cod stocks and two are whiting stocks from the North Sea and adjacent areas (Div. IIIa, Irish Sea and West of Scotland).

Table 4 presents the eighteen stocks with occasional strong year-classes. For some of them only one strong year-class is observed, despite a long data series. For stocks exhibiting 4-5 strong year-classes, North Sea sole, North Sea plaice and West of Scotland haddock, it is detected that these year-classes have been produced along the time-series. Focusing on year-classes it is noticed that they are strong in the same calendar year for different species included in Table 4, but besides the cases of North Sea sole and plaice, they do not suggest a particular area effect. However this could be further investigated.

COMMENTS

The exploratory analysis performed in this WD has raised several questions that may be addressed during the SGPA meeting. However there are general patterns in SSB-R relations and F-SSB trajectories, particularly links between them that can be used as guides to propose candidates to PA reference points. In fact, historical “evidence”, *per se*, is not enough to arrive at PA reference points since other important aspects must be taken into account, such as changes in the exploitation pattern, the stock current productivity, among others. Regarding F candidates to $\mathbf{F}_{pa}$ these should also be evaluated in terms of conservation properties, such as %BPR and %SPR (Azevedo and Cadima, 2002).

A framework to formulate advice focusing on longterm management objectives, aiming the optimum use of fisheries resources, with proposed target reference points, should be the way forward. In this context PA reference points should be settle to ensure that these longterm objectives are not compromised.

REFERENCES

ICES, 2001. Report of the ICES Advisory Committee on Fishery Management, 2001. *ICES Cooperative Research Report*, nº 246.

Azevedo, M. & Cadima, E. 2002. Stock conservative properties of F_{01}. (WD to SGPA, 2002)

Table 1 – List of stocks classified according to the defined SSB-R pattern.

Pattern 1

1a?	Anchovy in Subarea VIII (Bay of Biscay)
1a	Anglerfish -Lophius budegassa in Divisions VIIb-k and VIIIabd
1b	Anglerfish -Lophius piscatorius in Divisions VIIb-k and VIIIabd
1b, 1a?	Blue whiting combined stock (Subarea I-IX, XII and XIV)
1b	Faroe plateau Cod (Division Vb1)
1a	Iceland Cod – Div Va
1a	North East Artic Cod (Subarea I and II)
1b	Norwegian Coastal Cod
1b	Faroe Haddock (Division Vb)
1a	Haddock in Division VIIa (Irish Sea)
1a	Haddock in Subarea IV (North Sea) and Division IIIa (Skagerrak – Kattegat)
1a	Iceland Haddock – Div Va
1c	Northern Hake – Division IIIa, VIIIabd and Subarea IV, VI, VII
1a	Herring in Divisions VIa (West of Scotland) and VIIbc
1a	Herring in Subdivision 22-24 and Division IIIa (spring spawners)
1a	Herring in Subdivision 31, Bothnian Bay
1a	Herring in the Gulf of Riga
1c	Irish Sea Herring (Division VIIa)
1a	Norwegian Spring-spawning Herring
1a	Western horse mackerel (Trachurus trachurus) (Division IIa, IVa, Vb, VIa, VIIa-c, e-k, VIIIa,b,d,e)
1a	Mackerel (combined Southern, western and North Sea spawning components)
1a	Southern Four-spot-Megrim (L. boscii) in Divisions VIIIc and IXa
1c	Southern Megrim (L. whiffiagonis) in Divisions VIIIc and IXa
1a	Irish Sea Plaice (Division VIIa)
1a?	Celtic Sea Plaice (Division VIIfg)
1a	North Sea Plaice (Subarea IV)
1c	North East Artic Saithe (Subarea I and II)
1a	Saithe Subarea IV (North Sea), Division IIIa (Skagerrak) and Subarea VI (West of Scotland and Rockall)
1b	Faroe Saithe (Division Vb)
1a	North Sea Sandeel (Subarea IV)
1b	Sardine in Division VIIIc and IXa
1a	North Sea Sole (Subarea IV)
1a	Sole in Division VIId – Eastern Channel
1a	Sprat in Subdivisions 22–32

Table 1 (cont)

<u>Pattern 2</u>

2a	Cod in Division VIIe-k
2c	Cod in Kattegat
2a	Cod in Division VIa (West of Scotland)
2a	Cod in Division VIIa (Irish Sea)
2b	Cod in Subarea IV (North Sea), and Divisions VIId (Eastern Channel) and IIIa (Skagerrak)
2b	Cod in Subdivisions 22–24 (including Subdivision 23)
2b	Cod in Subdivisions 25–32
2c	Greenland halibut in Subareas I and II
2b, 1a?	Northeast Arctic Haddock (Sub areas I and II)
2c	Southern Hake (Divisions VIIIc and IXa)
2b	Herring in Subarea IV, Division VIId and Division IIIa (autumn spawners)
2c	Herring in Subdivision 30, Bothnian Sea
2b	Herring in Subdivisions 25–29 (including Gulf of Riga) and 32
2b,1a?	Iceland Summer-spawning Herring - Div Va
2b	Norway pout in Subarea IV (North Sea) and Division IIIa (Skagerrak – Kattegat)
2a	Plaice in Division VIId (Eastern Channel)
2a	Plaice in Division VIIe (Western Channel)
2a	Saithe in Icelandic waters – Div Va
2c	Sole Bay of Biscay (Division VIIIa,b,d)
2c	Sole in Western Channel (Division VIIe)
2b	Irish Sea Sole (Division VIIa)
2b	Whiting in Division VIa (West of Scotland)
2b,2a?	Whiting in Division VIIa (Irish Sea)
2a, 1b?	Whiting in Divisions VIIe-k
2a	Whiting Subarea IV (North Sea) and Division VIId (Eastern Channel)

<u>Pattern 3</u>

3b	Haddock in Division VIa (West of Scotland)
3a	Haddock in Division VIb (Rockall)
3a	Southern horse mackerel (Trachurus trachurus) Division VIIIc and IXa)
3a, 1b?	Megrim (L. whiffiagonis) in Subarea VII and Divisions VIIIa,b,d
3a	Plaice in Kattegat and Skagerrak (Division IIIa)
3b	Sole Celtic Sea (Divisions VIIfg)
3a	Sole in Division IIIa

Table 2 – $\mathbf{B}_{pa}$ set according to this WD procedure for stocks with SSB-R pattern 2 and $\mathbf{B}_{pa}$ as adopted by ACFM.

	Bpa (1000 t)			
Stock	**ACFM Bpa Basis**	**ACFM 2001**	**WD**	**WD-ACFM**
Cod Kattegat	Bloss	10.5	12.5	2
Cod in Division VIa (West of Scotland)	Hist. Evid.	22	18	-4
Cod VIIe-k	Hist. Evid.	10	10	0
Cod in Sub-area IV (North Sea), and Divisions VIId (Eastern Channel) and IIIa (Skagerrak)	MBAL	150	150	0
Cod in Division VIIa (Irish Sea)	MBAL	10	10	0
Cod in Sub-divisions 22–24 (including Sub-division 23)	MBAL	23	30	7
Cod in Sub-divisions 25–32	MBAL	240	160	-80
Whiting in Division VIa (West of Scotland)	Bloss	22	22	0
Irish Sea Whiting (Division VIIa)	Bloss	7	5	-2
Whiting in Divisions VIIe-k	Bloss	21	40	19
Whiting sub-area IV (North Sea) and Division VIId (Eastern Channel)	Bloss	315	250	-65
Plaice in Division VIIe (Western Channel)	MBAL	2.5	2.5	0
Plaice Eastern Channel (Division VIId)	Bloss	8	7.5	-1
Irish Sea Sole (Division VIIa)	Bloss	3.8	3.8	0
Sole in Division VIIIa,b (Bay of Biscay)	Hist. Evid.	13	13	0
Sole Western Channel (Division VIIe)	Hist. Evid.	2.8	2.8	0
Southern Hake (Divisions VIIc and IXa)	Bloss	33.6	28	-6
Herring in Sub-area IV, Division VIId and Division IIIa (autumn spawners)	Others	1300	600	-700
Herring in Sub-divisions 25–29 (including Gulf of Riga) and 32	ND	-	900	
Iceland Summer-spawning herring - Div Va	Hist. Evid.	300	220	-80
Herring in Sub-division 30, Bothnian Sea	Hist. Evid.	200	145	-55
Norway pout in Sub-area IV (North Sea) and Division IIIa (Skagerrak – Kattegat)	Others	150	150	0
North-East Arctic Haddock (Suba areas I and II)	Hist. Evid.	83.5	60	-24
Greenland halibut in Sub-areas I and II	ND	-	115	
Saithe in Icelandic waters – Div Va	Bloss	150	120	-30

WD more conservative

Table 3 – List of stocks classified according to the defined F-SSB patterns and identification of pairs (1,2)

	Pattern 1	
1	Cod in Division VIa (West of Scotland)	**(1,2)**
1	Cod in Division VIIa (Irish Sea)	**(1,2)**
1, 2a?	Cod in Subarea IV (North Sea) and Divisions VIId (Eastern Channel) and IIIa (Skagerrak)	**(1,2)**
1	Iceland Cod – Div Va	
1	Haddock in Division VIa (West of Scotland)	
1	Iceland Haddock Div Va	
1?	Herring in Division VIa (South) and VIId,c	
1, 3?	Herring in Subdivision 31, Bothnian Bay	
1	Herring in Subdivisions 25–29 (including Gulf of Riga) and 32	**(1,2)**
1	Herring in the Gulf of Riga	
1	Megrim (L. whiffiagonis) in Subarea VII and Divisions VIIIa,b,d	
1	North Sea Plaice (Subarea IV)	
1	Sardine in Division VIIIc and IXa	
1, 2b?	Faroe saithe (Division Vb)	
1	North Sea Sole (Subarea IV)	
1	Sole Bay of Biscay (Division VIIIa,b,d)	**(1,2)**
1	Sole Celtic Sea (Division VIIf,g)	
1	Whiting in Division VIa (West of Scotland)	**(1,2)**
1	Whiting in Division VIIe-k	**(1,2)**
	Pattern2	
2b	Anglerfish in Divisions VIIb–k and VIIIa,b,d (L. budegassa)	
2b	Anglerfish in Divisions VIIb–k and VIIIa,b,d (L. piscatorius)	
2b	Blue Whiting combined stock (Subarea I-IX, XII andXIV)	
2a	Cod in Kattegat	
2b	Northern Hake – Division IIIa, VIIIa,b,d and Subarea IV, VI, VII	
2a	Herring in Division IIIa and Subdivisions 22–24 (spring-spawners)	
2a, 2b?	Iceland Summer-spawning Herring Div Va	
2b	Mackerel (combined Southern, Western and North Sea spawning components)	
2b	Southern Four-Spot Megrim (L. boscii) (Division VIIIc and IXa)	
2b	Southern Megrim (L. whiffiagonis) (Division VIIIc and IXa)	
2a	Plaice in Division VIIe (Western Channel)	
2a	Celtic Sea Plaice (Division VIIf,g)	
2a	Sole in Division IIIa	
2b	Sole in Division VIId (Eastern Channel)	
2b	Irish Sea sole (Division VII a)	
2a?	Whiting in Division VIIa (Irish Sea)	
2b	Whiting in Subarea IV (North Sea) and Division VIId (Eastern Channel)	
	Pattern 3	
3	Anchovy in Subarea VIII (Bay of Biscay)	
3	Cod in Division VIIe-k	
3	Cod in Subdivisions 22–24 (including Subdivision 23)	
3	Cod in Subdivisions 25–32	
3	Faroe plateau Cod (Division Vb1)	
3	North East Artic Cod (Subarea I and II)	
3	Norwegian Coastal Cod	
3	Greenland Halibut in Subareas I and II	
3	Faroe Haddock (Division Vb)	
3	Haddock in Division VIb (Rockall)	
3, 2a?	Haddock in Division VIIa (Irish Sea)	
3,2a?	Haddock in Subarea IV (North Sea) and Division IIIa (Skagerrak – Kattegat)	
3	Northeast Arctic Haddock – Subareas I and II	
3?	Southern Hake (Division VIIIc and IXa)	
3	Herring in Subarea IV, Division VIId and Division IIIa (autumn spawners)	

3, 2a?	Herring in Subdivision 30, Bothnian Sea
3	Irish Sea Herring (Division VIIa)
3	Western Horse Mackerel (Division IIa, IVa, Vb, VIa, VIIa-c, VIIe-k, VIIIa,b,d,e)
3	Southern Horse Mackerel (Trachurus trachurus) Division VIIIc and IXa)
3	Norway pout in Subarea IV (North Sea) and Division IIIa (Skagerrak – Kattegat)
3	Irish Sea Plaice (Division VIIa)
3	Plaice in Division VIId (Eastern Channel)
3	Plaice in Kattegat and Skagerrak (Division IIIa)
3	North East Artic Saithe (Subarea I and II)
3	Saithe in Iceland waters – Division Va
3	Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak) and Subarea VI (West of Scotland and Rockall)
3	North Sea Sandeel (Subarea IV)
3	Sole in Western Channel (Division VIIe)
3	Sprat in Subdivisions 22–32
	Norwegian spring-spawning herring (not classified)

Table 4 – Stocks with occasional strong year-classes

Stock	Data series (years)	year-classes (n)	year-classes (year)
North Sea sole	45	5	1958, **1963**, **1987**, 1991, **1996**
Celtic Sea sole, VIIf,g	31	2	1970, 1989
North Sea plaice	45	4	**1963**, 1981, 1985, **1996**
Saithe IV+IIIa+VI	35	1	1973
North-East Arctic haddock, I+II	52	2	1950, 1969
Iceland haddock, Va	22	2	1985, 1990
North Sea and Skagerrak haddock, IV+IIIa	39	1	1967
West of Scotland haddock, VIa	24	4	1979, 1983, **1986**, 1999
West of Scotland cod, VIa	36	1	**1986**
Cod VIIe-k	31	1	**1986**
West of Scotland whiting, VIa	24	1	1979
Norwegian Spring-spawning herring	52	1	1950
Herring in Div. VIa+VIIb,c	32	2	**1982**, **1986**
Irish Sea herring, VIIa	30	1	1972
Western horse mackerel	20	1*	**1982**
Southern horse mackerel, VIIIc+IXa	17	1	**1986**
Megrim VII+VIIIa,b,d	18	1	**1987**
North Sea sandeel	25	1	**1996**

* - dominating

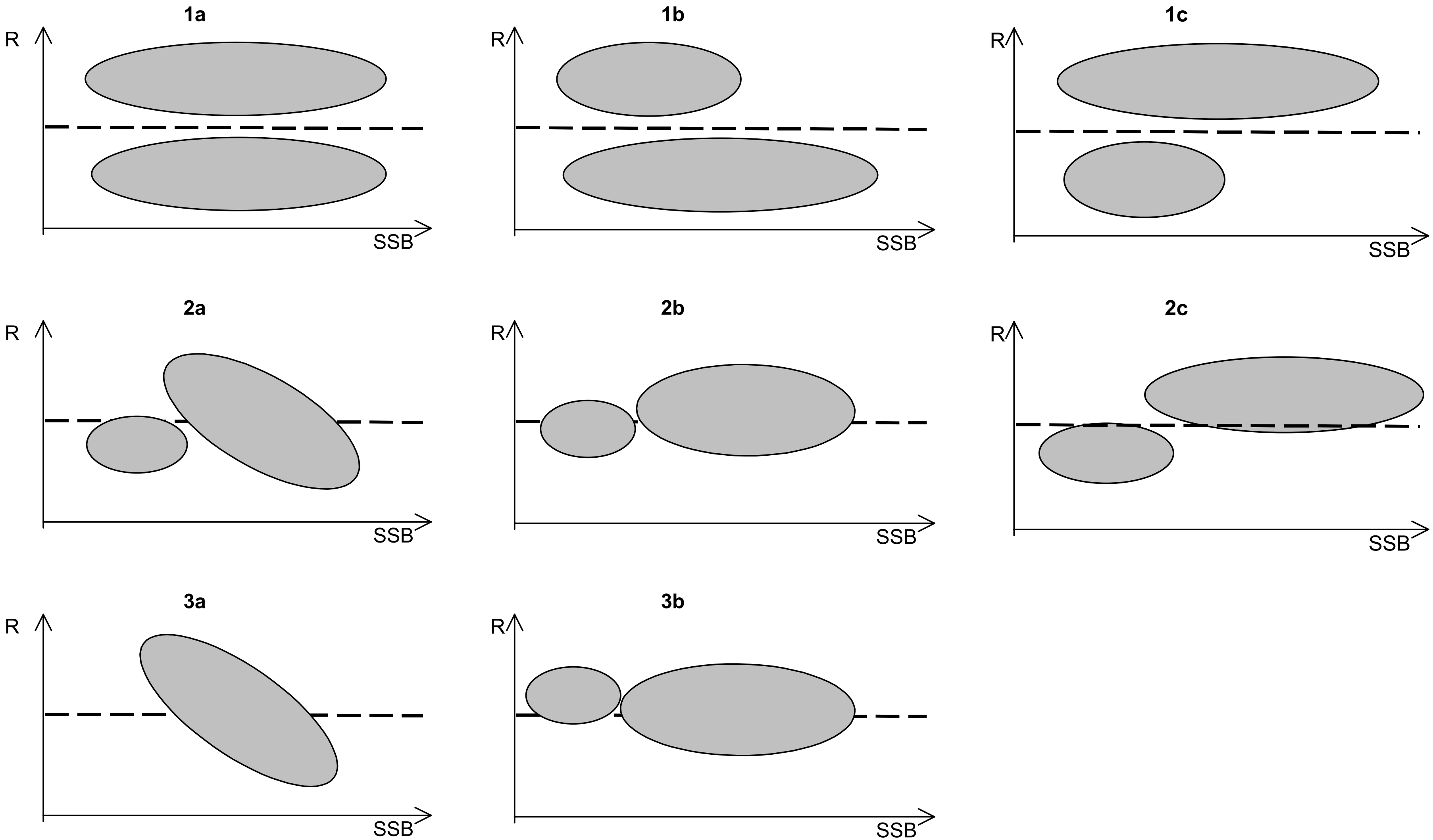
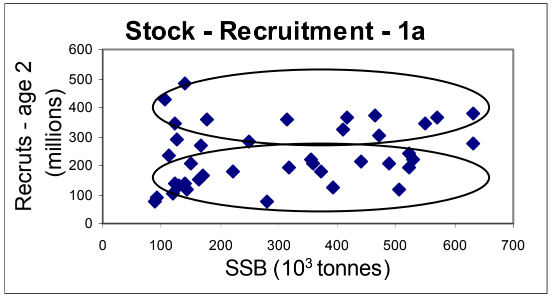
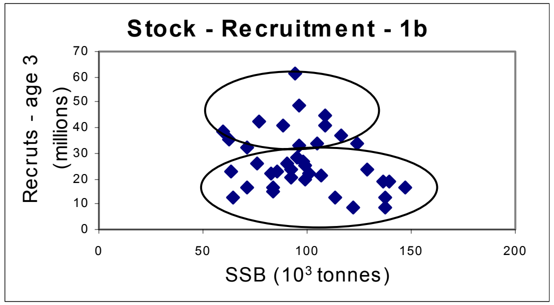


Figure 1 – SSB-R patterns and variants based on historical evidence.

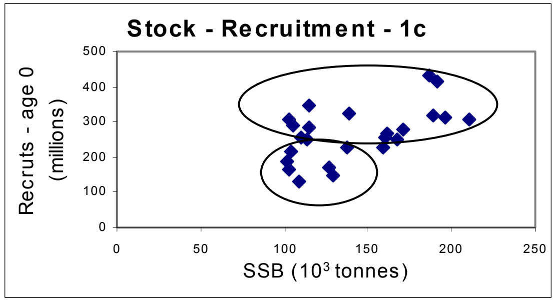
Northeast Arctic saithe (Subareas I and II)



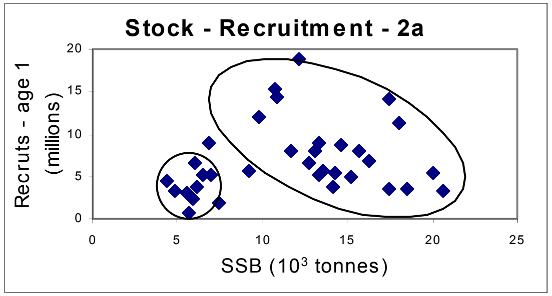
Faroe saithe (Division Vb)



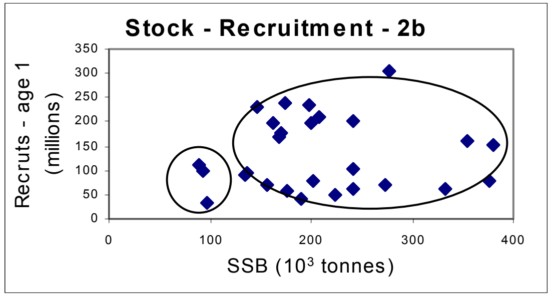
Hake – Northern stock



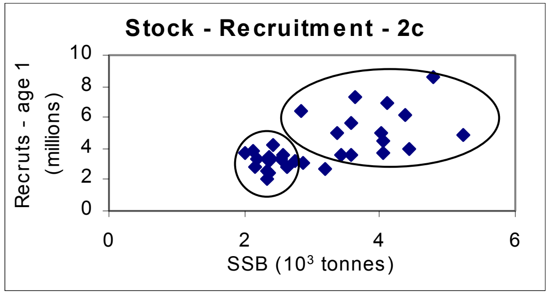
Cod in Division VIIa (Irish Sea)



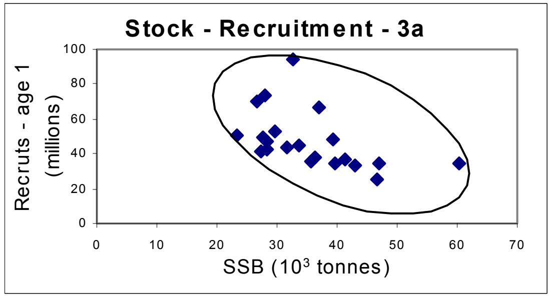
Norway pout in ICES Subarea IV and Division IIIa



Sole in Division VIIe (Western Channel)



Plaice in Division IIIa (Kattegat and Skagerrak)



Sole in Divisions VIIf and g (Celtic Sea)

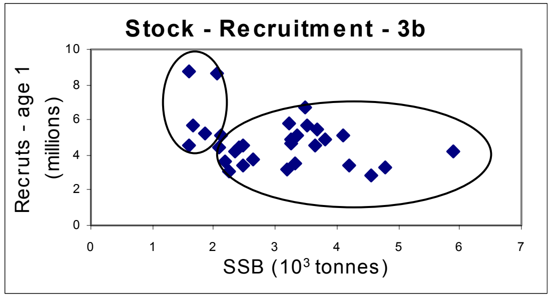


Figure 1 – cont. (typical examples of SSB-R patterns)

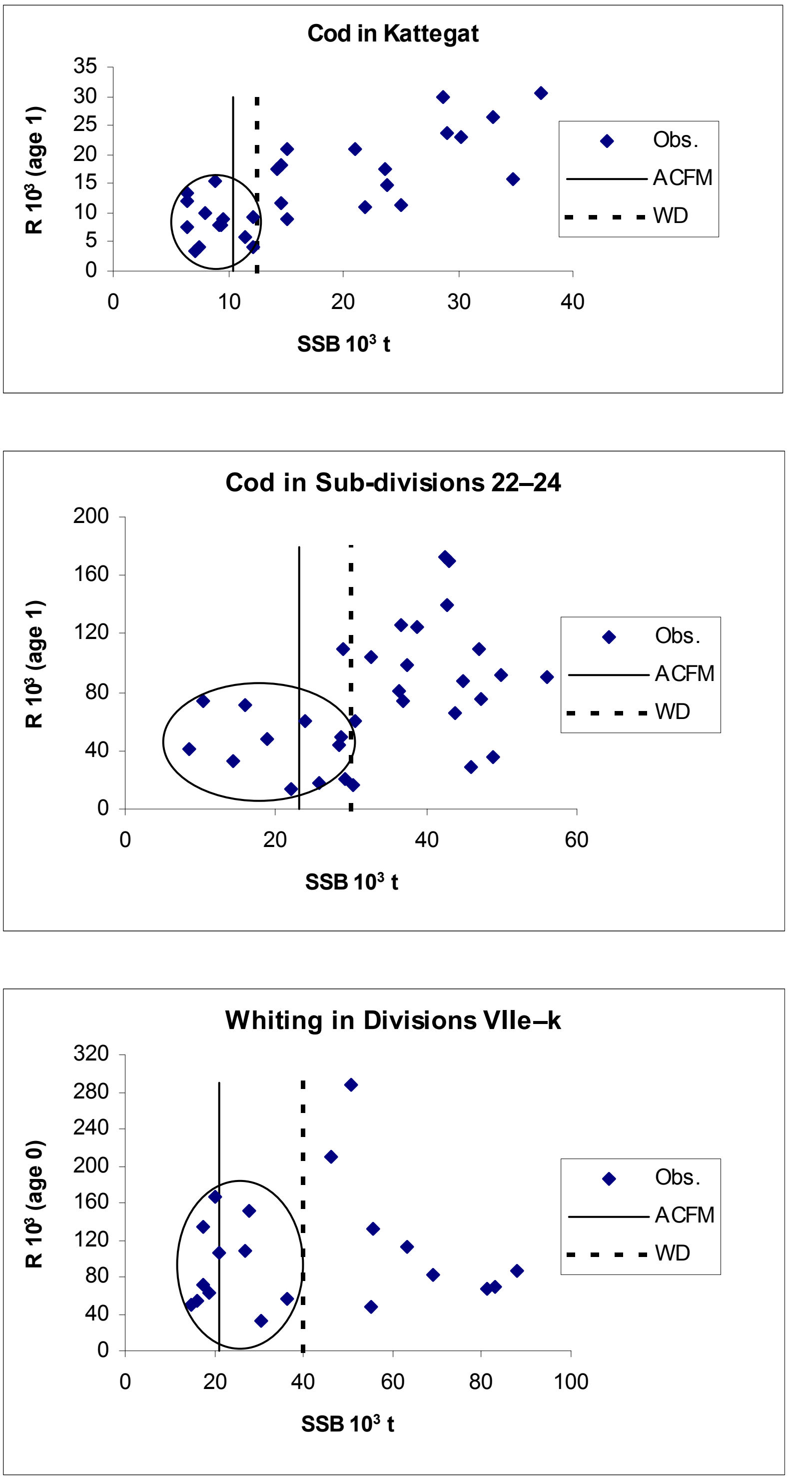


Figure 2 – Stocks with SSB-R pattern 2 and $\mathbf{B}_{pa}$ set according to the interseption line spliting the 2 areas (WD) and $\mathbf{B}_{pa}$ adopted by ACFM.

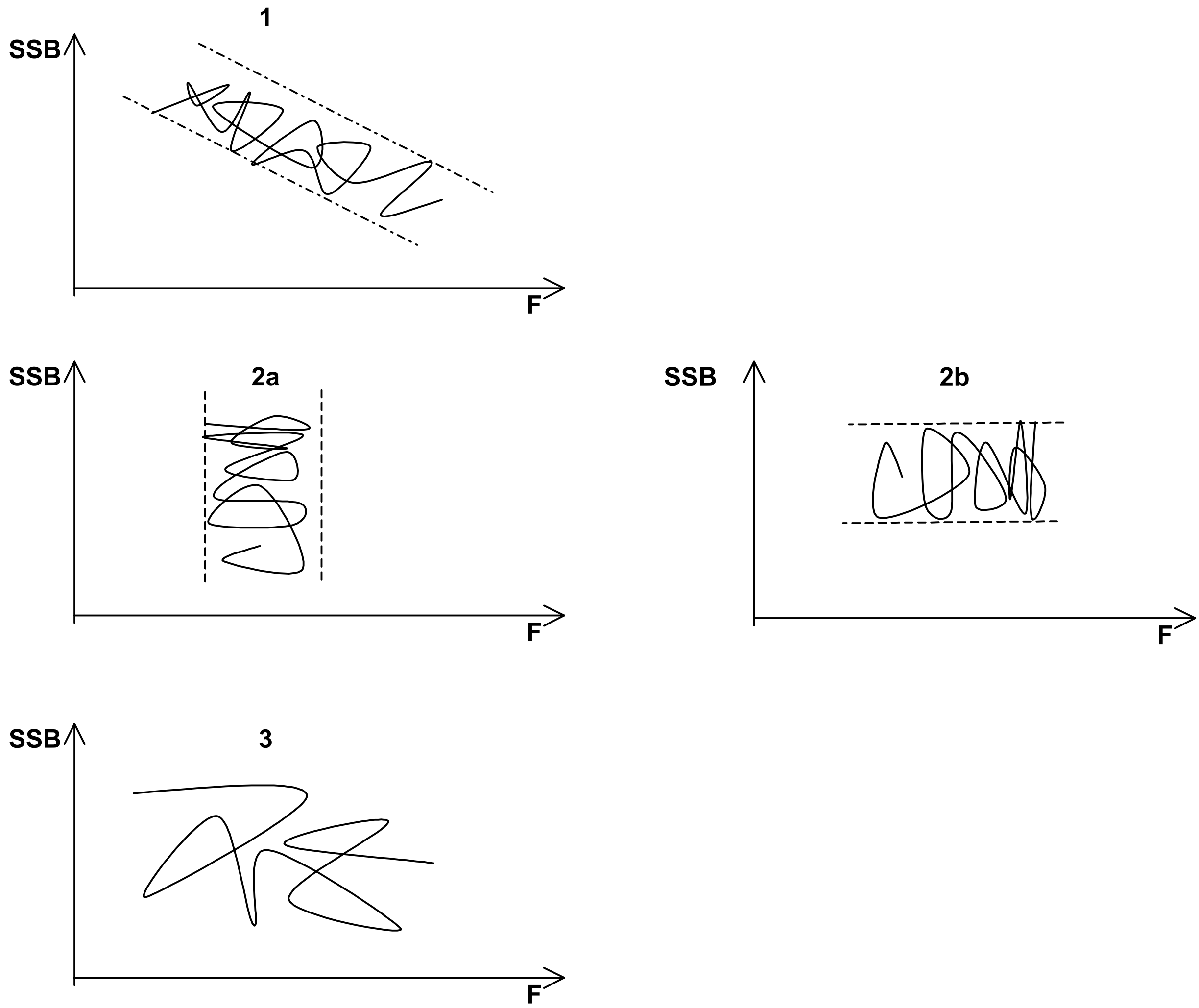
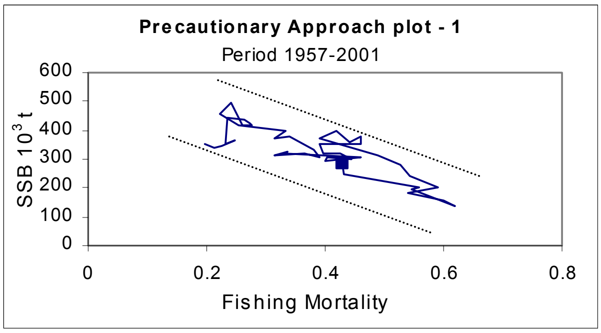
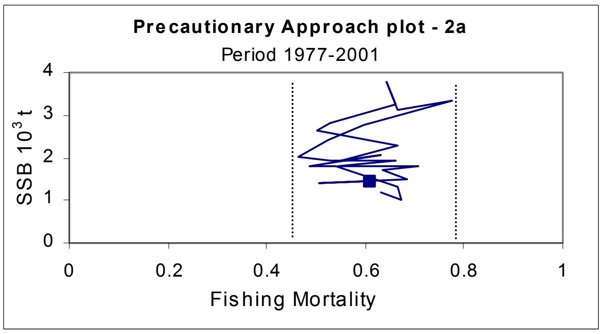


Figure 3 – F-SSB patterns based on historical evidence

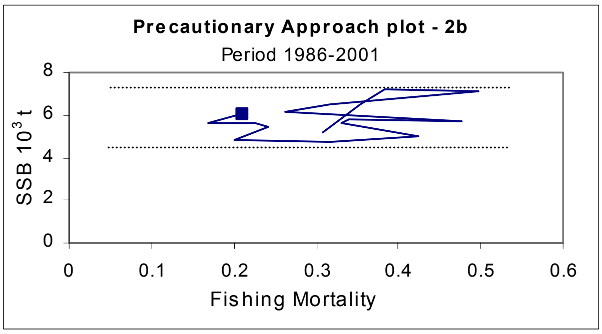
Plaice in Subarea IV (North Sea)



Celtic Sea plaice (Divisions VIIf and g)



Megrim (*L. boscii*) in Divisions VIIIc and Ixa



Northeast Arctic haddock (Subareas I and II)

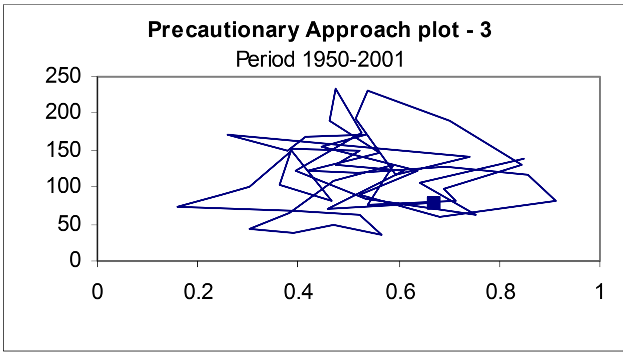


Figure 3 – cont. (typical examples of F-SSB patterns).

ANNEX 2

Working Document 8. - 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

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 $\boldsymbol{B}_{lim}$ *(lim stands for limit) and the fishing mortality threshold as* $\boldsymbol{F}_{lim}$.

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) < $\mathbf{B}_{\text{lim}}$
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,

$$
\begin{aligned}
f(x_i) &= \alpha_1 + \beta_1 x_i \qquad && X_0 \le x_i \le \delta, \\
&= \alpha_2 + \beta_2 x_i && \delta \le x_i \le X_1
\end{aligned}
\tag{1}
$$

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 $\square_1 = 0$, $\square_2 = 0$ and log-normal errors. The model is

$$
\begin{aligned}
R_i &= \beta_1 S_i \, e^{\varepsilon_i} \qquad && 0 \le S_i \le \delta, \\
&= \alpha_2 e^{\varepsilon_i} && \delta \le S_i
\end{aligned}
\tag{2}
$$

which on the natural logarithmic scale is:

$$
\begin{aligned}
\log R_i &= \log \beta_1 + \log S_i + \varepsilon_i \qquad && 0 \le S_i \le \delta, \\
&= \log \alpha_2 + \varepsilon_i && \delta \le S_i
\end{aligned}
\tag{3}
$$

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-α)% profile likelihood confidence interval for S* can be appropriately calculated using the expression:

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

(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-α)% 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-α)% profile likelihood confidence interval for S*; i.e. a lower limit S*(α_1) and an upper limit S*(1-α_2) may be defined such that (1-α_1-α_2) has the specified coverage probability of (1-α) 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:

– Northeast Arctic saithe (Subareas I and II) (O'Brien & Maxwell 2002a)

– northern hake (O'Brien & Maxwell 2002b)

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

– Northeast 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)

– Northeast 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 class; solid line is the change point model estimated; dotted lines are the change point models estimated by eliminating a single year class in turn.
- panel 2: change point 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).
Acknowledgements

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References

Atkinson, A.C. (1985). *Plots, Transformations and Regression*. Oxford: Oxford University Press.

Barrowman, N.J. and Myers, R.A. (2000). Still more spawner-recruitment curves: the hockey stick and its generalizations. *Canadian Journal of Fisheries and Aquatic Sciences*, **57**: 665-676.

Hinkley, D.V. (1988). Bootstrap methods. *Journal of the Royal Statistical Society, Series B*, **50**:321-337.

Hudson, D.J. (1966). Fitting segmented curves whose join points have to be estimated. *Journal of the American Statistical Association*, **61**: 1097-1129.

ICES (2001). Report of the ICES Advisory Committee on Fishery Management, 2000. *ICES Coop. Res. Rep.* **242**.

ICES (2002a). Report of the Working Group on Methods on Fish Stock Assessments, ICES Headquarters, Copenhagen, Denmark, 3-7 December 2001. ICES CM 2002/D:08 Ref. ACFM, G.

ICES (2002b). Report of the Study Group on the Incorporation of Process Information into Stock-Recruitment Models, Lowestoft, UK, 14-18 January 2002. ICES CM 2002/C:01 Ref. D, WGRP.

Julious, S.A. (2001). Inference and estimation in a changepoint regression problem. *The Statistician*, **50**: 51-61.

Kell, L.T., O'Brien, C.M., Smith, M.T., Stokes, T.K. and Rackham, B.D. (1999). An evaluation of management procedures for implementing a precautionary approach in the ICES context for North Sea plaice (*Pleuronectes platessa* L.). *ICES Journal of Marine Science*, **56**:834-845.

Lerman, P.M. (1980). Fitting segmented regression models by grid search. *Applied Statistics*, **29**: 77-84.

O'Brien, C.M. and Maxwell, D.L. (2002a). A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic saithe (Subareas I and II). Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002b). A segmented regression approach to the Precautionary Approach – the case of northern hake. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002c). A segmented regression approach to the Precautionary Approach – the case of plaice in Division IIIa. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002d). A segmented regression approach to the Precautionary Approach – the case of Northeast Atlantic mackerel. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002e). A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIa. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002f). A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIe-k. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002g). A segmented regression approach to the Precautionary Approach – the case of cod in Division VIa. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002h). A segmented regression approach to the Precautionary Approach – the case of cod in Subarea IV, Divisions IIIa and VIId. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002i). A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic cod (Subareas I and II). Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M. and Maxwell, D.L. (2002j). A segmented regression approach to the Precautionary Approach – the cases of anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa). Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M., Maxwell, D.L. and Roel, B.A. (2002). A segmented regression approach to the Precautionary Approach – the case of herring in Subarea IV, Divisions IIIa and VIId. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

O'Brien, C.M., Maxwell, D.L., Roel, B.A. and Basson, M. (2002). A segmented regression approach to the Precautionary Approach – the case of the Thames Estuary (or Blackwater) herring. Working paper to the ICES Study Group on the Further Development of the Precautionary Approach to Fishery Management, Lisbon, Portugal, 4-8 March 2002.

Quandt, R.E. (1958). The estimation of the parameters of a linear regression system obeying two separate regimes. *Journal of the American Statistical Association*, **53**: 873-880.

Ripley, B.D. (1981). *Spatial Statistics*. New York: John Wiley and Sons.

Worsley, K.J. (1983). Testing for a two-phase multiple regression. *Technometrics*, **25**:35-42.

ANNEX 3

Working Document 10. 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 Northeast 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 Northeast 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 Northeast 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 $\mathbf{B}_{\text{lim}}$ of 89 000 tonnes; whereas the upper 90% limit is ≈ 30% higher than the current $\mathbf{B}_{\text{pa}}$ of 150 000 tonnes.

Acknowledgements

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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:	Northeast 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 $\sigma = 0.3$

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 Subareas 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

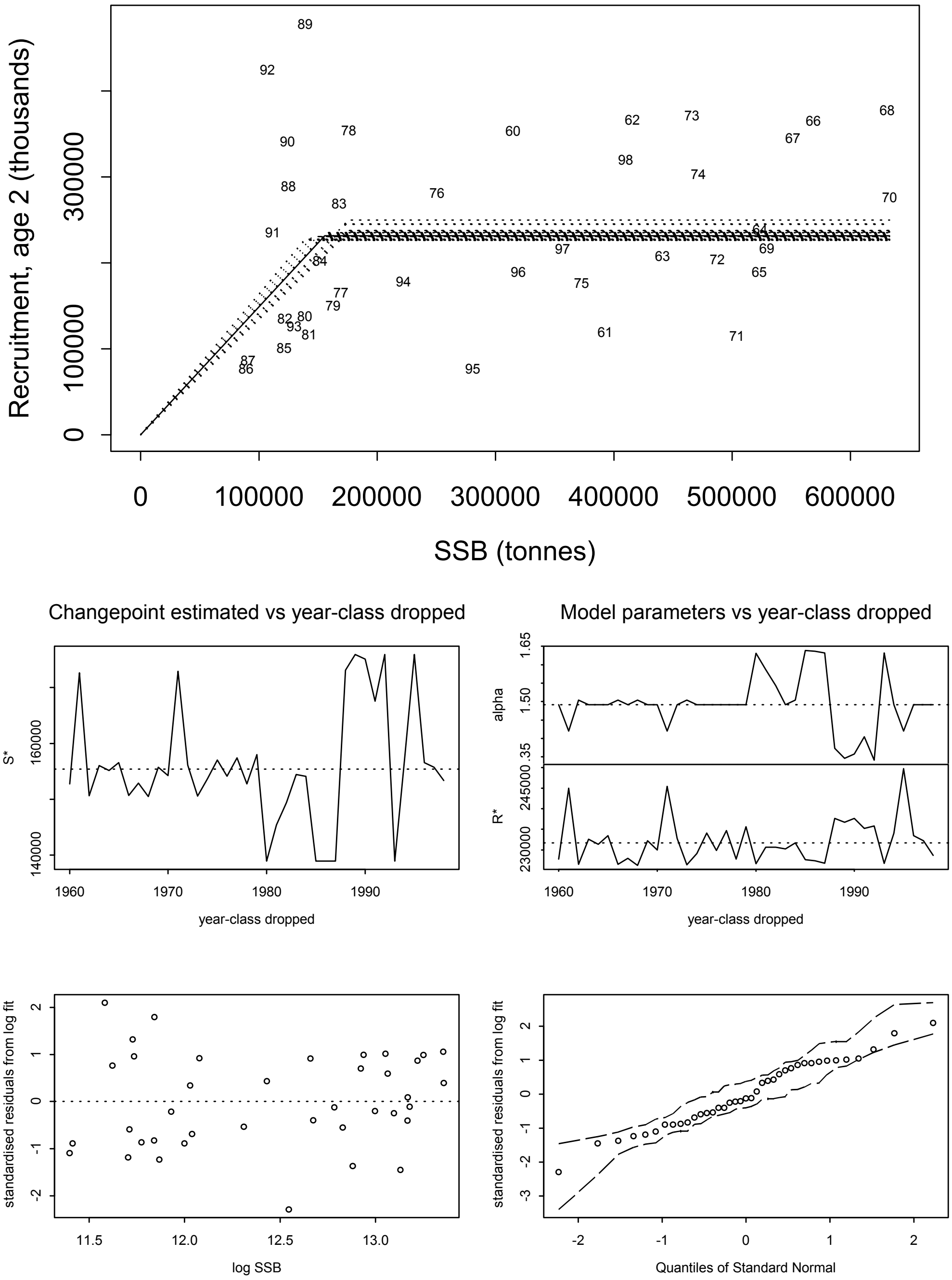
Saithe I & II

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 p-value**
mean	38	9.156				
changepoint	37	8.145	1	1.012	4.60	0.016

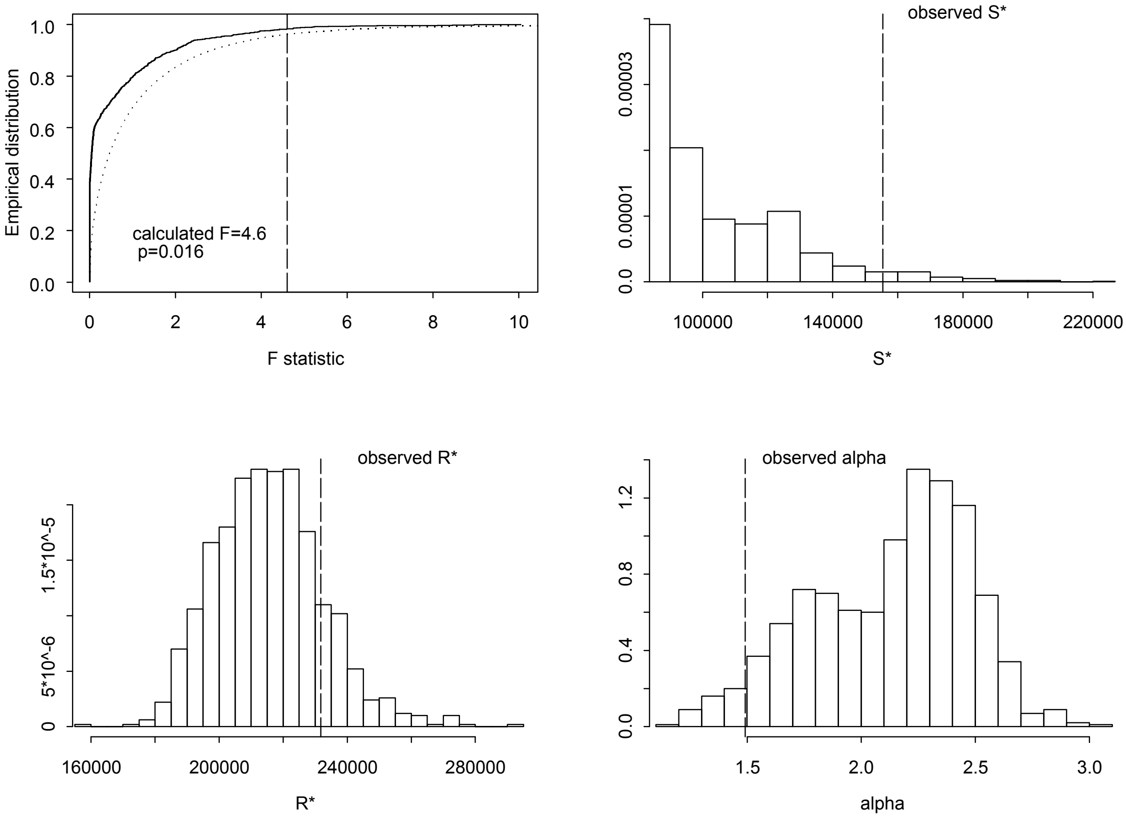
Panel B

Saithe I & II

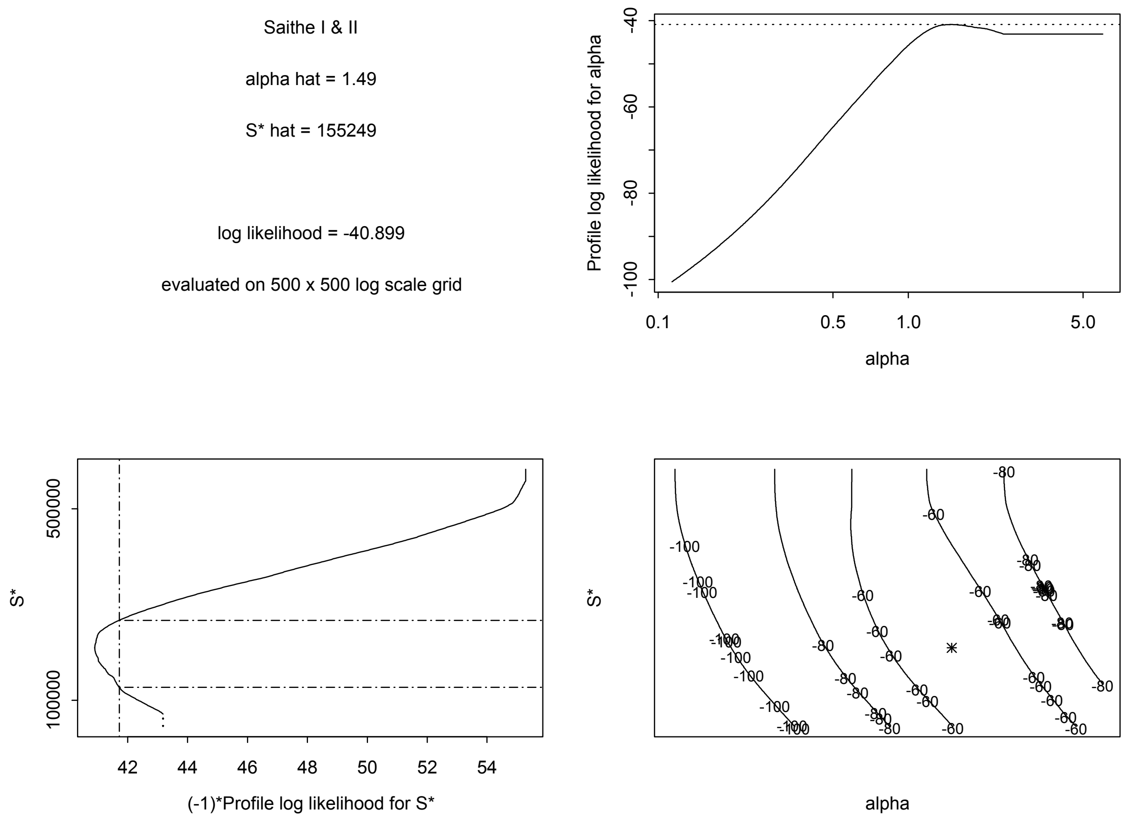


Panel C

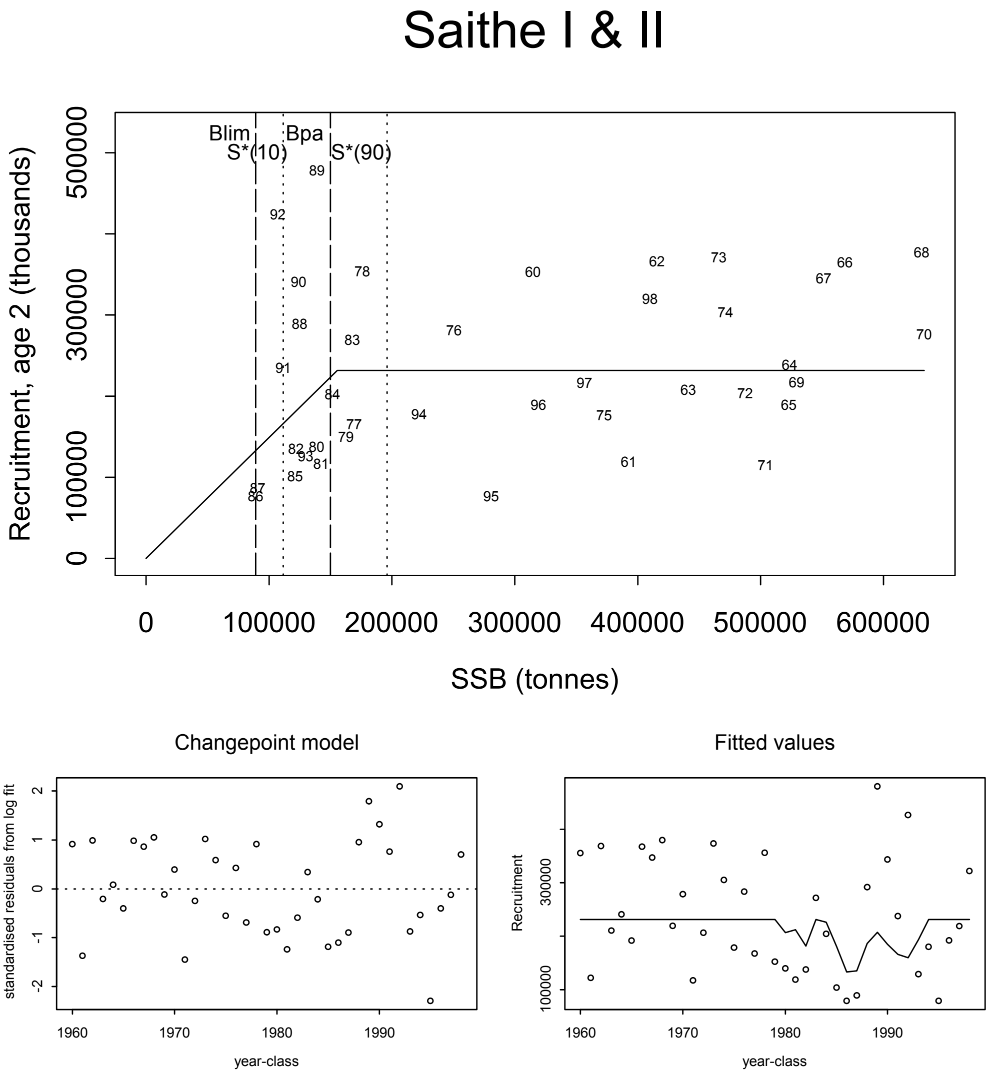
Saithe I & II. Bootstrap F and parameter distributions under H0.



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*
S*
alpha

Panel E



Saithe I & II
Blim
Bpa
S*(10)
S*(90)
Recruitment, age 2 (thousands)
SSB (tonnes)
Changepoint model
standardised residuals from log fit
year-class
Fitted values
Recruitment
year-class

Panel F

ANNEX 4

Summaries of Working Documents 10-21

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

C.M. O'Brien and D.L. Maxwell

Observations for Northeast Arctic saithe (Subareas I and II)

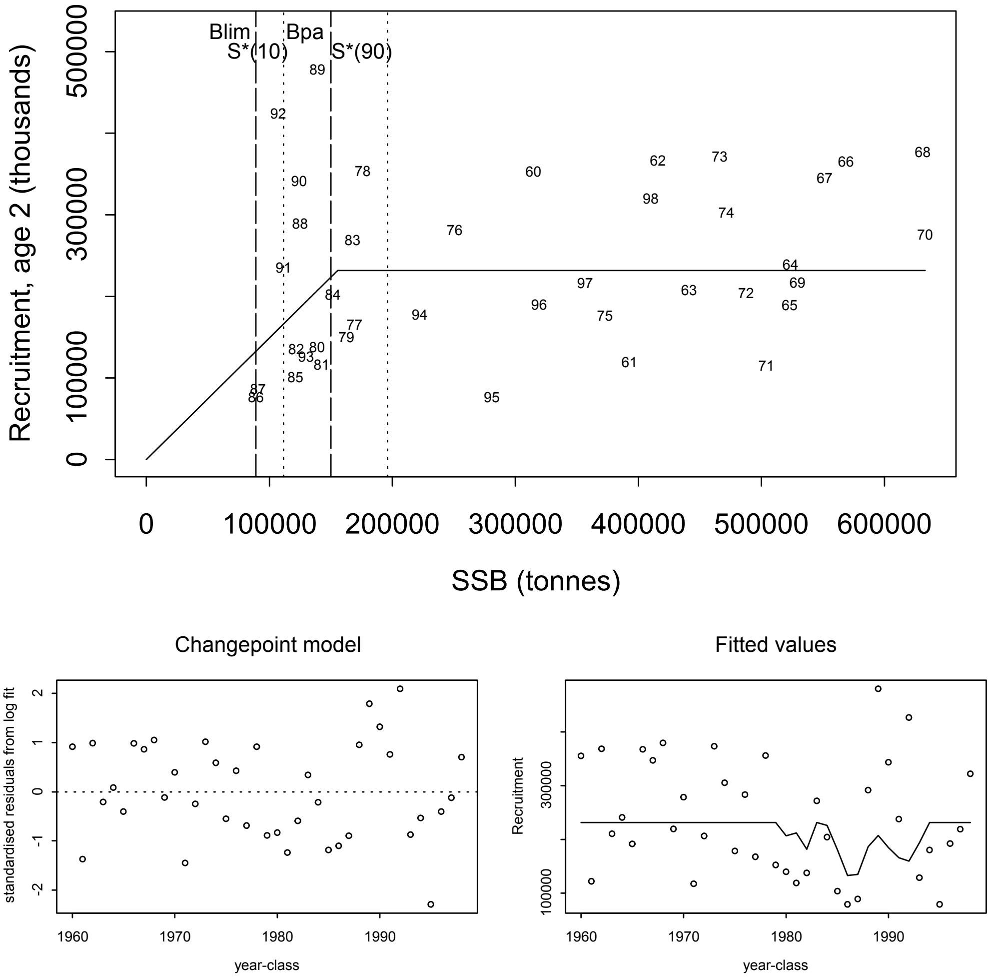
- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 155 398 tonnes
- 80% profile likelihood confidence interval is given by (111 425, 195 998) tonnes
- lower 10% limit of 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.

Changepoint Regression Results

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 p-value
mean	38	9.156				
changepoint	37	8.145	1	1.012	4.60	0.016

Saithe I & II



Panel F

A segmented regression approach to the Precautionary Approach – the case of northern hake

C.M. O'Brien and D.L. Maxwell

Observations for northern hake

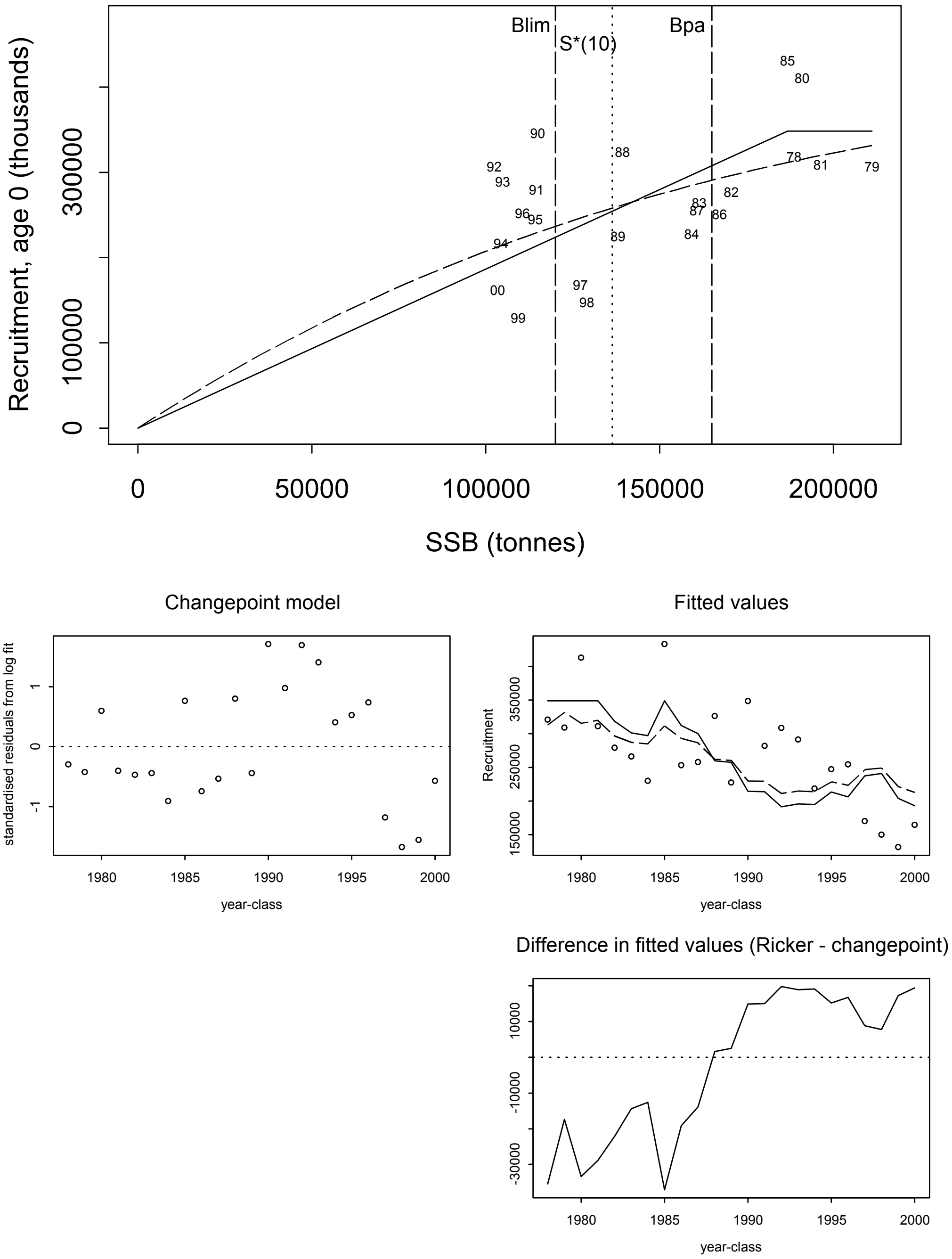
- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 186 782 tonnes
- lower 10% limit of the profile likelihood confidence interval is 136 393 tonnes which is ≈ 14% higher than the current $\mathbf{B}_{\mathrm{lim}}$ of 120 000 tonnes

Changepoint Regression Results

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 p-value**
mean	22	2.00				
changepoint	21	1.68	1	0.321	4.02	0.039

Northern Hake



Panel F

A segmented regression approach to the Precautionary Approach – the case of Northeast Arctic cod (Subareas I and II)

C.M. O'Brien and D.L. Maxwell

Observations for Northeast Arctic cod (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 278 687 tonnes

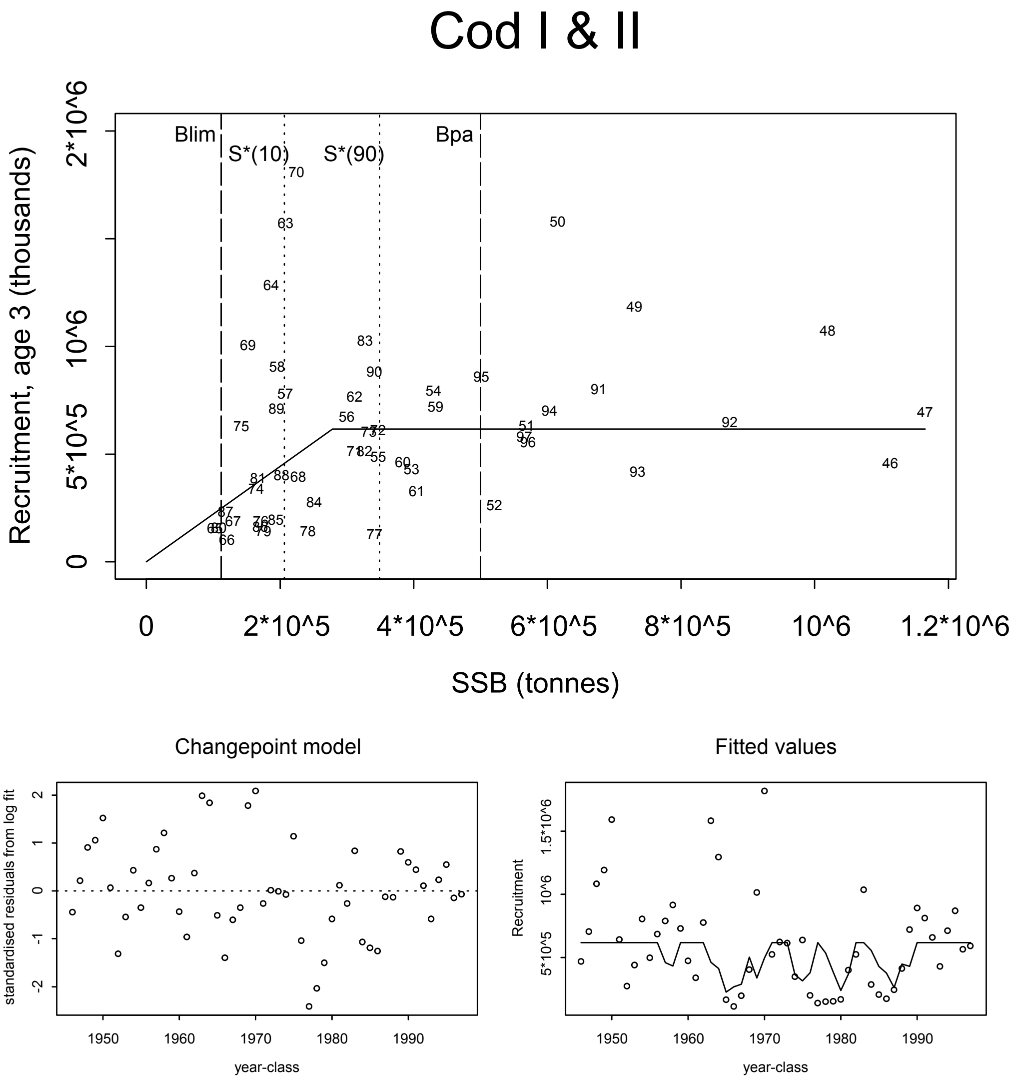
- 80% profile likelihood confidence interval is given by (205 762, 348 858) tonnes

- lower 10% limit of the profile likelihood confidence interval is ≈ 84% higher than the current $\mathbf{B}_{\mathrm{lim}}$ of 112 000 tonnes; whereas the upper 90% limit is ≈ 31% **lower** than the current $\mathbf{B}_{\mathrm{pa}}$ of 500 000 tonnes.

Changepoint Regression Results

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
278687	2.21	616621		205762	280140	348858

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap**
mean	51	24.96				**p-value**
changepoint	50	19.27	1	5.68	14.74	< 0.001


Cod I & II
Blim
S*(10)
S*(90)
Bpa
Recruitment, age 3 (thousands)
SSB (tonnes)
0
2*10^5
4*10^5
6*10^5
8*10^5
10^6
1.2*10^6
5*10^5
2*10^6
Changepoint model
standardised residuals from log fit
year-class
Fitted values
Recruitment
1.5*10^6
1950
1960
1970
1980
1990

Panel F

A segmented regression approach to the Precautionary Approach – the case of cod in Subarea IV, Divisions IIIa and VIId

C.M. O'Brien and D.L. Maxwell

Observations for cod in Subarea IV, Divisions IIIa and VIId

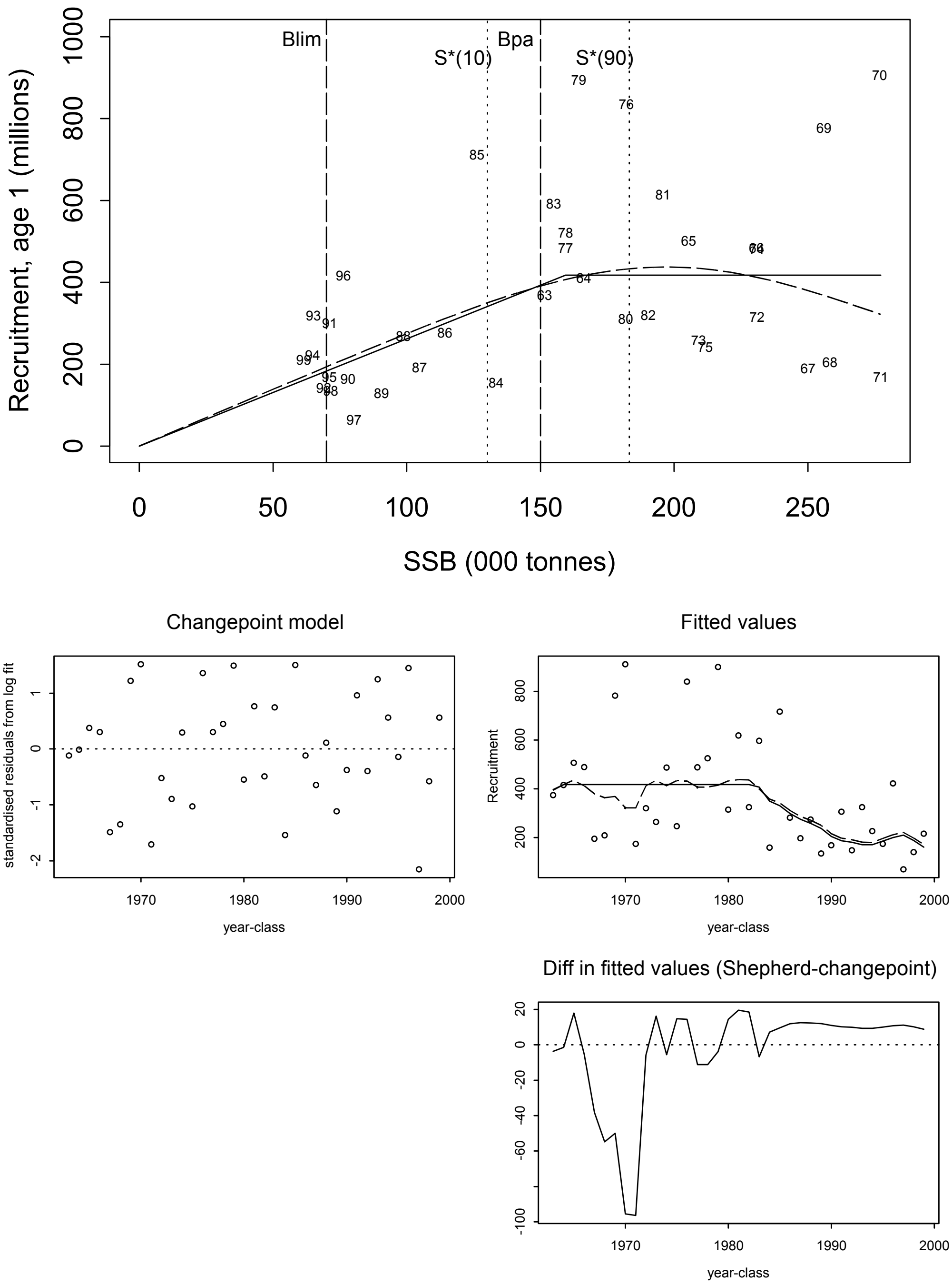
- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 159 349 tonnes
- 80% profile likelihood confidence interval is given by (130 609, 182 972) tonnes
- lower 10% limit of the profile likelihood confidence interval is ≈ 87% higher than the current $\mathbf{B}_{\mathrm{lim}}$ of 70 000 tonnes; whereas the upper 90% limit is ≈ 22% higher than the current $\mathbf{B}_{\mathrm{pa}}$ of 150 000 tonnes.

Changepoint Regression Results

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
159349	2.62	417758		130609	159334	182972

Model	Resid df	RSS	Test df	Sum of sq	F value	Bootstrap
mean	36	13.64				**p-value**
changepoint	35	9.52	1	4.12	15.13	<0.001

Cod IV, IIIa and VIId



Panel F

A segmented regression approach to the Precautionary Approach – the case of cod in Division VIa

C.M. O'Brien and D.L. Maxwell

Observations for cod in Division VIa

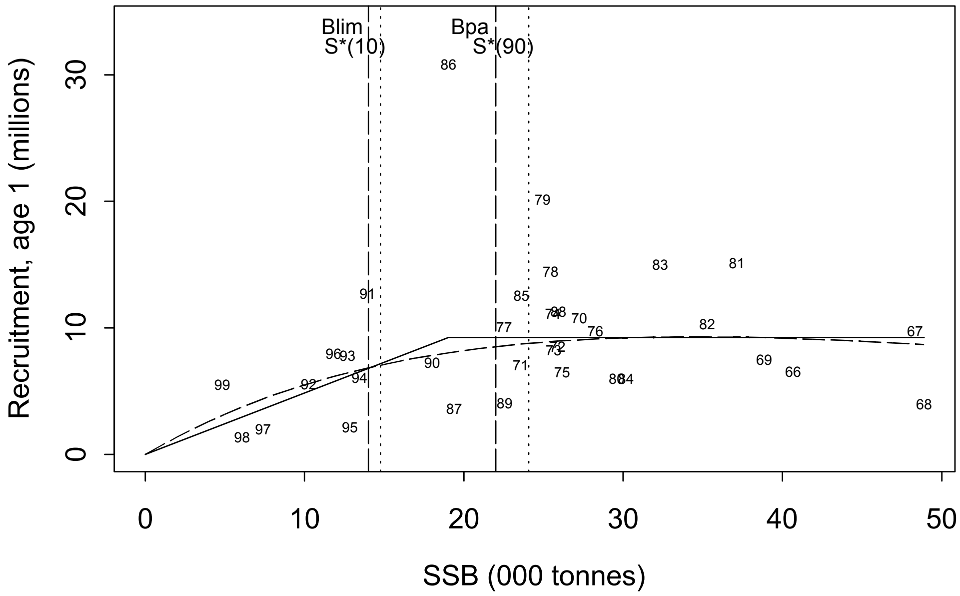
- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 19.04 '000 tonnes
- 80% profile likelihood confidence interval is given by (14.71, 24.25) '000 tonnes
- lower 10% limit of the profile likelihood confidence interval is ≈ 5% higher than the current $\mathbf{B}_{lim}$ of 14 000 tonnes; whereas the upper 90% limit is ≈ 10% higher than the current $\mathbf{B}_{pa}$ of 22 000 tonnes.

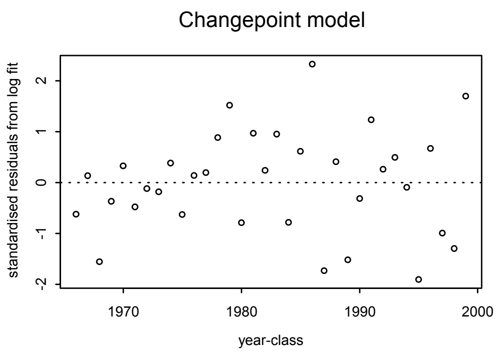
Changepoint Regression Results

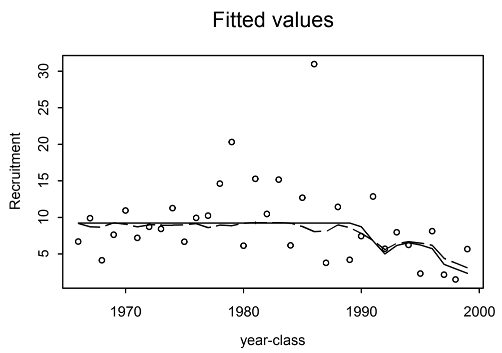
From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
19.04	0.485	9.24		14.71	19.05	24.25

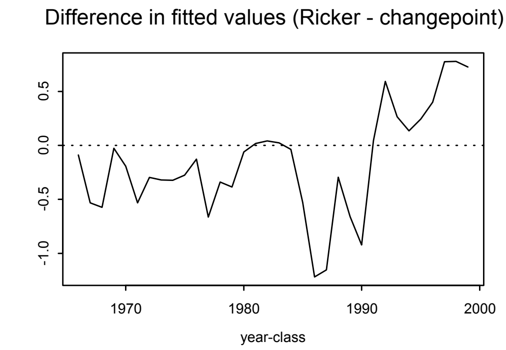
Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap**
mean	33	12.91				**p-value**
changepoint	32	8.92	1	3.99	14.32	< 0.001

Cod VIa









Panel F

A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIa

C.M. O'Brien and D.L. Maxwell

Observations for cod in Division VIIa

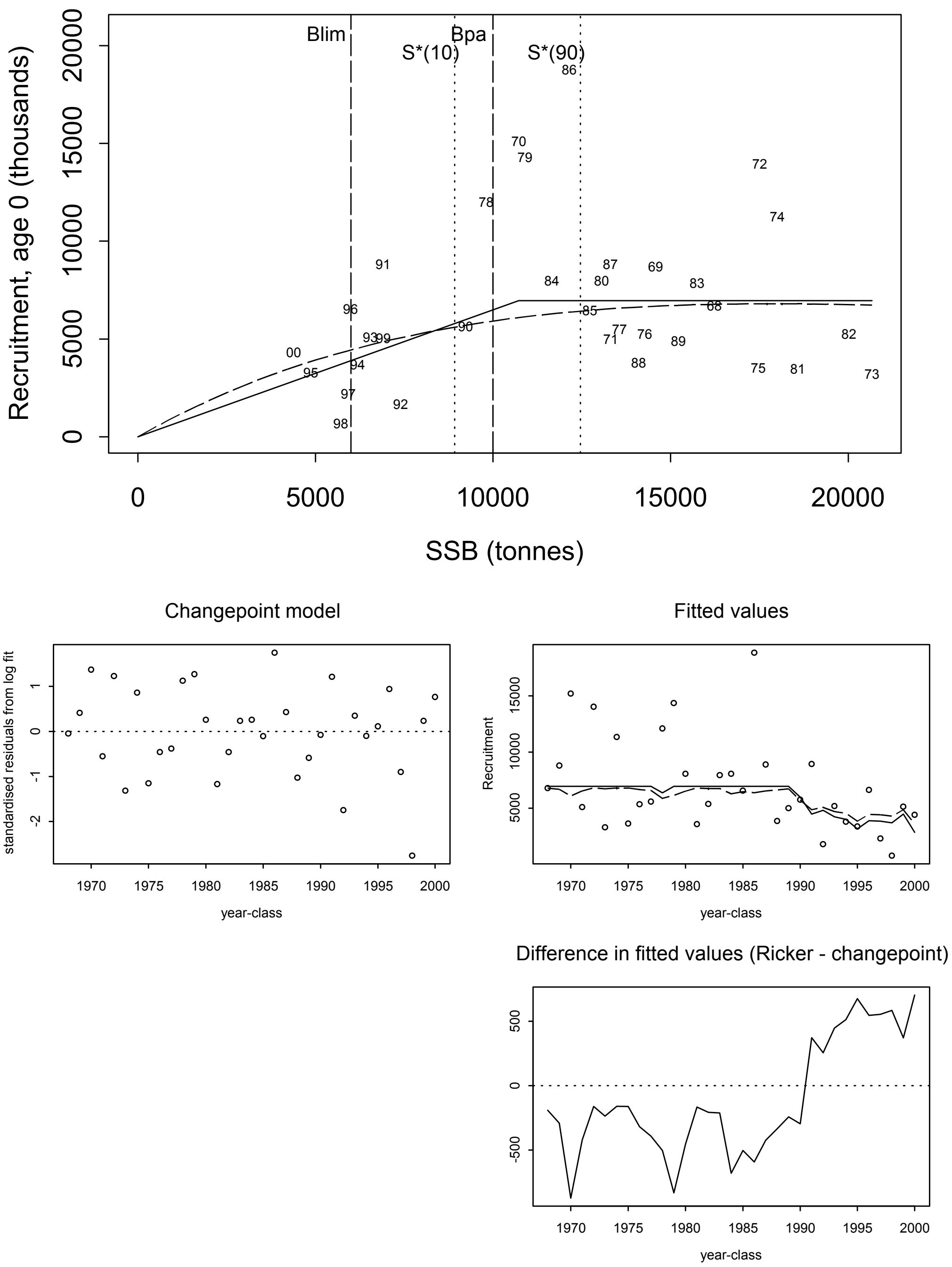
- segmented regression fit is statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 10 719 tonnes
- 80% profile likelihood confidence interval is given by (8 918, 12 458) tonnes
- lower 10% limit of the profile likelihood confidence interval is ≈ 49% higher than the current $\mathbf{B}_{lim}$ of 6 000 tonnes; whereas the upper 90% limit is ≈ 25% higher than the current $\mathbf{B}_{pa}$ of 10 000 tonnes.

Changepoint Regression Results

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
10719	0.649	6959.4		8918	10729	12458

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap**
mean	32	13.74				**p-value**
changepoint	31	10.38	1	3.365	10.05	0.003

Cod VIIa



Panel F

A segmented regression approach to the Precautionary Approach – the case of cod in Division VIIe-k

C.M. O'Brien and D.L. Maxwell

Observations for cod in Division VIIe-k

- 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 13 525 tonnes

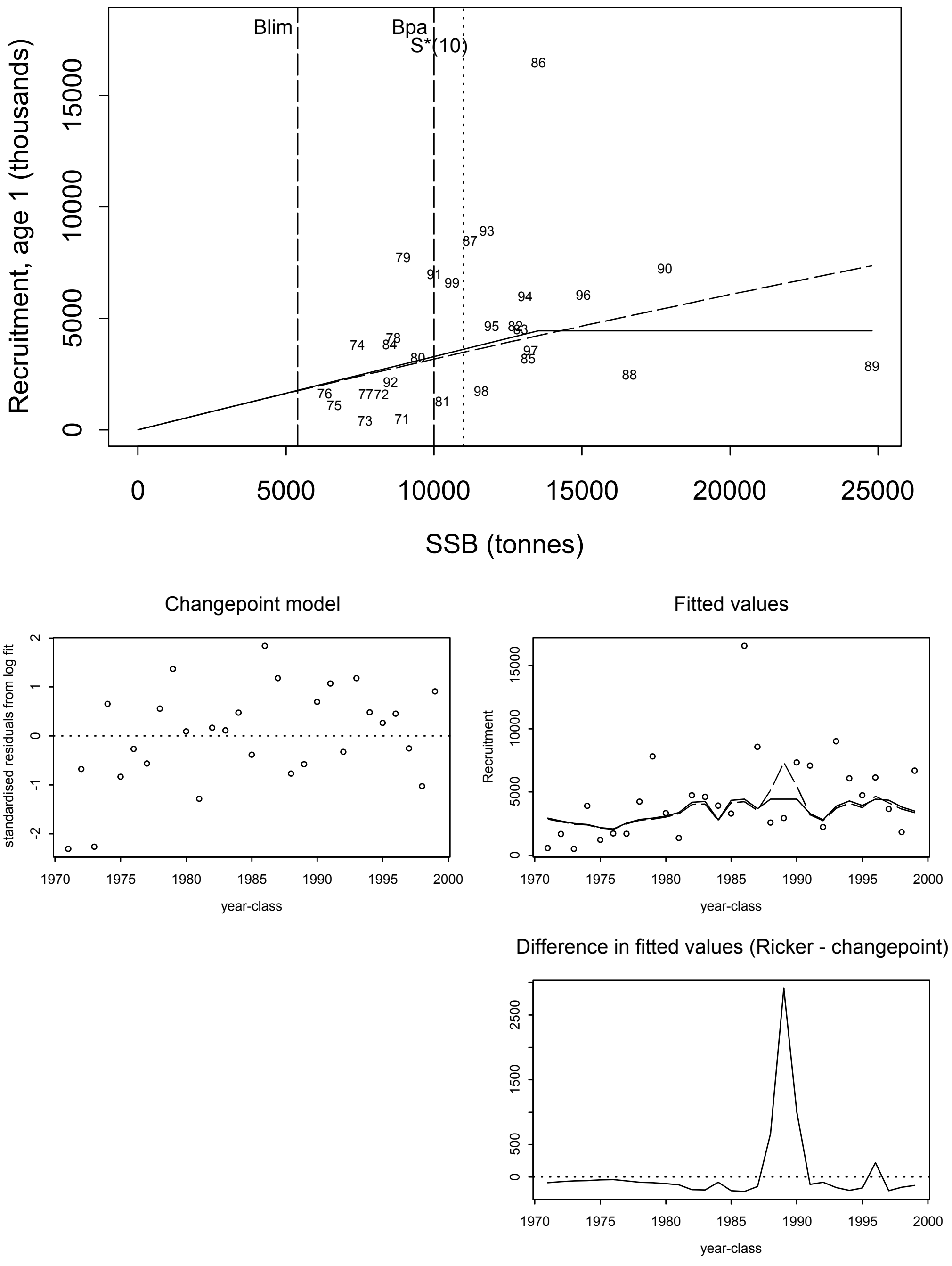
- lower S*(10) limit of the profile likelihood confidence interval is 10 992 tonnes which is ≈ 103% higher than the current $\mathbf{B}_{\text{lim}}$ of 5 400 tonnes

Changepoint Regression Results

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
13525	0.328	4442		10992	13525	undefined

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap p-value**
mean	28	18.63				
changepoint	27	14.27	1	4.36	8.24	0.007

Cod VIIe-k



Panel F

A segmented regression approach to the Precautionary Approach – the case of plaice in Division IIIa

C.M. O'Brien and D.L. Maxwell

Observations for plaice in Division IIIa

- segmented regression fit is **not** statistically significant at the 5% level of significance

- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is at or below the $\mathbf{B}_{loss}$ of 23 189 tonnes (1989 year-class)

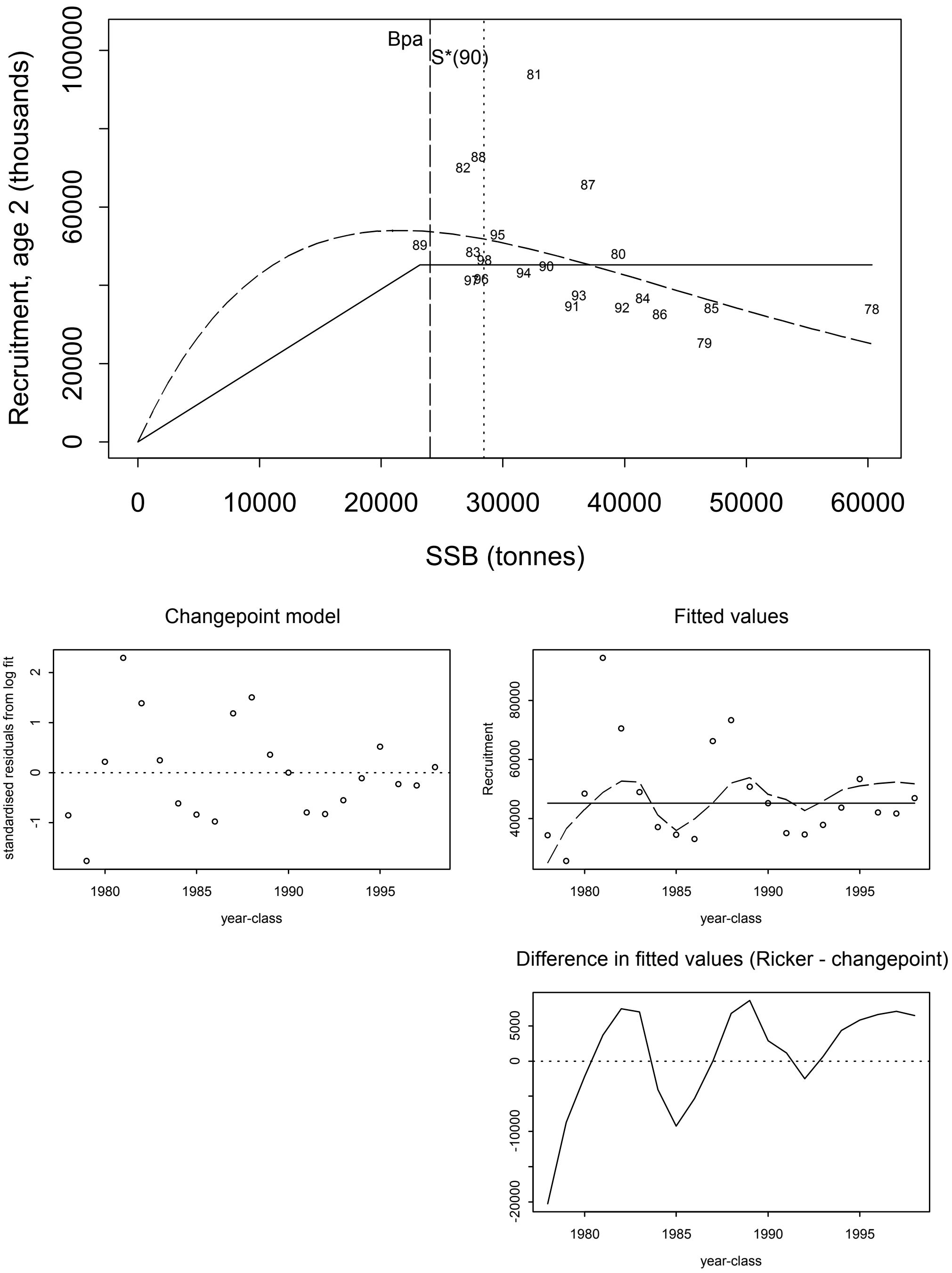
- upper S*(90) limit of the profile likelihood confidence interval is 28 439 tonnes which is ≈ 18% higher than the current $\mathbf{B}_{pa}$ of 24 000 tonnes

Changepoint Regression Results

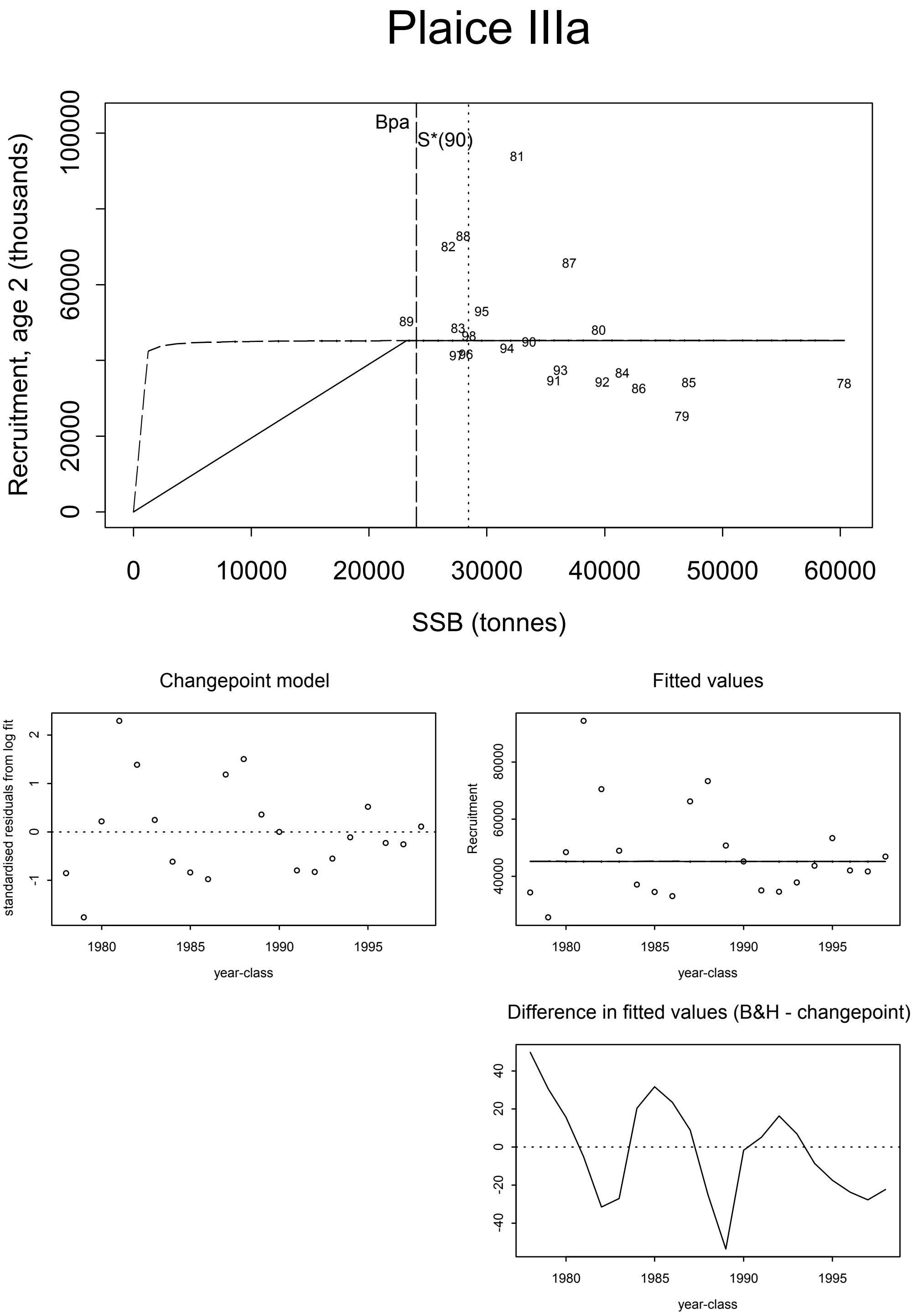
From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
≤ 23189	≥ 1.952	45256		not defined	≤23189	28439

Model	Resid df	RSS	Test df	Sum of sq	F value	Bootstrap
mean	20	1.947				**p-value**
changepoint	19	1.947	1	0	0	1

Plaice IIIa



Panel F(a)



Plaice IIIa
Recruitment, age 2 (thousands)
SSB (tonnes)
Bpa
S*(90)
Changepoint model
standardised residuals from log fit
year-class
Fitted values
Recruitment
year-class
Difference in fitted values (B&H - changepoint)
year-class

Panel F(b)

A segmented regression approach to the Precautionary Approach – the case of herring in Subarea IV, Divisions IIIa and VIId

C.M. O'Brien, D.L. Maxwell and B.A. Roel

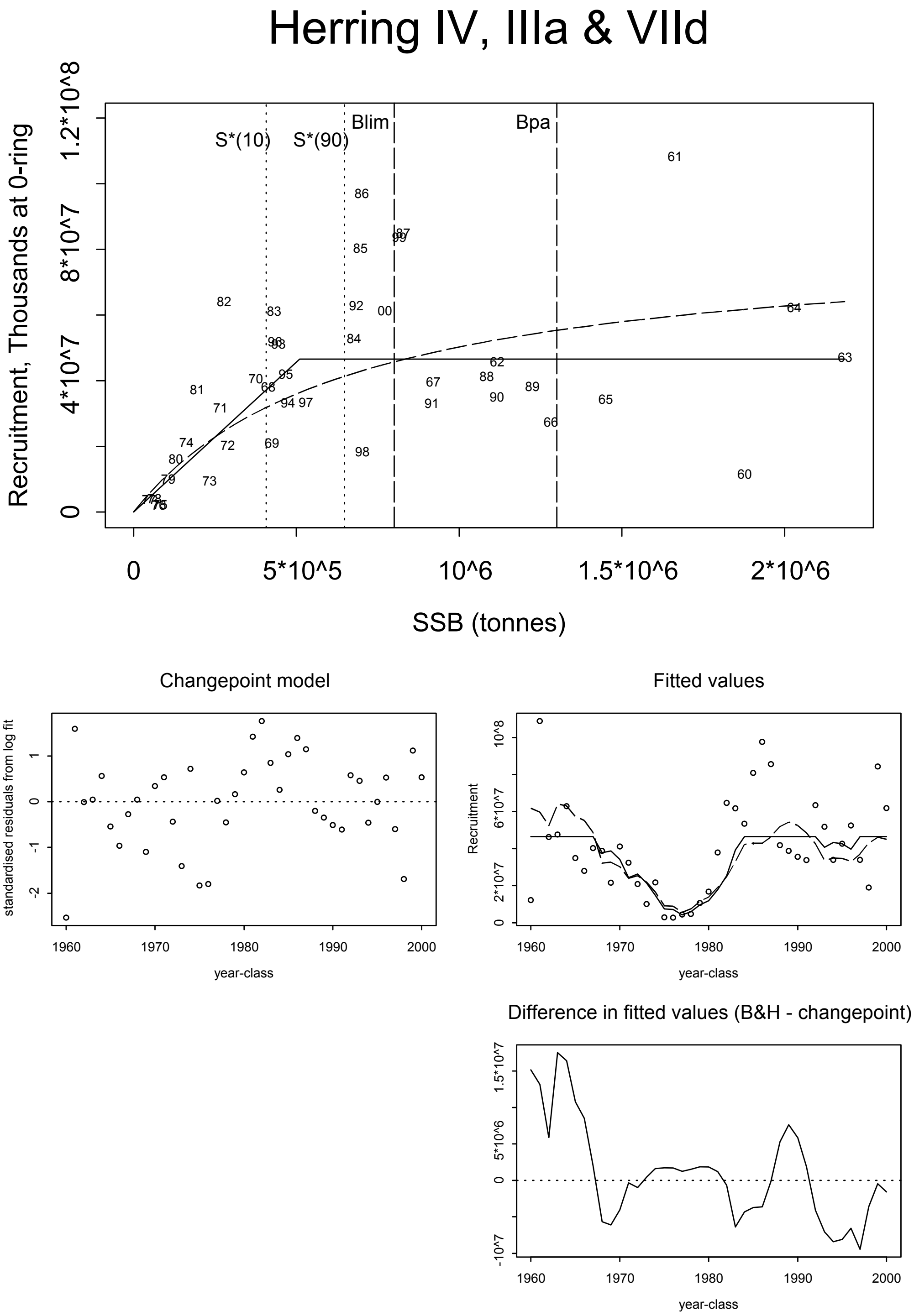
Observations for herring in Subarea IV, Divisions IIIa and VIId

- 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 509 609 tonnes
- 80% profile likelihood confidence interval is given by (406 960, 647 290) tonnes
- comparison of S*(10) with $\mathbf{B}_{lim}$ (800 000 tonnes) and S*(90) with $\mathbf{B}_{pa}$ (1.3 million tonnes) is uninformative given the way in which the biomass reference points have been identified for this stock as **part of a harvest control** based on simulations (HAWG ???).

Changepoint Regression Results

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
509609	91.33	46543672		406960	512405	647290

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap p-value**
mean	40	33.64				
changepoint	39	11.02	1	22.627	80.10	< 0.001


Herring IV, IIIa & VIId
Recruitment, Thousands at 0-ring
SSB (tonnes)
S*(10)
S*(90)
Blim
Bpa
Changepoint model
standardised residuals from log fit
year-class
Fitted values
Recruitment
year-class
Difference in fitted values (B&H - changepoint)
year-class

Panel F

A segmented regression approach to the Precautionary Approach – the case of the Thames Estuary (or Blackwater) herring

C.M. O'Brien, D.L. Maxwell, B.A. Roel and M. Basson

Observations for the Thames Estuary herring

- segmented regression fit is **not** statistically significant at the 5% level of significance

- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 82.5 tonnes

However, for this stock the shape of the Thames Estuary herring stock-recruitment (S-R) curve is determined by density-dependent mechanisms acting at a life-history stage after hatching (Fox 2001). A parametric stock-recruitment model based on the Ricker curve has previously been proposed for this stock.

Fitting a Ricker S-R curve gives an estimate of the spawning stock biomass at which recruitment is impaired of 275 tonnes. Bootstrapping the estimation of the maximum of the Ricker S-R curve by re-sampling S-R pairs reveals that the adopted $\mathbf{B}_{\mathrm{lim}}$ of 250 tonnes corresponds to the first quartile of the empirical distribution of that maximum statistic, whilst the $\mathbf{B}_{\mathrm{pa}}$ of 410 tonnes is situated above the 99th percentile.

Changepoint Regression Results

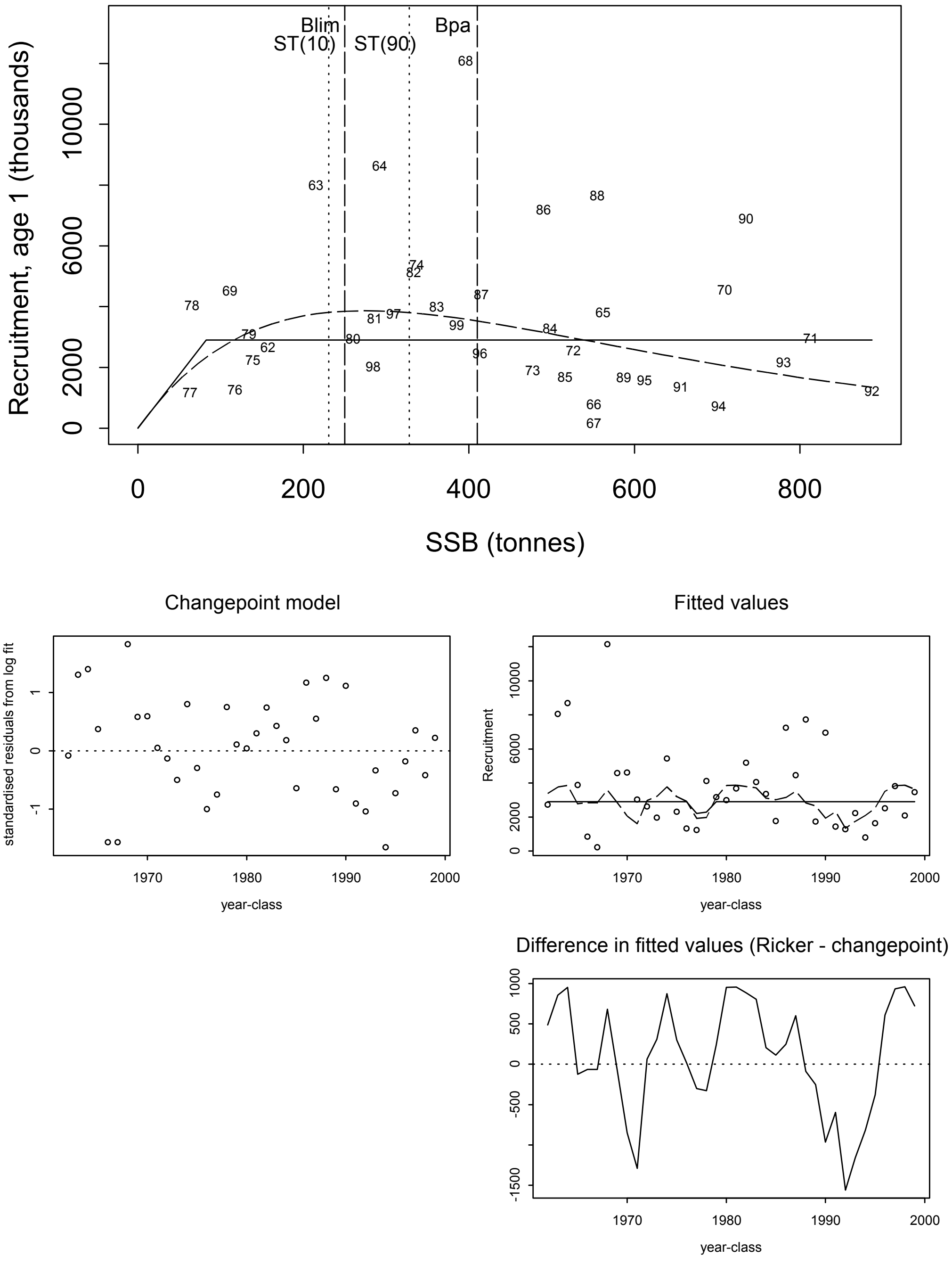
From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
82.5	35.2	2901		not defined	82.7	168.1

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap p-value**
mean	37	22.26				
changepoint	36	22.10	1	0.159	0.260	0.284

Turning point estimates for Ricker stock-recruitment model

Estimate of SSB at Turning point , S_T		**Percentiles for turning point from bootstrap**		
S_T		**$S_T(10)$**	**$S_T(50)$**	**$S_T(90)$**
274.9		230.8	275.2	327.9

Thames Estuary Herring



Panel F

A segmented regression approach to the Precautionary Approach – the case of Northeast Atlantic mackerel

C.M. O'Brien and D.L. Maxwell

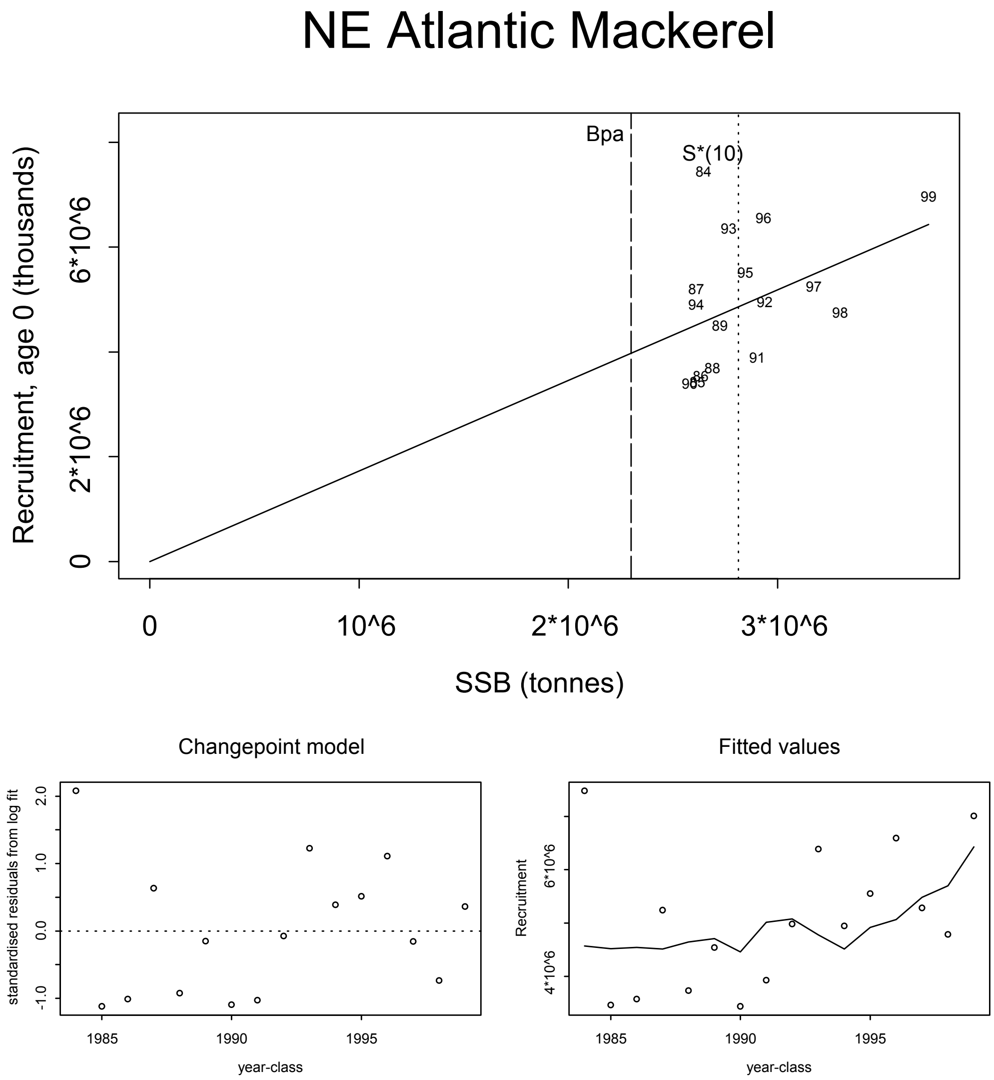
Observations for Northeast Atlantic mackerel

- segmented regression fit is only just **not** statistically significant at the 5% level of significance
- maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is at or above the B_{hoss} of 3 722 444 tonnes (1999 year-class)
- lower S*(10) limit of the profile likelihood confidence interval is 2 813 396 tonnes which is ≈ 22% higher than the current $\mathbf{B}_{pa}$ of 2 300 000 tonnes

Changepoint Regression Results

From algorithm in Julious (2001)				From search on 500x500 grid		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
≥3722444	1.728	≥6430535		2813396	≥3722444	not defined

Model	Resid df	RSS	Test df	Sum of sq	F value	Bootstrap
mean	15	0.965				**p-value**
changepoint	14	0.785	1	0.180	3.204	0.065


NE Atlantic Mackerel
Bpa
S*(10)
Recruitment, age 0 (thousands)
SSB (tonnes)
Changepoint model
standardised residuals from log fit
year-class
Fitted values
Recruitment
year-class

Panel F

A segmented regression approach to the Precautionary Approach – the cases of anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa)

C.M. O'Brien and D.L. Maxwell

Observations for anchovy in the Bay of Biscay, plaice (IV, VIIa, VIId), sole (IV, VIIa, VIId) and whiting (VIa)

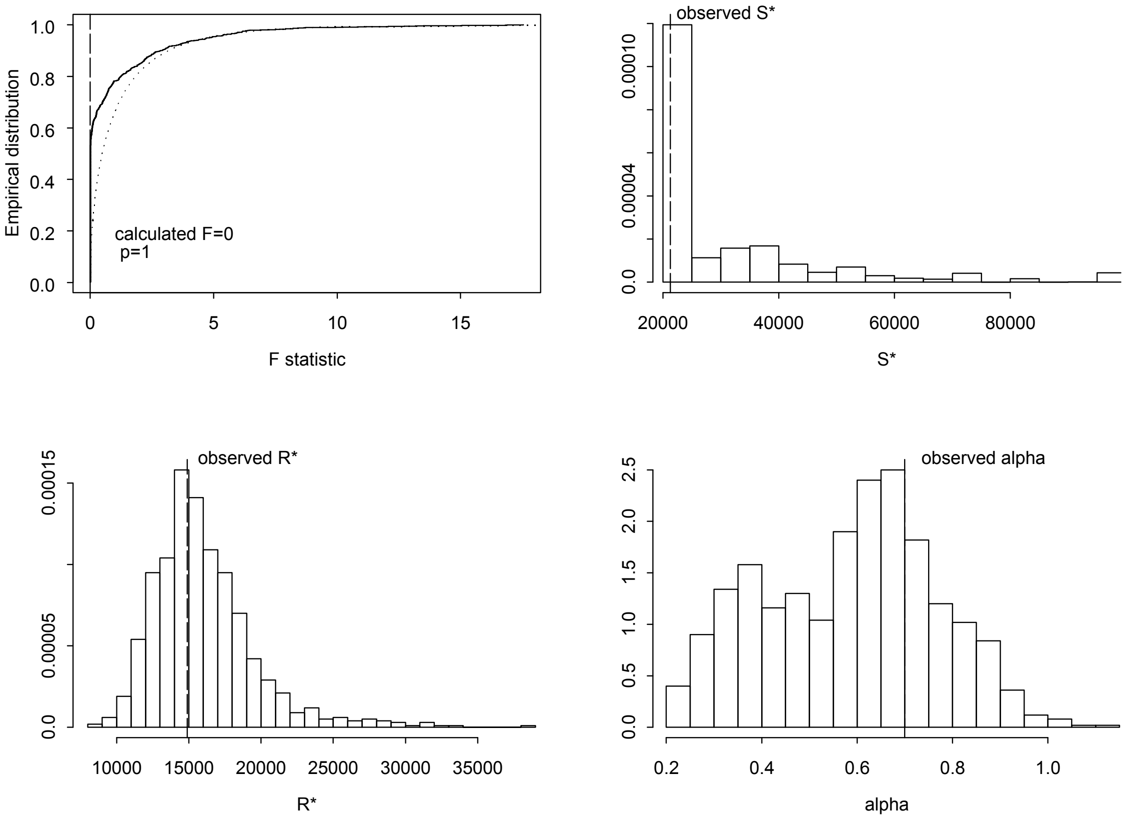
Below are bootstrap distributions comparing the change-point regression to the geometric mean for the following stocks:

- Anchovy VIII (Bay of Biscay)
- Plaice IV (North Sea)
- Plaice VIIa (Irish Sea)
- Plaice VIId (Eastern Channel)
- Sole IV (North Sea)
- Sole VIIa (Irish Sea)
- Sole VIId (Eastern Channel)
- Whiting VIa (West of Scotland)

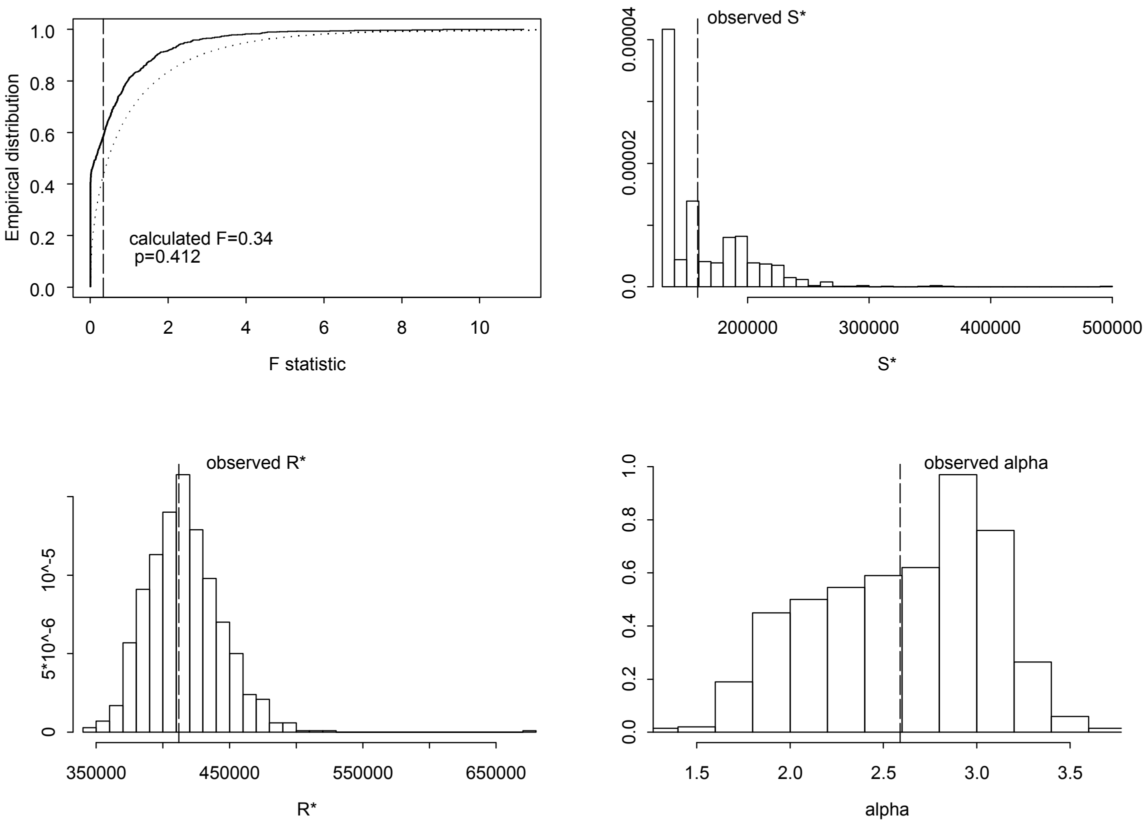
There is no statistically significant evidence (at the 5% level) for the change-point regression for any of these stocks, i.e. the statistical fits do not indicate that recruitment is significantly impaired for any of the observed SSBs.

Note: If p=1 then $S^* \leq \mathbf{B}_{loss}$. If p<1 then $S^* > \mathbf{B}_{loss}$.

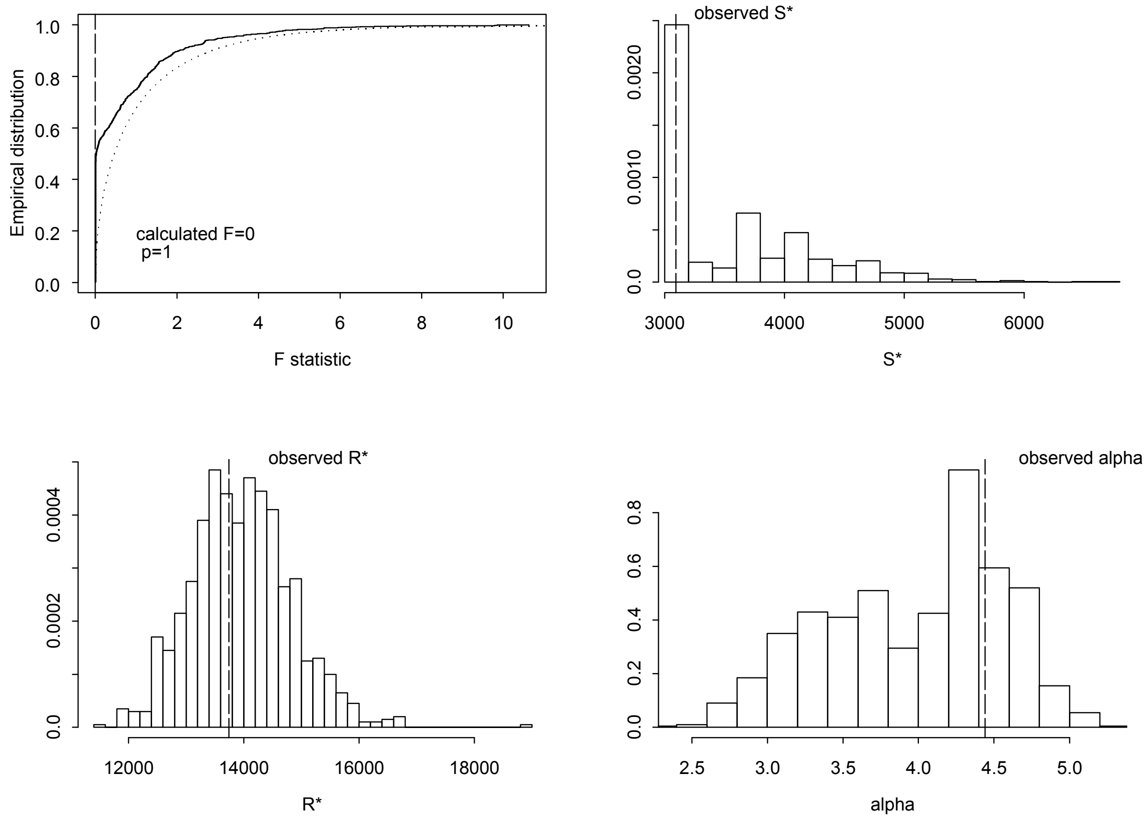
Anchovy Bay of Biscay. Bootstrap F and parameter distributions under H0.



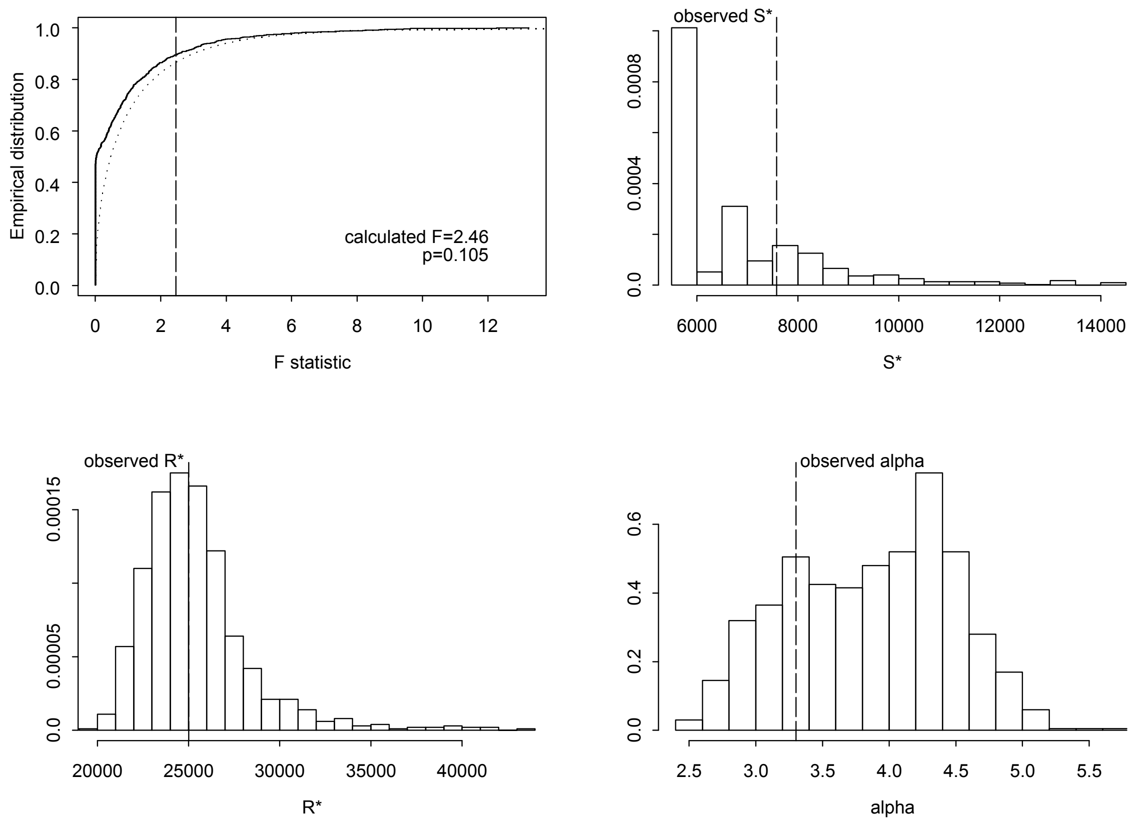
Plaice IV Bootstrap F and parameter distributions under H0.



Plaice VIIa Bootstrap F and parameter distributions under H0.



Plaice VIId Bootstrap F and parameter distributions under H0.



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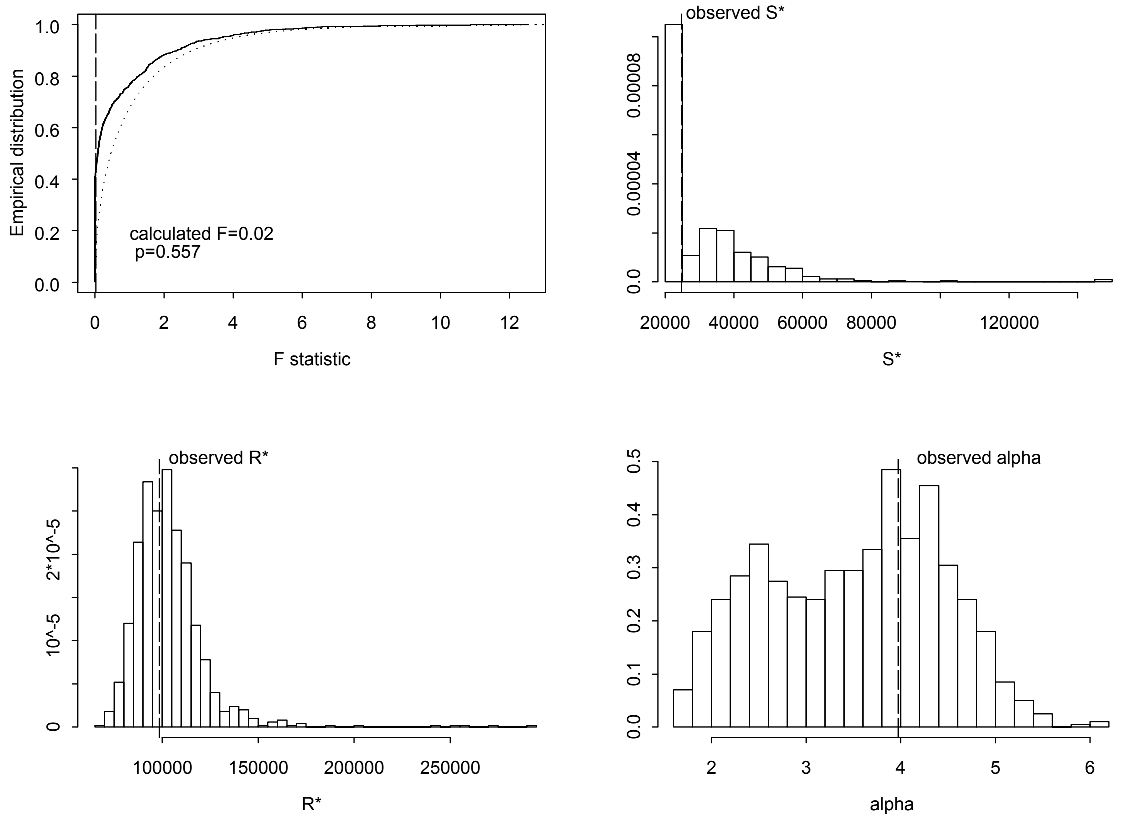
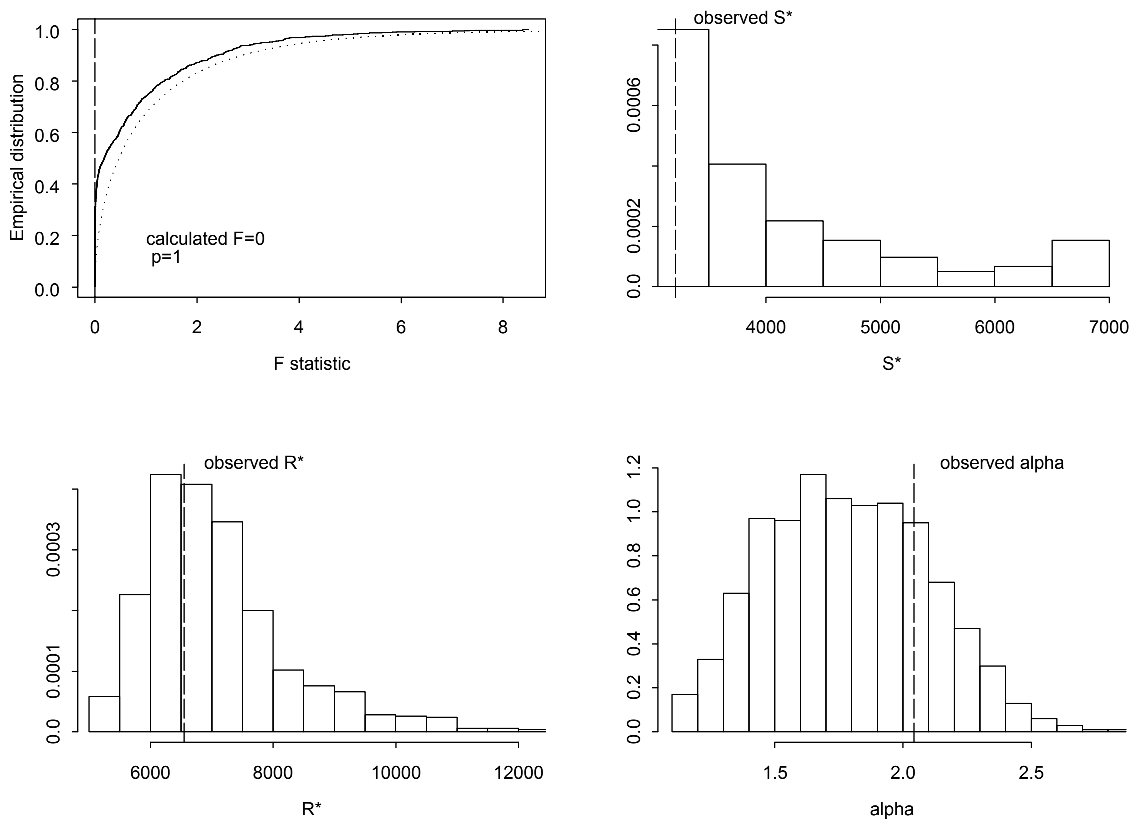
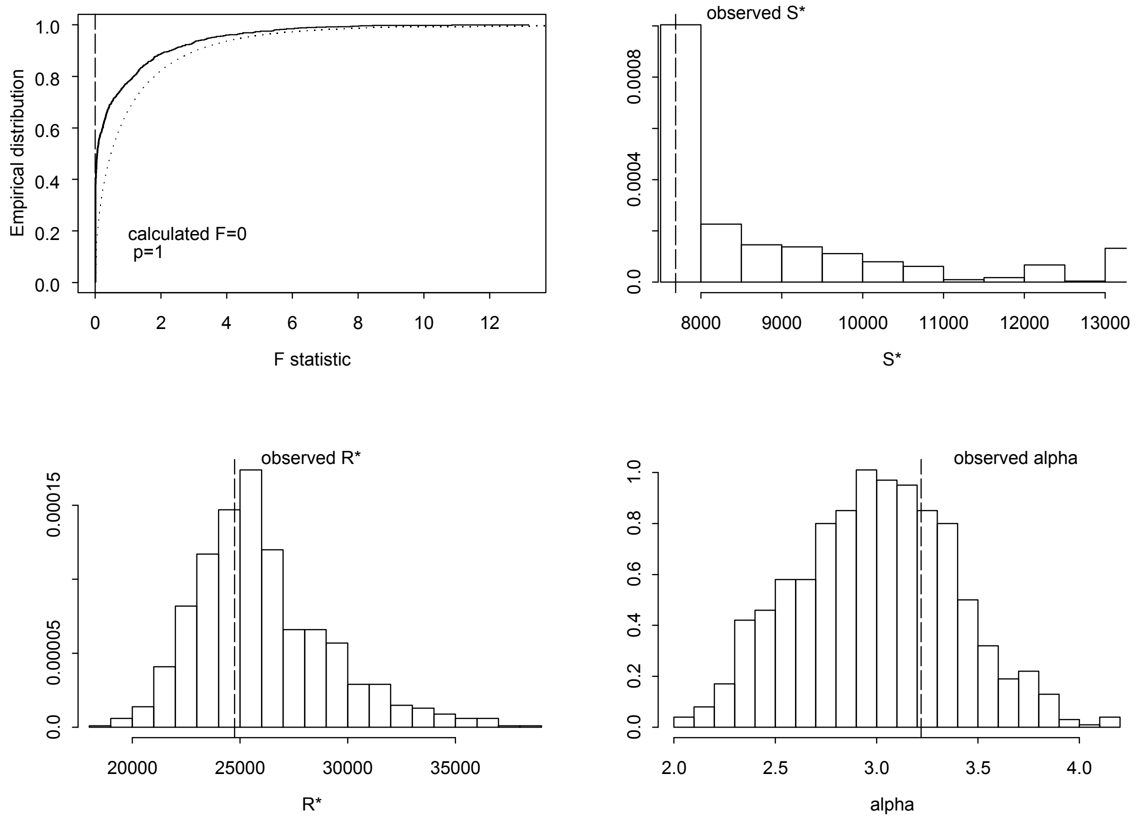


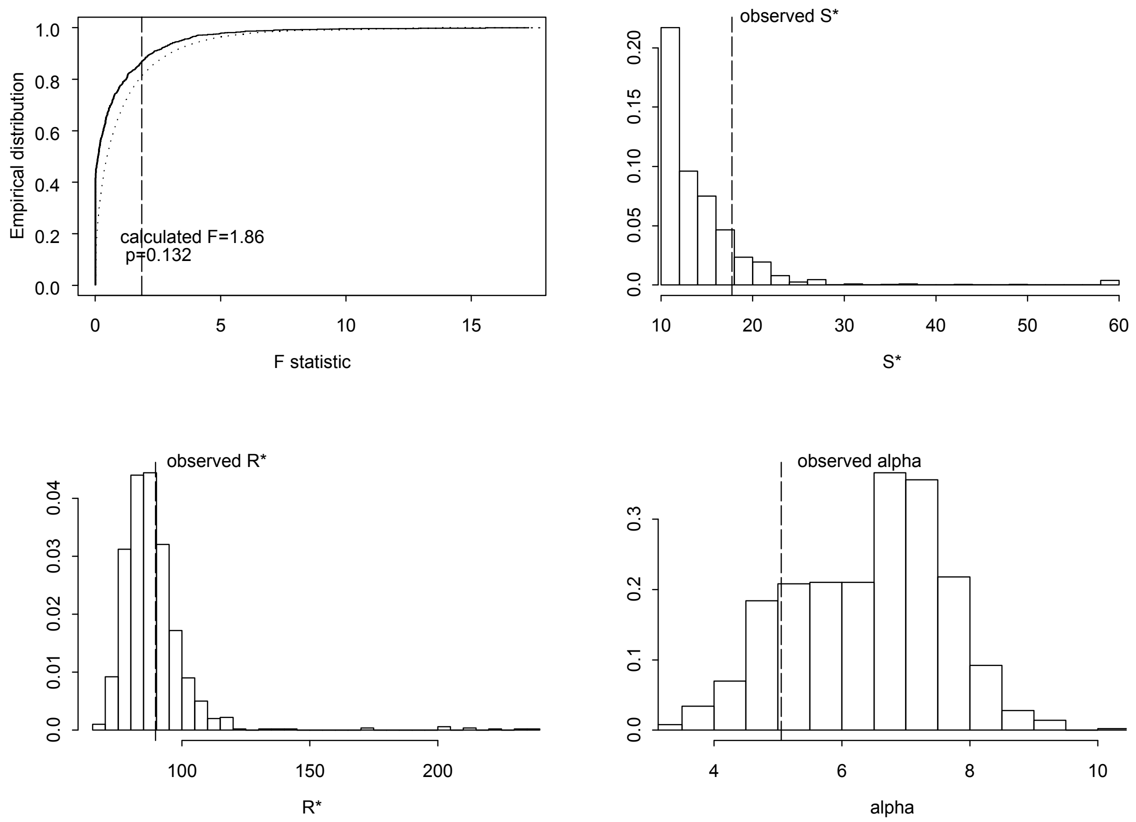
Sole VIIa Bootstrap F and parameter distributions under H0.



Sole VIId Bootstrap F and parameter distributions under H0.



Whiting VIa Bootstrap F and parameter distributions under H0.



ANNEX 5

Working Document 5

INCORPORATING AGE DIVERSITY INDEX AND TEMPERATURE IN THE STOCK-RECRUITMENT RELATIONSHIP OF NORTHEAST ARCTIC COD

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ABSTRACT

A novel model that incorporates an age diversity index for Northeast Arctic cod from the spawning grounds and temperature from the Kola section during August to December is developed to analyse the stock-recruitment relationship. We demonstrate that such a model:

$$R = a * ssb * EXP^{-b*ssb} * EXP^{c*H+d*T}$$

where R=recruits, ssb=spawning stock biomass, H=diversity index and T=temperature

accounts for 70% of the variation in the Northeast Arctic cod recruitment after 1970. This is a considerable improvement over the traditional Ricker Model (coefficient of determination R^2 =0.33). This model can be also used for prediction purposes based on climate forecast.

Materials And Methods

Data on the number of recruits and the spawning stock biomass were taken from the last report of the ICES Arctic Fisheries Working Group (ICES, 2001). Monthly temperature data from August to December were taken from a series of measurements from the Kola section in the Barents Sea during the period 1971-1995. The average temperature over the months of August-December (Fig. 5) was selected because this represents the first feeding period for 0-group cod in the Barents Sea. This coincides with the peak abundance of zooplankton during summer and early autumn, which represents the primary food source for 0-group cod. According to Ponomarenko (1983), the survival rates of the 0-group are mainly dependent on the condition (length, weight, condition factor and stomach fullness) of the fingerlings, the temperature of the first winter season, and the euphausiid abundance. However, trials indicate that the results are not very sensitive to the choice of temperature period within the year of spawning.

The diversity of the age structure of the spawning stock each year according to commercial sampling data from the Lofoten Islands is estimated using a Shannon diversity index (Magurran, 1988).

$$H = -\sum_{i=1}^{k} p_i \ln p_i$$

where p_i is the proportional abundance of age *i* and *k*=number of age groups.

Ricker (1975) proposed a functional form between the number of recruits and the spawning biomass, which is commonly used:

$$R = a * ssb * EXP^{-b*ssb} \qquad (1)$$

where a and b are parameters, R is the recruits and SSB is the spawning stock biomass. Following Stocker et al. (1985) one can extend the Ricker model to include an environmental factor, in this case temperature:

$$R = a * ssb * EXP^{-b*ssb} * EXP^{d*T} \qquad (2)$$

The above model can be extended further to include age diversity of the spawning stock and the final model becomes:

$$R = a * ssb * EXP^{-b*ssb} * EXP^{c*H+d*T} \qquad (3)$$

The parameter values (a, b, c and d) of the equation (3) were estimated using a non-linear least squares regression (SAS, 1993)

Results And Discussion

Spawning stock biomass and numbers of recruits at age 3 in the period 1946-1995 are given in Figure 1. A first trial with the model applied to the whole time-series showed that the model failed to predict the strong year classes 1963, 1964 and 1970 (Fig. 2). The fit in general seemed to improve after 1970 and applying the model only to the period 1971-1995 gave a much better fit. The analysis is restricted to this period.

Comparing the two periods, 1946-1970 is characterized by high level of recruitments and SSB, with overall means of 759 mill. and 419 000 t, respectively, and 1971-1996 with a low level both for recruits and SSB; 484 mill. and 339 000 t, respectively. In addition, the later period is characterized by a high rate of stock decline, a sustained period of very low temperatures from 1977 to 1982, the longest cold period since 1920 (Sætersdal and Loeng, 1983), and two collapses of the Barents Sea capelin stock (Gjøsæter, 1998) with severe implications for cod growth and cannibalism (Nakken, 1994).

The statistical relationship between SSB, age diversity and temperature is measured by the correlation coefficient. The text table below shows the correlation matrix of recruits to the SSB, the age diversity index H and T, the average temperature during August to December.

	SSB	H	T
Recruits	0.4879	-0.3971	0.6575

Positive and strong correlation between the recruits and the temperature is observed during the entire period (Fig. 3). In contrast, the age diversity index is negatively correlated with number of recruits (Fig. 4). A non-linear regression based on spawning stock biomass, diversity index and average temperature explained 70% of the observed variance of the recruits during 1971-1995. Spawning stock biomass alone explained 33%, but 67% of the variance was explained by adding the temperature (Table 1). Hence, only the remaining 3% was explained by adding the diversity index.

The diversity index generally increases with increasing number of age groups in the spawning stock. Since 1946, the tendency has been that fewer age groups have contributed to the spawning stock and the diversity index shows a declining trend (Fig. 6). The negative relationship indicates that the recruitment will increase with decreasing age diversity of the spawning stock. Although the effect is rather small and possibly not statistically significant, this result does not support the expectation that multiple spawners give more recruits because of higher egg survival (Marshall et al., 1998, 1999).

Observed and estimated recruits based on equation (3) are compared in Fig. 7. The model fit is very close for the strong year classes, except for 1995, and the largest deviations between observed and predicted value occur for some of the smallest year classes.

The stock-recruitment relationship of the Northeast Arctic cod is very important in management considerations, and in particular the biological biomass reference points are currently debated. However, the model has so far not included environmental factors or age diversity of the spawners. In the present study, a strong link between temperature and recruits at age 3 is evident. Including temperature in the model improves the stock-recruitment relationship, which for this period (1971-1995) is relatively strong (Fig. 8).

In evaluating biological reference points for this stock, the crucial question is whether the period after 1970 represents a regime that is different from the previous one and therefore more relevant to the present situation. The cold periods and capelin collapses referred to above may be indications of a regime shift. Another, perhaps additional explanation could be the observation of Ottersen et al. (1994) who concluded that with a reduction in the age distribution of the spawners, the recruitment of Northeast Arctic cod becomes more sensitive to changing environmental conditions. Because the reduction in the age distribution of the spawners is linked to the high level of exploitation, the high fishing mortalities in the recent period could therefore also have contributed to a change.

The possibility of predicting recruitment is still restricted by the lack of reliable temperature forecasts, and in the case of Northeast Arctic cod the usefulness of a prediction is also limited because of the relatively late age of recruitment to the fisheries. However, in medium-term forecasts the relationship implied by the model could be used to generate more realistic scenarios.

Acknowlegment

Thanks to John Alvsvåg for his help in a setting up a SAS program to estimate diversity index for the period 1932-2000.

References

ICES 2001. Report of the Arctic Fisheries Working Group. ICES CM 2001/ACFM :19.

Gjøsæter, H. 1998. The population biology and exploitation of capelin (*Mallotus villosus*) in the Barents Sea. Sarsia 83:453-496.

Magurran, A. E. 1988. Ecological diversity and its measurement. Chapman & Hall, London, PP:179.

Marshall, T., Kjesbu, O.,Yaragina, N., Solemdal, P. and Ulltang, Ø. 1998. Is spawner biomass a sensitive measure of the reproductive and recruitment potential of Notheast Arctic cod? Can. J. Fish. Aquat. Sci.55:1766-1783.

Marshall, T., Kjesbu, O., Thorsen, A. and Solemdal, P. 1999. Spawner quality effects on two measures of reproductive potential: have we been counting our eggs before they've hatched. ICES C.M 1999/Y:07.

Nakken, O. 1994. Causes of trends and fluctuations in the Arcto-Norwegian cod stock. ICES mar.Sci.Symp.,198 :212-228.

Ottersen, G., Loeng, H. and Raknes, A. 1994. Influence of temperature variability on recruitment of cod in the Barents Sea. ICES Mar. Sci. Symp.198 :471-481.

Panomarenko, I. Ya. 1983. Survival of bottom–dwelling young cod in the Barents Sea and factors determining it. Proceedings of Soviet-Norwegian Symposium. Leningrad: 213-229.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish population. Bull. Fish. Res. Board Can. Bull. 191.

SAS Institute Inc. 1993. SAS/ETS Users Guide, V6, PP: 1022.

Stocker , M., Haist, V. and Fournier, D. 1985. Environmental variation and recruitment of Pacific herring in the Strait of Georgia. Can. J. Aquat. Sci. 42:174-180.

Sætersdal, G. and Loeng, H. 1983. Ecological adaptation of reproduction in Arctic cod. Proceedings of Soviet-Norwegian Symposium. Leningrad: 13-34.

Table 1. Nonlinear parameters estimate.

Model	a	b	d	c	R^2
$R = a * ssb * EXP^{-b*ssb}$	2.6888	1.469E-6			0.339
$R = a * ssb * EXP^{-b*ssb} * EXP^{d*T}$	0.0824	1.698E-6	0.757		0.679
$R = a * ssb * EXP^{-b*ssb} * EXP^{c*H+d*T}$	0.0248	1.489E-6	0.294	0.905	0.704

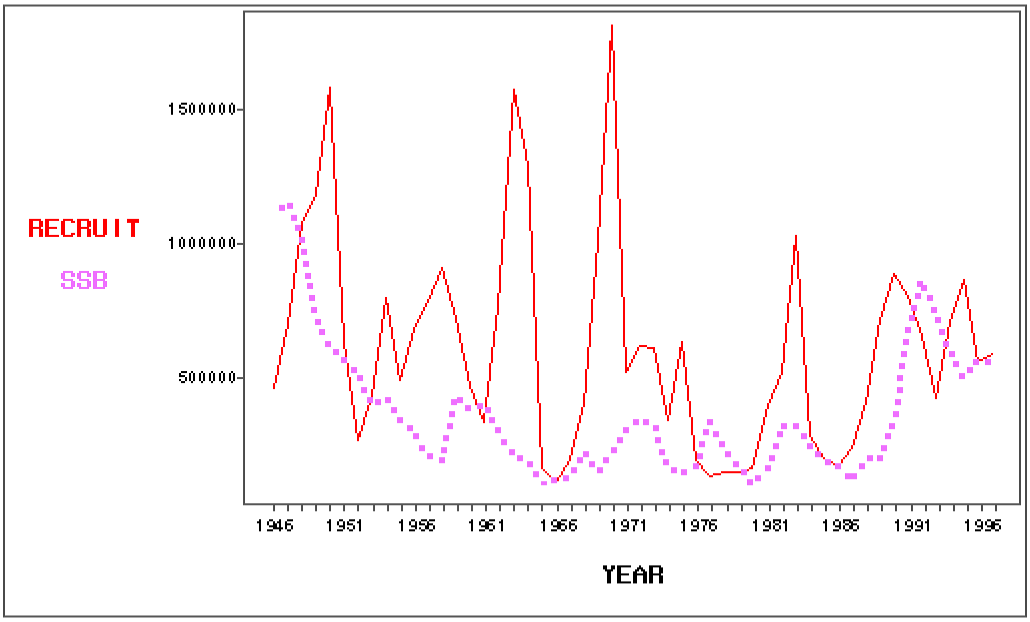

Figure 1. Recruits of Northeast Arctic cod at age 3 and the SSB, (dotted line) 1946-1996.

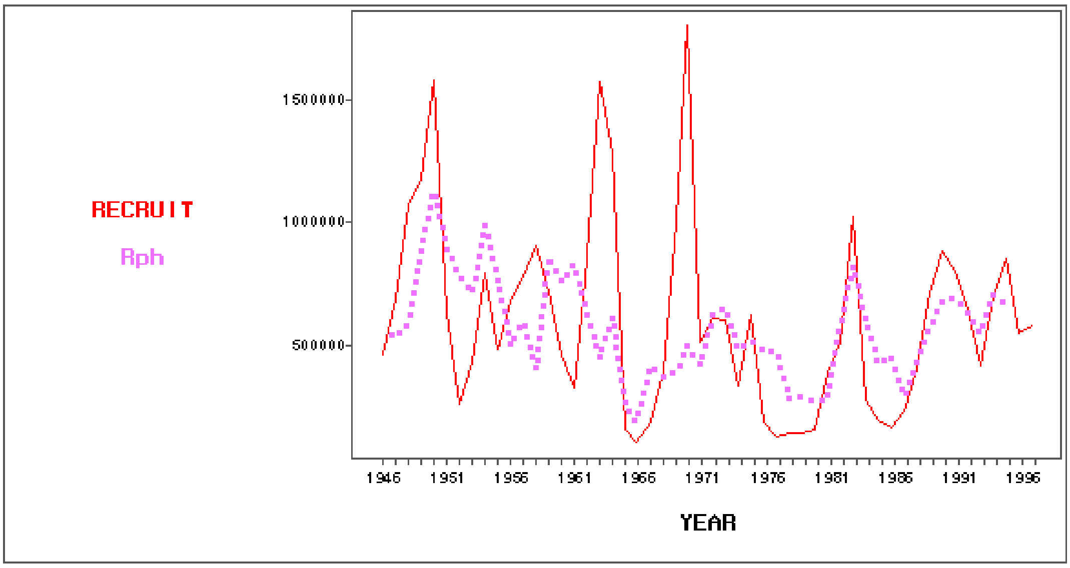

Figure 2. Observed and predicted (dotted) recruitments at age 3 by year.

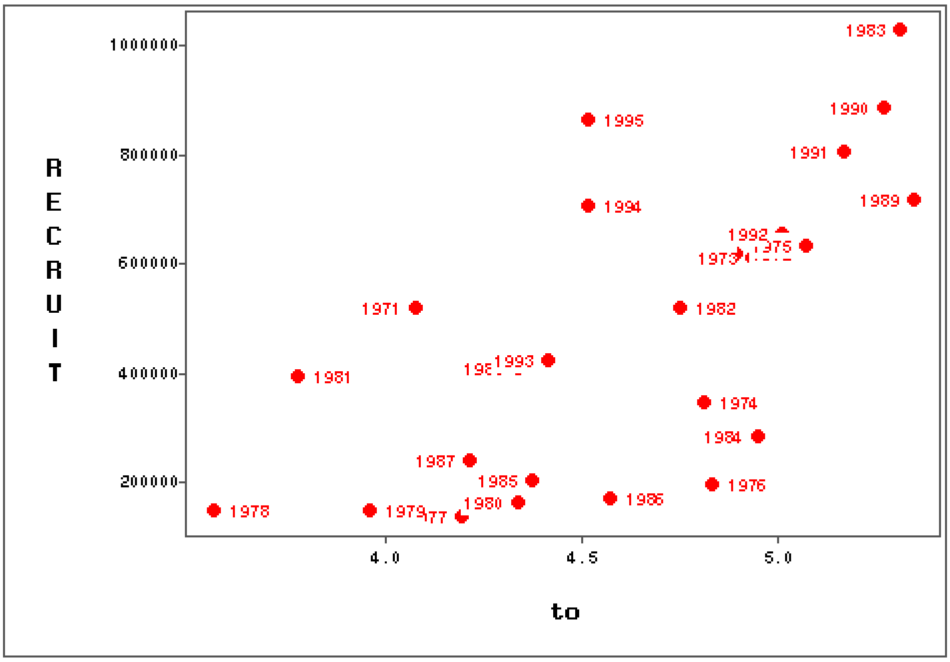

Figure 3. Recruits vs the average temperature (T) from August to December

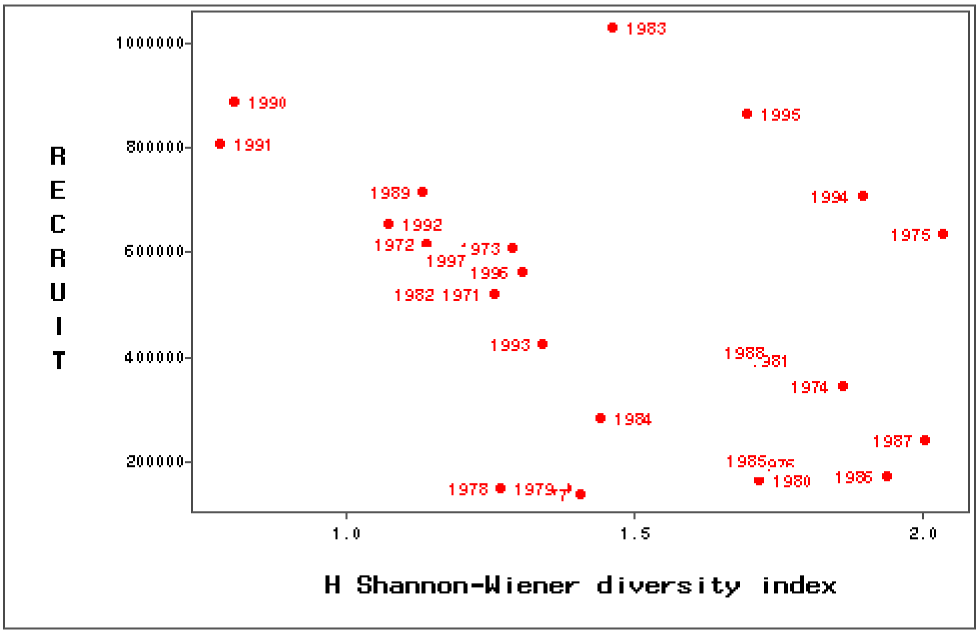

Figure 4. Recruits vs age diversity index.

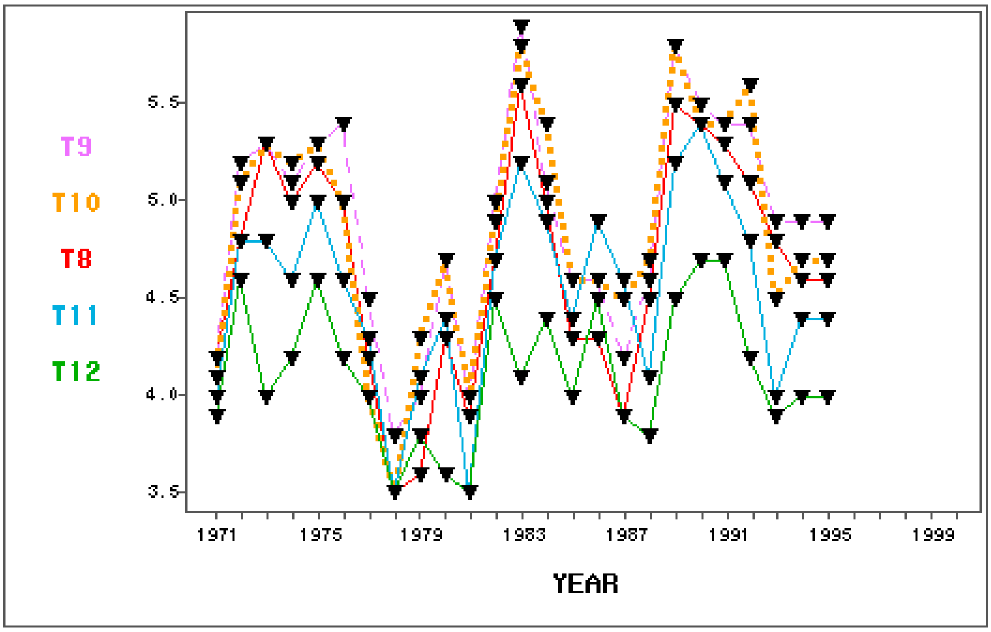

Figure 5 Temperature from August (T8) to December (T12) from the Kola section 1971-1995.

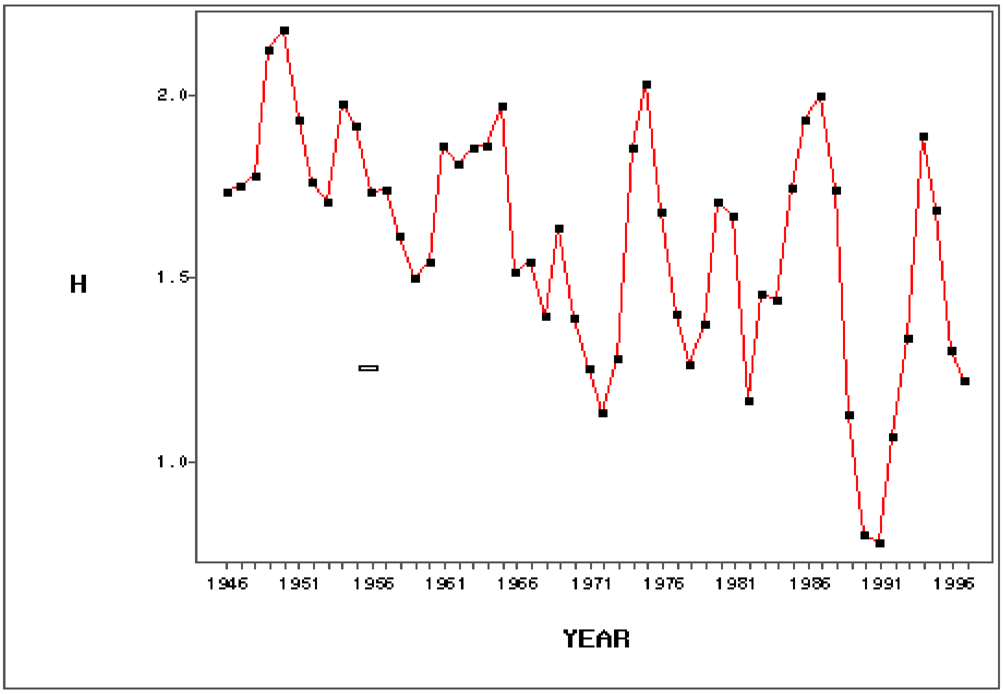

Figure 6 Diversity index (H) from 1946 to 1997

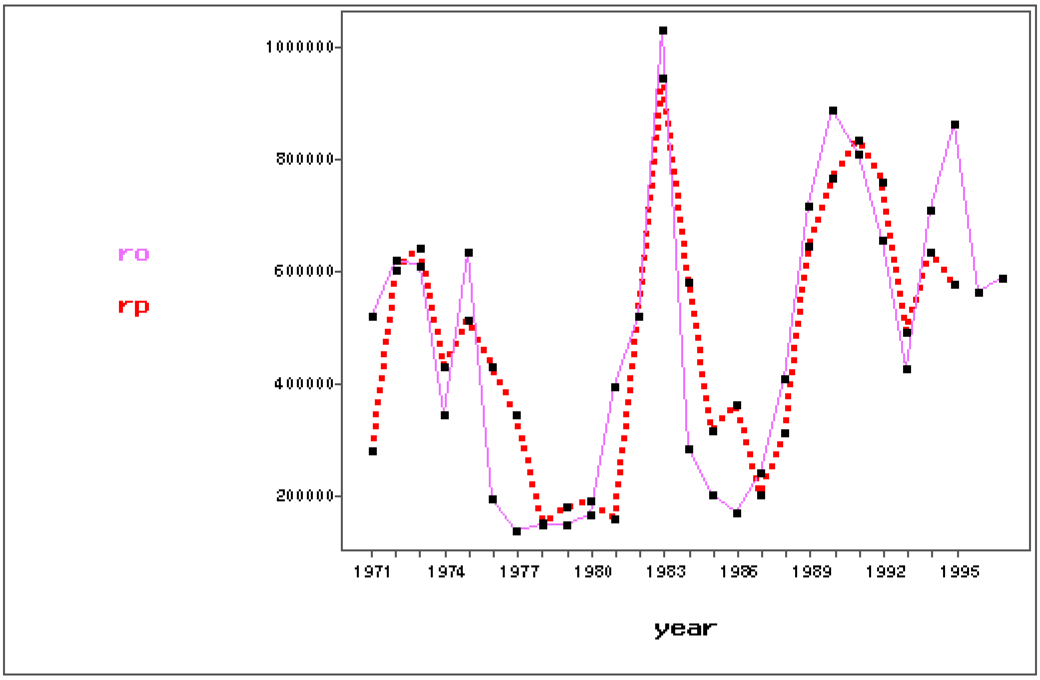

Figure 7 Observed recruits (ro) at age 3 and predicted (rp, dotted) using eq (3).

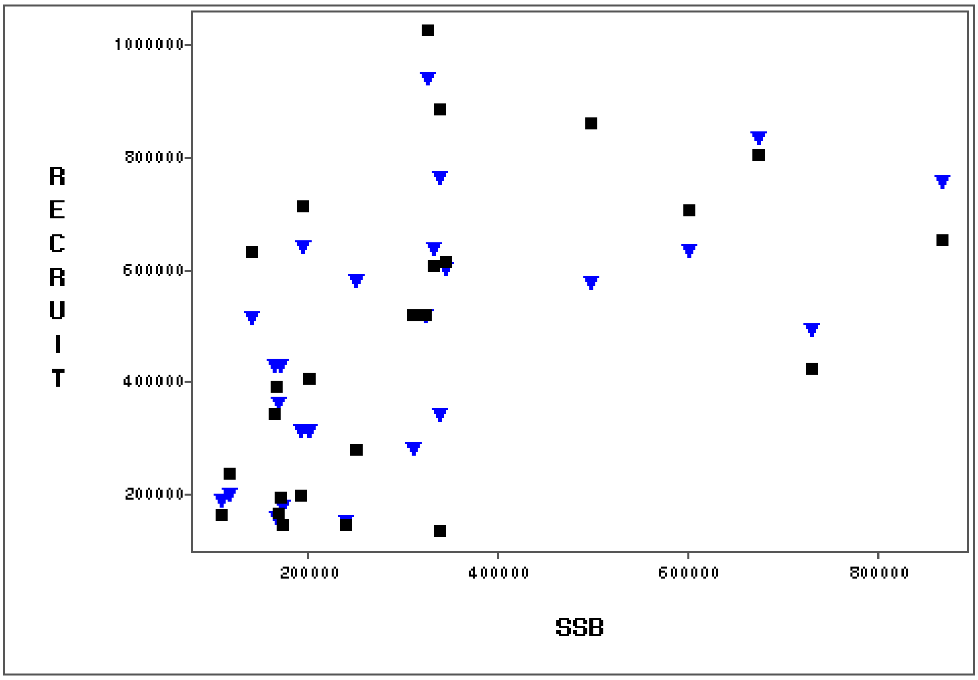

Figure 8 Stock-recruitment relationships observed and predicted (triangles) for the period 1971-1995.

ANNEX 6

Working Document 7

P A reference points for hake

by

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Data and plots used in this document are included in ICES CM 2002/ACFM:05 and ICES CM 1999/ACFM:04

The precautionary reference points were established for this stock by ACFM in 1998. The biomass limit ($\mathbf{B}_{\text{lim}}$) was fixed at an absolute value of SSB, which was the lowest observed level of spawning biomass which led to a later recovery ($\mathbf{B}_{\text{loss}}$). To fix this point, the last assessment available at the time was used, which corresponded to 1998.

In this assessment, $\mathbf{B}_{\text{loss}}$ was identified in the period 1993 (SSB = 120,000 t) to 1994 (SSB = 119,000 t) and it was therefore decided that 120 000 t be considered $\mathbf{B}_{\text{lim}}$ (*Fig. 1*). The point of precautionary biomass ($\mathbf{B}_{\text{pa}}$) was the result of increasing this biomass level by 40% ($\boldsymbol{B_{lim}}$ * *1.4*), which would correspond to the upper confidence limit of 95% of $\mathbf{B}_{\text{lim}}$, considering a CV of 0.2.

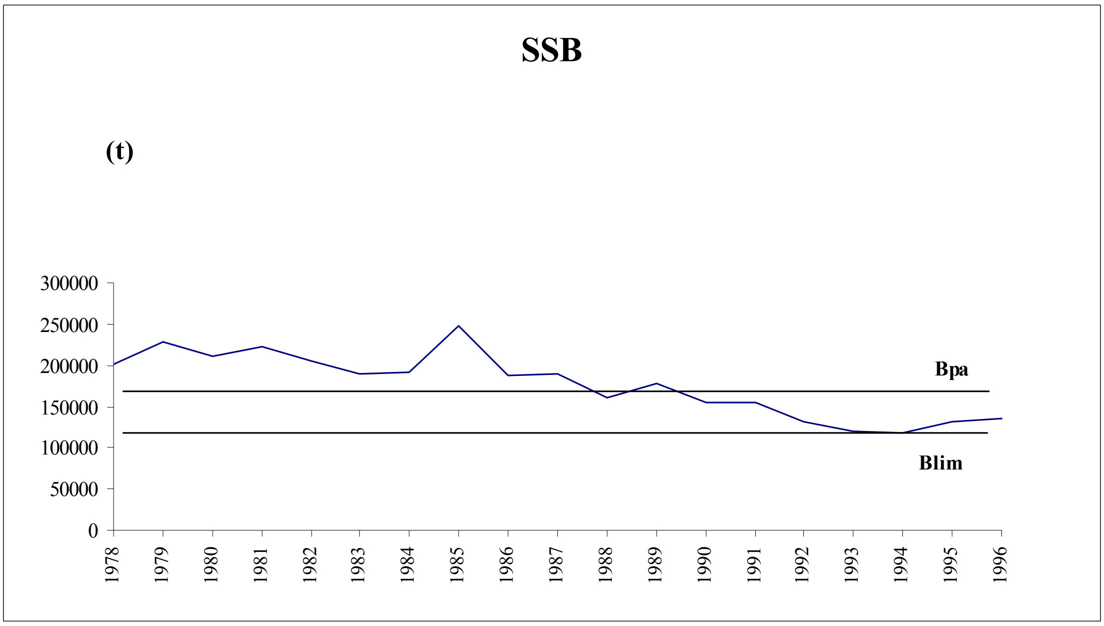


Figure 1

$\mathbf{F}_{\text{lim}}$ was estimated at 0.28, in agreement with the value chosen for $\mathbf{B}_{\text{lim}}$ ($\mathbf{F}_{\text{loss}}$), and the value for $\mathbf{F}_{\text{pa}}$ (0.2) was obtained by multiplying $\mathbf{F}_{\text{lim}}$ by 0.72, which implies less than 10% probability that $\text{SSB}_{\text{MT}} < \mathbf{B}_{\text{pa}}$.

Limit reference points are to be avoided with a high probability because they are associated with stock collapse. Yet, in the ICES 2001 assessment, the spawning stock biomass has been less than $\mathbf{B}_{\text{lim}}$ in 9 out of 23 years, and the fishing mortality was greather than $\mathbf{F}_{\text{lim}}$ in 14 years out of a total of 23 years and greater than $\mathbf{F}_{\text{pa}}$ in all the series (Fig. 2&3). Moreover, $\mathbf{F}_{\text{pa}}$ is lower than the 25$^{\text{th}}$ percentile of $\mathbf{F}_{\text{low}}$ and $\mathbf{F}_{\text{lim}}$ lower than the 25$^{\text{th}}$ percentile of $\mathbf{F}_{\text{med}}$, which seem to be inconsistent with the definition of these two parameters.

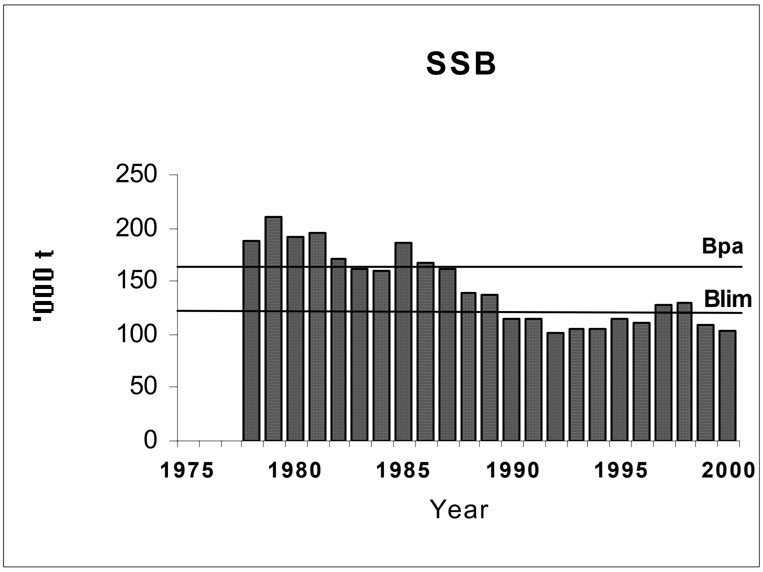


Figure 2

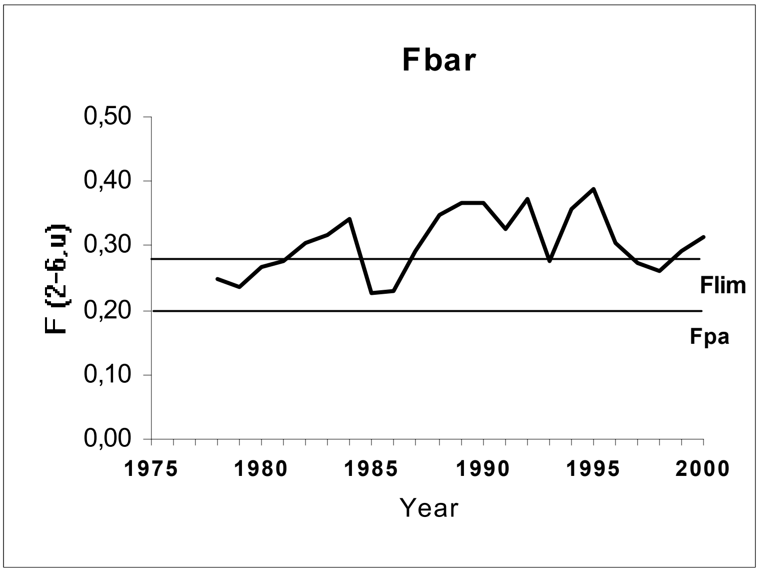


Figure 3

The 2001 assessment reduced the SSB estimates for the whole of that period, with respect to the 1998 assessment, so the new estimates run more or less parallel with those, but at a lower level (Fig. 4). The limit of 120,000 t which was previously at the level of the values of the 1993-94 period and sets the remaining years above it, now clearly sets the whole period between 1990 and 1997 below it, which is clearly inconsistent with the 1998 calculations. Using the same rationale as in 1998, $\mathbf{B}_{lim}$ would be set between 102,000 t and 105,000t and $\mathbf{B}_{pa}$ between 140,000t and 145,000 t.

This problem may occur in stocks in which, due to problems in aging old fishes, the plus group must be chosen near the age of first maturity, in this case SSB estimations are sensible to Fold inputs, because there is not enough time to reach convergence.

The use of absolute values of SSB in these stocks could cause problems in the formulation of advice; for example if the SSB estimations in the last analysis are about 20% larger for all the historical series, the ACFM may have problems to say that that value is the lowest observed biomass, because all the values in the series are higher. Moreover if this situation happens and the current value of SSB is at the level of $\mathbf{B}_{pa}$. Are we in a safe position?

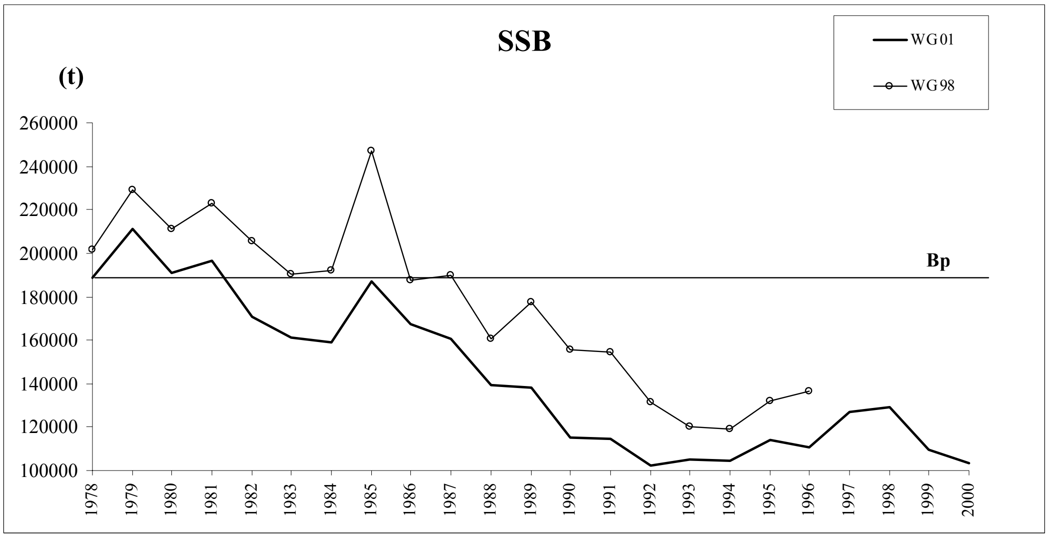


Figure 4

A proposal

A possible solution is refering $\mathbf{B}_{lim}$ to the level of SSB of a particular year or period, in this case 1993-94, rather than an absolute value of SSB. In this case we found every time a value of SSB for that period despite the estimated SSB increase or decrease for the overall series and our current SSB would be comparable with this value.

Knowing the SSB value for the reference period, we are in a position to estimate $\mathbf{B}_{pa}$ by applying the formula to calculate the upper 95% confidence limit:

$$\mathbf{B}_{pa} = \mathbf{B}_{lim} * \mathbf{exp}\ (\mathbf{1.645} * \sigma).$$

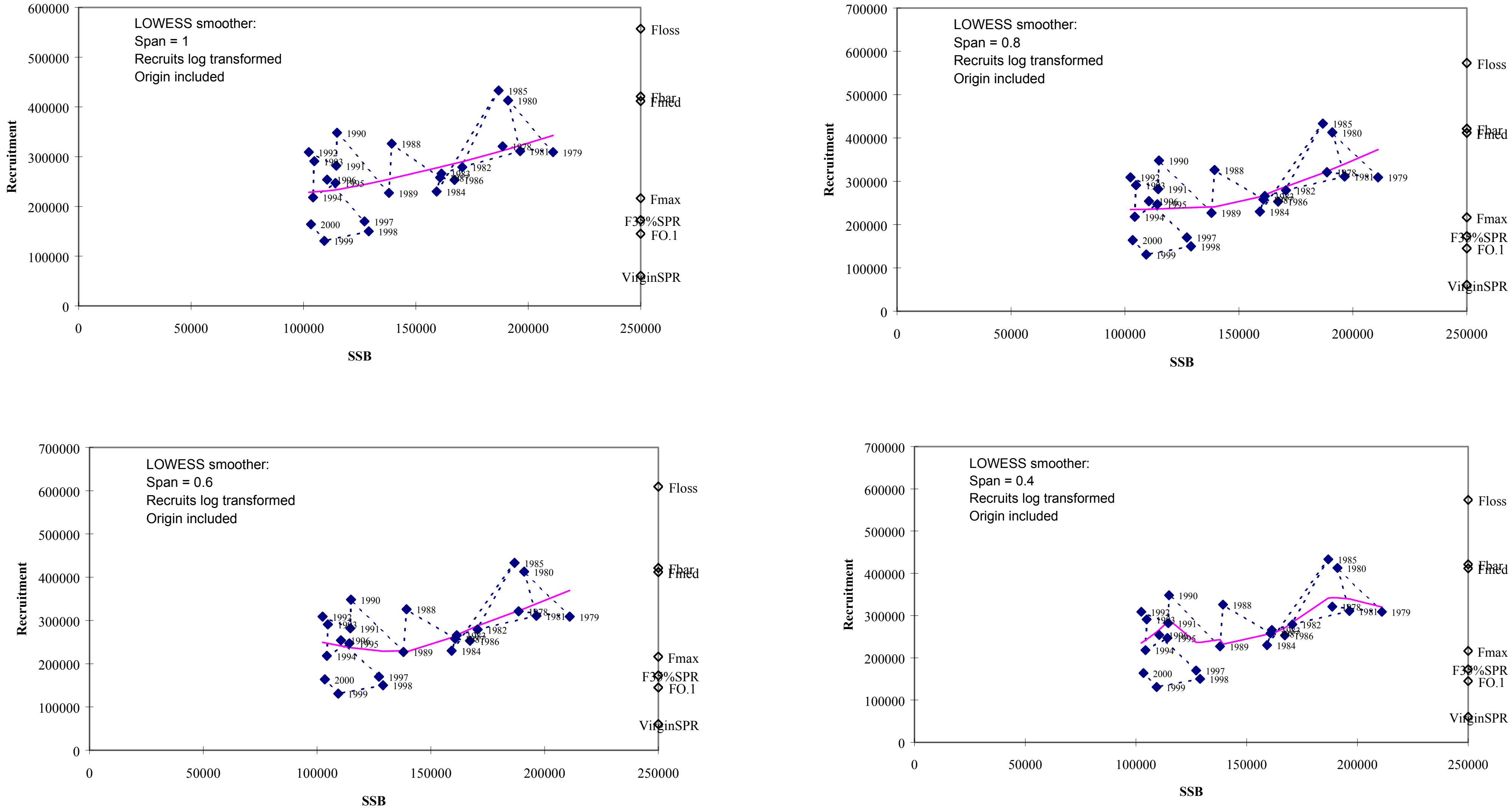
F reference points may be estimated in coherence with $\mathbf{B}_{lim}$, by obtaining the slope of the average recruitment at $\mathbf{B}_{lim}$ in the SSB/R. For this proposal we need to fit a model to these data, in our case, the best fit is done by a non-parametric smother local regresion (LOWESS), although the determination coefficient of this relationship is around 0.25. This fit is not very sensible to the span used, so lets take span = 1 (Fig. 5). The inverse of the slope corresponding to $\mathbf{B}_{lim}$ can be found in the SSB/R plot and we can take the F value corresponding to this point as $\mathbf{F}_{lim}$. Following the same rational that in ICES:

$$\mathbf{F}_{pa} = \mathbf{0.72}\ \mathbf{F}_{lim}.$$

In the our case this value correspond to values

$$\mathbf{F}_{lim} = \mathbf{0.34.}$$
$$\mathbf{F}_{pa} = \mathbf{0.24.}$$

Figure 5.- Northern Hake. S/R plots with different span values



ANNEX 7

Working Document 23. - 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

Assessment model structural uncertainty in the estimation of Precautionary Reference Points

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Introduction

The framework of the Precautionary Approach outlined in Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks states that:

Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

As outlined in SGPA 2001, ACFM/ICES has acknowledged that it must:

"... explicitly consider and incorporate uncertainty about the state of stocks into management scenarios; explain clearly and usefully the implications of uncertainty to fisheries management agencies."

In general, ICES has interpreted uncertainty as the errors associated with estimates obtained from stock assessment and reference point estimation algorithms. However, recent studies (Patterson et al. 2001, Gavaris et. al. 2001) have shown that the choice of estimation method can have an appreciable impact on the perception uncertainty and the risks associated with the consequences of fisheries management decisions.

This Working document highlights assessment model structural uncertainty in the reference point estimates estimated for the Northern hake stock (Divisions IIIa, Subareas IV, VI, VII and VIIIa,b,d). It is shown that the XSA assessment model structure used by the Southern Shelf Demersal Species Working Group (SSDS, ICES 2002a), is not a unique interpretation of the available assessment information; but is one of the most optimistic of a range of solutions. Alternative model specifications give equally valid interpretations of the development of the stock. A review of the model sensitivities and the underlying causes is presented.

The Northern Hake catch-at-age data set

The sensitivity of the trends in exploitation rate and biomass derived from alternative XSA model structures, arises directly from the decision made by the 1998 SSDS meeting (ICES 1999) to reduce the age range of the assessment from a 10+ age group to 8+. This has resulted, as illustrated in Figure 1, in 30% of the mature catch in numbers being aggregated into the plus group and the oldest age and ~50% in the oldest two ages and the plus group.

VPA based assessment models fitted to data sets with significant numbers in the oldest age and plus group, are extremely sensitive to the method by which fishing mortality at the oldest age is estimated, due to relatively poor VPA convergence at the oldest ages. Under the most commonly used VPA assumption, that the fishing mortality at the plus group age is equal to that at the oldest age, the uncertainty at the oldest age is mapped directly into uncertainty in the plus group abundance.

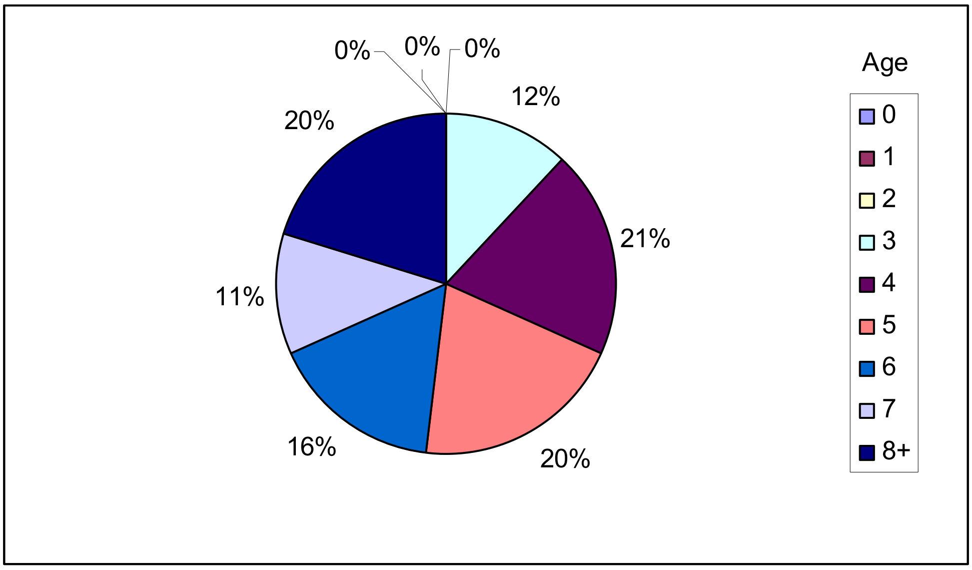

Figure 1. The average (1978-2000) proportions of the mature catch number-at-age in the Northern hake assessment data set.

In recent years the SSDS Working Group has made substantial changes to the XSA model used to assess the Northern hake stock. They have:

- relaxed the assumption of a flat-topped selection at age at the oldest ages;
- continually changed the range of years of CPUE data used for calibrating the model from 10 with equal weight in the 1997 assessment to 20 with a tri-cubic taper weighting in 2001;
- reduced the quantity of the information used from the French commercial cpue and survey series by removing older ages, this has resulted in a very low weight being given to the French data in the estimation of F at the oldest age;
- in 2001, added four new commercial fleet cpue series at a time when many assessment Working Groups are questioning the validity of commercial data due to spurious correlation with the catch data set (ICES 2002b).

It can be speculated that the sensitivity of the Northern hake assessment estimates to model structural assumptions and the time-series and age ranges of the data used for calibration has led to the continual change to the XSA model structure by the Working Group over the last five years. All of these changes suggest a Working Group that is struggling to maintain a stable assessment.

Selection at the oldest age

Figures 2 and 3 illustrate the fishing mortality-at-age and the selection pattern at age (fishing mortality-at-age relative to fishing mortality-at-age 4) as estimated by the XSA assessment fitted at the 2001 SSDS meeting (ICES 2002a).

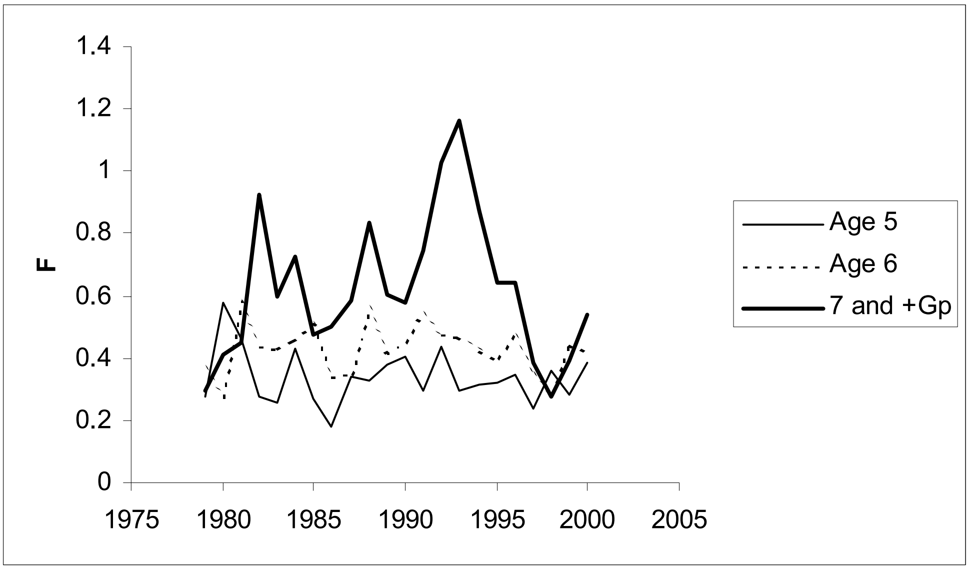

Figure 2. The time-series of fishing mortality-at-ages 5,6 and 7 as estimated within the XSA assessment fitted by the ICES 2001 SSDS Working Group.

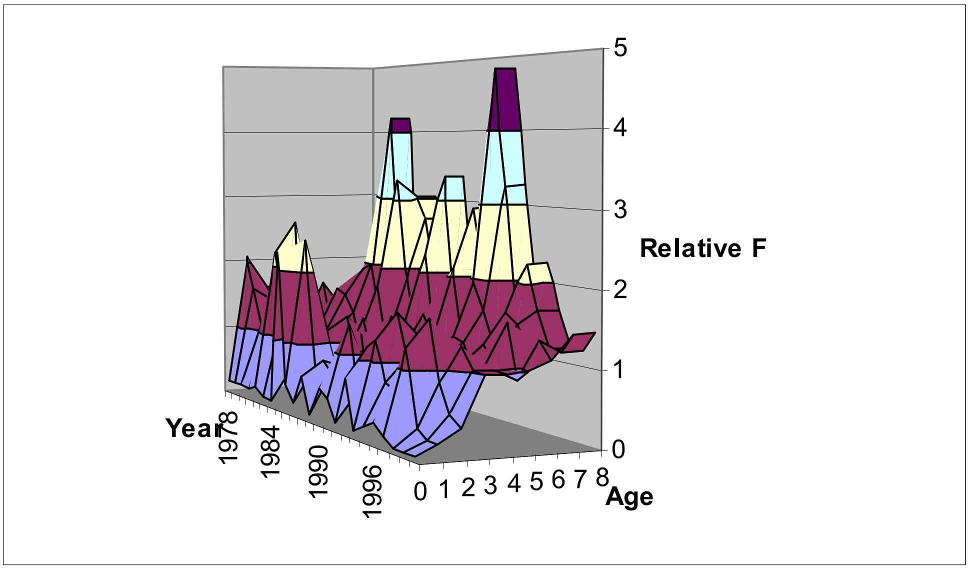

Figure 3. The time-series of selection at age (fishing mortality-at-age relative to the value at age 4) as estimated within the XSA assessment fitted by the ICES 2001 SSDS Working Group.

The figures illustrate that, the XSA specification applied by the Working Group, results in a selection value at age 7 the oldest age, which is estimated as 2 – 5 times the value at ages 3 – 6. Fishing mortality on the plus group is assumed to be equal to that at the oldest age. The SSDS assessment model estimates a substantially lower value of SSB at the oldest ages, when compared to the estimates derived under an assumption of a flat topped selection pattern. As the majority of mature individuals are found in the oldest age and plus group this results in a severe change in the overall assessment estimate of SSB.

The sensitivity to the assumed shape of the selection pattern is explored in Figures 4a, 4b and 5a, 5b. It is seen that when an increasing weight is given to a flat topped selection pattern (greater weight to F shrinkage at the oldest age only), fishing mortality at the oldest age decreases and historic SSB increases. The change in the level of the time-series is extremely sensitive to (conditional on) the assumed selection pattern. The Working Group assessment represents one end of a range of solutions for fishing mortality at the oldest age, namely that the fleets are selectively targeting fish at ages seven and older.

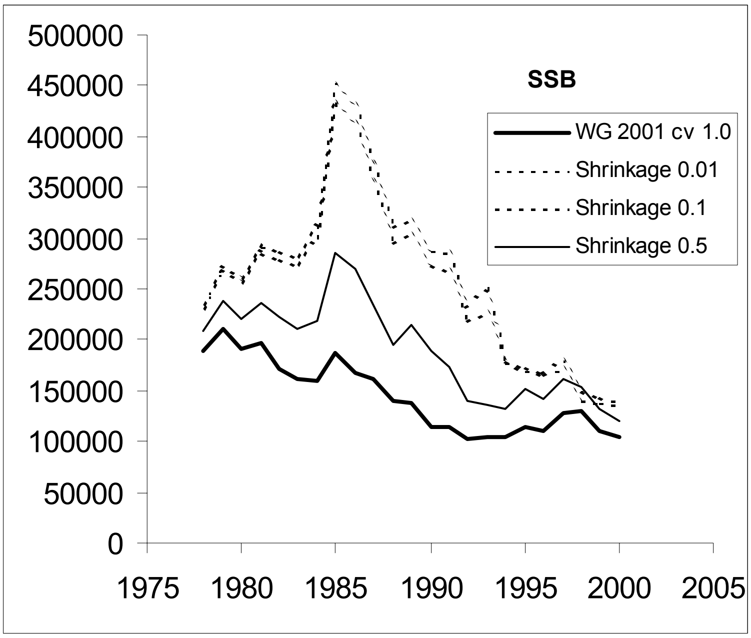

Figure 4a. The time-series of Spawning stock biomass as estimated within the XSA assessment fitted with increasing weight given to the assumption of a flat topped selection pattern at the oldest ages (lower cv = greater weight to constant selection).

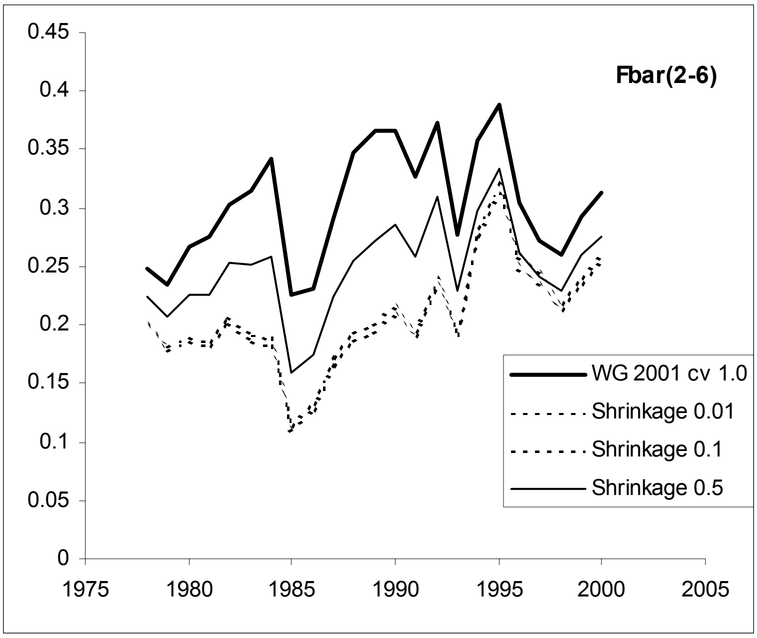

Figure 4b. The time-series of fishing morality as estimated within the XSA assessment fitted with increasing weight given to the assumption of a flat topped selection pattern at the oldest ages (lower cv = greater weight to constant selection).

Time-series weighting

The SSDS Working Group has also made a series of direct and indirect changes to the calibration information used to fit the assessment model. The direct changes have been the inclusion or exclusion of cpue series and the range of ages taken from the data series. The indirect changes have resulted from changes to the range of years of cpue information used for fitting the assessment model. This has ranged from 10 years of information with no time-series taper weighting, through 12, 13 and 14 years of information with no taper weighting, to the current model which has 20 years of data with the application of a tri-cubic time-series weighting function.

Figures 5.a and 5.b illustrate the sensitivity of the estimates of fishing mortality and SSB derived from the most recent SSDS XSA assessment model of the use of an alternative weighting function which uses only the last 10 years of cpue data for calibration. As with the assumption of selection at the oldest age the assessment estimates are extremely sensitive to the choice of weighting function. Higher historic SSB levels and a faster rate of decline are estimated if the historic cpue information is down weighted. Similarly fishing mortality is estimated to be at a lower level but has increased substantially since the late 1980's.

The difference in the estimates between models is directly correlated with the way in which fishing mortality at the oldest age is modeled. If there is no tuning information available for a historic series of catch-at-age data, XSA makes the assumption that the average exploitation at younger ages can be used as the expected value for the oldest age, perfect F shrinkage. This is the same as the assumptions used in the *ad hoc* tuning methods such as Laurec-Shepherd tuning (Pope and Shepherd) and the most commonly used ADAPT formulation (Gavaris). As established previously with the constant selection at the oldest age model, SSB estimates increase and F is reduced when a shorter cpue series is used. The time of the transition is directly dependent on the length of the cpue calibration series used to fit the XSA model.

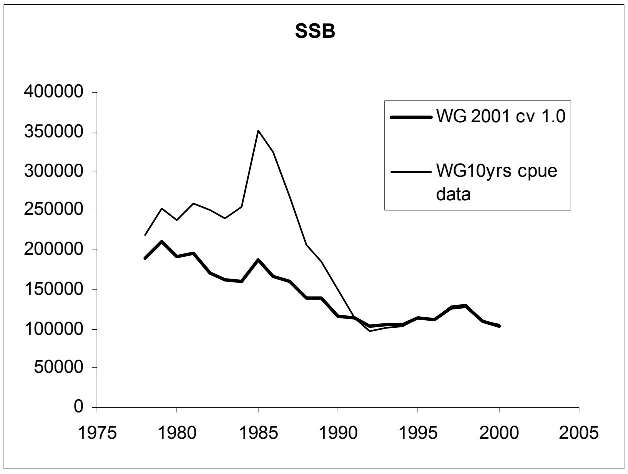

Figure 5a. The time-series of Spawning stock biomass as estimated within the XSA assessment fitted with a 20 year tri-cubic time-series weighting and no time-series weighting with cpue calibration data for only the final 10 years.

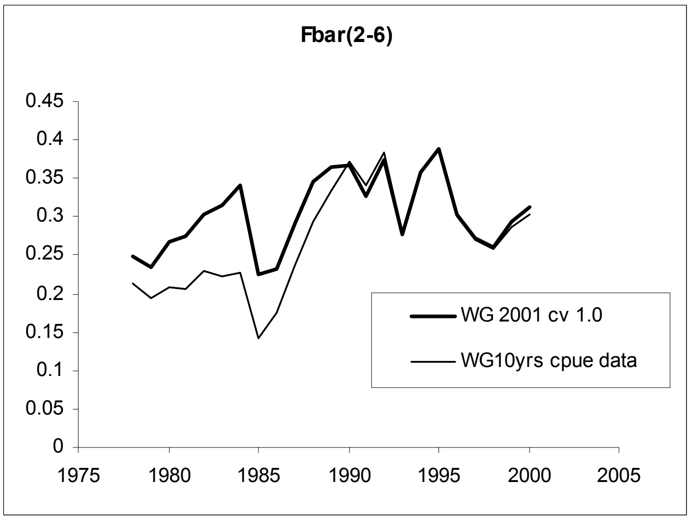

Figure 5b. The time-series of fishing morality as estimated within the XSA assessment fitted with a 20 year tri-cubic time-series weighting and no time-series weighting with cpue calibration data for only the final 10 years.

Removal of the older ages from the French commercial fleet and survey cpue series

Although cpue at age data is available from the French commercial and survey series for all of the ages to which the XSA assessment model is fitted, only ages 0-5 have been utilised by the Working Group. In order to examine the effect of this decision all ages in the French data (0-7) were included in an XSA analysis fitted to the French cpue data and compared with an XSA fitted to the and Spanish CPUE information. This allows a contrast of the diagnostic plots and time-series estimates from the two sets of information for the identification of potential conflicts. For each model the XSA diagnostics were examined for the appropriateness of the SSDS XSA specification for the catchability models and shrinkage settings; no change to the SSDS specification was required in order to fit XSA to each of the data subsets. The results are presented in Figures 6, 7, 8 and 9.

Figures 6 and 7 illustrate the time-series of log catchability residuals for each fleet within the two XSA model fits. Figure 6 presents the diagnostics for the model fitted to the Spanish cpue information. Figure 7 presents the diagnostics for the model fitted to the French cpue information. The catchability residuals indicate that there is a conflict in the assessment estimates derived from each information source. When the assessment is calibrated with the Spanish fleet information the French fleet and survey cpue series show trends in the catchability residuals. Similarly, when the assessment is calibrated with the French survey and fleet information the Spanish fleet series show trends in the catchability residuals. Although the Working Group has excluded age information from the French data series the alternative hypothesis that the Spanish data is inconsistent may be equally valid. It removes a trend estimated for a survey series where one would not be expected.

The estimated SSB and fishing mortality time-series are plotted in Figure 8 and 9. They also show the conflict in the estimates from the two subsets of data. The French series are consistent with a flat-topped exploitation pattern, an increase in fishing mortality in recent years and a severe decline in SSB. The Spanish information with the high fishing mortality at the oldest age, a slow decline in SSB and relatively constant higher historic fishing mortality rates.

In each of the figures the Working Group assessment time-series are shown. The decision by the Working Group to exclude the older ages from the French data sets has removed the conflict in the estimates from the fitted model but biased the assessment estimates towards the trends in the Spanish information.

Although the French information at the oldest ages has been removed from the assessment, the XSA results do not indicate a poor fit of the assessment model unless the Spanish data is included. It is known that the French fleet effort and survey are generally restricted to ICES area VIIIa,b,d and that the Spanish effort is directed more towards area VII. The differing signals in the assessment trends indicate that separate stock dynamics in the two areas are a likely cause of the disparity.

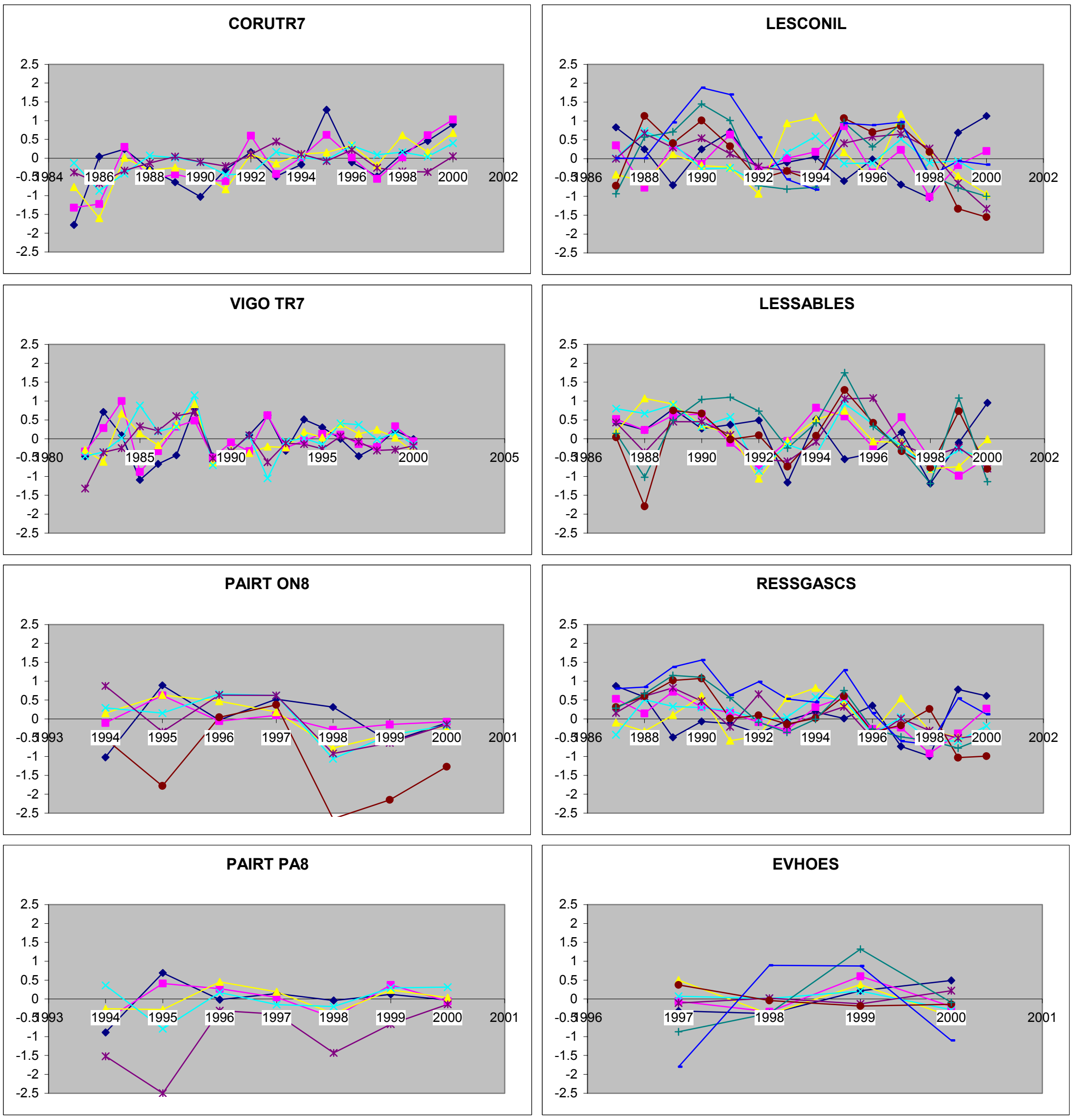

Figure 6. The time-series of log catchability residuals for each fleet data series within the Northern hake XSA assessment model. The XSA model is fitted to the Spanish cpue information.

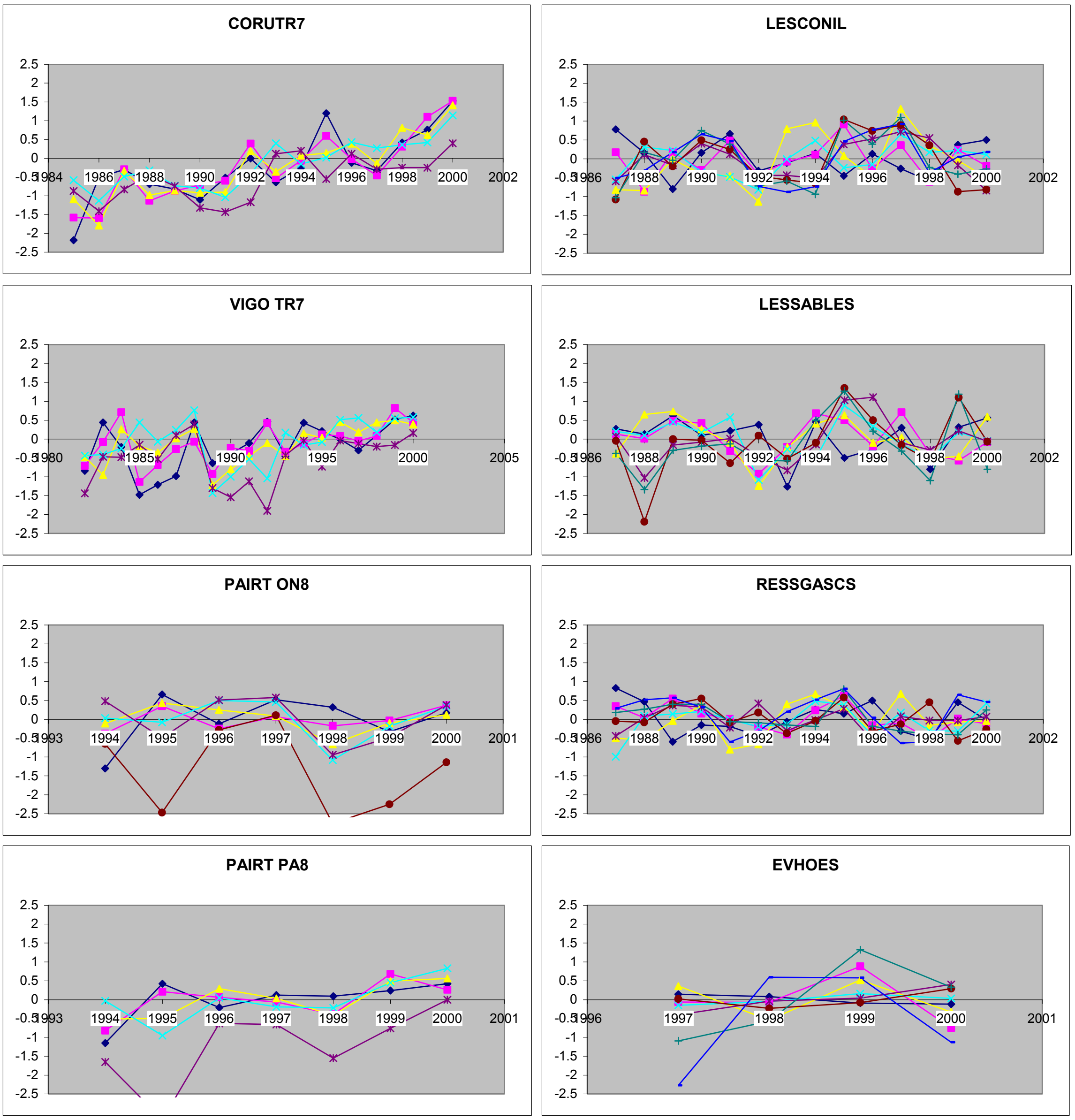

Figure 7. The time-series of log catchability residuals for each fleet data series within the Northern hake XSA assessment model. The XSA model is fitted to the French cpue information.

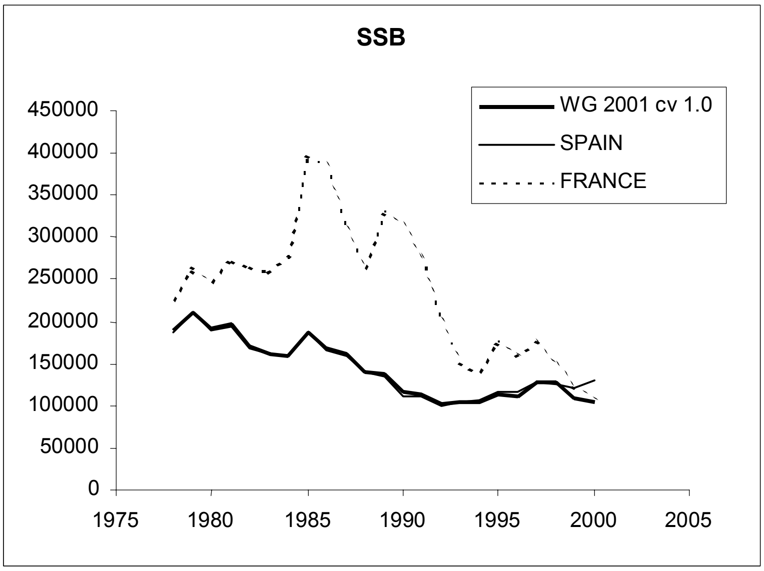

Figure 8. The time-series of Spawning stock biomass as estimated within the XSA assessment fitted independently to the Spanish and French cpue data series.

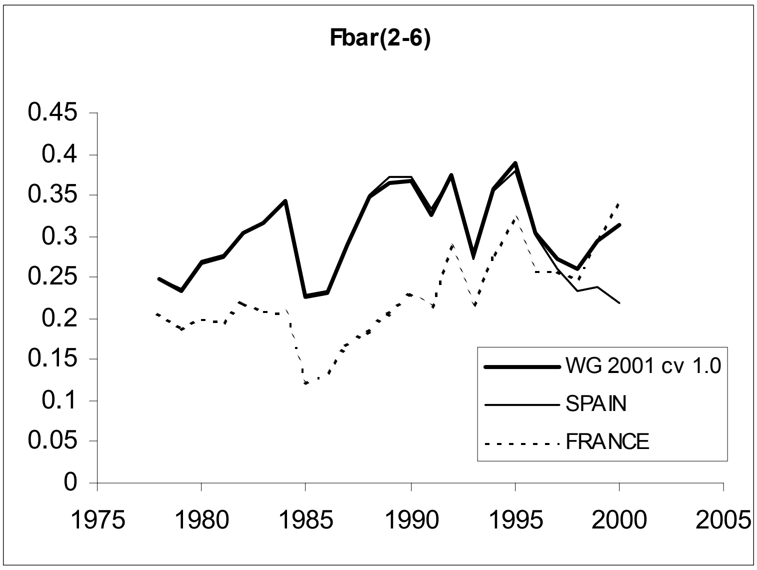

Figure 9. The time-series of average fishing mortality as estimated within the XSA assessment fitted independently to the Spanish and French cpue data series.

The effect of assessment model structural uncertainty on Precautionary Reference Points.

Figure 10 presents the spawning stock and recruitment plots for each of the XSA assessment fitted individually to the French and Spanish data series. The figure shows the change in the model structure, in terms of the fitted cpue series, on the scatter of the stock and recruitment XSA estimates. Clearly the series are very different. It would therefore be expected that the uncertainty in the assessment model structure would be transferred into uncertainty in the estimated Precautionary Approach reference points.

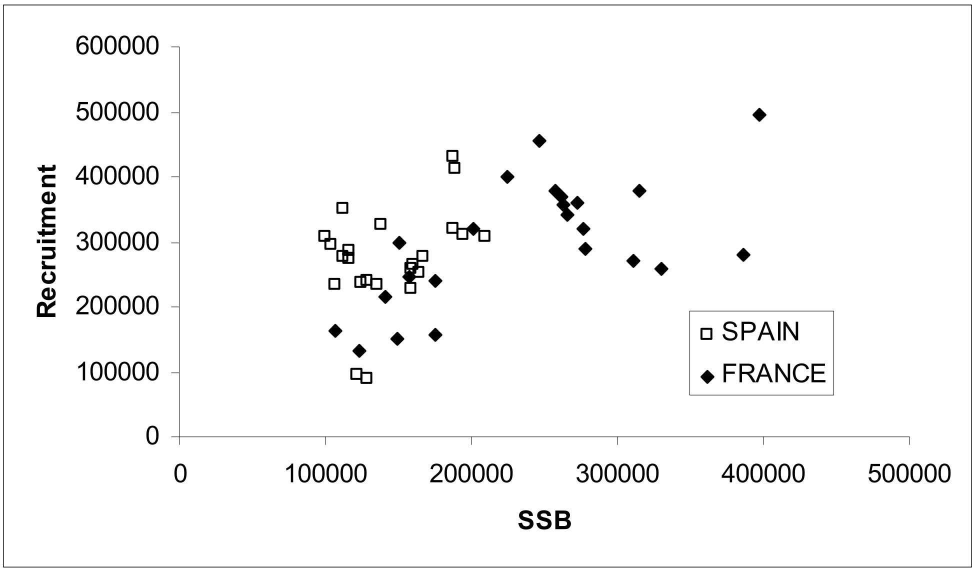

Figure 10 The spawning stock and recruitment estimates estimated using two XSA models fitted to Spanish and French cpue data series independently.

Figures 11 and 12 present the estimates of $\mathbf{F}_{loss}$ and the spawning stock corresponding to the intersection of the 90%ile of observed survival rate (R/SSB) and the 90%ile of the recruitment observations. It is clear that the expected uncertainty in the assessment model structure has been transferred to the estimates of the reference points. The estimates of $\mathbf{F}_{loss}$ under the assumption of a flat-topped selection pattern are lower and the SSB reference point estimates higher.

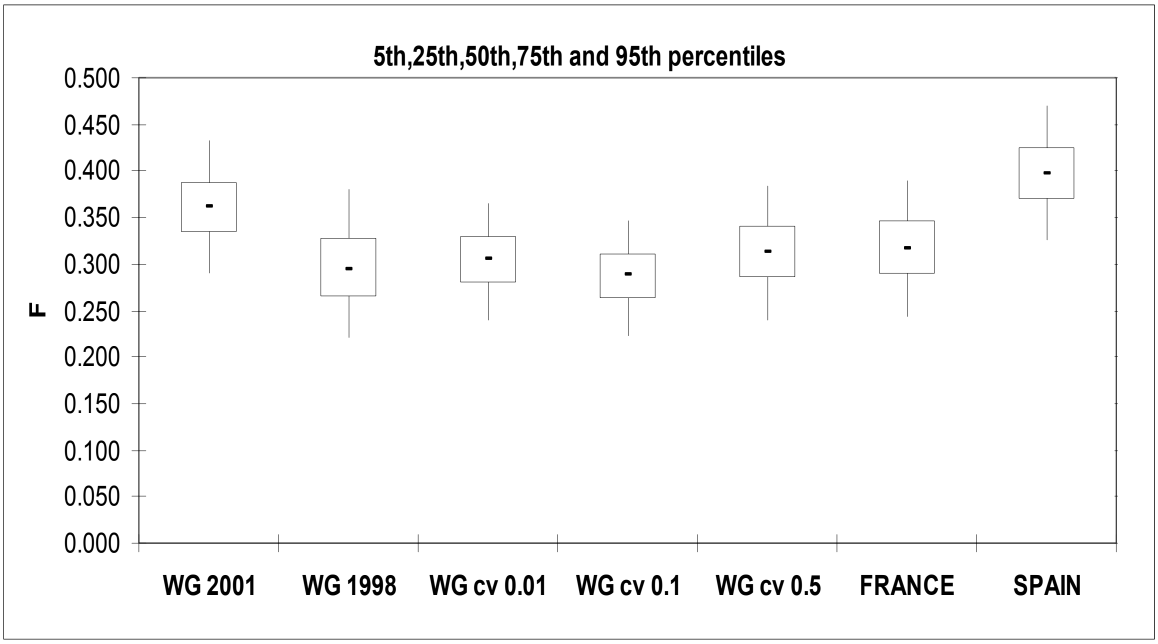

Figure 11 The estimates of $\mathbf{F}_{loss}$ derived from alternative XSA assessment model structures.

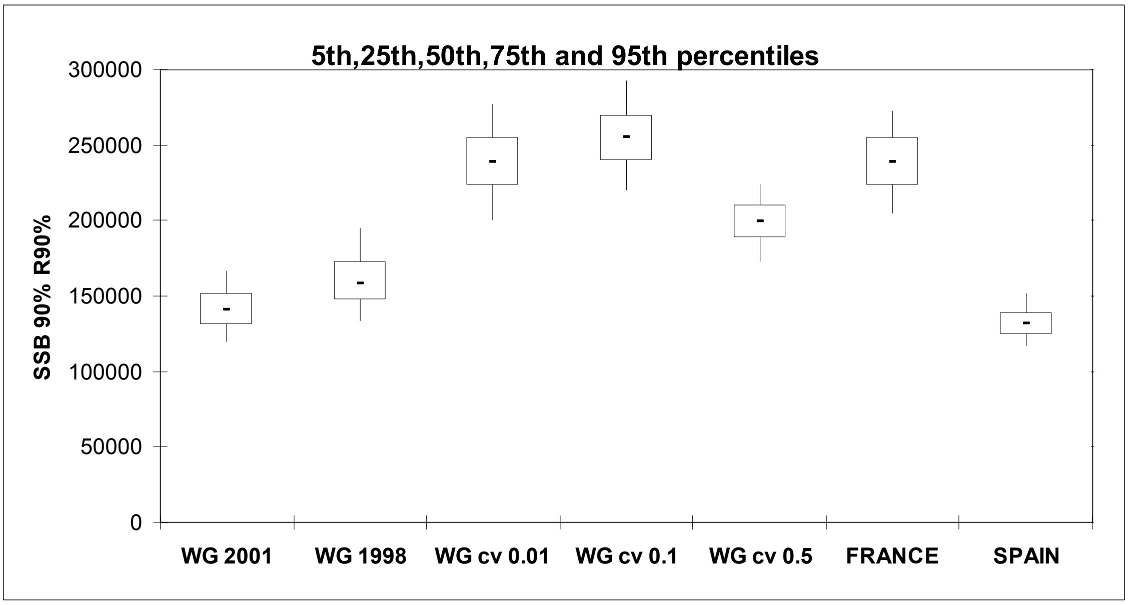

Figure 12 The estimates of spawning stock corresponding to the intersection of the 90%ile of observed survival rate (R/SSB) and the 90%ile of the recruitment observations, derived from alternative XSA assessment model structures.

Discussion

ICES has stated previously that uncertainty in the assessments should be incorporated within uncertainty associated with estimates of the Precautionary Approach reference points. In the current software used for estimating reference points this is achieved by the use of bootstrapping or Monte Carlo procedures. However the methods are conditioned on an assumption of the "correct" assessment model structure.

Recent studies have shown that choice of the assessment method and the method of uncertainty estimation can have a significant impact on the perception of risks associated with the consequences of fisheries management decisions (Patterson et al 2001, Gavaris et al. 2001). This has been demonstrated to be clearly the case for the Northern hake, in which very different perceptions of the trends in the stock dynamics can be achieved with minor variations to the assessment model structure. The current SSDS Working Group interpretation is the most optimistic.

Currently ICES does not have a formal method for the incorporation of structural model uncertainty into its management advice (Patterson et al 2001), although this approach has been under development in other regions (Schnute and Hilborn 1993)

Patterson et al (2001) state that:

"Many uncertainty estimates are predicated on a single structural population model which is accepted as the 'best' representation of reality. However, in some circumstances alternative representations of reality may be almost equally plausible (whether this is expressed as an expert opinion or as a likelihood function value) and the admission of such alternative representations as possibilities may greatly affect the perceived uncertainty. Conditioning of uncertainty estimates on a single structural model may result in such underestimation of uncertainty that for practical purposes the estimates of uncertainty in forecasts so generated bear little relation to the real likelihood of alternative eventual outcomes."

"It is not clear in general terms either how or to what extent model uncertainty should be communicated for management purposes. Current practice varies by institutional context. In most ICES situations uncertainty estimates are predicated on a single model which is accepted by the relevant experts as the best available. Practice in South Africa, Australia and New Zealand is more to recognise alternative structural assumptions explicitly (in some circumstances as Bayesian priors) and to communicate the consequent uncertainty to management agencies."

"The relative performance of different management options, and some parameters also will be more robust to structural uncertainty (for example, a parameter which is expressed in relative terms spawning biomass relative to virgin biomass is more robust than absolute measures of stock size). The importance of structural uncertainty will therefore depend on the parameters which are being used for management purposes."

In the case of the Northern Hake, due to the current catch-at-age data structure, changes to the model structure have resulted in changes in the perception of risk that may have nothing to do with any real change in the state of a stock. Unless the structural uncertainty in the model can be resolved by the inclusion of additional information, the interpretation of risk must be clearly linked to the XSA model assumptions and the alternative, more pessimistic alternatives considered.

The precautionary approach dictates that greater caution be used in the face of greater uncertainty.

References

ICES 1999. Report of the Working group on the Assessment of Southern Shelf Demersal Stocks ICES CM 1999/ACFM:04.

ICES 2002a. Report of the Working group on the Assessment of Southern Shelf Demersal Stocks ICES CM 2002/ACFM:05.

ICES 2002b. Report of the Working group on Methods on Fish Stock Assessment ICES CM 2002/D:08

Gavaris, S. 1988. An adaptive framework for the estimation of population size. *Canadian Atlantic Fisheries Scientific Advisory Committee Research Document* No. 88/29, 12 pp.

Gavaris, S., K.R. Patterson, C.D. Darby, P. Lewy, B. Mesnil, A.E. Punt, R.M. Cook, L.T. Kell, C.M. O'Brien, V.R. Restrepo, D.W. Skagen and G. Stefánsson (2000). Comparison of uncertainty estimates in the short-term using real data. ICES C.M. 2000/V:03

Patterson K.R, R. M. Cook, C. D. Darby, S. Gavaris, L. T. Kell, P. Lewy, B. Mesnil, A. E. Punt, V. R. Restrepo, D. W. Skagen, and G. Stefánsson. (2001). Estimating Uncertainty in Fish Stock Assessment and Forecasting. Fish and Fisheries, (in press).

Pope, J.G. and Shepherd, J.G. 1985. A comparison of the performance of various methods for tuning VPA's using effort data. *J Cons IntExplor Mer*, 42, 129-51.

Schnute, J.T. and Hilborn, R. (1993) Analysis of contradictory data sources in fish stock assessment. Canadian Journal of Fisheries and Aquatic Science 50, 1916-1923.

ANNEX 8

Working Document 3

SHORT-TERM FORECAST

Defining *status quo* F – The *status quo* F versus TAC constraint

F advice versus SSB advice

By Tore Jakobsen and Henrik Sparholt

Introduction

The technical aspects of a short-term forecast have been repeatedly discussed at ACFM. The first part of the problem is how to define *status quo* F. Working Groups do this in different ways and in some cases their choice has a considerable impact on the resulting advice. Basically there are two approaches. One is to define fishing mortality in the last VPA year as *status quo*, the other is to use a recent average, typically three years. In the latter case, and usually also in the first, the exploitation pattern used in the forecast is the recent three-year average. The usual argument for using a three-year average as *status quo* F is that it removes some of the noise in the assessment and therefore gives a more reliable estimate of current F, but it has also been claimed that it is more precautionary.

Last year the three-year average caused some confusion within ACFM about the advice formulation. In a couple of stocks the recent average F and the final F were on different sides of the $\mathbf{F}_{pa}$ and it became clear that this situation is not well covered in the current form of advice.

The second part is the median year problem. A debate is usually started at ACFM whenever there is a proposal to use TAC constraint in a forecast. The arguments vary, but there are some main elements: "It is difficult to explain to managers why a TAC forecast has not been used." "If there is a record in the fishery showing that the TAC has been realistic, this should be the best choice." "Even if TAC is respected, the realised F will be wrong." "The *status quo* F forecast is generally more reliable, and also more precautionary."

Typically, in these debates there has not been time to check the validity of the different statements. This paper is an attempt to show the implications of the different choices and to start a process where the aim is to establish clear guidelines for an ICES standard of short- term forecasts.

Examining historical assessments, there are examples of extreme errors in the forecast of the SSB remaining after the TAC is taken, which frequently is being used as basis for the advice. In this paper the effect of an error in the assessment on the advice, either F based or SSB based, is investigated.

Material and methods

The problems have been examined using two different approaches. One is to look at the properties of the forecast of a single cohort. This approach ignores the contribution from recruiting year classes and will therefore tend to exaggerate differences compared to a full stock forecast. The second approach is to investigate the outcome of historical forecasts and to use real data to make forecasts comparing the different methods. In this paper this has mainly been used as a check on the single cohort calculations.

Definition of *status quo* F

Results

The effect of defining *status quo* F as the recent average is dependent on the recent trend in fishing mortality. Applying the recent average implicitly assumes no trend, because if there is a real trend, it would not be logical to use the recent average. In fact, the logical assumption would be to assume that the trend continues, an option rarely if ever used in the forecasts. Nevertheless, in discussing the precautionary properties of using a recent average, the effect when there is a trend in F has been brought up. The following questions are addressed:

1. Will the recent average be a better predictor of current F than the most recent year?

2. Will using a recent average give a more reliable TAC forecast?

3. Does using a recent average have any precautionary value in the TAC forecast?

Regarding 1, examination of historical data indicates that the recent average tend to give a slightly better estimate of current F than the final VPA year. However, the examination of the historical data is not extensive and it is difficult to draw firm conclusions.

Regarding 2, the recent average F will in most cases be different from the F in the final VPA year, and it is implicitly assumed that the final F is wrong and should be at the same level as the recent average. Since the stock numbers are kept unchanged, there would then be a mis-match between F, N and catch in the final year, which violates the stability inherent in a *status quo* forecast.

If the recent average F is higher than F in the final year, the implication is that N at the start of the median year is overestimated, and *vice versa*. This will lead to corresponding errors in the TAC forecast. If the final year F is used in the forecast, however, the error here would tend to compensate for some of the error in N, thus giving a more precise forecast.

In a full stock forecast a large part of the projection may be influenced by recruiting year classes. In this case a better estimate of current F (i.e. the F realised in the median year) could improve the projection, depending on the influence of the recruiting year classes on the forecast.

Regarding 3, applying a recent average, ignoring the cases where there is no trend but some noise in F, and assuming that the catch is correct, there are 9 scenarios to consider (the statements refer to how F and N are estimated in the last VPA year):

1) F is underestimated, N is overestimated, increasing trend in F.

2) F is underestimated, N is overestimated, stable trend in F.

3) F is underestimated, N is overestimated, decreasing trend in F.

4) F is correct, N is correct, increasing trend in F.

5) F is correct, N is correct, stable trend in F.

6) F is correct, N is correct, decreasing trend in F.

7) F is overestimated, N is underestimated, increasing trend in F.

8) F is overestimated, N is underestimated, stable trend in F.

9) F is overestimated, N is underestimated, decreasing trend in F.

Assuming that the trend in F continues at the same rate, the scenarios transferred into the median year will be (for simplicity it is assumed that the error caused by the trend is of the same order as the error in the assessment, thus these errors are assumed to cancel out in some scenarios, giving a “correct” F):

1) F is severely underestimated, N is overestimated, Catch is underestimated

2) F is underestimated, N is overestimated, Catch is correct

3) F is correct, N is overestimated, Catch is overestimated

4) F is underestimated, N is correct, Catch is underestimated

5) F is correct, N is correct, Catch is correct

6) F is overestimated, N is correct, Catch is overestimated

7) F is correct, N is underestimated, Catch is underestimated

8) F is overestimated, N is underestimated, Catch is correct

9) F is severely overestimated, N is underestimated, Catch is overestimated

Brought further forward to the TAC forecast, which depends on the N left at the start of the TAC year, the scenarios, in very general terms, become:

1) TAC is severely overestimated

2) TAC is overestimated

3) TAC is correct

4) TAC is overestimated

5) TAC is correct

6) TAC is underestimated

7) TAC is correct

8) TAC is underestimated

9) TAC is severely underestimated

While Scenario 1 is the dream scenario, Scenarios 3 and 7 may also by chance give a precise TAC forecast. The precautionary effect will be in Scenarios 6, 8 and 9, while Scenarios 1, 2 and 4 should be avoided. The "bias problem" giving a too optimistic view of the state of the stock, is represented by the Scenarios 1,2,3 and there is only potentially a precautionary effect in Scenario 3, if the declining trend in F outweighs the error in the assessment. Thus, the "bias problem" is not repaired by using recent average F.

Conclusions

For a single cohort, a *status quo* forecast, i.e. in this case one that is based on the link between F, N and catch in the final VPA year, will give a more precise TAC forecast than one that is based on a recent average F. This may, however, give a poorer estimate of F in the median year. In a full stock forecast, a large impact of recruiting year classes could change this in favour of using a recent average F.

The TAC forecast will tend to be precautionary only in the cases where the right combination of an overestimate of F in the assessment and a declining trend in F occurs, and these will usually not be the most severe cases, i.e. those affected by the "bias problem".

Considering the need for consistency in assessment and advice, there appears to be little in favour of using a recent average F as basis for the forecast. Thus, it is recommended that *status quo* F is defined as F in the final VPA year.

The use of a recent average exploitation pattern has not been investigated, but it has some of the same logic as the recent average F. However, in this case the noise level is higher and some of the errors of a single cohort forecast will cancel out, so this practice probably does not represent a major problem as long as there is no indication of a recent change in the exploitation pattern.

***Status quo* forecast versus TAC constraint**

Results

There is no reason to dispute that given no other information, the best approach to a forecast is to assume *status quo* F. If other information exists, usually about management decisions, the issue becomes more complicated. Logically, if an agreed TAC is expected to be taken, this surely should be the best choice? At least the catch would then be correct in the forecast, and you would not have to explain to managers why the TAC is not used in the forecast. On the other hand, you may have to explain why the realised F and SSB are different from what managers expected their actions to produce.

Rather than focusing on the median year, the discussion should probably concentrate on the effect on the advice. The core of the problem is assessment errors. The status quo forecast is most robust to such errors, because the errors in F and N are linked and tend to some extent to cancel out in the forecast. If a TAC constraint is used, only the error in N is introduced to the forecast, giving a wrong F in the median year and a wrong stock number at the start of the TAC year.

Although using a TAC constraint based on an assessment with errors necessarily leads to errors in the forecast, they need to be compared to the errors introduced by assuming the wrong catch. A number of simulations based on the forecast of a single cohort were made to illustrate the differences between the two approaches. For a single cohort, Figure 1 shows the error in TAC (target F) as function of error in assessment F for a *status quo* forecast and TAC constraint. In general the TAC error will be larger using the TAC constraint, but the difference is dependent on the level of F in the assessment. Thus, if F is very small, the difference between the two forecasts is virtually nothing.

Table 1 shows the difference in error between the two forecasts for some combinations of F in the assessment year and F in the median year, assuming error both in the assessment and (for the TAC constraint) in the expected catch in the median year. The results indicate that a *status quo* forecast is clearly preferable when the change in F is small, but if the change is large enough a TAC constraint will give a more precise TAC forecast. Unless there is some prior indication of the error in the assessment, it seems that a change in F of about to 0.2 from the final VPA year to the median year represents a balance point. Thus, if the change in F implied by the TAC constraint exceeds ~0.2 the TAC would give the most precise TAC forecast.

There is, however, a link between the direction of the error in the assessment and the error in the forecast. The most common situation would be that F is underestimated in the assessment and is expected to decrease by applying a TAC constraint. This would be represented by the upper three lines in the three blocks down and left in the table which indicate that with an underestimate of more than 10% in the assessment F, a status quo forecast will cause the smallest error, even when the change in F is as large as 0.4.

Conclusions

If achieving the best possible TAC forecast is given a higher priority than avoiding the problem of explaining various apparent discrepancies in the forecast to managers, there seems to be no general rule that favours either status quo or TAC constraint. However, with some indication of the assessment error and knowing the estimated change in F caused by assuming a TAC constraint, some crude guidelines are indicated by the simulations. The main conclusion is that there needs to be strong evidence that the F in the assessment is not underestimated before a TAC constraint should be preferred.

Although it is not precautionary to use a *status quo* forecast in all cases, it is clearly indicated that it will be precautionary to use it when there are indications of underestimation of F, and this will apply to many of the most problematic stocks in ICES advice. However, in principle the precautionary approach is already built into the PA reference points and applying it to the forecast would therefore be an additional precaution. Thus, it becomes a question of policy whether the precautionary approach should be expanded to include other aspects than those already agreed. If so, this will have to be explained very well to managers and stakeholders to avoid accusations of inconsistency in the future.

F advice versus SSB advice

The ICES advice is in most cases either based on a target F, usually $\mathbf{F}_{pa}$, or a target SSB, usually $\mathbf{B}_{pa}$, that will be left the year after the TAC is taken. In both cases the error in the recommended TAC will depend on the error in the forecast, which in most cases will be heavily influenced by errors in the assessment.

It is obvious that basing the advice on $\mathbf{F}_{pa}$ rather than $\mathbf{B}_{pa}$ in some cases will be very different, notably in the cases where the $\mathbf{B}_{pa}$ advice will be a zero catch, while fishing at $\mathbf{F}_{pa}$ still will allow a catch. Furthermore, the SSB represents one step further in the forecast, which will increase the uncertainty of the estimate. The relative error in a TAC (disregarding growth) based on F is the same as the relative error in N at the start of the TAC year, and is therefore independent on the value of $\mathbf{F}_{pa}$. The relative error in a TAC based on SSB is much more complex and dependent on the target biomass.

Results

Using a *status quo* F forecast on a single cohort gave the results summarised in Figure 2, expressed as relative errors in TAC advice as function of fishing mortality and for different assumptions about assessment error (=error in $\mathbf{F}_{sq}$). N is here used as a substitute for biomass. Because the error in F advice is independent on target F, only one chart is shown for this option. For target biomass (N), there are three options where the target is the biomass left assuming $\mathbf{F}_{sq}$ in the TAC year multiplied by a factor (0.5, 1 and 1.5).

While the TAC error with F advice increases with increasing levels of fishing mortality, the trend is opposite for Biomass advice where the error increases rapidly at low levels of fishing mortality. The error in Biomass advice also increases with decreasing target biomass. However, most striking is the much larger error in Biomass advice than in F advice. An example: With F at 0.5 and a 10 % underestimate of F in the assessment, the F advice TAC has an error of 20 % while the Biomass advice TAC error varies between 38 and 91 % depending on the target biomass. Considering that 10 % error in the assessment is rather moderate, the effect on the Biomass advice gives cause for concern.

Even if the forecast of catch and biomass is largely dependent on recruiting year classes, the error in recruitment estimate will have a larger effect if F advice is used than if Biomass advice is used. The difference is, however, smaller than if the forecast is based on the outcome of the assessment where median year errors will add to the difference.

Figure 3 shows how the realised F corresponding to the TAC advice is affected by the assessment error and Figure 4 shows the realised N (biomass). In both cases the results are dependent on target F and target biomass and in all cases the error is larger for the target biomass option. At a fishing mortality of 0.5-0.6 an assessment error of 10 % underestimate of F will lead to an overestimate of about 30% in the F advice options (23-41 % in the examples shown) and there are scenarios where the recommended catch would wipe out the stock. The corresponding error in realised N after a target biomass advice is slightly larger, but clearly smaller than the corresponding error in TAC advice.

Discussion

The single cohort forecast does not take into account factors like recruitment, growth, maturity and exploitation pattern. Nevertheless, the effect of errors in the assessment appears to be very large. In the precautionary approach, ICES has aimed at taking assessment error into account when setting the reference points. This process has been fairly standardised and it is not clear to what extent the forecast errors really have been considered, but in most cases the factors between limit and PA reference points are between 1.4 and 2, which may not be unreasonable in light of the present results. It is, however, discomforting to see how sensitive the results are to underestimation of F in the assessment. There are scenarios where the precautionary approach will fail to secure the limit biomass and the working paper to the Methods WG by H. Sparholt shows examples of severe overestimates in the projected biomass.

Although the precautionary approach may give a reasonable guarantee that the stock remains above $\mathbf{B}_{lim}$, the fact that the catch resulting from a target biomass is so much more sensitive to assessment errors than catch based on target F, gives reason for concern. By aiming for a certain biomass instead of an F, ACFM markedly increases the uncertainty in the catch advice. Is this really an acceptable procedure for providing fisheries advice?

If not, what are the alternatives? The immediate reaction would be to look at F based advice. This does not necessarily mean that Biomass reference points are redundant, but they would have to play a different role in the advice formulation. In addition to reducing the noise in the TAC advice, F based advice means that the focus will be more on the fishing effort, which is at the core of fisheries management problems. Furthermore it could help shift the focus from the primary aim of avoiding stock collapse to more optimal harvest strategies. F based management also seems easier to deal with if there are regime shifts.

There are many potential ways of implementing advice based on F and it is beyond the scope of this paper to work out proposals for such a strategy. However, it is hoped that it will trigger a debate on alternatives to the present advisory framework of ACFM.