

# ICES WKREF Report 2007

ICES Advisory Committee on Fishery Management

ICES CM 2007/ACFM:05

## Report of the Workshop on Limit and Target Reference Points [WKREF]

29 January – 2 February 2007

Gdynia, Poland



**ICES**

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# 1 Introduction

## 1.1 Terms of reference

The **Workshop on Limit and Target Reference Points** [WKREF] (Co-chairs: Jan Horbowy, Poland and Martin Pastoors, ACFM chair) will be established and will meet from 29 January to 2 February 2007 in Gdynia, Poland to:

- a) review and update the biological basis of limit reference points for fish stocks in the ICES area, taking into account the possible effects of species interactions and regime shifts. As a minimum the limit reference points for North Sea herring, Norwegian spring spawning herring, North Sea cod, Baltic cod and Kattegat sole stocks;
- b) review the scientific and management literature on the implementation of maximum sustainable yield reference points in line with the Johannesburg agreement 2002;
- c) comment on potential target reference points for fish stocks in the ICES area as suggested by SGMAS, taking into account the possible effects of species interactions and regime shifts and the framework on the evaluation of management strategies.

WKREF will report by 9 February 2007 to the attention of ACFM, AMAWGC and WKEFA.

### Supporting Information

Priority:	The work is essential for ICES to progress in the development of its capacity to assist in the development and evaluation on management strategies. Such evaluations are necessary to fulfil the requirements stipulated in the MOUs between ICES and Commissions.
Scientific justification and relation to Action Plan:	<p>[Action numbers 3.2, 3.4, 3.5, 3.12, 4.2, 4.3, 4.5, 4.11.2, 4.13, 4.15, 7.2]</p> <p>The WKREF should oversee the process of reviewing and updating existing limit reference points for specific stocks in which indications exist that effects of species interactions and regime shifts have influenced productivity of the stocks substantially or assessments have undergone recent substantial revisions. WKREF should further review existing literature and suggestions for MSY reference points as a starting point to introduce these into ICES assessment and advice. Finally, WKREF should comment on and suggesting possible target reference points as suggested by SGMAS.</p> <p>Limit reference points in ICES have been established in 1998 via the SGPA and ACFM. Some of the limit reference points have been updated after 1998, e.g. because new information became available, because assessment methodologies changed or because the original value was inappropriately chosen. With the general change in orientation in fisheries management towards harvesting at MSY and the ecosystem approach to fisheries management, there is a need to review the basis for the limit reference points and to explicitly incorporate species interactions and regime shifts.</p> <p>In addition, the introduction of the MSY-concept in the Johannesburg 2002 declaration, means that ICES should be prepared to suggest target reference points for different management strategies. This requires a review of how the MSY-concept has been taken up in different parts of the world and how that can inform the application within ICES.</p> <p>The work of WKREF is closely linked to SGMAS (on management strategies), with its 2007 meeting preceding the WKREF meeting.</p>

Participants:	Experts with qualifications regarding institutional aspects of fisheries management biological limit reference points, MSY-concepts, environmental regime shifts in upper trophic levels, biological fish stock interactions, target reference points, ecosystem indicators, ecosystem drivers, fleet dynamics, analytical evaluations of management plans including harvest control rules.
Linkages to advisory committees:	ACFM, ACE
Linkages to other committees or groups:	RMC, OCC, BCC, SGMAS, AMAWGC, WKEFA, Assessment WGs, WGRED, WGEKO

## 1.2 Structure of the report

The structure of the report is as follows:

- general introduction and summary of working documents in Section 1
- background on history of reference points in ICES in Section 2
- revision of limit reference points (ToR a) in Section 3
- review of MSY and process of establishing target reference points (ToR b+c) in Section 4
- conclusions in Section 5

## 1.3 Summary of working documents

### WD1: Overview of stocks (Martin Pastoors)

The working document presented an overview of the history of reference points in ICES and an overview of the specific reference points for the case study stocks that were listed in ToR a).

### WD2: Safe stock levels for North Sea herring (Ad Corten)

A precautionary stock level of 1.3 million tons such as proposed by ICES is over-conservative in the light of the history of the stock. For the last 35 years, this level has been exceeded only in the last 5 years. Between 1966 and 2000, the stock has always been below 1.3 million tons. During many years, the stock was even below the Blim of 800 000 tons. This did not prevent the stock from recovering from the severe collapse in the 1970s. A stock of less than 800 000 tons even produced a series of strong year-classes in 1981–1986. Therefore, the Blim of 800 000 itself contains a sufficient safety margin. Setting a precautionary Bpa at 1.3 million tons appears to be over-conservative. A review of the stock/recruitment relationship including data up till 2005 shows that high spawning stocks produce less recruitment. The maximum recruitment is probably produced at a spawning stock between 800 000 and 1.0 million tons. It is a shortcoming of ICES assessments that negative effects of high stock sizes are not taken into consideration. Other stock assessment models than the ones used by ICES assume that at high stock levels the growth of the fish and recruitment is reduced. The current series of poor herring year classes was produced by a stock between 1.6 and 1.8 million tons. Arguments are presented for the hypothesis that the low recruitment at these stock levels is due to cannibalism.

### WD3: Density, Recruitment and Recovery in Herring (Mark Dickey-Collas and Richard Nash).

A paper was submitted by Mark Dickey-Collas and Richard Nash: Density, recruitment and recovery in Herring. The paper summarizes existing evidence and hypotheses on density dependent processes in herring stocks. They conclude that these processes can be

demonstrated and that they may differ in stocks which have recovered in biomass from a collapsed state with the situation before the collapse. They discuss the consequences of this observation on the use of stock recruitment scatterplots for terminating reference points.

**WD4: Note on a possible approach for defining Blim for NS herring (John Simmonds presented by Henrik Mosegaard).**

A paper was submitted to WKREF. The paper presents a simple probabilistic alternative approach to setting Blim for North Sea herring which is supposed to be much less sensitive to recruitment at high biomass than the prevailing SR-methods. The concept is that below some level of SSB there is an increased probability of below average recruitment. This parameter is defined as the probability of recruitment falling below some fixed level for all spawning biomasses  $B$  being lower than some level  $B$ . The method was demonstrated to apparently fit the NSAS herring well. The method is explored and further developed in sec. 3.1.1.

**WD5: Relevance for economic and biological management objectives of MSY-based reference points for multispecies, multifleet fisheries: a North Sea plaice (*Pleuronectes platessa* L.) and sole (*Solea solea* L.) case study. G.M. Pilling, L.T. Kell, T.P. Hutton, P.J. Bromley, A. Tidd and L.J. Bolle. (Presented by Martin Pastoors)**

We modelled interactions between two flatfish stocks and two fishing fleets, taking into account the impact of changes in fish distribution, stock productivity, and resilience on fishery sustainability and profitability. Biological changes had a considerable impact on the limit management reference points currently used by ICES. Biomass reference points shifted with changes in productivity, whilst fishing mortality reference points remained constant (although the resulting impact on the stock changed). Single-species reference points currently used are often conflicting and encourage high-grading and discarding of smaller fish. Alternative economic management targets were considered. In order to achieve maximum economic yield from the fishery, a considerable decrease in fishing effort of the southern fleet is required, owing to the smaller mesh size and increased vulnerability of young plaice before they move north with age. In contrast, sustaining maximum employment within the fishery could be achieved when fishing effort was close to the break-even level.

Common biological target reference levels (e.g. maximum sustainable yield and its proxy  $F_{0.1}$ ) were examined. They resulted in considerably different effort levels in the north and south, and different profit levels. While we examined a range of possible management objectives in a multifleet, multispecies fishery, selection of the most appropriate depends on priorities assigned by managers and users. Distribution of resulting effort between fleets in the fishery may not conform to the European aim of relative stability. The choice of alternative reference points should be evaluated through simulation, considering the system in place and the uncertainties inherent within it.

**Presentation: Baltic cod regime shift (Fritz Köster)**

Large-scale climatic conditions prevailing over the Central Baltic Sea resulted in declining salinity and oxygen concentrations in spawning areas of the eastern Baltic cod stock during the last 20 years. These changes in hydrography reduced the reproductive success of the stock, and combined with high fishing pressure, caused a decline of the stock to the lowest level on record in early 1990s, staying on this low level, with the exception of a short term intermediate increase in mid 1990's.

Under favourable hydrographic conditions the stock showed high reproductive success at intermediate spawning stock biomass in the 1970's and declining reproductive success at historically high spawning stocks from 1981 onwards. Since 1987 recruitment fluctuated more or less independent of the spawning stock size on a low level, increasing only somewhat after major Baltic inflows in 1993 and 2003. This stock and recruitment dynamics leads to a stock

recruitment relationships having two levels with a transition period with reduced recruitment originating from almost constant high spawning stock sizes in the first half of the 1980's.

Present biological reference points are based on stock recruitment relationships considering different time periods. For F reference points a truncated time series from 1981-1995 was utilised, thus omitting high recruitment at intermediate spawning stock size from before this period. Biomass reference points were determined on basis of stock recruitment relationships encompassing a longer time series (1976–1994), thus including the period of extraordinary high recruitment at intermediate spawning stock size, but not the preceding period of intermediate recruitment at similar stock sizes. This procedure is inconsistent and it raises the question which time series should be used to determine biological reference points, the entire series from 1966 onwards including also relatively low recruitment during the 1960's, from 1976 onwards, based on the most reliable data starting with the period of highest recruitment or a shorter period considering the shift in productivity of the stock as conducted for the present F reference points determination ?

To answer this question, the evidence of environmental impact on recruitment and the importance of the stock's reproductive effort on recruitment success were reviewed, the occurrence of a regime shift in the central Baltic during the 1980's was discussed and longer-term time series were investigated for evidence of a similar regime shifts in earlier time periods.

The decline in recruitment during the 1980s was related to declining salinity and oxygen concentrations in the deep Baltic basins serving as spawning grounds for the cod stock. Specifically anoxic conditions in deep water layers of the Gdansk Deep and the Gotland Basin caused high egg mortalities already in the first half of the 1980's. Declining salinities and oxygen concentrations enhanced the vertical overlap between cod eggs and clupeid predators in the remaining productive spawning area of the Bornholm Basin from mid 1980's onwards. A temperature-related increase in the sprat stock intensified egg predation further in late 1980's.

The lack of recovery in recruitment after the major 1993 inflow is related to low larval survival. A decline in the abundance of the copepod *Pseudocalanus acuspes*, related to lowered salinity and high predation pressure by sprat, caused food-limitation for first feeding cod larvae.

In order to better understand the causes of stock fluctuations an assessment of the Eastern Baltic cod extending backwards until the 2nd world war was presented. The estimated stock size was relatively low in the beginning of the time series and increased during the first half of the 1950s, but was far from reaching historic high levels observed in the early 1980s. The stock declined again towards the mid-1960s. The average SSB in the 1950's and 1960's was ca. 200 000 tons, compared to ca. 135 000 t since 1990. Average recruitment was double as high in the early compared to the most recent period, indicating that stock productivity might have been higher in the 1950's and 1960's than now. Fishing mortality was relatively low after the 2nd world war but increased rapidly, reaching already in the second half of the 1950s the high levels observed since the 1980s.

The extended assessment puts the high stock sizes in the late 1970's and 1st half of the 1980's into perspective as being rather outstanding than normal. However, conditions before and after this period of high productivity were not similar. The earlier period is characterized by successful reproduction in eastern spawning areas, confirmed also by ichthyoplankton surveys. This suggests that the present regime is in fact not just a shift back into a state which prevailed before the 1970's and that the productivity of the stock is at present lower than it has ever been since the 2nd world war, relying in reproduction basically only one spawning ground, the Bornholm Basin.



The decline of the cod stock is however not the only drastic change in the Central Baltic ecosystem during the 1980's. The decline of the cod stock released sprat from predation pressure, which in combination with high reproductive success, due to in general favourable temperature conditions, resulted in exceptionally high sprat stock sizes in the 1990s.

Concurrent with a shift from a cod to a sprat dominated system, the meso-zooplankton community showed pronounced changes as well, while the marine copepod zooplankton declined in abundance, the neritic copepod species *Acartia spec.* and *Temora* increased in abundance, mainly caused by increasing winter temperatures. Furthermore, climate mediated changes in the Baltic ecosystem are also apparent from lower trophic levels for the 2nd half of the 1980's. This regime shift in the Baltic cannot be allocated to a single year or event, as the timing and intensity of response of different species and life stages depends on whether the critical environmental factor is oxygen concentration or salinity in the deep Baltic basins, or water temperature in intermediate or bottom water layers.

In conclusion it can be stated, that cod recruitment declined at high SSB already in the first half of the 1980's and that a regime shift in environmental conditions caused a further decline in reproductive success. Abundant year-classes of sprat act as predator on cod eggs and affect food availability of cod larvae negatively since the 2nd half of the 1980's and as such stabilize the low reproductive success of cod. However, the main driving forces are absence of major Baltic inflows, increased river run-off and relatively warm winters and as such variables beyond control of fisheries or any ecosystem management.

**Presentation: Climate, fisheries and ecosystem regime shift: Baltic cod as a case study (Max Cardinale)**

It is now well established that a link between recruitment and climate exists for several fish stocks and that recruitment success ( $R_s$ ) is among the most important traits determining fish population dynamic. Here we show that, although the effect of temperature was generally significant, adult biomass has a much larger impact on  $R_s$  of 54 North Atlantic stocks as a significant effect of spawning biomass on recruitment success was evident for 81% of all stocks analysed in this study. For gadoids, the effect of SSB on recruitment is larger than the effect of temperature (both in frequency of stocks and proportion of explained variance). For clupeids, frequency of stocks with an SSB effect is larger than SST but the strength is similar between SSB and SST. This again highlight that failing to account for spawning biomass effect in climate-recruitment studies would mask any influence of climate variability on recruitment dynamic. Moreover, a clear relationship was found between the effect of the SST and the average SST experienced by the stock, with stocks living in colder areas having a positive effect of temperature and vice versa for both families. In light of those results, although management of several exploited fish populations cannot be entirely decoupled from the effect of temperature on their reproductive success, it is un-doubtful that observed shift in the marine ecosystem is mainly the consequences of an unsustainable fishing mortality and not of a climate changes.

We used the same approach and focus on the Baltic cod as a key study to investigate possible climate effect and ecosystem regime shift. The analysis revealed that SSB explains 20% of the variance of recruitment success (SSB effect), about 37% of the remaining variance of recruitment success is explained by reproductive volume (climate effect) while sprat abundance has a negative effect on recruitment of Baltic cod (competition effect) (around 20%). This leads to a complex four-dimensional interaction between recruitment, adult biomass, climate and inter-specific competition. At the current climate conditions and sprat abundance, the minimum SSB able to produce a recruitment of 285 millions individuals (median of the time series) is around 250 000 tonnes.

**Presentation: “An example of a simple management evaluation: North Sea haddock.” (Coby Needle)**

Management strategy evaluations (MSEs) are assuming increasing importance within ICES as methods by which fisheries scientists can test the likely efficacy of different management plans and target reference points. This presentation summarised the application of a simple MSE to the case of North Sea haddock. This stock is managed jointly by the EU and Norway via a management plan which was due for revision in December 2006. A simulation approach was developed within the FLR framework that estimated the risk of biomass falling below a specified value ( $B_{lim}$ ) in this case, under a range of assumptions about target  $F$  and TAC constraints. The analysis was used as the basis for the revised management plan. Further details and comments are given in Section 4.3.

**Presentation on Faroese stocks (J.J. Maguire)**

The results of the 2006 assessment of Faroe haddock and Faroe saithe by the North Western Working Group were reviewed. For haddock, the stock and recruitment scatter plot indicate that strong year classes have been produced below the existing Blim (40 000t). The SGPRP 2003 made the same observation and stated “According to the “standard method” Bloss could be a candidate for Blim.” This would correspond to 23 000t. For saithe, the stock and recruitment scatter plot is of the type “b. (6) Inverse relationship. Stocks where  $R$  increases as  $SSB$  decreases. For this inverse  $S/R$  relationship it is not possible to estimate limit reference points. Bloss may be estimated as a candidate value of  $B_{pa}$ .” (SGPRP, 2003). In looking specifically at Faroe saithe, the SGPRP 2003 suggested that  $B_{pa}$  be set at Bloss, that is 60 000t. The NWWG examined those suggestions in 2005 and in 2006 and endorsed the recommendations of SGPRP.

The results of medium term simulations were also presented showing that the  $F$  target defined by the Faroese authorities (exploitation rate of 33% for each of the three species corresponding to  $F = 0.45$ ) had low probabilities of bringing the stocks below the Blim suggested by SGPRP 2003 and below  $B_{pa}$  for saithe.

**Presentation on stock-recruitment or recruitment-stock relationship - Jan Horbowy**

Biological reference points are often derived by examining scatter plot of stock – recruitment relationship. When on the examined plot one can identify points showing low recruitment at low spawning stock biomass and points indicating higher recruitment at higher  $SSB$  it seems tempting to conclude that recruitment is dependent on stock size. However, similar pattern can be observed if recruitment is driven mainly by some external (environmental) factors or variables and there is trend or shift in these drivers.

Simulations were used to demonstrate such patterns. Initial stock numbers, weights and maturities at age, natural mortality, and selection pattern were assumed. Weights, maturities, selection pattern, and natural mortality were kept constant in the simulations. Two options were assumed for recruitment

- 1) Recruitment is following Beverton and Holt model with log-normal distribution at given  $SSB$  and constant variance. To add more contrast in that option, fishing mortality was increasing by 0.025 a year with small random errors.
- 2) Recruitment is independent on stock size and is driven by external variable, fishing mortality fluctuates along a constant. Within this option two sub-options were considered.
  - In first recruitment showed declining trend of 5% a year with log-normal errors
  - In the other sub-option recruitment was fluctuating without trends in first half of the simulated period and shifted to half of the previous values in the second half of the period. In both periods recruitment was disturbed by log-normal errors.

Examples of the simulation results are presented in Figure 3.1.1 (see Section 3.1 for Figures and other comments). In all presented cases one could conclude that there is stock recruitment relationship if examination of the patterns was based on stock-recruitment scatter plot only. Plotting both SSB and recruitment series against time may be helpful as it may show that e.g. recruitment changes were preceding biomass changes. However, often the patterns are not clear and concluding on the type of relationship may be difficult.

#### **Presentation of a method to incorporate environmental drivers for Baltic Cod (Pavel Gasyukov)**

The description of the method is presented in Annex 2 (Incorporating environment in Stock and recruitment for Baltic cod).

## **2 Background on reference points and the precautionary approach**

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The application of the Precautionary Approach in ICES was undertaken at two meetings of the ICES Study Group on the Precautionary Approach to Fisheries Management in 1997 (ICES, 1997) and 1998 (ICES, 1998). SGPA 1997 outlined the legal requirements, described how reference points should be defined and calculated, and proposed to maintain or restore stocks to within safe biological limits by using, respectively, pre-agreed harvest control rules or recovery plans. SGPA 1998 estimated for as many stocks as possible the first set of reference point values, and these were adopted by ACFM in 1998 (ICES, 1999) in giving advice. In some cases these values have been amended, but the majority are still in use.

Based on SGPA 1997 and SGPA 1998 (ICES, 1997, 1998), the ICES approach to advice is that for stocks and fisheries there should be a high probability that spawning stock biomass (SSB) is above a limit  $B_{lim}$  below which recruitment becomes impaired or the dynamics of the stock are unknown, and that fishing mortality is below a value  $F_{lim}$  that will drive the spawning stock to that biomass limit. The word 'impaired' is synonymous with the concept that on average recruitment becomes systematically reduced as biomass declines below a certain point due to the effect of fishing. Because of uncertainty in the annual estimation of  $F$  and SSB, ICES has defined operational reference points,  $B_{pa}$  (higher than  $B_{lim}$ ), and  $F_{pa}$  (lower than  $F_{lim}$ ), where the subscript  $_{pa}$  stands for precautionary approach. When a stock is estimated to be at  $B_{pa}$  there should be a high probability that it will be above  $B_{lim}$  and similarly if  $F$  is estimated to be at  $F_{pa}$  there should be a low probability that  $F$  is higher than  $F_{lim}$ .

ACFM had previously defined and used the Minimum Biologically Acceptable Level (MBAL) of biomass for a number of stocks. MBAL was originally chosen as the SSB below which the probability of poor recruitment increased, and is therefore comparable to the current usage of  $B_{lim}$ , but in some cases MBAL was more simply the biomass below which concerns were raised, and was therefore set as  $B_{pa}$ , the level where management action to improve stock status should be taken.

The status of the Precautionary Approach in ICES was subsequently reviewed and developed by the ICES Study Group on the Further Development of the Precautionary Approach to Fisheries Management in 2001 (ICES, 2001), March 2002 (ICES, 2002) and December 2002 (ICES, 2003a). The three meetings of SGPA in 2001 and 2002 suggested a new approach to the estimation of reference points (Figure 1):

- a revised framework for estimating reference points, starting with  $B_{lim}$ , and leading on to the estimation of  $F_{lim}$ ,  $F_{pa}$ , and  $B_{pa}$ .
- the methodology for estimating  $B_{lim}$ , using segmented regression
- a methodology for estimating  $F_{lim}$  from  $B_{lim}$  deterministically
- a proposed new methodology for estimating  $F_{pa}$  and  $B_{pa}$  in order to take into account assessment uncertainty
- clarification of the risks to be accounted for in this framework

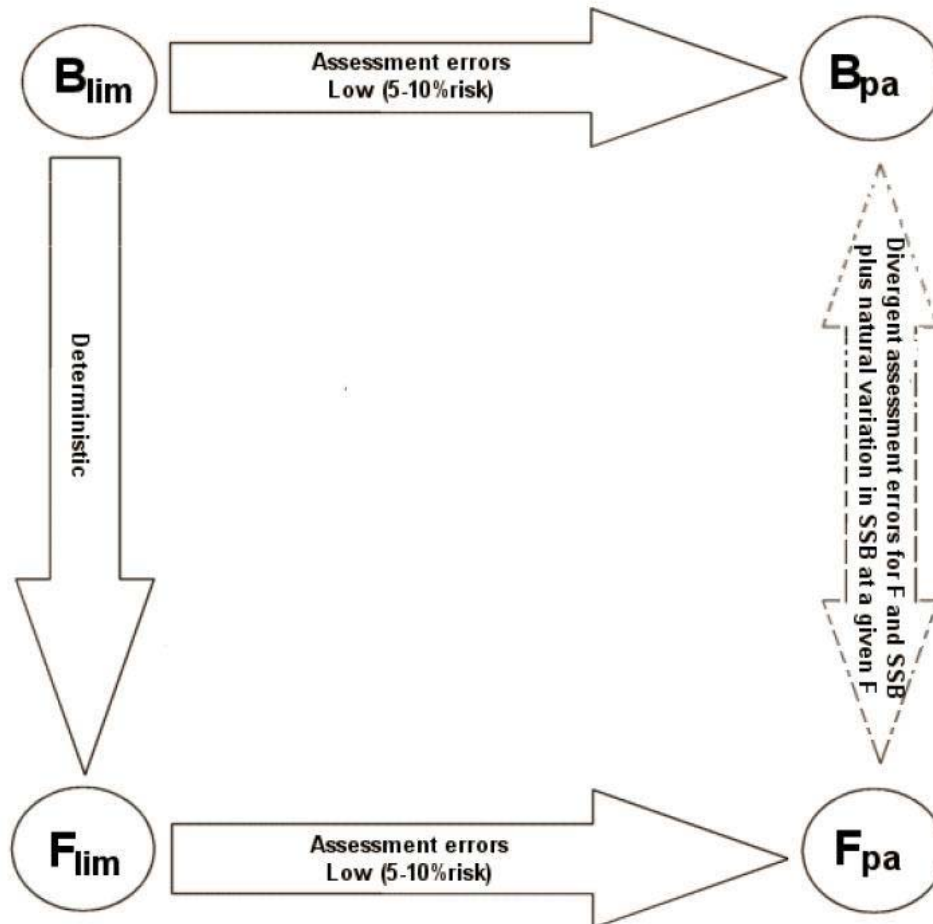
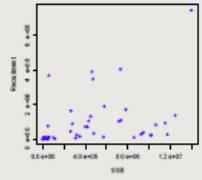
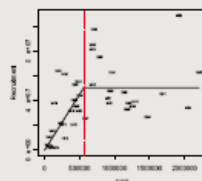
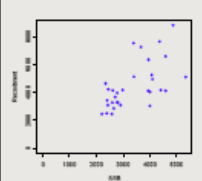
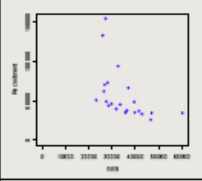
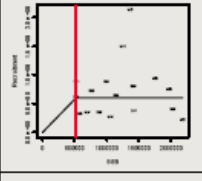
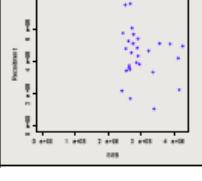


Figure 1. Scheme of derivation of limit and PA reference points (ICES 2003a)

$B_{lim}$  should be the SSB below which there is a substantial increase in the probability of obtaining reduced (or ‘impaired’) recruitment i.e. the estimate of  $B_{lim}$  should be risk averse, so that when the stock is at  $B_{lim}$  the probability that recruitment is substantially impaired is still small, but below  $B_{lim}$  that probability increases. Since the aim is to prevent impaired recruitment due to low SSB, then for those stocks where the stock-recruitment diagram is dome-shaped (i.e recruitment is reduced at both low and high SSB) it is the left-hand part of the stock-recruitment curve that is being considered.

Following the SGPA meeting in December 2002 (ICES, 2003a), a dedicated Study Group on Biological Reference points for Northeast Arctic cod (ICES, 2003b) implemented the proposed approach by SGPA. The Study Group on Precautionary Reference Points for Advice on Fishery Management (ICES, 2003c) estimated  $B_{lim}$  values for most stocks based on segmented regression and the recruitment typology for the different stocks.

Stock characteristics			Limit point estimation options dependent on data and specific stock information		
Stock type	S/R plot characteristics	Sample S/R plot	$B_{lim}$ estimation possible according to standard method	$B_{lim}$ estimation possible on basis of stock-specific method or judgement	$B_{lim}$ estimation not possible
1 Data poor situation	Not available				Present alternative basis for advice
2 Short-lived 1-time spawners				( $B_{loss}$ )	
3 Spasmodic stocks – occasional large year classes				Mortality based reference points such as $F_{loss}$ based on normal recruitment situation.	
S/R signal	4 Clear change point (slope line and plateau)		$B_{lim}$ Segmented regression change point		
	5 Relationship between S and R, no clear change point (there seems to be a positive slope but the plateau is not evident)			$B_{lim}$ may be close to highest SSB observed. Decision dependent on evaluation of historical fishing mortality	
	6 Inverse S/R relation (there seems to be a negative slope)		No LIMIT point, only PA point. ( $B_{loss}$ candidate for PA point)		
	7 Distinct plateau (wide range of SSB)		$B_{lim} = B_{loss}$		
No S/R signal,	8 No apparent plateau (narrow range of SSB)			No LIMIT point, only PA point ( $B_{loss}$ is candidate for PA point dependent on considerations involving historical fishing mortality)	

**Figure 2. SGPRP classification of stock-recruitment types and approaches to Blim.**

After SGPRP, the process of revising the limit and precautionary reference points has halted with a shift in focus towards target reference points.

The ICES interpretation of the precautionary approach has never been formally evaluated, except in some example cases. This was noticed by one of the stakeholder participants during the SGMAS 2007. A formal evaluation would consist of a HCR evaluation where the uncertainty in the assessment and forecast process would be taken into account.

**WKREF recommends** that evaluations of the standard ICES interpretation of the precautionary approach be carried out and be presented during the WGMG 2007, e.g. using the FLR framework.

The renewed focus on limit reference points is closely linked to the introduction of the ecosystem approach to fisheries management. The WKREF should oversee the process of reviewing and updating existing limit reference points for specific stocks in which indications exist that effects of species interactions and regime shifts have influenced productivity of the stocks substantially or assessments have undergone recent substantial revisions.

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## 3 Limit reference points

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### 3.1 General approach

ToR a) of WKREF asked the meeting “to review and update the biological basis of limit reference points for fish stocks, taking into account the possible effects of regime shifts and species interactions.” In particular WKREF were asked to consider the limit reference points for North Sea herring, Norwegian spring spawning herring, North Sea and Eastern Baltic cod, and Kattegat sole. In addition WKREF decided it was appropriate to consider the reference points of Faroe haddock and saithe, since SGPRP (ICES, 2003a) suggested such a review. Finally, the change in recruitment dynamics of blue whiting since the establishment of the reference points in 1998 justify a reconsideration of the limit reference points for that stock.

WKREF could not fully respond to this ToR. In particular the requirement of “*taking into account the possible effects of regime shifts and species interactions*” could not be met for most case studies because of lack of available expertise and data in this area among the participants of the meeting. The exception was Eastern Baltic cod. For this stock large changes in production have been observed in recent decades, and extensive research has been carried out which has attempted to explain these changes by examining the effects of variation in biological parameters and the environment (including species interaction).

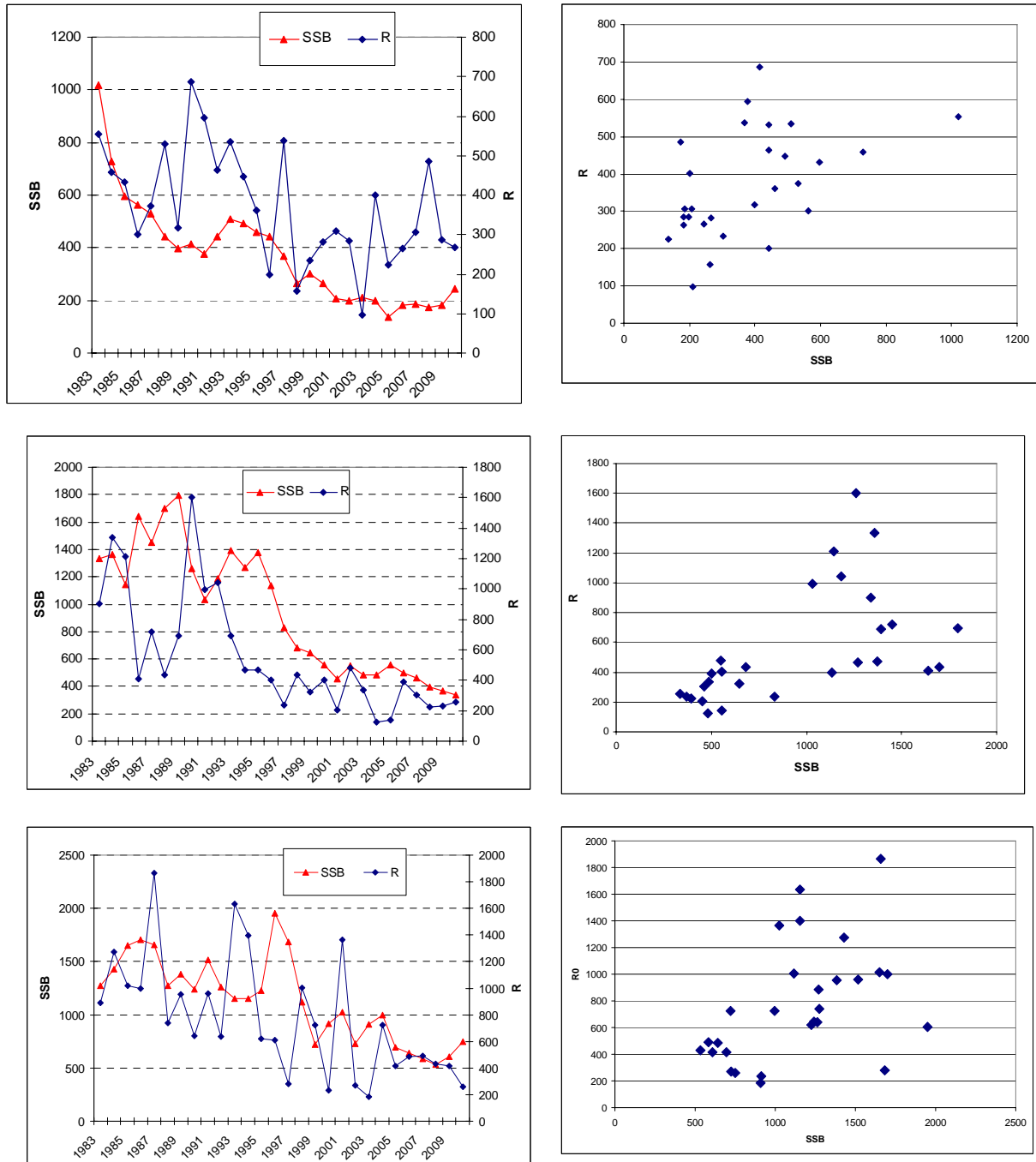
WKREF decided to use the information on Eastern Baltic cod as an example of how to deal with setting limit reference points if such information were available. This case study is considered in detail in Section 3.2.1 below.

For the other case studies, attempts were made to estimate candidates for limit biomass reference points using existing procedures and methods presented and evaluated by SGPA (ICES, 2003b) and SGPRP (ICES, 2003a). In addition a new method, proposed by John Simmonds (WD 04) was tested and further developed. These procedures and methods are based on examining pairs of spawning-stock biomass and recruit observations, and do not take into account changes in biological processes caused by regime shifts, species interaction or changes in stock structure.

A number of working documents were available to the meeting on the process and conditions for setting limit reference points. In addition, a number of presentations on these topics were given. These are summarised in Section 1.3. One conclusion of these discussions was that setting a reference point based on analyses of stock-recruit scatterplots alone will in many cases not be a correct procedure, because it will ignore patterns in stock and recruitment time series. These patterns are often described in terms of statistical autocorrelation and can, in a number of cases, be explained by changes in biological processes, interactions with other stocks or effects of changes in the environment. It was demonstrated with simulated stock data assuming various patterns of change in fishing mortality, and different assumption on auto correlated recruitment, that it is possible to construct stock-recruit scatterplots from these stock data indicating significant stock-recruitment patterns even when the underlying data contained no such assumption (Figure 3.1.1).

Time-series autocorrelation can be a severe problem with parametric stock-recruitment models. If environmental conditions are favourable for several years, it is likely that  $S$  and  $R$  will both rise. Density-dependent mortality will be overestimated, and a potentially spurious stock-recruitment relationship will appear (Hilborn and Walters, 1992). Such time-series bias is caused by "correlation between deviations and subsequent levels of the independent variables when these levels are not chosen through deliberate experimental design" (Walters, 1985). If this is present it can be detected using the standard Durbin-Watson test, and Monte Carlo simulation may be used to estimate its magnitude: an example of such analysis is given in Sparholt (1996). Walters (1990) suggested a tractable means by which the influence of autocorrelated environmental effects may be partially reduced, namely a correction equation for the estimated regression parameters in a two-stage Ricker process. The effect of this is usually to make both estimated terms smaller in modulus (desirable as they are generally overestimated), although the correction will not reveal much about the autocorrelation patterns and will thus not provide better forecasts. Sissenwine *et al.* (1988) described how to incorporate autocorrelation into a parametric relationship by fitting a time-series model to the residuals from the parametric.

Myers and Barrowman (1995) used 131 stocks from a stock-recruitment database (Myers 2000) to test the importance of time-series bias when a Ricker stock-recruitment model is applied to a variety of marine populations. The results of stochastic runs on simulated populations were used in conjunction with species information to give rough estimates of the time-series bias to be expected for each stock in question, and whether it is likely to be problematic. It was found that time-series bias is important for all semelparous (spawning once) species. For iteraparous species (spawning many times), the conclusion drawn depends on the value of  $\alpha$ , the slope of the Ricker curve at the origin. If this is high (as with cod, for example), bias may not be a problem, while it may be so if  $\alpha$  is low. Whatever the estimated value of  $\alpha$ , time-series bias is likely to be present if the stock is over-exploited.



**Figure 3.1.1. Time series of generated SSB and recruitment data and scatterplot of recruitment against SSB. Upper panel presents recruitment following Beverton and Holt dependence on SSB with log-normal distribution at given SSB. In middle panel recruitment is independent on stock size and declines 5% a year with log-normal errors. In lower panel recruitment is fluctuating without trends in first half of the simulated period and shifted to half of the previous values in the second half of the period. In both periods recruitment was disturbed by log-normal errors (further details in Section 1.3, presentation by J. Horbowy)**



### 3.1.1 A probabilistic approach to defining Blim for stocks with low recruitment at low SSB

A working document “Note on a possible approach for defining Blim for NS herring” by John Simmonds FRS Aberdeen (WD4) was presented to the WKREF. The document demonstrated a simple probabilistic alternative approach to setting Blim with the objective to be much less sensitive to recruitment at high biomass than the prevailing SR-methods. The method was scrutinised and further developed at the WKREF as a generic approach to stocks that typically have data on low recruitment at low spawning stock size.

Earlier methods have also considered nonparametric approaches to the stock –recruitment relationship where transition probabilities between different states of high or low recruitment versus high or low spawning stock have been evaluated (Rothschild and Mullen, 1985).

The present approach focus on low stock low recruitment where the concept is that below some level of SSB there is an increased probability of below average recruitment.  $P_{LRi}$  is defined as the probability of recruitment  $R$  falling below some level  $R_{bar}$  when spawning biomass  $B$  is below some level  $B_i$ .

$$P_{LRi} = (N_y | R_y < R_{bar} \text{ and } B < B_i) / (N_y | B < B_i)$$

where  $N_y$  is number of years,  $R_y$  is recruitment in year  $y$ . Thus, for specified reference recruitment  $R_{bar}$  (e.g. long-term average) and for each observed biomass  $B_i$  we count number of data pairs (years) in which biomass was lower than  $B_i$  and recruitment was lower than  $R_{bar}$  and we divide this number by number of all data pairs with biomass lower than  $B_i$ .

This function is expected to be high at low biomass and be asymptotic to the probability of the level of  $R_{bar}$  for the population. The biomass point  $B_{break}$  at which  $P_{LRi}$  reaches the asymptote is the point where the probability of low recruitment increases.

There are several options for choosing the reference level of  $R_{bar}$ , the mean recruitment was initially explored but due to the frequently observed skewness of recruitment distributions a percentile based level was found to be more appropriate.

The function fitted to the observed probabilities  $P_{LRi}$  has to have the capability to gradually decline from a value of 1 down to the asymptotes with a well defined breaking point. A segmented linear model (1) was assumed to approximately have these desired properties, but an inverse logistic curve (2) was also explored.

Each of the two model types were fitted by minimising the residual sum of squares by changing the three basic parameters:

$$(1) f(P_{LRi}) = (I - A) \times (B_{break} - B_i) / B_{break} \times \delta(B_i < B_{break}) + A$$

Where  $I$  is an intercept,  $A$  is an asymptote and  $\delta$  is a switch function being 1 for true and 0 for false.

$$(2) g(P_{LRi}) = 1 - (1 - A) \times (1 + (\text{EXP}(a + b \times B_i)))^{-1}$$

Where  $A$  is an asymptote and  $a$  and  $b$  are coefficients in an exponential function  $\text{EXP}$  of biomass  $B_i$ . The functions were fitted by solver in EXCEL.

For a more theoretical exploration of the probabilistic approach a synthetic SRR was set up based on the example of North Sea Autumn spawning herring. Three SRR curves with different levels of noise were explored 1) Beverton-Holt, 2) Ricker and 3) hockey stick.

The exploration of the method indicated a potential problem of inaccuracy with the linear two segment function for stocks with many data points of low recruitment at low biomass, where

the first many values of  $P_{LRi}$  are 1 and therefore rather suggests a three segment solution. The logistic function does to some degree solve this problem.

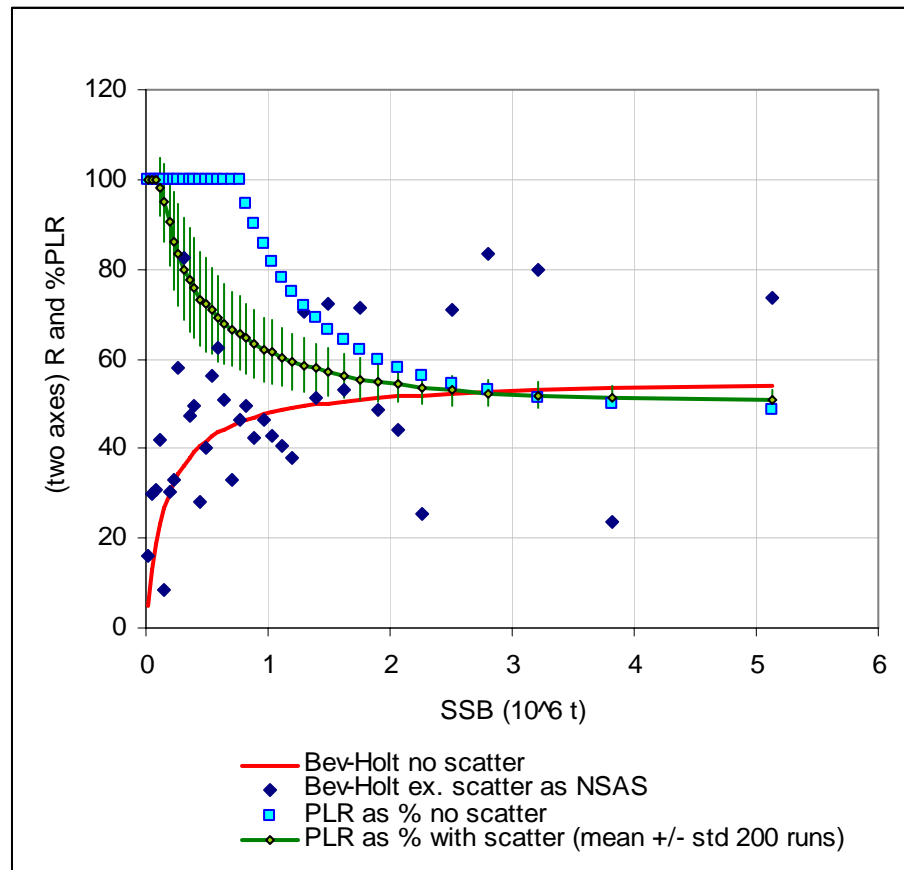
A more serious theoretical problem is the inherent curvature of the probability function after the initial series of  $P_{LRi} = 1$ , due to the decreasing distance in  $P_{LRi}$  following the relationship  $\Delta P_{LR} = \text{perc}(N)/i - \text{perc}(N)/(i - 1)$  and the increasing distance between  $B_i$  values  $\Delta B_i$  increasing at the high end of the B distribution. This problem appears independent of any particular stock-recruitment curve and may best be illustrated by a synthetic SRR with a close relationship between R and SSB (Figure 3.1.1.1).

The increasing distance  $\Delta B_i$  may be eliminated by using ranked  $B_i$  values. However, there remain some undesirable relationships between the behaviour of the probability function and the scatter of the SRR, i.e. with higher scatter of recruitment versus SSB the decreasing limb of the  $P_{LRi}$  -curve is steeper, having the doubtful quality of a higher SSB-break-point with a closer association between R and SSB. The problem is illustrated by a series of simulations using the synthetic population with an assumed underlying Beverton-Holt SSR and joint bivariate SSB - R distribution similar to North Sea autumn spawning herring (see Figure 3.1.1.1).

It may be possible that a more detailed analysis of the recruitment scatter on the  $P_{LRi}$  -distribution will reveal some transformation that makes the convergence towards the reference level independent of variation in the SRR.

The choice of reference level was considered to some degree but no decision rule for choosing the actual recruitment percentile was made. It may be noted that if it is desirable to set a relative low reference level where the probability of getting recruitment values e.g. below the low 10% percentile the number of observations making up the sloping and horizontal parts of the function will be unbalanced with possible consequences for the robustness of the method.

The following theoretical example is an illustration of how the calculations are carried out.



**Figure 3.1.1.1. Illustration of the influence of scatter in stock-recruitment relationship on the  $P_{LR}$  distribution with increasing SSB. The example is contrasted between no SSR variation and 200 simulation with a Beverton - Holt curve based on NSAS.**

A last reflection is that if it is assumed that density dependence reduce recruitment to lower than average values at high SSB then the method may be inverted to study the change in probability of low recruitment from the highest SSB towards lower values. This approach was tried for several options of selected time intervals. The result was expectedly less robust than the opposite.

WKREF concludes that the probability aspect of the method has interesting possibilities because it can specify the probability of obtaining low recruitment. However, the method appears to have some theoretical weaknesses because it does not allow a strict definition of a breakpoints because of the inherent curvature of the probabilistic approach. Further the curvature of probability for low recruitment is dependent on variation in SSR. The method needs further exploration on different typologies of SRR relationships before it can be applied in an advisory context.

## 3.2 Case studies

### 3.2.1 Baltic cod – eastern stock

#### History of reference points for Baltic cod

The first attempt to determine Blim and Bpa was conducted by SGPA (ICES, 1998a) suggesting a Blim equaling to Bloss of 79 000 t. Bpa and Fpa were determined according to Cook (1998) as 140 000 t (Blpg) with a corresponding Fpa of 0.81 (Flpg). Data for 1976–1996 were used because assessment data prior to 1976 was judged to be of poor quality.

SGBFS (ICES, 1998b) did not follow these suggestions, but determined Bpa as 240,000 t and Blim as 160 000 t. Bpa corresponds to the former MBAL estimate derived from a Ricker stock-recruitment relationship (with data covering 1976–1994) as the SSB at which 50% of the maximum recruitment (age-group 2) is originated, following a procedure suggested by Myers *et al.* (1994).

The Blim was derived from the Bpa value using the formula proposed by ICES (ICES, 1998a):

$$\text{Blim} = \text{Bpa} \cdot \exp(-1.645 \cdot \sigma)$$

where  $\sigma$  is the standard error of the total biomass estimate assumed at 0.25. . These reference points were determined from SSB values calculated using constant maturity ogives and constant weight-at-age for age-groups 1-3 over the whole period and for age-groups 4-8 for two time periods (1976–1982 and 1991–1993). A revision of the weight at age and maturity at age was conducted by the WGBFAS in 1997 (ICES, 1997), as time trends in weight at age and maturity ogives were detected (ICES, 1997). However, the biomass reference points were not updated accordingly.

Fpa was set to 0.75 or 0.65 (accounting for recent changes in growth) based on medium-term simulations. The goal was to determine an Fpa at which there is less than 10 % probability of SSB being below Blim. The medium-term simulations applied a Beverton and Holt stock recruitment relationship fitted to year-classes 1981–1995, thus omitting extraordinary high recruitment originated in preceding years, assuming log normal error. This period selection was justified by changed environmental conditions leading to on average lower recruitment in 1980's and 1990's. The underlying SSB was calculated using the updated weight at age and maturity ogives from ICES (1997) and for the simulation part average weight at age for the periods 1992–1996 and 1983–1987 were applied, the latter being lower than the former and thus accounting for a declining trend of weight at age in the 1990's.

WGBFAS (ICES, 1998c) revisited the Fpa determination again and based on the same methodology and stock recruitment relationship, but slightly changed input data for the simulation part Fpa was determined as 0.65 leading to an SSB corresponding to the 10% lower fractile of SSB's above Bpa. The simulations utilized an average weight at age, maturity ogive and exploitation pattern determined for the period 1995-1997.

ACFM in 1998 finally revised Fpa to 0.6 as the 5% percentile of Fmed derived from a stochastic stock recruitment relationship covering year-classes 1966–1995 applying updated weight at age in the stock as described above, but period specific maturity ogives (averages over 5 years) up to 1994 and afterwards yearly data. The limit fishing mortality Flim was set to 0.96 determined as Fmed.

An Fpa of 0.6 and Flim of 0.96 are the officially adopted limit reference points.

SGBFS (ICES, 1998b) and WGBFAS (ICES, 1998c) suggested to determine the F reference points with a truncated time series to account for productivity shifts in the Baltic system leading to reduced recruitment success since the first half of the 1980's. The impact of such a truncation of the time series on biomass reference points was explored by SGPA (2002) applying segmented regressions, concluding on page 36:

*“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 to 1986 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 Blim 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” (ICES, 2002, p. 36)*

*“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.” (ICES, 2002, p. 40)*

SGPA’s general conclusions on the role of environmental variables were:

- 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 ...
- 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 (SGPA 2002, p 40)

SGPA (ICES, 2003b) worked more conceptually on the links between reference points, and the related sources of uncertainty and risk as well as more generic aspects of different methods determining reference points. It did not specifically address the Baltic cod case. It did however raise the question of a potentially negative impact of revising biomass reference points downwards in a low productivity regime and getting stuck to these reference points when changing again to a high productivity regime.

SGPRP (ICES, 2003a) developed a framework for the revision of reference points, stating with respect to the Eastern Baltic cod (page 5):

*“The relation between stock and recruitment (and thus Blim) may change if the natural regime changes. This has been demonstrated to be the case in the Baltic (Köster et al., 2001a, 2001b). In such cases it could be relevant to limit the analysis to data representing the present regime. Such a procedure should however be implemented with caution because it will be difficult to identify the extent of a regime period and because a precautionary approach should include a consideration that the regime may have changed recently or may do so in the near future. An alternative approach could be to focus on reference points based on fishing mortality rather than biomass. This would require a specific framework to be developed because the F reference points in that case might need to be dependent on the state of the biomass.”*

In 2005 the WGBFAS dealt with the necessity to revise the limit reference points for Eastern Baltic cod stating that medium-term projections indicate a substantial reduction in F to be required to have a reasonable probability of rebuilding the stock above Bpa in the medium term. The stock has been below Blim since 1991, except for a brief period around 1995 when it rebuilt in response to a reduction in fishing mortality. There are no indications that recruitment has been further diminished due to this low stock size. Instead the indications are that the reduction in recruitment is primarily environmentally driven and that the spawning stock has decreased following the decline in recruitment rather than vice versa.

WGBFAS pointed further out that the stock and recruitment data do not indicate any difference in recruitment above and below the existing Blim value of 160 000t. As a result it is difficult to justify the existing Blim, although for similar reasons it is equally difficult to suggest a more appropriate value. Based on the segmented regression approach, WGBFAS determined a breakpoint to be approximately 90 000 t, representing a candidate for replacement of Blim.

WGBFAS in 2006 (ICES, 2006a) reiterated that the strong environmental influences on the recruitment of Eastern Baltic cod may mean that it is impossible to define a single biomass value below which recruitment is impaired. WGBFAS noted that there is a tendency to downplay the role of limit reference points for management advice in favour of target reference points (e.g. ICES, 2005b, 2006b), but that limit reference points are likely needed for establishment of future management plans and evaluation of these to be precautionary, and not least because council regulation 2371/2002, separates between recovery plans for stocks being in a depleted state and management plans for stocks being within safe biological limits requiring a definition when one or the other state is reached.

### **Conclusions on the history of reference points**

The conducted review of data sets and methodology used to determine the present limit reference points for Eastern Baltic cod made clear that the F reference points are based on an assessment revised with respect to weight at age and maturity ogives in 1997, while the biomass reference points are based on an older assessment. The biomass reference points are also not based on the full data series from 1966 onwards available, but start in 1976 with the period of outstanding high recruitment, while the F reference points determined by ACFM in 1998 are based on the entire time series. As such the F and biomass reference points are not consistent and the biomass reference points cannot be considered as adequately determined.

These inconsistencies are also obvious from simulations conducted by AGLTA (ICES, 2005b) and SGMAB (ICES, 2005c) suggesting that rebuilding to Bpa in the medium-term is impossible when fishing at Fpa and that rather a reduction to about half of Fpa is required to achieve this.

According to ICES (2005a), the eastern Baltic cod stock has been below or close to Blim in the last 15 years and there are no indications that recruitment has been further diminished due to this low stock size. Instead the indications are that the reduction in recruitment is primarily environmentally driven and that the spawning stock has decreased following the decline in recruitment rather than vice versa. As a result it is difficult to justify the existing Blim, although for similar reasons it is equally difficult to suggest a more appropriate value.

Based on elaboration by SGPA (ICES, 2002) and SGPRP (ICES, 2003a), the apparent change in productivity should be considered by identifying environmental regimes, either by separating time series into shorter periods of similar environment, but preferably by incorporation of the environmental drivers into stock recruitment relationships. Identification of different productivity regimes requires sound understanding of the underlying processes driving the stock in questions and related system components including presentation of data substantiating the shift in regimes.

A determination of biomass reference points for a specific productivity regime requires rules on revision procedures to be evoked if the regime shifts into another state, with indicators how to measure these being in place and monitored. This includes as well rules on related time lines of actions and identification of actors.

WKREF concludes that there are inconsistencies in the way the fishing mortality and biomass reference points have been established. The biomass reference point need revisiting in the

light of the new information that is now available. Evaluation of management plan should take account of different environmental regimes and possible new reference points.

### **Regime shift in the Central Baltic**

This section presents a summary of Annex 1 on environmental aspects in relation to Baltic cod. More details can be found in the Annex.

The upper trophic levels of the Central Baltic changed during the last 25 years from a cod- to a sprat-dominated system (Alheit *et al.*, 2005). The decline of the cod stock was caused by a recruitment failure, which was mainly driven by: i) anoxic conditions in deep water layers of eastern spawning sites causing high egg mortalities, ii) high egg predation by clupeid predators in the remaining productive spawning area, iii) reduced larval survival due to the decrease in abundance of the main food item *Pseudocalanus acuspes*, and iv) high juvenile cannibalism at high stock size. The intensity and significance of all these processes are in one way or the other steered by the hydrographic conditions, which were in the 1990's characterized by low salinity due to lacking inflow of saline water from the North Sea and increased river run off, but as well by warmer thermal conditions (Köster *et al.*, 2005). An increasing fishing pressure accelerated the decline of the cod stock, with current exploitation levels being still on a very high level.

The decline of the cod stock released sprat from predation pressure, and in combination with high reproductive success, due to in general favourable temperature conditions, this resulted in exceptionally high sprat stock sizes in the 1990s (Köster *et al.*, 2003a). The sprat stock affected cod recruitment negatively by acting as predator on cod eggs and on *Pseudocalanus* adults (Möllmann *et al.*, 2007), thus affecting the production of food for cod larvae. Indications for compensatory processes in growth, maturation and individual egg production exist for both species (Köster *et al.* 2003a, Möllmann *et al.*, 2005), however, appear to be of limited impact on the overall stock and system dynamics.

Concurrent with a shift from a cod to a sprat dominated system, the meso-zooplankton community showed pronounced changes as well (Hänninen, *et al.* 2000; Dippner *et al.*, 2000). While the marine copepod zooplankton declined in abundance, the neritic copepod species *Acartia spec.* and *Temora* increased in abundance, mainly caused by increasing winter temperatures.

Furthermore, climate mediated changes in the Baltic ecosystem during the 2nd half of the 1980's are apparent for lower trophic levels as well (Alheit *et al.* 2005, ICES, 2006c). This regime shift cannot be allocated to a single year or event, as the response time of different species and life stages depends on whether the critical environmental factor is oxygen concentration or salinity in the deep Baltic basins, or water temperature in bottom or intermediate water layers.

Cod egg survival already declined in eastern spawning areas with the absence of inflows in 1981 and 1982, while it declined in the Bornholm Basin not before 1986. Cod larval survival, being coupled via *Pseudocalanus* production to salinity, was seriously affected in eastern spawning areas in the 2nd half of the 1980's and in the Bornholm Basin after an extended stagnation period and increased predation pressure by sprat in early 1990's. The decline in the cod stock released sprat from predation pressure, but the low temperatures until winter 1986/87 prevented a successful sprat recruitment before 1988. Similarly, *Acartia spp.* production increases first in 1988 sustaining high sprat larval survival.

In conclusion, while cod recruitment declined at high SSB already in the first half of the 1980's a shift in a series of environmental conditions caused a further decline in cod reproductive success in the second half of the 1980's. While major inflows in 1986 and/or 1987 could have halted the development, the major inflow in 1993 came too late to destabilize

the new regime state. If choosing a date for a regime shift, 1987 or 1988 are thus the most obvious candidates.

### **Candidate limit reference points for Baltic cod**

As described in the preceding section, Eastern Baltic cod recruitment is to a considerable extent driven by environmental forcing, which in turn means that recruitment is partly driving the stock biomass and not only vice versa. A regime shift in environmental conditions and upper trophic level ecosystem structure is well documented for the Baltic in the 1980's. This has led to the separation of stock recruitment relationships into two levels representing favourable environmental conditions until early 1980's and after a transition phase unfavourable hydrographic conditions (Jarre-Teichmann *et al.*, 2000). This separation into two distinct environmental regimes has been acknowledged by SGBFS (ICES, 1998b) when determining the present F reference points. While SGBFS (ICES, 1998b) considered stock and recruitment data from 1981 onwards, new information presented in the preceding section suggests that the shift into another regime happened gradually between 1981 and 1987 and consequently, the present Group suggests to utilize data series from 1987 onwards only if environmental variables are not directly included in stock-recruitment model. A variety of different methods was applied to estimate Blim:

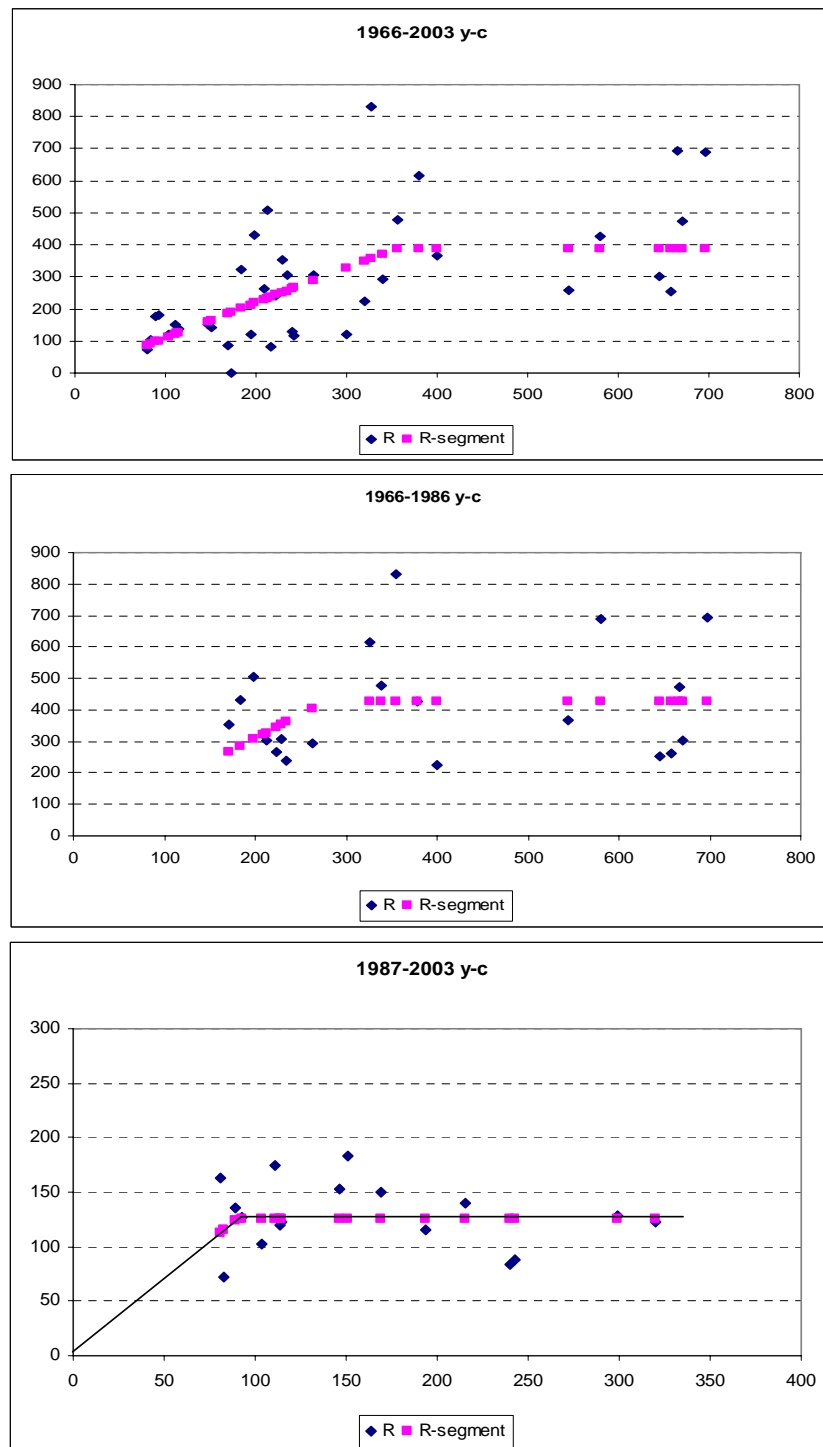
- 1) segmented regression (ICES, 2002),
- 2) method used by ICES (1996) to determine MBAL according to Myers *et al.* (1994) applying a Ricker stock - recruitment relationship,
- 3) Simmonds methods (described in Section 3.1.1.),
- 4) inclusion of reproductive volume as additional variable in a Ricker stock-recruitment relationship.

In order to explore the sensitivity of the methods to the truncation of the time series, alternatively the entire time series from standard assessment output (1966–2003) and the period characterized by more favourable hydrographic conditions (1966–1986) from standard assessment output were applied. In addition, an extended assessment time series (without uncertain years directly after the 2nd world war from Eero *et al.* (2007) was applied for method 4). In all cases recruitment at age 2 was considered, but in order to test for the sensitivity of the methods to cannibalism, methods 1) and 2) were applied additionally to recruitment at age 0 from MSVPA output (ICES, 2006d) for the time series 1987–2003.

### **Segmented regression**

The segmented regression fitted to the stock and recruit pairs, from a standard stock assessment output covering the years with poor environmental conditions (1987–2003) indicates a breaking point of 91 000 tons with bootstrap CV of 16%. Using the years characterized by favourable conditions (1966–1986) resulted in a breaking point at 280 000 tons (Figure 3.2.1.1). Using the entire time series (1966–2003) results in a higher breakpoint of 366 000 tons (Figure 3.2.1.1). Applying the MSVPA derived recruitment at age 0 results in corresponding breakpoints of 109 000 tons for the time series 1987–2003 (Figure 3.2.1.2).





**Figure 3.2.1.1. Eastern Baltic cod. Segmented regression for SSB – R relationship at age 2 (XSA) for the full time series (year-classes 1966–2003, top), year-classes 1966–1986 (middle) and year-classes 1987–2003 (bottom)**

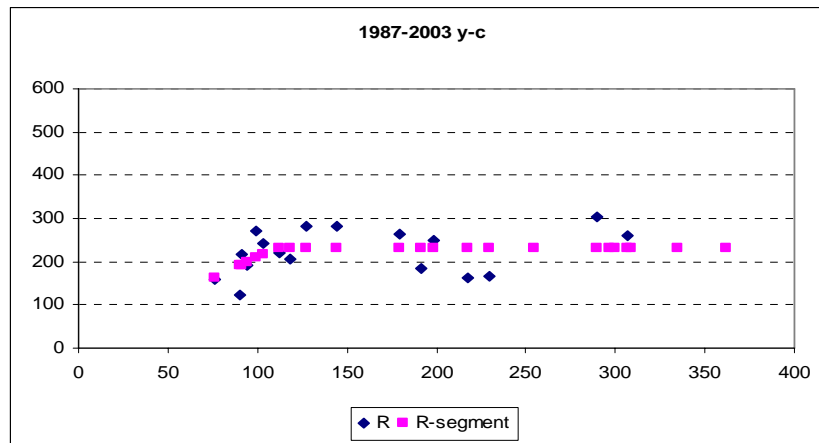


Figure 3.2.1.2 Eastern Baltic cod. Segmented regression for SSB – R at age 0 relationship (MSVPA) for year-classes 1987–2003

#### Myers *et al.* (1994) method for estimating MBAL

A re-analyses using the methodology applied to determine MBAL was conducted in which the spawning stock biomass is determined as the point on the curve where expected recruitment is half of the maximum value (Myers *et al.*, 1994). The analyses revealed that threshold SSB levels are different under different environmental regimes (Figure 3.2.1.3). In the recent period (1987–2003) the half of maximum recruitment is observed at SSB around 50 000 tons compared with around 150 000 tons in the period with favourable environmental conditions (1966–1986). In addition, for the whole time series that includes both favourable and unfavourable environmental conditions the corresponding biomass was determined as ca. 210 000 tons. Utilising recruitment at age 0 from MSVPA for 1987–2003 showed no significant differences in SSB threshold levels compared to recruitment age 2 (~60 000 tons), see Figures 3.2.1.4-5.

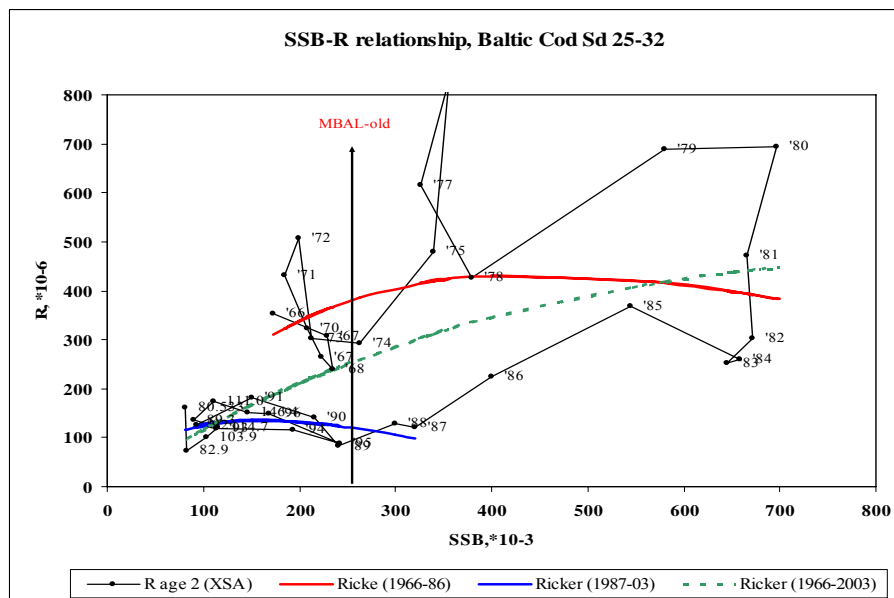


Figure 3.2.1.3. Fitted Ricker S-R relationship on standard XSA assessment data sets for different time periods.

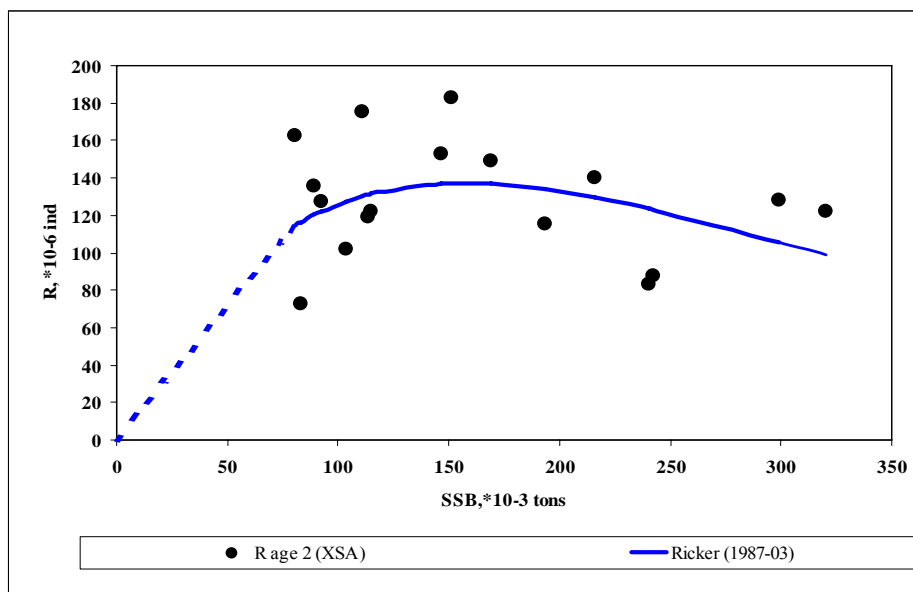


Figure 3.2.1.4. Fitted Ricker S-R relationship. Recruitment at age 2 from XSA for the recent period of an unfavourable environmental regime.

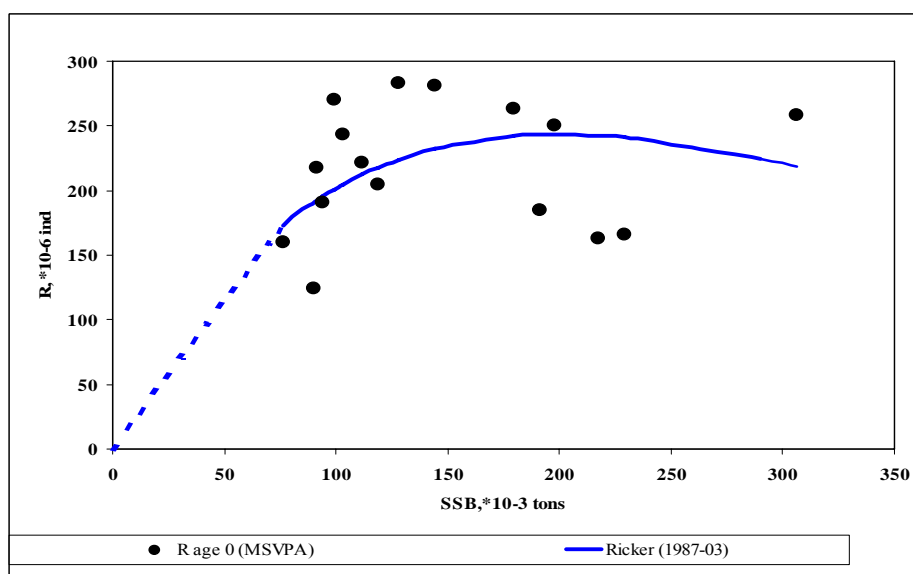
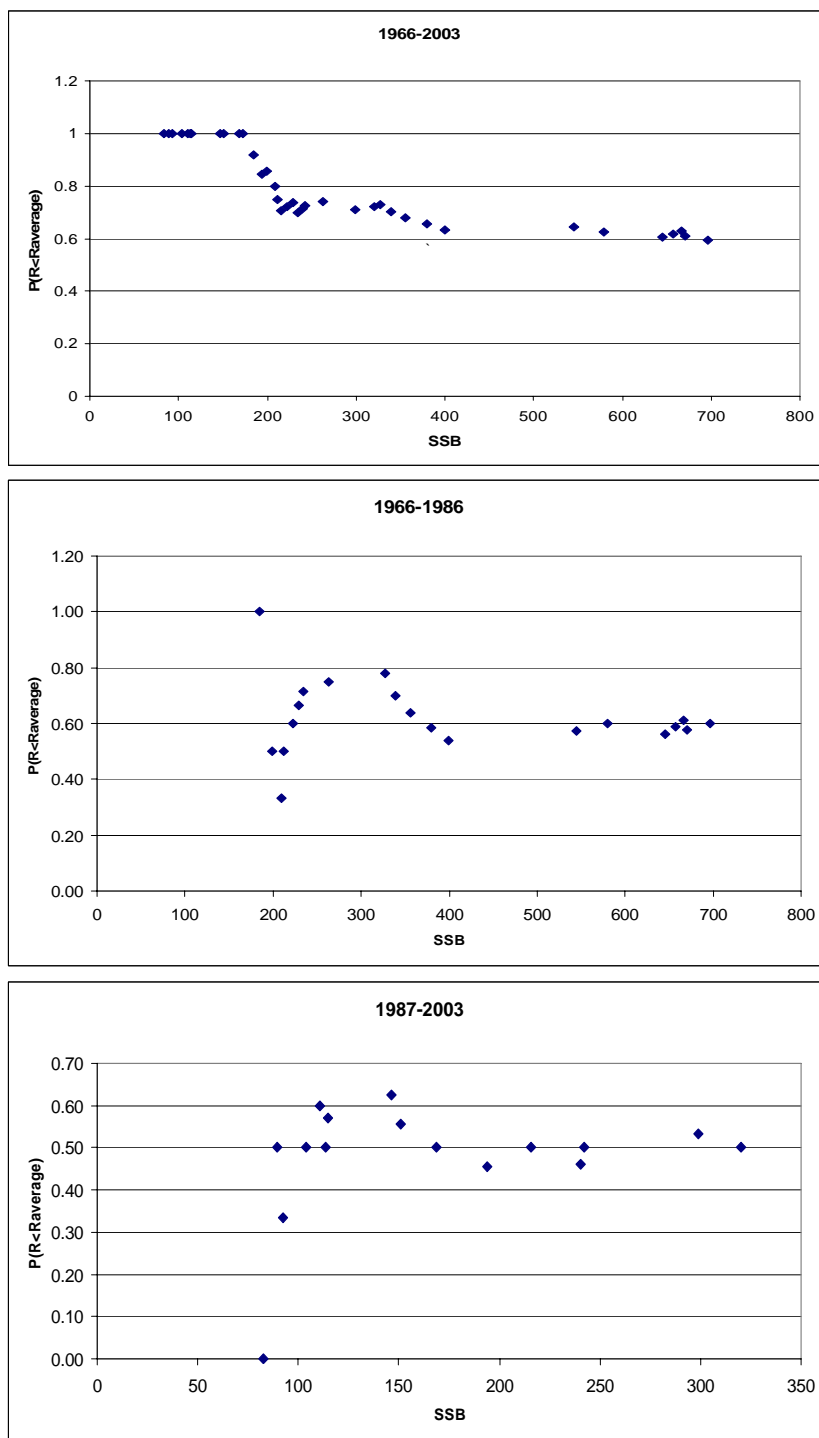


Figure 3.2.1.5. Fitted Ricker S-R relationship. Recruitment at age 0 from MSVPA for the recent period of an unfavourable environmental regime.

### “Simmond’s method”

The probabilistic method proposed by John Simmonds (see Section 1.3, WD4) was applied covering the same standard XSA output for the three different time periods (Figure 3.2.1.6). The results depend on the length of time series and only when all data points are included a clear breaking point is indicated (beginning of the asymptote, ca. at 400 000 tons). The method applied to period of poor environmental conditions indicates that for the spawning stock biomass in the range of 100 000–300 000 tons there is about 50% probability of having below (or above) average recruitment. Thus, recruitment is not dependent on stock size at this range of SSB.

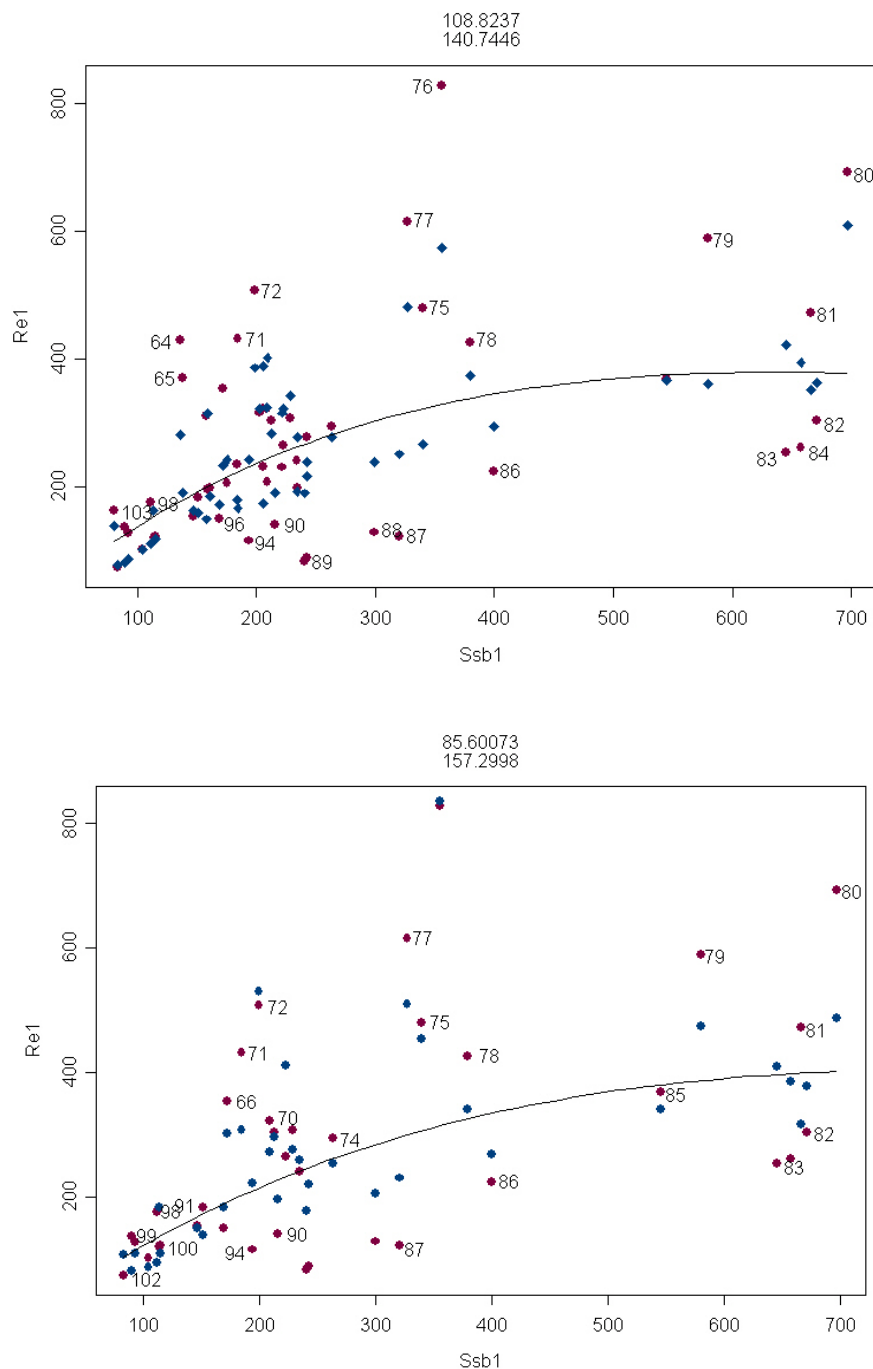


**Figure 3.2.1.6. Eastern Baltic cod. Probability of recruitment at age 2 being lower than average at given SSB for all yearclasses 1966–2003 (top), yearclassess 1966–1986 (middle) and yearclasses 1987–2003 (bottom).**

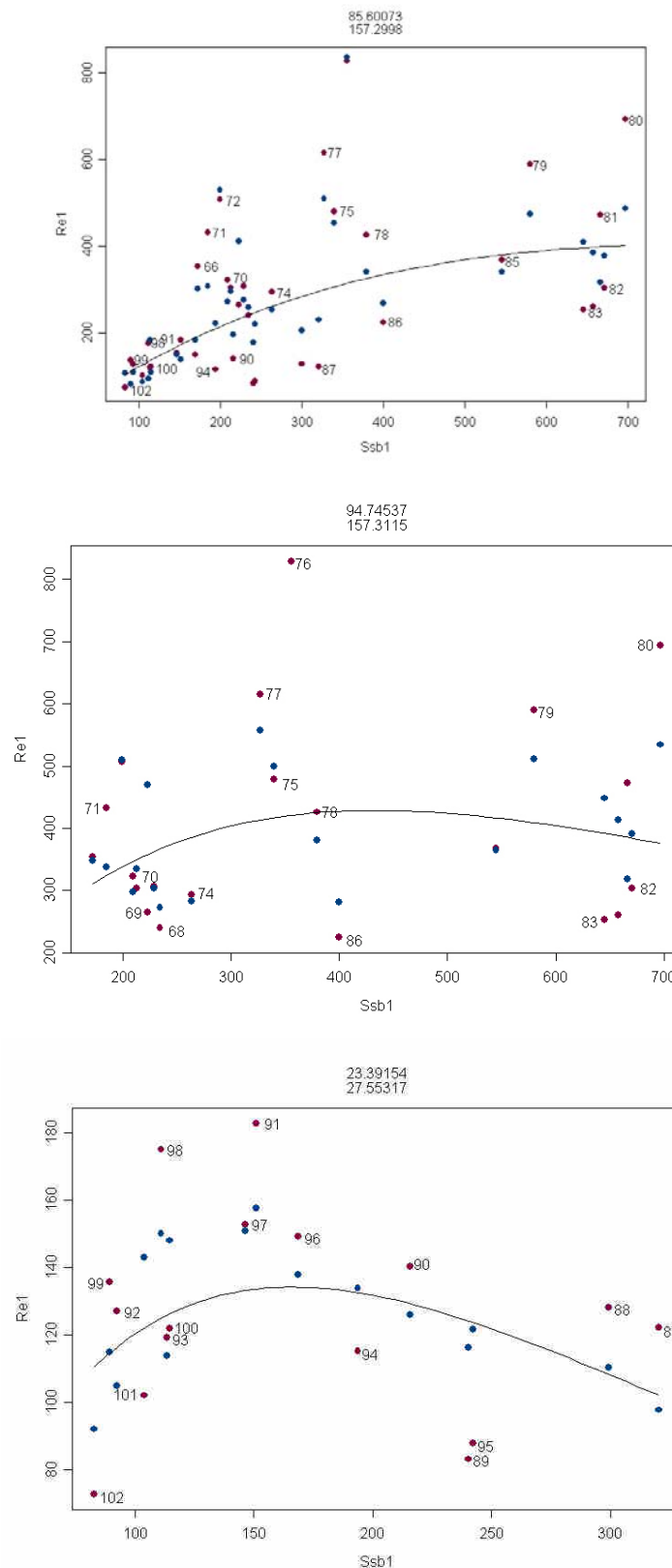
#### **Environmental sensitive stock recruitment relationship**

The reproductive volume at spawning time was included as variable into a Ricker stock recruitment relationship. Reproductive volumes were available for the period 1952–2003. The technical aspects of the methodology are described in Annex 2. The results are presented below.

A Ricker stock recruitment relationships based on the extended assessment output (1952–2003) incorporating the reproductive volume in the year of spawning exhibits an improved fit to the data compared to the standard Ricker model (Figure 3.2.1.7). Including the reproductive volume in the year following the spawning improves the fit further (Figure 3.2.1.7). Using only the standard assessment output (1966–2002) shows a better fit than using the entire time series (Figure 3.2.1.8). Fitting a Ricker stock recruitment relationship based on standard assessment output covering the periods of favourable and unfavourable environmental conditions, i.e. 1966–1986 and 1987–2002 respectively, revealed as well reasonable fits to the data (Figure 3.2.1.8).



**Figure 3.2.1.7. Ricker stock recruitment relationship based on extended assessment output (1952-2003), taking into account the reproductive volumes in spawning years (top) or in spawning years and in the following years (bottom). (●) – observed, (◆) – calculated by model 6 (see Annex 2). Numbers above the figure, upper: standard deviation between “observed” (XSA) recruitment values and those calculated with model (6); lower: standard deviation between “observed” (XSA) recruitment values and those calculated with the traditional Ricker model.**



**Figure 3.2.1.8. Ricker stock recruitment relationship based on standard assessment output covering the following periods: full time series (top), favourable environmental conditions (1966–1986, middle) and unfavourable conditions (1987–2003, bottom). Reproductive volumes in the spawning and the following year taken into account. (●) – observed, (◆) – calculated by model 6 (see Annex 2).**

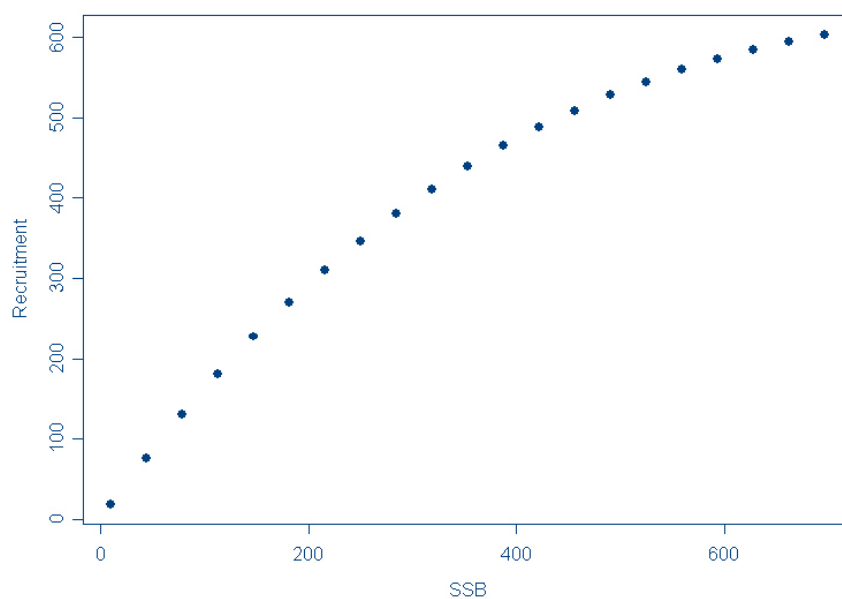


Figure 3.2.1.9. visualizes the response of recruitment to changes in SSB for the model fitted to data covering the period 1966–1986 and 1987–2002 at favourable (average reproductive volume (RV) for the period 1966–1986: 270 km<sup>3</sup>) and unfavourable environmental conditions (average RV for the period 1987–2003: 153 km<sup>3</sup>). While recruitment under favourable environmental conditions increases with increasing SSB at considered SSB range, the derived relationship for unfavourable conditions shows a maximum at ca. 150 000 tons. Half of maximum recruitment (Myers *et al.* (1994) approach for MBAL) would then be at ca. 50 000 tons.

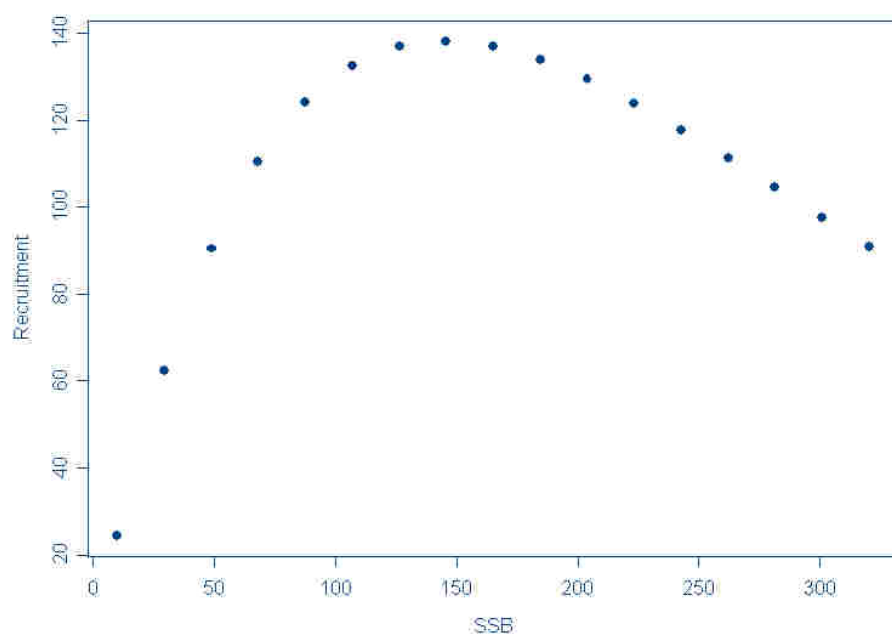


Figure 3.2.1.9. Prediction of recruitment in 1966–1986 at average high RV (269.8, top) and in 1987–2003 at average low RV (153.3, bottom) for various SSB to demonstrate the response of SR models to changes in SSB.



### Discussion on limit reference points for Baltic cod

The segmented regression produced a breakpoint of 91 000 tons for the stock recruitment time series derived from standard assessment output covering years 1987 onwards. However, the point is not well estimated and the scatterplot of data points suggests that recruitment is not dependent on SSB above ca. 90 000 tons. . The use of entire assessment time series (1966–2003) reveals a breakpoint of 356 000 tons, which is considerably higher than the breakpoint of 278 000 t. derived when using the time series characterized by favourable environmental conditions alone (1966–1986). This seems to be inconsistent and can be explained by the higher contrast in the data. When utilizing MSVPA output, the breakpoint for the data series 1987–2003 is 109 000 tons and thus quite similar to the one determined on basis of the standard assessment output. Utilizing the entire time series, however, results in a unrealistically high breakpoint of 780 000 tons.

The method proposed by Myers *et al.* (1994) applied earlier to estimate the present Bpa value produced very low values outside the observed data range when using data from 1987–2003, independent whether a Ricker or Beverton and Holt stock recruitment relationship is used. Using the data series characterizing favourable recruitment (1966–86) revealed 150 000 ton as candidate for Blim, while including the entire data series increased it to about 200 000 tons. Applying MSVPA derived data resulted for the time series 1987–2003 resulted in a very similar unrealistically low Blim candidate.

Results from Simmonds methods were very dependent on the time series applied. For the data since 1987, the interpretation is that at above ca. 100 000 tons the probability of having above or below average recruitment (as observed in 1987–2003) is 50%. However, at lower SSB the recruitment is in fact higher indicating only that there is no stock recruitment relationship apparent in the data. The result for the period of favourable environment are also inconclusive. This method cannot be applied to derive a limit reference point (see also discussion in Section 1.3)

Inclusion of the reproductive volume as additional variable in stock recruitment relationships resulted in an overall improved fit over all time periods compared to a corresponding fit of the traditional environmentally insensitive model, but application of a model based on the entire time series to an environment characterised by low reproductive volume overestimated recruitment substantially. This indicates that RV alone does not explain recruitment variability, and more complex approaches are needed to utilise the entire time series. Splitting the time series and refitting the model to data from 1987–2002, revealed a dome-shaped response to SSB at average reproductive volumes with a maximum at 150 000 tons, but a relatively flat contour between 100 000 and 200 000 tons.

It should be noted that stock recruitment relationships of Eastern Baltic cod are uncertain, as the assessment output suffers from:

- 1 ) poor landings data, i.e. under- and misreporting since early 1990's,
- 2 ) uncertain discard data, which may affect recruitment estimates,
- 3 ) age reading problems that affect the determination of the age structure of catches.
- 4 ) Questionable data quality prior to 1970.

### WKREF Conclusions

On the basis of the material presented, WKREF could not agree on a candidate reference point for Blim. The discussion focussed on the separation in two different time periods for recruitment and on the methodology to derive a limit reference point in such a situation. The preferred methodology would have been to include the main environmental drivers into the estimation procedure and to estimate a limit reference points dependent on level of variables characterising environmental regimes. This could not be achieved during the workshop.

WGBFAS is invited to further develop this methodology and to come with recommendations for a possible revision of  $B_{lim}$ .

### 3.2.2 North Sea cod

#### Historic values

Precautionary Approach reference points (unchanged since 1999). source: ICES, 2006.

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

Technical basis:

$B_{lim} = \text{Rounded } B_{loss} = 70\,000\text{ t.}$	$B_{pa} = \text{Previous MBAL and signs of impaired recruitment below: } 150\,000\text{ t}$
$F_{lim} = F_{loss} = 0.86$	$F_{pa} = \text{Approx. 5}^{th}\text{ percentile of } F_{loss}; \text{ implies an equilibrium biomass } > B_{pa} \text{ and a less than 10\% probability that } (SSB_{MT} < B_{pa}).$

#### *The North Sea cod stock status in 2006*

ICES classifies the stock as being harvested unsustainably and suffering reduced reproductive capacity. SSB is well below the  $B_{lim}$  of 70 000 t. Fishing mortality has shown a decline since 2000 and is currently estimated to be around  $F_{lim}$ . The 2001–2004 year classes are all estimated to have been well below average; the 2005 year class is estimated from surveys to be more abundant, but still below average.

#### *Developments in the North Sea cod assessment*

Since 2004 the age-based assessment model included discards for the first time in the age based assessment. The age range for the reference fishing mortality was reduced from ages 2–7 to 2–4. In addition, because of unreliable information on landings and effort, commercial indices were not used in the assessment. Instead, the assessment used only survey data for calibration. Quantities of additional unallocated removals were estimated by the B-ADAPT model on the basis of the total mortality indicated by the surveys. Unallocated removals estimates were considered to include components due to increased natural mortality and discarding as well as unreported landings. It is, however, assumed that these removals do originate in fishing activities.

WGNSK 2004 (ICES, 2005d) group recalculated the precautionary point reference levels and noted that

*“The revised assessment model and inclusion of discards set has not significantly altered the structure in the scatter plot of the estimates of SSB and recruitment. This implies that the position of the break point in the stock and recruitment plot is unchanged at about 150,000t. There remains a high probability of poor recruitment at SSB below this value. ACFM has previously recommended that this value should be used as Bpa but this is currently under review.*

*Using the previously applied criteria for the selection of fishing mortality reference points (ACFM report 2002)  $F_{lim} = F_{loss}$ , the new deterministic estimate of  $F_{loss}$  for the assessment including discards is 0.94 and the median of the bootstrapped values 1.01. Using the previous ACFM formulation  $F_{pa}$  is therefore taken from the 5th percentile of  $F_{loss}$  and is estimated to be 0.80. This compares with the previous value of 0.65 when the assessment data does not include discards.*

*The working group notes that the  $F_{loss}$  estimate may be an over-estimate. The PAsoft diagnostic plots indicate that non-parametric smoother is over estimating the majority of the recent low recruitment, near to the origin of the stock and recruitment relationship. Given that region around the origin of the stock and recruitment curve is currently being explored, and that there is a well defined curvature in the pairs of estimates, the working group consider that a parametric model estimate of the slope at the origin may be more robust to random variation in recent recruitment. This should be examined in detail before the  $F_{lim}$  and  $F_{pa}$  values are revised.”*

#### *Segmented regression estimation of the North Sea cod stock and recruit breakpoint*

The segmented regression model (O'Brien and Maxwell, 2002) was fitted to the stock-recruitment data of cod in Subarea IV, Divisions IIIa and VIId from the 2006 ICES WGNSSK (ICES, 2006d). The stock assessment model B-ADAPT uses a bootstrap procedure to estimate the uncertainty in the most recent stock and exploitation parameters therefore segmented regression was applied to the median estimates of spawning stock biomass and recruitment at age 1 in order to examine the fitted model diagnostics and to the individual iterations from the assessment bootstrap in order to examine the uncertainty associated fits.

The segmented regression fit to the median values was:

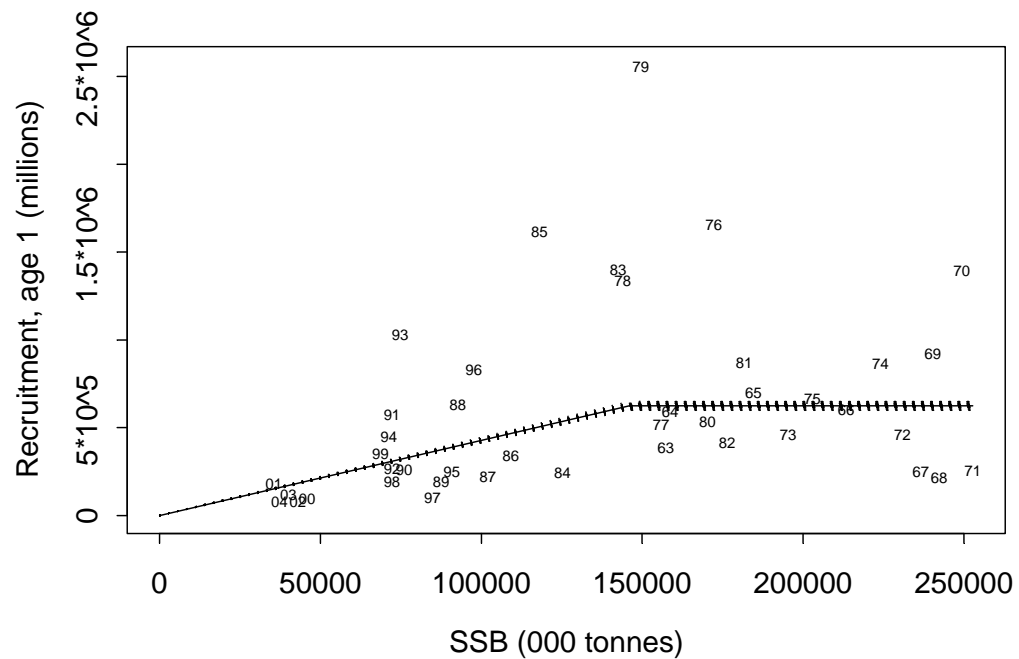
- statistically significant at the 5% level of significance (Figure 3.2.2.1)
- the maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired (breakpoint) is 145900 tonnes (Figure 3.2.2.1–3.2.2.2,)
- the 80% profile likelihood confidence interval is given by 125200–176700 tonnes (Figure 3.2.2.3)
- the maximum likelihood estimate of the slope at the origin is 4.28 which corresponds to a total fishing and discard mortality at ages 2–4 of 0.85 equivalent to the current value of  $F_{lim}$ .
- a jack-knife refitting to the median estimates of spawning stock biomass and recruitment and fit to the bootstrap iterations from the B-ADAPT model established that the segmented regression estimates are robust to the uncertainty included within the assessment model.

The addition of discards to the assessment and the extension of data range to 2005, has not resulted in significant change to the stock and recruitment parameters used as the basis for the precautionary reference points.

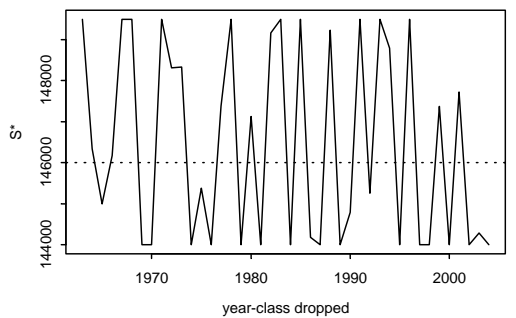
Section 8 of the SGPA (ICES, 2002) report noted that it appears that some ICES reference point values are not in conformity with the precautionary approach definitions, e.g. it would have been more correct if some previous Bpa values had been designated as Blim.

SGPRP (ICES, 2003a) noted that ACFM had previously defined and used the Minimum Biologically Acceptable Level (MBAL) of biomass for a number of stocks. MBAL was originally chosen as the SSB below which the probability of poor recruitment increased, and is therefore comparable to the current usage of Blim, but in some cases MBAL was more simply the biomass below which concerns were raised, and was therefore set as Bpa, the level where management action to improve stock status should be taken.

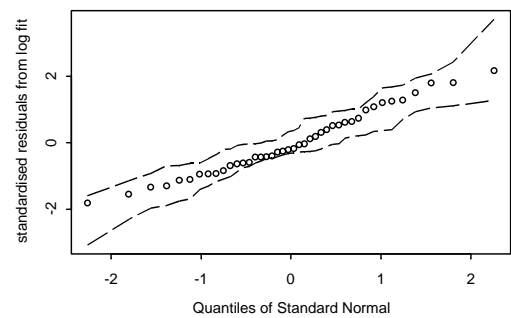
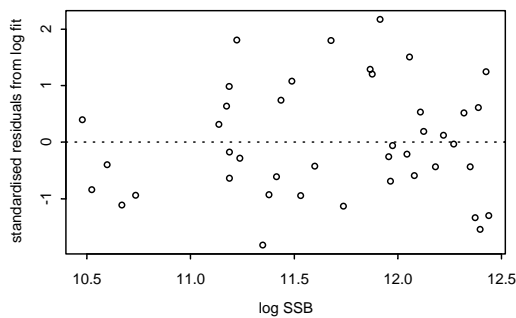
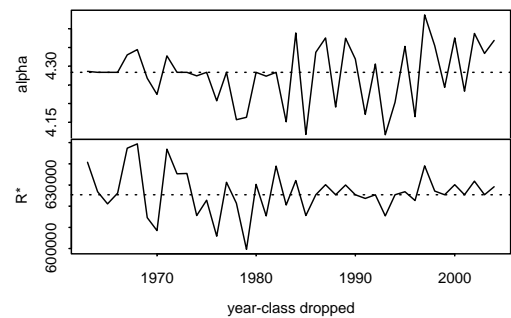
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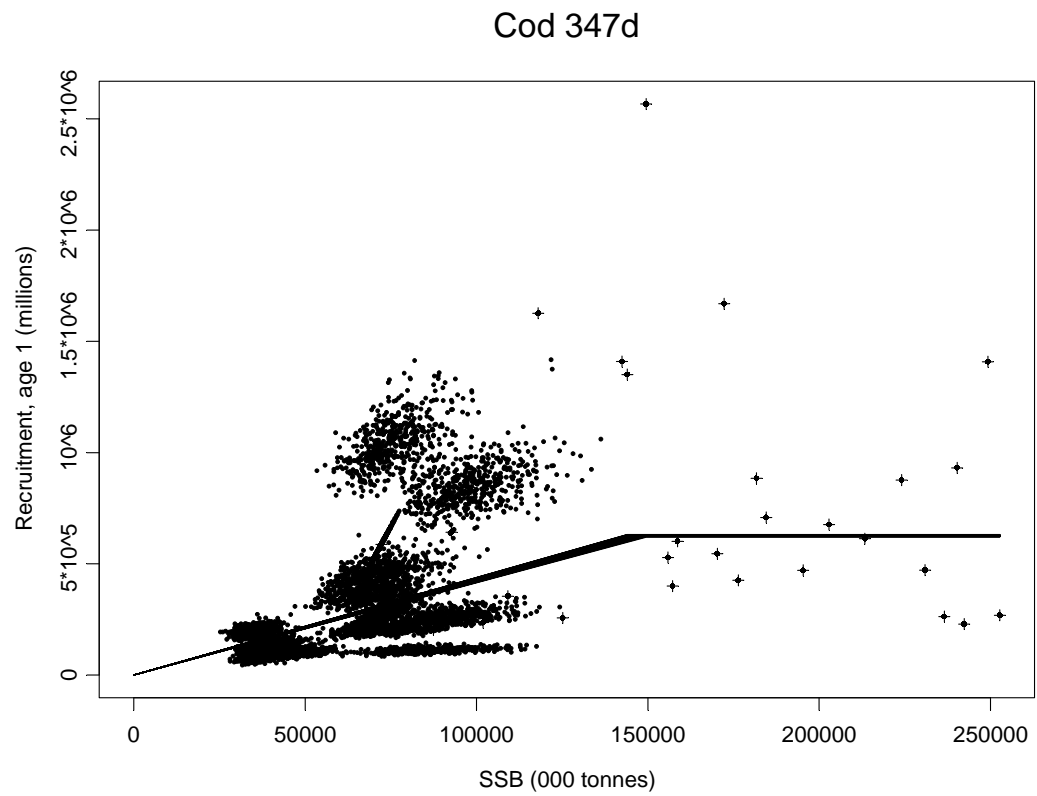
Changepoint estimated vs year-class dropped



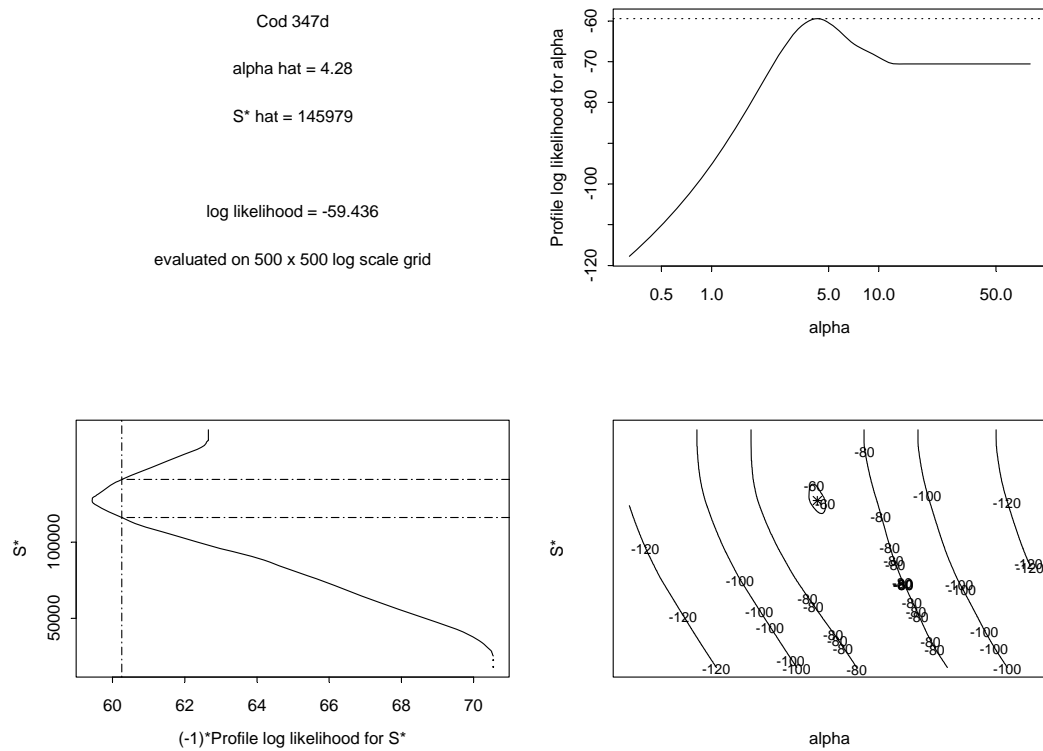
Model parameters vs year-class dropped



**Figure 3.2.2.1.** 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 change-point; panel 4: standardised residuals versus covariate; and panel 5: q-q plot with simulation envelope.

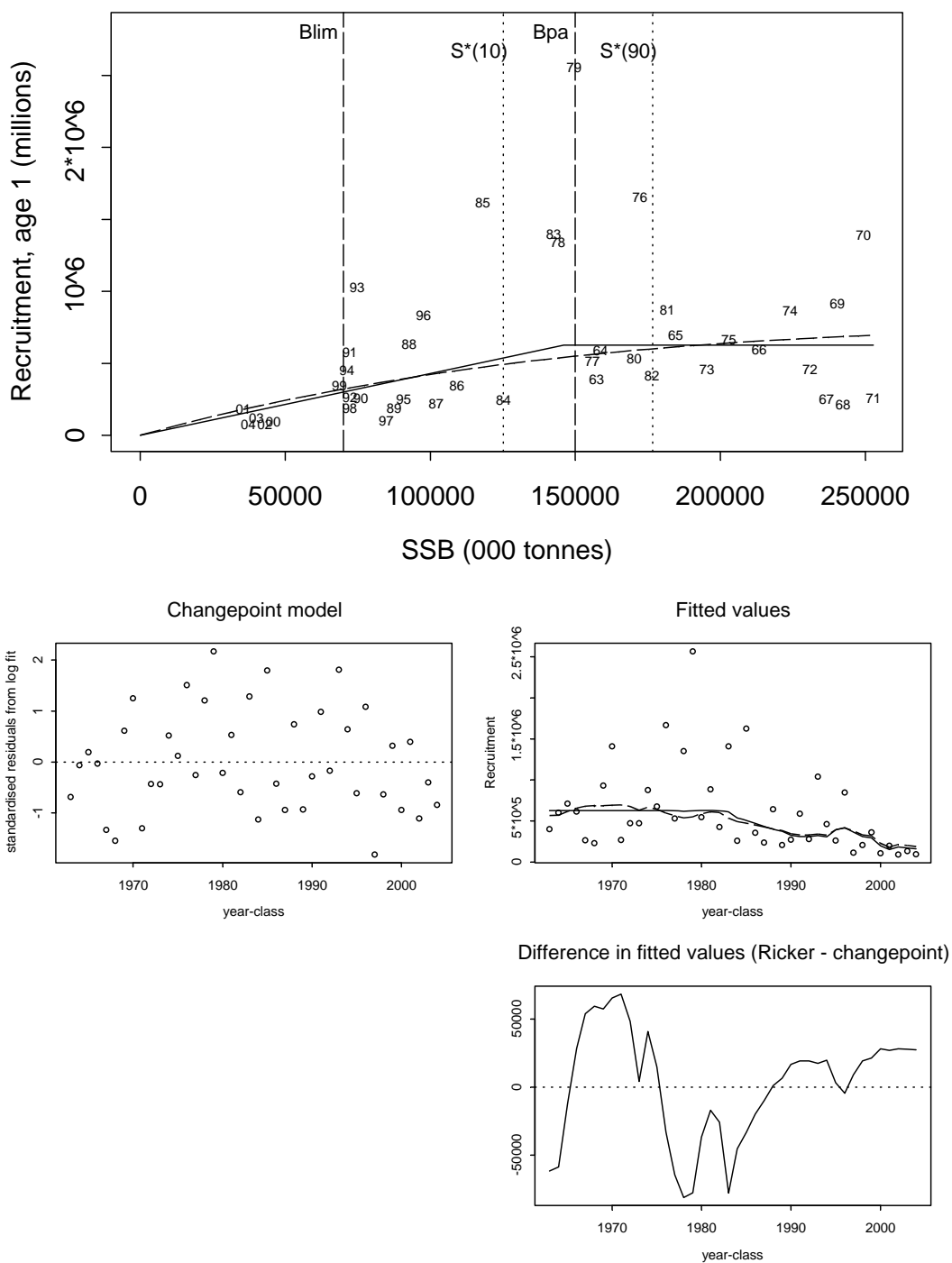


**Figure 3.2.2.2. 500 iterations of the B-ADAPT bootstrap estimates of spawning stock biomass and recruitment and the fitted change-point regression.**



**Figure 3.2.2.3. A four-panel figure. panel 1: text; panel 2: profile likelihood for slope at the origin; panel 3: profile likelihood for change-point; and panel 4: contour surface.**

Cod 347d



**Figure 3.2.2.4:** panel 1: stock-recruitment pairs identified by year-classes; solid line is the change-point model estimated; dotted line a Ricker two parameter model. panel 2: standardised residuals versus year-class; and panel 3: fitted values versus time (solid line – change-point; dotted line – Ricker two parameter model).



### 3.2.3 North Sea herring

#### State of the stock

ICES classifies the stock as having full reproductive capacity but at risk of being harvested unsustainably. SSB in 2005 was estimated at 1.7 million t, and is expected to decrease to B<sub>pa</sub> (1.3 million t) in 2006. Both the 1998 and the 2000 year classes were strong. However, all year classes since 2001 are estimated to be among the weakest since the late 1970s.

#### Reference points from ACFM report

Type	Value	Technical basis
B <sub>lim</sub>	800 000 t	below this value poor recruitment has been experienced.
B <sub>pa</sub>	1 300 000 t	part of a harvest control rule based on simulations.
F <sub>lim</sub>	not defined	
F <sub>pa</sub>	F <sub>0-1</sub> = 0.12 F <sub>2-6</sub> = 0.25	part of a harvest control rule based on simulations.

#### Revision history

##### *Blim*

The first proposal for a minimum stock limit in North Sea herring dates from 1976 (Anon., 1978). It was based on fitting a freehand curve to the data on stock and recruitment for the years 1952–1974. This graph suggested that average recruitment declined at spawning stock sizes below 800 000 tons. The figure of 800 000 tons was set as a threshold for reopening of the fishery after the closure in 1977. Although the fishery was reopened in fact one year before the stock was expected to reach the 800 000 mark, the appropriateness of the lower stock limit was not questioned for a long while. When ICES introduced the concept of Minimum Biologically Acceptable Level (MBAL) in 1992 (Serchuk and Grainger, 1992), the MBAL value for North Sea herring was maintained at 800,000 tons. Also in the management plan for North Sea herring, agreed between Norway and the EU in 1997, the minimum spawning stock size was set at 800 000 tons. With the introduction by ICES of limit reference points for precautionary management in 1998, the value of 800 000 tons previously used as MBAL was redefined as B<sub>lim</sub> (ACFM, 1998).

In recent years, ICES has recalculated B<sub>lim</sub> for North Sea herring using segmented regression analysis. This resulted in estimates of the breakpoint of 560 000 t (ICES, 2003a). Despite the fact that these calculations suggested that breakpoint was lower than the B<sub>lim</sub> actually used, ICES decided to refrain from changing the value of B<sub>lim</sub> used in management advice.

##### *Bpa*

The B<sub>pa</sub> limit reference point was established during the discussions on the joint EU-Norway management strategy for North Sea herring in 1997. It was presumably based on simulation runs, the details of which were not available to the group.

ICES has subsequently adopted the value of 1.3 million ton as the precautionary stock level used in its management advice. In the 1999 ACFM report, it was stated that the value was calculated as

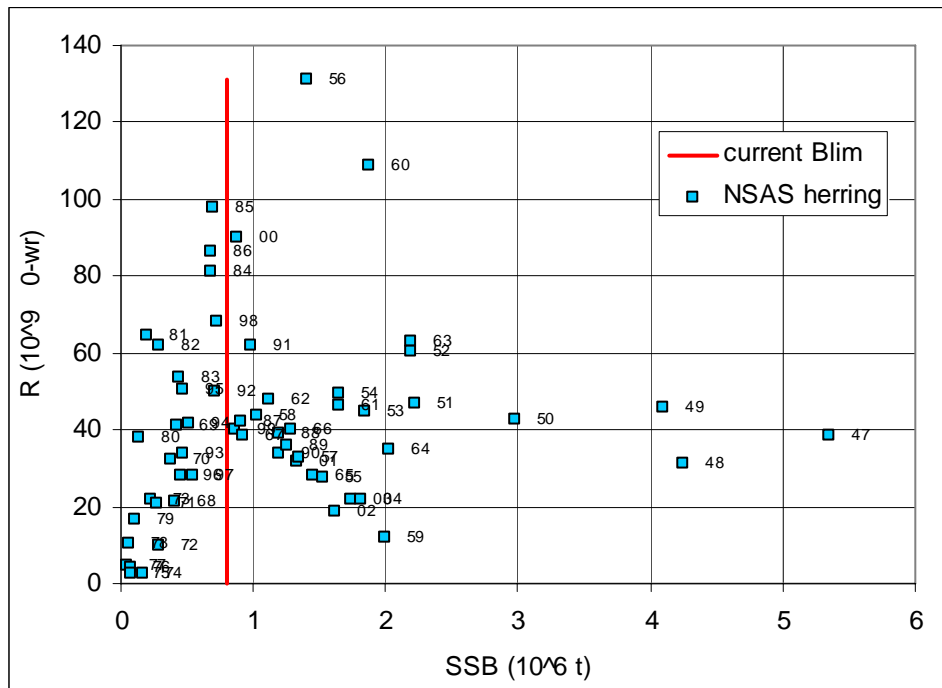
$$B_{pa} = B_{lim} * \exp(1.645 * 0.3)$$

There is no record of the justification for the choice of parameter values.

Subsequent ACFM reports state that the value of B<sub>pa</sub> is based on simulation runs. This refers to the calculations made for Norway and the EU in 1997.

The North Sea herring stock has in recent years (2002–2005) produced a series of weak year-classes while the spawning stock was at a very high level. The ICES study group on

recruitment variability in North Sea planktivorous fish (SGRECVAP) has met in 2006 (ICES 2006f) and suggested a number of hypothesis that could explain the current low recruitment. The group will continue in 2007 to investigate a range of possible explanations for the lower recruitment in herring (and also in sandeel and Norway pout).



**Figure 3.2.3.1. North Sea herring SSR (SSB and recruitment) 1947–2005.** Source SGRNH (ICES, 1998d) + HAWG (ICES, 2006g), Current Blim shown.

#### Defining a break point in the S/R scatter plot using segmented regression

Data used: HAWG (ICES, 2006) (longer time series available from SGRNH but not incorporated into standard assessment)

The segmented regression carried out by SGPRP in 2003 on the 2002-data (SSB and Recruitment pairs for 1960–1999) gave a change point at 558096. A segmented regression using data from the most recent assessment (ICES, 2006) data on SSB and recruitment for same period showed a relatively small difference. The results from the segmented regression based on 2006 data for same period (1960–1999) gave a very similar estimation of change point to those achieved by SGPRP (ICES, 2003).

The inclusion in the analysis of the most recent years shows that the segmented regression for this period estimates a change point at spawning biomass close to 500 thousand tonnes that is approximately 10% less than previous estimation (Figure 3.2.3.2). The position of the change point after inclusion of data for the last 10 years is relatively stable but it decreased in the last 3 year with about 10% (Figure 3.2.3.2). The reason for that is that last three points of the data were a relatively low recruitment from high SSB. The inclusion of each of them in data series had drawn median recruitment below what shifted change point to the left. The slope of the left part of the segmented regression does not change that means that estimations of Flim will be the same and stable for both data series and not sensitive to adding new data points from years 2000–2005.

The currently used Blim=800 000 was based on the consideration that there would be increased risk of low R below that. The segmented regression gives a change point that is considerably different from currently used Blim. However, the estimation of the break point is sensitive to adding points to the S/R plot at SSB well away (above) the break point. It was

concluded that given dome-shaped patterns in the S/R the use of segmented regression technique to establish a limit reference point was not considered appropriate.

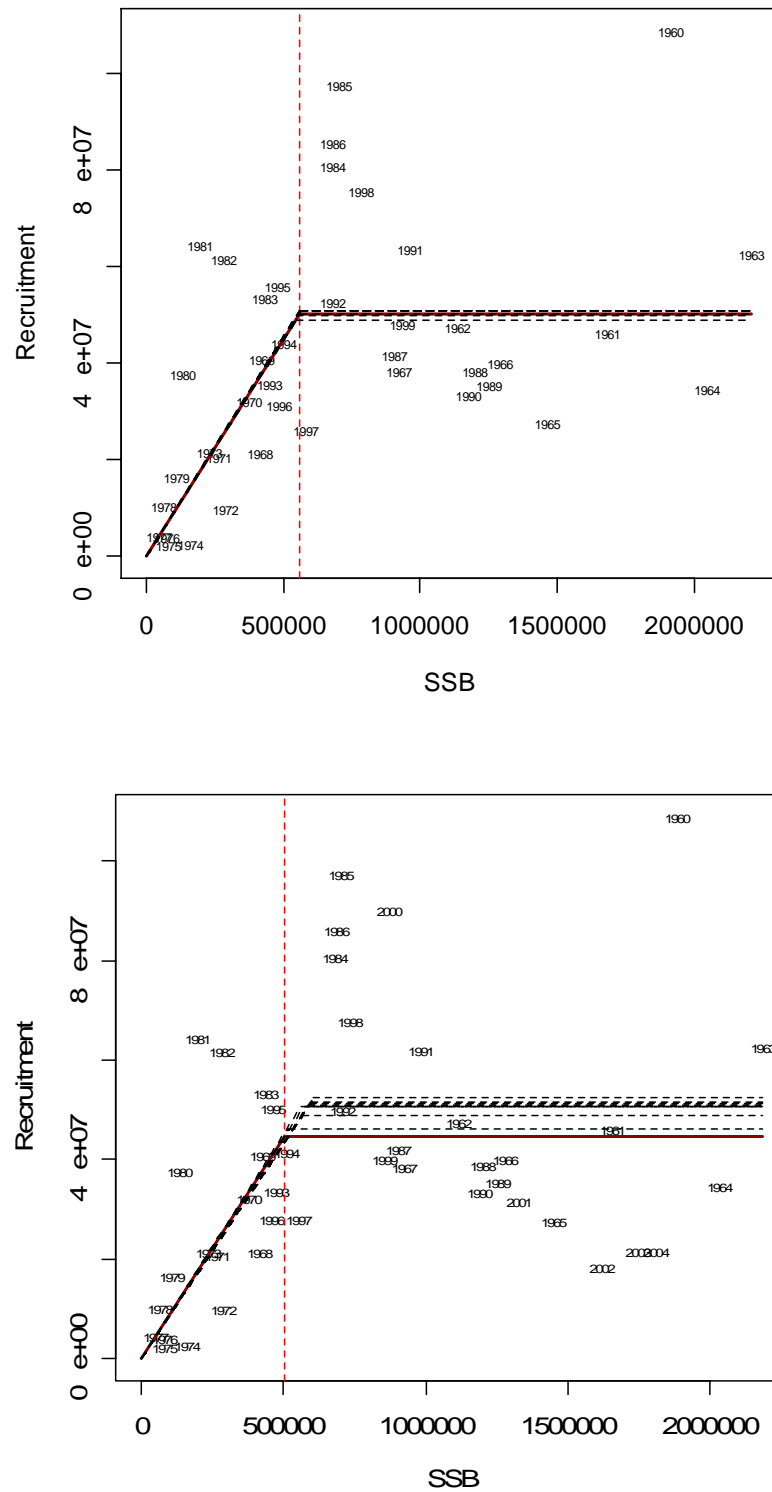
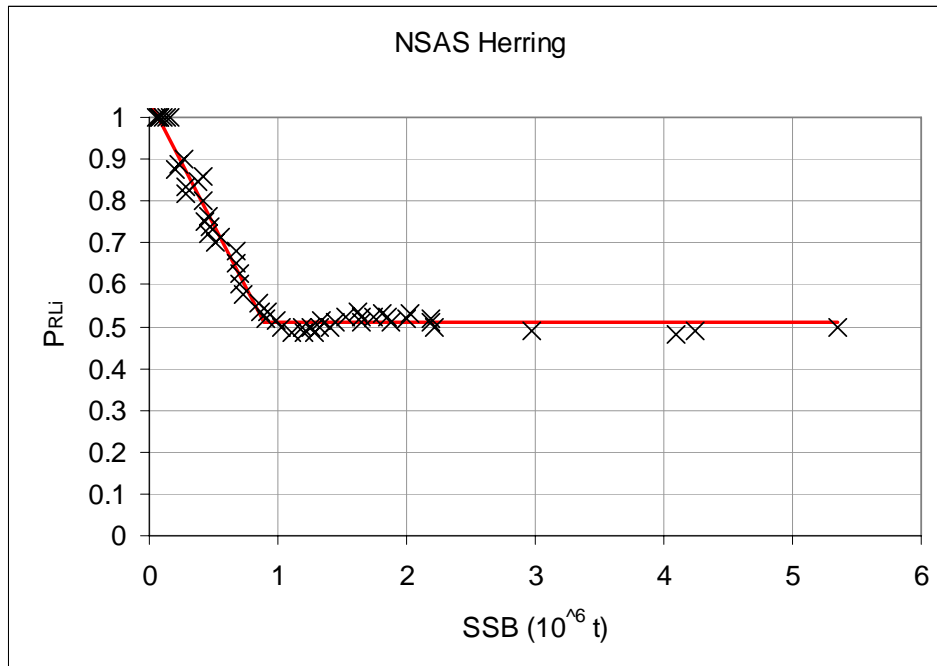


Figure 3.2.3.2. The comparison of results of the segmented regression to North Sea Herring made by SGPRP 2003 based on HAWG-2002 data for period 1960–1999 (upper figure) and WKREF 2007 based on HAWG-2006 data for period 1960–2005 (lower figure).

### Evaluation of $B_{lim}$ with the probabilistic approach

WKREF considered the probabilistic approach (Section 3.1.1) to the entire time series of North Sea herring SRR from 1947–2005. The breakpoint was evaluated in relation to the probability ( $P_{LRi}$ ) of being below the 50% percentile of recruitment. The breakpoint in logistic version was set at 10% above the estimated asymptotic value. The two model versions (Section 3.1.1 equations 1 and 2) gave similar break points ( $B_{break}$ ) of  $0.89 \times 10^6$  t and  $0.84 \times 10^6$  t for the linear and the logistic versions respectively (Figure 3.2.3.3). Model fit to data was similar for both linear and logistic version, ( $R^2 = 0.98$ ). Residual scatter was approximately normally distributed (Figure 3.2.3.4), however some autocorrelation is indicated in the Figure.



**Figure 3.2.3.3. Probabilistic breakpoint analysis of North Sea herring for the entire time series 1947–2005.**

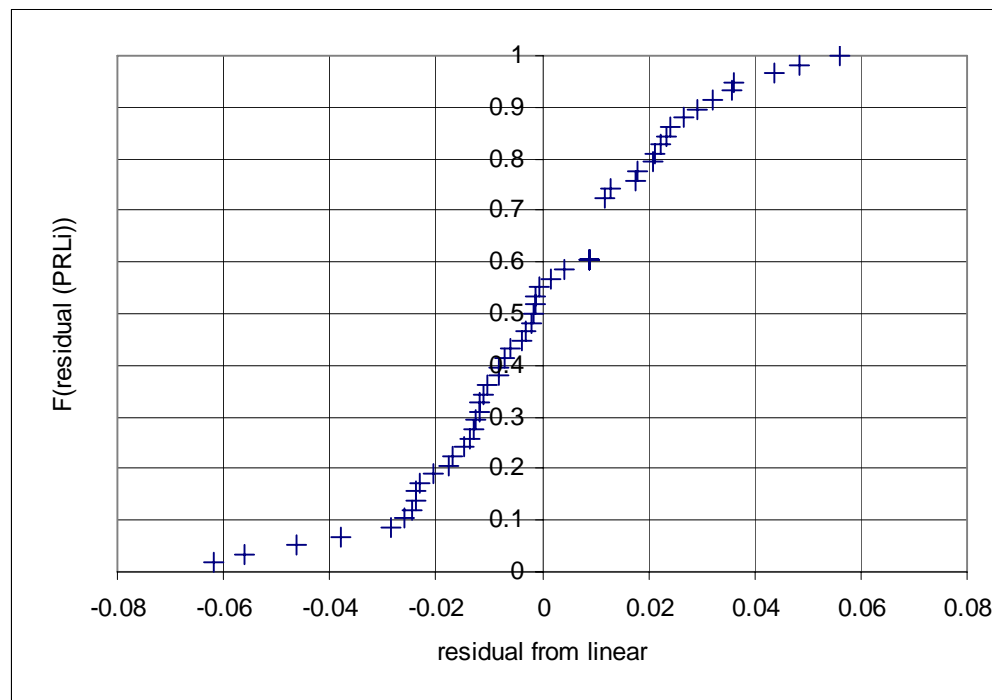


Figure 3.2.3.4. Cumulative distribution plot of residuals of  $P_{L Ri}$  from the linear model indicating a normal distribution.

### Conclusion on North Sea herring

WKREF concludes that there is no basis for changing  $B_{lim}$  based on current analysis. SGRECVAP results could be a basis for revisiting the reference points. The distance between a management reference point (here  $B_{pa}$  is used as trigger point) and  $B_{lim}$  defines a risk and should be evaluated in the context of harvest control rules in consultation with stakeholders and managers.

### 3.2.4 Blue whiting

#### State of the stock

ICES classifies the stock as having full reproductive capacity, but being harvested unsustainably. SSB increased to a historical high in 2003 but has decreased since 2004. Although the estimates of SSB and fishing mortality are uncertain, the estimate of SSB appears to be well above  $B_{pa}$ . The estimated fishing mortality is well above  $F_{pa}$ , and is estimated to have reached  $F_{lim}$  in 2004. Recruitment in the last decade appears to be at a much higher level than earlier, but indices from surveys indicate that the 2005 year class is at the pre-1996 level.

#### Reference points

Type	Value	Technical basis
$B_{lim}$	1 500 000 t.	$B_{loss}$
$B_{pa}$	2 250 000 t.	$B_{lim} \exp(1.645 \cdot \sigma)$ , with $\sigma = 0.25$ .
$F_{lim}$	0.51	$F_{loss}$
$F_{pa}$	0.32	$F_{med}$ (1998).

### Revision history

- SGPA 1998 (ICES, 1998): An SSB of 1 500 000 tonnes, representing approximately the lowest SSB on record, has been suggested as MBAL, and can be proposed as Blim. There is no clear trend in the stock-recruitment relation, so Floss, which is approximately 0.32, could be taken as an Flim. This coincides with Fmed, which has been proposed by the Working Group as Fpa. Following the policy of this Study Group, Fpa is suggested at 0.21, based on  $F_{pa} = F_{lim} \cdot \exp(-1.645 \cdot \delta)$ , and likewise, a Bpa of 2 250 000 tonnes is suggested as Bpa. These suggestions are quite arbitrary, and in particular the Bpa and Fpa should be evaluated by simulations.
- ACFM 1998: This stock has been fished with an average exploitation rate of  $F = 0.32 = F_{med}$ , without any apparent negative effects on recruitment. It is proposed that  $F_{pa} = 0.32$ . The lowest observed spawning stock biomass is 1.5 million t. Taking this as Blim and accounting for uncertainty, Bpa is proposed at 2.25 million t.
- SGPRP 2003 (ICES, 2003a): The current Blim a value of 1.5 million t is based on Bloss. As the segmented regression was not significant, a Bloss was computed. It has the value of 1.2 mill. t. This value does not deviate very much from the old Blim (1.5 million t) and as the assessments of the blue whiting are unstable, both current and historical, especially for the older years, there is no need to change the value of Blim.
- ACFM 2006: Because of the bias in the stock assessment and in implementation of the TAC, using  $B_{pa}$  as trigger point for the actions specified in paragraph 6 is expected to lead to a higher than 5% probability that the spawning stock biomass will fall below  $B_{lim}$ . This suggests that the trigger point for management action should be higher than  $B_{pa}$ .

### Evaluation of limit reference point

In the recruitment time series 2 periods can be distinguished. The period 1981–1994 with relative low recruitment and a period 1995–2005 with recruitment about twice as high. The present limit reference points for blue whiting were set in 1998 before the change in the productivity of the stock has been observed. The causes for the change in productivity are unknown and no initiatives to initiate research on this topic have been taken so far.

In 2005, the coastal states exploiting blue whiting, have agreed on a management plan and since 2006 a harvest control rule has been in force. The HRC is formulated around the existing limit and PA points. It was evaluated by ICES in 2005 (ACFM, 2005) in the situation of both observed productivity regimes. The HCR was considered not precautionary in the situation of a low productivity regime. It was also realized that it is presently not possible to identify when a change in productivity regime occurs. Also the evaluation of the rule hinted to a possible mismatch between  $F_{pa}$  and Blim, since fishing at  $F_{pa}$  would lead to a high probability of being below Blim.

WKREF considered the S/R scatter plots for the two different productivity periods following guidelines provided by SGPRP.

In the period of low recruitment there seems to be no sign of reduced recruitment at low SSB. The scatter plot suggests that increased recruitment may occur at lower biomass. The trend line (linear) through the scatter point is significant. Guidelines by SGPA indicate that in such situations  $B_{loss}$  is a candidate for  $B_{pa}$ . ( $B_{pa} = B_{loss} = 1.5$  million tonnes).

In the period of high recruitment no trend in recruitment over the range of biomass can be detected. Guidelines by SGPA indicate that in such situations  $B_{loss}$  is a candidate for  $B_{lim}$ . ( $B_{lim} = B_{loss} = 2$  million tonnes).

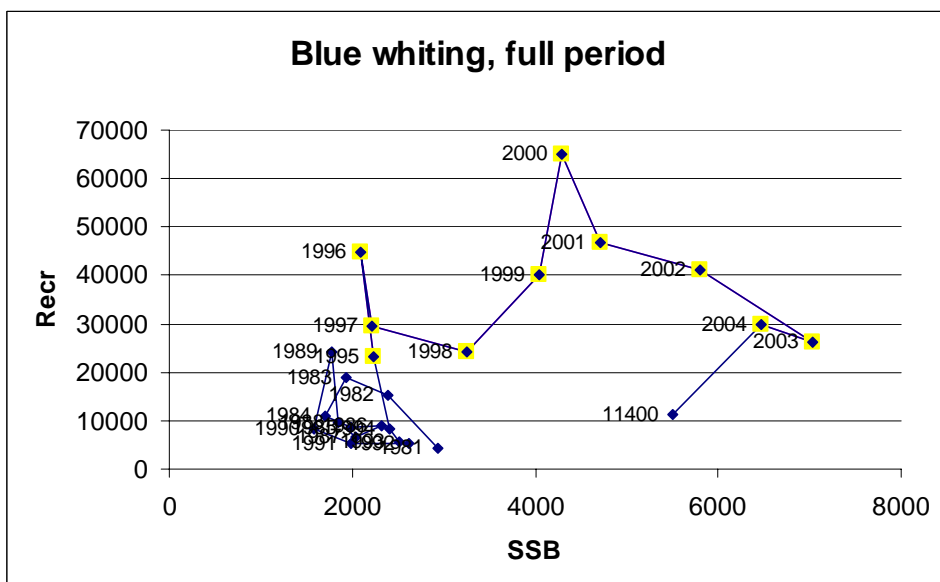
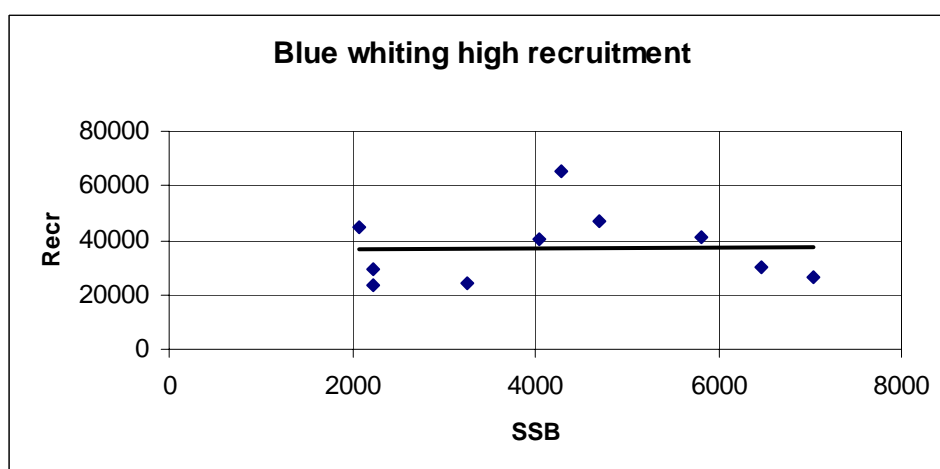
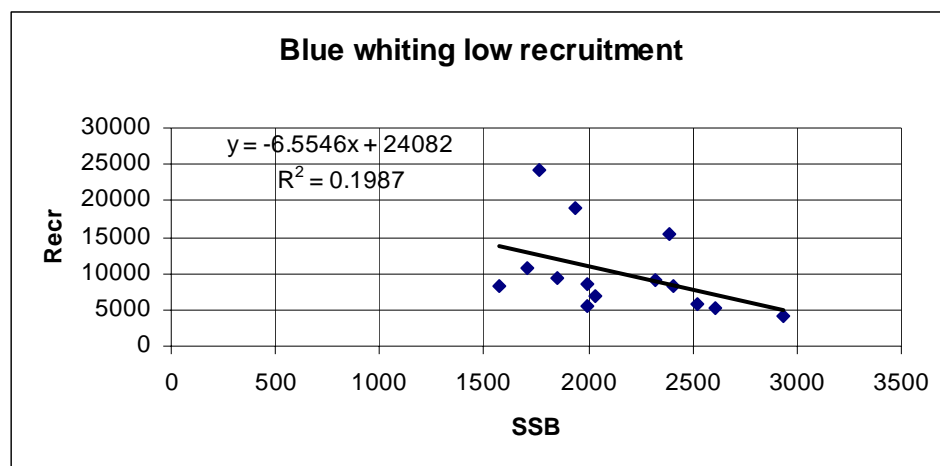


Figure 3.2.4.1. Stock – recruitment relationship for blue whiting for period of low recruitment (1981–1994), high recruitment (1995–2005), and full time series.

### Evaluation of $B_{lim}$ with the probabilistic approach

WKREF considered the probabilistic approach (Section 3.1.1) to the entire time series 1981–2005 with an estimated break point of 2.18 million t (Figure 3.2.4.2), whereas splitting into two periods 1981–1994 with low recruitment and 1995–2005 with recruitment about twice as high produced uncertain results for the first time series and no break point for the second.

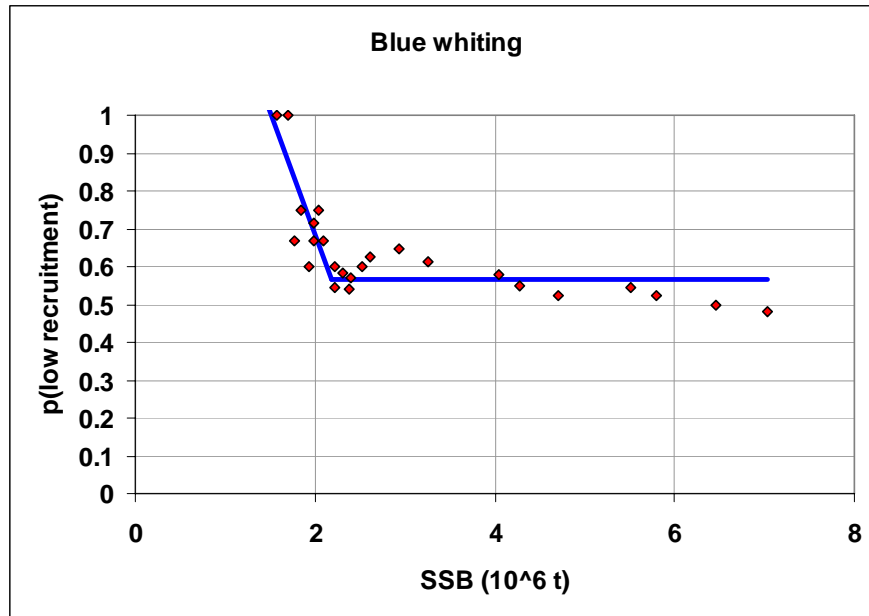


Figure 3.2.4.2. Probabilistic breakpoint analysis of blue whiting for the entire time series 1981-2005.

### Conclusion on Blue whiting

Splitting time series has the disadvantage that the shorter time series will often have less informative SRR points. If the SGPRP criteria are used on the split time series, very different estimates of  $B_{lim}$  and  $B_{pa}$  would result for Blue whiting. If different productivity regimes have occurred there could be just use one  $B_{lim}$  which would apply to both productivity regimes. There is no basis for splitting the time-series and therefore there is no basis for changing reference points for Blue whiting.

### 3.2.5 Norwegian Spring Spawning herring

#### State of the stock

In 2006 (ACFM, 2006), ICES classified the stock as having full reproductive capacity and being harvested sustainably. The estimate of the spawning stock biomass in 2006, although uncertain, was around 10.3 million t. Several good year classes contribute to the SSB, in particular the strong 2002, 1998 and 1999 year classes. Surveys indicate that recruitment from the 2003 year class is moderate, while the 2004 year class is also strong (comparable to the 1998 year class).



**Reference points**

<i>Type</i>	<i>Value</i>	<i>Technical basis</i>
$B_{lim}$	2 500 000 t	MBAL <sup>1</sup>
$B_{pa}$	5 000 000 t	$Blim * exp(0.4 * 1.645)$
$F_{lim}$	not defined	
$F_{pa}$	0.15	see reference (SGPA 1998)

**Revision history**

- SGPA 1998: “The Study Group suggests  $Blim=MBAL=2\,500\,000$  t,  $F_{pa}=0.15$ , indicated by medium-term simulations and adopted by the Working Group, together with a catch constraint of 1.5 mill. tonnes. No  $B_{pa}$  or  $F_{lim}$  are suggested. Since this is a stock which is dominated by a few outstanding year classes, management discussions have concentrated on how fast it is advisable to deplete the present year classes, rather than on harvest control rules that require a certain  $B_{pa}$  as trigger for special actions.” (ICES, 1998)
- ACFM 1998: “Examination of the stock recruitment data suggests that the probability of poor recruitment increases at SSBs below 2.5 million t, which defines  $Blim$ . In order to take into account uncertainty in estimating biomass, a  $B_{pa} = 5.0$  million t is proposed. Simulations indicate that  $F_{pa} = 0.15$  is adequate when used in conjunction with a catch ceiling.” (ICES, 1999)
- ACFM 1999 (ICES, 1999) explains that  $F_{pa}$  is derived from management simulations by SGPA 1998.
- Note that the management agreement uses an  $F=0.125$  to define the maximum catch.

**Defining a break point in the S/R scatter plot using segmented regression**

The request to reconsider the limit reference point for Norwegian spring spawning herring was on the terms of reference of WGNPBW in 2006 (ICES, 2006h). This WG did not deal with this terms of reference and it was decided to consider this term of reference in WKREF. It was not clear to WKREF why the stock has been put on the list of stocks to reconsider the limit reference points and WKREF is not aware of a request of ICES clients to do so.

The limit and PA reference points are part of an agreed harvest control rule. Although there has been no formal agreement of the implementation of this HCR between the countries exploiting this stock, the sum of national quotas has not exceeded the fishing mortalities and TACs implied by the rule. Under the present HCR, the stock has recovered and is estimated to have increased to about 10 million tonnes in 2007.

The segmented regression carried out by SGPRP in 2003 (ICES, 2003a) on the WGNPBW-2002 data (SSB and Recruitment pairs for 1950–1999) gave a statistically significant ( $p<0.05$ ) change point at 2.3 million t. That is relatively close to the currently used  $Blim$  of 2.5 million t based on MBAL previously. A comparison of the most recent assessment data on SSB and recruitment for the same period showed that there are some relatively small differences at SSB and rather big changes in recruitment but only in the most recent period: 1998–1999 (Figure 3.2.5.1). Nevertheless, the results from the segmented regression based on 2006 data in the same period (1950–1999), where there were not big difference in data, indicated a considerable different change point. The new estimate is close to 4 millions t. The inclusion in the data set of information from the most recent years (2000–2005) did not result any further changes in the break point (Figure 3.2.5.2).

Taking into account the rather small difference in SSB and recruitment data from WG-2002 (ICES, 2003c) and WG-2006 (ICES, 2006h) reports an additional exploration of the

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<sup>1</sup> Note that ACFM 1998 actually suggests that 2.5 milln t is the point below which recruitment is lower.

assessment results of both working groups have been carried out in order to find the source of the a big difference in estimates of the change point. The method used was replacement of the certain data of SSB and/or recruitment for particular years to see which ones caused difference of the change point estimates. It was found that the recruitment data alone do not cause the serious revision of the break point. If the SSB results from the 2002 assessment and recruitment from 2006 assessments were used to estimate the break point, the value is close to one calculated by SGPRP. If instead of this the SSB data of the most recent assessment were used with the recruitment data from the 2002 assessment, the estimate will be similar to one based on 2006 assessment.

The replacement in the 2002 assessment with data pairs from the 2006 assessment only where SSB was visibly different (Figure 3.2.5.1), this does not change break point significantly. A comparison of the percentage difference in SSB between both assessments showed that the biggest relative revisions were for the years 1969–1972. The SSB in these years differed by 47–88% in most recent assessment although their absolute values were very small and had increase only a little. It was observed that replacement only SSB data for any three of the 1969–1972 years does not cause big change, but using data on SSB for all four years shift break point from 2.3 millions t to approximately 4 million. The points of these years in the S/R scatter plot are hidden in the cluster of points near the origin. It appeared that a small revision of the position of these points on the x-axis had a large effect on the slope of the line through the origin in the segmented regression.

#### **Evaluation of $B_{lim}$ with the probabilistic approach**

WKREF considered the probabilistic approach (Section 3.1.1) to the entire time series of Norwegian spring spawning herring SRR from 1950–2005. The breakpoint was evaluated in relation to the probability ( $P_{L Ri}$ ) of being below the 50% percentile of recruitment. The breakpoint in logistic version was set at 10% above the estimated asymptotic value. The two model versions (section 3.1.1 equations 1 and 2) gave the following break points ( $B_{break}$ ) of  $7.88 \times 10^6$  t and  $6.69 \times 10^6$  t for the linear and the logistic versions respectively (Figure 3.2.5.3). Model fit to data was of similar quality for the linear version and for the logistic version ( $R^2 = 0.99$ ). Residual scatter was approximately normally distributed (Figure 3.2.5.4), however, some autocorrelation is indicated.

#### **Conclusion on NOSS herring**

WKREF could not explain the sensitivity of the break point to the very small changes in the position of a few points in the S/R plot close to the origin and considered this behaviour of the model highly undesirable. WKREF decided to ask the Methods Working Group to investigate this observation further. Given this, the use of segmented regression technique to establish a limit biomass reference point for Norwegian spring spawning herring was not considered appropriate until the observed methodological issue has been resolved.

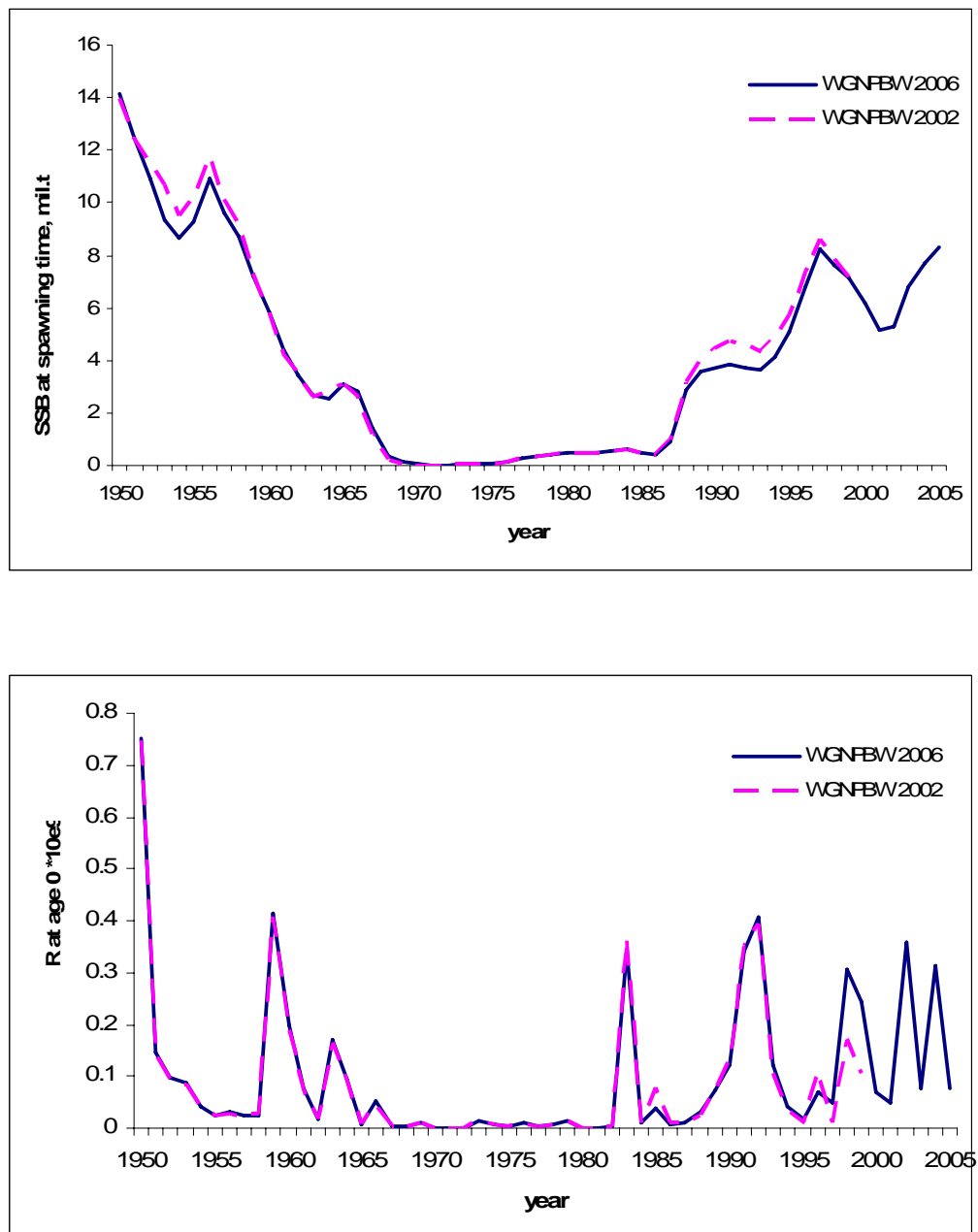
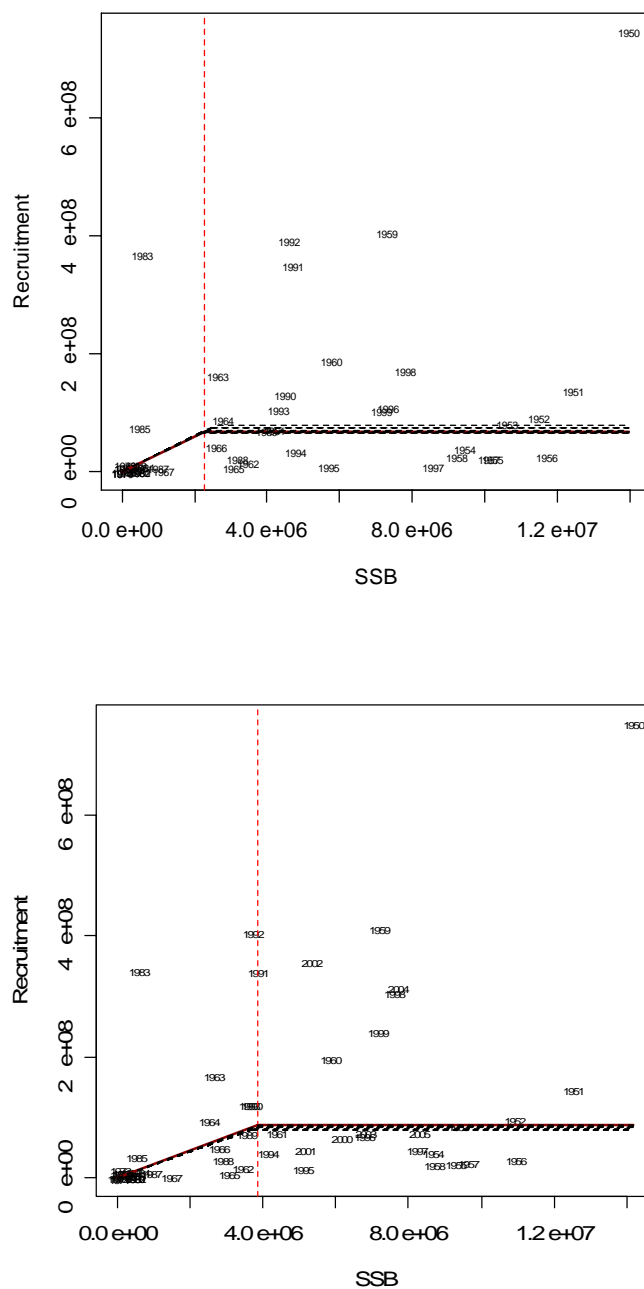
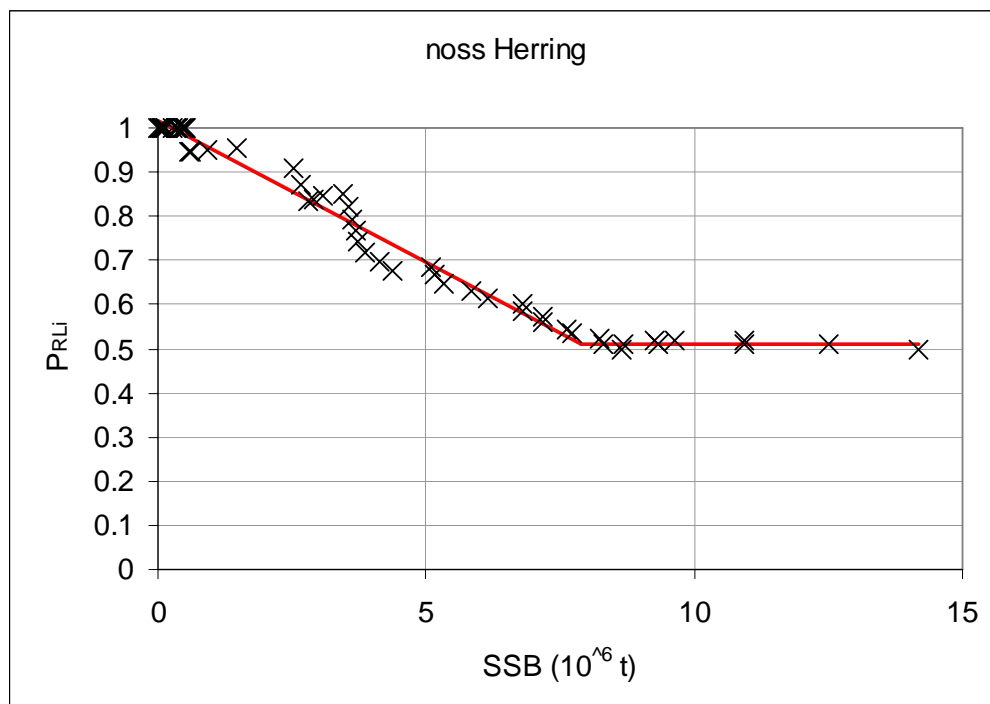


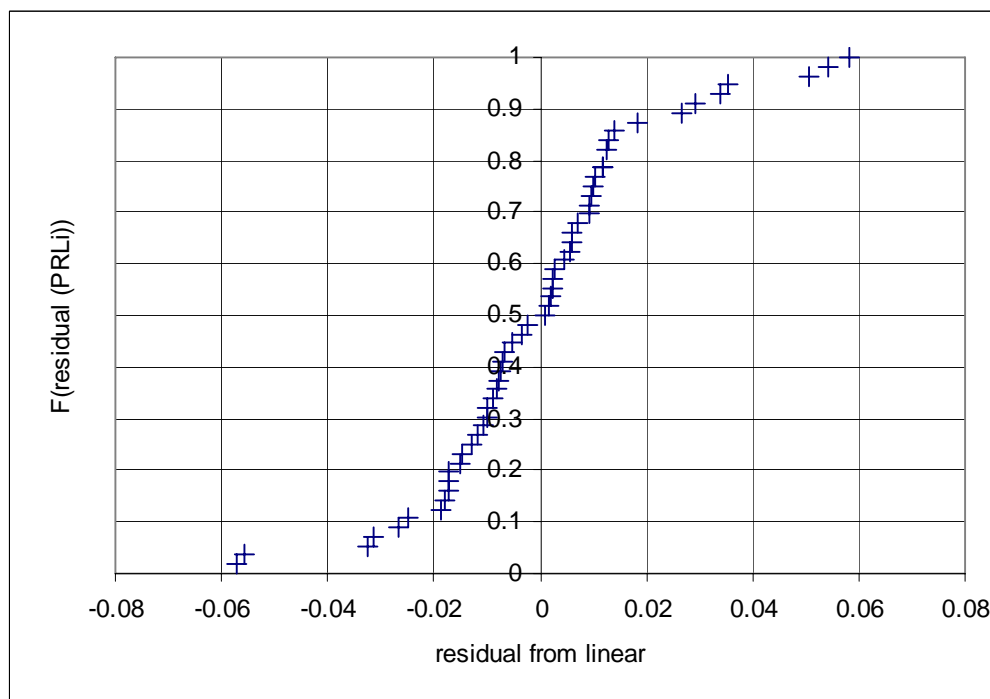
Figure 3.2.5.1. Comparison of SSB and Recruitment data from WGNBW assessments in 2002 and 2006.



**Figure 3.2.5.2.** The comparison of results of the segmented regression to Norwegian spring spawning herring made by SGPRP 2003 based on WGNPBW-2002 data for period 1950–1999 (upper figure) and WKREF 2007 based on WGNPBW-2006 data for period 1950–2005 (lower figure).



**Figure 3.2.5.3. Probabilistic breakpoint analysis of Norwegian spring spawning herring for the entire time series 1947–2005.**



**Figure 3.2.5.4. Cumulative distribution plot of residuals of  $P_{LRI}$  from the linear model indicating a normal distribution for Norwegian spring spawning herring.**

### 3.2.6 Faroe haddock

#### State of the stock

In 2006 (ACFM, 2006), ICES classified the stock as having full reproductive capacity and at increased risk of being harvested unsustainably. The 2005 estimate of fishing mortality is just above  $F_{pa}$ . SSB has increased as a result of strong recruitments, including the record high 1999 year class. Recent year classes are estimated to be small and combined with low individual growth, and SSB is now declining.

#### Reference points

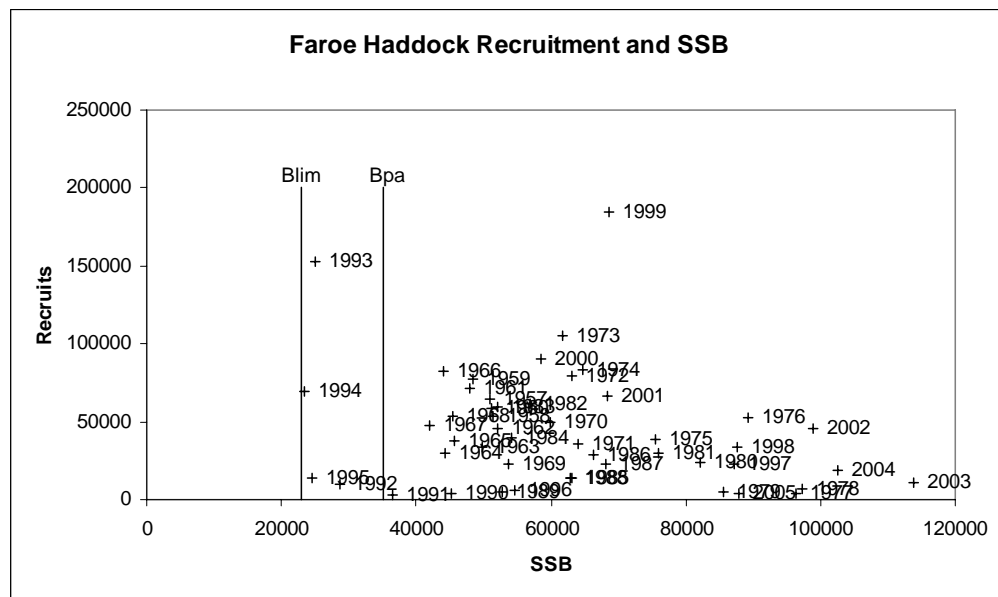
Type	Value	Technical basis
$B_{lim}$	40 000 t.	Former MBAL
$B_{pa}$	55 000 t.	Inspection of SSB-R plot
$F_{lim}$	0.40	2 st. dev above $F_{pa}$
$F_{pa}$	0.25	$F_{med}$ (1998)

#### Revision history

- SGPA 1998 (ICES, 1998): biomass reference point as described above, with argumentation:  $B_{lim}$  as Bloss and  $B_{pa}$  with the standard formula.  $F_{pa} = 0.30$  without argumentation.
- ACFM 1998 (ICES, 1999):  $B_{lim}$  be set at a previously established MBAL of 40 000 t above which the probability of good recruitment is high. A proposed  $B_{pa}$  of 55 000 t was calculated. It is proposed that  $F_{pa} = F_{med} = 0.25$ .
- ACFM 1999: added  $F_{lim}$  including the above argumentation
- SGPRP 2003 (ICES, 2003a): “The segmented regression method gives no change point for this stock. The Bloss is estimated to be 22 000 t. ICES has defined  $B_{lim} = MBAL = 40\ 000$  t. MBAL was established prior to the confirmation of the size of the large 1993 and 1994 year classes. Given the dynamics of recruitment patterns observed, including the observation that two large year classes were established at the Bloss, it is suggested that the derivation of  $B_{lim}$  should be revisited. According to the “standard method” Bloss could be a candidate for  $B_{lim}$ . Revision of the  $B_{lim}$  reference point should thus be addressed by the working group.”
- NWWG 2006 (ICES, 2006i): “The 1998 Study Group on the Precautionary Approach to Fishery Management (SGPAFM) (ICES, 1998) suggested that  $B_{lim}$  for haddock be set at the lowest biomass observed, that is 21 000 t. Instead, ACFM choose to set  $B_{lim}$  at the previously established MBAL above which the probability of good recruitment was said to be high. New stock and recruitment data pairs have been added since  $B_{lim}$  for haddock has been set in the 1998 ACFM advice and recruitment has not been particularly low when SSB was below  $B_{lim}$  (Figure 3.2.6.1). In fact, the 1993 yc, the second strongest on record was produced at an SSB below  $B_{lim}$ . This is consistent with the results of the SGPRP 2003 where segmented regression on the data available at the time suggested a break point in the order of 23 000 t. The NWWG recommends that  $B_{lim}$  for Faroe haddock be set at 23 000 t. Assuming sigma equal to 0.40, this would imply a  $B_{pa}$  of 35 000 t as suggested in the SGPAFM 1998.”

#### Conclusion on Faroe Haddock

The WKREF supported the views of the SGRP (ICES, 2003a) and the NWWG 2006 (ICES, 2006i) that existing limit and pa reference points need to be updated to  $B_{lim}$  at 23 000 t (BLOSS) and consequently a  $B_{pa}$  of 35 000 t as suggested by NWWG 2006.



**Figure 3.2.6.1. Stock and recruitment scatter plot from the 2006 assessment for Faroe haddock showing the suggested Blim and Bpa. The segmented regression in SGPRP was not statistically significant.**

The table below list the newly suggested biomass reference points and their technical basis. The fishing mortality reference should be reviewed for consistency with the biomass reference points. The Faroese authorities have a target exploitation rate of 33% for each of cod, haddock and saithe, corresponding to  $F = 0.45$  on each species. The conformity of the target  $F$  with the precautionary approach should be evaluated.

<i>Type</i>	<i>Value</i>	<i>Technical basis</i>
$B_{lim}$	23 000t	Bloss, no evidence of impaired recruitment, dynamics of the stocks unknown below this biomass
$B_{pa}$	35 000t	$Blim * \exp(1.645 * \sigma)$ , with $\sigma = 0.4$ to account for high uncertainty in the assessment
$F_{lim}$	0.40	Needs to be revised, was set 2 st. dev above $F_{pa} = F_{med}$ calculated in 1998
$F_{pa}$	0.25	Needs to be revised, was set at $F_{med}$ calculated in 1998

### 3.2.7 Faroe saithe

ACFM did not accept the assessment done by the NWWG in 2006. However, the 2005 assessment had been accepted by ACFM and the stock and recruitment scatter plots are almost identical, but for the addition of one point in the 2006 assessment. Existing reference points and their basis are given in the text table below.

#### Reference points

<i>Type</i>	<i>Value</i>	<i>Technical basis</i>
$B_{lim}$	60 000 t.	lowest observed (1992) SSB estimated in 1999
$B_{pa}$	85 000 t.	former MBAL
$F_{lim}$	0.40	consistent with $Blim$ of 60 000 t.
$F_{pa}$	0.28	consistent with $F_{lim}$ and previous estimate of $F_{med}$ .

### Revision history

- SGPA 1998 (ICES, 1998): biomass reference point of 70 000 t (Blim) based on Bloss and 100 000 t (Bpa) based on standard formula. Fishing mortality reference points of 0.28 (Flim) and 0.20 (Fpa) based on Fmed and standard formula respectively.
- ACFM 1998 (ICES, 1999): “An analysis of stock recruitment data suggests Blim be set at 85 000 t and correspondingly Flim at 0.40. The values Fpa is proposed to be set at 0.28 which is consistent with both estimates derived from Flim and Fmed. Bpa = 110 000 t is proposed.”
- ACFM 2000: reference points changed to the values and argumentation in the text table presented above. No argumentation was supplied about the reasons for the change.
- SGPRP 2003 (ICES, 2003a): “The segmented regression method gives no change point for this stock. The Bloss is estimated to be 60 000 t. ICES has previously defined Blim=Bloss=60 000 t. In the light of the relatively narrow range of SSB it was proposed that the Bloss estimates could be a candidate for Bpa. This should also be checked against alternative derivations of reference points, such as SSB at  $FX\%SPR$  values. Revision of the Blim reference point should thus be addressed by the working group.”
- NWWG 2006 (ICES, 2006i): “For saithe, the 1998 SGPAFM suggested Blim of 70 000 t (the lowest observed at the time). ACFM advice in 1998 raised Blim to 85 000 t, the 1999 ACFM advice also used Blim = 85 000t but Blim becomes 60 000 t in the 2000 ACFM advice as the lowest observed SSB. The SGPRP 2003 indicated that in cases where recruitment seemed to increase with decreasing biomass, as is clearly the case for Faroe saithe, it was more appropriate to use Bloss as an estimate of Bpa rather than as an estimate of Blim (Figure 3.2.7.1). The NWWG recommends that 60 000 t be the new Bpa for saithe as it is clear that recruitment has not been impaired below Bpa or near Blim, on the contrary. Assuming a sigma of 0.3 as a precautionary measure, this would imply a Blim of 45 000 t.”

### Conclusion on Faroe saithe

As indicated above, ACFM did not accept the 2006 assessment of Faroe saithe. WKREF did not want to propose new reference points in the absence of an accepted assessment.

#### 3.2.8 Kattegat sole

ACFM (2005) considers that the limit reference points (Blim = 770 tons, Bpa = 1060 tons, Flim = 0.47, Fpa = 0.30) should be re-evaluated in the light of the revised assessment submitted by WGBFAS in 2005. ACFM did not accept the assessment in 2006.

There is no S-R relationship and segmented regression is insignificant (ICES CM 2003/ACFM:15). Therefore, Bloss could be considered an estimate of Blim.

During the WKREF meeting, Fmed was estimated at 0.64 and Bloss at 925 tons using the PA software with input from the (not accepted) 2006 assessment.  $Bpa = Blim \times \exp(1.645 \times 0.2) = 1285$  tons.

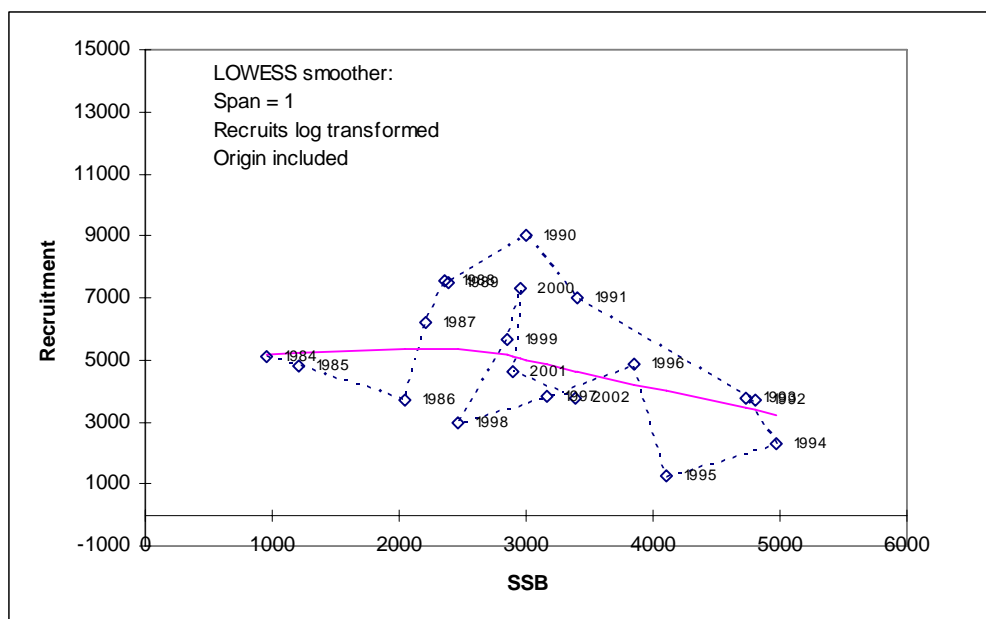
In order to evaluate the impact of the revised assessment on the reference points they were estimated using output from both the revised 2005 assessment (using the new tuning fleets) and output from an assessment using the 2005 data calibrated with the old tuning fleets.

#### 2005 assessment

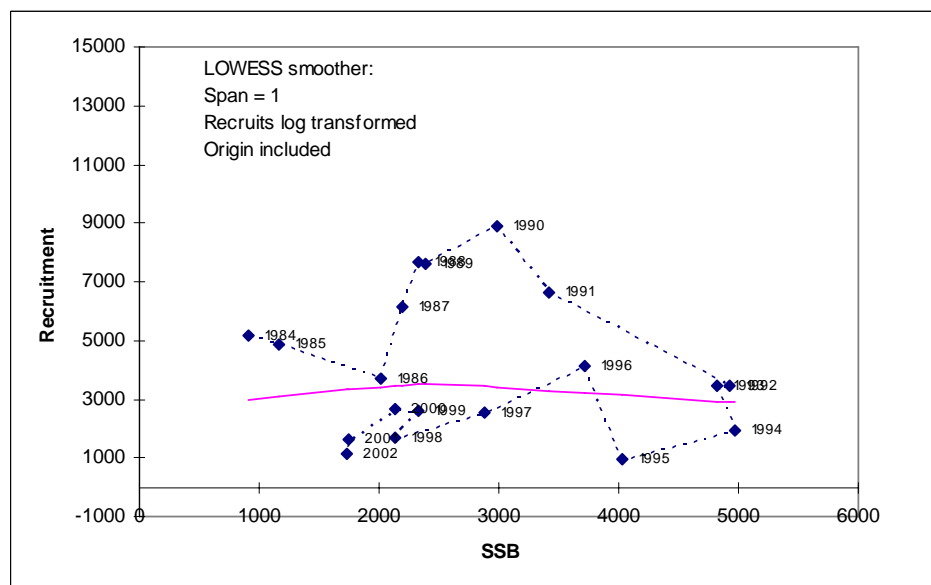
	Fmed	Bloss
Old tuning fleets	0.24	914
New tuning fleet	0.54	958



The significant change in the level of Fmed was due to revised perception of SSB and recruitment in recent years affecting the S-R plot as indicated in Figures 1 and 2.



**Figure 3.2.8.1. Stock and recruitment from revised 2005 assessment.**



**Figure 3.2.8.2. Stock and recruitment from XSA in 2005 calibrated with the old tuning fleets.**

As the revised assessment did not affect the SSB estimates in the beginning of the time series the estimates of Bloss are only affected to a minor extend by the revision.

Estimation of Bloss is based primarily on the data from 1984 and 1985 which is the beginning of the time series. As these SSB estimates are considerably smaller than any of the other SSB estimates in the time series, their exclusion from the PA analysis has a significant impact on the estimate of Bloss. When excluding the 1984 and 1985 data Bloss was estimated at 2025 tons (Bpa = 2814 tons) and Fmed at 0.56.

Medium term projections of SSB at different levels of fishing mortalities were conducted. The projections indicated that at fishing mortalities at 0.56 and 0.64 the projected SSB is about 1500 tons, i.e. above the present Bpa (Figure 3.2.8.3). With a probability 95% the present level of fishing (Fbar=0.18) would keep SSB above 3000 tons.

#### Conclusion on Kattegat sole

WKREF concludes that the revised Fmed is very high and likely dependent on assumptions that cannot be substantiated for this stock. Fmed should not be a basis for revising reference points at this stage. WKREF suggests that WGBFAS attempts to extend the time series of data for the assessment in order to have more observations from the earlier years when SSB was smaller.

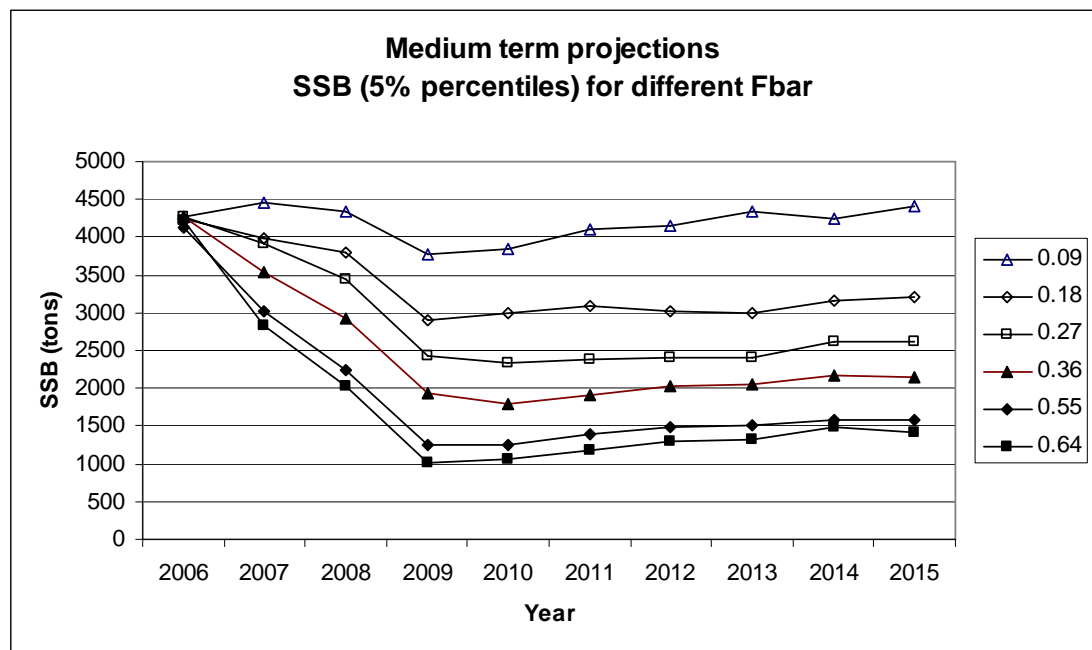


Figure 3.2.8.3. Medium-term projections of sole SSB for range of fishing mortality values.

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Review of MSY and target reference points

## 4 Introduction

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In this Section the discussion and the response to ToR b) is presented:

- f) review the scientific and management literature on the implementation of maximum sustainable yield reference points in line with the Johannesburg agreement 2002.

The WKREF had in its ToR also:

- g) comment on potential target reference points for fish stocks in the ICES area as suggested by SGMAS, taking into account the possible effects of species interactions and regime shifts and the framework on the evaluation of management strategies.

However, as SGMAS did not come with specific recommendations on target reference points, WKREF was not in a position to evaluate the recommendations.

### 4.1 Interpretations of MSY after WSSD

The World Summit on Sustainable Development (Johannesberg, 2002) stipulates the concept of maximum sustainable yield in the implementation plan as follows:

*“31. To achieve sustainable fisheries, the following actions are required at all levels:  
(a) Maintain or restore stocks to levels that can produce the maximum sustainable yield with the aim of achieving these goals for depleted stocks on an urgent basis and where possible not later than 2015;”* (UN, 2002)

In his keynote address to the 1976 Annual meeting of the American Fisheries society, Peter Larkin delivered a convincing “Epitaph for the Concept of Maximum Sustainable Yield”(Larkin, 1977). While recognising that the concept had been useful to curb the rapid expansion of the fisheries in the 1950s and 1960s, and that hypothetical animal populations could produce hypothetical maximum sustained yields, Larkin suggested that the same could

not be said of real animal populations that are really being harvested. Amongst the reason for his scepticism were:

- 1) the changes in the age structure of the stock as exploitation increases towards  $F_{MSY}$  means that recruitment can be expected to be lower when it is mostly younger animals that contribute to spawning;
- 2) a fish stock is likely to comprise several different subpopulations or substocks, some of which will be less productive than others. As exploitation increases towards  $F_{MSY}$  the less productive units will be depleted and will not be able to contribute their expected maximum sustained catch;
- 3) similarly in mixed fisheries, the less productive species would be expected to become depleted and not be able to contribute their expected maximum sustained catches to the mixed species maximum sustainable yield;
- 4) as a result of 3 above, it would seem unlikely that the best strategy would be to try to harvest MSY from each species of a community that is being fished;
- 5) traditional ways of calculating MSY values do not take into account species interactions nor regime shifts.

Larkin (1977) did not have an alternative to offer, but suggested that fishery management should aim for fishing mortality less than  $F_{MSY}$ .

Section 3.1.2 of the 1998 meeting of the ICES Study Group on the Precautionary Approach (ICES, 1998) discussed the potential uses of  $F_{MSY}$ . Noting that Annex II of the 1995 UN Fish Stock Agreement states that  $F_{MSY}$  is a minimum standard for a limit reference point, the SGPA observes that a global survey of fisheries would show that there are actually very few examples where fishing mortality has been limited to  $F_{MSY}$  over a significant period of time, even where MSY has been the stated management objective. The SGPA believed that, if  $F_{MSY}$  were to be used at all, it would be more appropriate to view  $F_{MSY}$  as an upper bound on a target reference point, which implies that there should be more than a 50% probability that  $F_{MSY}$  is not exceeded. The SGPA also noted that primary argument against using  $F_{MSY}$  at all is that it is highly dependent on the shape of the stock-recruitment relationship assumed, which is usually poorly determined. The workshop agreed with those observations and further noted that the numerical values of  $F_{MSY}$ ,  $B_{MSY}$  and MSY itself would be dependent on the exploitation pattern, maturity at age, and weights at age which can all change over time. The workshop therefore concluded that case specific harvest control rules should be developed to take into account the current situation of each stock.

## FAO

FAO Committee on Fisheries, 25<sup>th</sup> session, Rome, 24–28 February 2003: “The conditions of a healthy fish stock are inadequately described through an MSY-related abundance measure. Moreover, **economic and social considerations cannot be neglected** in decisions concerning the rate and time at which recovery to a healthy stock size can be attained” (FAO, 2003).

“The WSSD plan of implementation has implications for the FAO programme of work in the various sub-sectors for which FAO has responsibility in the UN System. Many of the specific fisheries provisions within the WSSD plan of implementation reflect the commitments in the four FAO international plans of action (IPOAs) that were adopted within the framework of the FAO Code of Conduct prior to the WSSD (FAO, 1999, 2001). FAO’s role in supporting national, regional and international efforts towards the implementation of the WSSD plan of implementation targets is an integral part of the organization’s efforts to promote the implementation of the FAO Code of Conduct and, through it, other post-UNCED instruments.” (Garcia and Doulman, 2005)

### **STECF 2005 comments on Johannesburg Declaration and the CFP**

STECF considered that the Johannesburg Declaration requires agreement on new operational management objectives within the CFP and as a consequence, impacts on the advisory criteria of STECF, ICES and other advisory bodies.

Paragraph 31 (a) of the Declaration defines that stocks should be recovered to levels that can produce maximum sustainable yields (MSY) by 2015. This objective was established in the "Rio Declaration" of 1992, but without an agreed time schedule of reaching the objective. The Johannesburg plan of implementation is a commitment to rebuild individual stocks to the states at which they can produce maximum sustainable yields. This means that each fish resource should be able to produce maximum sustainable yields within the constraints of the ecosystem that it inhabits. This excludes the possibility of attempting to manipulate ecosystem structure by over-fishing some species in order to improve the yields of others.

The productive capacity of the seas and oceans is limited and it may not be possible to achieve the maximum sustainable yield that would be predicted starting from current conditions for all stocks in an ecosystem simultaneously - mainly because species compete with each other for resources.

It has been stressed, that the practical problems of estimating the biomass required to reach MSY are so large, that biomass should not be used as an operational aim, even though it is used as the aim in the Declaration. The problems are related to the uncertain stock-recruit information and to the variability of the aquatic environment. STECF suggested that instead of using the uncertain  $B_{msy}$ , the use of  $F_{msy}$  would be a less uncertain management goal. STECF agrees that  $F_{msy}$  can be used instead of  $B_{msy}$ , if there is no useful SRR information available.

In order to reach the goal of Johannesburg Declaration, STECF considers that the fish stocks in year 2015 should consist of year classes which have been recruited to the stock as a result of applying  $F_{msy}$  earlier on in the management. For example, if the fishery on a stock is only substantial in terms of total fishing mortality for age groups 2–7, then  $F_{msy}$  must be achieved 6 years (number of significant age groups) before the target year of 2015 in order to reach the political aim. This would mean an operational objective to reach  $F_{msy}$  by 2009 at the latest. STECF recommended that a management objective satisfying the above criteria be set for each stock. STECF further recommended that  $F_{msy}$  or an agreed proxy should routinely be included in stock status reports and advice.

### **EC Communication MSY (EC 2006a; EC 2006b)**

*Note: the following section is a summary of the EC communication on MSY and the technical background document to it.*

Maximum sustainable yield is the maximum yield that may be taken year after year. It is characterized by a level of fishing mortality that will, on average result in a stock size that produces the maximum sustainable yield. Fishing at MSY levels would reduce discard problem costs and increase profits for the fishing industry, as the amount of effort (and associated costs, such as fuel) required per tonnes of fish caught decreases and size of the fish increases (and its value). Fishing for commercial species can often also disturb habitats and harm noncommercial species, including dolphins and porpoises. Reducing the fishing mortality rate from current levels towards MSY levels will reduce the by-catch of such non-target species.

It is highly uncertain how marine ecosystems will develop e.g. in relation to changes in climate. While environmental factors may certainly affect fish stocks, fishing has in many cases the most important impact. Exploiting fish stocks at a lower rate of fishing will make stocks more robust to ecological changes.

Fishing on all species in an ecosystem should normally take place at a rate that is less than the rate of fishing that corresponds to obtaining a maximum sustainable yield in the long run. In some fisheries ("mixed fisheries") a number of species may be caught on the same fishing trip. Where different stocks are normally caught together, it should be the possibility of exploiting some stocks more lightly than at MSY levels in order to achieve some gain in productivity of other species. In general, MSY targets must be subject to periodic review.

***EU position on how estimate MSY (or proxies of it)***

Scientific estimates of  $F_{msy}$  rely on proxies: fishing mortality rates that approximate to  $F_{msy}$  under assumed conditions. Two widely-used proxies are  $F_{max}$  (this is the fishing mortality rate that would produce the highest catch under the assumption that adequate recruitment of juvenile fish is maintained) and  $F_{0.1}$  (this is a fishing mortality rate where a yield close to the maximum sustainable yield can be taken and where the costs of fishing are lower and the risk of depleting the stock is lower;  $F_{0.1}$  is used as a target fishing mortality rate in a number of fisheries). These parameters can be evaluated with good precision for many stocks. Due to the high uncertainty associated with estimating the stock size that will produce the maximum sustainable yield, the Commission's starting-point for discussion about the Community's MSY strategy is that the  $F_{0.1}$  will probably be the most useful proxy for  $F_{msy}$ . The technical definition of  $F_{0.1}$  is that fishing mortality where the expected yield increase from adding another unit of effort is one tenth of the yield produced when the first unit of effort was launched on the formerly unfished stock. This definition of a reference point may seem rather arbitrary but the bottom line is that  $F_{0.1}$  has two desirable properties if one is to manage within  $F_{msy}$ :  $F_{0.1}$  is lower than  $F_{max}$  and there is thus better chances that it is at or below  $F_{msy}$  and the estimation of  $F_{0.1}$  has been found to be more robust to uncertainties than the estimation of  $F_{max}$ . For stocks where recruitment has been stable in the long term at  $F_{max}$ , and the yield-per-recruit curve has a clear maximum, the  $F_{max}$  would be a preferred proxy.

The Johannesburg commitment is to rebuild stocks to that biomass capable of providing a yield at the MSY level by 2015. This implies that fishing mortalities should be reduced to  $F_{msy}$  well before then - of the order of one generation time for the species concerned - in order for the fishery and the stock to come into balance. This may not however be a realistic option, in terms of its likely economic and social impact, in many cases.

**Reviewing MSY in the US**

Members of WKREF were aware of a recent evaluation of the US fisheries management plan. This will also have involved a review of the role of MSY in future management strategies. Unfortunately, no further information on this could be obtained in the course of the Workshop.

**Review of scientific literature**

In a reply to Larkins (1977) epitaph, Mace (2001) reviewed the further development of the precautionary approach between until 2001, noting that  $F_{msy}$  had been reborn within international agreements and advocating its use as an upper limit to exploitation within the precautionary approach.

Collie and Gislason (2001) used a qualitative sensitivity analysis of multispecies model estimates to examine the utility of the single-species biological reference points in a multispecies context. They concluded that reference points based on stock recruitment data ( $F_{high}$ ,  $F_{med}$ ,  $F_{low}$ ), or a fitted stock-recruitment relationship ( $F_{loss}$ ,  $F_{MSY}$ ) were adjusted in a compensating direction in response to changes in the demographic parameters. The reference values decreased with lower growth rates and with high predation rates; the reference points based only on per-recruit calculations ( $F_{0.1}$  and  $F_{40\%ypr}$ ) increased the risk to the stock with changes in growth or predation mortality rates. In contrast, when Walters *et al.* (2005) examined the utility of the maximum sustainable yield concept within an



multiplespecies ecosystem of predators and prey within an Ecosim framework, single species MSY harvest policies caused severe deterioration in ecosystem structure, in particular the loss of top predator species. The authors noted that the results supported the practice within fisheries management for protecting at least some smaller “forage” species specifically for their value in supporting larger piscivores.

Powers (2005) examined the complexity involved in the determination of MSY when two fisheries catch a species but one discards the catches. The determination of MSY was shown to be contingent on the selectivity of the various fisheries involved and the balance of relative effort between target and by-catch fisheries. The value of MSY could be derived for a combination of fleet selectivity and relative effort but “Before analysts can calculate MSY and associated parameters, managers must determine their desired mix of fishing and the definition of ‘to the extent practicable.’”

Kell and Fromentin (2006) comment that fisheries are one of the most complex systems to understand and manage because of the mix of biological, ecological, economic and social processes that are dynamic and interact with each other. MSY, therefore cannot provide, in many cases a robust objective in the face of uncertainty (i.e. due to the natural stochasticity in biological and economic processes). The authors recommend the development and use of Management Strategies as used within the the management procedures adopted by the International Whaling Commission and others. That the real objective is sustainability and that MSY is only one possible reference point or indicator of sustainability. The wide range of objectives and processes that the management of fisheries has to address, especially within an ecosystem perspective, make MSY too simplistic and insufficient, although useful.

## 4.2 Role of target reference points in management plans

### Examples of evaluations of management plans

The *ad hoc* WG (EU-Norway 2004) was convened to evaluate harvest-control rules for those North Sea and Northern Shelf stocks shared between the EU and Norway. It used stochastic forecast simulation software tools such as STPR3, LTEQ and CS4 for this purpose. These simulate the future dynamics of a stock-management complex<sup>2</sup>. They allow an evaluation of the risk to biomass and the likely long-term yield contingent on such parameters as the target  $F$  ( $F_{\text{target}}$ ), the trigger biomass level ( $B_{\text{trig}}$ ), constraints on TAC, biomass and  $F$ , and implementation and assessment error and bias. In all cases the limit biomass point ( $B_{\text{lim}}$ ; the biomass below which recruitment is impaired) is assumed to be determined in a separate procedure. The effects of the other parameters mentioned above are then evaluated contingent on this predefined value of  $B_{\text{lim}}$ .

For most of the stocks covered by the WG, the determination of the appropriate  $F_{\text{target}}$  (along with the other parameters) was made by finding those values which implied *both* a low risk of  $B < B_{\text{lim}}$  and a high long-term yield. This approach approximates a maximum sustainable yield (MSY) calculation, but MSY is only referred to directly in the sections on North Sea plaice and haddock. For plaice, estimates of MSY and  $F_{\text{msy}}$  were generated using equilibrium production models combined with different assumptions about recruitment. The results for  $F_{\text{msy}}$  ranged between 0.21 and 0.43, while the final recommendation for  $F_{\text{target}}$  (following stochastic simulations) was 0.25. For haddock, the MSY concept was mentioned only in the context of an initial estimate for  $F_{\text{target}}$  of 0.4, which was said to be equal to “ $F_{\text{msy}}$  in the MATES report”. Interestingly, that report (MATES, 2002) does not clearly specify  $F_{\text{msy}}$  (although it mentioned 0.39 as a possibility), so the origin of this value is not clear. The final conclusion of the WG for haddock was for an  $F_{\text{target}}$  of 0.3. A particular problem for the

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<sup>2</sup> although without the annual virtual assessments that are now possible in the FLR framework

haddock analysis was that the STPR3 program could not adequately replicate the sporadic nature of haddock recruitment, so this estimate of  $F_{\text{target}}$  was presented as an intermediate guideline pending further analysis.

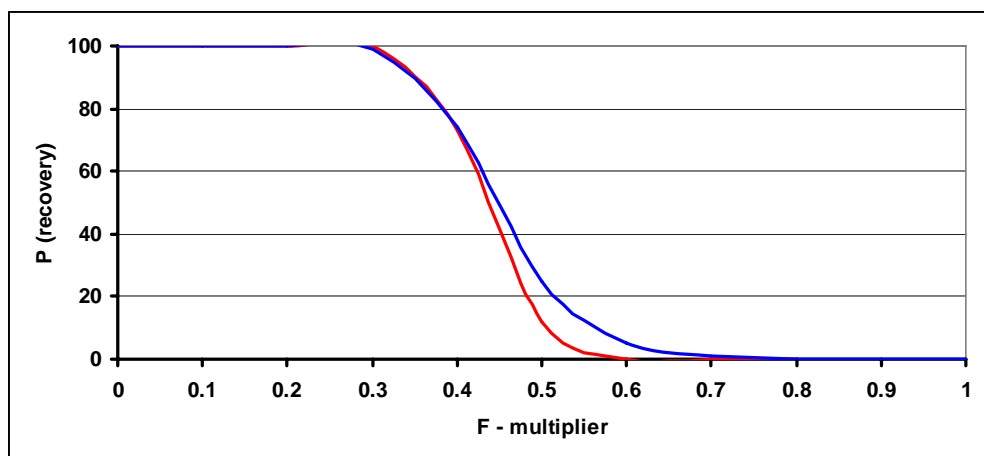
The target long-term values of  $F$  proposed by the WG therefore have an ambiguous relationship with the MSY concept. Although the stated goals of high long-term yield and low biomass risk are the essence of MSY, at no point in their report do the WG conclude that what they have proposed is  $F_{\text{msy}}$ . This interpretation would seem to have arisen sometime after the publication of the report, and has persisted in the light of the Johannesburg convention. Although the  $F_{\text{target}}$  values proposed by the WG may be appropriate tools to achieve high yield with low risk, it would be incorrect to conclude further that yield will be maximised from a sustainable stock (as is assumed for the MSY concept).

### **AGLTA 2005**

The approach taken by AGLTA was largely the same as that used by the EU-Norway *ad hoc* WG, and by other subsequent meetings such as SGMAS (ICES, 2005). The AGLTA report makes no reference to MSY at all, but (as for the EU-Norway WG) their conclusions on appropriate  $F_{\text{target}}$  values are based on evaluations of high yield and low risk and are therefore crude approximations to MSY. AGLTA focussed on cod and plaice in the North Sea, and cod in the Baltic. The analysis was complicated for North Sea cod by the need to run an initial phase leading up to recovery, followed by a more standard harvest-control rule evaluation thereafter. For both North Sea stocks, the simulations led to a very rapid increase in abundance which may not be feasible in reality, due to ecosystem constraints and related changes in stock dynamics, so (once more) the conclusions were presented as interim indications of the appropriate direction to take. Suitable values of  $F_{\text{target}}$ , leading to high yield with low risk, were <0.4 (North Sea cod), 0.2–0.3 (North Sea plaice), and 0.5–0.6 (Baltic cod). The importance of implementation bias was highlighted in this report.

### **Target fishing mortality levels for North Sea cod**

Horwood *et al.* (2006) noted that the progress of North Sea cod recovery is now under discussion within management bodies due to the uncertainties in the stock assessment process resulting from under reporting and discards. In addition, questions arise as to whether recovery targets are achievable in a changing and adverse environment for the cod. Horwood *et al.* (2006) demonstrate that current targets are achievable with fishing mortality rates that are compatible with recent international agreements even in a low productivity regime (Figure 4.3.1). The authors also note that recent collations of data on international fishing effort have allowed estimation of the cuts in fishing mortality achieved by restrictions on North Sea effort. By the beginning of 2005, the restrictions were estimated to have reduced fishing mortality rates by about 37% and that this is insufficient to ensure recovery of the North Sea cod over the next decade.



**Figure 4.3.1.** Probability of cod recovery, within a decade, against cuts in stats-quo fishing mortality (modelled at  $F_{sq\ 2003} = 1.1$ ); based on two different stock-recruitment scenarios - low productivity in red, recovery to historic levels in blue.

### Management strategy evaluations using FLR

A new management plan for North Sea haddock came into effect in January 2005, and was to be evaluated before December 2006. The evaluation was carried out using the FLR library in R (FLR Team 2006, R Development Core Team 2005). Methods and results are summarised in Needle (2006a-c), ICES (2006a), and ICES (2006b).

The R code used for these evaluations is similar in broad outline to the methods used before. The main addition to the simulation loop is a knowledge production module, which runs assessments on the population data generated by the underlying biological simulation. The virtual managers in the simulation then base their decisions on the results of an assessment, as would be the case in reality, rather than on the true population. Of key importance to the North Sea haddock case study was the generation of recruitment time-series appropriate to a sporadically-spawning species. The target  $F$  generated by the model (around 0.3) was obtained purely through considerations of risk, rather than yield.

The resulting code is flexible and could, in theory, be applied after suitable modification to a large number of management strategy evaluations. One side-effect of this flexibility is that the code is rather complicated, and the user needs a close understanding of the implementation to use it successfully. Notwithstanding this drawback, the study has reinforced the conclusion that it is feasible to evaluate a large number of candidate target mortality rates in different harvest-control rule structures without recourse to formal definitions of MSY (or, indeed, considerations of yield).

The approaches summarised above, used simulations to develop target  $F$ s that were intended to produce high yield with low risk. The methodology is therefore very similar to what would be used for MSY, but is not formally equivalent (since yield is not maximised, and sustainability is not defined). The interpretation of these targets as estimates of  $F_{msy}$  appears to have arisen later.

### NSRAC focus group on long term targets

The NSRAC convened a focus group to discuss MSY as a concept and its applicability to fisheries management. Several conclusions were drawn from the meeting, not least, that MSY was identified at the 2002 'Johannesburg Summit because it was the only one available'.

The focus group agreed that MSY is not stable over time in relation to both the carrying capacity of the environment and stock recruitment. Broadly, they felt MSY as a principle is a recipe for disappointment due to the high risk of failure.

Consensus was achieved in the group however with respect to the need for a progressive and meaningful reduction in mortality, although agreement was also met on the succinct point that  $F_{msy}$  was too simplistic a target for practical implementation. Furthermore, choosing targets based on the evaluation of harvest control rules that are robust to uncertainty, rather than through fixed definitions of reference points was judged to be the correct route.

The focus group believe that a new interpretation of MSY is required, one which takes into account the four aspects of sustainability, further confirming their understanding that MSY should not be a static one-dimensional concept or target.

### 4.3 Defining reference points: processes and values

In 1997, ICES has been asked by its clients to suggest an approach for implementing the precautionary approach into fisheries management in the North East Atlantic<sup>3</sup>. The precautionary approaches suggested by ICES consists of a dual system of conservation limits (limit reference points) and a buffer to account for the uncertainty of the knowledge about the present and future states relative to the conservation limit (precautionary approach reference points). The reference points are expressed in terms of single-stock exploitation boundaries (limits on fishing mortality) and biomass boundaries (minimum biomass requirements).

Already in 1997, it was acknowledged that there was a need for input from fisheries managers and stakeholders on the level of risk they were willing to accept. For that reason, the limit reference points have been presented as considerations from ICES and the precautionary reference points as proposals. However, in practice there has been almost no interaction on the values of precautionary reference points and they have become embedded in the ICES advisory framework without the interaction with stakeholders and managers.

WKREF identified three approaches from the review of MSY that could be followed in developing long term targets:

- 1) EC ( $B_{lim}$  not required;  $F_{0.1}$ - $F_{max}$  from yield per recruit analysis as a proxy for  $F_{msy}$ )
- 2) ICES ( $B_{lim}$  required, but if it is not available evaluation is also possible; HCR risk analysis: probability of SSB falling below  $B_{lim}$ )
- 3) Process/sustainability (NSRAC) (risk analysis also considering socio-economic implications)

The EU approach has the advantage that it does not need any definition of  $B_{lim}$ .  $F_{0.1}$  is low enough to be consistent with both the ecosystem approach and the ability to deliver larger yield per unit of effort. The disadvantages are that it lacks any involvement of stakeholders and that it is a theoretical concept that is difficult to communicate. Collie and Gislason (2001) found that reference points based only on per-recruit calculations ( $F_{0.1}$  and  $F_{40\%ypr}$ ) increased the risk to the stock with changes in growth or predation mortality rates.

The ICES approach has the advantage that it avoids *ad hoc* assumptions about what rate is likely to be appropriate, it involves considerations of risk analysis, and the process can be made inclusive for managers and stakeholders. The disadvantages are that it is dependent on  $B_{lim}$  and also the simulations themselves cannot include all the factors that can affect the fishery and the stock. The simplifying assumptions in the HCR evaluation must be determined

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<sup>3</sup> The Precautionary Approach was summarised in the UN Straddling Fish Stocks Agreement (UN 1995) as follows:

“States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.”

with great care. The evaluation requires a biomass that should be avoided with a certain probability. When  $B_{lim}$  cannot be estimated, management strategies could be evaluated relative to a test biomass rather than a limit reference point.

### Conclusion

Single species MSY is relatively simple concept but real fisheries are complex systems, often with multispecies and technical interactions, influenced by biological, ecological, economic and social processes. Therefore, implementation of MSY management in real ecosystems may be very difficult. For example, single species MSY and  $B_{msy}$  will not work for predators and prey at the same time, MEY is always less than MSY.

Process and HCR evaluation may be preferred option when appropriate data is available. They can provide  $F$ 's leading to high yield and low risk to biomass. Stakeholders and managers may take part in the evaluation process, suggesting desired rate of change and level of risk. When data are limited, the  $F_{0.1}$  would be alternative candidate approach.

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## 5 Discussion and conclusions

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### Framework for estimating reference points

The general approach of WKREF to estimating (limit) reference points was to look for case studies where environmental drivers or multispecies interactions would be likely to affect stock dynamics and how that would in turn affect the estimation of reference points. The main case study for this approach was the Baltic cod where substantial environmental information is available and where it is known to influence the recruitment pattern. However, WKREF did not finish intended analyses during the meeting and thus could not come to conclusions on the best approach to estimating a biomass limit reference point for that case-study.

WKREF was also a forum for discussing “small” updates of reference points in cases where the current reference points could be shown to be inconsistent with previously agreed approaches such as SGPRP 2003 (ICES, 2003). In those cases, WKREF applied the criteria of SGPRP on a single stock basis (without taking environmental drivers into account). The SGPA 2002 approach on estimating precautionary reference points could not be implemented during the workshop, so as a fall-back position the original SGPA 1998 approach was used to suggest possible precautionary reference points if the limit reference points were to be updated. This is clearly not a desirable approach.

WKREF found some methodological problems with the technique of segmented regression. It was found to be very sensitive to small changes around the origin (Norwegian Spring Spawning herring) and to the bending curve at high biomass (North Sea herring). Both sensitivities influenced the value of the breakpoint. WKREF concluded that in case of clearly dome-shaped recruitment pattern, segmented regression does not seem to be appropriate but also recommends further exploration in WGMG.

An alternative approach to finding a breakpoint was submitted by John Simmonds. The method attempts to estimate the probabilities of obtaining a below average recruitment. This method was explored during the workshop and tested on a number of case studies (North Sea herring, Norwegian Spring Spawning herring, Baltic cod and Blue whiting). Again the workshop found some methodological difficulties because the methods attempts to estimate a breakpoint in what is inherently a curved line. The method was extended by application of different percentiles of recruitment distribution as the reference for probability calculations and the method may be useful even if breakpoint is not clearly estimated as it provides probabilities of recruitment being lower than specified level (average, other percentile of recruitment distribution) at range of SSB estimates. If this method would be applied it would first need closer scrutiny during WGMG.

In line with SGMAS (ICES, 2007), WKREF identified a need to evaluate the standard ICES interpretation of the precautionary approach through a HCR evaluation process. This should preferably be presented to WGMG 2007.

### **Estimating Blim**

The definition of Blim is the biomass below which recruitment is impaired or the dynamics of the stock are unknown. Impaired means seriously decline and on average significantly lower than at higher SSB. This means that impaired recruitment can already occur when recruitment is just below average recruitment.

The general public's perception of Blim is much more dramatic than what is suggested from the above definition of impaired recruitment. The public perception is that the stock is really in dire problems when the stock is below Blim. The stakeholder participants in WKREF questioned whether the current use of Blim is in itself risk-neutral or that a risk assessment is already part of the definition of Blim.

ICES needs to communicate more clearly how it defines Blim and what kind of risk assessments are underlying the estimation (or not)

WKREF concluded that moving to a target F based management would probably remove the importance of Blim in a management context.

As indicated above, the question on the role of regime shifts in determining limit reference points was not resolved by WKREF. One approach could be to define different SRR curves for different environmental regimes and to evaluate the breakpoints in these two curves. The other approach could be to include environmental variables into S-R model and define Blim for different regimes using developed S-R model. One could also look for biomass limits that would be applicable in both environmental regimes. The distance between Bpa and Blim could take into account the uncertainty due to different regimes.

### **Maximum Sustainable Yield and target reference points**

WKREF concluded from the review of the scientific and management literature that Maximum Sustainable Yield (MSY) is a difficult concept for management purposes because it is difficult to assess, unstable over time and only applicable in a single species context. Single species MSY and Bmsy will not work for predators and prey at the same time.

The practical application of the MSY criterium in the Johannesburg declaration (WSSD, 2002) is to aim for a fishing mortality which would be low enough to allow the stocks to increase to a level where they could produce a maximum yield. Whether they would really produce such a stock size and yield would also depend on the productivity regime and the species interactions. MSY in such an approach is approximated by proxy fishing mortality (e.g.  $F_{0.1}$ ,  $F_{max}$ ) or through HCR evaluations that attempt to estimate a target  $F$ . A drawback of the  $F_{0.1}$  approach is that the concept of a yield-per-recruit curve is often difficult to explain to stakeholders, but in practice the  $F_{0.1}$  and HCR approach often end up with estimated target fishing mortalities which are reasonably close.

Stakeholder organizations such as RACs have been involved in developing ideas for long term management plans which could be an answer to the requirement for MSY in 2015. A clear message from the NSRAC workshop on long term targets was that sustainable development should be considered in a wider context than only biological reference points. They argued that economical, social and institutional aspects should also be considered in a strategy to develop long term plans, and in this context, the WS noted that Maximum Economic Yield is always less than MSY. The process of interactions between different groups would be very important in such a strategy development. The objective would be to implement changes in fishery management that would be expected to result in medium to long term improvements under all four components of sustainability, that is explicitly take into account the expected outcomes not only with respect to the stock status, but also in terms of the economic and social consequences.

WKREF concluded that the process-oriented approach advocated by the NSRAC workshop and the HCR evaluation approach would be the preferred options for moving to sustainable fisheries. It is important to be able to show risk-assessments of different strategies. The general direction should be towards low fishing mortalities and the direction of movement would probably be more important than the absolute values of the target reference points. When appropriate data is not available to apply the HCR approach,  $F_{0.1}$  could be used as a proxy for  $F_{msy}$  although that concept is more difficult to explain to stakeholders and managers.

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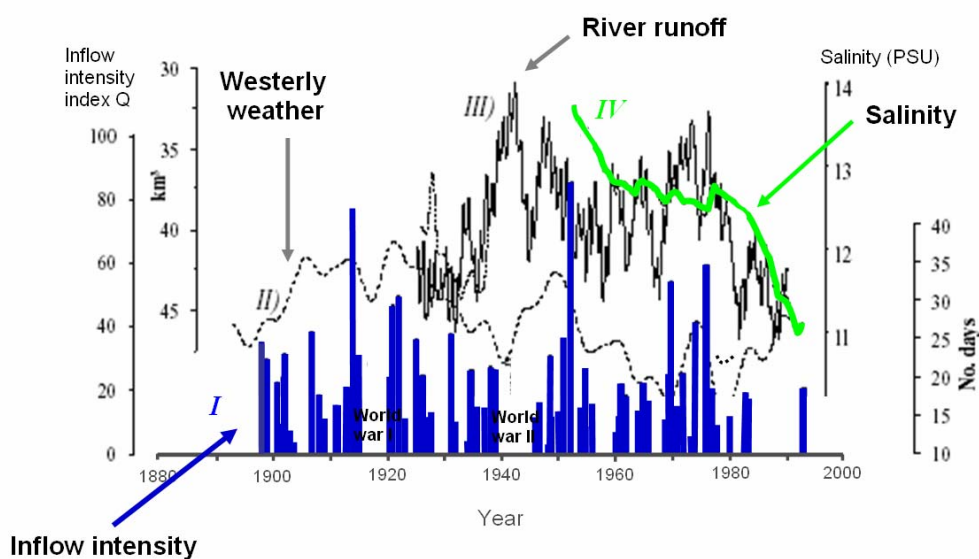
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## Annex 1: Environmental drivers and Baltic cod

### Spawning habitat

The Baltic Sea is characterised by a series of deep basins separated by shallow sills. Beside the development of a thermocline in spring, the characteristic hydrographic feature in the deep Central Baltic basins is a permanent halocline separating an intermediate cold water layer from a saline bottom water layer. Salinity and oxygen conditions in the bottom layer can only be enhanced by lateral intrusion of water originating from the Kattegat and the North Sea termed “Baltic inflows” (Matthäus and Frank, 1992). Minor inflows will usually enter the Bornholm Basin only, with little or no eastern transport. Inflows reach the Gdańsk Deep and the Gotland Basin only if (i) the transported volume of water has a substantial magnitude, a “major inflows” (definition see Matthäus and Nausch, 2003), ii) the advected water is replaced by an even denser water mass in a subsequent inflow (ICES, 2004), or iii) a subsequent inflow of less dense water glides over water from an earlier inflow (Matthäus and Nausch, 2003). Hydrographic conditions in the Central Baltic are affected by large-scale climatic conditions. Since late 1980s, prevailing weather with strong westerly winds resulted in mild winters, above normal rainfall, increased river runoff and reduced frequency of major inflows (Matthäus and Schinke, 1994; Hänninen *et al.*, 2000) (Figure 1). Consequently, higher than normal temperatures in the intermediate and the bottom waters were recorded, while salinity and oxygen concentrations in the deep Baltic basins declined (Matthäus and Nausch, 2003).

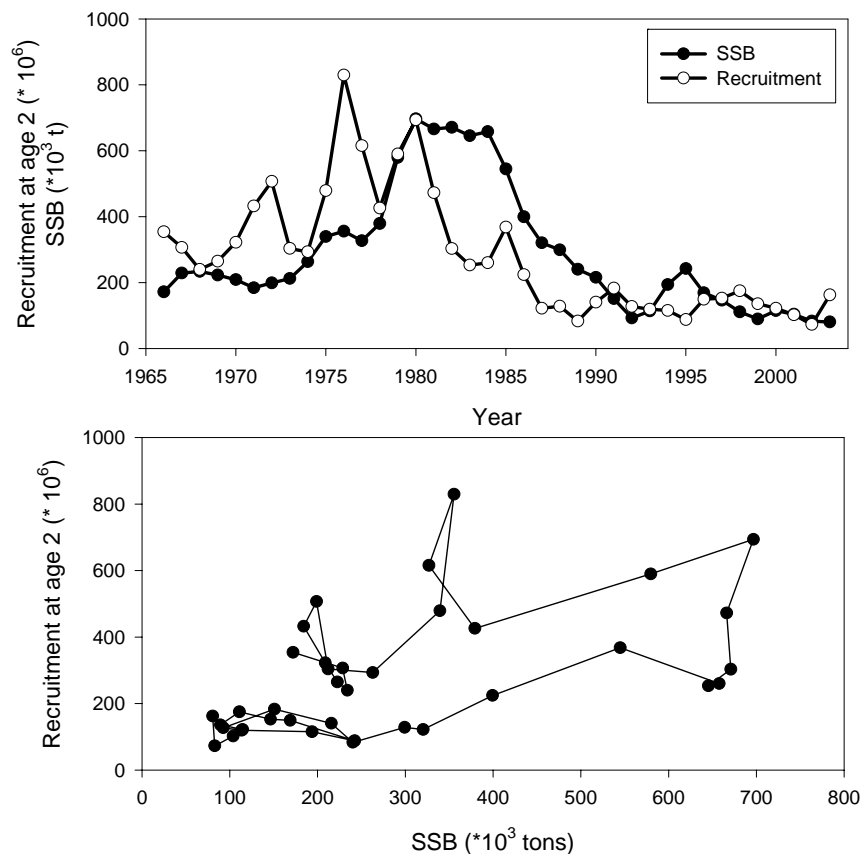


**Figure. 1. Climatic and hydrographic conditions during the 20th century: inflow intensity, number of days with westerly weather, magnitude of river runoff in km<sup>3</sup> and average salinity in the bottom water of the Gotland Basin, adapted from Hänninen *et al.* (2000)**

In contrast to cod spawning areas outside the Baltic, the ambient salinity is insufficient to keep cod eggs floating in the surface layers. They occur exclusively within and below the permanent halocline (e.g. Wieland and Jarre-Teichmann, 1997). Here they are exposed to variable and in general low oxygen concentrations, impacting on egg survival and subsequent recruitment success (e.g. Kosior and Netzel, 1989; Lablaika *et al.*, 1989).

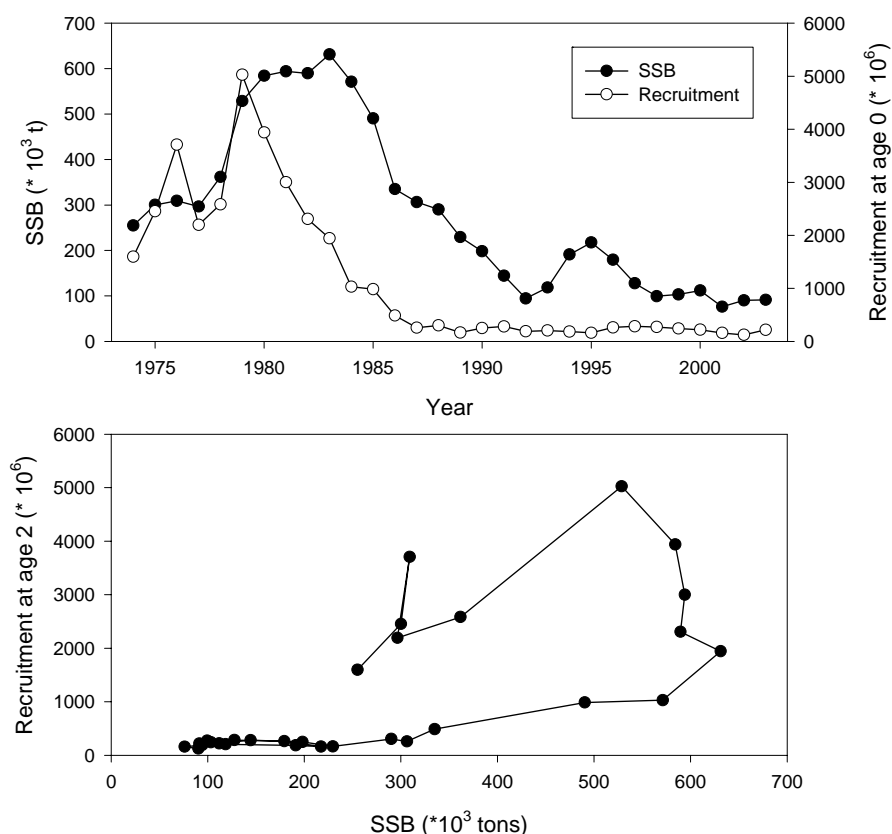
### Stock recruitment relationship

The eastern Baltic cod stock increased from early to mid 1970's and showed a very positive development from 1976 to 1980 reaching a historical high in 1980, remaining high until 1984, afterwards steadily declining to a record low in 1992, staying on this low level with the exception of a showed a short term intermediate increase in mid 1990's (Figure 2). Inspecting the recruitment originated by the spawning stock, reveals a high reproductive success at intermediate SSB values in the 1970's and declining reproductive success at historically high spawning stocks from 1981 onwards. This stock dynamics leads to a stock recruitment relationships having apparently two levels with a transition period with reduced recruitment originating from constant high SSB's in 1980–1982 (Figure 2).



**Figure 2. Eastern Baltic cod. Time series of recruitment at age 2 and spawning stock biomass as estimated in standard stock assessment (ICES, 2006b) (upper panel) and corresponding stock recruitment relationship with indicated time line.**

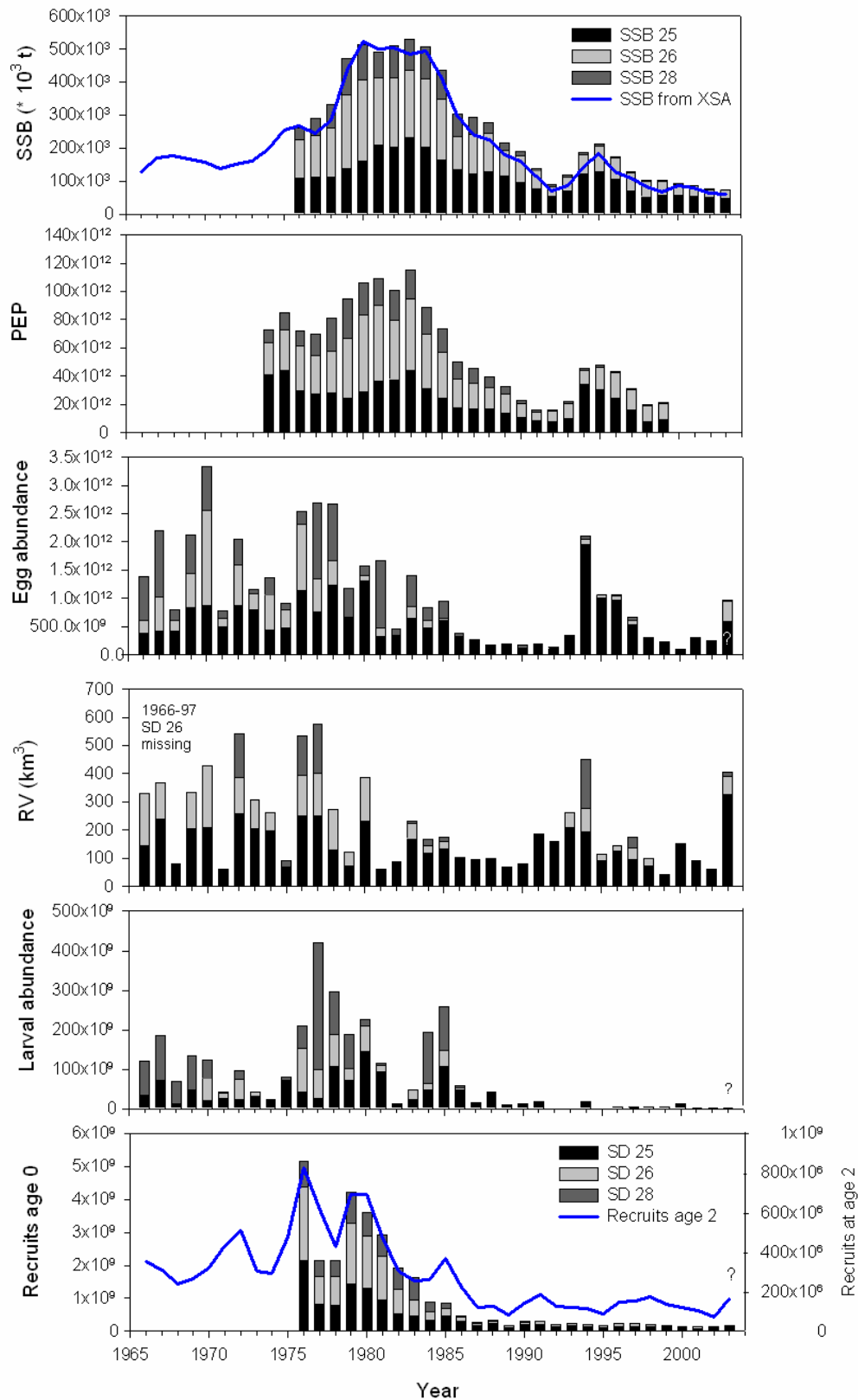
Since 1987 recruitment fluctuations appear to be largely independent of the SSB (2b). This result does also not change if applying instead of age 2 recruitment from the standard XSA assessment (ICES, 2006a), age 0 or 1 recruitment from MSVPA runs (ICES, 2006c). On the contrary, accounting for cannibalism increases the difference in level between recruitment prior to and after 1982. The decline in recruitment is not only more pronounced in the MSVPA output, the transition period from high to a low recruitment regime at similar SSB's is also longer, i.e. it lasts from 1981 to 1983 (Figure 3).



**Figure 3. Eastern Baltic cod. Time series of recruitment at age 0 and spawning stock biomass as estimated by MSVPA (ICES, 2007) (upper panel) and corresponding stock recruitment relationship with indicated time line.**

### Hydrography and egg survival

The decline of the cod stock in the 1980's has been attributed to a reduction in reproductive success in combination with increasing fishing pressure, which approximately doubled from 1979 to 1991 (Bagge *et al.*, 1994; Köster *et al.*, 2003a). The reproductive success of the stock is coupled to hydrographic conditions in spawning areas. Laboratory experiments confirmed that at least  $2 \text{ ml l}^{-1}$  oxygen is needed for successful egg development (Nissling, 1994; Wieland *et al.*, 1994). Further, low salinity affects the fertilisation of marine fish species (Westin and Nissling, 1991). Experimental studies revealed a minimum salinity of 11 for activation of spermatozoa and thus successful fertilisation in Baltic cod (Westin and Nissling, 1991). The combination of these two limiting factors, the oxygen and the salinity threshold, formed the basis for the definition of the so called "Reproductive Volume" (RV) or the water volume allowing for successful cod egg development (Plikshs *et al.*, 1993; MacKenzie *et al.*, 2000). The magnitude of the RV in the deep Baltic basins depends, besides frequency and the magnitude of inflows, on the temperature of the inflowing water affecting oxygen solubility (Hinrichsen *et al.*, 2002a) and oxygen consumption rates by biological processes (MacKenzie *et al.*, 1996).



**Figure 4. Eastern Baltic cod. Time series of a) spawning stock biomass in Sub-division 25, 26 and 28 and the entire central Baltic (SSB), b) potential egg production (PEP), c) egg abundance, d) reproductive volume (RV), e) larval abundance and f) recruitment at age 0 in Subdivision 25, 26 and 28 and recruits at age 2 in the entire central Baltic**

Comparing the potential egg production by the SSB as more reliable measure of reproductive effort than SSB (Kraus *et al.*, 2002) with the a measure of the RV at spawning time (Köster *et al.*, 2005) indicates a large portion of the egg production in the Gotland Basin spawned during the late 1970s and early 1980s in unsuitable environments (Figure 4b, d). Since the early 1980s hydrographic conditions were also adverse in the Gdańsk Deep, when especially from 1986–1992 virtually no RV was present. The only spawning site regularly sustaining a successful egg development was the Bornholm Basin. After the major inflow in 1993, oxygen concentrations allowed successful egg development in the Gdańsk Deep in 1993 and 1994, and resulted in one of the highest RV on record in the Gotland Basin in 1994. While a substantial potential egg production was estimated in the Gdańsk Deep, the corresponding production in the Gotland Basin was very low.

The estimation of the potential egg production depends on the distribution of the adult stock, which was derived from area disaggregated MSVPA runs, and thus on the distribution of commercial catches in the different Subdivisions (Köster *et al.*, 2001a). MSVPA results may be sensitive to spawning migrations from eastern areas into the Bornholm Basin, which regularly has the best reproductive conditions. Analyses of results from benthic-pelagic trawl surveys (Tomkiewicz and Köster, 1999) and commercial CPUE data (Lablaika and Lishev, 1961) confirmed this spawning migration. However, area-disaggregated MSVPA results summed over all areas are very similar to the standard XSA output (Figure 4a) and egg abundance data presented (Figure 4c) indicate spawning effort in the eastern spawning areas even at unfavourable hydrographic conditions. This confirms observations on pelagic pre-spawning and spawning concentrations from trawl surveys in the Gotland Basin also in years with unfavourable oxygen conditions (Uzars *et al.*, 1991). Consequently, a mis-match of reproductive effort and spawning habitat quality was one of the main causes of the declining reproductive success and recruitment failure of the stock during the 1980s (Köster *et al.* 2003b).

Despite being conceptually appealing, the RV explains only a limited amount of variance in cod recruitment (e.g. Köster *et al.*, 2001b). The RV may not be the best proxy for egg survival, because 1) egg mortality caused by low oxygen concentration above the 2 ml l<sup>-1</sup> threshold is not considered (Wieland *et al.*, 1994) and 2) that eggs may float outside the RV in water layers not sustaining their development (Köster *et al.*, 2001b). Finally, other processes (see below) affect egg survival as well as other early life stage survival. Comparing oxygen related egg survival estimated from hydrographic conditions during spawning time, a laboratory based oxygen concentration – egg survival relations and a vertical egg distribution model (thus accounting for short-comings 1) and 2) above) with field based egg survival rates from the Bornholm Basin revealed highly significant relationships, but also indicated other sources of egg mortality (Köster *et al.*, 2005). Other processes potentially affecting egg developmental success are: i) salinity-dependent fertilisation rate (Westin and Nissling, 1991), ii) predation by clupeids (Köster and Möllmann, 2000) and iii) endogenous processes as chromosome aberrations during embryonic development (Kjørsvik, 1994), contamination by toxicants (e.g. Schneider *et al.*, 2000), and endogene parasites (e.g. Pedersen and Køie, 1994).

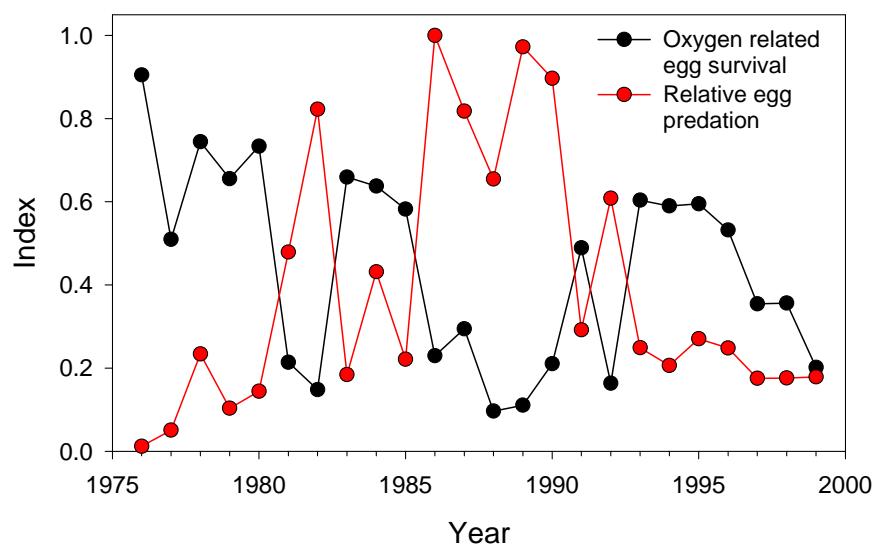
### **Egg predation by clupeids**

A substantial predation on cod eggs by clupeids has been described for the major spawning area of the cod stock, i.e. the Bornholm Basin. In contrast, the process appears to be of less importance in the more eastern spawning areas. This has been explained by a more limited vertical overlap between predator and prey in these areas (Köster and Möllmann, 1997). Egg predation in the Bornholm Basin is most intense at the beginning of the cod spawning season, with sprat being the major predator being very abundant since early 1990's as a consequence of reduced predation pressure by cod and increased reproductive success coupled to high water temperatures (Köster *et al.*, 2003b). At this time of the year spring spawning herring concentrate in their coastal spawning areas not contributing to the predation-induced egg

mortality. Sprat spawn in the Bornholm Basin from March to July, thus concentrating in cod spawning areas in times of high cod egg abundance. After ceased spawning activity sprat population leave their spawning area, resulting in a reduced predation pressure (Köster and Möllmann, 1997). With the return of the herring from the coastal areas to their feeding grounds in the Bornholm Basin, the predation on cod eggs by herring increases to considerable levels.

Comparing estimates of daily cod egg consumption rates by clupeid populations during cod spawning periods with daily production rates and standing stocks of cod, revealed predation to be above daily production and standing stocks in 1990–1992 and above the production in 1993 (Köster and Möllmann, 2000). The shift of cod peak spawning time from spring to summer (Wieland *et al.*, 2000) resulted in a decreasing predation pressure on cod eggs by sprat, due to a reduced temporal overlap between predator and prey. Additionally a decline in individual sprat predation on cod eggs was observed from 1993–1996, despite of relatively high cod egg abundance in the plankton.

Assuming estimated population consumption rates were unrealistically high, and expressing the predation pressure in relative terms, i.e. as the ratio of daily consumption to production scaled to the maximum value determined, confirms a reduction in predation pressure since 1993 (Figure 5). This is partly explainable by a reduced vertical overlap between predator and prey. Due to the increased salinity after the 1993 major Baltic inflow, cod eggs were floating in shallower water layers, while clupeids were deeper distributed, due to enhanced oxygen concentration in the bottom water (Köster and Möllmann, 2000a). Thus, predation pressure on cod eggs appears to be higher in stagnation periods when the vertical overlap between predator and prey is enhanced, meaning that cod eggs suffer in these periods from adverse hydrographic conditions and predation. Comparing an oxygen related egg mortality during stomach sampling cruises (Köster *et al.*, 2005) revealed a similar trend in hydrography induced egg mortality and predator - prey overlap and hence predation pressure (Figure 5). This can be explained by the same hydrographic parameters affecting the vertical predator/prey overlap and oxygen related egg mortality, i.e. salinity and oxygen concentration. Deviations in most recent years are caused by the shift of cod spawning time from spring to summer.



**Figure 5. Eastern Baltic cod. Time series oxygen related egg survival and relative egg predation pressure by clupeids in SD 25, adapted from Köster *et al.* (2005).**

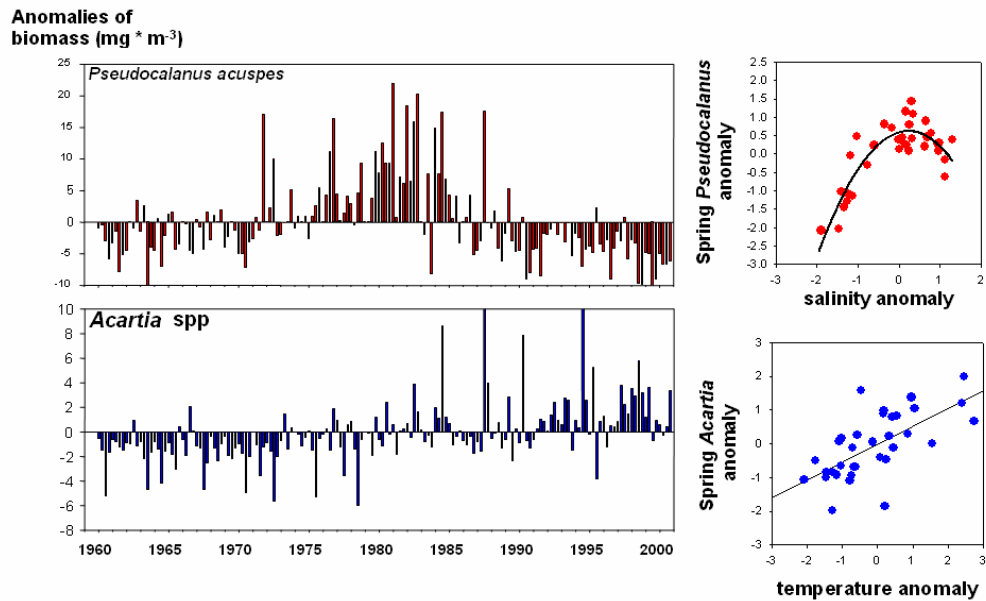
### Larval mortality

Comparing egg and larval abundances in the Bornholm Basin (Figure 4c, e) as well as observed and modelled egg survival with larval abundances indicated high mortality rates during hatching or in the early larval stage during the mid 1990s. While information on endogenous factors impacting on hatching success is limited, there are at least three different processes which can explain high mortality in the early larval stage: i) sub-lethal effects of egg incubation at low oxygen concentrations and/or direct effects of low oxygen concentrations on larval survival (Nissling, 1994), ii) predation by clupeids (Köster and Möllmann, 2000) and iii) food limitation and starvation (MacKenzie *et al.*, 1996).

Experimental studies demonstrated that low oxygen concentration at egg incubation impacts larval activity and the start of the vertical migration into upper water layers (Rohlf, 1999). Further Nissling (1994) demonstrated that low oxygen concentration negatively affected larval survival. However, given the favourable hydrographic conditions within and below the halocline in the Bornholm basin after the 1993 major inflow, it appears unlikely that sub-lethal oxygen effects during egg incubation or low oxygen concentrations in larval dwelling depths were responsible for the low larval survival in mid 1990s.

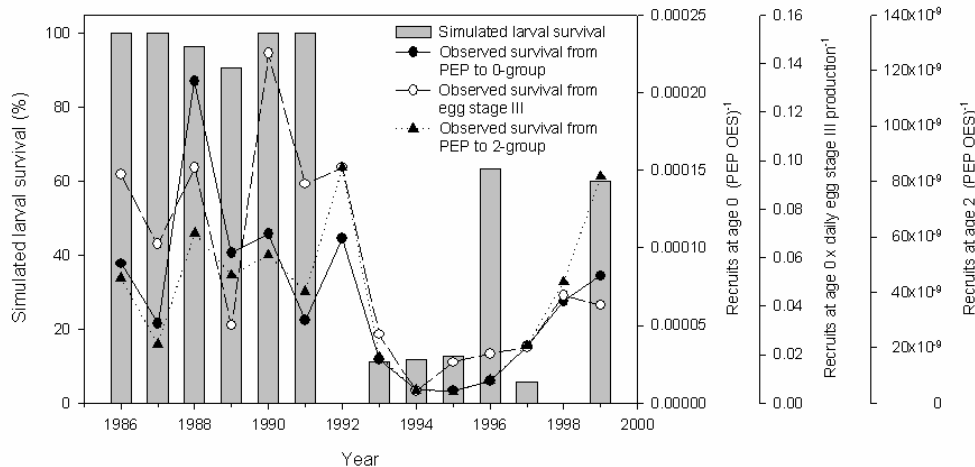
There is little evidence of substantial predation on cod larvae by clupeids (Köster and Möllmann, 1997). This can partly be explained by limited vertical overlap of larvae dwelling in upper and clupeids feeding in bottom water layers. Only newly hatched larvae concentrate in relatively high quantities within or below the halocline, where they are available as prey to herring and sprat. However, herring being the dominating predator in summer month, the main spawning time in mid 1990s, do feed seldom on these small larvae, potentially due to a mismatch in size preference (Köster and Möllmann, 1997).

The impact of food availability on larval growth and survival has been tested by Hinrichsen *et al.* (2002b) with a coupled hydro-/trophodynamic model. Model results indicated the importance of a match in calanoid nauplii and cod larval abundance in space and time for high survival of early larvae. High nauplii abundance of *Pseudocalanus acuspes* in spring or cod spawning in summer and a rapid transport into shallower areas with higher production of other calanoid copepod species assure high survival (Hinrichsen *et al.*, 2002b). The strong decline of *Pseudocalanus acuspes* since the end of the 1980s (Figure 6), associated with a decrease in salinity (Möllmann *et al.*, 2000, 2003) and increasing predation pressure by sprat (Möllmann *et al.*, 2007), resulted in low simulated larval survival in 1993–1995 and 1997 (Figure 7). The exception of 1996 can be explained by relatively high wind speeds (affecting transport and prey encounter via turbulence), below average temperatures and relatively high *Pseudocalanus* sp. availability.



**Figure 6.** Time series of biomass anomalies of key copepods in the central Baltic and relationship to hydrographic variables, adapted from Möllmann *et al.* (2003).

Low larval survival through the larval stage during the 1990s is also evident by the ratio of egg to larval abundance for the Bornholm Basin (Figure 7), and confirmed by relating 0-group recruitment to different measures of surviving egg production (Figure 7). Before 1992 observed survival rates were in general lower and more variable than the coupled model output, pointing to other larval or early juvenile mortality sources.



**Figure 7.** Eastern Baltic cod. Interannual variability in simulated larval survival in SD 25 from coupled hydro-/trophodynamic model based on idealized prey field (Hinrichsen *et al.*, 2002b), with exception of 1999 based on observed zooplankton abundance; measures of larval survival as recruits at age 0 per surviving egg production (PEP times OES) and per observed average daily egg stage III production as well as recruits at age 2 in the entire eastern Baltic per sum of surviving egg production in each SD (potential egg production times oxygen related egg survival).

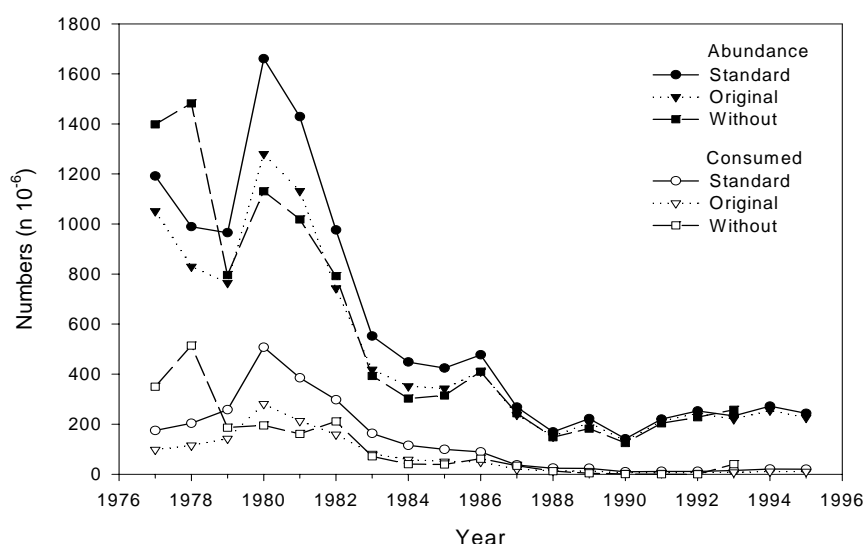
Larval abundance and recruitment at age 0 from area dis-aggregated MSVPA are significantly related in SD 25 and 26 (Köster *et al.*, 2005). However, recruitment in SD 28 is regularly observed despite larvae being absent in the ichthyoplankton surveys, a fact which is true also for SD 26 (Figure 4e and f). Comparing the time series of cod larval abundance in the Central Baltic, i.e. the integrated abundance of all spawning areas which should be unaffected by transport between spawning areas, with recruitment from the standard assessment revealed a highly significant relationship. This however does not imply that mortality from the larval to



the early juvenile stage is constant. On the contrary, high larval abundance observed in all spawning areas in 1984 and 1985 did not result in outstanding recruitment, indicating situations with higher than normal mortalities at the early juvenile stage.

### Juvenile mortality

Cannibalism is a significance source of mortality in juvenile cod (Sparholt 1994), which is however accounted for in the present analysis, as 0-group abundance from MSVPA runs are used. According to Neuenfeldt and Köster (2000), recruitment estimates from MSVPA runs are substantially affected by the choice of the suitability submodel and whether a suitability model is used at all. Deviations in recruitment estimates from MSVPA runs using different suitability models are obvious for the beginning of the time series (Figure 8). A MSVPA run without a suitability model (i.e. based on observed stomach content only) suggested highest recruitment for year-classes 1976 and 1977, while otherwise highest year-classes were determined for 1979 and 1980. The former result fits better to the larval abundance (Figure 4e), indicating that the 1977 year-class may be under- and the 1980 year-class overestimated by the present MSVPA runs (Figure 4f). Independent of how prey selection is modelled in the MSVPA, cannibalism is confirmed to be a significant source of juvenile mortality at high cod stock size.



**Figure 8.** Juvenile cod (age-group 1) abundance and consumption (cannibalism) estimated by MSVPA runs with the standard suitability model implemented in the Baltic, the original model and without suitability model, adapted from Neuenfeldt and Köster (2000).

### Impacts of climatic conditions on recruitment

Hydrographic conditions in the Central Baltic are affected by large-scale climatic conditions resulting during the last two decades in higher than normal temperatures in the intermediate and the bottom water, and declining salinity and oxygen concentrations in the deep Baltic basins utilized by cod as spawning areas.

The decline in cod recruitment during the 1980s was related to these climate-induced changes in the physical environment. Anoxic conditions in deep layers at eastern spawning sites, i.e. the Gdansk Deep and the Gotland Basin, caused high egg mortalities already in the first half of the 1980's. Declining salinities and oxygen concentrations enhanced the vertical overlap between eggs and clupeid predators in the remaining productive spawning area of the Bornholm Basin since mid 1980's. A temperature-related increase in the sprat stock intensified egg predation further since late 1980's.

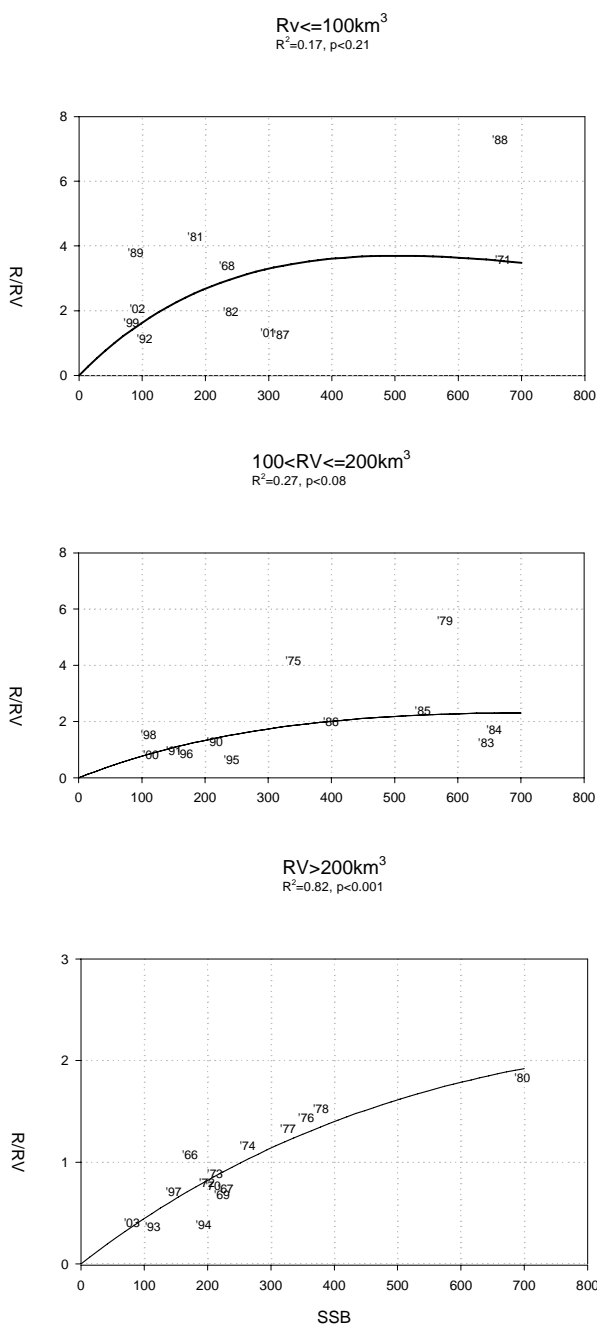
The lack of recovery in recruitment in mid 1990s, despite improved hydrographic conditions for egg development after the 1993 inflow, is related to low larval survival. A decline in the abundance of the copepod *Pseudocalanus acuspes*, mainly related to lowered salinity, caused food-limitation for first feeding cod larvae. The high sprat stock caused furthermore a substantial predation pressure on *Pseudocalanus acuspes* during spring affecting the copepods nauplii production and thus food availability for cod larvae negatively.

The case of the Eastern Baltic cod stock exemplifies the multitude of effects climate variability may have on a fish stock and it underscores the importance of knowledge of these processes for understanding the dynamics of such a fish stock.

The conclusion that recruitment is to a considerable extend environmentally driven and since 1987 on a low level apparently independent of the size of the spawning stock biomass or the magnitude of egg production, does not mean that SSB has no significant impact on recruitment. All statistical exploratory analysis conducted for Eastern Baltic cod considering environmental factors, include SSB or potential egg production as a significant variable (e.g. Sparholt, 1996; Jarre-Teichmann *et al.*, 2000; Köster *et al.*, 2001b).

Under favourable environmental conditions, i.e. with hydrographic conditions allowing reproductive success in all three spawning areas, a low SSB is likely a limiting factor for recruitment. This conclusion can be drawn from a significant relationships of recruitment per unit of reproductive volume against SSB, which is significant at high, but not at low reproductive volumes (Figure 9). On the other hand a high spawning stock size in eastern spawning areas without favourable reproductive conditions, will likely have only a limited impact on recruitment, but see above discussion on spawning migrations in dependence of hydrographic conditions.

Under present hydrographic conditions, with only the Bornholm Basin allowing regular reproduction, recruitment success will stay limited, depending on the hydrographic conditions within the basin, the abundance and overlap between cod eggs and clupeids as their predators and the availability of food for first feeding larvae.

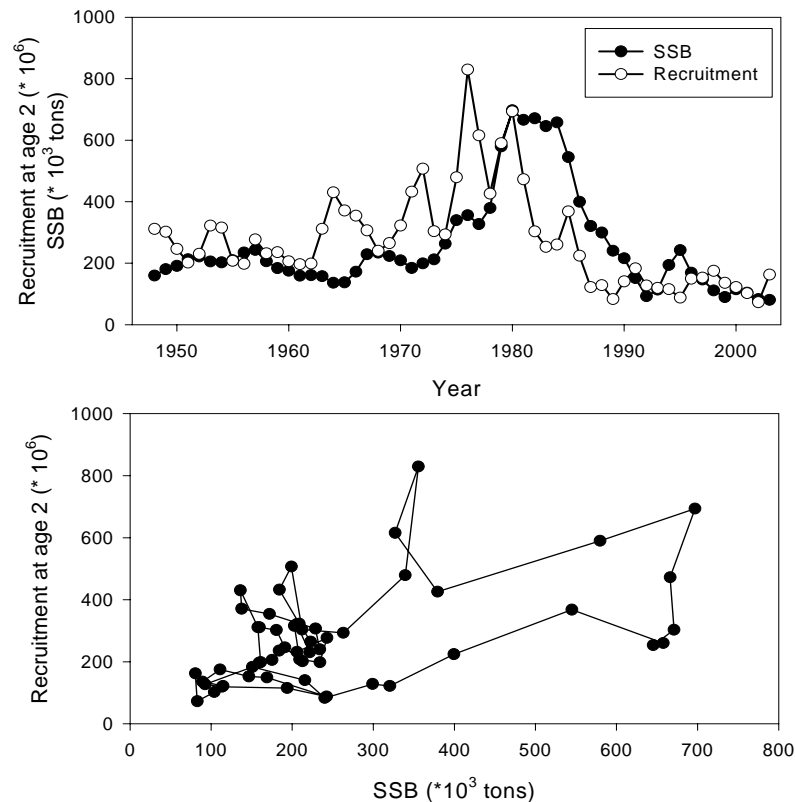


**Figure 9. Recruitment at age 2 (R) per unit of reproductive volume (RV) vs. spawning stock biomass (SSB) at low (upper panel), intermediate (middle panel) and high reproductive volume (lower panel).**

#### **Cod stock abundance and environment in a longer-term perspective**

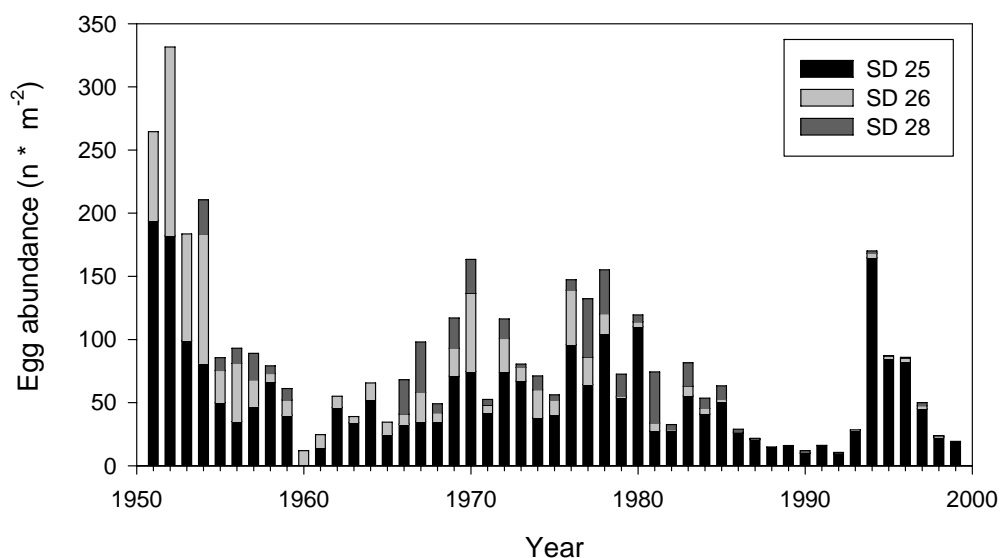
In order to better understand the causes of stock fluctuations and evaluate human impact on the stock relative to natural variability, Eero *et al.* (2007) conducted an assessment of the Eastern Baltic cod extending backwards until the 2nd world war. The estimated stock size was relatively low in the beginning of the time series and increased during the first half of the 1950s, but was far from reaching historic high levels observed in the early 1980s (Figure 10). It declined again towards the mid-1960s. The average SSB in the 1950's and 1960's was ca. 200 000 tons, compared to ca. 135 000 t since 1990. Average recruitment at age 2 was double as high in the first period compared to the latter, indicating that stock productivity might have been higher in the 1950's and 1960's compared to the 1990's. Fishing mortality was relatively

low after the 2nd world war but increased rapidly, reaching already in the second half of the 1950s the high levels observed since the 1980s.



**Figure 10. Eastern Baltic cod. Time series of recruitment at age 2 and spawning stock biomass as estimated in by an extended stock assessment (Eero *et al.*, 2007) (upper panel) and corresponding stock recruitment relationship with indicated time line.**

A time series of egg abundance data (Karasiova and Voss, 2004, Karasiova, unpubl.) and Makarchouk, unpubl.) shows substantial difference in 1950's and 1960's compared to the 1990's (Figure 11). While in the most recent period eggs were abundant only in the Bornholm area, in the early period eggs were regularly encountered in all spawning areas. Even if the egg abundances in the 2<sup>nd</sup> half of the 1950's and 1960's were in general lower than during the 1970's, spawning was obviously taking place regularly in all spawning areas and the water conditions allowed the eggs also to float. The extraordinary high egg abundance in early 1950's do not coincide with high SSB from the extended XSA assessment, but with outstanding high reproductive volumes, meaning that eggs were able to float and likely also develop. If the latter is the case, other mortality causes should have prevented high reproductive success. Available hydrographic information suggests a high frequency of inflow until mid 1950's and a shorter stagnation period until early 1960's resulting in a decline in salinity (Figure 1). This may also explain the negative anomalies in *Pseudocalanus* biomass in the 1960's, but does not indicate any food limitation for first feeding larvae in early 1950's.



**Figure 11. Eastern Baltic cod. Time series of egg abundance in different Subdivisions (SD), adapted from Karasiova and Voss (2004), Karasiova (unpubl.) and Makarchouk (unpubl.).**

In conclusion, the extended cod assessment puts the high stock sizes in the 2nd half of 1970's and 1st half of the 1980's somewhat into perspective as being rather outstanding than normal. Earlier periods are characterized by successful reproduction in eastern spawning areas, as visible not only from ichthyoplankton surveys but also from a separate assessments run by Eero *et al.* (2007) for Subdivision 26 and 28. This suggests that the present regime is in fact not just a shift back into a state which prevailed before the substantial increase of the eastern Baltic cod stock in the 1970's.

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## Annex 2: Incorporating environment in Stock and recruitment for Baltic cod

One way to achieve integration of environmental variables into stock recruitment relationships is described by SGPRISM (ICES, 2000) as incorporation of the random multiplicative component depending on environmental indices, into e.g. the Ricker model. A second way is that stock-recruitment model coefficients are smooth functions of values characterising the environment.

The traditional Ricker's model is as follows:

$$R = \alpha \cdot Ssb \cdot \exp(-\beta \cdot Ssb) \quad (1)$$

where  $\alpha$  and  $\beta$  are unknown parameters of the model. These parameters may be estimated using the classic methods of linear or non-linear regression. Another rather flexible approach is based on the application of generalized linear models (GLM) and generalized additive models (GAM), which require the linearized versions of model (1).

The linearized model by Ricker has the following form (Hilborn and Walters, 1992):

$$\log(R_y / Ssb_y) = a + \beta_1 \cdot Ssb_y \quad (2)$$

where  $a = \log \alpha$  and  $\beta_1 = -\beta$ .

Assuming the symbols by MacCulagh and Nelder (1989) or (S-Plus, 1999), this model is formulated in GLM terms as following :

$\eta(\mu) \sim Ssb$ , where  $\mu$  is a mean value of  $R_y / Ssb_y$  at the level of  $Ssb_y$  and  $\eta(\mu)$  is a link function.

For the complete GLM task it is necessary to specify the family of the distribution functions as well as to determine the relation between variance of  $\mu$  and the value of  $\mu$ .

The first way to include the environmental variables (V) into the Ricker's model implies the following formulation of the model:

$$R = \alpha \cdot Ssb \cdot \exp(-\beta \cdot Ssb) \cdot \exp(\gamma \cdot V), \quad (3)$$

where  $\gamma$  - constant coefficient.

The respective GLM form is as follows

$$\eta(\mu) \sim Ssb + V. \quad (4)$$

The second way provides the replacement of the constant term of equation (2) with the smooth parametric or non-parametric function of the environmental variables:

$$\eta(\mu) = -1 + f(V) + Ssb \quad (5)$$

Smoothing splines  $s(V)$ , the function of local-weighted regression *loess* (S-Plus, 1999) polynomial may be used as such smooth functions. The complexity of splines or *loess* - function may be changed by means of smoothing parameters or by the number of points in the local regression, while polynomial complexity may be changed with its exponent. If spare terms are additionally included into equation (5) they may be pooled with  $f(V)$  function. The resulting function will be a smooth function of variable V.

The model may be run in different model form (random component (4) or smoothing spline (5)), inner parameter of the model related to the structure (the order of smoothing spline) and GAM specification (family of distribution functions, variance relation to the mean value). For

models selection the approximation quality of “observed” recruitment values by “calculated” values is characterized by means of the standard deviation.

Best results were obtained when additional information was included into the model such as reproductive volume in the year after spawning, which was done as alternative to the application of the reproductive volume in the year of spawning alone.

The final version of the model is as follows:

For the first class (low values of reproductive volume)

$$\begin{aligned} &gam(R / Ssb \sim +1 + poly(V_1, 2) + s(V_2, df = 1) + Ssb, \\ &family = robust(quasi(link = log, variance = mu)), data = ...) \end{aligned} \quad (6)$$

For the second class (high values of reproductive volume)

$$\begin{aligned} &gam(R / Ssb \sim +1 + s(V_1, df = 1) + s(V_2, df = 1) + Ssb, \\ &family = robust(quasi(link = log, variance = mu)), data = ...) \end{aligned} \quad (7)$$

In these equations  $V_1$  is the reproductive volume in the spawning year,  $V_2$  the same parameter in the year following the spawning year.

The model is still under development. Actually there are two models applied depending on the condition. This approach has been criticized, e.g. for significant reduction of the number of data points to estimate the model for each condition. A promising approach is to apply linear and non-linear models with mixed effects where the fixed part common to the entire system is estimated with the full sample, while random effects are estimated by individual groups (classes) coordinated to the entire system as a whole.

Results of the method are presented in Section 3.2.1 of the report.

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