Advisory Committee on Fishery Management **ICES CM 2003/ACFM:11**
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REPORT OF THE

Study Group on Biological Reference Points for Northeast Arctic cod

Svanhovd, Norway
13–17 January 2003

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

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1.2 Terms of Reference

A **Study Group on Biological Reference Points for Northeast Arctic Cod** [SGBRP] (Chair: Y. Kovalev, Russia) will be established and will meet in Svanhovd, Norway from January 13 to 17 2003 to:

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

b) review the framework for calculating reference points established by SGPA in December 2002 and specify the technical basis for the reference point calculations;

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

SGBRP will report by 24 January 2003 for the attention of ACFM. It will report directly to SGPRP.

1.3 Scientific Justification and aims of the Study Group

The precautionary reference points (PRP) for Northeast Arctic cod have been debated for several years and the AFWG has had several attempts to resolve the issues. Also ACFM has been involved in this discussion. As a part of the general revision of the PRP used for providing fisheries advice Northeast Arctic cod needs special attention because of this past history of debate. AFWG therefore agreed that a special meeting devoted to a full discussion of the PRP for Northeast Arctic cod could be very beneficial to resolve the matters. The group is expected to hold one meeting only.

1.4 Structure of the report

Section 2 provides information relevant to the S/R relationship used for the determination of reference points and specifically addresses the issue of what time period is appropriate for the determination of the reference points (ToR a). Section 3 describes the methodology, technical basis and results of reference point determinations (ToR b and c). Section 4 describes future work that is either being undertaken or that should be undertaken for continued progress on the issue of biological reference points for NA cod. Section 5 summarizes the recommendations made by the SG to the ACFM. Appendix A refers the presentations made to the SG and subsequent discussions. Summaries of some working documents that were submitted to the SG are also included.

2 DETERMINATION OF THE TIME PERIOD TO BE USED FOR REFERENCE POINTS ESTIMATION

Over the full time period there is compelling evidence that several aspects of the stock dynamics, including life history parameters and size composition, changed dramatically in the early 1980s. The aspects of stock dynamics that changed at that point in time include the following:

- Age at 50% maturity (Kovalev and Yaragina WD6, Tretyak WD8)
- Weight at age (Kovalev and Yaragina WD6)
- Proportional representation of different components of spawning stock late vs. early spawners (Tretyak WD8)
- Mean length and condition of mature females (Marshall et al., unpub. data)

Furthermore, the environmental conditions might also have changed along with shifts in trend and oscillation pattern of the NAO index (Figure 2.1; Stiansen WD10).

At the same time there have been changes in the ecosystem resulting from the introduction of harvesting of important prey species and substantial reduction in the harvesting of predators (e.g., seals). Such changes may have influenced the carrying capacity of individual stocks. Fishing pattern have also changed over time due to changes in regulations (mesh size, landing size) and discarding practices. These changes were not necessarily coincident with the changes in stock dynamics noted above.

These factors influence the S/R relationship and therefore will affect the determination of reference points. An explicit term of reference was for the SG to decide whether or not the time-series for NA cod should be split at 1980 (or thereabouts) and the most recent time period used for the determination of reference points.

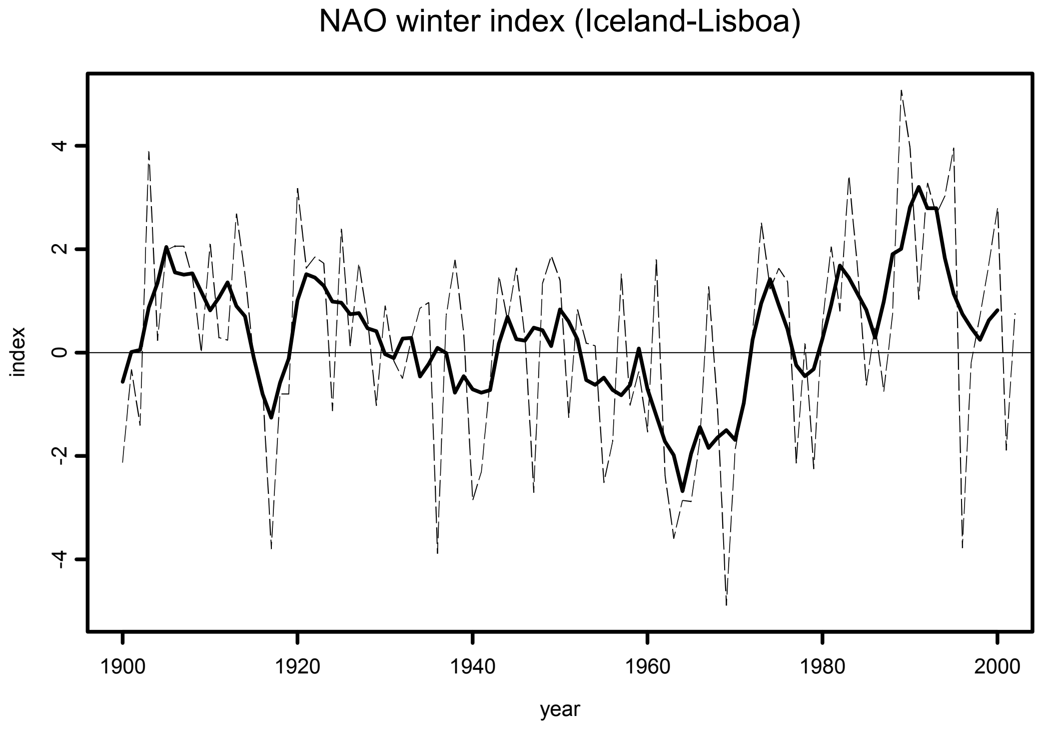

Figure 2.1. The NAO winter index between Iceland and Lisbon. The dashed line is the yearly data and the solid line is the 5-year running mean. Notice the increasing trend and oscillation pattern after the mid 70's.

2.1 Background information on revision of historical weights and maturities

In 2001, the AFWG replaced the constant values for maturity at age (1946-1981) and weight-at age (1946-1982) with year-specific values estimated by combining historical information from Russian and Norwegian sources. The new values of maturity- and weight at age are arithmetic averages of the Russian and Norwegian time-series. A complete description of the data sources is given in Sections 10.2 and 10.3 of the 2001 AFWG report (ICES CM 2001/ACFM:02).

This caused the long-term mean SSB to decrease from 577,425 t to 372,934 t. This change was part of the motivation for re-evaluating the reference points for NEA cod. Of concern to the reference point determination is the possibility that the time-series for maturities and weights at age are inconsistent due to changes in the data sources, e.g., the introduction of surveys by Norway in the early 1980's. This issue was reviewed by the AFWG in 2002 at the request of ACFM (see Section 10 of ICES CM 2002/ACFM:18). Relevant points are summarized briefly here.

- The historical Russian data were obtained mainly from surveys supplemented with some observations from sampling of the commercial catch. The year period used as well as sampling methodology was identical for the Russian time-series.

- Russian and Norwegian time-series for weight at age cover the entire historical period, whereas, only Norwegian values of maturity at age are available for the time period 1946-1958. The historical Norwegian data were primarily obtained from sampling of the commercial catch in Lofoten reflecting primarily mature individuals; however, limited data from sampling of the commercial catch taken in the spring around Finnmark reflecting both the immature and mature fractions were also used. The Gulland method, based on spawning checks in the otoliths, were used to construct the proportion mature at age for 1946-1981 whereas the survey – based data were used for the recent period (1982 – present).

- Both time-series represented similar temporal trends in weight at age and maturity at age and they were consistent with each other (Fig. 10.10 in ICES CM 2001/ACFM:02). Data reflected weight at age increase and decrease in the age of cod maturity in recent years compared to the historical period.

- The degree of synchrony between the Russian and Norwegian time-series is relevant to assessing the accuracy of the trends. The Russian and Norwegian estimates of weight at age for the historical period are uncorrelated except for age 9 (Table 10.1 in ICES CM 2002/ACFM:18). However, the long-term trends in the data are in reasonable agreement, particularly for the older age-classes (Figure 10.3 in ICES CM 2002/ACFM:18).

- The degree of synchrony between Russian and Norwegian maturity at age time-series varies for different age classes (Table 10.2 in ICES CM 2002/ACFM:18). The younger age-classes (ages 3-5) show a higher degree of synchrony for both the historical and recent time periods. For the older age-classes, the synchrony is higher from 1969 onwards.

Based on it's review in 2002, the AFWG determined that there was no reason at that time to conclude that the trends in weights and maturity were systematically biased due to changes in data sources and/or sampling methodology over time. The longterm changes in growth (body size and maturity) were potentially indicative of the stock experiencing sustained high rates of fishing mortality.

2.2 Background information on discarding mortality

The AFWG has identified two main sources of error in the recruitment time-series: discarding mortalilty and cannibalism mortality. The amounts of fish discarded at sea is not included in the catch at age matrix and, hence, both fishing moralities and stock numbers for the younger ages (3-5 years) are biased. For most recent years information on discards has become available from several sources. This information should be used to correct the catch at age data for cod.

Dingsøör (2001) estimated the numbers of 3,4 and 5 year old cod discarded at sea for each year in the period 1946-1998. These estimates were compared to published observations of discarding rates at sea for parts of the time period. He corrected the time-series of catch at age and re-estimated stock number at age. Stock numbers of age 3 (recruits) increased substantially as compared with the estimates produced by the AFWG, particularly in the early part of the time period (1950's and 1960's). From the early 1980's and onwards the differences in stock numbers at age 3 were small. Table 2.1 shows the main results from Dingsøör.

Sokolov (2001) and Schöne (WD submitted to AFWG 1999) have provided information on discards of cod in the Barents Sea fisheries to the AFWG. Sokolov (2001) estimated discarding by the Russian trawl fishery in the years 1996 to 2000. Table 2.2 gives the main results from that study and shows that estimated discarding was variable among years. Schöne estimated that 36% of the cod caught in the area between Bear Island and Svalbard in autumn 1998 were fish below legal landing size.

Table 2.1. Stock numbers at age (in thousands) estimated by VPA with the adjusted catch numbers estimated by method II (1946-1982) and IIIb (1983-1998). The percentages show the increases from the AFWG stock numbers at age (ICES, 2000) to the estimated stock numbers at age. (From AFWG 2002 after Dingsör 2001). Negative numbers in some years are indicative of modelling error.

Year	Estimated stock numbers (thousands)			Percent change		
	Age 3	Age 4	Age 5	Age 3	Age 4	Age 5
1946	875 346	602 579	407 163	20 %	4 %	1 %
1947	531 993	676 806	465 099	27 %	14 %	0 %
1948	570 356	392 309	497 476	29 %	14 %	5 %
1949	589 367	416 668	285 459	26 %	16 %	3 %
1950	799 732	414 016	291 200	13 %	9 %	1 %
1951	1 235 322	586 054	302 346	14 %	2 %	0 %
1952	1 388 731	889 509	401 768	17 %	3 %	0 %
1953	1 801 114	975 004	600 908	13 %	2 %	0 %
1954	830 653	1 321 053	684 303	29 %	5 %	0 %
1955	381 489	615 696	907 875	40 %	19 %	2 %
1956	567 555	274 235	399 344	29 %	25 %	3 %
1957	914 850	387 496	161 710	14 %	10 %	2 %
1958	552 600	672 221	262 135	11 %	4 %	2 %
1959	757 567	391 906	406 694	11 %	3 %	0 %
1960	855 470	534 350	240 047	8 %	1 %	0 %
1961	1 041 570	620 707	347 043	13 %	1 %	0 %
1962	894 728	739 196	382 556	23 %	4 %	0 %
1963	551 938	614 025	429 068	17 %	10 %	0 %
1964	389 151	396 165	361 790	15 %	5 %	0 %
1965	845 469	293 844	266 134	9 %	8 %	0 %
1966	1 618 188	647 435	203 168	2 %	4 %	2 %
1967	1 404 569	1 249 506	465 035	9 %	0 %	1 %
1968	210 875	1 088 071	876 095	24 %	6 %	0 %
1969	143 791	155 947	699 033	28 %	15 %	2 %
1970	222 635	104 415	92 541	13 %	17 %	4 %
1971	462 474	164 397	65 112	14 %	6 %	2 %
1972	1 221 559	358 357	115 892	20 %	10 %	1 %
1973	1 858 123	947 409	249 400	2 %	19 %	11 %
1974	598 555	1 246 499	583 612	14 %	2 %	9 %
1975	654 442	382 692	627 793	5 %	10 %	3 %
1976	622 230	477 390	233 608	1 %	2 %	1 %
1977	397 826	426 386	280 645	14 %	0 %	0 %
1978	653 256	277 410	198 204	2 %	11 %	0 %
1979	225 935	460 104	164 243	14 %	2 %	1 %
1980	152 937	171 954	300 312	11 %	11 %	0 %
1981	161 752	116 964	116 337	7 %	7 %	4 %
1982	151 642	125 307	81 780	0 %	4 %	1 %
1983	166 310	115 423	82 423	0 %	-1 %	3 %
1984	408 525	133 333	77 728	3 %	0 %	0 %
1985	543 828	324 072	96 327	4 %	2 %	0 %
1986	1 114 252	412 683	219 993	7 %	2 %	0 %
1987	307 425	767 656	268 642	7 %	4 %	0 %
1988	222 819	215 720	490 161	9 %	3 %	2 %
1989	180 066	166 955	151 576	4 %	6 %	0 %
1990	249 968	139 922	114 006	3 %	2 %	1 %
1991	418 955	200 700	105 559	2 %	2 %	0 %
1992	748 962	333 517	151 973	4 %	1 %	0 %
1993	1 002 933	576 112	238 980	10 %	2 %	0 %
1994	896 184	744 062	420 039	9 %	8 %	0 %
1995	733 664	584 808	476 048	10 %	6 %	3 %
1996	467 093	341 918	344 124	3 %	7 %	3 %
1997	765 234	238 202	193 102	3 %	0 %	4 %
1998	836 301	429 147	144 629	2 %	1 %	-1 %

Table 2.2: Estimated discards of small cod in the Russian bottom trawl fishery in the Barents Sea and adjacent waters in 1996-2000 by age, thou. Individuals.

Year	Age, years					Total
	1	2	3	4	5	
1996	0	795	2017	2226	324	5362
1997	21	901	4296	3488	788	9495
1998	23	1084	12765	7538	269	21678
1999	8	568	4687	4935	321	10518
2000	3	789	2897	3015	175	6879

2.3 Time period to be used in the estimation of reference points

Splitting the time-series for construction of the stock - recruitment relationship constitutes a large departure from previous methods used for estimating reference points for NA cod. The recent SGPA meeting provided several logical arguments against changing biomass reference points when productivity is fluctuating (ICES CM 2003/ACFM:09). The SGPA further specified that the supporting evidence should be compelling and that the decision should not simply rest on opinion.

On the basis of WDs presented at the SG meeting as well as information from other sources the SG summarized arguments in favour of retaining the full time-series (i.e., the current approach) as:

- Full time-series incorporates possible density-dependent effects on biological parameters (Kovalev and Yaragina WD6)
- Full time-series represents more generations
- The full dynamic range is only apparent in long time-series
- Using all data is, in principle, the more objective approach

Arguments in support of using the shortened time-series include:

- There have been large and seemingly abrupt changes in key life history parameters and stock structure (Tretyak WD8; Kovalev and Yaragina WD6)
- The S/R relationship for the recent time period shows stronger evidence of impaired recruitment at low SSB (by excluding the problematic observations for the 1963, 1964 and 1970 year-classes). This improves the performance of segmented regression in determining reference points.
- There is environmental evidence which provides a plausible mechanism for changes in stock structure and biological parameters (Stiansen WD10)
- Discarding rates might be more stable and/or low during this period due to changes in fisheries regulations (Section 2.2)
- Possible to take into account cannibalism for this time period

The approach taken was to closely scrutinise each of the arguments in favour of the shortened time-series since the burden of proof was on the proposed change. The evaluation of arguments supporting the use of the shortened time-series is summarised in Section 2.3.1 and the overall conclusion is summarised in Section 2.3.2.

2.3.1 Evaluation of arguments supporting the use of shortened time-series

2.3.1.1 Maturity issues

Determination of reference points requires two pieces of information: the stock/recruit relationship and the relationship between SSB/R (derived from the stock/recruit relationship) and F. In both of these relationships the maturity ogives have a large effect. Thus, one element of the debate concerns whether the maturity dynamics of the stock can revert back to values observed in the earlier time period. If the stock rebuilds to large biomasses then it is possible that growth will be reduced and maturity rates became delayed. Such feedback responses have been observed in other stocks (e.g., herring).

During the full time period the data sources used to estimate maturity at age have changed (Section 2.1). This was evaluated in detail by the AFWG in 2001 (ICES CM 2001/ACFM:02). At that time, it was felt that the time trends in

Norwegian and Russian data were sufficiently synchronous as to alleviate concerns about large biases resulting from the initiation of surveys by Norway in the early 1980s. However, for some age classes changes in maturity preceded the introduction of surveys. Furthermore, changes in weight and maturity were simultaneous, suggesting that changes growth of cod were real rather than artefacts. The issue is of sufficient interest that further work on the quality of data should be undertaken. In particular, the years 1981-1984 stand out in the Norwegian time-series as anomalous with respect to both maturity and weight.

2.3.1.2 Fishing pattern

For cod ages 3-5 there is a peak in relative F at age in the mid 1970s suggesting that there was heavy fishing on small cod during this period. Quotas for NA cod were introduced in 1978 causing changes in the behaviour of the fishery such that the catch of individual species was maximised. Mesh size and minimum legal landing size have increased at several points in the full time period. Since 1982 constant mesh sizes along with a closed area system for undersized fish have been in operation.

Discarding has occurred throughout the time period and has been estimated as being particularly severe in the early time period (Section 2.2). From the trend and variability in Table 2.1 an argument could be made that recruitment estimates have been more accurate since approximately 1982. However, there is also the possibility that substantial amounts of discarding mortality has occurred in recent years as well (Section 2.2).

Since the recruitment time-series of age 3 does not account for variable discarding mortality rates (Section 2.2) it was decided to use stock numbers at age 5 as recruits in a segmented regression using the full time-series. The use of numbers at age 5 has the further advantage of eliminating the influence of cannibalism on the recruitment index. Fig 2.2 compares the stock/recruit relationship for both age 3 and age 5.

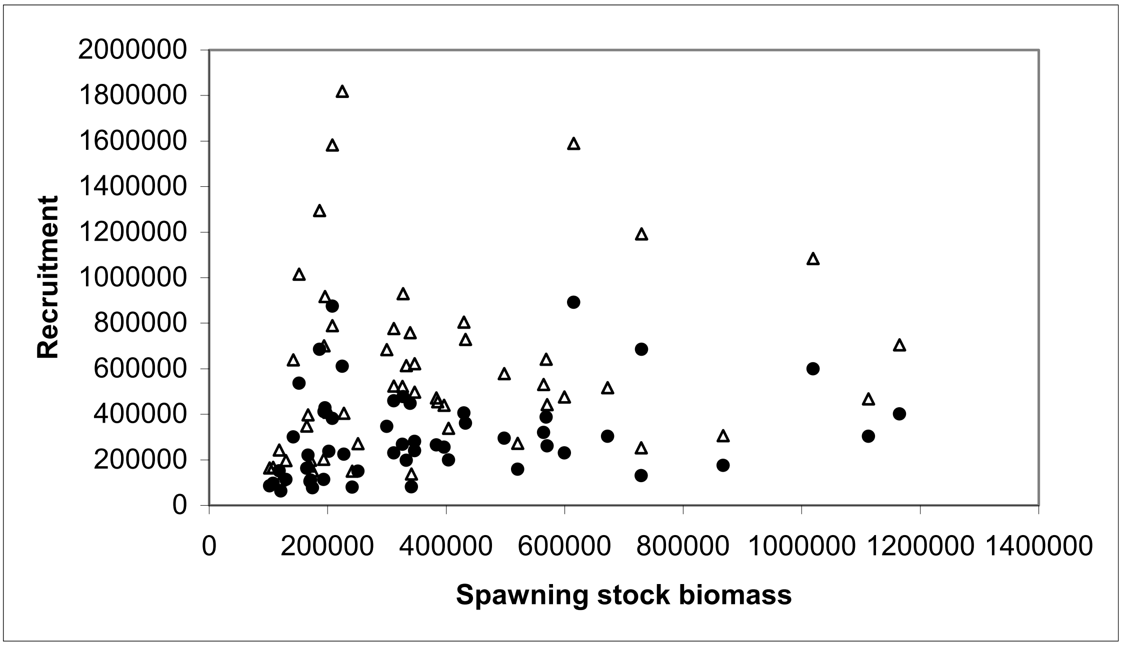

Figure 2.2: Stock/recruitment relationship using age 3 (open triangles) and age 5 (filled circles) as the recruitment index.

2.3.1.3 Weights

The concerns regarding the quality of the weight at age estimates are similar to those for maturity at age. There is greater potential for weight estimates to be in error for younger age classes, however, these age classes do not contribute very much to SSB

2.3.1.4 Cannibalism

Estimates of cod cannibalism based on cod stomach content data and a stomach evacuation rate model are available from 1984 onwards. Cannibalism has an effect on the recruitment time-series, lifting points higher (Kovalev WD5, Mehl WD3). In order to use a consistent time-series for calculating reference points, one may either try to extend estimates of cannibalism backwards in time, as indicated above, to get a long time-series which includes cannibalism, or one may use the time-series without cannibalism. For 1946-present, qualitative (frequency of occurrence) Russian cod stomach data are available, and they may be calibrated against the quantitative cod stomach content data to give reasonable estimates of cannibalism level also for the period 1946-1983. From 1973 onwards, abundance estimates of capelin are also available to supplement this hindcast. (Marshall *et al*. 2000).

It is the number of fish recruited to the fishery, which is of main interest in a limit and precautionary reference point context. Whether they are eaten by older conspecifics or die due to other reasons is less important. It is mainly cod of age 3 and younger that are subject to cannibalism, while the fishery on age 3 cod is small. The number of age 3 cod calculated without including cannibalism seems to be a reasonable recruitment time-series to use when calculating precautionary and limit reference points. When considering a target reference point for this stock, cannibalism should, however, be included in order to determine the optimal harvesting strategy for this stock. As cannibalism has a strong effect on the survival of age 1 and 2 cod, those age groups should also be included in such analyses.

Finally, different trial runs of segmented regression illustrated that including or excluding cannibalism had a relatively small influence on the estimation of the break point (Mehl WD3).

2.3.1.5 Spawning stock structure

The structure of the spawning stock has been relatively stable over the time period 1976-1997 (Tretyak WD8). This may partly reflect changes in fishing mortality (i.e., removal of large, old fish with increasing F). Restricting the S/R relationship to a period of stability constrains the dynamic range that is represented. However, it is desirable to have reference points that are effective in the case of decreasing F and not simply reference points that are conditioned on high F.

One argument in favour of using information on stock structure in reference point determination is that they may provide better evidence of a S/R relationship (see also Nakken WD2). Work on developing alternative indices of reproductive potential is ongoing (Section 4.1) and changes to existing practice would be premature.

2.3.1.6 Ecosystem changes

There have been changes to the ecosystem due to large changes to the exploitation patterns of several stocks in the Barents Sea. Harvesting of shrimp began in the late 1970’s, capelin in 1960’s, *Sebastes mentella* in 1960’s, whereas, the exploitation of sea mammals has decreased in recent decades. Changes in the predator and prey dynamics in the Barents Sea could influence the dynamics of cod via food availability and/or mortality. There is some evidence that the fisheries cause the rate of fluctuation in biomass of these prey stocks to be more rapid by acting as a competitor for cod. However, documentation was not sufficient to judge the importance of this.

2.3.1.7 Environmental changes

The North Atlantic Oscillation (NAO) index is one of the most robust mirrors of the atmospheric behaviour in the northern regions (Dickson *et al.*, 2000). Indications of a climatic regime shift is seen in a change of pattern of the NAO winter index around the mid 1970’s, from a slowly decreasing trend to an increasing trend with a strong oscillating pattern with a period of 8 years (Stiansen WD10). This influence the in$\mathbf{F}_{\text{low}}$ of warm Atlantic waters into the Norwegian Sea and further into the Barents Sea. Dickson *et al*. (2000) haves shown a good correspondence between the NAO winter index and both the volume transport through the Fugloya-Bjornoya section and the temperature anomalies in the Kola section temperatures in the period 1970-1995. Stiansen *et al*. (2002) showed that multiple regression models for recruits (0-group index and number of 3 year olds) of cod shows better fit using NAO as a variable (together with the SSB) after the late 70’s(with a R^2 of 58% and 46 %, respectively) than in the earlier period (with a R^2 of 31%).

2.3.1.8 Changes in reproductive potential

Preliminary estimates of total egg production suggest that the relationship between SSB and total egg production differs significantly between the time periods 1946 to 1979 and 1980 to 2001 (Marshall unpublished data presented to SG). Differences in weight, maturity, condition and fecundity have given rise to a spawning stock composed of smaller females that are growing faster and maturing earlier compared to the situation prior to 1980. However, given that these are preliminary estimates of total egg production only further work would be necessary before the implications for reference points can be evaluated properly.

2.3.2 Overall conclusion

The SG agreed on the use of the full time-series and the numbers at age 5 as the recruitment index (see Section 2.3.1.2) until more accurate estimates of the number at age 3 are available. Although several good biological and environmental arguments were raised concerning a shift in the stock around 1980, the SG did not find the evidence strong enough to support the use of the shortened time-series at the present time. The discarding problem (see Section 2.2) alone is a strong enough reason for not using the full time-series for recruitment at age 3. The SG therefore agreed on the use of number at age 5 as the recruitment index in order to minimise the problems introduced by discarding and cannibalism. The reference points determined here are therefore considered to be provisional until the effect of discarding on stock dynamics can be fully resolved or further analysis shows that recruitment at age 5 is as appropriate as age 3 for estimation of the $\mathbf{B}_{\text{lim}}$.

3 REFERENCE POINT ESTIMATION

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

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

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

The ICES definition of $\mathbf{B}_{\text{lim}}$ as the biomass below which recruitment becomes impaired implies a simple model of population dynamics in which recruitment is impaired at a particular threshold of SSB, and where fishing mortality is the only explicit factor that determines the size of the spawning stock, and that can be managed. In some stocks, where the stock-recruitment data do show a so-called 'change point' where recruitment declines, the change point corresponds to the definition of $\mathbf{B}_{\text{lim}}$.

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

The ACFM advice continues further:

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

In the remainder of this Section 3, a revision of the current estimates of the Precautionary reference points ($\mathbf{B}_{\text{lim}}$, $\mathbf{F}_{\text{lim}}$, $\mathbf{F}_{\text{pa}}$, $\mathbf{B}_{\text{pa}}$) for NEA cod is proposed; after a brief discussion of the reasons and the justification for such a revision. The steps involved in the revision are: to estimate the spawning stock biomass at which recruitment is impaired ($\mathbf{B}_{\text{lim}}$) using a segmented regression, to estimate the slope at the origin of the segmented regression in order to estimate $\mathbf{F}_{\text{lim}}$, and to incorporate uncertainty in the stock assessment and stock projection of NEA cod to estimate the Precautionary limits to fishing mortality ($\mathbf{F}_{\text{pa}}$) and biomass ($\mathbf{B}_{\text{pa}}$), respectively.

These estimates are to be calculated within the revised framework for defining and linking reference points proposed by the SGPA at its December 2002, and illustrated in the Figure 3.1 below.

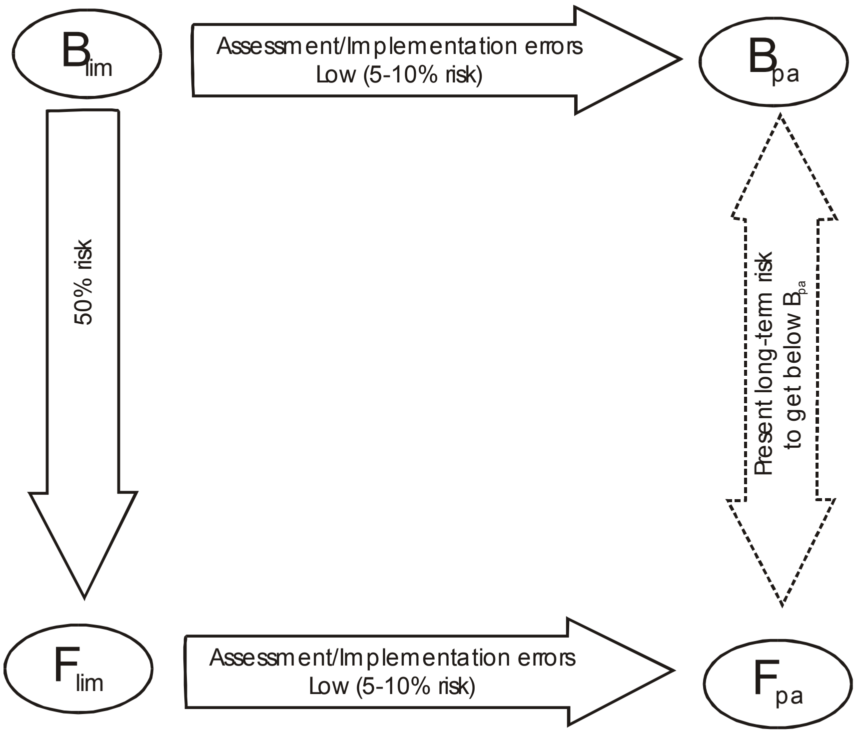

Figure 3.1 The links between reference points and the related sources of uncertainty and risk (Source: SGPA December 2002 meeting).

3.1 Management strategy and reference points for NEA cod

There is a need to evaluate the current values of reference points in the light of the revised SSB time-series and improved knowledge about the stock dynamics of NEA cod that have occurred over the recent years. The AFWG has been unable to develop and evaluate candidate values of reference points in addition to its normal assessment responsibilities. Instead, it was decided that this work should be undertaken by a dedicated study group that would meet before the next AFWG meeting in 2003 (see Section 1.3). The assumptions underlying the reference point determination, the time period for analysis and the basic input parameters have been discussed previously in Section 2 of this report.

Hence, the biomass reference points used for Northeast Arctic cod are reviewed in this Section 3 in the light of the substantial changes to the SSB time-series. Given the dependency of the fishing mortality reference points on the SSB/R relationship, the appropriateness of the current values of $\mathbf{F}_{lim}$ and $\mathbf{F}_{pa}$ are also reviewed.

The framework implemented for NEA cod is that proposed by SGPA at its December 2002 meeting; namely:

- To identify whether the existing reference points suffer from inconsistency, uncertainty, model structure, or regime issues, and identify what remedial action is needed.
- To fit a segmented regression to estimate $\mathbf{B}_{lim}$.
- To estimate $\mathbf{F}_{lim}$ from $\mathbf{B}_{lim}$.
- To estimate $\mathbf{F}_{pa}$ from $\mathbf{F}_{lim}$.
- To estimate $\mathbf{B}_{pa}$.
- To compare $\mathbf{F}_{pa}$ with $\mathbf{B}_{pa}$ and adjust $\mathbf{F}_{pa}$, if necessary.
- To carry out a reality check for consistency with historical exploitation.
- To compare SSB/R values.

3.2 $\mathbf{B}_{lim}$

The revised reference point framework proposed by ICES and developed further at the December 2002 meeting of SGPA deals with stocks where there is an analytical assessment, and a time-series of data for SSB and recruitment. NEA cod is one such stock.

In the ICES implementation of the PA, which seeks to prevent stocks being harmed seriously due to recruitment over-fishing, $\mathbf{B}_{\lim}$ is the cornerstone from which the other reference points are derived. Conceptually, $\mathbf{B}_{\lim}$ has an intrinsic biological basis as the biomass below which there is a substantial increase in the probability of obtaining poor year-classes. In practice the value of $\mathbf{B}_{\lim}$ is derived from historical stock-recruitment data, as the point below which there is evidence that recruitment becomes impaired. The word *impaired* is synonymous with the observation that recruitment becomes systematically reduced as biomass declines below a certain point due to the effect of fishing.

A new objective technique to determine the level of biomass ($\mathbf{B}_{\lim}$) at which recruitment is impaired was suggested at the 2002 SGPA meeting based upon a segmented (or piecewise linear) regression (O'Brien & Maxwell 2002a) and applied to a number of stocks within the ICES area prior to the meeting (O'Brien & Maxwell 2002b-k, O'Brien, Maxwell & Roel 2002, O'Brien, Maxwell, Roel & Basson 2002). The technique is presented in the next Section 3.2.1 and the basis for the description has been taken from the working paper by O'Brien & Maxwell (2002a).

3.2.1 Methodological basis for the re-estimation

The objective technique whereby biomass reference points are to be developed is based upon a segmented (or piecewise linear) regression. Piecewise linear regression involves fitting linear regression where the coefficients are allowed to change at given points. For one unknown change-point, for any interval (X_0 , X_1) on the real interval, the problem is defined as,

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

For stock and recruitment data the model is simplified, it must pass through the origin (α_1 = 0) and after the change point the line is horizontal (β_2 = 0).

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

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

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

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

which on the natural logarithmic scale is:

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

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

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

$\delta \equiv S^*$
$\beta_1 \equiv \alpha$
$\alpha_2 \equiv R^* = \alpha S^*$

(4)

An *F*-statistic can be derived (Worsley, 1983) that uses the ratio of the sum of squares between a one- and two-line model (H_0 versus H_1, respectively). If the change-point has to be estimated, this test statistic does not have an exact *F*-distribution under the null hypothesis (Hinkley, 1988). However, a bootstrap distribution for the *F*-test can be derived and a *P*-value can thus be calculated.

The methodology in applying the bootstrap method to the change-point problem is as follows:

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

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

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

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

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

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

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

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

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

For illustrative purposes, a (1-α)% of 80% has been adopted in the applications previously presented by O'Brien & Maxwell (2002a) to derive the lower 10% limit denoted by S*(10) and the upper 90% limit denoted S*(90) of S*. In principle, there is nothing that implies a symmetric treatment of the (1-α)% profile likelihood confidence interval for S*; i.e. a lower limit $S^*(\alpha_1)$ and an upper limit $S^*(1-\alpha_2)$ may be defined such that $(1-\alpha_1-\alpha_2)$ has the specified coverage probability of (1-α) but α_1 may be different from α_2.

The choice of the appropriate level of acceptable risk in both the lower and upper tails of the empirical distribution of the SSB at which recruitment is impaired is a management decision. The approach presented here will enable that choice to be made in an objective way. The evaluation of candidate biomass reference points through the use of scenario modelling within a management procedure could be a requirement for the adoption of specific values in the future (c.f. Kell *et al*. 1999). This is discussed further in Section 4.3 of this report.

An important plot, after fitting any statistical model, is that of standardized residuals against fitted values (with the latter transformed to the constant-information scale of the error distribution). The plot is capable of revealing isolated points with large residuals, or a general curvature, or a trend in the spread of residuals along the abscissa. Details of the technique are given in O'Brien & Kell(1996); together with residual-covariate plots. For the segmented regression model analysed in this report, it is recommended to assess distributional form by the quantile-quantile (Q-Q) plot with simulation envelope (Atkinson, 1985). In addition, influence and leverage diagnostics are important tools with which to identify departures from model assumptions. A number of these diagnostics are presented and discussed in Section 3.2.3 for NEA cod. Work is currently in progress (O'Brien, pers. comm.) to investigate further these and other diagnostic techniques.

3.2.2 Technical basis for the re-estimation for NEA cod

A class of segmented regression functions was used to estimate $\boldsymbol{B_{lim}}$. The software was re-written in the R language from the original S-PLUS script used to produce the results given in the WDs presented by O'Brien and Maxwell at the March 2002 SGPA meeting (ICES CM 2003/ACFM:10). Prior to the current SGBRP meeting, data from the 2001 NEA cod assessment, as used by O'Brien and Maxwell, were re-analysed in order to check that the same results were achieved.

The model was then fitted to data from the 2002 NEA cod assessment for SSB-recruitment at age 5 data pairs for the year-classes 1946-1995; namely, recruitment at age 5 during the period 1951-2000.

3.2.3 Results of re-estimation and diagnostics

Parameter values, including the change-point (**S* = $\mathbf{B}_{\mathrm{lim}}$**), slope in the origin ($\hat{\alpha}$) and recruitment plateau (**R***), were computed and are presented in Table 3.2.3.1. The estimate **S*** produced from the algorithm in Julious (2001) is merely shown for comparison with the maximum likelihood estimate (mle) resulting from a 500x500 grid search. The later approach provides the estimate of $\mathbf{B}_{\mathrm{lim}}$ from the segmented regression model since the former method is constrained to consider only historical values of SSB as candidates for the biomass at which recruitment is impaired.

Table 3.2.3.1. Results of a) fitting a segmented regression model; together with b) the analysis of variance (ANOVA) table comparing the residual sum of squares (RSS) from fitting the segmented regression model to the RSS from fitting an arithmetic mean. The significance of the segmented regression model over the one-line (mean) model is indicated by the low p-value of the bootstrapped F-test statistic.

a)

From algorithm in Julious (2001)				**From search on 500x500 grid**		
S*	$\hat{\alpha}$	**R***		**S*(10)**	**S***	**S*(90)**
224482	1.26	281832		190219	224252	306051

b)

Model	**Resid df**	**RSS**	**Test df**	**Sum of sq**	**F value**	**Bootstrap p-value**
mean	49	22.36				
change point	48	18.10	1	4.26	11.29	< 0.001

The segmented regression fit is statistically significant at the 5% level of significance and the maximum likelihood estimate of the spawning stock biomass at which recruitment is impaired is 224 252 tonnes. An approximate 80% profile likelihood confidence interval is given by (190 219, 306 051) tonnes.

Diagnostic plots for the segmented regression model are shown in Figures 3.2.3.1 and 3.2.3.2. These were produced using the S-PLUS code originally produced by O'Brien and Maxwell for the March 2002 SGPA meeting and available upon request from the first author. Of particular note is the panel in Figure 3.2.3.1 illustrating the influence of omitting each year-class individually from the fits of the model. The omission of each of four year-classes (1963, 1964, 1969 and 1977) individually from the estimation procedure has a similar effect on the estimate of the change-point but each revised estimate still lies within the approximate 80% profile likelihood confidence interval for the change-point estimated based upon the full time-series of data.

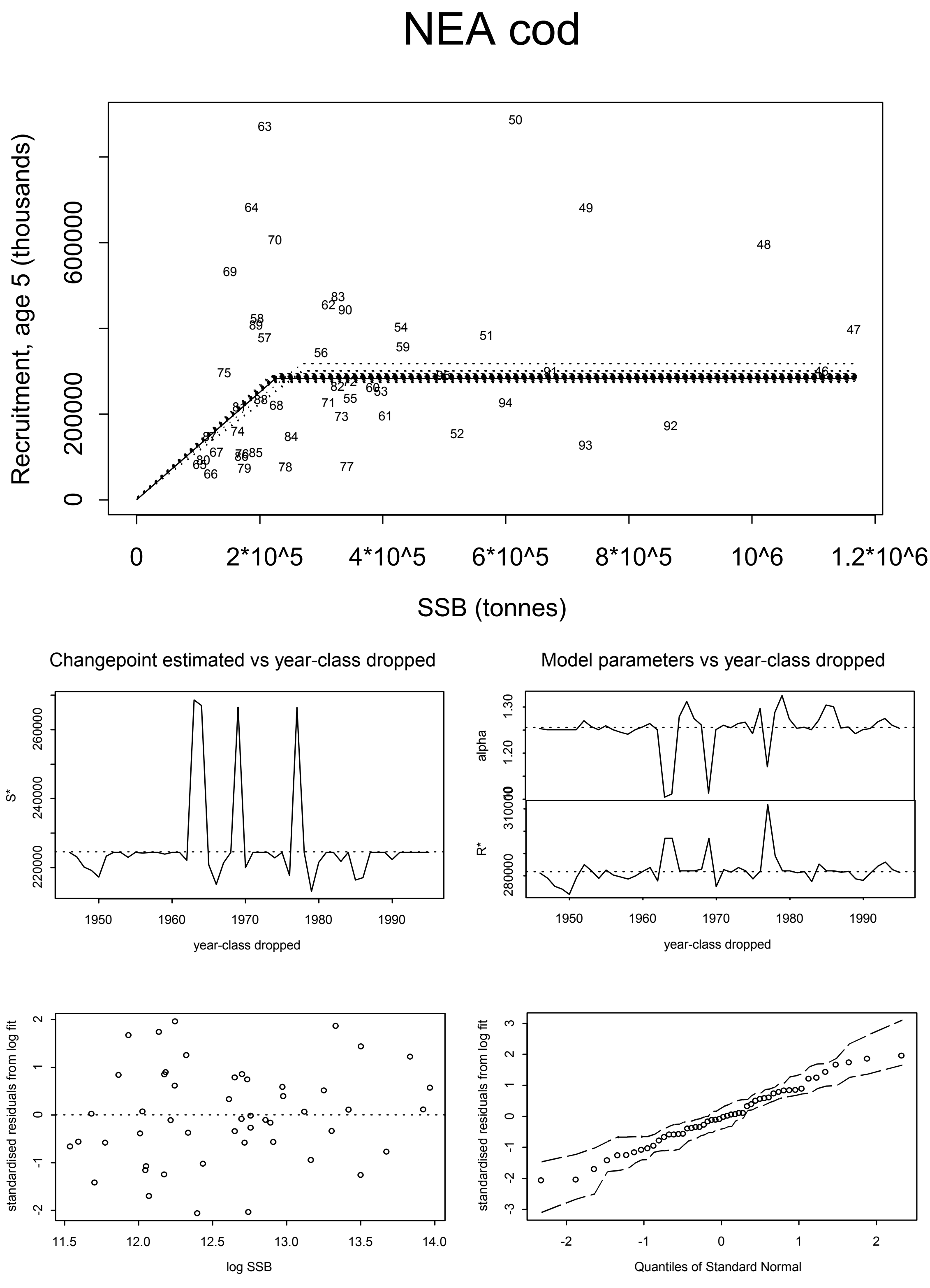

Figure 3.2.3.1. Diagnostic plots for the segmented regression model. Panel 1: stock-recruitment pairs identified by year class; solid line is the change-point model estimated; dotted lines are the change-point models estimated by eliminating a single year-class in turn. Panel 2: change-point versus year-class eliminated. Panel 3: slope at the origin and recruitment estimate above change point. Panel 4: standardised residuals versus covariate. Panel 5: q-q plot with simulation envelope.

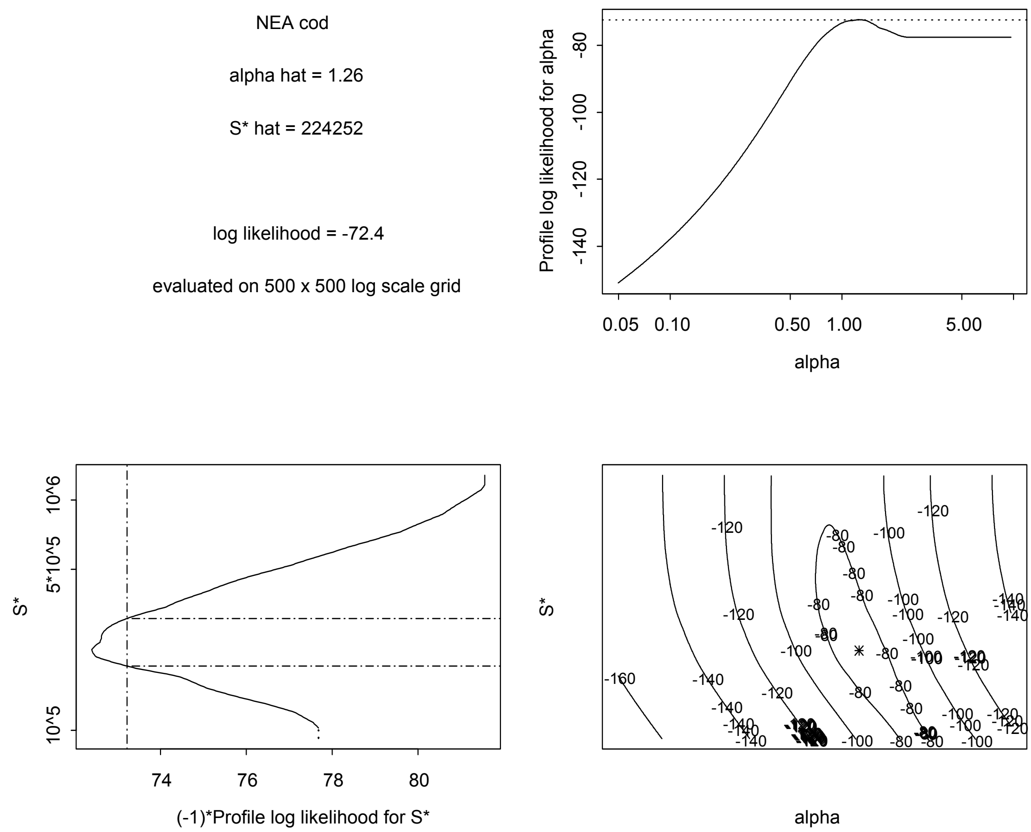

Figure 3.2.3.2. Profile likelihood plots. Panel 1: text. Panel 2: profile likelihood for slope at the origin. Panel 3: profile likelihood for change-point (vertical line – approximate 80% likelihood ratio confidence interval for S*). Panel 4: contour surface.

In this Section, an estimate of the spawning stock biomass at which recruitment is impaired ($\mathbf{B}_{\text{lim}}$) has been obtained using a segmented regression. The fitted regression model is next used in Section 3.3 to estimate the slope at the origin of the segmented regression and to estimate $\mathbf{F}_{\text{lim}}$.

3.3 $\mathbf{F}_{\text{lim}}$

Previous practice within ICES has been to set $\mathbf{F}_{\text{lim}}$ based upon the biological reference point $\mathbf{F}_{\text{loss}}$ (Cook 1998, O'Brien 1999). This reference point corresponds to the fishing mortality associated with the spawner-per-recruit that is the inverse of $\mathbf{G}_{\mathbf{loss}}$, the ratio of the expected recruitment at the lowest observed SSB to the value of the lowest observed SSB. This is derived from the stock-recruitment pairs and is a conservative proxy for the fishing mortality that would drive the stock to extinction. This assumes that the critical factor is the expected level of recruitment, which is a function of spawning stock, which in turn is determined by fishing mortality.

Although one could consider setting $\mathbf{F}_{\text{lim}}$ on the basis of some a priori considerations about population biology, it is proposed that $\mathbf{F}_{\text{lim}}$ should be set on the basis of $\mathbf{B}_{\text{lim}}$, As defined earlier, $\mathbf{B}_{\text{lim}}$ has been chosen to imply the lowest biomass at which there is still a low risk of impaired recruitment. It is therefore proposed that in order to avoid double counting of the risk, $\mathbf{F}_{\text{lim}}$ should be derived deterministically as the fishing mortality that will on average (i.e. with a 50% probability) drive the stock to the biomass limit.

The approach to be adopted is presented in the next Section 3.3.1.

3.3.1 Methodological basis for the re-estimation

$\mathbf{F}_{\text{lim}}$ is to be estimated by obtaining a value for the expected recruitment at $\mathbf{B}_{\text{lim}}$. This recruitment should be representative of the values to be expected at that level of SSB, and should be based on the same stock-recruitment function used for deriving $\mathbf{B}_{\text{lim}}$; namely, the segmented regression.

3.3.2 Technical basis for the re-estimation for NEA cod

It is proposed that $\mathbf{F}_{\mathrm{lim}}$ is derived from $\mathbf{B}_{\mathrm{lim}}$ as a deterministic equilibrium value (ICES CM 2003/ACFM:xx). The functional relationship between spawner-per-recruit and F will then give the F associated with the R/SSB slope derived from the $\mathbf{B}_{\mathrm{lim}}$ estimate obtained from the segmented regression.

Shepherd (1982) showed how it is possible to combine spawner *per* recruit (SPR) analyses and SSB-R estimates to generate reference fishing mortality (F) rates. The relationships are straightforward (see Gabriel *et al*, 1989; Mace and Sissenwine, 1993) and involve inversion of any SPR to form the slope of a straight line through the origin of the SSB-R curve (or a proxy therefore, such as a given percentile of the survival ratios). That line represents the average survival ratio required to support the given constant *F* associated with the SPR (Rosenberg *et al*, 1994).

3.3.3 Results of re-estimation

Arithmetic means of proportion mature, weight in stock, weight in catch, natural mortality and fishing pattern over the whole observation period (1946-2001) were used for calculating the spawner-per-recruit function using ICES Secretariat yield-per-recruit software (Figure 3.3.3.1).

Figure 3.3.2.1. Spawning biomass (kg) per recruit versus fishing mortality. The R/SSB slope from the segmented regression (1.255 recruits per kg) corresponds to 0.797 kg SSB per recruit.

R/SSB = 1.26 from the $\mathbf{B}_{\mathrm{lim}}$ estimation gives SSB/R = 0.797 and an $\mathbf{F}_{\mathrm{lim}}$ = 0.74.

In this Section, an estimate of the slope at the origin of the segmented regression has been obtained in order to estimate $\mathbf{F}_{\mathrm{lim}}$. Uncertainty in the stock assessment and stock projection of NEA cod are next used in Section 3.4 to estimate a Precautionary limit to fishing mortality ($\mathbf{F}_{\mathrm{pa}}$).

3.4 $\mathbf{F}_{\mathrm{pa}}$

Operationally, both $\mathbf{F}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{lim}}$ should be avoided with a high probability. This requires that ICES management advice should take account of uncertainty in the assessment process leading to that advice. $\mathbf{F}_{\mathrm{pa}}$ is therefore derived from $\mathbf{F}_{\mathrm{lim}}$ as a buffer that takes account of the assessment and implementation uncertainty. ICES advice is not to exceed $\mathbf{F}_{\mathrm{pa}}$, which should therefore be estimated in such a way that the fishing mortality realised by an advised catch at $\mathbf{F}_{pa}$ should have a very low probability of being at $\mathbf{F}_{lim}$.

The approach to be adopted is presented in the next Section 3.4.1.

3.4.1 Methodological basis for the re-estimation

The proposed procedure by SGPA December 2002 could be described as retrospective predictions. The following procedure was chosen here: Short-term predictions from each terminal year in a retrospective assessment were made. For each intended F ($\mathbf{F}_{pred}$) the resulting catch in the prediction year and the associated SSB ($\mathbf{B}_{pred}$) at start of the following year was observed. By applying this catch in the same calendar year in the "converged" assessment (2002 assessment) the realised F (Fobs), and the associated SSB in the following year was observed. This procedure gives one set of observations derived from each terminal year.

3.4.2 Technical basis for the re-estimation for NEA cod

The error distribution observed by such retrospective predictions could be regarded as a realistic representation of the combined assessment and prediction uncertainty, provided that the retrospective predictions are made by exactly the same procedure as used by the latest AFWG. For this assessments, two exceptions were made: The cod consumption by cod estimated by latest AFWG was used for all retrospective assessments (not fitted for each terminal year), and the recruitment at age 3 was not predicted in the retrospective prediction, but taken from the latest AFWG assessment. Therefore, the assessment uncertainty related to estimating cod cannibalism, and the prediction uncertainty caused by predicting recruitment are not included in the analysis. This was not considered to be a major problem since they both relate to age groups which make small contributions to predicted catch and SSB.

For many years AFWG has assumed a catch constrain in the intermediate year when making the prediction. In the two most recent years ACFM has asked the AFWG to provide predictions based on F *status quo* in the intermediate year. One of the arguments for $\mathbf{F}_{sq}$ has been that the method is more robust against assessment errors. The analysis was made for both cases.

Since no standard software is developed for this special purpose, an ad hoc solution was chosen. The retrospective XSA assessment was run by standard ICES software. A spread-sheet was used for calculating prediction input data and for making short-term prediction (estimating catch and SSB (Bpred) resulting form each intended F (Fpred)). Another spread-sheet was used for observing the consequences (Fobs and Bobs) of taking that catch in the same calendar year in the "converged" 2002 assessment.

The analysis was limited by the shortest tuning series starting in 1984. The minimum number of years for any tuning series was set at 5 years, so that the earliest terminal year was 1989. Then we are left with 12 years of observations. This means that the basis is rather weak for making reasonable fits to any assumed underlying probability distribution. The highest observed Fobs (Fobs,max) at any Fpred correspond to a cumulative frequency of 0.92 (11 out of 12 observations are lower), and this was considered as a reasonably proxy for the upper 90-95 percentile of realised Fs. Since the analysis was made only for 5 values of intended Fs, a line through the highest observed Fobs was fitted. Then $\mathbf{F}_{pa}$ could be set equal to the intended F giving an Fobs,max=$\mathbf{F}_{lim}$.

The obtained $\mathbf{F}_{pa}$ was checked by inspecting the risk profile for $\mathbf{B}_{lim}$ and $\mathbf{B}_{pa}$ relative to F, obtained from a probabilistic long-term equilibrium run (using the program LTEQ presented by Skagen (WD to the SGPA in December 2002)). Further details of the input parameters of the program and the results of using the software are presented later in Section 3.6.

3.4.3 Results of re-estimation

Table 3.4.3.1 and Figure 3.4.3.1 show the realised Fs sorted in increasing order and their associated cumulative frequency, both for $\mathbf{F}_{sq}$ and catch constraint. Figure 3.4.3.2 shows the Fobs,max for each Fpred and the fitted lines. An Fobs,max equal to the estimated $\mathbf{F}_{lim}$ (0.74) correspond to Fpred=0.40 for the $\mathbf{F}_{sq}$ predictions.

The analysis thus indicates an $\mathbf{F}_{pa}$=0.40 as relevant for the current prediction procedure. The analysis also indicates that predictions based on catch constraint would require a lower $\mathbf{F}_{pa}$ (0.35) to have the same probability of having a realised F below $\mathbf{F}_{lim}$.

The evaluation of this $\mathbf{F}_{pa}$ relative to the long-term equilibrium risk profiles is presented in Section 3.6.

Table 3.4.3.1. Realised Fs (Fobs) in increasing order corresponding to fixed intended Fs (Fpred) and the corresponding cumulative frequency of realised Fs.

F_{sq} in yr1						Catch constraint in yr1					
Fpred	0.2	0.42	0.6	0.8	1	Fpred	0.2	0.42	0.6	0.8	1
Cum. Freq	Realised Fs (Fobs)					Cum. Freq	Realised Fs (Fobs)				
0.08	0.117	0.237	0.329	0.423	0.510	0.08	0.158	0.319	0.440	0.564	0.678
0.17	0.152	0.306	0.422	0.540	0.647	0.17	0.167	0.334	0.460	0.588	0.708
0.25	0.175	0.350	0.482	0.617	0.743	0.25	0.183	0.380	0.534	0.700	0.859
0.33	0.186	0.390	0.555	0.737	0.918	0.33	0.184	0.383	0.544	0.720	0.894
0.42	0.209	0.433	0.614	0.809	1.000	0.42	0.214	0.452	0.648	0.868	1.091
0.50	0.211	0.447	0.641	0.861	1.083	0.50	0.229	0.487	0.702	0.948	1.201
0.58	0.236	0.503	0.729	0.989	1.258	0.58	0.237	0.505	0.730	0.987	1.253
0.67	0.239	0.510	0.740	1.003	1.276	0.67	0.258	0.555	0.809	1.105	1.417
0.75	0.243	0.519	0.751	1.017	1.293	0.75	0.285	0.619	0.907	1.242	1.599
0.83	0.259	0.548	0.790	1.064	1.345	0.83	0.289	0.622	0.909	1.251	1.618
0.92	0.342	0.756	1.131	1.595	2.121	0.92	0.317	0.693	1.026	1.429	1.873
1.00	0.350	0.781	1.186	1.716	2.371	1.00	0.402	0.924	1.447	2.201	3.287

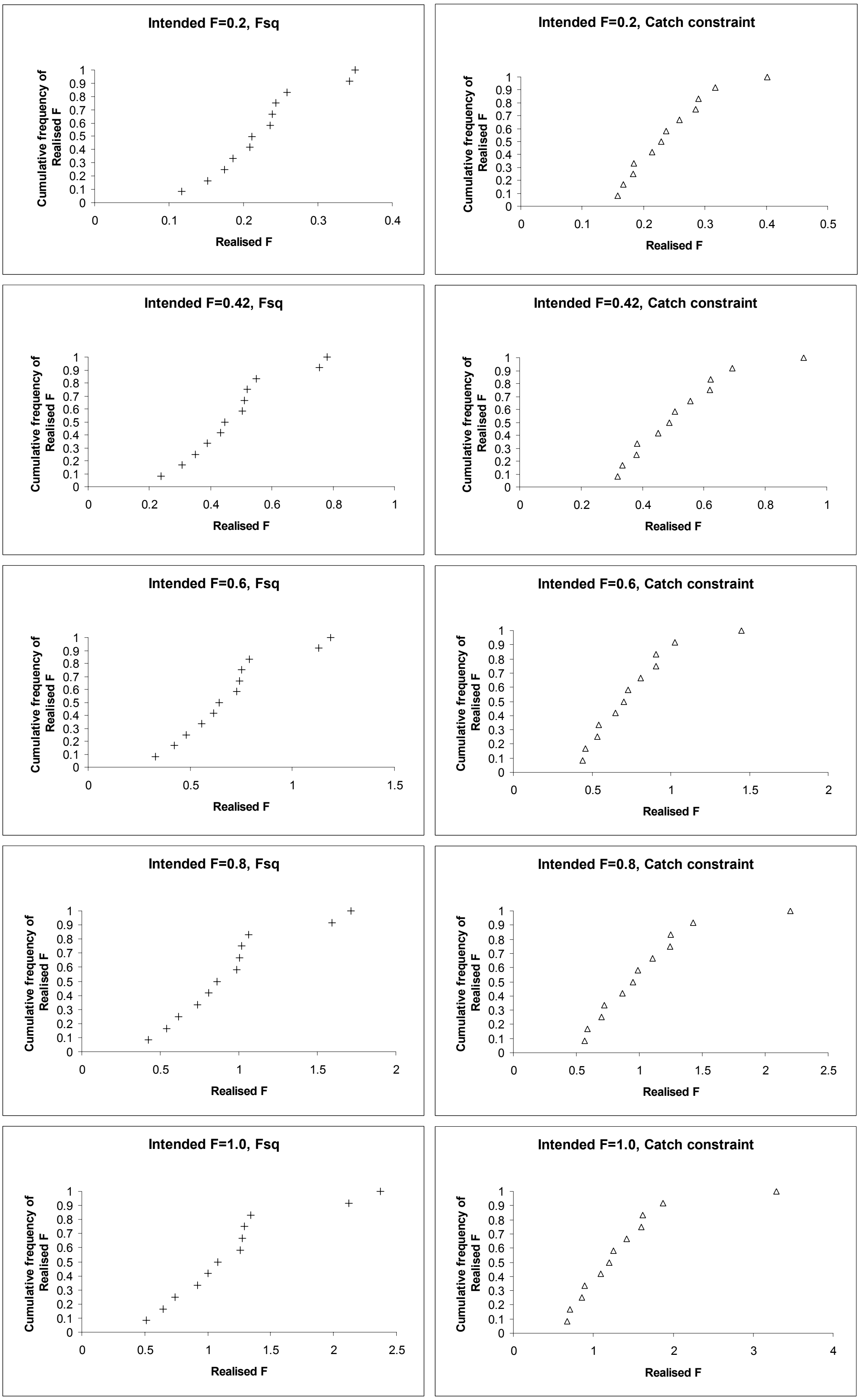

Figure 3.4.3.1. Cumulative frequency distributions of realised F at some fixed values of intended F.

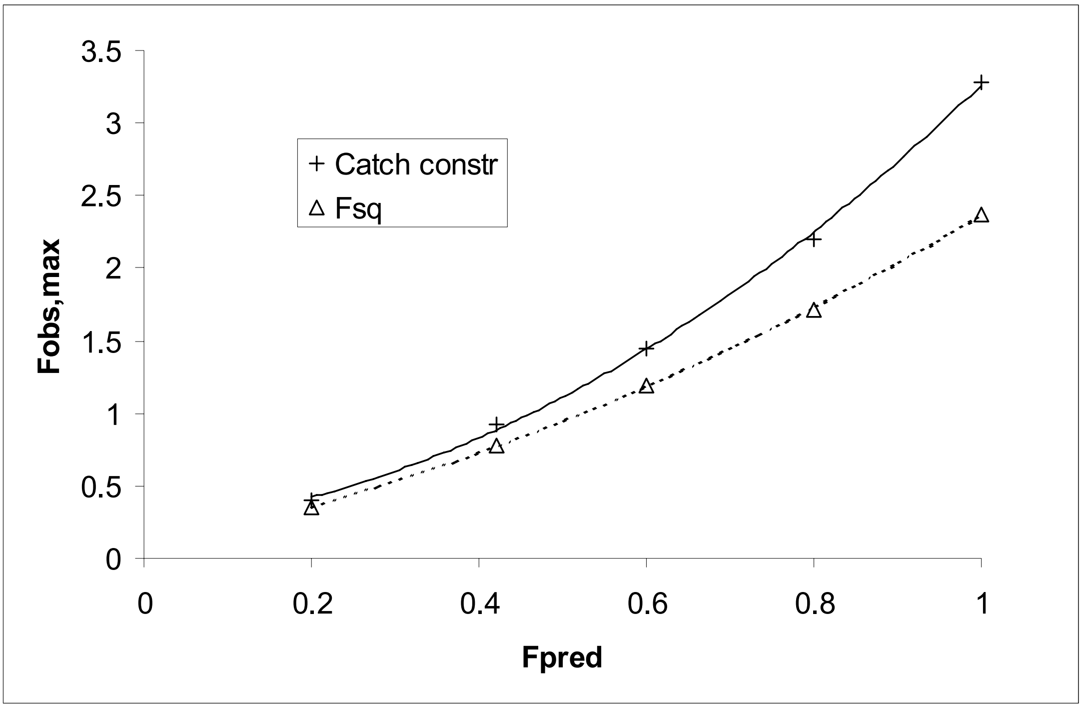

Figure 3.4.3.2. Highest observed realised F (Fobs,max) at fixed intended Fs (Fpred).

It has been demonstrated that the two different ways to formulate advice – one based on a TAC constraint and the other based upon *status quo* F - imply different precautionary reference values ($\mathbf{F}_{pa}$). One should note that any change to the current basis for advice is most likely to change the corresponding precautionary reference values.

In the earlier Section 3.2.3, an estimate of the spawning stock biomass at which recruitment is impaired ($\mathbf{B}_{lim}$) has been obtained using a segmented regression. Uncertainty in the stock assessment and stock projection of NEA cod are next used in Section 3.5 to estimate a Precautionary limit to biomass ($\mathbf{B}_{pa}$).

3.5 $\mathbf{B}_{pa}$

In a similar way to the argument presented in Section 3.4 in the context of $\mathbf{F}_{pa}$, $\mathbf{B}_{pa}$ should be derived from $\mathbf{B}_{lim}$ taking assessment and implementation uncertainty into account. $\mathbf{B}_{pa}$ should therefore be such that if SSB is estimated to be at $\mathbf{B}_{pa,}$ there is a very low probability that SSB is actually at $\mathbf{B}_{lim}$.

The approach to be adopted is presented in the next Section 3.5.1.

3.5.1 Methodological basis for the re-estimation

For setting $\mathbf{B}_{pa}$ relative to $\mathbf{B}_{lim}$ the recommended procedure is (section 3.2.3 of ICES SGPA 2003):

… When the procedure in Section 3.2.2 is followed, SSB values in each terminal year (Bassm) are estimated as part of the assessment, and can be compared with the SSB estimated for that year using the reference data set (Btrue). To derive $\mathbf{B}_{pa}$, a ratio B_{assm}/B_{true} can be obtained in a way that is analogous to the usual procedure for deriving $\mathbf{F}_{high}$ from a stock-recruit plot: plot pairs of values of Bassm and Btrue pairs with Btrue as the independent variable. Draw a line through the origin so that α% of the points are above and (100-α) are below the line. Here α is the acceptable risk, which may be 10% or less, depending on the availability of the data. If the number of pairs is small, the highest line passing through a point should probably be used, unless this is a clear outlier. The slope β of the line is the ratio between $\mathbf{B}_{pa}$ and $\mathbf{B}_{lim}$, thus $\mathbf{B}_{pa} = \beta * \mathbf{B}_{lim}$.

This method was applied, and since the number of pairs are low (12), the point giving the highest slope for a line through the origin (the Bassm/Btrue) was chosen.

Since the retrospective predictions also gives pairs of SSBs (Bpred and Bobs, as described in Section 3.4.2), this could be used to get similar ratios for the predictions, thereby including the effect of prediction errors. Again, with 12 points the highest observed Bpred/Bobs ratio would be a reasonable candidate for $\mathbf{B}_{pa}/\mathbf{B}_{lim}$ ratio. These ratios are quite dependent on the intended F and a fitting of max ratios was needed to able to estimate the max ratio corresponding to a given F. Since the standard ICES advice is restricted to Fs at or below $\mathbf{F}_{pa}$, the max Bpred/Bobs ratio at $\mathbf{F}_{pa}$ seems most relevant for establishing $\mathbf{B}_{pa}$.

3.5.2 Technical basis for the re-estimation for NEA cod

The Bassm/Btrue was obtained from the retrospective analysis, and the Bpred/Bobs values were obtained from the retrospective prediction. Both analysis are described in Sections 3.4.1 and 3.4.2.

3.5.3 Results of re-estimation

Naively, the plot of Bassm/Btrue is shown in Figure 3.5.3.1. This would indicate $\mathbf{B}_{pa}$=1.39*$\mathbf{B}_{lim}$ (310 kt). Note that this estimate is similar to that calculated as S*(90) in Section 3.2.3.

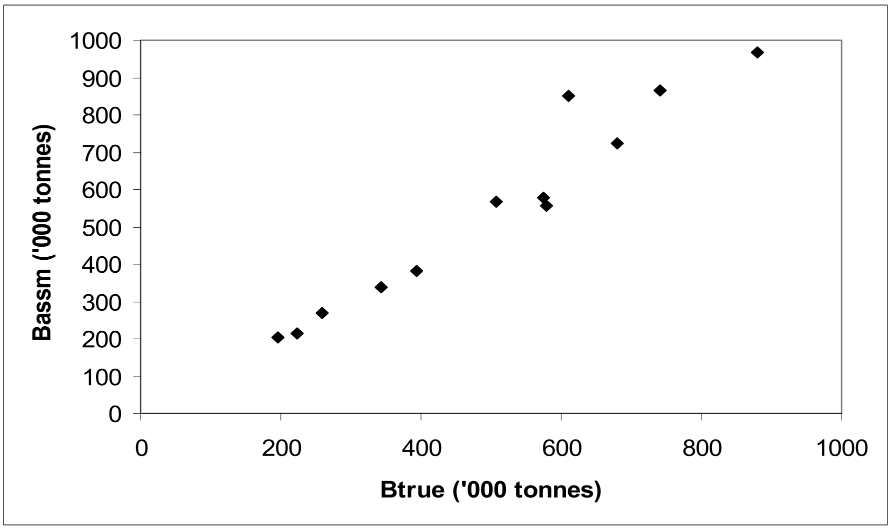

Figure 3.5.3.1. Spawning biomass in terminal years (Bassm) and spawning biomass in 2002 assessment (Btrue).

The calculated Bpred/Bobs ratios at fixed intended Fs and the associated cumulative frequencies are shown in Table 3.5.3.1 and Figure 3.5.3.2.

Table 3.5.3.1. Ratios between Bpred and Bobs in increasing order corresponding to fixed intended Fs (Fpred) and the corresponding cumulative frequency of Bpred/Bobs.

$\mathbf{F}_{sq}$ in yr1						Catch constraint in yr1					
Fpred	0.2	0.42	0.6	0.8	1	Fpred	0.2	0.42	0.6	0.8	1
Cum. Freq	Bpred/Bobs ratio					Cum. Freq	Bpred/Bobs ratio				
0.08	0.47	0.43	0.40	0.37	0.34	0.08	0.78	0.77	0.76	0.71	0.66
0.17	0.77	0.77	0.73	0.68	0.63	0.17	0.86	0.81	0.76	0.75	0.73
0.25	0.82	0.78	0.79	0.80	0.80	0.25	0.93	0.96	0.97	0.93	0.90
0.33	0.83	0.84	0.83	0.82	0.81	0.33	0.96	1.01	0.99	0.96	0.92
0.42	0.85	0.84	0.85	0.87	0.89	0.42	1.01	1.01	1.00	1.03	1.04
0.50	0.95	0.95	0.95	0.95	0.95	0.50	1.06	1.02	1.02	1.03	1.07
0.58	1.10	1.05	1.02	0.98	0.96	0.58	1.08	1.04	1.05	1.11	1.17
0.67	1.23	1.25	1.23	1.21	1.19	0.67	1.12	1.15	1.17	1.20	1.23
0.75	1.26	1.25	1.28	1.32	1.36	0.75	1.19	1.24	1.27	1.31	1.36
0.83	1.27	1.33	1.38	1.44	1.51	0.83	1.31	1.43	1.56	1.69	1.85
0.92	1.45	1.62	1.81	2.08	2.43	0.92	1.41	1.49	1.57	1.73	1.94
1.00	1.77	2.09	2.51	3.23	4.50	1.00	2.12	2.71	3.57	5.42	10.02

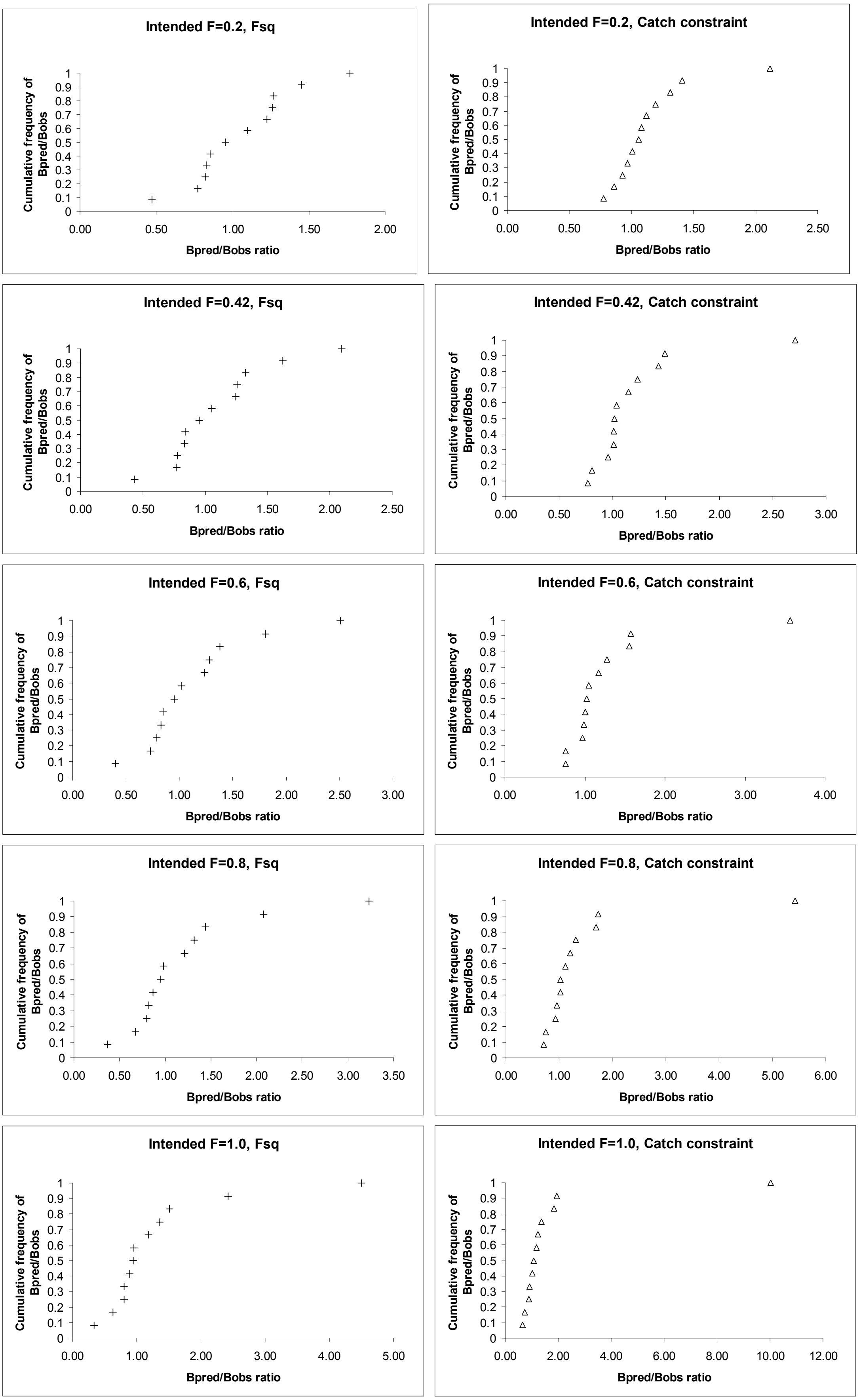

Figure 3.5.3.2 Cumulative frequency distributions of Bpred/Bobs at some fixed values of intended F.

The maximum observed Bpred/Bobs ratio for each intended F is plotted in Figure 3.5.3.3 and in Figure 3.5.3.4, the corresponding $\mathbf{B}_{pa}$ values are shown as function of F. The continuous function is obtained by a polynomial interpolation between the observations. For $\mathbf{F}_{sq}$ predictions, this gives a $\mathbf{B}_{pa}$ of 460 thousand tonnes. Since this latter method includes prediction errors, the resulting values were considered to be more in line with the Precautionary Approach.

It should be noted that predictions based on a catch constraint would give a higher max Bpred/Bobs ratio at $\mathbf{F}_{pa}$, which means that a higher $\mathbf{B}_{pa}$ (=550 thousand tonnes) is required to have a similar probability that the SSB should not fall below $\mathbf{B}_{lim}$.

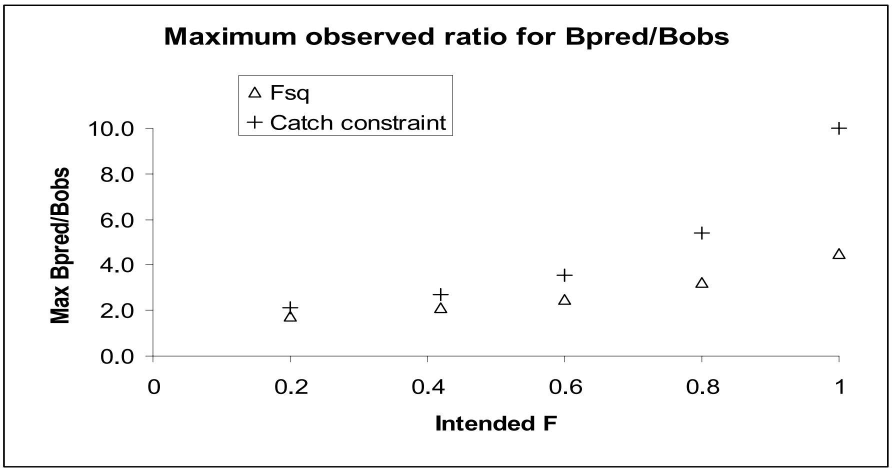

Figure 3.5.3.3. Highest observed Bpred/Bobs ratios from the retrospective predictions.

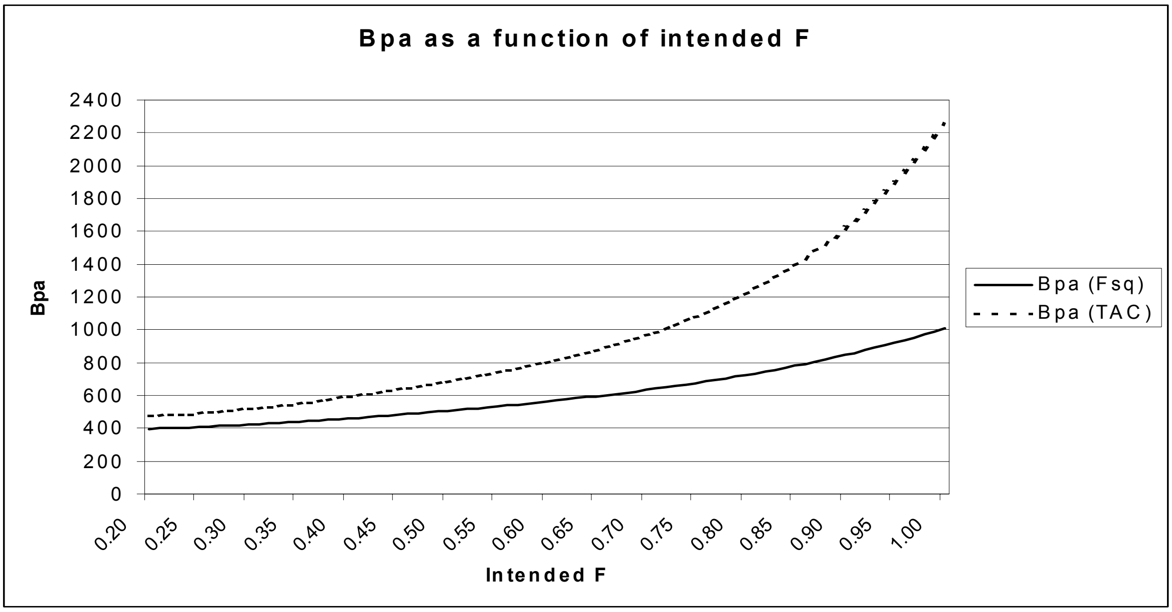

Figure 3.5.3.4. Graph of $\mathbf{B}_{pa}$ as a function of intended fishing mortality.

It has been demonstrated that the two different ways to formulate advice – one based on a TAC constraint and the other based upon *status quo* F - imply different precautionary reference values for fishing mortality and biomass. One should note that any change to the current basis for advice is most likely to change the corresponding precautionary reference values.

3.6 Relationship amongst reference points

As a check on the internal consistency between reference points, a probabilistic estimation of the long-term equilibrium SSB as a function of F was produced using the program LTEQ (see Section 3.4.2). A separate spread-sheet for estimating input parameters for the recruitment simulations in the LTEQ program was available and used to produce the estimates used later in this Section. Besides providing parameter estimates, the spread-sheet has useful diagnostics for evaluating various stock-recruitment (S-R) functions and the probability distribution of recruitment around the S-R function. The inputs to LTEQ are the fitted parameters of the S-R function, the estimated coefficient of variation (CV) of the recruitment residuals, annual historic values of proportion mature at age, weights at age in the catch and in the stock, and fixed values for the exploitation pattern and natural mortality (M) at age.

The output is presented in graphs showing percentiles of SSB and yield, as well as risk profiles (as function of F) for SSB relative to $\mathbf{B}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{pa}}$.

This software was used with input data for the full time-series (1946-2001 for weights and maturity, 1946-1995 year-classes at age 5 for stock-recruitment pairs). The exploitation pattern was set at the arithmetic average of relative Fs at age for the years 1946-2001, and M=0.2 for all ages (5-13+). The stock-recruitment pairs were fitted by a Beverton-Holt function, with an assumed log-normal distribution of residuals around the assumed parametric S-R function.

The stock-recruitment fit is shown in Figure 3.6.1, the log-residuals in Figure 3.6.2 and the probability coverage of the modelled recruitment in Figure 3.6.3.

The resulting percentiles of SSB versus F are shown in Figure 3.6.4, and the risk profiles of SSB are displayed in Figure 3.6.5. The cumulative frequency of modelled recruitment at three fixed Fs are shown in Figure 3.6.6, together with the empirical (observed) function.

It can be seen from Figure 3.6.5 that at F=0.4 ($\mathbf{F}_{\mathrm{pa}}$ estimated in Section 3.4.3) the risk (%) of SSB < $\mathbf{B}_{\mathrm{lim}}$ (as estimated in Section 3.2.3) is less than 1% and the risk for SSB < $\mathbf{B}_{\mathrm{pa}}$ (as estimated in Section 3.5.3) is 15%. It should be remembered, however, that this relates to a realised F=$\mathbf{F}_{\mathrm{pa}}$ but does not indicate that $\mathbf{F}_{\mathrm{pa}}$ is seriously high compared to $\mathbf{B}_{\mathrm{lim}}$ and $\mathbf{B}_{\mathrm{pa}}$.

At F=0.74 ($\mathbf{F}_{\mathrm{lim}}$) there is about a 70% risk for SSB < $\mathbf{B}_{\mathrm{lim}}$. Ideally one should aim at a risk near 50%. The $\mathbf{B}_{\mathrm{lim}}$ is estimated deterministically and is here checked by aid of a simulation tool, which has some particular underlying assumptions, different from those assumed in the deterministic model. In particular, the deterministic model assumes that there is not a trend in recruitment above $\mathbf{B}_{\mathrm{lim}}$ (derived from the segmented regression model); whilst the simulation model fits a parametric S-R curve that gives increasing recruitment over the full range of SSB. Thus producing a stronger reduction in SSB with increasing F.

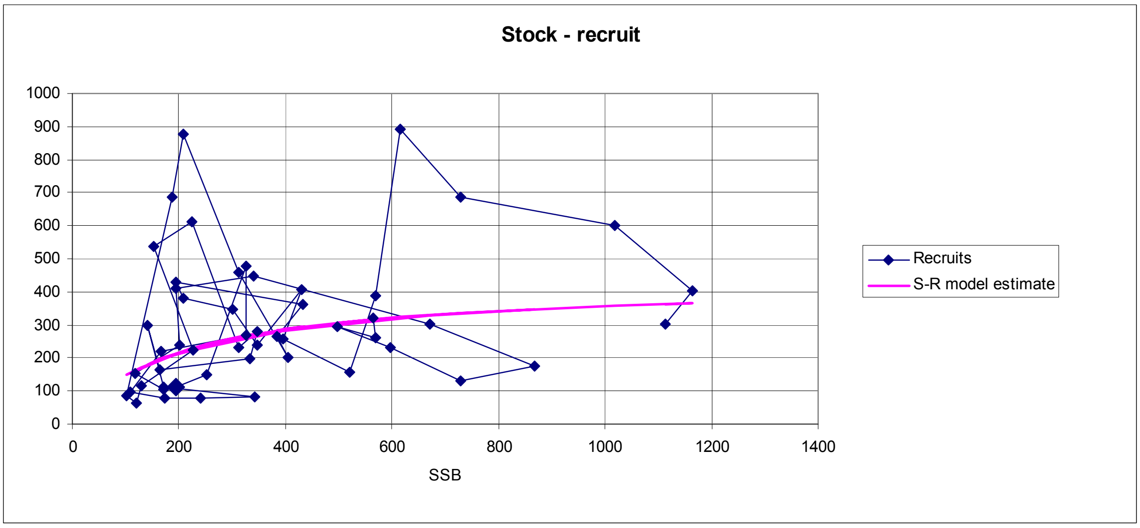

Figure 3.6.1. Fitted Beverton-Holt function and historic recruitment at age 5.

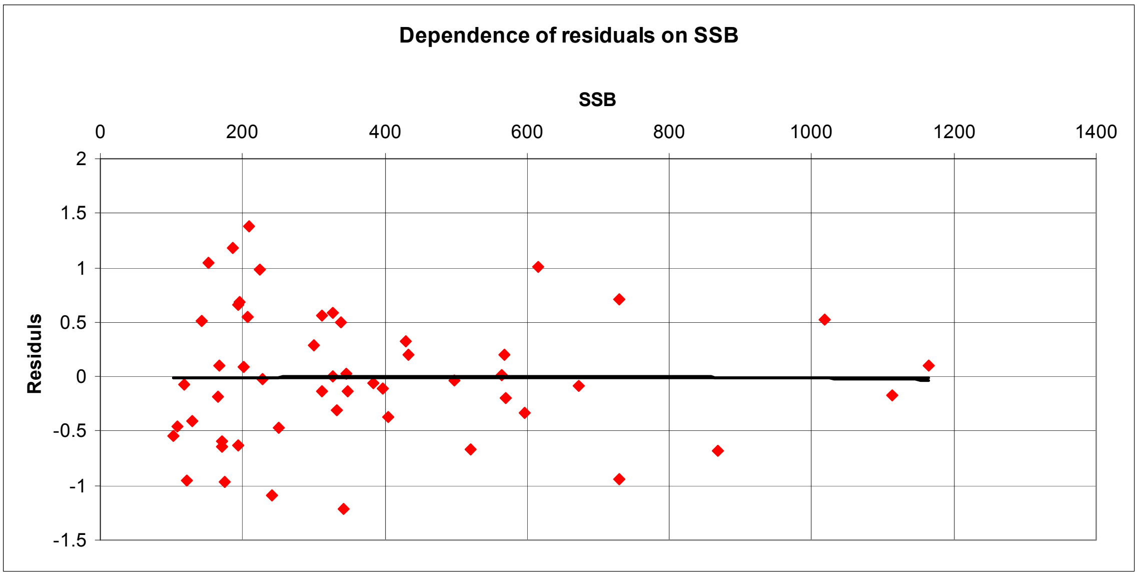

Figure 3.6.2. Log-residuals from the fitted stock-recruitment function.

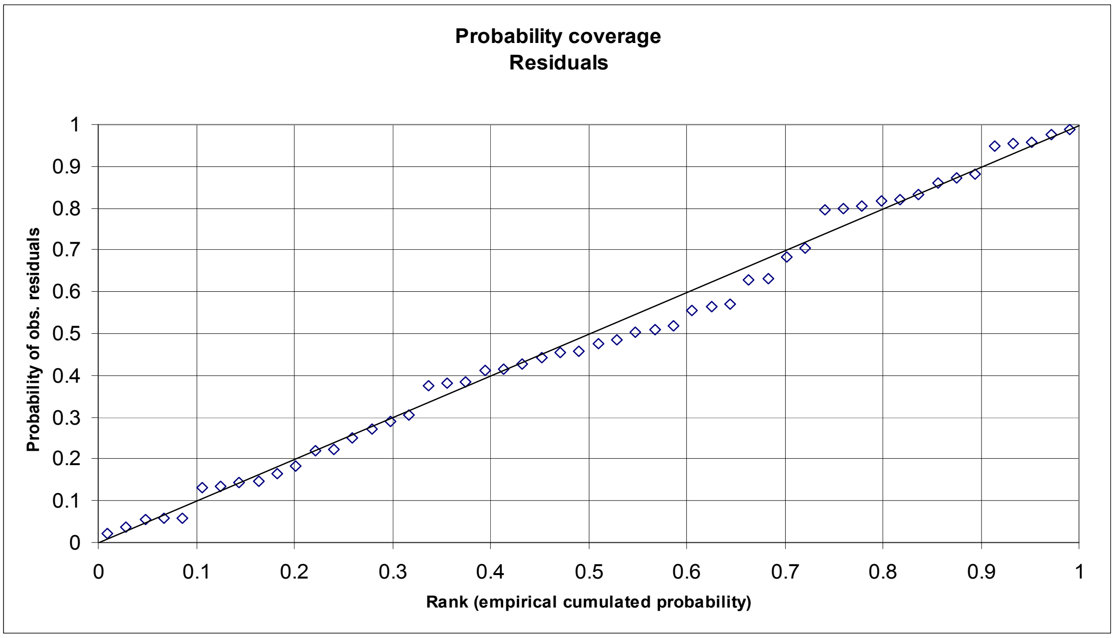

Figure 3.6.3 Probability coverage of the modelled recruitment.

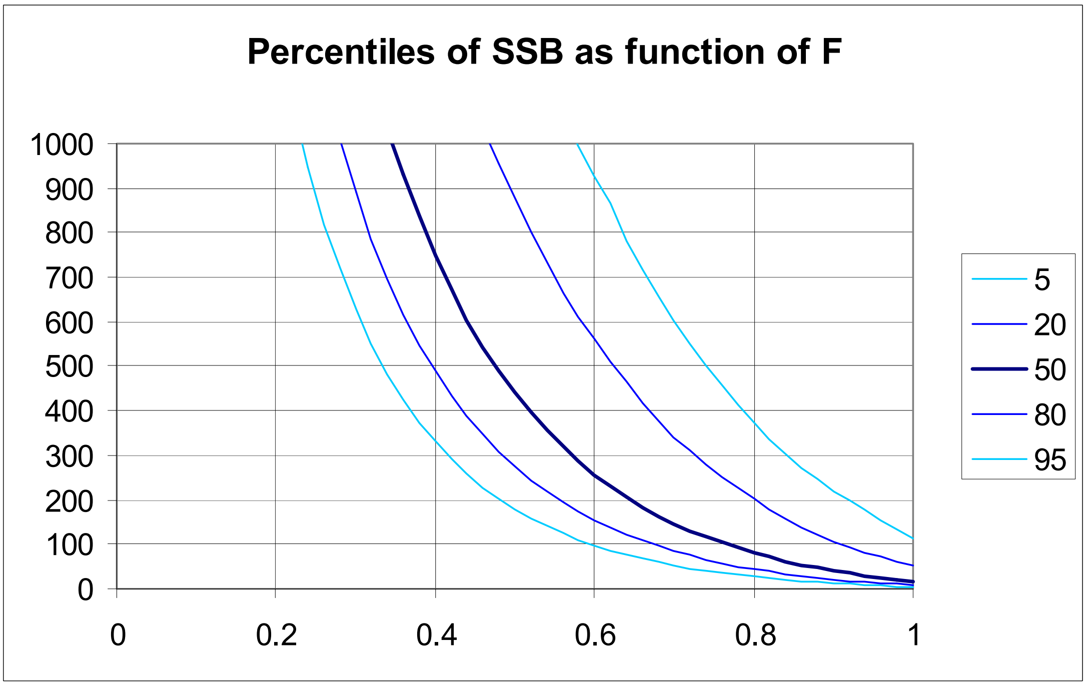

Figure **3.6.4**. Percentiles of the long-term equilibrium SSB.

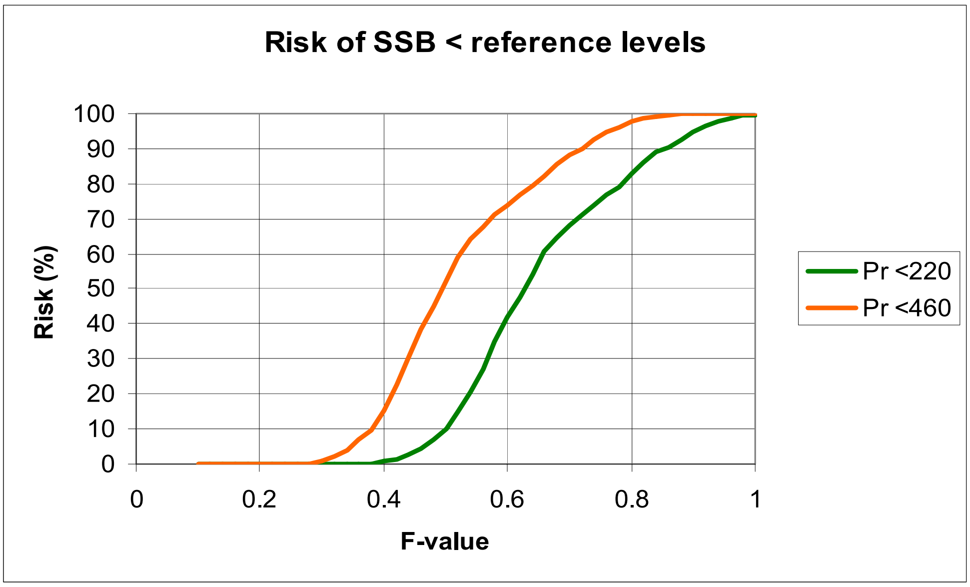

Figure 3.6.5. Risk profiles for SSB < *provisional* $\mathbf{B}_{\mathrm{lim}}$ (220 kt) and for SSB < *provisional* $\mathbf{B}_{\mathrm{pa}}$ (460 kt).

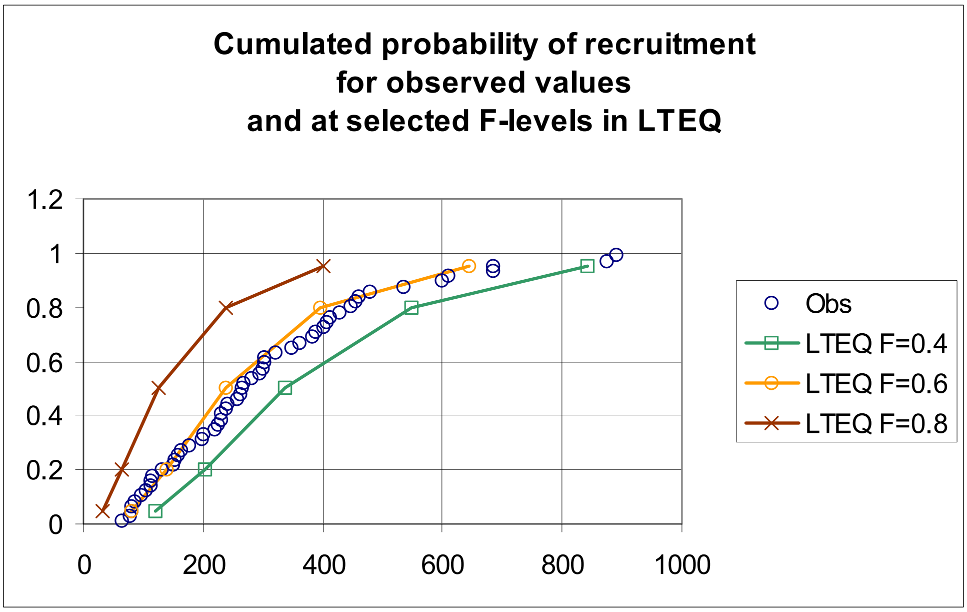

Figure 3.6.6. The cumulative probability of modelled recruitment at the three fishing mortalities of 0.4, 0.6 and 0.8; together with the empirical (observed) function.

3.7 Reference points estimates and comparison to current value.

The current reference points used by ICES are:

Reference points (1998)
source: ICES CM 2001/ACFM:19

ICES considers that:	**ICES proposes that:**
$\mathbf{B}_{lim}$ is 112 000 t, the SSB below which no above-average year-classes have been observed	$\mathbf{B}_{pa}$ is set at 500 000 t, the value below which the probability of below-average year-classes increases
$\mathbf{F}_{lim}$ is 0.70	$\mathbf{F}_{pa}$ be set at 0.42. This value is considered to have a 95% probability of avoiding the $\mathbf{F}_{lim}$

Technical basis:

$\mathbf{B}_{lim} = \mathbf{B}_{loss}$	$\mathbf{B}_{pa}$ = examination of stock-recruit plot
$\mathbf{F}_{lim}$ = Median value of $\mathbf{F}_{loss}$	$\mathbf{F}_{pa}$ = 5 th percentile of $\mathbf{F}_{loss} = \mathbf{F}_{lim} * 0.6$ from $\mathbf{F}_{pa} = \mathbf{F}_{lim}\, e^{-1.645\sigma}$ with $\sigma = 0.3$

At this meeting of SGBRP, *provisional* revised estimates have been calculated and these estimates are presented in the following table:

Reference points proposed at this meeting of SGBRP (2003)
source: provisional

SGBRP considers that:	**SGBRP proposes that:**
$\mathbf{B}_{lim}$ is 220 000 t	$\mathbf{F}_{sq}$: $\mathbf{B}_{pa}$ is set at 460 000 t TAC-constraint: $\mathbf{B}_{pa}$ is set at 550 000 t
$\mathbf{F}_{lim}$ is 0.74	$\mathbf{F}_{sq}$: $\mathbf{F}_{pa}$ be set at 0.40 TAC-constraint: $\mathbf{F}_{pa}$ be set at 0.35

The estimates of the reference points are considered as provisional since the AFWG will meet after this meeting of SGBRP in order to produce the latest stock assessment of the NEA cod. At the forthcoming meeting of AFWG in 2003, the methods and software presented in this report will be applied to the latest stock-recruitment values in order to re-estimate the Precautionary reference points ($\mathbf{B}_{lim}$, $\mathbf{F}_{lim}$, $\mathbf{F}_{pa}$, $\mathbf{B}_{pa}$) for NEA cod.

It has been demonstrated that the two different ways to formulate advice – one based on a TAC constraint and the other based upon *status quo* F - imply different precautionary reference values for fishing mortality and biomass. One should note that any future change to the current basis for advice is most likely to change the corresponding precautionary reference values. An example of such a change is the formulation of multi-annual advice (see the discussion in Section 4.3 of this report and the more general discussion in Section 4.4).

In addition to any possible changes in the agreed management procedure influencing the precautionary reference point values for this stock, if either the underlying assumptions or basic data is changed then there will be a need to re-calculate the values assigned to the Precautionary reference points ($\mathbf{B}_{lim}$, $\mathbf{F}_{lim}$, $\mathbf{F}_{pa}$, $\mathbf{B}_{pa}$) for NEA cod.

4 FUTURE WORK

4.1 Reference points for alternative indices of reproductive potential

Concerns were raised that SSB may not be an adequate index of reproductive potential, especially in periods when size/age composition and growth (including maturity, condition, fecundity) are changing. Spawning stock structure (*sensu* age or length composition) and in particular a sufficient number of old fish (repeat spawners) seem to affect recruitment positively (Nakken WD2, Tretyak WD8). F rates that are at or close to $\mathbf{F}_{pa}$ appear to conserve older spawners. However, F rates close to $\mathbf{F}_{lim}$ permit very few fish to become repeat spawners. A reference point indicating the number of fish above a given age (e.g., 8+) which has a high proportion of repeat spawners should be considered. Such a reference point would be an advantage for managers in periods when large temporal variations in growth and maturity generate conflicting signals from trends in the assessment estimates of F and SSB. The experience in recent years with an increasing SSB at F well above $\mathbf{F}_{lim}$ underscores the need for such a reference point.

In future, improved estimates of reproductive potential should become available for use by the AFWG. These estimates include the following:

- Total egg production (Marshall et al. 1998)
- Relative egg production (Borisov and Bulgakova WD2 in ICES AFWG 2002)
- Stock structural indices (number of 8+ fish Nakken WD2; number of repeat spawners Tretyak WD8; age diversity indices Ajiad and Jakobsen WD to SGPA March 2002)
- Total lipid energy (Marshall et al. 2000)

Such indices can be expected to reveal the effect that changes in stock structure and growth have on stock productivity and recruitment levels. They allow more detailed examination of possible compensatory mechanisms of cod to increased exploitation.

4.2 Age reading

During last year's ICES Arctic Fisheries Working Group (AFWG) meeting, concerns were raised about the possibility of age biases. The peer review has also recommended investigating the possibility that biases in age reading contributed to the long-term trends observed in growth and maturity.

Norway has a collection of cod otoliths dating back to the 1930's. To assess whether changes in age reading are influencing the time-series, the AFWG recommended that historic material from 1980 to 1985 and representative time periods prior to 1980 should be re-aged by both IMR and PINRO. The plan is to re-read and exchange/compare cod otoliths from 1947, 1957, 1967, 1977, 1980, 1981 and 1982 - 100 otoliths from each year.

Only historic material from 1967 have up to now been exchanged and read. Material from 1980, 1981 and 1982 (all from longline Lofoten) were exchanged during the present study group, and material from 1947, 1957 and 1977 will be exchanged during the March 2003 PINRO-IMR scientist meeting.

Preliminary results for 1967 show that in the case of the re-aged material from IMR the age/length values for the historic ages and the new ages are similar with the new age giving a slightly lower mean length at age (Figure 4.2). The discrepancy is a little higher for the re-aged material from PINRO such that the mean lengths at age for the re-aged material are consistently lower than the IMR mean lengths. This is also observed in an exchange otolith project conducted by IMR and PINRO in a more recent period (1992- onwards) (WD 16 in ICES AFWG 2002). However, all historic material planned to be re-read should be finished before the impact on the existing time-series can be fully evaluated.

In order to properly explain reasons for positive or negative relationship between SSB and recruitment, and further linkage to the environment, it is crucial that the recruits are aged correctly so that we compare parent stock, offspring and ecological/hydrographical conditions at the same time. It is therefore recommended that age determinations of young cod be verified by a joint PINRO-IMR project and preferably also back in history if material exists.

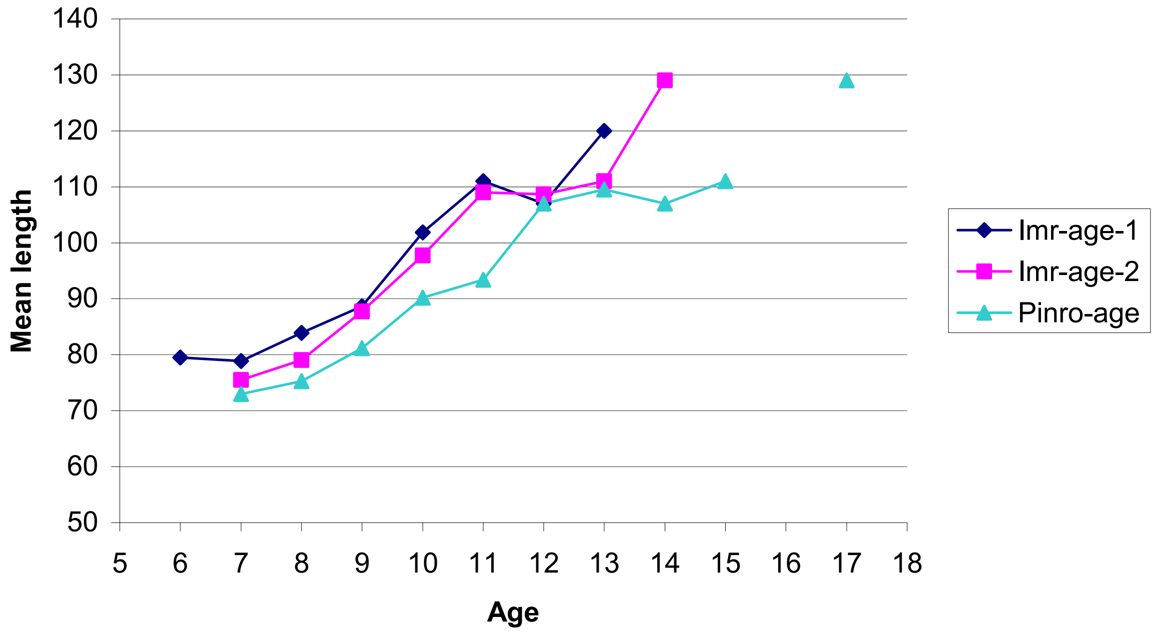

Figure 4.2. Resulting mean length at age from the re-ageing of 100 cod otoliths collected during the Lofoten fishery on spawning grounds in 1967. IMR-age-1 shows the mean length at age resulting from the reading in 1967 by O.Ananiassen, IMR; IMR-age-2 shows the mean length at age resulting from the re-reading in 2002 by H.Senneset and P.Ågotnes, IMR; PINRO-age shows the mean length at age resulting from the comparative age reading in 2002 by V. Koloskova and N. Zouikova, PINRO.

4.3 Reference points in the context of multi-annual TACs

4.3.1 New harvesting strategy adopted

At the 31st session of The Joint Norwegian-Russian Fishery Commission in autumn 2002, the Parties agreed that the new harvesting strategy for Northeast Arctic cod and haddock should incorporate the following considerations:

- to prepare the basis for a long-term high yield of the stocks
- the desirability to obtain a high degree of stability in the TAC from year to year
- full utilization, at all times, of the most recent information available on the stock development

On this basis, the Parties determined the following decision rule for setting the annual fishing quota for Northeast Arctic cod from 2004 onwards:

- estimate the average TAC level for the coming 3 years based on $\mathbf{F}_{pa}$. TAC for next year will be set to this level as a starting value for the 3 years period
- the year after, the TAC calculation for the next 3 years is repeated based on updated information about the stock development, though such that the TAC should not be changed by more than +/- 10% compared with the previous year's TAC.
- if the spawning stock falls below $\mathbf{B}_{pa}$, the Parties should consider a lower TAC than according to the decision rule above.

4.3.2 Comments to the new harvesting strategy

First, a clarification concerning the constraint on the change in quota from one year to the next: The intention is that the TAC for 2004 should be determined without any constraint on the change in TAC from 2003 to 2004, and that the TAC in subsequent years should not change by more than 10% from year to year. The appropriateness of the maximum percentage change will be evaluated by a dedicated working group before a final decision is made.

A “multi-annual” rule as described above for setting the TAC for Northeast Arctic cod has not previously been considered by ICES Working and Study Groups. The present Study Group did not evaluate this rule, but some general points relating to such rules were noted.

At present, F for Northeast arctic cod is above $\mathbf{F}_{pa}$. The medium-term prognosis shows that the new strategy will not bring F down to $\mathbf{F}_{pa}$ in the near future. The reason is that when F=$\mathbf{F}_{pa}$ is applied for a three-year period, the stock will increase, so that the catch corresponding to F=$\mathbf{F}_{pa}$ also will increase during the period. When applying the 3-year averaging method to find the TAC in the first year, this will thus be higher than the TAC corresponding to F= $\mathbf{F}_{pa}$ in the first year. This is illustrated in the text table below, which shows how the TAC is derived from the 3-year average and a maximum 10% change rule. The prognosis is based on the same input data as used at the 2002 meeting of the Arctic Fisheries Working Group (ICES CM 2002/ACFM:18). This prognosis does not include any strong recruiting year classes, which may give a different situation.

Year	TSB	SSB	F	TAC
2003	1294	429	0.63	426
2004	1274	512	0.48	356 =(318+364+385)/3
2005	1375	598	0.46	373 =(349+373+396)/3
2006	1446	662	0.46	394 =(364+389+429)/3

Involving the medium-term prognosis (three years into future) in the setting of quotas for next year also introduces additional uncertainty due to uncertainty in the prognosis of growth, maturation, recruitment and mortality. Thus, the fishing mortality associated with a multi-annual TAC rule may have to be set lower than $\mathbf{F}_{pa}$ in order to ensure the same probability of avoiding lim values. The ICES should provide guidelines on how to evaluate the effect on multi-annual TAC rules on reference points.

4.4 Reference points for alternative assessment models (e.g., Fleksibest)

For the last years, AFWG has provided assessments of NEA cod made by the new assessment model Fleksibest (Frøysa et al., 2002) in addition to the ‘standard’ XSA assessment. Fleksibest is structured by age and length, which makes it easier to include biological realism. Also, Fleksibest allows for uncertainty in catch data as well as survey data. In order to use Fleksibest for providing management advice for NEA cod, reference points would need to be calculated. It should be outlined how reference points could be calculated using Fleksibest. It should be noted that it is somewhat difficult to extend Fleksibest to the time period when survey data are not available (before 1981). Such an extension will require assumptions about the selection pattern of the various fishing fleets backwards in time.

4.5 Ecosystem effects on the S/R relationship

Data on different biological characteristics of cod for the full time period are available at both IMR and PINRO (including age-length keys). Quantitative cod stomach data are available at both IMR and PINRO from 1984 onwards. Qualitative cod stomach data (percent frequency of occurrence) are available at PINRO for the full time period (1947 onwards). These data could also be used to model the food resources available to Northeast Arctic cod, including cannibalism, over the full time period. This exercise may improve the S/R relationship.

The level of cod cannibalism should also be considered in a multispecies context because it is partly dependent on the abundance of alternative prey, especially capelin. The impact of the increase in the amount of cod predators (e.g., seals) on stock dynamics should be given high priority in future research.

4.6 Environmental effects on S/R relationship

The work on relationship between climate and recruitment (WD 10 and Stiansen *et al.* 2002) is still novice, and further work is planned. Some of the questions that will be addressed are: 1) Are climate effects more important when the SSB is low? 2) What are the coupling mechanisms between NAO and recruitment; through the food chain or through temperature in the spawning grounds or other? 3) How much of the recruitment variability can be explained by climate variation? 4) Can we see an effect of climate change in cod recruitment?

5 RECOMMENDATIONS

5.1 Incorporating discarding mortality into the assessment for NA cod

The SG recommends that AFWG evaluates the existing information on discards and the appropriateness of including discard estimates, both historic and future, in the stock assessment.

In principle, the SG supports the new techniques and methodology adopted in this report for the assessment of $\mathbf{B}_{\mathrm{lim}}$, $\mathbf{B}_{\mathrm{pa}}$, $\mathbf{F}_{\mathrm{lim}}$ and $\mathbf{F}_{\mathrm{pa}}$. Some technical details of the methodology are open to further discussion and possibly, for revision at the forthcoming meeting of the AFWG. If possible, the main software used at this Study Group should be circulated amongst participants prior to the next meeting of the AFWG.

5.2 Using age 5 as recruitment for NEA cod.

Further investigation should be undertaken on validity of age 5 as recruitment age for estimation of biological reference point for this stock (Section 2.3.2).

5.3 Multi-annual TACs

Multi-annual TACs have become an element of the harvesting strategy of NA cod SGBRP therefore recommends that ICES provide guidelines on how to evaluate the effect on multi-annual TAC rules on reference points. To achieve this the SG report should go to the upcoming WGMG meeting [Chair: Carl O'Brien]

5.4 Precautionary reference points for alternative assessment models

Alternative assessment models are currently being developed for NEA cod (e.g., Fleksibest). Methodology for integrating the precautionary approach with alternative assessment models with reference points should be considered. The Arctic Fisheries Working Group and the ICES Study Group on Age-Length Structured Assessment Models (SGASAM) [Chair: Kristin G. Frøysa] should outline how such a methodology could be developed.

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7 APPENDIX A. SCIENTIFIC PRESENTATIONS

7.1 List of Working Documents

WD 1. Asgeir Aglen and Kjell Nedreaas. Impoverishment of cod stocks with emphasis on Northeast Arctic Cod.

WD 2. Odd Nakken. Northeast arctic cod. Spawning stock and recruitment**.**

WD 3. Sigbjørn Mehl. Segmented regression trial runs for Northeast Arctic cod.

WD 4. Borisov V.M. To manage the stock by means of fishery or to conduct fishery in dependence on the expected variations in the stock?

WD 5. Kovalev Yu. A. Using data on NEA cod cannibalism in BRPs estimation.

WD 6. Kovalev Yu. A. and Yaragina N.A. On population density and biological characteristics of the Northeast Arctic cod.

WD 7 . Asgeir Aglen. An attempt to apply the latest SGPA procedure for setting the distance between lim and pa reference points of Northeast Arctic cod

WD 8. Tretyak V. L. A model of recruitment of the commercial stock of the Northeast Arctic cod

WD 9. Koloskova V., Yaragina N. , Zouikova N., Mjanger H., Nedreaas K., Senneset H. and P. Ågotnes. Joint PINRO-IMR re-ageing of cod otoliths from historic material.

WD 10. Stiansen, J.E. Changed response of climate after the late 70's on cod recruitment (?)

Other Working Documents received:

Kell L.T., O'Brien C.M. and G.M. Pilling. WD .A Comparison Of Limit Reference Points Based Upon Segmented Regression and G_{Loss}

7.2 Presentation. Asgeir Aglen. Review the framework for calculating reference points established by SGPA in December 2002.

$\mathbf{B_{pa}}$ and $\mathbf{F_{pa}}$ are the usual precautionary reference points (PRP) used by ICES. When these concepts were introduced it was unclear how they should be calculated however it has become increasingly clear that $\mathbf{B_{lim}}$ is the cornerstone of the PRP. Recent methodological developments have included developing more objective ways of estimating at what SSB levels there was evidence of impaired recruitment in the S/R relationship. At the recent SGPA meeting two methods for estimating $\mathbf{B_{lim}}$ were evaluated: segmented regression and the kernel method. The segmented regression method has been applied to NA cod to estimate $\mathbf{B_{lim}}$. $\mathbf{F_{lim}}$ is set by equilibrium considerations. Any biological uncertainties are included in the derivation of $\mathbf{B_{lim}}$. Thus, the use of the empirical ("magic") formula has been discontinued. $\mathbf{B_{pa}}$ and $\mathbf{F_{pa}}$ are determined using retrospective analyses. This establishes the empirical relationships between true SSB and evaluated SSB and between true F and assessment F, i.e, ratios that express the assessment error (for $\mathbf{B_{pa}}$) and the assessment and prediction error (for $\mathbf{F_{pa}}$). The disadvantage is that it is fairly time consuming to undertake these calculations.

Discussion

For some stocks the $\mathbf{F_{pa}}$ is set more conservatively by bringing in prediction uncertainty because that is often greater than the assessment uncertainty, whereas, only assessment uncertainty is included in the $\mathbf{B_{pa}}$. This is slightly inconsistent. However, often biomass prediction is more uncertain than F because of the time lags involved. Overall, the approach is more conservative because you start at a more conservative $\mathbf{B_{lim}}$. When determining these PRP you are limited to the shortest time-series in your tuning series for the retrospective analysis. $\mathbf{B_{lim}}$ is the key point and the value of $\mathbf{B_{lim}}$ is entirely dependent on the assessment method chosen. Variation in weight and maturities introduces uncertainty, but the methods assume that the appropriate data are incorporated into the assessment already. A simpler method would be to use the numerical abundance of older fish as an index of reproductive potential. Various age diversity indices have been examined as possibly explaining variation in recruitment and/or residual variation in SSB/R relationship.

7.3 WD 1. Asgeir Aglen and Kjell Nedreaas. Impoverishment of cod stocks with emphasis on Northeast Arctic Cod.

Sustained high F for NA cod has resulted in stock reductions that have been partly offset by occasional high recruitment. In North Sea cod a steadily increasing F has been accompanied by an erosion in SSB and generally lower recruitment levels. A similar trend has been observed for Icelandic cod. The picture is different for NA cod in several respects: there was a sharp reduction in F in the late 1980's in response to the very high exploitation rates combined with a sharp reduction in the capelin stock and in the early 1990's there was an increase in SSB due to reduced F and the strong 1983 yearclass. Comparison with the total biomass of 7+, 8+ and 9+ indicates that the contribution of old fish to the SSB has decreased. The age at 50% maturity decreased steadily from 1946 to the late 1970's and has flattened out since the early 1980s. There is a positive relationship between biomass of 8+ and recruitment when the data is aggregated at decadal time scales (see Nakken WD). There has been an increase in individual weight at age that could be a response to the high exploitation. The percentage of females in the spawning stock in Lofoten has declined, possibly because females mature later than males and fewer may be surviving to maturity. Most cod stocks are experiencing F in excess of $\mathbf{F}_{pa}$ over a sustained period. Long-term impoverishment is a term that describes the negative consequences of such high exploitation over time.

Discussion

The trends in age at 50% maturity are based on maturity ogives constructed for individual years not individual cohorts. However, similar trends were observed for cohort-specific ogives as published in the work of Tretyak (WD8) and Jørgensen. Features of present population, not historic populations, may be more relevant to the estimation of reference points. Trends in sex ratios could be indicative that too few females are allowed to mature and the spawning stock becomes dominated by smaller fish. It is also important to recall that sex ratios are length-dependent rather than age-dependent traits. Therefore, long-term trends in length at age will determine sex ratios.

7.4 WD2. Odd Nakken. Northeast Arctic cod. Spawning stock and recruitment

The importance of old cod for recruitment was noted by Ponomarenko in the 1960's. It was hypothesized to result from repeat spawners producing higher quality eggs and/or from spawning stocks having older age groups that have longer spawning periods and spawn over larger areas. In the latter case it is more likely that eggs and larvae will experience favourable environmental conditions.

There is some doubt as to the validity of the maturity ogives used for the historic time period. Increases in weights and maturities are masking the decline in old fish in the spawning stock biomass. It is therefore proposed to construct a precautionary plot using indices such as the total number of fish age 7, 8 or 9 years and older (i.e., 7+, 8+ or 9+). The total number of 8+ individuals is positively related to recruitment when the data is aggregated into 10 year time blocks.

Discussion

There could be depensatory dynamics in the relationship between total egg production and SSB such that the total egg production decreases non-linearly with decreasing SSB because of the disproportionate loss of females and older individuals at the low SSB values provoked by high F. Data were averaged over 10 year time periods to remove environmental effects and examine the underlying stock effect on recruitment. The same analysis was done using annual data rather than data averaged over 10 year time blocks. The resulting stock/recruitment plot is similar to the standard SSB/R plot in certain aspects. The paper indicates how important older fish are to recruitment. Repeat spawners are the most important. A practical conclusion would be that we should be more conservative regarding spawning stock structure. It is, however, a two step process: enough fish should survive to maturity and secondly enough should survive to be repeat spawners. The same rationale could be used to estimate the biomass of 8+ (or whatever) spawners.

7.5 WD4. Borisov V.M. To manage the stock by means of fishery or to conduct fishery in dependence on the expected variations in the stock(?)

A lack of visible relationship between SSB and R of cod is the decisive evidence that environmental factors have a considerable effect on survival of year classes until they enter the fishery. Therefore, when estimating biological reference points for cod based mostly on the SSB-R relationship in addition to fishery other factors on which value of R is strongly dependent should be taken

7.6 WD 5. Kovalev Yu.A. Using data on NEA cod cannibalism in BRPs

The S/R plot for the past 20 years (1981-present) shows that the relationship is highly influenced by whether or not cannibalism is incorporated into the recruitment index. Cannibalism is treated as an additional catch, therefore, recruitment without cannibalism increases the recruitment index. Including cannibalism is desirable because it is in closer correspondence with the survey estimates of abundance for young age classes. Cannibalism varies with the abundance of small cod (potential prey), the amount of alternative prey (capelin) and the abundance of older cod (predators). The decision to include or exclude cannibalism has important consequences for the fitting of the S/R relationship and hence the values of the reference points. It was pointed out that cannibalism is effective mainly at high biomass and it is not reliable to assume constant (density independent) natural mortality. That makes problems when we construct SPR and YPR curves and should be taking into account in scenario modelling.

Discussion

The highest cannibalism rates were observed in 1993, 1994 and 1995. However, these periods were associated with normal growth. Therefore, cannibalism potentially has a positive effect on the growth of the cannibals. Stomach contents show that the larger the cod becomes the larger the proportion of cod in the stomachs. These individuals require a high amount of food. The industry promotes the view that increased cannibalism is the cost of high SSB, however, managers are more often concerned about the gain.

7.7 WD 6. Kovalev Yu. A. and Yaragina N.A . On population density and biological characteristics of Northeast Arctic

Over the time period 1946-1980 temporal trends in weight at age show that long-term time trends become more accentuated with increasing age. Positive trends are significant for age 5 and older. For the time period 1981 to present there are no trends in weight at age. This is analogous to the trends in age at 50% maturity which shows a declining trend for the period prior to 1980 and flattening out since 1980. The causes of such underlying trends should have a similar time trend. Prior to 1980 commercial stock biomass which shows a decreasing trend in SSB accompanied by the increase in F and there has been no clear long-term trend in SSB or F since 1980. This suggests that growth rate (affecting weight and maturity at age) has changed directly in response to density-dependent factors and indirectly to F. These biological features of the spawning stock are conditioned on high F. This implies that equilibrium curves of SSB/R vs. F are highly dependent on the time period considered. Likewise, the S/R relationships differ with maximum recruitment levels being lower for the recent time period compared to the earlier time period. Biomass reference point estimates are higher for the recent time period compared to those estimated for the full time period.

Density dependent changes of the population are reversible and with regulation of fishery aimed at decrease of fishing mortality and increase of the stock biomass they will lead to slowing growth and maturity rates and by modifications of the stock-recruitment relationship. To have a full picture of stock dynamics including the dependence of NEA cod biological parameters on the population density was recommended to use data from 1946 to the present.

Discussion

If there has been any changes in density-dependent responses then that should be included in the reference points. There has been considerable discussion on genetic changes in the spawning stock due to selective forces associated with fishing. It is felt that it is not rapid and takes longer time to reverse. However, the time trends in weight at age do not show the same time trends which argues against genetic factors determining growth characteristics of the stock. It is difficult to disentangle the genetic effects from the density-dependent effects.

7.8 WD 7. Asgeir Aglen. An attempt to apply the latest SGPA procedure for setting the distance between <u>lim</u> and <u>pa</u> reference points of Northeast Arctic cod.

The procedure plays the game that you step backwards through time making an assessment (a "retrospective assessment") for that year and predicting the next year (terminal year (year 0) -> intermediate year (year 1) -> prediction year(year 2)). The number of retrospective assessments that can be performed is limited by the length of the shortest tuning series. For every Fpred (or intended F) there will be corresponding catches (the catch option table) and biomass (Bpred). These Fs are matched against the F (Fobs) required to generate the same catches in the converged assessment for the same calendar year. The resulting spawning stock is Bobs. When applying to NA cod cannibalism was treated as a part of the natural mortality. The choice of settings is made as close to assessment as possible. Both $F_{status\ quo}$ and catch constraint in year 1 options were evaluated. The extreme year was 1994, with the ratios between Fpred and Fobs being very large. If $\mathbf{F}_{lim}$ is 0.7 then the $\mathbf{F}_{pa}$ (intended F) would be approximately 0.35, depending on whether the $F_{status\ quo}$ or catch constraint in year 1 options were evaluated. The approach appears reasonable for stocks having a retrospective problem with respect to F values. However, the method is very labour intensive. A practical problem is that the catch option tables are F-based not biomass-based. The SGPA recommended using biomass in terminal years against the biomass in the latest assessment.

Discussion

Given that there are only 12 retrospective years the method could potentially be simplified by just using the "extreme" years. The analysis is dependent on the length of the data used. Results suggest that high Fs require higher $\mathbf{B}_{pa}$ than low Fs. It is often stated the $F_{status\ quo}$ should be more robust than the catch constraint F. This exercise illustrated problems with catch constraint, particulaly in the extreme years. Important to document discrepancy given that we are likely to formulate reference points using $F_{status\ quo}$. The rationale for using $F_{status\ quo}$ is that even though you have drastic TAC reductions you cannot necessarily assume that there will be accompanying reductions in F. The paper is an important documentation of such a difference. Different suites of reference points could be developed depending on how management advice is formulated ($F_{status\ quo}$ or catch constraint F). It is important to note that the exercise might have to be repeated if cannibalism is excluded from the time-series.

Underlying the analysis is the time development of the retrospective problem. When the stock is increasing, e.g., early 1990's, there was a tendency to underestimate the stock and overestimate F. This scenario reversed when the stock declined. This is typical of the retrospective problem.

7.9 WD 8. Tretyak V. L. A model of recruitment of the commercial stock of the Northeast Arctic cod.

A simplified model of cod recruitment has been developed for a fairly long historical period (1979-2000). The basis is the Ricker's "stock-recruitment" model and it accounts for the existence different qualitative composition of spawners and their different contribution into recruitment. To reveal these structures, a concept was introduced on a fine multiplt structure of the mature part of the population as a multi-aged structure of the first- and repeat-spawning fish. A hypothesis is proposed on the intra- and inter-annual qualitative heterogeneity of spawners. A theoretical thesis is formulated on a mechanism of self-regulation of abundance dynamics of cod population as an open biological macrosystem. Algorithms are worked out for determination of a multiplet structure of a spawning part of cod population and dividing of a time-series of spawners abundance (1949-1997) by periods in which the structures of qualitatively homogeneous fishes are different. The full time-series of abundance of mature part of cod population (1949-1997) is divided into three periods: 1949-1964, 1965-1975 and 1976-1997 with different by quality structural composition of spawners. In this time intervals the numerical characteristics of recruitment as a random function are different, therefore, the parameters of the dependence "stock-recruitment" should be objectively different in them. For the period of 1979-2000 three structural groups are revealed with different qualitative composition of spawners, the abundances of which are used as indices of a population reproduction potential. Intra-annual heterogeneity is stipulated by the existence in the spawning stock of structures with different qualitative composition of fish. Therefore, abundance (or biomass) of mature fish determined as a summarised number (or biomass) of mature cod from different age groups is not the exhaustive characteristics of index of reproduction potential of the population. In the explicit or inexplicit view it should take into account primarily their structural composition. In connection with that, the generally accepted index of the reproduction potential of cod (SSB) is not a realistic one and can not be used under determination of biological references of the stock.

It was further shown that for a fairly long historical period (1979-2000) the transition of 0-group to the bottom mode of life - the contribution of temperature factor into recruitment of the commercial stock can be either constant and negative or the constant and positive. Under low and middle water temperatures in the 0-200 m layer of the Main Branch of the Murmansk Current for August-December to 5.15˚C which is very often registered the abundance of year classes can decrease by 11%, where as under high temperature, higher than 5.,27˚C, which are occurred not often, it can increase by 26 %. The increase of the influence of water temperature on the abundance of year classes happens within very low range of its variation, from ,15˚ to 5.,27˚C.5.15˚ to 5.27˚C. Maximum range of this influence constitutes 37 %.

Discussion

The biological rationale for dividing the early maturing fish into two groups was given in the WD. The effect of temperature on recruitment was illustrated in a figure showing a sigmoidal relationship with temperature flipping between having a constant, negative effect to having a constant, positive effect. The problem with the predictive model which includes temperature is that it contains four additional parameters but gives a relatively small improvement in explanatory power. However, the temperature effect is restricted to the β_1 term. Since this term represents the early maturing fish spawning for the 1-3 time, it could be that the model could be simplified to include only the temperature effect on this spawning component. The model was developed on data from 1976 to 1997. It would not be appropriate to apply outside of that time period because of differences between the two time periods in total abundance and recruitment levels.

7.10 WD 9. Koloskova V., Yaragina N. , Zouikova N., Mjanger H., Nedreaas K., Senneset H. and P. Ågotnes. Joint PINRO-IMR re-aging of cod otoliths from historic material (Koloskova, Yaragina, Zouikova, Mjanger, Nedreaas, Senneset and Ågotnes)

A sub-sample of historic otoliths were re-aged by Norwegian readers in 2002, as was reported by ICES 2002. The ages were identical to historic ages in 72% of the cases. In case of disagreement there was a clear tendency for new ages to be one year higher than the historic age overall. Only historic material from 1967 was exchanged and re-read by PINRO (the plan is to re-read and exchange/compare cod otoliths from 1947, 1957, 1967, 1977 and 1982). Preliminary results for 1967 show that in the case of the re-aged material from IMR the age/length trends for the historic ages and the new ages are similar with the new age giving a slightly lower mean length at age. The discrepancy is a little higher for the re-aged material from PINRO such that the mean lengths at age for the re-aged material are consistently lower than the IMR mean lengths.

Discussion

The Russian age readers felt the quality of the 1967 otoliths was superior to contemporary otoliths so differences in ages should not be the result of any deterioration in quality. Also, the data should be analyzed statistically to determine if the differences are statistically significant.

7.11 WD 10. Stiansen, J.E. Changed response of climate after the late 70's on cod recruitment (?) (Stiansen)

The NAO index describes pressure differences between the Iceland low- and the South Europe high-pressure field. The NAO winter index (Iceland-Lisbon) shows a distinct increasing trend accompanied with strong oscillations with a period of about 8 years from the late 1970's until present. After the 70' stronger winds and higher influx of warm Atlantic water masses into the Norwegian Sea and further into the Barents Sea is following high NAO winter indices. The mean field in the period 1975-1999 has shifted eastward compared to the period 1948-1975 indicating stronger gradients in winds and a shift in climate. If climate is accounted for in the recruitment models (Stiansen *et al.*, 2002), the NAO index two years in advance of the SSB shows a good relationship with the 0-group index. The relationship is stronger for the time period after the 1980s suggesting a stronger effect of climate for this time period. This is also the case for recruitment at age 3 for a recruitment model based on NAO and SSB in the spawning year.

Discussion

The mechanism underlying the NAO effect on cod recruitment needs to be identified more clearly. Dickson et al. (2000) correlated NAO index with influx of water into the Barents Sea and the temperature anomalies in the Kola section in the period 1970- 1995. This indicates a positive response of the NAO winter index on the transport of warm Atlantic water masses, which could influence the survival of larvae because Atlantic inFlows enhance the production of Calanus in both the Norwegian and Barents Sea. The in$\mathbf{F}_{low}$ also increases the temperature for growth as well. Cod spawn in the western part of Norway too so it might have effects on the spatial distribution of eggs, larvae and juveniles. The decadal averages of Kola temperatures show that the highest was the 1930's, the second highest was the 1950's and the third highest was the 1990's. This shows that the NAO is not entirely consistent with temperature trends in the Kola time-series. It is also important to remember that the shift in the position of the pressure field indicates that there is a stronger effect of the NAO winter index after the mid 70's. It should also be recalled that the SSB/R relationship is better for the post- 1980 time period. If environmental information is included in the S/R relationship then the explanatory power improves. Since NAO index operates three years before the age 3 recruitment it is possible to forecast recruitment. It is not, however, possible for metereologistsmeteorologists to predict the pressure difference between Iceland and the Azores. There are a wide variety of mechanisms that could be influenced by temperature and some effects are negative while others are positive. In the models here the NAO was a positive effect.

7.12 Presentation. Marshall, Needle, Kjesbu, Thorsen, Yaragina, Aijad. Incorporating alternative estimates of reproductive potential into management: a worked example for Barents Sea cod.

The S/R relationship assumes that total egg production (TEP) is directly proportional to SSB, however, this assumption is rarely tested due to a lack of appropriate data. Because most aspects of reproduction are length-dependent rather than age-dependent historical age/length keys were compiled from Russian and Norwegian sources (ICES 2001). These keys allowed age-based data (numbers, maturities, weights) from the assessment to be converted to length-based data. Sex ratios show that the proportion of females increases linearly for fish larger than 80 cm. Thus, the loss of large cod disproportionately reduces females. The maturity data show that in 1980 a sudden increase in the proportions mature occurred. Reductions in maturity occur in years of low capelin stock biomass (e.g., late 1950s and late 1980s). Within a given length class the proportions mature at length are positively associated with higher weights-at-length (i.e., condition) suggesting that in years when cod are in good condition they mature earlier. The fecundity model used to hindcast fecundity at length includes terms for both length and condition. Thus, variation in condition determines the year effect on fecundity at length. Estimates of total egg production show a linear relationship with SSB, however, the slope and intercept of the relationship are statistically different for the historical and recent time periods (1946-1979 and 1980-2001). In future the total egg production estimates will be improved by incorporating female-only maturity ogives and size-dependent variation in egg quality. A suite of software is under development to estimate alternative indices of reproductive potential from assessment and biological data and use this information in S/R modelling and stock projections.

Discussion

There was not a large deviation between total egg production and SSB. However, using maturity ogives for females and accounting for size-dependent variation in egg quality will likely increase the deviation between the two. The relative fecundity (total egg production/SSB) in the period after 1980 appeared to be higher compared to the early years in the time-series. This indicates that there have been qualitative and structural changes in the population over the full time period. Further work into incorporating size-dependent egg quality will be undertaken and should help to clarify long-term trends in total egg production.

7.13 WD3. Mehl, S. Segmented regression trial runs for Northeast Arctic cod (not presented).

A few exploratory segmented regression analysis were performed for Northeast Arctic cod, using input data from the 2002 assessment. First SSB-R pairs from the full time-series (1946-1998), without and with cannibalism, was used as input. The segmented regression with cannibalism gave a change point of 274 000 t., while the run without cannibalism resulted in a somewhat lower change point (224 000 t). Leaving out year classes 1963, 1964 and 1970 gave change points of 321 000 t and 299 000 t with and without cannibalism.

Then runs, restricted to the part of the time-series with stomach data (1981-1998), was performed, both with and without cannibalism included. The resulting change points were higher than the corresponding for the whole time-series. The slope of the regression line is reduced and the change point is shifted to the right, indicating that recruitment starts to get impaired for higher SSB-values than in the past. Also for this option the run with cannibalism gave the highest change point.

Also some runs were performed using the number of 7 years and older cod (7+) and 8 years and older cod (8+) as a proxy for the spawning stock/spawning potential. The resulting change points were about 85 and 18 million fish for 7+ and 8+, respectively. The differences between runs using the whole time-series and only the last part, and between runs with and without cannibalism included, were relatively small.