Advisory Committee on Fishery Management

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REPORT OF THE

STUDY GROUP ON THE PRECAUTIONARY APPROACH TO FISHERIES MANAGEMENT

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

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1.2 Terms of Reference

It was decided at the 85th Annual Science Conference (C. Res. 1997/2:11:20) that the Study Group on the Precautionary Approach to Fishery Management [SGPAFM], with experts to be identified by ACFM, in consultation with ICES Delegates, and to be chaired by the Chairman of ACFM (Mr J.-J. Maguire, Canada), will meet at ICES Headquarters from 3–6 February 1998 to:

a) provide estimates of appropriate fishing mortality and spawning stock biomass limit reference points from the most recent ICES assessments for as many demersal, pelagic and shellfish stocks as possible (including stocks where analytical assessments are not available), taking into account estimation and process errors;

b) taking into account the uncertainties identified above, provide estimates of precautionary fishing mortality and spawning stock biomass reference points having high probabilities of keeping the stocks within safe biological limits;

c) identify generic features of harvest control rules, including recovery plans when the stock is outside safe biological limits, that are consistent with a precautionary approach;

d) provide guidance to assessment working groups and determine the requirements for new computer programs to be made available in the ICES Secretariat at Council expense;

e) review the work of the MAWG on the relevance of species interactions to precautionary approaches to fisheries management and rebuilding, and where appropriate carry that work further;

f) consider the implications of a precautionary approach and harvest control rules in relation to mixed fisheries and technical interactions.

Considerable work was done in advance of the Study Group meeting to estimate several reference points (using different software implementations) to be considered as either limit or precautionary reference points (see Section 9, Working Documents). Without this preparatory work, it would not have been possible to suggest reference points for as many stocks as are included in this report. Sincere thanks are therefore due to those individuals who were involved in this preparatory work.

The Study Group considered whether the reference points used by ACFM were consistent with a precautionary approach to evaluate if there was need to provide new precautionary reference points. ACFM has established biomass reference points for several stocks, but there are few instances where ACFM has provided reference fishing mortalities and therefore, the Study Group had to suggest values for most stocks. The Study Group attempted to use MBAL values previously established by ACFM, when appropriate, as either limit or precautionary reference point.

Study Group members represented an interesting mix of methodological experts and stock assessment specialists involved in specific Working Groups. However, not all stock assessment specialists for every stocks for which reference points are suggested participated in the Study Group meeting. Therefore, the reference points suggested must be reviewed and evaluated by relevant Working Groups before ACFM can make a decision on appropriate reference points. It is in ACFM's mandate to make final decisions on limit reference points, but fishery management agencies should be involved in decisions on precautionary reference points.

2 UNCERTAINTY

There are uncertainties in all reference points and those related to the precautionary approach are no exception. The uncertainties are due to measurement errors because of the inherent variability associated with sampling data, uncertainties about the most appropriate model(s) to approximate the fishery dynamics and, uncertainties in the natural variability of fish population parameters. While scientific research could be aimed at reducing sampling and model uncertainties, it cannot reduce the natural variability in population parameters, it can only characterize it. It must therefore be recognized that uncertainty will always be part of the fishery management process.

Both the estimates of reference points, e.g. the real value of F_{MSY} and the current estimate of the parameter, i.e. F_{97} are uncertain. Therefore uncertainties in both quantities have to be taken into account.

Few studies have adequately estimated the full range of uncertainties associated with assessing fish stock sizes and predicting future catches, particularly in the case of biased data such as is the case when misreporting, high-grading, and discarding occur to a variable extent from year to year. The results of studies not taking these factors into account have indicated measurement errors of 20 to 40% CV (Coefficient of Variation) for the projected catches for a particular year. Therefore, CVs of this magnitude were utilized (where appropriate) to evaluate uncertainty of the reference points. The overall real uncertainty, however, is likely to be greater than the CVs of 20–40% suggest.

For instance, unaccounted mortality which includes dead discards, fish dying after the discard process, fish dying during the capture process which are not actually captured, unreported landings, by-catch, ghost fishing mortality and other sources are often not accounted for in the assessment data. Therefore, both the status and productivity of the stock are not accurately estimated, and changes in estimated status or productivity may be related to unrecorded changes in practices which are not monitored.

Often, data for a particular stock are available only for a relatively short period of time (typically 15–20 years, in rare cases for up to 50 years, or for as little as 3–5 years) and the quantity and quality of data over the time period is generally variable. But in addition to variable quantity and quality of data, the (relatively) short time period of time for which data are available means that only a limited range of the population reaction to environmental factors has been observed and it is not possible to predict future behaviour for environmental conditions that have not been observed. Generally, we assume that ecological/environmental process are stationary when in reality they are not; this can be of special concern when there are biological and technological interactions in the fish populations and fisheries. Implementation errors, i.e. that the management recommendations are often not perfectly implemented due to technical, legal and political difficulties, is generally not taken into account either.

By not considering these sources of uncertainty, it is likely that the CVs used to calculate reference points in fact underestimate the real uncertainties, and according to the precautionary approach, this should call for even greater precaution.

3 REFERENCE POINTS

3.1 Background

3.1.1 Selected extracts from 1997 Study Group report (ICES CM 1997/Assess:7)

Reference points are a key concept in implementing a precautionary approach. The following points from Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks are relevant to the distinction between target and limit reference points:

> *"2. Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives.*
>
> *3. Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.*
>
> *5. Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average.*
>
> *7. The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target."*

Therefore, reference points stated in terms of fishing mortality rates or biomass, or in other units, should be regarded as signposts giving information of the status of the stock in relation to predefined limits that should be avoided or targets that should be aimed at in order to achieve the management objective.

The limit fishing mortality (F_{lim}) is defined as a fishing mortality which should be avoided with very high probability and is most naturally associated with a danger of stock collapse. This attribute certainly applies to F_{crash}, which is derived from the slope at the origin of the S-R curve, since it corresponds to a collapse of the fish stock. Estimates of F_{lim} should reflect this concept.

The fishing mortality F_{med} estimates a sustainable fishing mortality. Unfortunately, the only upper bound on the expected value of F_{med} is F_{crash} itself and this is attained when the stock has only been measured during a period of fishing at the F_{crash} level.

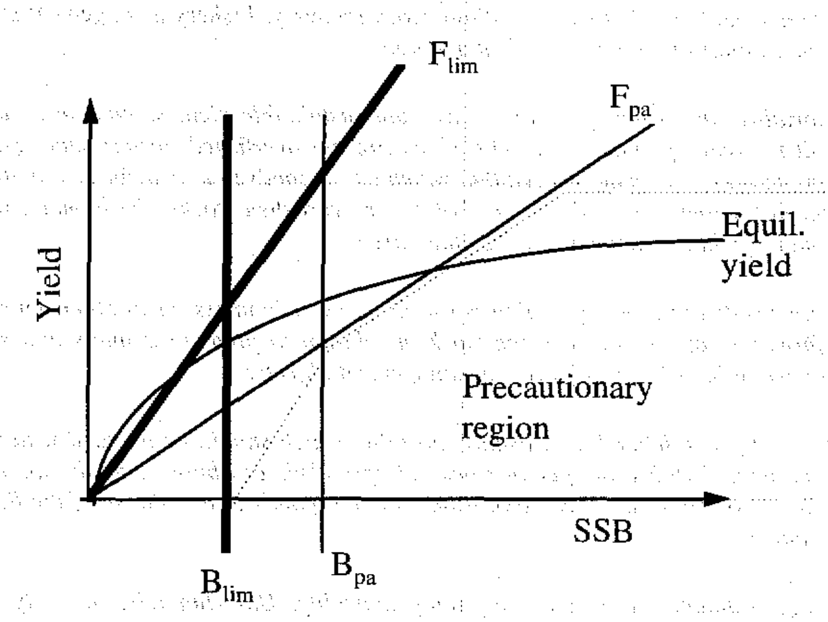
In cases when F_{crash} is not available, F_{loss} (Cook 1998) or F_{med} can be used as limit reference points. Both of these points will tend to be underestimates of F_{crash}. As further information becomes available these estimates may become revised upwards to higher mortality levels. However, the Precautionary Approach dictates that in the case when only such a biased proxy exists, it should be put into use immediately since lack of information cannot be used as a reason for the delay of action.

It would not be consistent with a precautionary approach to define safe biological limits only in terms of fishing mortality reference points and therefore corresponding and compatible biomass reference points will also be used, in *accordance with most international agreements considered during this [1997 SGPAFM] meeting. In addition, in cases where the slope at the origin of the stock-recruitment relationship or the replacement line are incorrectly estimated (e.g. due to a recent environmental change), the biomass may experience a sudden drop.*

ACFM has defined and used the Minimum Biologically Acceptable Level (MBAL) of biomass for several stocks. Whenever possible, MBAL corresponds to the spawning stock biomass below which the probability of impaired recruitment increases. Such MBAL values can be initially used as limit reference points, i.e. biomass below which the stock should drop only with very low probability. In other cases MBAL values refer to the biomass below which concerns are raised and some action should be taken.

The concept of safe biological limits was introduced in ACFM advice in 1981 and further developed in 1986 (Serchuk and Grainger, 1992). At first the term was used in relation to management actions, whereas latterly it has been used in relation to the state of a stock. In its recent implementation of the concept, ACFM has equated being within safe biological limits as being above MBAL and being outside safe biological limits as being below MBAL. This is a rather restricted interpretation of a concept which is clearly multi-dimensional involving at least reference points related to fishing mortality and biomass, but also factors such as age-distribution in the stock and in the catch, geographical range, condition factor etc. The concept of safe biological limits is explicitly referred to in the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks and ACFM will continue to use it, but in an expanded way, consistent with the precautionary approach.

Implementing the precautionary approach with precautionary reference points.



As derived above, the precautionary approach dictates that the predicted annual fishing mortality and estimated biomass should remain within safe biological limits. This implies a certain region which could be termed the precautionary region of fishing mortality, SSB and yields.

The first principle is that fishing mortality and hence annual yields are constrained by F_{pa}, if no obvious problems are seen.

The limit biomass level, B_{lim}, corresponds to the stock being in imminent danger. In this situation, a closure of the fishery is the only realistic action. In order to avoid that situation, fishing must be reduced drastically if the biomass appears to drop from B_{pa} to B_{lim}. This can be done by reducing fishing mortality or yield in accordance with how close the point estimate of biomass is to B_{pa} and B_{lim}, respectively.

For stocks in a healthy state it may be wise to also impose an upper limit on catches in order to avoid problems associated with severe overestimation of stock size and therefore define a C_{pa}.

3.1.2 F_{MSY}

Annex II of the Straddling Stocks Agreement states that F_{MSY} is a minimum standard for a limit reference point. There are a number of reasons why F_{MSY} has come to be thought of as a limit reference point rather than the traditional viewpoint of a target. Some of these reasons are valid and some less so. For example, MSY has been embodied in numerous fisheries management agreements for several decades and yet progressively more and more stocks have become overfished during that time. One interpretation is that MSY has failed as a fisheries management strategy. However, a global survey of fisheries would show that there are actually very few examples where fishing mortality has been limited to F_{MSY} over a significant period of time, even where MSY has been the stated management objective. Study Group members were unable to identify fisheries where stocks have collapsed despite fishing mortality being maintained near F_{MSY} over a substantial period.

Other potentially more valid reasons for this fundamental change in the treatment of F_{MSY} as a limit rather than a target are primarily related to ecosystem considerations (viz. multispecies interactions, species diversity, genetic diversity, habitat concerns and technical interactions), uncertainty and implementation failures. Most multispecies models imply that sustainable fishing mortality rates and other biological reference points need to be more conservative than in the corresponding single species cases. For this reason, ICNAF once used a two-tier system where the combined TAC for a multispecies assemblage was set 20–25% lower than the sum of the individual TACs (see O'Boyle 1985 for the modelling results supporting this decision). Multispecies and technical interactions mean that recovery plans for depleted stocks may also need to curtail fishing mortalities on associated stocks in order to be successful. In multispecies systems productive species may need to be fished at less than F_{MSY} to ensure that the viability of less productive species is not jeopardized. The conclusion emerging from working groups deliberating "ecosystem approaches" to fishing seems to be that across-the-board reductions in fishing mortality may be needed to achieve objectives such as maintaining genetic and species diversity.

Of equal or even greater concern is the difficulty of implementing agreed management actions in many fisheries. Measures to reduce fishing mortality are often circumvented. In part, this may be the result of fleet overcapacity resulting in challenges to numerous aspects of fisheries management systems (discussed elsewhere).

The high uncertainty inherent in fish stock assessments suggests that if F_{MSY} were to be used as a target in a risk-averse management strategy, that target should be based on some lower percentile of the F_{MSY} distribution. Setting F_{MSY} as a limit implies that F_{target} should be set such that the probability of exceeding F_{MSY} is small. Conceivably, in some cases, this could result in little change in the management strategy, even though it represents a fundamental change in management philosophy.

A more risk-prone approach would define F_{MSY} as an upper bound on target fishing mortality such that there must be more than a 50% probability that the annual F is below F_{MSY}, and any harvest control rule which satisfies the Precautionary Approach must lie below the control rule corresponding to F_{MSY}. The implication of this is not the same as the implication of harvesting below F_{crash} (equivalently, $F_{extinction}$), where F_{crash} is interpreted as a limit reference point that needs to be avoided with high probability. When $F_{lim} = F_{crash}$, a "high" probability would most likely be defined to be in the range 95–99%. If the same range is applied to F_{MSY}, the resulting target F would likely be exceedingly low.

Although F_{MSY} can, in principle, be used as a limit reference point, it would probably be more appropriate to redefine a "high probability of avoidance" as a number in the vicinity of 75% rather than 95–99%. However, the Study Group believes that, if F_{MSY} is to used at all, it is more appropriate to view F_{MSY} as an upper bound on a target reference point, which implies that there should be more than a 50% probability that F_{MSY} is not exceeded. The primary argument against using F_{MSY} at all is that it is highly dependent on the shape of the stock-recruitment relationship assumed, which is usually poorly determined. Likewise, F_{crash} is highly-dependent on the stock-recruitment relationship. Thus, it may be necessary to adopt proxies for both F_{MSY} and F_{crash}. It is suggested that F_{loss} and F_{med} could be considered as a basis for the definition of F_{lim}; and $F_{0.1}$, F_{max}, F_{med}, and $F_{30\%}$–$F_{40\%}$ as potential candidates for F_{pa}.

Similarly, B_{MSY} tends to be poorly defined but it may be easier to identify measures such as B_{loss}, or a biomass at which there is evidence of impaired recruitment, or the equilibrium biomass corresponding to the above proxies.

3.1.3 Stock and recruitment models

Stock-recruitment relationships have several distinct applications in the context of precautionary reference points.

1. The slope at the origin corresponds to F_{crash}, which is a candidate limit reference point.

2. Calculation of equilibrium reference points, including F_{MSY}.

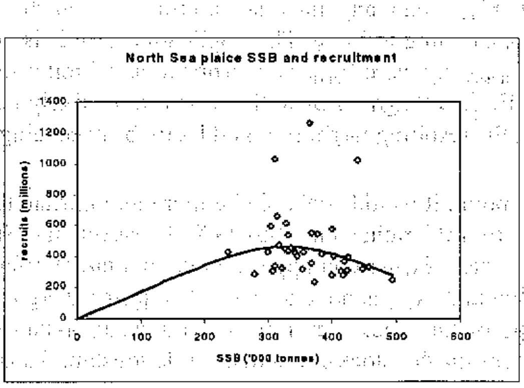
3. Simulations of future stock sizes and catches and associated risks caused by dependence of the recruitment on the SSB.

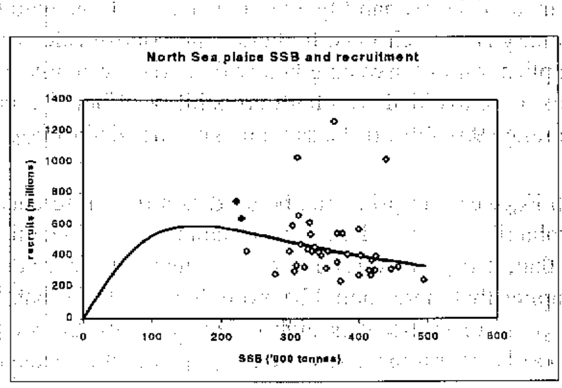
A stock recruitment function can be parametric or non-parametric. Amongst the parametric functions, two general types can be distinguished, those which assume that maximum recruitment is reached at some intermediate spawning stock biomass with a declining recruitment at large SSBs (like the Ricker function) and those that assume that recruitment does not decline after the maximum is reached (like the Beverton-Holt function). This difference in assumption has direct consequences for the expected effect of reducing fishing mortality in order to increase spawning stock biomass: under an assumed Ricker S/R relationship reducing fishing mortality should not be reduced too much, because recruitment will decrease at larger biomasses, while under an assumed Beverton-Holt S/R function there are no negative effects on expected recruitment of reducing F and increasing biomass.

Non-parametric functions may be regarded as filters or smoothers on the series of recruitments as function of the biomass. An example is kernel methods, where the expected recruitment is a weighted average of observed recruitments, the weighting being the nearness (Evans and Rice 1988, see Section 9, Working Documents) in the SSBs that gave rise to each recruitment. Smoothers (like LOWESS) have come into use recently. Although the non-parametric functions are not defined by assuming an explicit function, they still have underlying assumptions e.g. concavity and smoothness, or, in the case of kernel methods, assumptions about the weighting, which are necessary to fit a unique curve to the observation points. Hence, the final result also here relies both on the data and the underlying assumptions.

The choice of function should be guided by how the underlying assumptions conform with the assumed recruitment dynamics of the stock. Hence, to choose a Ricker function, one should have a clear opinion that the recruitment of this stock will actually decline at large SSBs. If there is no clear indication of such decline in the data, the Ricker curve will nevertheless be driven by the assumption that this is the case, and usually place the maximum within the observed range. Thus, this function will tend to support the hypothesis that the present exploitation is the optimal one. On the other hand, if the recruitment declines at higher SSBs, assuming a Beverton-Holt function will grossly overestimate the benefits of reducing exploitation.

Furthermore, stock-recruitment curves may be sensitive to new data on the outer edges of the distribution in the scatter plot. Pastoors and van Beek (WD 1) have shown that the Shepherd curve applied to North Sea plaice, is very sensitive to new recruitment data of the most recent two year classes (1995 and 1996), which causes the top of the curve to shift to the left (see figure below). This is a well known phenomenon for stocks which have relatively little pattern in the stock recruitment data.





Some applications use the function in a specific region. Thus, the calculation of F_{crash} depends on the behaviour just at the origin, and calculation of equilibria on the behaviour of the curve just where the equilibrium takes place. The estimation of the function characteristics, on the other hand, depends on the range of observations at hand. In particular, if points near the origin have never been observed (i.e. the stock has not collapsed), the slope at the origin is derived from the adjustment of the curve in a quite different region, and transferred to the region near the origin just through the underlying assumptions of the form of the function. The same applies at the other extreme. Therefore, the slope at the origin is virtually undefined unless there are data from that region. Even then, one should bear in mind that stock and recruitment numbers in a collapse phase usually are poorly estimated.

An alternative to estimating the slope at the origin is to find the smallest permissible values of the slope that are still consistent with the data at given significance levels. Bravington (WD 5) describes a likelihood profiling approach to estimating these minimal slopes for a non-parametric smooth, convex S-R relationship. The method has been applied to a number of stocks and may offer a useful alternative to more conventional approaches to estimating the slope at the origin.

Even if there is a wide range of observations, the behaviour of the function in one region will depend on the data also in other regions. A WD by Rice demonstrates that this dependence sometimes may differ from what one should expect intuitively. It may be a matter of concern that the perception of the F_{crash} relies on data from a period when the stock was large, and vice versa. In this case, kernel methods to a larger extent gives local estimates. The behaviour of both this and of smoother functions outside and in the border of the region with observations is still largely driven by the underlying assumptions, however.

For simulations, the uncertainty of the recruitment at given SSBs is as important as the expected values. This uncertainty is caused by natural variations in the recruitment, which is the prime interest of the stochastic modelling, but also by uncertainty in the observations and in the choice of model. It may be feasible to express this in terms of stochastic parameters in the function.

The stochastic element can either be expressed through a parametric distribution function, or represented by the collection of residuals. In either case, it is important that the term that is supposed to be random noise is uniformly distributed over the whole range of SSBs. This is because in simulations, this element is produced by a random number generator, without any prior knowledge of the prevailing conditions. Thus, if a lognormal stochastic term around a function is assumed, differences in expectations and variance along the SSB-axes must be included in the transform of the random term to the actual recruitment estimate. This may be done by adjusting the parameters in the stock-recruitment function. In that case, the function is a valid tool for simulations, but not the best deterministic stock-recruitment function.

In some cases, there will be strong periodic variations in the residuals, which are often taken as influenced by climatic variations etc. If there is good reason to believe that the periodic signal is real, it may be taken into account in a model as an autoregressive function, the parameters of which may be estimated along with the other model parameters. There is a close connection between the autoregressive coefficients and the power spectrum. The power spectrum should be inspected to ensure that the spectrum conforms with the assumed underlying cause before autoregression is included in the model.

A broader discussion of stock-recruitment relationships can be found in the ComFiE Working Group report 1996 (Assess:20), Section 5.4.

3.1.4 Time stability of reference points

The estimates of reference points depend on the exploitation pattern, natural mortality and growth. Thus their numerical values tend to change when the fisheries and/or the environment change. Reference points thus need to be revised from time to time.

To be precautionary it is particularly important to revise F_{lim} if the exploitation pattern shows a shift towards younger age groups, in which case F_{lim} will decrease. Shifting the exploitation towards older fish raises F_{lim}, thereby reducing the risk of exceeding it at a given level of F. Thus, in addition to scenarios implying changes in F, it would be useful to evaluate scenarios in which the exploitation pattern is changed.

3.2 Process Used During the Study Group Meeting to Select Reference Points

The Study Group considered possible candidates reference points (such as F_{loss}, F_{crash}, F_{med}, F_{MSY}, etc.) based on the information given in ICES Working Group reports, in the reports of ACFM, and in a number of working papers prepared specifically for the Study Group. As requested in the terms of reference, the Study Group attempted to propose reference points for as many stocks as possible, but it was not possible to suggest reference point for all stocks, nor for all Working Groups. The Assessment Working Groups have been asked in the terms of reference for their 1998 meeting to provide limit and precautionary reference points for all stocks. The reference points, proposed by the SGPAFM should be considered as first estimates and Working Groups should assess if they are adequate, and if not, make alternate proposals. The description of the process followed by the Study Group to select proposed reference points is intended to help Working Groups in their selection of reference points to be proposed to ACFM. In order to implement the precautionary approach in 1998, ACFM needs to adopt reference points for all stocks.

The criteria used by the SGPAFM to select reference points was as follows:

Biomass reference points

In a majority of cases, B_{lim} was selected based on an estimate of B_{loss}. In a few situations where recruitment on the S/R plot increases with decreasing biomass and there appears to be no danger of recruitment failure at low historical values of SSB, B_{loss} has been used for estimating B_{pa}.

When only B_{lim} was available from the above, B_{pa} was selected so that there is little probability that a biomass estimate which appears to be above B_{pa} will really be below B_{lim}. In this case, B_{pa} was estimated as $B_{lim}\, e^{1.645\sigma}$ where σ is a measure of uncertainty in the total biomass estimate, typically taken as 0.2–0.3.

This procedure always gave at least B_{pa}. In some cases B_{lim} is left undefined.

If the MBAL value previously defined by the relevant Working Group and/or ACFM was close to the calculated value of B_{lim}, then MBAL was taken as B_{lim}. In a few cases, MBAL was close to the calculated value of B_{pa}. In those cases, B_{pa} was set equal to the previously accepted MBAL.

Fishing mortality reference points

F_{lim} has been taken from estimates of F_{loss} or F_{crash} when these did not appear unrealistically high estimates of the collapse fishing mortality. If F_{loss} or F_{crash} appeared too high or were not available and if there were indications that F_{med} was not sustainable, then F_{med} was chosen as the estimate of F_{lim}. In some cases F_{lim} was left undefined.

If there is no F_{lim} and F_{med} goes through a cloud of points which appears to come from the right-hand limb of a stock-recruitment relationship, then F_{med} is used for F_{pa}. In a number of cases F_{pa} has been derived from the F_{lim} estimate $F_{pa}=F_{lim}\, e^{-1.645\sigma}$ or as F_{lpg}, where σ is a measure of uncertainty in the total F estimate, typically taken as 0.2–0.3 and F_{lpg} where F_{lpg} is defined as the F value having a 10% probability of giving a replacement line above G_{loss}, the slope corresponding to the lowest SSBs (see Cook 1998).

3.3 Stock by Stock Limit and Precautionary Reference Points to be Considered by Assessment Working Groups

The reference points suggested by the Study Group are listed by Working Group in Section 3.3.11. For some stocks, explanations are presented in the text and in the footnotes to the list. For others, the explanation is only provided in the footnotes.

3.3.1 Deep-water fisheries resources

Experience has shown that deep-water fisheries can develop rapidly and that resources which they exploit may be especially vulnerable to overfishing. Species such as these may become depleted before sufficient data has been accumulated to provide advice on appropriate management measures based on standard assessment methodology. There are generally very few time series of data from the regular sampling of commercial landings, and basic statistics on catches and effort are generally of poor quality or altogether lacking. It is therefore rarely possible to calculate the common biological reference points, and none are presented here. Instead, an approach to making decisions, based on an index of stock size is proposed (Bell and Stefánsson WP 4).

For many of these developing fisheries on previously unexploited stocks with low productivity, it is expected that biomass will decrease more or less monotonously over time. At some point, management will presumably want to halt the decline in biomass. A simple rule would be to set next year's quota as a function of this year's catch and recent biomass changes. The rule outlined is:

$$Y_t = Y_{t-1} * (1 + g [(B_{t-1} - B_{t-2}) / B_{t-2}])$$

where:

Y is catch, t is the year for which the quota is to be calculated, and t-1 is therefore the year prior to that for which the quota has to be calculated.

B is the biomass index such as from a survey or appropriate commercial CPUE.

g is a proportionally factor named feedback gain. A g of 1 means that the quota for next year is adjusted in direct proportion to the change in biomass observed between last year and the current year.

The effects of this harvest rule were studied by simulations using the methods of Bell and Stefánsson (WP 4) and with the same stocks. This has the virtue that some information is available on the stock structure and population dynamics for these stocks, and hence there is a possibility to evaluate what the stock and yield trajectories correspond to in terms of biological reference points.

In this scenario, ICES stock data for 27 stocks is used to first generate a run-in period using *status quo* fishing mortality, after which the feedback is introduced. The range of g used varied from 0.5–2.0 on all stocks.

For each value of feedback gain several different quantities can be estimated. Some of these are given in the text table below. It is seen that the average expected yield is maximum at g=1 and declines on both sides while the probability of staying within the PA bounds increases but with the expected high variability in yields.

	Gain			
	.5	**1**	**1.5**	**2**
Probability (%) of PA satisfied	13	32	73	79
Probability (%) of recovery in 10 years	3	12	35	46
Probability (%) of closure	0	0	38	67
Mean yield in % of MSY	58	73	38	26
CV of yield	96	75	157	205

There is therefore a high probability of fishing over F_{crash} if little heed is given to the relative abundance indices (i.e. g=0.5), whereas this probability decreases considerably at g=1 or more. Somewhat surprisingly, there is a fairly high probability of adhering to the PA in terms of catches being within the precautionary region, once g reaches 1.5 or more. This is no doubt in part due to an increased frequency of closures (38% of all stock-years when g=1.5). There is as always some trade-off between yield and probabilities. In this case, however, it would appear that g=1 strikes an interesting balance between yield, yield stability, few closures, yet considerable enhancement in probabilities.

As is to be expected, this procedure has low probabilities of stock recovery.

Given the assumed CV of 35% on the abundance index in the simulations, it is not too surprising that there is considerable variability in the behaviour of the resulting catches. Methods exist to smooth these results and incorporation of such smoothers is a promising area of future work.

A natural extension of the presented tests is to incorporate the ideas of a precautionary region through the use of historical survey data. With a time series of relative abundance indices it would be quite feasible to introduce concepts such as B_{lim} and B_{pa}, between which there should be further reductions in fishing activities in such a fashion that there is a cessation of fishing activities at B_{lim}.

Most importantly, however, it is quite clear that a year-to-year decline of many percent in reasonably reliable stock indices can not be sustained for many decades. For a fishery to be sustainable stock size cannot continuously go down. It is equally clear that not providing any advice or management measures in the light of decades of stock decline is contrary to operating within the precautionary approach.

3.3.2 Salmon

Baltic Salmon. Main Basin, Gulf of Bothnia and Gulf of Finland stocks

Baltic salmon in the Main Basin, Gulf of Bothnia and Gulf of Finland are under recovery plans. The objective of the plans is to achieve 50% of maximum potential recruitment for each river by the year 2010. Escapement targets are set for each river. B_{lim} would thus correspond to the escapement needed to achieve 50% of the maximum potential recruitment for each river.

Research on potential candidate reference points for B_{pa} and F_{lim} should be undertaken. One potential candidate for B_{pa} could be the escapement needed to achieve 50% of the maximum potential recruitment by river, raised by a factor reflecting variance in historical escapement or returns to that river. One potential candidate for F_{lim} could be the fishing mortality resulting in 50% of the maximum potential egg production per recruit which would be obtained under no fishing mortality [F(50%EPR)]. Because the post-smolt mortality is highly variable, F_{pa} could be estimated at 50% of the maximum potential egg production per recruit, but using the upper quartile of observed post-smolt mortality. This approach would require research to evaluate the consistency of the mortality-based reference points and the escapement-based reference points.

To summarize, therefore:

(1) B_{lim}: Escapement needed to achieve 50% of maximum potential recruitment by river.

(2) Potential F_{lim}: F(50% EPR) (modified eggs per recruit, from age structure of unexploited spawners, fecundity at age, average exploitation pattern).

(3) Potential F_{pa}: F(50% EPR) where post-smolt mortality is set to the highest quartile observed historically.

North Atlantic Salmon

For North Atlantic salmon, a "conservation limit" based on B_{MSY} has been proposed. B_{MSY} has been defined as escapement needed to achieve "target" egg deposition by river population. "Target" egg deposition by river population is not currently estimated for all rivers, however. "Target" egg deposition is a function of river area, "target" egg density, expected age composition of spawners and age-specific fecundity. It essentially corresponds to the carrying capacity of the river. A consistent limit reference point would be B_{lim} = 0.5 B_{MSY} and B_{pa} = B_{MSY}. Fishing mortality based reference points would be a topic for further research.

(1) Current B_{lim}: B_{MSY} = escapement needed to achieve "target" egg deposition by river population. "Target" egg deposition by river population is not currently estimated for all rivers, however. "Target" egg deposition is a function of river area, "target" egg density, expected age composition of spawners and age-specific fecundity. Alternative: $B_{lim} = 0.5\ B_{MSY}$, where B_{MSY} calculated as above.

(2) Current B_{pa}: Not possible in this context, because "target" already corresponds to carrying capacity of river. Alternative: $B_{pa} = B_{MSY}$.

3.3.3 Baltic Fisheries

For Baltic stocks most estimates of Biological Reference Points were selected from Cook (WD 3). For comparison the estimates provided by the Baltic Fisheries Assessment Working Group (WGBFAS) (CM 1997/Assess:12) were taken into account. All proposed Biological Reference Points are presented in the list in Section 3.3.11.

Herring Sub-divisions 25–29 + 32 including Gulf of Riga

Over the last several years the observed mean weight at age of herring have systematically decreased. Similarly the natural mortality, part of which is caused by cod predation, shows a decreasing trend in agreement with the decreasing biomass of cod stock. These phenomena have to be taken into account when estimating Biological Reference Point. The estimates provided in Cook (WD 3) were obtained assuming mean weights at age over a longer time period (1987–1996), and should be treated with caution. The Study Group suggests that B_{lim} be set at 860,000 t, equivalent to B_{loss}, and very close to the WGBFAS estimate of MBAL (834 kt) obtained using Myers *et al.* (1994) approach. B_{pa} could be set at 1,200,000 t, below which recruitment appears to decline, and F_{pa} could be set at 0.18 close to the WGBFAS estimate of F_{med} (0.19) equal the estimate of F_{lpg} (0.18) from Cook (WD 3).

The Biological Reference Point for herring depends on multispecies effects (see Section 6).

Herring in the Gulf of Riga

Similarly as for herring in Sub-divisions 25–29 + 32, a decreasing trend in weight at age since the middle of the 1980s has been observed. Thus the Biological Reference Point estimates depend on the period over which weights at age are averaged. The Study Group suggests $B_{lim}=B_{loss}$=34,000 t, $B_{pa}=B_{5,30}$ (which is defined as the upper 5th percentile of B_{loss} on the assumption that CV of the estimated biomass is 30%)=62,000 t, and F_{pa}=0.31, a sustainable F according to ACFM. F_{lim} is left undefined.

Herring in Sub-division 30

The Study Group suggests $F_{pa}=F_{lpg}$=0.16.

Sprat in Sub-divisions 22–32

In 1994–1996 the decrease in mean weight at age was observed. The natural mortality is highly variable, reflecting changes in cod stock biomass. The Study Group suggests $B_{lim}=B_{loss}$=150,000 t, $B_{pa}=B_{5,30}$=272,000 t, and F_{pa}=0.32 which was considered sustainable by ACFM.

The biological reference point of fishing mortality for sprat depends very much on predation by cod (see Section 6). When cod predation is low, F on sprat can be higher than when predation by cod is high.

Cod in Sub-divisions 22–24

The estimates of stock size and fishing mortality are uncertain. Recruitment appears to linearly increase with spawning stock biomass, as if on the ascending limb of a stock recruitment curve. The fishing mortality is apparently very high with $F_{current}$=1.36. The Study Group suggest $B_{lim}=B_{loss}$=10,000 t, $B_{pa}=B_{5,20or30}$=18–23,000 t and $F_{pa}=F_{lpg}$=0.60 with F_{lim} left undefined.

Cod in Sub-divisions 25–32

The stock has reached historic highs during 1980–1984 but declined to its lowest in 1992, but biomass increased again afterwards. Fishing mortality since 1993 has also increased. The Study Group suggests $B_{lim}=B_{loss}=79{,}000$ t, $B_{pa}=B_{lpg}=140{,}000$ t, and $F_{pa}=F_{lpg}=0.81$.

Data for 1976–1996 were used because assessment data prior to 1976 are of poor quality and not reliable. Therefore they should not be used for BRP (Biological Reference Point) calculations.

The reproductive success of cod in Sub-divisions 25–32 is highly dependent on environmental conditions and as a result two stock-recruitment relationship can be identified: one for the period with good recruitment (years prior to 1982), and one for the period of poor recruitment (since 1982).

MBAL evaluated by the WGBFAS using Ricker's S-R curve equals 240,000 t and it is significantly higher than B_{lim} and B_{pa}, based on approaches used for other stocks in this report.

The dependence of BRP (Biological Reference Point) for cod on multispecies effects in the Baltic is described in Section 6.

Cod in Kattegat

The Study Group suggests $B_{lim}=B_{loss}=7{,}000$ t, $B_{pa}=B_{5,30}=13{,}000$ t, and $F_{pa}=F_{lpg}=0.60$. The BRP for this stock should be treated with caution due to unreporting of landings in 1991–1994.

Sole in Division IIIa

The stock recruitment curve is based on very short time series. It also may include data from two environmental periods and therefore it should be interpreted with care. The Study Group suggests $B_{lim}=B_{pa}=800$ t, $B_{pa}=1{,}500$ t, $F_{lim}=0.63$, and $F_{pa}=F_{MSY}=0.38$. These suggested BRP should be considered as preliminary and therefore subject to changes.

Flounder in Sub-divisions 24–25

The Study Group suggests B_{lim}=MBAL=4,800 t, and $F_{pa}=0.42$.

3.3.4 Northern pelagic and blue whiting

Norwegian spring spawning herring

The Study Group suggests B_{lim}=MBAL=2,500,000 t, $F_{pa}=0.15$, indicated by medium-term simulations and adopted by the Working Group, together with a catch constraint of 1.5 mill. tonnes. No B_{pa} or F_{lim} are suggested. Since this is a stock which is dominated by a few outstanding year classes, management discussions have concentrated on how fast it is advisable to deplete the present year classes, rather than on harvest control rules that require a certain B_{pa} as trigger for special actions.

Barents sea capelin

Management is by measuring the stock acoustically, compute the loss due to predation between measurement and the spawning season, and set a quota as SSB-B_{lim}. The fishery occurs only on spawning stock. If SSB < $B_{lim}=500{,}000$ t, the fishery is not opened. Other standard reference points are not considered relevant in this case.

Icelandic summer-spawning herring

This fishery has been successfully managed by using $F_{0.1}$ as a target for many years. Therefore, the Study Group suggest $F_{pa} = F_{0.1} = 0.23$, $F_{lim} = F_{0.1}\, e^{1.645*\sigma} = 0.35$. Alternatively, F_{crash} is approximately 0.55 assuming a Ricker curve, or higher than 0.55 if other stock-recruit functions are assumed.

B_{lim} has not been suggested by the Working Group. It appears that the fraction of year classes being above the median rises quite sharply as SSB passes 200,000 tonnes, which makes this a candidate for B_{lim}. Raising this value by 2SD indicates a B_{pa} of 300,000 tonnes.

Capelin in the Iceland - Greenland - Jan Mayen area

This stock is managed basically by the same principle as the Barents sea capelin, with the escapement of 400,000 tonnes for spawning as a limitation to the TAC.

Blue whiting

An SSB of 1,500,000 tonnes, representing approximately the lowest SSB on record, has been suggested as MBAL, and can be proposed as B_{lim}. There is no clear trend in the stock-recruitment relation, so F_{loss}, which is approximately 0.32, could be taken as an F_{lim}. This coincides with F_{med}, which has been proposed by the Working Group as F_{pa}. Following the policy of this Study Group, F_{pa} is suggested at 0.21, based on $F_{pa} = F_{lim}\ e^{-1.645\ \sigma}$, and likewise, a B_{pa} of 2,250,000 tonnes is suggested as B_{pa}. These suggestions are quite arbitrary, and in particular the B_{pa} and F_{pa} should be evaluated by simulations.

3.3.5 Other fish and shellfish species

There is a wide range of stocks and species currently outside the main regional stock assessment process. This includes species or stocks which do not have TACs or which are not assessed at all, whether because they are of lesser importance internationally, or because the available data are limited. The list includes both fish and invertebrates.

In principle a range of conventional assessment methods could apply to these stocks or species, but in practice the available biological knowledge and fisheries data will either be short-term, or not comprehensive. Because of increased commitment to adopting the precautionary approach in management, there is, however, a need to develop an assessment framework, irrespective of poor data or limited biological understanding. This framework should provide a more rigorous basis for timely management decisions, and should identify specific objectives for increased data collection and analysis. In the longer term, it should also consider the contribution which these other species make to the ecosystem.

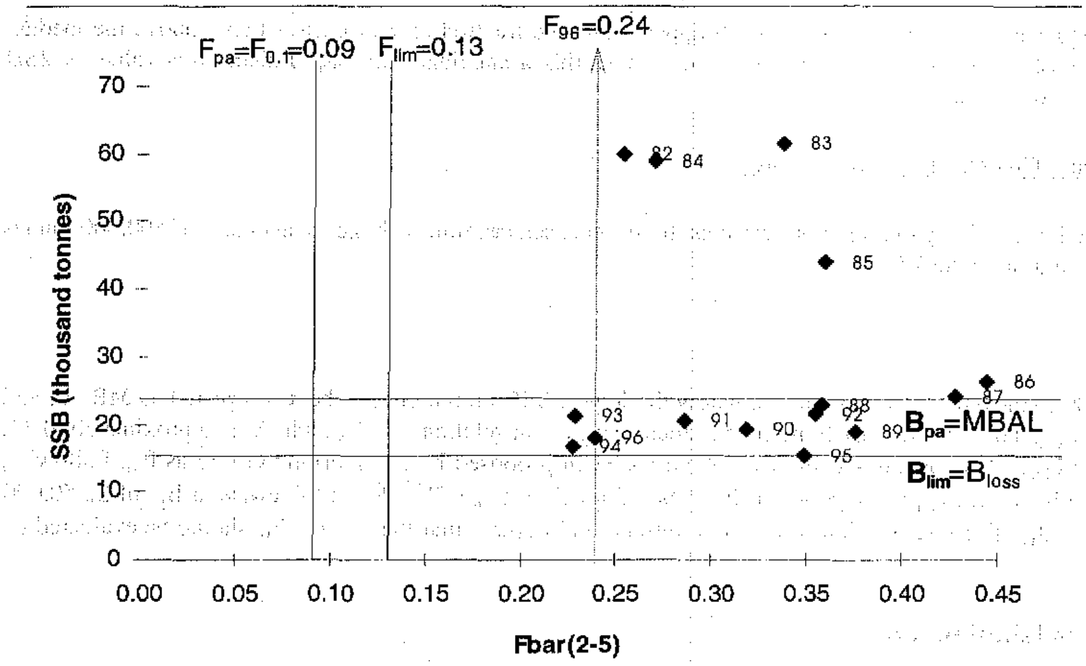
A few methods have been examined and analysis completed using several very provisional sets of data on other fish and shellfish just to illustrate the applicability of various methods or/and data requirements as well as interpretation of the analysis. At this stage it is, however, too early to make specific formal assessments or recommendations for management action.

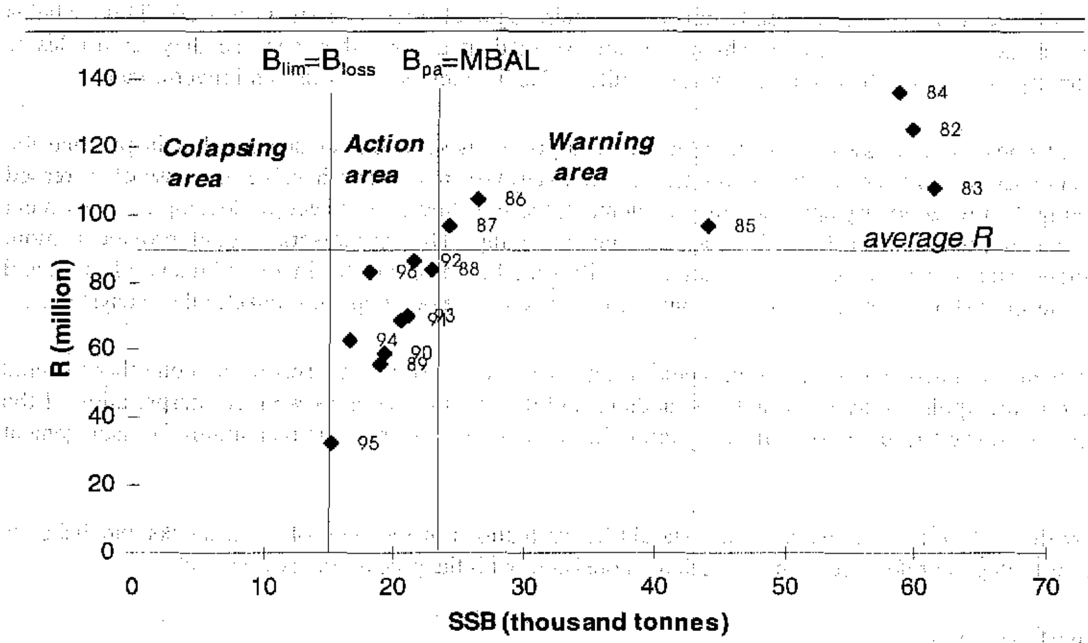
It is expected that by the end of 1998, however, there should be evaluations of the state of some stocks and fisheries including estimation of biological reference points, which are consistent with the precautionary approach.

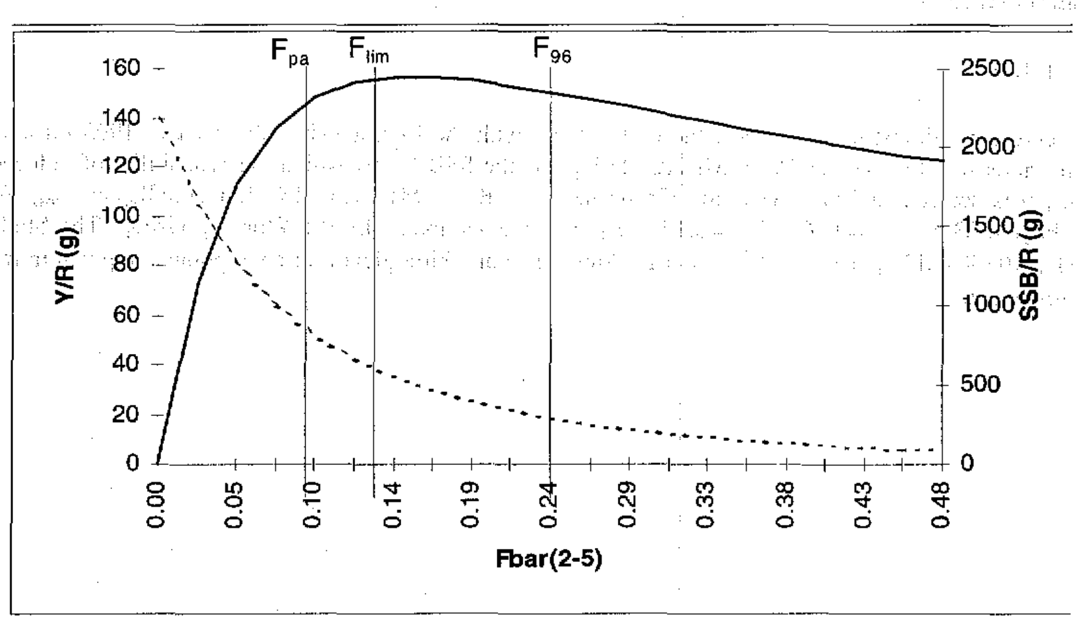
3.3.6 Southern shelf demersals

Southern hake (VIIIc+IXa)

The SSB has been decreasing almost steadily since the early 1980s with the lowest value observed in 1995 (around 15,000 t) and a slight increase estimated for 1996. MBAL, defined as the SSB below which the probability of reduced recruitment increases, was set at 23,000 t. The Study Group suggests B_{pa} = MBAL = 23,000 t and $B_{lim} = B_{loss}$. At present, $F_{96}=0.24 > F_{med}=0.23 > F_{max} = 0.16 > F_{loss}=0.13 > F_{0.1}=0.09$ as estimated by the Working Group. The Study Group suggests $F_{pa}=F_{0.1}=0.09$ and $F_{lim} = F_{pa}e^{1.645*\sigma} = 0.13$. Stock data and biological reference points are given in the figures on the following page.


F_{pa}=$F_{0.1}$=0.09
F_{lim}=0.13
F_{96}=0.24
SSB (thousand tonnes)
70
60
50
40
30
20
10
0
82
84
83
85
86
87
93
91
90
88
92
89
94
96
95
B_{pa}=MBAL
B_{lim}=B_{loss}
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Fbar(2-5)


B_{lim}=B_{loss}
B_{pa}=MBAL
Colapsing area
Action area
Warning area
average R
R (million)
140
120
100
80
60
40
20
0
84
82
83
86
87
85
98
92
88
93
94
90
89
95
0
10
20
30
40
50
60
70
SSB (thousand tonnes)


F_{pa}
F_{lim}
F_{96}
Y/R (g)
160
140
120
100
80
60
40
20
0
SSB/R (g)
2500
2000
1500
1000
500
0
0.00
0.05
0.10
0.14
0.19
0.24
0.29
0.33
0.38
0.43
0.48
Fbar(2-5)

3.3.7 Mackerel, horse mackerel, sardine and anchovy

Southern horse mackerel (VIIIc and IXa)

Since the shape of the stock-recruit relationship below the historical low SSB is unknown, a precautionary assumption about this relation would be a linear decrease in recruitment with decreasing SSB below the historical low, and a constant recruitment at the geometrical mean above it. Thus, under this assumptions, the lowest historical SSB has the properties of a limit biomass (B_{lim} = 130,000 t) and the corresponding F would appear as an F_{lim}. This F_{lim} value which is 0.27, is well above F_{max} =0.16 which is an obvious candidate for F_{pa} for this stock.

The risk of reaching an SSB of 130,000 t in a long-term at F_{max} modelled as described in Skagen (1996) is much less than 5%. The precautionary range of Fs is therefore limited by the F_{max} and not by an F representing danger of recruitment failure.

Sardine (VIIIc and IXa)

This stock has been considered by ACFM in October 1997 to be outside biological limits, with an SSB estimated in 1996 at the lowest level of the time series (1977–1996). ACFM advised a closure of the fishery because there are signs of collapse.

The relation between SSB and recruitment appears almost linear, with two distinct periods on the SSB-R relation time series considered in the assessment of the Working Group, which seems to be correlated with cyclical environmental factors. There are also indications that success of recruitment have been affected since 1992 by changes on the timing of upwelling (Borges *et al.* 1997).

The unit stock defined for assessment purposes does not contain the sardine which is distributed north of the Cantabrian Sea (Sub-divisions VIIIb,a, Division VII).

Recently there are strong indications of changes on the usual distribution patterns of the sardine covered by the assessment and also on the component which is not covered by the assessment (Sub-divisions VIIIb,a, Division VII). These changes in distribution may affect the historical perception of the usual assessment in the ICES Working Group on the sardine normally occupying the Division IXa and VIIIc, in relation to the SSB-recruit estimates.

Given the seriousness of the situation, the EU sponsored a special meeting with invited experts from Portugal, Spain, France, UK and Norway to update the state of the usual assessment and prepare information on the spawning grounds distribution, nurseries, adults and oceanographic systems. The EU requested ICES to update its advice in May 1998. Therefore the reference points are under revision and should be considered as provisional.

The WGMHSA suggested F_{crash} as F_{lim} equal to 0.34 and as a temporary F_{pa} for rebuilding the stock half of this value was suggested.

Anchovy VIII

For small pelagics, sustainability requires that the choice of a reference fishing mortality should be linked to the value of natural mortality: the higher M is, the higher the %SPR should be, with reference fishing mortality corresponding to SPR as high as 40% or even in some cases 60%. A reference F_{pa} for this population can be suggested at the level of 50% of SPR, what seem to be about 1.0 to 1.2, just at or below the average natural mortality. However, taking into account the variability of natural mortality, the uncertainties in the assessment and the risk in the fisheries of the small pelagics of increasing the catchability at low biomasses, a minimum biomass should also be taken into account in managing the fishery. The Study Group suggests that B_{lim} = 18,000 t, the minimum SSB over the past ten years, but has no suggestion for B_{pa}.

Northeast Atlantic mackerel (combined components)

The MBAL value of 2.3 million t, which corresponds to B_{loss}, has previously been regarded as a limit, below which strong measures were taken to bring the stock above this value. This is suggested as a B_{pa}. A B_{lim} cannot be defined in this case. A fishing mortality at $F_{0.1}$ = 0.175 has been suggested by the Working Group as a target, and can be taken as an F_{pa}. The fishing mortality at which the risk of stock depletion starts to increase in long-term simulations is suggested as a candidate F_{lim} = 0.25–0.3 depending on the assumptions about uncertainties in the models. This is based on an S-R relationship where R declines linearly to the origin below B_{loss}.

Western horse mackerel stock

This stock is characterised by infrequent extremely large recruitments. Due to the short time series of data and the presence of very few strong year-classes, it is not possible to quantify stock-recruit relationships. MBAL defined as the SSB that produced the strongest year class in the time series = 500,000 t. Given the extreme dynamics of the stock it is inappropriate to attempt to calculate F_{MSY}, F_{med} or F_{low} reference points. There are insufficient basis in the data to propose values of B_{pa}, B_{lim} or F_{pa}.

3.3.8 Joint ICES/NAFO harp and hooded seals

Hooded seals (*Cystophora cristata*) in the Greenland Sea

In 1997 for the first time a pup production of this stock was estimated. Based on the data of an aerial survey an estimate of 25,300 pups was derived. However, this was not corrected for temporal distributions of births or for scattered distribution of pups. Consequently no reliable total stock estimate could be produced.

Based on available information it is not possible at this time to determine limit and precautionary reference points for this stock.

Comment

Once revised estimates of pup production are available, an appropriate age structured population model can be developed. The Working Group expects to accomplish this for the 1998 assessment providing also the basis for determination of limit and precautionary reference points.

Harp seals (*Phoca groenlandica*) in the White Sea and Barents Sea

Total production, the population dynamics including natural mortality rates are not known. Therefore no conventional estimation of stock size is possible. An estimate of 700,000 individuals for the total stock was derived from similar pinniped populations in other areas. Only one estimate of pup production exists which was provided in 1997. The data of two aerial surveys were evaluated resulting in 100,000 pups produced in 1997.

Uncertainties are existing in stock size estimate and population dynamic parameters. The level of by-catches varied considerable in certain periods and is considered uncertain.

The growth rate and maximum length of individual seals decreased over the period 1960 to 1990. An increase of age at sexual maturity from about 5.5 to 8.1 years was observed over the same period.

Based on available information it is not possible at this time to determine limit and precautionary reference points.

Comments

The Working Group stated that a take of 40,000 individuals may not be sustainable considering a pub production of 100,000 individuals. The Working Group, however, provided no other argument for that conclusion except the decrease in growth rate, maximum length and increase in age at sexual maturity over the recent decades.

An age structured population model will be available for the 1998 assessment. Then there is a basis for determination of limit and precautionary reference points.

Harp seals (*Phoca groenlandica*) in the Greenland Sea

The last stock size estimate was obtained in 1991 and presented in the 1993 assessment. Based on mark-recapture data pup production in 1991 was estimated to 57,000 individuals (95% confidence interval: 46,000–69,000). Incorporating these estimates into a population model resulted in an estimate of 1+ population of 285,000 individuals (95% confidence interval: 220,700–345,900). Based on tag returns up to and including 1995 the 1991 value was re-evaluated as 67,300 individuals (95% confidence interval: 56,400–78,113). However, there was no new estimate of pup production since 1991 and hence no estimate of current stock size is available.

Based on only one assessment and a time series of catches it is not possible to determine limit and precautionary reference points for this stock unless new assessments are available.

Comment

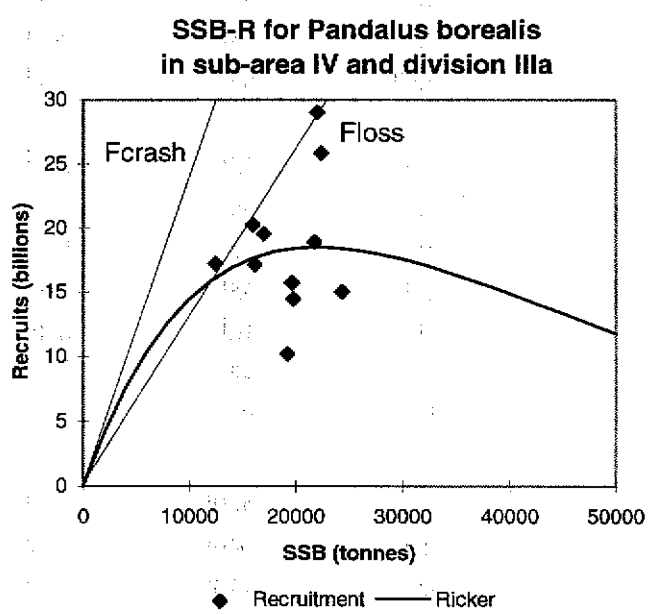
Catches since 1991 were less than 10,000 individuals with a declining trend due to reduced effort. There is no awareness of any major event affecting the stock adversely since the 1993 assessment. However, there is no basis at this time to prove that a level of catches of less than 10,000 individuals is sustainable.

3.3.9 *Pandalus borealis* in Divisions IIIa and IVa East

The range of SSBs is considerably more limited (12,500–24,200 tonnes) than that of the estimated recruitment (0.73–29 billion individuals). The Ricker stock recruitment curve bisects the cloud of points with the data straddling the apex rather than being distributed on either limb as is often the case. The vertically elongated data cloud with no points at low SSB, makes estimating F_{crash} imprecise thus F_{loss} is suggested as F_{lim}. F_{crash} is estimated to be 1.5, with F_{loss} as 1.26, $F_{0.1}$ is 0.8 and both F_{MSY} and F_{med} are 1.0. $F_{current}$ is 0.74.

Due to the lack of detailed age structure information, the uncertainty measure is the higher of the two σ=0.30 is used. Using F_{loss} as F_{lim} and following, using $F_{pa} = F_{lim}e^{-1.645*\sigma} = 0.77$, close to $F_{0.1}$, suggesting that $F_{0.1}$ is likely to be precautionary. F_{pa} is above $F_{current}$.

Using $B_{pa} = B_{lim}e^{1.645*\sigma}$ gives a B_{pa} of 20,500 tonnes.



$B_{lim} = B_{loss}$	12,453 t
$B_{pa} = B_{lim}e^{1.645*\sigma}$	20,500
$F_{lim} = F_{loss}$	1.26
$F_{pa} = F_{lim}e^{-1.645*\sigma}$	0.77

3.3.10 *Nephrops* and cephalopods

The Study Group does not suggest reference point for *Nephrops* nor for Cephalopods. A Study Group on *Nephrops* will meet during 1998 which is expected to consider precautionary reference points with particular consideration to the special life history characteristics of *Nephrops*. The same approach should apply to the Cephalopods.

3.3.11 List of reference points

	B_{lim} ('000t)	B_{pa} ('000t)	F_{lim}	F_{pa}
NWWG				
Iceland cod	200[a]	300[b]	f	.40[n]
Iceland saithe	f	150[a]	.47[d]	.23[e]
Greenland Halibut V+XIV	f	70[a]	f	.36[e]
Faroe saithe	70[a]	100[b]	.28[g]	.20[h]
Faroe Plateau cod	21[a]	40[b]	f	
Faroe haddock	21[a]	35[b]	f	.30
WGNSSK				
Plaice in IIIa	f	24[a]	f	.68[e]
NS cod	66[a]	150[j]	.90[l]	.64[p]
NS haddock	60[a]	150[i]	f	.64[p]
NS whiting	240[a]	350[b]	f	.83[c]
NS saithe	80[a]	150[i]	.63[d]	.40[h]
NS plaice	220[a]	300[j]	.40[d]	.30[n]
NS sole	25[a]	35[j]	.85[d]	.45[p]
Plaice in VIId	5.6[a]	8[b]	.54[d]	.40[o]
WGNSDS				
Cod in VIa	14[a]	25[i]	.75[d]	.50[o]
Haddock in VIa	22[a]	30[b]	f	.7[o]
Whiting VIa	15[a]	22[b]	f	.70[o]
Saithe in VI	11[a]	35[i]	.46[d]	.25-.30[p]
Cod in VIIa	6[a]	10[i]	0.86[e]	.62[h]
Whiting in VIIa	f	9[a]	f	.84[e]
Plaice in VIIa	f	F	f	.44[e]
AFWG				
Cod in I+II	138[a]	500[j]	.46[g]	.33[h]
Haddock in I+II	25[a]	140[j]	.35[g]	.25[h]
Saithe in I+II	89[a]	170[j]	.36[g]	.26[h]
WGNPBW				
Norwegian SS Herring	2500 j	F	f	.15 n
Barents Sea Capelin (SA I+II, excluding Div. IIa West of 5°West)	f	500 j	f	f
Icelandic Summer-spawning herring (Div. Va)	200 i	F	.35 w	.23 v
Capelin in the Iceland-East Greenland-Jan Mayen area (SA V and XIV and Div. IIa west of 5°West)	f	400 j	f	f
Blue whiting combined (SA I-IX, XII and XIV)	1500 j	2250 b	.32 d,g	.21 h

	Blim ('000t)	Bpa ('000t)	Flim	Fpa
WGSSDS				
Western Channel Sole (VIIe)	1800 a	2500 b,j	0.28 d	0.20 h
Western Channel Plaice (VIIe)	1300 a	2500 b,j	0.72 d	0.52 h
Celtic Sea Cod (VIIe–k)	7000 a	10000 b	0.77 d	0.55 h
Celtic Sea Whiting (VIIe–k)	13000 a	18,000 b,j	1.25 g	0.90 h
Celtic Sea Sole (VIIf,g)	2000 a	3000 b	0.44 d	0.32 h
Celtic Sea Plaice (VIIf,g)	1000 a	1,400 b	0.56 g	0.40 h
Northern Hake	119000 a	166000 b	0.27 d	0.19 h
Angler (*L. pis*) in VIIb–k and VIIIa,b	37000 a	52000 b	0.50 d	0.36 h
Angler (*L. bud*) in VIIb–k and VIIIa,b	33000 a	46000 b	0.16 g	0.12 h
Megrim (*L. whiff*) (VIIb,c e–k)	63000 a	88000 b	0.38 d	0.27 h
Bay of Biscay Sole	7200 a	10000 b	0.56 g	0.40 h
Southern Hake *	15000 a	23000 b,j	0.13 d	0.09 h
Southern Megrim (*L. whiff*)	700 a	1000 b	0.47 g	0.34 h
Southern Megrim (*L. boscii*)	3400 a	5000 b	0.44 d	0.32 h
WGMHSA				
Southern horse mackerel (VIIIc and IXa)	130 a	274	0.27	0.16 x
Sardine (VIIIc and IX a)	f	F	0.34 l	0.17 y
Anchovy (VIII)	18 a	36	f	1–1.2 z
Mackerel (combined Southern, Western and North Sea spawning components)	f	2300 a,j	0.25–0.3	0.175 v
Western horse mackerel (IIa, IVa, Vb, VIa, VIIa–c,e–k, VIIIa,b,d,e)	f	500	F	f
WGBFAS				
Herring in Sub-divisions 25–29 (including Gulf of Riga) and 32	860 a	1200 i	.31	.18[e,n]
Herring in Gulf of Riga	34 a	62 s	f	.31[t]
Herring in Sub-division 30, Bothnian Sea	f	F	f	.16[o]
Sprat in Sub-divisions 22–32	150 a	272 s	f	.32[t]
Cod in Sub-divisions 22 and 24	10 a	18-23 s	f	.60 o
Cod in Sub-divisions 25-32 [q]	79 a	140 u	f	.81 o
Cod in Kattegat	7 a	13 s	f	.60 o
Sole in Division IIIa	.8 a	1.5	.63	.38 r
Flounder in Sub-divisions 24-25	4.8 j	F	f	.42

(a) Lowest observed SSB (smoothed or B_{loss}).

(b) $B_{pa}=B_{lim}e^{1.645*\sigma}$

(c) From Ricker curve

(d) $F_{loss} = F_{lim}$

(e) $F_{med} = F_{precautionary\ approach}$

(f) Not defined

(g)$F_{med} = F_{lim}$

(h) $F_{pa}=F_{lim}e^{-1.645*\sigma}$

(i) Decline in R

(j) B_{pa}=MBAL

(k)F_{pa}=Pre-defined = F_{med}

(l) $F_{lim}= F_{crash}$

(m)For consistency with other stocks

(n) Derived from adopted/evaluated HCR

(o) $F_{pa}=F_{lpg}$

(p) Consistent with B_{pa}

(q) Period 1982-96

(r) $F_{pa} = F_{MSY}$

(s) $B_{5.30}$

(t) Sustainable F (ACFM)

(u) $B_{pa} = B_{lpg}$

(v) $F_{pa} = F_{0.1}$

(w) $F_{lim} = F_{pa}e^{1.645*\sigma}$

(x) $F_{pa} = F_{MAX}$

(y) $F_{pa} = ½ F_{lim}$

(z) $F_{pa} = F_{50\%SPR}$

*This reference points may change after the next assessment when new information on growth and maturity at age will be included.

4 GUIDANCE ON REFERENCE POINTS

4.1 Guidance to Working Groups in the Selection of Reference Points and their Future Usage

The definitions of F_{pa}, F_{lim}, B_{pa} and B_{lim} must be unambiguous and operationally useful for the assessment Working Groups and for ACFM. Normally only F_{pa} and B_{pa} will be used operationally by ACFM, but F_{lim} and B_{lim} may be derived for the purpose of calculating F_{pa} and B_{pa}, and in exceptional circumstances they may be used to formulate advice. Note that there need not be a direct relationship between the members of the pairs F_{pa} and B_{pa}, or F_{lim} and B_{lim}, in other words, B_{pa} does not represent the equilibrium biomass corresponding to F_{pa}.

The SGPAFM is suggesting limit and precautionary reference points for a number of stocks. However, assessment Working Groups need to make informed judgements about whether or not the proposed precautionary reference points are sensible. In order for ACFM to implement the precautionary approach in 1998, Working Groups meeting during the year must propose precautionary reference points at their 1998 meeting, for ACFM's consideration.

4.1.1 Fishing mortality reference points

F_{lim} is a fishing mortality which should be avoided with high probability because it is associated with unknown population dynamics or stock collapse. There are very few stocks for which F_{lim} is accurately known. Some stocks in the ICES area have collapsed in the past when fishing mortality exceeded F_{lim}, but generally speaking, the fishing mortality rate at which the probability of stock collapse becomes unacceptably high remains unknown. Therefore, there are uncertainties in the estimate of F_{lim}, and there are also uncertainties in estimates of current fishing mortality. In order to have a high probability that fishing mortality will be below F_{lim}, a precautionary reference point, F_{pa} lower than F_{lim}, is defined. Used as a constraint on fishing, F_{pa} is designed to ensure that there is a high probability that F_{lim} will be avoided and that the spawning stock biomass will remain above the threshold below which the probability of good to average recruitment is decreased. In other words, F_{pa} is a device to ensure that recruitment overfishing does not take place. F_{lim} and F_{pa} may be set in a variety of ways, depending on available information:

F_{lim}: will generally only be used for calculation purposes to arrive at F_{pa} and it will generally not be provided in scientific advice, nor used in management actions. F_{lim} might be set with reference to F_{loss}, F_{crash} or F_{med}. If F_{loss} or F_{crash} appear to be reliable estimates of a collapse fishing mortality, then either can be selected as F_{lim}. If neither is available and there is any doubt as to whether F_{med} is sustainable (see Figure below), then F_{med} can be taken as F_{lim}. For stocks where the fisheries are not currently managed according to the precautionary approach and where the exploitation rate is very high, F_{lim} may appear in the advice as current fishing mortality may be close to that value.

F_{pa}: is the upper bound on fishing mortality rate to be used by ACFM in providing advice. F_{pa}, given uncertainties, must have a high probability of being below F_{lim}, and it must have a high probability of being sustainable based on the history of the fishery; i.e. it should be set in the range, and imply a biomass, within those previously perceived to be acceptable. F_{pa} should also be chosen so that the corresponding equilibrium biomass is above B_{pa}, with high probability (say 9 out of 10 years) when fishing is held constant at F_{pa}. Working Groups may need to make appropriate calculations to make this determination. Fishing mortality rates in excess of F_{pa} will be regarded as "overfishing". F_{pa} might be set with reference to F_{med}, F_{lim}, F_{MSY}, $F_{0.1}$, etc. If F_{lim} is available then F_{pa} could be defined through $F_{pa} = F_{lim}e^{-1.645*\sigma}$ (where σ is a measure of uncertainty in the total F estimate, typically taken as 0.2-0.3) or as F_{lpg} where F_{lpg} is defined as the F value having a 10% probability of giving a replacement line above G_{loss}, the slope associated with the lowest SSBs. If there is no F_{lim} and F_{med} goes through a cloud of points which appears to come mostly from the right-hand limb of a stock-recruitment relationship, then F_{med} can be used for F_{pa}. If an accepted F_{pa} exists, then this should only be changed if there is a good reason to do so.

This procedure always gives at least F_{pa}, therefore, F_{lim} could be derived using the reverse procedure described above, that is: $F_{lim} = F_{pa}e^{1.645*\sigma}$.

If selected appropriately, and if adhered to as a maximum fishing mortality rate, F_{pa} would generally be expected to maintain the stock within safe biological limits.

4.1.2 Biomass reference points

Stocks may become depleted due to reduced recruitment even if fishing mortality is successfully maintained at or below F_{pa}. Furthermore, efforts to restrain fishing below F_{pa} may not be successful and biomass may decline as a result. Clearly, therefore, in addition to a constraint on fishing mortality, it is desirable to have a biomass-based constraint to prevent stock decline to values where expected recruitment is low or unknown. Whereas F_{pa} defines an "overfishing threshold", a definition of when the stock is regarded as being in a "depleted state" is also necessary. A threshold in this respect, B_{pa}, needs to be set to ensure a high probability of avoiding reducing the stock to a point, B_{lim}, at which the probability of recruitment failure is high or the dynamics of the stock are unknown. B_{lim} and B_{pa} may be set in a variety of ways, depending on available information:

B_{lim}: will generally only be used for calculation purposes, to arrive at B_{pa}, because management will ensure a high probability that B_{lim} is avoided; it will generally not be provided in scientific advice, nor used in management actions. B_{lim} might be set with reference to B_{loss}. If there is no obvious candidate for B_{lim}, consider a robust estimate of the lowest observed biomass (normally an average of those, perhaps omitting any clearly outlying values) and call this B_{loss}. Use B_{loss} as B_{lim}, if there is any indication of reduced recruitment at this low biomass or if the stock biomass has varied over a wide range of values.

B_{pa}: is the biomass below which the stock would be regarded as potentially depleted or overfished. It is the biomass threshold below which fishing mortality may need to be reduced below F_{pa}. It should be set to ensure a high probability that B_{lim} is not reached; it might be set with reference to B_{loss}, B_{lim} or previously defined MBAL. Use B_{loss} as B_{pa} if there is no indication of recruitment reduction at low biomass (e.g. the entire range of S-R points has a negative slope).

When only B_{lim} is available from the above, select B_{pa} so that there is little probability that a biomass estimate which appears to be above B_{pa} will really be below B_{lim}. In this case, use $B_{pa} = B_{lim}\, e^{1.645\sigma}$ where σ is a measure of uncertainty in the total biomass estimate, typically taken as 0.2–0.3.

This procedure always gives at least B_{pa}, therefore, $B_{lim} = B_{pa}\, e^{-1.645\sigma}$.

If an existing MBAL is close to B_{lim} or B_{pa} as defined above, then this might be substituted to maintain consistency and aid communication, so long as its use does not compromise the choice of F_{pa}.

4.1.3 F_{pa} vs B_{pa}

When fishing at a more or less constant value, the stock would be expected to fluctuate around a stable equilibrium point. While the true displacement of the stock from the equilibrium point will depend on a number of factors and will be heavily influenced by recruitment variability, the estimates of the displacement will also depend on uncertainties in the data and assessment results. Clearly, if the population cycles about an equilibrium, it will reach low values from time to time. It is important that, during periods when the stock is in equilibrium but below the average equilibrium point corresponding to F_{pa}, unnecessary management action not be triggered. The implication of this is that B_{pa} should not be too close to the normal low points of population fluctuations otherwise advice for changes in management response will occur frequently. This is undesirable if, overall, the stock is being fished appropriately. As a rule of thumb it might be desirable to ensure that measured biomass during normal fluctuations when fishing at F_{pa} only falls below B_{pa} about one year in ten. If the implied equilibrium biomass is sufficiently high, if F_{pa} is appropriately set, and if it is adequately implemented, there will be a low probability that B_{pa} will ever be reached and therefore a high probability that B_{lim} will be avoided.

4.1.4 Selection of limit reference points and precautionary reference points

The validity of F_{loss}, F_{med} and other statistics as precautionary or limit reference points depends on the history of the fishery. The guidelines above for fishing mortality and biomass reference points serve as a starting point. Assessment Working Groups, aware of stock and fishery details, may well make case-specific adjustments as appropriate; taking account, for example, of multispecies considerations (see Section 6) or technical interactions (see Section 7). As far as possible, however, following the guidelines will result in a consistent and simple way to implement scheme.

Working Groups should also calculate other biological reference points for the purpose of "groundtruthing" the precautionary reference points selected above. In particular, F_{MSY}, B_{MSY}, $F_{0.1}$, F_{max}, F35%SPR (the fishing mortality, in spawner per recruit calculations, providing 35% of the spawning stock biomass per recruit at zero fishing mortality) may be useful for comparison.

4.2 Framework for Advice

Advice from ACFM will be constrained by F_{pa} and B_{pa}. If fishery management decisions lead to F_{pa} being exceeded, then this would be regarded as overfishing and management would not be regarded as consistent with a precautionary approach. The development of a management plan to reduce fishing mortality to no greater than F_{pa} would be advised. If no such plan were developed, ACFM would generally advise that management was not consistent with a precautionary approach.

Because F_{pa} would be set such that B_{pa} were unlikely to be reached, and because B_{pa} is chosen to provide a high probability of avoiding recruitment failure, if SSB were to fall below B_{pa}, advice to reduce fishing mortality would be likely. This would depend, however, on whether or not F_{pa} were also being exceeded and on the prognosis for SSB trends and the probability of recovering to above B_{pa} in the short term. If SSB were predicted to remain below B_{pa} in the short to medium term, the development of a recovery plan would be advised. But in general, B_{pa} is the biomass threshold triggering advice for a reduction in F to a value below F_{pa}.

F_{pa} and B_{pa} are thus the main devices in ACFM's framework for providing advice. They are thresholds which constrain advice or which likely trigger advice for the implementation of management/recovery plans. If the development of plans were proposed, fishery management agencies, scientists and perhaps other parties would need to work together on their development. Such plans might involve explicit harvest control rules or sets of decision rules. If the development of plans were recommended but not taken up, ACFM would have to advise that management was not consistent with a precautionary approach. If plans were developed and not effectively implemented, again the advice would be that management was not consistent with a precautionary approach.

Note that if a stock is regarded as being in a depleted state, or even if overfishing is taking place, the development and effective implementation of a plan which is regarded as sufficient to reduce fishing mortality to no higher than F_{pa} and to rebuild SSB to above B_{pa}, within a "reasonable" period, would satisfy the condition that management were consistent with a precautionary approach.

4.3 Precautionary Science

With respect to stock assessments, the "precautionary approach" should be restricted to the selection of biological reference points, not to their estimation, nor to data fitting or other procedures in stock assessments. In other words, estimates of assessment-related quantities should be "best estimates", not "precautionary estimates". For example, if stock-recruitment data are fitted by two different theoretical curves, the fit chosen for further calculation should be based on scientific arguments, not on which curve has the most precautionary interpretation. As in other scientific circles, the term "scientific arguments" refers to statistical methodology, biological knowledge, relationship to ecological theory and so on.

It is poor scientific practice to deliberately bias estimators which are supposed to relate to biological entities. Nevertheless, it is imperative that any evaluation of risk (and determination of related biological reference points which avoid high risk) take into account possibilities such as the fact that assessments may be overly optimistic and that some stock-recruitment curves show maxima outside the range of the data and thus lead to results which can be considered highly suspect. It is particularly important to clearly deal with the latter since this can have a major effect on results from evaluations of management strategies. In particular, fitting to non-informative stock and recruitment data may well indicate that recruitment will increase dramatically at low stock sizes or that F_{crash} is unrealistically high.

In such instances good scientific judgement should first be used in order to determine whether better estimation techniques are possible. Results from such exercises should be clearly documented and should never be associated with the "precautionary approach", since the PA applies to management and not to scientific estimation. Alternatively, the best-fitting estimates can be used in spite of the fact that they result in unsupported extrapolations. In such cases it is imperative that a clear record be kept of relevant quantities such as the probability that the stock falls below its historical minimum in simulations. Such documentation allows tabulation which clearly illustrates how sensitive the interpretation of the results is when extrapolation occurs.

5 GENERIC FEATURES OF HARVEST CONTROL RULES

The objective of this Section is not to impose harvest control laws for the management of all stocks for which ACFM gives advice. Instead, this Section is intended to continue ACFM's deliberations on the formulation of harvest control rules, where agencies have asked us to provide advice in that form.

5.1 What is a Harvest Control Rule and Where Does it Fit in the Precautionary Management Process?

The harvest control rule is a form of the decision rule defined in the FAO guidelines on the precautionary approach (FAO, 1995a): "specification of how pre-agreed management actions will respond to estimated or perceived states of nature," where "states of nature" are defined to include biological conditions of the stock as well as economic conditions of the industry and environmental conditions. The rule is embedded in the management procedure, defined in the FAO guidelines as: "a description of the data to collect, how to analyse it, and how the analysis translates into actions." The recovery plan is a specialized decision rule which applies when the stock is outside safe biological limits.

The specification of pre-agreed management actions in response to fishery conditions is an important element of the precautionary approach. Pre-agreement ensures that management will be able to act quickly in response to changing conditions. Otherwise, if conditions change, management may delay actions until consensus is reached. In the case of deteriorating conditions, the result could be too little, too late.

The FAO guidelines recommend the development of decision rules in the management planning stage, and the involvement of industry, conservation and other interested groups at this stage. After decision rules are formulated, the management plan should be shown to perform effectively, exhibiting robustness to uncertainties in statistical estimates related to stock status, in environmental trends, in dynamic behaviour of harvesters and in managers' ability to change harvest levels (FAO, 1995a).

If decision rules are not specified by managers, "precautionary analysis requires that assumptions be made about these specifications, and that the additional uncertainty resulting from these assumptions be calculated. Managers should be advised that additional specification of targets, constraints and decision rules are needed to reduce this uncertainty" (FAO, 1995a). Finally, decision rules are implemented as part of the management procedure.

Another approach is for the management community to specify performance criteria for harvest control rules at the outset. These performance criteria would contain precautionary components, but could also contain economic or social components to be included once precautionary biological constraints were met. The fisheries science community would evaluate the performance of various alternative harvest control rules. Thus, pre-agreement would be focused on the performance criteria rather than any particular control rule. By extension, if a harvest control rule met the pre-agreed performance criteria, the action associated with the harvest control rule could be assumed to be agreeable as well. A form of this approach is used in the International Whaling Commission revised management procedure.

In practise, under either approach, more interaction between fisheries scientists and managers will be required in order to develop an understanding of what constitutes appropriate performance criteria and specific pre-agreed management actions that would satisfy the performance criteria.

5.2 Characteristics of Harvest Control Rules and Recovery Plans Based on International Agreements and Technical Consultations

Current international agreements and consultations allow considerable flexibility in the form of harvest control rules. The following characteristics of harvest control rules and recovery plans are based on Article 6 and Annex II of the UN Agreement (United Nations, 1995), the FAO Code of Conduct for Responsible Fisheries (FAO, 1995b), and the FAO guidelines (FAO, 1995a):

1. Precautionary harvest control rules are pre-negotiated or pre-agreed.

2. Precautionary harvest control rules implement management action without delay.

3. Precautionary harvest control rules ensure that when limit reference points are approached, they are not exceeded or have a very low probability of being exceeded.

4. Precautionary harvest control rules are appropriate when threshold reference points are reached, especially in cases involving high risk, to avoid reaching limit reference points.

5. Precautionary recovery plans are implemented immediately to restore stocks to levels consistent with previously agreed precautionary reference points.

6. Precautionary recovery plans should allow the achievement of desirable outcomes (i.e., with respect to limit reference points as minimum rebuilding targets) in less than two or three decades.

5.3 Performance Criteria and Harvest Control Rules

In the ACFM context, it may be productive to begin to elicit performance criteria to determine exactly what managers perceive as "precautionary ", in terms of acceptable levels of risk and impacts. Performance criteria may contain more components than just precautionary elements based on biological criteria.

The precautionary component of the performance criteria could resemble that noted in Butterworth and Berg (1993): agreement that application of a precautionary decision rule would have the "probability of less than X% of reducing the resource below Y% of K within a period of Z years." Performance criterion for a precautionary recovery plan would be an X% chance of stock sizes above the limit reference point and Y% chance of stock sizes above the threshold point after Z years of implementation.

An example of a precautionary criterion for management might be "probability of less than 5% of reducing the resource below B within 10 years." Additional criteria could be included conditional on meeting the precautionary ones, e.g. "inter-annual changes in catches of less than X%."

There may be several different harvest control rules which meet the criteria listed above, but with additional characteristics which may be desirable or undesirable to managers. (One can assert that managers likely do not care about the algorithm for setting TACs as a function of uncertainties, stock conditions, etc. if the results are acceptable in terms of criteria on which managers agree.) The process of developing performance criteria and harvest control rules will involve new forms of interaction between managers and fishery scientists. The process will not necessarily be achieved quickly. It will, however, lead to pre-agreed actions, implemented without delay, consistent with the precautionary approach.

5.4 Defining Harvest Control Rules

Given the flexibility in the definition of harvest control rules as decision rules, we are allowed a wide latitude in their specification. Formulation of generic harvest control rules are unlikely, because data are not of uniform quality for all stocks, and because of differences among biological and management systems. Up to six different control rules operate in the management system in the US EEZ portion of the North Pacific, depending on what types of data and information are available for the stock (Thompson and Mace, 1997).

Harvest control rules may be thought of as having two precautionary components: a functional form relating current stock status and reference points to catch; and the actual specification of the reference points or other relevant parameters. The two components act together to determine the degree of precaution afforded by the rule. There are interactions between the acceptable probability of overfishing, the consequences of exceeding limit reference points and the action to be taken when the stock is overfished (Rosenberg and Restrepo, 1996). For example, an acceptable probability of overfishing could be higher if the action to be taken when the limit is exceeded is an immediate and drastic reduction in catches, rather than a reduction which is phased in over a long time period. An acceptable probability of overfishing could be higher if the probability of poor recruitment increases slightly in only one year, rather than a significant increase in the probability of recruitment failure.

For recovery plans, guidelines for maximum time horizons for recovery vary from two to three decades (FAO, 1995a) to ten years to not more than one generation (maximum age in the unexploited stock) longer than the time needed for recovery under a complete closure (Rosenberg and Restrepo, 1996). Timing for recovery plans should vary as a function of life history characteristics of the stock and patterns of recruitment variability.

Kirkwood and Smith (1996) categorize decision rules based on whether they use future information (i.e. incorporation of feedback on stock status over time), designating as non-precautionary rules which are not altered by future data and analysis. The feedback strategies can also be categorized based on whether they are adaptive (i.e. whether the management strategy is likely to provide additional information about the system). An additional dimension of decision rules involves the extent to which they are stock-size-dependent: in those cases, catch quotas are prescribed based on current estimates of stock status. These rules can take the form of constant catch, constant F or constant escapement; or variations thereof. While some strategies may provide maximum catches and minimal risk to stock size, catches may fluctuate highly from year to year under those strategies. They describe additional variants in which absolute or proportional changes in catch quotas from year to year are limited, but note that this is at the expense of flexibility to reduce catches in the face of deteriorating stock conditions, and so is less precautionary. Rules may also incorporate uncertainty in stock size estimates, so that catch limits are reduced when stock size estimates are uncertain The role that precaution should play changes as stock status moves from limit levels to target levels.

5.5 Examples of Harvest Control Rules

Some harvest control rules described by the Study Group on the Precautionary Approach to Fishery Management (SGPAFM) (1997) have involved reductions in fishing mortality rate from F_{pa} to zero as stocks decline from precautionary levels of spawning stock biomass (B_{pa}), to B_{lim}. Thus, the rate of reduction in F is proportional to the difference between F_{pa} and 0, and the distance between B_{pa} and B_{lim}. When the stock biomass is above B_{pa}, fishing mortality rate cannot exceed F_{pa}. This insures that the stock remains within a precautionary region. Other forms of harvest control laws based on these parameters could be formulated, with different behaviours. For example, reduction in F could begin at levels above B_{pa}, which would slow the rate of reduction in F.

One variation on the rule would allow only limited percentage reductions in catches from year to year. This would be of interest if, for example, large and immediate catch reductions were required at the beginning of implementation of a recovery plan, but those changes would be destabilizing to the fishery. Example simulations have shown that as allowable change in catch from year to year increases, the probability that a rule meets precautionary criteria increases. Alternative targets also exhibit different probabilities of meeting precautionary criteria. Allowable increases in catch must be limited at the same rate as allowable decreases in order to be precautionary.

Where only an index of biomass and catch data are available, simple harvest control rules can be formulated which under some conditions can stabilize catch levels and halt stock declines. For example, next year's quota could be set as a function of this year's quota and recent biomass changes. If a times series of catch (Yt) and a commercial or survey CPUE index (Bt) is available, then the rule could be summarized as:

$$Yt = Yt\text{-}1\ [1 + g\ ((Bt\text{-}1 - B\ t\text{-}2)/Bt\text{-}2)]$$

where g is a feedback gain term. If the biomass fell below a limit reference point, the fishery would be closed. While this rule may not perform well under some circumstances, a simple feedback method to reduce catch by the same percentage as the observed reduction in the abundance index will perform better than no measure at all.

Alternatively, simple use of F_{pa} and B_{pa} as biological reference points would not imply the use of a particular harvest control rule. Use of these parameters alone would not be precautionary without specific pre-agreed immediate actions. Those reference points define a maximum allowable catch which could be taken under any particular stock situation.

5.6 Related Aspects of Harvest Control Rules

If a stock is depleted, or even if overfishing is taking place, the immediate development and implementation of a plan which is sufficient to reduce fishing mortality to no higher than F_{pa} within a "reasonable" period, and to rebuild SSB to above B_{pa}, would satisfy the condition that management were consistent with a precautionary approach.

It has been widely recognized that ability to reduce fleet capacity is a critical element in implementing the precautionary approach (e.g. FAO, 1995a; Mace, 1996). Consequently, management based only on harvest control measures cannot be considered precautionary unless capacity control measures are also in place. Otherwise, implementation errors may far outweigh any other uncertainties in data, model structure or analysis. Moreover, excess capacity may also make precautionary recovery plans difficult to implement when stocks are already beyond safe biological limits, presumably a highly risky situation. If complete monitoring and stringent enforcement is in effect, however, overcapacity would not necessarily compromise management efforts, and implementation errors could be significantly reduced.

The precautionary approach emphasizes a pro-active perspective. Before a depleted stock become rebuilt, managers should develop consensus about performance criteria for decision rules to apply when the stock reaches B_{pa}. This would also allow pro-active opportunities for implementing a cap on fishing capacity as stocks are rebuilt to more productive levels. This approach is advocated by the Canadian Fisheries Resource Conservation Council (FRCC) as part of its criteria for re-opening fisheries that have been closed: not only must the stock be in healthy condition, but the re-opened fishery must operate in a "conservationist" manner, keeping fishing mortality low (Serchuk *et al.* 1997). Similarly, it may be easier to develop a recovery plan for stocks while they are within safe biological limits. The most problematic case is the development of a recovery plan while the stock is beyond safe biological limits, because in many cases the difficulties may ultimately be due to overcapacity and implementation error rather than a technically acceptable harvest control rule. (From a precautionary perspective, inability to identify an appropriate target reference point is less problematic if threshold reference points are avoided with high probability under a management procedure and harvest control rule).

Kirkwood and Smith (1996) conclude that the concept of precaution should be broadened from the prevention of overfishing leading to stock collapse, to the maintenance of a flexible, resilient fishery including biological, ecosystem, fleet and management institution aspects. This alternative perspective emphasizes reversibility of biological changes and reversibility and flexibility of fleet effort patterns and management decisions. Under either concept of precaution, effective implementation of harvest control rules for many stocks critically depend on co-evolution of complementary management structures.

6 MULTISPECIES CONSIDERATIONS

The Multispecies Assessment Working Group at its meeting in August 1997 evaluated if and how multispecies interactions may effect biological reference points (Report of the Multispecies Assessment Working Group. ICES CM 1997/Assess:16). Although the Working Group stressed that further work is needed before the implications of multispecies interactions for precautionary approach is revealed the Group was able to demonstrate that multispecies interactions have direct effects on biological reference points, and on responses of populations to rebuilding strategies.

The importance multispecies interactions may have on reference points can be illustrated by the multispecies forecast model developed by Henrik Gislason and presented at the meeting of the Working Group on Ecosystem Effects of Fishing Activities in November 1997 (ICES CM 1998/ACFM/ACME:1). The model includes cod, herring and sprat in the central Baltic and produce medium-term predictions of biomass and yield of the three species. The model is available in three versions: a) classic single species version; b) ordinary multispecies version (with cod as predator on herring, sprat and young cod and with constant weight at age for all species); c) extended multispecies version with the mean weight and maturity at age for cod being predicted as a function of available food (herring, sprat and other food).

In the single species version recruitment are modelled by Ricker curves for all three stocks. In the multispecies versions recruitment of cod at age 0 is assumed to be directly proportional to the spawning stock biomass. Cannibalism subsequently changes the number of survivors at age two. The resulting stock-recruitment relationship is very similar to the Ricker model used in the single species version.

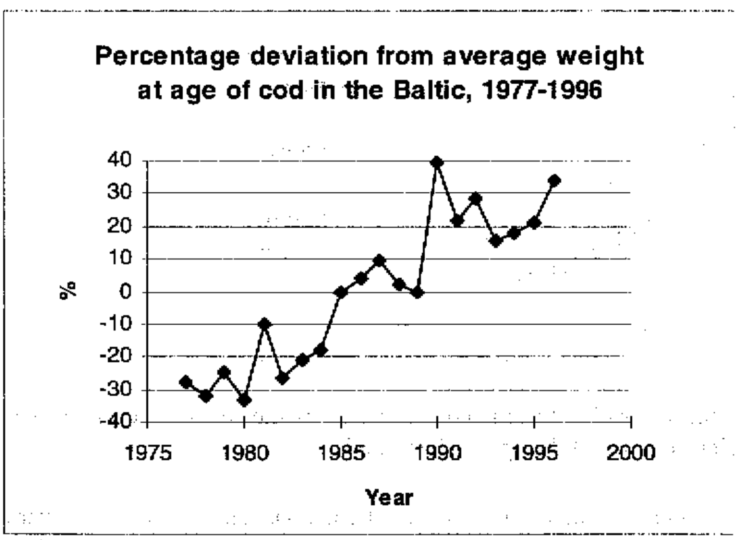
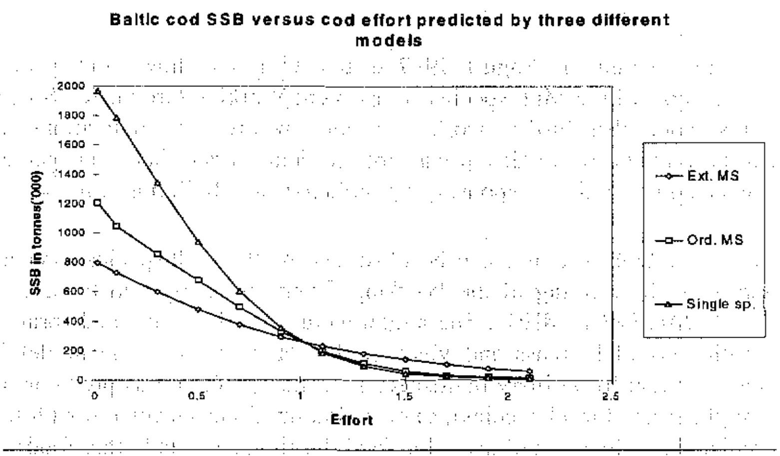


Figure 6.1 Percentage deviation from average weight at age of cod in the Baltic, 1977–1996. Data from ICES CM 1997/J:2.

Figure 6.1 shows how the mean weight at age for cod ages 2–4 has changed in the period 1977 to 1996. In the extended multispecies version these changes in growth of cod is simulated by assumed weight to be direct proportional to the amount of food available. The biomass of other food is modelled by a Fox type surplus production model. The parameters in the growth model was chosen to give, in the *status quo* situation, weight at age corresponding to the values used in the single species version. Maturity ogive is estimated as a function of mean weight at age. In the classic multispecies version the amount of other food is assumed to be constant irrespective of changes in cod biomass.

The exploitation patterns for the three stocks are the same in all three versions. The level of exploitation is controlled by two "effort" variables (cod effort and pelagic effort) and fishing mortality at age is estimated by multiplying the exploitation pattern with the "effort" value.

The average yield and SSB of cod as function of cod "effort" keeping the pelagic "effort" constant is shown in Figure 6.2 for each of the three versions. In all three situations SSB increase as effort decrease. The increase is most pronounced in the single species version, less in the ordinary multispecies version, where cannibalism counteract the increase in recruitment and even less in the extended multispecies version where the increase in biomass is counteracted by both cannibalism and a decline in mean weight.



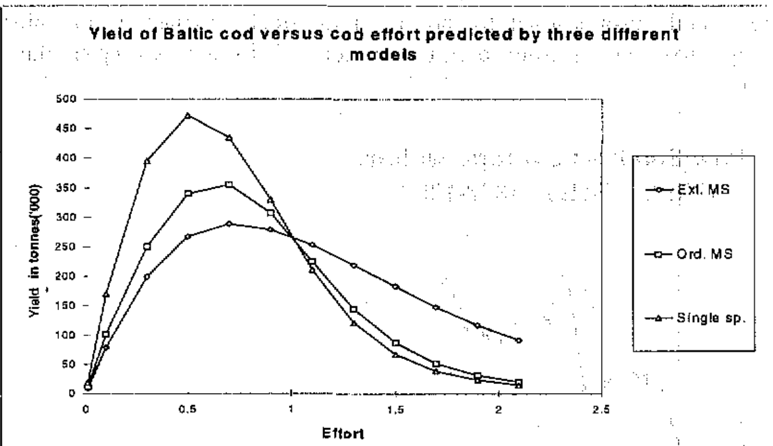


Figure 6.2 Average SSB and yield of Baltic cod predicted by the single species, ordinary multispecies and extended multispecies versions of the spreadsheet model.

Figure 6.2 shows that the yield as function of cod effort for constant pelagic effort varies considerable in the three versions. The largest variation in yield is observed in the single species version while multispecies interactions as well as variation in mean weight damp the change in yield.

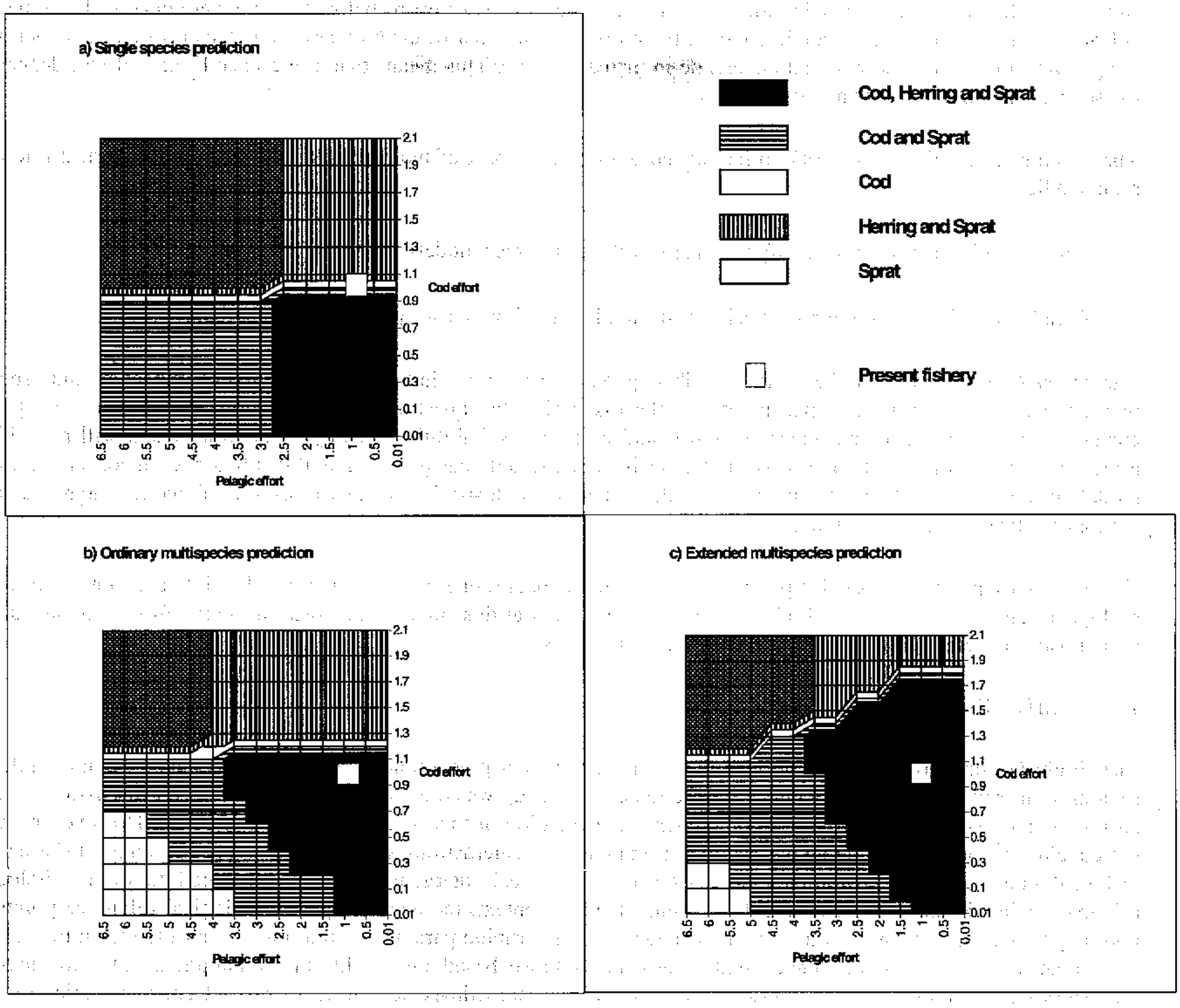


Figure 6.3a–c Combinations of effort levels in the cod and pelagic fisheries in the Baltic resulting in equilibrium SSBs above 10% of the unexploited SSBs for cod, herring and sprat. (a–c) Predictions assuming single species, ordinary multispecies and extended multispecies model structure.

Figure 6.3 shows plots of regions of combined cod and pelagic effort that produces spawning stock sizes of the three stocks above or below 10% of the unexploited SSBs in each of the three versions. The 10%, is arbitrary chosen and should not be taken as a recommendation for B_{lim}. The unexploited SSBs are calculated by setting the effort in both fisheries to zero. For cod the unexploited levels of SSB are 2.0, 1.4 and 0.9 million tonnes in the single species, ordinary multispecies and extended multispecies versions, respectively. The present level of "effort" is indicated on the plots.

In the single species version (Figure 6.3a) the biomass of cod is independent of the pelagic effort and opposite for herring and sprat. The herring SSB drop below the 10% level at a pelagic "effort" of app. 2.5 times the present. Sprat stays above the 10% level within the entire rage of pelagic "effort" applied. For cod the present "effort" is close to the one that reduces SSB below the 10% level.

In the ordinary multispecies version the interaction between cod as predator and the prey stocks herring and sprat is clearly reflected (Figure 6.3b). The limits for the pelagic species become curved, meaning that the level of pelagic "effort" that can be exerted without reducing the SSBs below the 10% level is depending on the cod "effort". With high cod "effort" the pelagic stocks can sustain a relative high effort without dropping below the limit SSB. A high cod "effort" will reduce the cod stock and thereby reduce the predation on herring and sprat leaving more of the pelagic production for the fishery. For cod there is very little change in the effort level at which the stock falls below the 10% level.

In the extended multispecies version all levels at which the biomasses drops below the limits are curved. If the pelagic "effort" is high the cod can sustain less mortality before it decline below the biomass limit. This is due to a reduction in the growth of cod and a corresponding decline in maturity ogive. This means that a reference F for cod will depend on the state of the pelagic stocks and visa versa.

The preliminary results of the work so far carried out on the impact of multispecies interaction on biological reference points indicate that:

- biomass limit reference points differ in single and multispecies models.
- if predation is increased the prey stock can sustain less fishing mortality before dropping below B_{lim}.

The Study Group finds that the work described gives a very good indication of the likely impact of multispecies interactions on biological reference points. In the discussion the question was raised how incorporation of growth changes in the extended multispecies version would effect the suitabilities. Change in growth of cod will most likely affect the predation mortality and it was not clear if the expected changes in suitabilities had been incorporated in the model. It was suggested that to include growth change in multispecies models a size-based model might be more appropriate than an age-based model.

The Study Group recommends that possible effects of multispecies interaction should be taken into account when setting biological reference points. The Study Group is, however, not at this stage in the position to give firm recommendation on multispecies reference points for specific stock complexes.

7 MIXED FISHERIES

The Study Group was asked to consider the implications of a precautionary approach and harvest control rules in relation to mixed fisheries and technical interactions. The Group was only able to undertake a brief discussion of these issues and so was unable to provide a comprehensive evaluation of this specific Term of Reference. However, many of the conclusions outlined in the above Section on multispecies interactions are also of relevance to mixed fisheries and technical interactions. For example, the existence of technical interactions implies the need to define biological reference points in an ecosystem or at least a multispecies context, the need to specify biological reference points for non-target species, and the need to consider changes in demographic parameters in terms of their effects on the validity of estimates of biological reference points, particularly those based on equilibrium assumptions. Due to technical interactions (and/or multispecies considerations), there may sometimes be a need to restrict entire fisheries to fully protect specific components. In fact, multispecies considerations and technical interactions are part of the reason why many people now believe that single-species F_{MSY} should be considered limit reference points rather than target reference points (see discussion elsewhere).

Multispecies considerations and technical interactions are also part of the reason why it may not be feasible or even practical to construct generic control rules. Case-by-case development is required. In fact, ideally, control rules should be multidimensional. Estimates of F_{pa}, B_{pa}, F_{lim} and B_{lim} for each stock of concern should be conditional on the status of the other stocks in the assemblage. If a Recovery Plan needs to be developed for one stock in a multispecies assemblage, then in order to ensure recovery of the stock of concern, that Plan should incorporate actions for all other (relevant) species in the assemblage. For two-species control where there are technical interactions between the two species, fishing could proceed at rates appropriate to each species individually if both species are above their respective B_{pa}. However, if one species falls below its B_{pa}, then fishing mortality rates may need to be reduced for both species simultaneously.

Another important factor of relevance to mixed fisheries is the need to take into account the ability of fleets to switch between stocks and the possibility that "latent" capacity may be mobilized in response to fisheries regulations and/or markets. Reductions in quotas for one species may result in increases in fishing pressure on other species. Quota reductions in combination with technical interactions may also result in increased discarding and increased cryptic mortality, both of which may be difficult to measure and incorporate into stock assessments. Of particular relevance to the demands on stock assessment advice is the situation where reductions in quotas on traditional species result in vessels switching effort to less-exploited and less well-known stocks, for which the scientific community may have to provide prompt guidance before sufficient demographic information is available. Scientists need to consider the wider system effects of their advice, as do managers.

In particular, fleet capacity needs to be considered on a multi-fleet (i.e. system-wide) basis. Many fisheries professionals consider that fleet capacity is solely a management issue, and should not enter into scientific debates. Yet, fleet capacity has profound effects on the quality and credibility of the science and demands on the science, as well as the management system. Overcapacity exacerbates a number of problems of relevance to fisheries science and management, including challenges to the validity of the science; pressure on fisheries managers to make risk prone management decisions; pressure on politicians to support calls for increased TACs and related measures or to provide financial bail-outs to the fishing industry to enable them to "survive" until stocks rebuild; pressure to increase access to controlled access fisheries; increased monitoring, surveillance and enforcement costs - or inadequate monitoring, surveillance and enforcement - because the incentive to circumvent regulations will increase as the average economic viability of individual fishing enterprises declines; reduced quality of data needed for stock assessments and evaluation of management actions; and an atmosphere of distrust between scientists, managers, fishers, and environmentalists.

Control of fishing capacity is an integral part of the FAO Code of Conduct and other international agreements. Because of such agreements, and for practical reasons, harvest control rules cannot be considered to be precautionary unless they are imbedded in a management procedure that addresses fleet capacity and other relevant issues. It is impossible to avoid considering fishing capacity as a fundamental element of the precautionary approach.

Inclusion of multispecies considerations, technical interactions, habitat considerations, other ecosystem considerations, and uncertainty generally demands a greater degree of precaution in fisheries. In addressing Terms of Reference 2a and 2b, the Study Group did not take account of multispecies or multi-fleet effects. In contrast, in some instances, ACFM advice has taken account of such effects.

Consider a simplistic harvest control rule where $F_{target} = F_{pa}$ (or F_{target} is some function of F_{pa}), F is reduced when biomass declines below B_{pa}, and fishing ceases when biomass declines to B_{lim}. A similar type of control rule is assumed to apply for a fictitious cod stock and a fictitious haddock stock, except that the absolute numerical values of the various biological reference points may vary between the two species.

If there are technical interactions between the two species, then the harvest control rules for each may need to be altered depending on the status of the other (Ta = Target; C = Cod; H = Haddock).

8 FUTURE WORK, IMPLEMENTATION OF THE PRECAUTIONARY APPROACH

Further meetings of the SGPAFM do not appear to be necessary in the immediate future. A Dialogue Meeting is planned for January 1999 to discuss, among other things, the implementation of the precautionary approach with fishery management agencies.

9 WORKING DOCUMENTS

1. Pastoors, M. A., F. A. van Beek. Explorations of biological reference points for North Sea plaice and herring.
2. Cook, R. M. A Sustainability Criterion for the Exploitation of North Sea Cod.
3. Cook, R. M. Glossing over the ICES Stocks: Some Suggested Limit Values.
4. Bell, E. D., G. Stefánsson. Performance of some harvest control rules.
5. Bravington, M. V. A minimally-subjective method for lower confidence intervals on the slope-at-origin of stock-recruitment relationships.
6. Horwood, J., R. Cook, J-J. Maguire, B. Mesnil. Proposal to Reduce the Frequency of Assessments.
7. Horwood, J., K. Stokes. The Precautionary Approach: Control Rules and Recovery Plans.
8. [Need to get info from JJ] Karin: I do not know what this is.

9. Smith, M., L. Kell, K. Stokes, C. Darby, C. O'Brien, B. Rackham. Estimates of Biological Reference Points.

10. Borges, M. F., D. Skagen. A precautionary approach applied to Southern Horse Mackerel (Divisions VIIIc and IXa).

11. Vasilyev, D. A. Separable Methods of Catch-at-Age Analysis from Point of View of Precautionary Approach.

12. Gabriel, W. L. Harvest Control Rules and the Precautionary Approach to Fisheries Management.

13. Powers, J. E., V. R. Restrepo. Evaluation of Stock Assessement Research for Gulf of Mexico King Mackerel: Benefits and Costs to Management.

14. Ehrhardt, N. M., C. M. Legault. The role of uncertainty in fish stock assessment and management: A case study of the Spanish mackerel, *Scomberomorus maculatus*, in the US Gulf of Mexico.

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APPENDIX 1

CHECKLIST OF CHARACTERISTICS OF PRECAUTIONARY ASSESSMENT (FAO 1995a)

Consideration of:

1. Uncertainties in data
    a) Estimates of abundance
    b) Model structure
    c) Parameter values used in model
    d) Future environmental conditions
    e) Effectiveness of implementation of management measures
    f) Future economic and social conditions
    g) Future management objectives
    h) Fleet capacity and behaviour

2. Alternative hypotheses about underlying biological, economic and social processes
    a) Depensatory recruitment or other dynamics giving rapid collapse
    b) Changes in behaviour of the fishing industry under regulation
    c) Medium-term changes in environmental conditions
    d) Systematic underreporting of catch data
    e) Fishery-dependent estimates of abundance not proportional to abundance
    f) Changes in price or cost to the fishing industry
    g) Changes in ecosystems caused by fishing

3. Response of system to range of alternative management actions
    a) Beyond 1-2 year short-term projections
    b) Assumptions about management objectives and associated increase precaution

APPENDIX 2

SOME BASES FOR HARVEST CONTROL RULES IN FAO CODE OF CONDUCT FOR RESPONSIBLE FISHERIES AND UN AGREEMENT RELATING TO STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

The basis for harvest control rules is found in Article 6 and Annex II of the UN Agreement relating to Straddling Fish Stocks and Highly Migratory Fish Stocks (1995) and the FAO Code of Conduct for Responsible Fisheries. The FAO Code of Conduct states that:

"When precautionary or limit reference points are approached, measures should be taken to ensure that they will not be exceeded. These measures should where possible be pre-negotiated. If such reference points are exceeded, recovery plans should be implemented immediately to restore the stocks."

In Article 6, Application of the Precautionary Approach,

"3.. In implementing the precautionary approach, States shall....

...(b) apply the guidelines set out in Annex II and determine on the basis of the best scientific information available, stock-specific reference points and the action to be taken if they are exceeded...

"4. States shall take measures to ensure that, when reference points are approached, they will not be exceeded. In the event that they are exceeded, States shall, without delay, take the action determined under paragraph 3 (b) to restore the stocks."

In Annex II,

"4. Management strategies shall seek to maintain or restore populations of harvested stocks... at levels consistent with previously agreed precautionary reference points. Such reference points shall be used to trigger pre-agreed conservation and management action. Management strategies shall include measures which can be implemented when precautionary reference points are approached."

"5. Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point, or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery."

"7. The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that biomass does not fall below a pre-defined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target."

Subsequent guidelines on the precautionary approach (FAO, 1995) indicate that the precautionary approach requires:

"b. prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;

c. that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a timescale not exceeding two or three decades;...

e. that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource, and that increases in capacity should be further contained when resource productivity is highly uncertain."

APPENDIX 3

Estimating MSY for poorly investigated stocks

Several empirical formulas have been developed with the objective of providing a first 'rough' estimate of MSY from limited data. Garcia, Sparre and Csirke (1989) suggested two alternative ways to estimate the potential yield of exploited fish stocks; these are derived from the Schaefer and Fox surplus production models respectively. Both assume that average biomass $\overline{B}$, and current yield Y are available.

The Schaefer model relates CPUE to effort as, $\frac{Y}{E} = a + bE$ where E is effort and a and b are constants. To obtain an estimate of the maximum sustainable yield, yield is first expressed as a function of effort, $Y = aE + bE^2$

This parabola has a maximum when $\frac{dY}{dE} = a + 2bE = 0$ *i.e.* $E_{msy} = -\frac{a}{2b}$ and an equivalent yield, MSY, found by solving $Y_{msy} = a\left(-\frac{a}{2b}\right) + b\left(-\frac{a}{2b}\right)^2 = -\frac{a^2}{4b}$

As $E = \frac{Y}{\overline{B}}$ the Schaefer model can be rewritten as $\overline{B} = a + b\frac{Y}{\overline{B}}$.

Solving for a and b we have:

$$b = -\frac{a}{2E_{msy}} = \overline{B} - a\left(\frac{\overline{B}}{Y}\right) \text{ and } a = -2bE_{msy} = \frac{Y}{\overline{B}}\left(\overline{B} - b\right)$$

$$a = -\frac{2E_{msy}\overline{B}^2}{2\overline{B}E_{msy} - Y} \text{ and } b = -\frac{\overline{B}^2}{2\overline{B}E_{msy} - Y}$$

Substituting for a and b in $MSY = -\frac{a^2}{4b}$ we obtain

$$MSY = \frac{E_{msy}^2\overline{B}^2}{2E_{msy}\overline{B} - Y}$$

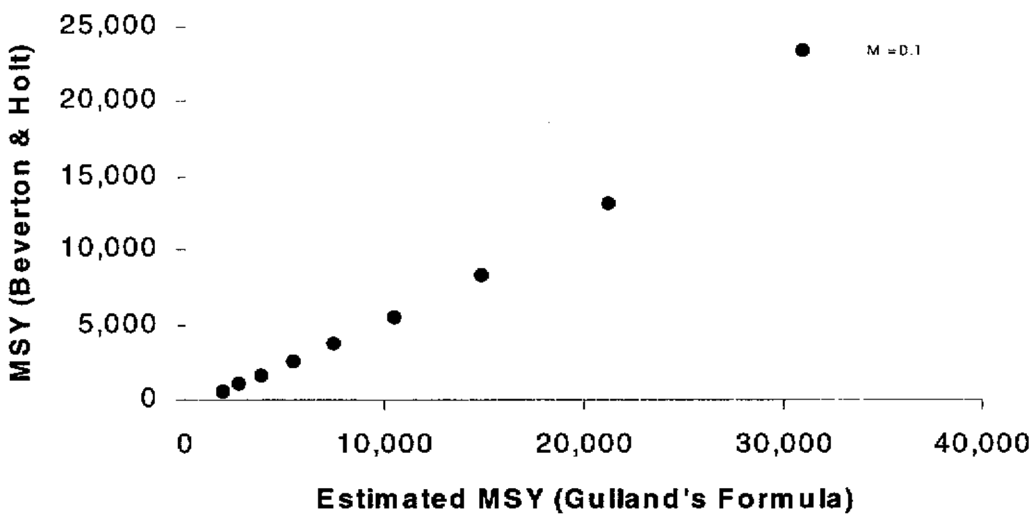
Both the Schaefer and Fox models further assume that natural mortality, M, is known and that there is a relationship between M and E_{msy} of the form $E_{msy} = kM$ where k is a constant. Therefore when E_{msy} is not known it may be replaced by kM, or in the special case where k = 1 by M, $MSY = \frac{M^2\overline{B}^2}{2M\overline{B} - Y}$. If the stock is unfished, *i.e.*

$E = 0$ $Y = 0$ $B = B_v$ this further reduces to $MSY = \frac{M\overline{B}_v}{2}$. This latter form was first proposed by Gulland (1971) as a way of estimating maximum sustainable yield.

To investigate the applicability of this formula, virgin Biomass, *Bv*, and Maximum Sustainable Yield was calculated using data provided to the Study Group and assuming a natural mortality ranging from 0.1 to 1. A Beverton Holt stock recruitment relationship was used to calculate *Bv* and MSY shown in the table below:

M	F_{MSY}	Bv	MSY	Gulland (0.5)	Gulland (0.2)
0.9	0.39	4,187	580	1,884	754
0.8	0.46	6,844	1,004	2,738	1,095
0.7	0.51	11,060	1,612	3,871	1,548
0.6	0.53	18,017	2,474	5,405	2,162
0.5	0.53	30,097	3,703	7,524	3,010
0.4	0.49	52,580	5,507	10,516	4,206
0.3	0.42	98,915	8,310	14,837	5,935
0.2	0.34	212,319	13,137	21,232	8,493
0.1	0.23	618,705	23,375	30,935	12,374

The relationship between MSY and that estimated using the Gulland formula is shown in the figure at the end of this paragraph. In each case the latter overestimates MSY by a factor close to 1 when M is low (0.1) and rising to 3 at high values of M (0.9). Beddington and Cooke (1983) drew similar conclusions from simulation studies. Replacing '0.5' by '0.2' results in lower estimates of MSY (overestimation only occurs when M exceeded 0.9). Such an adjustment retains the simplicity of the Gulland formulation while also incorporating a conservative estimate of MSY.



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APPENDIX 4

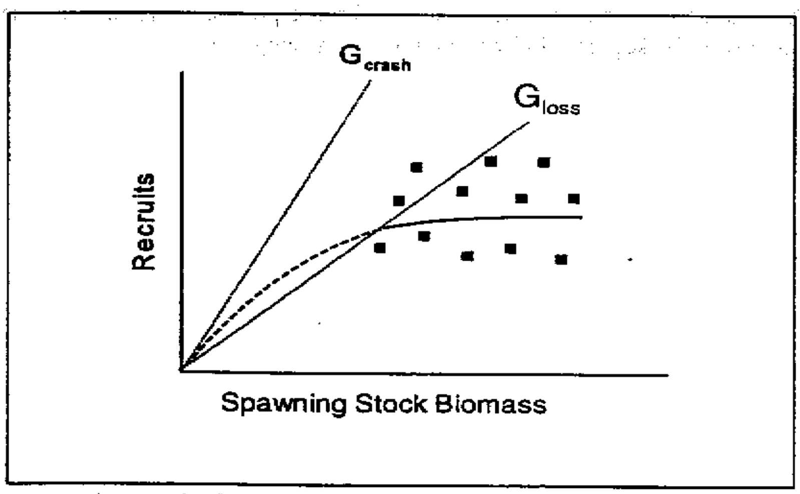
4.1 Considerations on Sustainability

A basic objective of fisheries management is that stock collapse should be avoided. In fact, any population, regardless of how lightly it is exploited, has a finite probability of extinction. No management strategy can guarantee that a population will not collapse. Defining safe biological limits is therefore an exercise in trying to define biomass thresholds below which it is considered that the risks of stock collapse are too high to be acceptable. This is difficult to do because if a stock has never collapsed (and fortunately most haven't) then it is virtually impossible to specify the conditions under which collapse is highly probable. A common rule of thumb used in the past was to examine the time series of spawning stock size and determine the lowest spawning stock size from which the stock had been seen to recover. However, the observation that the stock has recovered once does not mean it will recover again from the same spawning stock biomass.

More recently the idea of safe biological limits has been developed in the context of the Precautionary Approach. This changes the emphasis from trying to identify dangerous exploitation regimes to trying to keep exploitation away from regions of unknown, and possibly dangerous, exploitation. For stocks with a long measured history of exploitation, this effectively means trying to keep the stock in the region where exploitation is known to be "safe". This avoids the need to define areas of exploitation which are known to be dangerous and for which there are rarely adequate data. A framework which illustrates this problem is shown below. This shows the stock recruitment data partitioned by the replacement line, G_{loss}, in the region of the lowest observed biomass, B_{loss}. Replacement lines (and hence exploitation regimes) to the left of the line result in unknown population dynamics. For lines to the right of the partition, something is known of the population dynamics, and where there is no evidence of recruitment failure in the data, this region can be considered a minimally safe region. Where the stock recruitment data do show evidence of recruitment failure, G_{loss} is an approximation of G_{crash}, the replacement line at which stock collapse is expected. Here there is more knowledge about the region where stock collapse can occur.

For many stocks there will be insufficient data for G_{loss} to make a meaningful distinction between "known" and "unknown" regions of population dynamics. In these cases there may be reasons to choose limit values which allow a larger probability of exploring regions of unknown population dynamics. This might occur, for example, in a relatively new fishery exploiting a hitherto lightly exploited stock.

Replacement lines are identified above in relation to the stock-recruit data. It is possible to calculate the fishing mortality rate associated with these lines given estimates of the exploitation pattern, growth rate, natural mortality and maturity. Thus it is possible to find values of F corresponding to G_{loss} and G_{crash}. These values will often be the values of F_{lim} delimiting the region of parameter space where fishing is considered safe.



An example of typical stock recruit data where there is insufficient information to define the recruitment function near the origin (dotted line). G_{crash} is the slope of the stock-recruitment function at the origin and is the replacement line which would lead to stock collapse. G_{loss} is the replacement line which gives an equilibrium at the lowest observed spawning stock biomass.

APPENDIX 5

5.1 Alternate Text for Guidance to Working Groups

Fishery management is about managing the activities of humans, not those of the fish. Therefore, the scope for action, in a precautionary approach, is mostly concerned with ensuring that the fishing mortality which is the result of human actions does not exceed a certain undesirable threshold. Accordingly, in identifying reference points to be used in the precautionary approach, in most cases the starting point will be to suggest an F_{pa}, which satisfies the criteria of sustainability and low risk of stock collapse. The F_{pa} should be regarded as an upper limit to the range of fishing mortalities compatible with a precautionary approach.

F_{pa} should certainly not imply recruitment overfishing. Thus, if F_{MSY} is well defined, this would be a good candidate, if not, $F_{0.1}$ if it is smaller than F_{MSY} could be used. Simulations should be used, if possible, to verify that when fishing at F_{pa} there is a low risk of reaching B_{lim}. If simulations are not possible, F_{med}, computed from a range of SSB's where the recruitment does not seem to be reduced, can be used. If both F_{MSY} and F_{med} (from a range of SSB's where the recruitment does not seem to be reduced), are available, the lowest of the two values should be selected as F_{pa}.

B_{lim} is a limit reference point, it is a spawning biomass which should be avoided with high probability, when the stock is above that limit. When the biomass is below B_{lim}, management measures should aim at rebuilding biomass above B_{lim} as quickly as possible. B_{lim} should represent the biomass below which the recruitment is expected to be reduced. If it is not possible to identify such a threshold from available data, B_{lim} may be taken as the lowest observed biomass. There may be cases (lightly exploited stocks) where taking the lowest observed SSB as B_{lim} may be more restrictive than necessary. In such cases there will normally be no particular trend in the recruitment as function of SSB. A possible B_{lim} may then be the 5 percentile of the SSB variation at F_{pa}, assuming the distribution of recruitments in the existing data.

B_{pa} is a spawning biomass at which action should be taken to ensure a high probability that B_{lim} will not be reached. Normally, the action will imply some form of reduction in fishing mortality F_{pa}. Thus, the role of B_{pa} is to signal that something seems to go wrong and that action should be taken in order to try and rectify the situation. Therefore, B_{pa} should be set at a value below the equilibrium biomass at F_{pa}, a value unlikely to be reached if F_{pa} is adhered to. However, B_{pa} should be sufficiently high that there is a low risk that the true SSB is below B_{lim}. This will depend both on the precision of the assessment and the strength of the measures that can be taken when B_{pa} is exceeded. $B_{lim}*\exp(1.645*\delta)$, where δ is the assumed CV of the assessment (usually 0.2–0.3), can be a tentative value.

F_{lim} is a fishing mortality that is not sustainable, and which should be avoided with high probability. An obvious candidate for F_{lim} is F_{crash}. F_{lim} is not necessary for advising on precautionary management. Very often, estimates of F_{crash} will be very uncertain. F_{loss} can be a substitute if there is reason to believe that this will lead to collapse, if not, F_{lim} should be left undefined. If F_{lim} is defined, F_{pa} should be such that the risk that the true F is above F_{lim} when F_{pa} is intended, is small.

In exceptional cases, these guidelines will not give sensible reference points. Therefore, the use of the reference points, as outlined above, should always be kept in mind when numbers are suggested.