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**REPORT OF THE
STUDY GROUP ON
THE PRECAUTIONARY APPROACH
TO FISHERIES MANAGEMENT**

**ICES Headquarters
5-11 February 1997**

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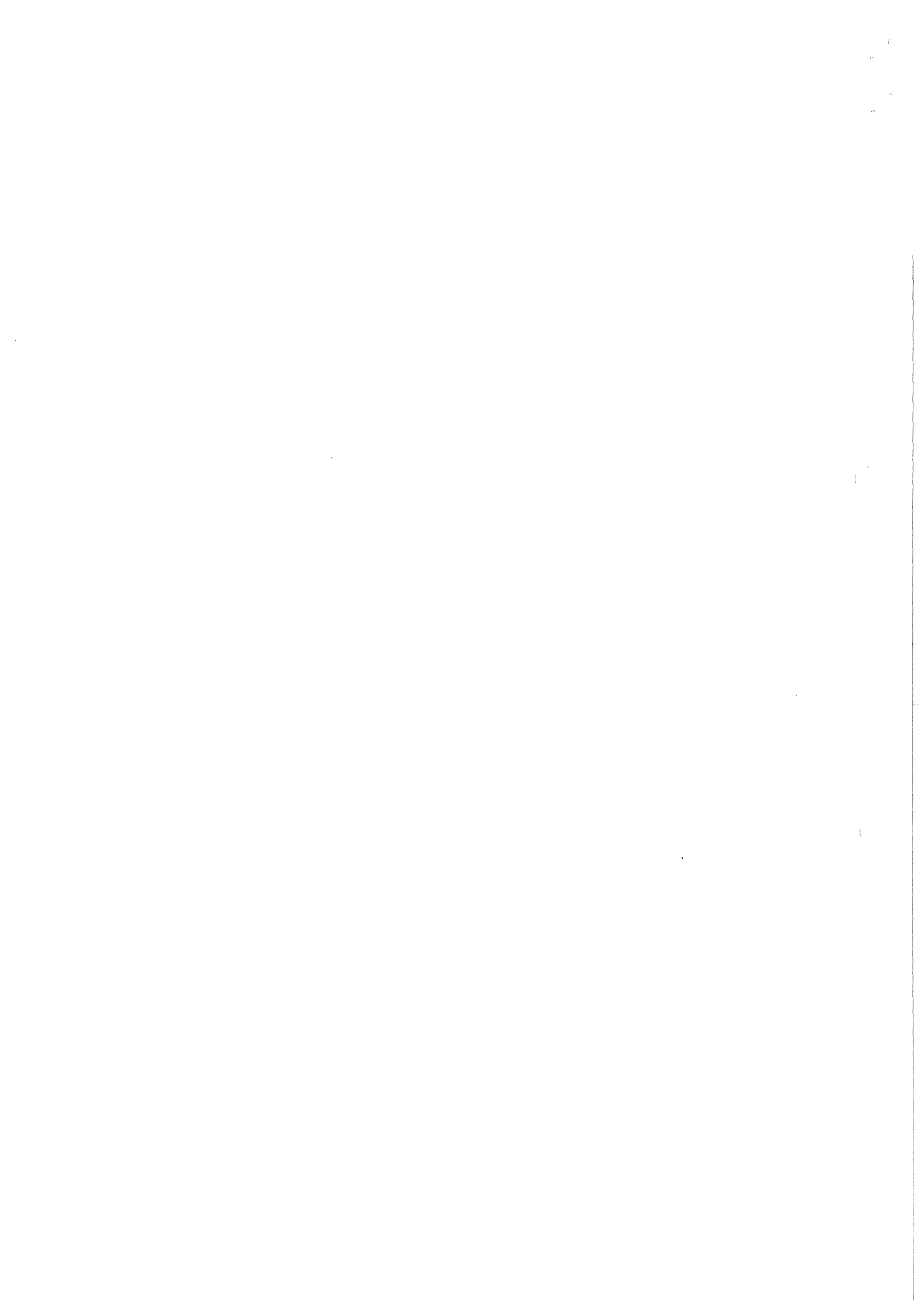


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1 INTRODUCTION

1.1 Participants

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1.2 Terms of Reference

It was decided at the 84th Annual Science Conference (C.Res. 1996/2:14:19) that a **Study Group on the Precautionary Approach to Fisheries Management** [SGPAFM], with experts to be identified by ACFM, in consultation with ICES Delegates, at its October/November 1996 meeting and to be chaired by the Chairman of ACFM, will meet at national expense at ICES Headquarters, from 5–11 February 1997, to draft a new form of ACFM advice incorporating the Precautionary Approach. A report will be provided to ACFM at its meeting in May 1997. The ACFM Chairman will attend at Council expense.

2 THE PRECAUTIONARY APPROACH

2.1 The Need for a Precautionary Approach

The precautionary approach, sustainable development, rational exploitation and responsible fishing have been given a central place in international conferences and agreements devoted to the environment and fisheries. Some of the more relevant definitions and statements are given below (FAO, 1995):

“Sustainable development has been defined as “the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable.” (FAO Council, 94th Session, 1988).

Principle 15 of the Rio declaration of the UN Conference on Environment and Development (Rio de Janeiro, 1992) states that “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.”

The General principles and Article 6.5 of the FAO International Code of Conduct for Responsible Fisheries adopted by the FAO Conference in 1995, prescribe a precautionary approach to all fisheries, in all aquatic

systems, and regardless of their jurisdictional nature, recognizing that most problems affecting fisheries result from insufficiency of precaution in management regimes when faced with the high levels of uncertainty encountered in fisheries.

The United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (New York, 1992–1995) developed a consensus on the need to introduce or strengthen the precautionary approach to fishery management, embedding the concept of its outcome, and outlining elements for its implementation.” (FAO, 1995, page 1)

As far as Member States of the European Union are concerned, explicitly binding provisions related to responsible use and management of natural resources can be found under Title XVI of the Treaty on European Union (Maastricht, February 1992) devoted to environmental issues (full text provided in Annex II). Specifically, the Treaty states that the *"Community policy on the environment shall contribute to pursuit of the following objectives: [...] prudent and rational utilization of natural resources; [...]"* (Article 130r(1)). Article 130r(2) further states that: *"Community policy on the environment [...] shall be based on the precautionary principle and on the principles that preventative action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay. Environmental protection requirements must be integrated into the definition and implementation of other Community policies."* The latter include the Common Fisheries Policy.

Not all international instruments are binding, and the precise wording of even the most legally stringent often leaves considerable room for interpretation. It is not easy, therefore, and possibly not wise, for ICES to attempt to reconsider the bases for its advice in such a way as to accommodate all aspects of all relevant instruments. These international instruments provide, nevertheless, a strong and useful point of departure.

Whilst detailed interpretation is open to debate, there can be no disagreement that sustainable, productive fisheries require management approaches which ensure a high probability of stocks being able to replenish themselves. Because of the inherent uncertainty in all aspects of fisheries management (assessment, regulation and enforcement), this can only be achieved by taking a precautionary approach. Such an approach needs to be adopted for all aspects of management, *"from planning through implementation, enforcement and monitoring to re-evaluation"* (FAO, 1995, page 7), not just in the scientific bases for advice.

This Study Group has been convened to examine how ICES should implement the precautionary approach in the provision of scientific advice in order to help fishery management agencies adopt a precautionary approach to decision-making and fishery management plan implementation.

2.2 What is the Precautionary Approach?

The international agreements and instruments referred to above show that a consensus view exists that a precautionary approach is required for conducting and managing fisheries. Because the introduction of the precautionary approach is likely to lead to controversial interpretations of what the precautionary approach actually is, the Study Group considered it precautionary to adhere as closely as possible to the interpretation of the concept expressed in approved international agreements. Two of the instruments, specifically dealing with fisheries, are of particular relevance: the FAO Code of Conduct for Responsible Fisheries (FAO, 1995b) and the UN Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (Doulman, 1995).

Article 7.5 of the FAO Code of Conduct is specifically devoted to the precautionary approach. Paragraph 7.5.1 stipulates

"States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures." Paragraph 7.5.2 states: "In implementing the precautionary approach, States should take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities, including discards, on non-target and associated and dependent species as well as environmental and socio-economic conditions".

Paragraph 7.5.3 points to the need of defining reference points:

"States and subregional or regional fisheries management organisations and arrangements should, on the basis of the best scientific evidence available, inter alia, determine:

- a) stock specific target reference points and, at the same time, the action to be taken if they are exceeded; and*
- b) stock specific limit reference points and, at the same time, the action to be taken if they are exceeded; when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded."*

In respect to Paragraph 12.13 of Article 12, on fisheries research:

"States should promote the use of research results as a basis for the setting of management objectives, reference points and performance criteria, as well as for ensuring adequate linkage between applied research and fisheries management."

In its Article 5(c), the UN Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks stipulates that the precautionary approach should be applied in accordance with Article 6. Three paragraphs are of particular relevance:

6.3. In implementing the precautionary approach, States shall:

- (a) improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty;*
- (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;*
- (c) take into account, inter alia uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions; and*
- (d) develop data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans which are necessary to ensure the conservation of such species and to protect habitats of special concern.*

6.4. 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.

6.5. Where the status of target stocks or non-target or associated or dependent species is of concern, States shall subject such stocks and species to enhanced monitoring in order to review their status and the efficacy of conservation and management measures. They shall revise those measures regularly in the light of new information.

Annex II, referred to in article 6.3(b) further specifies how reference points should be defined and handled. Since all its provisions are pertinent, it is reproduced in totality:

ANNEX II

GUIDELINES FOR THE APPLICATION OF PRECAUTIONARY REFERENCE POINTS IN CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

1. A precautionary reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management.
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.
4. Management strategies shall seek to maintain or restore populations of harvested stocks, and where necessary associated of dependent species, 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. Fishery management strategies shall ensure that target reference points are not exceeded on average.
6. When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. Provisional reference points may be established by analogy to similar and better-known stocks. In such situations, the fishery shall be subject to enhanced monitoring so as to enable revision of provisional reference points as improved information becomes available.
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.

The definition of Precautionary Approach agreed in these instruments was summarised at the FAO Technical Consultation on the Precautionary Approach to Fisheries held at Lysekil, Sweden (FAO 1995) as:

...the precautionary approach exercises prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values (page 6) [...] and the need to take action with incomplete knowledge (page 4).

The adoption of the precautionary approach has considerable implications for fishery management agencies and the fishing industry. It also provides an impressive list of tasks which the scientific community, in general, and ICES, in particular, needs to address.

In particular, point 5 in Annex II above says that a precautionary approach implies having more than a 50% probability of reaching the target reference point while point 7 suggests F_{MSY} as a minimum standard for a fishing mortality limit reference point. This implies that fishery management agencies that have chosen a limit fishing mortality above F_{MSY} would have to demonstrate why it is considered to be precautionary.

2.2.1 Approach vs Principle

There is often confusion between the Precautionary Approach and the Precautionary Principle. Garcia (1996) provides the following interpretation: "The term 'approach' is apparently more generally accepted by governments in the fisheries arena because it implies more flexibility, admitting the possibility of adapting technology and measures to socio-economic conditions, consistent with the requirement for sustainability. It is particularly more appropriate for fisheries because consequences of errors in their development or mismanagement are unlikely to threaten the future of humanity and, in most cases are reversible. On the contrary, the term 'principle' has developed a negative undertone because it is usually given a radical interpretation and has led to the outright ban of technologies, e.g., in the case of whaling and in the Large Scale Pelagic Driftnet Fishing, and is sometimes considered incompatible with the concept of sustainable use."(p. 6). ACFM will therefore try to apply the precautionary approach. Whenever ACFM will refer to the precautionary principle it will explicitly say so.

2.3 Implications for ICES

The tasks required of ICES in response to the adoption of the precautionary approach are both technical and advisory. The international instruments cited in Section 2.2 call for the following technical developments:

1. the determination of reference points, with a priority for limit reference points that define the constraints on long-term sustainability, both in theory and as applicable to each stock;
2. improvements in the methods for dealing with uncertainties, notably in relation to evaluating the risk of either approaching or exceeding the limit reference points;
3. the evaluation of how well alternative harvest control rules either maintain stocks in, or restore them to, healthy states.

These developments come in addition to assessments of the size, productivity and state of the stocks, and to improved understanding of their biology, which constitute essential pre-conditions of progress in these new directions.

The advisory implications suggest that ICES should:

1. explicitly consider and incorporate uncertainty about the state of stocks into management scenarios; explain clearly and usefully the implications of uncertainty to fishery management agencies;
2. propose thresholds which ensure that limit reference points are not exceeded, taking into account existing knowledge and uncertainties;
3. encourage and assist fishery management agencies in formulating fisheries management and recovery plans. To do this effectively may require ICES to assist fishery management agencies in the development of coherent, measurable objectives;
4. quantify and advise on the effects of fisheries on target and non target species, and on biodiversity and habitats;
5. provide advice on fishing fleets and multispecies fisheries systems as well as on single stocks;
6. evaluate fisheries management systems incorporating biological, social and economic factors as appropriate.

ICES could also advise and comment on how well other aspects of management conform to the precautionary approach with respect to:

1. the existence, compatibility and measurability of objectives which would influence advice and the choice of targets;
2. the existence and choice of limit and target reference points and management plans;
3. the existence, appropriateness and effectiveness of recovery plans;

4. the effectiveness of measures taken to monitor and restrict exploitation rate;
5. the effectiveness of measures explicitly taken to protect non target species, biodiversity and habitats.

In order for ICES advice to be helpful in maintaining stocks within safe biological limits, the above factors should be addressed by fishery management agencies. It is suggested that ACFM should formally evaluate whether this has been done. ICES cannot, however, comment on all aspects of the precautionary approach, such as adequate consultation, etc. Therefore, ICES could say that the management of certain stocks did not conform to the precautionary approach where the above factors were deficient. It would not be in a position to say whether or not management accorded fully with the precautionary approach.

It is intended that the new form of advice from ACFM will address all of the above points on which ICES is competent to advise and comment.

2.4 Implications for Current Fishery Management Agencies and the Fishing Industry

Most of the current fisheries management regimes in the NE Atlantic were established before the formulation of the precautionary approach and it should not come as a surprise that they are not fully in accordance with the precautionary approach as set out in the various international instruments cited above. To apply the precautionary approach, fishery management agencies will therefore need to improve and adapt numerous aspects of current practice. Only some aspects fall within the remit of ICES as indicated above.

Future ICES advice will allow for uncertainty in both the understanding of the state of the stocks and the effects of future management actions. This implies that when less is known fishery management agencies should adopt a more cautious choice. This may require a change in culture towards a management approach less focused on and influenced by short-term considerations, and more concerned with long-term sustainability.

Proximate objectives of fisheries management are sometimes expressed in terms of fishing mortality and of stock size to be achieved (c.f. the EU/Norwegian agreement). However, real objectives of fisheries management are not concerned with the parameters of fish stocks but with achieving the social and economic benefits compatible with the sustainable existence of the fishery.

Socio-economic factors to be considered in establishing objectives for the management of fisheries might, for example, imply the sustainable maximisation of yield, or of employment, either in the fishing industry or in the more general fishing sector. Unfortunately, all desirable objectives cannot usually be met simultaneously, and one of the main roles of fishery management agencies in a precautionary approach would be to derive trade-offs between competing objectives in consultation with interested parties. Fishery management agencies could, for example, pursue economic goals such as high profitability (which implies low exploitation rates and high fishing efficiency); social goals such as high employment (which require higher exploitation rates and/or lower efficiency); or some quantified trade-off between these conflicting objectives. Whichever approach is taken, it will be necessary to quantify objectives and trade-offs if ICES is to translate them into measurable factors such as levels of fishing mortality.

Fishery management is concerned with the management of the activities of humans, not those of the fish, and the way that fishery management agencies attempt to restrict and manage the level of exploitation of fisheries (e.g. through TAC controls, effort controls, technical measures, etc.) has implications for the way ICES provides advice. The fishery management tools used also have implications for the quality of data and the consequent ability of ICES to undertake adequate assessments - it should be obvious that the precision of the advice decreases when the quality of data deteriorates. Therefore, to provide advice of appropriate precision, alternative monitoring approaches may need to be developed when particular management approaches/tools reduce the quality of the data necessary to provide advice.

It cannot be sufficiently stressed that a precautionary approach to fisheries management requires fishery management agencies to find effective means to restrict fishing mortality within safe biological limits. In the absence of such means, fishing mortality will increase through learning and increased fishing efficiency and it will eventually reach unsustainably high values. Therefore, precautionary management advice from ICES would not by itself ensure resource sustainability if there are no means to effectively implement the advice.

3 REFERENCE POINTS

As seen in Sections 2.2 and 2.3 above, reference points are a key concept in implementing a precautionary approach. Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks is reproduced in Section 2.2 above, but points relevant to the distinction between target and limit reference points are given below:

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 introduction of the concept of limit reference points to be avoided with a high probability may in some cases complicate the utilisation of target reference points, especially when the precision of the data is low and the uncertainties are high. In such cases, it may be necessary to aim for a fishing mortality lower than the target in order to ensure that the limit is not exceeded (Caddy and McGarvey, 1996).

The table below lists some of the most commonly used reference points (adapted from Caddy and Mahon, 1995). Those reference points which could be considered as limit reference points are identified as such. The others could be either targets or thresholds depending on the particular case being investigated. This is intended as a preliminary classification, for indicative purposes and to avoid misinterpreting limit reference points as target reference points.

Ref. Pt.	Definition	Data needs	Possible PA-usage
$F_{0.1}$	F at which the slope of the Y/R curve is 10% of its value near the origin	Weight at age, natural mortality, exploitation pattern	
F_{max}	F giving the maximum yield on a Y/R curve	Weight at age, natural mortality, exploitation pattern	LIMIT ¹
F_{low}	F corresponding to a SSB/R equal to the inverse of the 10% percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.	

F_{med}	F corresponding to a SSB/R equal to the inverse of the 50th percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.	LIMIT ¹
F_{high}	F corresponding to a SSB/R equal to the inverse of the 90% percentile of the observed R/SSB	Data series of spawning stock size and recruitment, weight and maturity at age, natural mortality, exploitation pattern.	
F_{MSY}	F corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship or general production models	LIMIT ¹
2/3 F_{MSY}	2/3 of F _{MSY}	as above	
F_{30% SPR}	F corresponding to a SSB/R which is 30% of the SSB/R obtained when F=0	Weight and maturity at age, natural mortality, exploitation pattern.	LIMIT ¹
F_{crash}	F corresponding to the higher intersection of the equilibrium yield with the F axis as estimated by a production model; could also be expressed as the tangent through the origin of a Stock-Recruitment relationship.	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship	LIMIT ¹
F_{loss}	F corresponding to a SSB/R equal to the inverse of R/SSB at the Lowest Observed Spawning Stock -LOSS	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship	LIMIT ¹
F_{comfie}	F corresponding to the minimum of F _{med} , F _{MSY} and F _{crash}		LIMIT ¹
F ≥ M	Empirical (for top predators)	M and sustainable F's for similar resources	
F < M	As above (for small pelagic species)	M and sustainable F's for similar resources	
Z_{mbp}	Level of total mortality at which the maximum biological production is obtained from the stock	Annual data series of standard catch rate and total mortality	
B_{MSY}	Biomass corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship or general production models	LIMIT ¹
MBAL	A value of SSB below which the probability of reduced recruitment increases	Data series of spawning stock size and recruitment (not necessarily from a VPA)	LIMIT ¹
B_{50% R}	The level of spawning stock at which average recruitment is one half of the maximum of the underlying stock-recruitment relationship.	Stock recruitment relationship (not necessarily from a VPA)	LIMIT ¹
B_{90% R, 90% Surv}	Spawning stock corresponding to the intersection of the 90th percentile of observed survival rate (R/S) and the 90th percentile of the recruitment observations	Data series of spawning stock size and recruitment	LIMIT ¹

B_{20%} B_{virg}	Level of spawning stock corresponding to a fraction (here 20%) of the unexploited biomass. Virgin biomass is estimated as the point where the replacement line for F=0 intersects the stock-recruitment relationship or as the biomass from a spawning stock per recruit curve when F=0 and average recruitment is assumed	Weight at age, natural mortality, exploitation pattern and a stock recruitment relationship	LIMIT ¹
B_{loss}	Lowest observed stock size	Data series of spawning stock size	LIMIT ¹

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

3.1 Calculations of Reference Points

3.1.1 Background - Stock and Recruitment Relationships (S-R) and spawning stock biomass per recruit calculations (SSB/R)

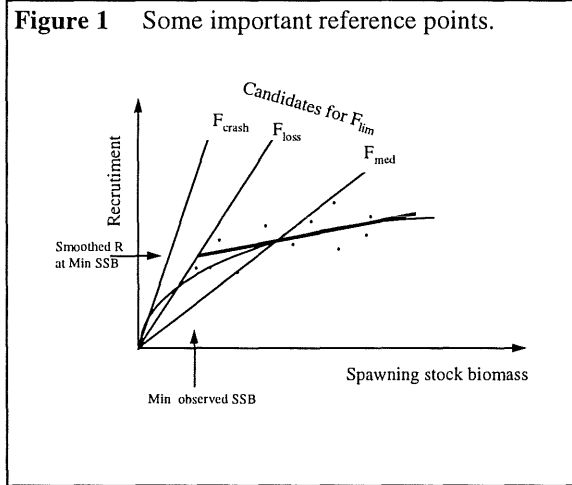
With a few rare exceptions, the identification of the relationship between the parent stock and subsequent recruitment has remained elusive for marine fishes. However, recent work (Marshall *et al.*, 1996) suggests that by taking into account the sex ratio and age composition of the spawning stock to refine the estimates of egg production, it is possible to see more clearly that such a relationship does indeed exist. The precautionary approach, however, dictates that unless it is scientifically demonstrated that there is no relationship between the parent stock and subsequent recruitment, such a relationship should be assumed to exist, even if the data are ambiguous. This represents a substantial philosophical change from past practice.

The sustainability of harvesting is largely determined by two factors, the relationship between the size of spawning stock (SSB) and the annual number of offspring (the recruits) produced, and the subsequent survival of the recruits on entering the fishery. This is illustrated in Figure 1 which shows a theoretical stock-recruitment curve and a few important survivorship lines. The intersection of the stock-recruitment line with one of the survivorship lines is an equilibrium point to which the population is attracted (Beverton & Holt, 1957). If the survivorship line lies above the stock recruitment curve (as in F_{crash}) there is no non-zero equilibrium point and the stock will eventually collapse to the origin. The slope of the survivorship line is affected by the fishing mortality rate, F , and the more heavily the stock is exploited, the steeper the slope. This line is also called a replacement line since it defines the survivorship needed to replace the spawning stock in the future. This line is estimated by fixing a fishing mortality rate and computing the biomass-per-recruit (SSB/R) corresponding to this fishing mortality. This quantity is used to draw the replacement line which has a slope of $1/(SSB/R)$ in the S-R diagram. Given a set of weights at age, maturity at age and natural mortality rate, any fishing mortality corresponds to a straight line through the origin and *vice versa*, i.e. given any line or R/S ratio, a corresponding fishing mortality can be found (within the limits implied by $0 < F < \infty$).

Typically, stock-recruitment plots contain a lot of noise and it is generally difficult to establish conclusively that there exists a relationship between the parent stock and subsequent recruitment. However, in a precautionary approach, as indicated above, such a relationship must be assumed to exist. Two alternative forms of analysis of stock and recruitment data have been used: a non-parametric and a parametric approach. In the non-parametric approach, smoothers have been used in an attempt to elucidate the, often weak, signal between spawning stock biomass and subsequent recruitment (Pope and Macer, 1996; Cook, Annex I; Evans and Rice, 1988) and in some cases a simple arithmetic or geometric mean has been used (Butterworth and Bergh, 1993). This approach will allow calculation of a recruitment value within the range of observed spawning stock biomasses, and in particular of the recruitment corresponding to the lowest observed spawning stock biomass.

The most commonly used parametric relationships within ICES are the Ricker, Beverton-Holt or Shepherd functions. These functions can be estimated using e.g. non-linear least squares on logged recruitment data (i.e. assuming log normal errors). The resulting fitted parameters allow the calculation of recruitment values for any spawning stock biomass, not only those observed in the past.

In a slightly different approach, Sissenwine and Shepherd (1987) suggested that the median R/S ratio observed for a stock with observations over a range of exploitation rates and stock sizes, provides an estimate of the typical productivity of the stock. By inverting this ratio to SSB/R, it is possible to calculate a fishing mortality (given a set of growth, maturity and natural mortality parameters) called F_{MED} in a spawning stock biomass per recruit calculation which corresponds to the median SSB/R. Note that changes in growth, maturity and natural mortality will imply changes in the numerical value of F_{MED} , even though the slope from the stock and recruitment plot does not change.



Whatever approach is chosen, it is clear that, given a point on an S-R curve, a fishing mortality and a replacement line which passes through this point can be found. For example, one can take the lowest observed SSB value and estimate the corresponding expected recruitment. When this expected recruitment is estimated using a non-parametric smoother, the slope of the line to the origin is termed G_{loss} and the corresponding fishing mortality is called F_{loss} (Cook, Annex I).

For a parametric curve such as the Ricker curve, one has a formula describing the S-R curve:

$$R = \alpha S e^{-S/K}$$

This formula can be rewritten as

$$S = K \ln(\alpha S/R)$$

When SSB/R is computed from the replacement at a given fishing mortality, as $(SSB/R)_F$, this formula can be used to compute the equilibrium SSB which corresponds to the intersection between the S-R curve and the replacement line (Beverton and Holt, 1957; Shepherd, 1982) according to the following formula for the equilibrium spawning stock biomass:

$$S_e = K \ln(\alpha (S/R)_F)$$

Such a formula enables the computation of an equilibrium biomass corresponding to a predefined fishing mortality. In particular, it is trivial to extend regular yield-per-recruit and spawning-stock-per-recruit computations to include the equilibrium SSB. This immediately also gives (through the S-R function) the equilibrium recruitment and hence also (through Y/R) the equilibrium yield.

3.1.2 Estimating MSY

MSY will follow automatically from the above computations, if the Y/R and SSB/R computations are given in a table for a range of fishing mortalities. This table is extended to give S, R and Y. The maximum in the yield is MSY and the corresponding fishing mortality is F_{MSY} . This fishing mortality may depend heavily on the assumed parametric relationship between stock and recruitment (Cook *et al.* 1997).

3.1.3 Obtaining F_{lim}

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.

When a parametric S-R curve has been estimated, a slope at the origin is also estimated, but it is based on the curve fitting to observations which are usually not close to the origin. This particular extrapolation can be very severe in some cases, particularly when the slope inherent in the data is zero or negative. It is therefore desirable to consider also data-driven approaches such as F_{med} and F_{loss} where replacement lines are forced to go through the S-R data range.

It is seen above that a given level of biomass and recruitment in the S-R plot can provide a corresponding fishing mortality. In particular, a risky level of biomass can be translated into a corresponding fishing mortality. In particular, the minimum observed SSB and corresponding recruitment value provides a fishing mortality which will probably drive the stock below the lowest observed. The fishing mortality F_{loss} estimates this fishing mortality rate.

The fishing mortality F_{med} , on the other hand, 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} 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.

3.1.4 F_{lim} in data-poor situations

The approach described above implied a stock and recruitment analysis based on a reconstruction of past recruitment and spawning stock biomass using an analytical method such as VPA. It could be possible, however, to perform such a stock and recruitment analysis from other sources of data, such as survey results which estimate reliably both spawning stock biomass and recruitment. Particular care should be taken, though, to ensure that the measurement units are on a comparable scale. If the recruits are less available to the survey than the mature portion of the stock, then the median SSB/R would equate to a lower fishing mortality and therefore would be precautionary. This would not be the case if the recruits were more available than the mature portion.

For stocks where little or no stock and recruitment data are available, yield per recruit and spawning stock biomass per recruit (SSB/R) computations could be undertaken. The Study Group agrees with Mace and Sissenwine (1993) and Rosenberg *et al.* (1994) that a fishing mortality which provides 30% of the virgin ($F=0$) SSB/R would be a reasonable first estimate of a limit reference point until more information is gathered.

3.1.5 Biomass limit points, B_{lim}

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 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.

3.1.6 B_{lim} in data-poor situations

Estimates of biomass and recruitment are not available for all stocks and there is a requirement to see what can be done in the case when the only information on a stock are landings and an index series.

Suppose, therefore, that a biomass index series is available. This can be a survey-based measure or a CPUE series. A simple approach in this case is to select a prespecified value for the index as a reference point. If no corresponding measure of virgin biomass is available, then the maximum index can be used in its place. Naturally, if the series is highly variable, then it should be smoothed. B_{lim} can now be set, e.g., at 30% of the maximum observed index. This may not correspond to a stock collapse, but it certainly corresponds to a considerable depletion. Since there should be a high probability of staying away from this biomass index, another value is required to trigger action to be undertaken in order to avoid dropping to B_{lim} .

3.1.7 Time stability of reference points

The estimates of reference points relating to fishing mortality depend on the exploitation pattern and natural mortality while those relating to yield (MSY, Y/R) and spawning stock size (B_{MSY} and SSB/R) depend on 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 Uncertainties

The need for a precautionary approach is closely linked to uncertainties: the greater the uncertainties, the greater the need to be precautionary. Indeed if the consequences of taking or not taking a given action were known perfectly, there would be no need to exercise precaution. Although it is unlikely that uncertainties will ever be entirely eliminated, the precautionary approach provides a strong justification for increasing the knowledge on how stocks and/or fisheries will react to various management measures.

3.3 Safe Biological Limits

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.

3.4 Multispecies Considerations

Fisheries management advice world-wide remains largely monospecific, although interactions between species and with the environment exist. ACFM incorporates multispecies considerations whenever the scientific basis for doing so exists, but this remains the exception rather than the norm. Therefore, this is a case where uncertainties exist and research would be required to reduce them.

3.5 Implementation

Limit reference points are defined as values to be exceeded only with a low probability, but the corresponding probability needs to be clearly defined. If exceedance is taken to refer to exceeding the limit for an extended time period, then obviously this probability must be very low.

When a single stock is followed through a number of years, one can compute the fraction of years in which e.g. the fishing mortality exceeds F_{crash} . This is the probability which needs to remain very small in order to maintain sustainability of the resource.

The precautionary basis for advice given by ACFM will be that, for a given stock, the probability of exceeding the limit should be no more than 5% in any given year.

For both biomass and fishing mortality limit reference points, therefore, ACFM needs to formulate the recommended limitations on fishing mortality in such a fashion that the probability is satisfied. This implies that ACFM must recommend that fishing mortality stays below a value considerably lower than F_{lim} . In fact, if F_{lim} were known with certainty, so that there is only uncertainty in each year's F , then the recommendation for a coming year should be along the lines that F should satisfy an equation of the type:

$$F e^{2\sigma} \leq F_{lim}$$

where σ is an appropriate estimate of the uncertainty in this relation and the constant 2 reflects approximate 95% confidence. The uncertainty used to define σ must at least include the uncertainty in the fishing mortality associated with a catch prediction. A full evaluation needs to be made of the effects of uncertainty in F_{lim} and annual fishing mortality associated e.g. with predicted catch levels.

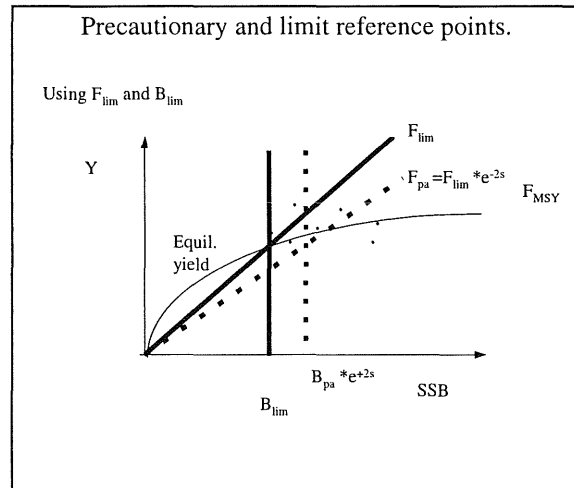
This type of upper bound on a fishing mortality satisfying the precautionary approach will be defined as the precautionary fishing mortality (see Figure above):

$$F_{pa} = F_{lim} e^{-2\sigma}$$

It must be reiterated that the value of σ needs to take into account several sources of variations and errors and will not merely reflect the current assessment uncertainty mentioned above.

Naturally, F_{pa} could be derived through a number of means:

- A medium-term simulation can provide a direct estimate of a fixed medium-term level, F_{pa} , of fishing mortality which only exceeds F_{crash} with low probability.
- It is common practice to estimate the probability distribution function $P(F_{t+1} > F_{s,q})$ as a function of next year's TAC. This can be used to deduce the TAC level that corresponds to a low probability. The usual short-term predictions will then provide the corresponding fishing mortality, F_{pa} . This approach will lead to variable precautionary fishing mortality levels.
- A precautionary fishing mortality level may have to incorporate other sources of concern. Notably, if the response time in resource management is very long, then this may have to be incorporated as a reduction in F_{pa} .
- F_{lim} is intended to be an underestimate of F_{crash} . If there is considerable uncertainty in whether this is the case, then that will have to be taken into account, leading to an increase in σ in the above notation.
- It is a general rule that any increase in any uncertainty must lead to an increase in σ .
- For most fish stocks assessed by ICES, σ is unlikely to be less than 0.2. If σ is as high as 0.35, F_{pa} will be half of F_{lim} .



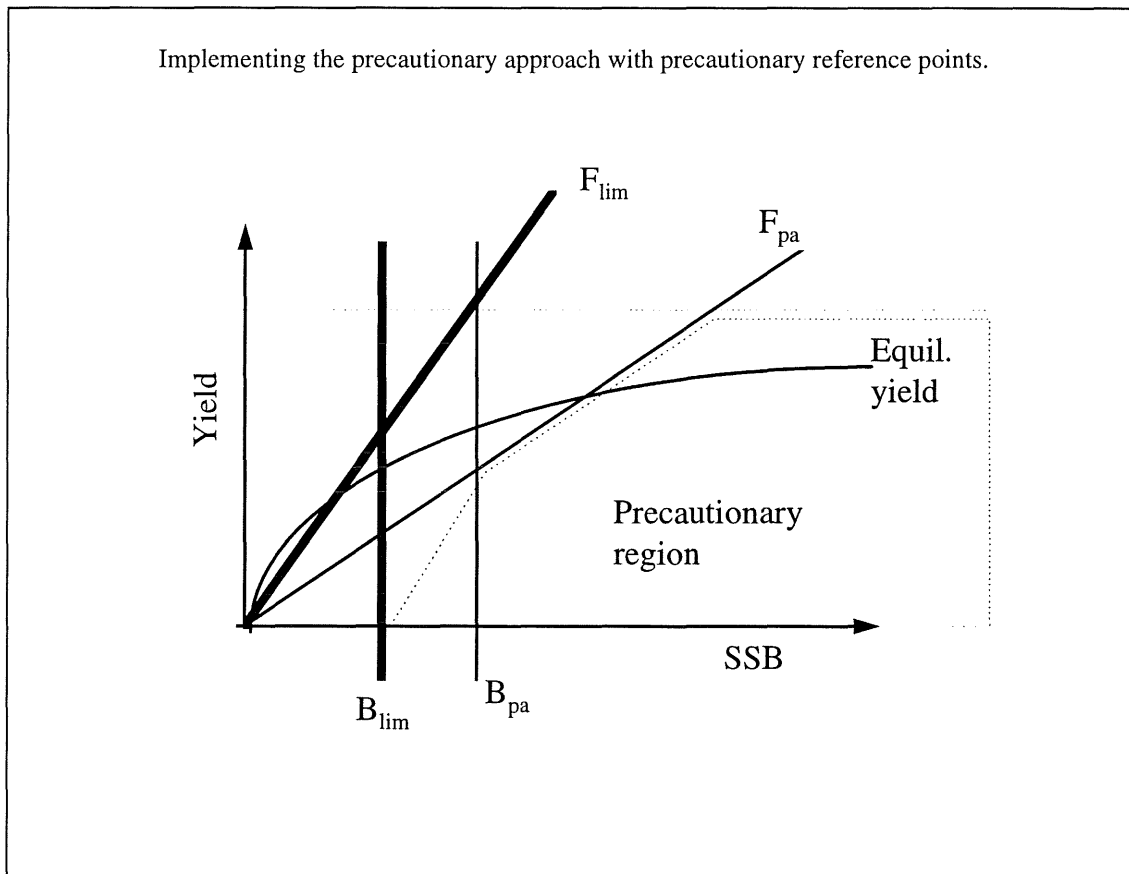
The crucial point about F_{pa} is that when the fishery is managed in such a fashion that the annual fishing mortality is at or below F_{pa} , there should be only low probability that the realised fishing mortality is not sustainable.

It should be noted that if management of the stock is such that the fishery is managed to the maximum recommended fishing mortality, then F_{pa} becomes an implicit target.

The same considerations apply to the biomass limit reference points. In particular, MBAL values which refer to critical points on the stock and recruit curve correspond to limit biomass levels, B_{lim} . In order to stay away from such levels with high probability, there is a need for the annual pointwise bounds to be set higher, i.e. the point estimate of biomass should stay above a precautionary biomass level, B_{pa} .

There are several ways of computing these biomass levels. For example, B_{pa} could be set at a level which reflects the natural fluctuations in recruitment, e.g. as the value below which it is unlikely for the stock to drift if all assumptions hold true and fishing is maintained with fishing mortality at or below F_{pa} . Alternatively, if B_{lim} is defined, then B_{pa} can be derived from this, as a higher value corresponding to the uncertainty in the annual biomass estimate.

3.6 Limit Points and Precautionary Advice



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} .

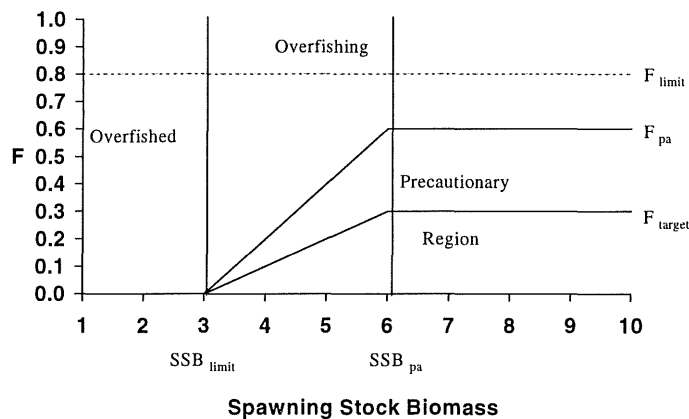
3.6.1 Harvest control rules

The precautionary approach can be implemented as a threshold harvest control rule which relates target and threshold fishing mortality rates to stock biomass. Under a control rule, fishing mortality varies as a function of stock condition. Components of a precautionary harvest control rule may include a threshold fishing mortality rate for a stock in healthy condition, a rule for progressively reducing F as biomass declines below a precautionary threshold stock biomass (regardless of the reason for low stock size) and a lower, limit biomass level, below which fishing mortality is reduced to zero (e.g., as described in Rosenberg *at al.*, 1994). An example of rules for implementation would be:

SSB	F	Catch
$SSB > SSB_{pa}$	$F < F_{pa}$ (Constraint) $F \Rightarrow F_{target}$	$C < C(F_{pa}, SSB)$ $C < C(F_{target}, SSB)$
$SSB_{limit} < SSB < SSB_{pa}$	$F = e.g., F_{pa} * \frac{(SSB - SSB_{limit})}{(SSB_{pa} - SSB_{limit})}$ (F control rule)	$C < C(F_{pa}, SSB)$ (Catch control rule)
$SSB < SSB_{limit}$	$F = 0$	$C = 0$

Graphically, this example would be depicted as:

Implementing harvest control rules consistent with the precautionary approach



Control rules may be formulated in terms of fishing mortality, fishing effort or catch. SSB and F can be indexed by proxies of stock condition through resource surveys or length structure, for example, but implemented through controls of catch. Rules can be implemented as more gradual reductions in catch or F as desired in response to changes in SSB: early warning rules can be applied to reduce F or catch even before the SSB_{pa} is reached. Similarly, more complex rules could be developed, e.g. contingent on strength of incoming year classes expected to recruit to the SSB in the near future. When SSB declines to near SSB_{pa} , F reductions would be applied regardless of whether F was close to F_{pa} or close to F_{target} . When SSB increases to levels well above SSB_{pa} , controls on catch may be desirable if estimates of yield or F are characterised by high variance.

There are several advantages to this approach (Rosenberg *et al.* 1994): The fishery continues at a reduced level after the threshold is crossed, resulting in continuity of yield; rather than open or closed fisheries depending on the stock's position relative to SSB_{limit} . At the same time, more stringent conservation measures are applied as stock status worsens; errors in estimation of SSB_{pa} become less critical; additional time and flexibility is obtained to evaluate whether the stock is in a transition phase from one stationary state to another; short-term changes in biomass levels imply only small changes in F rather than permanent or large-scale changes in fishing operations; and small changes in F may be less contentious and more easily accepted than large ones.

3.6.2 Recovery plans

Depleted stocks require rebuilding in order to prevent irreversible long-term adverse effects on the stock and the ecosystems in which they function. Stock rebuilding requires criteria for determining conditions of stock depletion and stock recovery. In a precautionary context, rebuilding is required 1) when SSB falls below SSB_{limit} , 2) when SSB falls below SSB_{pa} and F exceeds F_{pa} , or 3) when SSB is below SSB_{pa} and/or when SSB does not increase above SSB_{pa} even though $F < F_{pa}$.

Criteria for stock recovery should be an integral part of recovery plans. Any rebuilding programme should ensure that the stock increases to levels above SSB_{pa} over a pre-specified time horizon. One example of a time horizon would be one generation time in the stock, with this time reduced when SSB is close to SSB_{pa} , as:

$$\text{Rebuilding time} = \frac{SSB - SSB_{pa}}{SSB_{limit} - SSB_{pa}} * T$$

Generation time (T) could be estimated as the average age of the spawning stock in a stable age distribution where only natural mortality is acting. Generation time would then be the sum of products of the age (a), the proportion surviving to that age ($S_a = \exp(-\sum M)$), and the maturity at age (ma), divided by the sum of the products of S_a and ma or:

$$T = \frac{\sum a * S_a * ma}{\sum S_a * ma}$$

Alternatively, generation time could be the number of ages occurring naturally in the population if it were unfished (e.g. $T = 3/M$).

Exceptions may arise depending on the life history of the stock (e.g. for stocks with very high age at maturity) or when stocks fail to recover even when fisheries are closed for long periods of time (e.g. North Sea mackerel). Control rules for rebuilding should be developed to control fishing mortalities and catches in a pre-agreed way as spawning stock biomass increases. Simulation studies have demonstrated that rebuilding programmes are most effective when large reductions in fishing mortality are implemented immediately, rather than when small reductions are implemented over long periods of time. Rebuilding would also proceed more rapidly if exploitation patterns were improved at the same time, which would enable greater contributions of good year classes to spawning stock biomass.

Although a recovered stock may be defined as having spawning stock biomass above precautionary levels, additional criteria may also be applied. It may be desirable to restore an age structure to approximately that obtained at equilibrium at F_{pa} , in order to rebuild population fecundity or to buffer against recruitment failure; or, to restore a spatial distribution, to spread risk at spawning over a wider range of environmental conditions.

Similarly, any of these characteristics should be specified before stock recovery plans are implemented, so that it is clear when stock recovery is complete.

3.7 Presentation of Mortality Limits to Non Scientists

The fishing mortality rates in which ACFM expresses its advice are largely incomprehensible to non scientists. It does not give them a clear picture of the biological implications of proposals, and in this sense, it could be said that it is not precautionary. It is therefore worth considering if the information could be presented in a form more easily understandable by non-specialists.

For catch quotas the obvious form is the proportion that the TAC forms of the fishable stock, or of the spawning stock biomass.

For limits it might be worth considering expressing them in direct biological replacement terms. Possibilities might be:

Description	Example	Comment
SSB per Recruit	the stock needs each 1 year old fish to contribute 3.26 Kg of Spawning Stock	Rather obscure! Begs the question why not 2.35
Chance of Spawning	each 1 year old fish needs a 0.05 chance of spawning	Low probability will seem strange to laymen. Incomplete and emphasises reducing mortality on juveniles only
Number of spawnings per recruit	each 1 year old fish needs a chance of spawning 0.1 times	Low probability will seem strange to laymen. Incomplete and emphasises reducing mortality on juveniles only
Number of eggs per recruit	each 1 year old fish needs on average to spawn 10000 eggs	Number of eggs will seem large to laymen. However, this has some intuitive appeal
Number of eggs per egg	each egg needs to produce 2 eggs	Would need an arbitrary assumption of egg to recruit survival. Subject to challenge of the Density Dependent assumptions
Numbers of spawners per spawner	Each female spawner needs to produce at least 1 female spawner	Intuitive but subject to challenge of the Density Dependent assumptions. If we are honest it would be similar for a range of F values
Fitness etc.	Net life time contribution	Somewhat obscure

An advantage of any of these approaches over fishing mortality rate limits is that they would be invariant (or at least more invariant) to biological changes in growth, maturity and natural mortality. The simplest is probably the number of eggs per recruit. Of course this would also need translating to catch proportion for management reasons. An example of our advice would be "to sustain the fish stock requires each one year old fish to produce 10,000 eggs on average and this will require that only 25% of the stock is removed each year. This means that the amount of fishing (fishing capacity and usage) is reduced by 30% from its 1996 level."

4 THE FORM OF ADVICE

4.1 Objectives and Tasks

The terms of reference for ACFM are established as a result of requests from Commissions or ICES member governments which seek advice. The specific questions differ for each fisheries management agency, but the tasks can be summarized as follows for the major fish, shellfish, and in some cases marine mammal resources in the ICES area:

- a) To assess the stocks' historic development in terms of size, structure and biological characteristics, particularly in relation to how fisheries have affected them;
- b) To evaluate the present state of stocks and of fisheries taking account of the inherent uncertainty in the data and knowledge about underlying processes;
- c) To advise on the expected impact - short-term, mid-term and long-term - and associated biological risks, of various management measures on these stocks and, when possible, on the ecosystems in which they exist;
- d) To evaluate if fisheries management is consistent the precautionary approach;
- e) To make appropriate recommendations on management action.

Setting objectives and making decisions on strategies of fisheries management are within the province of the fisheries management agencies. The role of ACFM/ICES is to provide information and advice to help fisheries management agencies achieve the objectives they choose. In some cases, ACFM/ICES is in a position to comment on the implications of choosing certain objectives and on the feasibility of achieving them. Some objectives, such as achieving stability of both effort and yield when stock size fluctuates, may be mutually incompatible and in appropriate cases ACFM/ICES points out the biological constraints to the choice of a given set of fishery management objectives. The precautionary approach, sustainable development, rational exploitation, and responsible fishing have been the subject of international conferences and agreements devoted to the environment and fisheries. ACFM/ICES aims at providing scientific advice in accordance with such international agreements.

While it is not ACFM/ICES' role to set objectives for fisheries management it does need an objective of its own to enable it to formulate its advice according to consistent criteria conforming to the precautionary approach. ACFM/ICES' overall objective is

TO PROVIDE THE ADVICE NECESSARY TO MAINTAIN VIABLE FISHERIES WITHIN SUSTAINABLE ECOSYSTEMS¹

The actual advice takes different forms. In general, ACFM/ICES indicates the expected consequences of a variety of management scenarios relevant to each fishery. If management objectives have been explicitly defined and if they are consistent with a precautionary approach, ACFM/ICES attempts to identify options, which best meet, these objectives. In cases where management objectives have not been explicitly defined ACFM/ICES defines options which are consistent with a precautionary approach to management.

The flow of the process leading to the advice is as follows:

1. assessment of the stock/fishery: a synthesis and evaluation of available data to determine the current state of the stock or of the fishery;
2. comparison of the status of the resource/fishery with reference points in order to evaluate if conservation and sustainability criteria are met, if the resource is within safe biological limits, and if the fishery is sustainable;
3. evaluation of the effects of management actions on the stocks and on the fisheries, taking into account possible future states of nature;
4. formulation of advice – specific recommendations on management actions, which may be taken relative to the status of the resource and management objectives, including what must/could be done to improve the situation, and/or what may be done without detrimental consequences.

¹ An ecosystem is defined as sustainable if impacts of human action do not result in irretrievable loss of function of any component of the system.

4.2 Stock/Fishery Assessments

Assessments involve the use of quantitative analyses to make predictions about the reactions of fish populations or of fisheries to alternative management choices. In order to be able to perform such quantitative analyses, ACFM/ICES relies on the collection of fisheries and survey information by various national agencies. To carry out its work, ICES has established a number of working groups and the advice given represents a distillation of the assessments provided by these groups.

Stock assessment is aimed at understanding the dynamics of exploited resources and involves the estimation of a variety of population parameters, in particular mortality rates due to fishing and other causes, numbers at age (including recruitment) and spawning stock biomass. Stock assessments in which these parameters can be estimated and used in quantitative models are described as “analytical assessments”. In cases where data collection is advanced enough, interactions between exploited populations and/or technical interactions are included in the analyses, which are indicated as “multispecies assessments”. Increasingly it is recognized that the biological aspects must be considered along with socio-economic and administrative elements in more comprehensive fisheries evaluations.

While analytical assessments are attempted in as many situations as possible, this is not always successful for a number of reasons. In a number of fisheries the reliability of the data is inadequate. In others, further research is needed before reliable assessments can be made. However, it may be possible to make general statements about the state of exploitation of the stock or the degree of sustainability of the fishery.

In all cases some indication of the reliability of the assessments and forecasts will be given. A major source of uncertainty is the result of errors such as under-reporting and other forms of mis-reporting on catch records, which introduce a bias in the assessments and subsequent prognosis. This problem has, unfortunately, been growing in recent years, and is making prognoses less reliable in some fisheries and is forcing ACFM/ICES to increasingly rely on research vessel survey data.

To assess the state of stocks/fisheries and to make forecasts, ACFM/ICES is dependent on the provision of reliable data both from the fisheries and from research establishments. It cannot be stressed too forcibly that the reliability of ACFM/ICES assessments and advice depends on the quality of the data provided. In particular, the reliability of the reported national catch statistics is a matter of great concern because the reliability of some stock parameters is dependent upon the accuracy of estimated catches.

4.3 Biological Reference Points (BRP)

Once the assessment of the present state of the stock/fishery is completed, the exploitation rate and spawning stock biomass are compared with established reference points to judge if the stock is within safe biological limits and if the fishery is sustainable.

Reference points are a key concept in implementing a precautionary approach. Annex II of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks (as an example) describes the requirement for both target reference points (to be achieved) and limit reference points (to be avoided) as follows:

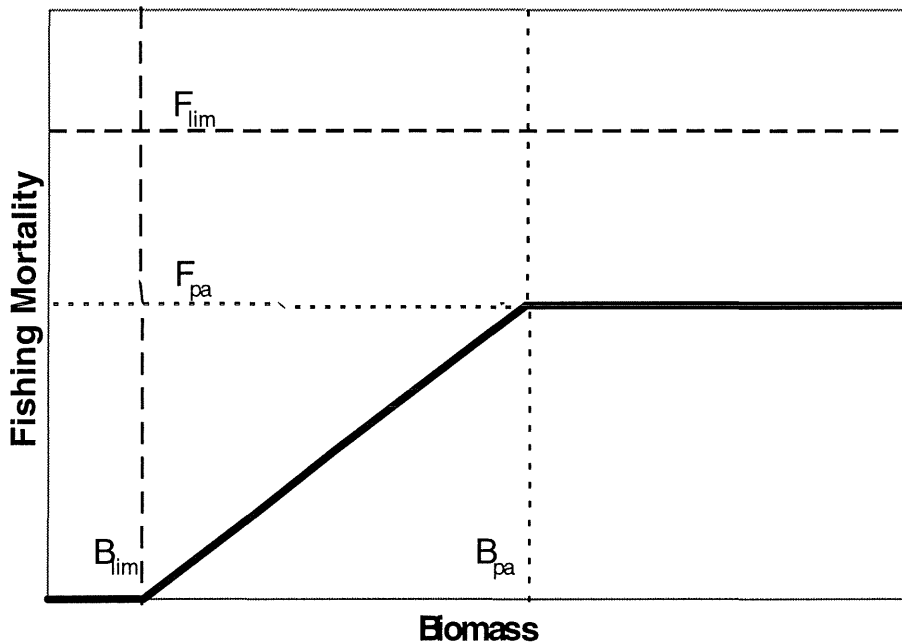
2. *Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum 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.*
4. *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.*

5. *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, in terms of 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.

Consistent with the Precautionary Approach, ACFM/ICES will establish limit reference points, beyond which the stock is considered to be outside safe biological limits and the fishery to be unsustainable. The value of F_{limit} will be defined for as many stocks as possible, and similarly, ACFM/ICES will define limit biomass (B_{limit}) and occasionally other limit reference points for each stock. International agreements suggest that interested parties agree ahead of time on actions to be taken when limit reference points are approached or exceeded. These actions (recovery plan) should ensure recovery as quickly as is possible.

The precautionary basis for advice given by ACFM/ICES will be such that it will, if implemented, ensure a very low probability of exceeding limit reference points. In order to avoid limit reference points, management actions should be taken before fishing mortality exceeds F_{limit} or biomass is below B_{limit} . ACFM/ICES may therefore identify additional reference points, F_{pa} ($F_{precautionary\ approach}$) and B_{pa} where remedial action would be advised in order to avoid the limit reference points being reached.



As indicated above, when limit reference points have been exceeded, a stock is considered to be outside safe biological limits and a fishery on this stock unsustainable. Similarly, the precautionary region (an area within which the probability of reaching any limit is very small) may be considered to be inside safe biological limits. A fishery which maintains stocks within this region would be expected, on the basis of an analysis of historical experience, to be sustainable.

While it will not be possible to define all reference points for all stocks, it will be possible to define safe limits for almost all stocks. It should be noted that while the numerical values of the reference points used to define safe

biological limits may change as biological characteristics of the stock change or when more information becomes available, the reference points themselves will probably not change.

NB: In the past, ACFM/ICES has provided advice on “precautionary TACs” for stocks whose state of exploitation could not be precisely assessed. This was done by advising catch thresholds designed to prevent an increase in fishing mortality and this terminology has been incorporated in legal texts relating to the management of fisheries. The original intent of the precautionary TACs was, in a sense, consistent with the present meaning of the precautionary approach. Recently, though, the reason for advising a “precautionary TAC” has in most cases little to do with the precautionary approach, but it is rather intended to remove opportunities for misreporting catches taken into other areas. In order to avoid any possible confusion, ACFM/ICES will discontinue its use of the phrase “Precautionary TAC”. It is suggested that management authorities may wish to find a new name for those TACs.

4.4 State of the Stock/Fishery

Each exploited stock has experienced a different historic pattern of exploitation and can be characterized by specific biological attributes. Each assessment presents a novel picture of the state of the resource/fishery. Stock status is characterised with respect to limit (B_{lim} , F_{lim} and/or others), and possibly target reference points. The current status is also put in the historical perspective of biological attributes including spawning stock biomass, fishing mortality, and recruitment. Stocks are evaluated with respect to state of knowledge, performance under likely management scenarios and ecosystem/multispecies considerations.

The state of the stock and degree of documentation determine the type of advice, which can be provided by ACFM/ICES. ACFM/ICES strives for consistency in the provision of advice by monitoring and comparing the advice for all stocks on an ongoing basis.

In the case of stocks which are outside of safe biological limits (i.e. SSB is below B_{limit} or F is above F_{limit}) or have a high probability of becoming so in the short or medium term, advice identifies as far as possible what measures are needed in a recovery plan to increase stock size above B_{limit} and/or to decrease F below F_{limit} . The severity of this advice and the extent to which management options are possible will normally depend upon the degree of depletion of the stock and on the historic series of stock and recruitment.

For stocks that have a high probability of remaining within safe biological limits a range of scenarios based on likely management actions are provided along with an indication of the risks of e.g., a decrease in stock below a certain biomass, under different rates of fishing mortality. The question of whether fishing mortality should be altered, and how, may be primarily an economic one. Therefore, indications on how longer-term benefits can be obtained in these cases (e.g., by action on effort) will be offered.

In cases for where data are inadequate to define the state in relation to limit reference points and where no analytical assessment can be made, or where no reference points have been defined, the uncertainty is high. Such situations are clearly undesirable, and the precautionary approach dictates that management must err on the side of caution. ACFM/ICES will recommend action, which it is confident, will have a high probability of moving the fishery towards or keeping the fishery within safe biological limits.

Fisheries will be evaluated in terms of whether continuation of current practice is sustainable in relation to both the stocks involved in the fishery and other ecosystem effects.

4.5 Forecasts and Uncertainty

The main objective of forecasts is to provide information on likely outcomes of various scenarios or choices which may be made in management. A forecast is a projection of future conditions (of, for example, yield and biomass), starting with the present situation. A range of scenarios which project future conditions for various exploitation rates may be given, focusing on the medium (5–10 years) and long term.

Where possible, uncertainty will be taken into account by providing indications of the biological risk associated with particular management options. Uncertainty is a product of aspects that cannot be measured, aspects that are measured with error, data and information that are incorrect, and erroneous assumptions.

Fisheries are inherently variable systems. Any prognosis contains uncertainty associated with both its input parameters and underlying processes. Uncertainties in input parameters include items such as errors in catch, uncertainties related to age interpretation, etc. Uncertainties about underlying processes include stochasticity associated with stock/recruitment relationships, growth in relation to environment, density dependence, and variation in natural mortality, etc.

The introduction of the concept of limit reference points to be avoided with a high probability may in some cases complicate the utilisation of target reference points, especially when the precision of the data is low and the uncertainties are high. In such cases, it may be necessary to aim for a fishing mortality lower than the target in order to ensure that the limit is not exceeded.

4.6 Advice in Light of the Precautionary Approach

The precautionary approach, sustainable development, rational exploitation and responsible fishing have become key themes in international conferences and agreements devoted to the environment and fisheries and in requests to ICES from fisheries management agencies. Considerable background documentation on this issue is presented in the report of the ICES Study Group on the Precautionary Approach (Ref. XXXX)

International agreements show that there is consensus that a precautionary approach is required for conducting and managing fisheries. The precautionary approach involves the application of prudent foresight, taking account of the uncertainties in fisheries systems and the need to take action with incomplete knowledge. Sustainable, productive fisheries require management approaches which ensure a high probability of stocks being able to replenish themselves. Because of the inherent uncertainty at all stages of fisheries management, this can only be achieved by taking a precautionary approach, and this forms the basis for ACFM/ICES advice. It is important to stress that a precautionary approach needs to be adopted at all stages of fishery management from planning through implementation, enforcement and monitoring to re-evaluation of fishery management, not only to the scientific advice.

Consistent with the precautionary approach, ACFM/ICES will attempt in its advice to:

- explicitly consider and incorporate uncertainty about the state of stocks into management scenarios; explain clearly and usefully the implications of uncertainty to fishery management agencies;
- propose precautionary reference points which ensure that limit reference points are not exceeded, taking into account existing knowledge and uncertainties;
- encourage and assist fishery management agencies in formulating fisheries management and recovery plans;
- quantify the effects of fisheries on target as well as on non target species, and on structural and functional aspects of the ecosystem;
- incorporate information on fishing fleets and multispecies fisheries systems as appropriate;
- evaluate fisheries management systems incorporating biological, social and economic factors as appropriate.

Most of the current fisheries management regimes in the ICES area were established before the formulation of the precautionary approach and it should not come as a surprise that they are not fully in accordance with the precautionary approach as set out in the various international instruments. To apply the precautionary approach, fishery management agencies will therefore need to improve and adapt numerous aspects of current practice. ACFM/ICES will advise and comment on how well aspects of management conform to the precautionary approach with respect to:

- the existence, compatibility and measurability of objectives which would influence advice and the choice of targets;
- the existence and choice of limit and target reference points and management plans;
- the existence, appropriateness and effectiveness of recovery plans;
- the effectiveness of measures taken to monitor and regulate exploitation rate;

- the effectiveness of measures explicitly taken to protect non-target species, biodiversity and habitats.

While ACFM/ICES will not be able to comment on all aspects of the precautionary approach (such as adequate consultation, etc.) and therefore would not be in a position to say whether or not management accorded fully with the precautionary approach, it will note that the management of certain stocks does not conform to the precautionary approach where the above factors are deficient.

Future ACFM/ICES advice will allow for uncertainty in both the understanding of the state of the stocks and the effects of future management actions. A key element of the precautionary approach is that when less is known fishery management agencies should adopt a more cautious choice. This may require a change in culture towards a management approach less focused on and influenced by short-term considerations, and more concerned with long-term sustainability.

4.7 Advice and Management

The statement of stock/fishery status will be followed by advice on actions which have a high probability of keeping the stock within (or, in the case of a recovery plan, moving the stock into) an acceptable range according to the precautionary approach. ACFM/ICES will highlight advice that is consistent with stated (or implied) objectives.

In addition, ACFM/ICES has the responsibility to draw attention to issues such as growth overfishing, discarding and side effects of fishing - and will indicate measures which will reduce negative impacts related to management objectives for the population and other parts of the ecosystem.

Consistent with the precautionary approach, ACFM/ICES will move increasingly toward evaluation of a broader range of aspects of the fishery system, including economic, social and administrative issues.

4.8 Ecological and Multispecies Consideration

In providing advice to fishery management agencies, ACFM/ICES wherever possible considers the interactions between the fisheries, and the ecosystem. These include both technical interactions and ecological interactions.

4.8.1 Technical interactions

Several fisheries take a mixture of stocks of different species. Fishing targeted at one species therefore has an impact on the other species caught in the same fishery. These technical interactions present a particular problem, and are essential when evaluating management of the fishery. Where possible these interactions will be taken into account when pointing out the constraints to management. Progress in this developing process is expected to be enhanced by the continued move to area-based, as distinct from species-based assessment working groups.

4.8.2 Ecological interactions

Marine ecosystems are complex. In recent years considerable progress has been made in collecting information on the quantitative nature of the interactions between fish stocks (competition and predation), and other components of the ecosystem, which have allowed the development of multispecies assessment models in the North Sea, boreal waters, and the Baltic. Some of the results, including estimates of predation mortality, have been incorporated in the single species assessments.

4.8.3 Ecosystem effects of fishing

Fisheries have both direct and indirect impacts on components of marine ecosystems other than the targeted species. Examples include bycatch mortality, alteration of seafloor habitats, and changes to the relative species composition of fish and benthic communities. Even on target species, harvesting may be associated with medium and long term changes in life history characteristics which have consequences for both the exploited species and ecologically related species. Although these effects of fishing are receiving increasing attention within ICES and in national laboratories, they generally have not been included explicitly in considerations of reference points and

precautionary approaches to advice. Moreover, at present in very few cases are data likely to be adequate to allow any quantitative treatment of these concerns in ICES advice.

To be consistent with the precautionary approach, however, the effects of fisheries on the ecosystem will have to be brought into the ICES advice to fisheries management agencies. Assessment Working Groups must begin to develop a scientific foundation for this task within their current activities, for example by ensuring data are brought forward on bycatches as well as discards, to facilitate estimation of non-target mortalities; by providing information on spatial aspects of fleet operations, to facilitate evaluation of impacts of gears on habitats and benthos; and by considering the effects of estimated levels of fishing mortality on the species' life history. These types of tasks are likely to require collection of additional data by the appropriate laboratories and agencies. Moreover, the current Working Group on Ecosystem Effects of Fishing will continue to expand its activities, and move from a largely exploratory approach to questions on ecosystem effects of fishing, into providing specific aspects of advice.

4.9 Template for Stock/Fishery Summary Sheet

4.9.1 State of stock/fishery

Presents the bottom line with respect to biological status. Statements are brief and generally in relative terms (few if any numbers or details). Contains three elements:

An opening statement of classification with respect to safe biological limits and/or sustainability criteria.

- of the stock/fishery itself
- and/or in light of the state of knowledge
- and/or in of multispecies considerations

Current situation with respect to biological limit reference points B_{lim} and F_{lim} (or other limit reference points defined for stock).

A brief, punchy statement of the historical perspective of SSB, F and R.

4.9.2 Management objectives

Summarizes stated objectives for the fishery if they have been specified, or articulates assumed default objectives.

4.9.3 Advice on management

ACFM/ICES recommendation of what needs to be done with respect to the state of the stock.

Comments on the success of recent/current management measures (how they have worked) and presents alternative management scenarios consistent with advice recommendations, with impact statements. This section may contain a few paragraphs with scenario documentation.

A brief statement of the results of the "precautionary approach audit" lists management issues and changes required to comply with the precautionary approach.

4.9.4 Relevant factors to be considered when managing this fishery

Present here any biological and fishery descriptions that are necessary for the interpretation of the advice. This might include items such as life history, unusual recruitment feature, and fishery features.

4.9.5 Catch forecast

4.9.6 Elaboration and special comment

Several pieces of information required for interpretation of advice, including:

Historical development of the fishery.

How/why assessment differs from previous assessment.

An advice rating, based on the amount and quality of data, and the quality of the assessment. (Under the p.a. the less certain the assessment, the more caution is required).

Multispecies aspects...features of this stock in light of other fisheries.

Pertinent additional features of biology or of the fishery*, or details of the assessment of relevance to management.

Relevant details of recovery plan if required.

Data and assessment.

Others.

4.9.7 Source of information: Working Group Report ###, etc.

4.9.8 Tables and figures

* note: more elaborate, meaningful description of fisheries to be included in overview.

4.9.9 *Tobinus grandstandicus*

State of the Stock

Current exploitation of this stock is not sustainable. Both present spawning stock size and recent recruitment levels are the lowest observed in the time series of data.

Current fishing mortality is at F_{pa} but the current estimated SSB is well below B_{lim} .

After many years of stable recruitment, the data indicate severe declines beginning in about 1986. The current population age structure is dominated by older fish because of this recruitment decline.

Management Objectives

There are no explicit management objectives set by the management body. In the absence of any defined management objective, the default objective is to rebuild the stock so as to achieve and maintain sustainability at an SSB above B_{pa} , and fishing mortality below F_{pa} .

Advice on Management

ICES recommends that no fishing should take place in the absence of a Recovery Plan, and that a Recovery Plan be established as soon as possible.

Because of concerns for this resource, management has eliminated any directed fishery by trawls in recent years and limited the catch of longline and gillnet vessels less than 27.5 m to less than their long-term average catch. The mandatory use of sorting grids in shrimp trawls in the early 1990s has reduced the by-catch of juveniles in the shrimp fishery.

By-catch restrictions for other fleets have also been put in place and these resulted in lower overall catches and a reduction in fishing mortality.

There is, however, a clear lack of any explicit recovery plan and steps should be taken to put one in place as soon as possible.

Year	ICES advice	Catch corresp. to advice	Agreed TAC	Official landings	ACFM catch
1987	Precautionary TAC	-	-	19	19
1988	No decrease in SSB	19	-	20	20
1989	$F = F(87)$; TAC	21	-	20	20
1990	$F = F(89)$; TAC	15	-	23	23
1991	F at F_{med} ; TAC; improved expl. pattern	9	-	33	33
1992	Rebuild SSB(1991)	6	7 ¹	8	9
1993	TAC	7	7 ¹	12	12
1994	$F < 0.1$	<12	11 ¹	9	9
1995	No fishing	0	2.5 ²	11	11
1996	No fishing	0	2.5 ²		

Elaboration and Comments

Survey data are available since 1970, with landings data available since the 1930s.

An analytical assessment is used, with calibration using 4 'young fish' surveys and 1 'experimental fishery' survey. The results are very dependent upon the estimated recruitment from the surveys. Natural mortality was assumed to be 0.15.

There are clear problems with this assessment. The survey data do not include the entire area of juvenile distribution. The recent commercial catch rate estimates are not directly comparable to those from the earlier period because they are not derived from a full-scale competitive fishery.

Nevertheless, the resource is clearly well below a Limit Reference Point (B_{lim}).

The adult portion of the stock occupies relatively deep water (400–1,500 m). It is size stratified, with juvenile fish generally being found in shallower water. Thus there is only limited overlap between juveniles and adults. They are relatively slow growing, and males and females do not reach maturity (M_{50}) until age 5 and age 9 respectively. They are fully mature by about age 7–8 and age 13. There are only slight differences in growth rates between the sexes at mature ages. However, females grow to larger sizes because of apparent lower mortality.

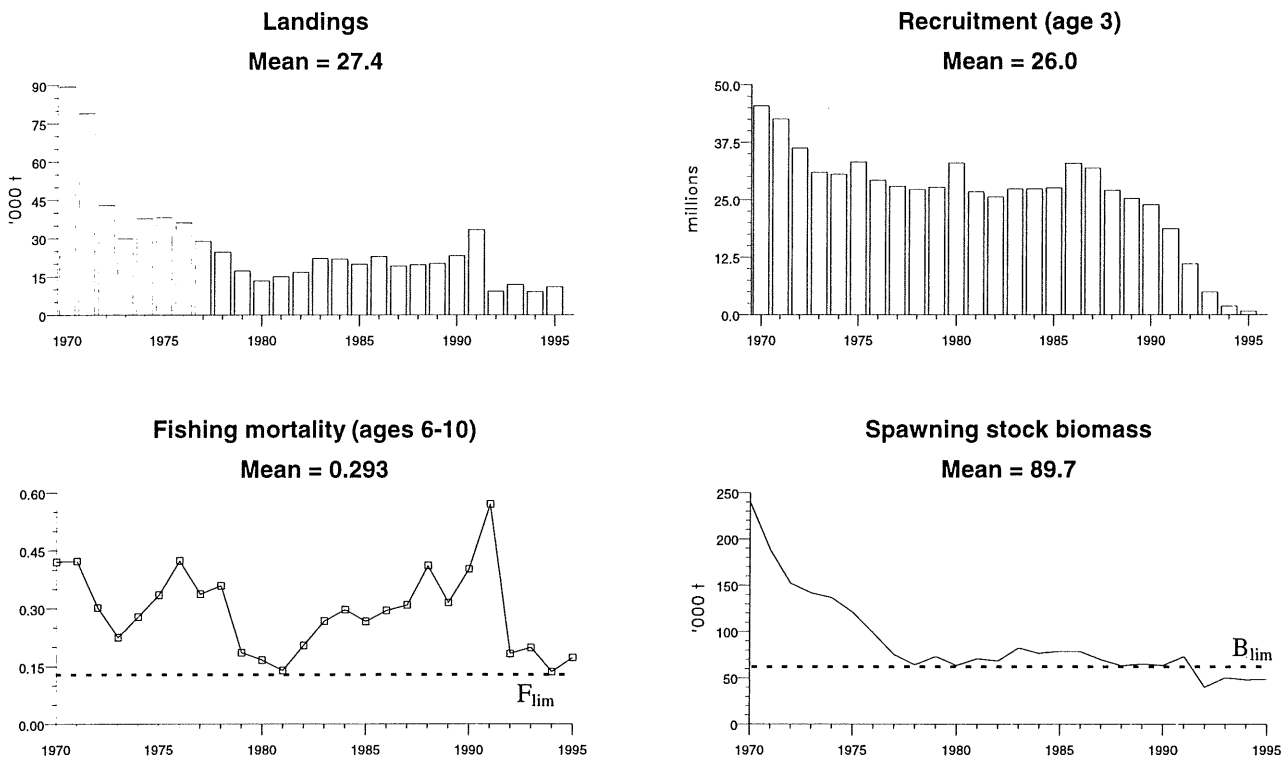
From the 1930s to the mid 1960s, the fishery was mainly a coastal longline fishery off eastern Heaven and Valhala in Wonderland. In more recent times gillnets have also been used. Throughout its history, annual landings were about 3,000 t on average.

During the 1960s an international trawler fishery developed and total landings increased rapidly to an historical high in the early 1970s, then declined rapidly again thereafter.

Beginning in 1992, a directed fishery was restricted to longline and gillnet vessels less than 27.5 m. Trawl catches were restricted first to a by-catch limit of 10% by weight per haul through 1994, then reduced to 5% for 1995 and 1996. These restrictions resulted in a reduction of the total catch to about 10,000 t but the by-catch of the trawlers in the directed fisheries for angels is still in excess of the permitted directed fishery for *Tobinus*. In addition, the longline and gillnet vessels are exceeding their TAC by up to 100% due to increased entries.

Source of information

Report of the Fun Fisheries Working Group, March 1995 (Evening Telegram).



4.9.10 Scottish Spring Spawning Fish

State of Stock

Current exploitation rates are unsustainable for this stock.

Fishing mortality has increased continuously for many years and exceeds the precautionary point (F_{pa}). Spawning stock biomass has decreased continuously over the past twenty years to historical low levels and is below the precautionary reference point (SSB_{pa}).

The stock dynamics are summarized in Figure 1. It shows that recent estimates of SSB are consistent with expected stock decline at fishing mortality rates typical of the last five years. Long-term trends are shown in Figure 2.

Management Objectives

No specific objectives have been articulated for this stock by fishery management agencies.

Management of this stock consistent with the Precautionary Approach implies a fishing mortality less than 0.7 and spawning stock biomass being kept above X tonnes.

Management Advice

ICES recommends that fishing mortality should be reduced to below 0.7 as rapidly as possible.

The main management measure used to regulate fishing mortality is the TAC. Recent experience indicates that the application of TACs has not been successful in reducing fishing mortality. It is necessary to reduce F directly, which could be achieved through the use of controls in fishing vessel activity. This would imply a reduction in fishing activity (such as days at sea) of at least 30%.

The high level of fishing mortality on this and related stocks indicates that the exploiting fleets are over-capacity. Continued reductions in fleet capacity would address many of the chronic problems related to high exploitation rates. A fleet reduction of at least 40% would be required to produce a significant reduction in fishing mortality.

Basis: *Status Quo* F in 1996

F(97)	Catch(97)	SSB(98)	Long-term effect of fishing at given level
0.6*	110	150	Exploitation at this level is likely to be sustainable
0.7 (F_{pa})	145	130	Exploitation at this level is likely to be sustainable but with SSB below its limit reference point in the short term.
0.8 (F_{sq})	158	120	Moderate probability that exploitation is not sustainable.

*Limited by SSB_{limit}

Options consistent with the precautionary approach are presented in bold.

Elaboration and Comment

Fish in the North Sea are caught as part of a mixed fishery which also targets haddock and whiting. The latter are less endangered than fish. Establishing management objectives for these stocks in isolation is likely to adversely affect the fish stock. A precautionary approach would require that objectives for haddock and whiting would have to be set in a manner consistent with protecting fish. In general this will mean reducing fishing mortality for haddock and whiting by a similar amount to that for fish. Fishing effort reductions and fleet capacity reductions are likely to help in addressing the problem of excessive fishing mortality on all three stocks. Although mortality rate reductions to satisfy sustainability criteria for fish are more than is required for haddock and whiting alone, additional benefits to the SSB and yield might be expected for these stocks from such reductions.

Large fish of over 1 m constituted a significant component in the landings in the 1950s but are an exception in recent years.

Fish are fully exploited by the fishery at age 2, and thus experience high mortality before reaching maturity. This makes stock rebuilding very slow even when good year classes appear in the sea. A small increase in fishing mortality would be expected to lead to a large reduction in spawning stock. In order to assist in stock recovery, measures to reduce mortality of juveniles should be investigated.

Data used in the assessment are regarded as adequate for the purpose of judging the state of the stock. Recent landings statistics are known to have been affected by misreporting and this may influence the catch forecast to a significant degree. TACs based on such forecasts may not be sufficiently accurate to achieve adequate control of fishing mortality. Discard data are not available for major components of the fleets exploiting the stock. Discarding may be significant and it is important to ensure such information is collected.

Table on historical catch.

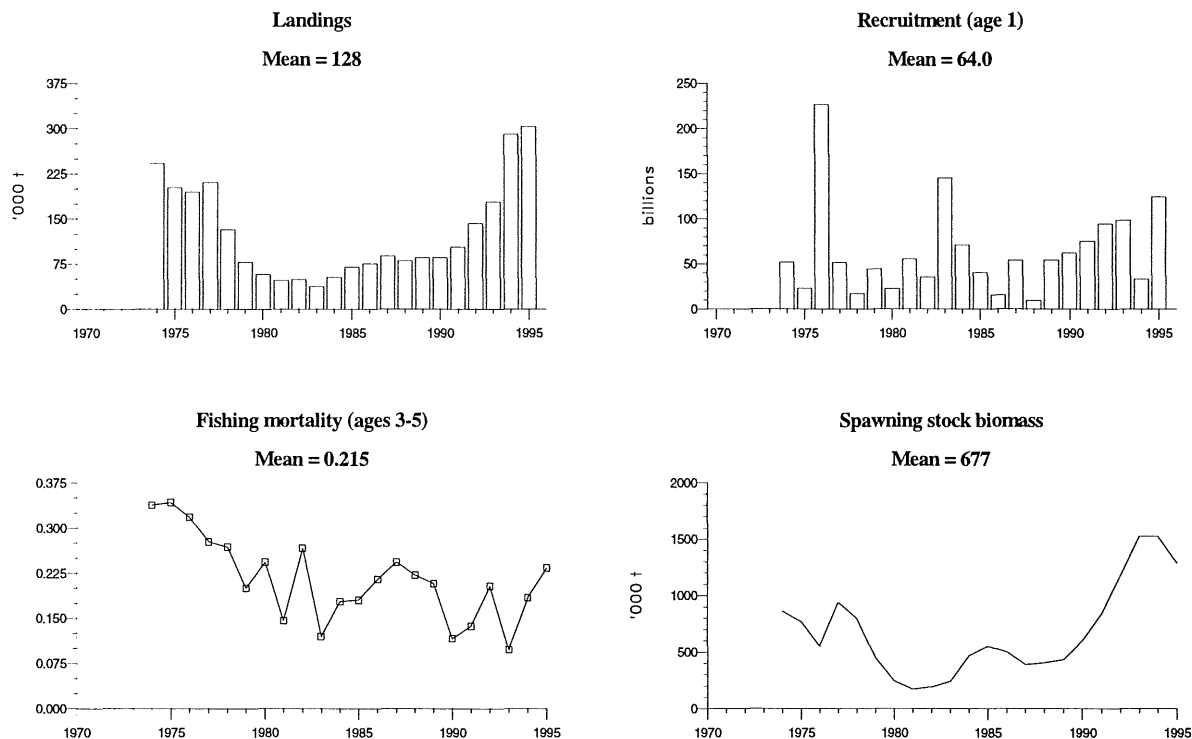
Figures: Historical landings, recruitment, F, SSB. (Include limit points on F, SSB).

4.10 Stocks Not in Imminent Danger of Falling Outside Safe Biological Limits

4.10.1 Smallpel in Blueseaa

State of the stock

The stock is considered to be within safe biological limits. SSB has increased in recent years and is at its highest historical level, being more than 6 times higher than B_{PA} . Natural mortality is highly variable and depends on Predator abundance. Predator abundance in the Blueseaa is presently low. Fishing mortality appears to have increased from 1993 to 1995, but is estimated to be in the same order as natural mortality. The 1994 year class is well above average and a preliminary estimate of the 1995 year class indicates it at average.



Management objectives

There is no explicit management objective set out by the management body.

Appropriate management objectives for this stock will need to account for the multispecies interactions in the Blueseaa.

The Smallpel fishery should be managed to maintain SSB above B_{PA} and the total mortality below Z_{PA} .

Management advice

The management advice for this stock takes account of the importance of Smallpel as prey species for the Predator. The fishing mortality this stock can sustain is dependent on natural mortality which is linked to the abundance of the Predator. At present the Smallpel SSB is at a high level due to strong recruitment and low predation in recent years. Under these conditions fishing mortality can be increased in the short term but should not exceed F_{PA} of 0.55 complementing the current natural mortality of 0.3 to give Z_{PA} of 0.85. The management advice for the Blueseaa Predator stocks is aiming at increasing stock sizes and it is unlikely that an F in the order of 0.5 can be maintained in the medium term.

Forecast for 1997: Basis reduction of fishing mortality by 20% compared to 95

F (97)	M (97)	SSB (98)	Catch (97)	Lndgs (97)	Medium-term advice
0.14	.27	1542	243	243	for all options sustainability of the fishery
0.18		1455	317	317	depending on abundance of Predators
0.23 (F _{sq})		1374	387	387	in the Bluesea
0.27		1298	454	454	
0.32		1227	518	518	

Weights in '000 t.

Evaluation of fisheries management

Agreed TACs have been set considerably higher than the recommended TAC. Actual catches have never reached the TAC. To fully comply with the PA management, plans are needed which take into account objectives for the whole Bluesea ecosystem. Preagreed recovery plans need to be established.

Catch data

Year	ICES advice	Catch corresp. to advice	Agreed TAC	ACFM catch
1987			117.2	88
1988	Catch could be increased in Bluesea	-	117.2	80
1989		72	142	86
1990		72	150	86
1991	TAC	150	163	103
1992	Status quo F	143	290	142
1993	Increase in yield by increasing F	-	415	178
1994	Increase in yield by increasing F	-	700	291
1995	TAC	205	500	304
1996	Little gain in long-term yield at higher F	279	550	

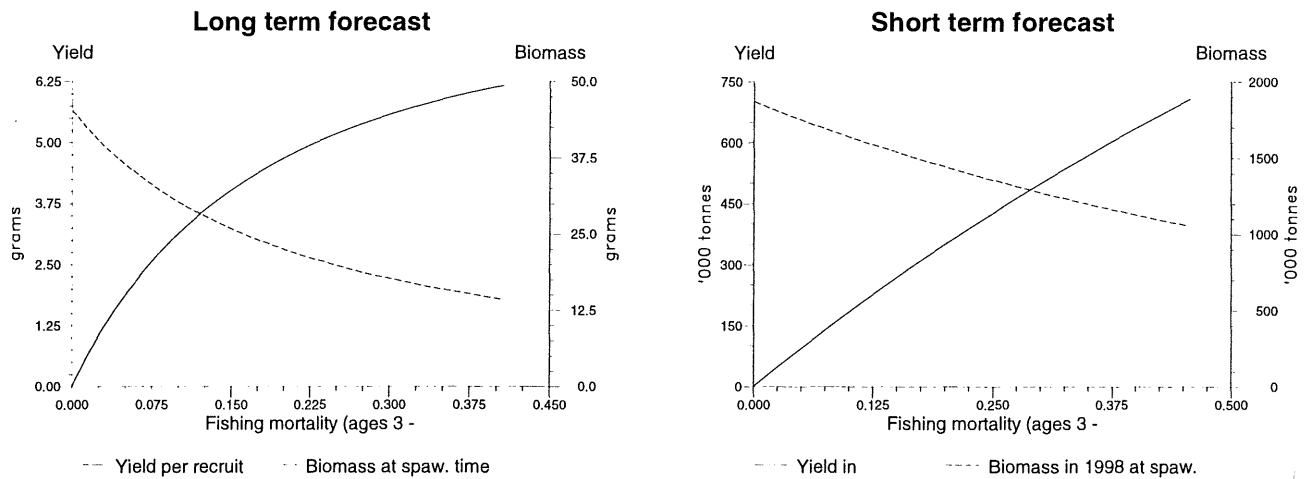
Weights in '000 t.

Elaboration and comments

Landings increased from 1983 to 1995. The increase in landings since 1992 is due to the development of an industrial pelagic fishery. The catches in this fishery consist mainly of Smallpel (about 70%) and another species. Smallpel is fished with pelagic trawls during the first half and in the last few months of the year. Most catches used for human consumption are taken in mixed fisheries for Smallpel and the other pel species.

Smallpel in the Bluesea is a long-lived pelagic species with schooling behaviour. It spawns in batches and matures to 70% at age 2. Recruitment is highly variable. Overwintering concentrations are found in the bights. Natural mortality is variable depending on abundance of Predator in the Bluesea. It is also known that Smallpel predate on Predator eggs. The full range of year classes is observed in the stock. Recently mean weight at age decreased.

Yield and Spawning Stock Biomass



4.11 Stocks with Inadequate Data to Assess their Status with Respect to Safe Biological Limits

In a precautionary approach, the advice should be more cautious in these cases, and include mechanisms to increase the knowledge.

5 IMPLEMENTATION

5.1 Within ICES

5.2 With Clients

6 REFERENCES

- Beverton, R. J. H. and Holt, S. J. (1957). On the dynamics of exploited fish populations. Chapman and Hall. Fascimile reprint, 1993. 533 pp.
- Butterworth, D.S. and M.O. Bergh. 1993. The development of a management procedure for the South African anchovy resource. P. 83–99. *In* S.J. Smith, J.J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.
- Caddy, J.F. and R. Mahon. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper No. 347. Rome, FAO. 83p.
- Caddy, J.F. and R. McGarvey. 1996. Targets of Limits for Management of Fisheries. *North American Journal of Fisheries Management*. 16(3): 479–487.
- Cook, R. M., Sinclair, A. and Stefánsson, G. (1997). Potential collapse of the North Sea cod stock. *Nature*, 385 (6616): 521–522.
- Doulman, D.J. 1995. Structure and Process of the 1993–1995 United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. FAO Fisheries Circular. No. 898. Rome, FAO. 1995. 81p.
- Evans, G.T. and Rice, J.C. 1988. Predicting recruitment from stock size without the mediation of a functional relation. *Journal du Conseil pour l' Exploration de la Mer*. 44:111–122.
- FAO. 1995. Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. Elaborated by the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6–13 June 1995 (A scientific meeting organized by the Government of Sweden in cooperation with FAO). FAO Fisheries Technical Paper. No. 350. Part 1. Rome, FAO. 1995. 52 p.
- FAO. 1995b. Code of Conduct for Responsible Fisheries. 46p.
- Garcia, S.M. 1996. The Precautionary Approach to Fisheries and its Implications for Fishery Research, Technology and Management: An Updated Review. Pages 1–65 *in* FAO. 1996. Precautionary approach to fisheries. Part 2: Scientific Papers. Prepared for the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6–13 June 1995 (A scientific meeting organized by the Government of Sweden in cooperation with FAO). FAO Fisheries Technical Paper. No. 350. Part 2. Rome, FAO. 1996. 210 p.
- Gislason, H. and E. Kirkegaard. 1997. The industrial fishery and the North Sea sandeel stock. Seminar report: The Precautionary Approach to North Sea Fisheries Management, Oslo 9–10 September 1996. *Fisken og Havet* Nr. 1 - 1997.
- Mace, P.M. and M.P. Sissenwine. 1993. How much spawning per recruit is enough? *In* S.J. Smith, J.J. Hunt, and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.
- Marshall, C.T., Kjesbu, O.S., Solemdal, P., Ulltang, O.L. and Yaragina, N.A. 1996. Using individual-based measures of reproductive potential to estimate the realised egg production of Northeast Arctic cod. Abstract in Report of the Working Group on Recruitment Processes, 17-20 June 1996. ICES, C.M.1996/L:6.
- Pope, J. G. and Macer, C. T. 1996. An evaluation of the stock structure of North Sea cod, haddock and whiting since 1920, together with a consideration of the impacts of fisheries and predation effects on their biomass and recruitment. *ICES J. Mar. Sci.*, 53:1157–1169.

- Rosenberg, A., P. Mace, G. Thompson, G. Darcy, W. Clark, J. Collie, W. Gabriel, A. MacCall, R. Methot, J. Powers, V. Restrepo, T. Wainwright, L. Botsford, J. Hoenig, and K. Stokes. 1994. Scientific review of Definitions of Overfishing in U. S. Fishery Management Plans. NOAA Technical Memorandum NMFS-F/SPO-17.
- Sissenwine, M. P. and Shepherd, J. G., 1987. An alternative perspective on recruitment overfishing and biological reference points. *Can. J. Fish. Aquat. Sci.* 44:913–918.
- Shepherd, J. G. 1982. A versatile new stock-recruitment relationship of fisheries and construction of yield curves. *J. Cons. Int. Explor. Mer.* 40:67–75.

Annex 1

G_{LOSS} , A SUSTAINABILITY CRITERION FOR EXPLOITED FISH STOCKS

by R.M. Cook

Theory

The sustainability of harvesting is largely determined by two factors, the relationship between the size of spawning stock (SSB) and the annual number of offspring (the recruits) produced, and the subsequent survival of the recruits on entering the fishery. This is illustrated in Figure 1 which shows a theoretical stock-recruitment curve and a recruit survivorship line. Where the two lines intersect is an equilibrium point to which the population is attracted (Beverton & Holt, 1957). If the survivorship line lies above the stock recruitment curve there is no non-zero equilibrium point and the population is attracted to the origin. The slope of the survivorship line is affected by the fishing mortality rate, F . The more heavily the stock is exploited, the steeper the slope. This line is also called a replacement line since it defines the survivorship needed to replace the spawning stock in the future. It is important to note the distinction between a replacement line and fishing mortality. A replacement line (referred to as G), while dependent on F , is also dependent on a number of biological parameters including growth, maturity and natural mortality. Thus a unique value of F can give a variety of replacement lines if the biological parameters vary.

With perfect information of the type in Figure 1 it is easy to define conditions of sustainability and collapse but this ignores estimation errors and the limitations of real data. Consider the stock recruitment data illustrated in Figure 2. This shows the typical problem where data are scattered and are inadequate to define the left hand part of the stock-recruitment curve (the broken line). If we knew the stock recruitment curve we could define the slope of the line, G_{crash} , the replacement line for the fishing mortality which results in stock collapse. However, the best we can do is to define G_{loss} , the replacement line which corresponds to the lowest observed spawning stock (LOSS). Although this is not the replacement line we seek it has certain value because;

- a) G_{loss} is a minimum estimate of G_{crash} ,
- b) any fishing mortality which corresponds to a replacement line to the right of G_{loss} should be sustainable and,
- c) any fishing mortality which corresponds to a replacement line to the left of G_{loss} should result in an equilibrium stock size below the lowest observed value or stock collapse.

Clearly we wish to establish a fishing mortality rate which is below G_{crash} with some degree of confidence. If it can be established that F gives a replacement line below G_{loss} then this condition is satisfied.

Methods

- a) Distribution of G_{loss}

The replacement line, G_{loss} , can be defined as the line joining the origin of the stock-recruitment plot to the point given by the fitted recruitment value, R_{loss} , at the lowest observed spawning stock biomass, S_{loss} . The slope of this line is then simply calculated from;

$$G_{loss} = \frac{\bar{R}_{loss}}{S_{loss}} \quad (1)$$

In order to calculate G_{loss} it is necessary to describe a stock-recruitment relationship in the region of S_{loss} . There are many parametric stock recruitment which can be used to summarize the data (Deriso, 1980; Shepherd, 1982, Schnute, 1985). Although these are quite flexible in shape the choice of function to use is usually stock-dependent. To avoid the need to choose a particular function a non-parametric approach has been used here. Non-parametric methods have been used before (Evans and Rice, 1988) and have the advantage that the data determine the shape of the curve. The particular method used here is to fit a lowess curve (Cleveland, 1981) assuming log-normal errors and

use the smoothed value at S_{loss} as an estimate of R_{loss} . It was found that the best results were obtained with the 'stiffest' smoother, so all the data points were used for each of the local regression estimates.

These calculations take no account of the uncertainties in the data. Of particular concern is the uncertainty in G_{loss} replacement line. Uncertainty in G_{loss} can be considered by calculating a frequency distribution of the estimate in equation (1). This can be achieved by bootstrapping the lowess fit to the stock recruitment data. It has been done here by re-sampling with replacement using a similar approach to Gabriel (1994). For n observations, n stock recruitment pairs were drawn at random and the lowess curve fitted. For each of one hundred realisations, G_{loss} was calculated using equation (1). This allowed a distribution for G_{loss} to be calculated.

b) Equilibrium curves

The equilibrium yield, Y_e , and equilibrium spawning stock, S_e , can be easily calculated if an adequate description of the stock-recruitment function is available. Such curves can be useful in understanding the likely spawning stock and yield associated with a given exploitation regime. Given the lowess estimated values of recruitment these equilibrium curves can be obtained simply by multiplying the fitted recruitment value, by the appropriate yield per recruit value, $y(q)$, or spawning stock biomass per recruit value, $b(q)$ i.e.;

$$Y_e = \bar{R}y(\theta) \quad (2)$$

The parameters, q , are the standard vital quantities of weight at age, w , proportion mature at age, p , fishing mortality rate, F and natural mortality rate, M .

c) Distribution of G_F

The position of the G_{loss} is determined directly from the stock-recruitment data. The calculation of replacement lines for given fishing mortality rates can be made from the standard 'per recruit' formulae (Table 1). The slope, G_F , of the replacement line for a particular value of fishing mortality rate, F , is simply $1/b(q)$ i.e.;

$$G_F = \frac{1}{b(\theta)} \quad (3)$$

The parameters, q , are generally measured with error or are by their nature variable quantities. Growth, for example would be expected to vary from year to year leading to different annual mean weights at age. These sources of error need to be considered when calculating a frequency distribution of G_F . The calculation of such a frequency distribution has been achieved here by simulation. A mean and variance for each parameter was specified with an associated distribution. The quantity G_F was then calculated repeatedly by drawing parameter values at random from the specified distributions. The methods for estimating the parameters, q , and their variances are given in (f) below.

d) Probability that $G_F > G_{loss}$

Given the estimated distributions of the replacement lines it is simple to calculate the probability that the present fishing mortality rate, F has a replacement line above G_{loss} . This probability is given by considering the distribution of the ratio G_{loss}/G_F . The ratio will be centred on one if $G_{loss}=G_F$. If $G_{loss}<G_F$, then the ratio will be less than one. Hence the probability we seek is simply the probability that this ratio is less than or equal to one, i.e.;

$$pr \left[\frac{G_{loss}}{G_F} \right] \leq 1 \quad (4)$$

It can be calculated by drawing at random values of G_{loss} and G_F as described above, forming the ratio and then accumulating the proportion of the total sample which is less than or equal to one.

e) F_{loss} distribution

For a unique value of G_{loss} and a unique set of parameters, q , it is possible to calculate a multiplier, f_{loss} , on the exploitation pattern, s , which satisfies the equation;

$$G_{loss} = \frac{1}{b(\theta)} \quad (5)$$

This multiplier leads to the fishing mortality rate, F_{loss} , above which the stock would be expected to decline to an equilibrium spawning stock below the lowest observed value. A distribution of F_{loss} , can be obtained by combining the procedures described in (a) and (c). For each bootstrapped value of G_{loss} , a set of parameters q is selected at random from their given distributions and equation (6) is solved. This gives a distribution of fishing mortality rates which are likely to lead to stock decline below the lowest observed spawning stock.

f) Parameter estimates and their coefficients of variation (CV) for North Sea cod

The input values required to estimate G_F are fishing mortality rate at age, natural mortality rate at age, weight at age and maturity at age. In order to obtain a distribution of G_F , it is necessary to estimate these values and their variances. Nominal values for these quantities have been obtained from standard ICES assessments (ICES 1997) and the required parameter values and CVs were calculated as follows:

Fishing mortality: In the examples presented in this paper, fishing mortality is estimated from XSA (Darby and Flatman, 1994) which gives annual estimates by age. It is assumed that fishing mortality can be decomposed into an age specific selectivity effect, s_a , and a year effect f_y ;

$$F_{ay} = s_a f_y \quad (6)$$

Values of f_y were estimated as the mean F over a standard age range in each year. The sample variance of the f_y s was taken as the required variance for the parameter. This variance expresses the annual year on year variability of F caused by both process and measurement error.

Values of s_a were calculated by dividing the age specific F s by the f_y s each year and then taking a mean across a standard range of years. The sample variance for each s_a was then used as the appropriate variance for selectivity. This will approximate the variability in selectivity when year effects are removed.

Natural mortality: A similar approach to that for fishing mortality was adopted. The natural mortality, M , was decomposed into an age effect, m_a , and year effect k_y such that;

$$M_{ay} = m_a k_y \quad (7)$$

The values for m were taken as the conventional values of M used in the assessment. An approximate value for the CV was obtained by taking a ten year mean of the predation mortalities estimated by the Multispecies Working Group (ICES 1994). These values are about 0.2–0.3. For the year effect, k , a nominal value of one was used with an arbitrary CV of 0.1.

Weight at age: This quantity was taken as the mean over a range of years. The sample variance was used as an estimate of the variability in weight. This variance will not adequately describe longer-term systematic changes in growth rate but should serve as an estimate of cohort specific growth rate changes assuming an overall stationary mean over time.

Maturity: For the stocks considered there is little information about changes in maturity and a 'conventional' maturity ogive is generally used. The CV for maturity was taken to be 0.1 for those age classes which were partially mature.

For fishing and natural mortality, the parameter distributions were assumed to be normal. For weight the distribution was assumed log-normal. In the case of proportion mature, this was taken to be normally distributed after a logit transformation.

Results

The analysis for cod is summarised in Figure 3. The stock recruitment scatter plot shows the fitted smoothed line from the lowess analysis. Also shown are the regions containing G_{loss} (vertical shading) and G_F (horizontal shading). These regions overlap and give a probability of 32% that current exploitation will produce an equilibrium below the lowest observed value. Given the proximity of the the smallest SSBs to the origin this is probably a good indication of the probability of collapse for this stock.

Figure 3 also shows the equilibrium SSB and yield curves with the observed data included on the plot. The curves indicate that both SSB and yield decline rapidly with increasing fishing mortality.

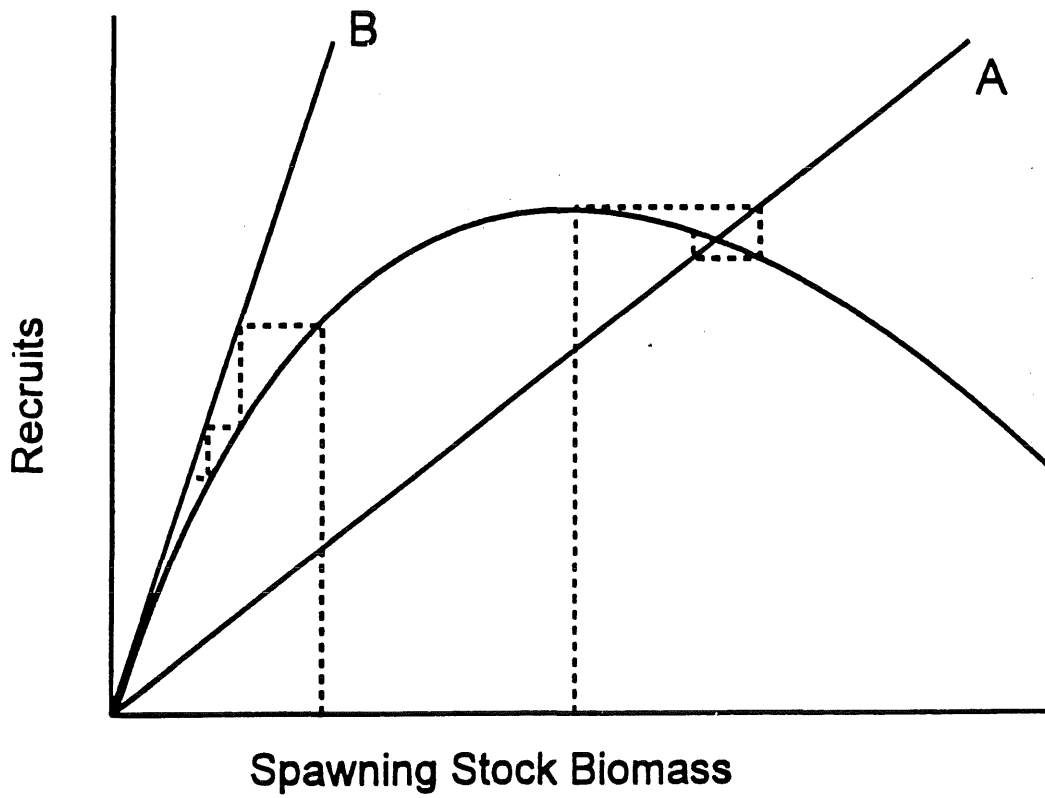
Finally, Figure 3 shows the cumulative probability of F exceeding F_{loss} . Given a value of F , this plot gives the probability of fishing above F_{loss} .

References

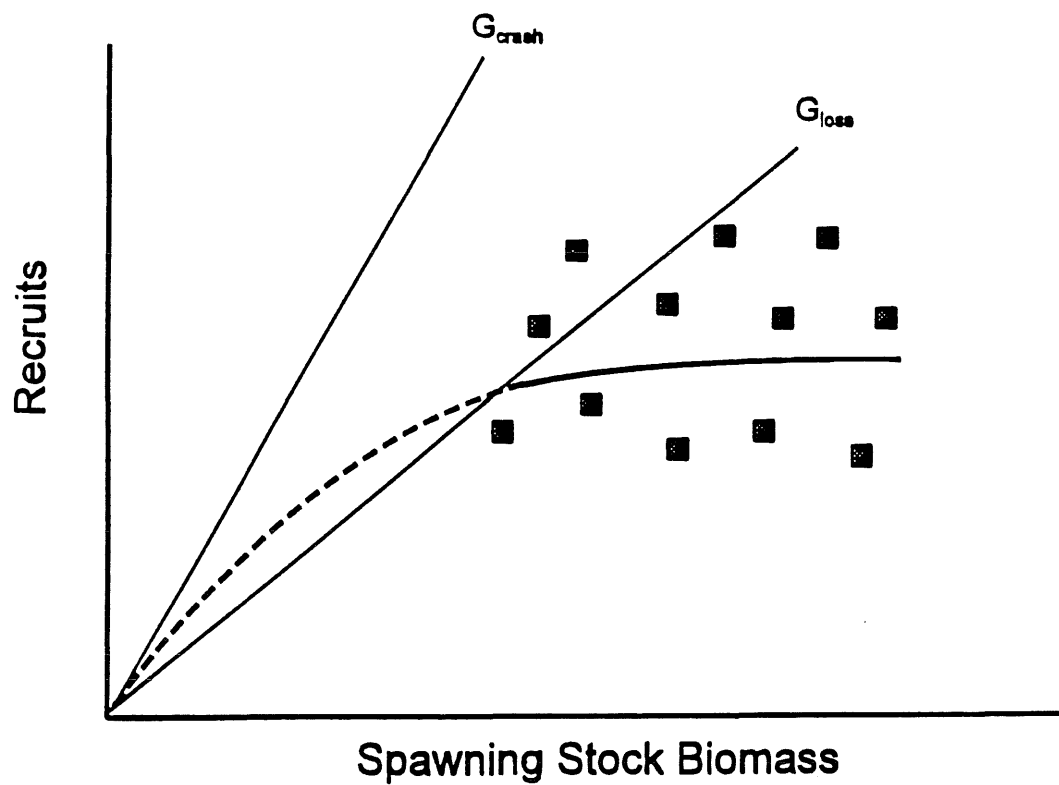
- Beverton, R.J.H. and Holt, S. (1957). On the dynamics of exploited fish populations. Fisheries investigations, Ser. 2, vol 19.
- Cleveland, W.S. 1981. LOWESS: A program for smoothing scatterplots by robust locally weighted regression. The American Statistician, 35:54.
- Darby, C.D. and Flatman, S. 1994. Virtual Population Analysis: version 3.1 (windows/Dos) user guide. MAFF Information Technology Series No. 1. Directorate of Fisheries Research, Lowestoft, 85pp.
- Evans, G.T. and Rice, J.C. 1988. Predicting recruitment from stock size without the mediation of a functional relation. Journal du Conseil pour l'Exploration de la Mer. 44: 111–122.
- Deriso, R.B. 1980. Harvesting strategies and parameter estimation for an age-structured model. Canadian Journal of Fisheries and Aquatic Sciences. 37: 268–282.
- Gabriel, W. L. 1994 . A simple method for estimating uncertainty associated with F_{med} . ICES C.M. 1994/D:5.
- ICES 1994. Report of the Multispecies Assessment Working Group. ICES C.M. 1994/Assess:9.
- ICES (1997). Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. ICES C.M. 1997/Assess:6.
- Schnute, J.T. 1985. A general framework for developing sequential fisheries models. Canadian Journal of Fisheries and Aquatic Sciences. 42:414–429.
- Shepherd, J.G. 1982. A versatile new stock-recruitment relationship for fisheries and the construction of sustainable yield curves. Journal du Conseil pour l'Exploration de la Mer. 40: 67–75.

Annex Figure 1 Theoretical stock-recruitment curve and recruit survivorship lines.

- A. Line showing equilibrium point to which population is attracted.
- B. Line with no intersection point indicating that population is attracted to the origin.



Annex Figure 2 Stock-recruitment scatter diagram with solid curve fitted to the data and dashed curve showing extrapolation of left-hand part of the curve.



Annex Figure 3 Scatter plots and fitted relationships between:
 Top left : Recruitment and spawning stock biomass;
 Top right : Spawning stock biomass and fishing mortality;
 Bottom left : Probability that $F \geq F_{loss}$ and F
 Bottom right : Yield and fishing mortality
 See text for explanation

Cod, North Sea

